DELFT INVERSION

# Using the Wave Equation based Inversion to address the subsurface challenge in geothermal

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Delft Inversion MD

**Geothermal Get – Together**
**30 / 03 / 23**

## AGENDA

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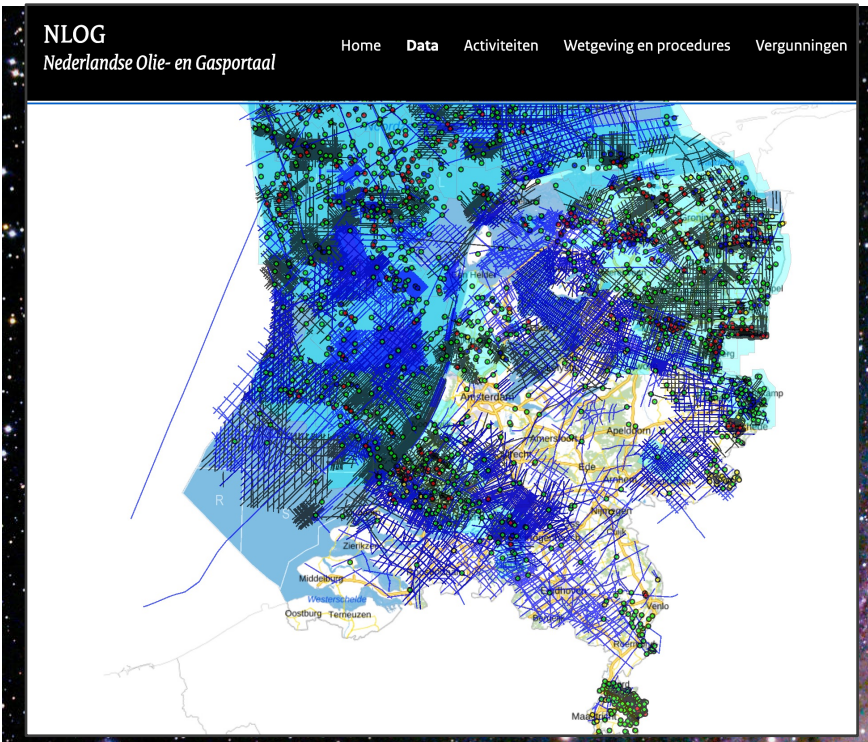
- Motivation: The missing link
- WEB-AVO Inversion
- Case study: Rotliegend
- Case study: Triassic

# Motivation: The missing Link




**GEOTHERMAL**

Key uncertainties
- Reservoir quality
- Reservoir `thickness
- Geomechanical properties

- **Well / core information**
- **Seismic (2D / 3D)**

**through seismic inversion**

# Inversion: Why do we need it?

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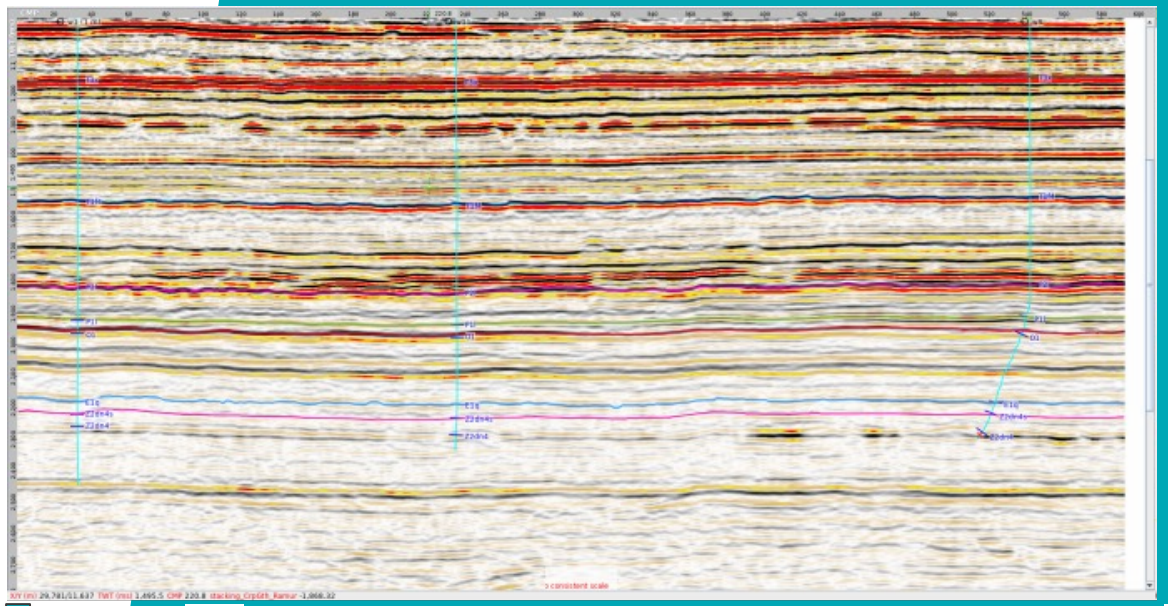
**Inversion is a process that converts seismic data to layer properties.**

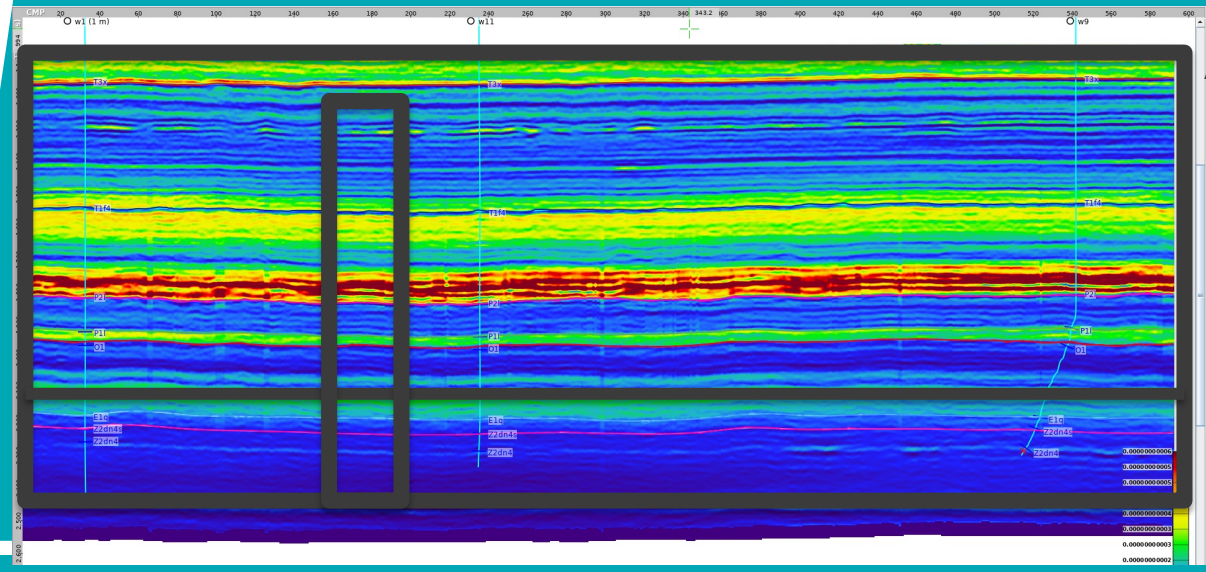
- Many flavors of inversion exist, acting on different types of input:
  - Full Waveform Inversion – Surface data
  - AVO inversion – Migrated Stacks
  - Simultaneous inversion – Migrated Gathers
  - WEB-AVO – Migrated Gathers

Too expensive!

Too simple!!

Just about right!





# Potential Impact

of WEB-AVO work-flow on geothermal exploration

### Reduce P10-P90 range

- Update reservoir model with rock properties derived from seismic data
- Better prediction of yield and facilities cost

### Optimise well placement

- Maximize yield
- Reveal intra-reservoir channel systems
- Reduce uncertainty of reservoir connectivity

### Detect residual hydrocarbons

- Help optimise facility costs by avoiding hydrocarbons

### Mitigate drilling hazards

- Reduce risk of failed wells by detecting
  - residual hydrocarbons
  - hard layers
  - soft shales

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# Extract more information out of seismic

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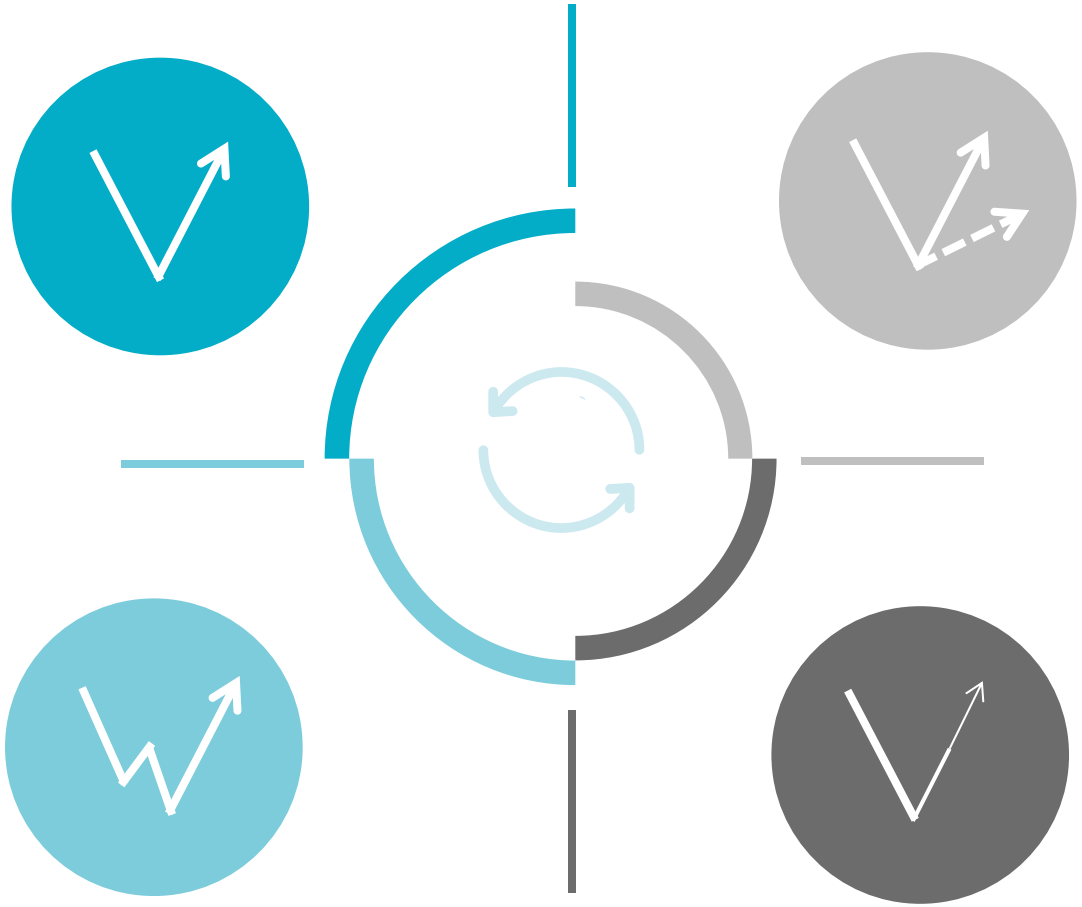
## PRIMARIES

Energy used by commercially available linear inversion tools



## MODE CONVERSIONS

Regarded as noise by commercially available linear inversion tools, properly accounted for by WEB-AVO

## INTERBED MULTIPLES

Regarded as noise by commercially available linear inversion tools, properly accounted for by WEB-AVO

## TRANSMISSION

Neglected by commercially available linear inversion tools, properly accounted for by WEB-AVO

**WEB-AVO inversion solves for parameters that are very sensitive to lateral porosity/permeability variations**

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# Geothermal Exploration NL

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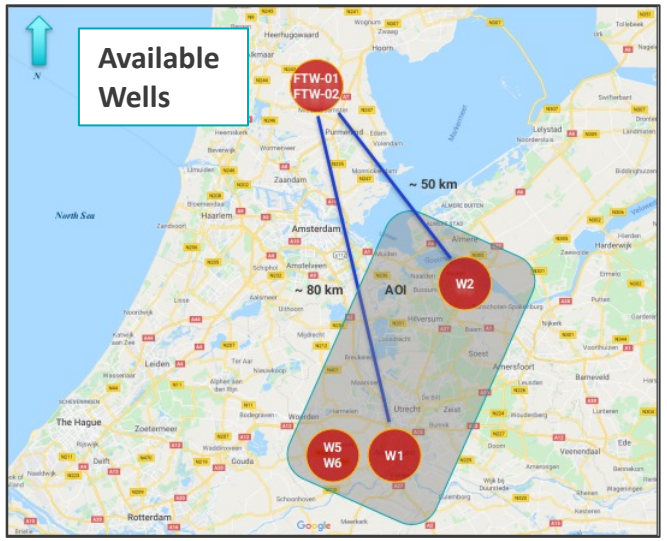
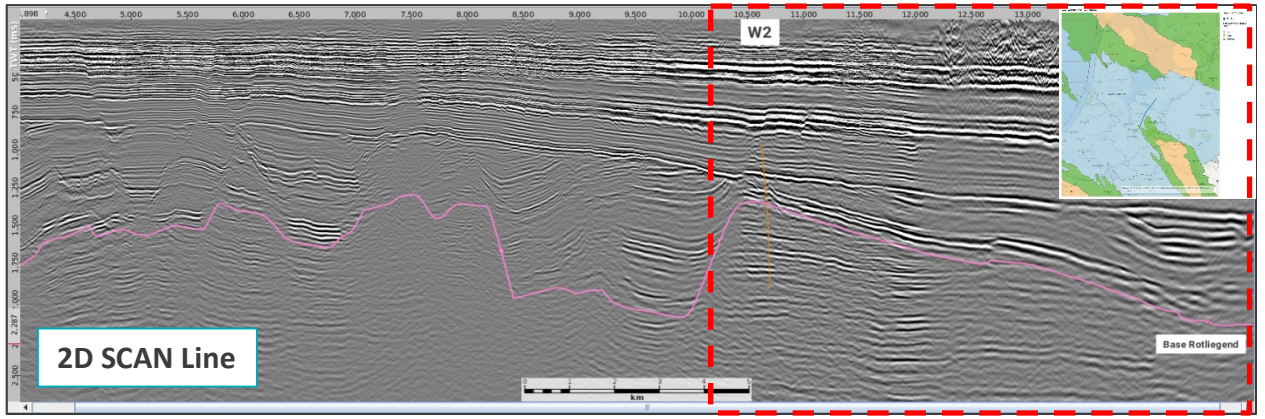
- All data obtained through public repositories (www.nlog.nl).
- South Permian Basin: Upper Slochteren Fm. aquifer target, “Rotliegend”.
- 2D Seismic Data: Recent migrated SCAN[1] data, NMO corrected offset gathers. RMS velocities, with no significant pre-processing done.
- Core-derived poro-perm data from same formation, similar depositional environment.
- Data from 6 wells (W1 - W6):
  - GR, Density, RES. Calculated PHI, SW, PERM.
  - P-wave sonic.
- Two wells (FTW) were used for S-wave calibration and fluid calibration.




[1] Seismische Campagne Aardwarmte Nederland

# Rock Physics: From κ to Permeability

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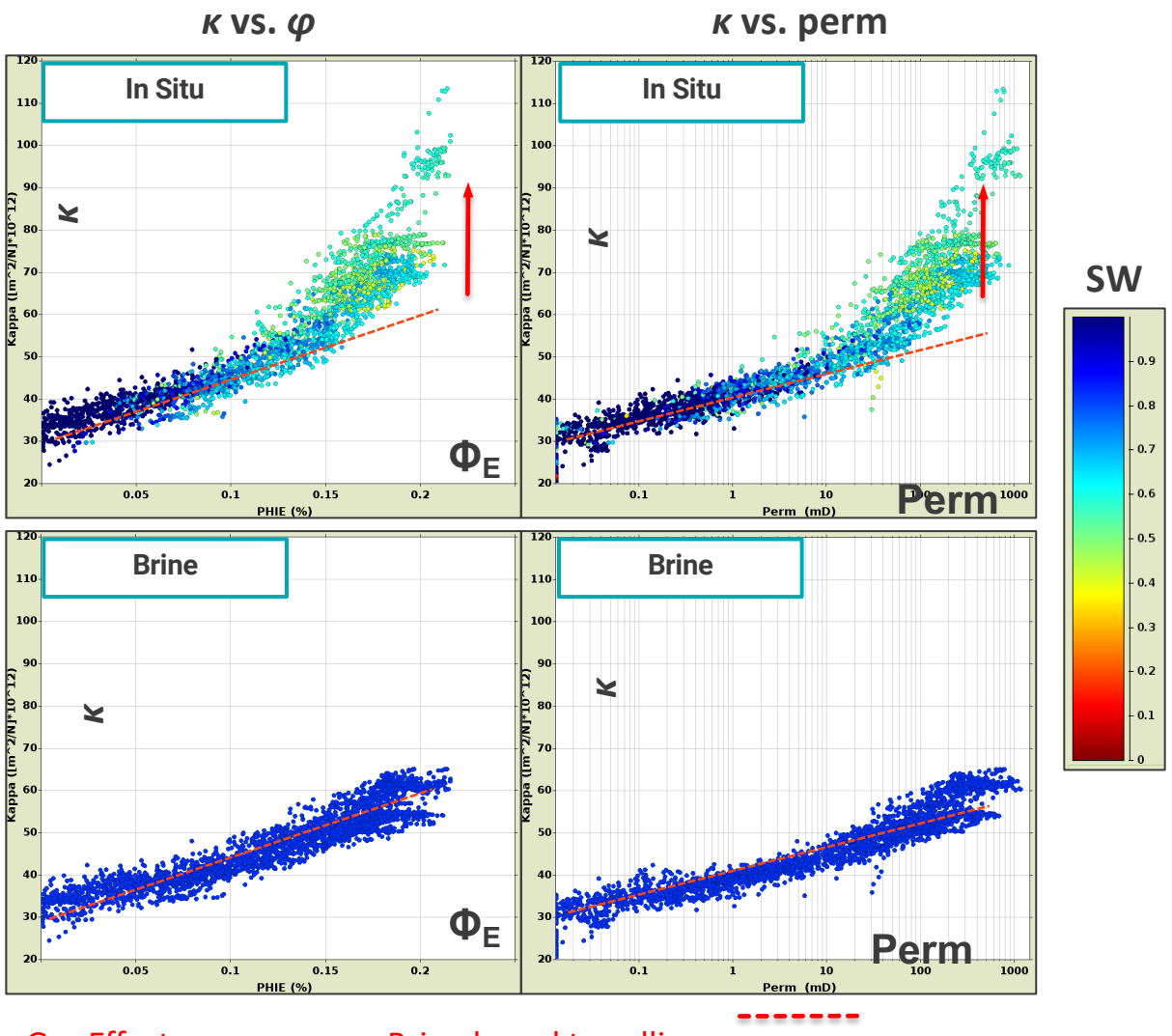
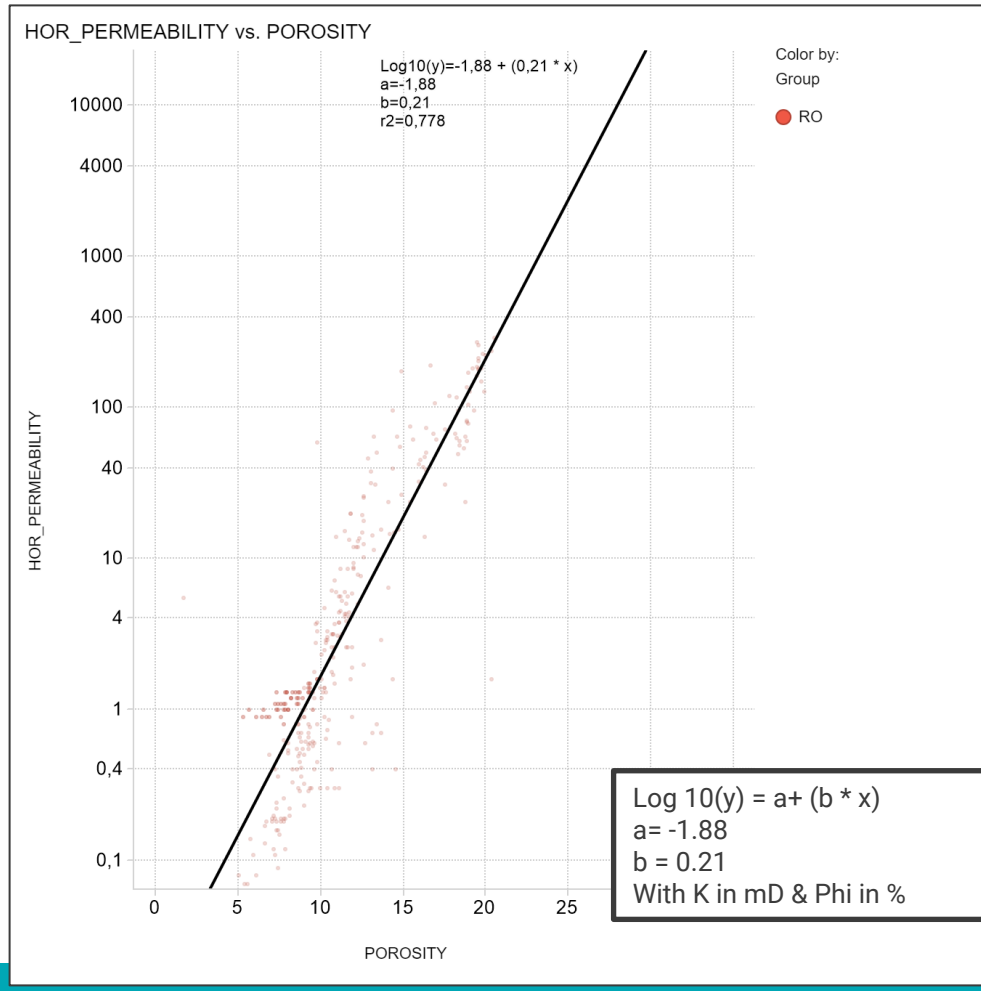
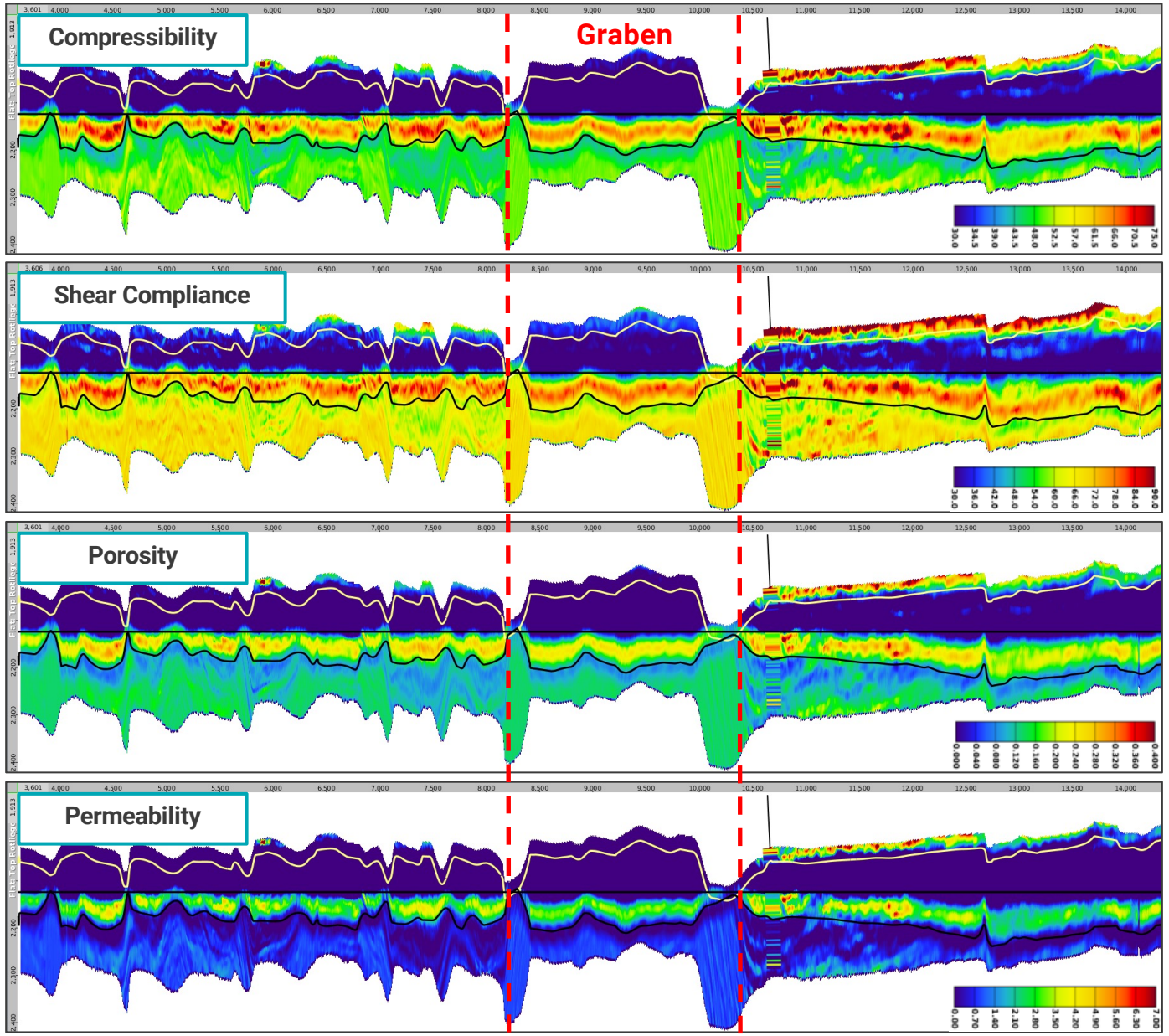


# Rerservoir properties along the line




ROTL

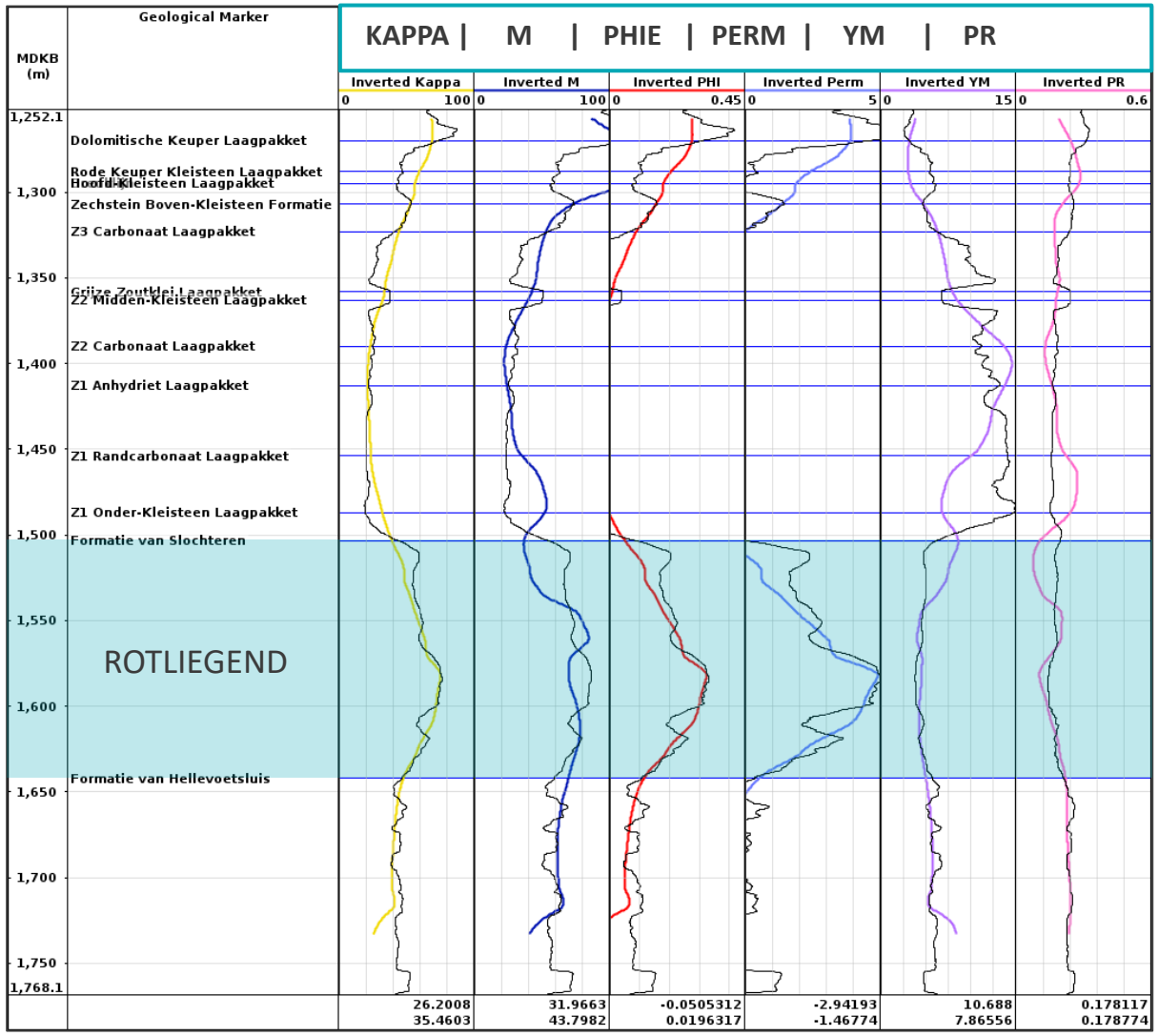
ROTL

ROTL

ROTL

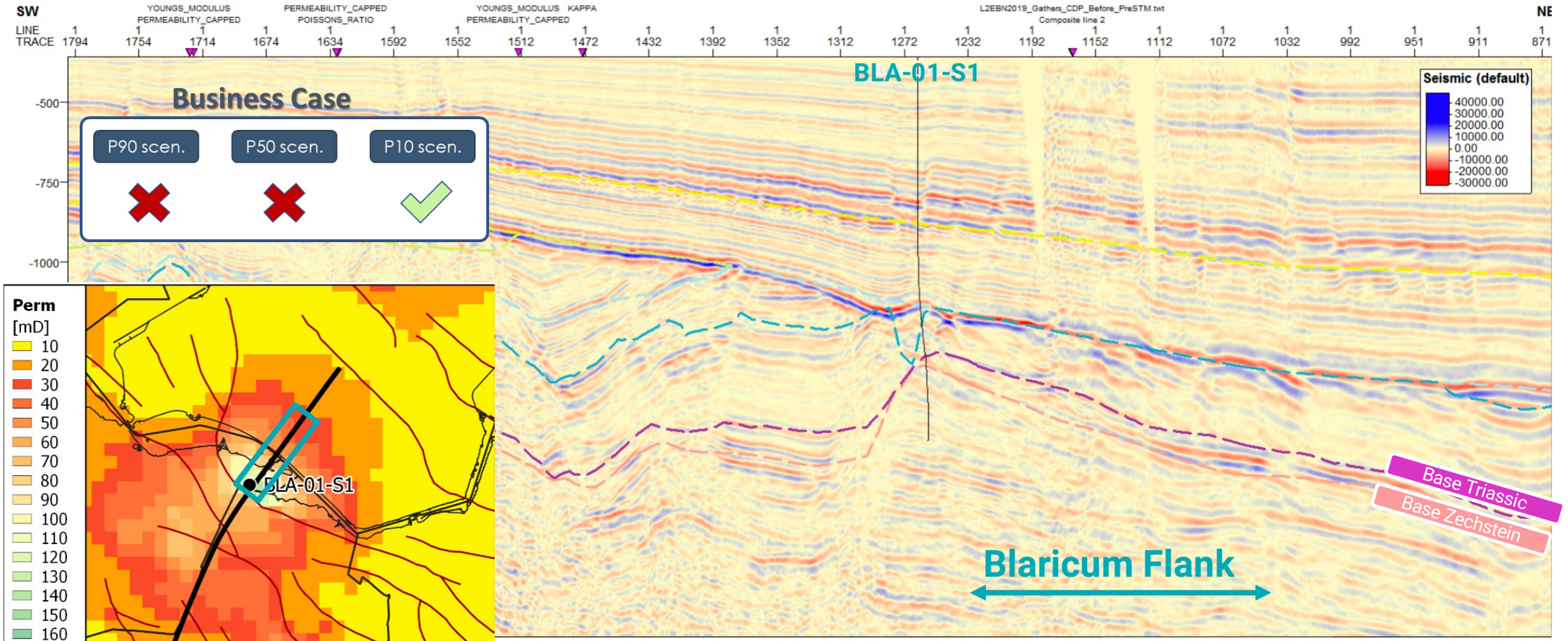
- Lateral variability is noticeable for all the properties within the Rotliegend interval.
- Most detail is shown where the seismic was of better quality.
- Highest detail closer to the well in the section east of the graben
- However, interesting features are seen to the west of the graben.
- Within the graben, detail is lost due to the poor reflectivity at that depth.

# 1D Results




- We have demonstrated a workflow to obtain key reservoir and geomechanical parameters using the SCAN line and well data through Wave Equation Based AVO seismic inversion.
- The results show excellent to very good correlation at the well for Compressibility and PHI, PERM, and good to adequate correlation to Shear Compliance, PR and YM.
- These output parameters can be used for static, dynamic and MEM modeling.
- Stacked seismic data (kappa only) can be used to obtain porosity and permeability.
- Pre-stack seismic data (kappa and M) is required for geomechanical parameter derivation.
- PHI and PERM results are robust with standard processing, while Geomechanical parameters could benefit from improved seismic processing.

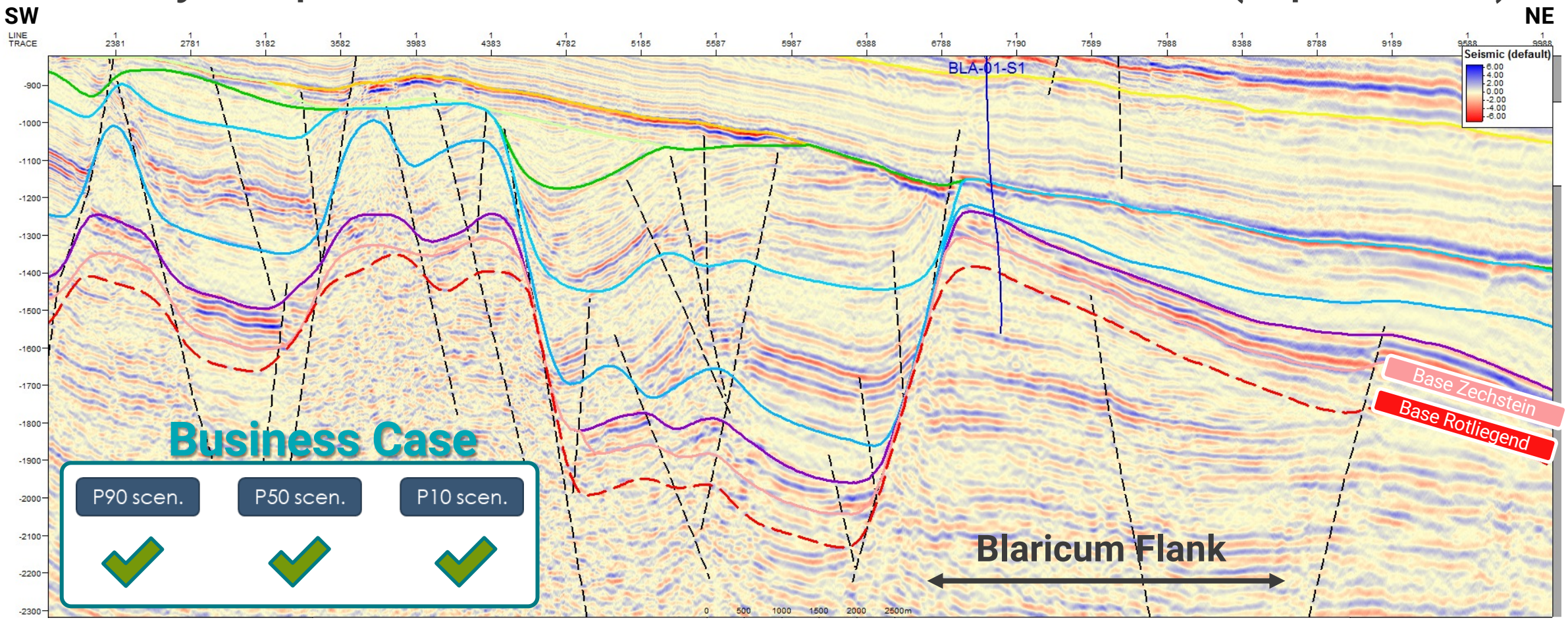
# Pre-inversion geothermal power assessment




- Legacy data with original interpretation.
- Deemed uneconomic.
- P10 - P90 range was 3 x P90 case

# WEB-AVO seismic inversion

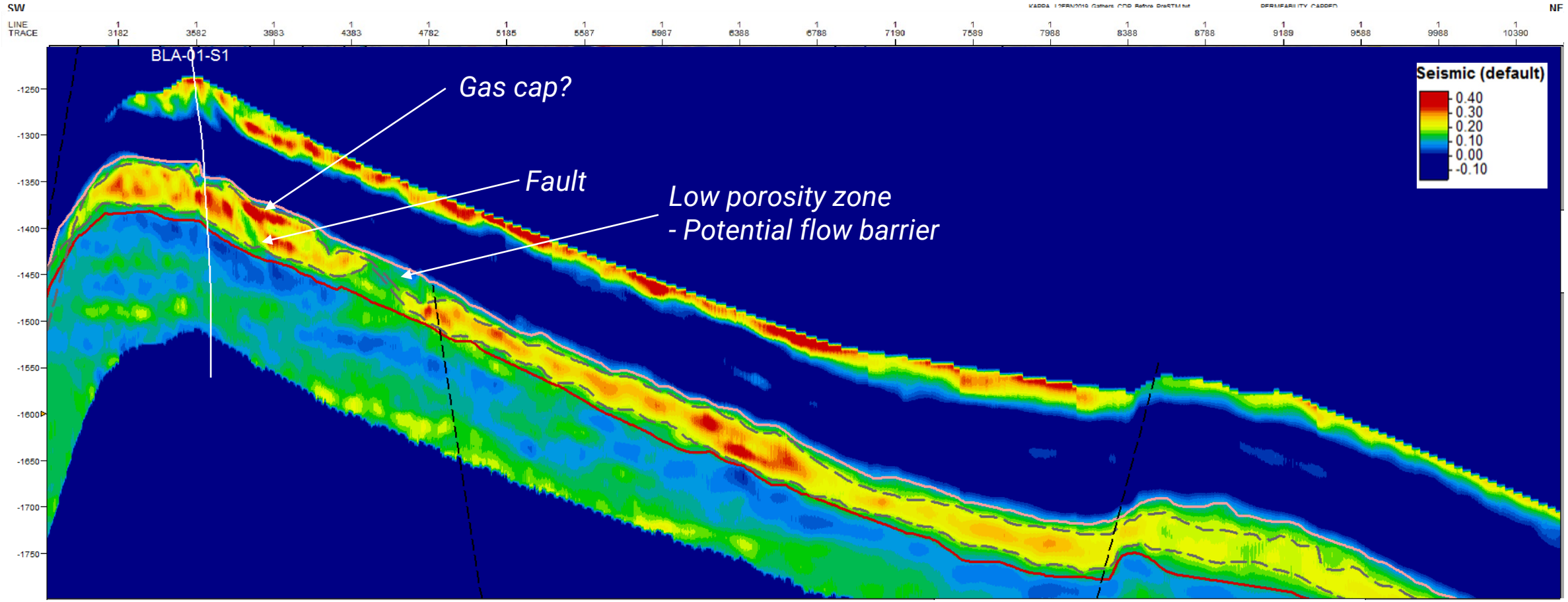
- Newly acquired SCAN seismic – Line SCAN001(input data)




- SCAN data with inversion-based interpretation.
- Deemed economic.
- P10 - P90 range is 0.6 x P90 case

# WEB-AVO seismic inversion

- Output – Porosity cube




- Top and base reservoir interpretation is improved incl. identification of net pay zone
- Thickness and N/G estimates of the reservoir are improved
- Allows more optimal doublet placement through the identification of potential faults/flow barriers

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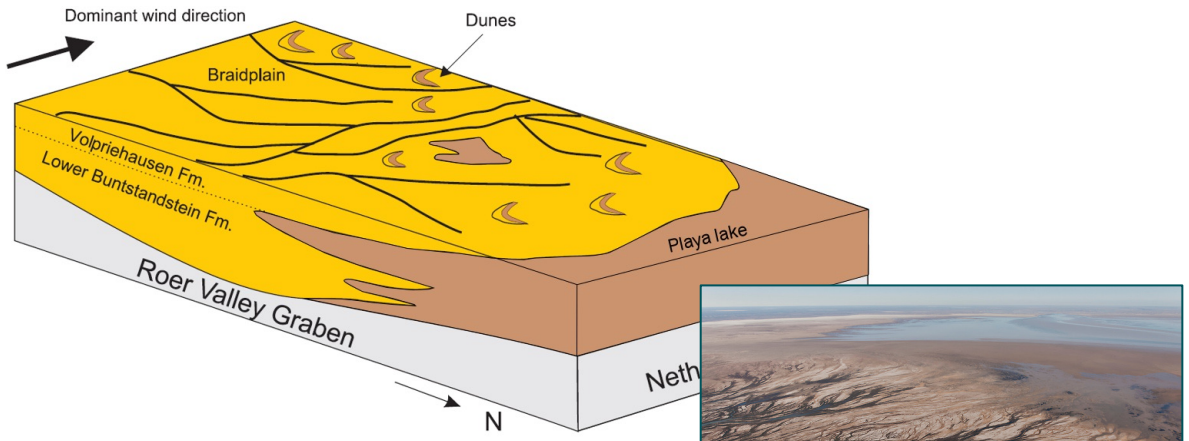
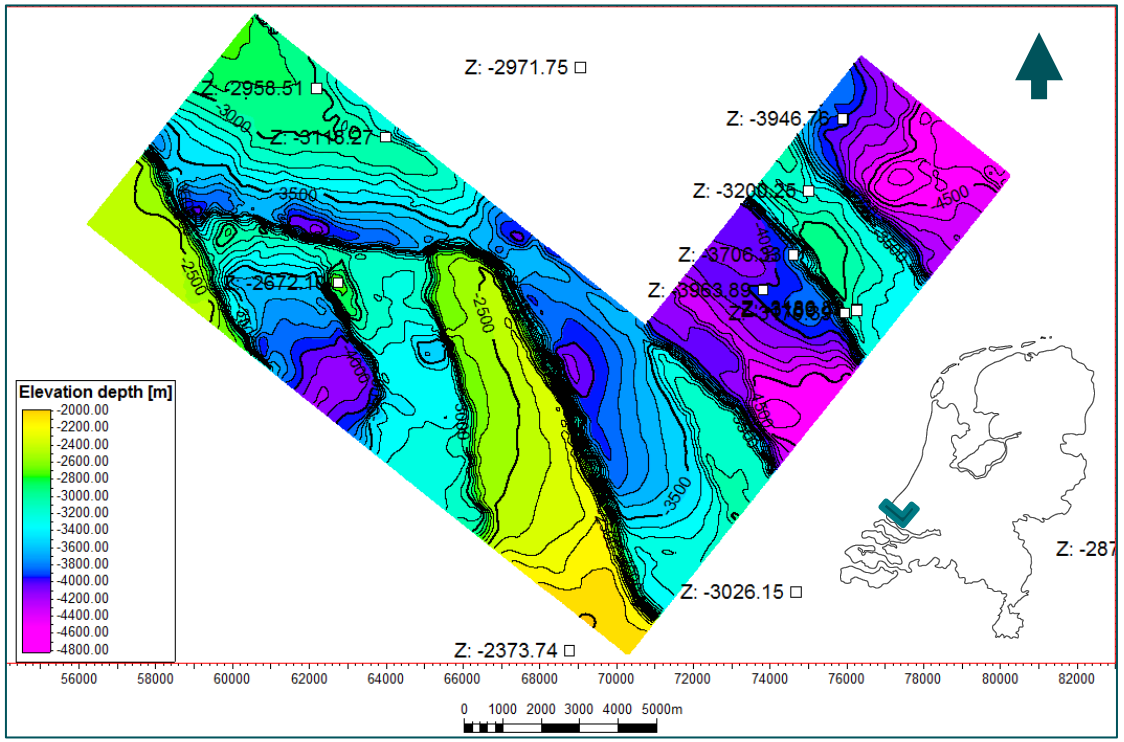
# Triassic 3D case study

- Main Buntsandstein
- Fluvial / Aeolian facies
- Arid climate
- West Netherlands Basin

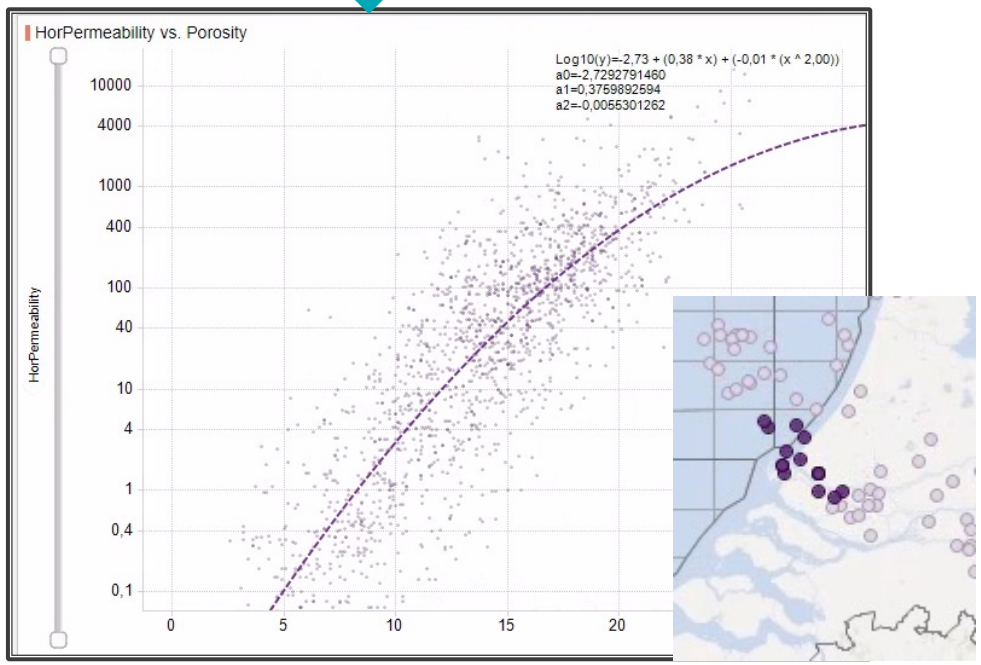


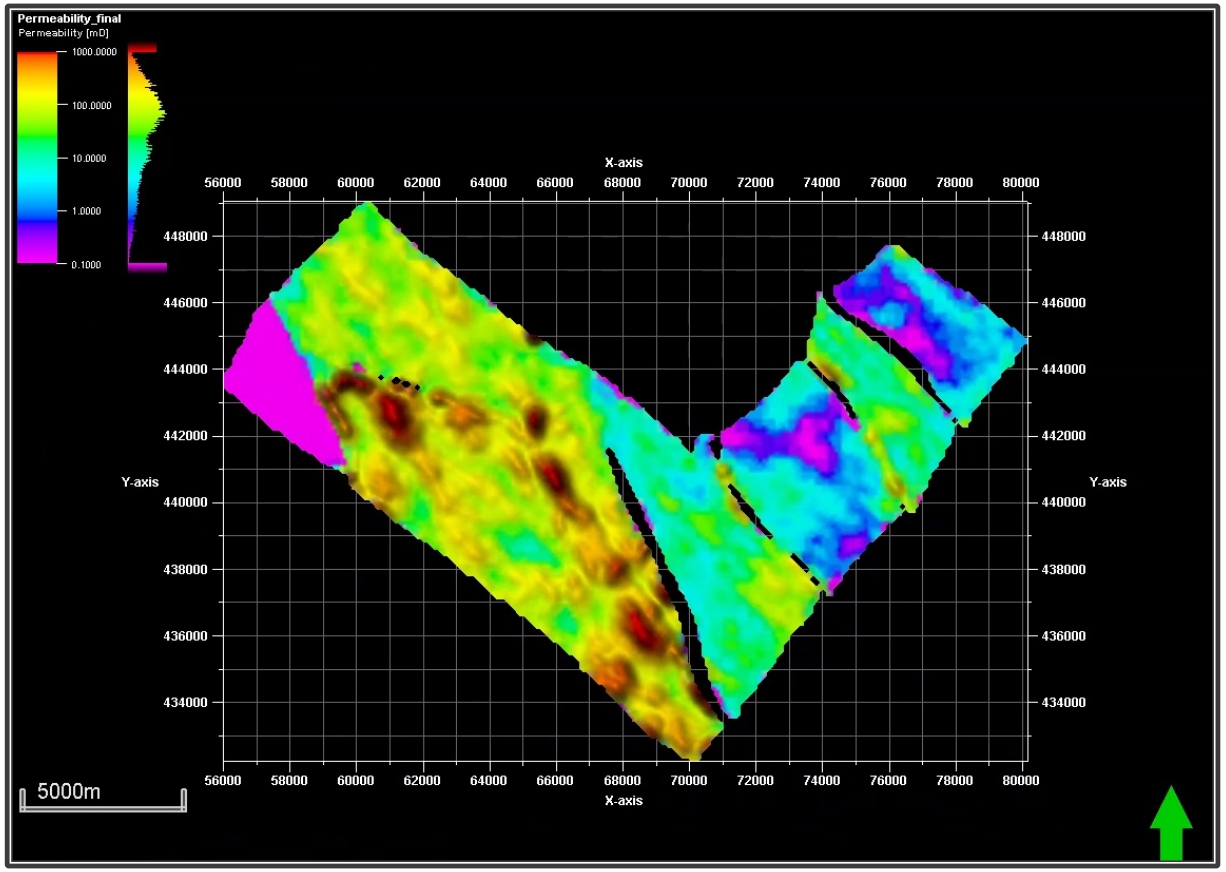

Geology of the Netherlands, 2008



# Average permeability map

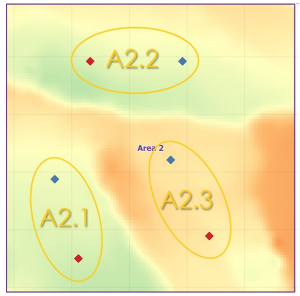
- Can be used as direct input for doubletcalc 2D
- Based on poro-perm relation of local core plug measurements

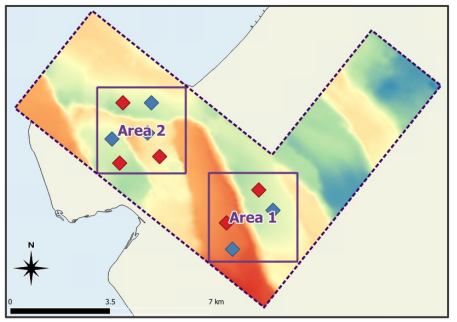



*Average Permeability over the reservoir based on the inverted compressibility volume.*

# Doubletcalc (Doublet 2.3)




Pre Inversion

## Geotechnical input

| Property | min | median | max |
|---|---|---|---|
| aquifer permeability (mD) | 25 | 30 | 35 |
| aquifer porosity (-) | 0.13 | 0.14 | 0.15 |
| aquifer net to gross (-) | 0.7 | 0.8 | 0.9 |
| aquifer gross thickness (m) | 210 | 230 | 250 |
| aquifer top at producer (m TVD) | 2700 | 3000 | 3300 |
| aquifer top at injector (m TVD) | 2700 | 3000 | 3300 |
| aquifer water salinity (ppm) | 100000 | 125000 | 150000 |
| aquifer net transmissivity (Dm) | 0 | 0 | 0 |

| base case (median value input) | value |
|---|---|
| aquifer kH net (Dm) | 5.52 |
| mass flow (kg/s) | 39.35 |
| pump volume flow ($m^3/h$) | 134.8 |
| required pump power (kW) | 803 |
| geothermal power (MW) | 9.61 |
| COP (kW/kW) | 12 |

Post Inversion

## Geotechnical input

| Property | min | median | max |
|---|---|---|---|
| aquifer permeability (mD) | 20 | 80 | 300 |
| aquifer porosity (-) | 0.13 | 0.16 | 0.19 |
| aquifer net to gross (-) | 0.7 | 0.8 | 0.9 |
| aquifer gross thickness (m) | 210 | 230 | 250 |
| aquifer top at producer (m TVD) | 2700 | 3000 | 3300 |
| aquifer top at injector (m TVD) | 2700 | 3000 | 3300 |
| aquifer water salinity (ppm) | 100000 | 125000 | 150000 |
| aquifer net transmissivity (Dm) | 0 | 0 | 0 |

| base case (median value input) | value |
|---|---|
| aquifer kH net (Dm) | 14.72 |
| mass flow (kg/s) | 75.55 |
| pump volume flow ($m^3/h$) | 259.1 |
| required pump power (kW) | 1144.3 |
| geothermal power (MW) | 19.09 |
| COP (kW/kW) | 16.7 |

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## Observations

- Improves the interpretation of the reservoir section (top and base acquifer)
- Enables more optimal doublet placement through the identification of sweet spots, faults and potential flow barriers that can potentially have a huge impact on economic feasibility
- Enables a more detailed modelling of the reservoir and the cold water front which enhances confidence and de-risks the investment.

## Remaining Challenges

- Data availability and data quality impact on the results need to be assessed prior to commencing any project
- Quantification of uncertainty is key to drive decision making further.

# ACKNOWLEDGEMENTS




# STAY IN TOUCH

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