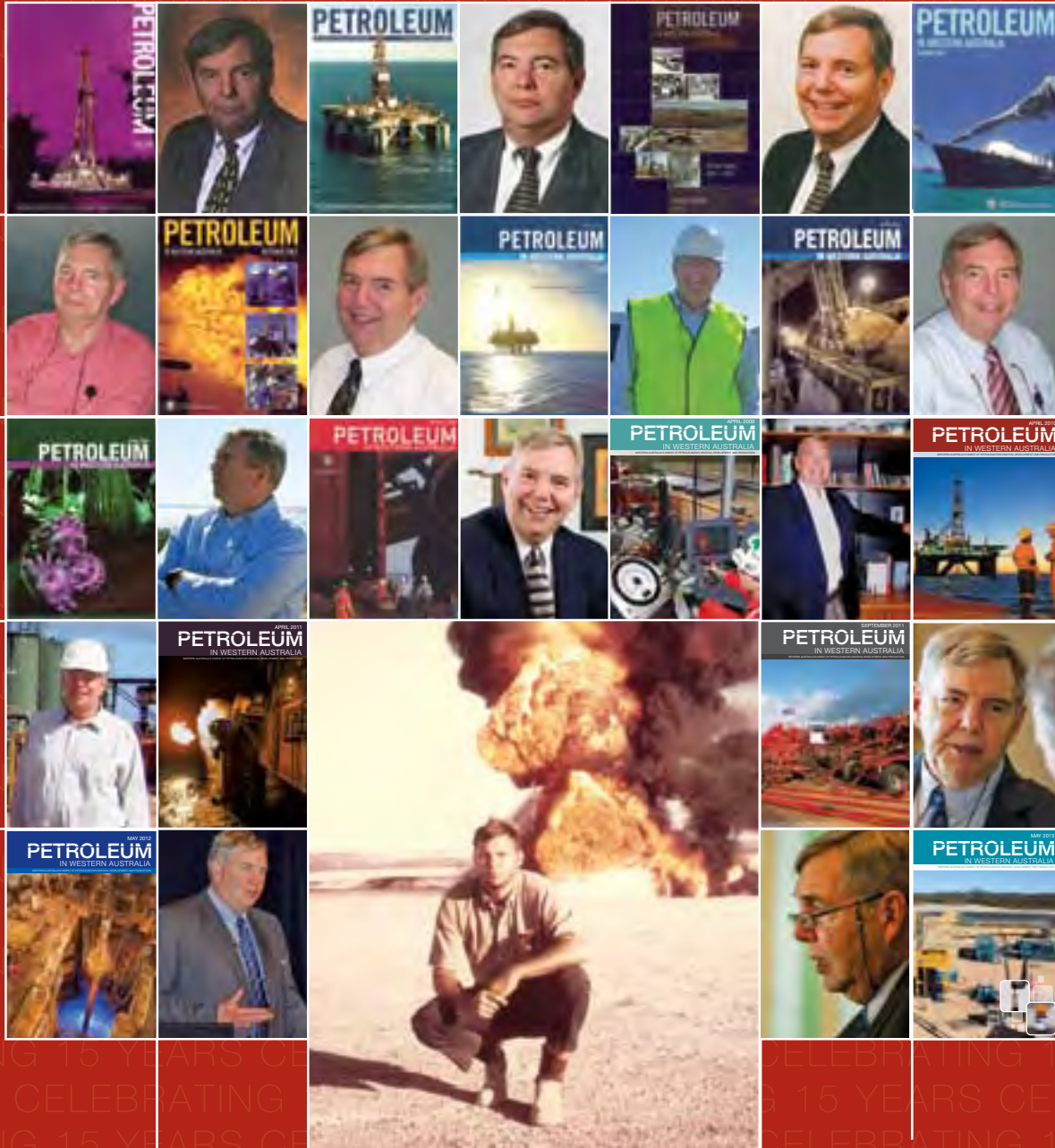


SEPTEMBER 2013

PETROLEUM

IN WESTERN AUSTRALIA

WESTERN AUSTRALIA'S DIGEST OF PETROLEUM EXPLORATION, DEVELOPMENT AND PRODUCTION



BILL TINAPPLE – RECOGNISING 15 YEARS OF SERVICE

Contents



The Wannamal 3D Heliseismic survey – lifting drilling equipment to site
(Photo courtesy of Empire Oil and Gas)

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Cover photos: Bill Tinapple during his years at the department from 1998 to 2013 with covers of the PWA magazine. Feature image – Bill on a well test in Libya in the early days of his career

(Photo courtesy of Bill Tinapple)

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Key Petroleum Contacts



Find out more

The Department of Mines and Petroleum (DMP) has a range of up-to-date resources available in hard copy and online.



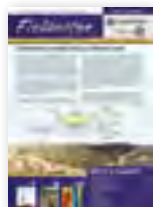
PRINTED PUBLICATIONS



PETROLEUM IN WESTERN AUSTRALIA

Petroleum in Western Australia (PWA) is a biannual publication highlighting petroleum exploration, development and production activities in State waters and onshore areas of WA.

To access this publication online, visit:
www.dmp.wa.gov.au/petroleumwa



FIELDNOTES

Fieldnotes is a quarterly publication released by Geological Survey WA (GSWA), which provides the State's exploration industry and other geoscientists with an update on our latest work and ongoing programs.

The publication provides updates on other GSWA products and services, and is available free from the Information Centre located on the first floor of Mineral House, 100 Plain Street, East Perth 6004.

To access this publication online, visit:
www.dmp.wa.gov.au/gswafieldnotes



WESTERN AUSTRALIA'S PETROLEUM AND GEOTHERMAL EXPLORER'S GUIDE

This publication provides general information and guidance on the legislative framework for companies considering exploring and investing in Western

Australia's upstream petroleum and geothermal energy industries and for companies currently involved in those industries. It may also be a reference for the public and other government agencies.

Information in this guide relates predominantly to petroleum and geothermal energy resources activity in Western Australia, its onshore and State water areas including islands.

To access this publication online, visit:
www.dmp.wa.gov.au/petroleumwa



PROSPECT

Prospect is Western Australia's international resources magazine, providing a comprehensive overview of the State's resources industry. The magazine is produced quarterly and is aimed at industry executives, financiers, suppliers and others involved in

the mineral and petroleum industries.

It includes articles on resources issues, current and forthcoming Western Australian development projects, and industry news. It also includes maps of the major resources projects around the State.

To access this publication online, visit:
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ELECTRONIC PUBLICATIONS



DG'S E-NEWS

The Director General's eNews is a quarterly email update on departmental activities, opportunities and endeavours.

The eNews addresses projects in progress, upcoming events and changes to the industry. Subscriptions can be completed online.

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The Quarterly Approvals Report measures the department's assessment timelines for both electronic and hard copy lodgements.

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To access this publication online, visit:
www.dmp.wa.gov.au/approvalsreport



STATISTICS DIGEST

The Statistics Digest contains key statistical information and analysis of the Western Australian resource sector. It provides a comprehensive coverage on the composition, magnitude and performance of the WA mineral and petroleum industry.

It includes an assessment of selected major commodities, as well as price trends, the State's position as a resources exporter, royalty receipts, mineral titles, employment and investment, and contact details for principal producers.

The publication is available electronically and is published for each financial year and calendar year.

To access this publication online, visit:
www.dmp.wa.gov.au/statisticsdigest



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Department, industry and Minister news articles are published on the department's website, to highlight the mining and petroleum sector,

departmental programs and current issues.

Subscribing to DMP news alerts allows you to receive news updates as they are posted on the website. Subscriptions can be completed online.

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geothermal energy and dangerous goods sectors in Western Australia.

The weekly alerts include information about Resources Safety publications, safety alerts, events and opportunities to provide feedback.

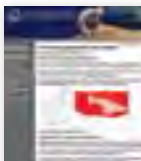
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This RSS Feed provides the latest industry news and updates on shale and tight gas.

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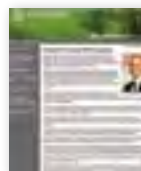


GSWA eNEWSLETTER

DMP's GSWA emails all of its subscribers a monthly eNewsletter. This contains details about new product releases, geophysics and aeromagnetic data, current geological topics of

interests, and technological advances in mapping and GIS systems.

To access this publication online, visit:
www.dmp.wa.gov.au/gswaenewsletter

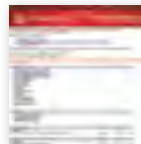


ENVIRONMENT eNEWSLETTER

This bi-monthly newsletter covers a range of topics including approvals reform initiatives, responsible resource exploration and development, new guidance

material and policies, and performance reports. You'll also receive the latest environmental news from DMP, as well as upcoming events and achievements.

To access this publication online, visit:
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The Data and Software Centre enables the download of State-wide geoscience and resource data. These datasets are available in various formats.

In addition, the Data and Software Centre contains various spatial applications software, including GeoMap. WA and the Mineral Exploration Reporting Templates tool.

To access this publication online, visit:
www.dmp.wa.gov.au/datacentre

GSWA ANNUAL WORK PROGRAM

GSWA publishes a yearly review in its Annual Work Program – which covers GSWA's products, achievements and outlines work projects for the coming year.

To access this online, visit:
www.dmp.wa.gov.au/annualreview



Hon. Bill Marmion
Minister for Mines and Petroleum

Minister's Message

In what is my second Minister's message for Petroleum in Western Australia (PWA) magazine, I would like discuss how the State is developing our natural gas resources and incorporating carbon capture storage into our legislation – facilitating a cleaner energy mix for Western Australians.

As part of the State's Strategic Energy Initiative, we recognise the important role natural gas has to play in terms of meeting our growing energy demands and providing a cleaner energy alternative to coal and oil-based products.

Currently, the State Government requires 15 per cent of gas exported as LNG from State areas to be reserved for domestic use including electricity generation and support of our core industries including mining, manufacturing and transport.

To ensure WA's rising energy demands continue to be met, new gasfields must be discovered and developed.

An emerging Western Australian industry that has the potential to meet these rising demands is natural gas from shale and tight rocks, also known as shale and tight gas.

Advancements in hydraulic fracturing (fracking) and horizontal drilling technologies mean the State's estimated vast natural gas resources found deep underground in shale and tight rocks can now potentially be unlocked.

These resources are tipped to be large enough to supply the State with more than 500 years of gas, based on current domestic consumption levels.

The location of the resources, mainly in the onshore Canning and Perth basins, also provides the State the opportunity to diversify its natural gas sources – reducing reliance on domestic gas sources from our North West Shelf.

Incidents such as the one that occurred on Varanus Island in 2008, which temporarily cut off one third of the State's gas supply, demonstrate how important multiple supply sources are when it comes to securing our domestic gas future.

Recently, the State Government signed a State Agreement with Buru Energy and Mitsubishi to supply domestic gas from the Canning Basin region.

As part of this agreement, a gas pipeline is set to be built from the inland Kimberley region to Port Hedland.

I believe the development of the State's natural gas resources, combined with other greenhouse gas initiatives such as carbon capture and storage (CCS), will leverage technological advancements – moving the State towards a cleaner energy future.

In other developments, the State's Legislative Council is currently reviewing the *Petroleum and Geothermal Energy Resources Act 1967 Amendment Bill*, which will amend the State's leading petroleum act, to incorporate onshore geological storage of greenhouse gases – more commonly known as carbon capture storage.

The amendments would provide property rights for greenhouse gas storage formations, acreage release provisions, exploration and retention, and injection licences. The Bill would accommodate the transportation of greenhouse gases via pipelines.

If passed, the Bill would also allow greenhouse gases created at major industrial sites to be stored deep underground, reducing the amount of airborne emissions.

The State's Gorgon gas project is currently the only committed project in WA to include carbon capture and storage. This activity is being regulated under the *Barrow Island Act 2003* State Agreement.

The Federal Government has, through the CCS flagships program, funded a joint State Government and industry project in the South West – which aims to prove up geological storage for South West industry.

Currently the Department of Mines and Petroleum is analysing results from the Harvey 1 well. The next stage of data acquisition will be 3D seismic in early 2014.

Moving further abroad to our petroleum export industry, I'm pleased to announce the 2012 figures for Western Australia's petroleum industry were extremely positive.

LNG production and export, in particular, continue to provide the State with significant economic benefits. In 2012, production reached a record 18.3 million tonnes, reflecting an increase of 14 per cent and \$11.3 billion in sales.

In terms of commodity values for 2012, LNG was second only iron ore and continues to be a significant contributor to the State's economy. ■

**Bill Tinapple**

Executive Director
Petroleum Division

Executive Director's Message

At the end of this year, I will be retiring as Executive Director Petroleum for the department (DMP) after 15 years in the role. Having been involved in the petroleum industry for over 40 years, I would like to take this opportunity to reflect on the changes I have witnessed in the Western Australian industry.

These changes have included incredible advances in technology, shifts in global supply and demand, and the emergence of a cleaner, more diverse energy supply.

The scene in the early 80s was mainly onshore gas production from Dongara, oil production from Barrow Island and large undeveloped gasfields on the North West Shelf (NWS) discovered in the 70s. To harness the vast reserves of the NWS required developing a large pipeline infrastructure, sourcing markets and building offshore facilities. The State Government's commitment to domestic gas supply not only provided 25 years of reasonably priced gas but also "kick started" LNG development.



(Photo courtesy of Woodside Energy)



(Photo courtesy of Norwest Energy)

Gas from the North West Shelf project first flowed into our homes in the 80s, following the completion of the Dampier to Bunbury natural gas pipeline in 1984, supplementing the Perth Basin gas supplies through the Parmelia pipeline from Dongara. The joint government/industry cooperation formalised in the DomGas State Agreement ensured our State's energy security. In the late 80s and 90s the Karratha gas plant was the largest engineering project in the world with three LNG trains. Capacity was increased to 16.3 million tonnes per year with the construction of the fourth and fifth LNG trains from 2001 to 2005.

It wasn't until the mid-80s when significant offshore oil discoveries were made, such as Harriet, Saladin and Yammaderry, that the perception that the offshore was only gas-prone was shown to be false. These smaller oilfields were quickly developed using new technologies including monopods and unmanned platforms.

The change in the philosophy of 3D seismic technology as an appraisal tool in the 80s to an exploration tool in the 90s, coupled with multi-streamer acquisition which lowered costs, enabled WA petroleum explorers and geologists to understand the geology like never before. During the 90s, seismic contractors carried out large scale, multi-client seismic surveys over the NWS, which led to an increased rate of discovery in the offshore waters, mainly in the "mighty Mungaroo" Formation. However, the industry did not yet have the technology to develop these discoveries, coining the term "stranded gas" for deep water giant discoveries such as Scarborough and Torosa.

In the 90s, new technologies facilitated the development of offshore discoveries. These new technologies included floating production storage and offloading vessels (FPSOs) and the expansion of liquefied natural gas (LNG), which revolutionised how the offshore industry stored oil and transported hydrocarbons to overseas markets. The growth in subsea

completion technology has resulted in more cost-effective developments enabling a string of oil discoveries, starting with Wanaea in 1989 and Cossack in 1990, to be brought online. To date, there have been more than 15 FPSOs operating offshore Western Australia.

In 2008, a gas explosion on Varanus Island reduced the State's gas supply by one third for six months. In 2009, the Montara oil spill off the northern coast spilled light oil into the ocean for 74 days before it could be capped. As a result of these incidents and recommendations from the investigations, governments took action to minimise the risk of another incident occurring off our coast.

The National Offshore Petroleum Safety Authority (NOPSA) already existed in 2005, to regulate safety for the offshore. However, legislative changes saw the commencement of the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) in 2012. These changes were aimed to clearly define the regulator responsible for Commonwealth waters with the aim of minimising the risk of such offshore incidents from happening again.

2012 also saw the creation of the National Offshore Petroleum Titles Administrator (NOPTA), moving Titles administration and other functions from the Designated Authority (DMP in WA). This has realigned Petroleum Division's functions to focus on the State areas and maintain the State Joint Authority role.

While WA is currently experiencing an LNG boom, with \$120 billion worth of projects committed or currently under construction, including the Gorgon and Wheatstone projects, fields on the North West Shelf are maturing. LNG production and export, in particular, continue to provide the State with significant economic benefits. We will soon see the pioneering floating LNG (FLNG) technology utilised at Prelude. Other developments may follow in a quest to control development expenditures.

The next growth opportunity for the State is likely to be shale and tight gas and oil. In the State's onshore, shale and tight gas potential resources are estimated at 8000 Gm³ (280 Tcf), while shale oil is estimated at 1600 GL (10 Bbbl). With the majority of this

resource in remote areas of the Canning Basin, exploration and subsequent production is likely to be gradual, but the resource is significant.

As with previous oil and gas development in this State, advanced technologies like horizontal drilling and hydraulic stimulation will be essential to harness these resources.

As the lead regulator for this sector, DMP is working with other government agencies, communities and industry to understand issues surrounding shale gas development so that we ensure that appropriate regulation of the industry occurs. DMP has taken the initiative to visit local communities to hear these issues first hand and explain the role of the department as the regulator.

As the industry moves to develop resources in more remote areas and in deeper waters farther away from existing infrastructure, having regard for the environment is a high priority. An aspect of this is the carbon capture and

storage (CCS) technology being used as part of the Gorgon project. DMP's role has been to ensure due diligence is maintained during the planning and implementation stages of the project and to ensure Chevron performs to internationally accepted high standards.

Witnessing and being involved in these developments during the past 30 years has been an incredible privilege for me and I look forward to seeing how this State responds to the future challenges that will arise in this ever-evolving industry.

A recent trip overseas brought home to me how Western Australia is a lucky state in a lucky country. Fortunately, we have resources yet to be discovered and developed. Much of the benefits from previous resource developments have been used for immediate needs and little has been used for longer term, sustainable development. I am hopeful that some benefits from these finite resource developments can be set aside for future generations. ■



(Photos courtesy of Woodside Energy)



Jeffrey Haworth

Director Technology,
Petroleum and Geothermal
Petroleum Division

Director's Message

Later this year, the Department of Mines and Petroleum (DMP) will be rolling out the last of the suite of new objective based regulations to replace the current more prescriptive *Schedule of Onshore Petroleum Exploration and Production Requirements 1991* and the *Schedule of Geothermal Exploration and Production Requirements 2009*. This is the final part of a four year program that commenced with the introduction of the *Petroleum and Geothermal Energy Resources (Occupational Safety and Health) Regulations 2010* and last year with the *Petroleum and Geothermal Energy Resources (Environment) Regulations 2012*.

This is a part of a nationally agreed harmonisation of petroleum regulation throughout all the States, the Northern Territory and Commonwealth to ensure, as much as practicable, operators are subject to similar requirements and obligations throughout Australia.

The proposed *Petroleum and Geothermal Energy Resources (Resource Management and*

Administration) Regulations 2013 (RMA) will regulate petroleum field development, geothermal energy projects, well construction and data submission and release. As with all new regulations the RMA is an objective-based, risk management regime of regulation, which requires operators to manage their operations ensuring world's leading practice and a "fit for purpose" design.

As part of our continuous improvement process, DMP has been monitoring developments in regulation worldwide including legislation from the US, Canada, Europe and the UK. The department has also researched many papers published on drilling, completion, hydraulic fracturing and production for traditional oil and gas development, as well as shale and tight gas and oil development, to ensure the new regulations are robust and cover all aspects of emerging technologies.

Apart from moving from prescriptive to objective-based regulation, the new regulations embrace a "whole of life" approach to wells and field development. By this I mean the new requirement for "Well Management Plans" (WMP) rather than "Well Operation Management Plans" (WOMP) will require titleholders to consider what maintenance and monitoring programs will be in place for the periods a well is shut in or suspended, when no operations are occurring.

It will also require titleholders to address well management in their WMPs to cover spud to plug and abandonment (P&A) for a well. Similarly for Field Development Plans (FDP), the regulations will require titleholders to consider and address the full lifecycle of the field including decommissioning and closure.

Many of these changes address the issues raised in the 2011 report¹ on regulation by Tina Hunter and also issues identified through our previously mentioned research subsequent to the report.

The regulations also cover geothermal energy both for exploration and production and follow the same WMP and FDP approach as petroleum.

Data submission and release provisions in the regulations are similar to the Commonwealth model, however, they will cover more activities especially in regards to wells.

The NSW Chief Scientist and Engineer, Professor Mary O'Kane, in releasing the Initial Report on the Independent Review of Coal Seam Gas Activities in NSW said, "the industry will have to operate at the very highest of world standards, the government will have to have the very highest standards of legislation and compliance, and we'll all have to have the best standards of monitoring". The department aspires to similar goals for the shale and tight gas and the conventional petroleum industry in Western Australia.

Western Australia has a huge potential for onshore petroleum development in the future. These regulations, complementing the safety and environment regulations, will provide the regulatory framework to ensure these developments are conducted according to world's leading practice and in a responsible manner. ■

¹ Regulation of Shale, Coal Seam and Tight Gas Activities in Western Australia (July 2011), by Dr. Tina Hunter can be found at: www.dmp.wa.gov.au/15139.aspx



DMP inspector on an audit at Buru's Ungani oilfield

Long Serving Petroleum Leader to Retire

“Any achievements that I have made as director over the years, have only been possible due to the contributions made by teams which I have been part of. When I first joined the department, a management development initiative was being implemented, applying Stephen Covey’s “Seven Habits of Effective People”. Over my 15 years with the department, I have continually tried to apply these principles, through jointly setting team goals, delegating responsibility to achieve the targeted outcomes and monitoring progress. Individuals have readily stepped up to take on responsibilities. I owe a debt of gratitude to my fellow team members for making this approach work and helping to achieve the outcomes of our work together.”

– Bill Tinapple



On the occasion of Bill's 25 years in government in 2010, with DMP Director General, Richard Sellers and former Minister for Mines and Petroleum, Norman Moore.



Some of the Petroleum and DMP team from 2009

Petroleum industry identity and Department of Mines and Petroleum's (DMP) Executive Director Petroleum Bill Tinapple, is set to retire after more than 40 years in the oil and gas industry including 15 years at the department.

Bill has a unique perspective of the industry due to his background in engineering and as a regulator in both the Northern Territory and Western Australia. He has been around for so long that most industry people over 30 have worked with him at some time over the years.

Originally from Ohio, in the mid-US, Bill's qualifications are in engineering with a Masters of Business Administration from Ohio State University.

“I’m a Mechanical Engineer by qualification but when I started in the industry there was a shortage of petroleum engineers – as a result of one of the ‘up and down cycles’ that we all have experienced. Mobil put me through a training program of a year of set courses and on-the-job training, to convert me to a Petroleum Engineer. I went overseas and worked in Libya, came back to the US and completed an MBA, before returning to work in the international industry,” he said.

Bill spent nine years based in the UK working on projects there and overseas.

Overall, he worked internationally for about 18 years on several oil and gas projects in the US, Libya, Indonesia, North Sea, Norway, Nigeria, Japan, Australia and Abu Dhabi, before making the permanent move to Australia in 1985.

Bill has been integrally associated with development of the oil and gas industry in Australia, from initial involvement in engineering studies for the North West Shelf through the development of the first floating production, storage and offloading (FPSO) unit. He was also involved in gas pipeline development, including the Amadeus to Darwin gas pipeline. The Australian petroleum industry has benefitted ever since.

“It was 1979 when I first came to Western Australia. I was with an engineering company doing conceptual design work on the North Rankin A platform,” he said.

“I always liked Perth from that time, and although it took me a few years, I finally got here after a bit of a journey. I came back to Perth in 1984, doing more consulting work. At the tail end of 1985 I ended up migrating to Australia and went to Darwin, working in a regulatory role with the Northern Territory Government.”

After 12 years with the NT, Bill accepted the position of Director Petroleum with the Western Australian Government, commencing with the department in 1998.

One of his early decisions was to reinstate the Petroleum Division's publication 'Petroleum in Western Australia' which hadn't been published for a couple of years. Around the same time the first Petroleum Open Day was held, so that the division could communicate better with its stakeholders. Both of these are ventures still going today.

Bill was instrumental in facilitating and encouraging the large multiclient 3D survey offshore campaign in the 1990s which greatly improved the rate of discovery of gasfields on the North West Shelf. He has also been a fervent promoter of the prospectivity of the onshore for oil and gas.

In his role as a regulator, he oversaw the changes within the department resulting from amendments to the Commonwealth's offshore petroleum legislation (the *Offshore Petroleum and*

Greenhouse Gas Storage Act 2006) which came into effect on 1 January 2012.

While heading the Petroleum Division, Bill has assisted in a number of new initiatives, which have been focussed on improving customer service, increasing investment in WA, and sustaining production.

He said presently Western Australia was the leading province in the world for liquefied natural gas (LNG) development and the largest user of domestic gas in Australia. At first glance, it seems as though the State has more than enough gas resources for many years. However, given the lead times involved, the State needs to encourage exploration for and development of other sources of gas for future energy needs.

Recognising the potential for unconventional gas in Western Australia, particularly tight gas and shale gas, five years ago he turned his efforts towards facilitating this aspect of the industry and making sure the Western Australian regulatory framework is

appropriate for this activity. This was initially done through an independent review of the legislation which provided recommendations which are currently being implemented.

"Exploration for unconventional gas is in its infancy here, but all the predictions point to potentially huge resources of tight gas and shale gas. However, while offshore Western Australia has all the benefits of available technology and equipment, it does not have enough onshore equipment, such as drilling rigs and fracing units and associated technology."

This will be a challenge to be addressed by Bill's successor.

The department has been fortunate in having Bill's experience and guidance in developing Western Australia's policy and regulation over the past 15 years and everyone in the department wish him the best for his retirement. Bill is being cagey about his future plans but we expect that he will continue to play some role in oil and gas. ■

Bill on a well test in Libya a "few" years ago
(Photos courtesy of Bill Tinapple)



Petroleum Exploration, Development and Production Activities in Western Australia – January to June 2013

Karina Jonasson

Petroleum Resource Geologist
Resources Branch



Drilling shot holes to provide optimal recording parameters for the Wannamal 3D Seismic Survey over the Gingin Gasfield area and Wannamal Prospect
(Photo courtesy of Empire Oil and Gas)

Overview

This article summarises petroleum exploration, production and development activities for the second half of the 2012–13 fiscal year. Production, reserves by basin, drilling, and seismic survey statistical summary tables for the Western Australian onshore and territorial waters covering the fiscal year can be found in the back of the magazine. A summary of activities carried out in the 2012 calendar year can be found in the May 2013 edition of *Petroleum in Western Australia*.

Wells drilled during the period 1 December 2012 to 30 June 2013 consisted of three new field wildcat wells, two appraisal (extension) wells, three development wells, two water service wells (Barrow WSW 8B and 8C) on Barrow Island and one shallow geothermal exploration well. Of these, only one was drilled offshore, in territorial waters. Drilling activities took place in the Canning, Carnarvon and Perth basins and in the Albany-Fraser Orogeny.

Exploration Activities

Drilling

Cyrene 1 was spudded late in 2012 and the rig released in February 2013. The well was operated by Gulliver Productions, a wholly owned subsidiary of Key Petroleum. The well was targeting oil and gas, including shale

gas resources. Cyrene 1 was reported to have intersected oil shows over a 43 m interval prior to coring in the lower Grant and Goldwyer formations. Additional oil shows were reported from cores collected from the lower Goldwyer Formation suggesting it is an oil-generating source rock in this part of the Canning Basin. The primary target, the Willara Formation, did not contain hydrocarbons. The well was plugged and abandoned with non-commercial oil shows.

Following on from Nicolay 1 in 2012, New Standard drilled the Gibb-Maitland 1 well in EP 450 targeting the shales of the Goldwyer Formation. Stuck drill pipe and failed efforts to retrieve the bottom-hole assembly led to the plug back of the open hole section of the well, which was eventually suspended following problems with the drilling rig. PetroChina has farmed into the Southern Canning Project via ConocoPhillips, taking a 29 per cent stake in the project.

Buru Energy continued its appraisal of the Yulleroo field in EP 436 in the Canning with a fourth well drilled early in the year, noting good gas shows while drilling.

Titan Energy drilled the only petroleum exploration well in the Perth Basin,

Warradarge 1, under a Drilling Reservation located approximately 280 km north of Perth. The well was spudded using the UDER 1500 HD rig (Dominion Drilling), targeting the Cadda Formation and the Cattamarra Coal Measures. Warradarge 1 is located 10 km west of the Woodada gasfield and about 20 km northwest of the Arrowsmith 2 well.

Apache's Taunton 5/5H well in Production Licence TL/2 was drilled as a deviated well in TL/2 that extended into TP/7 to evaluate the Early Cretaceous reservoir section. The Taunton field was first discovered in 1991.

Norwest Energy returned to the Arrowsmith 2 well early in the year to complete flow back of the Carynginia Formation, which was not completed in 2012. Further evaluation of the other hydraulically stimulated formations is planned for later in 2013.

On the geothermal front, Greenpower drilled a 400 m deep geothermal well at Mt Ridley 1 in GEP 38 near Esperance to test a radiogenic granite for hot dry rock (HDR) geothermal energy generation. This is the first HDR exploration in Western Australia and the first "deep" drilling to take place in this part of the Albany-Fraser province.

Mt Ridley 1 is the first of two drill holes in GEP 38 and GEP 39. In June 2012 Greenpower signed a government co-funded drilling grant of \$120,000 for two planned holes for its Mt Ridley geothermal project. Preliminary qualitative analysis of the geothermal tenements suggests at least one granite body with strong thermal potential. Interpretation of available imagery indicates a granite body in the Mt Ridley area with a northeast to southwest strike and a northwesterly dip.

Surveys

Seismic surveying activities were confined to the mainland, with four surveys carried out in the Carnarvon and Perth basins. In addition, four aeromagnetic surveys were conducted

in the onshore Bonaparte and Canning basins, with a total of 33,584 line km of data acquired by Beach Energy, Hess and Goshawk Energy.

Empire completed the Wannamal 3D seismic survey in onshore permit EP 389, which was carried out via helicopter in the first airborne seismic survey on the Western Australian mainland. The heliseismic survey, which included the Boonanarring Nature Reserve, was programmed to de-risk the Wannamal and Wannamal Deep, as well as other prospects in the survey area. The company also conducted a 2D seismic survey covering three of their Perth Basin permits, with the Launer survey in EP 321, EP 430 and EP 454.

Data acquisition on the Badgingarra 2D Seismic Survey at Greenpower's EP 447 in the northern Perth Basin has also been completed. Greenpower is exploring for conventional and tight gas. Total survey length was 212 line km over 17 lines. Land rehabilitation operations commenced on 24 April.

Production

34 fields were online producing hydrocarbons in Western Australia's onshore and State Waters areas in the first half of the year.

Production testing at Buru's Ungani oilfield ceased in March 2013.

The EPT produced more than 16,000 kL (100,000 bbl) of oil from the Ungani 1 and 2 wells. Production from Ungani 2 did not having any discernible impact on reservoir pressure.

Development Activity

Three development wells were drilled by Chevron for the WA Oil Asset on Barrow Island (Barrow F24B MB, F55A MB and G48B MB). These were all drilling into the Mardie B greensand.

Gorgon Project

The latest progress on the Chevron-operated Gorgon Project included the following milestones as at 26 April 2013:

- Gorgon's materials-offloading facility is now fully operational and the adjacent LNG jetty is under construction.
- The first of three amine absorber columns were placed in position on the plant site.
- The first of the Gorgon LNG Train 1 Modules – the central pipe rack modules, known as TAJA and TAJB – were recently placed on their foundations.
- Work has begun on the concrete pour for the outer shell of the two LNG tanks, following the installation of the roof on the second tank last November.

Wheatstone Project

Construction on the Wheatstone Project at Ashburton North began in late 2011. The Chevron-led project includes a two-train, 8.9 million-metric-ton-per-year LNG facility and a separate domestic gas plant. The LNG will be stored in two tanks each with a capacity of 150,000 m³. Recent developments on the project are:



Work continues on the 2.1 kilometre (1.3 mile) LNG jetty with more than 24 caissons in place. Installation of the jetty roadways is underway.
(Photo courtesy of Chevron Australia)



Aerial view of the Red Gully gas and condensate processing facility near Gingin, in the northern Perth Basin
(Photo courtesy of Empire Oil and Gas)

- The first phases of the Wheatstone Project workforce accommodation facilities are now complete.
- Construction of the Wheatstone Project platform continues at the DSME shipyard in Okpo, Korea.
- Micro-tunneling technology is being used to bring Wheatstone's trunkline onshore to help reduce impacts to environmentally sensitive areas, such as onshore mangroves and lagoons, and fauna.
- The main access road to the Wheatstone LNG plant site is nearing completion.
- The upgrade to the Onslow Airport, which is being funded by Chevron, is well under way, with the new 1900 m long runway nearing completion.

Browse Development

The Browse development project has been returned to the drawing board for Woodside (and the Browse Joint Venture) to review alternative development options after deciding

that the James Price Point development concept would not meet the company's commercial requirements for a positive final investment decision. The Browse Joint Venture will begin evaluating other development concepts to commercialise the Browse resources, which could include floating LNG technology, a pipeline to existing LNG facilities in the Pilbara or a smaller onshore option at the proposed Browse LNG Precinct near James Price Point.

Red Gully

Final commissioning of the Red Gully gas and condensate facility in the northern Perth Basin by Empire commenced at the end of May. The plant will process gas and condensate from the Red Gully 1 and Gingin West 1 wells, both of which produced high levels of condensate during initial testing. The gas will be piped to the Dampier to Bunbury natural gas pipeline (DBNGP) while the condensate will be trucked to the BP refinery at Kwinana. Petroleum engineers from DMP were on site for the commissioning process. An Initial

Production Test is being conducted on Red Gully 1 and Gingin West 1.

Rig News

Australian rig contractor Advanced Energy Services Pty Ltd has brought a new drilling rig to Western Australia, the LOC 400. See the article beginning on page 14 for this story. Enerdrill has established itself in Western Australia as a new rig contractor, with two drilling rigs and a workover rig, capable of drilling depths from under 1000 m to over 5000 m. All of these rigs have been designed to handle working in remote areas and the rigs are based in WA.

Abandonment Activities

Industry activity has been on the increase in one area in particular — that of well abandonment. So far this year, there have been more applications for abandonments than there have been for new wells as more fields reach the end of their life. Last year, Sinbad and Tubridgi fields were decommissioned. This year, the remaining Campbell wells, along with Hovea 1 and Yardarino 1 were decommissioned. ■

Grant of Petroleum Titles

Richard Bruce and Chris Ferrinda
Petroleum Division



Aerial view of the Wheatstone Plant Site. Petroleum pipeline licences PL 99 and TPL/2 5 have recently been issued to Chevron Australia by Petroleum Division for the conveyance of gas and condensate from the Wheatstone field to the Ashburton North Strategic Industrial Area (Photo courtesy of Chevron Australia)

State Award

From 1 January 2013 to the end of June 2013, the following petroleum titles were awarded in State areas:

Petroleum Exploration Permits

In January 2013, EP 483 in the offshore Northern Carnarvon Basin was awarded to Finder No. 3 Proprietary Limited. The firm two year period program consists of 1500 km 2D seismic reprocessing and a 115 km² 3D seismic survey. The remaining program consists of geotechnical studies and an exploration well, to an estimated value of A\$6,550,000.

In January 2013, EP 484 in the Perth and Southern Carnarvon basins was awarded to Dynasty Metals Australia Limited. The firm two year period program consists of two stratigraphic wells and 60 km of 2D seismic acquisition, to an estimated value of A\$660,000. The remaining program consists of five stratigraphic wells, geotechnical studies and 120 km of 2D seismic acquisition, to an estimated value of A\$1,585,000.

In January 2013, EP 485 in the Perth and Southern Carnarvon basins was awarded to Dynasty Metals Australia Limited. The firm two year period program consists of two stratigraphic wells and 65 km of 2D seismic

acquisition, to an estimated value of A\$710,000. The remaining program consists of five stratigraphic wells, geotechnical studies and 120 km of 2D seismic acquisition, to an estimated value of A\$1,585,000.

Petroleum Production Licences

In April 2013, L17 (formerly EP 129) over the Lloyd oilfield in the Canning Basin was awarded to Buru Energy Limited for an indefinite term.

Special Prospecting Authorities and Access Authorities

In January 2013, SPA 8 AO in the Carnarvon Basin (vacant acreage) was awarded to Fleet Resources Pty Ltd for the Sth Carnarvon 2D Seismic Survey. The SPA/AO expired 1/07/13. From this date the title holder has six months to apply for an Exploration Permit.

In April 2013, SPA 9 AO in the Perth/Southern Carnarvon basins was awarded to Palatine Energy Pty Ltd and Green Rock Energy Limited for the Murgoo Gravity Survey. The SPA/AO expires on 15/10/13.

In March 2013, AA 1 in EP 447 in the Perth Basin was awarded to GCC Methane Pty Ltd for the Badgingarra 2D Seismic Survey, which is now completed.

Pipeline Licences

PL 99, the Wheatstone Pipeline (onshore) was issued in April 2013 to convey gas and condensate from the coastal waters pipeline to the onshore LNG and domestic gas plants within the Ashburton North Strategic Industrial Area. Estimated length is 2.0 km.

PL 100, the Wagerup Cogen Meter Station pipeline was issued in April 2013 to DBNGP (WA) Nominees Pty Limited. The gas pipeline is 0.08 km in length.

PL 101, the Pinjarra Cogen Meter Station pipeline was issued in April 2013 to DBNGP (WA) Nominees Pty Limited. The gas pipeline is 0.08 km in length.

TPL/2 5, the Wheatstone Pipeline (WA Coastal Waters) was issued in May 2013 to Chevron (TAPL) Pty Ltd (operator) to convey gas and condensate from the Wheatstone Pipeline at the intersection of the outer limits of the Territorial Sea Boundary to the shore crossing at mean low water mark near Onslow, Western Australia. Estimated length is 37.0 km.

Commonwealth Award

Under the State Joint Authority, the Petroleum Division participated in the award of the following new Petroleum Exploration Permits from the first round of the 2012 Acreage Release that closed on 8 November 2012.

Commonwealth award information was sourced from the July 2013 Australian Petroleum News.

WA-483-P (released as W12-8), located offshore Western Australia, 75–100 km offshore from Onslow, predominately in the northern Exmouth Sub-basin, has been awarded to Woodside Energy Ltd.

WA-484-P (released as W11-7), located in waters offshore Western Australia 250–450 km north of Dampier over the north-eastern Plateau and Beagle Sub-basin of the Northern Carnarvon Basin, has been awarded to CNOOC Australia E&P Pty Ltd.

WA-485-P (released as W12-3), located offshore Western Australia in the Caswell Sub-basin, Prudhoe Terrace and Yampi Shelf of the Browse Basin, has been awarded to IPM West Pty Ltd.

WA-486-P (released as W12-9), over the waters in the Barrow Sub-basin

approximately 45–50 km offshore from Onslow, has been awarded to Apache Northwest Pty Ltd.

WA-487-P (released as W11-6), located approximately 250 km north-northeast of Port Hedland and 150 km west of Broome, has been awarded to Pathfinder Energy Pty Ltd.

WA-488-P (released as W12-2), located offshore Western Australia in the shallow waters of the Joseph Bonaparte Gulf in the Petrel Sub-basin, has been awarded to MEO Australia Limited.

WA-489-P (released as W12-12), located offshore Western Australia on the Exmouth Plateau, Carnarvon Basin, has been awarded to Shell Development (Australia) Pty Ltd.

WA-490-P (released as W12-13), located offshore Western Australia on the Exmouth Plateau, Carnarvon

Basin, has been awarded to Shell Development (Australia) Pty Ltd.

WA-491-P (released as W12-14), located offshore Western Australia, 75–100 km offshore from Onslow, predominately in the northern Exmouth Sub-basin, has been awarded to Shell Development (Australia) Pty Ltd.

WA-492-P (released as W11-16), located offshore Western Australia on the continental shelf and slope of the Cuvier margin, has been awarded to Total E&P Australia.

WA-493-P (released as W11-17), located offshore Western Australia on the continental shelf and slope of the Cuvier margin, has been awarded Total E&P Australia.

WA-494-P (released as W12-4) located offshore Western Australia on the Prudhoe Terrace of the Browse Basin has been awarded to Inpex Browse, Ltd. ■



Vibroseis trucks passing cableless geophones on the Launer 2D seismic survey
(Photo courtesy of Empire Oil and Gas)

Deep Gas Advanced Drilling Technology: Company Focus – Advanced Energy Group

Cameron Manifold
Managing Director



The Crusader 405 with its crew
(Photo courtesy of AEG)

Introduction

Background

The onshore oil and gas sector in Western Australia has struggled in recent years to secure suitable resources (drilling equipment, people and related services) to support the exploration, appraisal and development of onshore oil and gas across the State.

This lack of resources is partially due to the surge in onshore oil and gas activity in eastern Australia, driven by the massive investment in coal seam gas in Queensland and the rapidly growing investment in deep tight gas and shale gas in central Australia (specifically the Cooper and Eromanga basins).

Constraints

In addition to the lack of suitable resources, infrastructure constraints also exist within the more remote regions of Western Australia. These constraints limit the ability of the exploration and production community to undertake significant exploration investment and include:

- **access to infrastructure** – there is a lack of pre-existing infrastructure to support the commercialisation of onshore oil and gas (pipelines, roads, airstrips, logistics facilities, etc);
- **access to customers** – the Western Australian domestic market is at the ‘wrong’ end of the existing pipelines and there is limited spare pipeline capacity to satisfy domestic demand;
- **access to funding** – there is limited funding for onshore unconventional gas exploration (tight gas and shale gas) resulting in thinly capitalised companies and increased risk to the industry as a whole;
- **permits and approvals** – companies need to plan and manage the approvals process across government to ensure approvals are completed in a timely manner preventing delays in operations. This may result in increased costs to the company.

The combination of these factors, in conjunction with strong demand from eastern Australia, severely limits

the willingness of service providers to divert existing resources from long term contracts to the more sporadic short term contracts that are currently available in Western Australia.

Advanced Energy Group Company Background

The Advanced Energy Group (AEG) is one organisation that views the current situation as a major opportunity to develop a local well construction capability in a high demand market, while introducing step-change improvements to operational health, safety and environmental protection.

AEG is a privately owned Western Australian provider of well advisory, well construction and contract drilling services. The group was established in January 2013 by Cameron Manifold and is dedicated to supporting the development of conventional, unconventional and geothermal energy in Western Australia.

The company has been established to provide experienced people, advanced equipment and streamlined systems

and services in order to deliver, high quality, low cost exploration, appraisal and production wells.

AEG is committed to supporting local companies and creating employment opportunities to develop a sustainable onshore oil and gas industry within Western Australia.

Selected Rig Technology

The shale gas and shale oil sector in North America is driving a rapid revitalisation and modernisation of the onshore drilling rig fleet. New rigs being developed and constructed are focused on mobility, efficiency and automation in order to construct the massive numbers of wells that are required to commercialise their unconventional energy resources. Through this process of technological innovation, the efficiency of drilling rigs is improving, time spent on drilling wells is decreasing and our environmental impact is reducing.

The need to reduce overall well construction costs drive innovation, and we are now seeing an increasing number of technologies entering the sector that support our focus on cost reduction. These technologies include:

- Duel fuel power generation (diesel and gas fired units);
- Casing drilling technology (removal of redundant pipe handling operations);
- Automation of manual handling functions on the rig floor (greater efficiency and enhanced safety); and
- Integration of data capture and transfer technology providing office personnel with 24/7 access to well-site data (fewer people at site).

AEG invested significant time and effort identifying leading providers of innovative rig technology and eventually selected a Low Operating Cost (LOC) rig from Huisman Equipment B.V. (Huisman), a leading provider of heavy construction equipment to the global offshore oil and gas industry.

Founded in 1929, Huisman designs and manufactures a range of specialist equipment, including:

- Deep water and high capacity cranes;

- Pipelay equipment;
- Compensating winches;
- Deep water drilling equipment; and
- Related vessel design.

Much of the knowledge, experience and high quality engineering from Huisman's offshore technologies have been incorporated into the onshore rig technology that is now available in Western Australia via the LOC-400 drilling rig that is operated by AEG.

The LOC-400 drilling rig, known as Crusader 405, is the most advanced deep gas drilling rig currently available in Australia. Key features of Crusader 405 include:

- **Small footprint** – reducing site preparation requirements;
- **Highly mobile** – modular and containerised design improves mobility and reduces intra and inter basin transportation costs;
- **Highly automated** – automated rig floor reduces manual handling operations and improves crew health and safety;
- **Cyber drilling** – cyber control station in air conditioned control room centralises all primary rig functions and provides a comfortable working environment;
- **Enhanced reliability** – high degree of redundancy on power generation and control functions enhances the reliability and safety of the rig and the well;
- **Casing drilling** – integrated casing drilling capabilities enable a step-change reduction in well construction time and cost;
- **Small crew** – smaller rig crews (including removal of some third party well-site services) reduces the number of personnel at site thereby lowering overall well construction costs.

These key features make Crusader 405 attractive to operators seeking to conduct exploration and appraisal programmes in the more remote basins of Western Australia and the Northern Territory.

Current Status

At time of publication, Crusader 405 is being commissioned and prepared

for field operations at Kwinana Beach. Final commissioning and compliance verification is expected to be completed by the end of August 2013. This programme is designed to test all functions of Crusader 405 (in particular safety interlocks for automated equipment functions), enable verification of compliance to Australian standards and support crew familiarisation and training.

Senior crew members will also undertake comprehensive training on a purpose-built LOC-400 simulator located in Houston, Texas.

Work Programme

AEG has secured two initial contracts for the rig. The first contract will involve operations at the Whicher Range field located approximately 230 kilometres south of Perth. The contract will involve re-entry of the existing Whicher Range #4 well for the following purpose:

- remove the existing 89 mm (3-1/2") completion and packer;
- set a whipstock and mill a window at approximately 3950 metres within the target Willespie Formation;
- drill approximately 440 metres of new reservoir using underbalanced drilling technology; and
- re-install the 89 mm (3-1/2") completion underbalanced.

Upon completion of drilling operations at Whicher Range, Crusader 405 is contracted to Buru Energy Limited for an initial four well campaign in the Canning Basin. This will involve a 2600 kilometre journey to the Canning Basin.

Future Activities and Technologies

AEG is committed to working closely with Western Australian operators to continuously improve well construction efficiency; raise health, safety and environmental standards; and reduce overall well construction costs. As our clients achieve exploration and appraisal success, their focus will shift from remote exploration wells to enhanced efficiency of development drilling, as well as minimisation of the environmental impact of remote operations.

By working closely with its business partners, AEG will provide enhanced capabilities that are aligned to our client's objectives. These services and technologies are likely to include:

- Closed-loop drilling fluid management systems enabling fluid conditioning and recycling with greatly reduced environmental impact;
- Directional casing drilling technology enabling efficient construction of horizontal development wells, significantly reducing overall well construction time and cost;
- Underbalanced drilling capabilities enabling optimisation of reservoir performance for development wells and a reduction in overall well numbers; and
- New rig (such as the design shown in Figure 1) which enable extremely efficient rig moves at multi-well pads ('walking rig') and between fields and basins.

It is clear that a step-change is required in the onshore drilling services sector, a change that will reduce overall well construction costs, reduce our environmental impact and greatly improve the health and safety of well-site personnel.

AEG believes that these changes can only be delivered by the embracing new technologies and adopting a management philosophy that enables closer collaboration and alignment between operators and service providers.

This will not be an easy change to realise, however it is crucial to improving productivity and reducing overall well construction costs within the onshore oil and gas sector. If this can be achieved it will deliver significant value to exploration and production companies, service providers and the Western Australian community. ■



Figure 1. Illustration of the Huisman LOC-400 'walking rig'
(Image courtesy of AEG)

Groundwater Salinity of the South West Hub Carbon Storage Project Area

Philip Commander¹, Sunil Varma² and Dominique Van Gent³



The Harvey 1 data well
(Photo courtesy of Mark Mitchell)

Introduction

The area of the Harvey Ridge structural high about 50 km north of Bunbury is being assessed for its feasibility of storing significant quantities of CO₂. The SW Hub carbon capture and storage (CCS) project aims to store up to about 6 Mt/y for 40 years as a means of greenhouse gas (GHG) reduction in the atmosphere.

A series of investigations have been conducted to date to characterise the site for CO₂ storage, which includes a 2D seismic survey and the drilling of a 2945 m deep data well, from which a total of 217 m of core and extensive wireline logs have been taken. Several research projects are underway looking at facies distribution, geochemistry, geophysical properties and fault behaviour, based on which the static, dynamic and forward models for the study area are being updated.

The SW Hub project area is within the Harvey Ridge structural subdivision of the Perth Basin. The Perth Basin is a sedimentary basin which extends from Geraldton in the north to Augusta in the south. The sandstones in the basin form major confined aquifers, containing groundwater, which are used for domestic, stock, irrigation, industry and town water supply.

The Department of Mines and Petroleum recently commissioned a description of the hydrogeology and groundwater resources of the broader project area (between Mandurah and Bunbury) for an improved understanding of the groundwater resources of the area in the context of CO₂ storage in the Lesueur Sandstone. The following is a summary of the outcomes of the study.

Superficial aquifer

The superficial formations cover the Swan Coastal Plain, extending from the Darling Scarp, where they overlie granitic rocks, to the coast. They include a number of formations which range in age from late Pliocene (1.5 million years) at the Darling Scarp to mid to late Pleistocene and Holocene (less than 10,000 years) at the coast. In general, the sediments are mostly clay in the east, and mostly sands and limestone in the centre and west. Together, the superficial formations form the superficial aquifer, though the included Guildford Clay does not transmit or store groundwater readily. Recharge to the superficial aquifer takes place locally, to sandy deposits along the foot of the Darling Scarp from runoff and from rainfall where there are sandy sediments, but most recharge is in the centre and west of the coastal plain.

There are small areas of low salinity groundwater in the superficial aquifer along the more elevated parts of the foothills, at Harvey and to the north. In general, the groundwater is brackish in the east of the coastal plain, and saline near Benger Swamp (Figure 1). The superficial aquifer is widely used for stock and domestic purposes, except in areas of high salinity, associated with the Guildford Clay. The aquifer is used extensively for irrigation of vegetables and lucerne and there has been minor use for mineral sands close to the Darling Scarp.

Leederville aquifer

The Cretaceous Leederville Formation underlies the superficial formations across almost the entire area, being absent only in a small area east of Pinjarra and at Bunbury. In the Harvey Ridge area the formation is mainly shale with thin interbedded sands, likely to correlate with the Mariginiup Member (Lower Leederville aquifer). Recharge to the Leederville aquifer can only take place by leakage from the superficial aquifer, generally where the Guildford Clay is absent. Recharge takes place locally in elevated areas along the Darling Scarp, and from beneath the water table mounds in the central part of the coastal plain.

Groundwater salinity is quite variable, both spatially and with depth. Generally, the groundwater is brackish in the east of the coastal plain in the Harvey Ridge area, with comparatively thin horizons of fresh water in the centre and west where recharge conditions are more favourable (Figure 2). Groundwater with a salinity of less than 1000 mg/L total dissolved solids (TDS) occurs only in the upper part of the Leederville aquifer. The remainder

of the Leederville aquifer contains brackish to saline water. There is little use of the Leederville aquifer in the Harvey Ridge area because of the high salinity. The aquifer supplies Preston Beach, and there are a few irrigation licences in the Myalup and Coolup areas, and some licensed domestic supplies (mainly 1500 kL/a), and there has been use for mining at Cookernup. However, these supplies are marginal to brackish.

Yarragadee aquifer

The Late Jurassic Yarragadee Formation is absent on the Harvey Ridge, having been removed by erosion at the time of continental rifting and breakup about 130 million years ago. The southern Yarragadee aquifer extends only as far north as Australind, whereas the northern Yarragadee aquifer does not extend farther south than North Dandalup (Figure 3). The southern Yarragadee aquifer is used for Australind, Eaton and Bunbury public water supply.

Cattamarra aquifer

The Early Jurassic Cattamarra Coal Measures are present below the Leederville Formation in the Kemerton area and to the south, and to the north of Waroona. The formation consists of grey shale interbedded with weakly consolidated sandstone, and minor coal measures. Recharge to the formation is very restricted. East of Pinjarra, and to the north along the Darling Scarp, small areas occur immediately below the superficial aquifer allowing recharge, but elsewhere the Cattamarra aquifer is blanketed by the shales in the Leederville Formation.

Groundwater salinity in the top of the formation in Harvey Line 1 observation bore is less than 3000 mg/L reflecting leakage from the overlying Leederville aquifer. Elsewhere in the Harvey ridge area, the groundwater salinity exceeds 3000 mg/L, reaching over 30,000 mg/L at the base of Harvey Line 1.

Eneabba aquifer

The Early Jurassic Eneabba Formation underlies the Cattamarra Coal Measures, and directly underlies the Leederville Formation, where the Cattamarra Coal Measures are absent (Figure 4). It occurs in the Harvey and Binningup Lines but has not been identified as a separate unit in petroleum exploration wells south of the Binningup Line.

Groundwater salinity in the Eneabba Formation increases with depth. In the Binningup Line observation bores, the salinity is only less than 5000 mg/L in the western part. In the east the salinity exceeds 20,000 mg/L. The Eneabba Formation is not used for groundwater supply on account of the high salinity and depth.

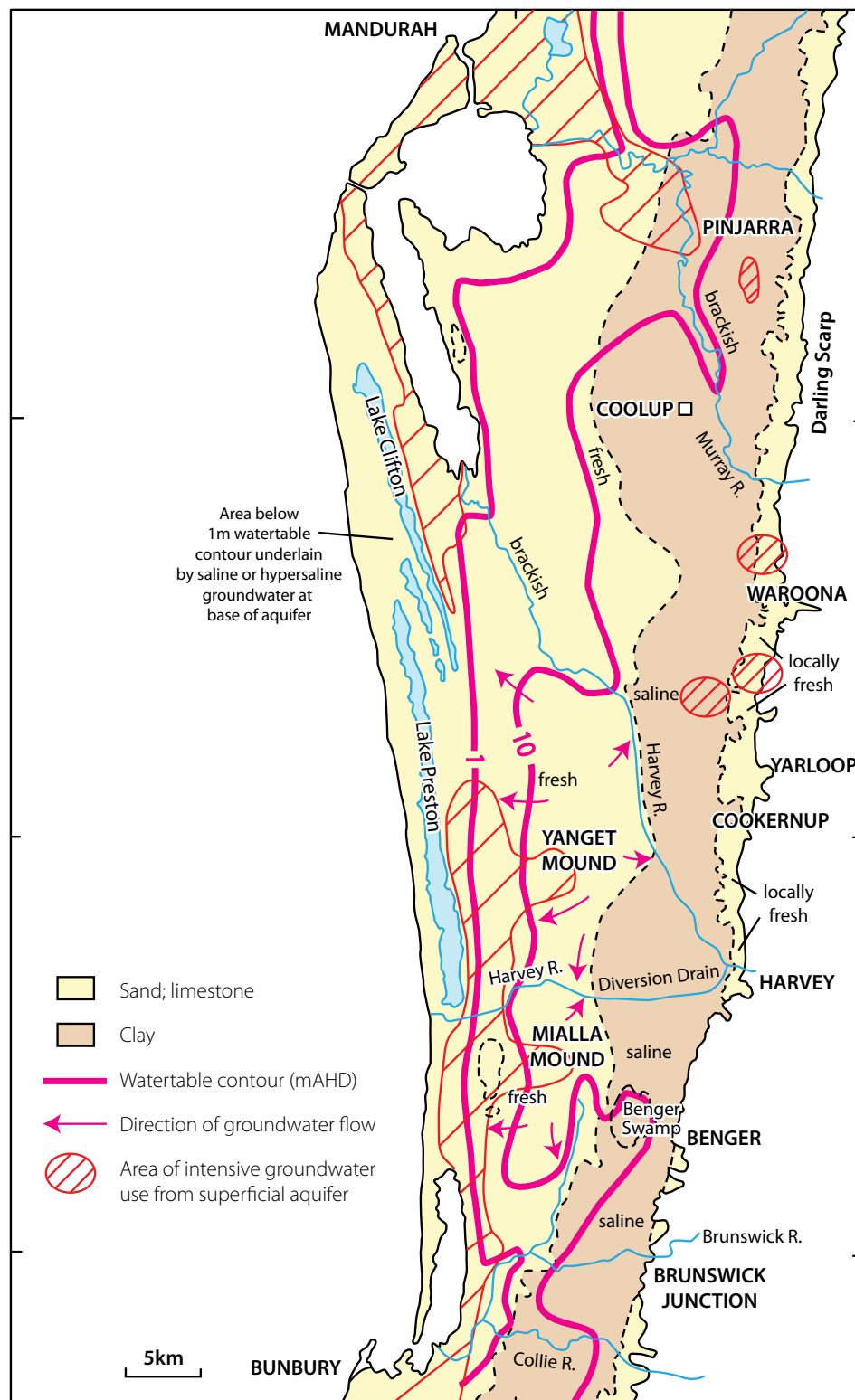


Figure 1 | Superficial aquifer – hydrogeology and groundwater use

Lesueur aquifer

The Late Triassic Lesueur Sandstone extends over the whole area at depths generally exceeding 700 m, and has only been intersected in deep petroleum exploration wells and the GSWA Harvey 1 geosequestration data well (Figure 4). The Lesueur Sandstone is subdivided into the basal Wonnerup Member, which consists of medium to coarse-grained sandstone with interstitial kaolin, and the upper Yalgorup Member (previously also known as the Myalup Member) containing finer sands and dark grey siltstone beds. The formation is about 1200 m thick in Lake Preston 1. The reported presence of interstitial kaolin, and the depth of burial indicate low hydraulic conductivity. Wireline logs through the formation indicate that the groundwater is saline or hypersaline. In GSWA Harvey 1 the salinity is estimated to be 60,000 mg/L in the Wonnerup Member and around 50,000 mg/L in the Yalgorup Member. One fluid sample was taken from the Yalgorup member at 856 m, which gave a salinity of 52,320 mg/L (Figure 4). The log derived water salinity at this depth is about 53,000 mg/L, giving good agreement between estimated and measured formation water salinity.

The nearest parts of the Lesueur aquifer containing low salinity groundwater are locally at Augusta and at Jurien, where the formation comes near the surface, but these localised flow systems are not considered to be well connected with the formation at depth in the central parts of the Perth Basin, particularly near the Harvey Ridge. The Lesueur aquifer is everywhere overlain by the low permeability Eneabba Formation, therefore there is little opportunity for recharge of lower salinity water.

Like the Eneabba and Cattamarra Coal Measures, the saline groundwater can be considered to be stagnant or flowing extremely slowly, isolated from the meteoric water cycle. Groundwater in the Lesueur Sandstone is likely to be highly compartmentalised by faulting, further reducing the hydraulic connectivity and opportunity for groundwater flow.

Conclusions

The Harvey Ridge structural subdivision is one of the least prospective areas for groundwater in the Perth Basin, because of the low elevation, clay soils and unfavourable structure which result in high salinity. Fresh groundwater is generally only available from the superficial aquifer in the centre and west

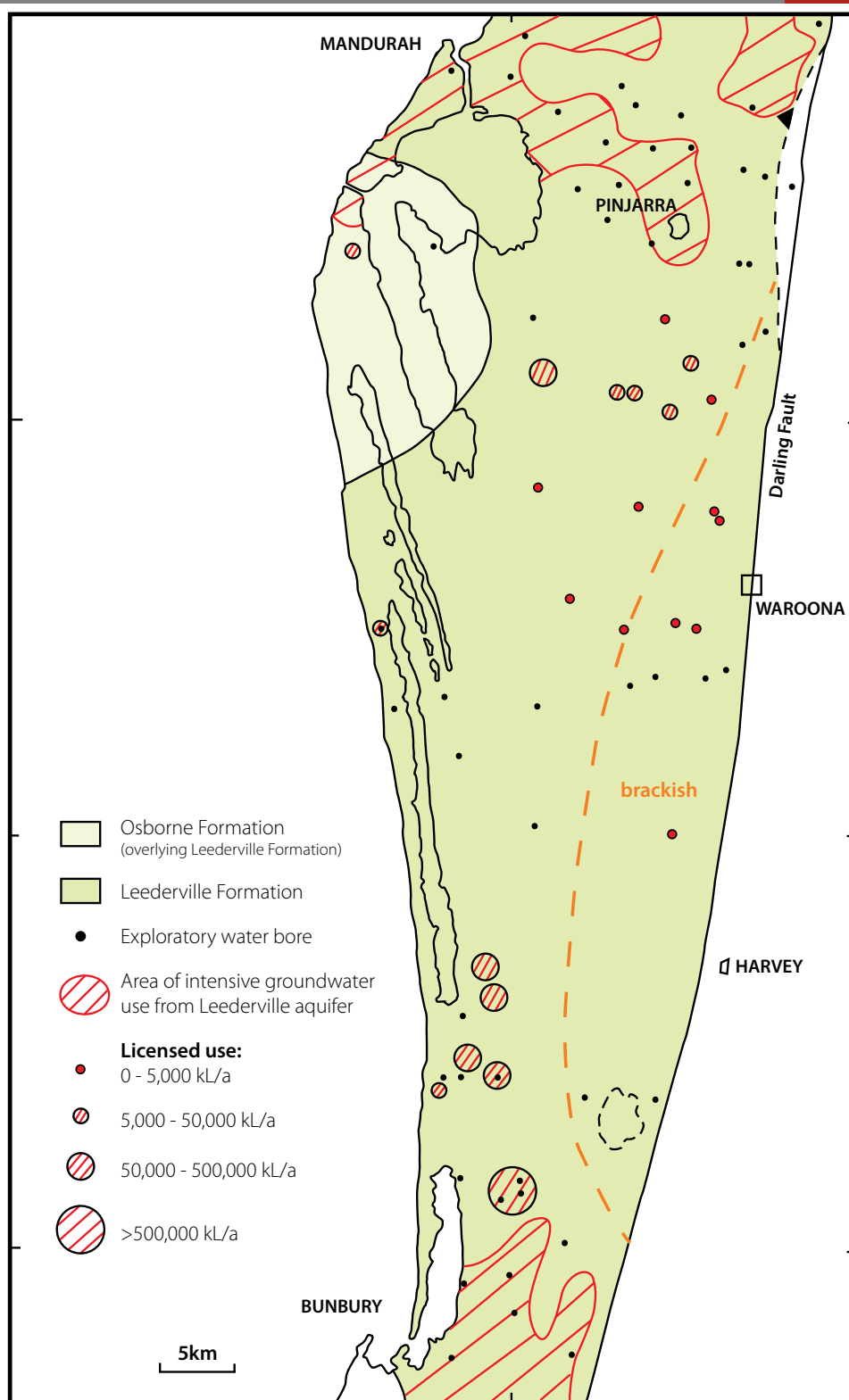


Figure 2 | Leederville aquifer

of the coastal plain, and locally along the Darling Scarp. Groundwater use is generally restricted to shallow bores in the superficial aquifer and the upper part of the underlying Leederville aquifer. Most of the groundwater in the underlying confined aquifers is brackish or saline, with hypersaline groundwater at depth in the Cattamarra, Eneabba and Lesueur aquifers considered to be stagnant and

isolated from meteoric groundwater flow and hence would not be considered as being at risk from CO₂ storage.

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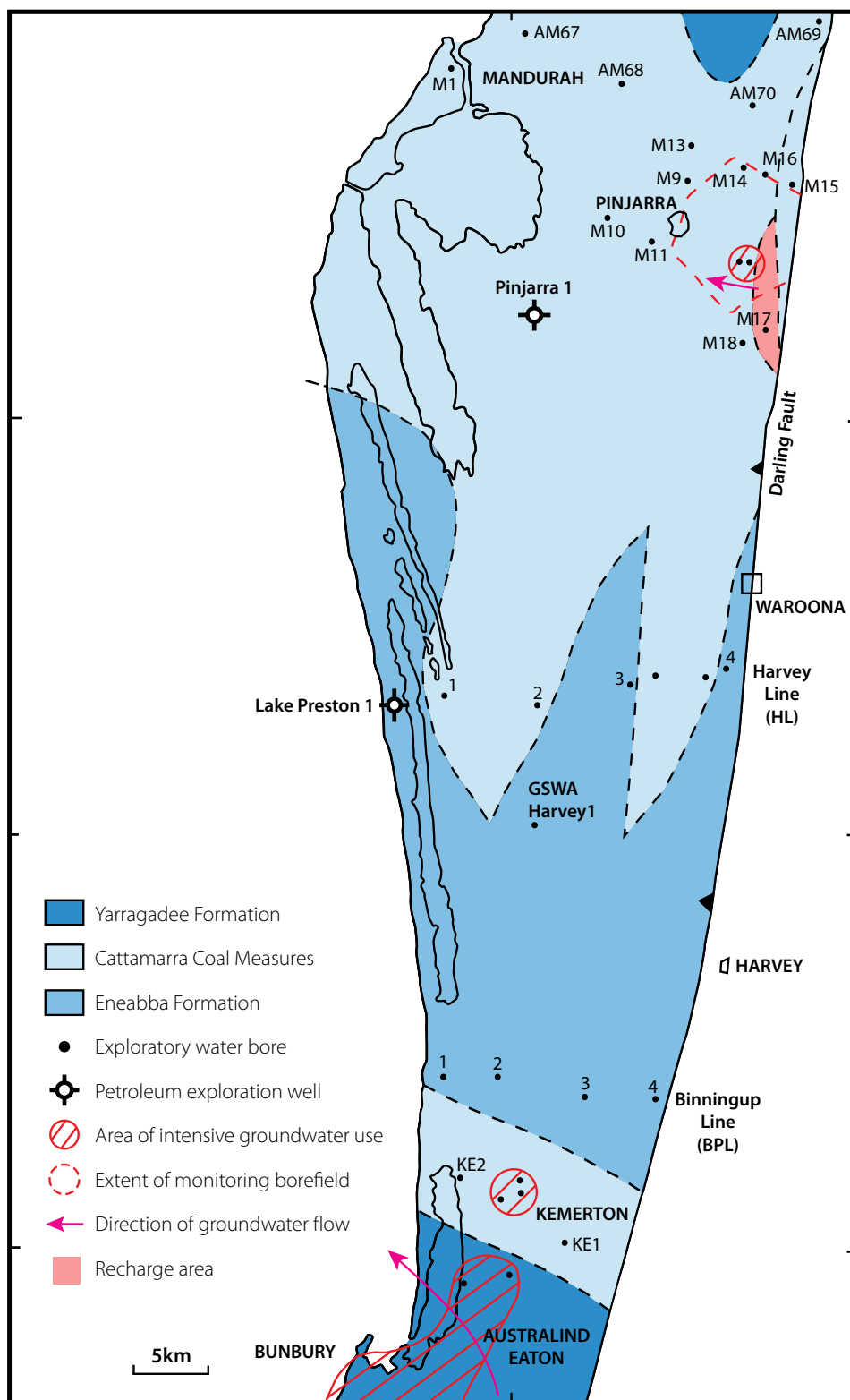


Figure 3 | Eneabba, Cattamarra and Yarragadee aquifers

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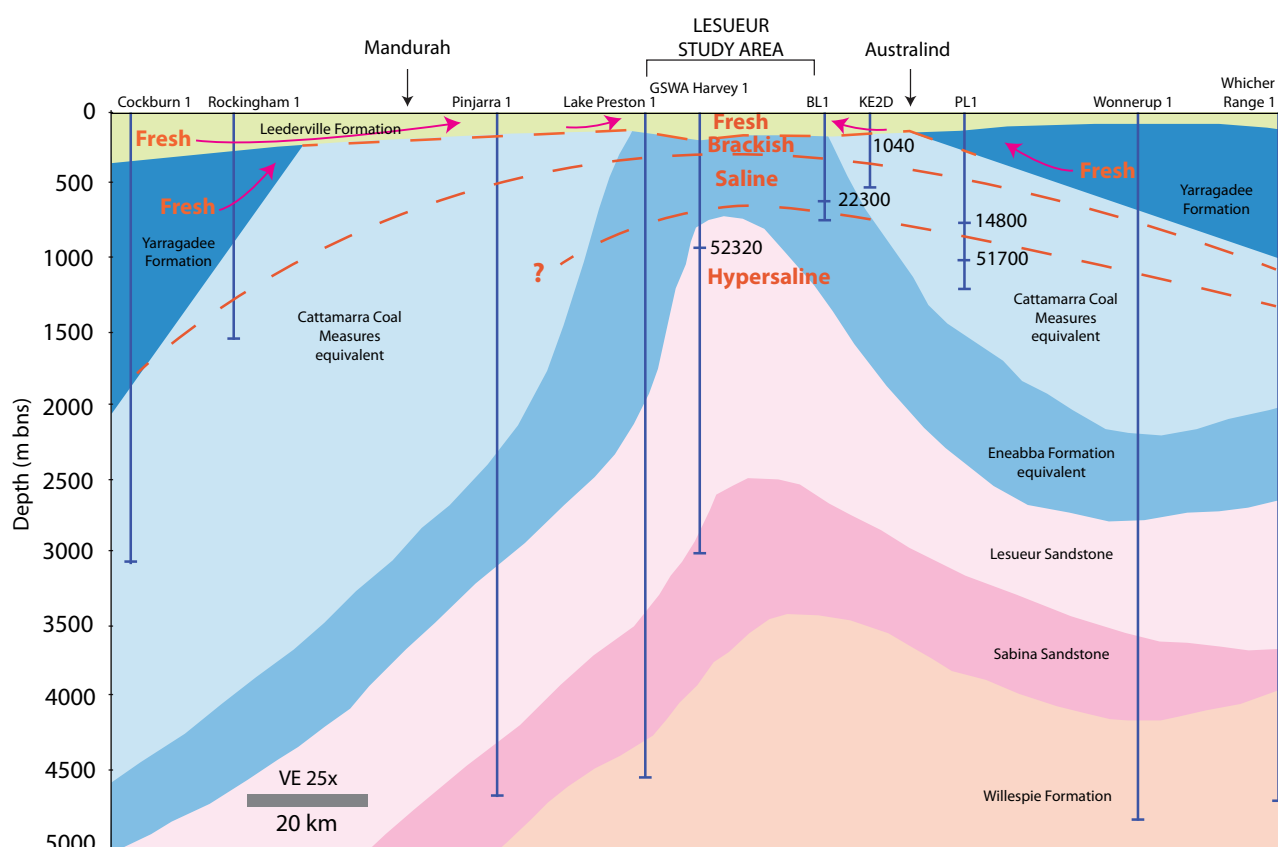
Published GSWA Reports can be accessed at:
www.geodocs.dmp.wa.gov.au

Unpublished GSWA Hydrogeology Reports are held by the Department of Water. ■

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Note: The strata interfaces in the petroleum wells are based on Crostella and Backhouse (2000); while those at the water wells are based on the relevant GSWA reports. Interpretation of interfaces at GSWA Harvey 1 is based on Arthur Mory (DMP) pers comm. This geological section is based on a simple interpolation of interfaces between the wells that are not along a straight line. Hence, there is a large uncertainty in the depths of interfaces between the wells. The DMP is currently reviewing these interpretations.

52320 Salinity of groundwater sample (mg/L TDS) | Well

→ Direction of groundwater flow

Fresh < 1000 mg/L
Brackish 1000 - 3000 mg/L
Saline 3000 - 35000 mg/L
Hypersaline > 35000 mg/L
Note: Seawater salinity is 35000 mg/L

Figure 4 | North-South cross-section showing groundwater salinity in the confined aquifers

Gorgon CO₂ Injection Project Due Diligence Reviews

Jianhua Liu

Senior GHG Storage Reservoir Engineer
Resources Branch



Gorgon Project work continues to progress with the installation of the three amine absorbers, two condensate stabilisation modules and a recycled gas compression module (centre).
(Photo courtesy of Chevron Australia)

The Department of Mines and Petroleum (DMP) recently commissioned the fifth due diligence review of the Gorgon CO₂ injection project on Barrow Island, the largest commercial scale CO₂ injection facility in the world.

In September 2009, the Gorgon Joint Venture (GJV) made the final investment decision for the Gorgon Project that would develop gas resources from Gorgon and Jansz-lo fields with 3x5 million tonnes per annum (Mtpa) LNG trains and a domestic gas processing plant on Barrow Island. One important element of the project includes the Gorgon CO₂ Injection Project on Barrow Island, where CO₂ will be separated from reservoir gas, compressed and injected into a deep saline sandstone formation below Barrow Island.

In the lead up to the approval of the Gorgon CO₂ Injection Project under Section 13 of *Barrow Island Act 2003* (WA), DMP, on behalf of the Western Australian Government, had outsourced four phases of independent due diligence technical reviews of the CO₂ injection project to understand the associated risks and its feasibility.

The first three due diligence reviews dealt with the concept of 2x5 Mtpa LNG trains with feeding gas from Gorgon field only. This was revised to 3x5 Mtpa LNG and domestic gas development in July 2008 with feeding gas from both Gorgon and Jansz-lo fields.

The initial due diligence review was completed in 2003. It was a general review of the project and concluded that the risks of CO₂ sequestration into the Dupuy Formation under Barrow Island could be managed with good risk management, monitoring and verification plans. This assisted the “in-principle” approval of the injection project under the *Barrow Island Act 2003* (WA).

The Phase II and Phase III due diligence reviews were completed in 2004 and early 2008, respectively. The Phase II review concluded that the target reservoir, the Dupuy Formation, had the capacity to store several times the proposed volume of CO₂ from the Gorgon field, and the primary seal was adequate for long term containment of the injected CO₂. The Phase III review assessed and verified in detail the effectiveness of a series of programs,

including reservoir storage capacity, containment issues, CO₂ disposal management plan, well integrity, CO₂ injectivity, CO₂ plume monitoring and surveillance programs, and uncertainty (risk) management plan. It concluded that, based on the information available at the time, the proposed Gorgon CO₂ injection project was technically feasible, many of the major requirements for CO₂ disposal were satisfied, and the associated risks were manageable through a comprehensive monitoring and surveillance plan and the Uncertainty Management Plan of the project was deemed exemplary.

The development plan variation in 2008 resulted in a series of changes to the design of the project, such as the reference case injection rate, the number of drill centres and injection wells, and most importantly the size of the CO₂ plume. Consequently, a Phase IV due diligence study was conducted to review the impact of revised development on containment risk, injectivity, storage capacity, monitoring and verification plan, reservoir static and dynamic modelling and any future remediation plans for wells penetrating the Dupuy Formation.

The major conclusions of this review were that there appeared to be “no significant issues which may compromise the feasibility of the project”, and based on the available data, “the overall technical assessment of the project by the GJV is sound” and that there were “no significant new or additional risks for the updated Gorgon CO₂ injection project” resulting from the increased CO₂ injection rate and the P50 and P10 production scenarios.

These due diligence studies assisted the Barrow Island Act Minister in deciding to grant the approval of the proposal of the Gorgon CO₂ Injection Project on Barrow Island in September 2009, with a string of conditions attached.

While praising the CO₂ injection project, these due diligence reviews had made many technical recommendations and suggestions for the GJV to consider in their future work. Together, there were more than 150 recommendations coming out of Phase III and Phase IV reviews.

The Gorgon CO₂ injection wells on Barrow Island will be spudded in September 2013 with the CO₂ injection project operations starting in 2015. To assess how the due diligence recommendations were being addressed in GJV’s ongoing work after the grant of approval of the project in 2009, the Western Australian Government Department of Mines and Petroleum outsourced a fifth round review of the GJV’s implementations of recommendations in 2013.

The 2013 review was conducted by Kema Australia Pty Ltd. The review started in April and was completed in June. It included the geology, geophysics, geochemistry, geomechanics, reservoir engineering and reservoir simulation aspects that were identified in the previous recommendations in order to assess the injectivity, containment, monitoring and verification, and risk management aspects of the project.

The review team comprising experts in the various areas of CO₂ storage projects has found out that the majority of the recommendations (104 out of 153) were addressed adequately by the GJV and were given green lights; and five recommendations were rejected by the GJV and this was supported by

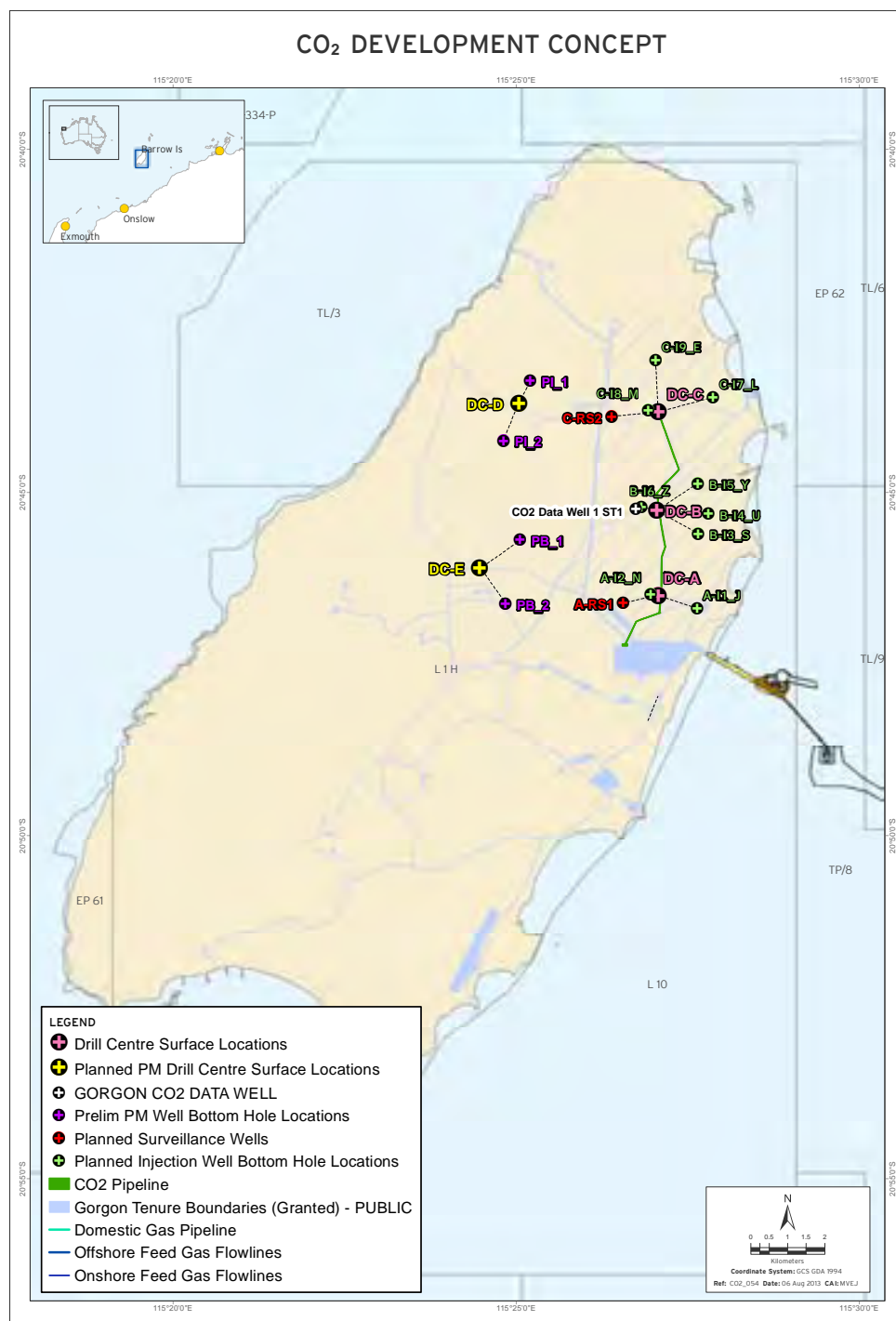


Figure 1 | Gorgon CO₂ development concept showing well locations for the injection project (Trupp, M., Frontczak, J., and Torkington, J., 2013, CO₂ Injection Project — 2012 Update, Energy Procedia, vol. 8, pp 6237-6247)

the review team. Further work needs to be done to fully address the remaining 44 recommendations, of which 15 will need ongoing commitment, seven will need to be addressed in due course, and 22 were not addressed satisfactorily and further actions were recommended by the due diligence review team to address these issues adequately.

Briefly, the review team recommends actions in the following four areas:

geomechanical modelling and analysis, a holistic containment risk management and monitoring approach, geochemical characterisation and monitoring, and integration of measurements for dynamic model calibration. In total, the review team has proposed 26 action items for the GJV, which will be the focus of DMP’s internal due diligence reviews in the future. ■

Land Access 2012-13 Update

Allison Cohen
Manager Land Access
Petroleum Tenure and
Land Access Branch



The year ending June 2013 has seen an increase in the number of petroleum title applications moving through the native title process and being managed by the Petroleum Division's Land Access Section. In 2012-13, there were 10 petroleum applications finalised through the Department's native title process for grant. In 2011-12, that number was six. Last year, the applications for production licences in both the Perth and Canning basins made good progress through the native title process. Production from the Red Gully (Perth Basin) and Ungani (Canning Basin) fields will broaden the energy security base of the State and herald a new chapter for petroleum in WA. Currently there are three production licence applications in the Perth Basin and two in the Canning Basin.

As at June 2013, there were 61 applications with the Land Access Section. Most applications are currently in negotiation (between the grantee party and the native title party/ies), which is a good sign. It means that parties are talking about how the activity/ies can be done while taking into account native title rights and interests. It also provides an opportunity to address any issues concerning Aboriginal heritage. Some applications are more than three years old and the team will be targeting these to see why, how and if they can be brought to a close and the applications granted.

The last 12 months have seen the production of a series of Information Sheets titled *An Introduction to the Oil and Gas Industry in Western Australia*. A DVD will be available shortly, as well as the ability for the Land Access Section to deliver a supporting presentation. Team members from the Land Access Section have often been invited to attend native title working group meetings on-country to deliver information about the petroleum industry in general, or to petroleum exploration and development companies to deliver information about the native title process.

The next 12 months will continue to be busy for the Land Access Section including:

- Identifying current key issues and concerns with respect to the grant of petroleum titles and how that interacts with land access issues
- Maintaining stakeholder relationships and establishing a stakeholder engagement plan in conjunction with the rollout of the Information Sheets and DVD mentioned above
- Investigating emerging legal issues
- Investigating applications that are more than two years old to see why, how and if they can proceed to grant.

Recently, the Petroleum Division's Tenure and Land Access Branch said farewell to a long serving member, Maryie Platt, who has moved to the Department of Aboriginal Affairs. Allison Cohen has been appointed to the position of Manager Land Access. Allison has over 20 years of experience dealing with native title and resource development in the minerals industry.

Please feel free to contact one of the Land Access Section team members should you have any land access issues. ■

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Petroleum Division Heralds a New Era and Farewells the Electronic Petroleum Register (EPR)

Hazel Harnwell

Manager Compliance
Strategic Business Development

Some of the development and testing staff involved in the migration of EPR to PGR



On 30 July 2013, the Petroleum Division of the Department of Mines and Petroleum saw the decommissioning of its ageing EPR system, when data and functionality was fully migrated into the Petroleum and Geothermal Register (PGR). The EPR system was over 14 years old and did not have the capability to expand to deal with emerging technologies or legislative changes. Neither could it be enhanced to have online functionality.

Development of PGR involved staff from Petroleum Division and Information Services Branch. As part of the process, Petroleum Division business areas reviewed their processes and procedures to provide a more streamlined approvals process.

Stringent testing programs were undertaken to ensure that data was carried across into PGR correctly and that each of the functions performed as required.

From an IT perspective, the challenge was to design and develop a framework that would accommodate extremely complex business and legislative rules, yet have the flexibility to capture,

display, assess and finalise the myriad of application types the Petroleum Division deals with.

PGR integrates seamlessly with other DMP systems including:

- Environmental Assessment and Regulatory System (EARS)
- Financial Online Reporting System (FORS)
- Records Management System (RMS)
- Petroleum and Geothermal Information Management System (WAPIMS)
- Mineral Titles Online (eMits)
- Quality Management System (QMS)
- Ourdocs
- Tengraph

Acting Executive Director Petroleum Division, Jeff Haworth, said that PGR has become an integral part of managing regulatory functions within the Petroleum Division, particularly in relation to well integrity and resource management matters. "It's vital that there is a system in place that can be

easily expanded or enhanced to meet the rapidly changing demands of the petroleum and geothermal industries. With the decommissioning of EPR the Petroleum Division will be able to meet these demands more readily. I congratulate all staff for their efforts," Jeff said.

In addition to PGR Development, Petroleum Division has continued to meet its petroleum and geothermal approvals obligations by refining title application workflows, increasing the efficiency of information systems, maintaining procedure/document management processes to ISO-9001:2008 quality assured standards, establishing Memorandum of Understandings and consulting with major stakeholders to ensure agreed timelines are met.

So what's next for PGR? There is still a lot more work and development required for its continued growth and enhancement. Apart from refining a few things related to the replacement of EPR, PGR will be expanded to deal with resource management issues as well as automating approval processes in a paperless environment. ■

Heat Generation in the Vasse Shelf Region: Implications for Geothermal Exploration

**Mike Middleton and
Mark Keith Stevens**

Petroleum Division
Resources Branch



Mike Middleton measuring surface values of uranium, thorium and potassium from granite outcrops in the Vasse region
(Photo courtesy of Mark Keith Stevens)

Geothermal energy is one of the few renewable energy sources that promise to provide a substantial supplement to base-load electrical power. It is currently used for space heating (e.g. swimming pools) in a number of applications in the Perth region, and major projects are underway to apply geothermal energy to generate electricity in the Mid-west region. These projects draw geothermal energy from hot water in sedimentary rocks buried between 1000 and 3000 m beneath the Earth's surface. These are considered as relatively *low temperature* geothermal resource projects, compared to those in volcanic regions elsewhere in the world. Temperatures expected for hot sedimentary projects range between 100°C to 200°C.

Little is known of the geothermal potential of the South West region of Western Australia. This article reports a preliminary study in the Vasse region to investigate the potential for geothermal energy. The study suggests that temperatures up to 150°C may be encountered at drillable depths.

It is commonly recognised that granitic "basement" rocks, informally referred to as granites herein, with a high content of the radiogenic elements uranium (U), thorium (Th) and potassium (K), also referred to as "hot granites", provide a dominant component to the heat flow in Hot Dry Rock (HDR) geothermal regimes. The "Dry" refers to the likelihood that water will have to be injected into

basement rocks and recovered from a separate production well, hopefully in a closed loop to minimise water loss. In HDR regimes, these hot granites reside beneath a thermal blanket comprised of between three to five kilometres of sedimentary rocks. This is the main paradigm driving geothermal exploration in the Cooper Basin and elsewhere in South Australia.

In contrast to HDR geothermal regimes, this article reports the results of a study of heat generation and corresponding temperatures at depth in overlying water-sediments: these are known as hot sedimentary aquifer (HSA) geothermal regimes. These areas also have layers of sediments to act as thermal blankets; however the hot water to supply geothermal energy is derived from the sediments themselves. More importantly, the deep hot-water aquifers generally have inherent porosity and permeability, therefore not requiring fracture stimulation of the deep formations as is required for HDR geothermal projects.

Heat generation in the granites of the Leeuwin Complex, which crops out immediately to the west of the Vasse Shelf, may have relevance for the exploration for geothermal energy "hot spots" in the Vasse Shelf sediments of the southern Perth Basin (Figure 1).

Western Australia has several regions where hot granites are known to

occur in outcrop. The locations of high radioactivity rocks, including hot granites, can initially be detected by airborne radiometric surveys, which measure the concentrations of U, Th and K. These data have been acquired for Western Australia through a number of cooperative projects between the Geological Survey of Western Australia (GSWA) and Geoscience Australia, and maps showing these data are publically available. The Vasse region was flown in 2011.

The uranium concentration map for the northern part of the Vasse region, derived from this survey, is shown in Figure 2a, and the thorium map for the same region is shown in Figure 2b. A ground-truthing survey was carried out by officers from the Petroleum Division (PD) of the Department of Mines and Petroleum was carried out in May 2013. This survey used a RS-125 gamma-ray spectrometer to obtain surface values of U, Th and K to compare to the airborne data. Middleton (2011, 2013) carried out a similar study to investigate geothermal heat generation for the Darling Range granites.

Surface sampling of granites of the Leeuwin Complex was previously carried out by the GSWA, and some of these sites these were visited during the May 2013 PD field trip to compare the spectrometer values to those obtained by laboratory-based measurements of U and Th (locations shown in Figure 1).



Figure 1 | Location diagram showing the Vasse Shelf, Leeuwin Complex, and Yilgarn Craton, and the measurement/sample locations for the May 2013 field trip. The locality SR relates to the Sugarloaf Rock locality

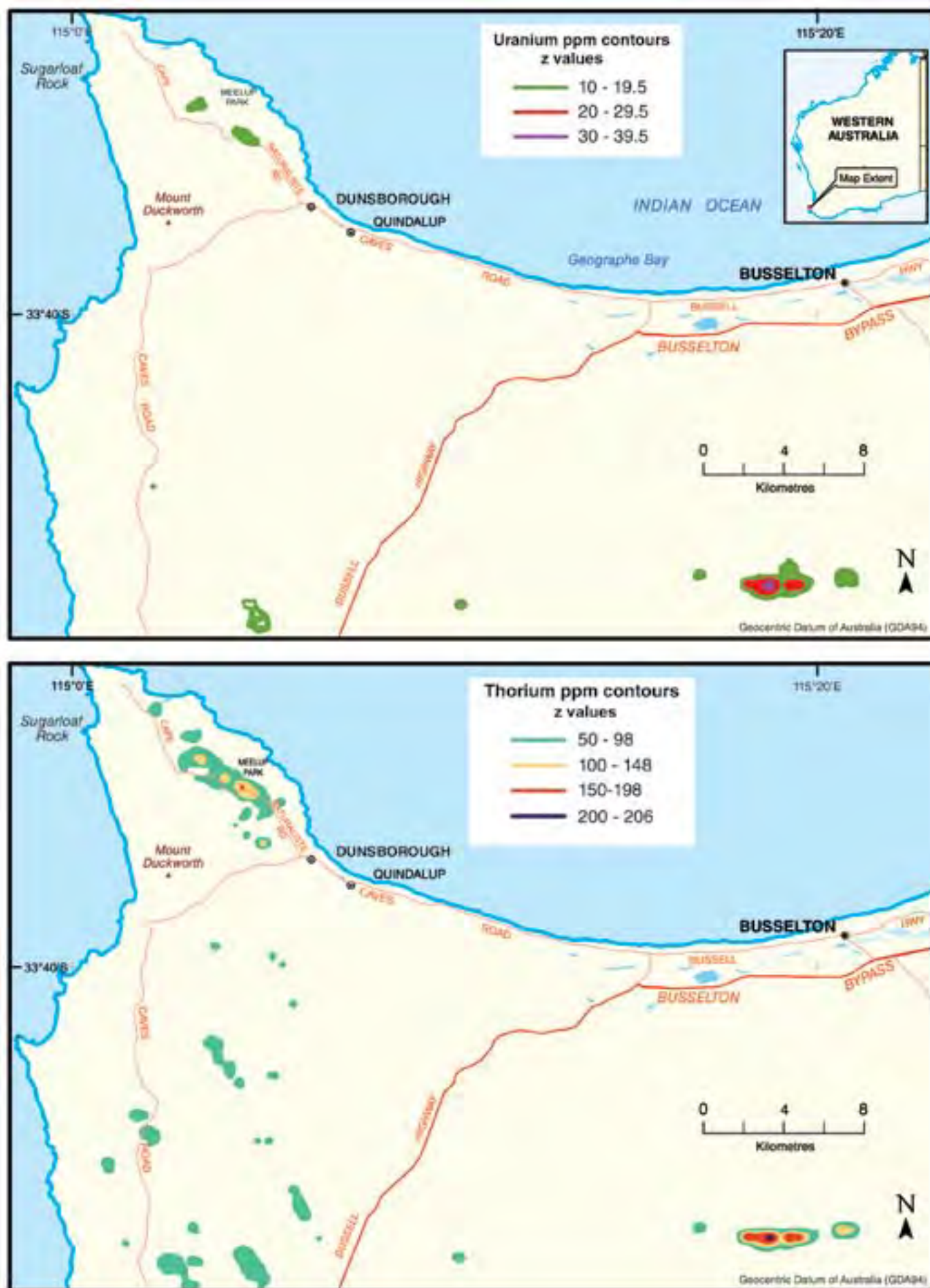


Figure 2 | Maps showing (a) U concentrations and (b) Th concentrations in the northern Vasse region, based on airborne radiometric data

The U, Th and K concentrations in the granites can be converted into approximate radiogenic heat generation by using appropriate factors, based on energy produced by the radioactive decay of the unstable isotopes of these elements (Kappelmeyer and Haenel, 1974, pg. 28). The factors to convert U, Th and K concentrations into an approximation of heat generation (expressed in units of microwatts per cubic metres, μWm^{-3}), are 0.26 for U concentration expressed as parts per million (ppm), 0.07 for Th concentration expressed as ppm, and 0.10 for K concentration expressed as percentage by weight (%). These factors are used for this study, and the contribution to heat generation of each of the three elements are combined as additive contributions.

Previous work (Jaeger, 1970, Sass *et al.*, 1976; Hot Dry Rocks Pty Ltd, 2008; Middleton, 2011 and 2013) has been published on heat generation in granites of the western part of the Yilgarn Craton. The heat generation of outcropping hot granites in the Yilgarn Craton has been measured in the range of 1 to 10 μWm^{-3} , and are similar to published values for the Cooper Basin HDR granites (ca. 10 μWm^{-3}). No heat generation values have been previously published for the Leeuwin Complex, although U, Th and K analyses have been measured by laboratory techniques from outcrop samples for selected locations (see Figure 1).

Table 1 shows the mean U, Th and K concentrations (measured with at least repeats) at the seven localities in this study. The elemental abundances observed at these sites were converted to heat generation in units of μWm^{-3} using the factors mentioned above.

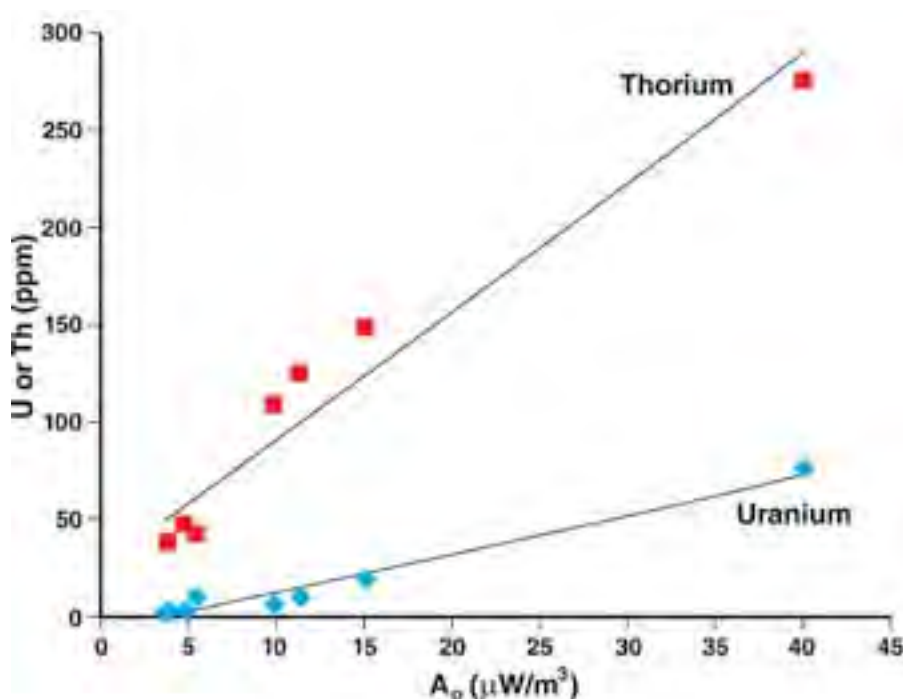


Figure 3 | Plot of heat generation (A_0 in units of $\mu\text{W/m}^3$) versus U concentration (blue diamonds), and Th (red squares) for the various locations investigated in the Leeuwin Complex (see Figure 1 for locations). The figure shows that heat generation varies between 3.8 and 40.1 $\mu\text{W/m}^3$. Linear regression lines are shown for both elements (U and Th) versus the heat generation (A_0)

Figure 3 shows the relationship between U, Th, K and heat generation (designated as A_0), and indicates that the observed mean heat generation at the locations investigated ranged between 3.8 μWm^{-3} and 40.1 μWm^{-3} throughout the Leeuwin Complex region. The heat generation data exhibit a good linear relationship between U and Th concentration.

These data also indicate that the Leeuwin Complex does indeed contain particularly hot granites at some locations, and may support relatively high temperatures at drillable depths,

if these granites extend beneath the Vasse Shelf sediments.

The airborne signature suggests that the underlying hot granite may have an areal extent of about 5 km². Figure 4 shows the thorium anomalies superimposed on the aeromagnetic data at Meelup Park in the Yallingup region. The anomalous Th appears to be located in a magnetically low region in the range of -50 to -200 nanoTesla (nT) (green to light blue in Figure 4). The low magnitude of the magnetic signature of the Th-rich regions implies that the Th may be associated with low magnetic crystalline rocks.

Table 1. Mean U, Th and K concentrations measured at the seven localities in this study, and derived heat generation

URANIUM (ppm)	THORIUM (ppm)	POTASSIUM (%)	HEAT GENERATION (μWm^{-3})	COMMENT
6.0	108.4	7.4	9.9	Sugarloaf Rock (SR); Leeuwin Complex; previous GSWA site
2.1	37.9	5.7	3.8	Leeuwin Complex; previous GSWA site
2.8	37.8	5.6	3.9	Leeuwin Complex; previous GSWA site
3.3	46.8	6.2	4.8	Leeuwin Complex; previous GSWA site
10	125	0.4	11.4	Vasse Shelf sediments
9.9	42.1	0.1	5.5	Vasse Shelf sediments
18.7	147.2	0.4	15.2	Vasse Shelf sediments
75.8	275	11.7	40.1	Meelup Park (MP); Leeuwin Complex

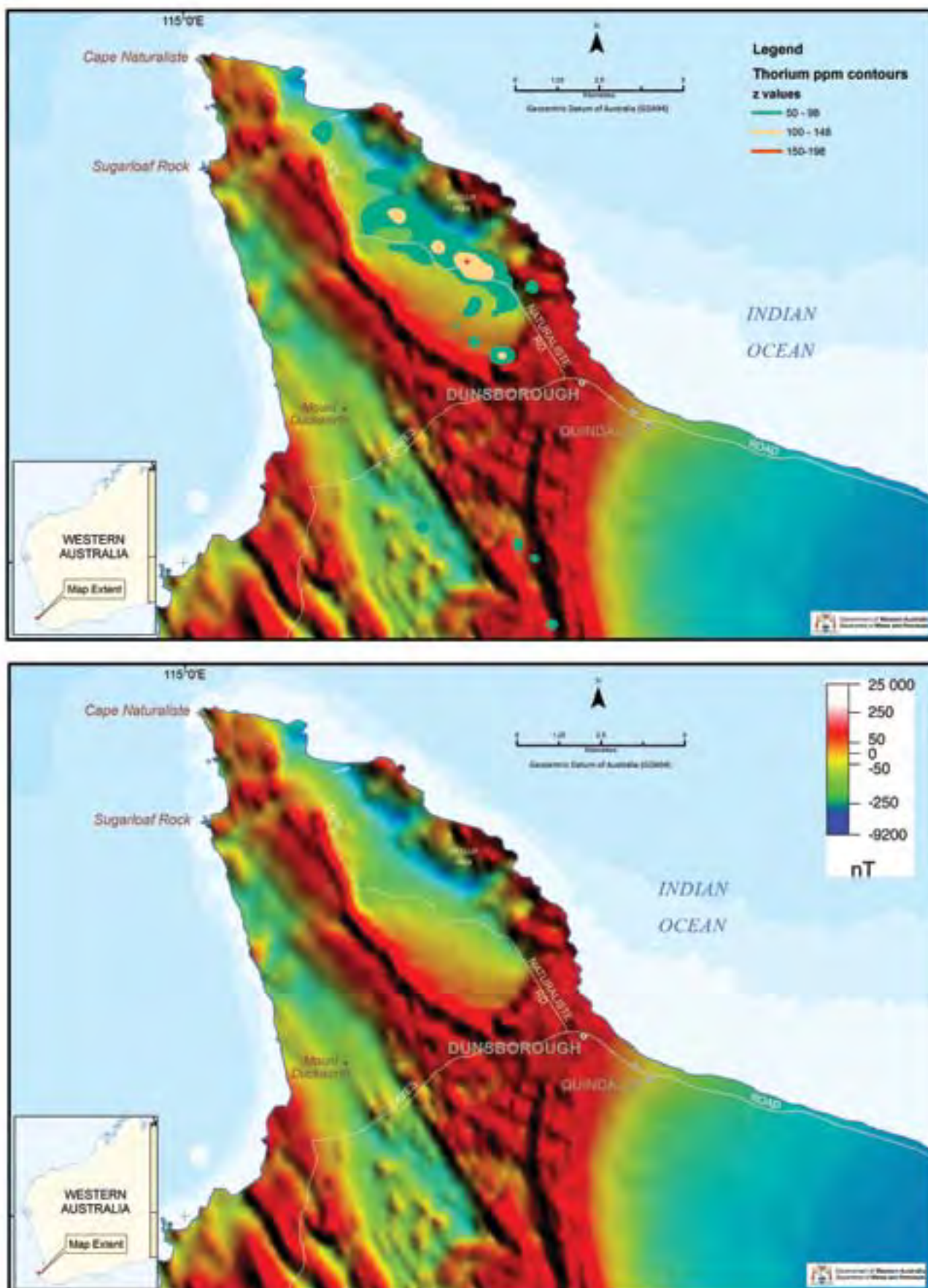


Figure 4 | Map showing the aeromagnetics in the vicinity of Dunsborough (Geological Survey of Western Australia, 2013) with the approximate location of the Th anomalies superimposed on the upper image. The lower image shows the aeromagnetics without the Th anomalies superimposed, and the colour scale of magnetic intensity in units of nanoTesla (nT). The magnitude of the Th anomalies in the upper image is represented as green indicating 50 to 100 ppm, light orange indicating 100 to 150 ppm, and red indicating 150 to 200 ppm. Ground measurements indicated Th concentrations in the order of 280 ppm in the light orange regions

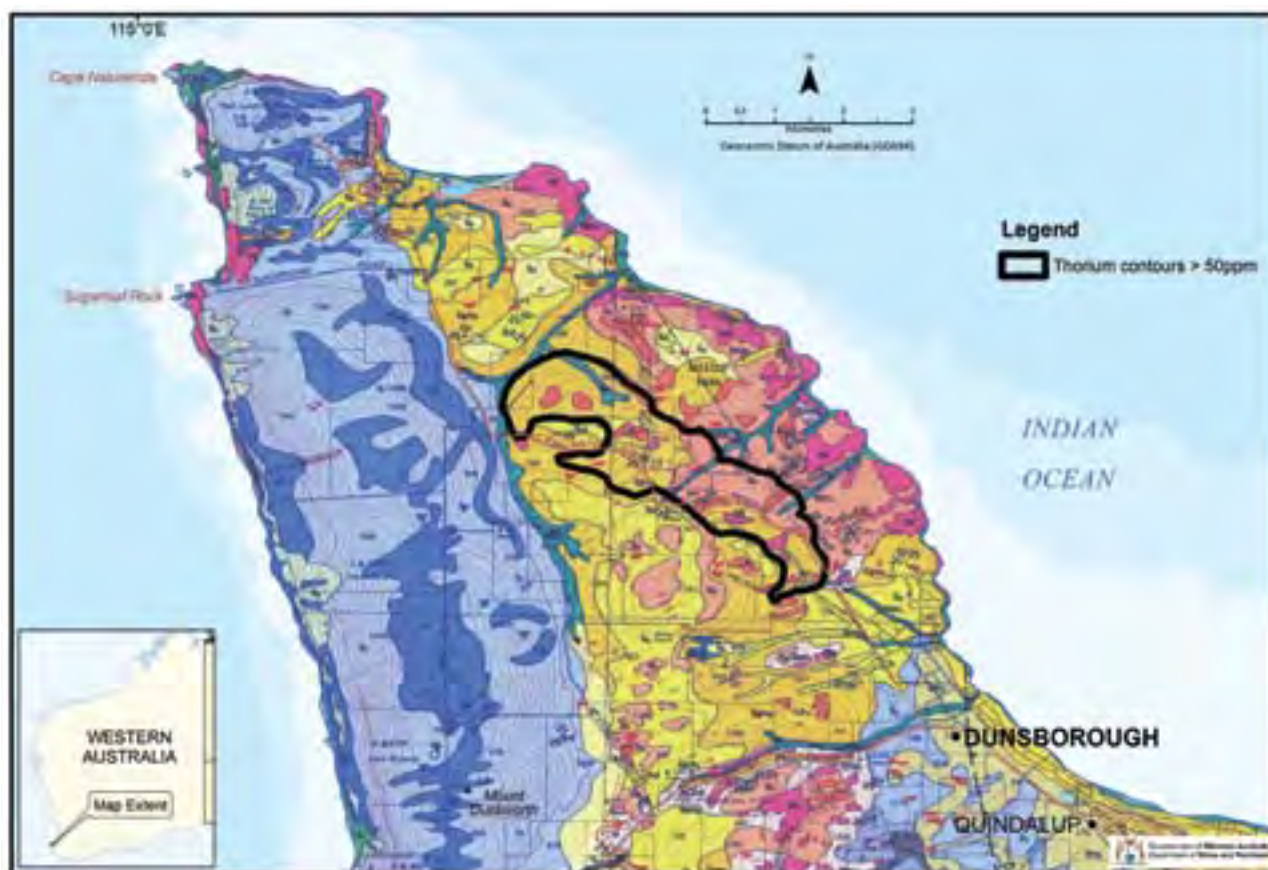


Figure 5 | **Map showing the surface geology in the vicinity of Dunsborough (Lennard, 1991) with the approximate location of the large Th anomaly seen at the Meelup Park location in Figure 2b. The anomaly (outline in black) extends over a variety of surface geological units, including the “basement” granitic gneiss**

The Sugarloaf Rock locality is located on the coast about 3 km south of Cape Naturaliste (see Figure 1). Laboratory measurements by the GSWA indicate at least two igneous rock suites at the locality: (a) with U ~ 3.9 ppm and Th ~ 92.6 ppm, and (b) U ~ 1.7 ppm and Th ~ 25.4 ppm. Surface measurements with the spectrometer yielded (a) U ranged between 3 – 8.5 ppm and Th ~ 108 ppm for an observed felsic suite of rocks, and (b) U ~ 1.3 ppm and Th ~ 21 ppm for a mafic suite. It should be noted that the felsic suite of igneous rocks are expected to have a low magnetic signature, and the mafic suite a high magnetic signature. Measurements at this site support the observations at Meelup Park that the low magnetic rocks seem to possess a higher concentration of radioactive elements than do the high magnetic rocks.

The very high U and Th concentrations, and calculated heat generation of $40.1 \mu\text{Wm}^{-3}$, at the Meelup Park location near Dunsborough (see Table 1) is indeed anomalous, which was investigated because of the high airborne radiometric signal (see Figure 2). This anomaly may be

due to concentration of these elements in a thin laterite or gravel layer residing on the top a hot underlying “granite” body, which is mapped as a gneiss (Lennard, 1991).

Figure 5 shows the approximate location of the Th anomaly superimposed on the mapped surface geology (Lennard, 1991). Further work is necessary to establish why the U and Th concentrations are so high in these regions, but the magnetic signature of the underlying igneous rocks may provide a clue. Nevertheless, it is highly unlikely that the underlying granite has a heat generation reading as high as $40.1 \mu\text{Wm}^{-3}$ over its total extent, and may be somewhere between 10 and $20 \mu\text{Wm}^{-3}$ on average.

The thicknesses of granitic gneiss intrusions in the Leeuwin Complex are largely unknown at present. Similar bodies in the Yilgarn Craton have been assumed to range between 2000 and 6000 m thick. It does not seem unreasonable to expect a similar range for the Leeuwin Complex.

A simple 1D model (Carslaw and Jaeger, 1959, p. 79) is used to determine the temperature at depth in sediments, which are underlain by a granitic body with uniform heat generation and limited depth extent. The main unknown parameters

in this modelling exercise are heat generation within the layer of hot granite (A_0) and its thickness (L). The other parameters, such as thermal conductivity (k), heat flow at the base of the crust (Q_b) and surface temperature (T_s) are relatively well known (Schön, 1996; Jaeger, 1970), and commonly observed values have been assumed (see Table 2).

Several cases with different heat generation and thickness of hot granites are modelled to investigate temperatures at depth within the western part of the Vasse Shelf. Granite bodies with thicknesses of 2000, 3500 and 6000 m are considered for this modelling. Heat generation is assumed to vary between 4 and $20 \mu\text{Wm}^{-3}$. Figure 6 shows temperature versus depth for each of the four cases with corresponding parameters shown in Table 2.

The modelling suggests that temperatures at 3000 m depth in the Vasse Shelf may have temperatures as high as 170°C , if underlain by a very hot granite (ca. $20 \mu\text{Wm}^{-3}$).

It is valuable to note that the hydrogeological study by Wharton (1982) reported temperatures within

Table 2. Parameters assumed for seven cases, where the temperature profile with depth is calculated and shown in Figure 7

PARAMETER	VALUE						
	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
A_o (μWm^{-3})	4	10	20	4	10	20	8
k ($\text{Wm}^{-1}\text{K}^{-1}$)	3	3	3	3	3	3	3
L (km)	2	2	2	6	6	6	3.5
Q_b (mWm^{-2})	26.3	26.3	26.3	26.3	26.3	26.3	26.3
T_s ($^{\circ}\text{C}$)	20	20	20	20	20	20	20

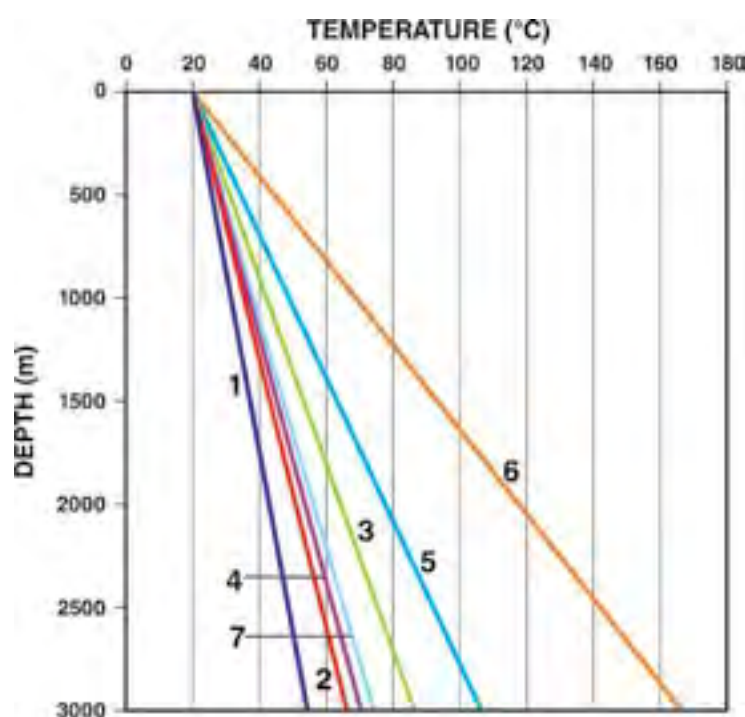


Figure 6 | Temperature versus depth for the seven cases proposed in Table 2. The number on each curve identifies the appropriate case in Table 2. The Wharton (1982) study suggests that the temperature at 1000 m depth is approximately 40°C. Cases 2, 3, 4 and 7 most closely satisfy this observation

the sediments in the range of 38 to 40°C at approximately 1000 m depth. The modelled temperatures in Figure 6 are consistent with the temperatures reported by Wharton (1982) for cases 2, 3, 4 and 7 in Table 2. For example, the average case for a hot granite, with thickness of 3500 m and heat generation of $8 \mu\text{Wm}^{-3}$, can satisfactorily yield the temperatures observed in Wharton (1982), as can a thickness of 2000 m and heat generation of $20 \mu\text{Wm}^{-3}$. Interestingly, for the former case, the temperature extrapolated to 5000 m will be 111°C, and 133°C in the latter case.

If the hot granitic rocks of the Leeuwin Complex extend beneath the Vasse Shelf to the east, then the sedimentary cover (especially if mudstone rich) may provide an excellent thermal blanket over

the granites. However, the sediments themselves can provide the source of the geothermal hot water instead of artificially fractured granites, as in the HDR system.

In conclusion, from this study, it can be recognised that temperatures between 3000 m and 4000 m in the Vasse Shelf may fall in the range of 90°C to 150°C. This temperature range is sufficient to permit electricity generation with organic rankine cycle (ORC) or variable phase cycle (VPC) turbines (Welch and Boyle, 2009). However, significant future work needs to be carried out in the region to confirm the geothermal potential. It is planned to revisit and evaluate the Meeup Park anomaly in more detail, and to investigate further some of the larger U and Th anomalies on the northern Vasse Shelf, and analyse existing GSWA sample sites for potassium.

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New Plays and New Players in the Canning Basin

Dr. Nina Triche

Petroleum Geologist
Resources Branch



The first well on the Ungani oilfield, drilled in 2011 by Buru and Mitsubishi
(Photo courtesy of Buru Energy)

Recent industry and government activity in Western Australia has highlighted the availability of new exploration and production opportunities in the Canning Basin, an area of WA that has long remained under-explored. This basin is the largest in the State, covering approximately 530,000 km² and is also the largest basin in Australia that is prospective for shale gas. The Canning Basin lies in the northwest portion of the State and is equivalent in size to Texas (Petroleum Division and GSWA 2012).

Since 1922, 269 onshore wells have been drilled in the Canning Basin, but activity has been very localised, mainly focusing on the northern, coastward portion of the area. In the past decade, companies such as Buru Energy Limited (Buru) and New Standard Energy (NSE) have extended exploration further into the basin, and new players such as Hess Corporation (Hess), Mitsubishi Corporation and ConocoPhillips acquired acreage. Scheduled work programs for the next few years include exploration for shale gas, Basin Centred Gas Accumulation (BCGA) plays and new production from known conventional discoveries.

Many additional areas of the basin may also be highly prospective, but remain frontier, for example the Kidson Sub-basin, which covers nearly 100,000 km² and contains only 11 wells (WAPIMS 2013), but has been suggested to contain extremely large shale gas resources.

Canning Basin Prospectivity

The Canning Basin is a northwesterly-trending intracratonic sag basin that lies between the Pilbara and Kimberley cratons. It consists of two main depositional centres separated by an arch; the northern depocentre contains the Fitzroy Trough and Gregory Sub-basin, while the southern includes the Kidson and Willara sub-basins. Each depocentre is bounded by major fault systems. Sedimentary fill in the basin is mainly Paleozoic; this and the youngest Cretaceous units all overlie a Proterozoic basement (Figure 1, D'Ercole *et al.* 2003). Deposition included major episodes of evaporite formation and subsequent salt tectonism, a major section of Devonian carbonate reefs and repeated episodes of continental to marine shelf deposition (D'Ercole *et al.* 2003).

Exploration in the Canning Basin traditionally centred on the Fitzroy Trough and Lennard Shelf, as well as parts of the Broome Platform and Barbwire Terrace, partly owing to a lack of infrastructure in more inaccessible parts of the basin (e.g. the Kidson Sub-basin) and partly because of the thick sedimentary successions to the north and structural development to the southwest (Petroleum Division and GSWA 2012). The Fitzroy Trough and Kidson and Gregory sub-basins are potentially the most prospective areas of the Canning Basin, owing to their substantial sediment-filled depths and proven carbonate reservoirs. Numerous shows and producing oilfields confirm the presence of four functional petroleum systems in the basin, sourced by the Ordovician Goldwyer and Bongabinni formations, the Devonian Gogo Formation, the Lower Carboniferous Laurel and Anderson formations, and the Carboniferous-Permian Grant Group and Noonkanbah Formation (D'Ercole *et al.* 2003).

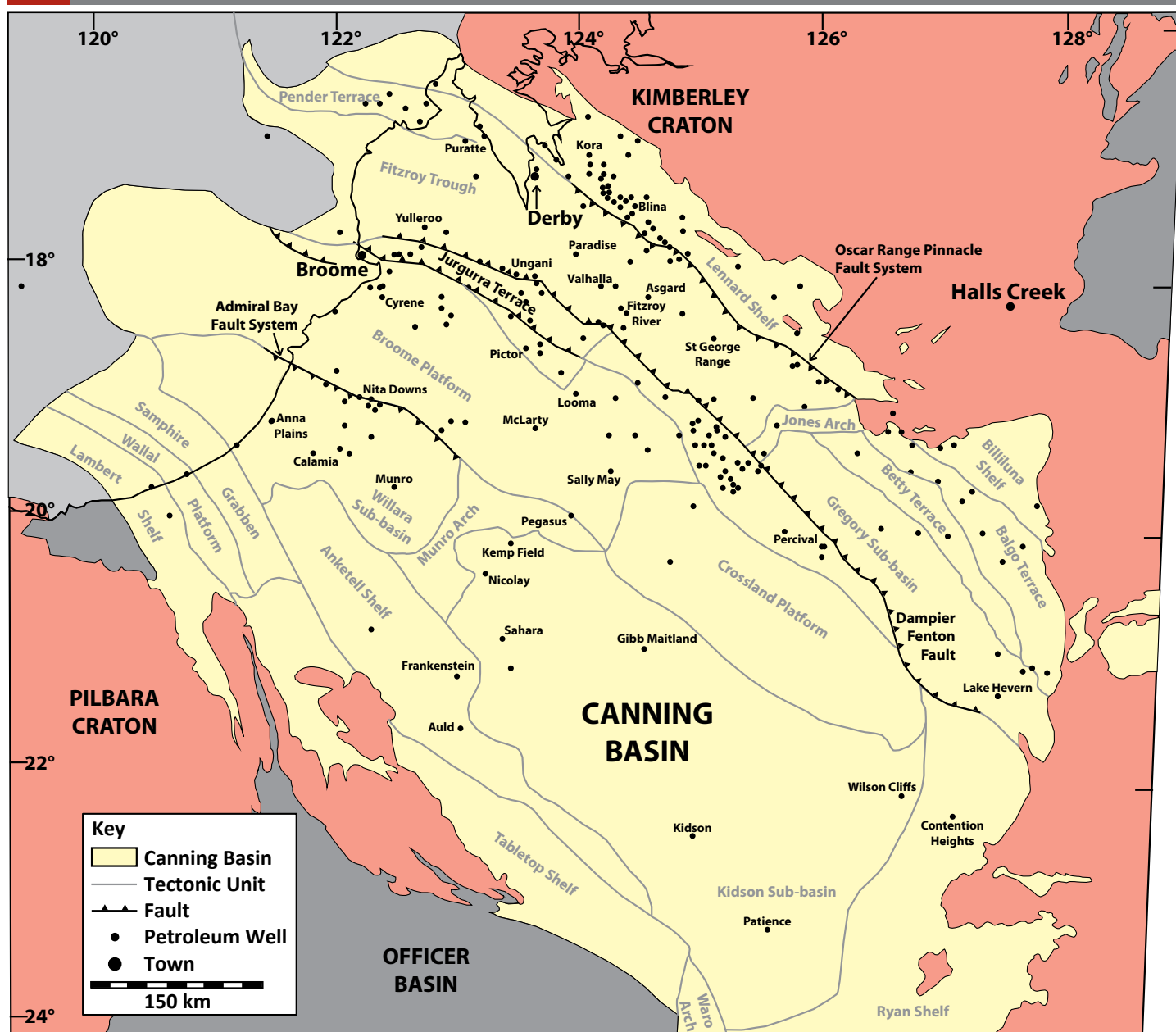


Figure 1 | Onshore Canning Basin, showing recently drilled wells

Recent Exploration

In recent years, successful appraisal drilling expanded the Yulleroo gasfield (2010 and 2013) and new discoveries occurred at the Ungani oilfield (2011) and the Valhalla gas prospect (2011), all of which were drilled by Buru along the southern margin of the Fitzroy Trough. Additionally, NSE commenced an exploration program in the Kidson Sub-basin with the drilling of Nicolay 1 and Gibb Maitland 1, which spudded in August and December 2012, respectively. Substantial acreage has been leased by Hess in the far south-eastern part of the basin (Figure 2), while Buru and NSE have entered into joint ventures with large international partners (Mitsubishi and ConocoPhillips, respectively).

Much of the increased interest in the Canning Basin stems from estimates of potentially vast shale-gas accumulations in the Goldwyer and Laurel formations, as well as tight gas in the Laurel Formation and a new appreciation of the potential for unexplored and new plays in the southern part of the basin. Three recent assessments of shale gas potential resulted in estimates of risked Original-Gas-in-Place for the Goldwyer Formation of 21,553,673 to 22,273,088 m³ (749 to 774 Tcf) and for the Laurel Formation of 3,625,852 m³ (126 Tcf; Figure 3; Cook *et al.* 2013, EIA 2013, Triche and Bahar 2013). Although methodologies differed in these studies and data in the basin is exceedingly sparse, nearly all researchers agree that the potential shale gas resource in the Canning Basin

is enormous and includes both wet and dry gas. Production from such a large resource would dramatically increase the amount of natural gas available to Western Australia, nearly doubling our current holdings and providing enough energy to power a city of one million people for more than 5000 years (Petroleum Division and GSWA 2012).

Given the recent mapping of gas at Yulleroo and the discovery of Valhalla, Buru has proposed the presence of a BCGA that may cover most of the Fitzroy Trough. BCGA plays typically require an abnormal pressure regime, low permeability (< 0.1 mD), pervasive gas saturation and lack of a down-dip water contact (SPE 2011). While this play remains to be fully explored, it seems clear that a large tight gas

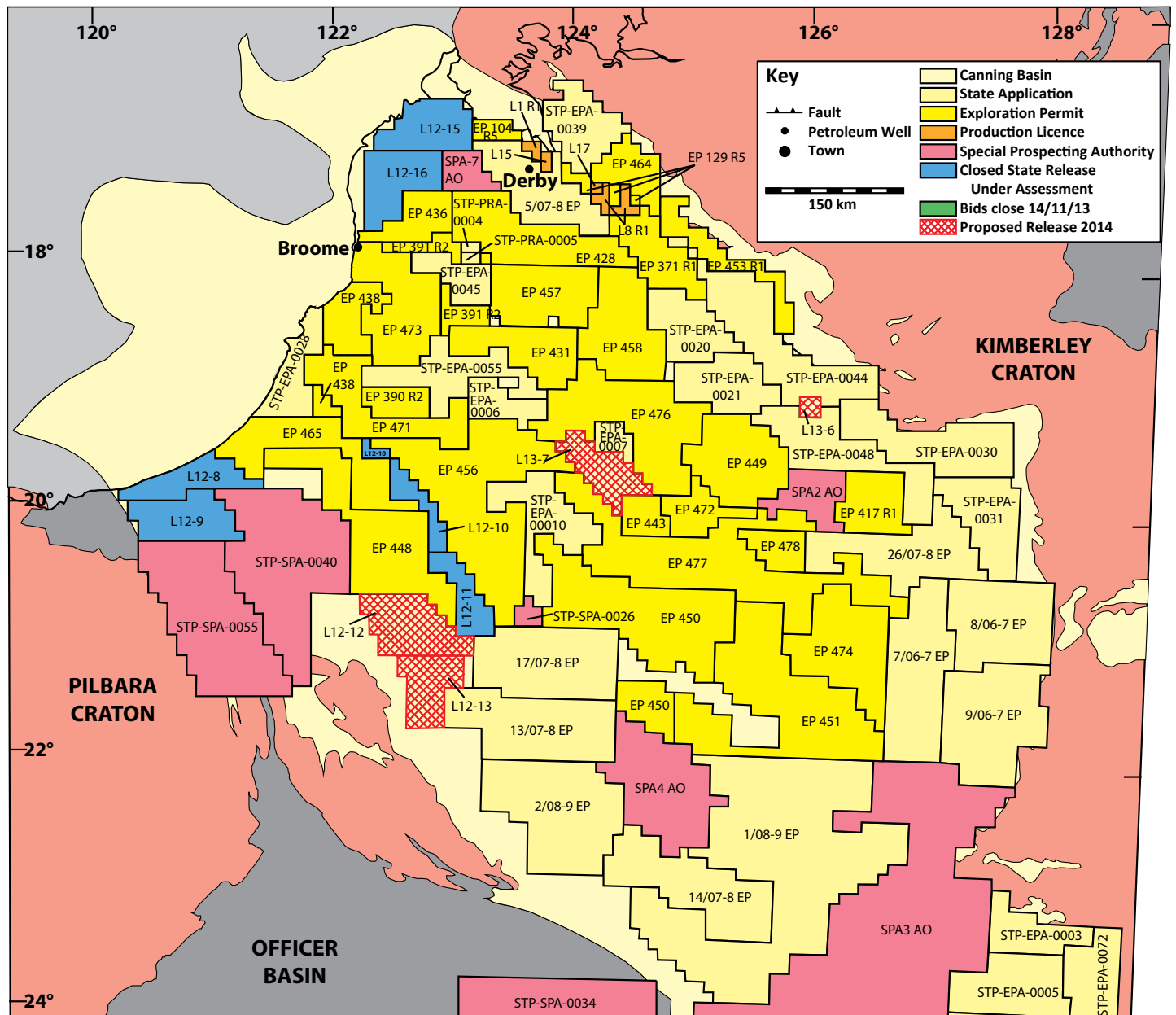
resource of some sort does exist in this area of the Canning Basin. In 2012, Buru tested their concept at the Valhalla Prospect with the appraisal wells Asgard 1 and Paradise 1 Deepening. Results were similar to those from Valhalla North 1, indicating gas saturation over the entire Laurel section. They also drilled the Yulleroo 4 appraisal well in the first quarter of 2013, identifying a large gas column and supporting their interpretation of a BCGA play in the Yulleroo area.

Although the Goldwyer Formation is best known from wells in the Fitzroy Trough and Broome Platform, some findings suggest that the Kidson Sub-basin may also be prospective for this shale layer. The extent of the formation, its maturity and its organic richness are

known only from very limited data in the southern Canning Basin, but NSE and ConocoPhillips are also targeting areas of potential wet gas production that may lie along the shallower margins of the sub-basin, along the southern edge of the Crossland Platform. Nicolay 1, completed by NSE in 2012, encountered elevated gas readings in the Goldwyer and Nita formations, which are interpreted to be in the late-oil / early-gas maturity window by NSE. Hess also plans to pursue the Goldwyer Formation shale gas play, as well as possible conventional targets, in the southern part of the Kidson Sub-basin. Additional shale gas potential exists in the Laurel and Gogo formations, as evidenced by numerous gas shows in the shale sections of various wells.

Recent GSWA and Resources Branch Research

Work by the GSWA recently revised the Paleozoic and Mesozoic stratigraphy of the Canning Basin (Zhan and Mory 2013) and remapped the extent of the basin (Mory and Haines 2013); both these projects were presented at the Western Australian Basins Symposium (WABS), held in Perth in August. Changes to the stratigraphic section were minor, but interpretation of seismic lines in the northern Fitzroy Trough reveals details about a major, E-W, Triassic-Jurassic, strike-slip fault that bisects the Fitzroy Trough from Yulleroo in the west to Valhalla in the east (Zhan and Mory 2013). Predating this, there is evidence of elongated, Carboniferous crustal extension in the middle of the



	GOLDWYER FORMATION				LAUREL FORMATION	
	GOLDWYER III				LOWER LAUREL	
	Triche and Bahar	Cook et al 2013	EIA 2013	EIA 2011	Triche and Bahar	Cook et al 2013
GIIP	783.9	2580.0*	2496*	2547*	193.6	420*
Recoverable Resource	117.6	387.0	374.4*	382.1*	29.0	63.0
Riskied GIIP (30%)	235.2	774*	748.7	764.0	58.1	126*
RRR (15% ReF)	35.3	116.1*	112.3*	114.6*	8.7	18.9
RRR (20% ReF)	47.0	154.8*	149.7	152.8*	11.6	25.2*
RRR (30% ReF)	70.6	232.2	224.6*	229.0	17.4	37.8*

* extrapolated from published data

ReF: Recovery Factor

RRR: Risked Recoverable Resource

Figure 3 | Comparison of estimates of total Gas-Initially-in-Place (GIIP, in Tcf) for Canning Basin shale gas formations. Modified from Triche and Bahar 2013

Fitzroy Trough that breached most large structures and leaves only small fault blocks and stratigraphic traps as likely exploration targets in the area.

The second GSWA study attempted to correlate stratigraphy across the State through the Paleozoic, in intervals of 10–30 million years, resulting in a series of time-isopachs (Mory and Haines 2013). Conclusions also included an appreciation for the influence exerted by the Devonian-Carboniferous Alice Springs Orogeny on the orientation and evolution of northern WA basins such as the Canning and the interpretation of a greatly expanded area to the south of the traditionally mapped Canning Basin that probably represents both Canning and Officer Basin rocks.

Concurrent research in the Resources Branch addresses the prospectivity and size of Canning Basin shale and tight gas accumulations at locations such as the Laurel tight gas play in the Fitzroy Trough and shale gas plays basin-wide. These internal reviews have already resulted in an independent estimate of the volume of shale gas contained in the Goldwyer and Laurel formations (Triche and Bahar 2013) and will shortly complete a number of independent models of various tight gas provinces of the Laurel Formation.

Additionally, the fifth WABS, which was held last month at the Perth Convention and Exhibition Centre, involved numerous presentations and

publications relating to the Canning Basin. These included addresses by the Executive Director of Buru and that of DMP's Petroleum Division, as well as technical presentations discussing Devonian carbonate and reef stratigraphy, structural patterns, oil compositions, and petroleum geochemistry of the basin. Papers presented at WABS will be published in a PESA volume in the coming year.

2014 and Beyond ...

Submitted work programs by various companies for the next few years continue to show increased interest in the Canning Basin. Buru has recently completed a new assessment of Laurel tight gas prospectivity in the Fitzroy Trough (Buru 2013, Kingsley 2012), with revised estimates of BCGA extent and gross recoverable volumes of 1,352,500 m³ (47 Tcf) of gas and 188,167 m³ (1177 MMbbl) of condensate in the overpressured Laurel section alone. Partly owing to the large gas potential in Buru's acreage, they and partner Mitsubishi were granted the Natural Gas (Canning Basin Joint Venture) State Agreement by the West Australian Parliament on June 19. The agreement will initially last for 25 years, with the possibility of an additional 25 year extension, and will provide for long-term tenure over 14 per cent of Buru's held acreage and for a long-term domestic gas supply in the State and pipeline development by the company in the basin.

Production on Buru's Ungani field was suspended in March after an extended production test, which was promising for increased production. The Ungani 3D survey planned by Buru will recommence data acquisition in the coming month, following a delay for engagement with Traditional Owners. This 243 km² survey will significantly aid the development of the field and allow the submission of a pre-field development plan for the Ungani accumulation.

Although the second well in NSE's Kidson Sub-basin program, Gibb Maitland 1, was suspended owing to drilling issues, the Enerdrill Rig 3 was later secured to complete this well and at least one other planned in the basin in mid-2014, after the end of the wet season. NSE also completed a farm-in with PetroChina, the largest energy company in China, for a 29 per cent stake in their Southern Canning Joint Venture (in addition to ConocoPhillips' 46 per cent holding). This transaction values the venture at more than \$110 million, with NSE remaining as operator. The joint venture plans to evaluate data obtained from Nicolay 1 and Gibb Maitland 1, as well as new seismic data interpretation, before recommencing drilling operations.

NSE is also showing an increased interest in the Laurel Formation, with a successful agreement to acquire Green Rock Energy Ltd's interest in the Buru-operated Laurel Project last March,

an agreement that increased NSE's acreage in the basin by 49 per cent. This joint venture will complete a gravity survey in the coming year, adding greatly to the structural data available for their Laurel play and, along with new seismic and geochemical data, allowing planning for a new well in 2014. NSE plans to focus on large conventional structures in their operating acreage, with the potential for pursuing the Laurel tight-gas resource play in future.

Given the massive size, complex and extensive stratigraphic section and insufficient amount of data and infrastructure present in the under-explored Canning Basin, there remains major potential for undiscovered plays, play types and exploration activity in the area. The upcoming drilling season will undoubtedly add to our knowledge of this fascinating frontier basin, but much work remains before the Canning Basin will be truly understood.

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Poole Range in the Canning Basin, potentially prospective for shale gas resources
(Photo courtesy of Peter Haines)

Table 1. 2012 Production by Field and Cumulative Production, WA Onshore and State Waters as at 31 December 2012

Field	Operator	2012 Production by Field			Cumulative Production			Permit
		Oil	Condensate	Gas	Oil	Condensate	Gas	
		kL	kL	10 ³ m ³	kL	kL	10 ³ m ³	
Agincourt	Apache	13,414.4	169.9	8296.1	546,298.4	4,219.9	38,979.1	TL/1
Albert	Apache	4084.6	41.4	1516.1	74,205.6	137.4	9557.1	TL/6
Apium	AWE	0.0	6.5	803.3	0.0	391.5	33,744.3	L1
Bambra	Apache	29,958.5	4835.9	77,828.7	383,374.5	158,114.9	1,347,582.7	TL/1
Barrow Island	Chevron	314,576.0	0.0	30,965.4	50,904,050.0	0.0	5,374,374.4	L1H
Blina	Buru Energy	903.0	0.0	0.0	298,698.0	0.0	0.0	L6
Boundary	Buru Energy	217.0	0.0	0.0	21,180.0	0.0	0.0	L6
Corybas	AWE	0.0	16.3	866.1	0.0	232.3	12,443.1	L2
Cowle	Chevron	1311.0	0.0	568.0	537,068.0	0.0	91,871.0	TL/4
Crest	Chevron	254.0	0.0	1099.0	275,465.0	108.0	64,247.0	L12, L13
Dongara	AWE	849.3	0.0	17,649.9	195,070.3	49,681.0	12,927,489.9	L1, L2
Double Island	Apache	2793.6	40.1	2549.3	708,510.6	2943.1	59,149.3	TL/9
Eremia	AWE	23.2	0.0	29.6	244,037.2	0.0	14,629.6	L1
Harriet	Apache	9153.7	140.8	7555.1	8,232,653.7	61,226.8	1,510,682.1	TL/1
Hovea	AWE	1364.8	0.0	993.0	1,170,005.8	251.0	104,830.0	L1
Jingemia	Origin	12,610.0	0.0	1001.9	745,616.0	0.0	36,542.9	L14
Lee	Apache	0.0	1699.3	11,185.8	4.0	110,094.3	726,034.8	TL/1
Little Sandy	Apache	1726.9	24.5	1950.3	95,189.9	491.5	15,906.3	TL/6
Mohave	Apache	5481.1	216.8	8609.5	167,857.1	585.8	39,044.5	TL/6
North Alkimos	Apache	18.9	0.0	17.3	12,652.9	98.0	22,699.3	TL/6
Pedirka	Apache	6680.9	58.6	4739.6	340,076.9	1366.6	45,437.6	TL/6
Redback	Origin	0.0	290.0	186,882.3	0.0	432.0	311,985.3	L11
Roller	Chevron	28,420.0	0.0	11,748.0	7,184,779.0	0.0	781,782.0	TL/7
Rose	Apache	0.0	3751.2	28,566.2	0.0	208,820.2	1,027,695.2	TL/1
Saladin	Chevron	55,517.0	0.0	23,361.0	15,584,814.0	0.0	1,785,246.0	TL/4
Simpson	Apache	10,766.6	2028.5	3137.8	857,264.6	14,299.5	90,199.8	TL/1
Skate	Chevron	0.0	0.0	105.0	266,950.0	8873.0	178,287.0	TL/7
South Plato	Apache	1876.2	0.5	91.8	704,788.2	899.5	51,782.8	TL/6
Sundown	Buru Energy	604.0	0.0	0.0	74,112.0	0.0	0.0	L8
Ungani	Buru Energy	12,095.0	0.0	4461.0	12,095.0	0.0	4461.0	EP 391
Victoria	Apache	3882.0	41.4	1397.0	61,014.0	470.4	11,374.0	TL/6
West Cycad	Apache	2600.8	8.5	777.0	217,393.8	535.5	36,581.0	TL/9
West Terrace	Buru Energy	67.0	0.0	0.0	39,589.0	0.0	0.0	L8
Wonnich	Apache	0.0	10,173.5	142,573.1	0.0	476,894.5	4,828,573.1	TL/8
Yammaderry	Chevron	109.0	0.0	11,016.0	858,332.0	0.0	128,954.0	TL/4
Total		521,358.5	28,606.3	617,242.5	90,813,145.5	1,101,166.7	31,712,166.2	

Table 2a. Petroleum Reserves Estimates by Basin for WA State Onshore, State Waters and Territorial Waters, as at 31 December 2012 (metric units)

Basin	Oil		Sales Gas		Condensate	
	GL		Gm ³		GL	
Category 1	P50	P90	P50	P90	P50	P90
Canning	0.000	0.000	0.000	0.000	0.000	0.000
Carnarvon	6.710	1.450	1.590	0.830	0.130	0.060
Perth	0.010	0.000	0.18	0.120	0.000	0.000
Total	6.72	1.45	1.77	0.95	0.13	0.06
Category 2	P50	P90	P50	P90	P50	P90
Carnarvon	0.930	0.520	0.500	0.380	0.000	0.000
Total	0.93	0.52	0.50	0.38	0.00	0.00
Category 3	P50	P90	P50	P90	P50	P90
Canning	0.000	0.000	0.000	0.000	0.000	0.000
Perth	0.000	0.000	0.960	0.270	0.000	0.000
Total	0.00	0.00	0.96	0.27	0.00	0.00
Category 4	P50	P90	P50	P90	P50	P90
Canning	0.050	0.020	2.740	0.710	0.620	0.150
Carnarvon	6.100	1.290	9.500	4.390	0.000	0.000
Perth	0.000	0.000	5.500	5.500	0.000	0.000
Total	6.15	1.31	17.74	10.60	0.62	0.15
GRAND TOTAL	13.80	3.28	20.97	12.20	0.75	0.21

Table 2b. Petroleum Reserves Estimates by Basin for WA State Onshore, State Waters and Territorial Waters, as at 31 December 2012 (field units)

Basin	Oil		Sales Gas		Condensate	
	MMbbl		Bcf		MMbbl	
Category 1	P50	P90	P50	P90	P50	P90
Canning	0.000	0.000	0.000	0.000	0.000	0.000
Carnarvon	42.180	9.120	56.230	29.270	0.830	0.380
Perth	0.080	0.020	6.210	4.150	0.000	0.000
Total	42.26	9.14	62.44	33.42	0.83	0.38
Category 2	P50	P90	P50	P90	P50	P90
Carnarvon	5.850	3.250	17.570	13.570	0.000	0.000
Total	5.85	3.25	17.57	13.57	0.00	0.00
Category 3	P50	P90	P50	P90	P50	P90
Canning	0.000	0.000	0.000	0.000	0.000	0.000
Perth	0.000	0.000	33.940	9.430	0.020	0.010
Total	0.00	0.00	33.94	9.43	0.02	0.01
Category 4	P50	P90	P50	P90	P50	P90
Canning	0.290	0.110	96.660	24.990	3.900	0.950
Carnarvon	38.360	8.110	335.310	154.850	0.000	0.000
Perth	0.000	0.000	194.230	194.230	0.000	0.000
Total	38.65	8.22	626.20	374.07	3.90	0.95
GRAND TOTAL	86.76	20.61	740.15	430.49	4.75	1.34

NOTES

Canning Basin reserves are too small to measure.

Category 1 comprises current reserves of those fields which are producing hydrocarbons or have been declared commercial (FFDP approved and FID).

Category 2 comprises estimates of recoverable reserves which are held under Retention Leases and have not yet been declared commercially viable.

Category 3 comprises estimates of contingent resources which are held in other licences and have been declared commercially viable but may or may not have a FFDP and have not yet reached FID.

Category 4 comprises estimates of contingent resources which are held in other licences and have not yet been declared commercially viable and are not held under a Retention Lease.

Table 3. Petroleum Wells in Western Australia, Onshore and State Waters: 2012-13 Fiscal Year

Well Name	Class	On Off	Title	Operator	Latitude	Longitude	Gnd Elev/ Water Depth (m)	RT/ KB (m)	Spud Date	TD Date	Rig Release Date
Canning Basin											
Yulleroo 4	EXT	On	EP 436	Buru	122.8780	-17.8230	47.0	52.9	19/01/2013	2/03/2013	17/03/2013
Cyrene 1	NFW	On	EP 438	Gulliver	122.4014	-18.2763	47.0	53.0	13/12/2012	21/01/2013	24/02/2013
Gibb-Maitland 1	NFW	On	EP 450	New Standard	124.6407	-20.9956	296.0	305.3	5/12/2012	16/01/2013	7/02/2013
Carnarvon Basin											
Barrow F24B MB	DEV	On	L 1H R2	Chevron	115.3833	-20.8331	35.0	42.1	20/04/2013	8/05/2013	14/05/2013
Barrow F55A MB	DEV	On	L 1H R2	Chevron	115.3899	-20.8459	12.5	19.4	26/05/2013	19/06/2013	23/06/2013
Barrow G48B MB	DEV	On	L 1H R2	Chevron	115.3668	-20.8408	49.5	53.0	20/12/2012	7/02/2013	17/02/2013
Taunton 5H	EXT	Off	TL/2 R1	Apache	115.1075	-21.3251	38.0	45.5	15/04/2013	6/06/2013	29/06/2013
Barrow WSW 8B	WSW	On	L 1H R2	Chevron	115.3823	-20.8186	46.6	53.7	4/03/2013	3/04/2013	9/04/2013
Barrow WSW 8C	WSW	On	L 1H R2	Chevron	115.3822	-20.8187	46.6	53.7	28/02/2013	20/03/2013	9/04/2013
Perth Basin											
Mt Ridley 1	GEOTHERMAL	On	GEP 38	Green Power	122.0933	33.2983	n/a	n/a	13/06/2013	25/06/2013	28/06/2013
Warradarge 1	NFW	On	DR 11	Titan Energy	115.2587	-29.8731	86.0	94.0	27/03/2013	20/04/2013	27/04/2013

Classification

DEV	Development Well
EXT	Extension Well
NFW	New Field Wildcat
WSW	Water Service Well

Table 4. Surveys in Western Australia State Onshore, State Waters and Territorial Waters: 2012-13 Fiscal Year

Survey Name	Class	On Off	Title	Operator	Commenced	Completed	2D/ Line km @ 30/06/2013	3D /km ² @ 30/06/2013
Bonaparte Basin								
2012 Bonaparte Airborne Geophysical Survey	AEROMAG	On	EP 386 R3	Beach Energy	24/01/13	18/03/13	15,732	
Canning Basin								
Bracken 2011 Aerial Gravity and Magnetic Survey	AEROMAG	On	SPA 4 AO	Hess	26/11/12	16/01/13	3029	
Fitzroy Aeromagnetic Impulse Survey	AEROMAG	On	SPA 7 AO	Goshawk Energy	10/06/13	11/06/13	900	
Hassen 2011 Aerial Gravity and Magnetic Survey	AEROMAG	On	SPA 3 AO	Hess	26/11/12	16/01/13	13,923	
Carnarvon Basin								
South Carnarvon 2D S.S.	2D	On	SPA 8 AO	Fleet Resources	25/04/13	04/05/13	142	
Perth Basin								
Badgingarra 2D S.S.	2D	On	EP 407 R1, EP 447	Green Power Energy	04/04/13	22/04/13	212	
Launer 2D S.S.	2D	On	EP 321 R4, EP 430, EP 454	Empire Oil & Gas	28/03/13	04/04/13	56	
Wannamal 3D S.S.	3D	On	EP 389 R2	Empire Oil & Gas	29/05/13	09/06/13		74

Classification

2D	2D Seismic Survey
3D	3D Seismic Survey
AEROMAG	Aeromagnetic Survey

Table 5. List of Petroleum and Geothermal Titles and Holders in Western Australia as at 3 July 2013

PETROLEUM (SUBMERGED LANDS) ACT 1982 Exploration Permit	
Title	Registered Holders (* denotes Nominee)
TP/7 R4	Hydra Energy (WA) Pty Ltd
	Santos (BOL) Pty Ltd
	Tap (Shelfal) Pty Ltd
	* Apache Oil Australia Pty Ltd
TP/8 R4	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TP/15 R2	Westranch Holdings Pty Ltd
TP/23 R1	Apache Northwest Pty Ltd
TP/25	Finder No 3 Pty Limited

PETROLEUM (SUBMERGED LANDS) ACT 1982 Pipeline Licence	
Title	Registered Holders (* denotes Nominee)
TPL/1 R1	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TPL/2 R1	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TPL/3 R1	Hydra Energy (WA) Pty Ltd
	Santos (BOL) Pty Ltd
	Tap (Shelfal) Pty Ltd
	* Apache Oil Australia Pty Ltd
TPL/4 R1	Apache Oil Australia Pty Ltd
	Hydra Energy (WA) Pty Ltd
	Santos (BOL) Pty Ltd
	Tap (Shelfal) Pty Ltd
TPL/5 R1	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TPL/6 R1	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
TPL/7 R2	Hydra Energy (WA) Pty Ltd
	Santos (BOL) Pty Ltd
	Tap (Shelfal) Pty Ltd
	* Apache Oil Australia Pty Ltd
TPL/8	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TPL/9 R1	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
TPL/10	Inpex Alpha Ltd

	Mobil Exploration & Producing Australia Pty Ltd
	* BHP Billiton Petroleum (Australia) Pty Ltd
TPL/11	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
TPL/12	Apache East Spar Pty Ltd
	Apache Kersail Pty Ltd
	Santos (BOL) Pty Ltd
	* Apache Oil Australia Pty Ltd
TPL/13	Apache East Spar Pty Ltd
	Apache Kersail Pty Ltd
	Apache Northwest Pty Ltd
	Apache Oil Australia Pty Ltd
	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	Santos (BOL) Pty Ltd
TPL/14	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TPL/15	BHP Billiton Petroleum (North West Shelf) Pty Ltd
	BP Developments Australia Pty Ltd
	Chevron Australia Pty Ltd
	Japan Australia LNG (MIMI) Pty Ltd
	Shell Development (Australia) Proprietary Limited
	* Woodside Energy Ltd
TPL/16	BHP Billiton Petroleum (North West Shelf) Pty Ltd
	BP Developments Australia Pty Ltd
	Chevron Australia Pty Ltd
	Japan Australia LNG (MIMI) Pty Ltd
	Shell Development (Australia) Proprietary Limited
	* Woodside Energy Ltd
TPL/17	Apache Northwest Pty Ltd
	Santos (BOL) Pty Ltd
TPL/18	ARC (Offshore PB) Limited
	AWE Oil (Western Australia) Pty Ltd
	Roc Oil (WA) Pty Limited
TPL/19	Kansai Electric Power Australia Pty Ltd
	Tokyo Gas Pluto Pty Ltd
	Woodside Burrup Pty Ltd
TPL/20	Apache Northwest Pty Ltd
	Santos Offshore Pty Ltd
TPL/21	Chubu Electric Power Gorgon Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Osaka Gas Gorgon Pty Ltd
	Shell Development (Australia) Proprietary Limited
	Tokyo Gas Gorgon Pty Ltd
	* Chevron (TAPL) Pty Ltd
TPL/22	Chubu Electric Power Gorgon Pty Ltd

Table 5. List of Petroleum and Geothermal Titles and Holders in Western Australia as at 3 July 2013

	Mobil Australia Resources Company Pty Limited
	Osaka Gas Gorgon Pty Ltd
	Shell Development (Australia) Proprietary Limited
	Tokyo Gas Gorgon Pty Ltd
	* Chevron (TAPL) Pty Ltd
TPL/23	Apache PVG Pty Ltd
	BHP Billiton Petroleum (Australia) Pty Ltd
TPL/24	Chubu Electric Power Gorgon Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Osaka Gas Gorgon Pty Ltd
	Shell Development (Australia) Proprietary Limited
	Tokyo Gas Gorgon Pty Ltd
	* Chevron (TAPL) Pty Ltd
TPL/25	Apache Julimar Pty Ltd
	KUFPEC Australia (Julimar) Pty Ltd
	Kyushu Electric Wheatstone Pty Ltd
	Shell Development (Australia) Proprietary Limited
	* Chevron (TAPL) Pty Ltd

PETROLEUM (SUBMERGED LANDS) ACT 1982 Production Licence	
Title	Registered Holders (* denotes Nominee)
TL/1 R1	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TL/2 R1	Hydra Energy (WA) Pty Ltd
	Santos (BOL) Pty Ltd
	Tap (Shelfal) Pty Ltd
	* Apache Oil Australia Pty Ltd
TL/3 R1	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
TL/4 R1	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
TL/5 R1	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TL/6 R1	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TL/7	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
TL/8	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd

	* Apache Northwest Pty Ltd
TL/9	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TL/10	Apache Northwest Pty Ltd
	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd

PETROLEUM (SUBMERGED LANDS) ACT 1982 Retention Lease	
Title	Registered Holders (* denotes Nominee)
TR/1 R2	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
TR/3 R2	Apache Northwest Pty Ltd
TR/4 R1	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
TR/5 R1	BHP Billiton Petroleum (North West Shelf) Pty Ltd
	BP Developments Australia Pty Ltd
	Japan Australia LNG (MIMI Browse) Pty Ltd
	Shell Development (Australia) Proprietary Limited
	Woodside Browse Pty. Ltd.
TR/6	Chevron (TAPL) Pty Ltd
	Chevron Australia Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd

PETROLEUM AND GEOTHERMAL ENERGY RESOURCES ACT 1967 Access Authority to Deviated Well	
Title	Registered Holders (* denotes Nominee)
ADW 8/90-1	Chevron (TAPL) Pty Ltd
ADW 12/91-2	Harriet (Onyx) Pty Ltd
ADW 10/92-3	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
ADW 12/91-2	Kufpec Australia Pty Ltd
ADW 8/90-1	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
ADW 10/92-3	* Apache Northwest Pty Ltd
ADW 12/91-2	* Apache Northwest Pty Ltd
ADW 8/90-1	* Chevron Australia Pty Ltd

PETROLEUM AND GEOTHERMAL ENERGY RESOURCES ACT 1967 Drilling Reservation	
Title	Registered Holders (* denotes Nominee)
DR 11	Titan Energy Ltd

Table 5. List of Petroleum and Geothermal Titles and Holders in Western Australia as at 3 July 2013

PETROLEUM AND GEOTHERMAL ENERGY RESOURCES ACT 1967 Exploration Permit	
Title	Registered Holders (* denotes Nominee)
EP 61 R7	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
EP 62 R7	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
EP 104 R5	Arc Energy Limited
	FAR Ltd
	Gulliver Productions Pty Ltd
	Indigo Oil Pty Ltd
	Pancontinental Oil & Gas NL
	Phoenix Resources PLC
EP 110 R5	Pancontinental Oil & Gas NL
	Strike Energy Western Australia Pty Limited
EP 129 R5	Buru Energy Limited
EP 307 R5	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
EP 320 R4	ARC (Beharra Springs) Pty Ltd
	* Origin Energy Developments Pty Limited
EP 321 R3	Alcoa of Australia Limited
	* Latent Petroleum Pty Ltd
EP 325 R3	Advent Energy Ltd
	Bow Energy Pty Ltd
	Rough Range Oil Pty Ltd
	Strike Energy Western Australia Pty Limited
EP 357 R3	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
EP 358 R3	Harriet (Onyx) Pty Ltd
	Kufpec Australia Pty Ltd
	* Apache Northwest Pty Ltd
EP 359 R2	Bounty Oil & Gas NL
	Lansvale Oil & Gas Pty Ltd
	Pace Petroleum Pty Ltd
	Phoenix Resources PLC
	* Rough Range Oil Pty Ltd
EP 368 R3	Westranch Holdings Pty Ltd
	* Empire Oil Company (WA) Limited
EP 371 R1	Buru Energy Limited
	Diamond Resources (Canning) Pty Ltd
EP 381 R3	Whicher Range Energy Pty Ltd
EP 386 R3	Onshore Energy Pty Ltd

EP 389 R2	ERM Gas Pty Ltd
	Empire Oil Company (WA) Limited
	Wharf Resources PLC
EP 390 R2	Buru Energy Limited
	Diamond Resources (Canning) Pty Ltd
EP 391 R2	Buru Energy Limited
	Diamond Resources (Fitzroy) Pty Ltd
EP 407 R1	Alcoa of Australia Limited
	* Latent Petroleum Pty Ltd
EP 408 R2	Whicher Range Energy Pty Ltd
	* CalEnergy Resources (Australia) Limited
EP 412 R2	Bounty Oil & Gas NL
	* Rough Range Oil Pty Ltd
EP 413 R2	Arc Energy Limited
	Bharat PetroResources Limited
	Norwest Energy NL
EP 416 R1	Allied Oil & Gas Plc
	ERM Gas Pty Ltd
	* Empire Oil Company (WA) Limited
EP 417 R1	Buru Energy Limited
	New Standard Onshore Pty Ltd
EP 424	Pancontinental Oil & Gas NL
	Strike Energy Western Australia Pty Limited
EP 426	Allied Oil & Gas Plc
	ERM Gas Pty Ltd
	Empire Oil Company (WA) Limited
	Westranch Holdings Pty Ltd
EP 428	Buru Energy Limited
	Diamond Resources (Canning) Pty Ltd
EP 430	Empire Oil Company (WA) Limited
EP 431	Buru Energy Limited
	Diamond Resources (Fitzroy) Pty Ltd
EP 432	Allied Oil & Gas Plc
	ERM Gas Pty Ltd
	* Empire Oil Company (WA) Limited
EP 433 R1	Lansvale Oil & Gas Pty Ltd
	Pace Petroleum Pty Ltd
EP 434 R1	Pace Petroleum Pty Ltd
	Rough Range Oil Pty Ltd
	* Lansvale Oil & Gas Pty Ltd
EP 435 R1	Australian Oil Company No 3 Pty Limited
	Bounty Oil & Gas NL
	Rough Range Oil Pty Ltd
EP 436	Buru Energy Limited
	Diamond Resources (Fitzroy) Pty Ltd
EP 437	Empire Oil Company (WA) Limited
	Key Petroleum (Australia) Pty Ltd
EP 438	Buru Energy Limited
	Diamond Resources (Canning) Pty Ltd

Table 5. List of Petroleum and Geothermal Titles and Holders in Western Australia as at 3 July 2013

	Gulliver Productions Pty Ltd	EP 469	Warrego Energy Pty Ltd
	Indigo Oil Pty Ltd	EP 470	Energetica Resources Pty Ltd
EP 439	Falcore Pty Ltd	EP 471	Buru Energy Limited
	Indigo Oil Pty Ltd		Diamond Resources (Canning) Pty Ltd
	Jurassica Oil & Gas Plc	EP 472	Buru Energy Limited
	Longreach Oil Limited		Diamond Resources (Canning) Pty Ltd
	Vigilant Oil Pty Ltd	EP 473	Buru Energy Limited
	* Rough Range Oil Pty Ltd		Diamond Resources (Canning) Pty Ltd
EP 440 R1	Empire Oil Company (WA) Limited	EP 474	Buru Energy Limited
EP 441 R1	Apache Northwest Pty Ltd	EP 475	Energetica Resources Pty Ltd
EP 443	ConocoPhillips (Canning Basin) Pty Ltd	EP 476	Buru Energy Limited
	New Standard Onshore Pty Ltd		Diamond Resources (Canning) Pty Ltd
EP 444 R1	Rough Range Oil Pty Ltd	EP 477	Buru Energy (Acacia) Pty Ltd
EP 447	GCC Methane Pty Ltd		Diamond Resources (Canning) Pty Ltd
EP 448	Gulliver Productions Pty Ltd	EP 478	Buru Energy (Acacia) Pty Ltd
	Indigo Oil Pty Ltd		Buru Energy Limited
	United Orogen Limited	EP 479	ERM Gas Pty Ltd
EP 449	Hess Australia (Canning) Pty Limited		Empire Oil & Gas NL
EP 450	ConocoPhillips (Canning Basin) Pty Ltd	EP 480	ERM Gas Pty Ltd
	New Standard Onshore Pty Ltd		Empire Oil & Gas NL
EP 451	ConocoPhillips (Canning Basin) Pty Ltd	EP 481	New Standard Onshore Pty Ltd
	New Standard Onshore Pty Ltd	EP 482	New Standard Onshore Pty Ltd
EP 453 R1	Goshawk Energy (Lennard Shelf) Pty Ltd	EP 483	Finder No 3 Pty Limited
EP 454	Empire Oil Company (WA) Limited	EP 484	Dynasty Metals Australia Ltd
EP 455	Titan Energy Ltd	EP 485	Dynasty Metals Australia Ltd
	* Arc Energy Limited	EP 486	Exceed Energy (Australia) Pty Ltd
EP 456	ConocoPhillips (Canning Basin) Pty Ltd		
	New Standard Onshore Pty Ltd		
EP 457	Rey Resources Ltd		
	* Buru Fitzroy Limited		
EP 458	Rey Resources Ltd		
	* Buru Fitzroy Limited		
EP 460	Falcore Pty Ltd		
	Indigo Oil Pty Ltd		
	Jurassica Oil & Gas Plc		
	Longreach Oil Limited		
	Vigilant Oil Pty Ltd		
	* Rough Range Oil Pty Ltd		
EP 461	Falcore Pty Ltd		
	Indigo Oil Pty Ltd		
	Jurassica Oil & Gas Plc		
	Longreach Oil Limited		
	Vigilant Oil Pty Ltd		
	* Rough Range Oil Pty Ltd		
EP 464	Exceed Energy (Australia) Pty Ltd		
EP 465	Australia Zhongfu Oil Gas Resources Pty Ltd		
EP 466	Rough Range Oil Pty Ltd		
EP 467	ERM Gas Pty Ltd		
EP 468	Officer Petroleum Pty Ltd		

PETROLEUM AND GEOTHERMAL ENERGY RESOURCES ACT 1967
Geothermal Exploration Permit

Title	Registered Holders (* denotes Nominee)
GEP 1	The University of Western Australia
	* Green Rock Energy Limited
GEP 2	Green Rock Energy Limited
GEP 5	Granite Power Limited
GEP 6	Granite Power Limited
GEP 8	CSIRO
GEP 13	New World Energy Limited
GEP 14	New World Energy Limited
GEP 15	New World Energy Limited
GEP 16	New World Energy Limited
GEP 17	New World Energy Limited
GEP 18	New World Energy Limited
GEP 19	New World Energy Limited
GEP 20	New World Energy Limited
GEP 21	New World Energy Limited
GEP 22	AAA Energy Pty Ltd
GEP 23	Mid West Geothermal Power Pty Ltd
GEP 24	Mid West Geothermal Power Pty Ltd
GEP 25	Mid West Geothermal Power Pty Ltd

Table 5. List of Petroleum and Geothermal Titles and Holders in Western Australia as at 3 July 2013

GEP 26	Mid West Geothermal Power Pty Ltd
GEP 27	Mid West Geothermal Power Pty Ltd
GEP 28	Mid West Geothermal Power Pty Ltd
GEP 30	New World Energy Limited
GEP 31	New World Energy Limited
GEP 32	New World Energy Limited
GEP 33	New World Energy Limited
GEP 34	New World Energy Limited
GEP 35	New World Energy Limited
GEP 36	New World Energy Limited
GEP 37	Greenpower Energy Limited
GEP 38	Greenpower Energy Limited
GEP 41	Mid West Geothermal Power Pty Ltd
GEP 42	GT Power Pty Ltd
GEP 43	Kagara Ltd

PETROLEUM AND GEOTHERMAL ENERGY RESOURCES ACT 1967 Production Licence	
Title	Registered Holders (* denotes Nominee)
L 1 R1	APT Parmelia Pty Ltd
	Arc Energy Limited
	Origin Energy Developments Pty Limited
L 2 R1	Origin Energy Developments Pty Limited
	* Arc Energy Limited
L 4 R1	Arc Energy Limited
L 5 R1	Arc Energy Limited
L 6 R1	Buru Energy Limited
L 7 R1	Arc Energy Limited
L 8 R1	Buru Energy Limited
L 9 R1	DBP Services Co Nominees Pty Limited
L 10 R1	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
L 11	ARC (Beharra Springs) Pty Ltd
	* Origin Energy Developments Pty Limited
L 12	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
L 13	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd
L 14	Arc Energy Limited
	Geary, John Kevin
	Norwest Energy NL
	Origin Energy Developments Pty Limited
	Roc Oil (WA) Pty Limited

L 15	Buru Energy Limited
	FAR Ltd
	Gulliver Productions Pty Ltd
	Indigo Oil Pty Ltd
	Pancontinental Oil & Gas NL
L 16	Australian Oil Company No 3 Pty Limited
	Bounty Oil & Gas NL
	Rough Range Oil Pty Ltd
L 17	Buru Energy Limited
L 1H R2	Chevron (TAPL) Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
	* Chevron Australia Pty Ltd

PETROLEUM AND GEOTHERMAL ENERGY RESOURCES ACT 1967 Retention Lease	
Title	Registered Holders (* denotes Nominee)
R 1 R1	Arc Energy Limited
	FAR Ltd
	Gulliver Productions Pty Ltd
	Indigo Oil Pty Ltd
	Pancontinental Oil & Gas NL
	Phoenix Resources PLC
R 2 R1	BHP Billiton Petroleum (North West Shelf) Pty Ltd
	BP Developments Australia Pty Ltd
	Japan Australia LNG (MIMI Browse) Pty Ltd
	Shell Development (Australia) Proprietary Limited
	Woodside Browse Pty. Ltd.
R 3 R1	Oil Basins Limited
R 4	Chevron (TAPL) Pty Ltd
	Chevron Australia Pty Ltd
	Mobil Australia Resources Company Pty Limited
	Santos Offshore Pty Ltd
R 5	Apache Oil Australia Pty Ltd
	OMV Australia Pty Ltd

PETROLEUM PIPELINES ACT 1969 Pipeline Licence	
Title	Registered Holders (* denotes Nominee)
PL 1 R1	APT Parmelia Pty Ltd
PL 2 R1	APT Parmelia Pty Ltd
PL 3 R1	APT Parmelia Pty Ltd
PL 5 R1	APT Parmelia Pty Ltd
PL 6 R3	Arc Energy Limited
PL 7 R1	Buru Energy Limited
PL 8 R1	Mitsui Iron Ore Development Pty Ltd
	Nippon Steel Australia Pty Limited
	North Mining Limited
	Sumitomo Metal Australia Pty Ltd
	* Robe River Mining Co Pty Ltd

Table 5. List of Petroleum and Geothermal Titles and Holders in Western Australia as at 3 July 2013

PL 12 R1	Harriet (Onyx) Pty Ltd	PL 40	DBNGP (WA) Nominees Pty Limited
	Kufpec Australia Pty Ltd	PL 41	DBNGP (WA) Transmission Pty Limited
	* Apache Northwest Pty Ltd	PL 42	Apache East Spar Pty Ltd
PL 14 R1	Apache Oil Australia Pty Ltd		Apache Kersail Pty Ltd
	Hydra Energy (WA) Pty Ltd		Apache Northwest Pty Ltd
	Santos (BOL) Pty Ltd		Apache Oil Australia Pty Ltd
	Tap (Shelfal) Pty Ltd		Harriet (Onyx) Pty Ltd
PL 15 R1	Chevron (TAPL) Pty Ltd		Kufpec Australia Pty Ltd
	Mobil Australia Resources Company Pty Limited		Santos (BOL) Pty Ltd
	Santos Offshore Pty Ltd	PL 43	Regional Power Corporation
	* Chevron Australia Pty Ltd		* APT Pipelines (WA) Pty Limited
PL 16	DBP Services Co Nominees Pty Limited	PL 44	APT Parmelia Pty Ltd
PL 17	Harriet (Onyx) Pty Ltd	PL 45	APT Parmelia Pty Ltd
	Kufpec Australia Pty Ltd	PL 46	APT Parmelia Pty Ltd
	* Apache Northwest Pty Ltd	PL 47	DBNGP (WA) Transmission Pty Limited
PL 18	ARC (Beharra Springs) Pty Ltd	PL 48	Energy Generation Pty Ltd
	* Origin Energy Developments Pty Limited	PL 52	APT Parmelia Pty Ltd
PL 19	DBP Services Co Nominees Pty Limited	PL 53	APT Parmelia Pty Ltd
PL 20	DBP Services Co Nominees Pty Limited	PL 54	Regional Power Corporation
PL 21	Chevron (TAPL) Pty Ltd		* APT Pipelines (WA) Pty Limited
	Mobil Australia Resources Company Pty Limited	PL 55	Global Advanced Metals Wodgina Pty Ltd
	Santos Offshore Pty Ltd	PL 56	APA (WA) One Pty Limited
	* Chevron Australia Pty Ltd	PL 57	Australian Gold Reagents Pty Ltd
PL 22	APA (Pilbara Pipeline) Pty Ltd	PL 58	BHP Billiton Petroleum (North West Shelf) Pty Ltd
PL 23	APT Parmelia Pty Ltd		BP Developments Australia Pty Ltd
PL 24	Alinta DEWAP Pty Ltd		Chevron Australia Pty Ltd
	Southern Cross Pipelines (NPL) Australia Pty Ltd		Japan Australia LNG (MIMI) Pty Ltd
	* Southern Cross Pipelines Australia Pty Limited		Shell Development (Australia) Proprietary Limited
PL 25	Southern Cross Pipelines Australia Pty Limited		* Woodside Energy Ltd
PL 26	Southern Cross Pipelines Australia Pty Limited	PL 59	Esperance Pipeline Co. Pty Limited
PL 27	Southern Cross Pipelines Australia Pty Limited	PL 60	Gas Transmission Services WA (Operations) Pty Ltd
PL 28	Southern Cross Pipelines (NPL) Australia Pty Ltd	PL 61	APT Parmelia Pty Ltd
PL 29	Apache East Spar Pty Ltd	PL 62	Harriet (Onyx) Pty Ltd
	Apache Kersail Pty Ltd		Kufpec Australia Pty Ltd
	Santos (BOL) Pty Ltd		* Apache Northwest Pty Ltd
	* Apache Oil Australia Pty Ltd	PL 63	Gas Transmission Services WA (Operations) Pty Ltd
PL 30	Apache East Spar Pty Ltd	PL 64	Arc Energy Limited
	Apache Kersail Pty Ltd		Origin Energy Developments Pty Limited
	Santos (BOL) Pty Ltd	PL 65	Dalrymple Resources Pty Ltd
	* Apache Oil Australia Pty Ltd		Norilsk Nickel Wildara Pty Ltd
PL 31	APA (Pilbara Pipeline) Pty Ltd	PL 67	Hamersley Iron Pty Ltd
PL 32	APT Pipelines (WA) Pty Limited	PL 68	Gas Transmission Services WA (Operations) Pty Ltd
PL 33	APT Pipelines (WA) Pty Limited	PL 69	DBNGP (WA) Nominees Pty Limited
PL 34	Newmont Yandal Operations Pty Ltd	PL 70	ARC (Offshore PB) Limited
PL 35	Plutonic Operations Limited		AWE Oil (Western Australia) Pty Ltd
PL 36	Australian Pipeline Limited		Roc Oil (WA) Pty Limited
PL 37	Norilsk Nickel Cawse Pty Ltd	PL 72	EDL NGD (WA) Pty Ltd
PL 38	APA (Pilbara Pipeline) Pty Ltd	PL 73	Redback Pipelines Pty Ltd
PL 39	Origin Energy Pipelines Pty Limited	PL 74	EDL LNG (WA) Pty Ltd

Table 5. List of Petroleum and Geothermal Titles and Holders in Western Australia as at 3 July 2013

PL 75	EIT Neerabup Power Pty Ltd	PL 91	DBNGP (WA) Nominees Pty Limited
	ERM Neerabup Pty Ltd	PL 92	Chubu Electric Power Gorgon Pty Ltd
PL 76	APA Group		Mobil Australia Resources Company Pty Limited
PL 77	Sino Iron Pty Ltd		Osaka Gas Australia Pty Ltd
PL 78	Hamersley Iron Pty Ltd		Shell Development (Australia) Proprietary Limited
PL 80	Latent Petroleum Pty Ltd		Tokyo Gas Gorgon Pty Ltd
PL 81	Apache Northwest Pty Ltd		* Chevron (TAPL) Pty Ltd
PL 82	APA (Pilbara Pipeline) Pty Ltd	PL 93	Chubu Electric Power Gorgon Pty Ltd
PL 83	WA Gas Networks Pty Ltd		Mobil Australia Resources Company Pty Limited
PL 84	Chubu Electric Power Gorgon Pty Ltd		Osaka Gas Gorgon Pty Ltd
	Mobil Australia Resources Company Pty Limited		Shell Development (Australia) Proprietary Limited
	Osaka Gas Gorgon Pty Ltd		Tokyo Gas Gorgon Pty Ltd
	Shell Development (Australia) Proprietary Limited		* Chevron (TAPL) Pty Ltd
	Tokyo Gas Gorgon Pty Ltd	PL 94	DBNGP (WA) Nominees Pty Limited
	* Chevron (TAPL) Pty Ltd	PL 95	DBNGP (WA) Nominees Pty Limited
PL 85	Chubu Electric Power Gorgon Pty Ltd	PL 96	ERM Gas Pty Ltd
	Mobil Australia Resources Company Pty Limited		Empire Oil Company (WA) Limited
	Osaka Gas Gorgon Pty Ltd		Wharf Resources PLC
	Shell Development (Australia) Proprietary Limited	PL 97	Mitsui Iron Ore Development Pty Ltd
	Tokyo Gas Gorgon Pty Ltd		Nippon Steel Australia Pty Limited
	* Chevron (TAPL) Pty Ltd		Rio Tinto Limited
PL 86	Apache Northwest Pty Ltd		Sumitomo Metal Australia Pty Ltd
	Santos Offshore Pty Ltd	PL 98	Esperance Pipeline Co. Pty Limited
PL 87	Apache PVG Pty Ltd	PL 99	Apache Julimar Pty Ltd
	BHP Billiton Petroleum (Australia) Pty Ltd		KUFPEC Australia (Julimar) Pty Ltd
PL 88	Apache PVG Pty Ltd		Kyushu Electric Wheatstone Pty Ltd
	BHP Billiton Petroleum (Australia) Pty Ltd		Shell Development (Australia) Proprietary Limited
PL 89	Crosslands Resources Ltd		* Chevron (TAPL) Pty Ltd
PL 90	Apache PVG Pty Ltd	PL 100	DBNGP (WA) Nominees Pty Limited
	BHP Petroleum (Australia) Pty Ltd	PL 101	DBNGP (WA) Nominees Pty Limited

Please consult DMP's online Petroleum and Geothermal Register for the most current information on Titles and Holdings.

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