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

Sandra A. Menpes[1]

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[1]Energy Resources Division, DMITRE, Heathfield, Australia (sandy.menpes@sa.gov.au)

Abstract

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.

A recent sequence stratigraphic interpretation of the Arckaringa Basin has resulted in a better understanding of the basin fill, in particular the distribution of the organic rich marine shales in the succession. A sequence boundary cuts down into underlying glaciogenic sediments in the landward part of the basin but shows little evidence of erosion in the more seaward part of the basin. Sediments above the sequence boundary, deposited during the marine transgressive phase, onlap paleo-topographic highs. A maximum flooding surface at the base of the overlying delta succession has been identified and flattening of seismic lines on this horizon demonstrates the downlapping of clinoforms onto the surface. A prominent peak in the gamma-ray curves of wells in the basin coincides with the maximum flooding surface.

Thick organic rich shales with Type II source potential have been intersected in both the southern Arckaringa troughs (TOC's ranging 4.1-7.4% over 160 m) and the Boorthanna Trough (TOC's ranging 3.9-10.4% over 70 m). The organic rich shales fall below the gamma ray peak marking the maximum flooding surface, and are transgressive systems tract deposits.

Seismic data shows that the valleys were not completely filled with sediment when the sea transgressed, resulting in long and narrow fjords with a complex paleo-bathymetry. Abundant algal material recorded in the organic rich shale, including the marine alga Tasmanites, suggests that nutrient rich surface water and anoxic bottom water conditions were present at times in the restricted seaways. These conditions have been recorded in modern fjords associated with density stratification of the water column. Micropalaeontological assemblages indicate lacustrine to brackish to restricted marine environments through much of the Early Permian succession.

The thick organic rich shales of the Arckaringa Basin are now being pursued as a potential shale oil play. The shale is at the threshold of oil generation over parts of the basin, but oil shows have been recorded elsewhere. Exploration efforts are currently directed at determining if a shale oil play fairway is present in the basin.

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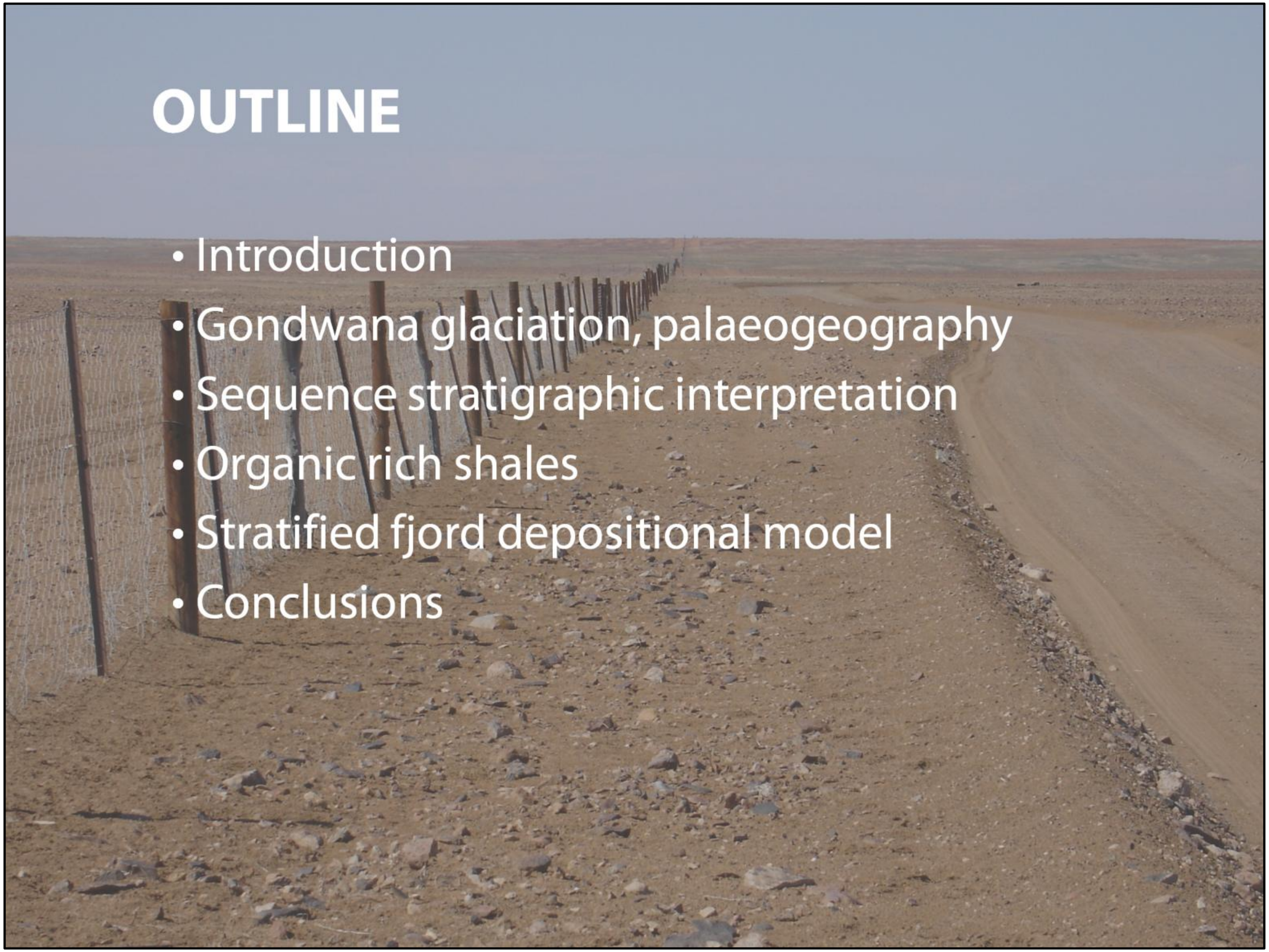
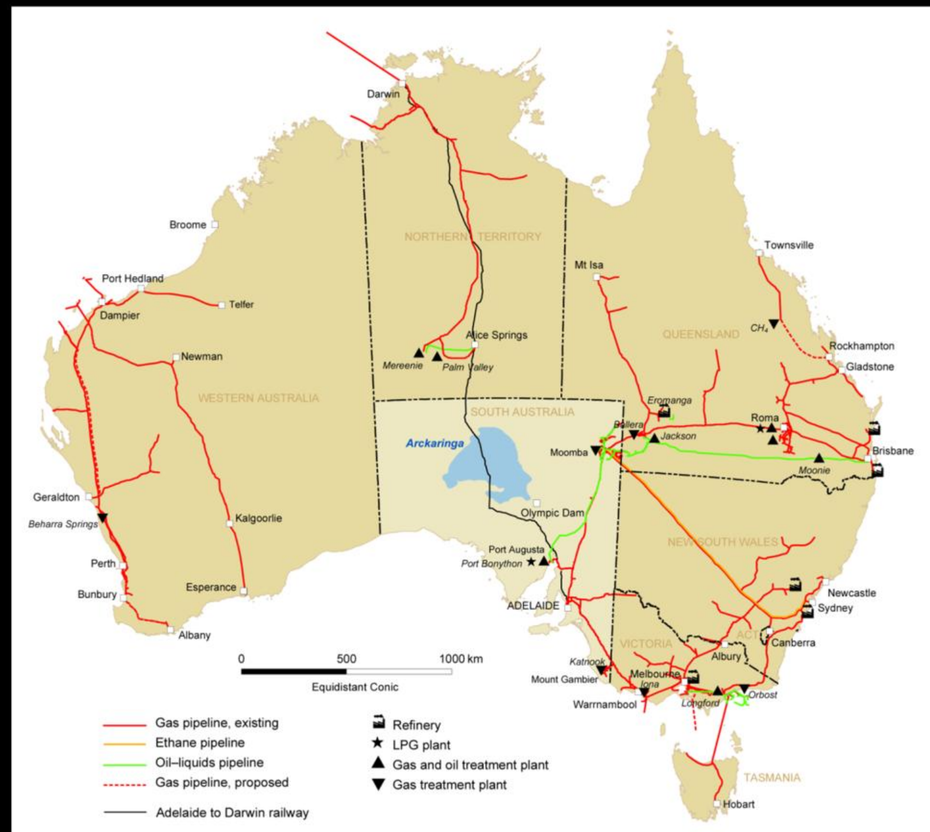
Sandy Menpes
Principal Geoscientist
DMITRE Energy Resources Division


OUTLINE
• Introduction
• Gondwana glaciation, palaeogeography
• Sequence stratigraphic interpretation
• Organic rich shales
• Stratified fjord depositional model
• Conclusions

ARCKARINGA BASIN - LOCATION



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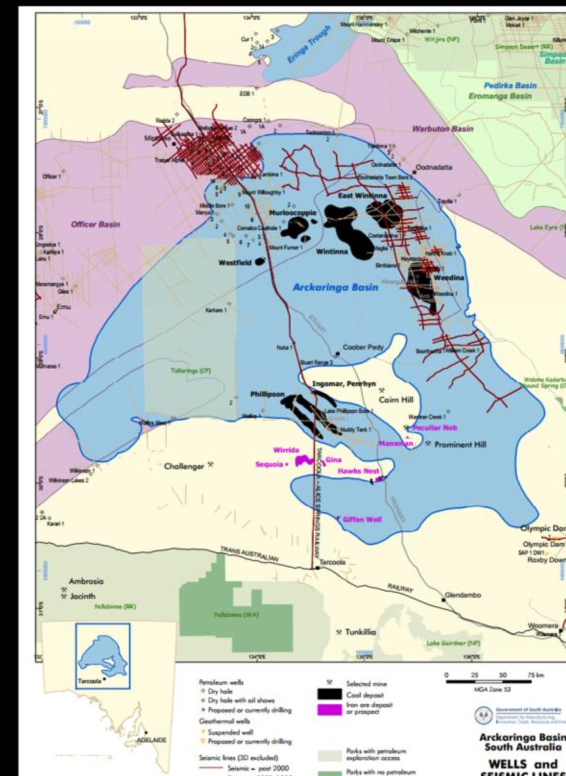
Presenter's notes: This map shows the location of the Arckaringa Basin, and pipeline infrastructure.
There are no pipelines in the vicinity of the basin, but the Adelaide to Darwin railway line runs through the centre of the basin.

PERMIAN BASINS IN SOUTH AUSTRALIA



FRONTIER BASIN

Wells: 7 petroleum, 9 coal seam gas, 14 stratigraphic Seismic line km

Seismic: 6938 line km 2D.

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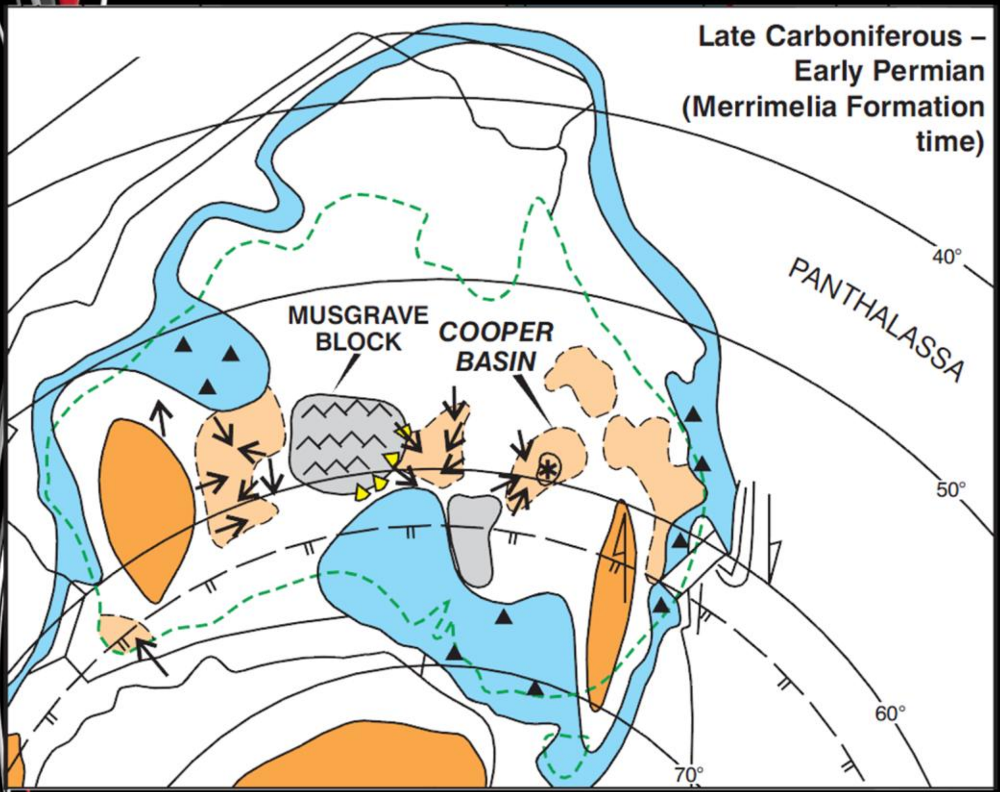
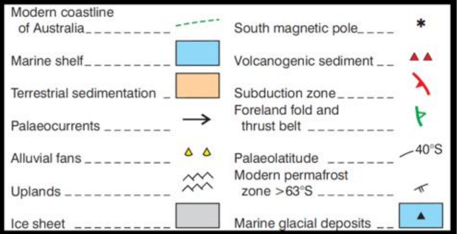
Presenter's notes: The figure on the left shows the extent of Permian basins in South Australia.

The Arckaringa Basin is a frontier basin – It covers an area of 80,000 sq km or 31,000 sq miles. However only 7 petroleum exploration wells have been drilled in the basin, and around 7000 line km of 2D seismic data has been acquired.

Seismic data acquisition has focused on the deeper troughs in the basin. The black polygons are Early Permian coal deposits.

PALAEOGEOGRAPHY 290-300Ma





Palaeogeographic reconstruction of the Australian Plate (after Veevers, 1984 and Baillie et al., 1994).

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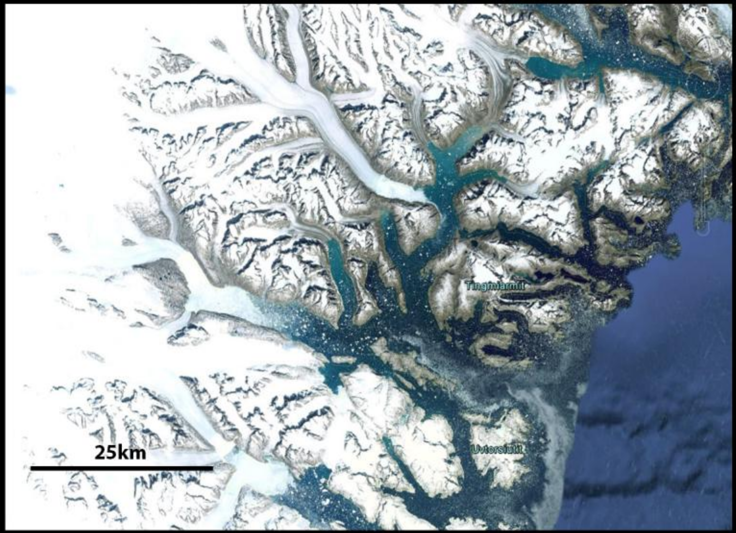
Presenter's notes: Global and regional palaeogeography is a key to understanding the Arckaringa Basin.
This map shows the high latitude position of Australia during the Permian, and the interpreted palaeogeography. Australia was attached to Antarctica at the time, forming part of the Gondwana Supercontinent.
Around 290-300 Ma ice sheets were present over the Musgrave Block and Adelaide Geosyncline feeding sediments into the Cooper and Pedirka basins.
The Arckaringa Basin is not shown but would be here, where a marine shelf is interpreted.

PALAEOGEOGRAPHY

YOSEMITE NATIONAL PARK - HALF DOME

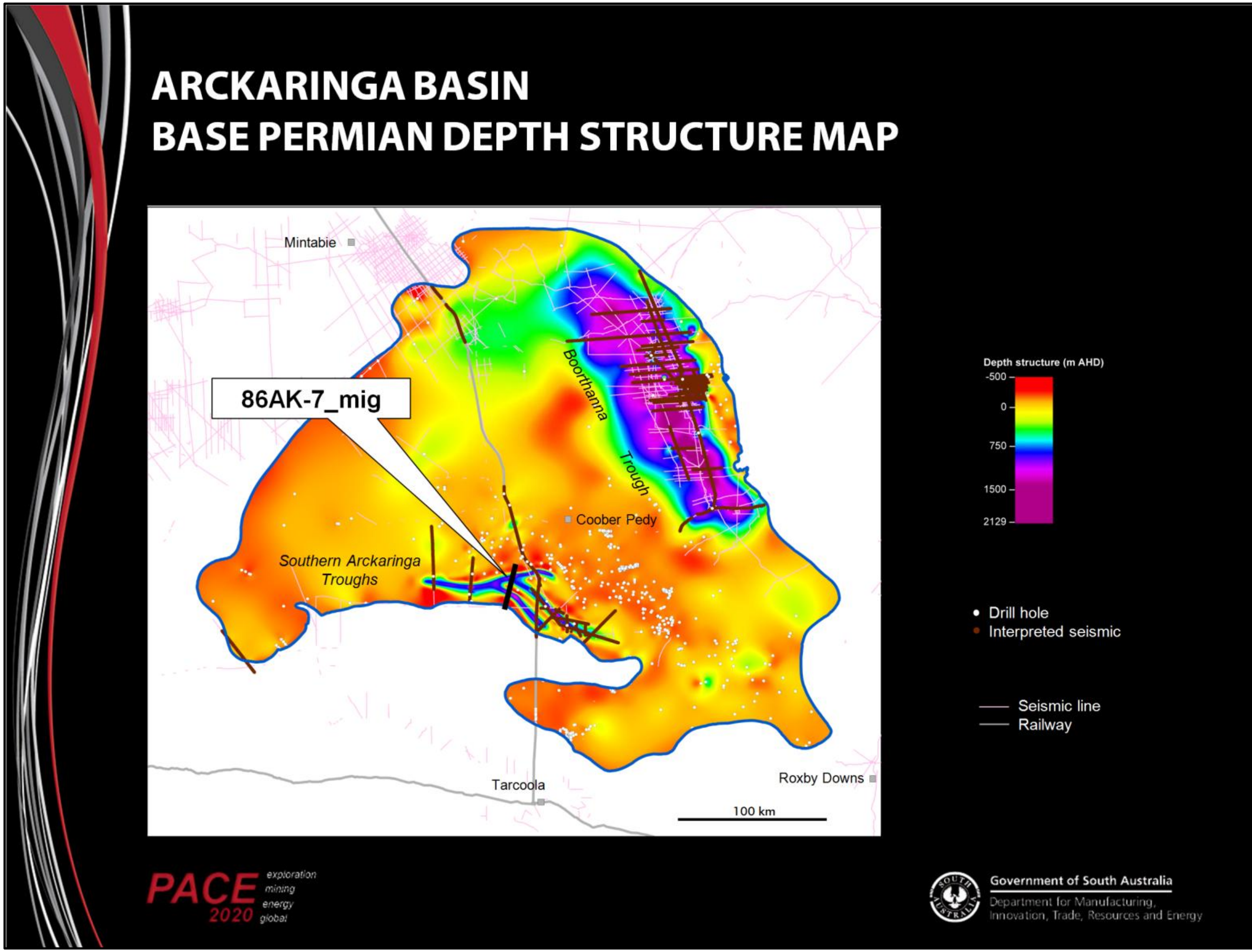
http://www.nationalparkguides.com/images/yosemite/yosemite-half-dome-l.jpg

ICE SHEET, GLACIERS AND FJORDS, SE COAST OF GREENLAND

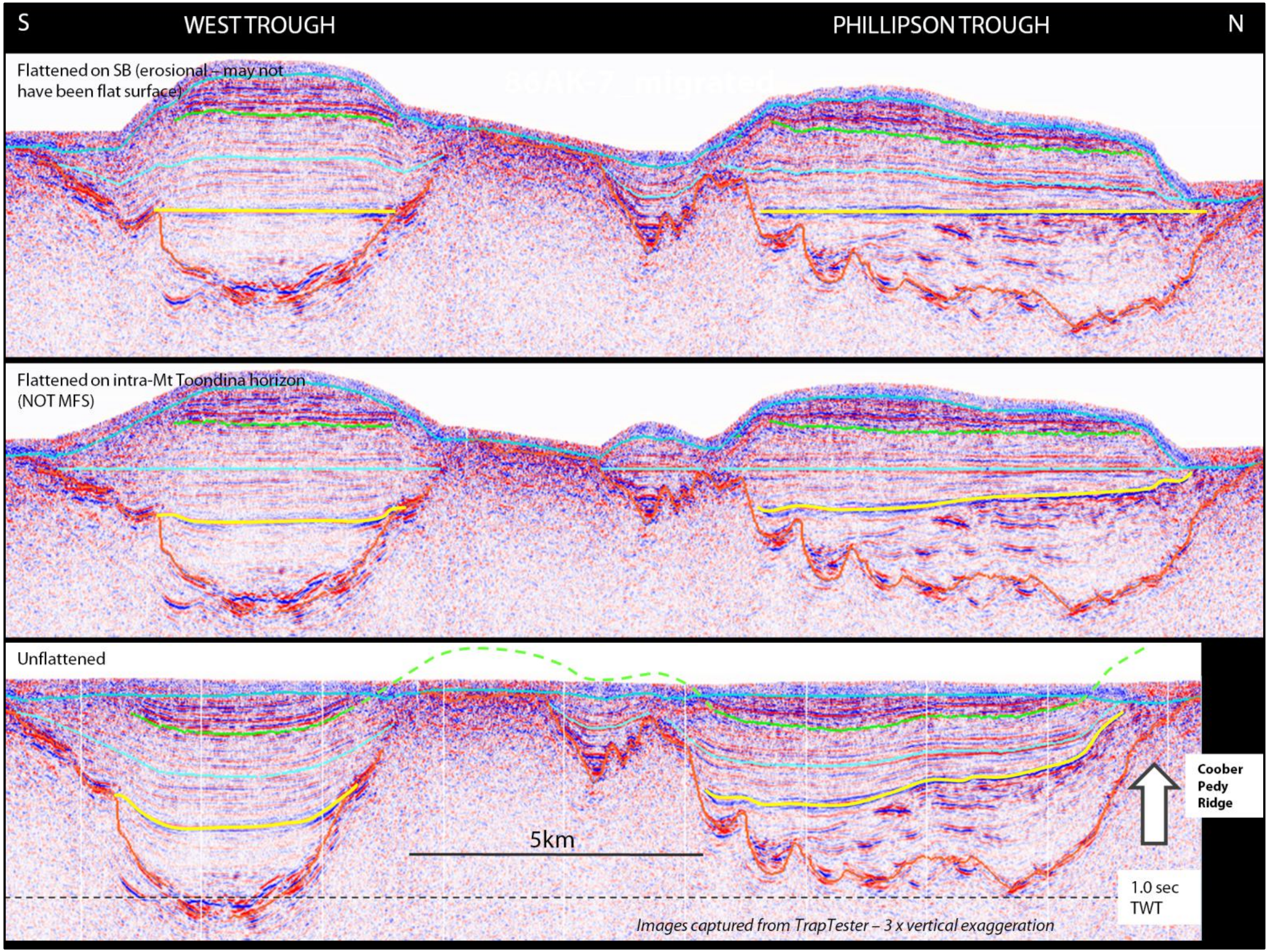


Google Earth image

Presenter's notes: So lets consider a few present day examples of glacial activity.
How deep can glacial valleys be?
Half Dome in Yosemite National Park, rises more than a kilometre above the valley floor. The granitic rocks that form Half Dome were exposed by deep erosion and glaciation.
The glaciers and fjords draining the Greenland ice sheet are shown in the Google Earth image on the right.
Keep these features in mind as we look at the Arckaringa Basin.

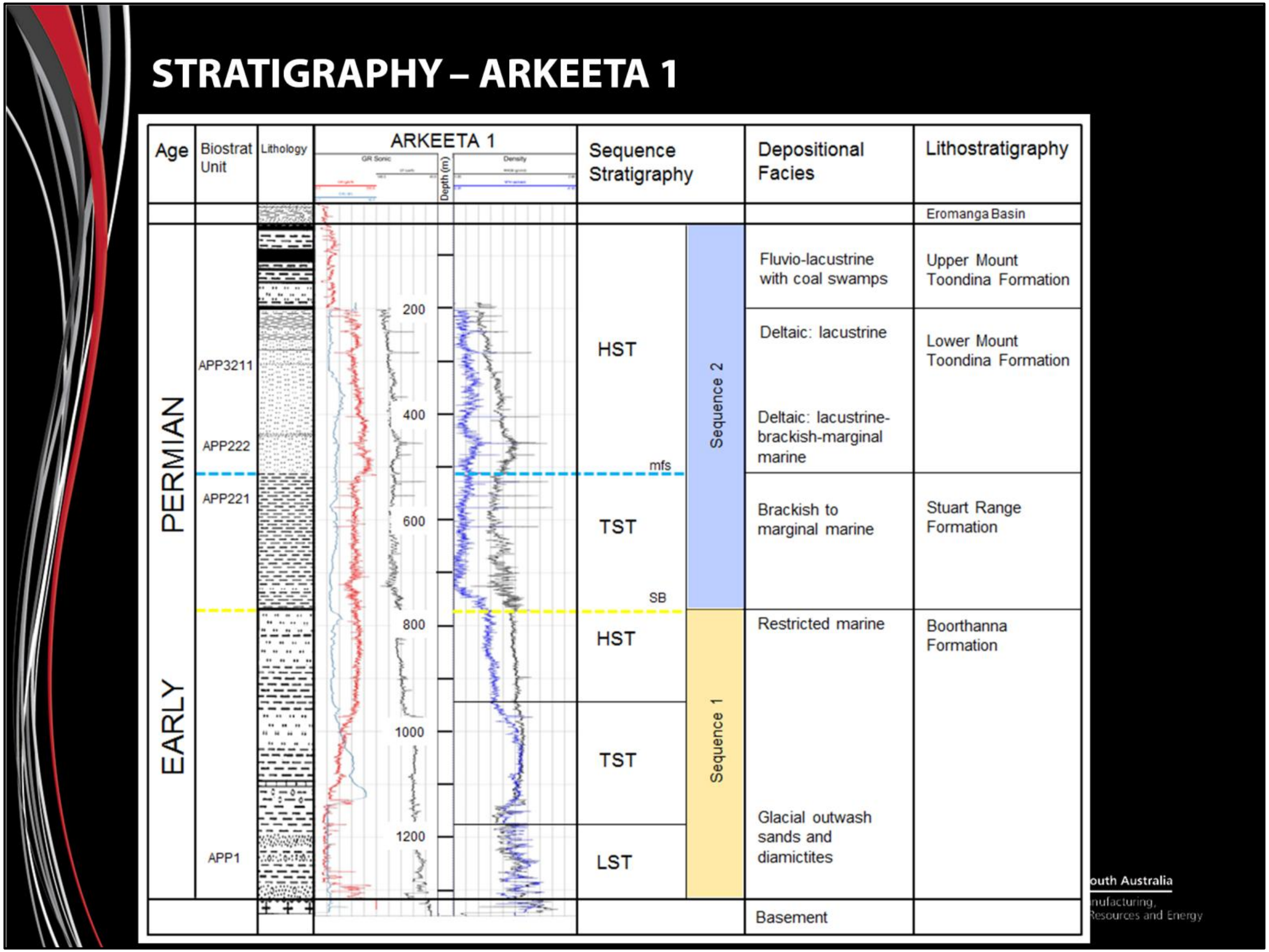


Presenter's notes: This map is the base Permian depth structure map for the Arckaringa Basin.
You can see that Permian sediments are actually quite thin over much of the basin.
However there are deep narrow troughs in the southern Arckaringa Basin that form a distinct drainage pattern as we saw on the satellite image of the Greenland coastline. There is a broader trough in the eastern Arckaringa Basin known as the Boorthanna Trough.
Maximum depth to the base Permian generally does not exceed around 1300 to 1500m in the troughs.
The next slide shows seismic line 86AK-7 over the southern Arckaringa Troughs.



Presenter's notes: Flattening on various horizons highlights the depositional history of the troughs.

- Firstly the erosion of deep glacial valleys into Mesoproterzoic basement rocks.
- These valleys are filled with sediment
- A delta then progrades over the filled valleys – high amplitudes reflectors at the top are coal seams of the Phillipson Coal Deposit.
- Deposition is terminated with gentle folding of the succession, uplift and erosion.



Presenter's notes: So having established the glacial origin of these troughs we will now look at the sediment fill.

I use the Arkeeta 1 well to describe the stratigraphy as it penetrates the full Early Permian succession.

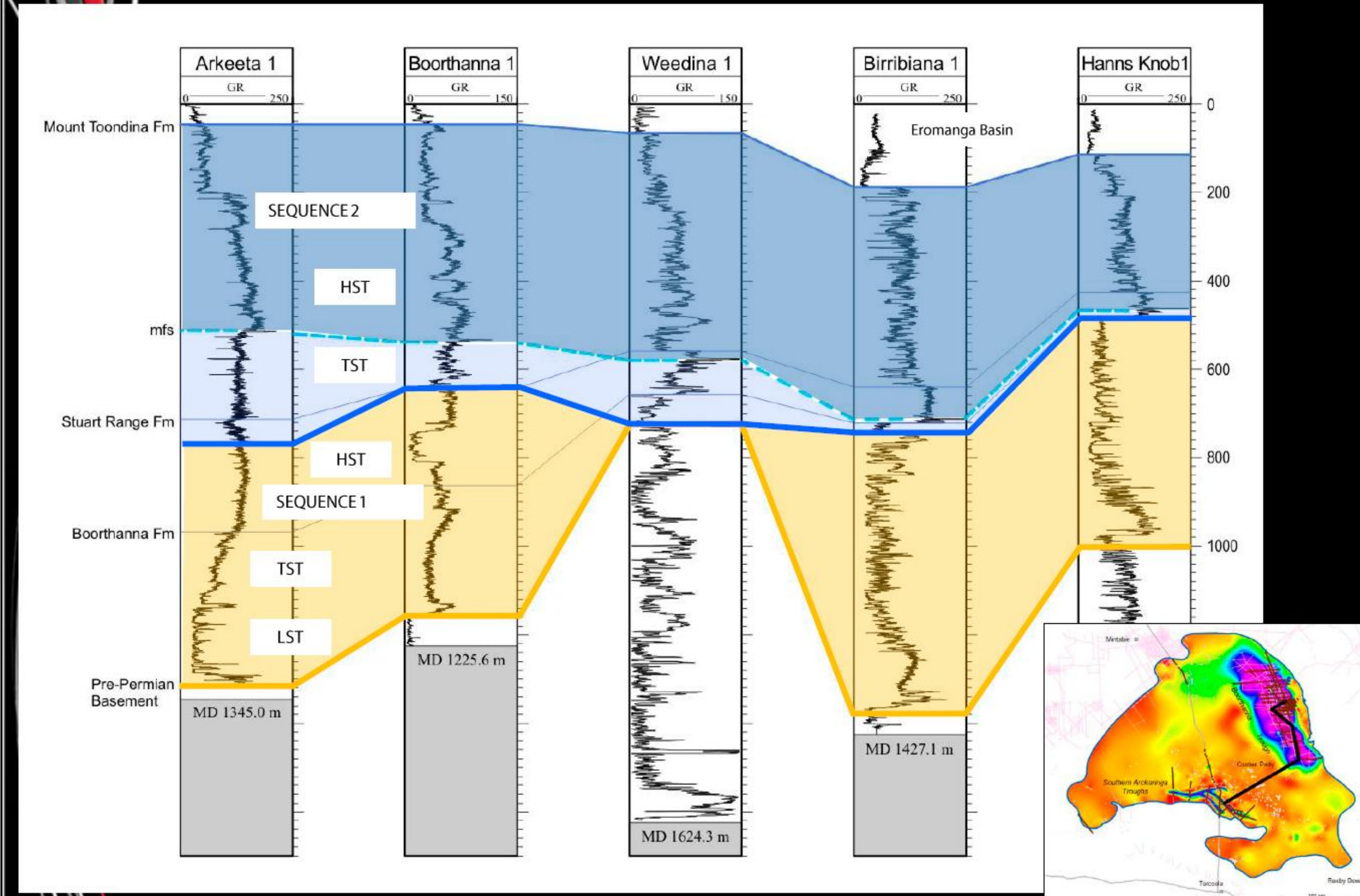
Deposition in the troughs began with glacial outwash sands and diamictites deposited as the glaciers that cut the valleys retreated. The sea then transgressed into the troughs and partly calcareous mudstones and siltstones with arenaceous foraminifera were deposited.

I interpret a sequence boundary at the base of the overlying highly carbonaceous mudstones and siltstones. In this part of the basin a prominent seismic horizon indicates the exposure surface, with higher density marine mudstones below the sequence boundary, and low density, highly carbonaceous marine mudstones above the sequence boundary.

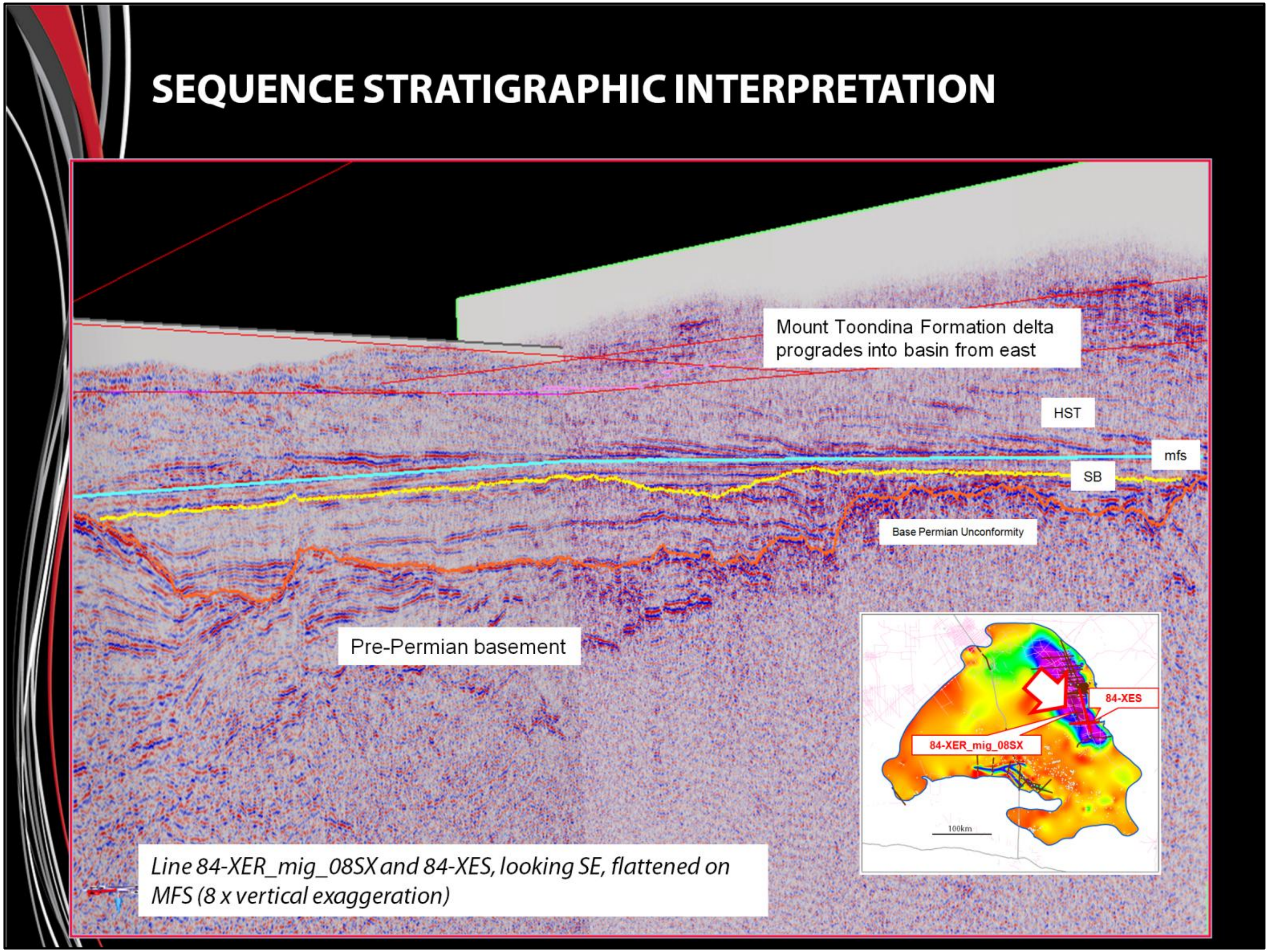
Organic rich muds were deposited during the Sequence 2 marine transgression. Palynology indicates that deposition occurred in a brackish to marginal marine environment. The Sequence 2 maximum flooding surface is marked by a prominent gamma-ray peak. The overlying highstand sediments comprise siltstones, mudstones and very fine sandstones in a shallowing upward succession topped by mudstones, fine sandstones and coal seams.

So to summarise I have divided the Early Permian succession into 2 sequences.

SEQUENCE STRATIGRAPHY



Presenter's notes: The two sequences are recognised in both the southern Arckaringa troughs and the Boorthanna Trough.
The prominent gamma-ray peak marking the Sequence 2 maximum flooding surface is easily recognised in all wells, and palynology across the peak confirms the correlation.
The Sequence 2 transgressive package is very thin at Birribiana and Hanns Knob as these wells were drilled on palaeo-highs.

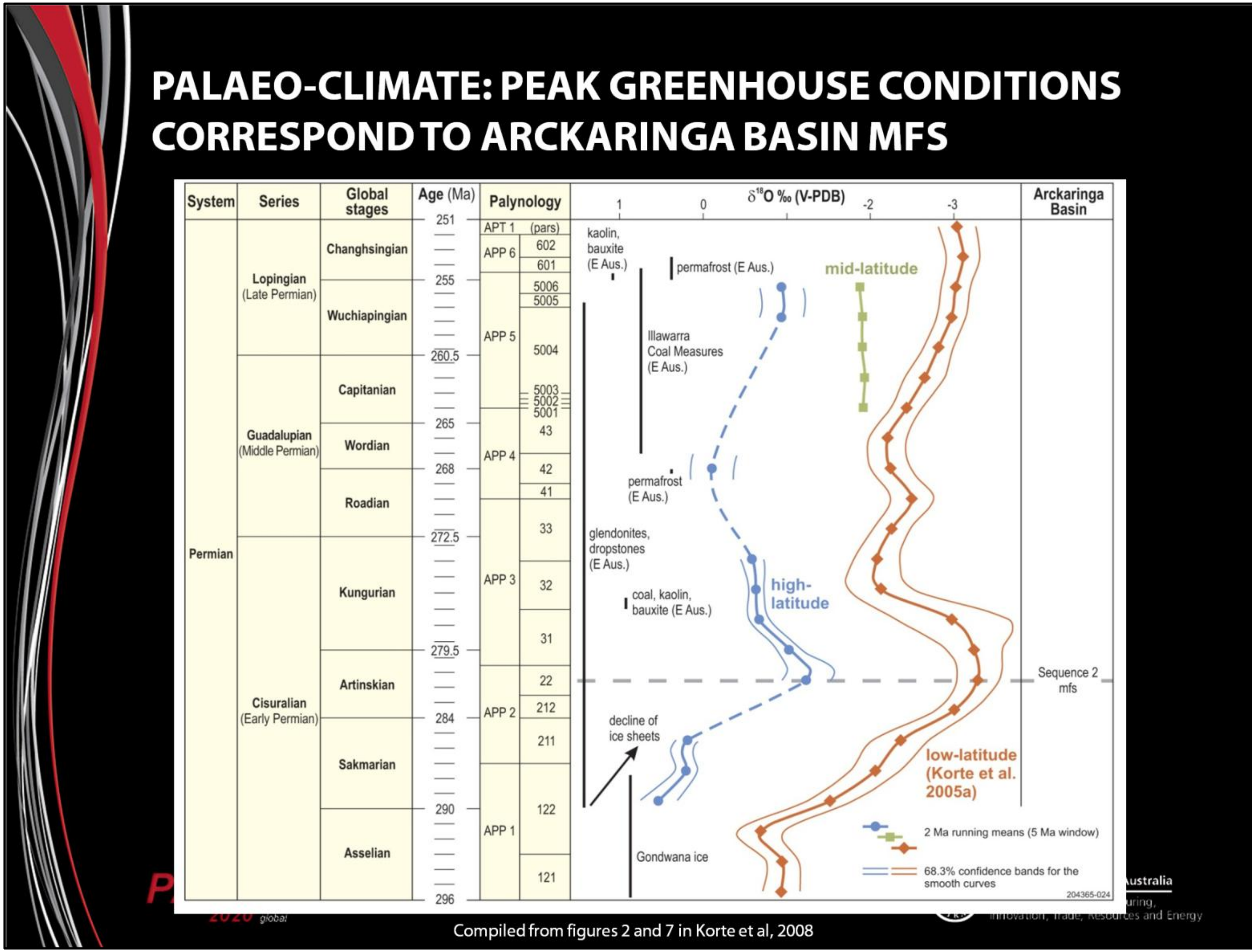


Presenter's notes: The two sequences are also clearly visible on 2D seismic data.

The orange horizon marks the base of the Permian – You can see the deep erosion that is then in-filled by Sequence 1.

The yellow horizon is the sequence boundary at the base of Sequence 2 – there is clear evidence of erosion at this boundary in the Boorthanna Trough.

The blue horizon is the Sequence 2 maximum flooding surface. The seismic line has been flattened on this horizon to highlight the downlap of the overlying highstand sediments.

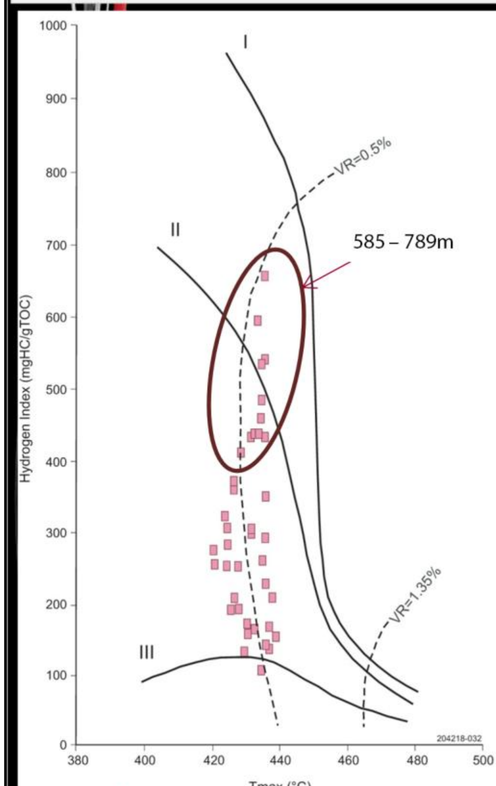


Presenter's notes: This figure has been compiled from a paper by Christoph Korte and others. The paper describes their work on Oxygen isotope values from brachiopods and bivalves as clues for Late Palaeozoic deglaciation.

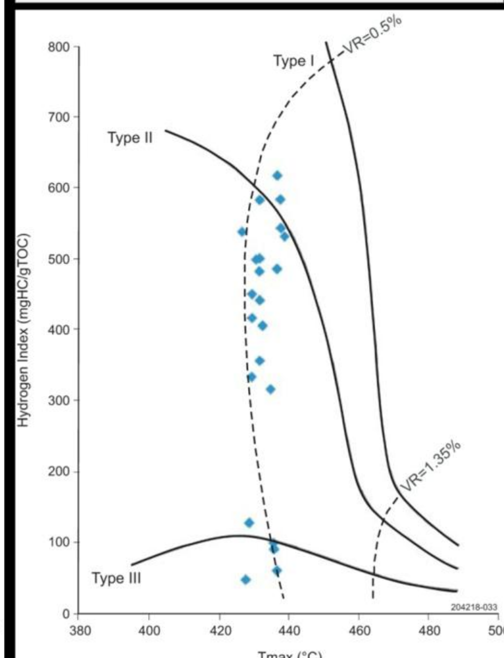
The oxygen isotope trends of low, mid, and high latitudes suggest overall warming of the global climate during the Early Permian. The peak greenhouse conditions indicated in zone APP 22 correspond to the Sequence 2 maximum flooding surface in the Arckaringa Basin.

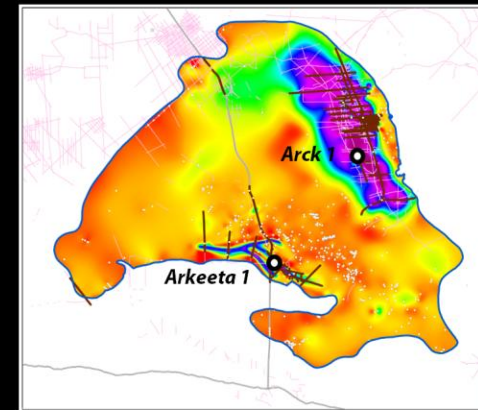
ORGANIC RICH SHALES

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

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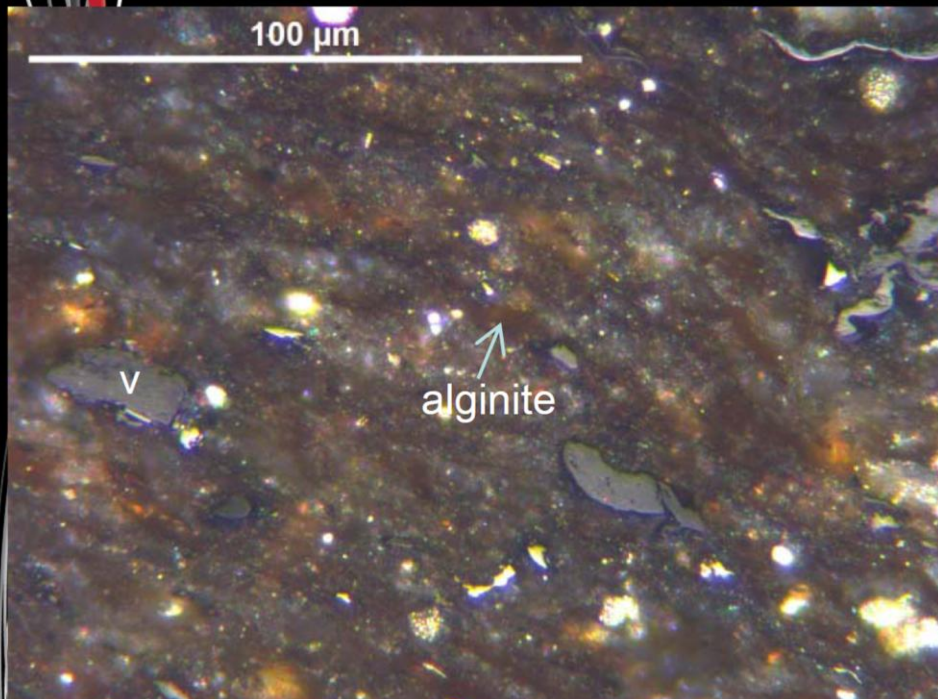
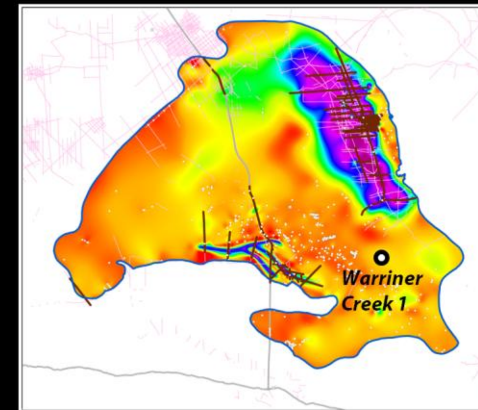
Presenter's notes: So now we'll have a look at the organic rich shales deposited during the Sequence 2 transgression.
Tmax vs HI cross plots for the Arkeeta and Arck wells are shown here. Arkeeta was drilled in the Phillipson Trough and Arck was drilled in the Boorthanna Trough.
These wells both intersected a thick interval of organic rich marine shale. The shales plot as Type II source rocks with some humic material. The shales are at the threshold of oil generation.
Palynology indicates brackish, marginal and restricted marine environments. And abundant algal material has been described by organic petrologists.

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

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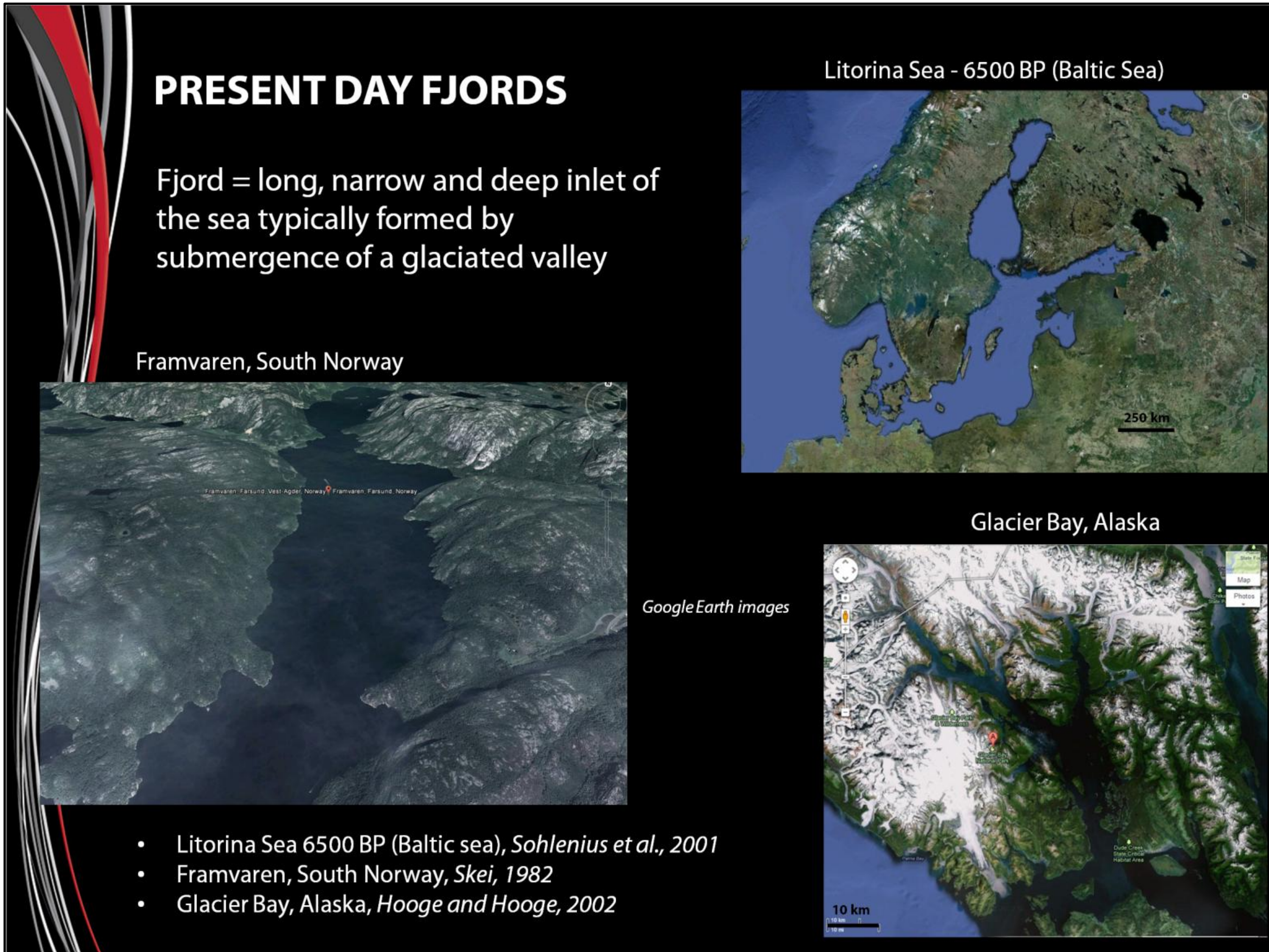
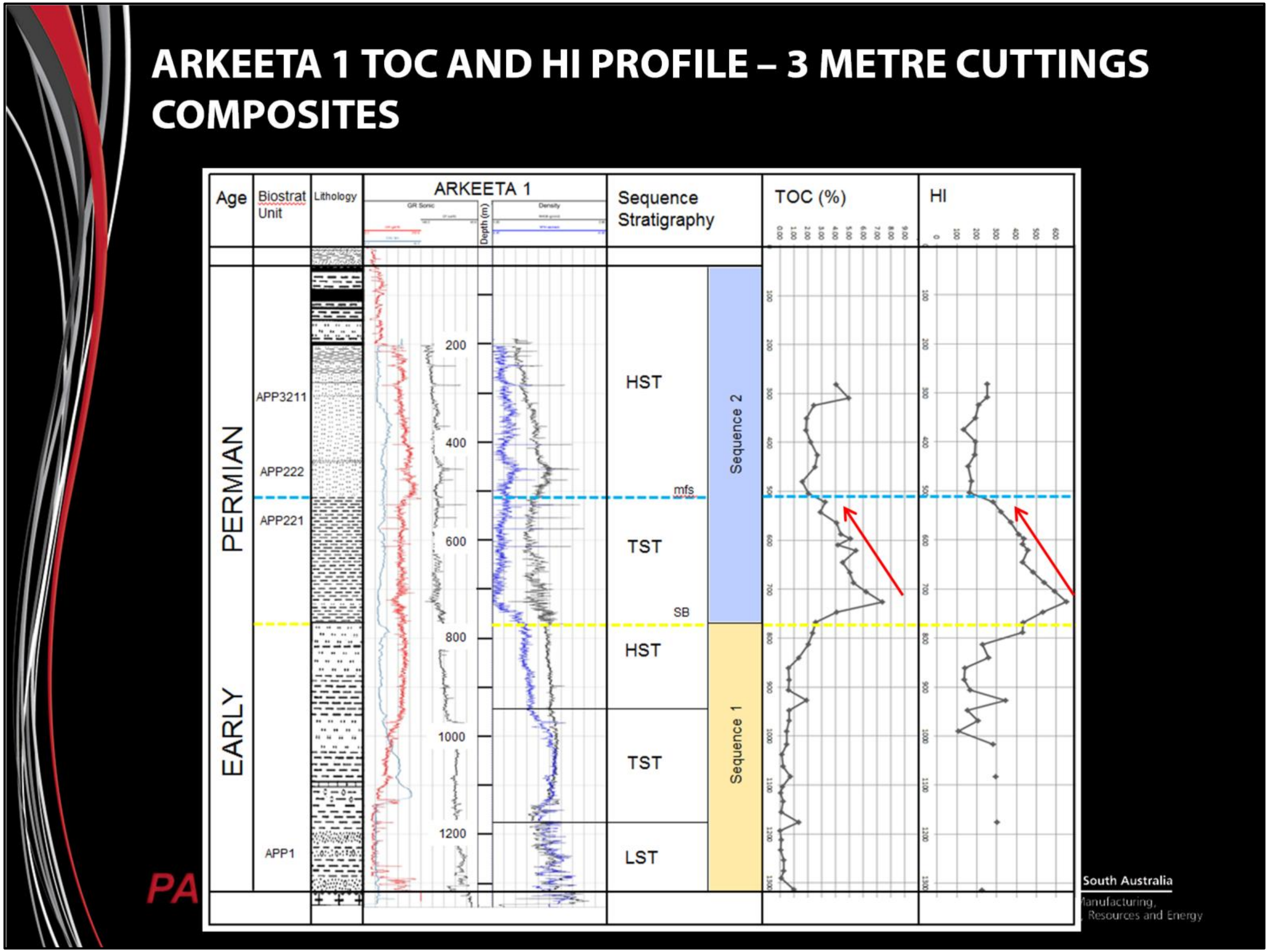
Presenter's notes: This example from core acquired in a shallow mineral exploration hole shows the alginite that has been described. The sample was described as comprising ~40% by volume organic matter, with the dominant organic material being alginite.



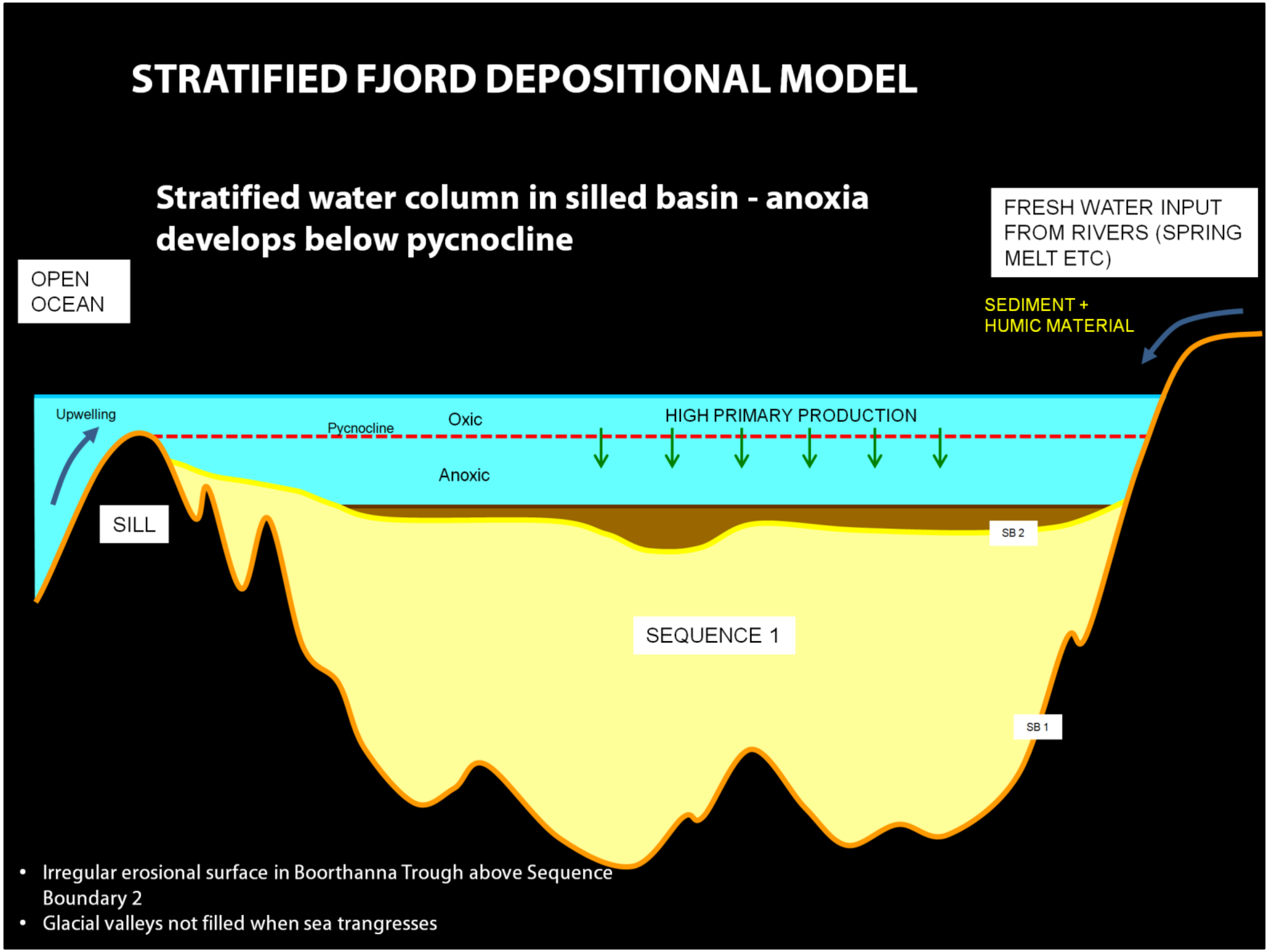
Presenter’s notes: So palaeogeography, palaeontological assemblages and the abundance of algal material suggests a stratified fjord depositional model may be appropriate for the organic rich shale.
I have reviewed some of the literature on present day fjords to determine their common characteristics.
I have looked at Framvaren , in Norway , the Litorina Sea, and Glacier Bay in Alaska.

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%)



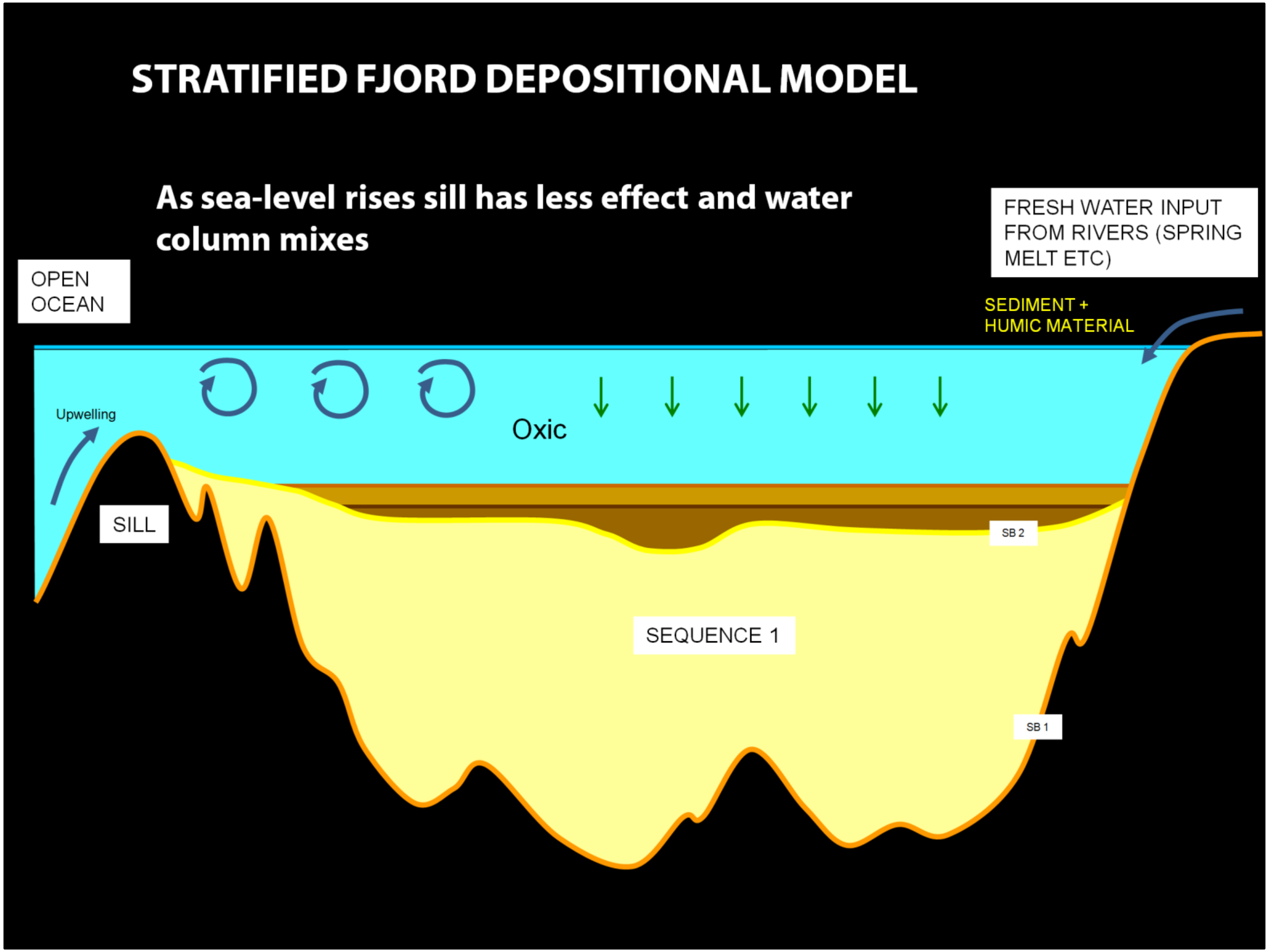
Presenter's notes: The TOC profile from Arkeeta 1 also influences the stratified fjord depositional model that I am proposing. Note that the organic geochemistry was carried on 3m composite cuttings samples, not core. Looking at the TOC profile – this is not a typical 'Christmas tree' TOC pattern with maximum TOC corresponding to the maximum flooding surface. Maximum TOC occurs at the base of the transgressive package and declines upward to the maximum flooding surface.



Presenter's notes: The model I am proposing is as follows:

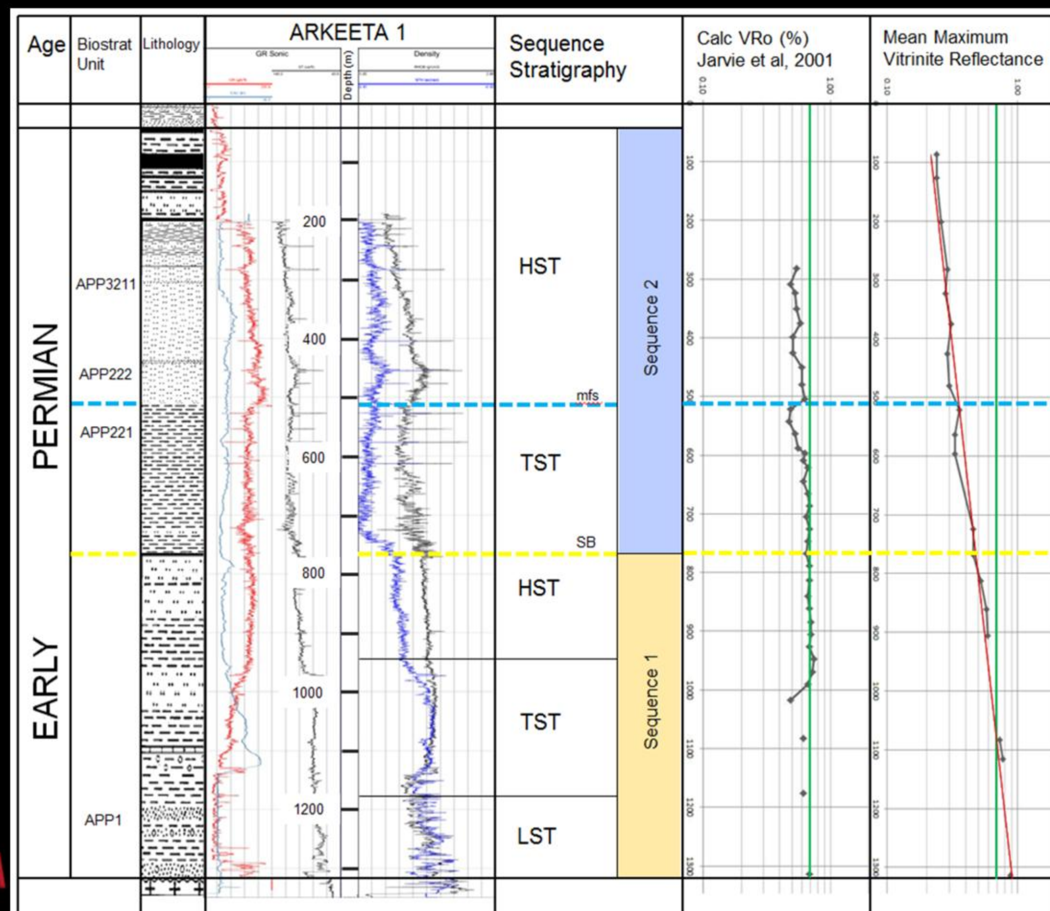
The Sequence 2 marine transgression results in sea-water entering a silled basin, being a partly filled glacial valley.

The sill, and periods of high fresh-water input , result in the development of a pycnocline. Nutrient rich surface waters result in algal blooms. The stratified water column results in oxygen depleted bottom water conditions and organic matter is preserved.



Presenter's notes: As sea-level rises the sill begins to have less effect and increasing water column mixing occurs. Oxygen depletion of the bottom waters occurs less frequently and less organic matter is preserved.

MATURITY



Presenter's notes: Before I finish I want to say something about maturity levels in the basin.

The organic rich shales in both Arkeeta 1 and Arck 1 are at the threshold of maturity. A few hundred metres extra sediment loading or a higher geothermal gradient would push the shale into the oil window.

The Olympic Dam Cu-U mine lies near the south-eastern margin of the basin along with a number of uranium deposits. Higher heat flows would be expected where basement is more radioactive.

CONCLUSIONS

- 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 (alginite, 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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