4-7 NOVEMBER 2024
ROTTERDAM, THE NETHERLANDS

GET2024

GEOTHERMAL ENERGY CONFERENCE

GEOMECHANICAL DATA ACQUISITION IN SCAN WELLS

Parameters and constraints for future geothermal development in The Netherlands

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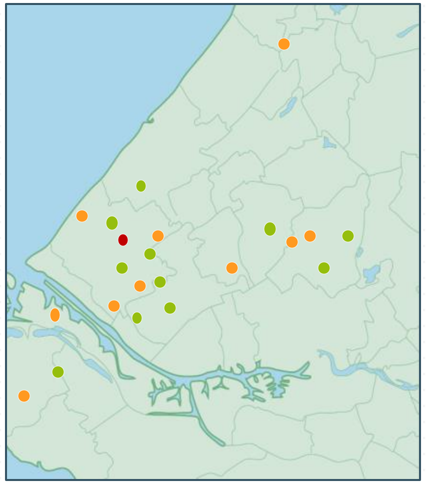
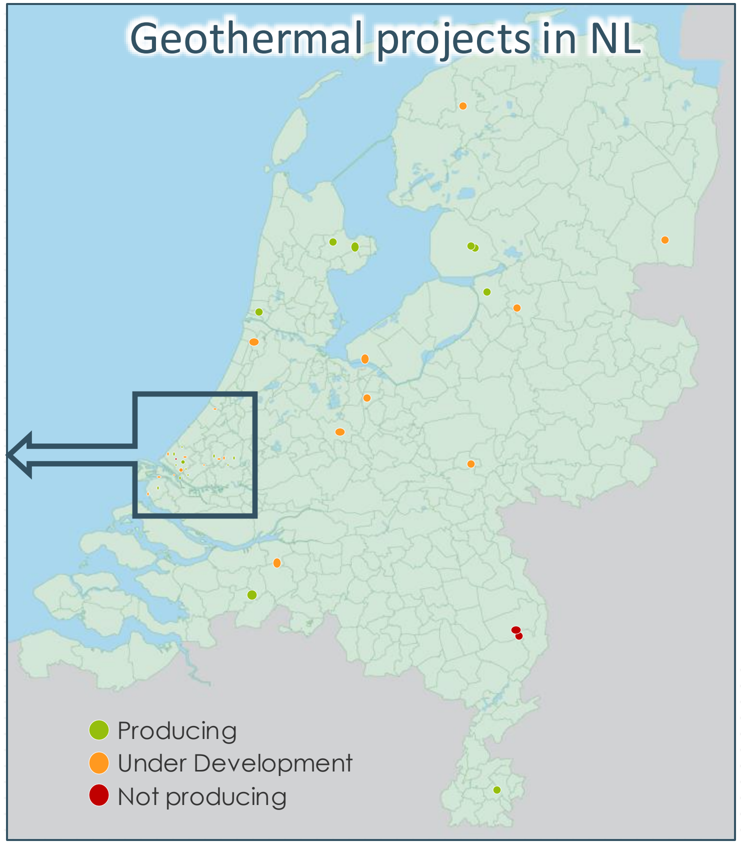
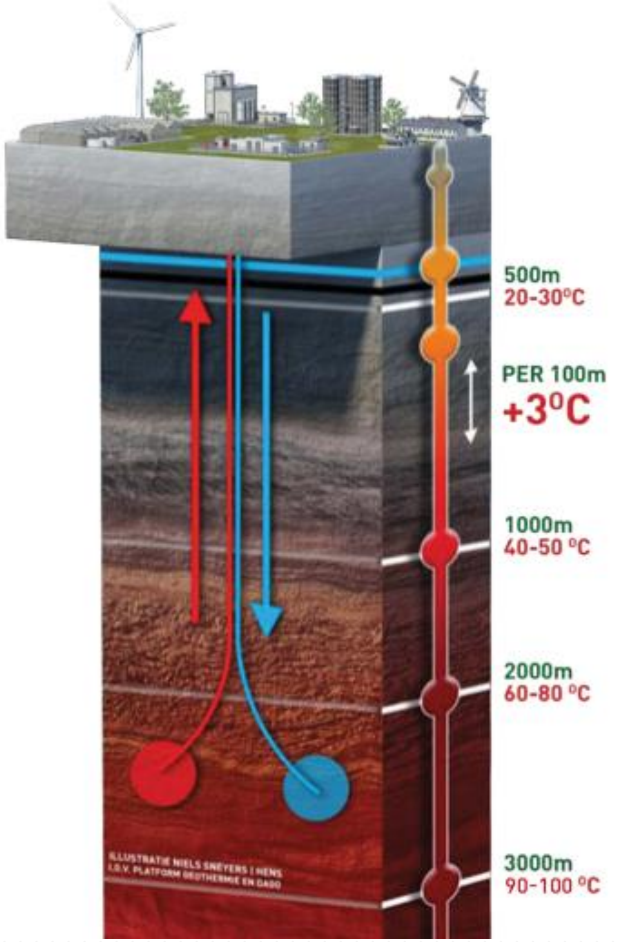
Geothermal Energy in the Netherlands

- 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
- 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



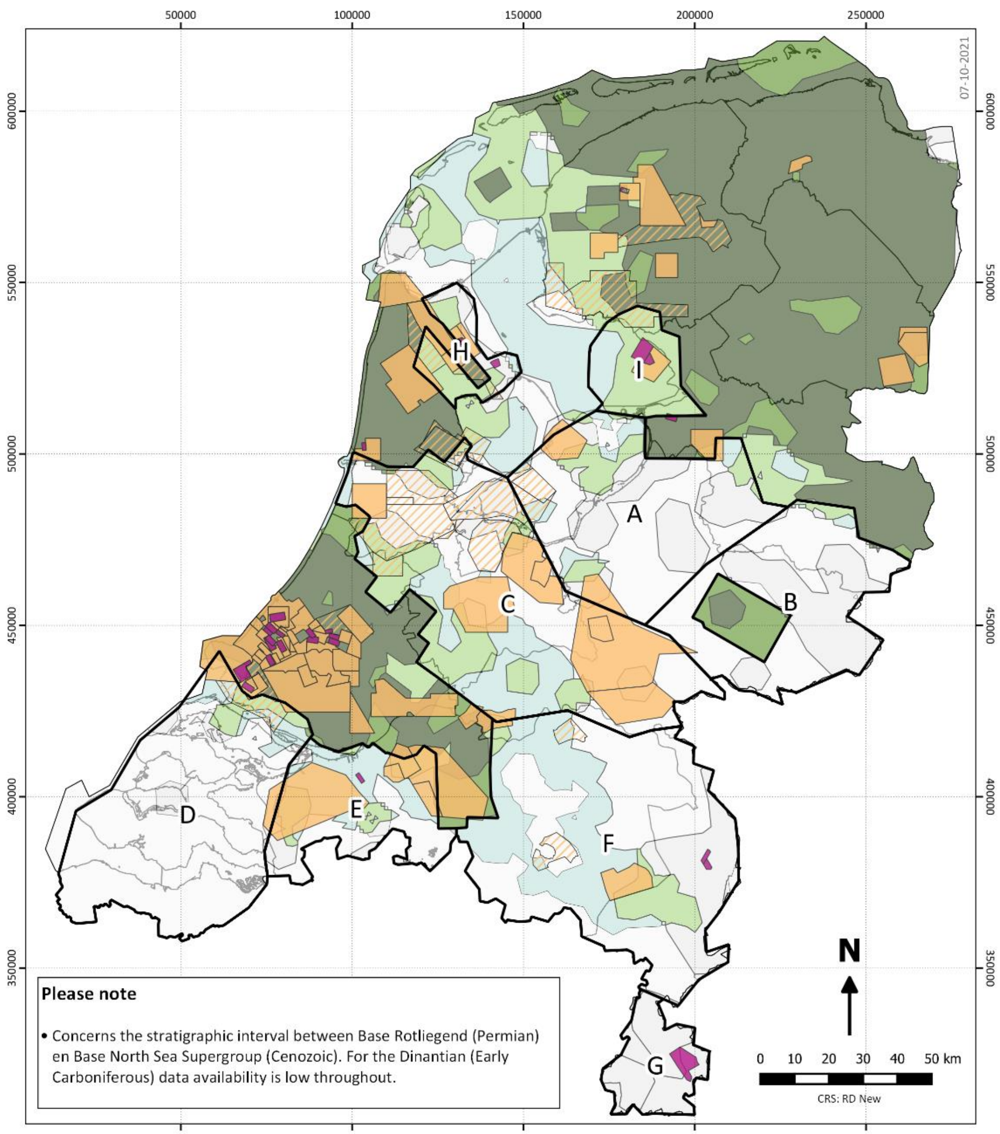




Sources: Geothermie Nederland Production Numbers 2023 & NLOG

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
- ➔Funded by the Ministry of Climate and Green Growth, executed by EBN and TNO



Data availability deep subsurface (Base Upper Rotliegend Group - Base North Sea Supergroup)

- Depth, thickness and reservoir quality highly uncertain, very limited seismic coverage, very limited well data
- Depth, thickness and reservoir quality known locally from well data, very limited seismic coverage
- Depth moderately certain, thickness and reservoir quality highly uncertain, moderately limited 2D seismic coverage, very limited well data
- Depth, thickness and reservoir quality moderately certain, good 2D seismic coverage, well data available
- Depth fairly certain, thickness and reservoir quality moderately certain, good 3D seismic coverage, limited well data
- Depth, thickness and reservoir quality fairly certain, good 3D seismic coverage, well data available

Geothermal Licences

- Production licence (under application)
- Production licence
- Exploration licence (under application)
- Exploration licence

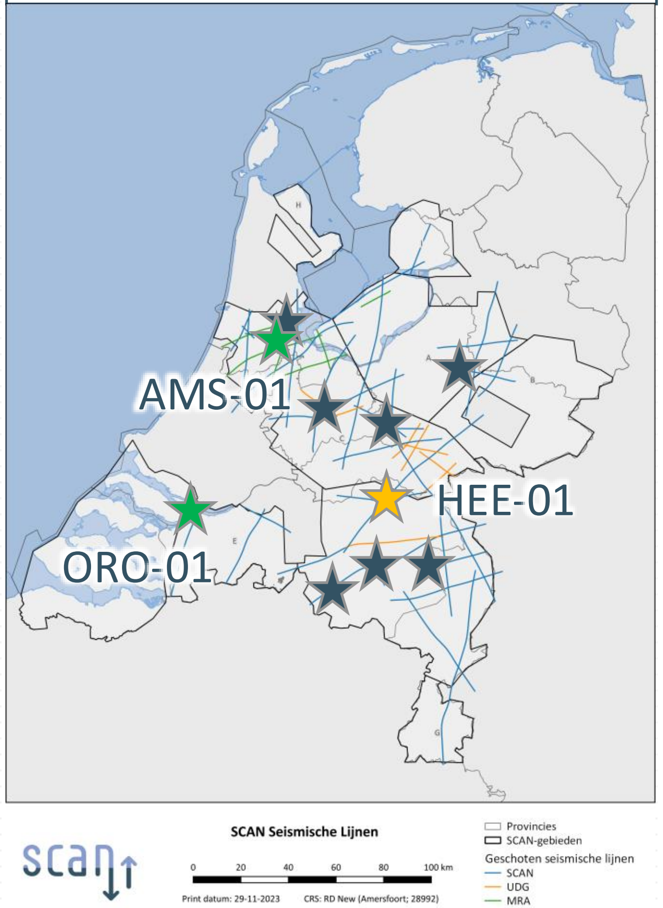
scan

Components SCAN-program

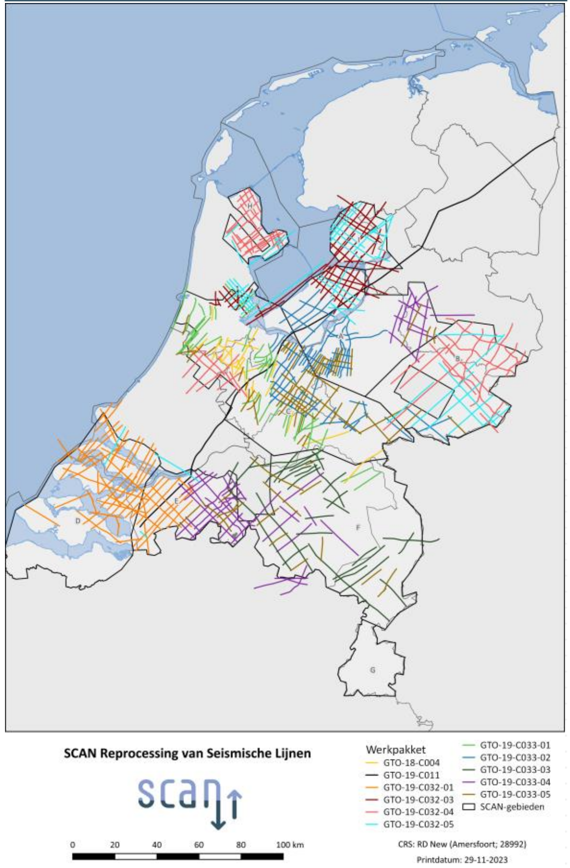
- **Acquisition 1900km new and re-processing 7500km old 2D seismic data**
  - ✓ **Completed**
- **Drilling data-acquisition wells**
  - First two wells (Amstelland-01 & Oranjeoord-01) finalised and decommissioned, third well currently drilling (Heesch-01)
  - In each well, extensive data acquisition on geothermal reservoirs, caprocks and overburden
  - Significant amount of geomechanical data acquired

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

New seismic lines



Re-processed seismic



★ Search area ★ Drilling completed ★ Drilling ongoing

Importance of geomechanical data for geothermal projects

➔Project Construction
- ➔Well planning (trajectory , casing points, etc)
- ➔Wellbore stability

➔Operational window during production/injection
- ➔Sand production
- ➔Caprock integrity
- ➔Injection pressure/rate
- ➔Seismicity potential

Impact on project economics, safety and public perception and acceptance

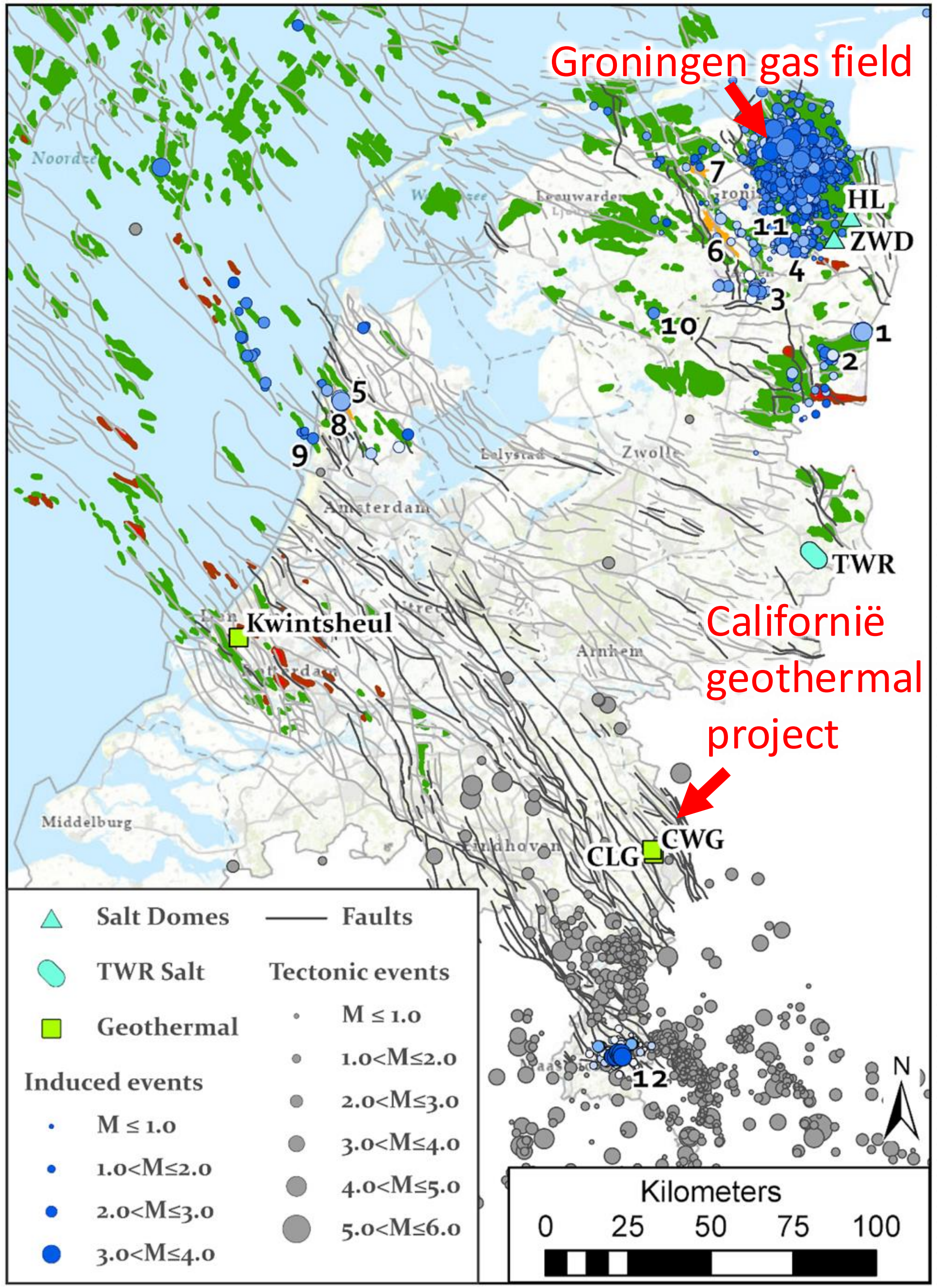
Induced seismicity associated with geothermal production in NL

➔Public awareness and concern related to induced seismicity associated with subsurface activities following events at Groningen gas field

➔Induced seismicity observed at Californië project where geothermal water was produced from a large fault zone, no seismicity observed at other projects

➔Traffic Light System used in case induced seismicity occurs during geothermal production

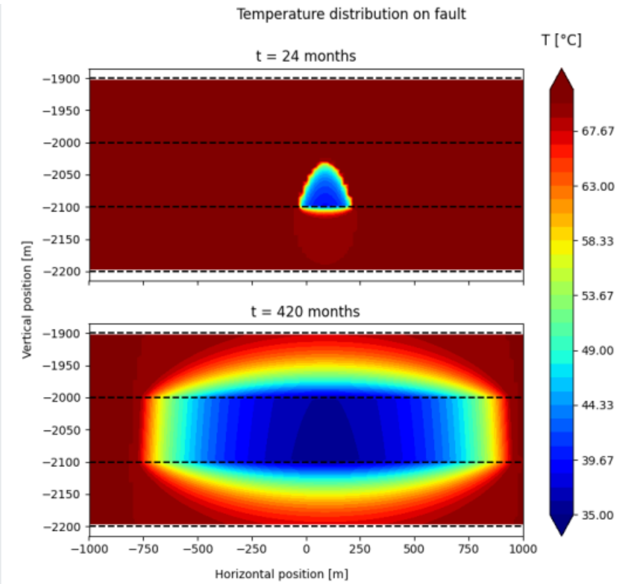
➔Strict regulatory requirements for geothermal operators to assess risk of induced seismicity and caprock integrity prior to operations start

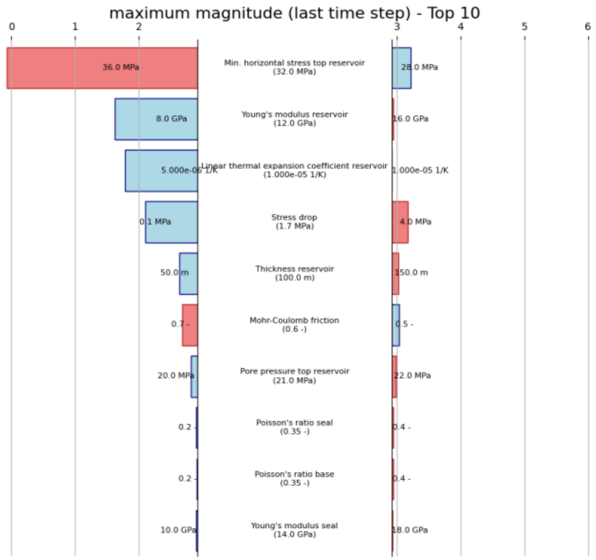


Overview of seismicity in NL (01-01-2021)
Muntendam-Bos et al., 2022

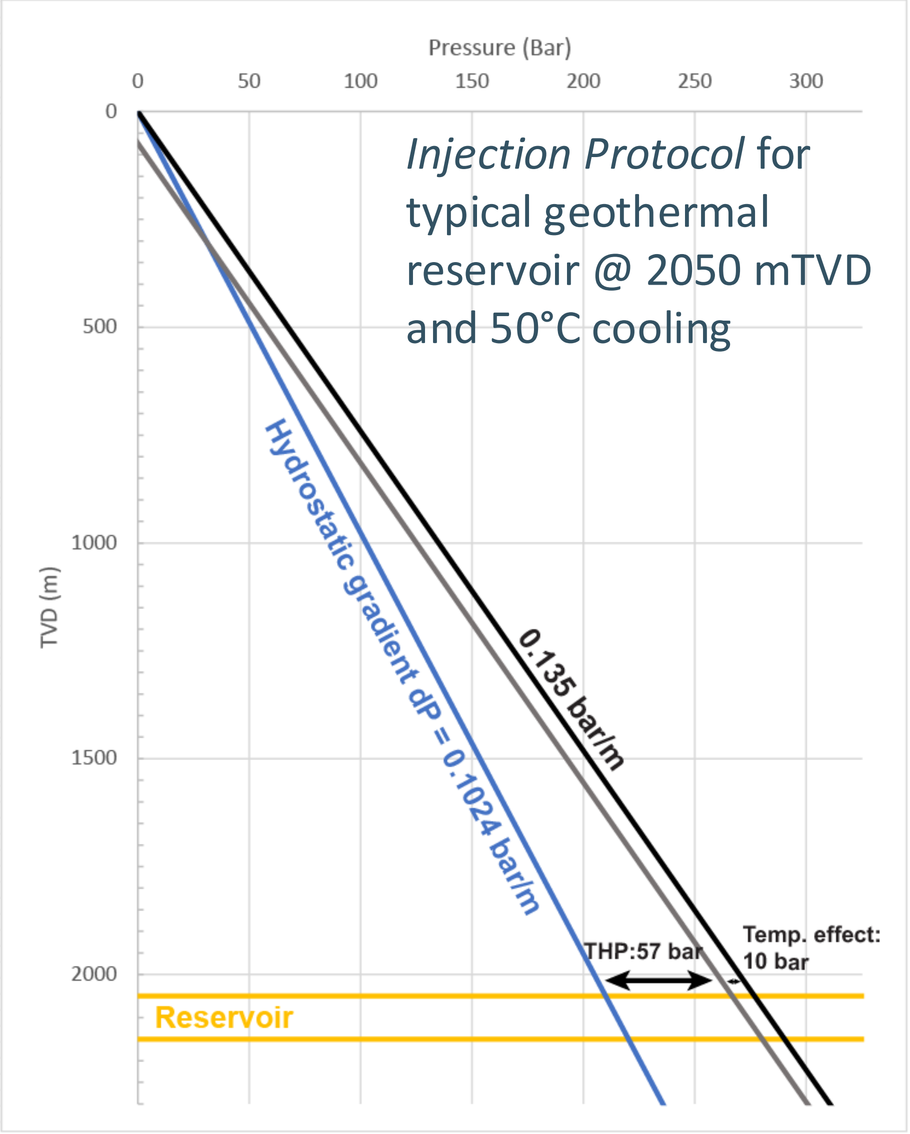
Seismic Hazard Risk Analysis and Caprock Integrity

- ➜ 2013: *Injection Protocol* for geothermal projects between 1500-3000m depth
- ➜ 2023: Seismic Hazard Risk Analysis (SDRA) and Tensile failure Assessment of Seal (TAS) methodologies to evaluate seismicity and seal integrity risk of geothermal projects (Mijnlieff et al., 2023):
- ➜ Calculated using the Seal and Reservoir Integrity through Mechanical Analysis (SRIMA) tool – stochastic, semi-analytical tool to determine failure probabilities
- ➜ **Requirement of detailed knowledge of geomechanical parameters!**

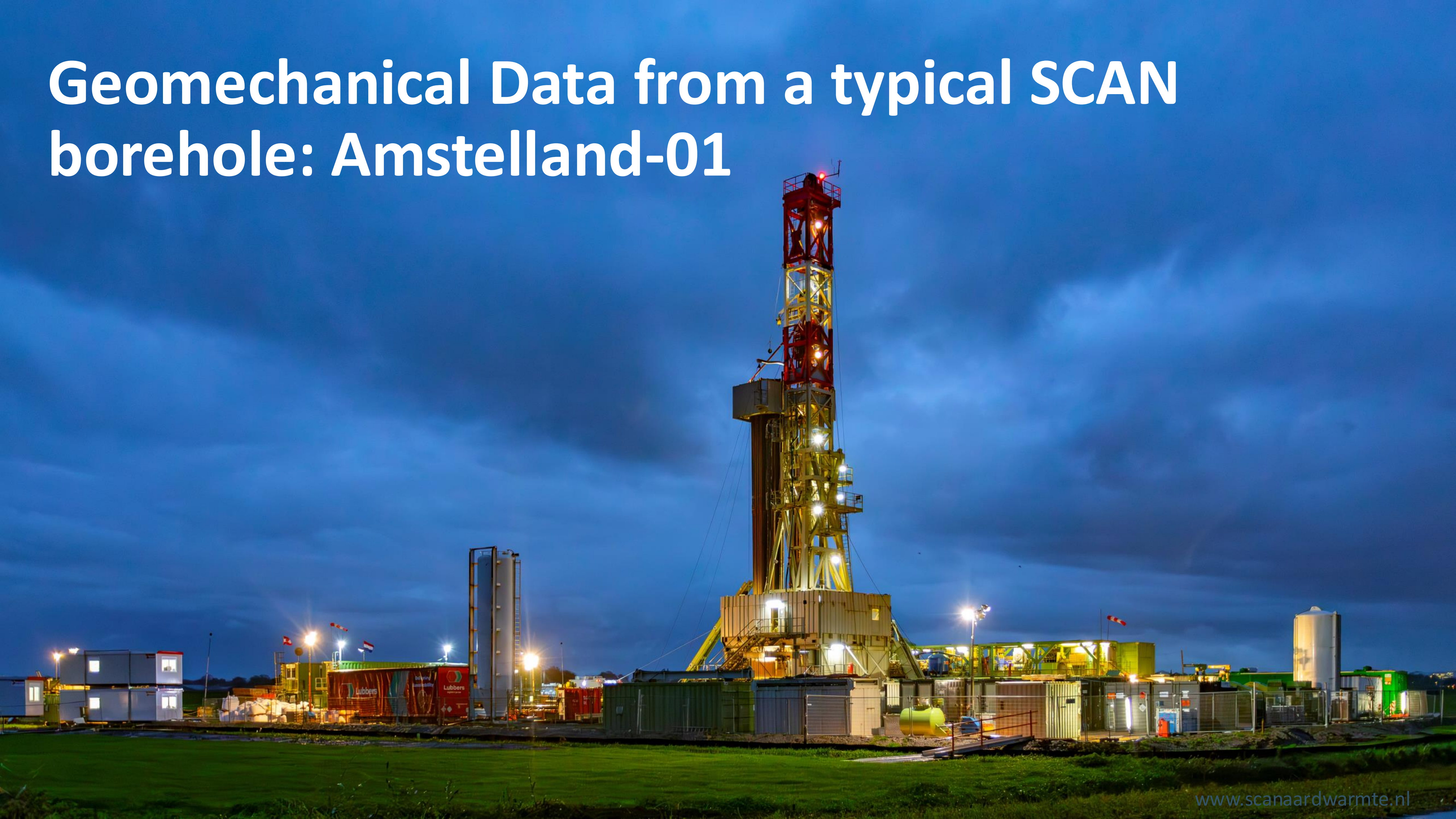




Example SRIMA output, Mijnlieff et al., 2023

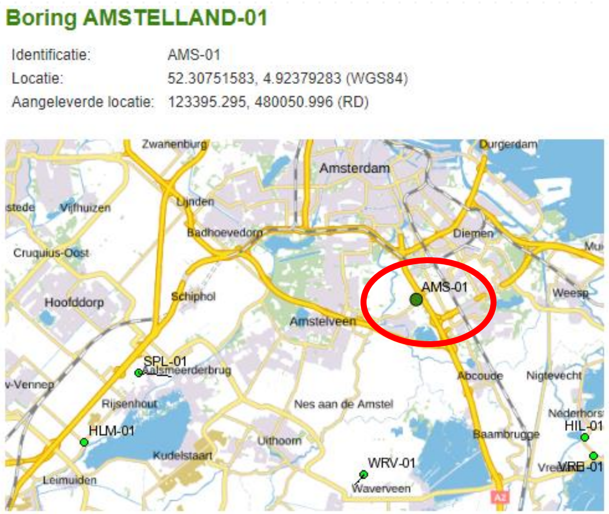


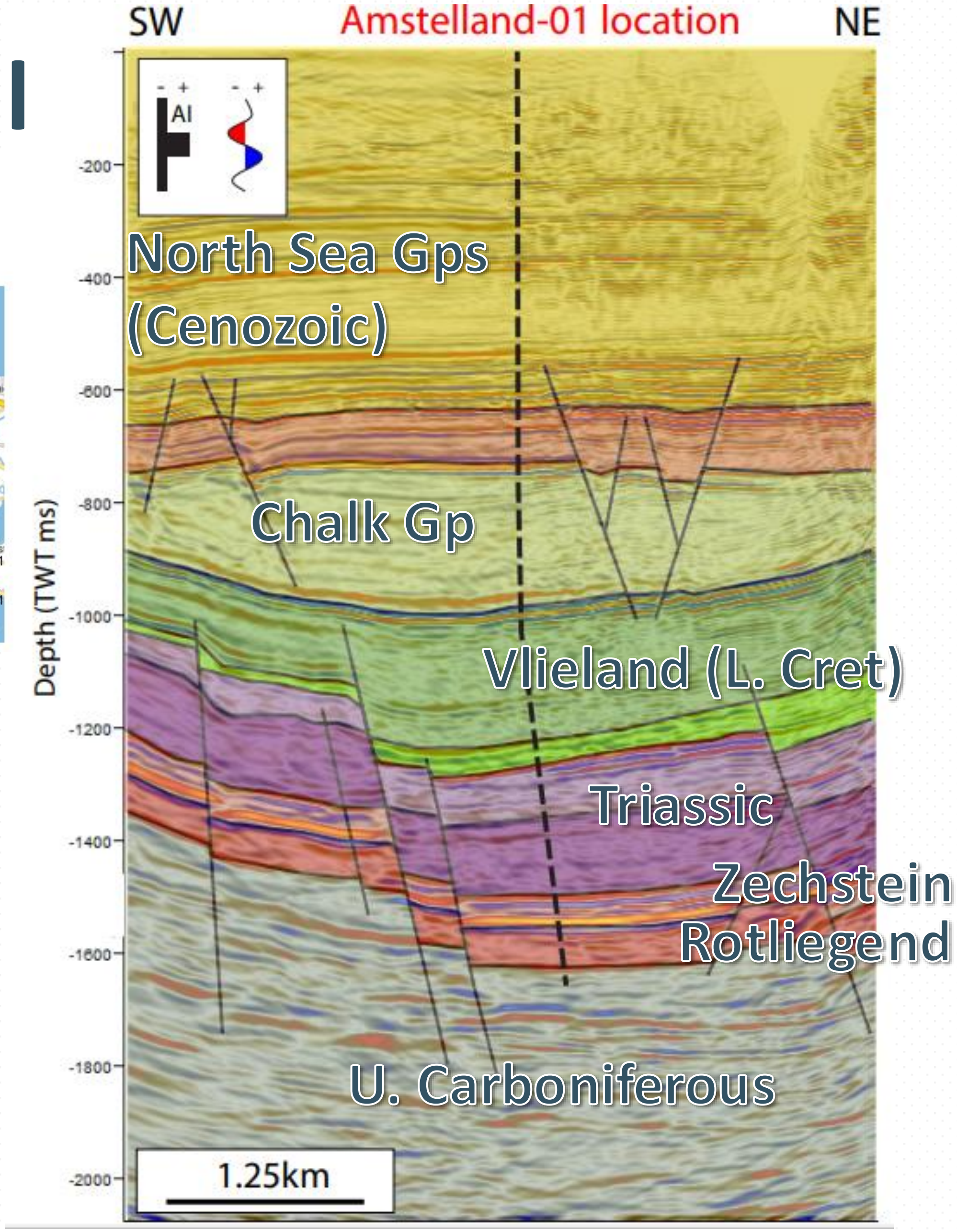
Geomechanical Data from a typical SCAN borehole: Amstelland-01



Objectives of the Amstelland well

- ➔ Determine geothermal reservoir properties for three target intervals:
  - ➔ Primary: Permian Rotliegend sandstones
  - ➔ Secondary: L. Cret. Vlieland Sandstone Fm
  - ➔ Secondary: U. Cret. Chalk Gp (CK)
- ➔ Determine reservoir formation fluid properties, pressure 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 published on NLOG.nl

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

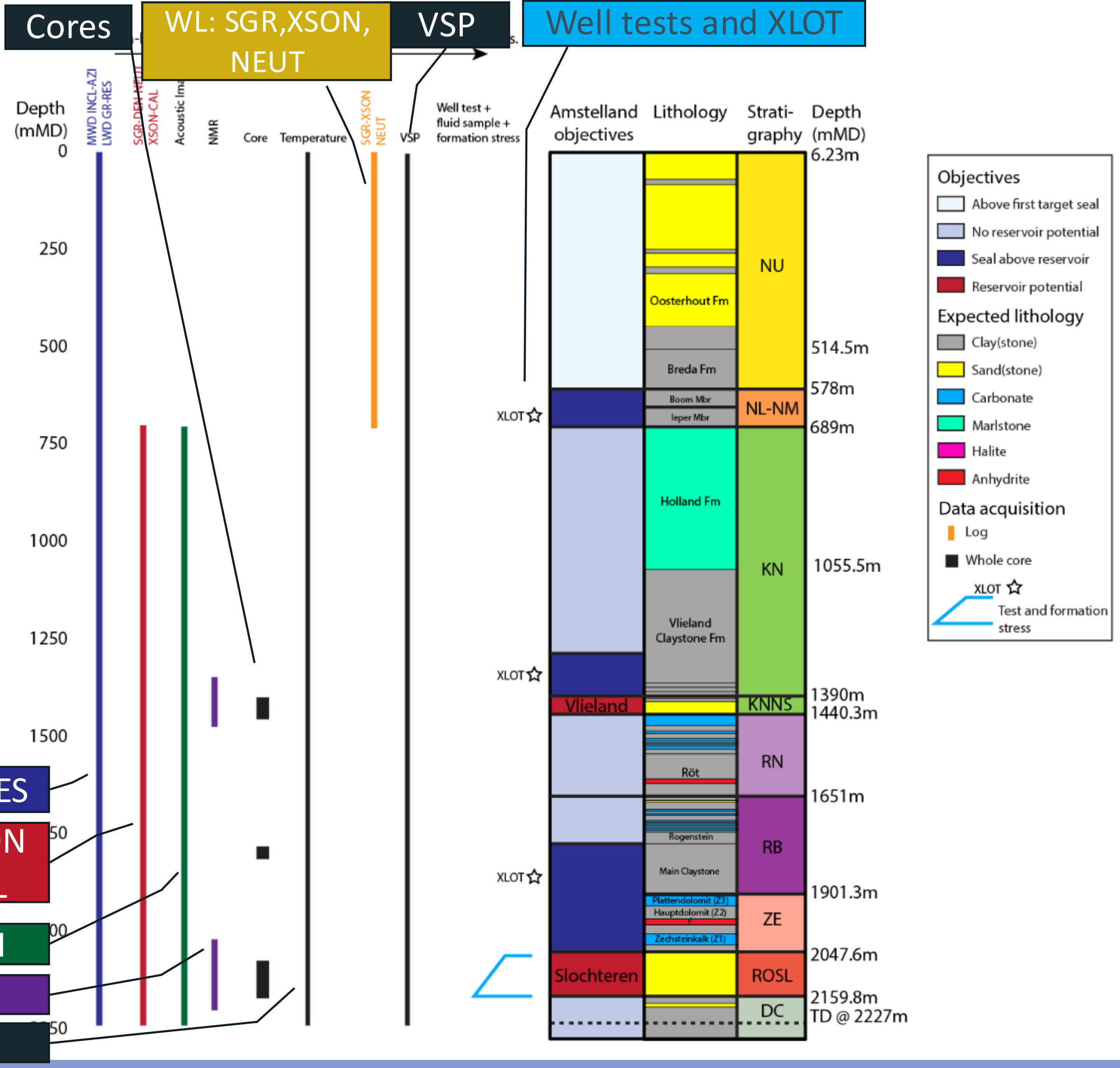
Category	Document
Borehole/Well - Final rapport	SODM EOWR(08 Feb 2024)
Documents containing borehole logs	12.25in_LWD_Run200_RM_MD(665-1395)(08 Nov 2023) 12.25in_LWD_Run300_RM_MD(1365-1803)(08 Nov 2023) 12.25in_Run1.1.1_AST_ANISOTROPY(700-1790)(14 Nov 2023) 12.25in_Run1.1.1_AST_SEMBLANCE(31-1790)(14 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/

Data Acquired

- ➔Cuttings
- ➔**LWD and wireline log data**
  - ➔(S)GR,RES,**XSON**,**DEN**,NEUT,**IMAGE**,NMR
  - ➔Temperature
- ➔VSP
- ➔Production/Injection test
- ➔**Core (193m)**
  - ➔Routine core analysis, SCAL, core description
  - ➔**Specific geomechanical tests**
- ➔**Extended Leak-Off Tests (XLOTs) (3x)**



Extended Leak-Off Test (XLOT)

➔Determine magnitude minimum horizontal stress

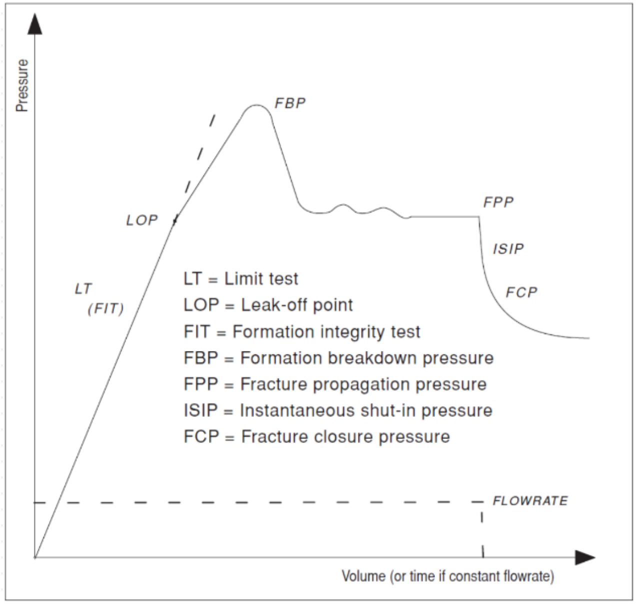
➔SCAN performs XLOTs through a 1.5m perforated interval before well decommissioning

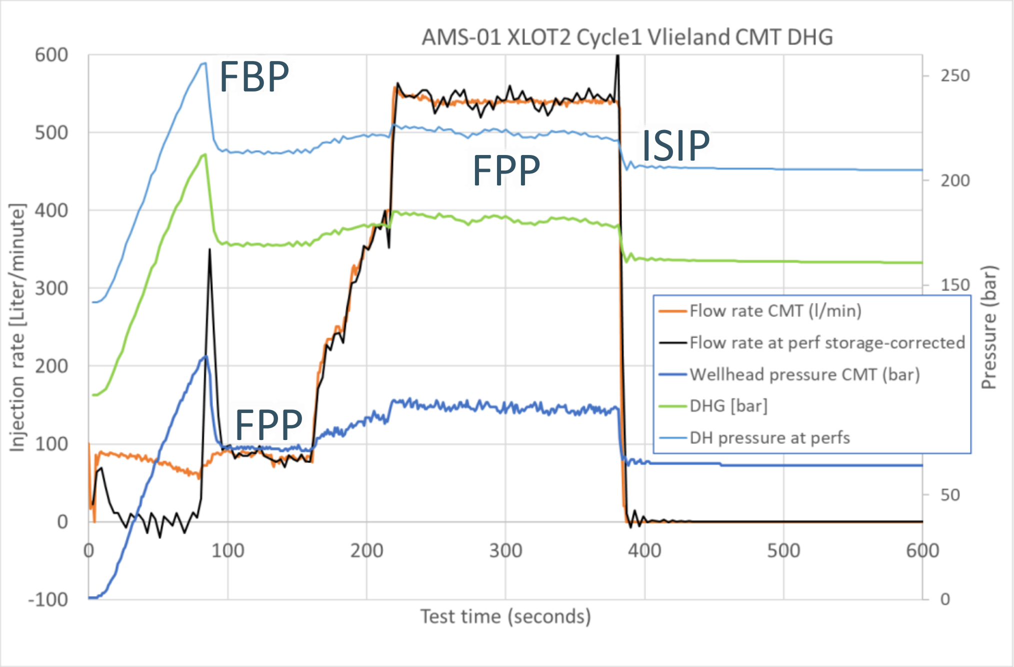
➔Three potential geothermal caprocks tested

➔For each interval determine:

- ➔Formation breakdown pressure (FBP)
- ➔Fracture propagation pressure (FPP)
- ➔Instantaneous shut-in pressure (ISIP)
- ➔Fracture closure pressure (FCP)
- ➔Fracture re-opening pressure (FRP)

Gaarenstroom et al., 2003

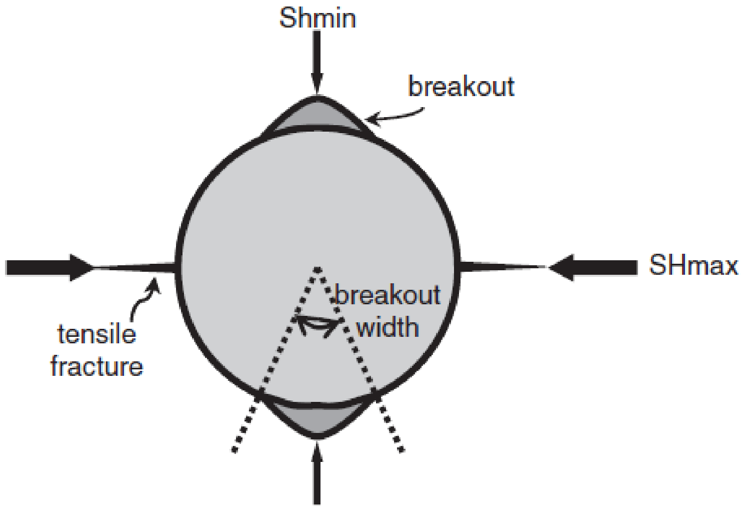




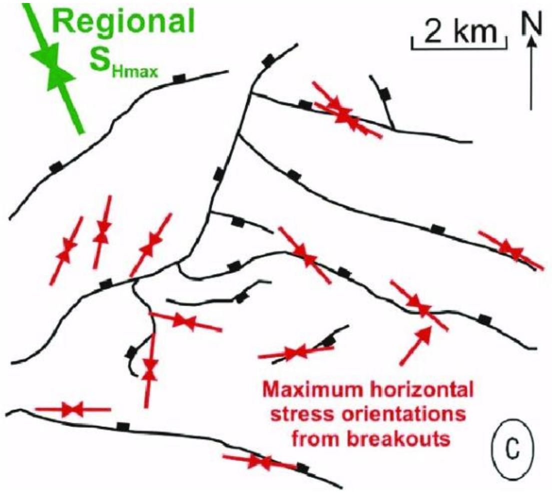
Geomechanical Results: Amstelland-01

Borehole break-outs and drilling induced fractures

- Borehole break-outs and drilling induced fractures can be used to determine stress-field orientation
- Appears to be a rotation of horizontal stress between with Vlieland Claystone and Zechstein Group
- Shmax NW-SE (127° +/- 3°) in shallow section, consistent with published regional orientation
- Shmax N-S (179° +/- 3°) in deep section

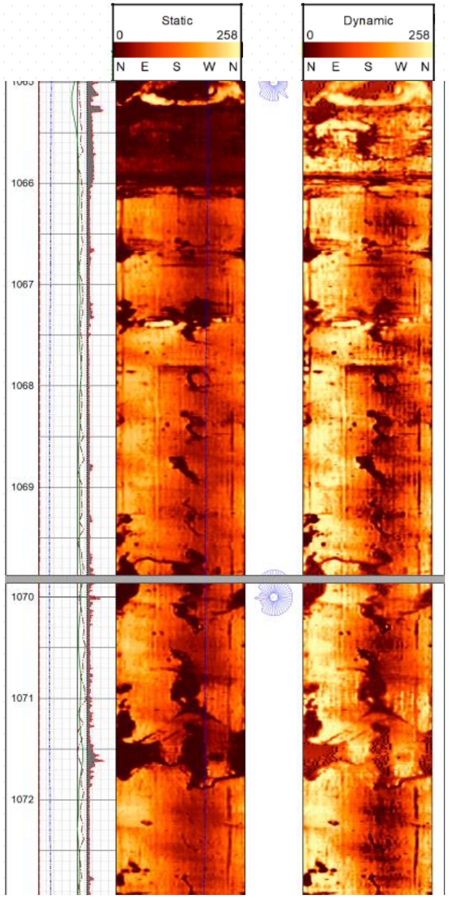


Trautwein-Bruns et al., 2010

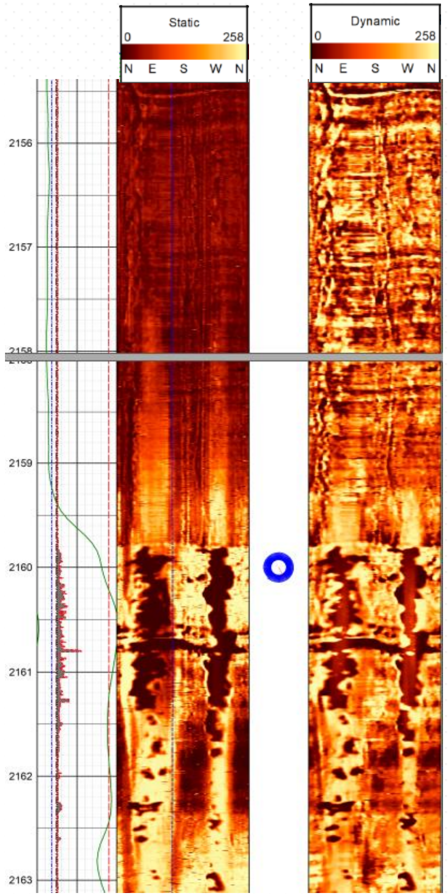


Maximum horizontal stress orientation in UK Quad 15 Central North Sea, Yale (2003)

Breakouts in Vlieland Claystone (1070mMDRT)

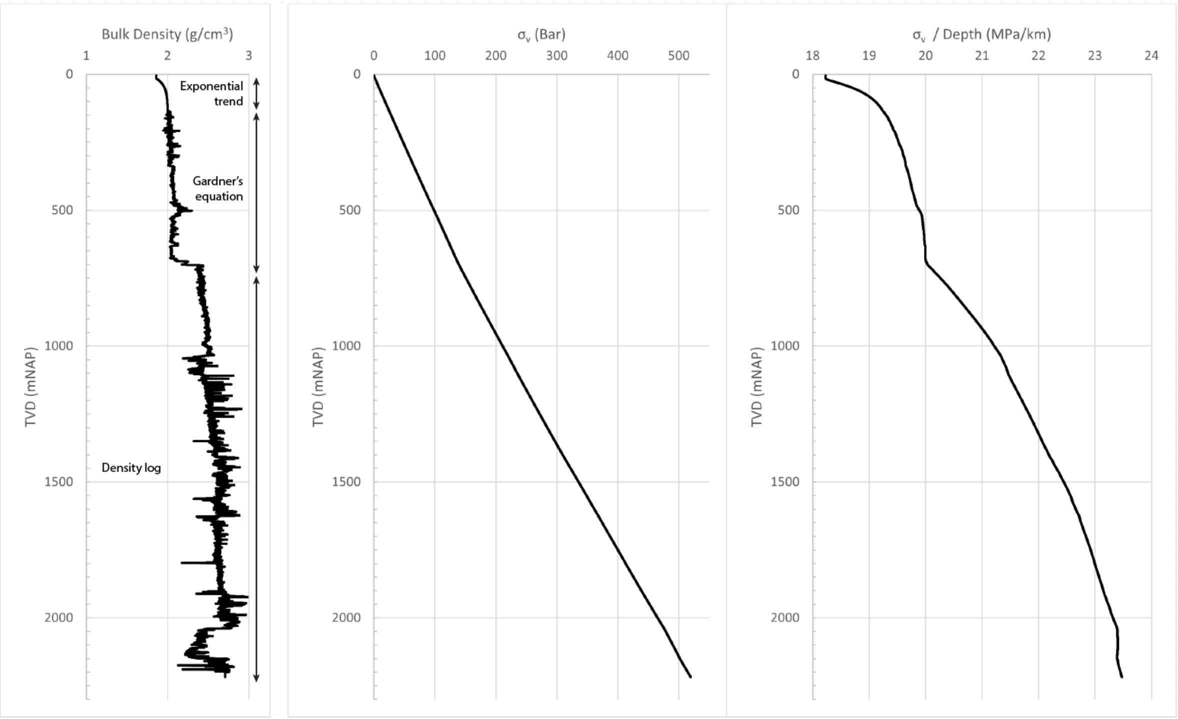


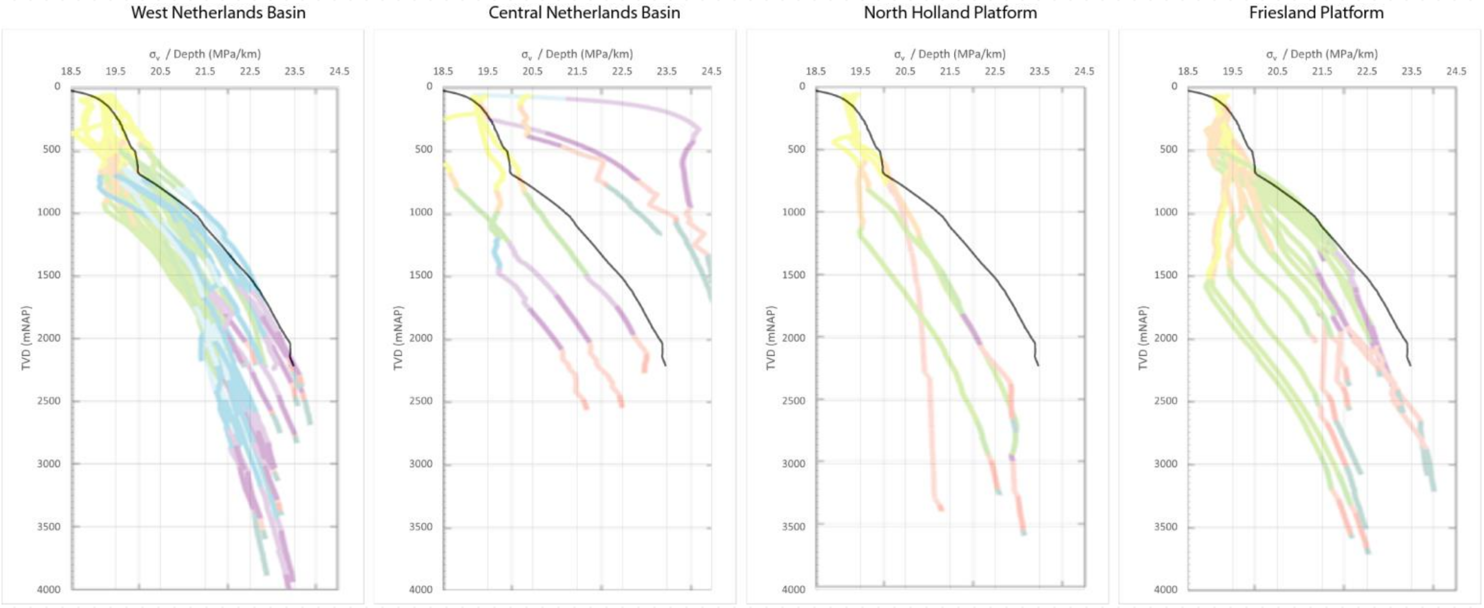
Tensile fractures in Slochteren and breakouts in Limburg (2160mMDRT)



Vertical-Stress Magnitude

- ➜Density log acquired from 700m depth to TD
- ➜In majority top hole high quality sonic data acquired: converted to density using Gardner's equation
- ➜Exponential function used above this depth
- ➜Relatively high vertical stress gradient compared with other geological domains (Buijze et al., 2024)





Modified from Buijze et al., 2024

Minimum-Horizontal Stress Magnitude

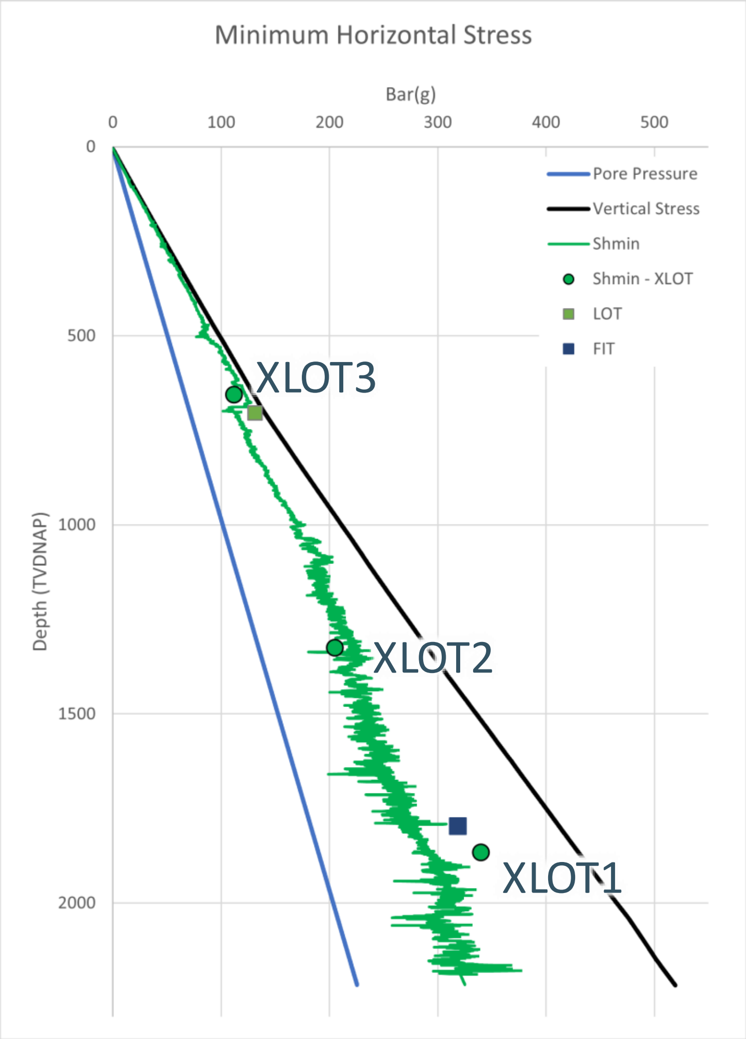
➔Minimum-horizontal stress derived from 3 XLOTs at three elevations

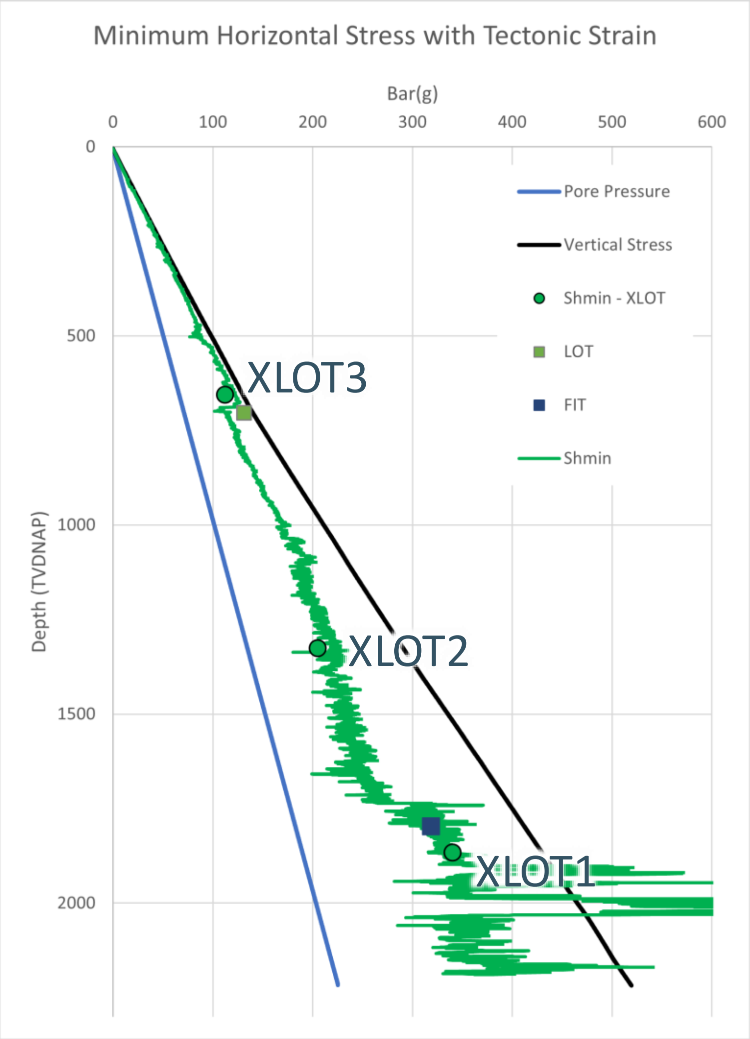
➔Continuous Shmin calculated using Eaton's equation with Poisson's Ratio from X-dipole sonic (Andrews and de Lesquen; Hettema, 2022)

➔Good match for XLOT 2 and 3

➔Underestimation of XLOT 1

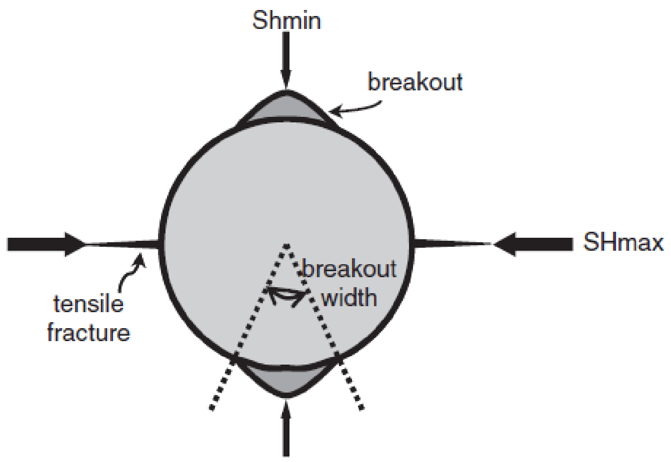
➔Underestimate of pore pressure or are there additional tectonic stresses in deep part of the well?



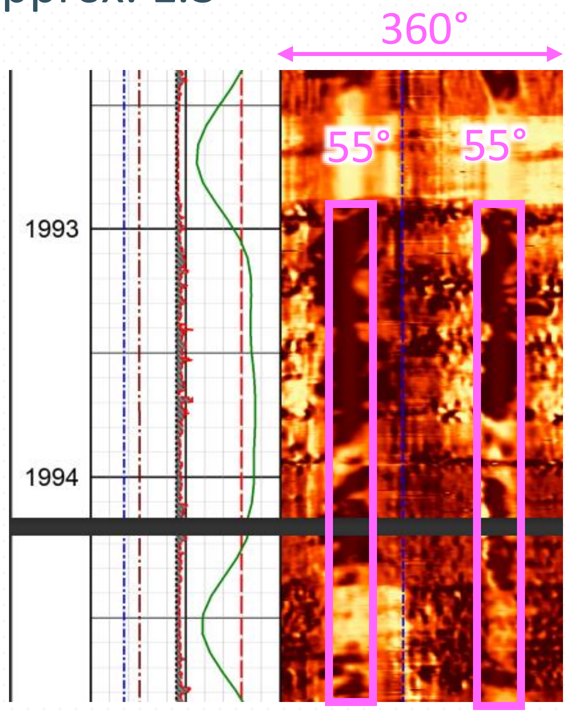


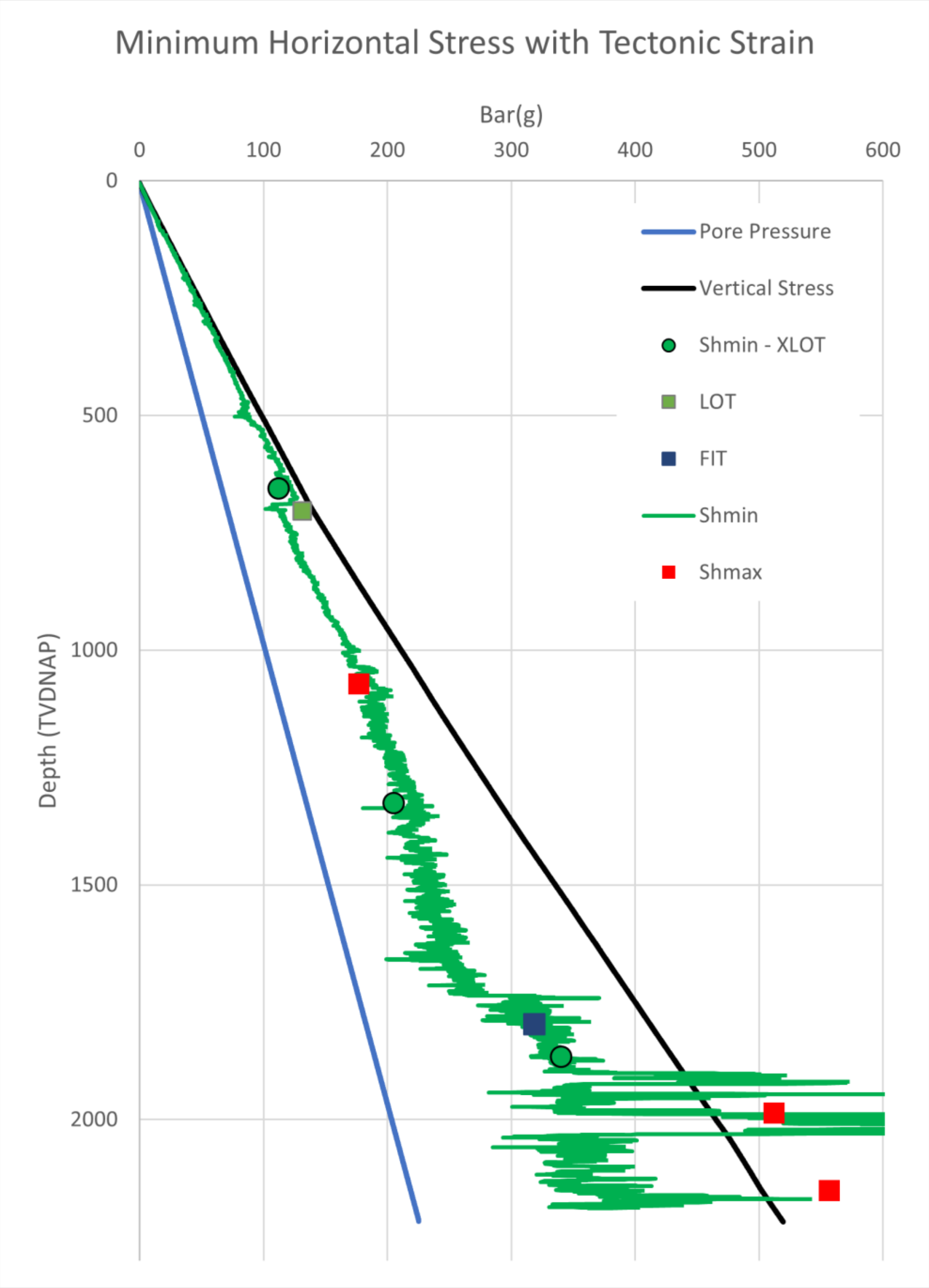
Maximum-Horizontal Stress

- ➔Maximum-Horizontal Stress magnitude can be derived from the borehole breakout angle (Barton et al., 1988)
- ➔$S_{Hmax} = \frac{C_0 + \Delta P_W + 2P_P}{(1-2cos2\theta)} - S_{hmin}\frac{(1+2cos2\theta)}{(1-2cos2\theta)}$
- ➔Ratio max/min horizontal stress in the shallow section is 1, in the deeper section this increases to approx. 1.3



Trautwein-Bruns et al., 2010



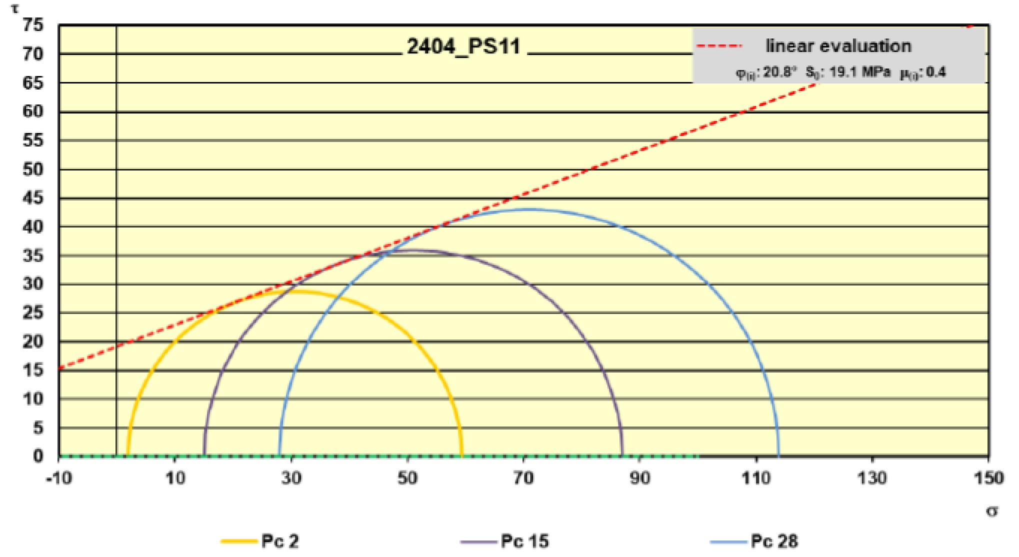


Core laboratory testing

- ➔Measurements on core of reservoirs and caprocks
- ➔Scratch test to determine continuous record of the Unconfined Compressional Strength (UCS)
- ➔Strain-controlled tri-axial tests to determine elastic parameters, strength and post-failure slip
- ➔Linear thermal expansion coefficient measured

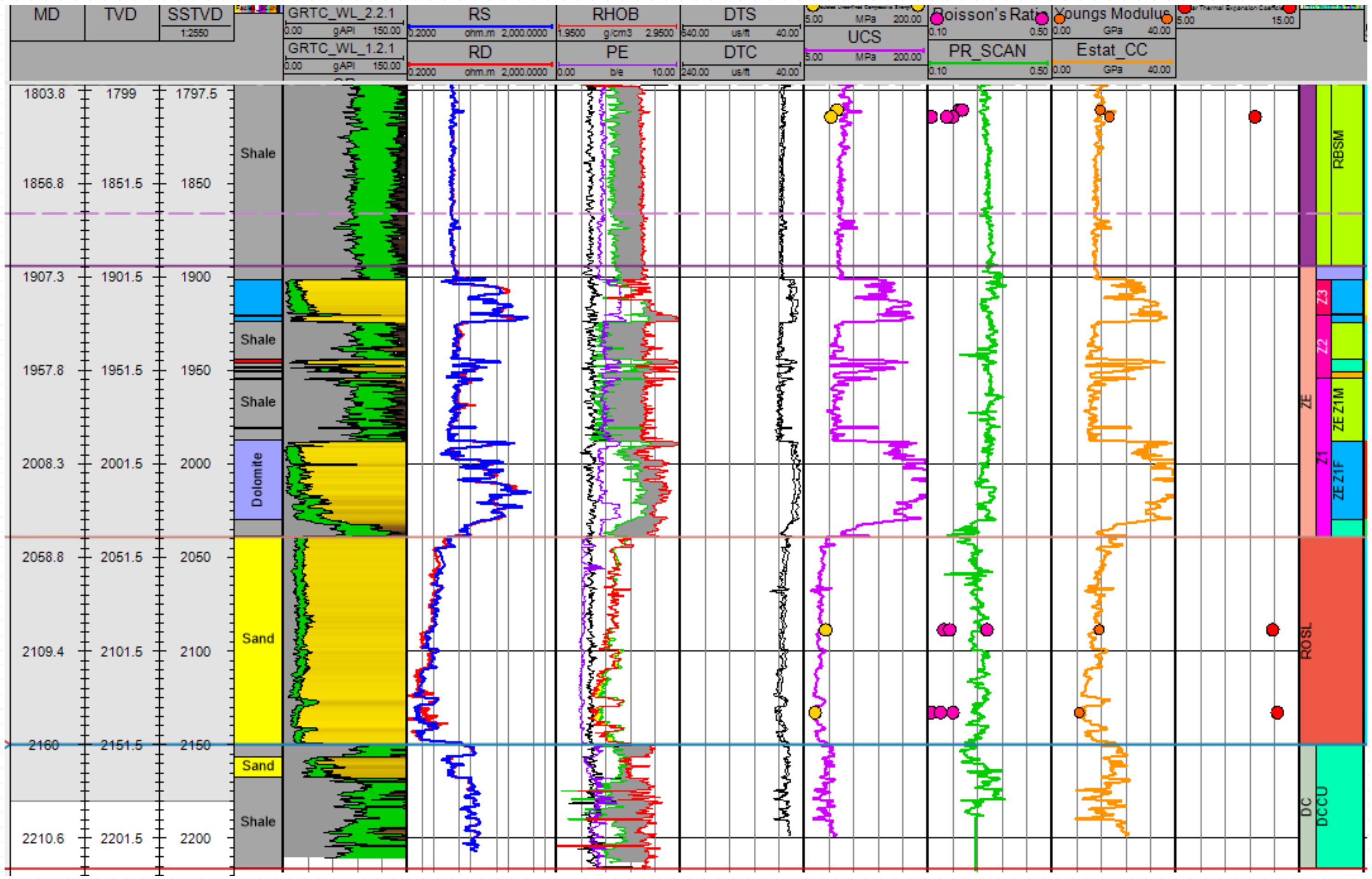
Main Claystone Fm - Caprock

Rotliegend Gp - Reservoir

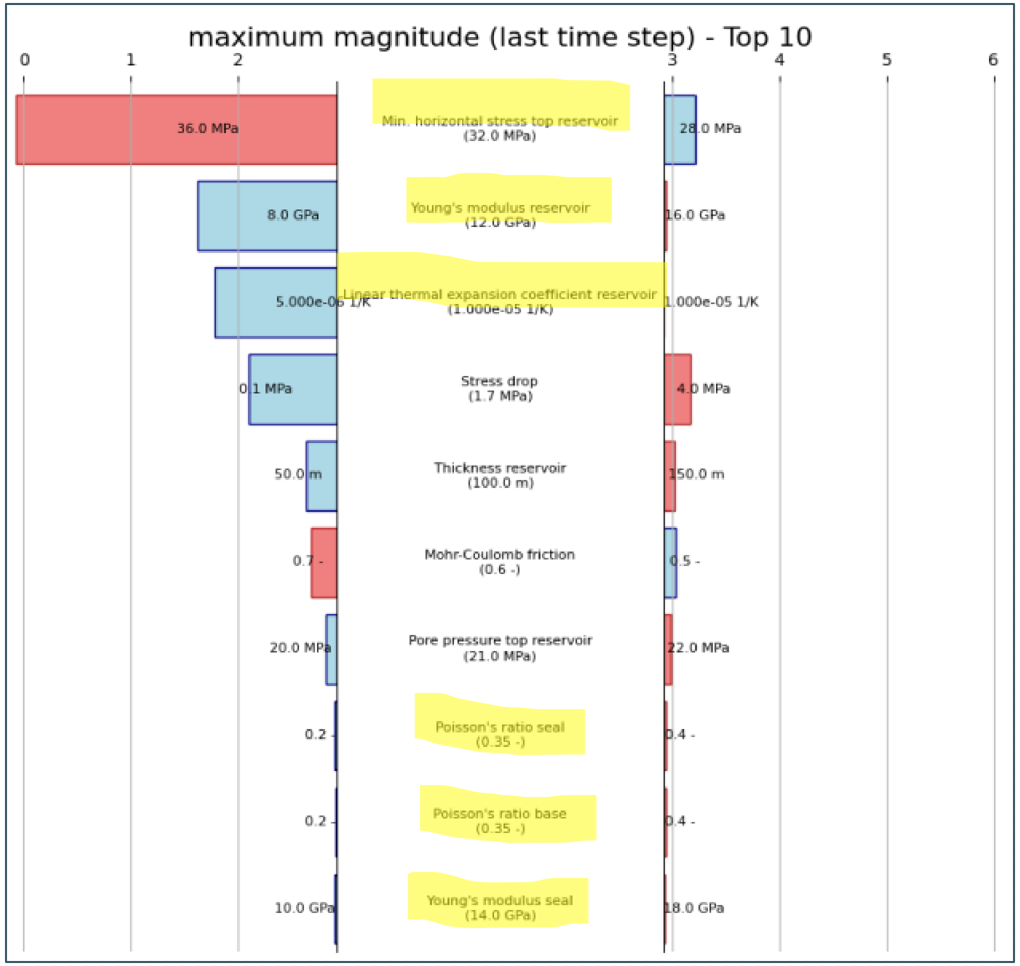


Additional Geomechanical Parameters

GR RES RHOB/ NPHI DTC/ DTS UCS Poisson's Ratio Youngs Modulus Linear Thermal Expansion

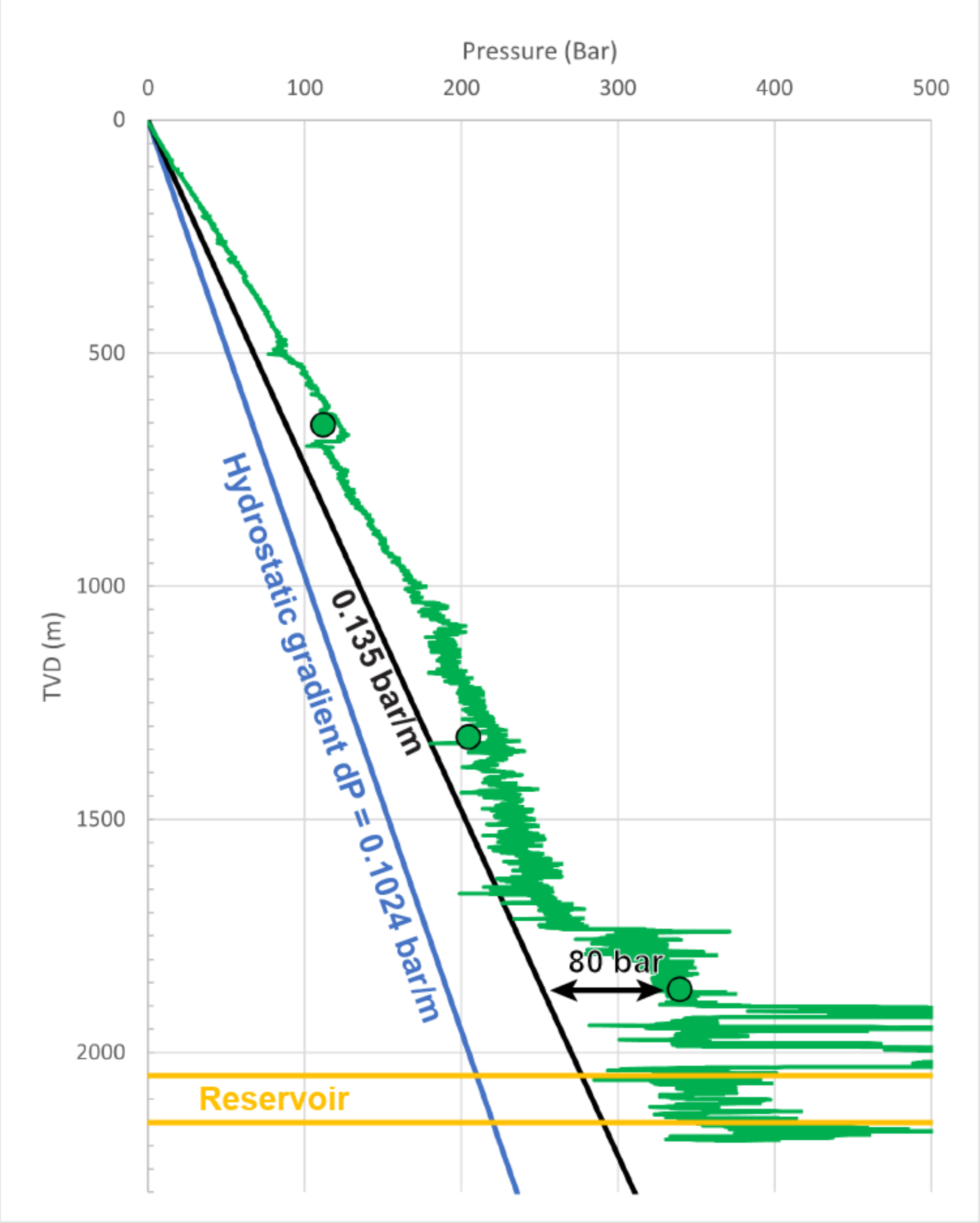


Example SRIMA output, Mijnlieff et al., 2023



Implications for geothermal projects

- ➔SCAN project provides geomechanical parameters and insight in areas with little previous data and high heat demand
- ➔Allows use of local parameters, rather than generic conservative estimates
- ➔Provides input to induced seismicity and caprock integrity workflows required for geothermal permits



Other SCAN contributions at EAGE GET2024

5 November	14:30-14:50	Johannes Rehling	Look-back on 5 years of SCAN 2D seismic acquisition and re-processing
	17:00-17:20	Milan Brussée	Exploring the shallow: results of data a data acquisition well in the Dutch Cenozoic succession
6 November	11:30-11:50	Pieter Bruijnen	Impact of lift methods and shutin techniques on welltest analysis in geothermal wells
7 November	15:50-16:10	Marten ter Borgh	Geothermal exploration in the Netherlands: the SCAN program
8 November	9:00-15:00	PanTerra Geoconsultants	CCS and geothermal at its core: geological risk assessment for geological risk assessment for geothermal and CCS on core material