Quantitative Interpretation

Lee Hunt

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CSEG Foundation

Canadian Society of Exploration Geophysicists
CSEG
Since 1949

Quantitative Interpretation

Scott Reynolds

Scott Hadley

Mark Hadley

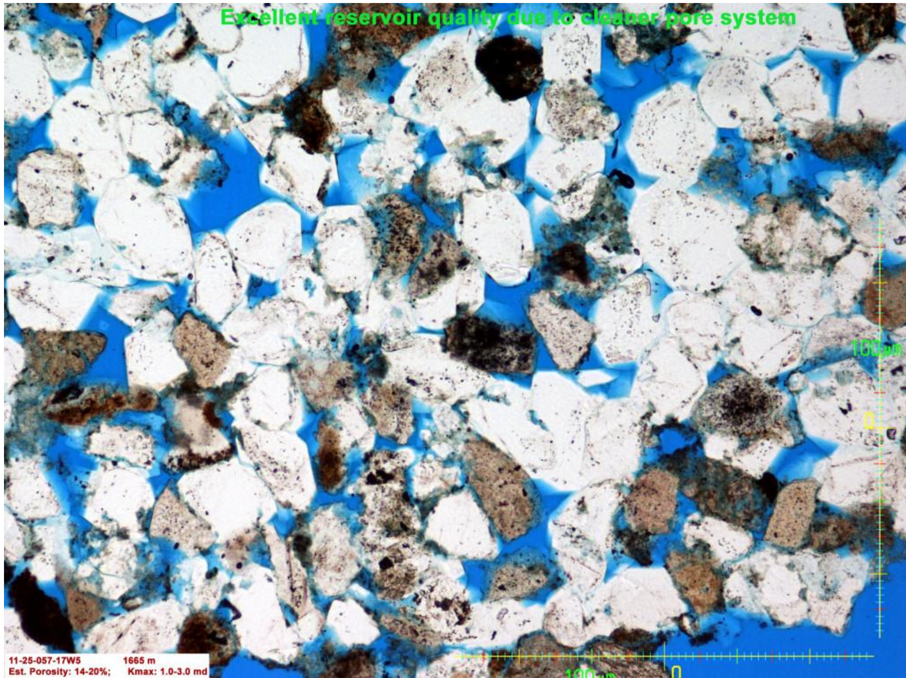
Jon Downton

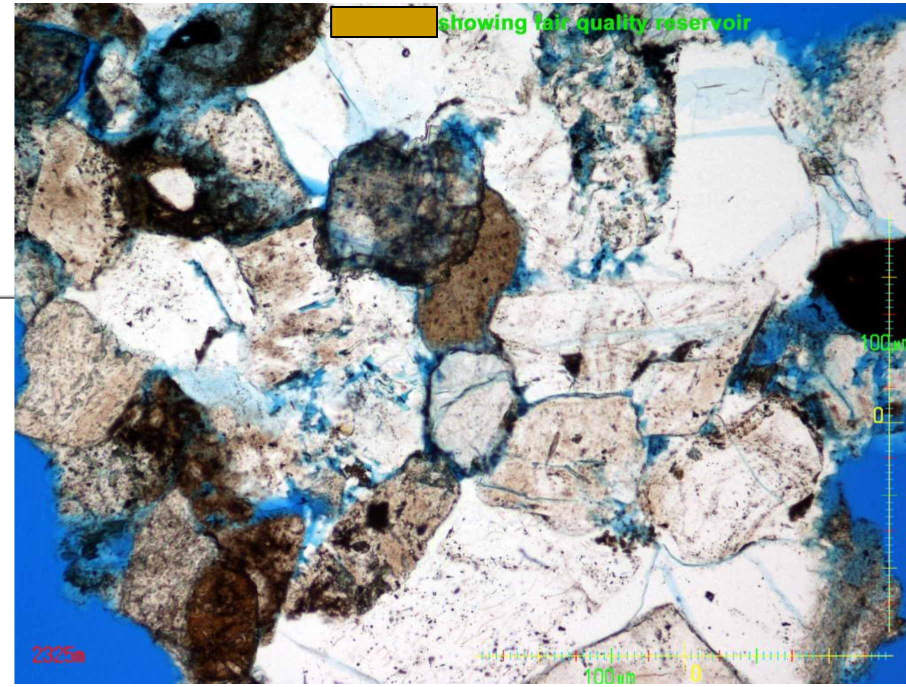
Satinder Chopra

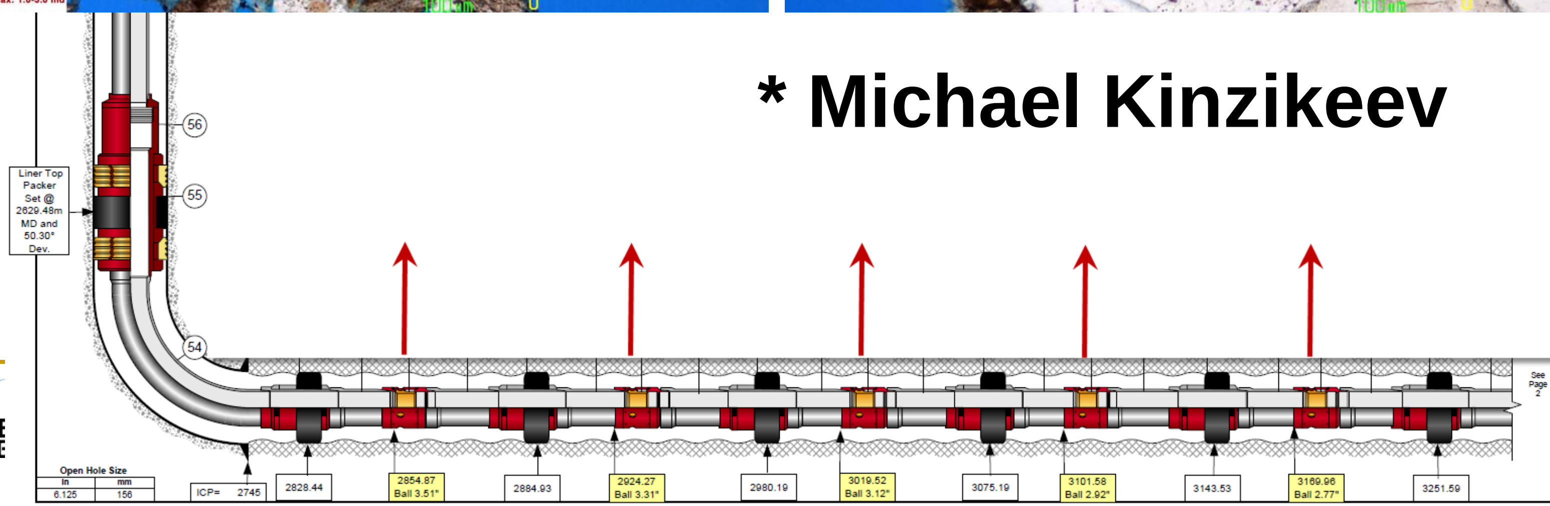
Changing reservoirs, world

Conventional

Unconventional







* Michael Kinzikeev

Beginning of the end?

Some say geosciences are in their twilight

The art has gone out of the science

It is all engineering now

End of the beginning

Some say geosciences are in their twilight

The art has gone out of the science

It is all engineering now

This is untrue, however we must change

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Outline

Quantitative method

Case study I: Interpolation / economics

Case study II: Steering horizontals

Case study III: Fractures & production

Conclusions

Quantitative method

Begin with the end in mind

Begin with the physics in mind

***** Stephen R. Covey**

Quantitative method

Begin with the end in mind

Begin with the physics in mind

And then make measurements

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No more colors and times

We need to speak in the language of the earth

Earth properties *from* seismic properties

- **More scientific**
- **Results oriented**
- **Transferable to others**
- **Measureable success and accuracy**
- **Forces conclusions and commitment**
- **Hi-lights need for improvement**
  - **Directs investment & research**

Scientific method is quantitative

Heart of the scientific method is quantitative

We always needed to use quantitative methods

The new challenges require it more

No measure = no meaning

History

Time vs depth	
Amplitude / quality	**Rummerfield (1954)**
CMP	**Mayne (1962)**
Inversion	**Lindseth (1979)**
AVO	**Ostrander (1984), Shuey (1985)**
AVO Inversion	**Goodway et al (1996)**
Azimuthal methods	**Ruger (1996), Lynn et al (1996), Gray et al**
Curvature	**Roberts (2001), Chopra and Marfurt (2007)**
Multi-attribute methods	**Schultz et al (1994), Hampson et al (2001)**
Engineering	**Goodway et al (2006), Perez et al (2011)** **Gray (2010, 2011), Dunphy & Campagna (2011)**

See also Barnes (2001), Avseth et al (2005)

Attribute soup

Nearly infinite number of attributes

Can be combined in multi-attribute methods

Can be confusing ….

Can be used as a washing machine

Schultz et al (1994), Hampson et al (2001)

Simplify and … physics

The best physical property is usually known

Don't think of the problem as hundreds of attributes

Simplify and … physics

The best physical property is usually known

Don’t think of the problem as hundreds of attributes

…. But a few key seismic properties

Simplify and … physics

The best physical property is usually known

Don’t think of the problem as hundreds of attributes

…. But a few key seismic properties

And many ways of measuring them (attributes)

Properties, then attributes

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A. Some of the seismic data types or properties											
Information	**Type**	**Property**	**Thin bed / tuning**	**Structure**	**Fluid**	**Lithology**	**Fault / frac**	**Strain**	**Stress**	**edges**	**bedding continuity**
Fundamental Stack	Stack	Time section									
		Velocity									
		Depth section									
Fundamental pre-stack rock properties	AVO	Intercept, Gradient, Rp, Rs									
		Fluid Factor, Poisson's ratio									
		$\lambda\rho$									
		$\mu\rho$									
		$\lambda\rho - \mu\rho$									
		$\lambda\rho / (\lambda\rho + 2 * \mu\rho)$									
		Young's Modulus									
	Azimuth	Anisotropic gradient									
		VVAz- velocity anisotropy									

B. Examples of both properties and attributes											
Information	**Class**	**Attribute**	**Thin bed / tuning**	**Structure**	**Fluid**	**Lithology**	**Fault /frac**	**Strain**	**Stress**	**edges**	**bedding continuity**
Horizon	Horizon	Time pick (horizon)									
		Depth pick (horizon)									
Horizon or volume attribute / property	Spatial, shape, or texture	Curvature									
		Dip									
		Dip-azimuth									
		Second derivative									
		Lambertian reflectance									
		Strike									
		Throw									
		Semblance									
		Texture attributes									
		Discontinuity									
		Simple difference									
		Waveform difference									

C. Some of the attributes or measurements on properties											
Attributes of a property (or of traces within a volume)	Window, or interval of any size: observations of amplitude and trace shape	Amplitude, at horizon or windowed									
		Isochron between horizons									
		Ave amplitude, ABS, Mean, RMS, etc									
		Ave or instantaneous frequency									
		Variance									
		Maximum									
		Number of peaks									
		% above Threshold									
		Energy halftime									
		Spectral components									
		Waveform									
	Time-Frequency	Spectral decomposition									
		Attenuation									
	Complex Trace	Instantaneous amplitude									
		Instantaneous phase									
		Instantaneous Frequency						?			
		Relative Acoustic Impedance									
		Average Weighted Frequency									
		Instantaneous Q									

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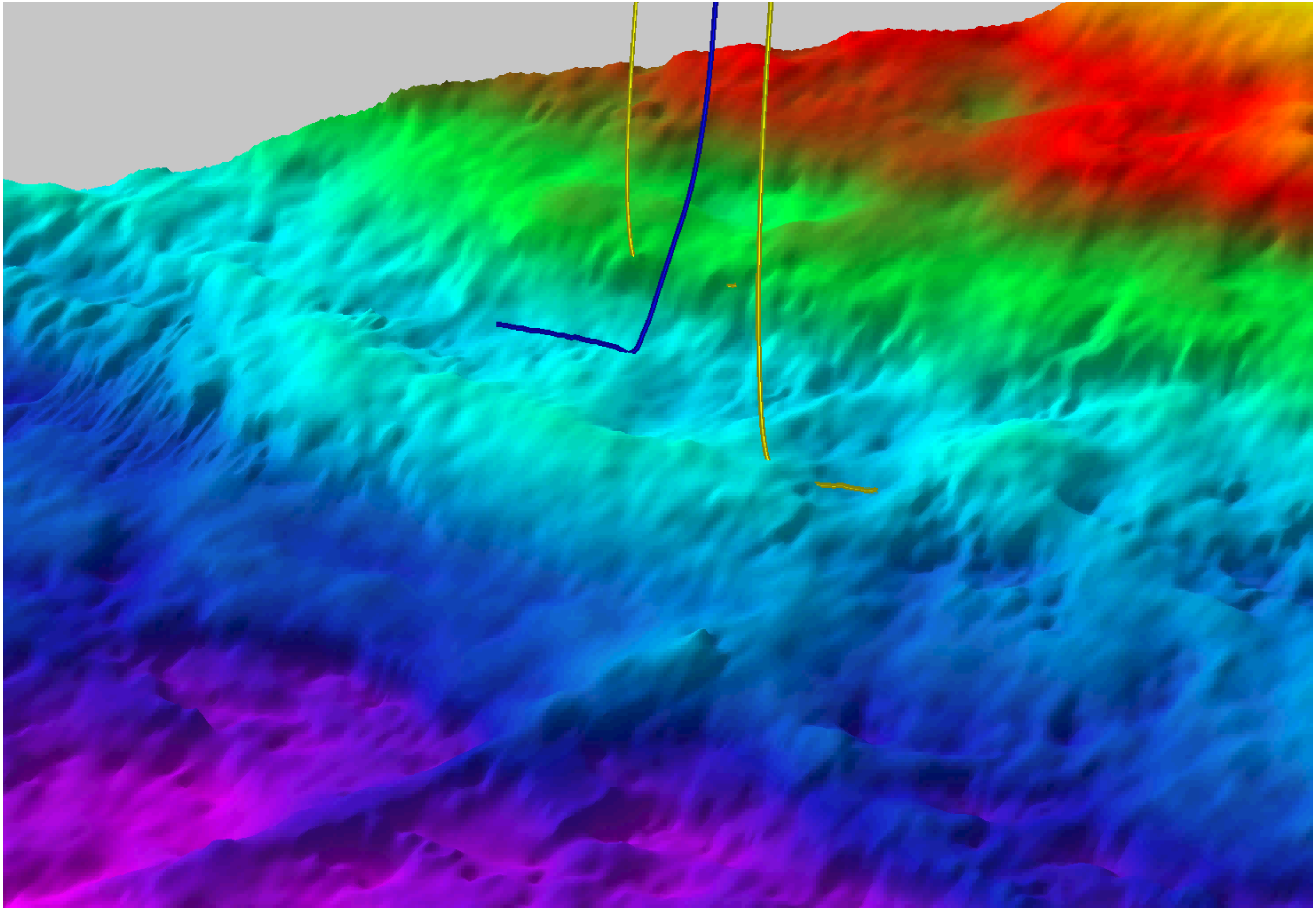
Attributes or properties



Validating data

May or may not be a "log"

May or may not require data in time or depth

Different experiments, different ways of relating data

Every interpretation is a scientific experiment

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

Case study I: Viking AVO and NPV

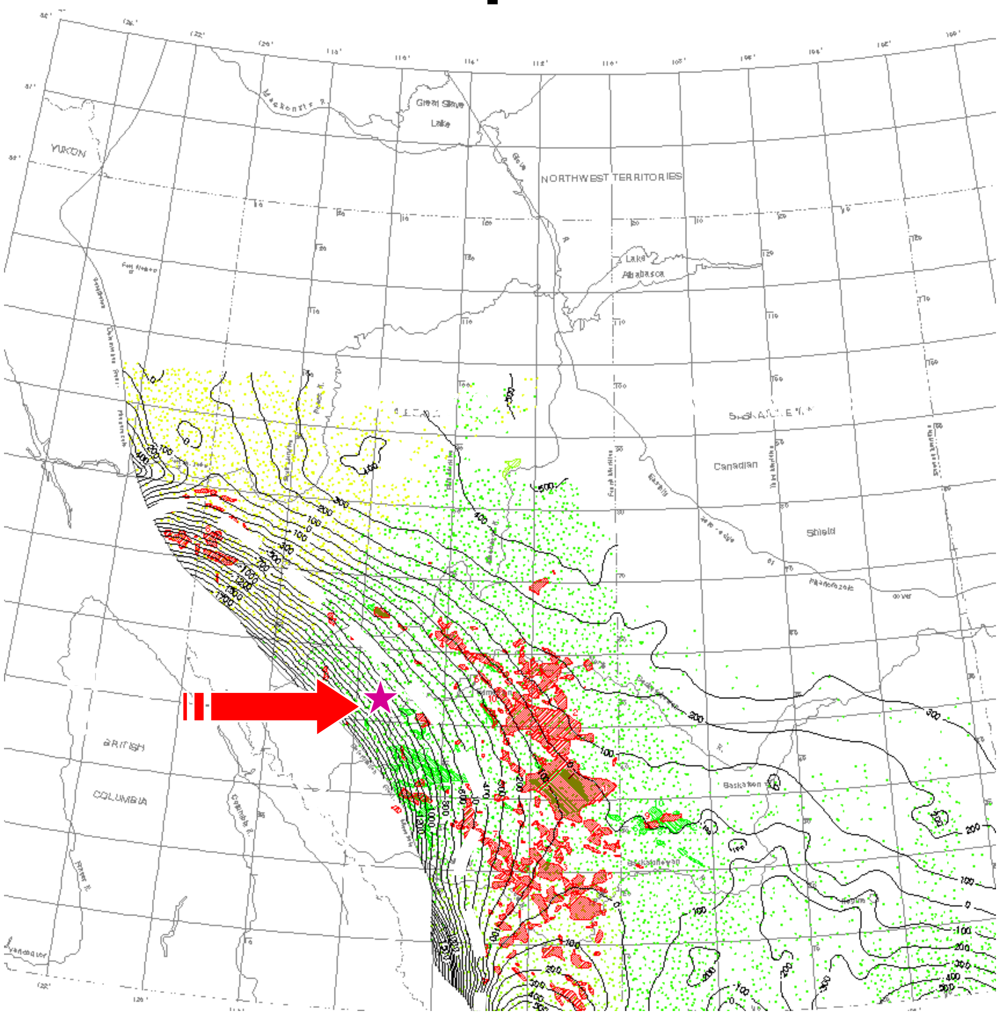
- Follows work published in 2008
- 29 wells drilled prior
    - Interpolation to improve imaging
    - Improved imaging to improve AVO
    - Improved AVO to map porosity

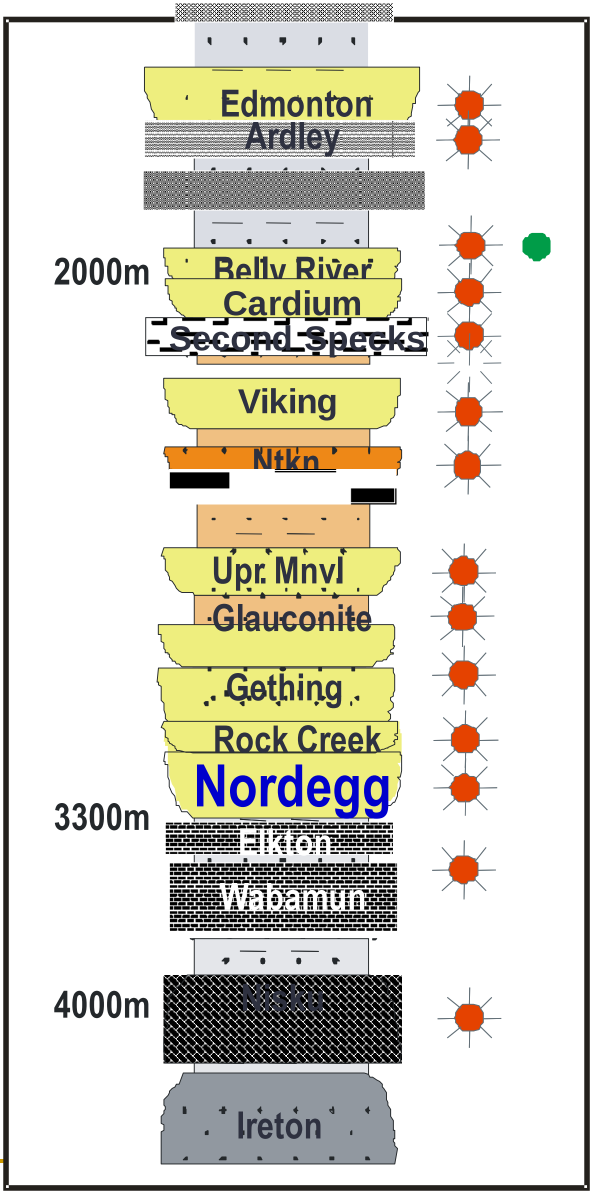
Now let us look at the economic impact

New wells drilled

West Central Alberta

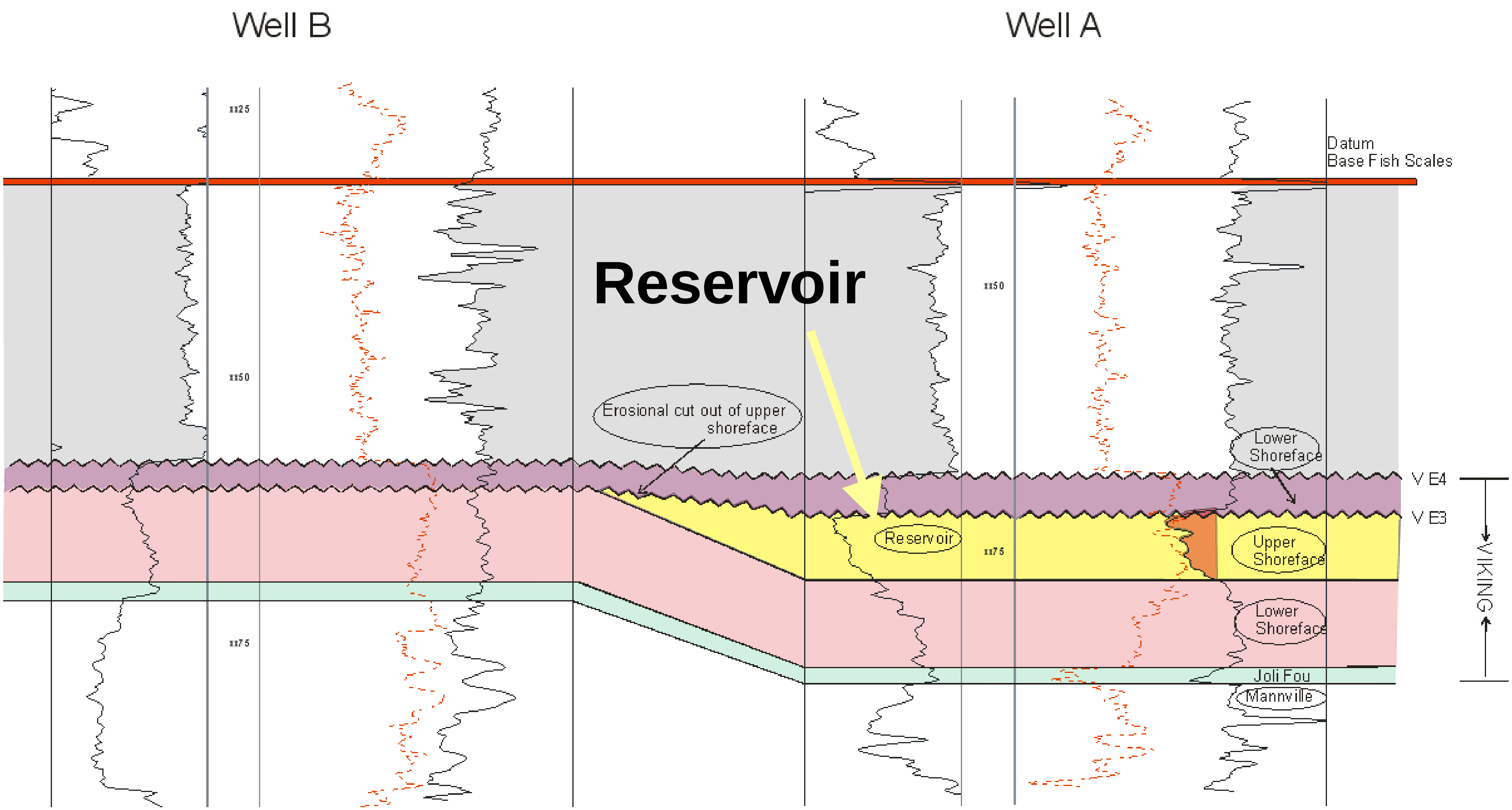
Deep basin





The area is structured and many zones are gas charged

The Viking is erosionally preserved



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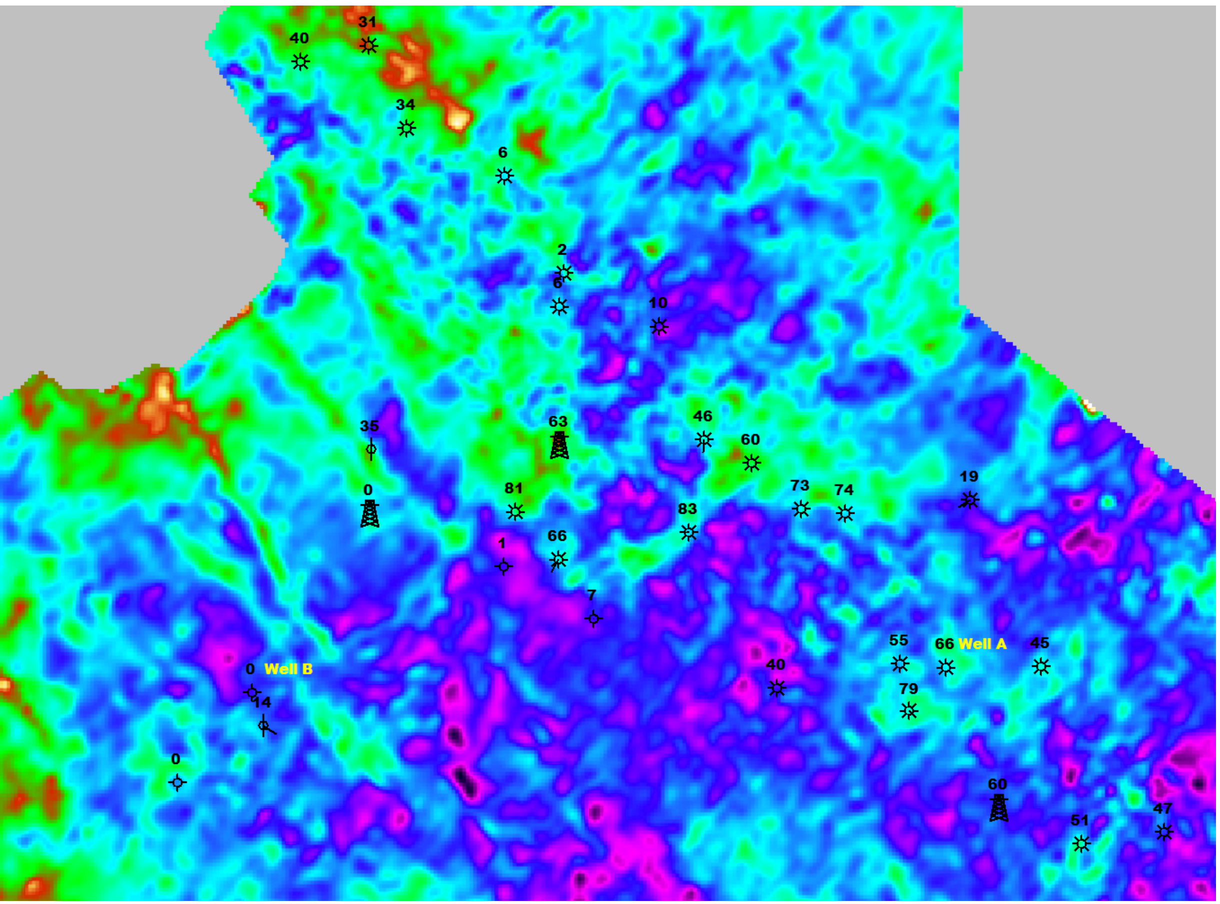
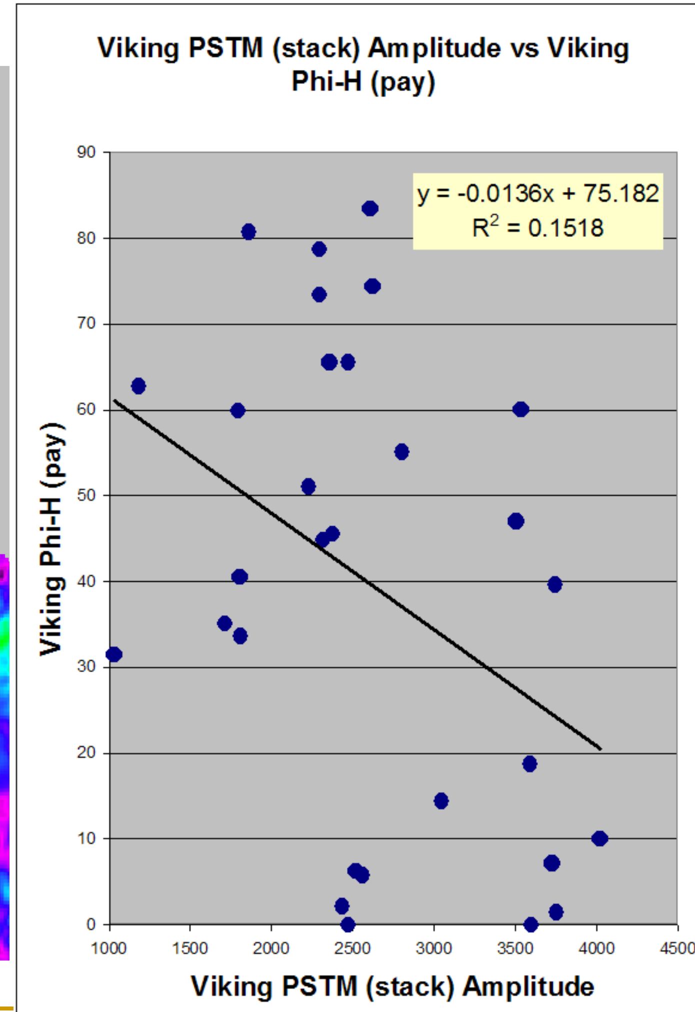
Old method: stack amplitudes





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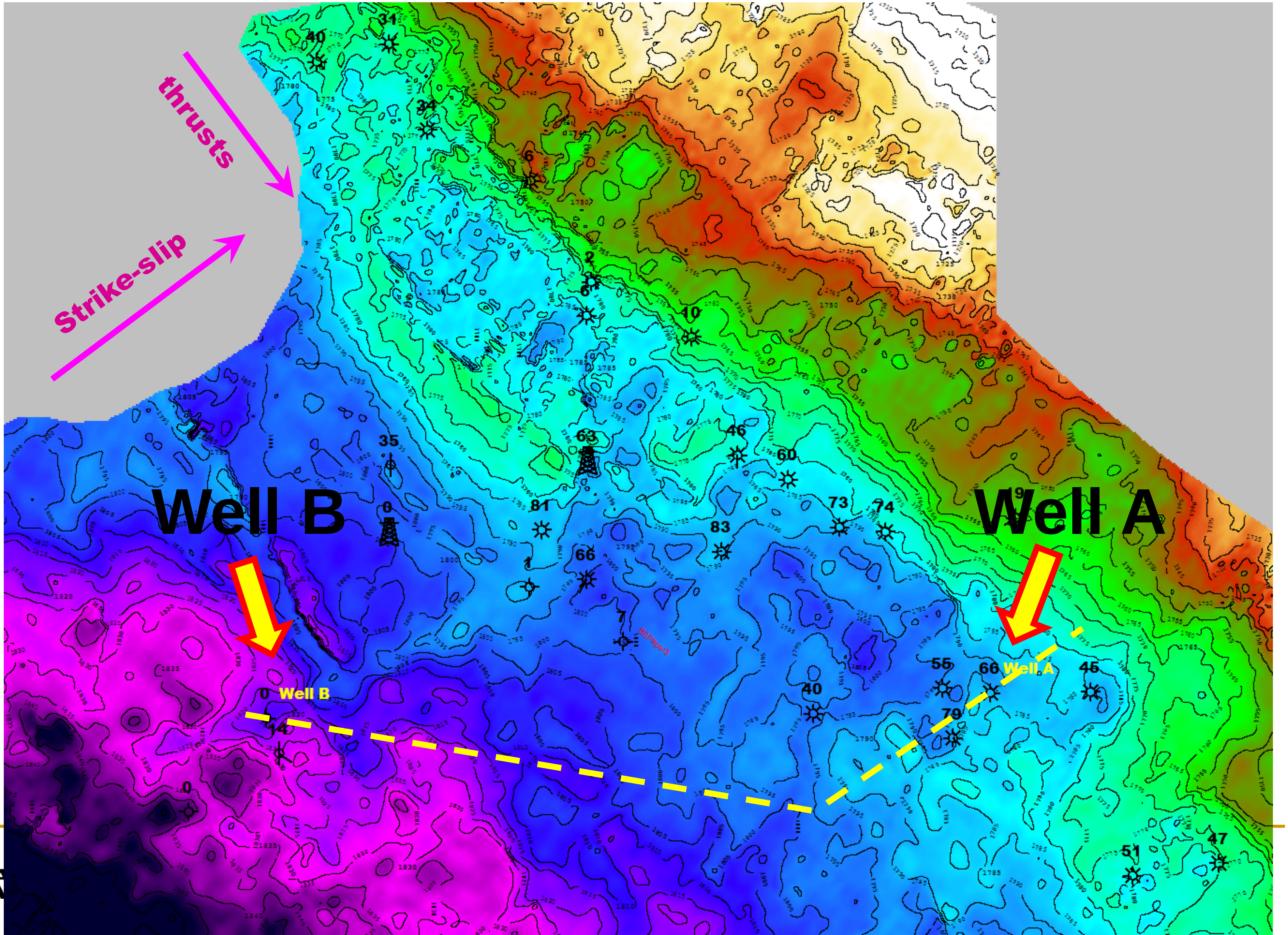
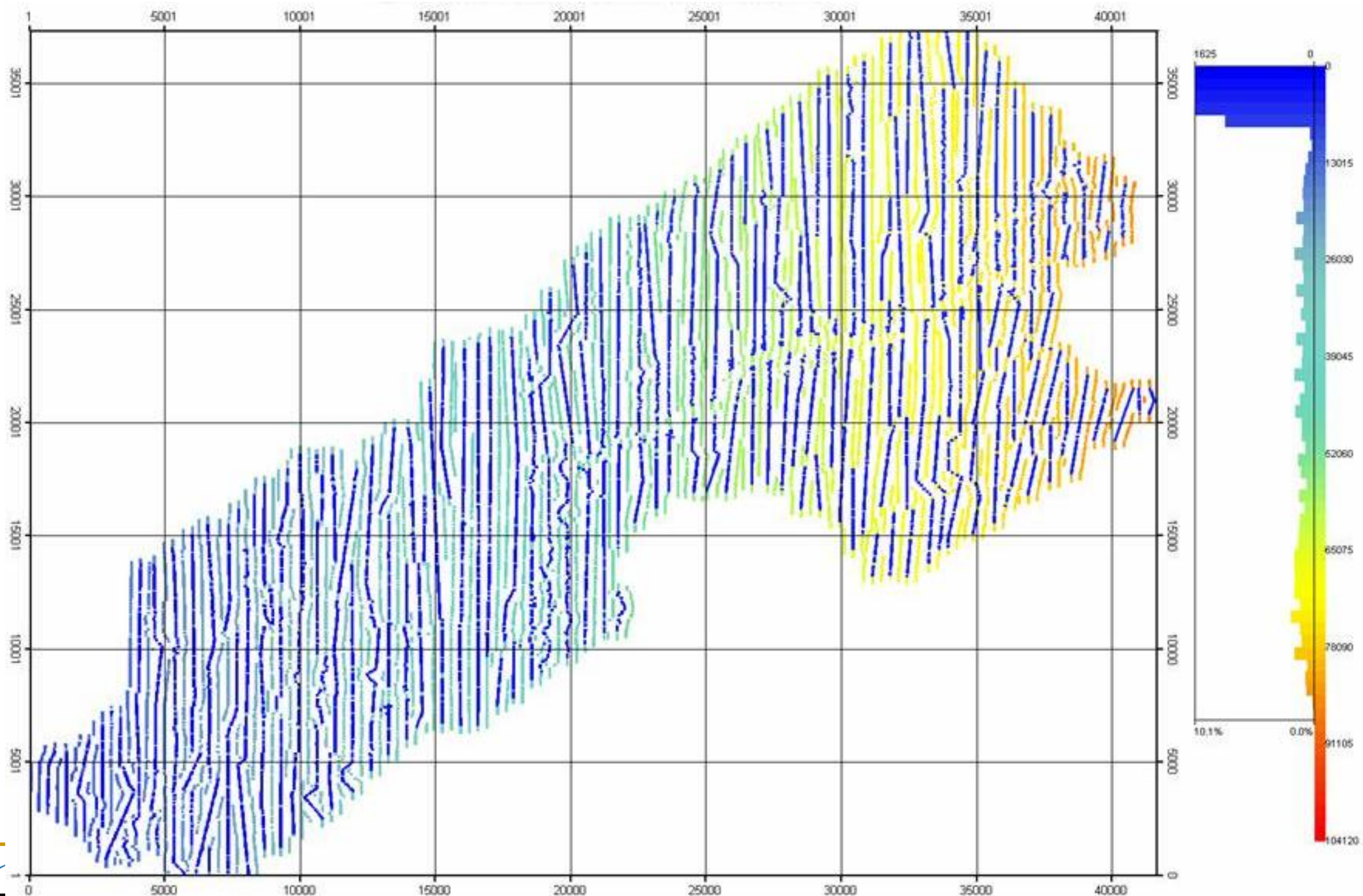
Use AVO to do better

The Viking is structured



Source line map after interpolation



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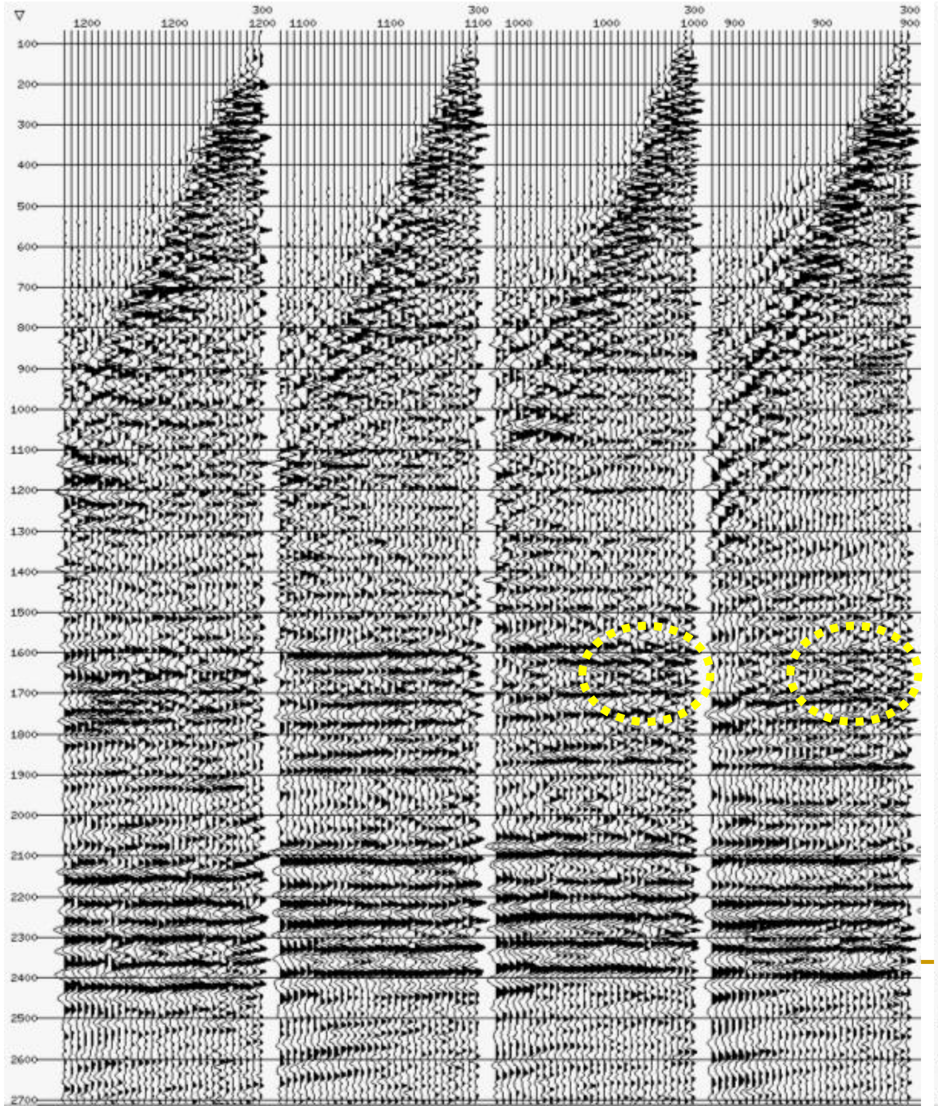
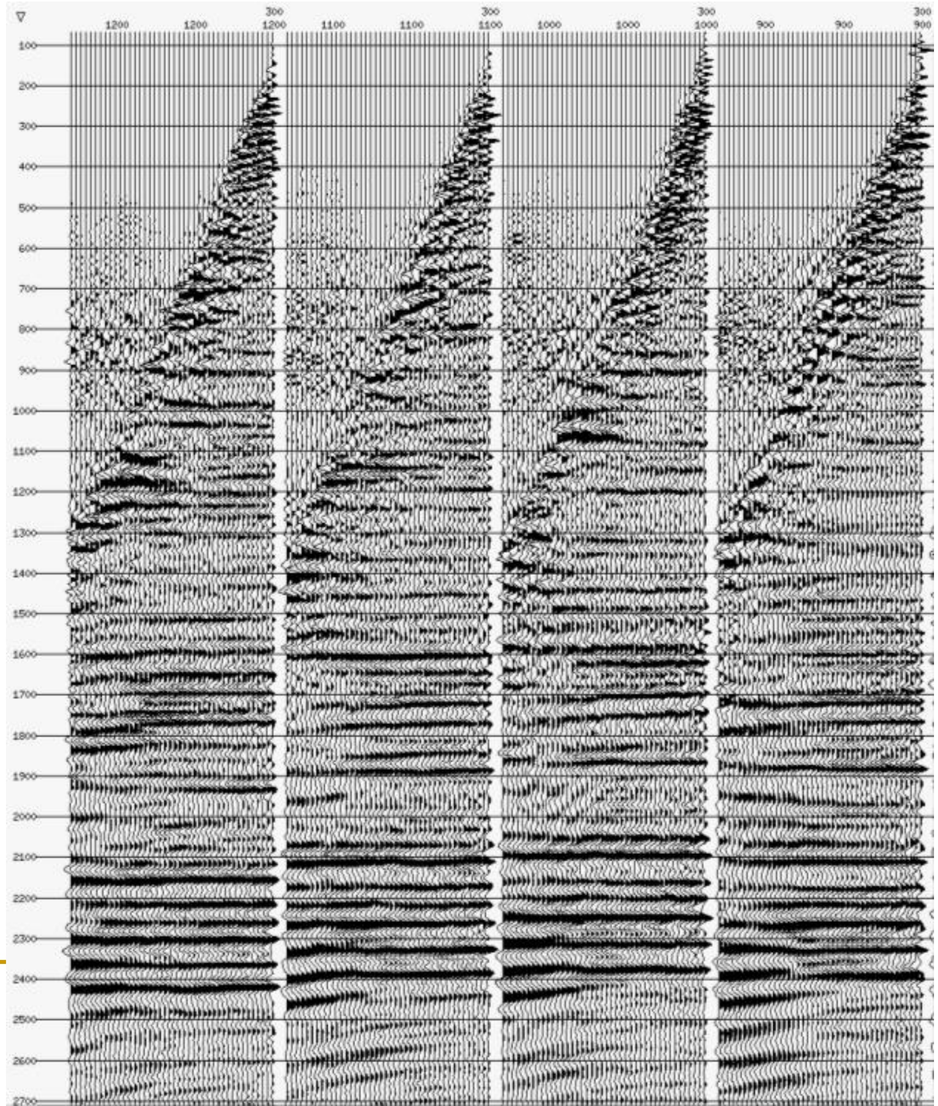
PSTM Gathers

Key observation

PSTM

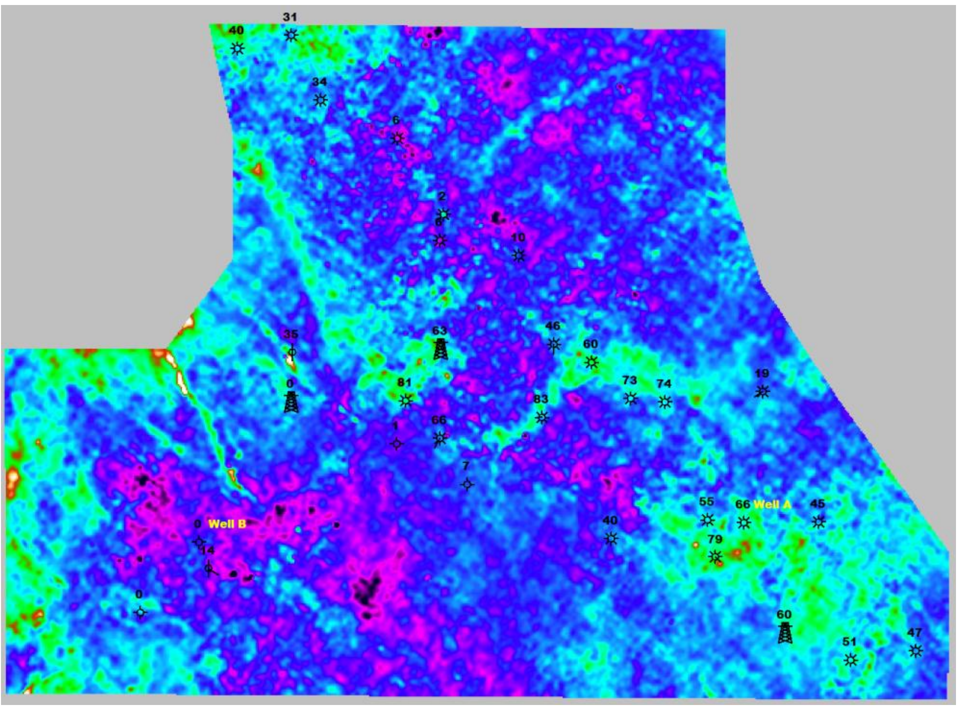


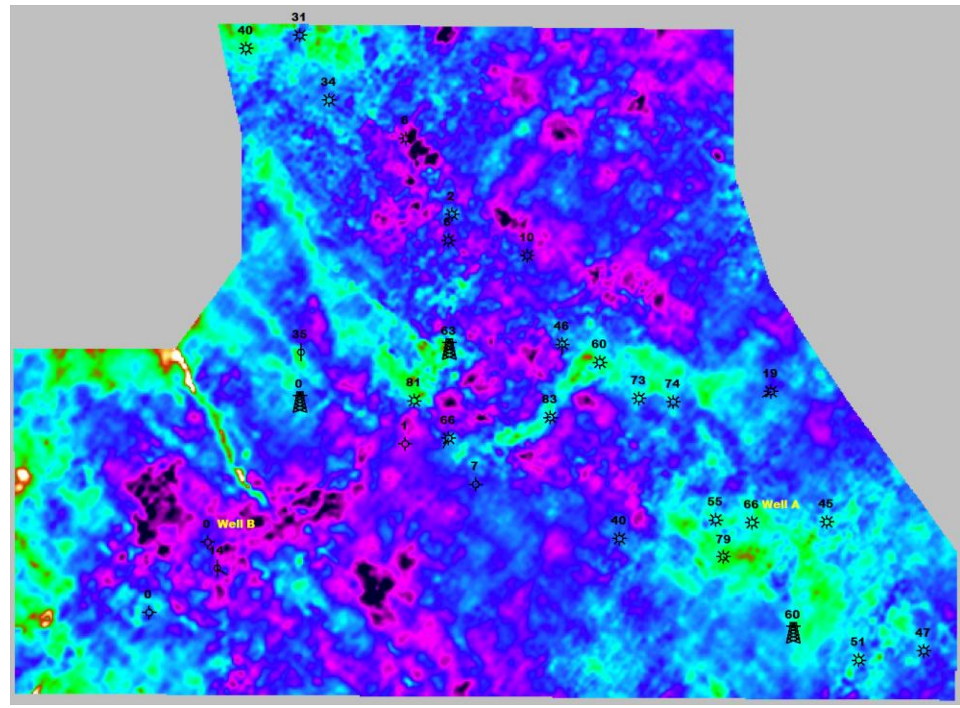
Interpolation + PSTM



Map Comparisons (Rp Rs ratio)

PSTM AVO vs **Interpolation + PSTM & AVO**





The interpolated version is cleaner

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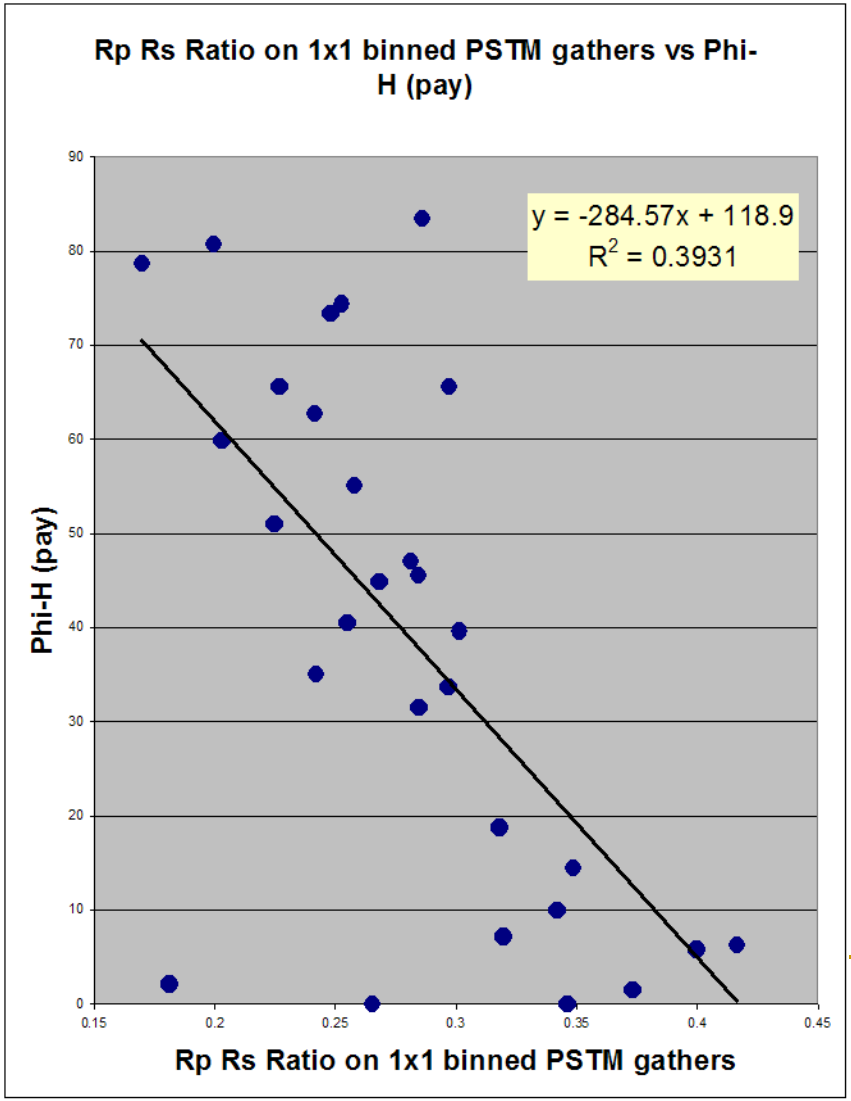
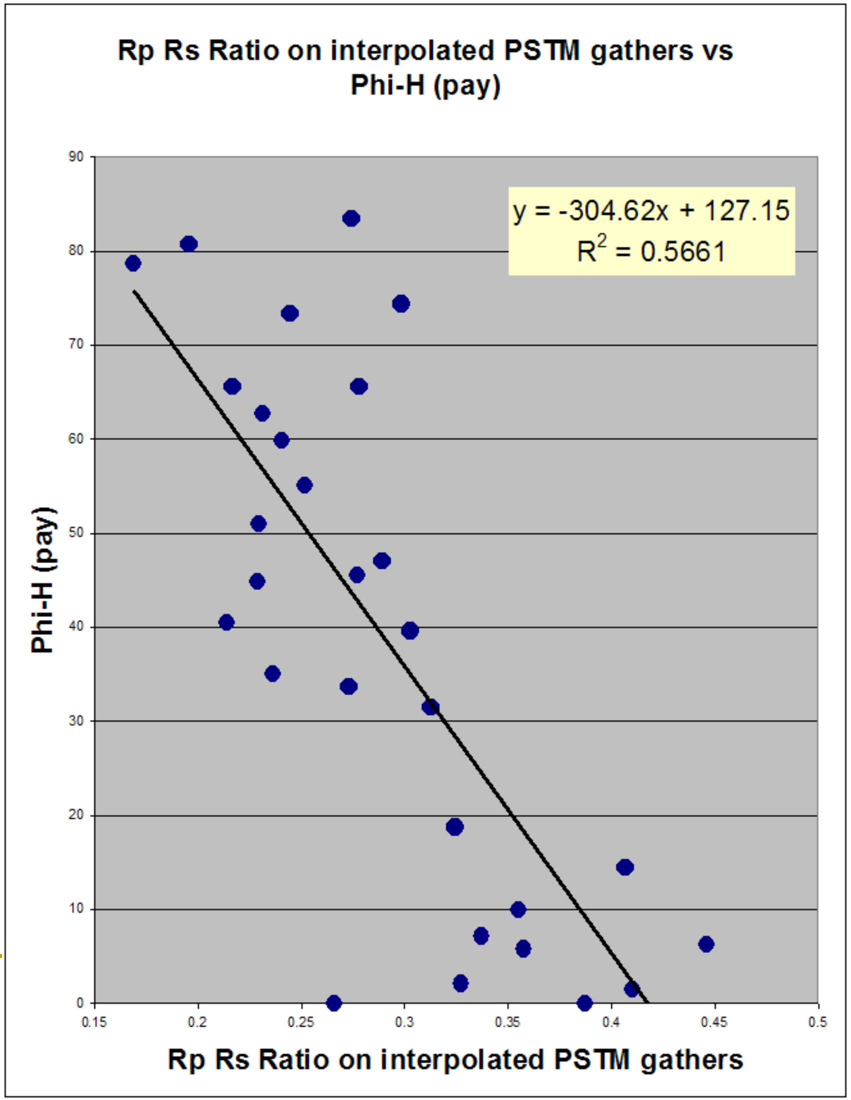
Correlation *results: PSTM comparisons*

PSTM AVO

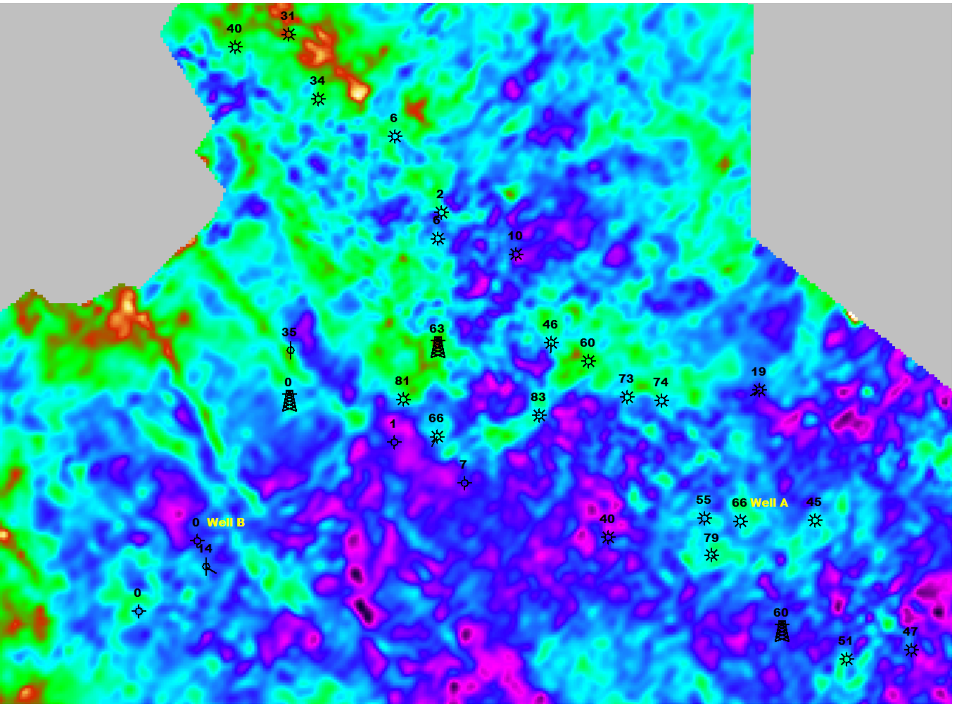


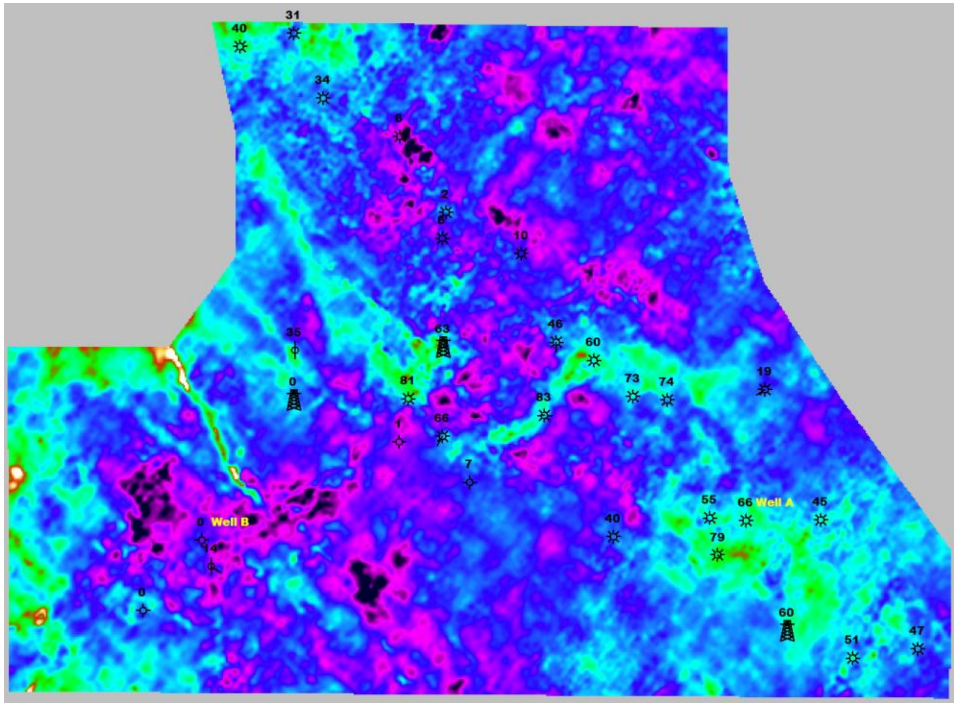
Interpolation + PSTM & AVO



Map Comparisons (stack vs AVO)

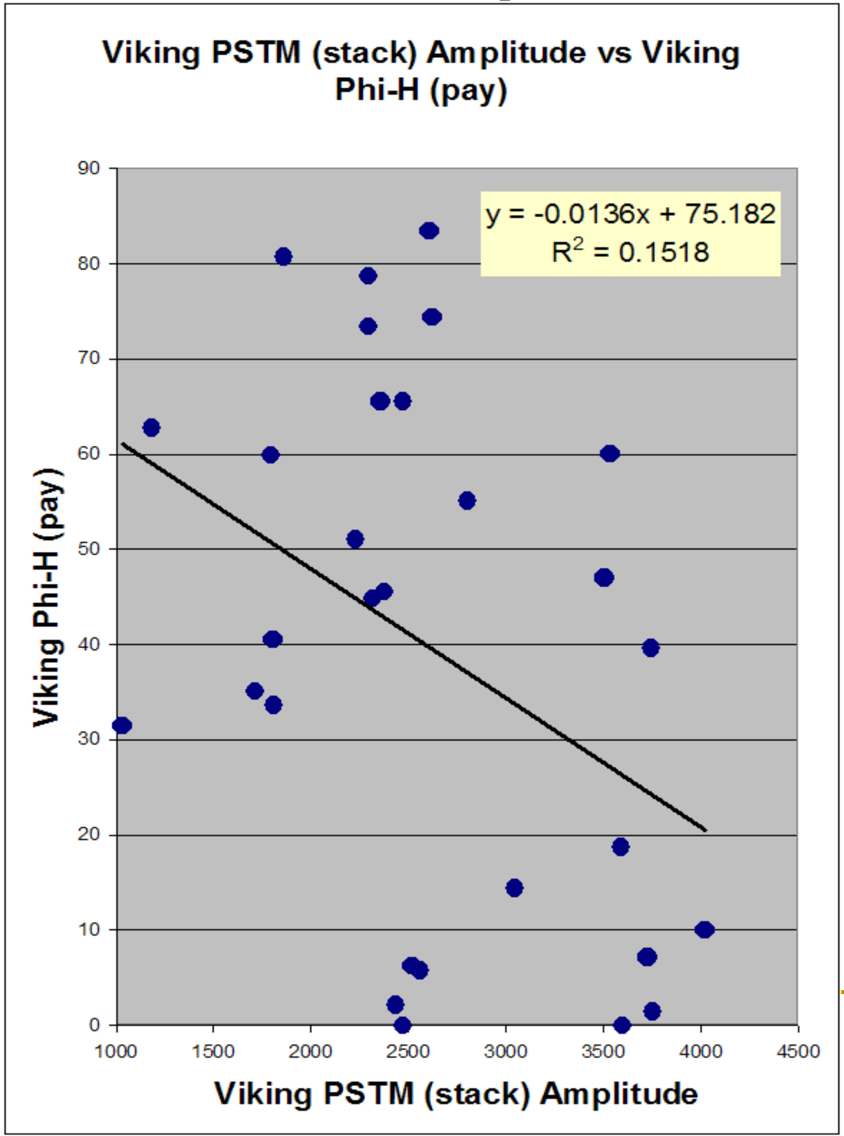
Stack Amplitude vs Interpolated AVO

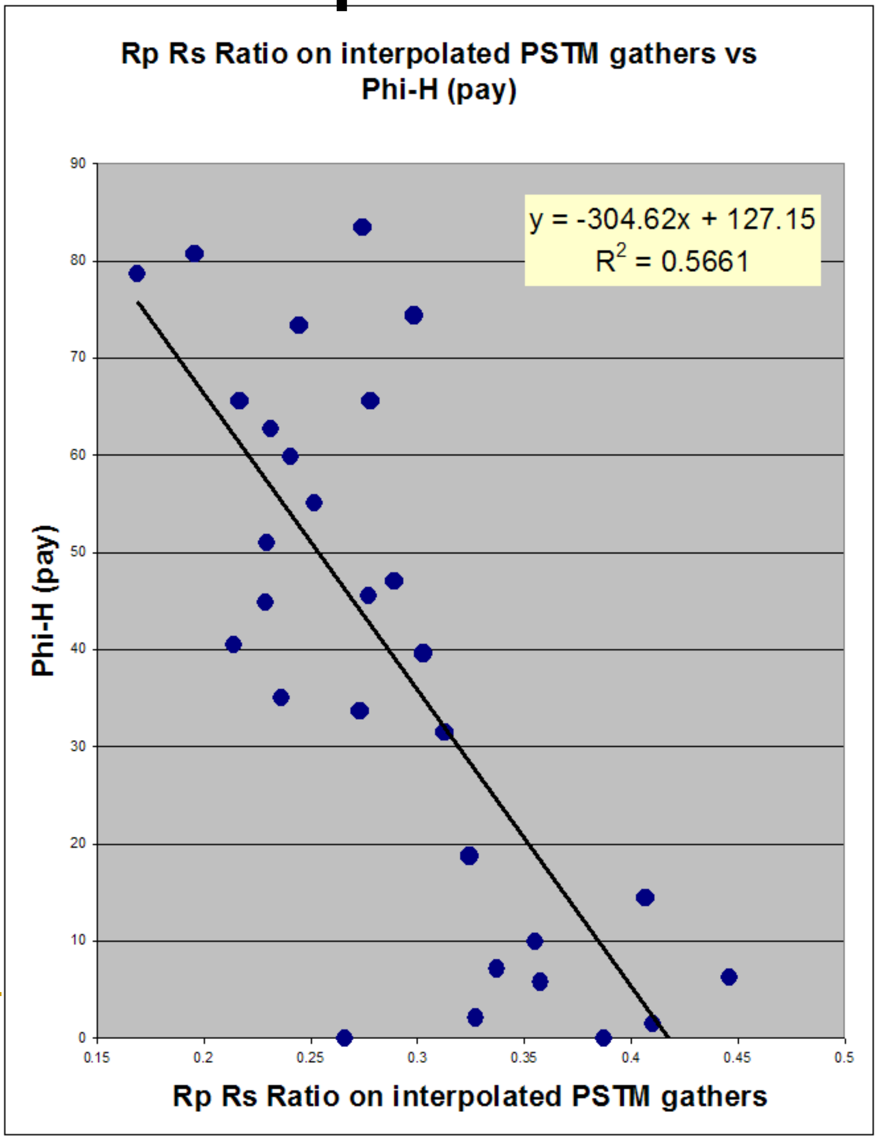




Correlation results: Stack vs AVO

Stack Amplitude vs Interpolated AVO



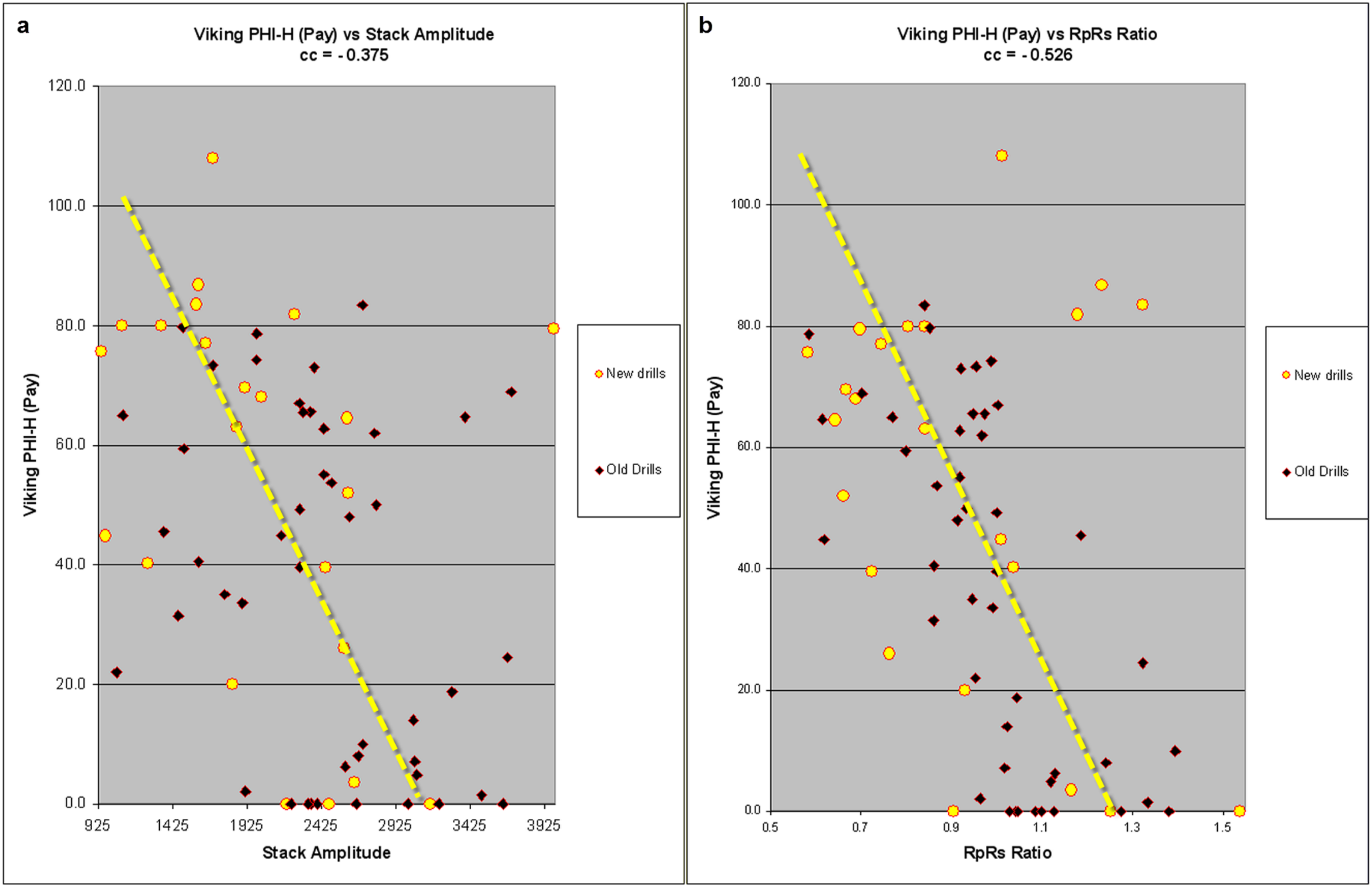


How do we determine value?

- 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
- Rate and reserves model to Phi-h
- Average Phi-h for each class
- Model economics for each class

Economic model

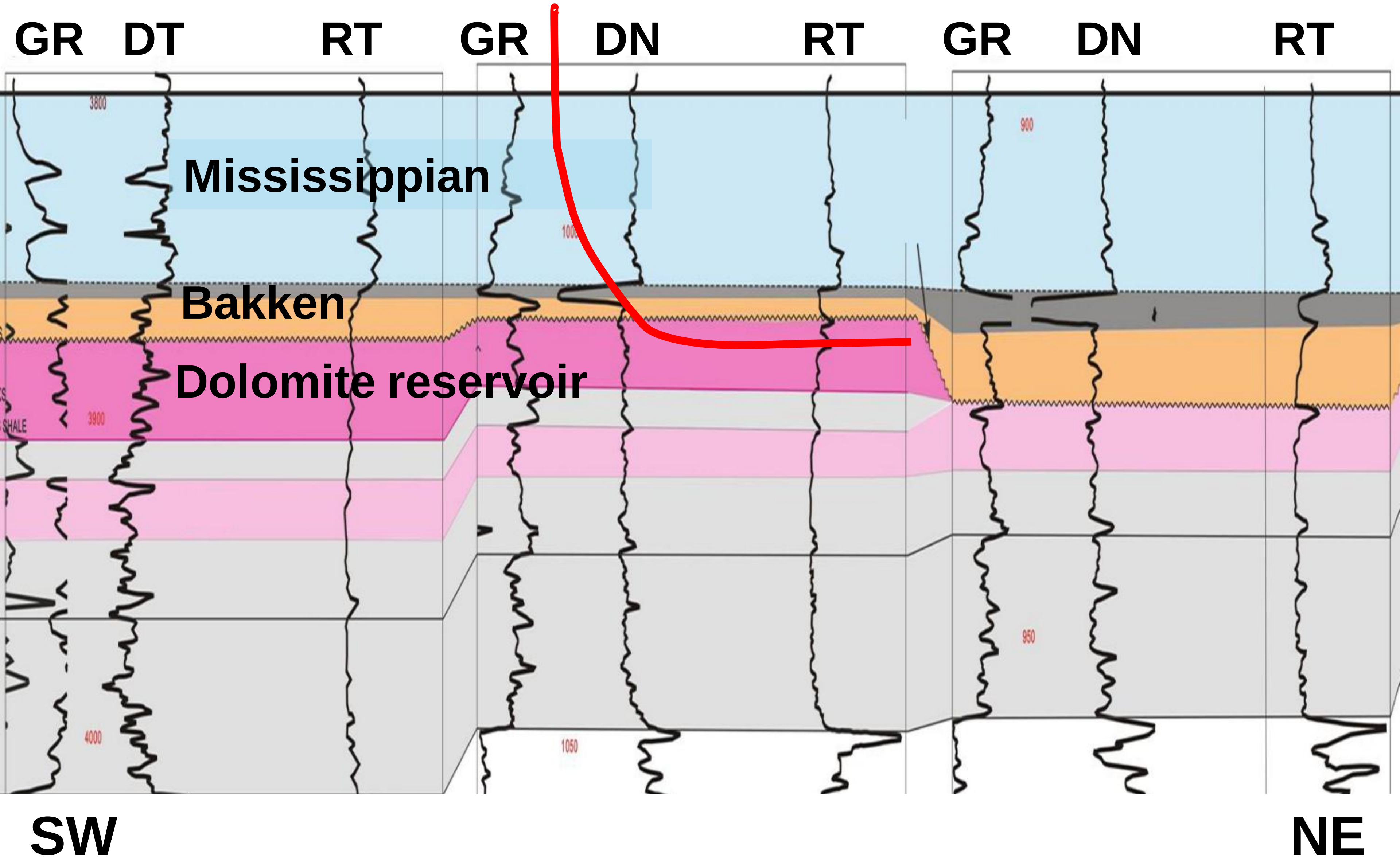
Economic models	Count	Average PHI-H	% Diff	3 Month IP Prediction (mcf/d)	EUR Prediction (mmcf)	NPV 10 high price deck ($M)	IRR high price deck (%)	Pay Out (yrs) high price deck	NPV 10 low price deck ($M)	IRR low price deck (%)	Pay Out (yrs) low price deck
All Wells	69	39.8	-20%	859	1535	$ 3,125	25	2.6	$ 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

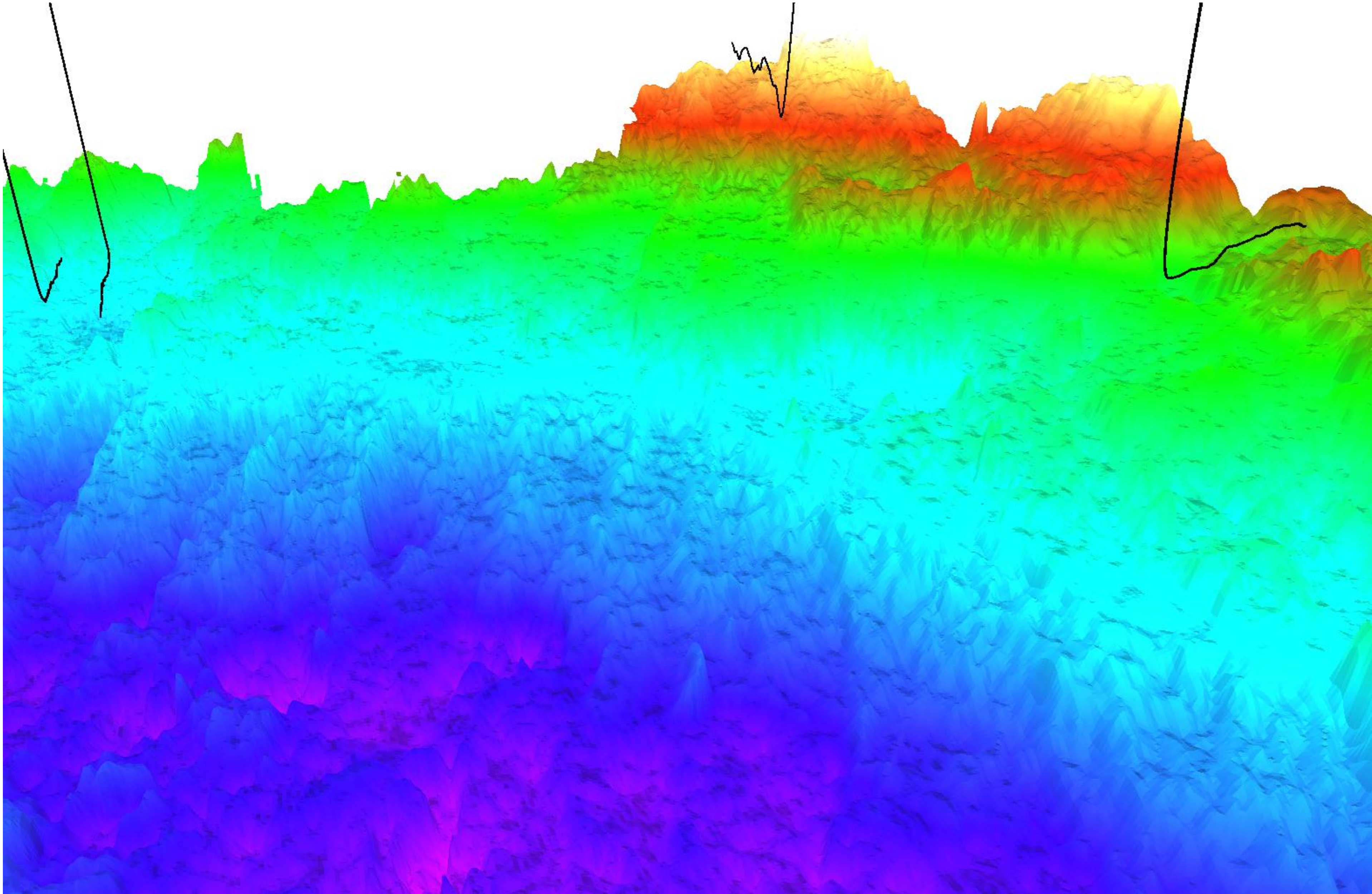
~ 1 million dollars NPV per well

Case study II: steering horizontals
and improved production

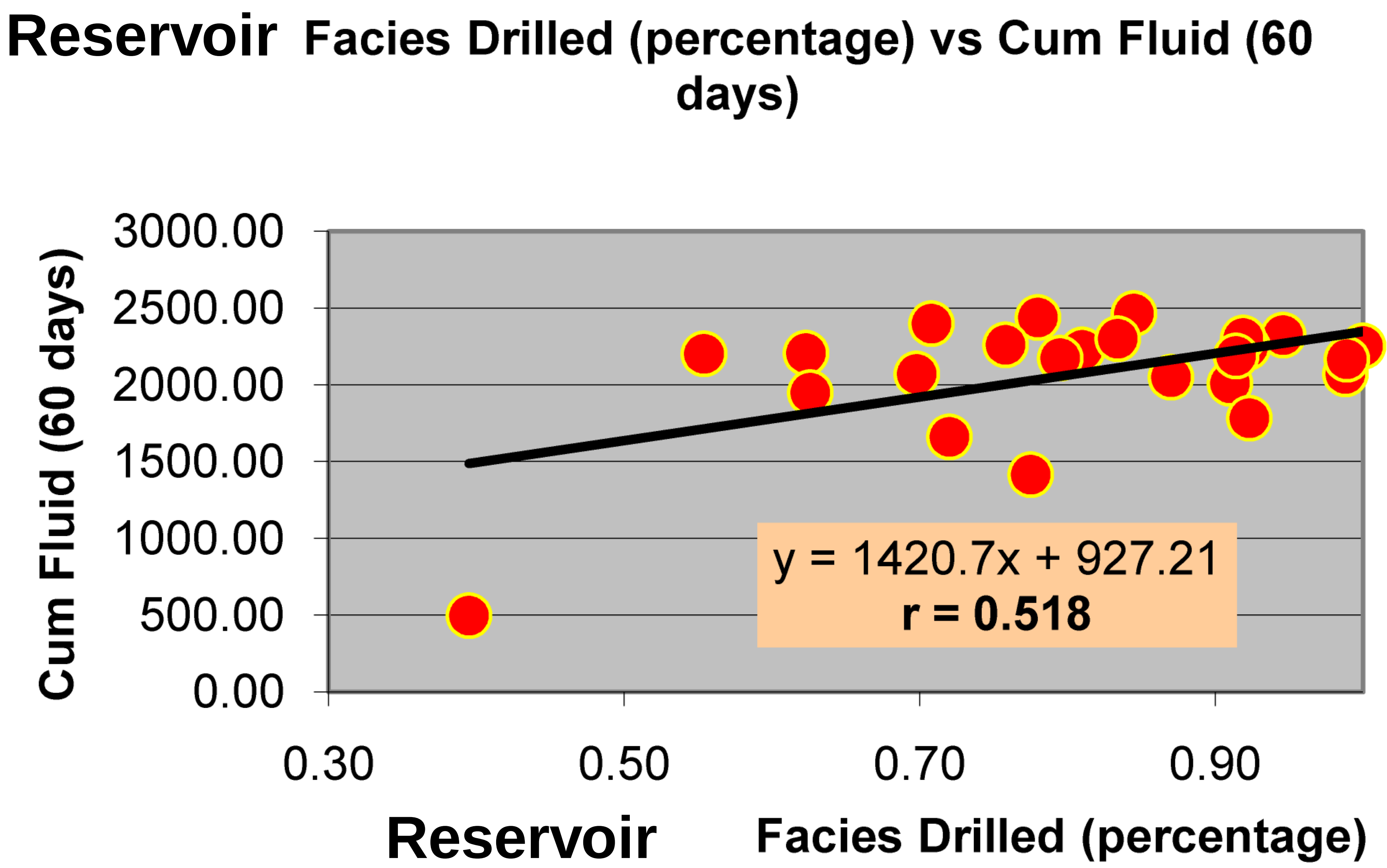
Devonian oil Sask



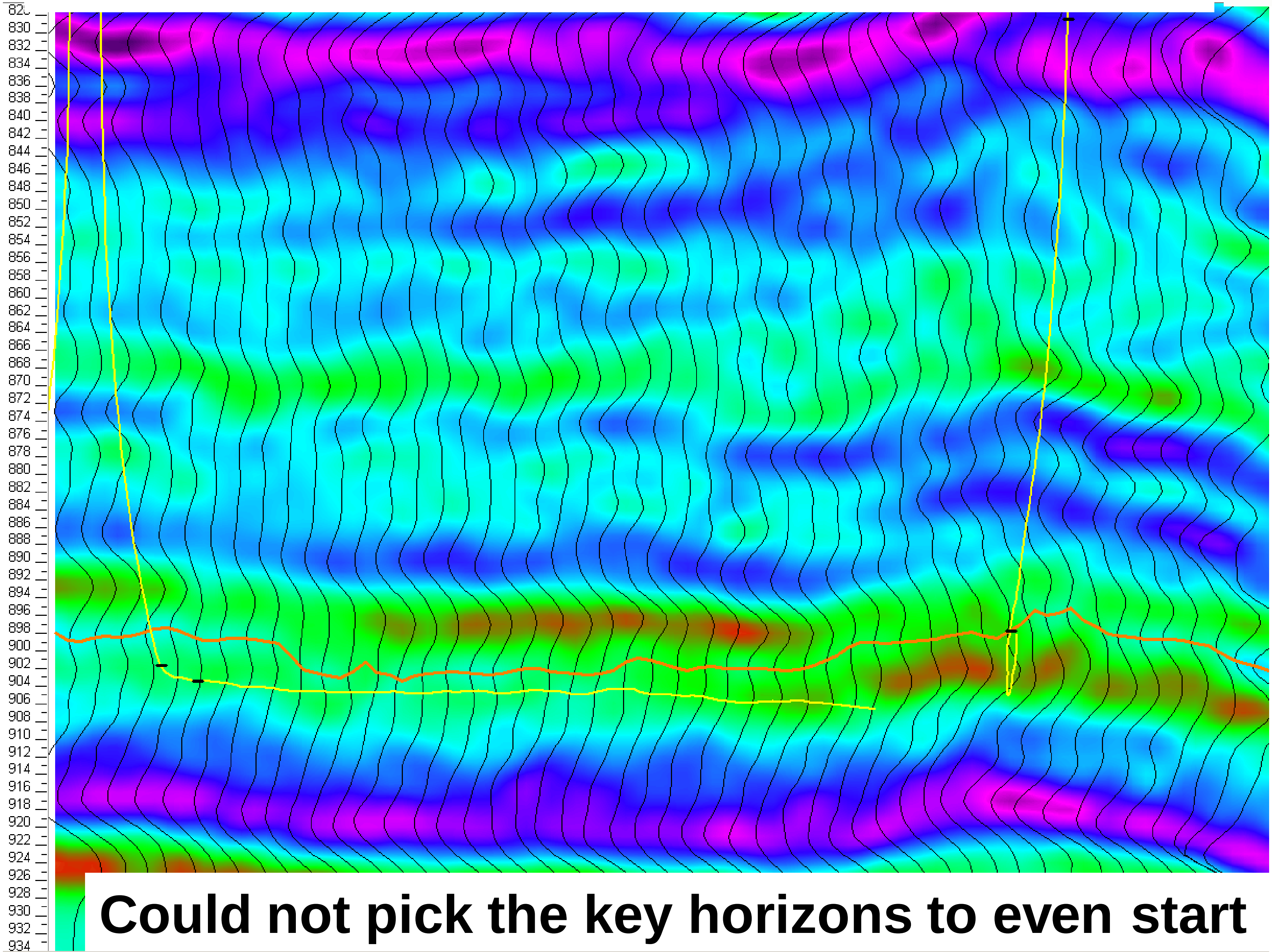
Devonian oil play



Fluid rate related to steering

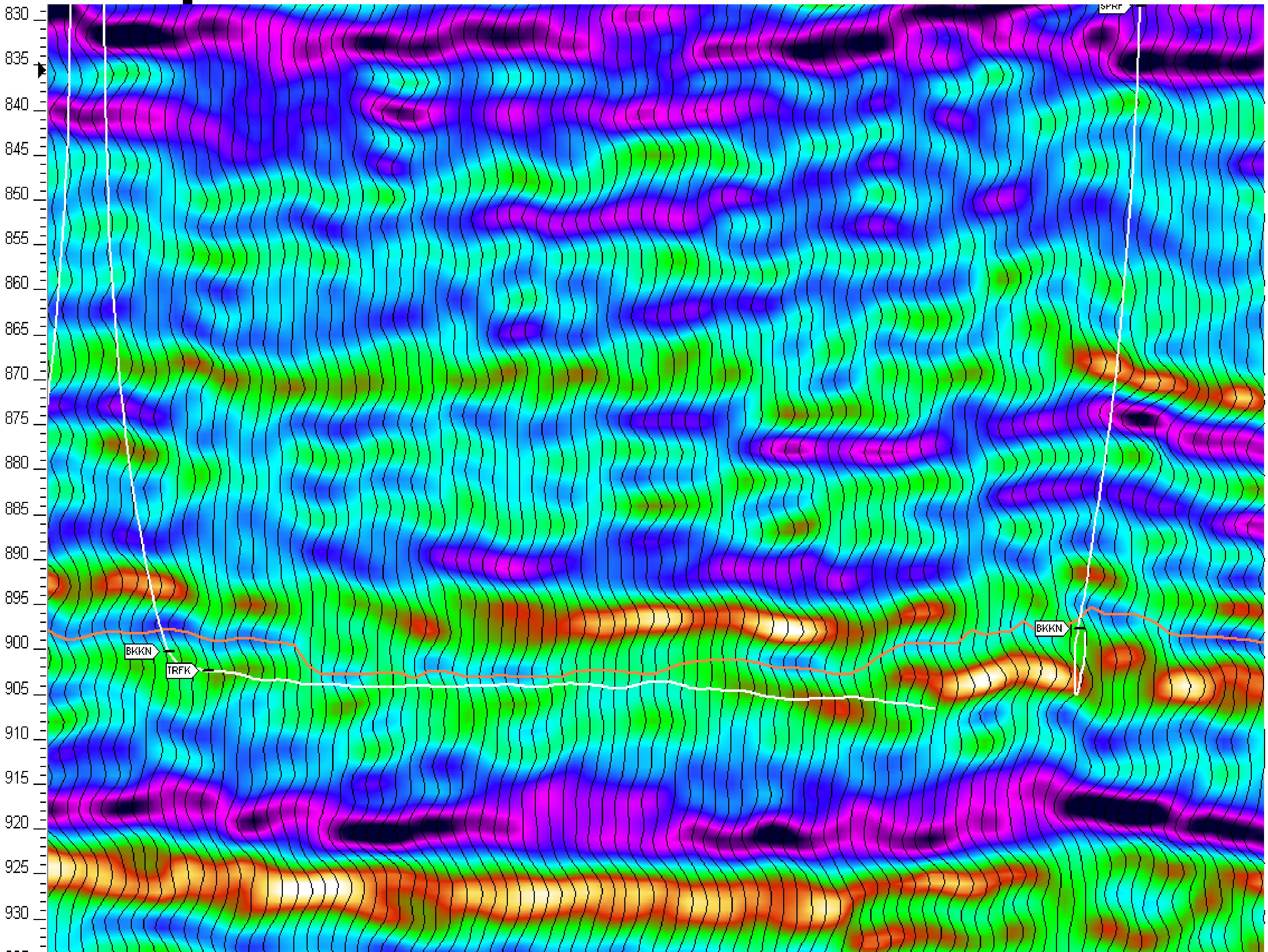


Old method could not use seismic

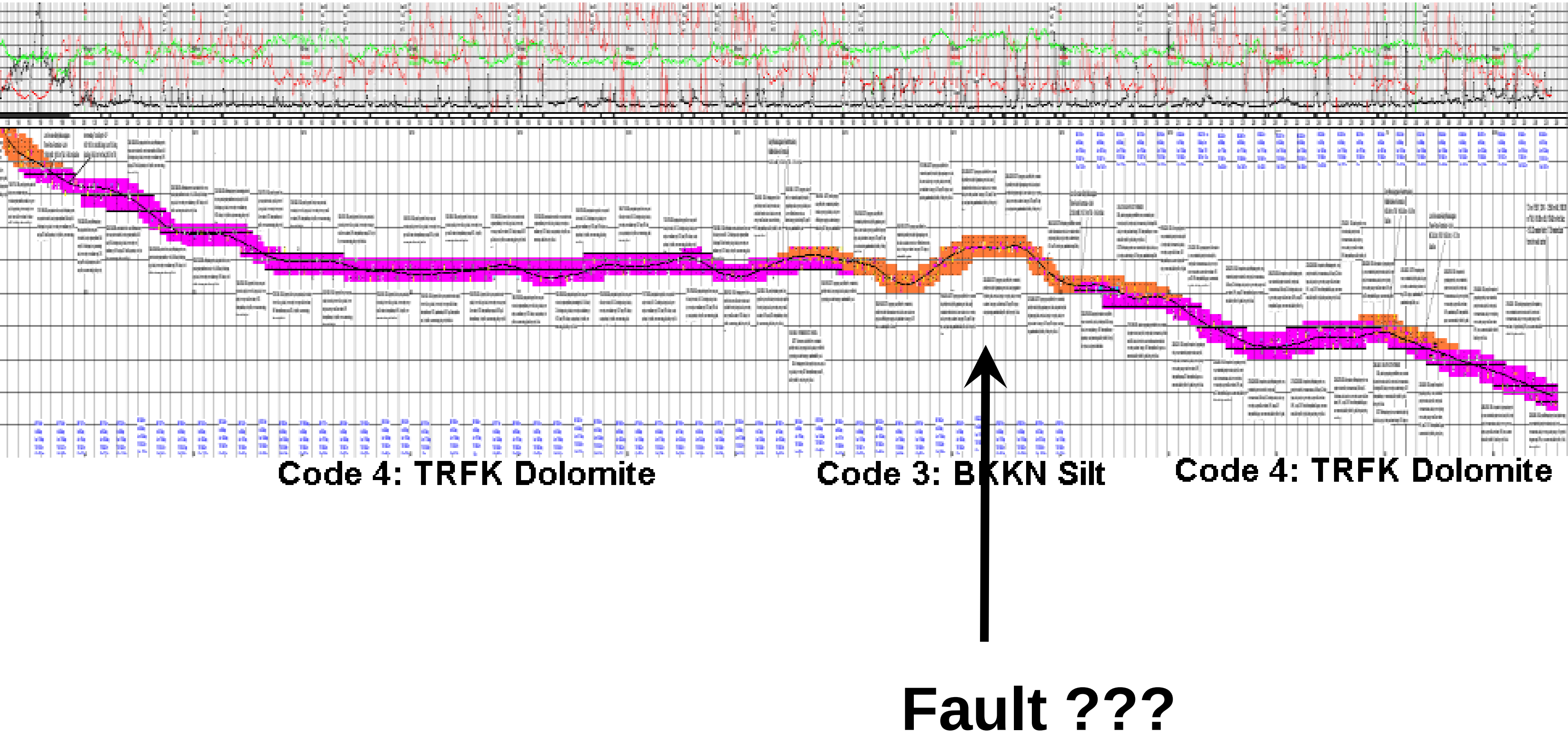


Could not pick the key horizons to even start

Spectral balance cannot fix it



Demon haunted world



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**

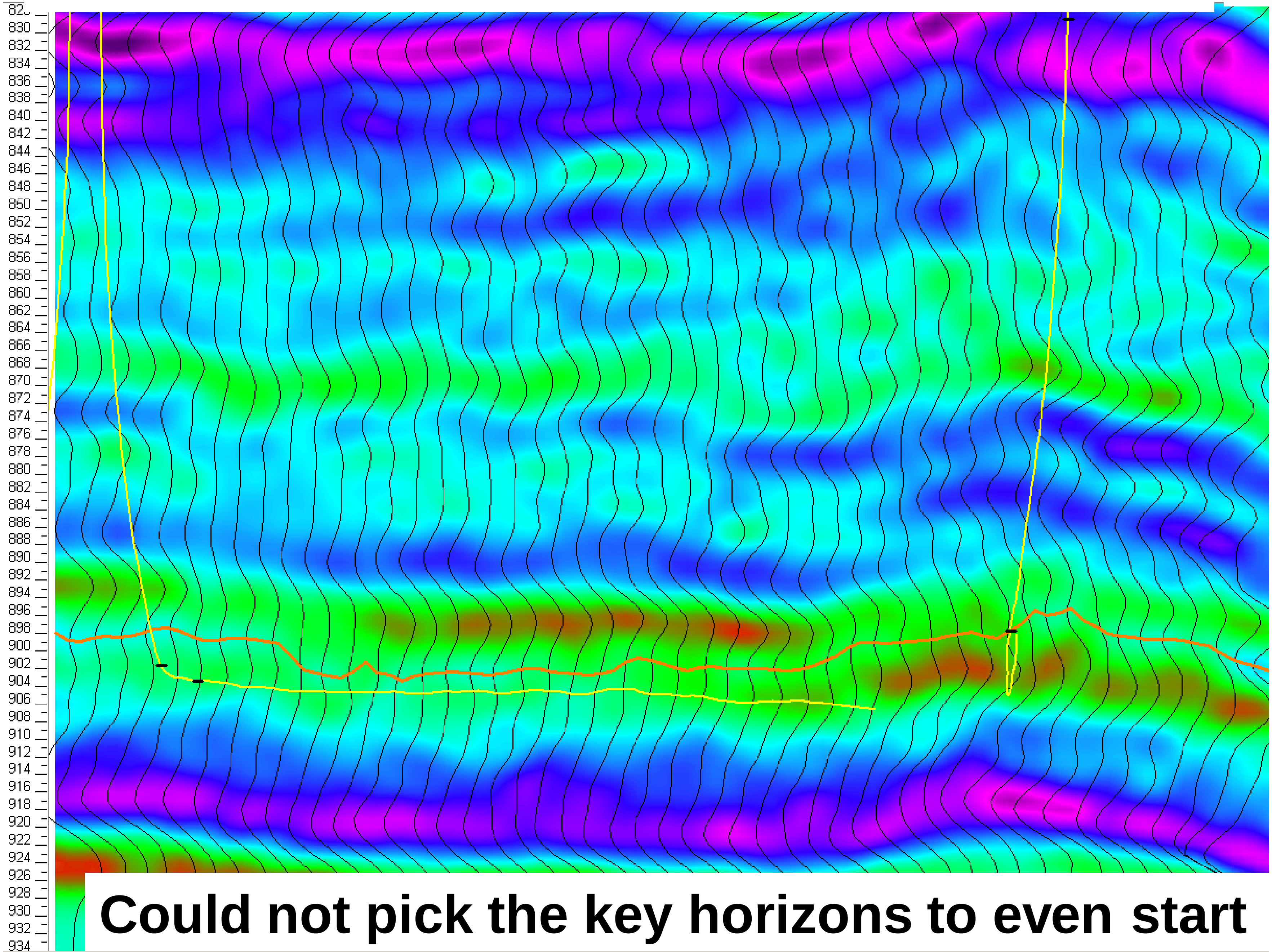
Reprocessing

Goal: high frequencies with veracity

S/N ⟷ Deconvolution

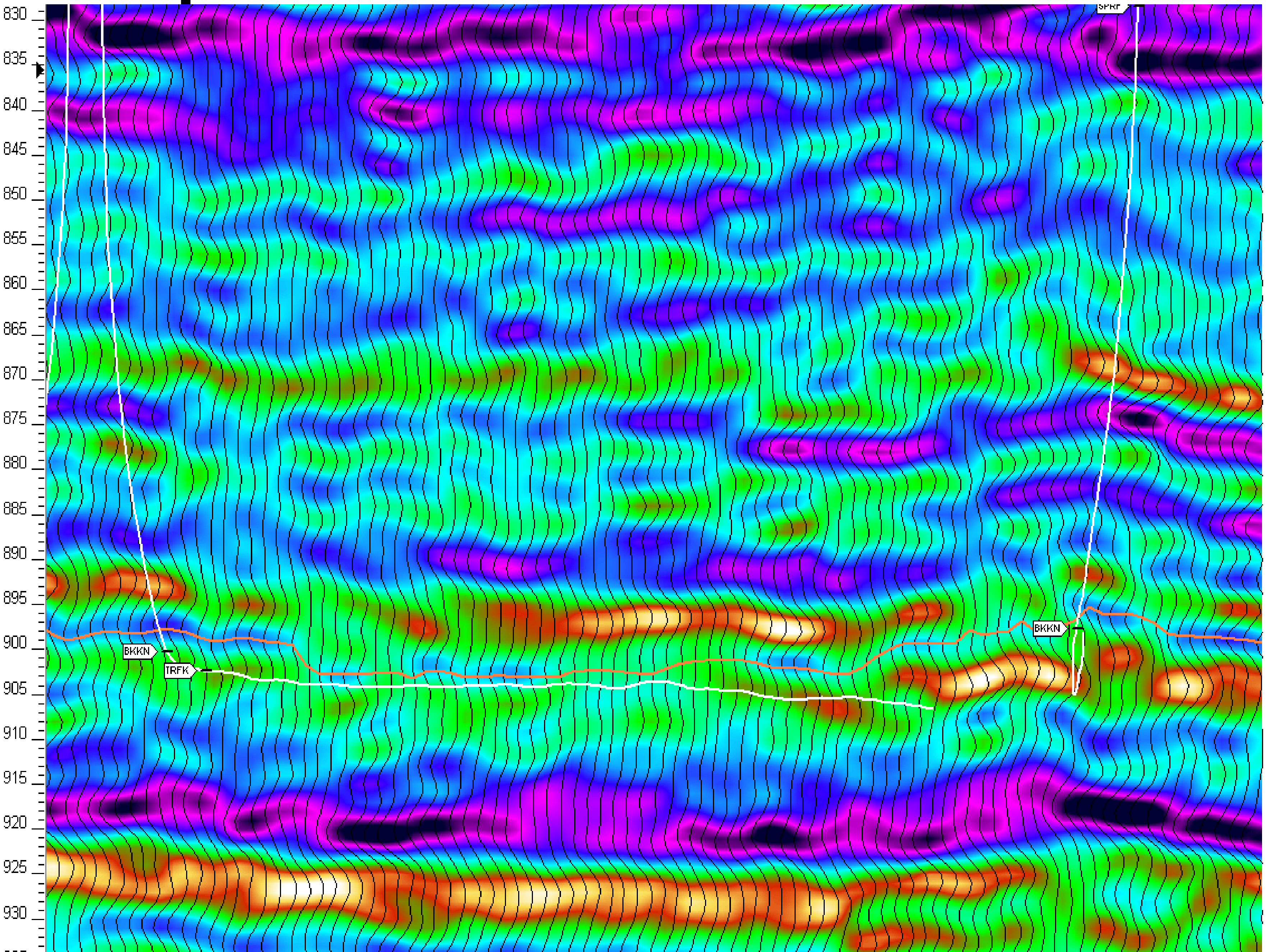
- **Hybrid surface consistent deconvolution**
- **Interpolation**
- **Spectral balance**
- **Horizon consistent velocities**

Old method could not use seismic

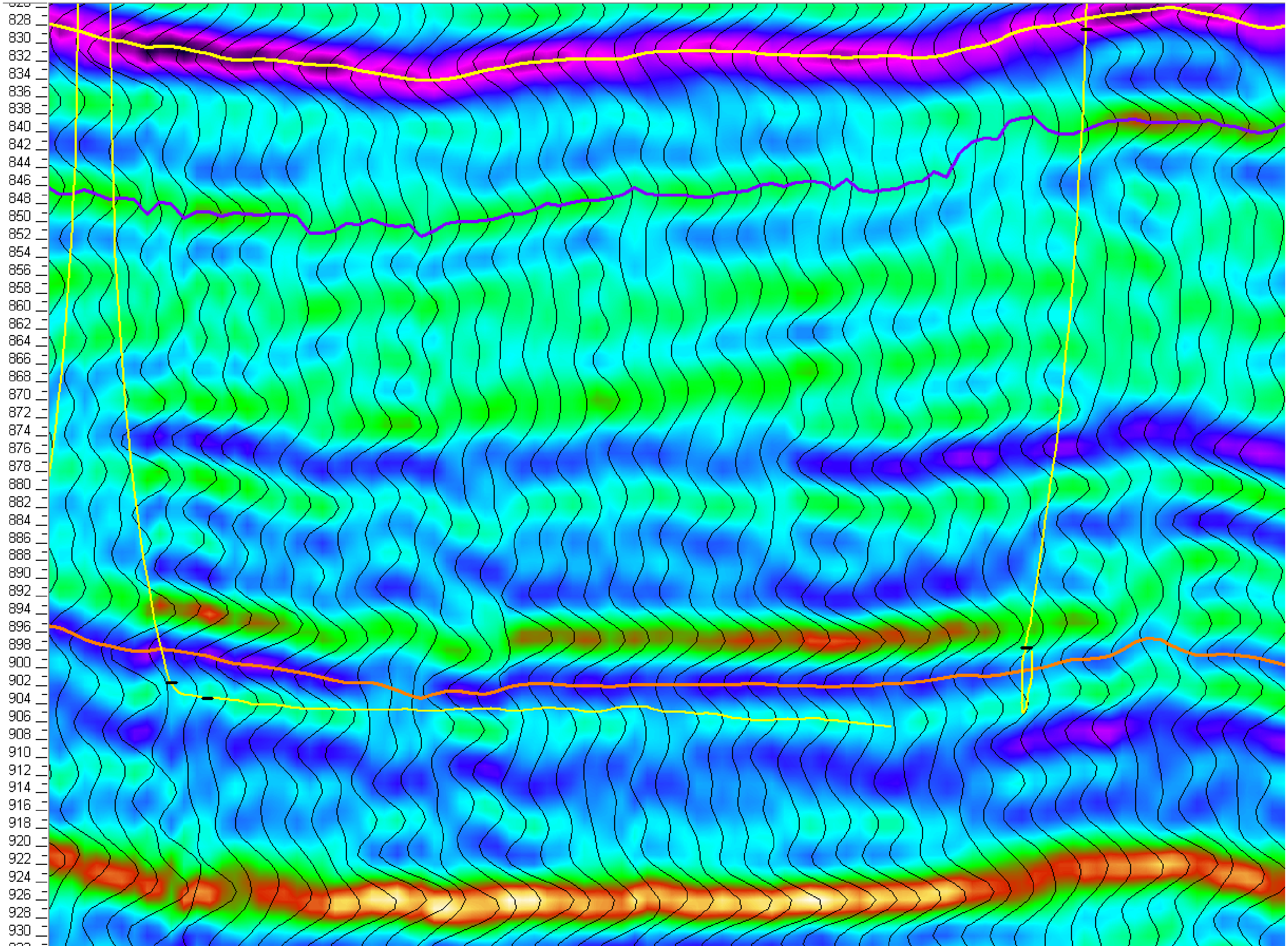


Could not pick the key horizons to even start

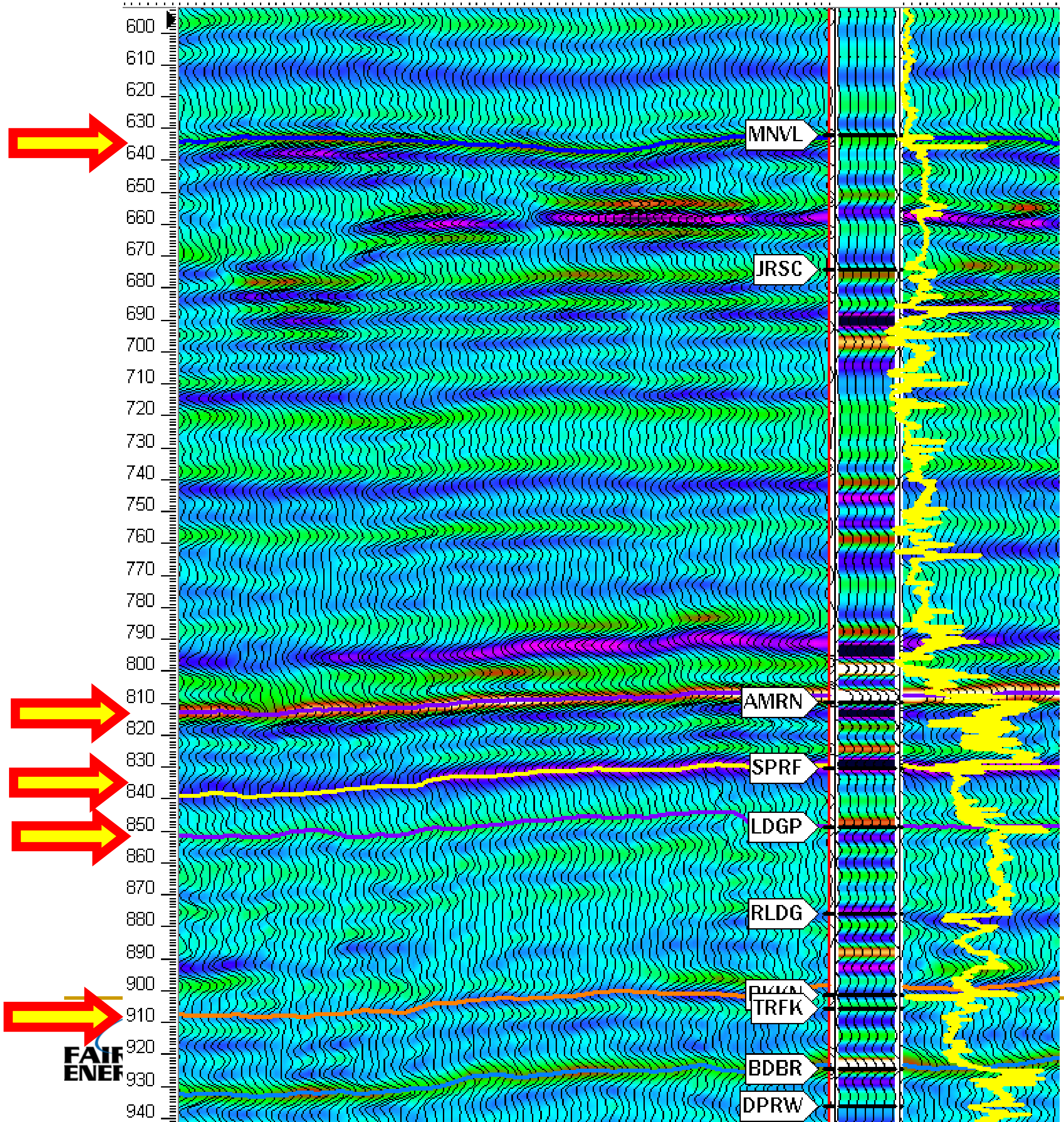
Spectral balance cannot fix it



New data: can pick better



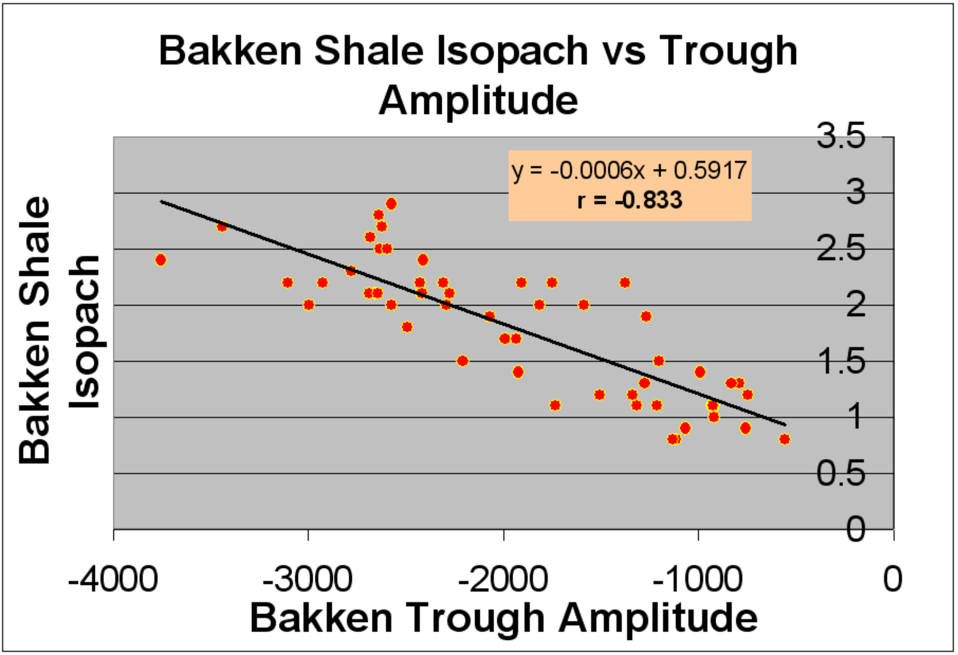
Depth map to the Bakken

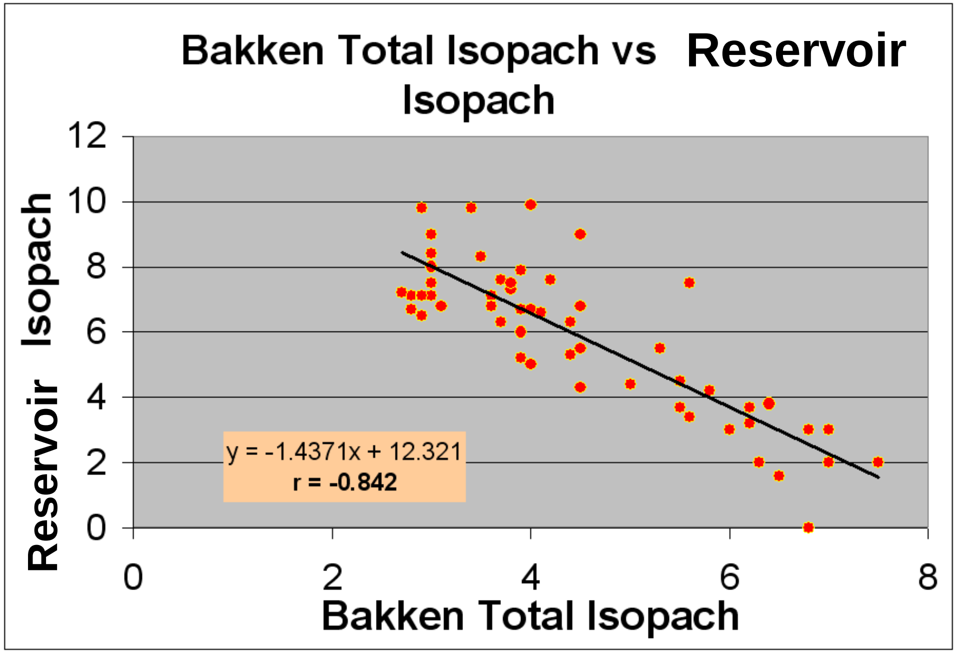


Start:

A depth map

Unlocking details beyond T-D





So our depth estimate involves the reservoir

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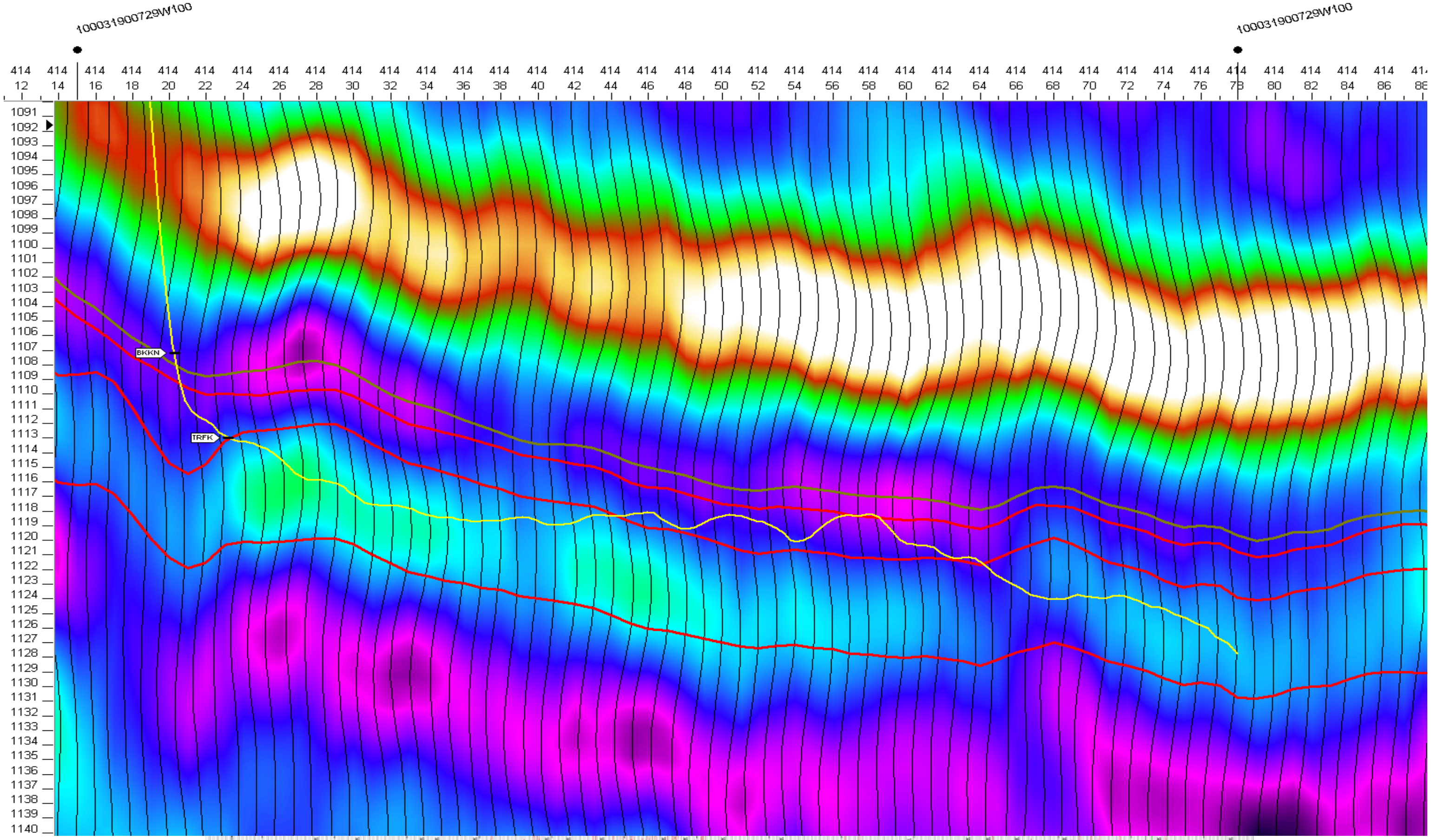
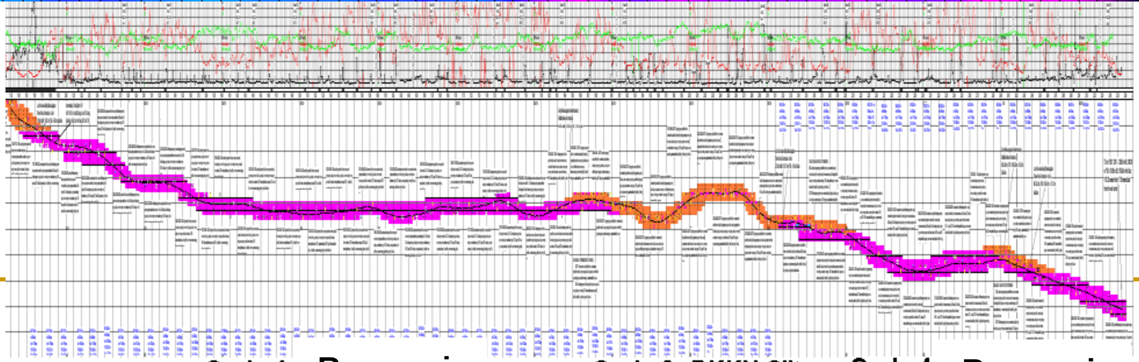
New data: no more mystery





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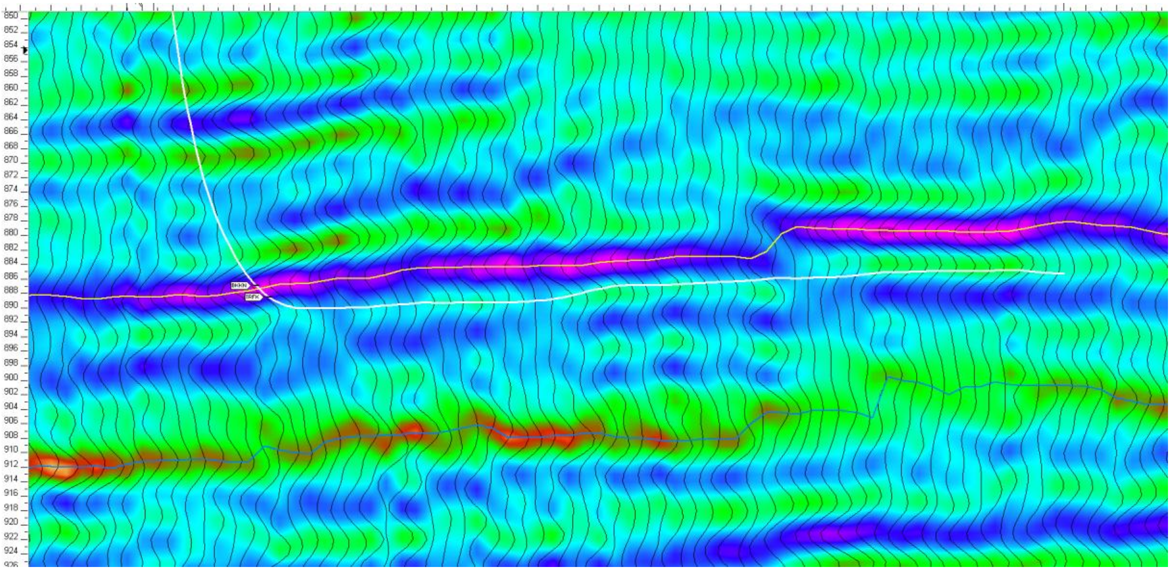
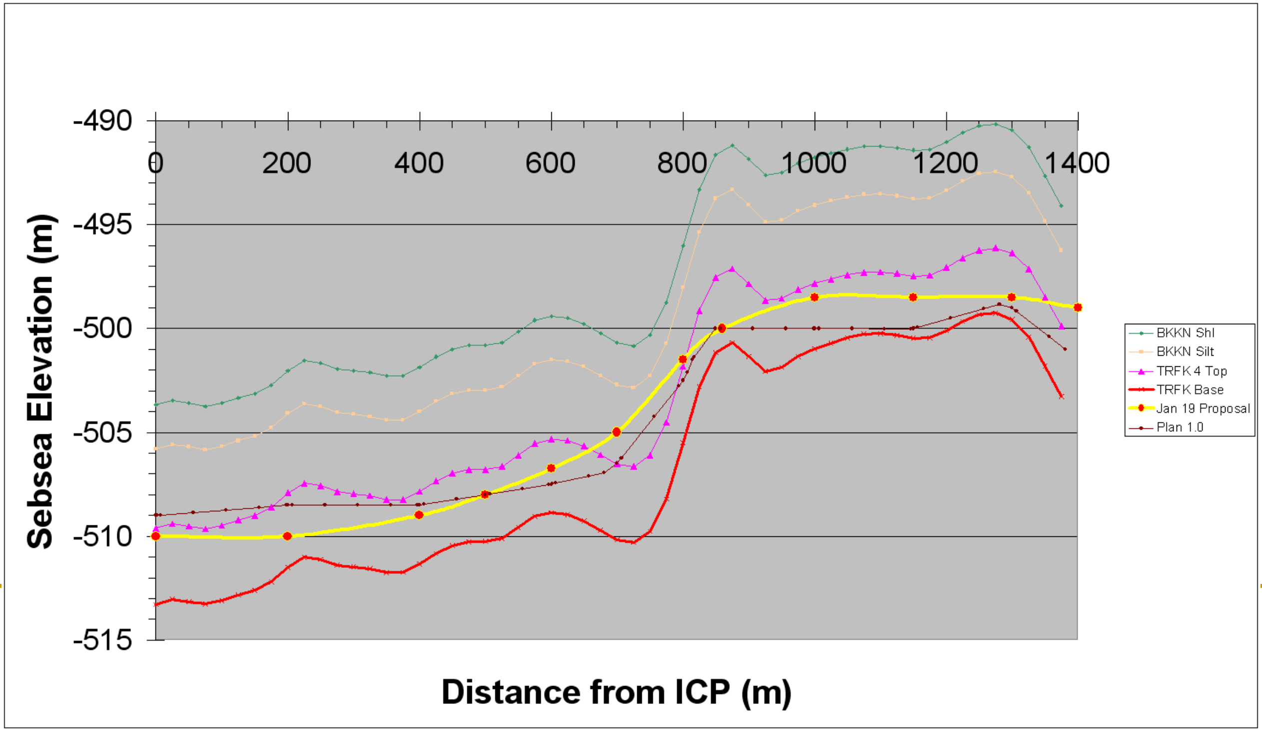
Seismic now the key to horizontals





96% in zone

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Comparative method

- **25 old horizontals**
- ***New program of 19 horizontals were drilled***

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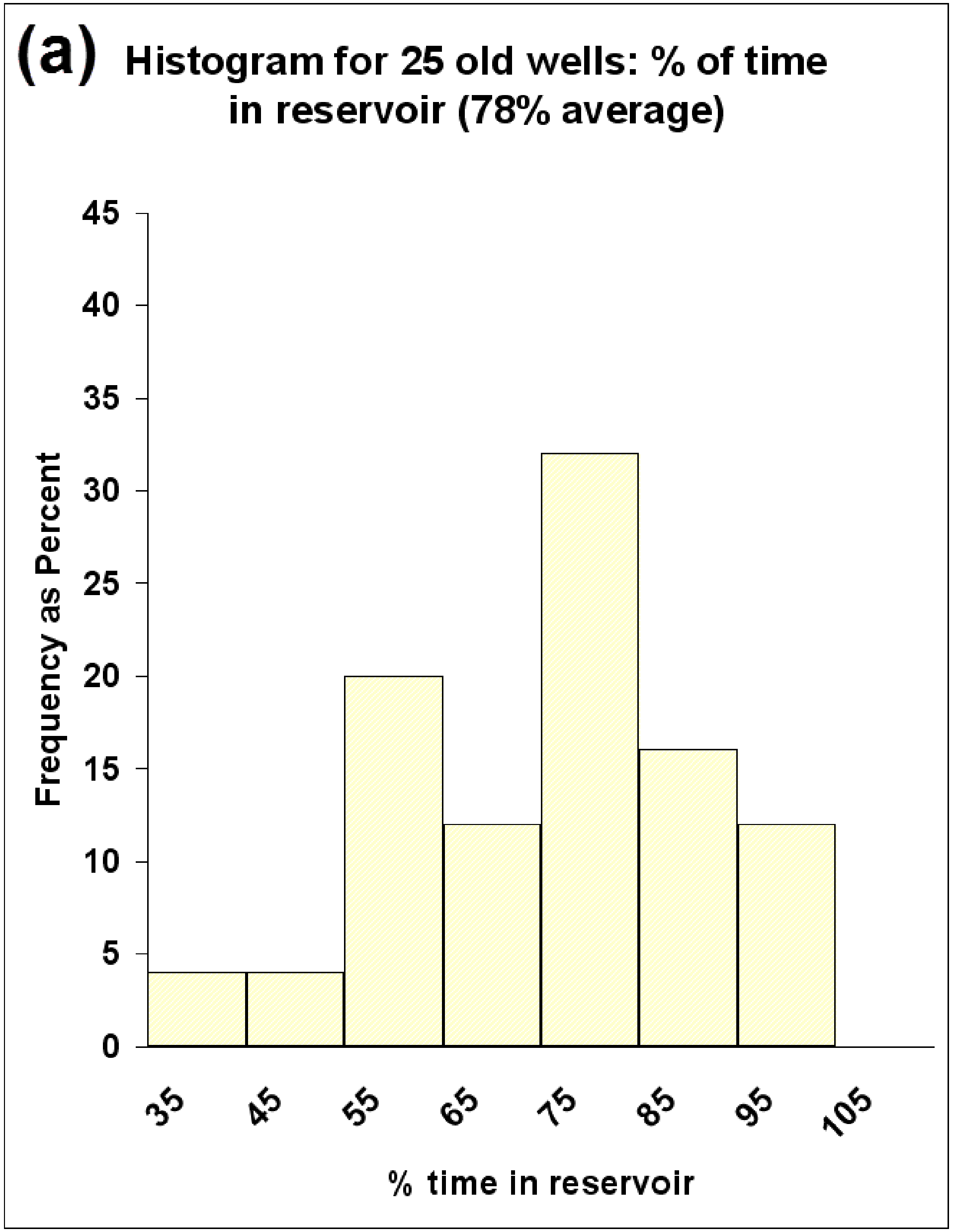
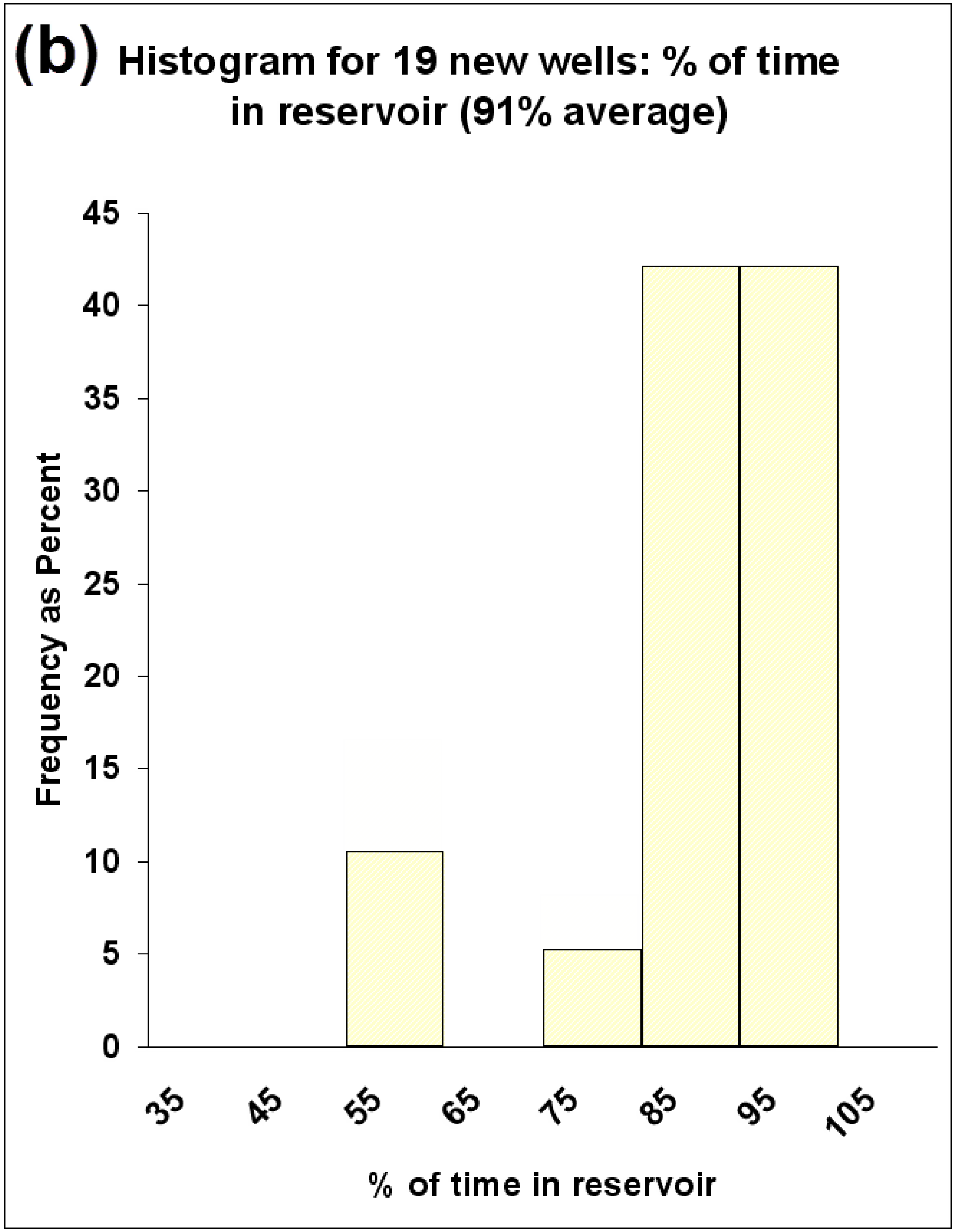
Accuracy comparison

Old | **New**





Fluid (model) value

91% accuracy vs 78% accuracy implies:

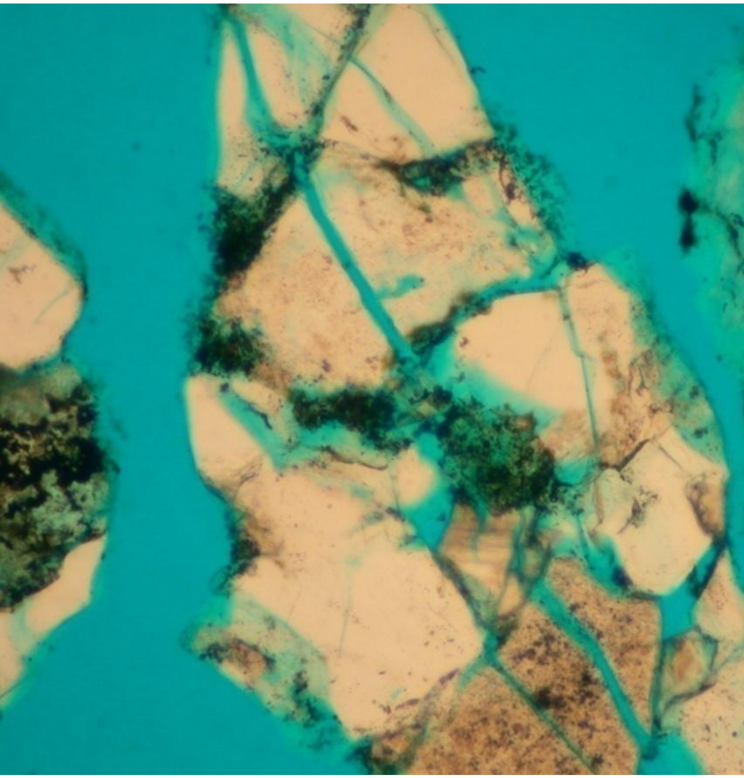
>19 more barrels of fluid per day

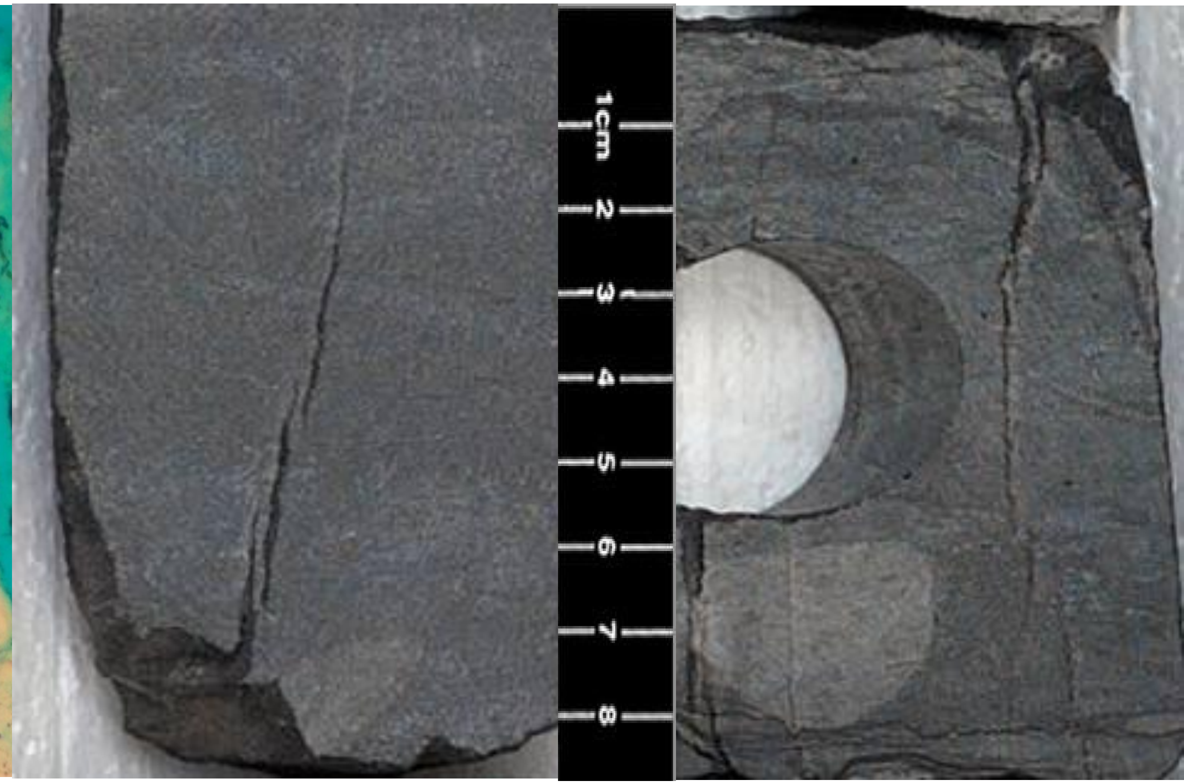
Models to:

> $400 per day per well

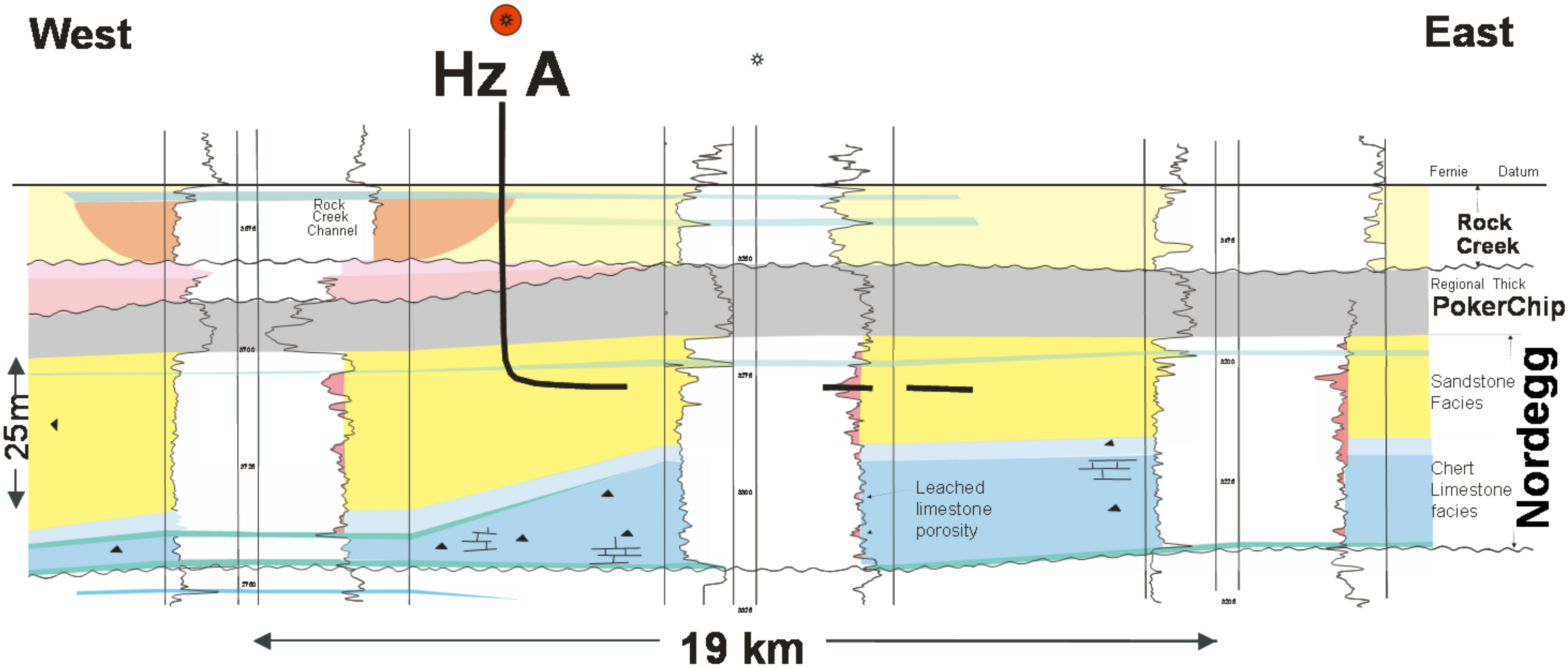
Our wells appear to be doing better than this:

Case study III: fractures & production





Introduction- Nordegg



Aerially extensive gas charged sandstone

Deep basin

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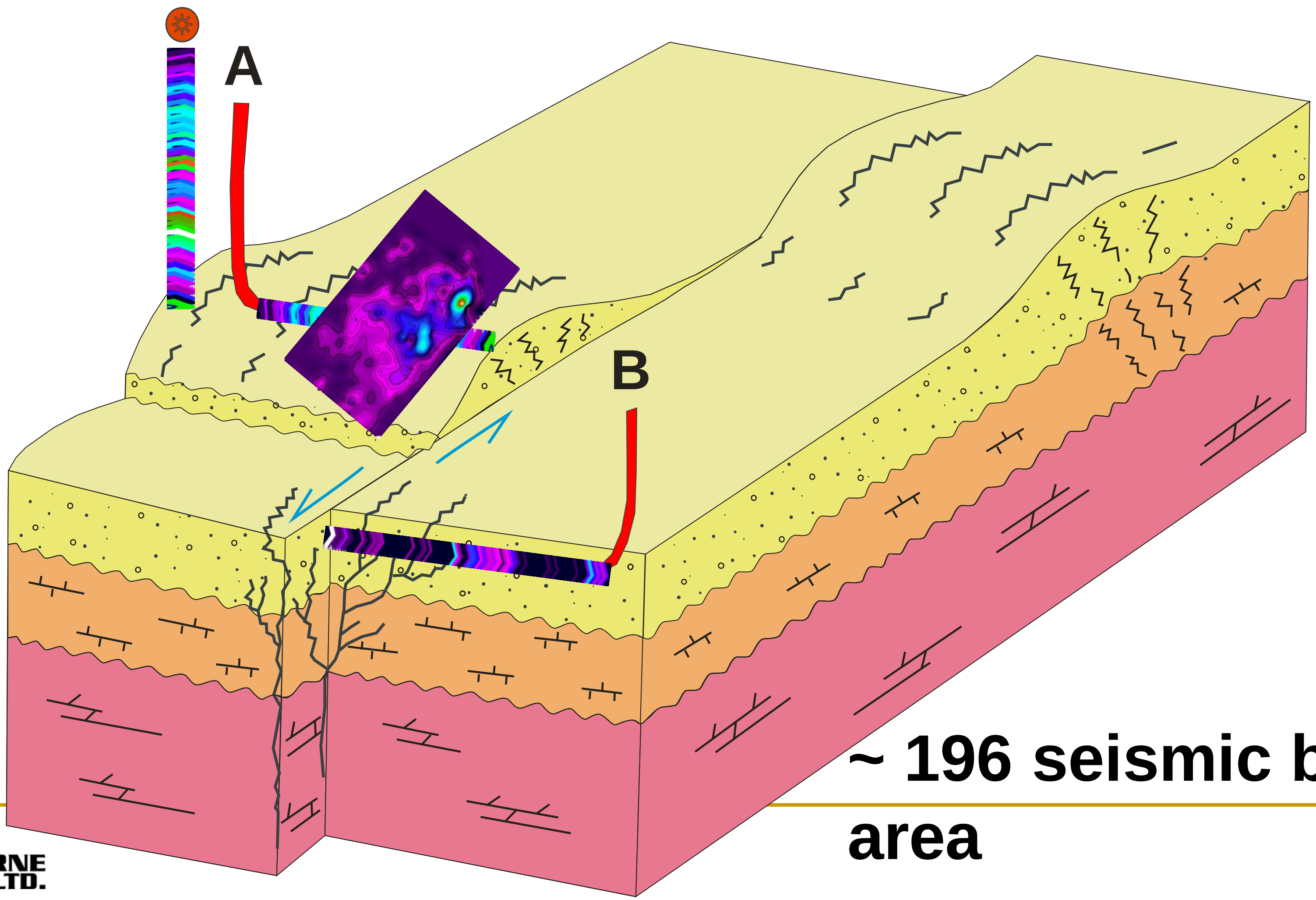
Hrz, vertical well, & Microseismic

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



~ 196 seismic bin area

Direct Methods- AVAz and VVAz

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

AVAz & VVAz ⇨ requirements on data & media

- **HTI media**
- **equation solve-able on the data**

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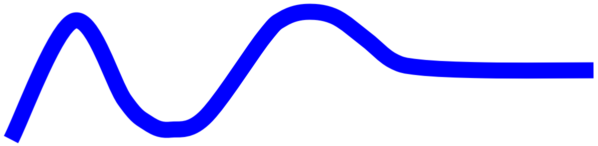
Indirect Method- Curvature

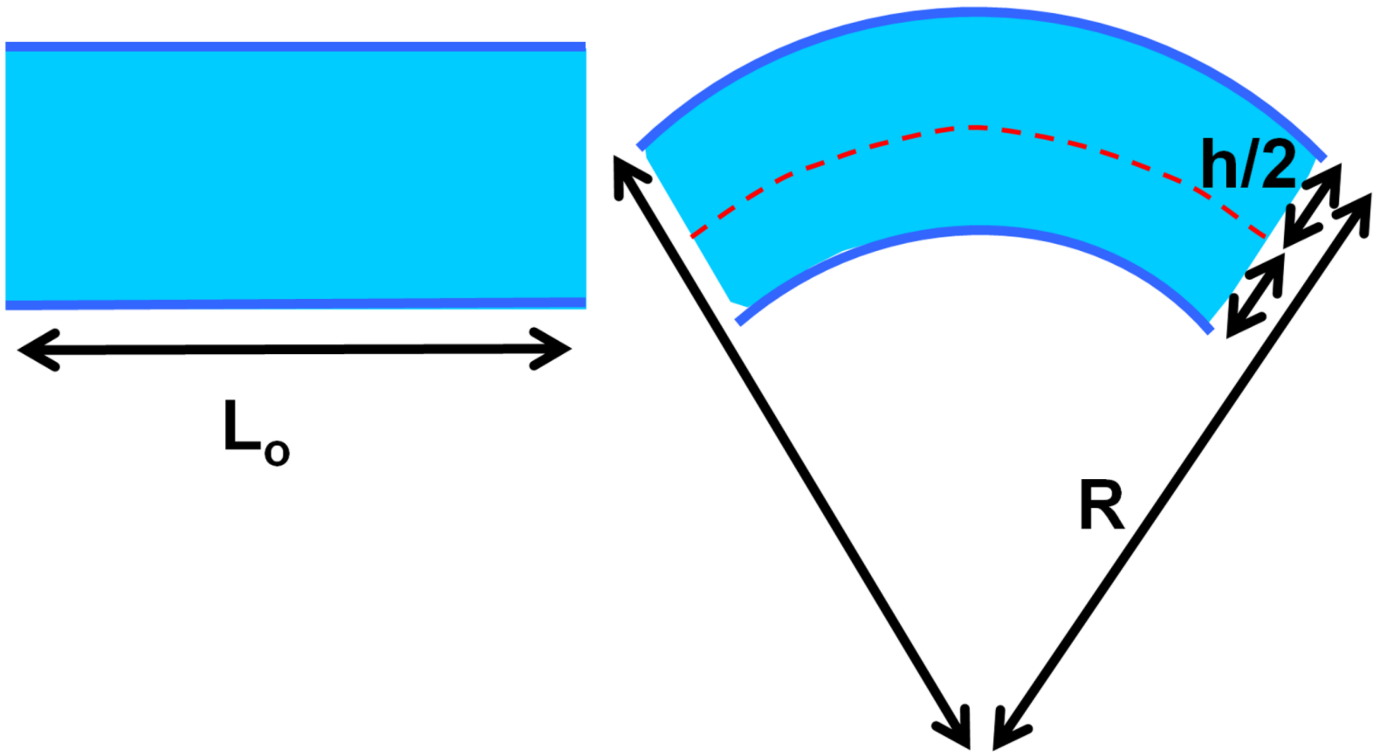
(Murray, 1968; Roberts, 2001; Chopra & Marfurt, 2007)



+ Curvature ⇨ + strain

+ strain ⇨ + fractures

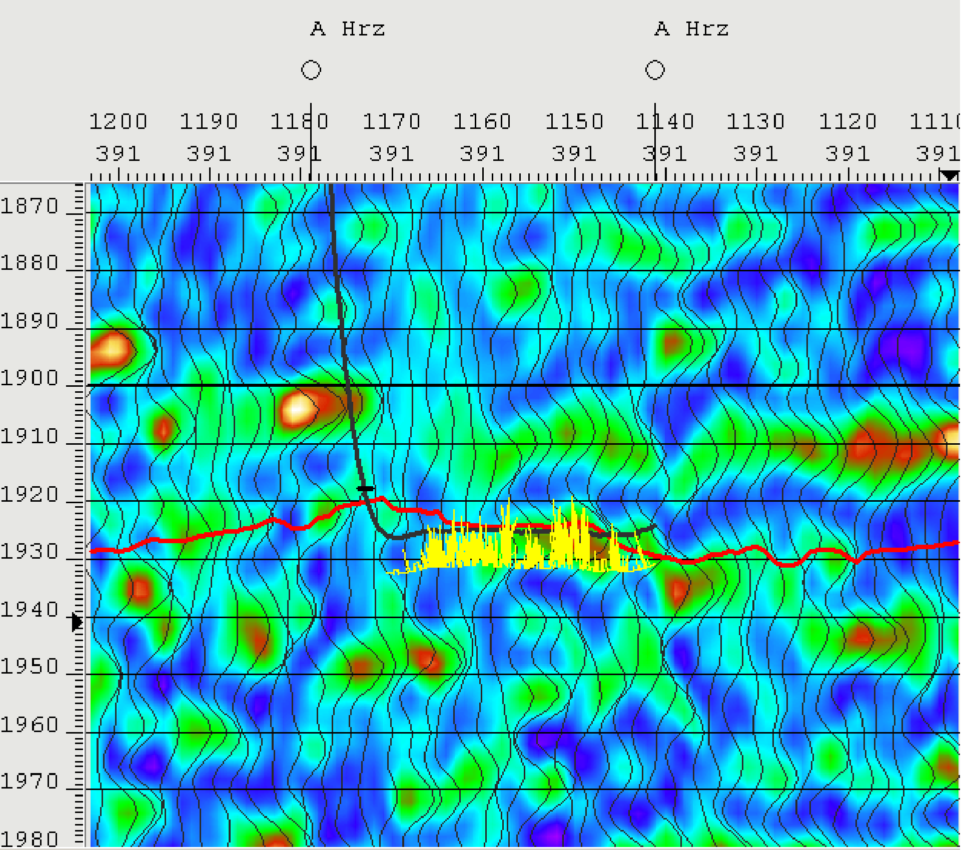
$$e = (h/2) / R = (h/2) * K$$



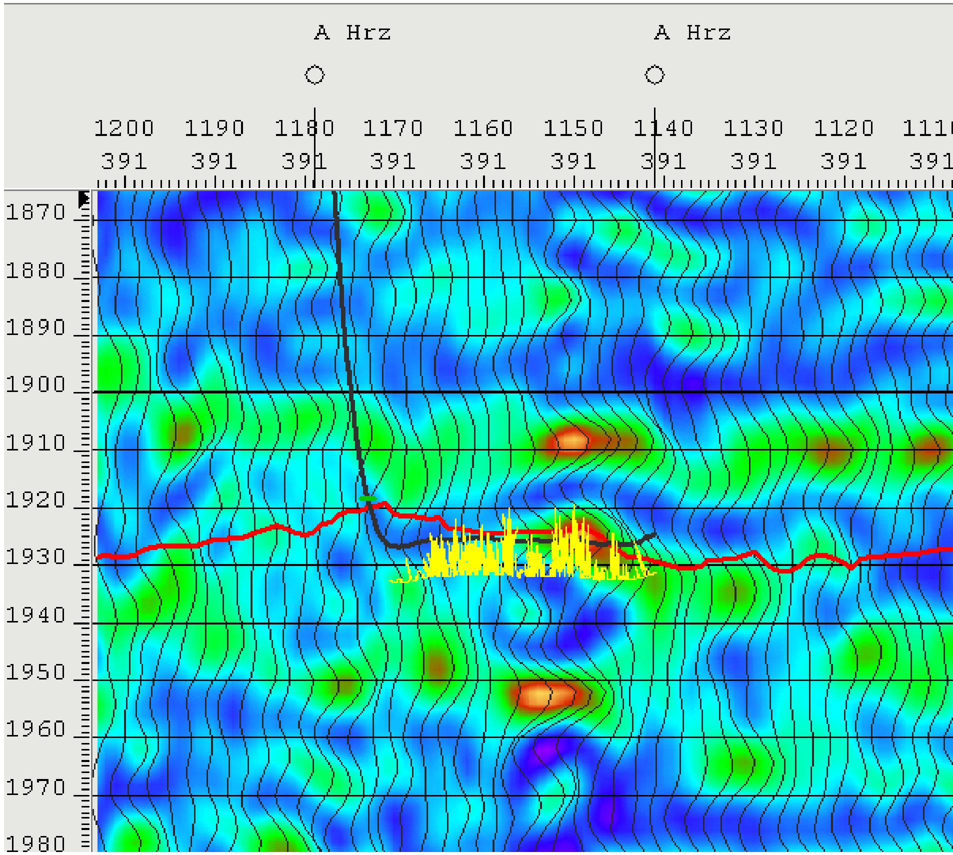
$$\sigma = E\ e = E * (h/2) * K$$

Interpolation and AVAz

5 x 3 special scaling



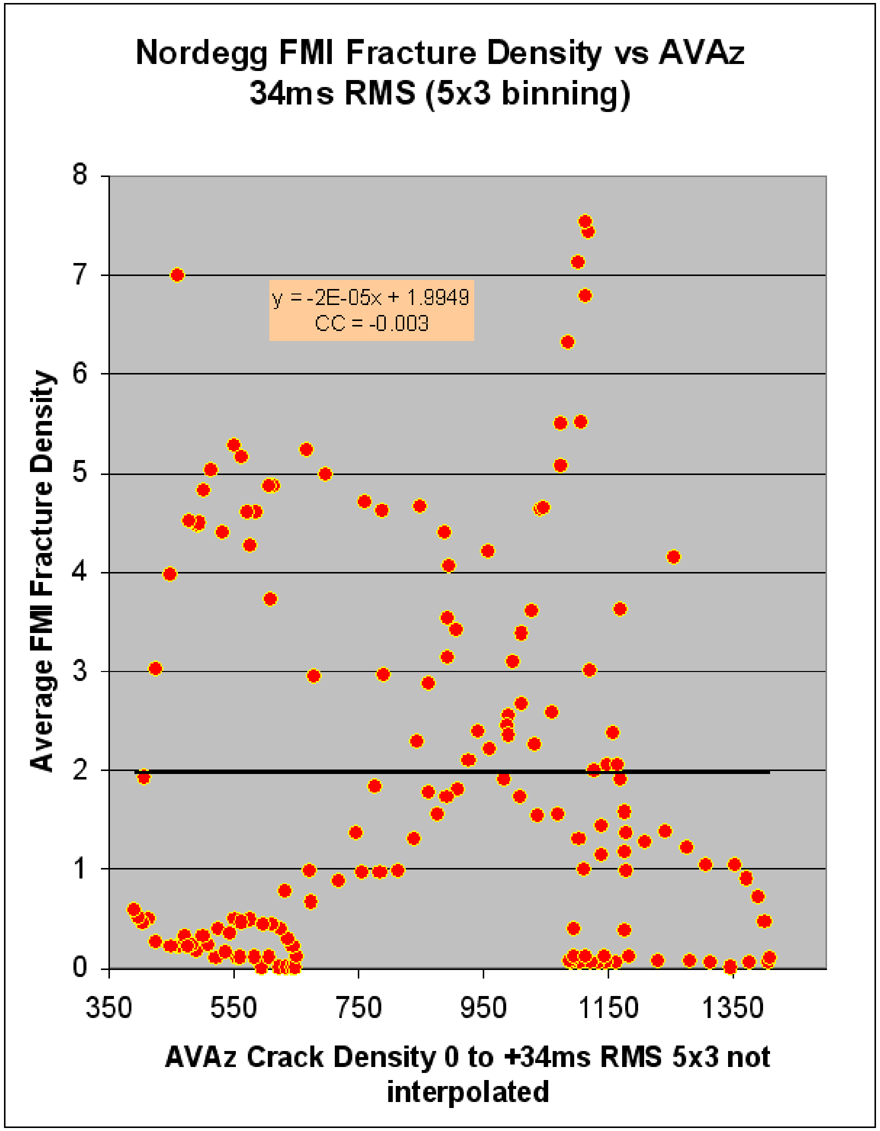
Interpolation, 5x3



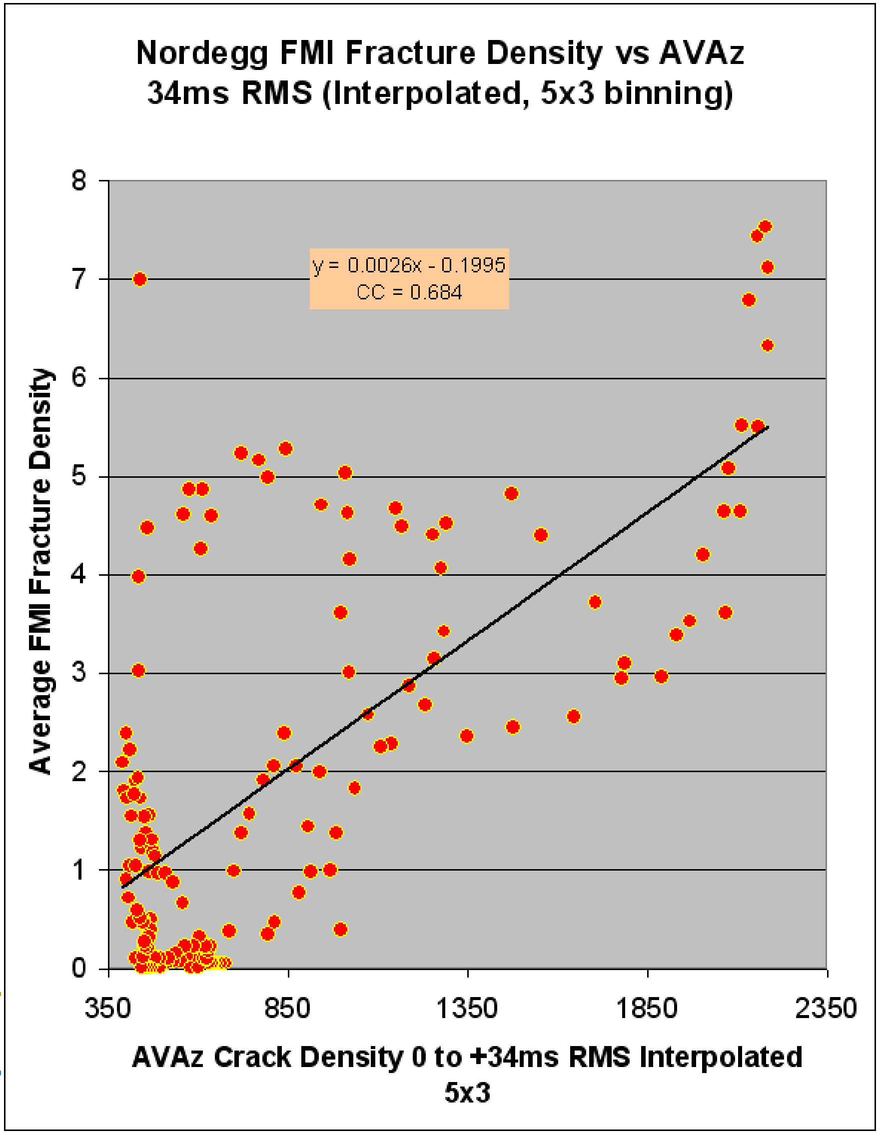
FAIRBORNE ENERGY LTD.   CGGVERITAS   arcis

Interpolation and AVAz

5 x 3 binning



Interpolation, 5x3

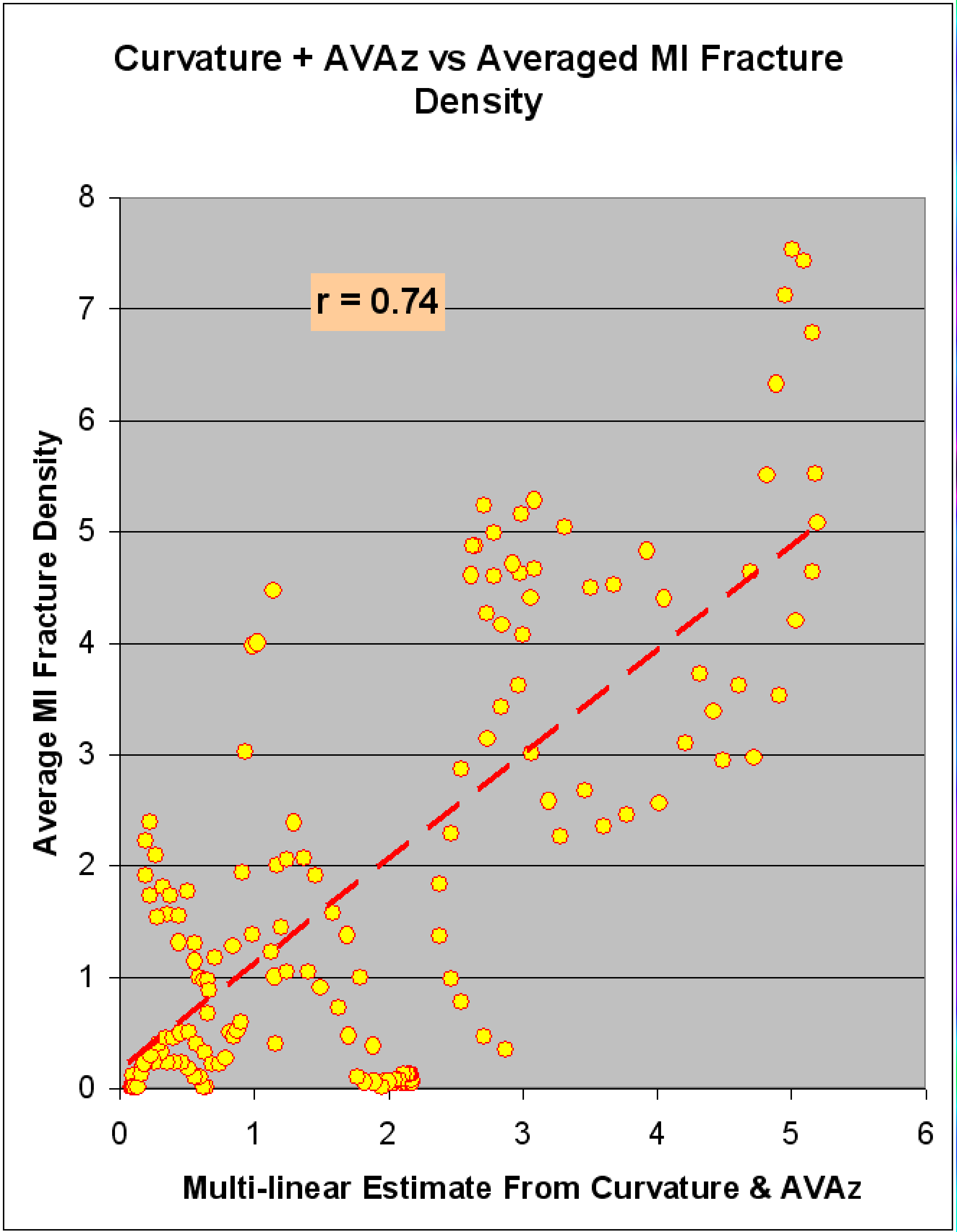


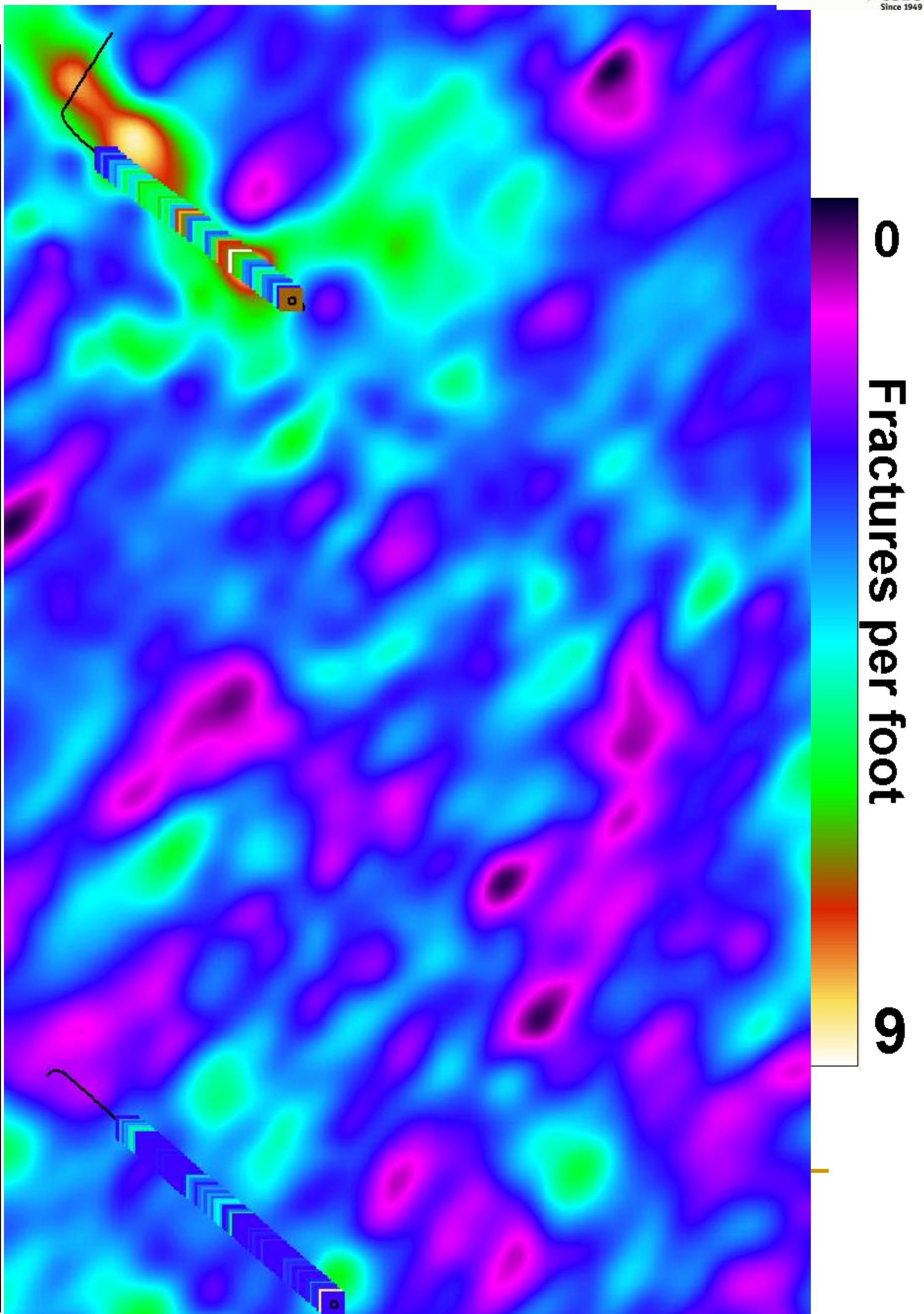
Fracture estimation roll-up

	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

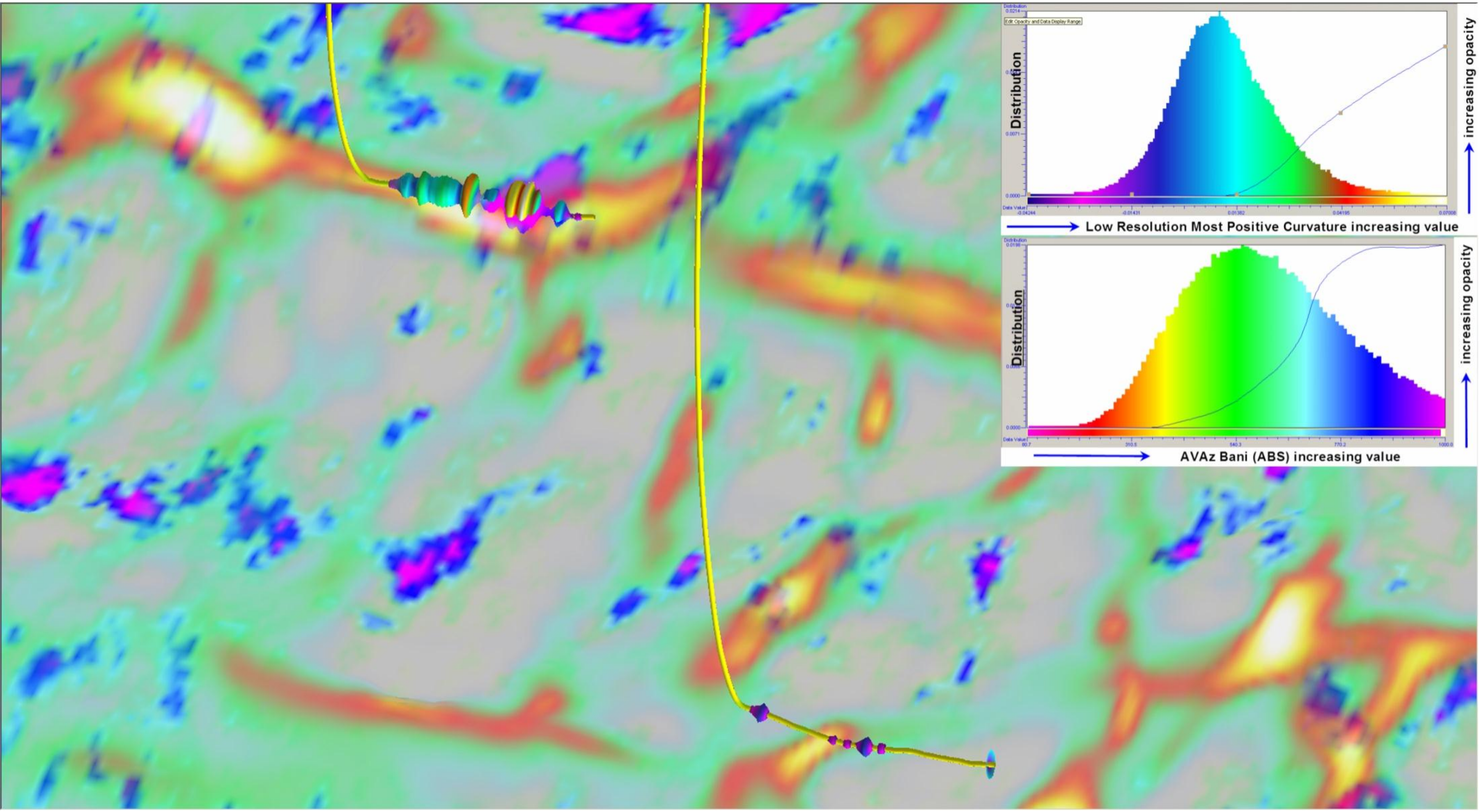
- Each method gets it partly right
- … and partly wrong

Map Using AVAz and Curvature





AVAz and Curvature: co-render



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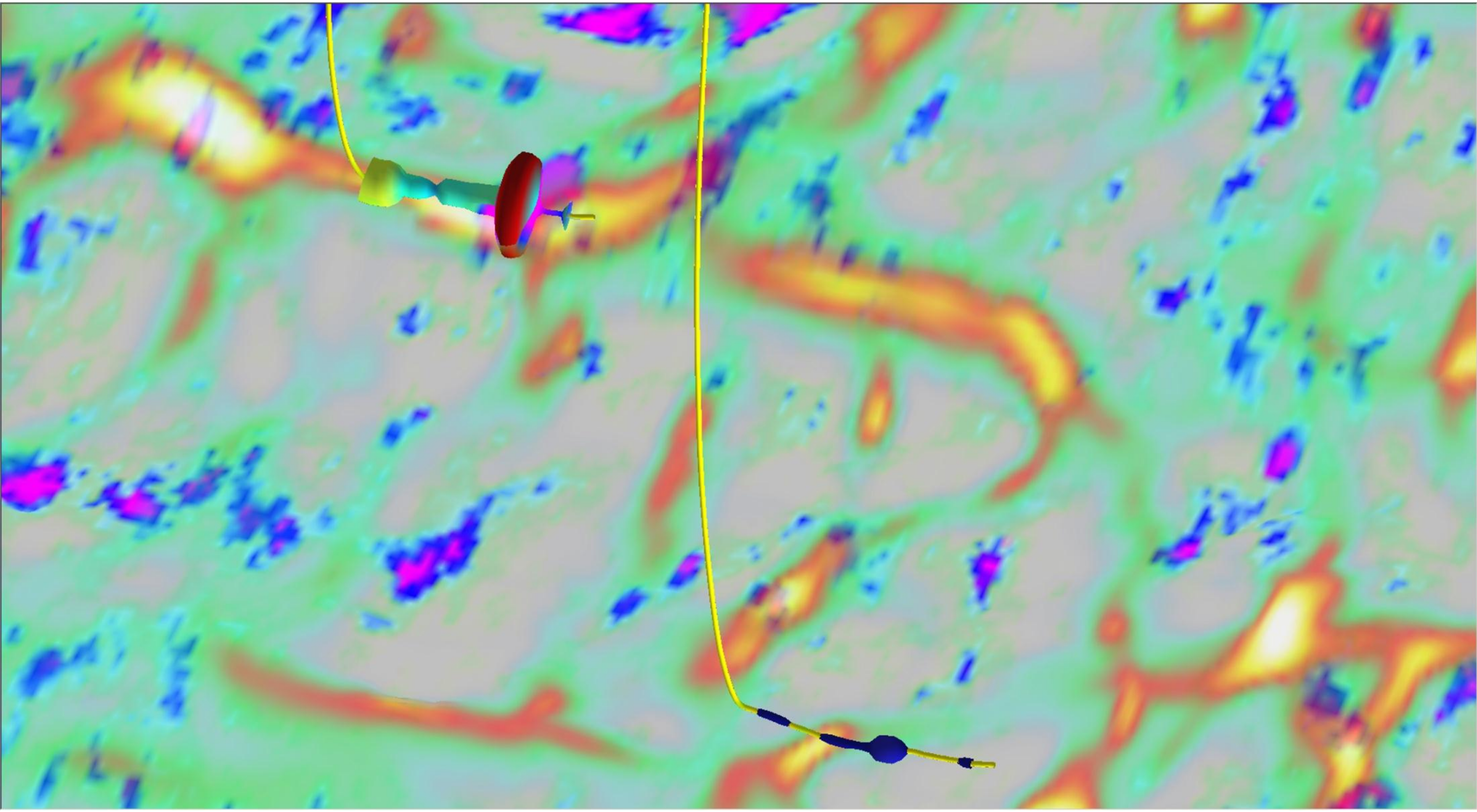
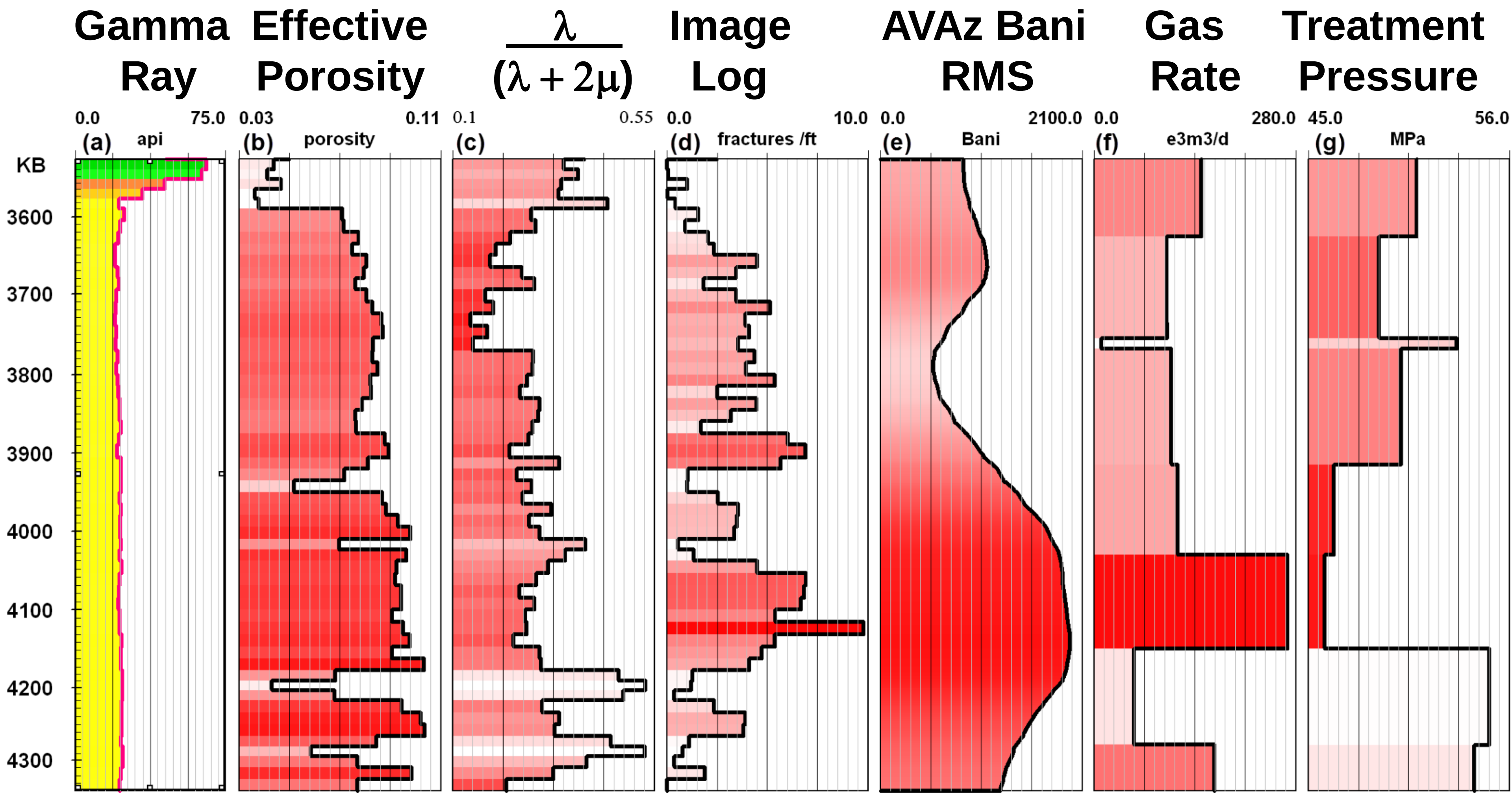
With production data



Wellbore / log extraction: well A



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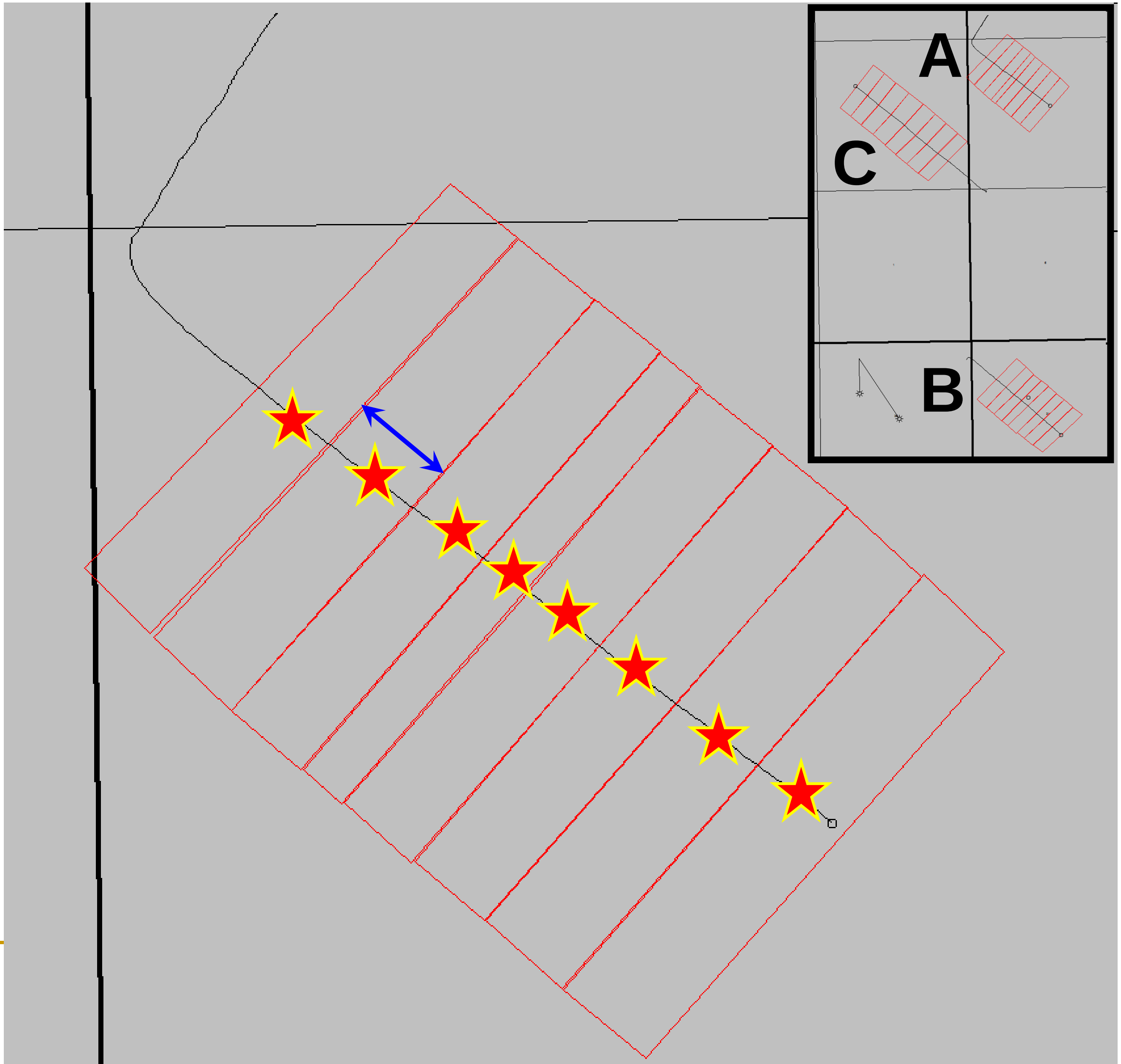
Experimental Set-Up

3 wells

8 Frac intervals Per well

Different length ~40 to 180m

***Attempted* same size of frac (100 tonnes)**



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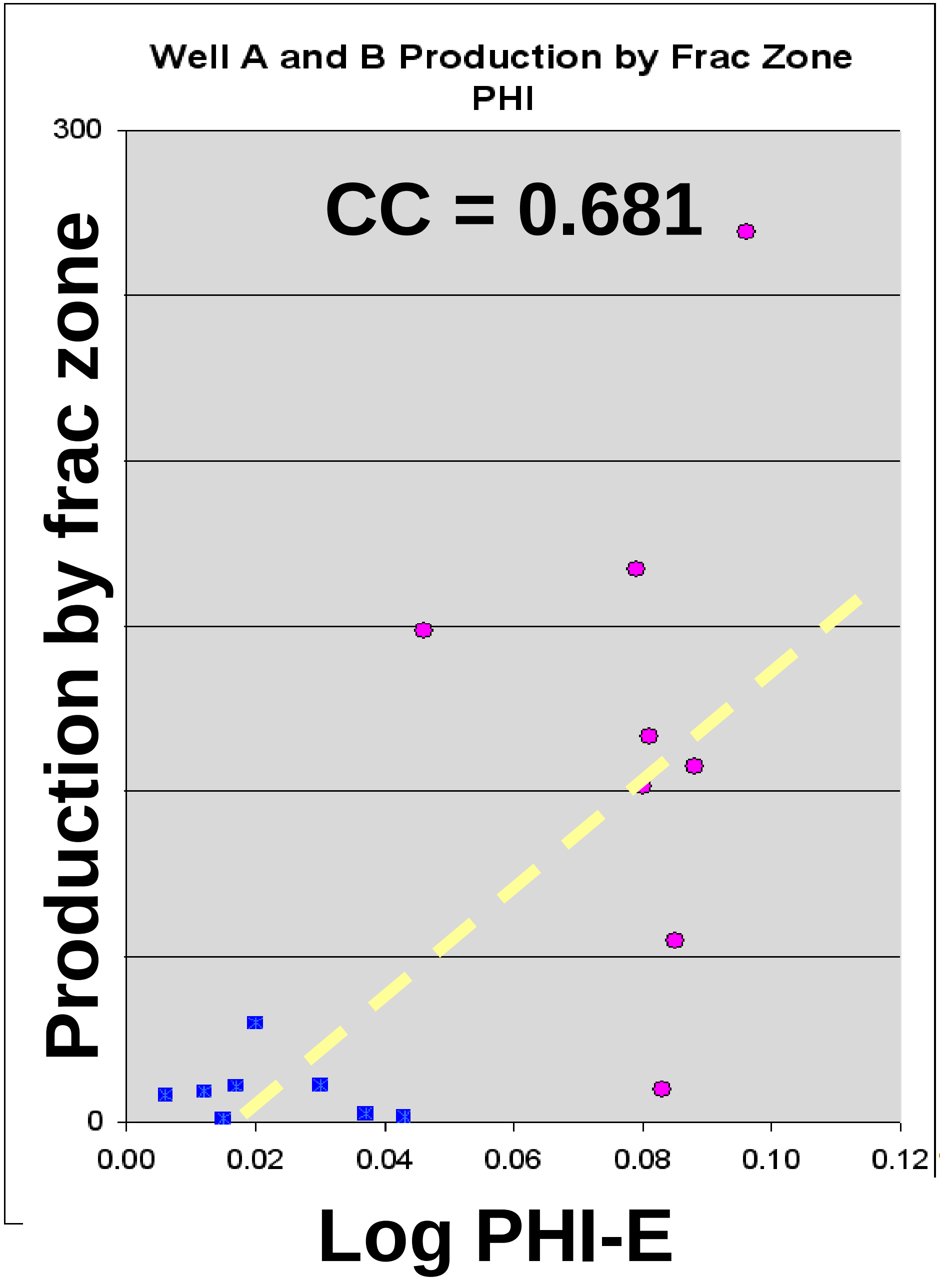
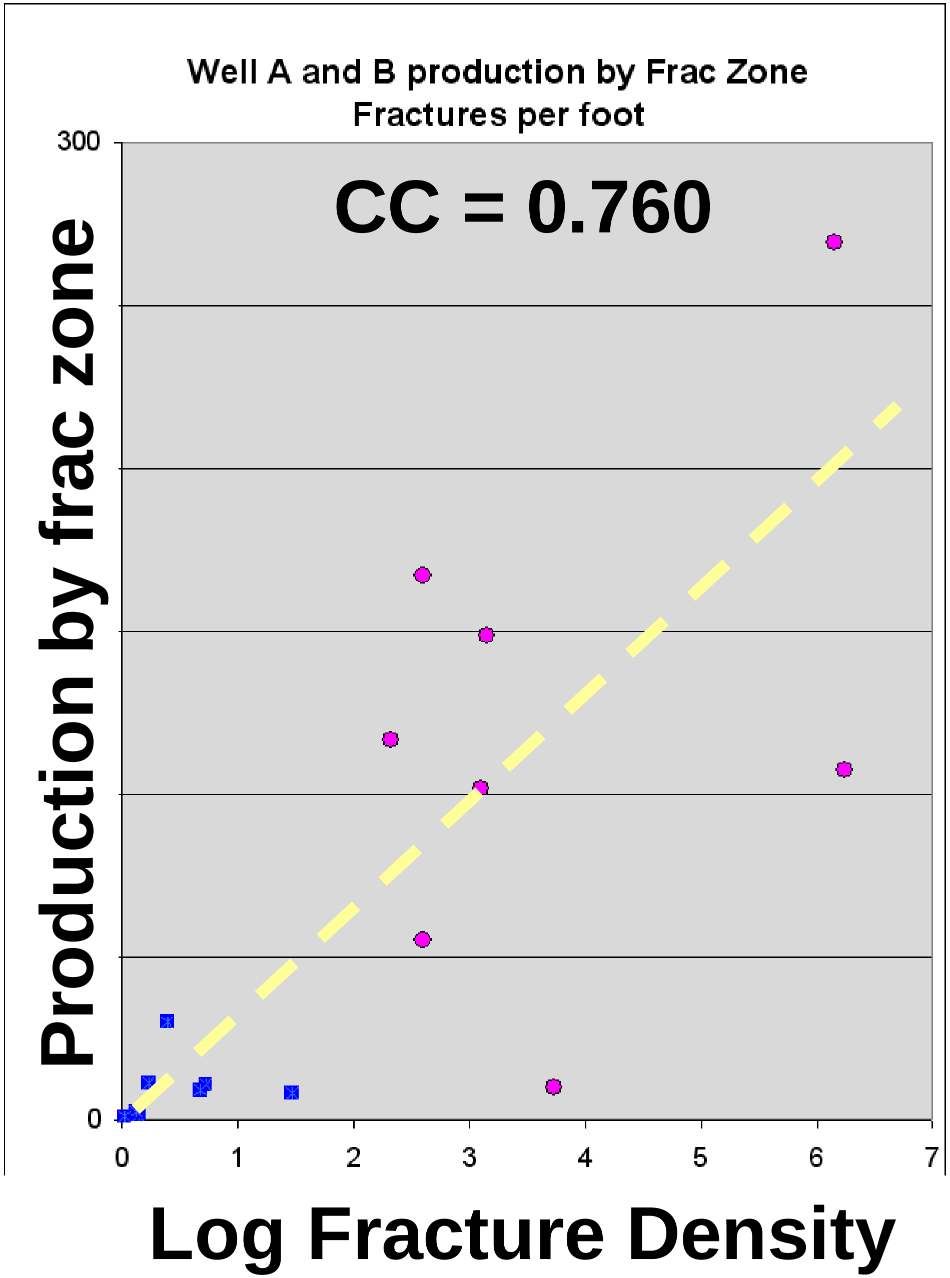
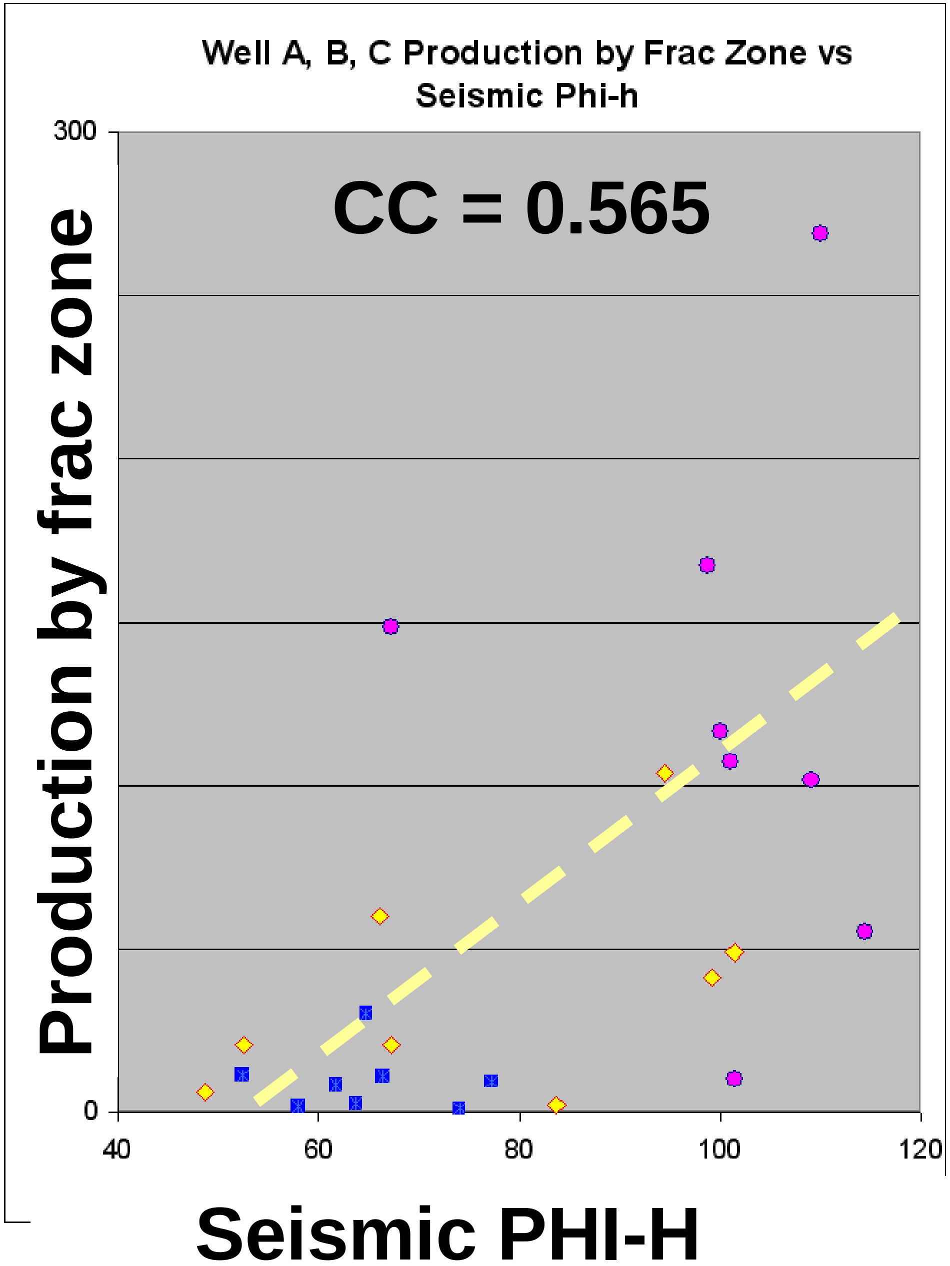
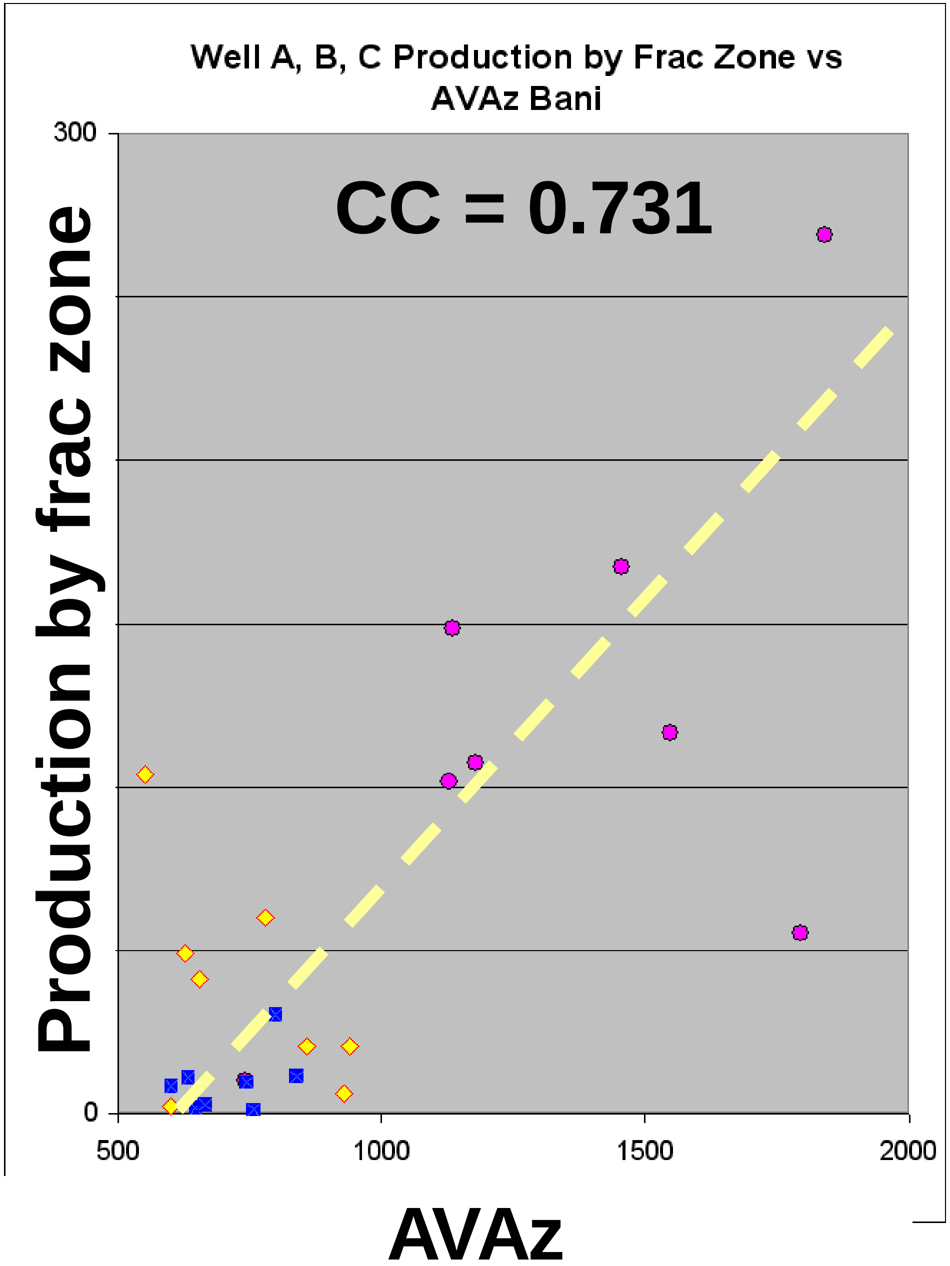
Production: 2 wells with full logs



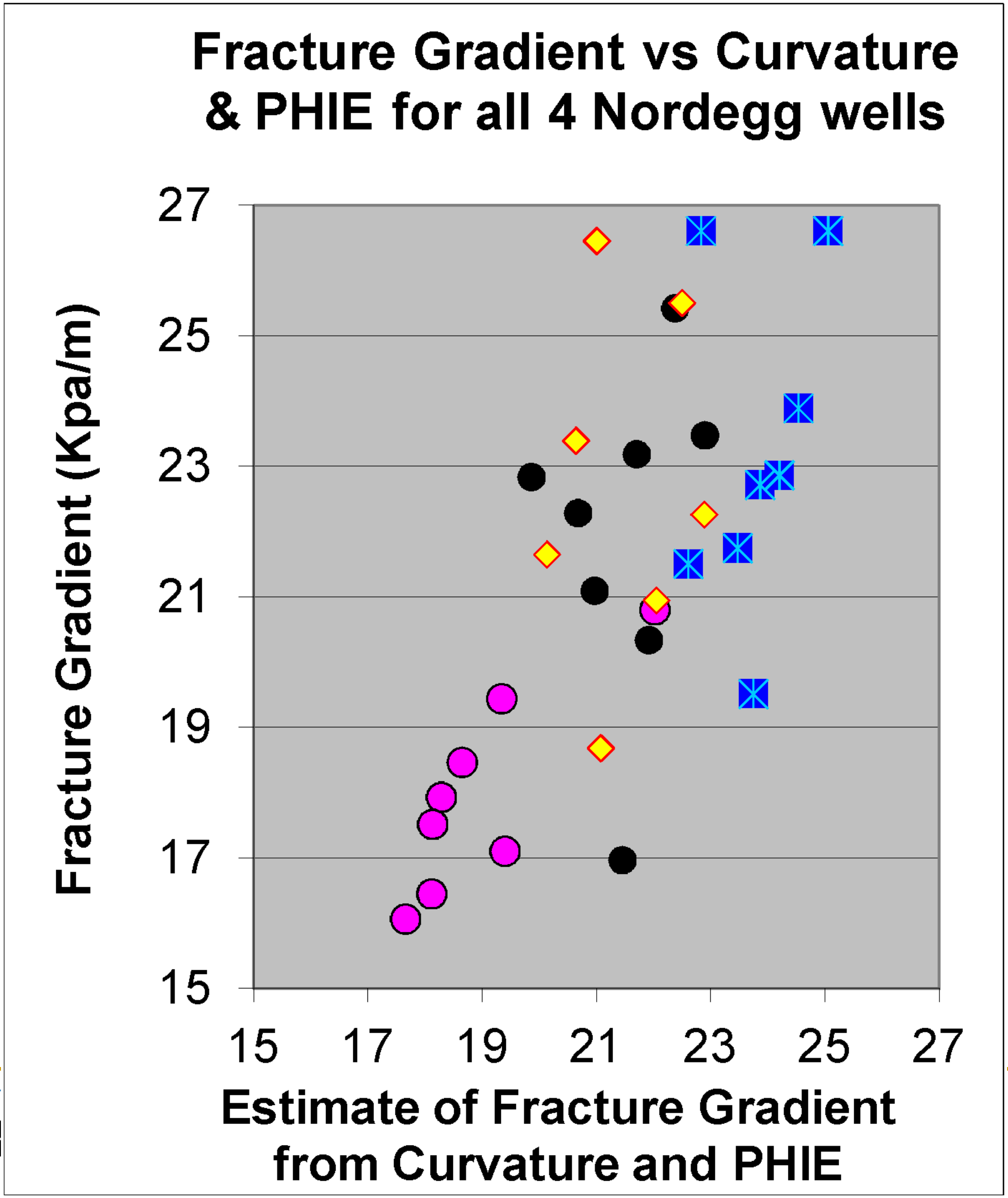


Production: 3 wells with seismic





4 wells with Fracture Gradients



CC = 0.666

What does all this mean?

- Just illustrations...

- Of a larger point

End of the beginning

- 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

This is our attempt to be better

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