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AV The Bauer Field, Cooper/Eromanga Basin: Case Study of a Low-Relief, High-Productivity Oil Field*

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Abstract

This presentation provides a case study of the exploration, appraisal, and development of the Bauer Oil Field; its transformation from a small anticlinal prospect to what is now the largest Namur Sandstone oil pool on the western flank of the Patchawarra Trough in the Cooper Basin, South Australia. Low-relief anticlinal closures with oil pooled within the Namur Sandstone reservoir is the primary play on the western flank of the Patchawarra Trough. The Bauer prospect was first identified using 3D seismic data and mapped as an anticlinal closure with 9 metres of relief. The prospect was estimated to have a mean recoverable resource of 0.5 million barrels of oil prior to being drilled in 2011. The discovery well, however, intersected a 14-metre oil column, and as of January 2015 the field has 19 wells on production and an estimated ultimate recovery of 13 million barrels. Growth of recoverable resource estimates continued through appraisal and early development drilling, due to high-side structural results and better than expected reservoir performance. Drilling at Bauer has consistently demonstrated a ±5-metre depth uncertainty at the reservoir level. Critical drills to the north of Bauer-1 were higher than expected and extended the field, while wells to the south were lower, but increased mapped closure height. Variations of this magnitude have a dramatic impact on low-relief structures and can result in large uncertainties for recoverable resource estimates, field development planning, and commerciality. Static and dynamic modelling was undertaken during the early development phase, which focused studies toward characterisation of the Namur Sandstone reservoir. This work showed that understanding the subtle geological variations was key to obtaining a history-matched reservoir model. Model results were most sensitive to facies distribution, permeability, and kv to kh ratio. With a high-permeability reservoir combined with a strong aquifer displacing a low GOR, low-viscosity, and high API oil, a primary recovery of more than 75% is indicated. Well and core data obtained after the initial modelling studies

confirm the primary parameters, with permeabilities of up to 13 Darcys recorded. The lessons learnt during the discovery and development of the Bauer Field may benefit the future exploration, appraisal, and development of low relief, high- productivity fields, and analogous prospects.

The Bauer Field: Case Study of a Low-Relief, High-Productivity Oil Field

Glen Buick

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International Conference & Exhibition 2015
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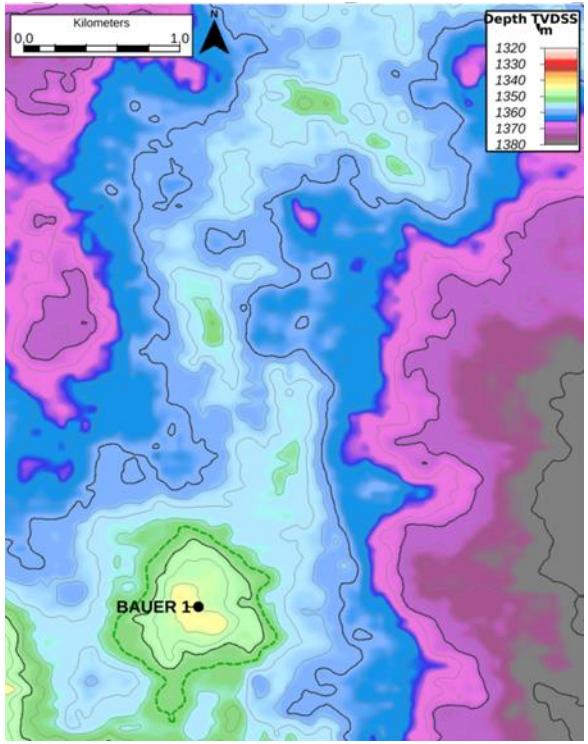
Compliance statements

Competent Persons Statement

The reserves and resources information in this presentation is based on, and fairly represents, information and supporting documentation prepared by, or under the supervision of, Mr Tony Lake (Reservoir Engineering Manager). Mr Lake is an employee of Beach Energy Limited and has a BE (Mech) degree from the University of Adelaide and is a member of the Society of Petroleum Engineers (SPE). The reserves and resources information in this presentation has been issued with the prior written consent of Mr Lake in the form and context in which it appears.

Bauer Field summary

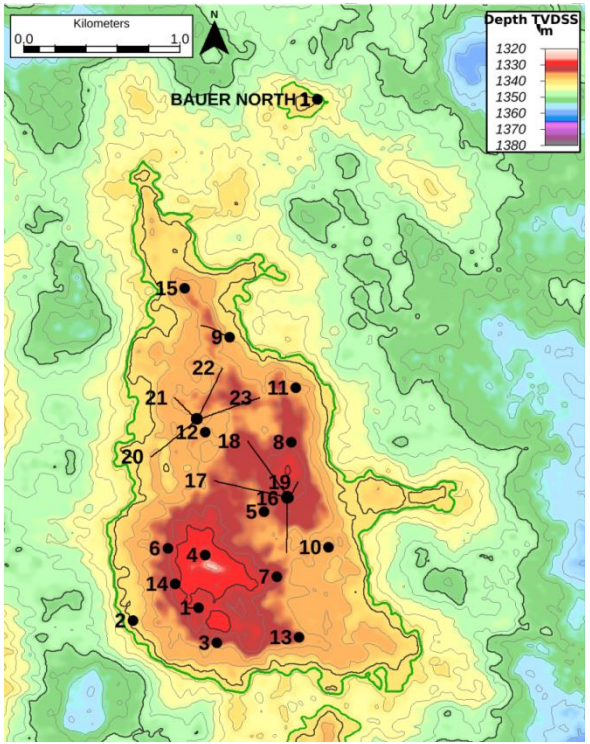
Pre-Drill (July 2011)



Top Namur Sandstone Depth Map. 2m Contours.

- 6m Closure
- Mean prospective resource ~850k bbls oil
- Good quality fluvial sandstone reservoir
- Estimated recovery factor of ~60%

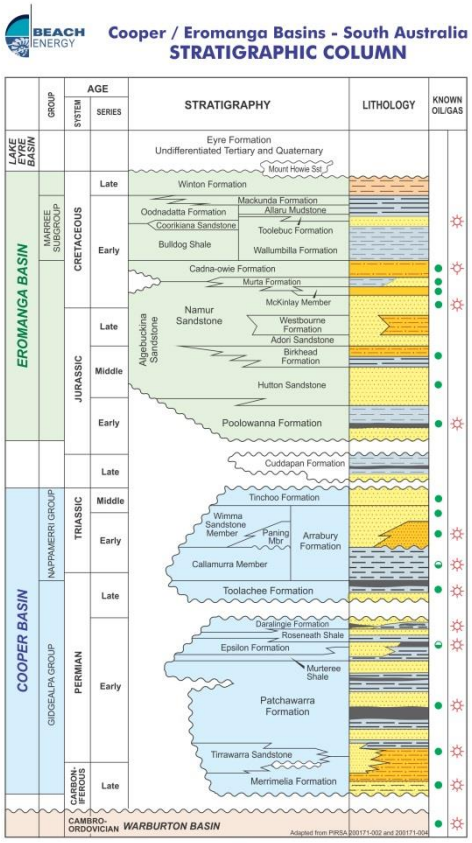
Current

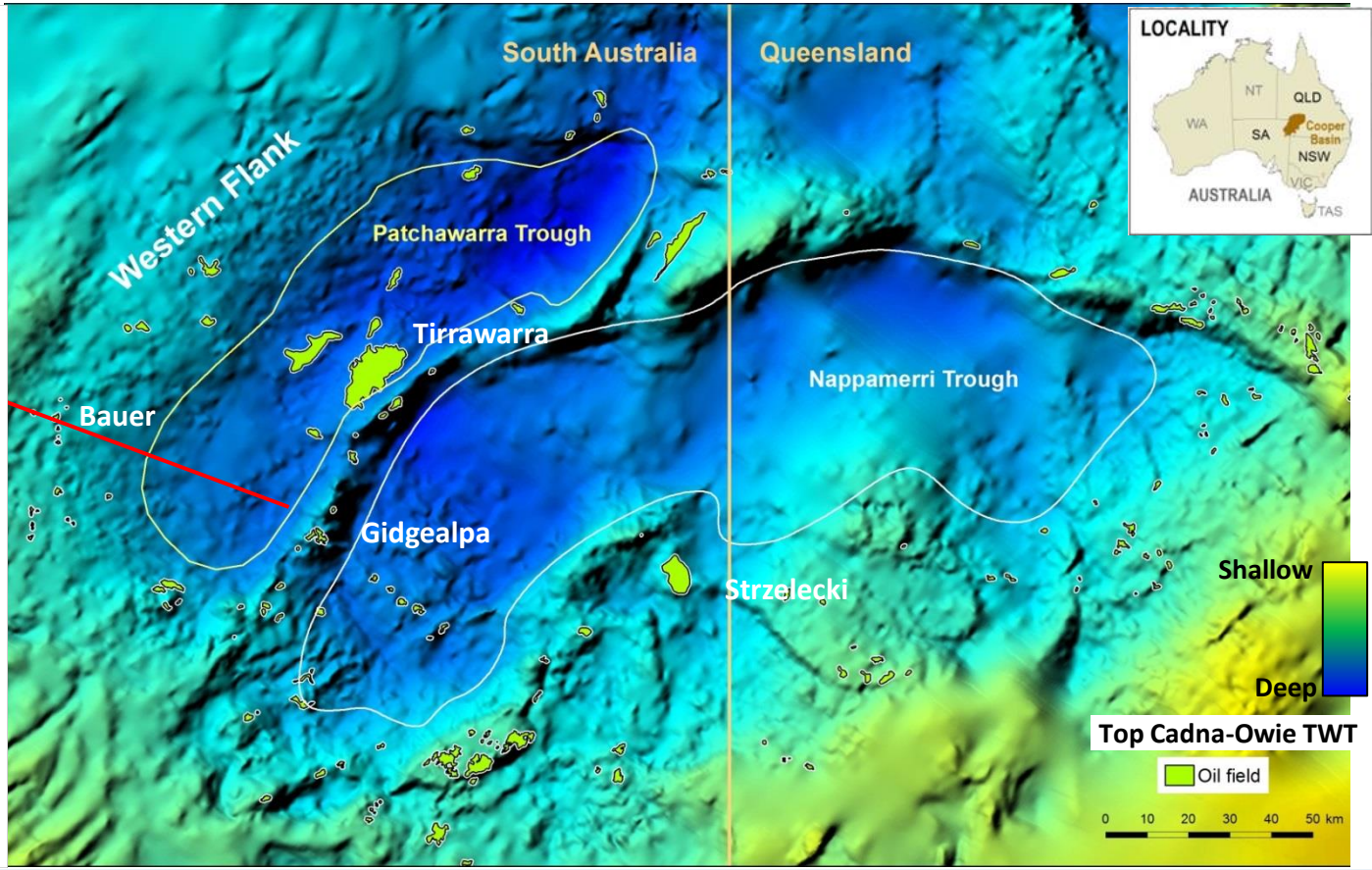


Top Namur Sandstone Depth Map. 2m Contours.

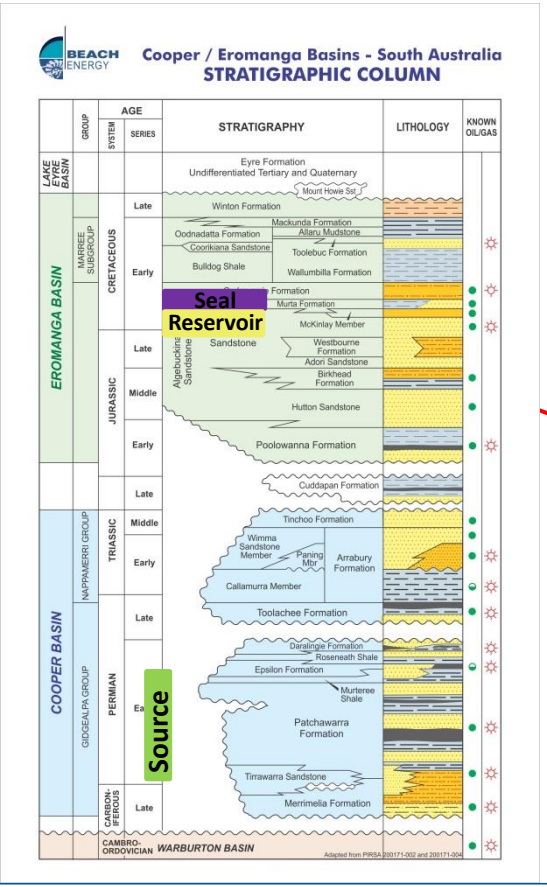
- 17m Gross oil column
- 2P EUR 19.4 MMBbls
- Permeability up to 13.6 Darcys
- 75% Recovery factor

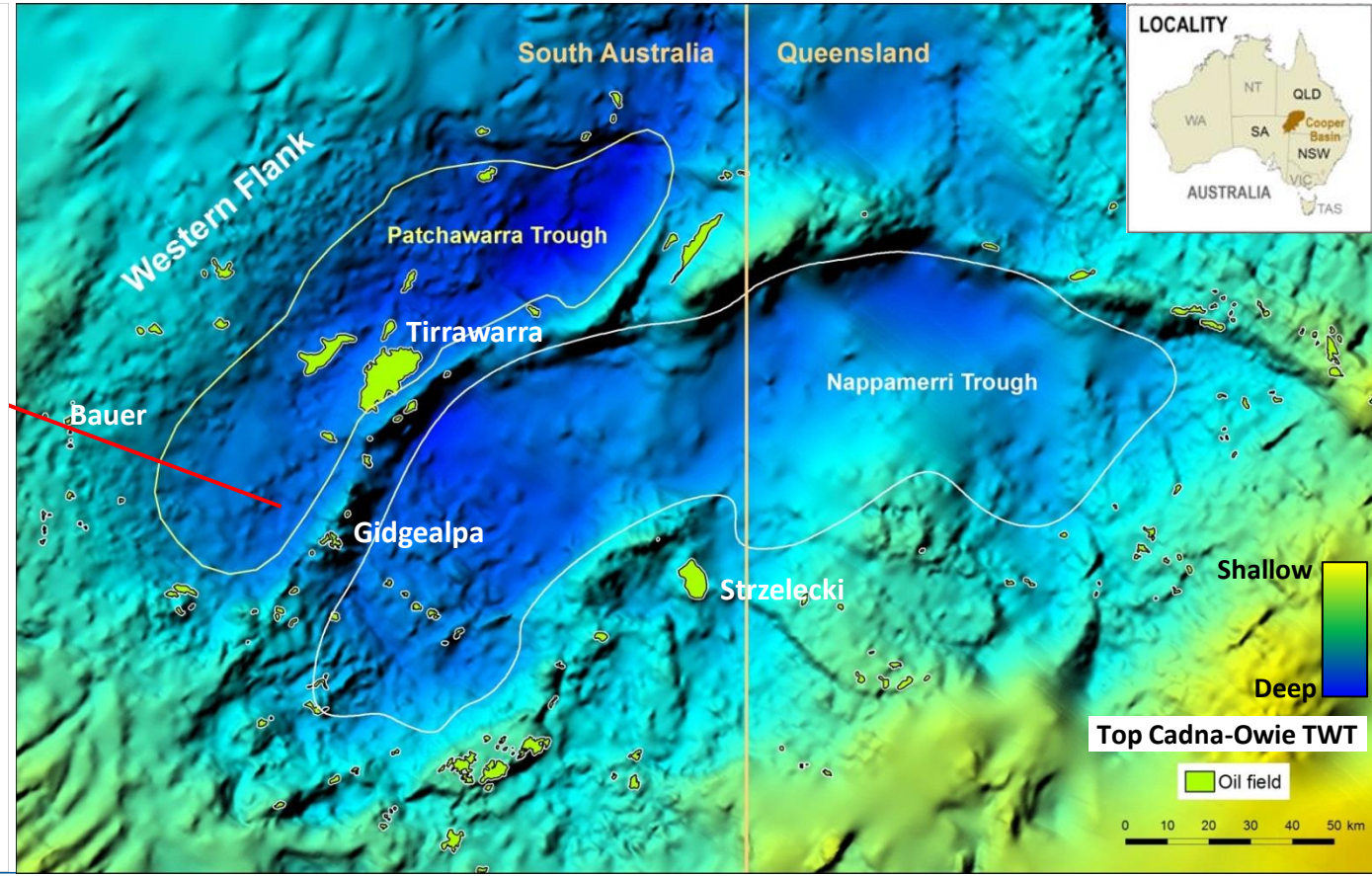
Cooper/Eromanga Basin oil discoveries





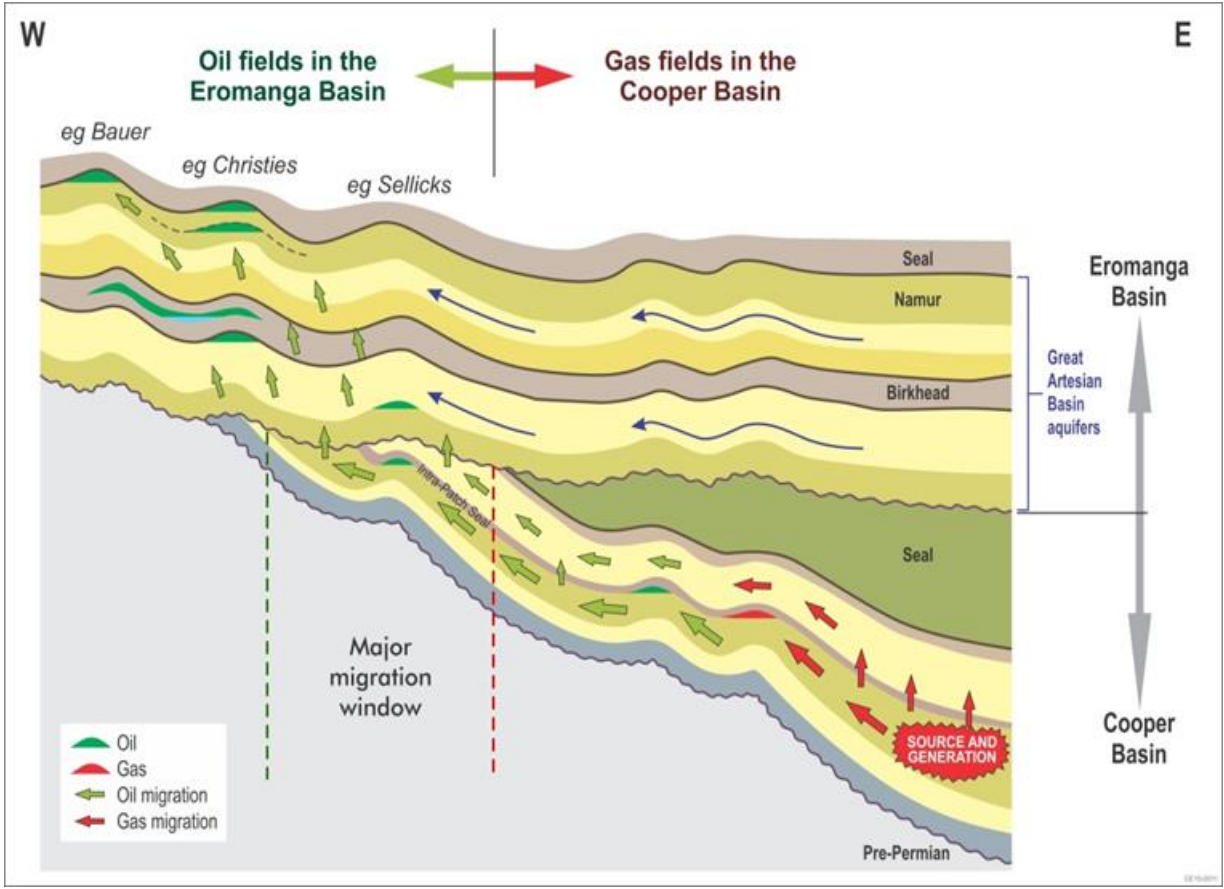
Cooper/Eromanga Basin oil discoveries





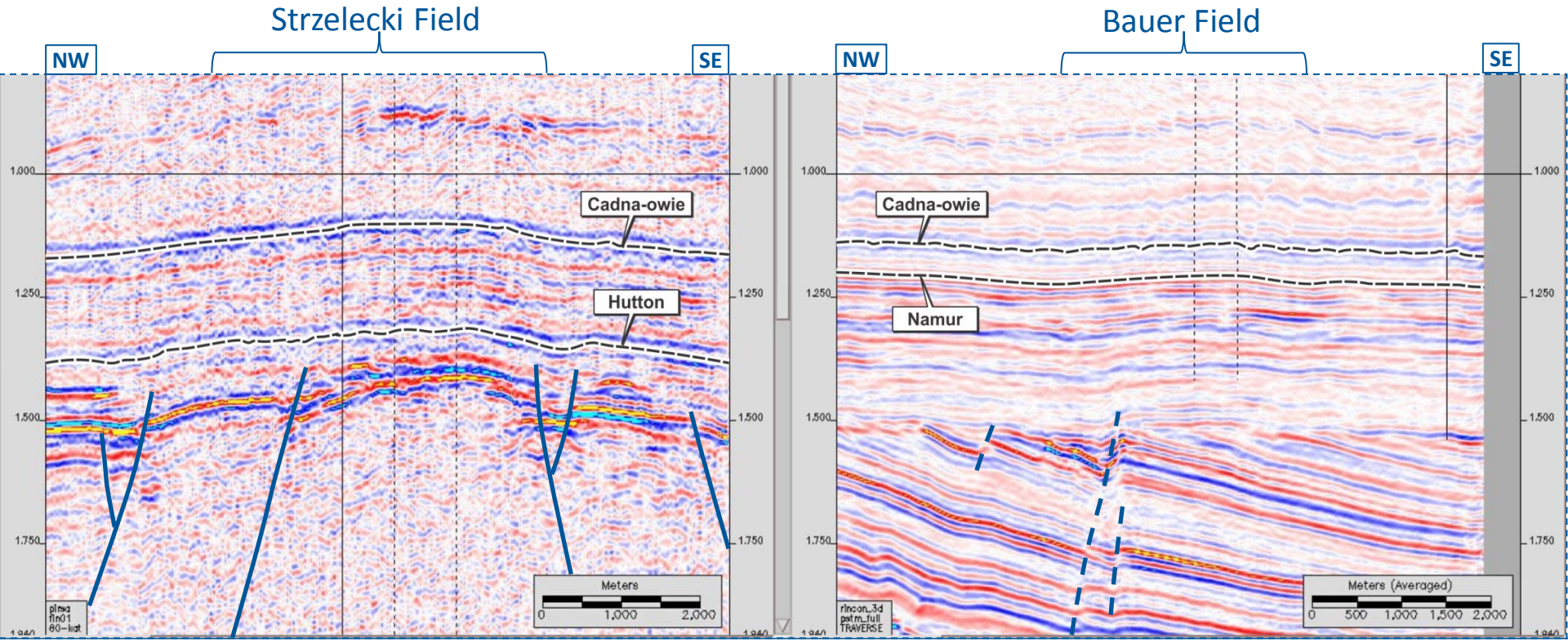
Regional context

- Hydrocarbon generation is interpreted to be from Permian coal measures with migration into Eromanga (Great Artesian) Basin
- Vertical and lateral migration possible where Permian carrier beds are truncated on the basin margin by a basal Jurassic unconformity.



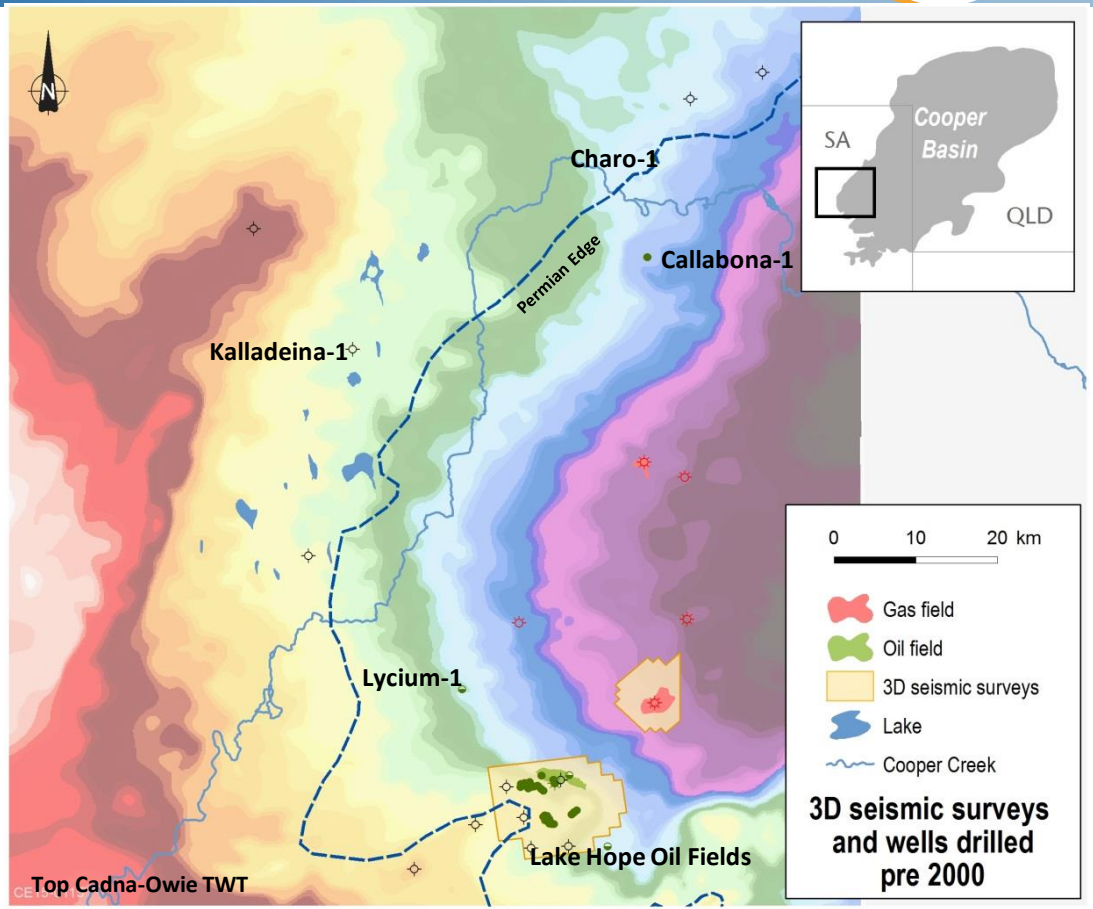
Strzelecki and Bauer Field Comparison

- Western Flank fields may be structurally subtle compared to those developed on the major structural trends, but they can recover similar volumes; e.g., both Strzelecki (Hutton) and Bauer (Namur) are expected to recover similar volumes



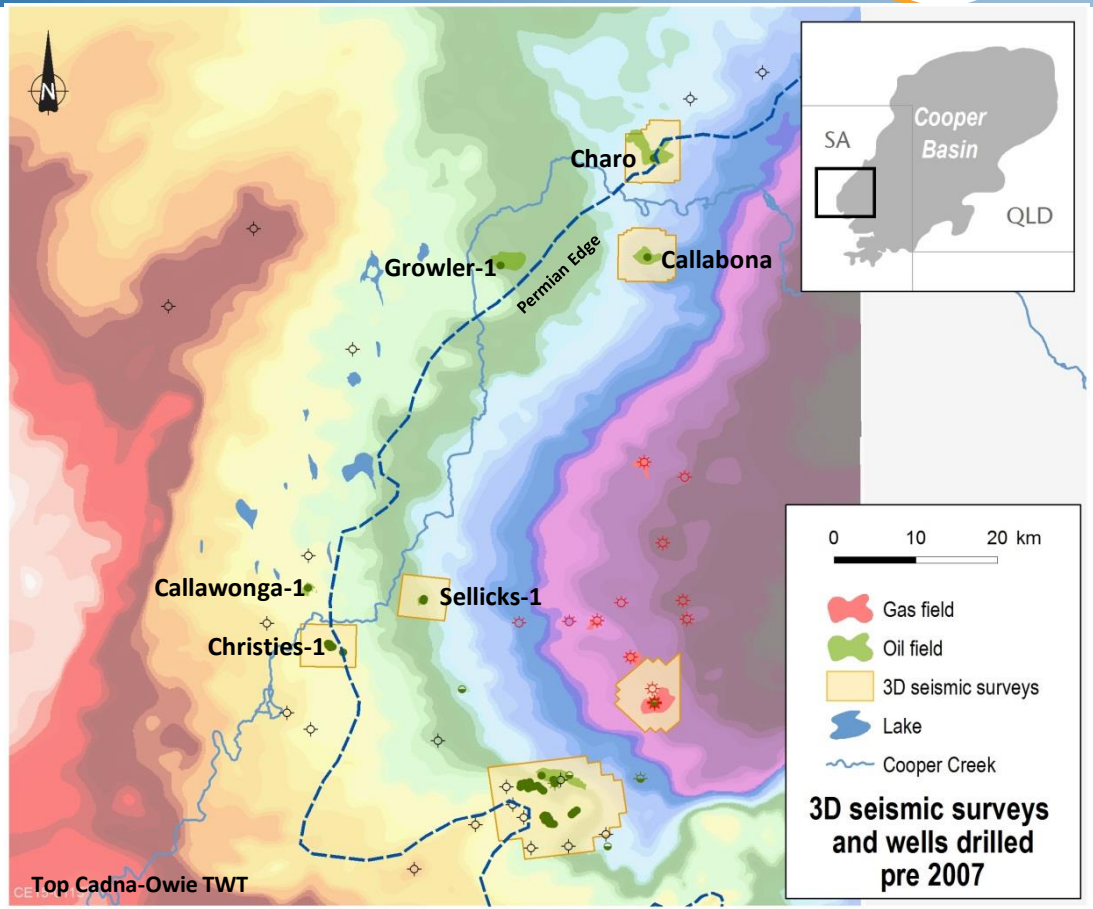
Western Flank historical activity – pre-2000

- Prior to 2000, just seven wells had been drilled in the Western Flank region
- Five of those seven wells recovered live oil or intersected oil
  - Bypassed in Kalladeina-1 Namur Sandstone (drilled 1967)
  - Charo and Callabonna Birkhead Oil discoveries
- Flank area devoid of basement structuring not attractive based on prior exploration model
- Area relinquished in 1999 and gazetted in 2001



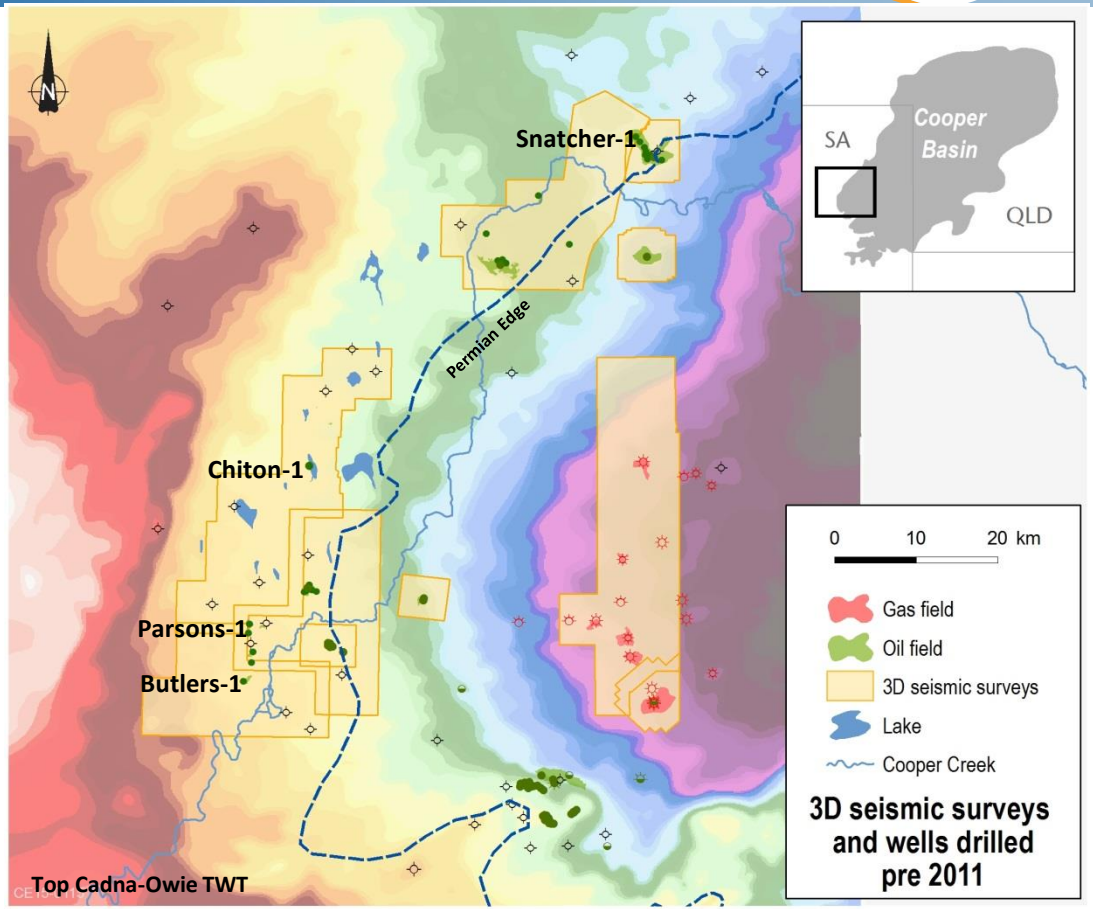
Western Flank activity – Gazettal to 2007

- Following gazettal award in 2001 success at Sellicks-1 in 2002 testing at 1,915 bopd (Patchawarra Formation)
- Follow-up discoveries at Growler (Birkhead) , Christies (Namur) and Callawonga (Namur)
- Discoveries targeted structural closures mapped on 2D seismic data



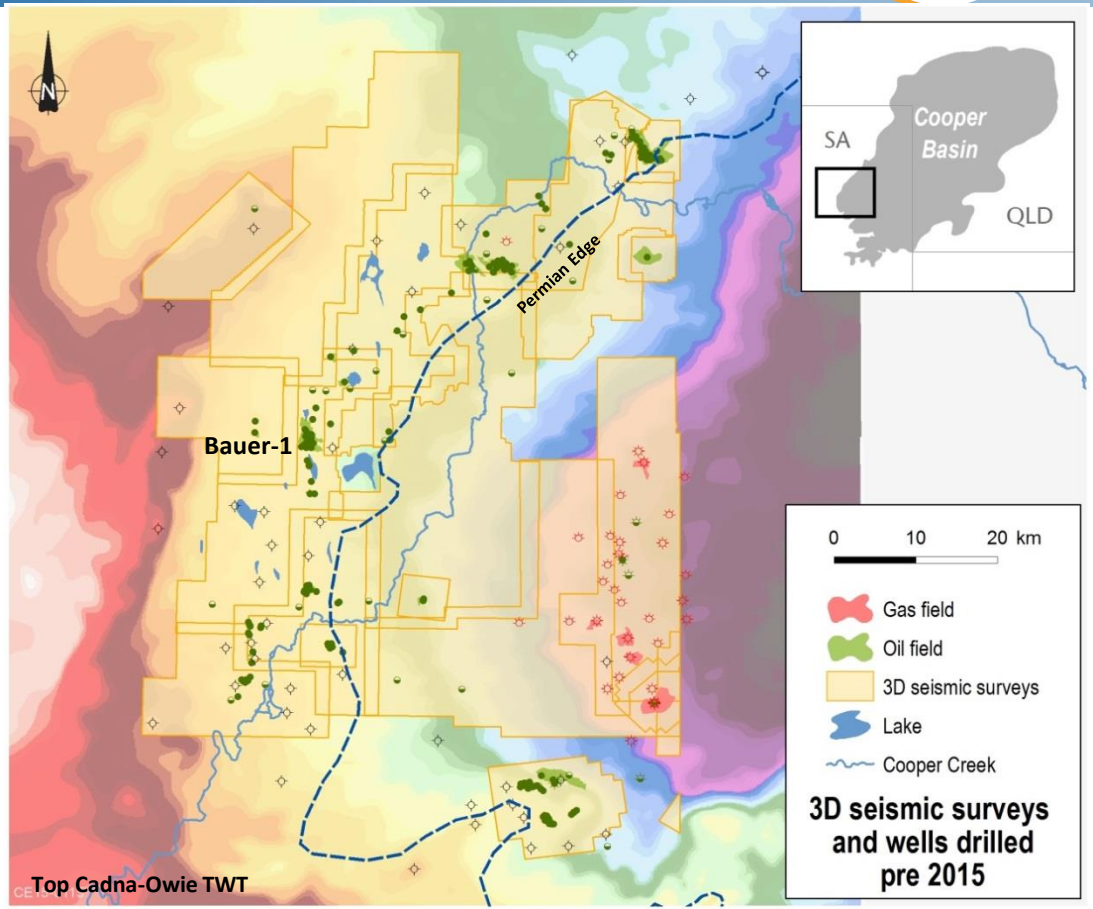
Western Flank historical activity – 2007 to 2011

- Prior to drilling of Bauer-1 in August 2011
  - First large 3D acquired in 2007
  - Multiple discoveries in 2007-2009 notably at Parsons, Butlers, Snatcher, and Chiton
  - 13 fields had been discovered on the western flank area
  - Bauer structure mapped on Modiolus 3D dataset (acquired in 2008)



Western Flank activity – to September 2015

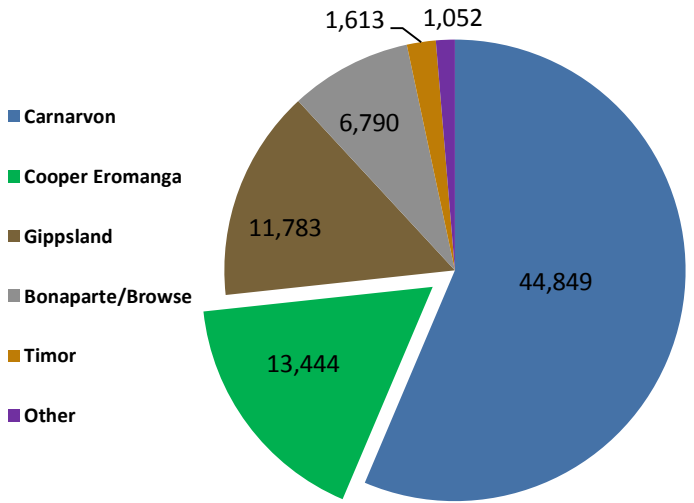
- Aggressive 3D acquisition has led to ~3500 km^2 of 3D seismic through the prime fairway
- Exploration drilling accelerated between 2007 and 2015 with 73 wells drilled with success rate of over 40%
- 36 discovered oil fields on the western flank
- Seismic re-processing and inversion ongoing



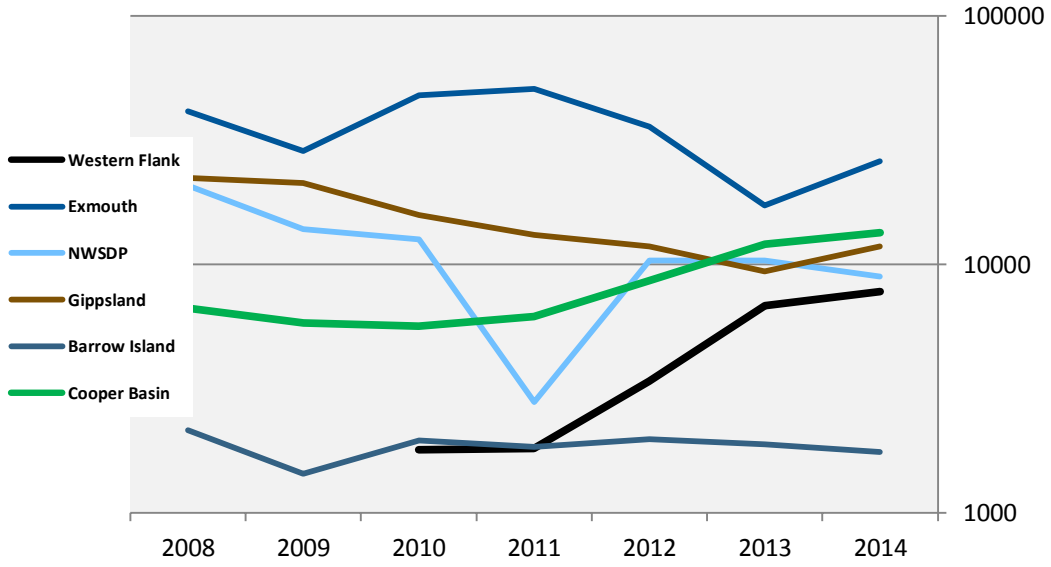
Western Flank oil production

- The Western Flank:
  - Currently produces in excess of 7.5 million bbls of oil per year
  - Has produced ~24 MMBbls from 16 active fields to July 2014
  - Pushed the Cooper Basin to be the second highest oil production region in Australia

2014 Australian Oil Production (kbbls) By Region



Regional Australian Oil Production history (kbbls/annum)



Western Flank exploration

- Highly productive reservoir (Namur Sandstone)
- Light (~45 API), sweet, low GOR (<10scf/bbl) crude
- Strong aquifer support (Great Artesian Basin)
- Low cost drilling – reservoir at ~1400m
- The highly favourable economics of Namur oil leads to the opportunity to target very low-relief closures (as low as 5 metres), and flank areas of fields at or near the OOWC
  - Depth error of +/- 5m would be considered a reasonable prediction – yet this can make or break a drilling opportunity
    - 5-metre error at 1400m = <0.5% depth error

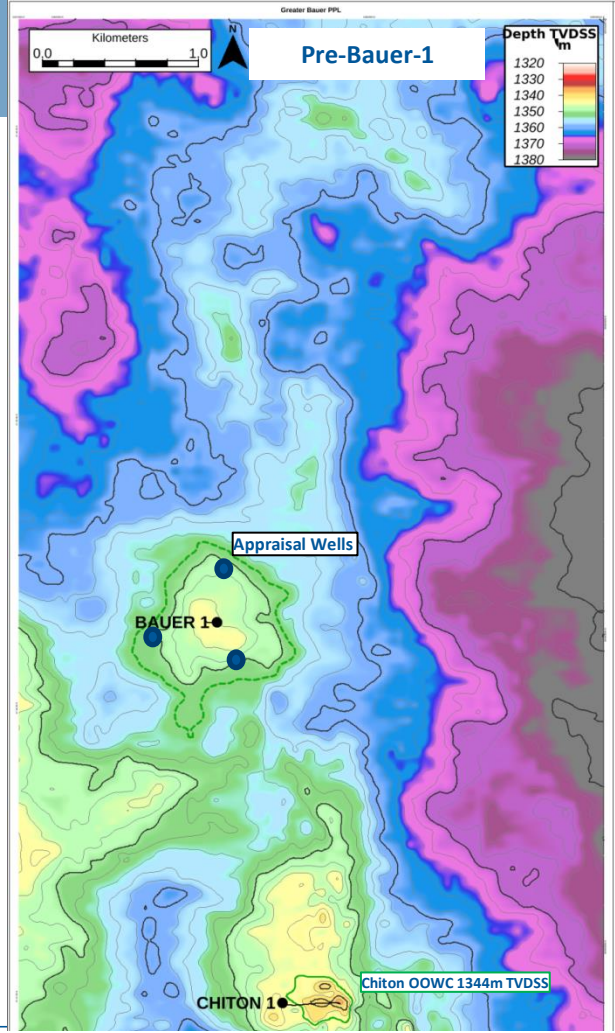
Bauer prospect – July 2011

Pre-Drill Predictions

- Targeting ~0.7 km^2 closure, with 6 m relief
- Mean prospective resource of ~850kbbls Oil
  - Assumed 63% recovery factor
- Mapped on 2008 3D seismic acquisition dataset
  - Modelled statics

Bauer-1 Results

- Intersected top Namur reservoir 15m High
- Intersected a 11m Namur oil column
- Intersected 4m oil-bearing McKinlay member overlying the Namur Sandstone reservoir

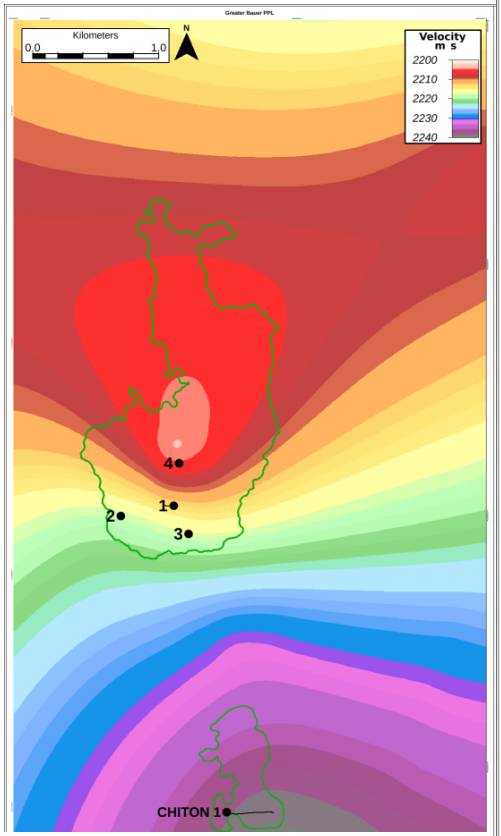


Top Namur Sandstone Depth Structure Map. 2m Contours

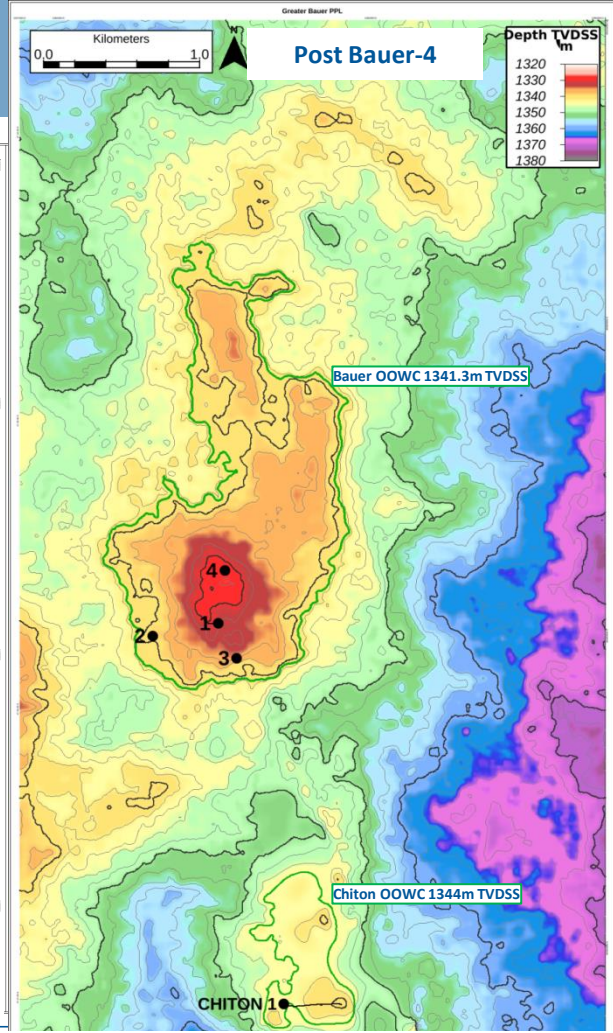
Bauer appraisal – September 2011

Bauer Appraisal Results

- Bauer-2: 2.0m Namur oil column
- Bauer-4: 13.6m Namur oil column
- 2P EUR: 5.2 MMBbls
  - Assumed 63% recovery factor
- Mapped on 2008 3D acquisition dataset
  - Modelled statics



Gridded Average Well Velocity to top Namur

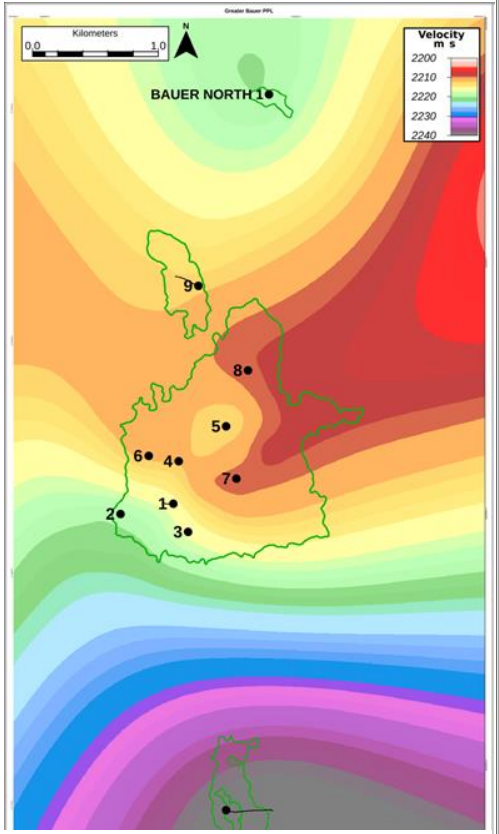


Top Namur Sandstone Depth Structure Map. 2m Contours

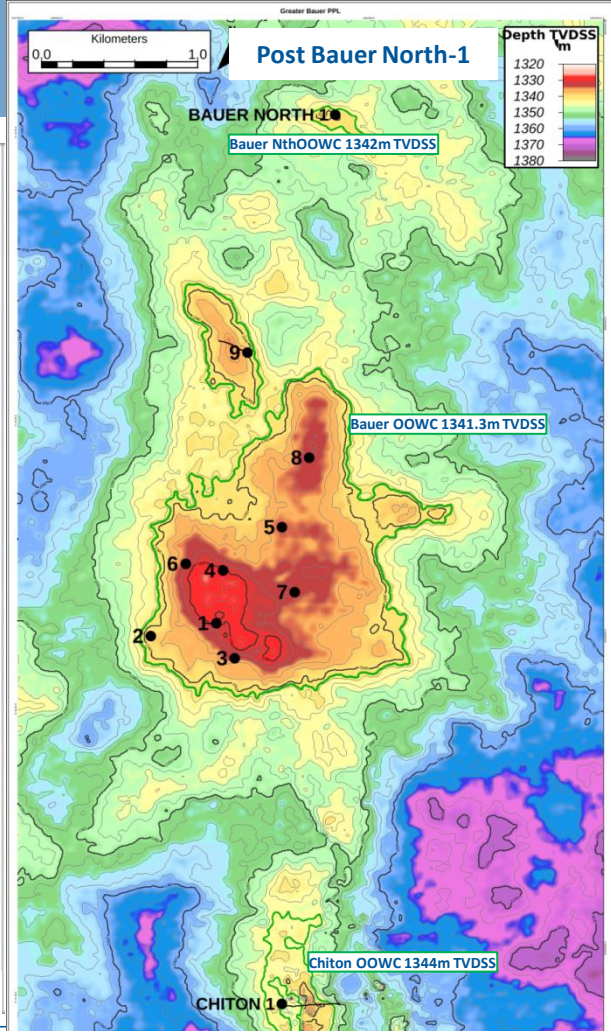
Bauer appraisal – November 2012

Bauer Appraisal Results

- 2012 re-processed 3D dataset
  - Refraction statics
- 2P EUR: 10.6 MMBbls
  - Assumed 72% recovery factor



Gridded Average Well Velocity to top Namur

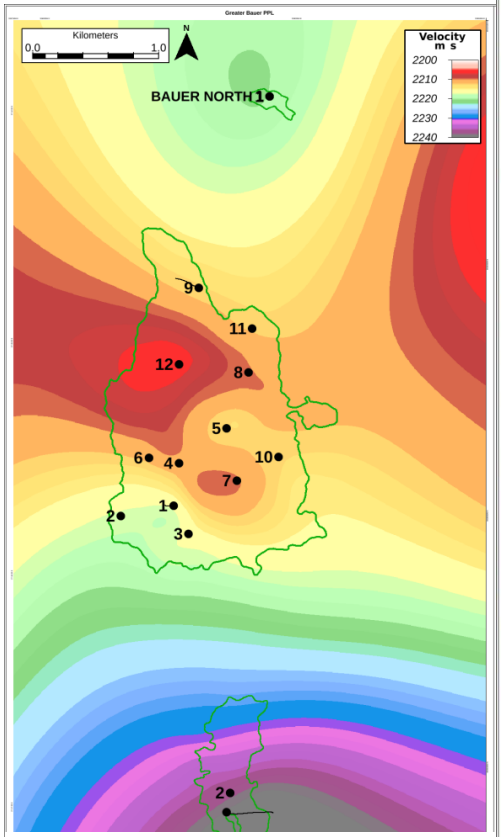


Top Namur Sandstone Depth Structure Map. 2m Contours

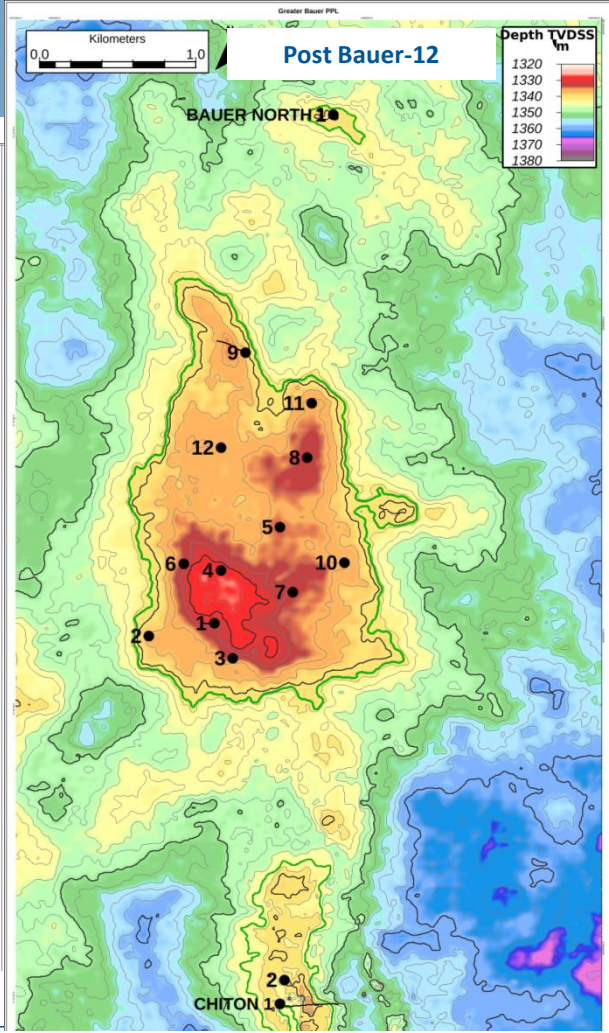
Bauer appraisal – February 2014

Bauer Appraisal Results

- 2012 re-processed 3D dataset
  - Refraction statics
- 2P EUR: 13.2 MMBbls
  - Assumed 72% recovery factor
- Bauer-12 slowest velocity in the field



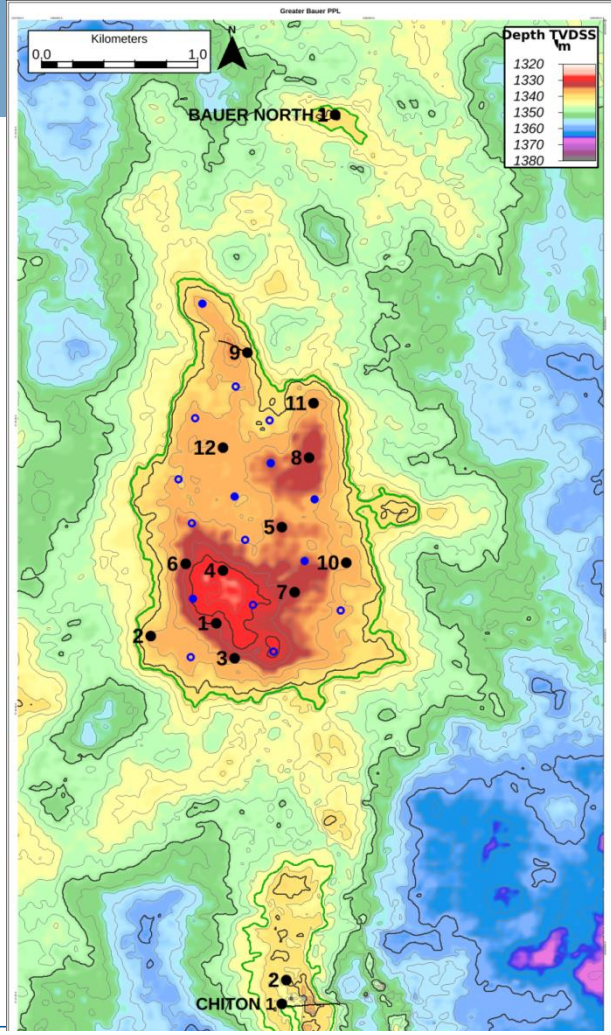
Gridded Average Well Velocity to top Namur



Top Namur Sandstone Depth Structure Map. 2m Contours

Bauer Field development planning

- Field development plan - August 2014
- 2012 re-processed 3D dataset
  - Refraction statics
- 20-acre spacing for full field Namur Sandstone reservoir development



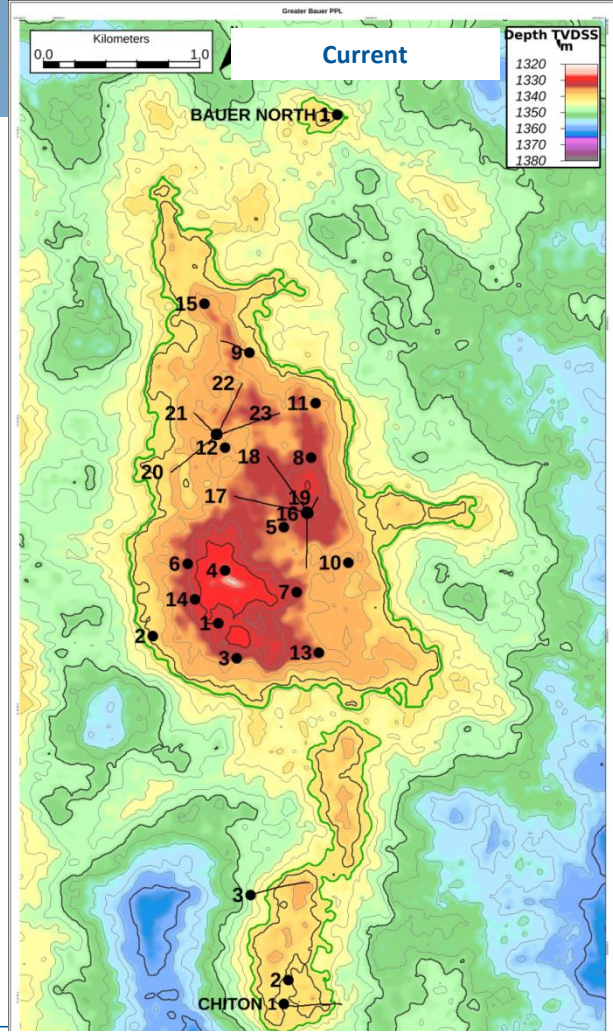
Top Namur Sandstone Depth Structure Map. 2m Contours

Bauer Field development – December 2014

Bauer Development Results

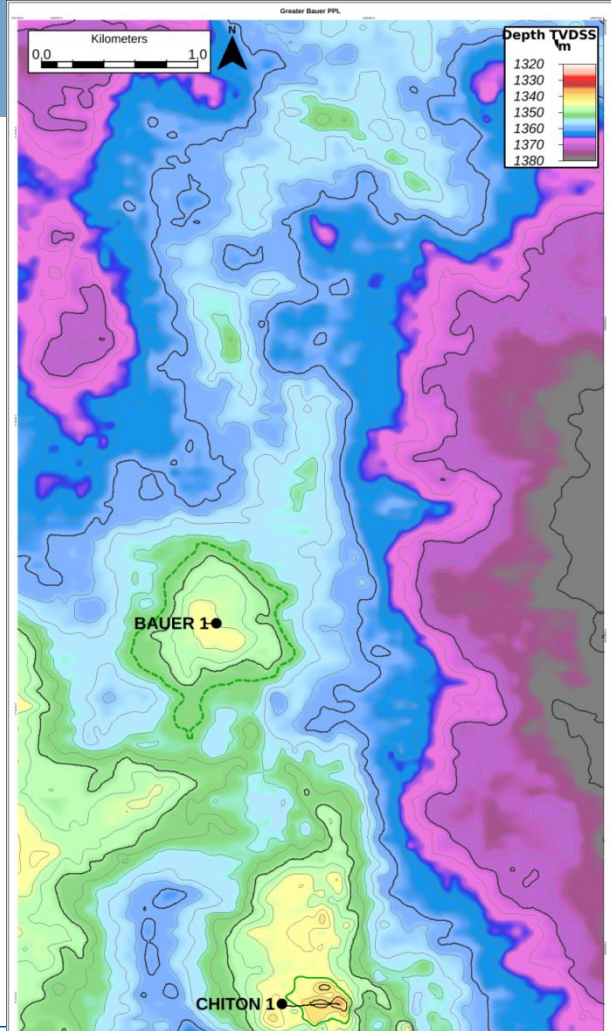
- Post Bauer-23 2P EUR: 19.4 MMBbls
  - Assumed 72% recovery factor
- Post Bauer-23 mapping based on 2012 re-processed 3D – Tomographic statics
  - Improved depth prediction compared to 2012 re-processed 3D with refraction statics

Well name	ACTUAL DEPTH (mTVDSS)	3D - Refraction Statics		3D – Tomographic Statics	
		Zvav (mSS)	Error (+ low) m	Zvav (mSS)	Error (+ low) m
BAUER 14	1330.81	1329.9	0.9	1331.4	-0.6
BAUER 15	1334.93	1337	-2.1	1334.8	0.1
BAUER 16	1335.27	1334.1	1.2	1334.3	1.0
BAUER 17	1334.01	1337.9	-3.9	1336.4	-2.4
BAUER 18	1332.62	1333.2	-0.6	1334.4	-1.8
BAUER 19	1331.71	1336	-4.3	1333.2	-1.5
BAUER 20	1337.51	1336.85	0.7	1335.28	2.2
BAUER 21	1335.46	1336.33	-0.9	1335.82	-0.4
BAUER 22	1334.64	1338.32	-3.7	1335.49	-0.9
BAUER 23	1333.73	1338.85	-5.2	1336.77	-3.0
		RMS ERROR (m)	2.9		1.7



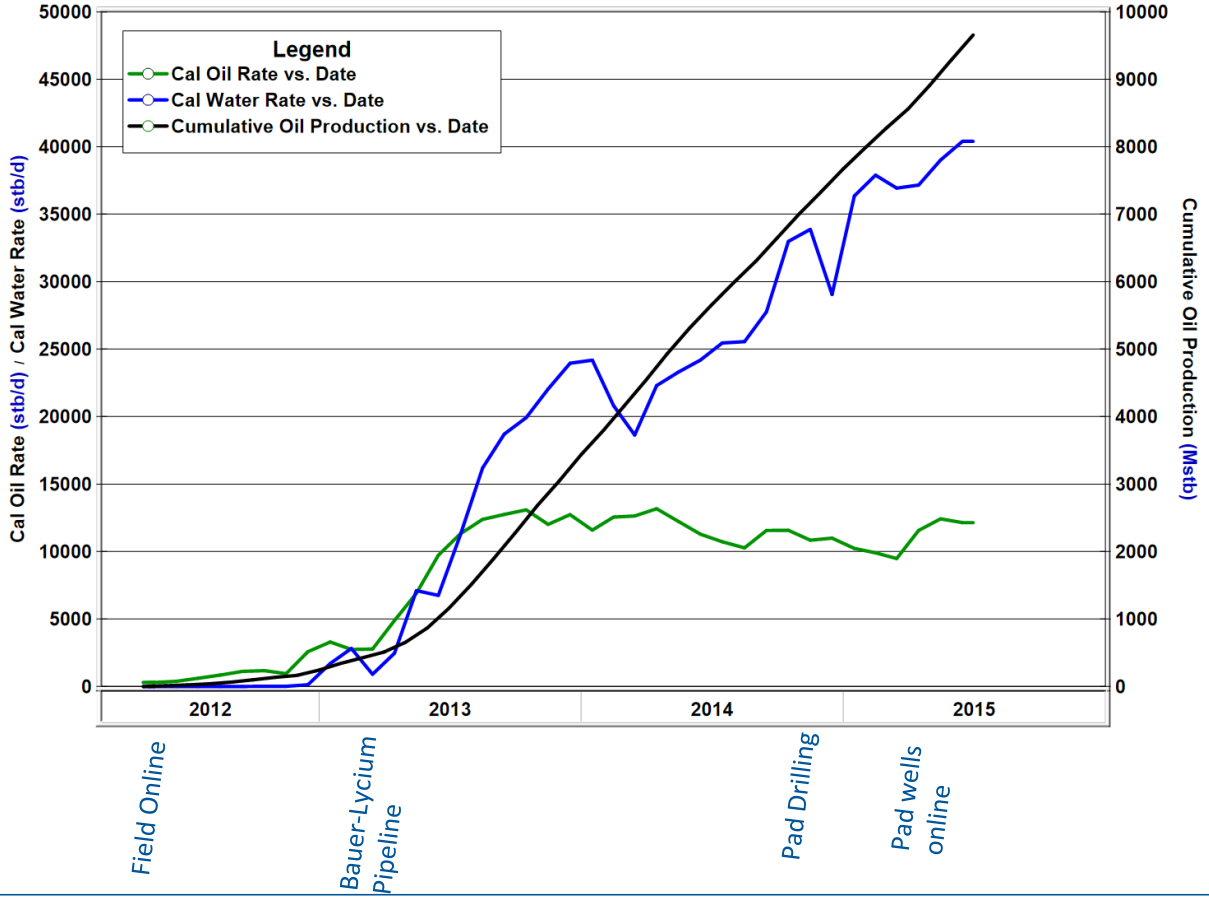
Top Namur Sandstone Depth Structure Map. 2m Contours

Bauer prospect - Predrill



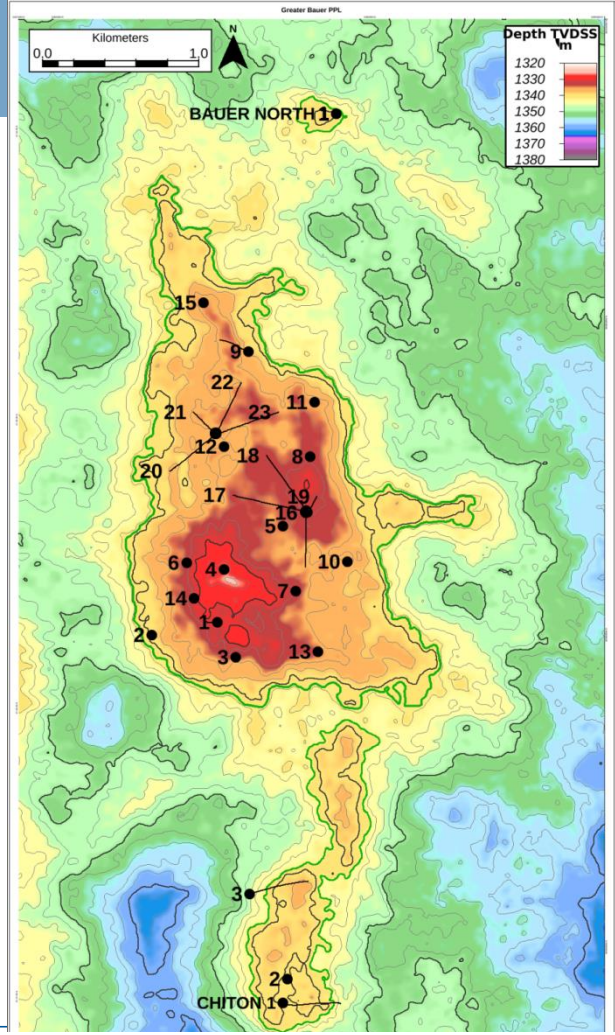
Top Namur Sandstone Depth Structure Map. 2m Contours

Bauer Field production history



Recovery Factor

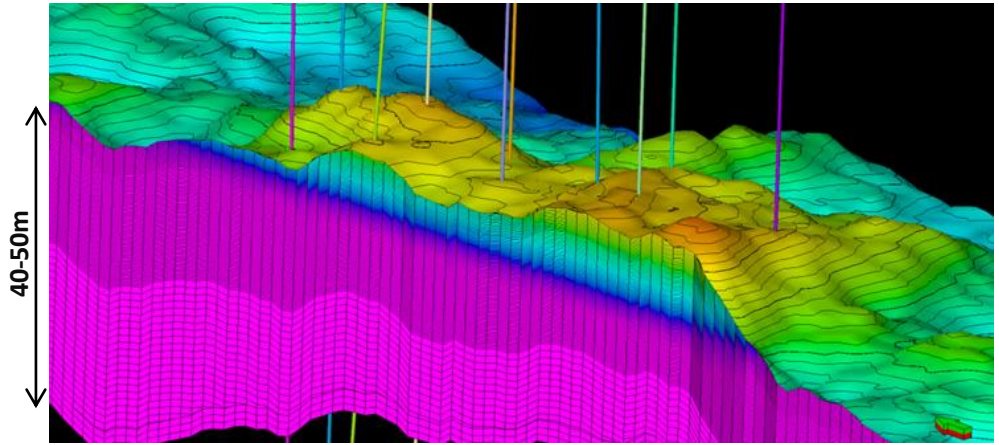
- Reservoir modelling and SCAL data from offset fields suggests a recovery factor of ~75% - however may be >80% - among highest in the world.
- Can such high RF be justified?
  - High displacement efficiency
    - Strong aquifer
    - Low mobility ratio (~1.5)
    - Low residual oil saturation (5 to 15%)
  - High volumetric sweep efficiency
    - High permeability (up to 13.6 Darcys)
    - Well connected reservoir
    - Subtle structure with high well density



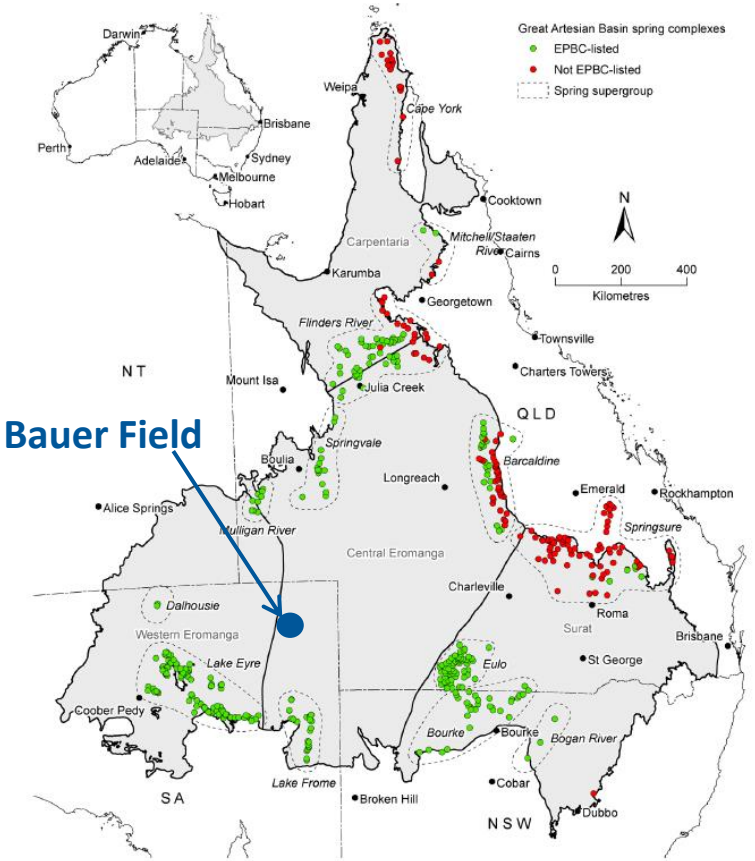
Top Namur Sandstone Depth Structure Map. 2m Contours

Great Artesian Basin Aquifer

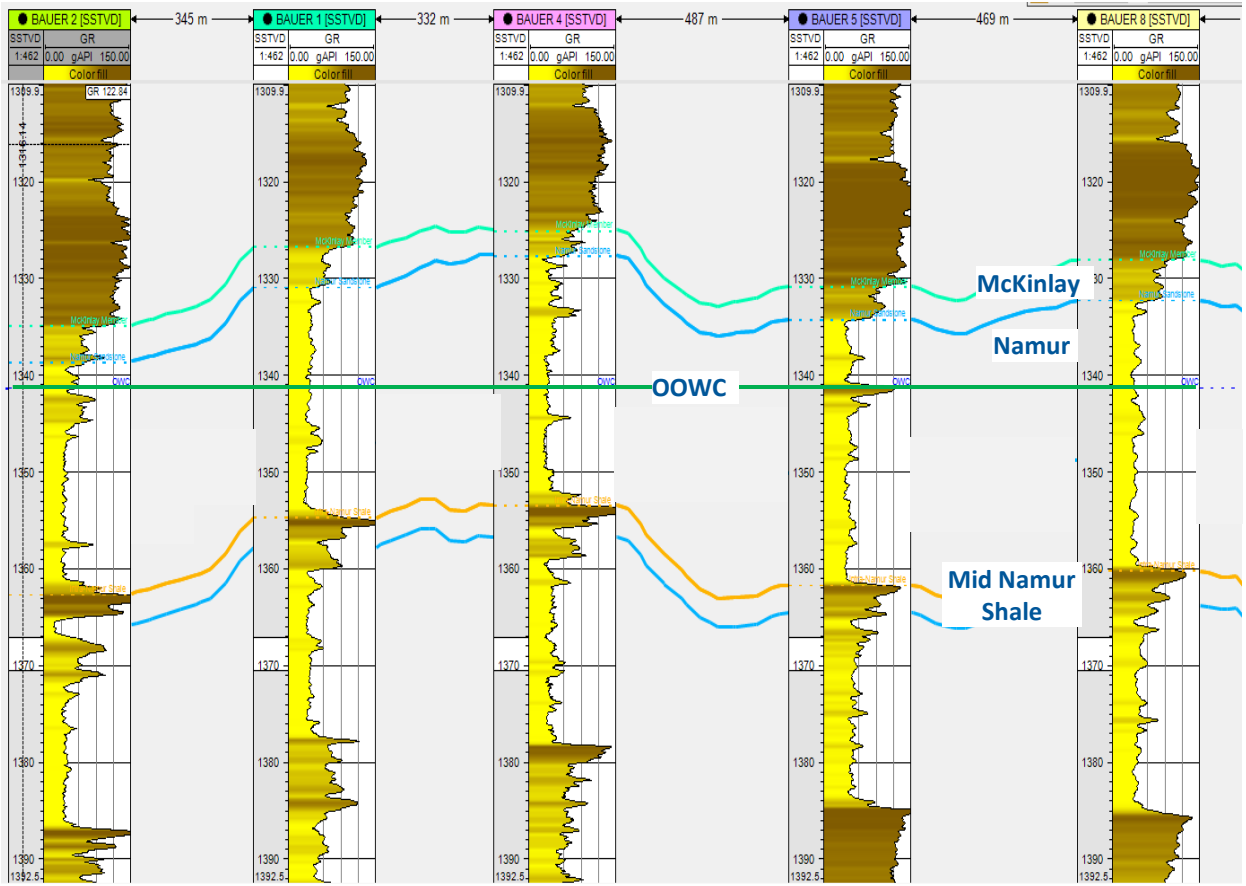
- The world's largest artesian basin – covers 23% of the Australian continent. 1.7 million square kilometres
- Active aquifer providing strong water drive to Eromanga Basin oil fields
- 40-50m thick Namur Sandstone reservoir

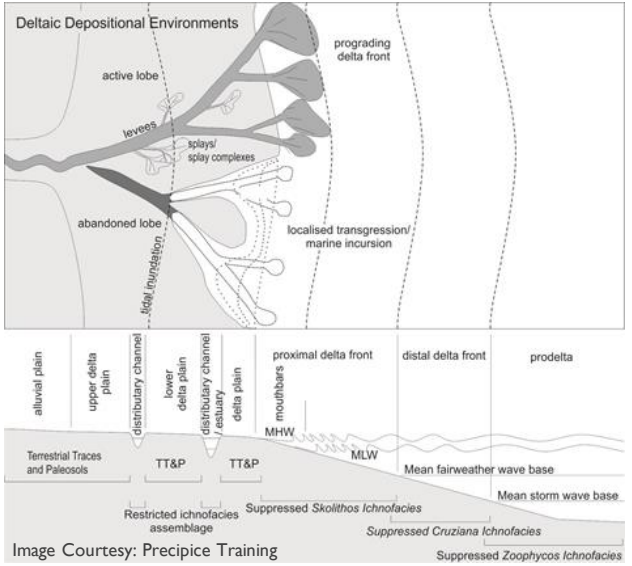


N-S Intersection through Bauer Field Static Model.



Namur Sandstone reservoir

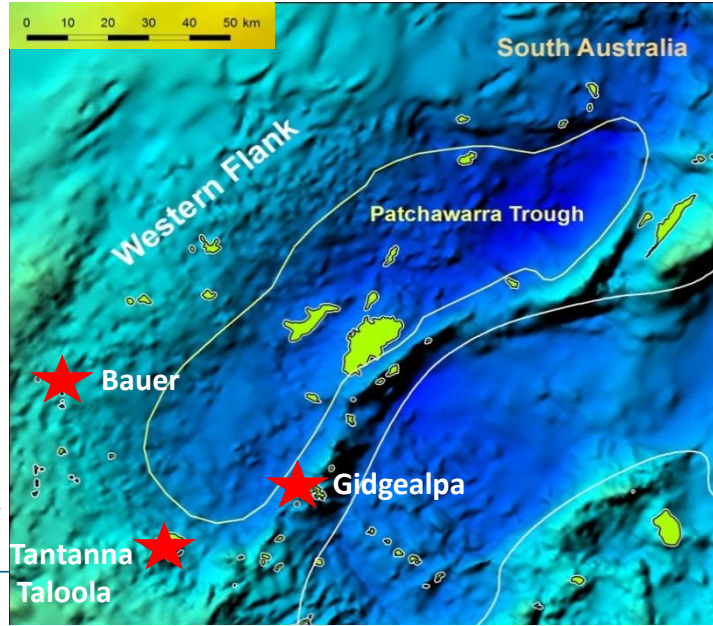




- Namur Sandstone - Very high net to gross, fluvial to deltaic medium- to coarse-grained sandstone
- McKinlay member – laminated and bioturbated fine- to medium-grained deltaic sandstone
    - Oil-bearing and productive

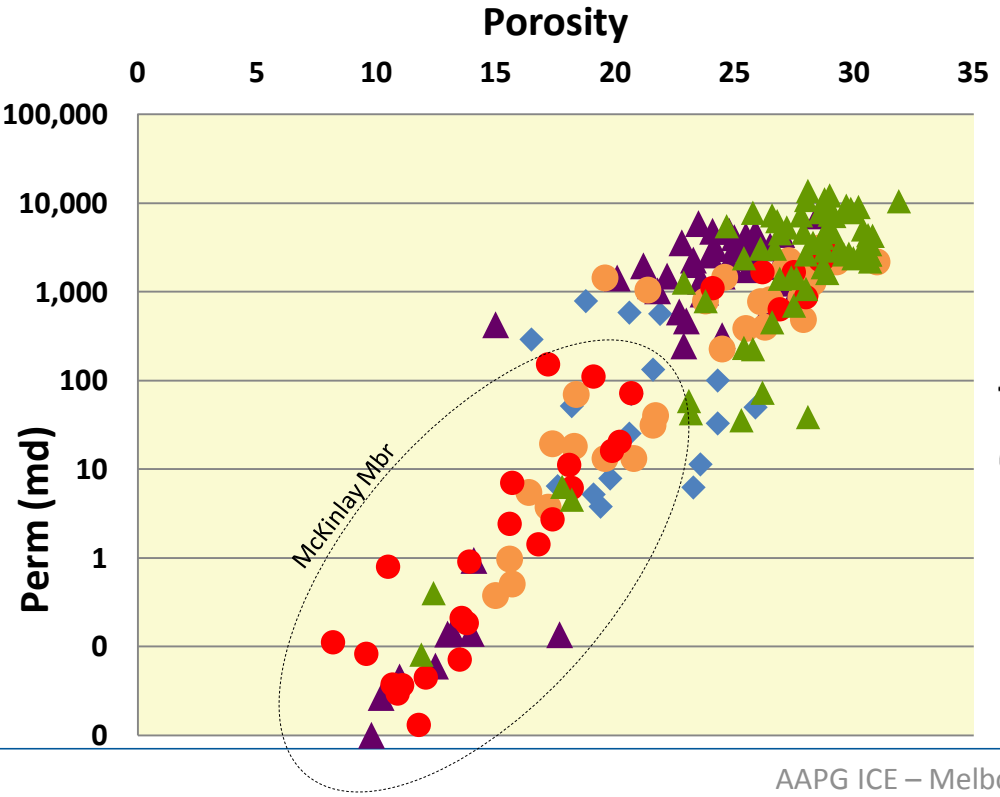
McKinlay / Namur core data

- Bauer-5 Core
  - McKinlay recovered
  - Namur poorly consolidated (not recovered)
- Nearest Namur Core (RCA and SCAL) >50kms distant
  - Tantanna, Taloola, Gidgealpa
- Bauer-14 Namur Core (recently acquired)
  - Recovered 100%, weakly cemented yet intact
  - RCA data available
    - higher poro/perm to offset fields
  - SCAL data not yet available

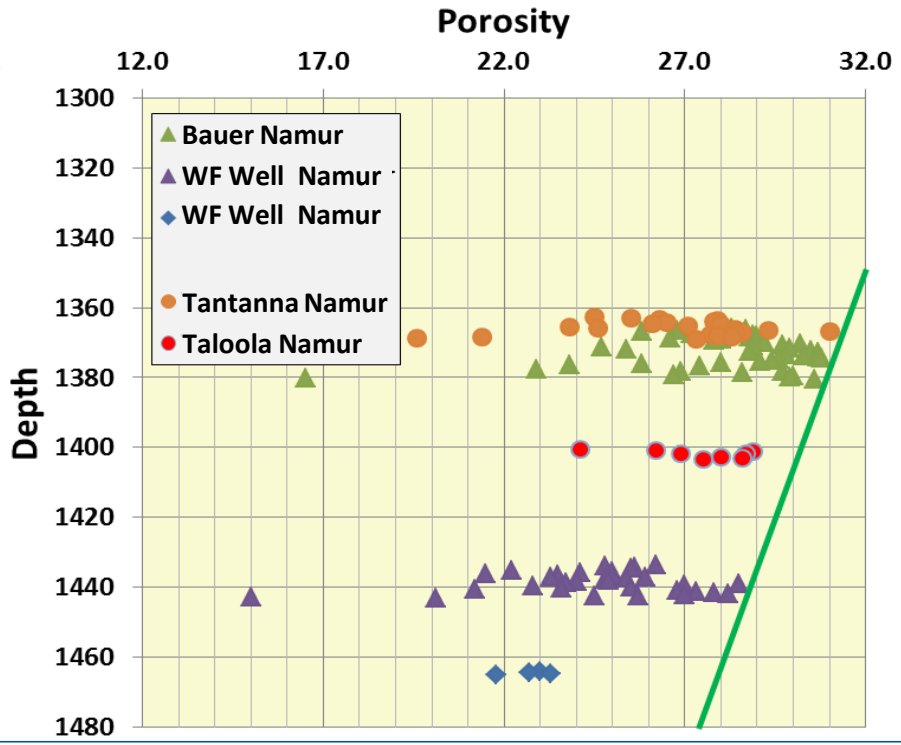


Namur Sandstone Reservoir

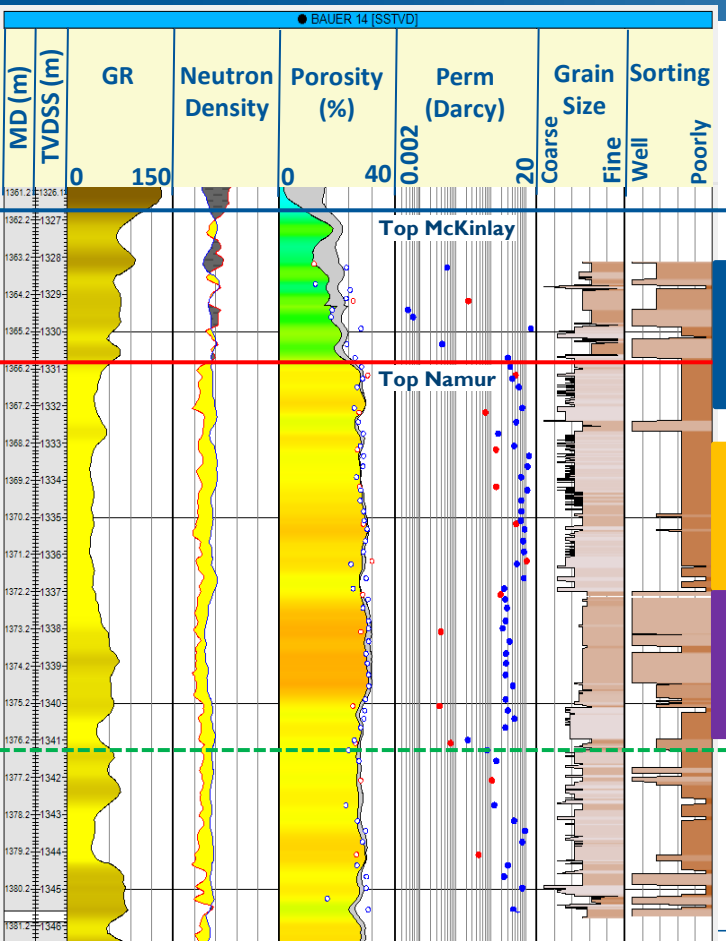
- Tantanna, Taloola, and Gidgealpa Namur core data lower average porosity (and permeability) than Bauer.

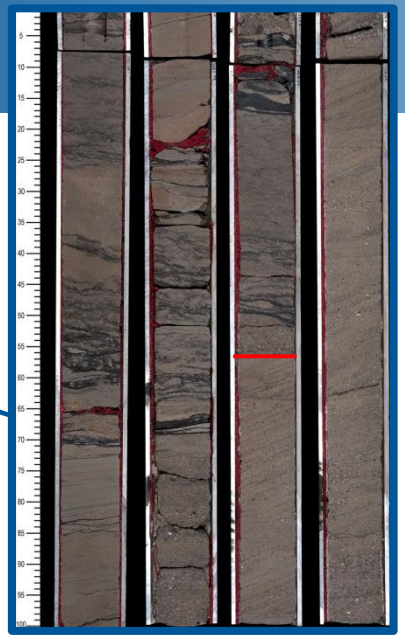


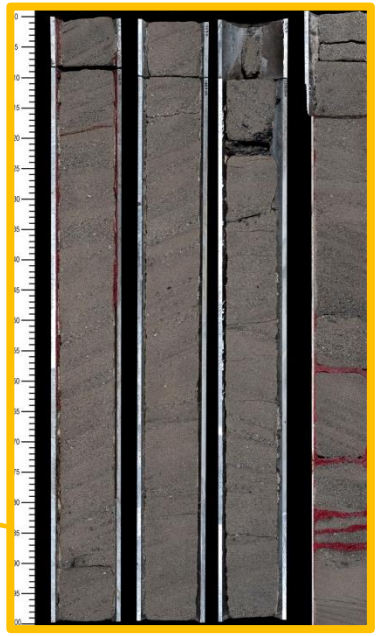
- Different burial history and/or textural maturity of Namur sands in offset fields.

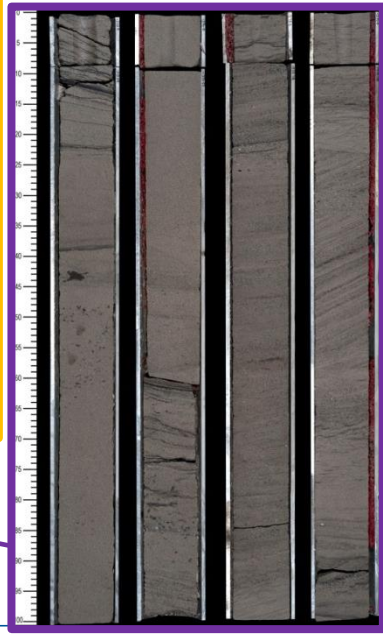


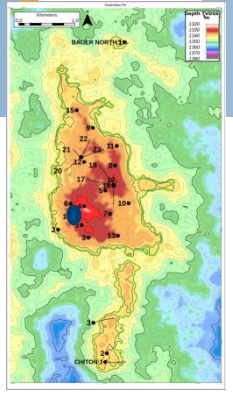
Namur Sandstone reservoir





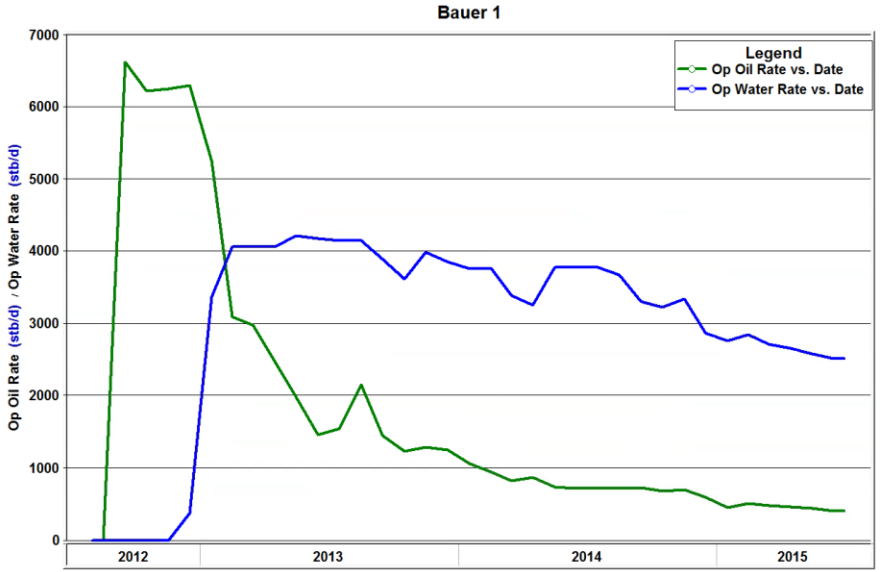


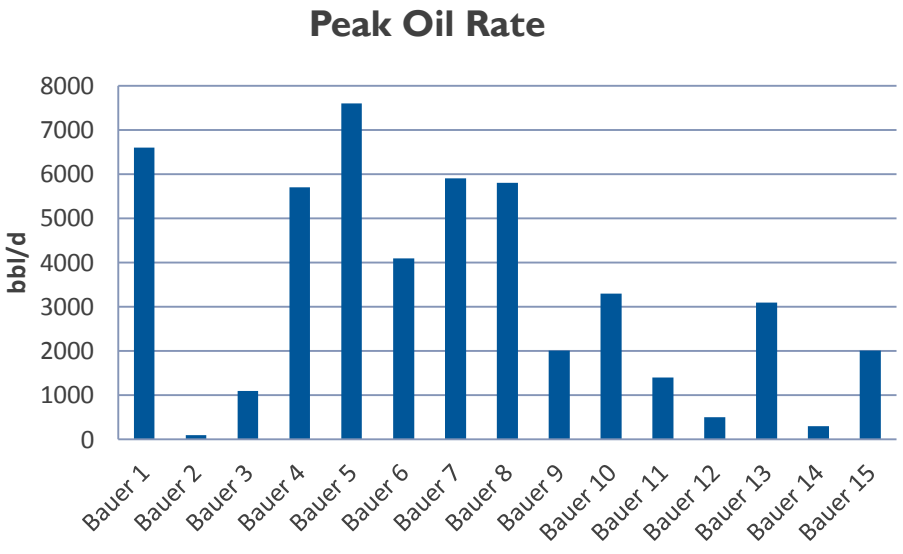




High productivity

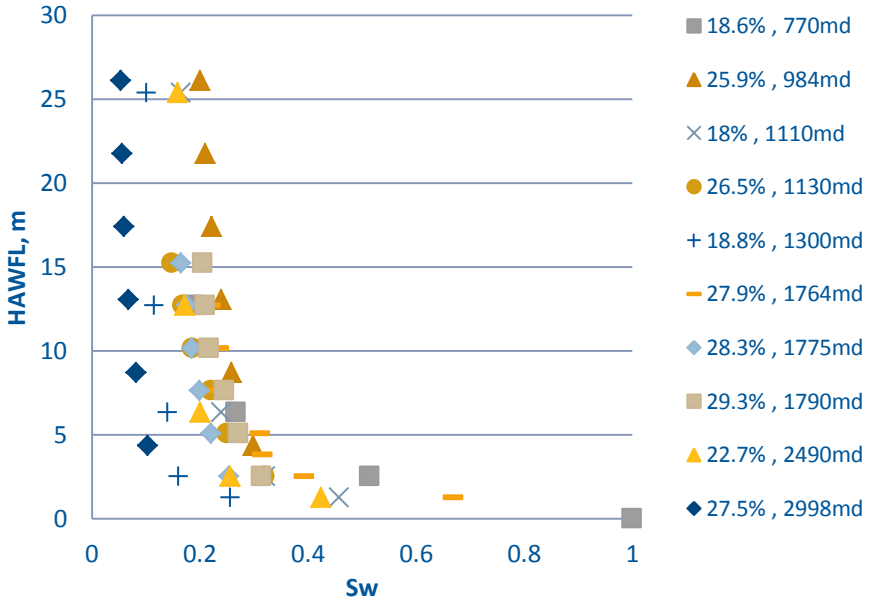
- Vertical wells with ~20 acre spacing
- Single zone, free-flow completions
- Very high flow rates from typically 0.5m of Namur perforations

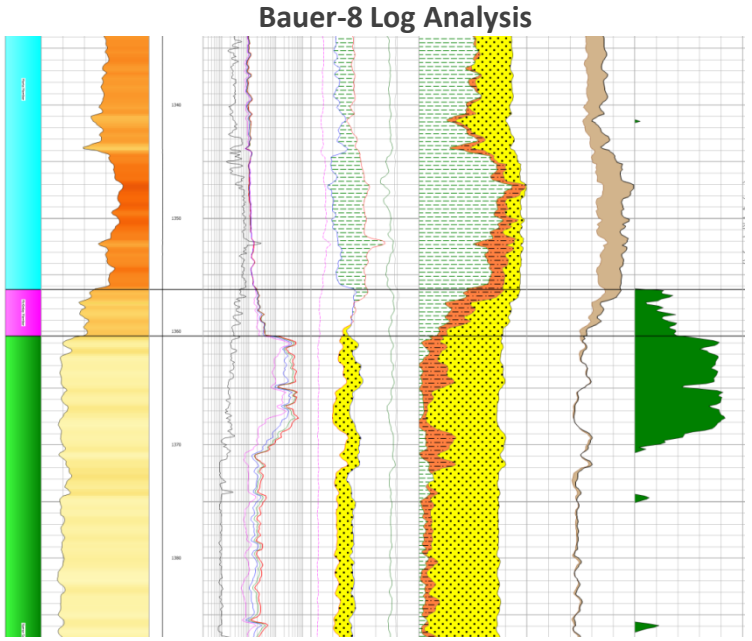




High initial oil saturations

- SCAL (from offset fields) suggests ~75-80% average initial oil saturation for 1-2-Darcy Namur. How high could it be for 10-Darcy Namur? – currently acquiring data for Bauer core
- Short 1-2m transition zone.

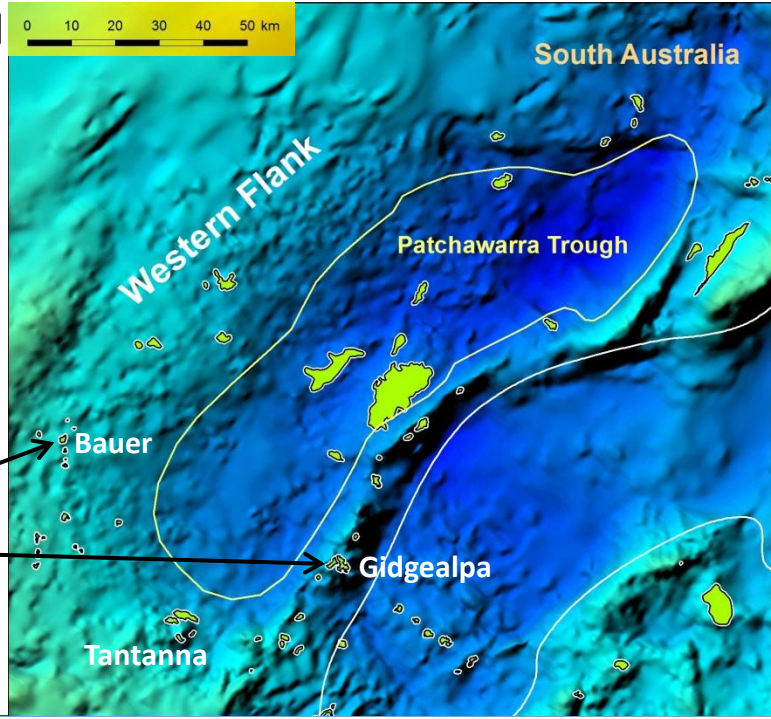




High displacement efficiency

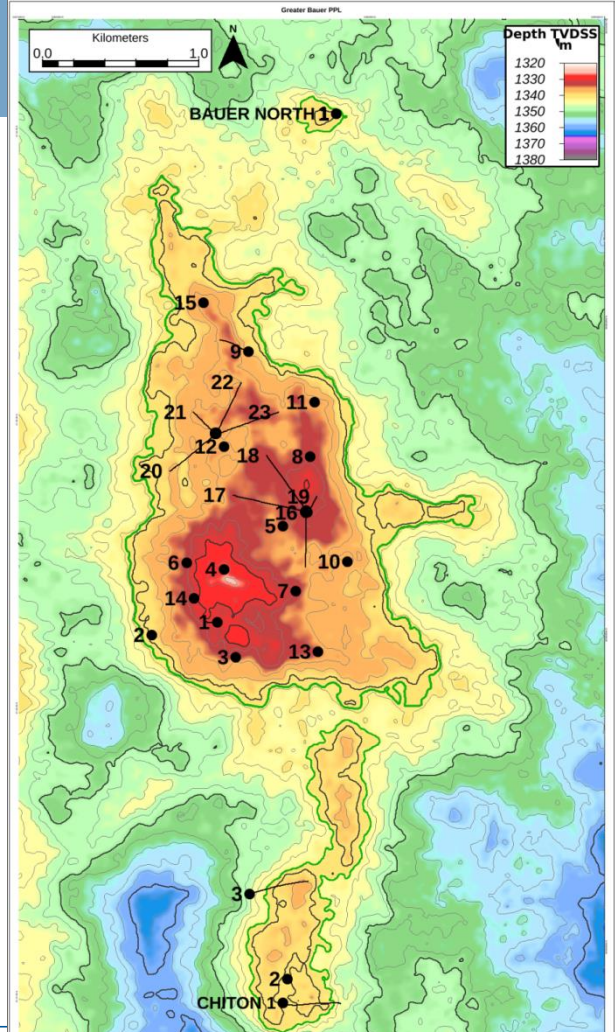
- Available SCAL data indicates 78% recovery factor – but Bauer Namur is expected to be higher
  - Namur SCAL data available from offset fields only (>50kms offset)
    - Significantly lower porosity due to depth of burial
  - McKinlay SCAL data available from Bauer-5 Core
    - 770 mD, 18.6% Porosity
  - Bauer Namur RCA >10 Darcys, and ~30% porosity

Sample Formation	Permeability md	Porosity %	Initial Sw % pore space	Terminal So % pore space	Recovery % oil in place
McKinlay	130	21.6	22.2	16.7	78.5
McKinlay	770	18.6	6.6	20.3	78.3
Namur	1960	18.9	6.4	28.5	69.6



Recovery Factor

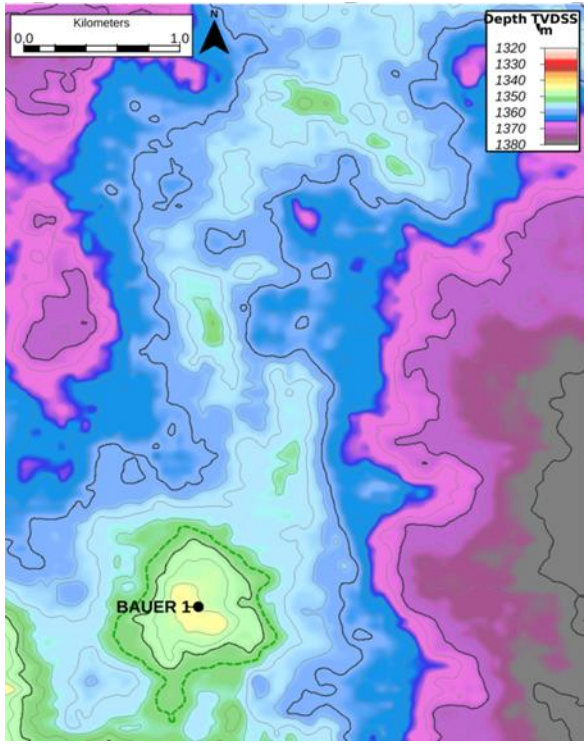
- Reservoir modelling and SCAL data from offset fields suggest a recovery factor of ~75% - however, may be >80% - among highest in the world.
- Can such high RF be justified?
  - High displacement efficiency
    - Strong aquifer
    - Low mobility ratio (~1.5)
    - Low residual oil saturation (5 to 15%)
  - High volumetric sweep efficiency
    - High permeability (up to 13.6 Darcys)
    - Well connected reservoir
    - Subtle structure with high well density



Top Namur Sandstone Depth Structure Map. 2m Contours

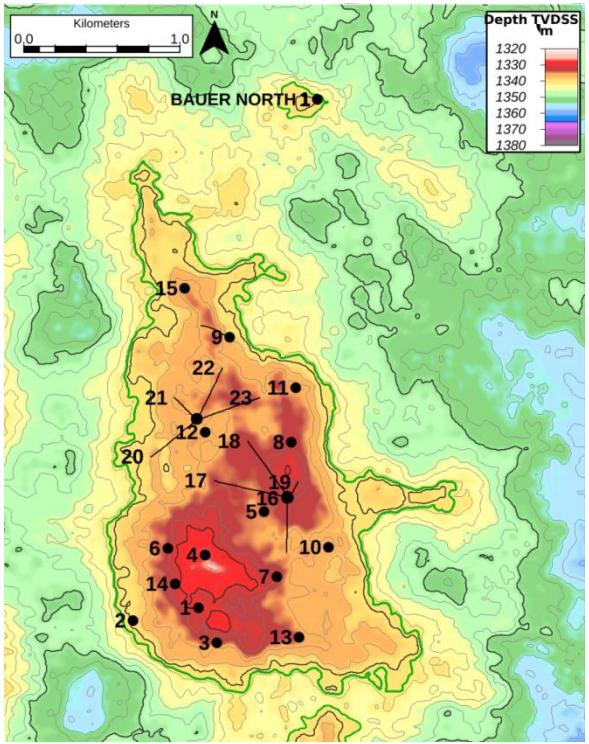
Bauer Field summary

Pre-Drill (July 2011)



- 6m Closure
- Mean Prospective Resource ~850k bbls Oil
- Good Quality Fluvial Sandstone Reservoir
- Estimated Recovery Factor of ~60%

Current



- 17m Gross Oil Column
- 2P EUR ~20 MMBbls
- Permeability up to 13.6 Darcys
- Recovery Factor over 80% possible

Conclusions

- The Bauer Field was discovered late in the basin exploration history, yet is the third largest oil pool (EUR terms) in the basin.
- Onshore, gently dipping basin margins can be commercial areas.
- Improvements in seismic acquisition and processing techniques may reveal further opportunities; however, structural definition on the Western Flank is pushing the limits of seismic resolution.
- Whilst structural risk is the key risk in appraising low relief field, structural uncertainty allows for significant upside.
- The Namur Sandstone reservoir on the western flank is exceptional, with porosities of over 30%, and permeability of over 10 Darcys. Current estimates of recovery factor for Bauer are ~75%, however a recovery factor of over 80% may be realised.
- The Bauer Field is not a ‘magic pudding’ but continued strong production gives encouragement for further upside.

Acknowledgements

- I would like to gratefully acknowledge:
  - Beach Energy and Drillsearch for permitting the material to be presented
  - Numerous co-workers of Beach Energy who contributed to the Bauer Field discovery, appraisal, and development over the past 5 years
  - AAPG