Quantitative Interpretation

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Quantitative Interpretation

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Outline

Introduction

Research and applied science

Quantitative method

Case study: Interpolation / AVO

Case study: steering horizontal wells

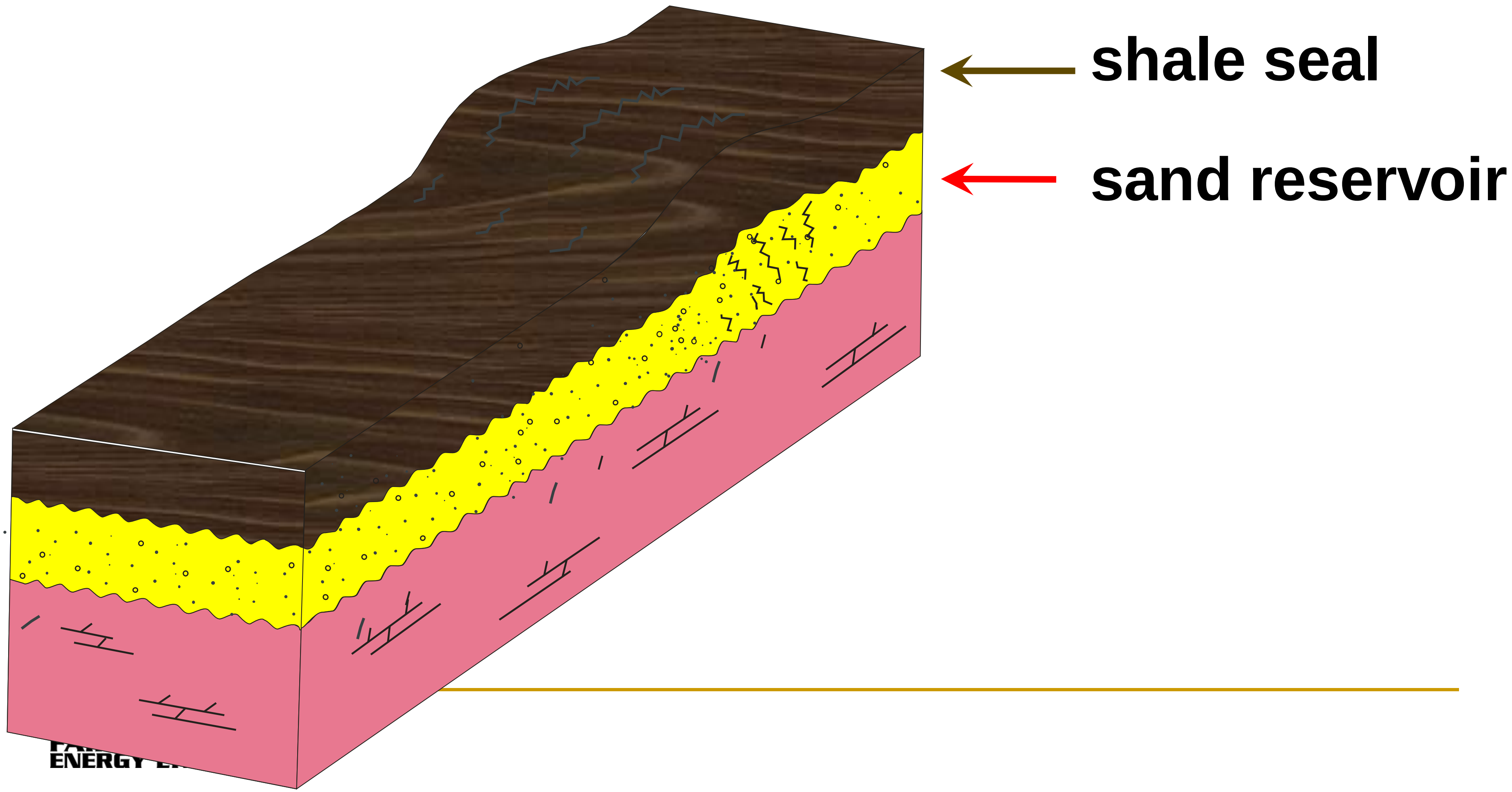
Case study: fracture estimation & production

Research examples

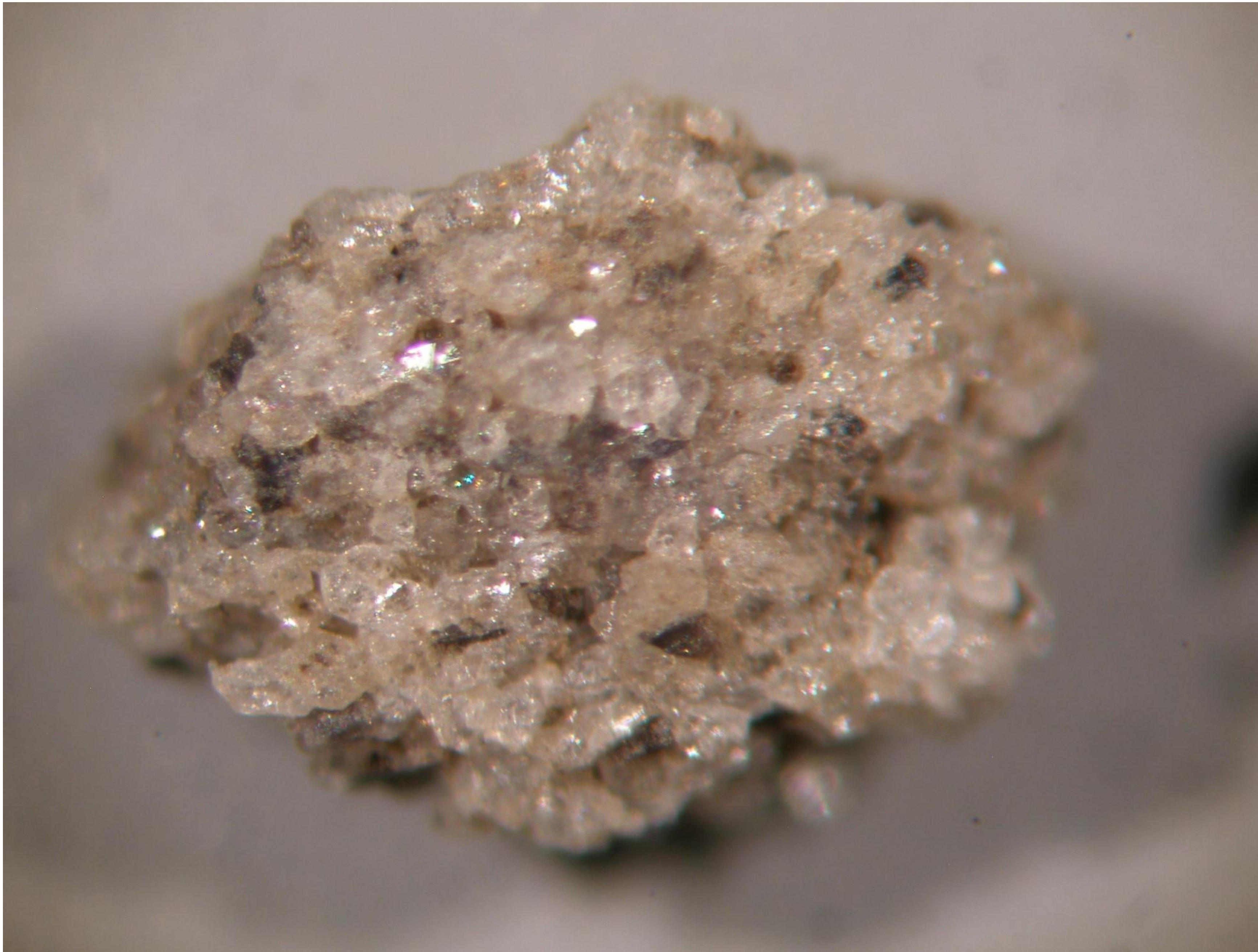
Conclusions

Map the layers of the earth

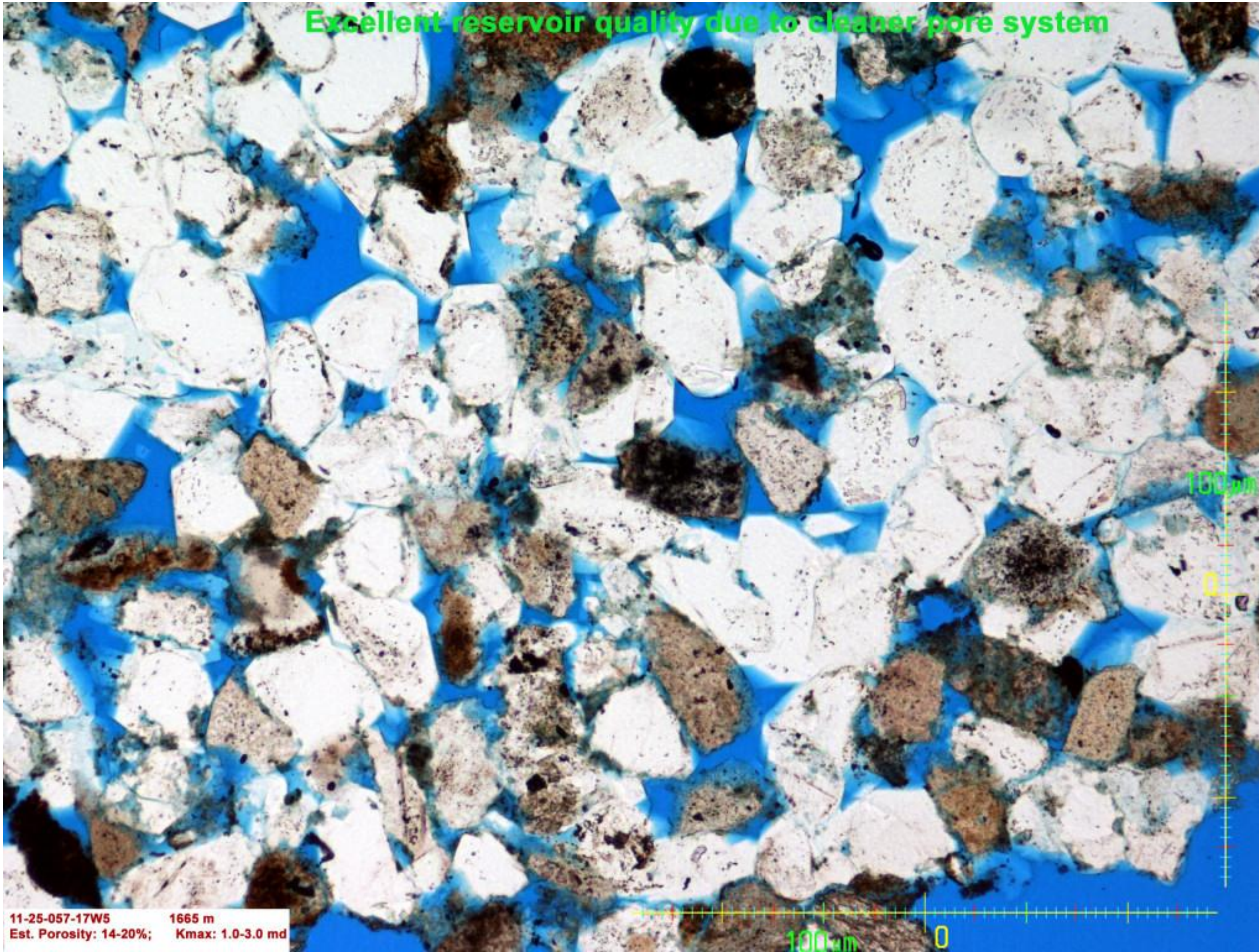
- Hydrocarbons flow through reservoir
- They are trapped by seals



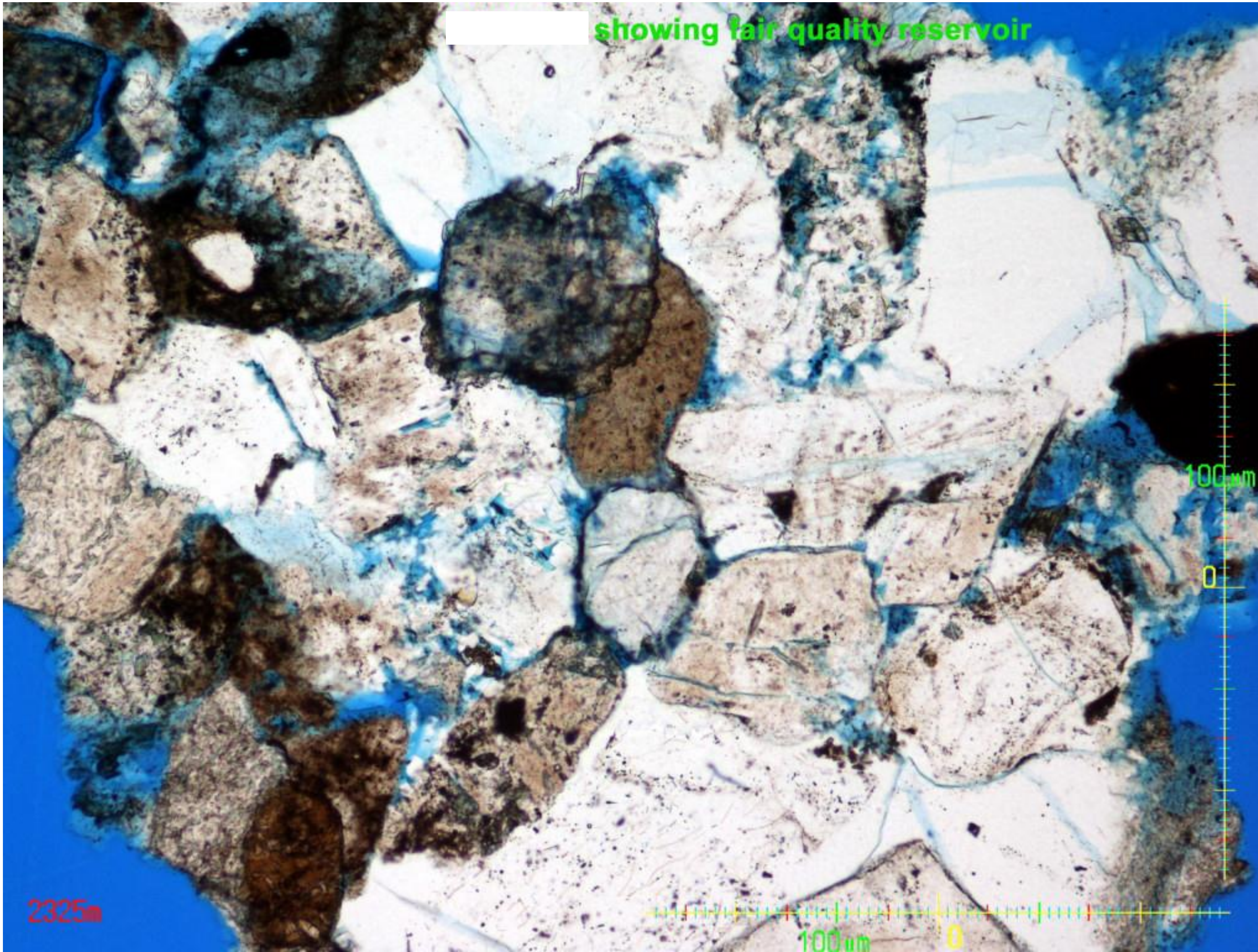
Excellent reservoir (Cardium)



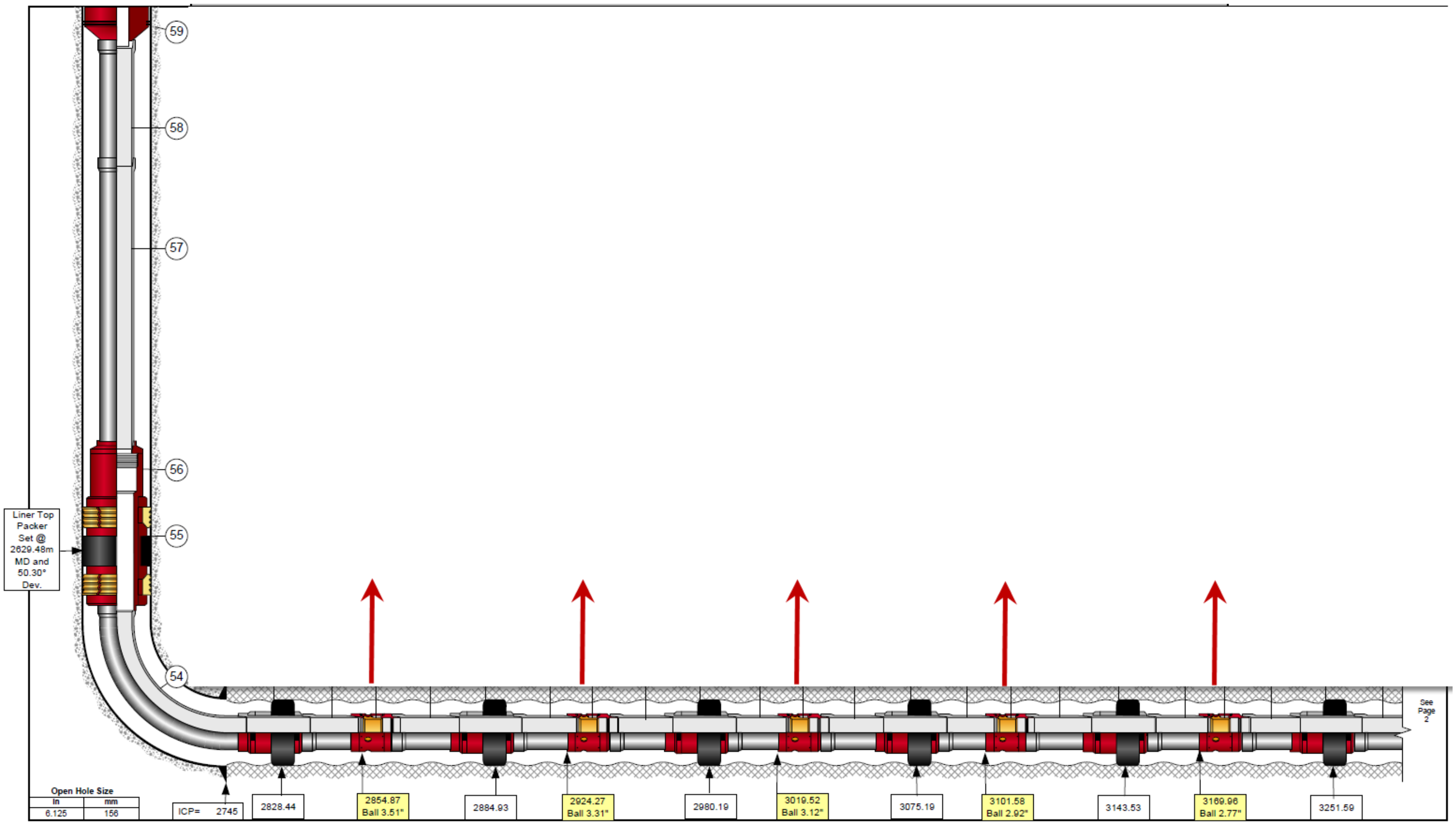
Excellent reservoir (Cardium)



Unconventional reservoir



Introduction: oil & gas & horizontals



- Fracture stimulate many times in each well
- All these activities can be of concern

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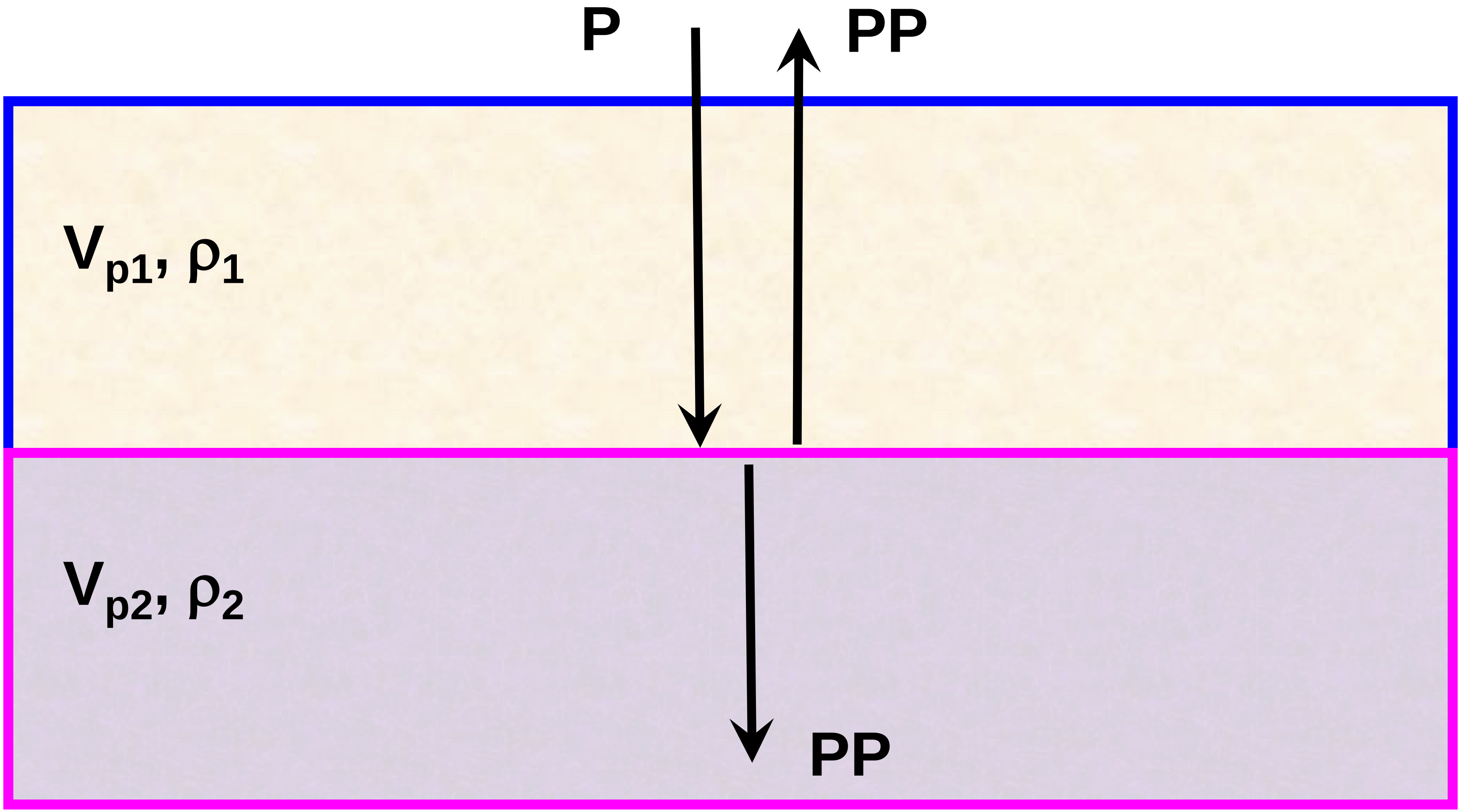
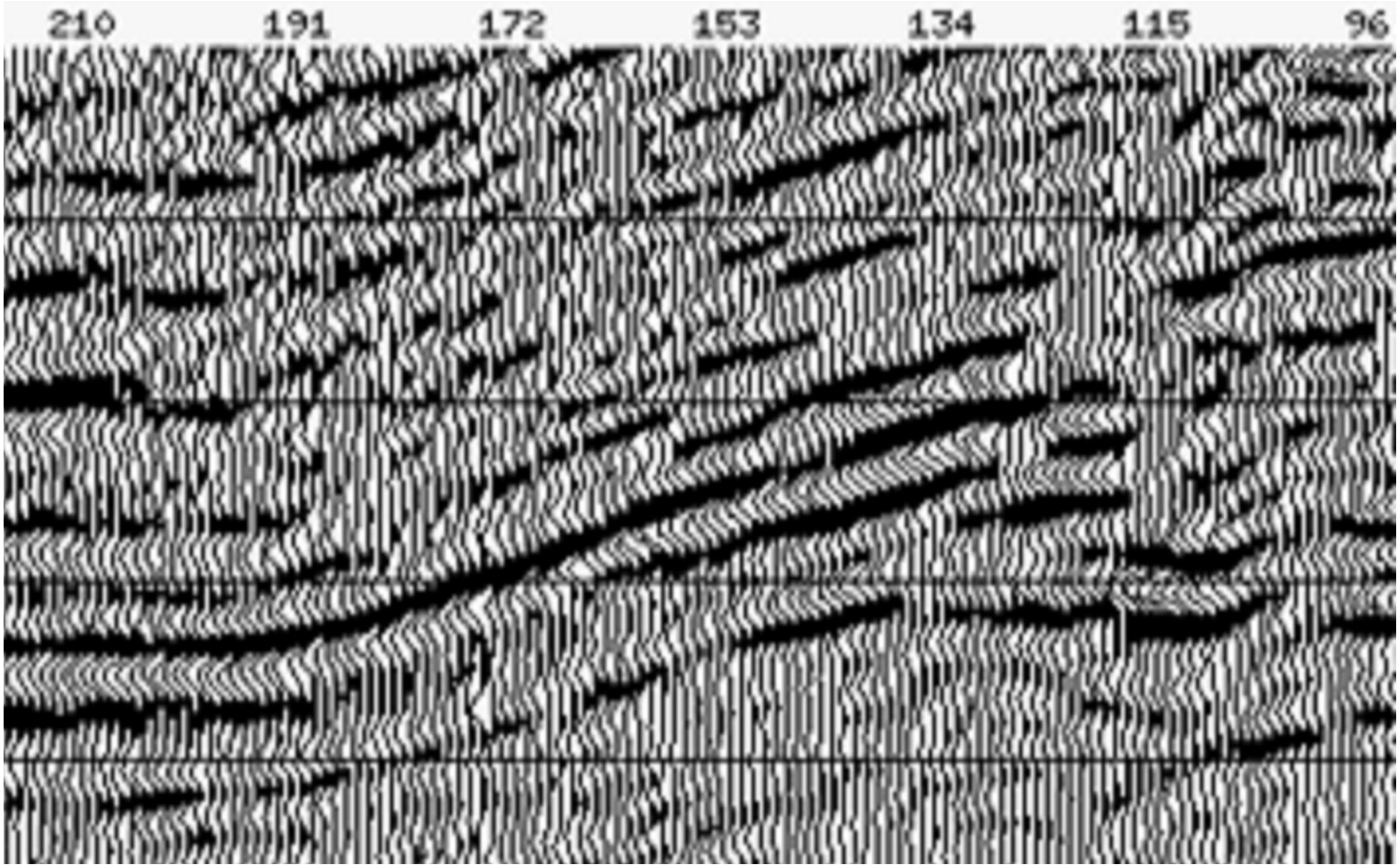
In the beginning… simple earth



P wave reflectivity (Rp)

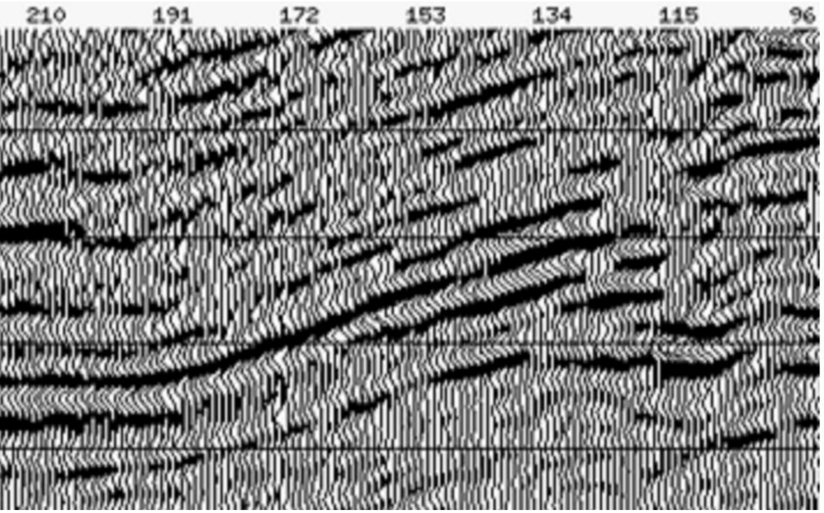
First use: up / down



Single fold: find the apex

from Hunt et al 2009

How hard is it to make predictions?



We measure in time

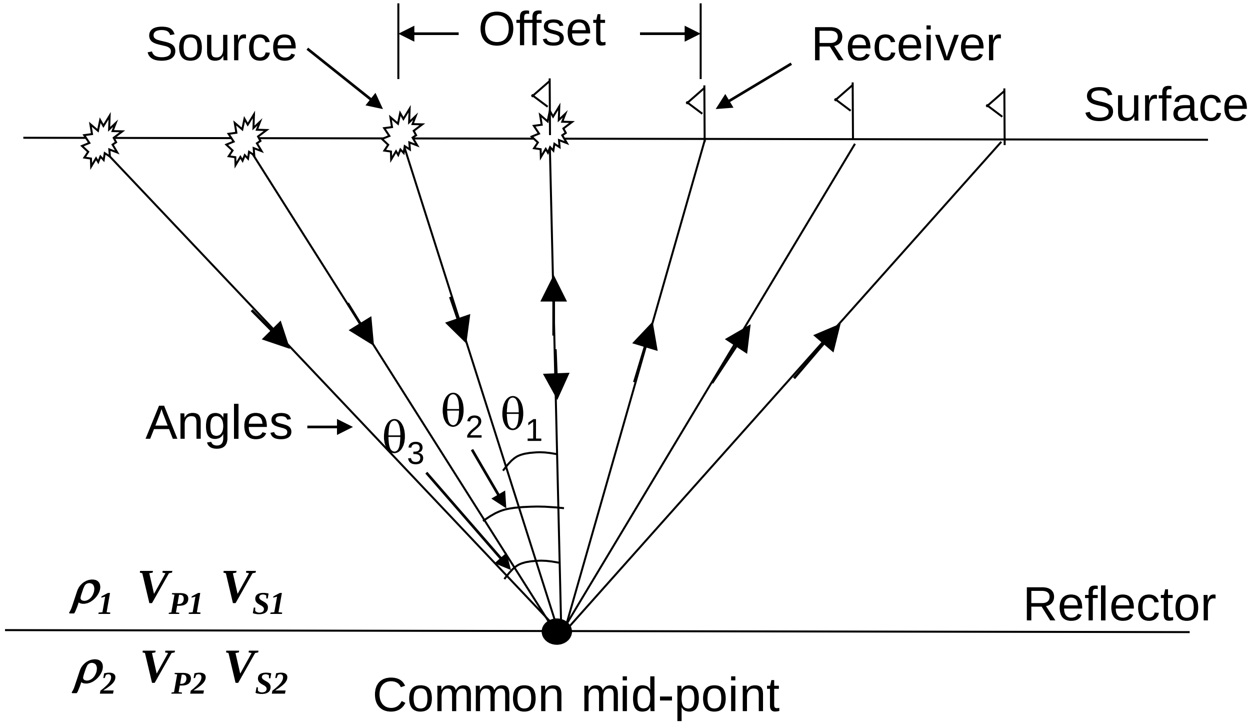
We never “see” the rock

We do not “see” oil or gas

We do not “see” porosity

How far away is that light pole?

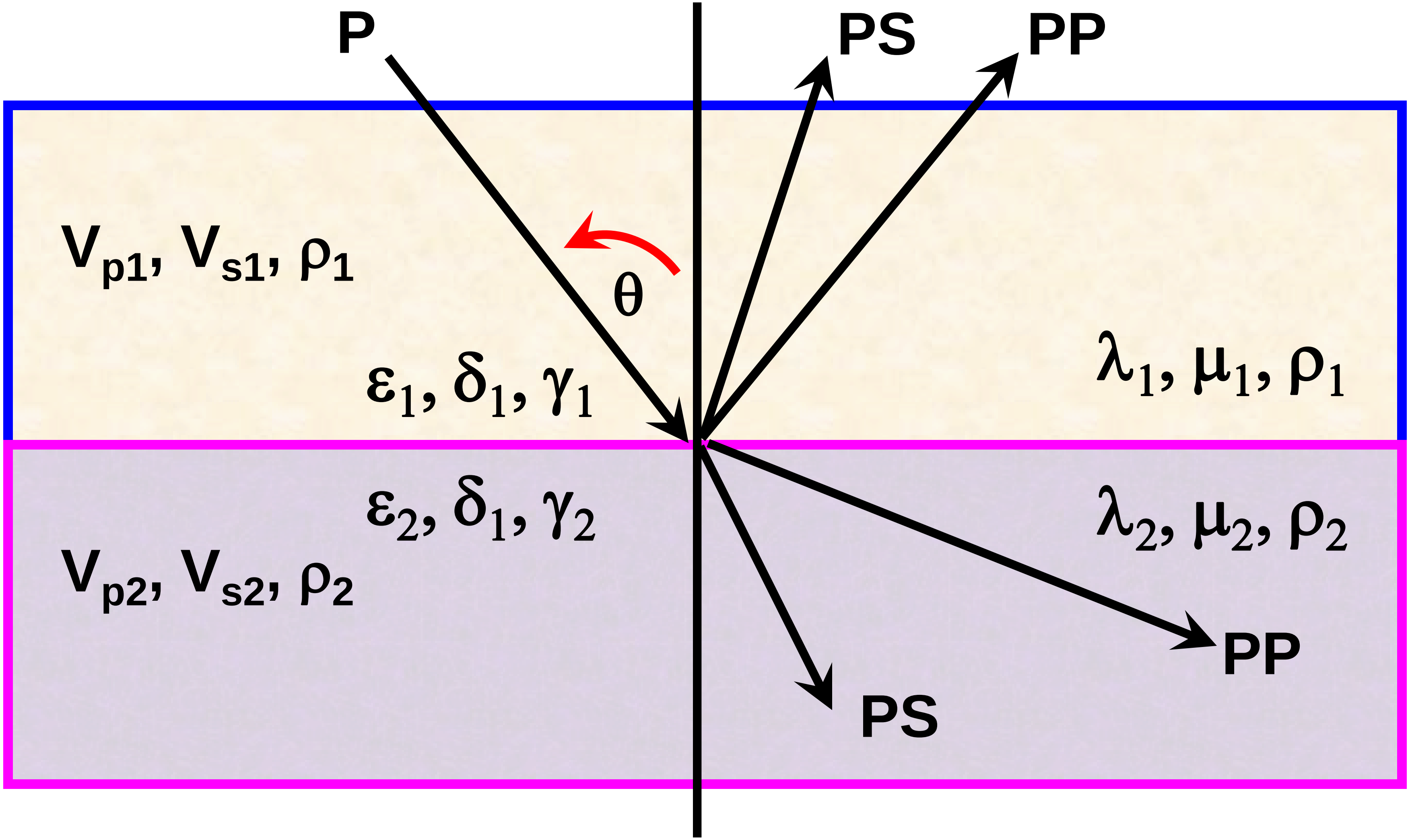
CMP developed (Mayne, 1962)



With 3D surveys, offsets (angles) and azimuths

From Russell, CCGVeritas

Complex earth



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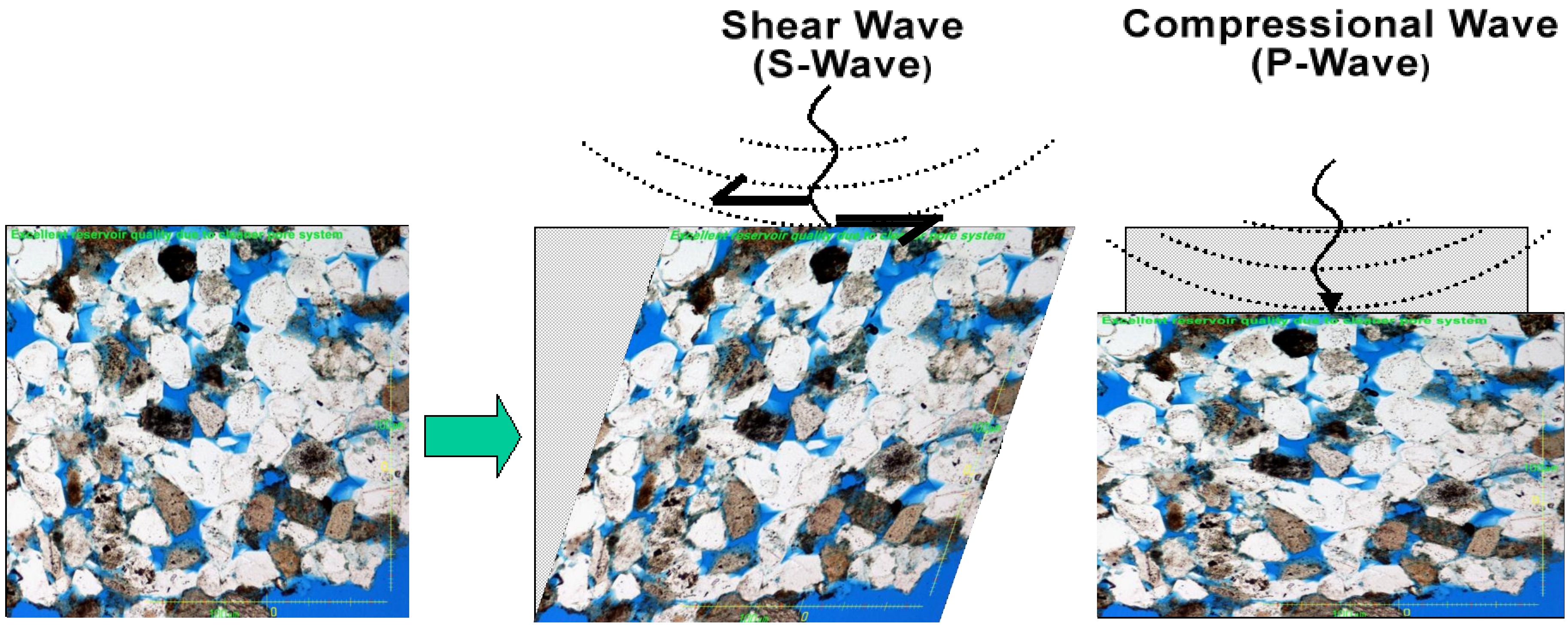
Aki and Richards (1979), Thomsen (1986)

Complex: P and S-wave Velocities



Undeformed schematic rock volume of porous sandstone

Shear Velocity

Change in shape only

Compressional Velocity

Change in volume and shape

After Goodway (CSEG Recorder 06/2001)

Complex is difficult

AVO Inversion

$$R(\theta,\phi) = A + [B_{iso}]\sin^2\theta$$

AVAz, VVAz (fractures) (Ruger and Tsvankin (1997)

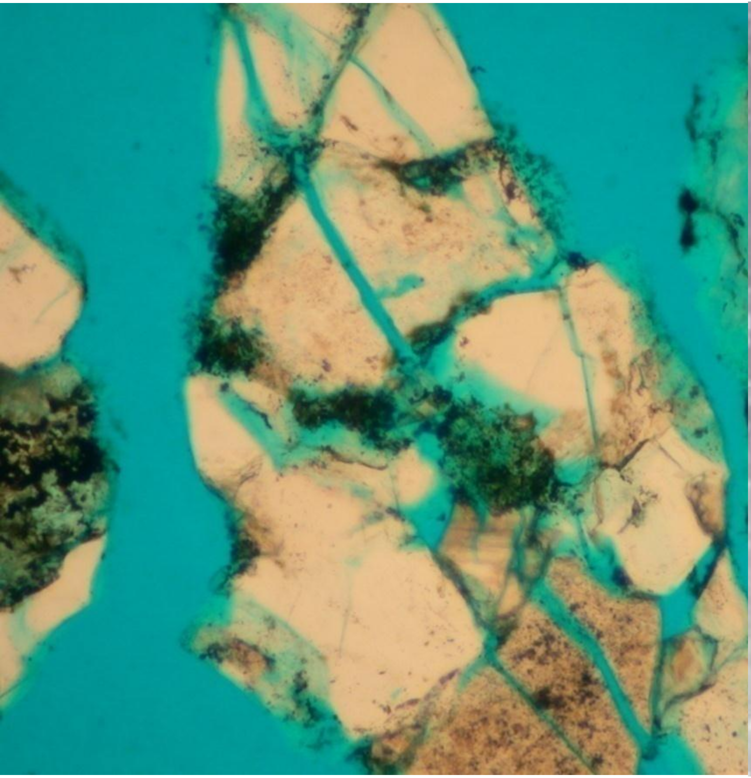
- $$R(\theta,\phi) = A + [B_{iso} + B_{ani}\cos^2(\phi - \phi_{sym})]\sin^2\theta$$

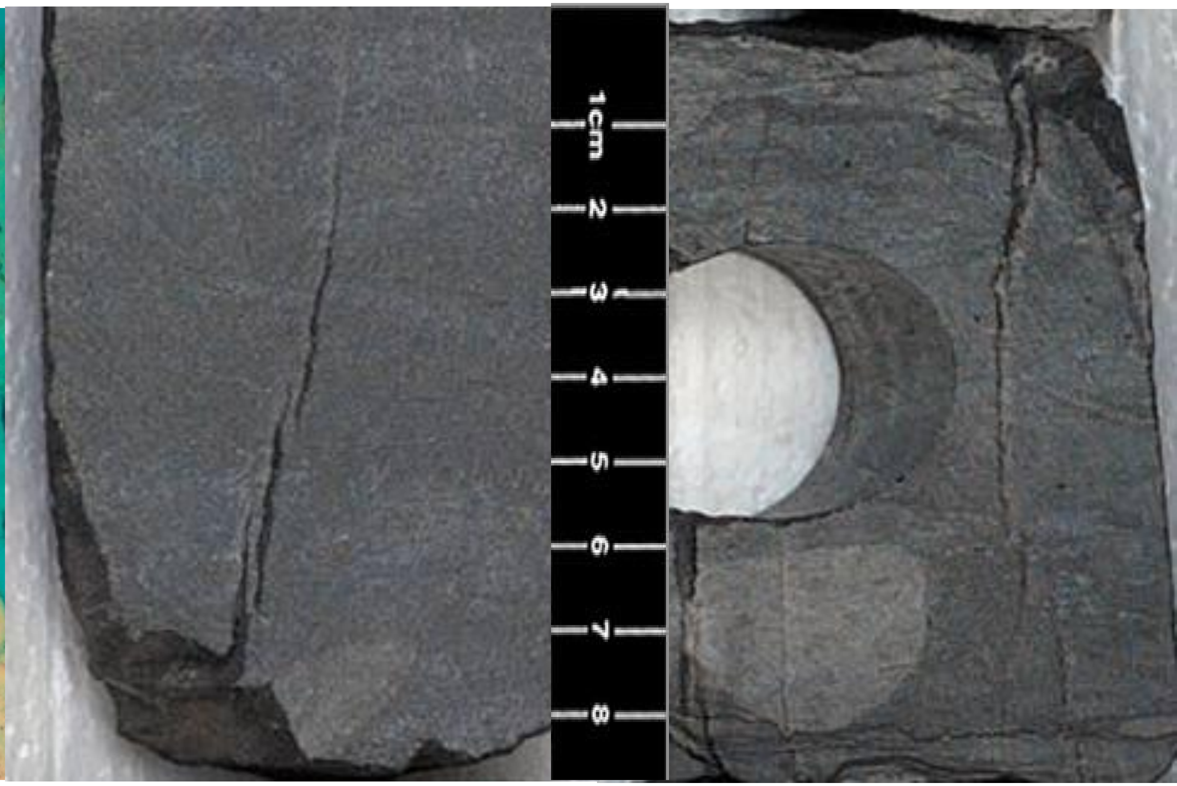
B_{ani}: Anisotropic gradient ⇨ crack density

VVAz: Velocity difference ⇨ crack density

Heavier data requirements & earth assumptions

Fracturing: ε, δ, γ
(vertical well)





A rotation of Thomsen parameters

End properties, imaging, sampling

Migration transforms an input wavefield into an output image:

$$p'(t,x') = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{0}^{\infty} W(\ldots)\delta(\ldots)p(\tau,x)\,d\tau\,dx$$

Getting the best results requires that there is no:

- **Input Data Aliasing**
- **Output Data Aliasing**
- **Migration Operator Aliasing**

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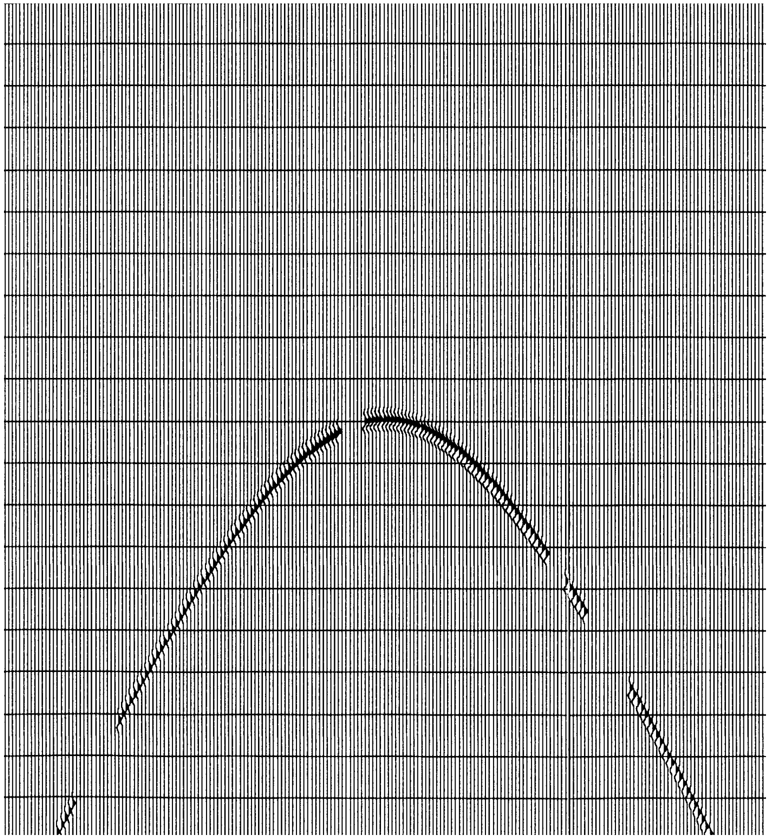
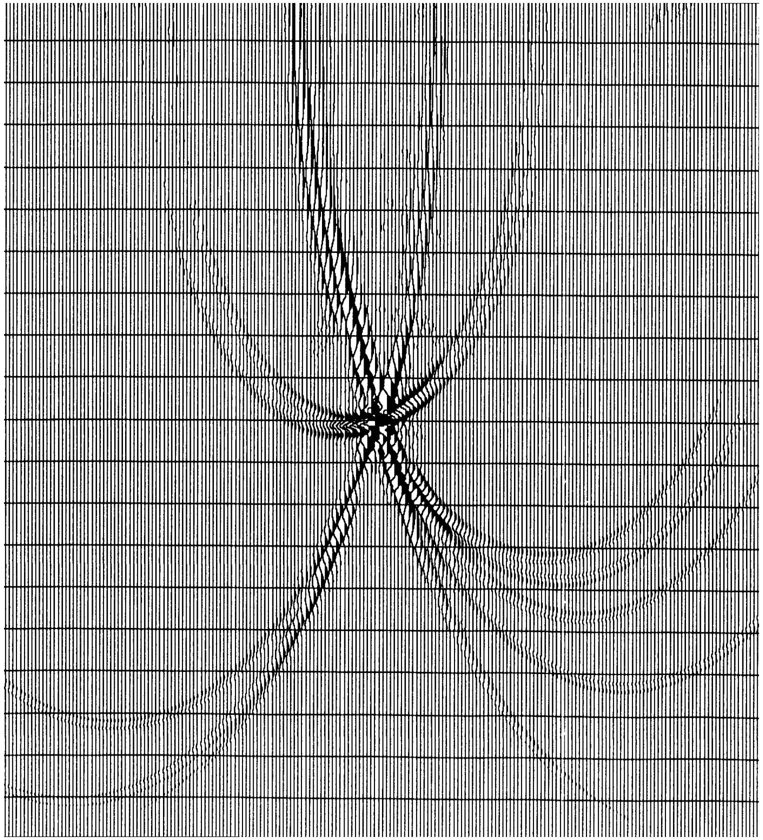
From Cary, 2007

End properties, imaging, sampling



Input



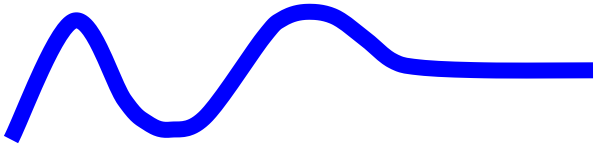
Migration

we must be well sampled in offsets & azimuths

From Cary, 2007

Fracture inference: Curvature

(Murray, 1968; Roberts, 2001; Chopra & Marfurt, 2007)



+ Curvature ⇒ + strain

+ strain ⇒ + fractures

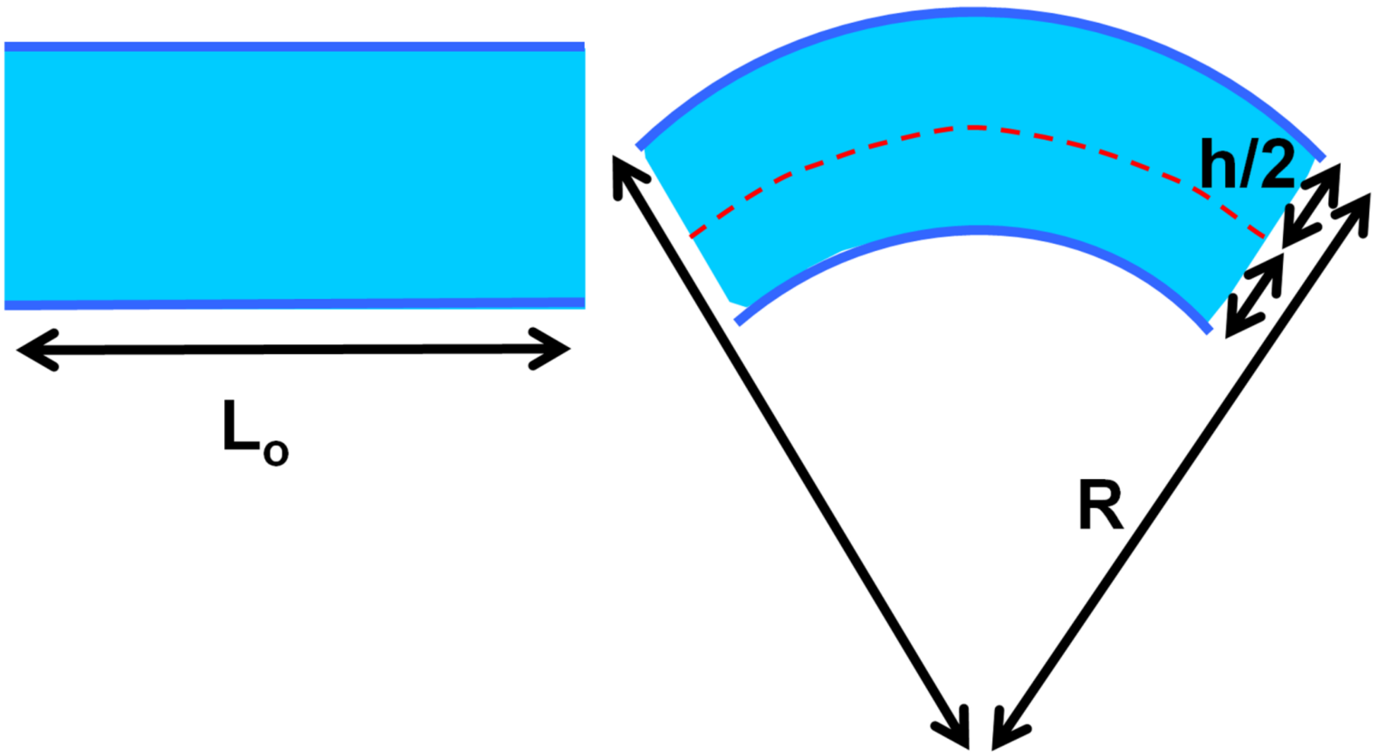
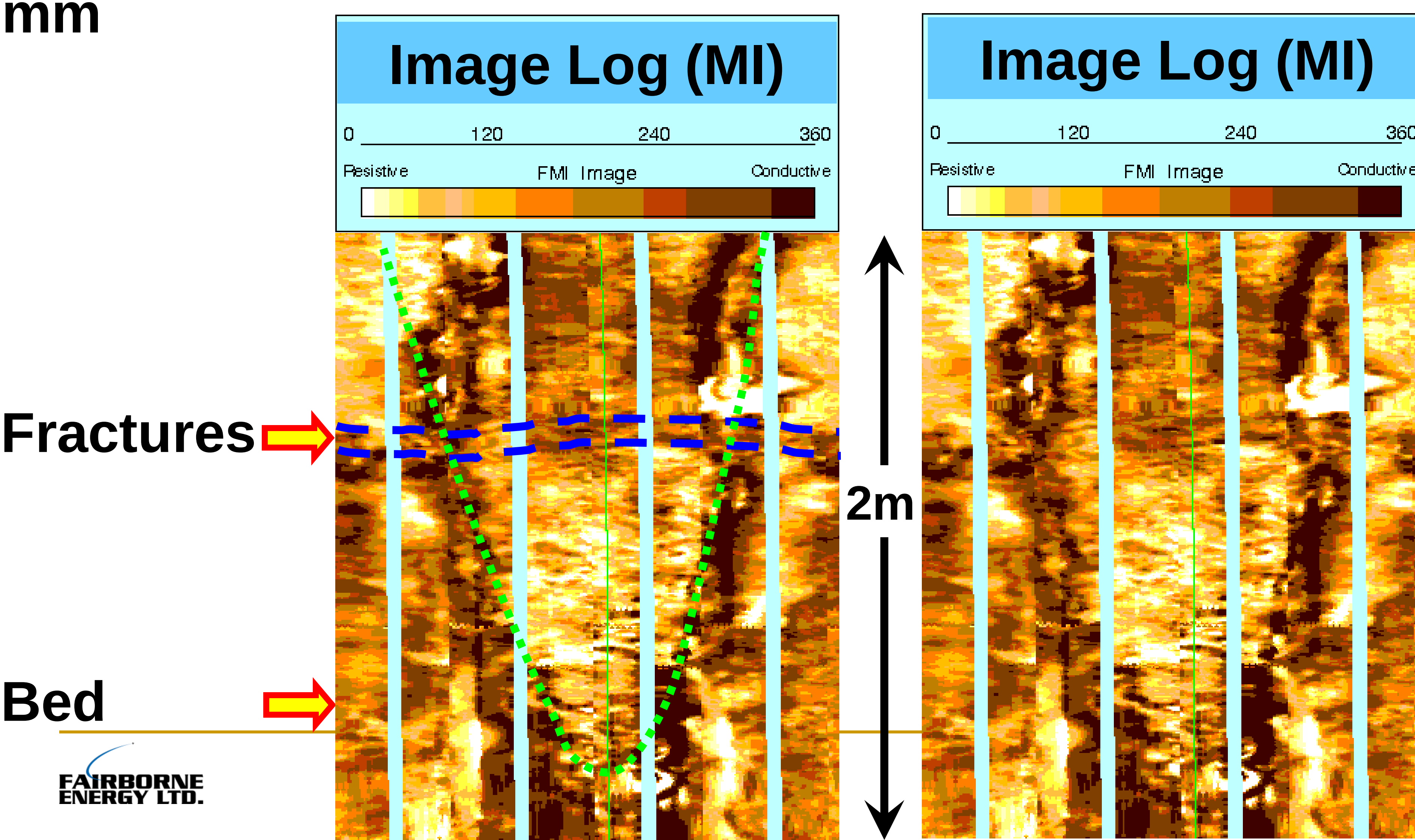


Image log fracture validation

(Luthi, 1990)

An electrical image that can see fractures down to mm



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Applied Science: Research happens

"Physics" is seldom wrong

…but our use of it often is

De-simplified physical model

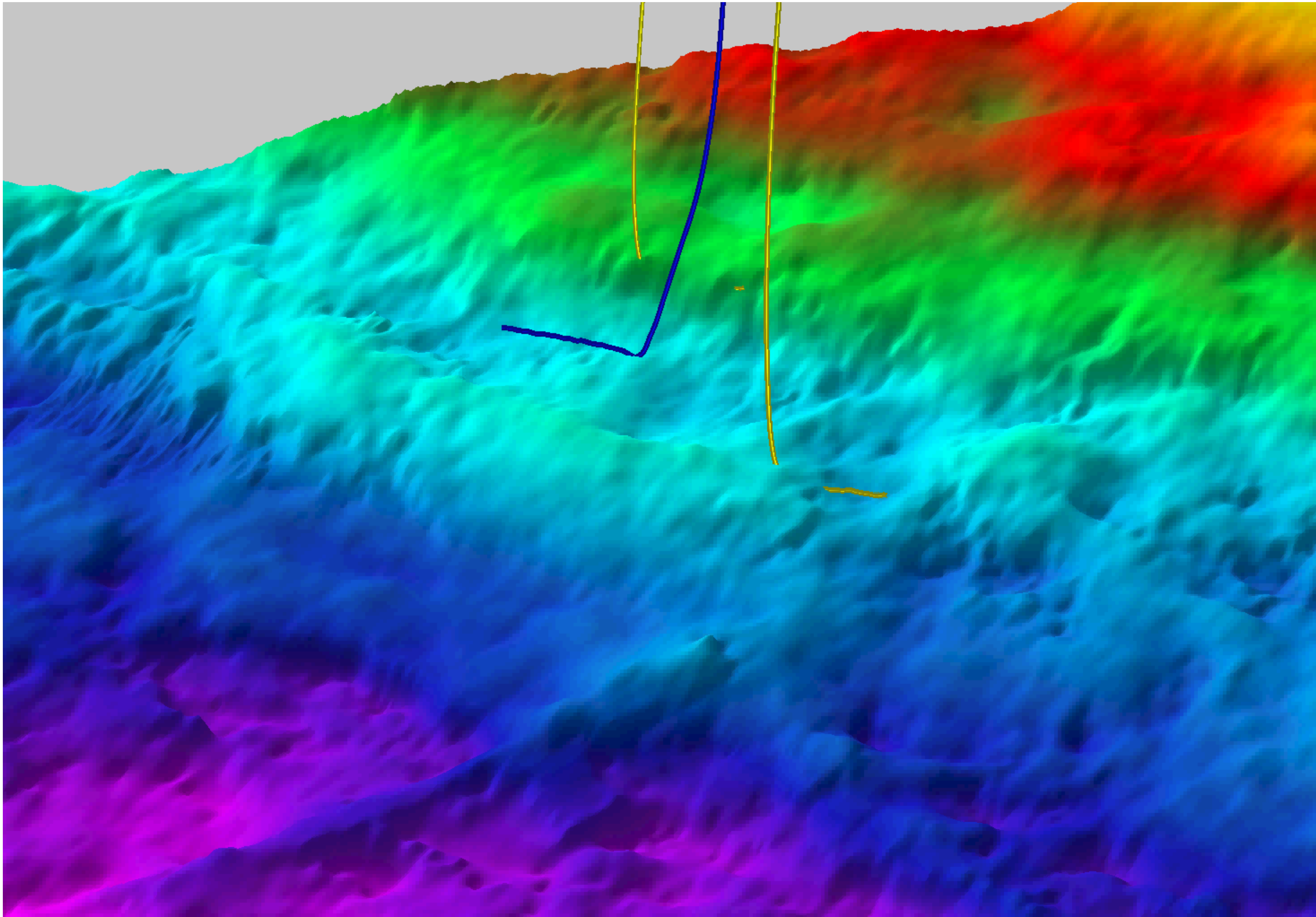
Our experiments have issues

…which lead to opportunities

Balance of validity vs practicality

This balance changes

Attributes or properties



Quantitative Method

- Earth property of interest
- Seismic properties (physics)
- Process to succeed
- Accumulate control data (earth properties)
- Accumulate seismic attributes
- Explore for relationships (compare / correlate)
- Create estimated earth property maps

*** better software will help the comparisons

Case study I: Viking AVO and NPV

- Follows work published in 2008
  - New drilling

- Interpolation to improve imaging
- Improved imaging to improve AVO
- Improved AVO to map porosity
- Enjoy better economics

Applied Science

U. of A. (Lui and Sacchi, 2004)

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CGGVeritas (Trad, 2007)

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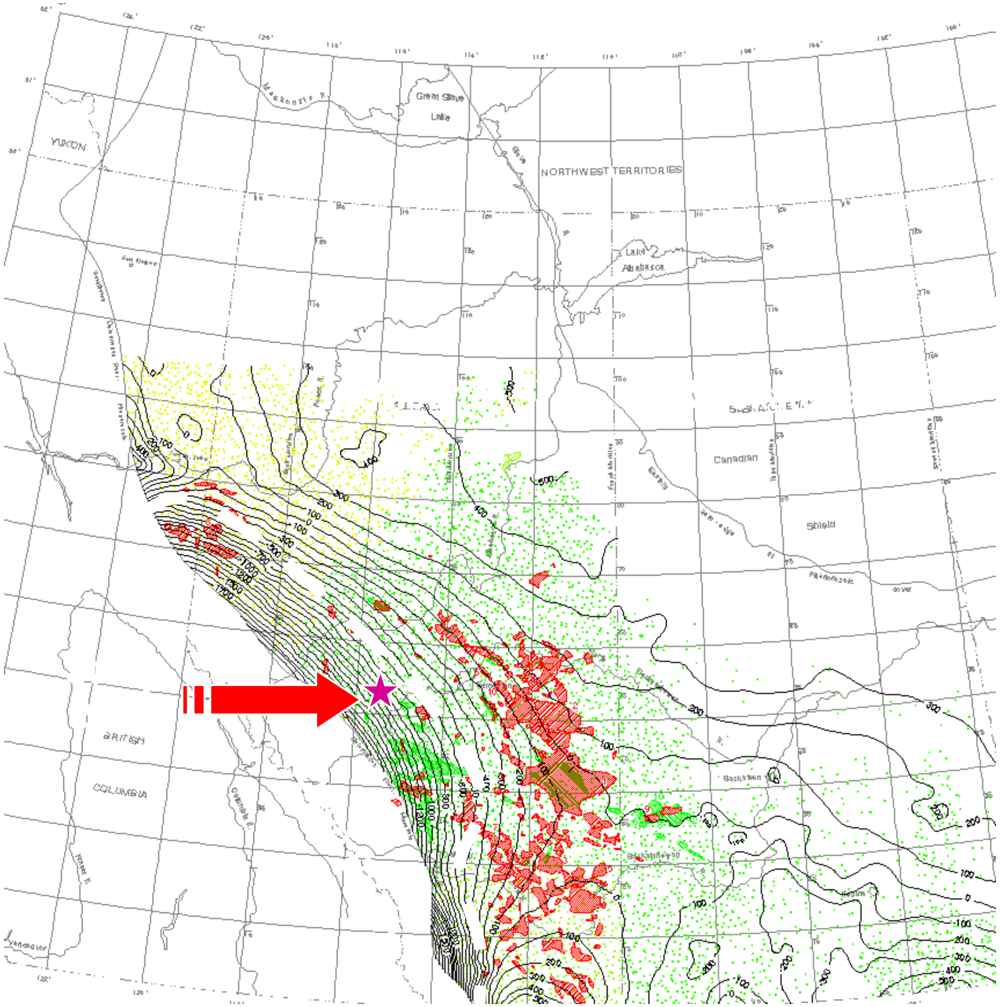
Fairborne Energy and CGGVeritas (Hunt et al, 2008)

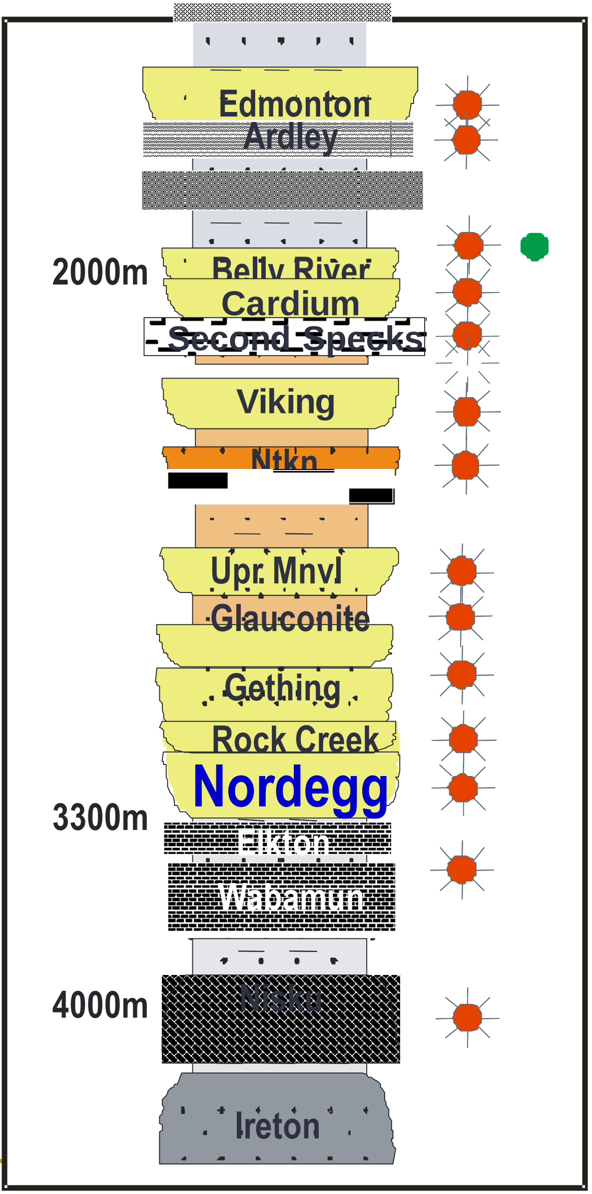
⇓

Value

West Central Alberta

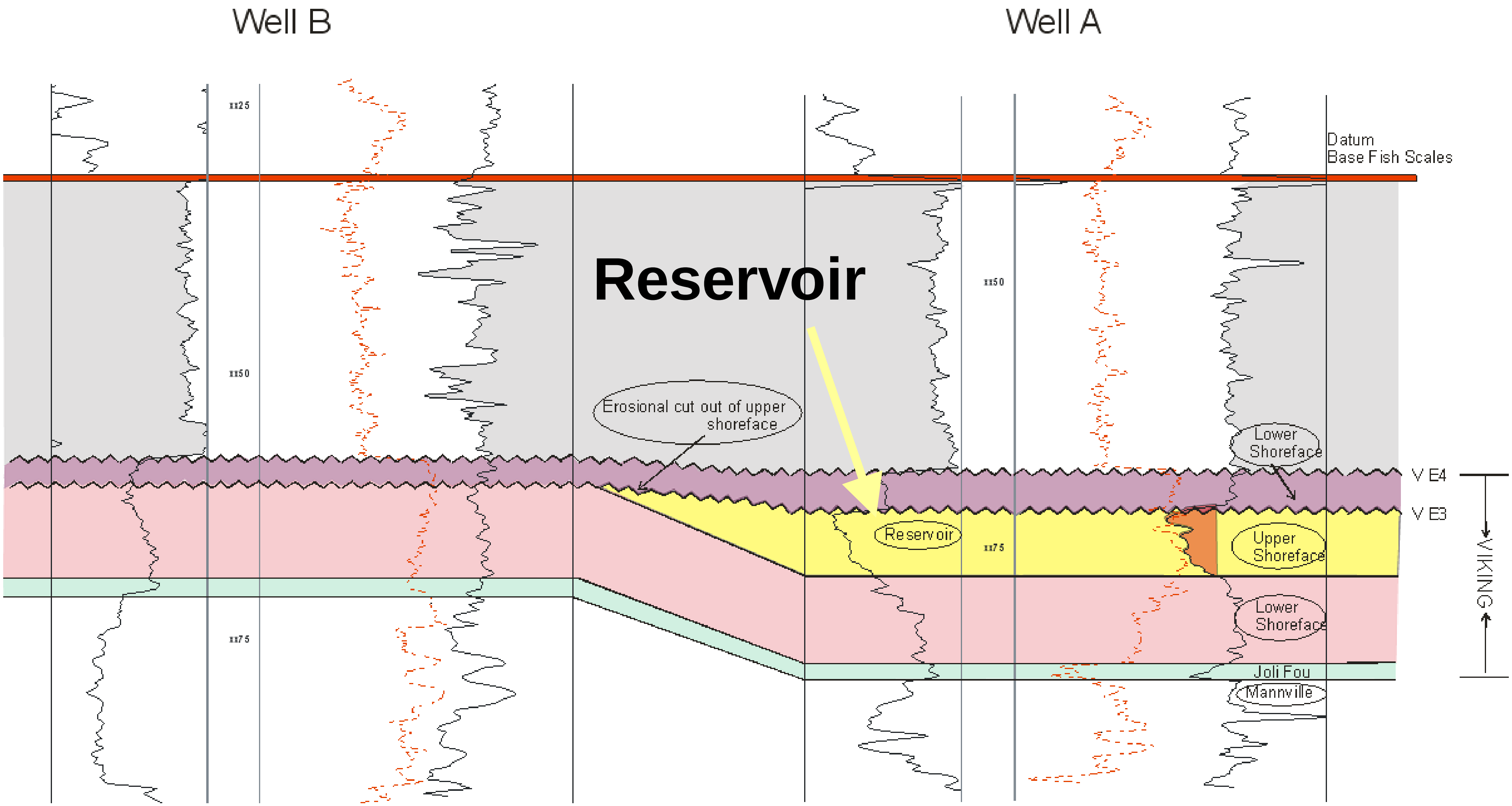
Deep basin





The area is structured and many zones are gas charged

The Viking is erosionally preserved



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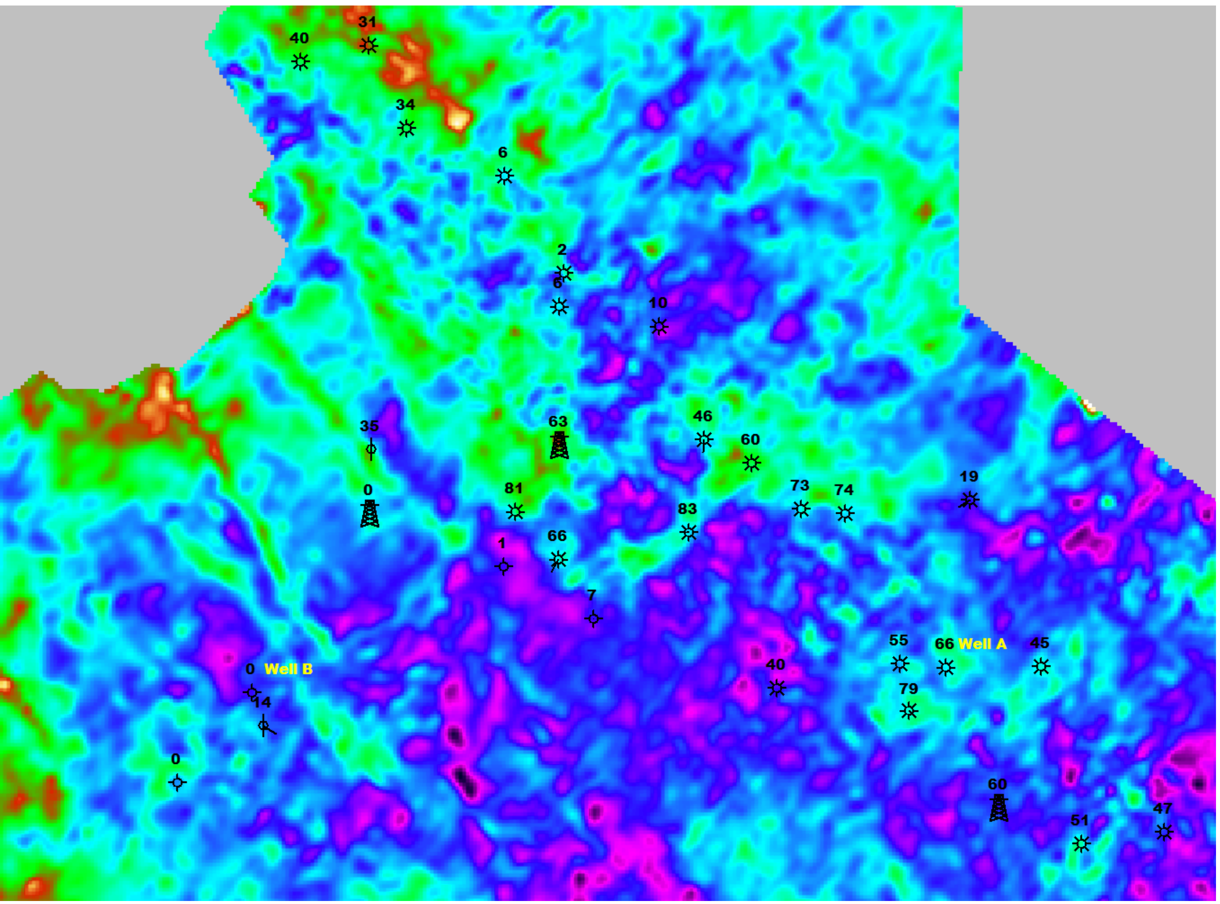
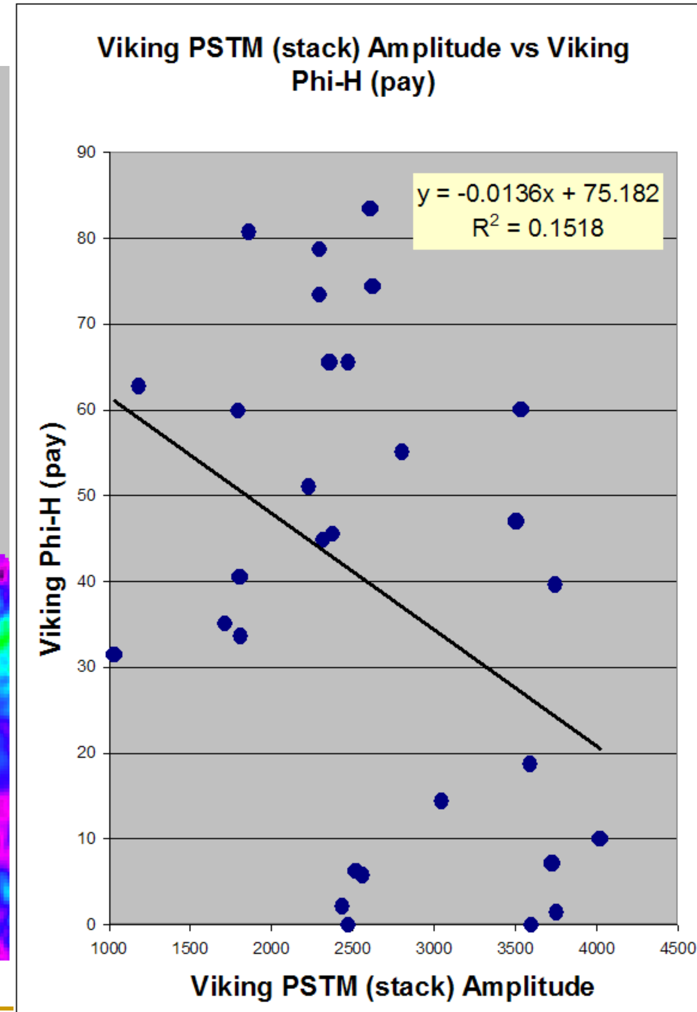
Old method: stack amplitudes





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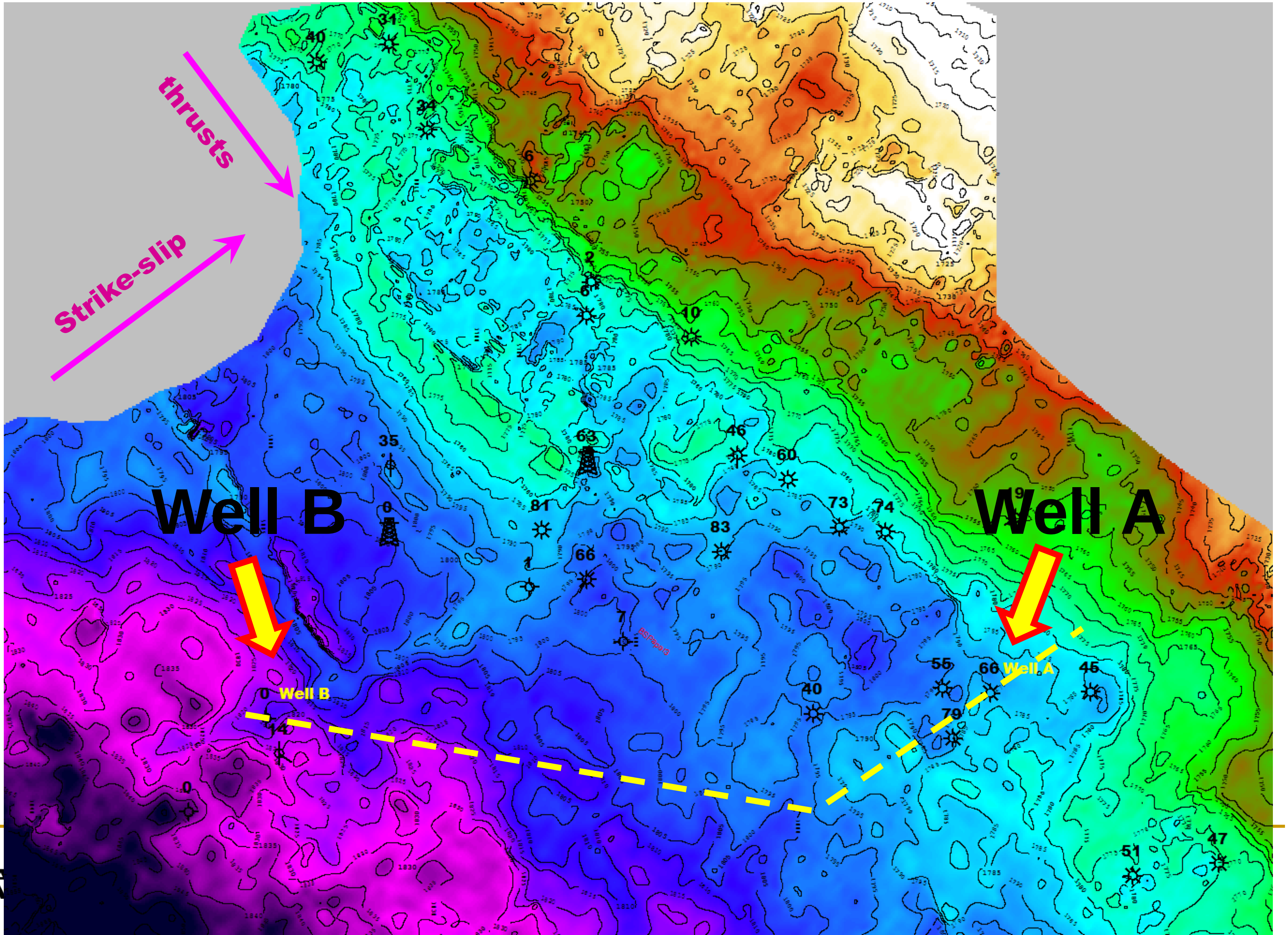
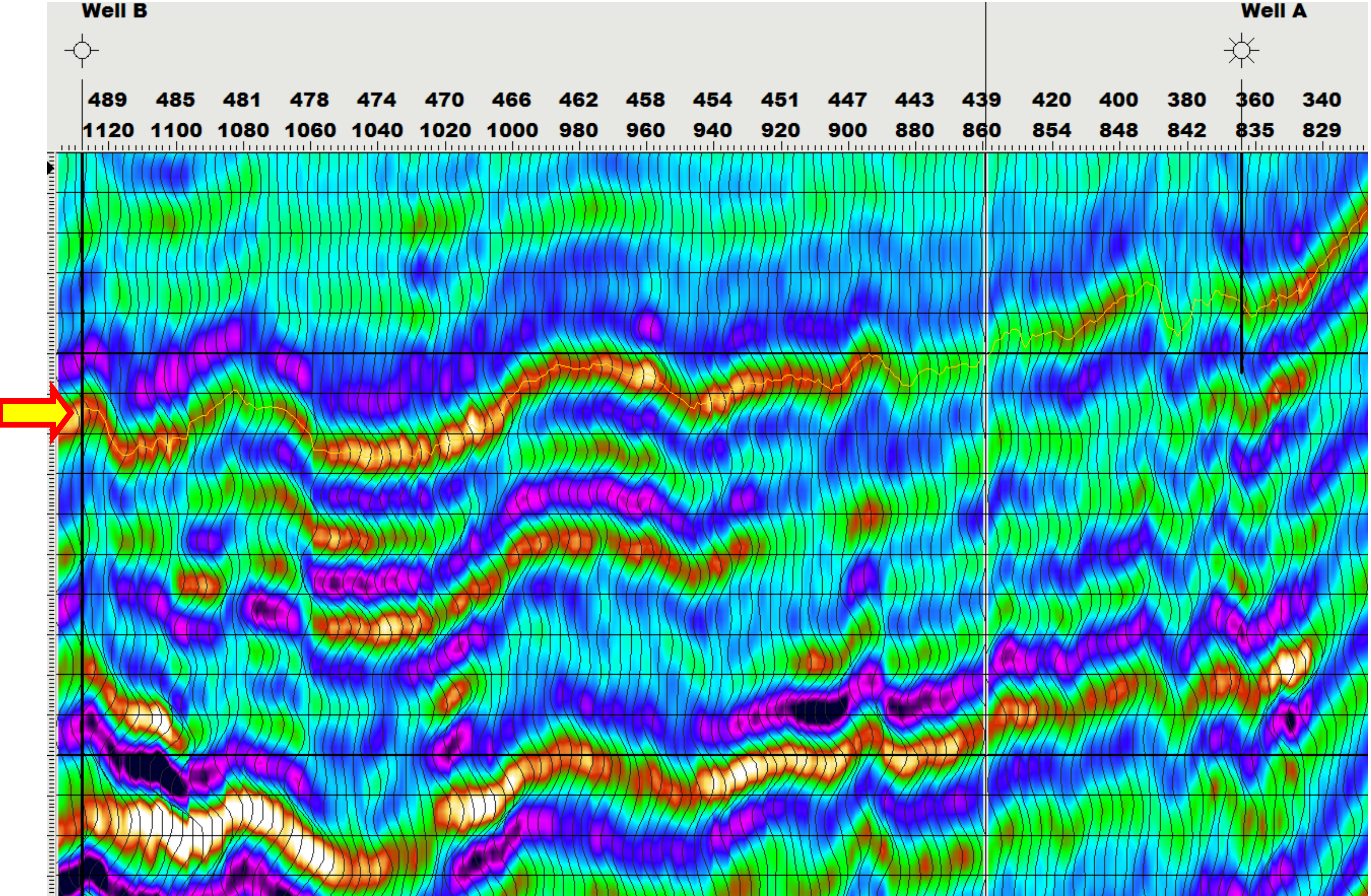
The Viking is structured

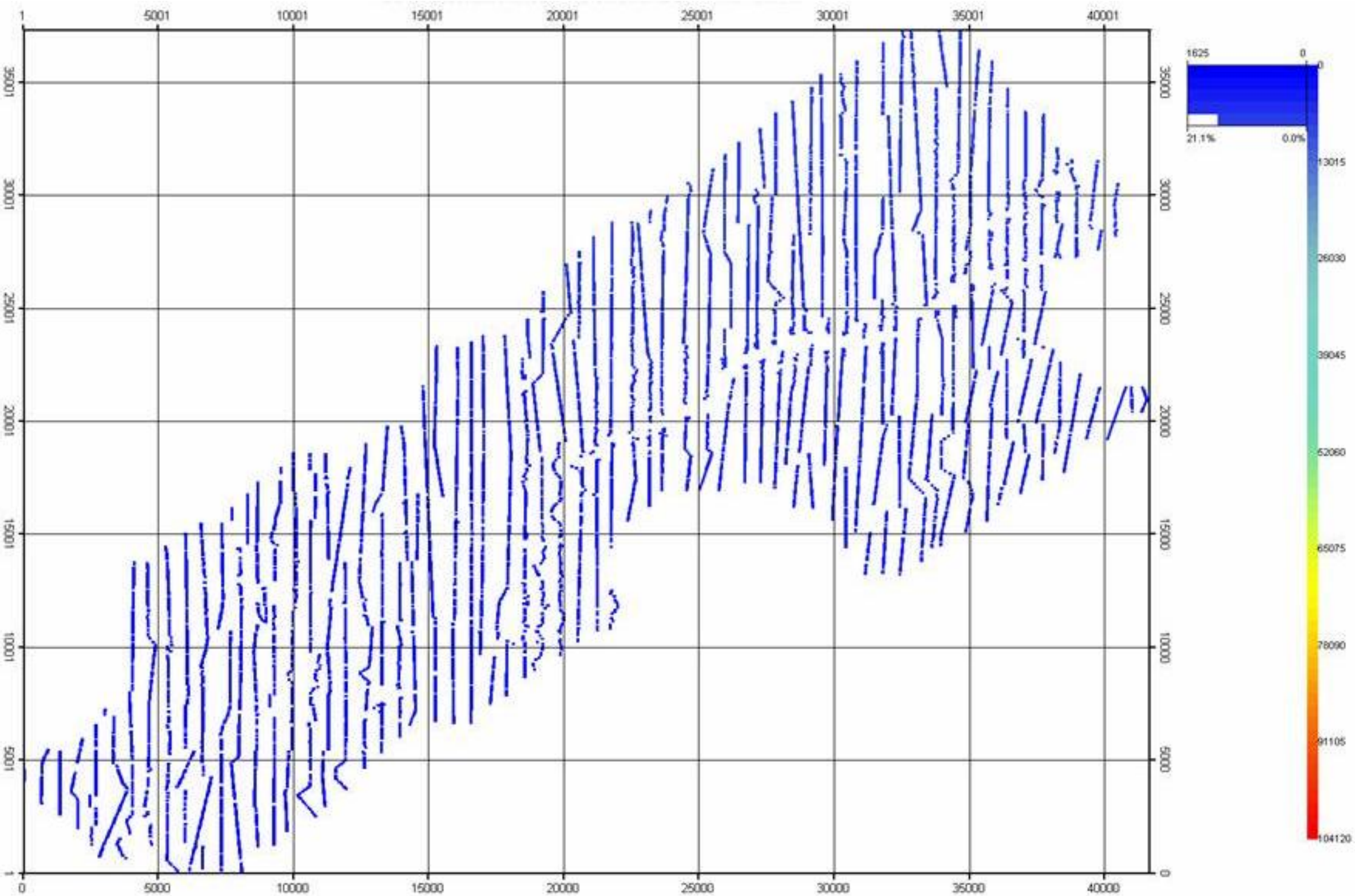


Example line from Well B to Well A



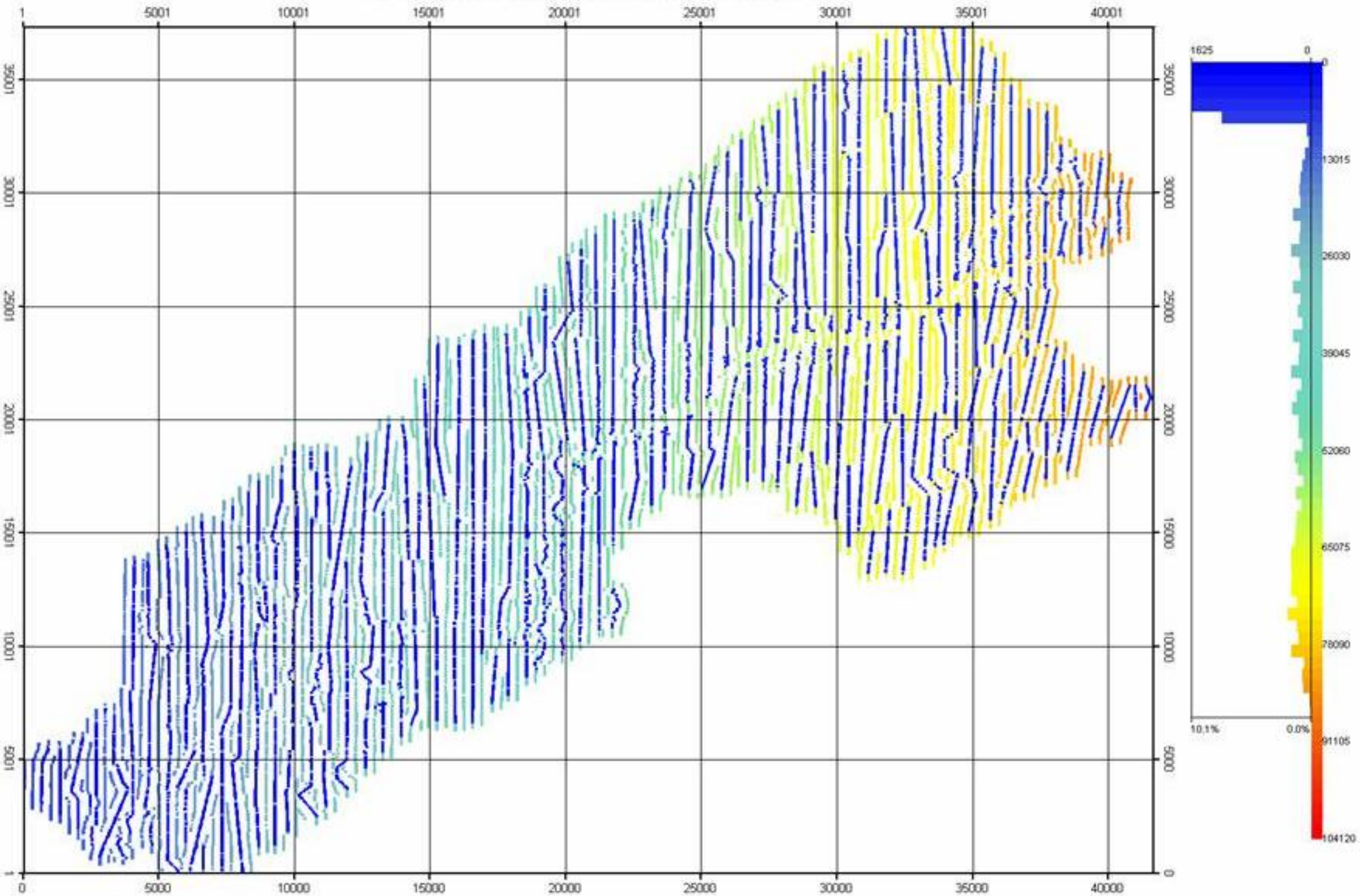
Sparse shooting

Source line map before interpolation



5D Interpolation

Source line map after interpolation



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5D interpolation (Lui & Sacchi, 2004, Trad, 2007)

Least Squares inversion: at every temporal frequency solve…

$$J = \|\mathbf{d} - \mathbf{T}\mathbf{x}\|^2 + \lambda \|\mathbf{x}\|_{\mathbf{W}}$$

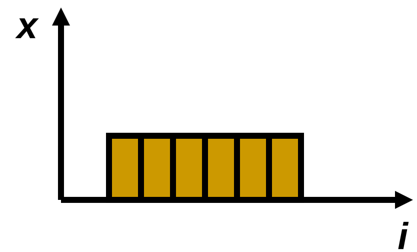
Data residuals | **The model norm**

The sampling operator

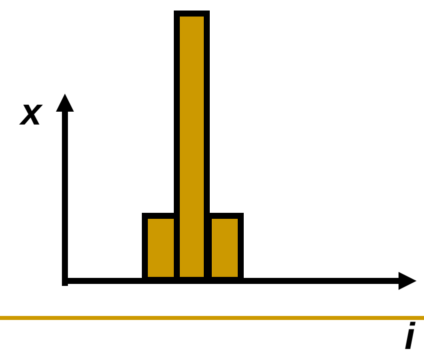
$$\mathbf{d} = \mathbf{T}\,\mathbf{x}$$

$$\begin{pmatrix} x(2) \\ x(3) \\ x(5) \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x(1) \\ x(2) \\ x(3) \\ x(4) \\ x(5) \end{pmatrix}$$

W weights such that



$$\sum_i |x_i|^p = a$$

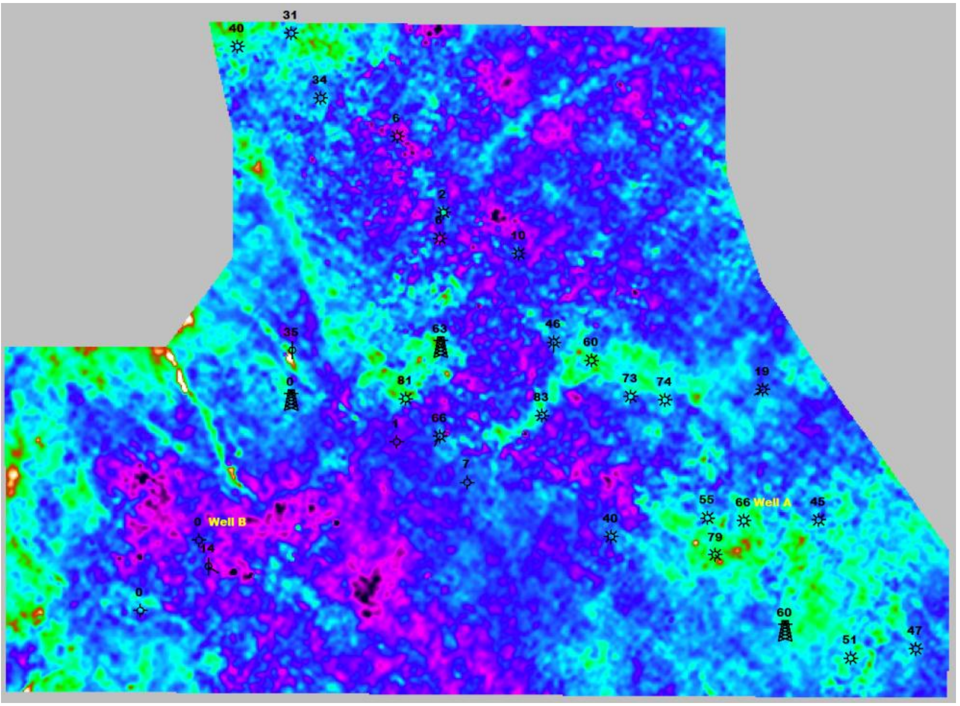


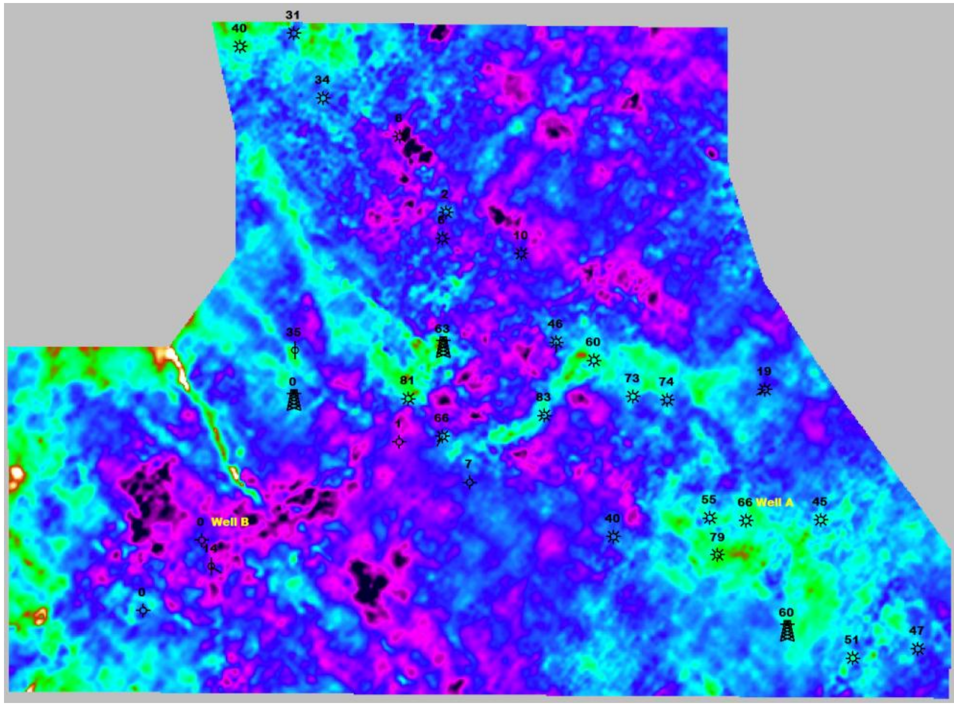
$$\sum_i |x_i|^p = b$$

for p =1 a > b

Map Comparisons (Rp Rs ratio)

PSTM vs Interpolated + PSTM





The interpolated version is cleaner

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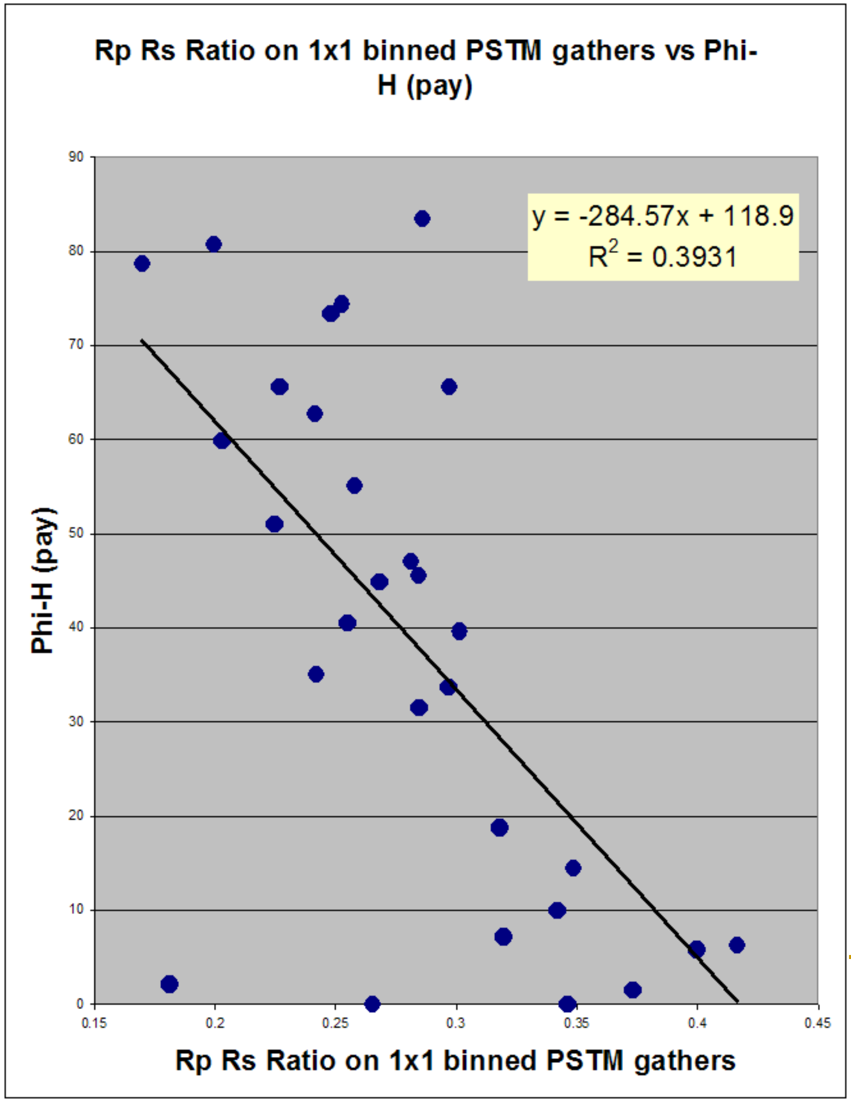
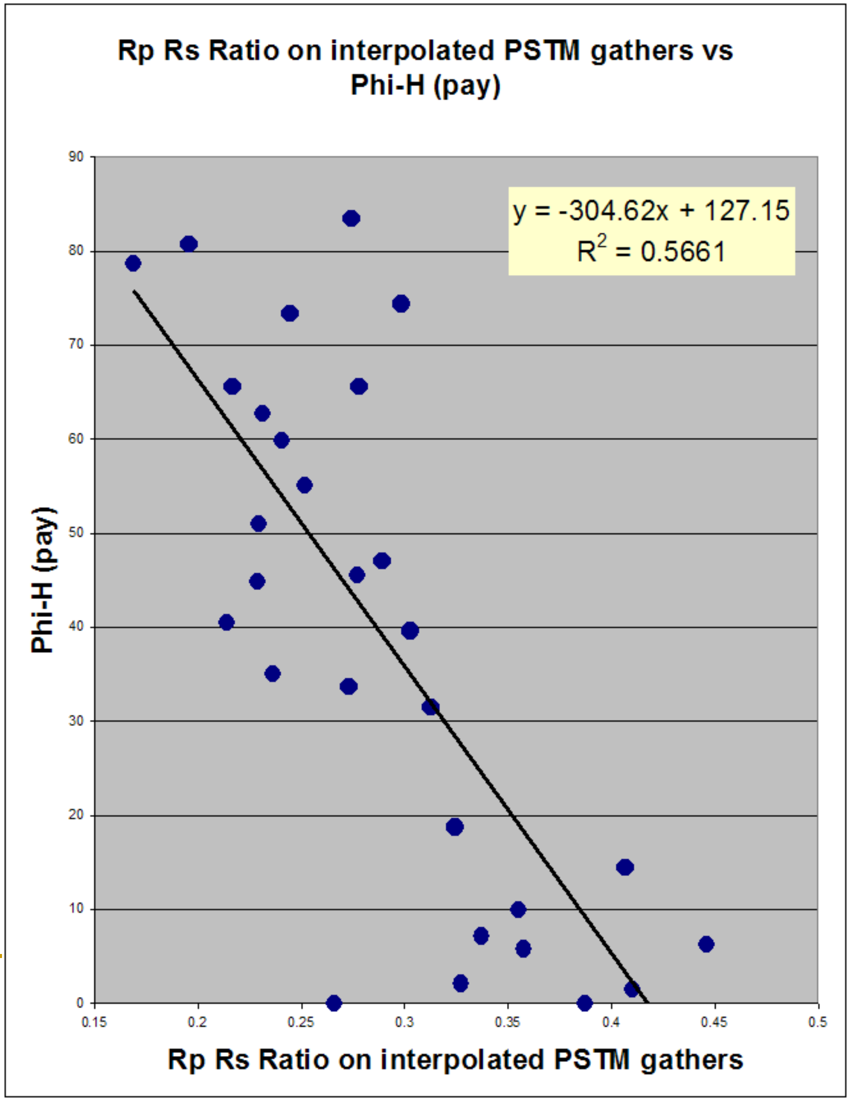
Correlation *results: PSTM comparisons*

PSTM

Interpolation + PSTM



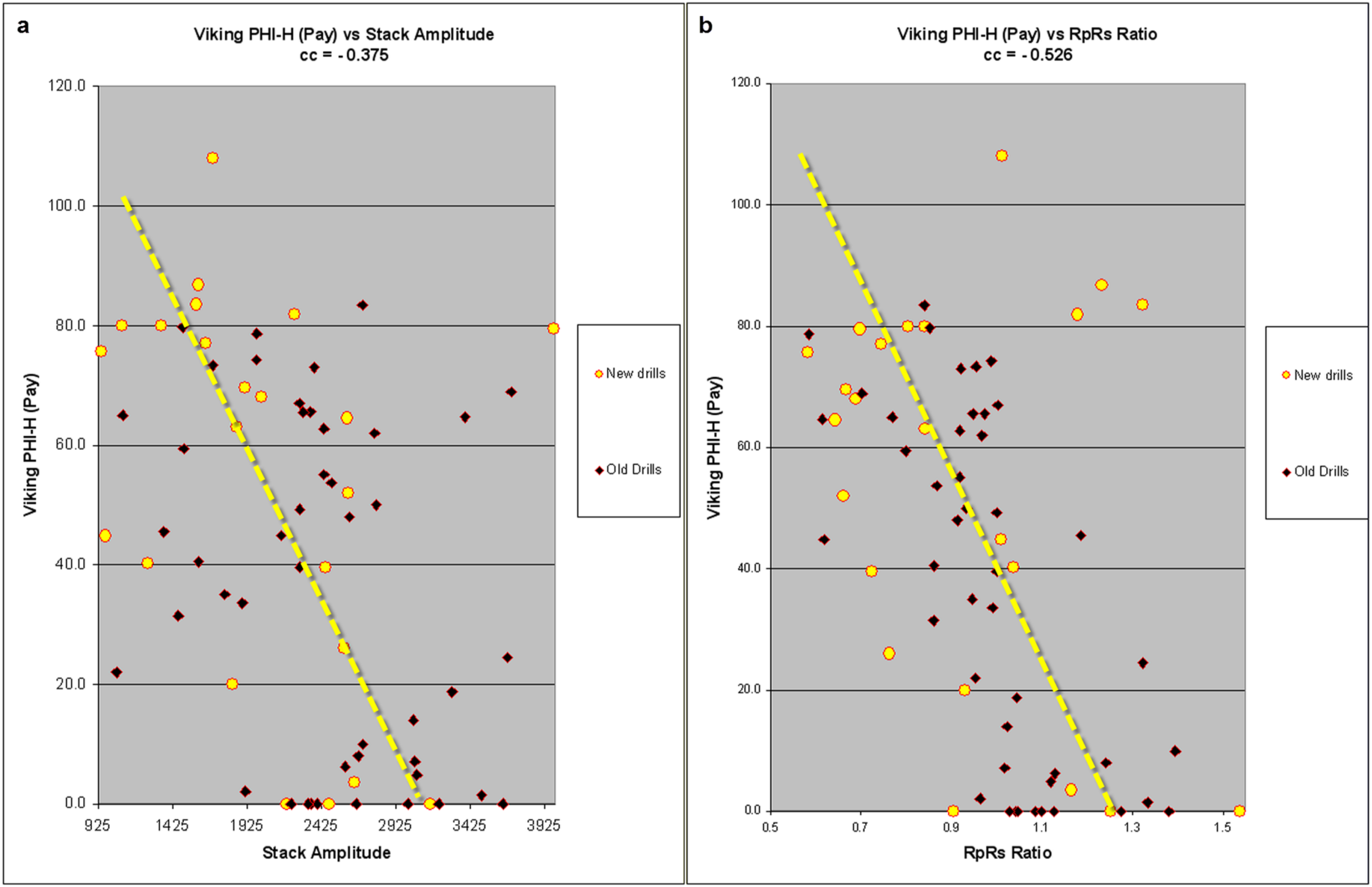


How do we determine value?

- A posterior to a piori:
  - New results have more meaning

- Interpolation AVO vs stack amplitudes
- Accuracy
- Economics

New Drilling: 29 to 69 wells



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Value calculation

- Independent classification of all wells
  - All wells
  - No seismic at all, or Viking not a target
  - Viking target, old method
  - Viking target, new method
- Phi-h by class
- Average Phi-h for each class
- Phi-h modeled to rate, reserves, NPV
- Model economics for each class

Economic model

Economic models	Count	Average PHI-H	% Diff	3 Month IP Prediction (mcf/d)	EUR Prediction (mmcf)	NPV 10 high price deck ($M)	IRR high price deck (%)	Pay Out (yrs) high price deck	NPV 10 low price deck ($M)	IRR low price deck (%)	Pay Out (yrs) low price deck
All Wells	69	39.8	-20%	859	1535	$ 3,125	25	2.6	$ 1,525	17.2	3.6
Wells not targetting Viking	18	6.0	-88%	665	1176	$ 1,575	18	3.4	$ 335	10.7	4.6
Old Wells, targetting Viking	32	49.5	0%	948	1707	$ 3,800	29	2.3	$ 2,095	20.1	3.2
New Wells, targetting Viking	19	65.3	32%	1144	2092	$ 5,000	35	1.9	$ 3,100	24.5	2.7

32% higher Phi-h on average

~ 1 million dollars NPV per well

Case study II: steering horizontals

and improved production

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Applied Science

U. of A.
(Lui & Sacchi, 2004)

Stanford University
(Morley & Claerbout,1983)

↓

Pulsonic Geophysical (Cary & Lorentz, 1991)

↓

Ketch Resources, Divestco, & KTI (Hunt et al, 2005)

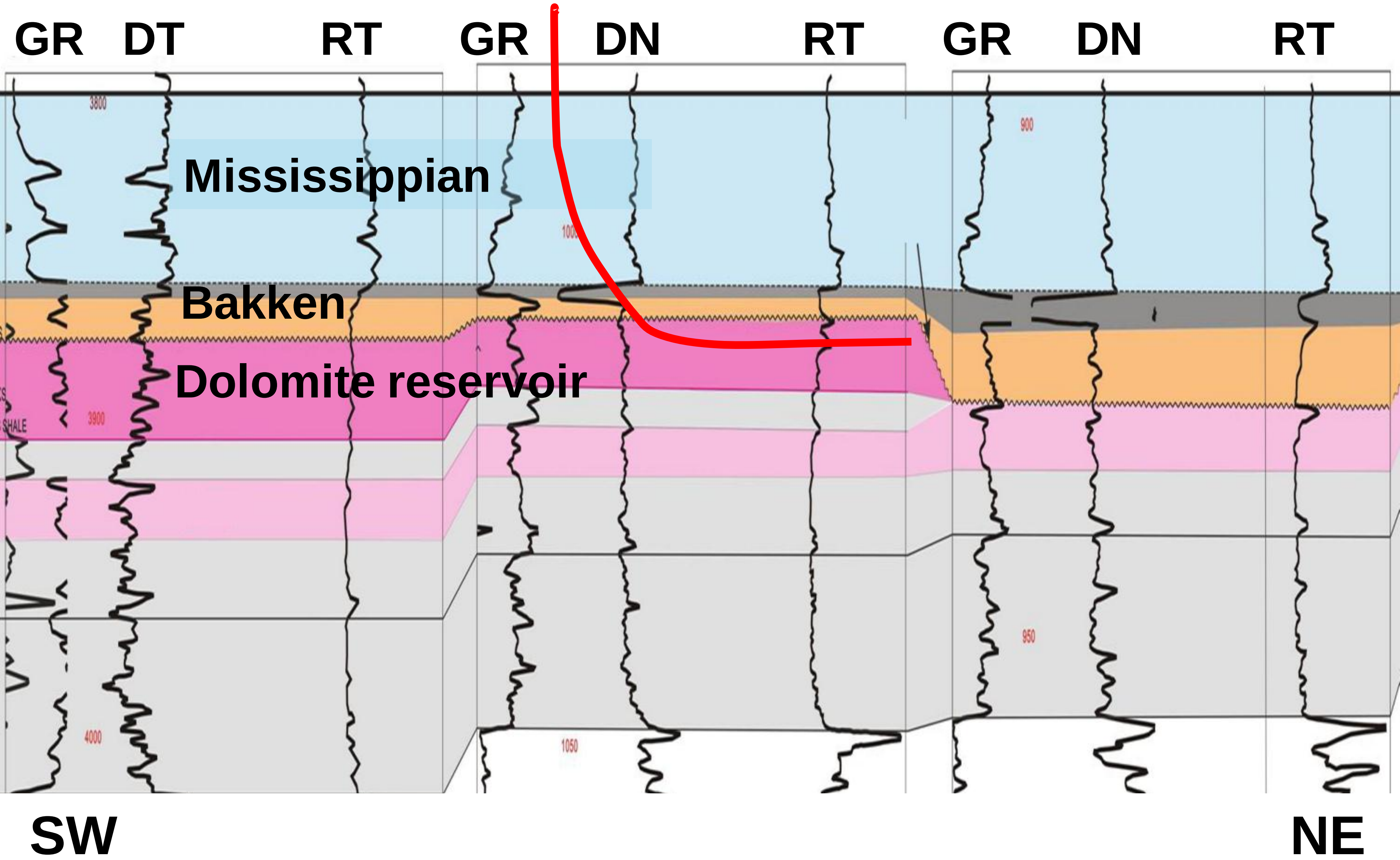
↓

CGGVeritas (Trad, 2007)

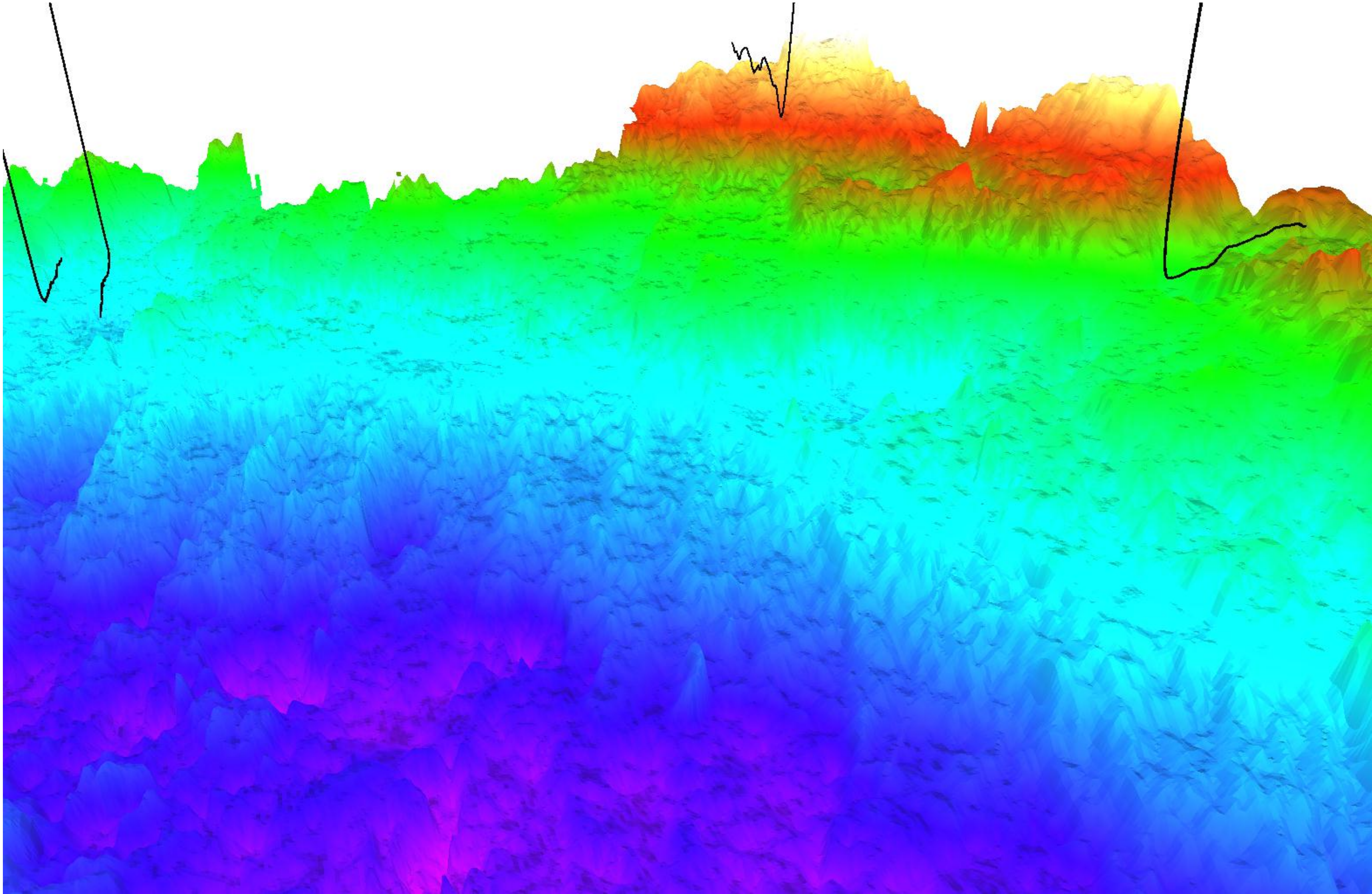
↓

Value

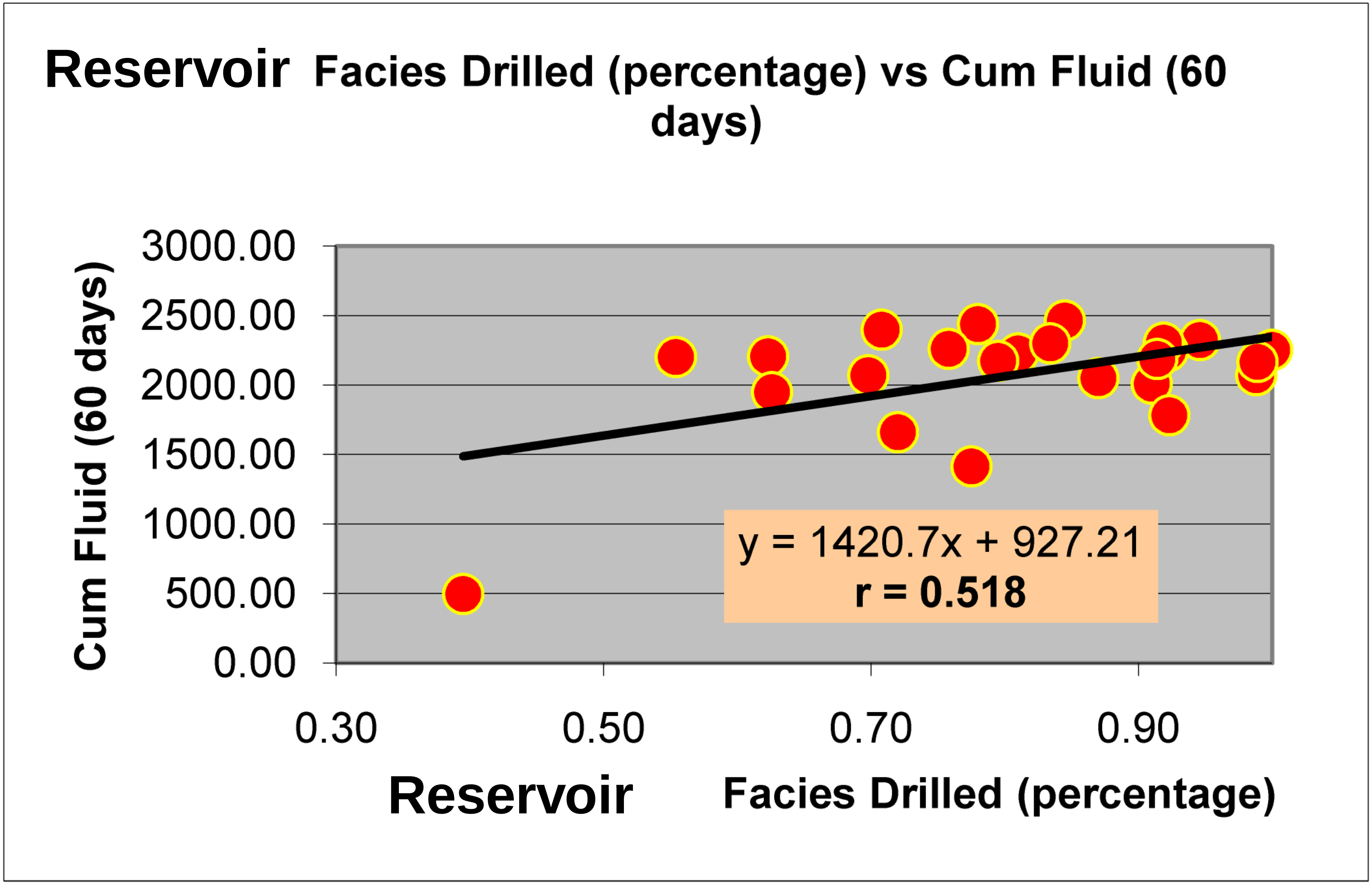
Devonian oil Sask



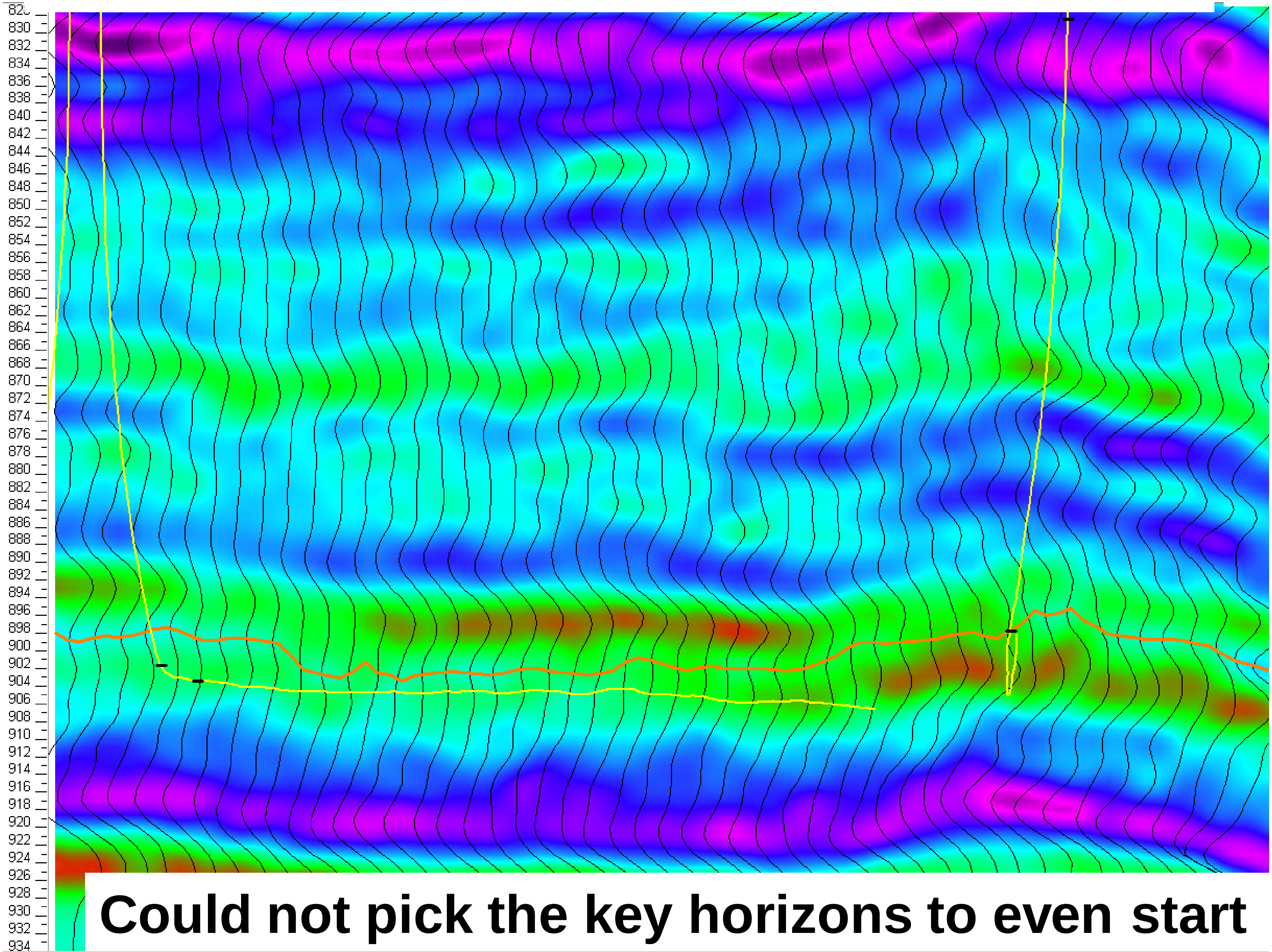
Devonian oil play



Fluid rate related to steering

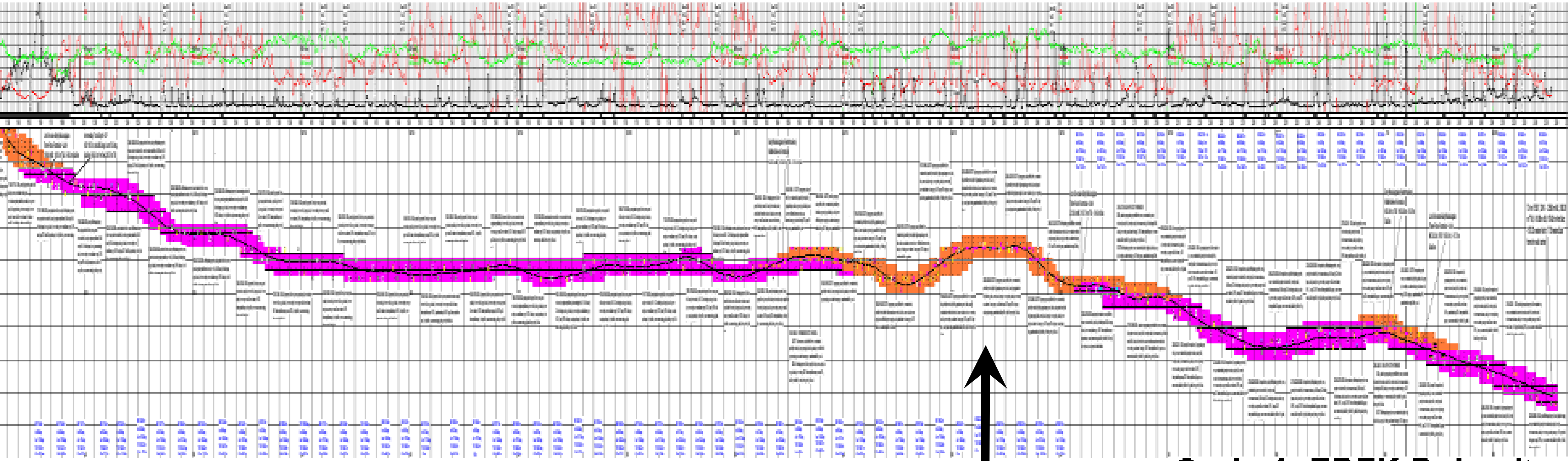


Old method could not use seismic



Could not pick the key horizons to even start

Demon haunted world



Code 4: TRFK Dolomite

Code 3: BKKN Silt

Code 4: TRFK Dolomite

Fault ???

2:00 A.M. calls

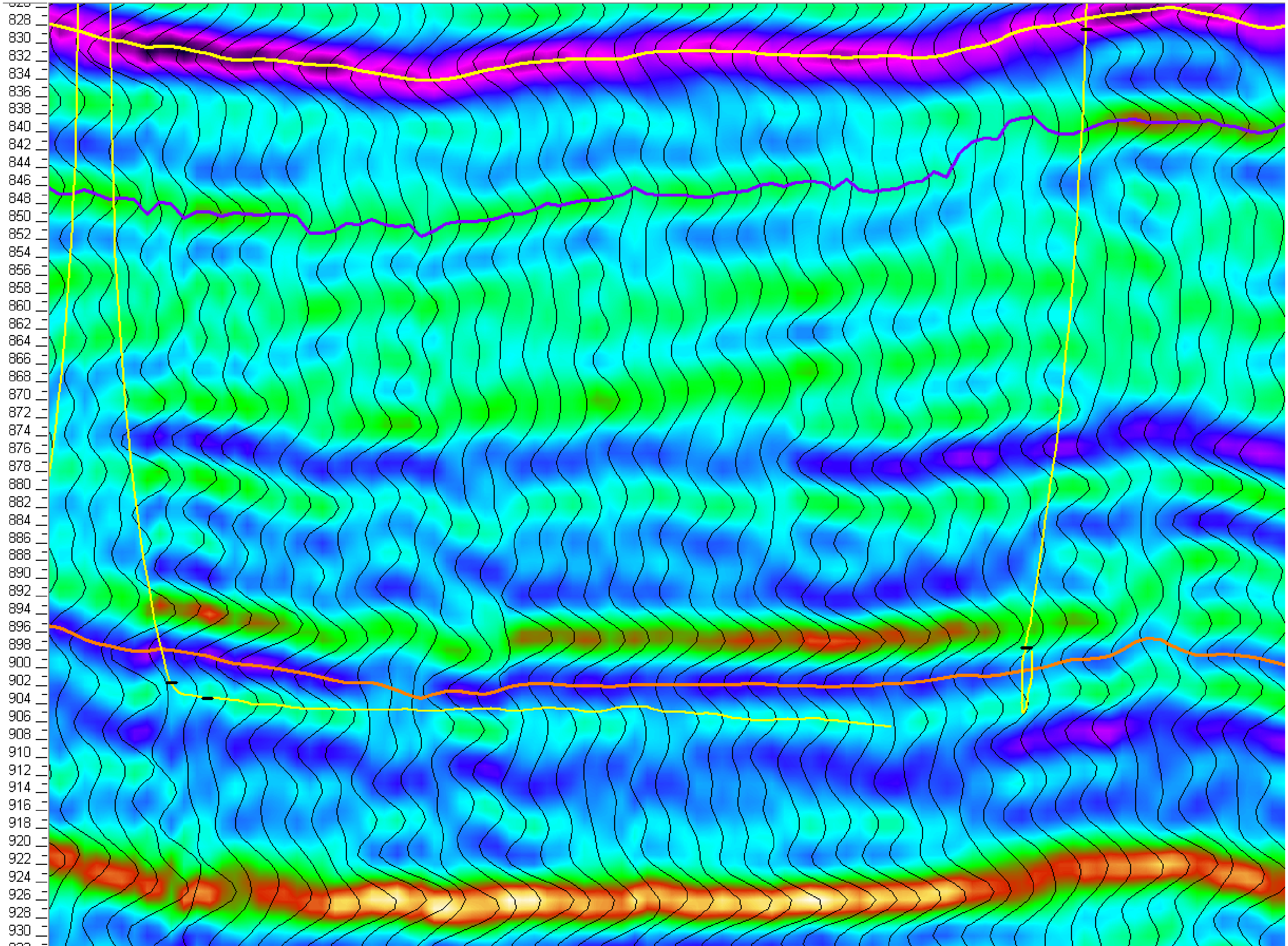
Improvement scheme

Goal: estimate top and base of reservoir

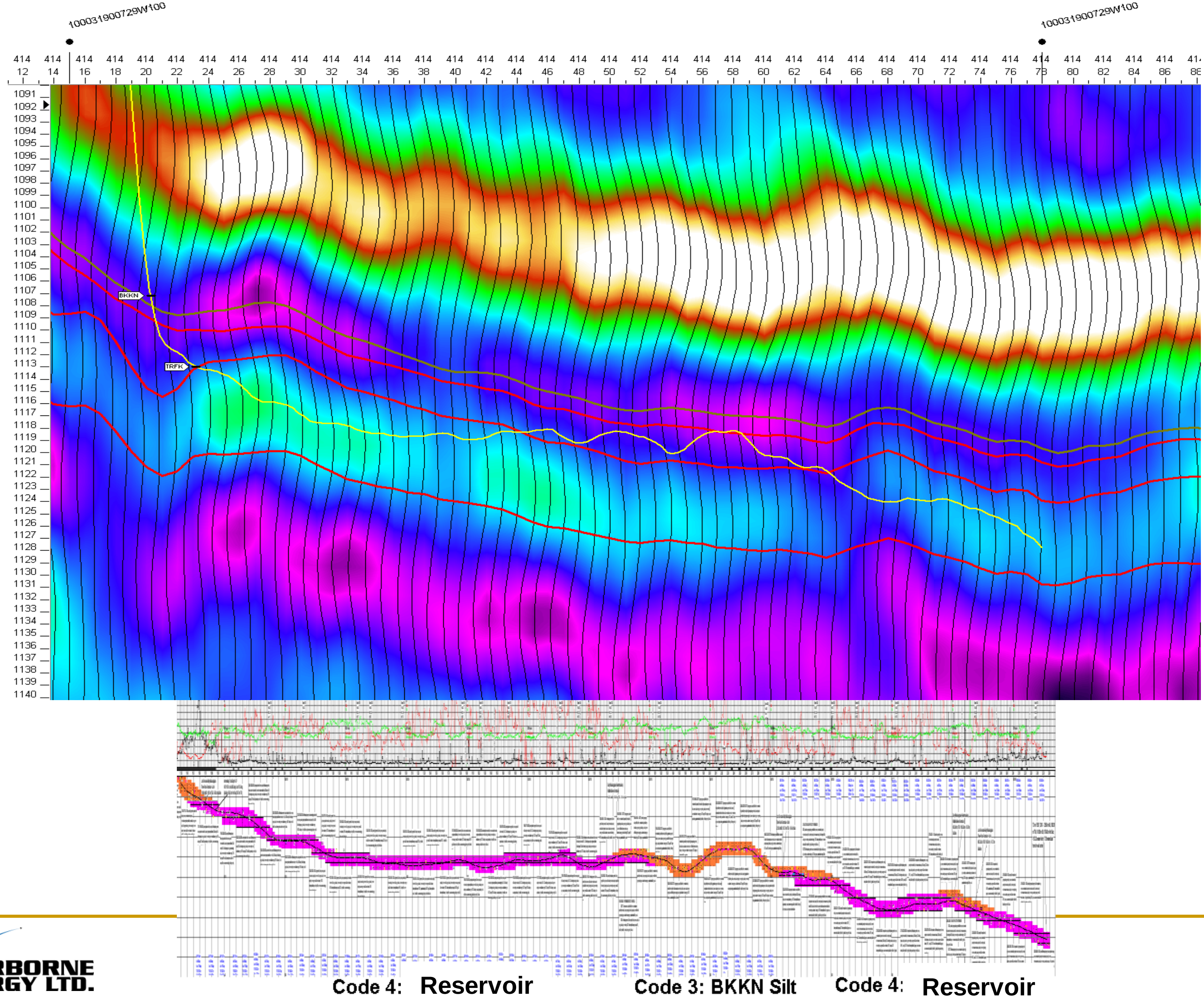
Three elements:

- **Reprocess for high frequencies**
- **Use all control points for T-D to Bakken**
- **Use amplitudes for some isopachs**

New data: can pick better



New data: no more mystery



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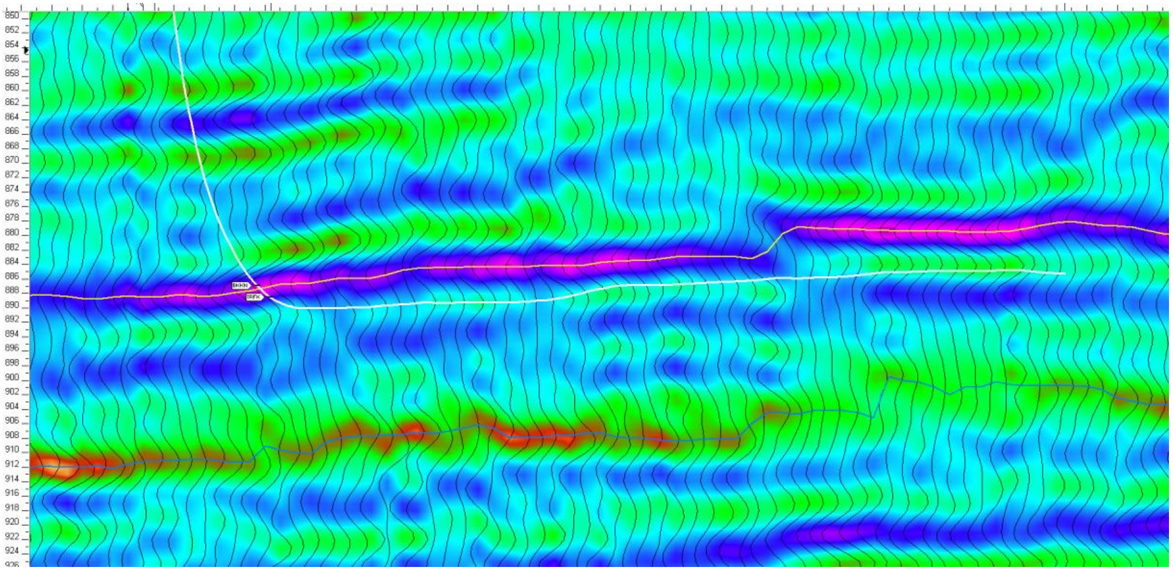
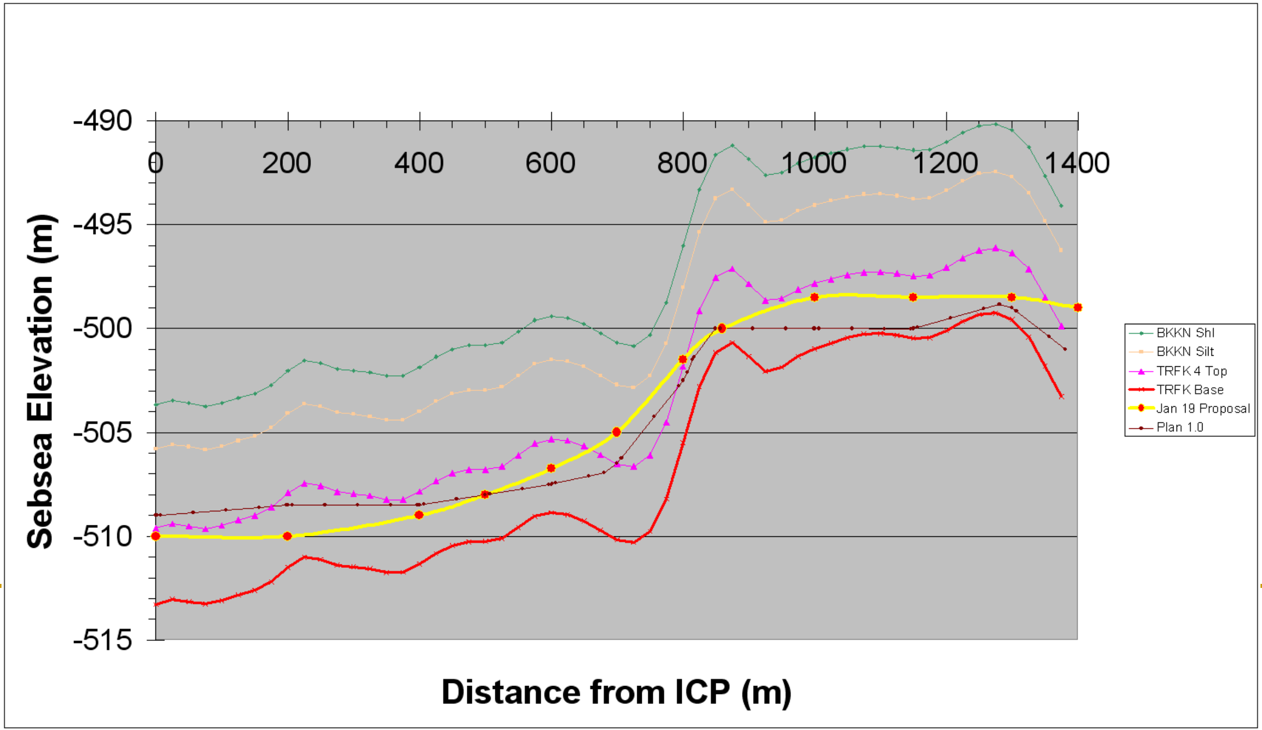
Seismic now the key to horizontals





96% in zone

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Comparative method

- **25 old horizontals**
- ***New program of 19 horizontals to be drilled***

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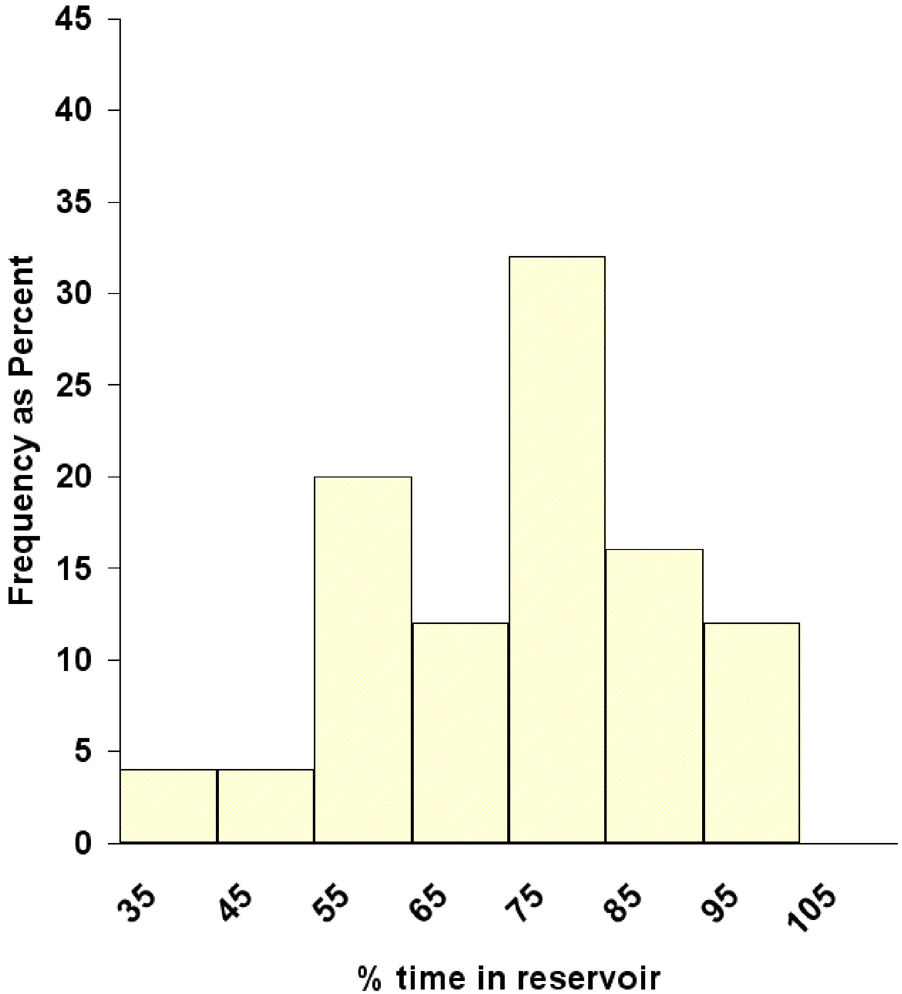
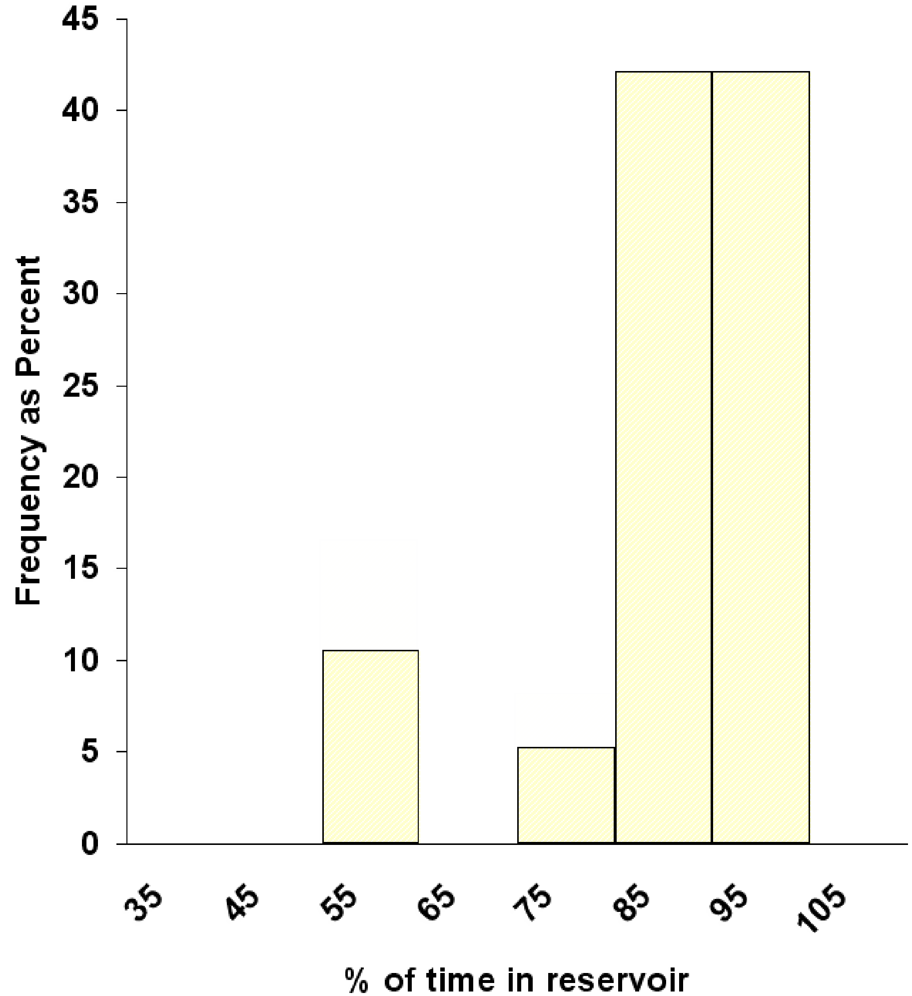
Accuracy comparison

Old | New

(a) Histogram for 25 old wells: % of time in reservoir (78% average)



(b) Histogram for 19 new wells: % of time in reservoir (91% average)



Fluid (model) value

91% accuracy vs 78% accuracy implies:

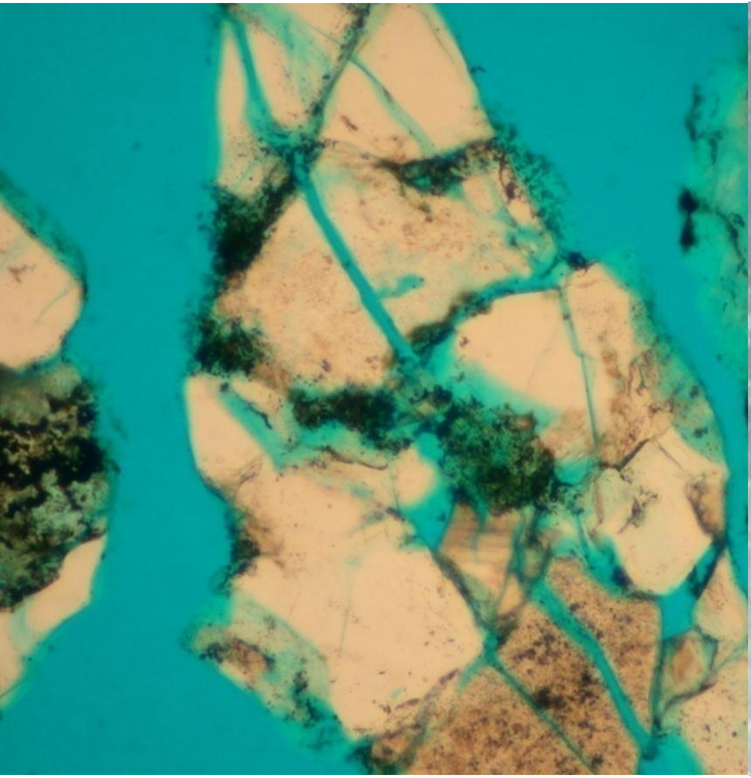
>19 more barrels of fluid per day

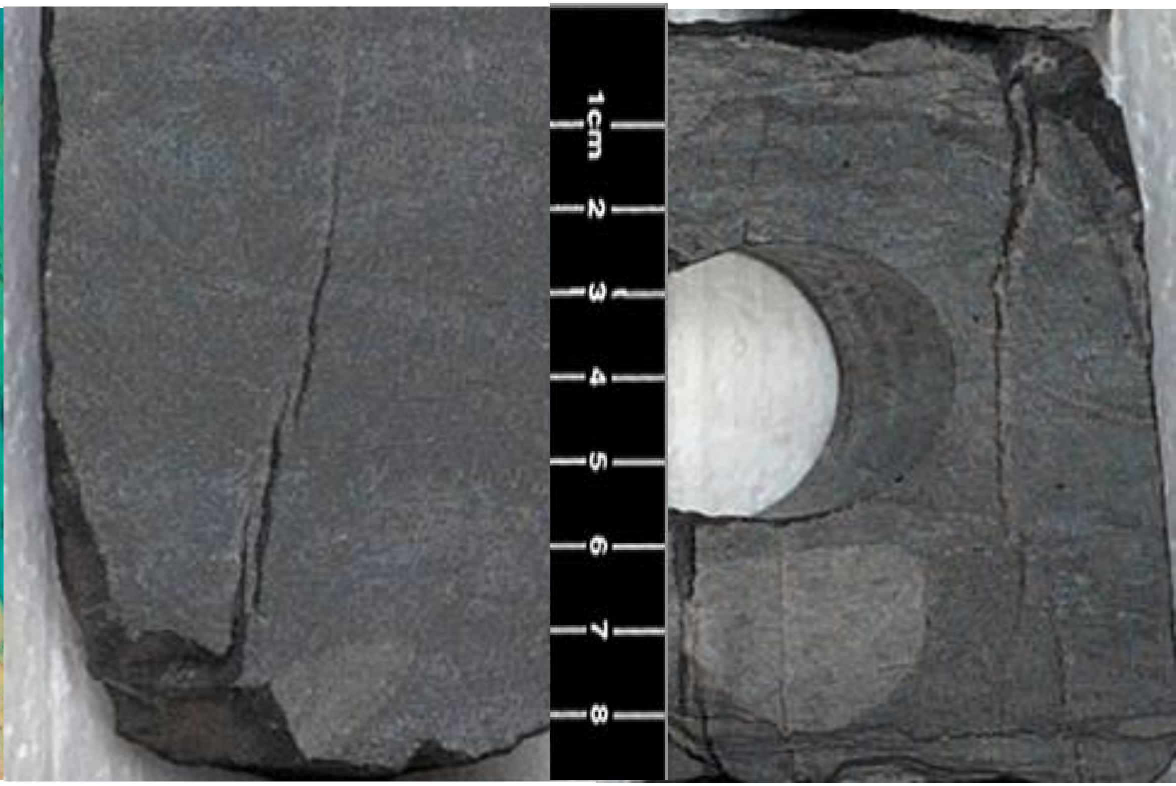
Models to

> $400 per day per well

Our wells appear to be doing better than this:

Case study III: fractures & production





Applied Science

CSM
(Ruger, 1996)

U. of A.
(Lui & Sacchi, 2004)

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CGGVeritas (Gray, 2003, Trad, 2007)

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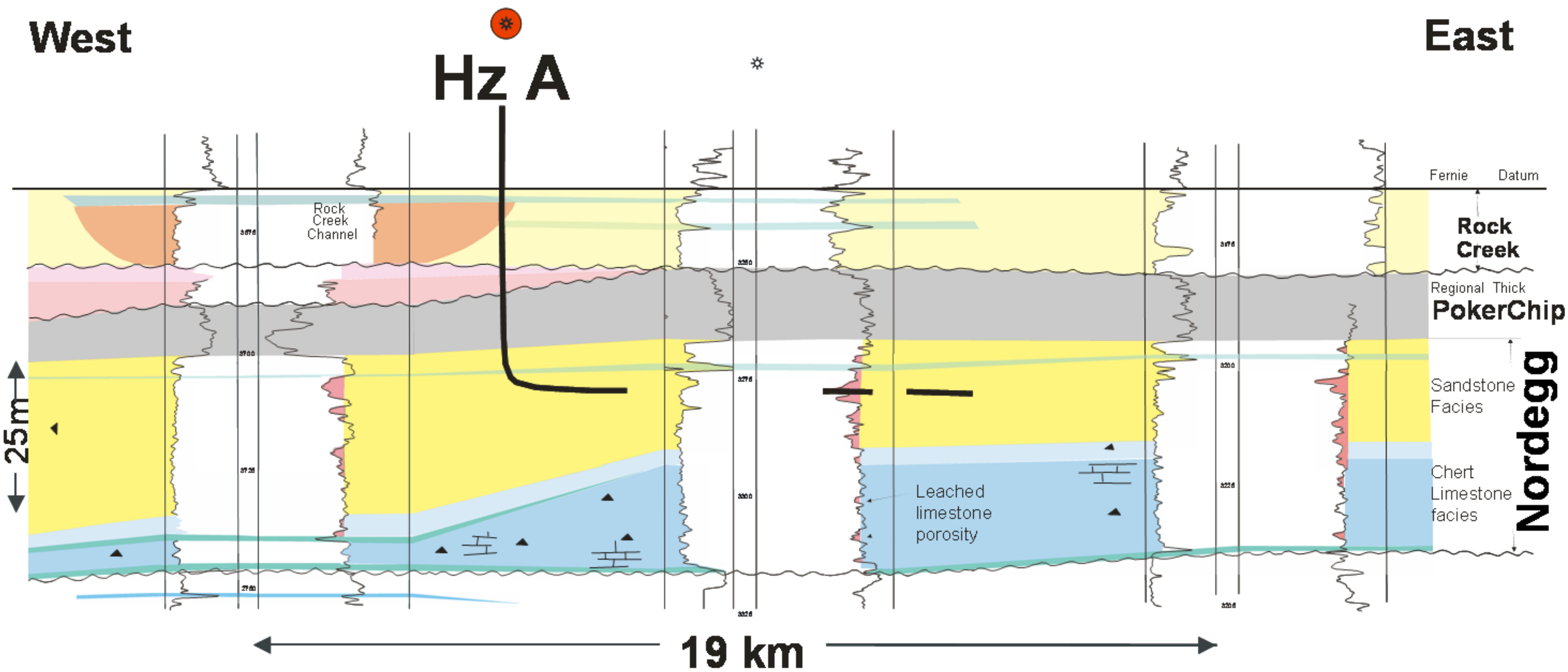
FairborneEnergy and CGGVeritas (Hunt et al, 2010)

⇩

Value

Introduction- Nordegg



Aerially extensive gas charged sandstone

Deep basin

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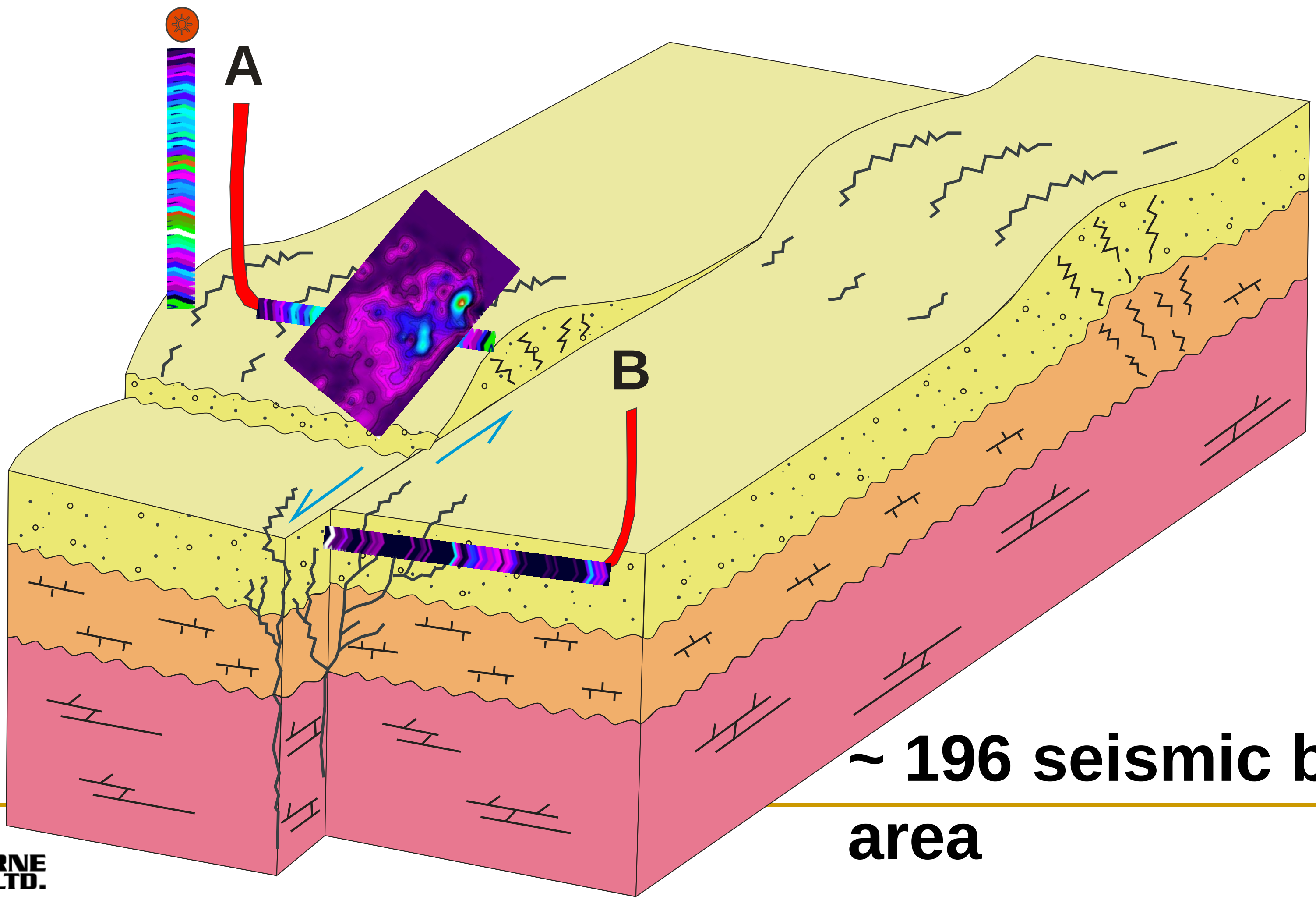
Hrz, vertical well, & Microseismic

62 bins hrz + 400,000 meters^2 of *variation*



~ 196 seismic bin area

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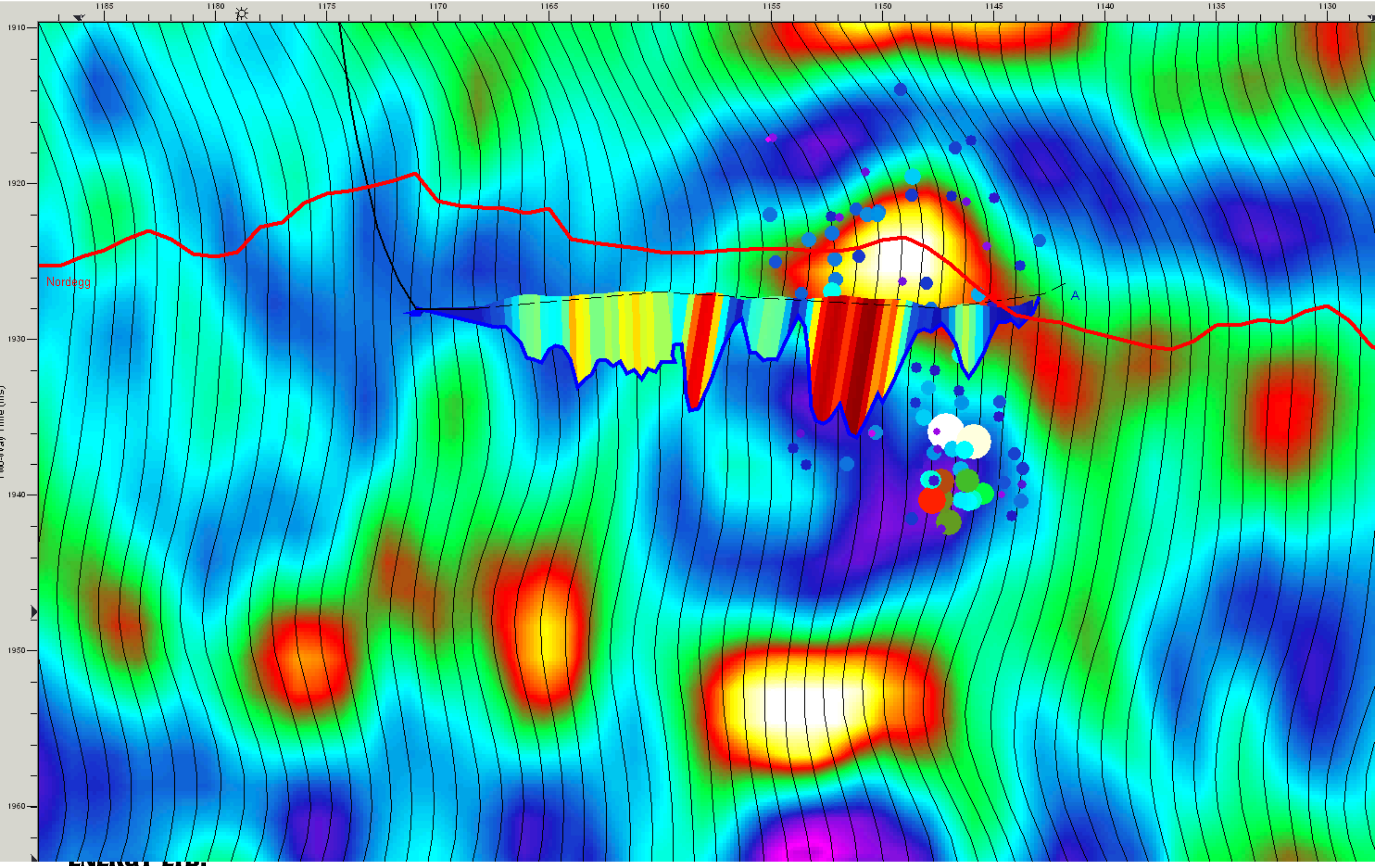
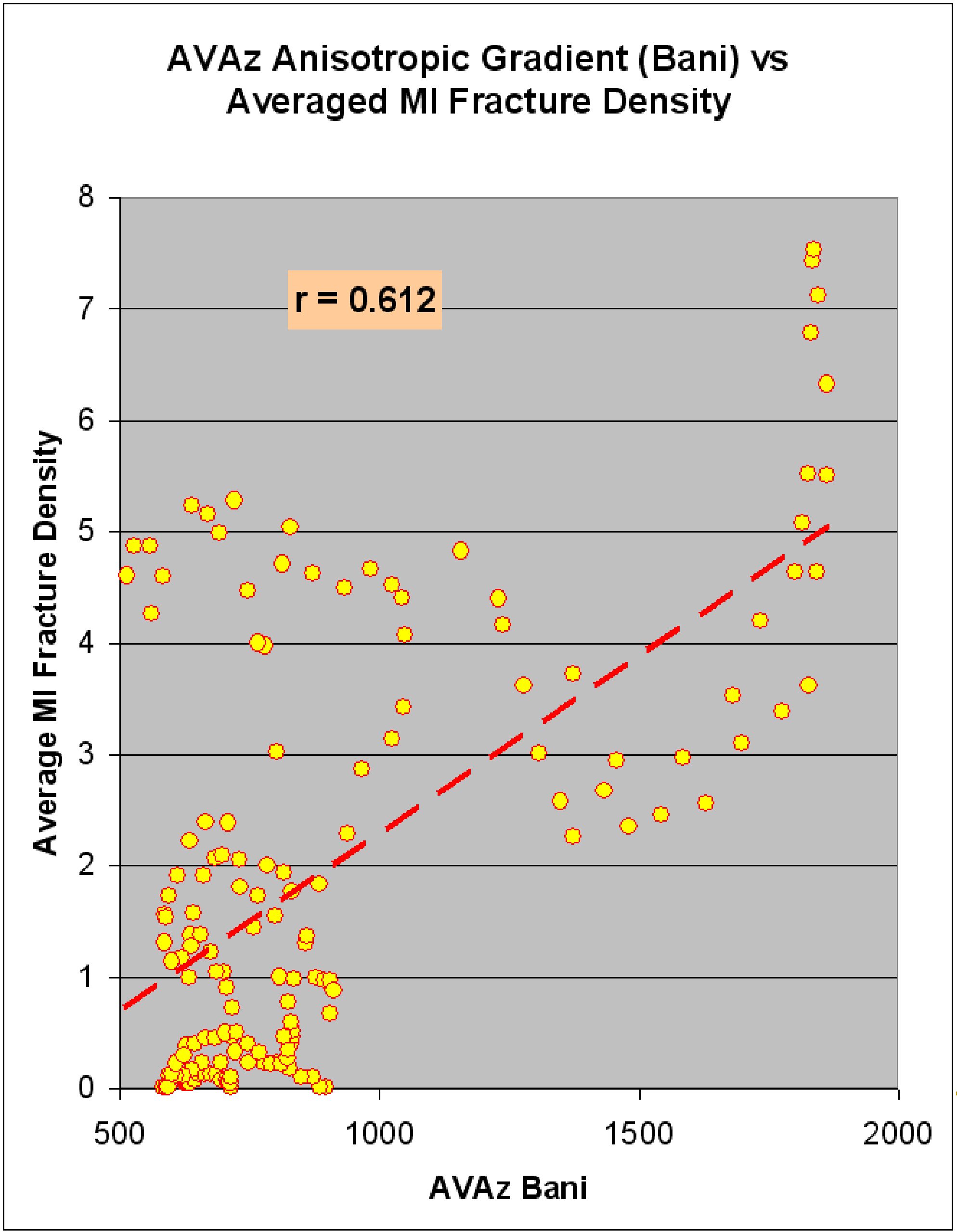
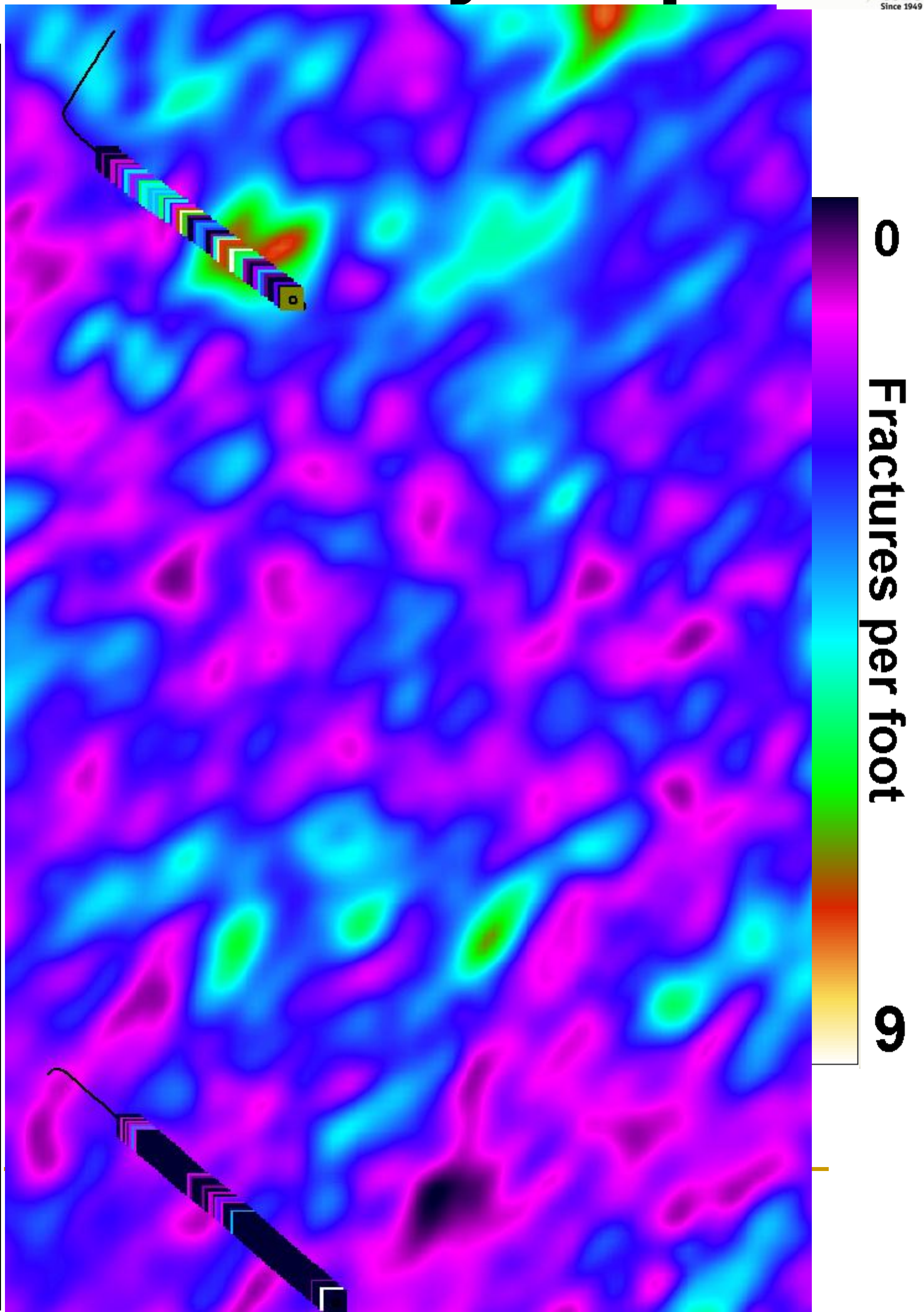
Qualitative analysis



AVAz vs MI Fracture Density Map



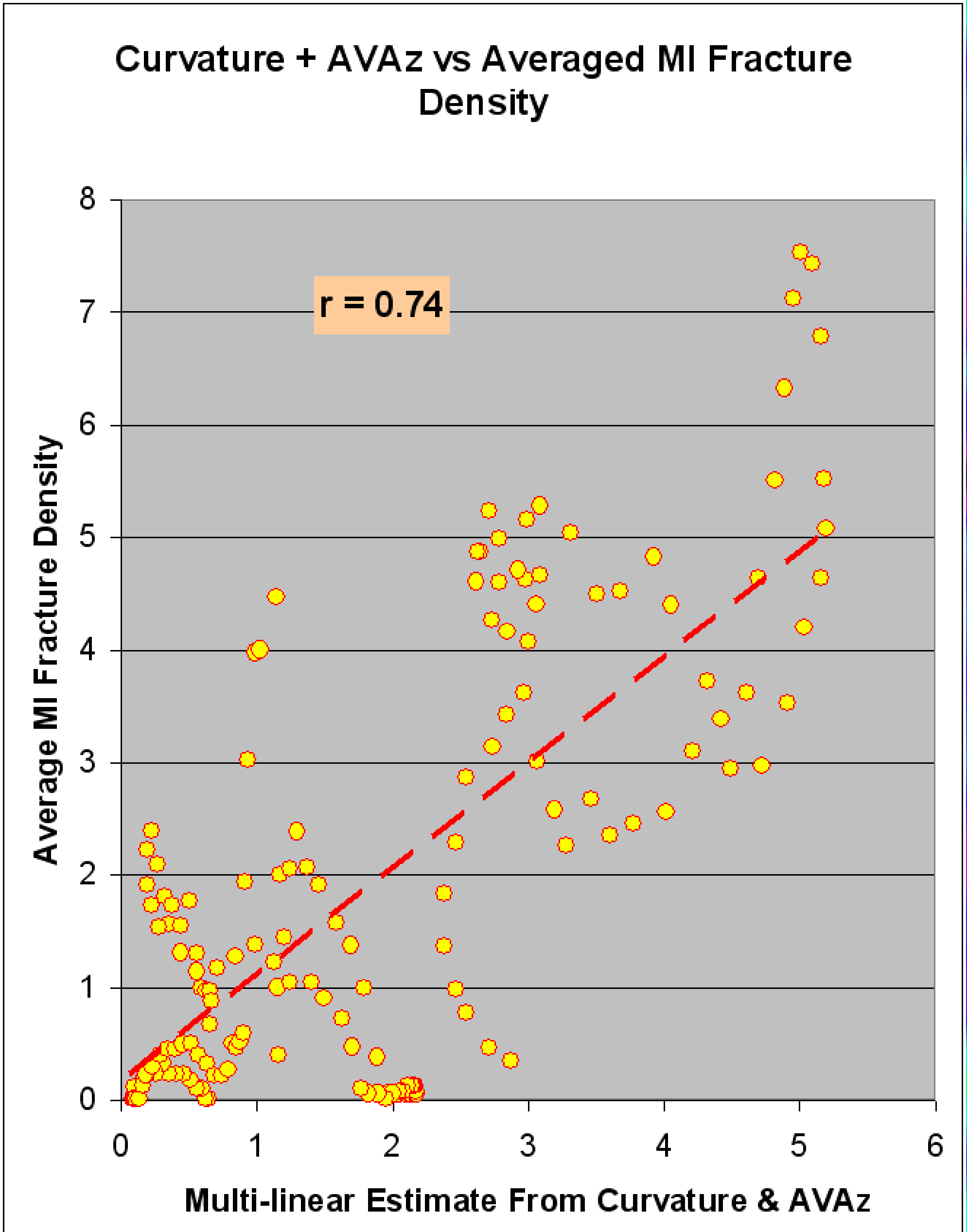


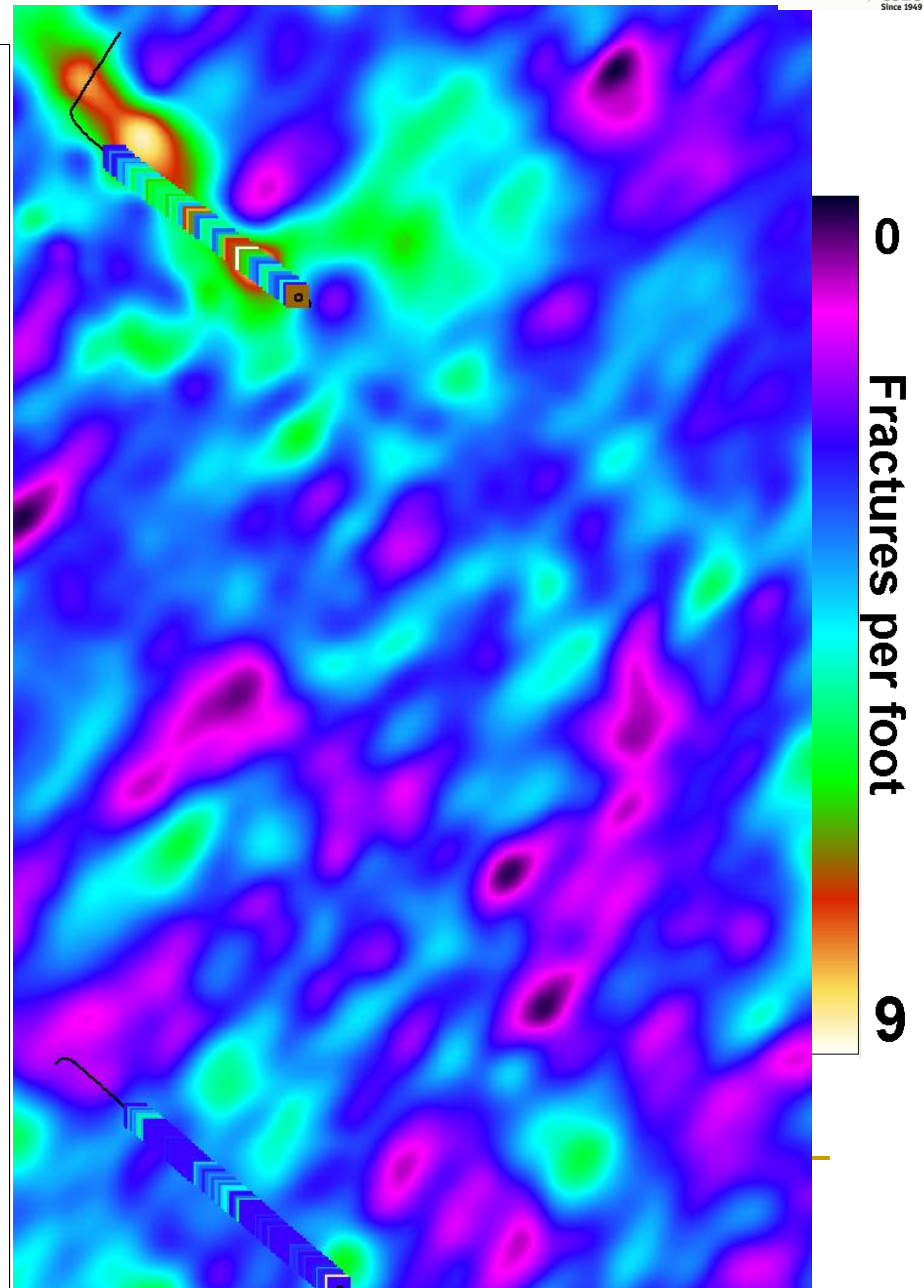
Discussion: Roll-up

	Best Correlation Coefficient	
	MI Fracture Density	Microseismic (195 points)
AVAz	0.612	0.638
VVAz Anisotropy	0.539	0.310
Curvature	0.739	0.370
Coherence	-0.215	0.065

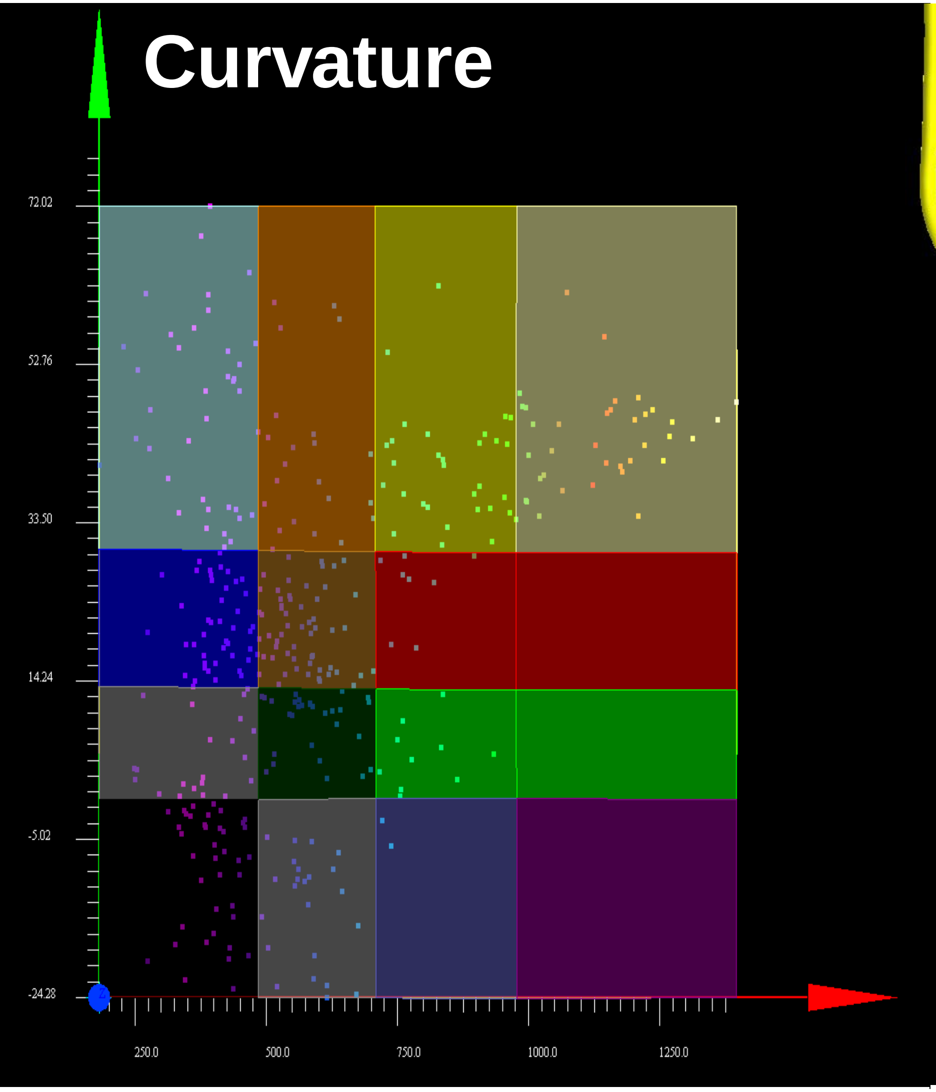
- **Consistency in the results**
- **Statistical significance is achieved**
- **We *can* draw conclusions**

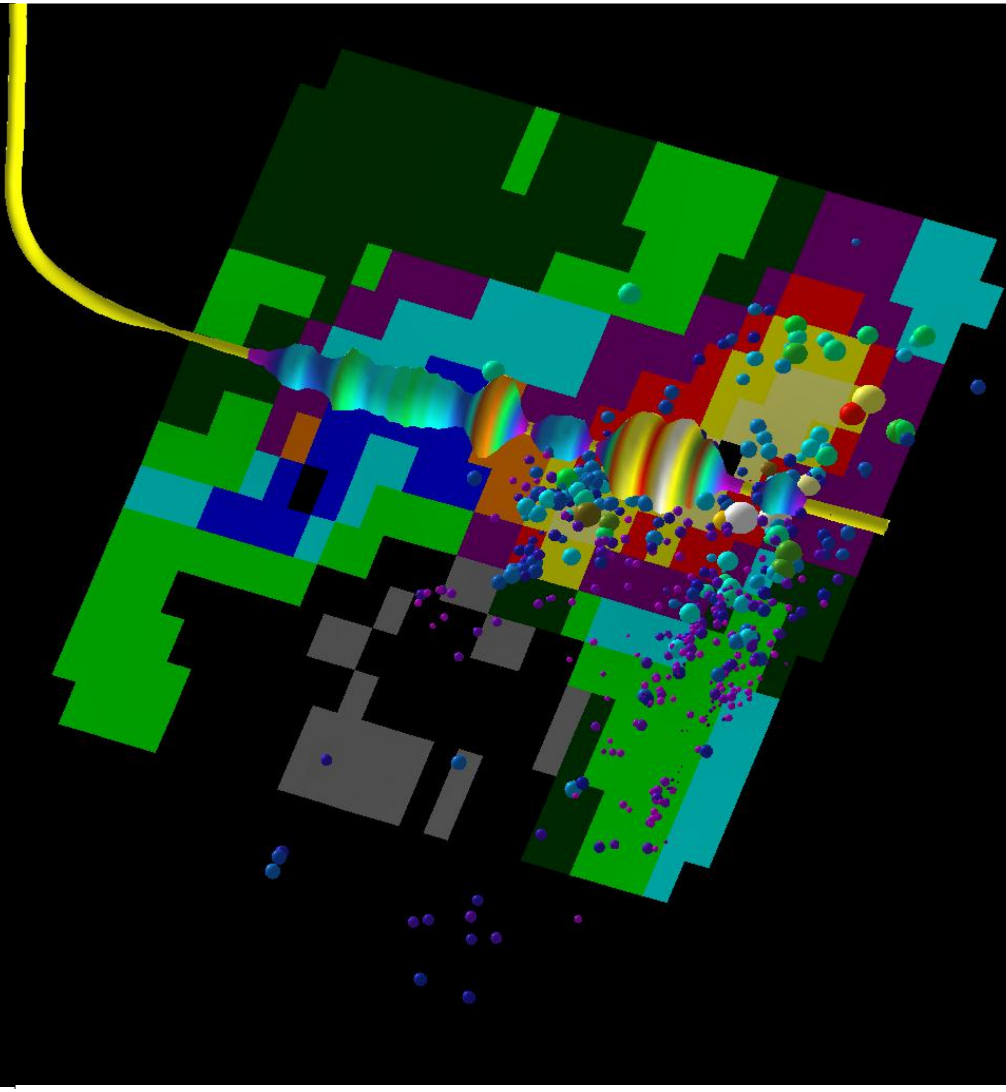
Map Using AVAz and Curvature





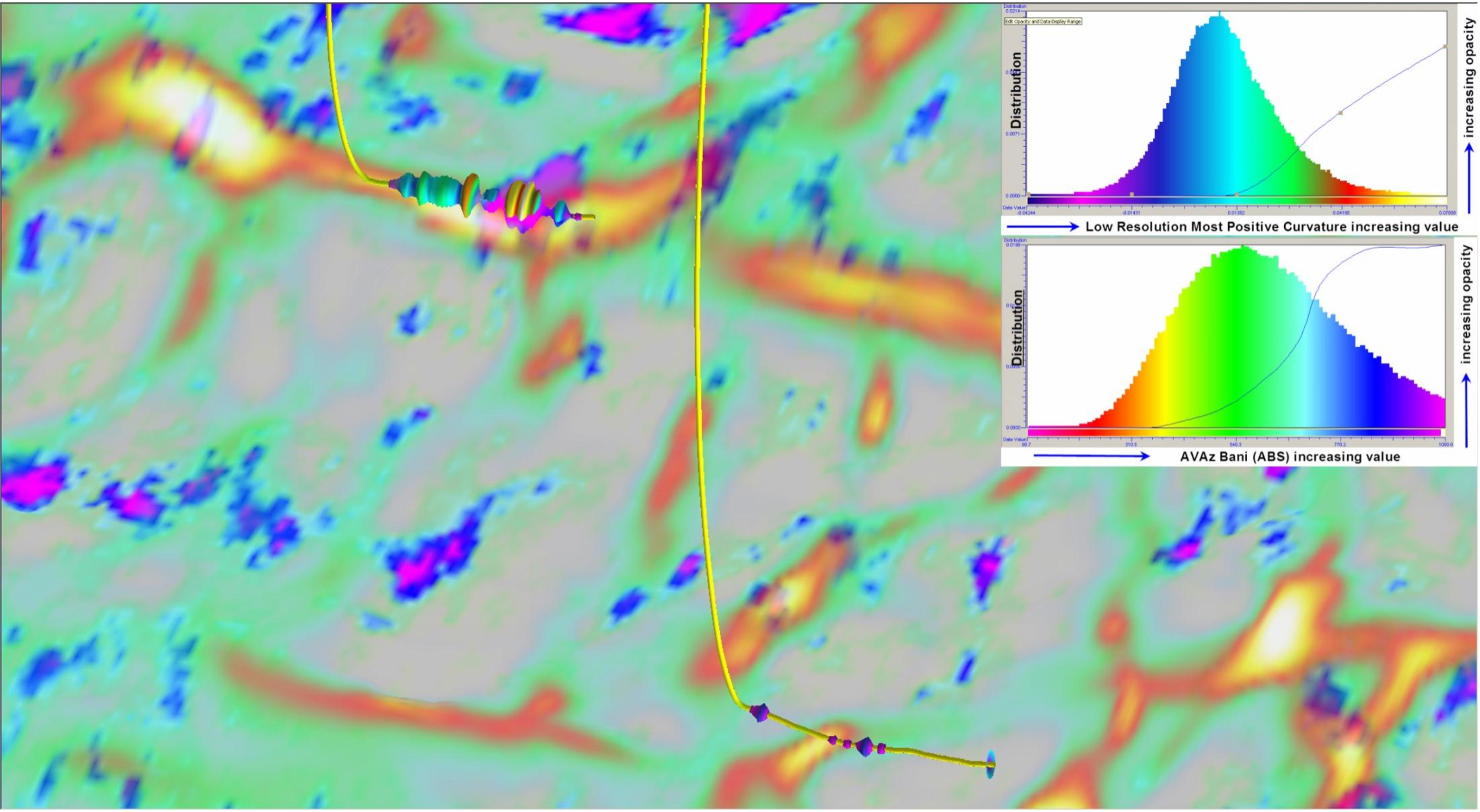
AVAz and Curvature: Cross Plot





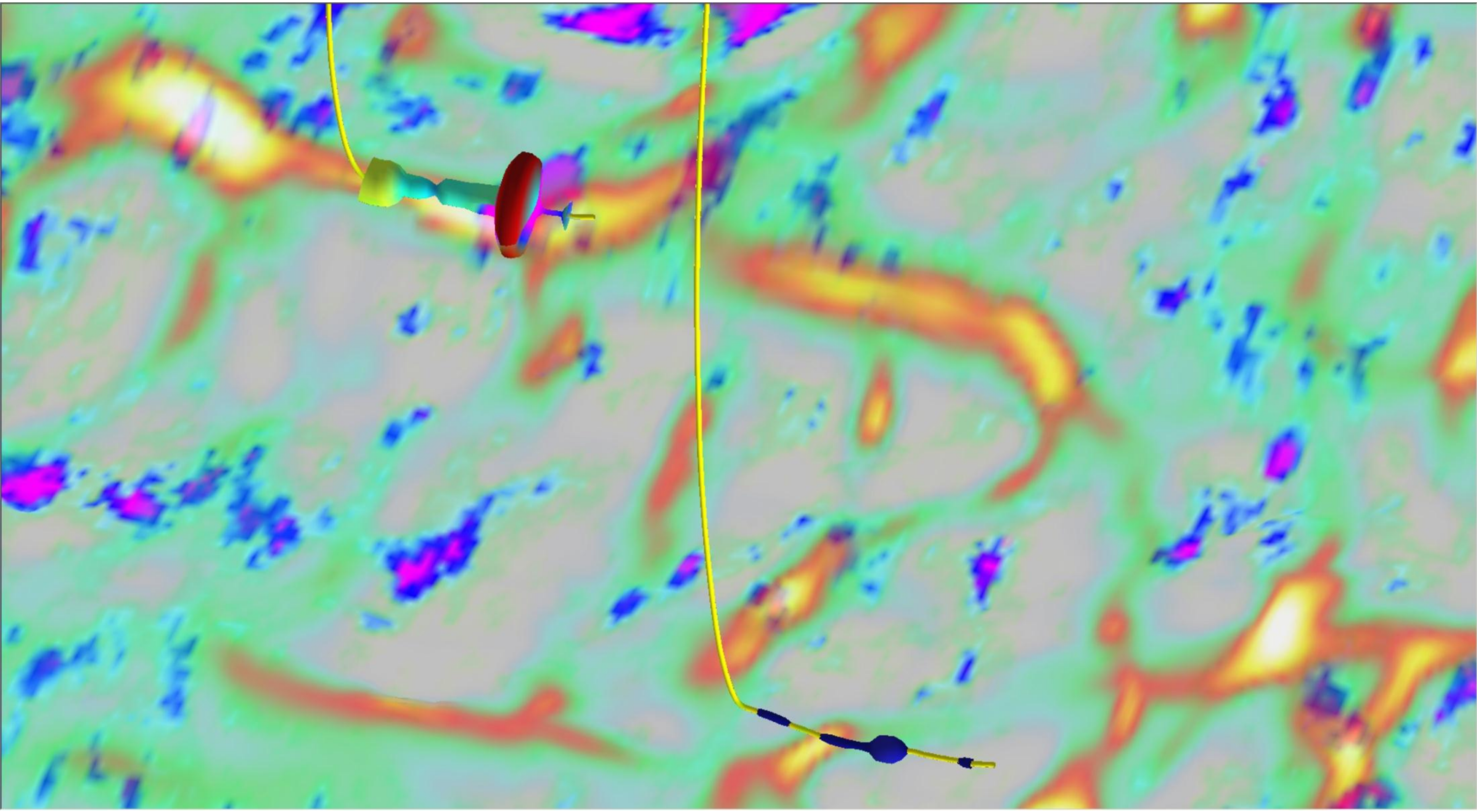
AVAZ RMS

AVAz and Curvature: co-render



FAIRBORNE ENERGY LTD.

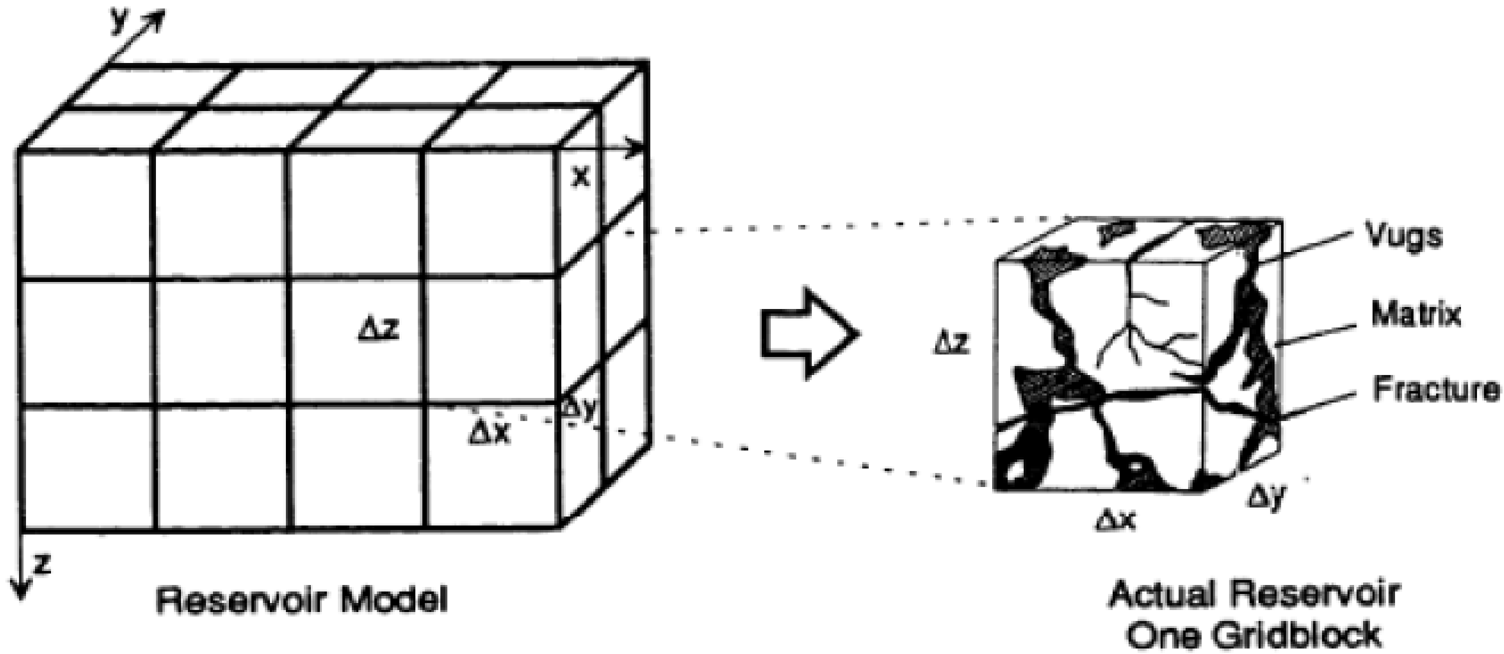
With production data



FAIRBORNE ENERGY LTD.

Production: reservoir

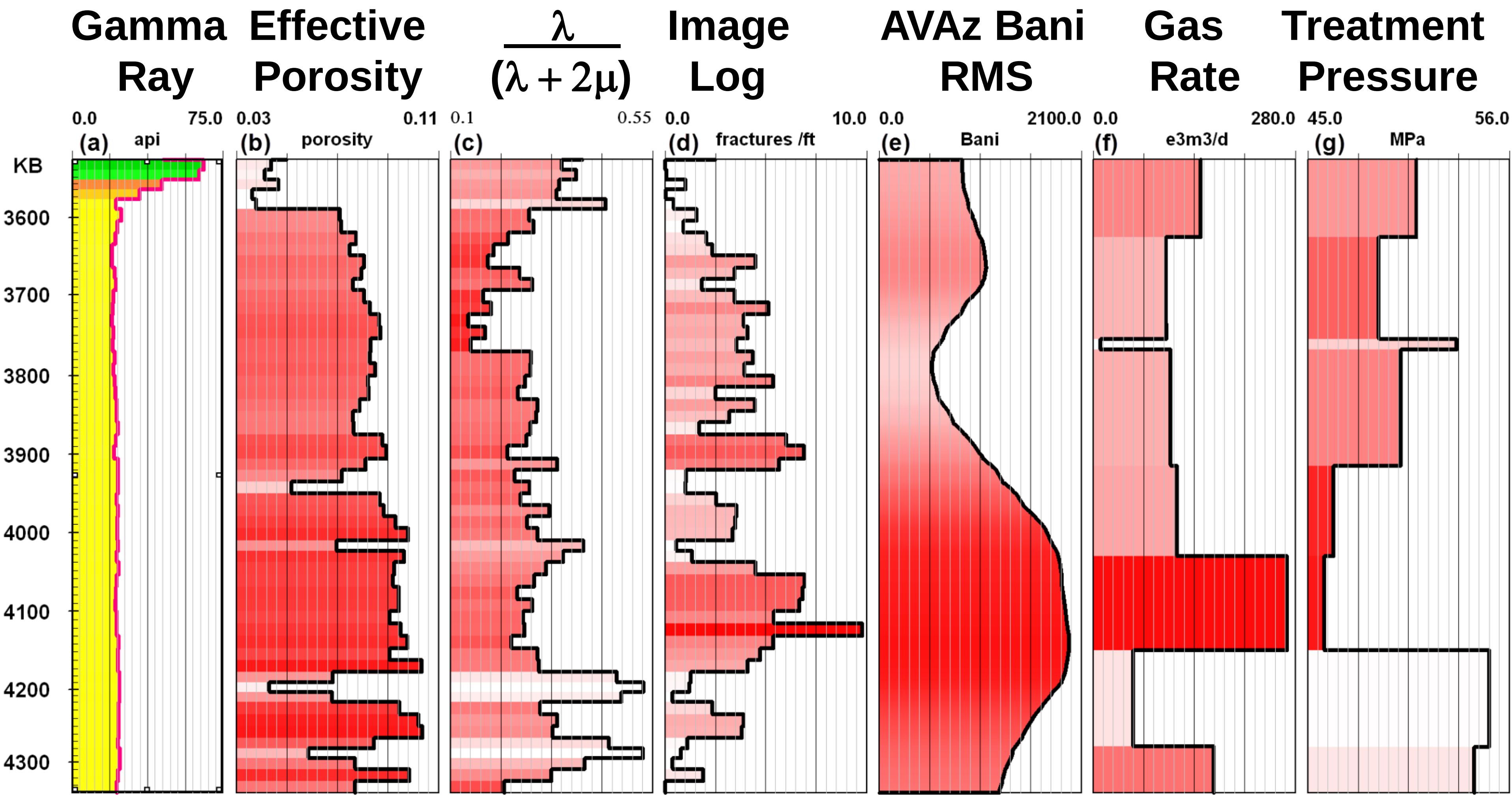
➢ Dual Porosity



➢ **Fracture porosity is very low**
➢ **Fractures could help or hinder**

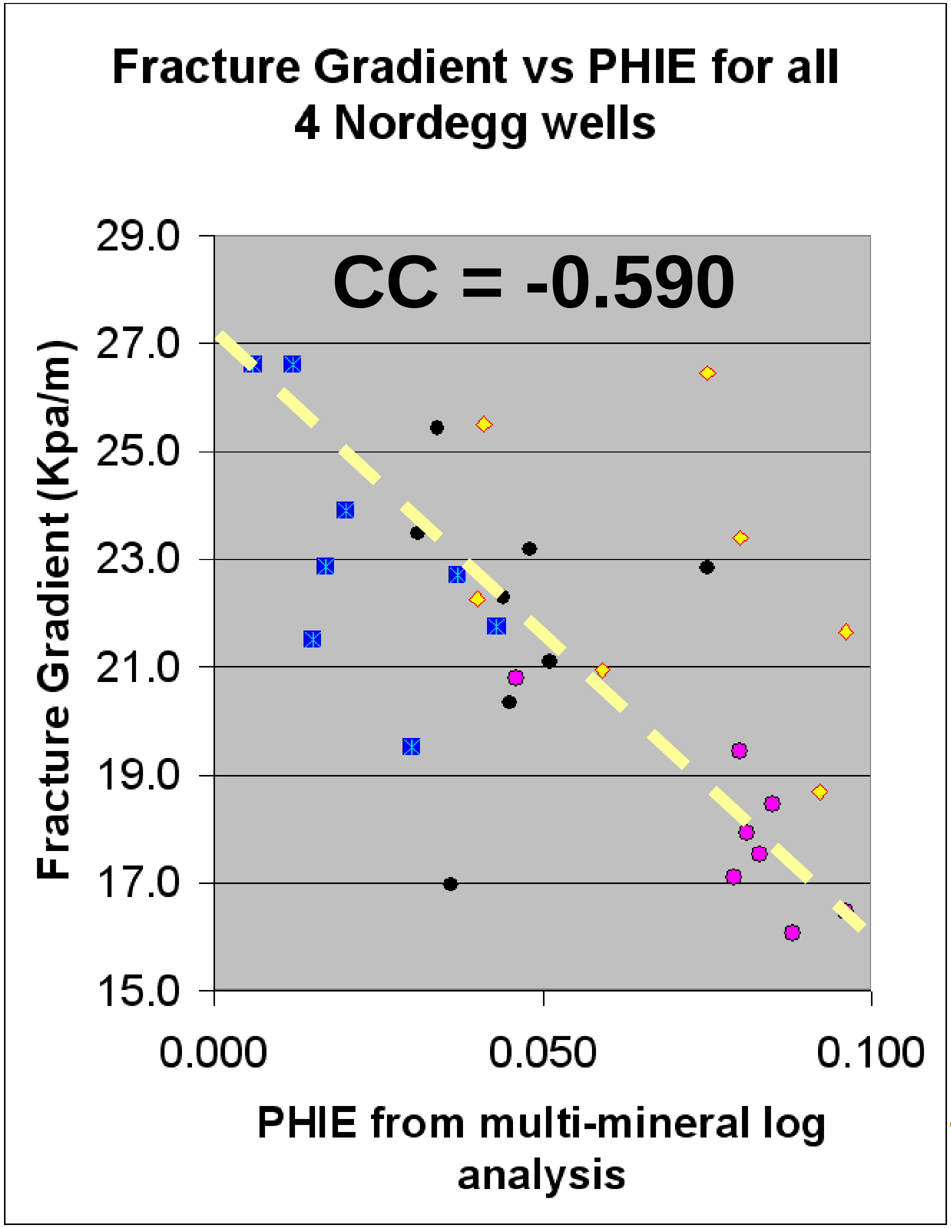
From Wang 2008

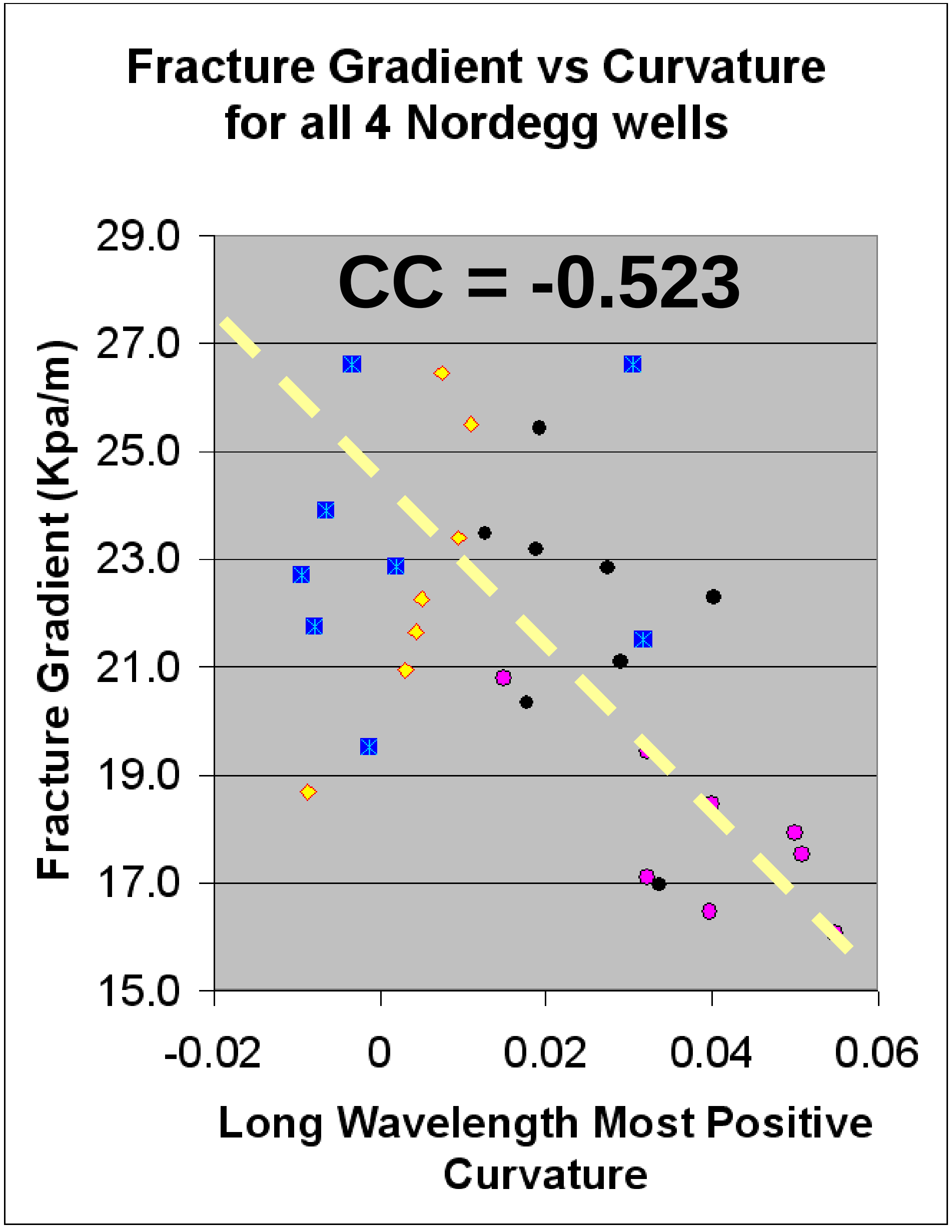
Wellbore / log extraction: well A



FAIRBORNE ENERGY LTD.

4 wells with Fracture Gradients





Conclusions

- Modern role: science + business
- We must be quantitative
- Leads to increased involvement (all disciplines)
- The work guides us to best efforts
- There is value in this
  - better Phi-h = NPV
  - better steering = Rate
  - better stimulation = Rate

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