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# UNCONVENTIONAL HYDROCARBON POTENTIAL OF THE ARCKARINGA BASIN, SOUTH AUSTRALIA

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## Introduction

In South Australia, Early Permian sediments infill an erosional land surface shaped by the Late Carboniferous-Early Permian Gondwana glaciation. The Arckaringa Basin in South Australia comprises a number of deep erosional troughs recording Australia's time in the southern polar region.

Early exploration undertaken by the South Australian Government first identified the energy potential of the Arckaringa Basin. Coal was discovered in the Lake Phillipson stratigraphic bore drilled over a century ago and gassy formation water was recovered from the Cootanoorina 1 stratigraphic well in 1967. Extensive coal drilling in the 1970's and 1980's and a phase of seismic acquisition and oil exploration drilling in the mid 1980's did not result in an oil discovery or coal mining activities. However the basin is currently being re-evaluated and explored for coal seam gas, underground coal gasification, mined coal gasification, shale oil and conventional hydrocarbon accumulations.

Thick, organic rich marine shales at the threshold of oil generation have been intersected in the Phillipson and Boorthanna troughs of the Arckaringa Basin. These shales will be an exciting shale oil target and source for conventional hydrocarbon accumulations if sufficient maturity levels can be identified in parts of the basin. Higher in the succession coal deposits in the upper part of the Mt Toondina Formation are being explored for coal seam gas and coal gasification projects. A bankable feasibility study for the conversion of mined coal to liquid hydrocarbons (10 MMbbls/year) and power generation is currently underway for part of the Wintinna Coal Deposit (Schrape, 2011).

## General Geology

The Arckaringa Basin is a Permo-Carboniferous intra-cratonic basin located approximately 750km north-west of Adelaide in South Australia (FIG 1). The Basin comprises two main depocentres, the Boorthanna Trough in the east, and the southern Arckaringa troughs (West, Phillipson, Penrhyn and Wallira) in the south, separated by shallow basement with a thin veneer of Permian sediments (FIG 2). The troughs contain up to 1300m of Carboniferous-Early Permian sediments overlain by up to 300m of Late Jurassic to Early Cretaceous Eromanga Basin sediments and generally less than 10m of Tertiary cover.

The Boorthanna Trough is broad, and underlain in part by Neoproterozoic and early Palaeozoic sediments of the Adelaide

Rift complex. The southern Arckaringa troughs are narrow, and underlain by Archaean to Early Mesoproterozoic rocks of the Gawler Craton. Both depocentres show evidence of infill of basement topography.

The Permo-Carboniferous succession in the Arckaringa Basin has been divided into three formations, based on lithology and stratigraphic relationships (Hibburt, 1984). The Boorthanna Formation, possibly extending into the Late Carboniferous, comprises a basal glaciogene facies with marine facies towards the top. Lithologies include diamictite, rhythmically bedded sandstone (probably representing deposition by turbidity currents) and laminated mudstone (Hibburt, 1984). The overlying Stuart Range Formation is generally a homogeneous shale with minor siltstone and sandstone, deposited in quiet, restricted marine conditions but with occasional lacustrine intervals. This is in turn overlain by the Mt Toondina Formation consisting of a lowermost deltaic sequence and an uppermost fluviolacustrine succession with intermittent coal swamp development. A stratigraphic section for the basin based on the Arkeeta 1 petroleum well is presented in Figure 3.

The history of the basin is summarised as follows (see Menpes et al, 2010):

1. Incision of glacial valleys (FIG 4)
2. Valleys fill with glacial and marine sediments of the Boorthanna and Stuart Range formations – some seismic evidence of sea-level fluctuations and minor contraction.
3. Progradation of the Mount Toondina delta system over the basin. Minor differential growth of this succession, as indicated by seismic and coal seam geometries, may be the result of ongoing minor contraction and differential compaction.
4. Contraction culminates with gentle folding of the succession, uplift and erosion. Vitrinite reflectance profiles from exploration wells suggest that the Permian has been subjected to pre-Jurassic uplift and erosion in the order of 0.5–1 km. Coal seam correlations demonstrate the subcrop relationship of the coal seams beneath the Eromanga Basin, indicating that folding and erosion occurred prior to deposition of the Eromanga Basin.

The absence of sediments younger than Sakmarian in age suggests the termination of deposition in the Arckaringa Basin and gentle folding of the succession may be related to the breaks in deposition identified within the Patchawarra Formation of the Cooper Basin (Gravestock and Jensen-Schmidt, 1998). Alternatively the final contractional event may be related to the Daralingie unconformity between the Early and Late Permian in the Cooper Basin, or the end of the Hunter-Bowen Orogeny, which is essentially coincident with the unconformity at the top of the Cooper Basin succession.

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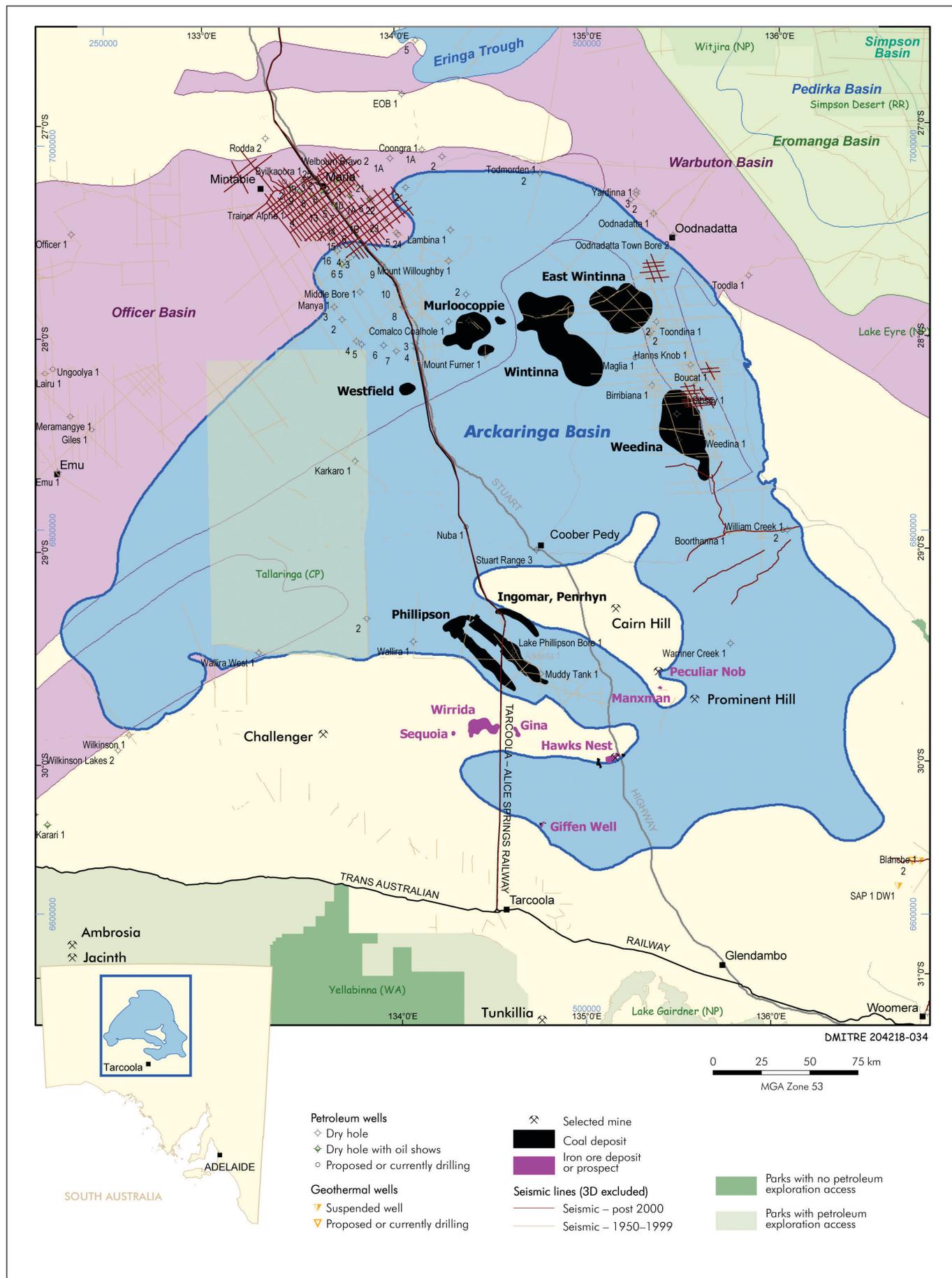


Figure 1. Arckaringa Basin, South Australia, location map with wells, seismic lines and coal deposits.

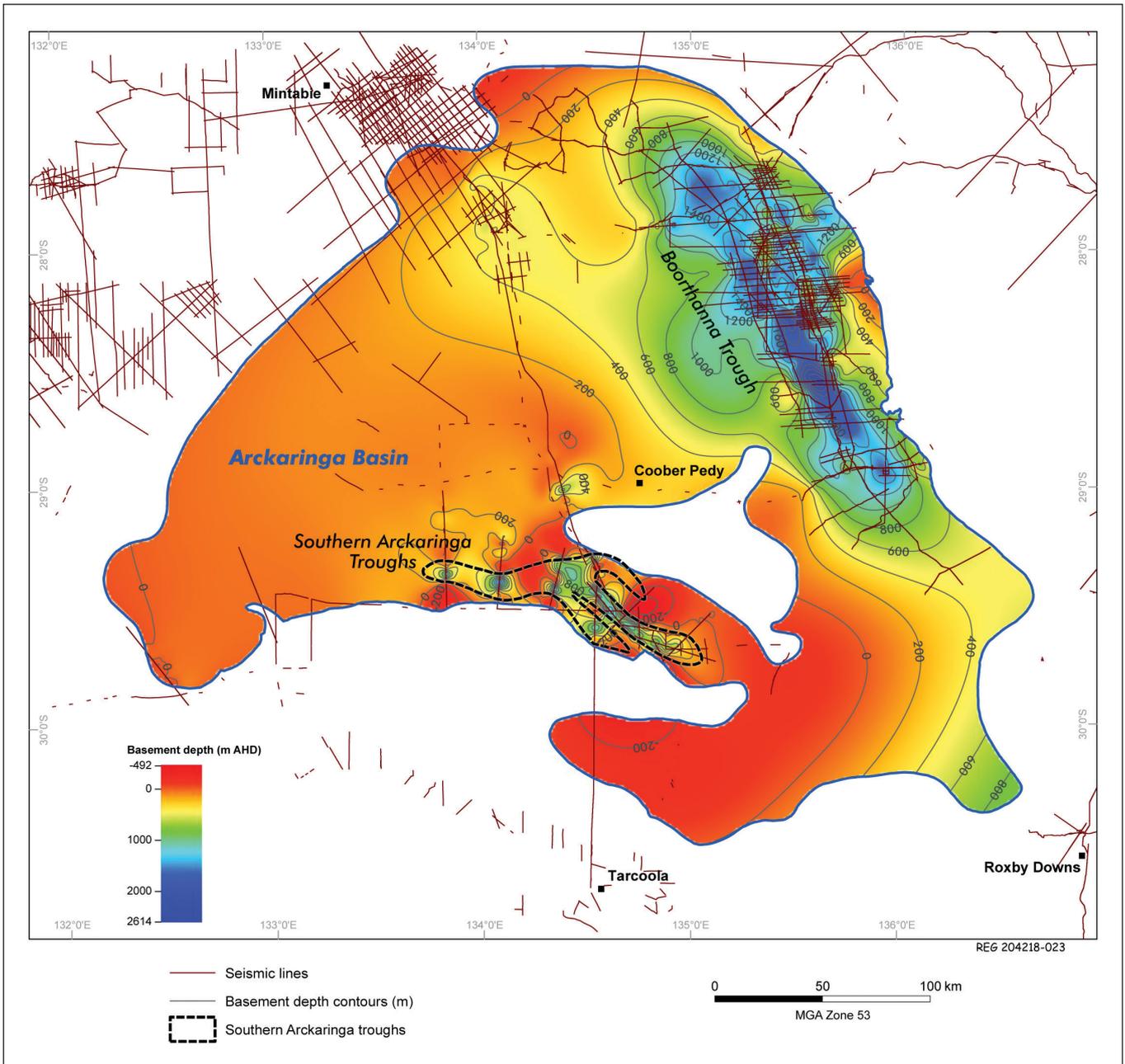


Figure 2. Arckaringa Basin, basement depth structure map.

## Sequence Stratigraphy

DMITRE's Energy Resources Division has recently undertaken preliminary work to identify sedimentary packages in the Arckaringa Basin in a sequence stratigraphic framework, focused on understanding the distribution of the organic rich marine shales.

A maximum flooding surface at the base of the prograding Mount Toondina delta succession has been identified on seismic lines in the Boorthanna Trough. Flattening seismic lines on this horizon clearly demonstrates the downlapping of clinoforms onto the surface (FIG 5). A prominent gamma-ray peak corresponds to the maximum flooding surface in the Weedina 1, Hanns Knob 1, Birribiana 1 and Boorthanna 1 wells.

In the Phillipson Trough, a prominent gamma-ray peak is also present in the Arkeeta 1 well. The Arkeeta 1 gamma-ray log indicates an overall coarsening-upward succession above the peak, and coals appear at the top of the succession (FIG 3). This is consistent with deposition in a prograding delta system. The gamma-ray peak in Arkeeta 1 has therefore been interpreted to be the same maximum flooding surface as that identified in the Boorthanna Trough.

A sequence boundary below the maximum flooding surface has been identified in the Boorthanna Trough. The sequence boundary cuts down into the underlying succession (FIG 5). Intervening sediments, deposited during the marine transgressive phase, onlap palaeo-topographic highs. A prominent seismic reflector in the southern Arckaringa troughs is currently interpreted to be the same

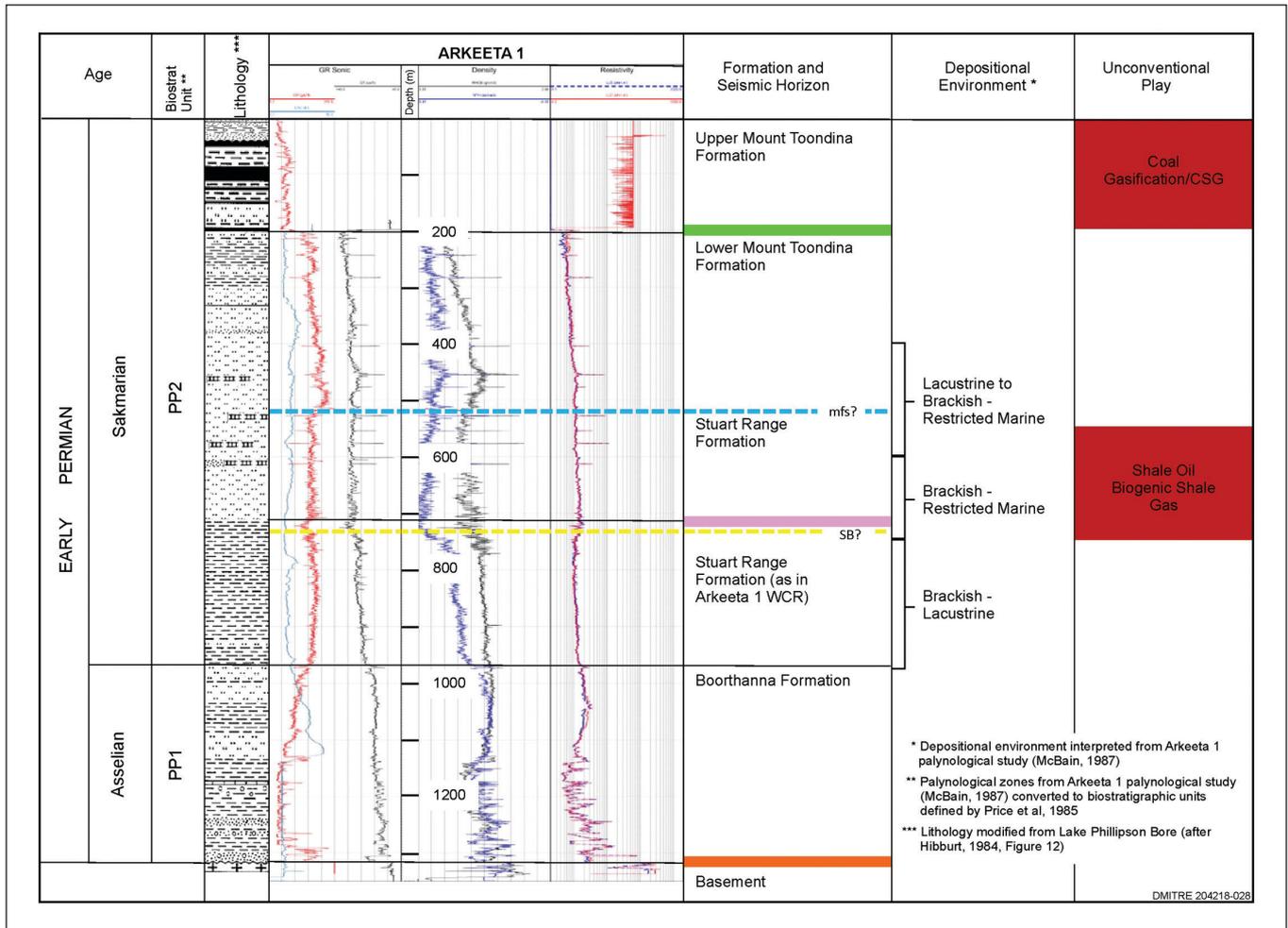


Figure 3. Stratigraphic column for the southern Arkaringa Basin based on the Arkeeta 1 petroleum exploration well.

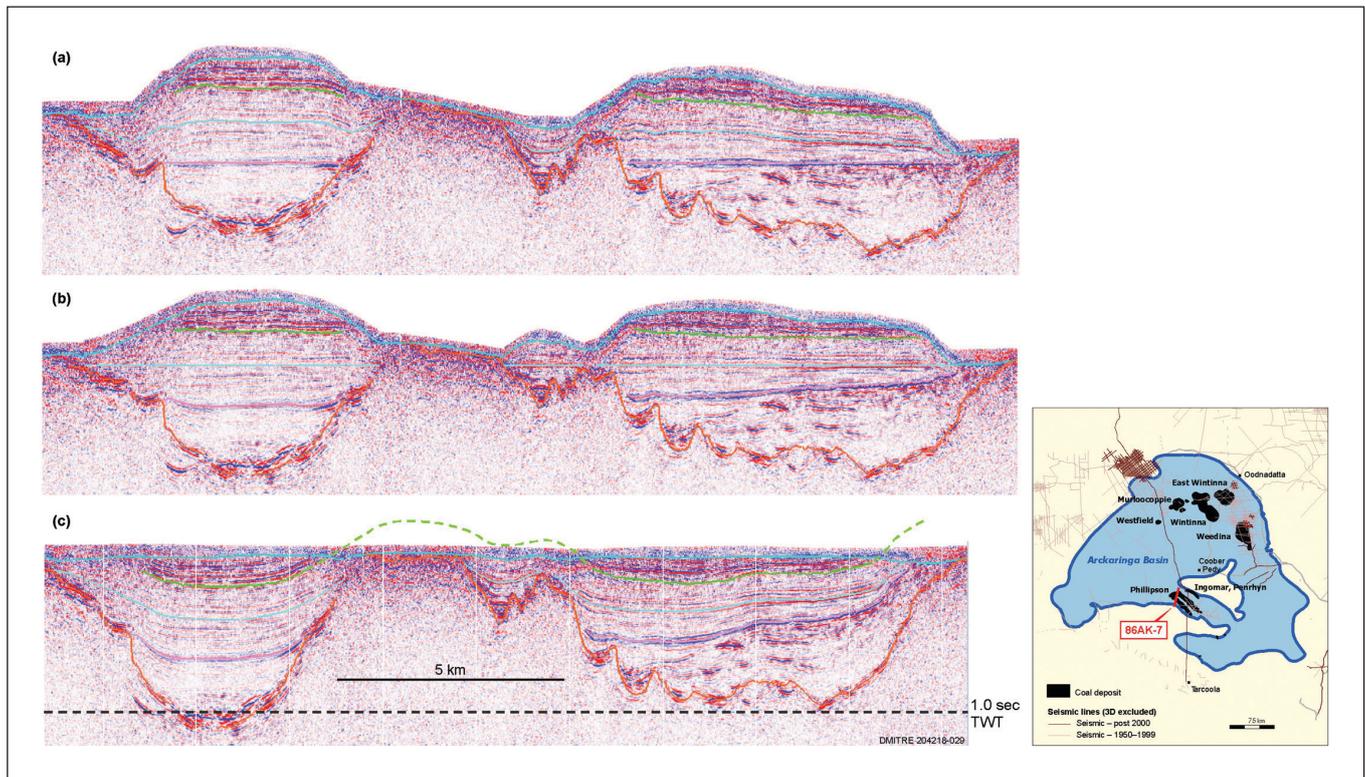
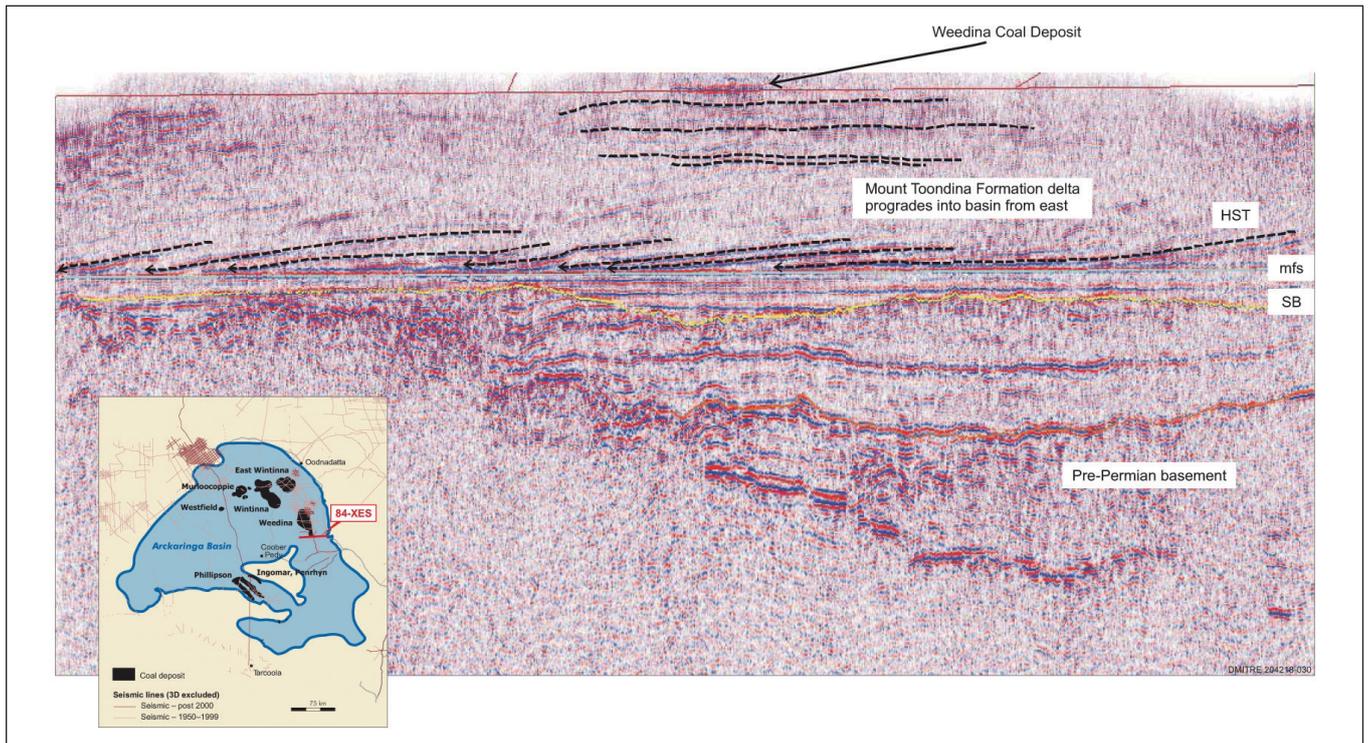


Figure 4. Interpretation of seismic line 86AK-7 (migrated), showing the West Trough (left) and the Phillipson Trough (right). (a) Flattened on the Top Stuart Range horizon (pink), (b) flattened on the intra-Mount Toondina horizon (light blue – NOTE: THIS IS NOT THE MFS HORIZON), (c) unflattened section. Seismic images from TrapTester.



**Figure 5.** Seismic line 84-XES, Boorthanna Trough, flattened on blue horizon interpreted to be a maximum flooding surface. 8 x vertical exaggeration. Organic rich marine shales are interpreted between the yellow horizon (sequence boundary) and blue horizon (maximum flooding surface). Seismic image from TrapTester.

sequence boundary (FIG 3). In Arkeeta 1 there is no real change in the lithologies described other than the appearance of a dolomitic siltstone in cuttings, however there is a distinct increase in the neutron porosity trace and decrease in the density trace above the interpreted sequence boundary.

Additional work is required to properly identify other chrono-stratigraphic packages within the Early Permian succession and construct palaeo-geographic maps. This work would include detailed seismic interpretation and mapping, palynological studies, and seismic facies analysis.

## Shale Oil Potential

Sakmarian organic rich marine shales have been intersected in both the southern Arckaringa troughs and the Boorthanna Trough. In Arkeeta 1 (Phillipson Trough), all twelve samples from a 200m interval recorded total organic carbon (TOC) values >2% (up to 7.4%) and hydrogen index (HI) values >400 (Amdel report, Appendix 5 in McBain, 1987). The Tmax vs HI cross plot shows that these organic rich shales are Type II source rocks at the threshold of oil generation (FIG 6). In the Boorthanna Trough Linc Energy's 2011 Arck 1 stratigraphic well intersected around 70m of organic rich shale (Type I/II kerogen) with very high potential oil yields (Linc Energy ASX Announcement, 27 September 2011). Analyses indicate that the shales are at the onset of oil generation (FIG 7).

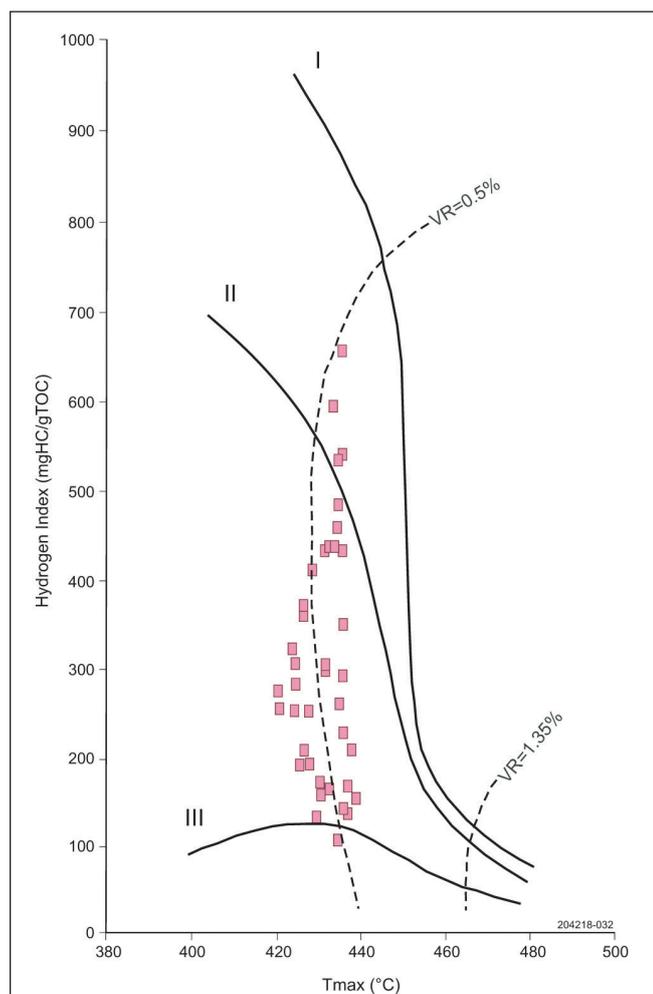
In the Phillipson Trough the organic rich marine shales in the Arkeeta 1 well lie between the interpreted sequence boundary and maximum flooding surface. In the Boorthanna Trough, an 18m interval above the sequence boundary in the Weedina 1 well returned TOC contents ranging 4.6 to 5.6%. It is therefore reasonable to conclude that conditions suitable for the preservation

of organic matter occurred during the marine transgression as has been recognised in basins in other parts of the world (eg. Upper Cretaceous Eagle Ford Formation, Texas, see Donovan and Staerker, 2010).

A detailed palynological study of cuttings and sidewall core samples from Arkeeta 1 (ECL Australia report, Appendix 6 in McBain, 1987) indicates a lacustrine to brackish-restricted marine environment during deposition of the organic rich shales. High organic carbon contents and hydrogen indices indicate anoxic bottom water conditions suitable for the preservation of organic matter. The presence of mixed lacustrine to brackish marine environments and anoxic bottom water conditions suggests a Baltic Sea analogy, where high fresh-water runoff into a restricted sea-way results in density stratification of the water column. High fresh-water runoff (including melt-water) into restricted seaways along the Arckaringa troughs is likely to have resulted in similar conditions.

An organic petrology study of the organic rich shales in the Boorthanna Trough has shown that very abundant alginite is present in a significant number of samples, and the dominant alginite form is a small tasmanitid (Cook, 1981, Moore, 1982). The samples which showed oil shale potential in Weedina 1 and Boorthanna 1 (see Moore, 1982) are transgressive systems tract deposits.

The organic rich shales will be an exciting shale oil target if sufficient maturity levels can be identified in the basin. These shales are at the threshold of generation in both Arkeeta 1 and Arck 1 and the possibility that they are in the oil window elsewhere in the basin should not be discounted. The Maglia 1 well, drilled by Linc Energy in 2009, encountered oil shows in the upper Mount Toondina Formation. One oil show was analysed and interpreted to be derived from a highly mature (VR 1.5%) marine carbonate



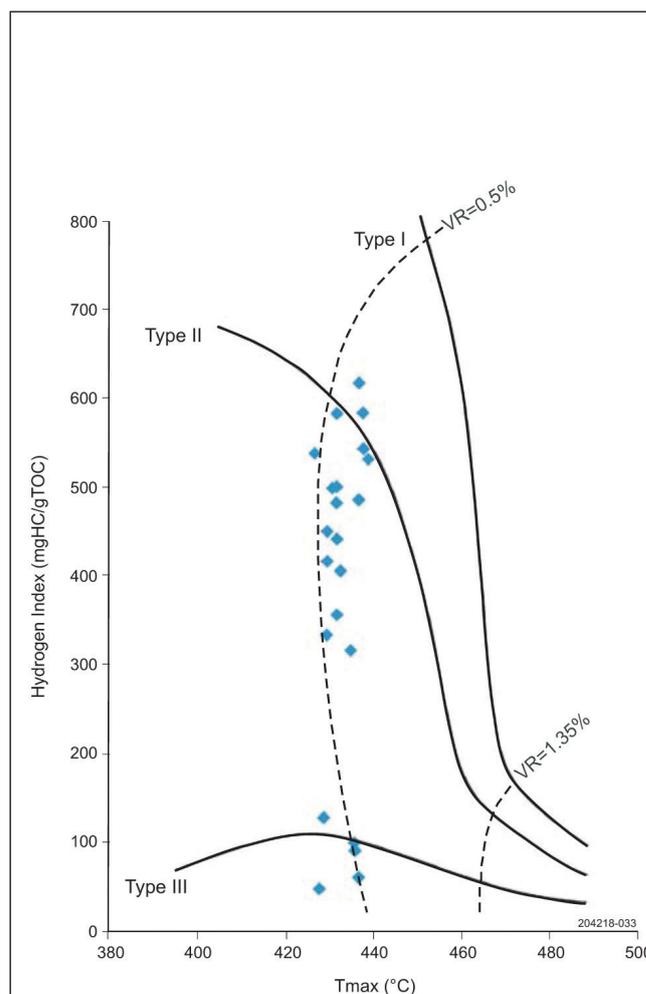
**Figure 6.** Tmax vs HI cross plot for cuttings samples from Arkeeta 1, Phillipson Trough (from Arkeeta 1 Well Completion Report)

source (Barber, 2010). The author concluded that the hydrocarbon source must be Cambrian carbonates, but seismic data shows that the Early Permian sediments overlie crystalline basement in the vicinity of Maglia 1. DMITRE, in collaboration with geochemists from Geoscience Australia, is planning an oil-source study to determine if the Maglia oil show was sourced by the organic rich marine shales of the Arckaringa Basin.

## Coal Gasification and Coal Seam Gas Potential

Seven deposits of lignite A/sub-bituminous C rank coal (American Society for Testing and Materials classification) aggregating more than 20 Gt of measured, indicated and inferred resource have been identified in the upper part of the Early Permian Mt Toondina Formation (see figures 1 and 3). These are multi-seam deposits with individual seams ranging up to 10m, with a cumulative thickness of up to 35m (DMITRE Resources and Energy Group, 2012).

The Arckaringa Basin coals are not sufficiently mature to have generated significant thermogenic gas volumes. However the coal seams subcrop the Jurassic Algebuckina Sandstone aquifer in part, meaning that methanogenic bacteria carried in meteoric waters



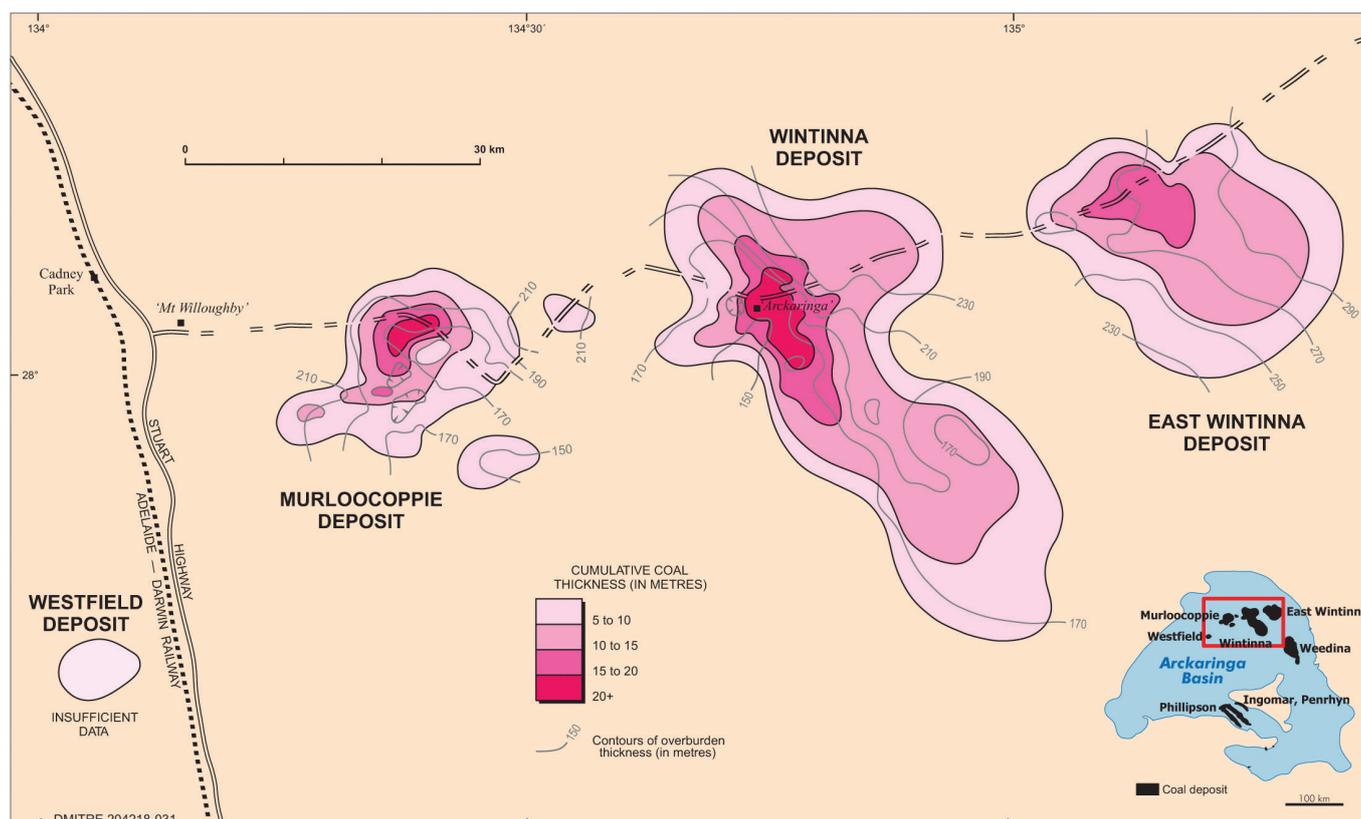
**Figure 7.** Tmax vs HI cross plot for core samples from Arck 1, Boorthanna Trough (modified from Linc Energy ASX Announcement, 27 September 2011)

can be introduced to the coal seams, and biogenic gas generation is possible.

A bankable feasibility study is currently underway for mining part of the Wintinna coal deposit (10Mtpa base case), supplying coal to a coal-to-liquids plant with an output of 10 MMbbls per annum liquid fuels (mainly ultra clean diesel) as well as a co-generation power plant delivering 560 MW per annum to the national power grid (FIG 8). Elsewhere in the Arckaringa Basin explorers are assessing coal deposits for in-situ gasification and coal seam gas prospectivity.

## Conclusions

More than a century after the energy potential of the Arckaringa Basin was first recognised, increasing energy demand and the application of new technologies may result in the future harnessing of this energy. The distribution of the coal measures at the top of the succession is well understood and the coal deposits have been defined by extensive drilling programmes. However, controls on the distribution of the deeper organic rich shales have been poorly understood until the current work to understand the distribution in a sequence stratigraphic framework. The Arckaringa Basin remains a frontier basin, but a detailed sequence



**Figure 8.** The Arckaringa Coalfield, South Australia

stratigraphic analysis of integrated seismic and well data will lead to a much better understanding of the Basin, and may result in the identification of new plays.

## References

- Barber, C., 2010. Hydrocarbon characterisation study, Maglia-1. Appendix 13 in Maglia-1 Well Completion Report. Linc Energy (unpublished).
- Cook, A.C., 1981. The organic petrology of samples from a selected group of wells in or near the Arckaringa Block. Delhi Petroleum Pty Ltd. (unpublished)
- DMITRE Resources and Energy Group, 2012. Coal deposits in South Australia. South Australia Earth Resources Information Sheet M23, February 2012
- Donovan, A.D. and Staerker, S., 2010. Sequence Stratigraphy of the Eagle Ford (Boquillas) Formation in the Subsurface of South Texas and Outcrops of West Texas AAPG Search and Discovery Article #90117. GCAGS-GC SEPM Meeting, San Antonio, Texas, 10-12 October 2010. [http://www.searchanddiscovery.com/abstracts/pdf/2010/gcags/abstracts/ndx\\_DonoStae.pdf](http://www.searchanddiscovery.com/abstracts/pdf/2010/gcags/abstracts/ndx_DonoStae.pdf)
- Gravestock, D. I., and Jensen-Schmidt, B., 1998. Chapter 5: Structural Setting. In Gravestock, D.I., Hibbert, J.E., and Drexel, J.F (Eds). Petroleum Geology of South Australia, Volume 4, Cooper Basin, pp 47-67. Primary Industries and Resources SA
- Hibbert, J.E., 1984. Review of Exploration Activity in the Arckaringa Basin Region 1858-1983. Report Book No. 84/1. Department of Mines and Energy, South Australia
- Linc Energy ASX Announcement, 27 September 2011. Linc Energy discovers significant oil shale deposit in South Australia's Arckaringa Basin. <http://www.lincenergy.com/data/asxpdf/ASX-LNC-348.pdf>
- McBain, D. 1987. Arkeeta No. 1 Well Completion Report. PEL 24, South Australia. CRAE Report No. 302889. CRA Exploration Pty Limited (unpublished)
- Menpes, S.A., Korsch, R.J. and Carr, L.K., 2010. 2008 Gawler Craton-Officer Basin-Musgrave Province-Amadeus Basin (GOMA) seismic survey, 08GA-OM1: Geological interpretation of the Arckaringa Basin. In: Korsch, R.J. and Kositsin, N., editors, GOMA (Gawler Craton-Officer Basin-Musgrave Province-Amadeus Basin) Seismic and MT Workshop 2010. Geoscience Australia, Record 2010/39, 16-31.
- Moore, P.S., 1982. Oil shale potential of the Arckaringa region. Delhi Petroleum Pty Ltd. (unpublished)
- Schrape, C., 2011. The Arckaringa CTL and Power Project. Altona Energy Presentation to the South Australian Major Projects Conference. Adelaide, 24 August 2011. [http://www.altonaenergy.com/pdfs/SA%20Major%20Projects%20Conference%202011%20\(2\).pdf](http://www.altonaenergy.com/pdfs/SA%20Major%20Projects%20Conference%202011%20(2).pdf)