Petrophysical and seismic signature of a heavy oil sand reservoir: Manitou Lake, Saskatchewan

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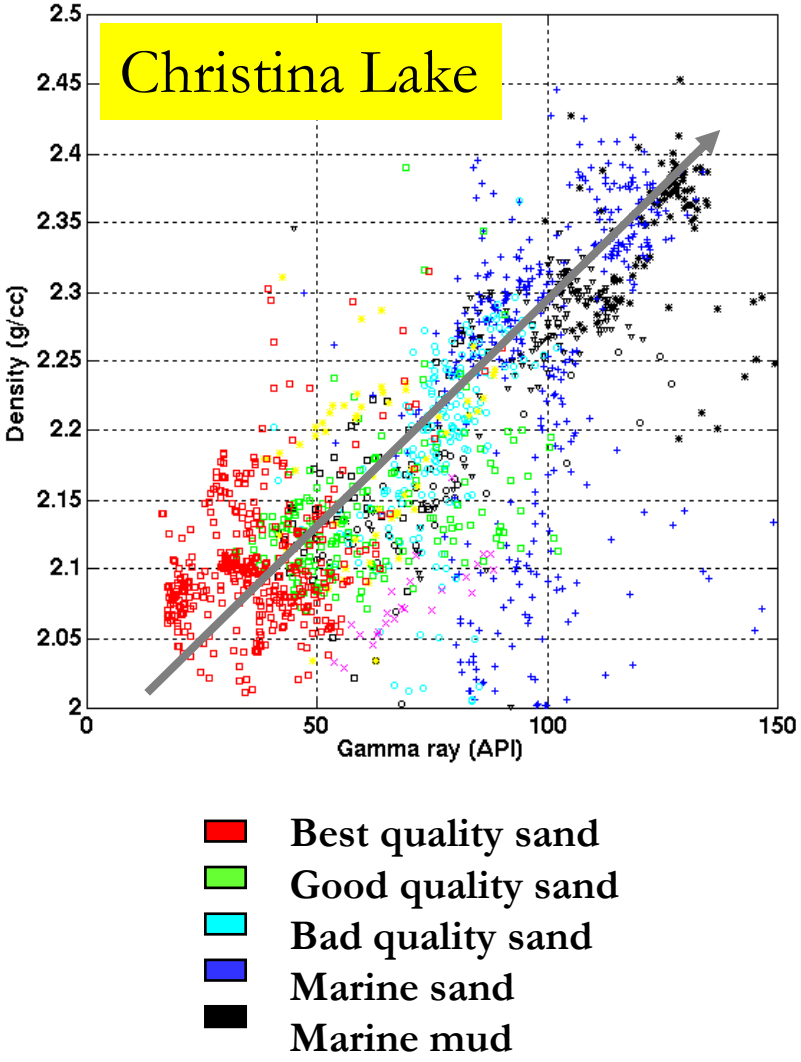
Robert R. Stewart

Outline

- Introduction
- Area of Study & geological setting
- Log analysis and rock properties
- Log modelling
  - Log response
  - Kuster-Toksöz
- Synthetic seismograms
- Model based inversion
- Conclusions

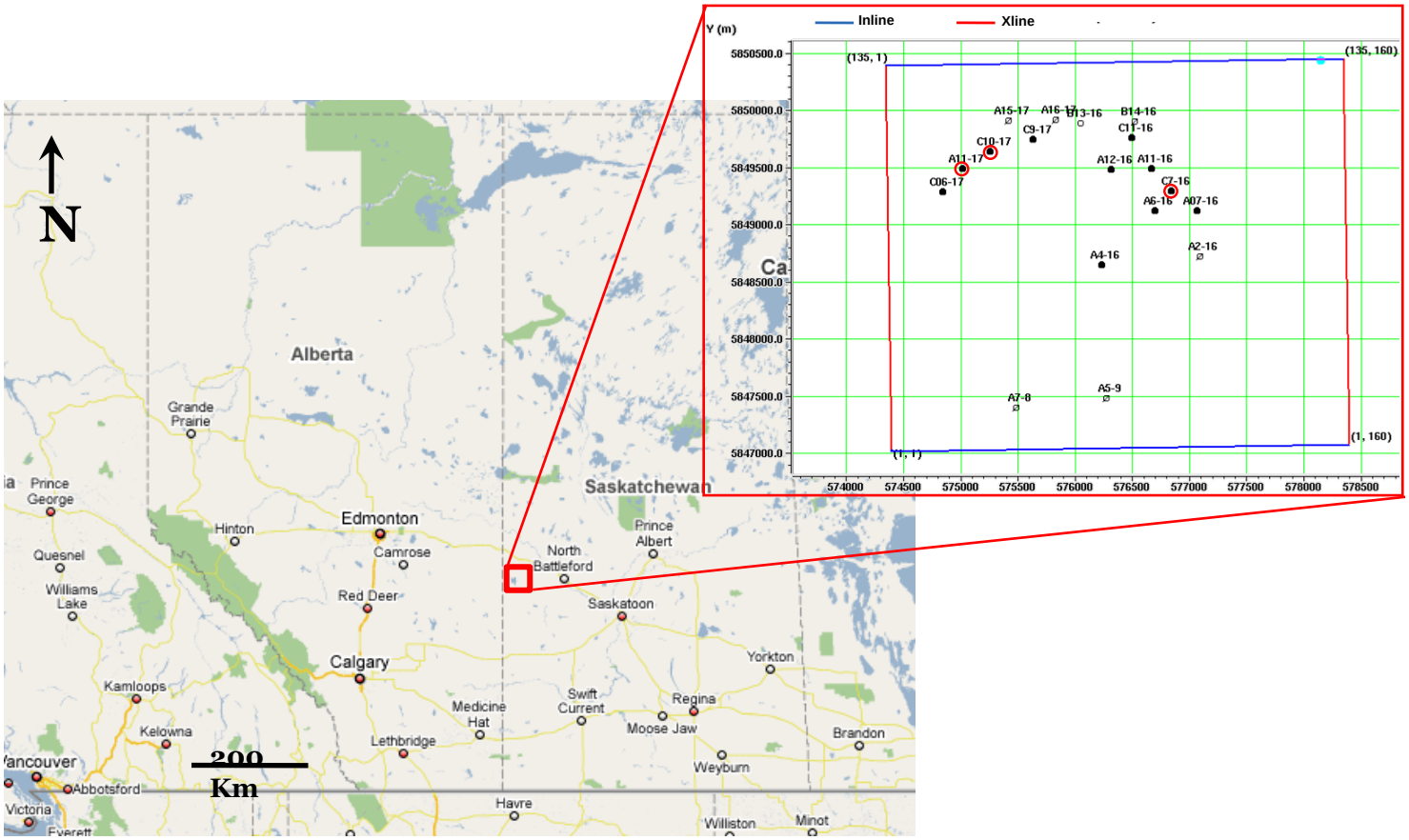
- How to relate elastic properties to rock properties
  - Lithology
  - Fluid saturation
  - Porosity
- Additional information from PS data
- Improve interpretation using different log modelling approaches.

From Xu, Yong



Area of study

- Manitou Lake, Saskatchewan
- Lloydminster heavy oil: 12-16 °API



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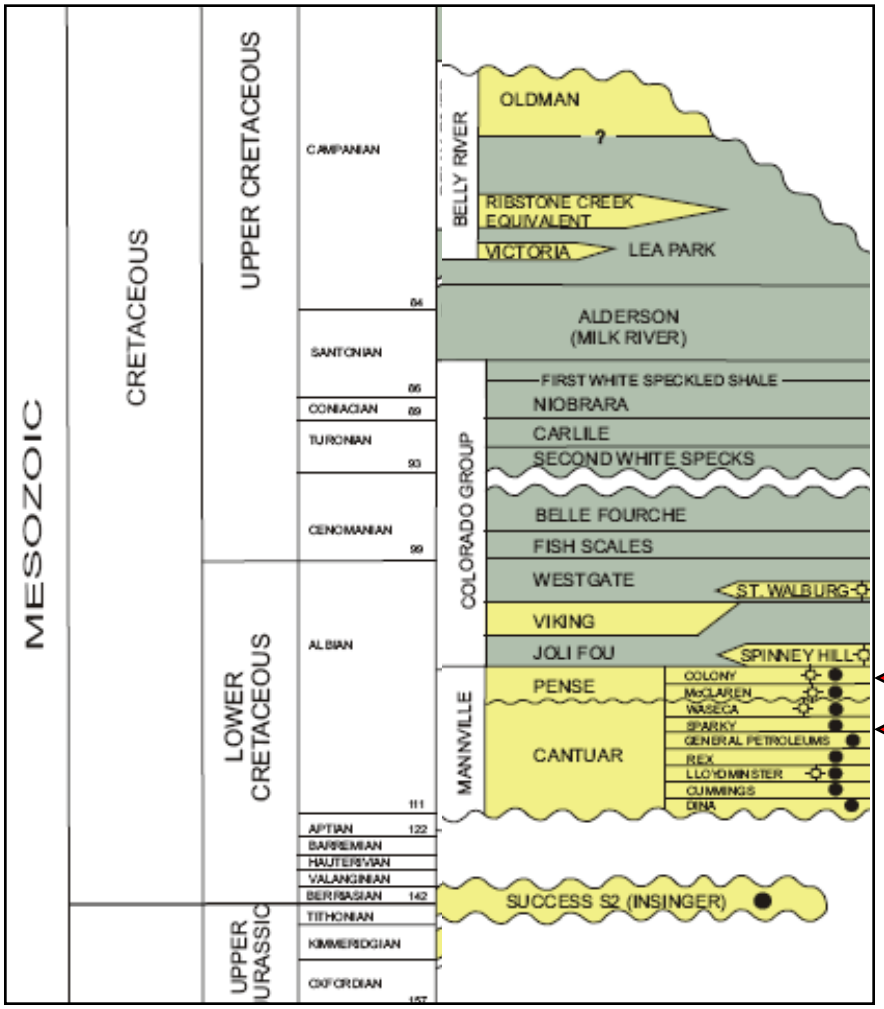
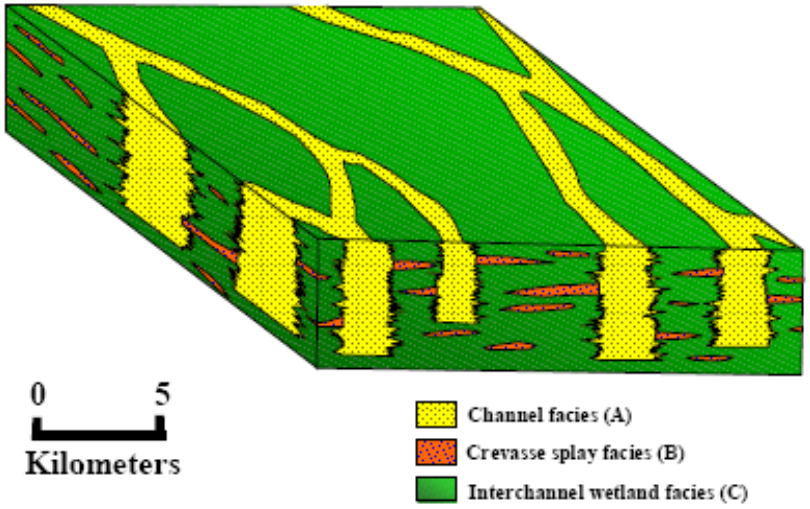


From Saskatchewan Industry and Resources, 2006



Depositional model for the Colony sand member after Putnam and Oliver (1980) (From Royle, 2002)

Colony
Sparky
} **Targets**

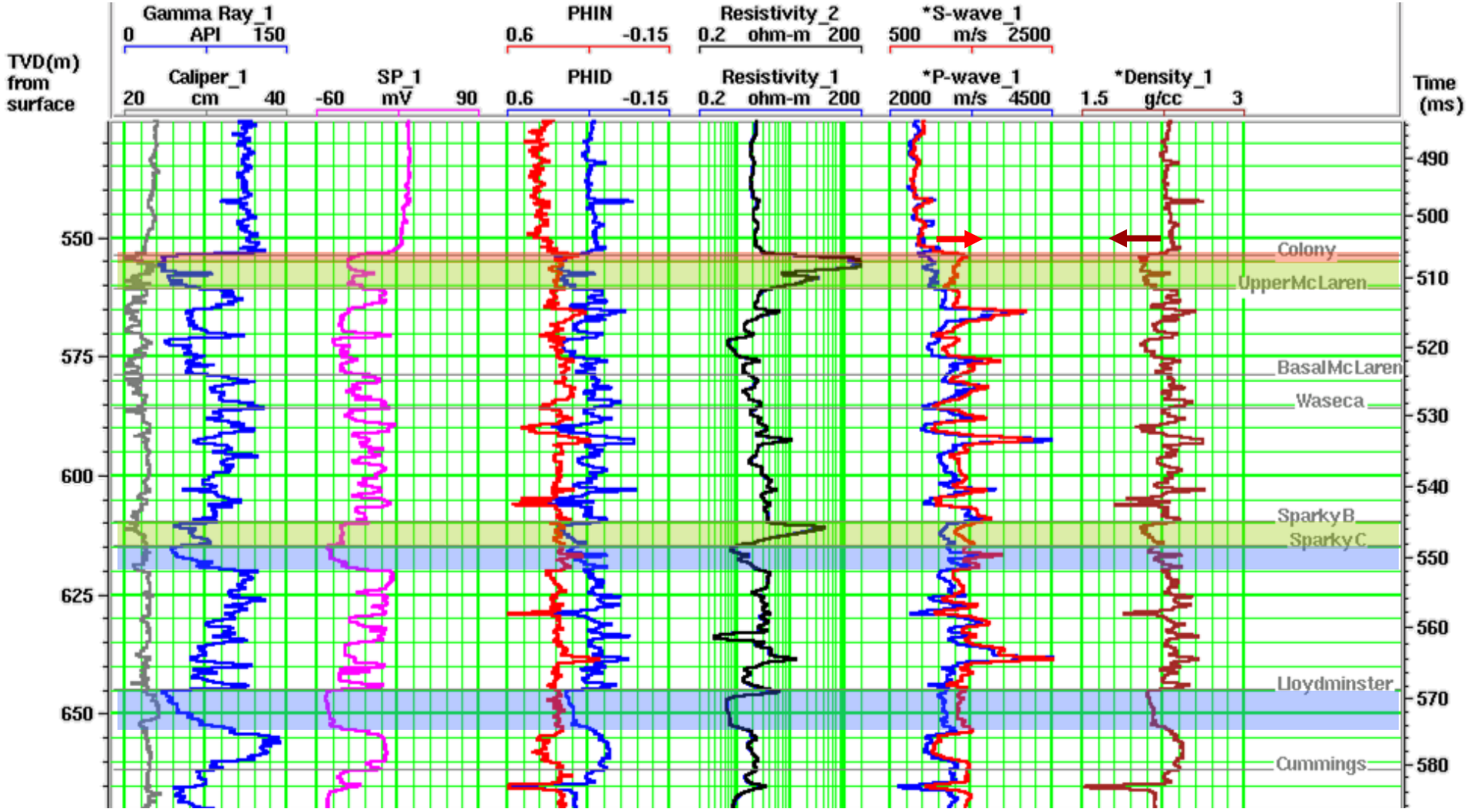
Lower Cretaceous Mannville Gr.

- Colony member: Fluvial deposition in an anastomosed river network
- Sparky member: Wave dominated shoreline environment

Log analysis

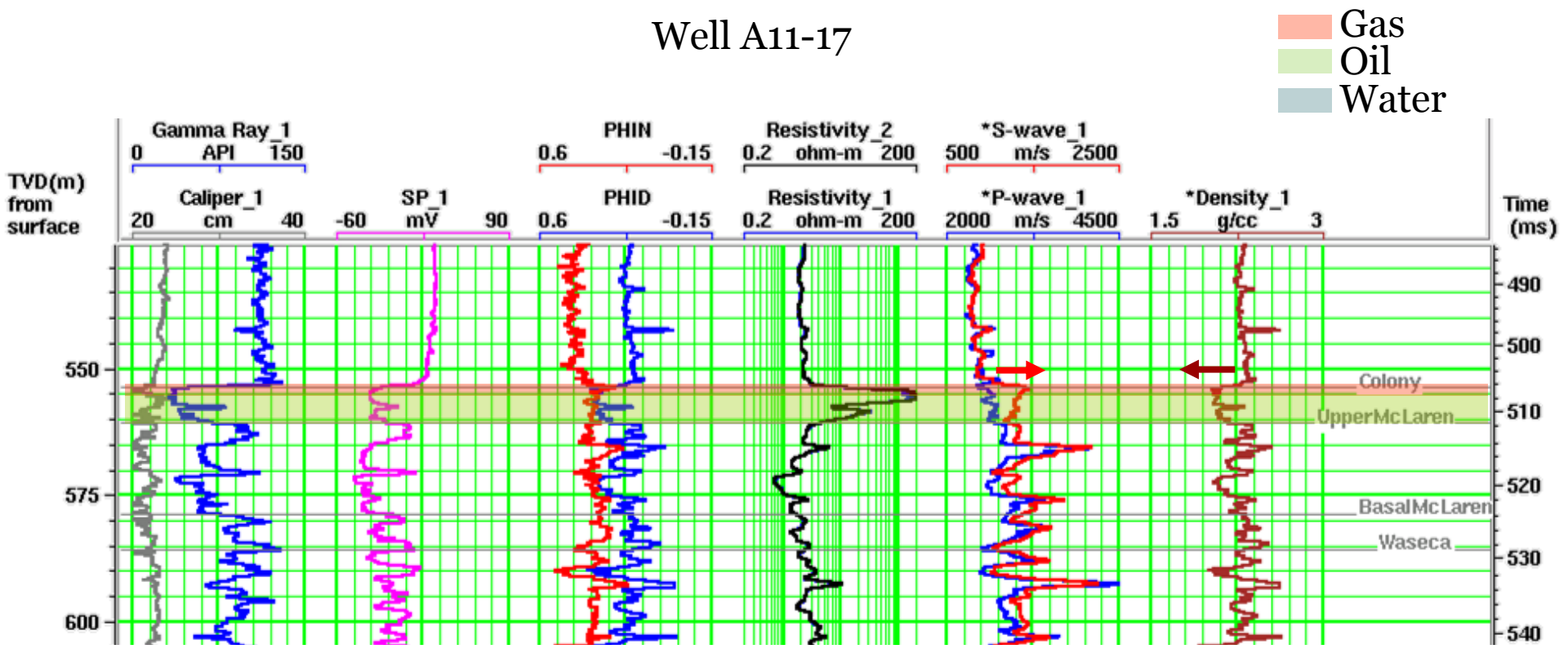
Well A11-17

Gas
Oil
Water



Log analysis

Well A11-17

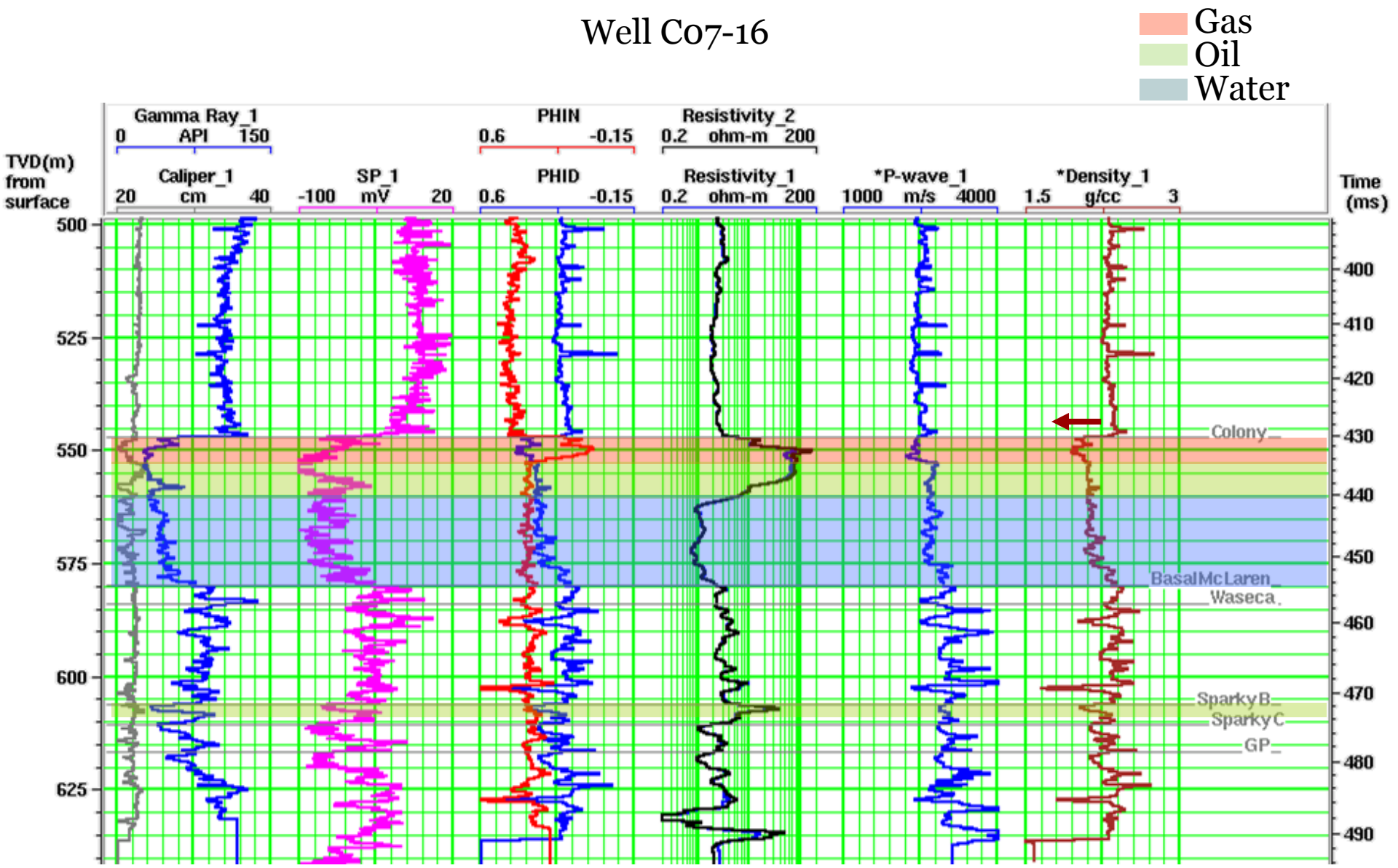


Top of the sands:

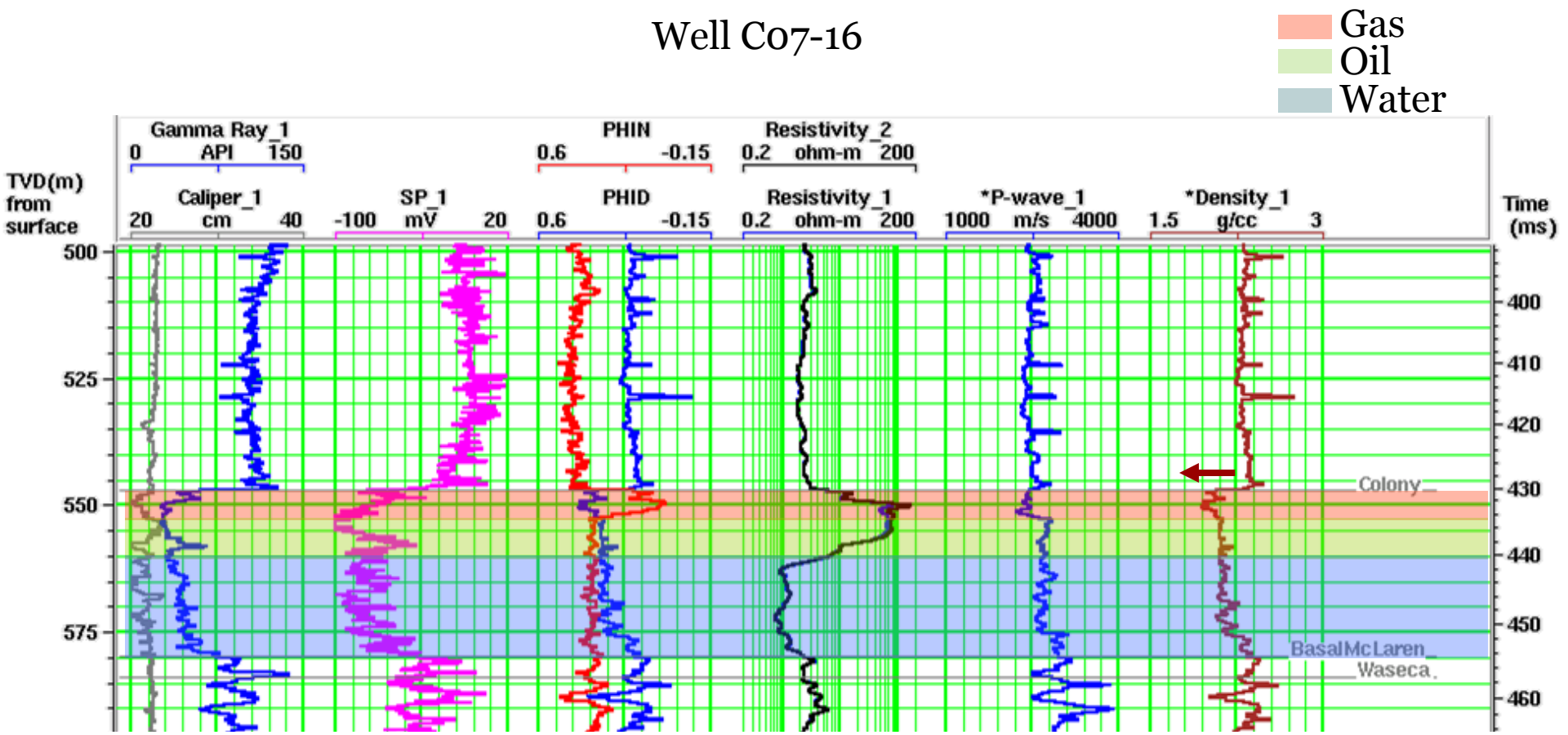
- Increase in S-wave velocity
- Decrease in density
- No change in Vp

Log analysis

Well C07-16



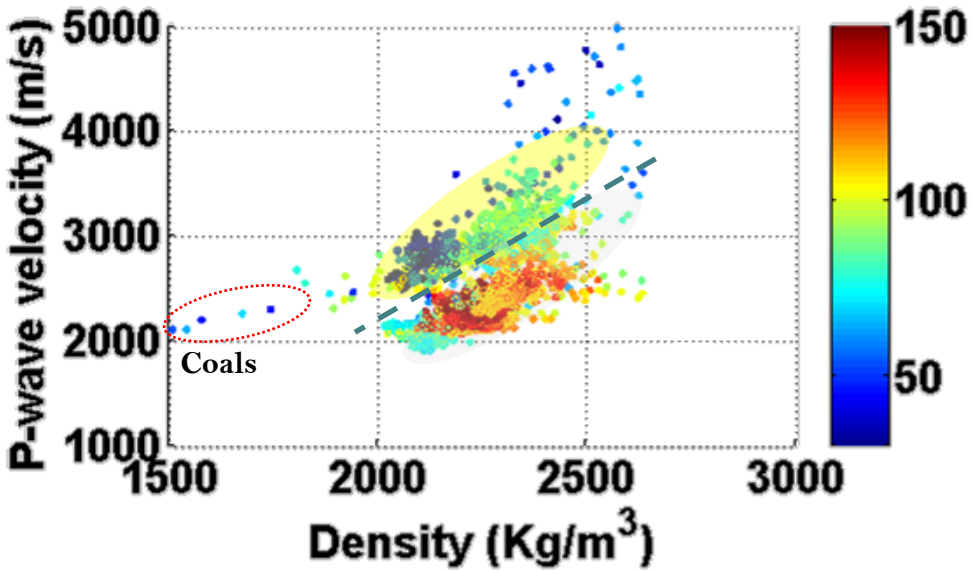
Well C07-16

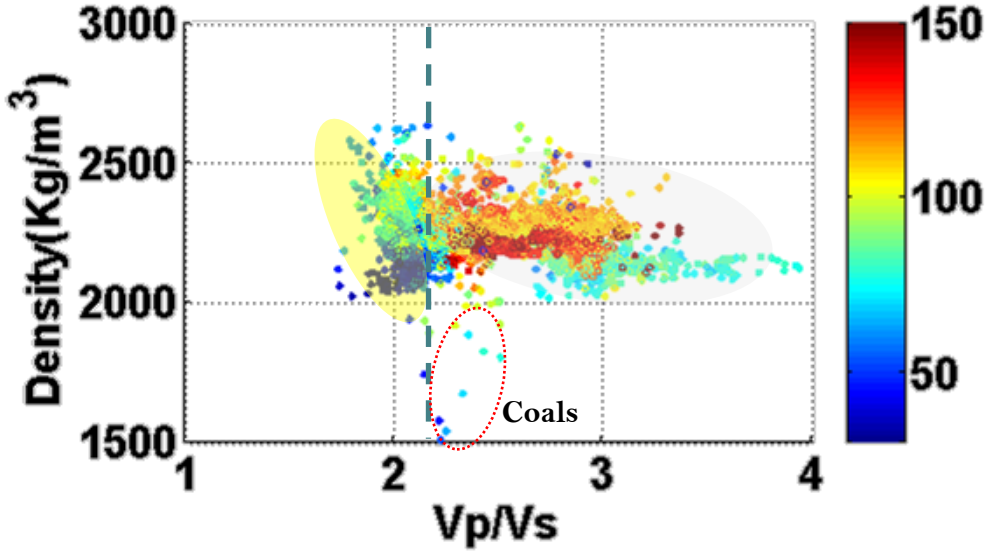


Top of the sands:

- Decrease in density
- Decrease in Vp → Gas effect

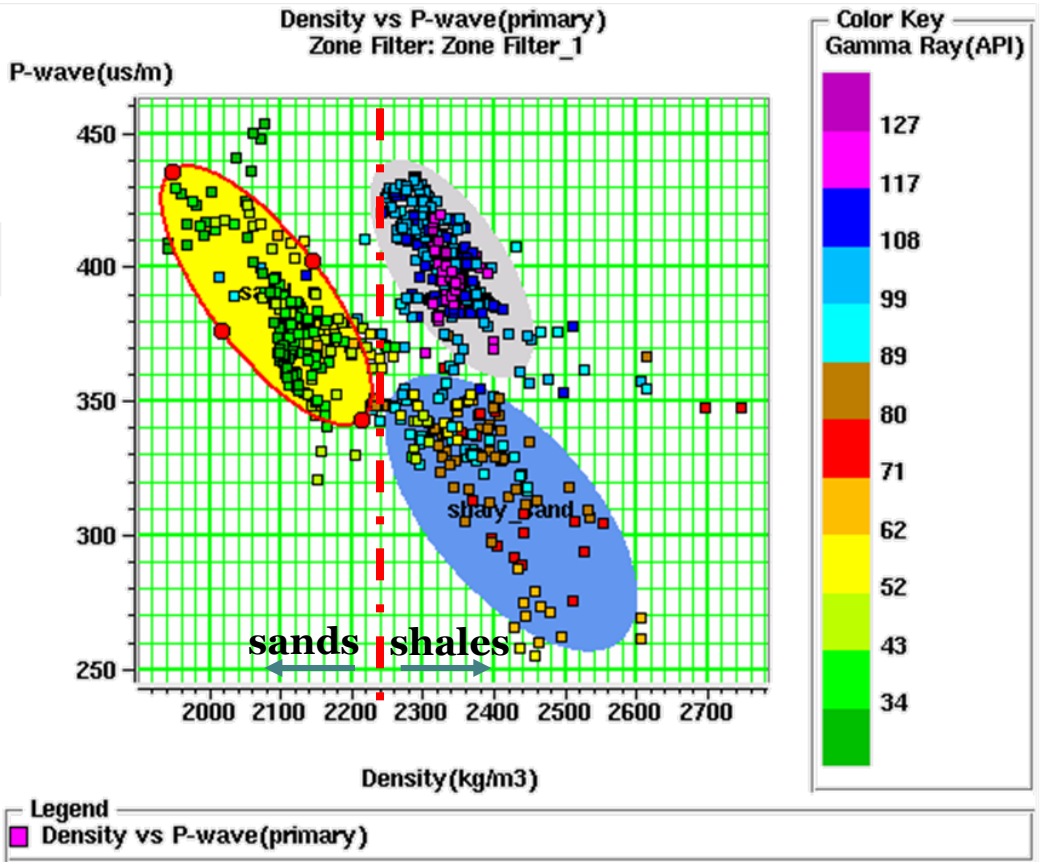
Rock Properties





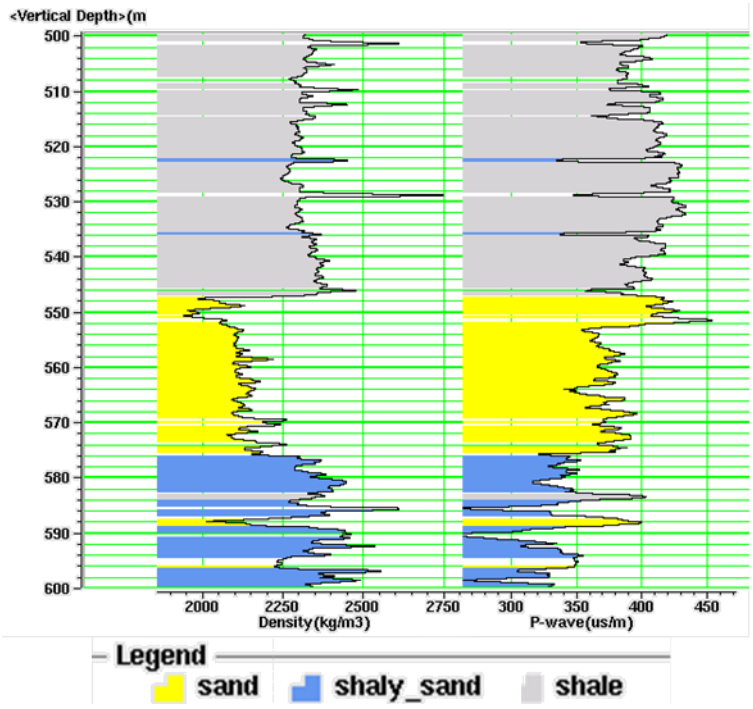
- Overlap in density for sands and shales over complete depth interval
- Good separation with Vp/Vs.

Rock Properties



- Overlap in density for sands and shales over complete depth interval
- Good separation with Vp/Vs.
- Target interval: 500-600 m

  Densities lower than 2.25 g/cm^3 indicate sands



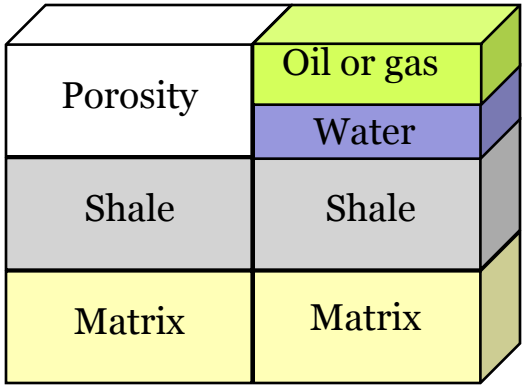
Log response modeling

- Log response equation (Crain, 1986)

$$Model = \underbrace{(\phi_e * S_w * l_{water})}_{\text{water}} + \underbrace{(\phi_e * (1 - S_w) * l_{hydro})}_{\text{hydrocarbon}} + \underbrace{(V_{sh} * l_{shale})}_{\text{shale}} + \underbrace{((1 - V_{sh} - \phi_e) * l_{matrix})}_{\text{matrix}}$$

- Volume of shale calculated from GR log

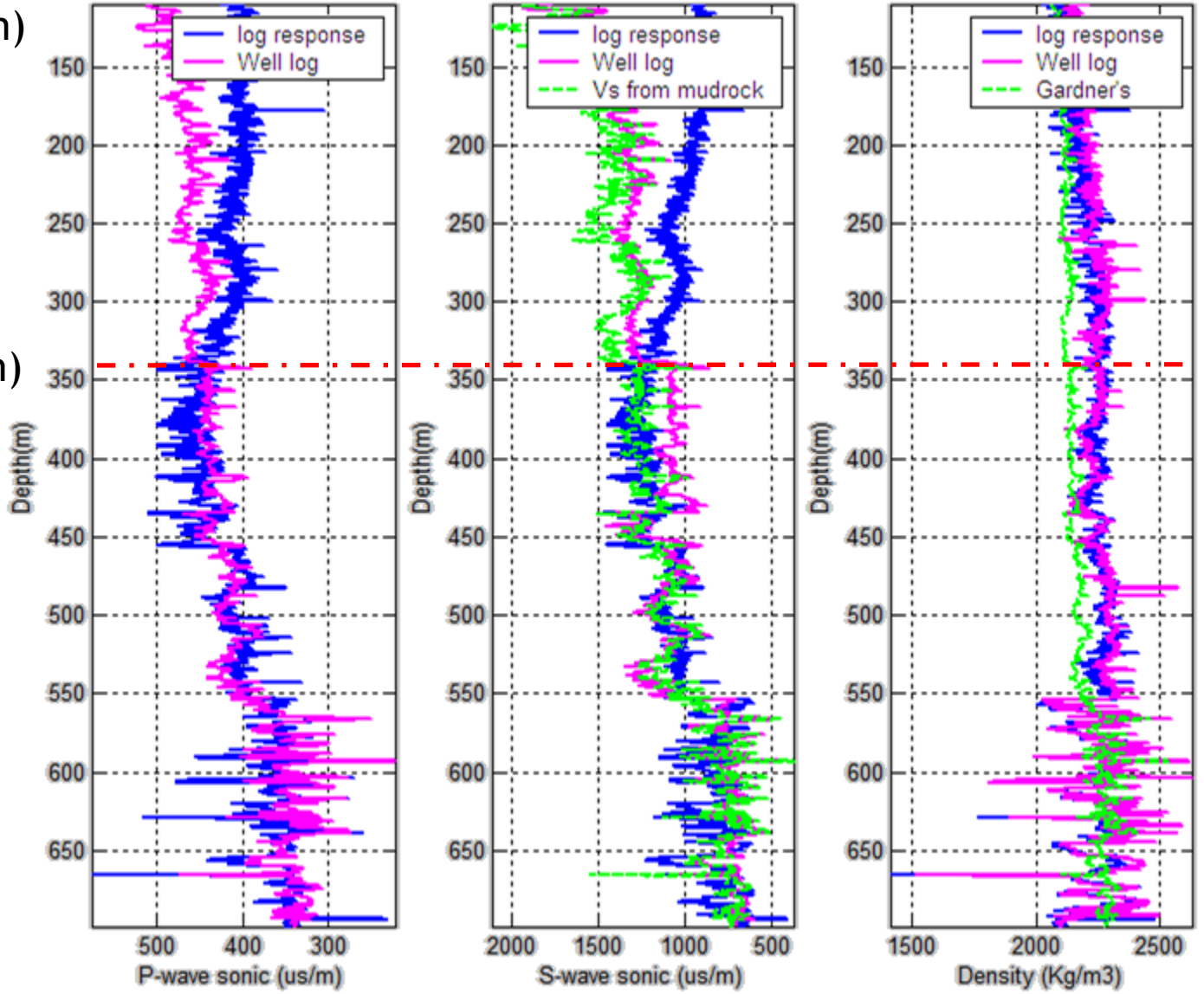
- Water saturation using Archie's equation and default values for sandstone
  a=0.62 , m=2.15, and n=2.

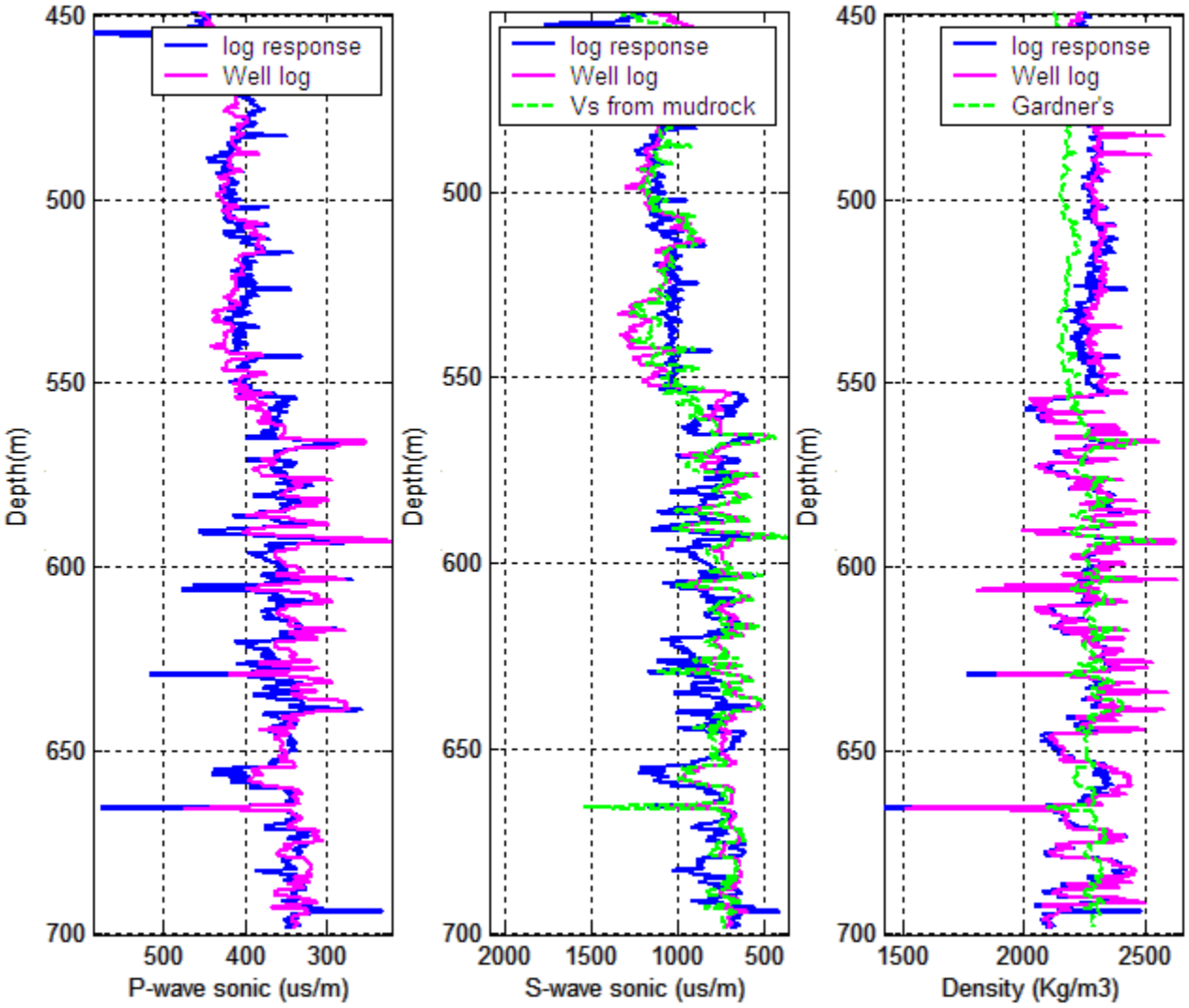


- Effective porosity from the density-neutron complex lithology crossplot

Log response modelling

- P-wave sonic (μs/m)
  - matrix=182
  - Water=616
  - Shale=500
  - Oil=664
- S-wave sonic (μs/m)
  - Matrix=292
  - Water=1200
  - Shale=1450
  - Oil=1200
- Density (g/cm^3)
  - Matrix=2650
  - Water=1000
  - Shale=2200
  - Oil=950




log response
Well log
Depth(m)
450
500
550
600
650
700
500
400
300
P-wave sonic (us/m)
log response
Well log
Vs from mudrock
2000
1500
1000
500
S-wave sonic (us/m)
log response
Well log
Gardner's
1500
2000
2500
Density (Kg/m3)

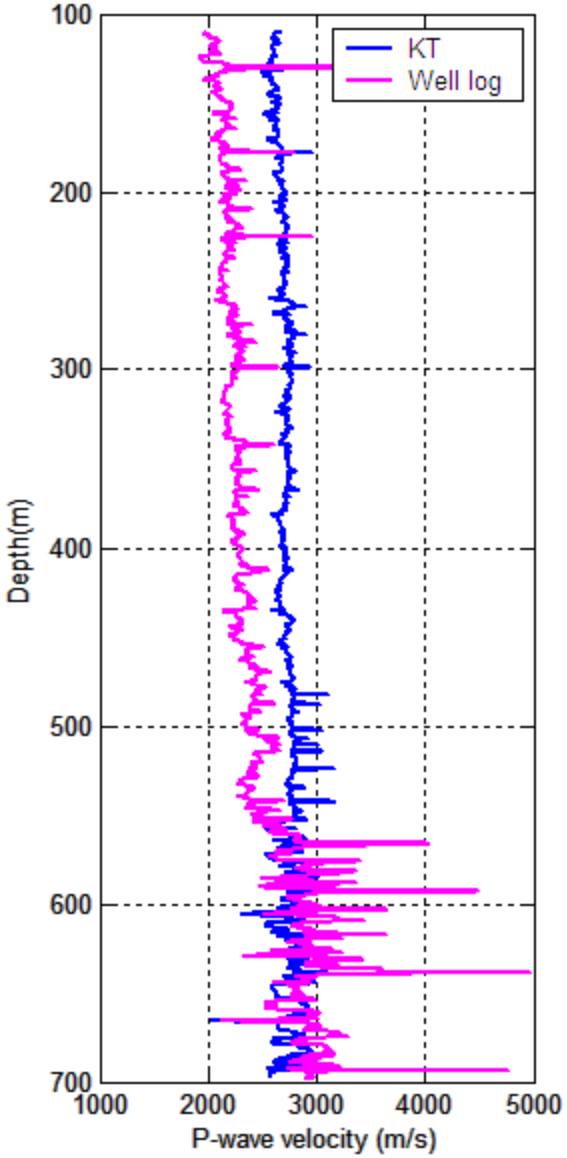
Kuster-Toksöz formulation

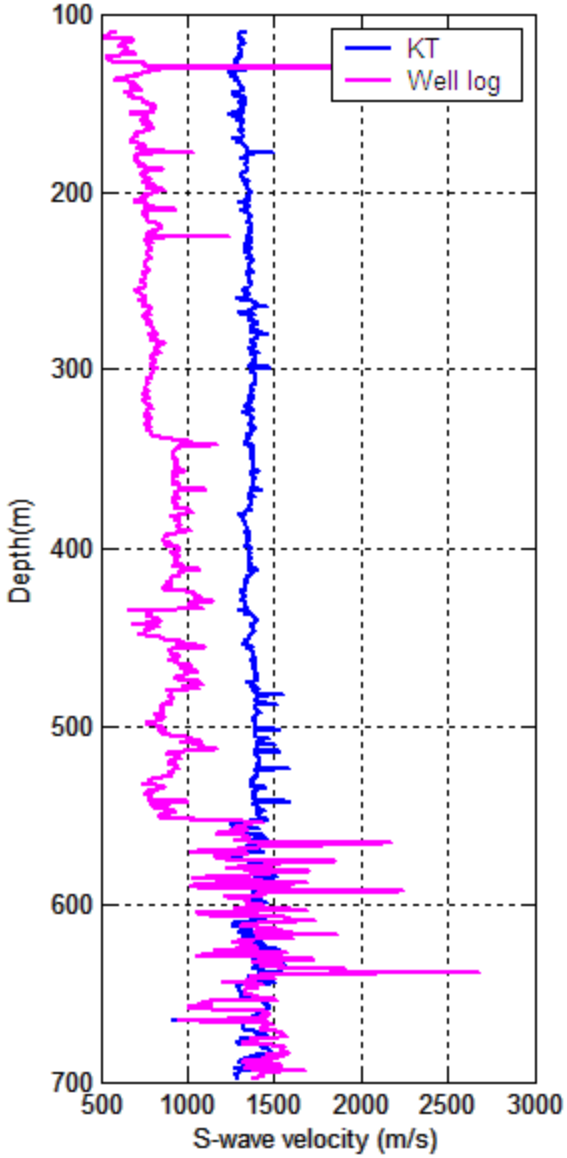
- Estimate Vp and Vs using a long-wavelength first-order scattering theory.
- Takes pore geometry into account
  - Spheres, needles, disks and penny cracks
- Inclusions must be randomly distributed
- Dilute concentration ($\phi/\alpha<<1$)
- Cavities are isolated with respect to flow
- At low frequencies it is better to find the effective moduli for dry cavities and then saturate them with the Gassmann low frequency relations (Mavko et al., 1998).

$$\frac{K_{sat}}{K_0 - K_{sat}} = \frac{K_{dry}}{K_0 - K_{dry}} + \frac{K_{fl}}{\phi\left(K_0 - K_{fl}\right)}$$

Kuster-Toksöz modelling

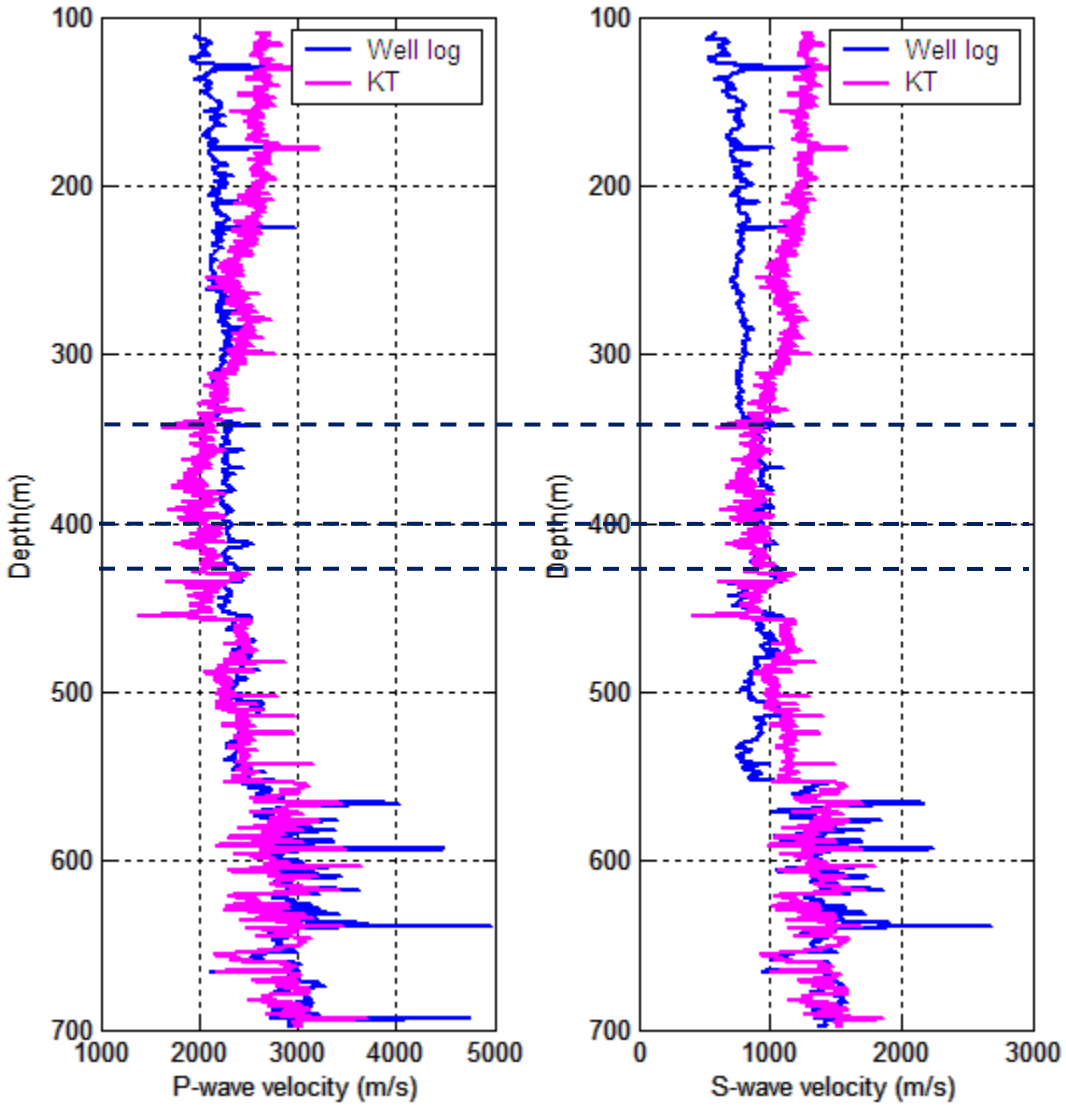
- Sphere pores
  - α=0.3
  - Dens=2.65
  - Vp=3.2
  - Vs=1.6





Kuster-Toksöz modelling

- Velocity linearly changing with shale volume
  - Dens1=2.65
  - vp_sand=4
  - vs_sand=2
  - vp_shale=2
  - vs_shale=0.8
- Vp/Vs for sand=2
- Vp/Vs for shale= 2.5



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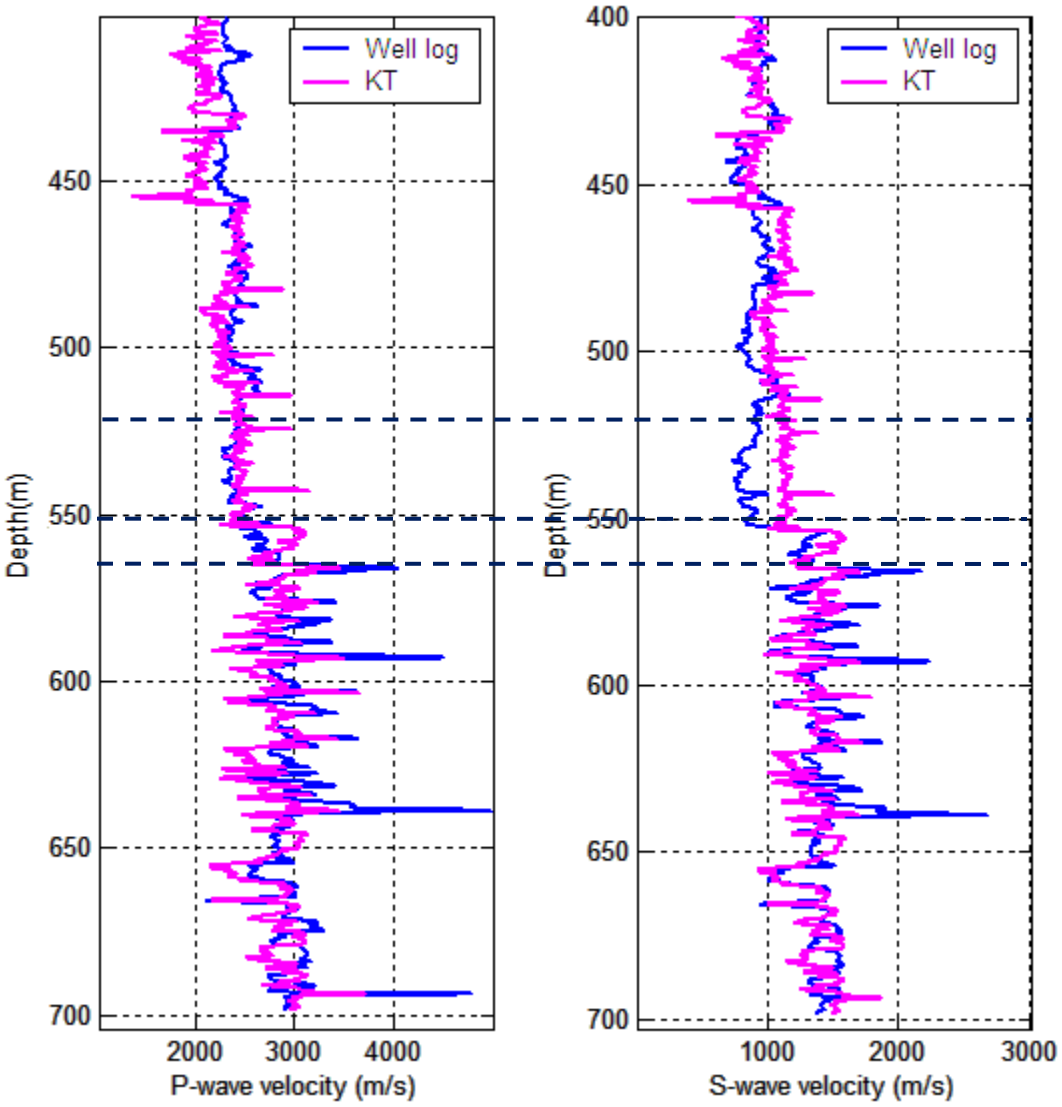
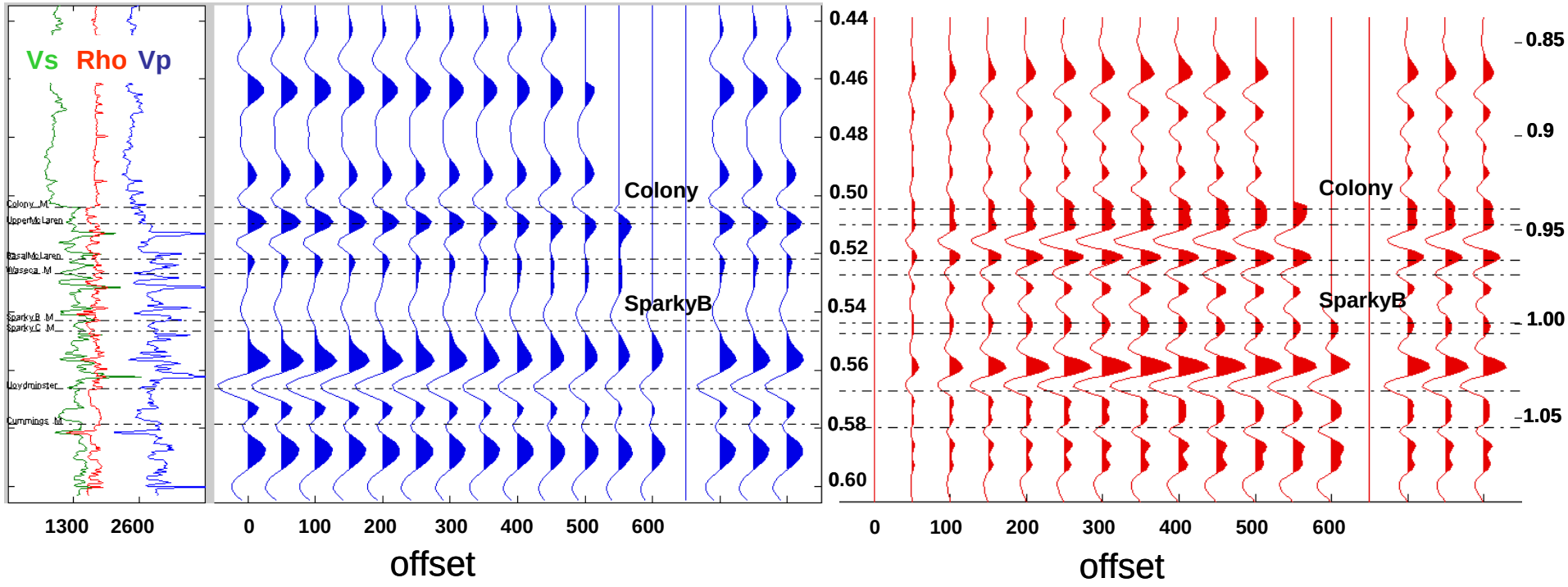


Xu and White (1995) approach (clay-sand mixtures)

- Overcomes low porosity limitation
- Total number of pores divided into N sets
- Iterative process to calculate effective properties
- Different aspect ratios for sand and shale related pores.

Synthetic seismograms

- 60 Hz Ricker wavelet for the PP section
- 40 Hz Ricker wavelet for the PS section



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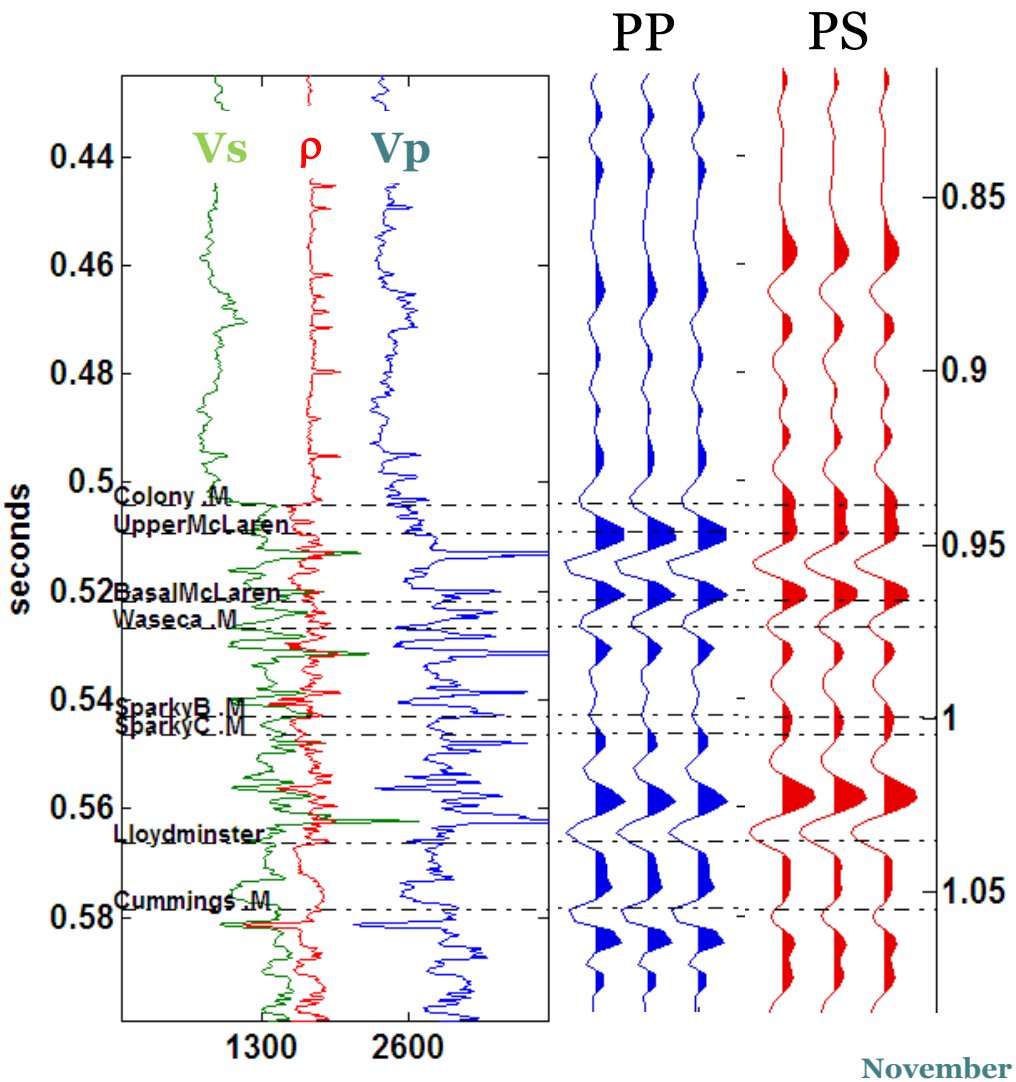
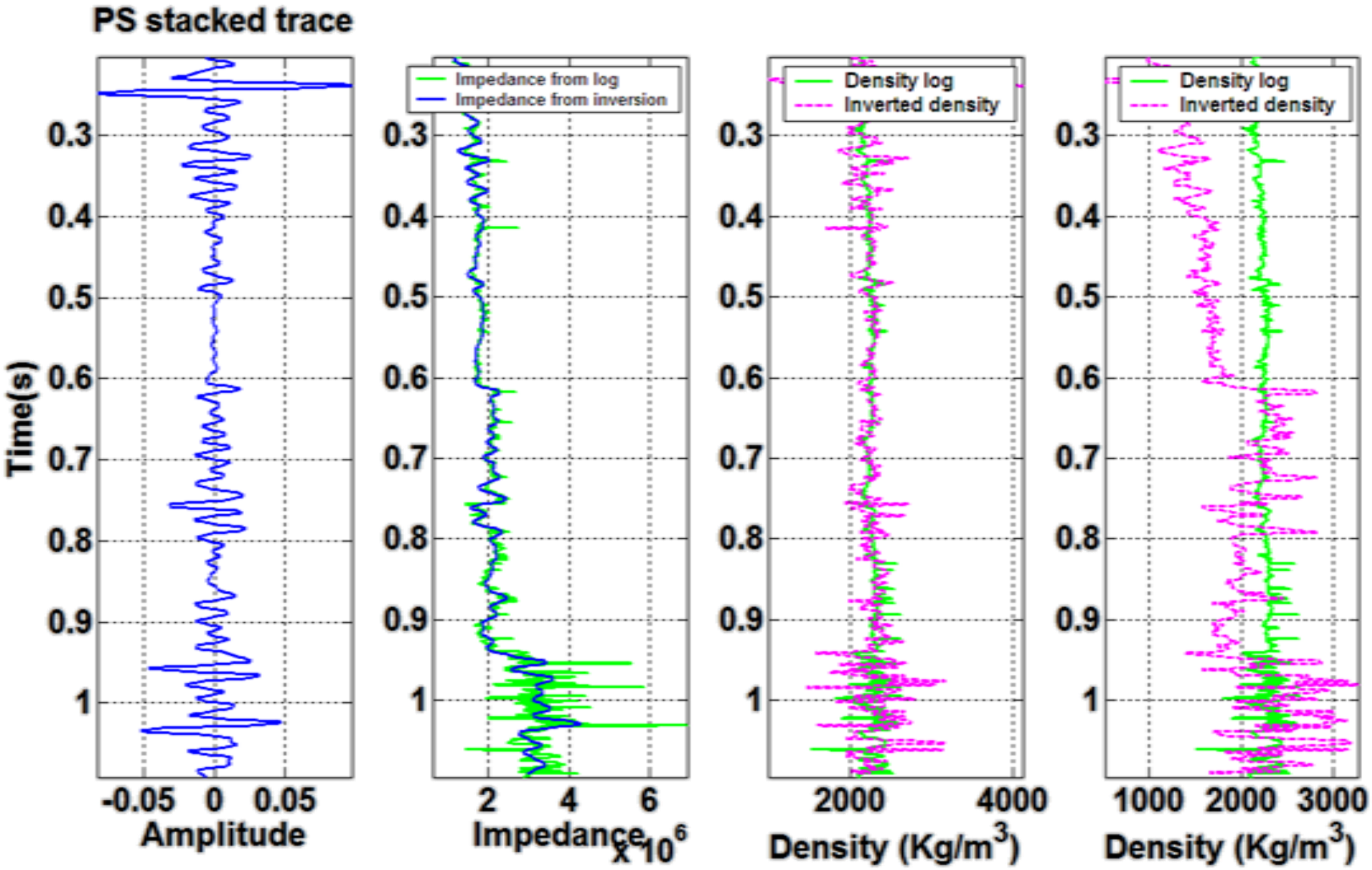
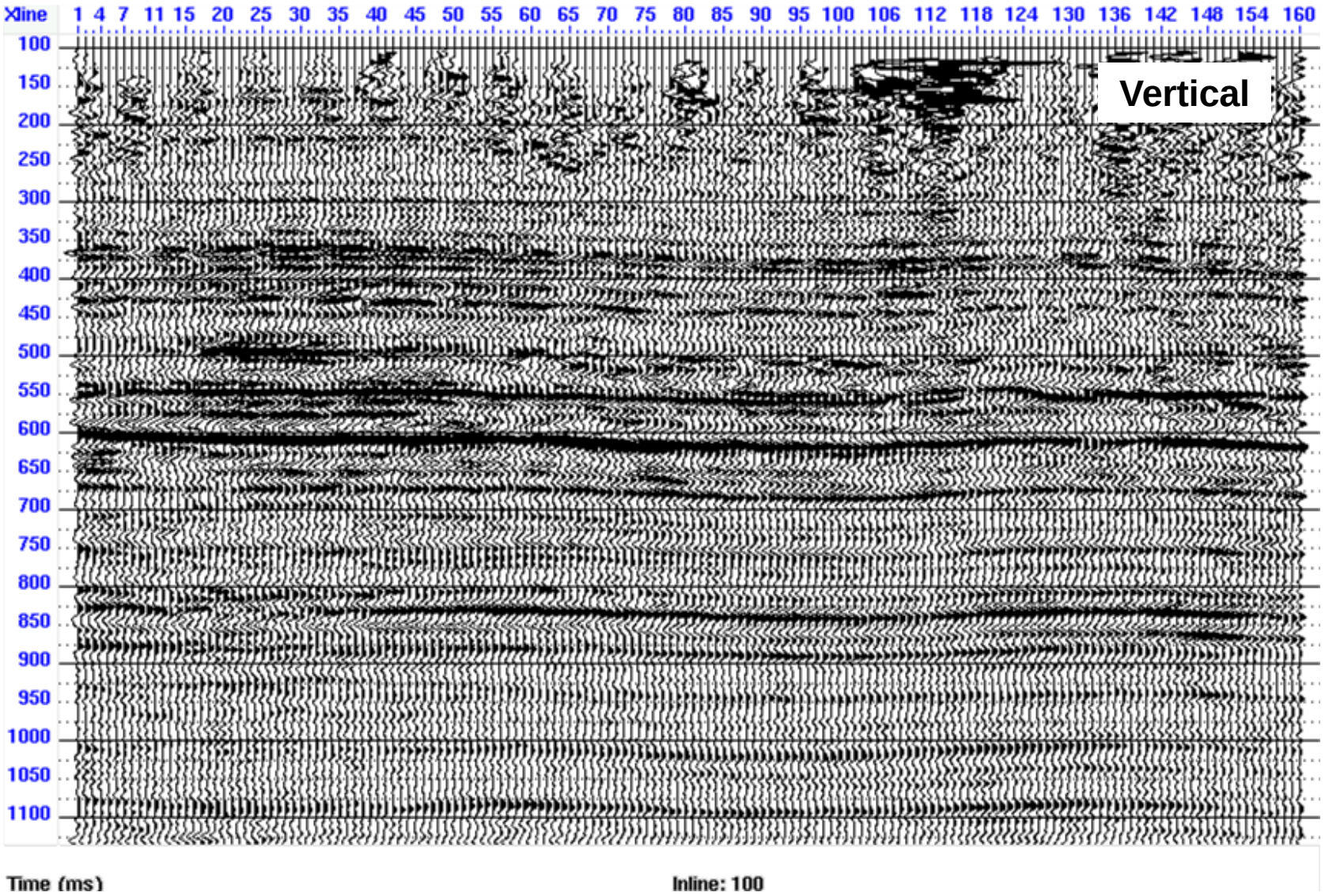


- Change in reflection polarity at the top of the Colony and Sparky members
- Bright spots on the PS seismic section

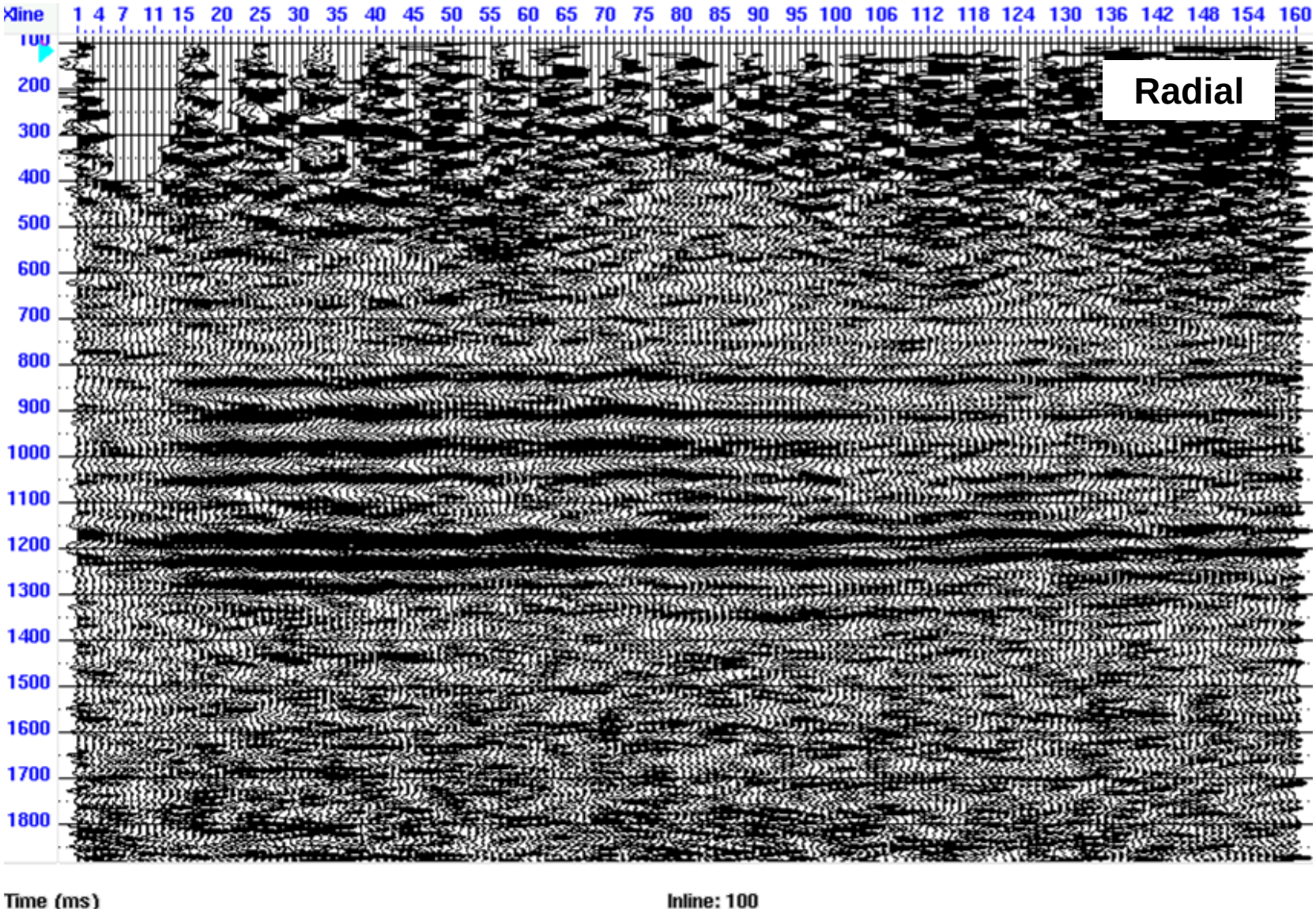
Band-limited inversion



Seismic data

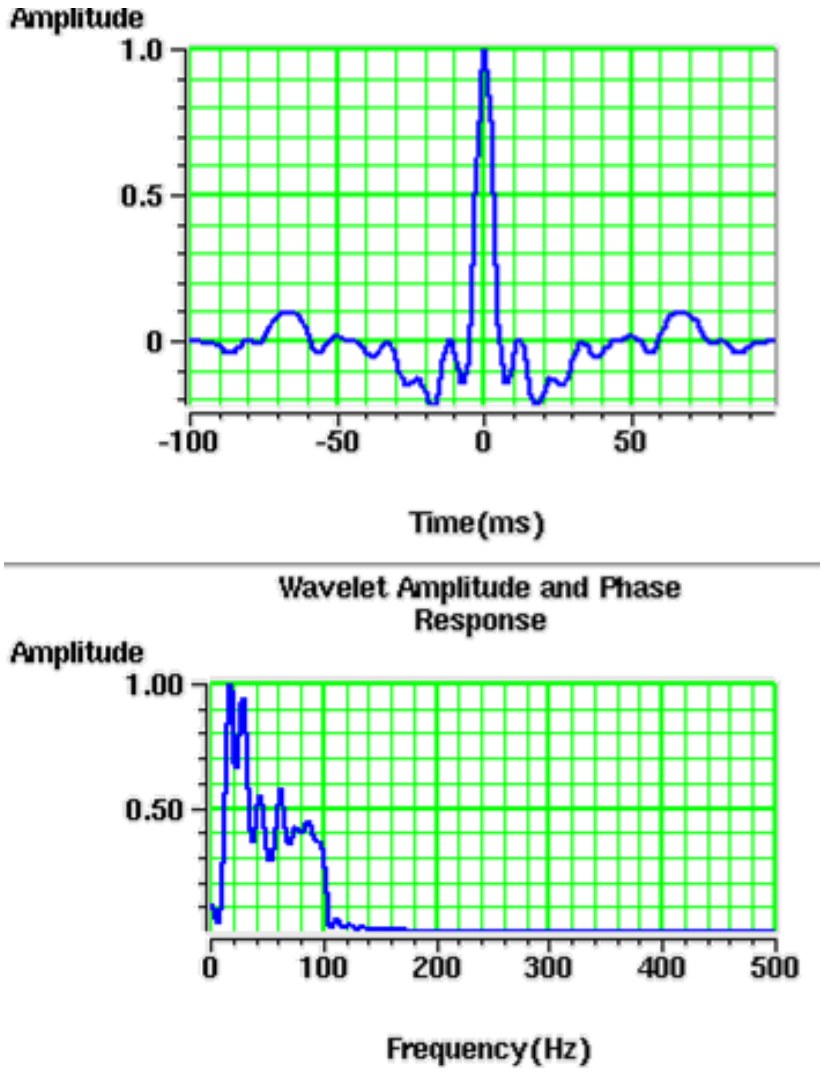


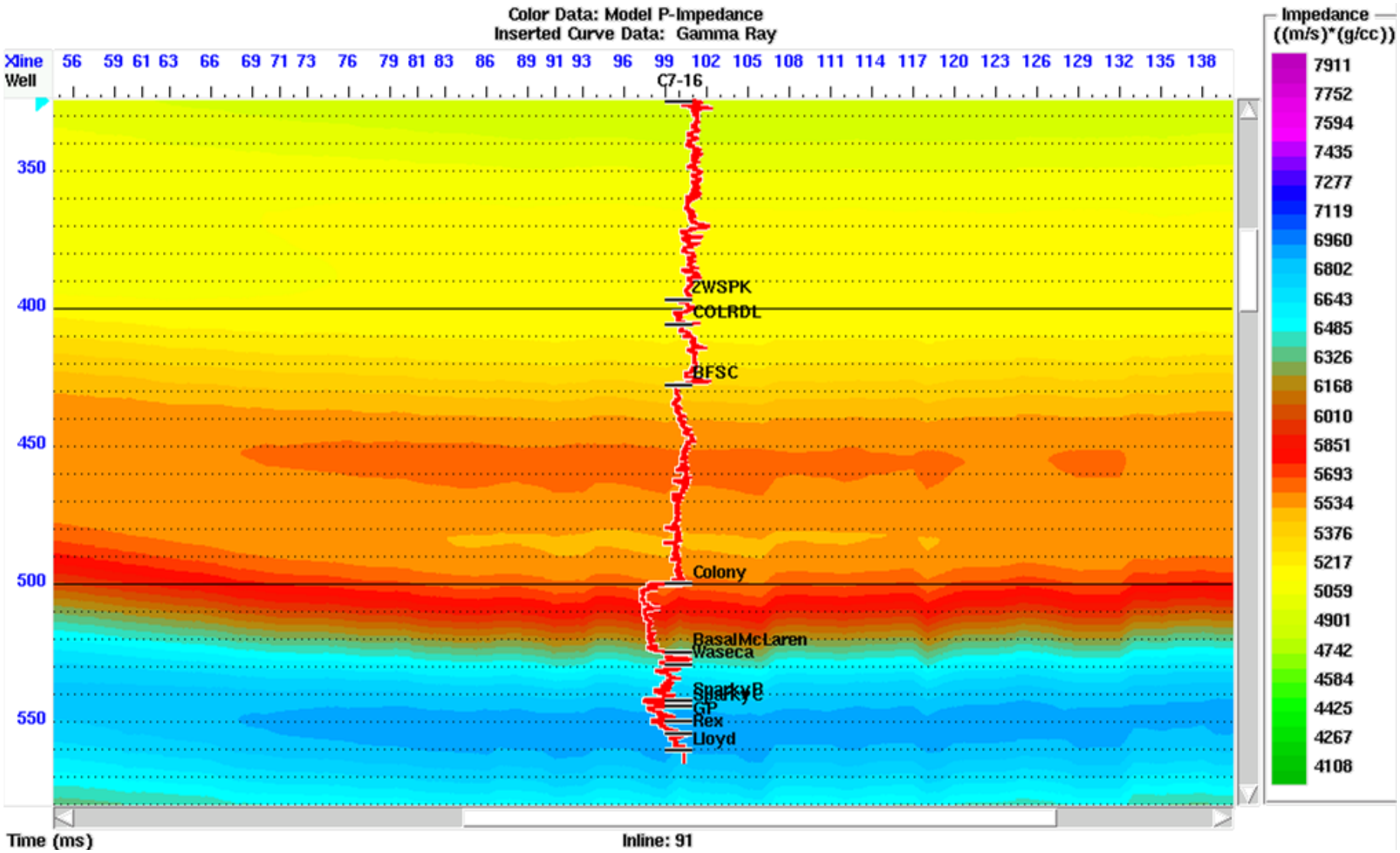
Seismic data

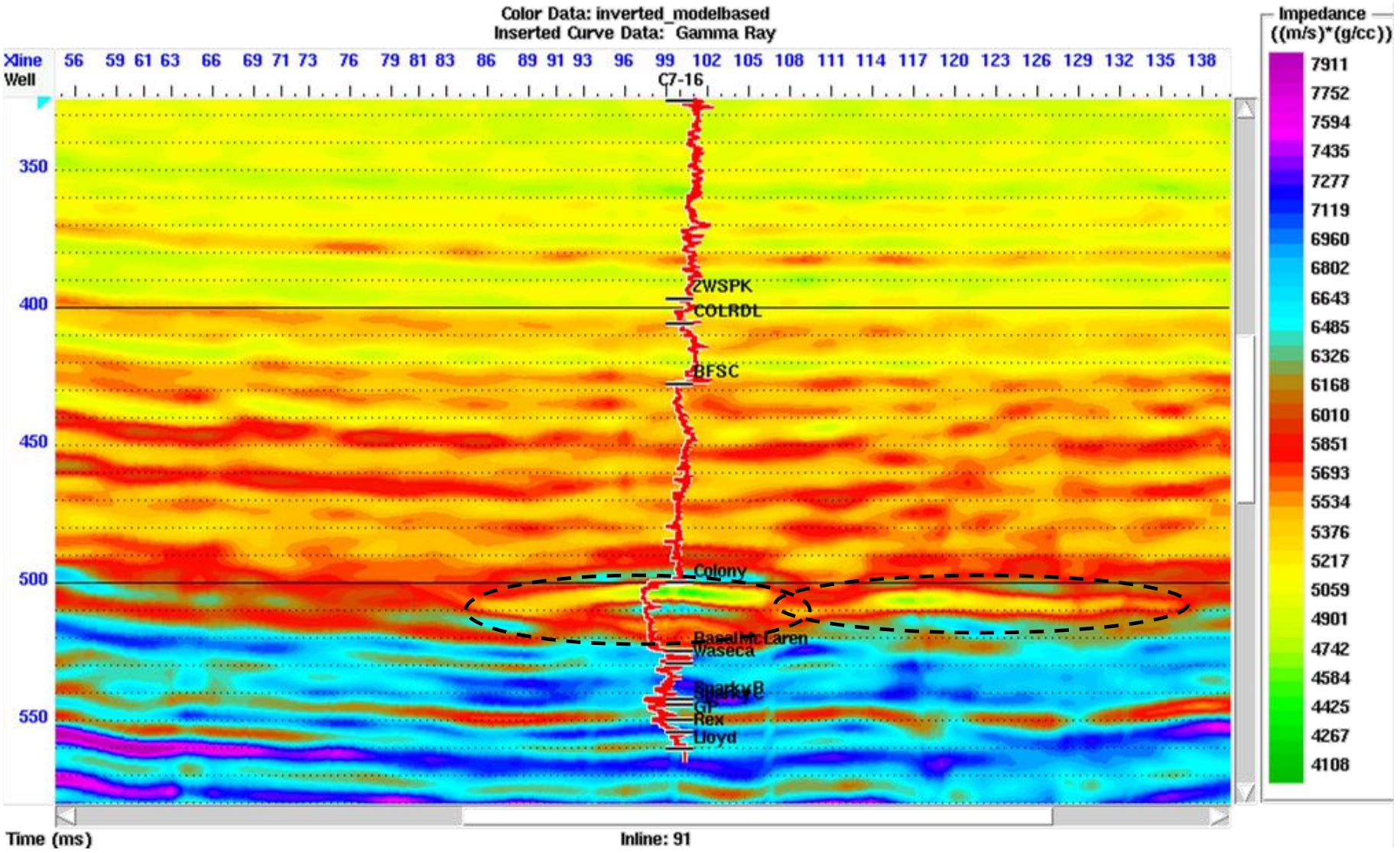


Model based inversion

- Initial model using impedance from 2 wells and high cut filter at 10/15 Hz, guided by horizons
- Wavelet extracted from the seismic, between 400 and 650 ms (Target zone)
- Hard constrain, 100 % change in impedance




Color Data: Model P-Impedance
Inserted Curve Data: Gamma Ray
Xline
Well
56 59 61 63 66 69 71 73 76 79 81 83 86 89 91 93 96 99 102 105 108 111 114 117 120 123 126 129 132 135 138
C7-16
350
400
450
500
550
ZWSPK
COLRDL
BFSC
Colony
BasalMcLaren
Waseca
SparkyB
SparkyC
GP
Rex
Lloyd
Impedance
((m/s)*(g/cc))
7911
7752
7594
7435
7277
7119
6960
6802
6643
6485
6326
6168
6010
5851
5693
5534
5376
5217
5059
4901
4742
4584
4425
4267
4108
Time (ms)
Inline: 91


Color Data: inverted_modelbased
Inserted Curve Data: Gamma Ray
Impedance
((m/s)*(g/cc))
7911
7752
7594
7435
7277
7119
6960
6802
6643
6485
6326
6168
6010
5851
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Well
56 59 61 63 66 69 71 73 76 79 81 83 86 89 91 93 96 99 102 105 108 111 114 117 120 123 126 129 132 135 138
C7-16
350
400
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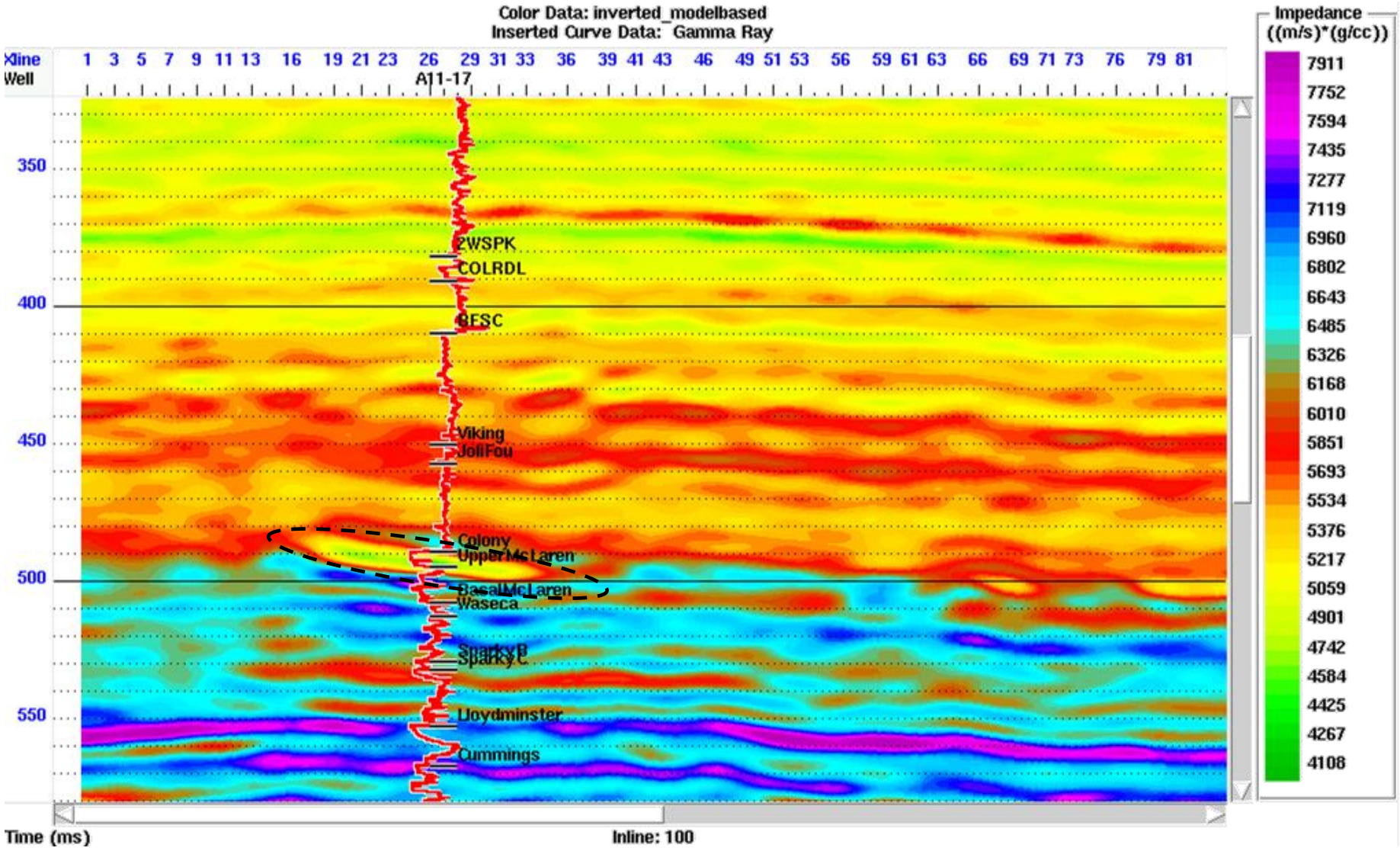
SparkyB
GP
Rex
Lloyd
Time (ms)
Inline: 91


Color Data: inverted_modelbased
Inserted Curve Data: Gamma Ray
Impedance
((m/s)*(g/cc))
7911
7752
7594
7435
7277
7119
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6168
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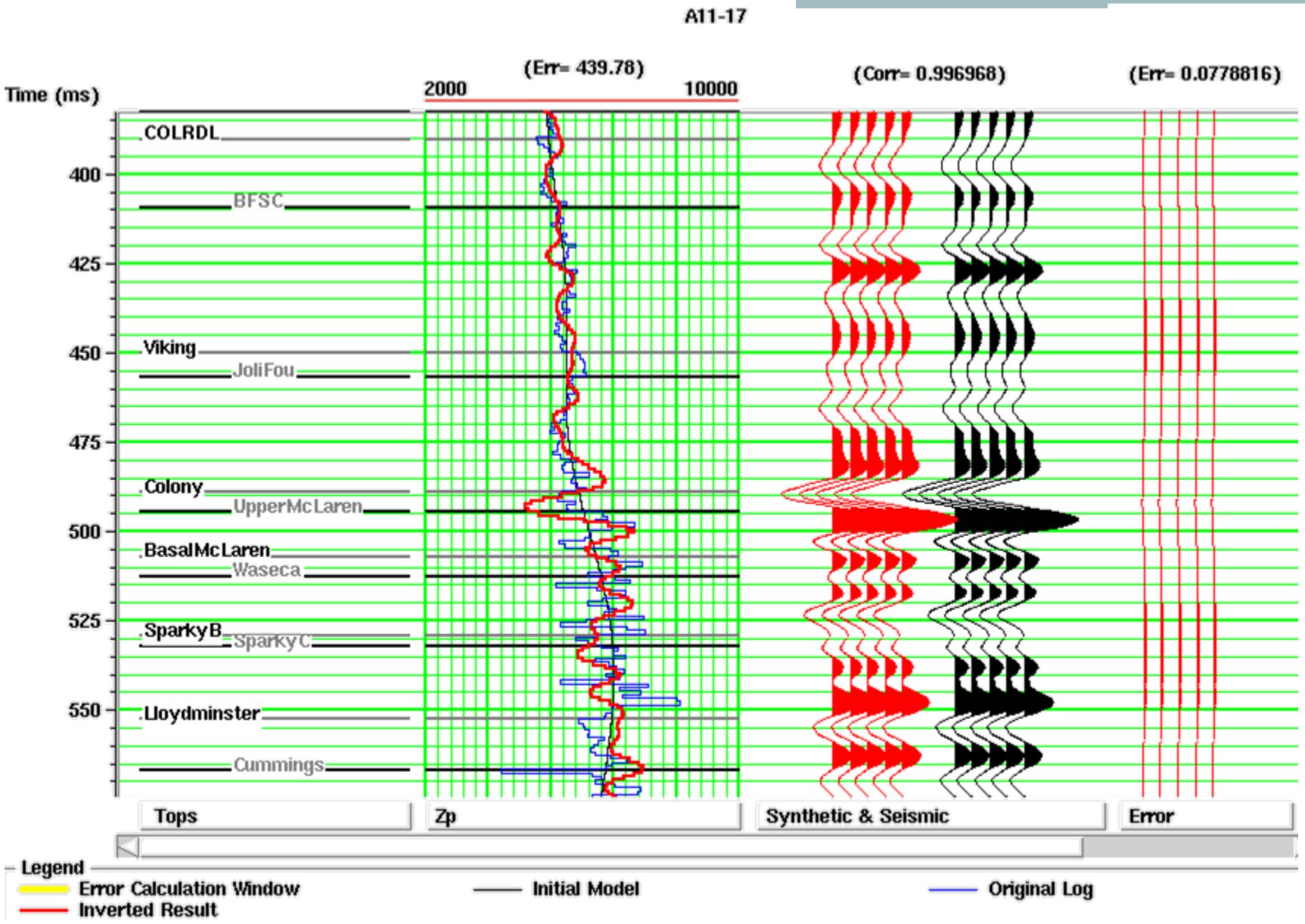
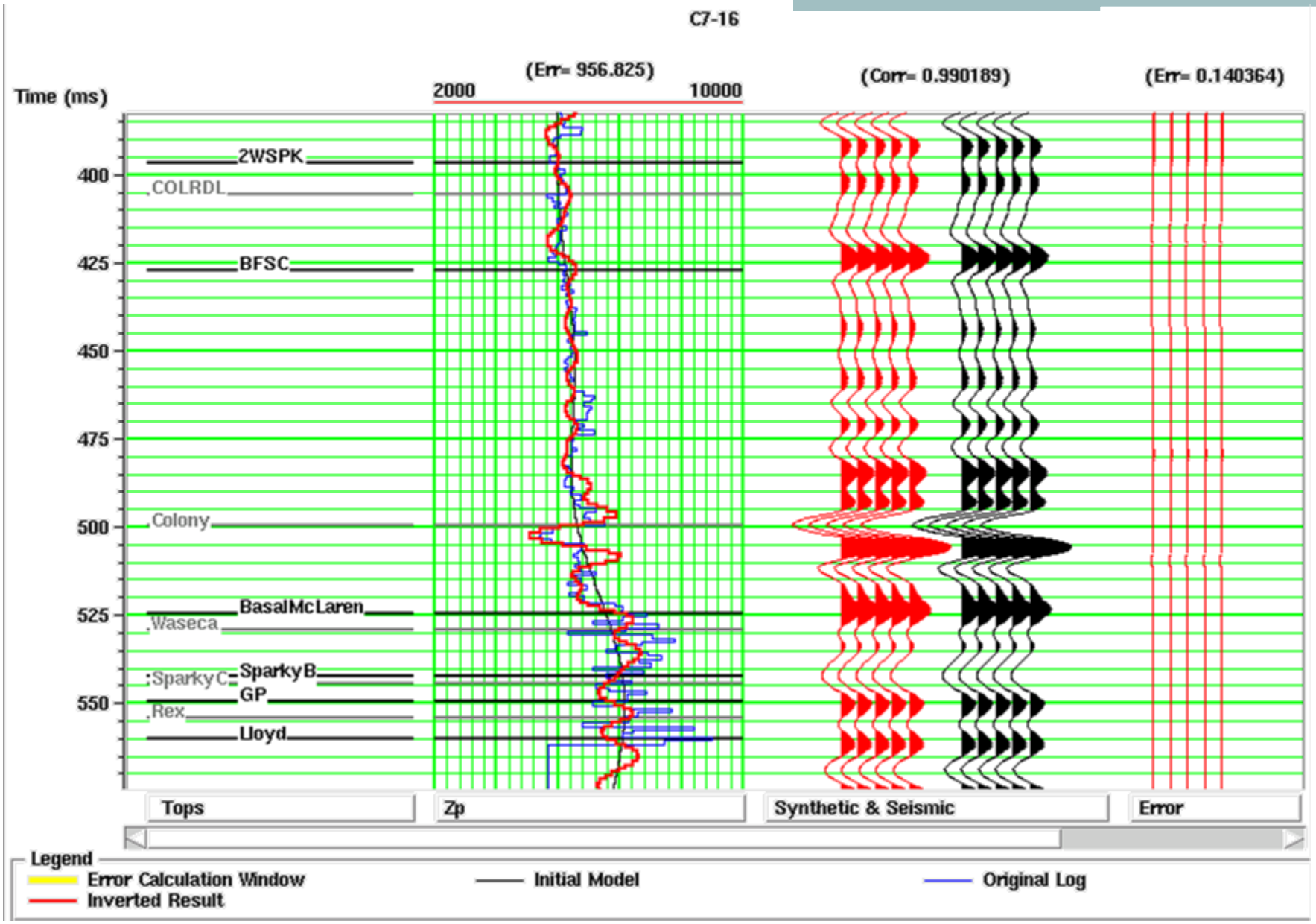
4742
4584
4425
4267
4108
Xline
Well
1 3 5 7 9 11 13 16 19 21 23 26 29 31 33 36 39 41 43 46 49 51 53 56 59 61 63 66 69 71 73 76 79 81
A11-17
350
400
450
500
550
2WSPK
COLRDL
BESC
Viking
JoliFou
Colony
Upper McLaren
Basal McLaren
Waseca
SparkyB
SparkyC
Lloydminster
Cummings
Time (ms)
Inline: 100

Inversion analysis



Inversion analysis



Conclusions

- Shear-wave velocity is the best lithological indicator in the area, showing a change of 500 m/s at the sand/shale interface (Top of the Colony sands).

- Variations in density are more complex, showing effects of fluid content and lithology. Within the target interval densities below 2.25 g/cm^3 indicate sands.

- Velocity estimations using Kuster-Toksöz are very sensitive to the choice of pore-aspect ratio. Local geology is a significant issue.

Work in progress:

- Effective media approach.
- Density estimations using Emerge.

Thank you!

- Ross Crain, Zimin Zhang, Roxana Varga
- Calroc Energy Ltd
- Hampson-Russell
- CREWES sponsors

References

- Crain, R., 1986, The Log Analysis Handbook: Pennwell.
- Ferguson, R. J., and G.F. Margrave, 1996, A simple algorithm for band-limited impedance inversion: CREWES Research Report, **8**.
- Mavko, G., T. Mukerji, and J. Dvorkin, 2003, The rock physics handbook: Cambridge University Press.
- Putnam, P.E. and T. A. Oliver, 1980, Stratigraphic traps in channel sandstones in the Upper Mannville (Albian) and east-central Alberta. Bulletin of Canadian Petroleum Geology, **28**, 489-508.
- Xu, S, and R.E. White,1995, A new velocity model for clay-sand mixtures: Geophysical Prospecting, **43**, 91-118.
- Zimmer, M.A., M. Prasad, G. Mavko, and A. Nur, 2007, Seismic velocities of unconsolidated sands: Part I – Pressure trends from 0.1 to 20 MPa: Geophysics, **1**, E1-E13.