

Sub-salt Petroleum Potential of the Neoproterozoic Adelaide Rift, South Australia*

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Abstract

The Adelaide Rift is a Neoproterozoic to Cambrian rift complex extending over 1000 km in South Australia. The northern-most extension of the Adelaide Rift outcrops in the Peake and Denison Ranges, and underlies the younger Permo-Carboniferous Arckaringa Basin west of the Ranges. In the Peake and Denison Ranges the Neoproterozoic section comprises basic volcanics, evaporites, carbonates and clastics, deposited in a rift valley, overlain by a sequence of clastics and platform carbonates, including glacial sediments recording two periods of glaciation.

Seismic data acquired over the Arckaringa Basin in the 1980's shows distinct salt-tectonic features in the underlying Neoproterozoic section. Salt withdrawal basins indicate significant syn-deposition salt movement during the Neoproterozoic and early Cambrian. Minor salt-remobilisation during later deformation events is also evident. Interpreted salt withdrawal basins adjacent to disturbed diapiric breccias are exposed in the Peake and Denison Ranges to the east.

The presence of tilted fault blocks sealed by inferred massive salt horizons are tantalising, given the success of sub-salt rift block plays elsewhere in the world. Overmaturity may be an issue, however significant oil shows intersected in nearby Permo-Carboniferous sediments suggest that the sub-salt play is worth further consideration. The Permo-Carboniferous section is not sufficiently mature for oil generation, hence the oil shows are assumed to have been sourced from the older sediments.

References

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Sub-salt Petroleum Potential of the Neoproterozoic Adelaide Rift, South Australia

**AAPG 2011 Annual Convention and Exhibition
Houston, Texas**

**Sandy Menpes
Principal Petroleum Geoscientist
April 2011**

**Division of Minerals and Energy Resources
PIRSA**

Presentation Outline

- Brief history of the Adelaide Rift, South Australia
- Salt tectonics in outcrop
- Salt tectonics in seismic – possible traps
- Well intersections
- Sub-salt play
- Supra-salt play

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Presenter's notes: My presentation today covers the northern end of the Neoproterozoic Adelaide Rift. The area has received virtually no exploration targeting the Neoproterozoic succession. This is based on the assumption that the sediments are too old, too tight and probably overmature. However a recent oil show has led us to re-evaluate the potential of the area.

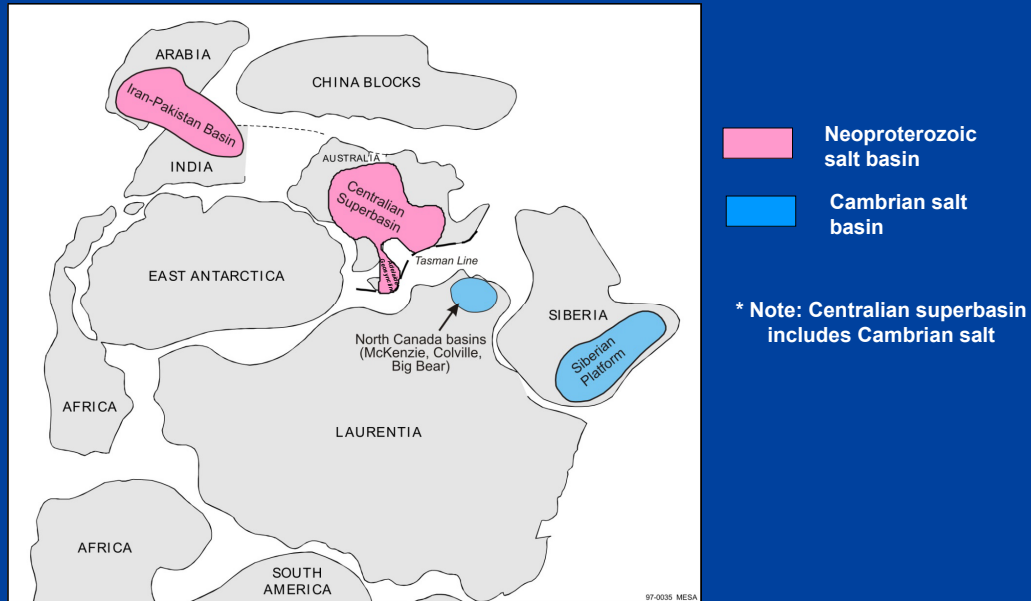
The outline of my talk is shown here –

I will briefly describe the history of the Adelaide Rift. We will then have a look at some examples of salt tectonics in outcrop, followed by salt tectonics and possible traps in seismic. We'll have a look at what we know from the few well intersections, and then I will summarise the petroleum plays in this frontier area.

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Rodinia Supercontinent – Neoproterozoic Reconstruction



From Morton and Drexel, 1997
(after Hoffman, 1991)

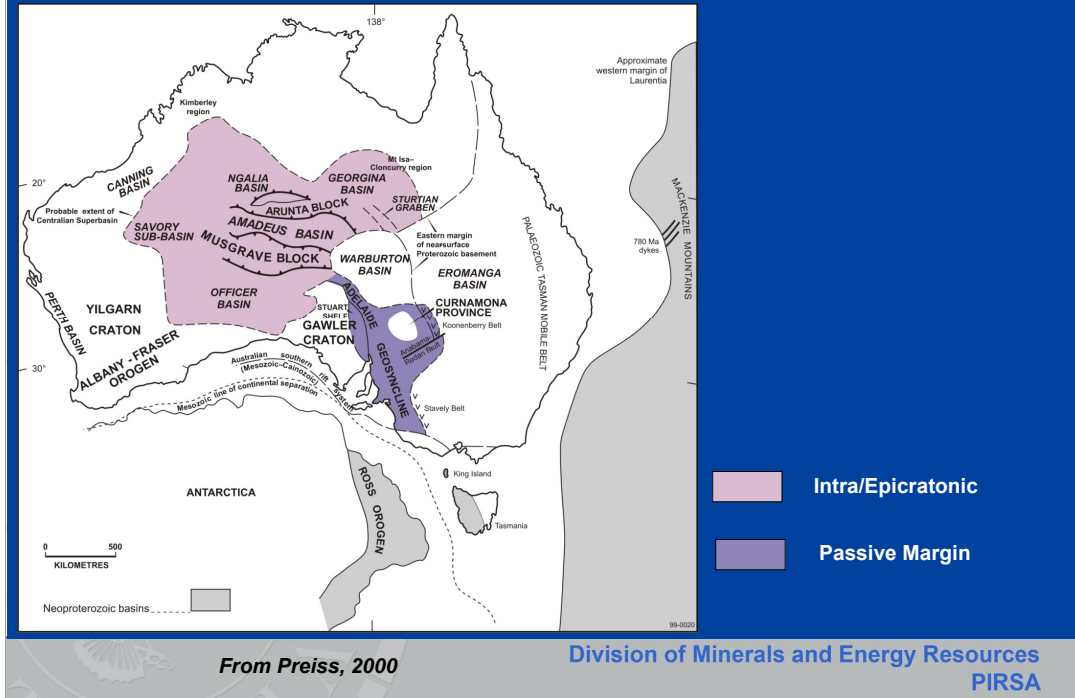
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Presenter's notes: This figure shows the position of Australia relative to other continents during the Neoproterozoic. Laurentia is opposite East Antarctica and Australia prior to the opening of the Palaeopacific Ocean in the Early Cambrian.

You will notice the obvious alignment of the major Neoproterozoic and Cambrian salt basins.

This arm here is known as the Adelaide Geosyncline. This is the non-genetic name given to the Neoproterozoic to Cambrian sediments outcropping over more than 1000km in South Australia. I will use the term Adelaide Rift specifically for those sediments deposited during Neoproterozoic rifting.

Centralian Superbasin and Adelaide Geosyncline

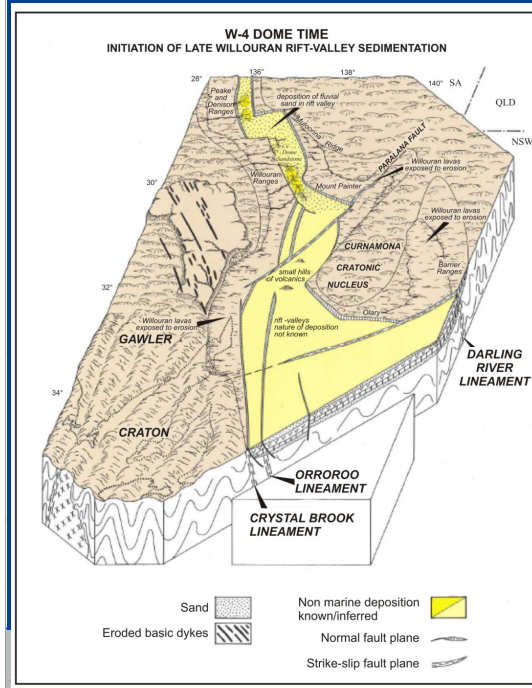


Presenter's notes: The Adelaide Geosyncline is a zone of deep subsidence and extremely thick sediment accumulation, comparable with many present-day passive margins. It developed through several episodes of Neoproterozoic rifting that preceded the separation of Laurentia and Australia-Antarctica along the Tasman Line.

In contrast the Centralian superbasin is largely cratonic, representing a continental sag.

Adelaide Rift

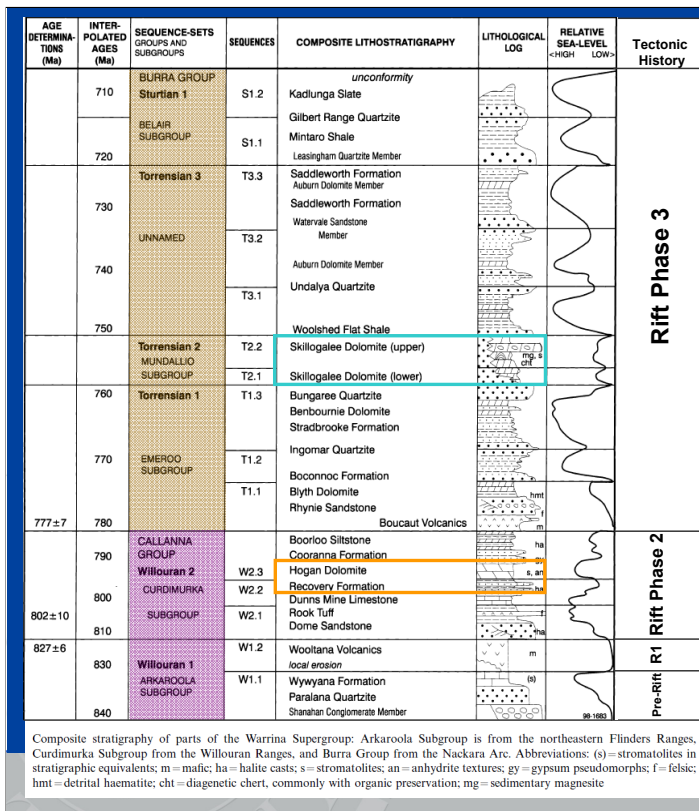
Late Willouran - Rift Valley sedimentation



From Preiss, 1987

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Presenter's notes: This figure is a snapshot of the Adelaide Rift at around 810 my. Non-marine rift valley sedimentation commences around this time following a period of basic volcanism. The area of focus for my talk today is the northern most extent of the rift around the present day Peake and Denison Ranges.



Stratigraphy

From Preiss, 2000

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Presenter's notes: This slide is a composite stratigraphy for the oldest sediments of the Adelaide Geosyncline, compiled by Wolfgang Preiss. The Callanna Group comprises basic volcanics, fluvial sands, carbonates and evaporites deposited in the rift valley. Conditions were strongly evaporitic during deposition of the Recovery Formation and Hogan Dolomite as evidenced by halite pseudomorphs in outcrop. Preiss has suggested that the massive salt beds of the Adelaide Rift could have formed at this time. However whilst there is plenty of evidence of diapirism in outcrop no salt beds are known.

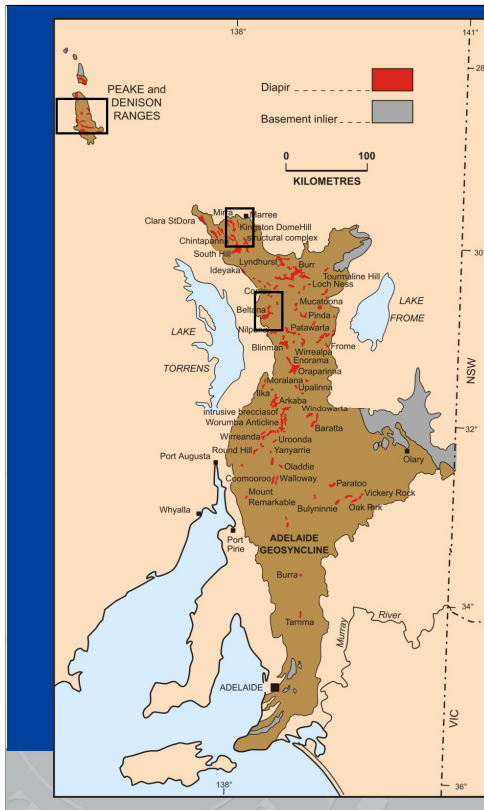
The younger Burra Group comprises a series of prograding deltas overlain by carbonates of the Skillogalee Dolomite. In the Peake and Denison Ranges, the Skillogalee Dolomite comprises dolomite, siltstone, quartzite and sandstone, with minor chert and magnesite. The depositional environment is interpreted to be lagoons and bays that received considerable clastic influxes.

Both the Callanna and Burra groups were deposited during rifting. Continental separation is interpreted to have commenced soon after.

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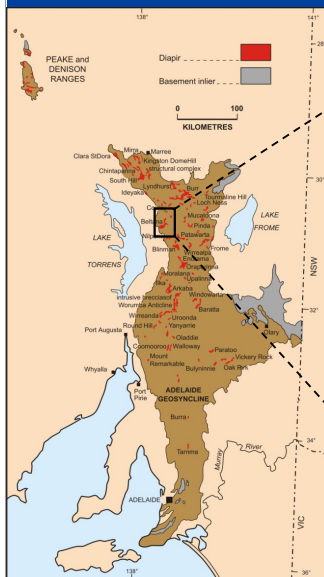
Neoproterozoic diapirs in outcrop



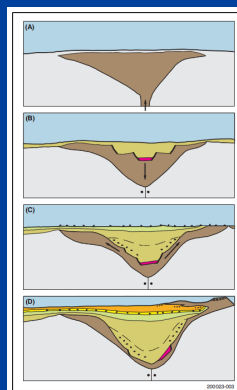
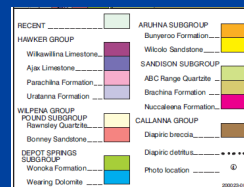
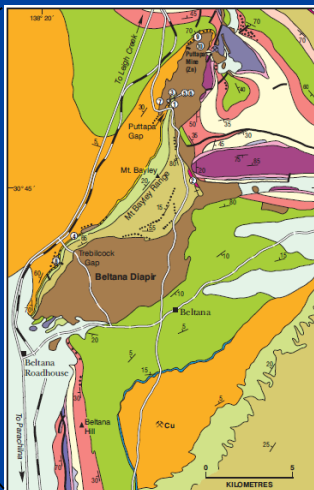
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Presenter's notes: The figure on the left shows the Callanna Group diapirs that outcrop in the Adelaide Geosyncline. The diapirs are shown in red, and other sediments in brown. We will have a closer look at three of these diapirs.

Mt Bayley Range secondary minibasin Northern Flinders Ranges



Basin ~ 5km wide



From Dyson, 1999

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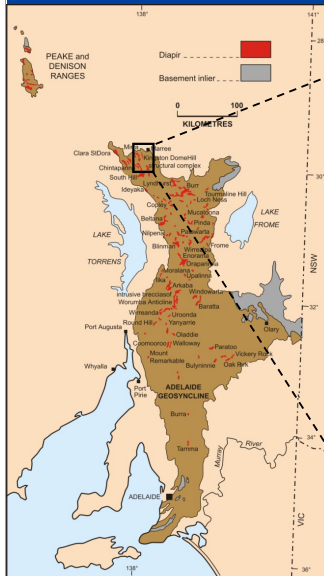
Presenter's notes: Firstly the Beltana Diapir in the northern Flinders Ranges.

Dyson interpreted the Beltana diapir as a diapiric stock that rose and fell during extension. He interprets the Mount Bayley Range mini-basin as formed by salt withdrawal with continued extension after stock emplacement.

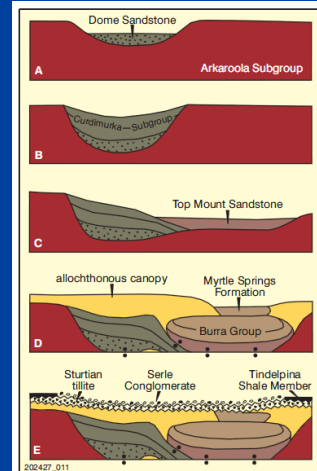
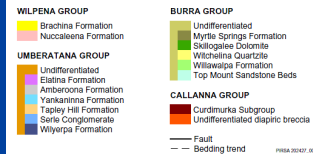
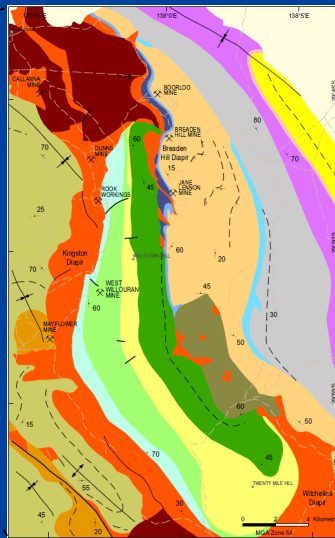
Diapiric breccia of the Callanna Group is shown here in brown. The sub-basin comprises Ediacaran Wilpena Group sediments.

Breaden Hill – Witchelina minibasin

Northern Willouran Ranges



Basin ~ 20km wide



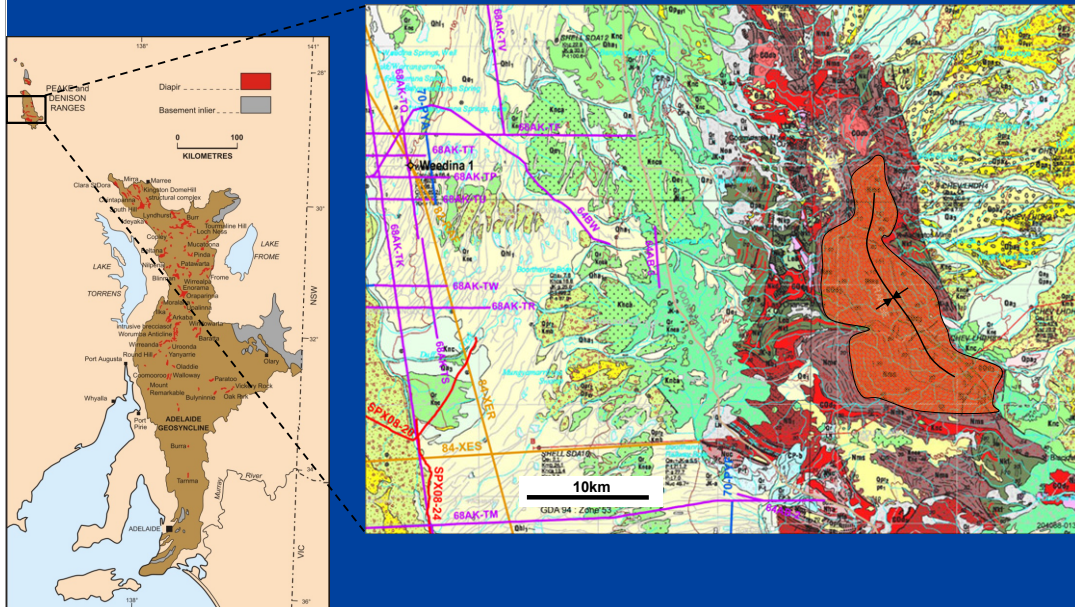
From Dyson, 2004

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Presenter's notes: Next we move north to the Willouran Ranges.

Here Dyson has interpreted the Breaden Hill – Witchelina mini-basin as formed by salt dissolution and salt withdrawal within Callanna Group sediments. Diapiric breccia is shown in this map in orange. Sediments of the Burra Group, including the Skillogeale Dolomite shown in bright green, form a mini-basin that is approximately 20km across.

Primary minibasins in the Peake and Denison Ranges?



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Presenter's notes: And now we move to the northernmost outcrop of the Adelaide Geosyncline, the Peake and Denison Ranges.

The map on the right shows the southern part of the Peake and Denison Ranges. Geologists mapping here in the 80's and 90's described open basins and tight, disrupted domes in the Neoproterozoic sediments. These features were attributed to folding and diapirism coincident with the Ordovician Delamerain Orogeny.

My interpretation is different. I interpret the open basins as primary salt withdrawal minibasins that developed during deposition of Burra Group sediments with rifting. The Skillogalee Dolomite outcrops in the centre of the minibasin, and I have highlighted it in orange. The Breden Hill-Witchelina primary minibasin in the previous slide is the same age.

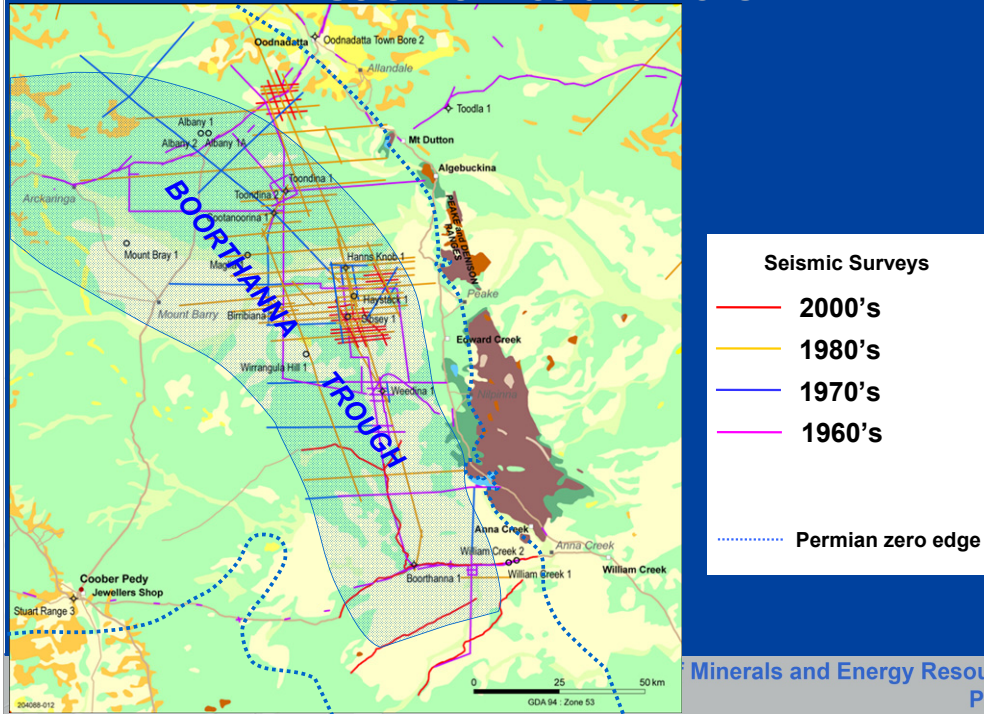
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Presenter's notes: We'll now have a look at the Adelaide Rift succession in seismic, in the area immediately west of the Peake and Denison Ranges known as the Boorthanna Trough.

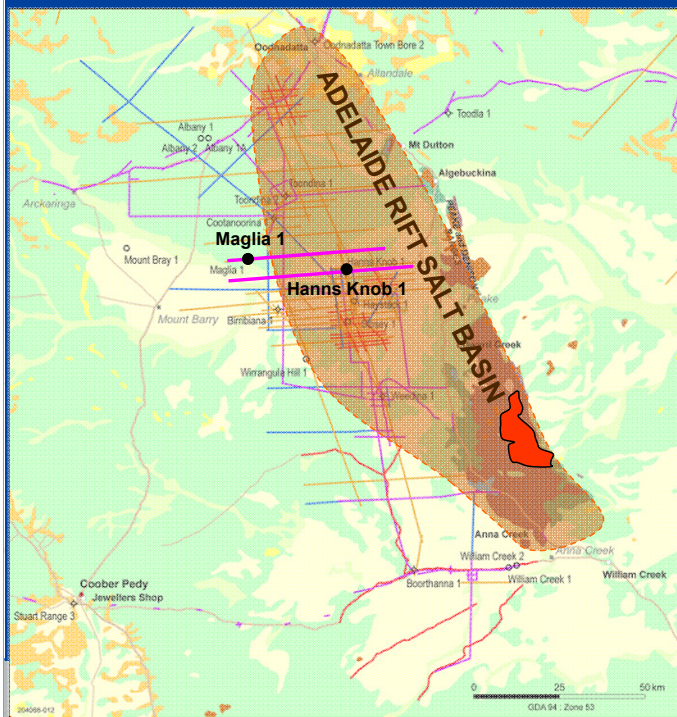
Early Permian Boorthanna Trough

Seismic lines and wells



Presenter's notes: The Peake and Denison Ranges form the eastern boundary of the Early Permian Boorthanna Trough. Only two petroleum wells targeting the Early Permian have been drilled in the trough. The Early Permian reaches a maximum thickness of around 1300m and the source rocks in the succession are immature.

Adelaide Rift Salt Basin



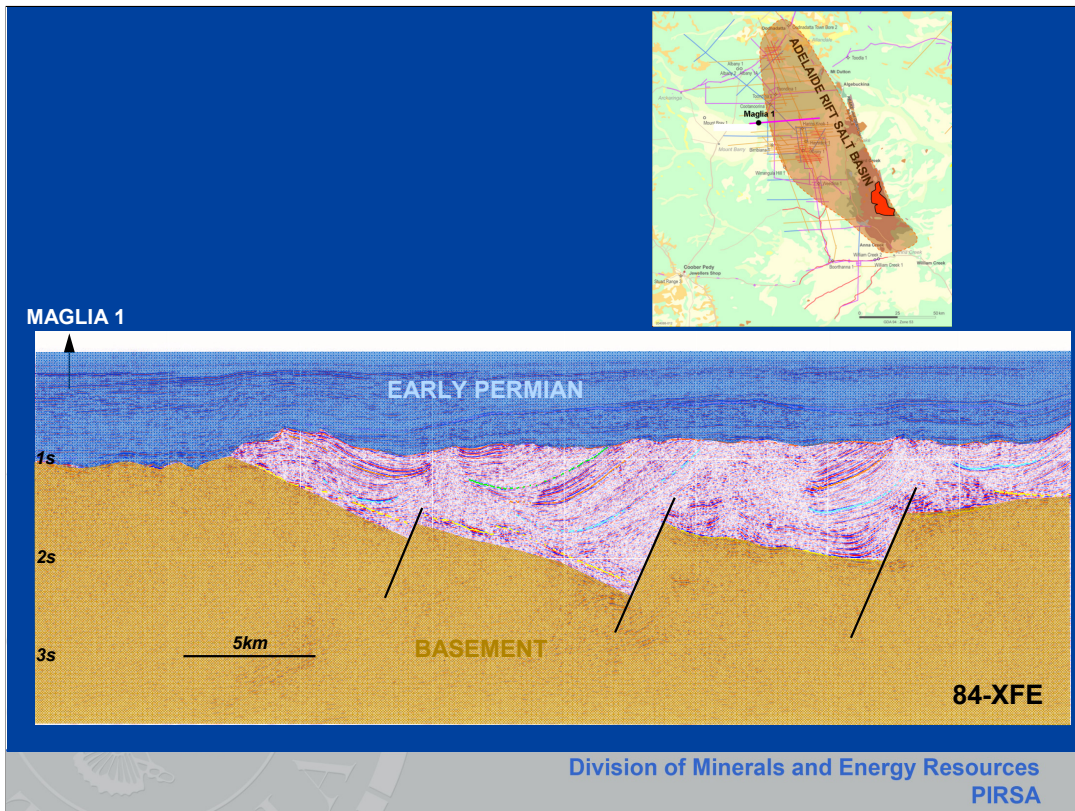
Interpreted minibasin –
Skillogalee Dolomite
(Burra Group)

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Presenter's notes: This figure shows the approximate extent of the Adelaide Rift salt basin that underlies part of the Boorthanna Trough.

The 2D seismic grid acquired to identify Early Permian targets in the Boorthanna Trough is relatively sparse. There are very few tie lines, most of which run along disrupted zones associated with diapirs. It is therefore very difficult to correlate minibasin stratigraphy between adjacent dip lines.

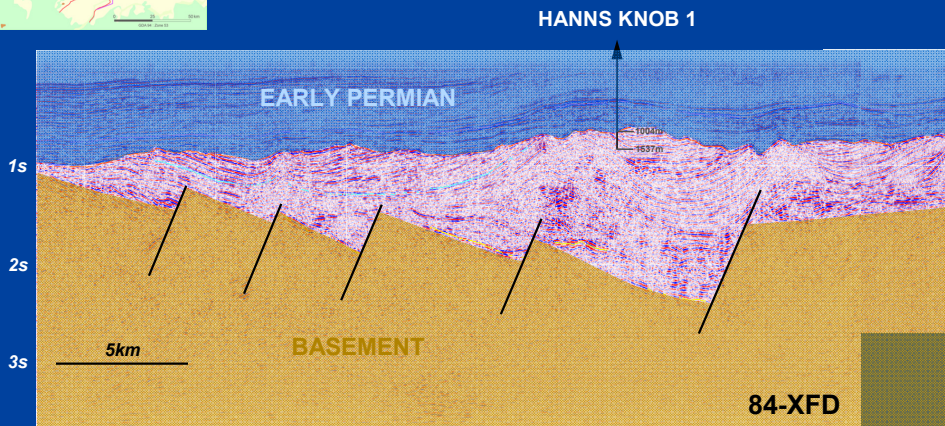
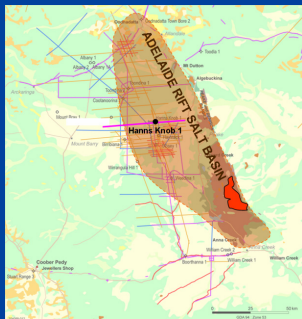
We'll now have a look at two of these dip lines, their locations are shown here in pink.



Presenter's notes: The first seismic line illustrates the structural history of the area:

1. The offset of high amplitude discontinuous reflectors deeper in the section provides some evidence of the Neoproterozoic rifting.
2. Salt movement is evident with the development of a number of mini-basins separated by poor data zones being the diapirs or salt feeders.
3. Compression and some fault inversion during the Ordovician Delamerian Orogeny is suggested by the steepening of the minibasin stratigraphy.
4. The unconformity here is the erosional land surface shaped by the Permo-Carboniferous Gondwanan glaciation. It is overlain by the Early Permian succession.

Maglia 1 is a shallow coal exploration hole drilled in 2010 and is currently not in the public domain. However the licence operator announced that this shallow hole intersected oil shows in Early Permian sandstones over two intervals. Oil samples were extracted and analysed and determined to be sourced from pre-Permian carbonates. The only Pre-Permian carbonates in the vicinity are in the Neoproterozoic succession.



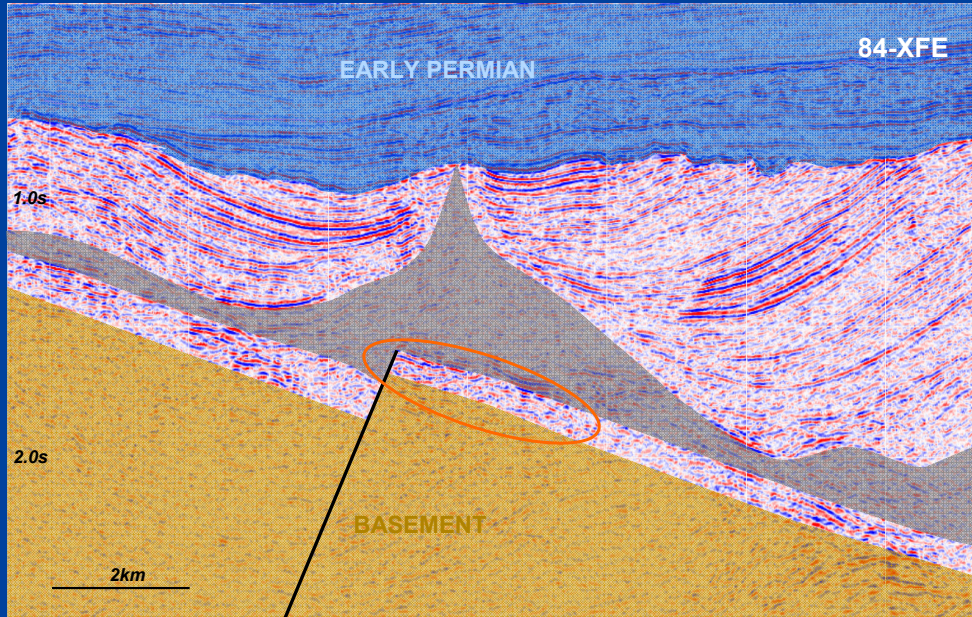
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Presenter's notes: This line shows similar features to the previous line.

Hanns Knob 1 was drilled in 1984 targeting a closure in the Early Permian succession. The well also penetrated ~500m of the Neoproterozoic succession at the margin of a salt withdrawal minibasin.

3-4 km of Neoproterozoic sediments are preserved in the deepest parts of the rift.

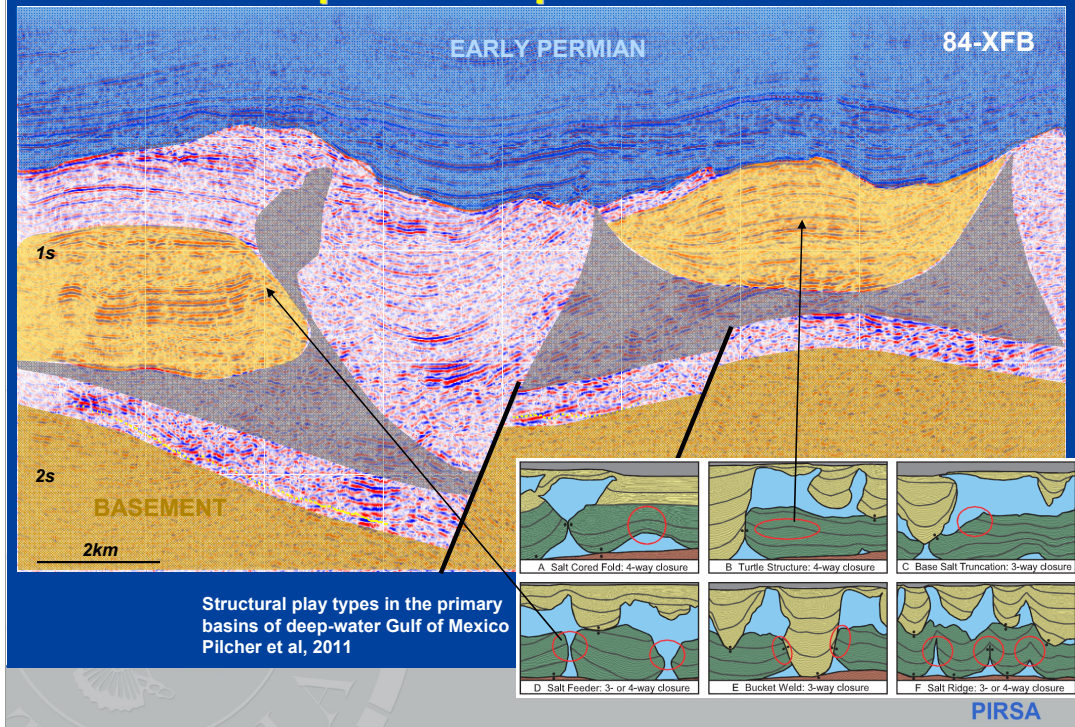
Potential sub-salt traps – tilted fault blocks



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Presenter's notes: The tilted fault blocks beneath autochthonous salt are an obvious trap to target. However as this part of the Neoproterozoic succession has not been drilled, the presence of source, reservoir and seal is unknown. You can see the primary mini-basins very well on this slide, with thickening of units away from the salt feeder.

Potential supra-salt traps



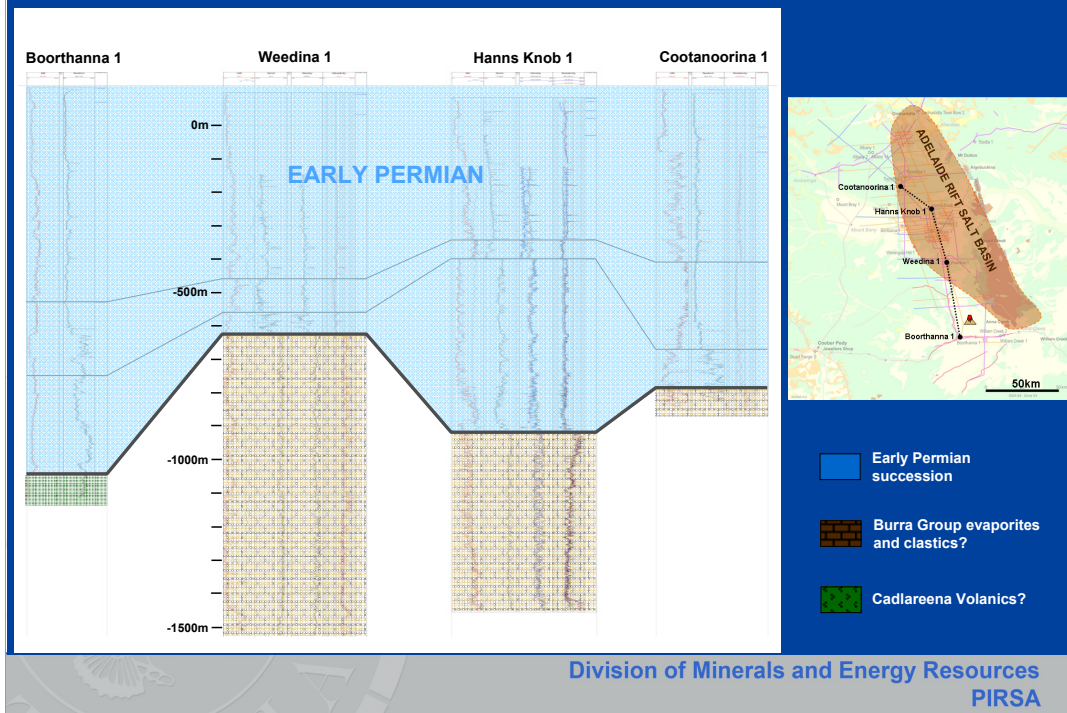
Presenter's notes: Possible supra-salt traps include turtle structures and updip truncation against salt feeders or welds.

The figure on the bottom is from a recent AAPG paper by Pilcher et al and shows the various primary basin traps in the deep water Gulf of Mexico.

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Wells intersecting Neoproterozoic succession



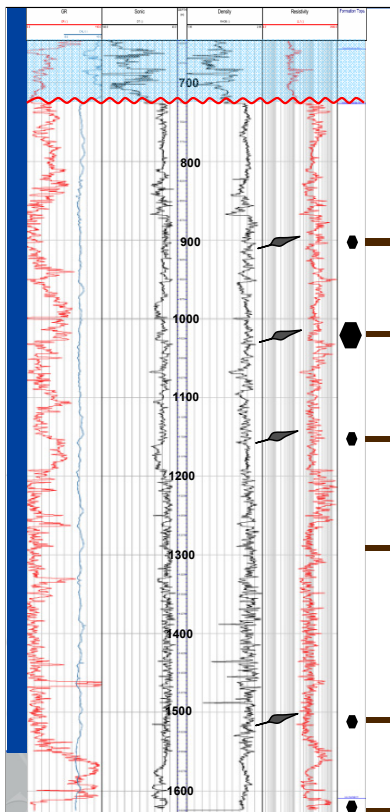
Presenter's notes: The figure on the right shows the main salt basin and the location of the 4 wells that have penetrated the Neoproterozoic succession below the Early Permian.

Boorthanna 1 was a deep mineral hole drilled targeting potash in the Neoproterozoic evaporites. Below the Early Permian, Boorthanna 1 intersected a massive, fine grained, altered, amygdaloidal basalt. Boorthanna 1 is located outside the main salt basin on the rift shoulder.

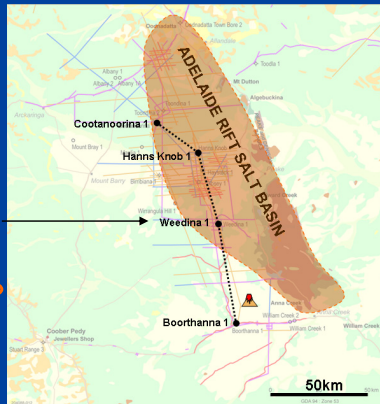
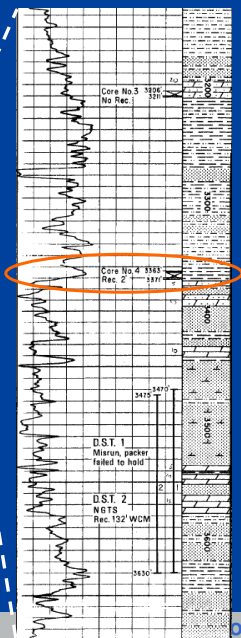
The other three wells intersected Neoproterozoic sediments comprising dolomite and anhydrite cemented clastics, rebedded siltstones, dolomites, magnesian shale and interbeds of pink anhydrite. The depositional environment is interpreted to be a low to moderate energy tidal mud flat. The succession is similar to that described for the Skillogalee Dolomite outcropping in the Peake and Denison Ranges.




Most importantly a petrographic study of side-wall cores from Hanns Knob 1 indicated that the generally tight nature of the Neoproterozoic sediments in the well is due to a complex diagenetic history rather than metamorphism.

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Weedina 1

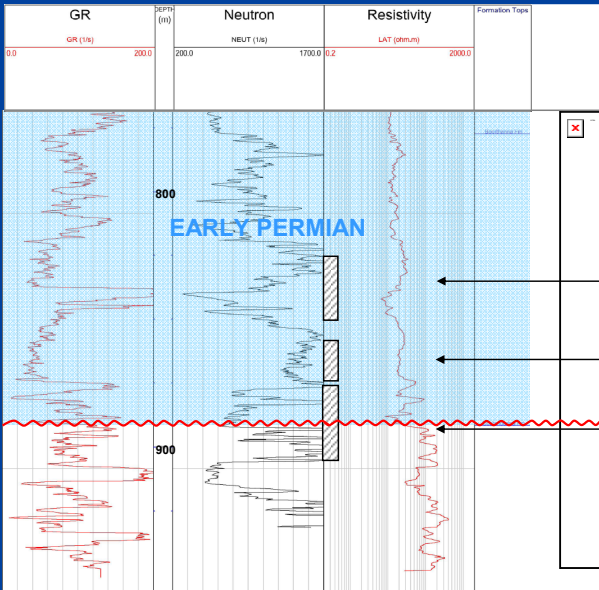


-  Palyngology
-  Rock eval
-  Core

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Presenter's notes: Rock eval data for the Neoproterozoic sediments intersected in the three wells is limited to 22 samples. One of these samples from a grey dolomitic shale in Weedina 1 returned a TOC value of 3.74%.

Cootanoorina 1



GAS ANALYSIS					
D.V.T. No.	Sample No.	Methane	Ethane	Propane	Isobutane
1	A1592/67	3600	35	1	nd
1	A1593	1500	20	3	nd
2	A1594	nd	nd	nd	nd
2	A1595	1500	50	1	nd
2	A1596	3000	50	1	nd
2	A1597	3000	90	1	nd
3	A1598	450	22	1	10
3	A1599	50	2	1	nd
3	A1600	3500	200	4	95

**DST 3: 827-852m:
~610m of gassy salt water**

**DST 2: 877-905m:
~750m of gassy salt water**

**DST 1: 877-905m:
>800m of gassy salt water**

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Presenter's notes: Cootanoorina 1 was a stratigraphic well drilled on a structural high by the SA Government in 1967. Three DST's over the base of the Early Permian and top Neoproterozoic recovered gassy salt water. The Early Permian source rocks are immature for hydrocarbon generation so again the Neoproterozoic is the likely source of the gas encountered in this well.

Sub-salt Play

- Tilted fault blocks - footwall
- ~3000 – 4000m target depth
- No well penetrations – source/reservoir unknown
- Salt seal – excellent seal in old basins – how much autochthonous salt?

Presenter's notes: To summarise the Sub-salt play:

We have possible traps in the footwall locations of tilted fault blocks

Target depth is likely to be 3000-4000m

There are no well penetrations so we don't know if there are source and reservoir rocks beneath the salt.

Salt provides an excellent seal in old basins – however we don't know how much autochthonous salt remains.

Supra-salt Play

- Traps include turtle structures, updip truncations against salt feeders or welds, updip pinchouts
- ~1500 – 3000m target depth
- Source-reservoir-seal packages deeper in mini-basins?
- Limited rock eval data (22 samples). One sample TOC 3.74% (grey dolomitic shale, Weedina 1)
- Succession penetrated generally tight (complex diagenetic history) – trapped hydrocarbons preserve porosity/secondary porosity development?

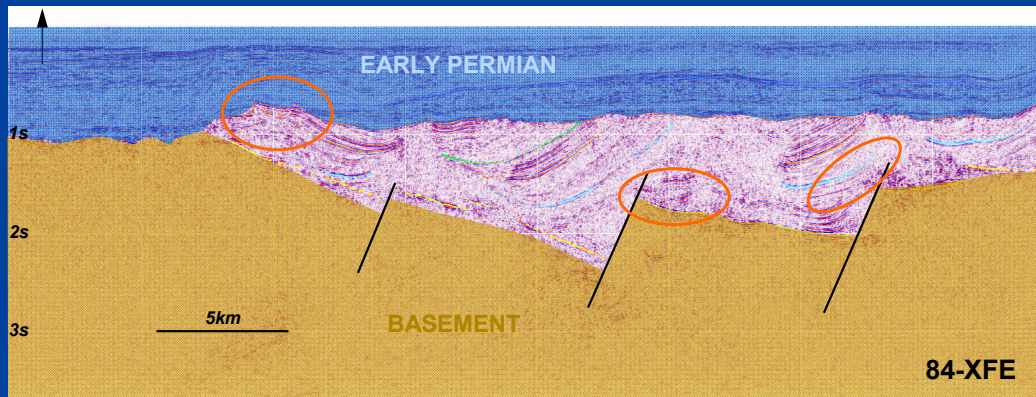
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Presenter's notes: The Supra-salt play:

- Targets include turtle structures, updip truncations against salt feeders or welds, updip pinchouts
- target depth range from ~1500 – 3000m
- Only the top of the mixed clastic/evaporite succession has been penetrated
- Rock eval data is limited however one sample returned a TOC value of 3.74%
- The succession penetrated is generally tight however trapped hydrocarbons might preserve porosity/permeability. The sandstones are feldspathic and carbonate cemented so secondary porosity development is also possible.

PRE-PERMIAN CARBONATE SOURCED OIL IN MAGLIA 1!

MAGLIA 1



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Presenter's notes: I'll leave you with this thought.

This is a frontier area undoubtedly a very high risk given the age of the rocks. But... the oil at Maglia 1 suggests oil generation and migration from Neoproterozoic carbonates. Where is this oil trapped?