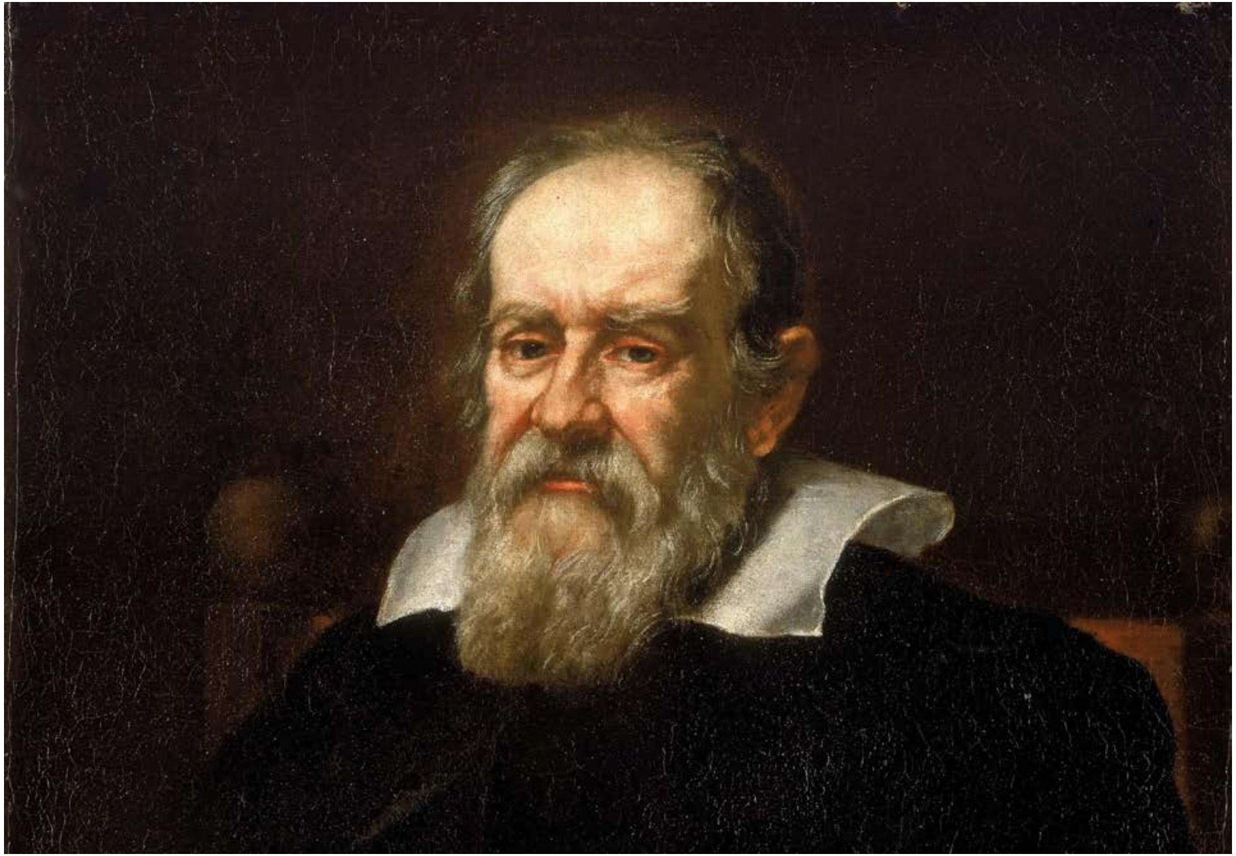
Review of Fault Seal in the Exmouth Sub Basin, North West Australia

Titus Murray and William L. Power
Southern Highlands Structural Geology NSW
Power Geoscience WA

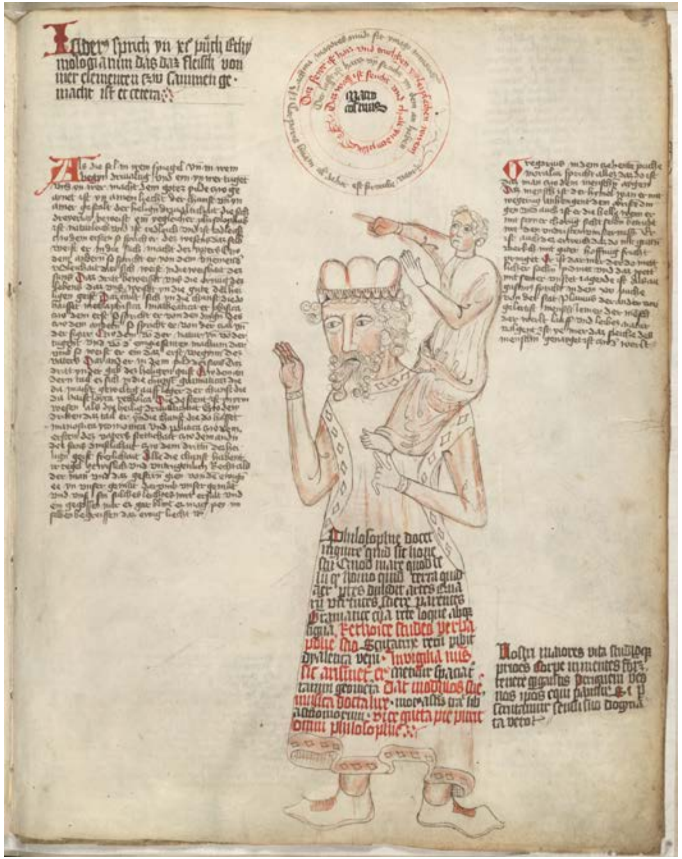
Science is not a Popularity Contest



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Complex Models Don’t Solve Uncertain Problems

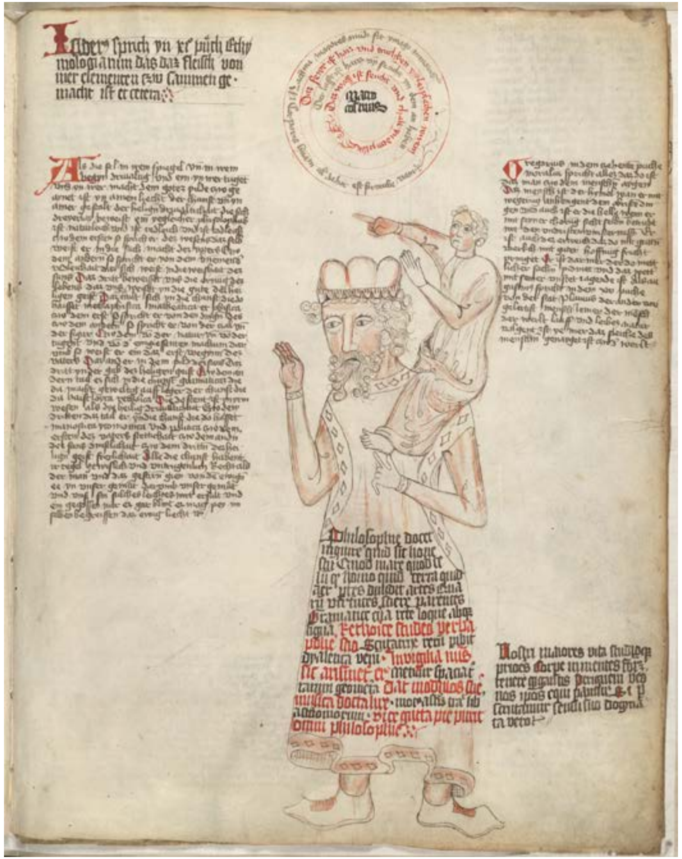
- Trapping of hydrocarbons over geologic timescales (100,000’s of years to Millions of years).



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Reproducibility in Subsurface Geoscience

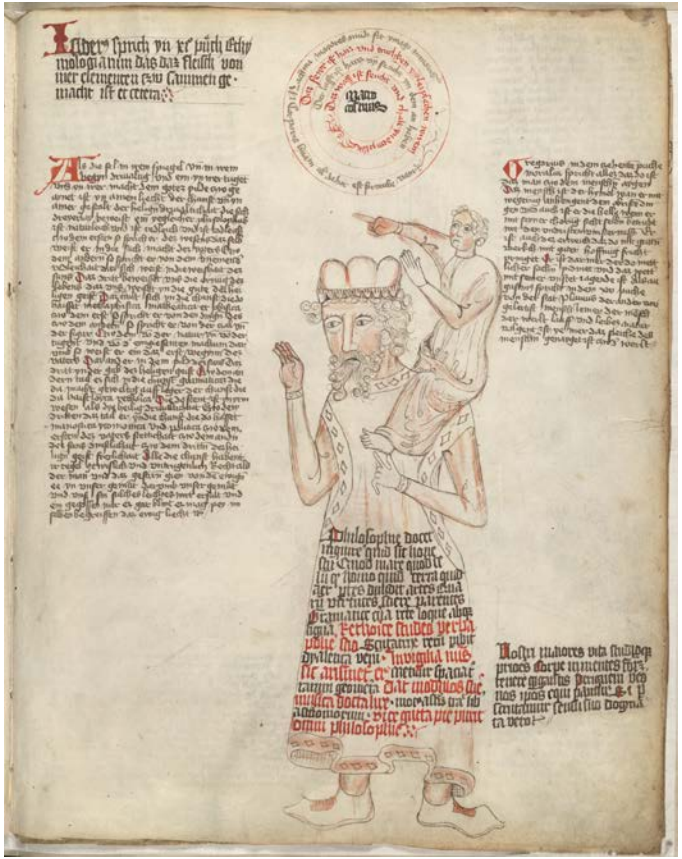
- Trapping of hydrocarbons over geologic timescales (100,000’s of years to Millions of years).
- In all our studies we use open file data so you can check our statements!



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Standing on the Shoulder of Giants

- Trapping of hydrocarbons over geologic timescales (100,000's of years to Millions of years).
- In all our studies we use open file data so you can check our statements!
- We can only make our observations because of the work of many authors.



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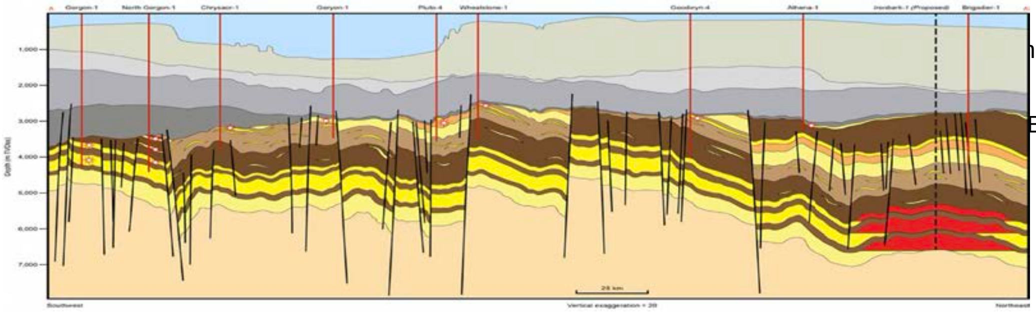
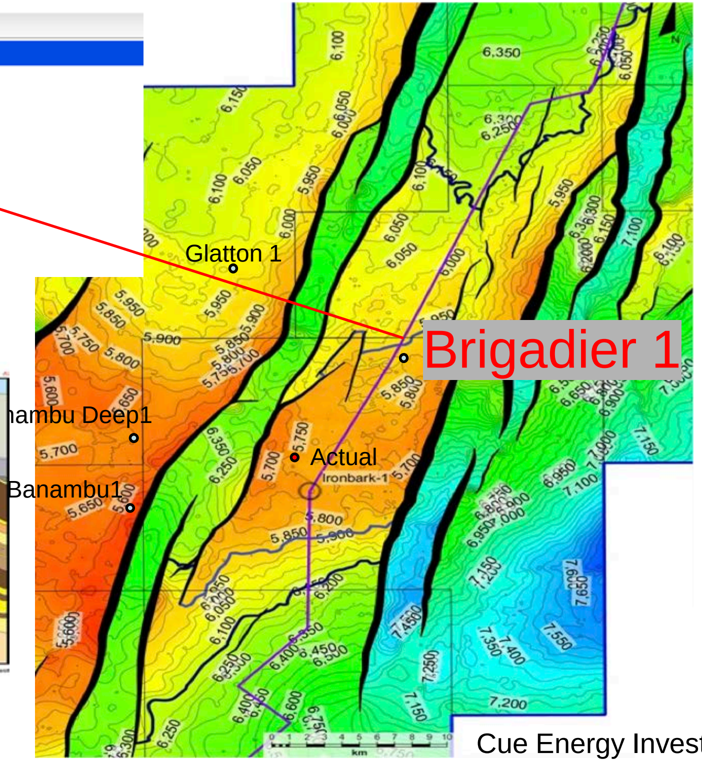
STRUCTURAL GEOLOGY

Ironbark Prospect NW Australia

Layer	Foot Wall Type	Thickness	VShale
TR30	Thief	[Δ] 200.0 m	[Δ] 20.0 %
TR23	Seal	[Δ] 500.0 m	[Δ] 50.0 %
TR20_Seal	Seal	[Δ] 500.0 m	[Δ] 50.0 %
TR19	Reservoir	[Δ] 200.0 m	[Δ] 20.0 %
TR18_Seal	Seal	[Δ] 180.0 m	[Δ] 50.0 %
TR17	Reservoir	[Δ] 200.0 m	[Δ] 20.0 %
TR15_Seal	Seal	[Δ] 80.0 m	[Δ] 50.0 %
TR14	Reservoir	[Δ] 200.0 m	[Δ] 20.0 %





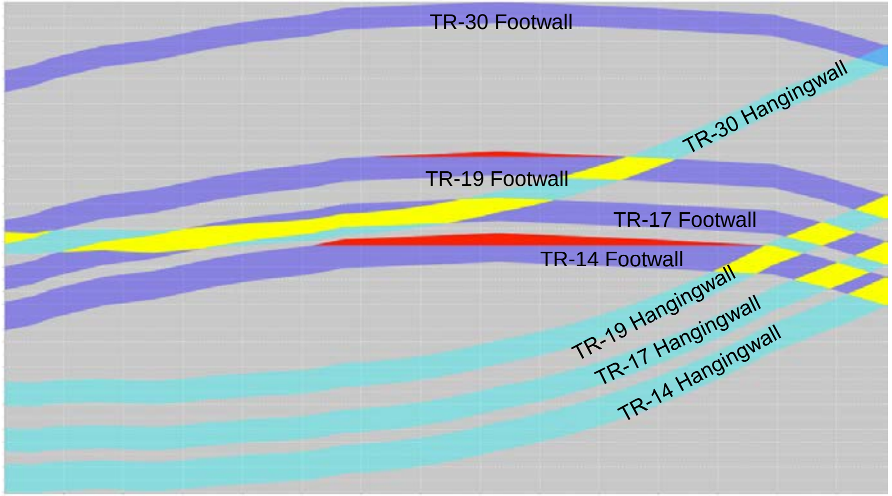
Cue Energy Investor Pack

Mungaroo TR17 Depth Map

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Dry Well Due to Lack of Lateral Seal

- SGR forecast big columns.

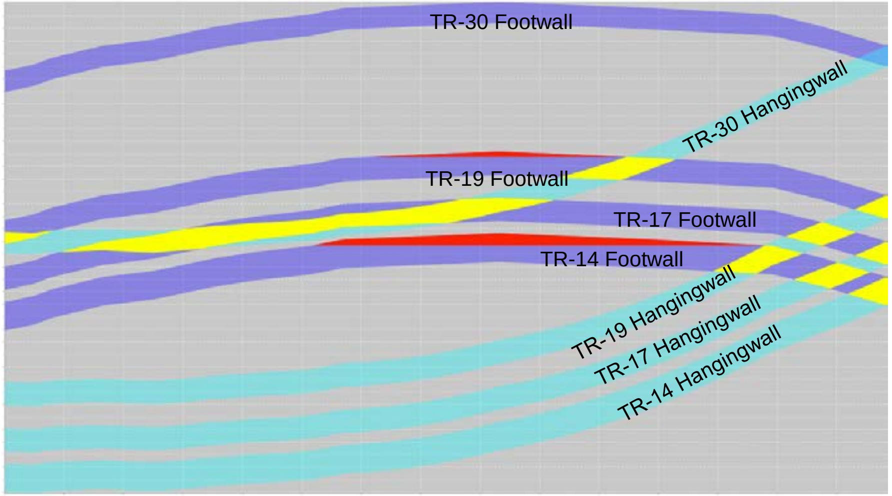


Infinte Top Seal	Layer	Prob	Column	
			mean	Std Dev
Juxt	TR19	78%	62	32
	TR17	53%	19	13
	TR14	50%	37	27
SGR	TR19	100%	290	54
	TR17	100%	276	52
	TR14	85%	62	39

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Dry Well Due to Lack of Lateral Seal

- SGR forecast big columns.
- Predict “dry-well” despite;
  - A charge is almost certain,
  - The reservoir is highly likely,
  - Top Seal is highly likely, thick



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SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Dry Well Due to Lack of Lateral Seal

- SGR forecast big columns.
- Predict "dry-well" despite;
  - A charge is almost certain,
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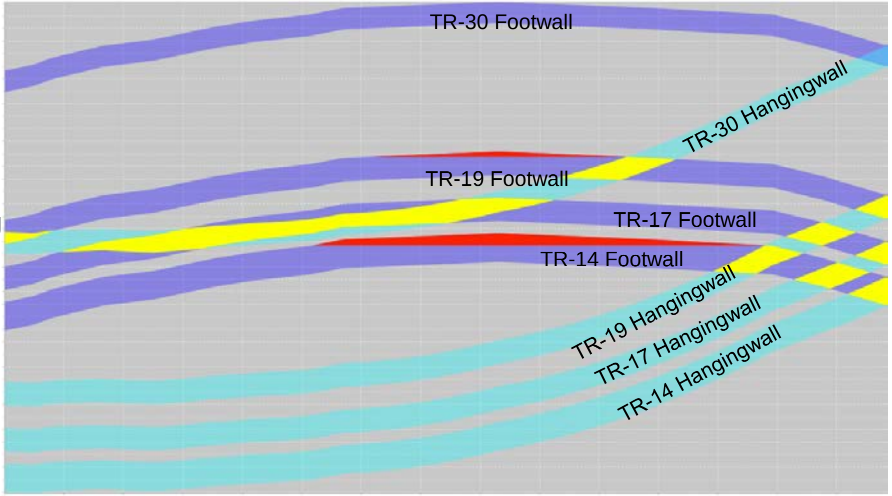
  - Top Seal is highly likely, thick
- Pre-drill predicted failure lack of reservoir gave a 0.27 P_g



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Between Explorer and Shareholders

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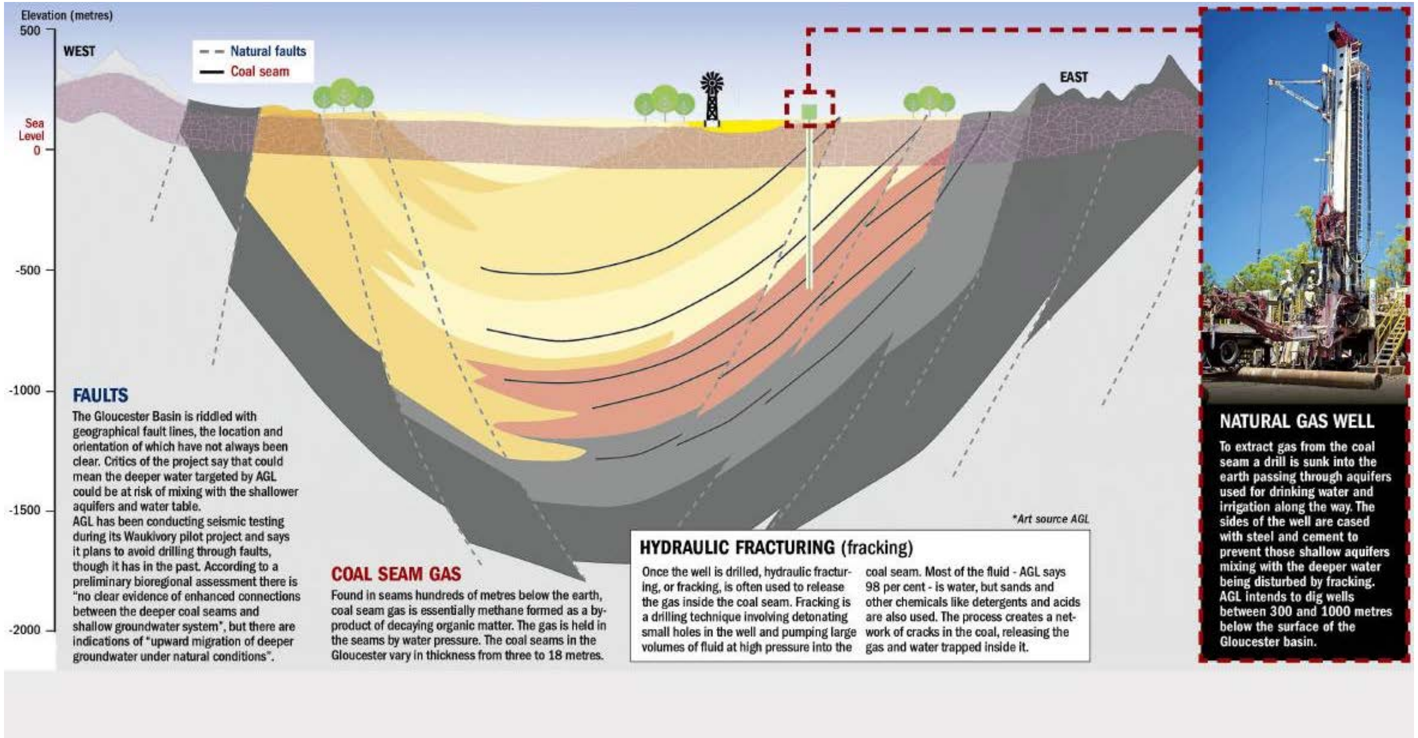
STRUCTURAL GEOLOGY

Faulting and Ground Water



Coal seam gas impact on water security key issue for Gloucester residents
Michael McGowan Newcastle Herald 2014

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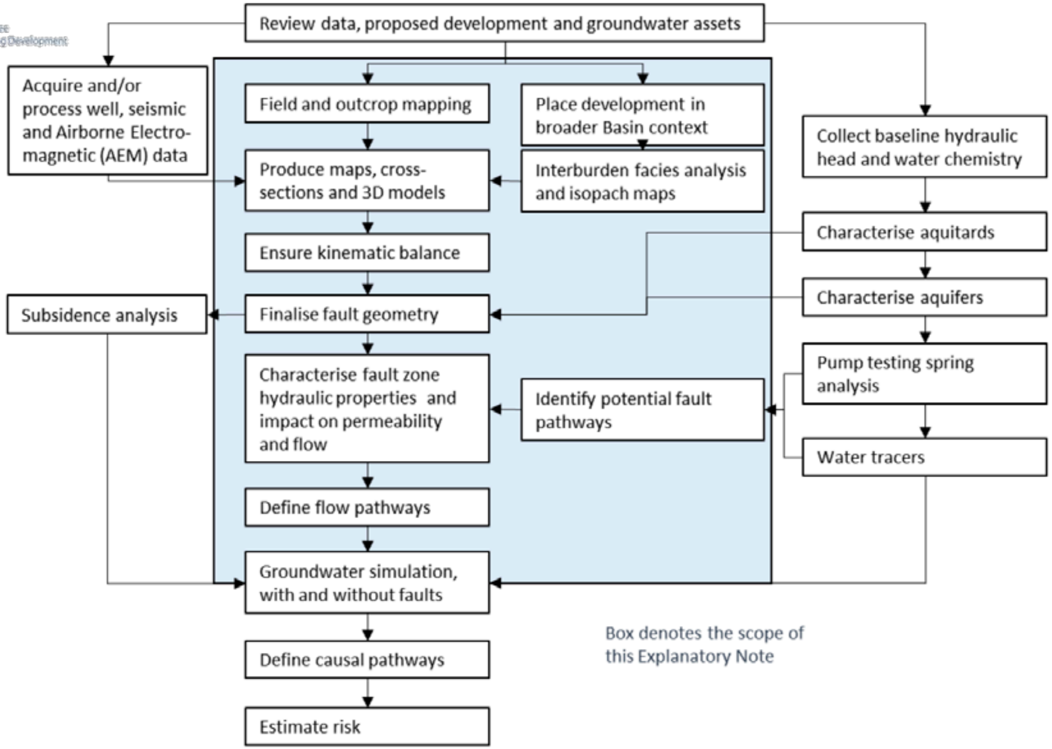
STRUCTURAL GEOLOGY



Murray TA, Power WL 2021. Information Guidelines Explanatory Note:
Characterisation and modelling of geological fault zones.
Report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of Agriculture, Water and the Environment, Commonwealth of Australia 2021’.

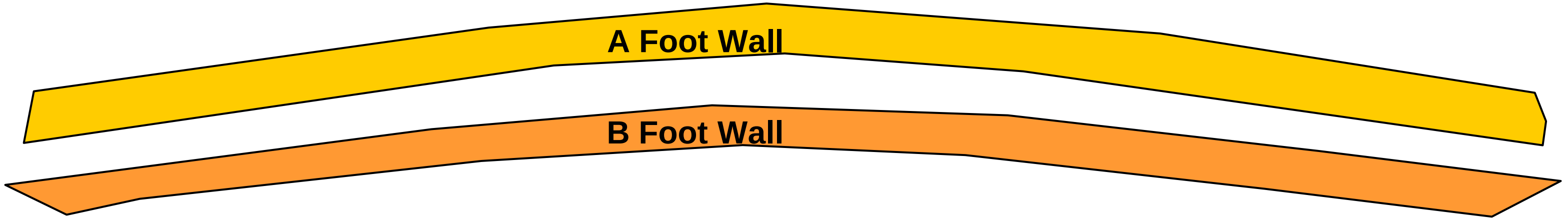

THIS IS A
NO GO
REGION FOR
COAL SEAM GAS
Santos

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Stochastic Fault Seal and Trap Analysis

Model for Hydrocarbon Migration and Entrapment Within Faulted Structures

... a fault is neither a seal or a conduit. Therefore the effects of faulting and on both migration and entrapment depends on the … strata juxtaposed by the fault … Allan 1989



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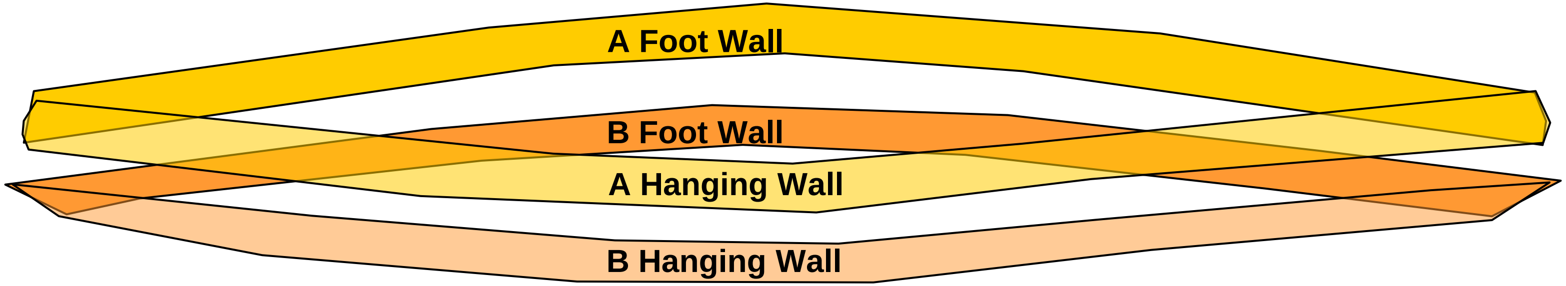

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

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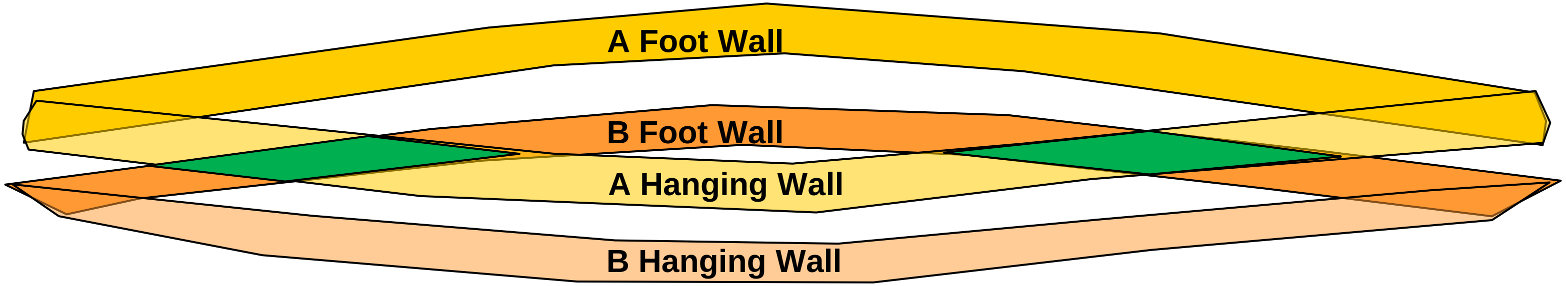

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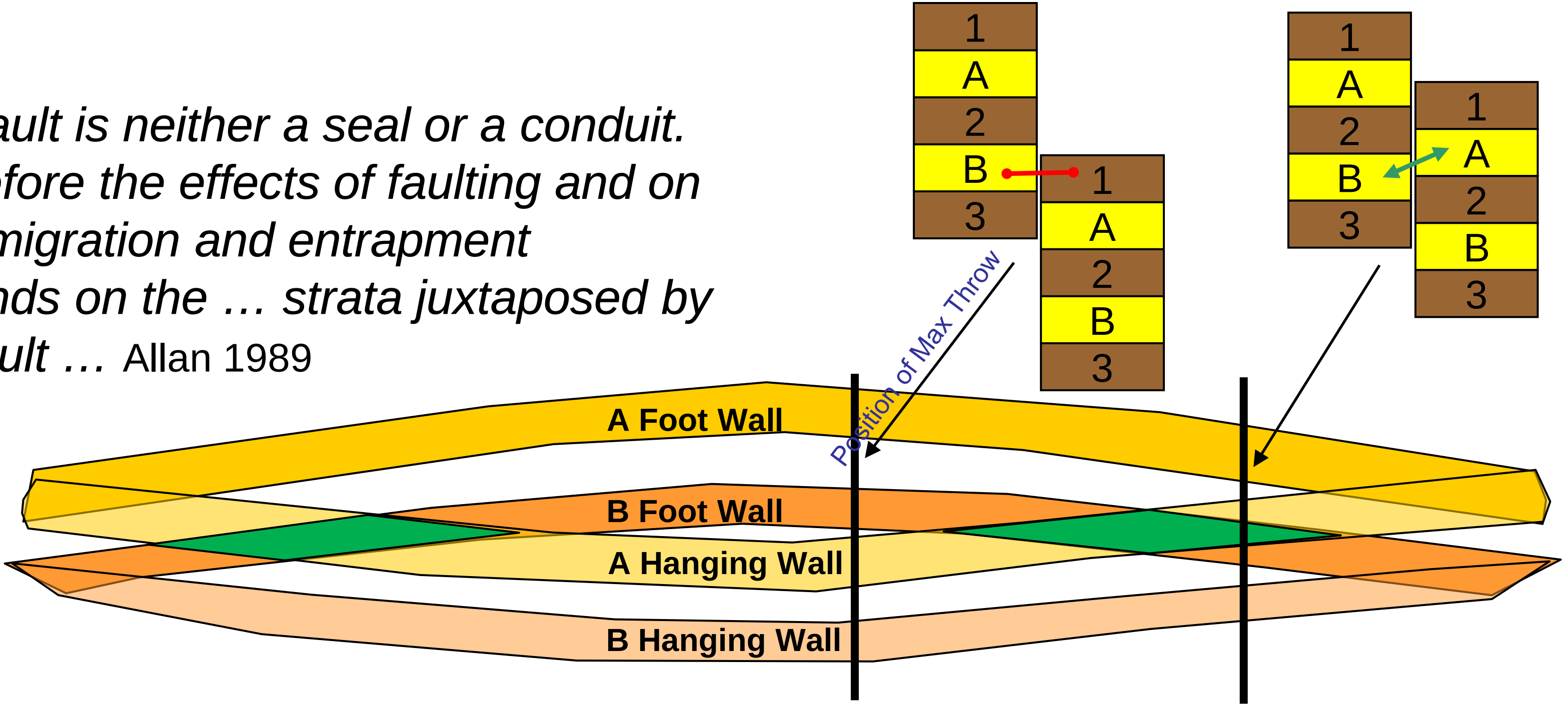
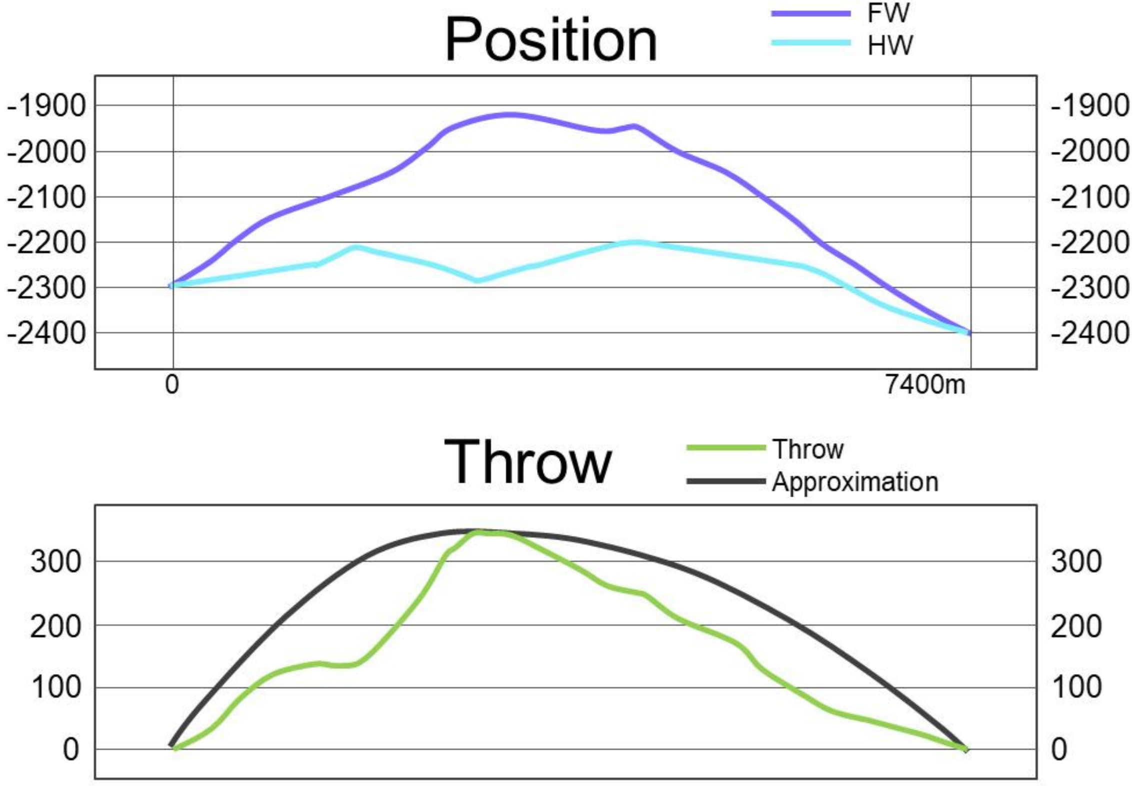


This can be done in Excel or with Pencil and Paper

Fault Displacement & Throw Profile

- Length
- Maximum throw
- Symmetry



γ= throw/length = 346m/7400m = ~0.047

Murray et al 2019

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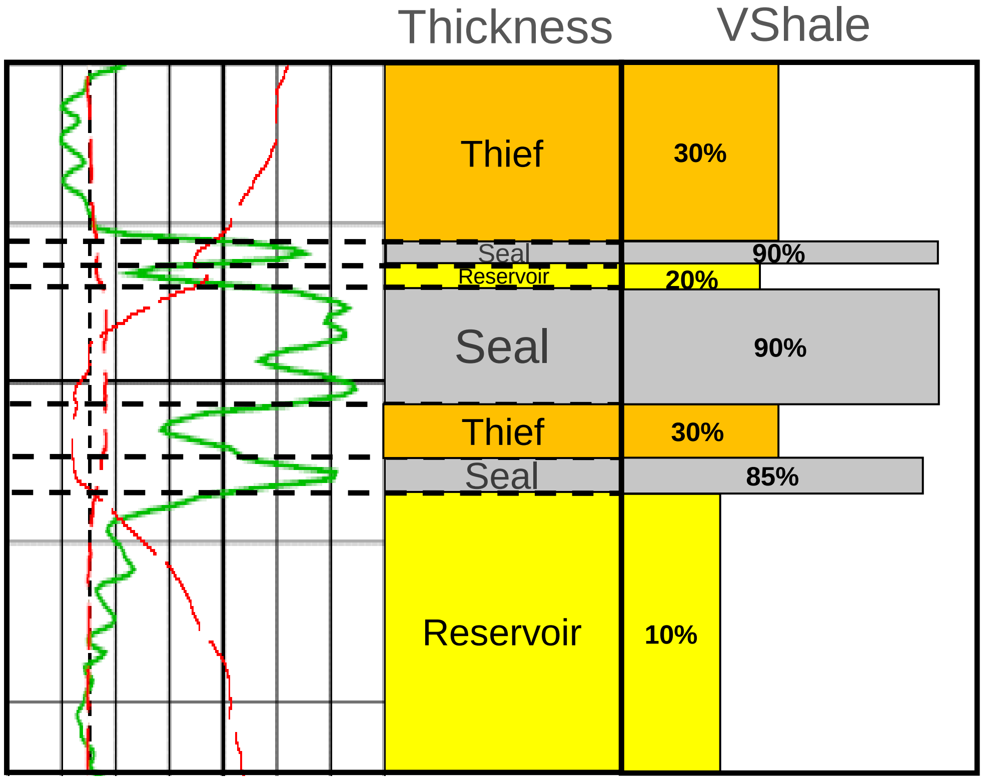
Stratigraphic Thickness and Seal Character

- Reservoirs
- Seals
- Thief zones (permeable over geologic time)

Thickness and VShale values are described using statistical distributions



Murray et al 2019

Stochastic Trap Analysis

- One Fault Block at a time
- Each fault block can have one or more faults
- Monte Carlo Simulation produces 10,000 Allan maps/fault – and varies:

– Spill point elevation – Crest elevation – Fault geometry	Geometric
– Stratigraphic thicknesses – VShale	Stratigraphic
– Hydrocarbon specific gravity	Hydrocarbon

- For each Allan Map, the Juxtaposition and SGR leak points are calculated/found

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Murray et al 2019

Validation Process

- For each fault block and for each Monte Carlo instance, the juxtaposition and SGR predictions levels are compared to the structural spill point

Fault A Controls HWC (%) | Fault B Controls HWC (%) | Block is filled to spill (%)

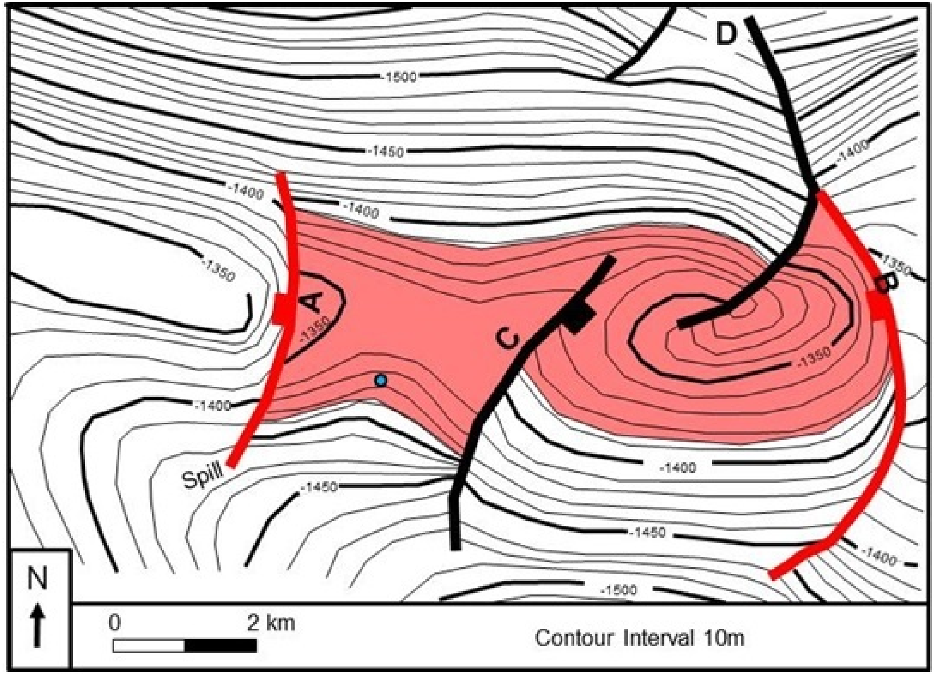
- Distributions of the HWC levels and the column heights are created

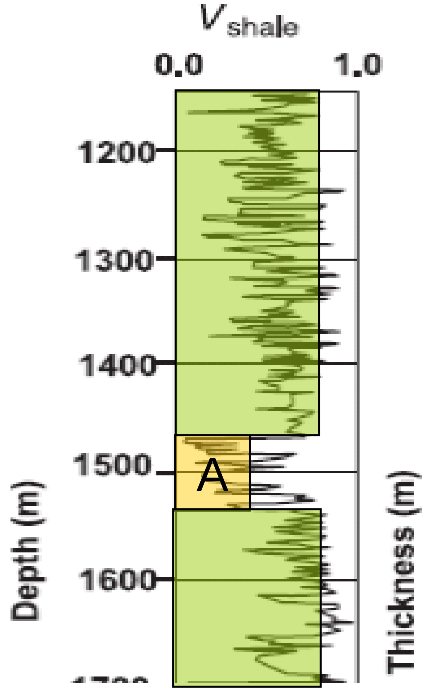
- The modelled HWC ⟷ Observed HWC

Comparison

Murray et al 2019

Ling Gu Case Study (Malay Basin)





Data from ***James et al (2004)***

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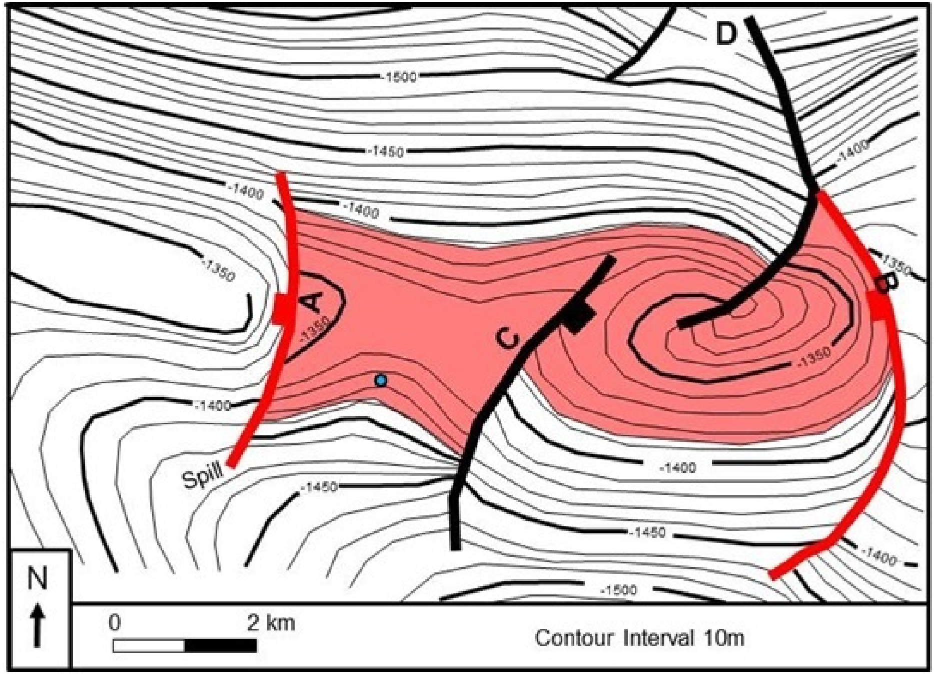
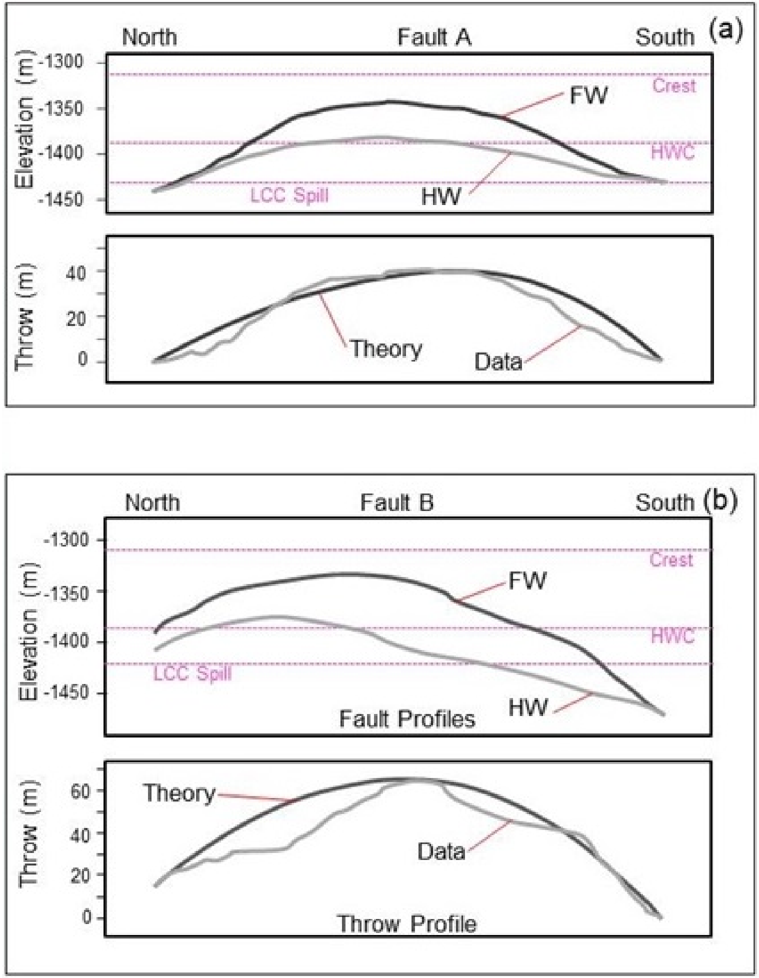
Ling Gu Faults





Murray et al 2019

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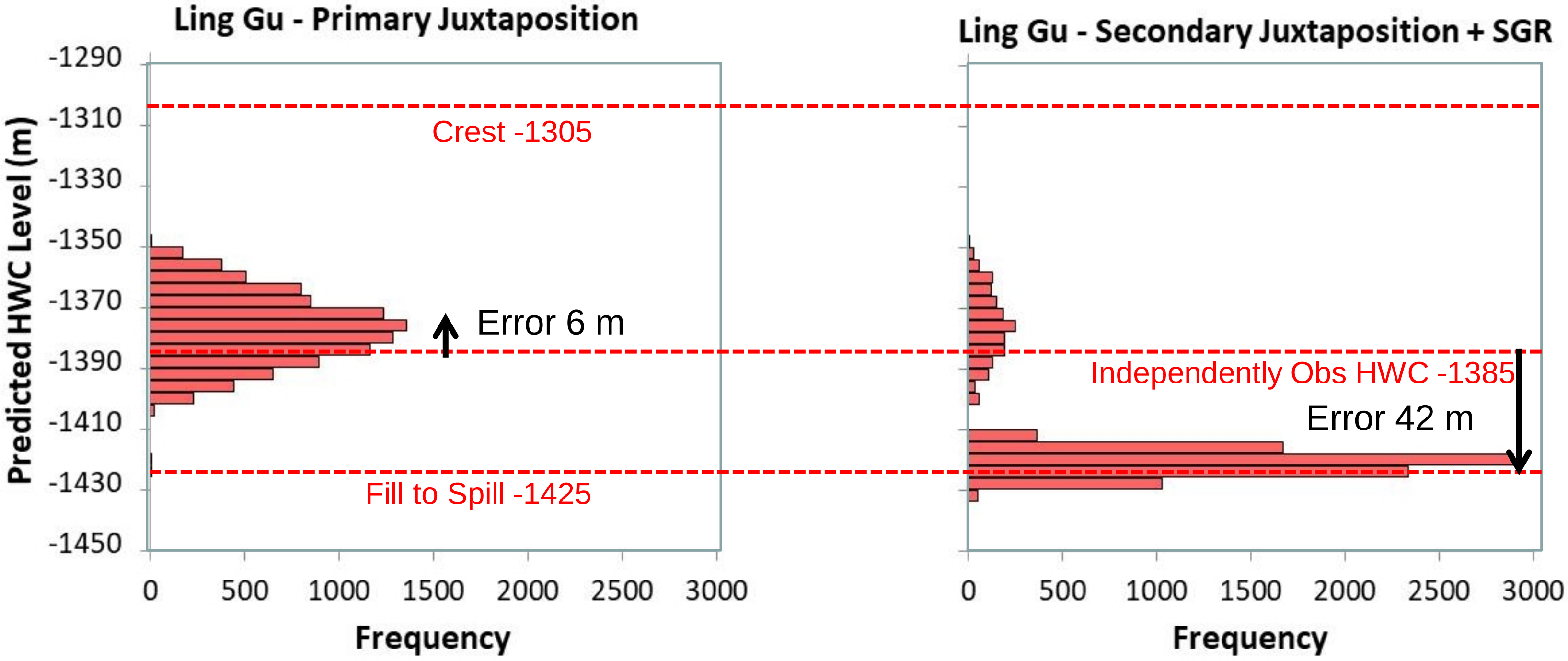
Ling Gu SGR over predicts most of the time



Mean Error 6 m StdDev 6.4 m

Mean Error 42 m StdDev 9.6 m

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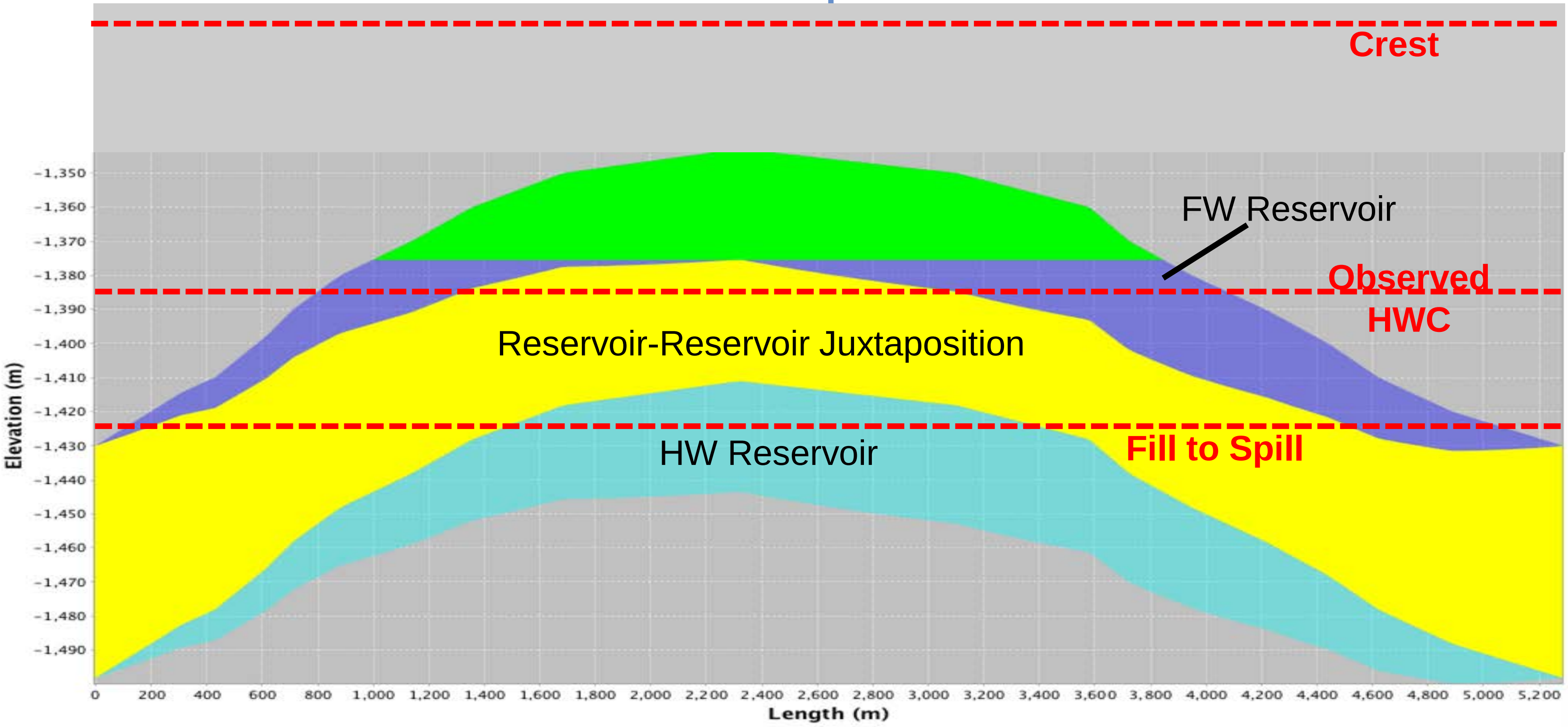
Murray et al 2019

West Fault P50 Allan Map



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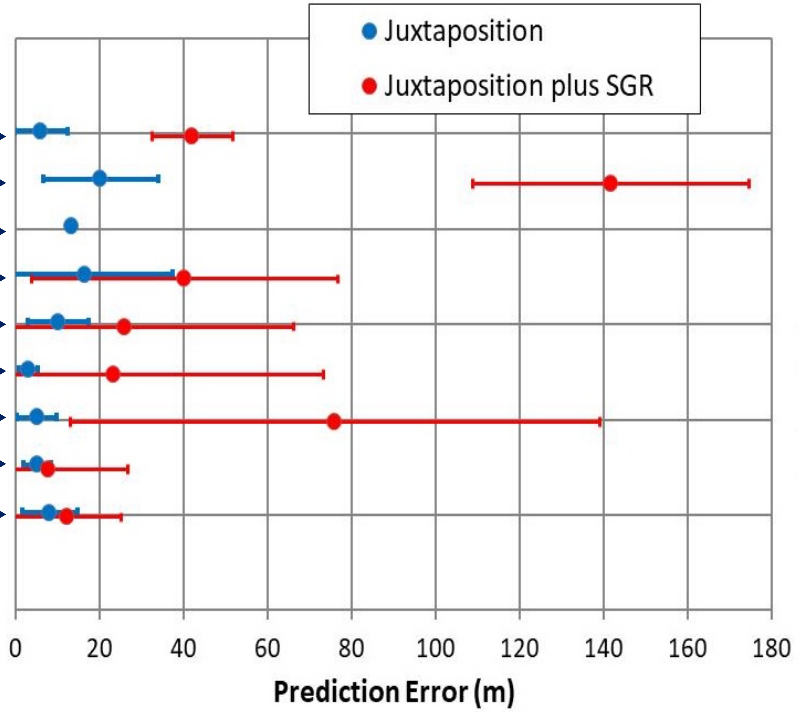
Murray et al 2019

Summary – Prediction Errors for 6 Case Studies

Prediction Error	Reservoir	Juxtaposition		Juxtaposition plus SGR	
		Mean	Std Dev	Mean	Std Dev
Ling Gu	A Sand	6.0	6.4	42.0	9.6
Corallina	Laminaria	20.2	13.7	141.7	32.9
Dory	Leman	13.2	0.3	272.7	42.1
Minerva	Minerva	16.3	21.0	40.2	36.5
Sea Horse	N0-N1	10.1	7.3	26.0	40.2
	N2_3	3.0	2.2	23.3	50.0
	N2_6	5.0	4.7	76.0	63.0
	P1	5.1	3.4	7.6	19.1
Griffin	Zeepard	8.1	6.5	12.1	12.9



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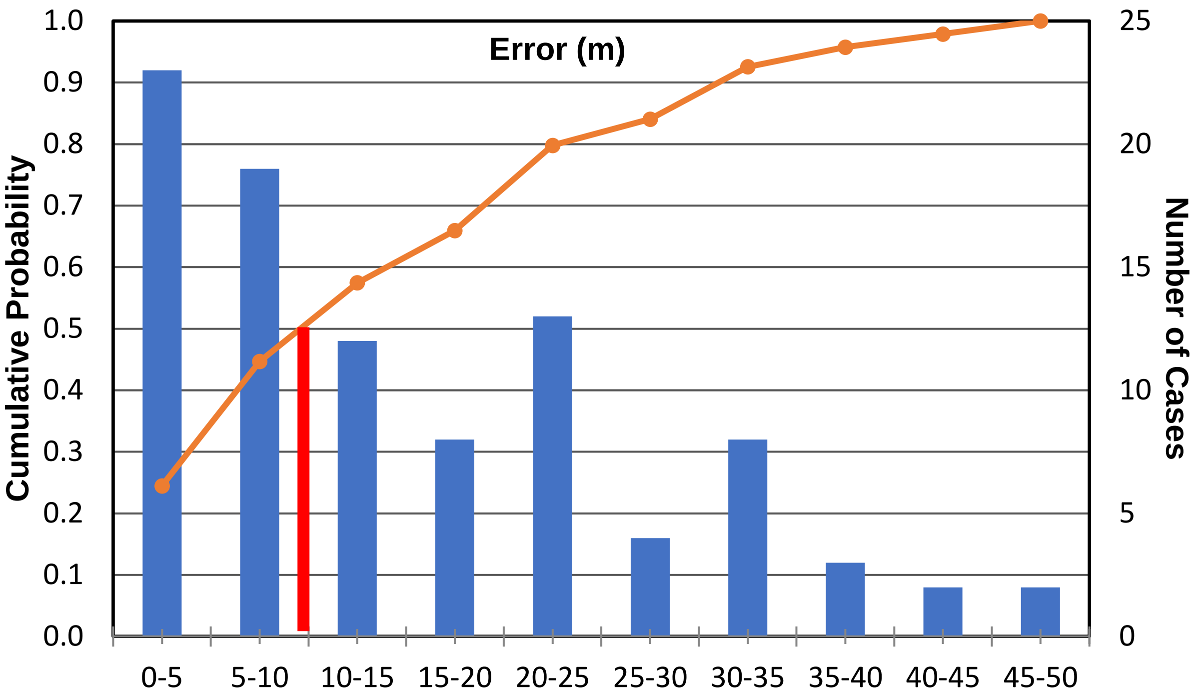
Murray et al 2019

Subset of Global Practice



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STRUCTURAL GEOLOGY

Murray et al 2019

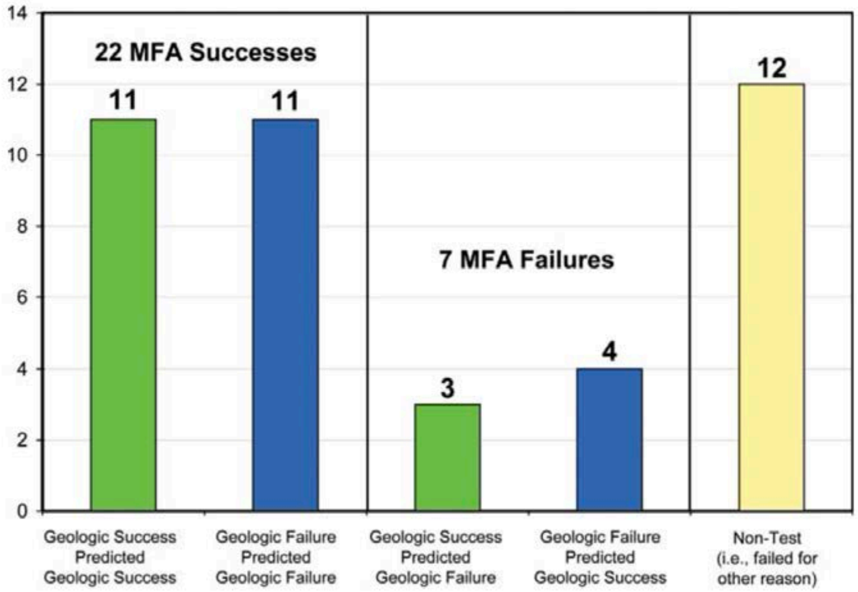
Multi-fault analysis scorecard: testing the stochastic approach in fault seal prediction

F. V. CORONA[1]*, J. S. DAVIS[2], S. J. HIPPLER[2] & P. J. VROLIJK[2]

[1]*ExxonMobil Production Deutschland GmbH, Riethorst 12, 30659 Hannover, Germany*

[2]*ExxonMobil Upstream Research Company, P.O. Box 2189, Houston, Texas 77252, USA*

**Corresponding author (e-mail: franco.v.corona@exxonmobil.com)*



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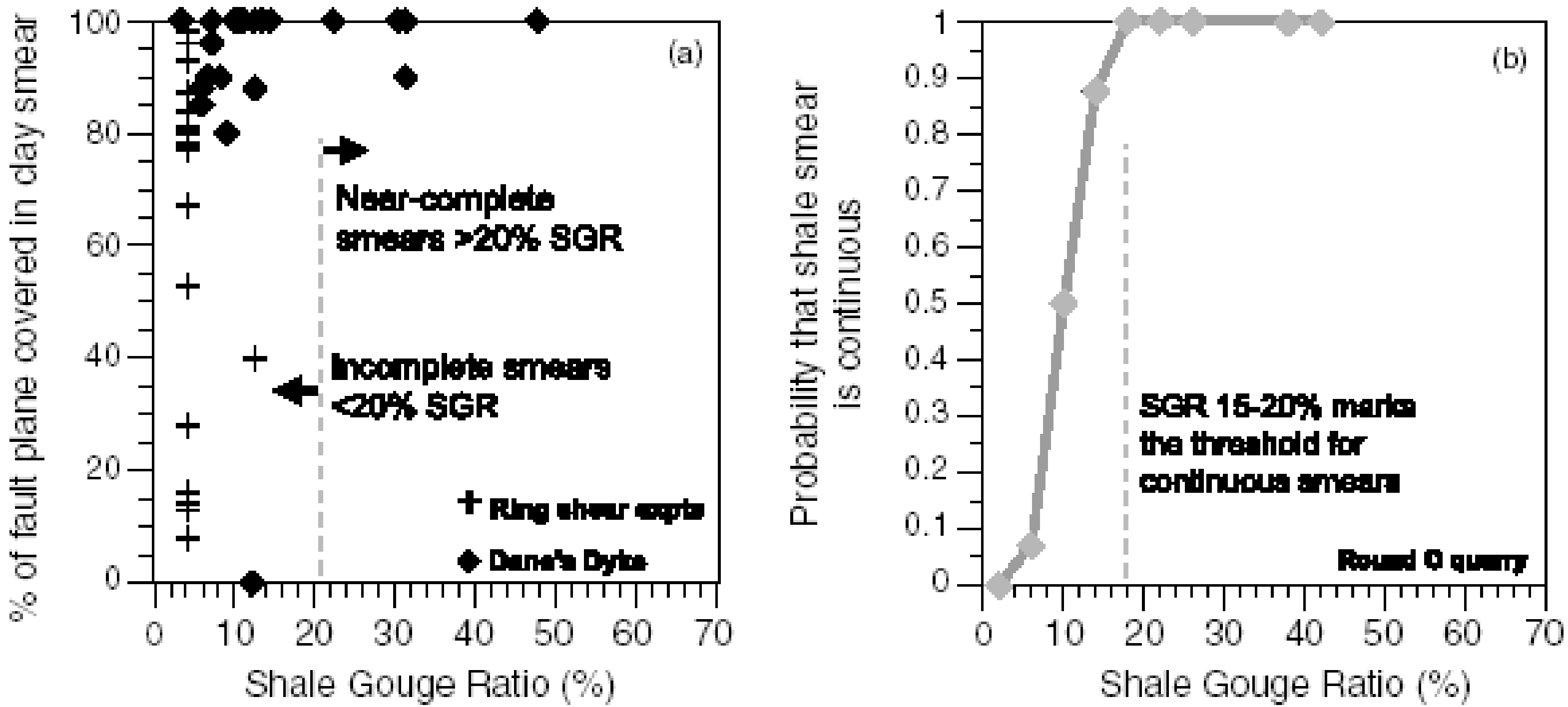
SGR Seal Threshold

SGR >20% Continuous Smear



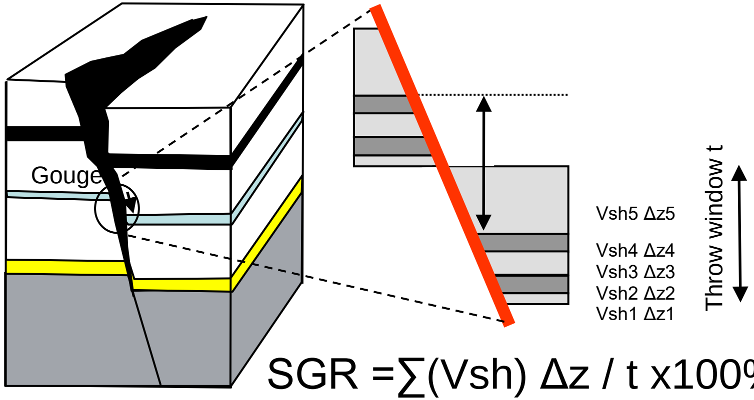
Yielding et al 2002

Strike section
~5-10m throw
Airport Road Miri

http://www.gigapan.com/gigapans/160733

- Along strike mapping fault rock.
- Same throw and stratigraphy.`

Strike section
~5-10m throw
Airport Road Miri



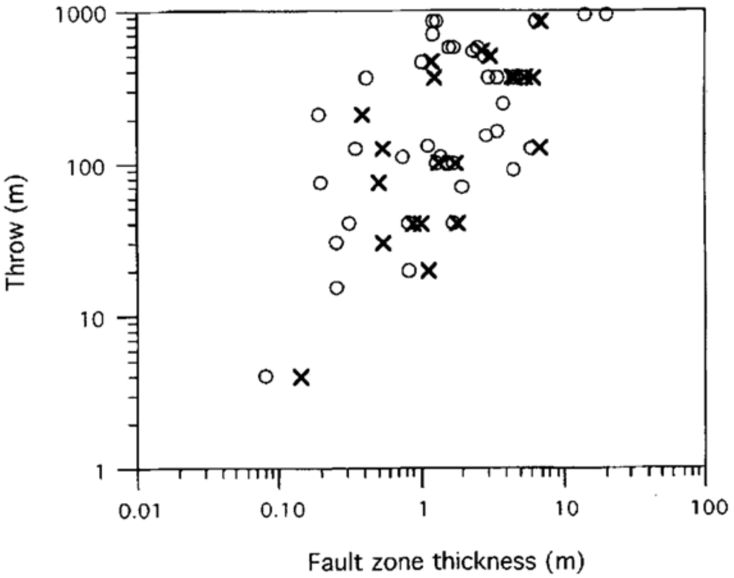
$$SGR = \sum (Vsh)\ \Delta z / t \times 100\%$$

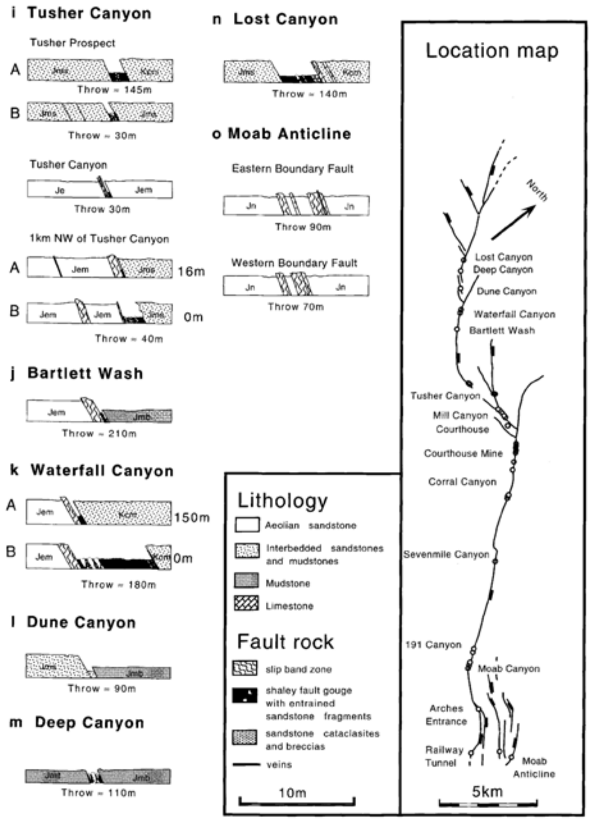
After Yielding 2002

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Structure and content of the Moab Fault Zone, Utah, USA, and its implications for fault seal prediction

K. A. FOXFORD[1], J. J. WALSH[1], J. WATTERSON[1], I. R. GARDEN[2*], S. C. GUSCOTT[3†] & S. D. BURLEY[3*‡]





FOXFORD, K. A., WALSH, J. J., WATTERSON, J. *et al.* 1998. Structure and content of the Moab Fault Zone, Utah, USA, and its implications for fault seal prediction. *In*: JONES, G., FISHER, Q. J. & KNIPE, R. J. (eds) *Faulting, Fault Sealing and Fluid Flow in Hydrocarbon Reservoirs*. Geological Society, London, Special Publications, **147**, 87–103.

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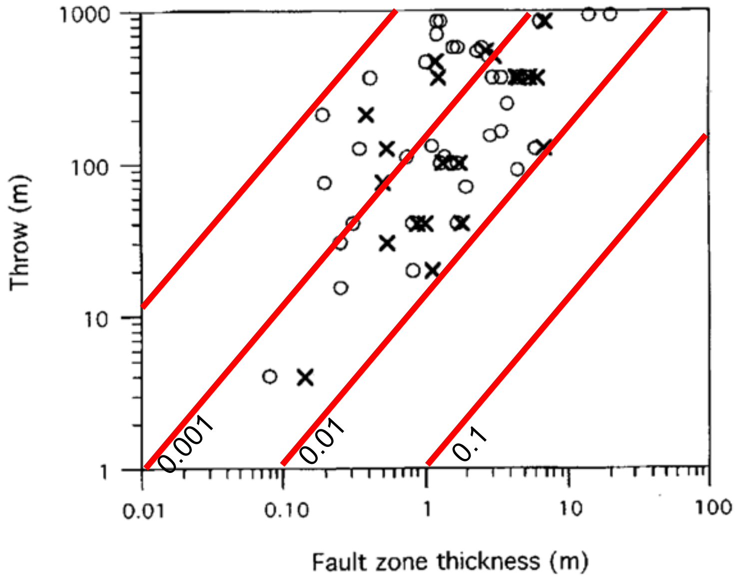

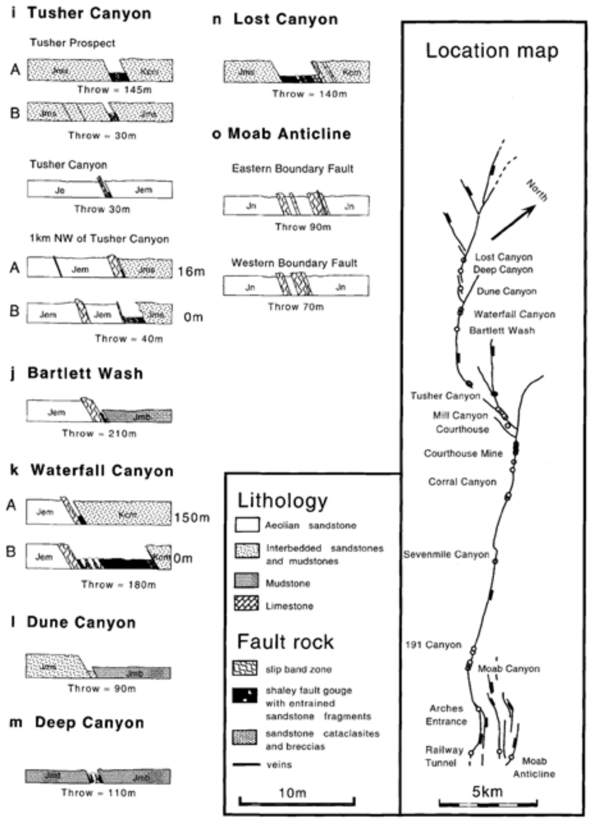

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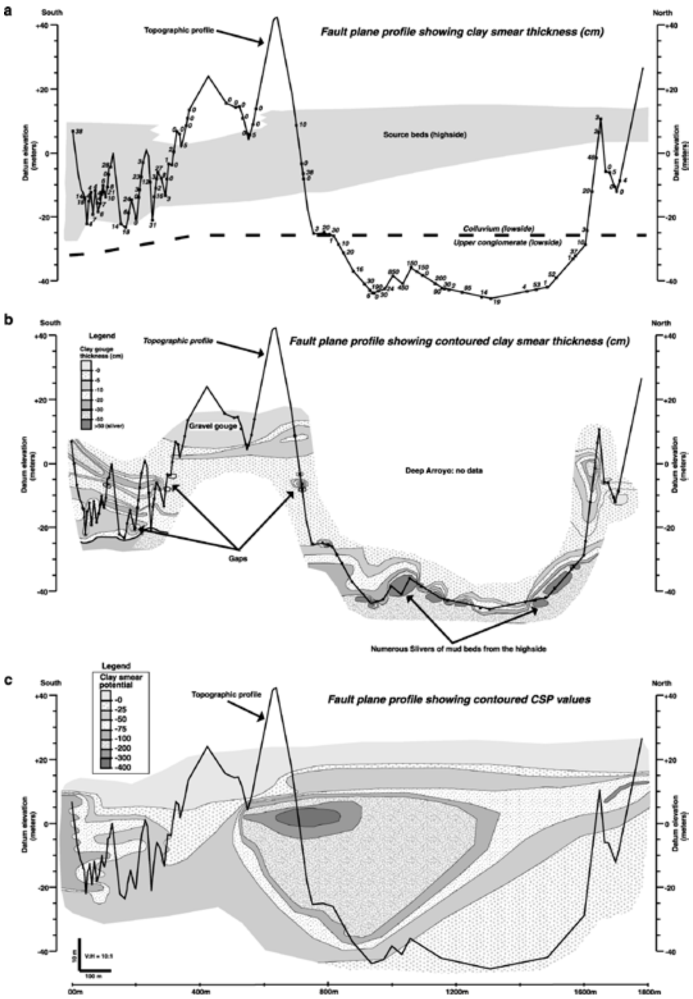
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Clay smear seals and fault sealing potential of an exhumed growth fault, Rio Grande rift, New Mexico

P. Ted Doughty

AAPG BULLETIN, V. 87, NO. 3 (MARCH 2003), PP. 427–444



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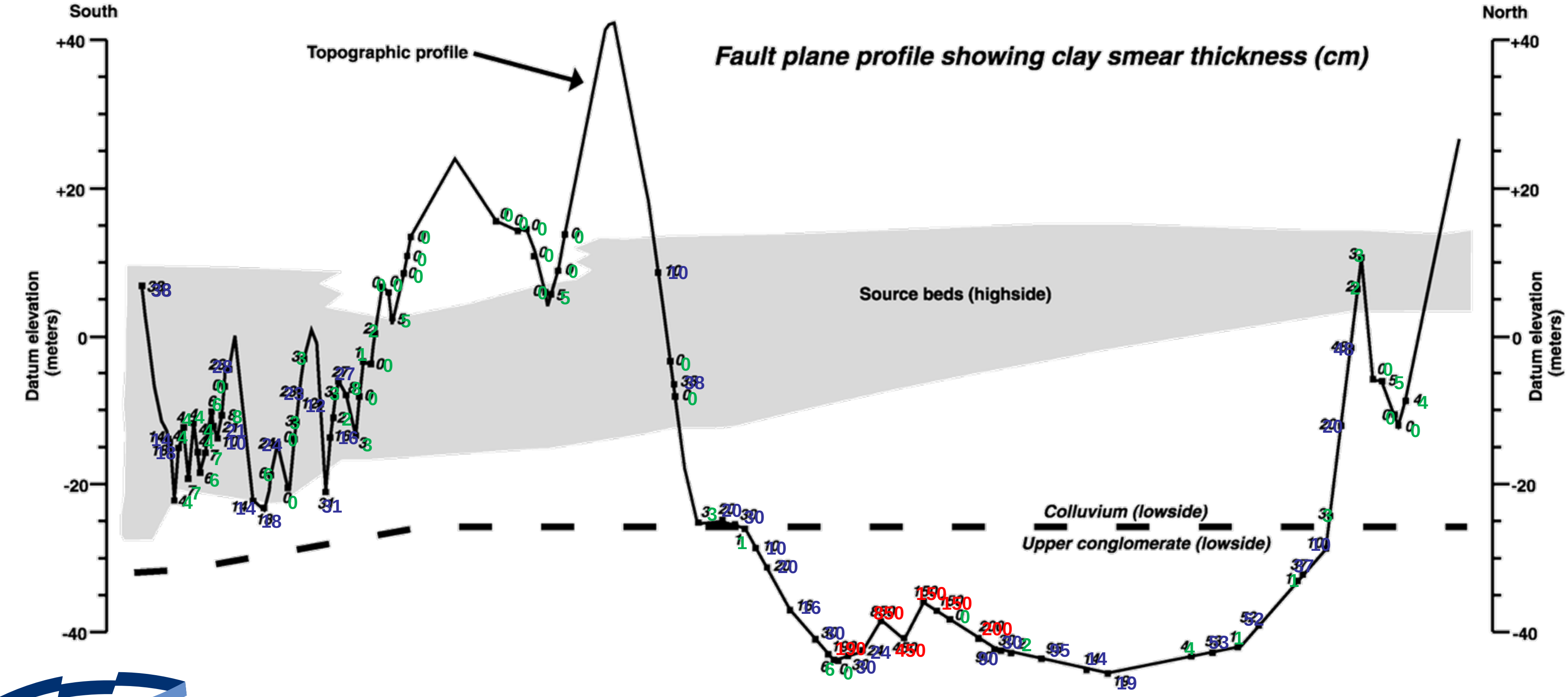
STRUCTURAL GEOLOGY



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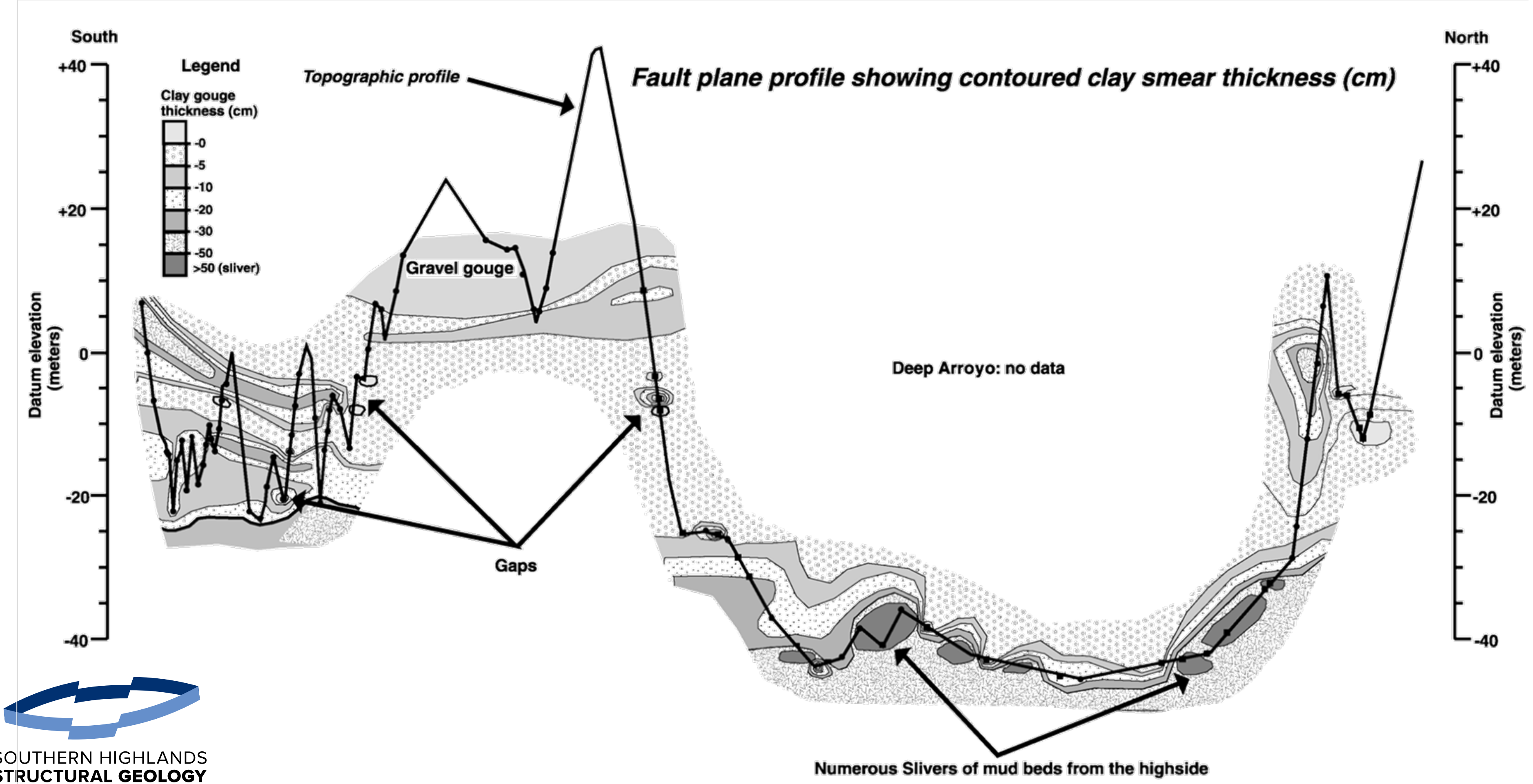

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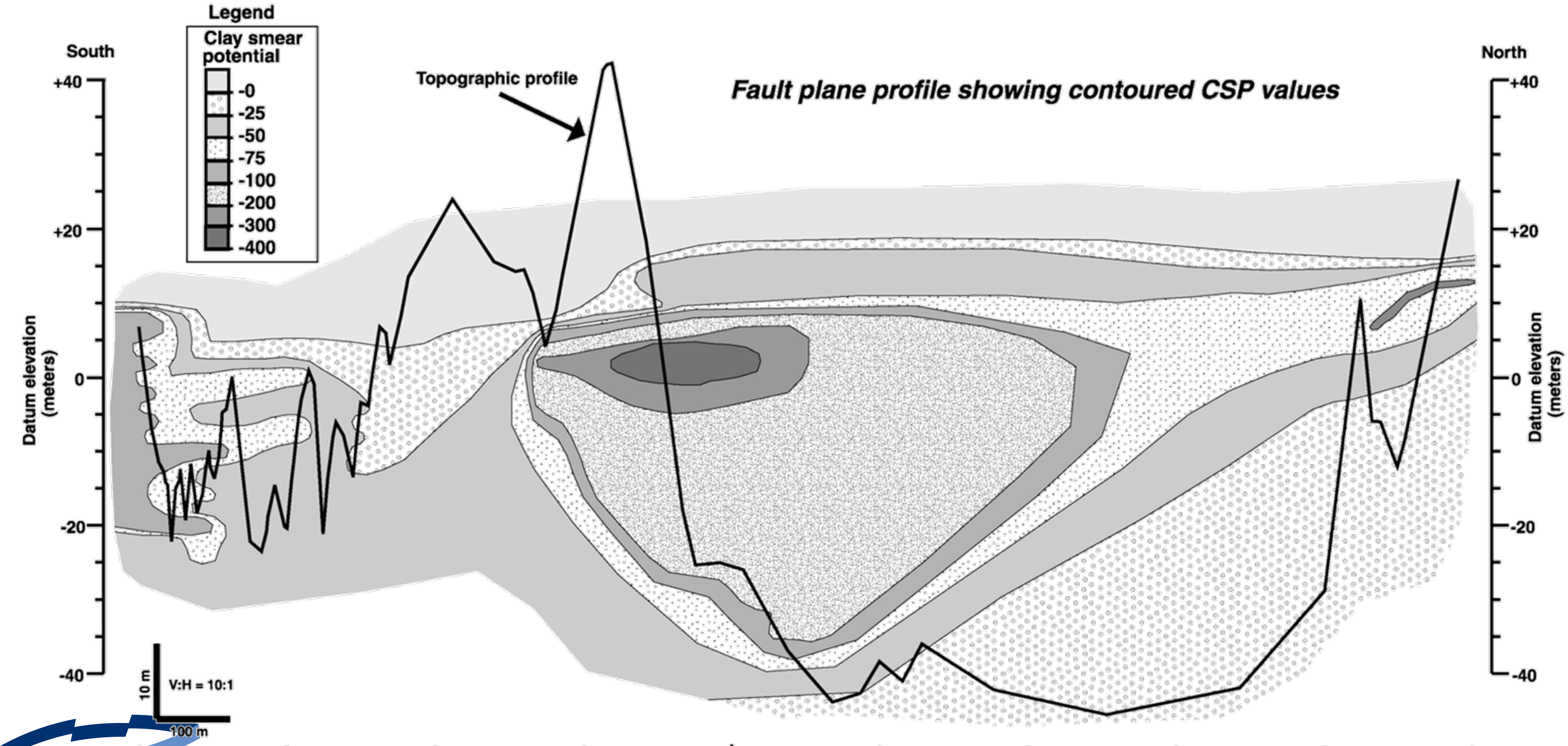
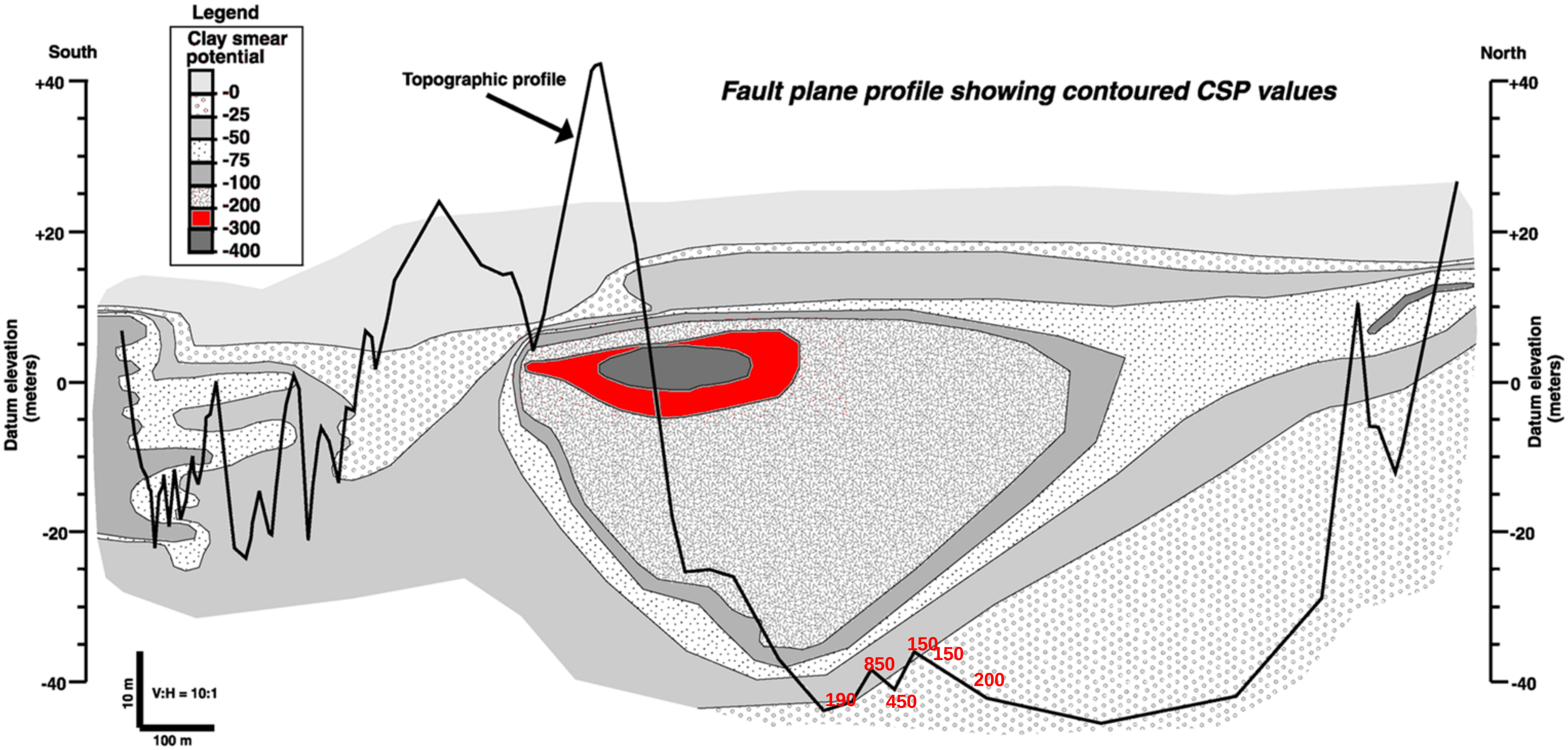
STRUCTURAL GEOLOGY


Fault plane profile showing contoured CSP values
Legend
Clay smear potential
-0
-25
-50
-75
-100
-200
-300
-400
Topographic profile
South
North
Datum elevation (meters)
+40
+20
0
-20
-40
10 m
V:H = 10:1
100 m
00m
400m
800m
1200m
1600m
1800m



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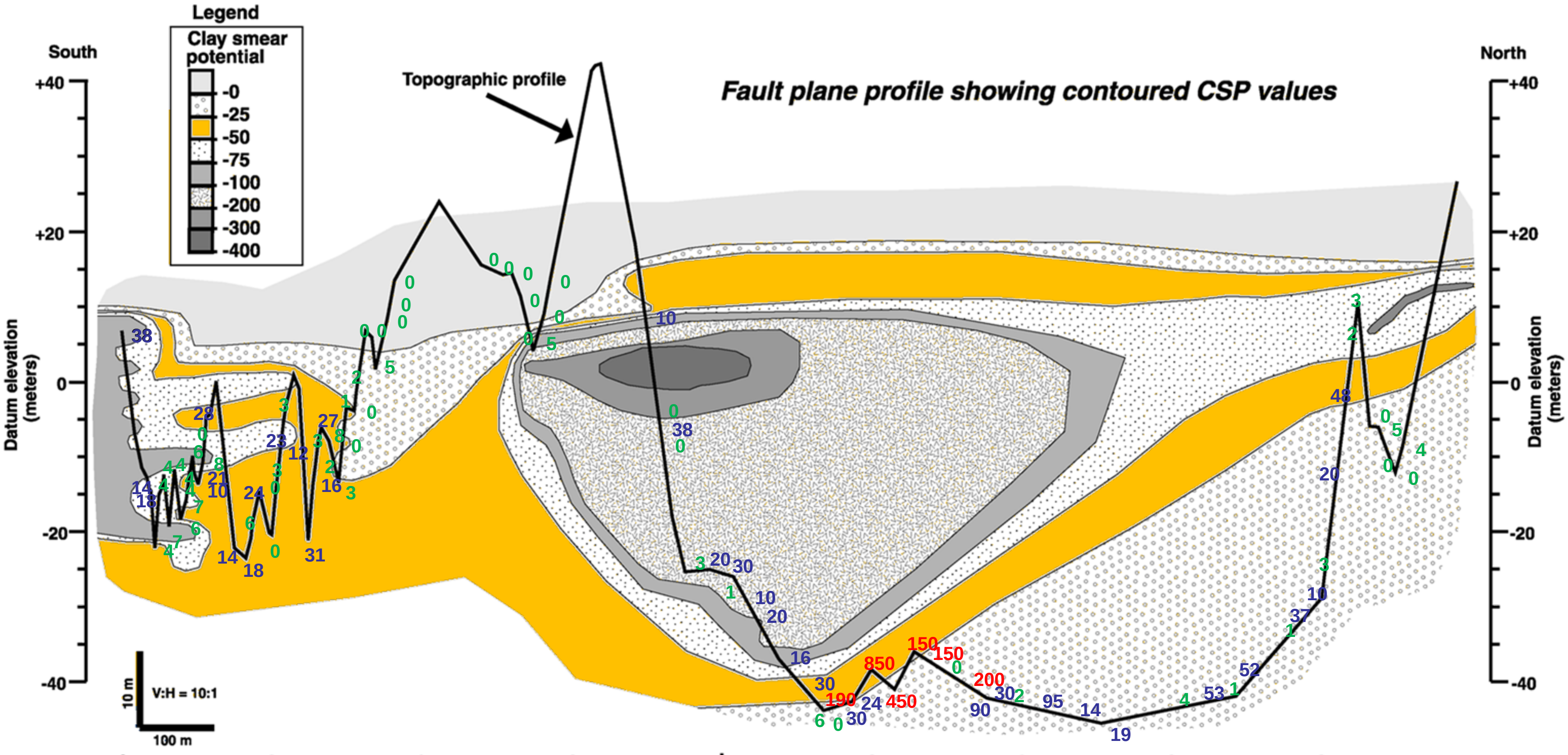
1800m
190
850
450
150
150
200



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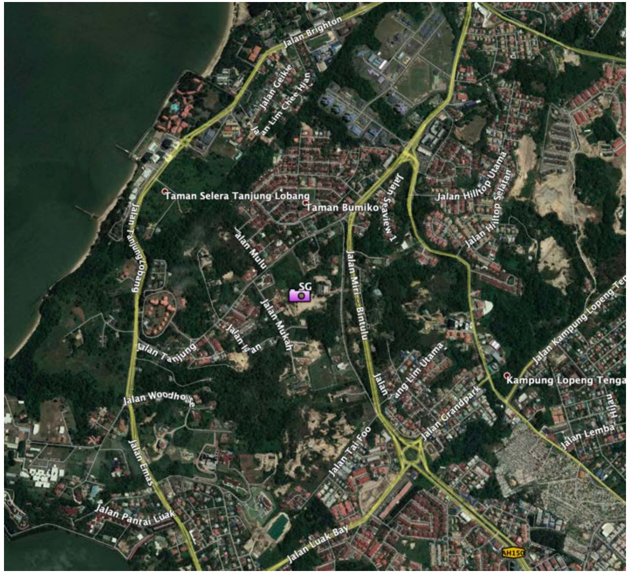
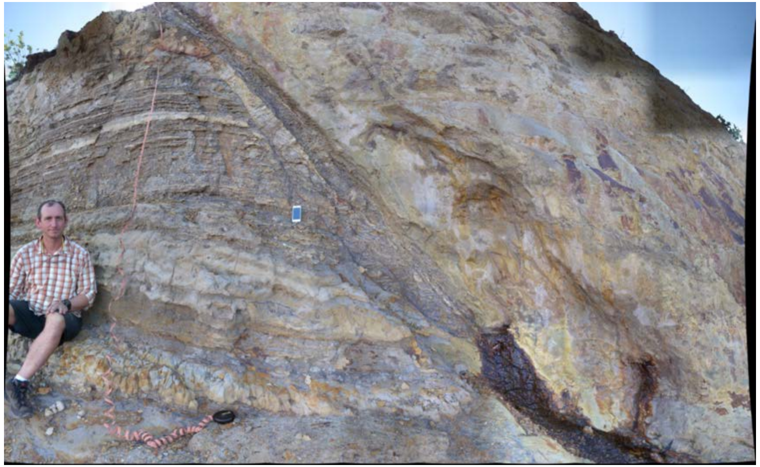
Miri Sarawak

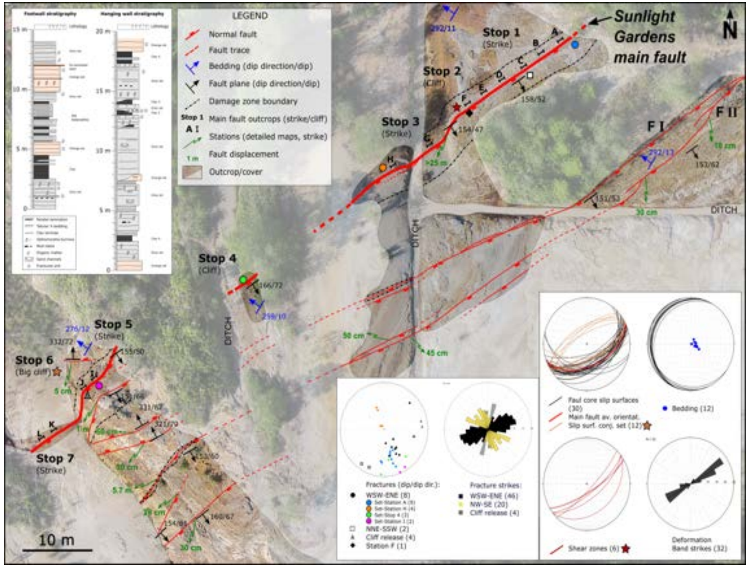


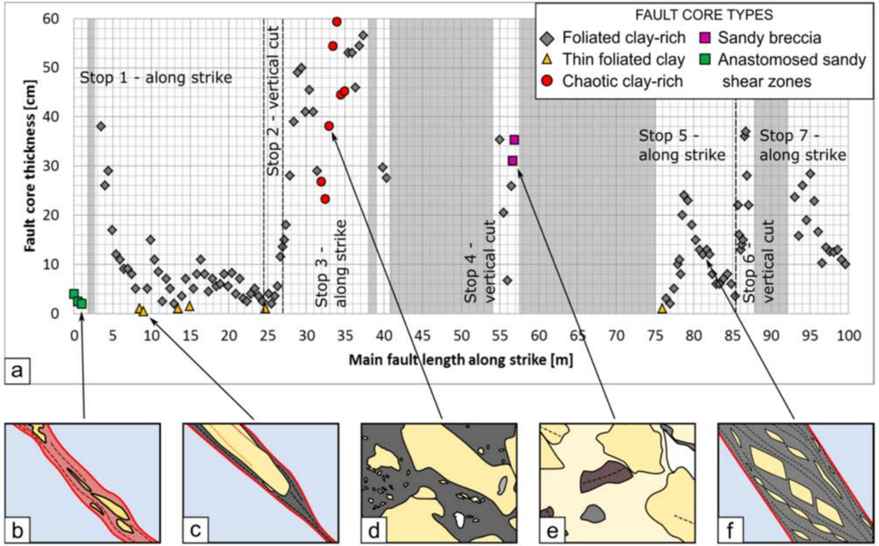


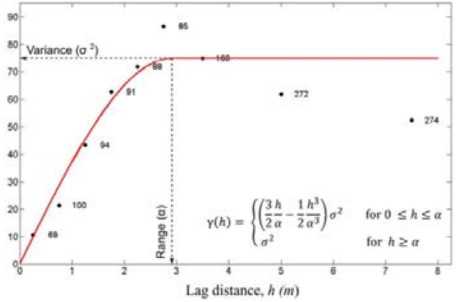
http://www.gigapan.com/gigapans/160802

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Miri Sarawak Fault Rock







Journal of Structural Geology 116 (2018) 189–206

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journal homepage: www.elsevier.com/locate/jsg

ELSEVIER

Along-strike fault core thickness variations of a fault in poorly lithified sediments, Miri (Malaysia)

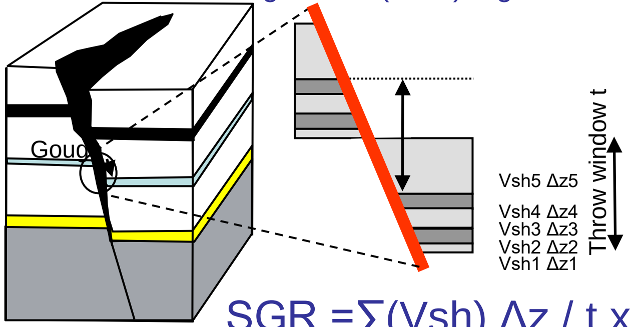
Silvia Sosio De Rosa[a,*], Zoe K. Shipton[a], Rebecca J. Lunn[a], Yannick Kremer[a], Titus Murray[b]

[a] Department of Civil and Environmental Engineering, University of Strathclyde, G1 1XJ, 75 Montrose St., Glasgow, UK
[b] FaultSeal Pty Ltd, Sydney, Australia

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

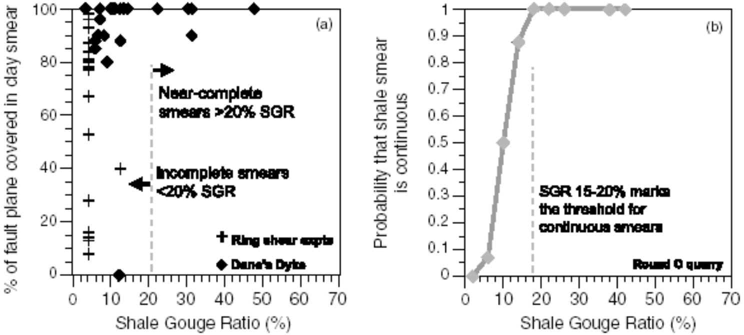
Miri Sarawak Fault Rock

Shale Gouge Ratio (SGR) Algorithm



$$SGR = \sum(Vsh)\,\Delta z / t \times 100\%$$

After Yielding 2002



- Along strike mapping fault rock.
- Same throw and stratigraphy.
- Map how *thin* not how thick!

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Gabriel Watson PhD Mt Messenger NZ

FAULTS AND FLUID FLOW: AN INVESTIGATION INTO THE PRODUCTION OF LOW PERMEABILITY FAULT ROCK IN WEAKLY LITHIFIED SILICICLASTIC SEQUENCES IN NEW ZEALAND

Gabrielle Watson

A dissertation submitted in partial fulfilment of the requirements for the Degree

of

DOCTOR OF PHILOSOPHY IN GEOLOGY

UC UNIVERSITY OF CANTERBURY

University of Canterbury 2020

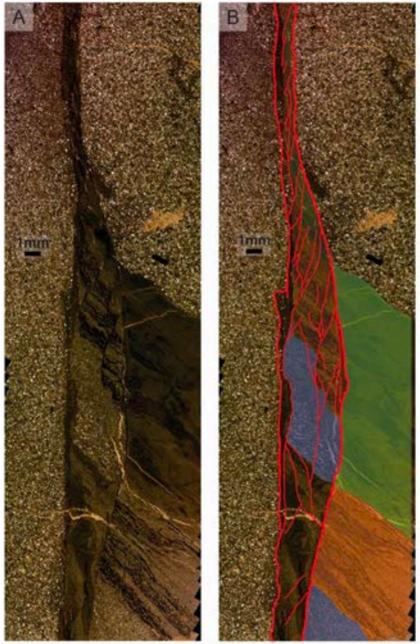


Figure 3.16. RAP 102 ductile shale smear thin section across the footwall of a smeared siltstone bed from Rapanui Beach showing micro scale slip surfaces and slices. A) Uninterpreted thin section. B) Interpreted thin section showing micro-faults and source beds. Blue granular unit is a fine sandstone, the orange unit is a siltstone with organic rich horizons (dark, long and thin layers), green is another siltstone.

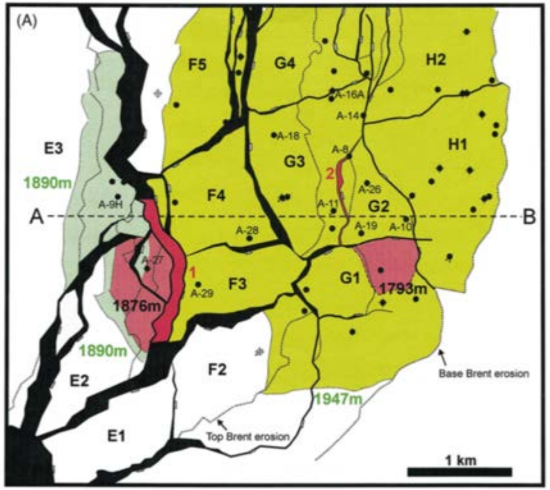
- Outcrop data for nearly 200 small faults … compared with (CSP, SSF and SGR)

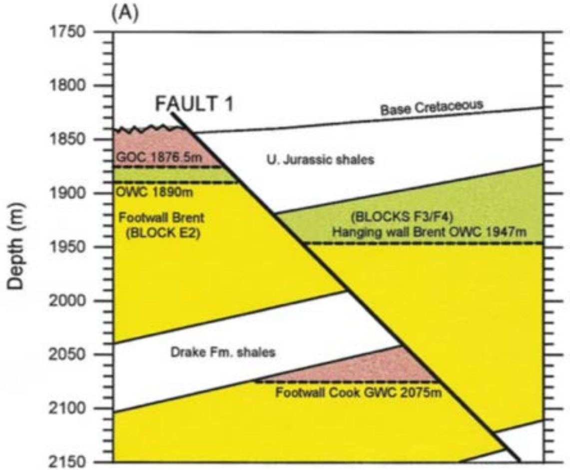
…

- Implications of outcrop observations of small faults for the utility of fault-seal algorithms show **no correlation with the occurrence of discontinuous and non-smears.**
- Comparison of fault-rock thickness measurements and fault-seal estimates from the three algorithms indicate that the algorithms do not reproduce the short wavelength (<0.5 m) up to order of magnitude variations in fault-rock thickness, most likely due to the calculations being based off only two variables.
- **The algorithms are not designed to identify locations of minimum fault-rock thickness on the fault surface despite these being the most likely sites of across-fault flow.**

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Compare SGR & Juxtaposition





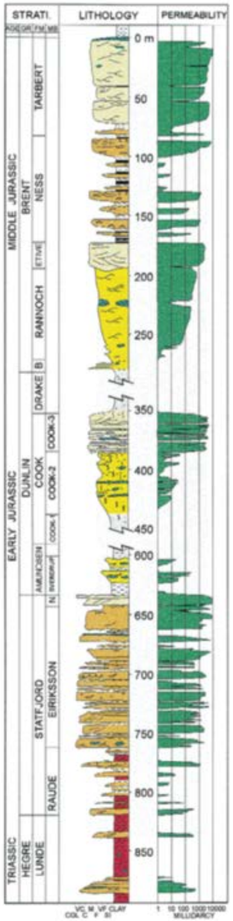


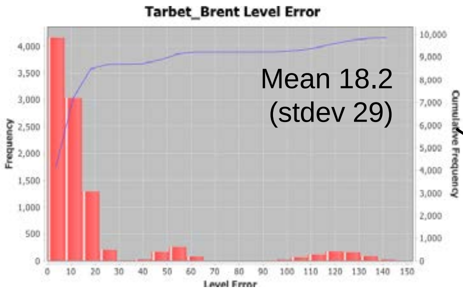
Figure 3—Summary stratigraphic column (from Hesthammer, 1998b) illustrating the properties of the Brent, Cook, and Statfjord reservoirs in the Gullfaks field. Production is from the high-permeability zones of the Tarbert, Ness, Etive, Rannoch, Cook, and Statfjord formations. B = Broom Formation, N = Nansen member.

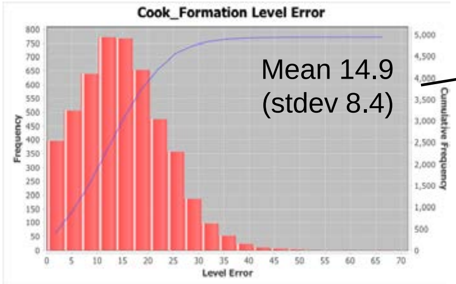
Characterization of Fault Zones for Reservoir Modeling: An Example from the Gullfaks Field, Northern North Sea[1]

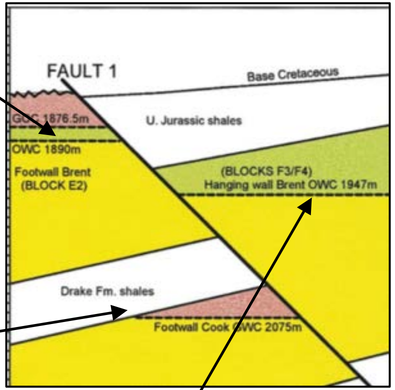
G. Yielding,[2] J. A. Øverland,[3] and G. Byberg[4]

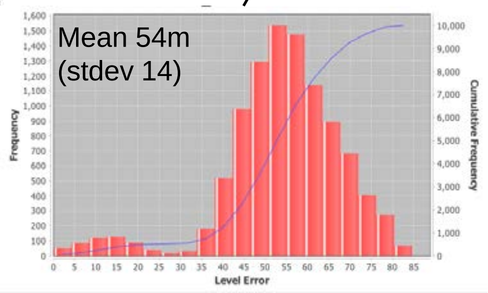
AAPG Bulletin, V. 83, No. 6 (June 1999), P. 925–951.

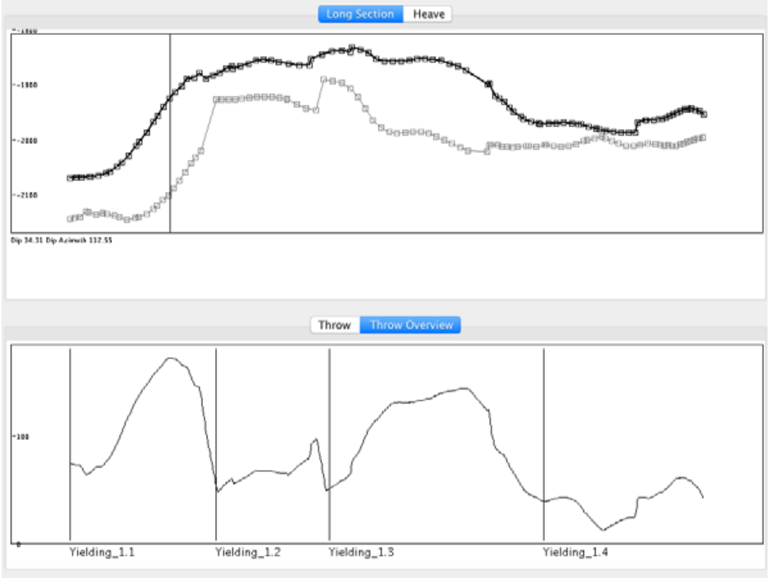
Petrel Model: Juxtaposition Outperforms SGR



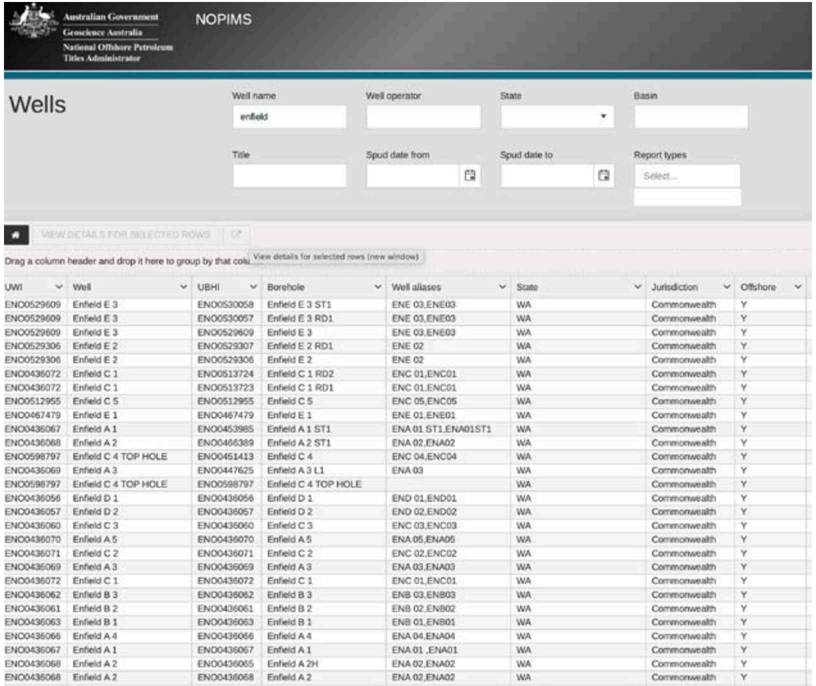








Reservoir	Juxtapostion		SGR		Ratio
	Mean	Stdev	Mean	Stdev	
Tarbet Footwall	18.2	29.4	130	75	714%
Cook Footwall	14.9	8.4	22.7	38.9	152%
Tarbet Hagingwall	54	13.9	61.8	42.4	114%



Australian Government
Geoscience Australia
National Offshore Petroleum Titles Administrator

NOPIMS

Wells

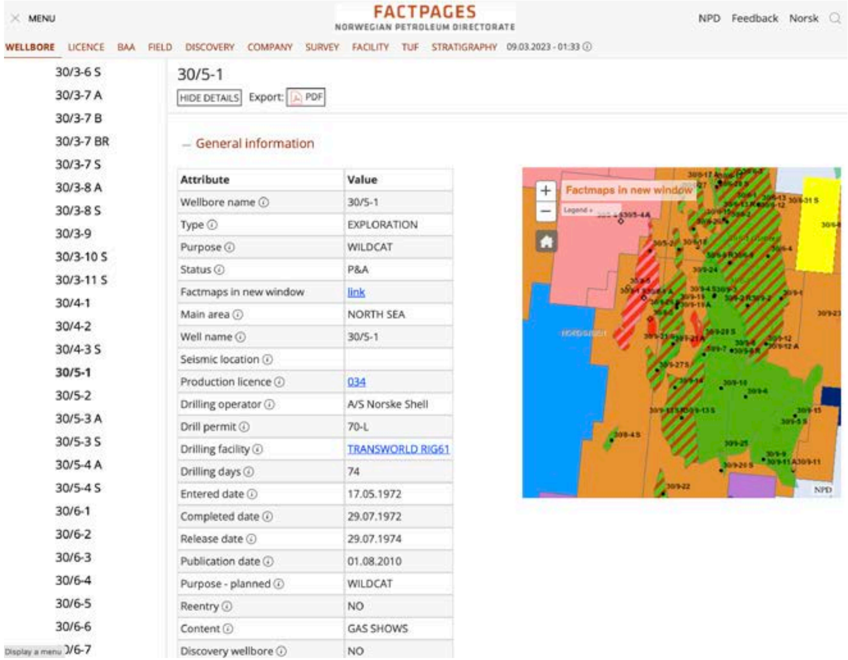
Well name: enfield | Well operator | State | Basin
Title | Spud date from | Spud date to | Report types: Select...

VIEW DETAILS FOR SELECTED ROWS

Drag a column header and drop it here to group by that colu...

View details for selected rows (new window)

UWI	Well	UBHI	Borehole	Well aliases	State	Jurisdiction	Offshore
ENO0529609	Enfield E 3	ENO0530058	Enfield E 3 ST1	ENE 03,ENE03	WA	Commonwealth	Y
ENO0529609	Enfield E 3	ENO0530057	Enfield E 3 RD1	ENE 03,ENE03	WA	Commonwealth	Y
ENO0529609	Enfield E 3	ENO0529609	Enfield E 3	ENE 03,ENE03	WA	Commonwealth	Y
ENO0529306	Enfield E 2	ENO0529307	Enfield E 2 RD1	ENE 02	WA	Commonwealth	Y
ENO0529306	Enfield E 2	ENO0529306	Enfield E 2	ENE 02	WA	Commonwealth	Y
ENO0436072	Enfield C 1	ENO0513724	Enfield C 1 RD2	ENC 01,ENC01	WA	Commonwealth	Y
ENO0436072	Enfield C 1	ENO0513723	Enfield C 1 RD1	ENC 01,ENC01	WA	Commonwealth	Y
ENO0512955	Enfield C 5	ENO0512955	Enfield C 5	ENC 05,ENC05	WA	Commonwealth	Y
ENO0467479	Enfield E 1	ENO0467479	Enfield E 1	ENE 01,ENE01	WA	Commonwealth	Y
ENO0436067	Enfield A 1	ENO0453985	Enfield A 1 ST1	ENA 01 ST1,ENA01ST1	WA	Commonwealth	Y
ENO0436068	Enfield A 2	ENO0466389	Enfield A 2 ST1	ENA 02,ENA02	WA	Commonwealth	Y
ENO0598797	Enfield C 4 TOP HOLE	ENO0451413	Enfield C 4	ENC 04,ENC04	WA	Commonwealth	Y
ENO0436069	Enfield A 3	ENO0447625	Enfield A 3 L1	ENA 03	WA	Commonwealth	Y
ENO0598797	Enfield C 4 TOP HOLE	ENO0598797	Enfield C 4 TOP HOLE		WA	Commonwealth	Y
ENO0436056	Enfield D 1	ENO0436056	Enfield D 1	END 01,END01	WA	Commonwealth	Y
ENO0436057	Enfield D 2	ENO0436057	Enfield D 2	END 02,END02	WA	Commonwealth	Y
ENO0436060	Enfield C 3	ENO0436060	Enfield C 3	ENC 03,ENC03	WA	Commonwealth	Y
ENO0436070	Enfield A 5	ENO0436070	Enfield A 5	ENA 05,ENA05	WA	Commonwealth	Y
ENO0436071	Enfield C 2	ENO0436071	Enfield C 2	ENC 02,ENC02	WA	Commonwealth	Y
ENO0436069	Enfield A 3	ENO0436069	Enfield A 3	ENA 03,ENA03	WA	Commonwealth	Y
ENO0436072	Enfield C 1	ENO0436072	Enfield C 1	ENC 01,ENC01	WA	Commonwealth	Y
ENO0436062	Enfield B 3	ENO0436062	Enfield B 3	ENB 03,ENB03	WA	Commonwealth	Y
ENO0436061	Enfield B 2	ENO0436061	Enfield B 2	ENB 02,ENB02	WA	Commonwealth	Y
ENO0436063	Enfield B 1	ENO0436063	Enfield B 1	ENB 01,ENB01	WA	Commonwealth	Y
ENO0436066	Enfield A 4	ENO0436066	Enfield A 4	ENA 04,ENA04	WA	Commonwealth	Y
ENO0436067	Enfield A 1	ENO0436067	Enfield A 1	ENA 01 ,ENA01	WA	Commonwealth	Y
ENO0436068	Enfield A 2	ENO0436065	Enfield A 2H	ENA 02,ENA02	WA	Commonwealth	Y
ENO0436068	Enfield A 2	ENO0436068	Enfield A 2	ENA 02,ENA02	WA	Commonwealth	Y



MENU

FACTPAGES
NORWEGIAN PETROLEUM DIRECTORATE

NPD Feedback Norsk

WELLBORE LICENCE BAA FIELD DISCOVERY COMPANY SURVEY FACILITY TUF STRATIGRAPHY 09.03.2023 - 01:33

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30/3-7 A
30/3-7 B
30/3-7 BR
30/3-7 S
30/3-8 A
30/3-8 S
30/3-9
30/3-10 S
30/3-11 S
30/4-1
30/4-2
30/4-3 S
30/5-1
30/5-2
30/5-3 A
30/5-3 S
30/5-4 A
30/5-4 S
30/6-1
30/6-2
30/6-3
30/6-4
30/6-5
30/6-6
30/6-7

Display a menu

30/5-1

HIDE DETAILS Export: PDF

General information

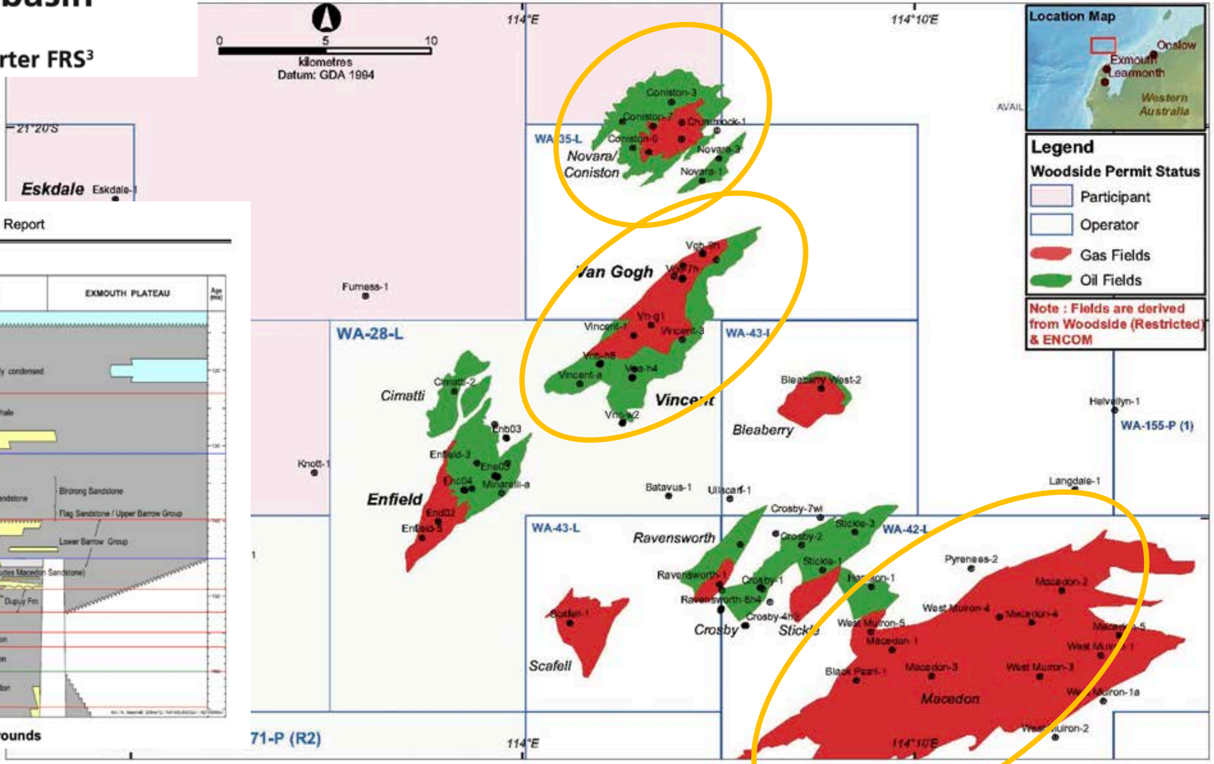
Attribute	Value
Wellbore name	30/5-1
Type	EXPLORATION
Purpose	WILDCAT
Status	P&A
Factmaps in new window	link
Main area	NORTH SEA
Well name	30/5-1
Seismic location	
Production licence	034
Drilling operator	A/S Norske Shell
Drill permit	70-L
Drilling facility	TRANSWORLD RIG61
Drilling days	74
Entered date	17.05.1972
Completed date	29.07.1972
Release date	29.07.1974
Publication date	01.08.2010
Purpose - planned	WILDCAT
Reentry	NO
Content	GAS SHOWS
Discovery wellbore	NO

Factmaps in new window

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Reservoir Fluid Property Variation at the Metre-scale: Origin, Impact and Mapping in the Vincent Oil Field, Exmouth Sub-basin

A.P. Murray[1], D.A. Dawson[1], D. Carruthers[2] & S. Larter FRS[3]



VNB-H1ST2, VNB-H1ST2-L1 & VNB-H1ST2-L2ST1 Final Well Completion Report

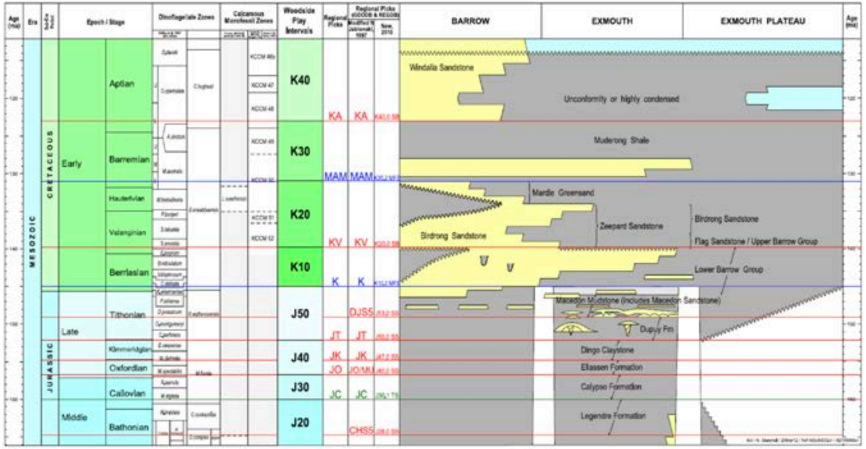


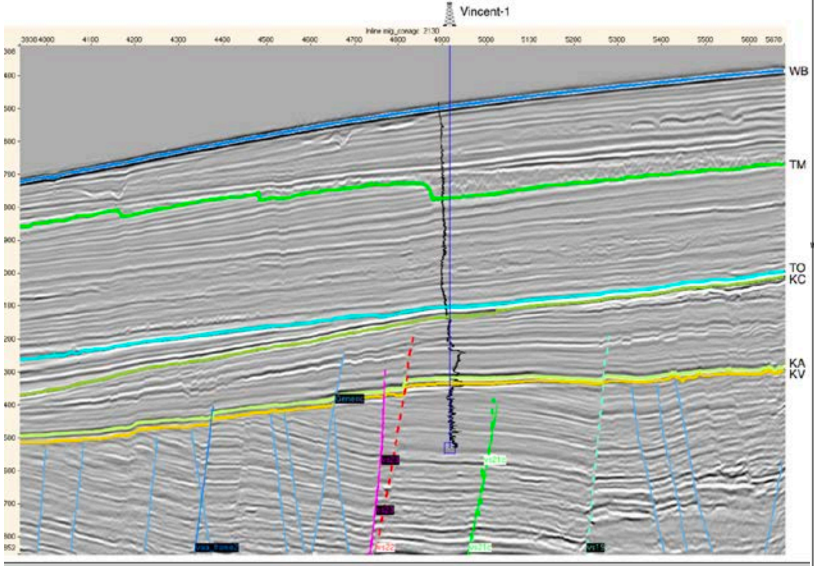
Figure 4: Exmouth Sub-basin Stratigraphic Chart, WA-271-P and Surrounds

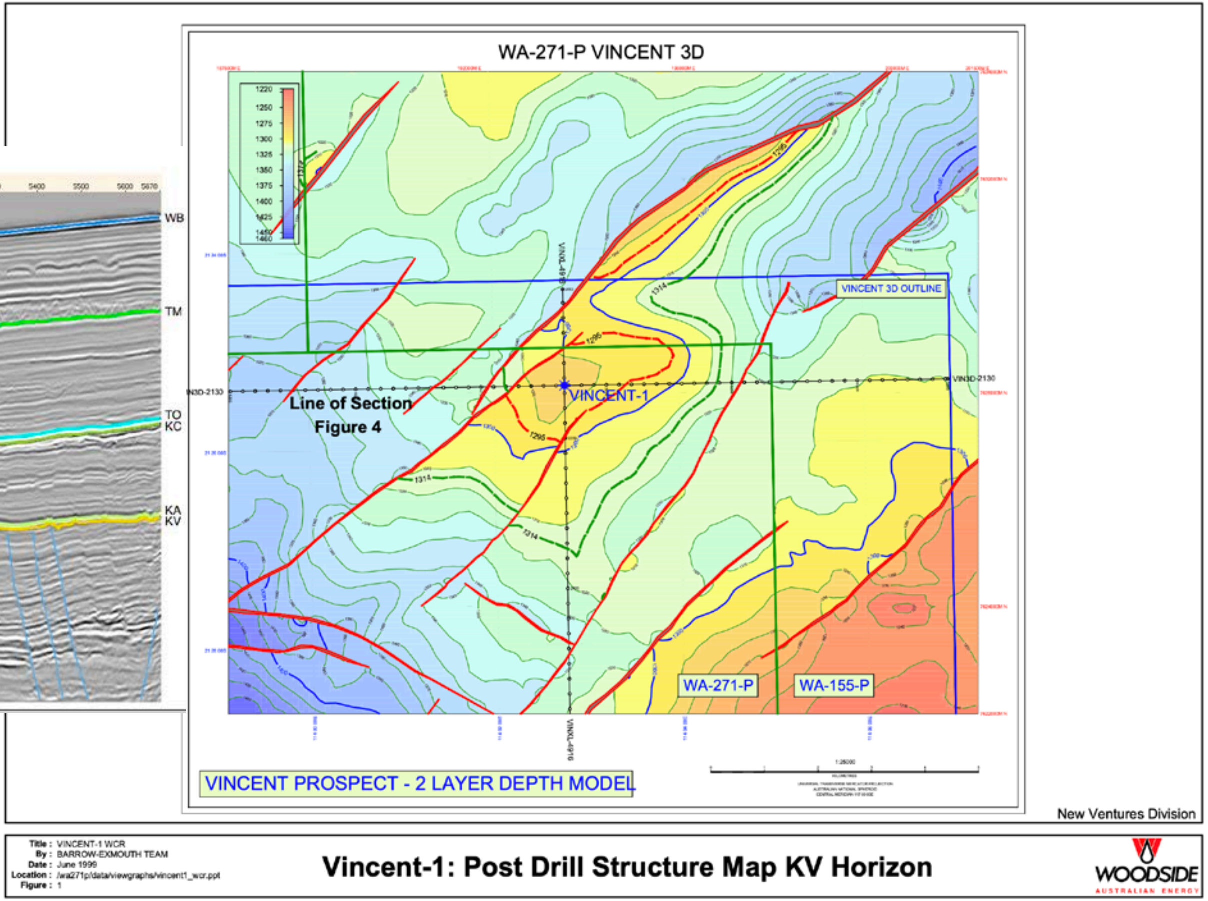
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

WABS 2013

PESA
Petroleum Exploration Society of Australia

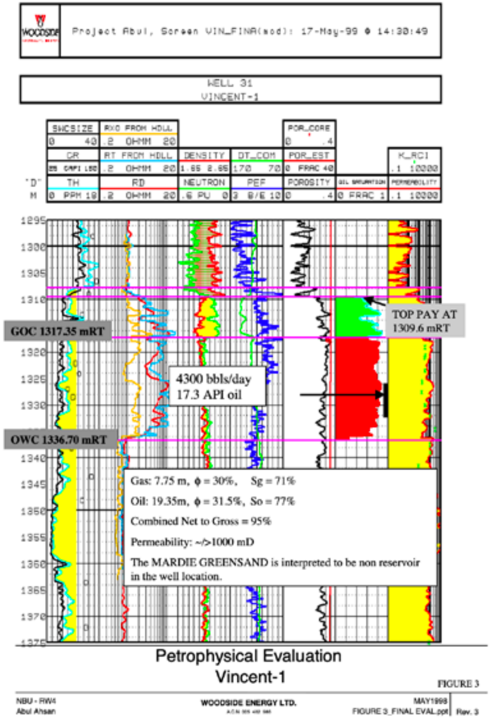
Vincent

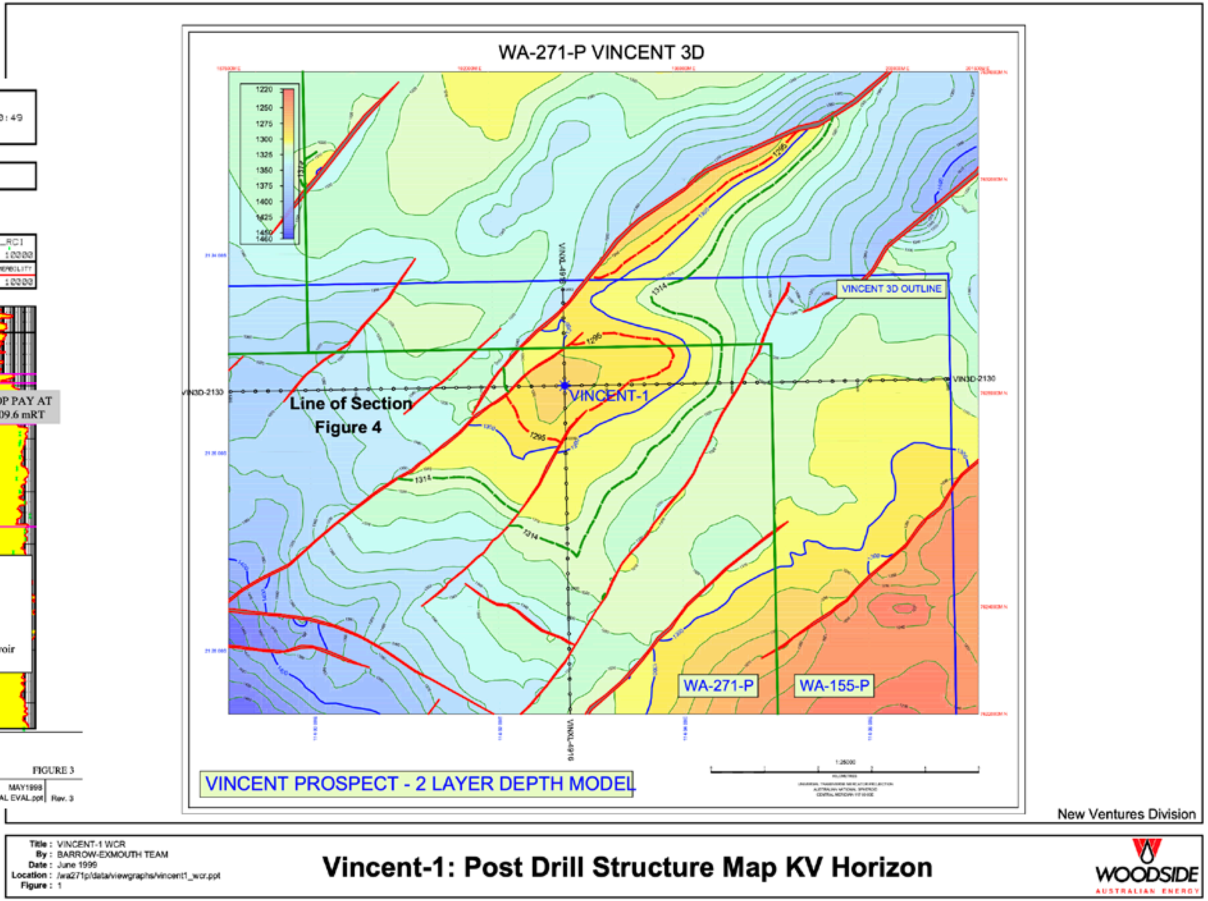




SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Vincent





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STRUCTURAL GEOLOGY

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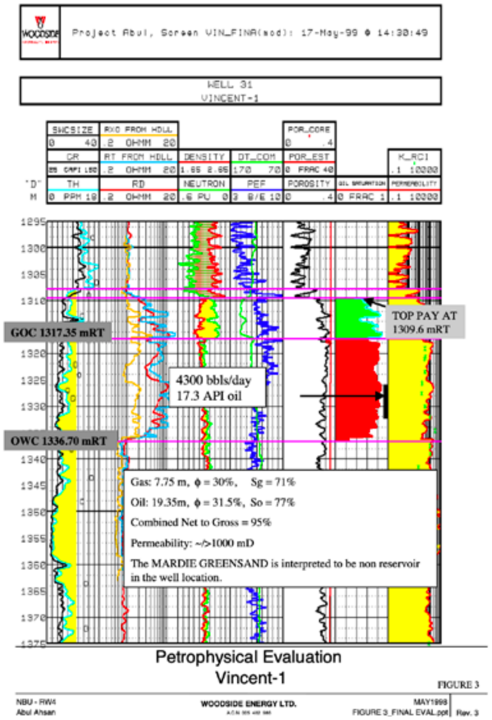

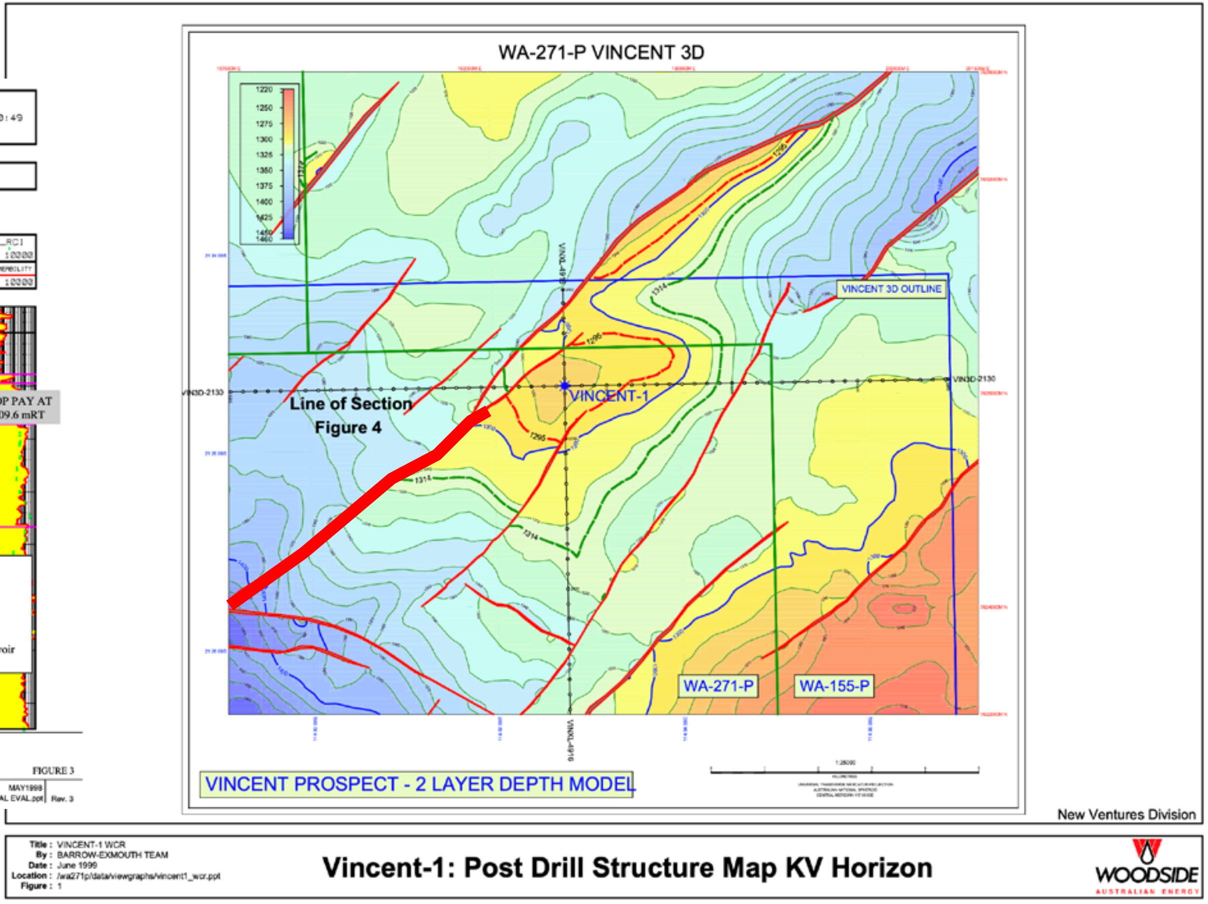

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

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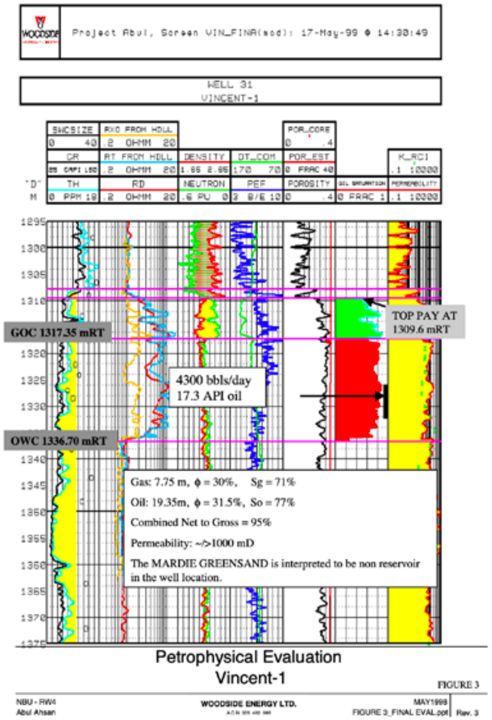

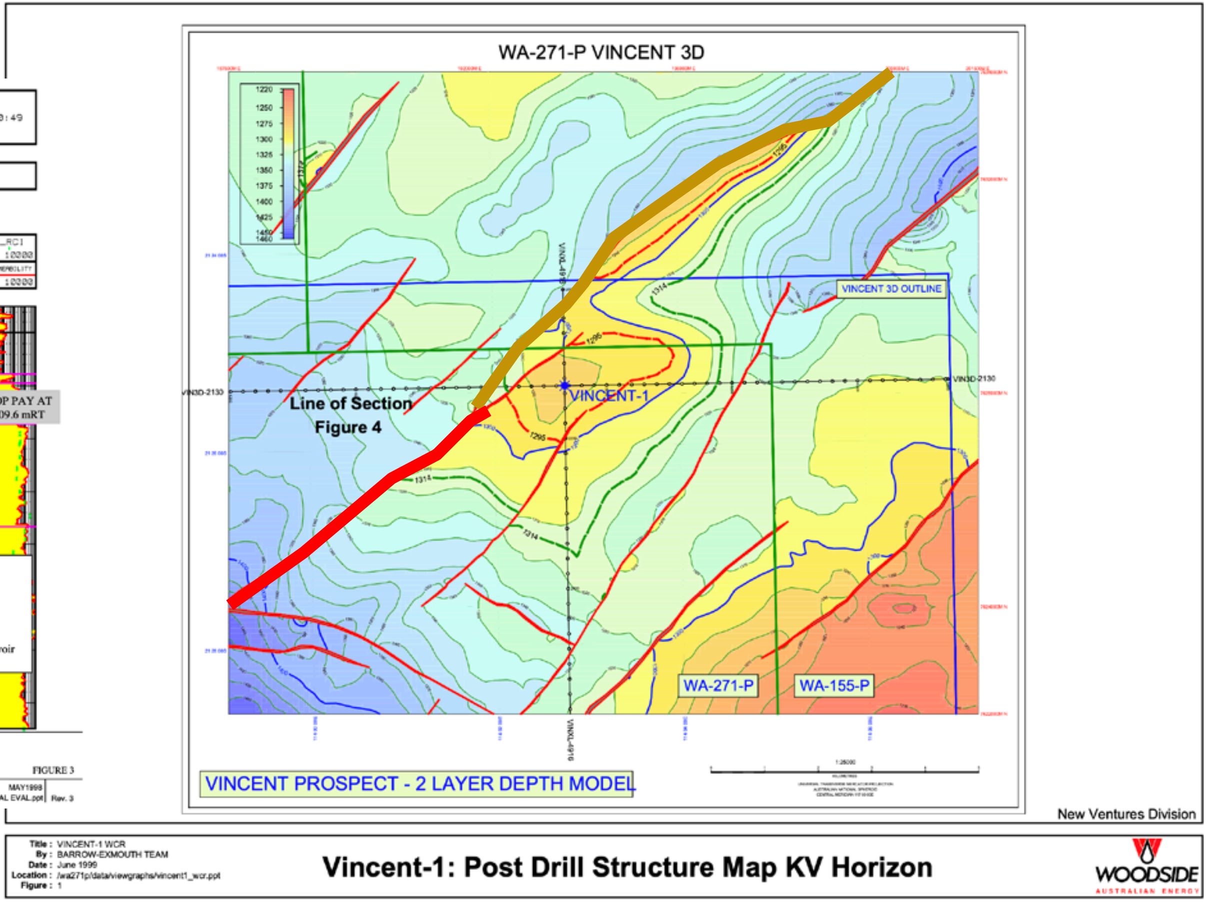

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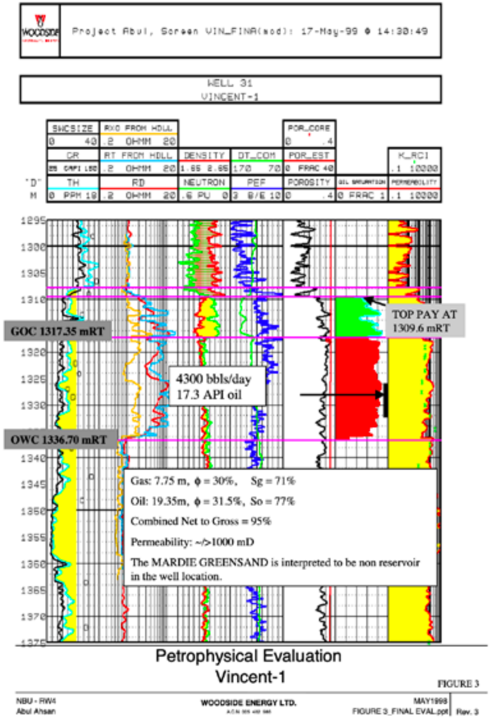
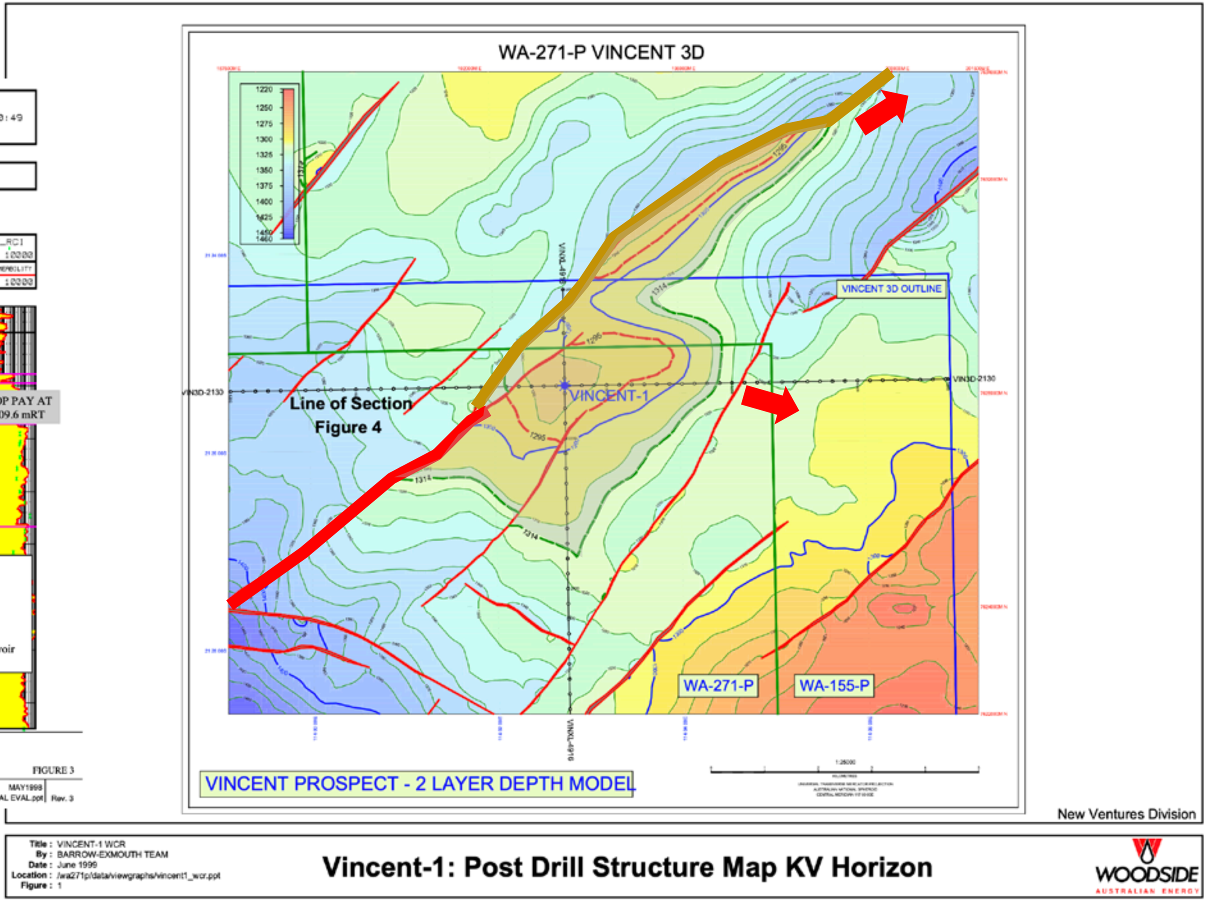
STRUCTURAL GEOLOGY

Vincent

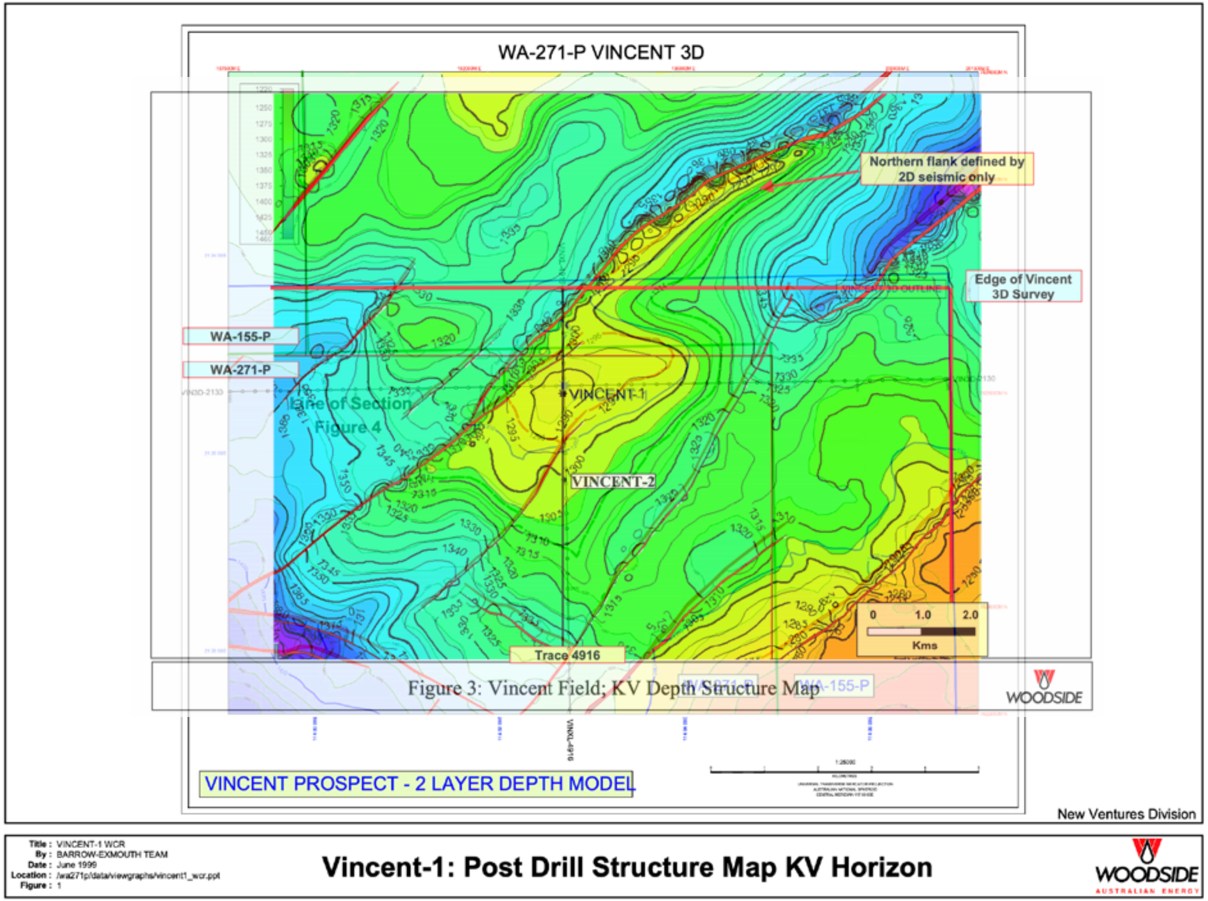


Project Abul, Screen VIN_FINA(mod): 17-May-99 @ 14:30:49
WELL 31
VINCENT-1
GOC 1317.35 mRT
OWC 1336.70 mRT
TOP PAY AT 1309.6 mRT
4300 bbls/day
17.3 API oil
Gas: 7.75 m, ϕ = 30%, Sg = 71%
Oil: 19.35m, ϕ = 31.5%, So = 77%
Combined Net to Gross = 95%
Permeability: ~/>1000 mD
The MARDIE GREENSAND is interpreted to be non reservoir in the well location.
Petrophysical Evaluation
Vincent-1
FIGURE 3
NBU - RW4
Abul Ahsan
WOODSIDE ENERGY LTD.
MAY1999
FIGURE 3_FINAL EVAL.ppt
Rev. 3



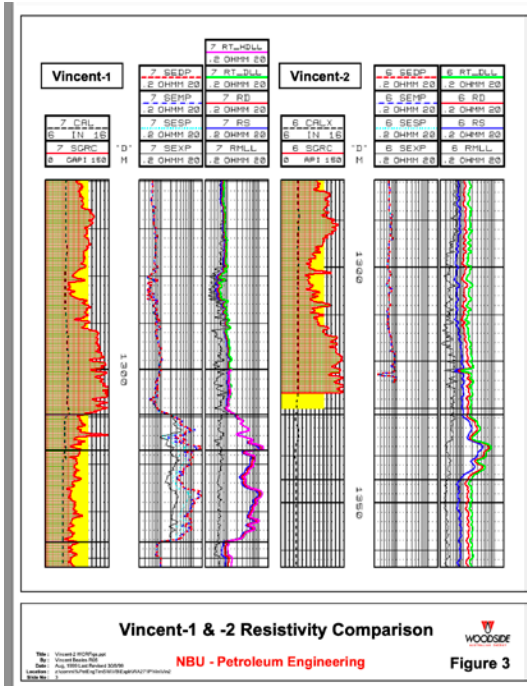
WA-271-P VINCENT 3D
VINCENT 3D OUTLINE
Line of Section
Figure 4
VINCENT-1
VIN3D-2130
WA-271-P
WA-155-P
VINCENT PROSPECT - 2 LAYER DEPTH MODEL
New Ventures Division
Title : VINCENT-1 WCR
By : BARROW-EXMOUTH TEAM
Date : June 1999
Location : /wa271p/data/viewgraphs/vincent1_wcr.ppt
Figure : 1
Vincent-1: Post Drill Structure Map KV Horizon
WOODSIDE
AUSTRALIAN ENERGY

Vincent



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Vincent



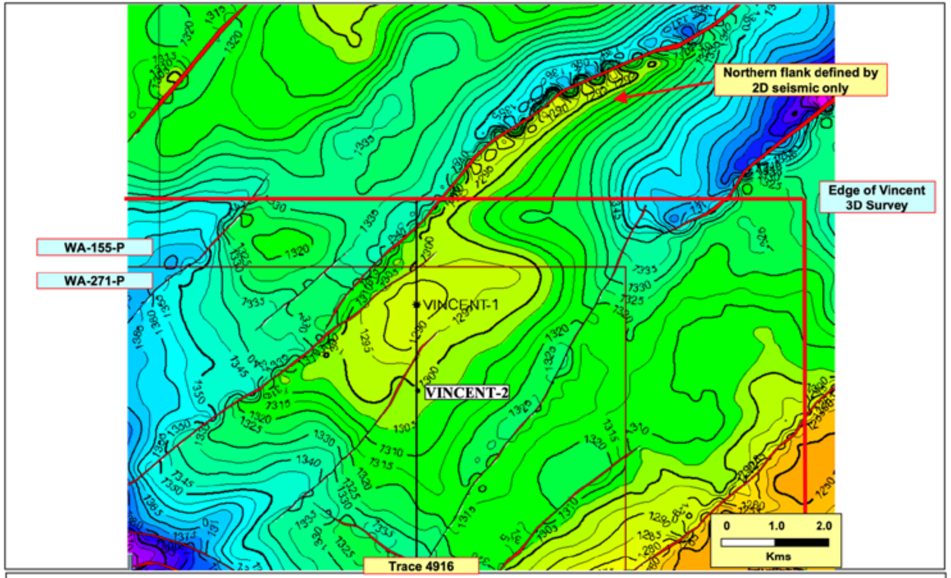
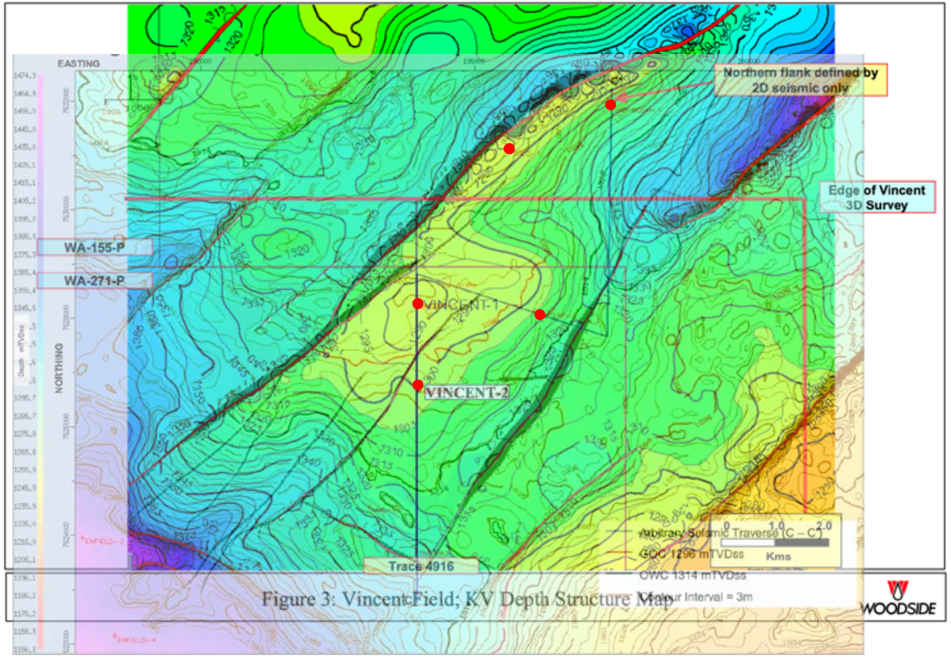


Figure 3: Vincent Field; KV Depth Structure Map

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

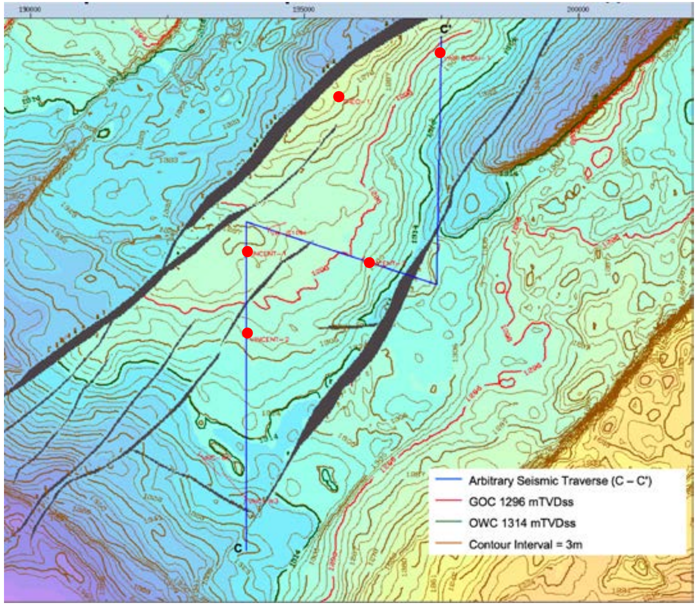
Vincent



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Vincent

Field		OWC	Variance
Vincent	1	-1314.7	-3.7
	2	-1314.5	-3.5
	3	-1310.8	0.2
Theo	1	-1309.4	1.6
Van Gough	11-H	-1305.4	5.6



Vincent

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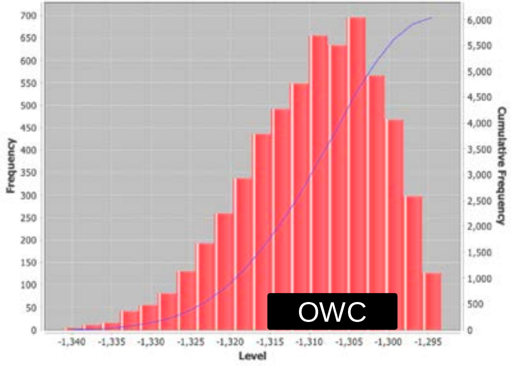
	3	-1310.8	0.2
Theo	1	-1309.4	1.6
Van Gough	11-H	-1305.4	5.6

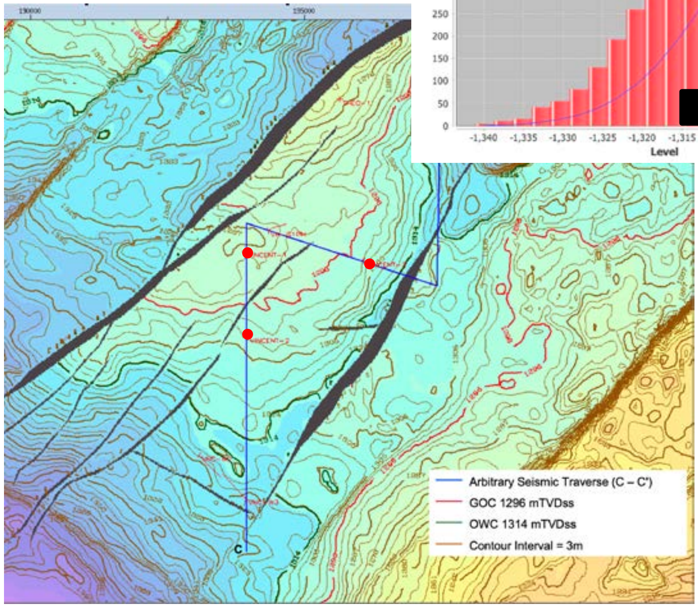
60.4% chance of Fault_West_South controlling OWC

- OWC: Mean -1309.5 m, Standard Deviation 8.5 m
- Error: **Mean 7.3 m**, Standard Deviation 6.0m

39.6% chance of Fault_West_North controlling OWC

- OWC: Mean -1316 m, Standard Deviation 9.7 m
- Error: **Mean 11 m**, Standard Deviation 9.2 m





SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Vincent

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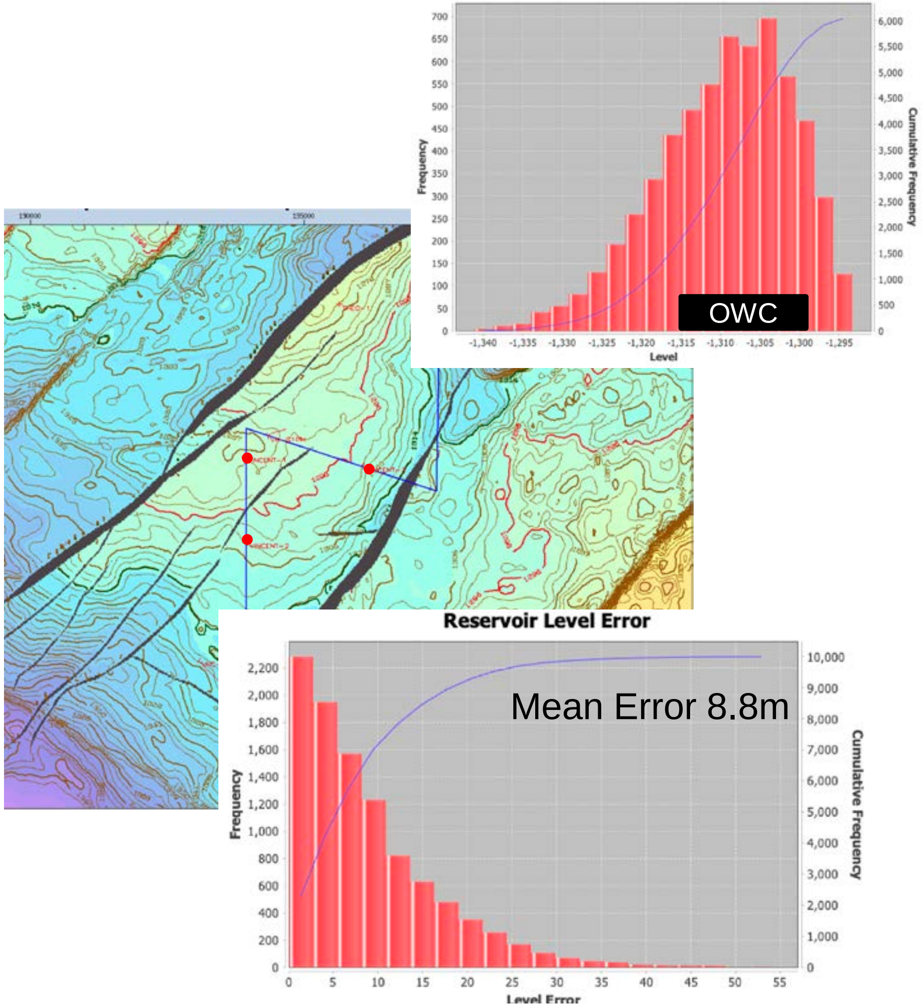


60.4% chance of Fault_West_South controlling OWC

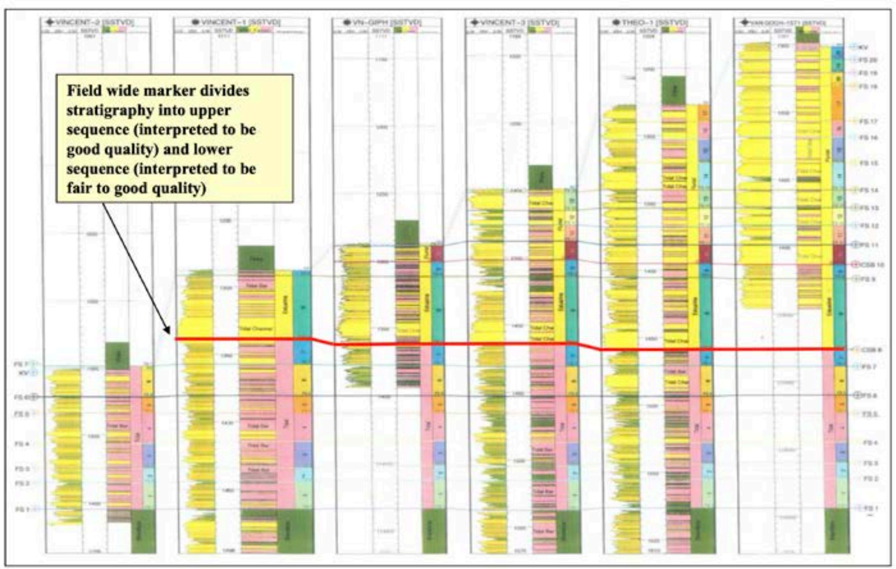
- OWC: Mean -1309.5 m, Standard Deviation 8.5 m
- Error: **Mean 7.3 m**, Standard Deviation 6.0m

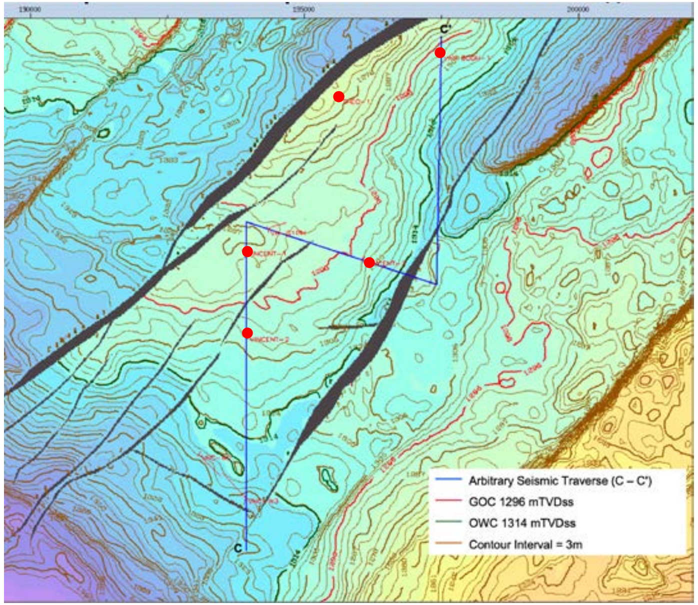
39.6% chance of Fault_West_North controlling OWC

- OWC: Mean -1316 m, Standard Deviation 9.7 m
- Error: **Mean 11 m**, Standard Deviation 9.2 m

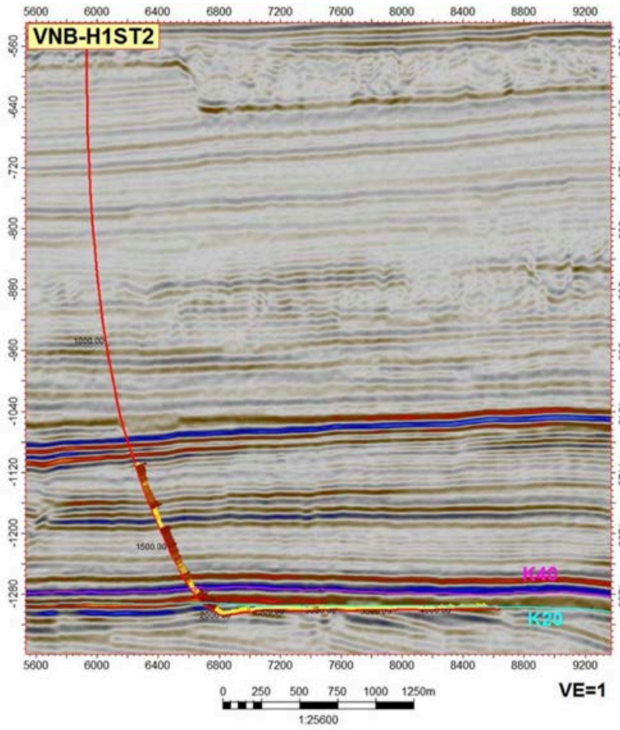
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

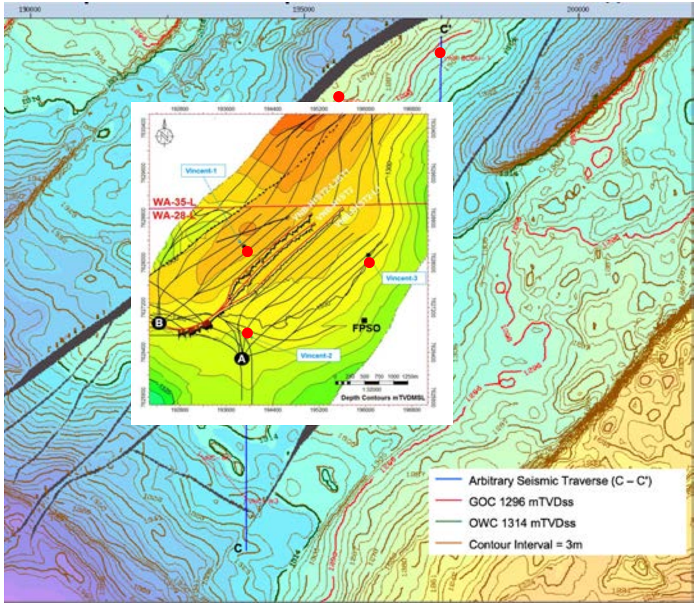
Vincent


Field wide marker divides stratigraphy into upper sequence (interpreted to be good quality) and lower sequence (interpreted to be fair to good quality)


C'
C
Arbitrary Seismic Traverse (C – C')
GOC 1296 mTVDss
OWC 1314 mTVDss
Contour Interval = 3m

Vincent





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STRUCTURAL GEOLOGY

Vincent

woodside

Schlumberger

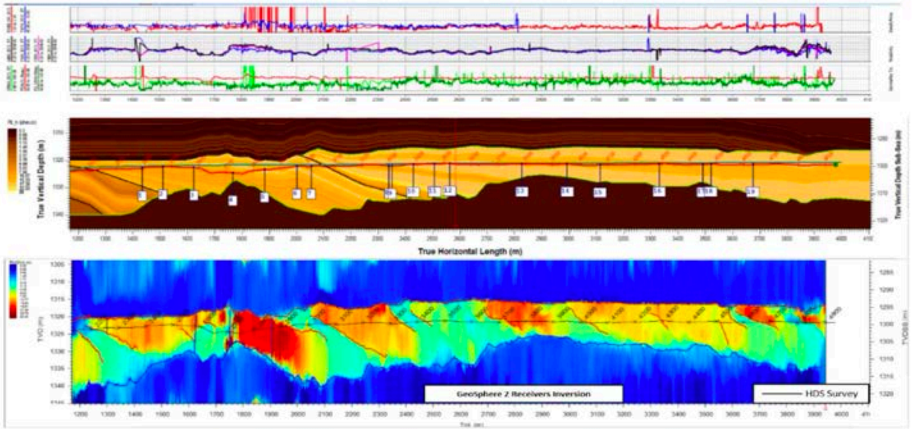
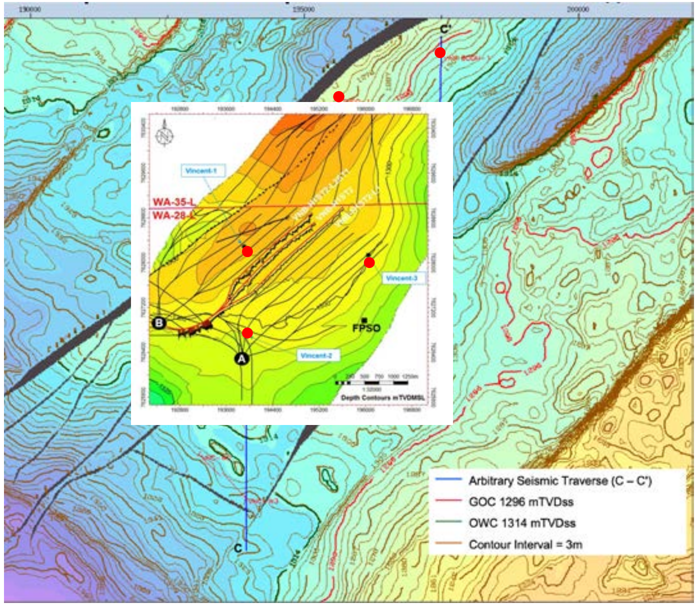


Figure 8: VNB-H1ST2-L1 GeoSphere Inversion canvas, from the beginning of the section to TD.



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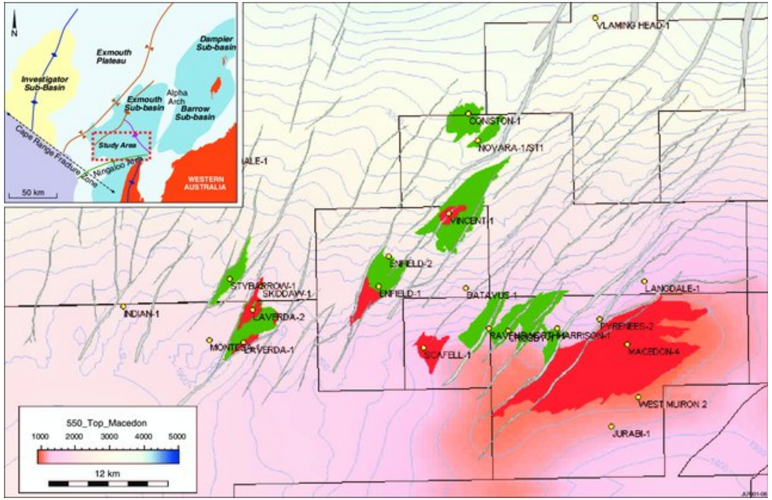
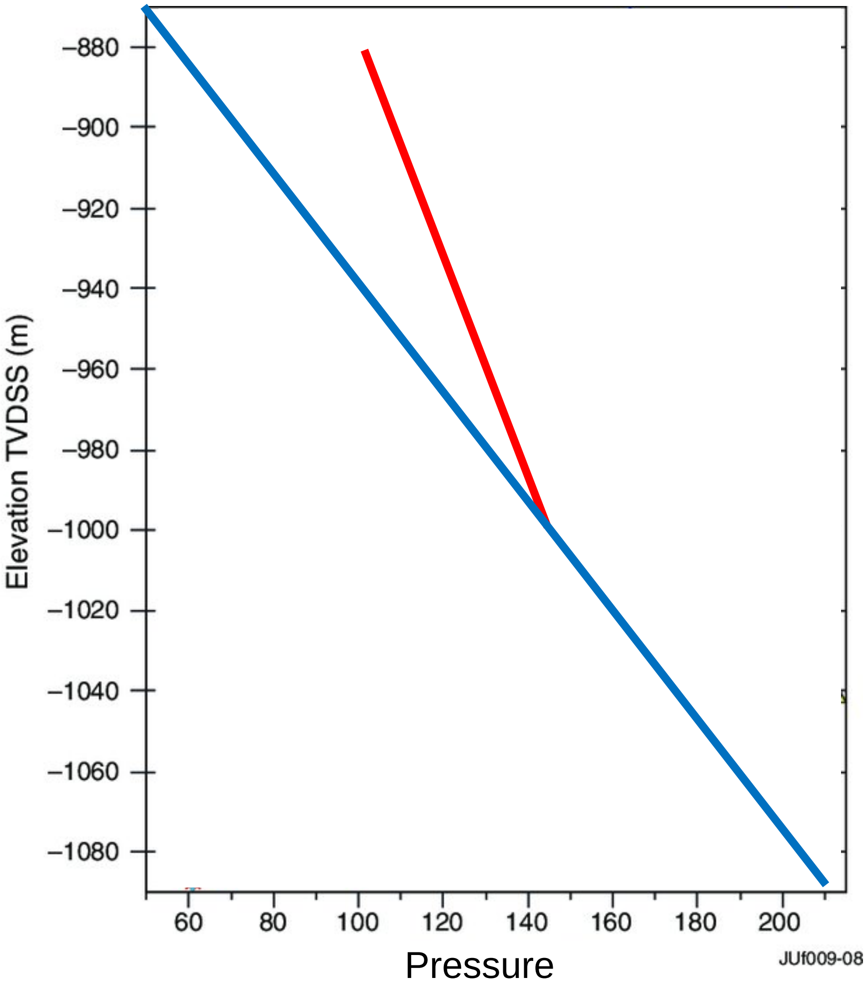
CSIRO PUBLISHING
www.publish.csiro.au/journals/eg Exploration Geophysics, 2008, 39, 85–93

The hydrodynamics of fields in the Macedon, Pyrenees, and Barrow Sands, Exmouth Sub-basin, Northwest Shelf Australia: identifying seals and compartments*

J. R. Underschultz[1,3] R. A. Hill[2] S. Easton[2]

[1]CSIRO Petroleum, PO Box 1130, Bentley, WA 6102, Australia.
[2]BHP Billiton Petroleum, 152-158 St Georges Terrace, Perth, WA, 6000, Australia.
[3]Corresponding author. Email: james.underschultz@csiro.au





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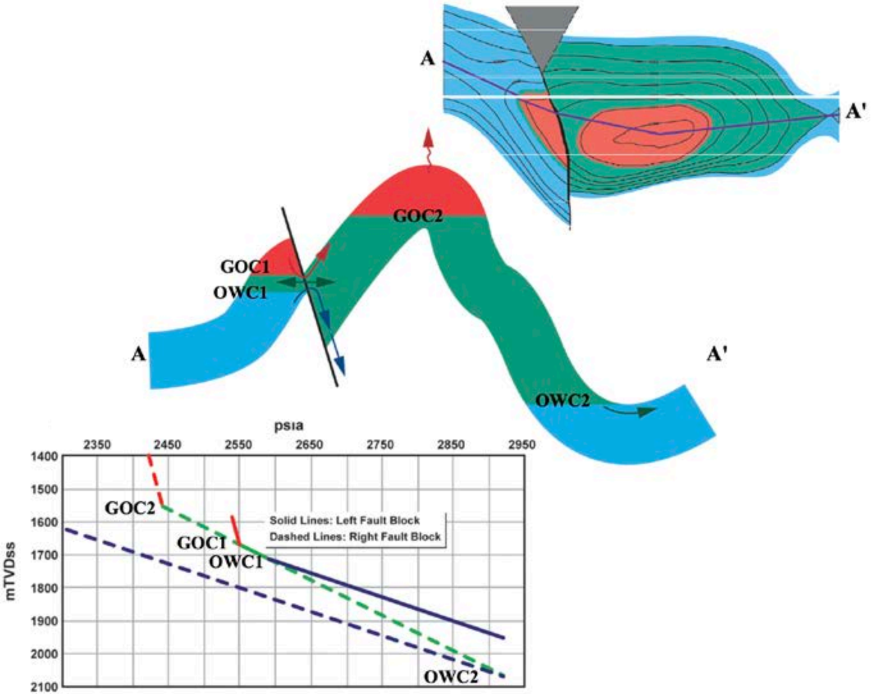
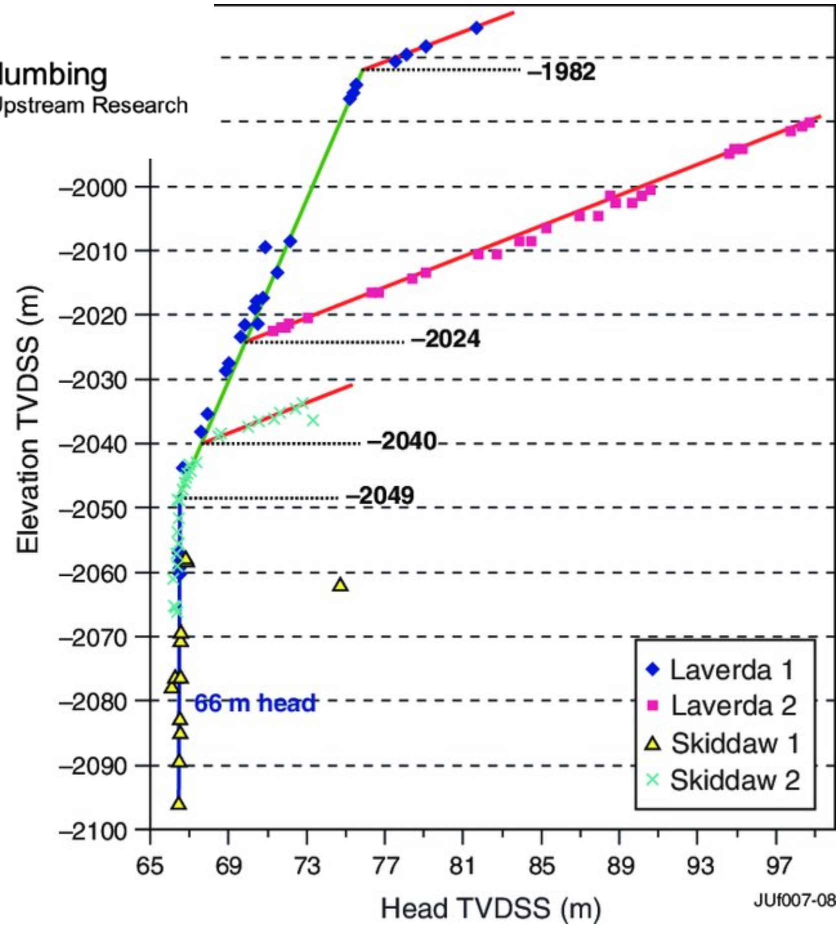
SPE-93577-PP

Reservoir Connectivity Analysis - Defining Reservoir Connections and Plumbing

Peter Vrolijk, Bill James, Rod Myers, James Maynard, Larry Sumpter, and Mike Sweet (ExxonMobil Upstream Research Company)





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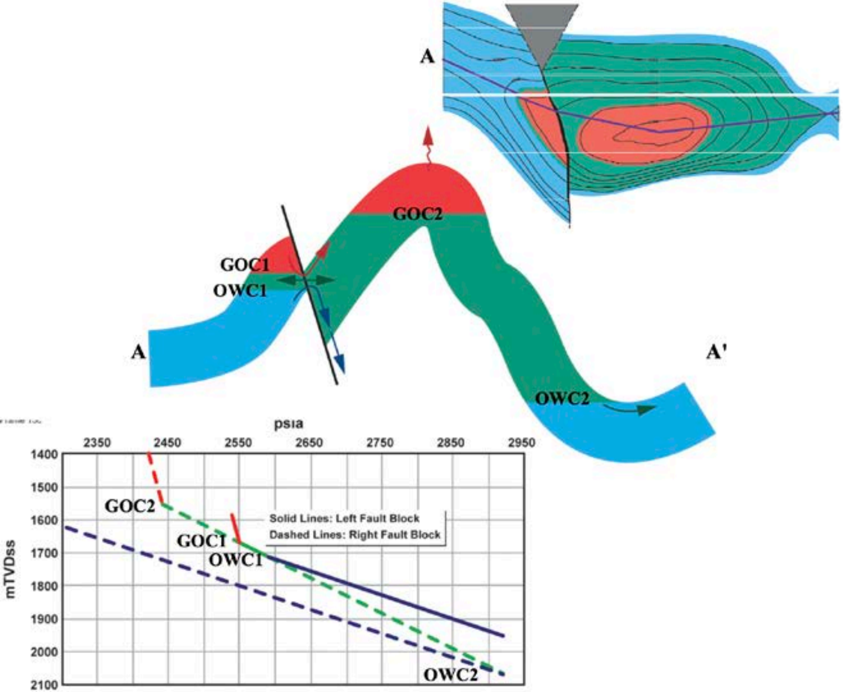
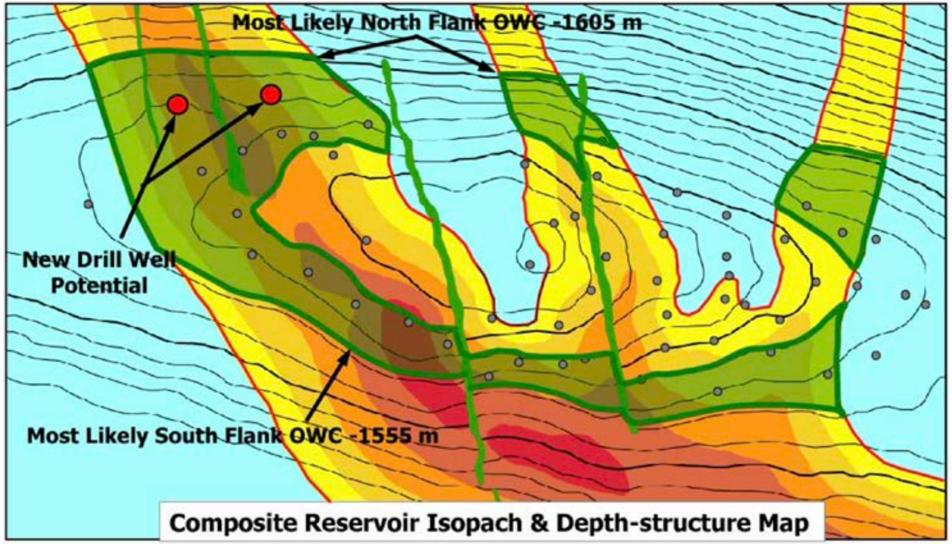




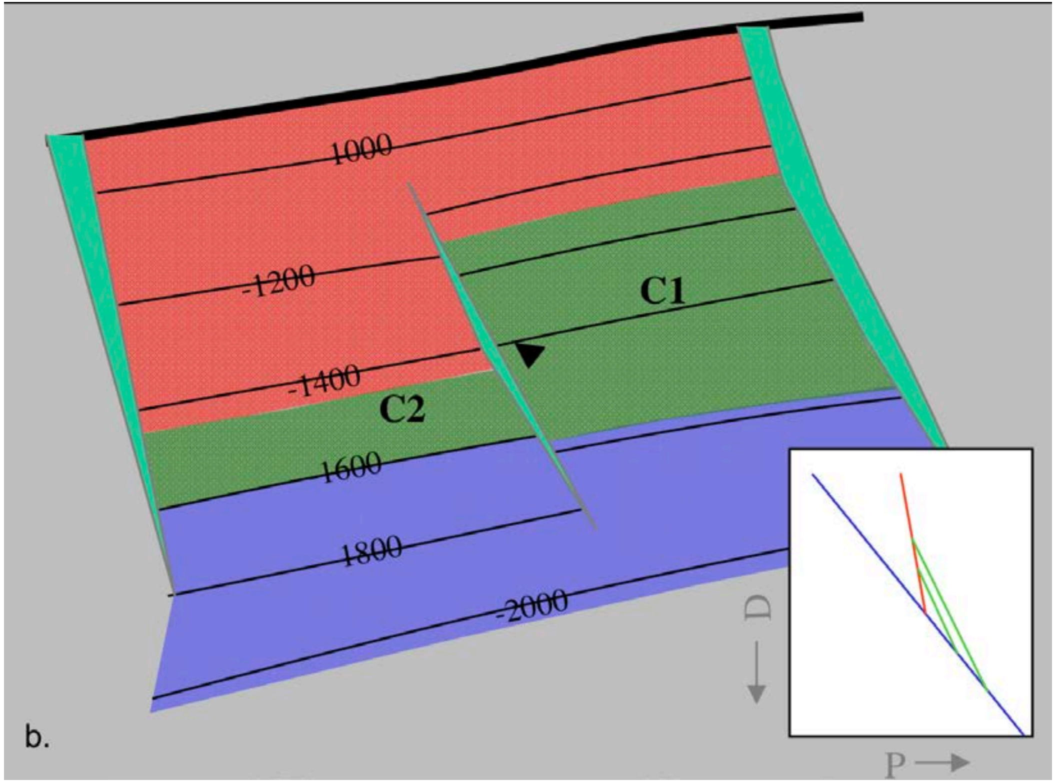
Tabu Field, Malaysia, reservoir connectivity analysis

IPTC 11375

Reservoir Connectivity: Definitions, Examples, and Strategies

John W. Snedden, Peter J. Vrolijk, Larry T. Sumpter, Mike L. Sweet, Kevin R. Barnes, Elijah White and Mike E. Farrell,
ExxonMobil Upstream Research Company

This paper was prepared for presentation at the International Petroleum Technology Conference held in Dubai, U.A.E., 4–6 December 2007.

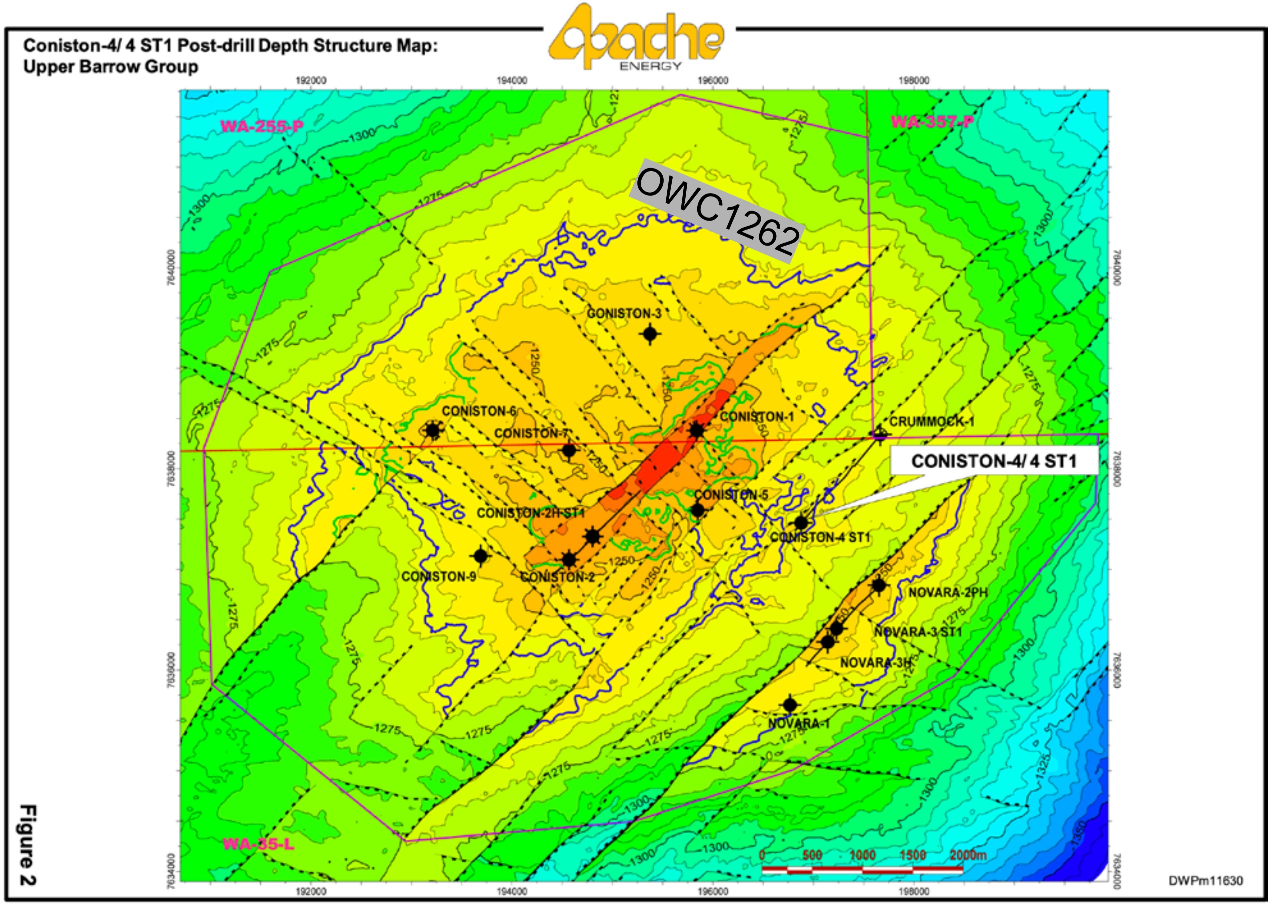


SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Coniston Novara Crumnock

Field		OWC	Variance
CONISTON	1	-1262.5	-0.80
	2	-1260.6	1.10
	3	-1261.9	-0.20
	4ST1	-1257.0	4.70
	5	-1257.8	3.90
	6	-1265.5	-3.80
	7	-1263.7	-2.00
	9	-1264.6	-2.90
	15	-1262.5	-0.80



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

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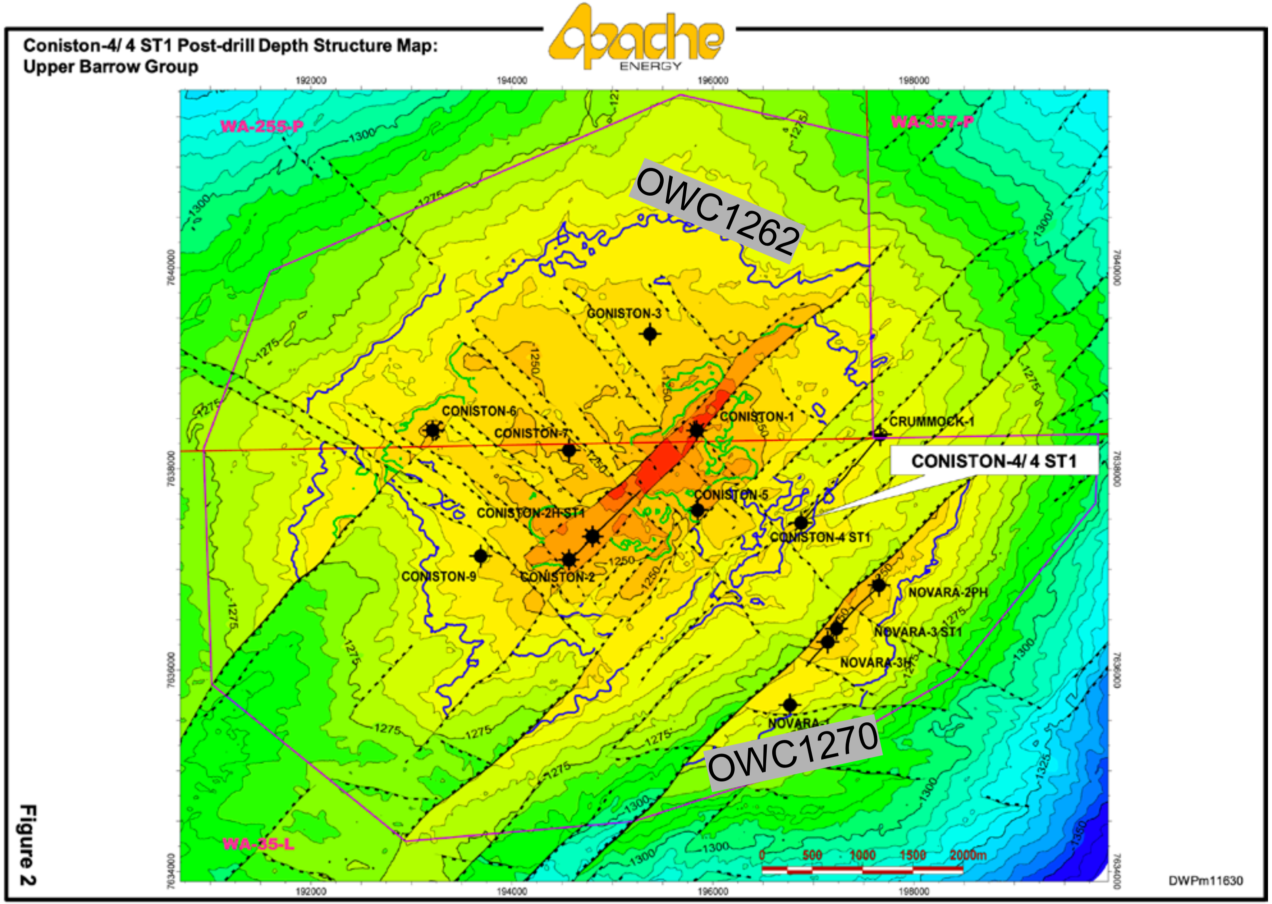
	15	-1262.5	-0.80
Novara	1	-1270.0	0
	2	-1259.0	-11
	3	-1266.0	-4



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

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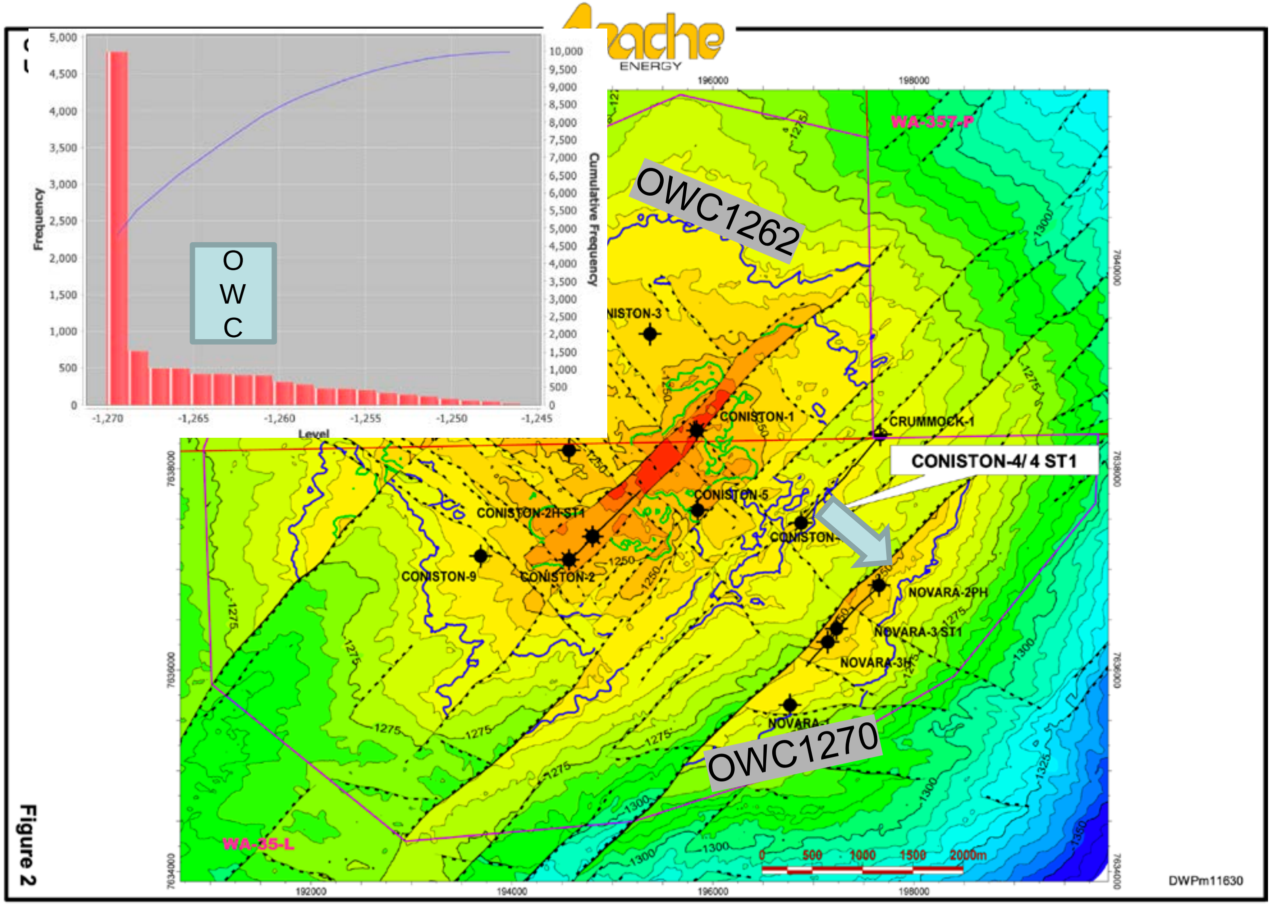

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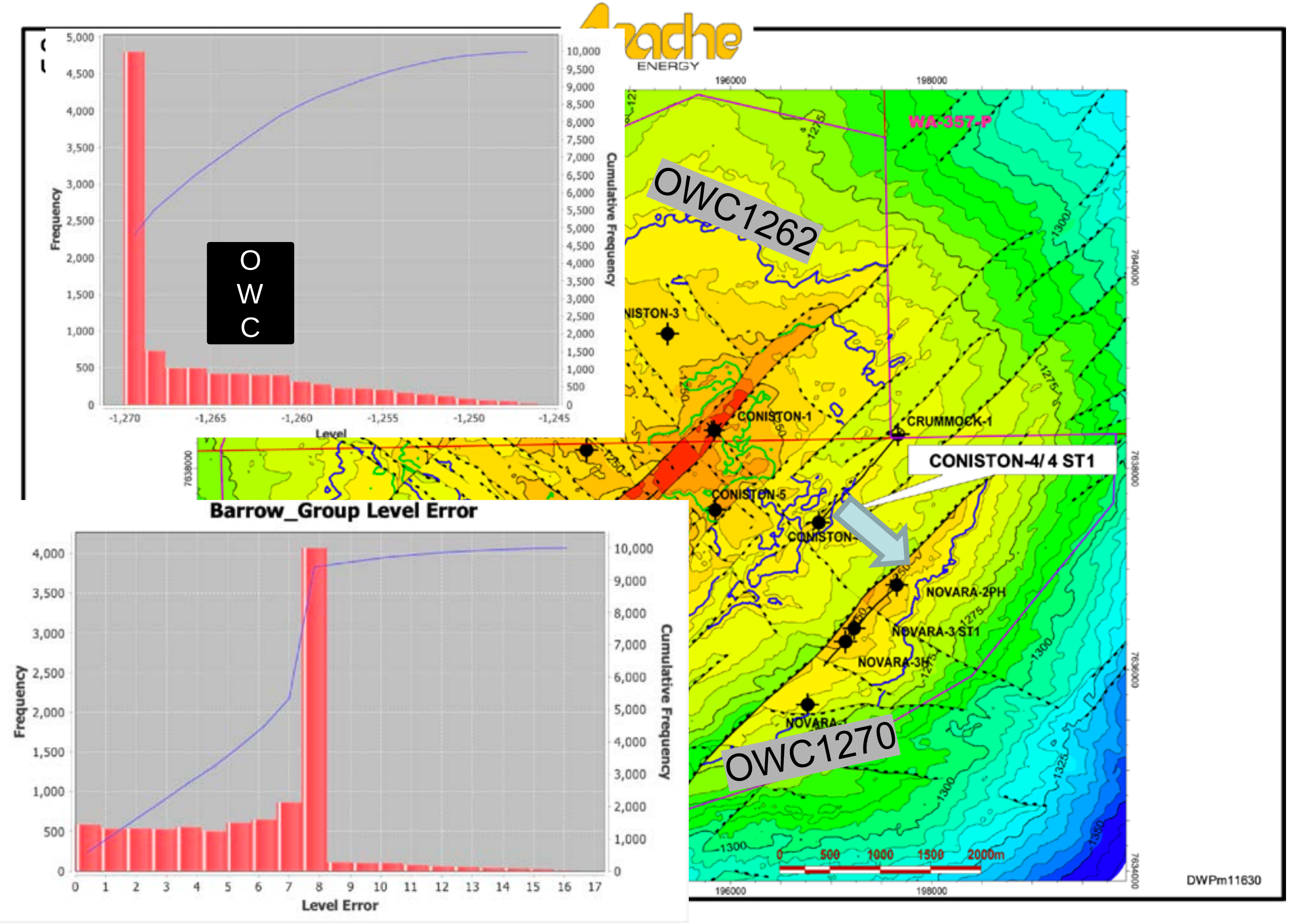

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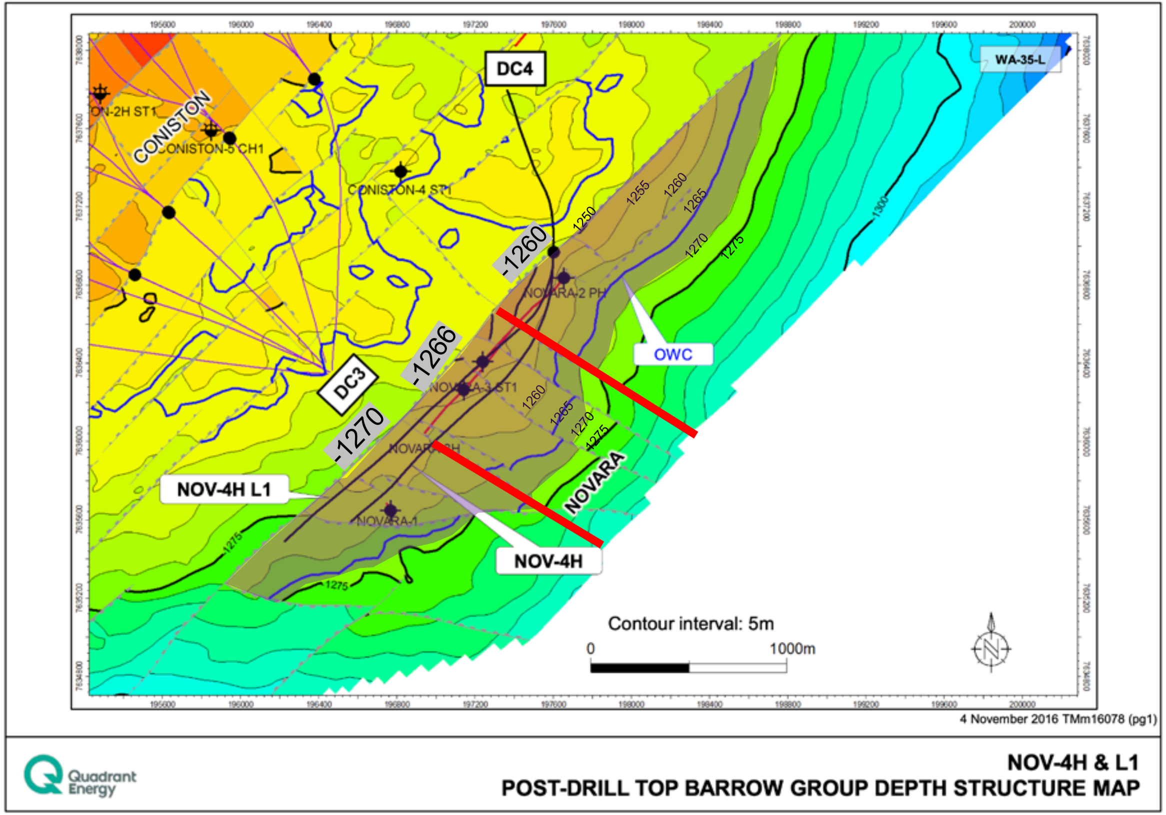
Fault Seal Model Proposed



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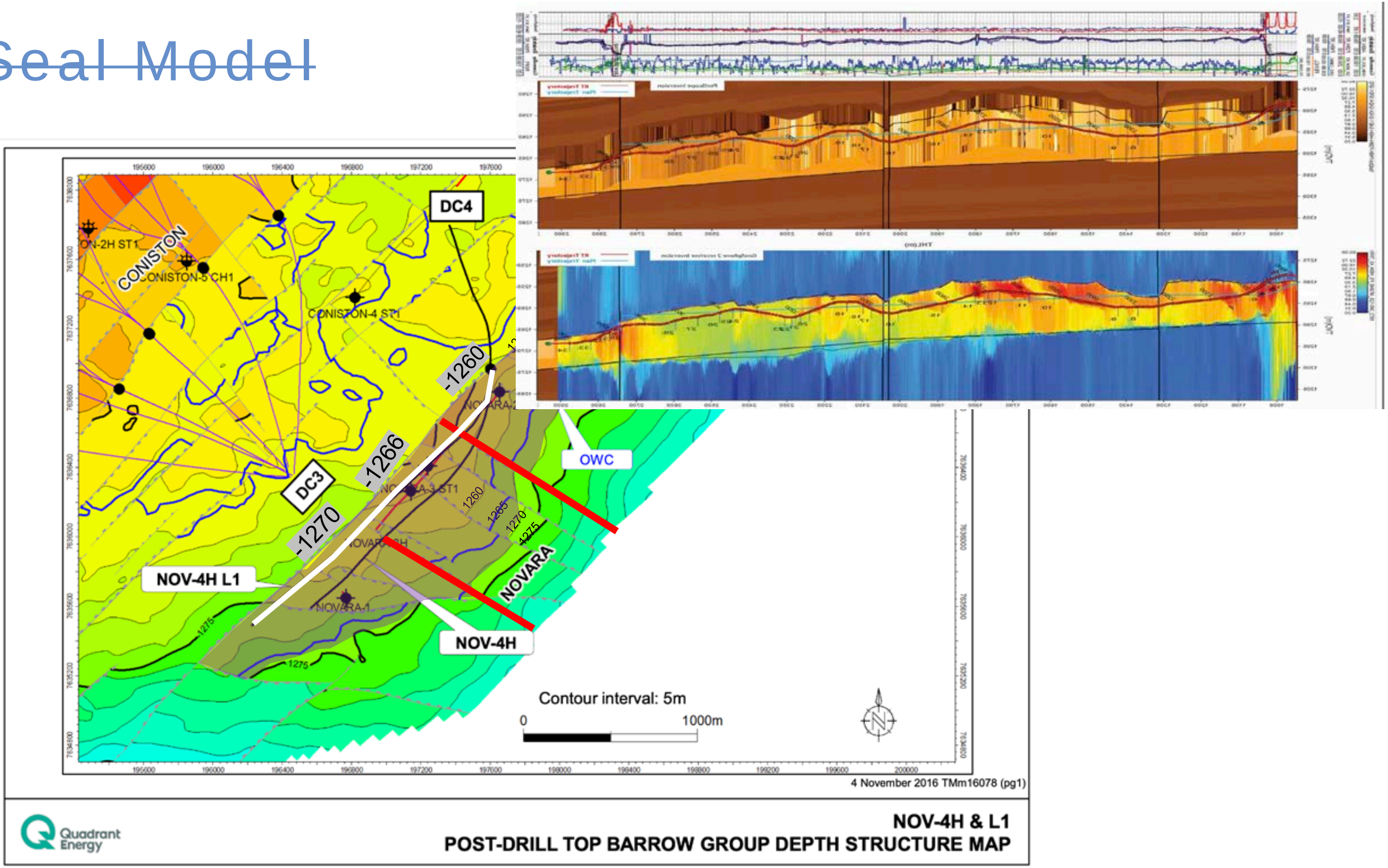
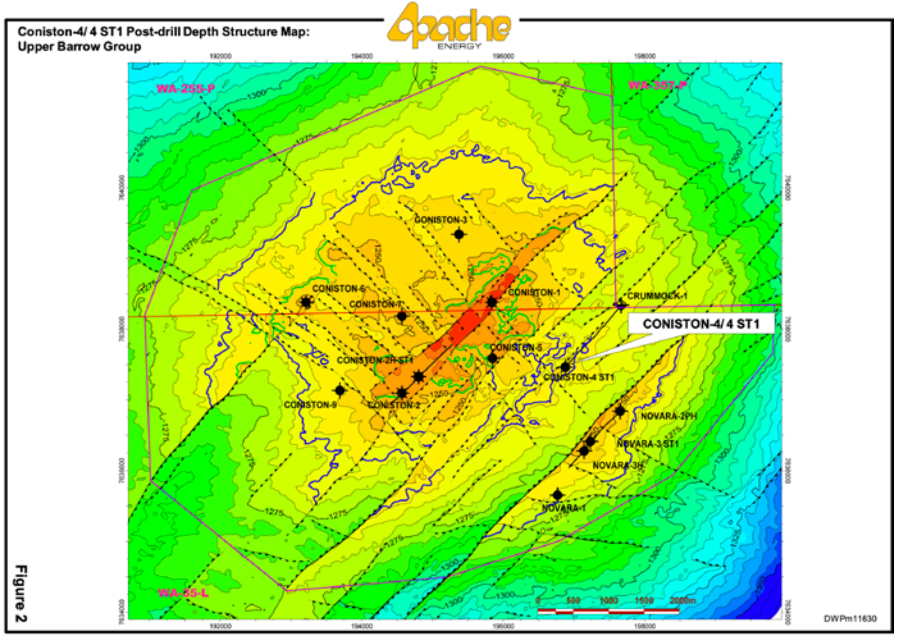
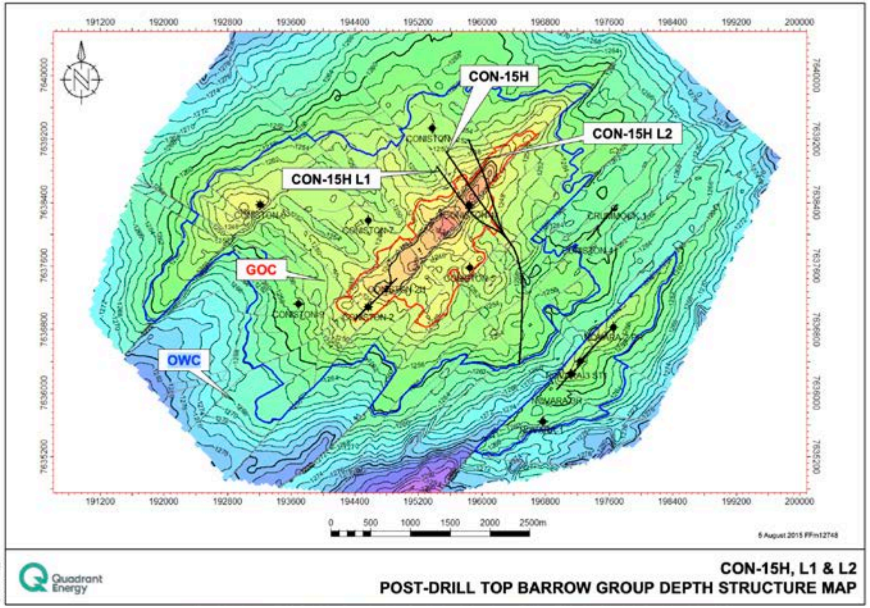
~~Fault Seal Model~~



Why Underfilled?





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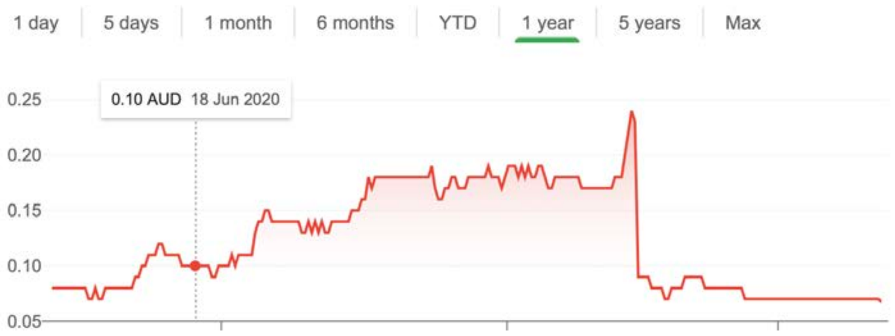
Groundwater, CO2, Toxic and Rad Waste

- Getting it wrong with Oil and Gas is an issue for us and the shareholders



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Groundwater, CO2, Toxic and Rad Waste

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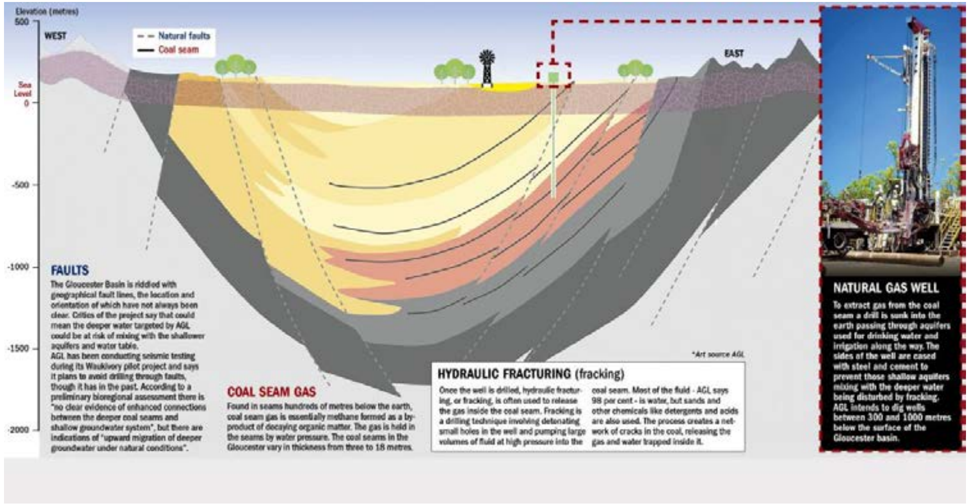
- Getting it wrong with CCS, Groundwater and waste is an issue with regulators and society.



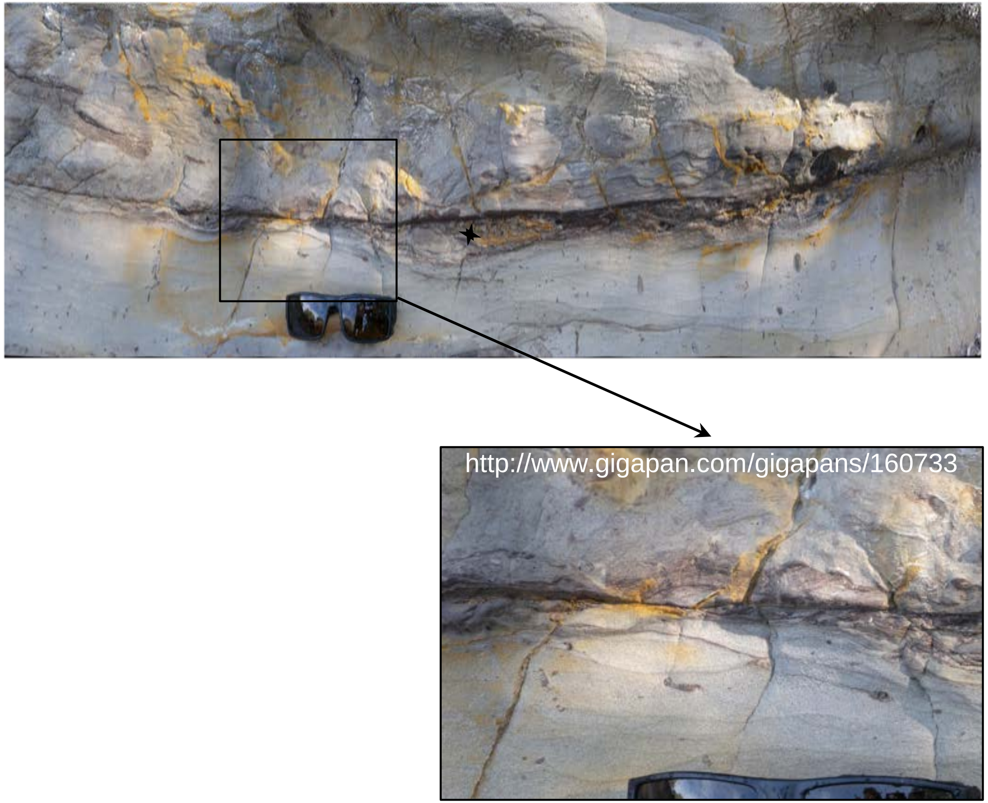
Public Trust

- Getting it wrong with Oil and Gas is an issue for us and the shareholders
- Getting it wrong with CCS, Groundwater and waste is an issue with regulators and society.
- Publications/algorithms must include data allowing invalidations

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Conclusions

- If juxtaposition works why use SGR?



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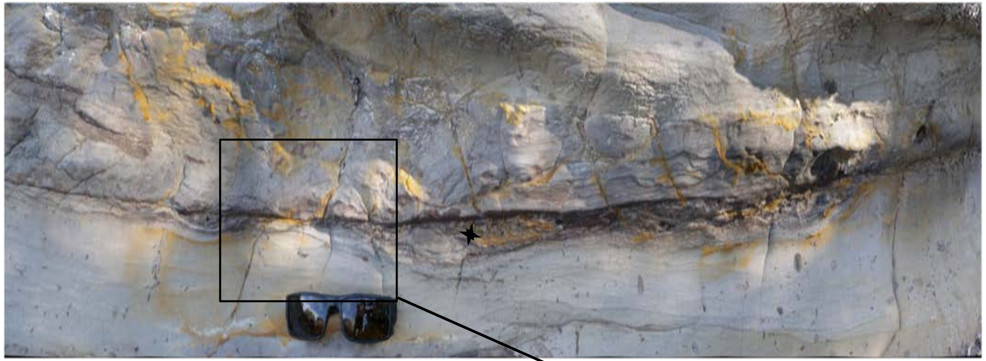
Conclusions

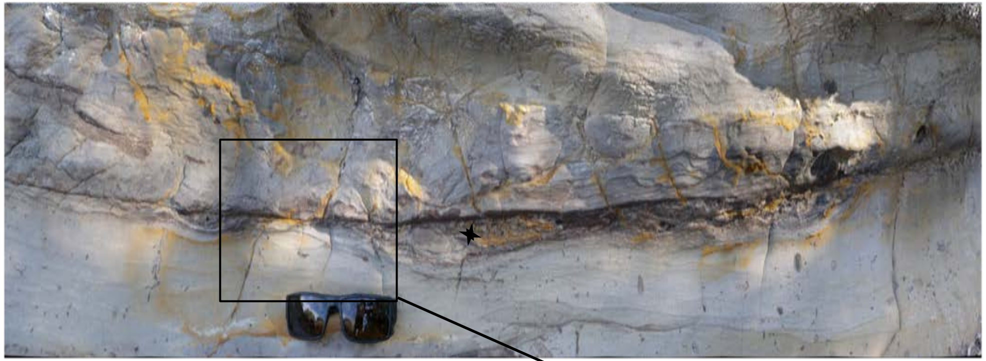
- If juxtaposition works why use SGR?
- Key control on fluid contacts the interplay between
  - Displacement
  - Stratigraphic seal thickness



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Conclusions

- If juxtaposition works why use SGR?
- Key control on fluid contacts the interplay between
  - Displacement
  - Stratigraphic seal thickness
- Faults have uncertainty and complexity thus it is vital to use geological valid stochastic modelling.



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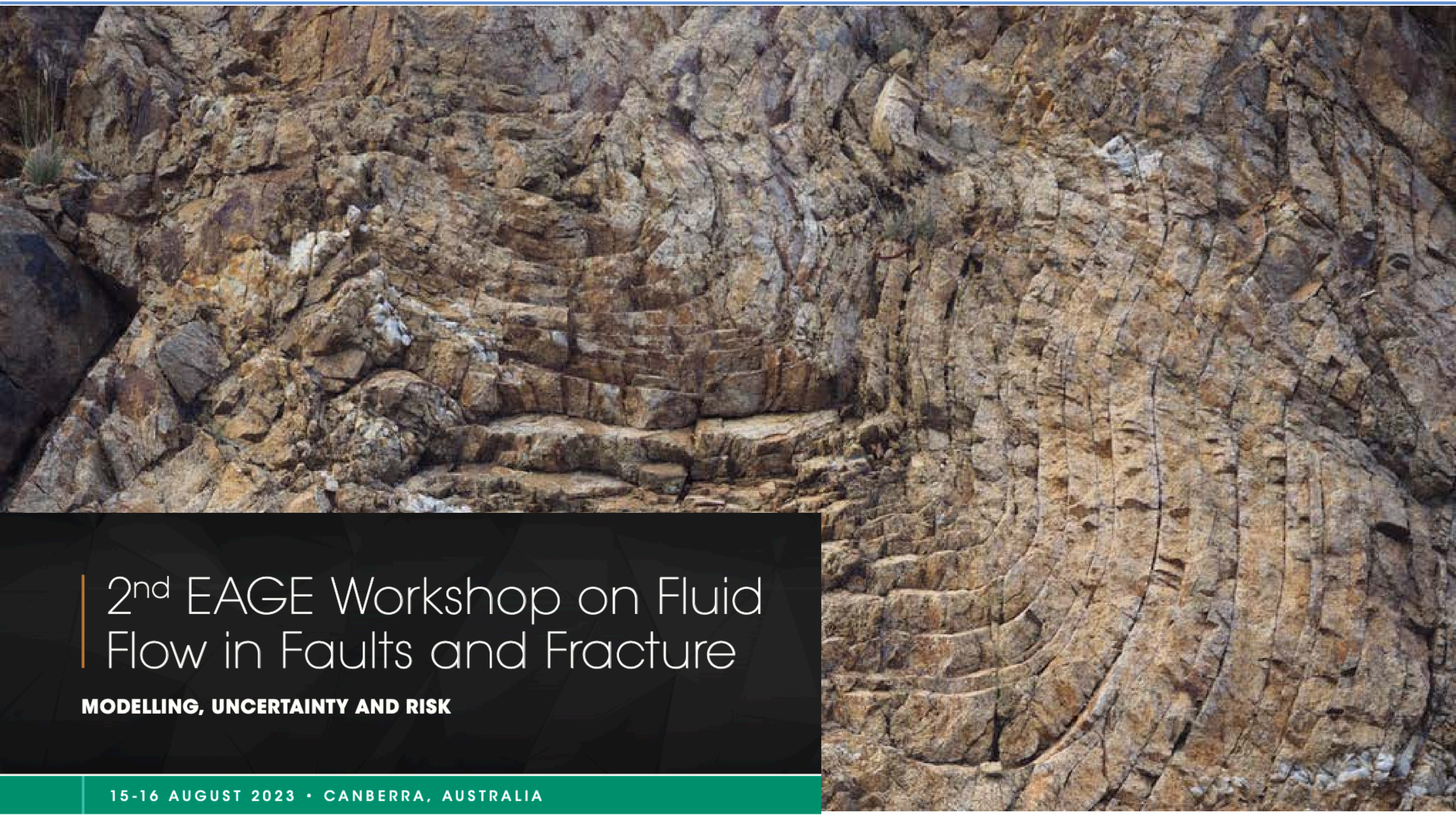

2nd EAGE Workshop on Fluid Flow in Faults and Fracture

MODELLING, UNCERTAINTY AND RISK

15-16 AUGUST 2023 • CANBERRA, AUSTRALIA

Questions

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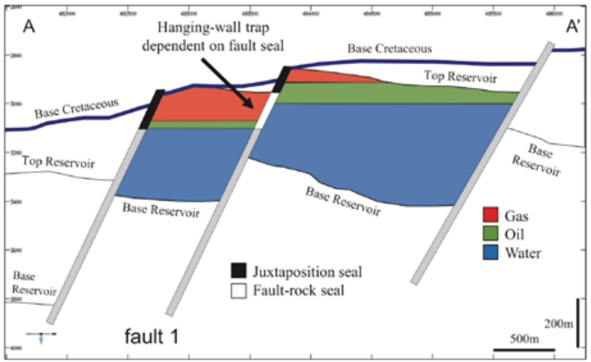
Value of Open File Data Sets

Published Stratigraphy



Discussion

PG
Petroleum Geoscience

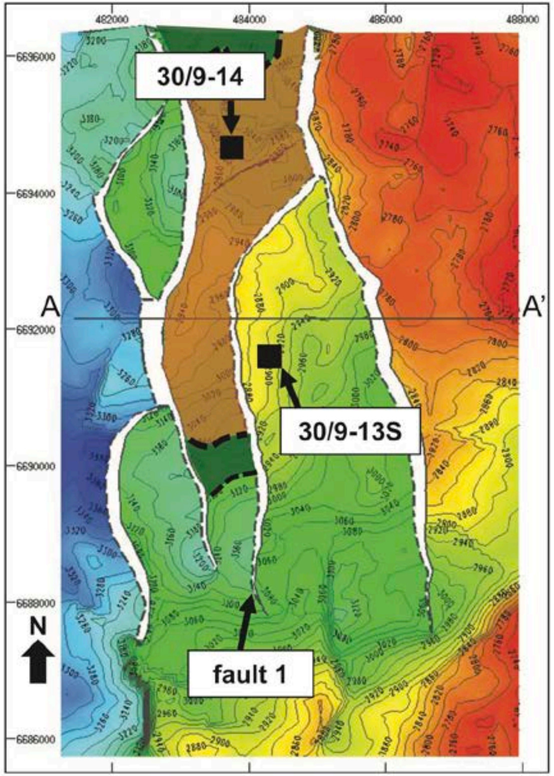
https://doi.org/10.1144/petgeo2020-081 | Vol. 27 | 2020 | petgeo2020-081

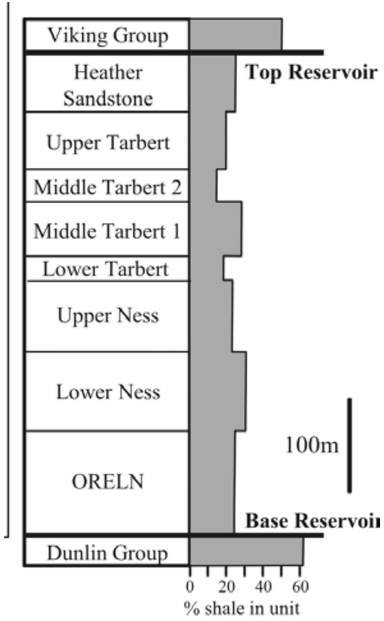
Discussion on 'A knowledge database of hanging-wall traps that are dependent on fault-rock seal', *Geological Society, London, Special Publications*, 496, 209–222, https://doi.org/10.1144/SP496-2018-157

William L. Power[1]* and Titus A. Murray[2]

[1] Power Geoscience, Perth, Western Australia, Australia
[2] Southern Highlands Structural Geology, Bowral, New South Wales, Australia
WLP, 0000-0001-7934-5092; TAM, 0000-0003-2043-196X
* Correspondence: bill.power@powergeoscience.com

Received 31 July 2020; **revised** 9 September 2020; **accepted** 9 October 2020





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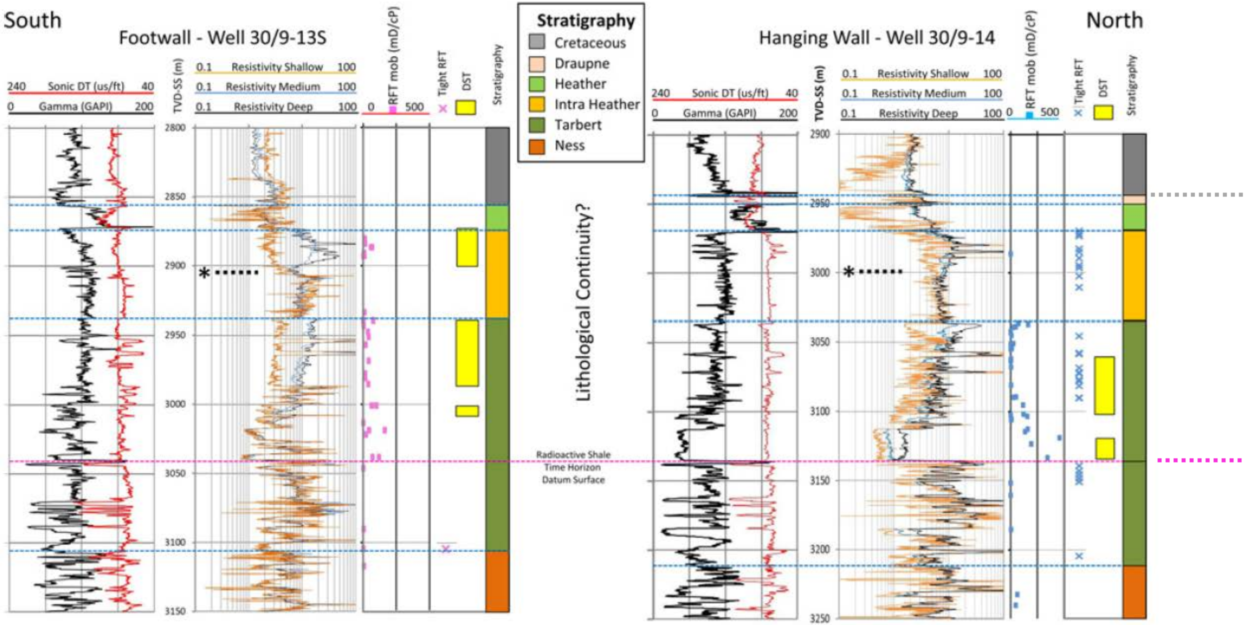
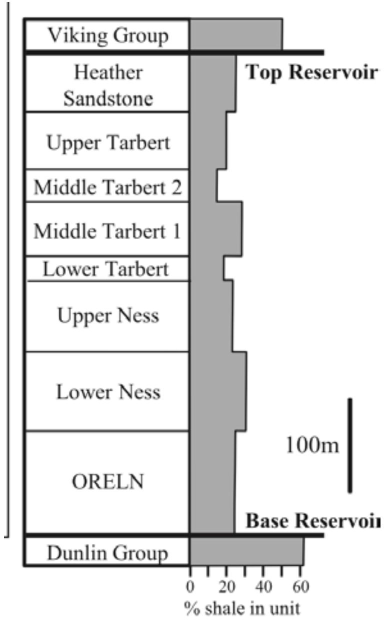
NPD Public Data Not In the Publication





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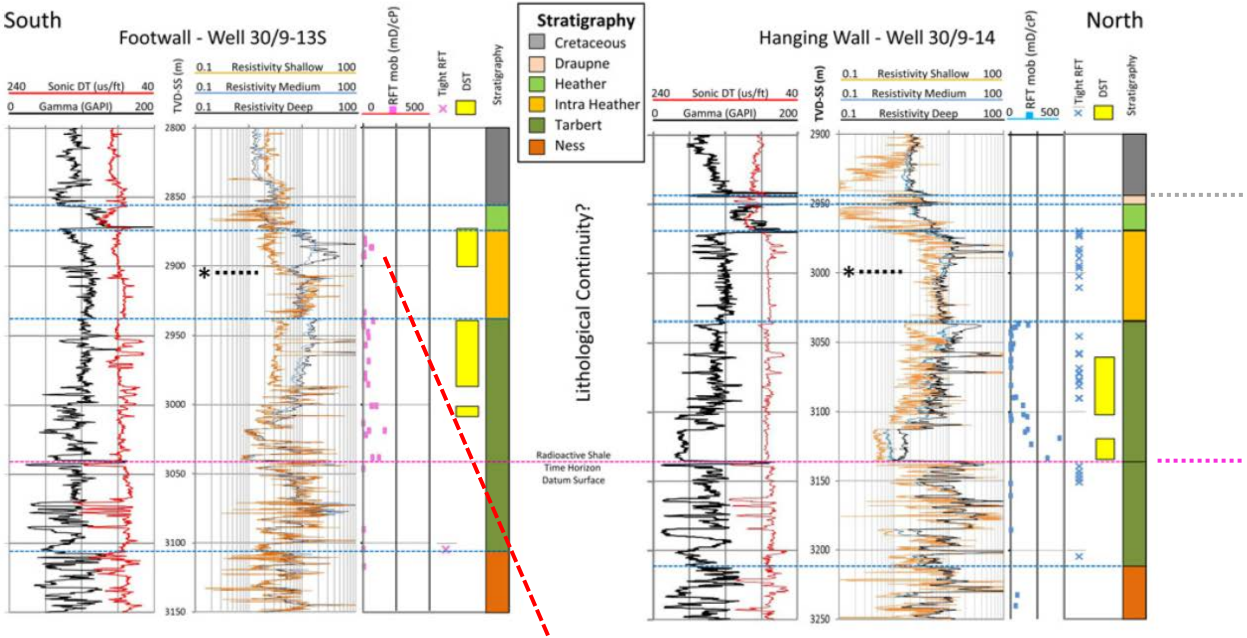
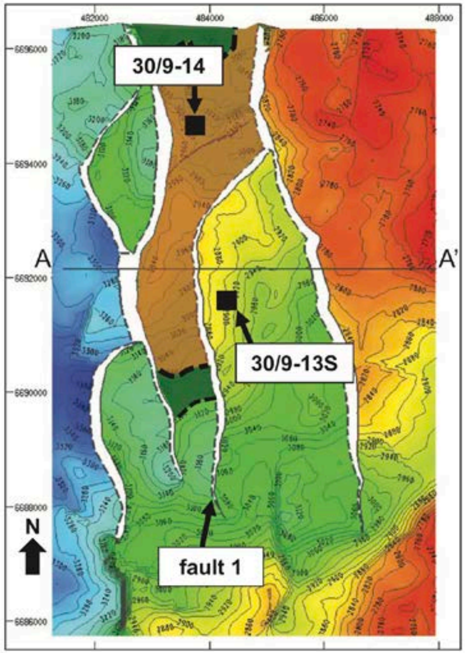


Good reservoir



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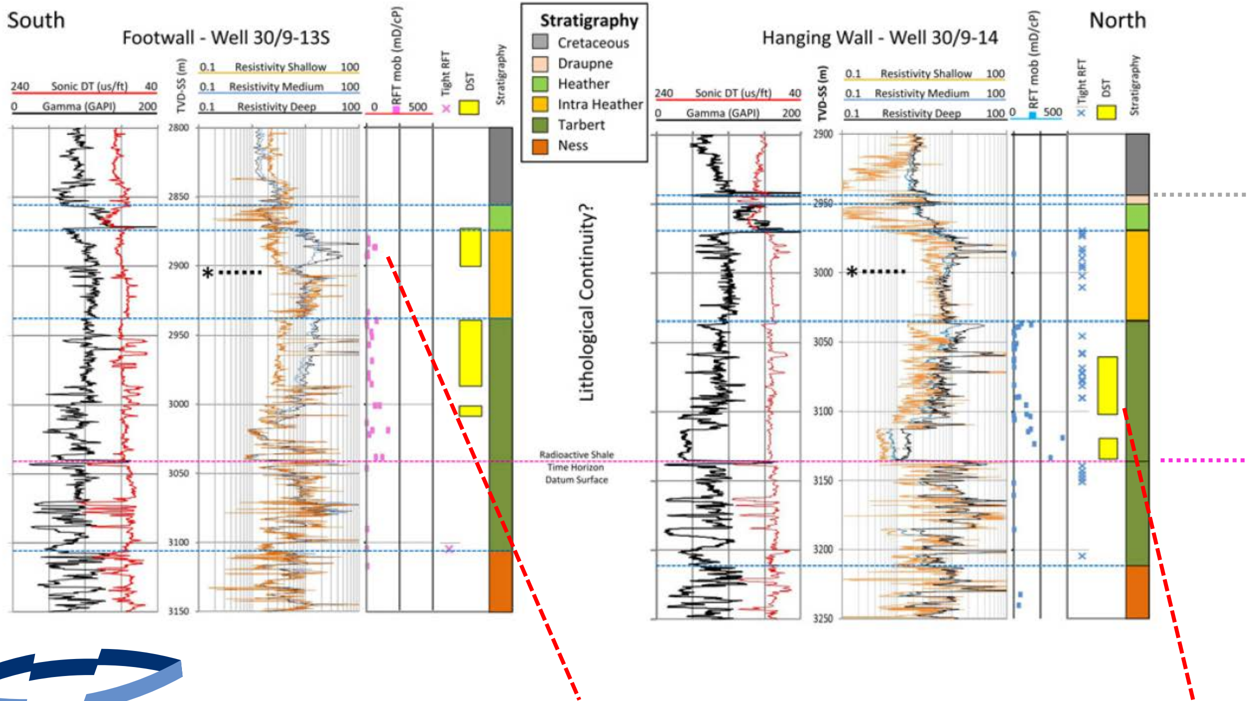
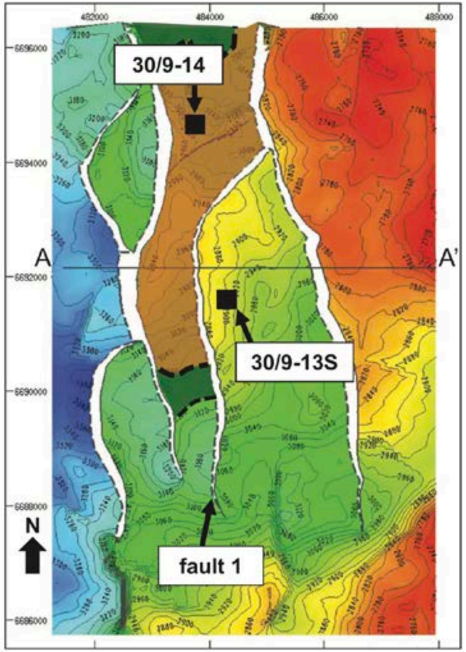
Now Where is the Reservoir?





Good reservoir

Good reservoir

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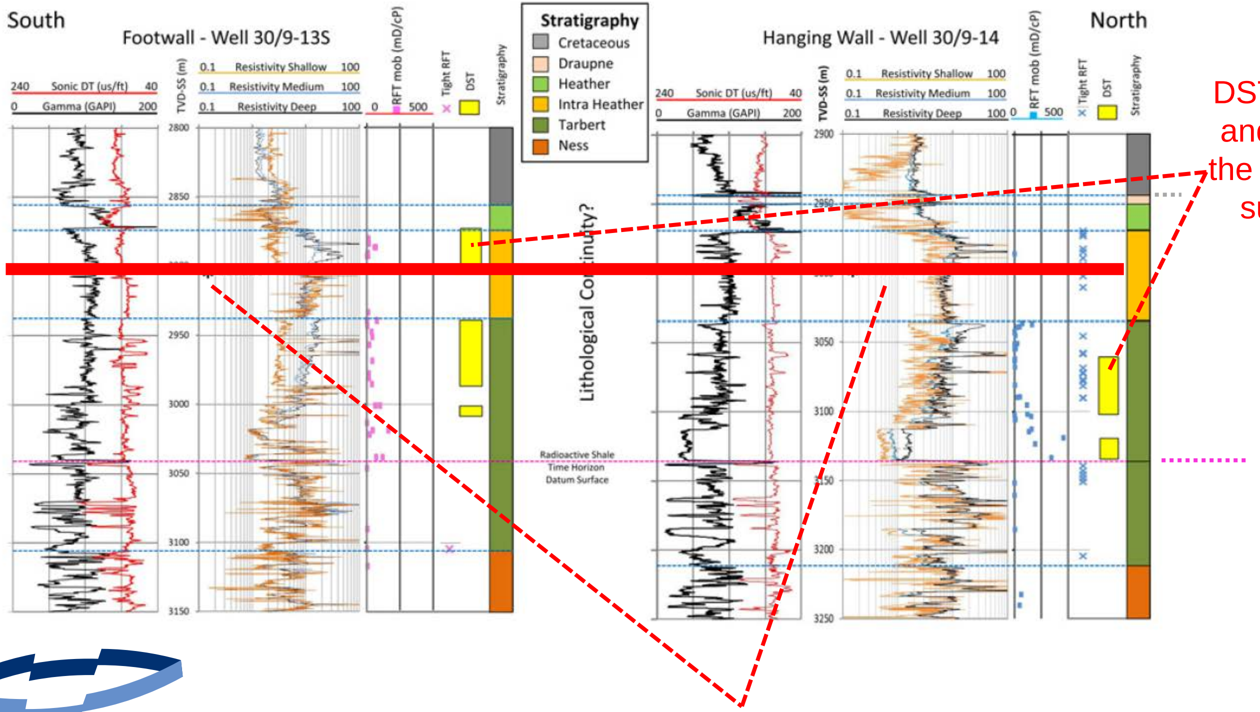
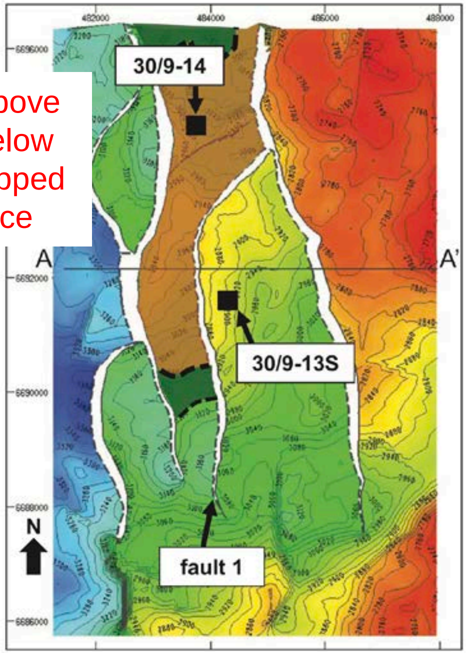
Map and Reservoir!



DST above and below the mapped surface



Map Ties – same level, but not at the BCU, not at “Top Reservoir”

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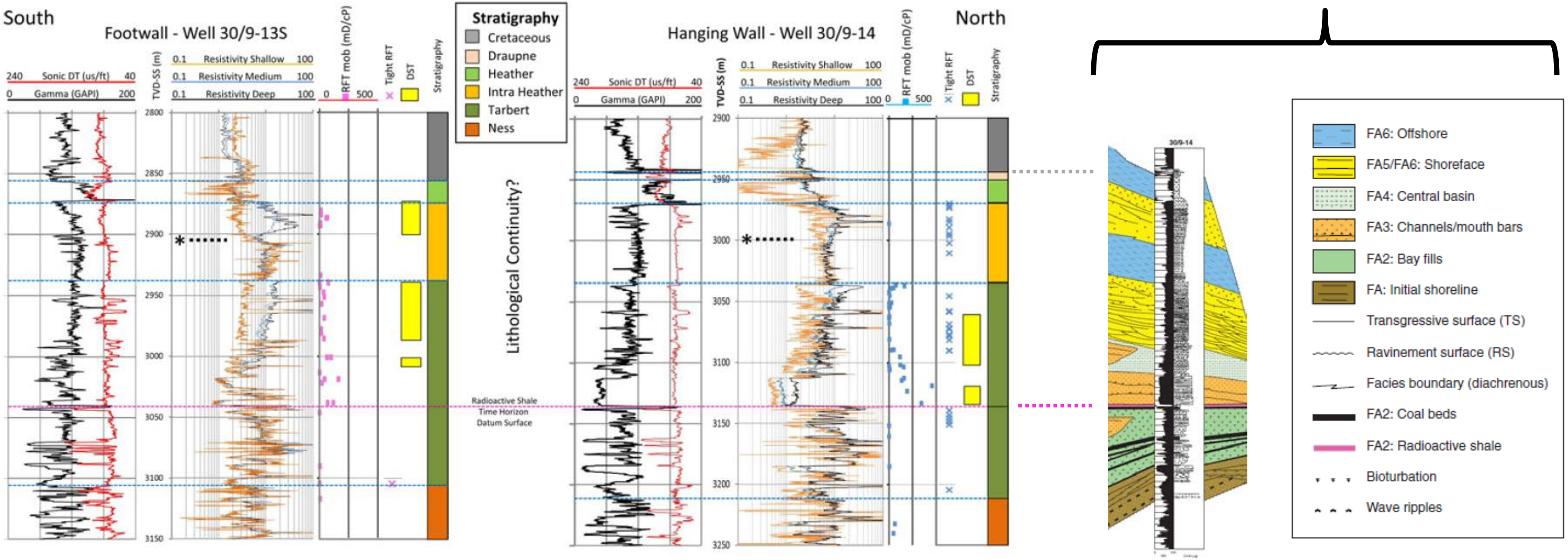
Sequence Stratigraphy

Well 13 Drilled 1991

Well 14 Drilled 1993

Stratigraphic Study by Løseth et al 2009



Tarbert Stratigraphy

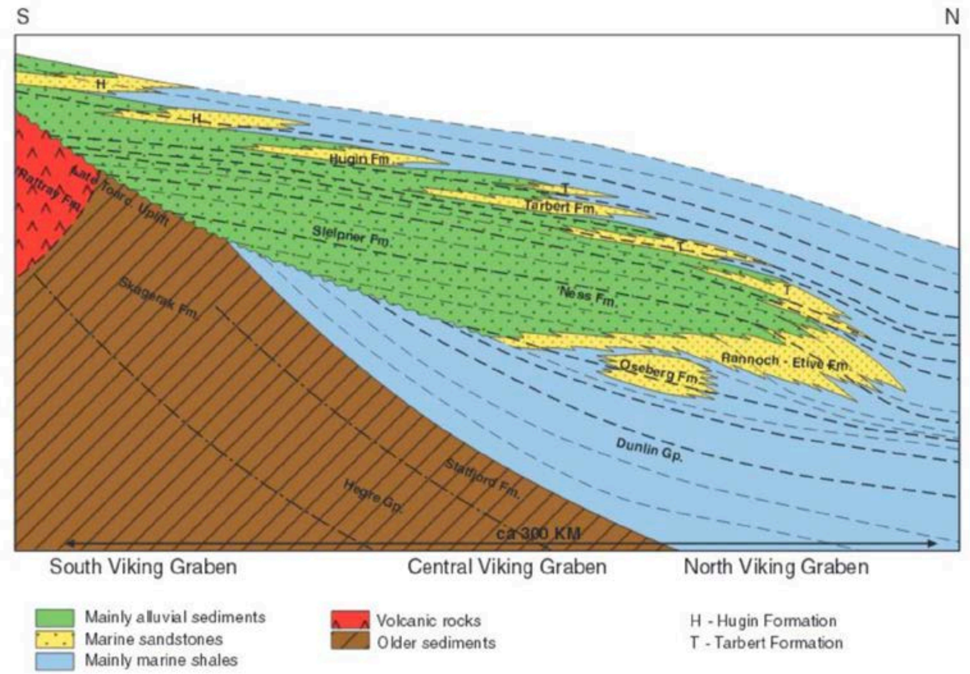


Figure 2-2: Schematic stratigraphic section of Brent-and Vesland groups, showing formations and timelines within the overall regressive-to transgressive megasequence (Helland-Hansen et al., 1992; Løseth et al.,2009).

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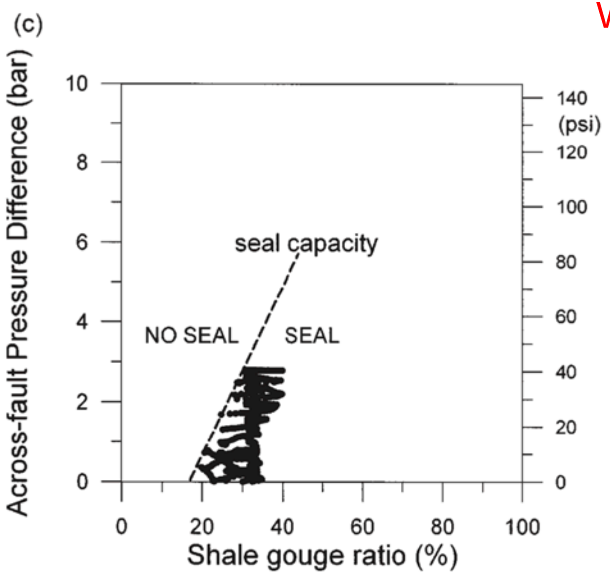
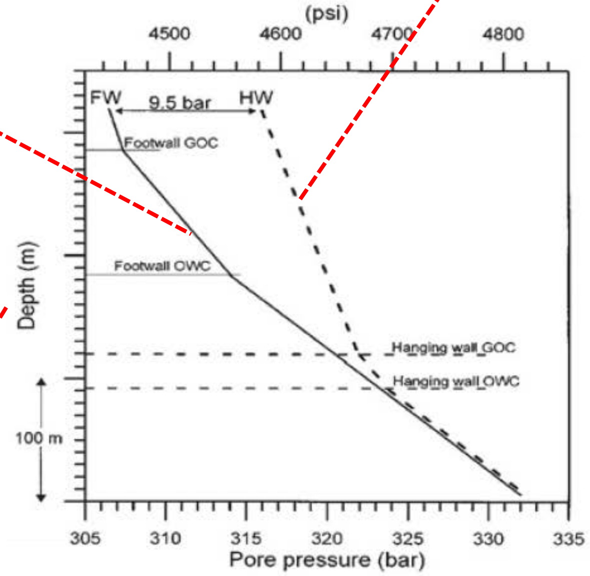
Anonymised Pressure Data



Well 13 – Footwall

Well 14 – Hanging wall



Pressure interpretation from Yielding (1997)

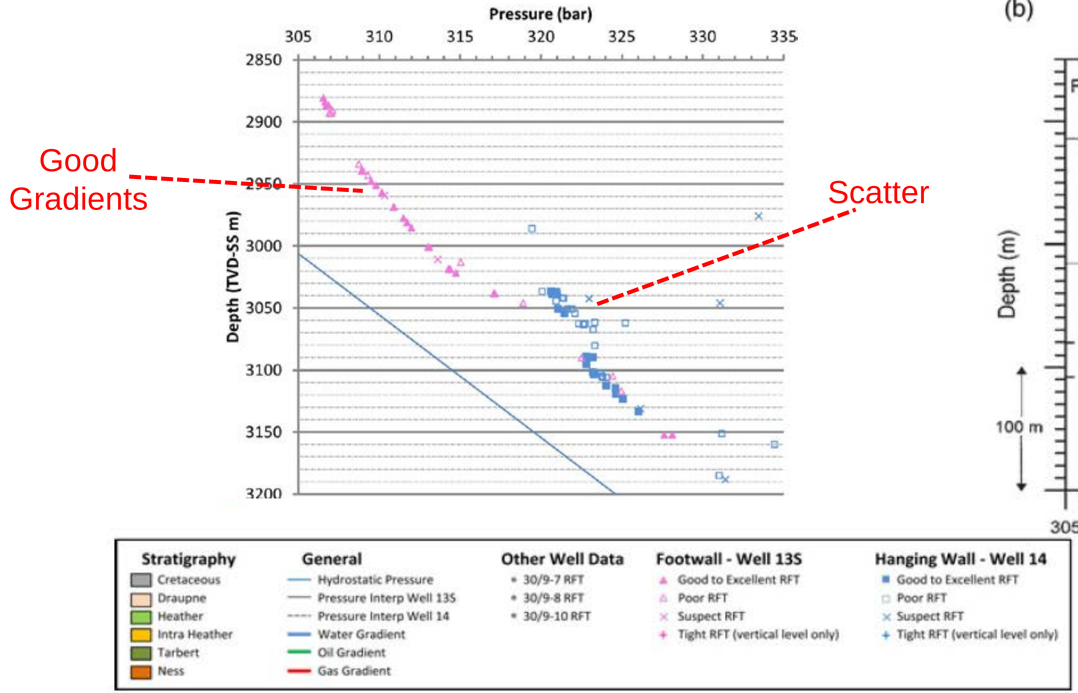
Vertical Position Not Shared in Publications

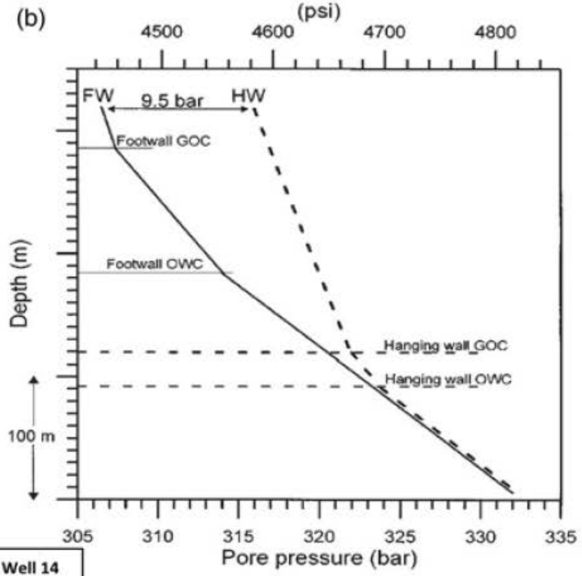
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Wells Drill 92 & 93
NPD Pressure Data Available 94 and 95

Well 13 Footwall

Well 14 Hanging Wall





Pressure interpretation from Yielding (1997) is shown in both (a) and (b)

Parts (a) and (b) share the same vertical axis

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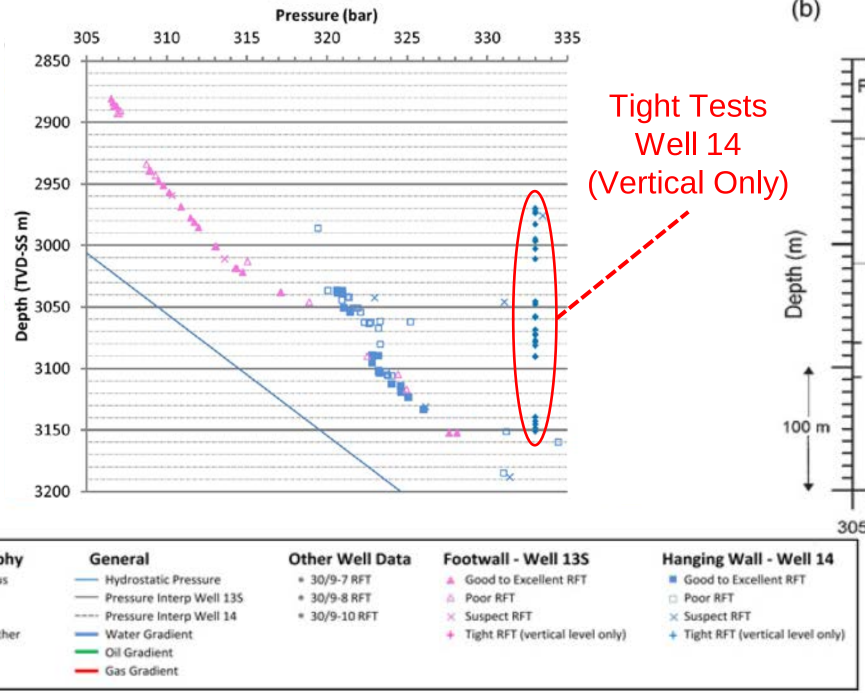
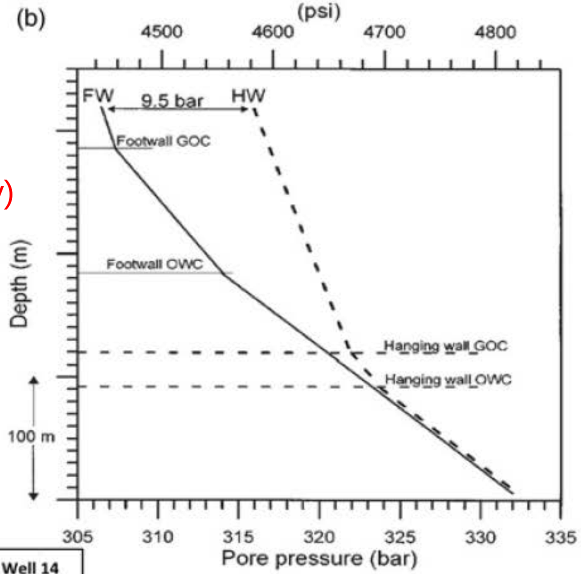
Omission of Tight Tests

Well 13 Footwall

Well 14 Hanging Wall

Tight Tests
Well 14
(Vertical Only)





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SOUTHERN HIGHLANDS
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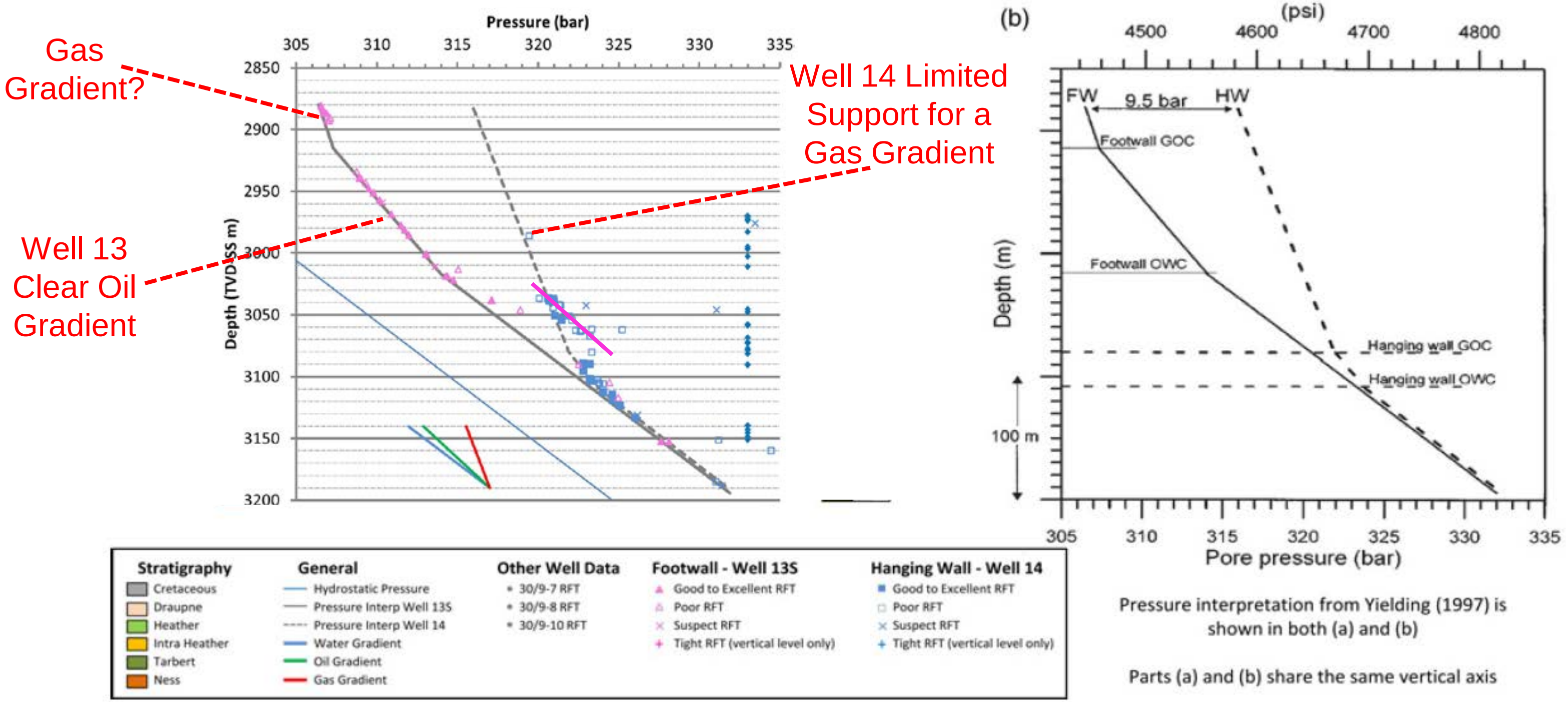
Pressure data



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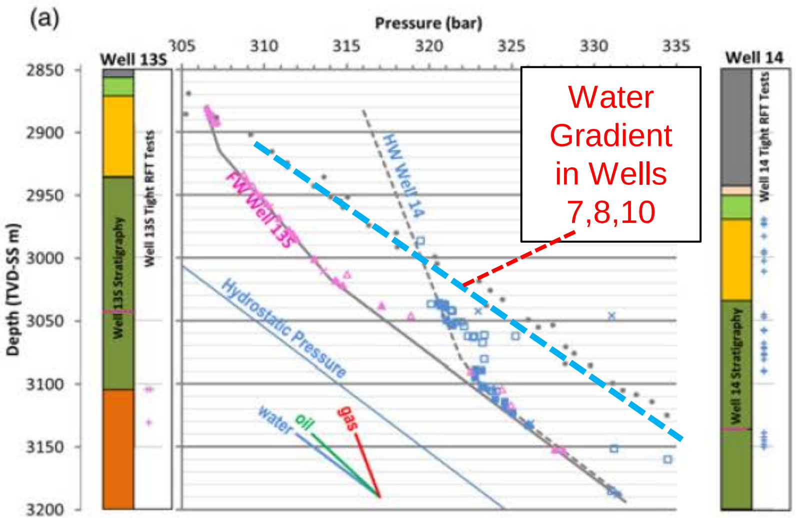
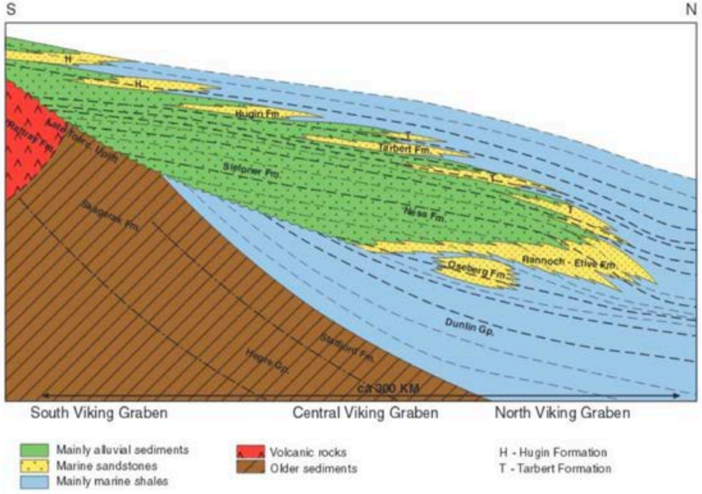
WHOW Moment





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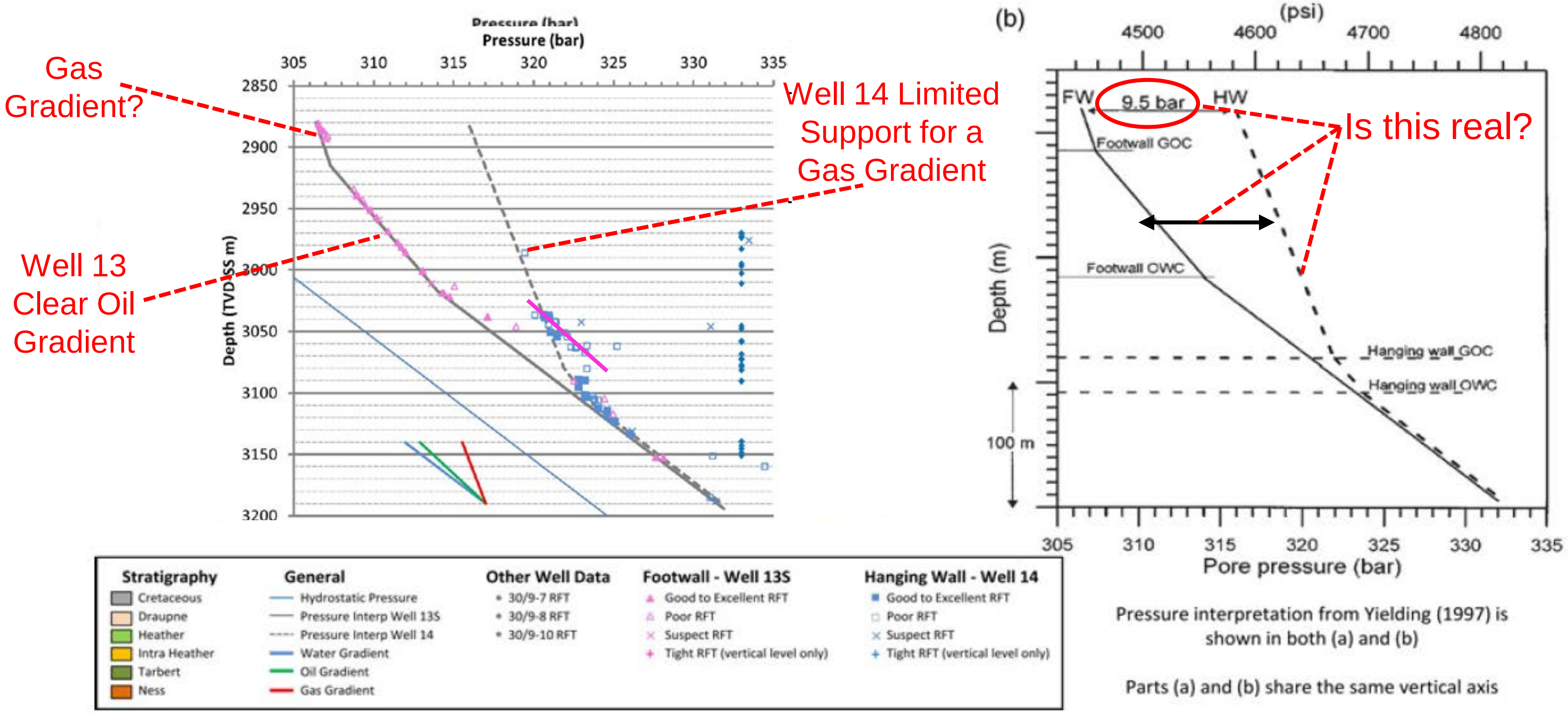
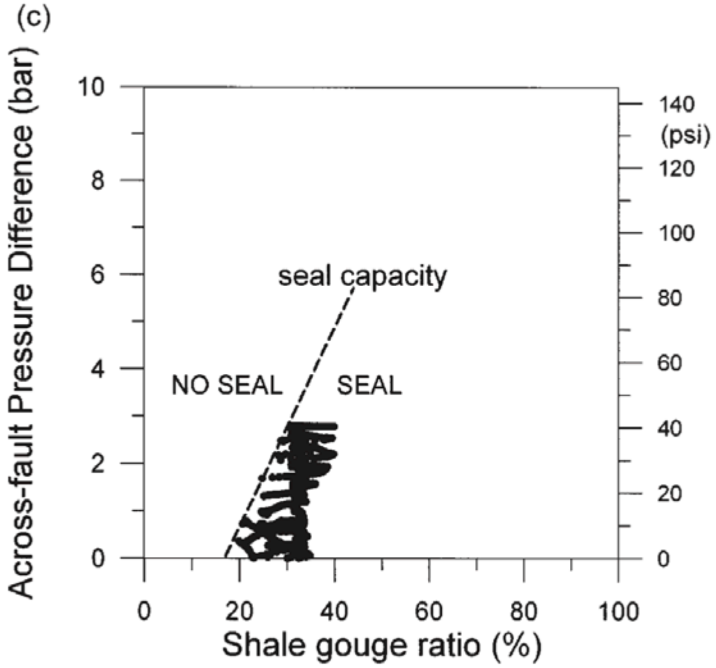
Pressure data

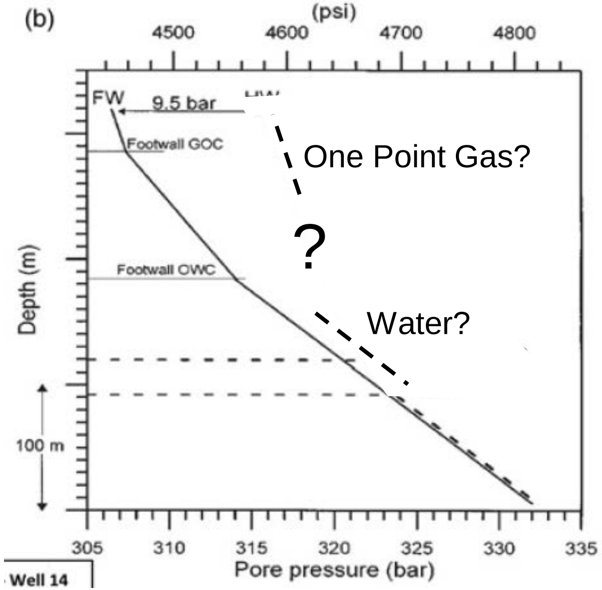


Pressure interpretation from Yielding (1997) is shown in both (a) and (b)

Parts (a) and (b) share the same vertical axis

AFPD Calculations





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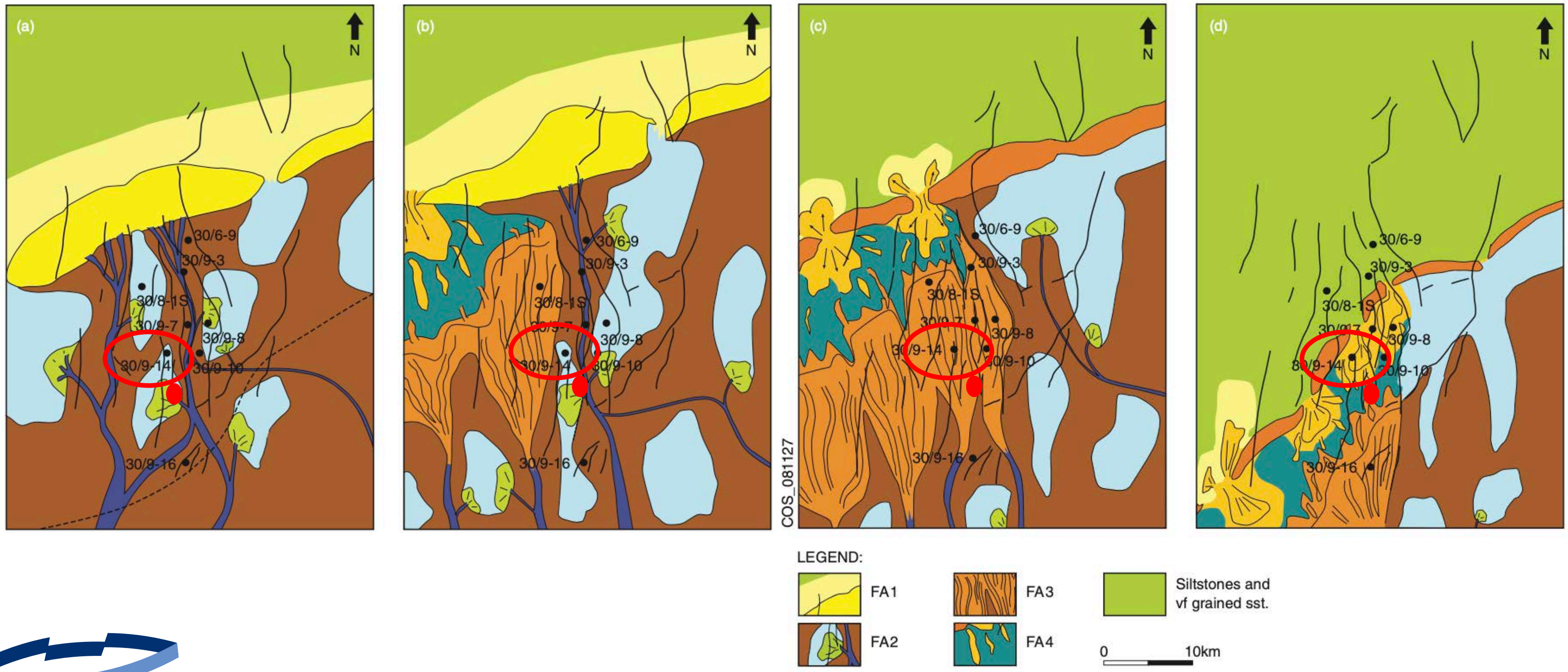
FaultSeal or Stratigraphy



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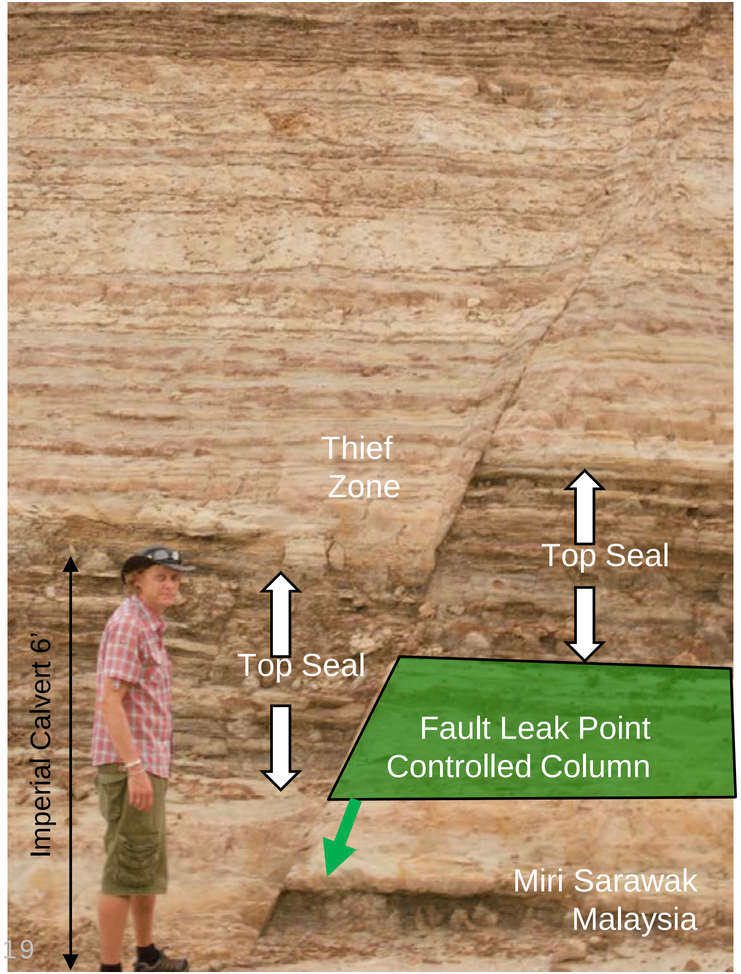
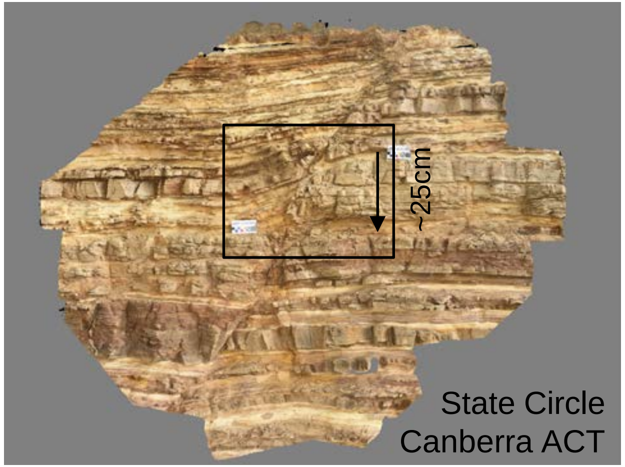
Thought Experiment

- Think of a trap that has:
  - 100Million Barrels of Oil.
  - Trapping 10Million years.
- Fault Trap:
  - 1km long,
  - reservoir 10m thick.
- Juxtaposition area ~1 Hectare (10,000m^2)
- Lose 10 barrels /year (1590*l/year*) will drain the field
- Equates to 4.3*l*/ha/day.
- Proponents of membrane seal invoke capillary seal.



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

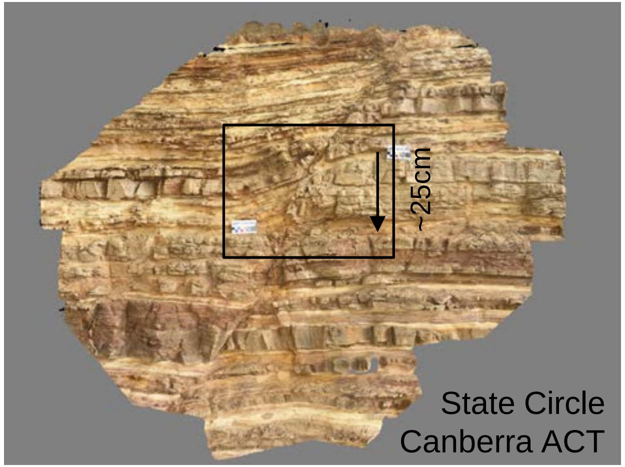
Geologic Processes vs Engineering

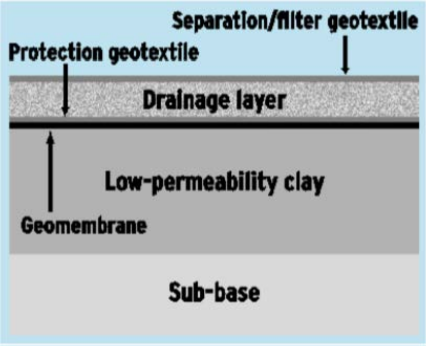


- Compare 4.3l/ha/day
- Victorian Government design code for municipal waste
  - Less than 0.3m head (significantly less pressure than an Gas field)
  - Aim for leakage of less than 10l/ha/day
  - Containment of leachate for decades, at least 30 years.

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Geologic Processes vs Engineering



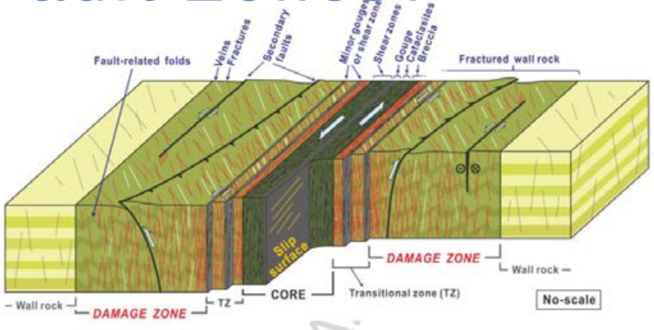


- Compare 4.3l/ha/day
- Victorian Government design code for municipal waste
  - Less than 0.3m head (significantly less pressure than an Gas field)
  - Aim for leakage of less than 10l/ha/day
  - Containment of leachate for decades, at least 30 years.

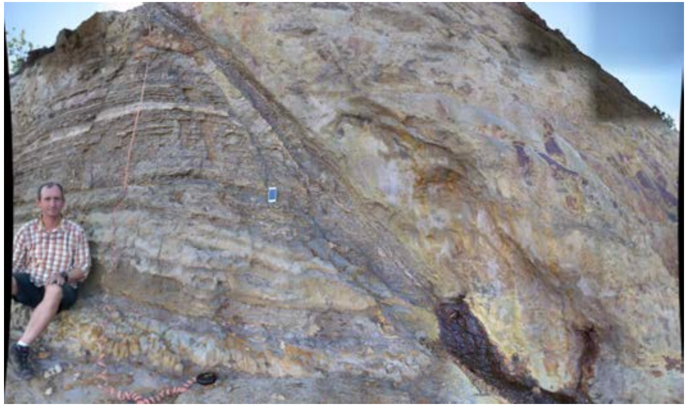
https://waste-management-world.com/a/specialist-concrete-lining-at-900-000-cubic-metre-landfill-cell-in-herts-uk

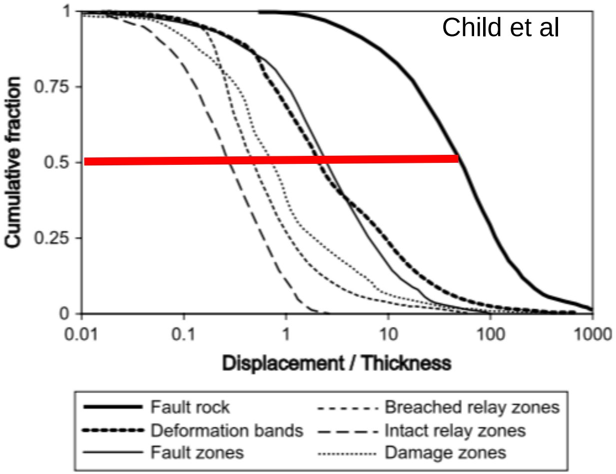
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

A4 - Fault Zones?

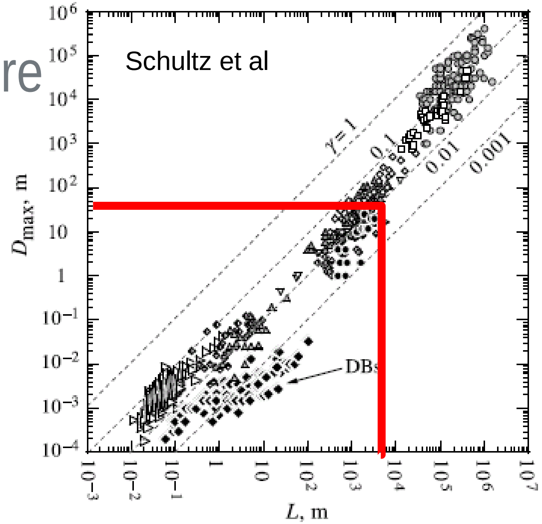


Definition and classification of fault damage zones: A review and a new methodological approach





- 50m Throw Fault Core
  - length 2500-5000m
  - ~ 20m damage zone
  - ~ 0.5m fault core
- 300mm A4 Paper
  - 0.05mm thickness

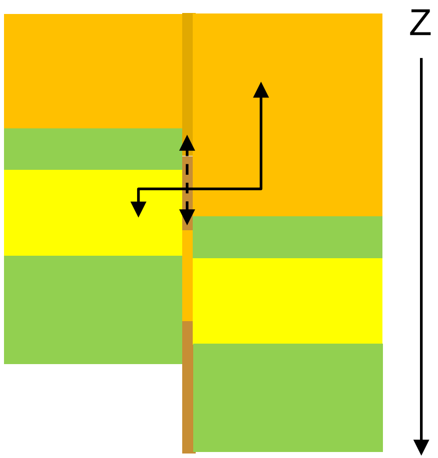


SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Fault Flow

$$q = \frac{k_f}{F} A \frac{\Delta P}{\mu}$$

- Connection between two aquifers
  - 2000m long
  - 20m throw fault along length of the fault.
  - 5m thick aquitard
  - 0.5m Very Thick fault rock (Miri 0-0.17m)



- Across fault area
  - Area 20m x 2000m = 40,000m^2
  - Tk_f 0.5m

$$q = \frac{k_f}{0.5} 40{,}000 \frac{\Delta P}{\mu}$$

- Up fault
  - Area (A) 2000m x 0.5m = 1,000m^2
  - Tk_f 5m

$$q = \frac{k_f}{5} 1000 \frac{\Delta P}{\mu}$$

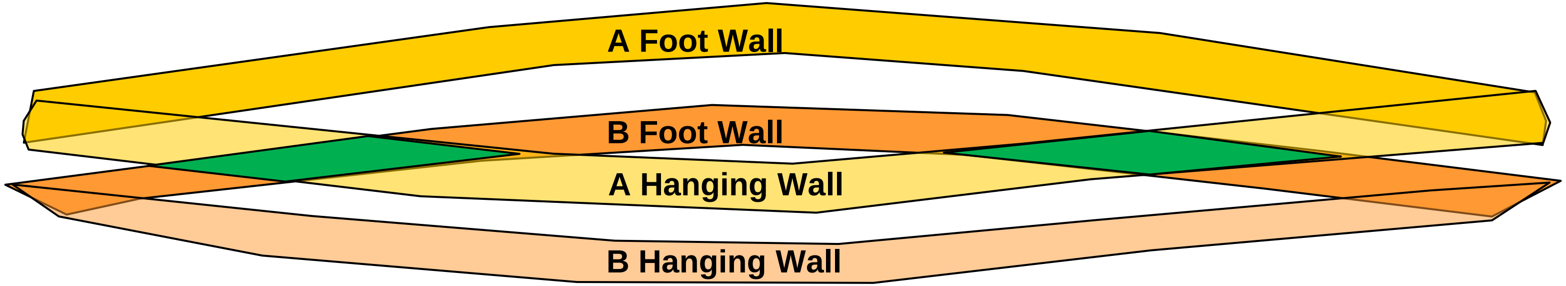
Across fault flow 800 times greater than up fault flow

Fault Length Dominant Term

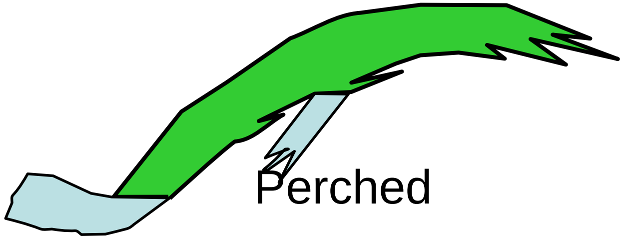
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

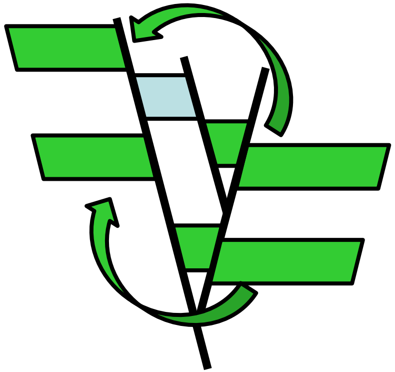
Model for Hydrocarbon Migration and Entrapment Within Faulted Structures

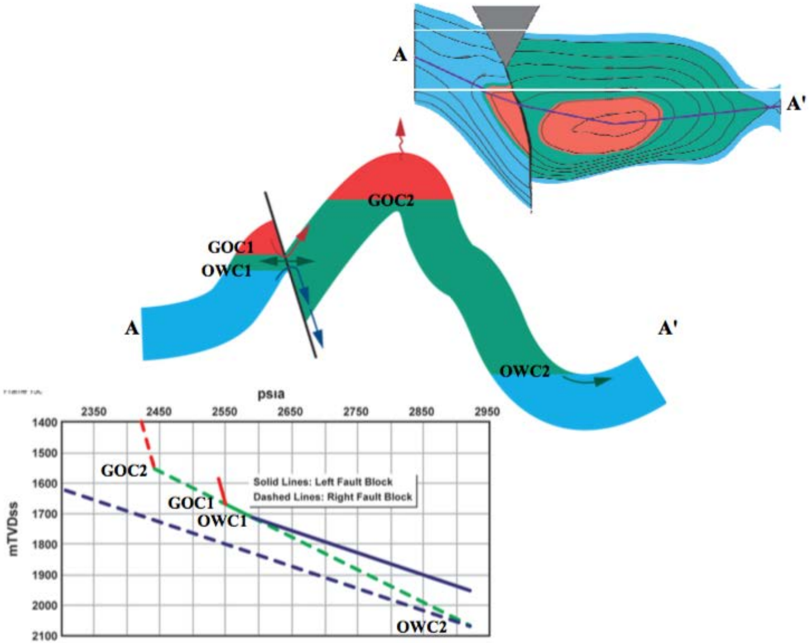
... a fault is neither a seal or a conduit. Therefore the effects of faulting and on both migration and entrapment depends on the … strata juxtaposed by the fault … Allan 1989



Perched and Breakover





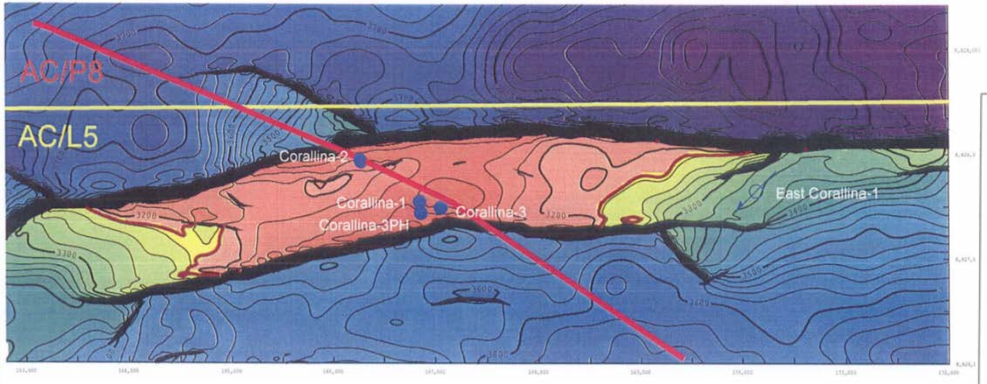


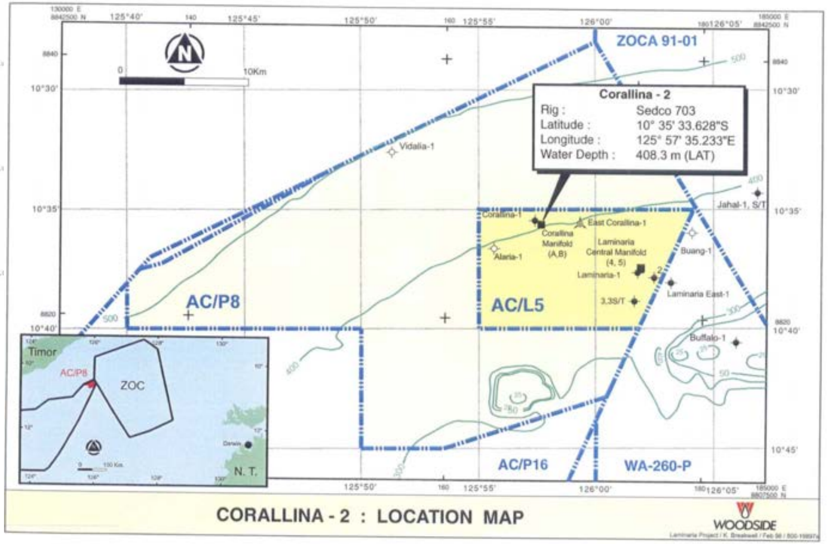
Reservoir Connectivity Analysis
Defining Reservoir Connections and Plumbing
P. Vrolijk etal 2010

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Corallina Timor Sea





Drilled by Woodside in 1990's – underfilled with a paleo oil column

https://nopims.dmp.wa.gov.au

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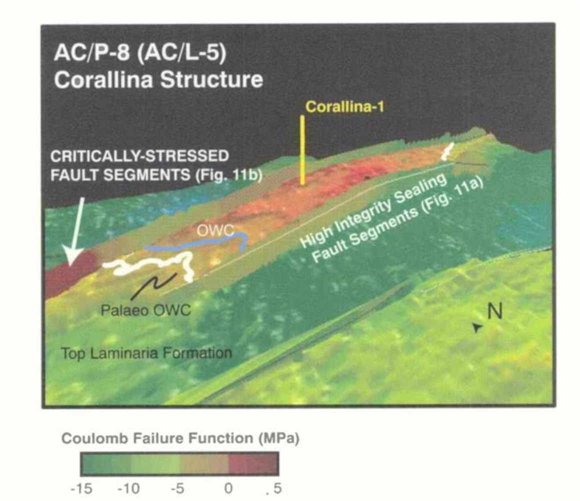
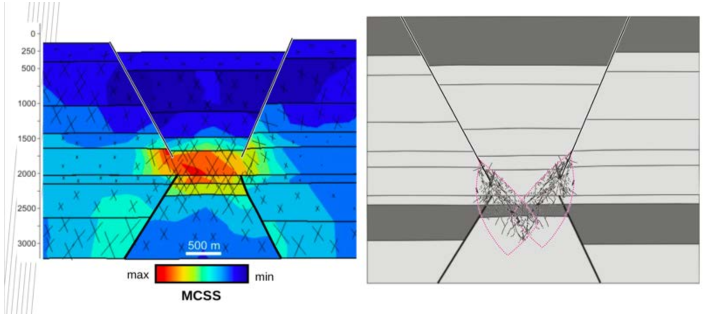
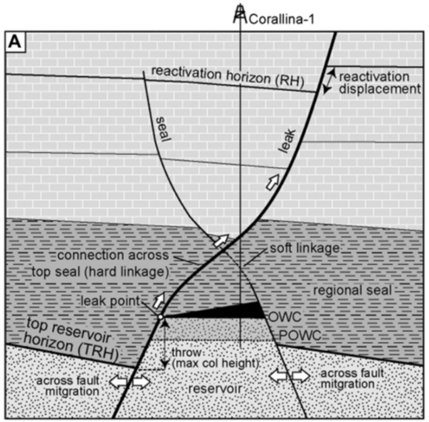
Corallina OWC Thought to be Stress Related



Castillo et al (2000).
Trap integrity in the Laminaria High-Nancar Trough region



Ciftci et-al 2010
Time-transgressive fault evolution and its impact on trap integrity: Timor Sea examples



Dyt et al 2011
Automating conceptual models to easily assess trap integrity and oil preservation risks associated with fault reactivation

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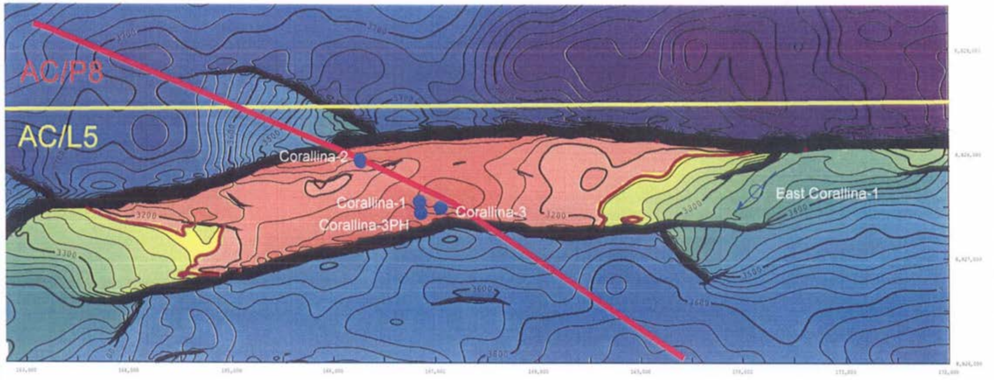
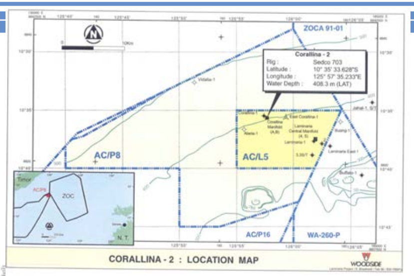
STRUCTURAL GEOLOGY

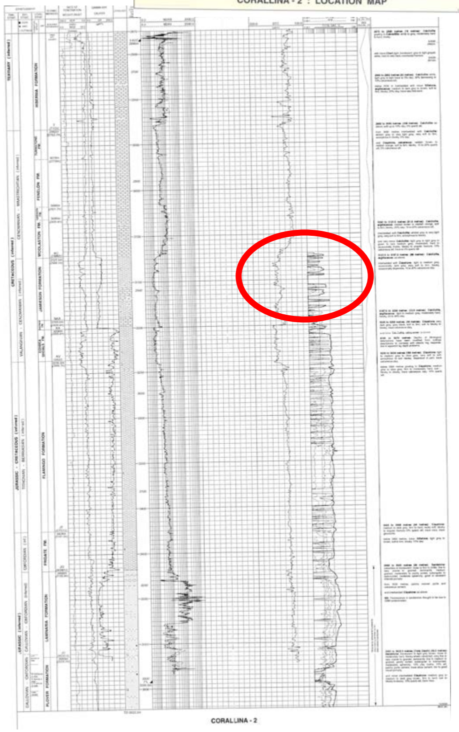
Look at the Mud Logs



https://nopims.dmp.wa.gov.au/Nopims/GISMap/Map

Key observation is that there are elevated mud gas in the Echuca Shoals





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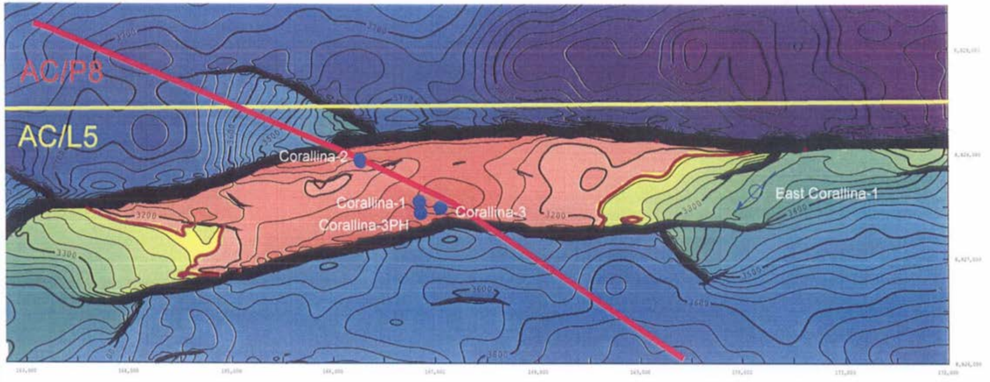
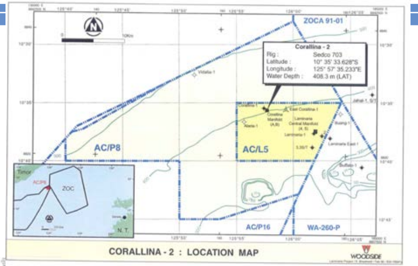
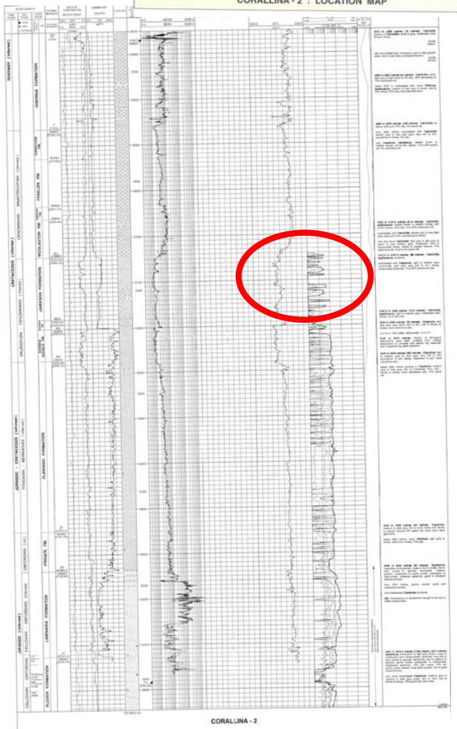
Source Rock Thief Zone







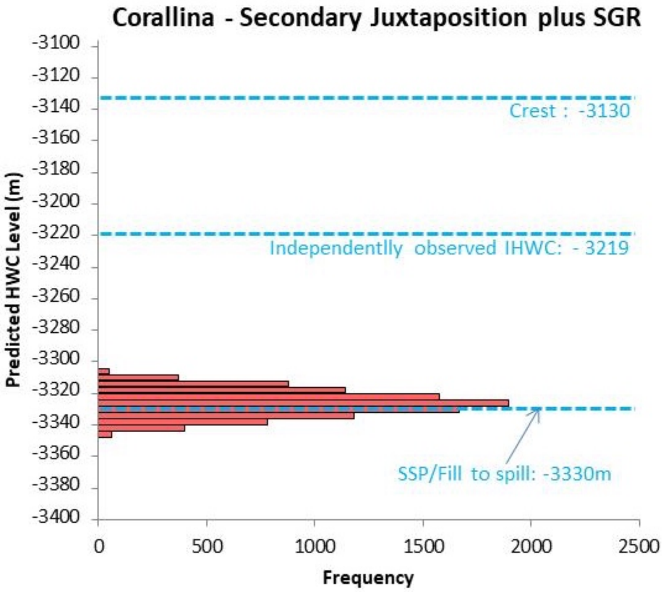
Key observation is that there are elevated mud gas in the Echuca Shoals

Stratigraphy	Type	Thicknes			Vshale		
		Min	Mean	Max	Min	Mean	Max
Prion TO	Seal	400	500	600	5%	15%	30%
Hibernia TE	Seal	300	400	500	5%	15%	30%
Bathurst T	Seal	85	115	140	10%	35%	50%
Jamieson KC	Seal	75	85	95	10%	40%	70%
Darwin NKA	Seal	8	10	12	10%	40%	70%
Echuka KA	Thief	20	25	35	20%	40%	60%
Flamingo-Frigate	Seal	190	215	220	50%	70%	90%
Laminaria JO	Reservoir	110	130	150	10%	20%	30%

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Lack of Charge (SGR) Error

Error of 110M



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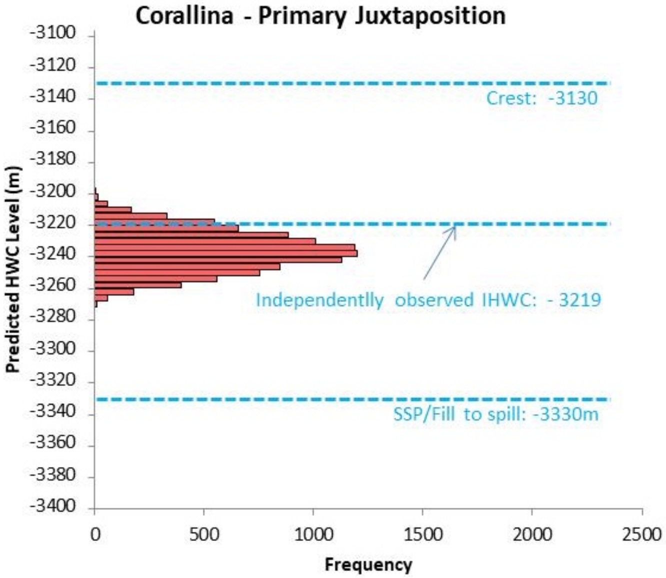
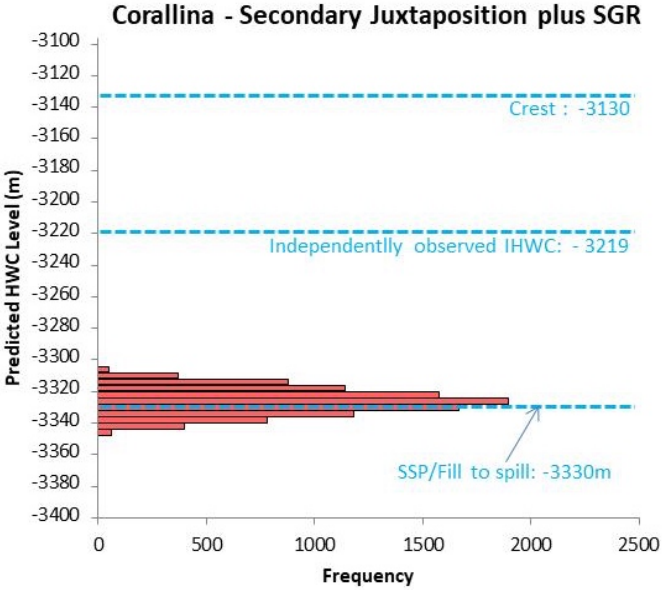
Juxtaposition Better than SGR

Error of 11.2m



Error of 110M



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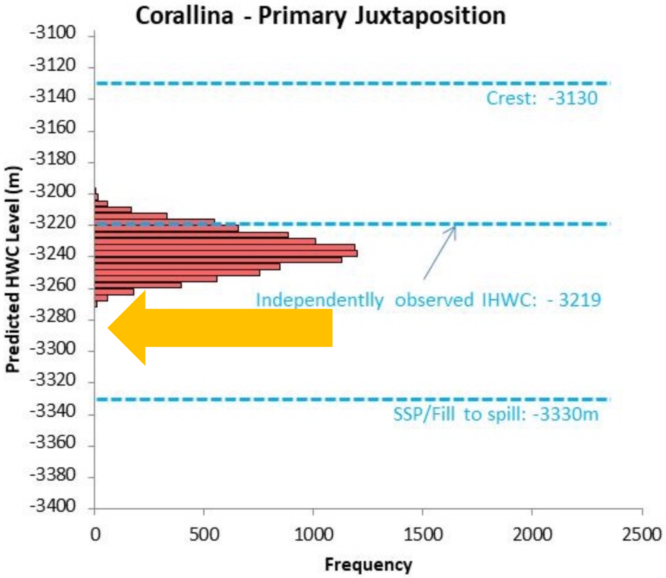
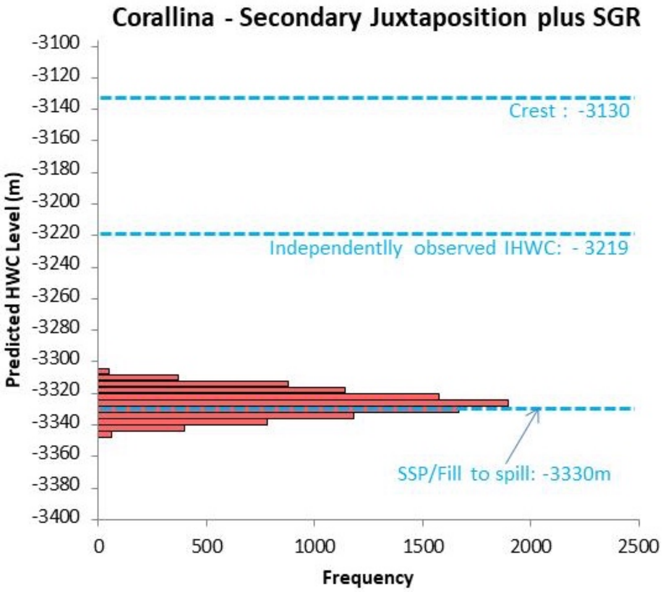
Juxtaposition not Stress

Error of 11.2m



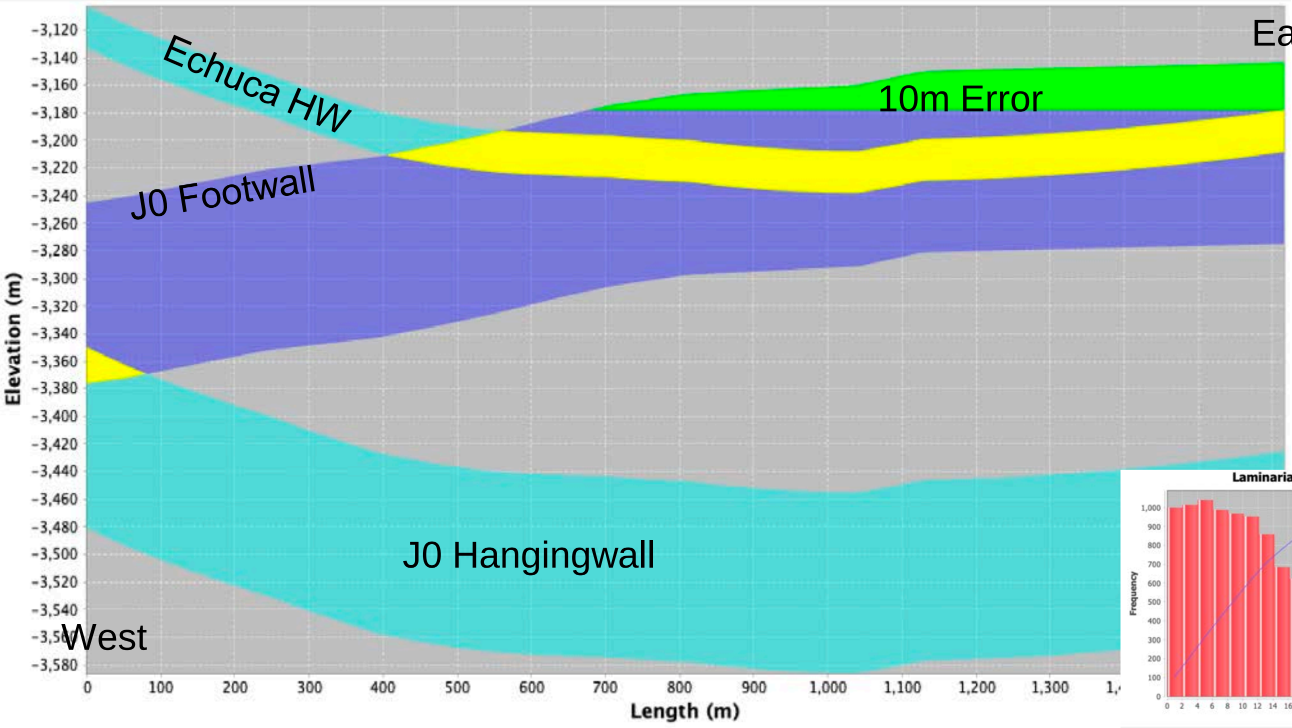
Error of 110M

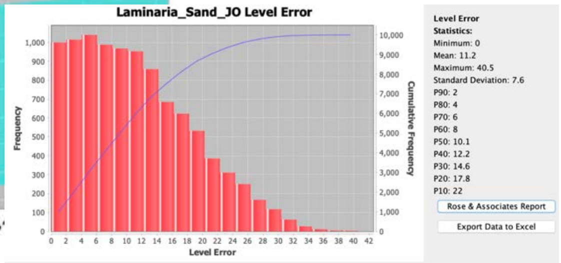


Reactivation leak point error approximately 57 m (de Ruig et al 2000).

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

P50 Allan Map South Fault





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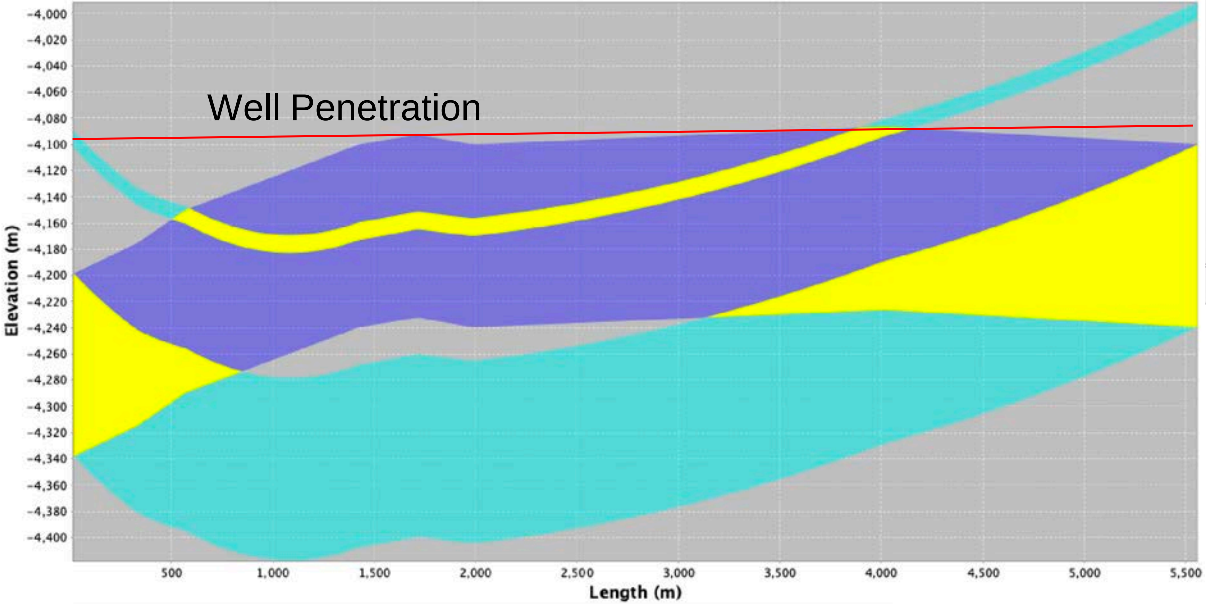
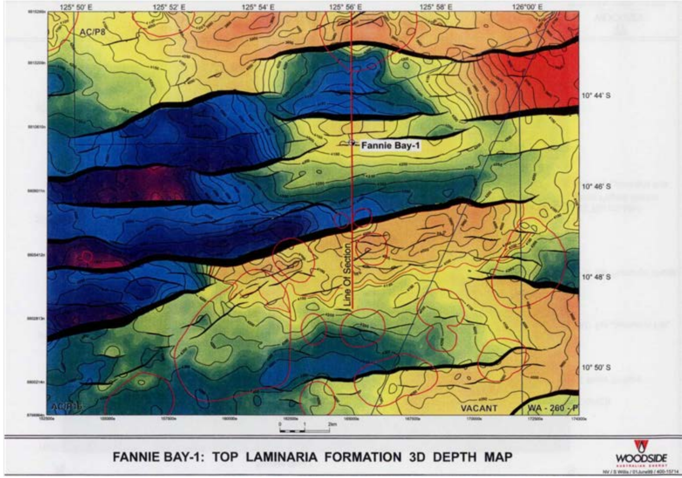
Underfilled SGR Trap

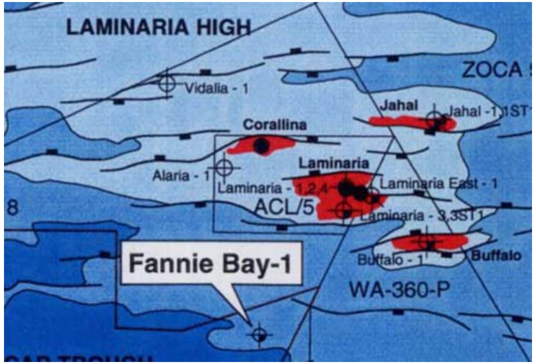
Predicting The Dry Well

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Dry Well Fannie Bay







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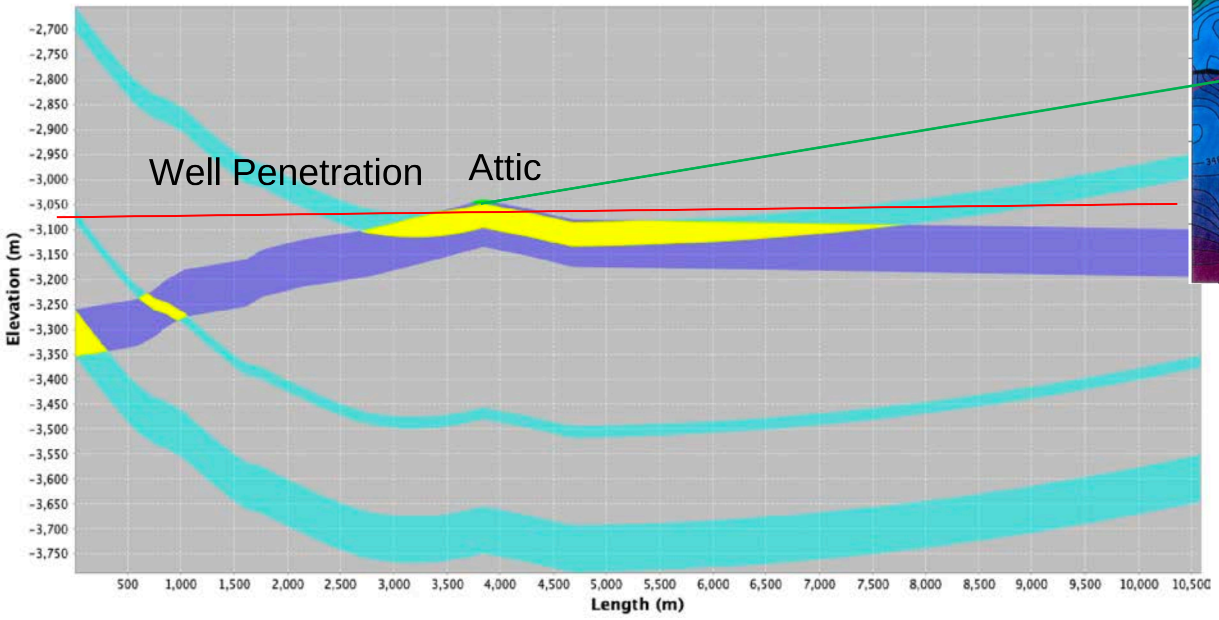
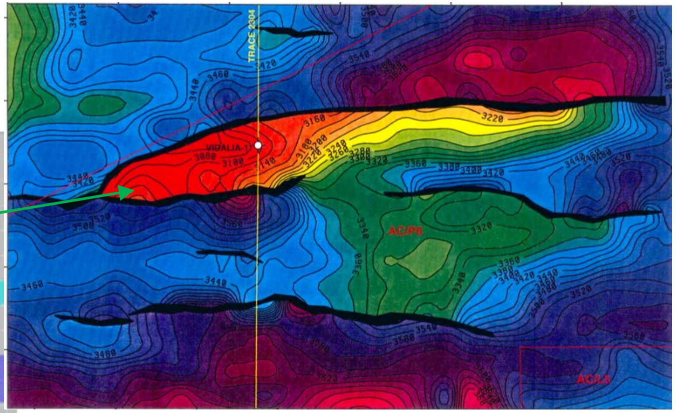
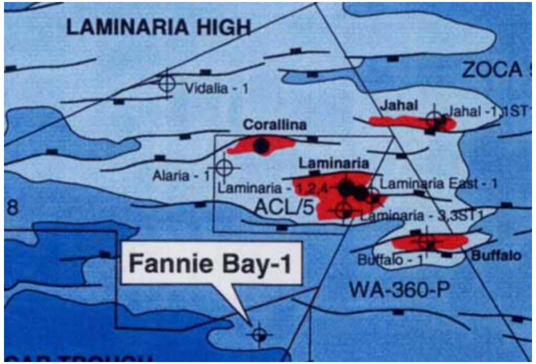
STRUCTURAL GEOLOGY

Dry Well Vidalia







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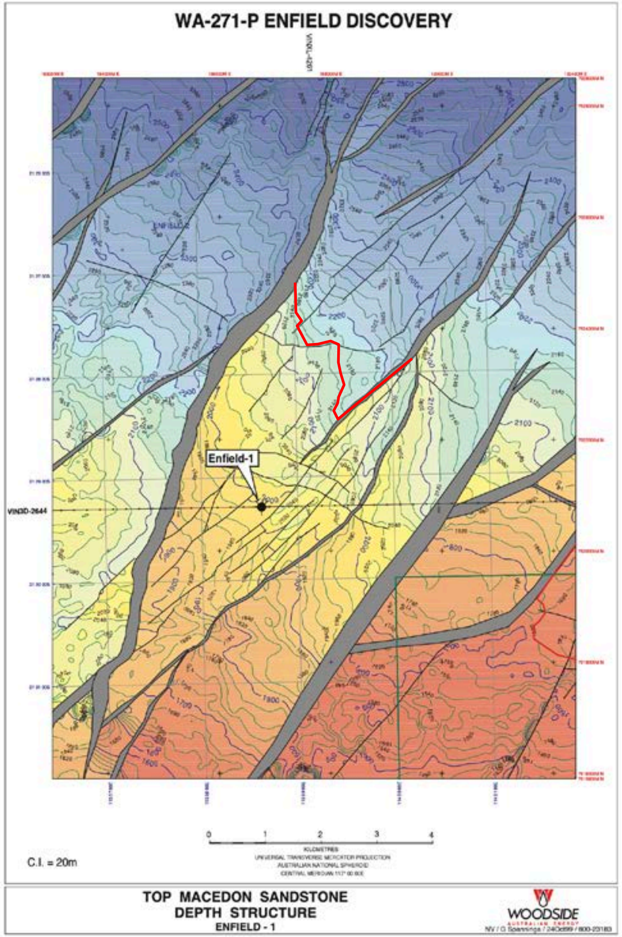
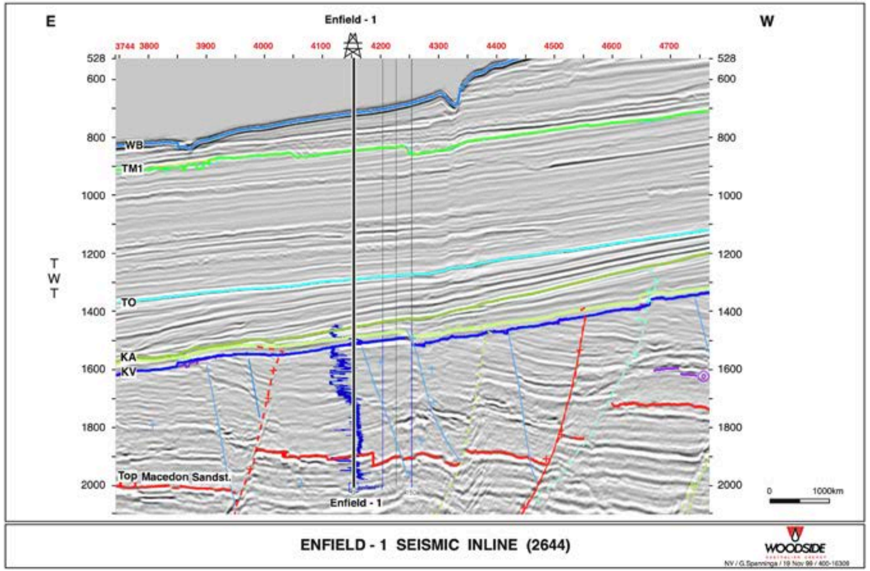
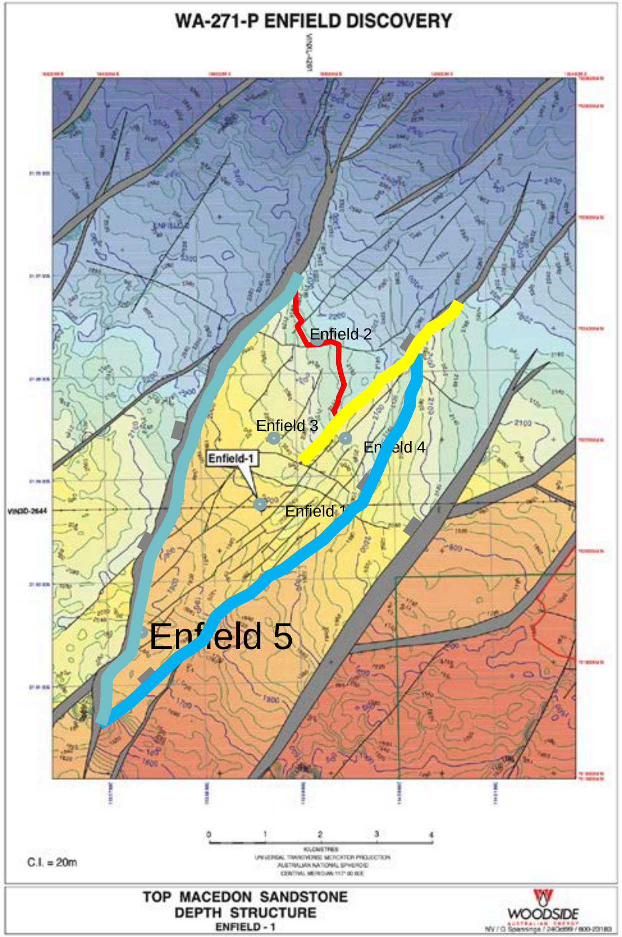
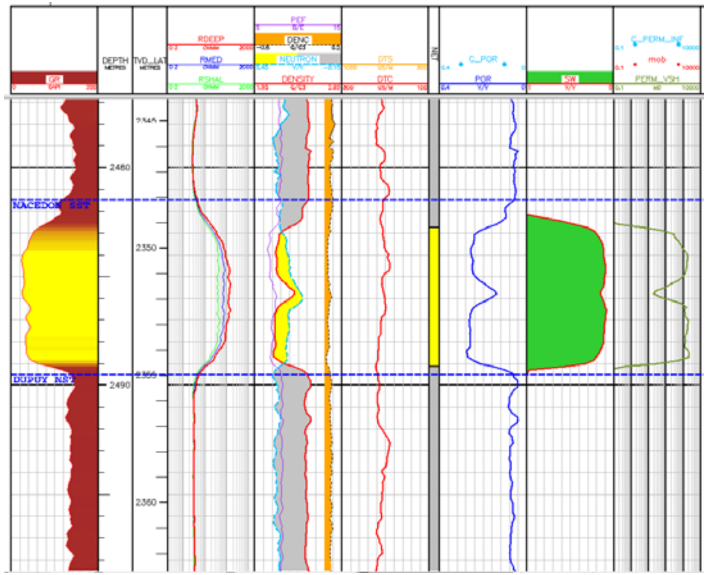
Enfield





SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY





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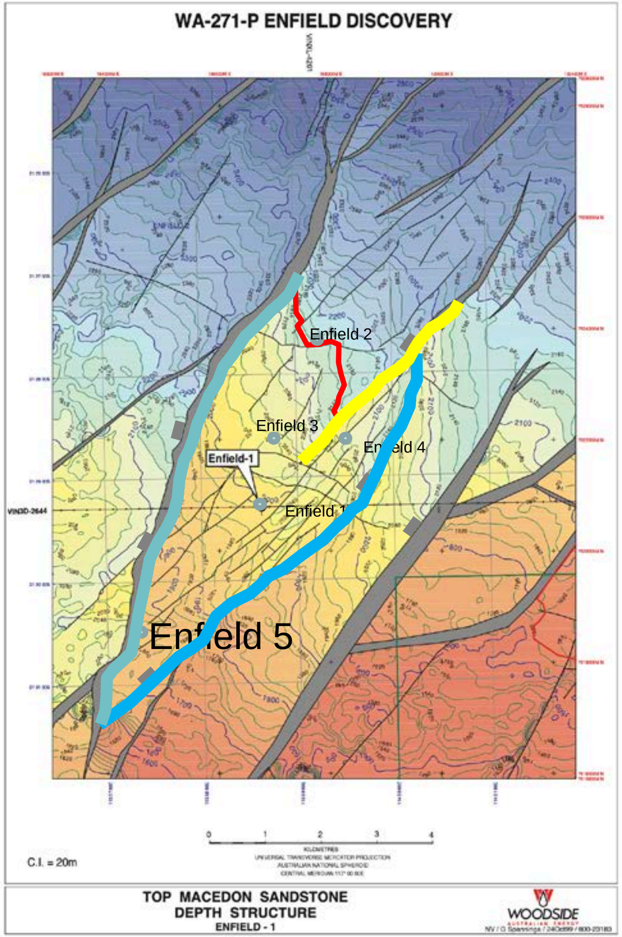
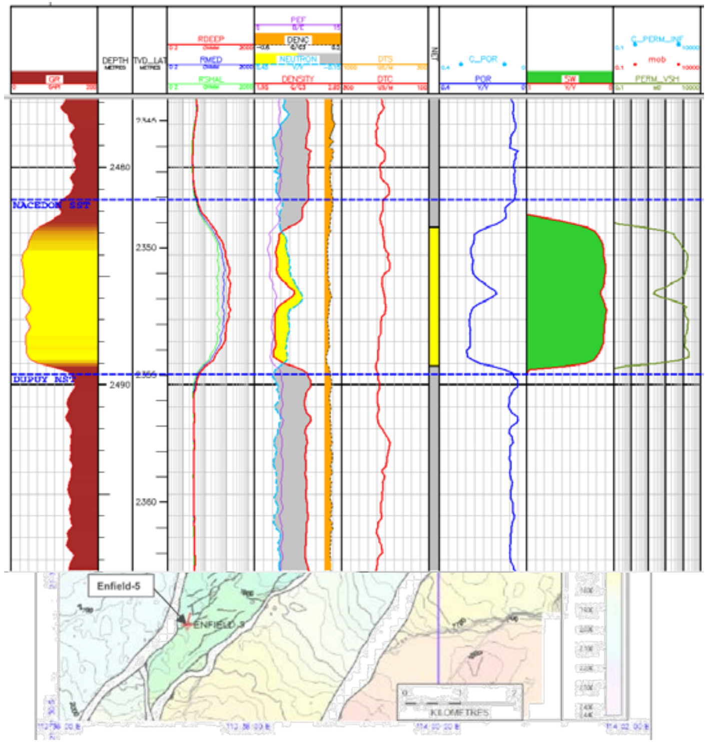
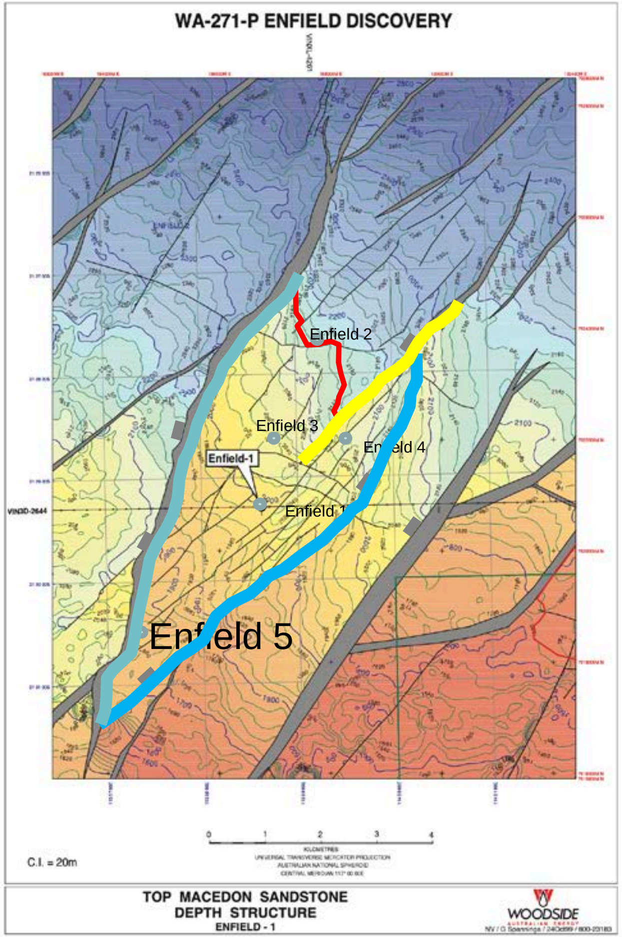
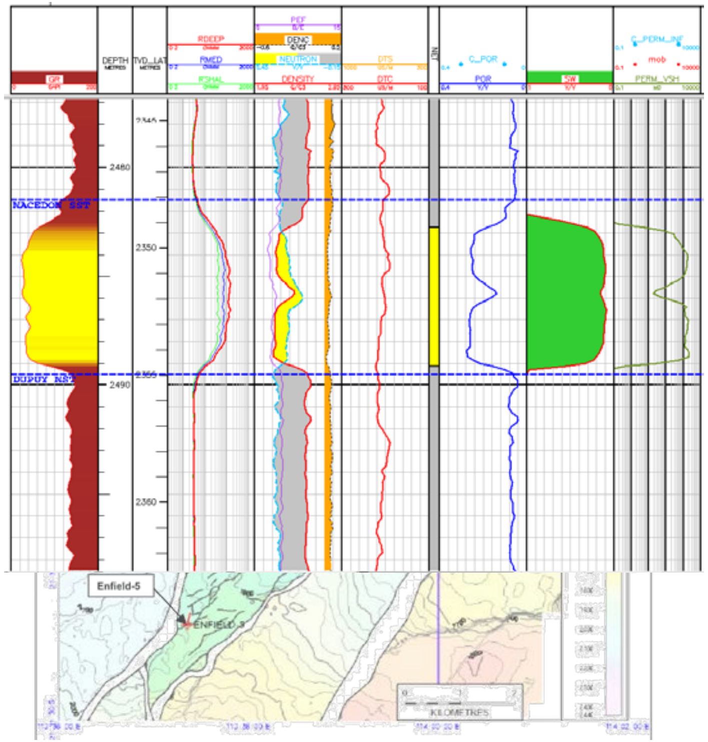


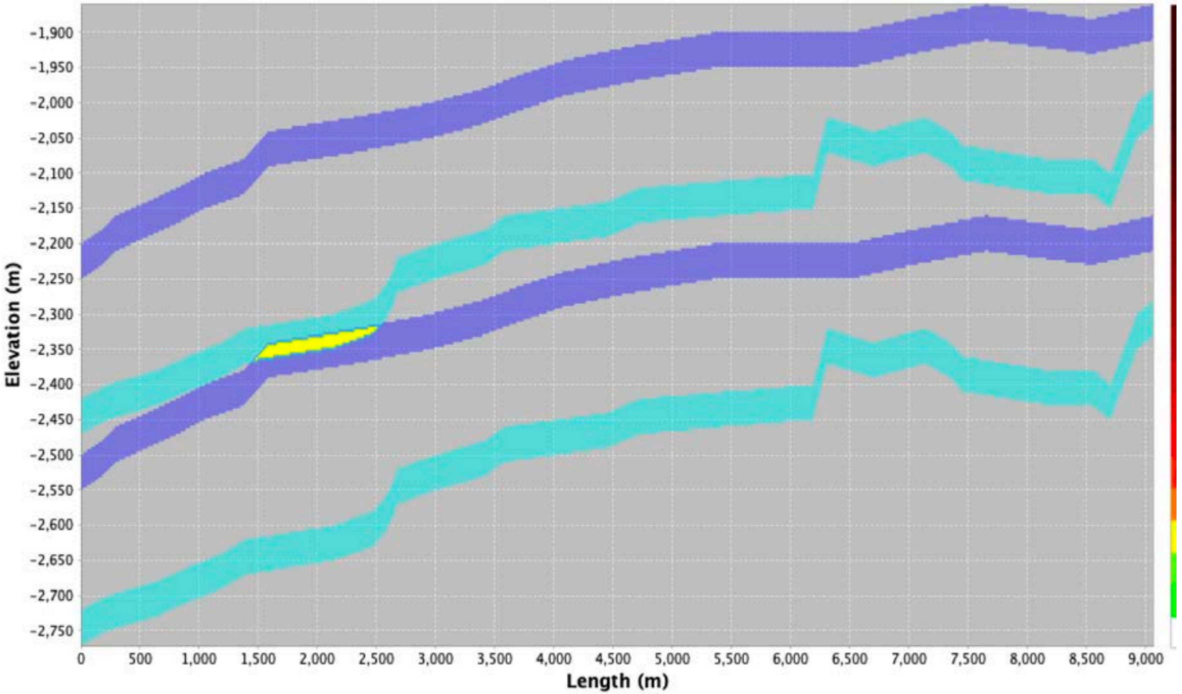


SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY





SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

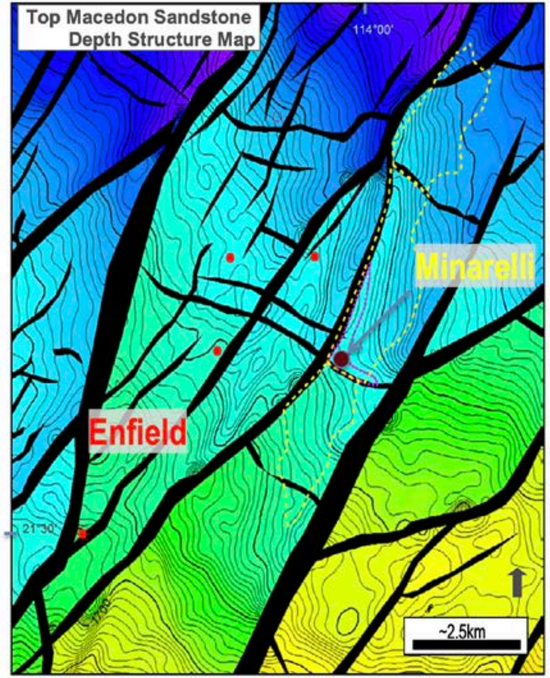


Figure 5: Depth Map of the Top Macedon Sandstone at Minarelli and Enfield. Three fault-separated compartments are visible for Minarelli, which sits above and to the east of Enfield.

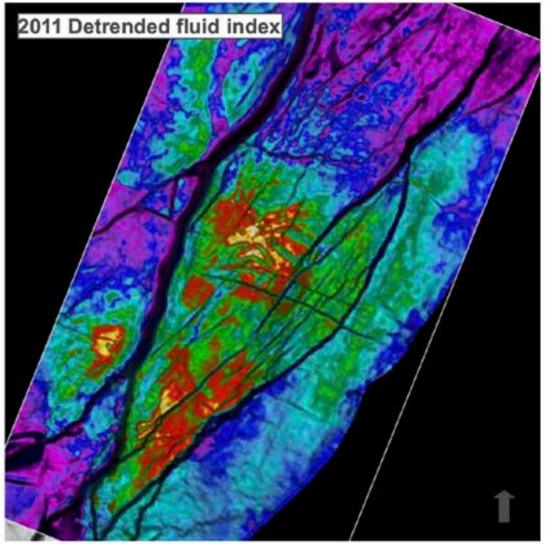


Figure 6: De-trended fluid index volume extraction over the Macedon Sandstone Level across Minarelli and Enfield. Minarelli shows a similar fluid index response to the eastern portion of Enfield.

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

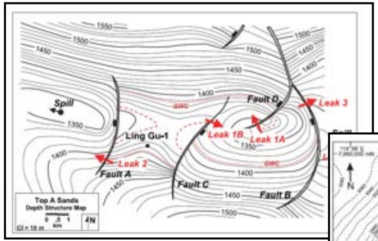
How About All the Literature

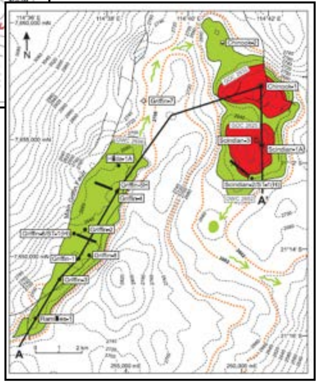
April 2020

AAPG Fault Seal Papers

- Since 1989 AAPG have published 92 papers with key words “fault seal”
- 15 of these cover outcrop analogues
- 77 remain:
  - 37 use unreferenced data that is not available
  - 18 reference Allan (1989)
  - 14 have Allan maps and/or structure maps
  - 13 have independently observed HWC (post drilling)
  - 12 have lithology/stratigraphic information
- Only two have sufficient information to apply the stochastic trap analysis
  - James et al (2004) - Ling Gu
  - Brincat et al (2006) - Griffin

Prediction Error	Reservoir	Juxtaposition		SGR	
		Mean	Std Dev	Mean	Std Dev
Gu Ling	A Sand	6.0	6.4	42.0	9.6
Dory	Leman	13.2	0.3	272.7	42.1
Bazar	Mirador	9.9	6.2	9.9	6.2
Minerva	Minerva	16.3	21.0	40.2	36.5
Sea Horse	N0-N1	10.1	7.3	26.0	40.2
	N2_3	3.0	2.2	23.3	50.0
	N2_6	5.0	4.7	76.0	63.0
	P1	5.1	3.4	7.6	19.1
Griffin	Zeepard	8.1	6.5	12.1	12.9

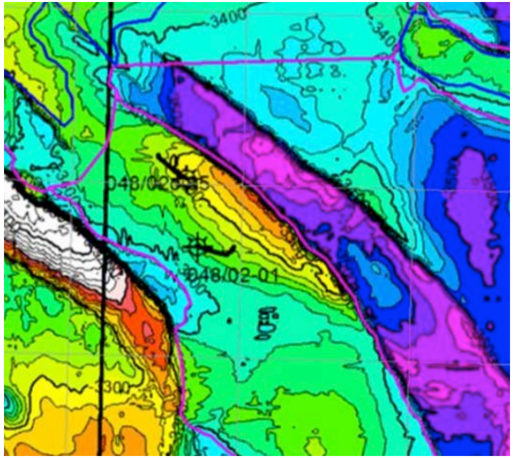




SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Geological Society Journals

- Since 1989 GSL have published 116 journal with key words “fault seal”
- 15 of these cover outcrop analogues
- 63 remain:
  - 30 use unreferenced data that is not available
  - Only 11 reference Allan (1989)
  - Only 6 have Allan maps and/or structure maps
  - Only 11 have independently observed HWC (post drilling)
  - Only 17 have lithology/stratigraphic information
- Only one has sufficient information to apply the stochastic trap analysis
  - Cobra in Bretan 2017
- A worked example was produced in 2016 on our web site illustrating that juxtaposition produces a very good result
- We are waiting on the current paper to publish a reply to Bretan 2017



Juxtaposition Error
-Premier Map 4.4m
-E.EoN Map 6.4m

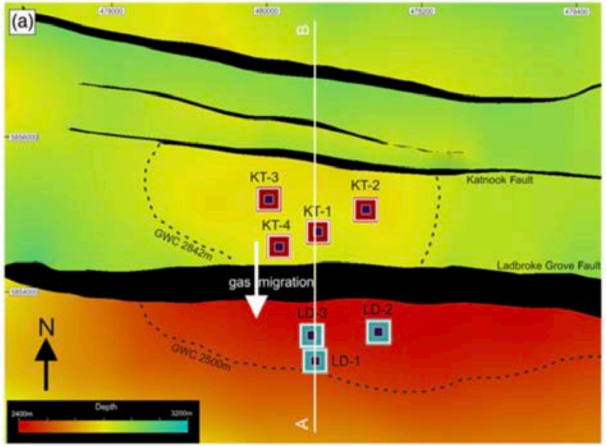
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

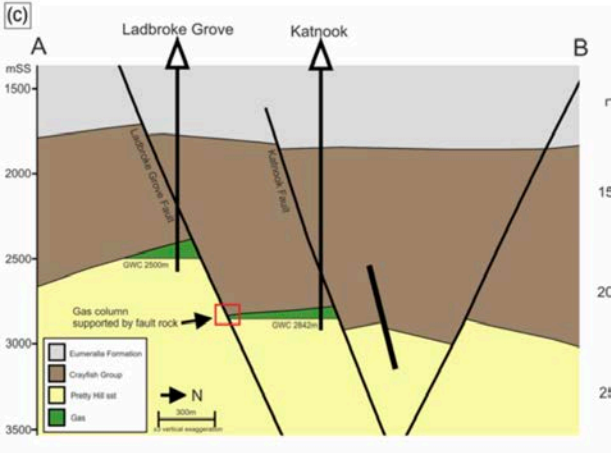
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

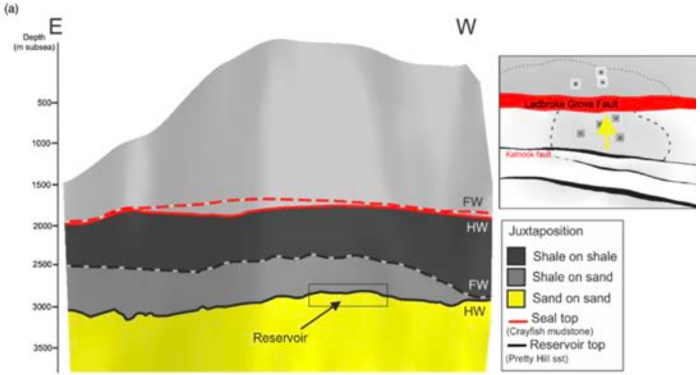
Katnook Field

Katnook Field

- In the Karolyte etal paper a “cartoon” map and cross section are provided, along with a 3D representation of an Allan Map



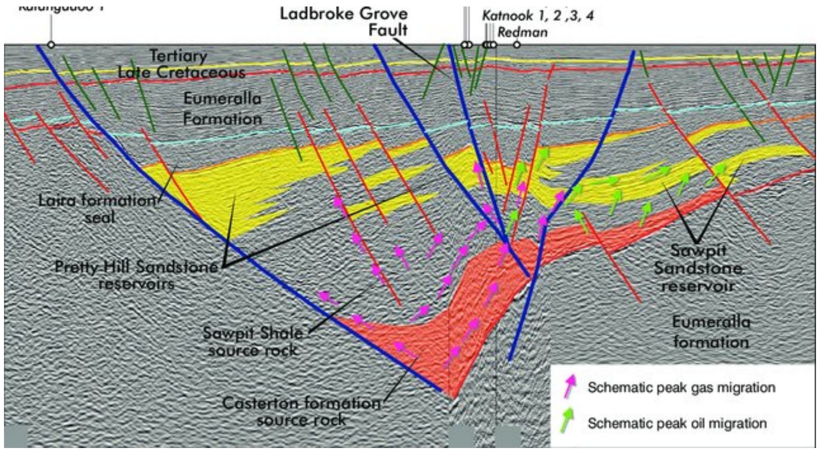




SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Katnook Field Fault Seal

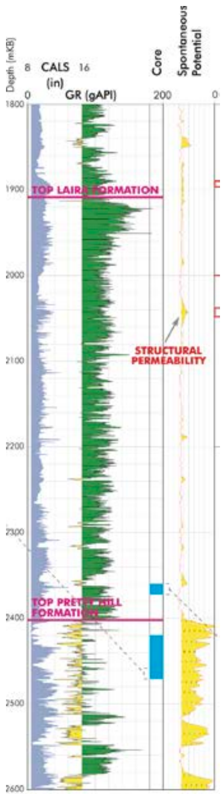
- Series of fault bounded gas fields in the Pretty Hill Sandstone.
- Thick Laira formation acts as a top seal.
- Significant thickness changes across a series of growth faults.

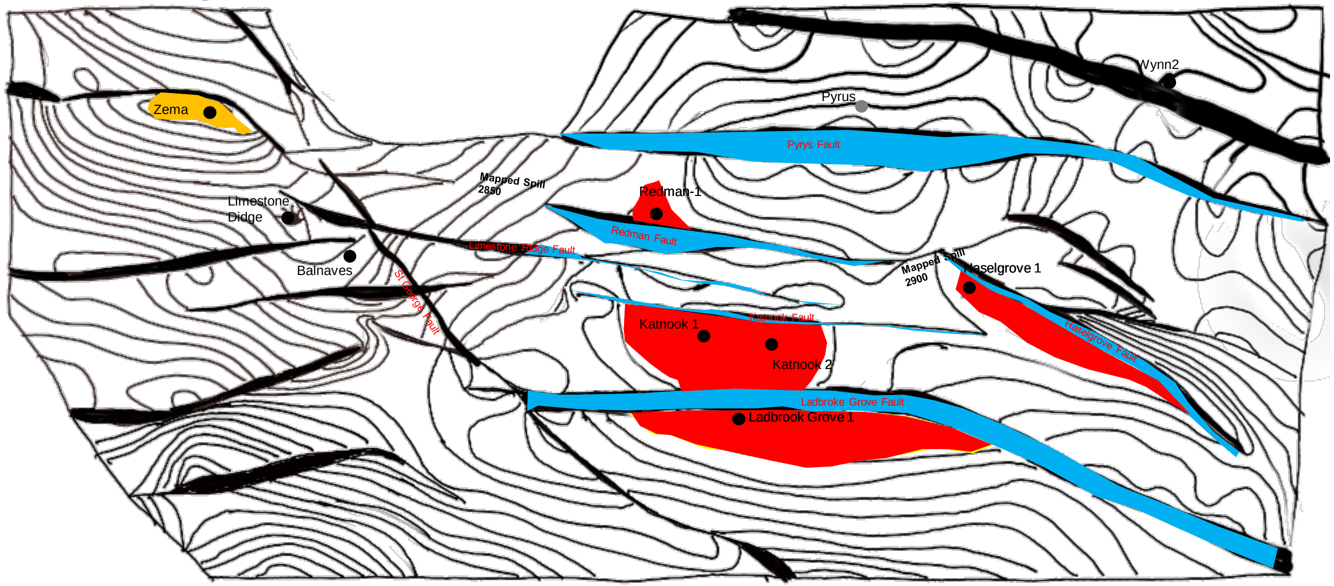


https://www.researchgate.net/publication/260962517_Subsurface_plumbing_of_the_Crayfish_Group_in_the_Penola_Trough_Otway_Basin

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Published Map



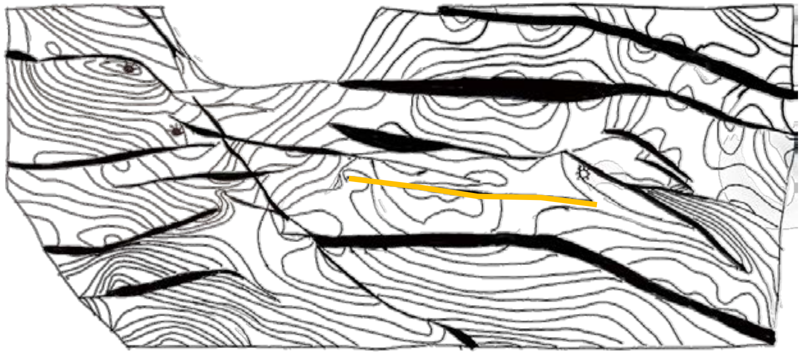


- It is common that improving maps enhances trapped area and thus gross rock volumes.

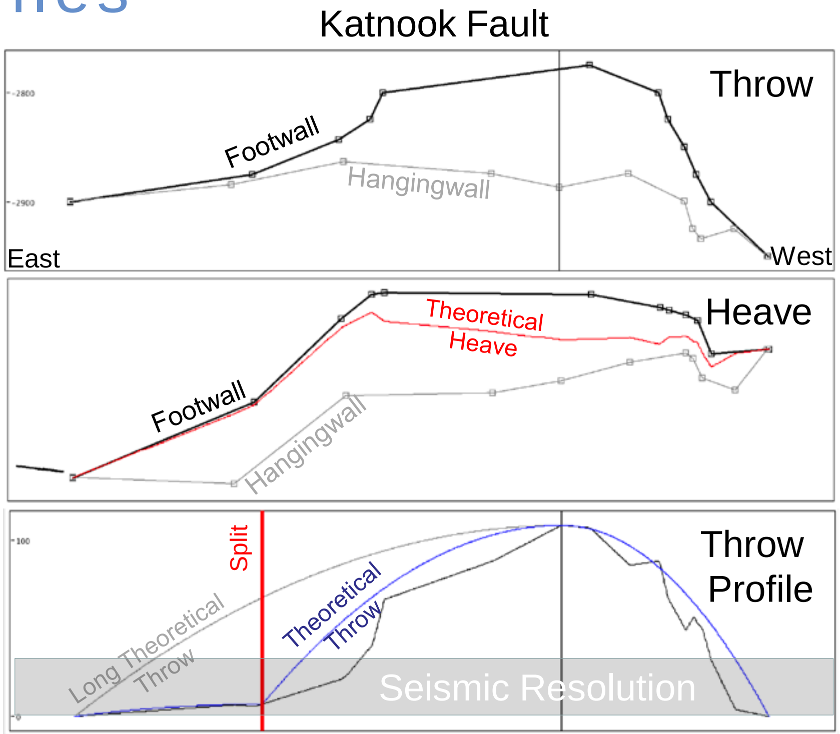
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Revision Displacement Profiles

- A key part of the FaultRisk approach is to ensure that faults have a consistent displacement profile.
- Most of the faults were too shallow.



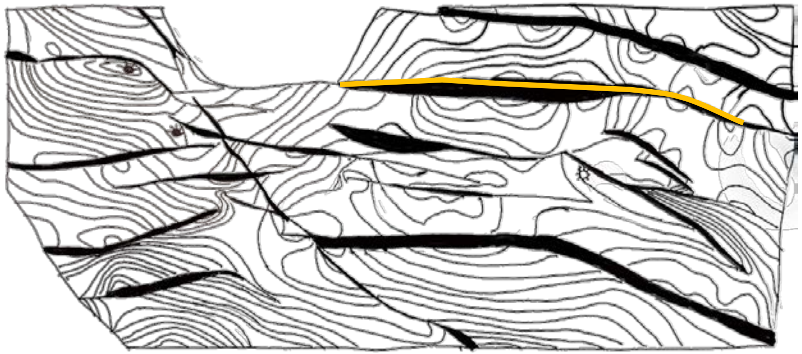
Fault	Length	Throw	Before Dip	Edit
Haselgrove	6913	256	63	77
Katnook	7837	108	49	70
Ladbroke_Grove	14581	569	53	75
LImestone_Ridge	5939	138	26	75
Pyrus_Fault	13965	887	53	70
Redman	7308	184	19	68
Zema	8881	225	56	70



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Revision Displacement Profiles

- In many cases the faults needed to be edited and split to improve the displacement geometry.



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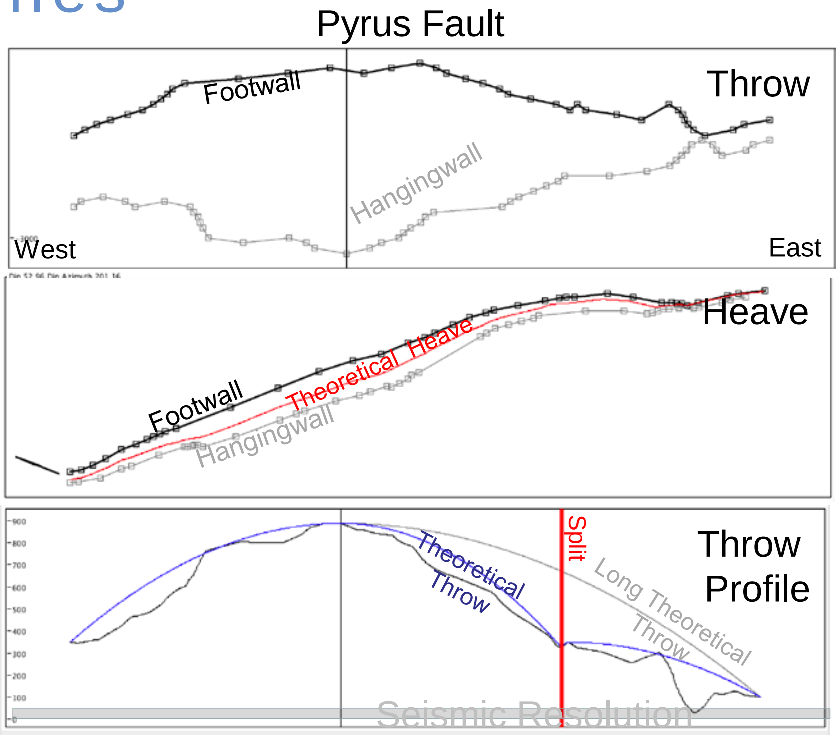
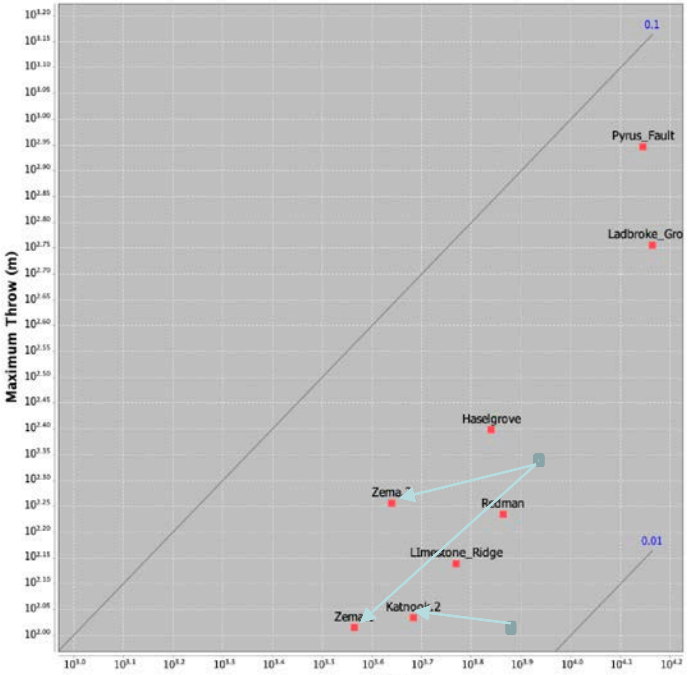


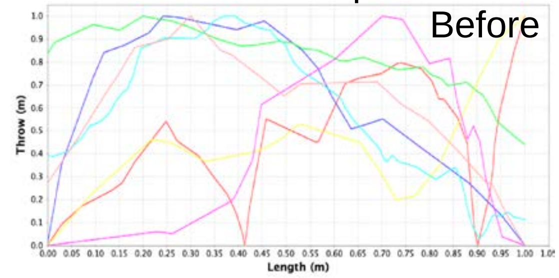
Normalized Displacement

Revision Displacement Profiles

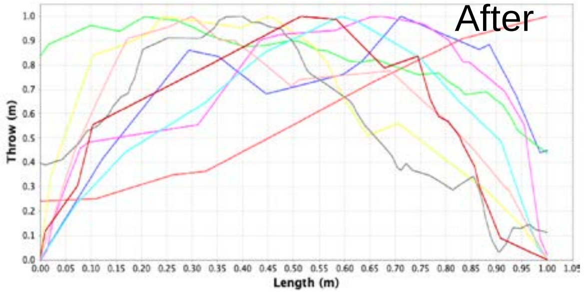
- Revision of the fault profiles improves
  - Length throw ratio
  - Displacement Profiles
  - Fault Dip



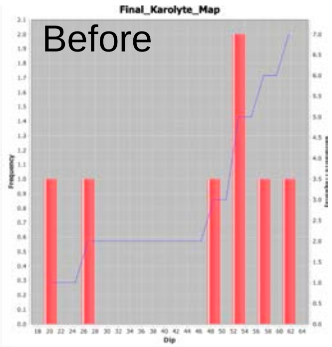
Before



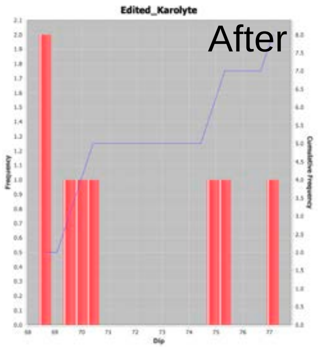
After



Before

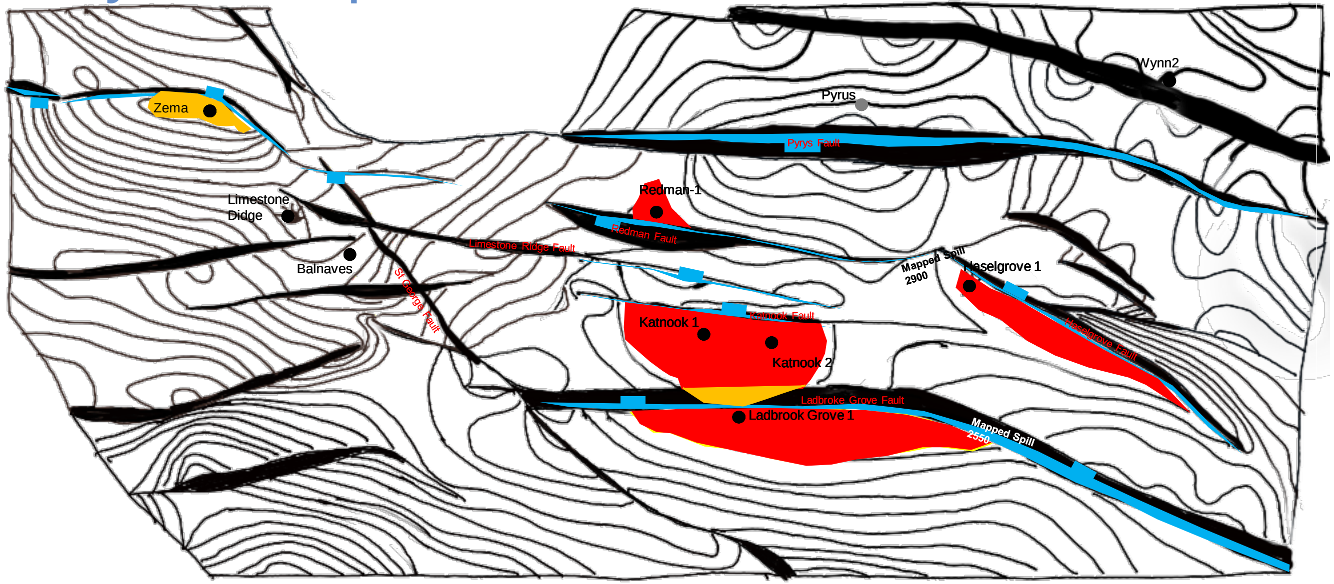


After



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

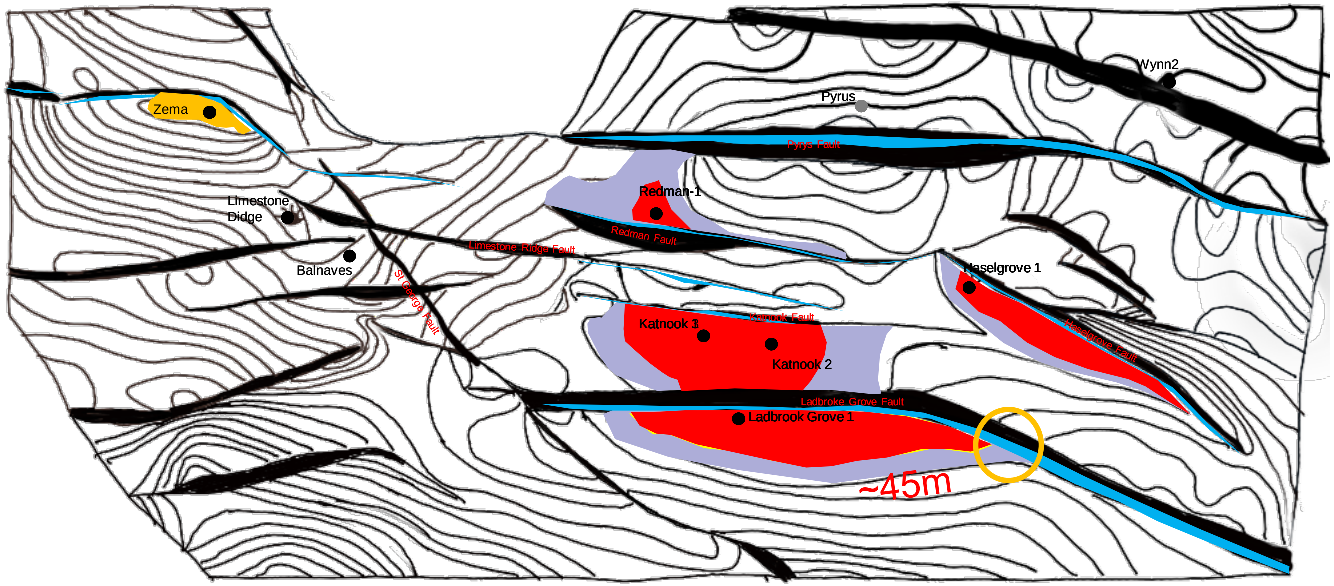
Opportunity to Improve Volumes



- It is common that improving maps enhances trapped area and thus gross rock volumes.
- With very large heave errors modification of the map may be necessary.

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

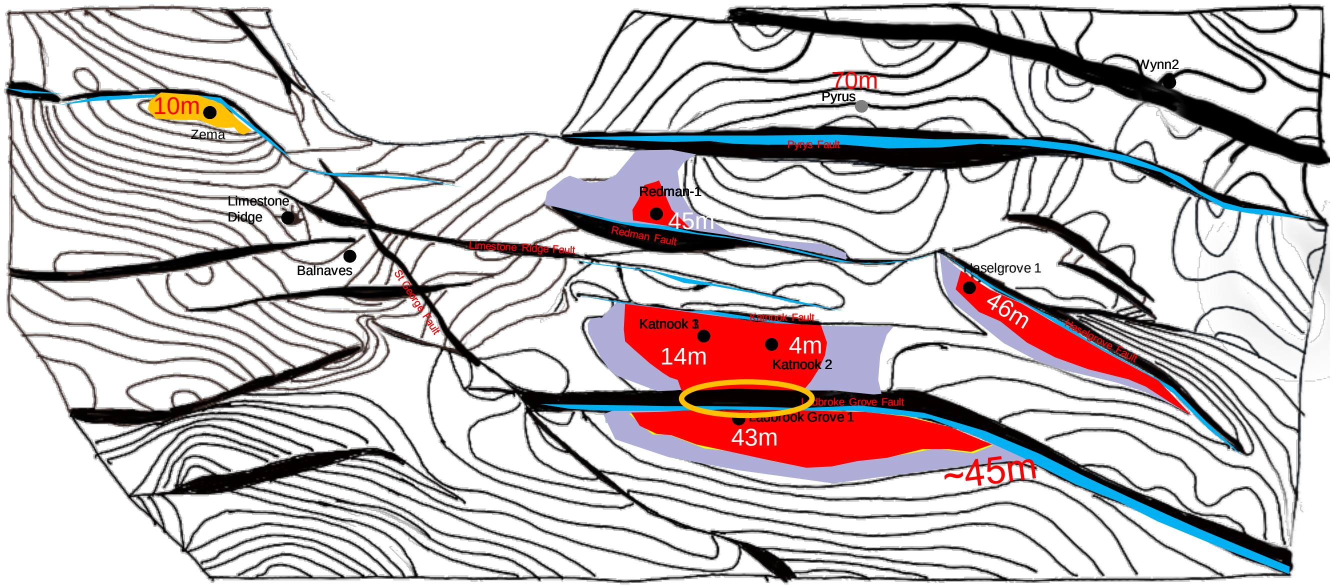
GWC Mistie



- Boult et al 2005 stated that Ladbroke Grove and Haselgrove are both filled to spill.
- The recent paper suggested that the structures were underfilled (Purple).
- There is a Signiant miss-tie with the map and the observed GWC for the Ladbroke Grove trap.

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

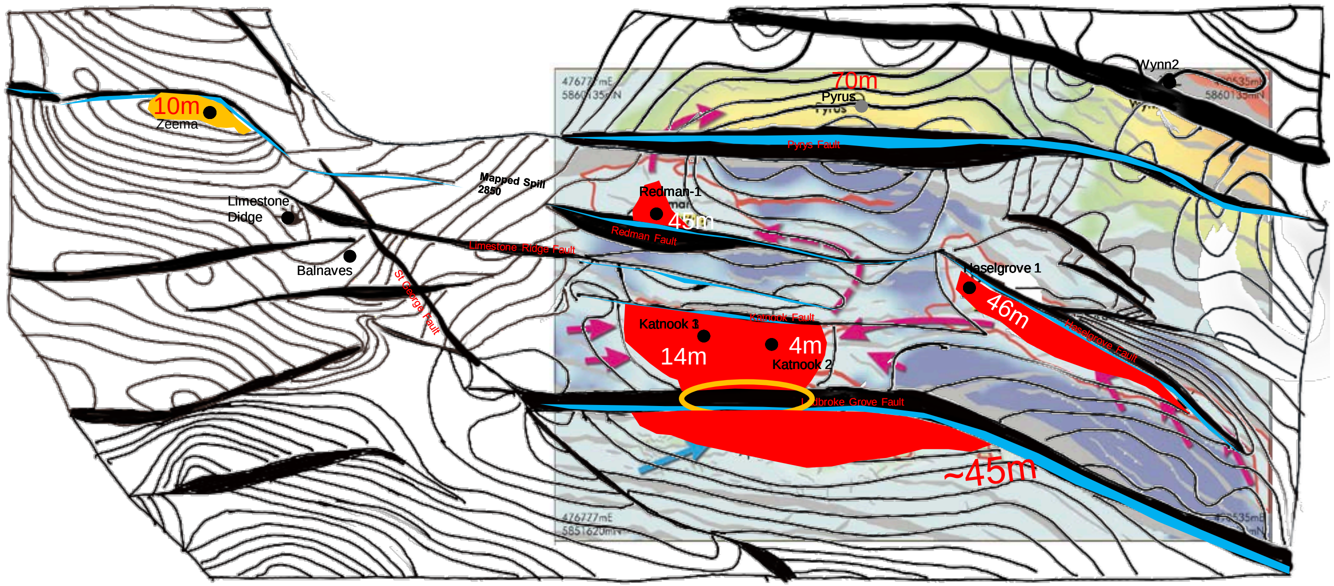
Well Mistie



- The map also has a significant miss-tie with the vertical wells.
- Combining the spill point and well tie errors gives an average 36m error.
- The recent paper suggest 15m of of fault seal for the Katnook field to the south

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Well Mistie



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SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

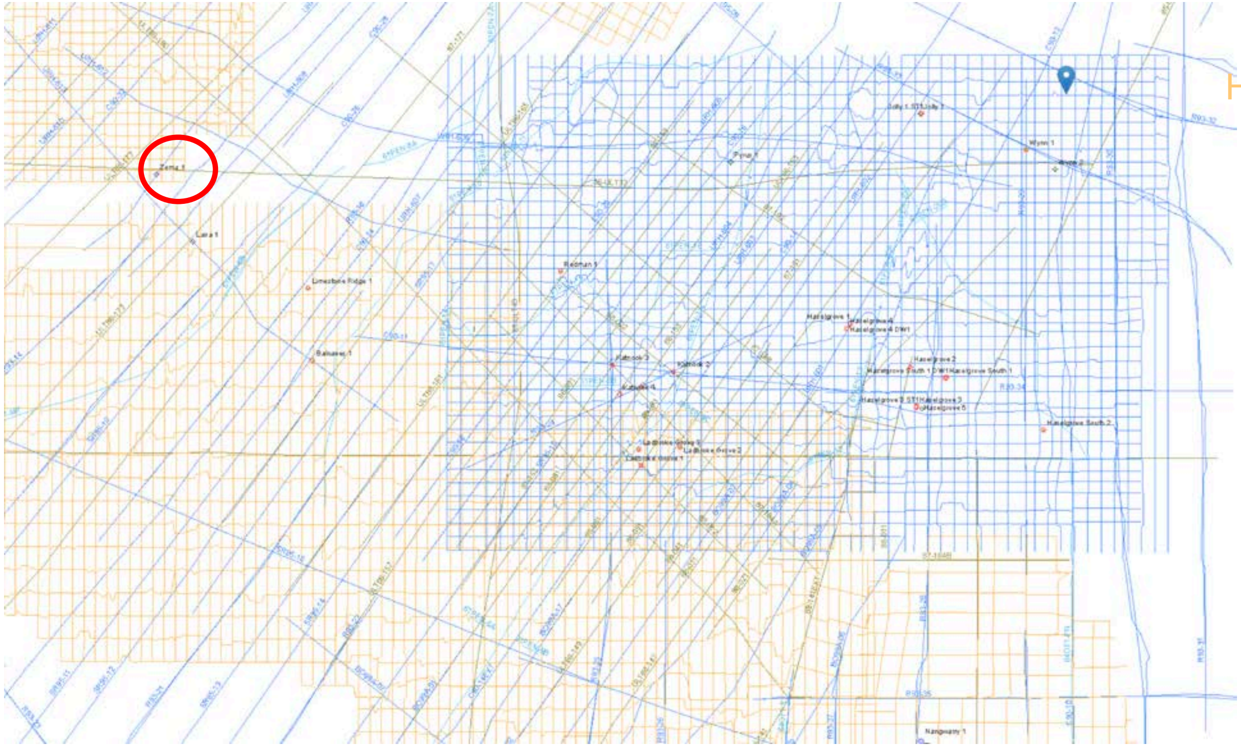
Zema Drilled on 1990's 2D Seismic

St George 3D

Haselgrove 3D

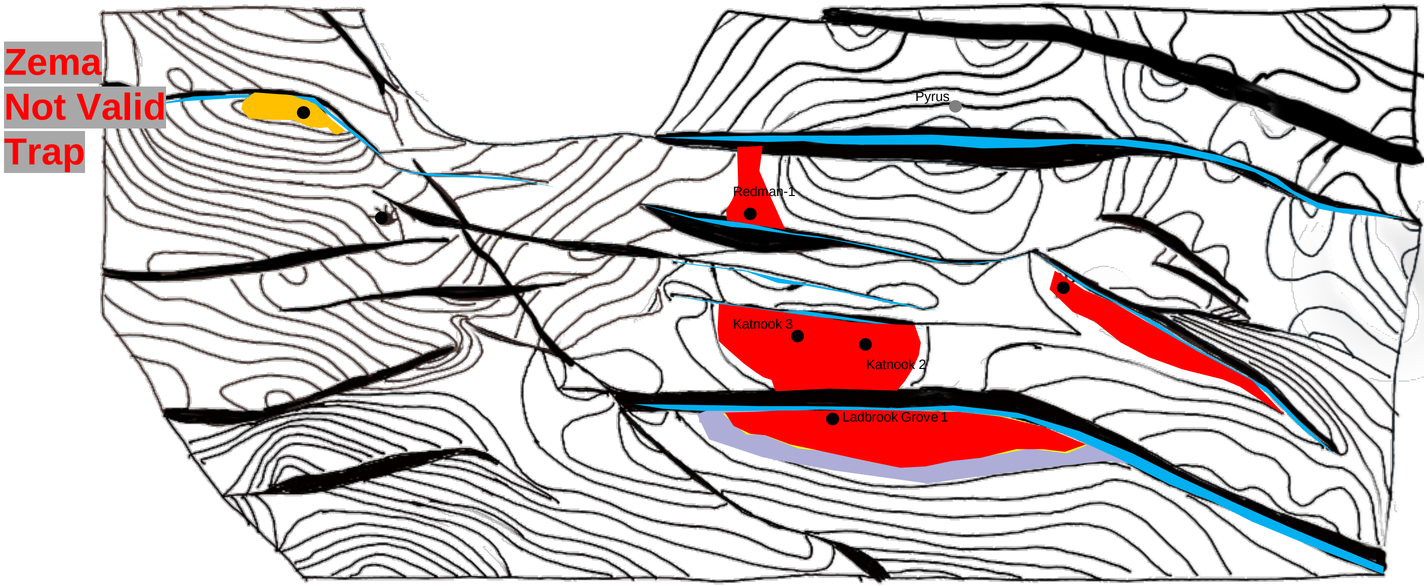
2000-2009 Seismic

Balnaves 3D



Maps made with Haselgrove and Balnaves 3D plus 2Ds

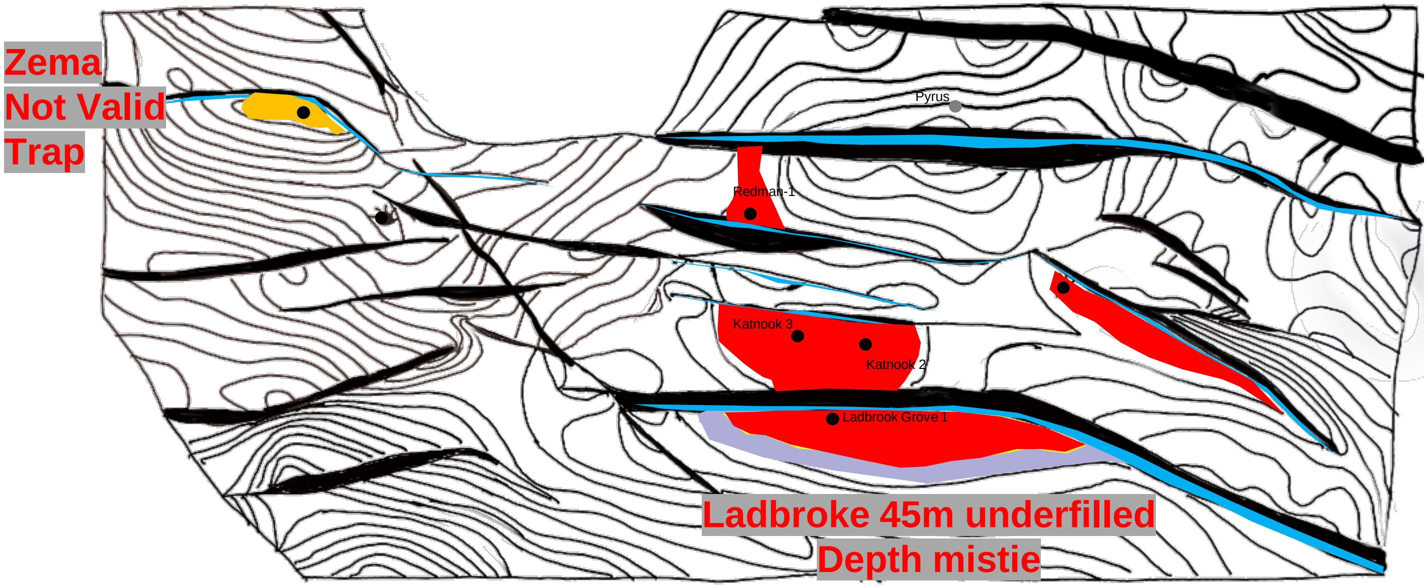
FaultRisk Results



- It is important to do an analysis on all the fields not just one!
- There are issues with the maps but by introducing an 10-40-50m error in the base of the top seal it can be shown that the fields are filled to fault juxtaposition leak points.

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

FaultRisk Results



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STRUCTURAL GEOLOGY

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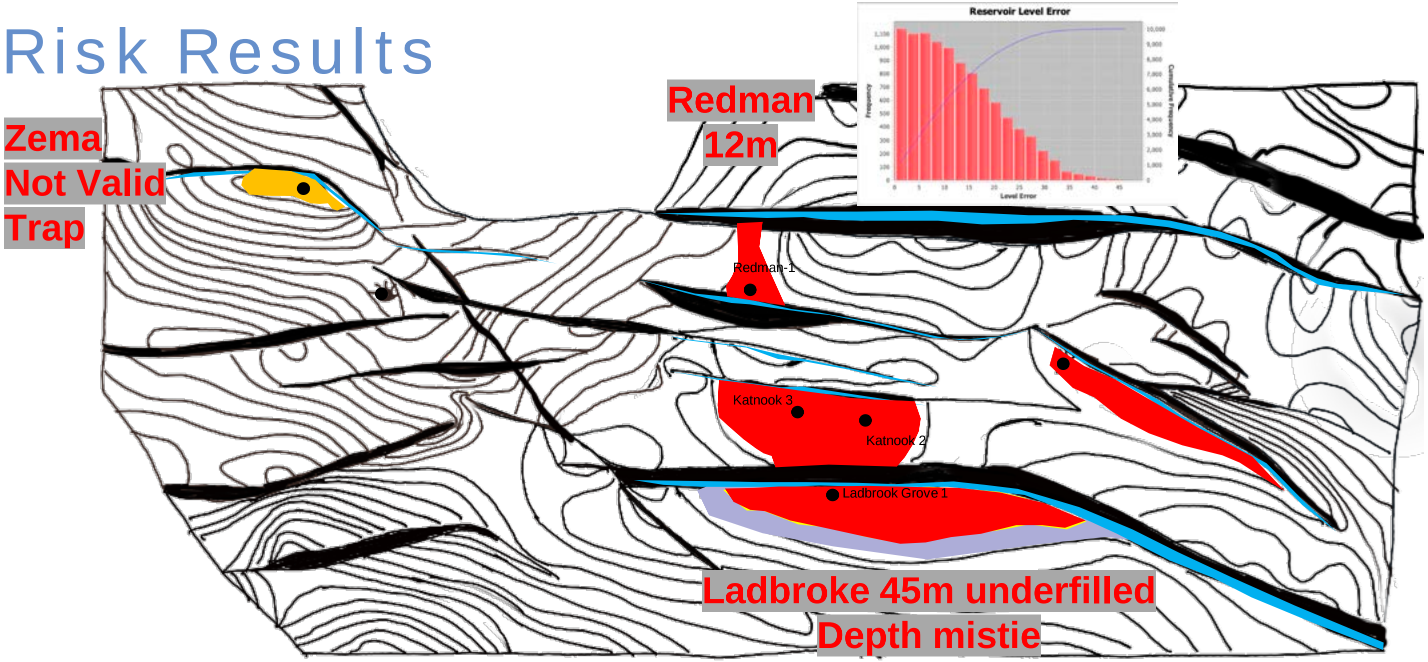

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SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

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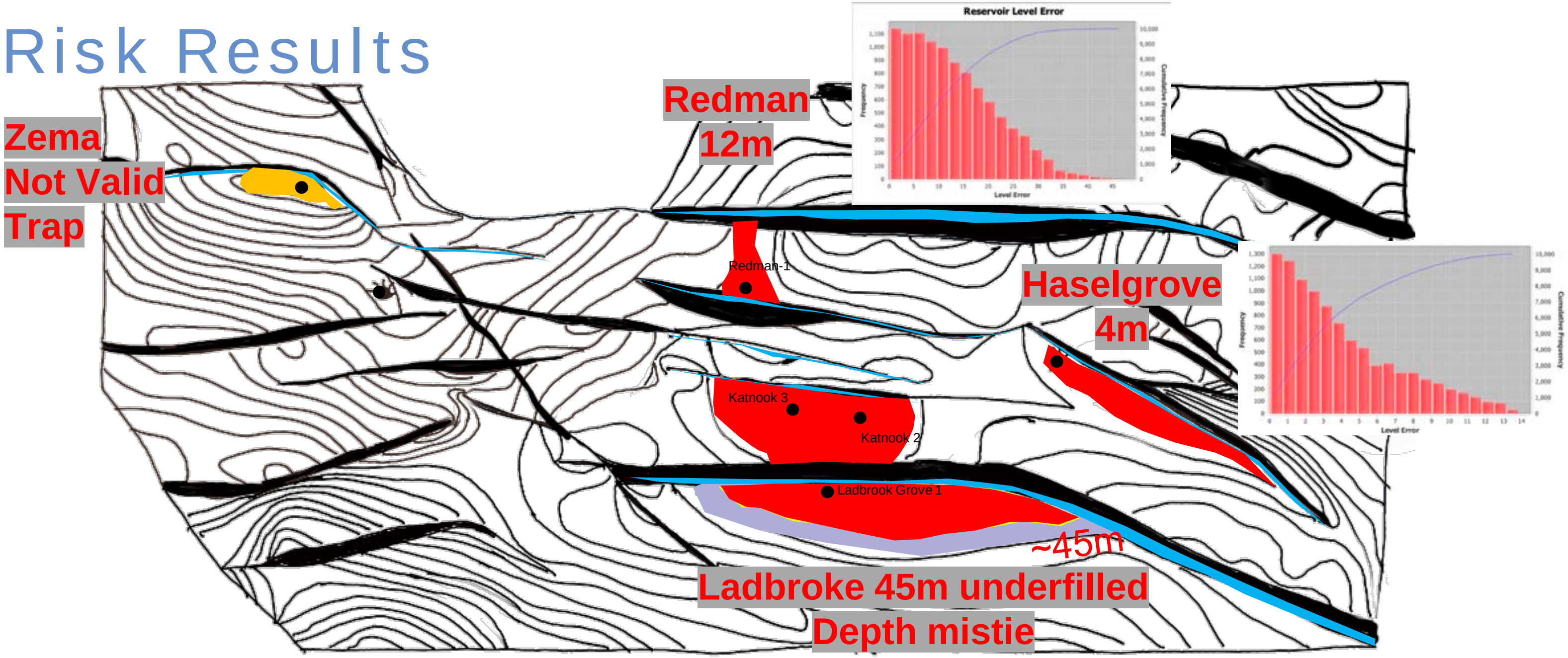

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SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

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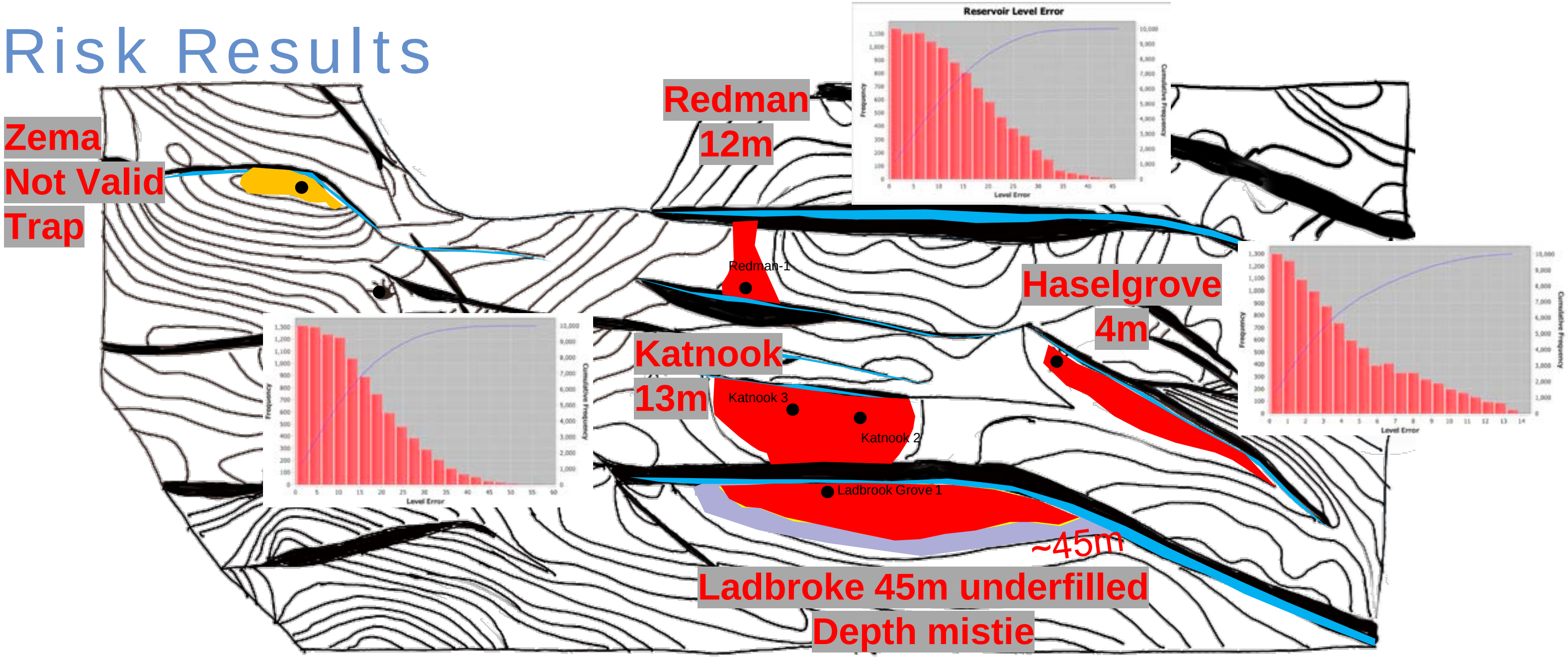

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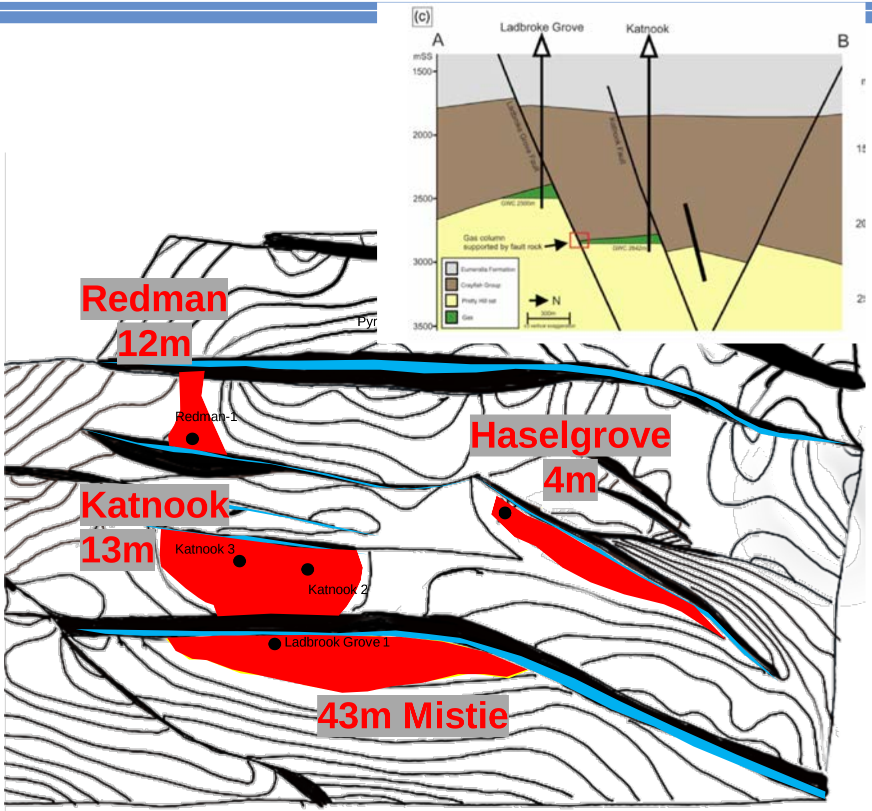
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Summary

- Good geology can improve field volumes.
- Juxtaposition leakage explains
  - Redman mean 12m error 8.6Stdev
  - Hazelgrove mean 3.9m error 3.2Stdev
  - Katnook mean 13.2m error 9.7Stdev
  - Ladbroke Grove underfilled due to mapping error
- Its vital to get depth conversion right,
- Map need to tie the wells.
- Doing fault and trap analysis means sweating the little things.



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STRUCTURAL GEOLOGY

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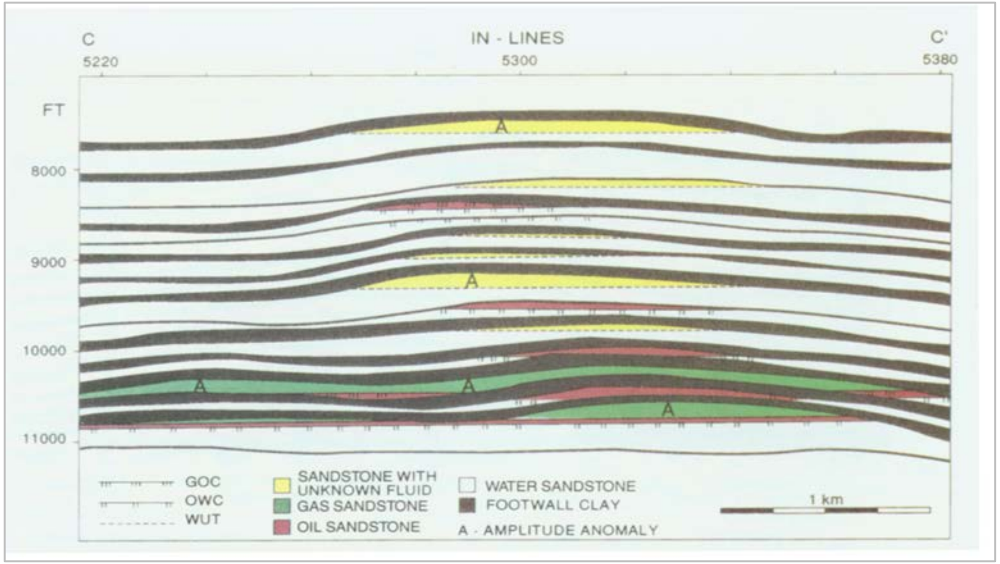
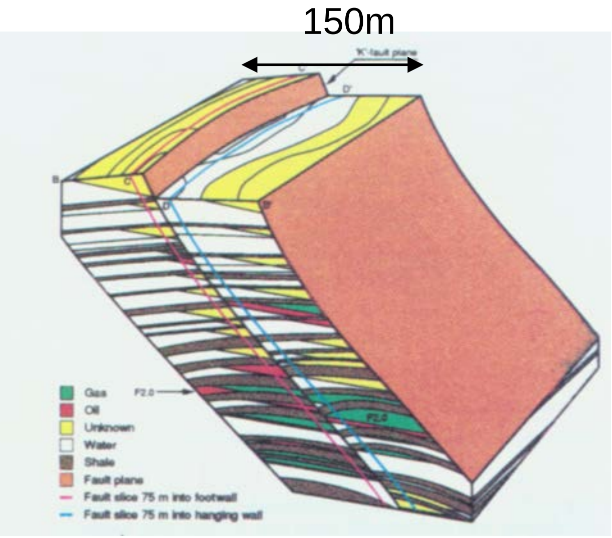
STRUCTURAL GEOLOGY

Shell Nun River

Publication confusion: Nun River Field

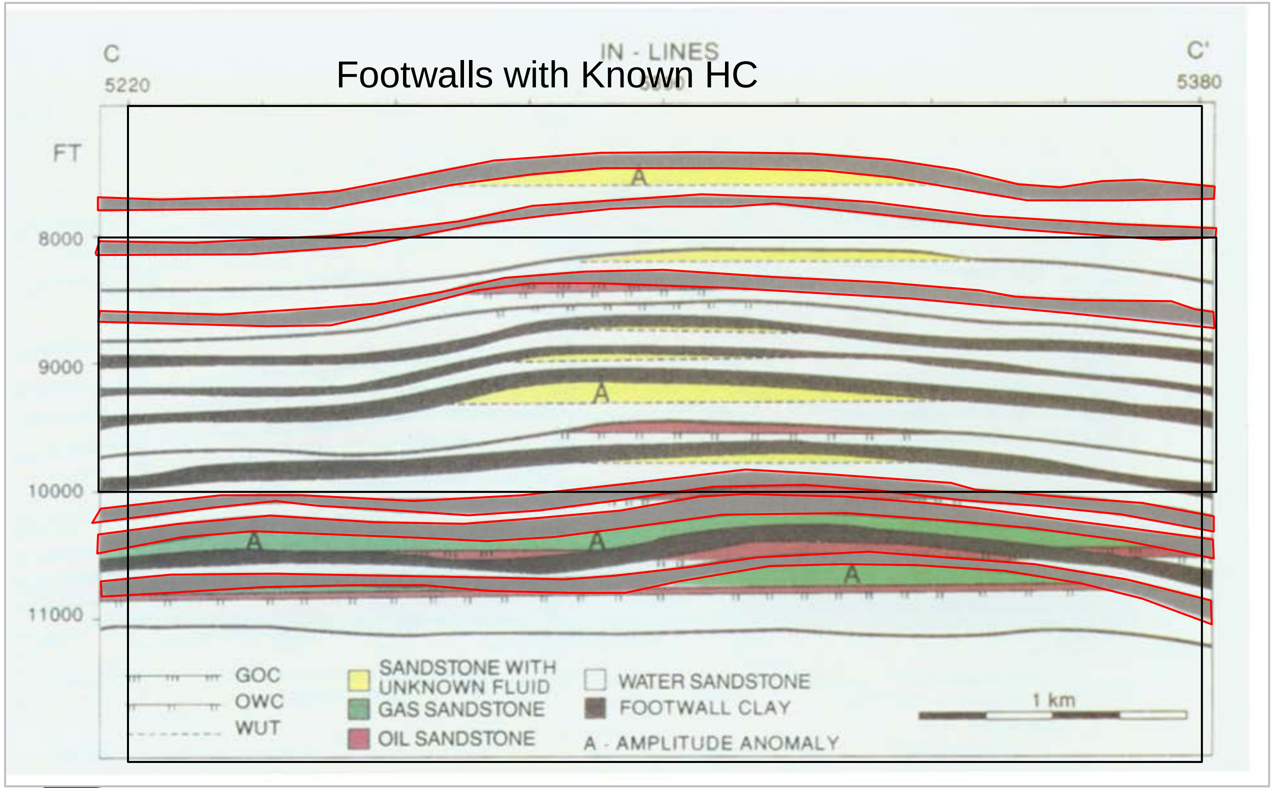


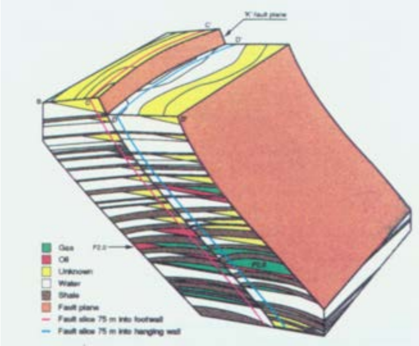


- Bouvier et al 1989 Allan Maps?

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

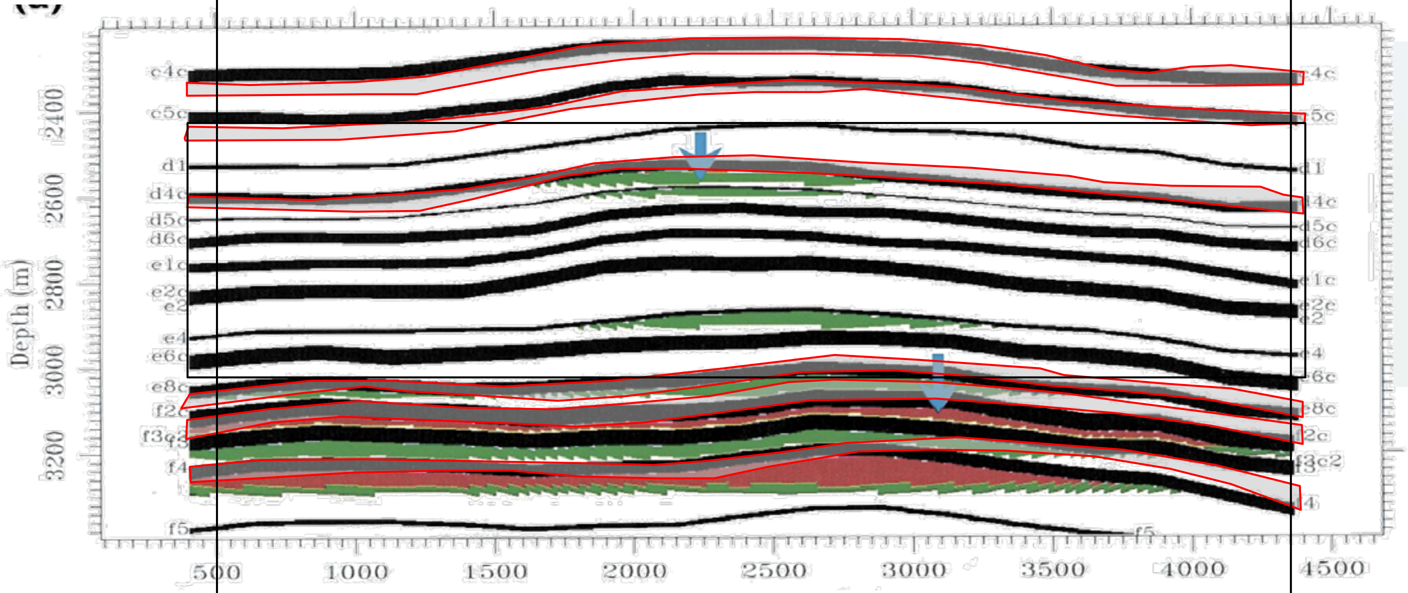
Bouvier 1989 Inherent Uncertainties

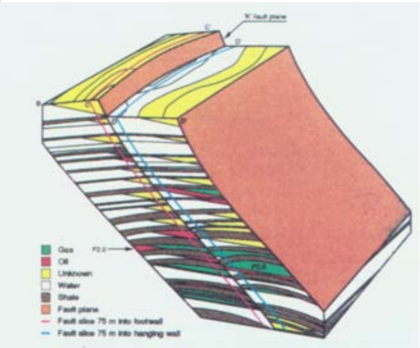




Bouvier 1989 Inherent Uncertainties

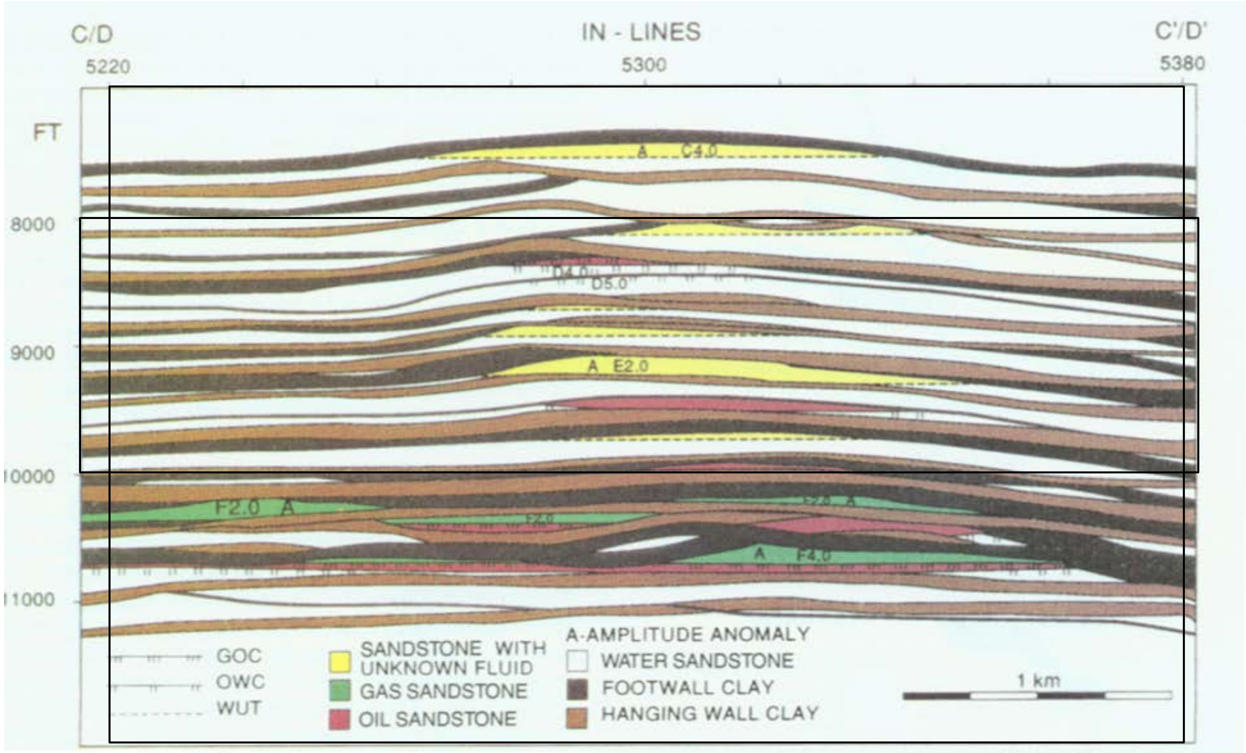
Footwalls with Known HC

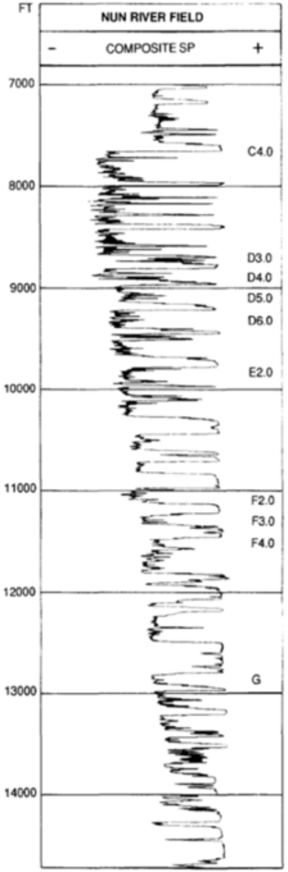




SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

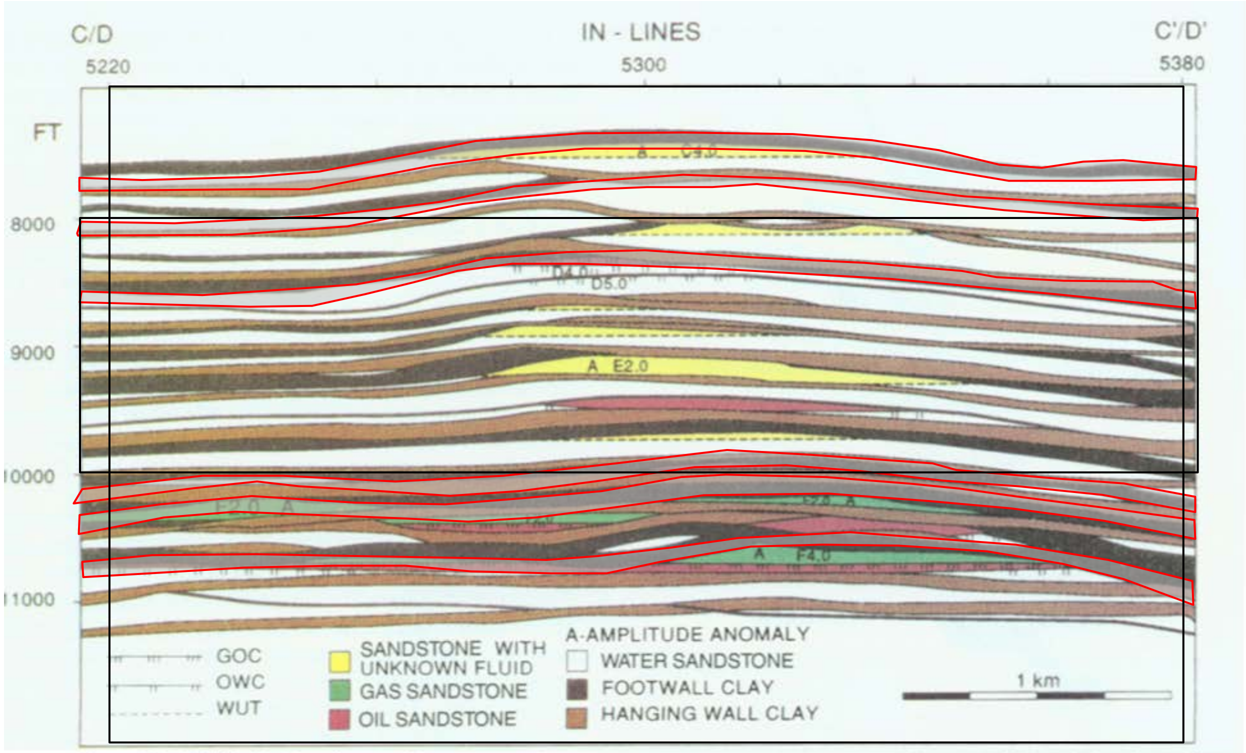
Based on SP

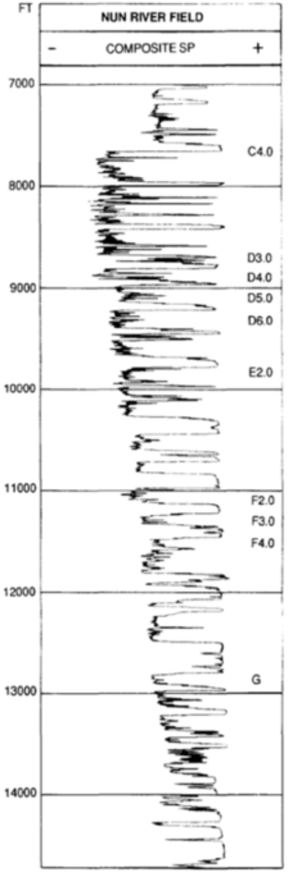




SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Allan Maps don't work & based on SP



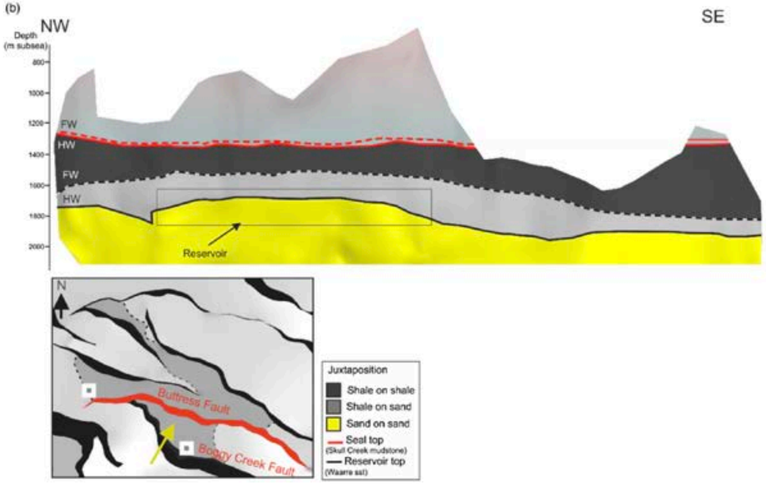


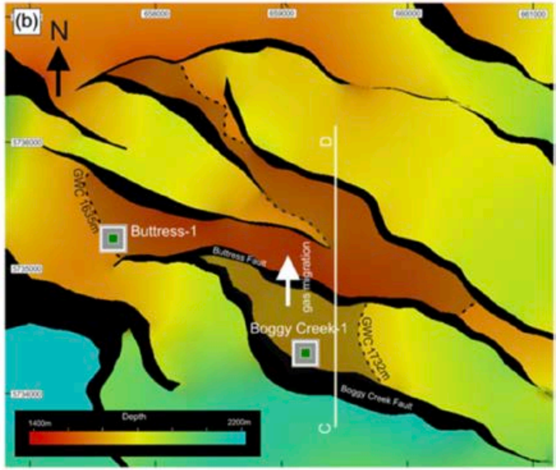
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

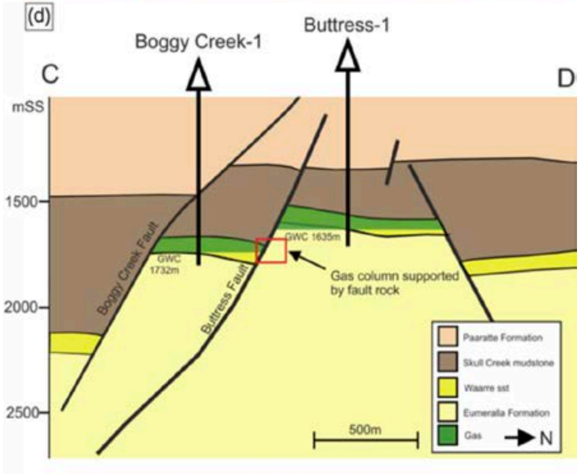
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Boggy Creek

- In the Karolyte etal paper a "cartoon" map and cross section are provided, along with a 3D representation of an Allan Map.

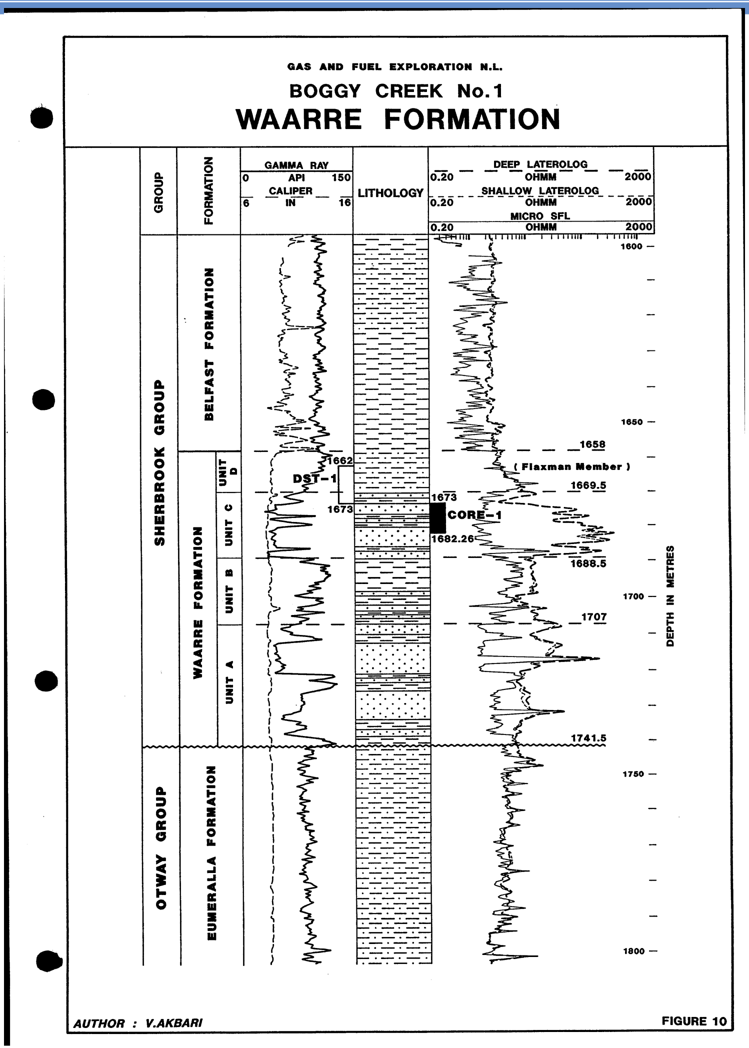






Boggy Creek Field

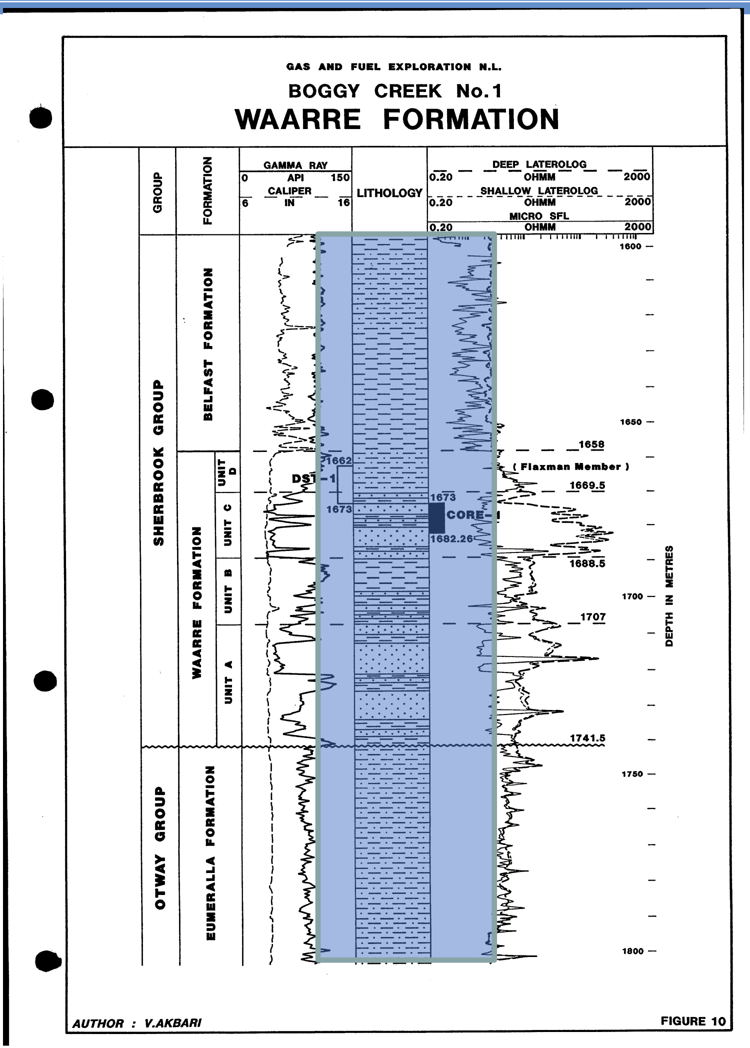
- The Boggy Creek well completion report well log shows;
- An 83m thick Warre formation and 159m intersection with the Eumeralla Formation



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Boggy Creek Field

- A quick and simple review of the lithology, gamma ray (GR) and latralog shows
- The Eumarella formation has a high GR and very little mud fluid infiltration.
- Based on the logs presented that Eumarella would appear to be a base seal to the Warrre formation.



SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Naylor Field

- The Naylor 1 well is provided in the in the Santos Buttress Creek well proposal.
- As with Boggy Creek well the Eumarella formation has a high GR and very little mud fluid infiltration.

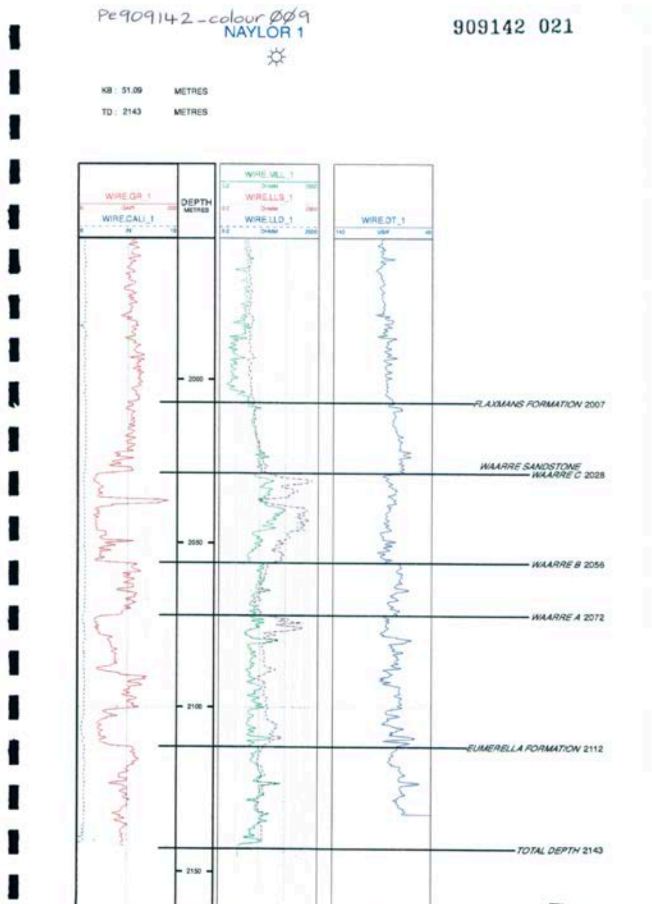
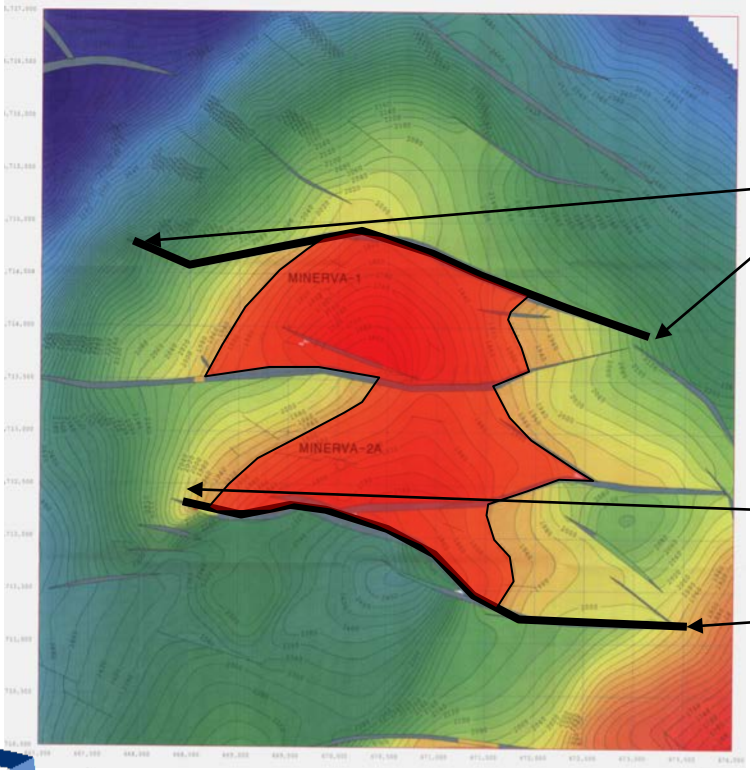
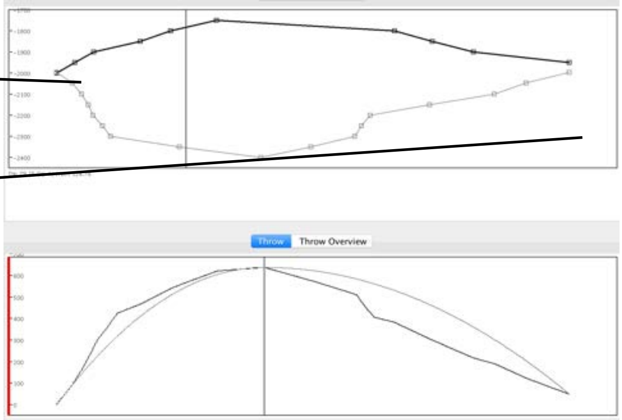


Figure 9

Example 4 Minerva Field Otway Basin Victoria Southern Australia

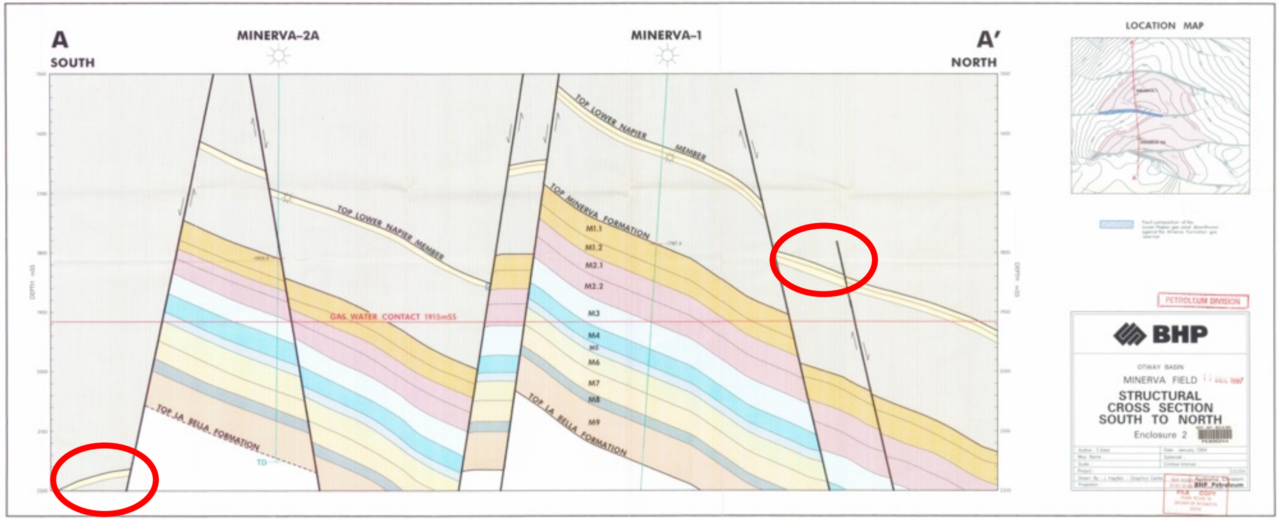




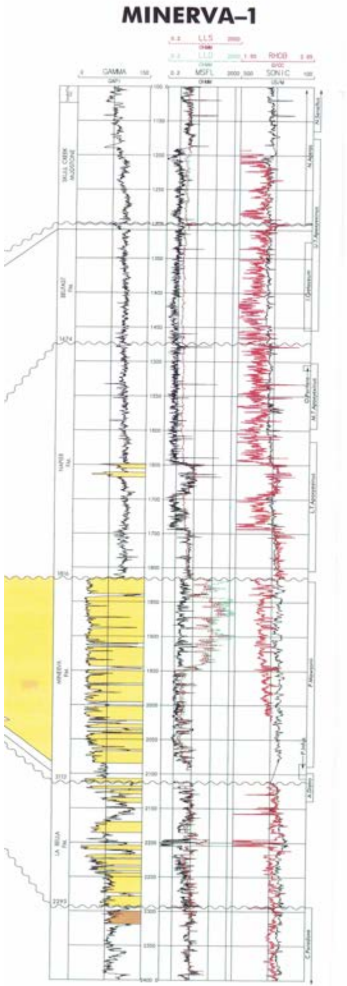
Victorian Geologic Survey

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Stratigraphic Template



Victorian Geologic Survey



Layer	Foot Wall Type	Thickness	VShale
Napier_Thief	Thief	[Δ] 20.0 m	[Δ] 20.0 %
Napier_Seal	Seal	[Δ] 150.0 m	[Δ] 90.0 %
Minerva_Formation	Reservoir	[Δ] 300.0 m	[Δ] 30.0 %

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Bimodal Error
P50 9.7m

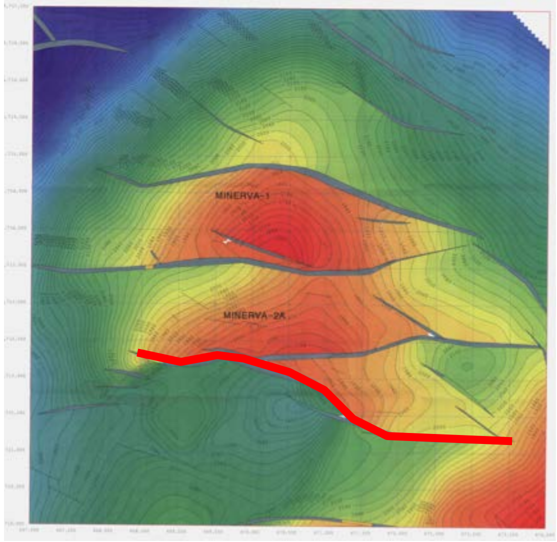
- Leak Point Southern Fault

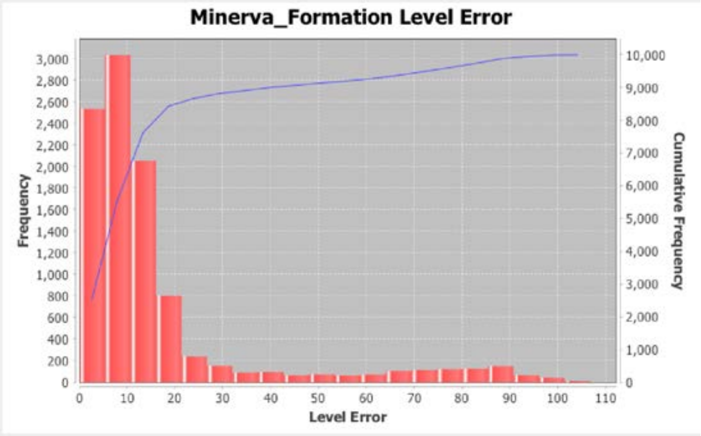
JUXTAPOSITION :

- Total Trapped Column: Mean 111 m, Standard Deviation21 m
  - Level: Mean -1931 m, Standard Deviation 21 m
  - GWC Error mean 16.3 Standard Deviation 21m

SGR :

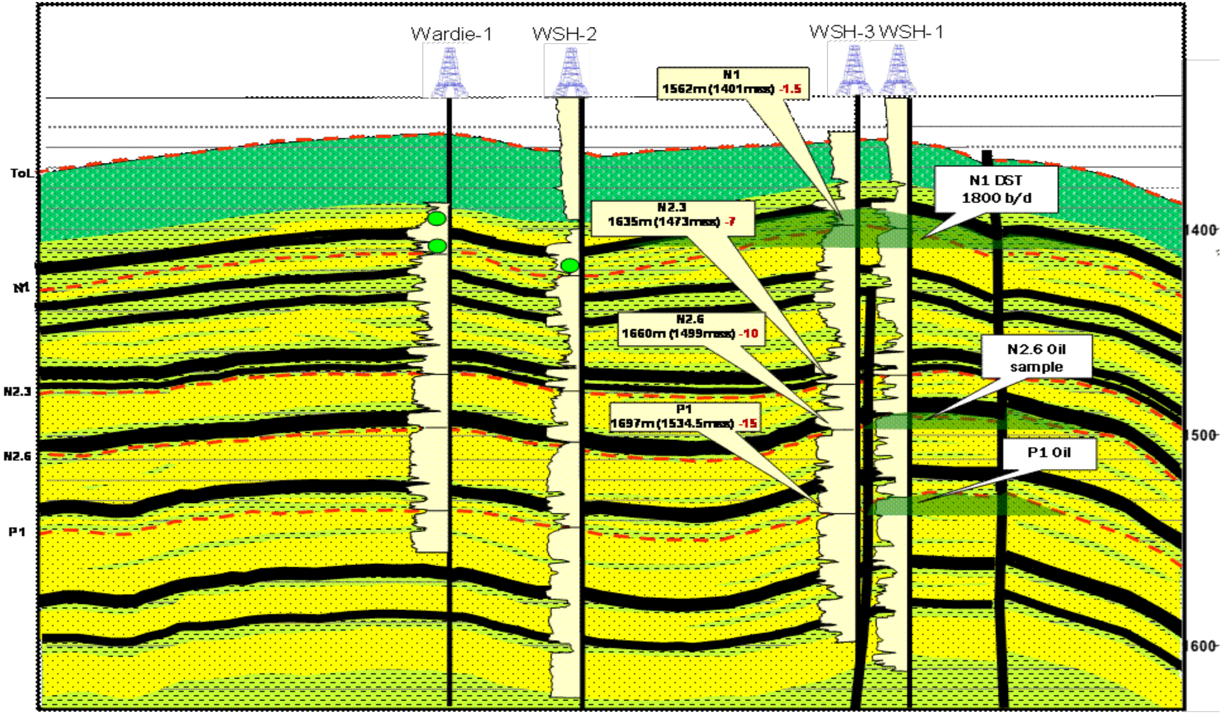
- Total Trapped Column: Mean 157.6 m, Standard Deviation 71.1 m
  - Level: Mean -1977.6 m, Standard Deviation 71.1 m
  - GWC Error Mean 63 Standard Deviating 70m





Example 5: West Sea Horse Gippsland Basin SE Australia

Name	Type	Thickness Distribution		
		Min	Most Likely	Max
N0-N1	Reservoir	15	31	50
Top_N2_Coal_Seal	Seal	4	8	12
N2_2	Reservoir	18	22	26
N2_3_Coal	Seal	4	8	12
N2_3	Reservoir	9	14	22
N2_6_Coal	**Seal-Reference**	**6**	**10**	**14**
N2_6	Reservoir	17	22	31
P1_Coal	Seal	4	8	12
P1	Reservoir	22	40	48



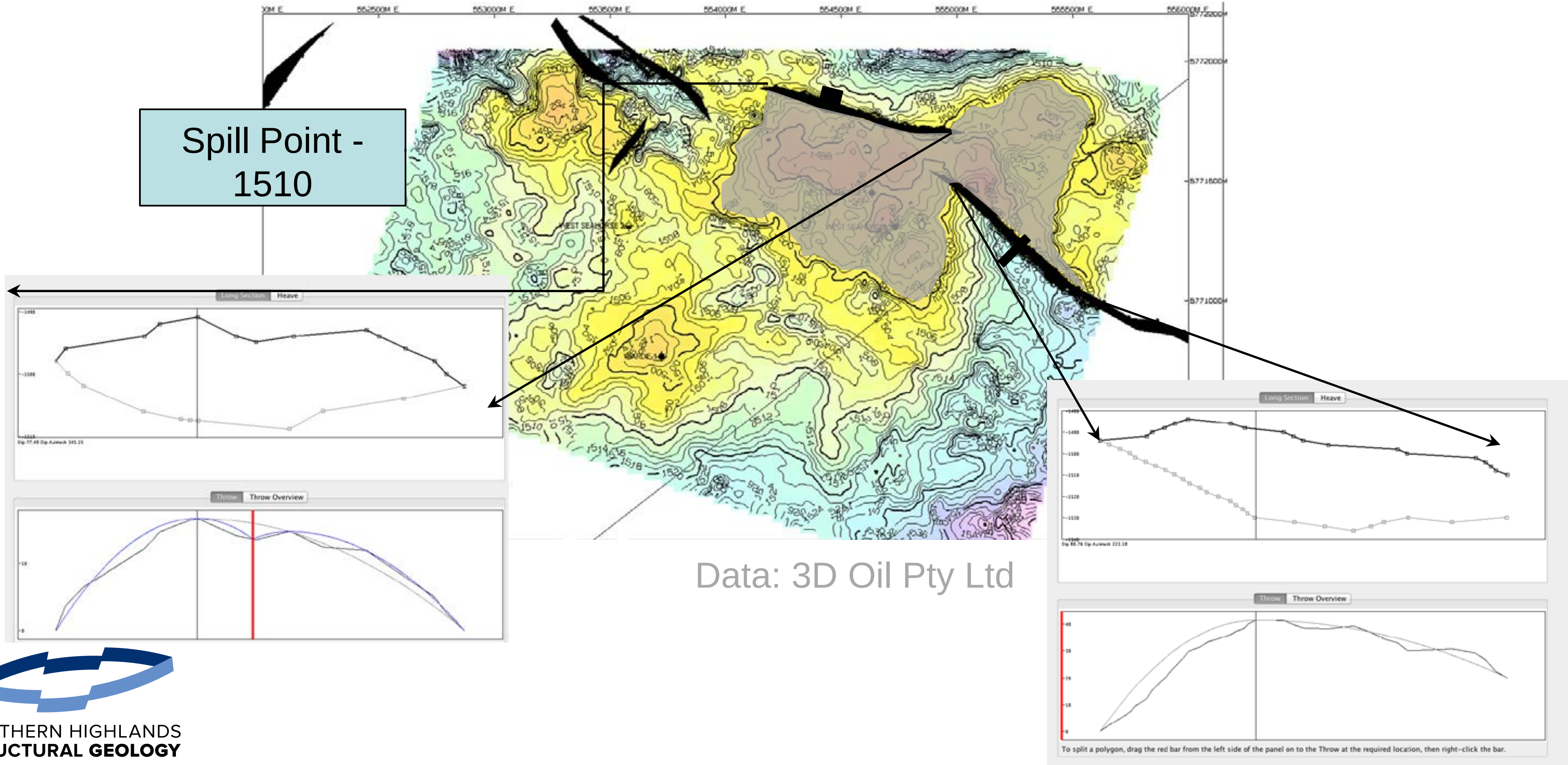
Data: 3D Oil Pty Ltd

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

West Sea Horse Data

Crest - 1486

Spill Point - 1510



Data: 3D Oil Pty Ltd

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

- A Deterministic model behaves the same every time

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

- A Deterministic model behaves the same every time
- Give two geoscientist the same data and they will often come up with more than two answers!

Corrected for compaction

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

- A Deterministic model behaves the same every time
- Give two geoscientist the same data and they will often come up with more than two answers!
- There is substantial parameter uncertainty so deterministic geologic models do not exist.

Corrected for compaction

I Am A Geologist:
The Only Thing I Know Is that I Am Wrong

- A Deterministic model behaves the same every time
- Give two geoscientist the same data and they will often come up with more than two answers!
- There is substantial parameter uncertainty so Deterministic geologic models do not exist.
- It is vital to conduct robust stochastic modelling.

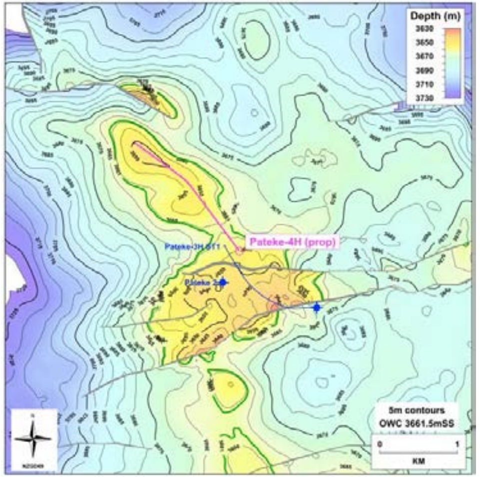
Corrected for compaction

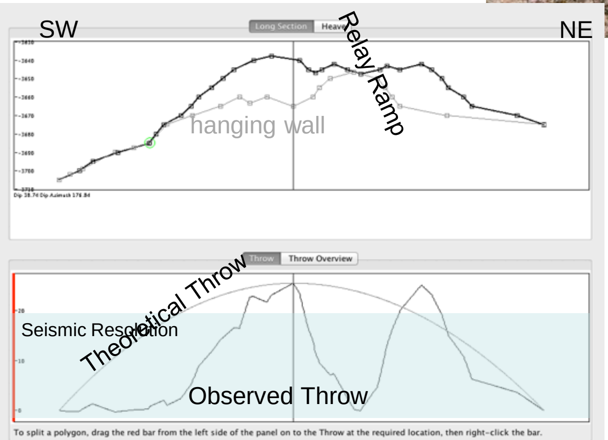
SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Finding Oil and Gas

SOUTHERN HIGHLANDS
STRUCTURAL GEOLOGY

Pateke Tarinaki Basin NZ





- The NZOG map shows an anomalous fault throw profile:
  - The fault has no throw to the West and very small throw at the Eastern end
  - Most importantly, there is no throw near the crest of the structure where the fault changes strike
- This reduction in throw in the center of the fault is commonly seen in Relay Ramps, as illustrated by the photography from Fault Analysis Group, Dublin, website.

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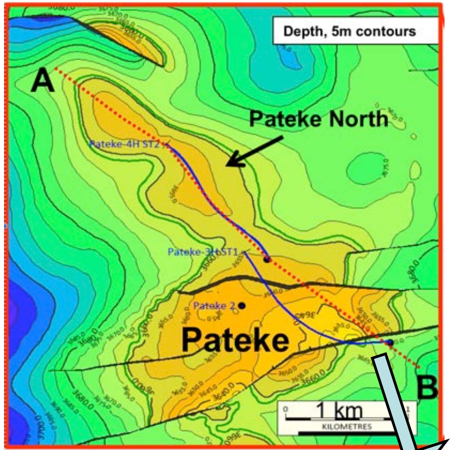
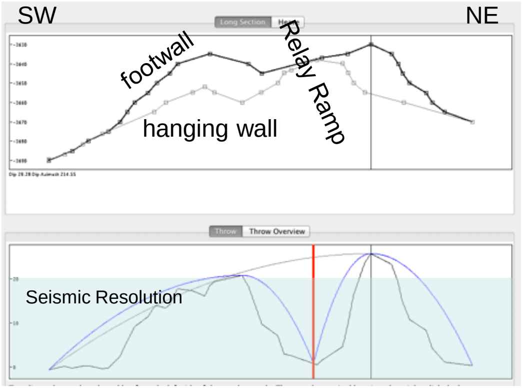
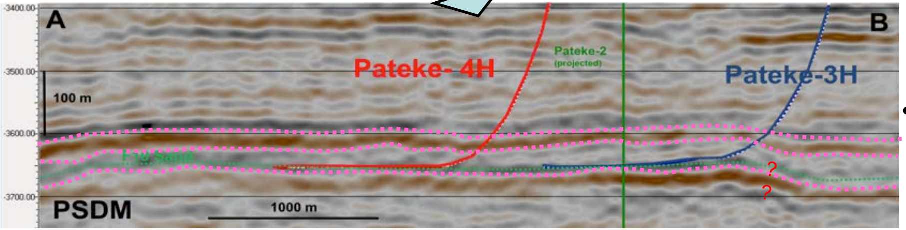
Data: Pateke Field from Pan Pacific Mapping

Fault is not Field Limit







- As with the NZOG mapping the throws are less than seismic resolution, and there is a relay ramp near the Crest.
  - Looking at this image of the seismic, and annotating **Zero Phase,** it is hard to see the fault.
  - Rather, it appears to be a Monocline and therefore not a field limiting Feature.

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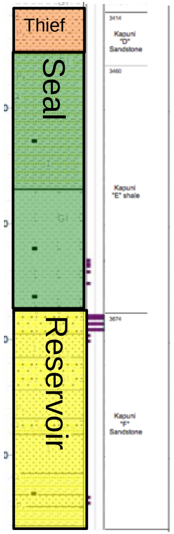
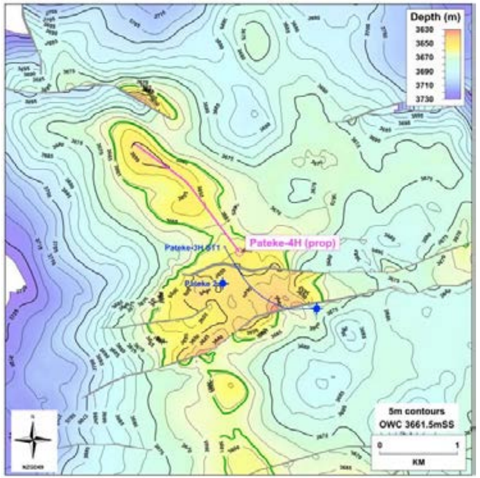
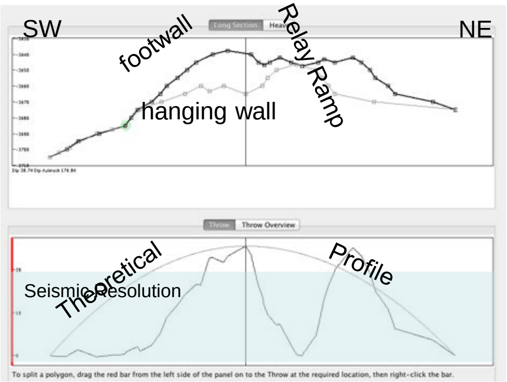
Data: Pateke from NZOG







Layer	Foot Wall Type	Thickness	VShale
Kaimiro_D_Sand	Thief	[Δ] 15.0 m	[Δ] 20.0 %
Farewell_E_Shale	Seal	[Δ] 215.0 m	[Δ] 90.0 %
Farewell_F1	Reservoir	[Δ] 200.0 m	[Δ] 90.0 %

- Using the NZOG mapping, a highly optimistic FaultRisk model was defined, ignoring the relay ramp and assuming the Theoretical Profile.
- A stratigraphic template was defined based on the Pateke 2 Vertical well.
- FaultRisk was run in calibration mode such that for each of the 10,000 realizations, the Juxtaposition and SGR leak points were compared with the observed Free water level at -2660.

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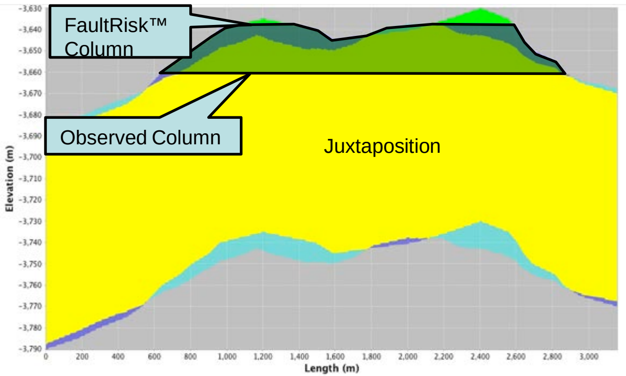
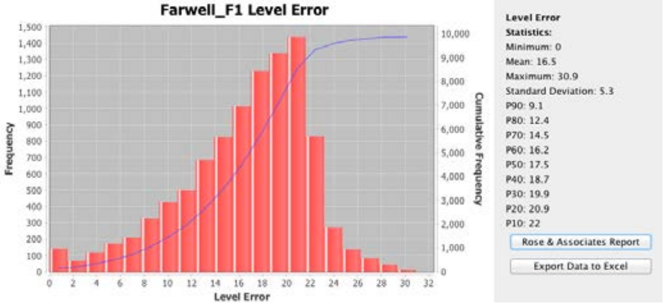
Results: FaultRisk™ Allan Map & Results

Fault Profile





- FaultRisk analysis of the South bounding fault show that it can not be the field limiting feature.
- The Juxtaposition leak point to the south is a mean 17.5m structurally higher than the observed OWC.
- As can be seen in the Allan Map, the FaultRisk columns are insignificant compared to the Observed column.
- Given that this was an optimistic model ignoring the relay ramp, the simplest solution is that the accumulation is limited to the south by some other feature to the south.

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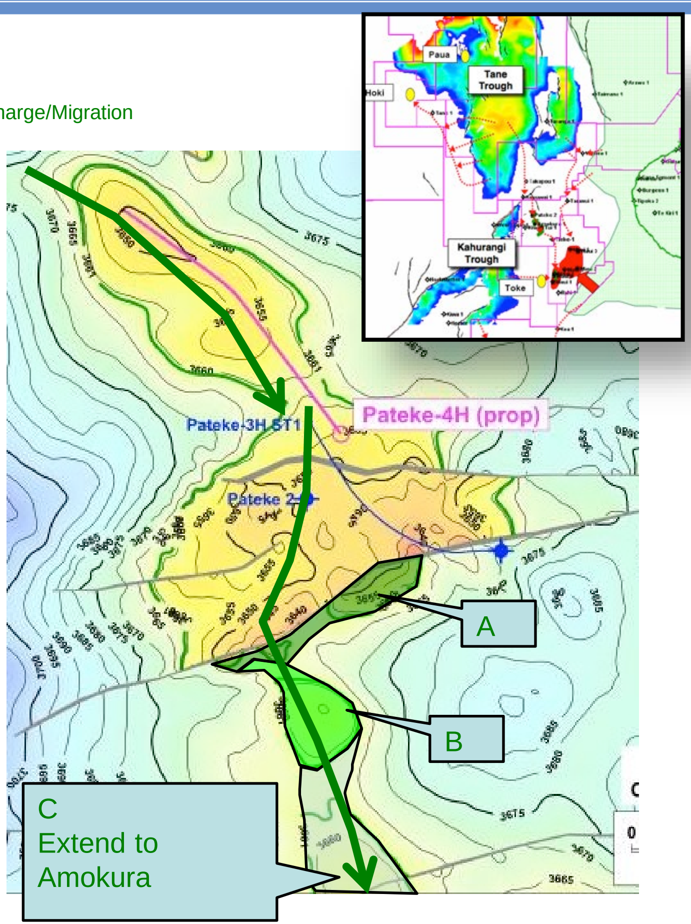
FaultRisk™ Results

- Three Scenarios for fill are shown as A, B, or C.
- The up-dip Tui & Amokura fields are filled to spill.
- Given the modest size of this structure it is most likely that it is not charge limited, and filled to spill.
- Further, the published GNS basin models (Sykes & Funnell 2013) show fill spill migration of hydrocarbons from the Tane Trough through Pateke-Amokura-Tui to the giant Maui Field.

Charge/Migration



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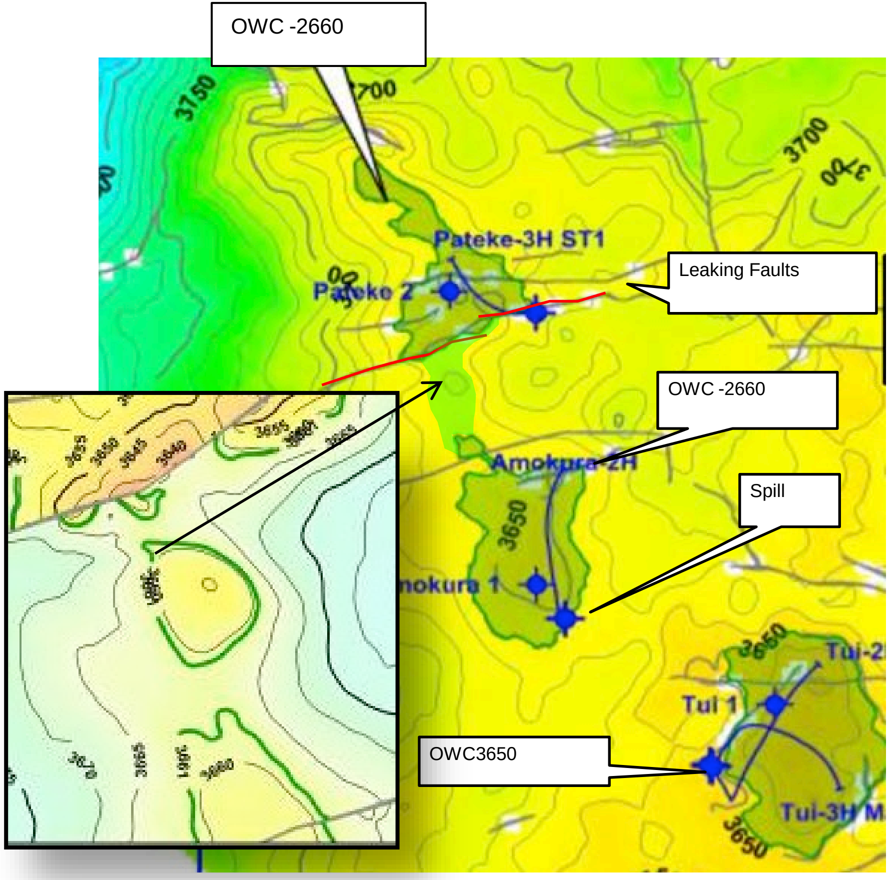
Results Link Pateke-Amokura Fields



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