Organic Rich Shale in Permian Fjords – A Potential Resource Play in the Arckaringa Basin, South Australia

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OUTLINE

• Introduction
• Gondwana glaciation, palaeogeography
• Sequence stratigraphic interpretation
• Organic rich shales
• Stratified fjord depositional model
• Conclusions
ARCKARINGA BASIN - LOCATION
PERMIAN BASINS IN SOUTH AUSTRALIA

FRONTIER BASIN
Wells: 7 petroleum, 9 coal seam gas, 14 stratigraphic Seismic line km
Seismic: 6938 line km 2D.
Palaeogeographic reconstruction of the Australian Plate (after Veevers, 1984 and Baillie et al., 1994).
PALAEOGEOGRAPHY

YOSEMITE NATIONAL PARK - HALF DOME

ICE SHEET, GLACIERS AND FJORDS, SE COAST OF GREENLAND

http://www.nationalparkguides.com/images/yosemite/yosemite-half-dome-l.jpg

Google Earth image
ARCKARINGA BASIN
BASE PERMIAN DEPTH STRUCTURE MAP

- 100 km
- Tarcoola
- Roxby Downs
- Mintabie
- Coober Pedy
- ARCKARINGA BASIN
- BASE PERMIAN DEPTH STRUCTURE MAP
- Drill hole
- Interpreted seismic
- Seismic line
- Railway
- Southern Arckaringa Troughs
- 86AK-7_mig
- Depth structure (m AHD)
- -500
- 0
- 750
- 1500
- 2129
- Tarcoola
- Roxby Downs
- 100 km
Flattened on SB (erosional – may not have been flat surface)

Flattened on intra-Mt Toondina horizon (NOT MFS)

Unflattened

Images captured from TrapTester – 3 x vertical exaggeration
<table>
<thead>
<tr>
<th>Age</th>
<th>Biostrat Unit</th>
<th>Lithology</th>
<th>ARKEETA 1</th>
<th>Sequence Stratigraphy</th>
<th>Depositional Facies</th>
<th>Lithostratigraphy</th>
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<tbody>
<tr>
<td>PERMIAN</td>
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<td></td>
<td>HST</td>
<td>Fluvio-lacustrine with coal swamps</td>
<td>Eromanga Basin</td>
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<td>APP3211</td>
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<td>HST</td>
<td>Deltaic: lacustrine</td>
<td>Upper Mount Toondina Formation</td>
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<td>TST</td>
<td>Deltaic: lacustrine-brackish-marginal marine</td>
<td>Lower Mount Toondina Formation</td>
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<td>LST</td>
<td>Restricted marine</td>
<td>Boorthanna Formation</td>
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<td>HST</td>
<td>Glacial outwash sands and diamicrites</td>
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<td>LST</td>
<td>Basement</td>
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</table>
Line 84-XER_mig_08SX and 84-XES, looking SE, flattened on MFS (8 x vertical exaggeration)

Mount Toondina Formation delta progrades into basin from east

Base Permian Unconformity

Pre-Permian basement

HST

SB

mfs

100km
PALAEO-CLIMATE: PEAK GREENHOUSE CONDITIONS CORRESPOND TO ARCKARINGA BASIN MFS

<table>
<thead>
<tr>
<th>System</th>
<th>Series</th>
<th>Global stages</th>
<th>Age (Ma)</th>
<th>Palynology</th>
<th>(\delta^{18}O) % (V-PDB)</th>
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<tbody>
<tr>
<td>Permian</td>
<td>Lopingian (Late Permian)</td>
<td>Changhsingian</td>
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<td>APT 1 (pans)</td>
<td>602, 601, 6006, 6005</td>
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<td>Wuchiapingian</td>
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<td>Capitanian</td>
<td>260.5</td>
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<td>Guadalupian (Middle Permian)</td>
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<td>5003, 5002, 5001, 43</td>
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<td>Roadian</td>
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<td>Cisuralian (Early Permian)</td>
<td>Kungurian</td>
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<td>279.5</td>
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Compiled from figures 2 and 7 in Korte et al, 2008
ORGANIC RICH SHALES

ARKEETA 1
Organic rich shales (TOC>2%, HI >400) are Type II source rocks at the threshold of oil generation.

ARCK 1
(Modified from Linc Energy ASX Announcement, 27 September 2011)

- Type II organic matter
- Micro-palaeontological assemblages indicate brackish, marginal marine, restricted marine environments
- Abundant algal material
ORGANIC RICH SHALES
WARRINER CREEK 1: 200.85m

Mean Ro = 0.59%
Leco TOC = 9.63%
HI = 443
S1 = 0.51
S2 = 42.49
Tmax = 431ºC

Organic matter:
65% alginite, 20% amorphous, 5% other liptinite, 2% vitrinite, 8% inertinite

Sample ~40% by volume organic matter – dominantly dull yellow fluorescing alginite
PRESENT DAY FJORDS

Fjord = long, narrow and deep inlet of the sea typically formed by submergence of a glaciated valley

- Litorina Sea 6500 BP (Baltic sea), Sohlenius et al., 2001
- Framvaren, South Norway, Skei, 1982
- Glacier Bay, Alaska, Hooge and Hooge, 2002
PRESENT DAY FJORDS

- Complex bathymetry, restricted marine water inflow (sill)
- Stratified water column (periodically/permanently)
- Periods of high primary productivity (phytoplankton blooms)
- Restricted circulation leads to oxygen depleted bottom waters
- Increased nitrogen and phosphorus in the surface waters (low capability for anoxic sediment to denitrify and store phosphorus)
- Organic rich sediments (eg. Framvaren - 25% organic matter, organic carbon content ~13%)
ARKEETA 1 TOC AND HI PROFILE – 3 METRE CUTTINGS COMPOSITES
Irregular erosional surface in Boorthanna Trough above Sequence Boundary 2
Glacial valleys not filled when sea trangresses
As sea-level rises sill has less effect and water column mixes.
MATURITY

<table>
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<th>Mean Maximum Vitrinite Reflectance</th>
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- HST
- TST
- LST

South Australia
Manufacturing, Resources and Energy
Early Permian organic rich shales in the Arckaringa Basin were deposited during a marine transgression caused by eustatic sea-level rise.

Organic material is predominantly Type II (alginate, amorphous organic matter) with some Type III (vitrinite, inertinite) material.

Palaeogeography, micro-palaeontology and organic macerals suggest a stratified fjord depositional model is appropriate.

A shale oil play fairway may be present in the basin if deeper burial or higher geothermal gradient can be identified.
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