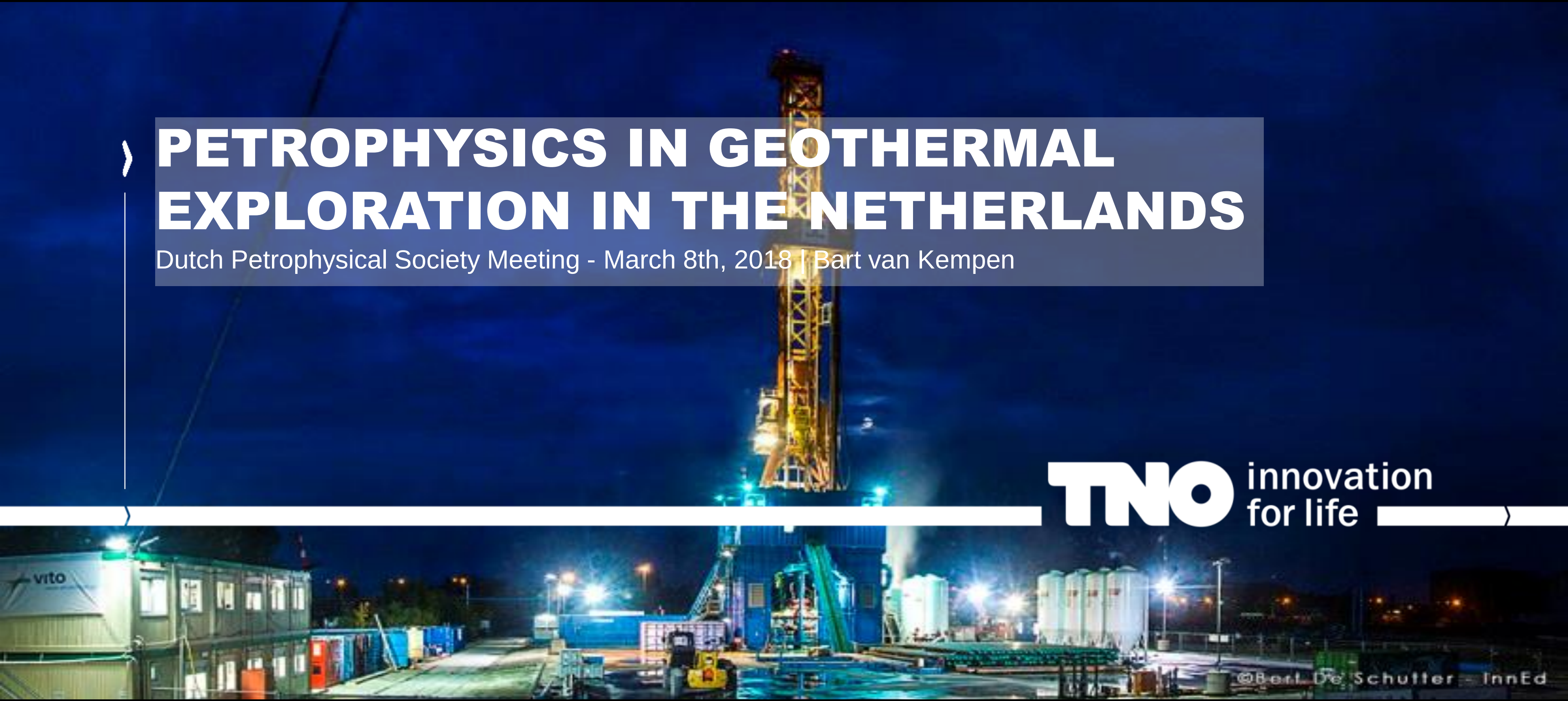
PETROPHYSICS IN GEOTHERMAL EXPLORATION IN THE NETHERLANDS

Dutch Petrophysical Society Meeting - March 8th, 2018 | Bart van Kempen



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PERSONAL INTRODUCTION

Bart van Kempen

Background

- MSc in Earth Sciences, graduated in 2010.

Working experience

- 2010 – 2012: PanTerra Geoconsultants
  Special Core Analyst

- 2012 – present: TNO – Geological Survey of The Netherlands
  Advisory Group for the Ministry of Economic Affairs (AGE)
  Cluster Lead Geothermal Energy
  Specialised on reservoir characterisation (Petrophysics, Well Testing)

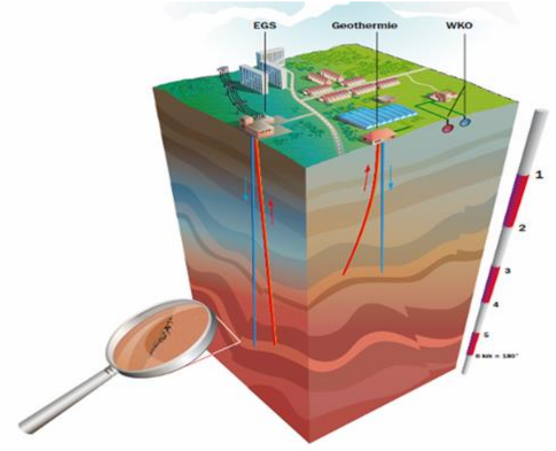
GEOTHERMAL ENERGY @ TNO-AGE

<u>Purpose and task TNO-AGE (Advisory Group for Economic affairs)</u>

- Supporting <u>Ministry of EZK</u> and <u>SodM</u> in formulating and executing policy regarding subsurface activities covered by the Mining Law.

- Geothermal related work at AGE includes:
  - Collecting, QC and analysis of operator data
  - Licence applications
  - Financial support measures
  - Policy making
  - Reservoir potential studies
  - Informing parties ((local) government, (potential) operators, etc.)

- Geotechnical evaluations → major role for reservoir characterization.



GEOTHERMAL =>AQUIFERS<= O&G

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Noordzee Group *(storage radioactive waste, shallow applications, **<u>geothermal energy</u>**)*

Chalk Groep *(limited potential)*

Rijnland Group *(oil/gas, **<u>geothermal energy</u>**)*

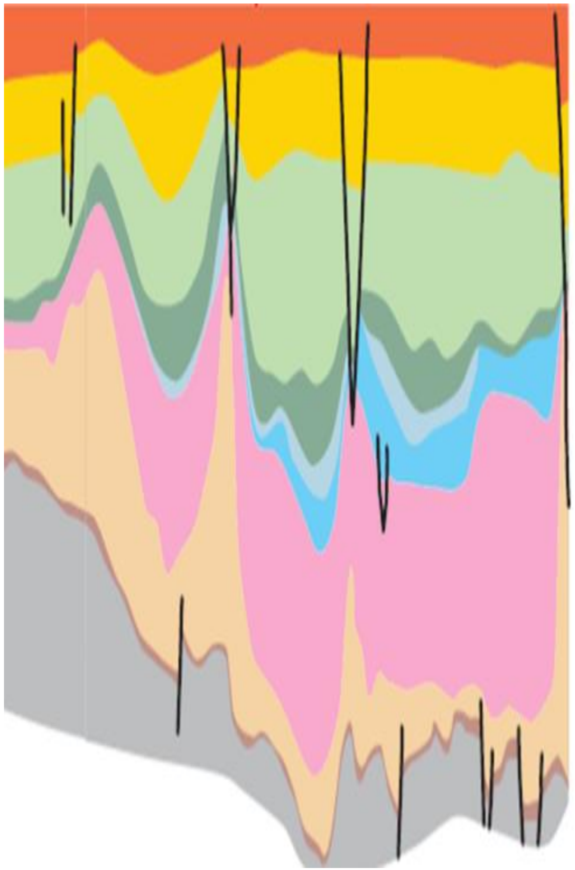
Altena, Schieland Groups *(oil/gas, **<u>geothermal energy</u>**)*

Trias Group *(gas/oil, **<u>geothermal energy</u>**, storage, salt)*

Zechstein Groep *(salt, storage, oil/gas)*

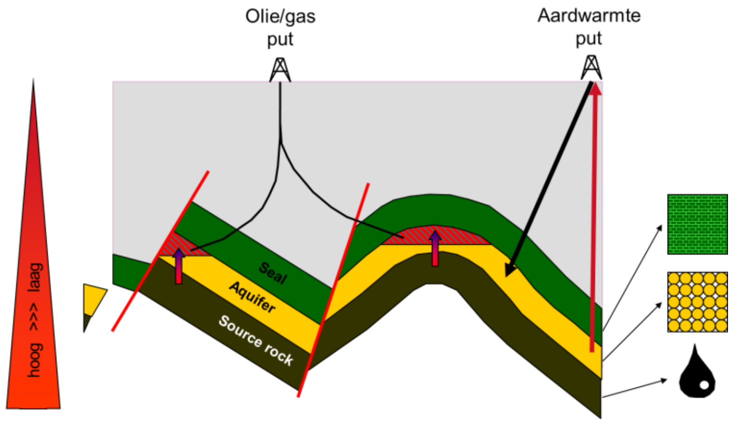
Rotliegend Group *(gas, **<u>geothermal energy</u>**, storage, buffering)*

Carboniferous *(gas, **<u>ultra deep geothermal energy</u>**, shale gas, CBM)*



PETROPHYSICS IN GEOTHERMAL PROJECTS

Oil & Gas	Geothermal
Porosity	***Permeability***
Saturation	***Net Thickness***
Net Thickness	Porosity
Permeability	~~Saturation~~



- Similar to petrophysics in oil & gas E&P, but different focus.
- Geothermal energy still small scale.
  - Highly dependent on data from oil & gas industry, lack of data in geothermal wells.
- Geothermal projects mainly in grabens, gas fields in horst blocks.
- (Primary) permeability and net thickness govern success of geothermal project.
  - Fraccing not yet applied and difficult onshore.

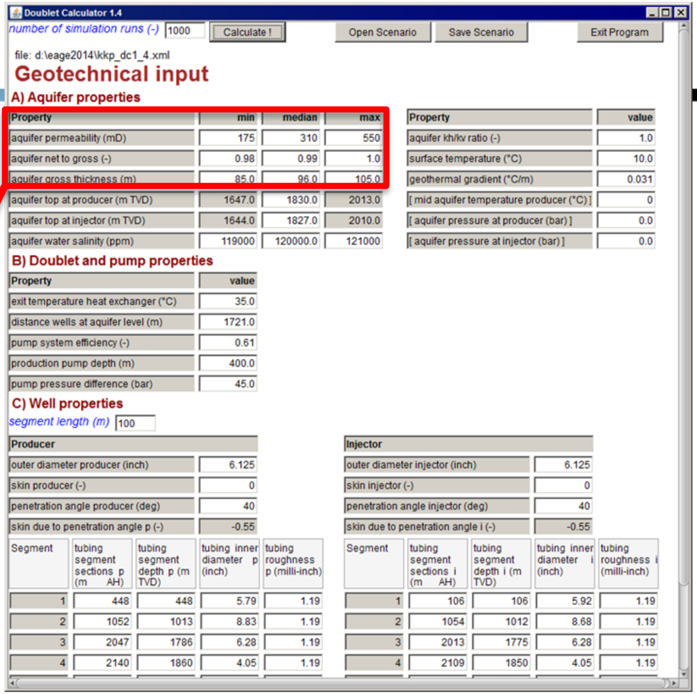
RESERVOIR EVALUATION OF A GEOTHERMAL PROJECT

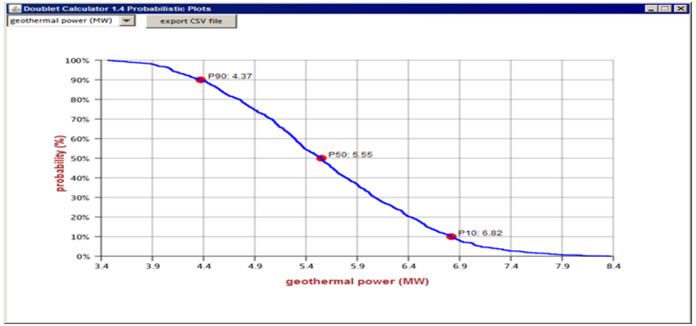
ESTIMATING GEOTHERMAL POWER

- Calculations based on DoubletCalc software, developed by TNO.
- DoubletCalc 1D, DoubletCalc 2D.

- Flow equation (Verruijt 1970, Dake 1978):

$$\Delta p_{w,aq} = p_w - p_{aq} = Q_v \frac{\mu}{2\pi k H R_{ntg}} \left(\ln\left(\frac{L}{r_{out,w}} \right) + S \right)$$





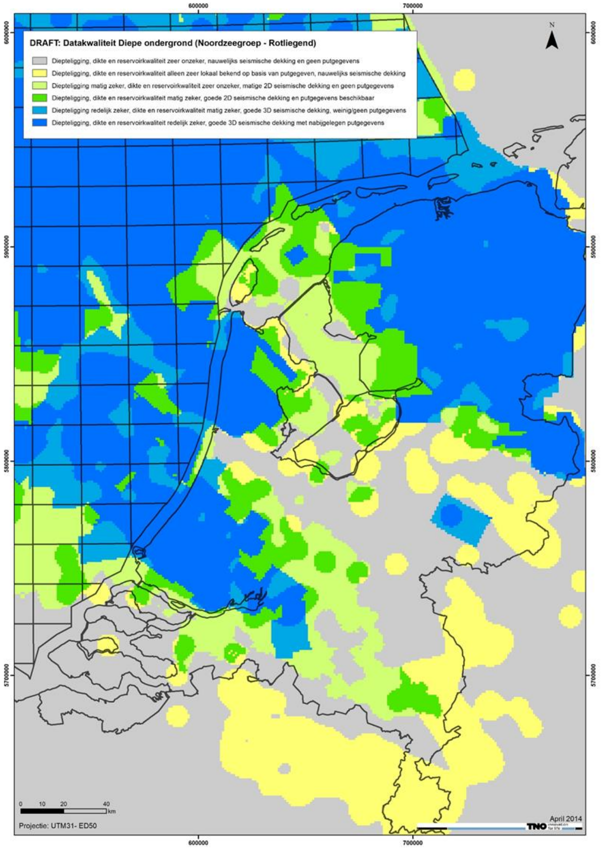
Property	min	median	max
aquifer permeability (mD)	175	310	550
aquifer net to gross (-)	0.98	0.99	1.0
aquifer gross thickness (m)	85.0	96.0	105.0

GROSS THICKNESS

- Good seismic data coverage, especially in oil & gas provinces.
- Sufficient amount of wells.
- Triassic & Rotliegend: thickness laterally highly continuous.

<u>However:</u>

- Heat demand also outside oil & gas provinces.
  - Need for additional seismic data.
- Nieuwerkerk Fm. primary target reservoir in the Westland area.
  - Fluviatile, syn-sedimentary interval → highly variable thickness.
  - Oil & gas wells usually in highs, geothermal wells in lows.



Seismic data coverage (ref: TNO).

NET-TO-GROSS RATIO

Hydrocarbons

Vcl cutoff *Phi cutoff* *Sw cutoff*

Gross	Net Rock	Net Reservoir	Net Pay
All Rock Between geological markers	Rock that can store hydrocarbons	Rock that can store hydrocarbons that can flow	Rock that contains hydrocarbons that can flow
			Rock that contains no hydrocarbons
		Rock that can store hydrocarbons	*Rock that can store hydrocarbons*
	Rock that can not store hydrocarbons	*Rock that can not store hydrocarbons*	*Rock that can not store hydrocarbons*

Geothermal

Phi cutoff

Gross	Net Reservoir
All Rock Between geological markers	Rock able to flow water
	Rock not able to flow water

- In geothermal reservoirs: Sw = 100% → Vcl & Sw cutoffs not required.
- Phi cut-off majorly important:
  - Based on lower k limit for water to flow (1-2 mD).
  - N/G lower for water than for gas.

What about fractured reservoirs?

- Possibly pressure dependent N/G
- Use PLT to assess Net thickness and N/G

POROSITY

- Approach to determine porosity: local porosity map based on well data.
  - Requirement: availability of local to sub-regional well log data.
  - Use results from conventional petrophysical analyses.
  - **Most important: incorporate geological concepts!**
    - Sedimentary facies, diagenesis, burial depth, faulting, etc.
    - Give more weight, or exclude data points.
    - Distance to the target location

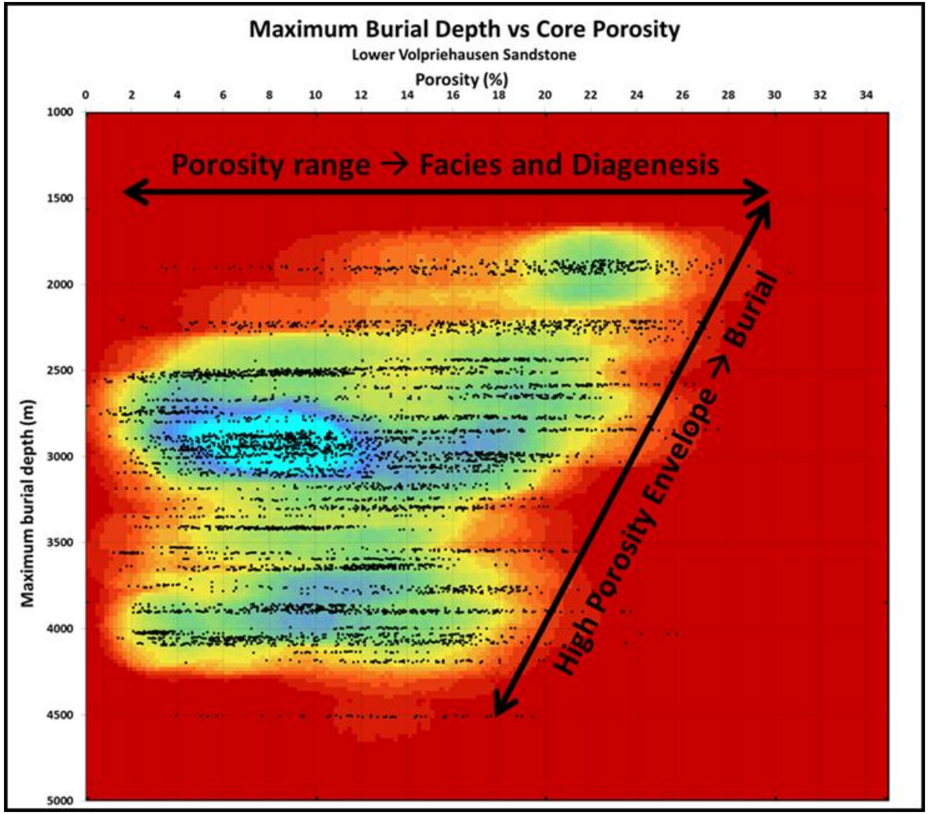
- Lack of porosity logs in most geothermal wells is problematic:
  - Unable to calculate accurate porosity.
  - Rough indication of porosity possible via GR-Phi transform.
  - Or from interference well test.

- Other estimation methods, e.g. seismic inversion, but geothermal projects are usually low budget w.r.t. hydrocarbon projects.

POROSITY DECREASE WITH BURIAL DEPTH

- Decrease of porosity with depth is irreversible, therefore maximum burial depth should be taken into account when:
  - Local wells from horst blocks, but project in graben.
  - Project is located in heavily inverted fault block.

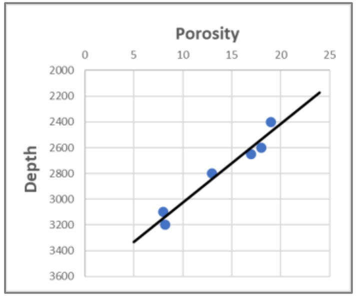
- Adequate poro-depth trend not easy to determine:
  - Scatter due to clay and pore cement.
  - But high-porosity envelope usually visible.

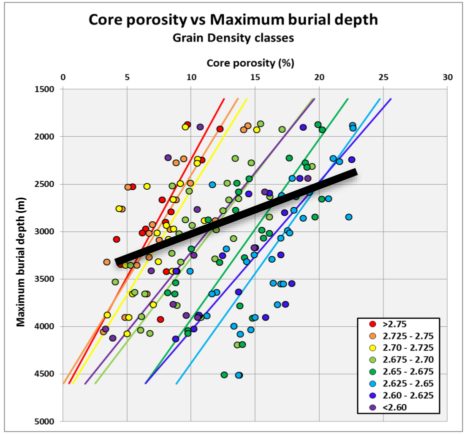


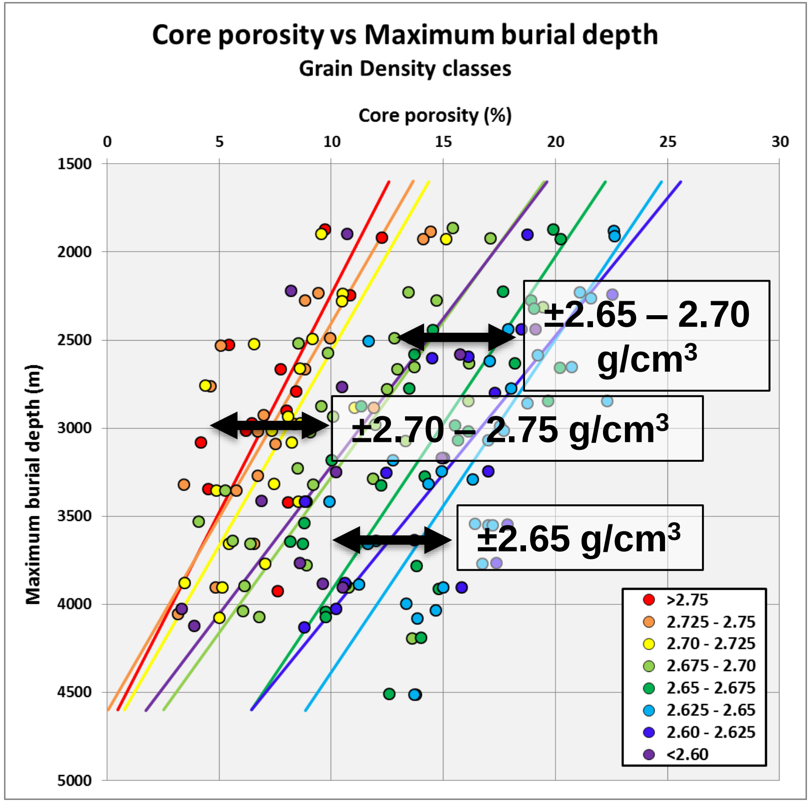
POROSITY DECREASE WITH BURIAL DEPTH

- Poro-depth trend becomes more clear when adding matrix density attributes.
- Based on an indication of the mineralogy (and expected matrix density) a porosity range can be determined.

- Note: careful with small data sets.
  - Good fit, but unrealistic trend due to facies & diagenesis.







Van Kempen et al., 2018 (in prep.)

PERMEABILITY

- Permeability has major impact on flow rate, but is usually most uncertain.

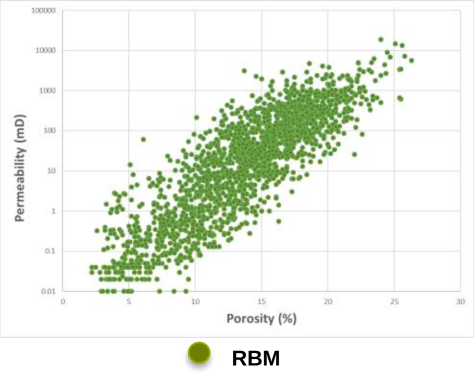
- Permeability can be calculated from:
  - Petrophysics
  - Core data
  - Well Test
  - Production data

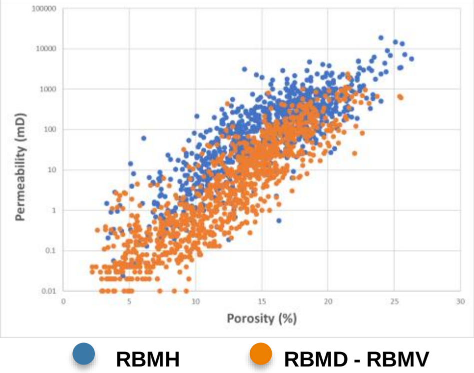
- Well Test results generally preferred → most representative reservoir average.

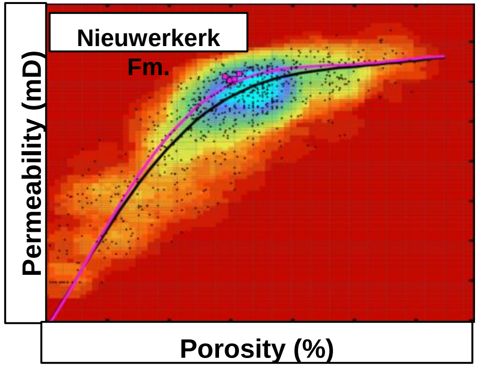
PERMEABILITY FROM PETROPHYSICS

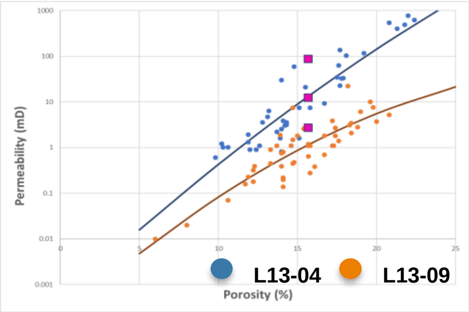
- Important to define representative poro-perm relation based on core data.
  - Use intrinsic permeability, e.g. Juhasz (1986).
  - Use curved or bi-linear transforms.
  - Use representative data selection.
    - Proper stratigraphic interval(s)
    - Complete core data collection
    - Same sedimentary facies
- Use appropriate averaging method that reflects reservoir geometry.
  - Arithmetic, geometric, or different…

- Underexplored intervals → e.g. Brussels Sand
  - Use alternatives: k based on grain size and sorting (Van Baaren, 1978).

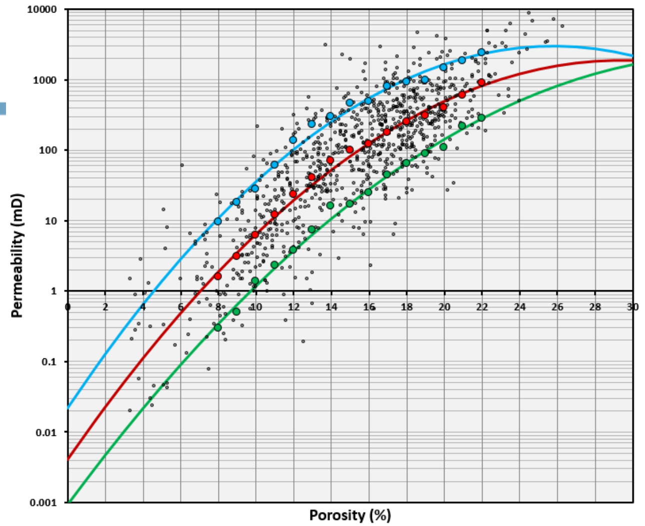








PERMEABILITY UNCERTAINTY

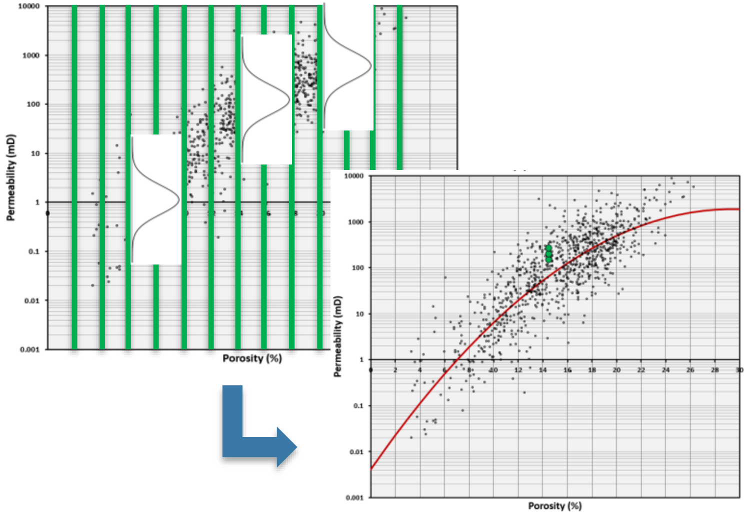


<u>Uncertainty based on core data:</u>

- Define phi bins → calculate P10, P50, P90 of k value per bin.
- Result: P10, P50 and P90 poro-perm transform.
- ***However***, this implies certain <u>geological concept</u>.

Alternative: independent uncertainty analysis

1) Define phi bins → define norm. dist. of k values per bin.
2) For each value of phi curve: randomly pick k value from normal distributions.
3) Calculate average reservoir k.
4) Repeat n times and calculate P10, P50 and P90 from reservoir k averages.



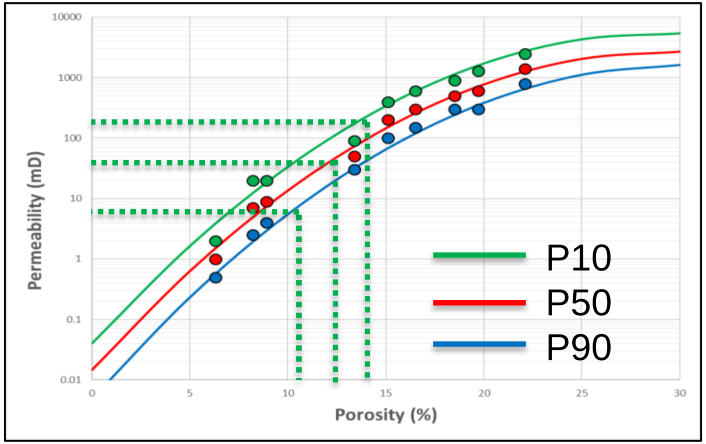
- **Define uncertainty based on geological concept.**

RESERVOIR AVERAGE PERMEABILITY

Next step: reservoir permeability at target location.

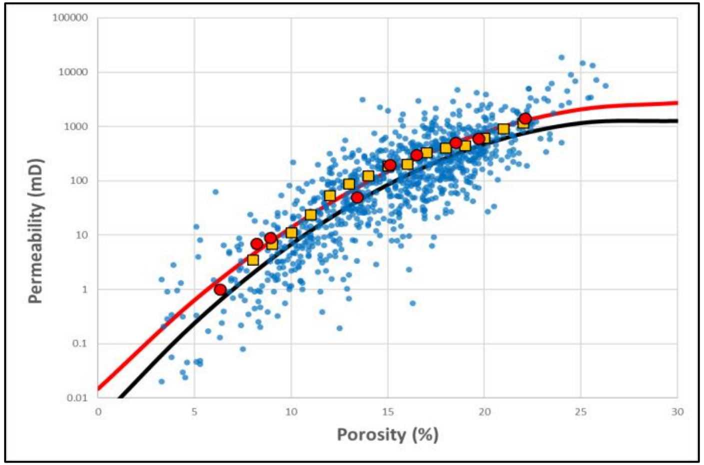
<u>Reservoir average poro-perm plot</u>

- Based on reservoir averages.
- Different scale w.r.t. core poro-perm plot.
    - Difference due to averaging method.



<u>Directly from core poro-perm plot</u>

- When petrophysical analyses are lacking.
- Based on Swanson's Mean Average (SMA).
    - Define phi bins, calculate SMA.
    - SMA: 0.3*P10 + 0.4*P50 + 0.3*P90.
- Validation with well test data required.
    - Some recent geothermal wells show good match.



(MIS)-MATCH PETROPHYSICS – WELL TEST DATA

- Often mis-match between permeability from well test and petrophysics. Many reasons:
  - Non-representative poro-perm transform.
  - Inappropriate averaging of permeability curve.
  - Rel-perm effects in case of gas wells.
  - Uncertainty in net thickness.
  - Quality of well test data.
  - Etc.

- General observations of permeability:
  - Upper Jurassic/Lower Cretaceous reservoir: well test > petrophysics
  - Triassic/Permian reservoirs: well test < petrophysics

- Most recent geothermal projects show better fit.
  - Quality of well tests is improving.
  - Better understanding of reservoir behaviour and translation into petrophysical analysis.

REFERENCES

- Baaren, J.P. van, 1978. Quick-look permeability estimates using sidewall samples and porosity logs. Publication 534; Koninklijke Shell Exploratie en Produktie Laboratorium, Rijswijk.
- Juhasz, I, 1986. Conversion of routine air-permeability data into stressed brine-permeability data. SPWLA 10th European Formation Evaluation Symposium, September 1986, London.
- Kempen, B.M.M. van, Mijnlieff, H.M., Molen, J. van der, 2018 (in prep). Data Mining in the Dutch Oil and Gas Portal: a case study on the reservoir properties of the Volpriehausen Sandstone interval. Mesozoic Resource Potential in the Southern Permian Basin. Geological Society, London, Special Publications.

THANK YOU FOR YOUR ATTENTION

QUESTIONS?

Take a look:
TIME.TNO.NL

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