SCAN

Update SCAN project
inclusief boring Amstelland-1

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Ministerie van Economische Zaken en Klimaat

ebn

TNO

Interreg North-West Europe
DGE-ROLLOUT

Introduction to EBN

- EBN (Energie Beheer Nederland, www.ebn.nl) was founded 50 years ago. It is a 100% state-owned company with 200 employees based in Utrecht, The Netherlands.

- Our mission is 'Towards a sustainable energy system, faster, together'

- Our strategic pillars:
  - A sustainable gas system
  - Responsible CO_2 storage
  - System Development for the public interest
 - A sustainable heat transition

A sustainable **heat transition**

Implementing collective and sustainable heat systems

- Geothermal energy
- SCAN
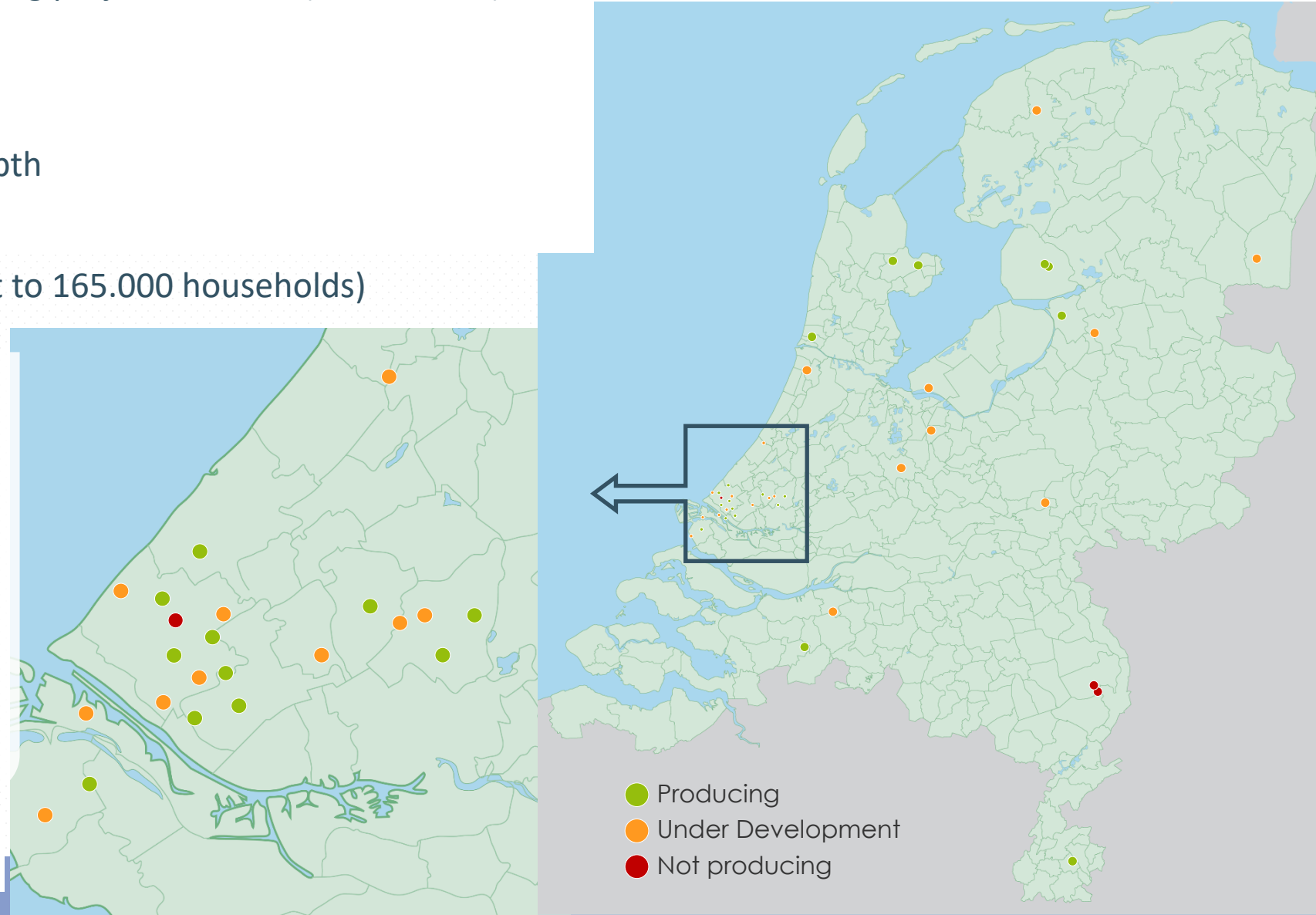- Heat systems
- Heat storage

scan

Geothermal Energy in the Netherlands

- Proven source of energy; 27 producing projects in 2023 (39 doublets)

- Low enthalpy, from saline aquifers

- Direct use: heat for heat

- Between about 700 m and 3 km depth

- Between about 30 °C and 100 °C

- 6.8 PJ of heat generated (equivalent to 165.000 households)

Energy use in the Netherlands

- 41% Heat
- 16% Electricity
- 21% Mobility
- 22% Raw Materials
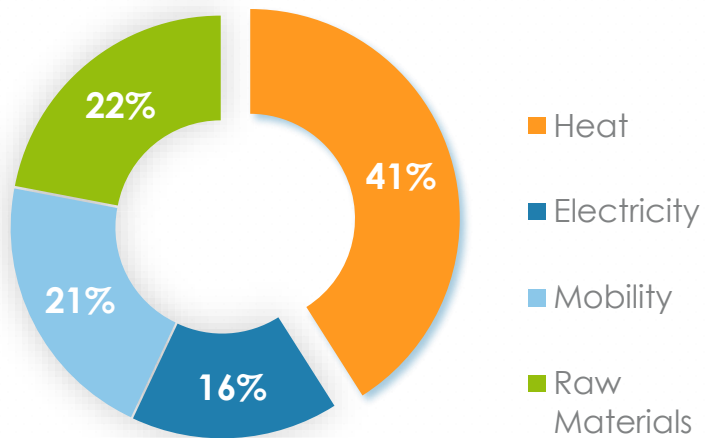
Sources: energieinnederland.nl, Geothermie Nederland Production Numbers 2023 & NLOG
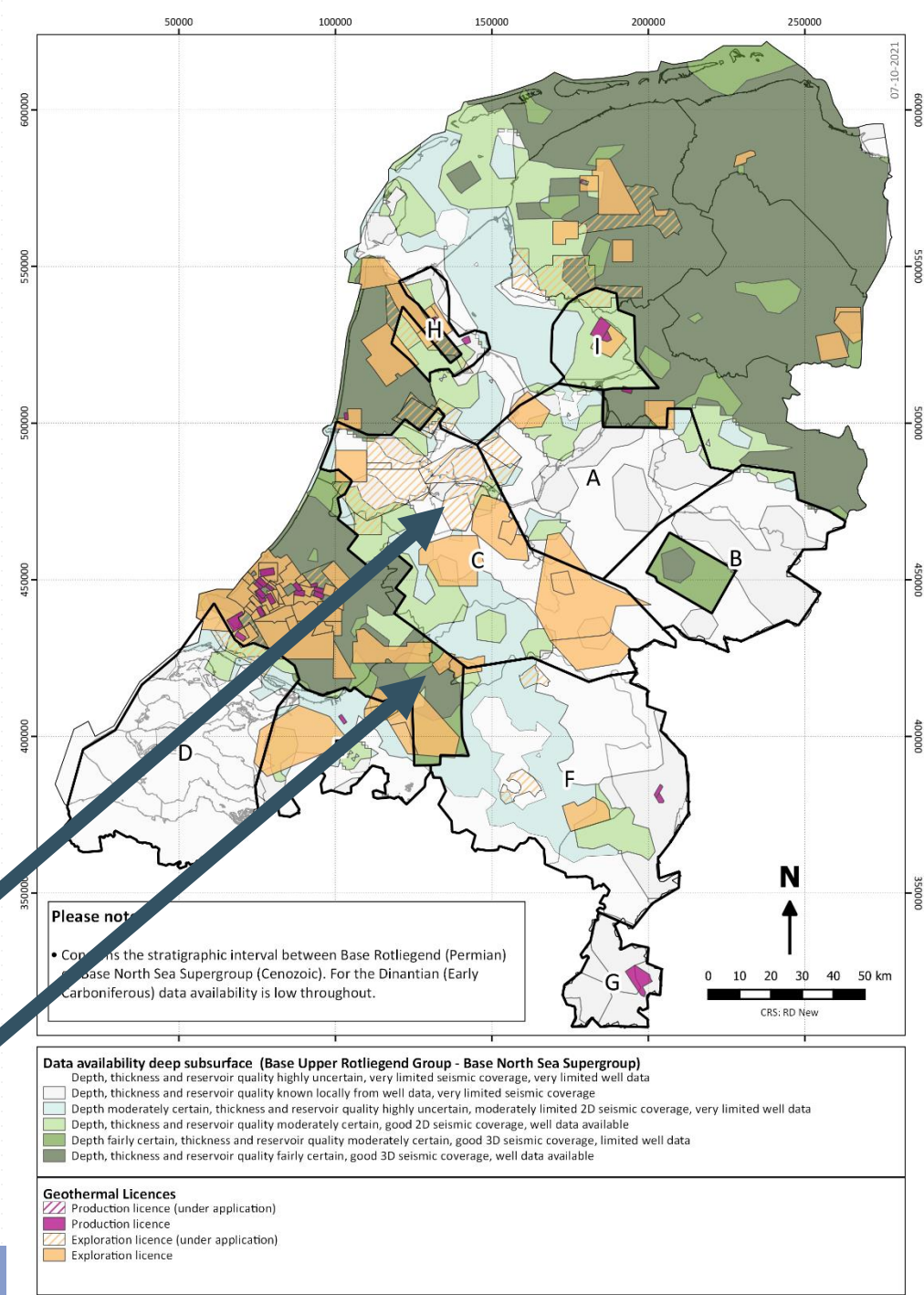

- Producing
- Under Development
- Not producing

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

➜ Aimed at shallow and deep geothermal (500-4000m)

➜ Provides a regional exploration dataset. For development of commercial projects more seismic and more local studies will generally be needed

➜ Funded by the Ministry of Economic Affairs and Climate, executed by EBN and TNO.

SCAN focuses on the 'white spots'. On this map they're actually coloured white, grey and light green

3D seismic and abundant well data available: <u>not</u> a 'white spot', <u>not</u> part of SCAN

Please note

- Contains the stratigraphic interval between Base Rotliegend (Permian) - Base North Sea Supergroup (Cenozoic). For the Dinantian (Early Carboniferous) data availability is low throughout.

0 10 20 30 40 50 km

N

CRS: RD New

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

Onderdelen SCAN-programma

1. **Acquisitie nieuwe 2D seismiek**

   ➜ Gereed (regionale lijnen; processing laatste lokale lijnen t.b.v. boringen bijna afgerond)

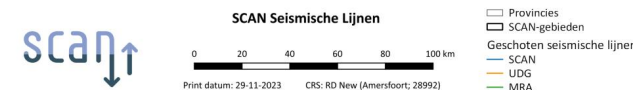2. **Herbewerken van oude 2D-seismiek**
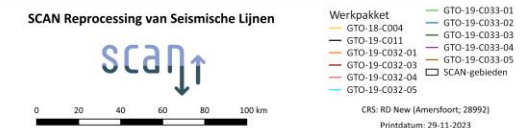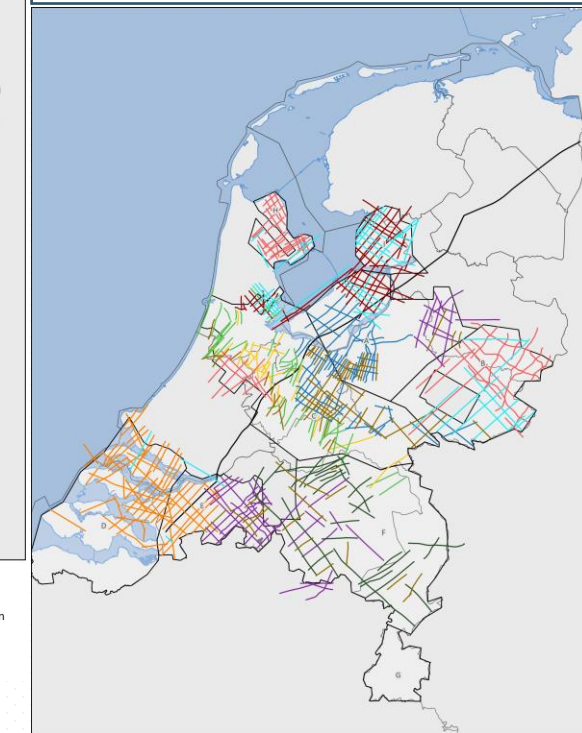
   ➜ Gereed

3. **SCAN-boringen**

   ➜ Eerste onderzoeksboring (Amstelland) afgerond en put ontmanteld

Alle resultaten worden publiek gemaakt via scanaardwarmte.nl en nlog.nl/scan
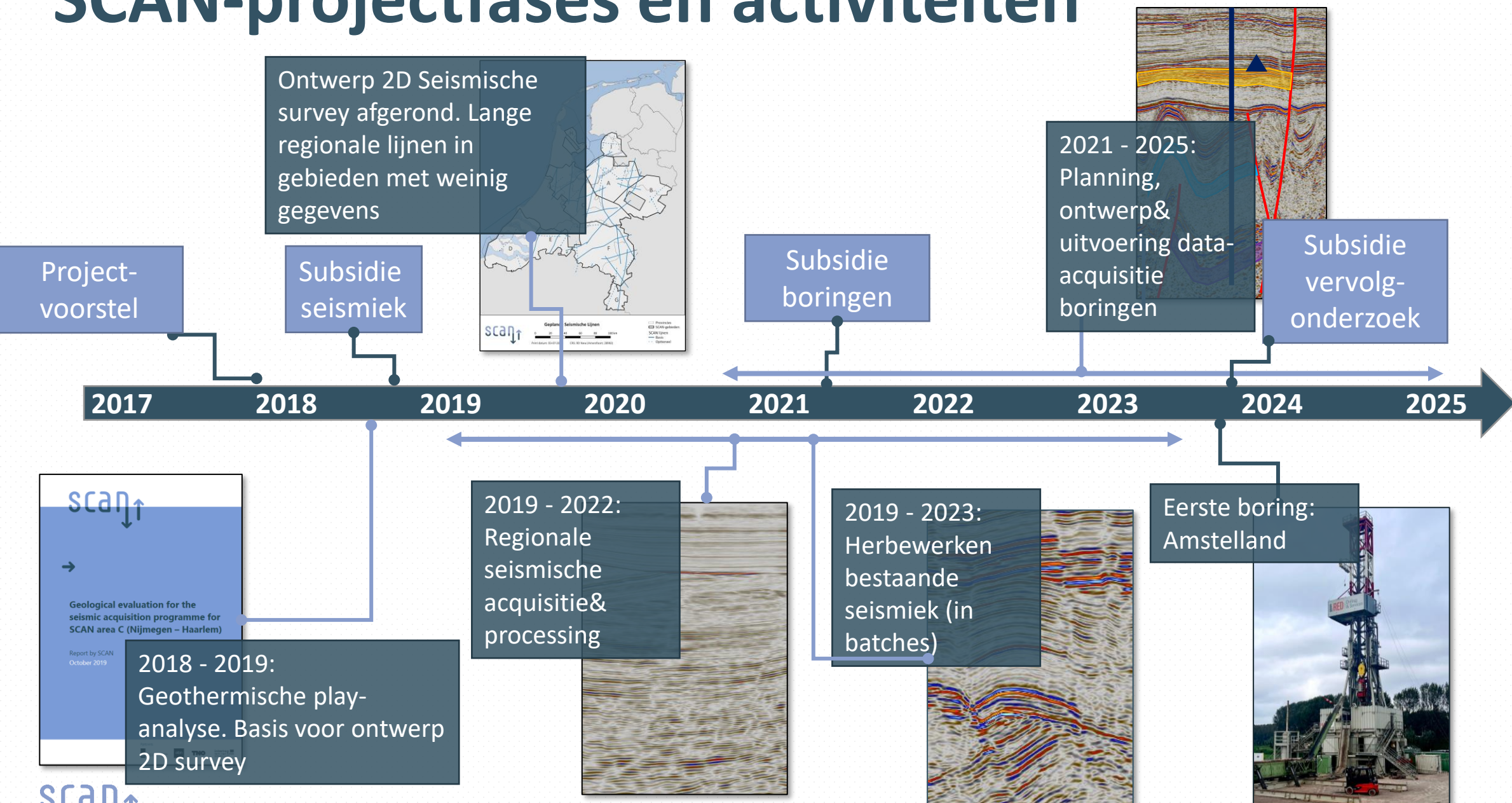

Nieuwe seismische lijnen

Herbewerkte seismiek

SCAN-projectfases en activiteiten

Ontwerp 2D Seismische survey afgerond. Lange regionale lijnen in gebieden met weinig gegevens

2021 - 2025: Planning, ontwerp& uitvoering data-acquisitie boringen

Project-voorstel

Subsidie seismiek

Subsidie boringen

Subsidie vervolg-onderzoek

2017　2018　2019　2020　2021　2022　2023　2024　2025

Geological evaluation for the seismic acquisition programme for SCAN area C (Nijmegen – Haarlem)

Report by SCAN
October 2019

2018 - 2019: Geothermische play-analyse. Basis voor ontwerp 2D survey

2019 - 2022: Regionale seismische acquisitie& processing

2019 - 2023: Herbewerken bestaande seismiek (in batches)

Eerste boring: Amstelland

SCAN 2D seismic acquisition

- Acquired 1.837 line km of new regional 2D (46 lines) and 20 local lines (106 km) to support the SCAN well locations with zero LTIs

- Recorded 30.196 shots and 383.467 receivers planted

- SCAN acquisition is combined with local seismic acquisition programs for UDG and MRA

- Visited > 164 municipalities, distributed > 135.000 letters into the neighbourhoods prior to acquisition

- Land access permissions from some 6.200 land users

- All 46 regional lines & 11 local lines are available on the NLOG website (https://www.nlog.nl/scan-2d-seismische-data)

MRA = Metropoolregio Amsterdam

SCAN Seismische Lijnen

| 0 | 20 | 40 | 60 | 80 | 100 km |

Print datum: 29-11-2023   CRS: RD New (Amersfoort; 28992)

Provincies
SCAN-gebieden
Geschoten seismische lijnen
— SCAN
— UDG
— MRA

SCAN 2D seismic acquisition

Key numbers:

- Zero LTIs
- Shot spacing: 60 m
- Shot depth: Nominally 20 m
- Shot type: Seismic explosives
- Receiver spacing: 5 m
- Receiver type: Wireless nodes
- Spread type: Split-spread
- Maximum offset: 7 km
- Recording length: 10 seconds

Land drill tractor,
usually 5 tractors deployed,
up to 100 shot points/day

Geophones

Shooting crew,
up to 160 shot points/day,
usually 1 crew deployed

Barge/pontoon mounted drill tractor, usually 3 barges
and 1 pontoon deployed, up to 58 shot points/day

Cumulative shot points drilled

Acquisition pause

Holiday

Holiday

Holiday

Holiday

Covid-19 shutdown

Start up period
2-3 km/day

Up to
4 km/day

Bad weather
< 1 km/day

Steady as she goes
+/- 4 km/day

Slow down due to water
works and urban areas
1-3.5 km/day
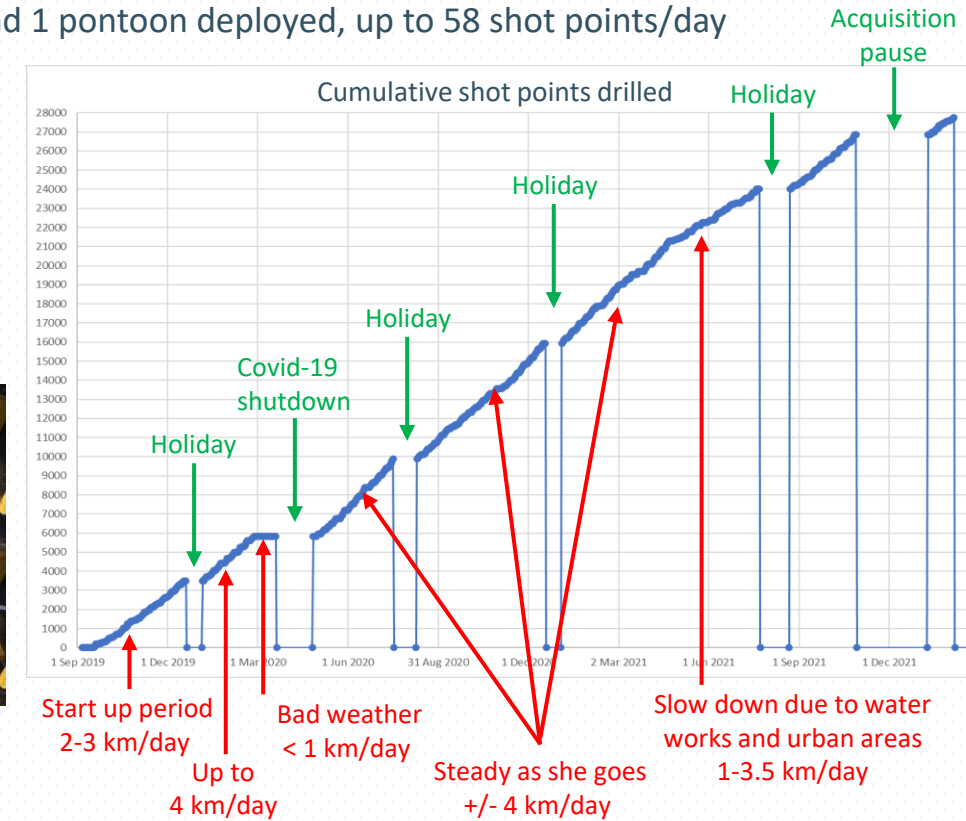
Average shot point drilling since acquisition start
(477 days of shot point drilling) is 3.7 km/day.

SCAN 2D PreSTM processing – MRA037
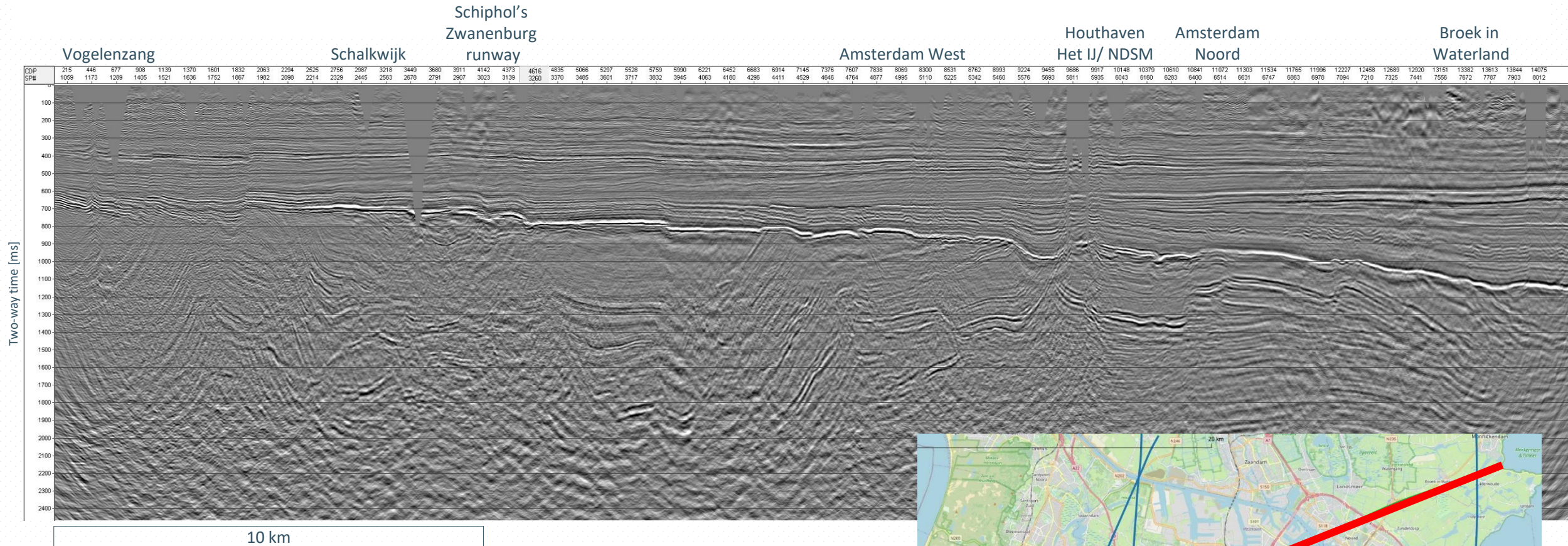
- With careful planning it was possible to acquire several 2D seismic lines through Amsterdam.
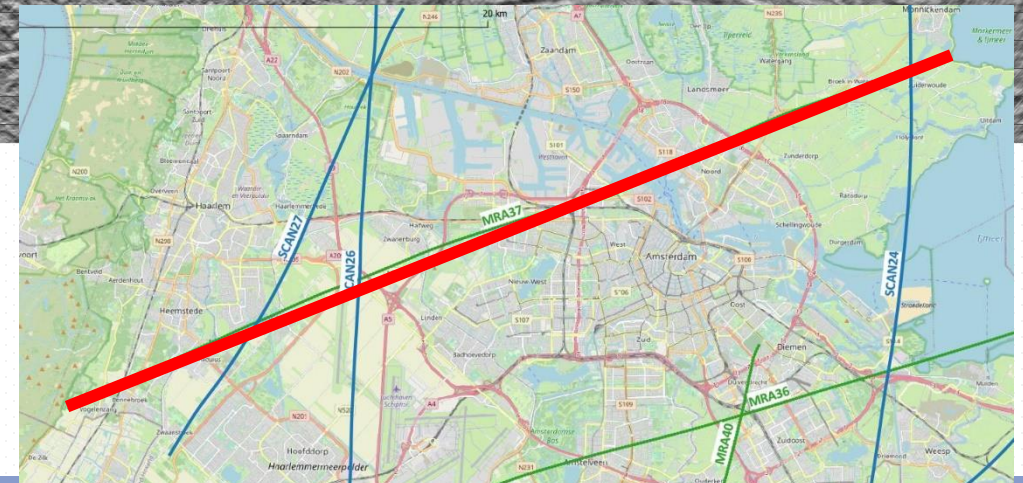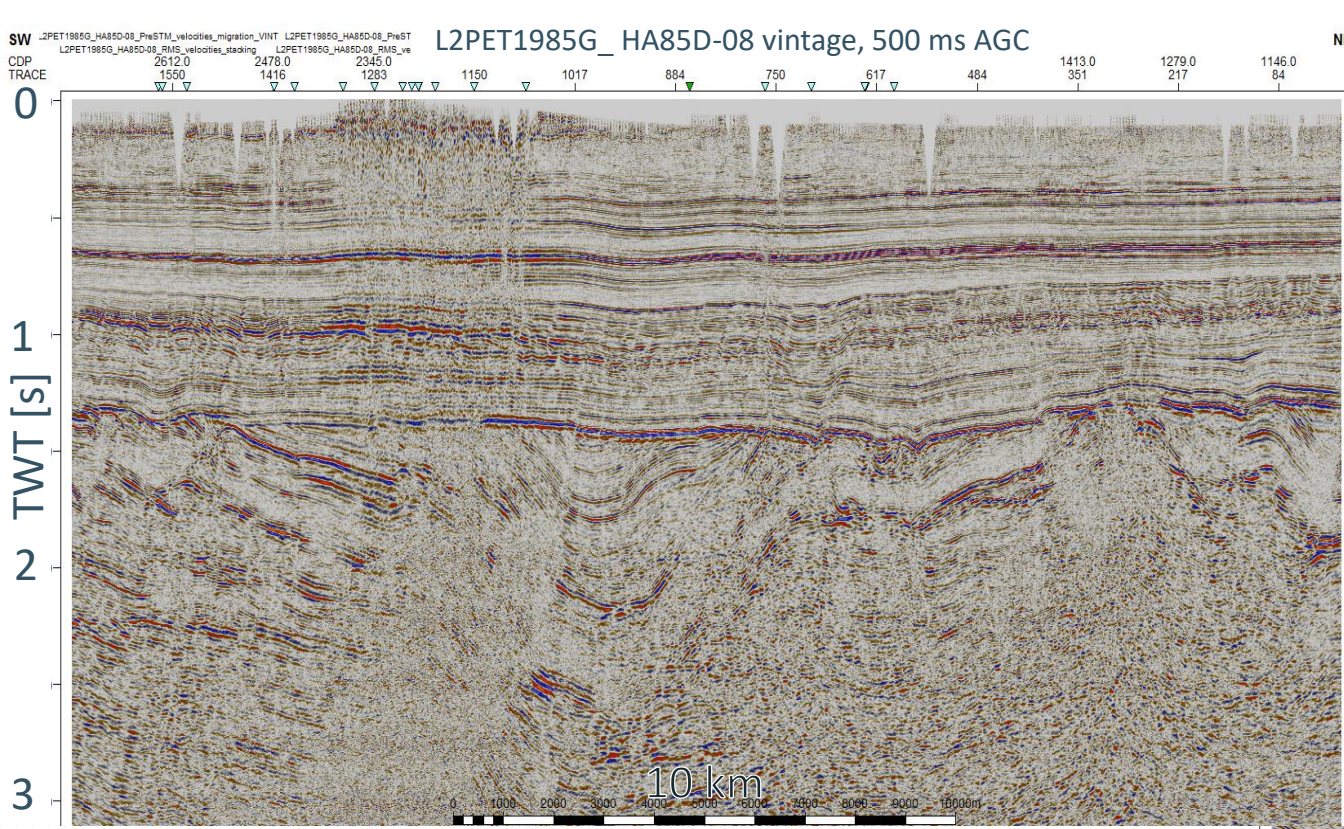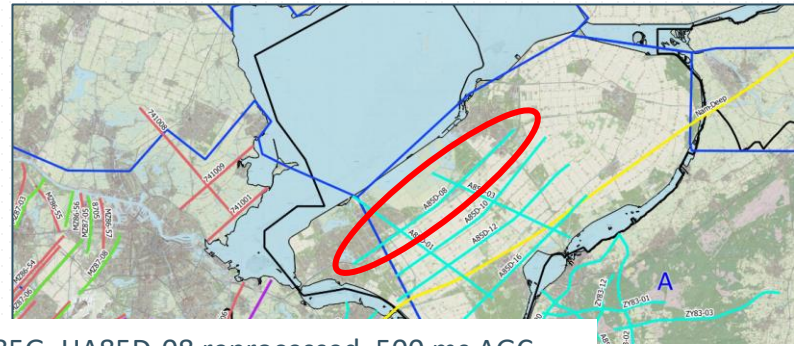
SCAN 2D reprocessing

- 2D seismic data, acquired mainly from the early 70s to early 90s, is reprocessed through a broad-band Pre-Stack Time Migration sequence

- Retrieval and QC of vintage data performed by TNO and EBN took more than 6.500 hrs (> 3.5 FTE years)
  - Completeness check of raw field shots, observer logs and navigation data
  - Readability check of raw field shots (SEGY format)
  - If need be, reconstruction of navigation data
  - If need be, reconstruction of elevation data

- A total of 11 reprocessing projects have been released to NLOG, which amounts to 7.504 line km (451 lines)

- Time spend by EBN on QA/QC of seismic processing contractors was more than 5.100 hrs

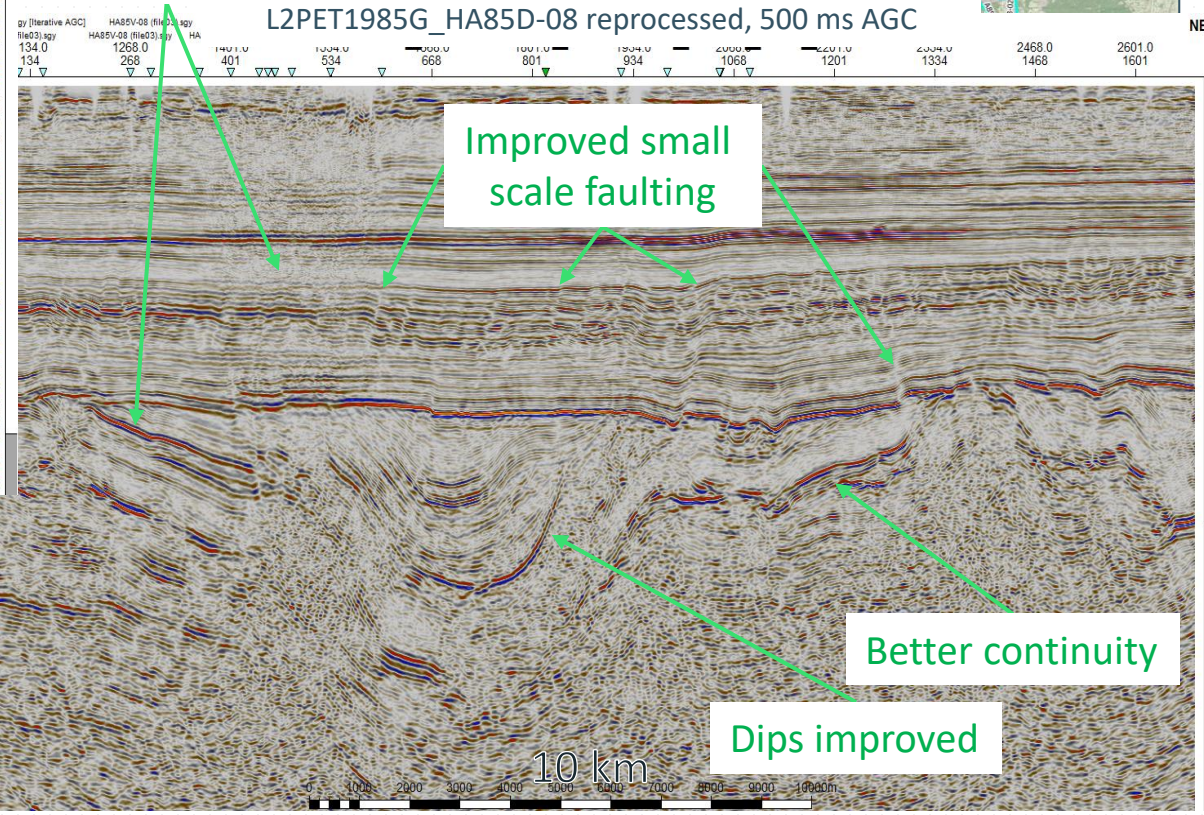SCAN Reprocessing van Seismische Lijnen

Werkpakket
GTO-18-C004
GTO-19-C011
GTO-19-C032-01
GTO-19-C032-03
GTO-19-C032-04
GTO-19-C032-05
GTO-19-C033-01
GTO-19-C033-02
GTO-19-C033-03
GTO-19-C033-04
GTO-19-C033-05
SCAN-gebieden

0 20 40 60 80 100 km

CRS: RD New (Amersfoort; 28992)
Printdatum: 29-11-2023
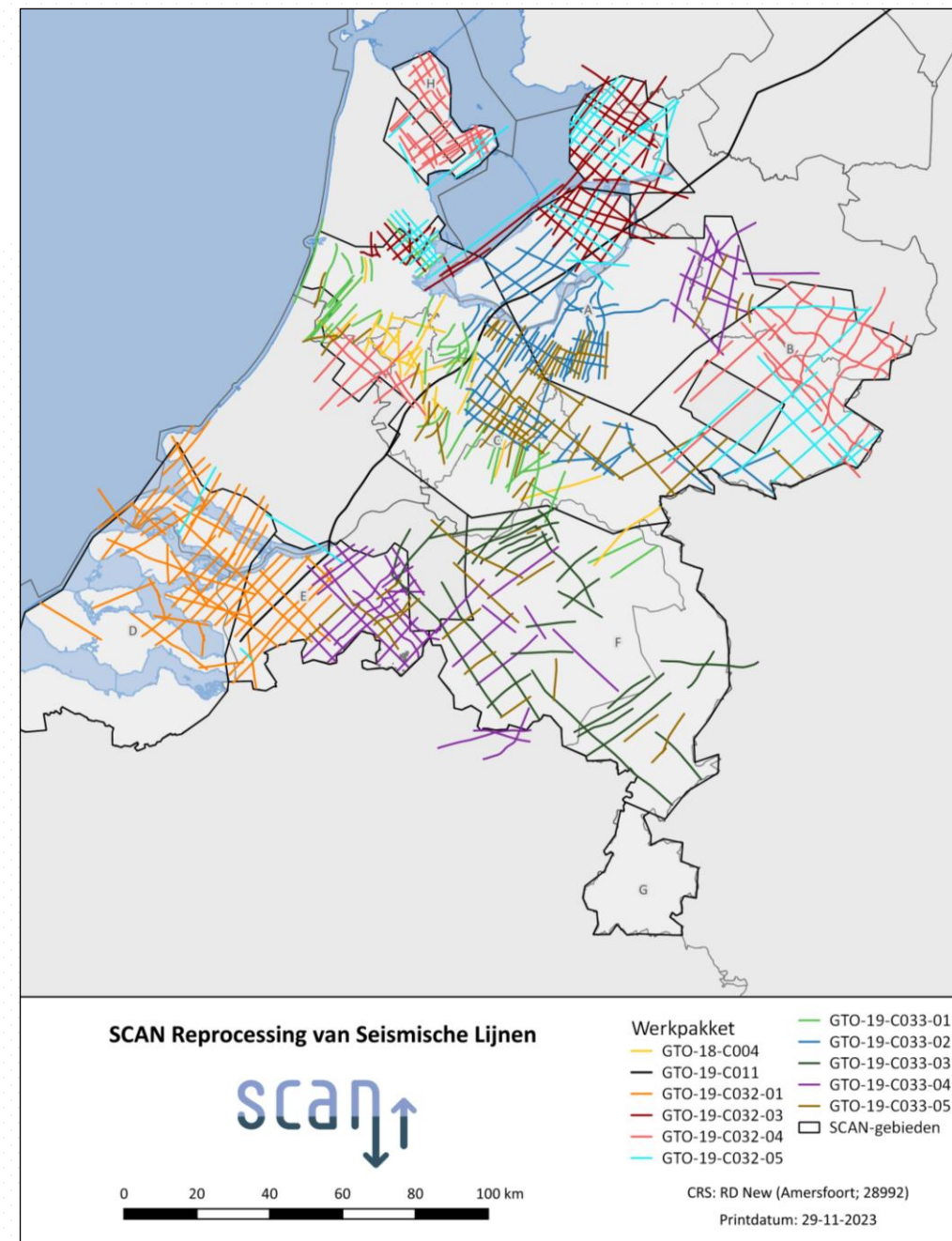
SCAN 2D reprocessing - Old digital vs. new digital

L2PET1985G_ HA85D-08 vintage, 500 ms AGC

Flevopolder
Almere-Lelystad

Better S/N

L2PET1985G_HA85D-08 reprocessed, 500 ms AGC

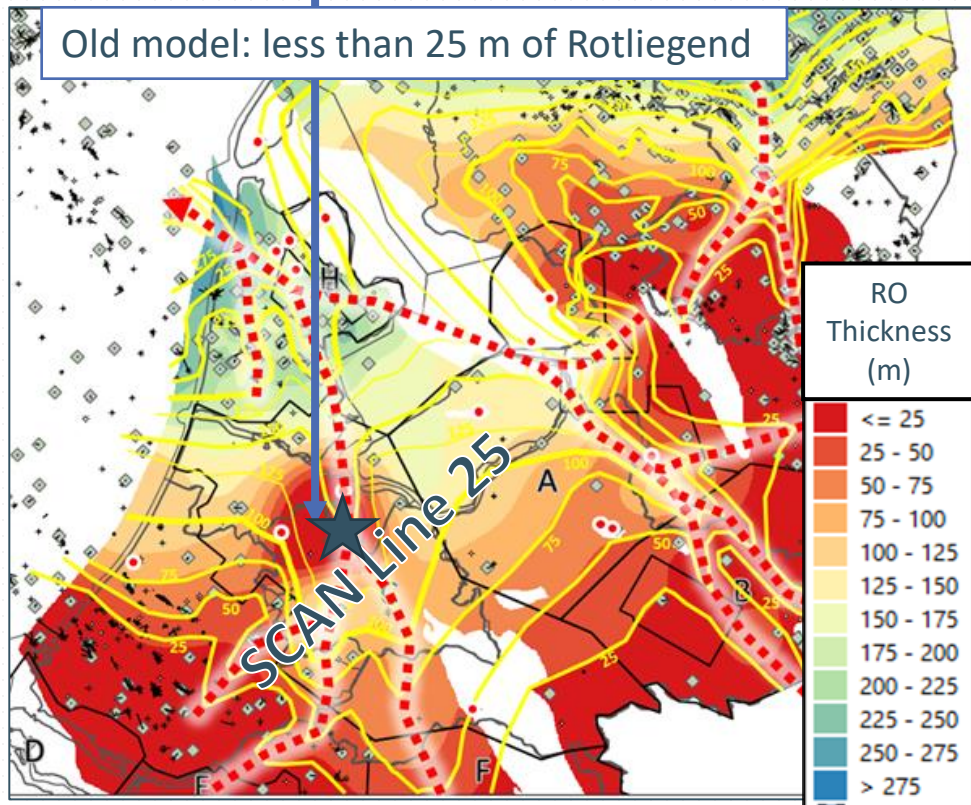Improved small scale faulting

Better continuity

Dips improved

10 km

- Reprocessing usually improves Signal-to-Noise, event continuity as well as fault & dip imaging

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 the Weesp and Waverveen wells, drilled in the 1970s

Weesp-01 (1970)

Neogene
Paleogene
Lower Cret.
Lower Jurassic
Triassic
Zechstein
Rotliegend
Carboniferous

2 km

ms TWT

Survey: L2EBN2020A
Line: L2EBN2020ASCAN025
Vintage: Final PreSTM, Full Stack, AGC
Seismic convention: AI increase is negative number, displayed in white

Old model: less than 25 m of Rotliegend

SCAN Line 25

RO Thickness (m)

<= 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
175 - 200
200 - 225
225 - 250
250 - 275
> 275

Yellow isopachs: SCAN thickness model
Colours in background: thickness in DGM-Diep v4
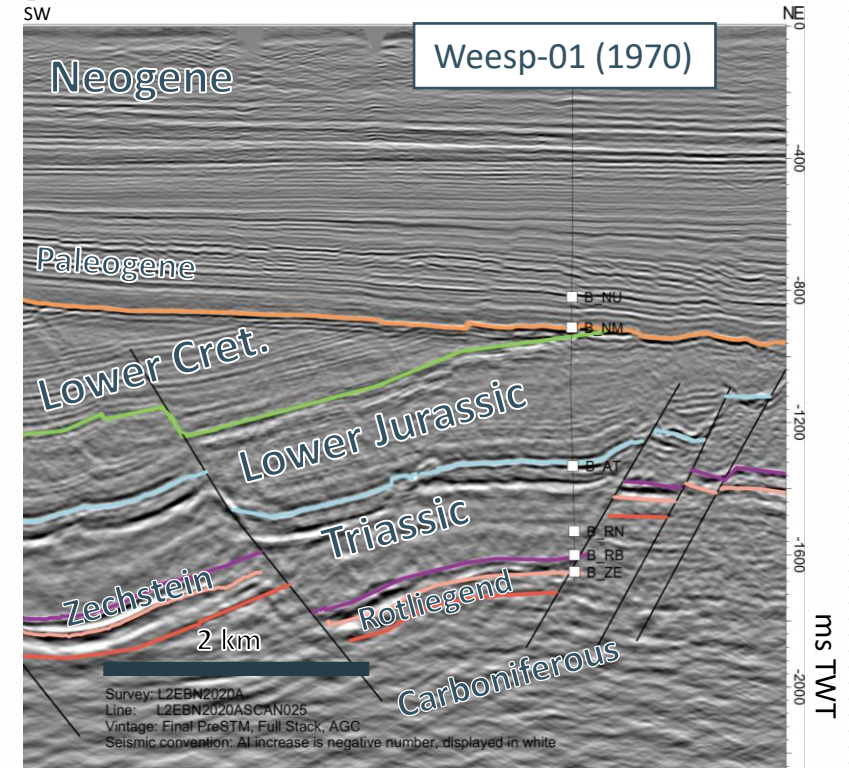
➔ Insufficient seismic data was present at the well locations.

➔ 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, which is good news for the geothermal potential of the region

➔ Uncertainties remain; AMS-01 well designed to provide relevant data.
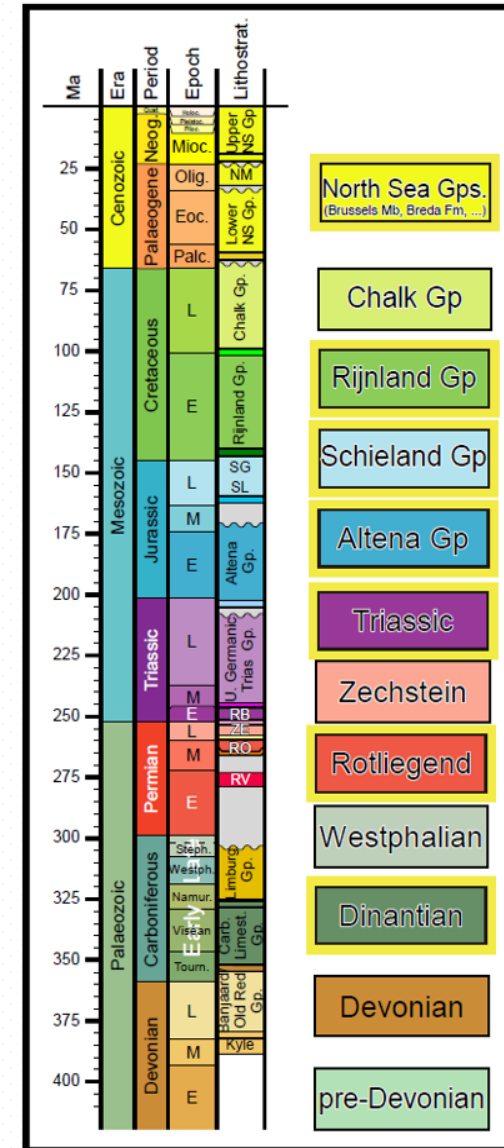
SCAN: Geothermal plays

➜ SCAN looks at a wide range of geothermal plays

➜ **Focus on:**
  ➜ Deep and Shallow geothermal (500 m – 4000 m)
  ➜ Primary permeability
  ➜ Secondary permeability (from karst or leaching)

➜ <u>No</u> **focus on:**
  ➜ Ultra Deep Geothermal (UDG; >4000 m)
  ➜ Fracture / fault permeability
 ➜ Artificial/man made permeability systems (fracking, mine galleries, etc.)

✓ Primary play
● Secondary play

A Play-Based Exploration approach for Geothermal

➡️ To select search areas, target intervals and well locations we applied a Play-Based Exploration workflow (van Lochem, 2020)

➡️ Together, the play segments associated with the search areas have a wide area of influence

➡️ Urban areas with high heat demand covered.

Combined extent of play segments for SCAN search areas

www.scanaardwarmte.nl
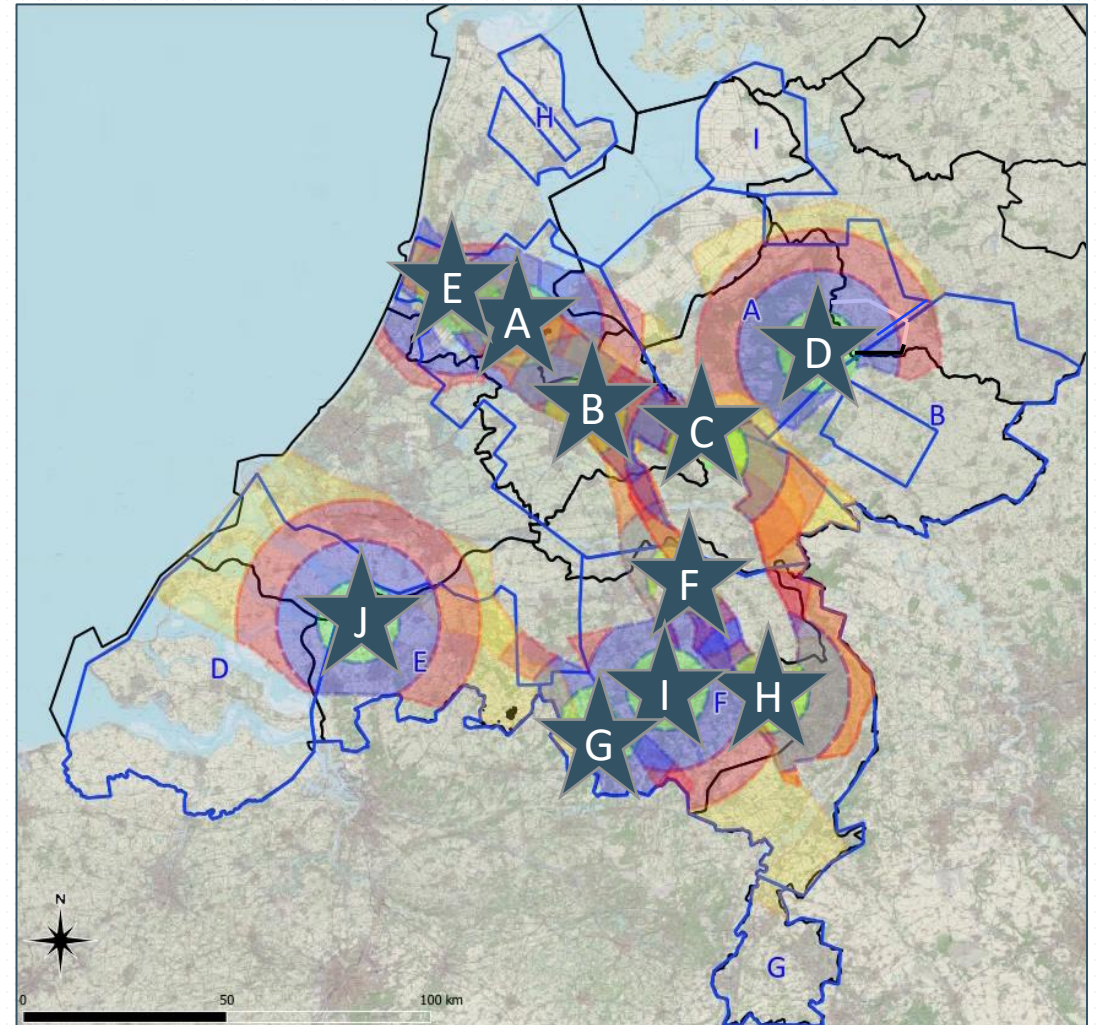
SCAN-zoekgebieden boringen

	SCAN-zoekgebied	Primair doel	Secundair(e) doel(en)
A	Amstelland	Rotliegend (Perm)	Chalk, Rijnland (O. Krijt)
B	Utrecht	Rotliegend (Perm)	Triassic, Rijnland (O.Krijt), Krijt Gp.
C	Ede-Veenendaal	Rotliegend (Perm)	Rijnland (O. Krijt)
D	Apeldoorn-Deventer	Rotliegend (Perm)	Noordzee (Paleogeen), B. Carb.
E	~~Haarlem-Amsterdam-West~~	Rijnland (L. Cret)	Schieland (B. Jura/O. Krijt), Krijt Gp.
F	Oss	Trias	Rijnland, Rotliegend, Krijt Gp (Vaals Fm)
G	Kempen	Trias	B. Carboon
H	Deurne	Trias	Krijt Gp (Vaals Fm)
I	Eindhoven	Noordzee (Neogeen& Paleogeen)	None
J	West-Brabant Noord	Noordzee (Paleogeen)	None

➜10 Zoekgebieden

➜Verwachting dat er budget is voor ~7 boringen

➜Lijst gesorteerd op primair doel; impliceert geen drilling sequence of ranking

⭐ Zoekgebied

SCAN well objectives

The drilling, completion and testing program adheres to the following key subsurface objectives, which are to address:

Uncertainties in reservoir presence and quality to assess well injectivity/deliverability:

- Lithology: Clay/sand/carbonate content
- Porosity
- Sedimentology (facies)
- Thickness
- Horizontal and vertical permeability
- Transmissivity
- Fractures and karst
- Mineralogy and diagenesis
- Net-to-gross ratio

Uncertainties related to fluid properties and temperature:

- Fluid composition: dissolved gas (hydrocarbons, CO_2, H_2S, etc), salinity, corrosives, micro-biology, lithium content, etc
- Temperature,
- Thermal conductivity
- Formation pressure

Uncertainties in the "consequences of geothermal heat harvesting" (e.g. induced seismicity)

- Geo-mechanical properties of seal, reservoir and overburden

Data acquisition in a typical geothermal well
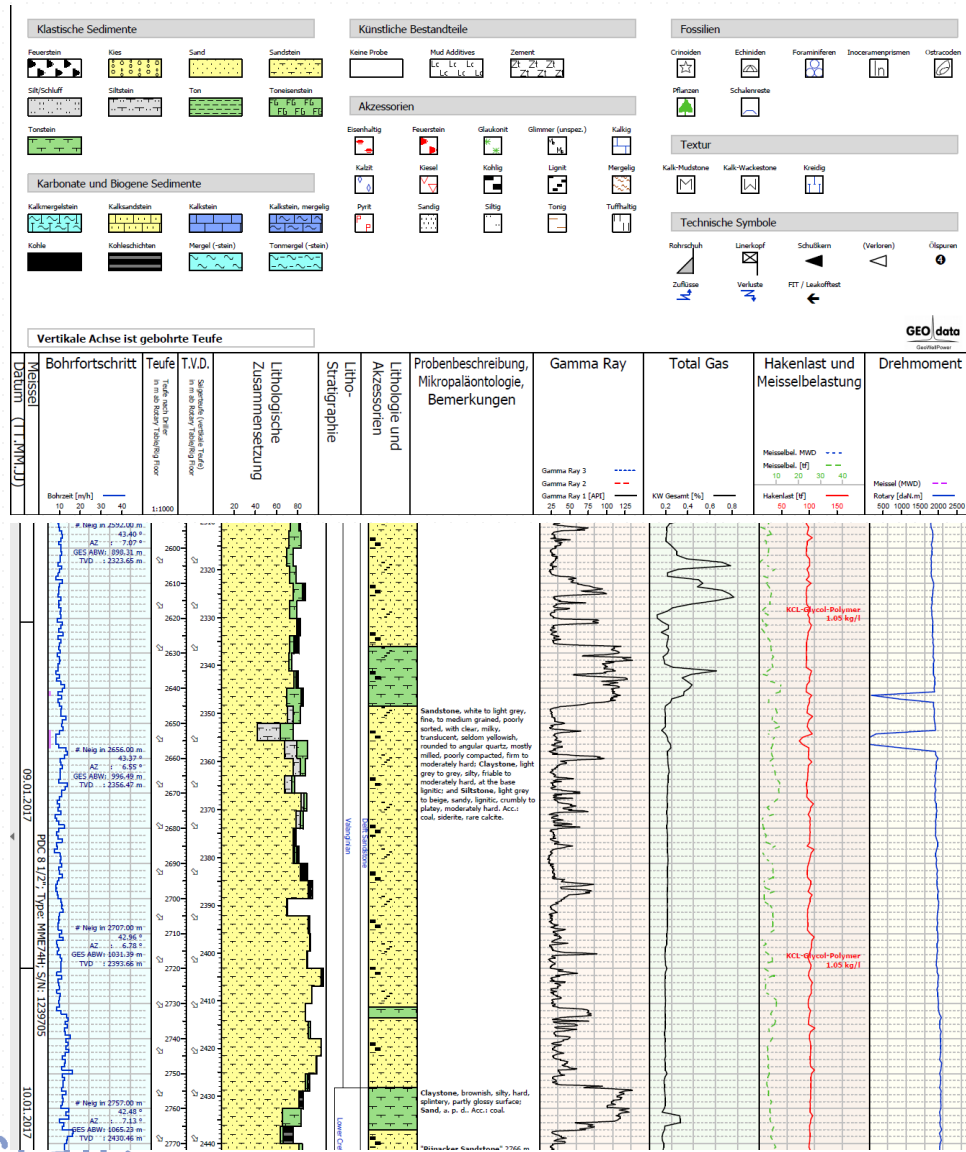
- Cuttings
- Basic petrophysical logging (gamma ray)
- Well tests

But very few:
- More advanced logs
- Cores
- Geomechanical data

All figures from NLOG.nl
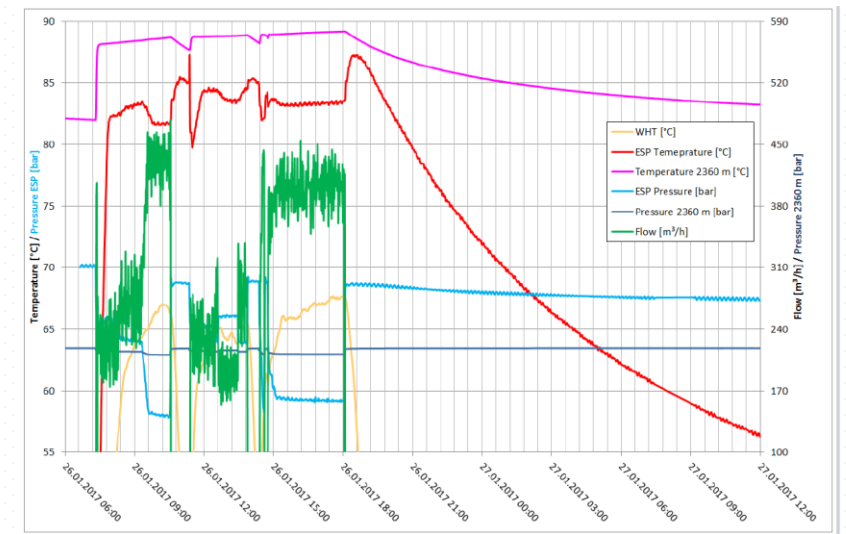
Figure 1: Overview Production Test, selected parameters of the electronic measurement system

Data-acquisition in SCAN wells

Extensive data acquisition is planned in SCAN wells. Amstelland well shown as example

➔ Cores
  ➔ Reservoirs: Porosity/permeability data
  ➔ Reservoirs: Sedimentology and diagenesis (incl. descriptions and thin sections)
  ➔ Geomechanical tests (note: also for sealing intervals)

➔ Production / injection tests
  ➔ Flow rate and transmissivity
  ➔ Temperature, pressure and water composition

➔ Well Logs, both reservoirs and overburden
  ➔ Gamma Ray, Sonic (Vp/Vs), density/neutron, resistivity (whole well)
  ➔ Image logs (for sedimentology and diagenesis, fractures and stress directions)
  ➔ NMR log (for permeability)
  ➔ Temperature

➔ Vertical Seismic Profile (for robust correlation onto regional seismic grid)

➔ XLOT (Extended Leak-off Test)
  ➔ Determination of caprock integrity

➔ Cuttings and biostratigraphy
  ➔ Vitrinite reflectance, apatite fission track, …
  ➔ Dating and correlation of relevant intervals
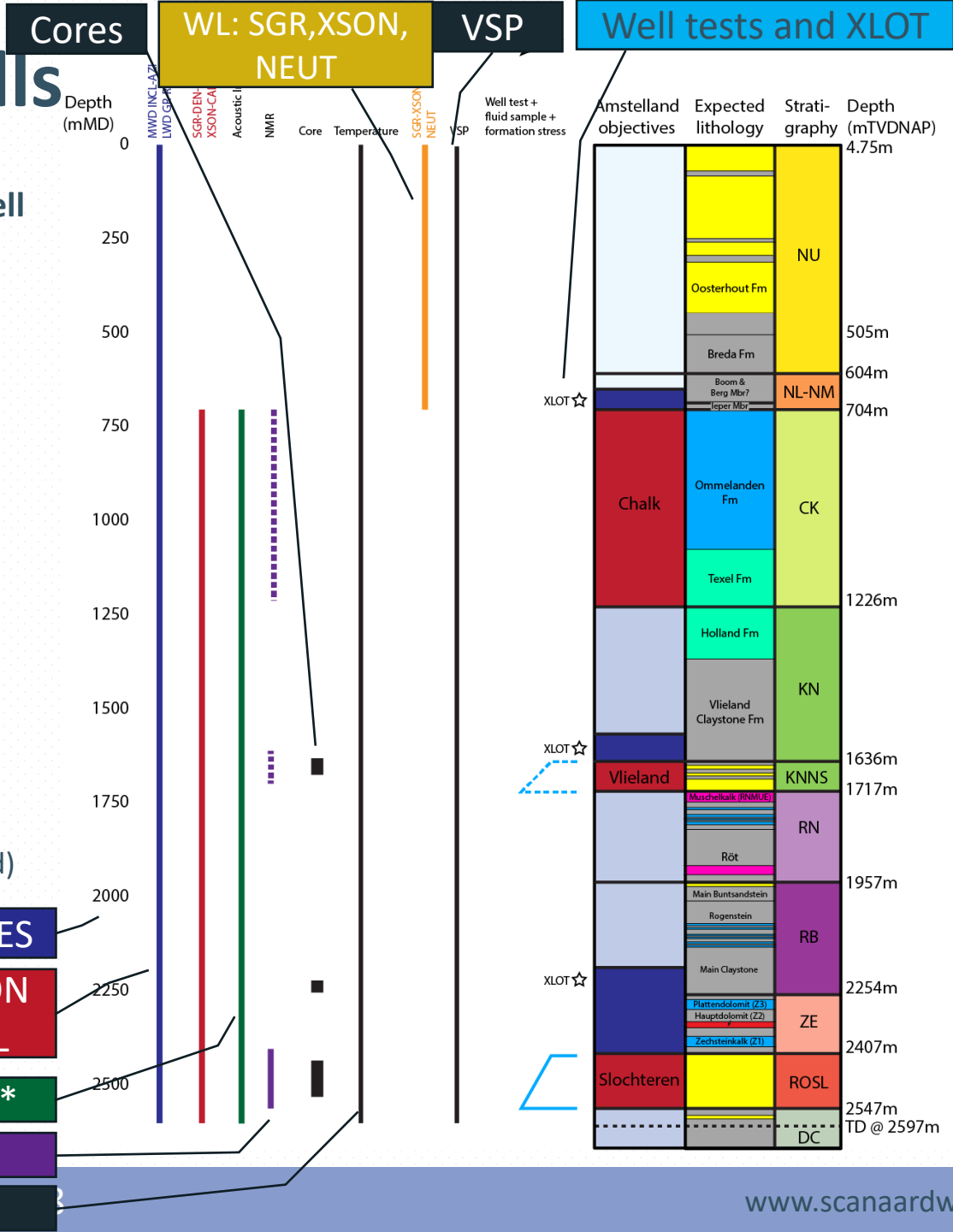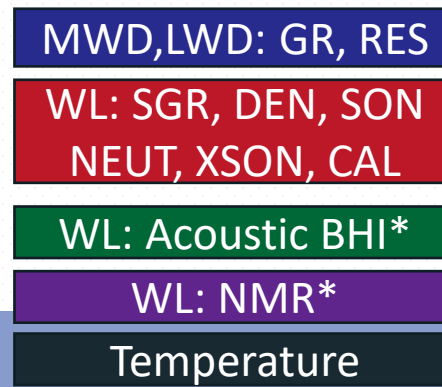
Cores | WL: SGR,XSON, NEUT | VSP | Well tests and XLOT

MWD,LWD: GR, RES
WL: SGR, DEN, SON NEUT, XSON, CAL
WL: Acoustic BHI*
WL: NMR*
Temperature

Objectives
- Above first target seal
- No reservoir potential
- Seal above reservoir
- Reservoir potential

Expected lithology
- Clay(stone)
- Sand(stone)
- Carbonate
- Marlstone
- Halite
- Anhydrite

Data acquisition
- Log / Conditional log
- Whole core
- XLOT ☆ Test and formation stress
- XLOT ☆ Conditional test and formation stress

SCAN Well Amstelland

➜First SCAN geothermal data-acquisition well

➜Drilled in fall/winter 2023

➜ Geothermal targets:
- ➜Primary: Permian Rotliegend (ROSL) sandstones (~87°C)
- ➜Secondary: L. Cret. Vlieland Sandstone Fm (KNNS) (~62°C)
- ➜Secondary: U. Cret. Chalk Gp (CK) (~39°C)

➜Main pre-drill uncertainty for ROSL: permeability. Chance of presence of sufficiently permeable reservoir estimated at 65%

➜GPOS KNNS: 30%

➜GPOS CK: 40%
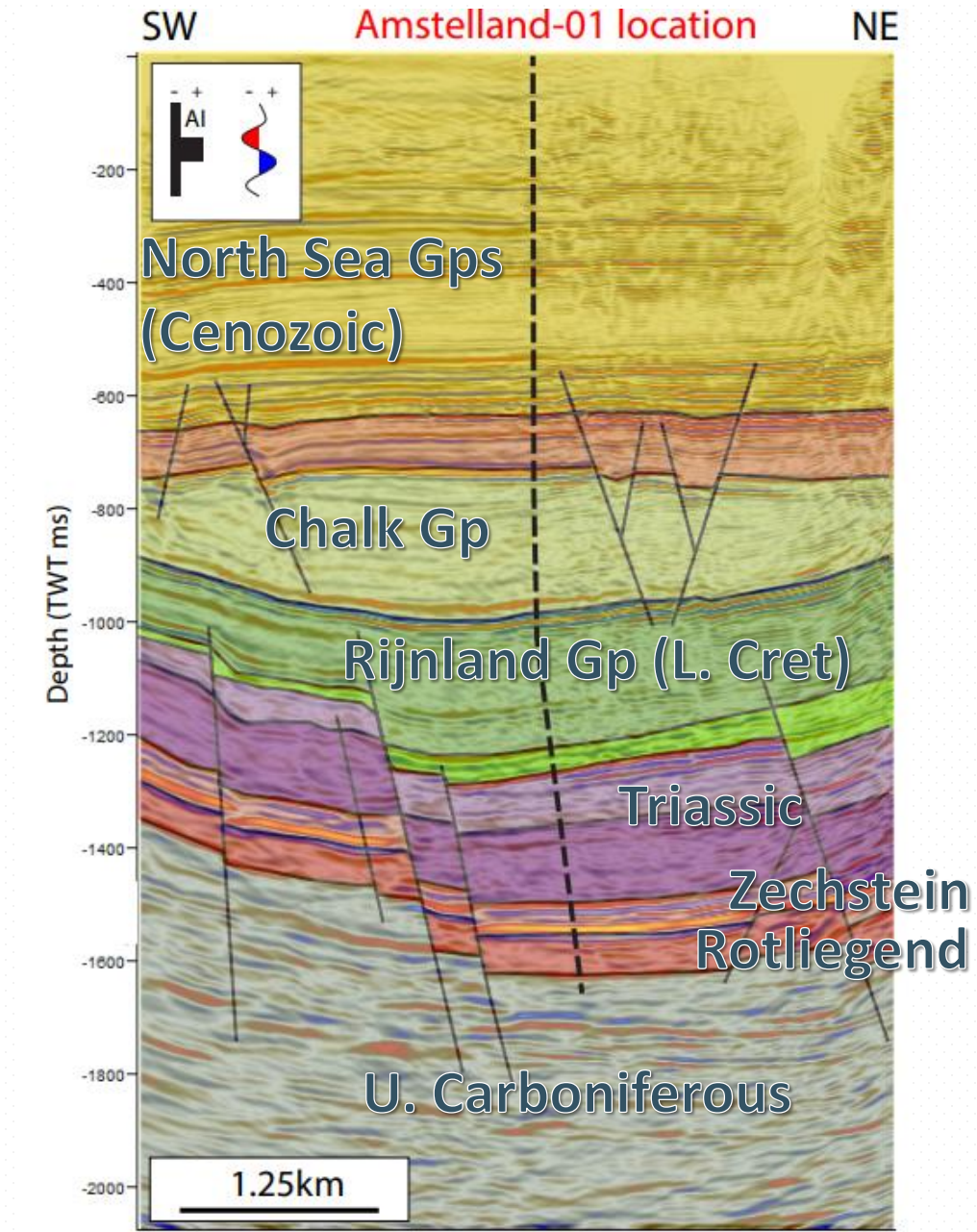
Area of influence

- Amstelland search area and well location selected so that data collected is representative and relevant for a large area with high heat demand
- Three geothermal "plays" of varying depth and temperature tested extensively

Play Segment map SCAN Amstelland well, Rotliegend target
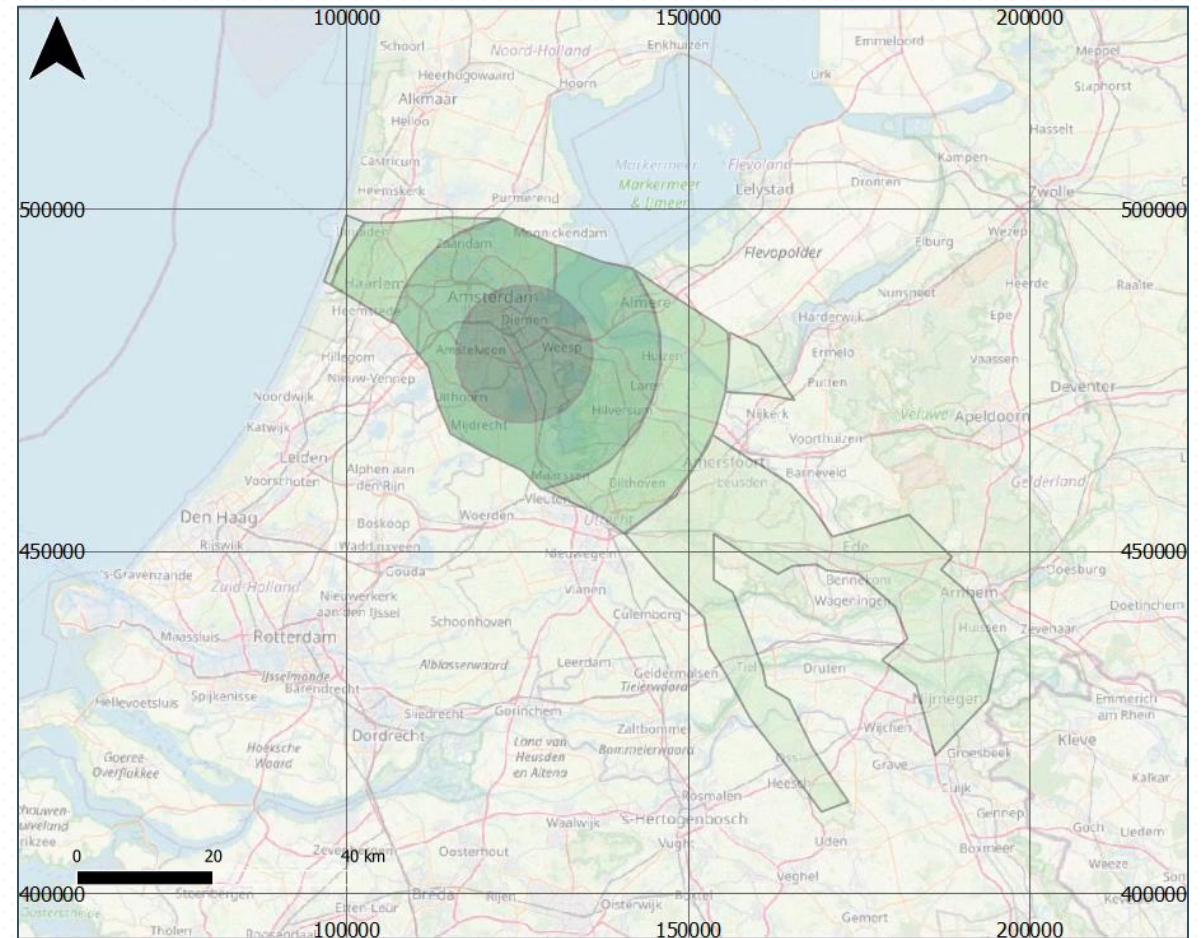
AMS-01 Highlights

Successfully drilled, logged and decommissioned first SCAN well

Safety Culture and Performance

- No LTI's or major safety events
- 200+ Safety Cards Submitted on site

Successful Data Acquisition

- 100% recovery/efficiency of all cored intervals
- All logging intervals successfully recorded
- Successfully produced and re-injected $1000m^3$ of formation water

Communication with Public and Stakeholders

- Royal visit to wellsite and NOS visit
- 20+ wellsite visits of stakeholders
- Good feedback and communication with landowner and neighbours

First data on NLOG

Follow www.SCANaardwarmte.nl for latest updates

Data Acquired

bold data currently available on NLOG

➜ **LWD and (OH/CH) wireline log data**
  - ➜ **(S)GR,RES,XSON,DEN,NEUT,IMAGE**
  - ➜ NMR (calibration with core in progress)
  - ➜ Temperature

➜ **VSP (geophone and fibre-optic)**

➜ Core (193m)
  - ➜ **Screening analysis**
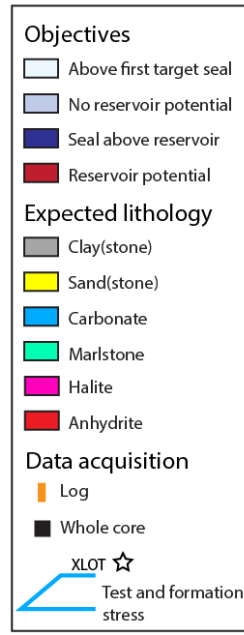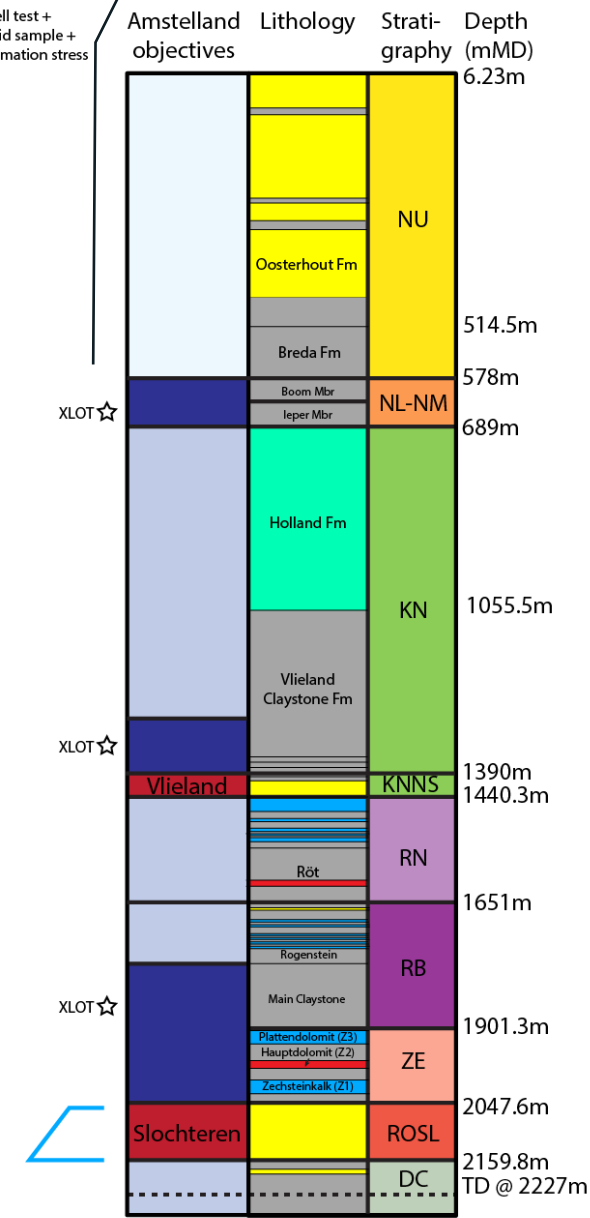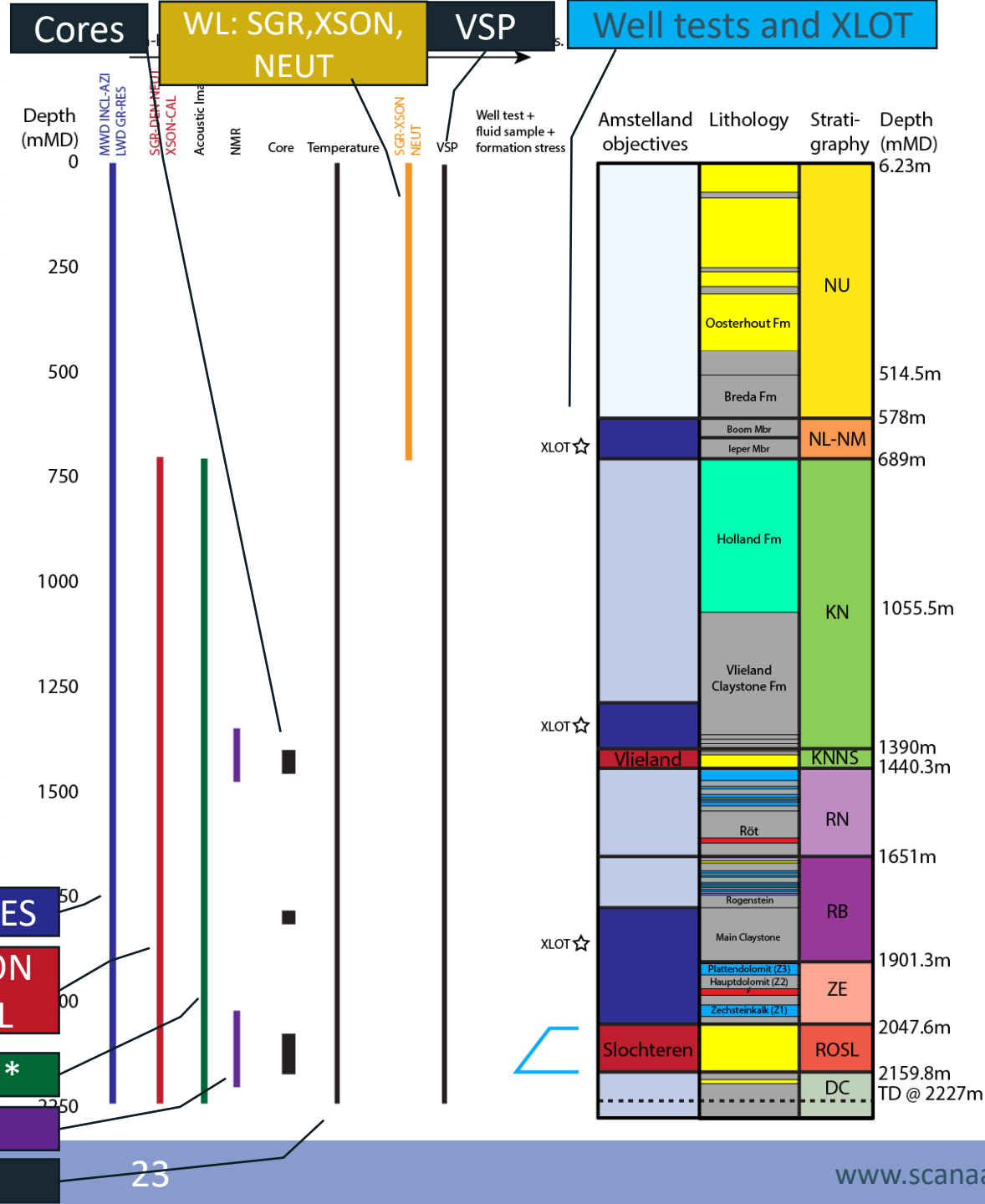 - ➜ Routine core analysis, SCAL, core description
  - ➜ Geomechanical tests

➜ Cuttings (*biostratigraphy*)

➜ *Production/Injection test*
  - ➜ *PLT*
  - ➜ *Fluid samples*

➜ *XLOT (3x)*

MWD,LWD: GR, RES

WL: SGR, DEN, SON NEUT, XSON, CAL

WL: Acoustic BHI*

WL: NMR*

Temperature

Cores

WL: SGR,XSON, NEUT

VSP

Well tests and XLOT

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- Above first target seal
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Expected lithology
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- Halite
- Anhydrite

Data acquisition
- Log
- Whole core
- XLOT ☆
- Test and formation stress
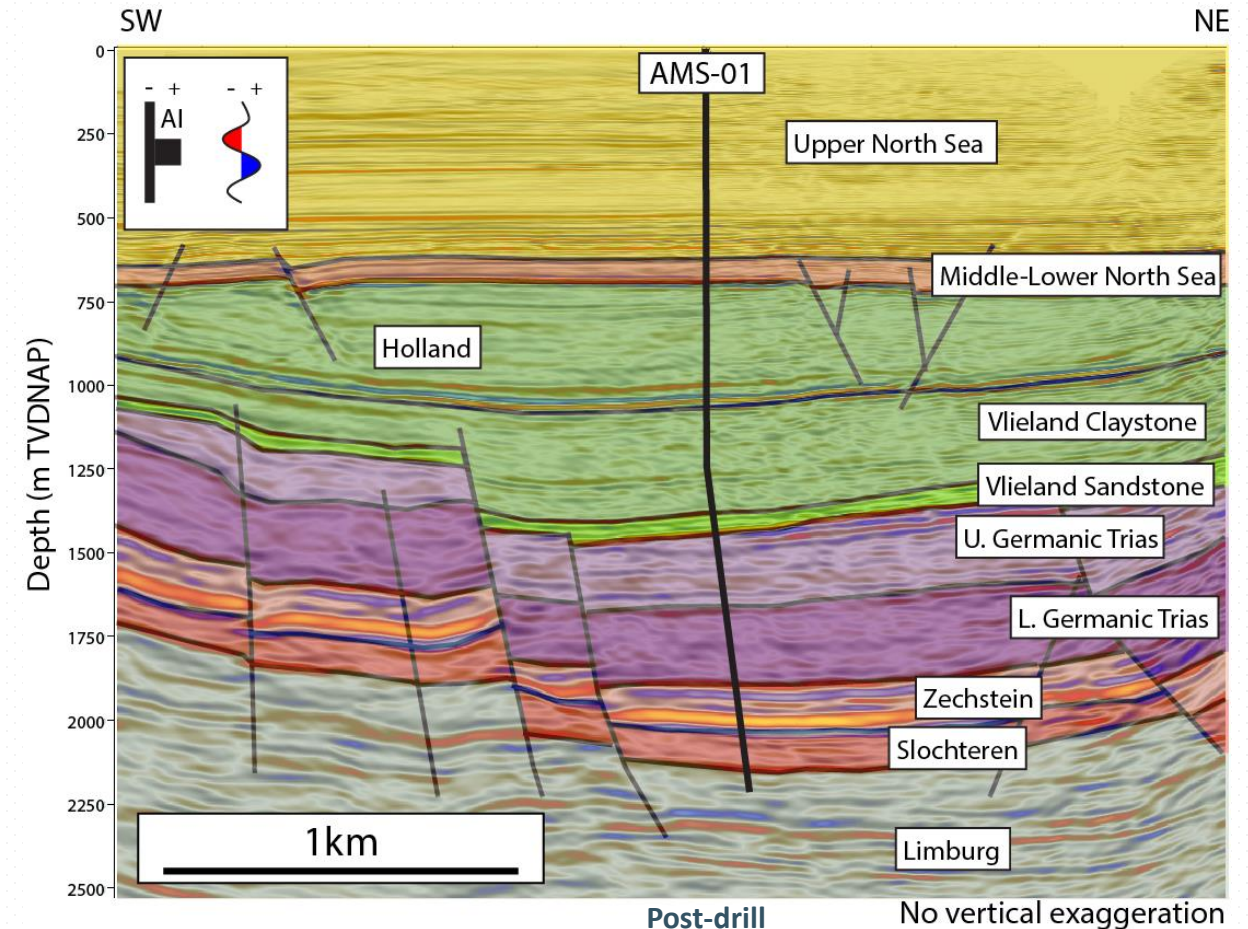
Key results

➜56 days operations, TD 2217.67m MD in Carboniferous Limburg Group

➜Extensive data acquisition performed throughout well, including over reservoirs, caprocks and overburden

➜Primary target Slochteren Fm:

  ➜112 mAH thickness

  ➜Average porosity 18%, up to 26%

  ➜High permeabilities measured on cores

  ➜Produced and injected 1000m^3

  ➜Formation temperature approx. 82°C

➜Secondary target Vlieland Sandstone Fm:

  ➜50 mAH encountered, insufficient porosity and permeability; not flow tested

➜Secondary target Chalk Gp:

  ➜Not present; eroded at the well location

Pre-drill   **Post-drill**

As we are drilling in a "white spot", the pre-drill scenarios carried a large depth uncertainty due to a lack of offset wells, especially for the Rijnland Gp and Chalk Gp intervals. This uncertainty was incorporated in well and operations planning.

www.scanaardwarmte.nl

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Slochteren Temperature

➜ Large amount of different temperature data acquired

➜ 82°C Slochteren reservoir temperature

➜ 5°C higher than pre-drill best estimate at this depth

➜ Thermal conductivity measured on core

35 hours after end flow period production test
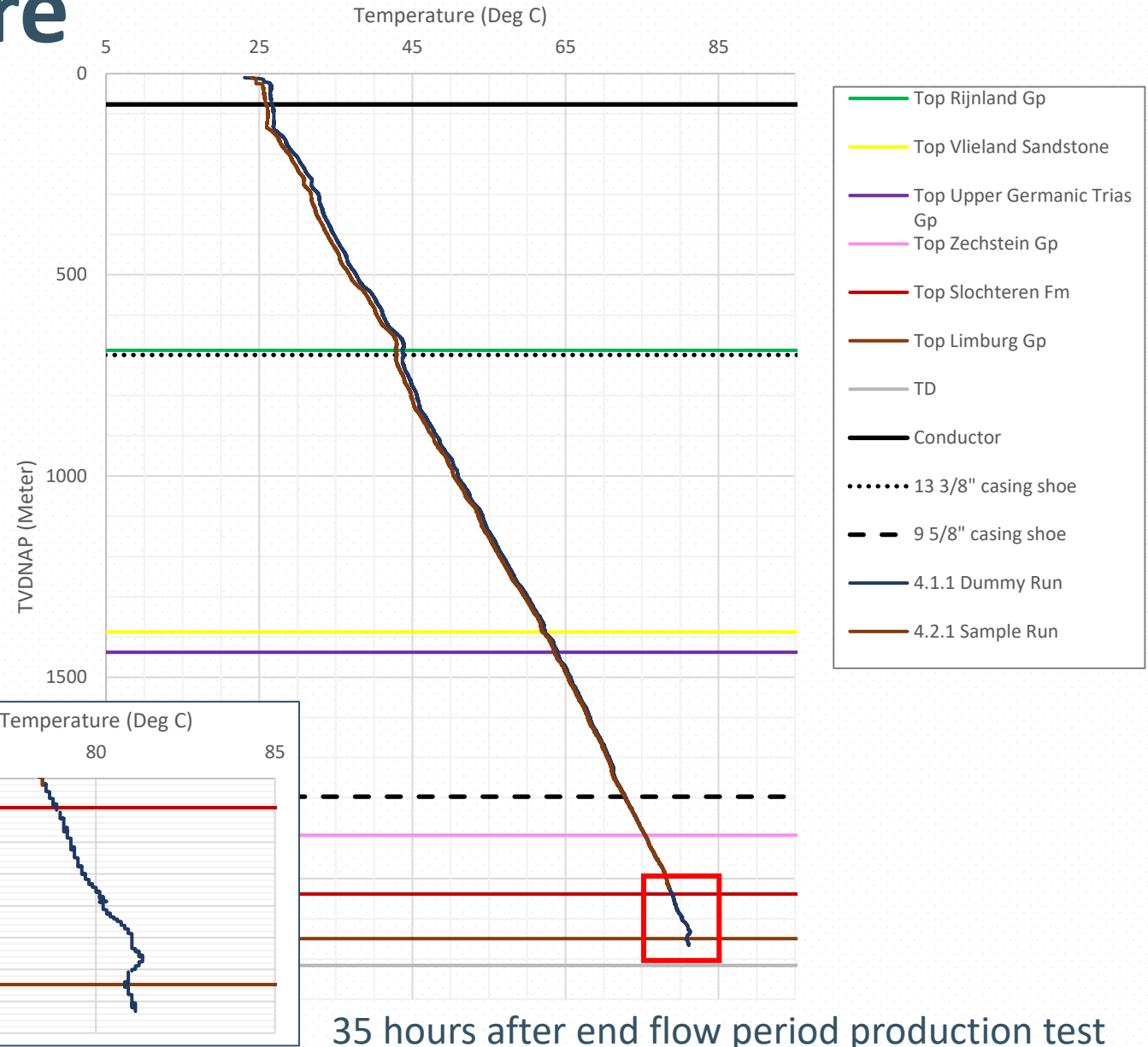
Slochteren Reservoir Quality

➜Clean (eolian?) sandstone

➜Average porosity 18%, up to 26%

➜High (probe and helium) permeabilities in core

➜Well test:
- ➜Produced/re-injected 1000m³ of formation fluid
- ➜90% of flow taken by two flow zones of 10m thickness each
- ➜Productivity/ injectivity lower than could be expected base on logs; investigation ongoing (geology/formation damage)
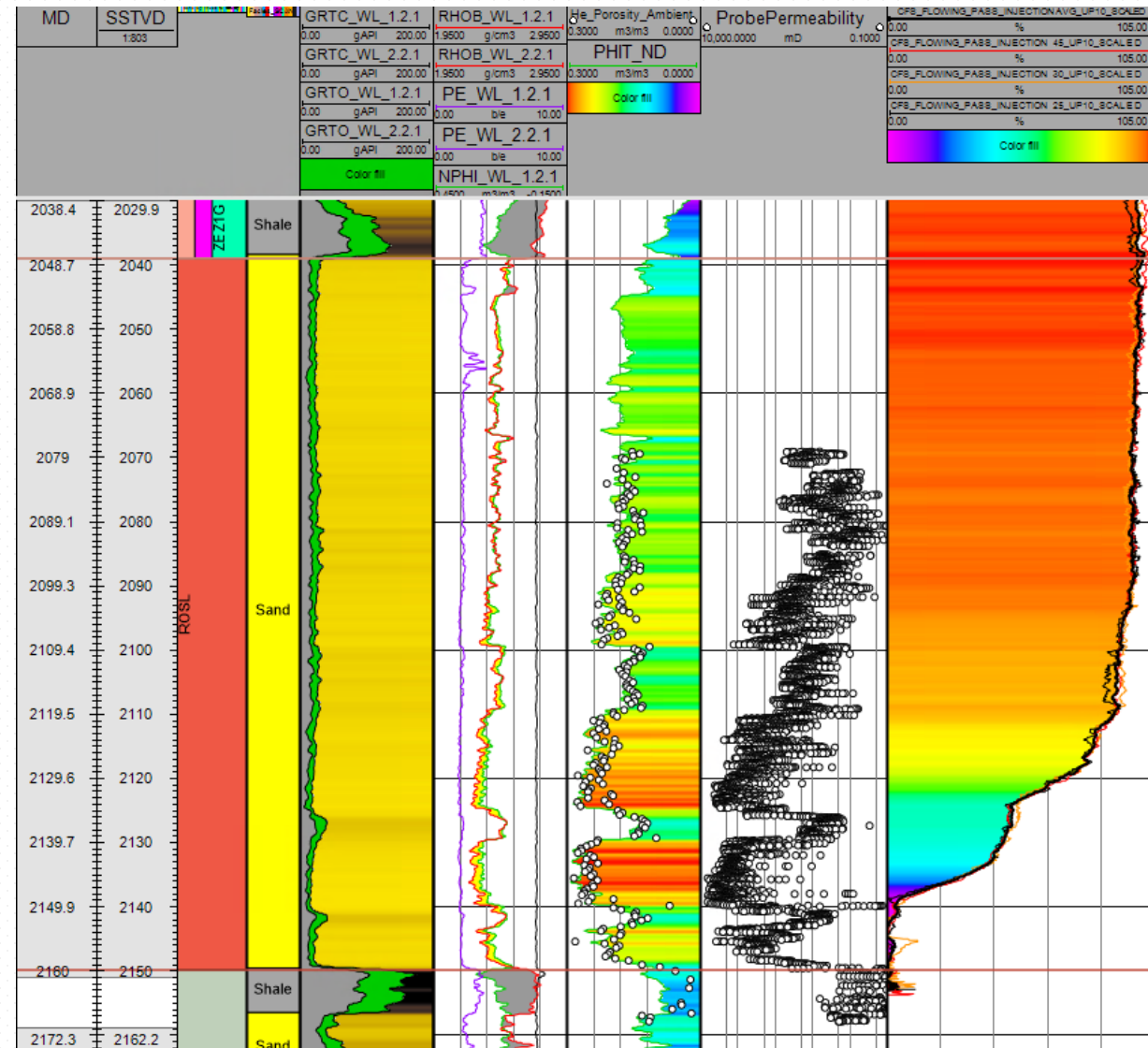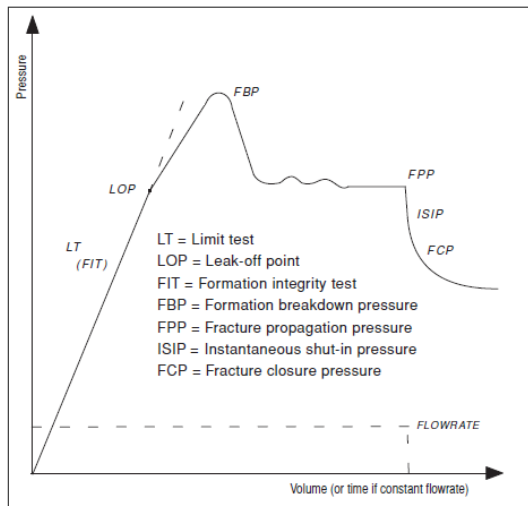
Fractures/deformation bands

➜ High number of fractures observed in acoustic image logs

➜ EW to NE-SW striking conjugate set

➜ Highest density in highest permeability units (up to 3 fractures/meter)

➜ Majority of these appear to be high or mixed amplitude

➜ Quartz cemented based on XRF

Static-Dynamic acoustic image:
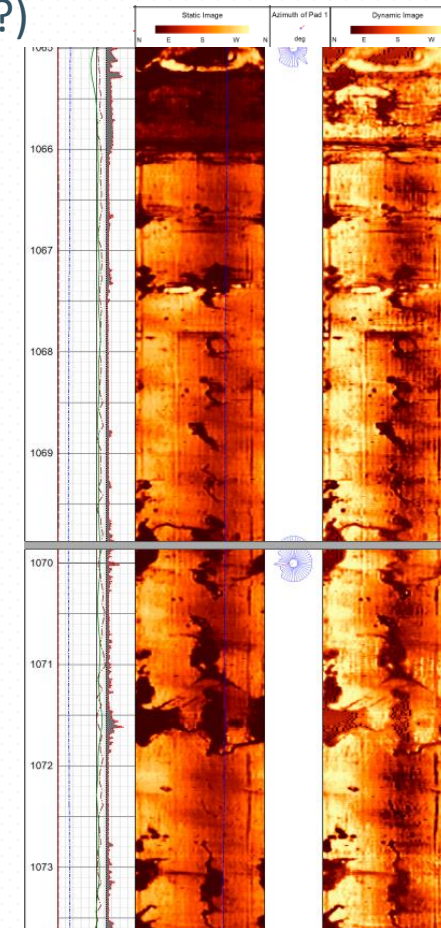Light means high velocity = low porosity
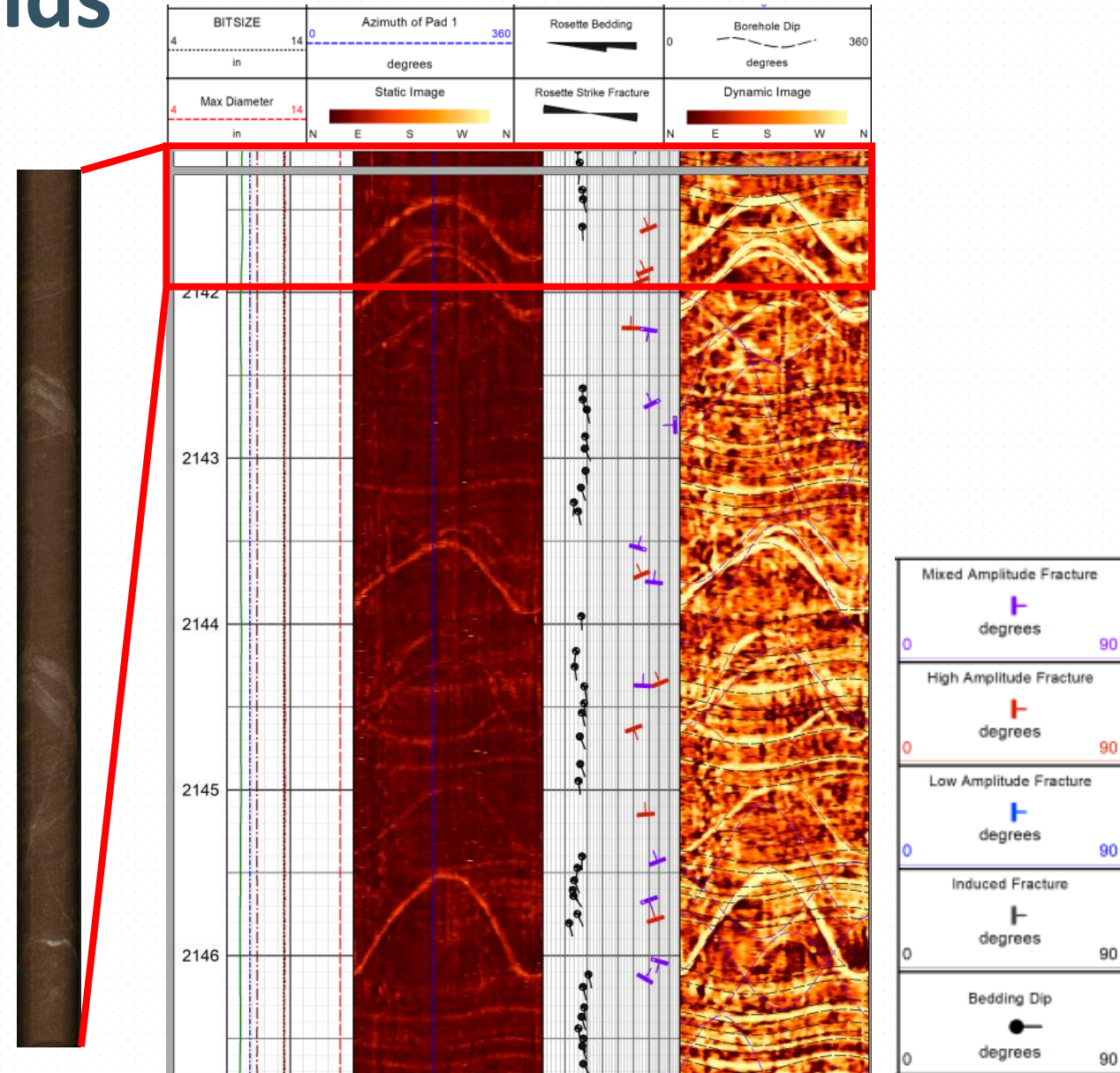
Geomechanical Properties

➜ Borehole breakouts and tensile fractures in acoustic image logs

➜ Appears to be a rotation of horizontal stress somewhere between with Vlieland Claystone and Zechstein (possibly at top of the Main Claystone?)

➜ Shmax NW-SE in shallow section, consistent with regional stress field

➜ Shmax N-S in deep section

➜ Performed three XLOT's to determine <u>magnitude</u> Shmin

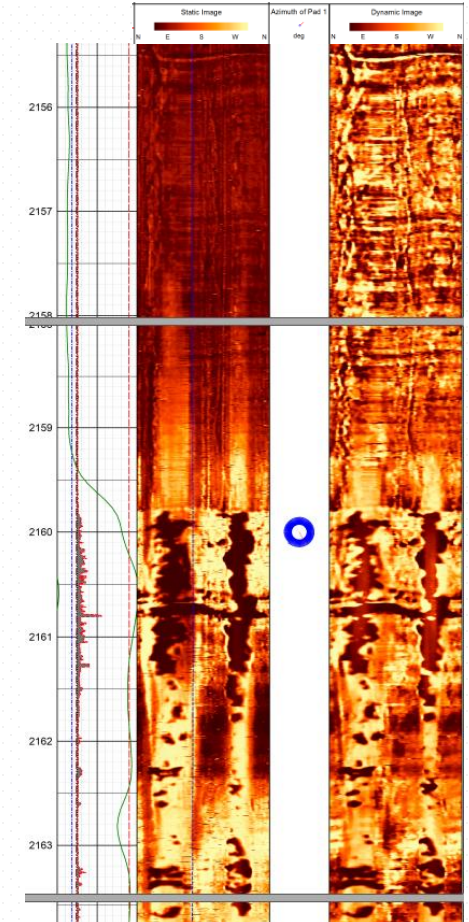➜ Density and sonic data to estimate Sv, Poissons Ratio, etc to make geomechanical models

Breakouts in Holland Fm

Tensile fractures in ROSL and breakouts in DC

Schematic of an extended leak-off test (Zoback, 2007).
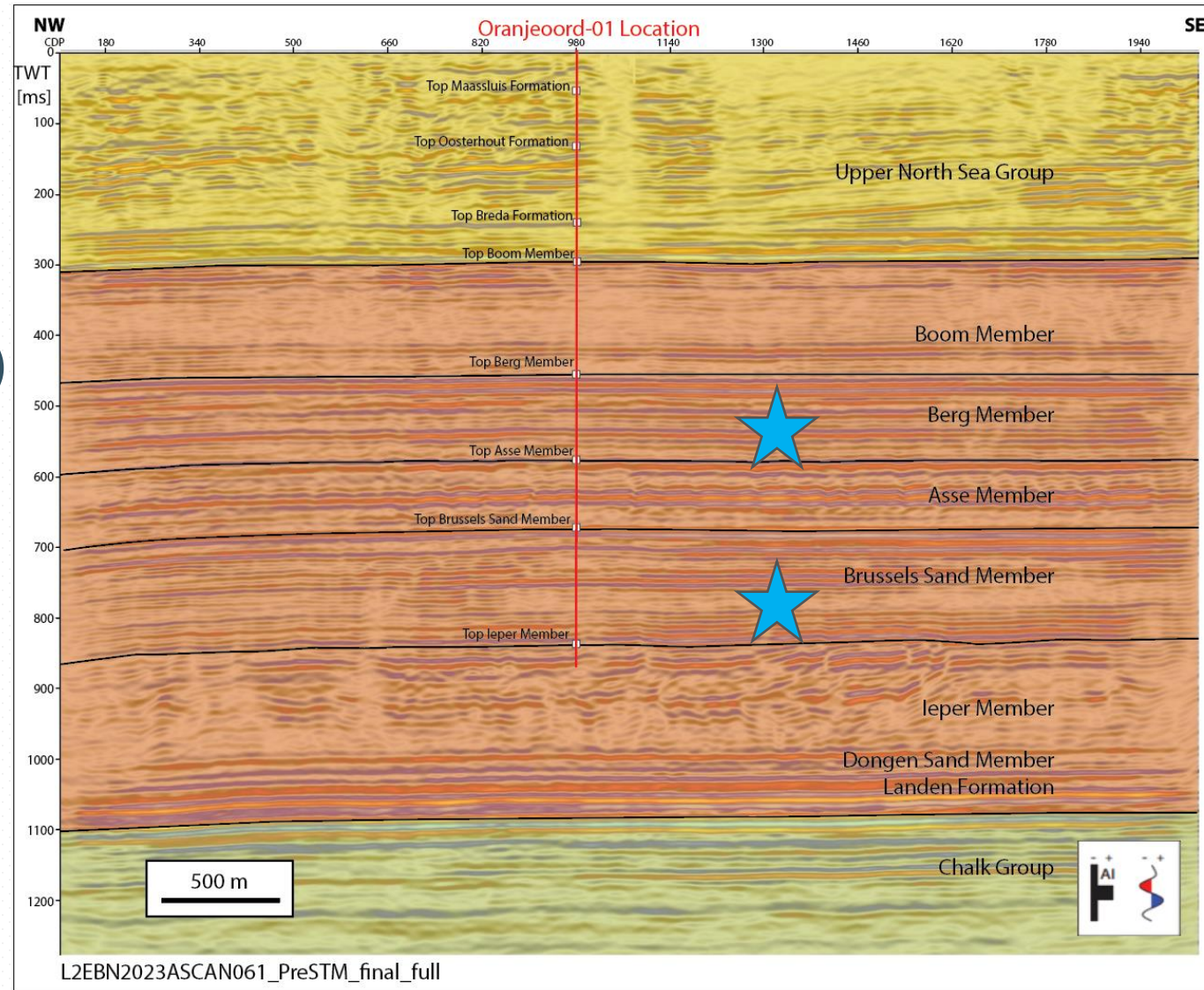
SCAN Well Oranjeoord-01 (ORO-01)

➜Second SCAN data-acquisition well

➜Location: Heijningen, Moerdijk

➜Total depth: 836 mTVD NAP

➜Geothermal targets:

➜**Primary: Brussels Sand Member (NLDOBR)**

➜Secondary: Berg Member (NMRUBE)

➜Each target includes the caprock above
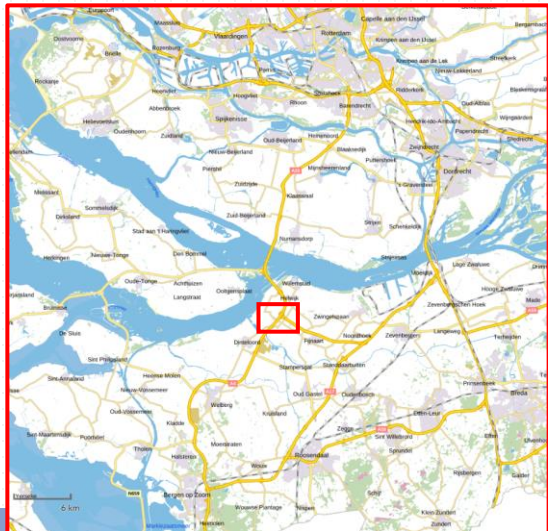
Oranjeoord-01

well location

L2EBN2023ASCAN061_PreSTM_final_full

ORO-01 data acquisition

→ Cores
  → Reservoirs: Porosity/permeability data
  → Reservoirs: Sedimentology and diagenesis (incl. descriptions and thin sections)
  → Geomechanical tests (note: also for sealing intervals)

→ Production / injection tests
  → Flow rate and transmissivity
  → Temperature, pressure and water composition

→ Well Logs, both reservoirs and overburden
  → Whole well: (Spectral) Gamma Ray, Sonic (Vp/Vs), density/neutron, resistivity
  → Reservoirs/seals: Image logs (for sedimentology and diagenesis, fractures) and XSON (Vp/Vs, stress field orientation)
  → Reservoirs: NMR log (for permeability)
  → Temperature

→ Checkshot (for seismic to well correlation)

→ XLOT (Extended Leak-off Test)
  → Determination of min. horiz. stress

→ Cuttings and biostratigraphy
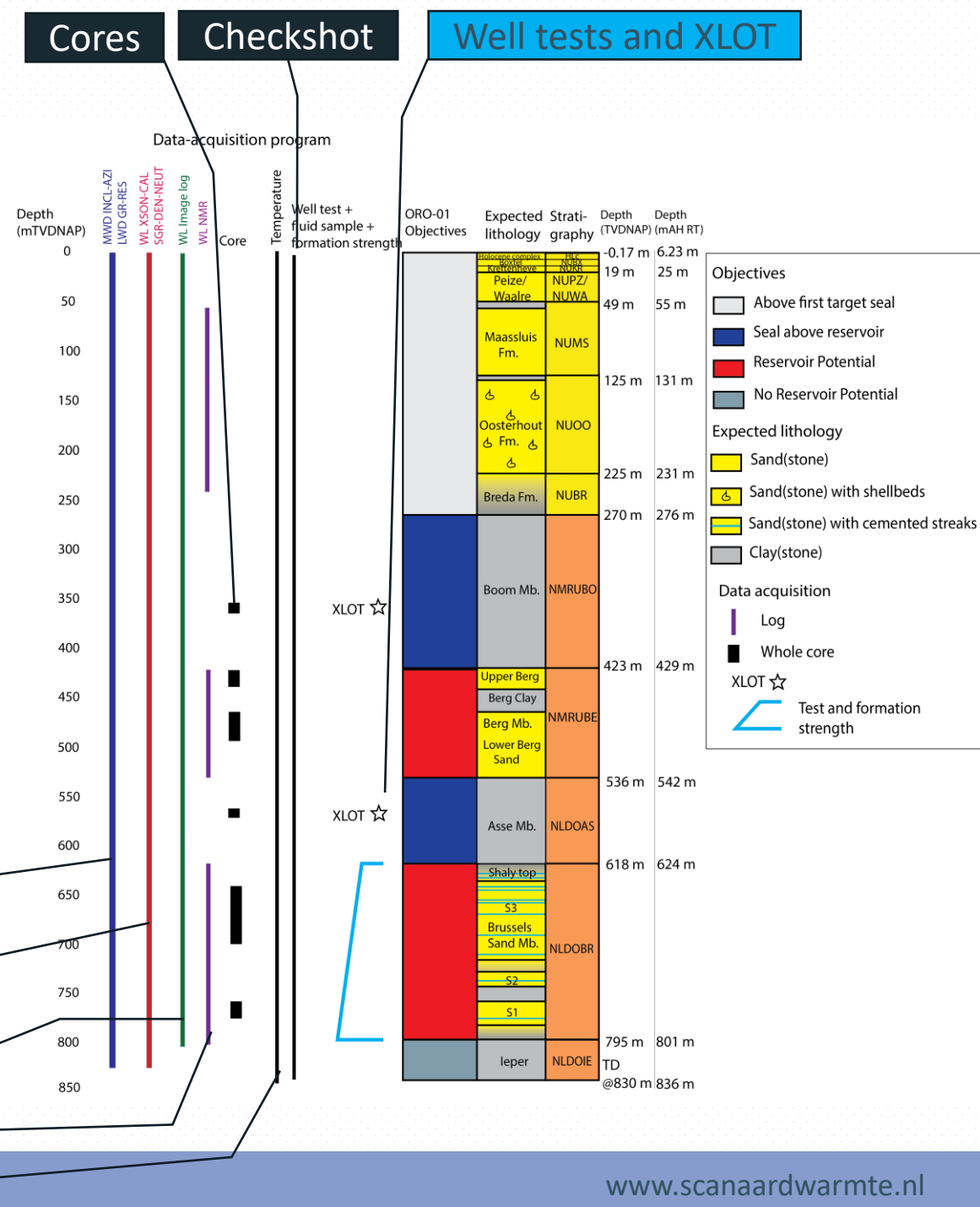
Take Home Messages

SCAN is a **geothermal exploration project** that will accelerate the development of **geothermal energy projects** in areas where little data is available, by:

➔ Acquiring over 1900 km of **new** 2D regional **seismic** lines (complete)

➔ **Reprocessing** over 7500 km of vintage seismic data (complete)

➔ Drilling of **data acquisition wells** and publication of results ongoing

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