# Reservoir Petrophysical Modeling from Seismic Impedance Volumes

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# 1. Background

- Initially (1980's) HC volumes in the 3D space were determined using the Gross Rock Volume (GRV), net reservoir to gross thickness (NTG), average porosity (PHI), average saturation (So) and an expansion constant (Bo) determined from at least one discovery well, according to the following equation: -

  STOIIP = GRV * NTG * PHI * So * 1/Bo

- This should only be used as a "quicklook" estimation.
- Averages remove the variation in reservoir quality.
- The GFC could never have been predicted using averages.
- Similarly, good reservoir quality will never be predicted using averages.

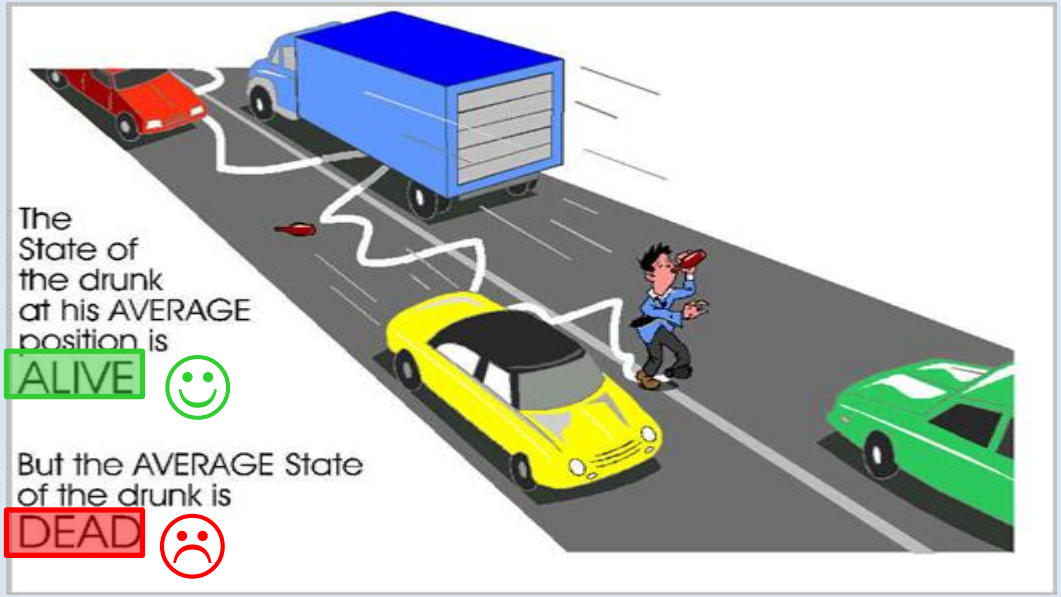
# 2. Current Condition/Situation

- 5-10 Exploration/Appraisal wells are typically required (at approx. $100mill each) before Financial Investment Decision is made.
- Approx. 5 years of conceptual based modelling is required before Development drilling starts.
- The "end of field" HC volumes from too many MCP's are found to be outside the initial uncertainty range and most of these are below the initial low case.


- Petrophysical cut-offs and averaging often over-estimate net pay (due to cognitive bias), but this results in under-estimating permeability, requiring perm scale factors of 3x-5x at best to material balance the field production.
- Too often, the variation around the average value of the property is modelled, without regard to the probability of the precise value.

# 2. Current Condition/Situation

Consider the state of a drunk, wandering around on a busy highway. His average position is the centerline, so.....



# 3. Objective

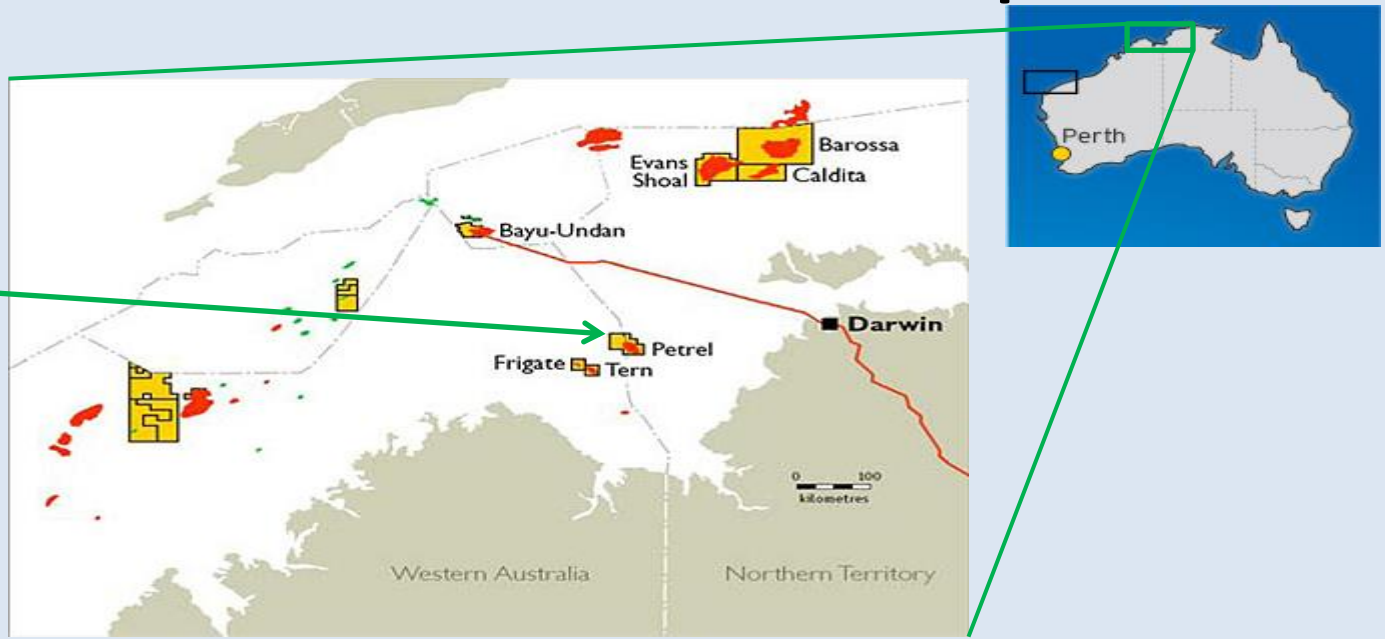
- Increased accuracy – validation with blind testing.
- Reduced cost – requiring less appraisal wells and less processing time.
- Use science, physics and mathematical relationships rather than conceptual/stochastic models based upon averages.
- Use a deterministic approach calibrated to an exploration/discovery well(s).
- Develop a robust 3D prediction, that can be used with “old” or “new” Seismic.

# 4. Action

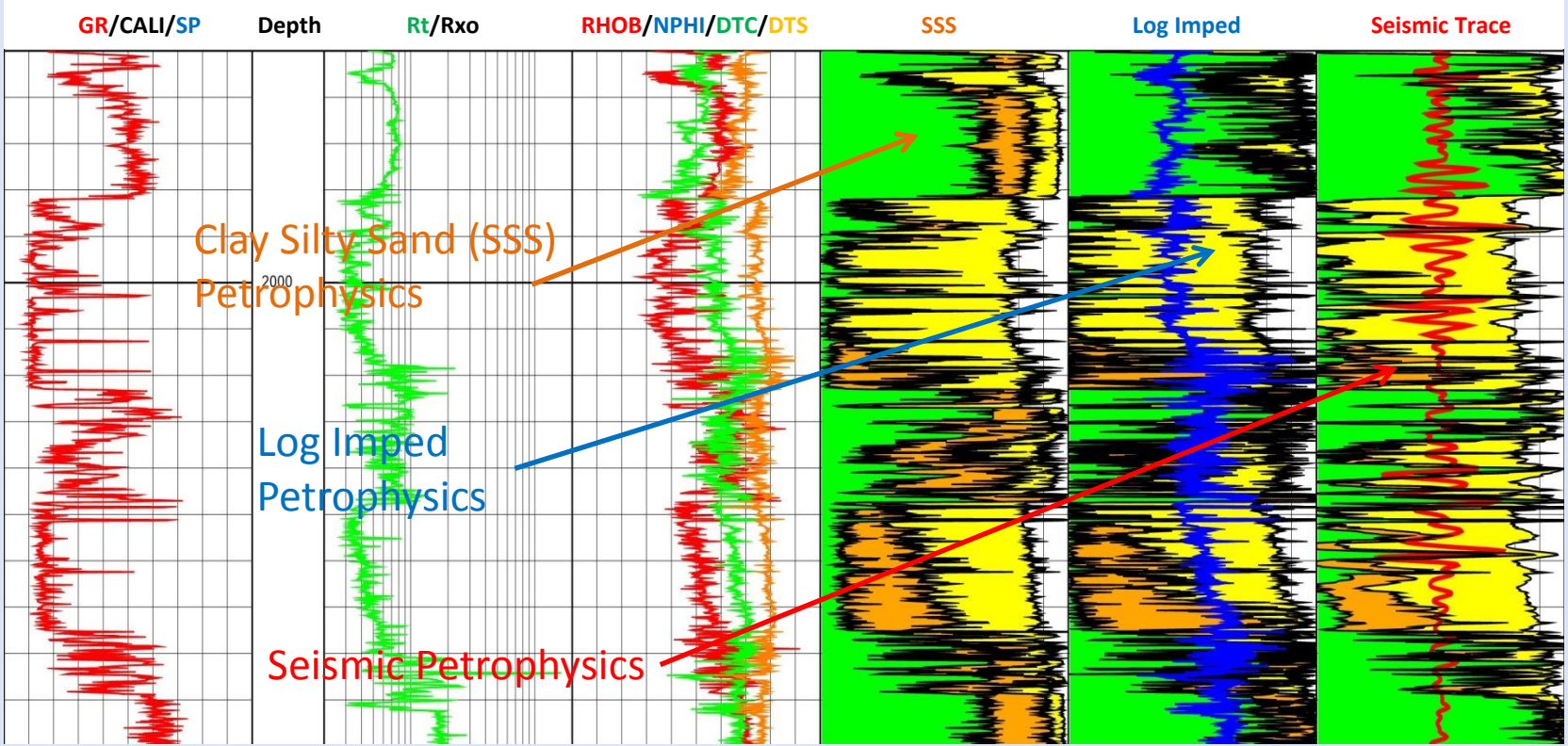
- Calculate the reservoir Petrophysical properties constrained/referenced to the 3D seismic trace/impedance.
- Develop relationships for water, gas, oil and residual HC at the calibration well(s). (e.g. Gassmann)
- Blind test predictions with new or existing well(s). This will validate the model.
- Populate into the 3D space with the predictions based upon the calibrated well(s)
- Use existing relationships of permeability and saturation, in the 3D volume.

# 5. Petrel Field - example

Petrel Field

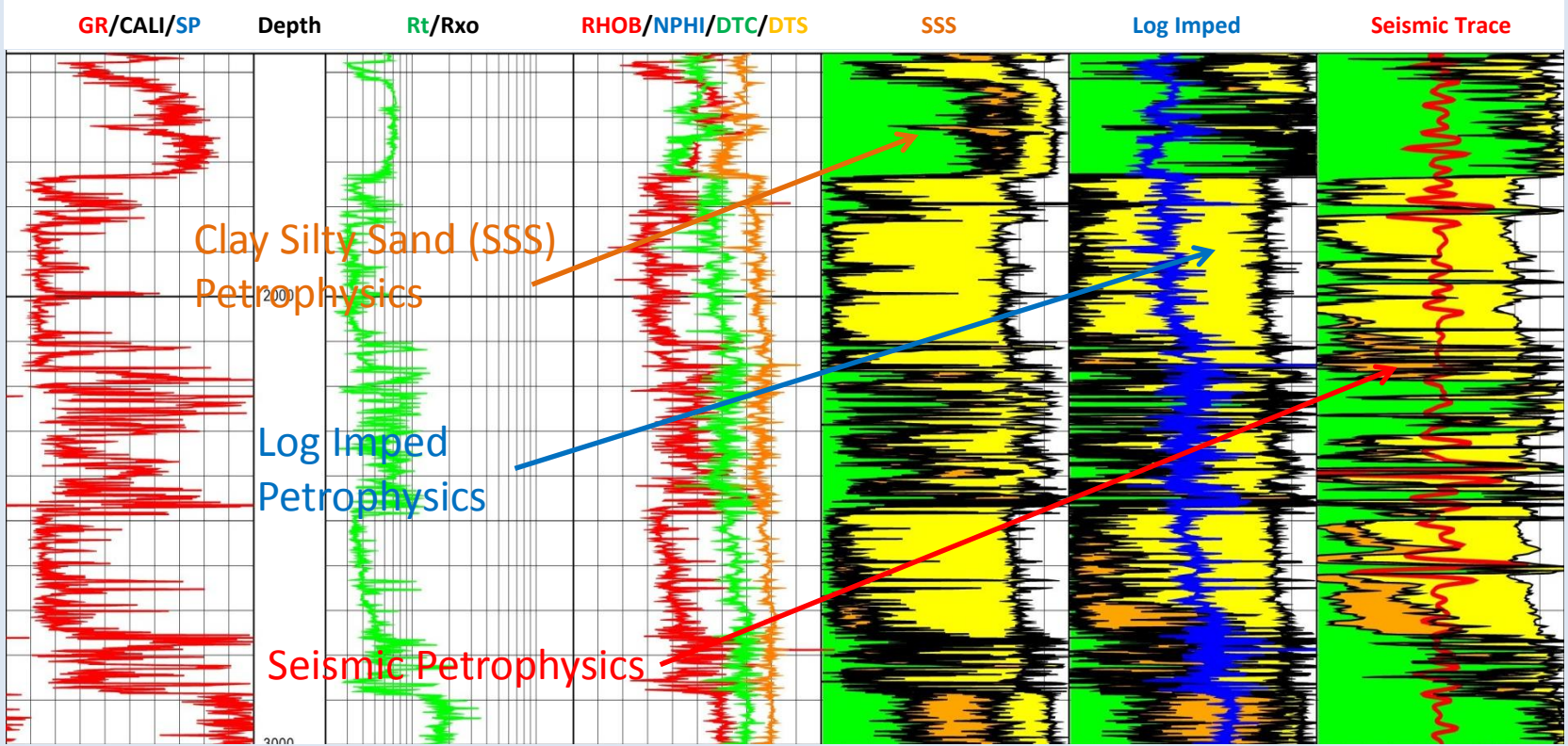


# 5. a) Calibration: - Petrel-1A



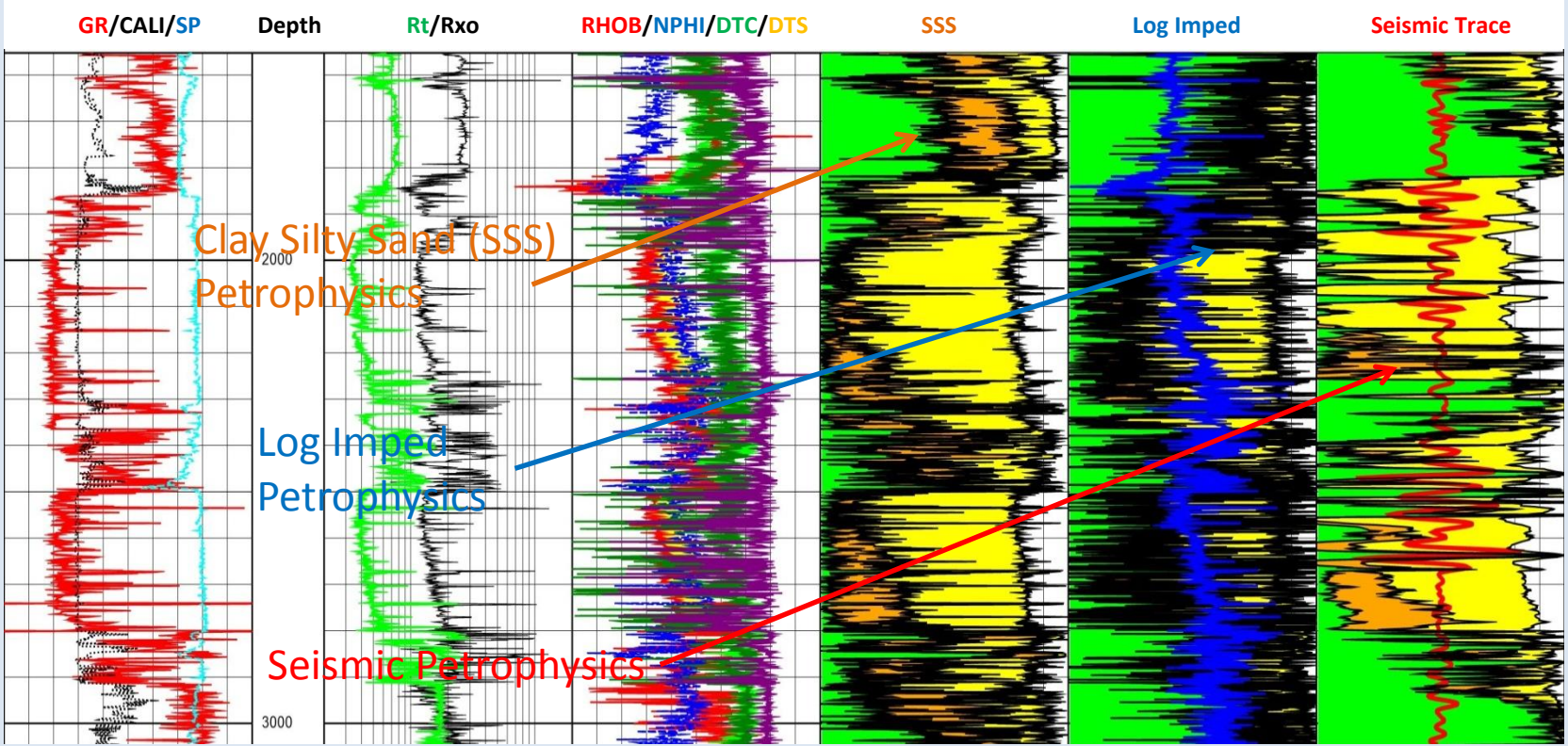

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

# 5. b) Blind Test: - Petrel-4



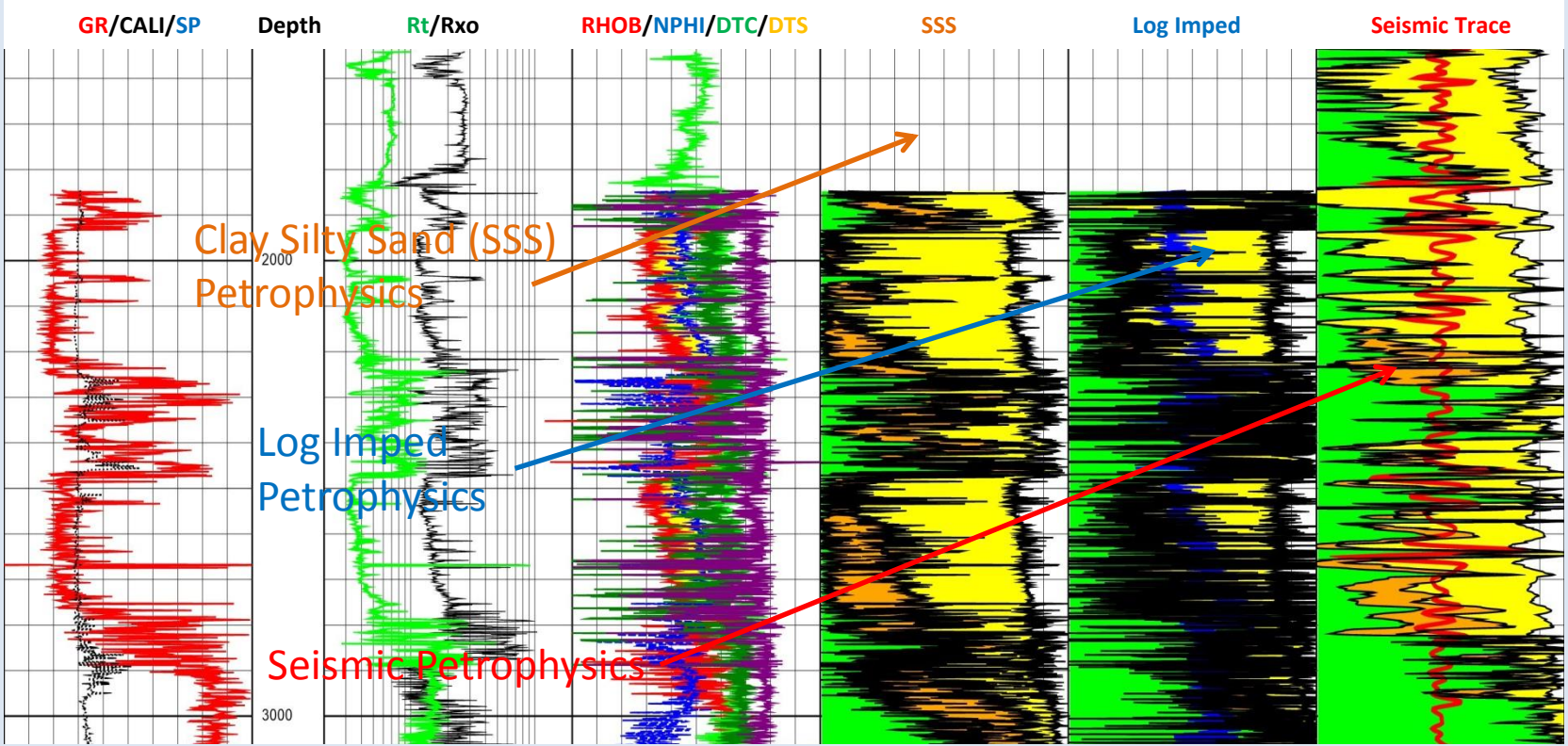

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

# 5. b) Blind Test: - Petrel-5



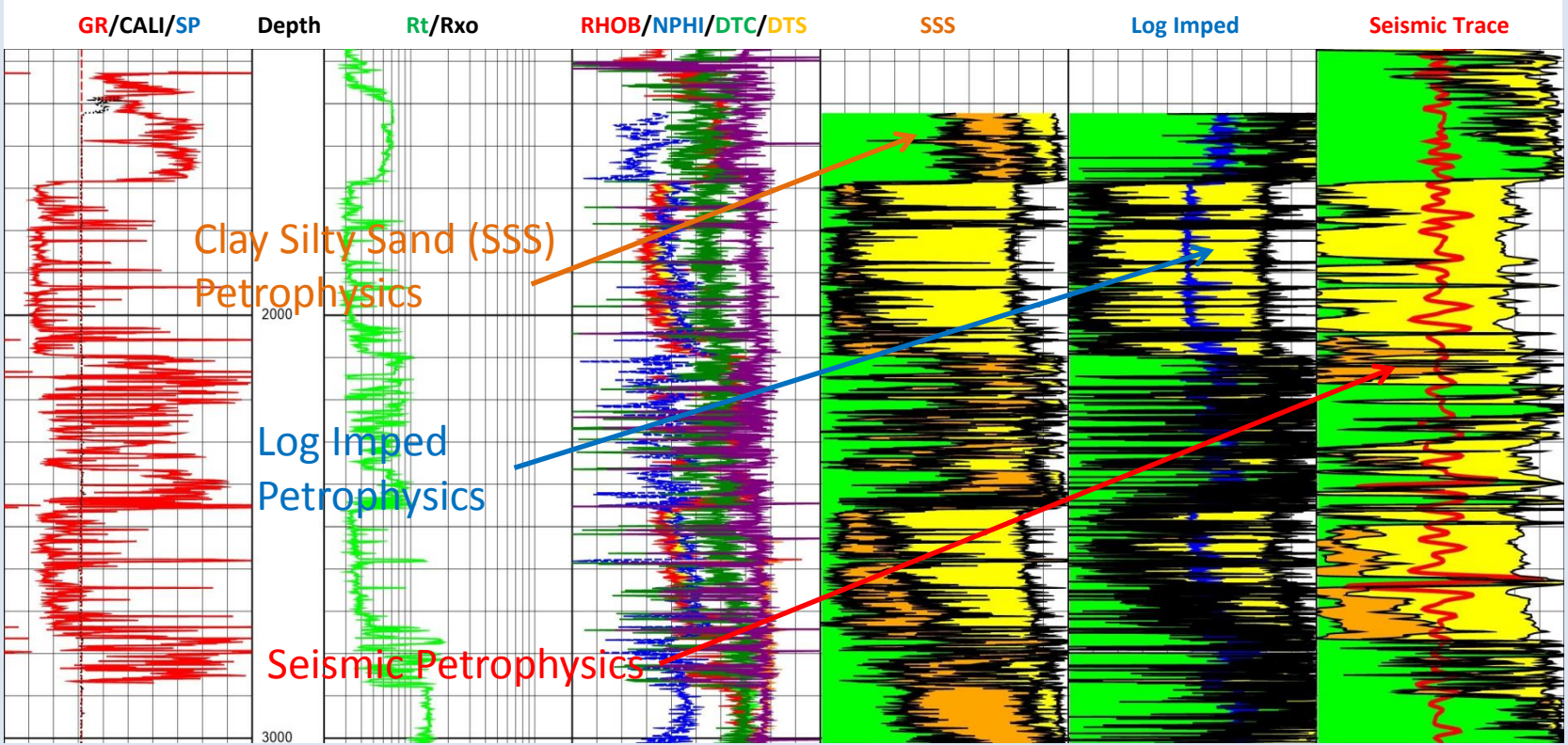

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

# 5. b) Blind Test: - Petrel-6



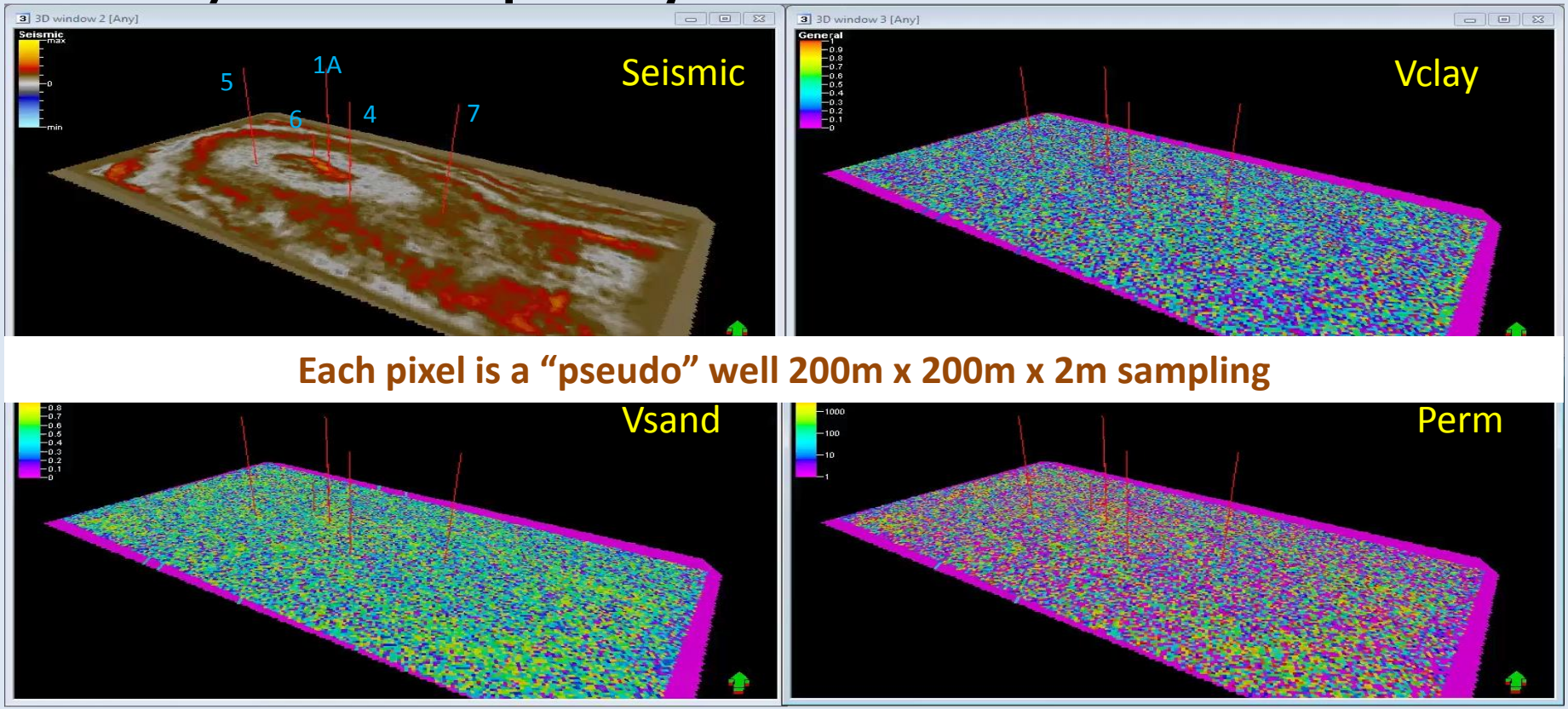

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

# 5. b) Blind Test: - Petrel-7




Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

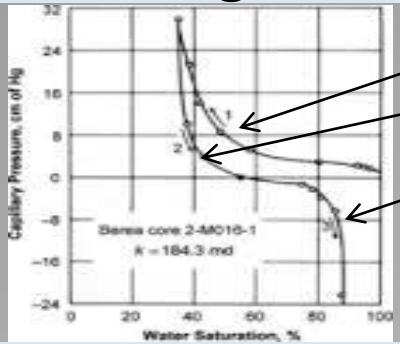
# 5. c) 3D Property Model: - Petrel Field




**Each pixel is a "pseudo" well 200m x 200m x 2m sampling**

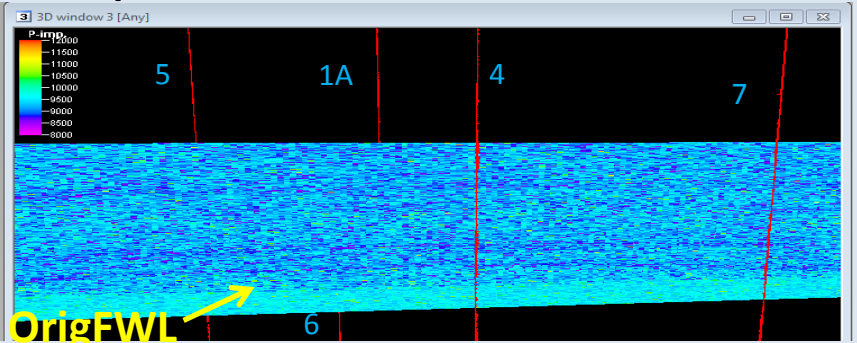
# 5. d) 4D Property Model: - Petrel Field

## Drainage/Imbibition

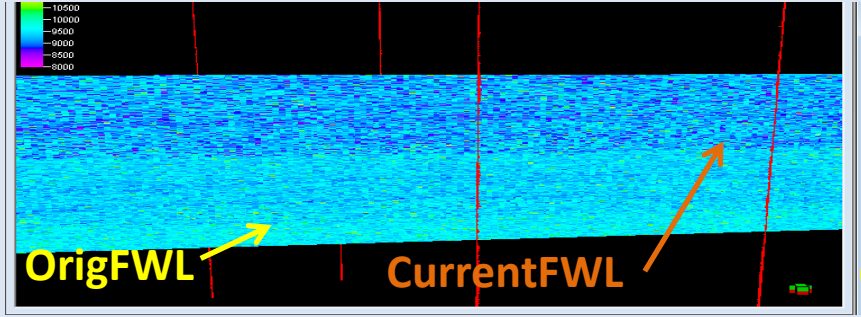



1. Drainage
2. Spontaneous Imbibition
3. Forced Imbibition (EOR)

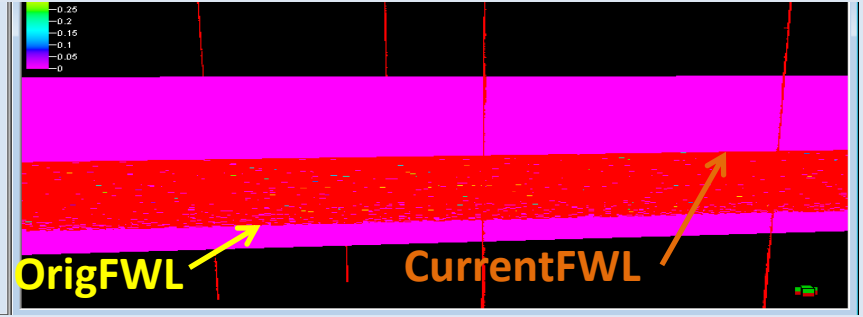
## Imped. Vol. STOIIP/Drain



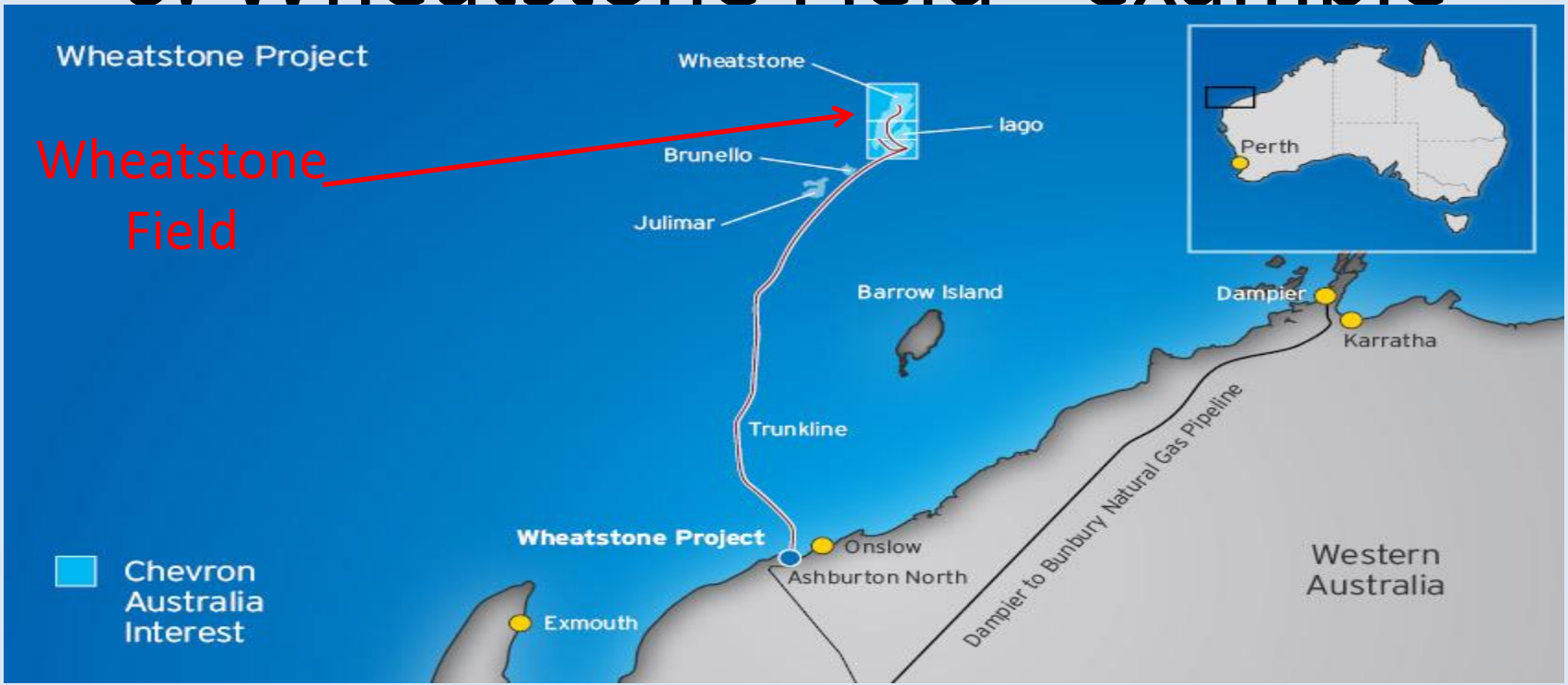

## Imped. Vol. Resid./Imbib.



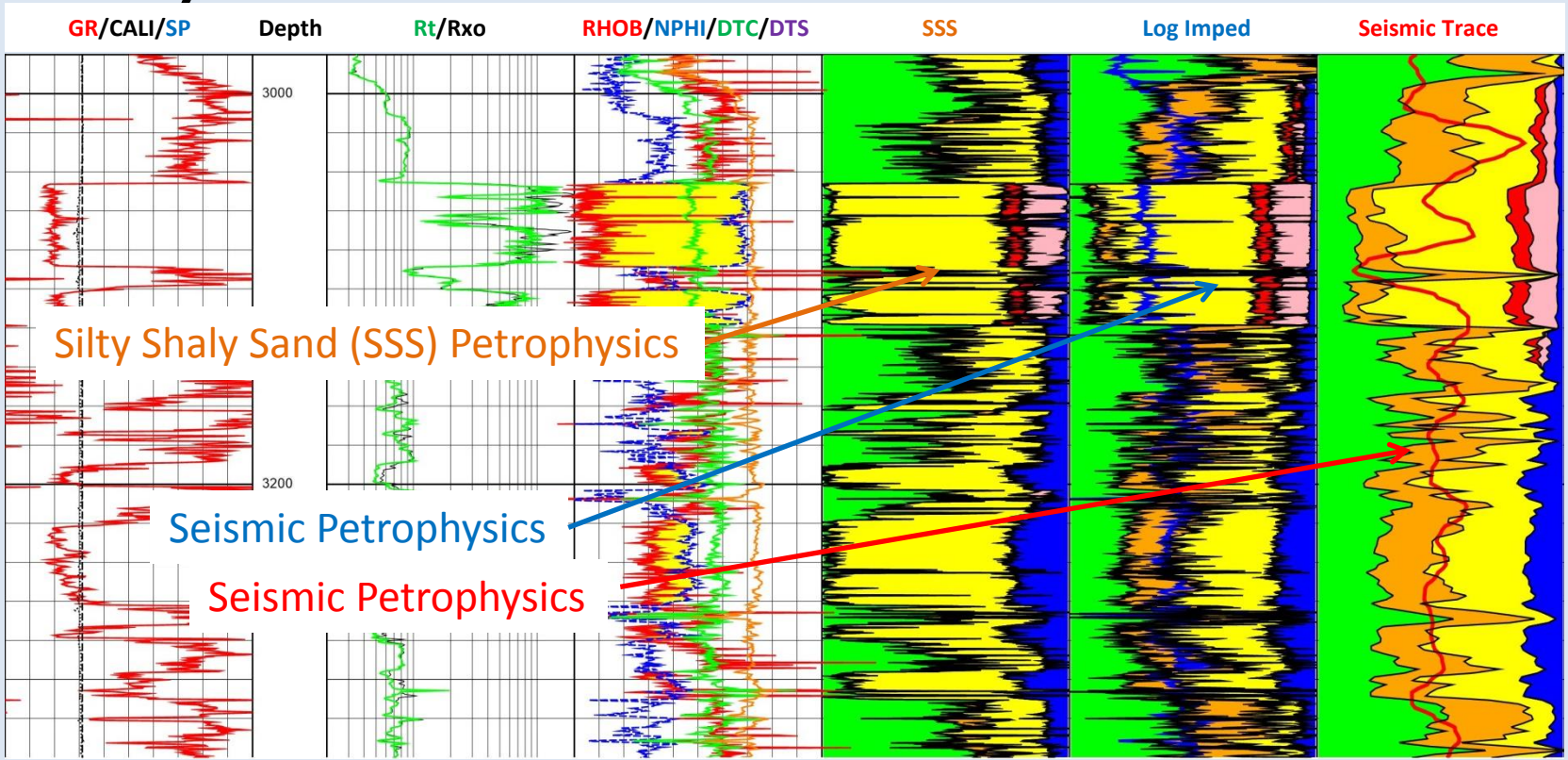

## Imped. Vol. Difference



# 6. Wheatstone Field - example

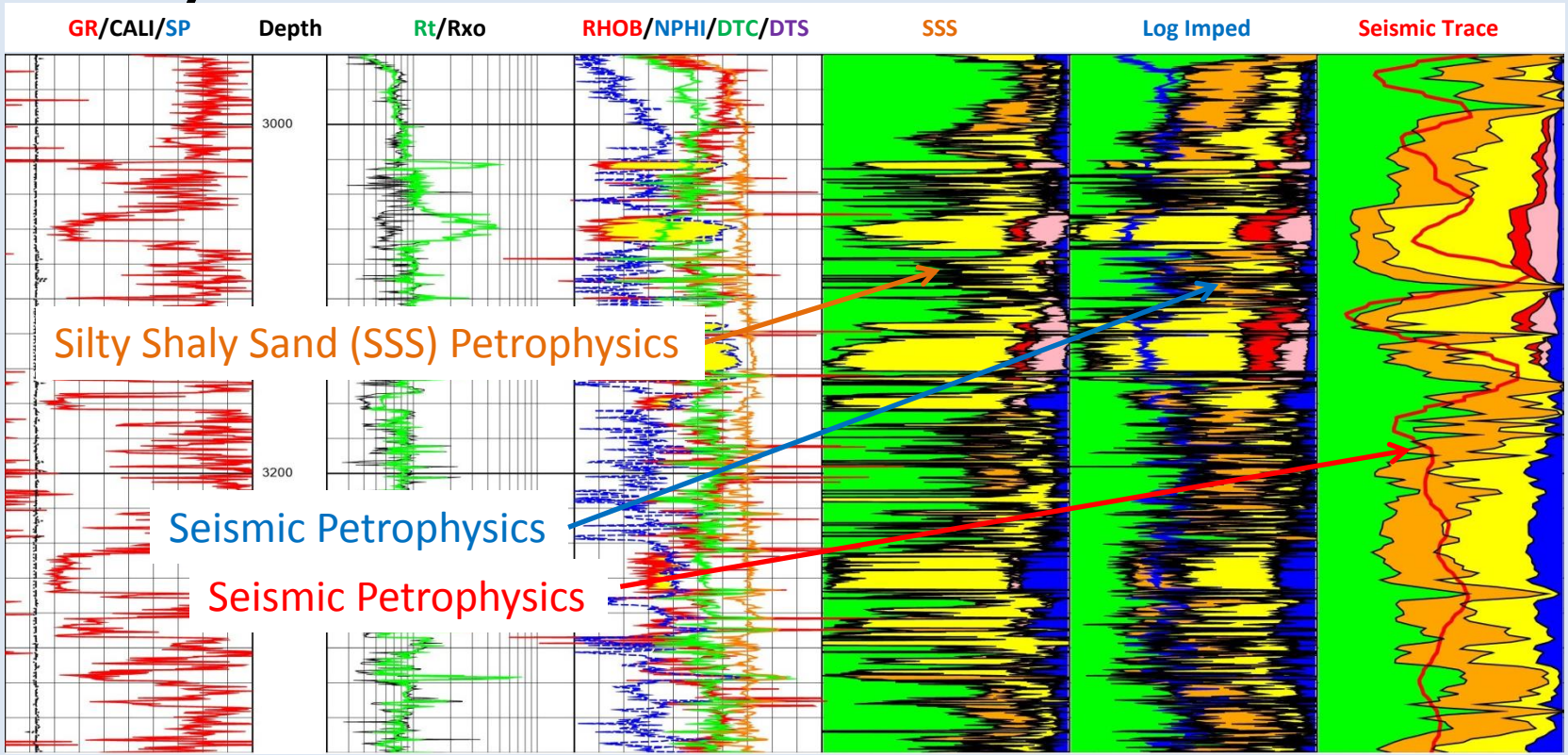


# 6. a) Calibration: - Wheatstone-3



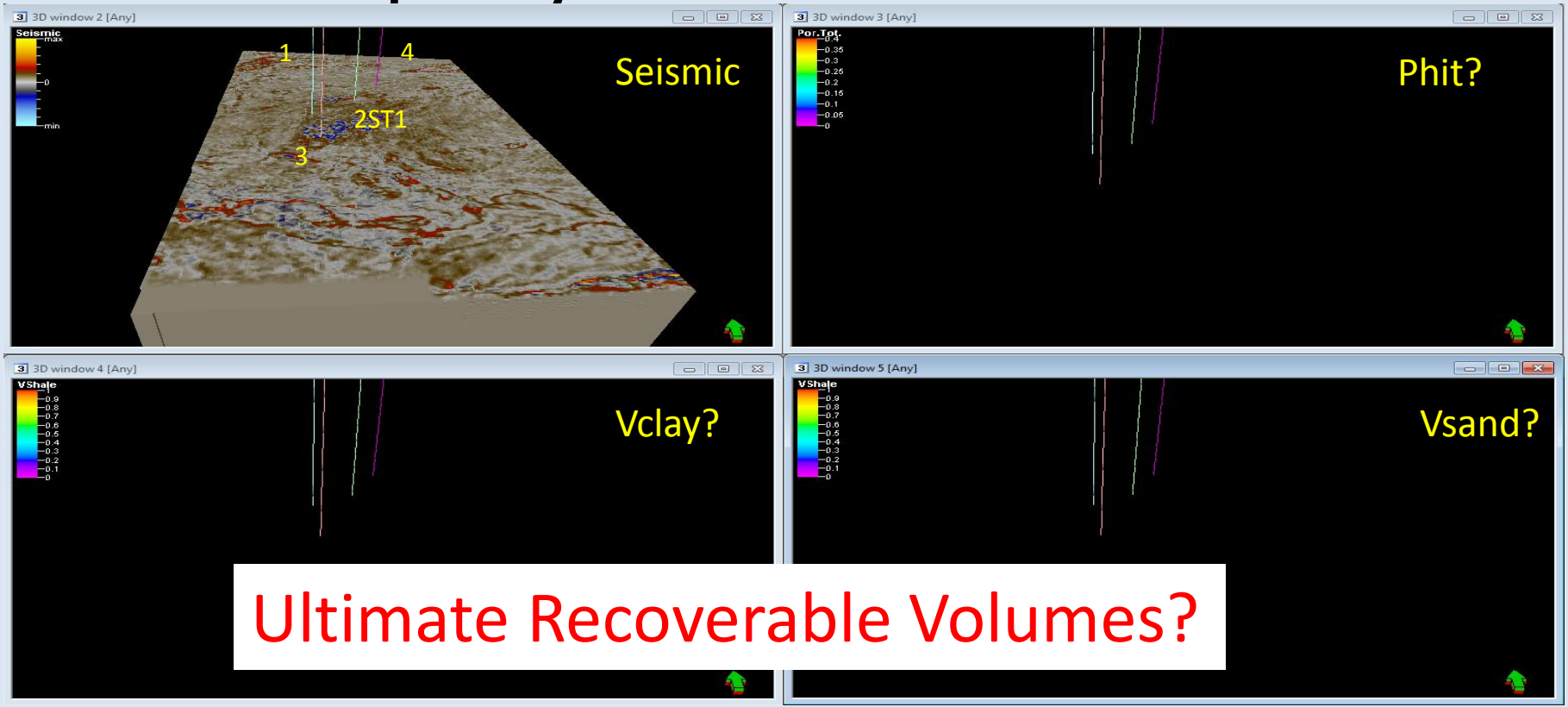

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

# 6. b) Calibration: - Wheatstone-1




Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

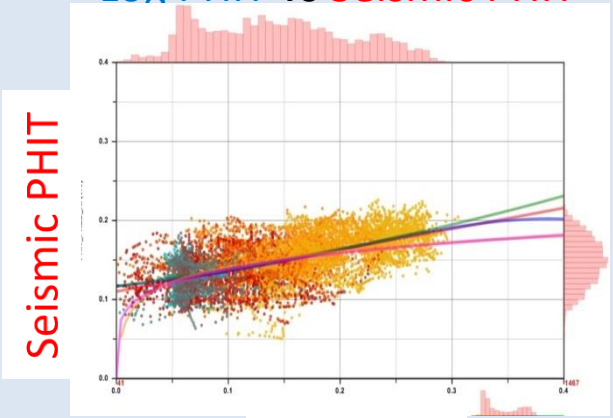
# 6. 3D Property Model: - Wheatstone




Ultimate Recoverable Volumes?

# 7. Uncertainty:

Log PHIT vs Seismic PHIT




Log PHIT

P10 P50 P90

PHIT diff

**PHIT uncert.**

**P10 = -0.1**

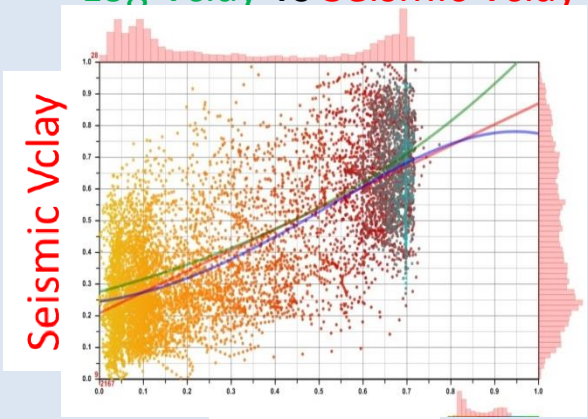
**P90 = +0.1**

**Vclay uncert.**

**P10 = -0.35**

**P90 = +0.15**

Log Vclay vs Seismic Vclay




Log Vclay

P10 P50 P90

Vclay diff

# 8. Conclusions

- Differences to current Industry standard modelling: -
  - Significant reduction in appraisal wells with blind testing possible.
  - No Geological conceptual based modelling used, no stochastic predictions, no co-kriging of dependant variables/properties.
  - No use of averages, no probabilities or “spread” of data varying from the average, no facies and no cut-offs used.
  - Property predictions take 2 to 4 weeks rather than 6 months or more.
- Products: -
  - Porosity, Vclay, Permeability and Saturation properties populated into the **3D Seismic space**
  - Uncertainty around the precise predicted value of the property not uncertainty around the average property.
  - 4D Seismic prediction using drain/imbib SHF.

# 8. Conclusions

- Data Requirements: -
  - Minimum of one exploration/appraisal well, preferable 3-4 wells for calibration if available.
  - Super-combo logs – GR, CALI, SP, RXO, RT, RHOB, NPHI, PEF, DRHO, DTC, DTS
  - Well location/coordinates, directional data.
  - 3D Seismic cube, preferably Impedance depth data.
  - Preferably WFT to determine fluid levels.
  - Preferably RCA (poro-perm) and SCAL (CapPress – Drain/Imbib, XRD)
  - FMI, NMR, Tensor Resistivity etc not required.
- Seismic Uncertainty: -
  - Accuracy of Seismic band-limited trace matched to Impedance values?
  - Seismic quality, high frequency loss and constructive/destructive interference?
  - Seismic to log resolution matching?
  - TWT to log depth match?

# 9. References


1. Kuttan K, Stockbridge C.P, Crocker H, Remfry J.G, July 1980 SPWLA, Log Interpretation in the Malay Basin.
2. Chiew Fook Choo, June 2010 SPWLA, State-of-the-art Permeability Determination from Well Logs to Predict Drainage Capillary Water Saturation in Clastic Rocks.
3. Savage, S (Professor Stanford University), The Flaw of Averages, Wiley Publications
4. Whitcombe, D, 2000 SEG Expanded Abstracts, Extended elastic impedance for fluid and lithology prediction.
5. Connolly, P, 1999 The Leading Edge 18, Elastic Impedance.
6. Ribeiro C, Oct 2004 SEG 74th Annual Meeting, A petroelastic-based approach to pressure and saturation estimation using 4D seismic.
7. Zhijing Wang, 1998 SEG Expanded Abstracts, Elastic Properties of Solid Clays.
8. Smith T M, Mar-Apr 2003 Geophysics Vol. 68 No2, Gassmann fluid substitutions: A tutorial.
9. Gassmann, F., 1951 Geophysics, v.16, p. 673-685, Elastic waves through packing of spheres.
10. Phillippe, L., Aug 1999 SPE Reservoir Eval. & Eng., From Seismic to Reservoir Properties with Geostatistical Inversion.
11. Adams, S., PE 84298, Modelling Imbibition Capillary Pressure Curves
12. Young, R., Oct 2005 E&P, AVO analysis demystified.

# 10. Questions?