Edinburgh Geoscience Advisors Ltd

Multi-physics analysis: Extracting the most from diverse datasets

MTNET EMINAR

Dr. Lucy MacGregor

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SEG

SOCIETY OF EXPLORATION GEOPHYSICISTS

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RSI

OFG Ocean Floor Geophysics

Many colleagues, former colleagues and collaborators:

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- ….and many more

- Introduction
  - Why consider multi-physics data ?
  - What are the challenges of multi-physics analysis ?
  - What do we mean by multi-physics analysis ?
- Examples
  - Integrated interpretation
  - Petrophysical joint inversion
- Thoughts on future applications
- Conclusions

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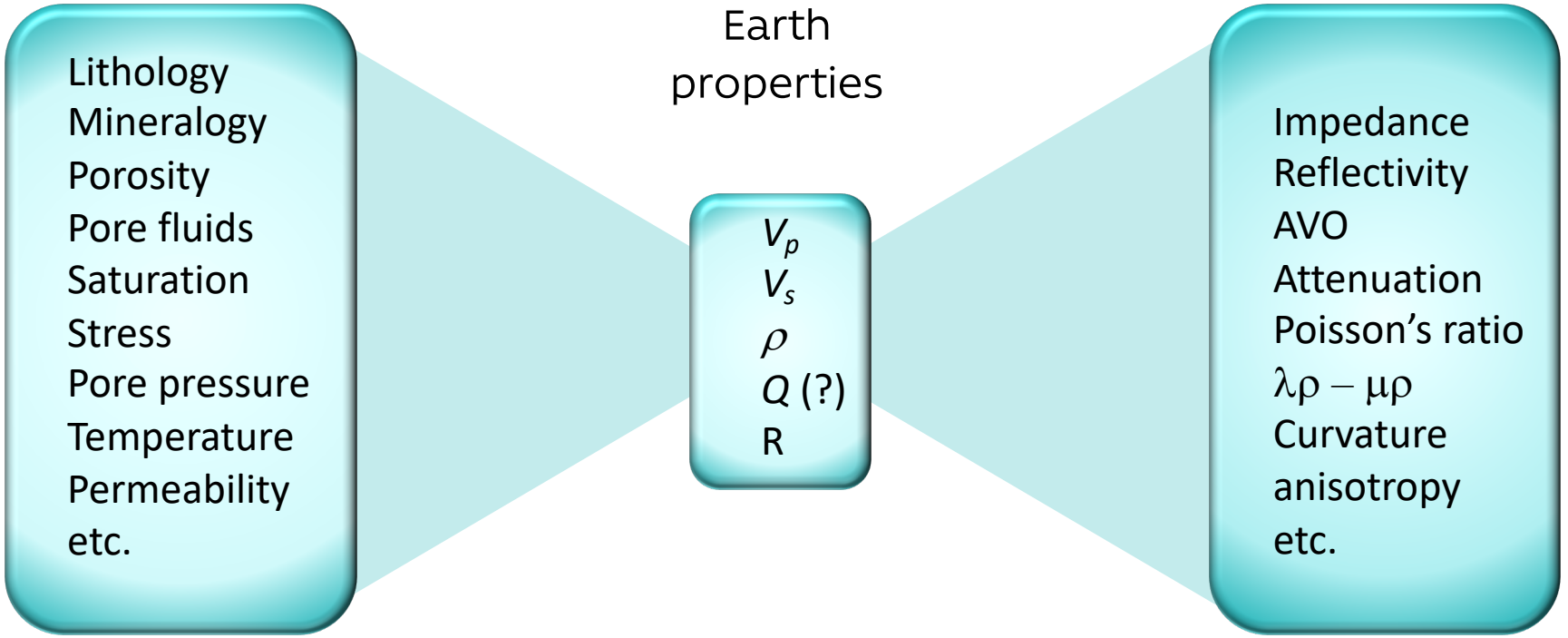
Properties of the earth

What do we want to know ?

Reservoir properties and condition

What can we measure ?

Geophysical Attributes

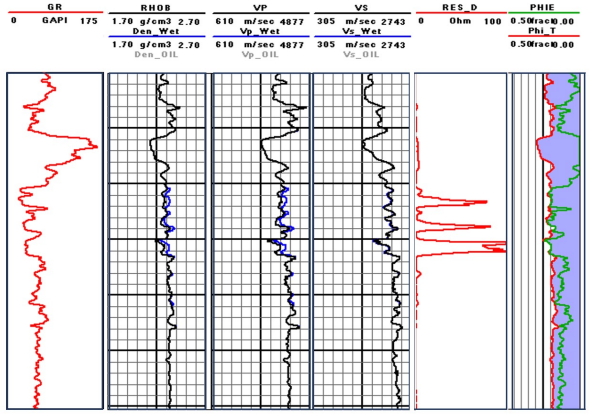


At any point in the Earth there is only a small number of properties that can be measured.

Benefits of a multiphysics approach

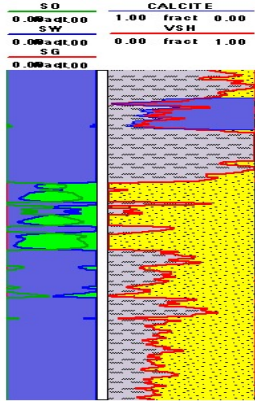
Well log analysis

Measured well log data



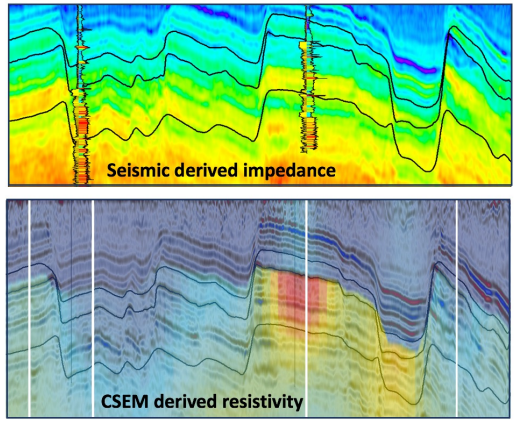
Multiphysics: Petrophysics and rock physics

Interpreted lithology and fluid



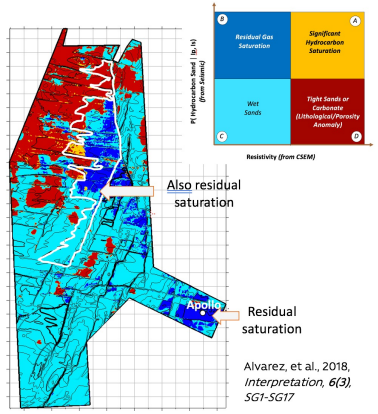
Geophysical analysis

Measured geophysical attributes



Multiphysics: Modelling, inversion, analysis

Interpreted lithology and fluid

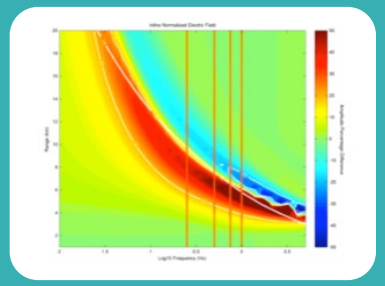


Alvarez, et al., 2018, *Interpretation, 6(3), SG1-SG17*

Challenges and pitfalls in integration

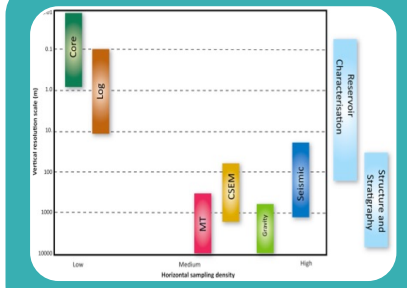
Physics

- Electric and elastic properties must be coupled through a single earth model that accurately and consistently describes each.



Sensitivity

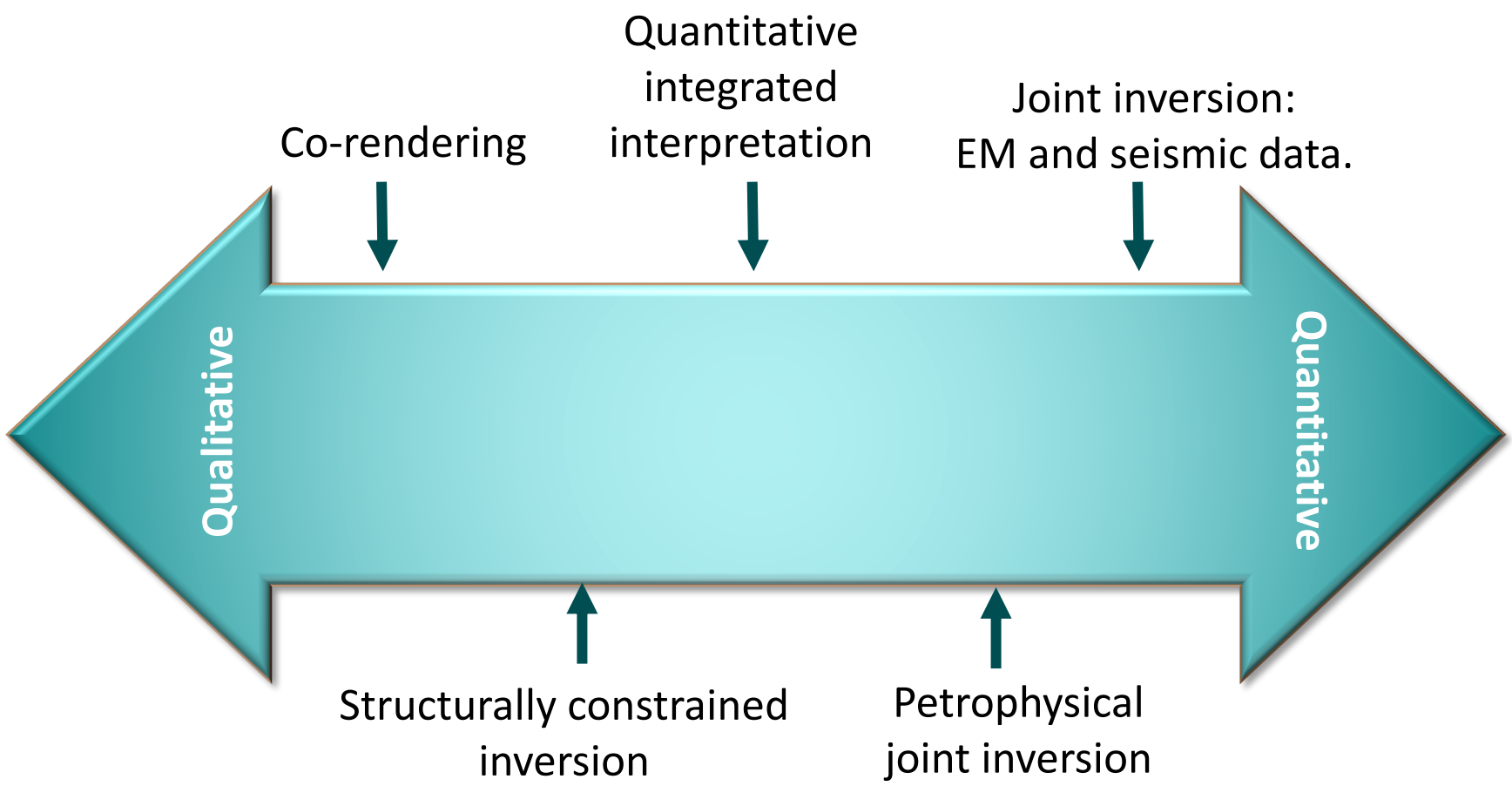
- There must be overlap in sensitivity of the methods applied to the properties within the intervals of interest.



Scale

- Seismic, CSEM and well log data sample the earth at very different scales, which must be reconciled in an integrated interpretation.

Approaches to multi-physics integration



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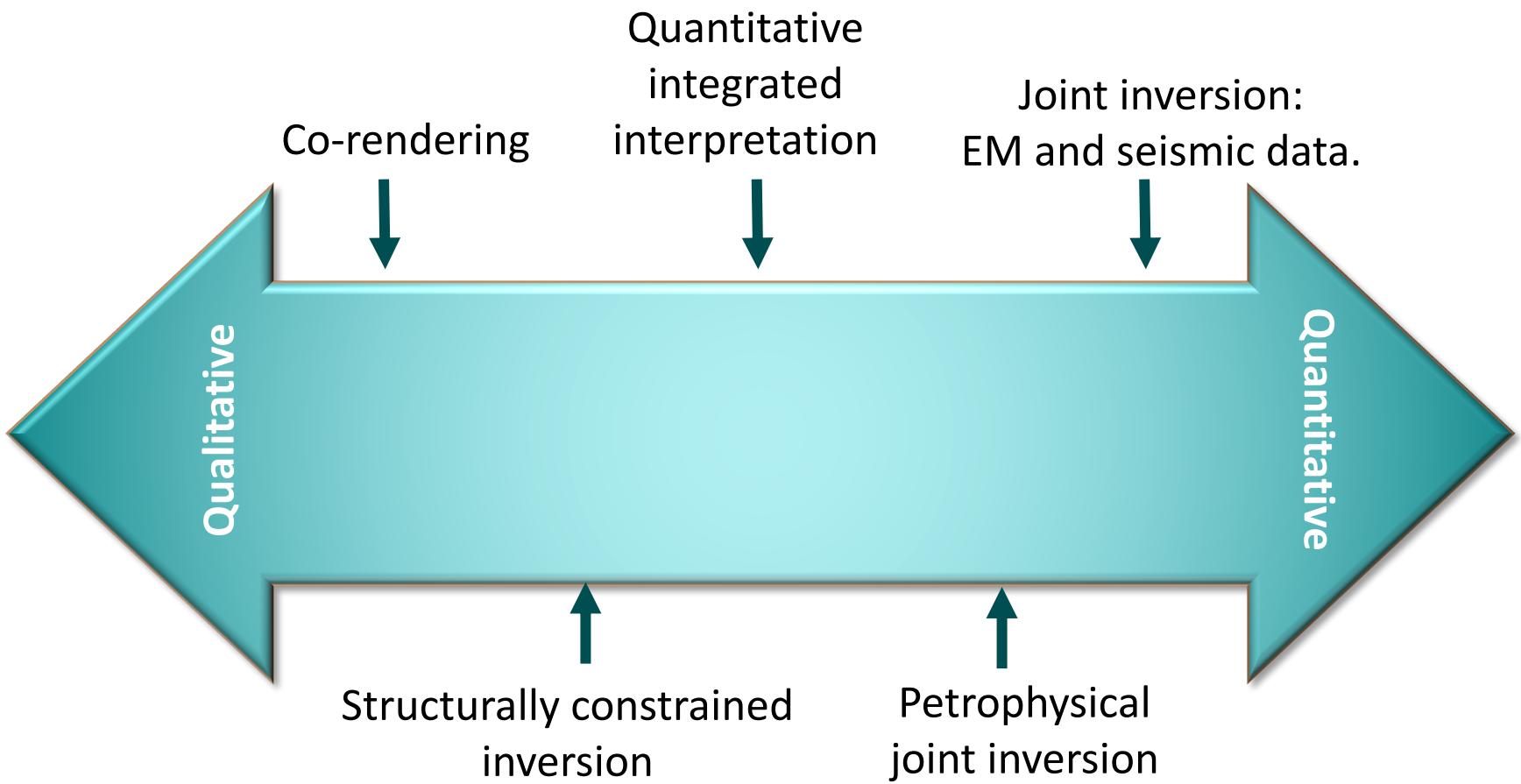

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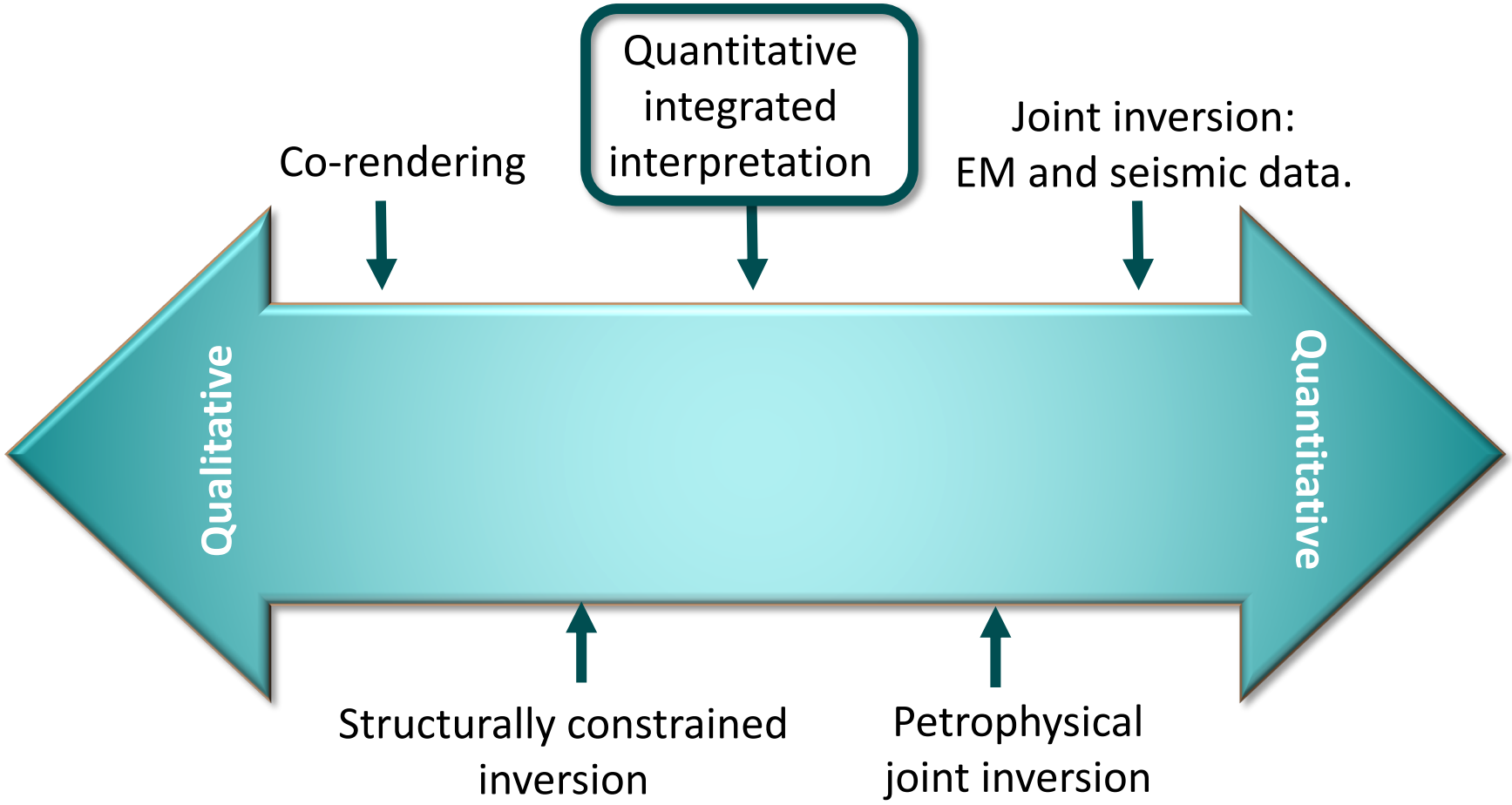
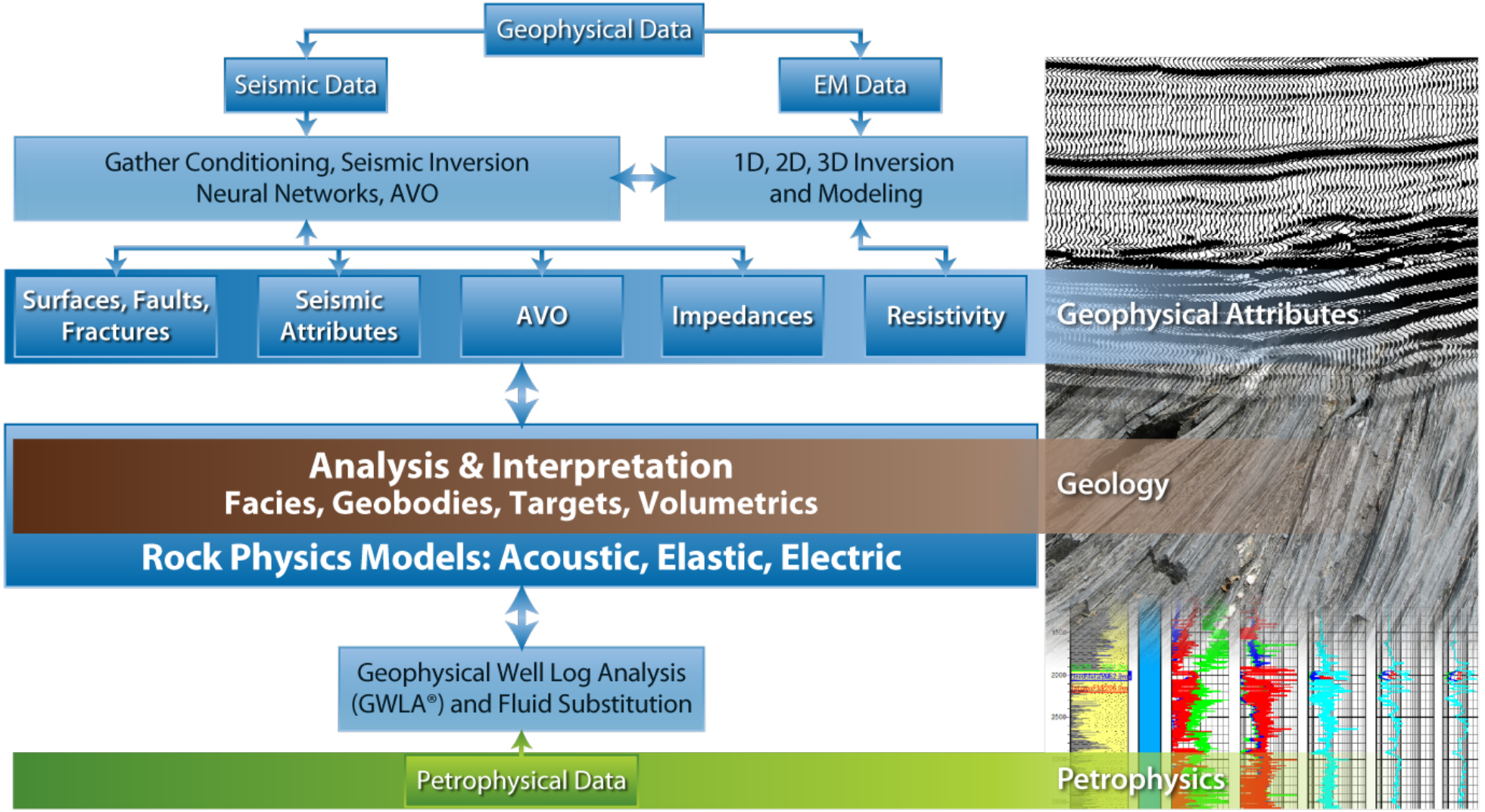
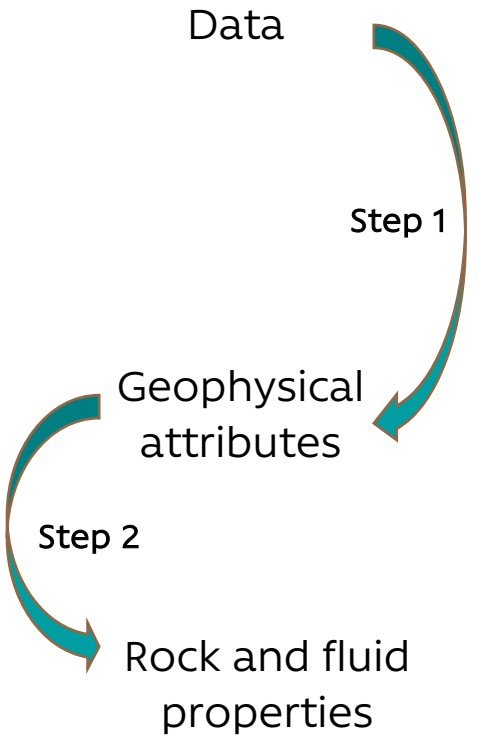
Approaches to multi-physics integration: properties

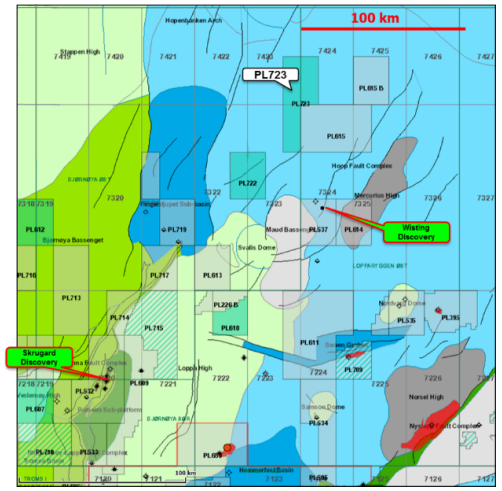


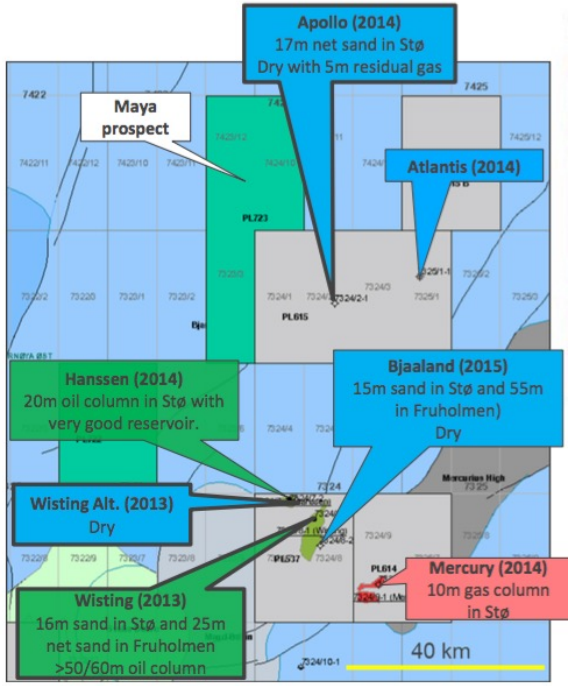
Integrated analysis

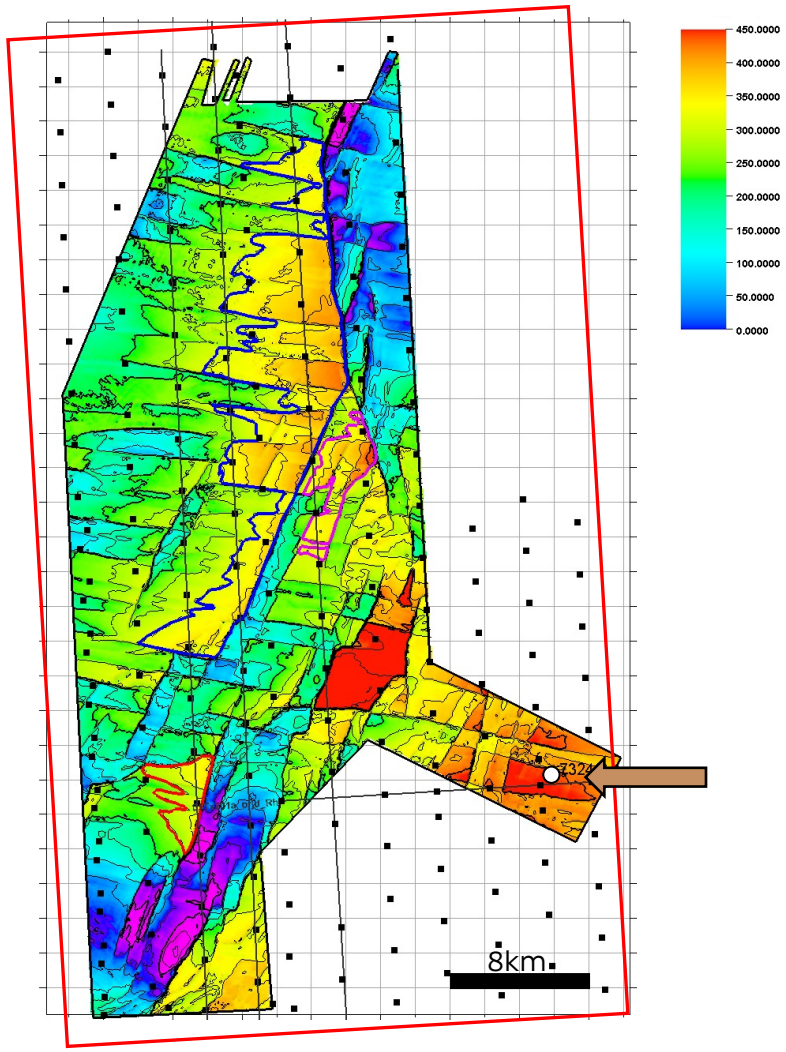




Introduction to the study area







Data available:

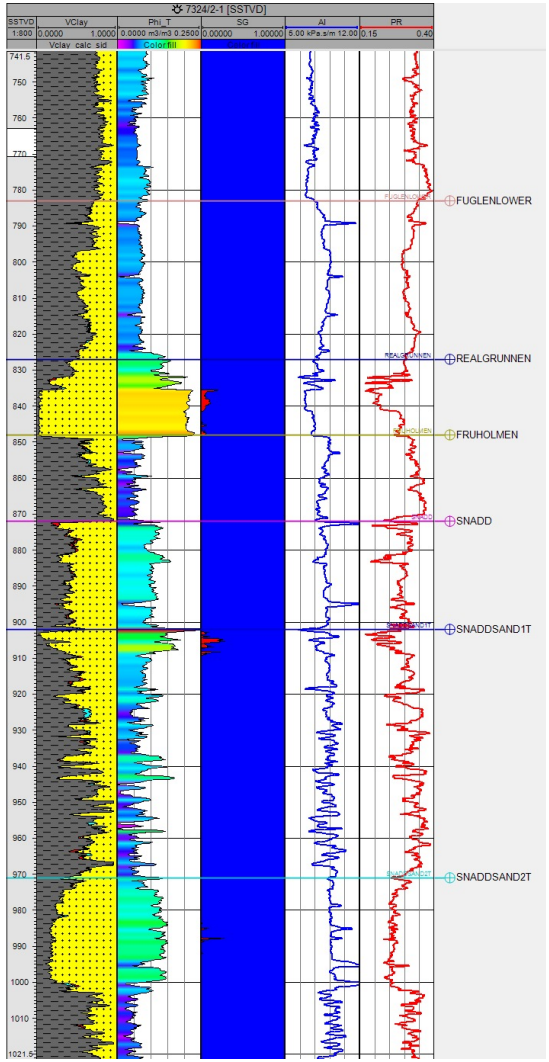
- 936 km^2 3D seismic
- 1912 km^2 nodal CSEM data
- Well: 7324/2-1 (Apollo)

Drill or drop decision: how prospective is the block ?

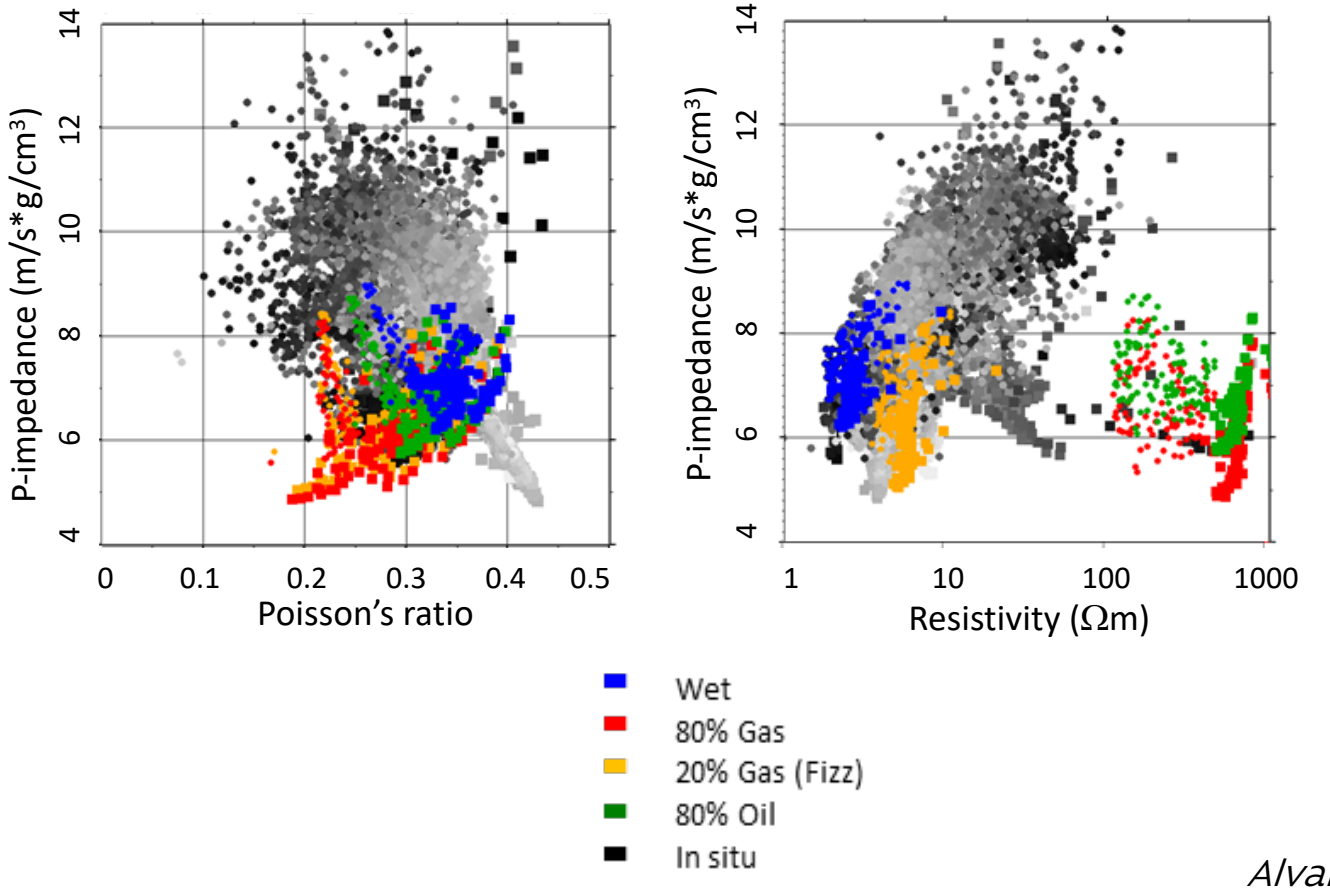
Alvarez et al., 2018

Mixed drilling results: Seismic doesn't have all the answers…

Type Log (Apollo)

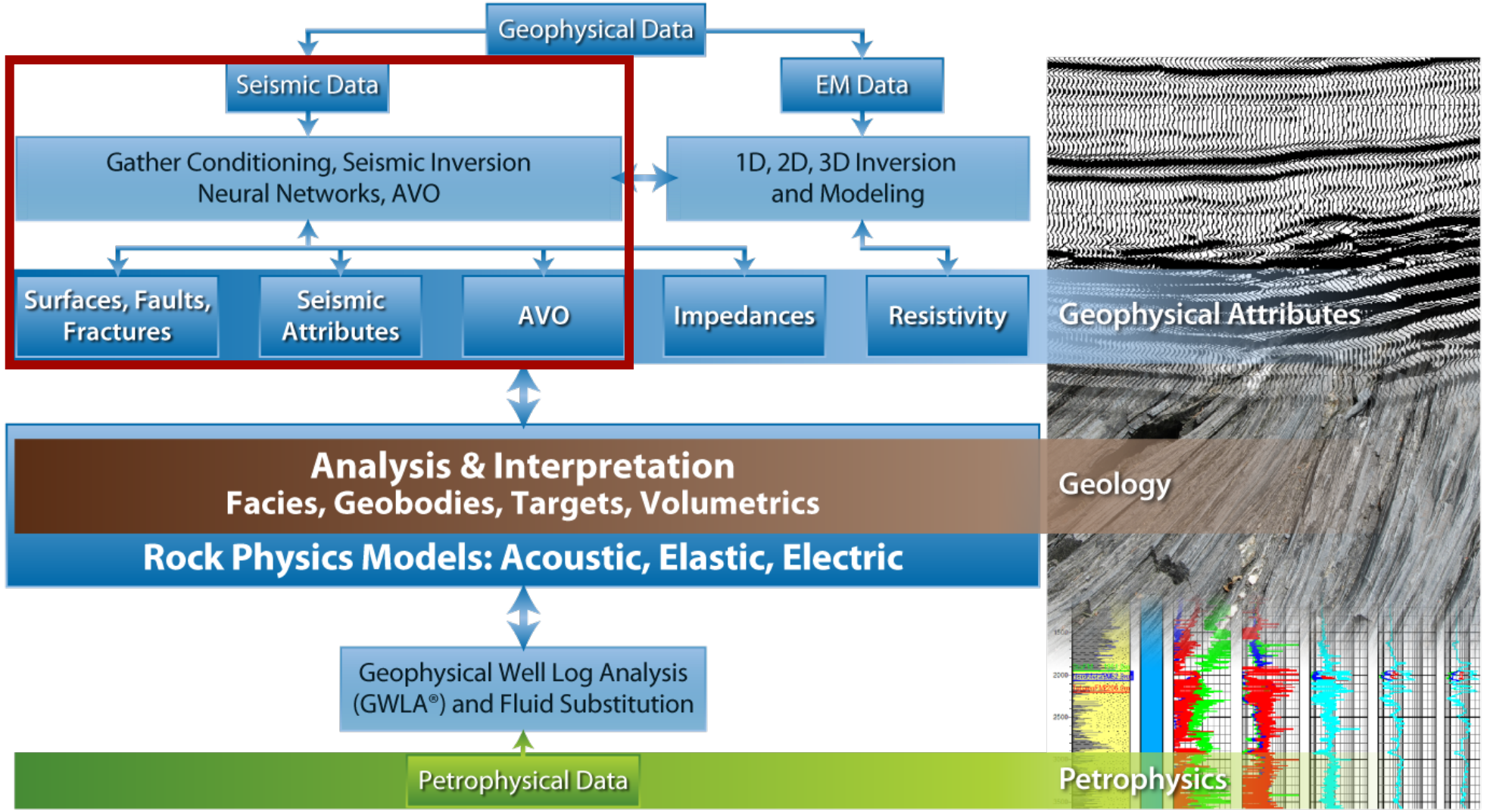


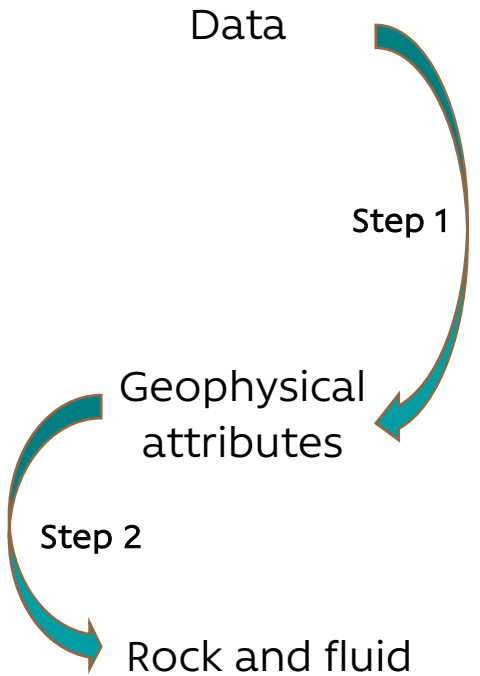
Multi-well cross plots: Stø formation



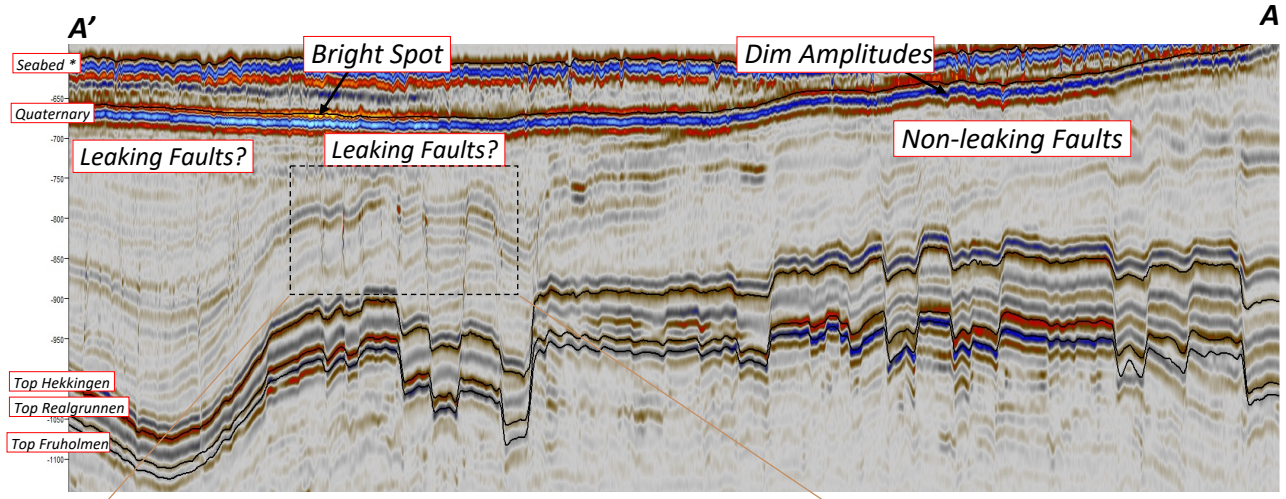
Alvarez et al., 2018

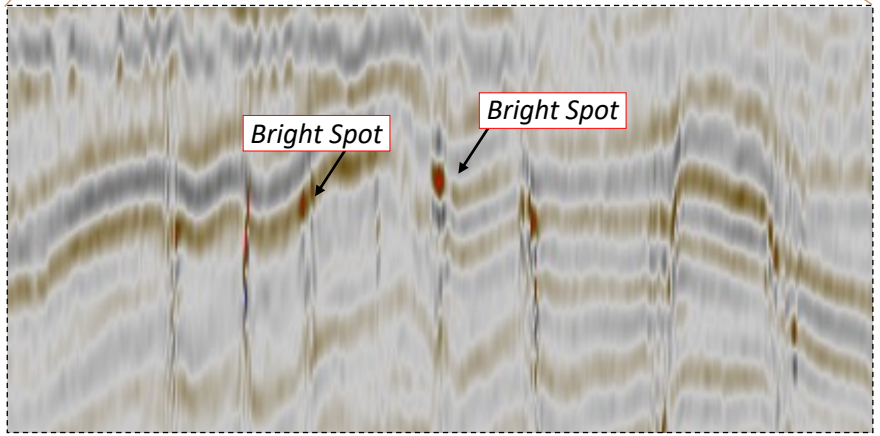
Integrated analysis

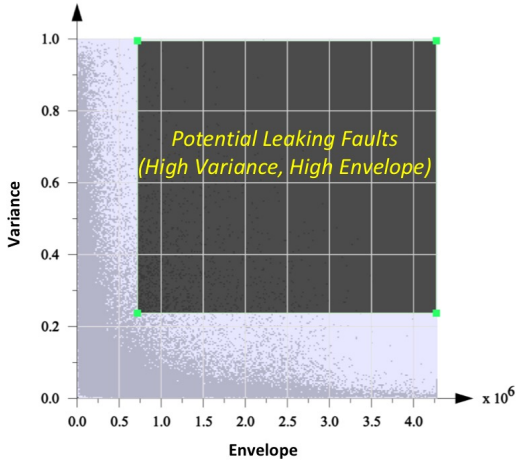




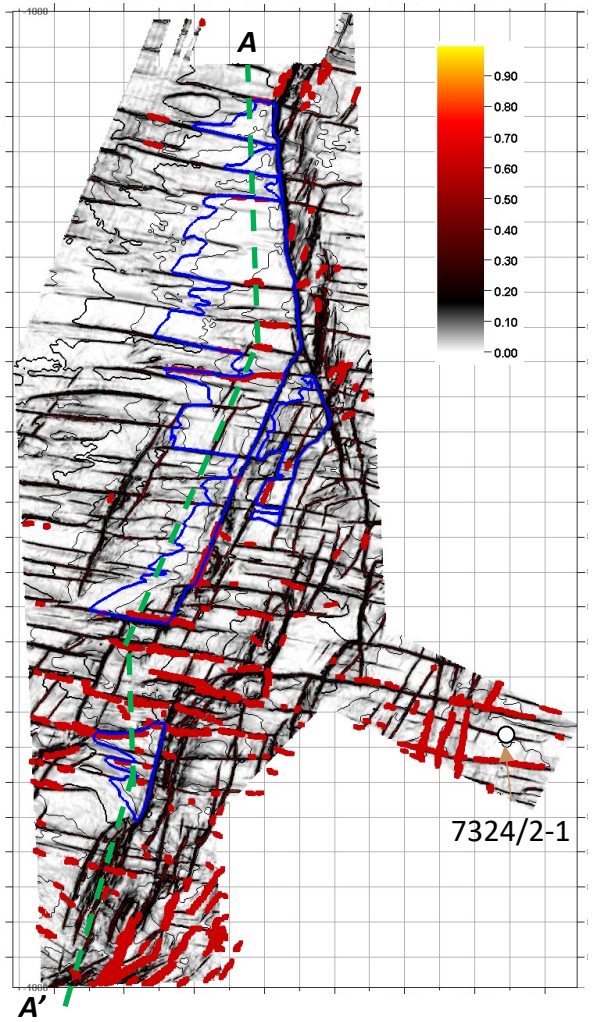
Seismic setting







Variance extraction at top Realgrunnen
Highlighting potential leaking faults

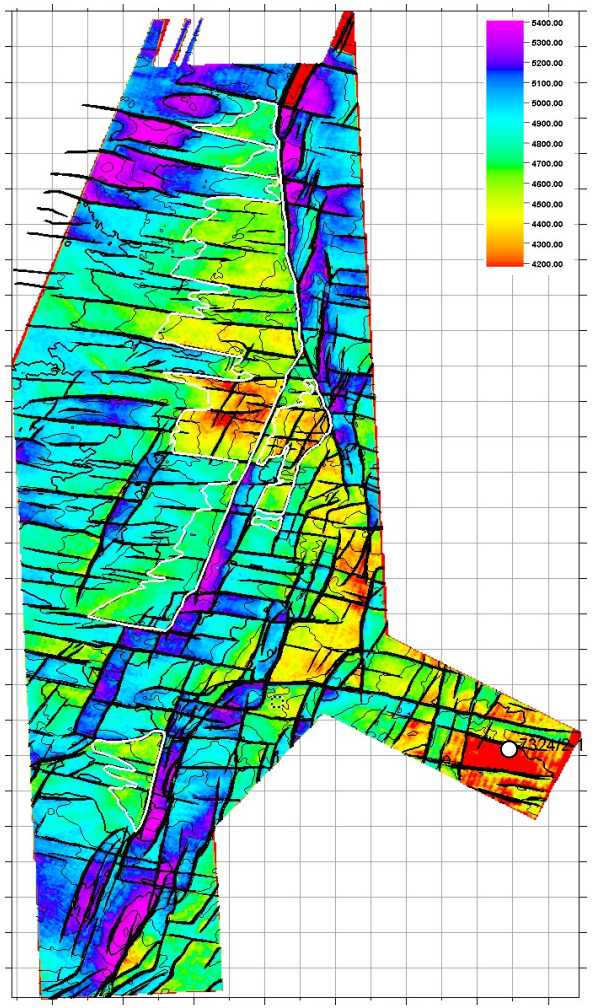


Alvarez et al., 2018

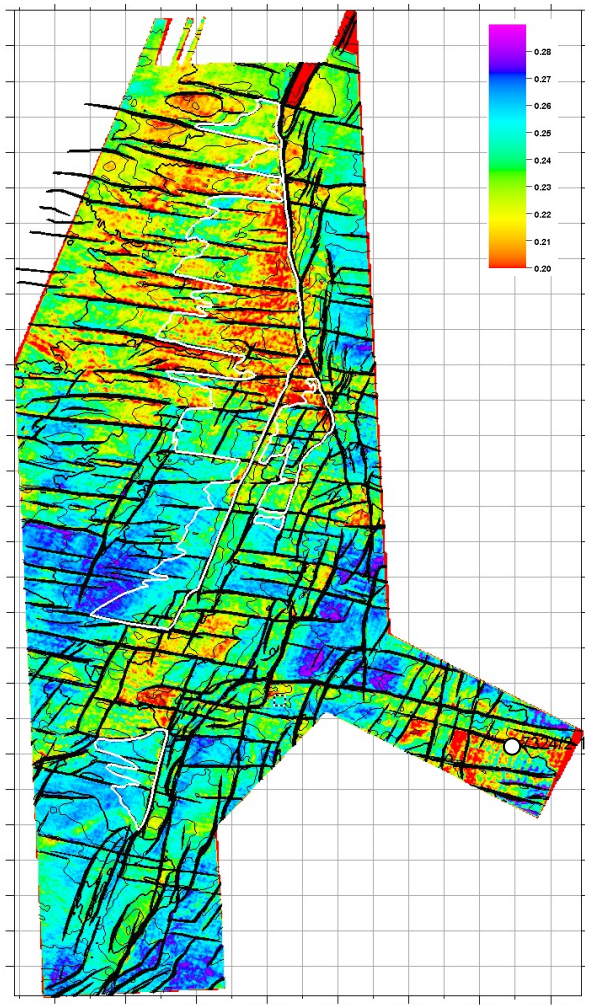
Potential leaking faults

Starting point: Elastic attributes

P-wave Impedance
Minimum Amplitude Top Realgrunnen – Top Fruholmen minus 5 msec



Poisson's ratio
Minimum Amplitude Top Realgrunnen – Top Fruholmen minus 5 msec

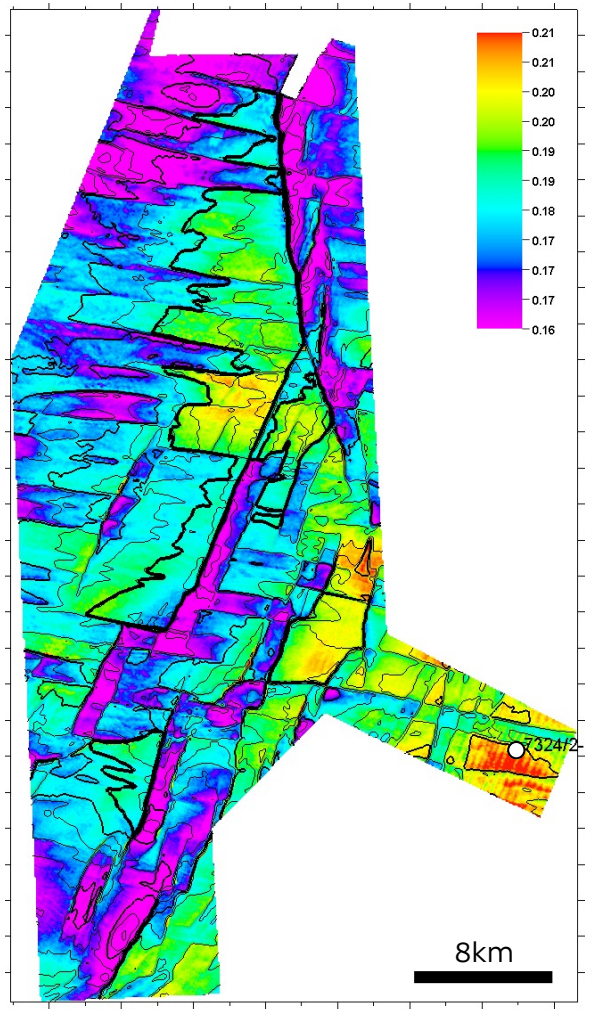


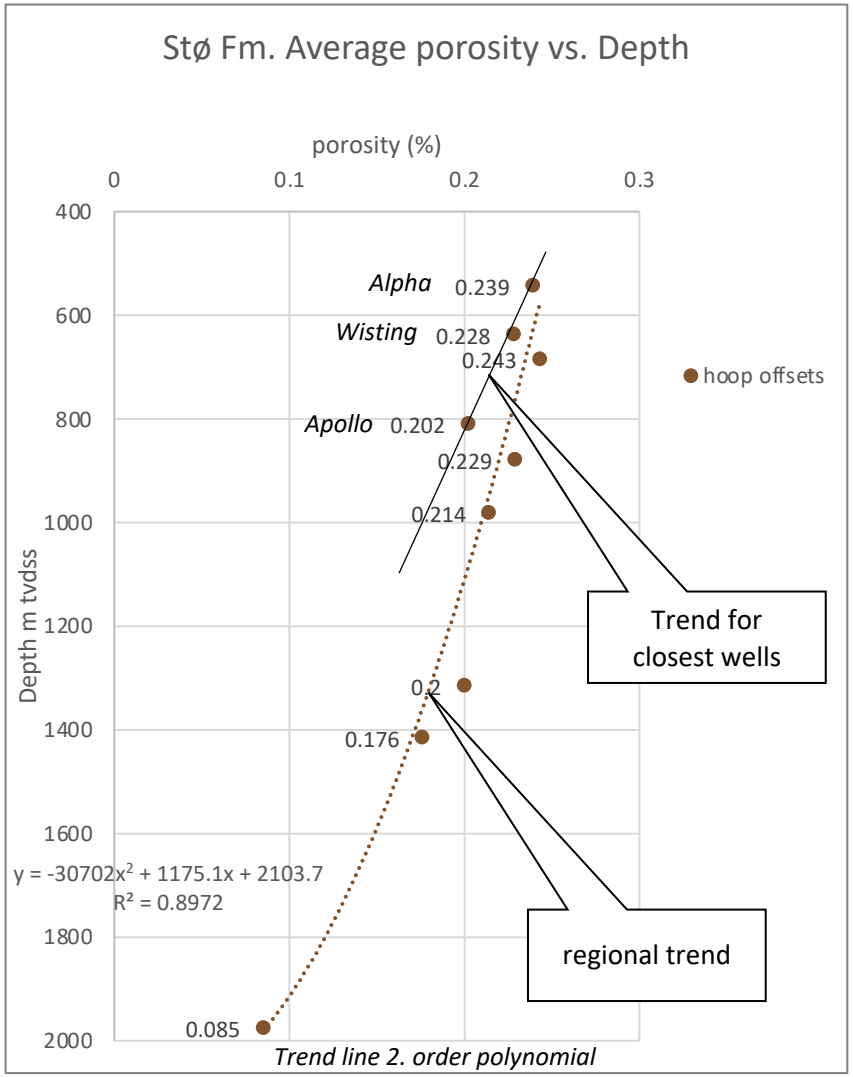
Alvarez et al., 2018

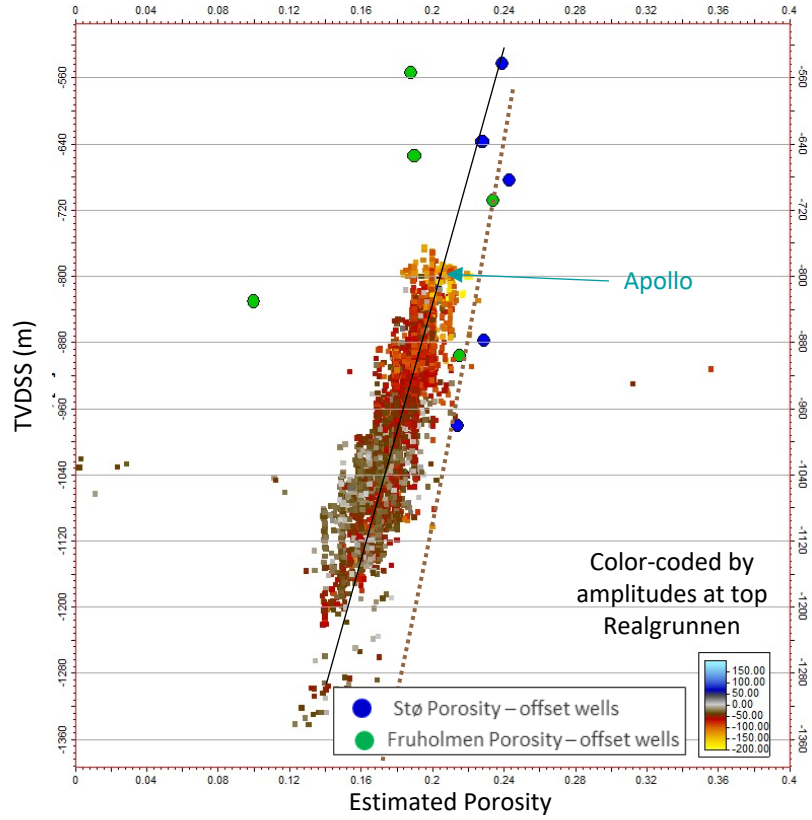
Porosity Estimation

Porosity Map

Arithmetic Average Top Realgrunnen – Top Fruholmen







Alvarez et al., 2018

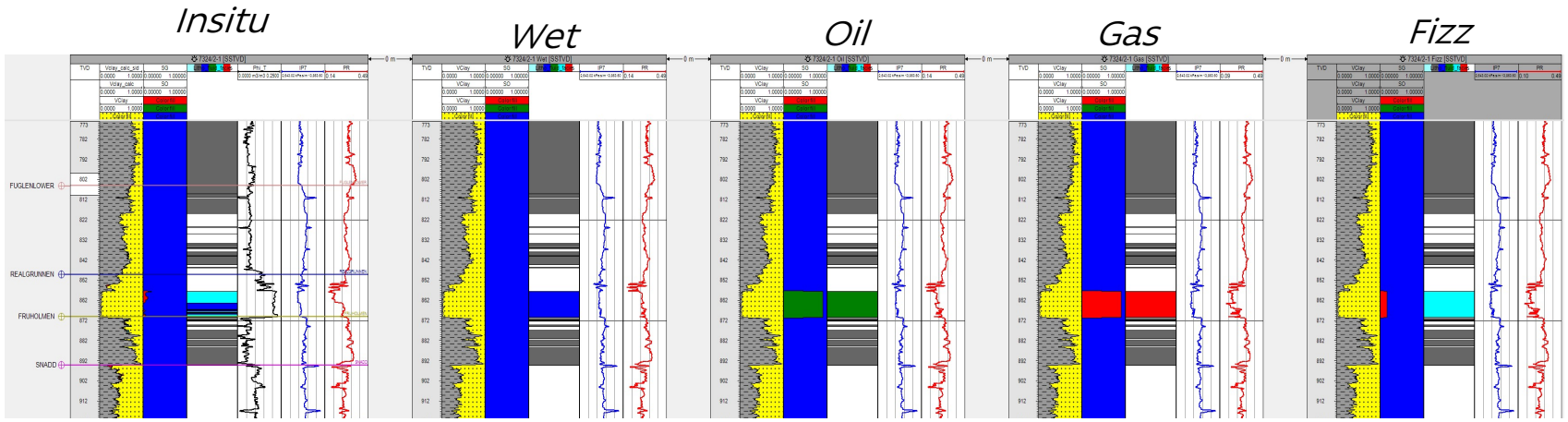
Statistical rock physics: facies definition

Well log analysis and litho-fluid facies definition

2D PDF estimation

Bayesian classification of seismic data.

Apollo Well at different fluid conditions



Litho-fluid facies definition

	Facies	Vclay	Sw	So	Sg
	Shale	>60%	--	--	--
	Wet Sand	<10%	=100%	--	--
	Oil Sand	<10%	<20%	≥80%	--
	Fizz Gas Sand	<10%	>80%	≤1%	≤20%
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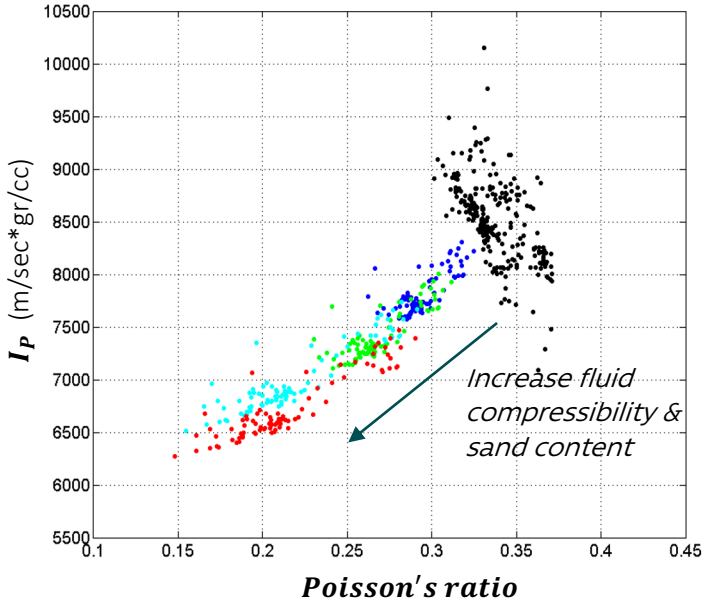

Alvarez et al., 2018

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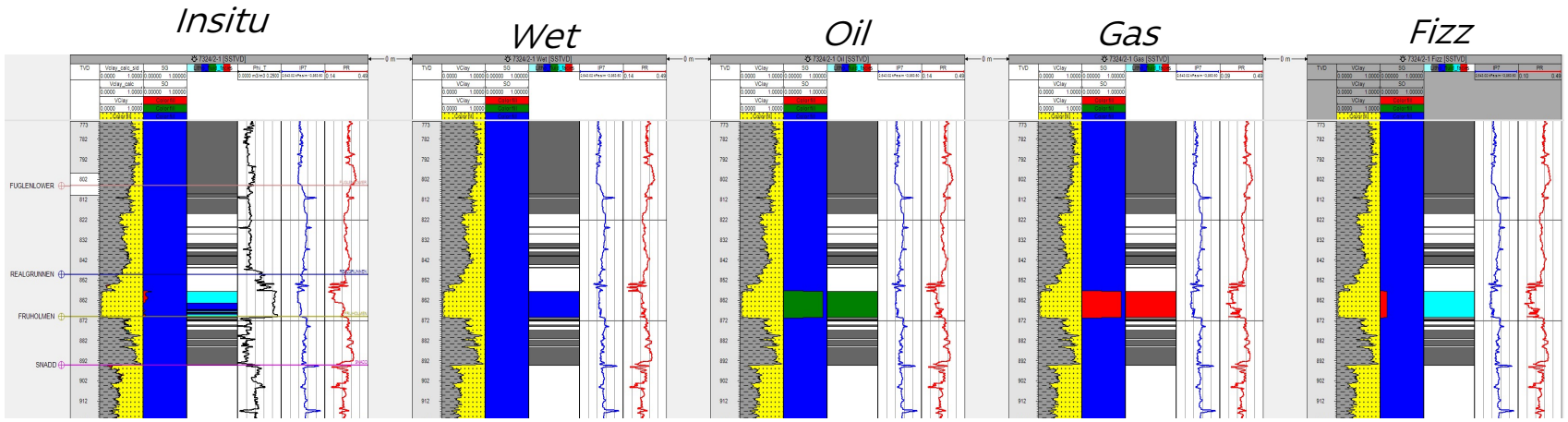

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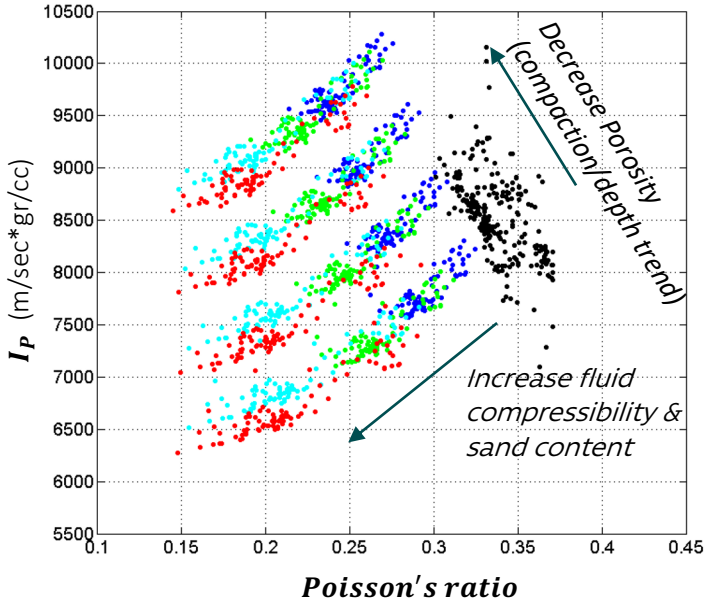
Porosity Scenarios

- (A) *In situ Porosity*
- (B) *In situ Porosity minus 2 %*
- (C) *In situ Porosity minus 4 %*
- (D) *In situ Porosity minus 6 %*



Statistical rock physics:2D PDFs

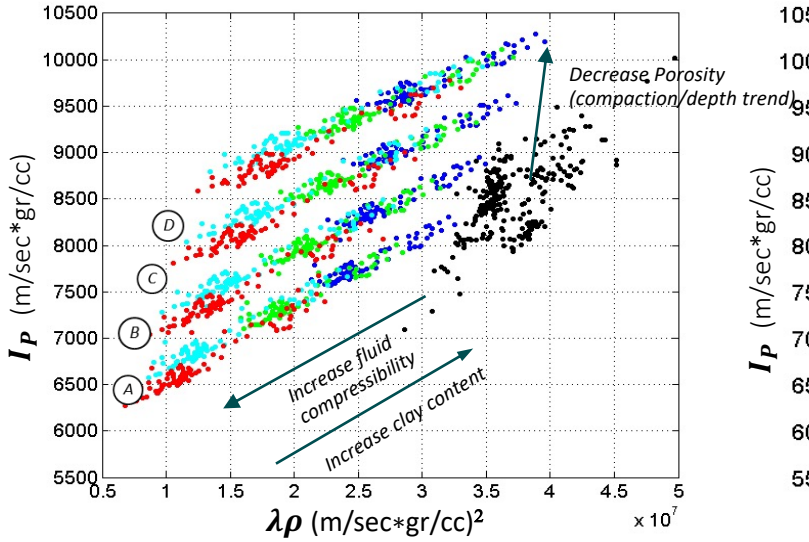
Well log analysis and litho-fluid facies definition

2D PDF estimation

Bayesian classification of seismic data.

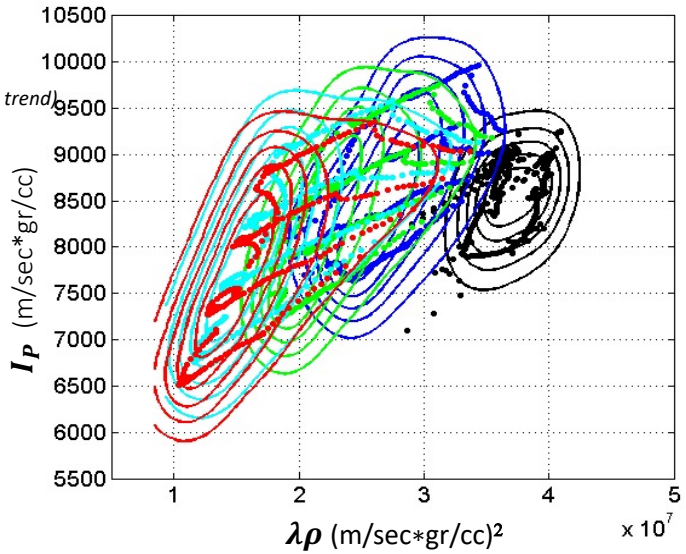
Ip vs $\lambda\rho$ for different Fluid & Porosity Scenarios

Log Resolution



Ip vs $\lambda\rho$: PDFs estimated using upscaled logs through Backus Average

Seismic Resolution



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Alvarez et al., 2018

Statistical rock physics: Bayesian classification

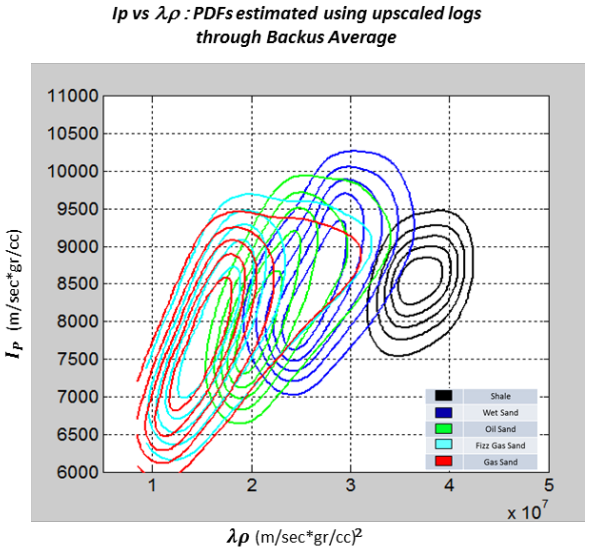
Well log analysis and litho-fluid facies definition

2D PDF estimation

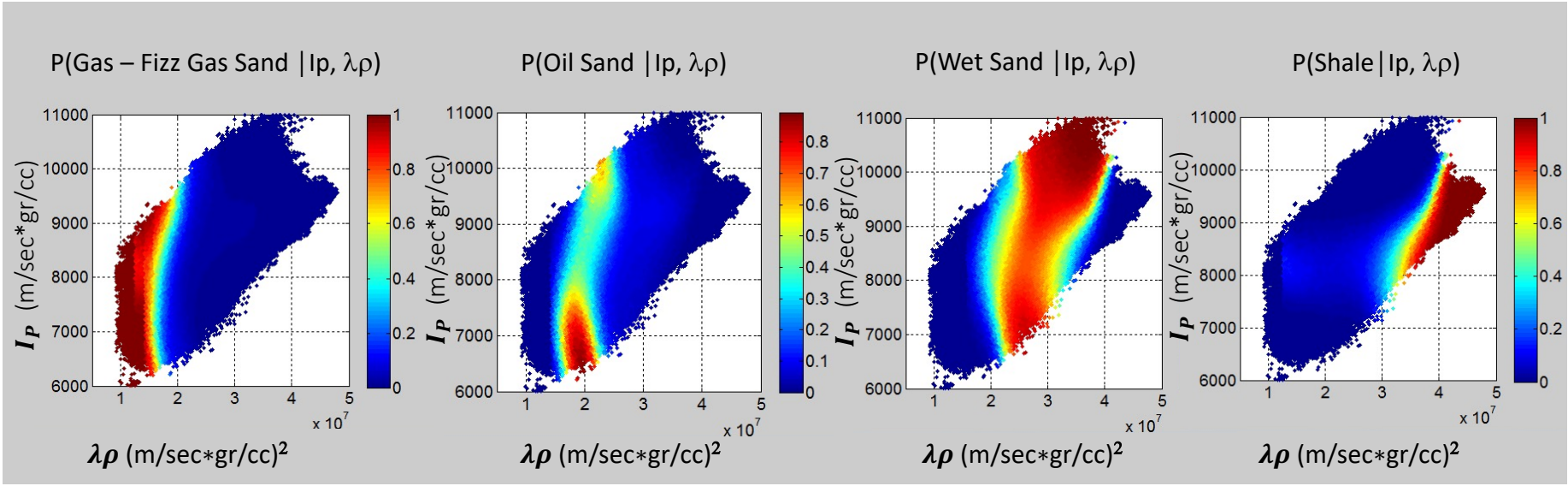
Bayesian classification of seismic data.

$$P(C_j|x) = \frac{P(x|C_j)P(C_j)}{P(x)}$$

- $P(C_j|x)$ ➔ Probability of a particular class (C_j) given an observed x
- $P(x|C_j)$ ➔ Conditional Probability of x given C_j
- $P(C_j)$ ➔ Prior probability of a particular class (C_j)
- $P(x)$ ➔ Describe the distribution of the seismic data point

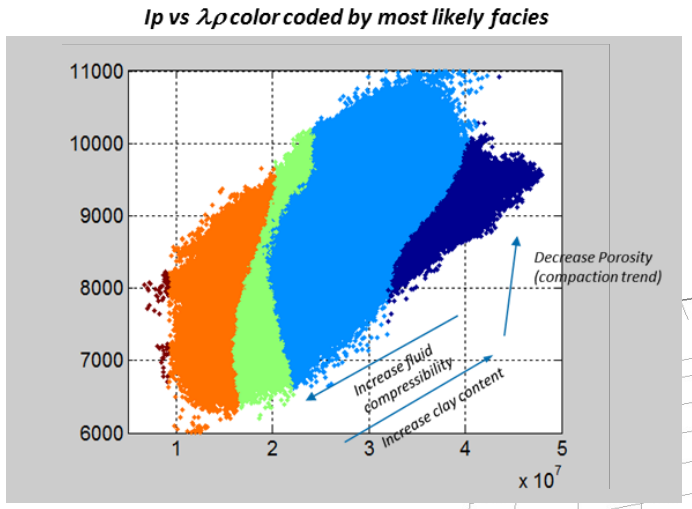


Probability of belonging to each facies

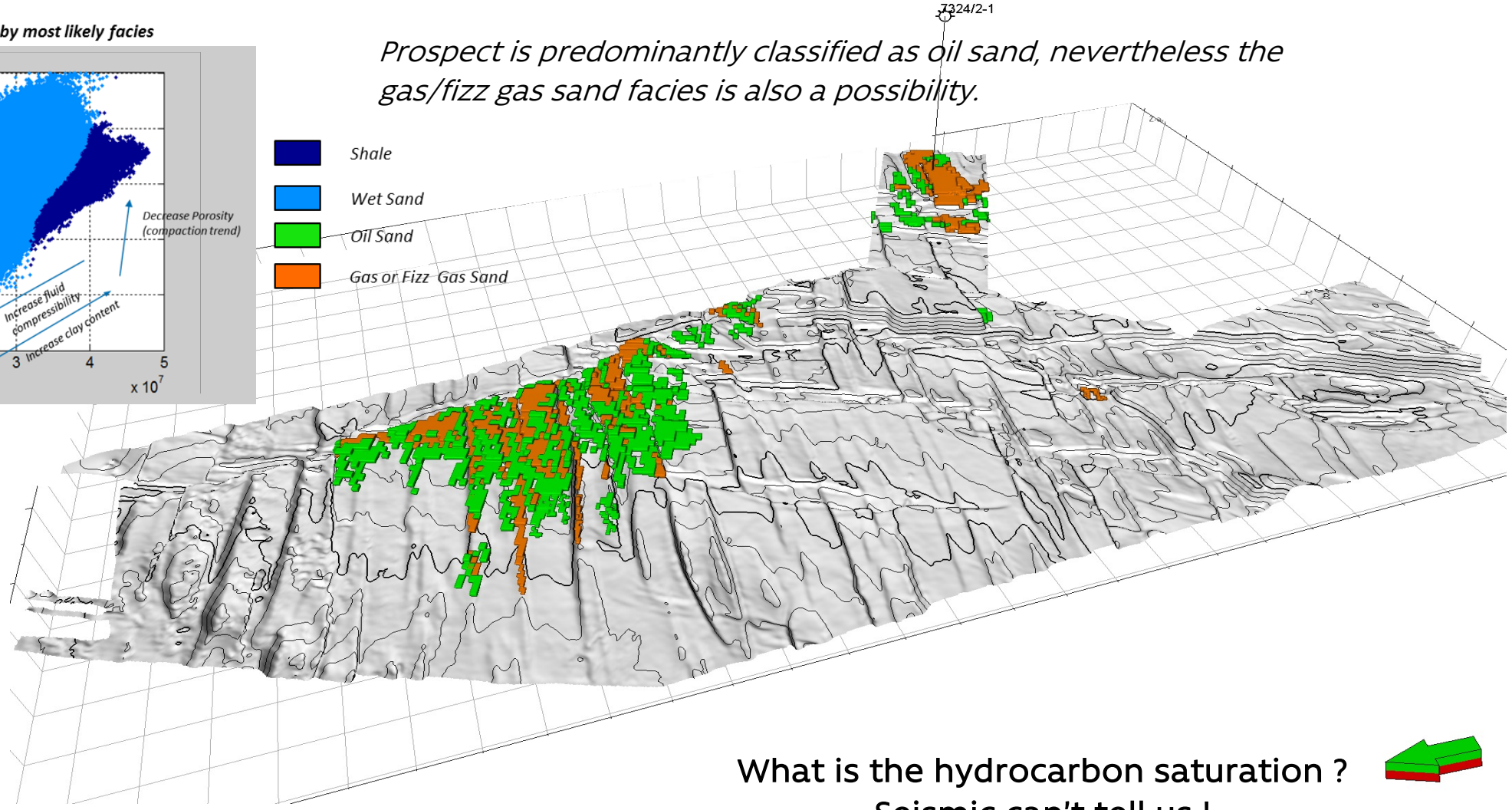


Alvarez et al., 2018

Most likely facies



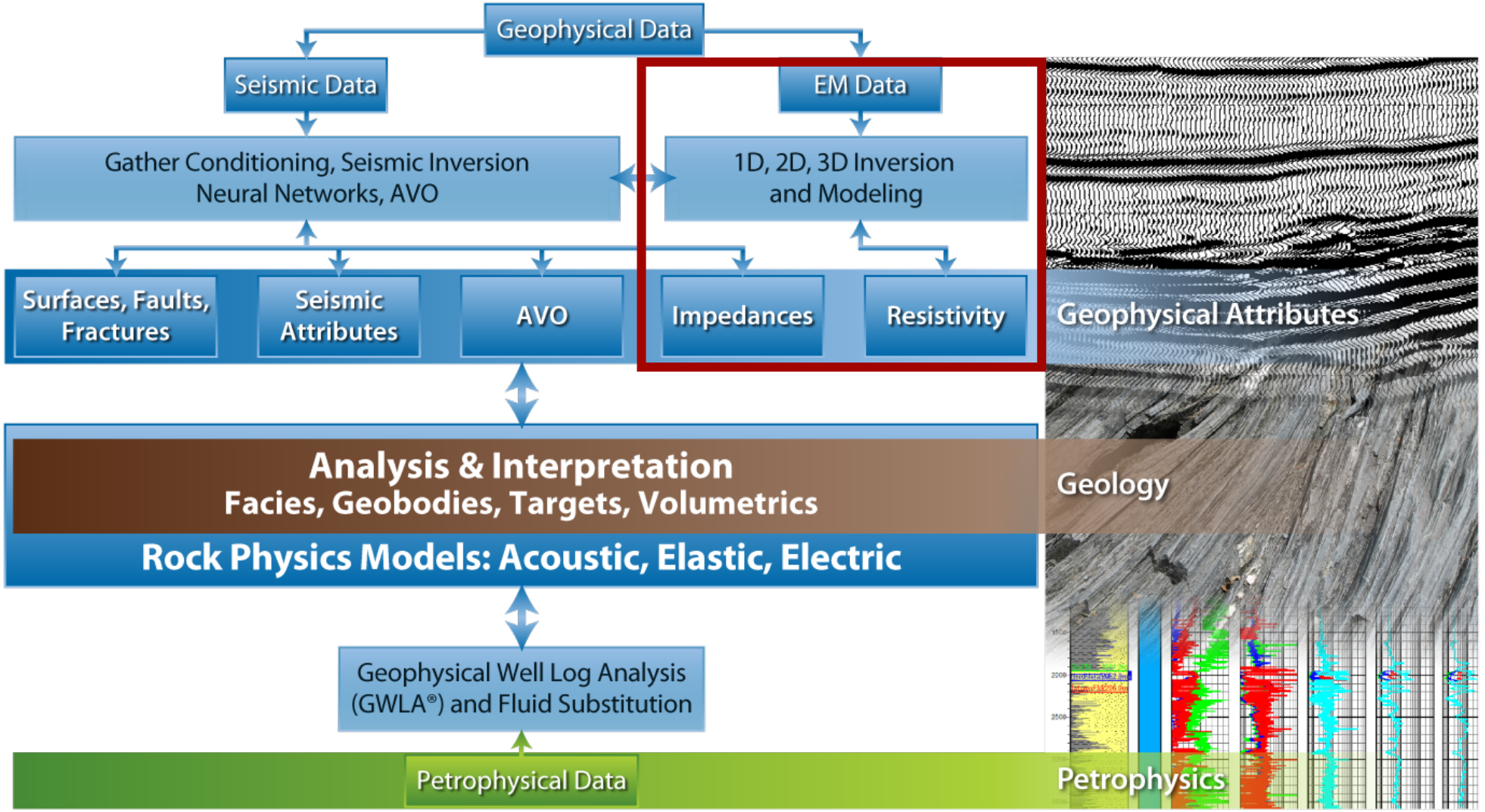
Prospect is predominantly classified as oil sand, nevertheless the gas/fizz gas sand facies is also a possibility.

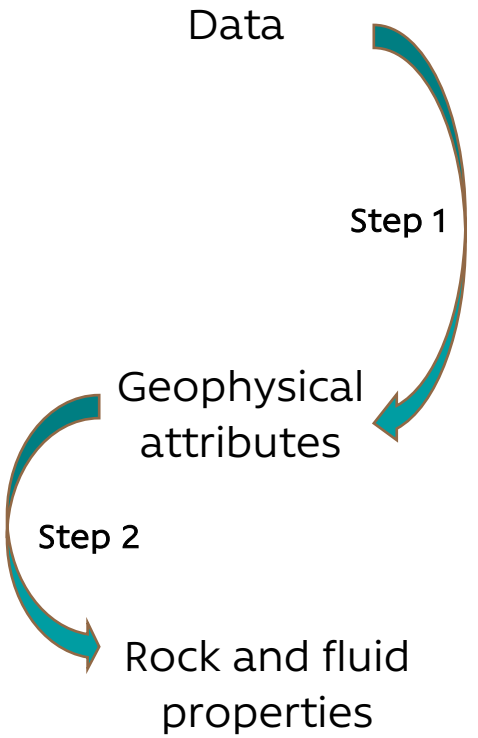


What is the hydrocarbon saturation ?
Seismic can't tell us !

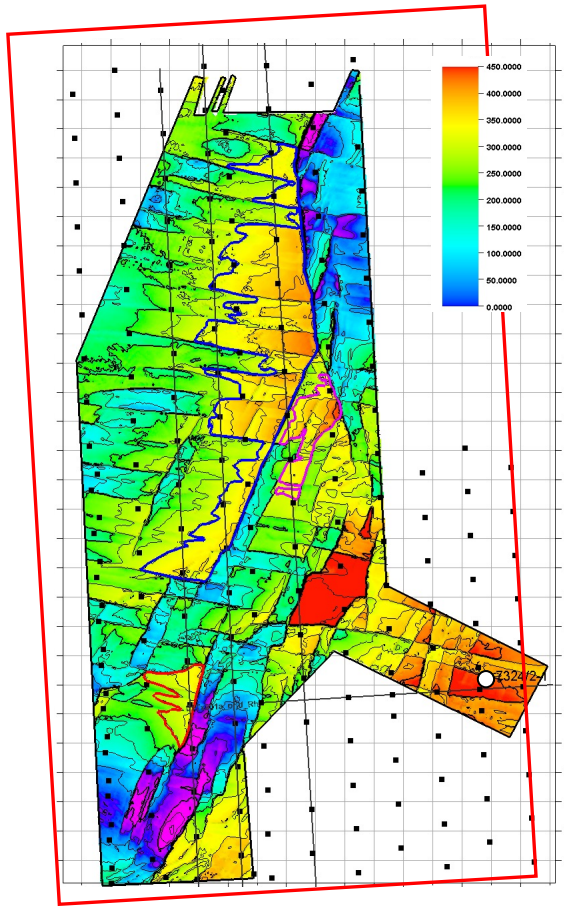
Alvarez et al., 2018

Integrated analysis



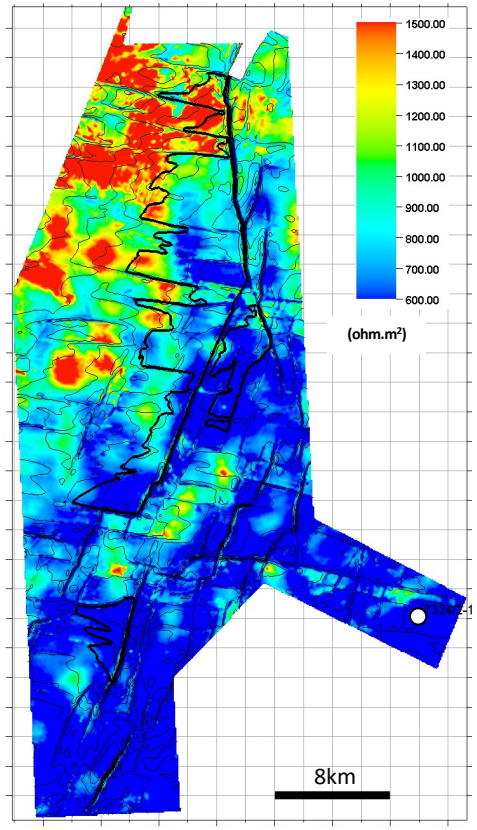


CSEM derived transverse resistance



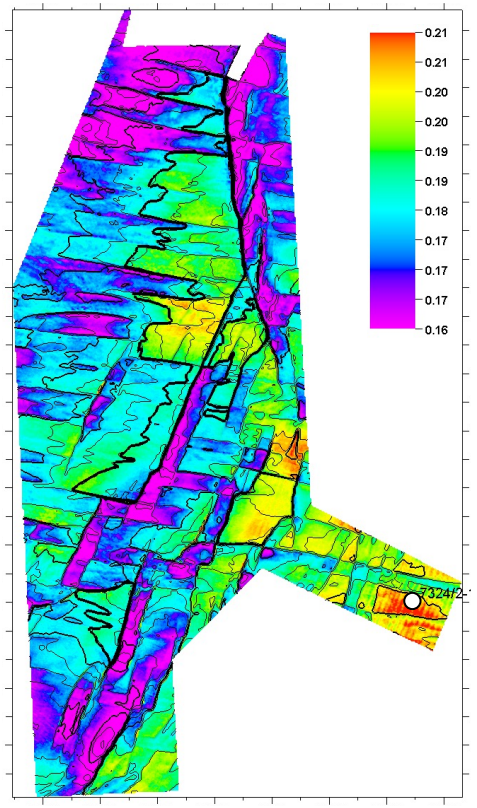
Transverse Resistance from CSEM

*TR=Average resistivity * thickness In depth from seismic*



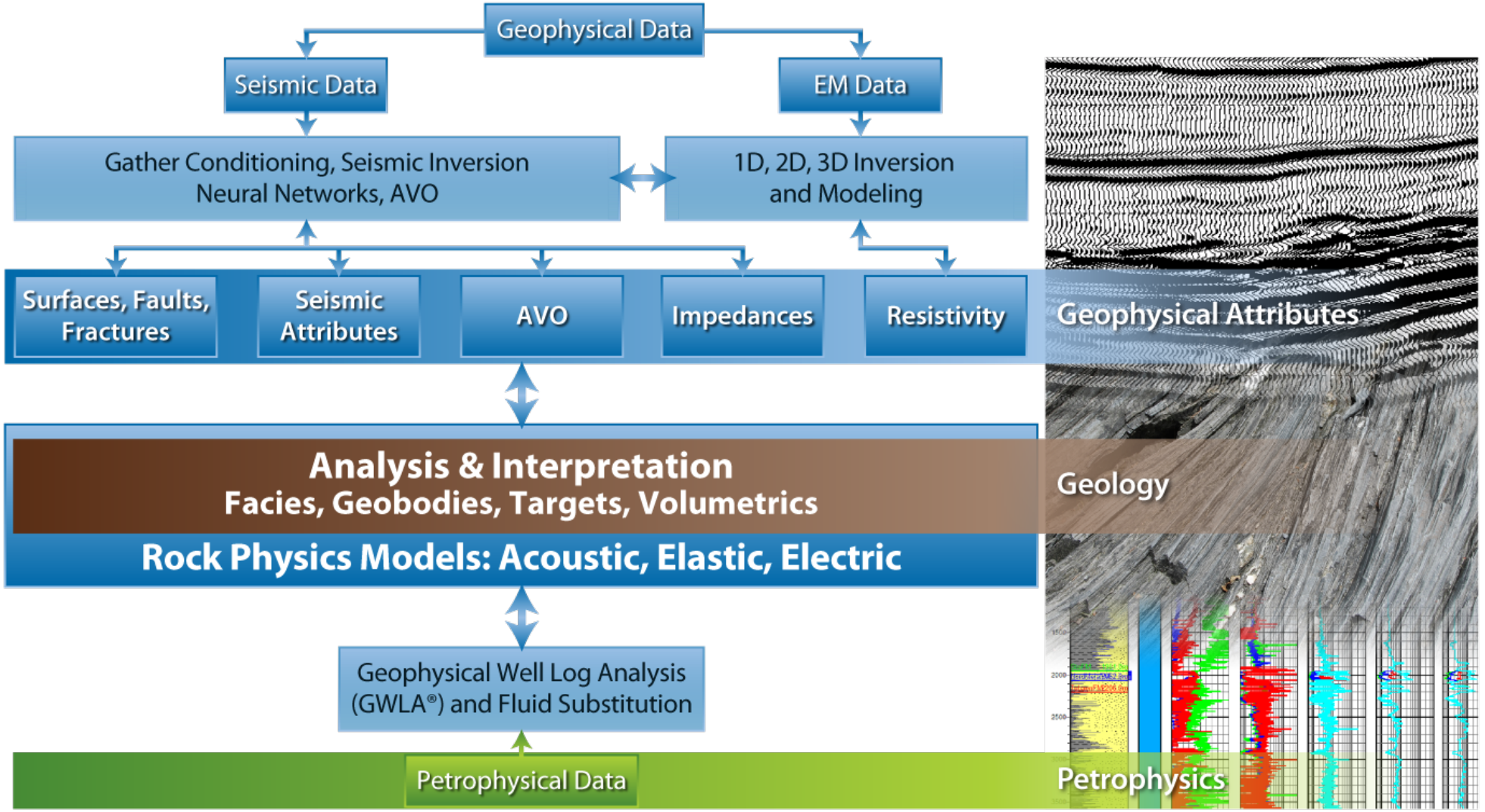
Porosity Map

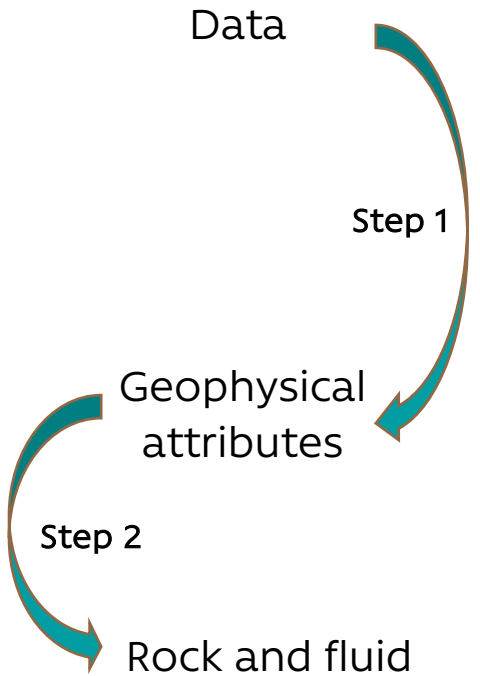
Arithmetic Average Top Realgrunnen – Top Fruholmen



Alvarez et al., 2018

Putting it together



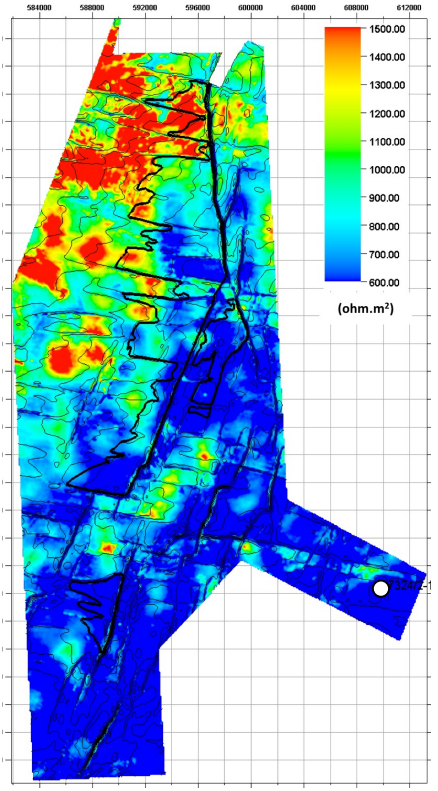


Scaled TR from CSEM and Seismic

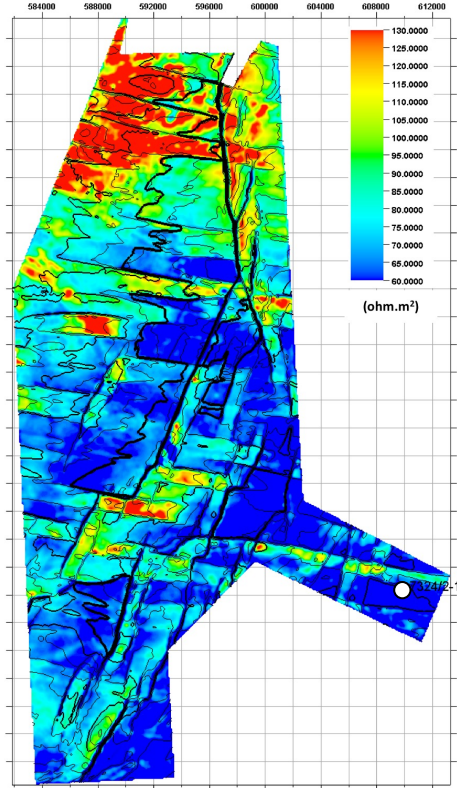
Simandoux relationship:

$$\frac{1}{\rho_b} = \frac{\phi^m S_w^n}{a\rho_w} + \frac{V_{cl}}{\rho_{cl}}$$

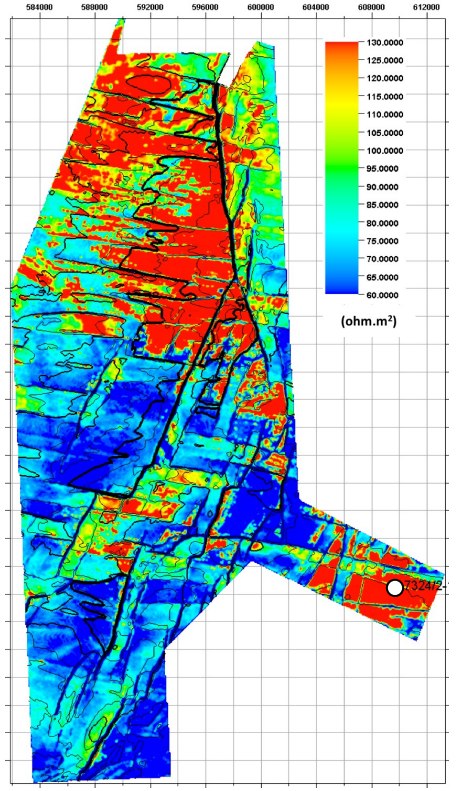
CSEM derived



Seismic derived
Sw=100%



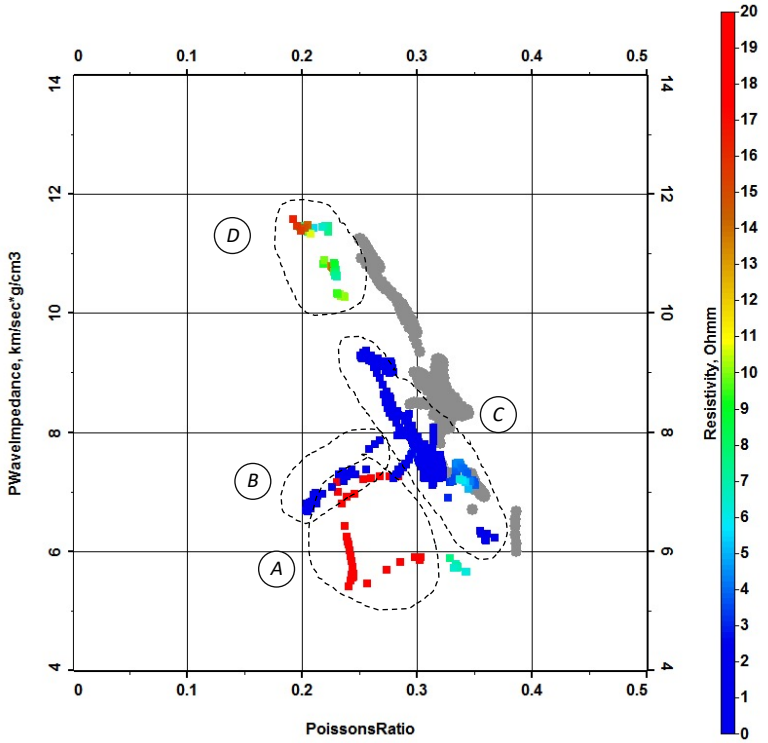
Seismic derived
Sw=40%

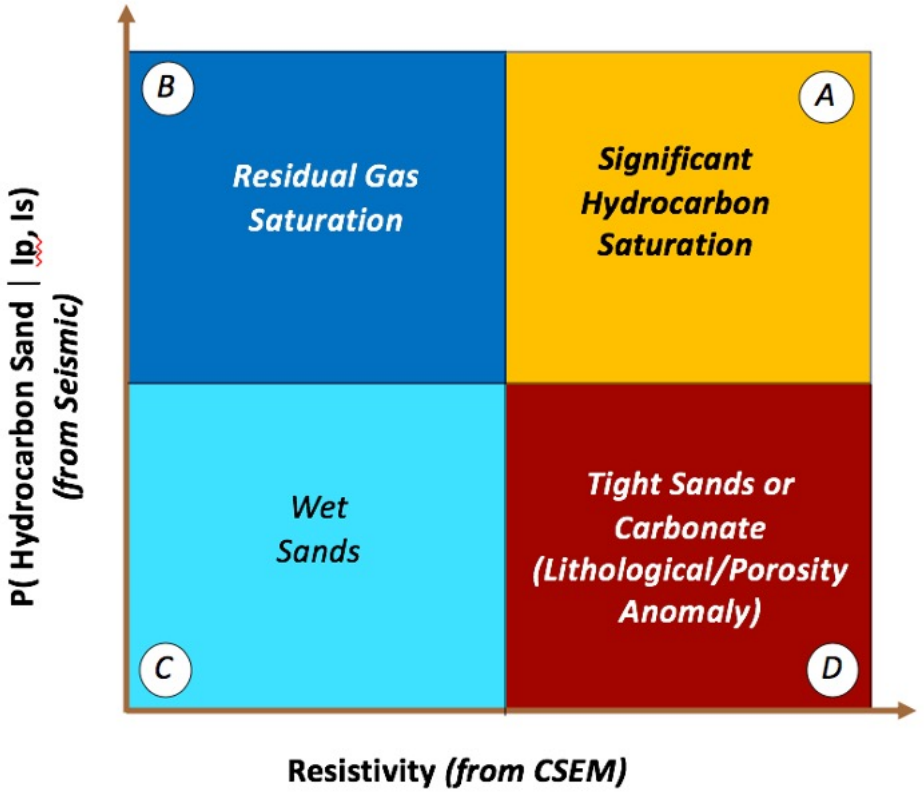


- Transverse resistance is scaled to account for anisotropy and resolution differences.
- Lithology driven variations in resistivity are clear
- CSEM results are more consistent with the water wet case than the 60% hydrocarbon saturated case.

Litho-fluid facies from Seismic & CSEM

Multi-well crossplot from offset wells





A *Commercial Hydrocarbon Saturation*

B *Residual Gas Saturation*

High P(Hydrocarbon Sand | Ip, Is)

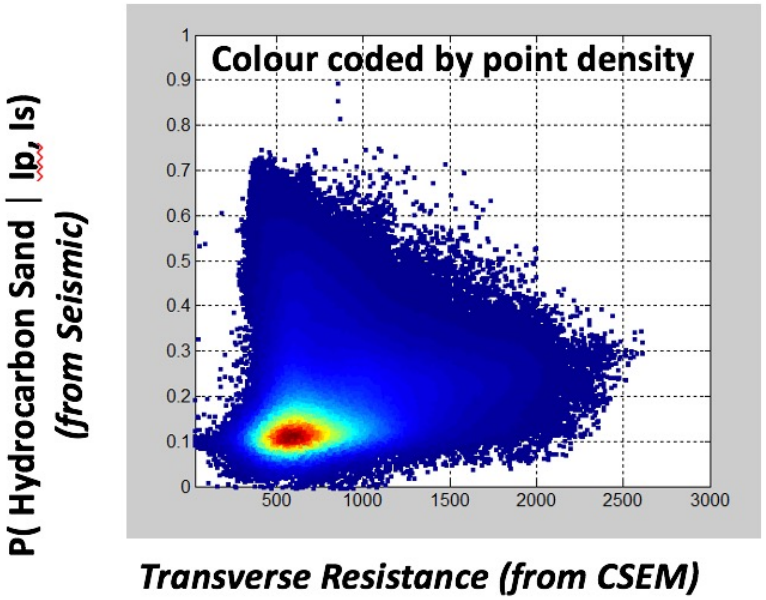
C *Wet Sands*

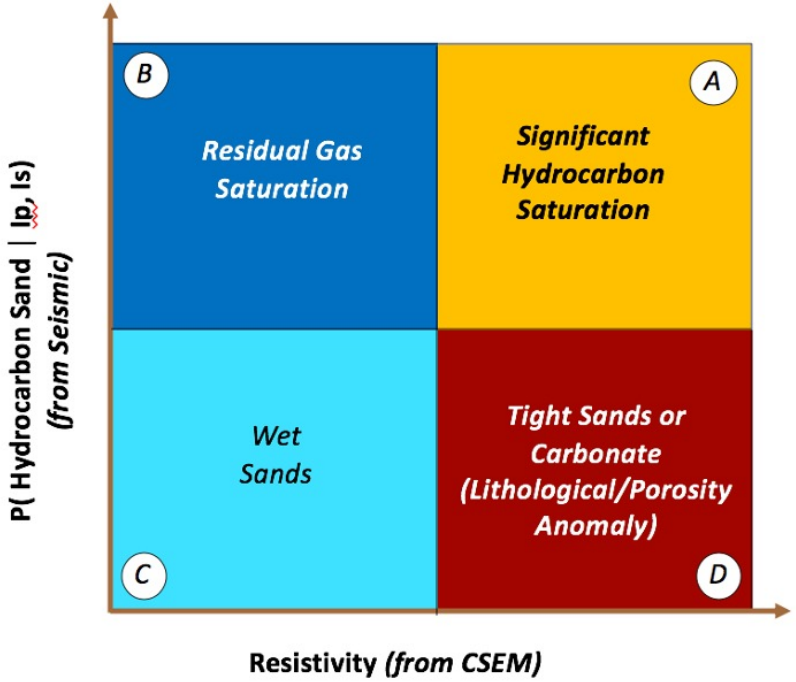
D *Carbonate*

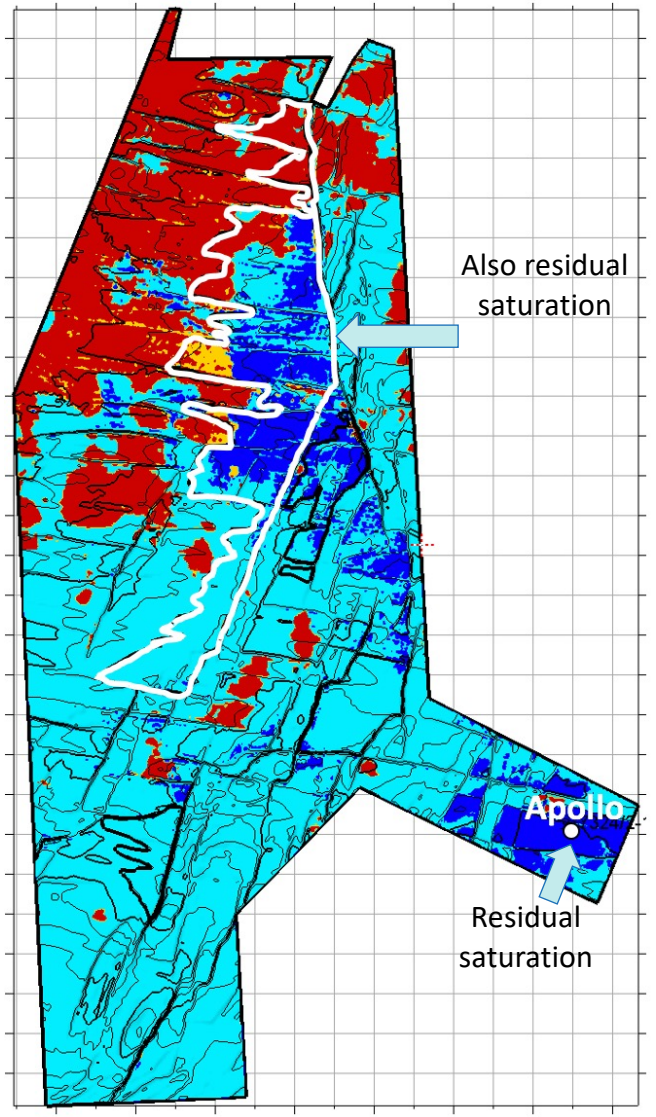
Low P(Hydrocarbon Sand | Ip, Is)

Alvarez et al., 2018

Litho-fluid facies from Seismic & CSEM

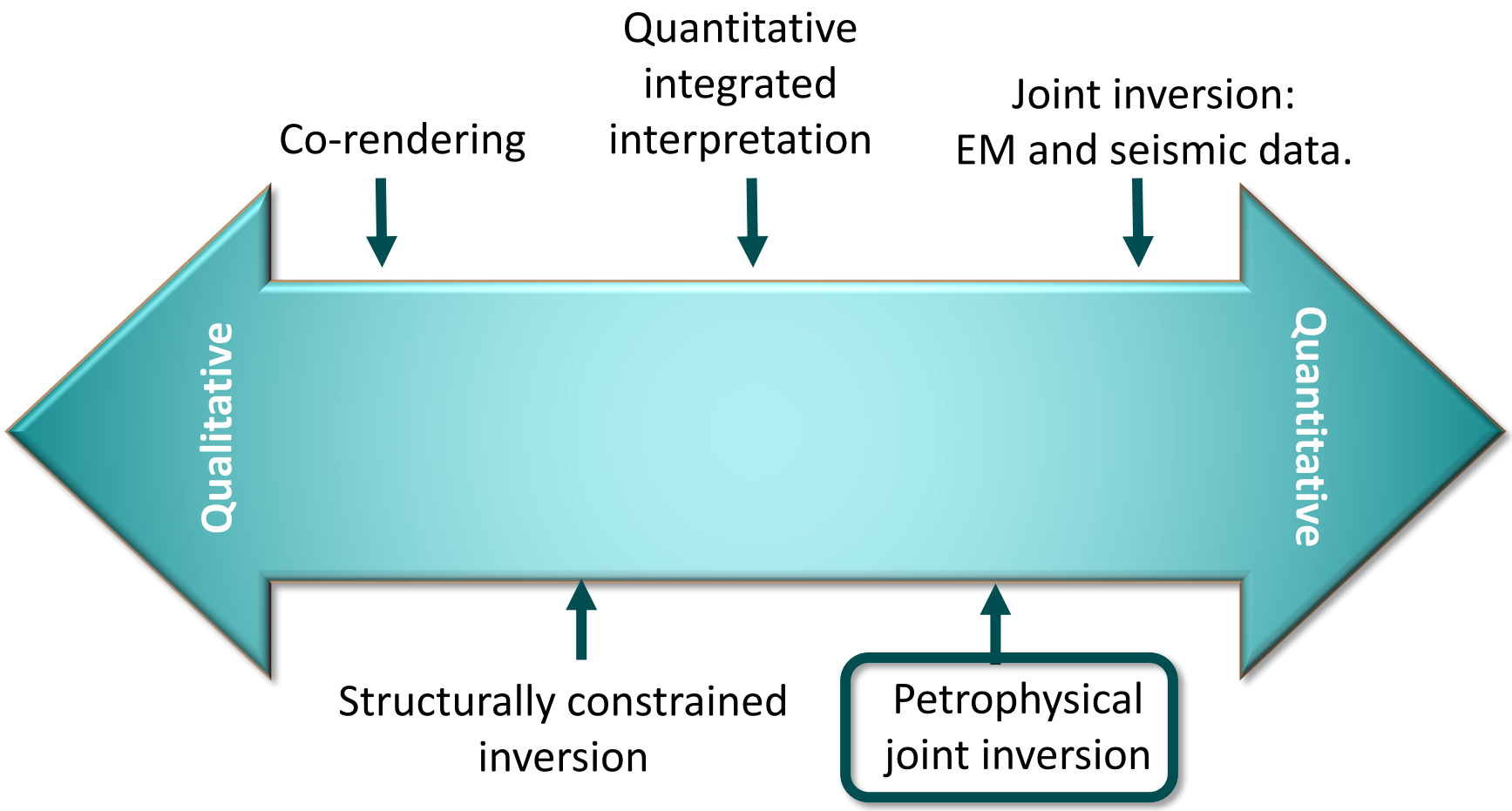






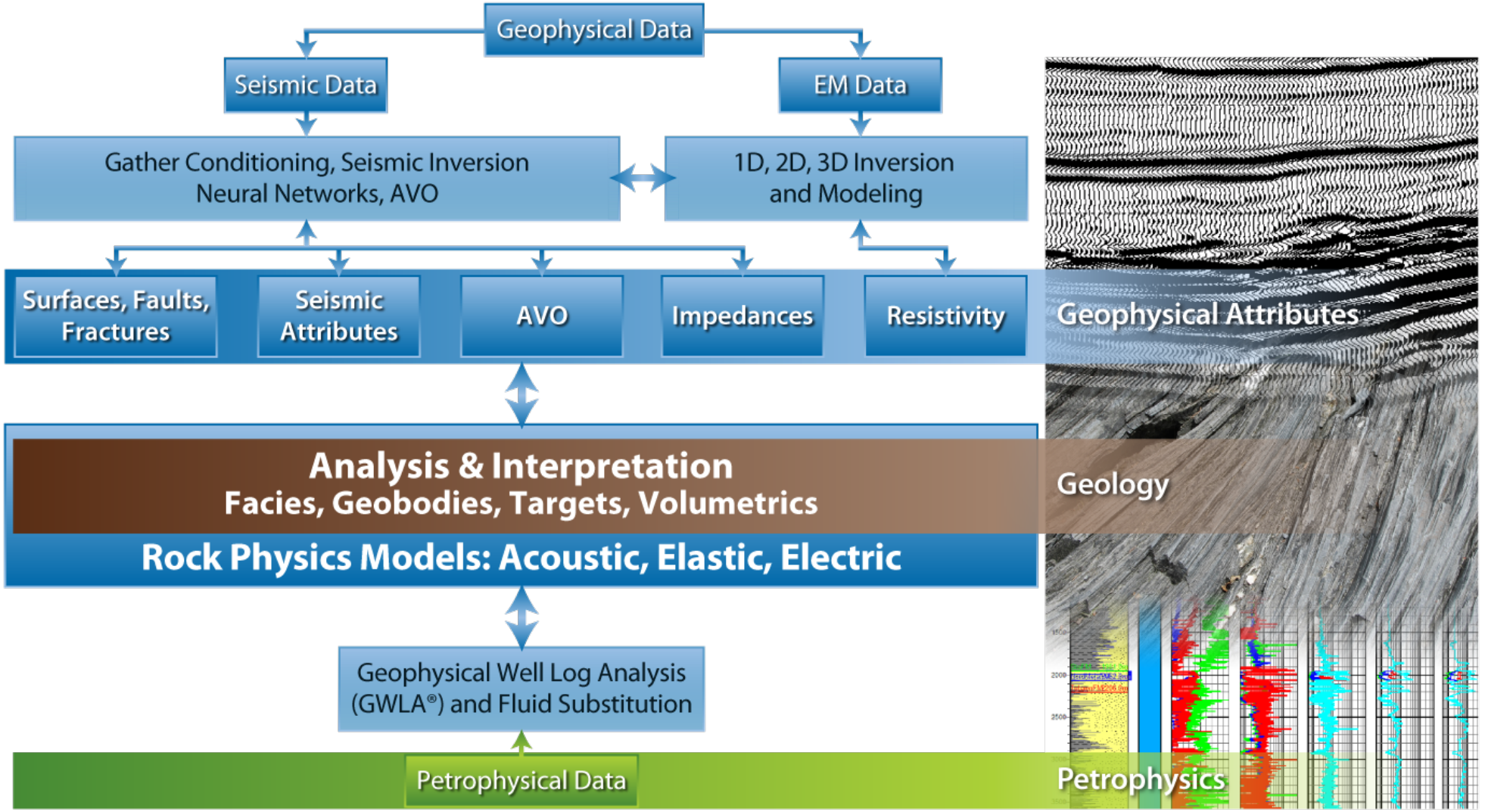
Alvarez et al., 2018

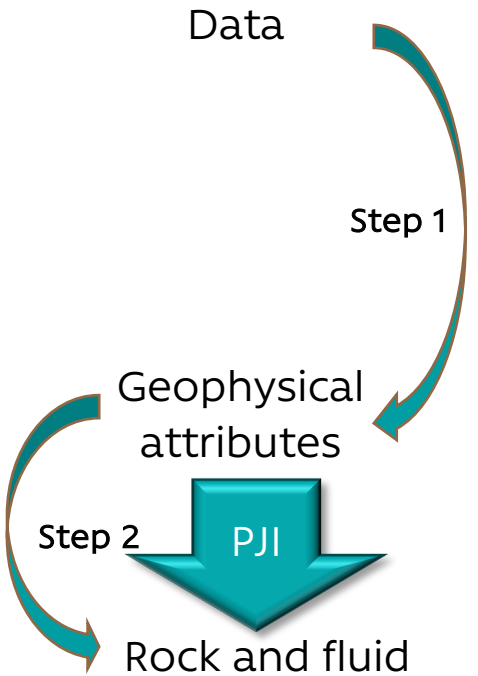
Approaches to multi-physics integration: properties



Andreis et al, 2018
Alvarez et al., 2017
Miotti et al., 2018

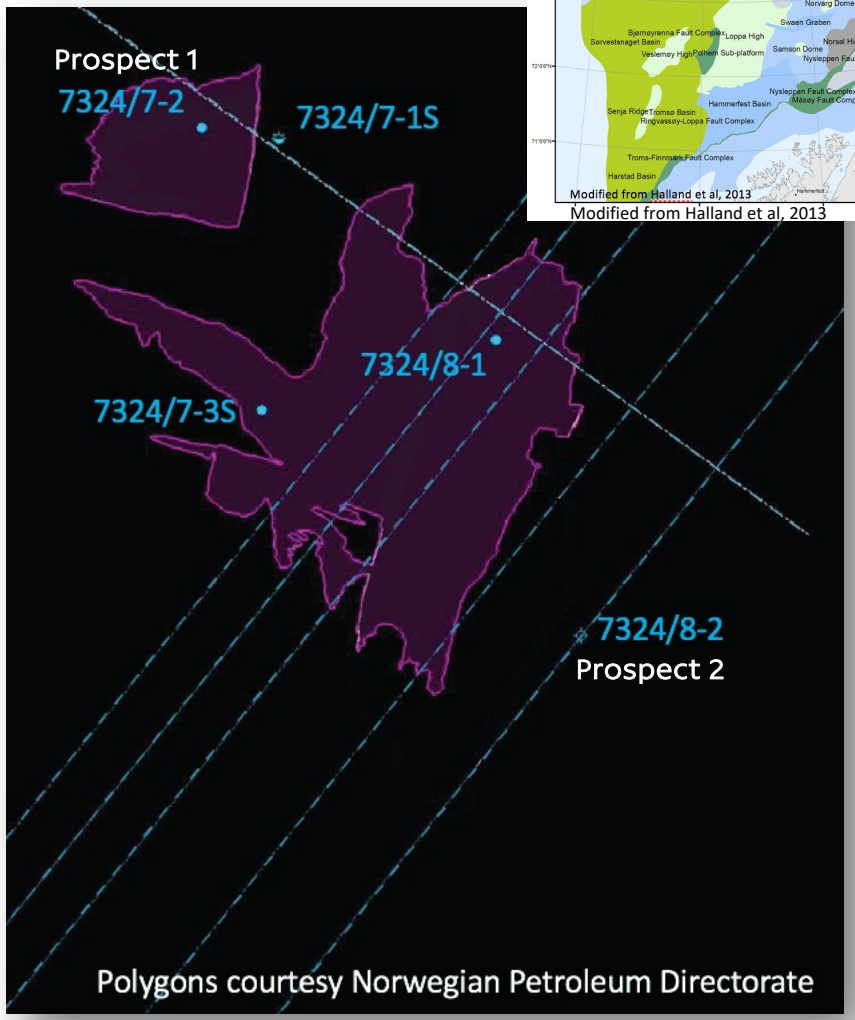
Petrophysical joint inversion (PJI)

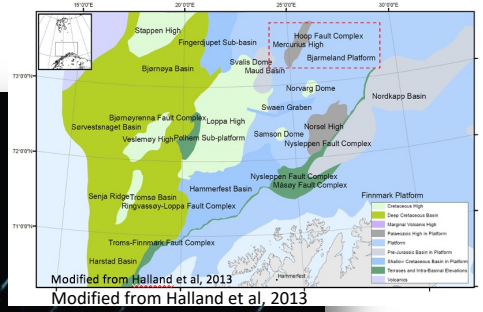




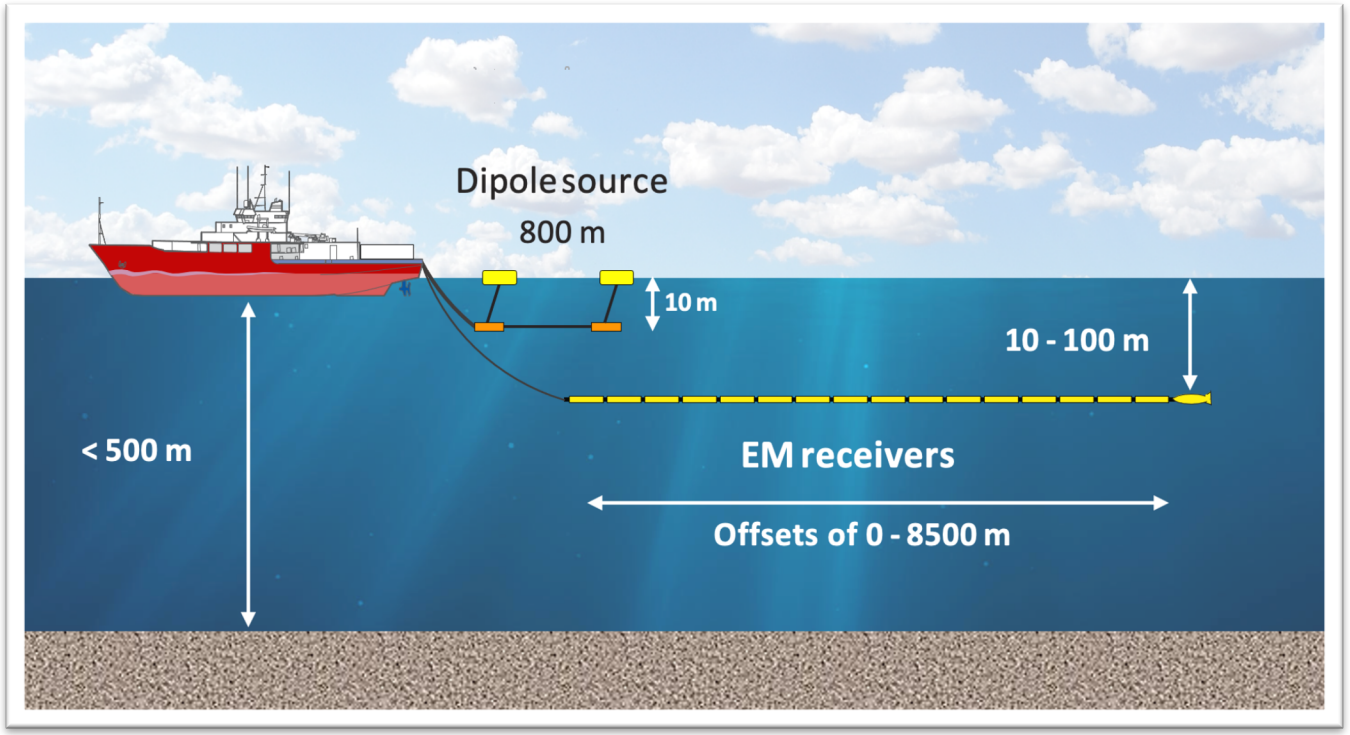
Jointly invert electric and elastic attributes for rock and fluid properties

Study area





Modified from Halland et al, 2013

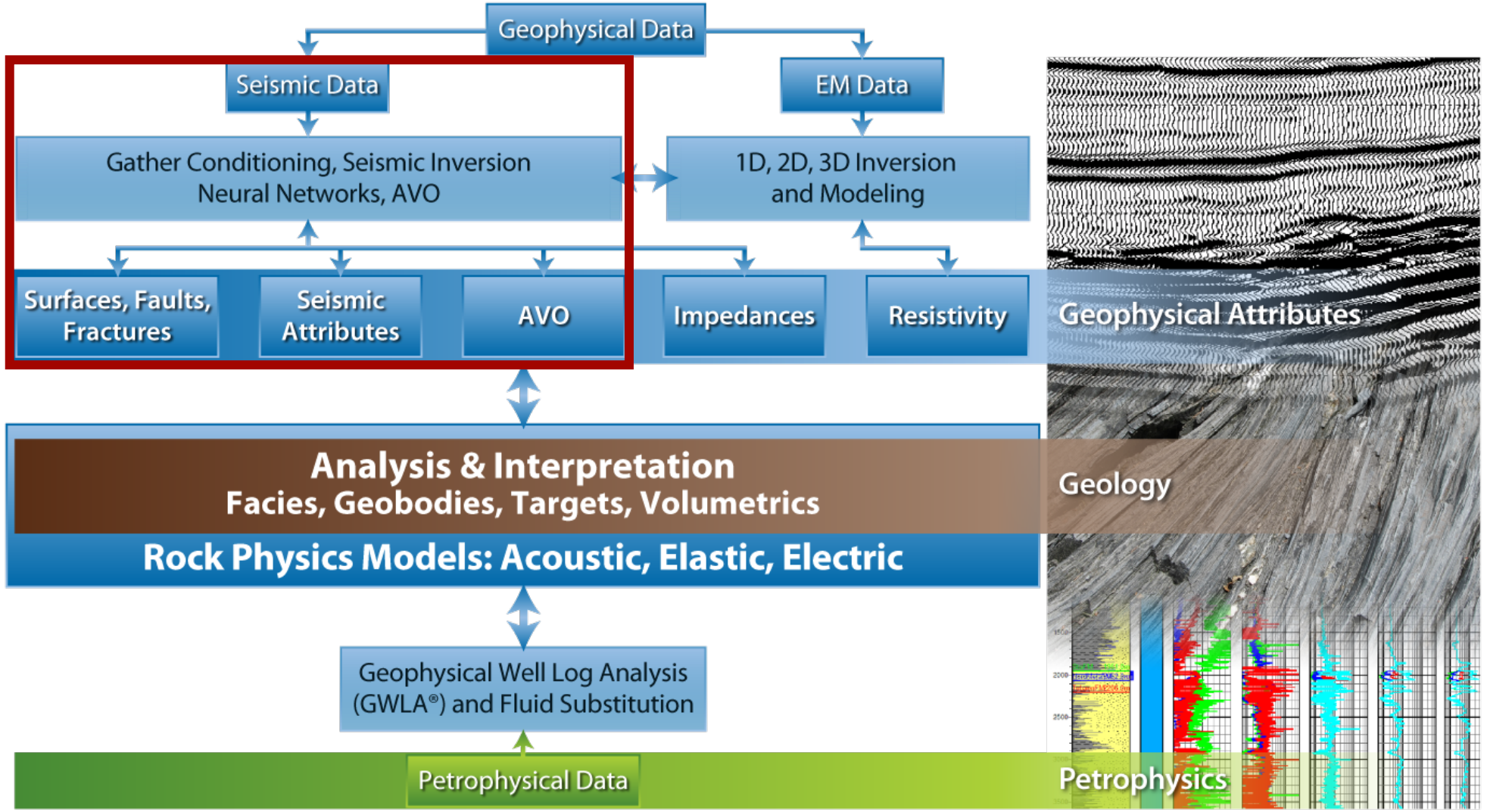


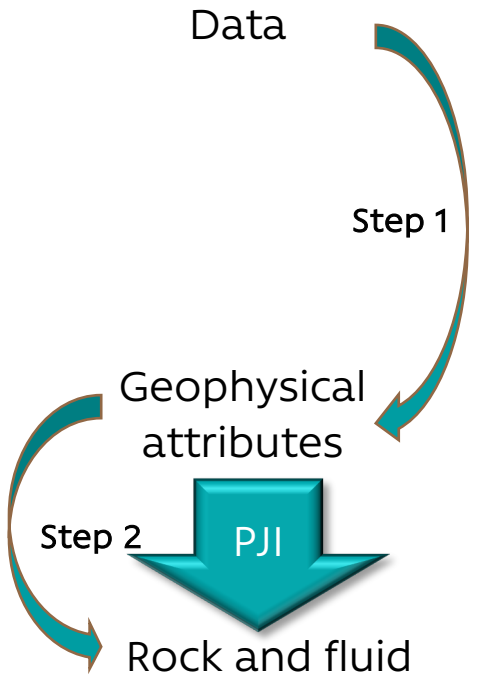
Data available:

- 2D seismic (PGS GeoStreamer®)
- Towed streamer EM
- Two well logs: 7324/8-1 (Wisting Central) and 7324/7-1S (Wisting Alternative)

Example courtesy PGS. Alavrez et al, 2017.

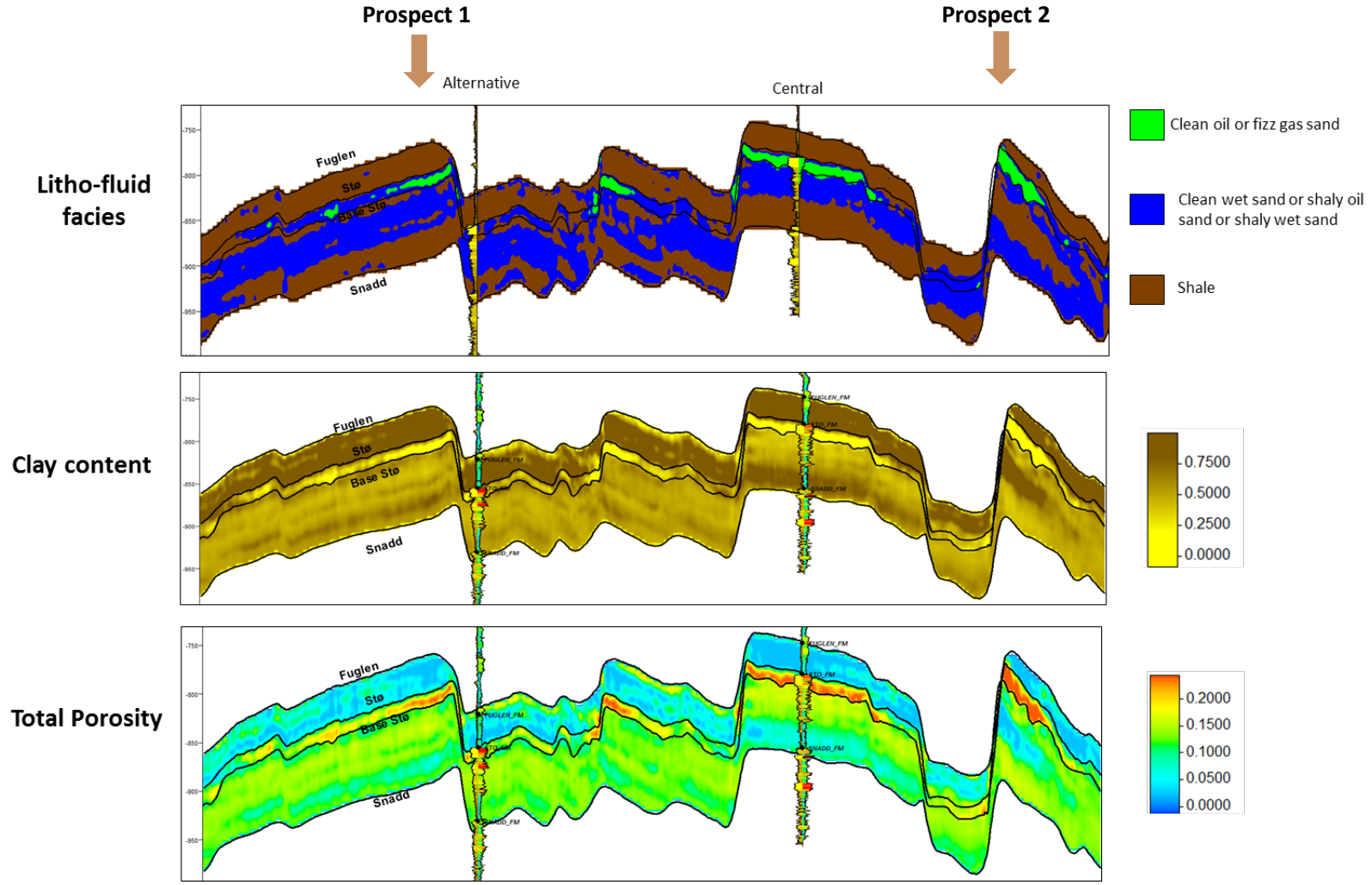
Petrophysical joint inversion (PJI)





Jointly invert electric and elastic attributes for rock and fluid properties

Rock property estimation from seismic & well-log data

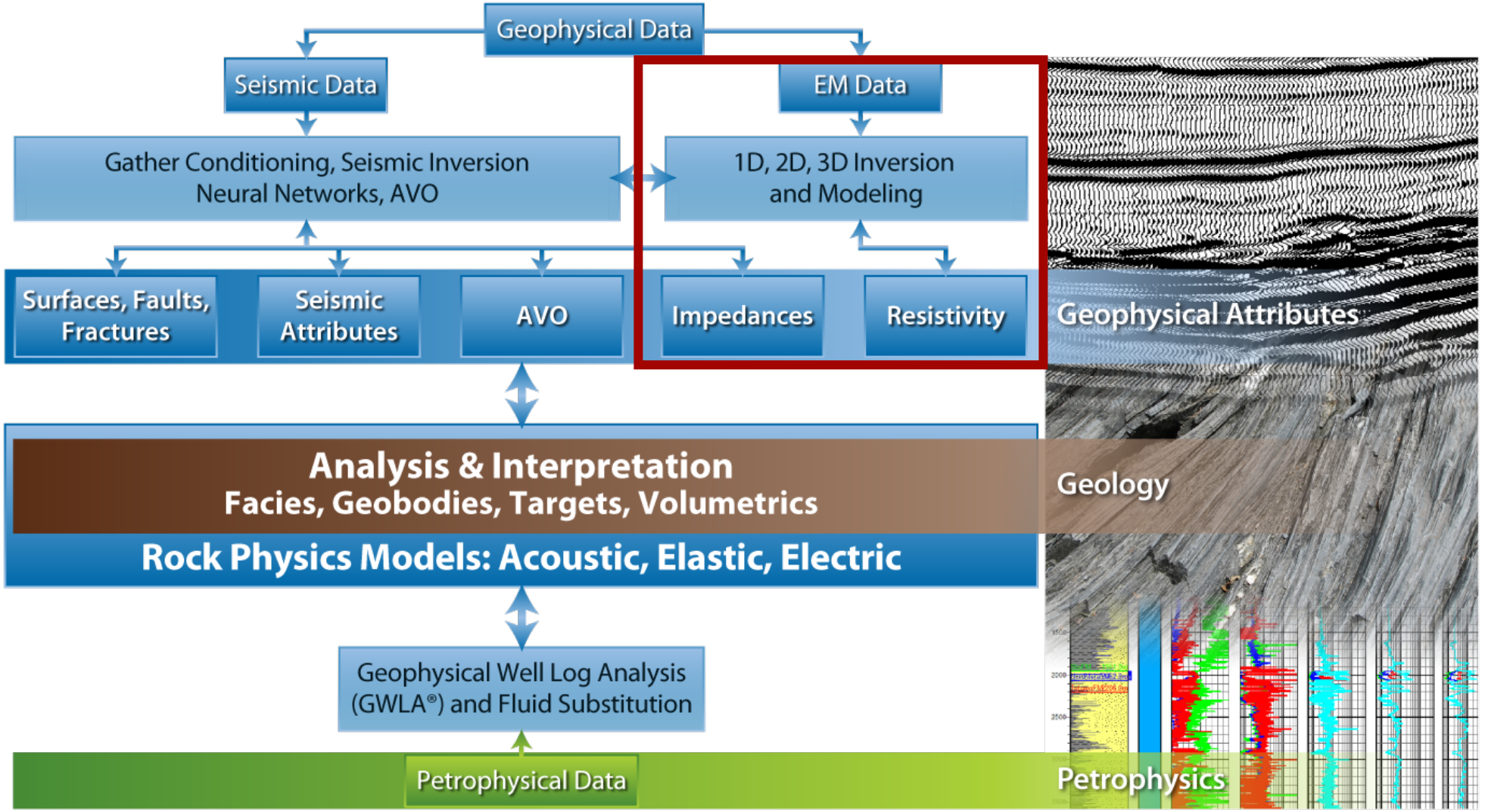


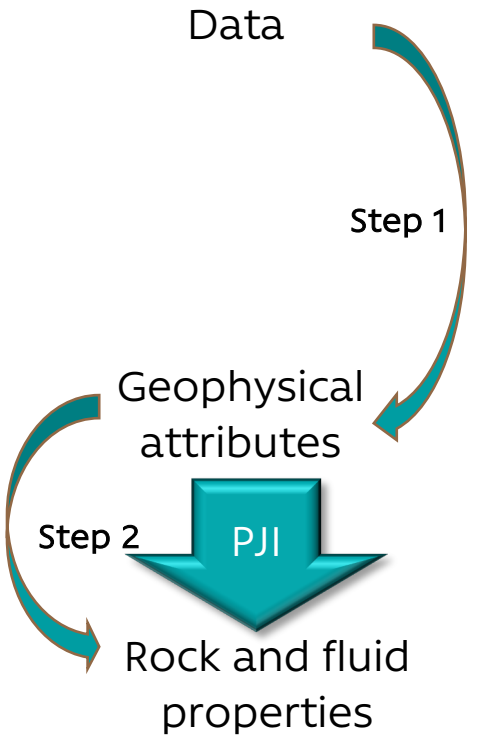
Is this the answer ?

No….we still don't know the saturation: could be fizz or commercial

Alavrez et al, 2017.

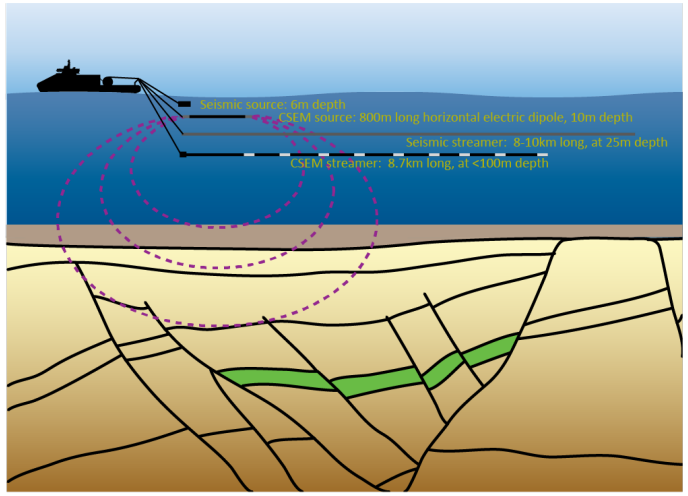
Petrophysical joint inversion (PJI)

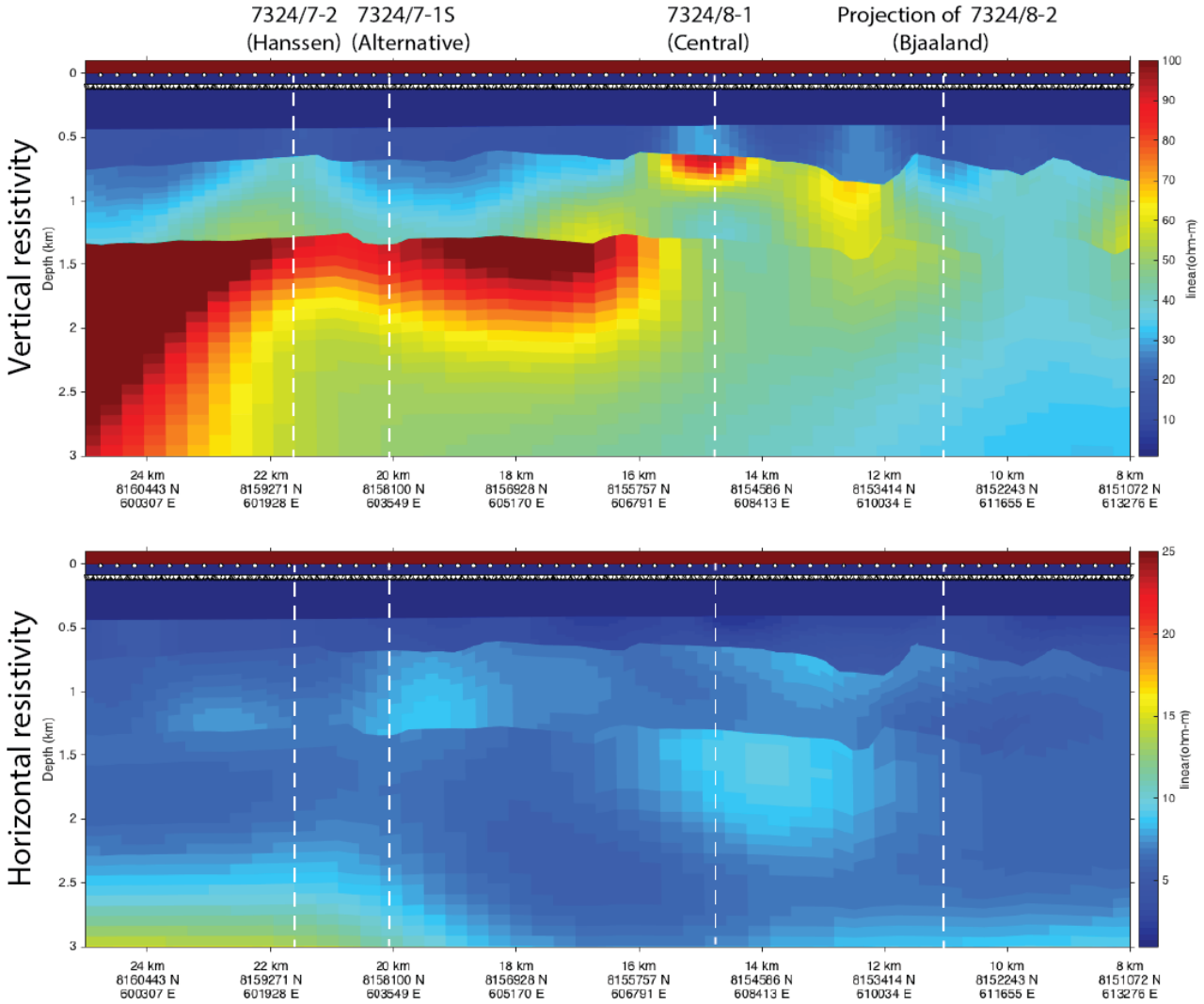


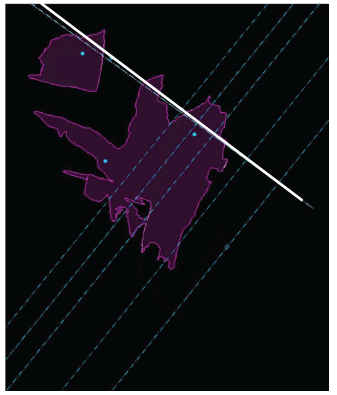


Jointly invert electric and elastic attributes for rock and fluid properties

Structurally constrained CSEM inversion



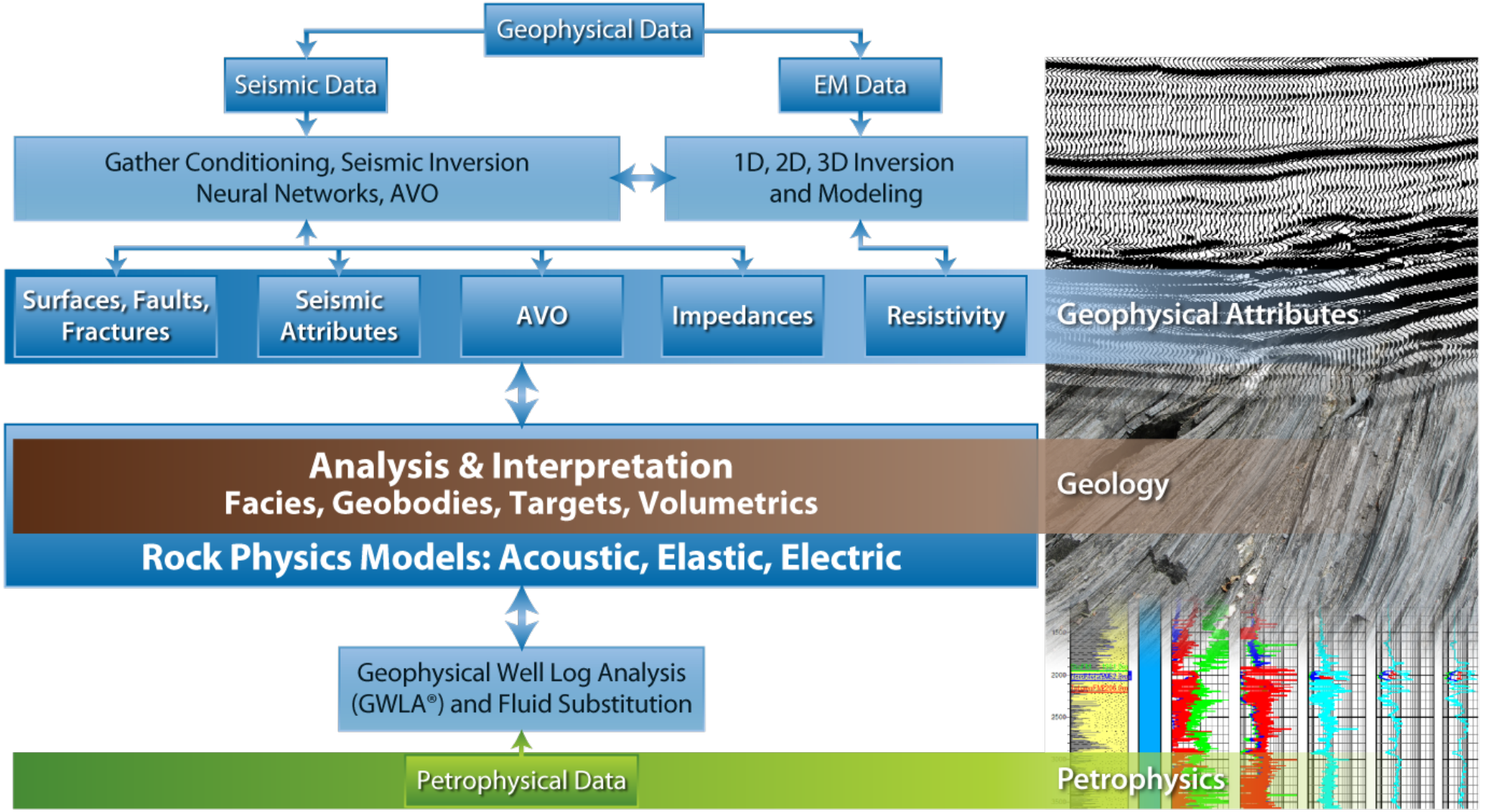


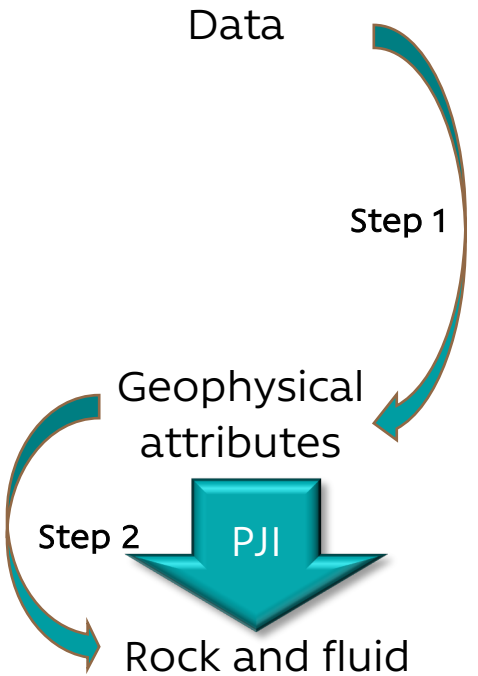


Note: color scale differences !

Alavrez et al, 2017. Inversion performed using MARE2DEM (Key, 2016)

Petrophysical joint inversion (PJI)



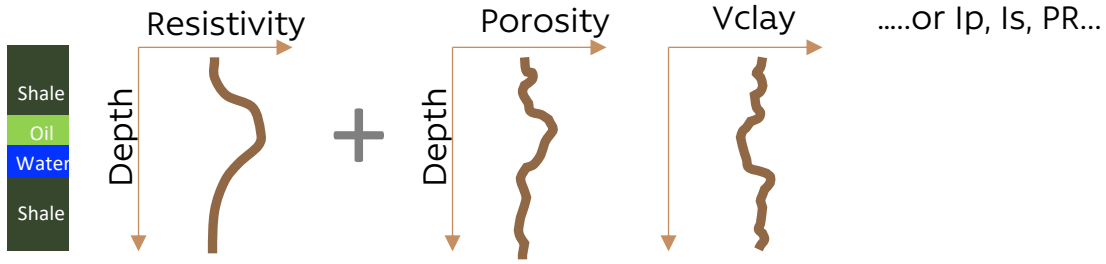


Jointly invert electric and elastic attributes for rock and fluid properties

Reconcile scales: Invert for saturation at seismic scale

How to do this ?

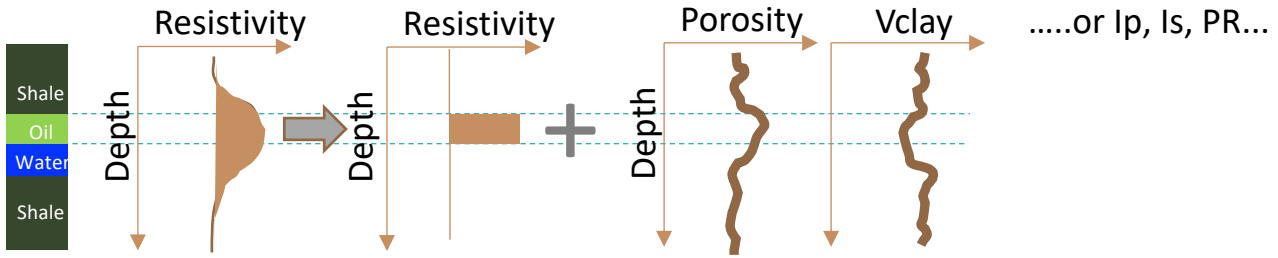
Jointly invert CSEM derived resistivity and seismic properties:



BUT
Does not account for difference in scale – measurements are not pointwise consistent.
SO
Just plain wrong !

X

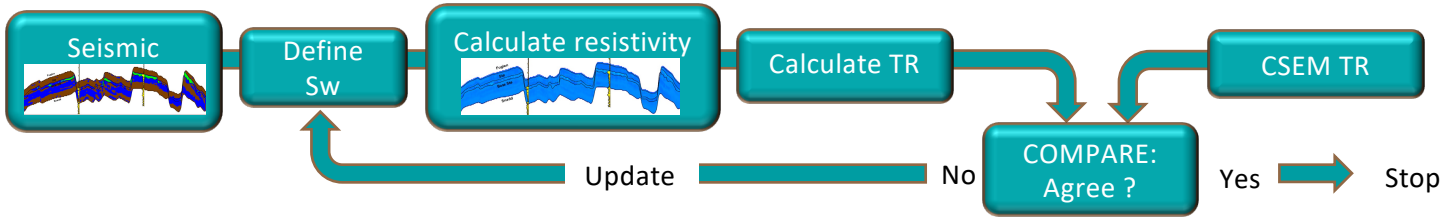
Map through transverse resistance and then combine or jointly invert:



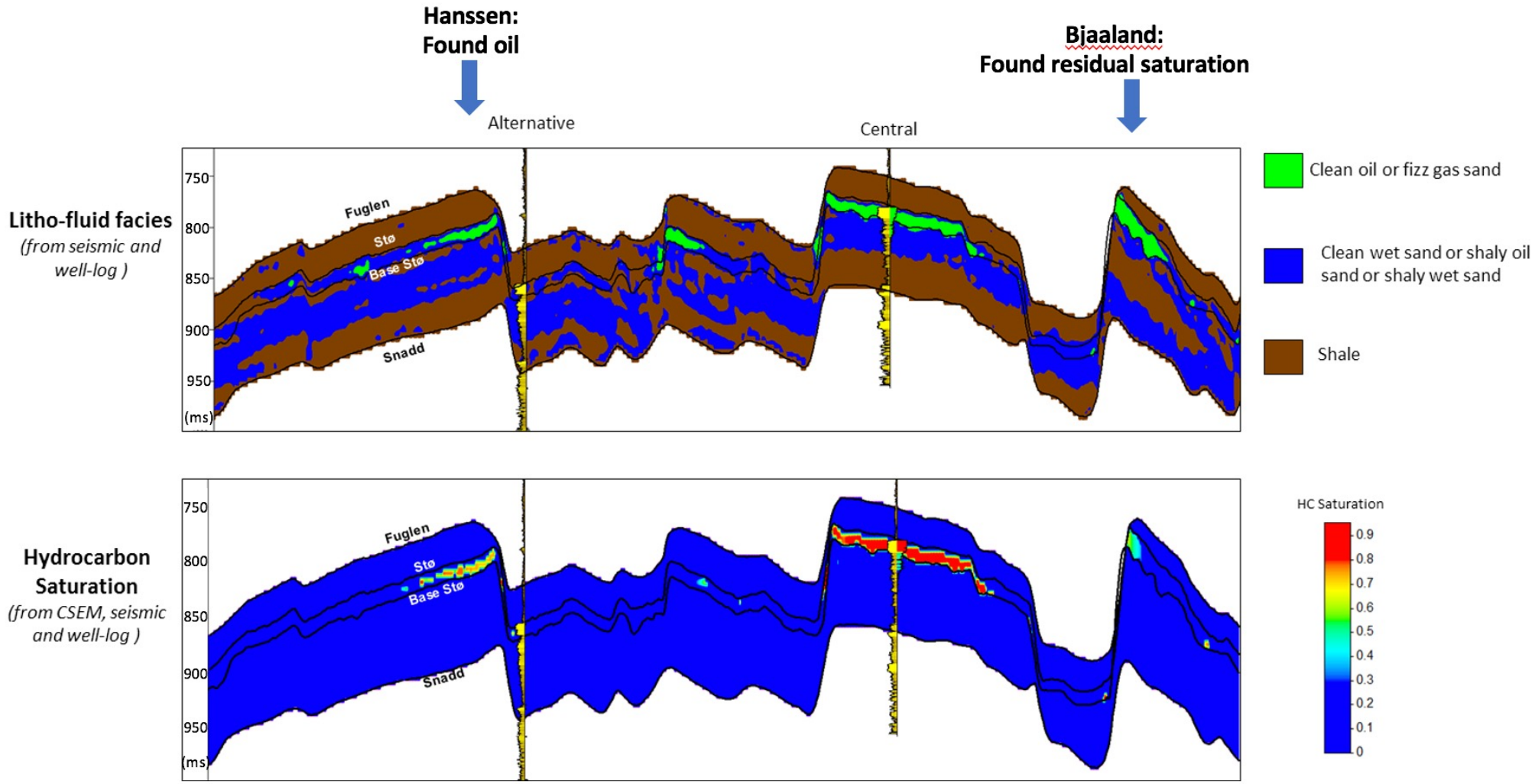
BETTER
Everything mapped to the same scale
BUT
Takes no account of non reservoir facies.

~

Jointly invert transverse resistances using seismic facies as a framework:



Rock Property Inversion for Sw



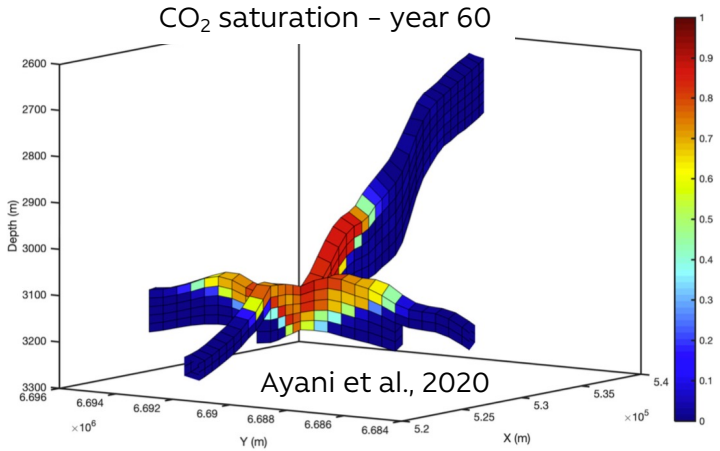
- The seismic data alone cannot distinguish between commercial and non-commercial hydrocarbon saturation
- The inclusion of the CSEM resistivity information within the inversion approach allows for the separation of these two possible scenarios

Alavrez et al, 2017.

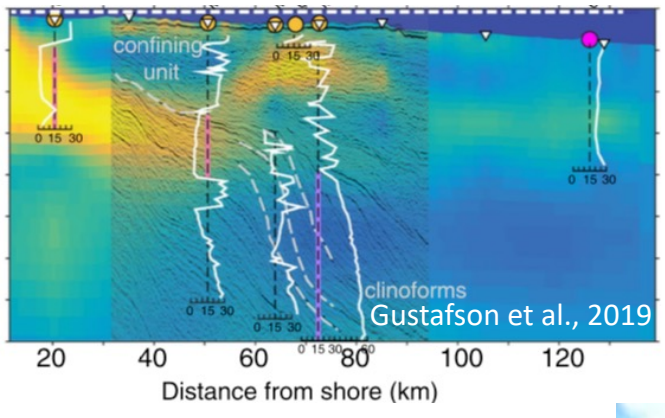
- Introduction
  - Why consider multi-physics data ?
  - What are the challenges of multi-physics analysis ?
  - What do we mean by multi-physics analysis ?
- Examples
  - Integrated interpretation
  - Petrophysical joint inversion
- **Thoughts on future applications**
- Conclusions

Future applications

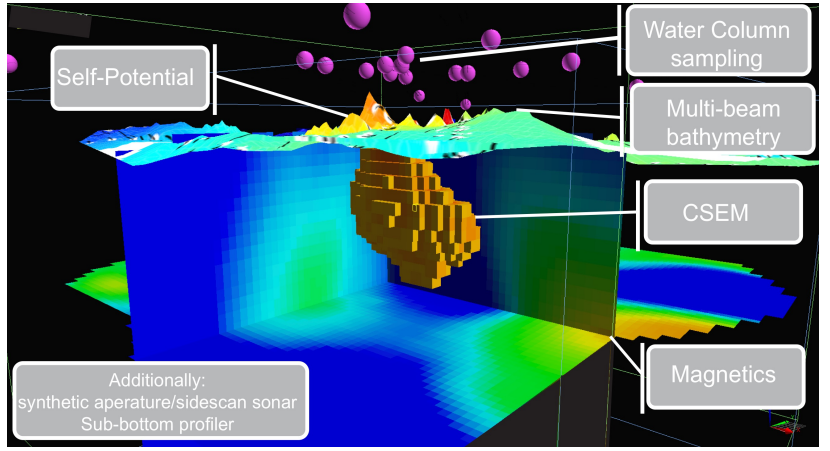
Carbon capture and storage



Offshore groundwater mapping

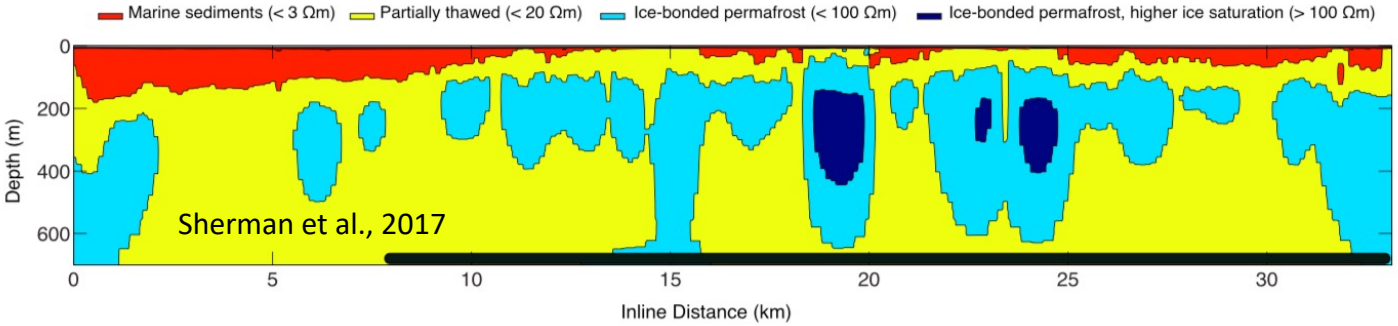


Seafloor hydrothermal systems and massive sulphides

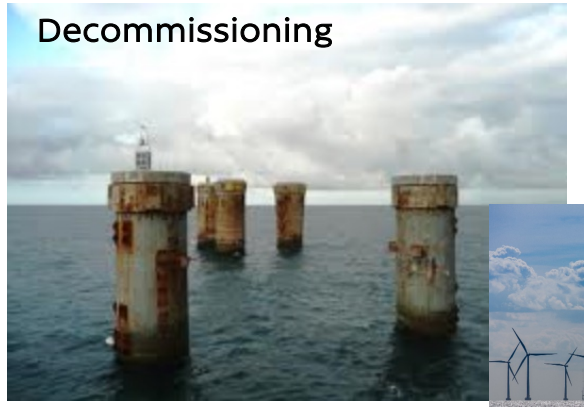


Weitemeyer, 2020, Eminar, MacGregor et al., 2021

Environmental studies: Permafrost mapping



Decommissioning



Windfarms

....EM and multiphysics are useful anywhere you need to know something about the earth.

- Introduction
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Conclusions

- Multiphysics analysis has applications in a range of resource characterisation, environmental and engineering problems.
- Approaches are developing fast and becoming ever more quantitative
- Multiple data types doesn't necessarily mean multiple surveys – with careful planning, data can be acquired from a single platform, keeping costs down.
- **Always use multiple data types – you'll get a better answer !**

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