DrilSeis

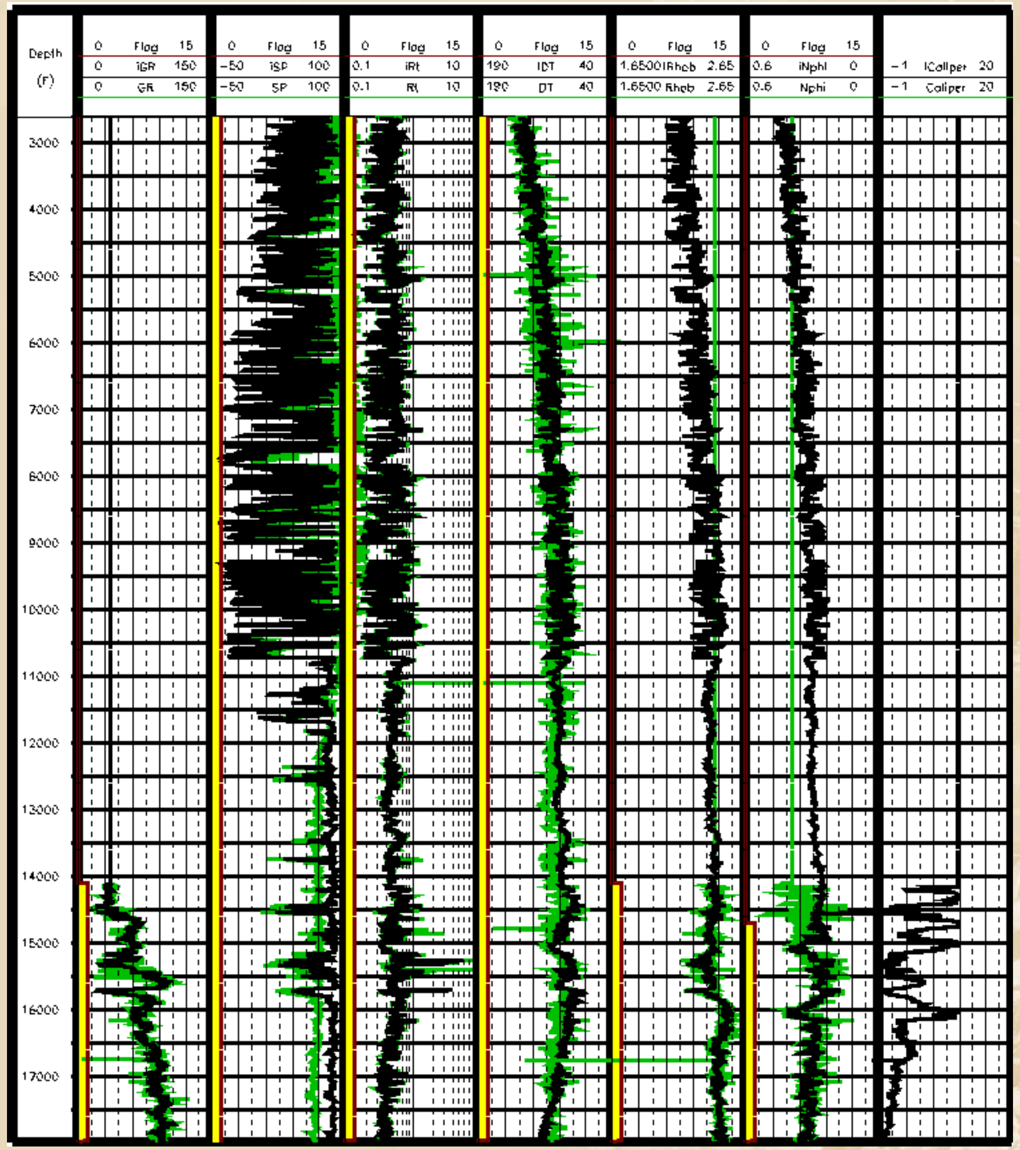
Pore Pressure from Seismic

- eSeis Inc. Work Flow
  - **Assess** Shale Pore Pressures From Key Wells
  - **Calibrate** Well Shale Pore Pressures With Shale Pore Pressures From Seismic (Velocity and Frequency)
  - **Predict** Shale and Sand Pore Pressures At The Proposed Well Location

eSeis

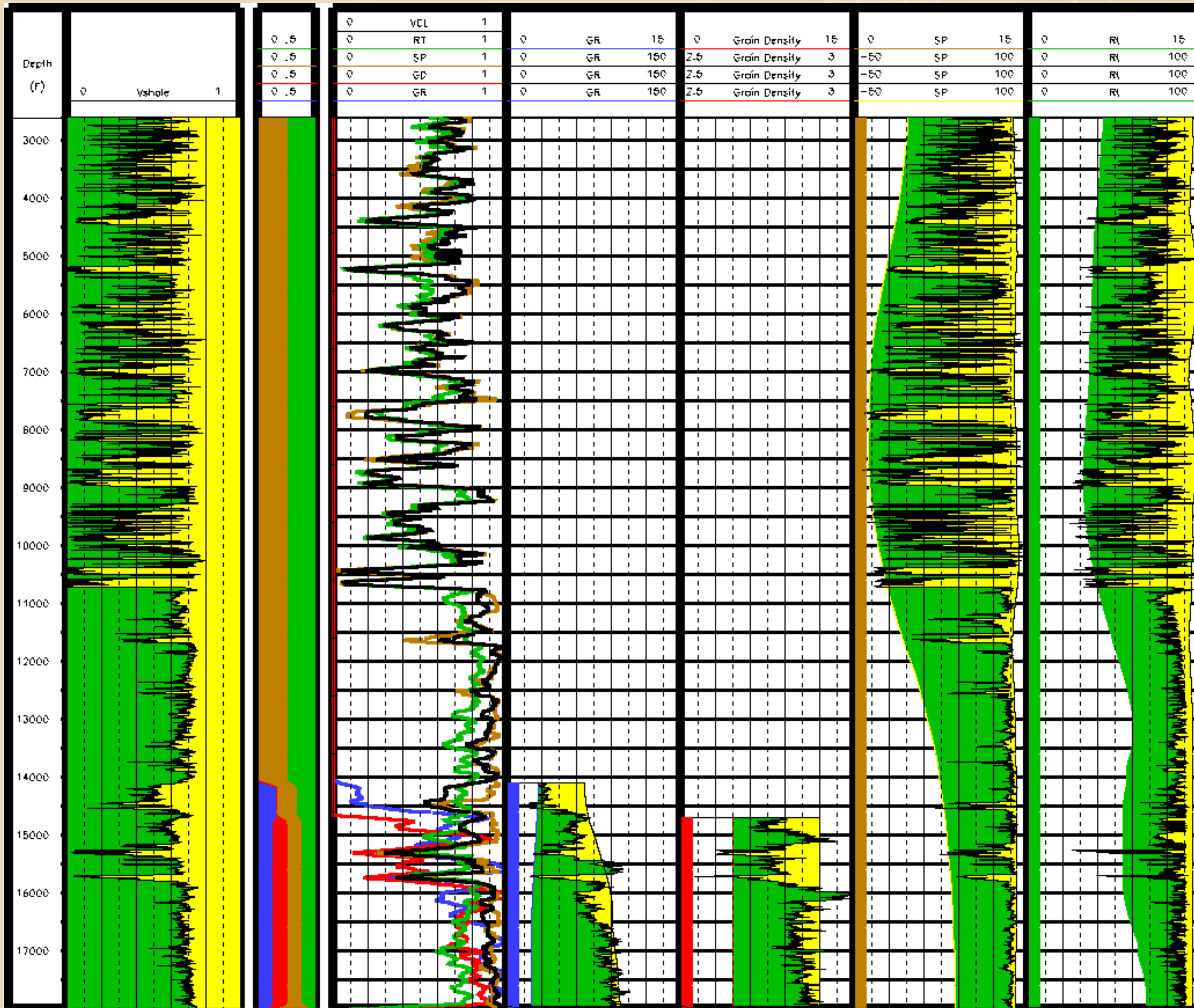
Assessment begins with editing the logs

Raw Logs – Green
Edited Logs - Black



Vclay Calculation

All GR RHOma SP Rt



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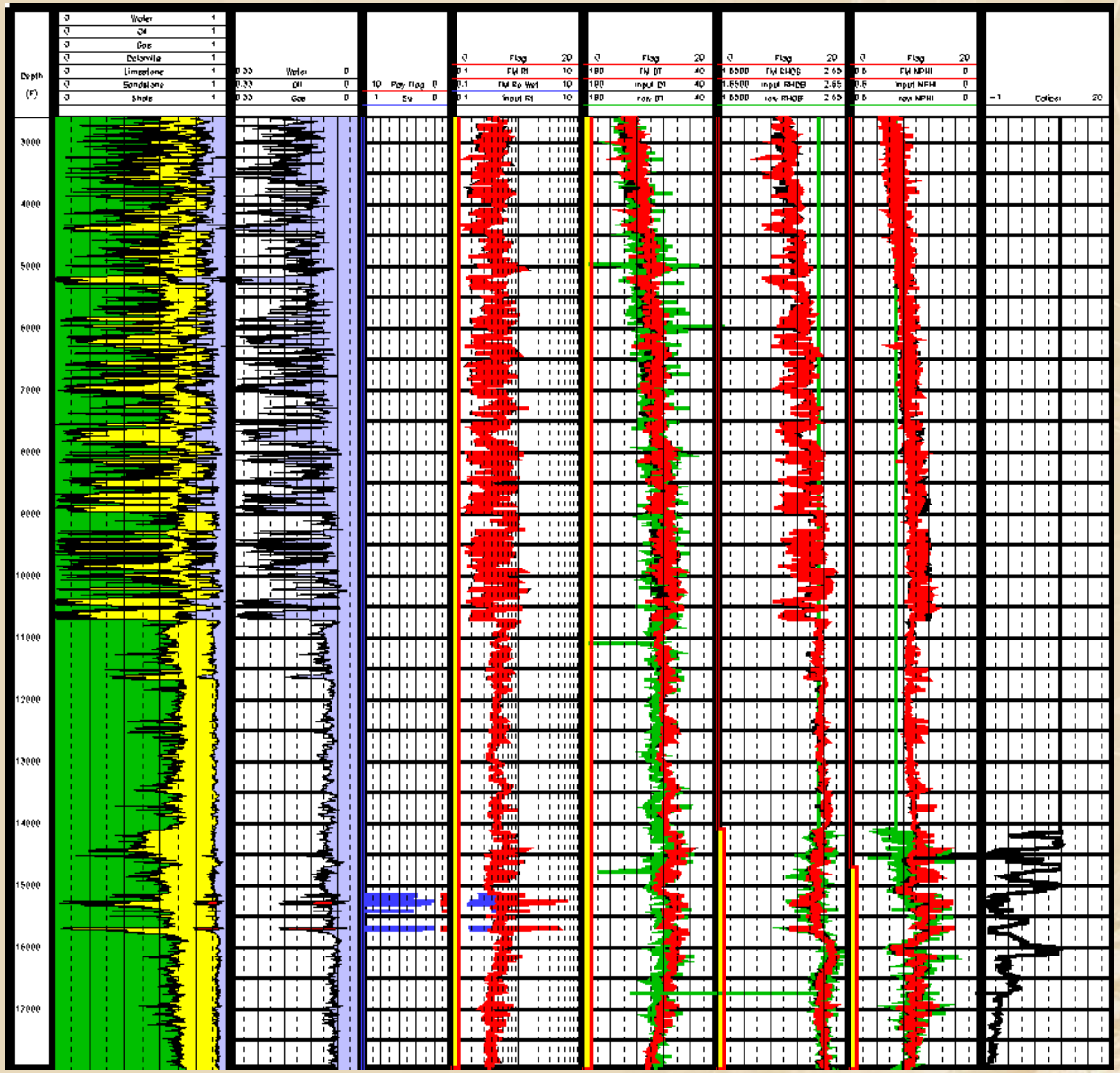
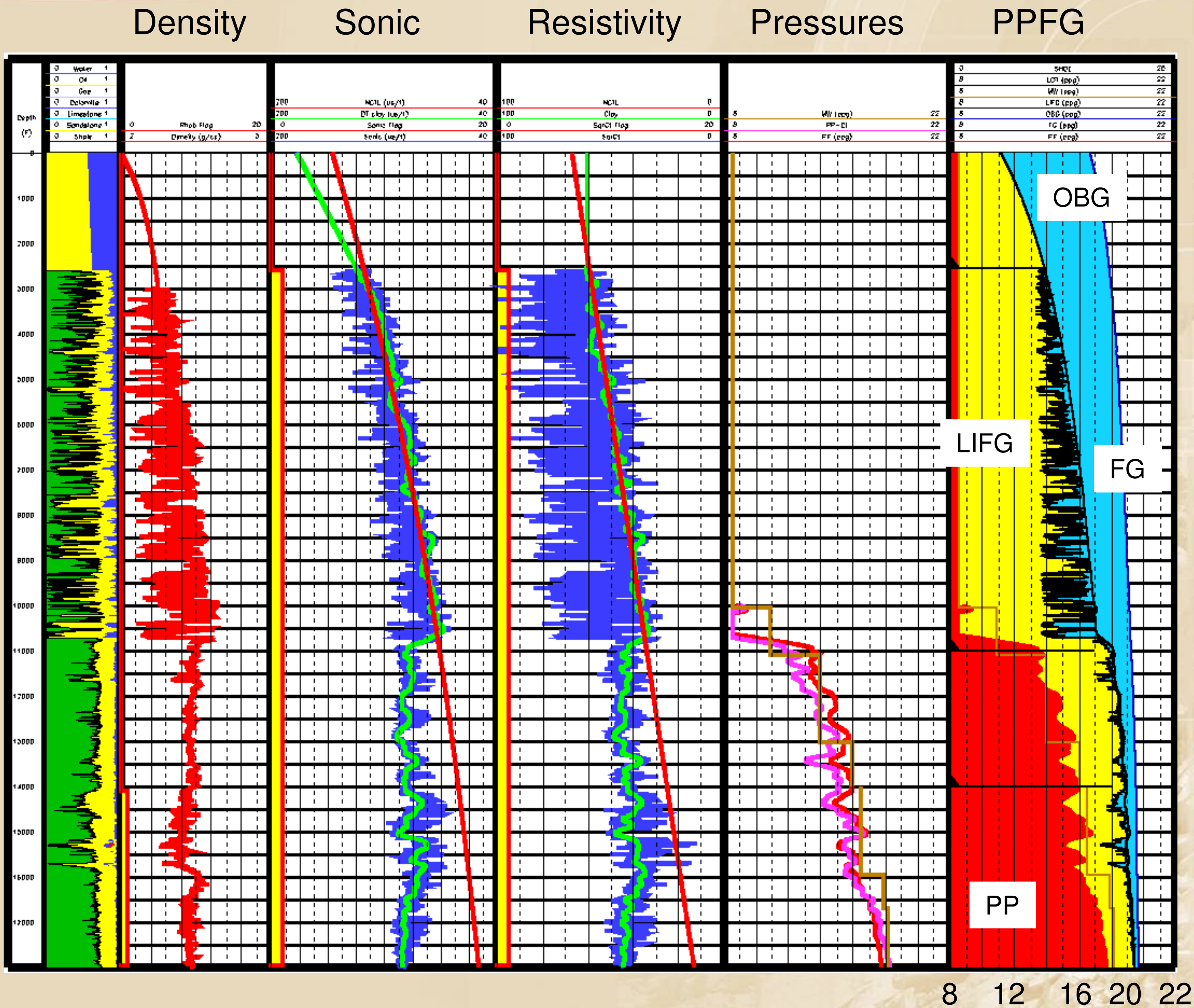
Log Analysis



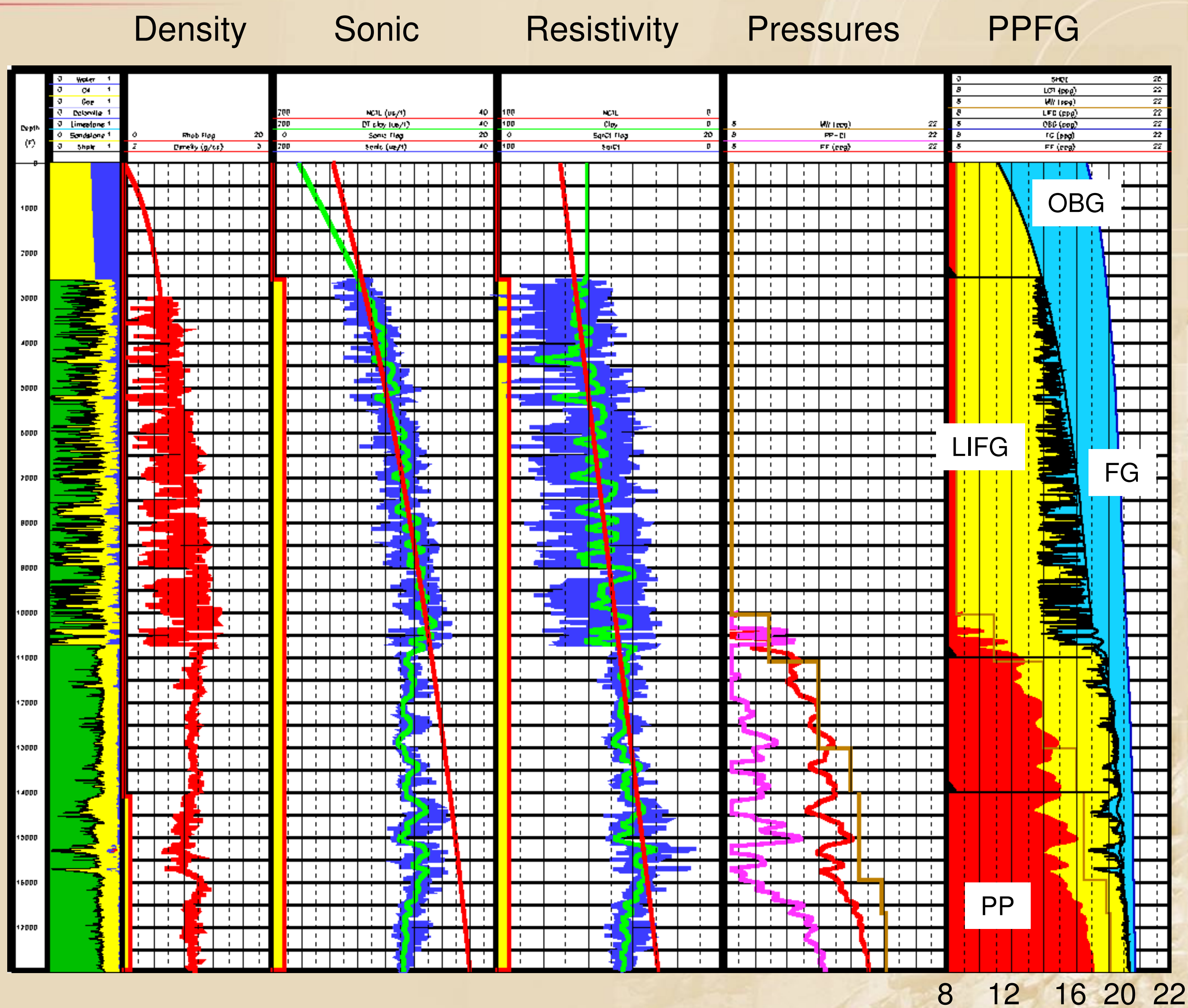
PPFG Assessment

Done Correctly



eSeis

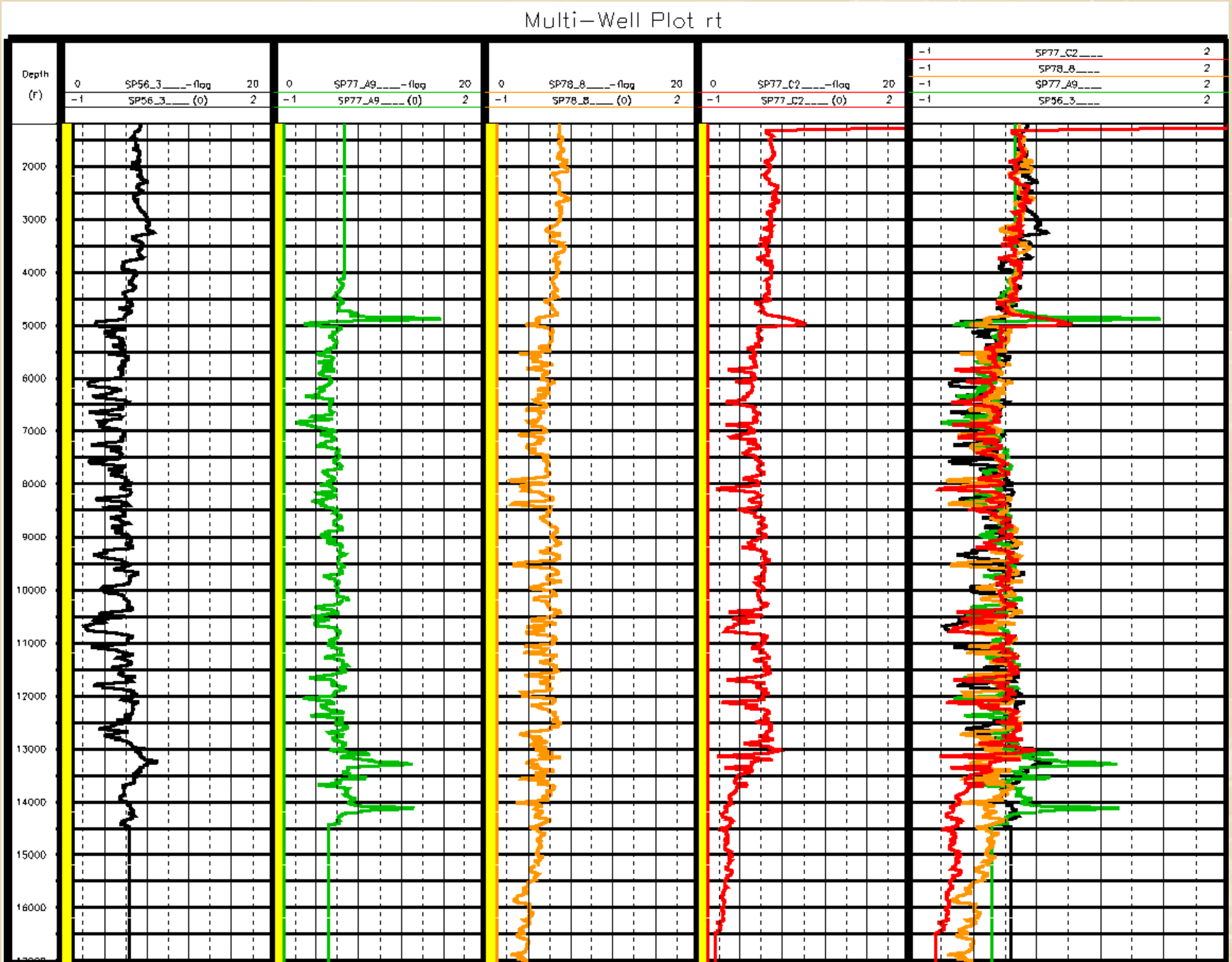
PPFG Assessment



Not using only clay points resulting in a poor assessment of shale PP.

Logs are Not “Ground Truth”, Correcting Logs for a Better Earth Model

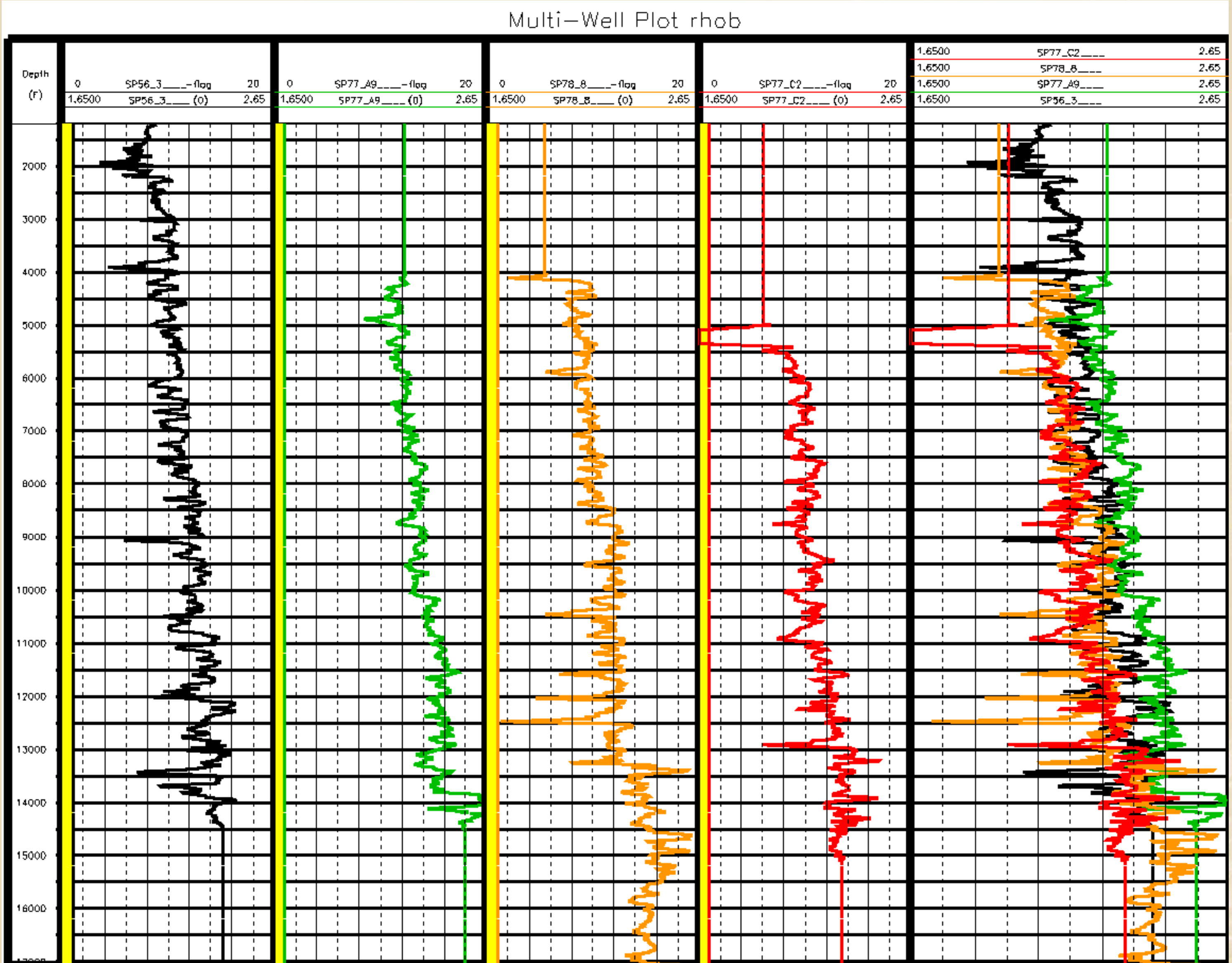
Deep Resistivity



All RT curves are in alignment

Unedited Densities

Not the case with Rhob



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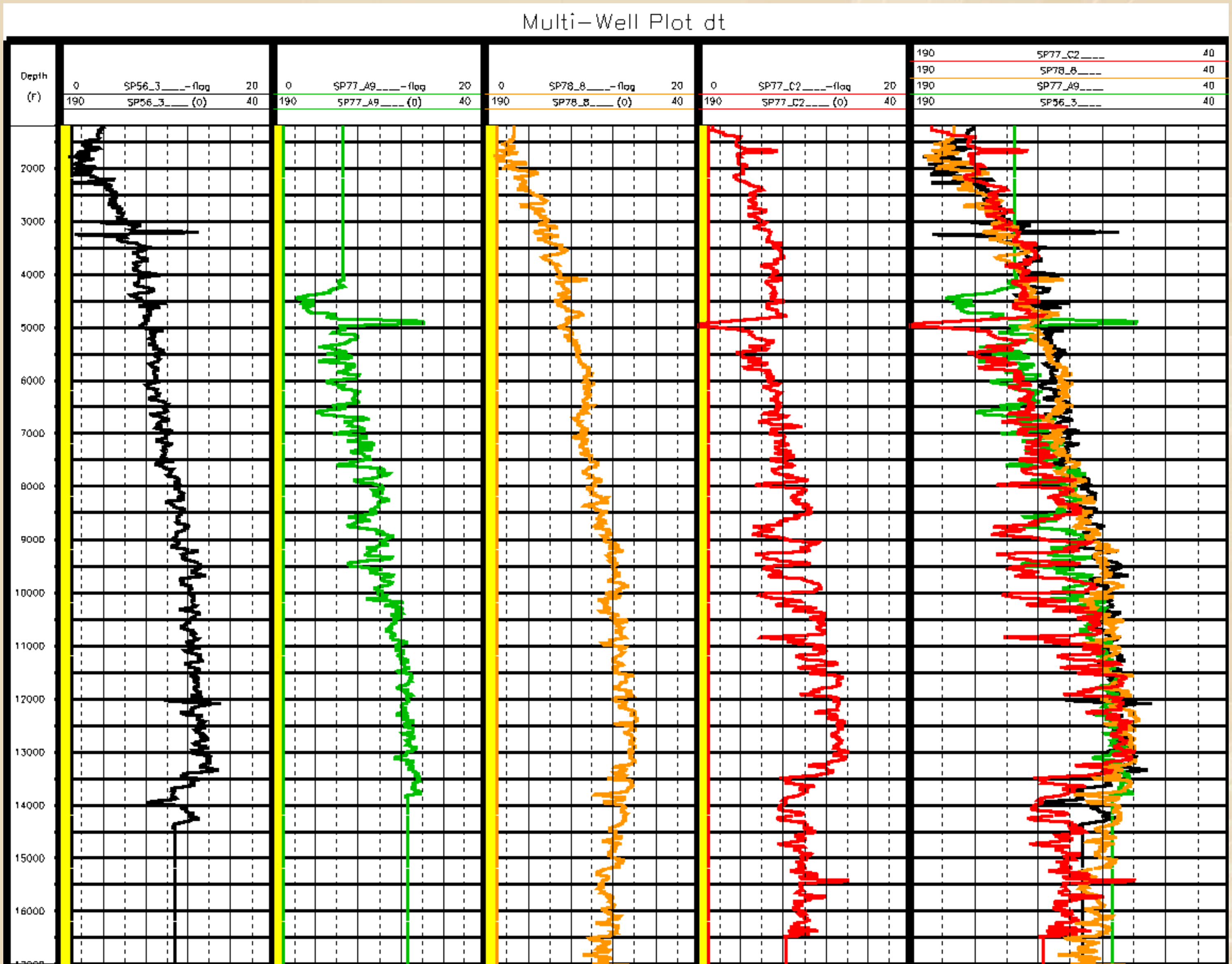
Unedited Sonics

Not the case with DT



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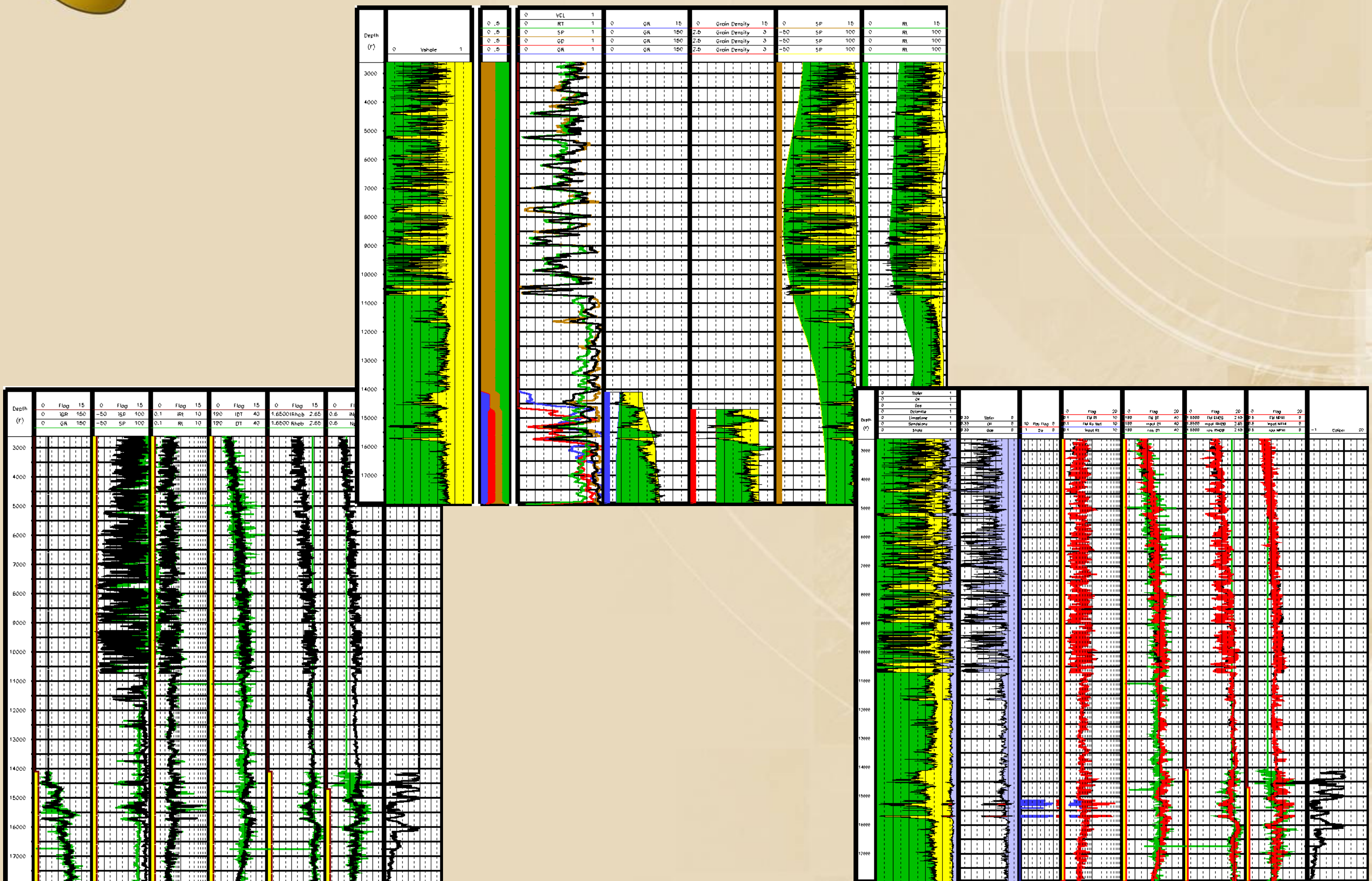
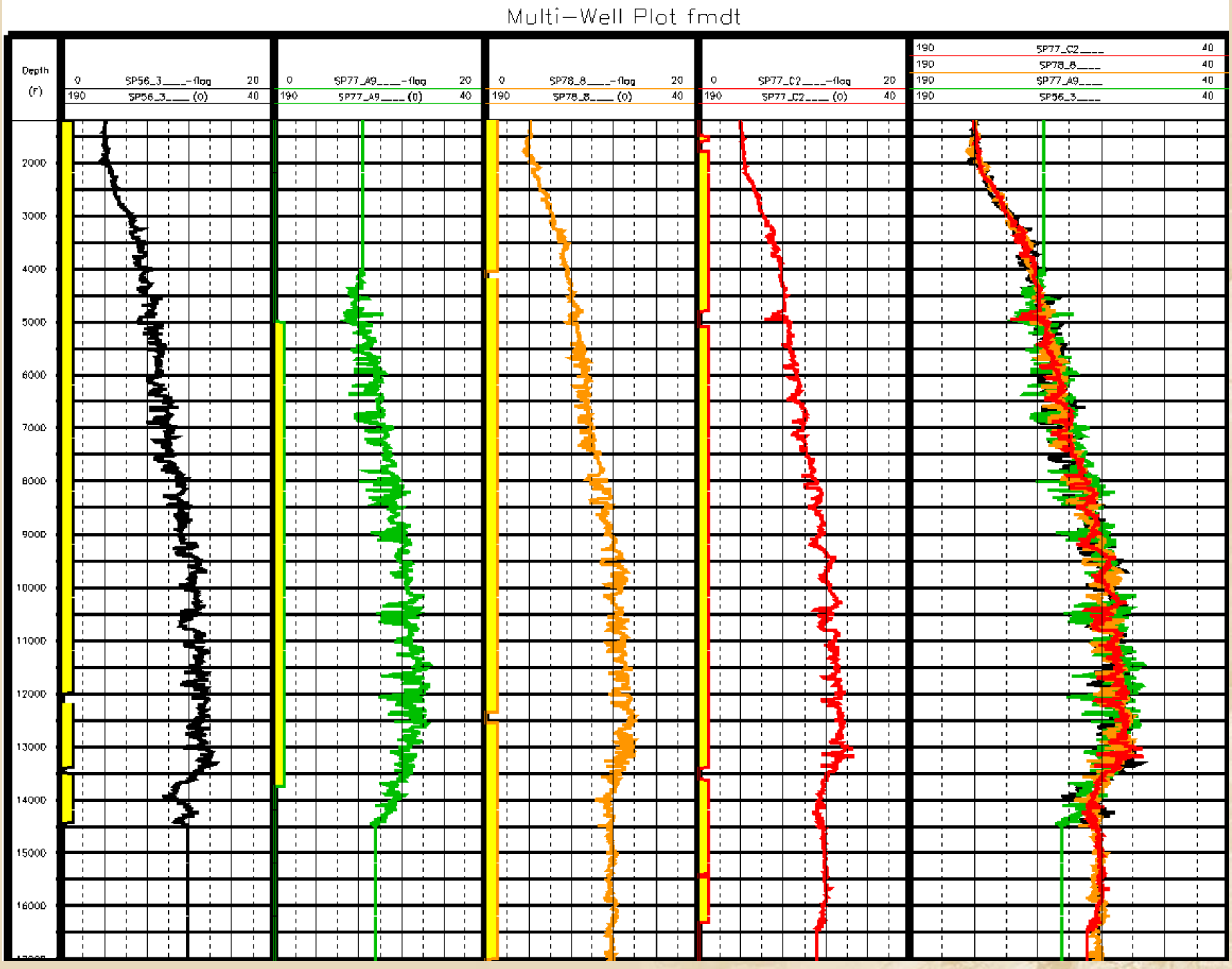
Inverse and Forward Modeling of Logs



Edited Sonics



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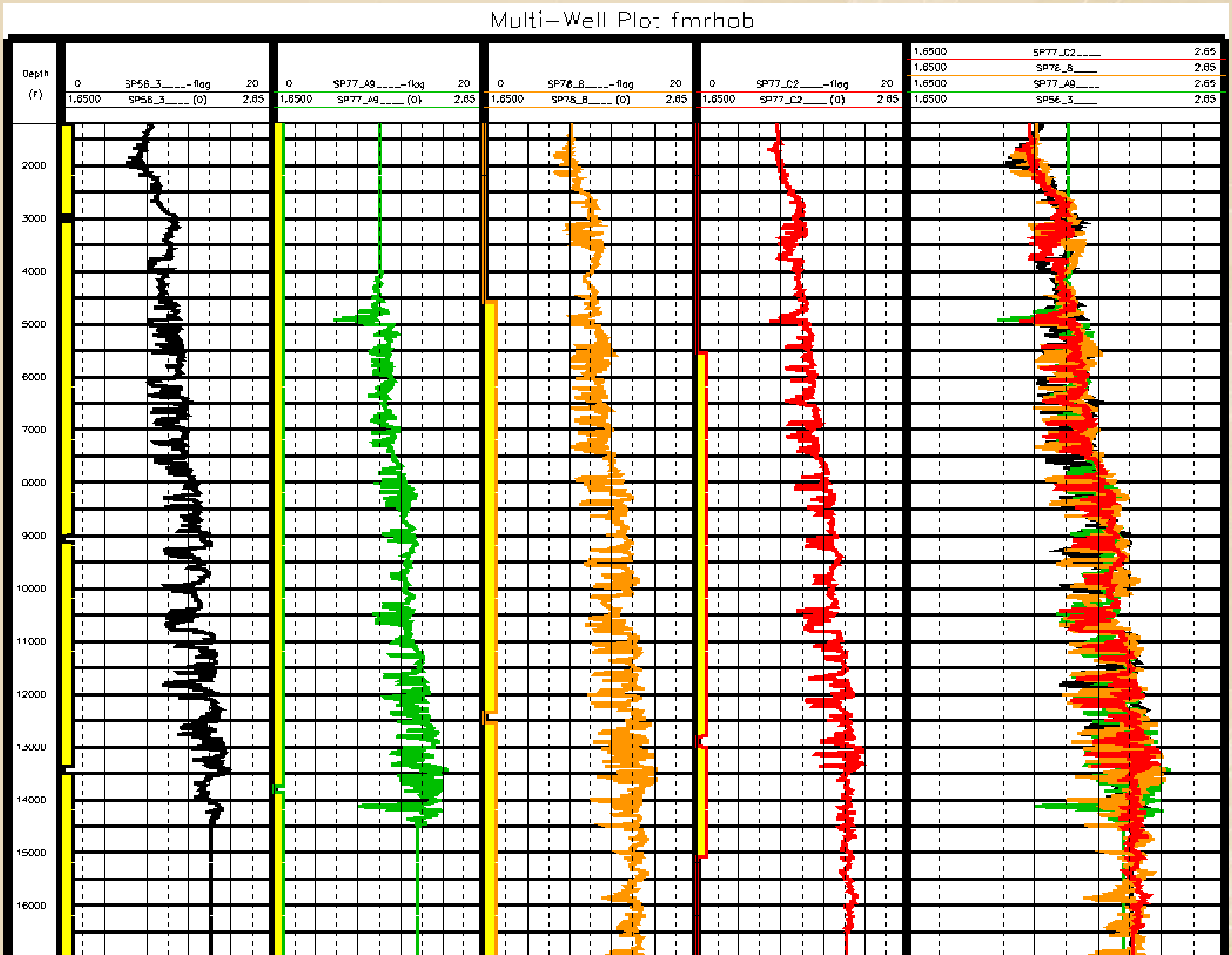
Edited Densities



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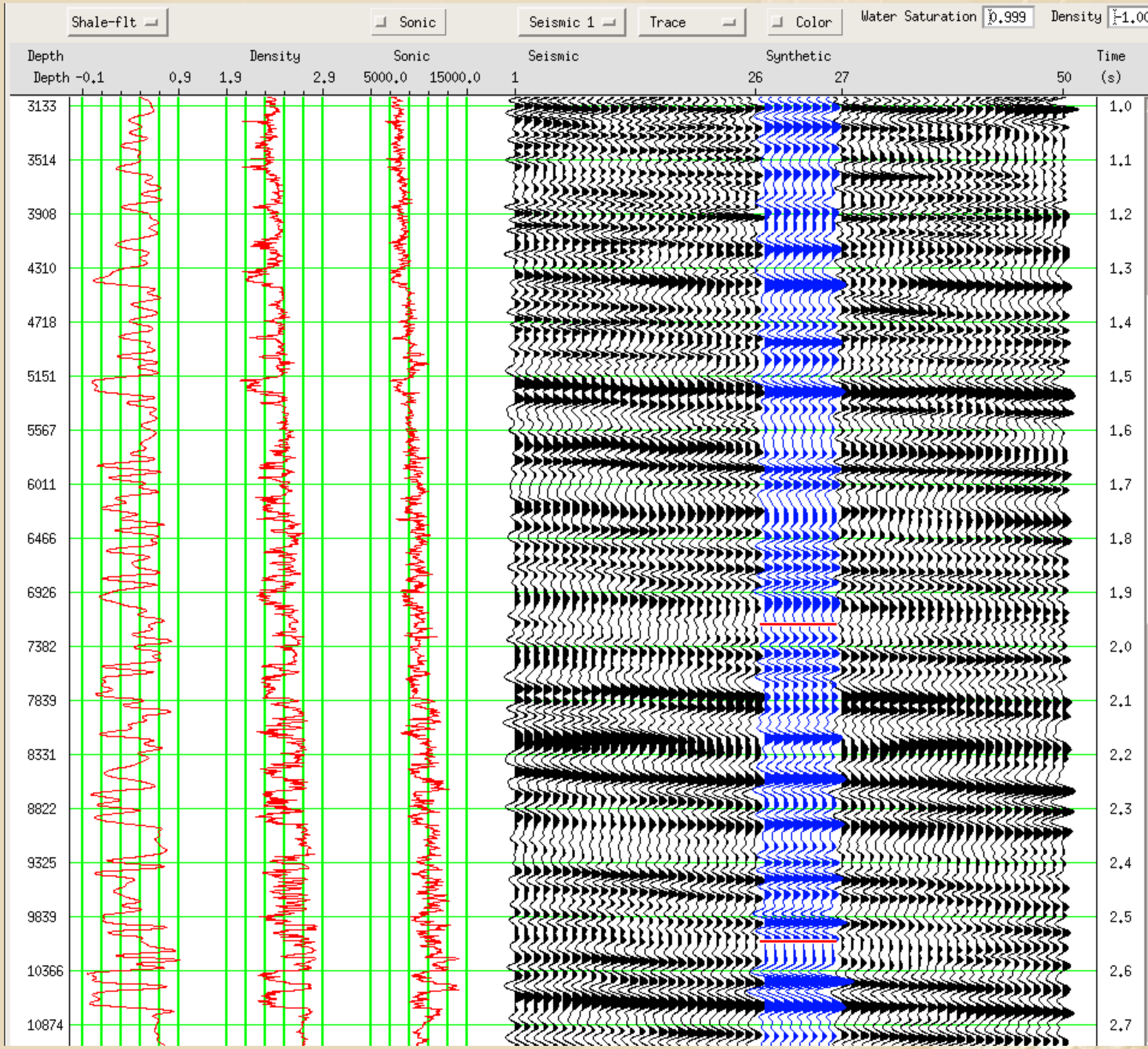
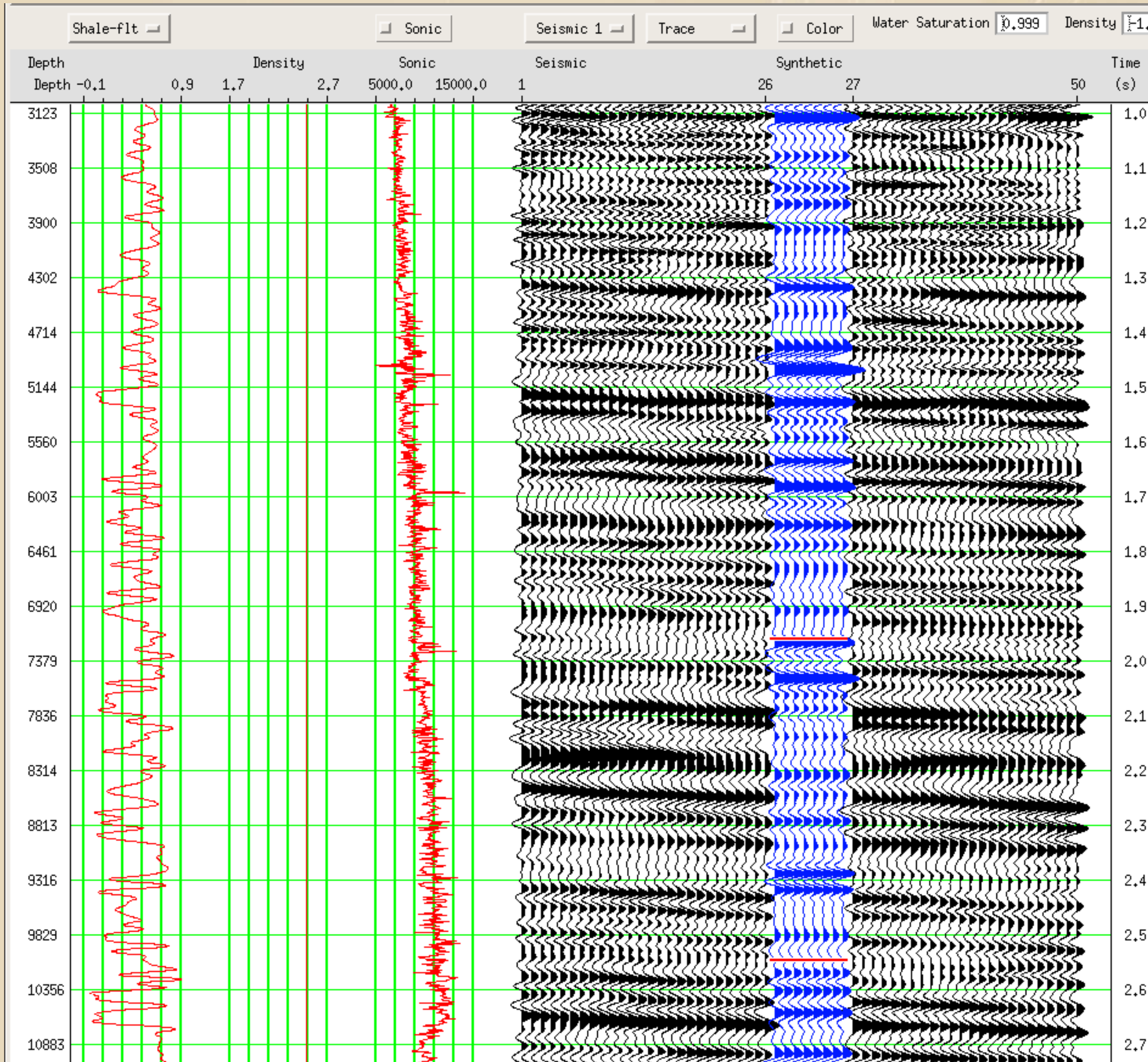
Well Tie Synthetic

Synthetic created from forward modeled logs



Well Tie Synthetic

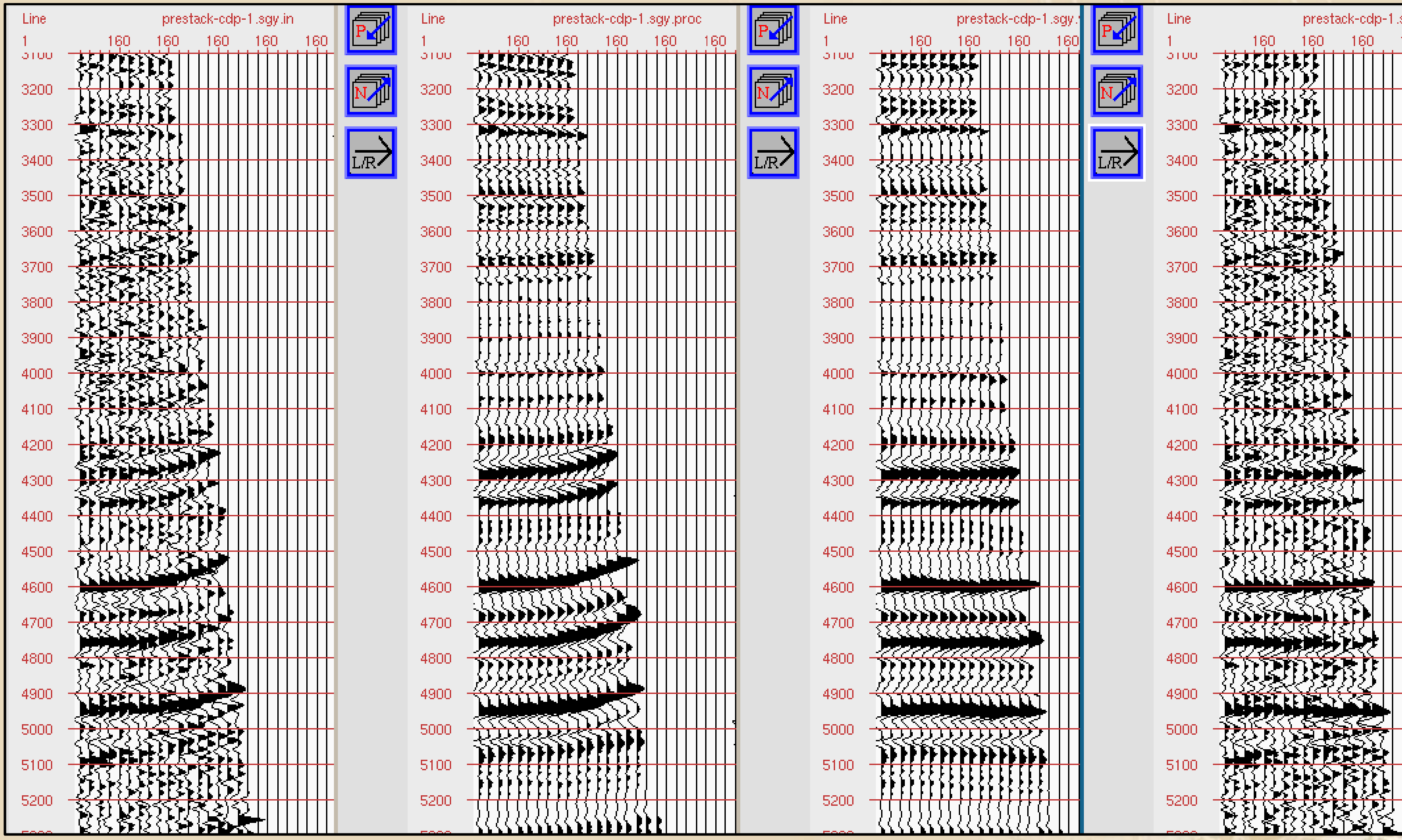
Synthetic created from forward RAW logs



VVO Workflow

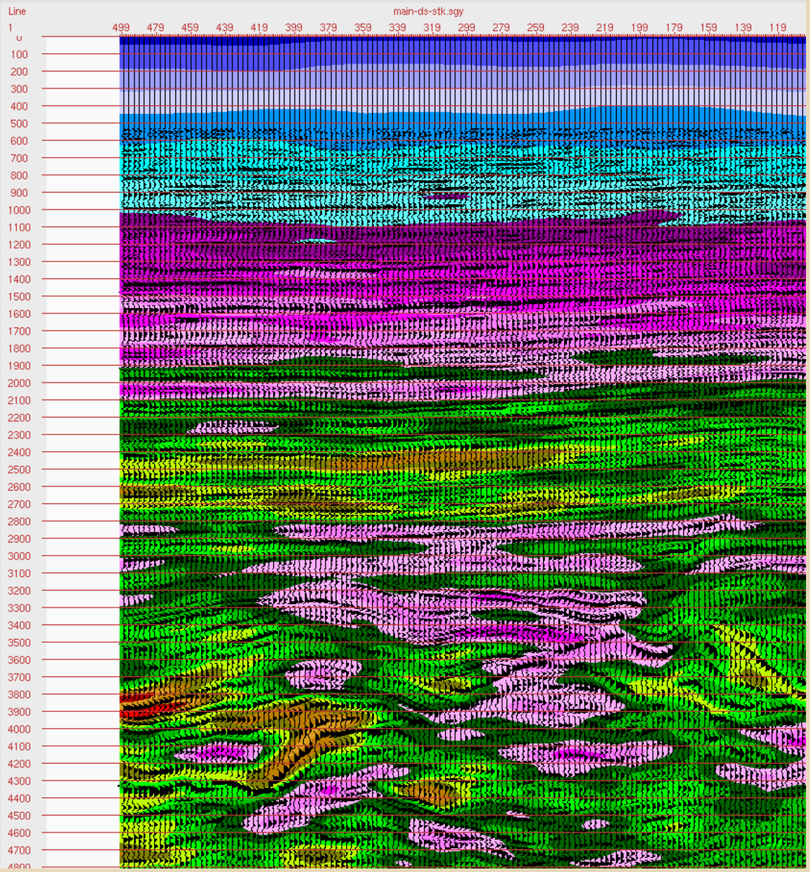
eSeis

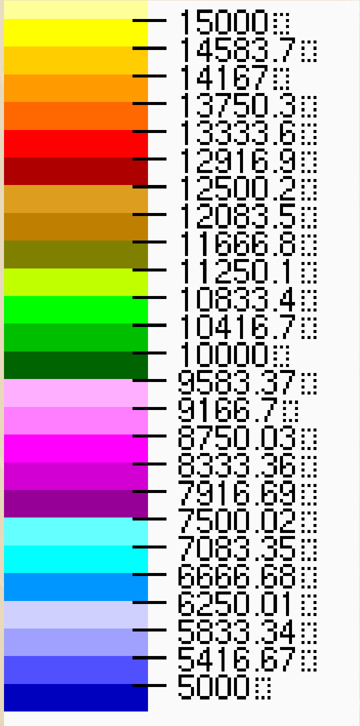
Input | Modeled | Vel Picks | Applied



PP-V

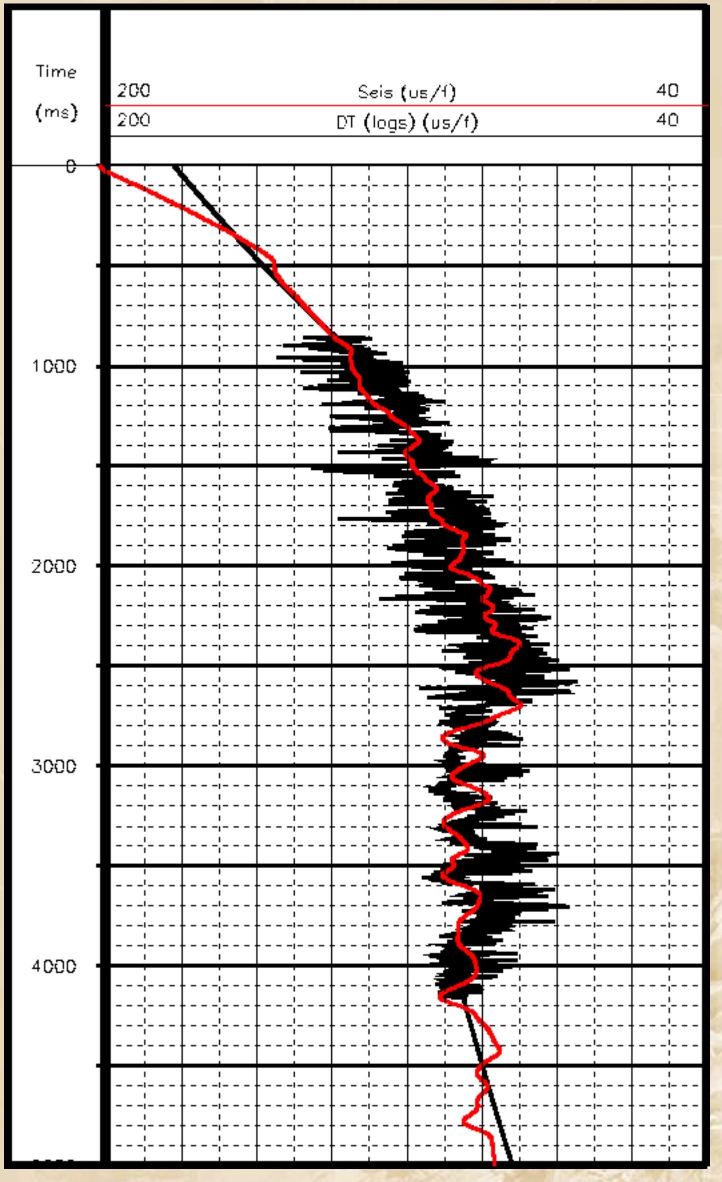
Interval Velocity





PP-V

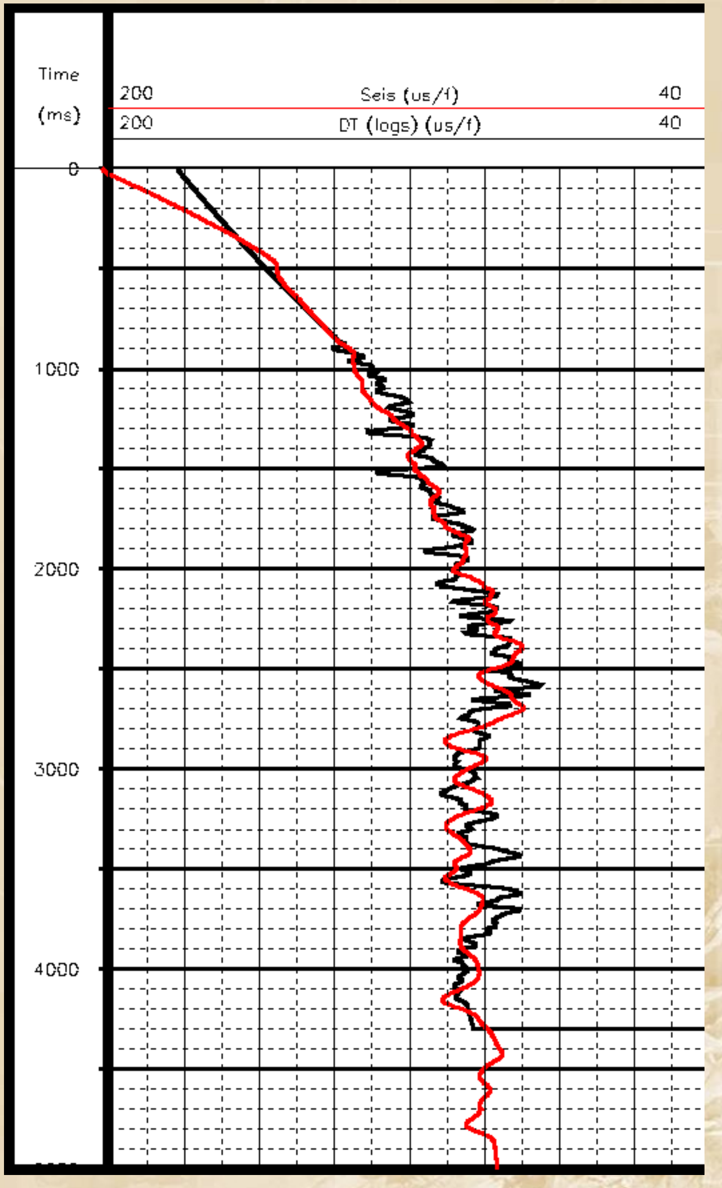
Velocity Analysis from Seismic
Sonic Log - Black



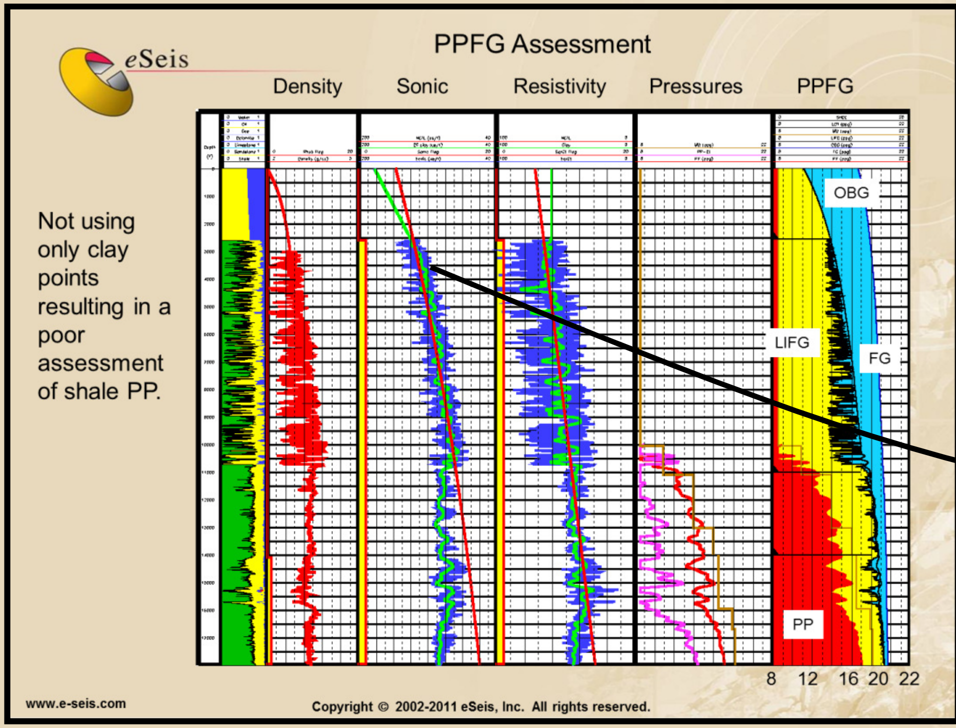
PP-V

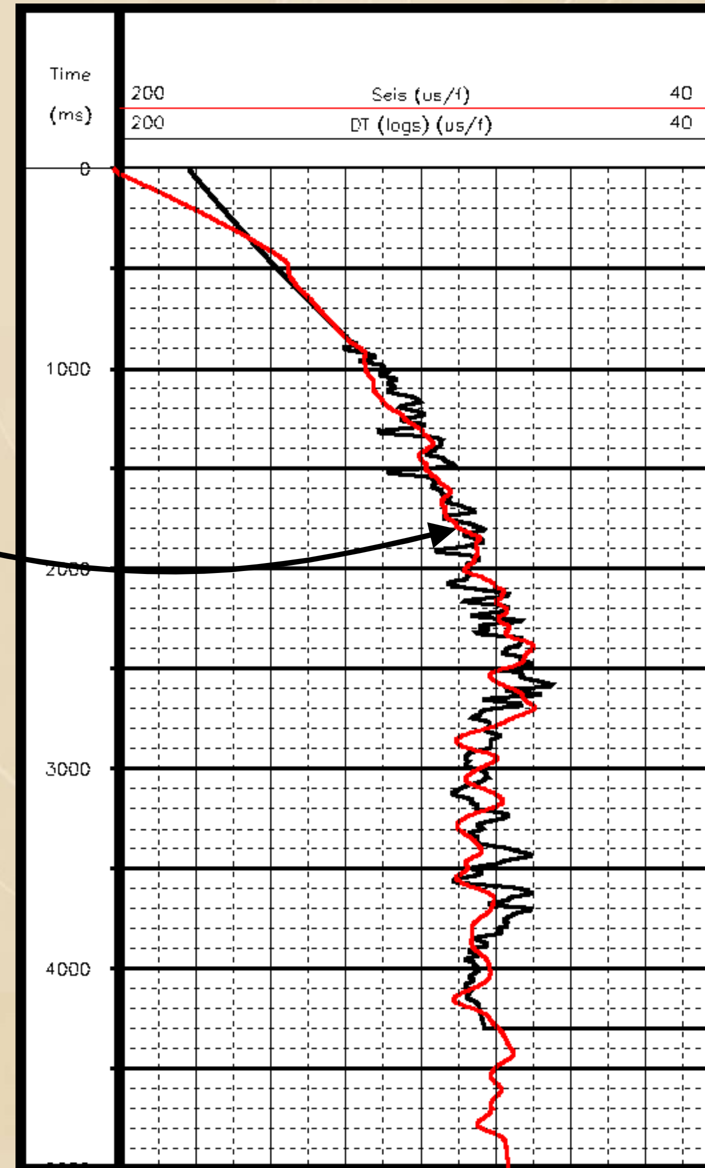
Velocity Analysis from Seismic

Smoothed Sonic Log - Black



PP-V



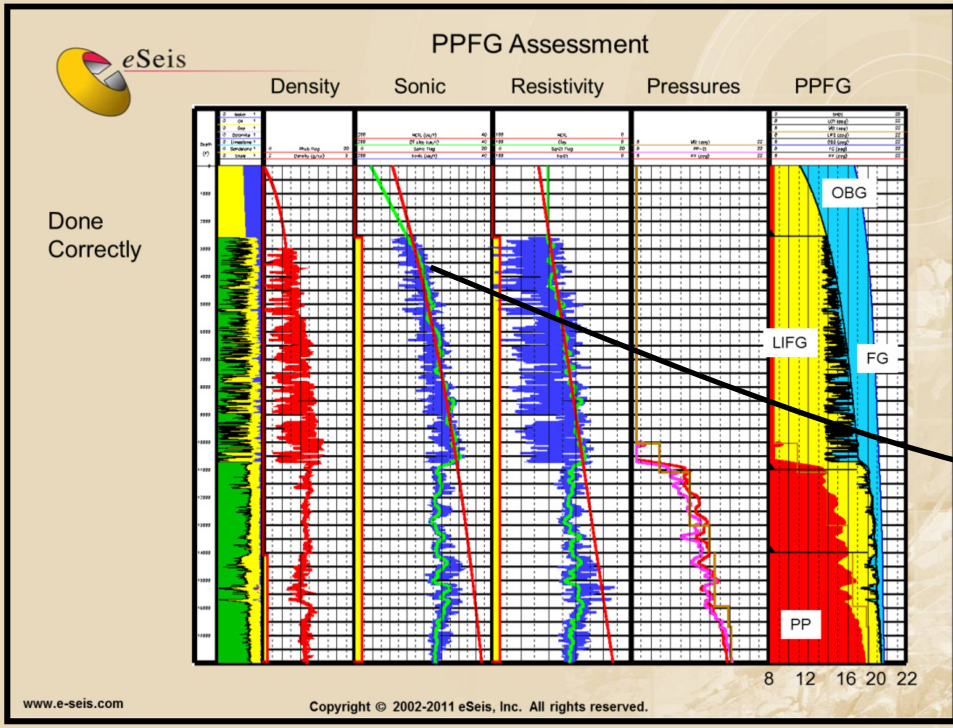


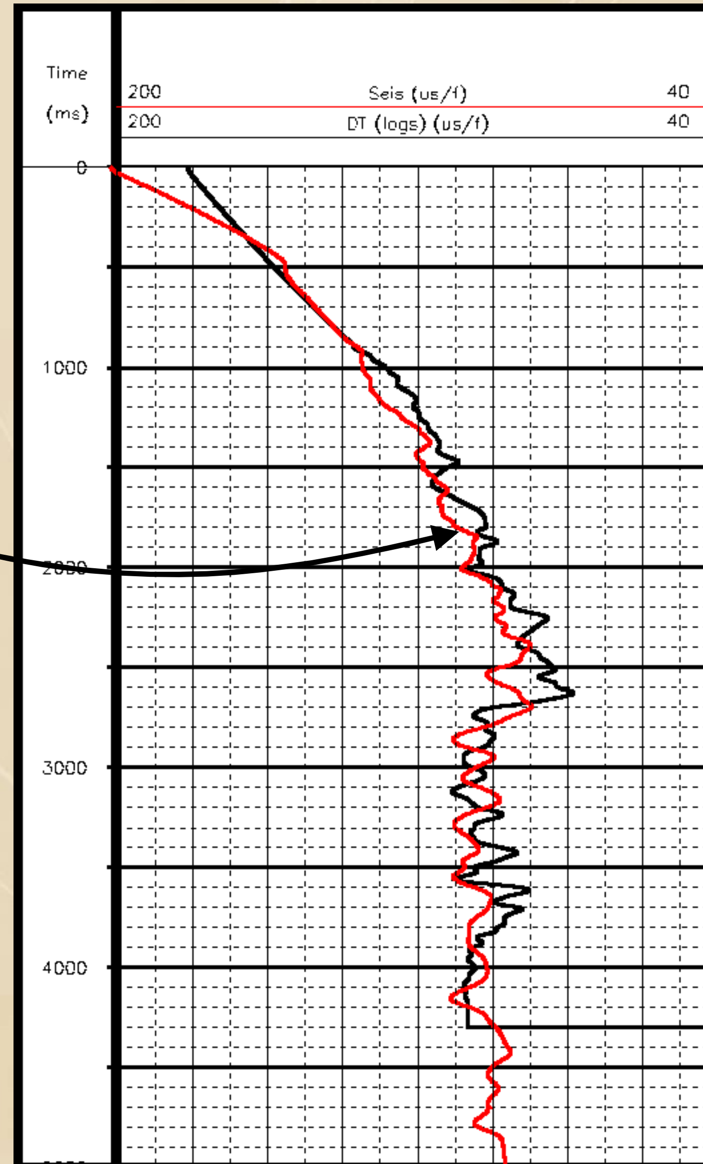
Velocity Analysis from Seismic

Smoothed Sonic Log - Black

PP-V

Done Correctly





Velocity Analysis from Seismic

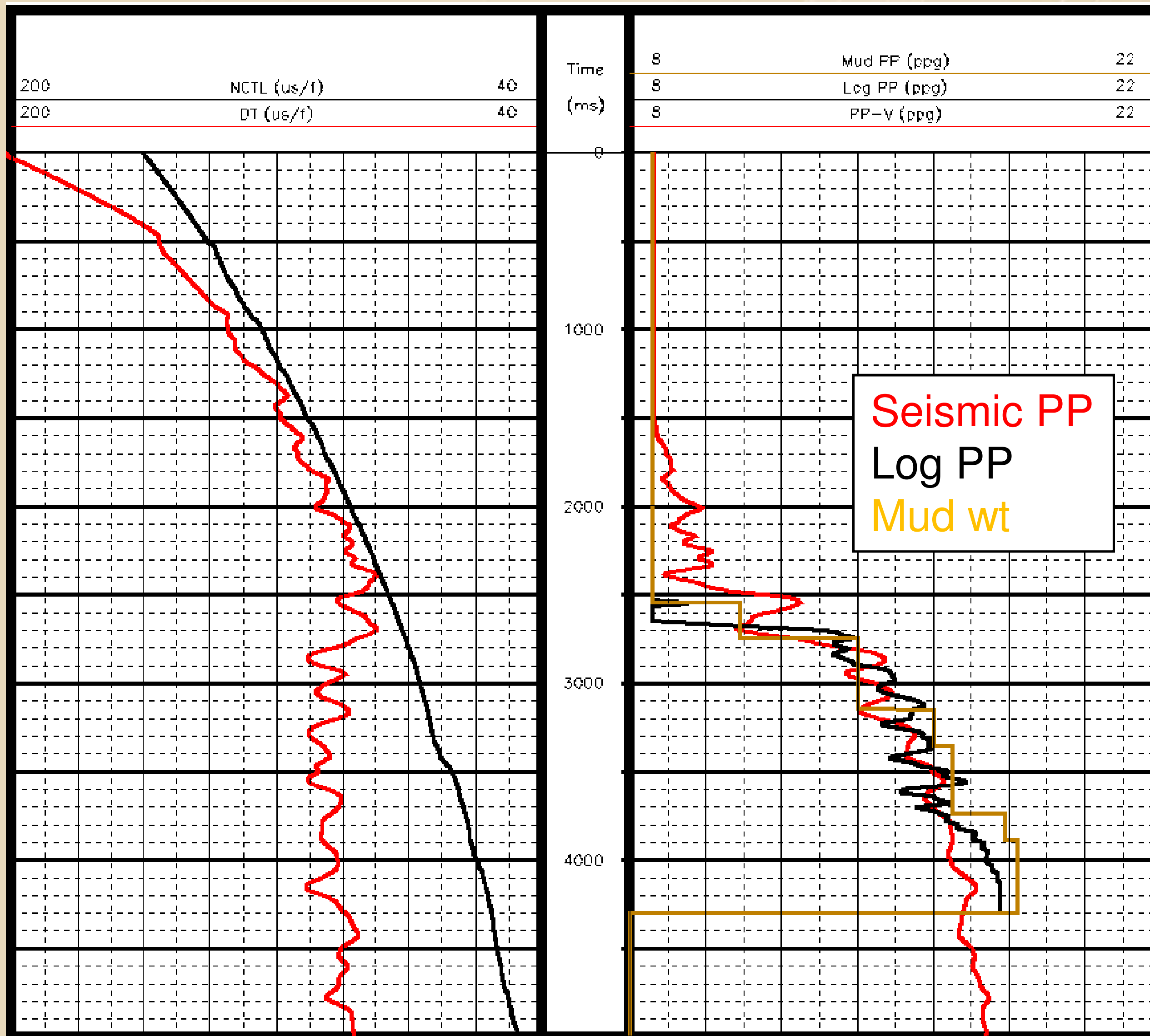
Smoothed Sonic Log (Shale Points) - Black

PP-V

Seismic Slowness

Pressures

PP from seismic



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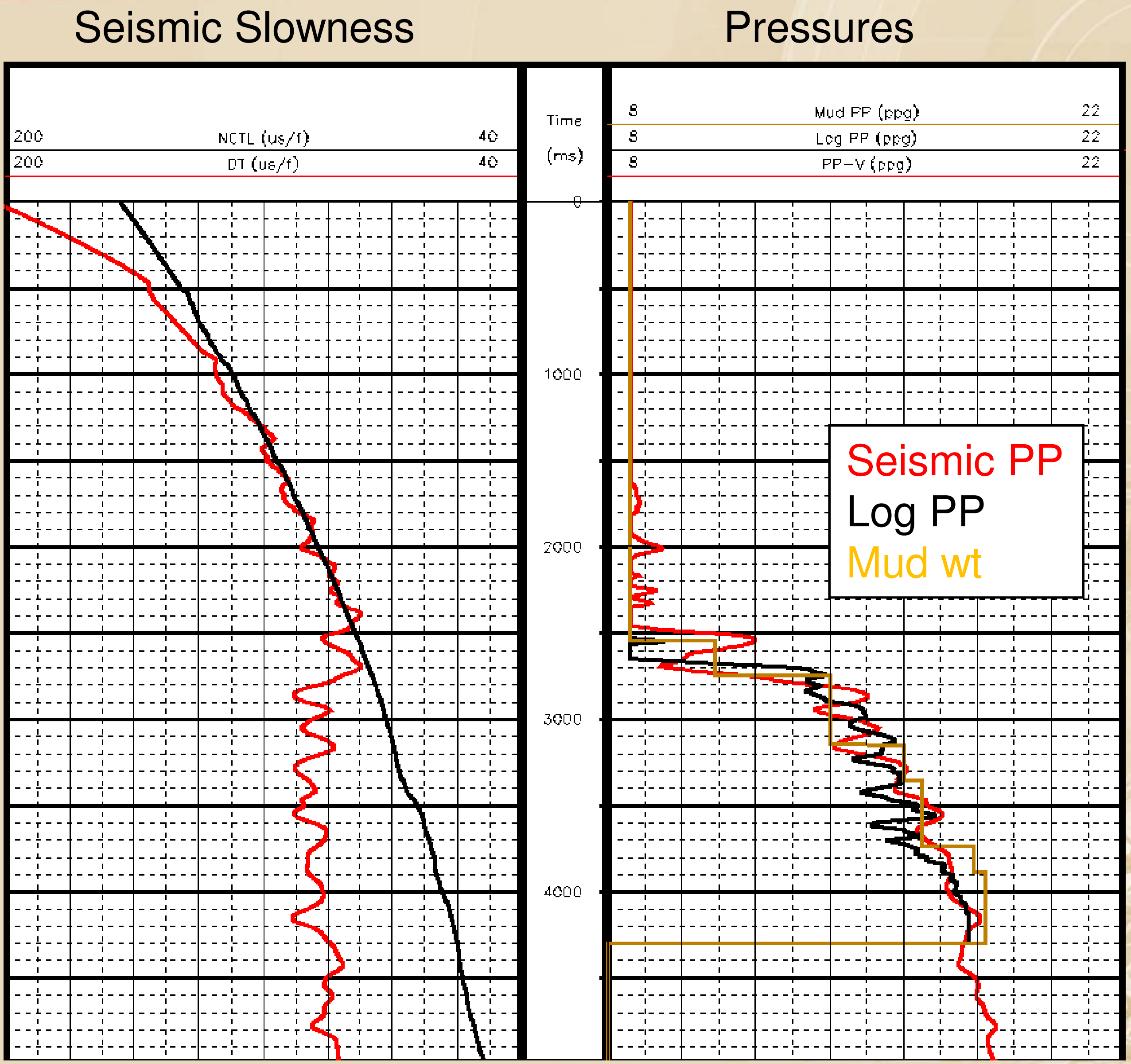
PP-V

PP from seismic



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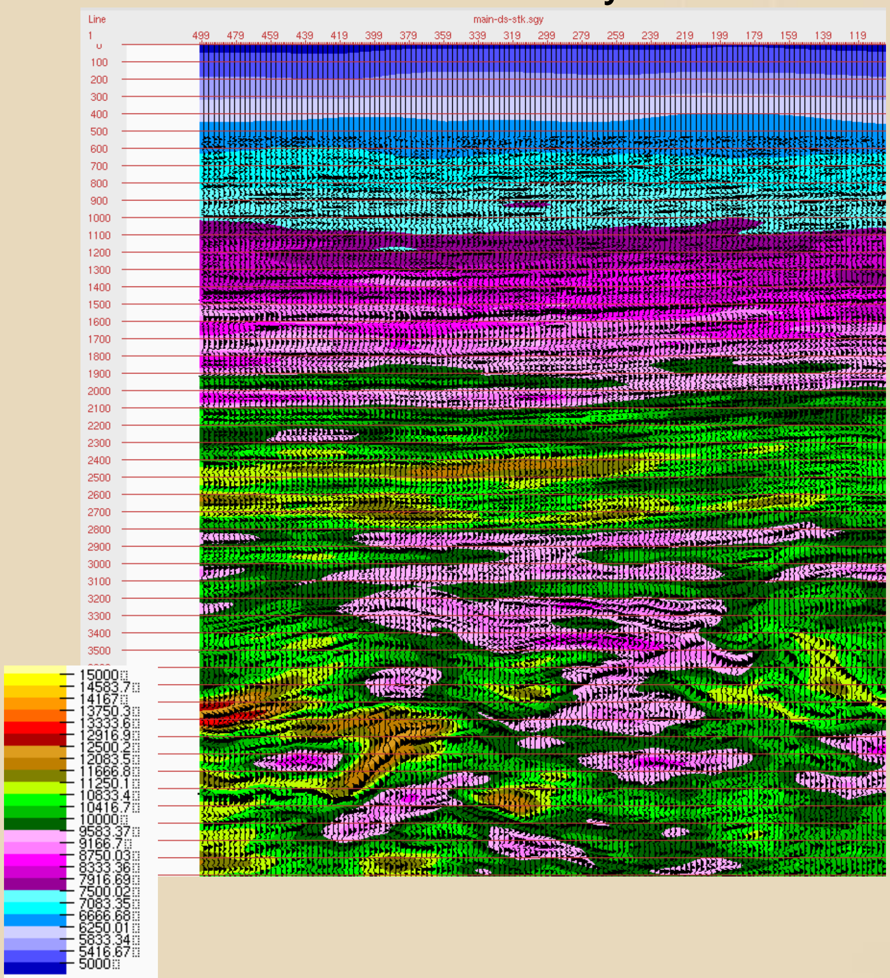
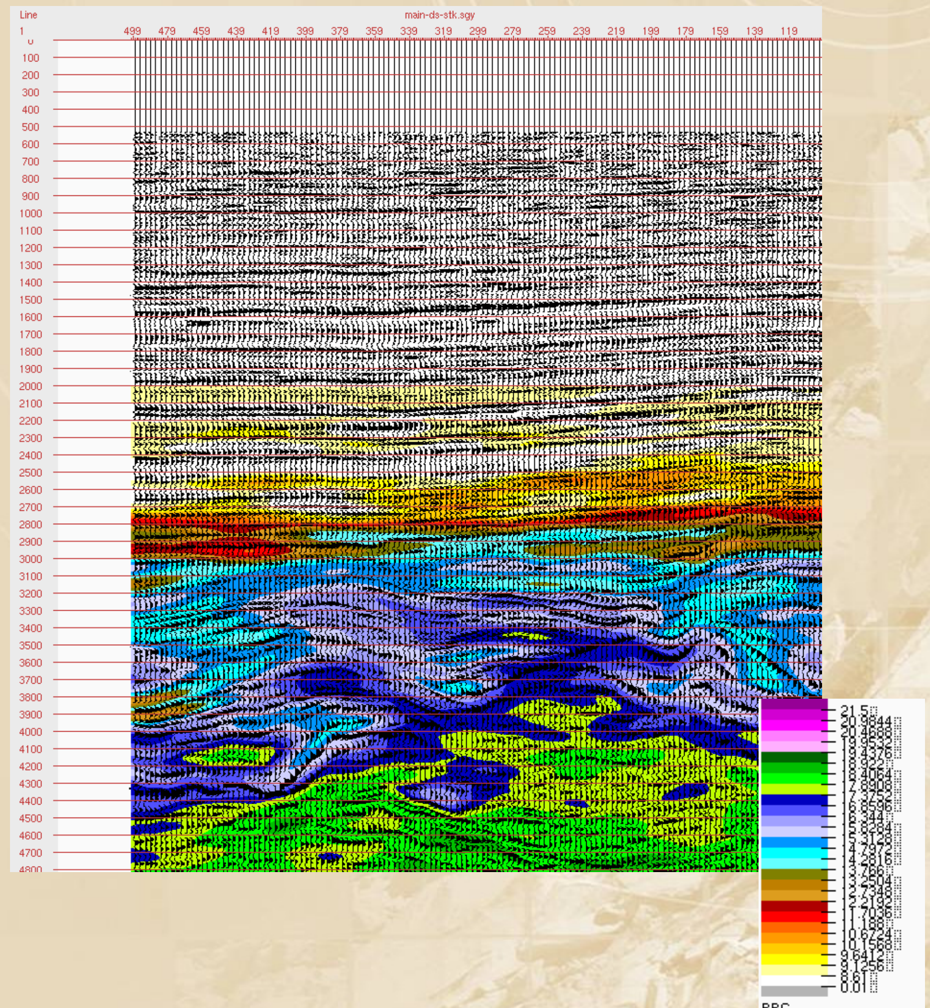
PP-V

Interval Velocity



PP-V

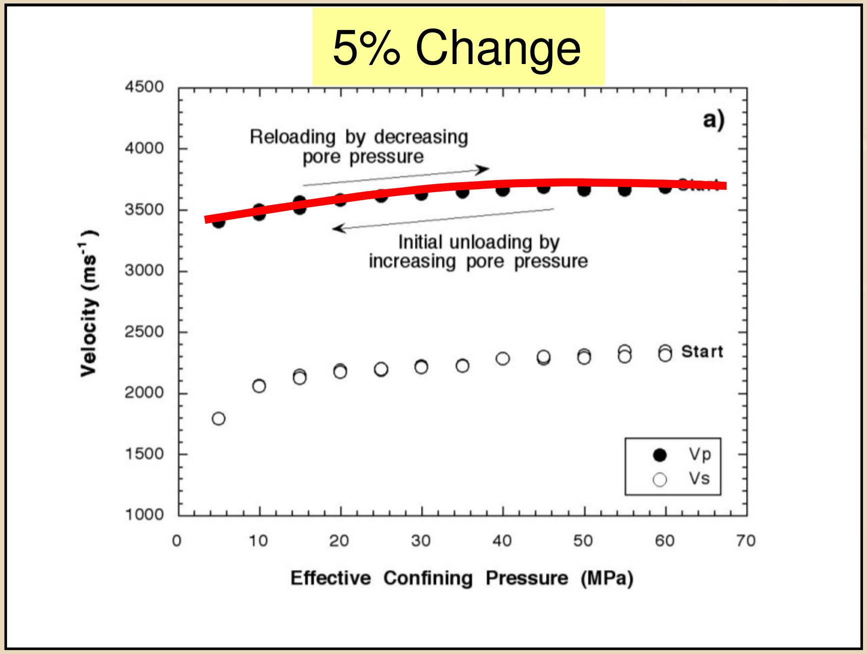


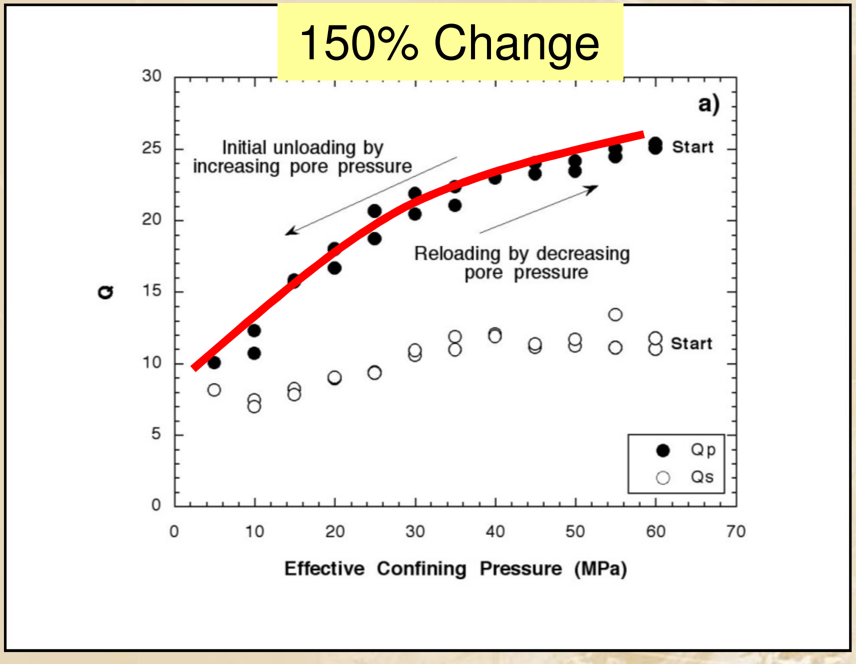
Lab Results

OTC 13043

Stress Path, Pore Pressure and Microstructural Influences on Q in Carnarvon Basin Sandstones

A.F. Siggins and D.N. Dewhurst (CSIRO Petroleum, Australia) and P.R. Tingate (National Centre for Petroleum Geology and Geophysics, University of Adelaide, Australia).





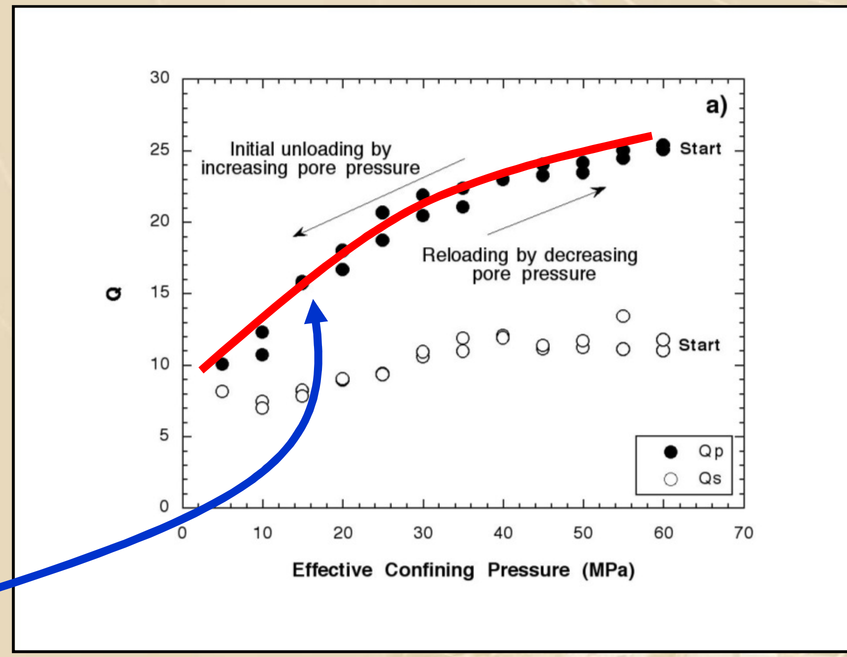
Experimental Results

Numerous authors have reported on the experimental relationship between Q_p and Pressure ($P_{eff\ stress}$,P_p) .

Such as:

Birch and Bancroft	1938
Johnston et al	1979
Lucet and Zinszner	1992
Best and Sams	1997
Carcione	2000
Siggins and Dewhurst	2001

With results like this



Q-Based Pore Pressure

What is Q?

Q stands for Quality Factor

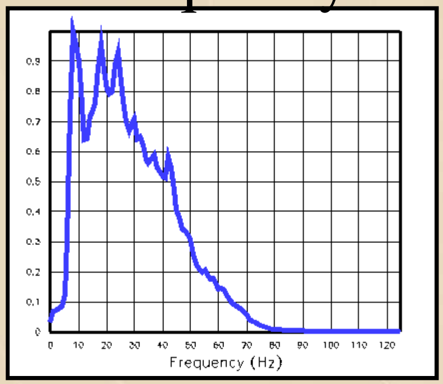
Q is the inverse of attenuation

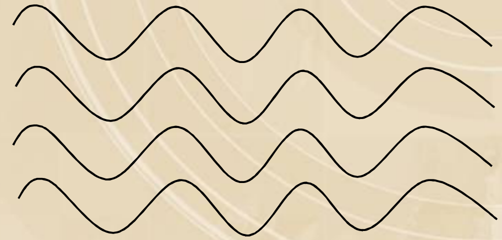
$$\frac{2\pi}{Q} = \frac{\Delta E}{E}$$

An Intuitive Explanation

Q-Based Shale Pore Pressure

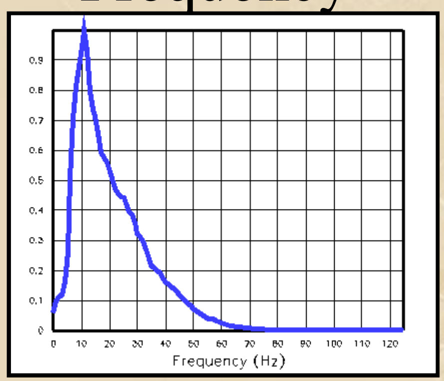
Frequency





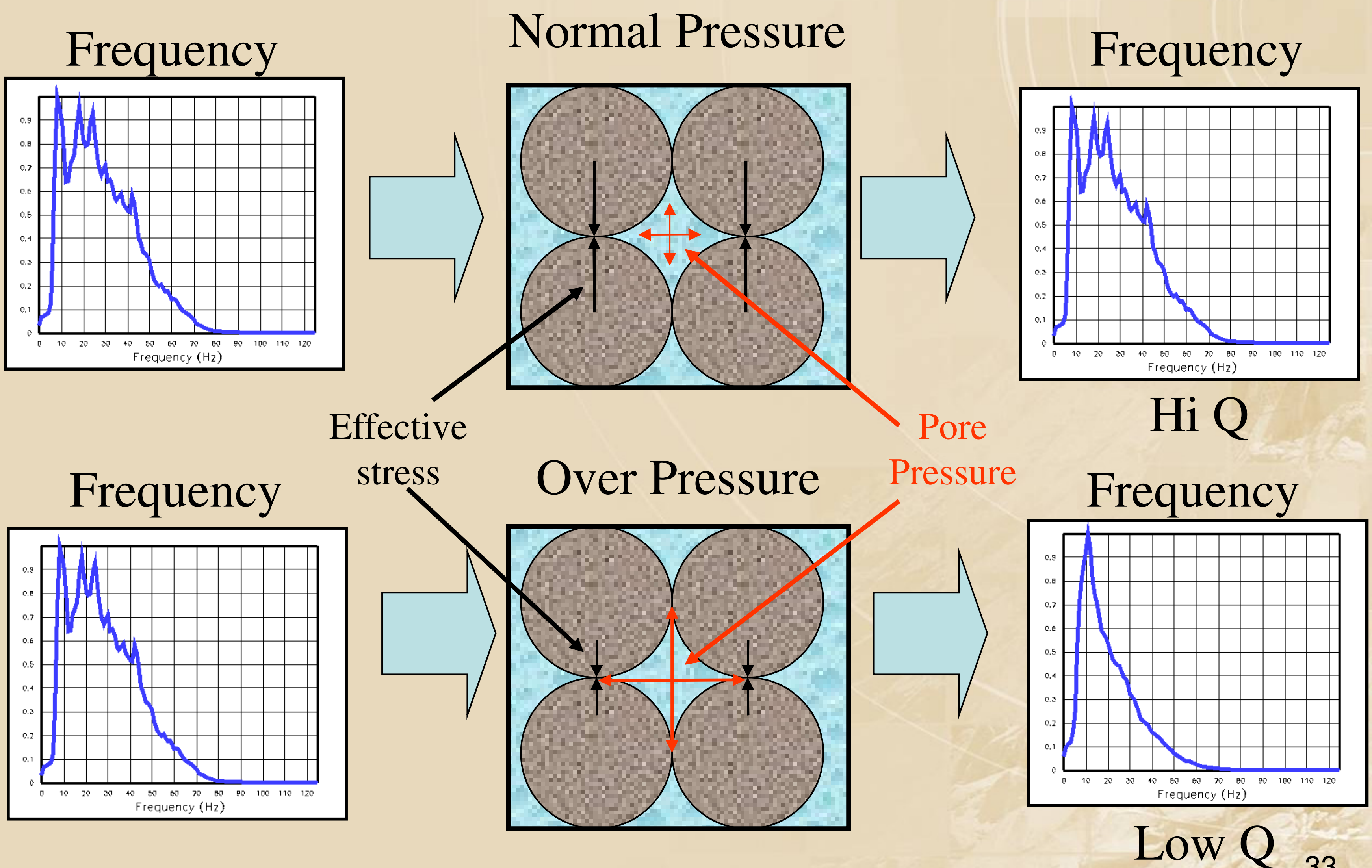
Hi Q

Frequency



Low Q

Q Responds to Effective Stress

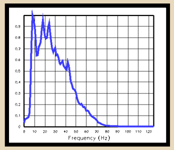


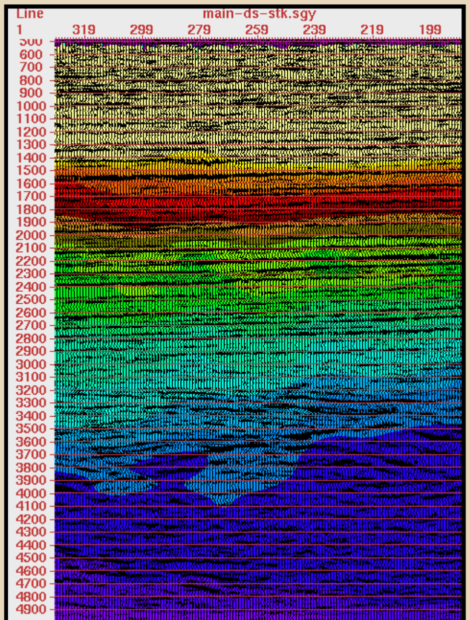
Q-Based Pore Pressure

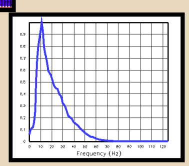
Procedure

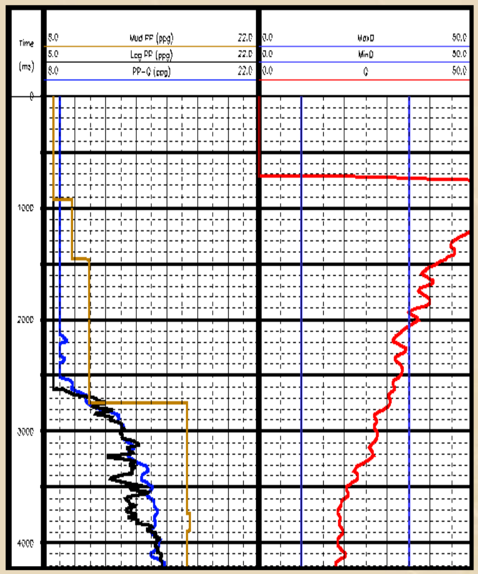
Q-Based PP Procedure

Frequency Decay

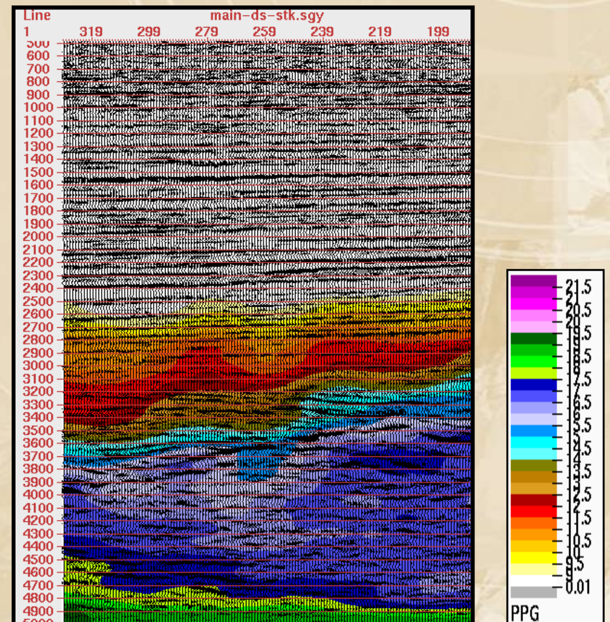






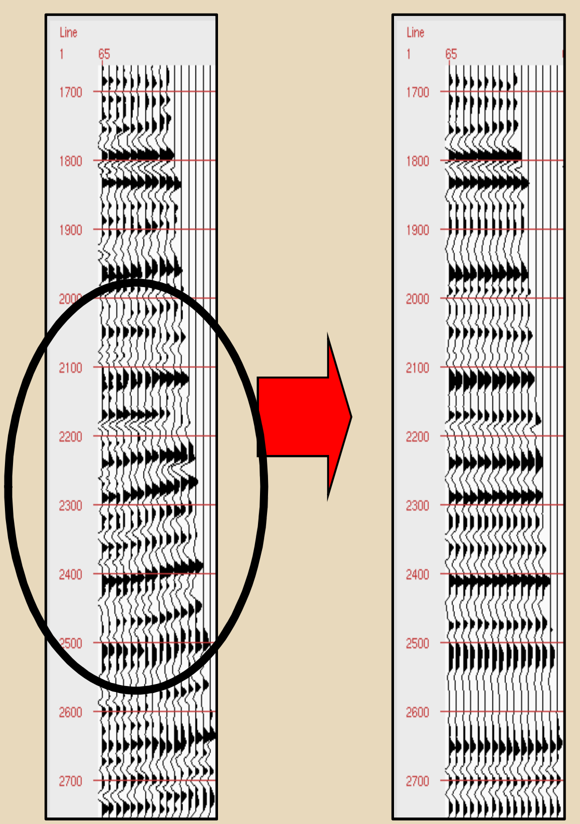


Pore Pressure

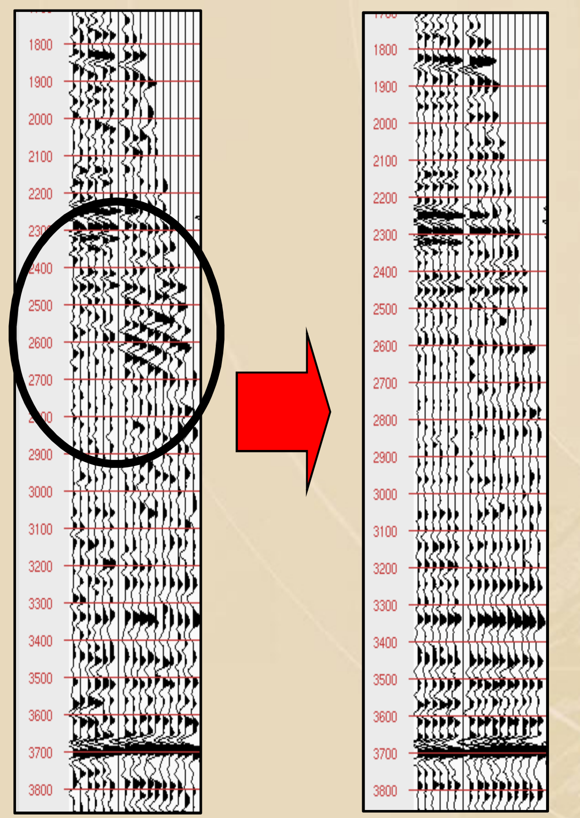


PP-Q
More Detail

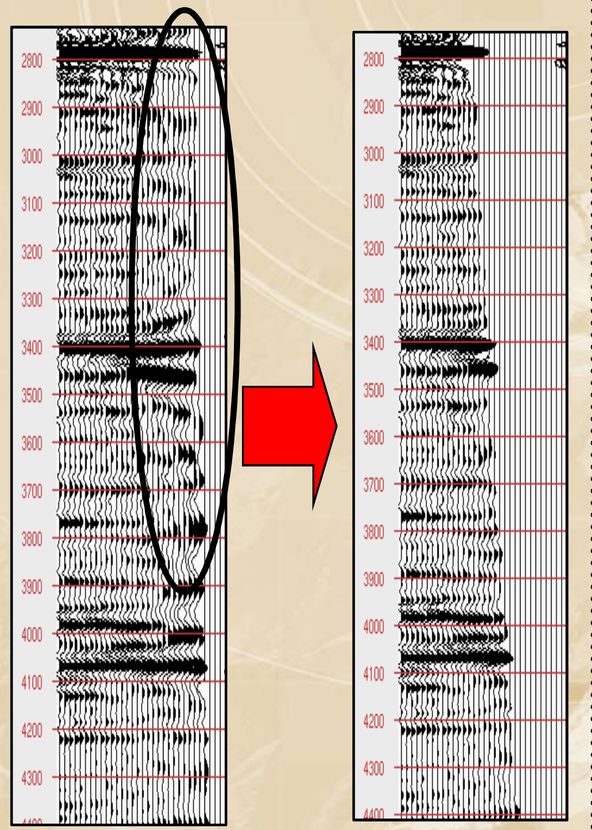
Seismic Data Preparation



Residual NMO

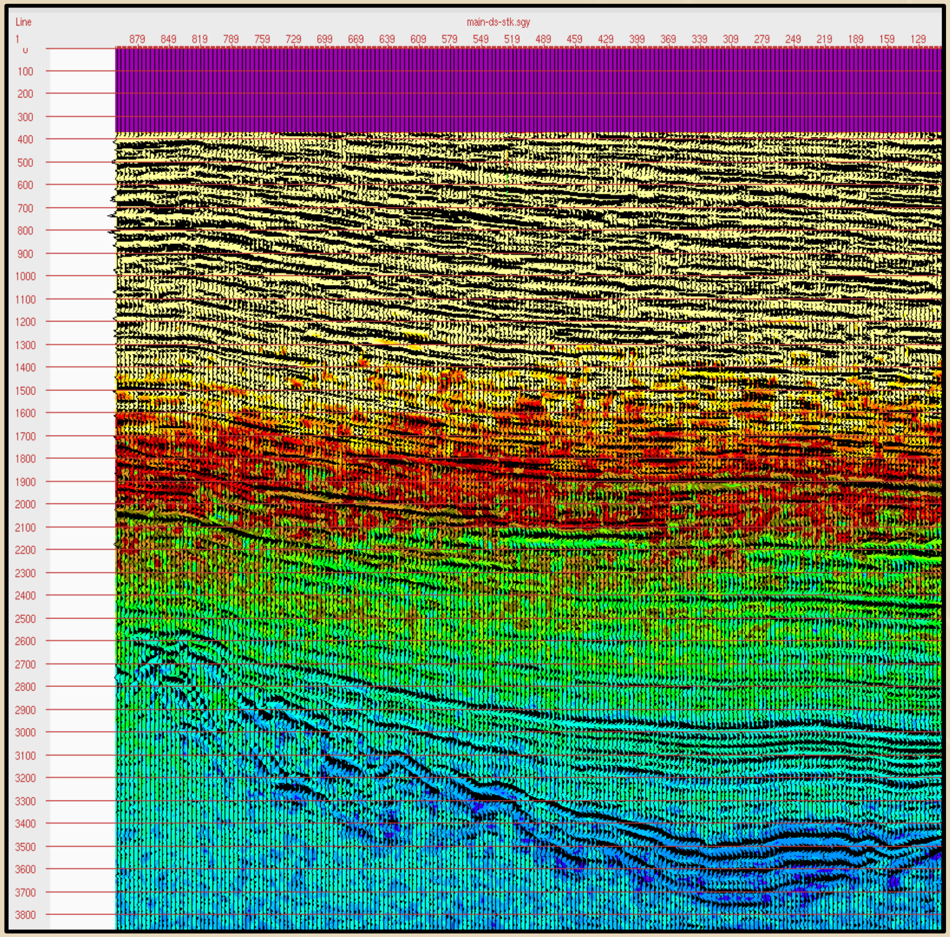


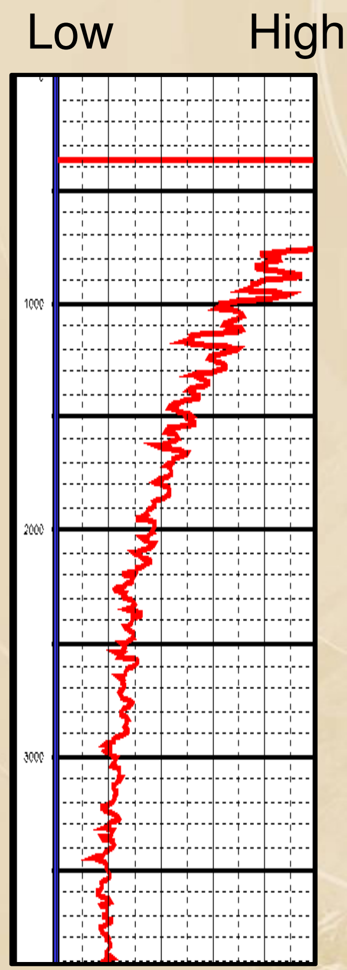
Multiple Removal

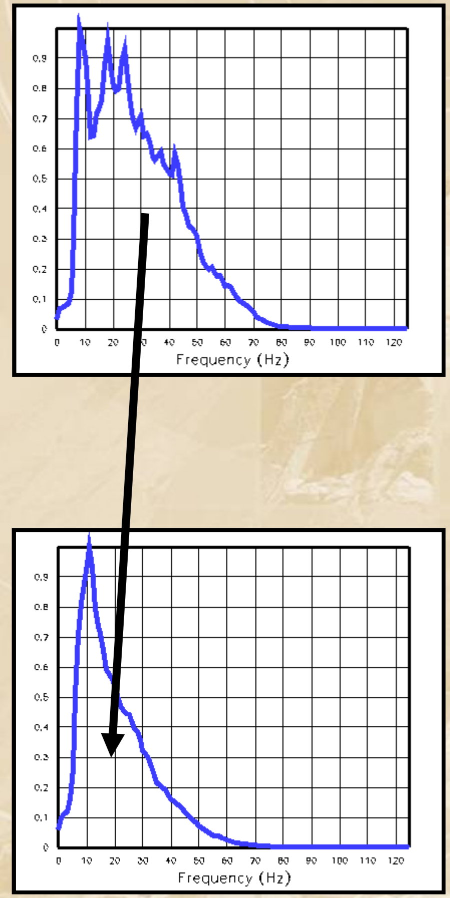


NMO Stretch

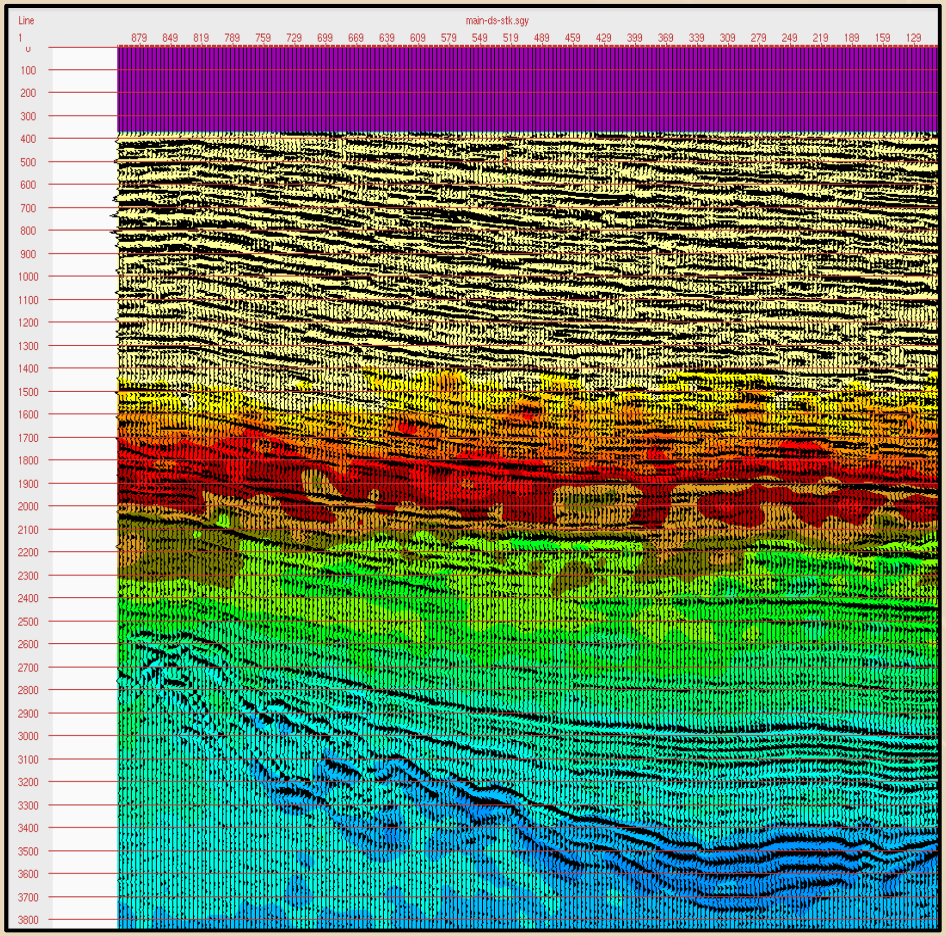
Seismic Frequency



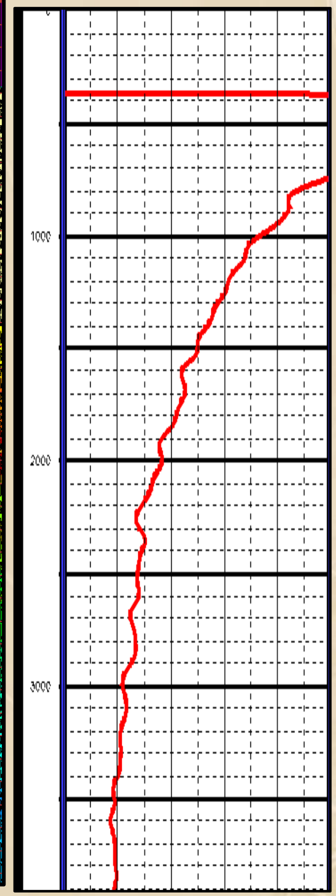


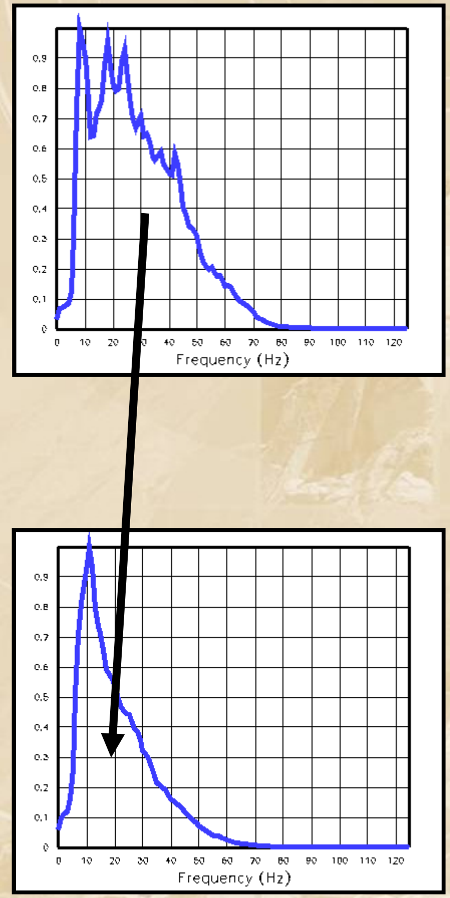


Seismic Frequency

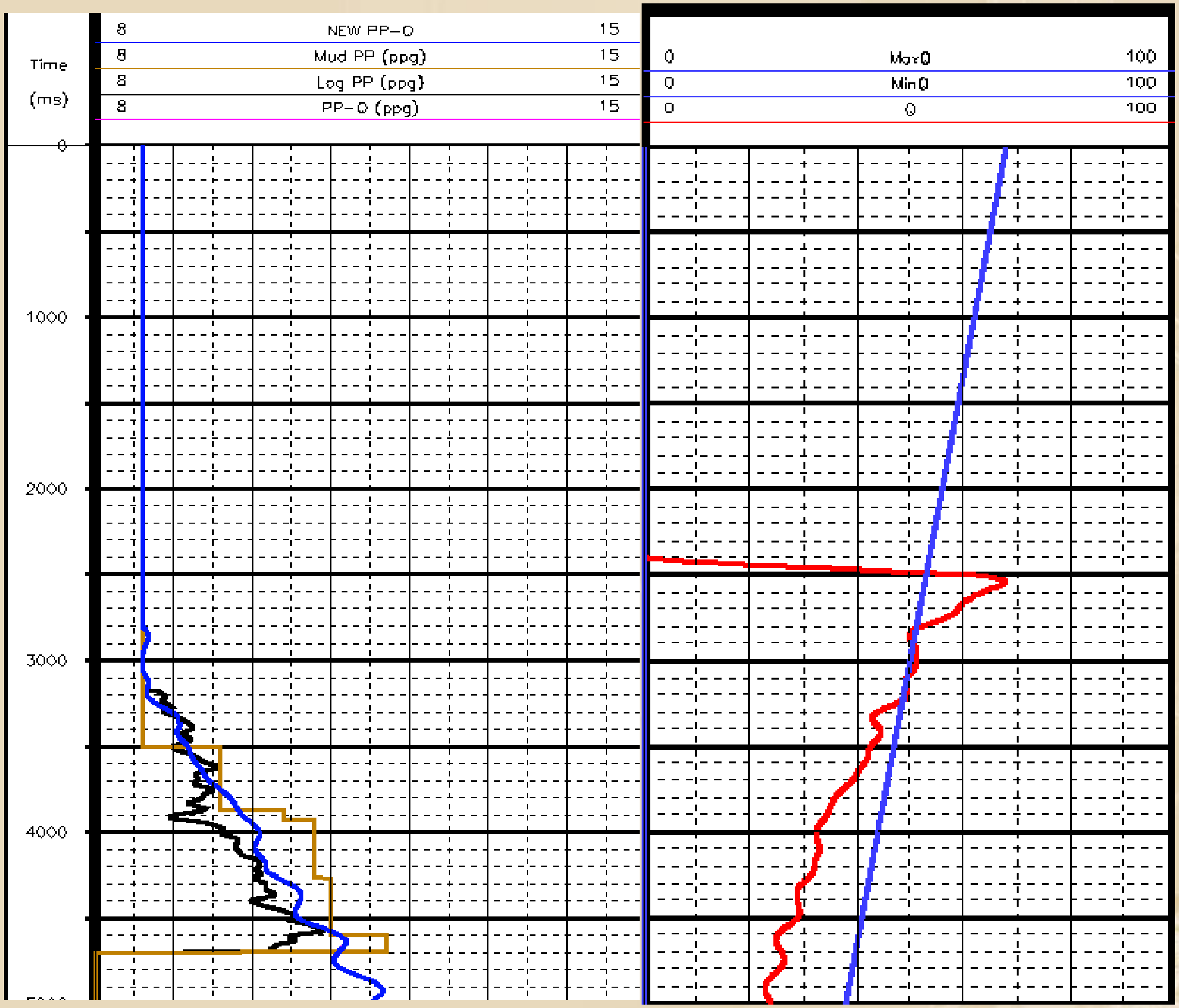


Low High

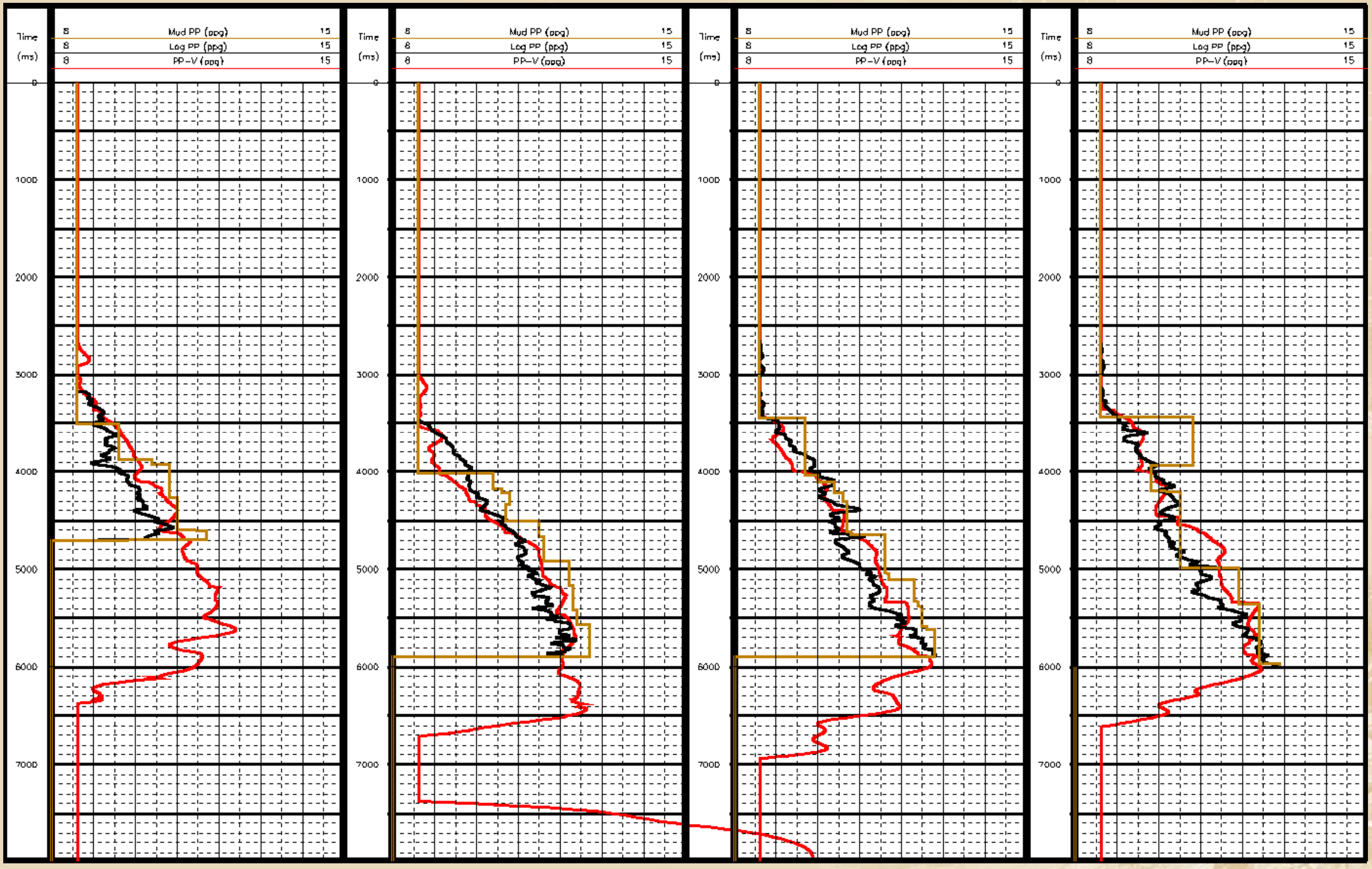




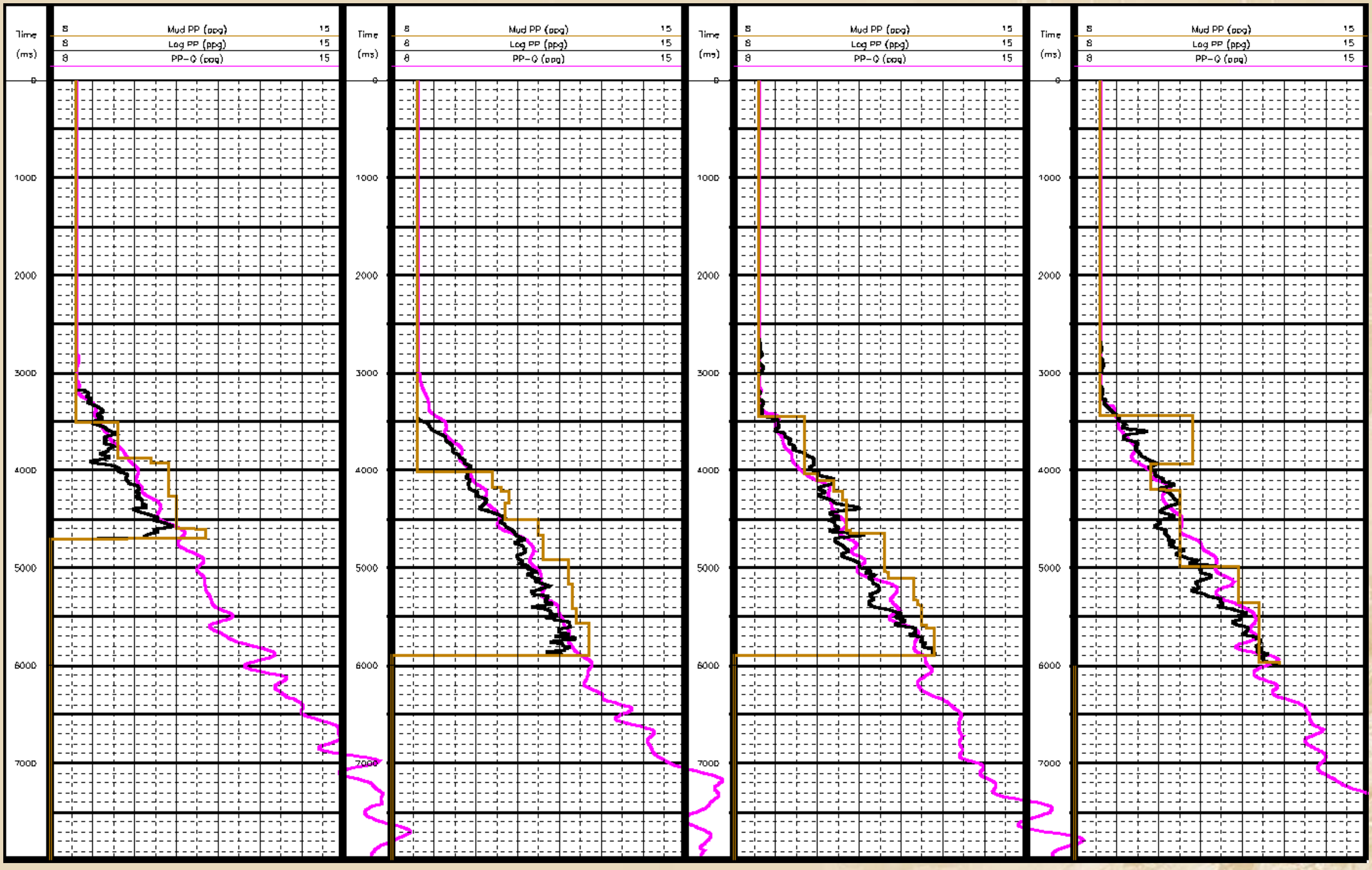
Deep Water Frequency Trend



PP-V Calibration



PP-Q Calibration



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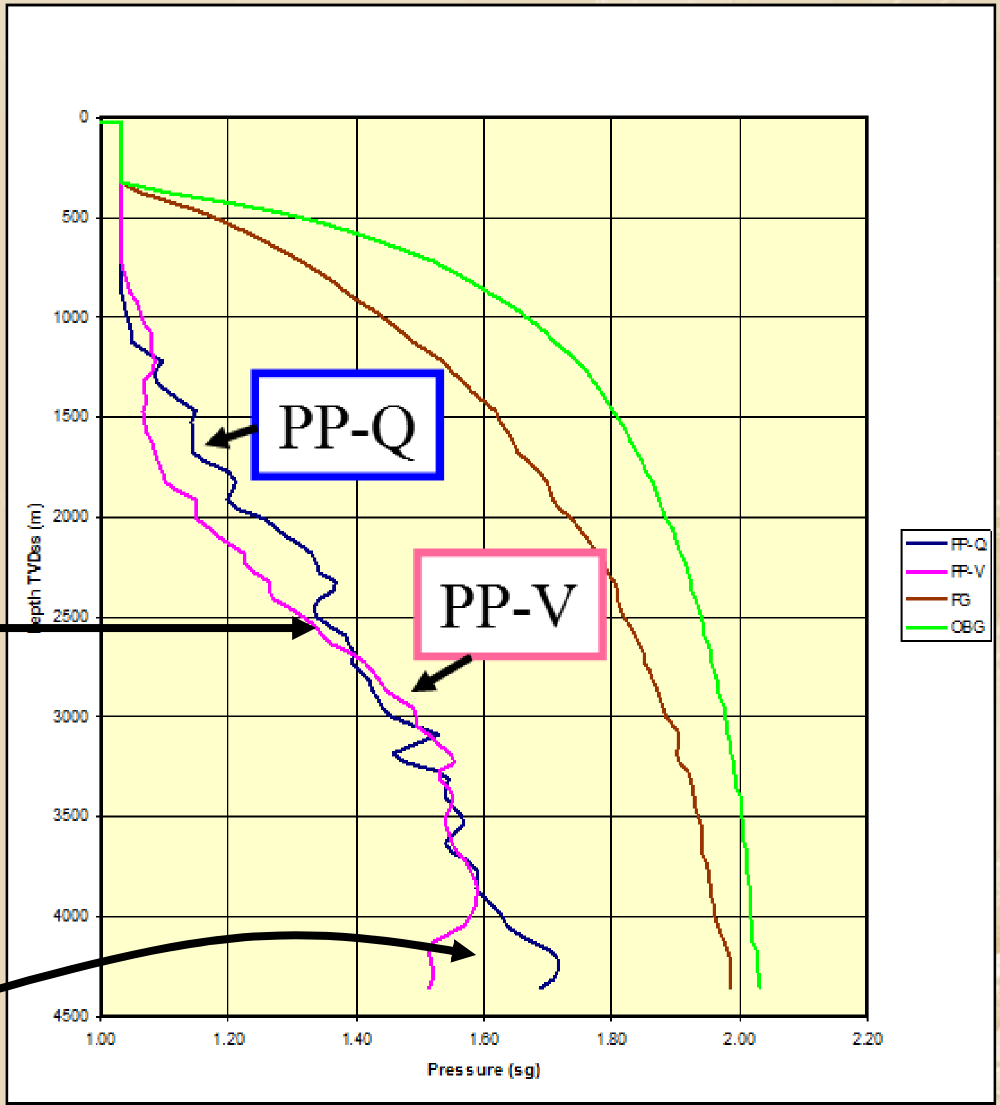
Examples

Water Bottom

Moderate Sand/Shale Ratio

Shale

Steep Structure
Causing
Seismic Velocity Issues

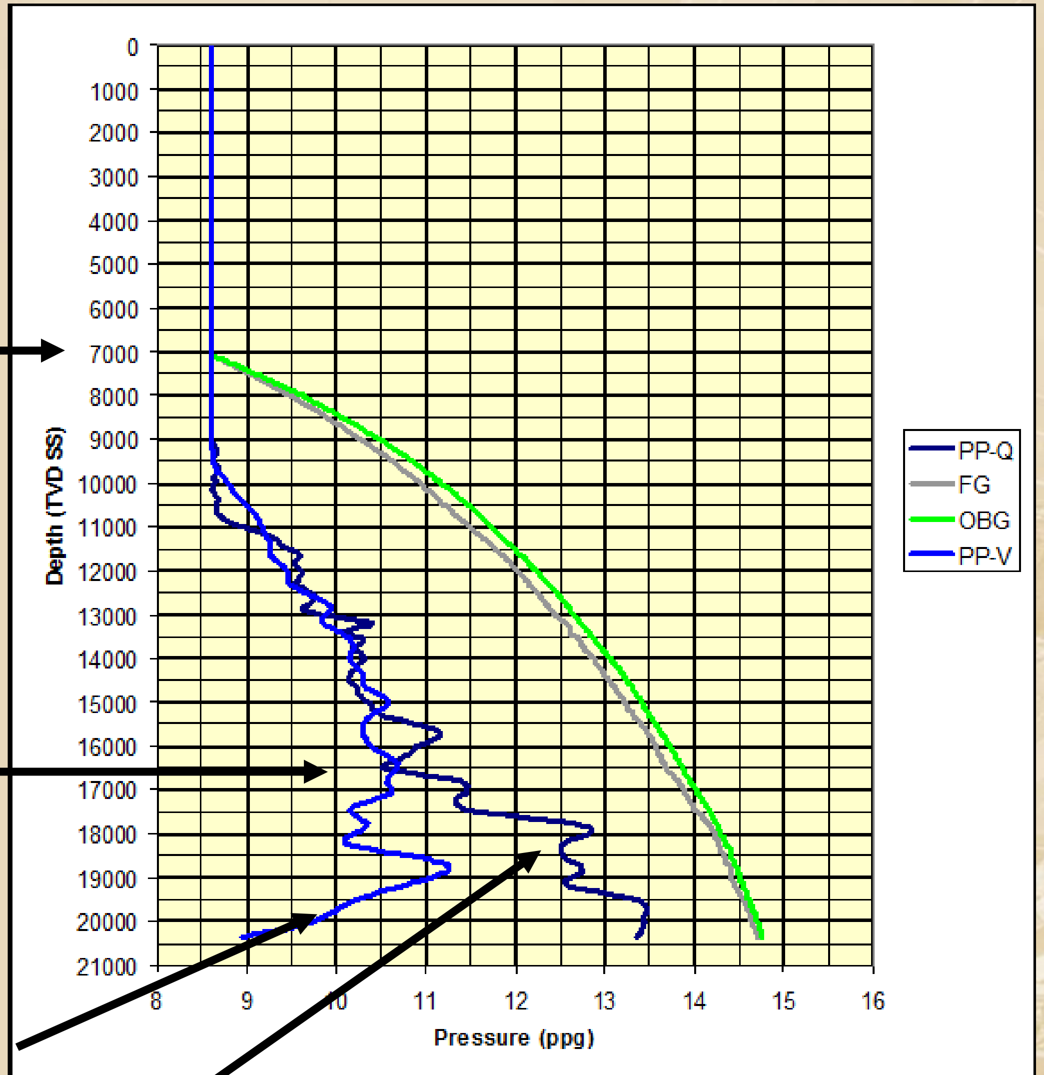


Water Bottom

Shaley

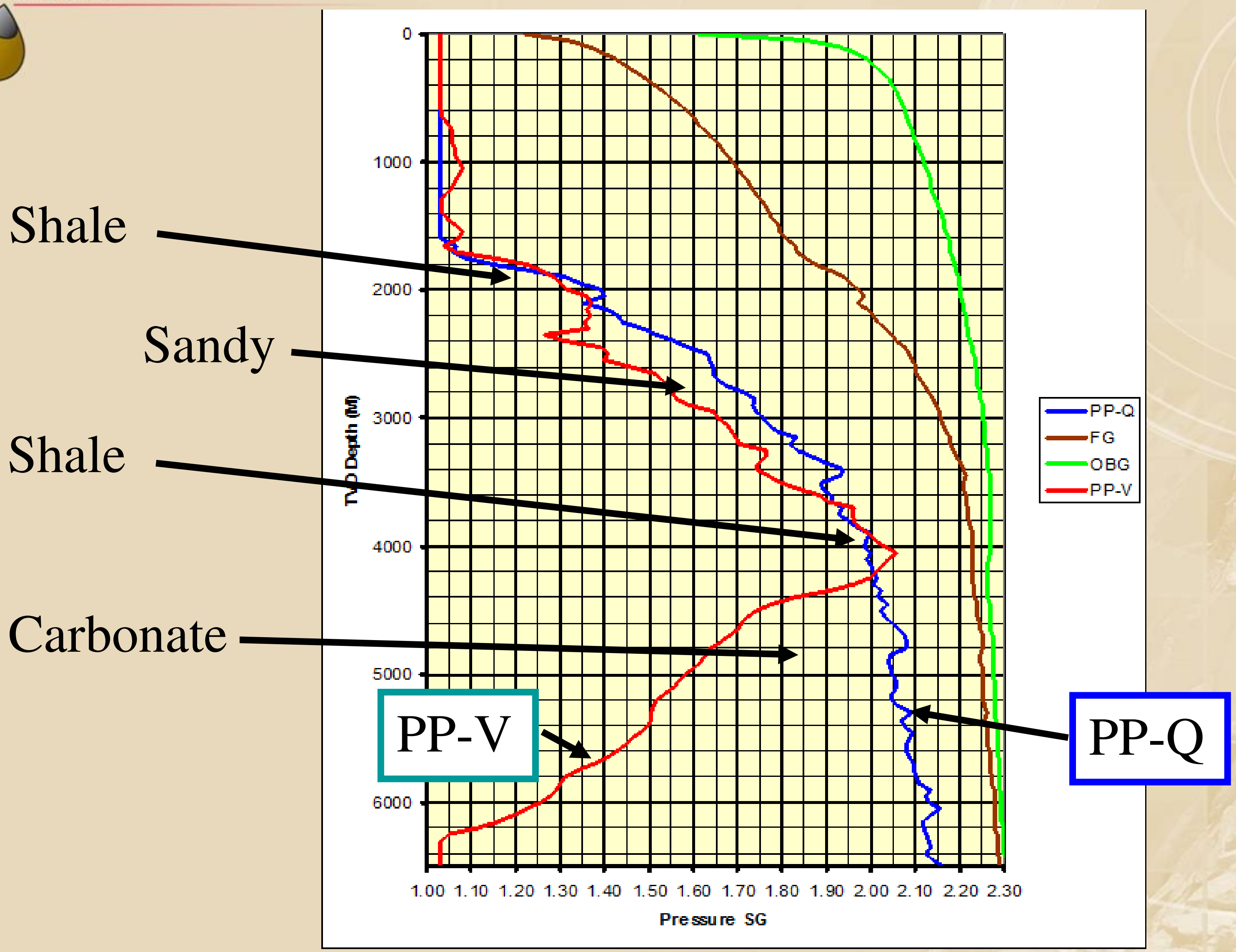
Clastics

Sandy and Tight

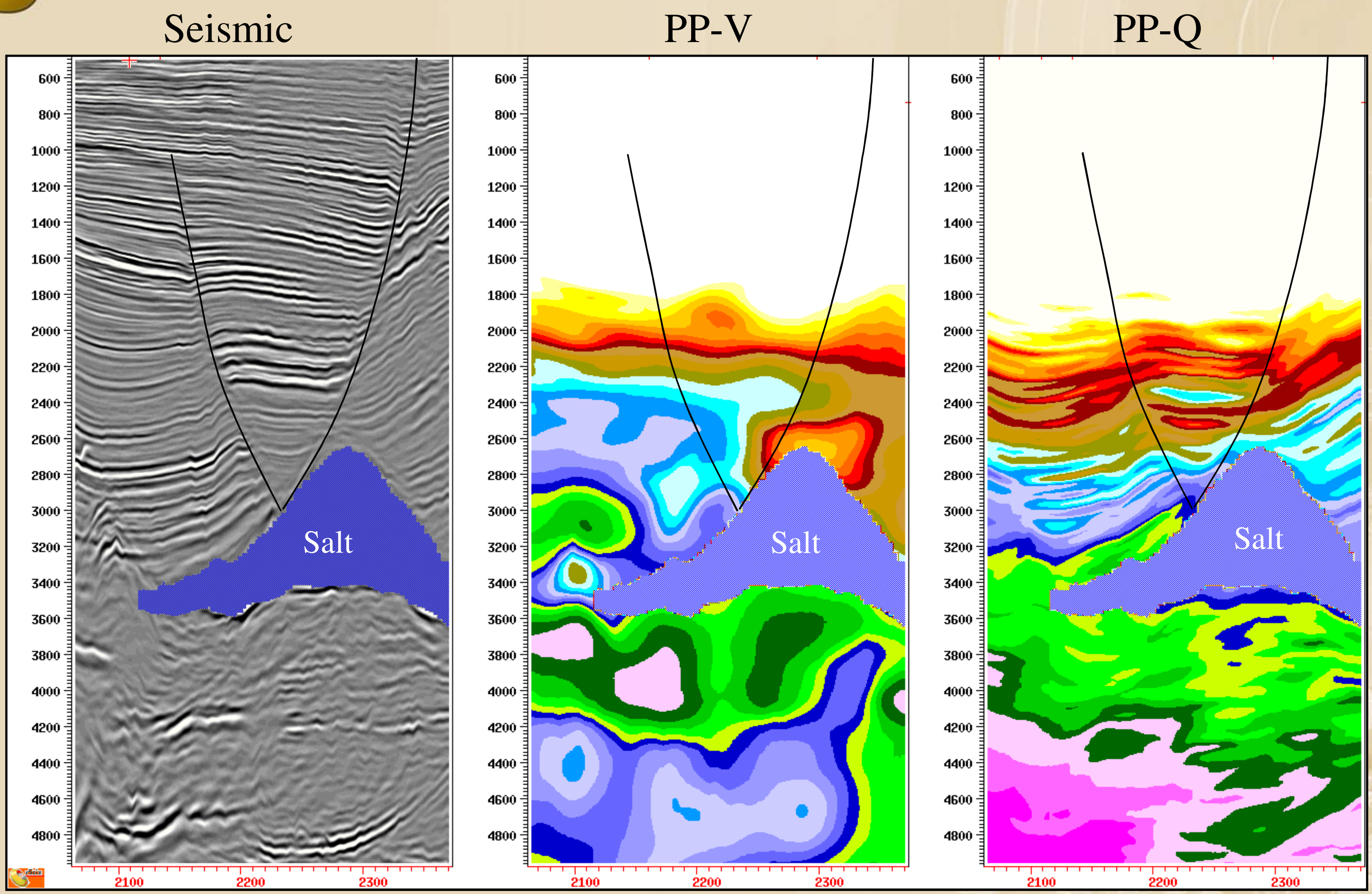


PP-V

PP-Q


Shale
Sandy
Shale
Carbonate
PP-V
PP-Q
0
1000
2000
3000
4000
5000
6000
TVD Depth (M)
1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00 2.10 2.20 2.30
Pressure SG
PP-Q
FG
OBG
PP-V

Q-Based PP and V-Based PP



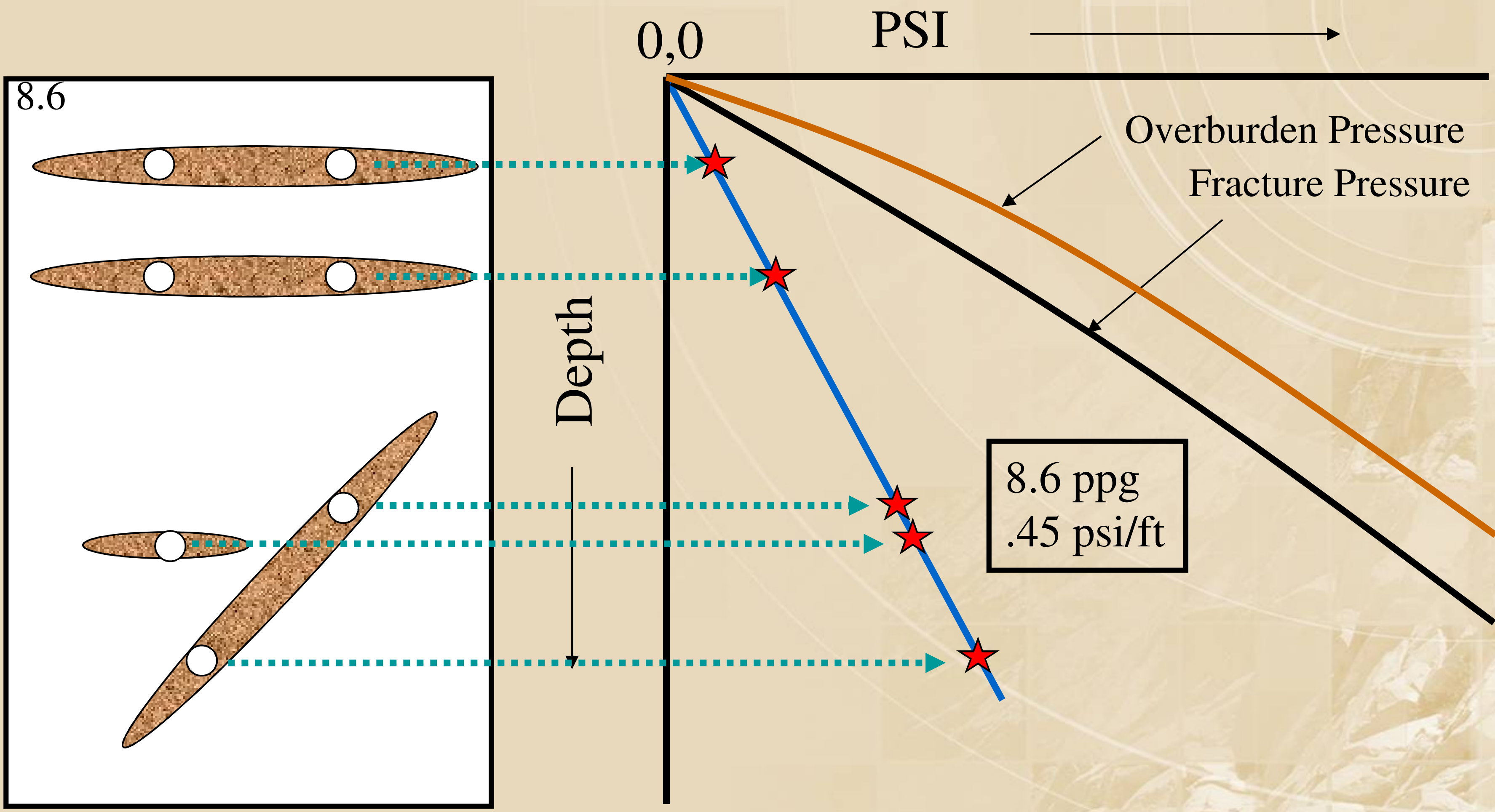
Conclusion

Using Multiple Pore Pressure Prediction Techniques provides a way to mitigate risk.

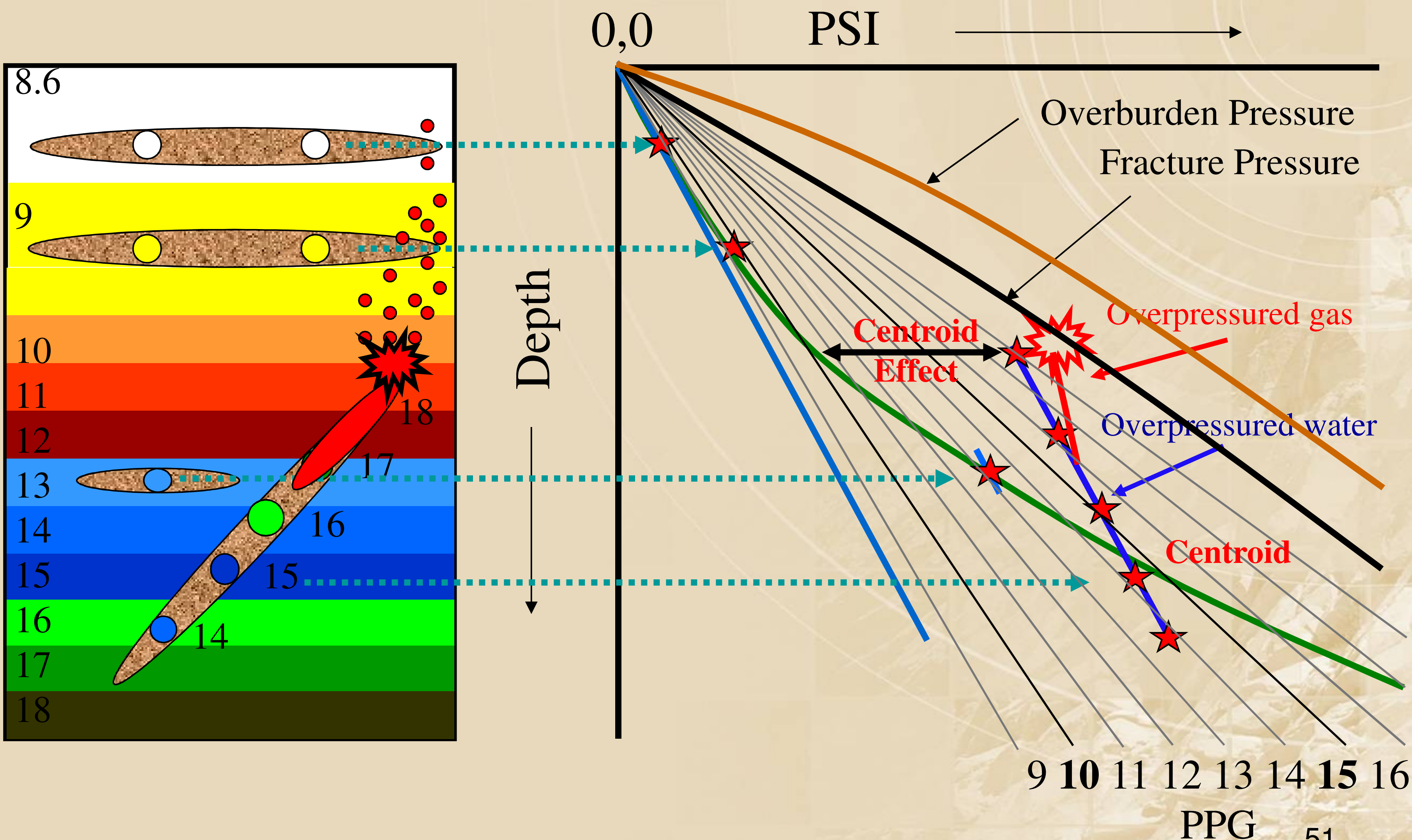
Shale PP is NOT Sand PP

The Centroid Effect

Normal Pore Pressure



Abnormal Pore Pressure



Calculating Sand PP
Spreadsheet Approach

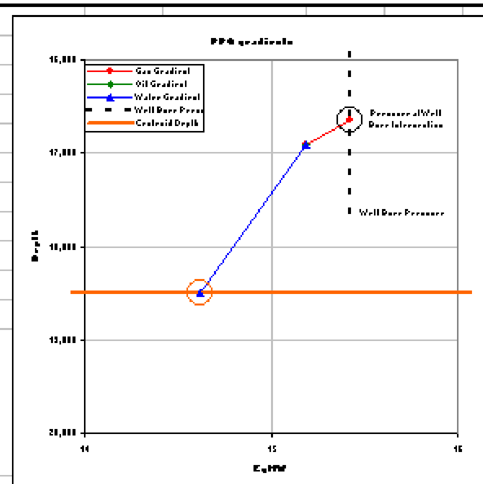
Centroid Speadsheet

Prospect A - PPQ

Case:

PP Centroid Calculations

	Input Values in RED	
Depths and Heights in Feet	Calculated Values in BLUE	
EqMW's Referenced to RKB		
Air Gap (Flowline Elev Abv SL)	86	
Reservoir Water Gradient (ppg)	8.6	
Oil Gradient (ppg)	6.9	
Gas Gradient (psi/ft)	0.1	



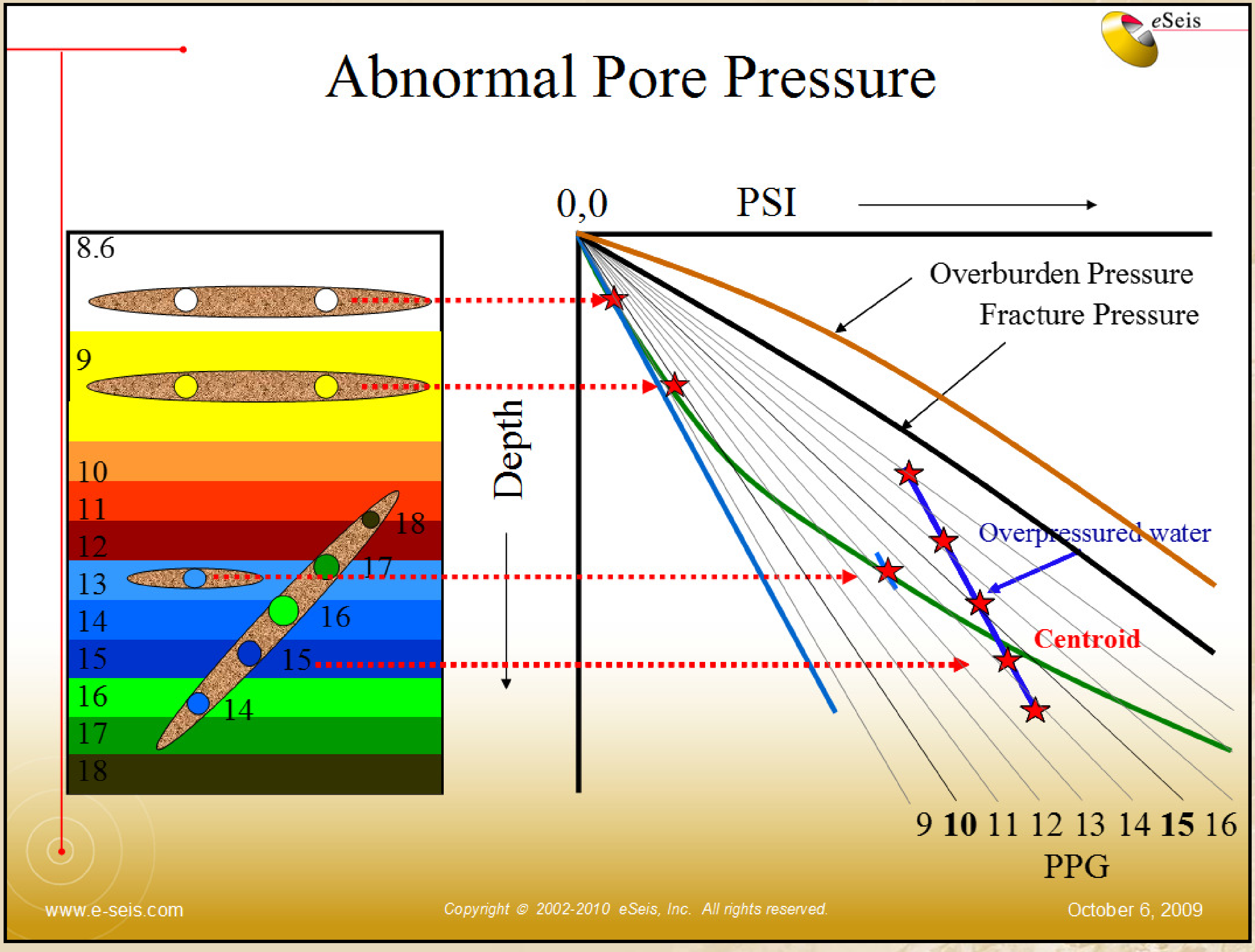
Water, Oil and Gas Column Parameters (Effective Fluid Columns are those between the Centroid and the Well Bore Intersection)

	Depths (tvd-ss)	Q-based PP (EqMW)	
Well Bore Intersection	16638	15.42	<-------- Calculated Pore Pressure at Wellbore Intersection
Effective Gas column	262		
Nominal Gas/Oil Contact	16900	15.18	<-------- Calculated Pore Pressure at Gas / Oil Contact
Effective Oil Column	0		
Nominal Oil/Water Contact	16900	15.18	<-------- Calculated Pore Pressure at Oil / Water Contact
Effective Water Column	1590	PPQ	
Centroid Depth SS and PP	18490	14.62	

Calculating Sand PP

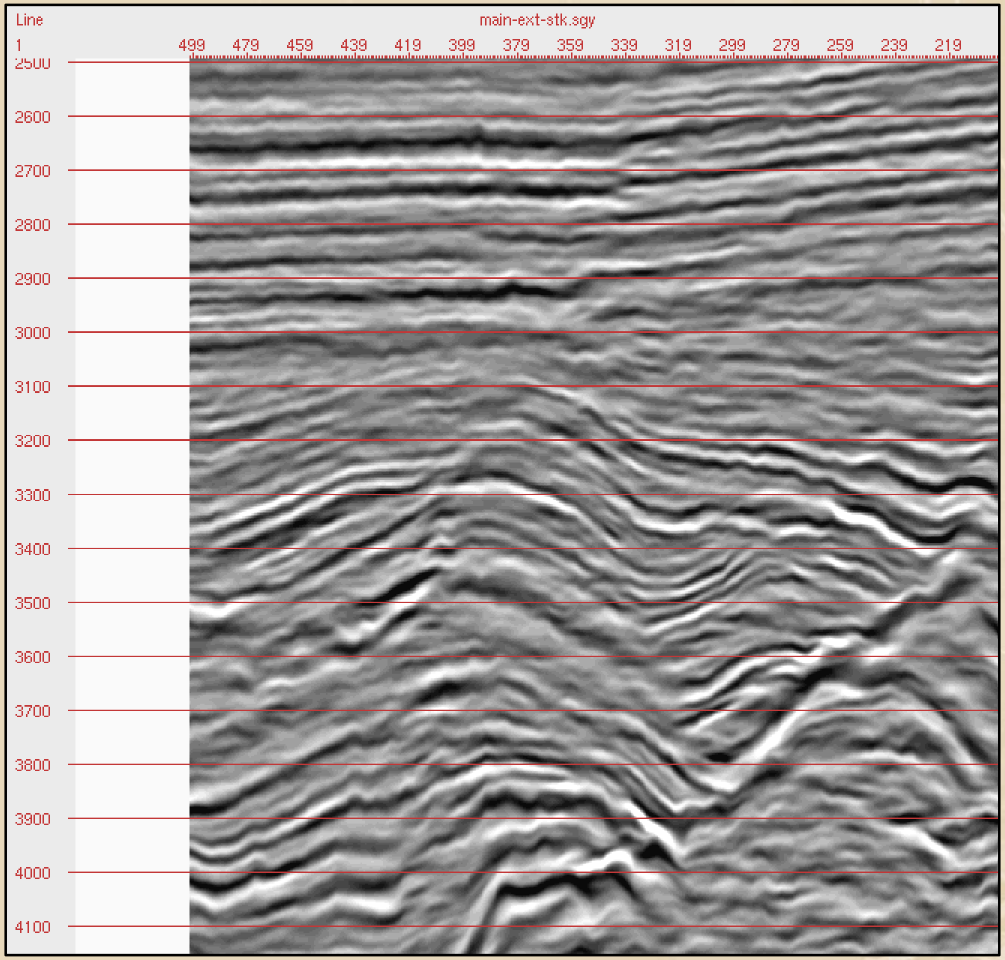
Graphic Approach

Calculating Sand Pressure

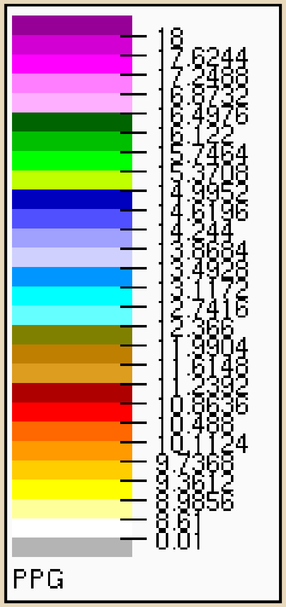


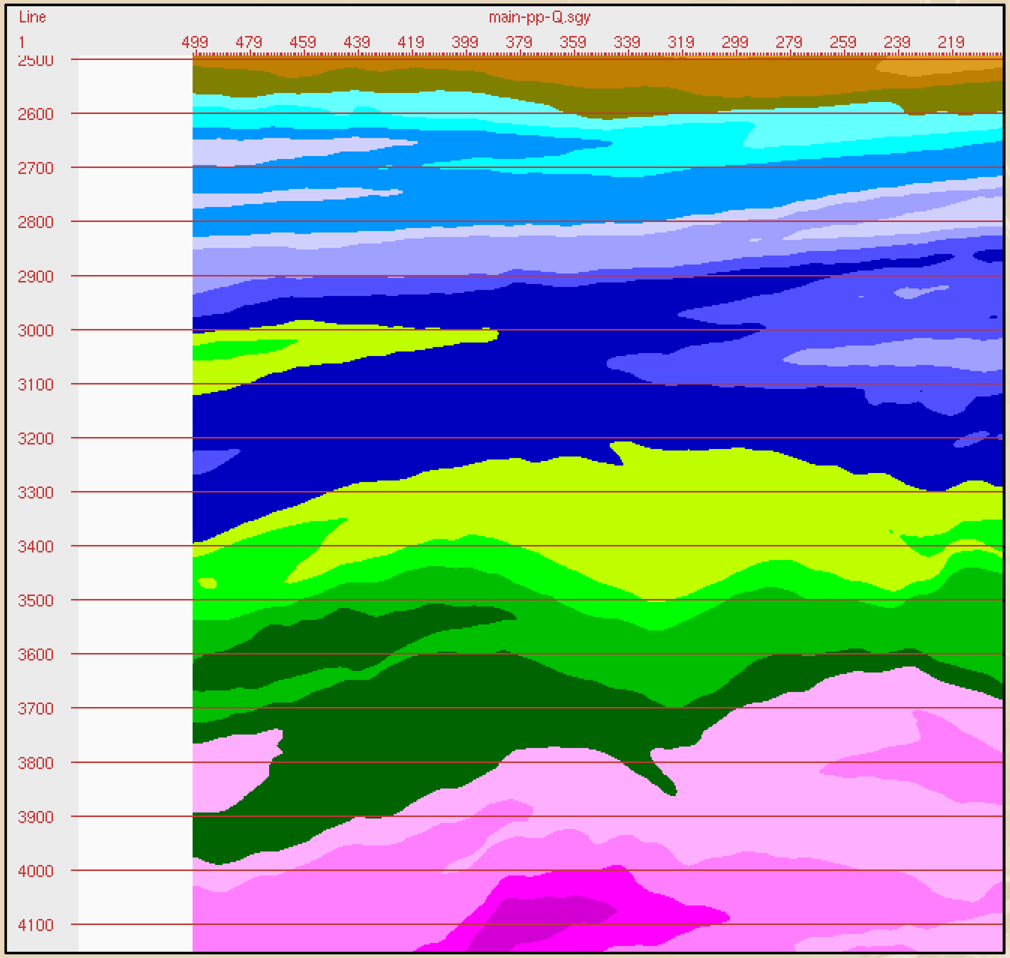
Calculating Sand PP
Volume Approach

Seismic showing structure



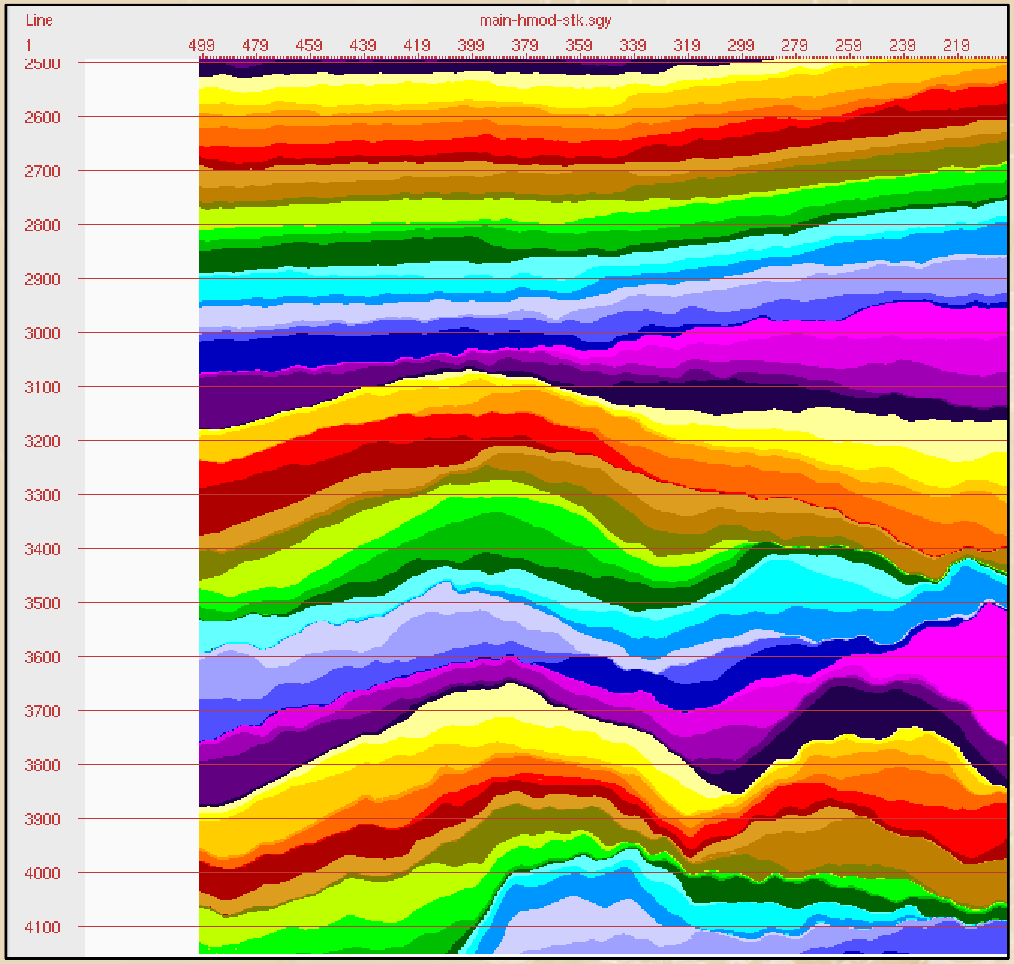
Shale PP-Q


18
17.6244
17.2488
16.8732
16.4976
16.122
15.7464
15.3708
14.9952
14.6196
14.244
13.8684
13.4928
13.1172
12.7416
12.366
11.9904
11.6148
11.2392
10.8636
10.488
10.1124
9.7368
9.3612
8.9856
8.61
0.01
PPG


Line
main-pp-Q.sgy
1
499 479 459 439 419 399 379 359 339 319 299 279 259 239 219
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100

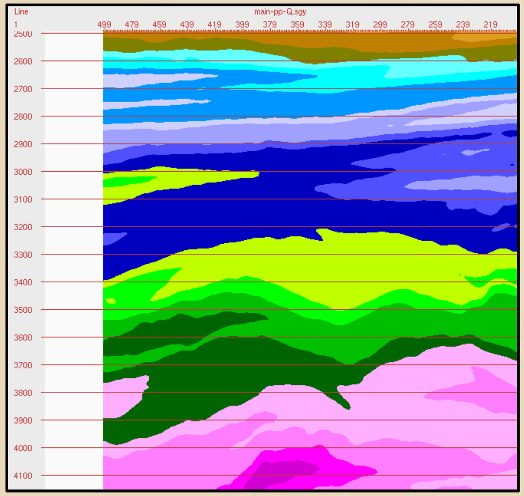
Hydraulic Units

Hydraulic units are found throughout the survey area. The value the color represents is the average time of each horizon.



PP-Q Sand Calculation

Along each hydraulic unit surface, the average shale PP is found. The average time (actually depth) of each unit is already known. This pair defines the centroid. A water gradient is then assumed and the sand PP is calculated on a volumetric basis.



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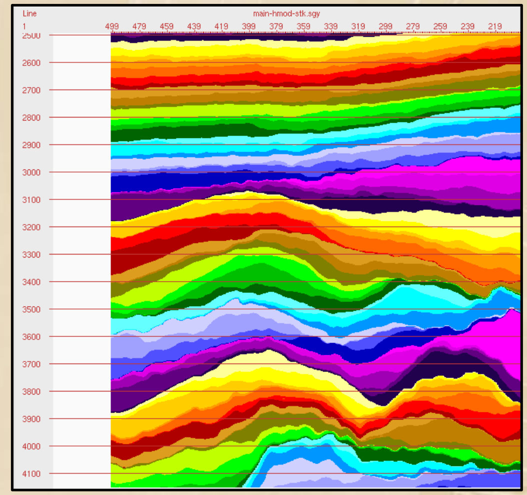

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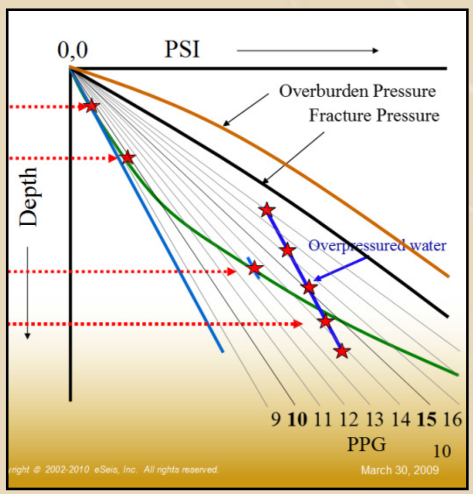

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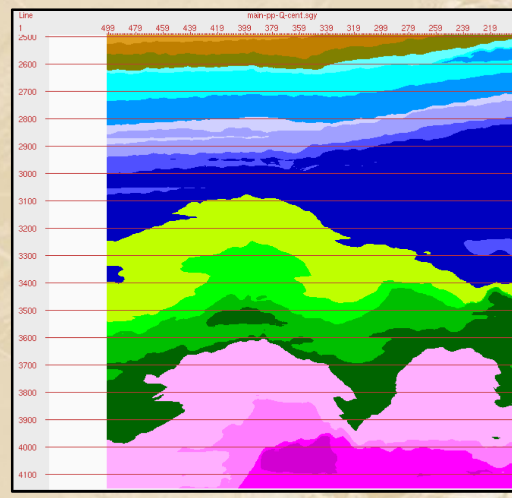
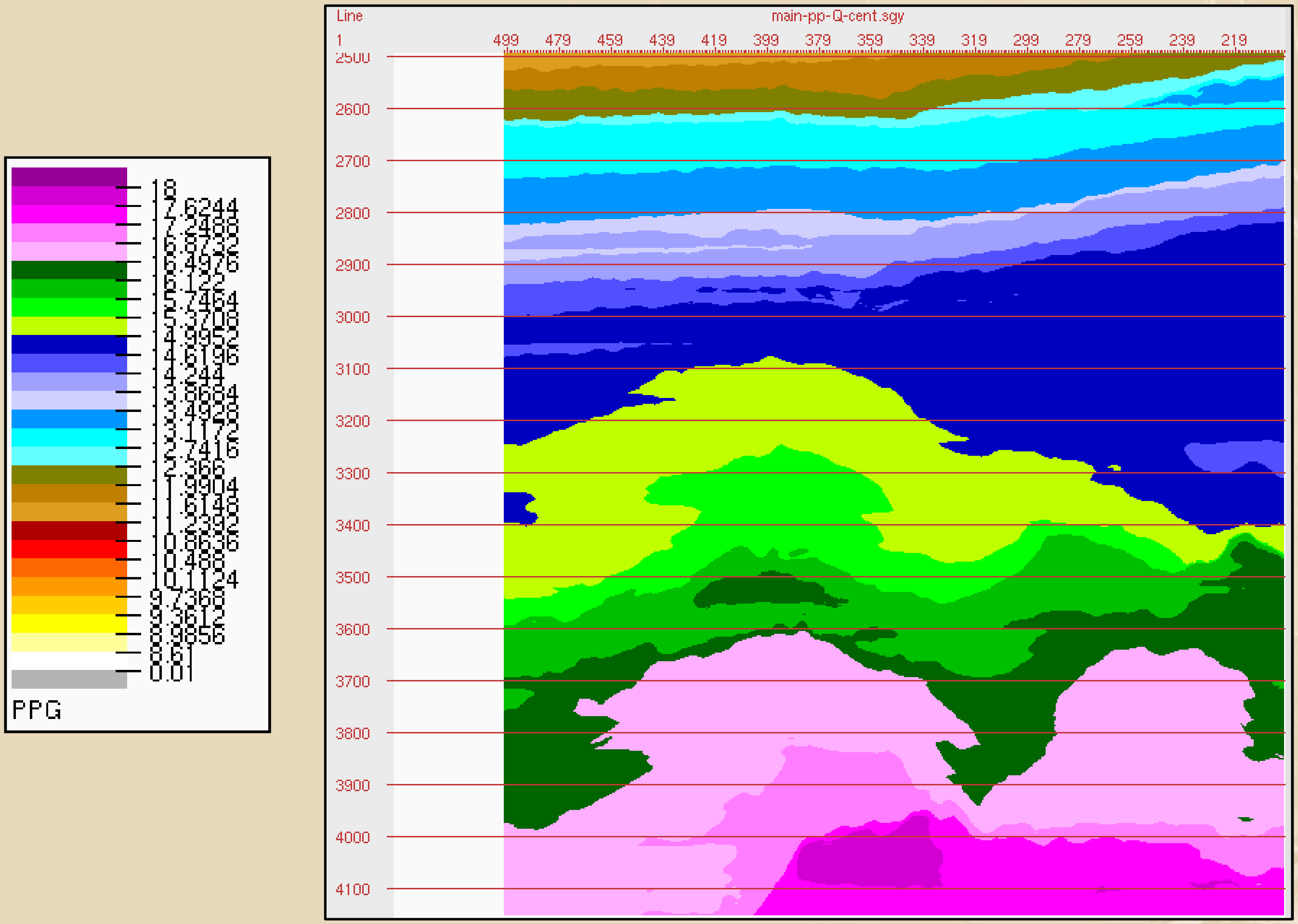
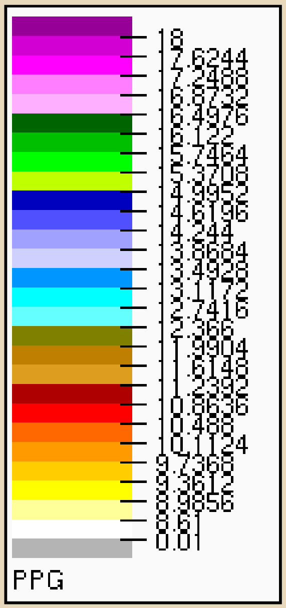
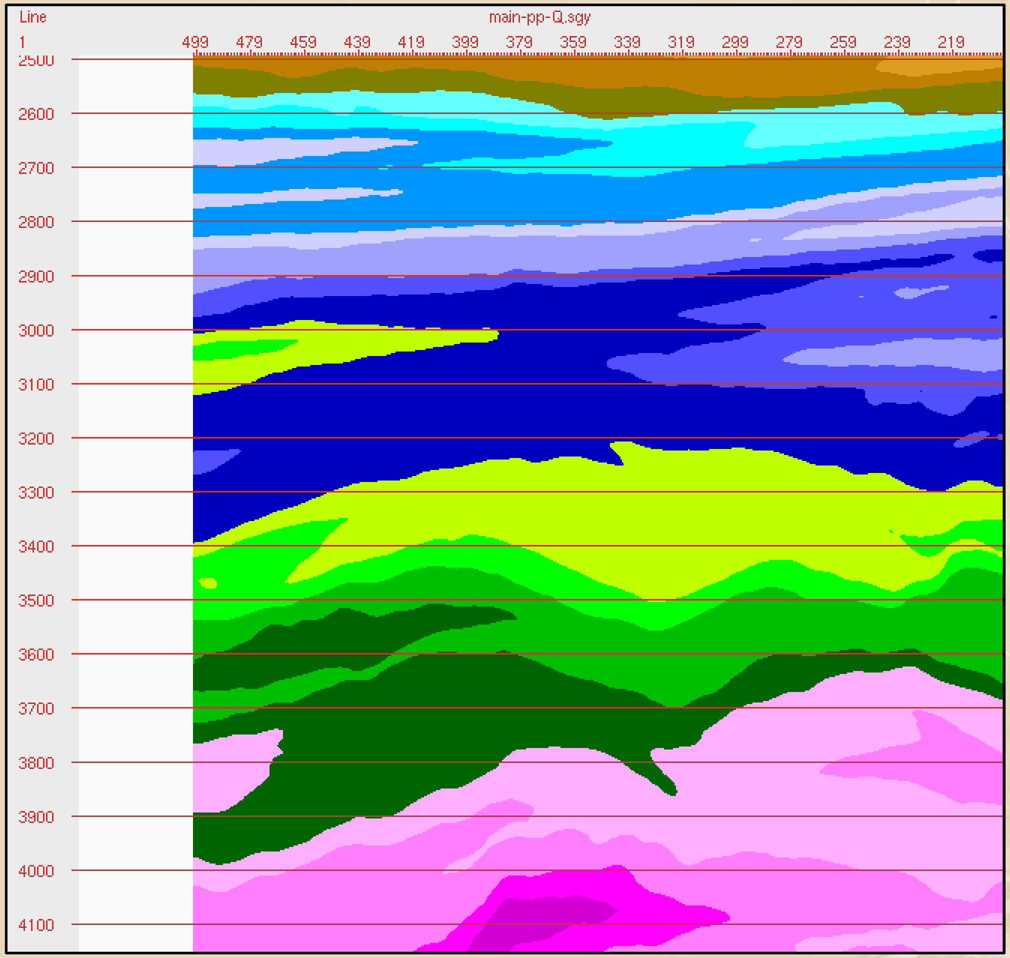


Instantaneous Sand PP-Q



Shale PP-Q





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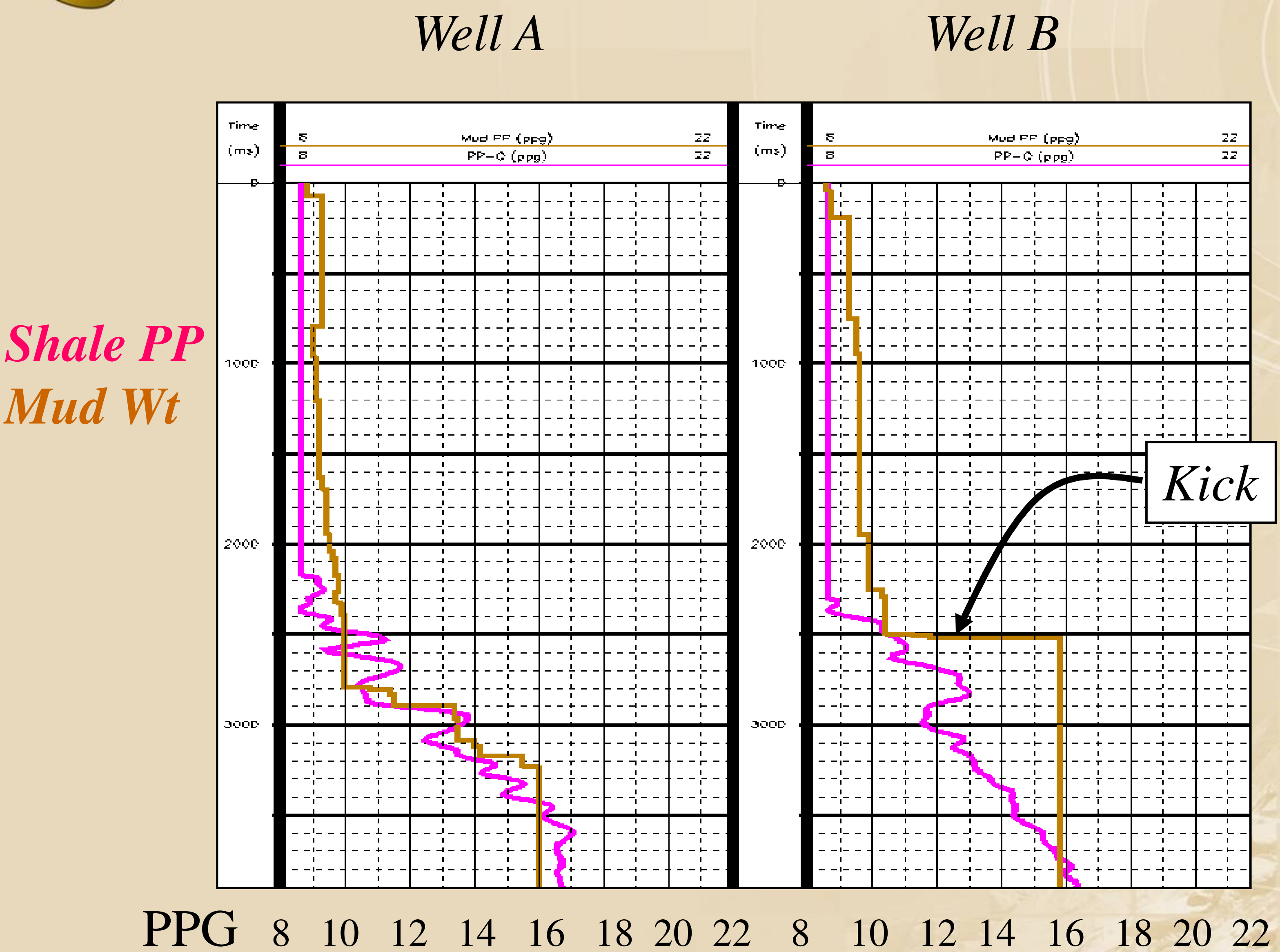
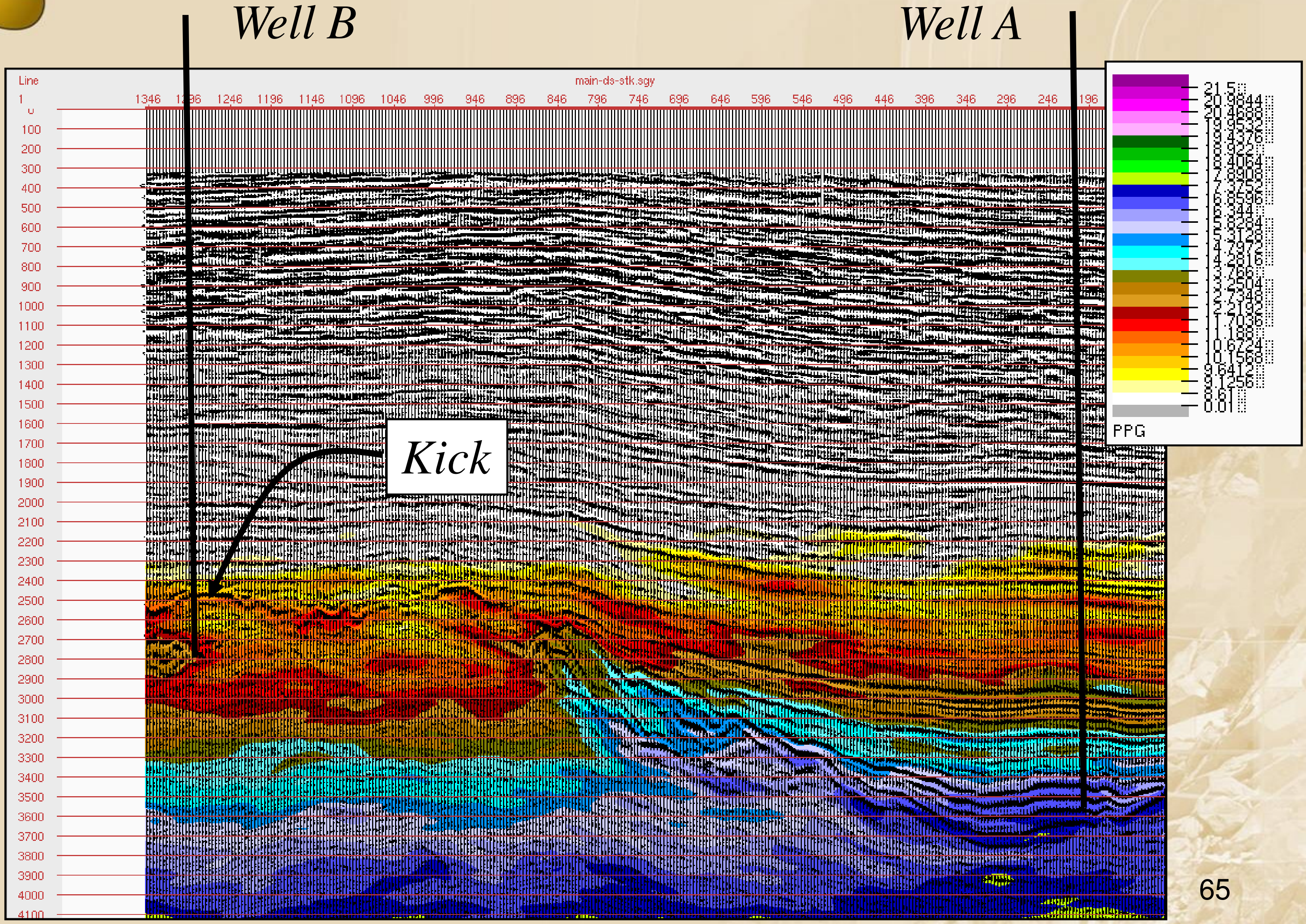
5 ppg Kick Example

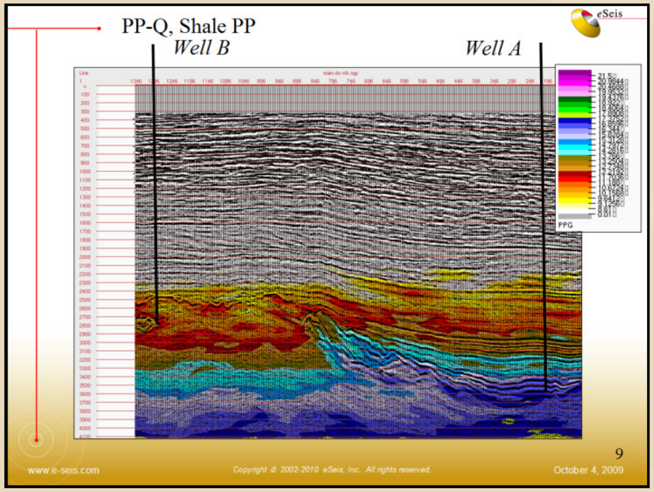
PP-Q, Shale PP Calibration



PP-Q, Shale PP



PP-Q Sand Calculation



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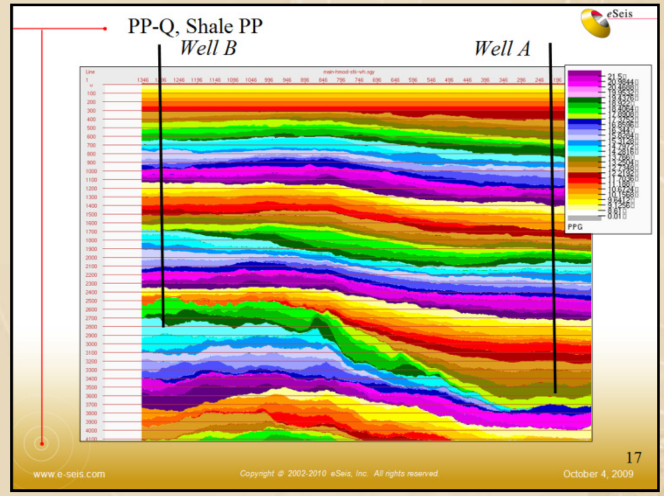

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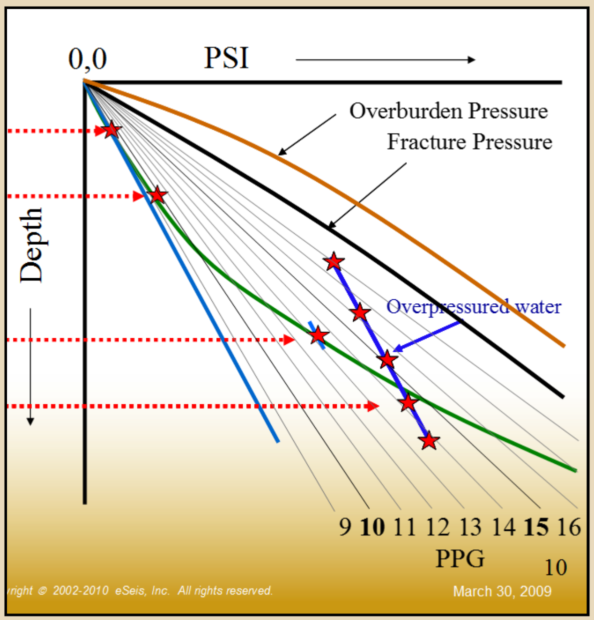

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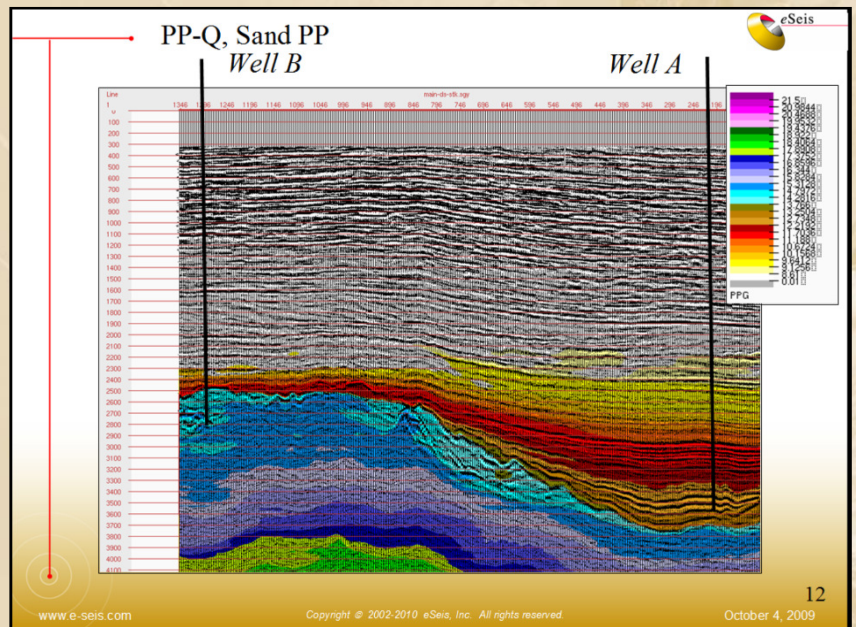
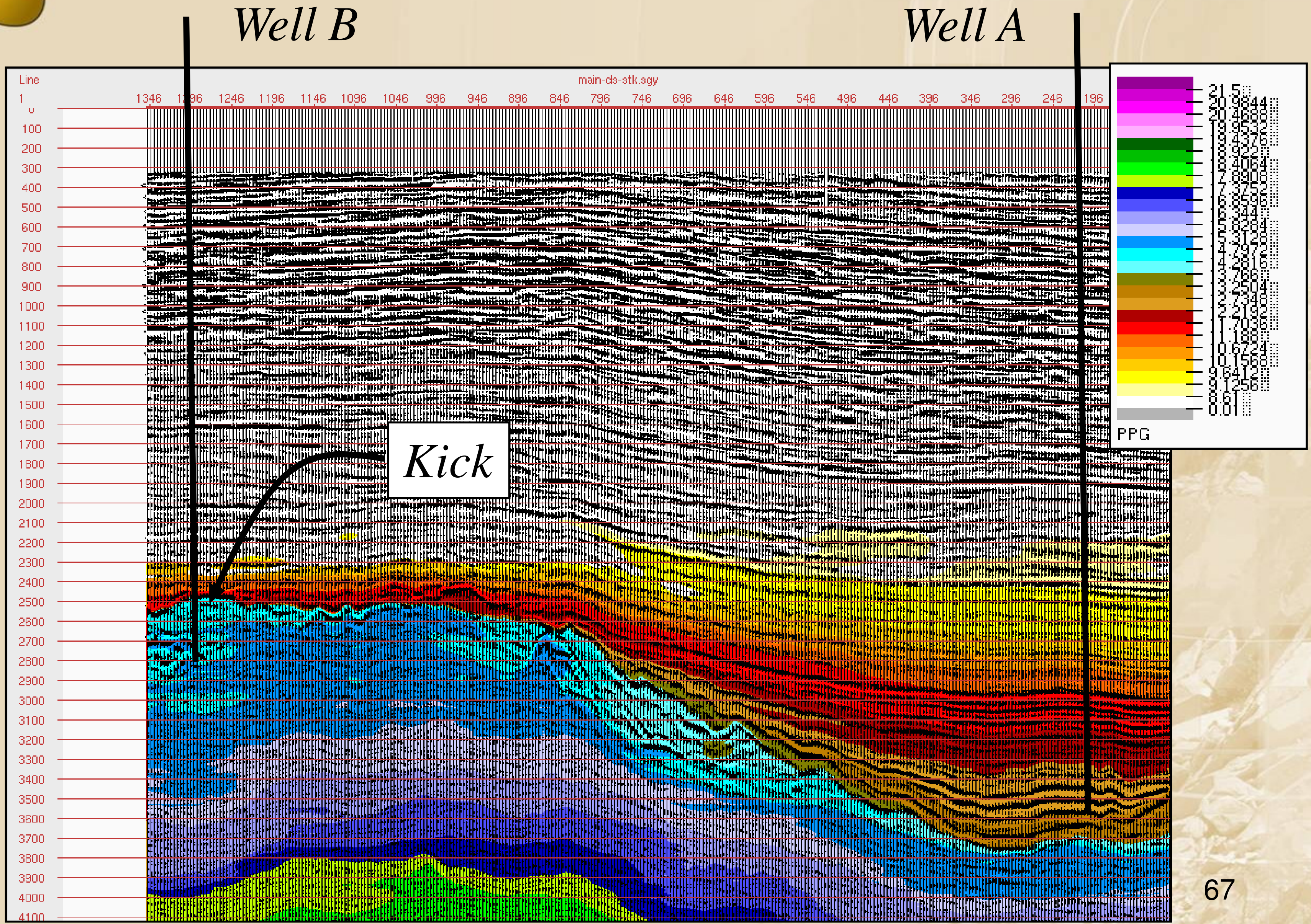
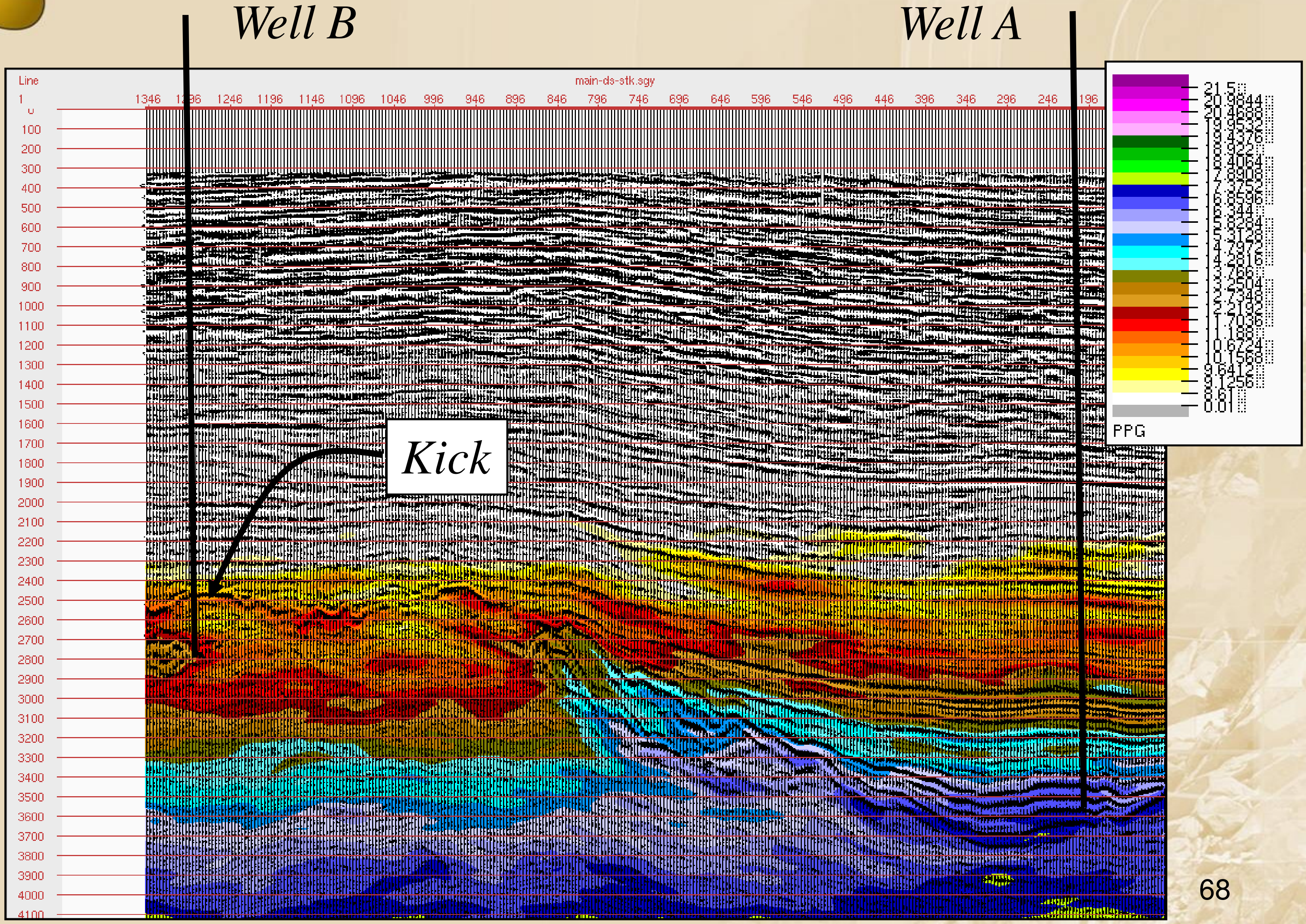


PP-Q, Sand PP



PP-Q, Shale PP


Well B
Well A
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0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
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2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
Kick
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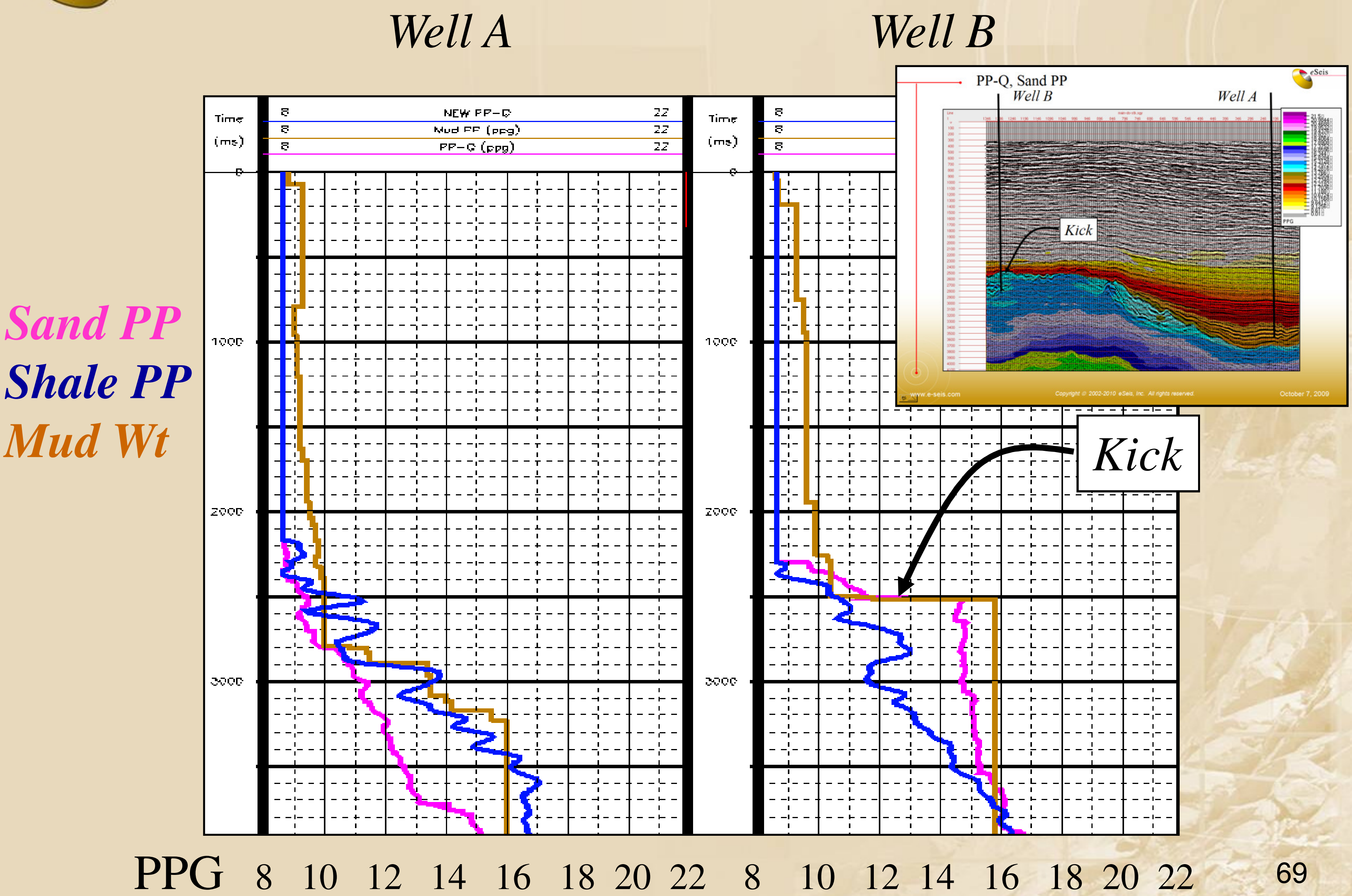
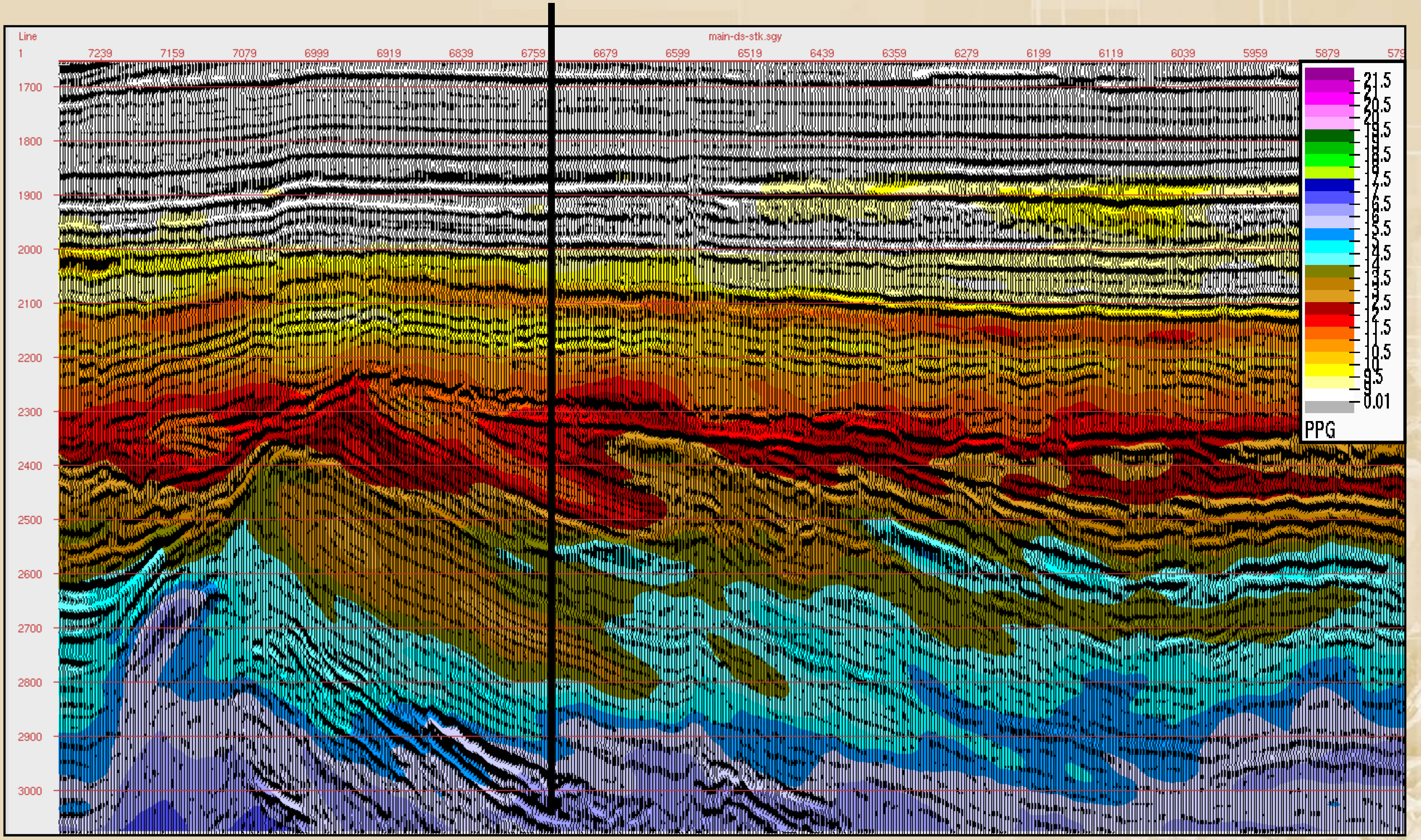
20.9844
20.4688
19.9532
19.4376
18.922
18.4064
17.8908
17.3752
16.8596
16.344
15.8284
15.3128
14.7972
14.2816
13.766
13.2504
12.7348
12.2192
11.7036
11.188
10.6724
10.1568
9.6412
9.1256
8.61
0.01
PPG

PP-Q, Shale PP Calibration, Sand PP Prediction



Calculating Sand PP
Volume Approach

PP-Q Shale



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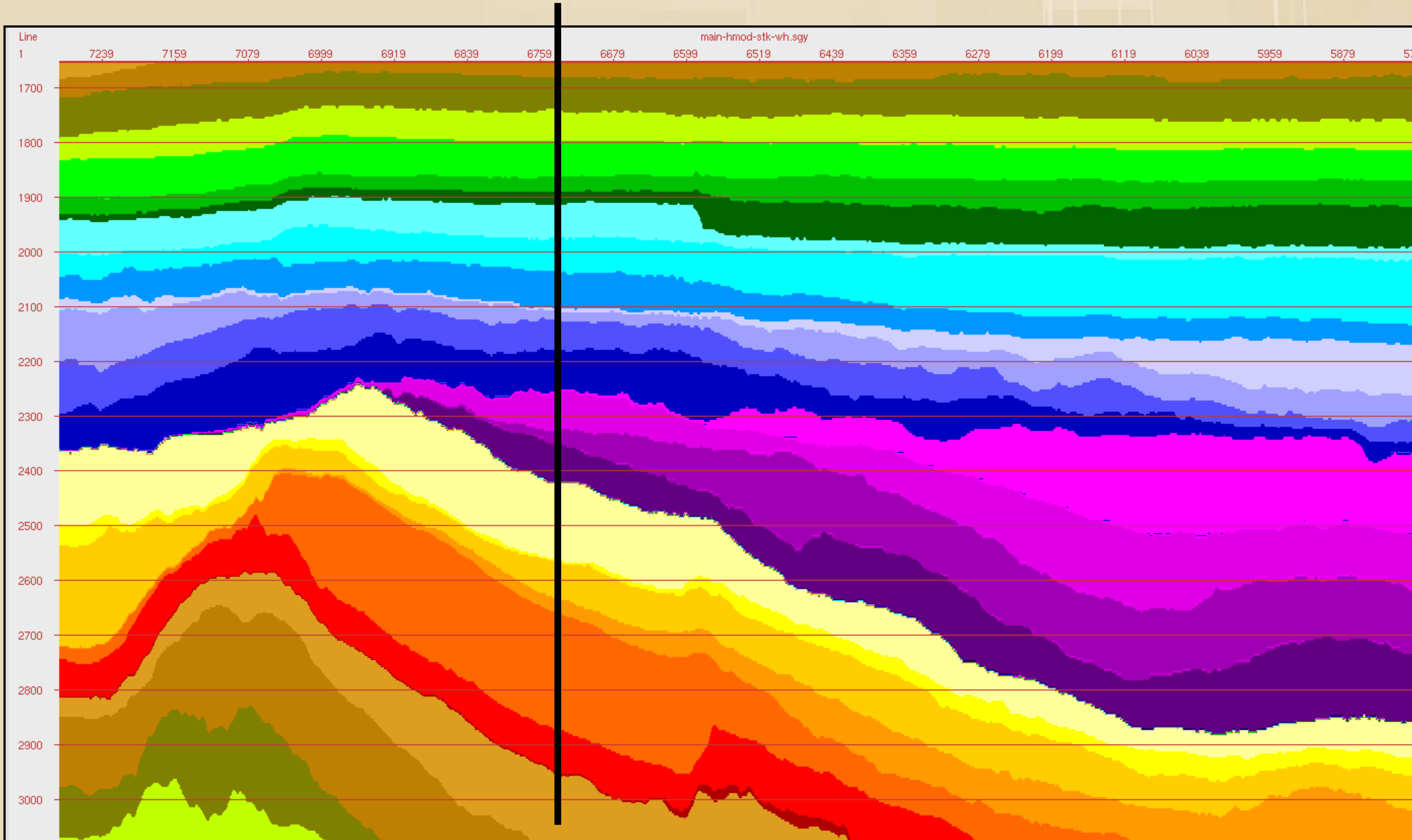
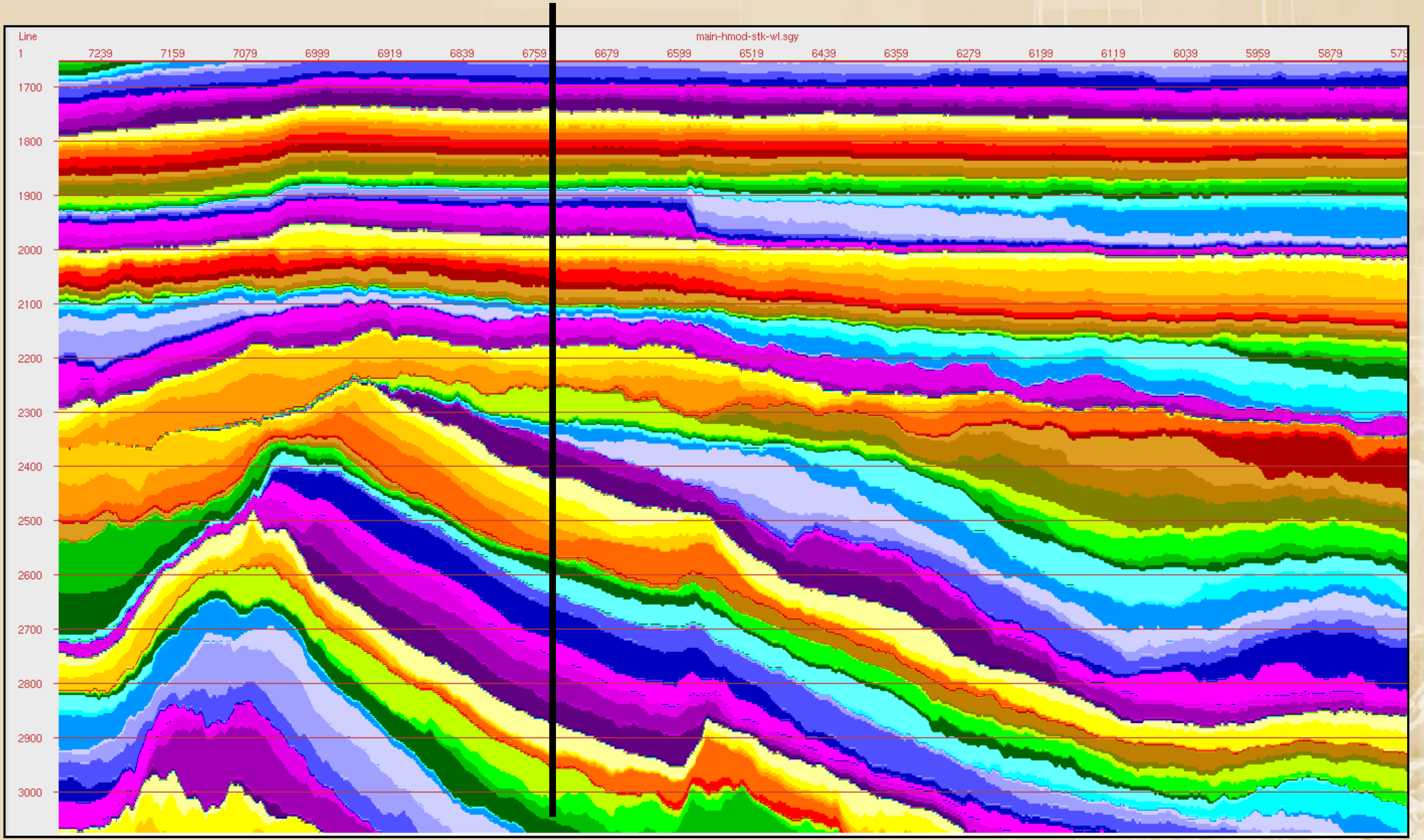
Hydraulic Units



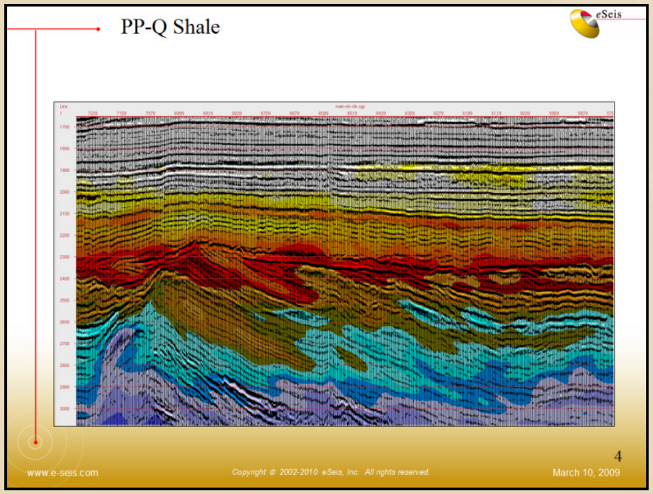
www.e-seis.com

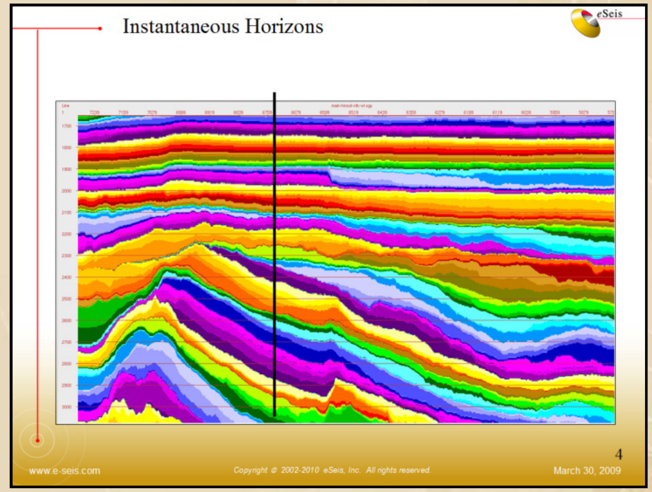
Hydraulic Units

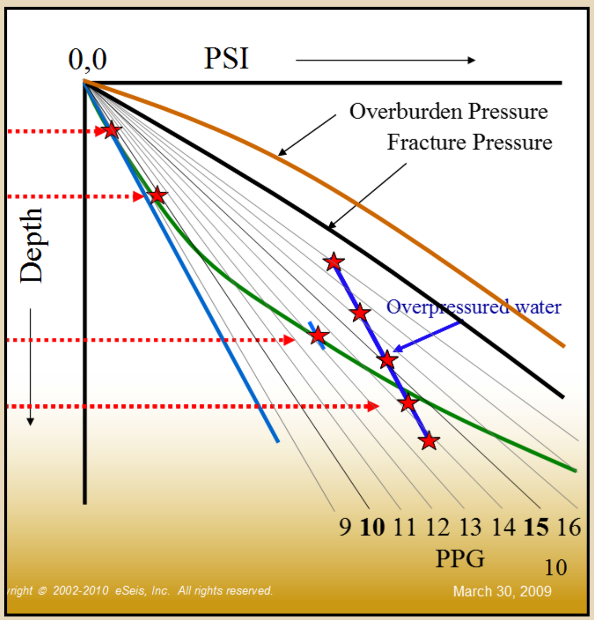


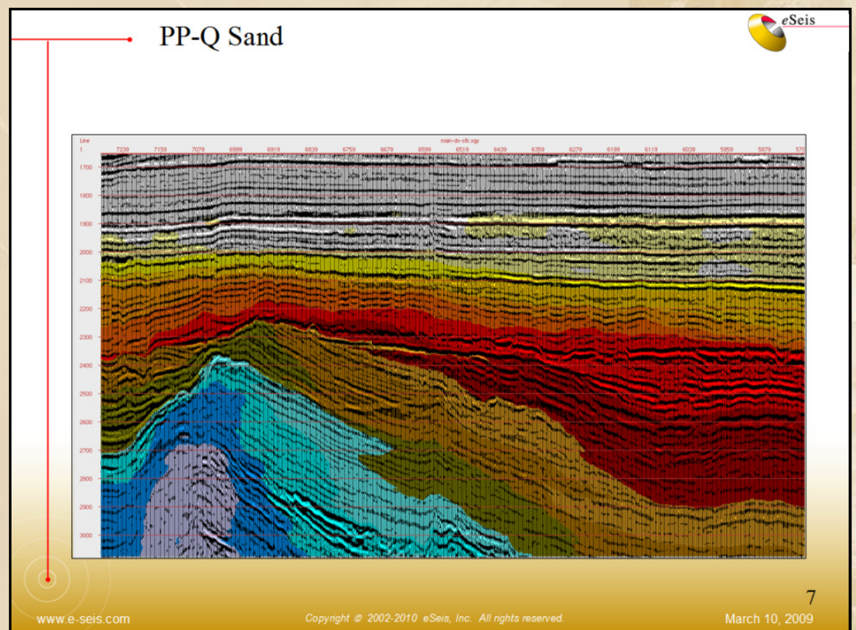
www.e-seis.com

PP-Q Sand Calculation

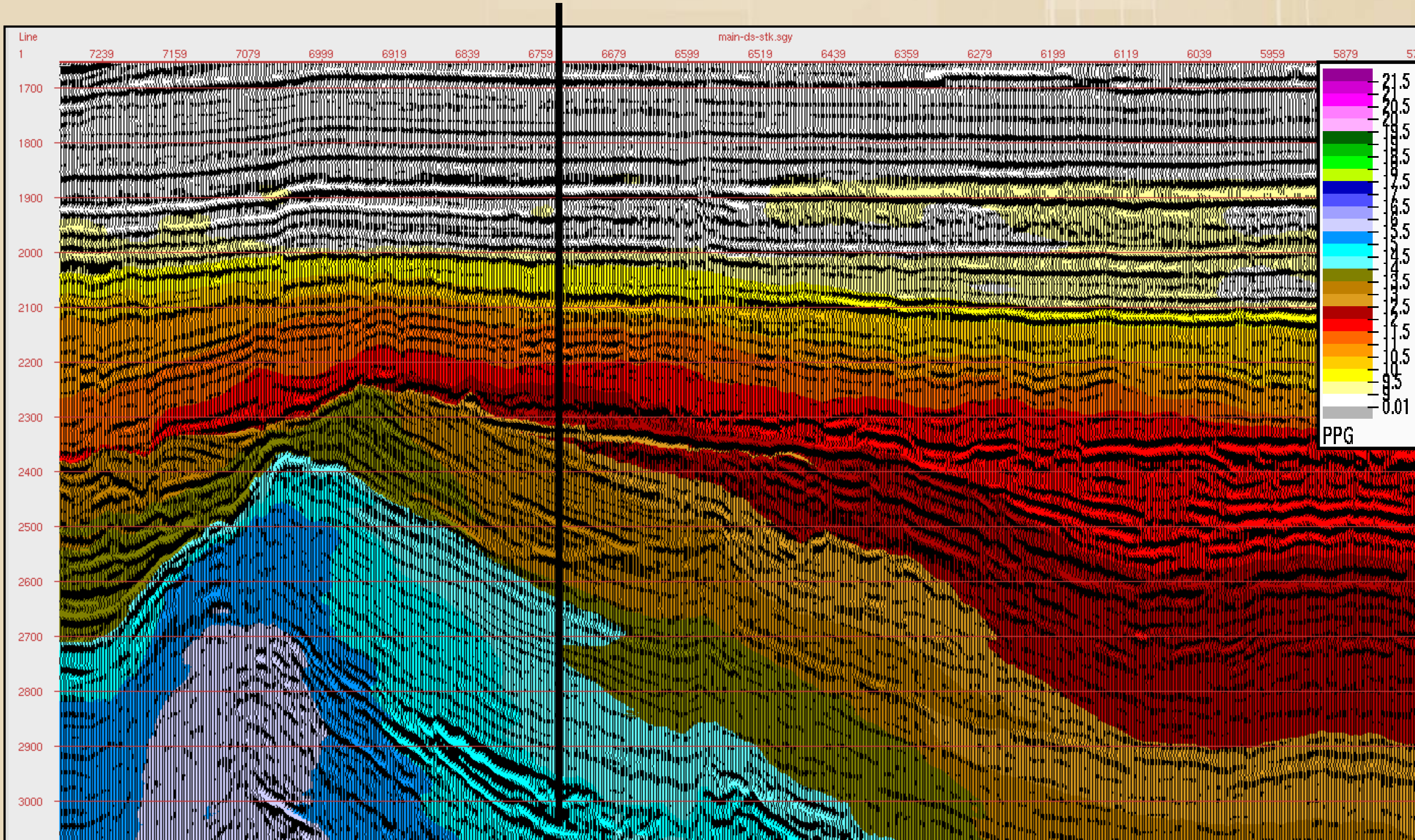








PP-Q Sand



Line
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main-ds-stk.sgy
7239
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6679
6599
6519
6439
6359
6279
6199
6119
6039
5959
5879
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
21.5
20.5
19.5
18.5
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14.5
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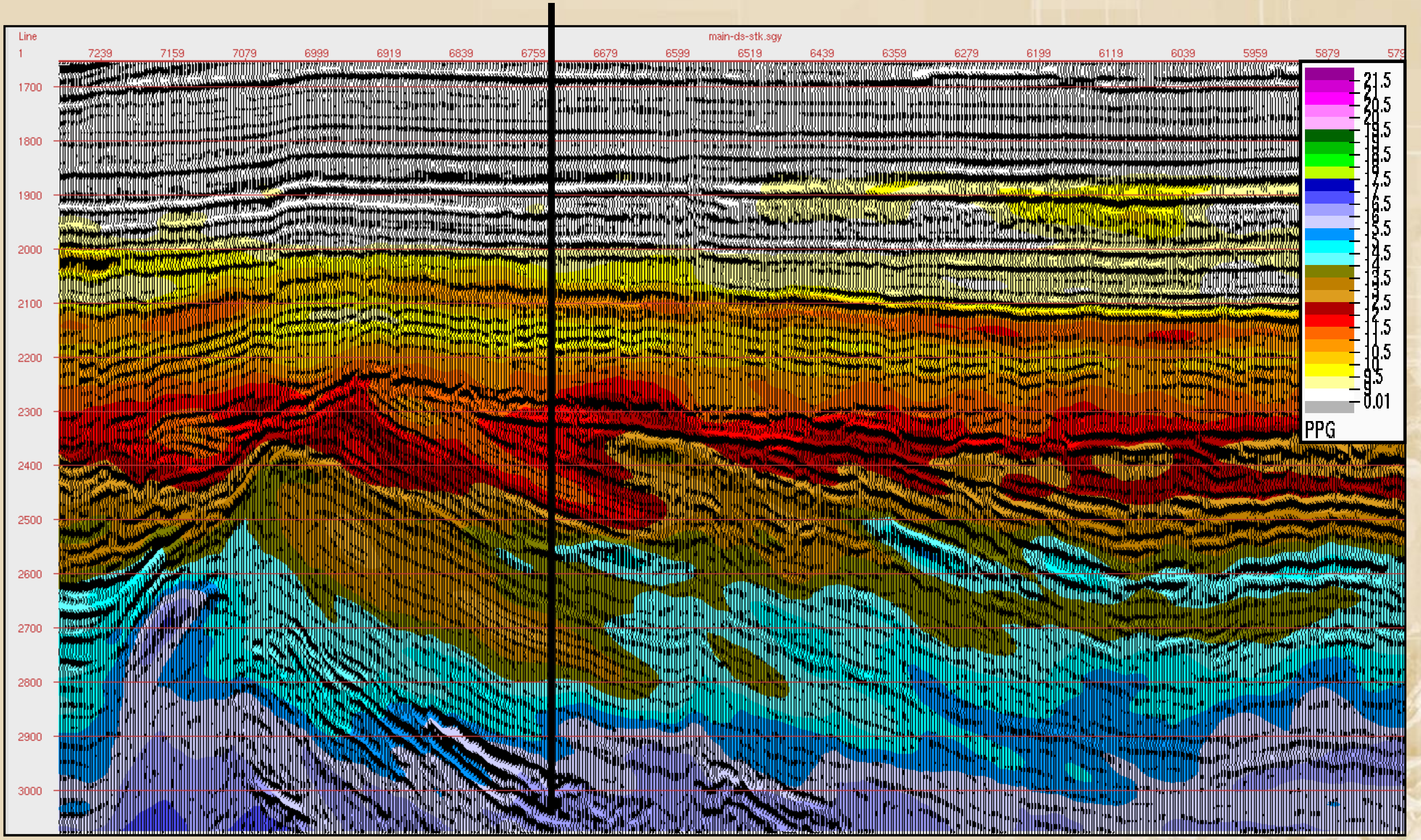
12.5
11.5
10.5
9.5
0.01
PPG

PP-Q Shale



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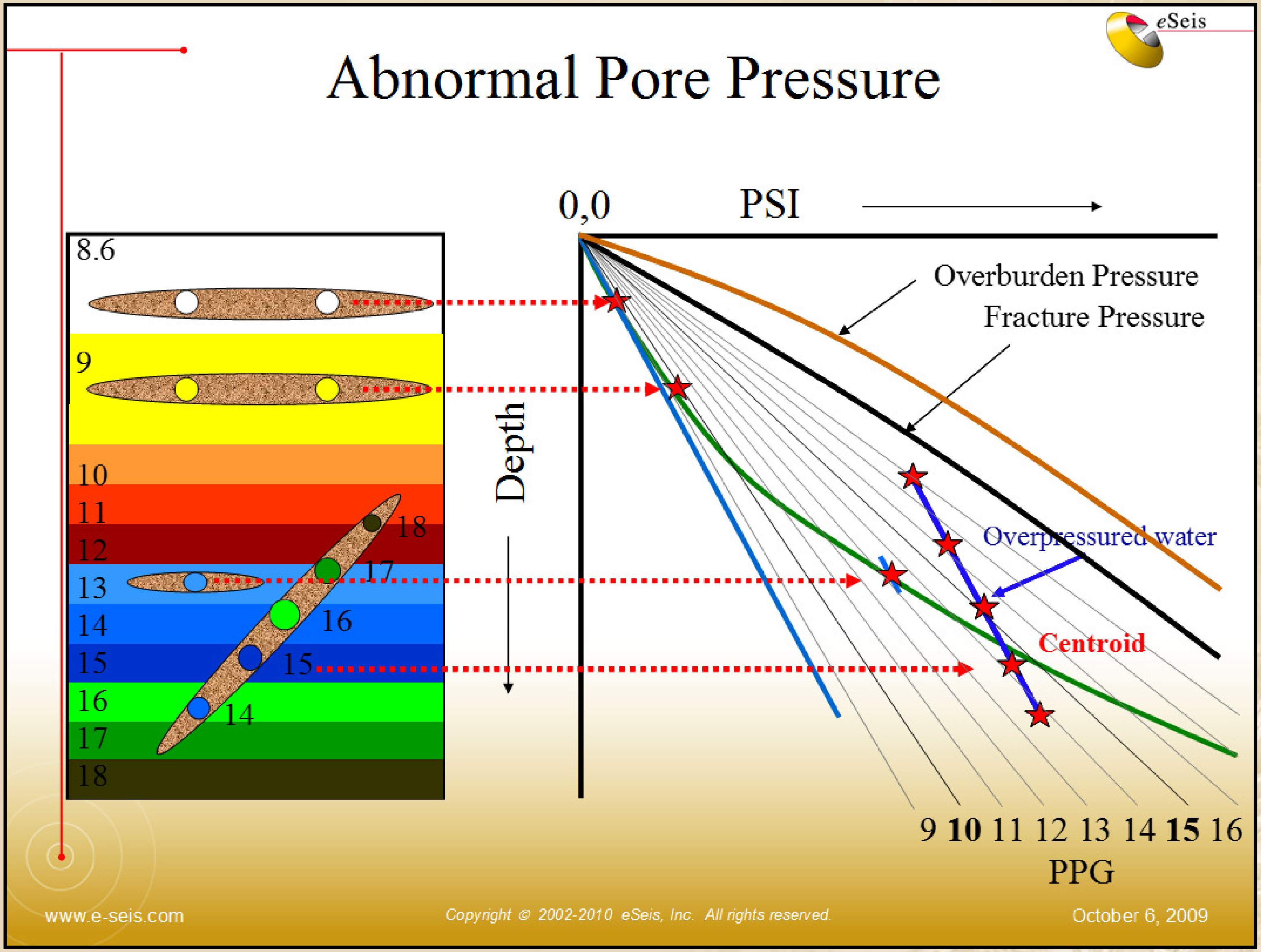
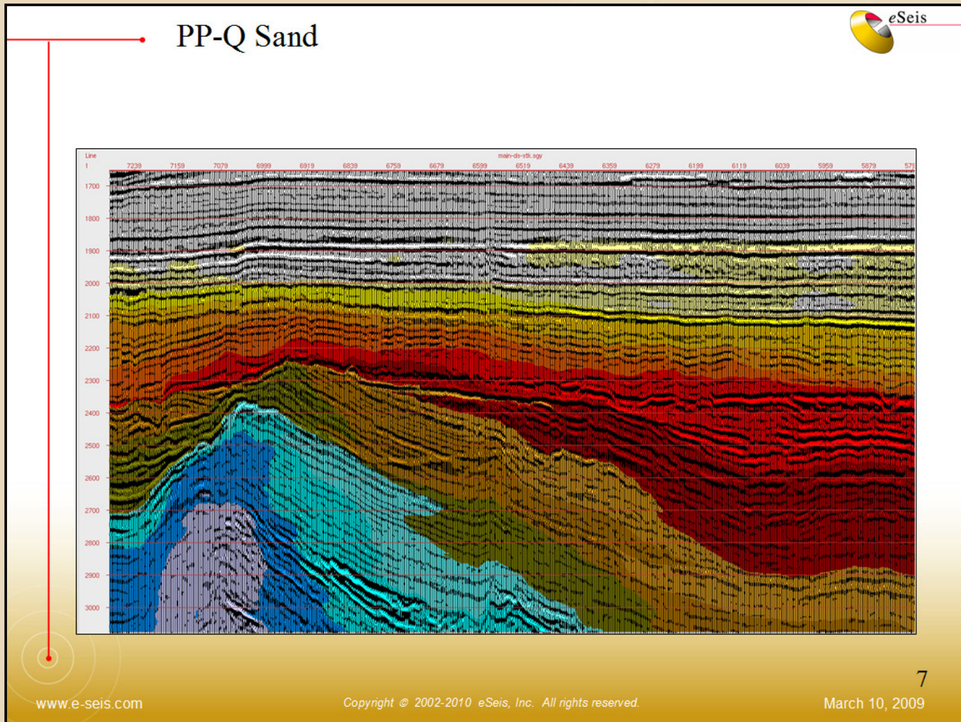
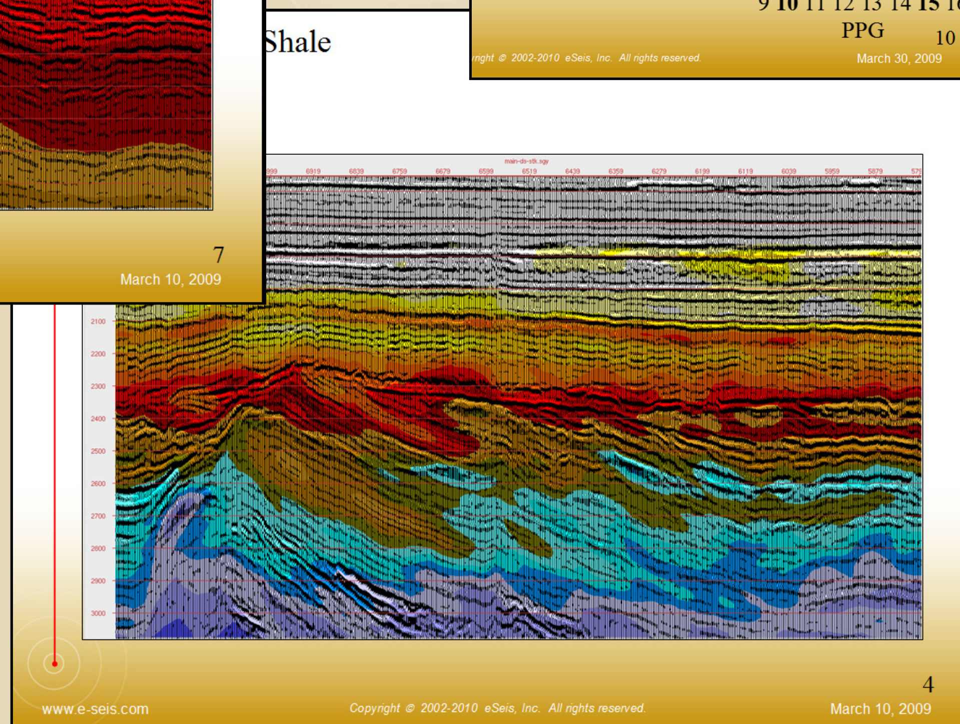
Does Your Prospect Leak?

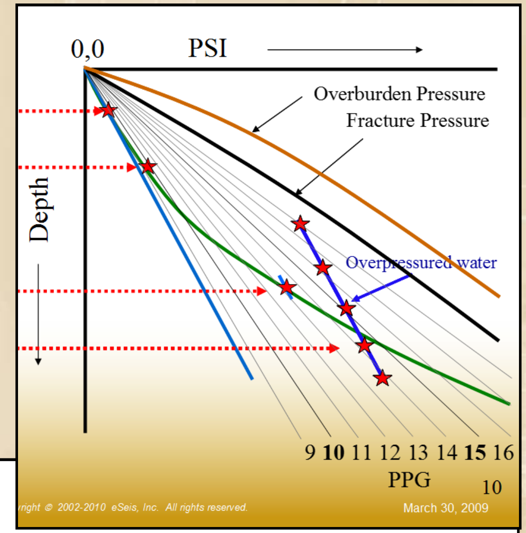
Calculating Sand Pressure



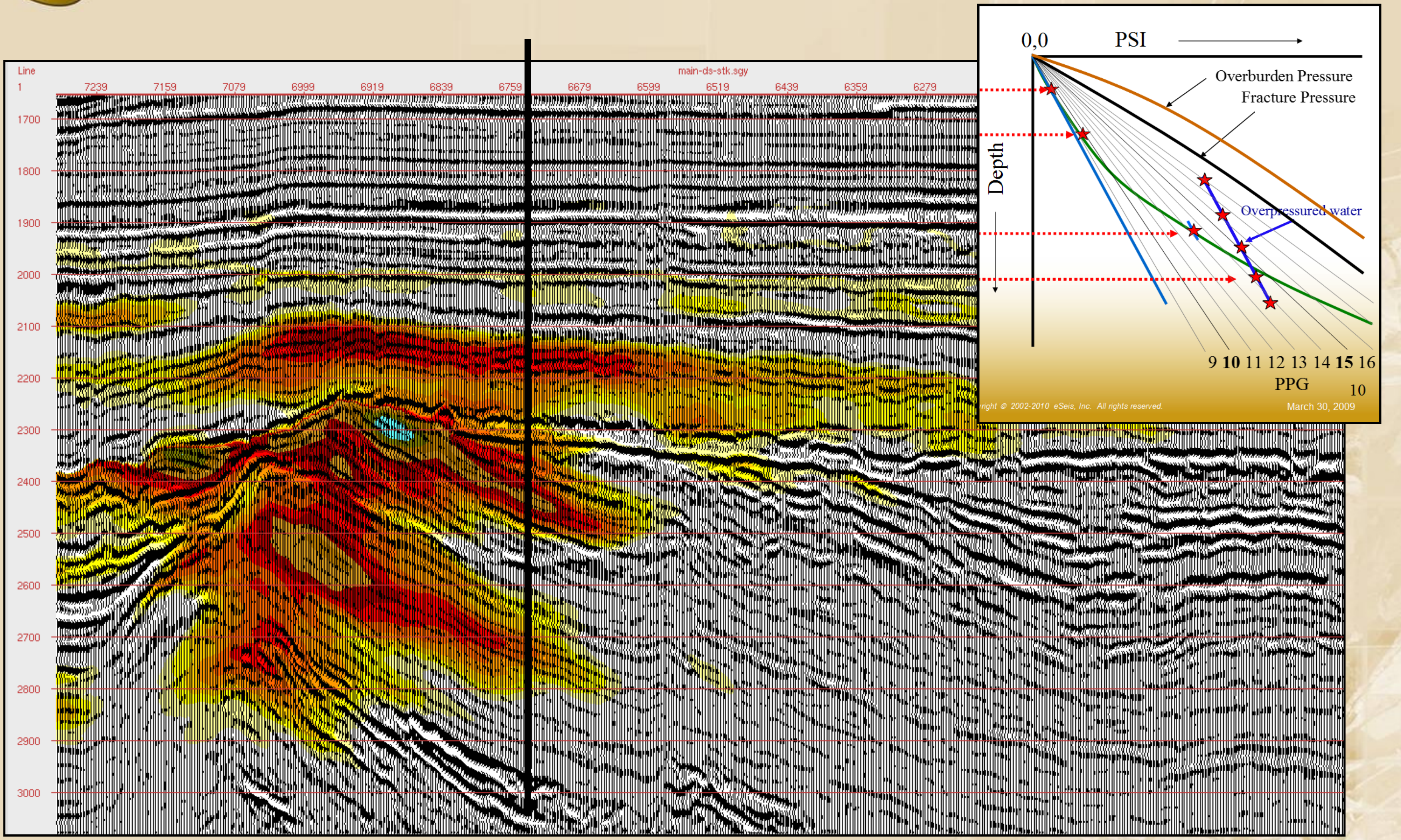
PP-Q Sand – PP-Q Shale







PP Sand > PP Shale



Conclusion

Why Use Multiple Methods to Calculate PP?

WHY NOT!

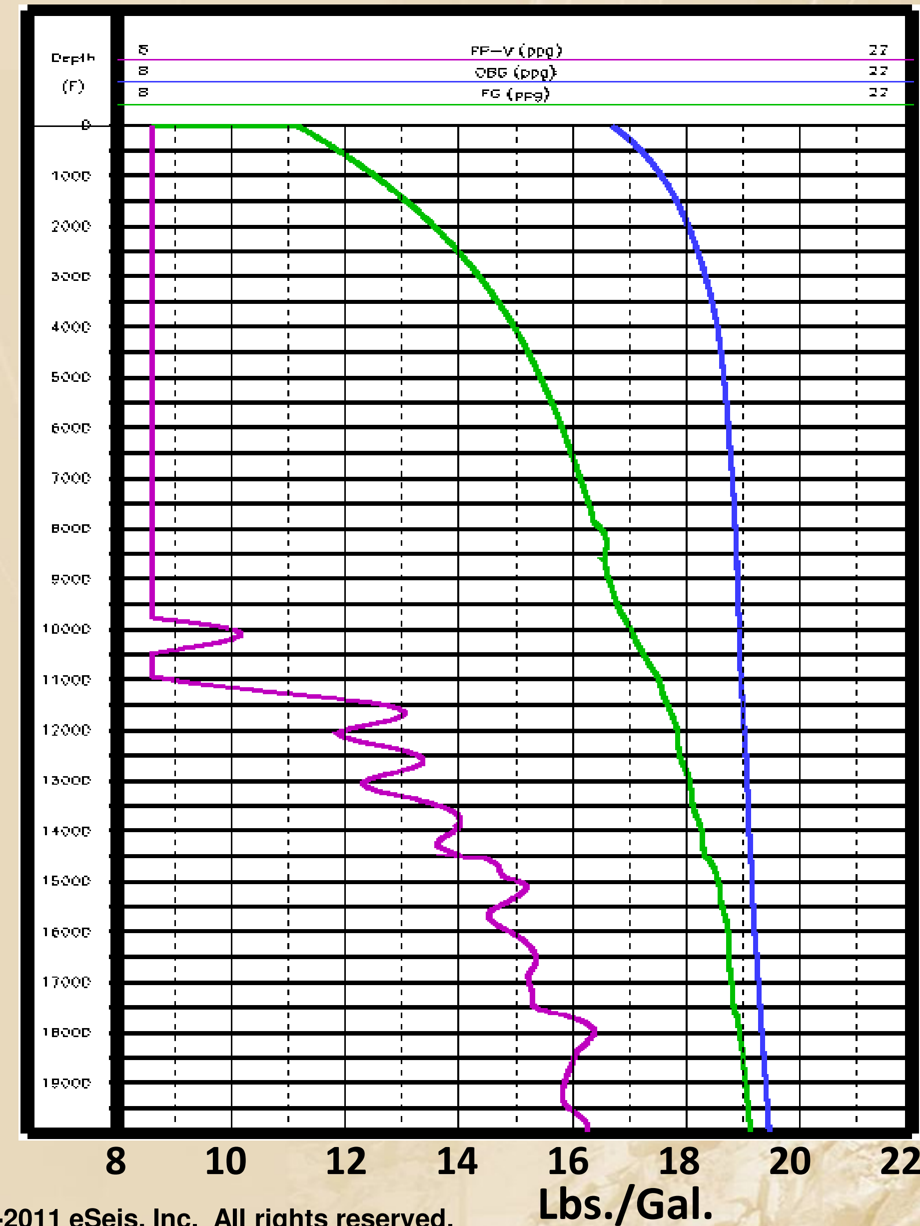
"PDML"
Pre-drill Mud Log
(With Daily Updates)

"PDML"
Pre-drill Mud Log

We believe the full power of "Seismic Petrophysics" should be utilized to provide the best possible basis of design for planning a well.

Typical Pore Pressure/Fracture Gradient (PPFG) Product

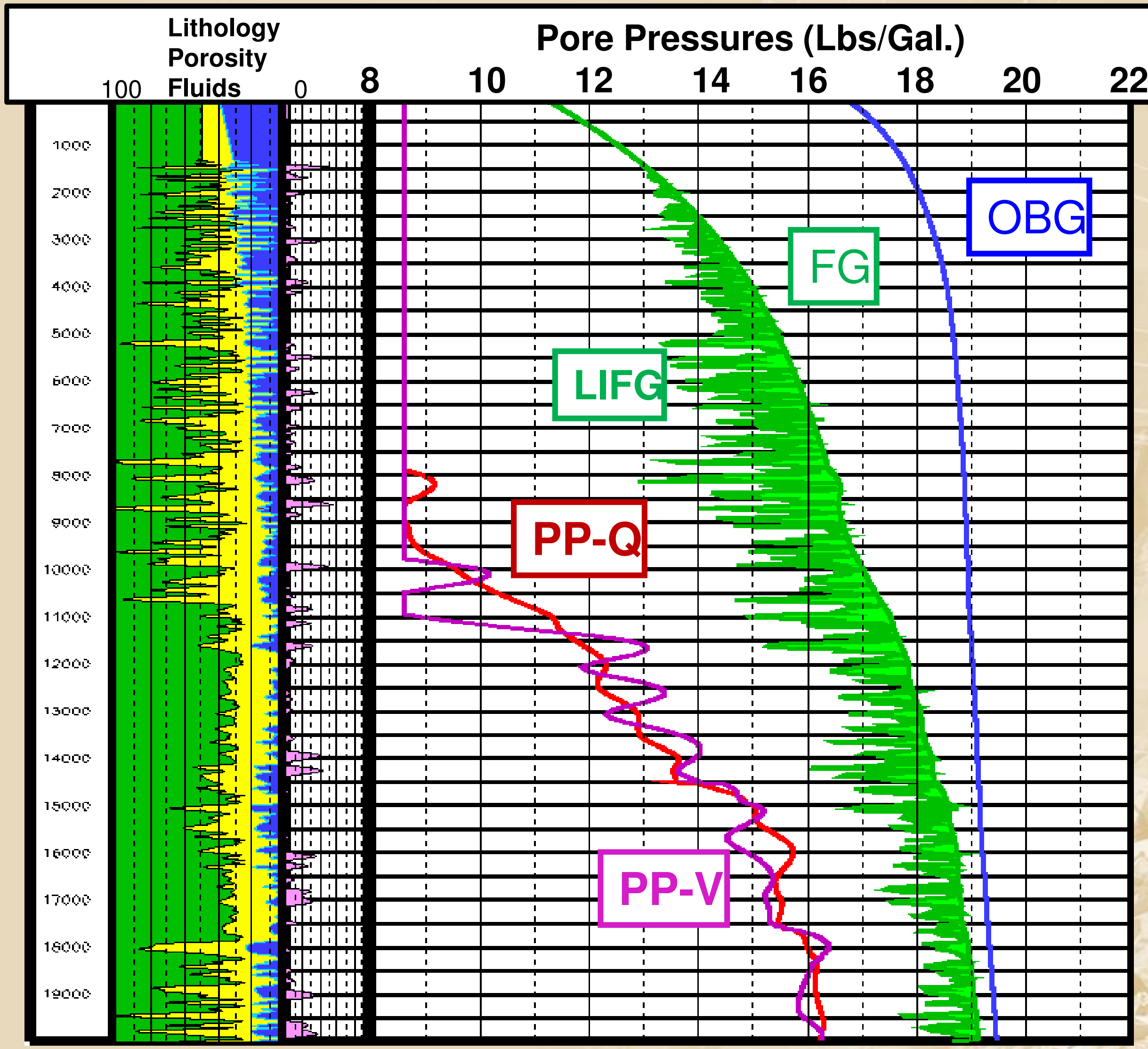
Typically pore pressure work results in a plot as shown here:
Curves shown represent:
PP-Velocity-based
Shale Fracture Gradient (FG)
Overburden Gradient (OBG)



The "Pre-Drill Mud Log" (PDML)

The **PDML** contains predictions of:

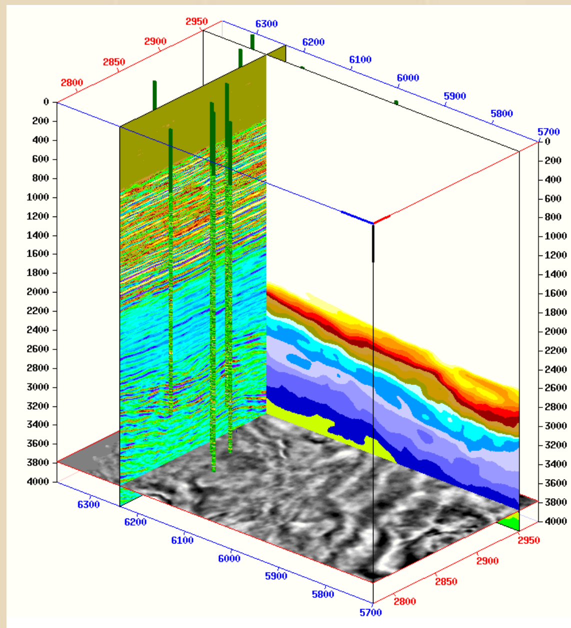
1) **Pore pressure**
   a) PP-Q (freq-based)
   b) PP-V (vel-based)
   c) centroids
2) **Fracture Gradient**
   a) shale
   b) sand (LIFG)
3) **Lithology**
   a) shale/"not-shale"
   b) porosity



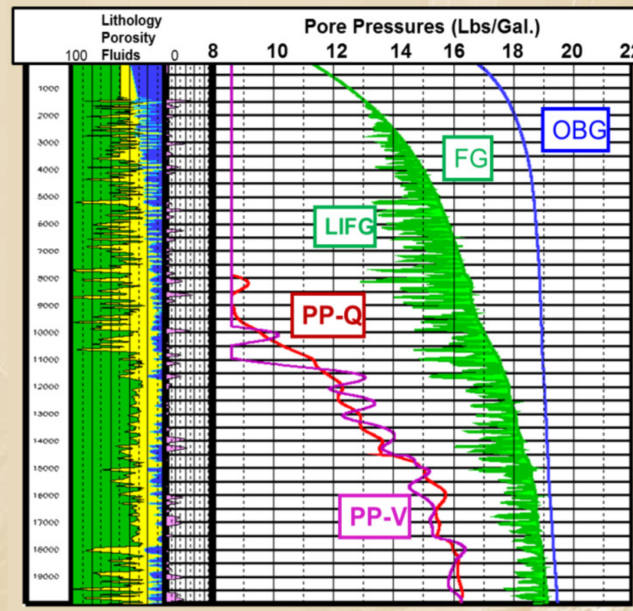
The “Pre-Drill Mud Log” (PDML)

3D Volumes Include:

1) **Pore pressure**
   a) PP-Q (freq-based)
   b) PP-V (vel-based)
   c) centroids
2) **Fracture Gradient**
   a) shale
   b) sand (LIFG)
3) **Lithology**
   a) shale/“not-shale”
   b) porosity



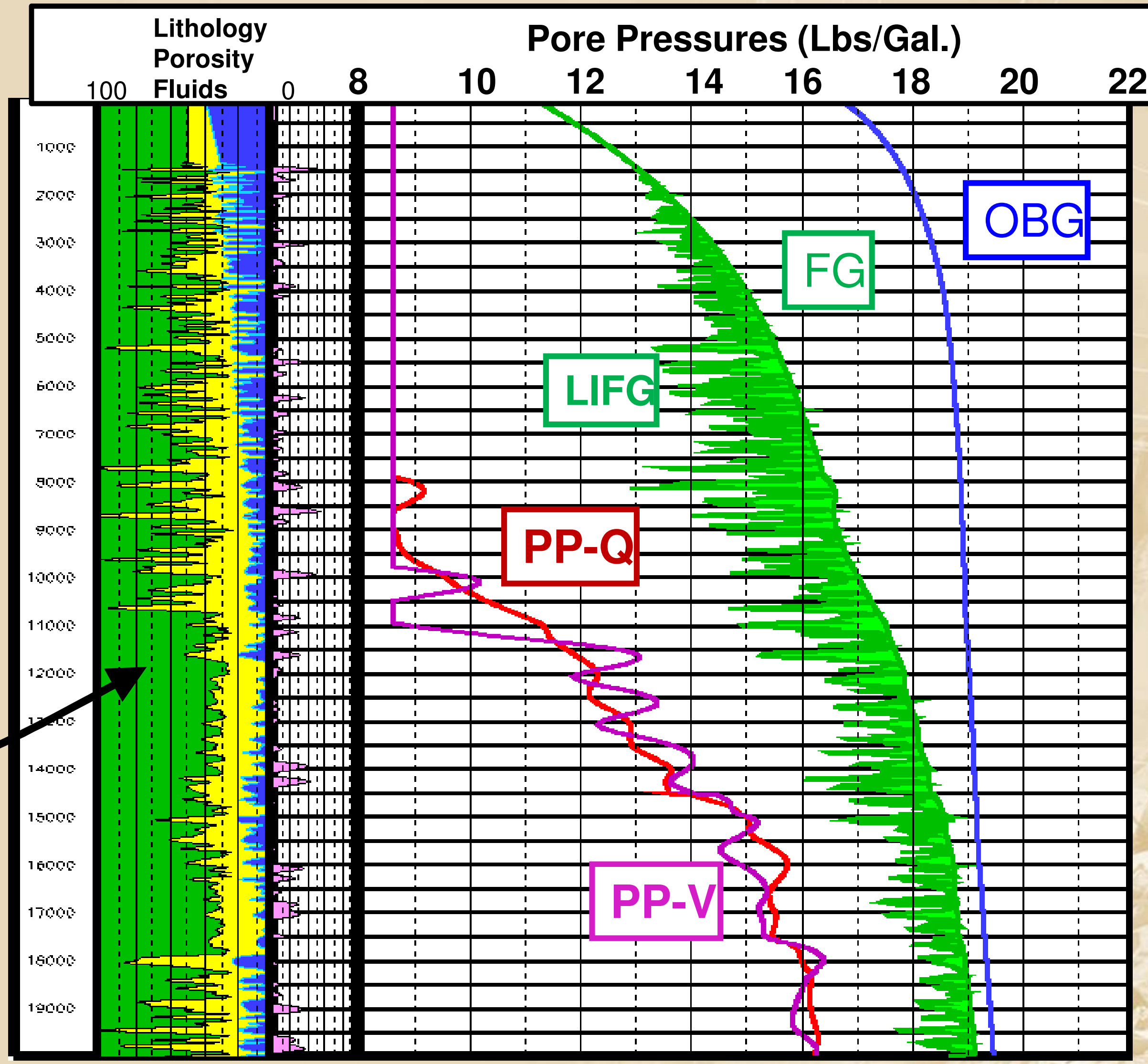
PDML



The PDML is an extraction of over 10 different inversions/calculations along a proposed well path.

The Elements of the PDML

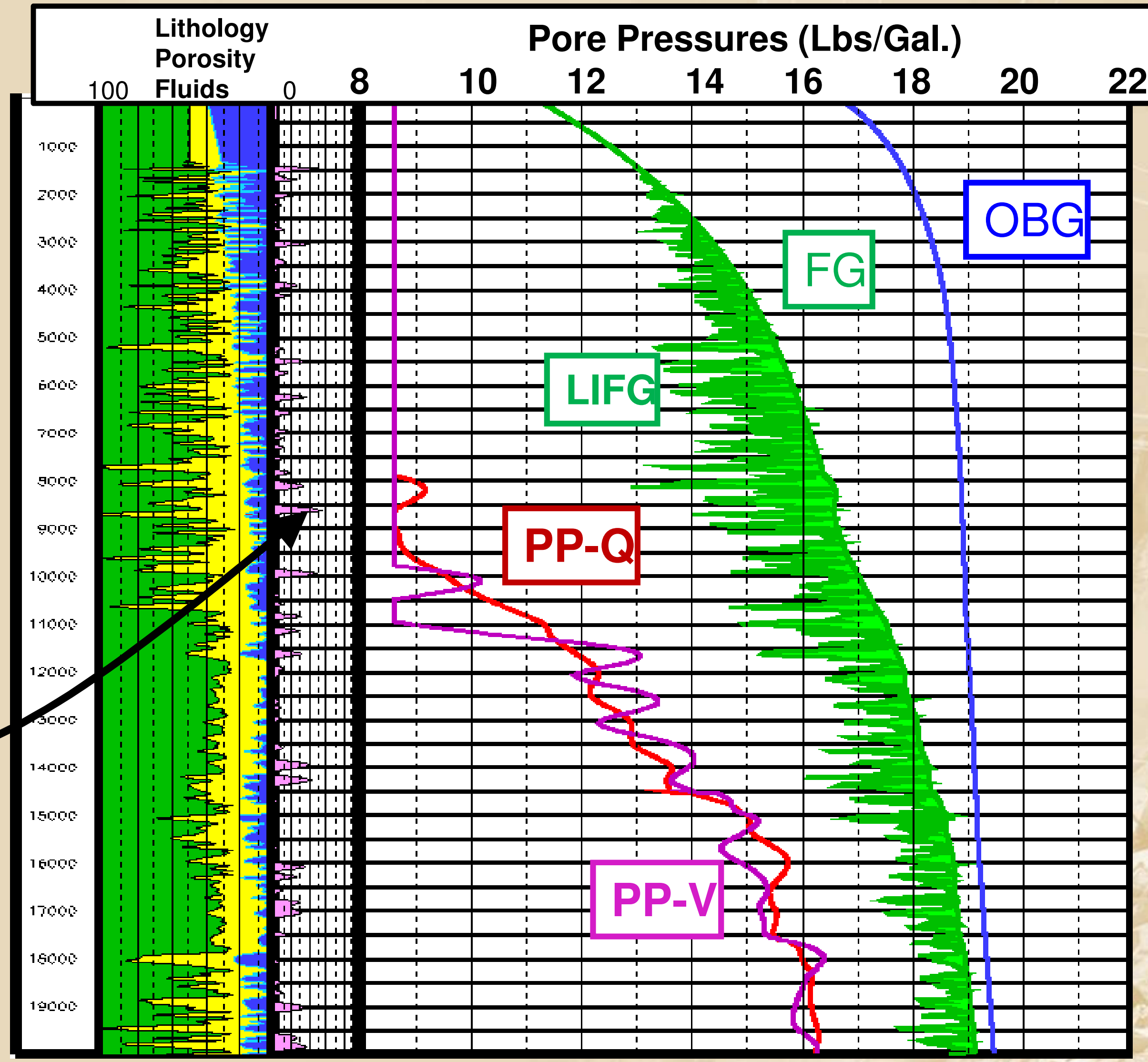
The first column shows a prediction of lithology, porosity and fluids (from seismic). The source is "SAIL" (Spectral AVO Inversion for Lithology). This is a pre-stack spectral inversion that does not need well control.



Green – Shale volume
Yellow – Sand Volume
Blue – Water
Red – Light H/C's

The Elements of the PDML

Track 2 shows seismic "absorption" and can be a warning of gas.



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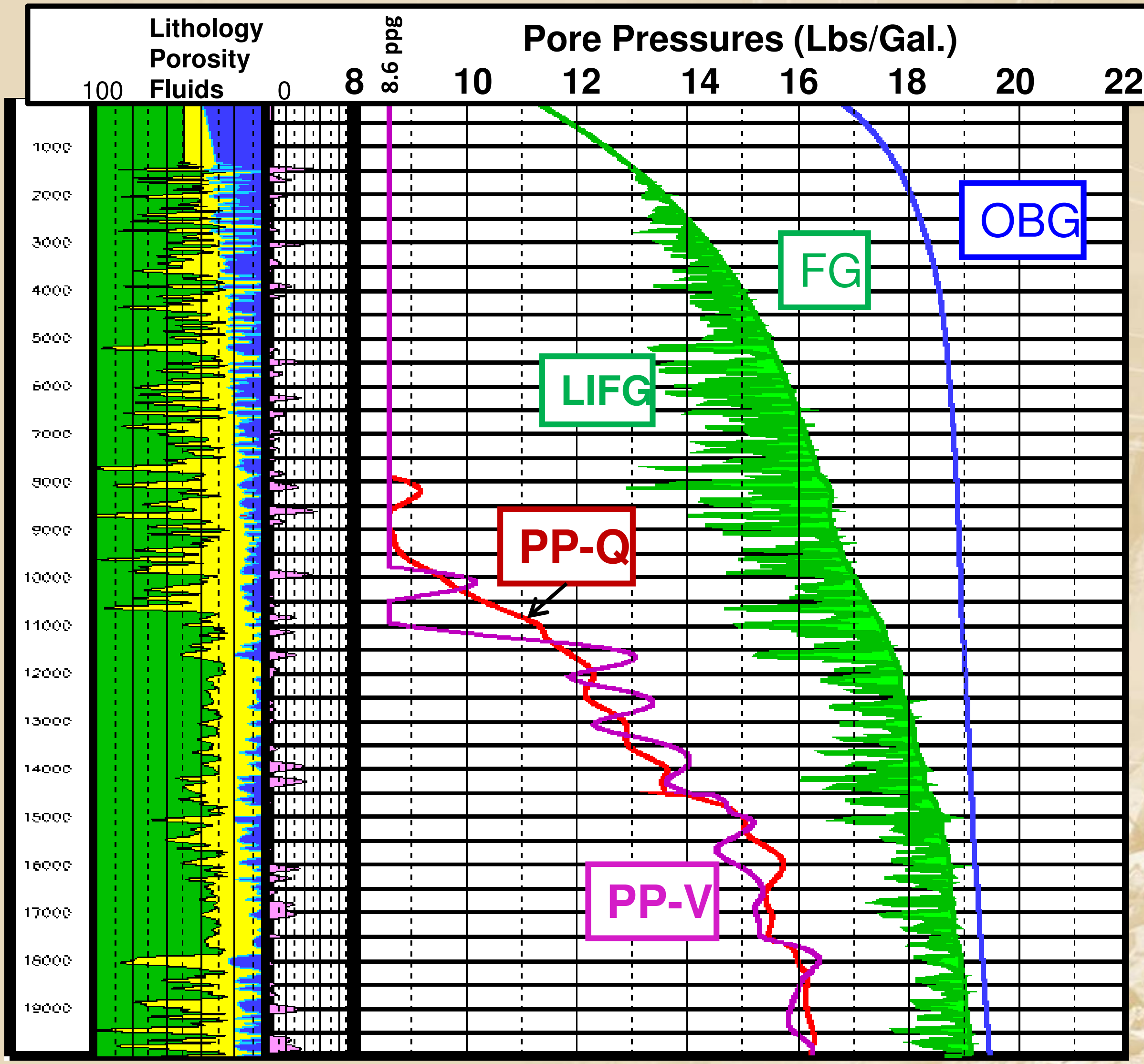
The Elements of the PDML

Track 3 contains:

- PP-V
- PP-Q
- LIFG
- FG
- OBG

Shale PP is calculated from seismic velocity, PP-V, and seismic frequency, PP-Q. Ten years of history using both indicates that **PP-Q is the better choice 95% of the time**. In this example they are in close agreement with each other.

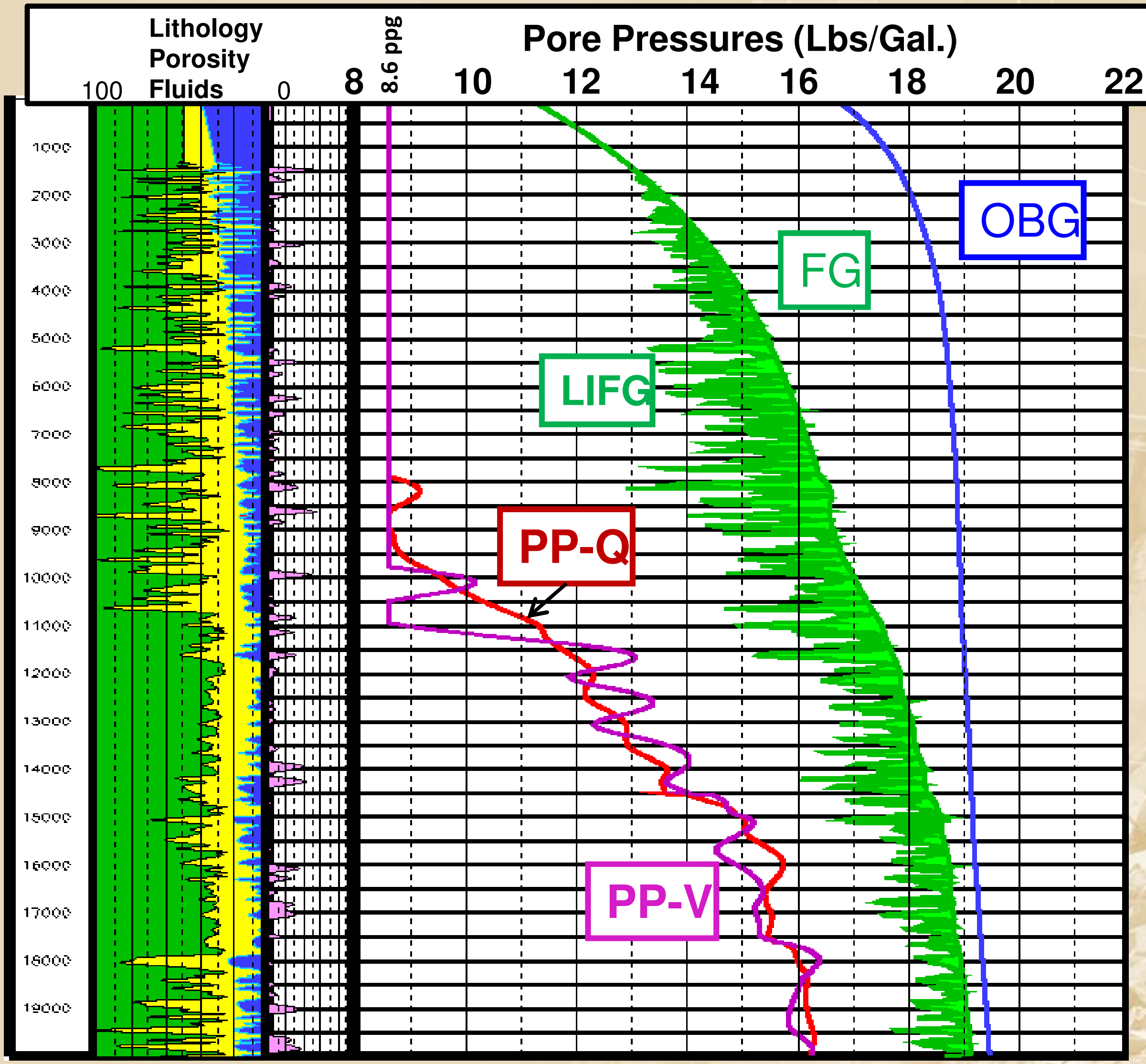


The Elements of the PDML

Track 3 contains:

PP-V
PP-Q
LIFG
FG
OBG

PP only defines half of the drilling window. The other half is defined by the LIFG (lithology influenced fracture gradient). Displayed in green is the shale FG and sand LIFG indicating potential fluid loss sections in the lower pressure sands.

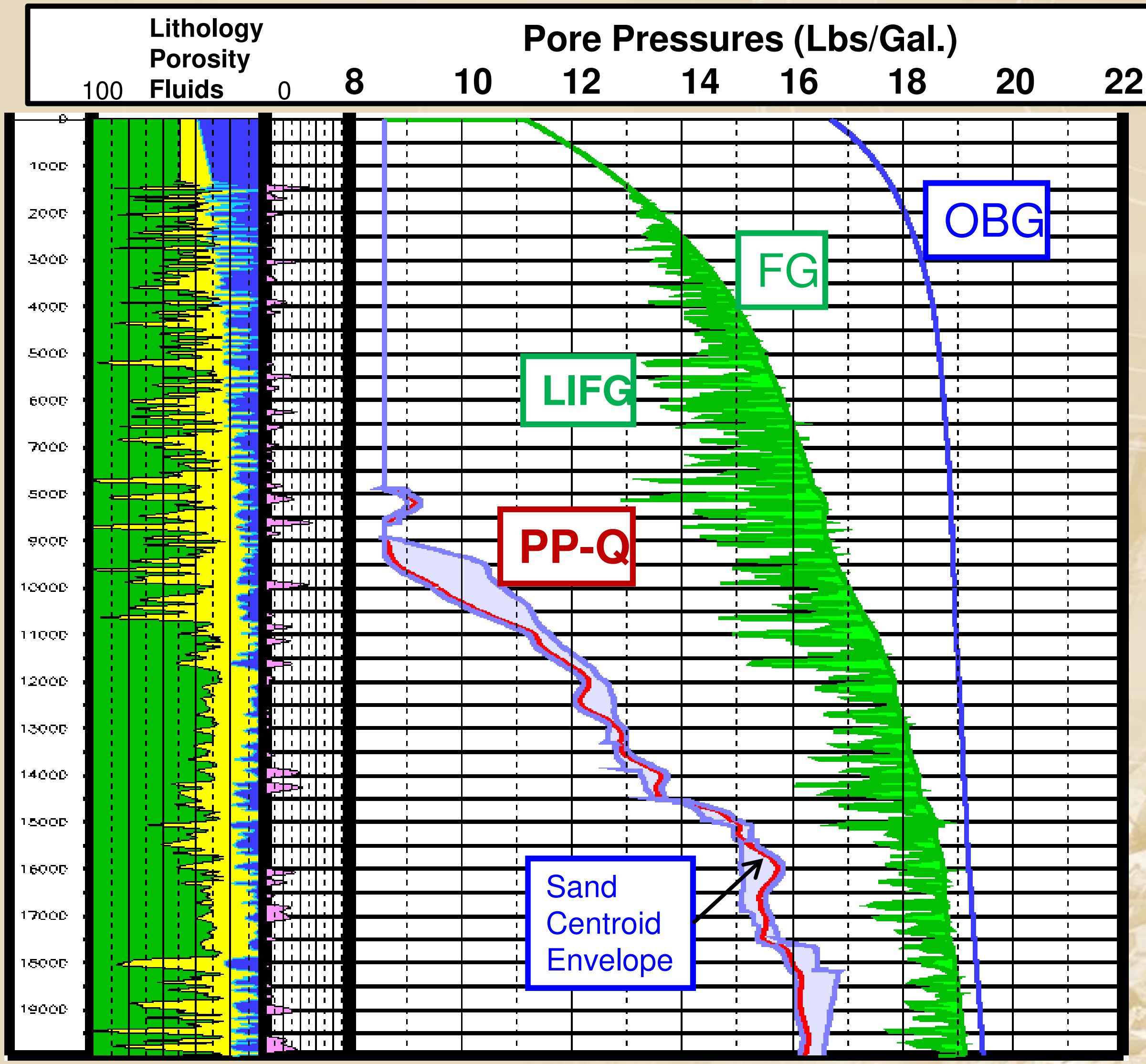


www.e-seis.com

The Elements of the PDML

Track 3 contains:
PP-Q
Centroids (min,max)
LIFG
FG
OBG

PP from seismic is PP of the **shales.** Sand PP must be calculated and has a range (depending on the amount of structure). The light blue envelope shows the range of sand centroid pressures.

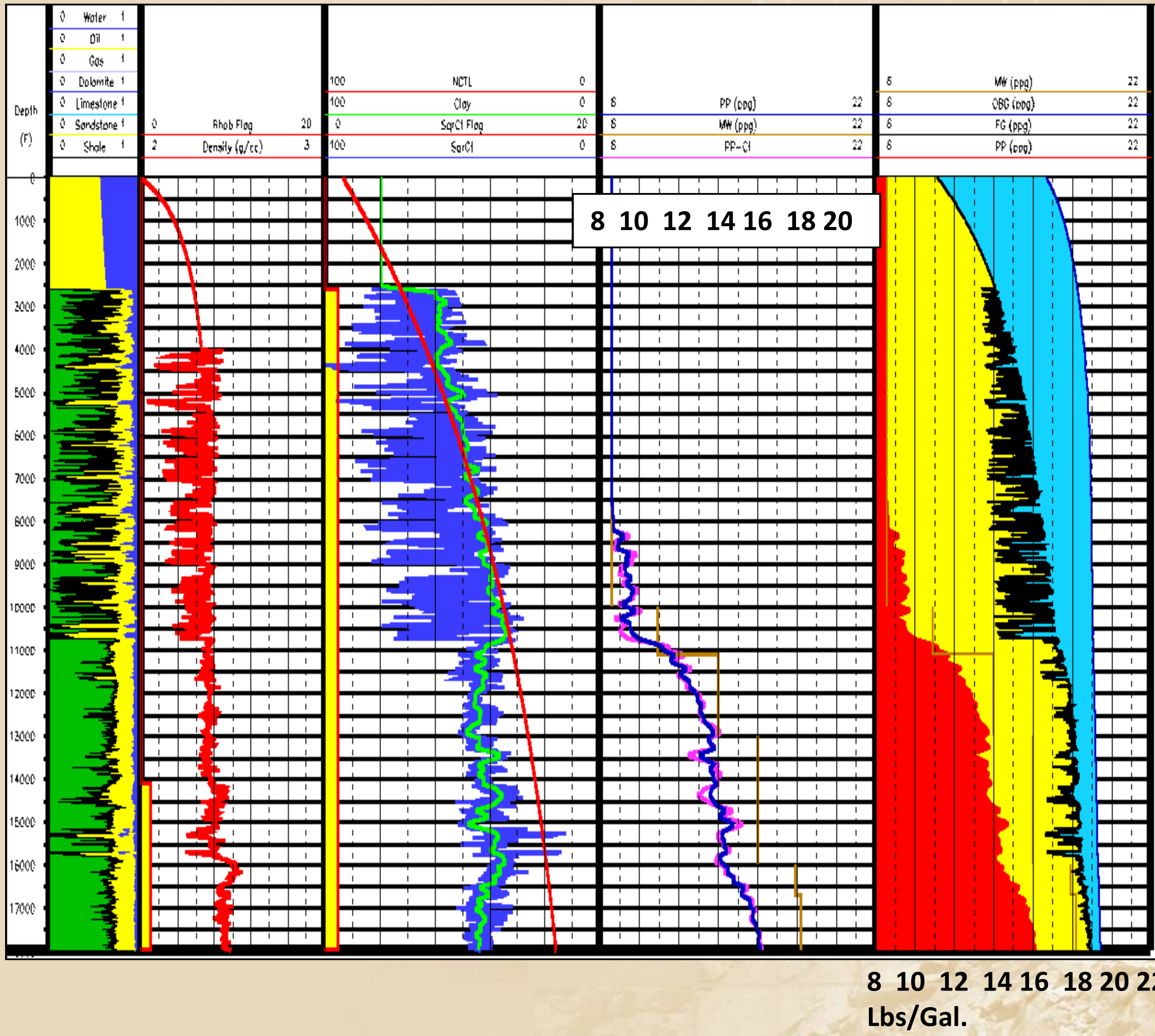


www.e-seis.com

Daily Update of the PDML

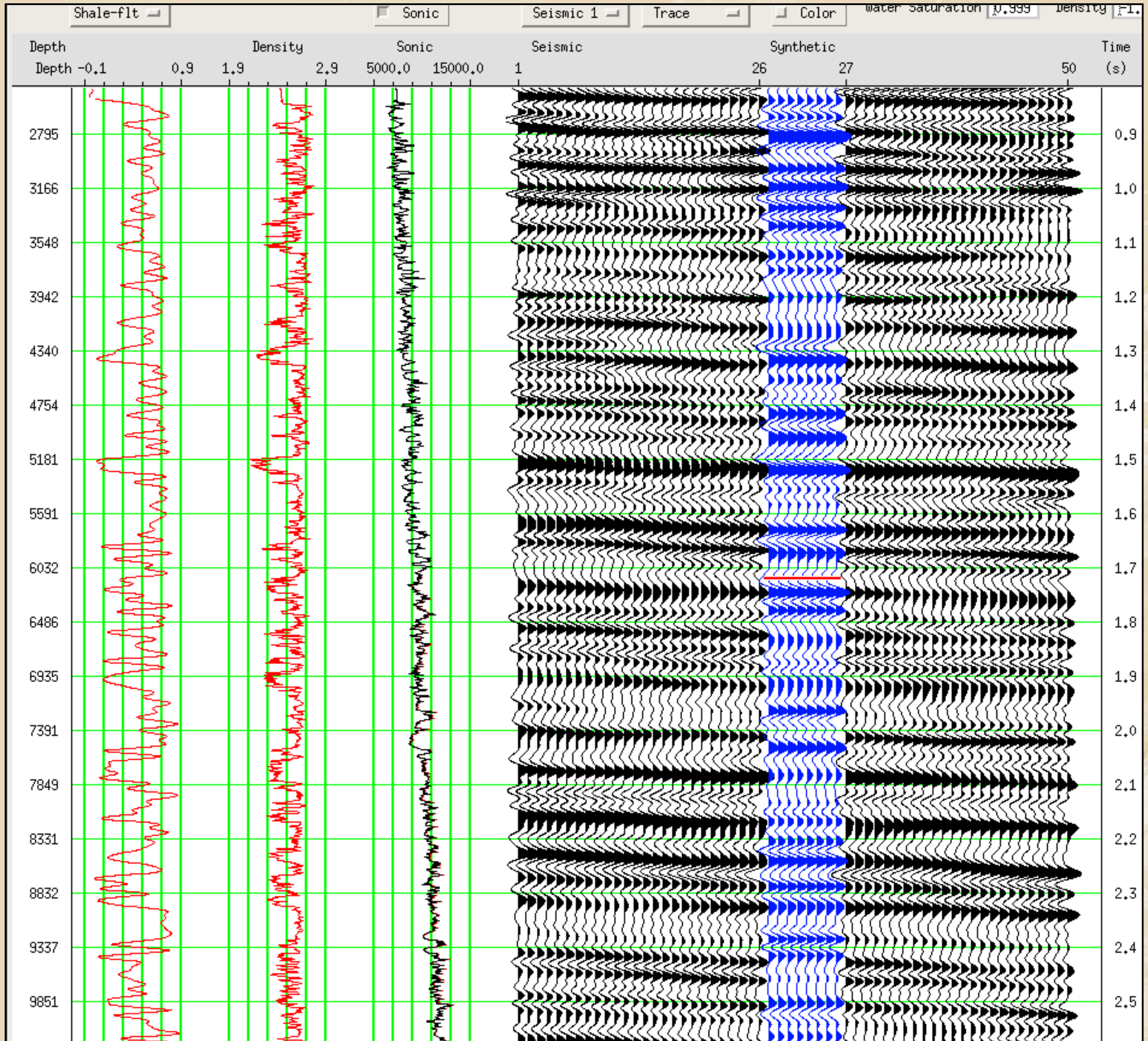
The Daily Assessment of PP and FG

When the drilling starts. The shale pore pressure is assessed using info from LWD logs, wireline logs and other drilling parameters (such as mud weight, LOT's, MDT's, RFT's).



The Daily Update Of Time/Depth

The PDML is a prediction of rock properties for designing the well. These predictions are provided in depth, however the data source is seismic which is in time. The time/depth relationship for the well is assessed by re-tying the well synthetic (shown in blue)to the seismic, as drilling proceeds, This is done using a synthetic from LWD info. The new time/depth relationship is used to convert the PDML to depth.



www.e-seis.com

The Daily Update of the Pre-Drill Mud Log

The latest drilling information is posted on the PDML. Predicted and actual pore pressures and mud weights are displayed, along with the well's GR curve. If required, the PDML can be recalibrated, therefore providing the best prediction of what lies ahead of the bit.