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GEOTHERMAL ENERGY CONFERENCE

EBN LEGACY CORE PROJECT

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INTRODUCTION

Rationale

The Legacy Core Project was carried out by PanTerra Geoconsultants B.V. as part of the broader **EBN SCAN** program.

- The SCAN program aims to collect new subsurface data and reprocess existing data to stimulate and accelerate the use of geothermal energy in the Netherlands.
- The Legacy Core Project was conducted on wells with cores from the Rotliegend Slochteren Formation in the **central part of the Netherlands** (mostly D&A wells from 1950 – 2012, limited studies done)

The aim of this study is to **support the development of geothermal resources** in the scope area.

INTRODUCTION

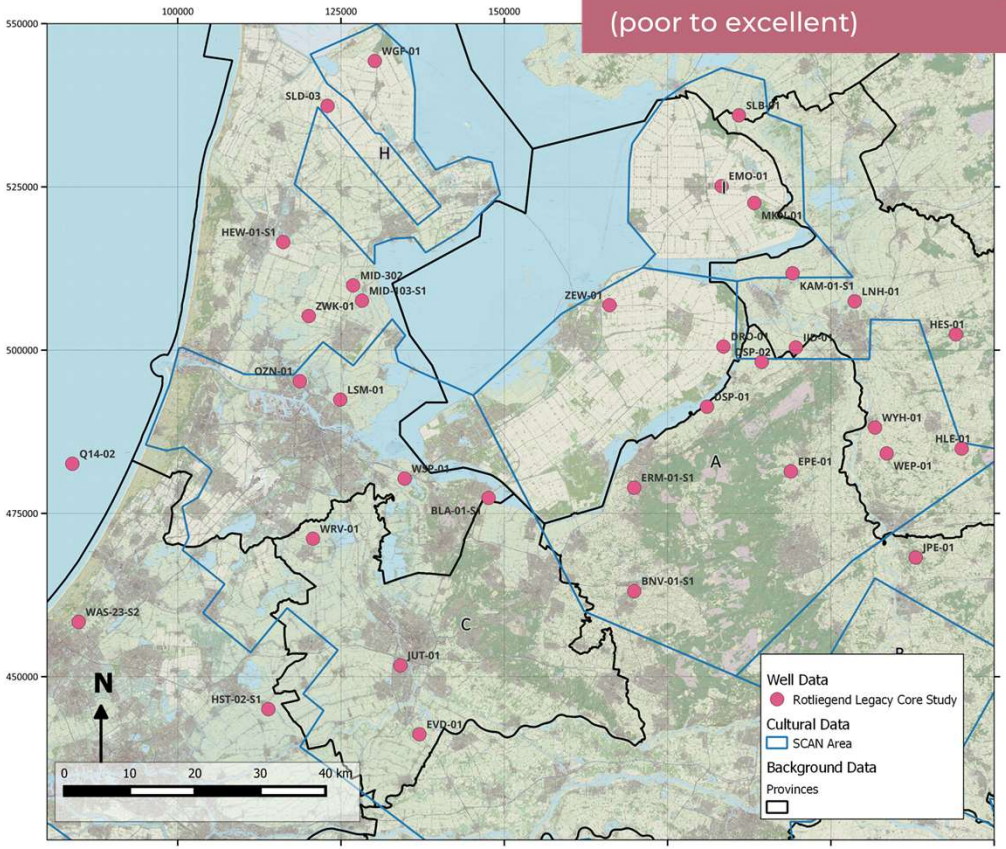
Outline

- Objectives
- Workflow
- Rotliegend primer
- Results
  - Sedimentology
  - Petrography
  - Reservoir quality
- Summary

34 wells with cores: ~ 900m

- Core lengths from 3m to 167m
- Core depths from 870m to 3173m (TVD)
- Drilled between 1950 and 2012

Cores are in variable state of preservation (poor to excellent)

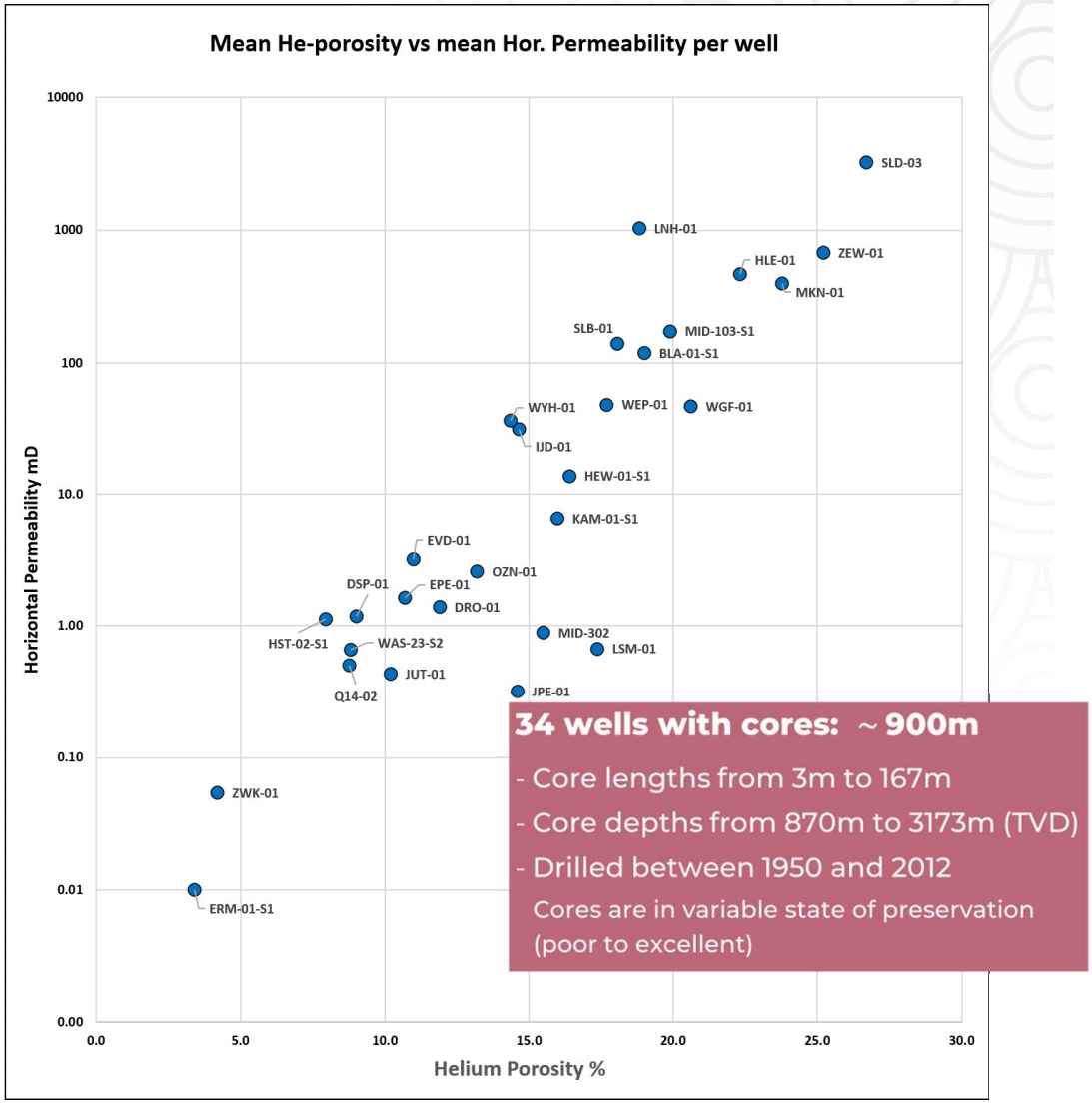


INTRODUCTION

Objectives

Unlock data from cores in the Rotliegend Slochteren Formation from legacy onshore wells

- Core description, petrographic analysis, integration with reservoir quality data (legacy RCA data)
- Data and conclusions documented in single well reports
- Publication in the public domain (TNO – NLOG website)



INTRODUCTION

Data set

- **34 wells with cores: ~900 meters**

- Core lengths from 3m to 167m
- Core depths from 870m to 3173m (TVD)
- Drilled between 1950 and 2012

  Cores are in variable state of preservation (poor to excellent)

- **163 new samples for petrography**
- **Well data from TNO - NLOG website**

INTRODUCTION

Workflow

1:20 scale Core Description in WellCAD

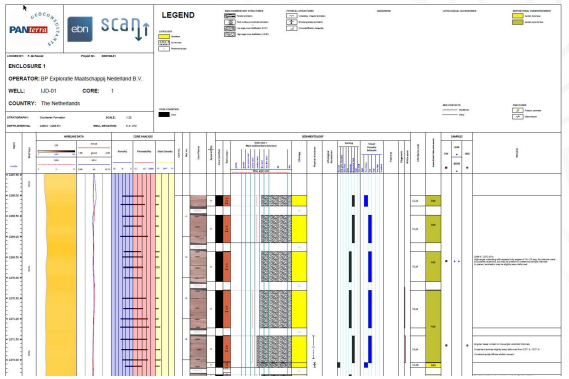
- Sedimentary properties, diagenetic features and fracture occurrence

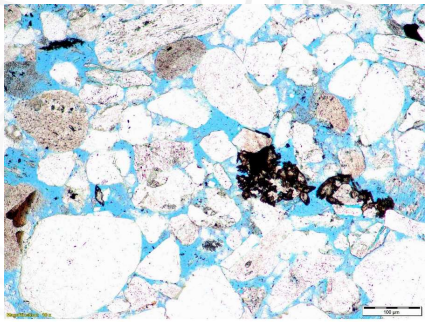
Petrographic Analysis

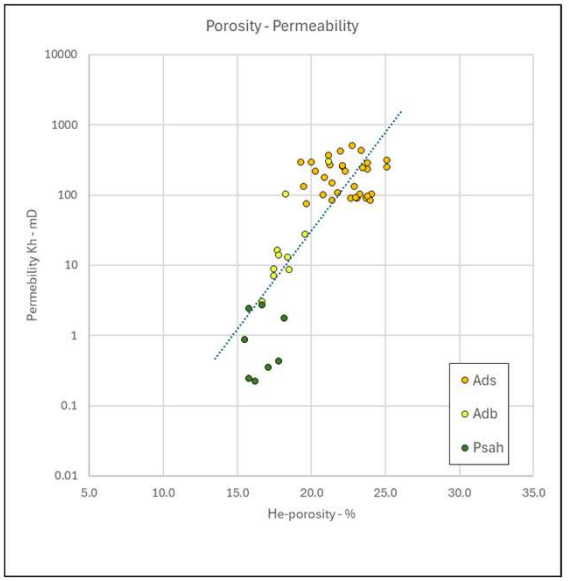
- Thin section description (136 new samples)
  - Textural properties, detrital and authigenic mineralogy, pore characterization
- SEM/BSEM analysis
  - mineralogy and pore characterization
- XRD analysis
  - Whole rock and clay mineralogy

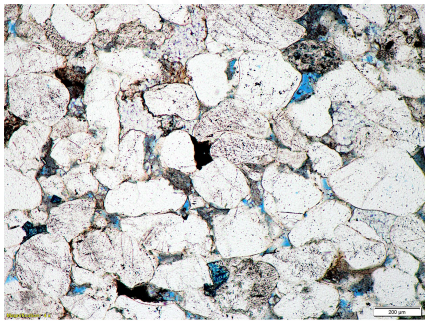
Reservoir Quality Assessment

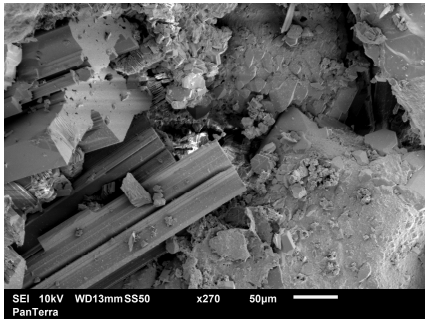
- Integration of RCA data – determine impact of
  - sedimentary facies
  - diagenesis (compaction, cementation, secondary porosity)







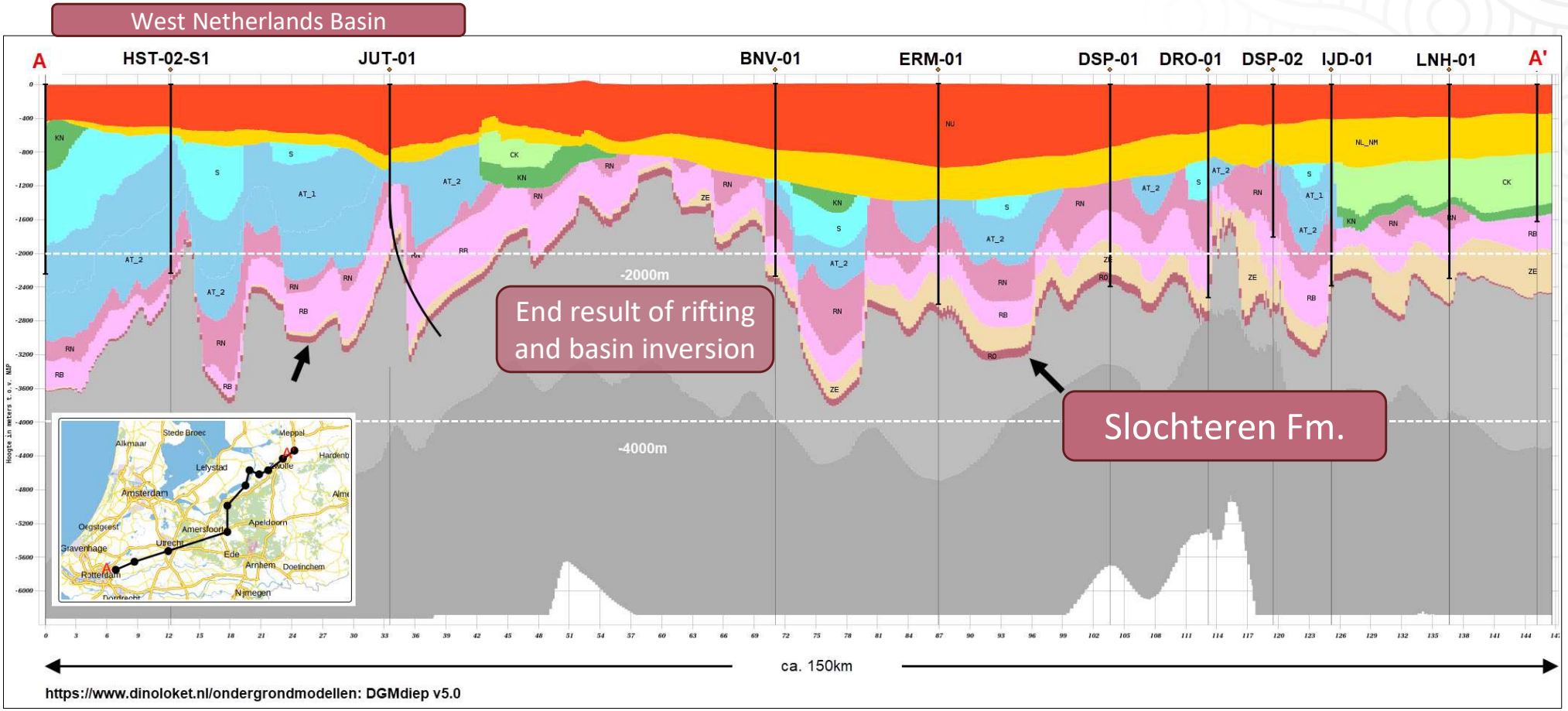




34 individual well reports
1 summary report
Limited regional integration

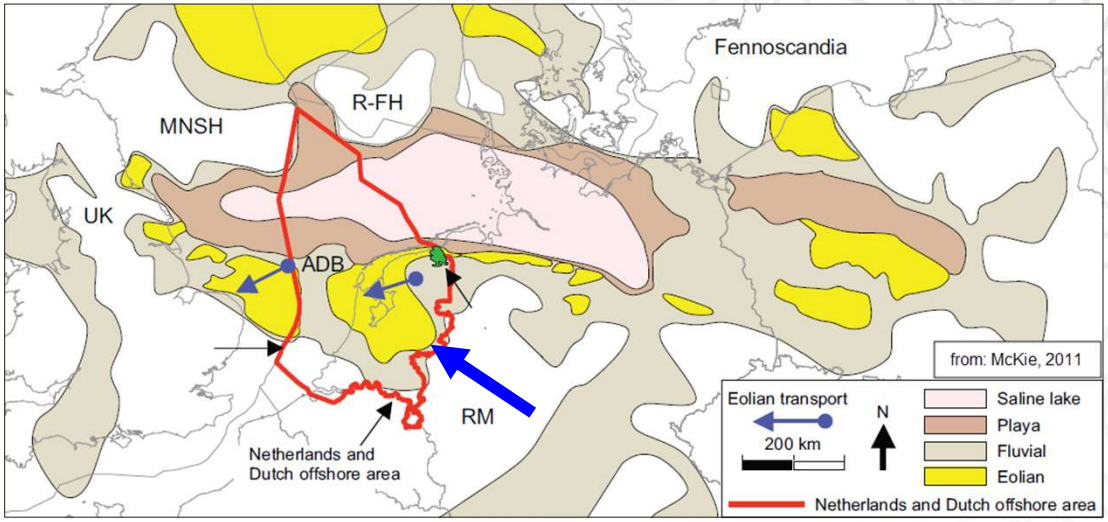
ROTLIEGEND PRIMER

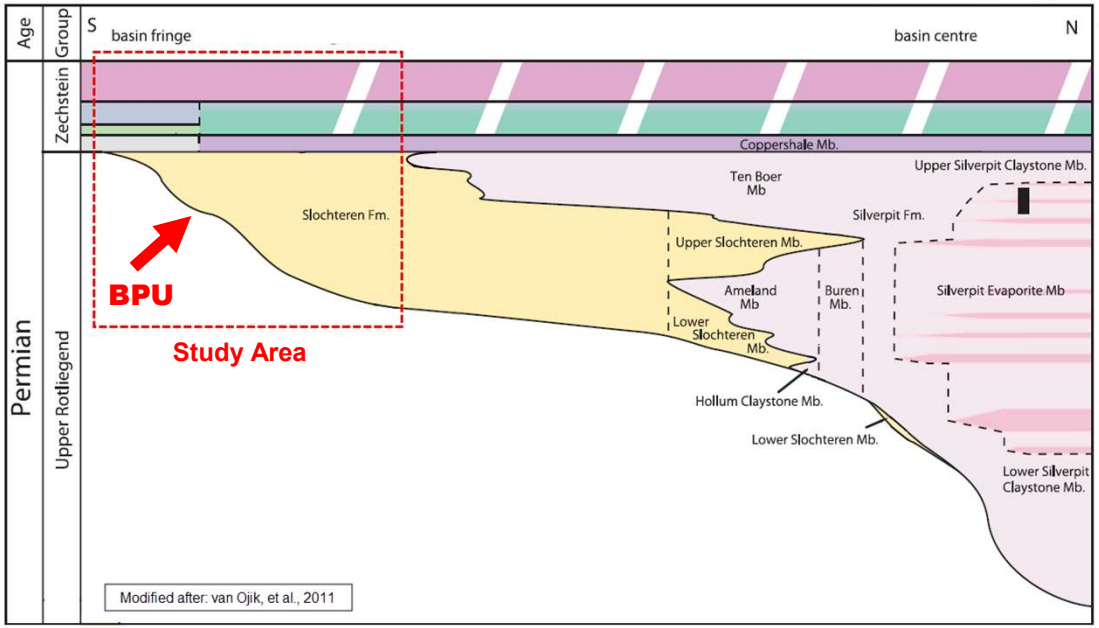
SW – NE cross section shows complex present-day structuration



ROTLIEGEND PRIMER

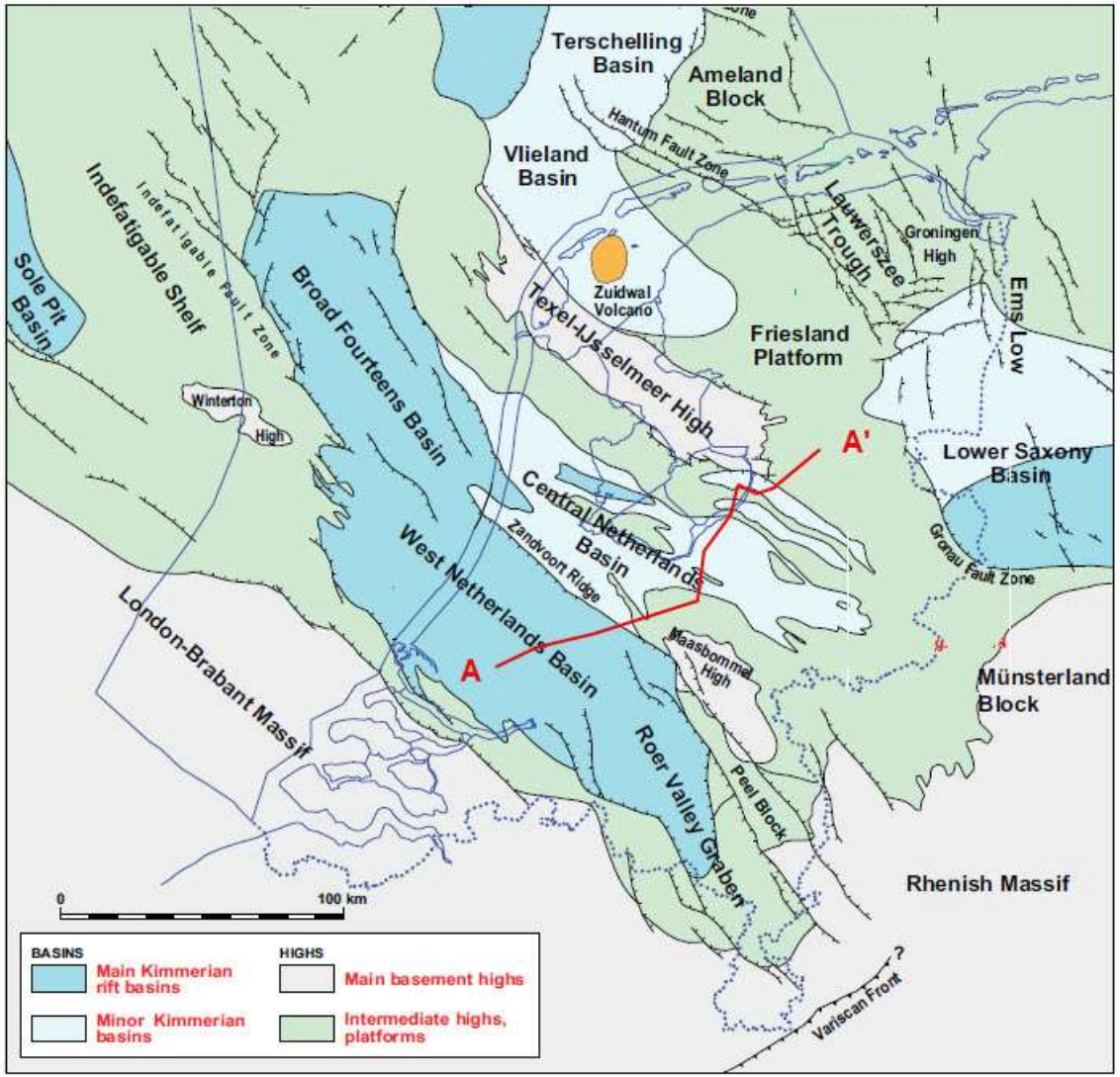
- Deposited during Upper Permian in Hot, Arid to Semi-arid Climate
- Southern Permian Basin with Central Saline Lake fringed with Playa mudflats
- Southern basin edge dominated by sandstone deposition in fluvial and aeolian settings
- **Study area** is dominantly aeolian (yellow shaded) with minor fluvial deposits at the base.
- Slochteren Fm. unconformably overlies Carboniferous deposits and is conformably overlain by the Coppershale (Zechstein age)





ROTLIEGEND PRIMER

- Complex structuration at various periods in time
- Jurassic/Cretaceous rifting phase caused formation of subsiding basins and relatively stable platforms
- Subsequent (Alpine) compression caused reactivation of faults and inversion (uplift) of basin fills
- Slochteren Formation experienced different burial history pathways across the Dutch subsurface
- Burial history strongly influences diagenesis and reservoir quality



RESULTS

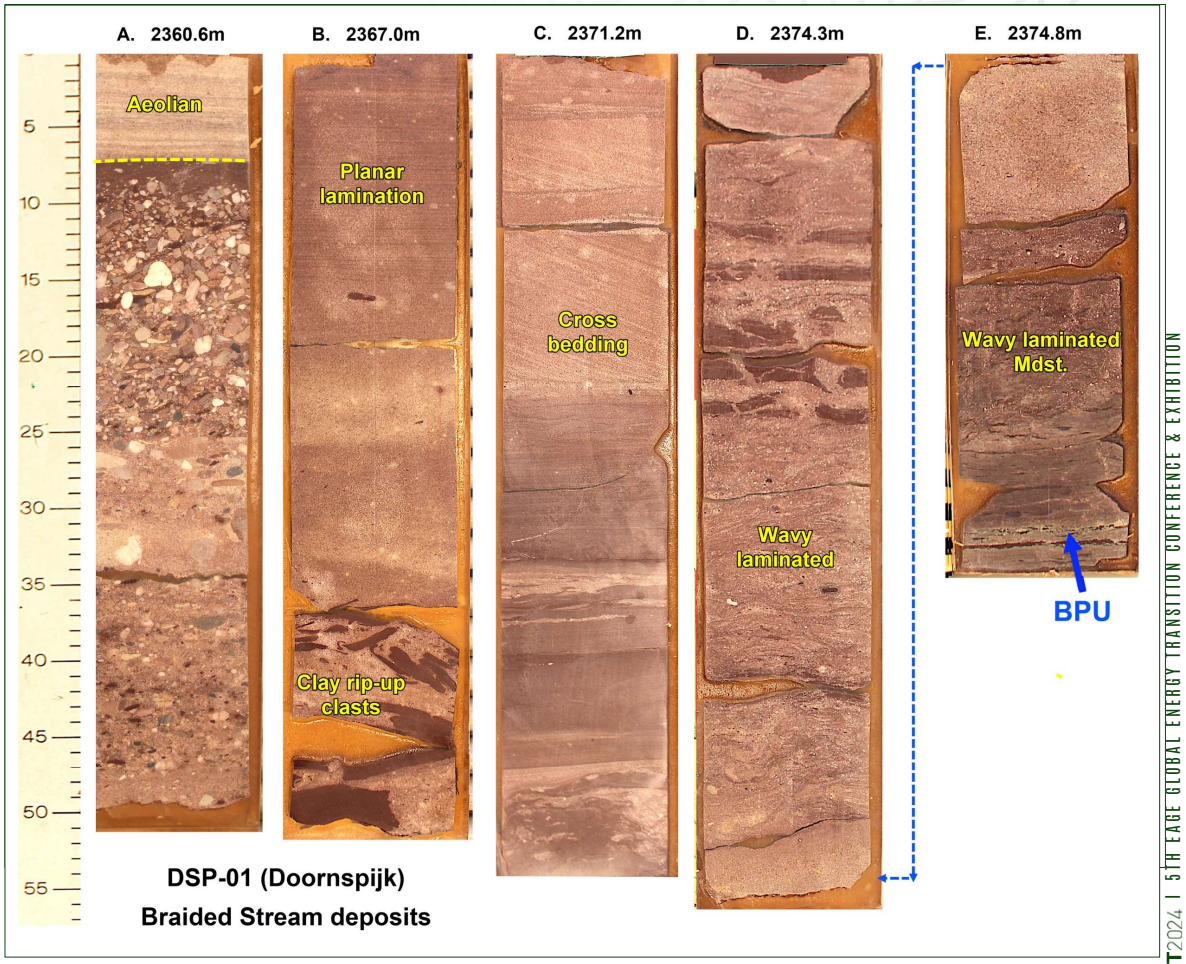
Sedimentology

Fairly uniform depositional setting

- Aeolian Dune and Dry Aeolian Sandflat deposits
- Less common, thin Fluvial Braided Stream deposits
  Mostly directly above the BPU

Typical sedimentary features

- Aeolian
  - Horizontal lamination, low- and high-angle cross-lamination. Occasional wavy lamination
  - Common sharp truncation surfaces
  - Bimodal grain-size lamination
- Fluvial
  - Planar laminated and cross-bedded (pebbly) sandstones and conglomerates
  - Occasional thin mudstone interbeds
  - Rip-up clasts



RESULTS

Fractures

Fracture occurrence is variable between investigated wells (no detailed classification)

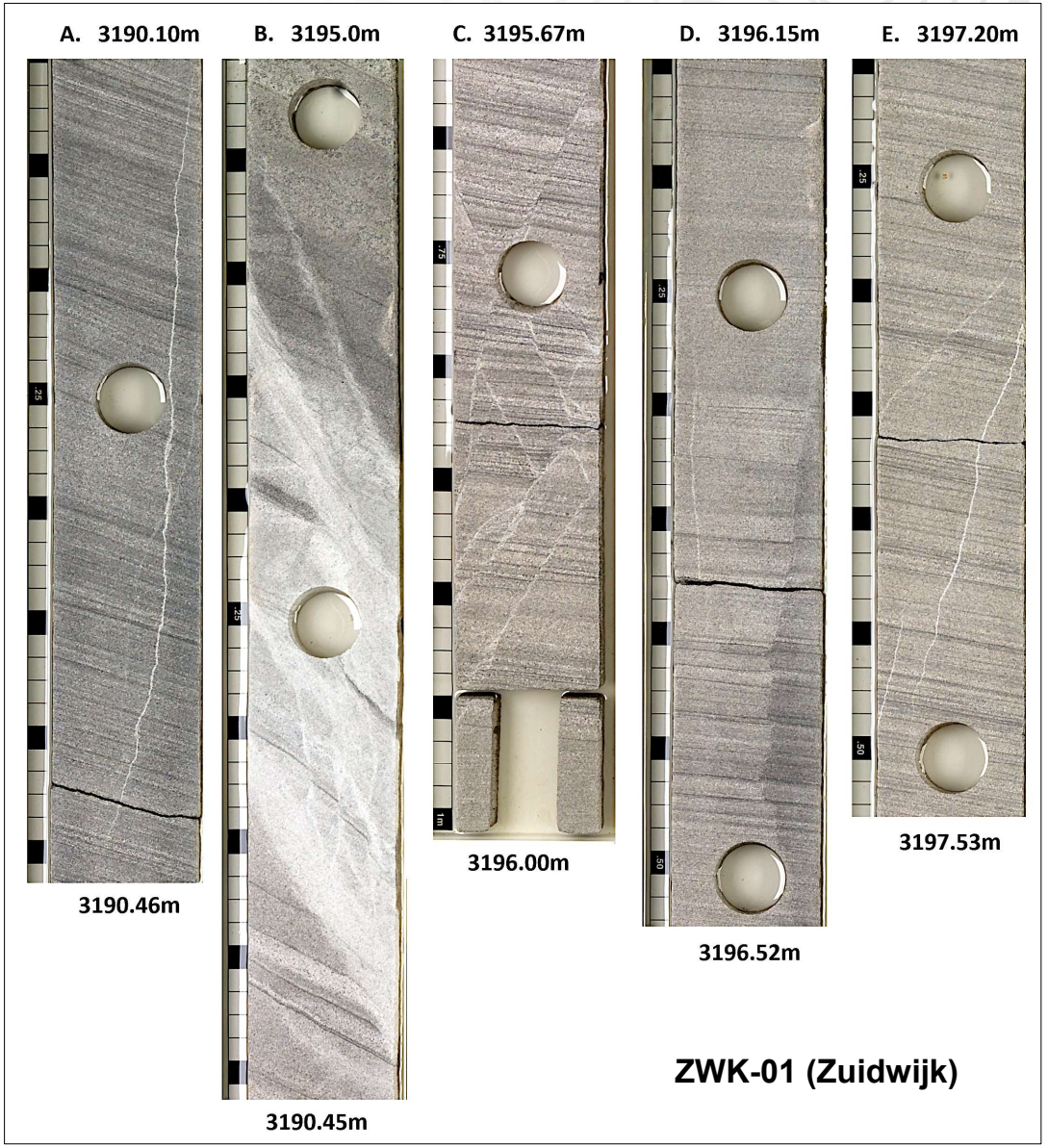
Mostly cemented and/or cataclastic in nature.

Will influence reservoir connectivity, but only relevant in high permeability reservoirs

Fractures are likely more common in the vicinity of faults (not verified w. seismic)

Faults were encountered in cores of 3 wells: WYH-01, WSP-01, and WRV-01

Wells have high fracture density

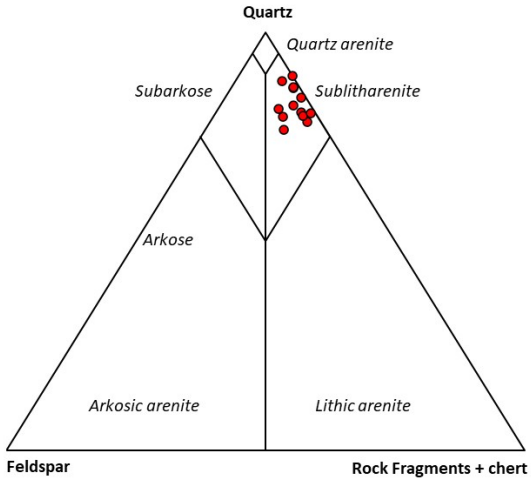


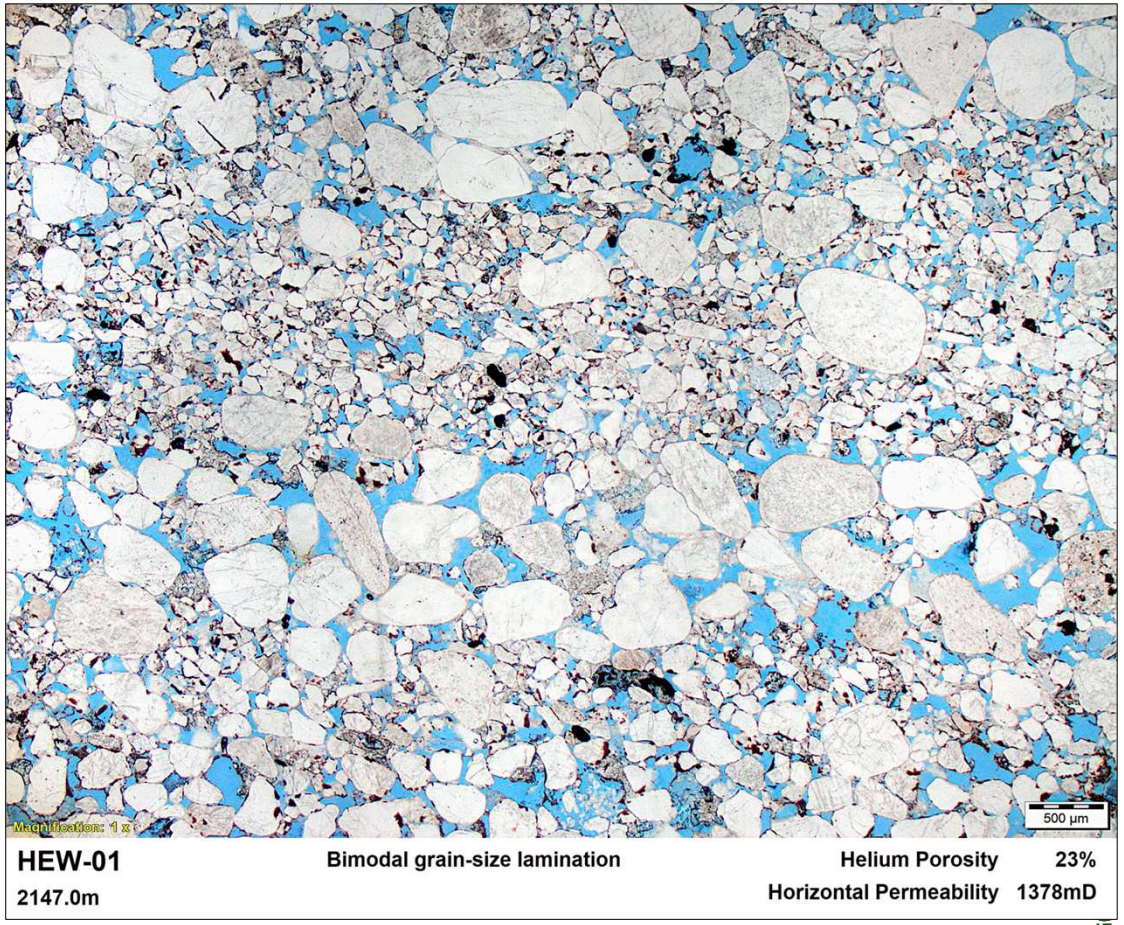
RESULTS

Petrography

Detrital mineralogy

- Sublitharenitic sandstones:
  >75% quartz, low amounts of rock fragments, rare feldspar grains (mostly dissolved)
- Moderate to good sorting,
  often w. bimodal grain-size lamination



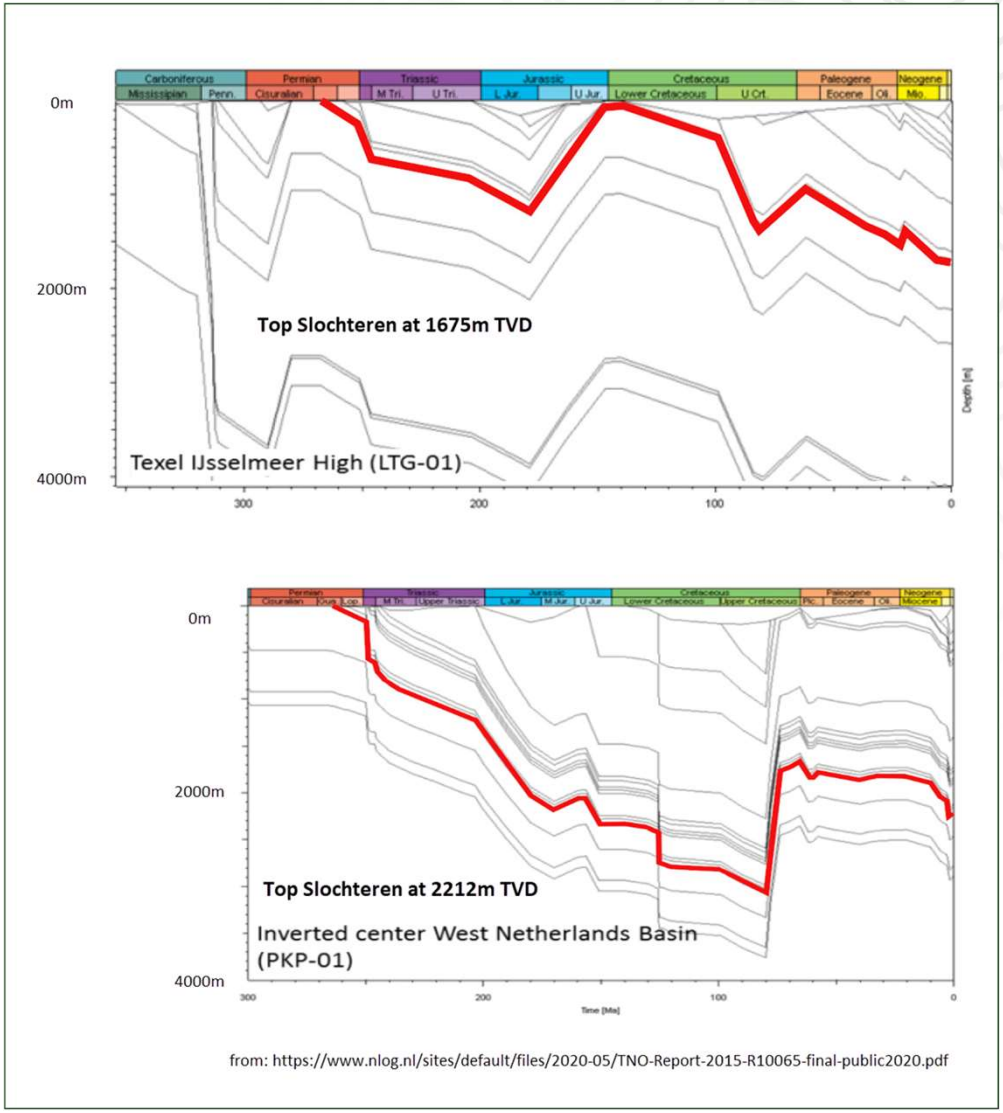


RESULTS

Petrography

Diagenesis

- Complex and regionally diverse burial history
  → strongly variable reservoir quality (RQ)
- Compaction, mineral precipitation and grain dissolution/replacement
  → modification of the initial pore network and RQ



from: https://www.nlog.nl/sites/default/files/2020-05/TNO-Report-2015-R10065-final-public2020.pdf

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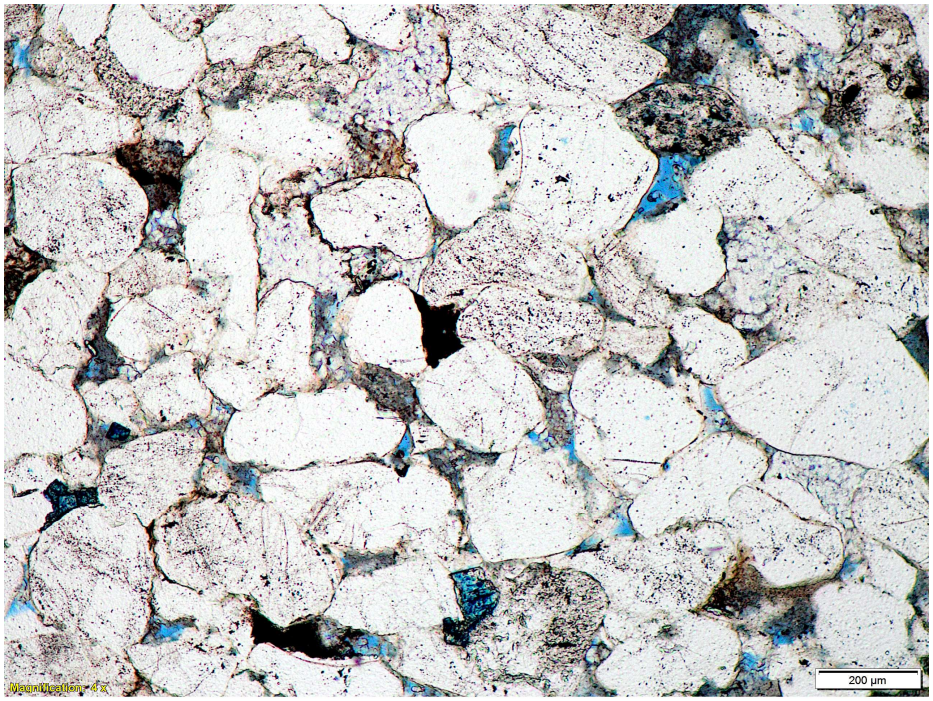
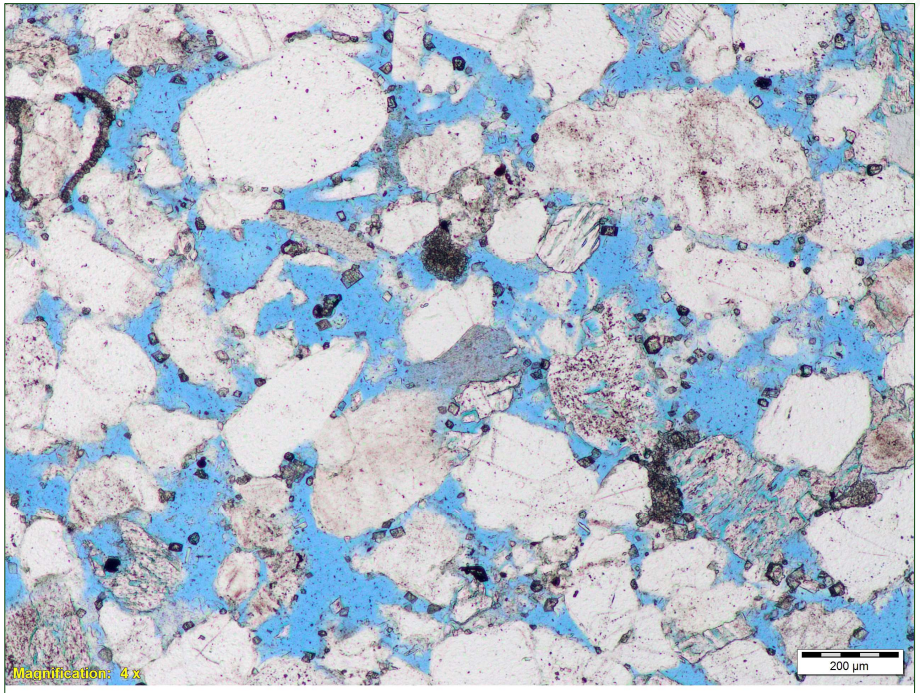


HST-02-S1 He-porosity 7.8%
2192.0m TVD Hor. permeability 1.0mD



MKN-01 He-porosity 21.3%
1686m TVD Hor. permeability 150.8mD

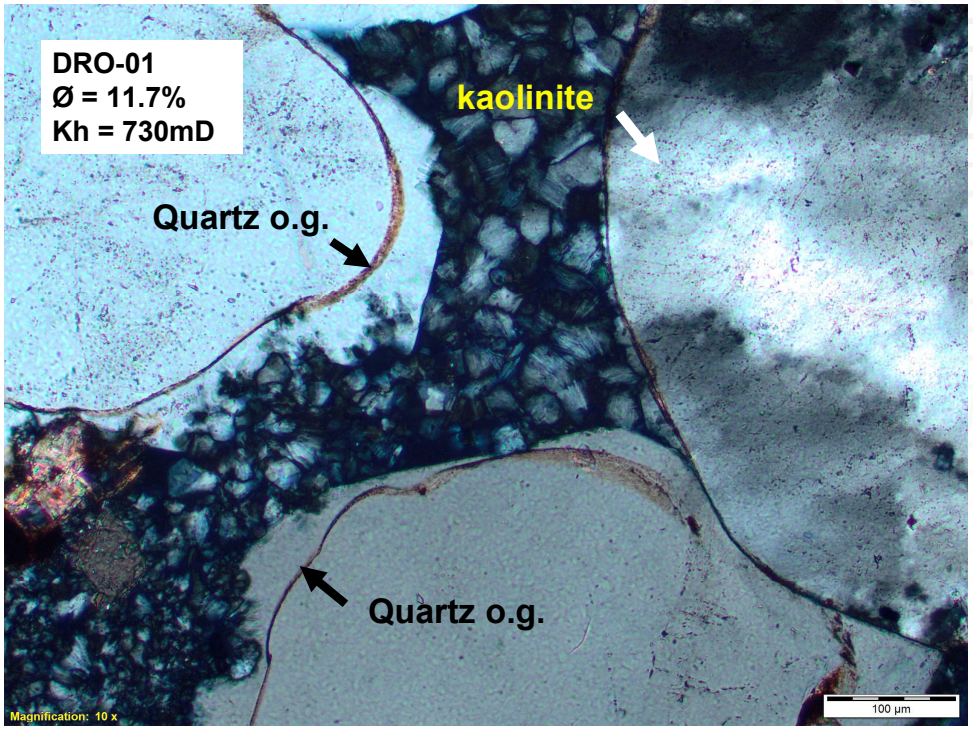
RESULTS

Petrography

Diagenetic products

The usual suspects:

Type	*Impact on RQ*
Early, grain-rimming clays	⊕
Kaolinite (several phases)	⊖
Quartz cement	⊖/⊖
non-Fe / Fe-dolomite, siderite, (calcite)	⊖/⊖
Anhydrite (barite)	⊖
Meshwork and fibrous illite	⊖⊖
Secondary porosity generation	⊕



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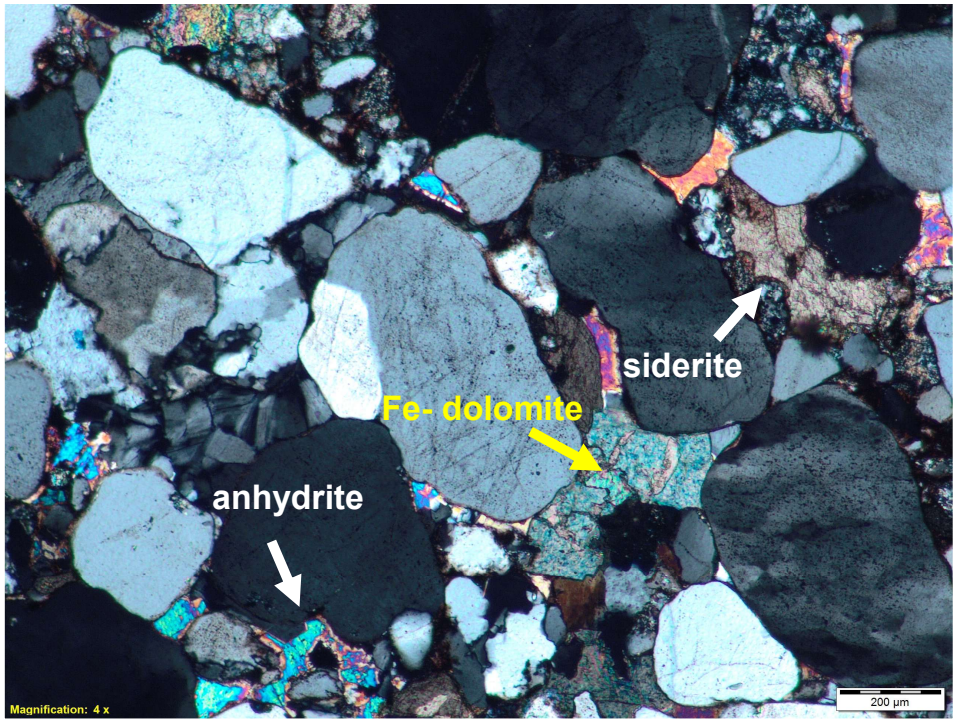

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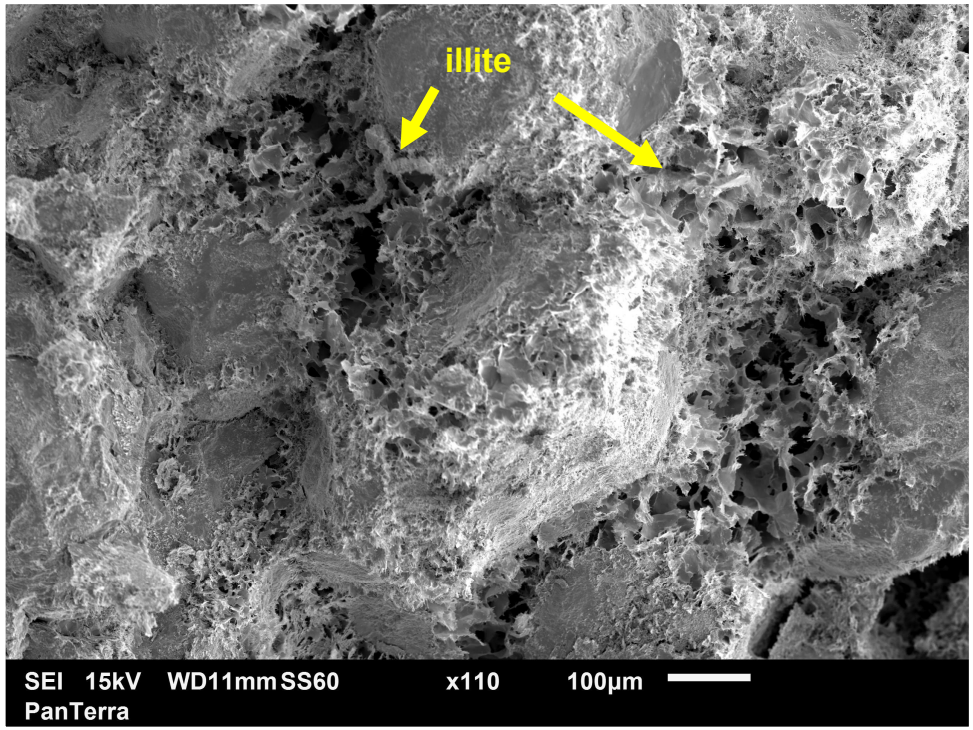


RESULTS

Petrography

Diagenesis

Special case:

Dawsonite - $NaAlCO_3(OH)_2$

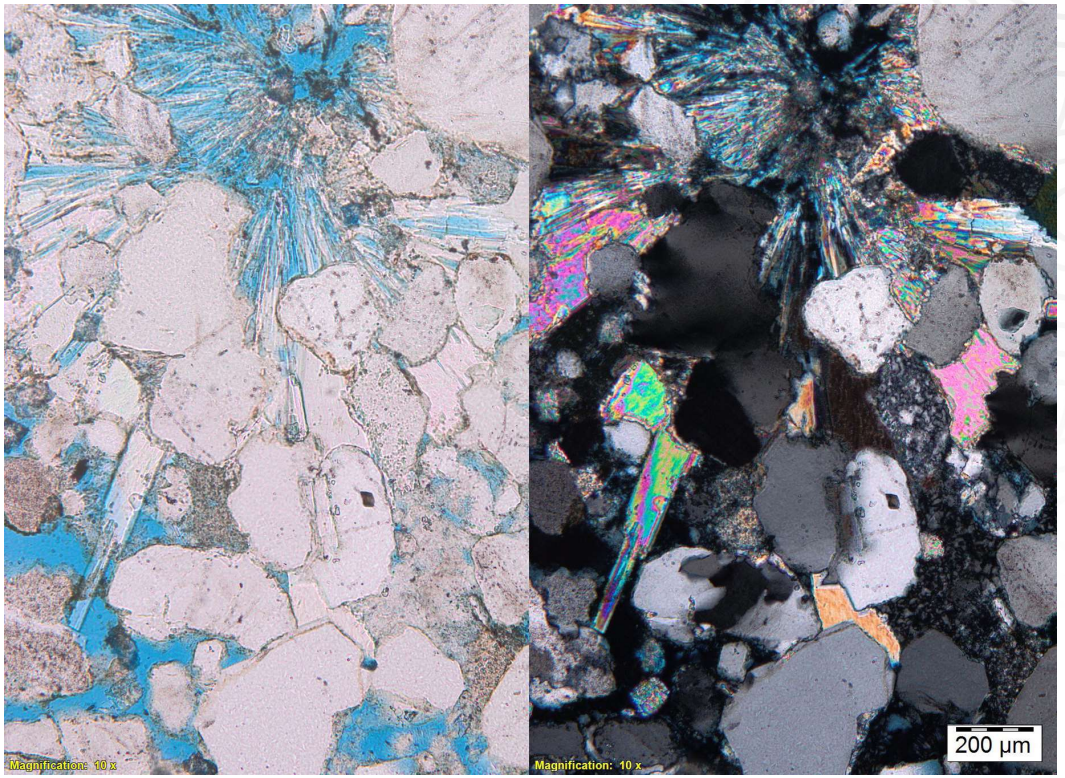
May form at high partial CO2 pressures

- Common constituent in well HLE-01
- Trace in well MID-103 – **gas reservoir with 29% CO2**

Abundant secondary porosity and very good reservoir quality characterizes both wells!

	Porosity	Permeability
HLE-01	23.2%	464mD
MID-103*	21.3%	387mD

* = exclucing Weissliegend facies



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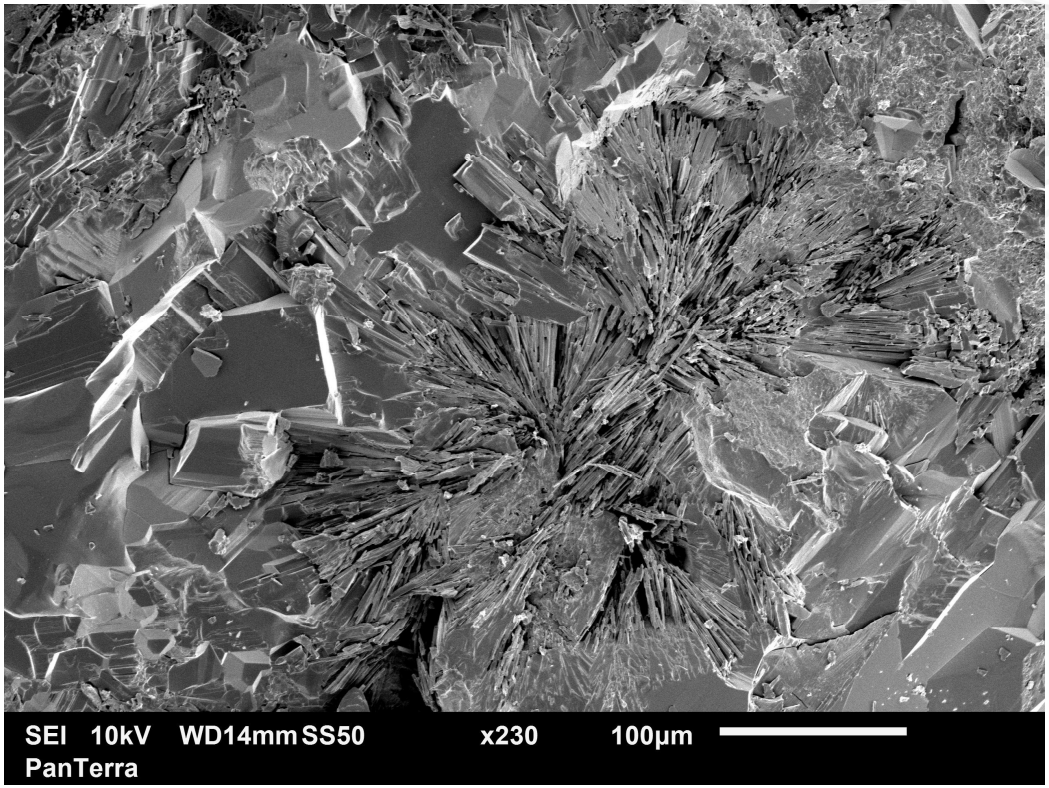


RESULTS

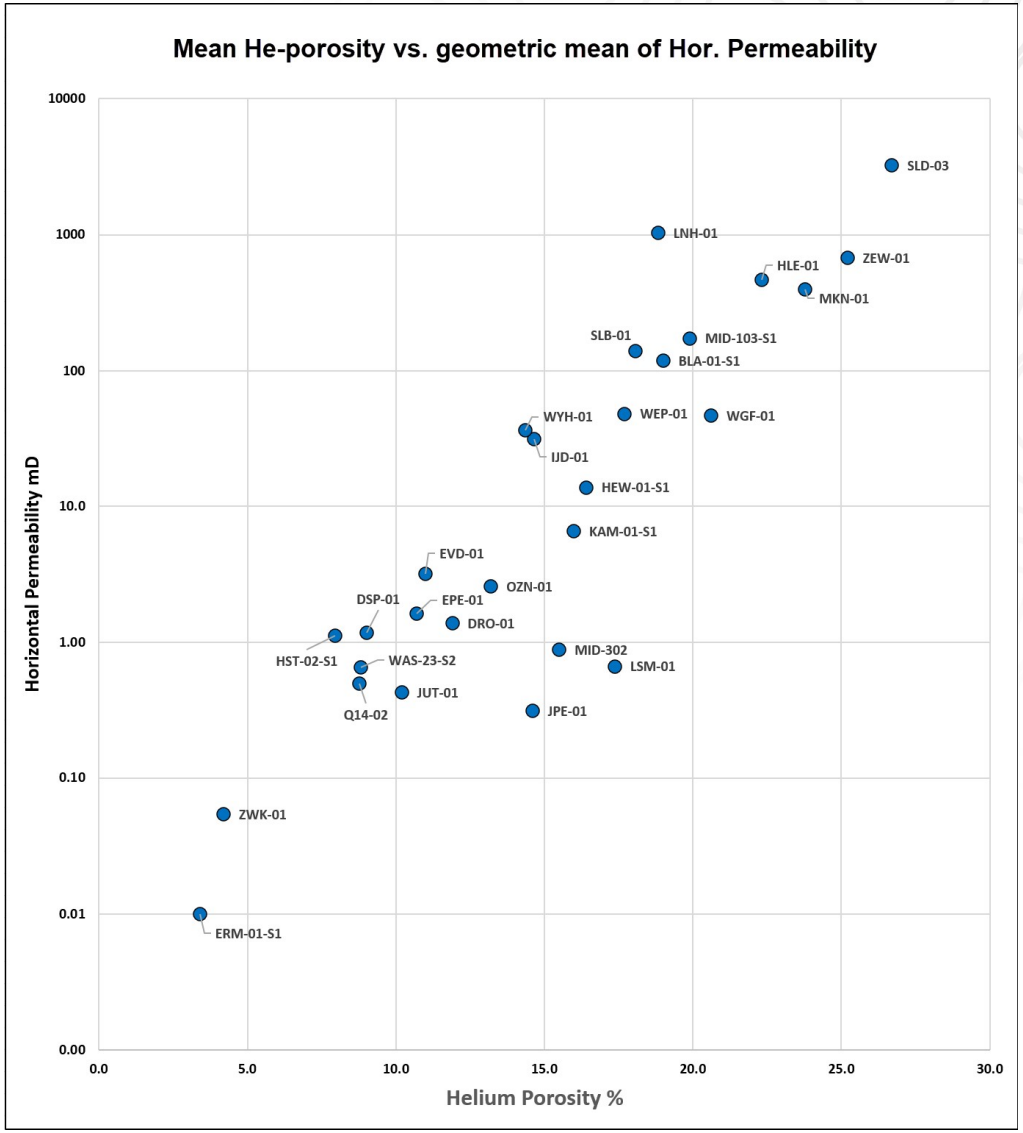
Reservoir Quality

Legacy RCA data:

2200 measurements in 28 wells

Mean porosity and permeability (geometric) for cored intervals

(only applies to cored sections of the Slochteren interval)



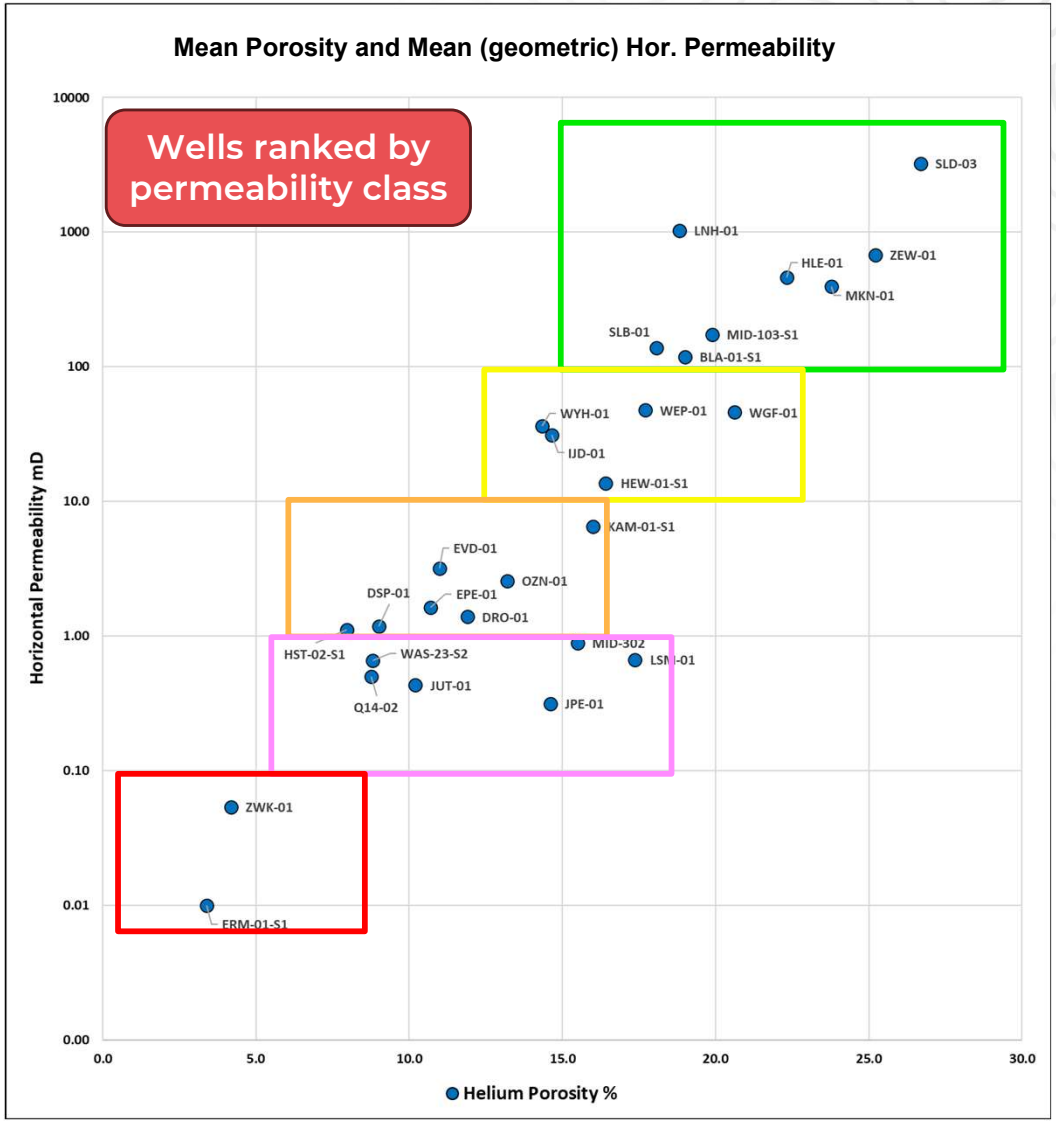
RESULTS

Reservoir Quality

Wells arbitrarily divided into 5 permeability classes:

- **>100mD**
- **10 – 100mD**
- **1 – 10mD**
- **0.1 – 1mD**
- **< 0.1mD**

Previous projects executed by PanTerra Geoconsultants show that a *mean permeability of 50 - 100mD* is the lower limit for successful geothermal projects in the Slochteren Formation dependent on reservoir thickness



Ranking based on mean permeability of the cored intervals based on core plug measurements

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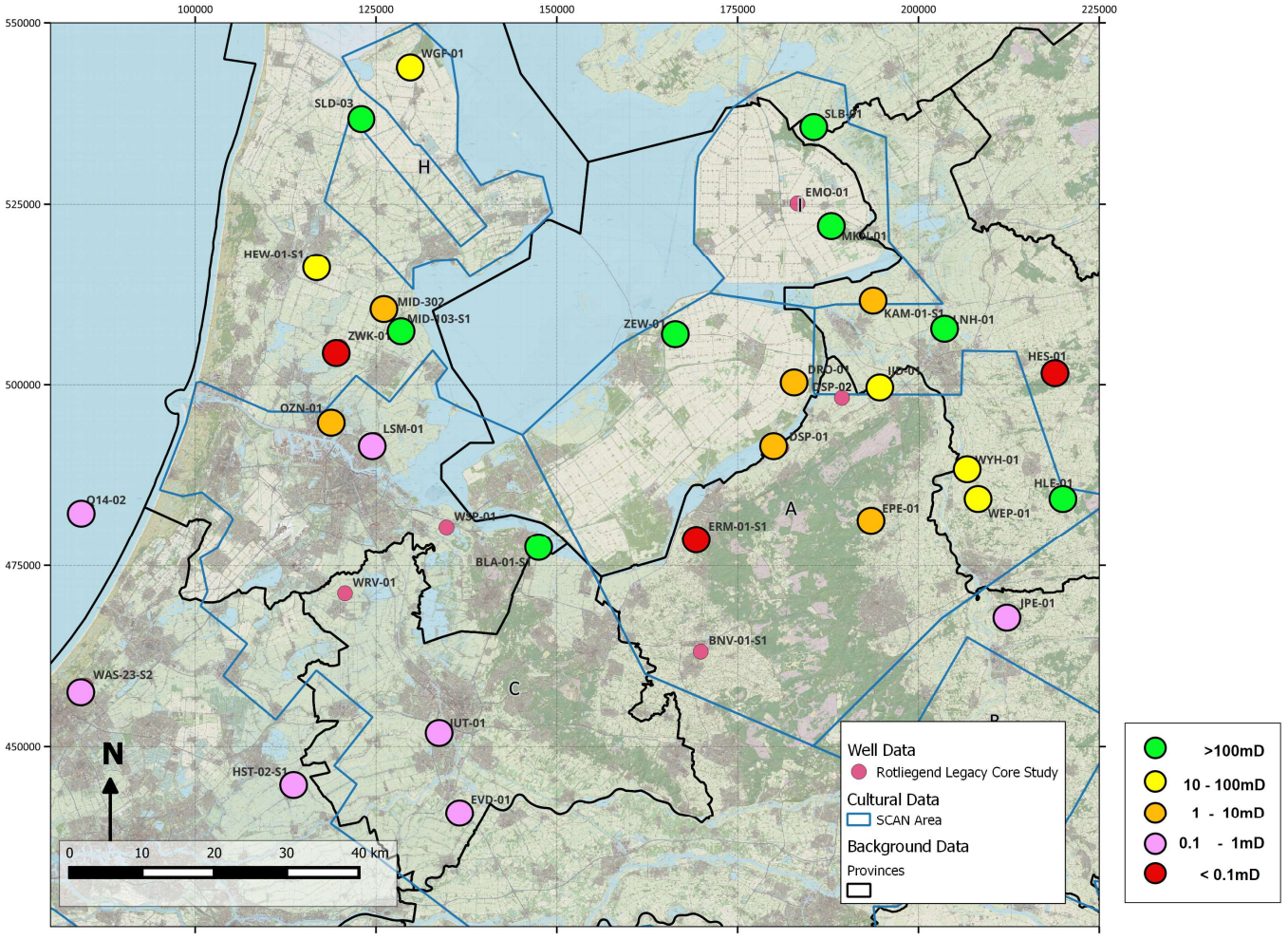

Ranking based on mean permeability of the cored intervals based on core plug measurements

SUMMARY

Cores from 34 wells and 163 petrography samples were described and analysed.

Integration with reservoir quality data shows:

- Limited control of depositional setting on reservoir quality
- Compaction and diagenesis governed by burial history exert a much greater control
- Ranking of wells based on mean permeability shows best wells are in areas E. of the IJsselmeer and the upper part of the North Holland province
- Reports and data are expected to provide support in de-risking geothermal projects

Reports and data are/will be posted on the NLOG website.

Link: https://www.nlog.nl/datacenter/brh-overview/<well name>/documenten

Thanks for your attention!