TNO innovation for life

Interreg North-West Europe DGE-ROLLOUT

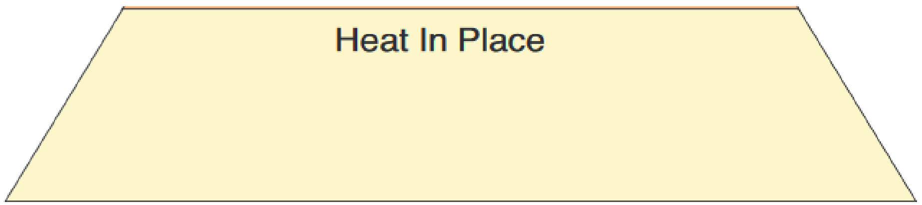
UNCERTAINTIES IN GEOTHERMAL POTENTIAL CALCULATION

ThermoGIS and beyond | Hans Veldkamp

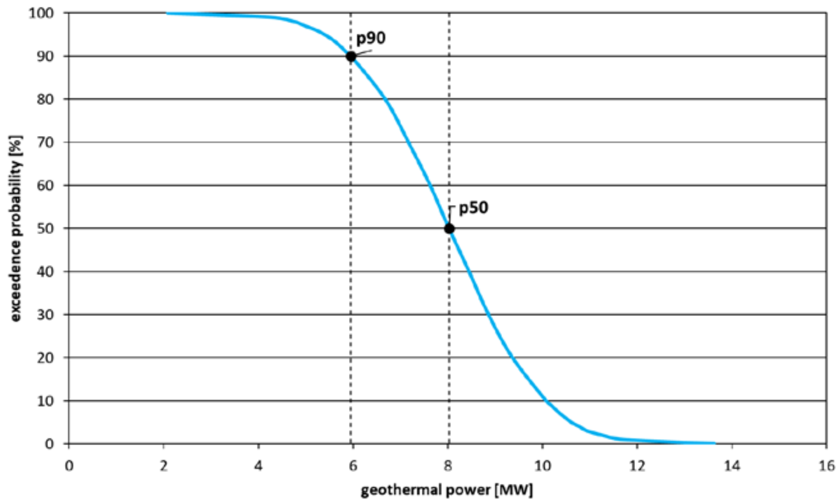
CONTENTS

GEOTHERMAL POTENTIAL

It is not just how much is in there, but how much you can get out – against economic rates



Muffler & Cataldi, 1978, Kramers et al. 2012



DOUBLET POWER

$$E\ [MW_{th}] = Q \times dT \times Cp$$

FLOW RATE Q

permeability × thickness

pressure

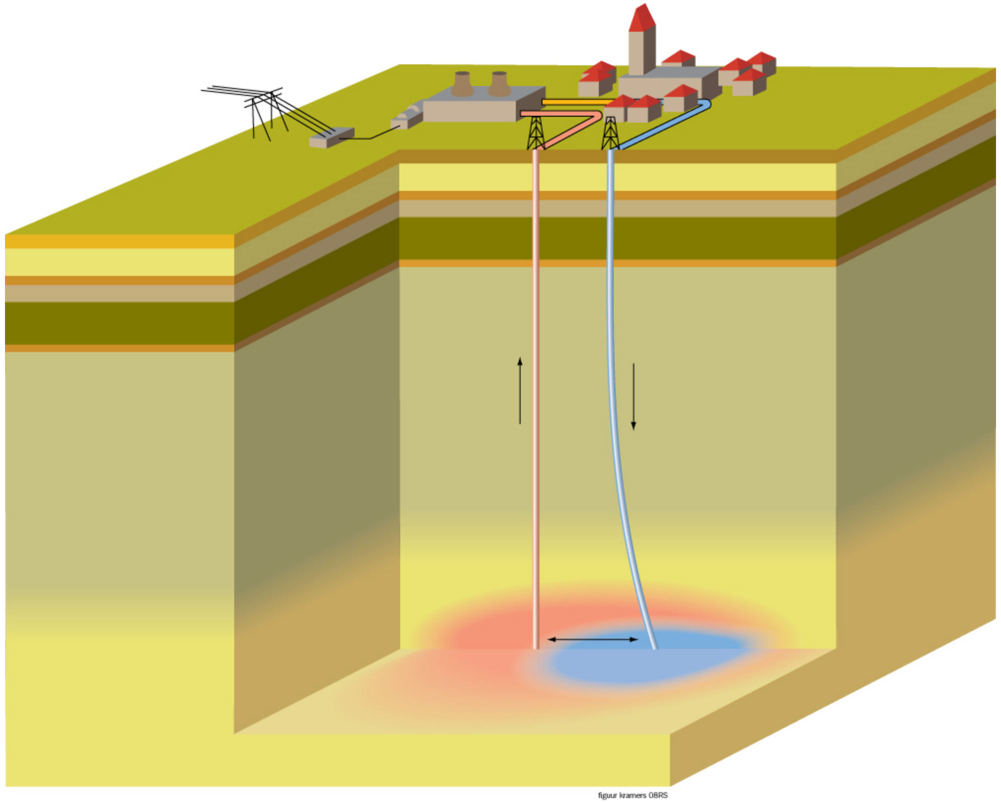
$$Q = \Delta p \frac{2\pi k H}{\mu \left(\ln\left(\frac{L}{r_w} \right) - S \right)}$$

viscosity

skin factor

well distance

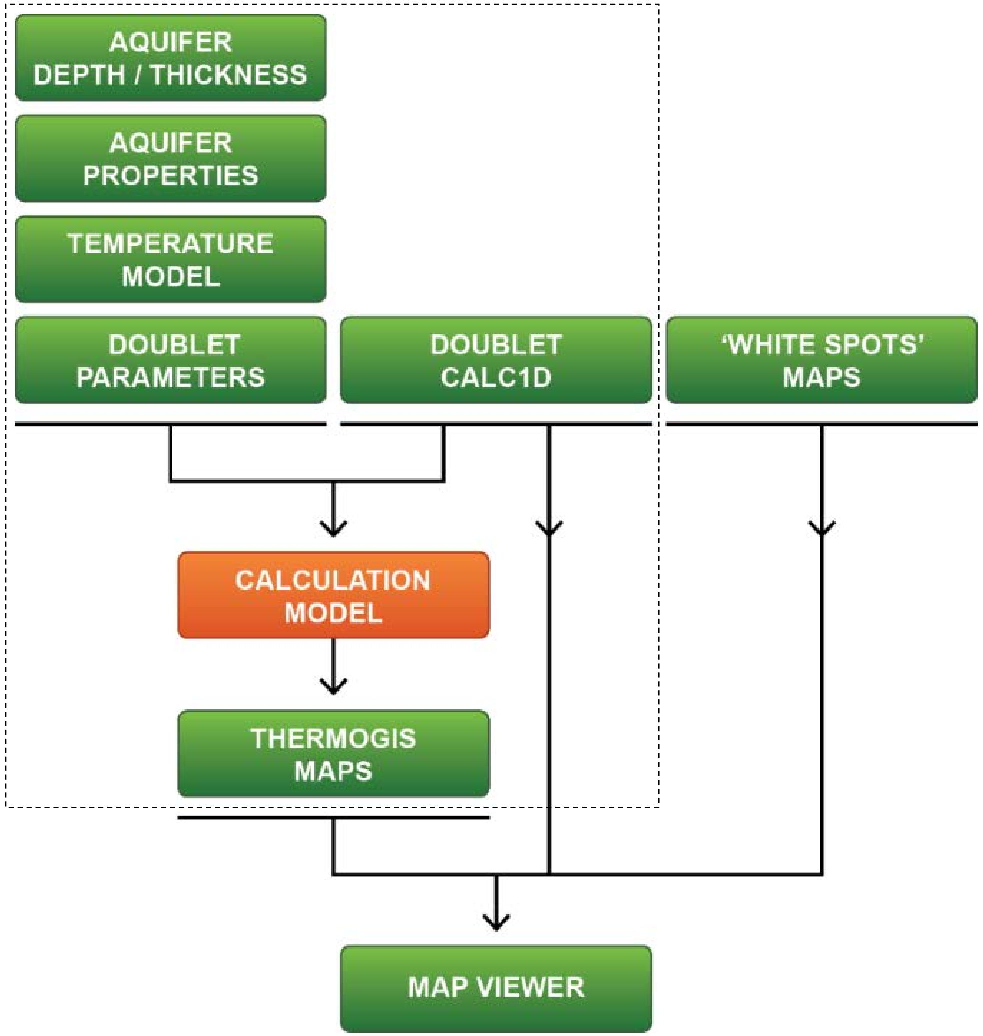
well radius



Take home message for doublet power: all you need is...

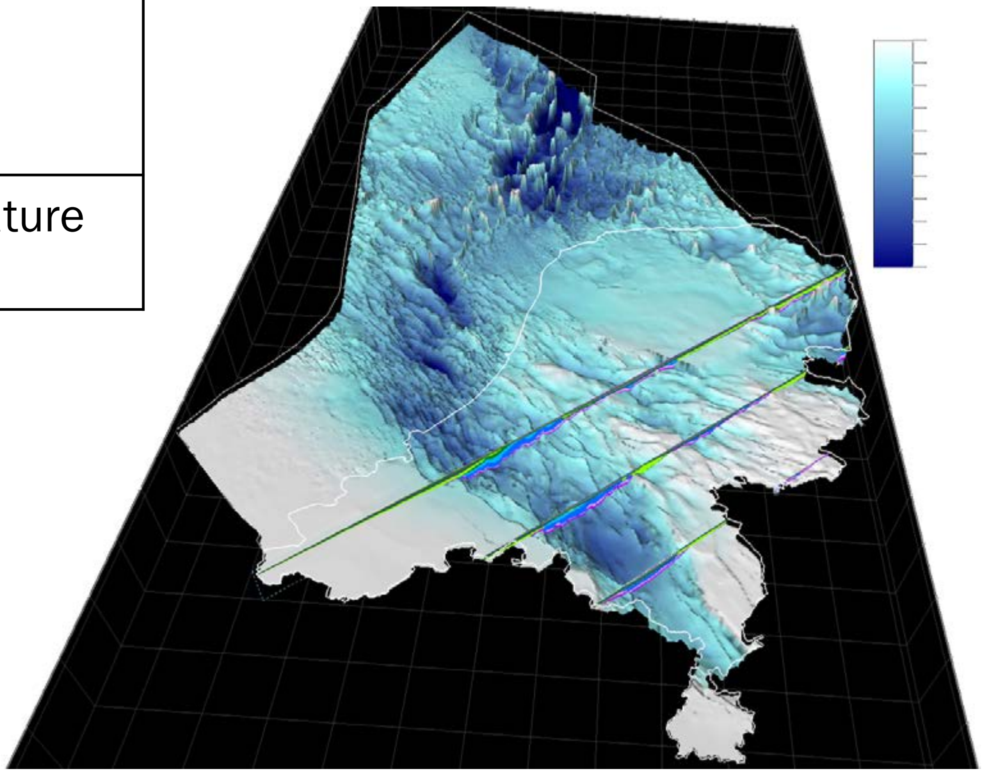
- Depth and thickness
- Permeability
- Temperature
- and calculate Q×dT×Cp at every X, Y, Z

THERMOGIS WORKFLOW

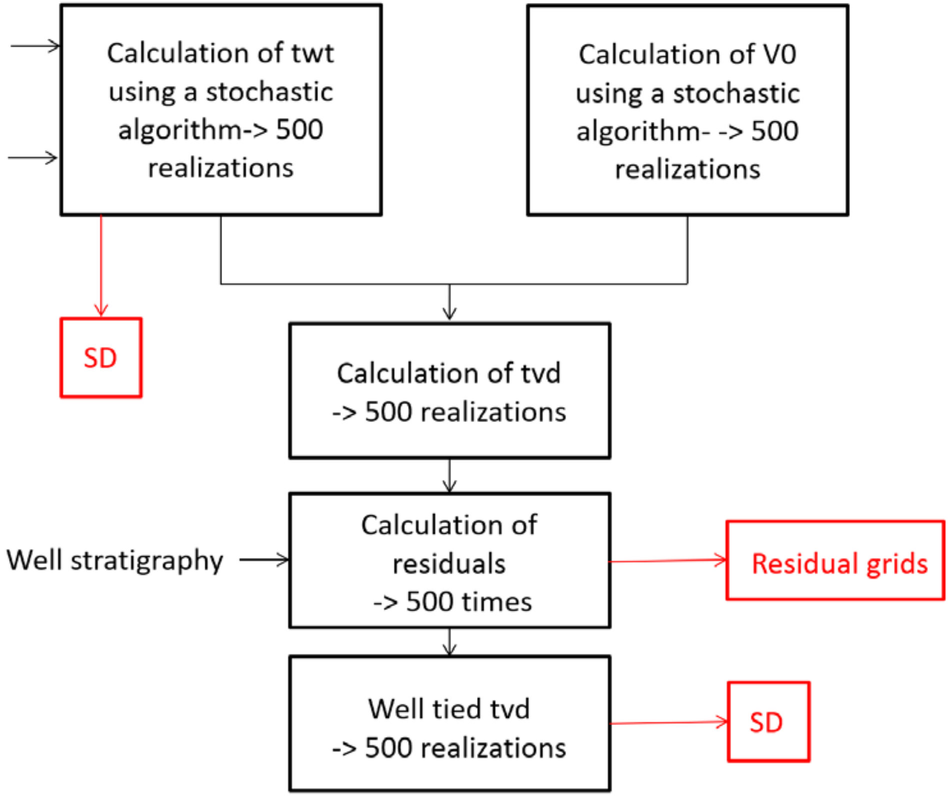


RESERVOIR DEPTH AND THICKNESS

3D and 2D seismic Wells
Well logs Core plugs Well tests Burial / uplift
Borehole temperature Heatflow model



currently 14 layers interpreted, more to come

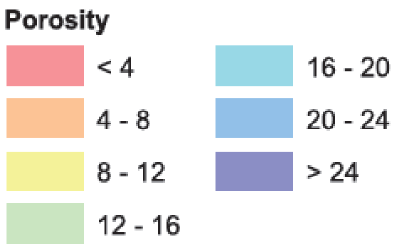


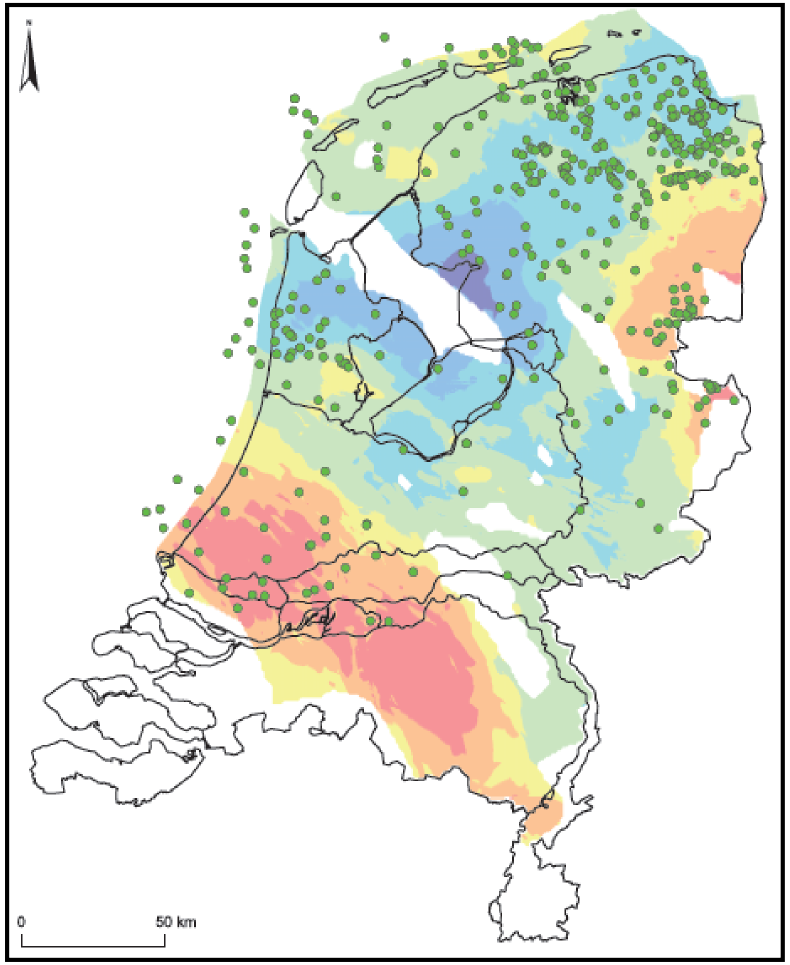
Seismic interpretation and time-depth conversion result in depth, thickness and error maps for *main geological units*
28 *aquifers* are then added by using well-controlled isopachs

Kombrink et al. 2012

› POROSITY AND PERMEABILITY

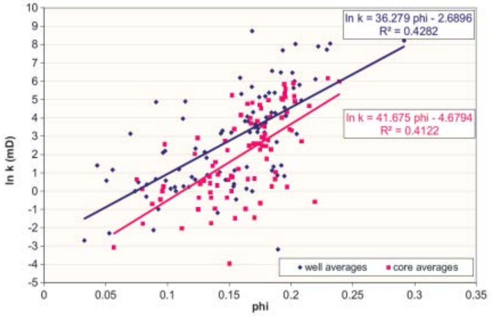
3D and 2D seismic Wells
Well logs Core plugs Well tests Burial / uplift
Borehole temperature Heatflow model



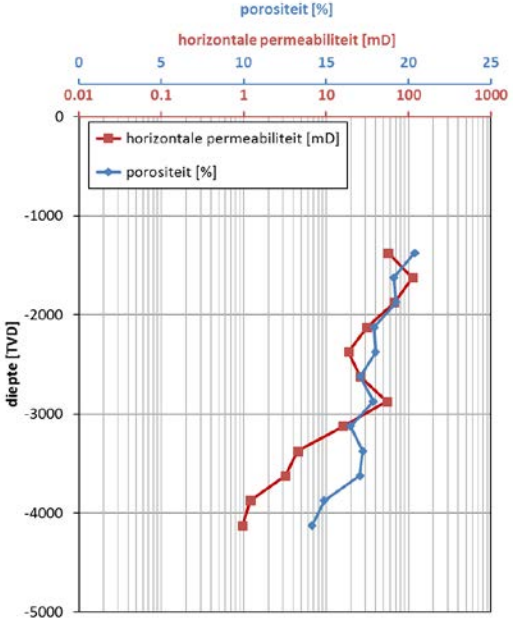


Vrijlandt et al. 2019
Pluymaekers et al. 2012

relationship between porosity and permeability, varies per layer



porosity and permeability decrease with depth – take maximum burial into account



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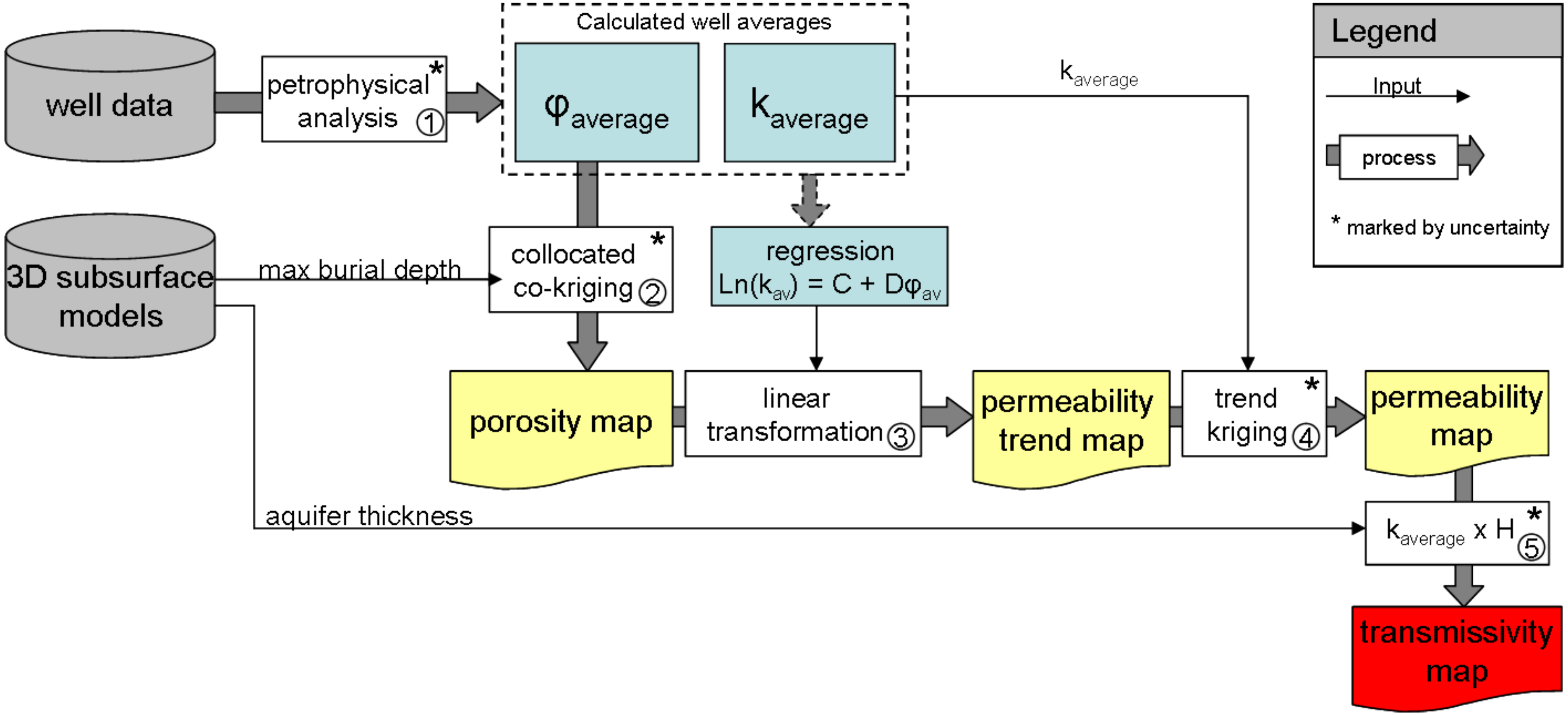
PERMEABILITY MAPPING WORK FLOW

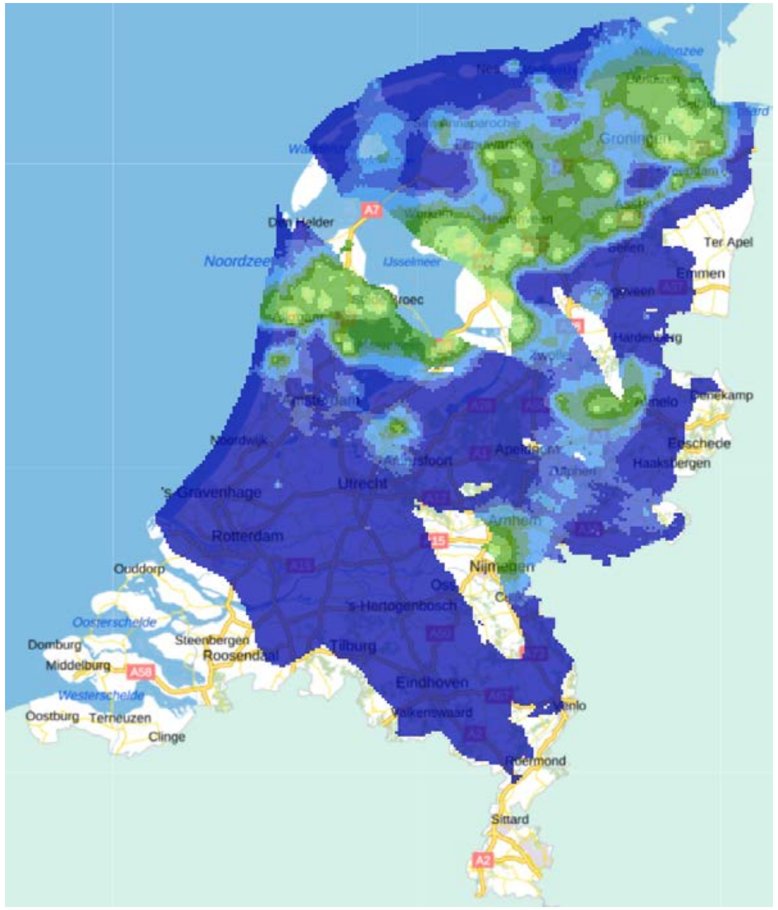


TRANSMISSIVITY: OPTIMISTIC AND PESSIMISTIC CASES

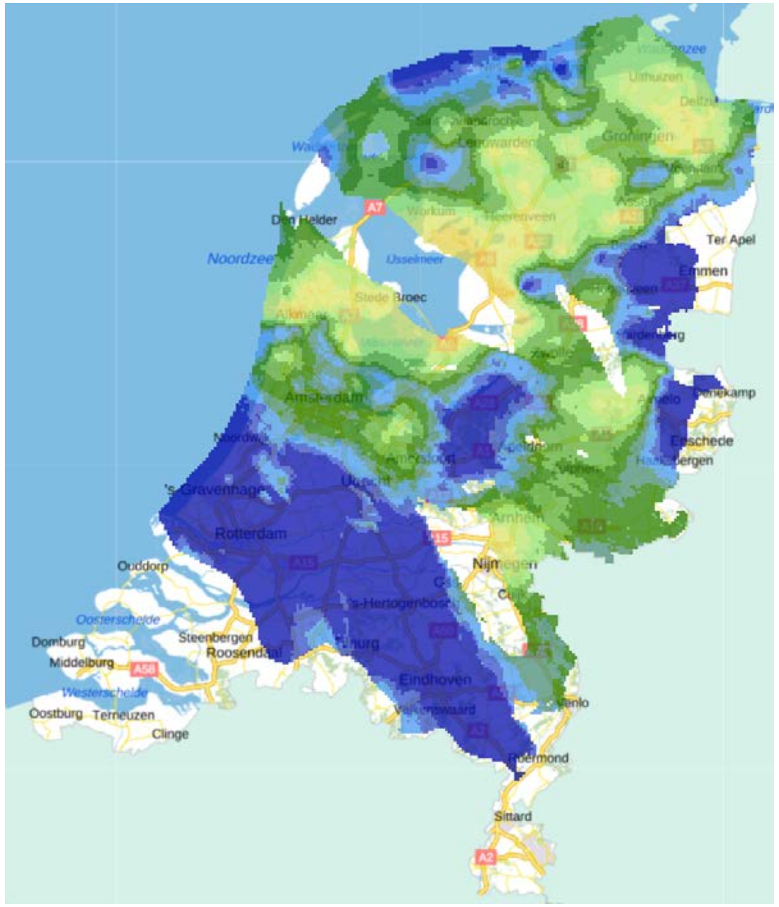
ROSL_ROSLU permeability P50 [mD]

- < 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200
- 200 - 500
- 500 - 1,000
- 1,000 - 2,000
- 2,000 - 5,000
- > 5,000

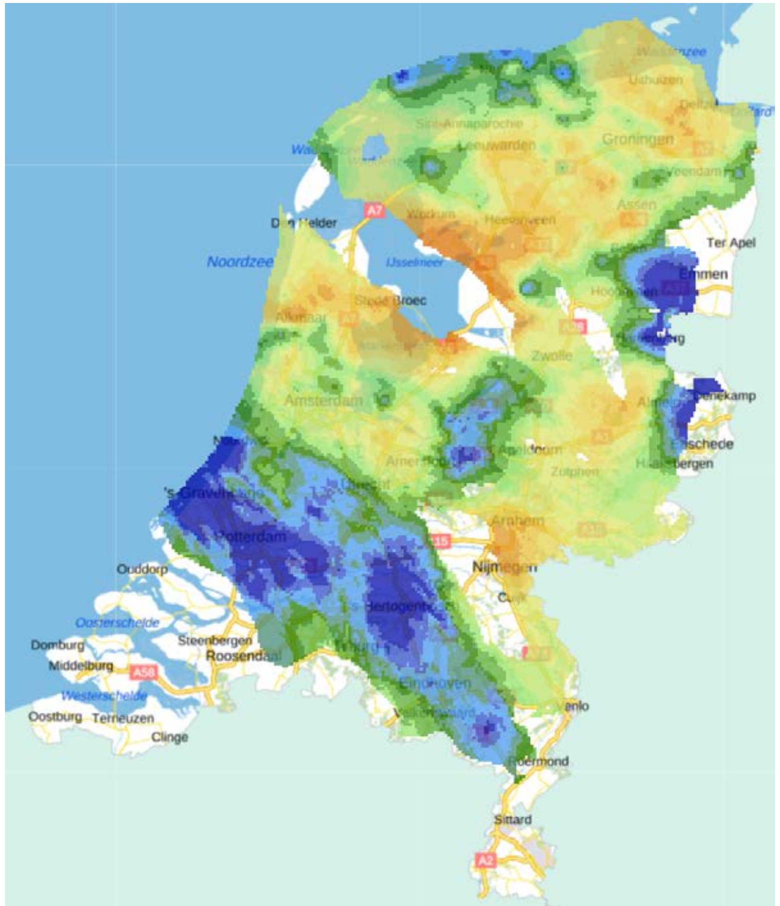
P90



P50

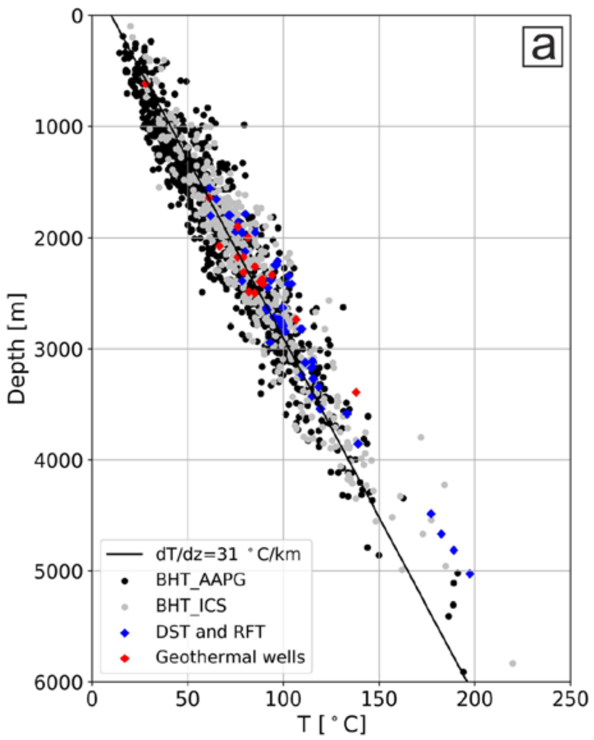


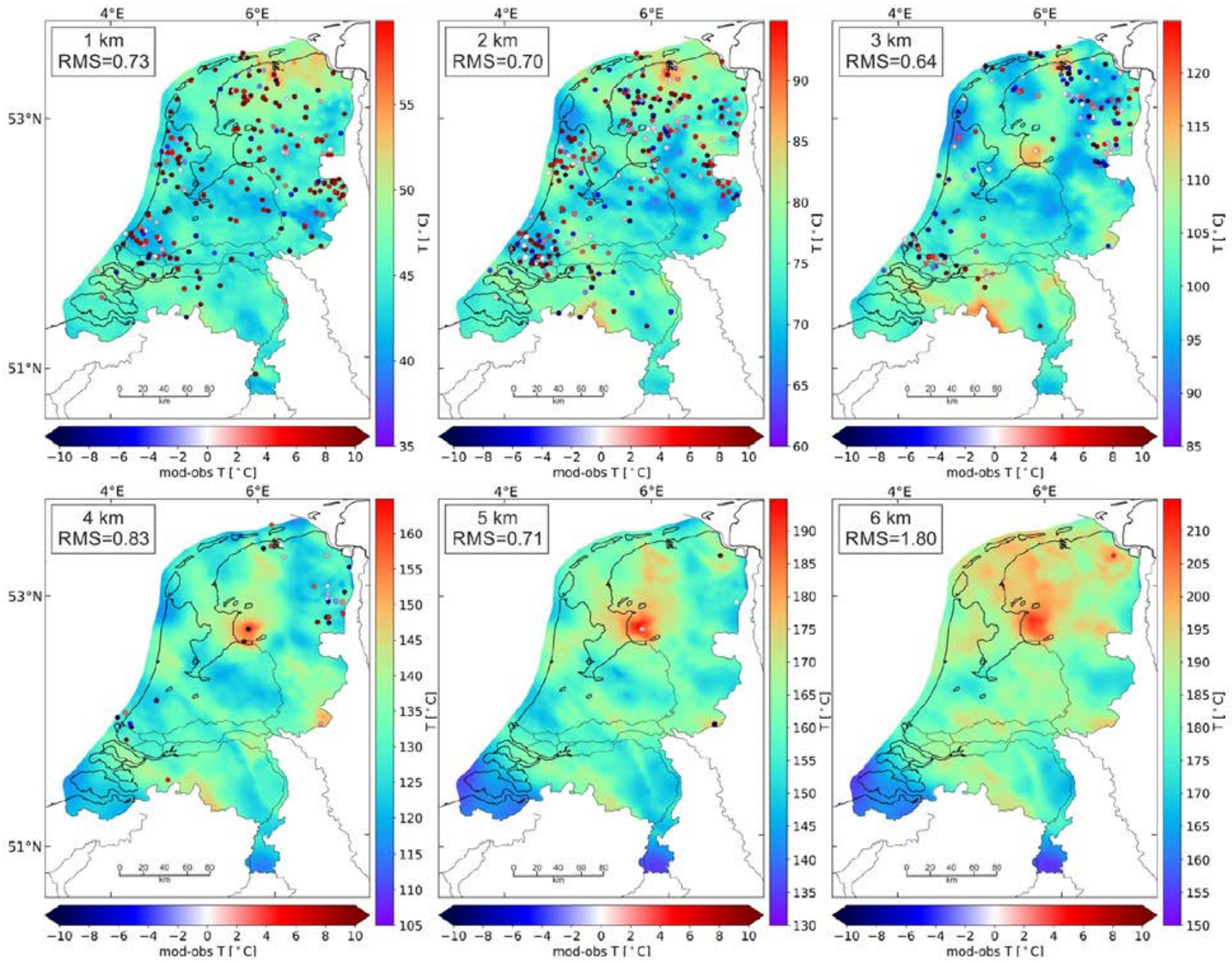
P10



TEMPERATURE

3D and 2D seismic Wells
Well logs Core plugs Well tests Burial / uplift
Borehole temperature Heatflow model

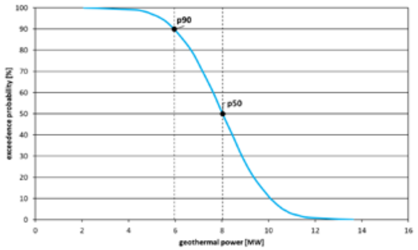




Bekesi et al. 2020

ECONOMICAL MODEL

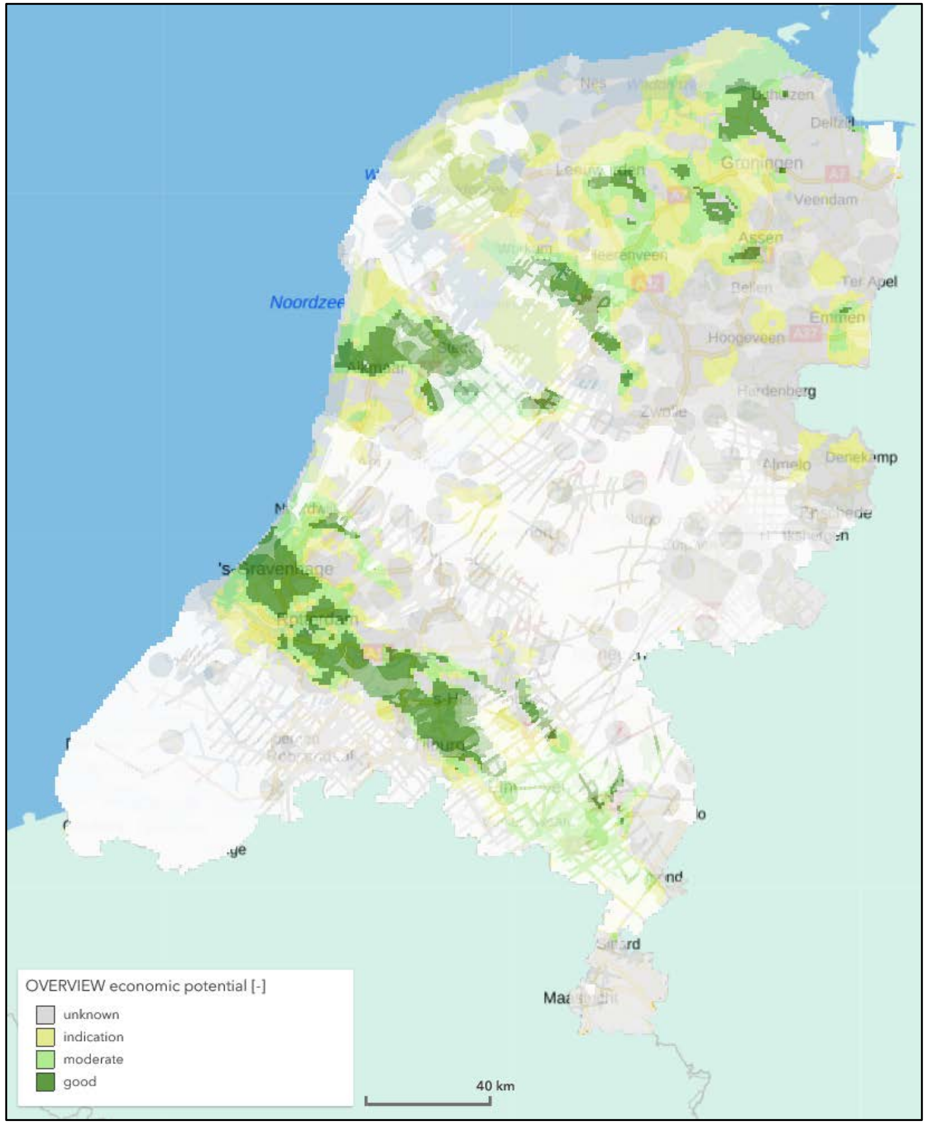
- Discounted cash flow model
- Generalized cost model based on Dutch doublets
  - Well costs depth dependent
  - Facility costs: base amount and power/energy dependent
  - Benchmarked with SDE+ figures
- Main output: cost maps (P90-P50-P10)
  - Levelized (net present) cost of energy [€ct/kWh]
  - Geothermal economic potential



Economic parameters	Value	Unit
economic lifetime	15	year
drilling time	2	year
annual load hours	6000	hour
well costs	depth dependent	M€
CAPEX base expense (excl. wells)	3	M€
CAPEX variable expenses (excl. wells)	300	€/kW
CAPEX contingency	15	%
annual OPEX per unit power	60	€/kW
annual OPEX per unit energy produced	0.19	€ct/kWh
electricity purchase price for operations	8	€ct/kWh
tax rate	25	%
interest on loan	5	%
inflation	2	%
required return on equity	7	%
debt ratio	80	%

OVERVIEW GEOTHERMAL POTENTIAL

- ThermoGIS is a <u>regional</u> geothermal prospectivity assessment tool
- Over 1000 maps
  - Overview maps aggregating all aquifers
  - Input/output maps per geothermal aquifer
  - P90-P50-P10 probability maps
  - Different development scenarios
- Location specific calculation tool

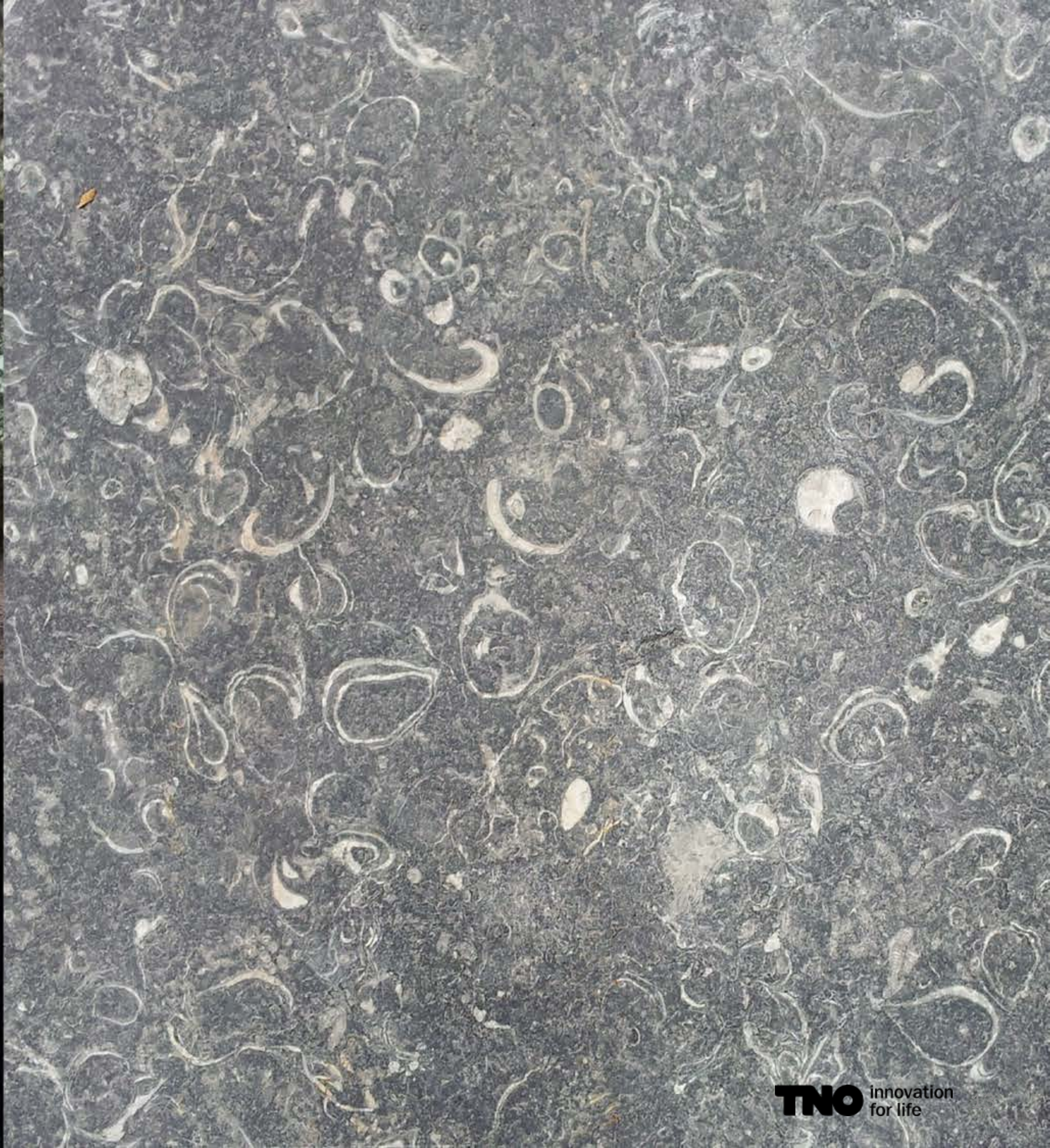


Economic potential classes

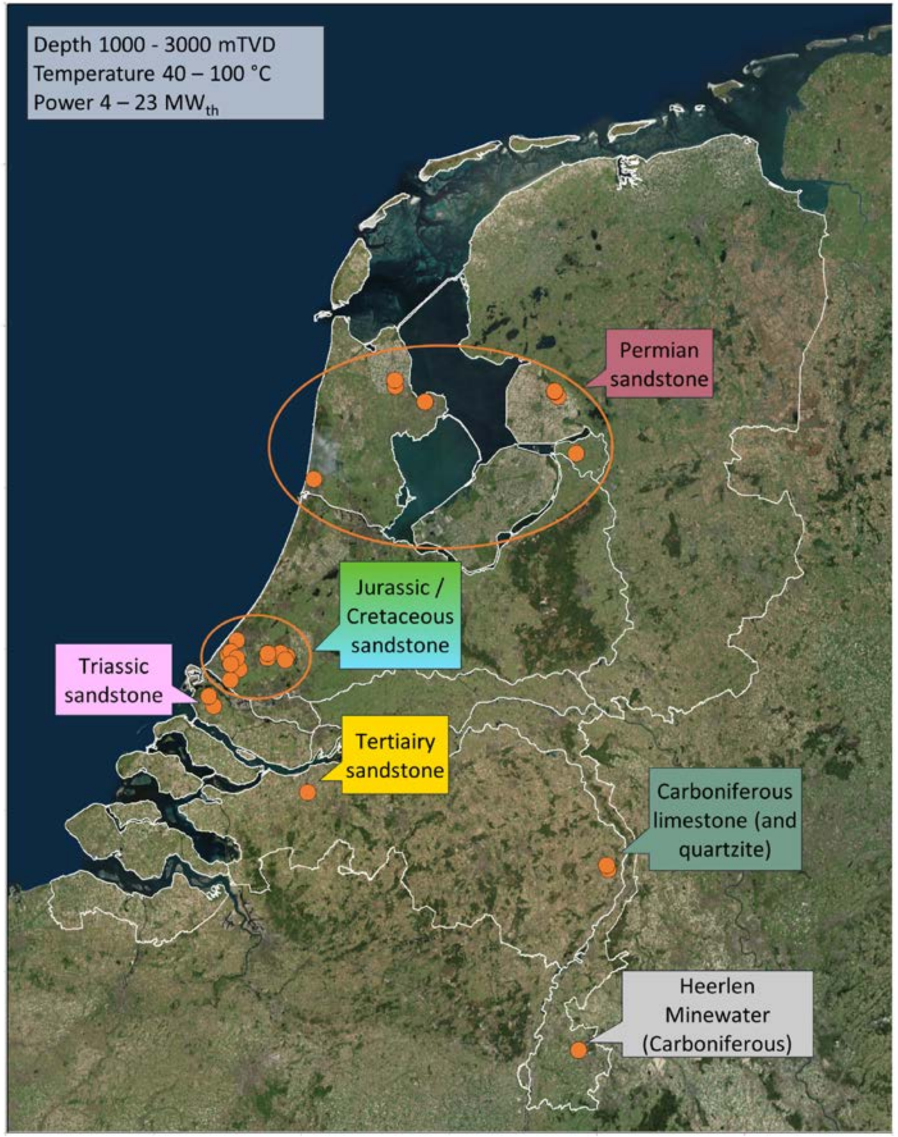
- *Good*: P50 unit cost < reference price
- *Moderate*: P30 unit cost < reference price
- *Indication*: P10 unit cost < reference price
- *Poor/unknown*: P10 unit cost > reference price

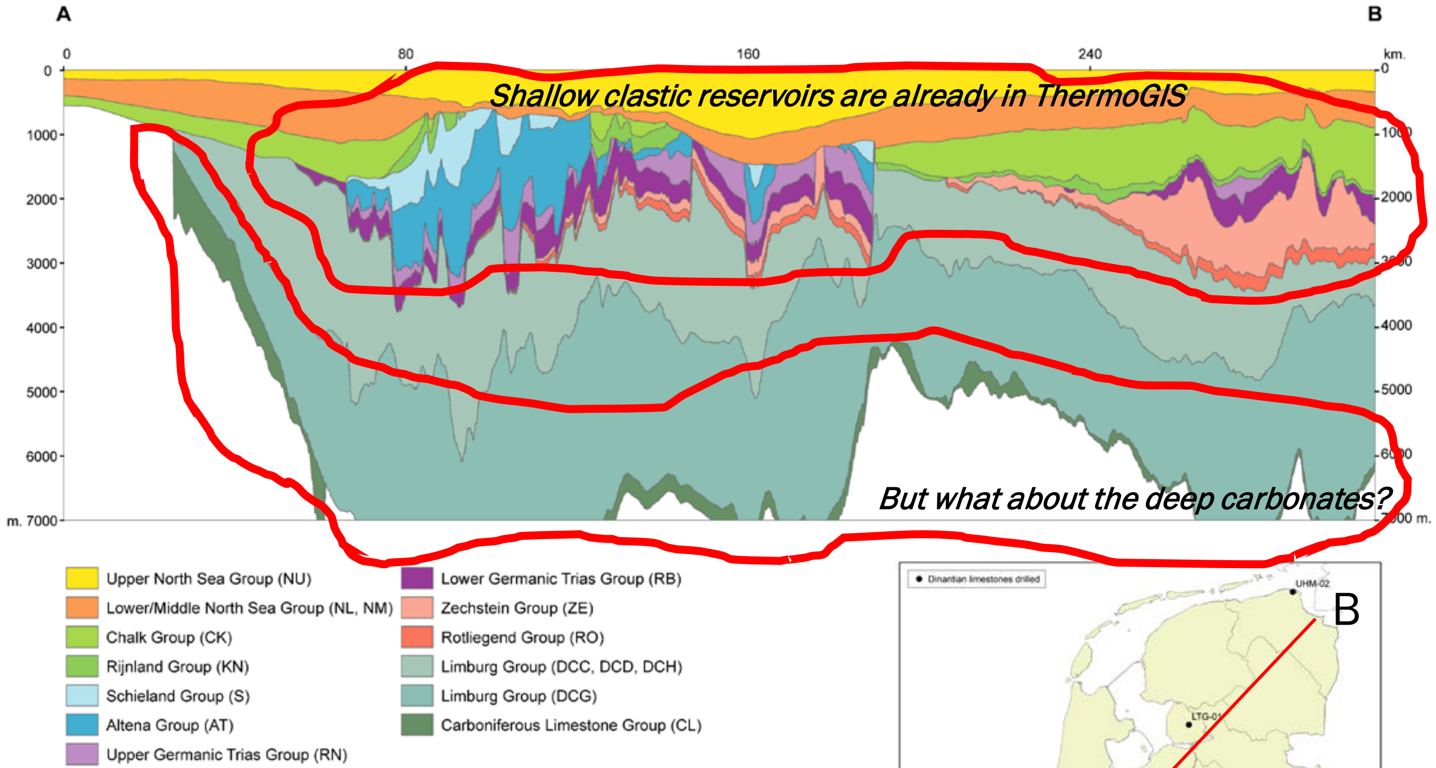
unit cost: cost per unit energy [€ct/kWh]

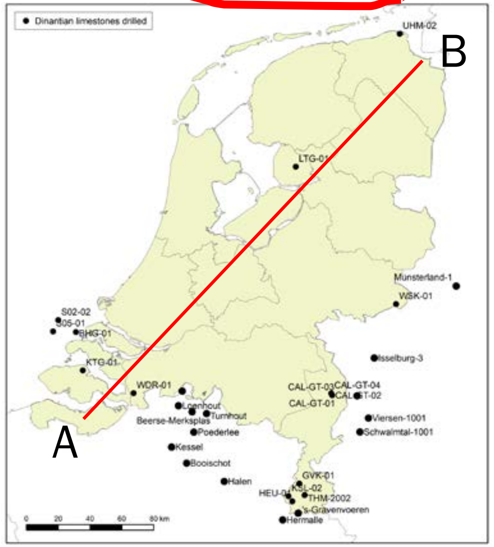
white areas: poor data availability



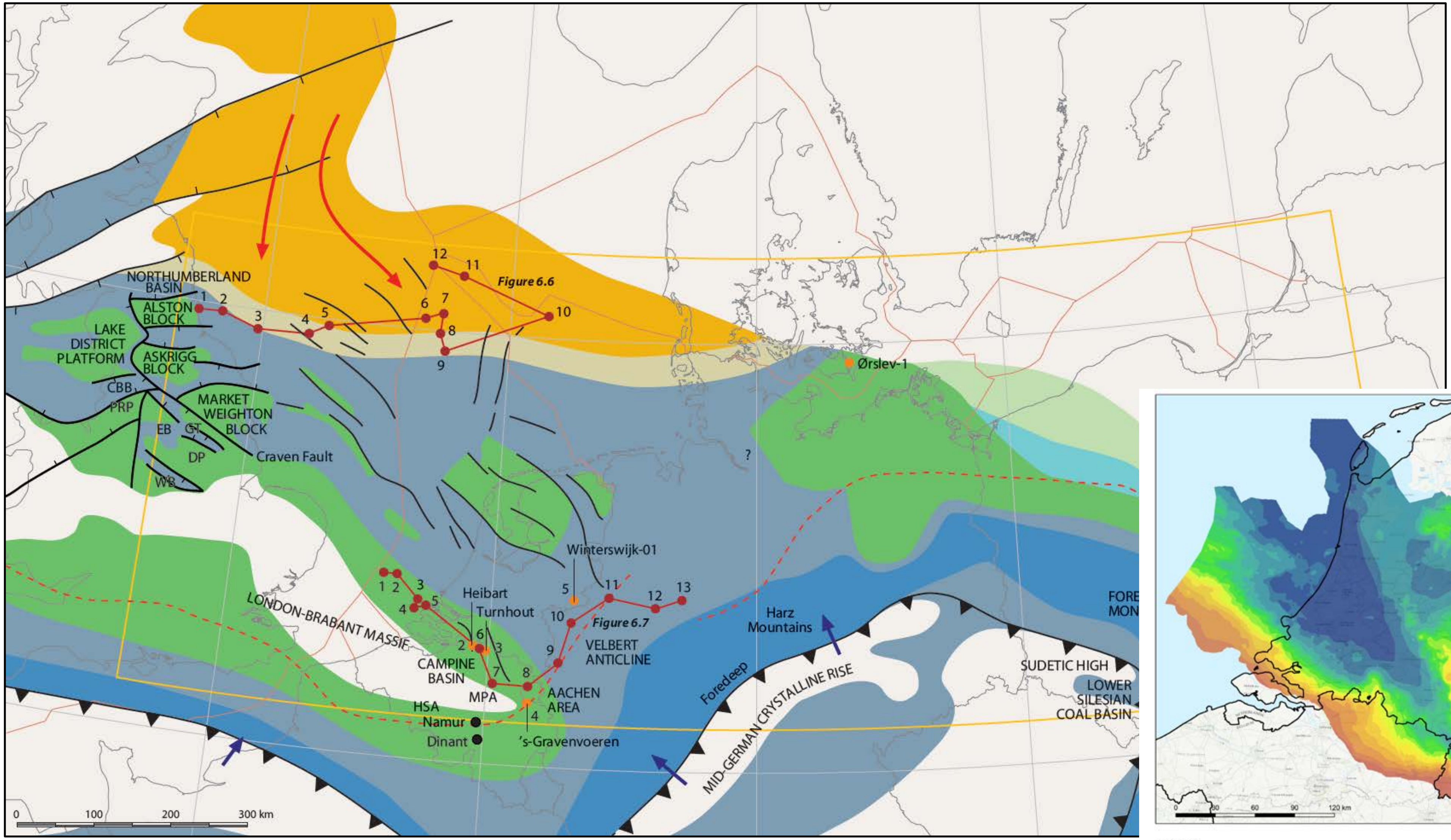
CURRENT DUTCH GEOTHERMAL LANDSCAPE

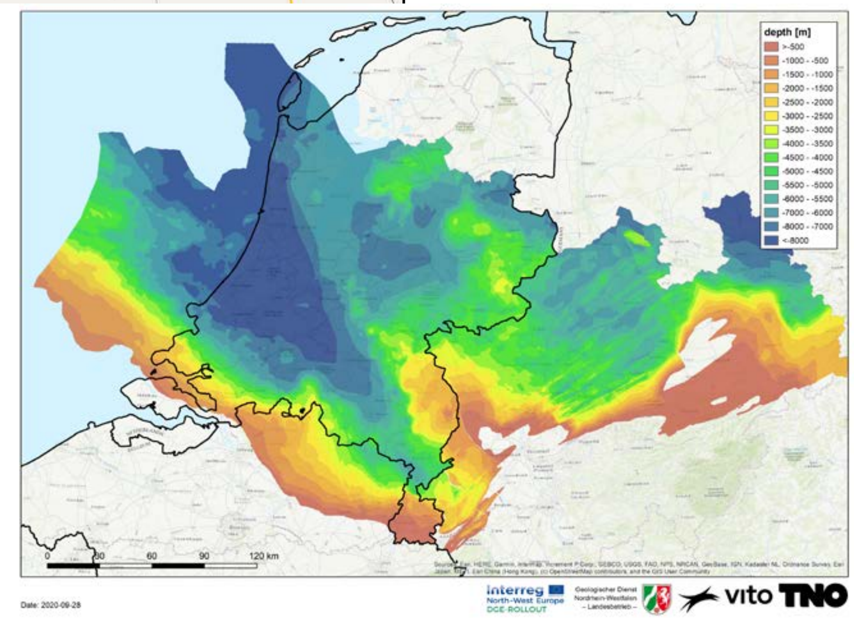






DINANTIAN PALEOGEOGRAPHY

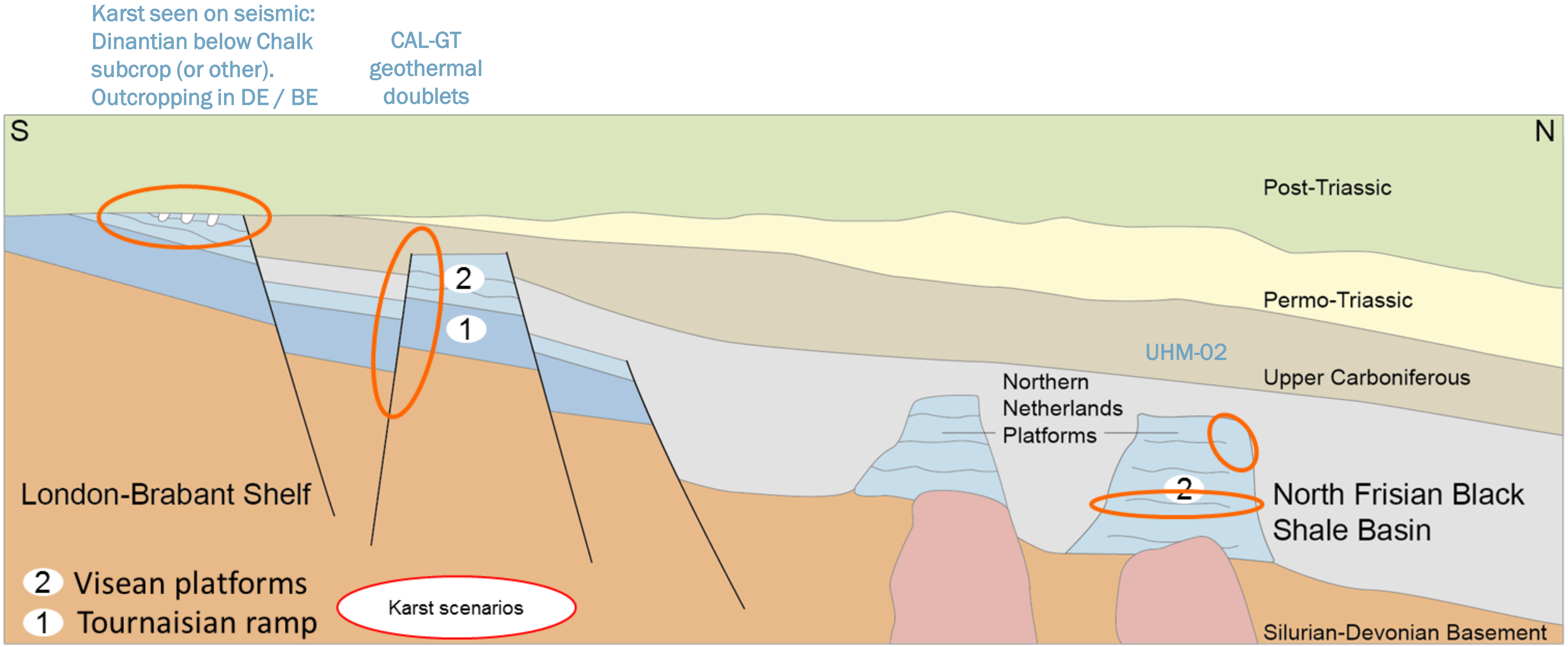




From: Kombrink et al. (2010). Carboniferous (SPBA Atlas)

DINANTIAN PLATFORM CARBONATES – CONCEPTUAL MODEL

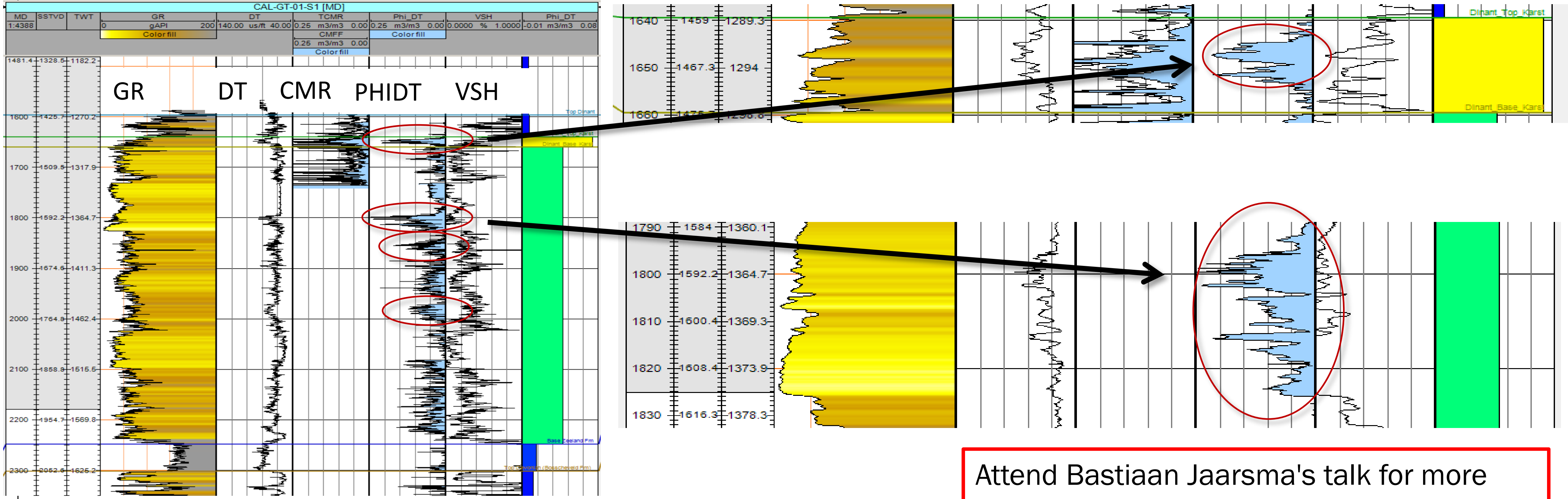
permeability scenario's



EBN 2019

POROSITY IN CALIFORNIË GEOTHERMAL WELL

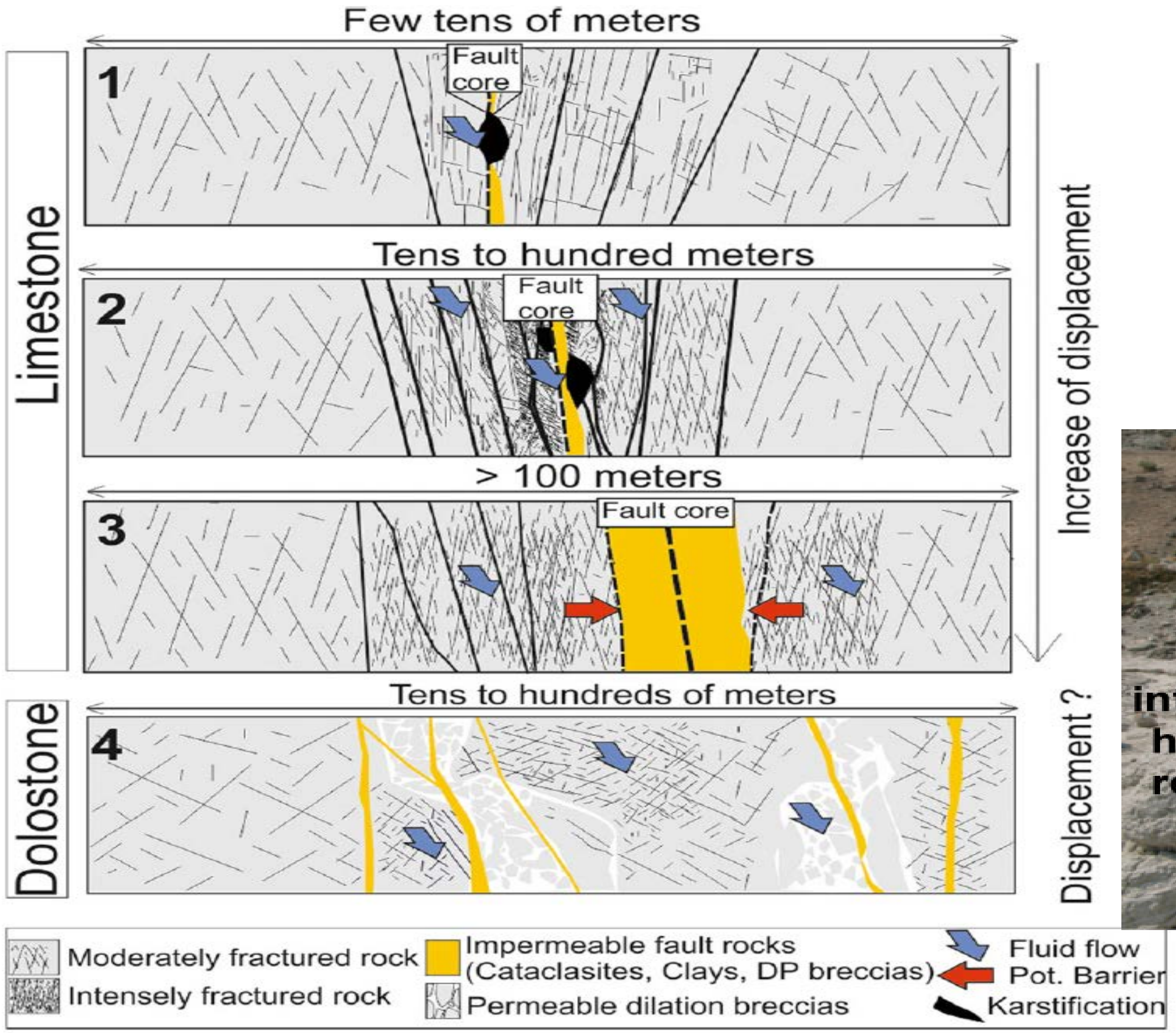
Average Dinantian porosity only 4% but zones with higher porosity found (~10%, streaks to 20%)



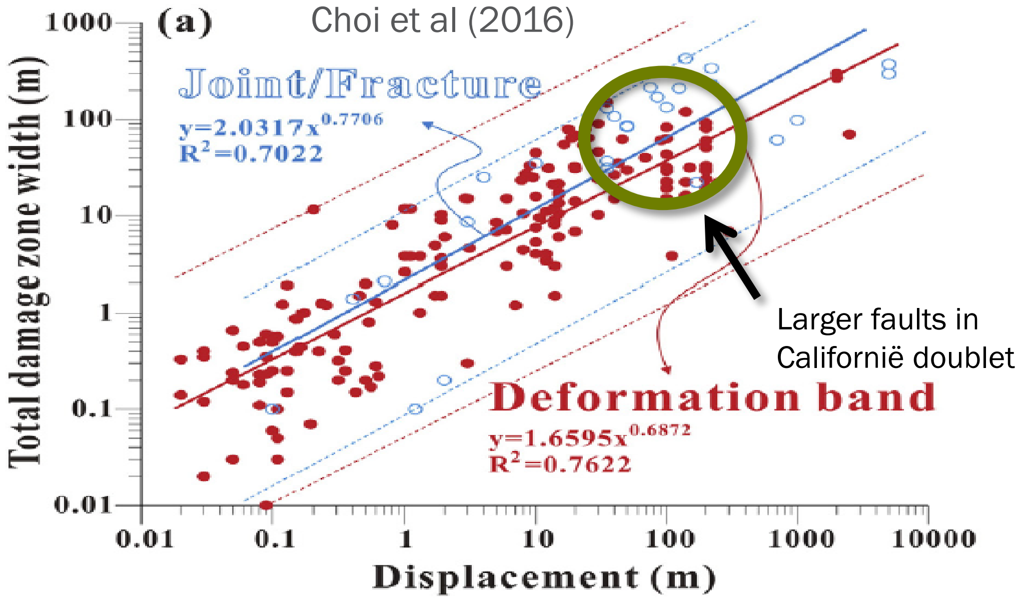
Attend Bastiaan Jaarsma's talk for more information on results of the SCAN-project

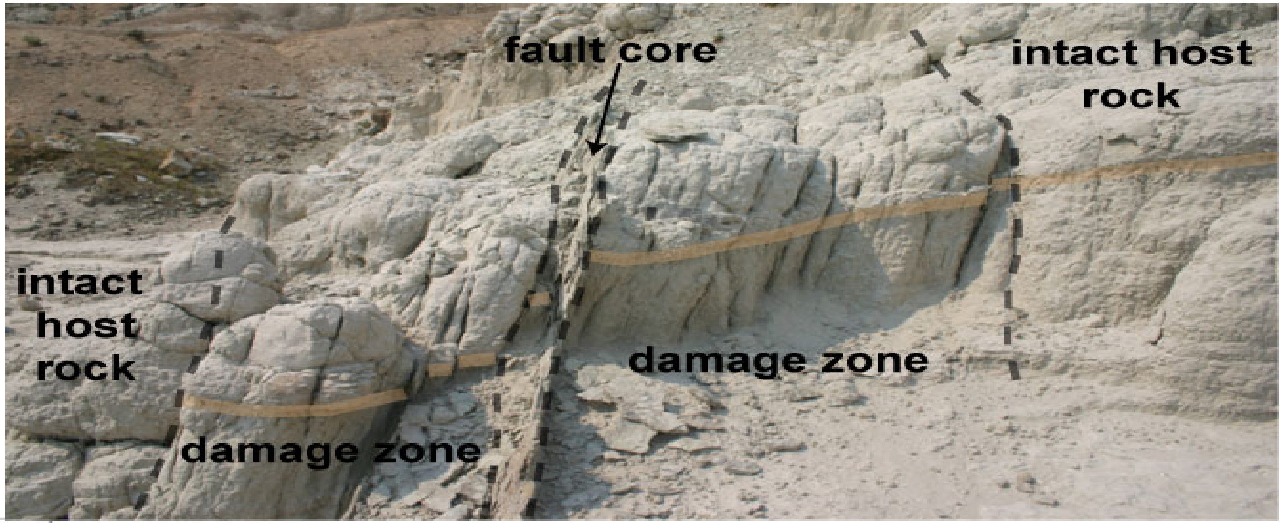
Petrophysical analysis reports available from https://www.nlog.nl/en/scan

FAULTS AND FRACTURES.. THE IDEA



Bauer, Schröckenfuchs & Decker (2016)
Hochschwabkarst Massif (Austria)

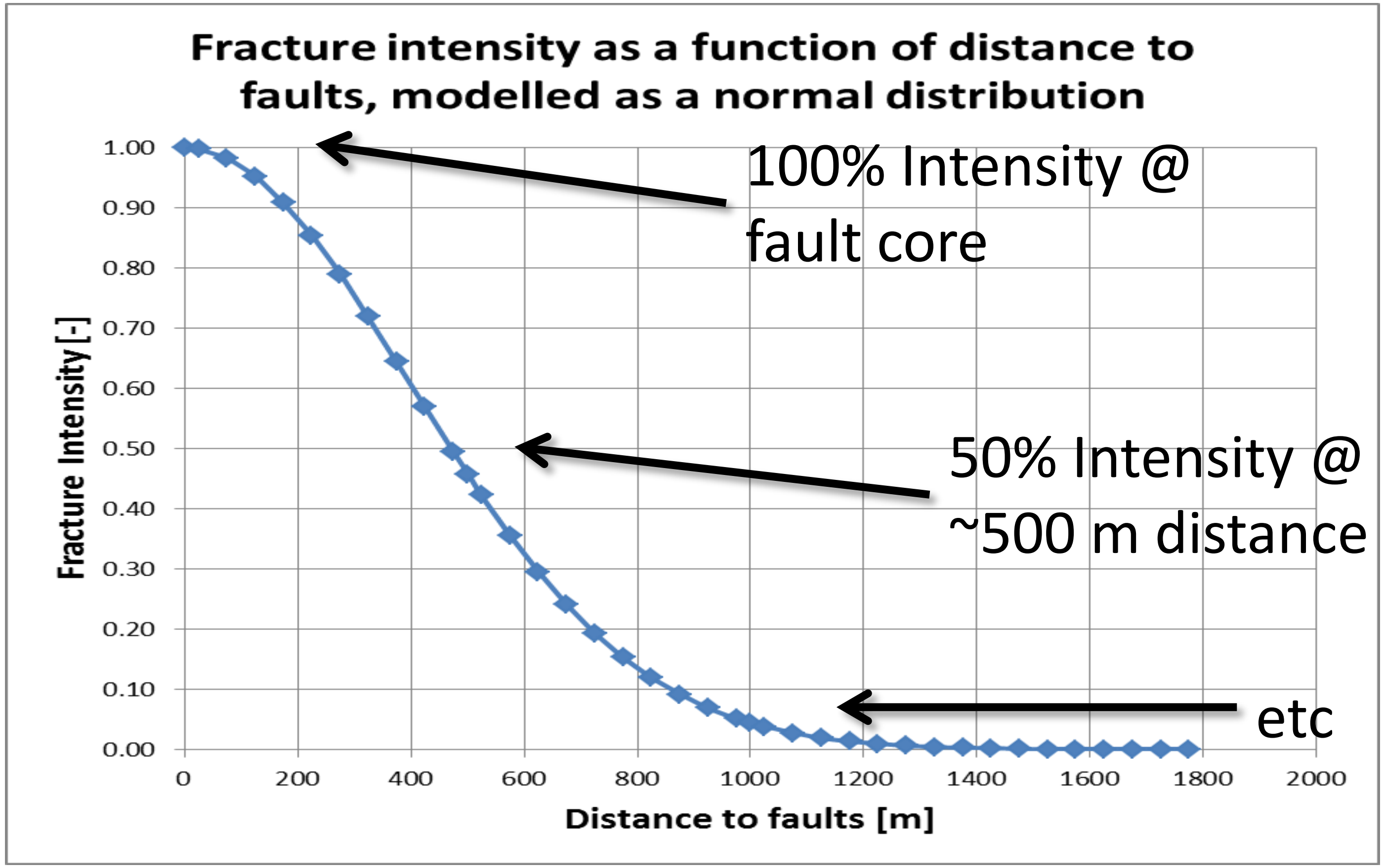


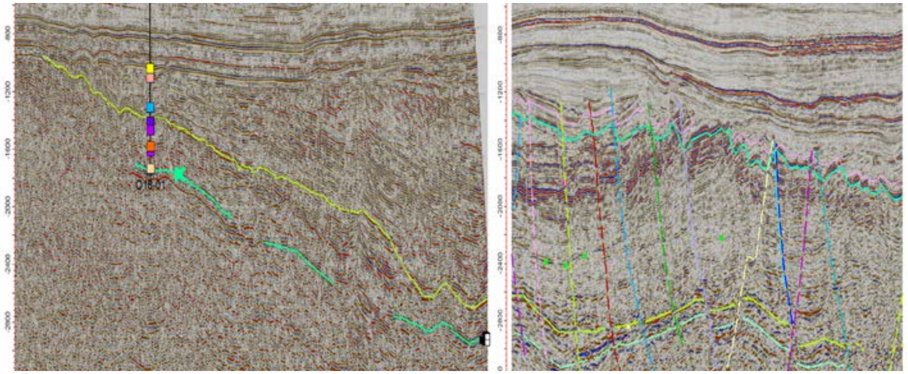


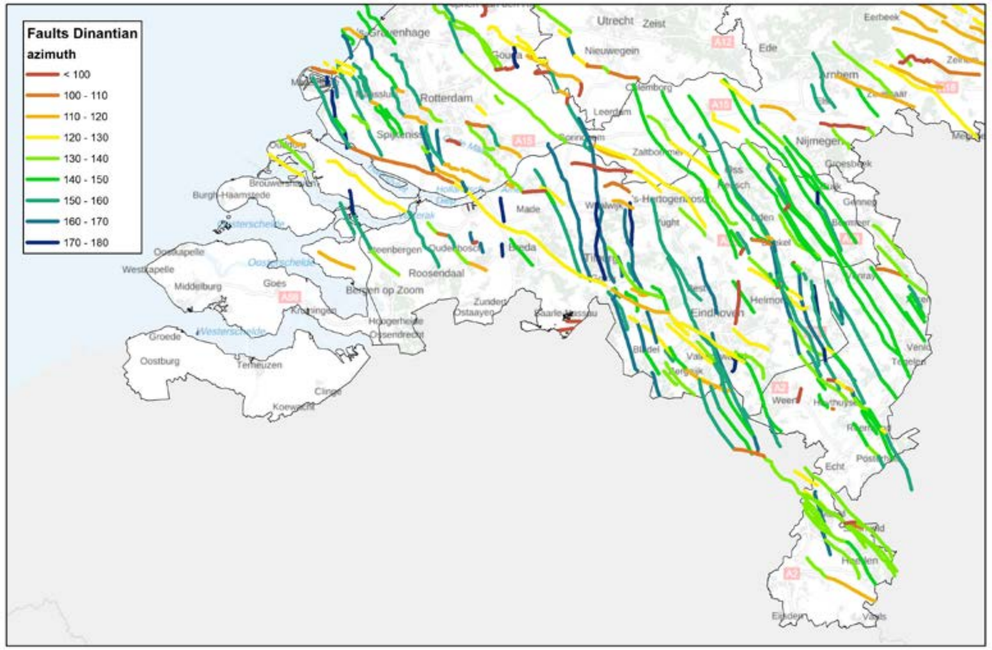
R. Bouroullec, Faille de Ferques

MODELLING PERMEABILITY: FRACTURE INTENSITY

- Fracture intensity (I_f) determines fracture permeability (K_f)
- 'Fracture intensity' modelled as normal distribution with μ=0m and σ=400m.





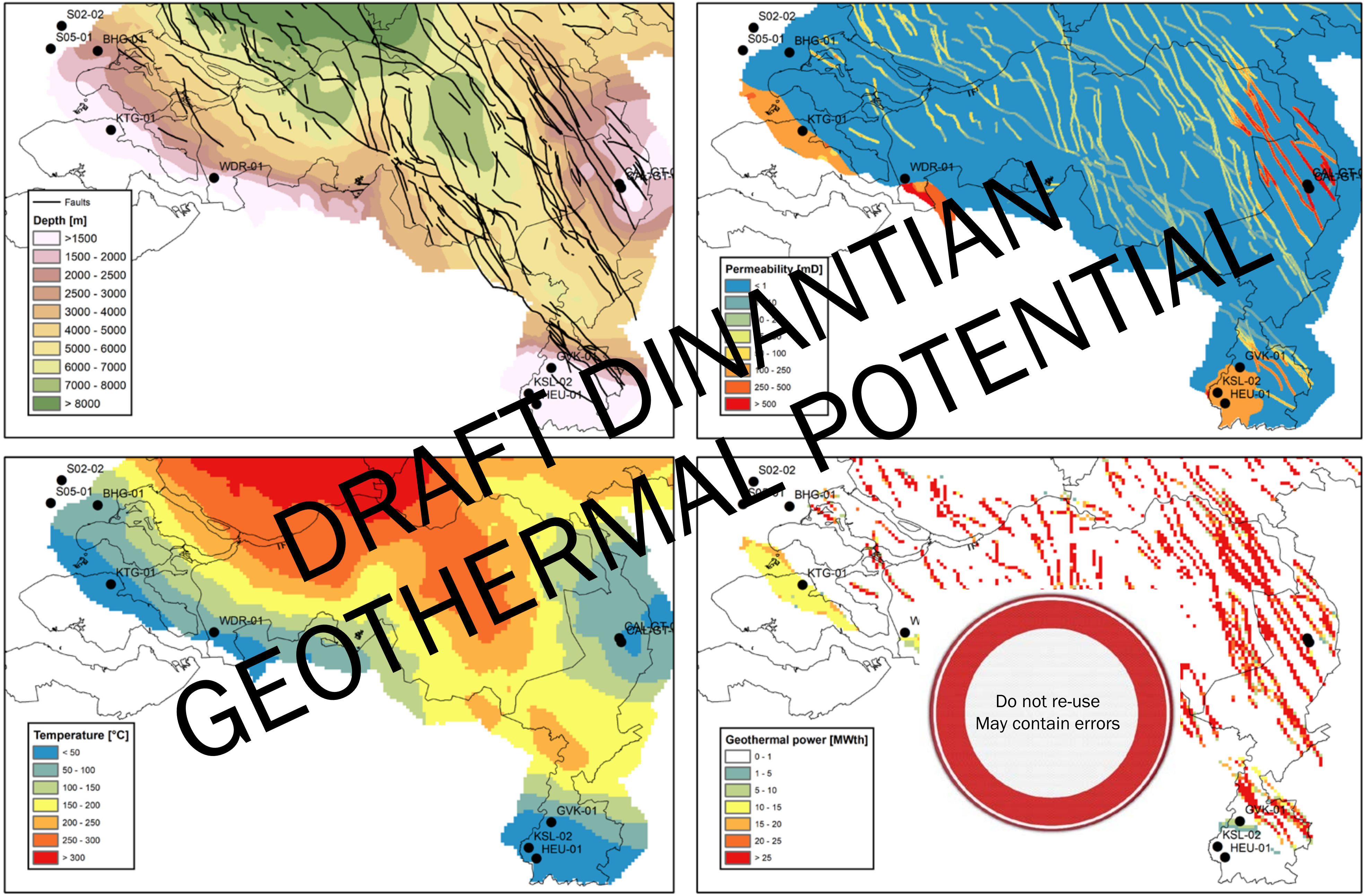


Faults as mapped on 2D seismic, two main directions. Abundant NNW-SSE demonstrated in Californië doublet. Sparse WNW-ESE direction unlikely to be 'open'?

PERMEABILITY ASSUMPTIONS

- NNW-ESE faults:
  - Maximum distance 500 meter (Californië)
  - Maximum transmissivity in fault core 300 Dm (Californië (TNO AGE)
  - Minimum transmissivity at outside fault zone 0.1 Dm (analogue??)
  - Option: decrease permeability with depth > not proven
- WNW-ESE faults:
  - Maximum distance 500 meter (arbitrary)
  - Maximum transmissivity 1/3 of NNW-ESE (arbitrary based on perpendicular principal stress direction)
  - Minimum transmissivity 0.1 Dm (arbitrary)
- Chalk (and other?) subcrop:
  - Buffer around subcrop ~1 kilometer
  - Transmissivity 100 Dm (arbitrary)
- Background transmissivity:
  - Assume near tight: 0.0025 Dm (based on petrophysical analysis)

Given large uncertainty, downside (P90) will go down to ~0, whereas upside (P10) will be large


S02-02
S05-01
BHG-01
KTG-01
WDR-01
CAL-GT
GVK-01
KSL-02
HEU-01
Faults
Depth [m]
>1500
1500 - 2000
2000 - 2500
2500 - 3000
3000 - 4000
4000 - 5000
5000 - 6000
6000 - 7000
7000 - 8000
> 8000
Permeability [mD]
< 1
100 - 250
250 - 500
> 500
Temperature [°C]
< 50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
> 300
Geothermal power [MWth]
0 - 1
1 - 5
5 - 10
10 - 15
15 - 20
20 - 25
> 25
DRAFT DINANTIAN
GEOTHERMAL POTENTIAL
Do not re-use
May contain errors

CONCLUSIONS

- Both technical and economical geothermal potential reliably calculated for clastic reservoirs
- Permeability estimate plays a major role..
- .. but don't count out the economic part

- Dinantian limestone geothermal potential not calculated before (except for HIP)
- Extreme uncertainties regarding location and range or permeabilities
- Learn from existing doublets
- But anyhow we can produce a first estimate

THANK YOU FOR YOUR TIME

TNO innovation for life