Everything old is new again: The Rotliegend geothermal play, results from the SCAN Amstelland exploration well and legacy cores

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Content

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Geothermal Energy in the Netherlands

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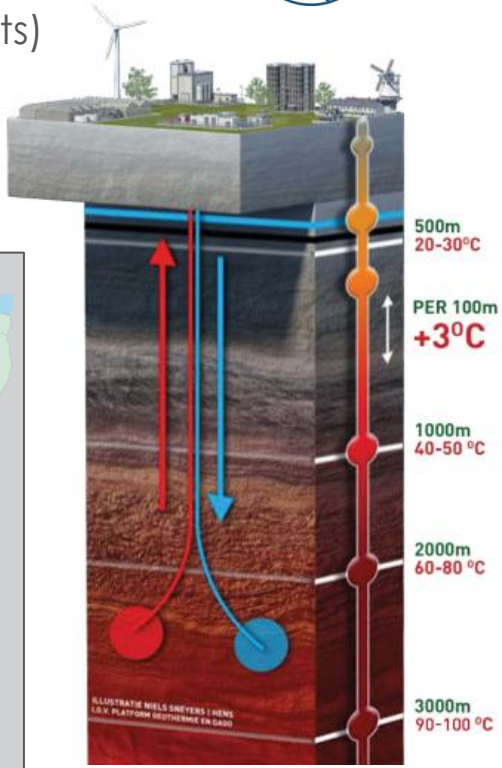
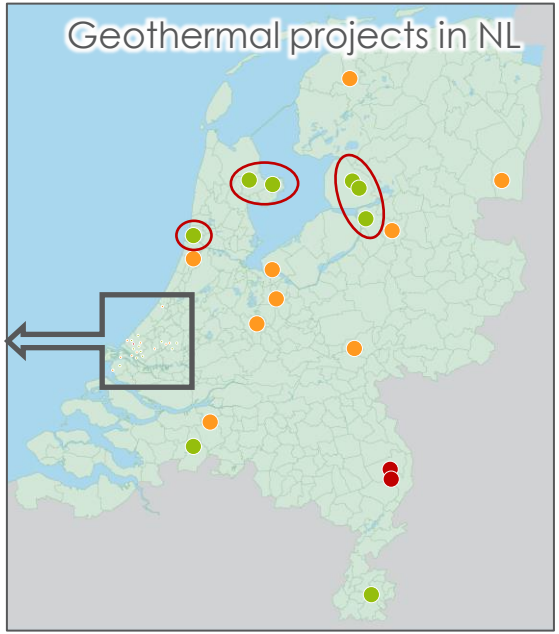
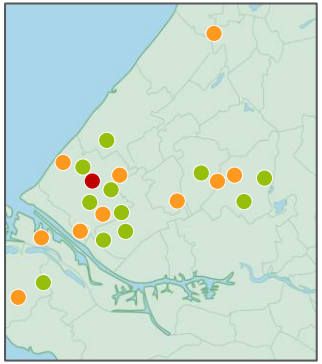
- Proven source of energy; 27 producing projects in 2023 (39 doublets)
- Low enthalpy, saline aquifers; direct use => heat for heat
- Between about 700 m and 3 km depth => 30-100 °C
- Typical Rotliegend geothermal project circulates 175-350 m^3/h
- 6.8 PJ of heat generated (equivalent to demand of 165.000 households)
- Geothermal development focused on regions where abundant subsurface data exists from O&G





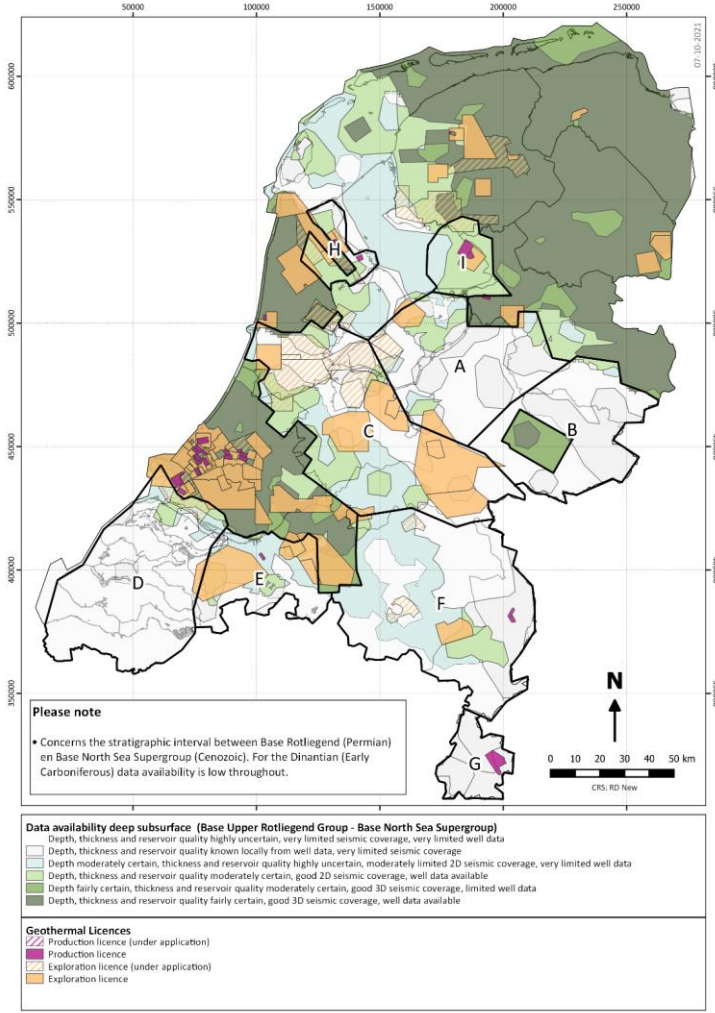


- Producing Rotliegend Project
- Producing
- Under Development
- Not producing

Sources: Geothermie Nederland Production Numbers 2023 & NLOG

Introduction to SCAN

- SCAN stands for Seismische Campagne Aardwarmte Nederland
- SCAN acquires new data in areas where insufficient subsurface data is presently available for a reliable estimation of geothermal potential (‘white spots’)
- Aimed at shallow and deep geothermal (500-4000m)
- Provides a regional exploration dataset. For development of commercial projects more seismic and studies are generally needed
- Funded by the Ministry of Climate and Green Growth
- Executed by EBN and TNO.



Components SCAN-program

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1. **Acquisition 1900km new 2D seismic data**

   ➜ Completed

2. **Re-processing 7500km old 2D-seismic data**

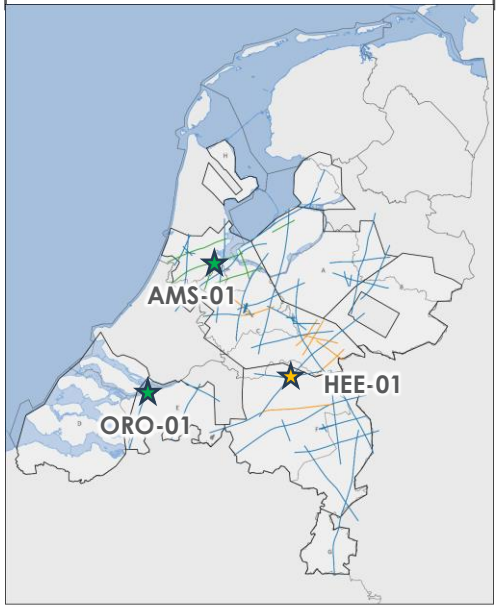
   ➜ Completed

3. **SCAN-drilling**

   ➜ First 2 wells (Amstelland-01 & Oranjeoord-01) finalised and decommissioned, 3rd well currently drilled (Heesch-01)

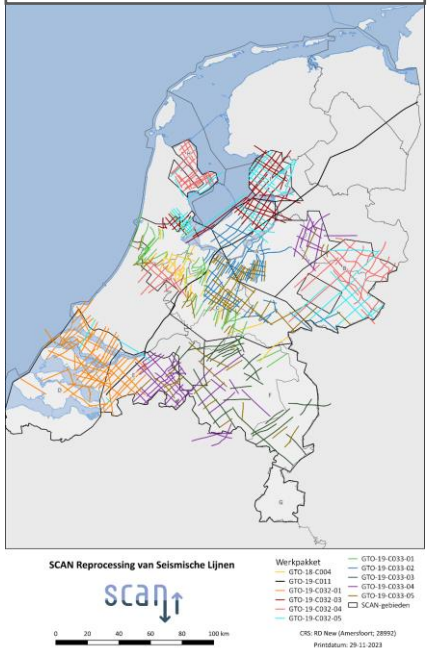
All data and results are published via scanaardwarmte.nl and nlog.nl/scan

New seismic lines



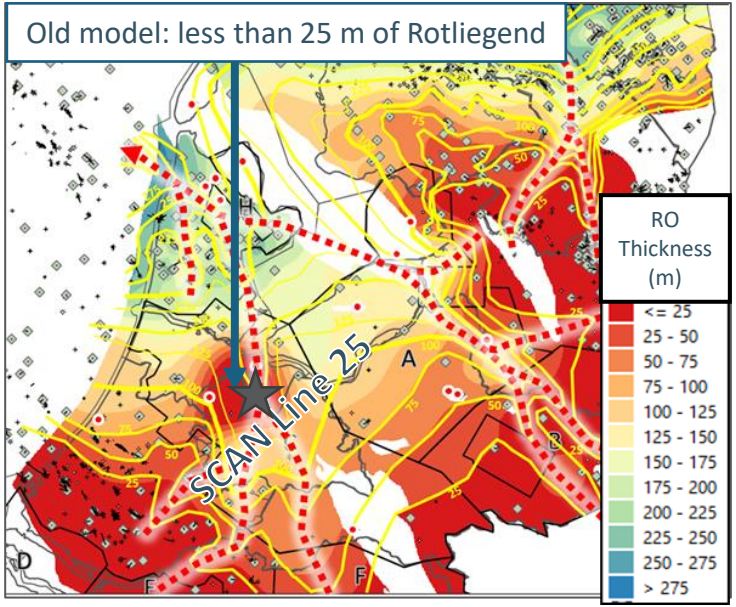
★ Drilling completed
★ Drilling ongoing

Re-processed seismic

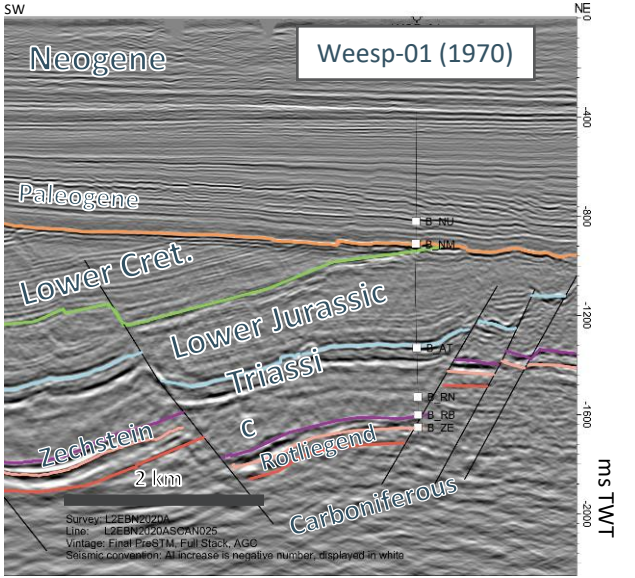


Thickness of the Permian Rotliegend reservoir

- ➜ Thickness of the main geothermal reservoir in the Amsterdam/Almere area (Rotliegend) was uncertain prior to SCAN: according to some models hardly any Rotliegend was present
- ➜ These models were based on Weesp and Waverveen wells, drilled in the 70s



Yellow isopachs: SCAN thickness model
Colours in background: thickness in DGM-Diep v4



- ➜ Insufficient seismic data was present at the well locations
- ➜ New SCAN-seismic data shows that the Weesp well drilled the Rotliegend at a location where the reservoir is truncated by a fault. The well is therefore not representative for the region
- ➜ Thickness de-risked, good news for geothermal potential of the region
- ➜ Reservoir quality uncertainties remain; AMS-01 well designed to provide relevant data.

Rotliegend in Amstelland-01

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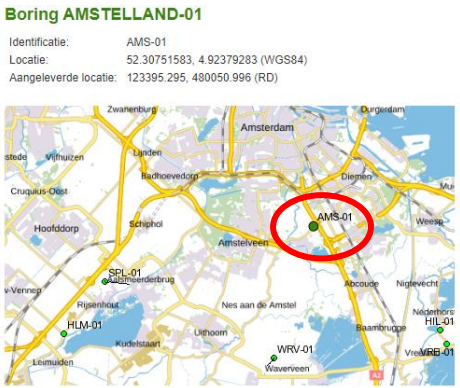
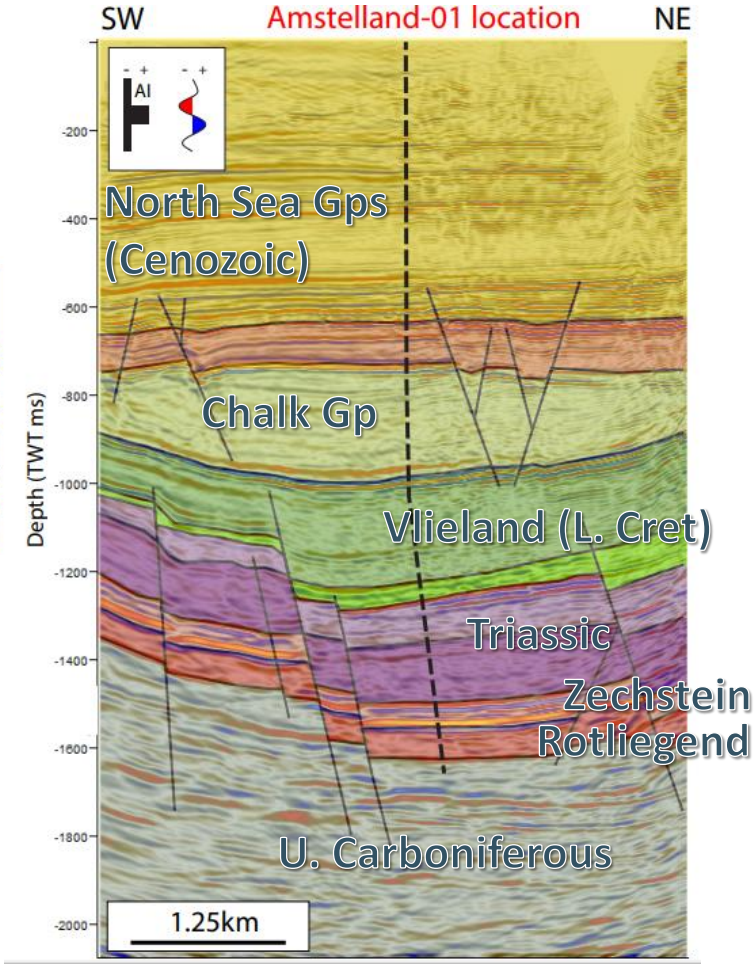
Objectives of the Amstelland well

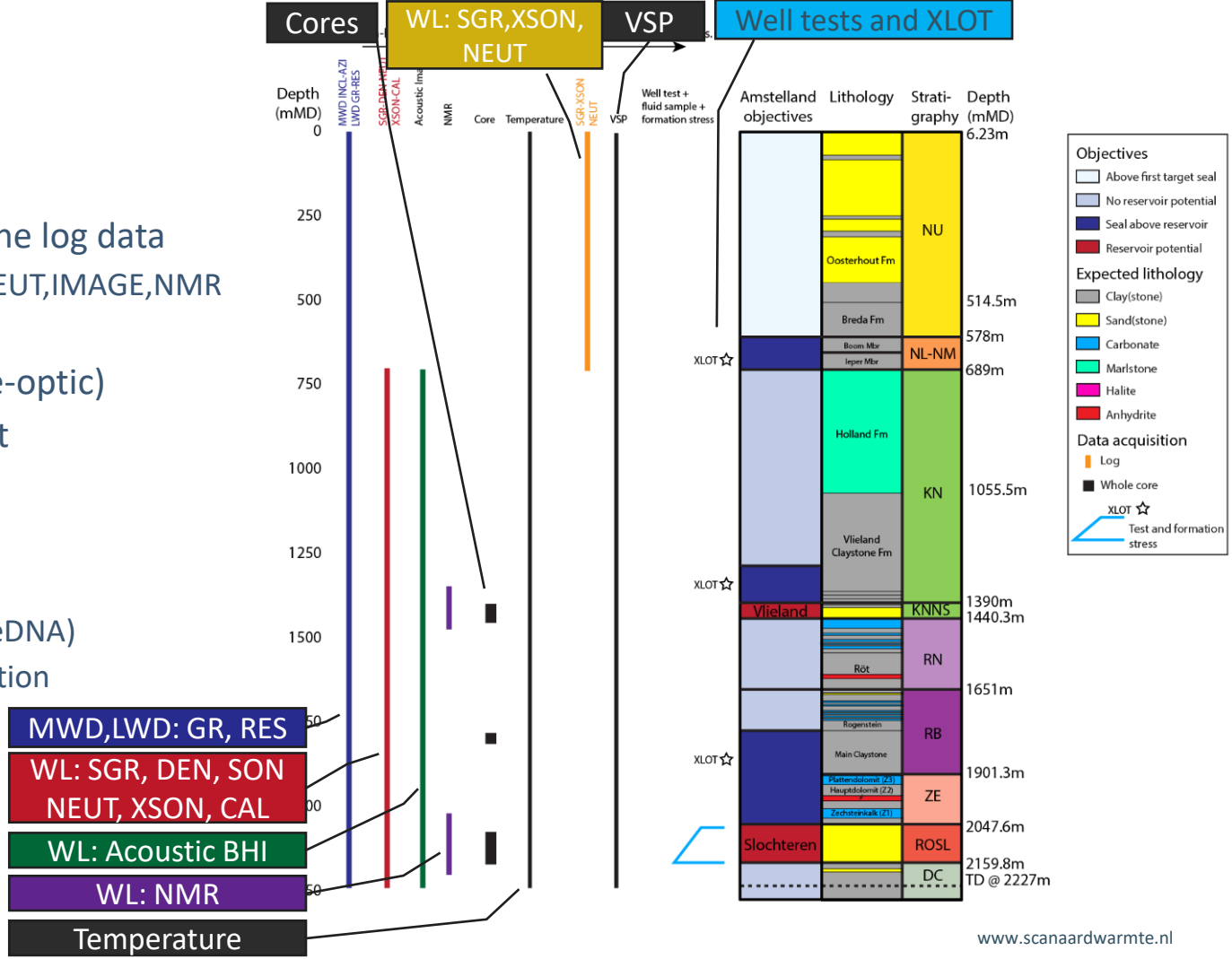
- ➜ Drilled in area with high heat demand
- ➜ Determine geothermal reservoir properties for three intervals:
  - ➜ Primary: Permian Rotliegend sandstones
  - ➜ Secondary: L. Cret. Vlieland Sandstone Fm
  - ➜ Secondary: U. Cret. Chalk Gp (CK)
- ➜ Determine reservoir formation fluid properties and temperature
- ➜ Determine geomechanical properties of the reservoirs, caprock and overburden
- ➜ AMS-01 spud in October 2023, TD @ 2217.67m MD in Carboniferous Limburg Group
- ➜ Extensive data acquisition performed throughout well, including over reservoirs, caprocks and overburden





Data Acquired

- Cuttings
- LWD and (OH/CH) wireline log data
  - (S)GR,RES,XSON,DEN,NEUT,IMAGE,NMR
  - Temperature
- VSP (geophone and fibre-optic)
- Production/Injection test
  - PLT
  - Fluid samples
- Core (193m)
  - Screening analysis (CoreDNA)
  - RCA, SCAL, core description
  - Geomechanical tests
- XLOT (3x)



Data published on NLOG.nl

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Well

1 of 1

Well AMSTELLAND-01

Identification: AMS-01
Location: 52.30751583, 4.92379283 (WGS84)
Delivered location: 123395.295, 480050.996 (RD)

Basic data | Deviation | Documents | Lithostratigraphy | Samples | Core analyses | Production figures | Logs LIS/LAS

Well AMSTELLAND-01

Category	Document
Borehole/Well - Final rapport	SODM EOWR(08 Feb 2024)
Documents containing borehole logs	12.25in_LWD_Run200_RM_MD(665-1395)(08 Nov 2023) 12.25in_LWD_Run300_RM_MD(1365-1803)(08 Nov 2023) 12.25in_Run1.1.1_AST_ANISOTROPY(700-1790)(14 Nov 2023) 12.25in_Run1.1.1_AST_SEMBLANCE(31-1790)(14 Nov 2023) 12.25in_Run1.2.1_CSNG(30-1798)(10 Nov 2023) 12.25in_Run1.2.1_DSN_SDLT(30-1803)(10 Nov 2023) 17.5in_LWD_Run100_RM_MD(25-690)(24 Oct 2023) 8.5in_LWD_Run400_RM_MD(1755-2077)(22 Nov 2023) 8.5in_LWD_Run500_RM_MD(2045-2227)(22 Nov 2023) 8.5in_Run2.1.1_AST_ANISOTROPY(1801-2212)(24 Nov 2023) 8.5in_Run2.1.1_AST_SEMBLANCE(1741-2210)(24 Nov 2023) 8.5in_Run2.1.1_CAST_Borehole_Shape(1801-2222)(24 Nov 2023) 8.5in_Run2.1.1_CAST_Manual Dip Analysis_Listing(15 Dec 2023) 8.5in_Run2.1.1_CAST_Manual Dip_Analysis(1801-2222)(24 Nov 2023) 8.5in_Run2.1.1_CAST_Static_Dynamic_Image(1801-2222)(24 Nov 2023)

Link to this page: https://www.nlog.nl/nlog-mapviewer/brh/3894840289?lang=en

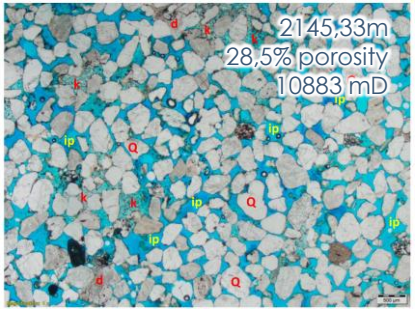
Overview of status of deliverables at https://scanaardwarmte.nl/onderzoek-in-amstelland/

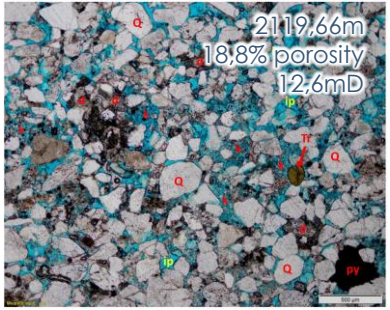
Rotliegend core analysis

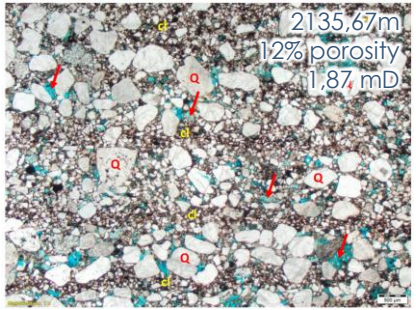
Thick-bedded sandstone
Depositional environment:
Aeolian dune base

Cross-bedded sandstone
Depositional environment:
Aeolian dune slipface

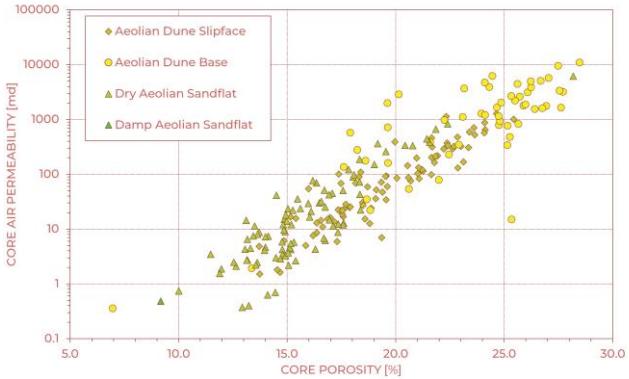
Bimodally laminated sandstone
Depositional environment:
Aeolian sandflat, interdune





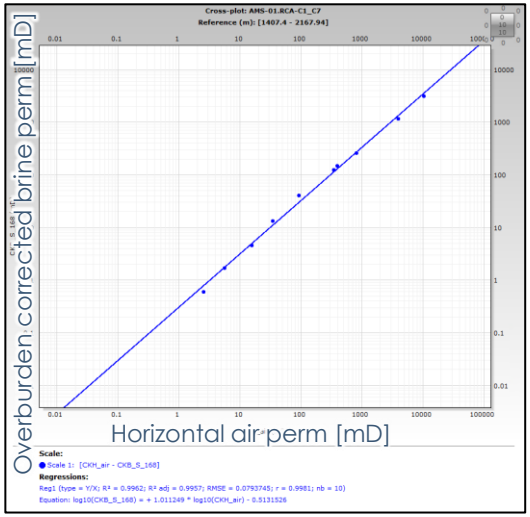


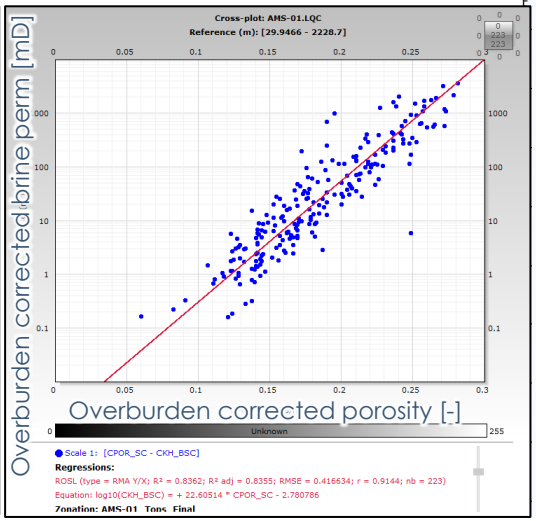
- 83m of Rotliegend core
- Three depositional environments
- Mineralogically dominated by quartz, kaolinite, dolomite and anhydrite
- Porosity and permeability linked to depositional environment

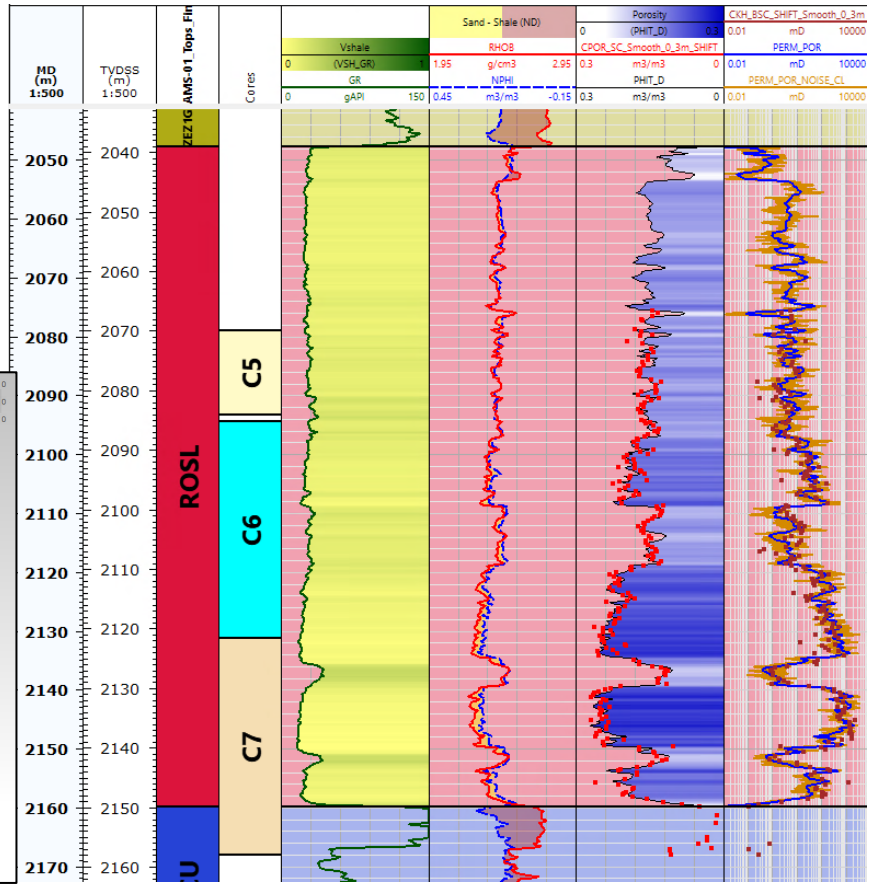


Rotliegend core-to-log integration

- 240 horizontal and 80 vertical plugs for RCA
  - Helium porosity and air permeability
  - *Empirical* Klinkenberg correction
- Porosity and air permeability at confining stress on 10 plugs
- Brine permeability at confining stress on 10 plugs
- Average horizontal brine permeability at reservoir conditions of matrix: **~150mD (~1/3rd of air perm)**







Production & Injection Tests

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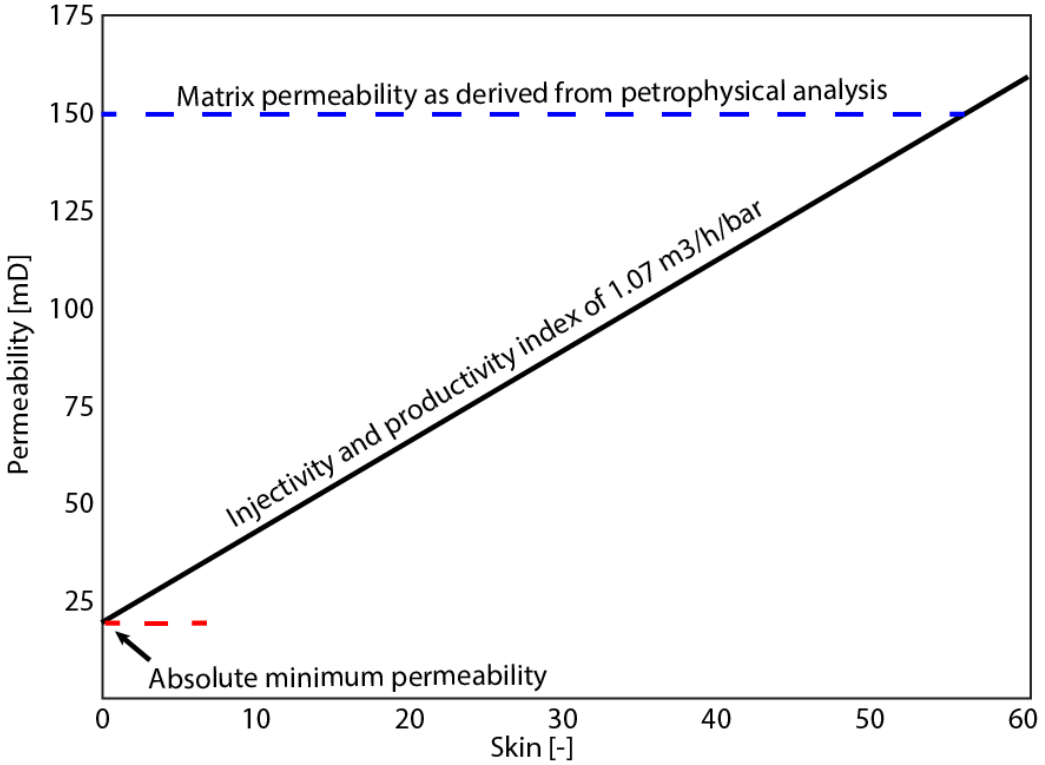
- 1000 m^3 produced and re-injected
- Several build-ups and fall-offs performed
- Signal dominated by severe wellbore storage effects and non-isothermal behaviour: PTA highly unreliable
- P.I. = I.I. = **1.07 m^3/h/bar**

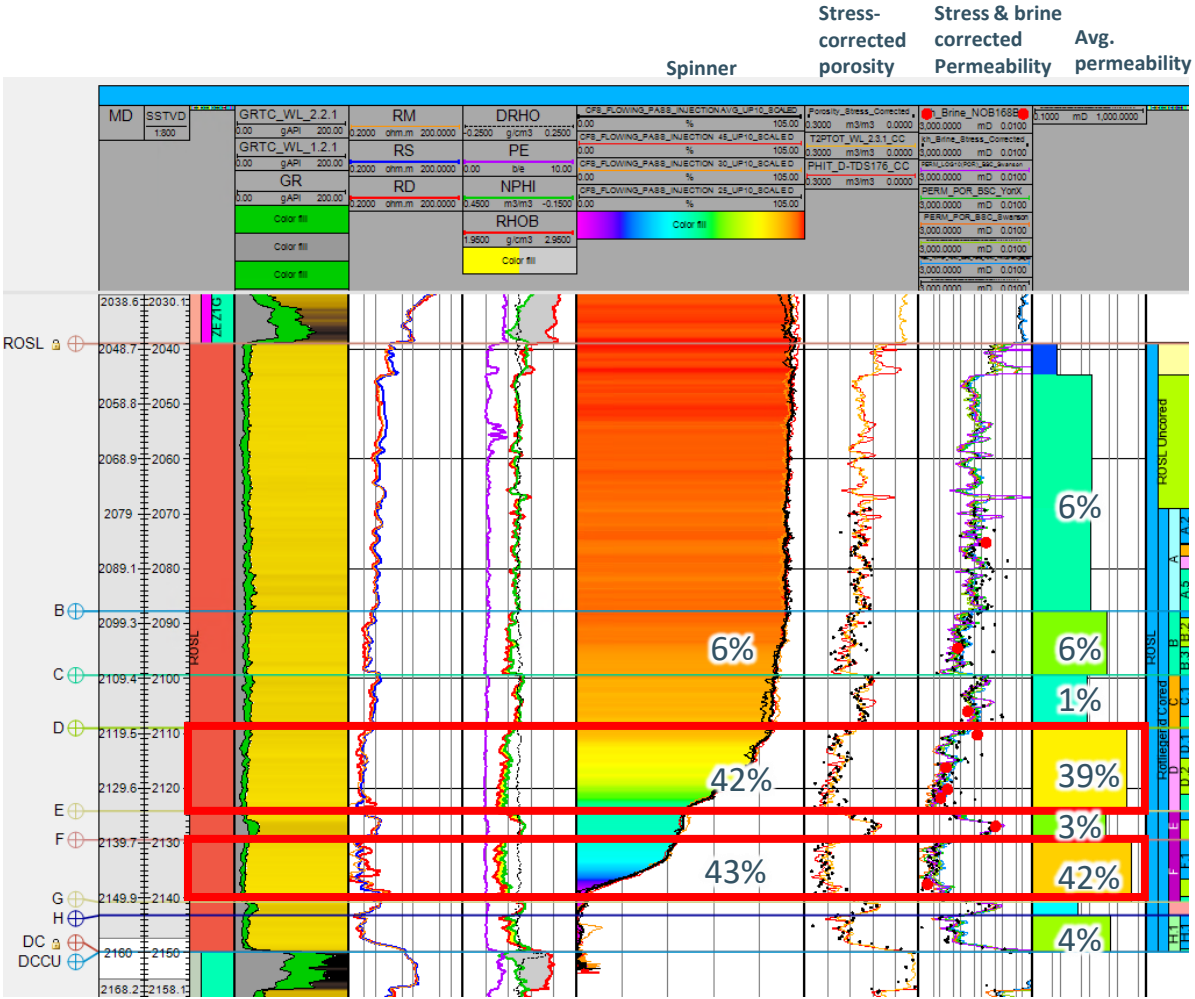
Why is the P.I./I.I. relatively low?

- Option 1: kh much lower than what the logs + cores tell us?
- Option 2: skin much higher than expected?



Transmissivity Distribution

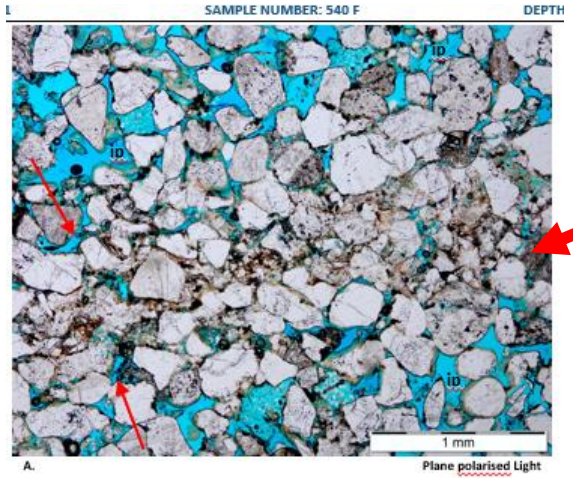
- Spinner run during injection test
- 85% of injected water into two flow units with highest measured porosity and permeability
- Relative flow contribution consistent with calculated relative transmissivity (kh) for each unit

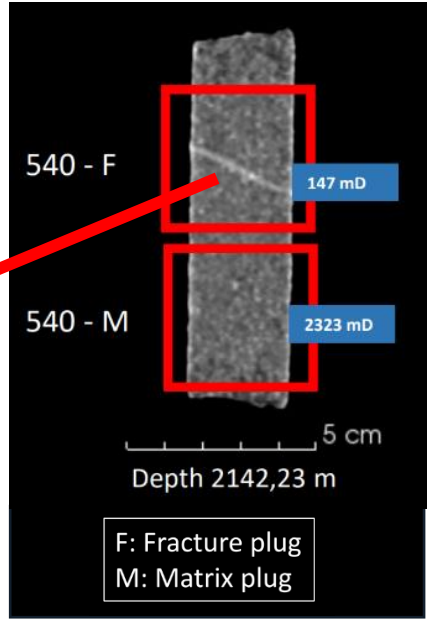


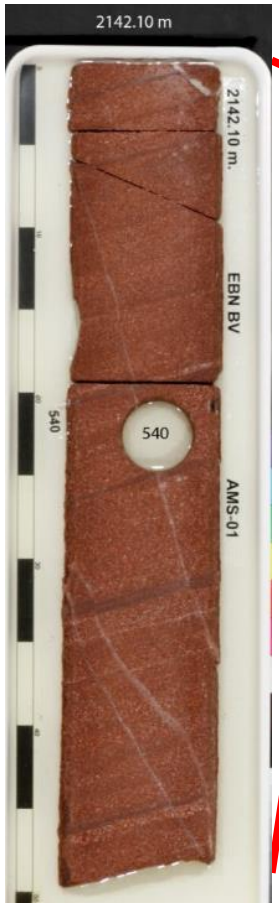
Deformation bands

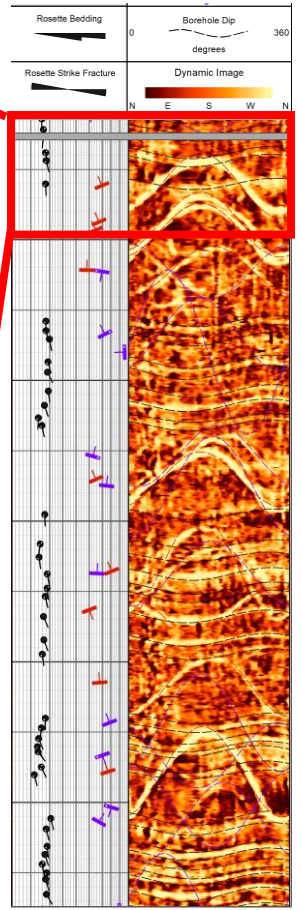
- Large number of high-angle features in acoustic image log
- EW to NE-SW trending conjugate set
- Highest density in highest permeability units (up to 3 bands/meter)
- Deformation bands are significantly less permeable than matrix. But what is the net effect on productivity?

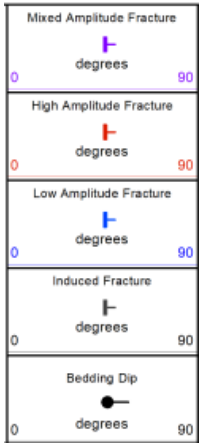
Dynamic acoustic image:
Light means high velocity = low porosity









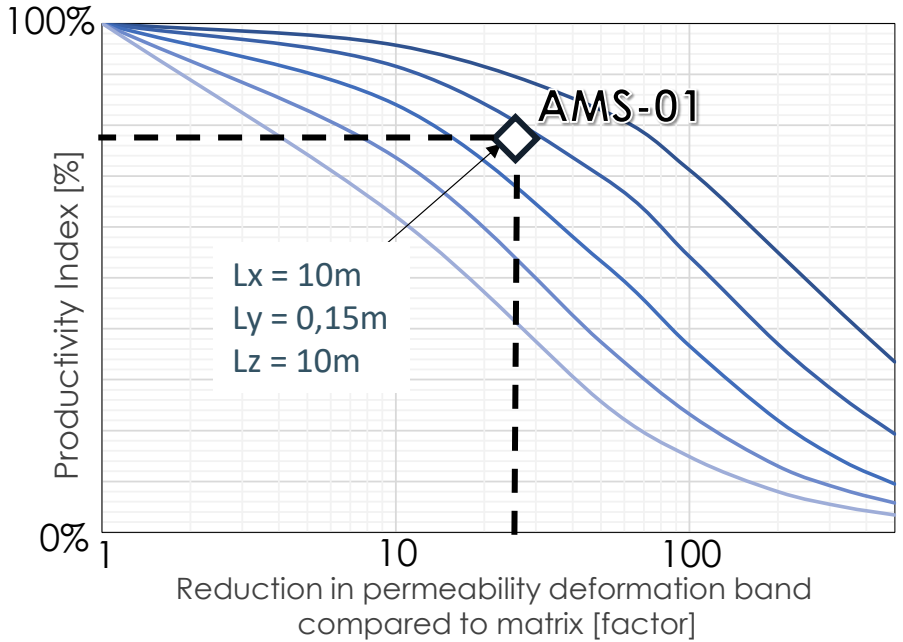


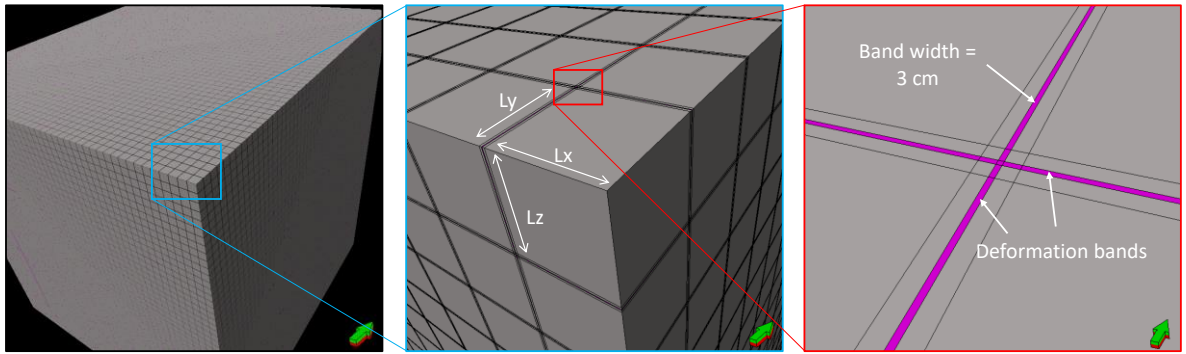
Deformation bands

➜ Numerical model in Eclipse to determine reservoir-performance reduction caused by observed deformation bands

➜ **Conclusion: no more than 22% reduction in productivity/injectivity**

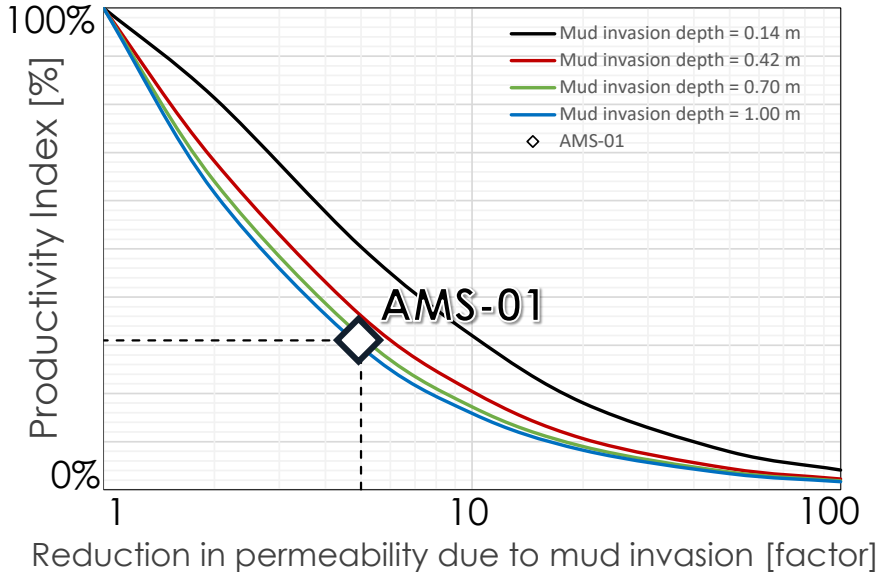
➜ Overall transmissivity after taking into consideration deformation bands: **~13 Dm**



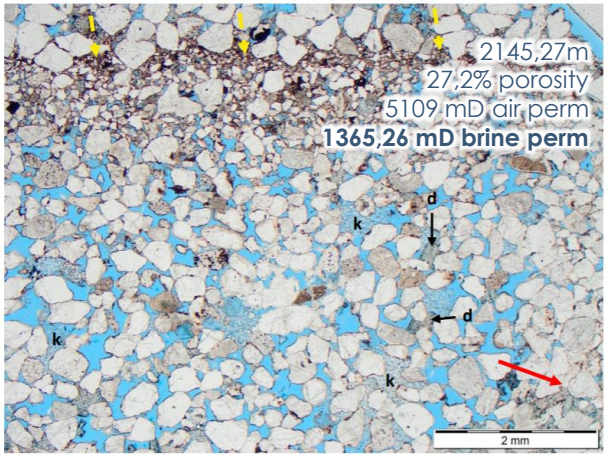


Formation damage

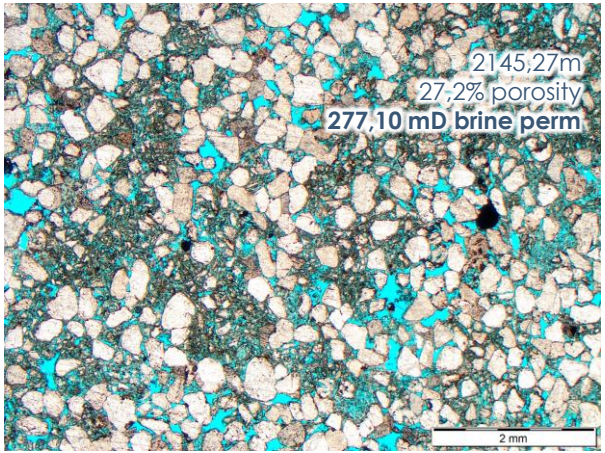
- OBM filtrate invasion observed in cores and (deep) resistivity logs (Sw<0,5), deeper than modelled perforation depth (38-47cm)
- Effect quantified in formation damage study: ~20% of brine perm remains
- **Numerical modelling => productivity 32% of undamaged reservoir**
- **Formation damage likely root cause behind disappointing flow rates**



Initial sample



After formation damage study



Legacy Core Study

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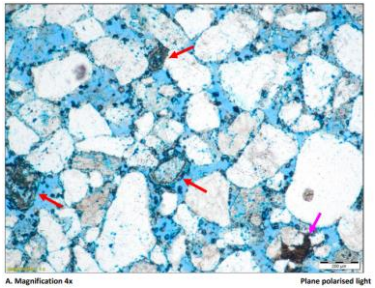
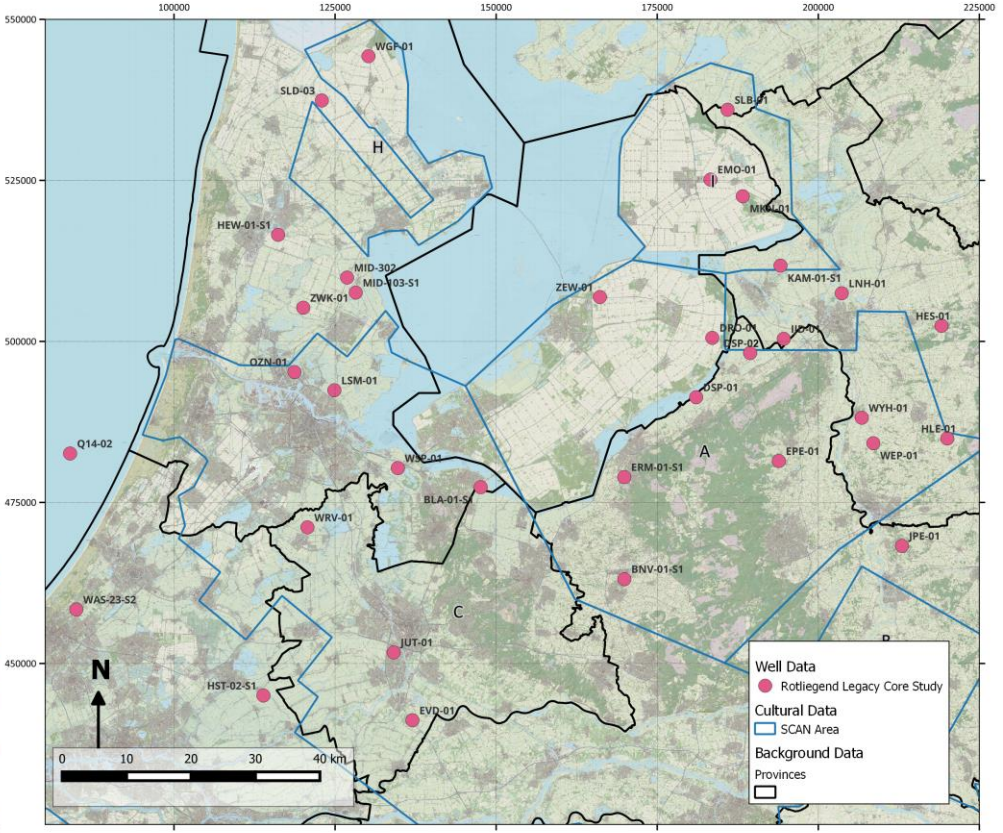
- ➜ Consistent description of legacy Rotliegend cores from central part of the Netherlands (drilled between 1950 -2012)
  - ➜ 34 wells with >900m core
- ➜ New petrographic analysis
- ➜ Integrated with existing RCA data
- ➜ Executed by Panterra Geoconsultants
- ➜ 28 wells published on NLOG


DSP-01 (Doornspijk)

SLD-03


A. Magnification 4x

Plane polarised light



Take home messages

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- ➜Rotliegend section in AMS-01 111m thick sand-dominated aeolian deposit
- ➜Reservoir matrix properties linked to depositional facies
- ➜Average matrix brine permeability of approximately 150 mD
- ➜Fluid flow somewhat affected by deformation bands
- ➜Overall transmissivity of approximately 13 Dm
- ➜Significant formation damage resulted in relatively low productivity during well test

- ➜Legacy core study provides regionally consistent insight in Rotliegend reservoir quality trends to aid understanding and prediction


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