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Sand, shale, and steam: Imaging reservoirs with full-wave seismic methods

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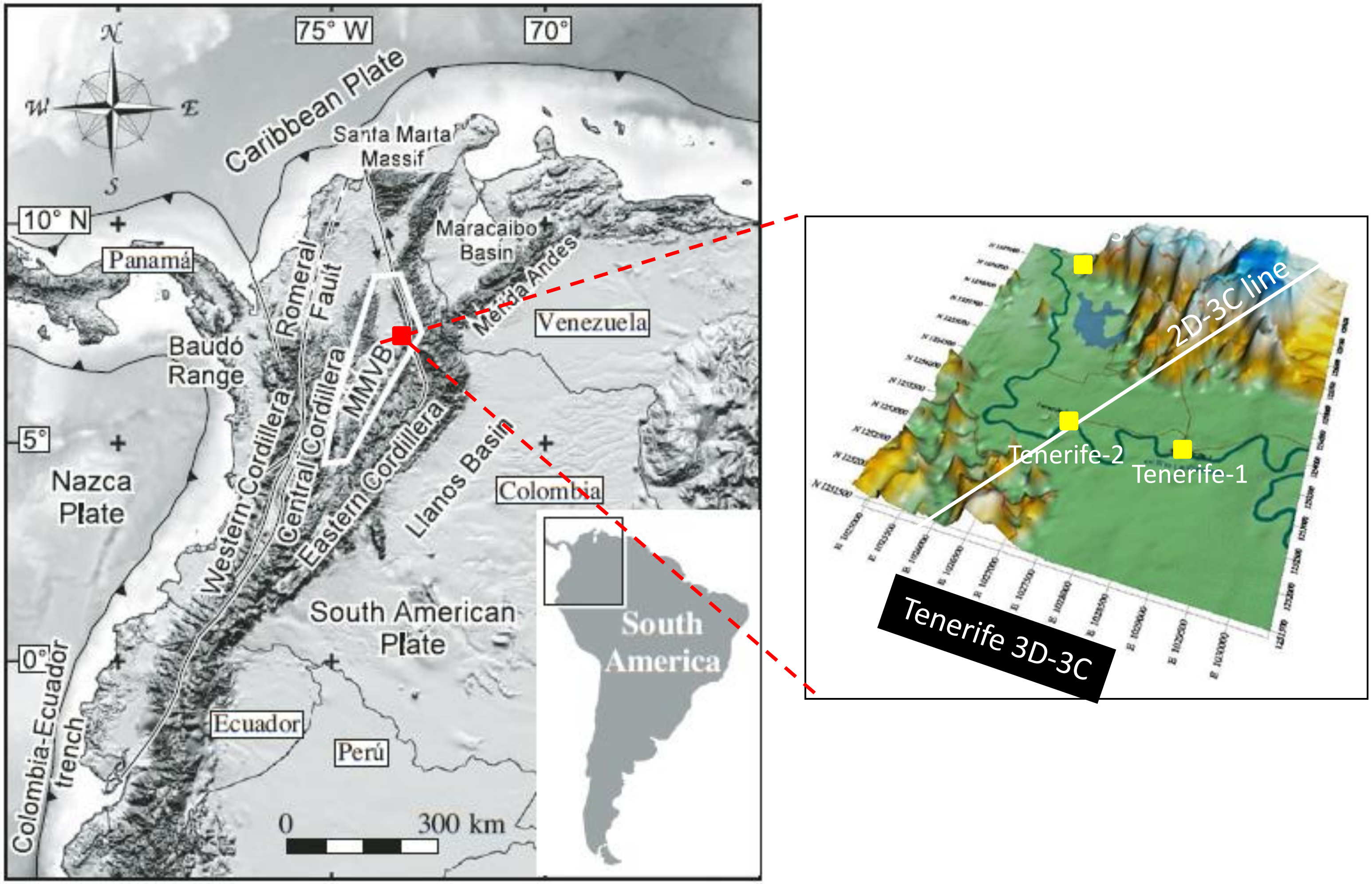
Full-wave seismic exploration: A tale of three cases

- Tenerife oilfield, Colombia: 3C seismic tests and sand indicators (Mason, M.S., 2013)
- Marcellus shale: Shale quality characterization (Gargouri, M.S., 2012)
- Steam monitoring in Oman (Mukherjee, Ph.D., 2013)

Tenerife oilfield, Colombia – find the sand



Location of the Middle Magdalena Valley Basin, the Tenerife 3D-3C survey area (~29 km^2), 2D-3C line and wells available (modified from Gomez et. al. 2005).

Tenerife 2D-3C test lines – acquisition parameters

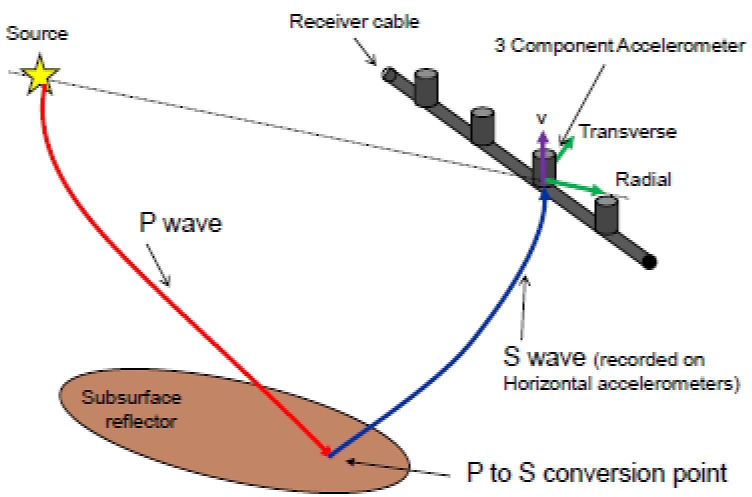
	A1	A2	A3	A4	A5
Hole Depth (m)	10	15	15	15	20
Charge (kg)	2.7	1.8	3.6	4.5	2.7
Source Interval (m)	40	150	150	150	150
Receiver Interval (m)	10	10	10	10	10
Minimum Offset (m)	4.25	4.25	4.25	4.25	4.25
Maximum Offset (m)	7525	7525	7525	7525	7525
Nominal Fold	150	38	38	38	38

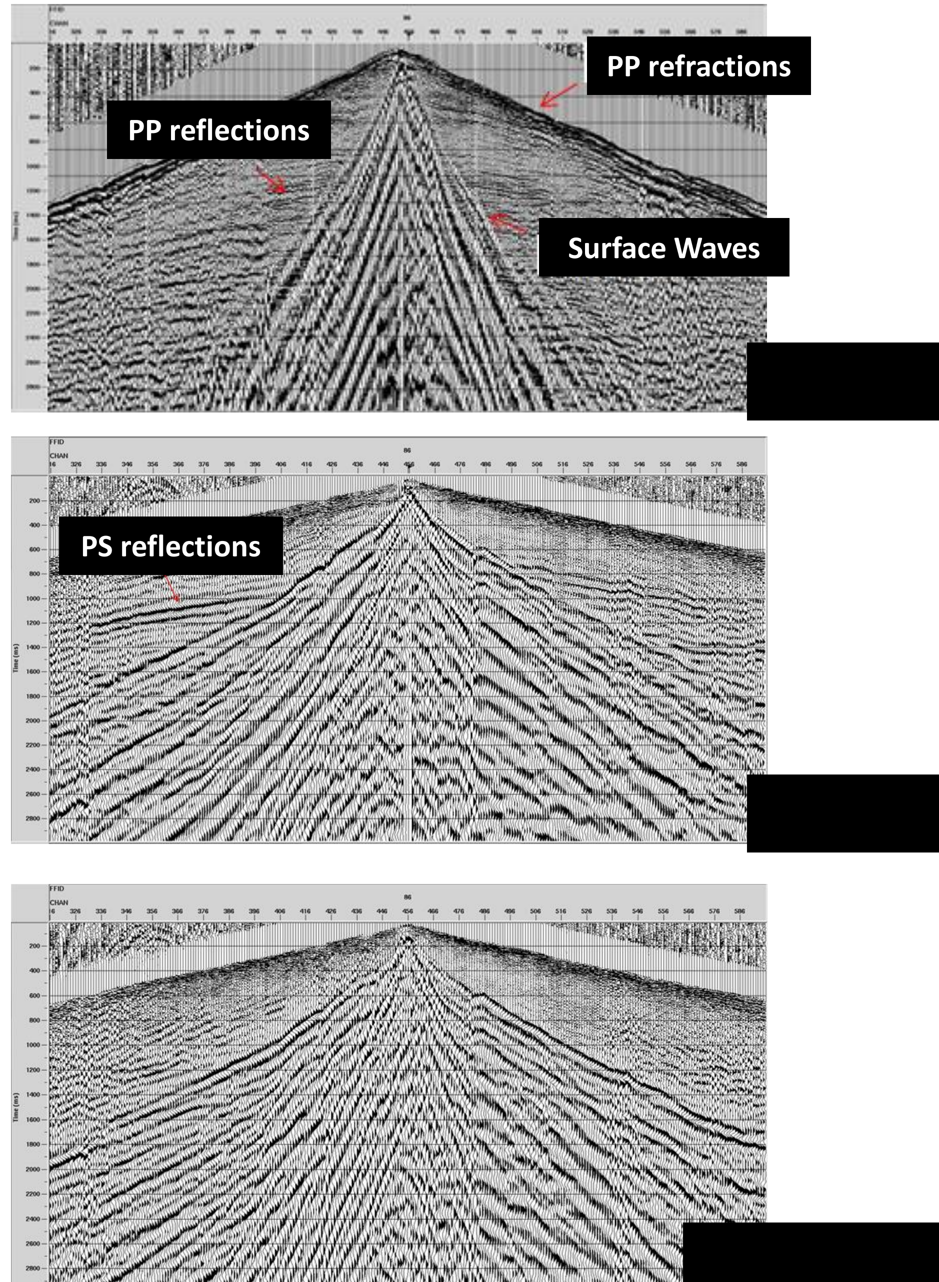
Table providing the different source intervals, shot size, and emplacement depth

Tenerife 2D-3C

<u>2D-3C Processing</u>:

Data preparation



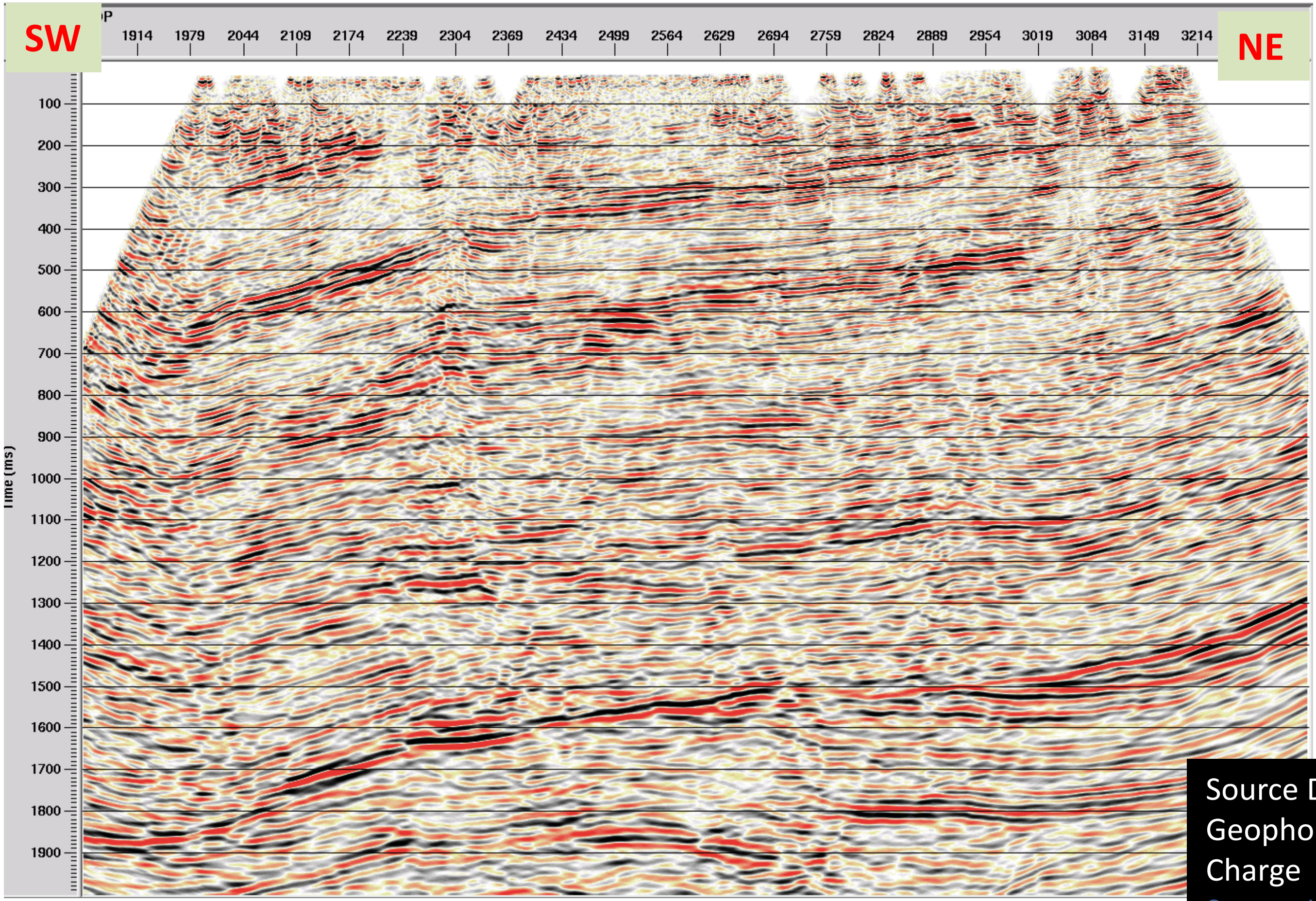


Schematic figure of 3C recording (top – from ION processing report) ; shot gather examples for the three components (right).

Source spacing influence

Tenerife 2D-3C

Results : Vertical channel

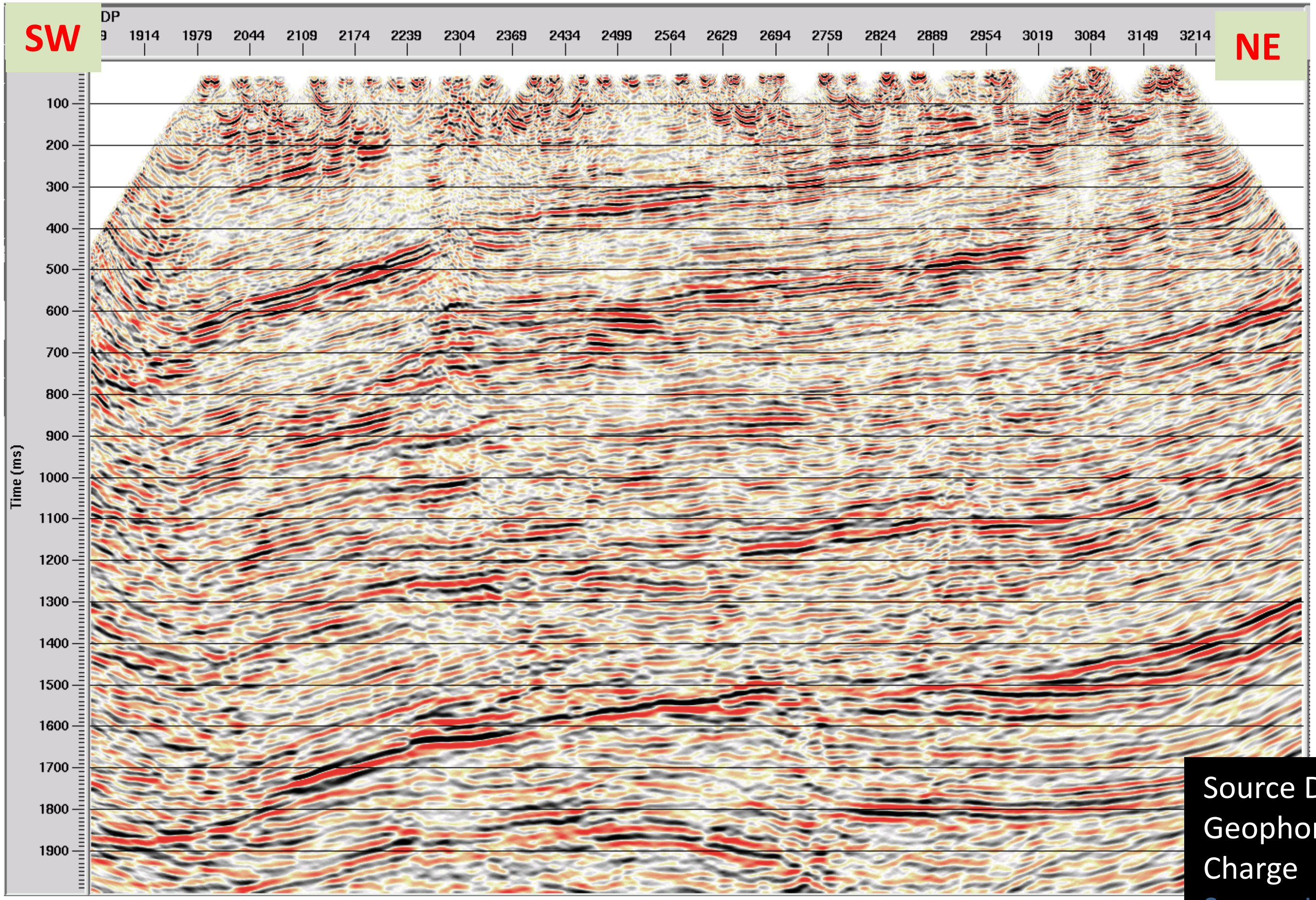


Source Depth = 10m
Geophone Depth = 10cm
Charge = 2.7 kg
Source Interval = 40m
Nominal Fold = 150

Source spacing influence

Tenerife 2D-3C

<u>Results</u> : Vertical channel

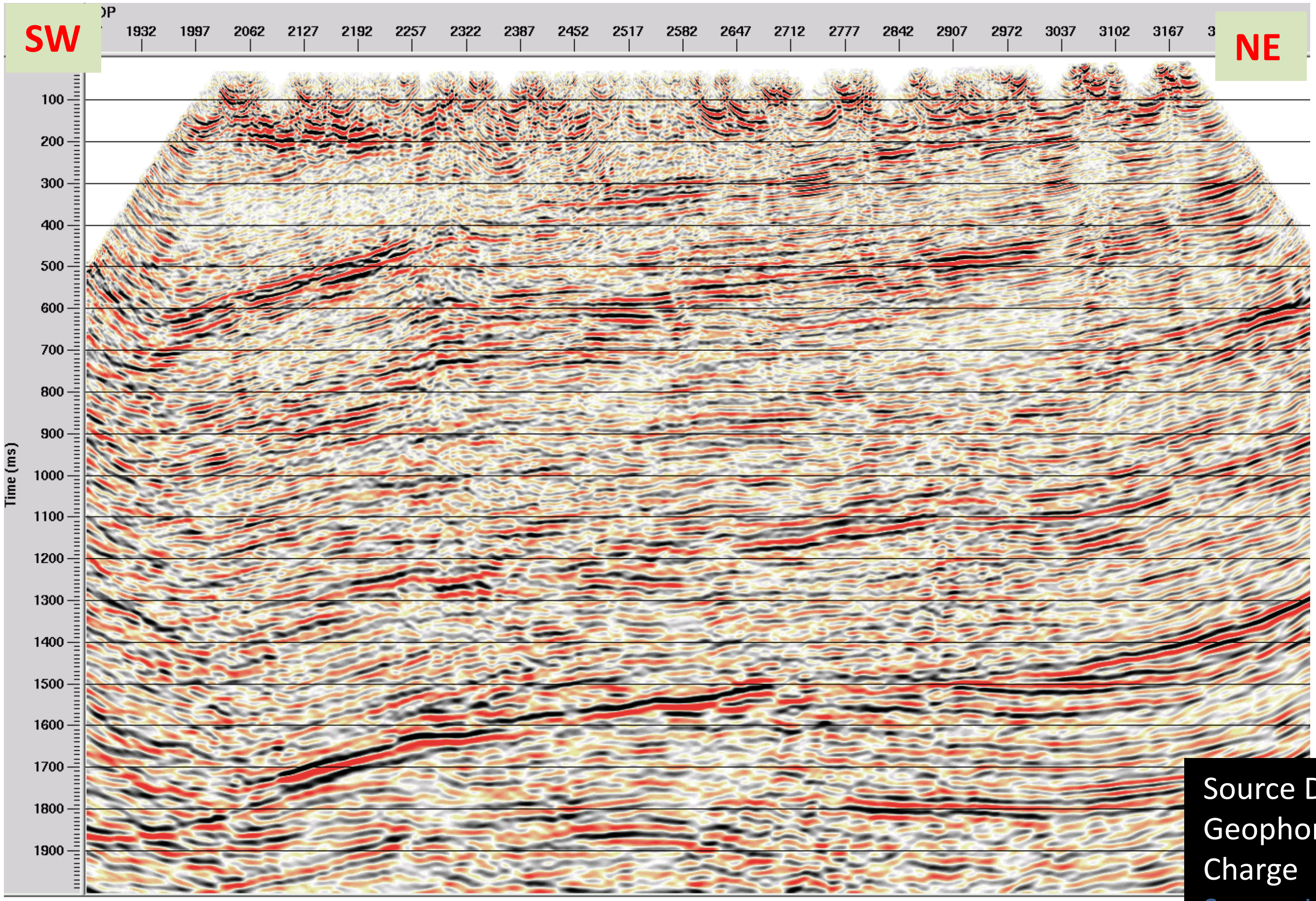


Source Depth = 10m
Geophone Depth = 10cm
Charge = 2.7 kg
Source Interval = 150m
Nominal Fold = 38

Source depth influence

Tenerife 2D-3C

Results : Vertical channel

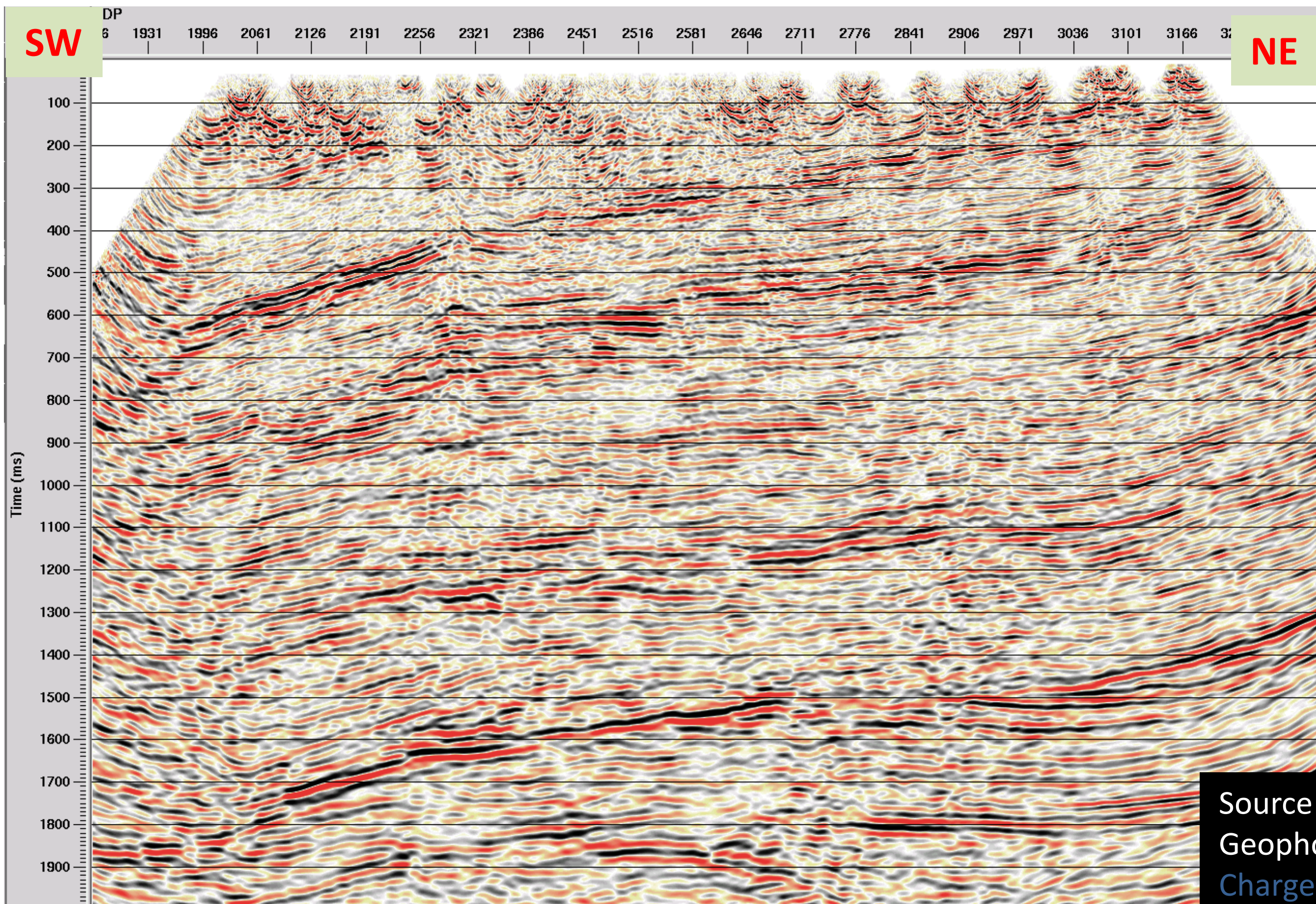


Source Depth = 20m
Geophone Depth = 10cm
Charge = 2.7 kg
Source Interval = 150m
Nominal Fold = 38

Source size influence

Tenerife 2D-3C

Results : Vertical channel



Source Depth = 15m
Geophone Depth = 10cm
Charge = 4.5kg
Source Interval = 150m
Nominal Fold = 38

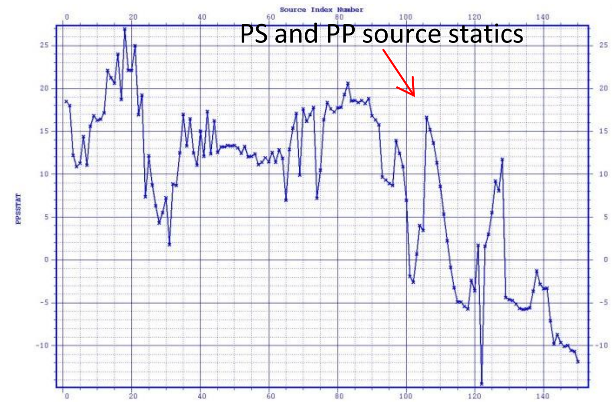
Tenerife 2D-3C

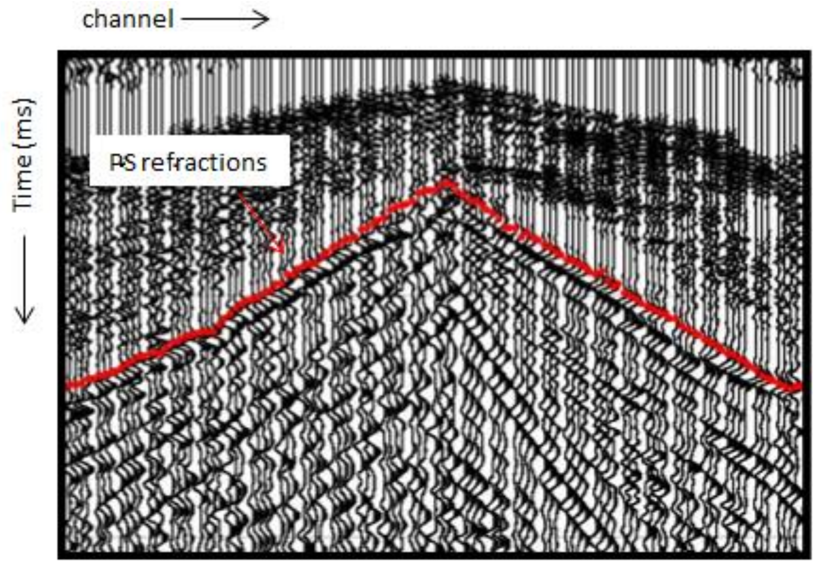
Results: Vertical channel

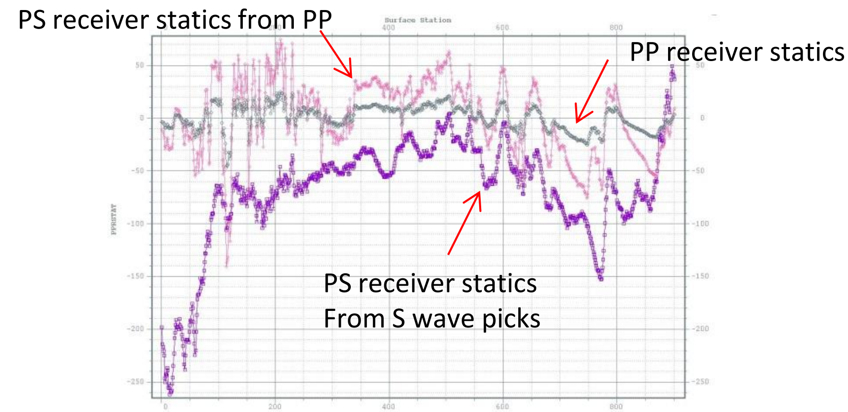
- Amazingly, increasing the fold, source size, source and receiver depth has only a small effect on the P-wave section quality (continuity, resolution)!

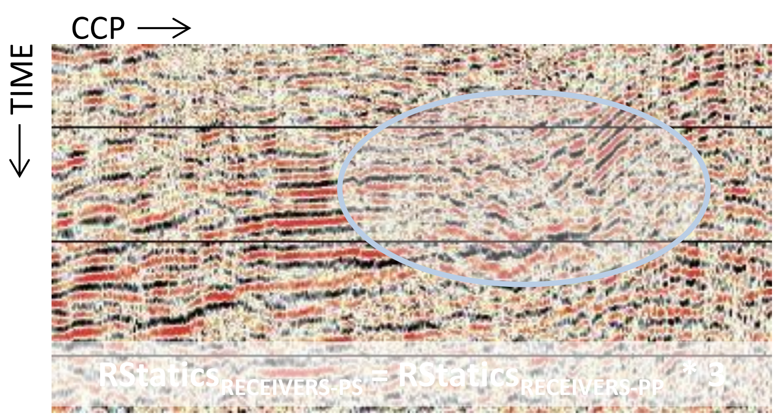
Tenerife 2D-3C

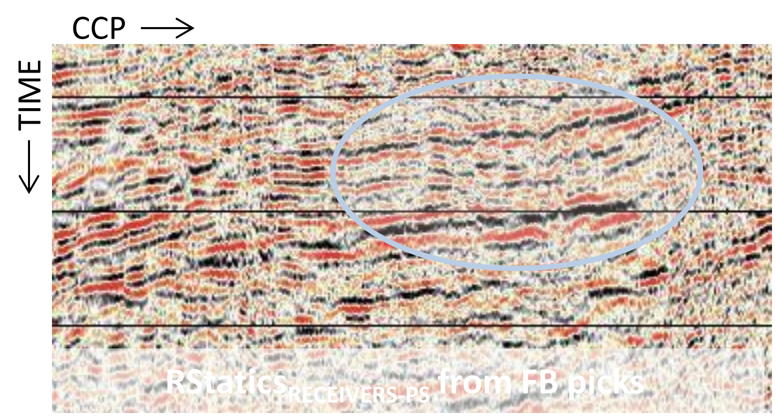
Radial – Statics (scaled vs refraction)







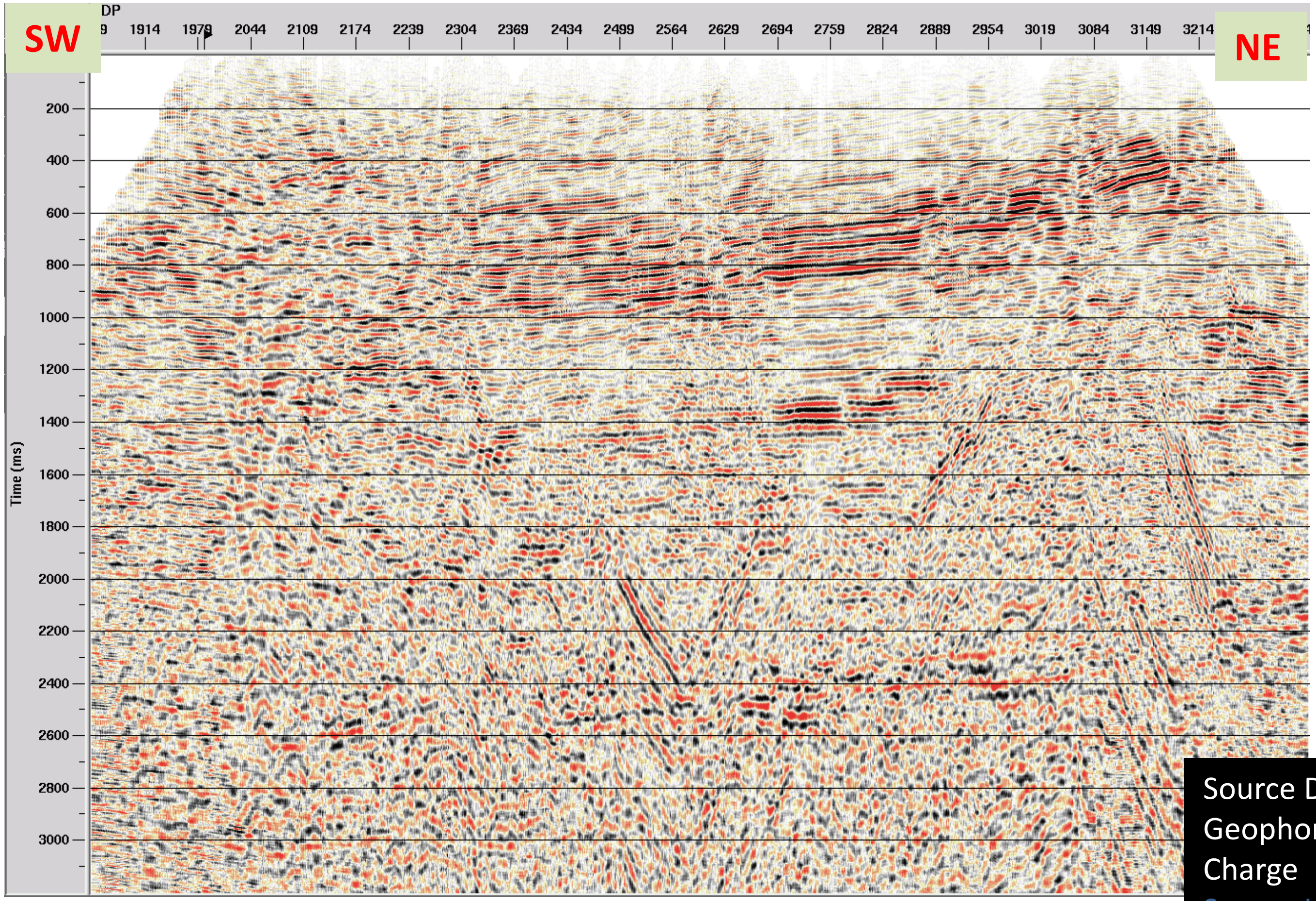




Source spacing influence

Tenerife 2D-3C

Results : Radial channel



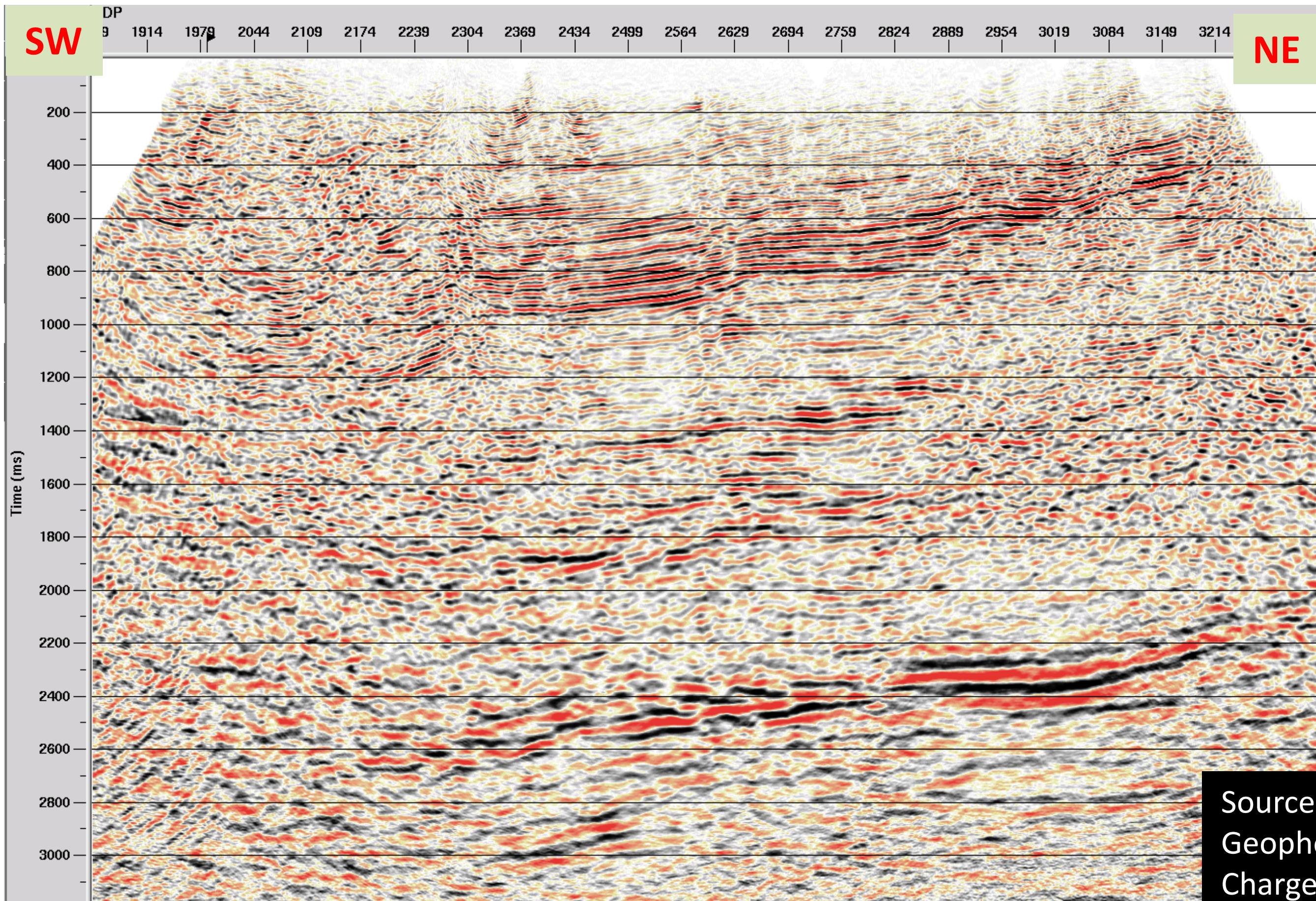
More fold gives better S/N and improves continuity of events

Source Depth = 10m
Geophone Depth = 10cm
Charge = 2.7 kg
Source Interval = 150m
Nominal Fold = 38

Source spacing influence

Tenerife 2D-3C

Results : Radial channel

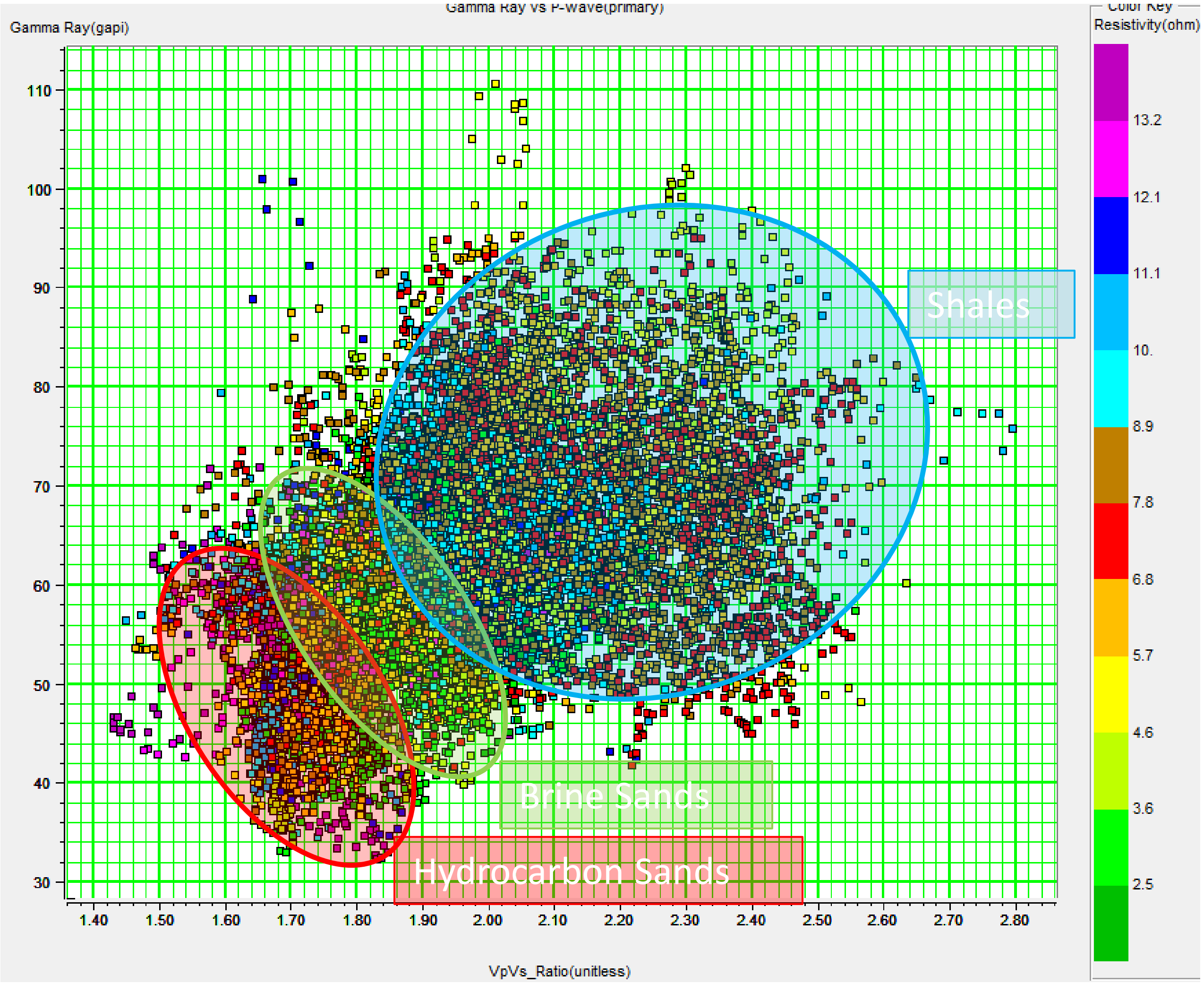


More fold gives better S/N and improves continuity of events

Source Depth = 10m
Geophone Depth = 10cm
Charge = 2.7 kg
Source Interval = 40m
Nominal Fold = 150

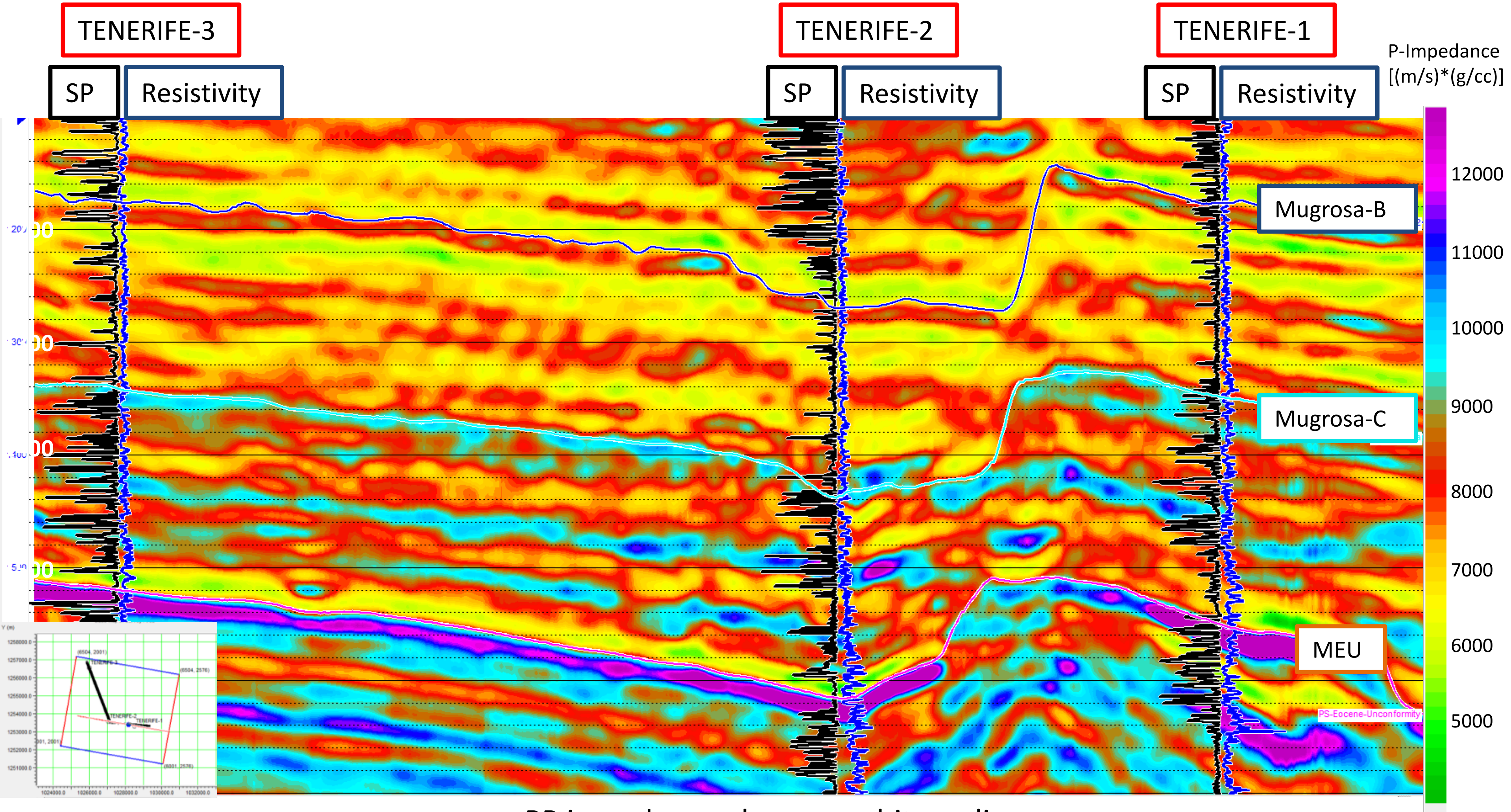
Interpretation

Cross-plots from well logs



Interpretation

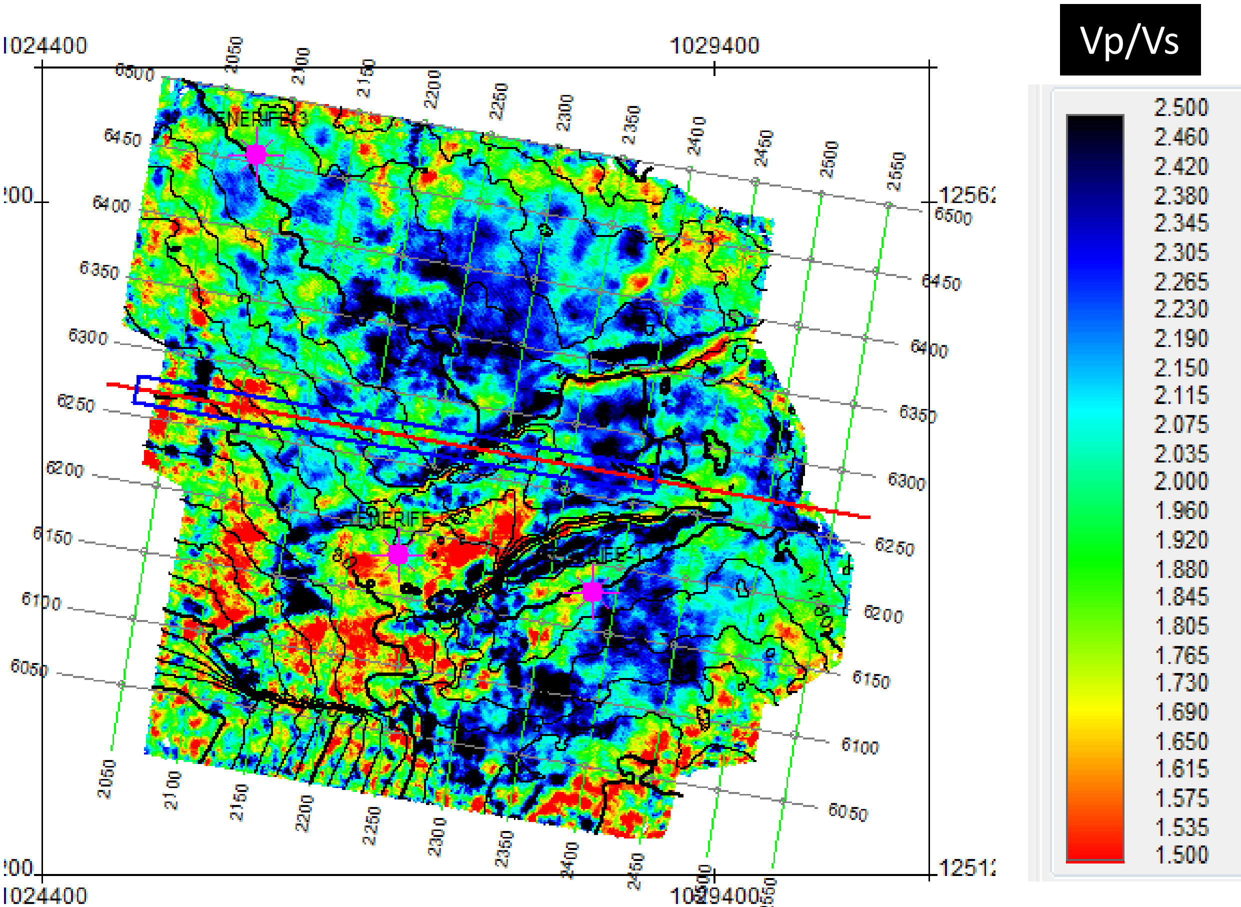
Vp/Vs : High resolution map



PP impedance along an arbitrary line

Interpretation

Vp/Vs : High resolution map

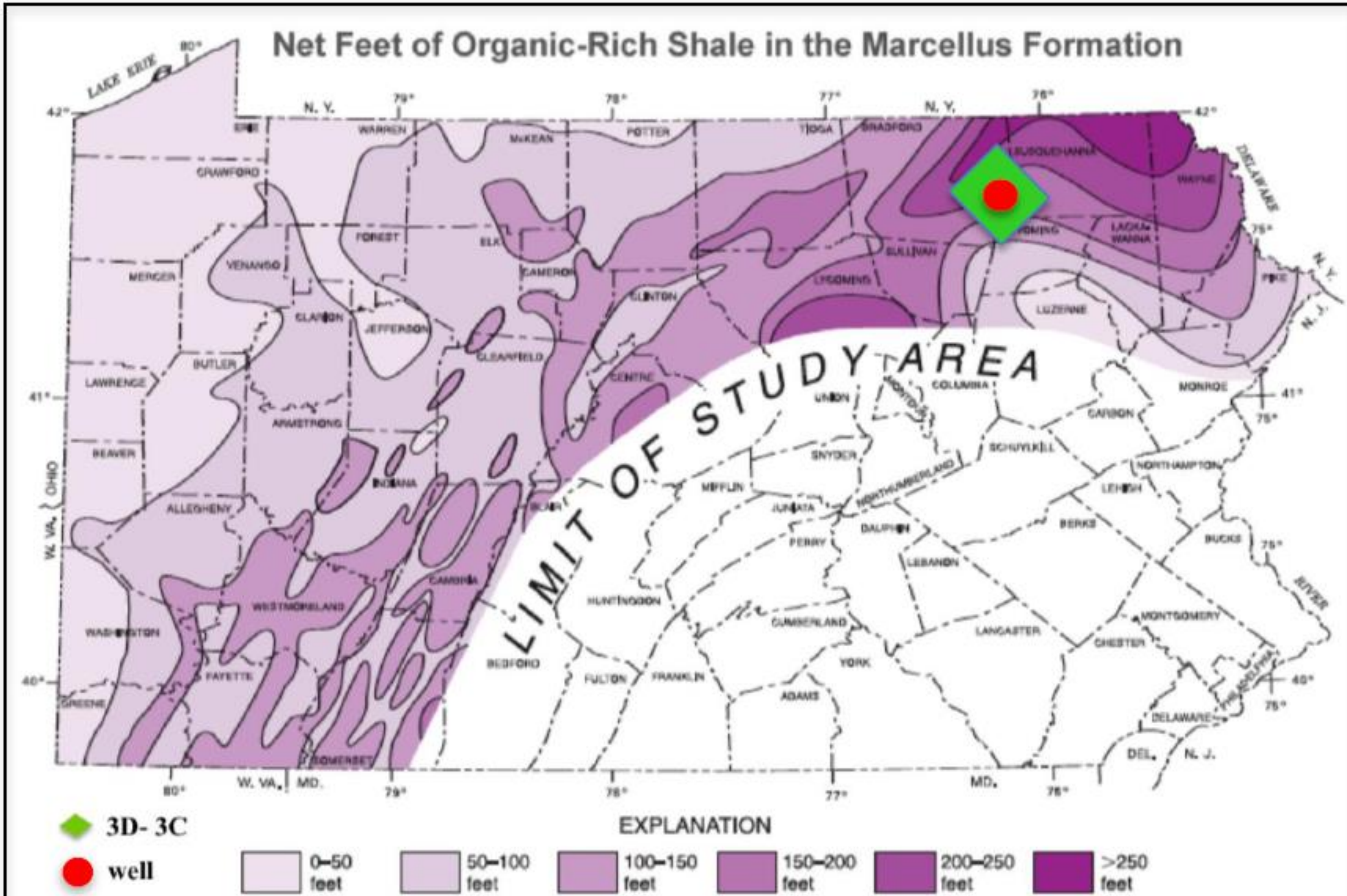


Vp/Vs for a horizon map coincident with the top of Mugrosa-B Formation over imposed to the structural map in PP time.

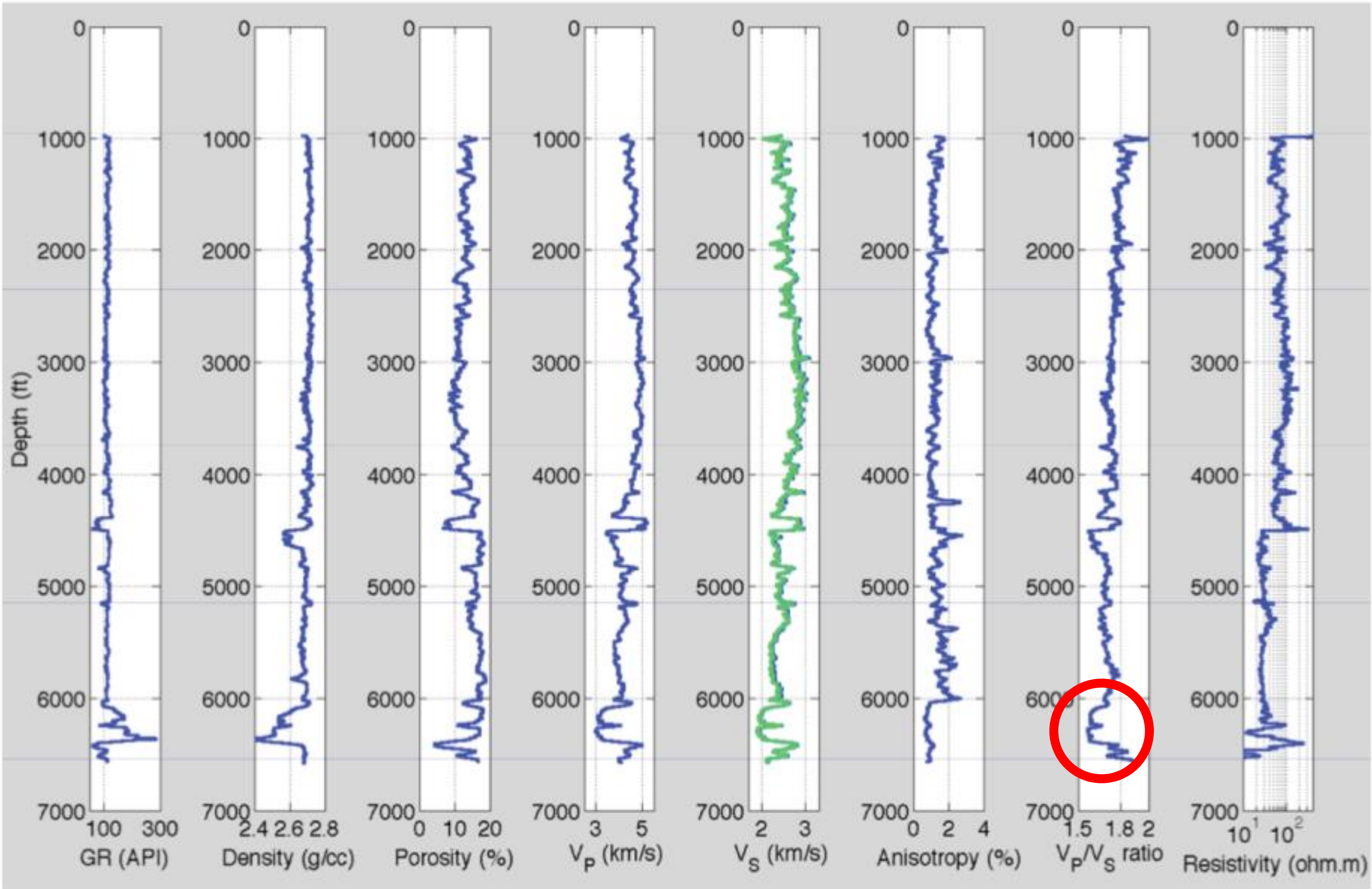
Conclusions

- For PP-waves, increasing the fold, source size, and source & receiver depths makes only a small difference.
- For PS-waves, huge improvements are observed when increasing the fold, source size and depth (and using S-S refraction statics
- Joint 3D PP and PS inversion and interpretation give detailed new leads
- Muchas gracias a Ecopetrol y Dr. Agudelo

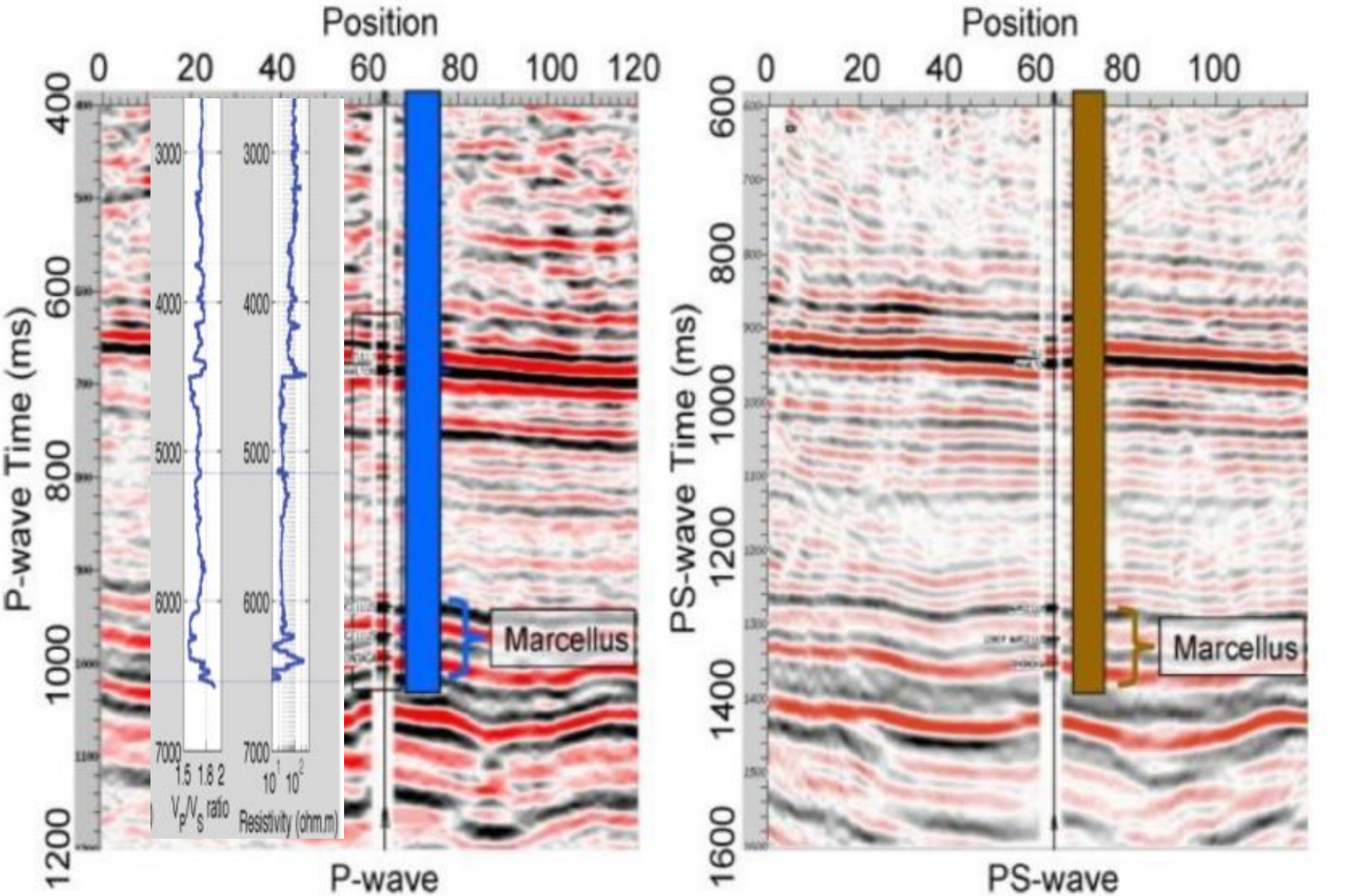
Bradford 3C-3D Pennsylvania



Well logs from the Marcellus shale – anomalous Vp/Vs

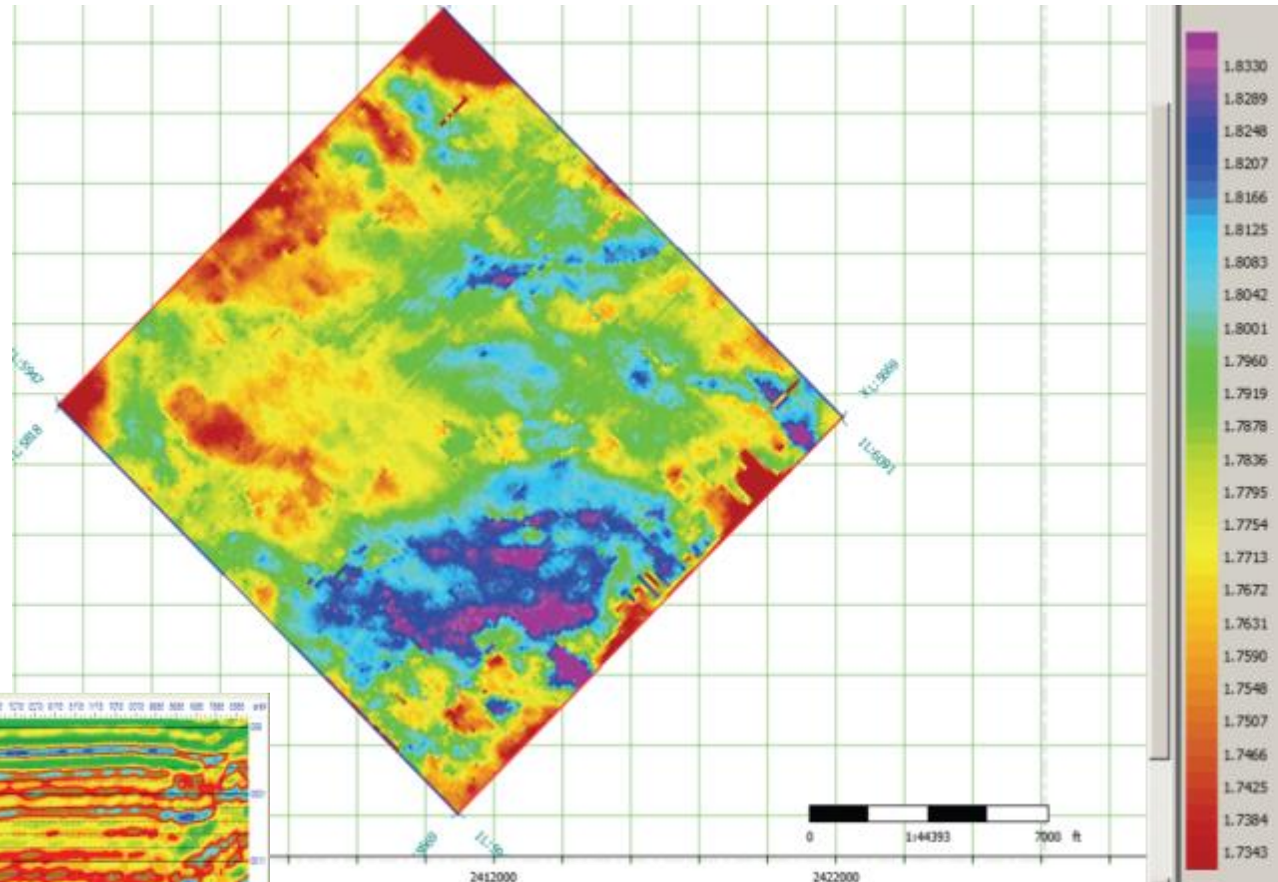


PP and PS Sections: Bradford 3C-3D

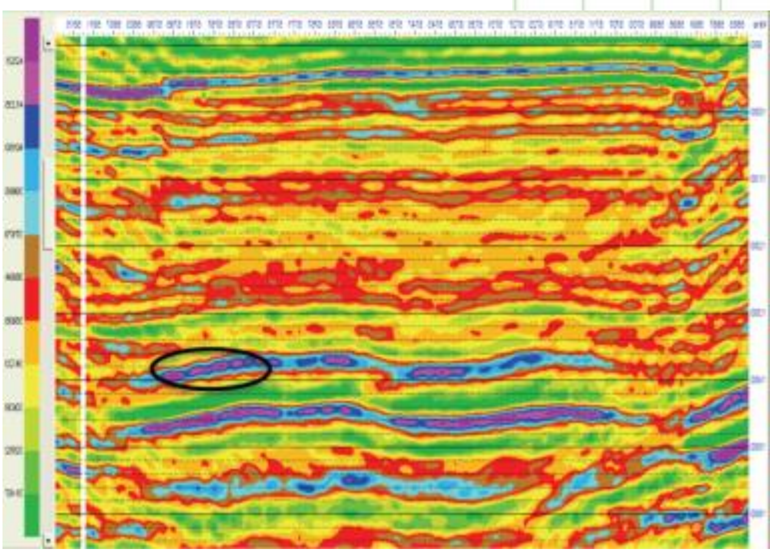


From Gaiser, 2011; Gargouri, 2012 – UH M.S. thesis

Bradford 3C-3D seismic survey – Vp/Vs over Marcellus interval



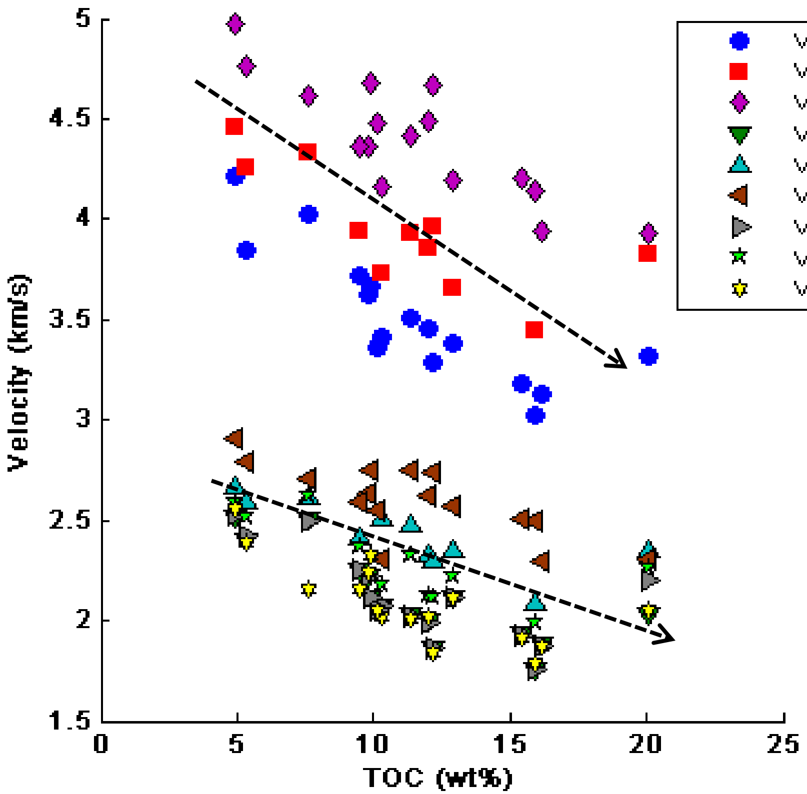
Shear velocity section from inversion

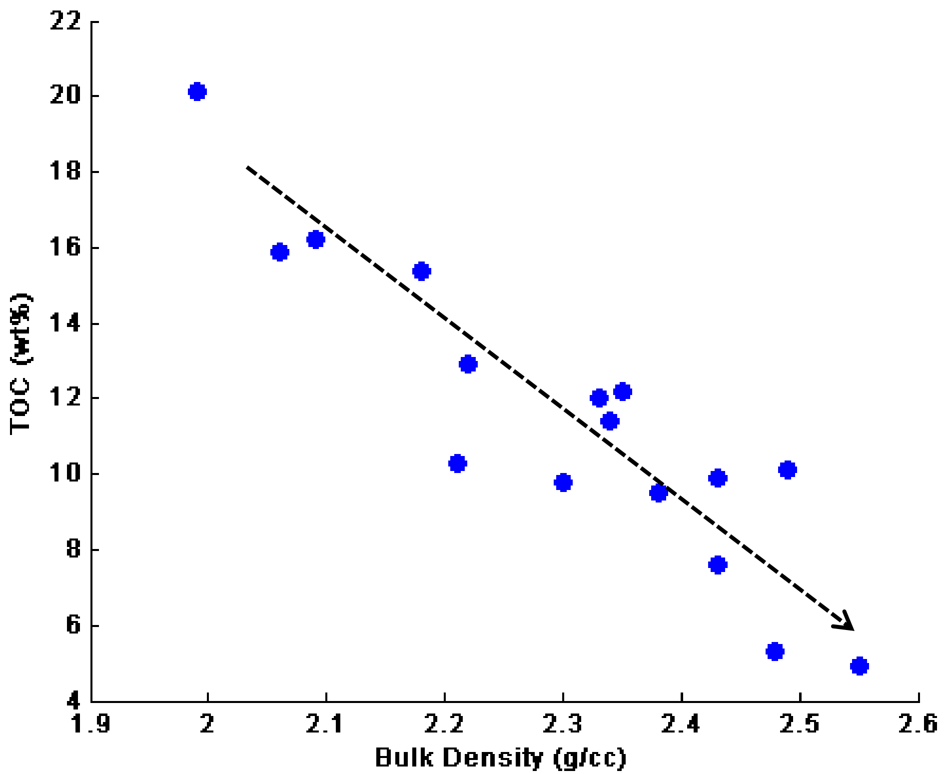


From Gargouri, 2012, M.S. Univ. of Houston

Data generously provided by Geokinetics, Geophysical Pursuit, Chesapeake

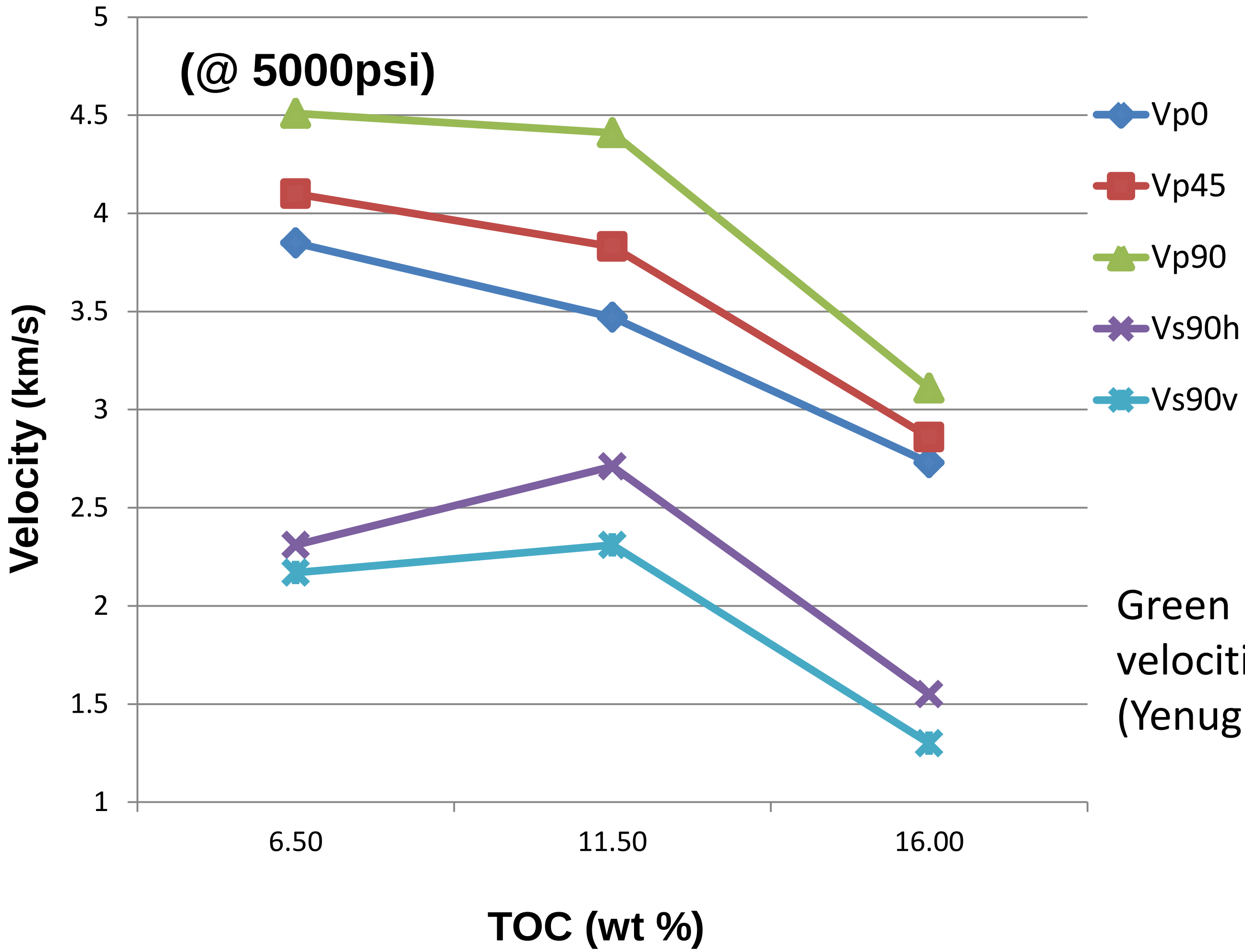
TOC vs. Velocity and Bulk Density (Bakken shale)





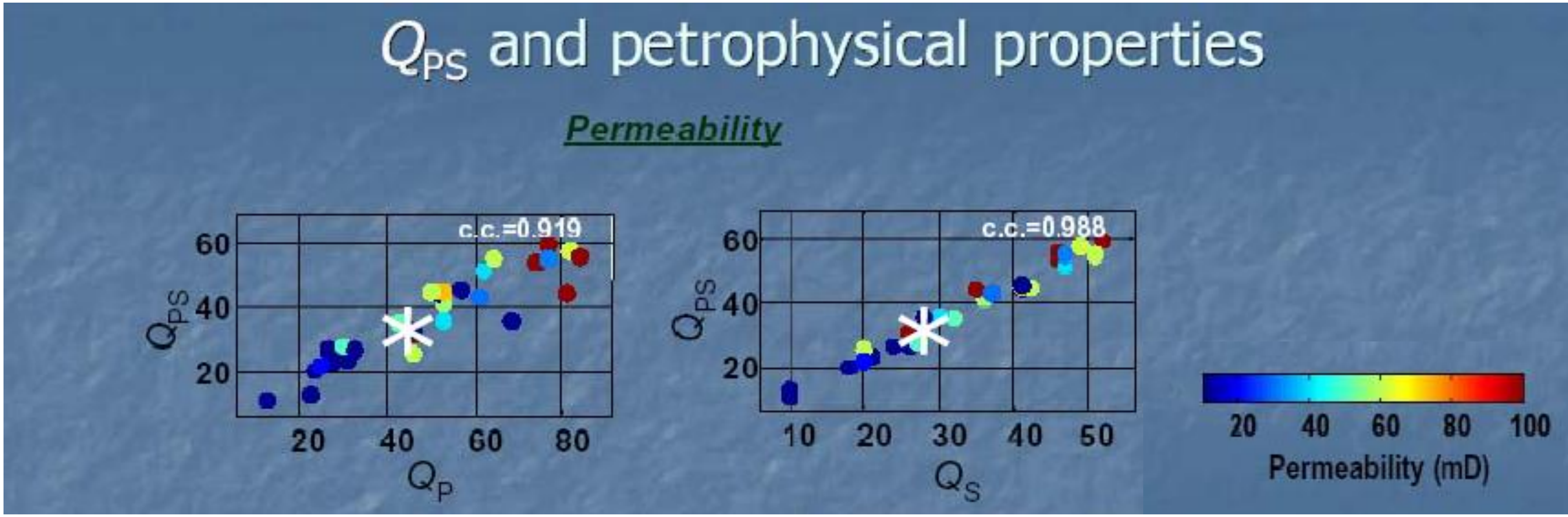
(Data from Vernik and Nur, 1992)

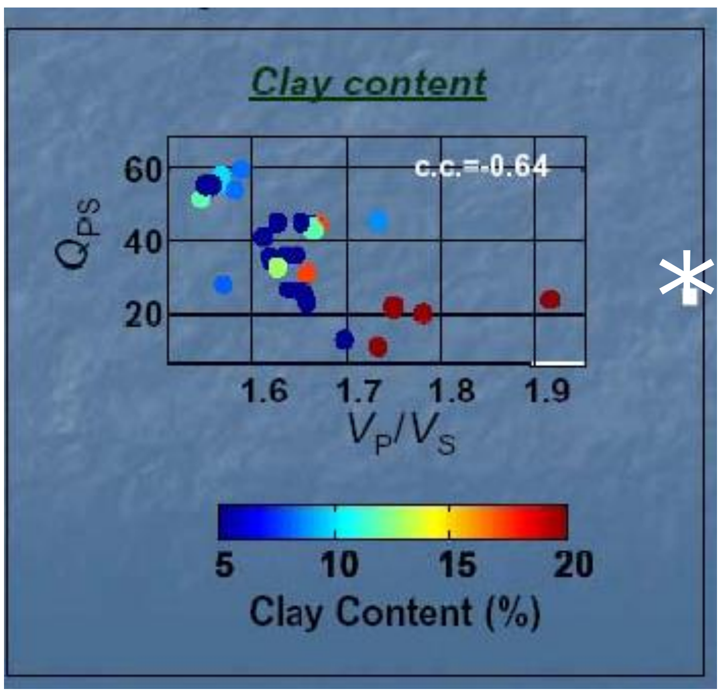
Velocities and bulk density decrease with TOC increase. So the seismic reflectivity is affected by the organic richness of shales.



Green River shale: Ultrasonic lab velocities
(Yenugu, 2012 – Univ. of Houston)

Can we use elasticity and anisotropy to better characterize shale?





Using spectral seismic values for lithology

* Q values from Ross Lake VSP

From Best et al., 1994; Calderon-Macias et al., 2004; and Zhang & Stewart, 2012

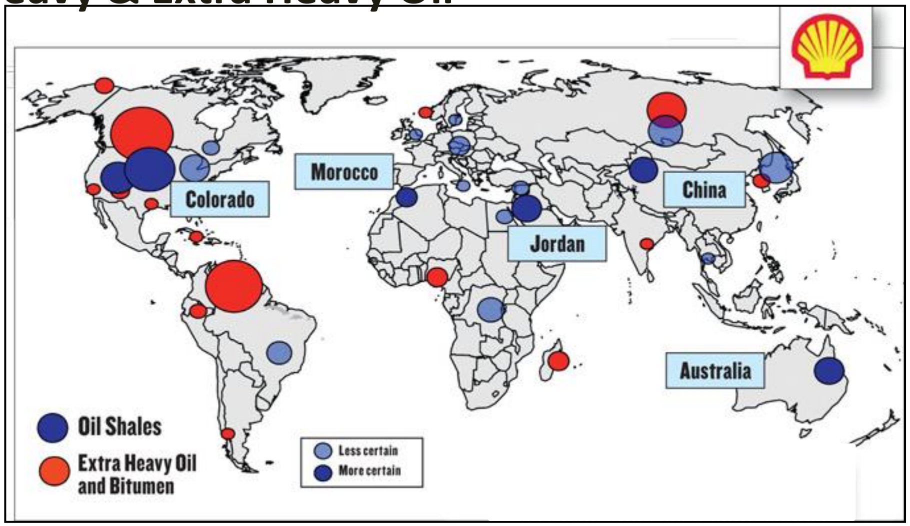
Summary – Shale geophysics

- Vast hydrocarbon resource in shales
- Pressing E & P issues (economic, geologic, environmental, political)
- Geophysics can provide
  - structural & stratigraphic image of subsurface
  - TOC and brittleness indicators
  - Hydraulic fracture mapping
  - Follow-on monitoring

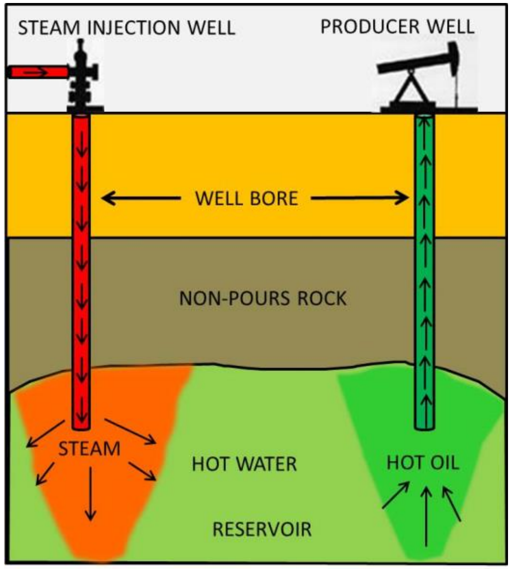
We recommend …

Enhanced Oil Recovery - Oman

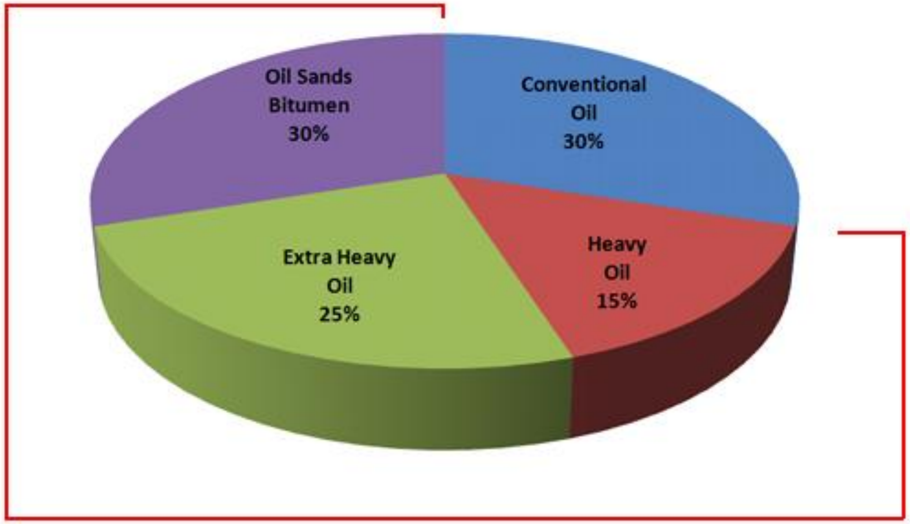
Heavy & Extra Heavy Oil



EOR by Steam injection



Total World Oil Reserves



Study area

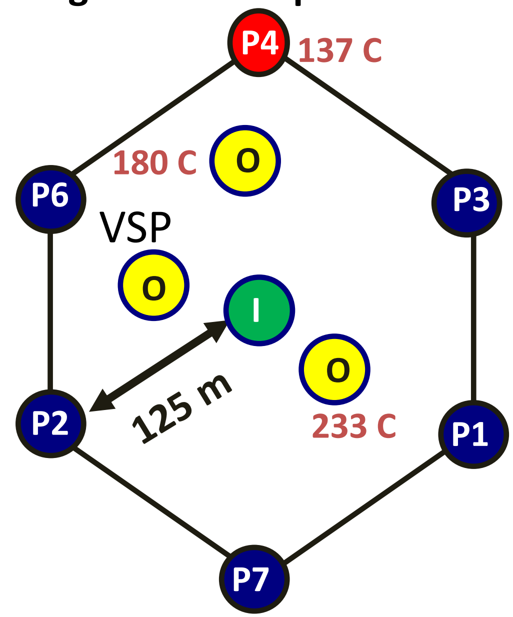
EOR field, Oman (PDO & Shell)
Steam injection , 4D Monitor area.
API 19°

Objective

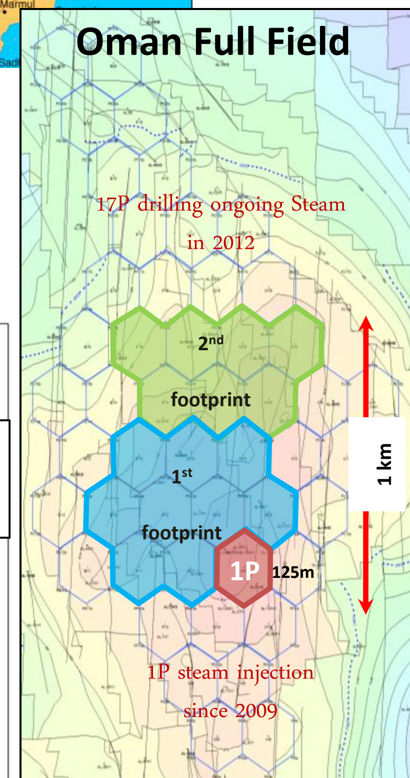
Objective:

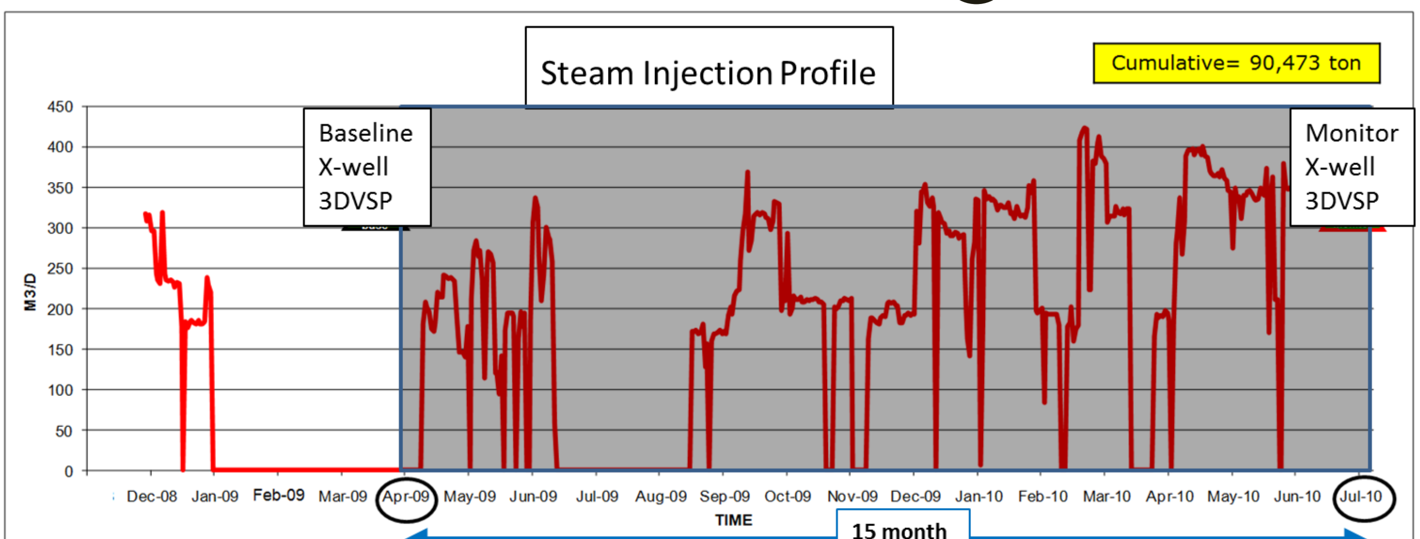
1. EOR response in 4D
2. VSP processing to detect 4D anomaly
3. Differentiate steam from the heated zone

Hexagonal steam pattern



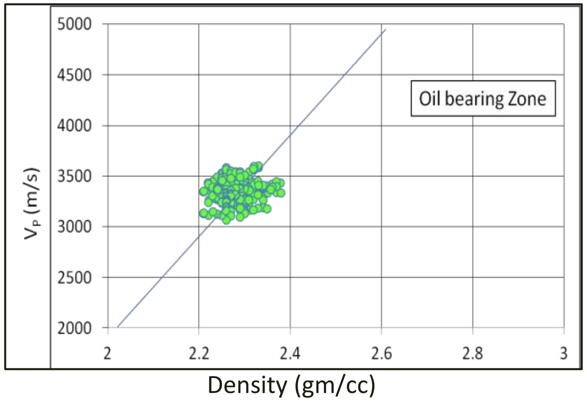
Study area





Predicted Velocity

From logs



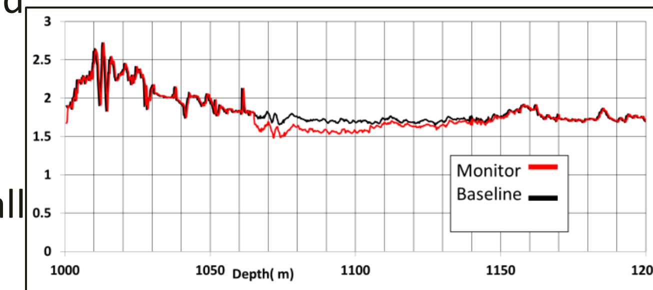
Establish V_{P}, V_{s} relatioship

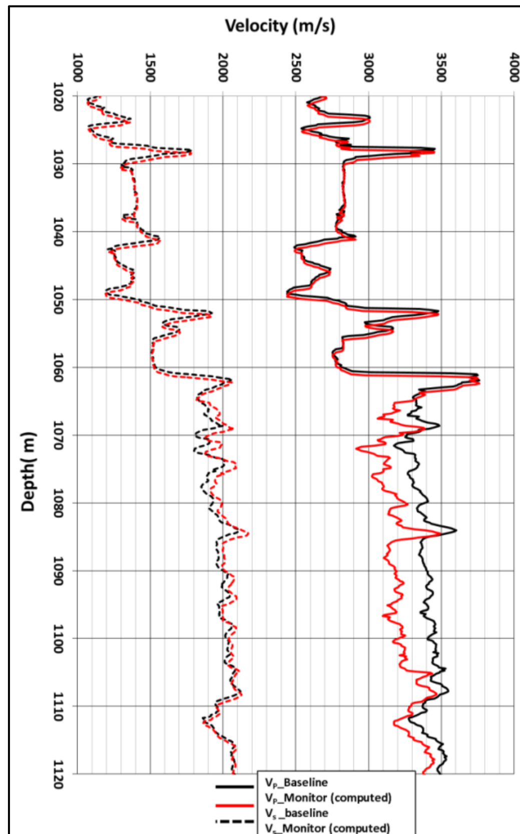
$V_P = +5477.116*\text{density} - 9074.37$

$V_S = +0.73565\, V_P - 537.8$

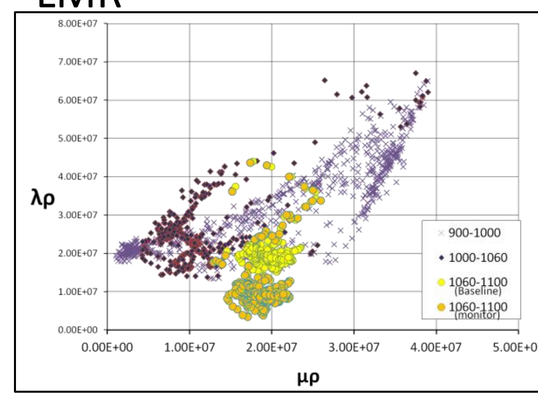
- Used Gassmann substitution and FLAG modeling.
- V_P/V_S decreases for steam injection interval.
- Changes are extrapolated laterall to VSP well.

V_P/V_S



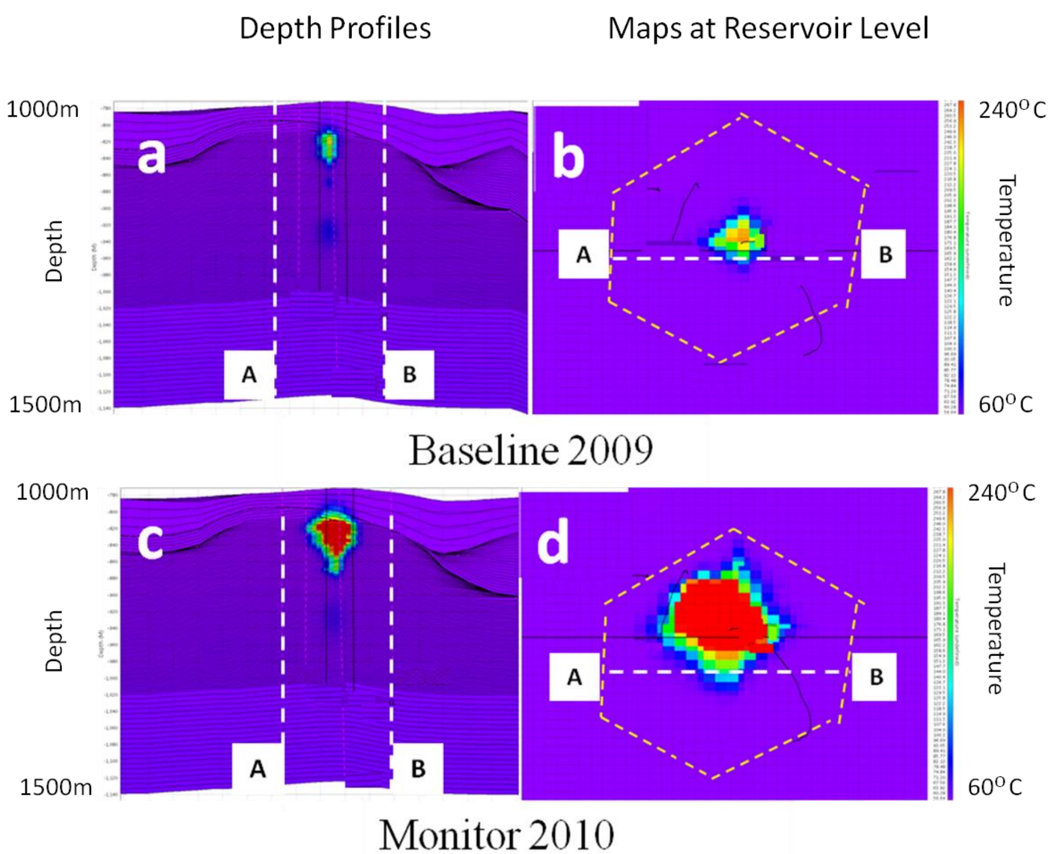


LMR



Scenarios vs Reference model

Temperature profiles and maps of Reference Model for two time vintages

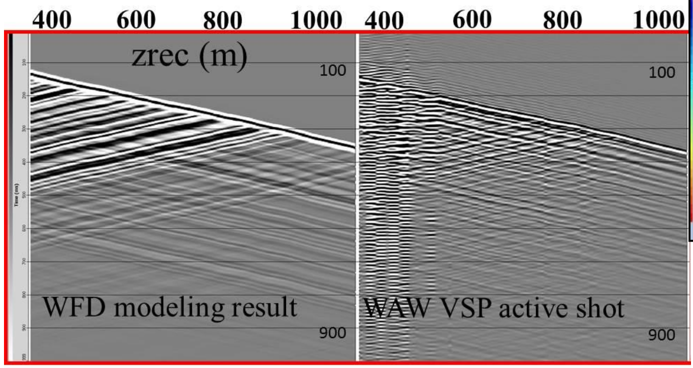


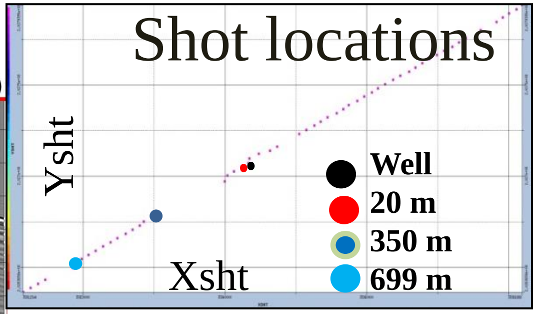
Scenarios having same porosity but different permeability distribution

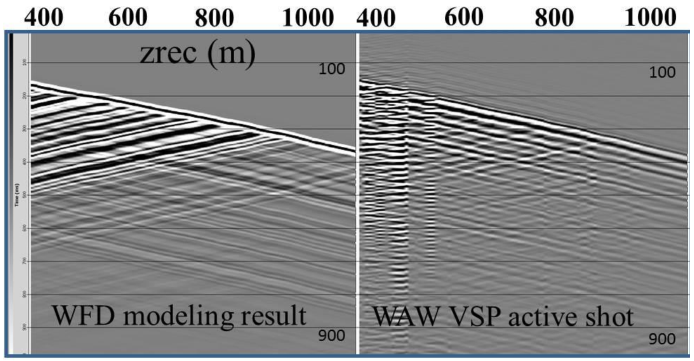
- ***Scenario S2***: Horizontal permeabilities for the top few layers within the reservoir are overwritten to 10 D.
- ***Scenario S3***: Horizontal permeabilities (top thick)
- ***Scenario S4***: Horizontal permeabilities (top thin).
- ***Scenario S5***: Scaled version of S3 (top thick)
- ***Scenario S6***: Scaled version of S4 (top thin)
- **Scenario Sb**: There are many 0.5 m thick baffles

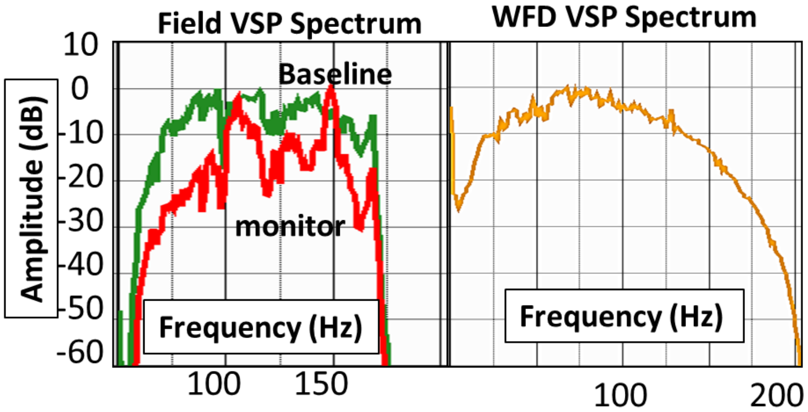
Compare (temperature and 4D attributes)

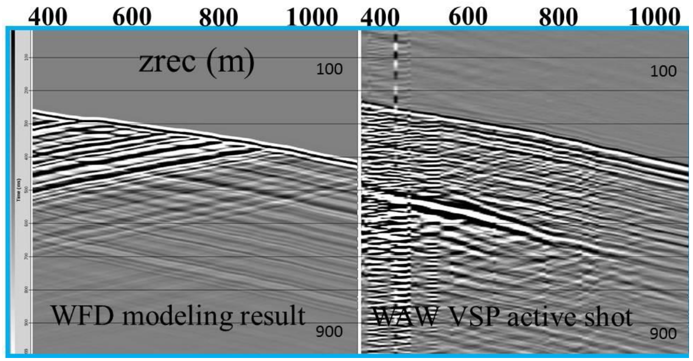
Comparison with field VSP



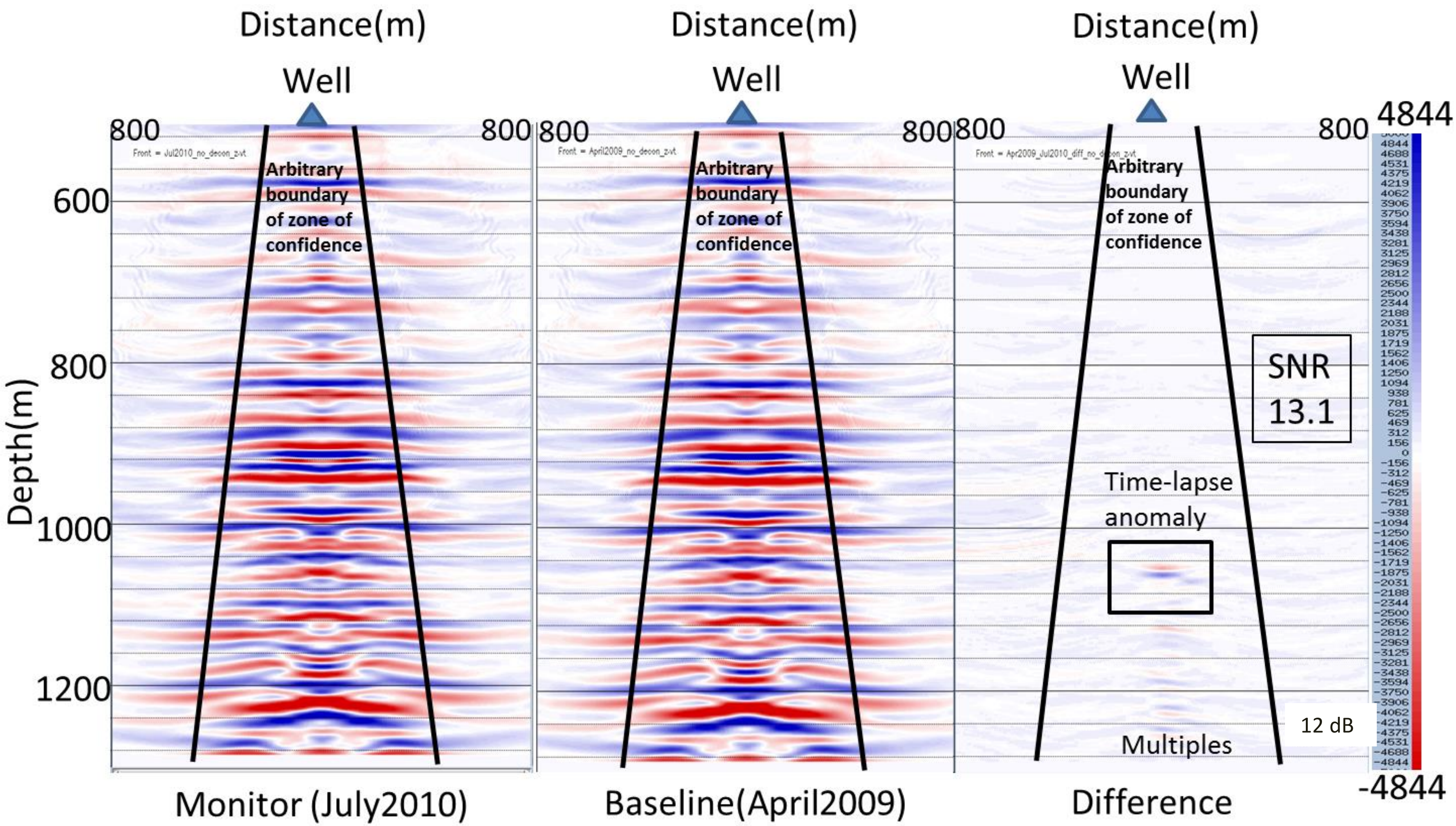




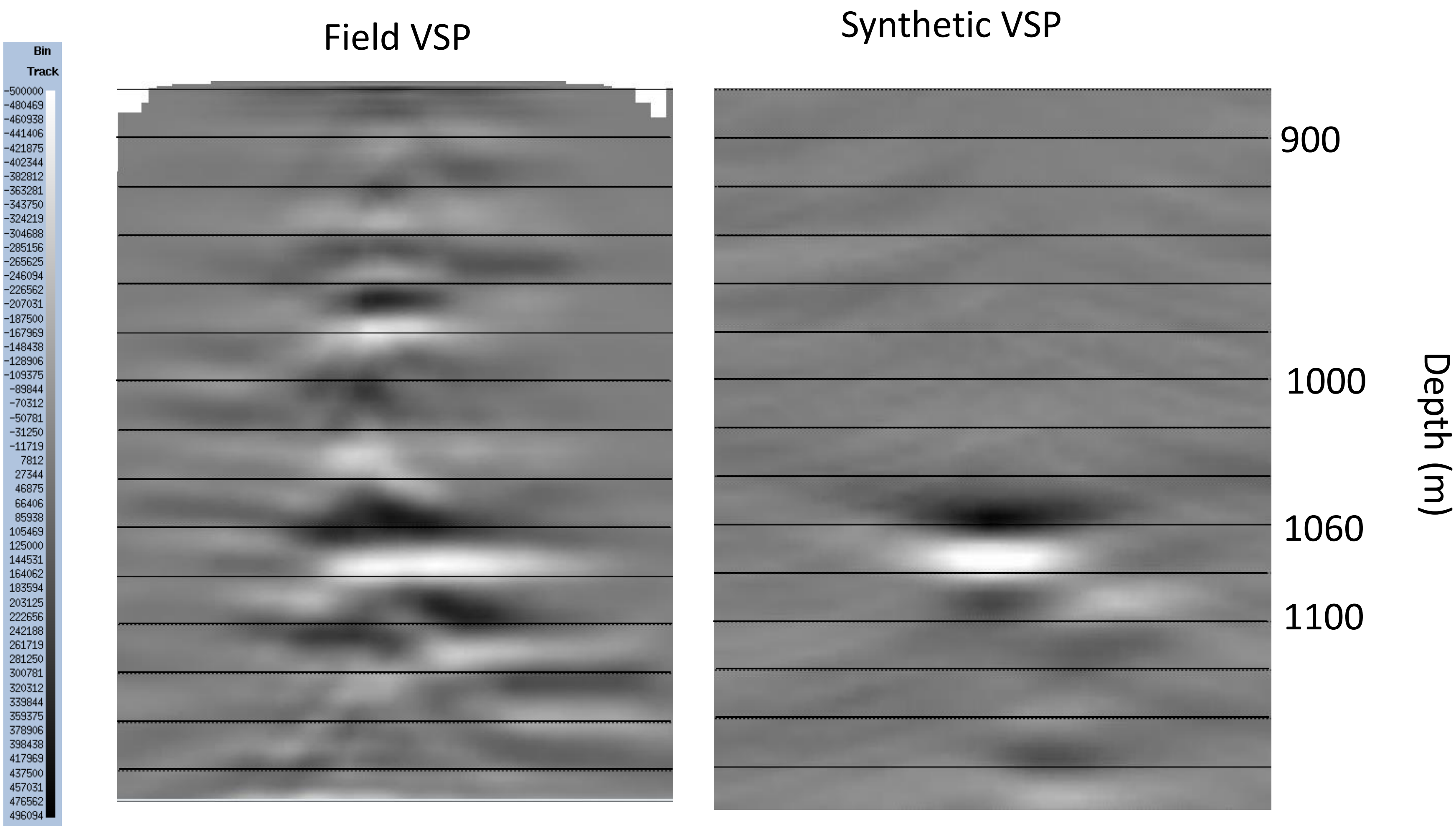




PP imaging migrated

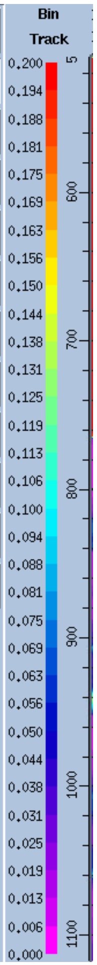


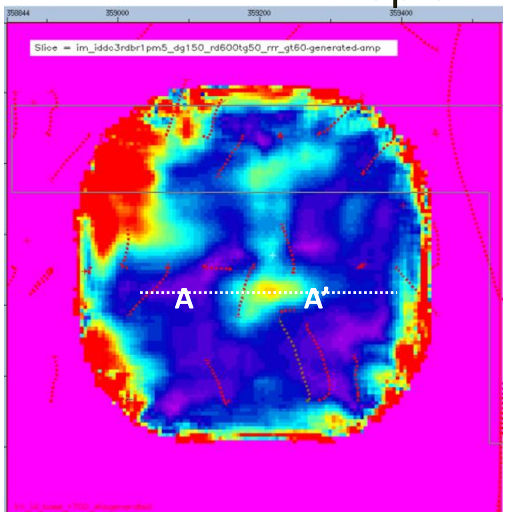
Comparison with real data



Comparison with real data

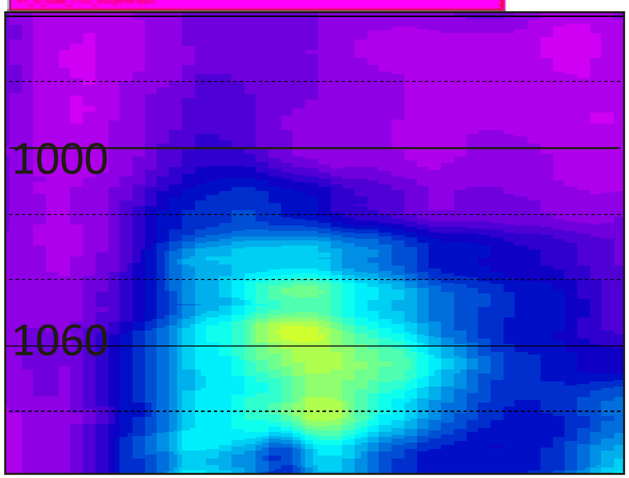
Map of RRR at reservoir level (field 3D VSP)

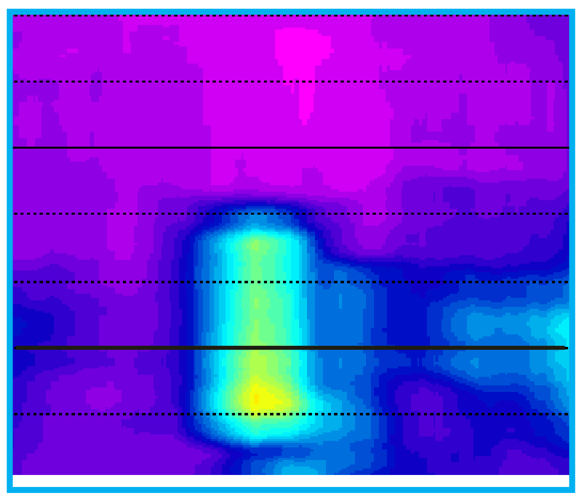


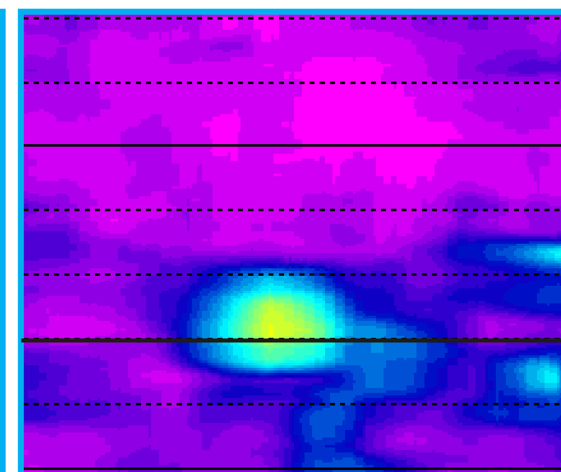


- 4D effect is very prominently visible (for PP)
- Temperature effect coincides with temperature data in wells
- Velocity prediction for monitor was sufficient for PP

VSP walkaway Line (East west)



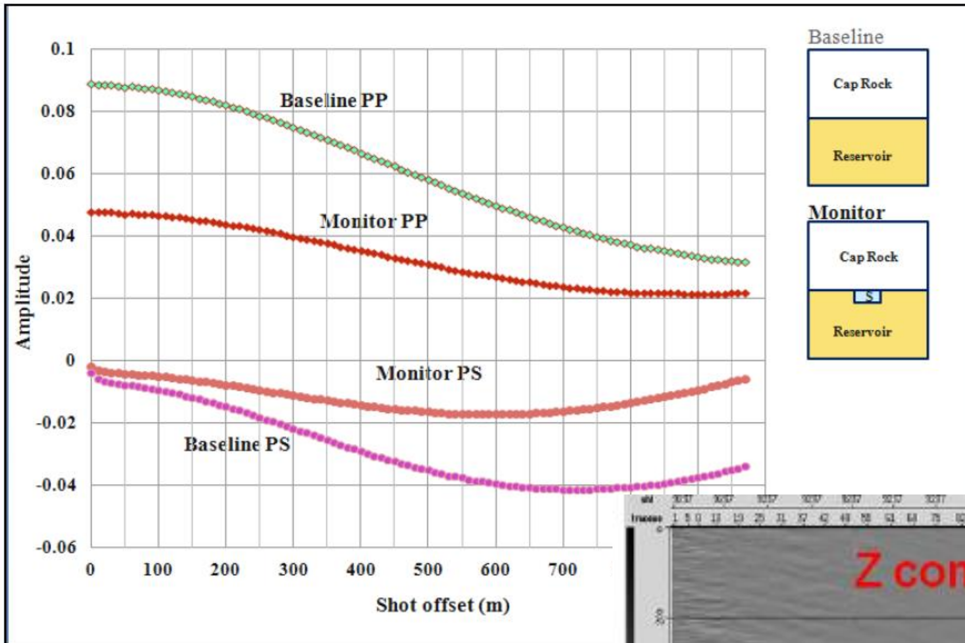


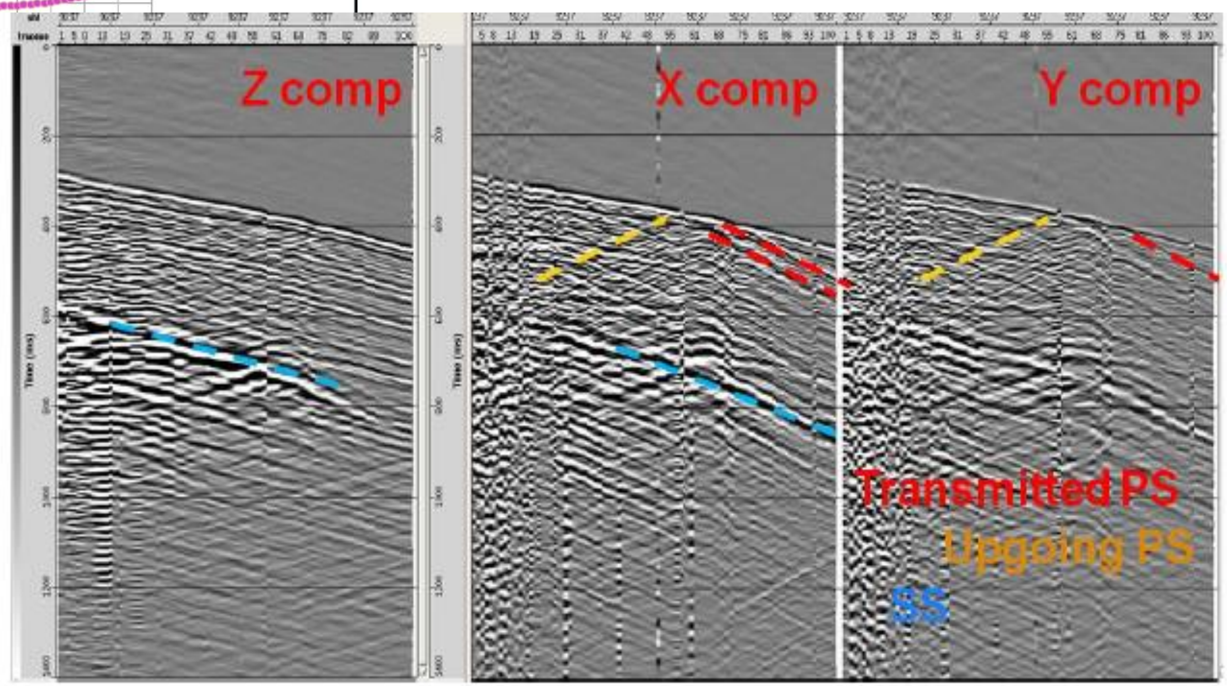


Line extracted from Field VSP
60 ms RRR window

EW synthetic VSP
(60ms RRR window) (40ms RRR window)

Moving to converted waves





Summary

- Time-lapse anomalies are predicted from reservoir simulations and fluid substitution modeling
- Field VSP data shows anomalies that are simialr to those predicted
- Converted-wave data show promise
- Thank you to Shell & PDO for releasing these data