Rock Flow Dynamics

Reducing Subsurface Uncertainty for Sustainable Heat Production:

Integrated Ensemble Modelling of the Delft Campus Project

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TU Delft

Integrated Ensemble Modelling of the Delft Campus Project

Geothermie Delft

Over Half of the Netherlands energy consumption is used for heating, the Geothermie Delft project aims to harness the geothermal power under the University of Delft, providing clean energy to heat the campus and surrounding city.

Geothermie Delft

Delft University and a consortium of other companies and research groups built Geothermie Delft.

They want to scale up direct use heating for the university and surrounding city and create a scientific research facility to answer geothermal questions to help progress the industry.

The two primary aims of the Geothermal Delft project are Scientific Research and to supply a commercial thermal energy supply.

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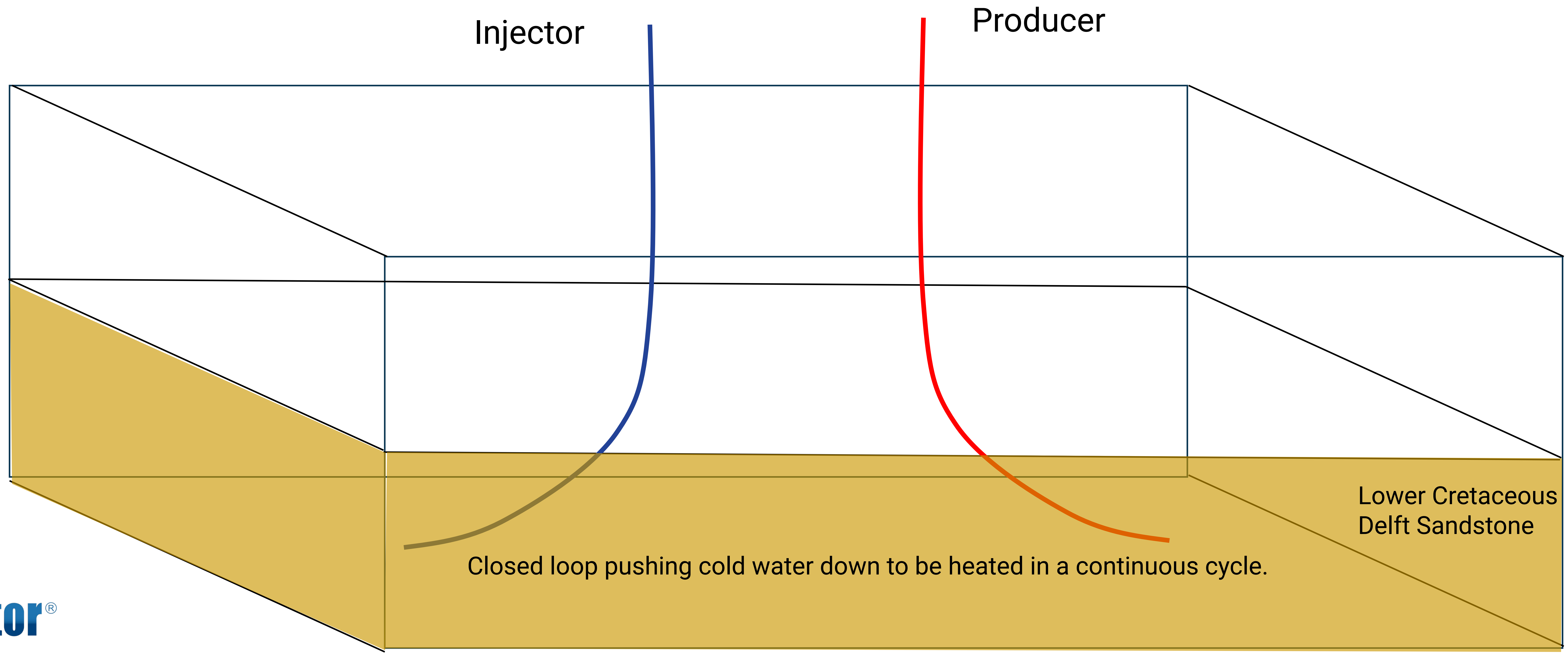
Geothermie Delft

This is done by drilling 2.5km deep into the earth and using a geothermal doublet, so 2 wells working in tandem, one injector and one producer, who form a closed loop pushing cold water down to be heated in a continuous cycle.

Once the heat is siphoned off into campus , the cooled water 20°C is reinjected back down. The system connects directly to a campus wide heating grid.



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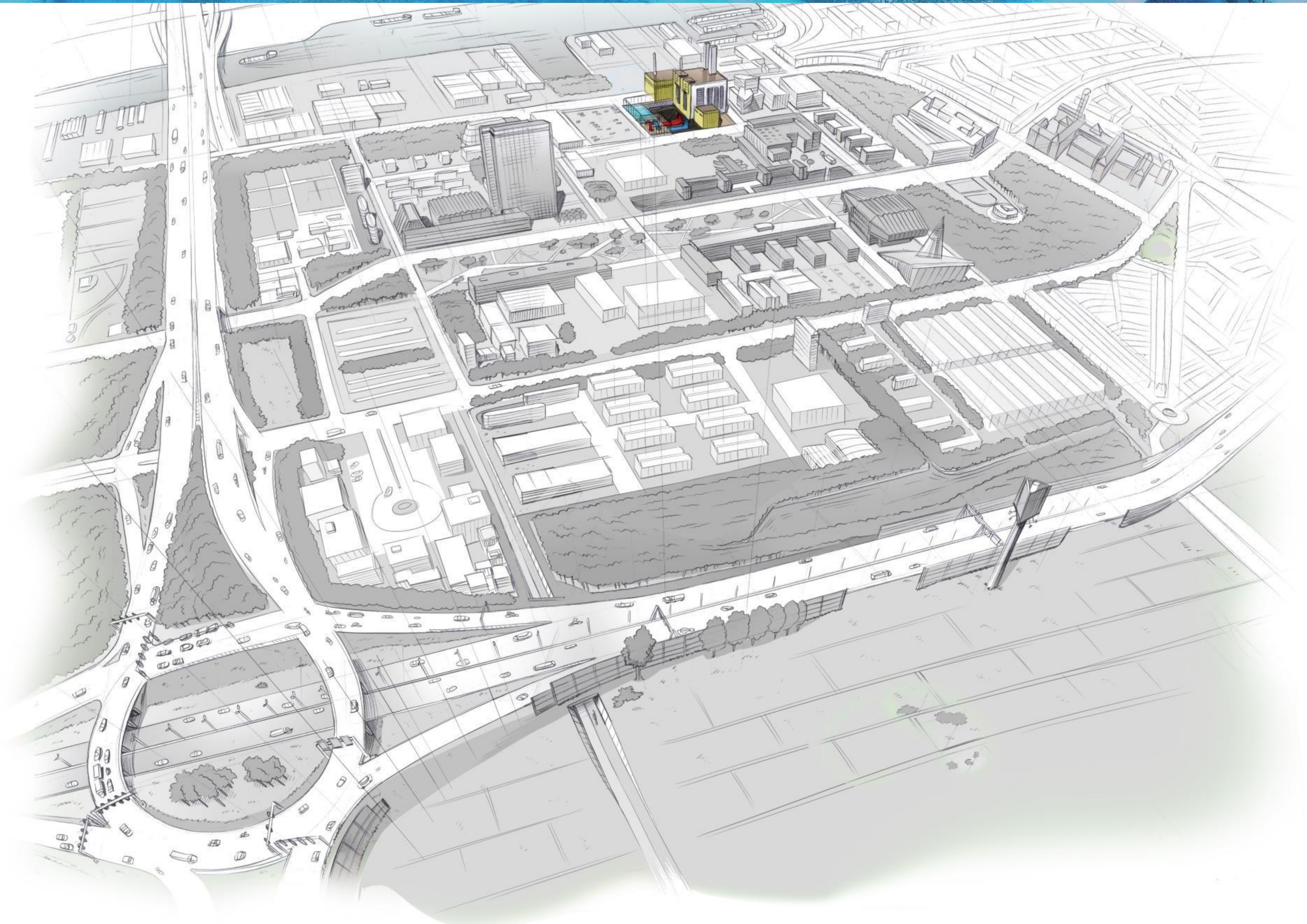
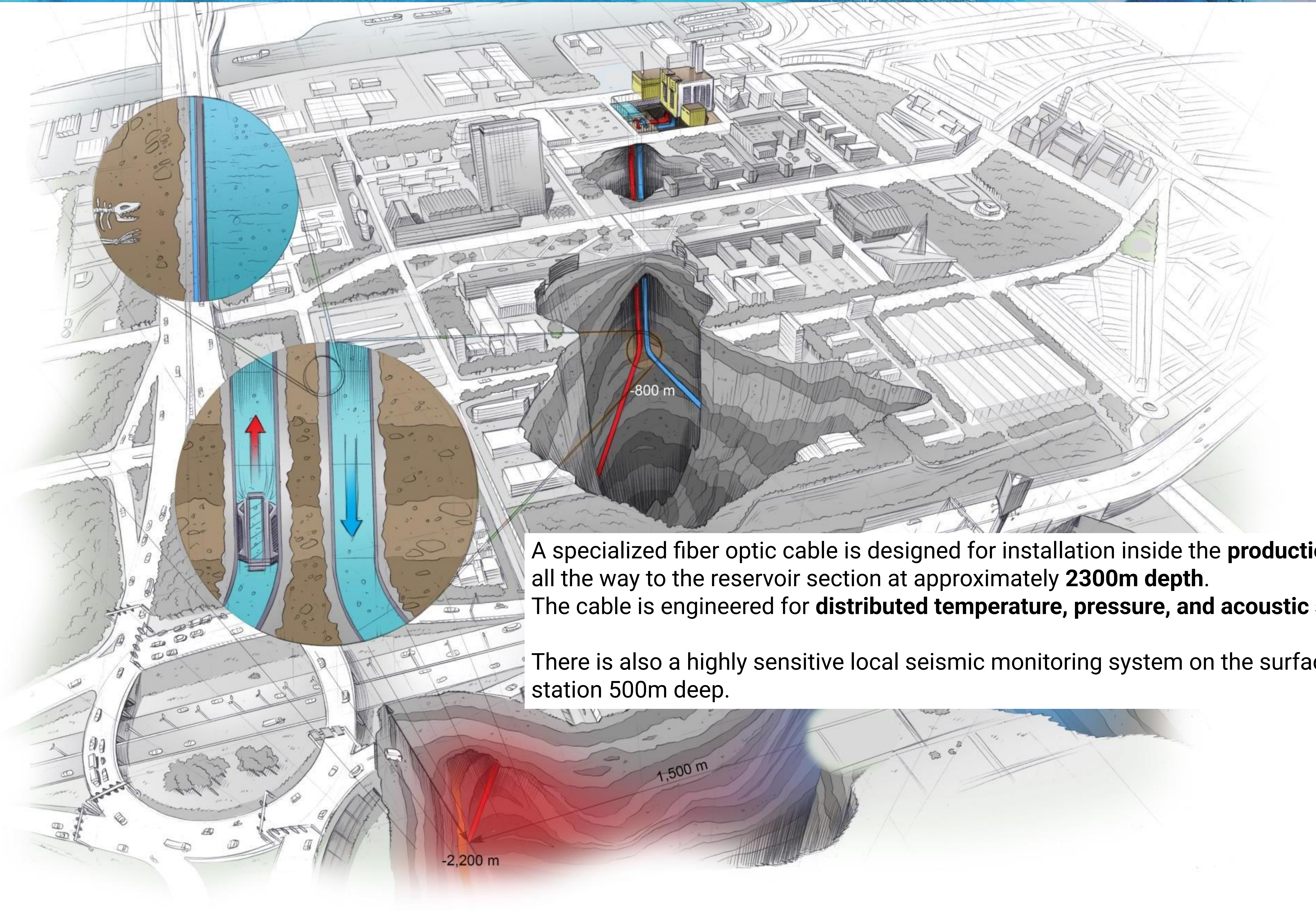
Delft Subsurface Urban Energy Laboratory



Delft Subsurface Urban Energy Laboratory



A specialized fiber optic cable is designed for installation inside the **production well casing** reaching all the way to the reservoir section at approximately **2300m depth**.
The cable is engineered for **distributed temperature, pressure, and acoustic sensing.**

There is also a highly sensitive local seismic monitoring system on the surface, with an observation station 500m deep.

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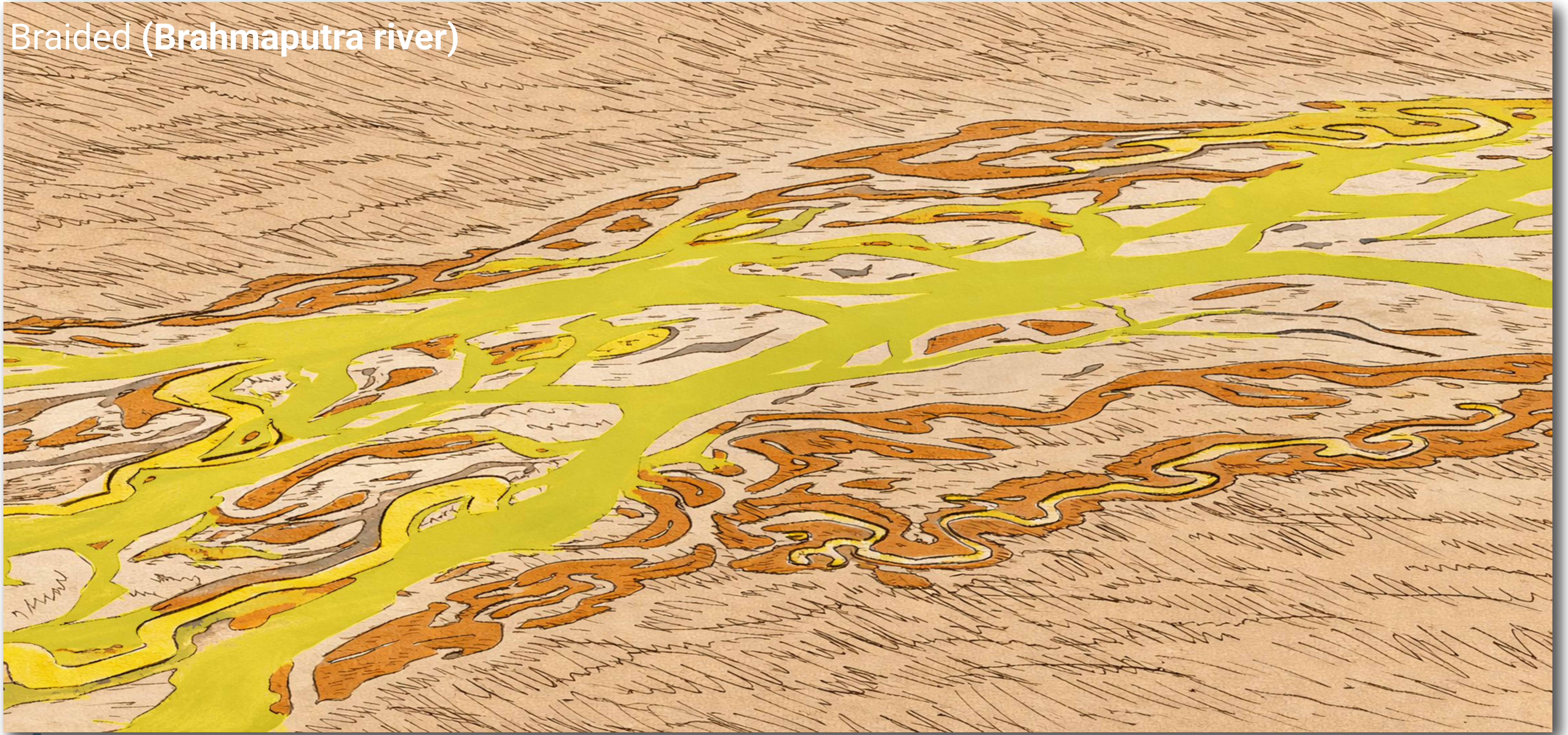
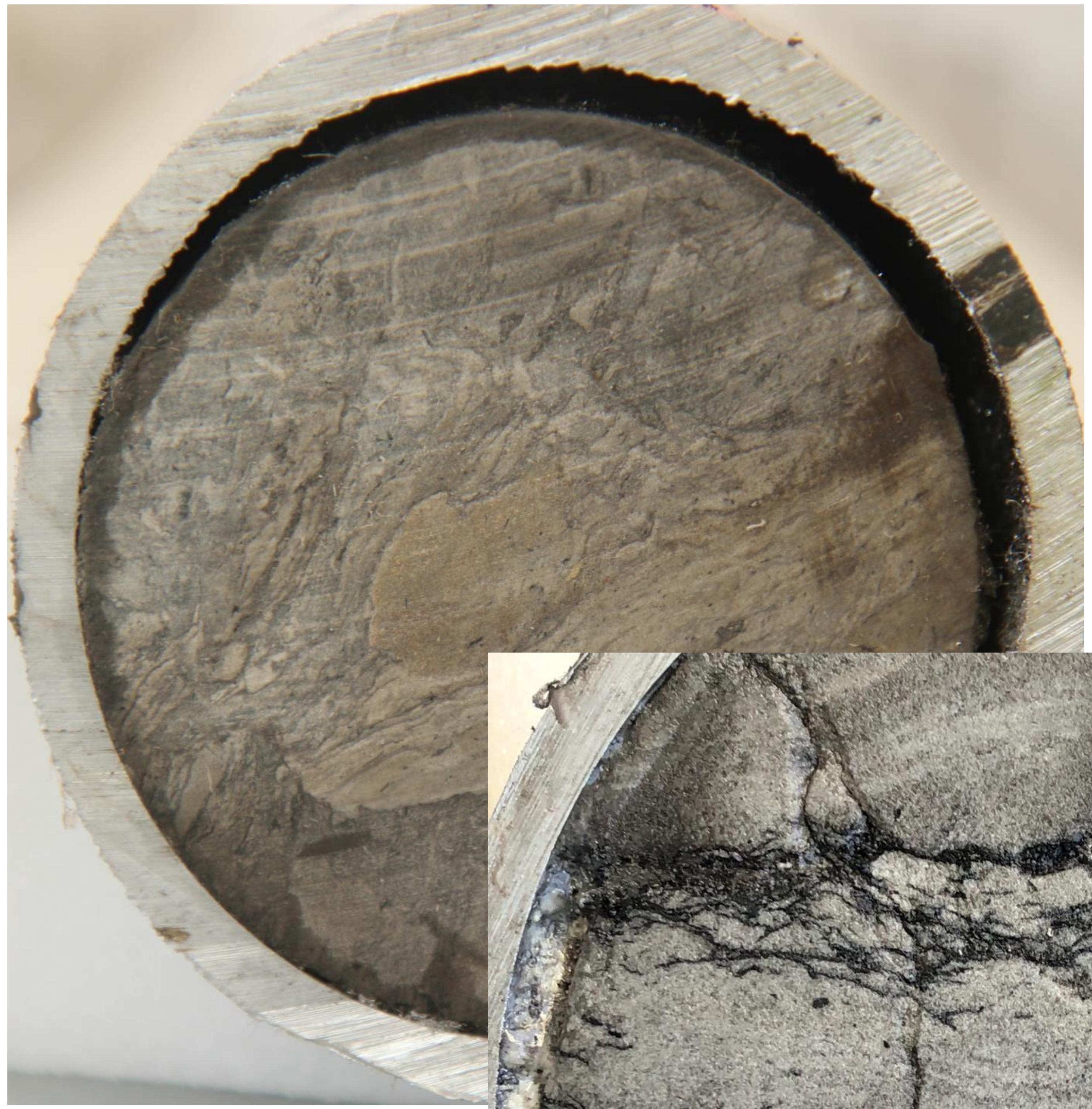
Geological Setting



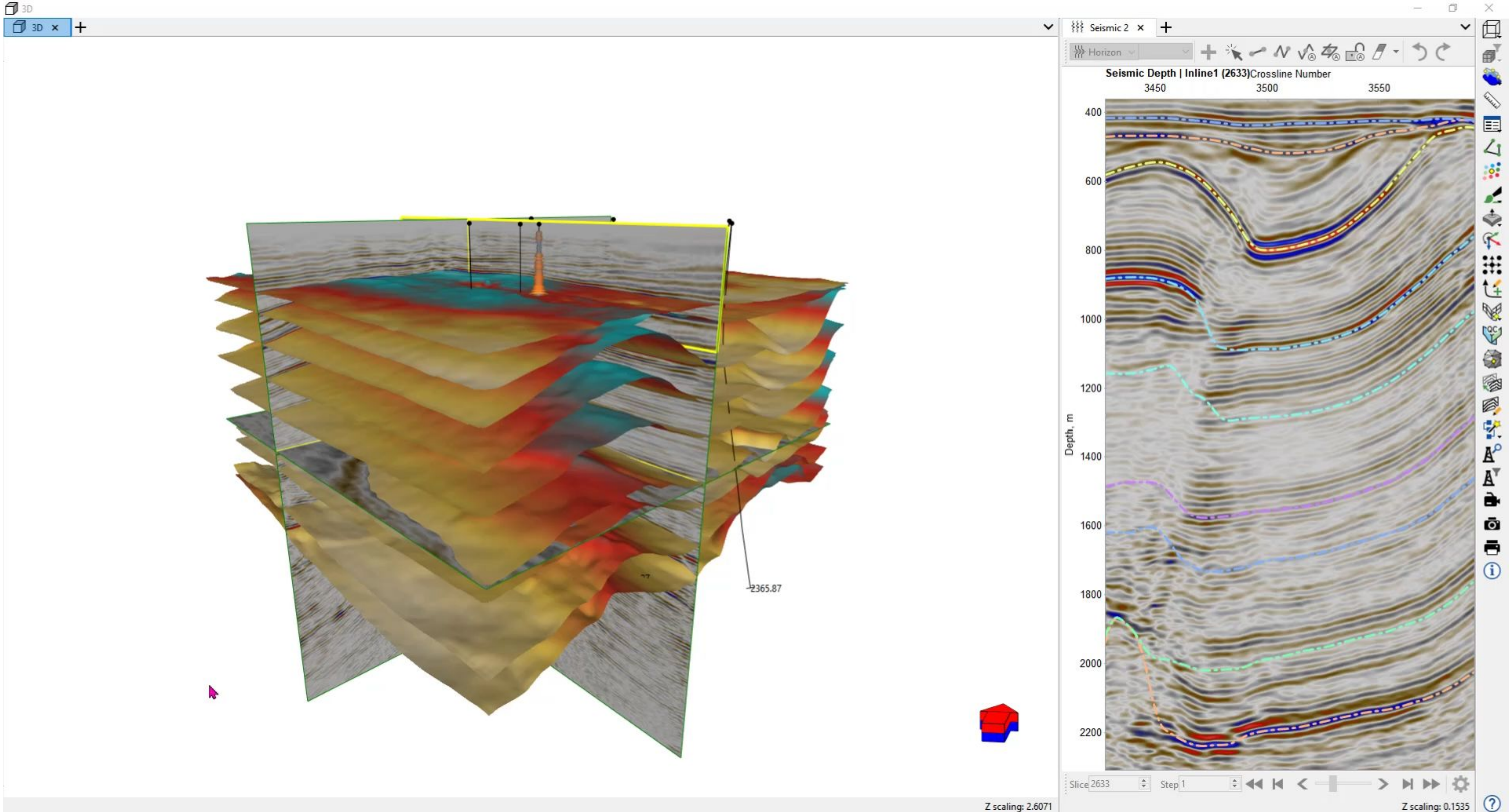
Geological Setting



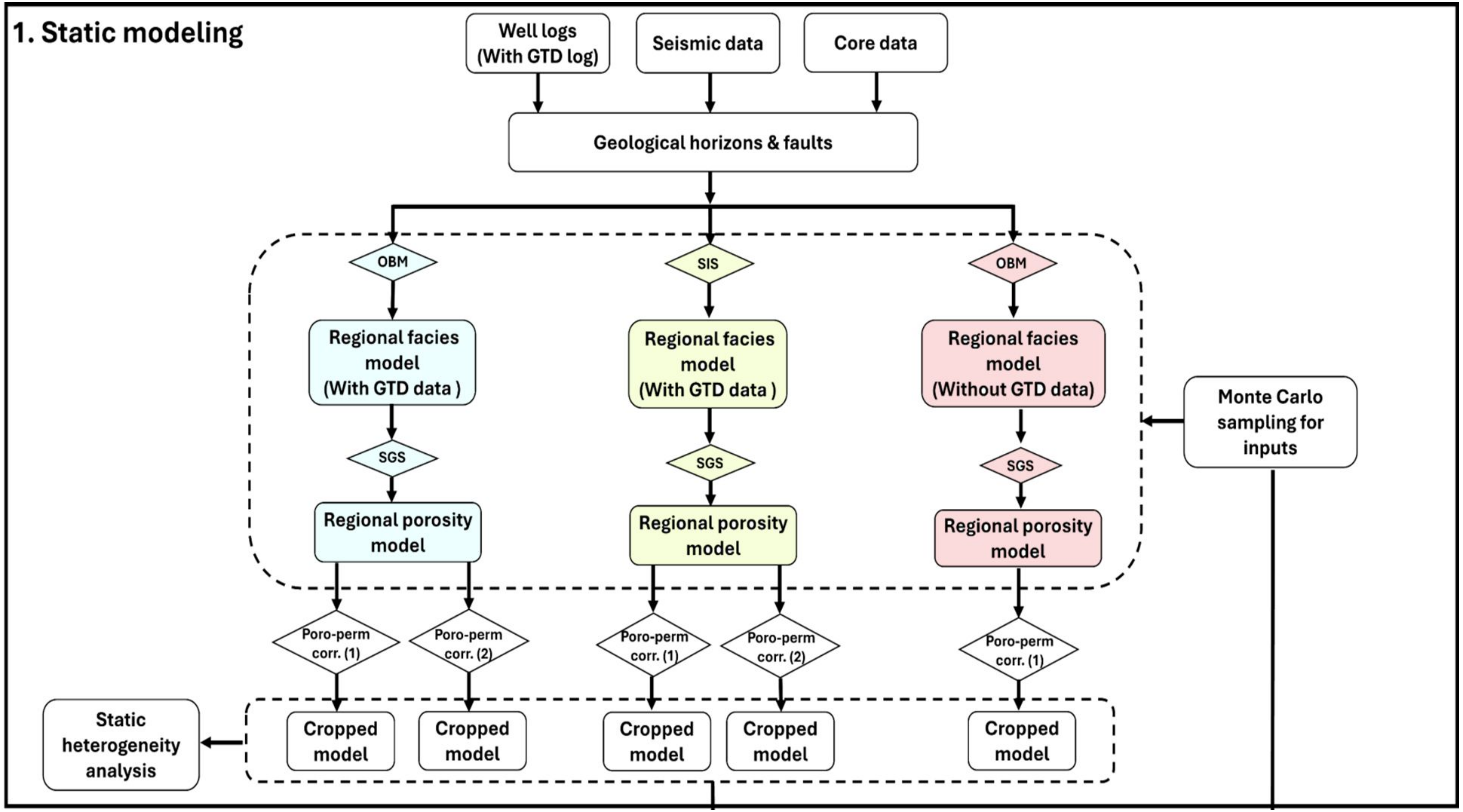
Lower Rodenrijs claystone Stratigraphy and caprock properties

Delft sandstone Sedimentology and properties

Seismic Data

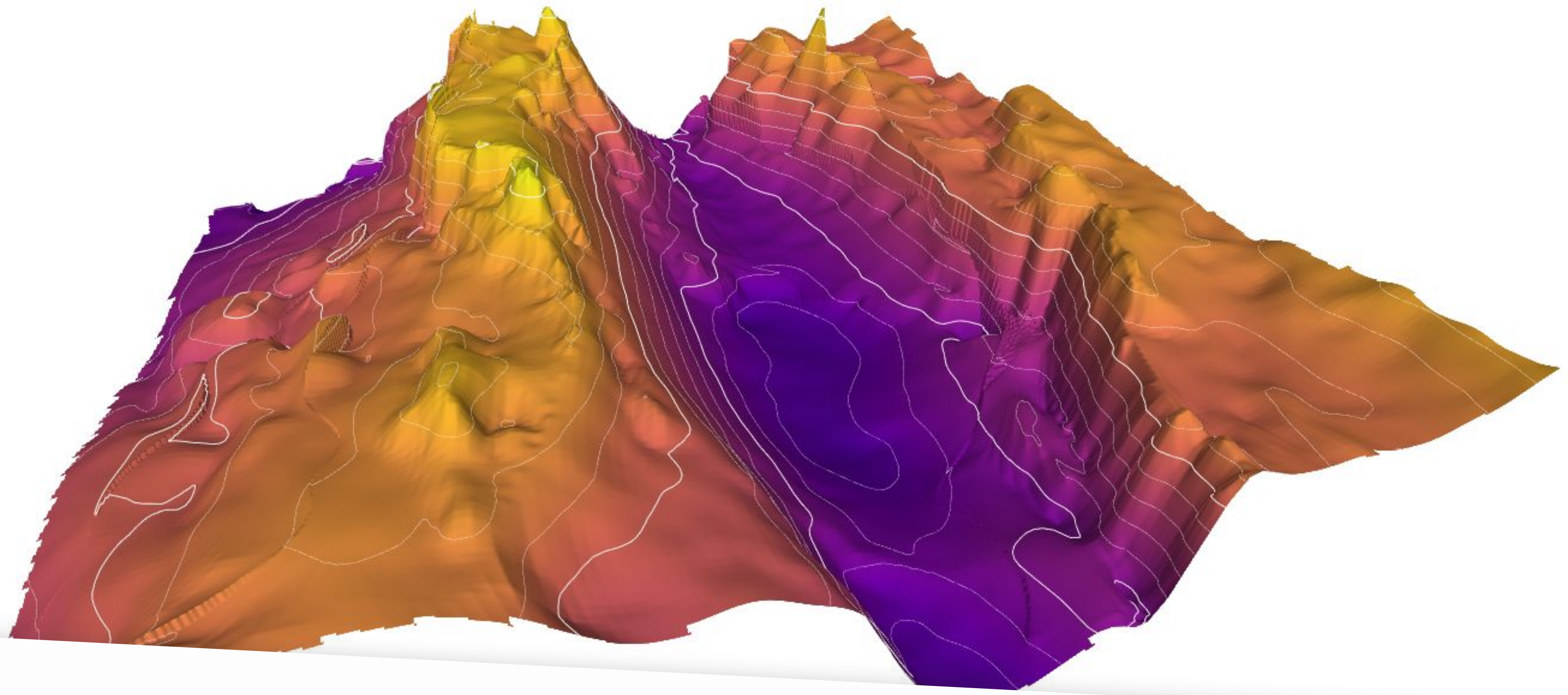


Workflow

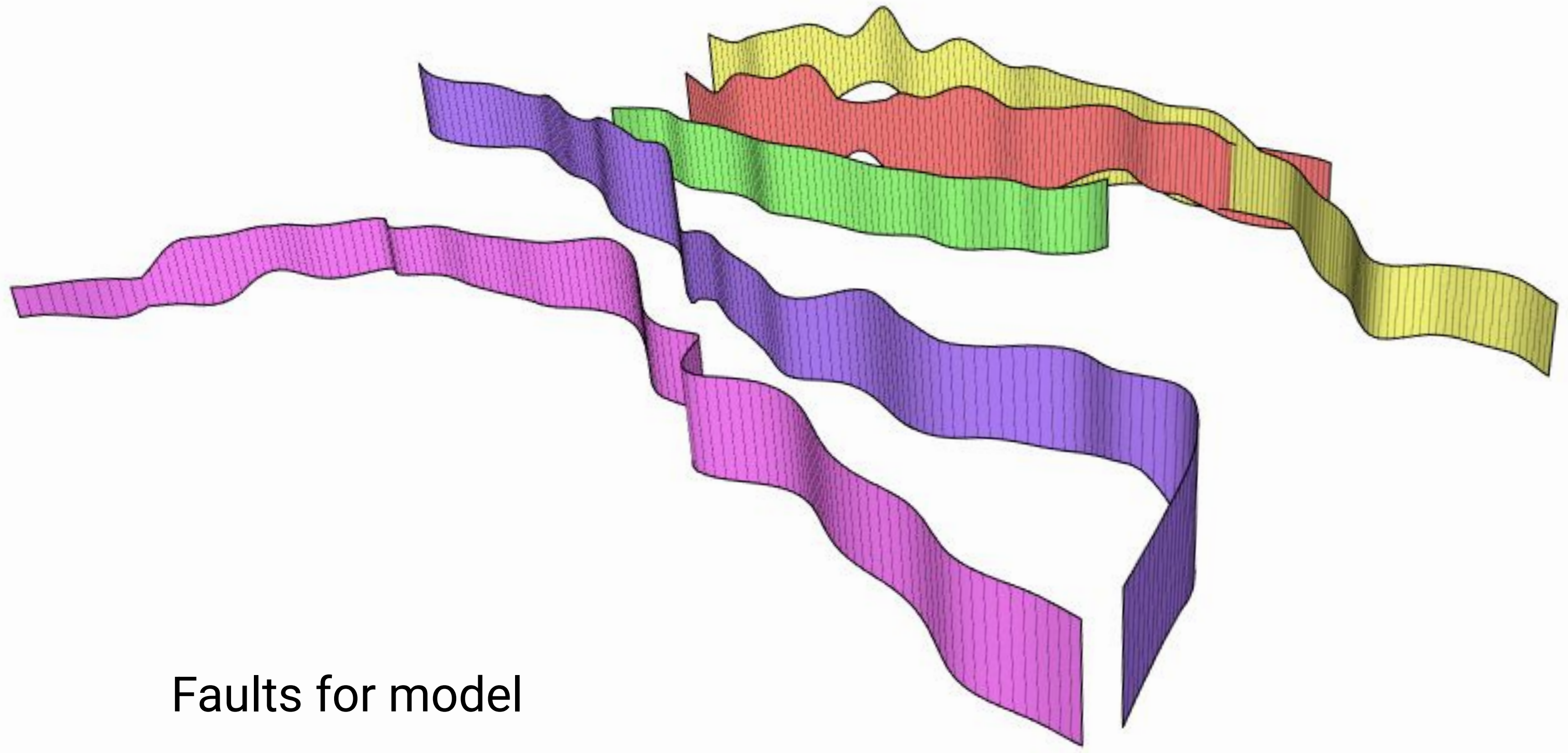


1. Static modeling
Well logs (With GTD log)
Seismic data
Core data
Geological horizons & faults
OBM
SIS
OBM
Regional facies model (With GTD data)
Regional facies model (With GTD data)
Regional facies model (Without GTD data)
Monte Carlo sampling for inputs
SGS
SGS
SGS
Regional porosity model
Regional porosity model
Regional porosity model
Poro-perm corr. (1)
Poro-perm corr. (2)
Poro-perm corr. (1)
Poro-perm corr. (2)
Poro-perm corr. (1)
Static heterogeneity analysis
Cropped model
Cropped model
Cropped model
Cropped model
Cropped model

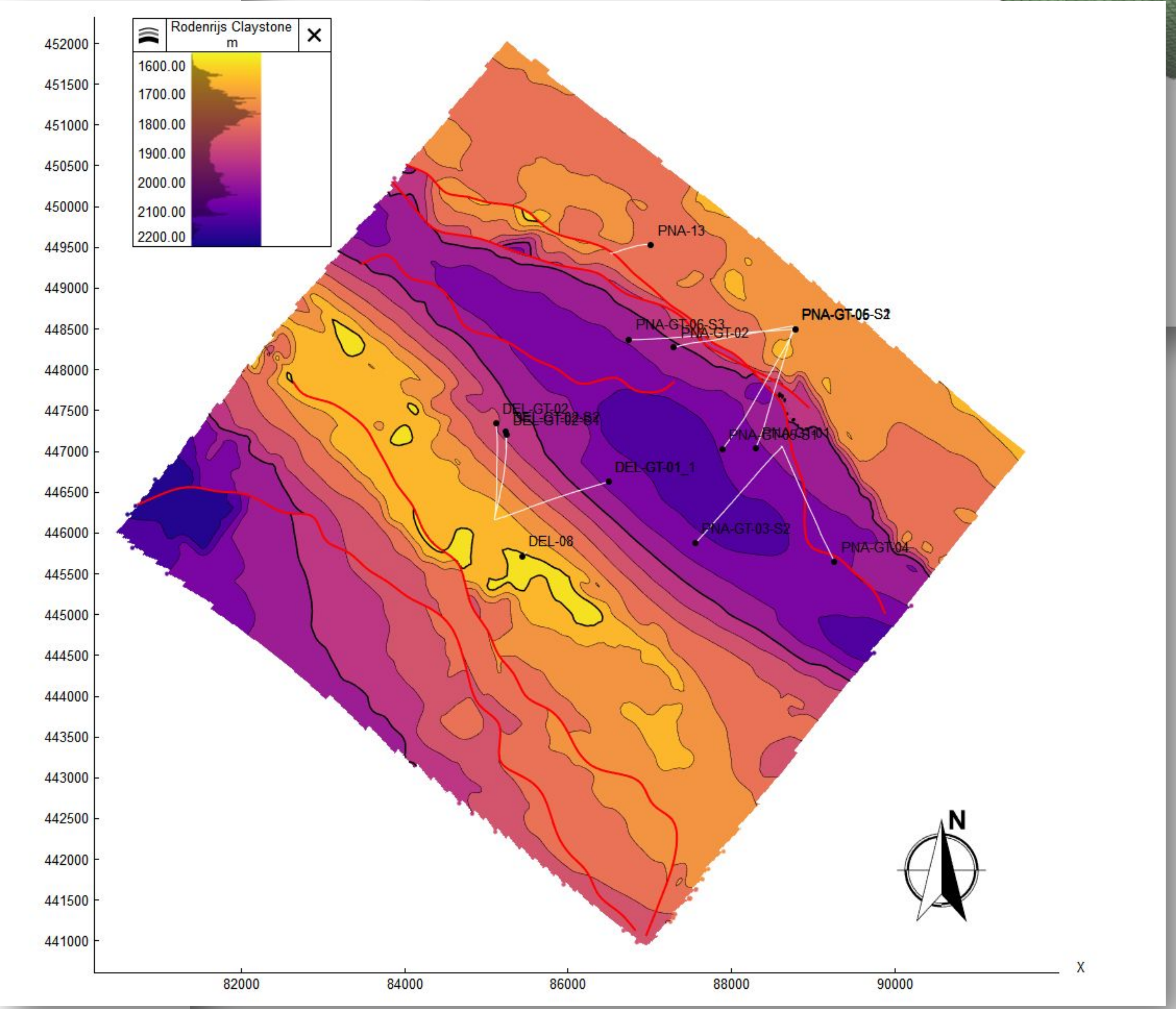
Structural Model

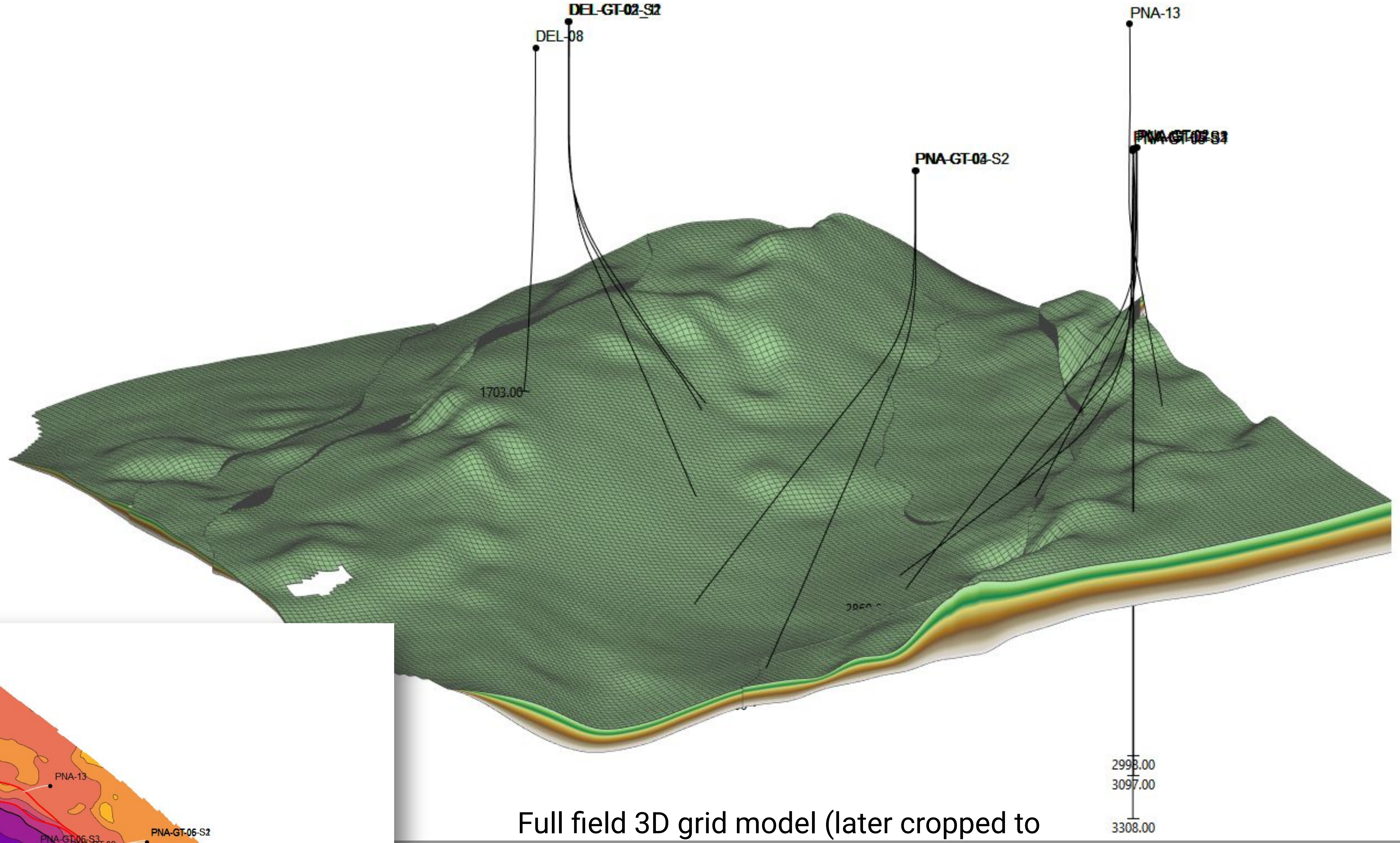


Surfaces picked by geophysicist



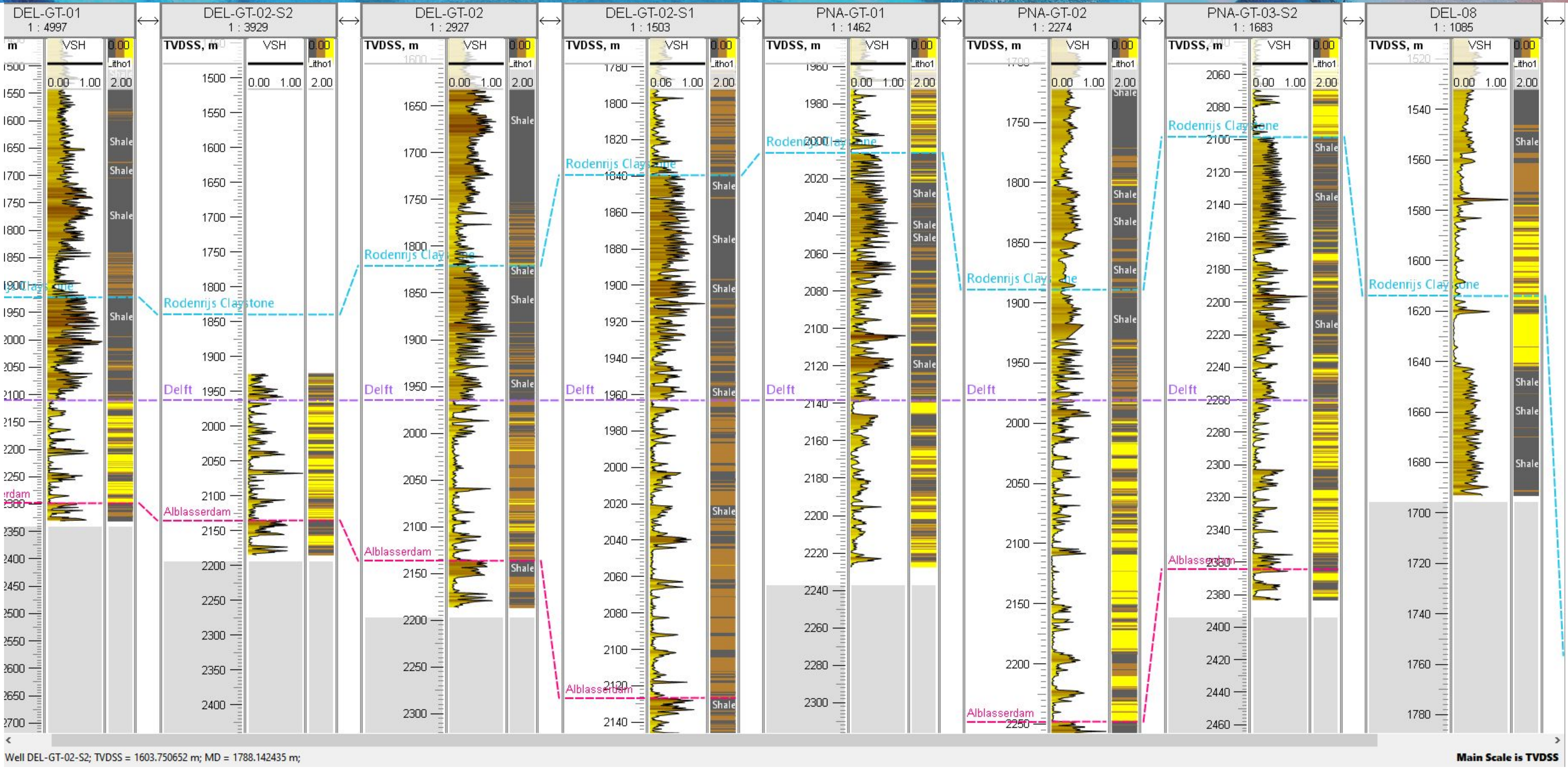
Faults for model





Full field 3D grid model (later cropped to smaller Delft area)

Well section



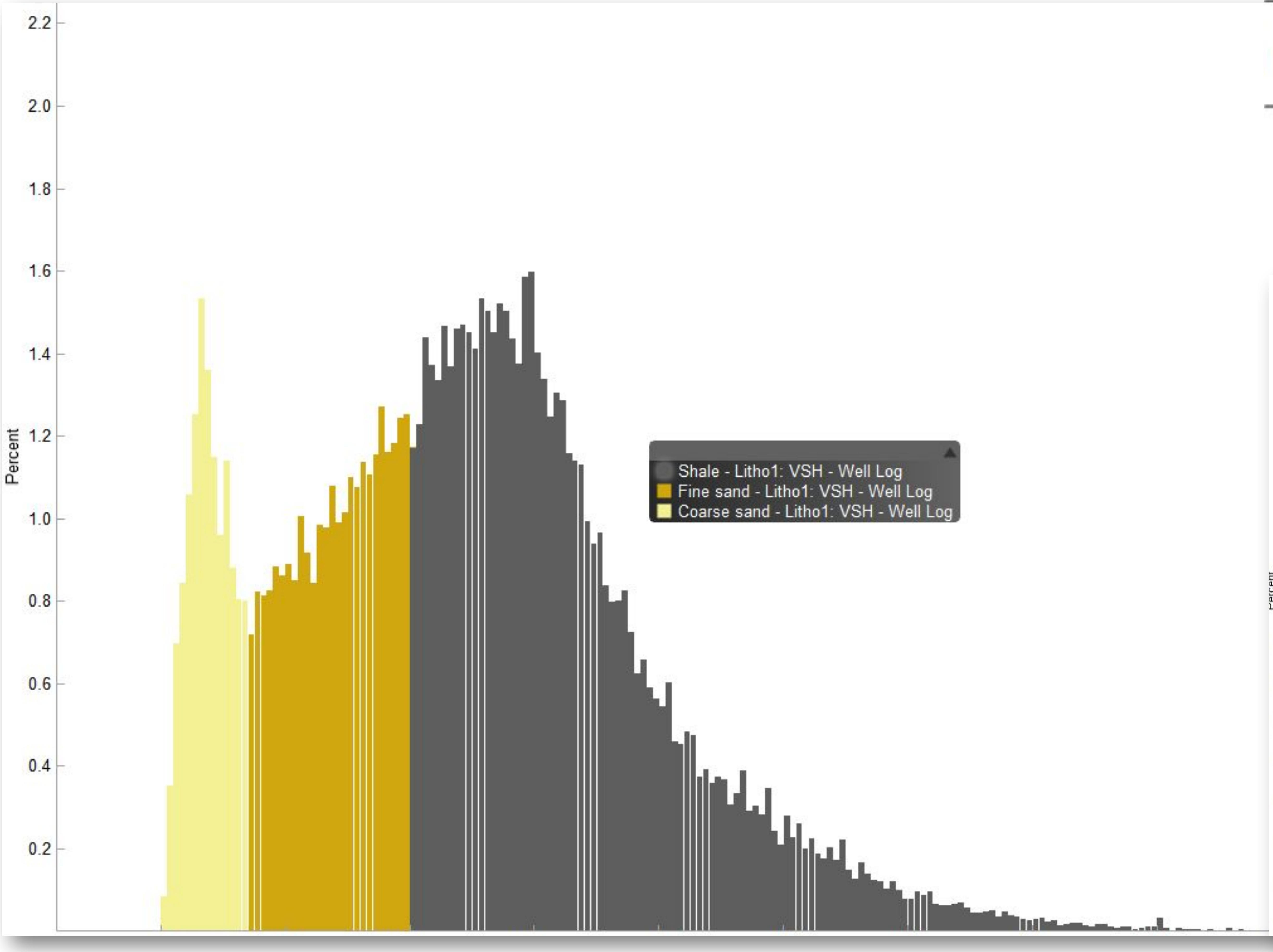
Facies Model

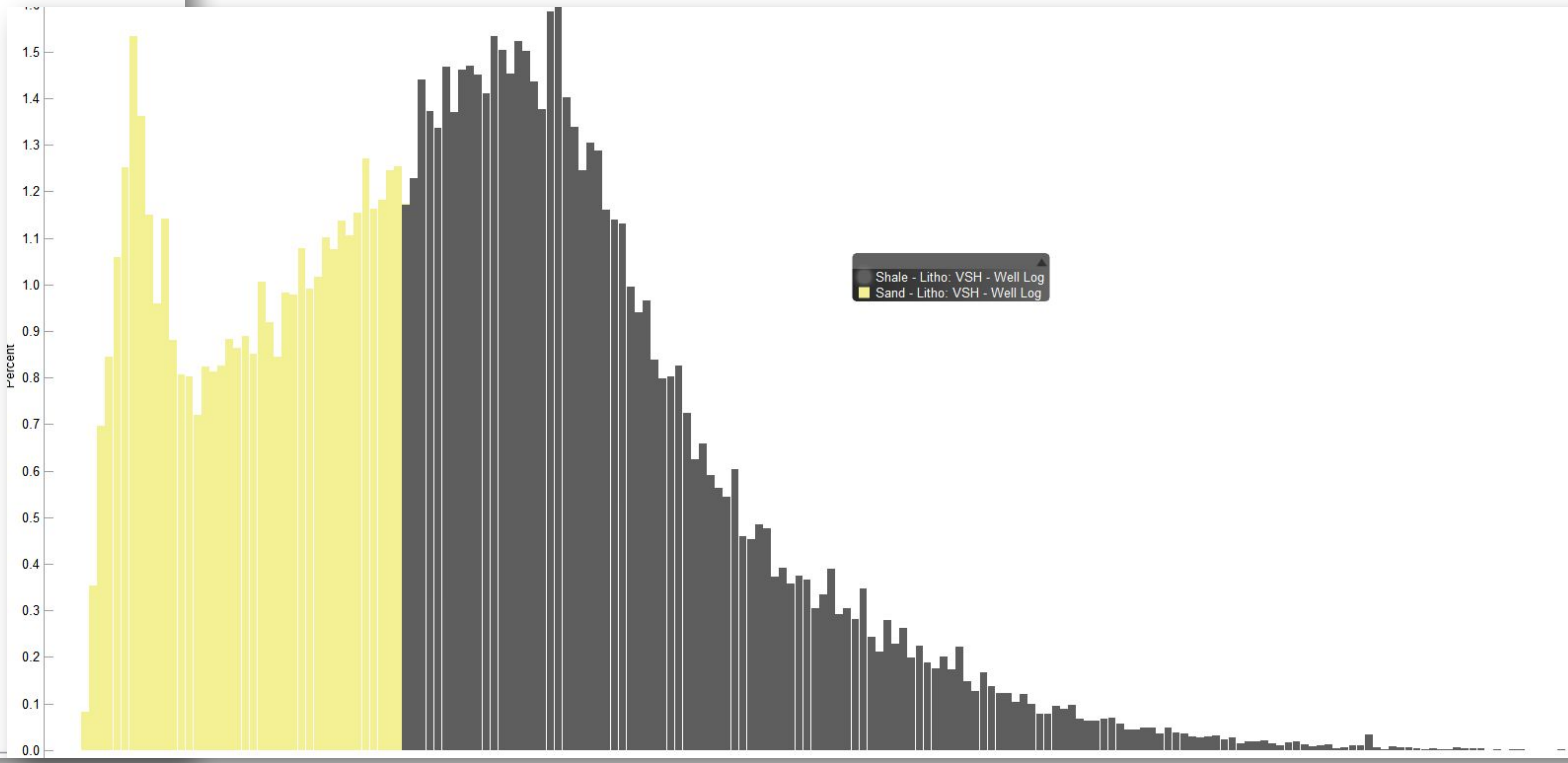
Range	Lithofacies
$V_{sh} \leq 0.2$	Coarse sand
$0.2 < V_{sh} < 0.3$	Fine sand
$V_{sh} \geq 0.3$	Shale

(a) Three lithofacies

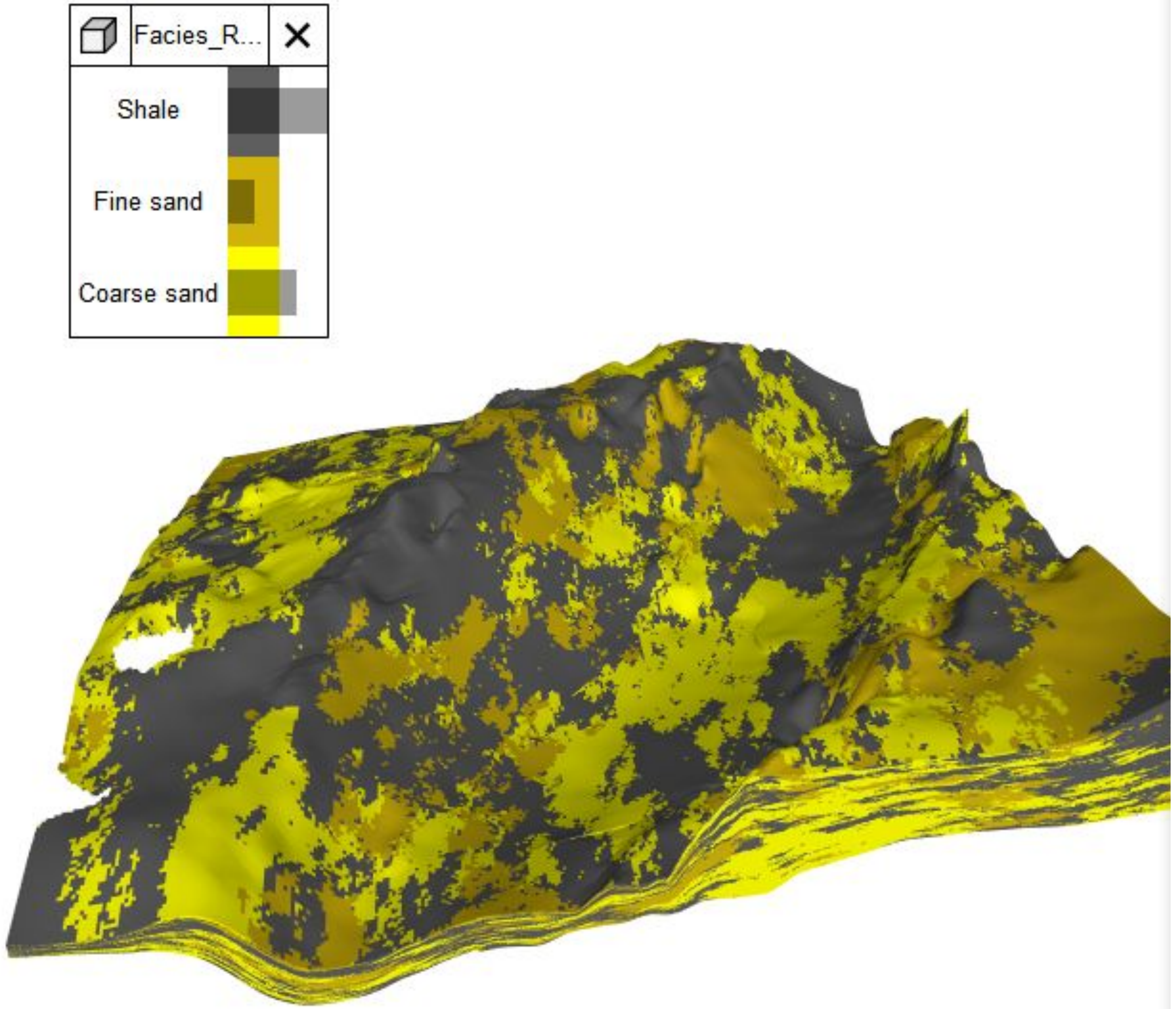
Range	Lithofacies
$V_{sh} < 0.3$	Sand
$V_{sh} \geq 0.3$	Shale

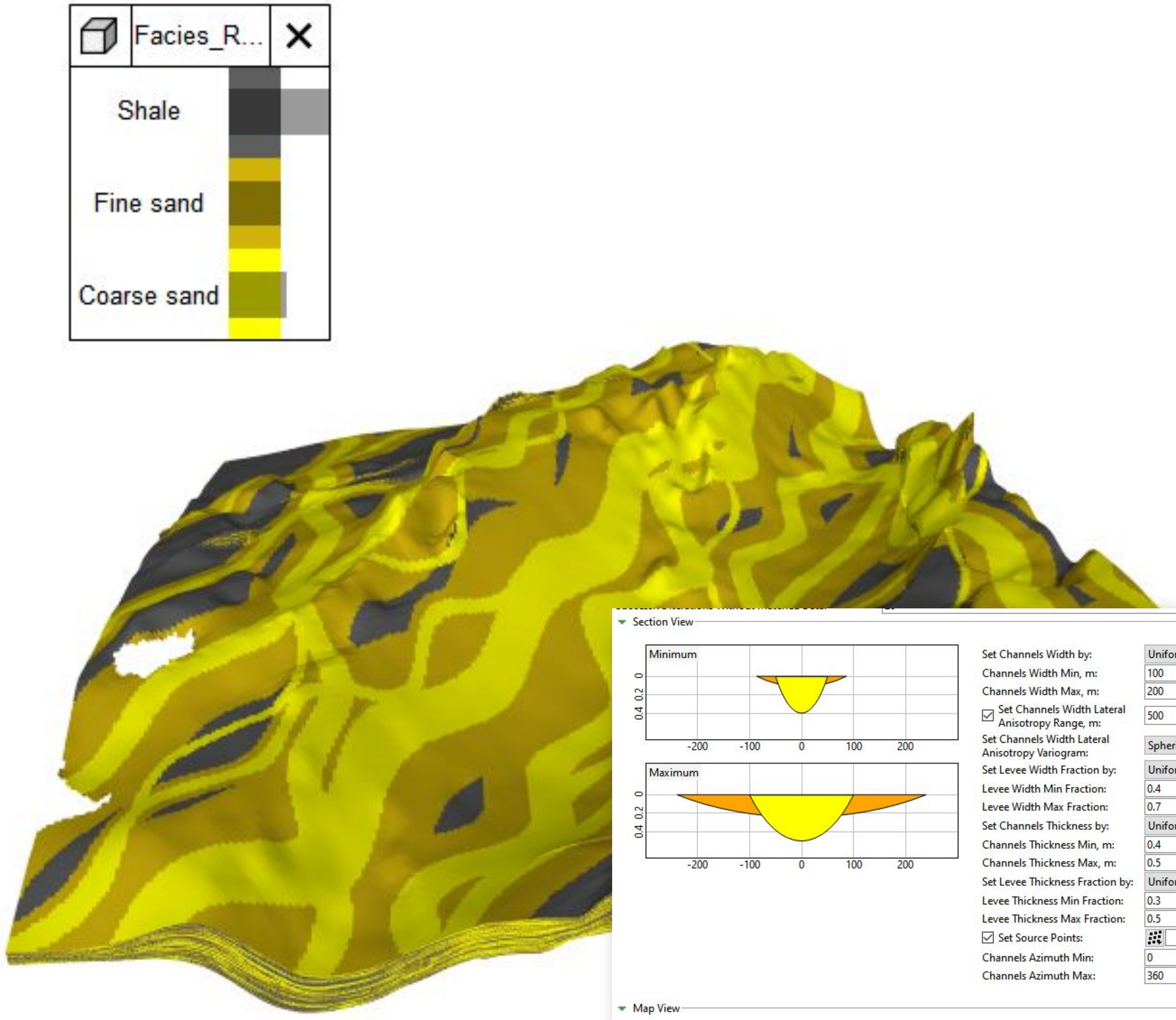
(b) Two lithofacies

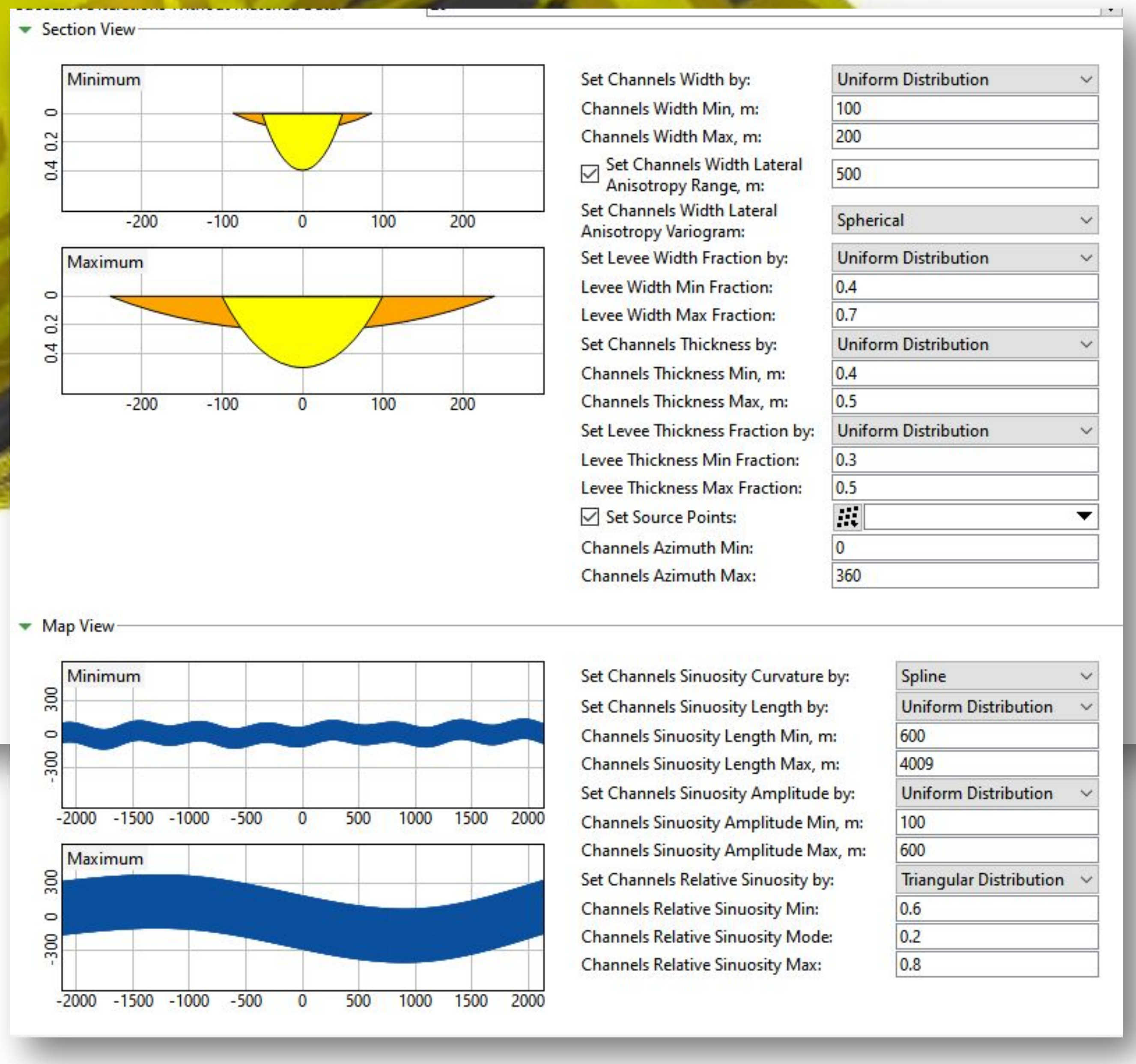




Facies Model







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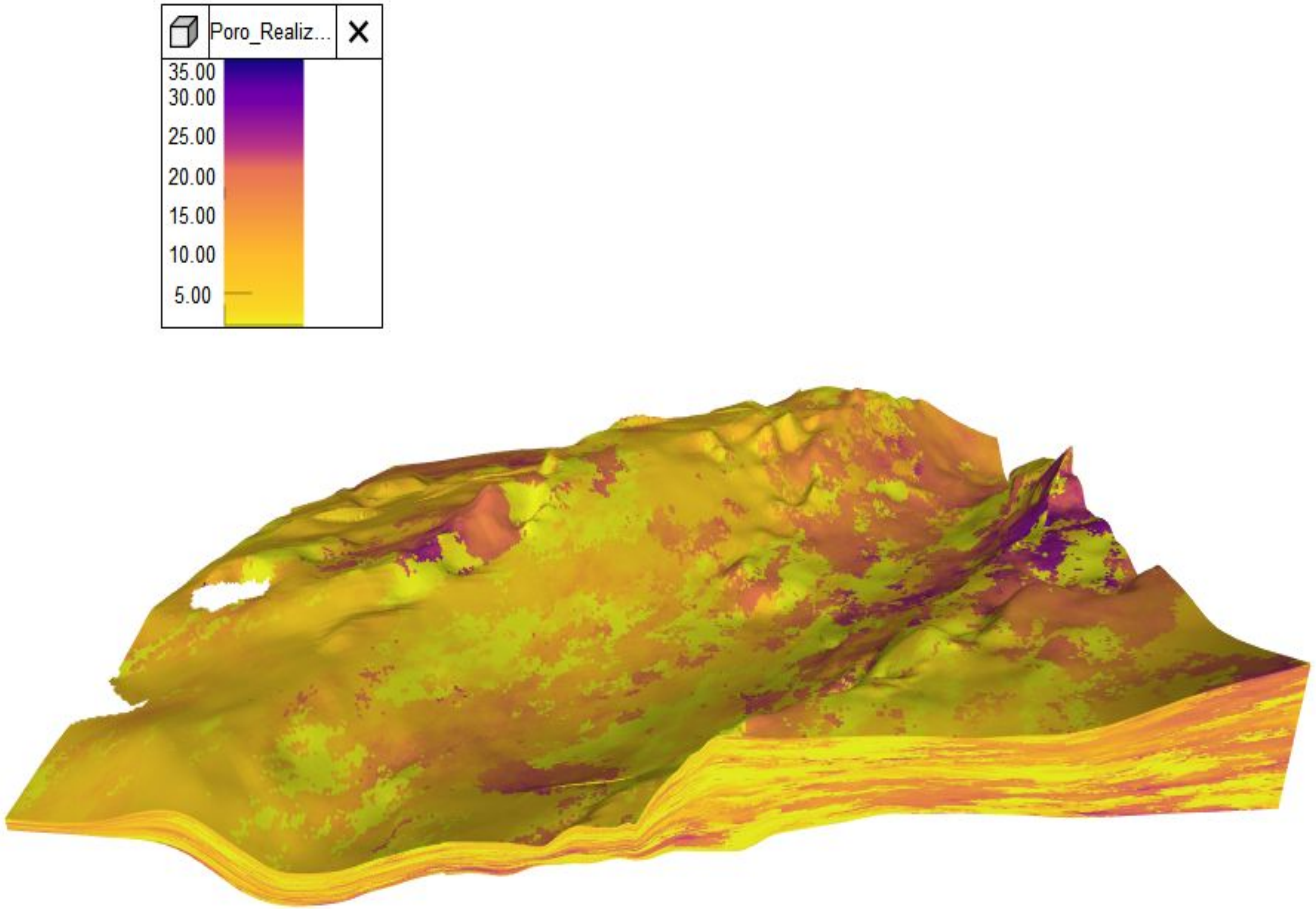
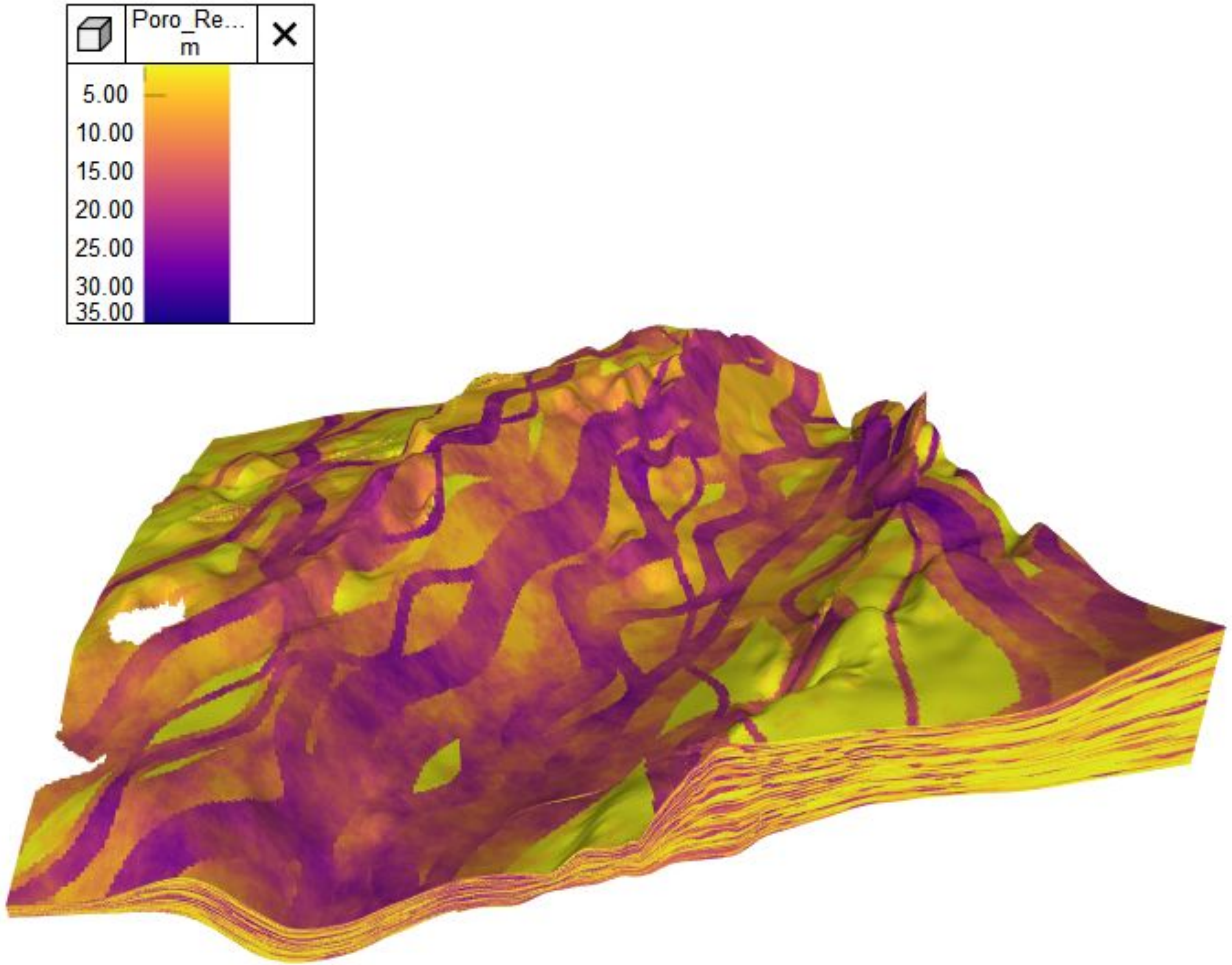
Petrophysical Model





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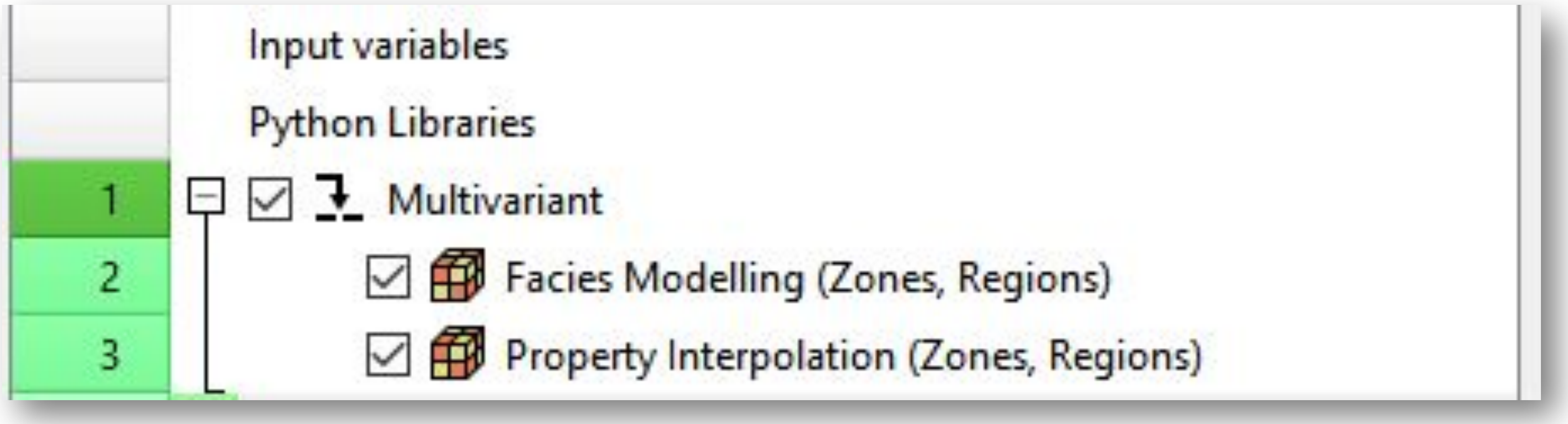
Ensemble of Models

Parameter name	Abbreviation	Distribution
N/G ratio	NTG	U[20%, 80%]
Maximum channel width	CW_MAX	U[192 m, 600 m]
Minimum channel width	CW_MIN	U[12 m, 30 m]
Semivariogram major range (Coarse sand/Sand)	CSNAD_MAJOR/SAND_MAJOR	U[362 m, 1086 m]
Semivariogram normal range (Coarse sand/Sand)	CSNAD_NORM/SAND_NORM	U[181 m, 724 m]
Semivariogram vertical range (Coarse sand/Sand)	CSNAD_VERT/SAND_VERT	U[5.89 m, 17.67 m]
Semivariogram major range (Fine sand)	FSAND_MAJOR	U[850 m, 1086 m]
Semivariogram normal range (Fine sand)	FSAND_NORM	U[212 m, 850 m]
Semivariogram vertical range (Fine sand)	FSAND_VERT	U[7.28 m, 21.84 m]
Maximum levee width fraction	LV_WIDTH_FRA_MAX	U[1.5, 2]
Minimum levee width fraction	LV_WIDTH_FRA_MIN	U[0.5, 1]
Maximum channel thickness	CH_THICK_MAX	U[4 m, 5 m]
Minimum channel thickness	CH_THICK_MIN	U[0.5 m, 1 m]
Maximum levee thickness fraction	LV_THICK_FRA_MAX	U[0.8, 1]
Minimum levee thickness fraction	LV_THICK_FRA_MIN	U[0.2, 0.5]
Maximum channel wavelength	WAVE_MAX	U[1000 m, 1200 m]
Minimum channel wavelength	WAVE_MIN	U[2000 m, 2400 m]
Maximum channel amplitude	AMPL_MAX	U[200 m, 300 m]
Minimum channel amplitude	AMPL_MIN	U[800 m, 900 m]
Maximum channel azimuth	AZIMU_MAX	U[260, 270]
Minimum channel azimuth	AZIMU_MIN	U[310, 330]
Porosity permeability correlation	POROPERM	[1, 2]



Multivariant

Algorithm type: Monte Carlo
Number of Variants: 28
Random Seed: 343536
Suffix: Realization32
Folder: Workflow2
☑ Overwrite Existing Objects

	Base value	Min. value	Max. value	Type	Distribution
NTG	0.4	0.2	0.8	real	Uniform ...
SEED_FACIES	100	0	1000	inte...	Discrete (0...
SEED_PORO	1100	1000	5000	inte...	Discrete ...
CW_MAX	300	192	600	real	Uniform ...
CW_MIN	20	12	30	real	Uniform ...
CSAND_MAJOR	724	362	1086	real	Uniform ...
CSAND_NORM	362	181	724	real	Uniform ...
CSAND_VERT	11.78	5.89	17.67	real	Uniform ...
FSAND_MAJOR	850	425	1275	real	Uniform ...
FSAND_NORM	425	212	850	real	Uniform ...
FSAND_VERT	14.56	7.28	21.84	real	Uniform ...
LV_WIDTH_FRA_MIN	0.7	0.5	1	real	Uniform ...
LV_WIDTH_FRA_MAX	1.7	1.6	2	real	Uniform ...
CH_THICK_MAX	4.5	4	5	real	Uniform ...
CH_THICK_MIN	1	0.5	1.5	real	Uniform ...
LV_THICK_FRA_MAX	0.9	0.8	1	real	Uniform ...
LV_THICK_FRA_MIN	0.3	0.2	0.5	real	Uniform ...
WAVE_MIN	1100	1000	1200	real	Uniform ...
WAVE_MAX	2200	2000	2400	real	Uniform ...
AMPL_MIN	250	200	300	real	Uniform ...
AMPL_MAX	850	800	900	real	Uniform ...
AZIMU_MIN	265	260	270	real	Uniform ...
AZIMU_MAX	320	310	330	real	Uniform ...

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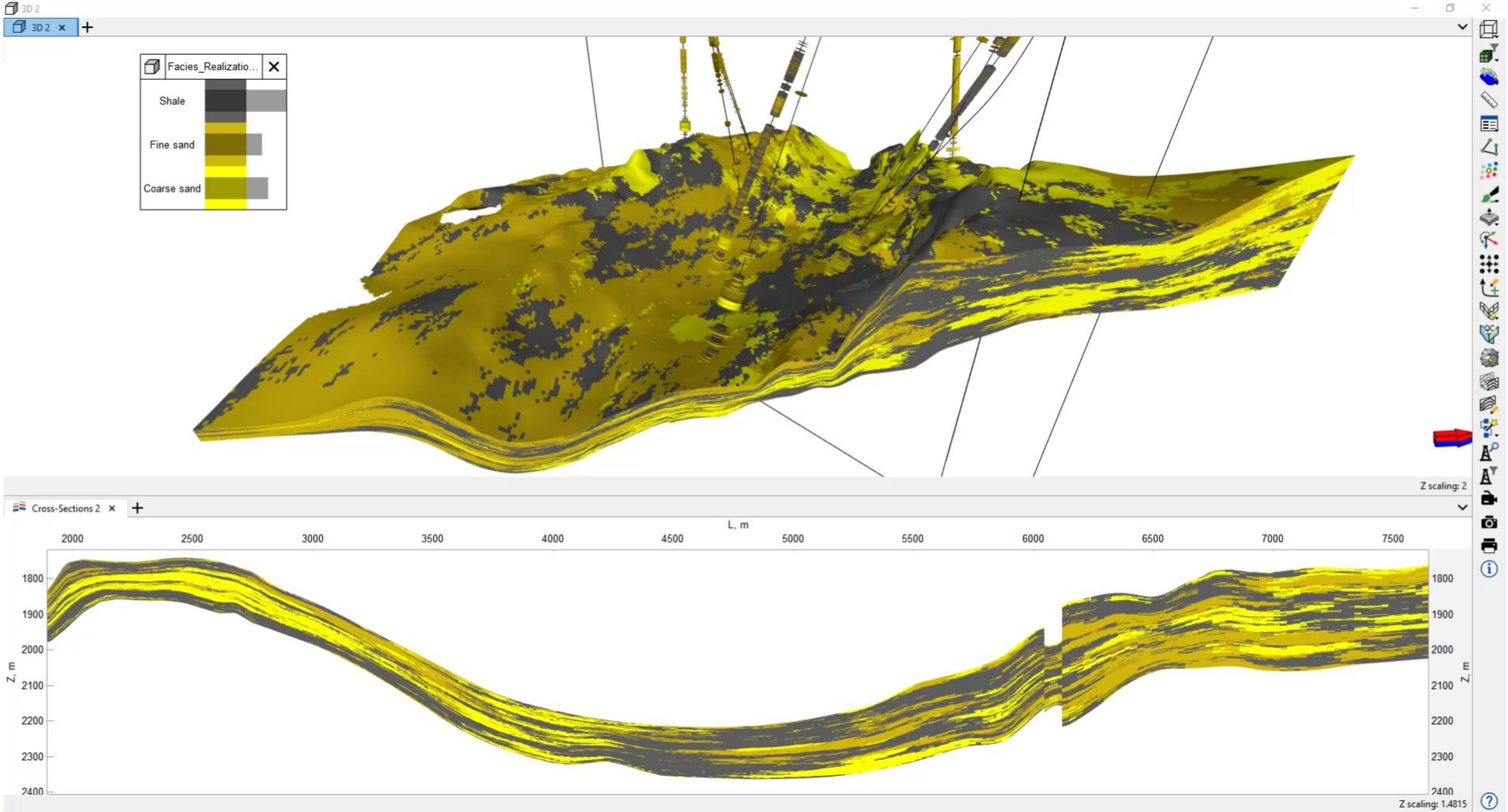
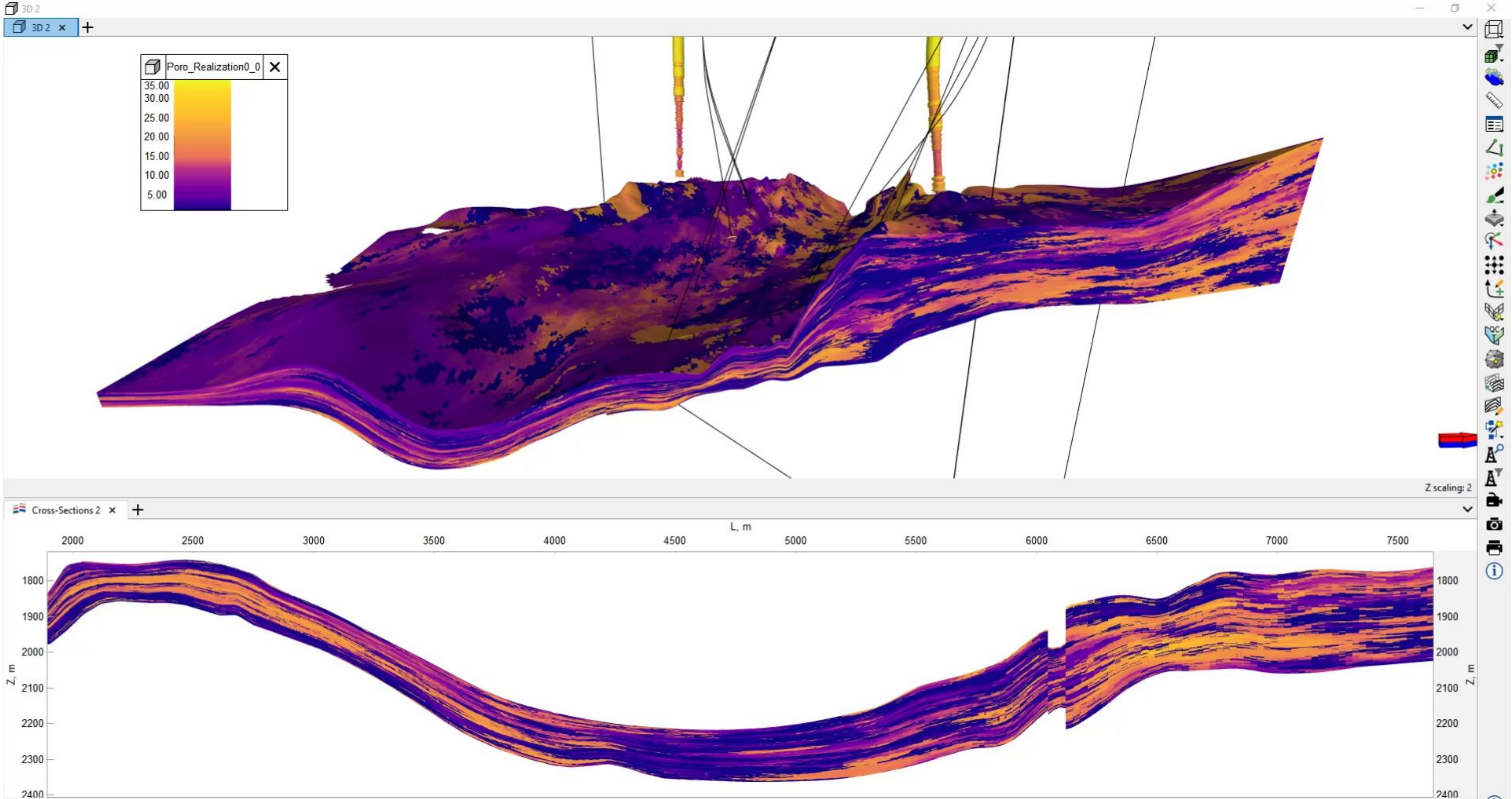
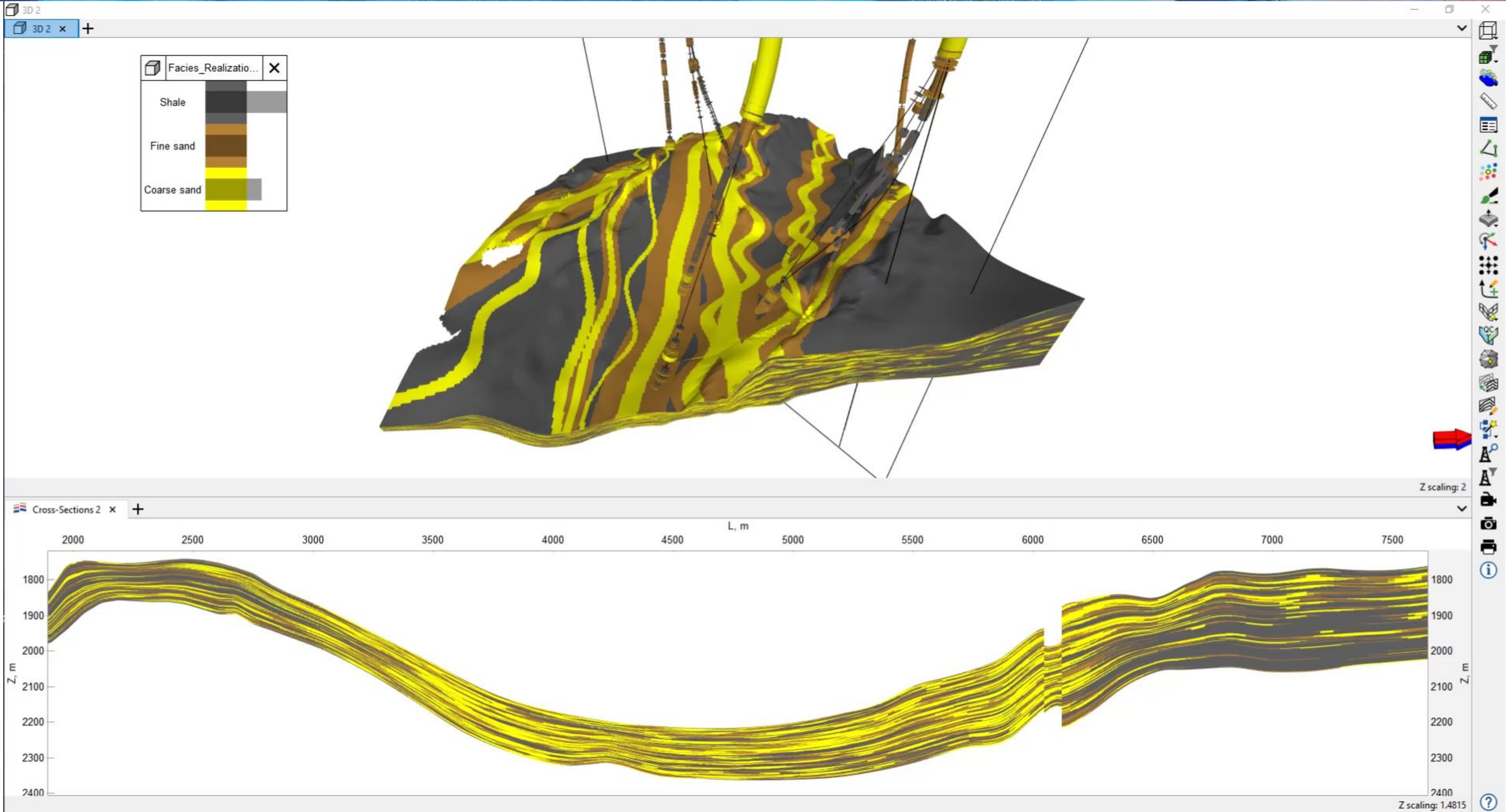
Facies SIS


3D 2
Facies_Realizatio...
Shale
Fine sand
Coarse sand
Z scaling: 2
Cross-Sections 2
L, m
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
1800
1900
2000
2100
2200
2300
2400
Z, m
Z scaling: 1.4815

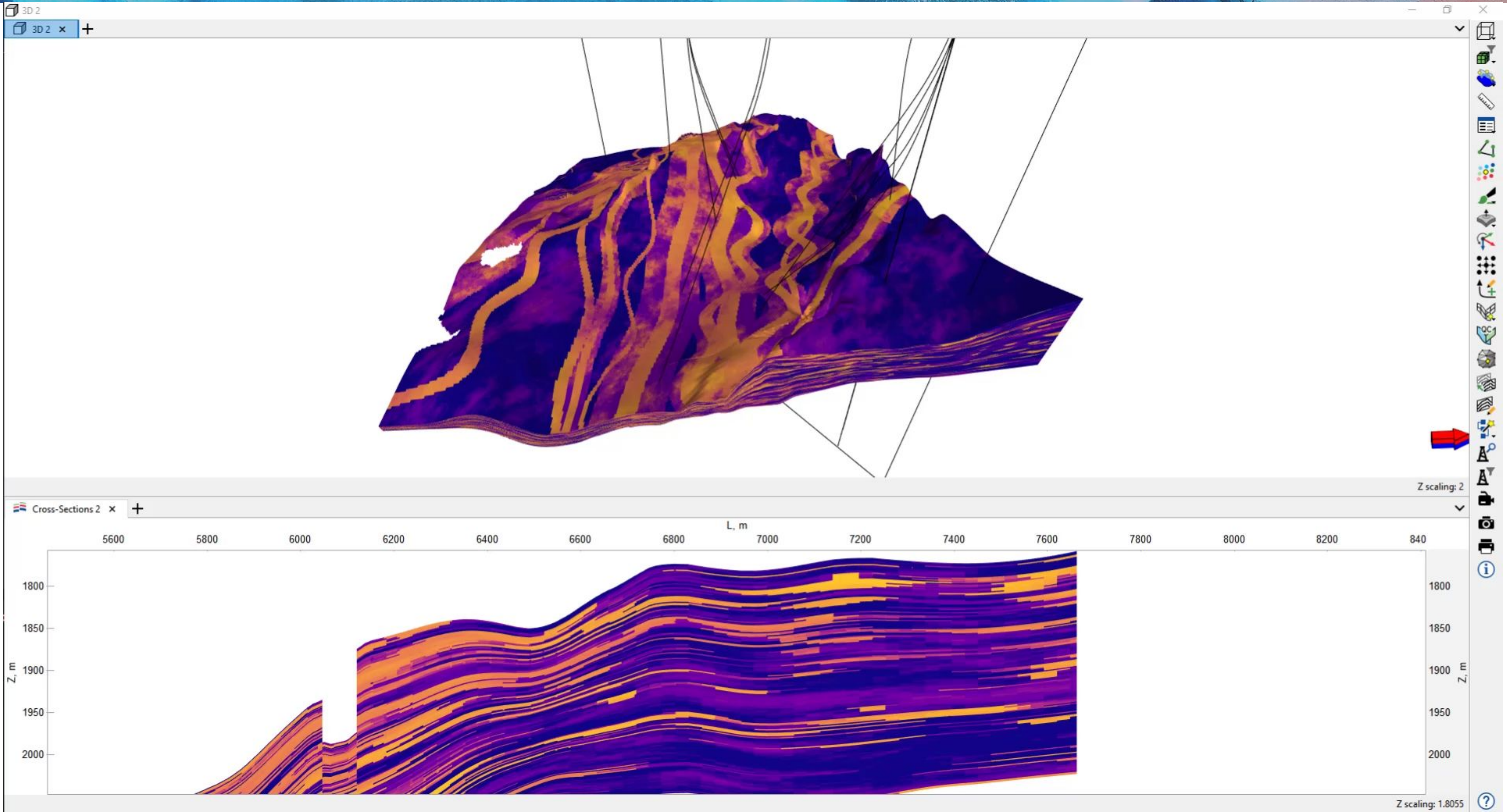
PHIE SGS


3D 2
Poro_Realization0_0
35.00
30.00
25.00
20.00
15.00
10.00
5.00
Z scaling: 2
Cross-Sections 2
L, m
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
Z, m
1800
1900
2000
2100
2200
2300
2400

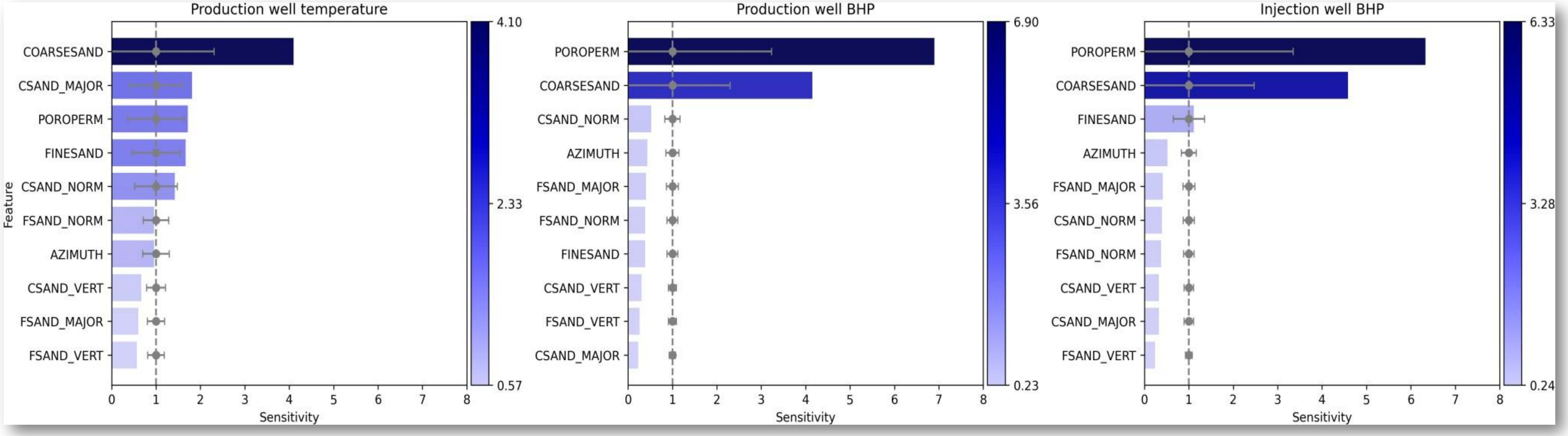
Facies Object Model

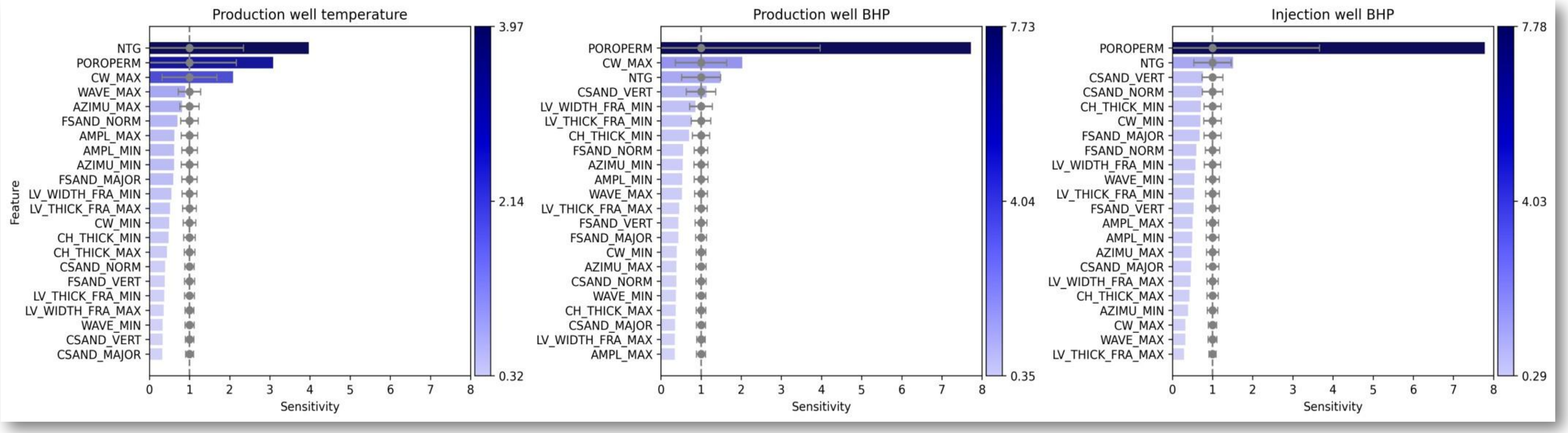


PHIE Object Model

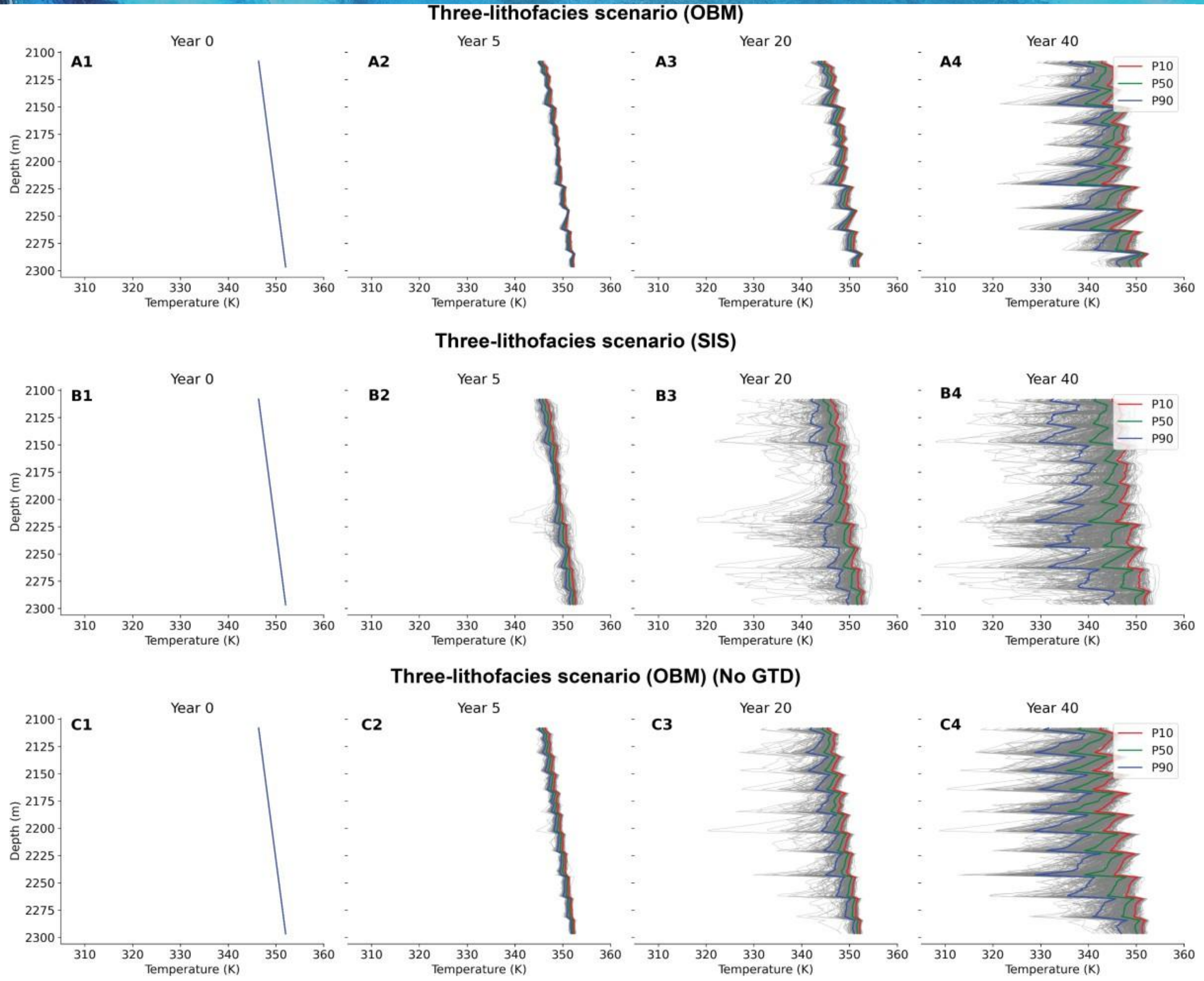


Sensitivity Analysis





Dynamic Simulation

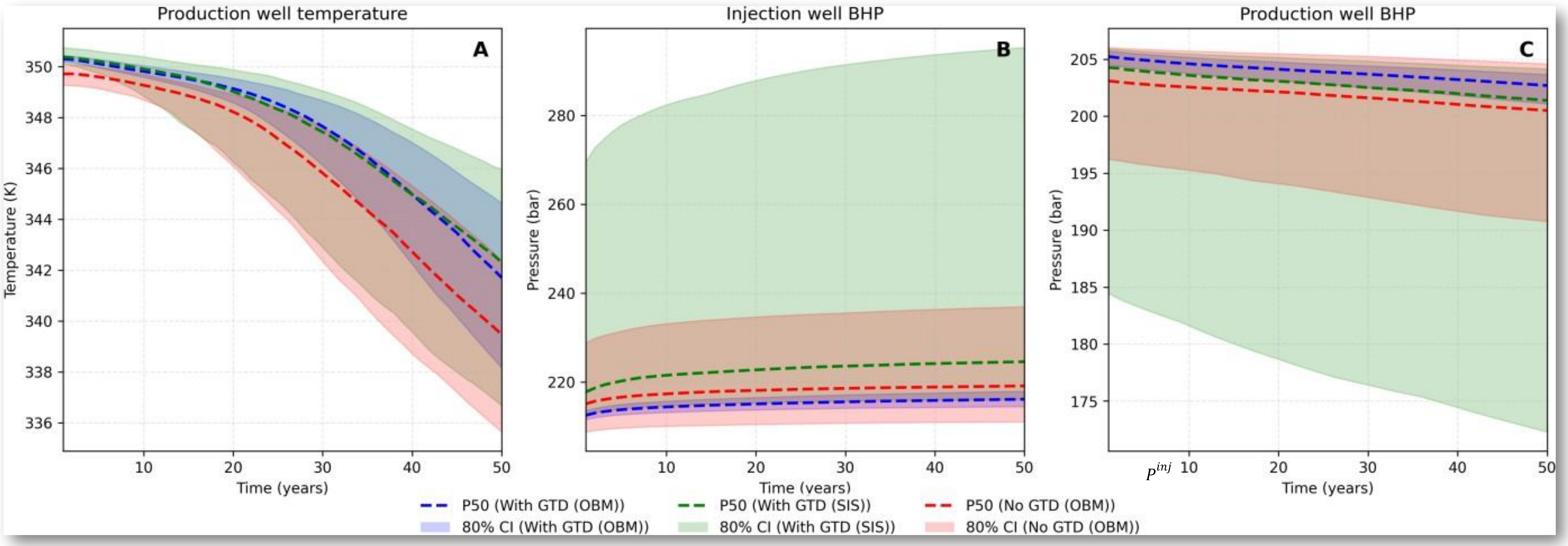


- Before *(regional geological data only)* Temperature variance across models: ±25 K
- After *(Geothermie Delft well data integrated)* Temperature variance across models: ±15 K
- Incorporating new well data constrained predicted arrival temperatures by 40%, shrinking model spread from 25 K to 15 K.

Government regulation for injection well:

$$_{max} = P_{ini} + 0.0135 \cdot TVD$$

Simulation

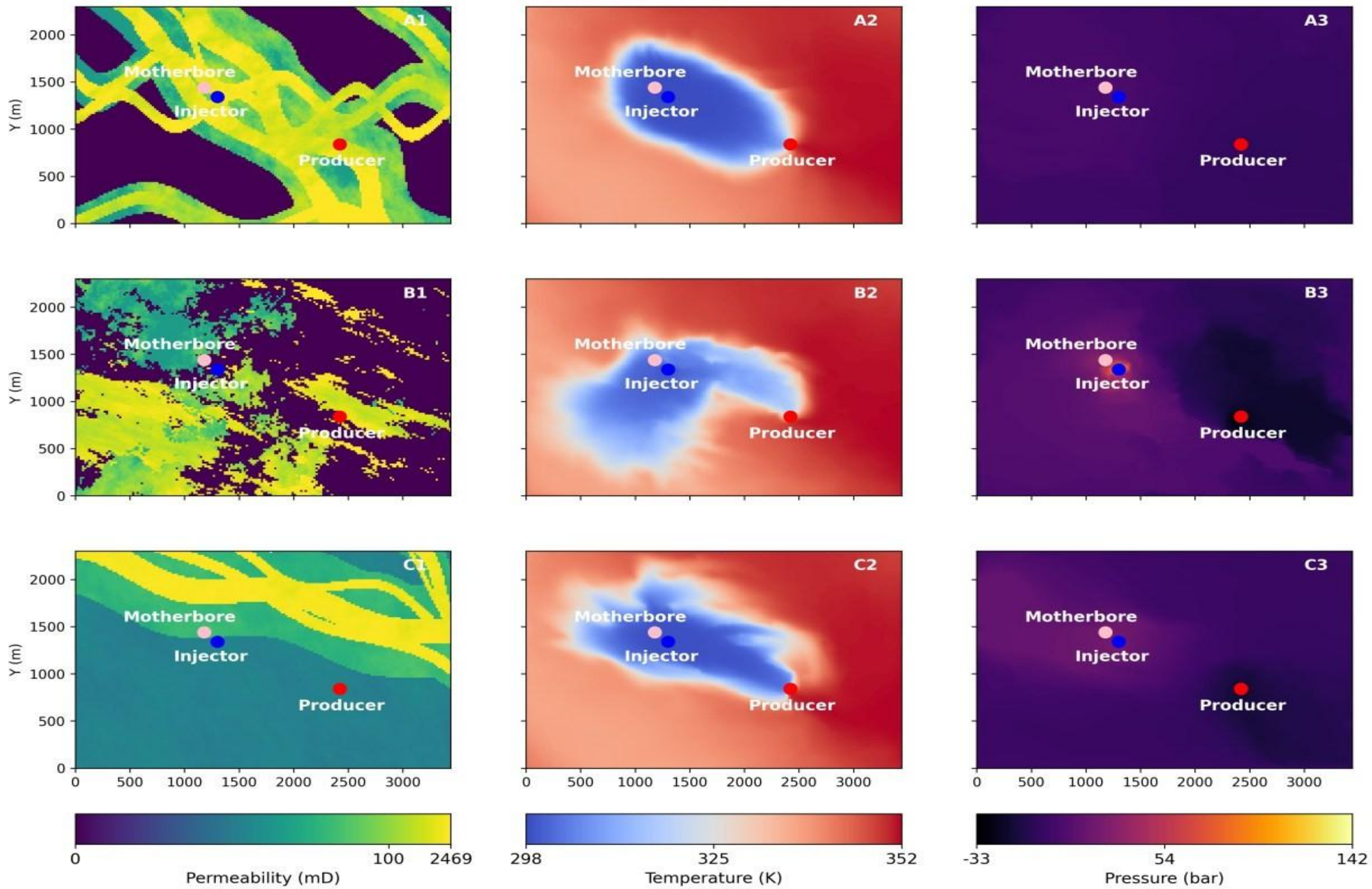


Local well data cuts pressure uncertainty by **80%** — from a 10 bar spread to just 2 bar — and tightens production temperature and BHP modelling across the constrained simulations.

Cold Plume Propagation

90% of 120 Geological Models Remain Within SodM Regulatory Limits

Across most simulated scenarios, injection well BHP stays below the State Supervision of Mines pressure threshold demonstrating that the Delft campus geothermal system is expected to operate safely despite geological uncertainty.



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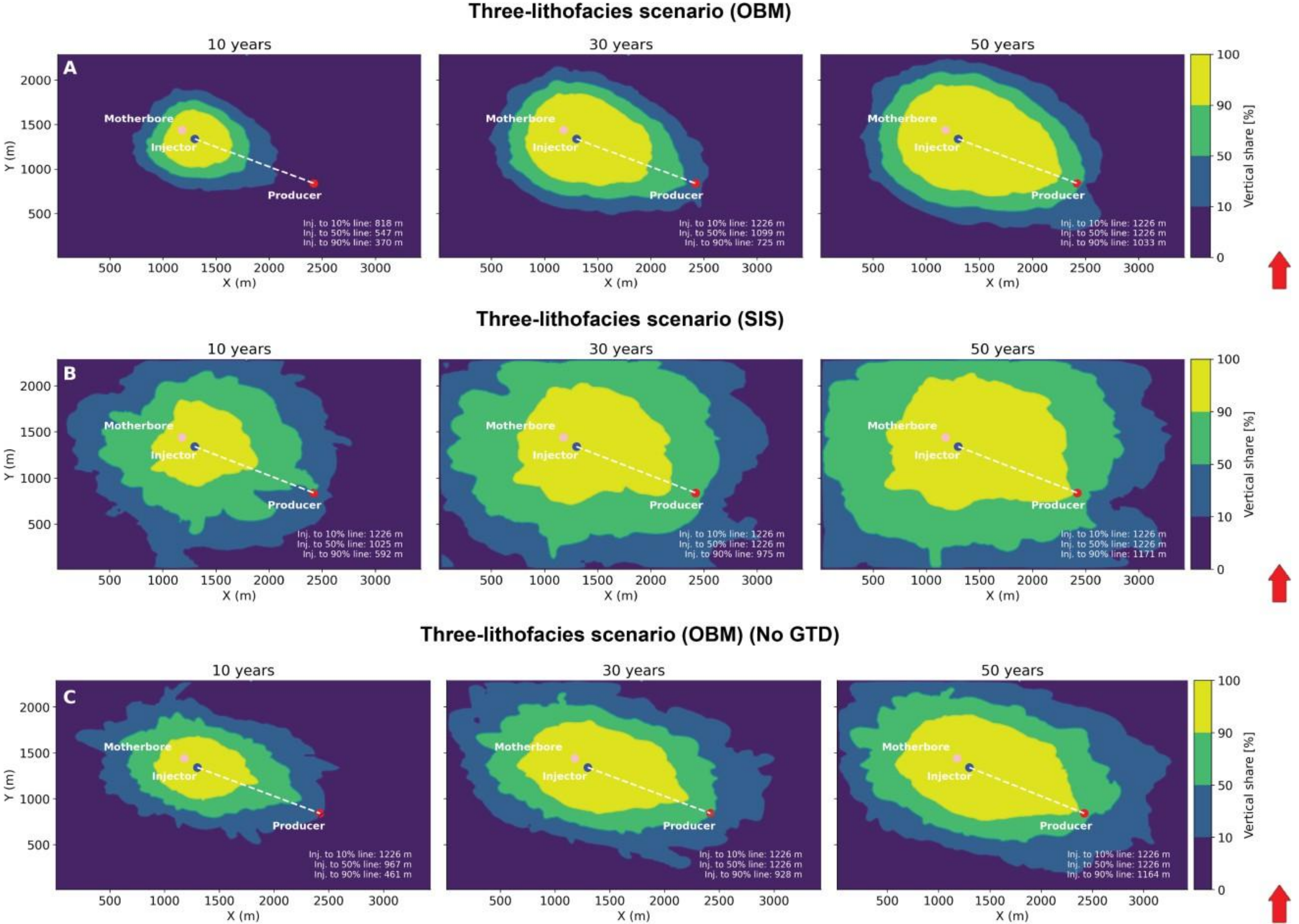
Cold Plume Propagation



Conclusion Current status

As of 25th February 2026 this geothermal well is operating and heating the campus already

- Next steps some history matching with the data coming from the sensors to assess the potential risks associated with the cooling down of the larger formation volume above the reservoir layers

- Important to properly characterize the heterogeneity of the reservoir to reflect the real thermal response

- 90% geological models exhibit the injection well BHP lower than the regulation

- Introduction of GTD well data constrains the geological models to reduce the uncertain distribution of dynamic output

Thank you





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Papers & References

- **Y. Chen**, D. Voskov, A. Daniilidis, Rigorous Numerical Methodology and Heat Recovery Analysis for Modeling of Direct Use Geothermal Systems. *Geoenergy Science and Engineering [J]*, 2025
- **Y. Chen**, G.Rongier, D.Voskov, A.Daniilidis, Robust framework to evaluate the representative heterogeneity for the simulation of the Direct Use Geothermal Systems, SPE RSC 2025, Galveston


Thank you for Listening