NEW REGIONAL DEEP SUBSURFACE MODELLING IN THE NETHERLANDS

3rd Dutch Exploration Day

21-11-2018

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Johan ten Veen

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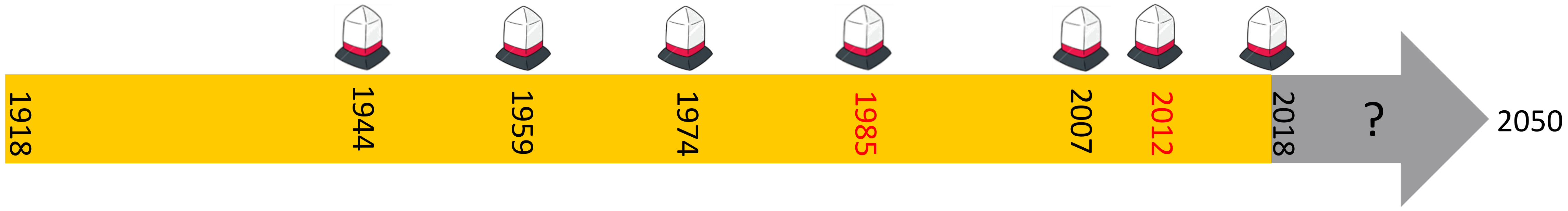
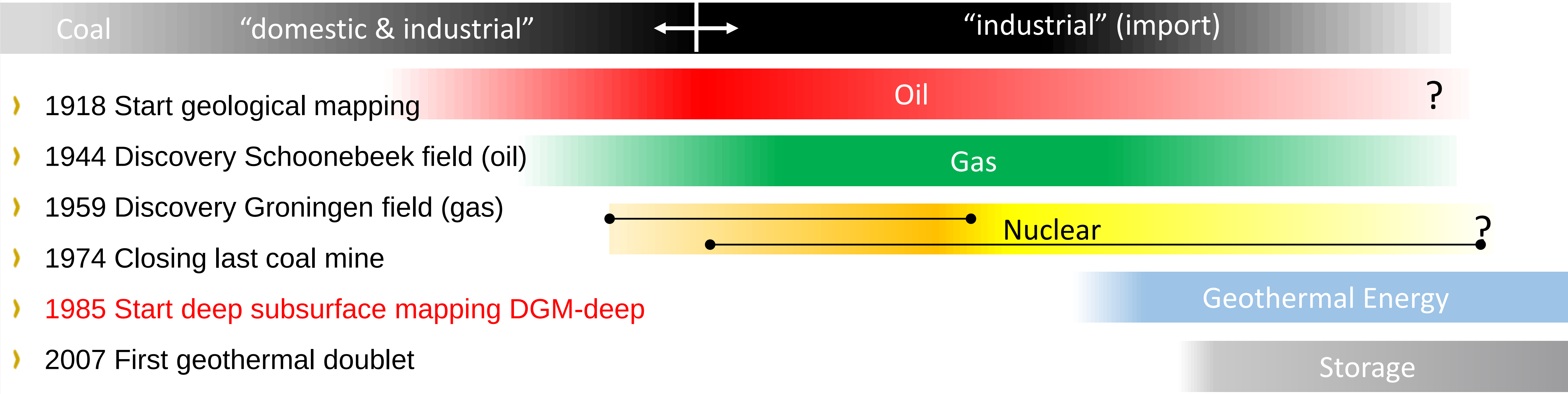
ENERGY TRANSITIONS

100 YEARS OF GEOLOGICAL MAPPING

Subsurface resources for Dutch energy supply

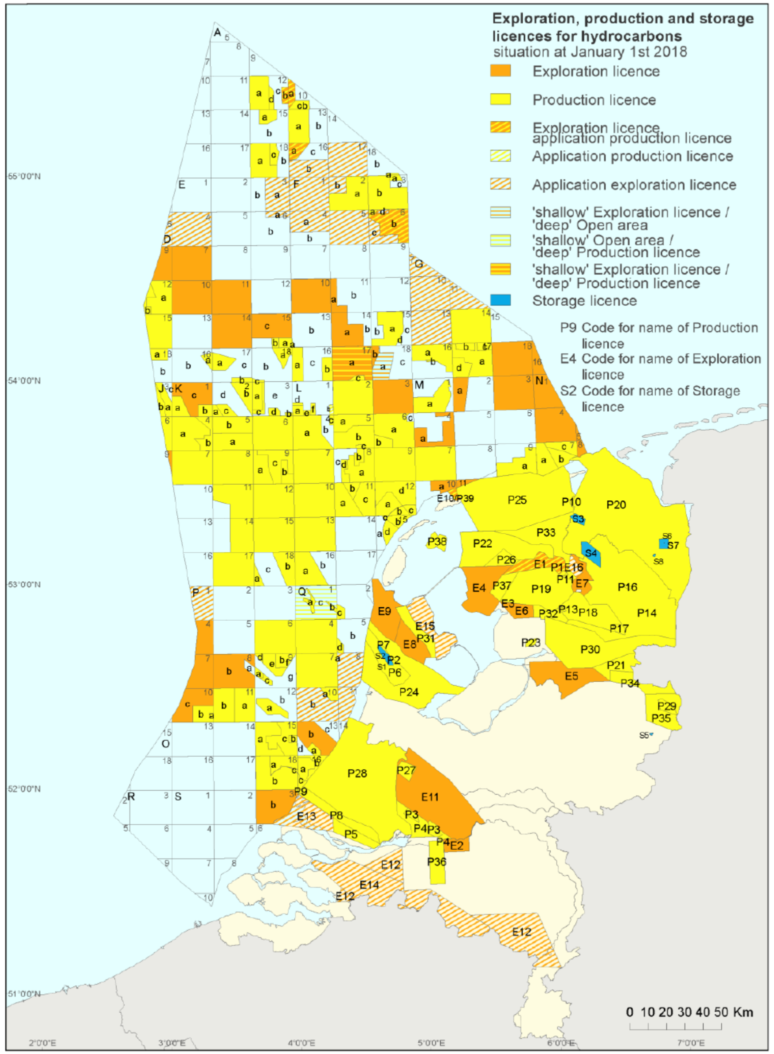


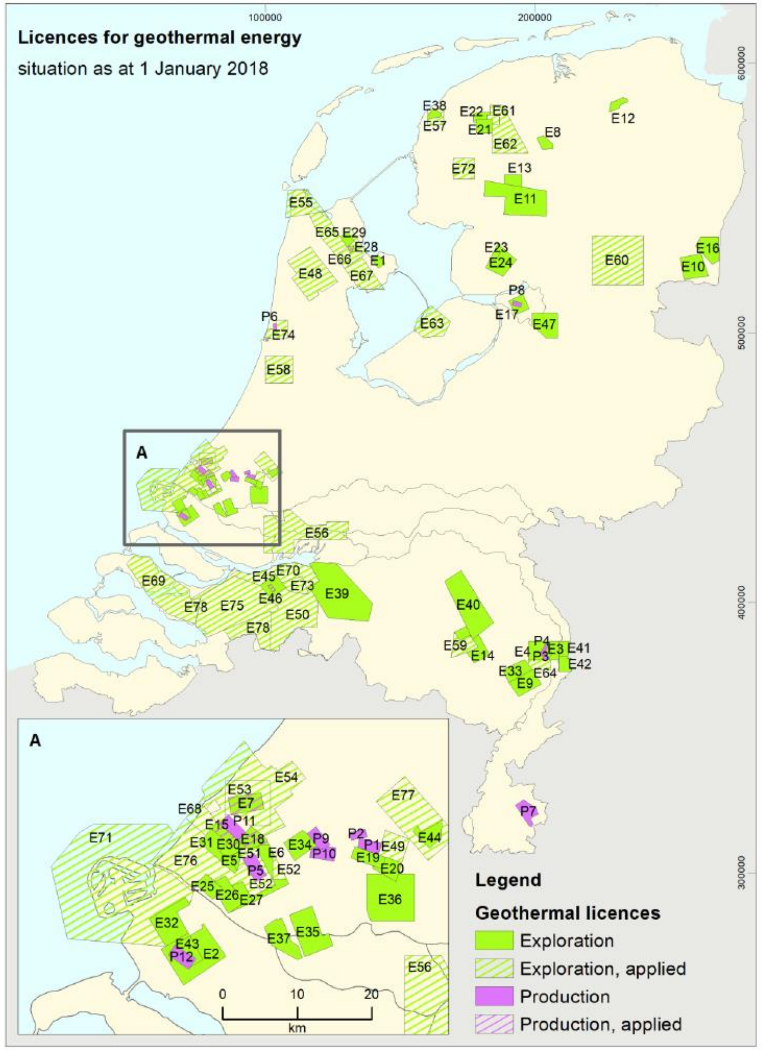


- 1918 Start geological mapping
- 1944 Discovery Schoonebeek field (oil)
- 1959 Discovery Groningen field (gas)
- 1974 Closing last coal mine
- 1985 Start deep subsurface mapping DGM-deep
- 2007 First geothermal doublet
- 2012 First regional on- and offshore model DGM-deep

OIL & GAS ⇔ GEOTHERMAL

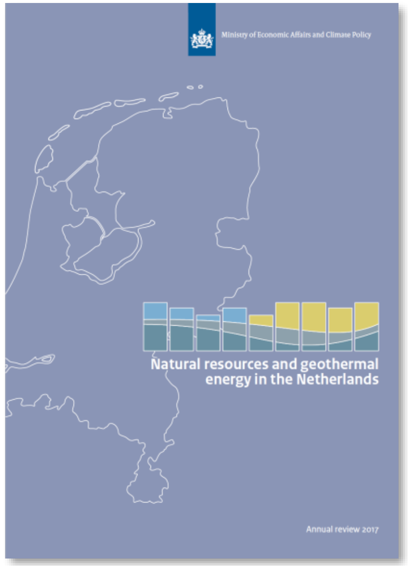
100 YEARS OF GEOLOGICAL MAPPING





- Exploration synergy
- Exploration frontiers

Source:

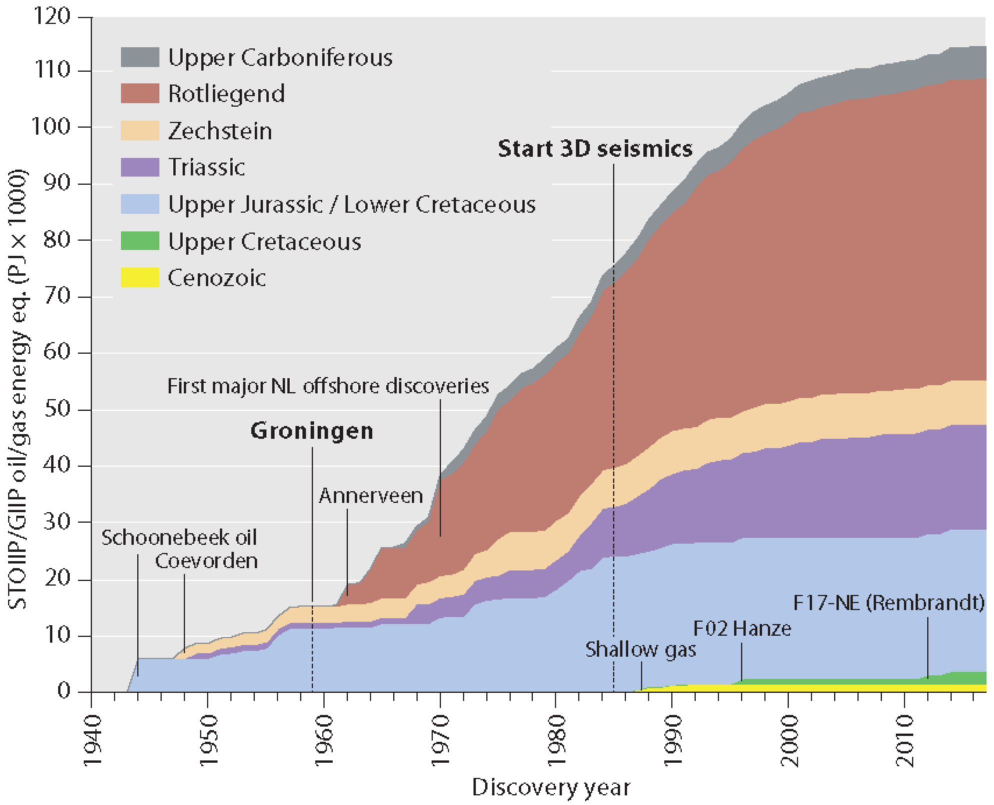


TNO innovation for life

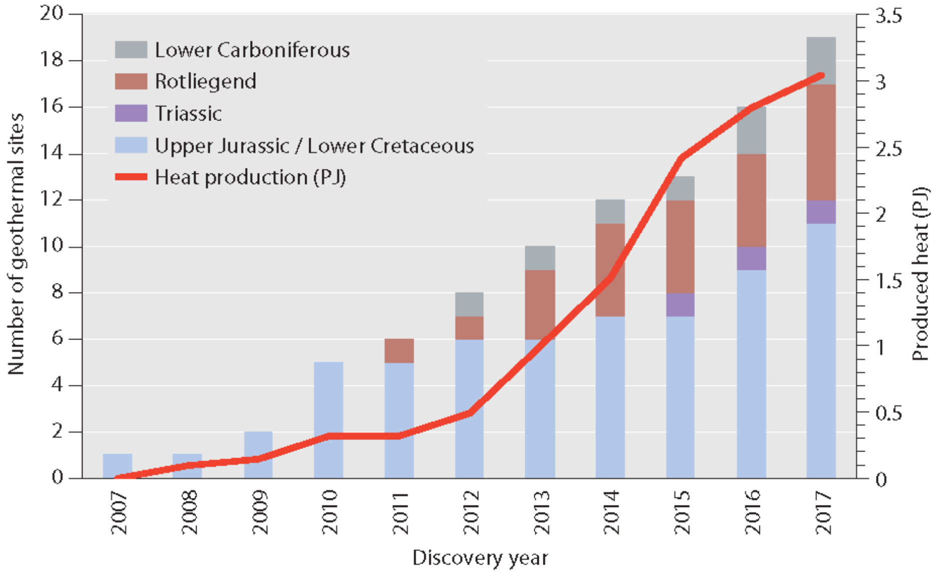
SHIFT OF FOCUS in SNSB area

100 YEARS OF GEOLOGICAL MAPPING

From: Doornenbal et al. (2019) New insights on subsurface energy resources in the Southern North Sea Basin area. GSL Special Issue: Cross-Border Petroleum Geology and Exploration: The North Sea



***Cumulative volumes** of oil (STOIIP) and natural gas (GIIP), excluding Groningen field, in energy equivalent per lithostratigraphic unit versus discovery year in the Netherlands.*

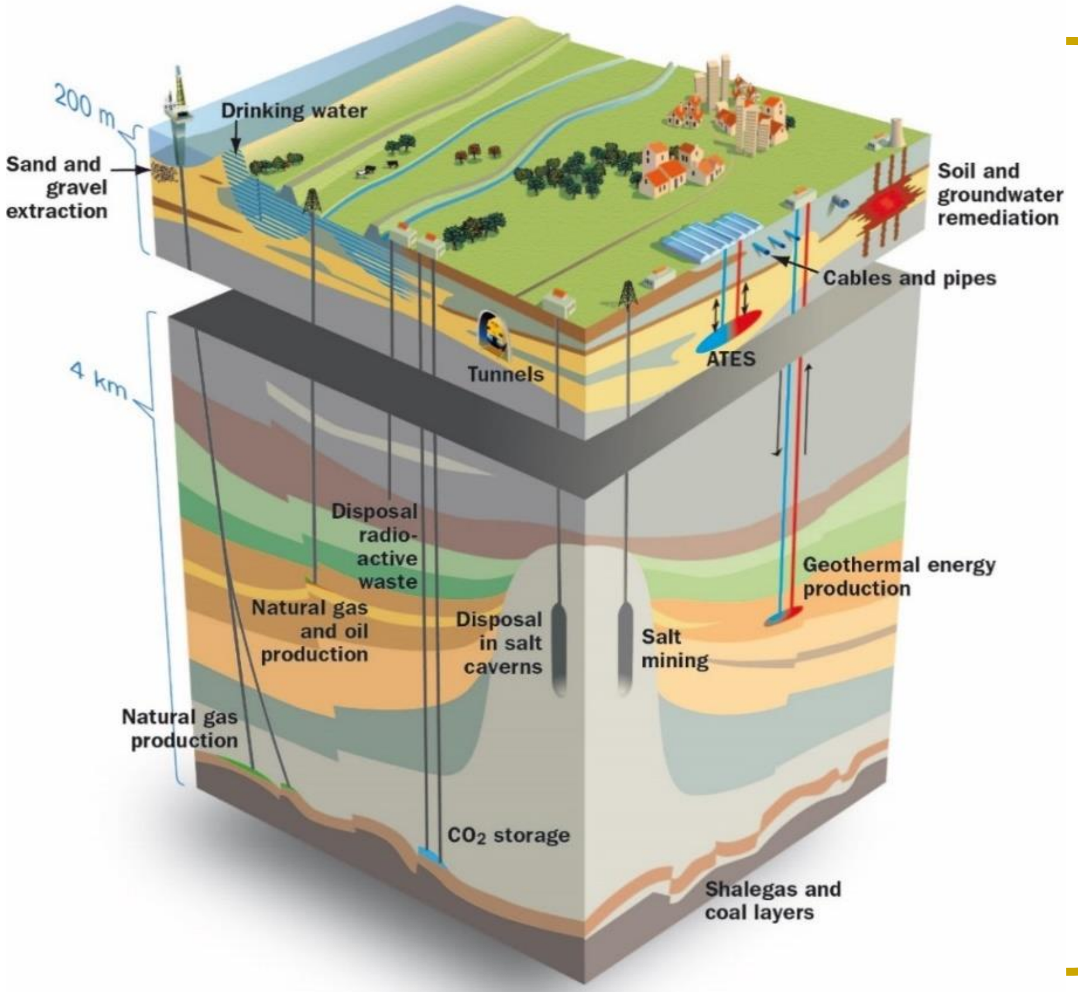


*Cumulative number of **geothermal sites** per lithostratigraphic unit in period 2007-2017 in the Netherlands (stacked bar). Annual geothermal heat produced from all operating geothermal sites (red line).*

- Still new plays: basal Upper Rotliegend (Ruby), Chalk (oil) and Dinantian (geothermal)
- hydrocarbon exploration in SNSB area will likely still experience a **slight growth in coming decade** before slowing down as the energy transition further matures.
- geothermal exploration is expected to continue growing in NL onshore

WHY WE NEED SUBSURFACE MODELS

100 YEARS OF GEOLOGICAL MAPPING

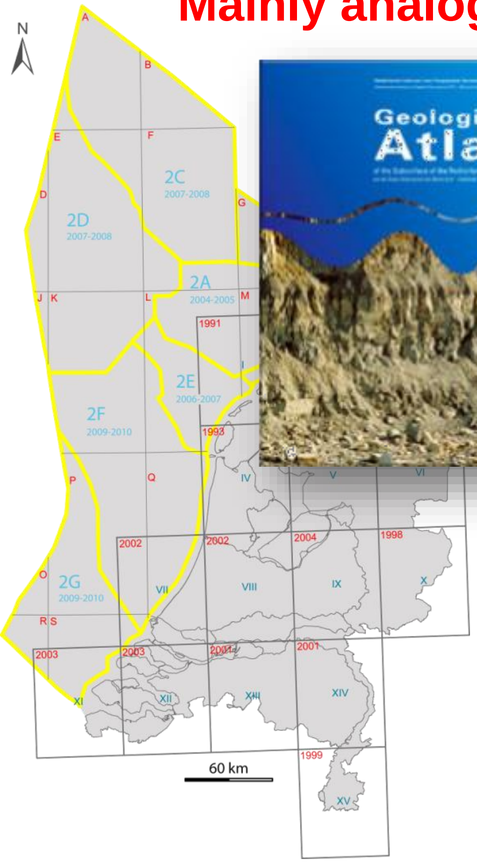


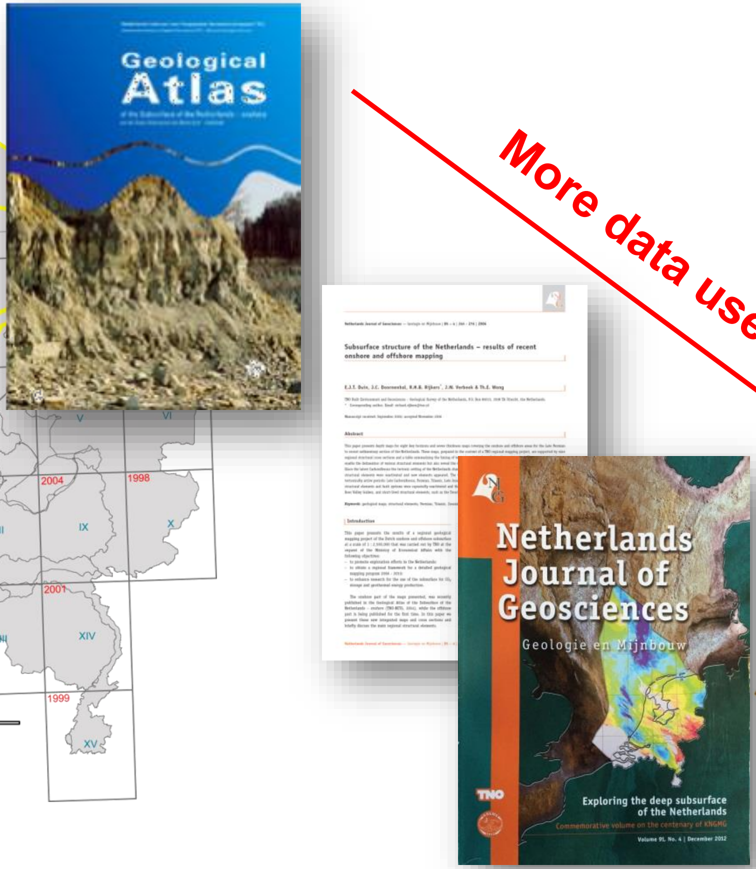
- Drinking water
- Building & infrastructure
- **Energy subsurface resources**
- Subsurface planning
- Policy making

Regional deep subsurface model

- **DGM-deep** - continuous activity at TNO-GSN
  - Started in 1985
  - 5 main releases: 2004, 2006, 2012, 2015, **Q1-2019**

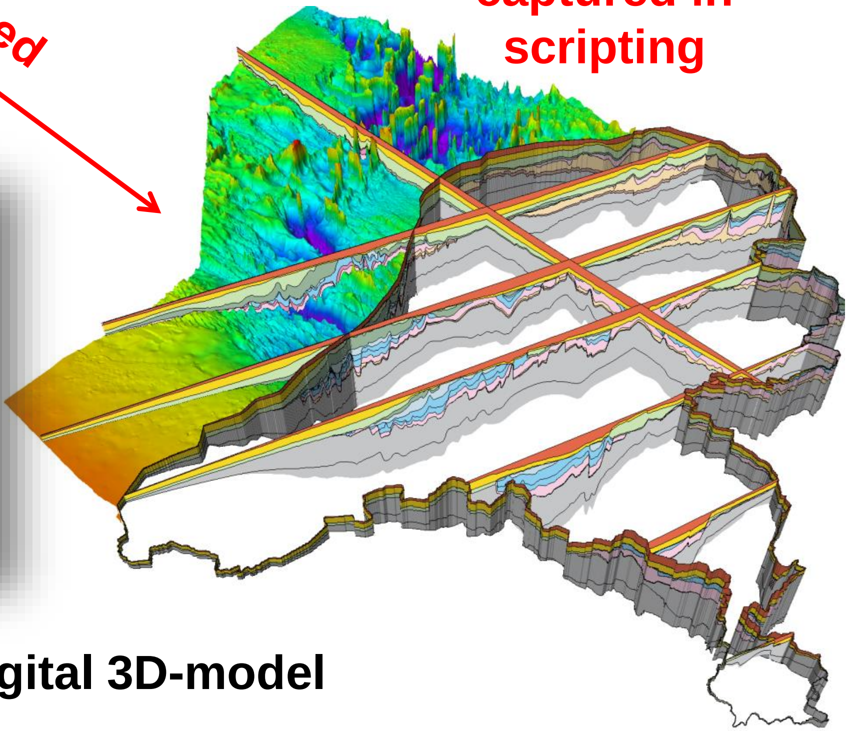
Mainly analogous





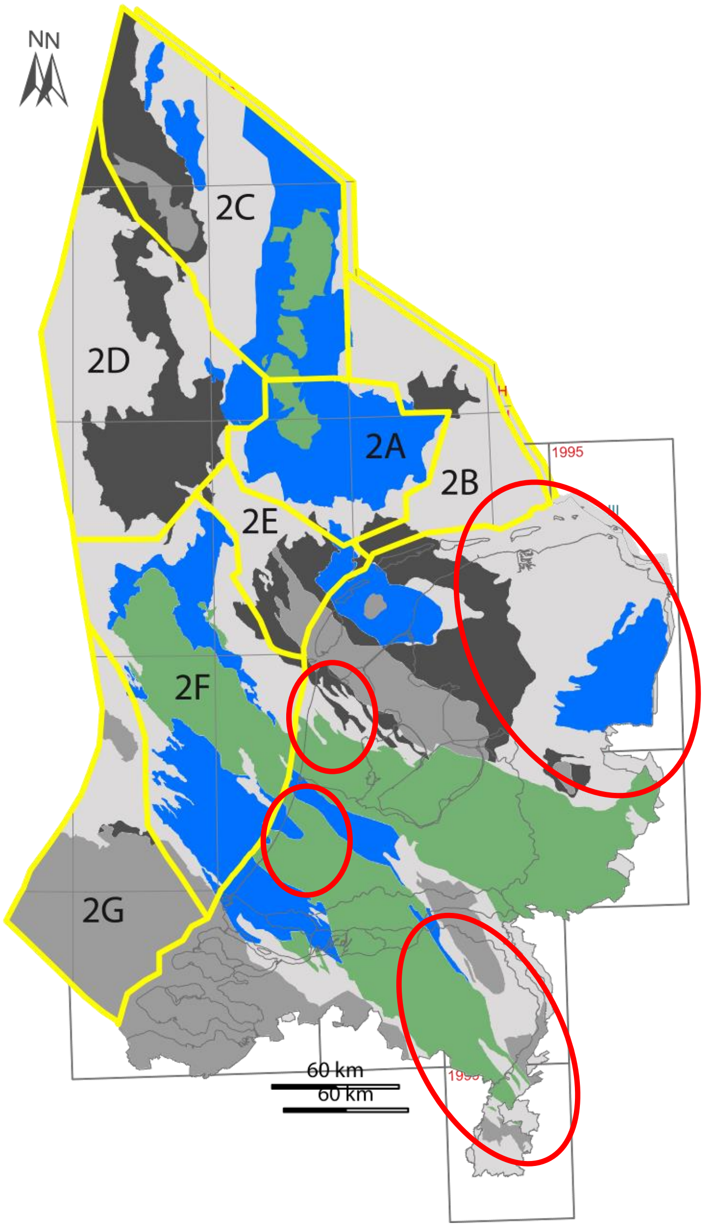
More data used

Digital & workflow captured in scripting



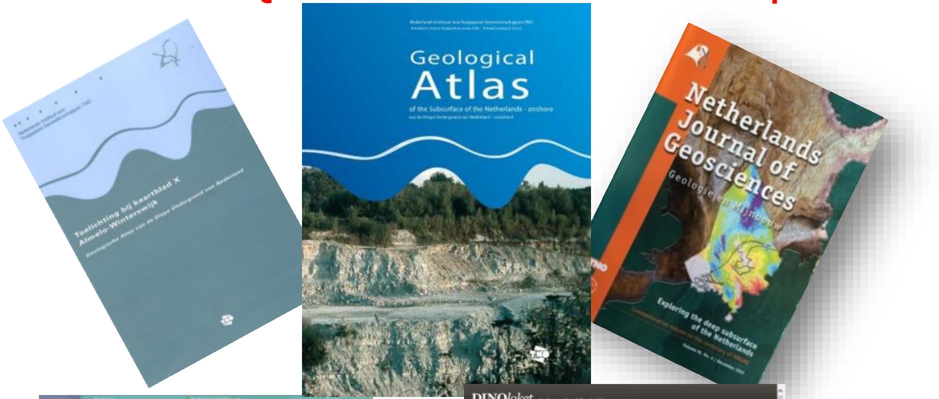
From paper product to digital 3D-model

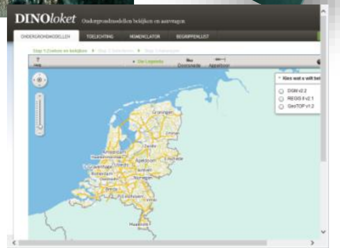
Publications



Geological mapping deep subsurface DGM-deep

- 1985-2004: V1.0 - Onshore – 15 mapsheets
  - 2004 blue Atlas - DGM-deep V1.0
- 2004-2006: V2.0 - Offshore quickscan
  - 2006 Duin et al.,NJG - DGM-deep V2.0
- 2005-2010: V3.0 - Offshore 7 subareas
  - 2012 Kombrink et al.,NJG - DGM-deep V3.0
- 2011-2015: update onshore in 4 regions
  - 2015-Q1 - DGM-deep V4.0
- 2016-2018: on- + offshore
  - **2019-Q1 - DGM-deep V5.0**



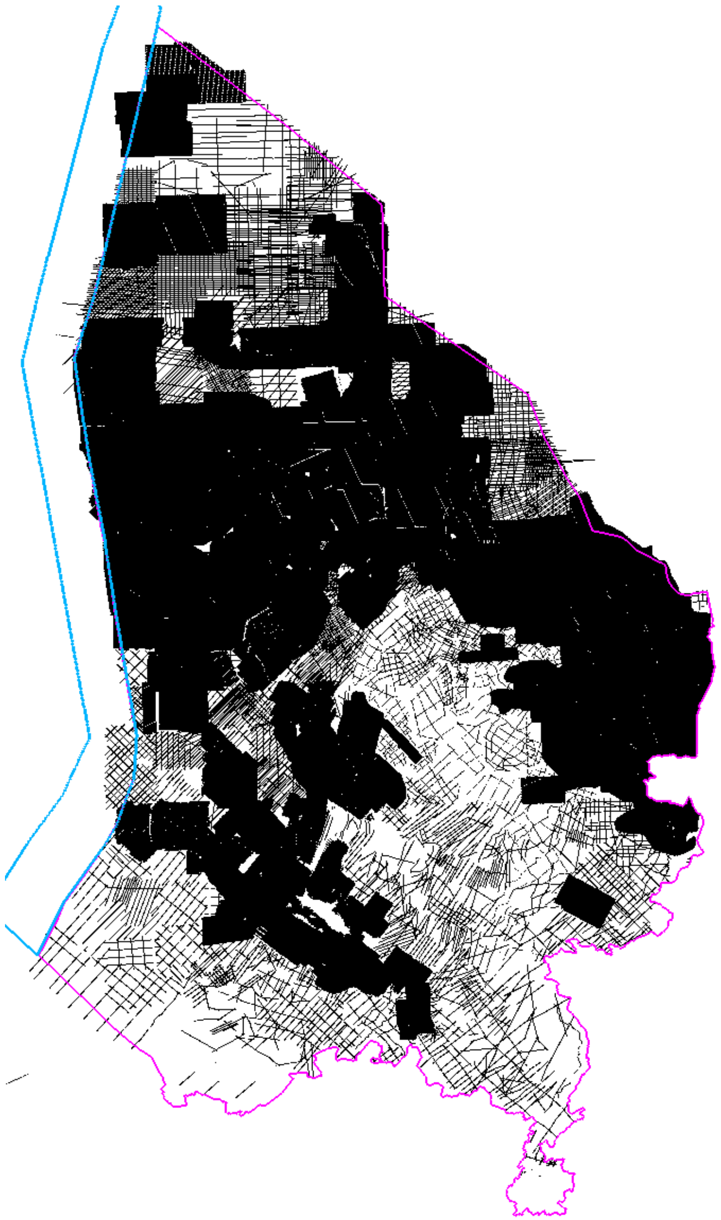
www.nlog.nl www.dinoloket.nl

DGM-deep – Published models

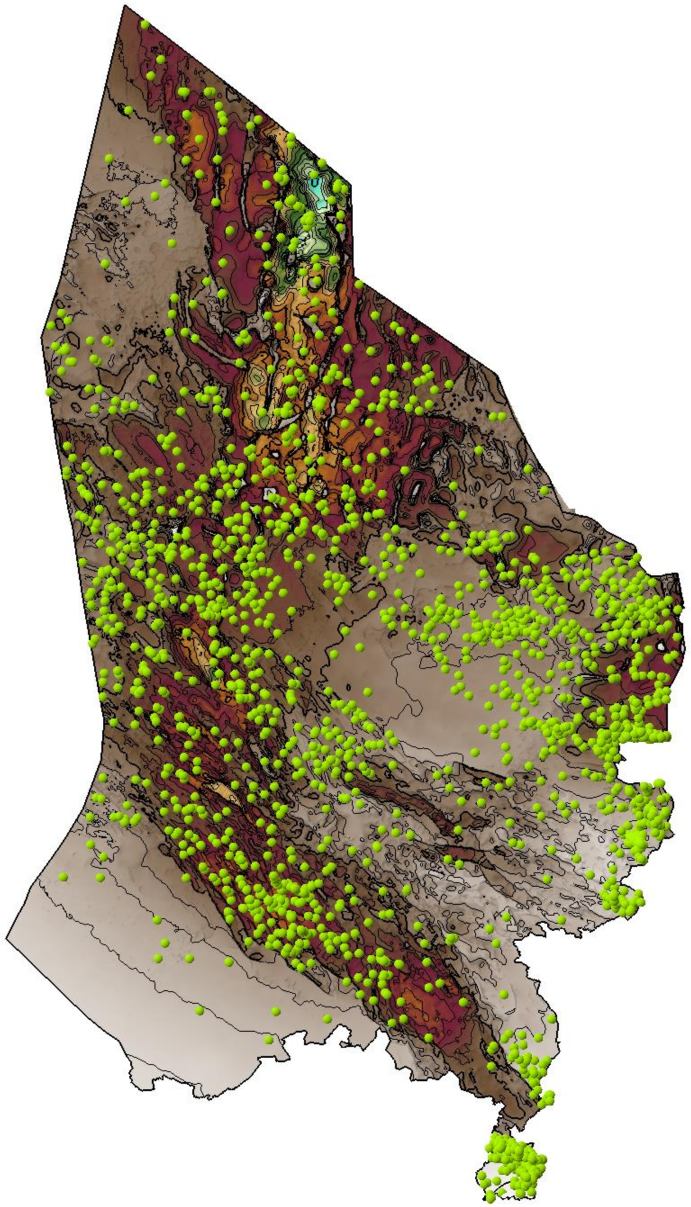
Versie	Vrijgave digitale data	Gepubli-ceerd in	Gebied	Project	Projectie	Snelheidsmodel	Breuken	3D breuk-vlakken	Dino *loket*
v1.0	2002	2004	Onshore	GEO-atlas	RD-Bessel 1841	Verschillende	Ja	Nee	
v2.0	2006	2006	On-Offshore	NCP-1	ED50-UTM31	VELMOD-1	Ja	Ja	
v3.0	2010	2012	Offshore	NCP-2	ED50-UTM31	VELMOD-2	Ja (Sub-gebieden A-G)	Ja	
v4.0	2014		Onshore		RD-Bessel 1841	VELMOD-3	Nee	Nee	Ja

- New release DGM-deep V5 **>>> Q1 2019 on nlog.nl**
  - on- & offshore in one model (ED50-UTM31)
  - VELMOD 3.1
  - Cross-border harmonization with UK (OGA-TNO)
  - Previous map sheet interpretations used for onshore grids in central part NL

DGM-deep V5 – Data used

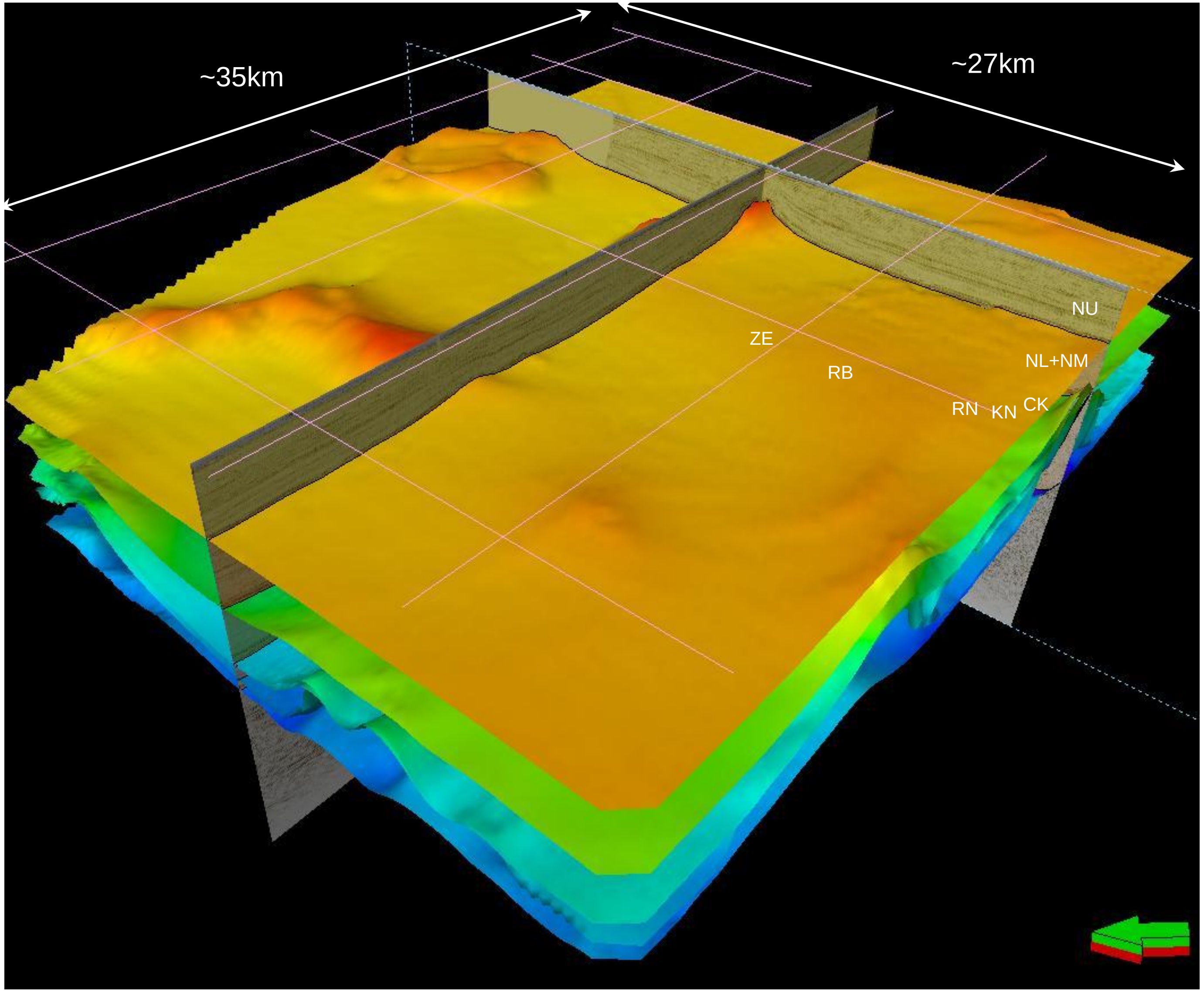


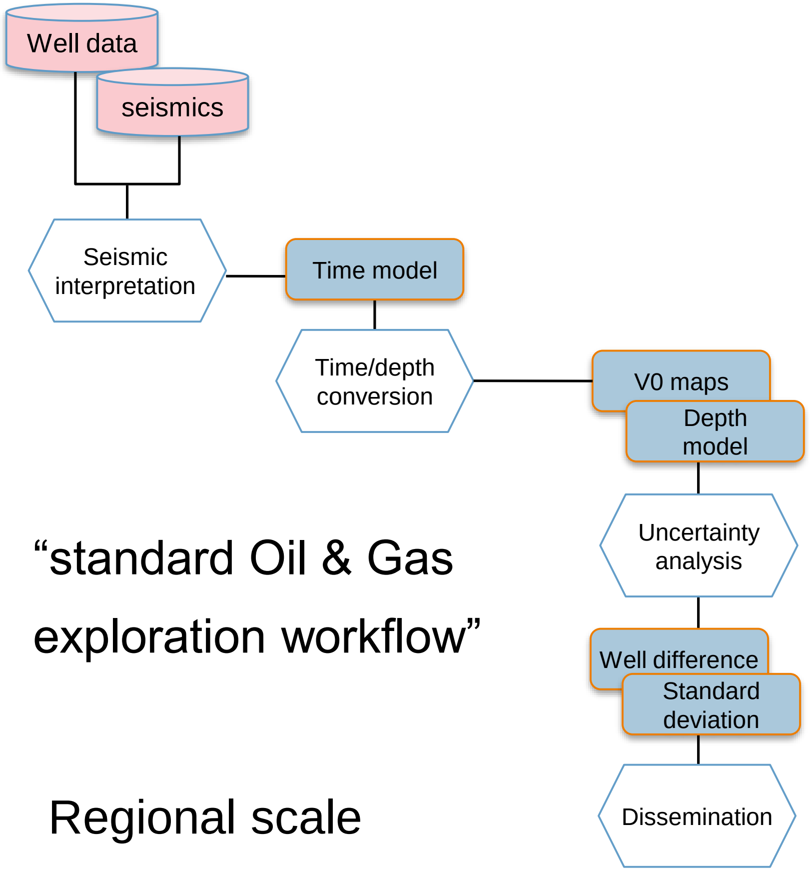
- On&offshore
  - 2D & 3-D public seismic data: ~60% coverage 3D
    - 179 offshore and 98 onshore surveys
  - 5841 wells - cores & well logs (GR, sonic, neutron)
    - ca 600-3700 used for well corrections



100 JAAR GEOLOGIE IN KAART

“MODERN” MAPPING

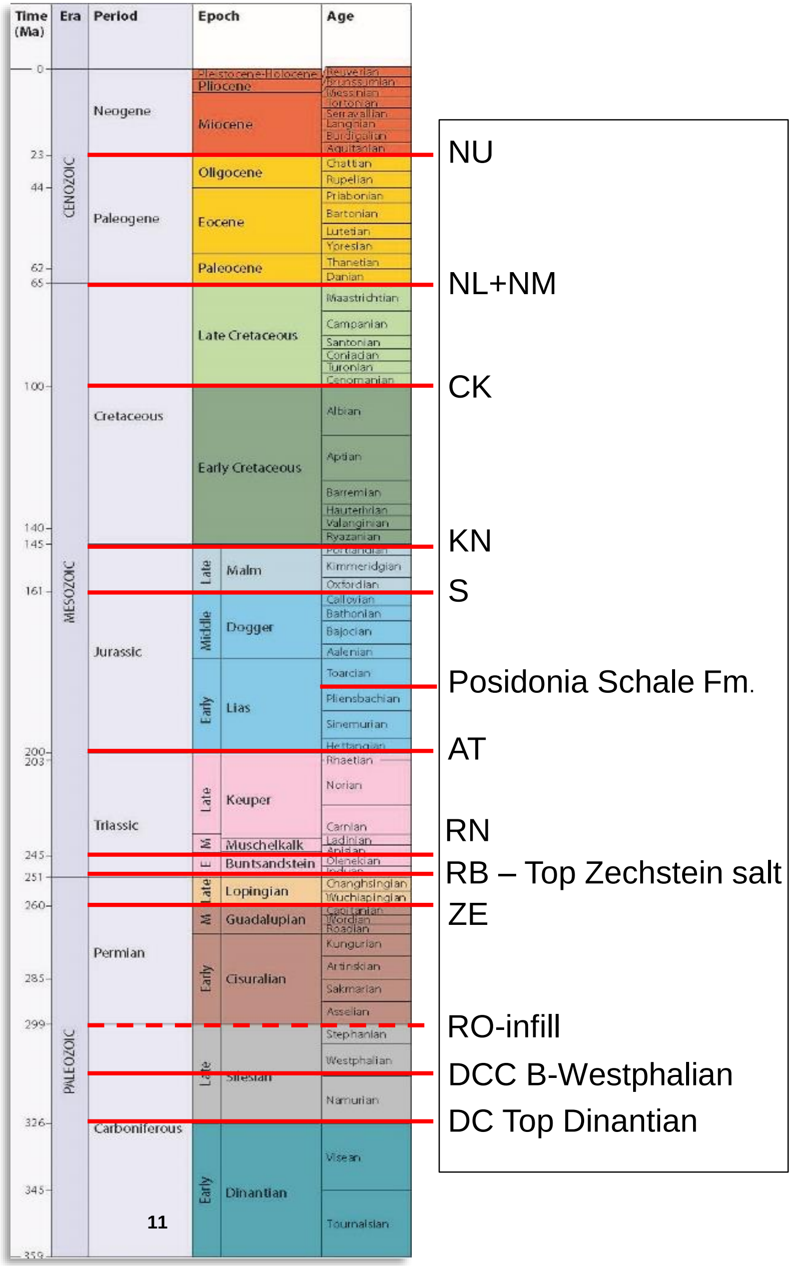




“standard Oil & Gas exploration workflow”

Regional scale

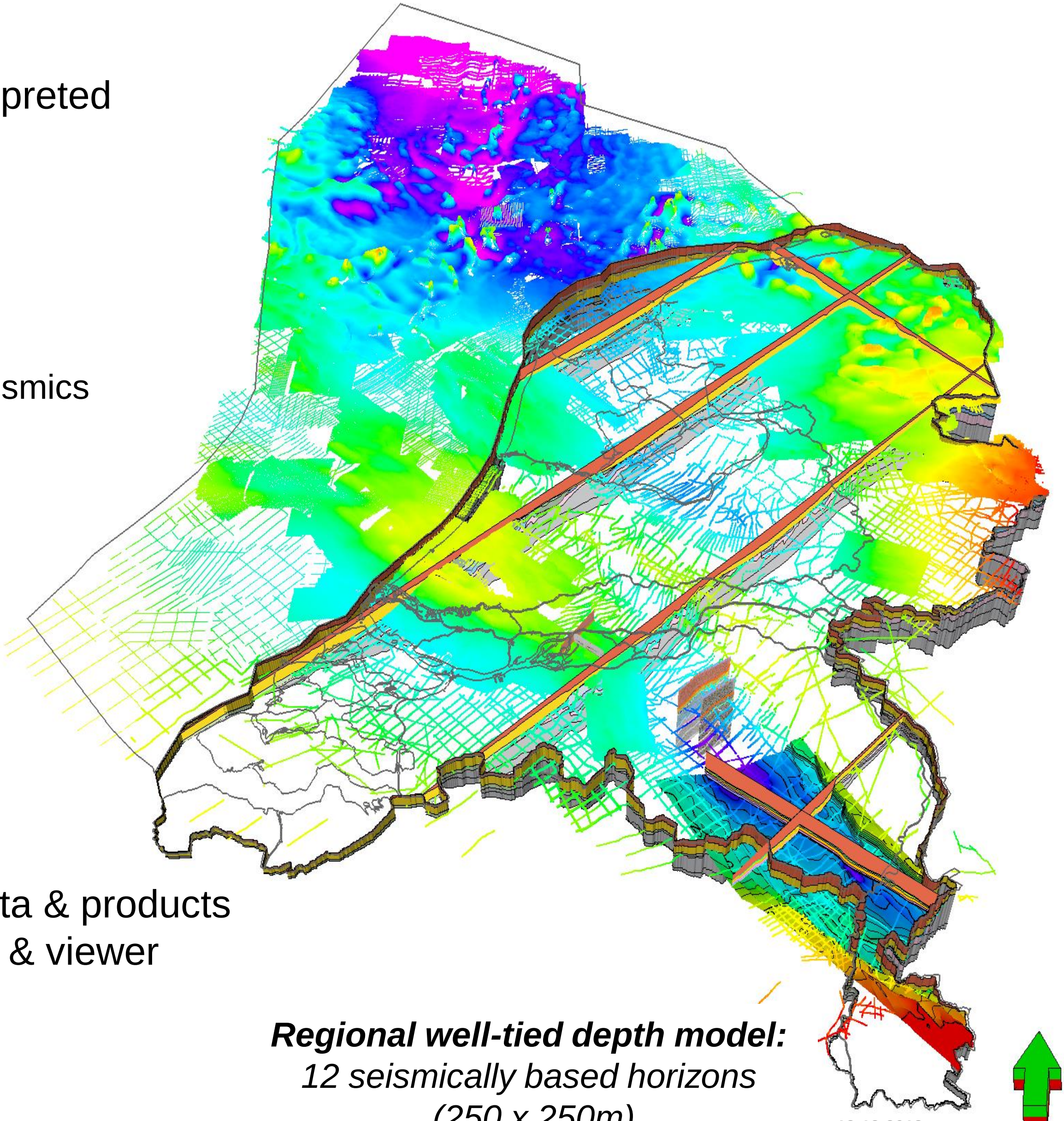
Deliverables DGM-deep V5



- 12 main layers seismic interpreted
  - Time
  - Isochore
  - Velocity V0 (ZE – Vint)
  - Depth
  - Thickness
  - Residu
  - Locationpoints of used seismics
- 1 infill (RO)

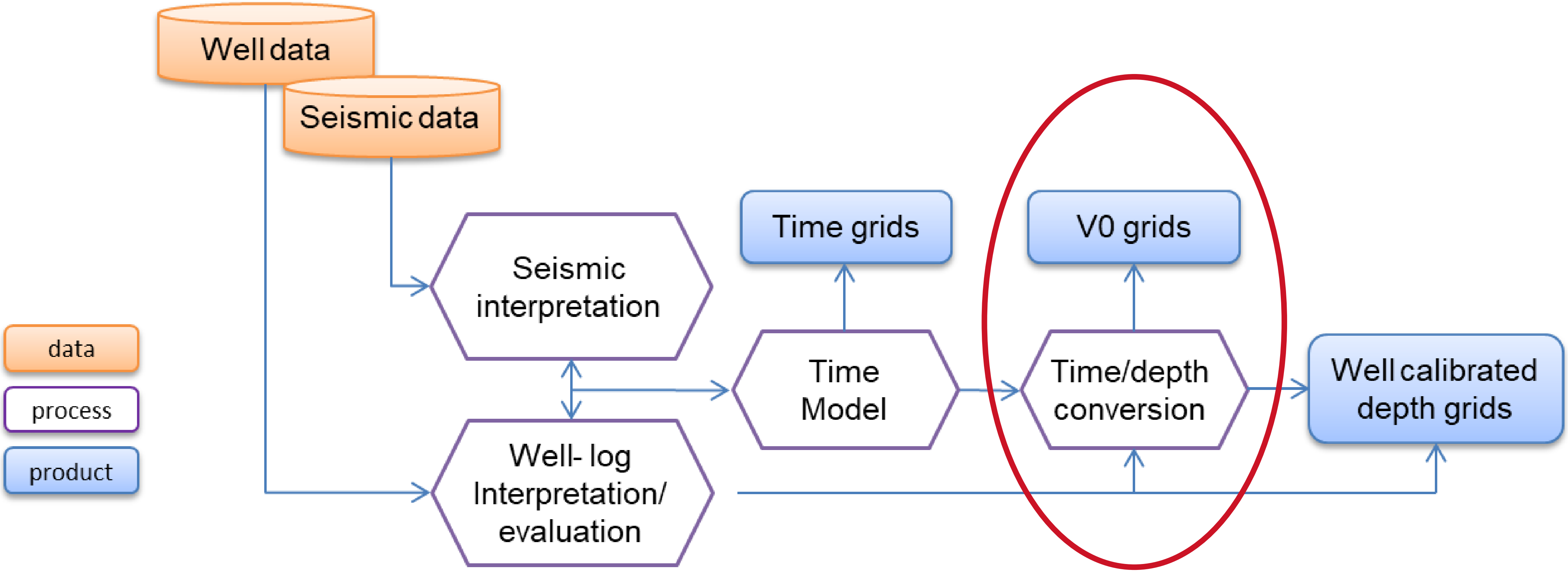
- Formats
  - ArcGIS
  - Zmap
  - Pdf

- Dissemination
  - nlog.nl – underlying data & products
  - dinoloket.nl – products & viewer



Regional well-tied depth model:
12 seismically based horizons
(250 x 250m)

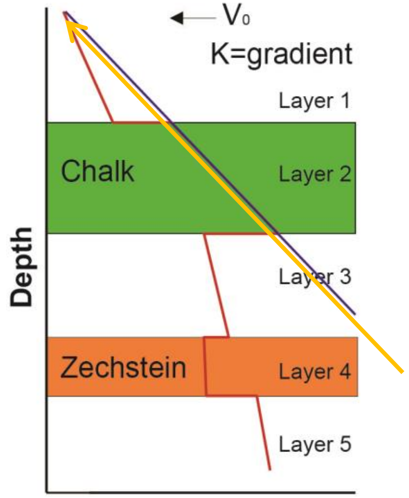
Time-depth conversion

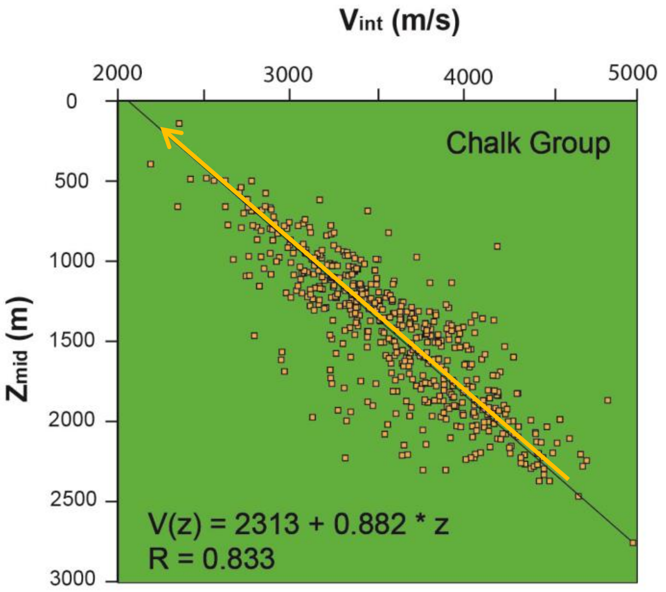


VELMOD: REGIONAL VELOCITY MODEL FOR TD-CONVERSION

- V1.0: 2006; V2.0: 2007; V3.1: 2018
  - based on velocities from well data (sonic, checkshots)
  - V0, k method (V increases linearly under influence of burial & compaction)
  - Interval velocity for Paleozoic Zechstein Group
    - Vint=4500, dt>170ms;   Vint=4950-450cos(dt+10), dt<170ms
- V4.0: based also on seismic stacking velocities (start: Q1 2017)

$$V(xyz) = V_0(xy) + K \cdot z$$





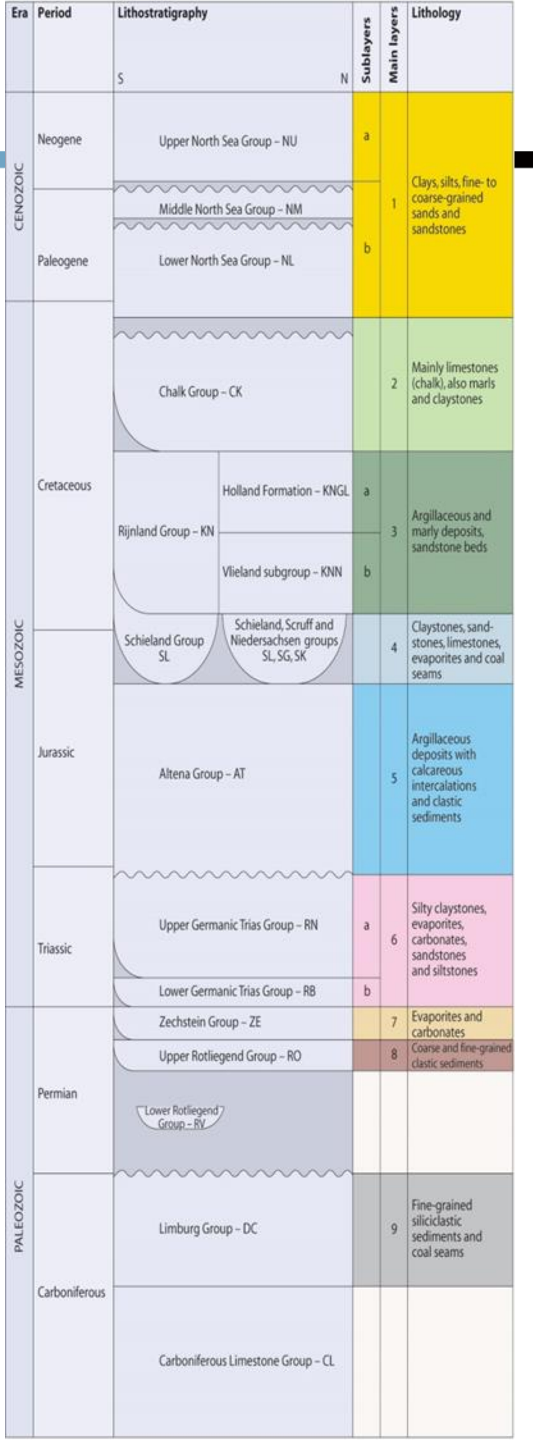
(Van Dalfsen et. al, 2006)

VELMOD-3: DATA

- All available velocity information from wells
  - Sonic logs (all flavours)
  - Check shots / VSP surveys
  - TZ curves

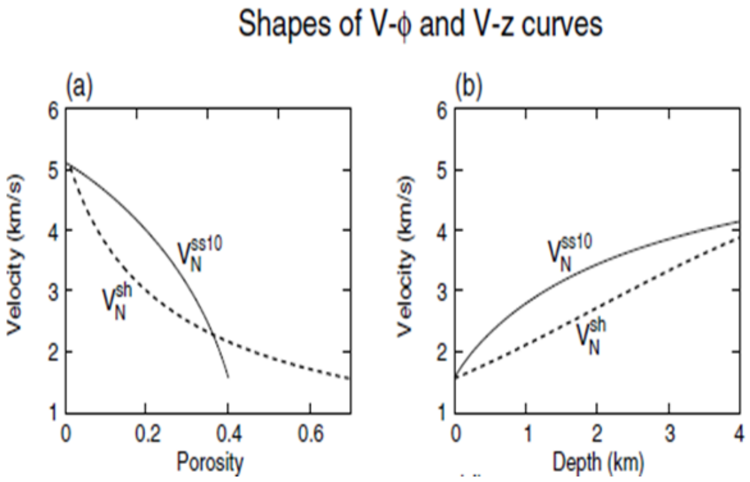
- Stratigraphic interpretation of main strat units (DINO)
- Borehole deviation surveys (DINO)

- 1642 wells
- 3475 velocity data sources

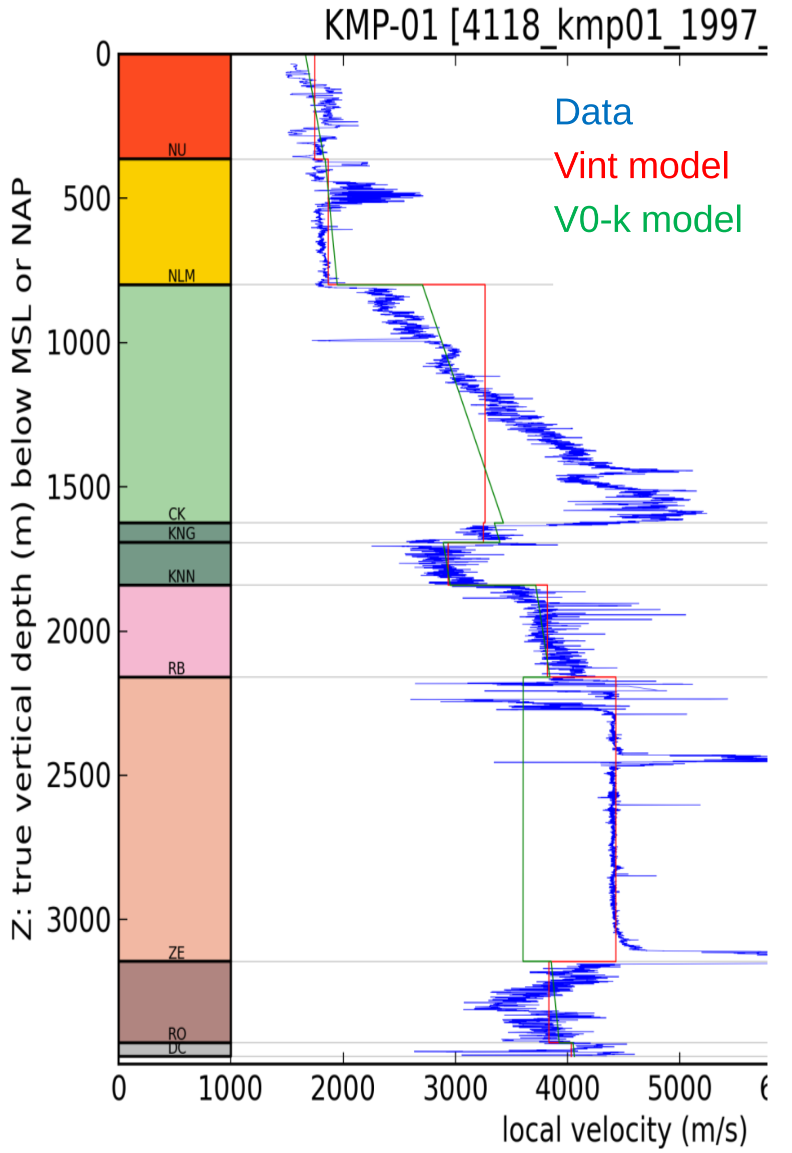


VELMOD-3: LAYER CAKE MODEL

- Velocity data from borehole log measurements (point set)



  - Velocity increases due to compaction.
  - Compaction increases due to burial
  - Velocity increases due to burial



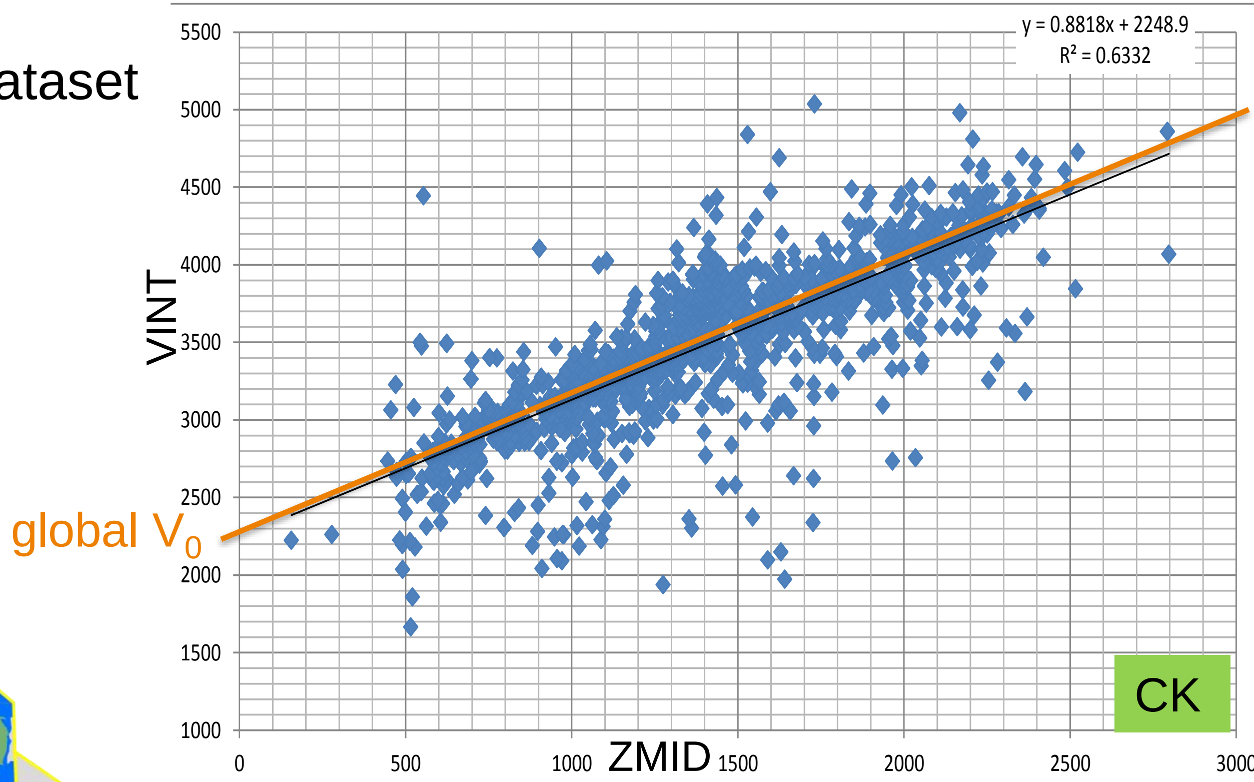
- Within each stratigraphic interval linear (!?) relation between depth and velocity assumed: $V=V_0+k*z$

- Zechstein Group: no compaction assumed → interval velocity :
  - Vint=4500, dt>170ms; Vint=4950-450cos(dt+10), dt<170ms

VELMOD-3: REGIONAL DETERMINATION OF K

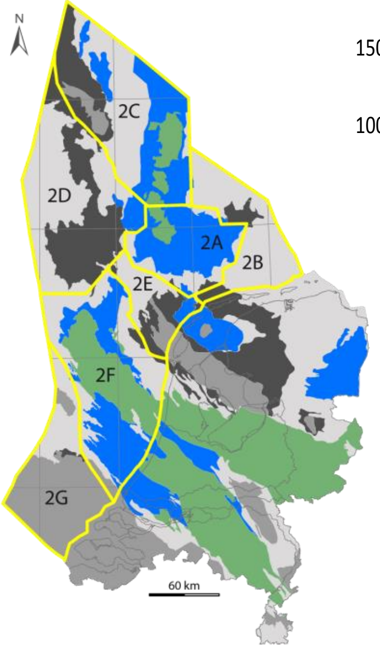
- V_{int} – Z_{mid} plots >>> Find common k for your dataset
  - Calc regression on total (filtered) dataset
  - Determine residuals
  - Select datapoint with smallest residual as preferred

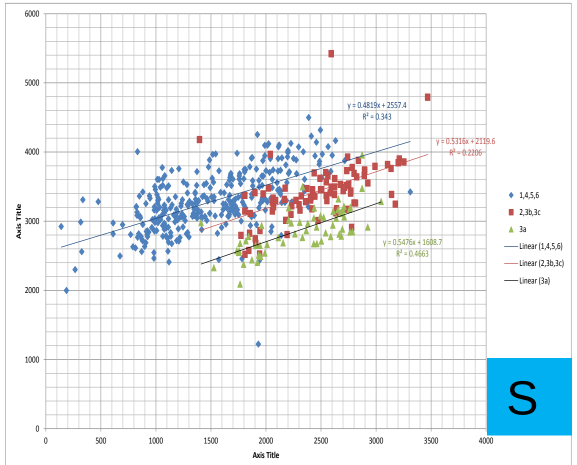
  - Calc new regression
  - Filter outliers around regression line (99% interval)
  - Calc new regression based in filtered dataset



- Derive global V0 and k from regression

- Split data set into regions? same k
  - LSB, WNB, B14 (high global V0)
  - Vlieland, Terschelling, Step Graben
  - Central Graben (low global V0)



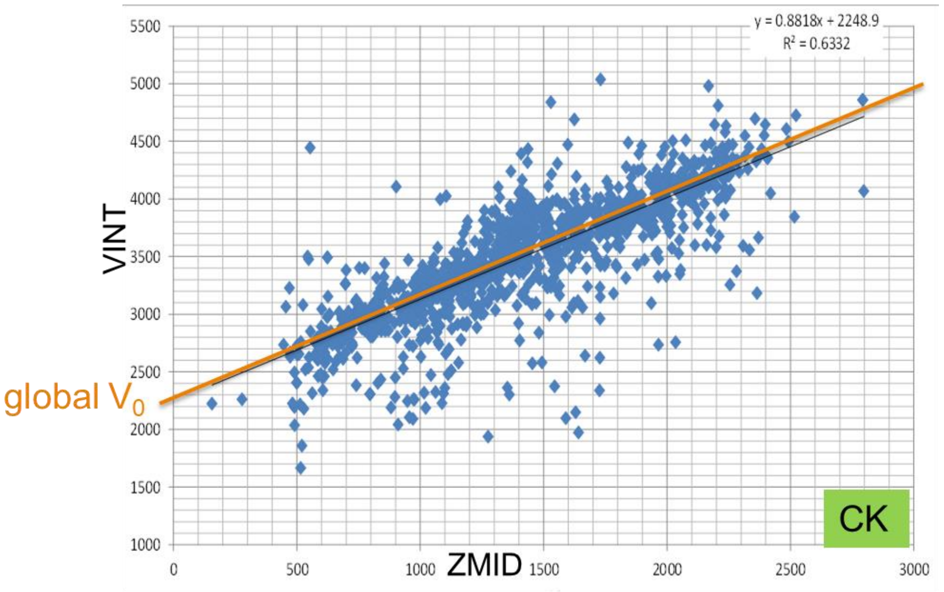


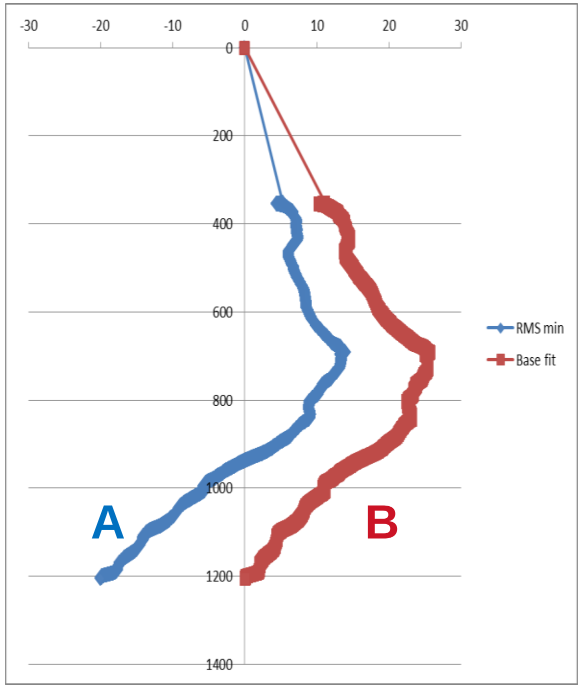
VELMOD-3: LOCAL DETERMINATION OF V_0

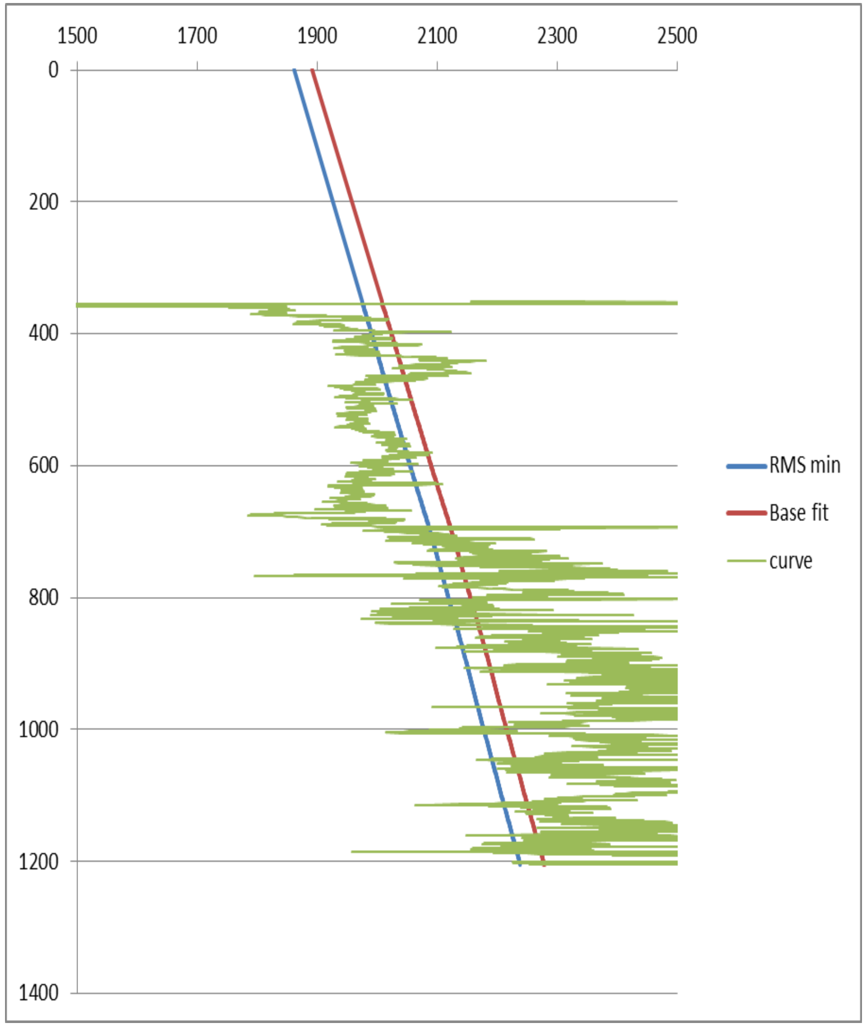
- Regional k determined from Vint-Zmid

- A local V_0 calculated from best curve fit (min RMS error)
- B local V_0 calculated where total transit time error at base is 0 !!

  - VELMOD 3.1 : best base fit (B)



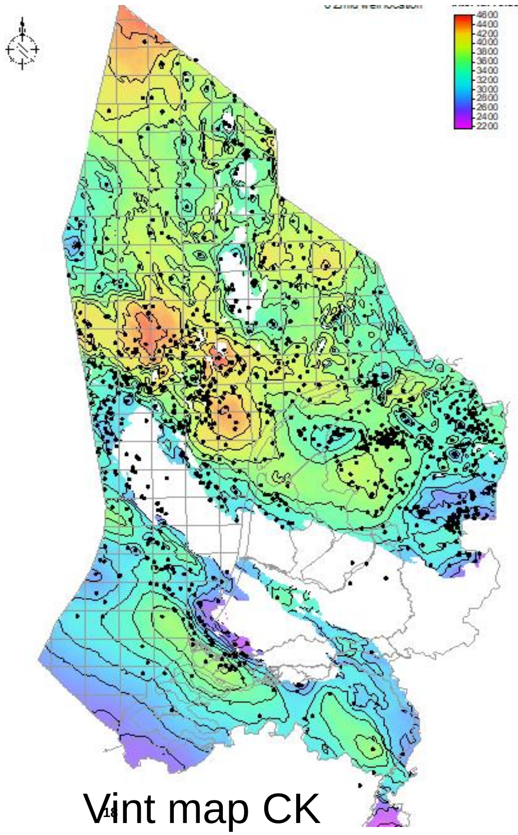




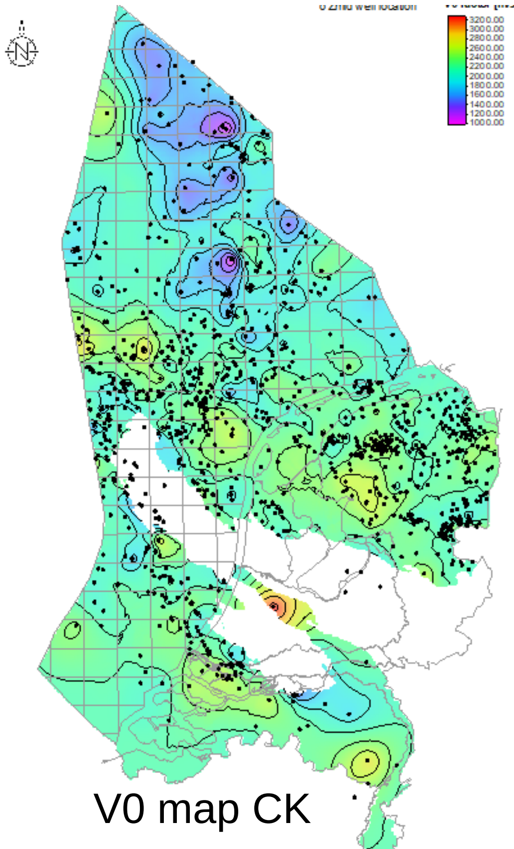
VELMOD-3 RESULTS

TNO innovation for life

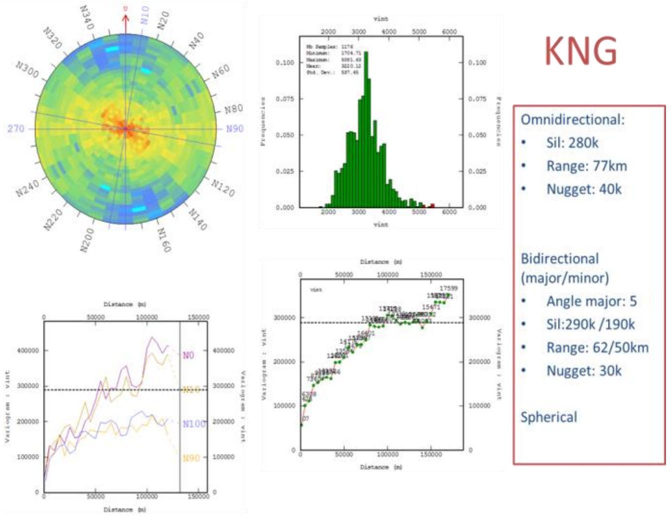
- Well plots
- Vint and V0 maps/grids
  - Variogram analysis (isatis)
  - simple kriging, co-kriging with time horizon (Vint only)
- Excel point dataset

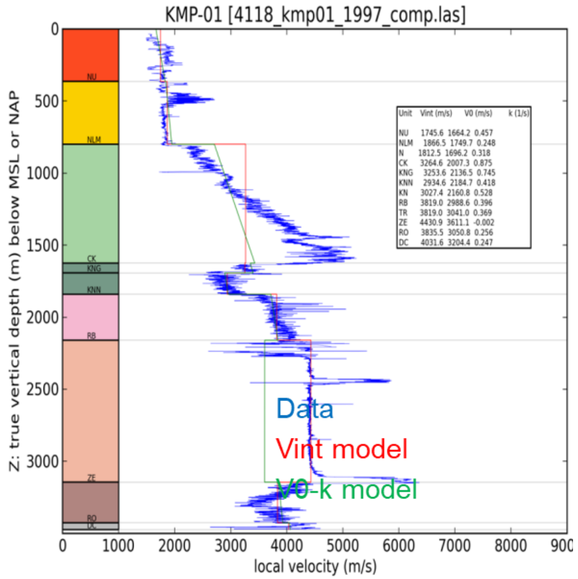


Vint map CK



V0 map CK





Well plot for all input data curve
Visual QC of data

Published on NLOG : July 2018

Strat interval		Wells used		Total data		Method	Maps
NU	N	660	1075	1506	2544	$V=V_0+k*z$	V_0 , V_{int}
NLM		757		1763		$V=V_0+k*z$	V_0 , V_{int}
CK		1160		2556		$V=V_0+k*z$	V_0 , V_{int}
KNG	KN	1128	1224	2439	2710	$V=V_0+k*z$	V_0 , V_{int}
KNN		1109		2455		$V=V_0+k*z$	V_0 , V_{int}
S		458		1016		$V=V_0+k*z$	V_0 , V_{int}
AT		419		951		$V=V_0+k*z$	V_0 , V_{int}
RN	TR	638	817	1423	1792	$V=V_0+k*z$	V_0 , V_{int}
RB		937		2026		$V=V_0+k*z$	V_0 , V_{int}
ZE		1063		2270		$V = V_{int}$	V_{int}
RO		901		1912		$V=V_0+k*z$	
RV		11		18		$V = V_{int}$	
DC		780		1566		$V=V_0+k*z$	
DCG		19		36		$V=V_0+k*z$	
CL		7		11		$V = V_{int}$	
CF		8		17		$V = V_{int}$	
O		10		15		$V = V_{int}$	

VELMOD-4

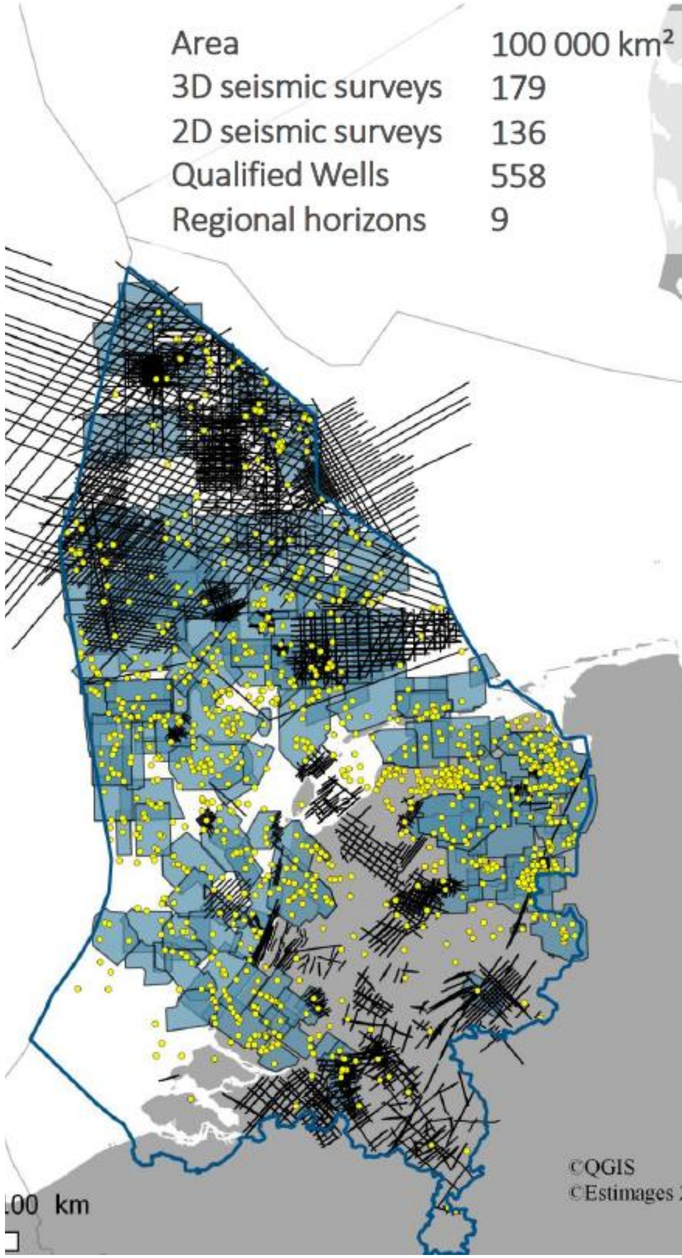
- **Collaboration between TNO and ESTIMAGES**
  - Complemetary expertise

- **Innovation: integration of seismic velocities**
  - Feed the model with 3D heterogeneities coming from the seismic velocities
  - *New product for the Dutch exploration*!!!

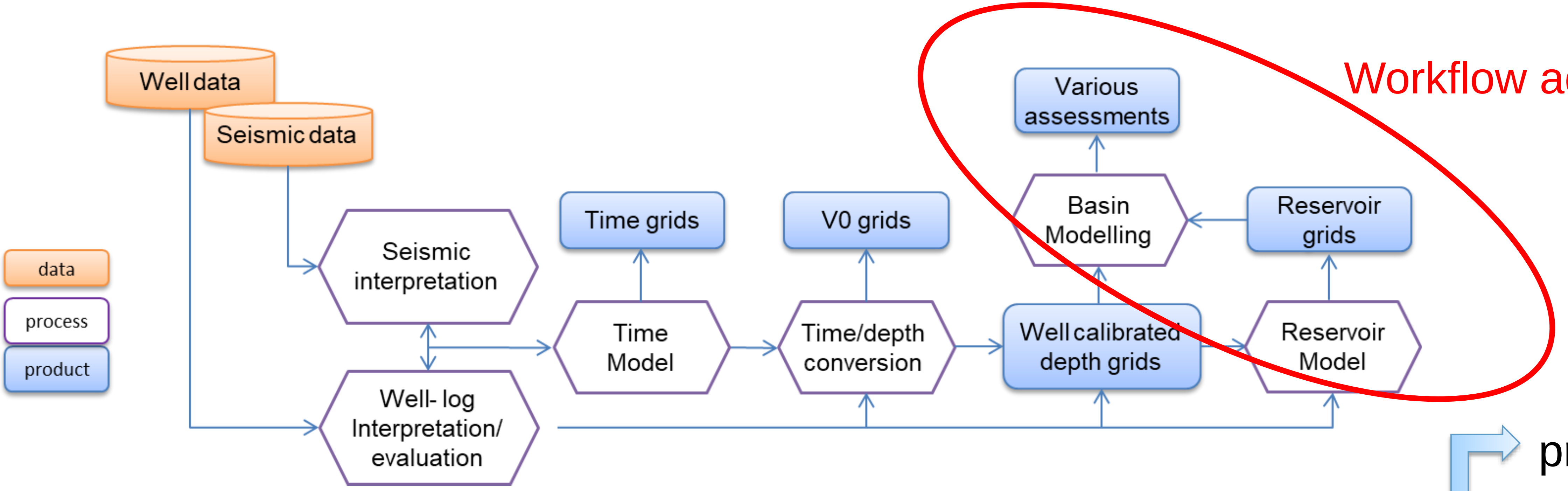
- **Deliverables**
  - Qualification report for each velocity dataset
  - Velocity volumes (SEGY): VINT, VAVG (1000m x 1000m x 40msTWT)
  - Uncertainty volume (SEGY)

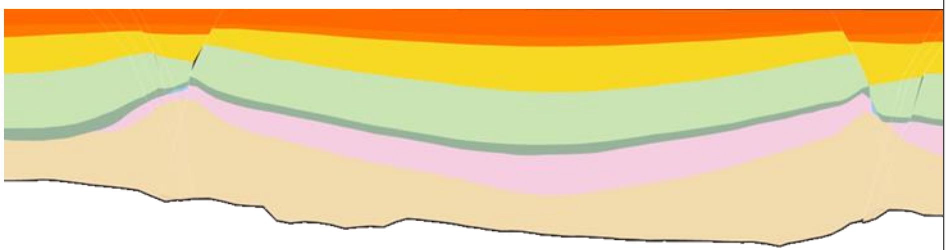
- **VELMOD 4.0** > close-out meeting: Jun 18, 2018; 1 participant

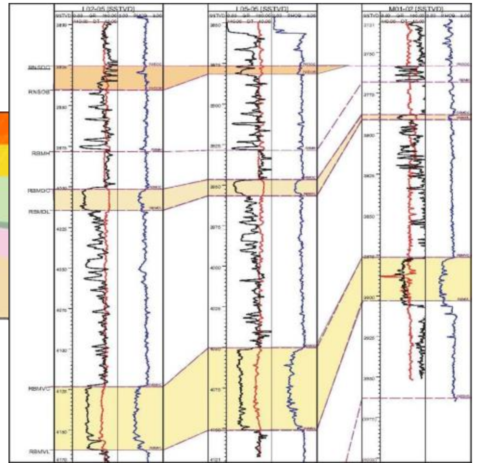
- **VELMOD 4.1 > Q1 2019**
  - Geostatistical analysis
  - Better fit to VELMOD 3.1 horizons

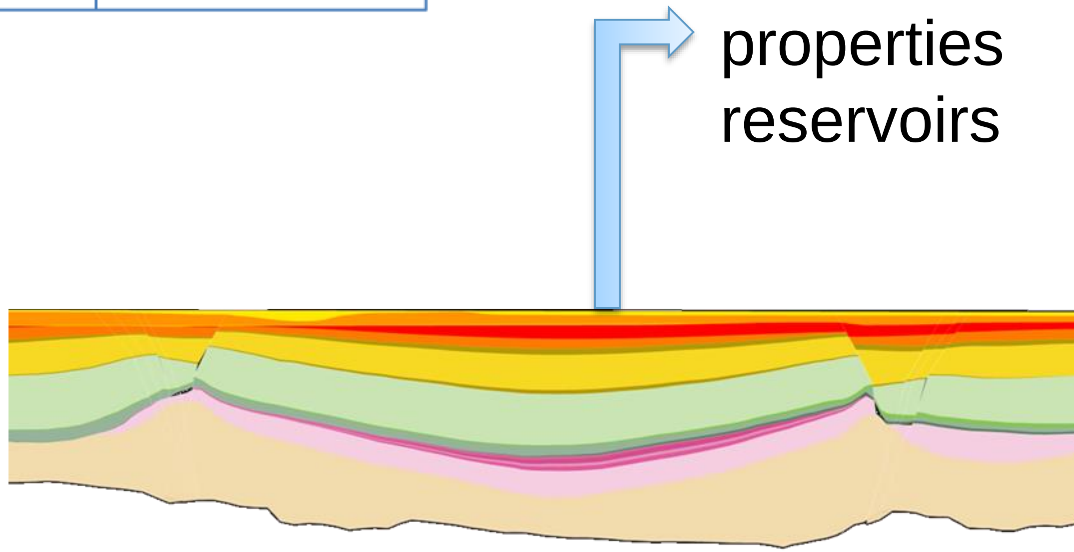


MODELING RESERVOIRS & SEALS









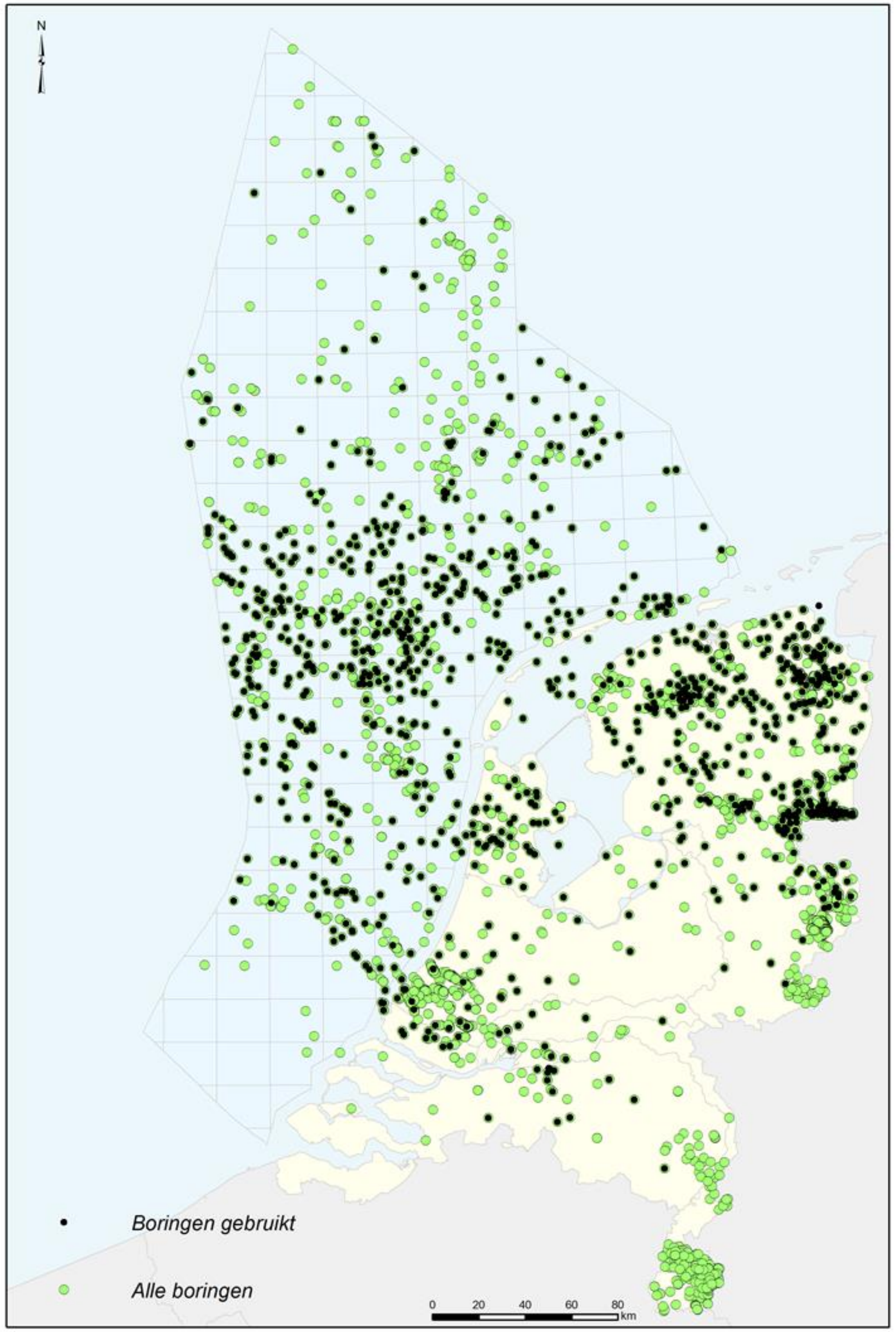
properties
reservoirs

THERMOGIS V2.0

Input

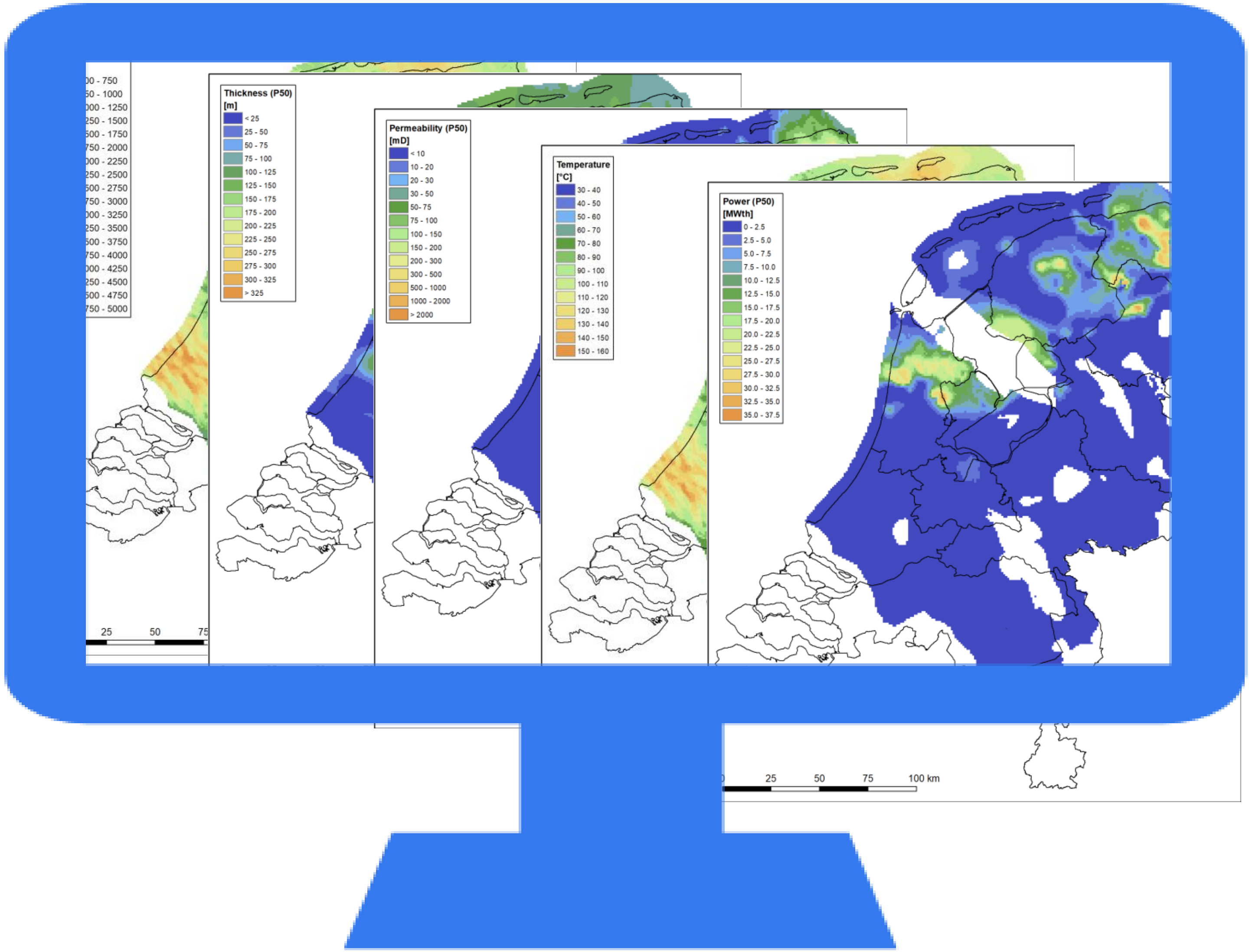
- Depth/distribution maps main horizons (DGM-deep)
- Stratigraphic interpretation of reservoirs (DINO)
- Property database (AGE)

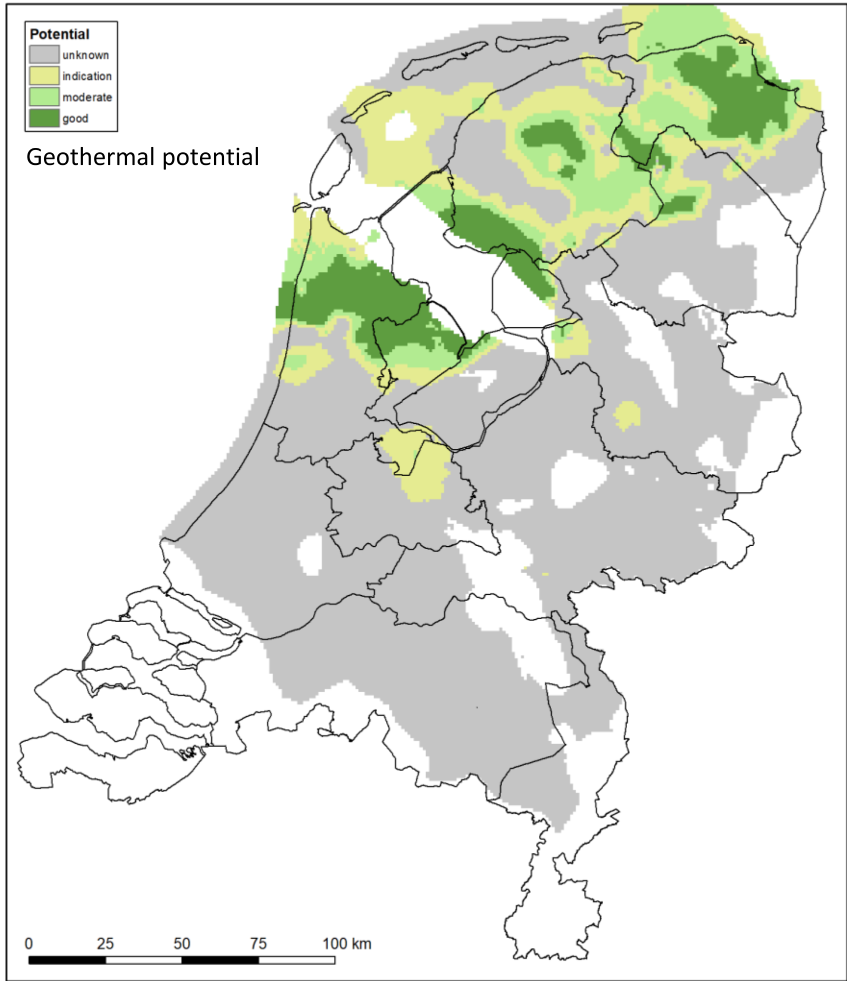
- All wells in DINO
- Wells with porosity and/or permeability measurements (AGE-property database – mainly confidential)



ThermoGIS

100 YEARS OF GEOLOGICAL MAPPING

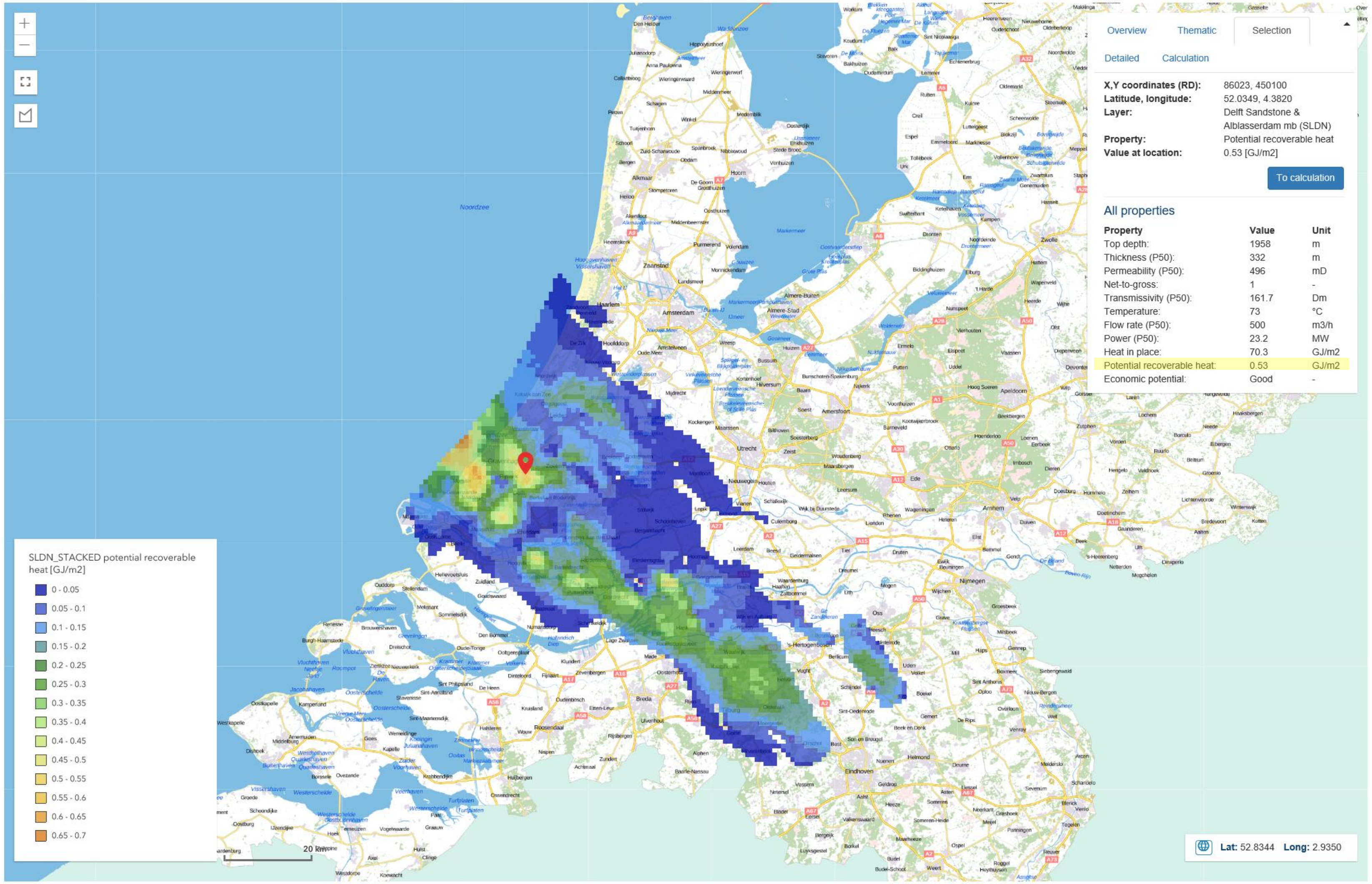




TNO innovation for life

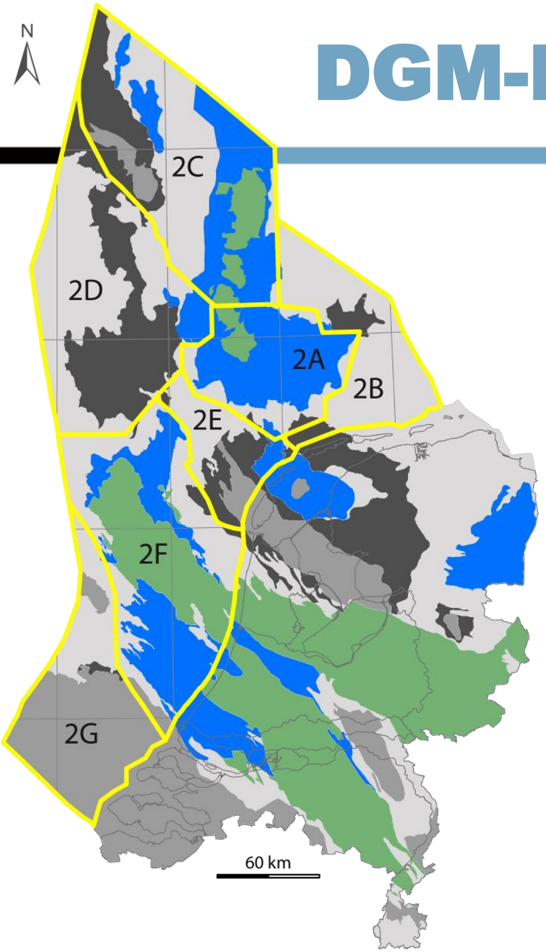
ThermoGIS

100 YEARS OF GEOLOGICAL MAPPING



- Online tool
- www.thermogis.nl
- From regional to site-specific potential
- Newest release 1-10-2018

TNO innovation for life



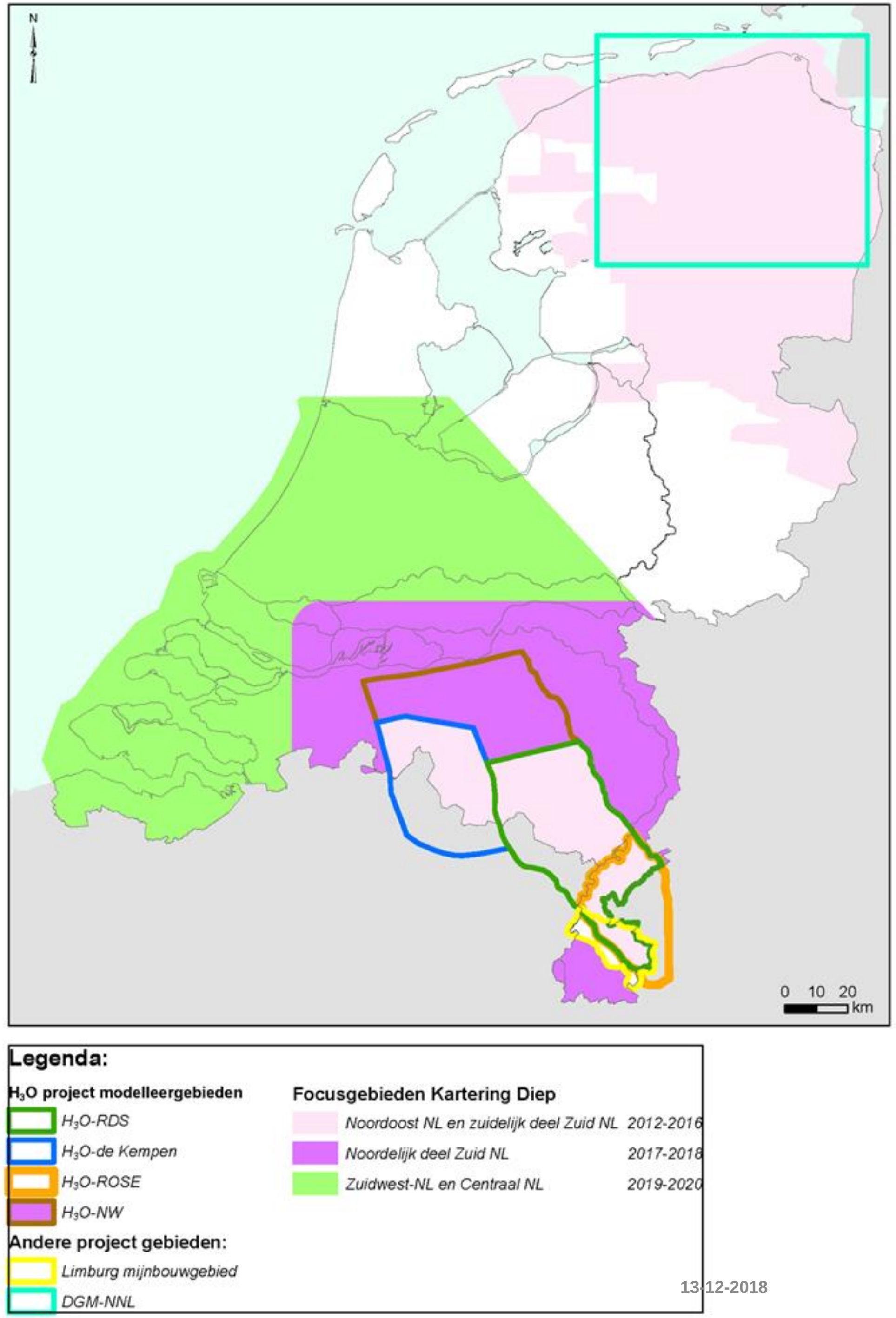
DGM-DEEP: SHIFT TO DETAIL

2012 First regional model of the deep subsurface of the NL

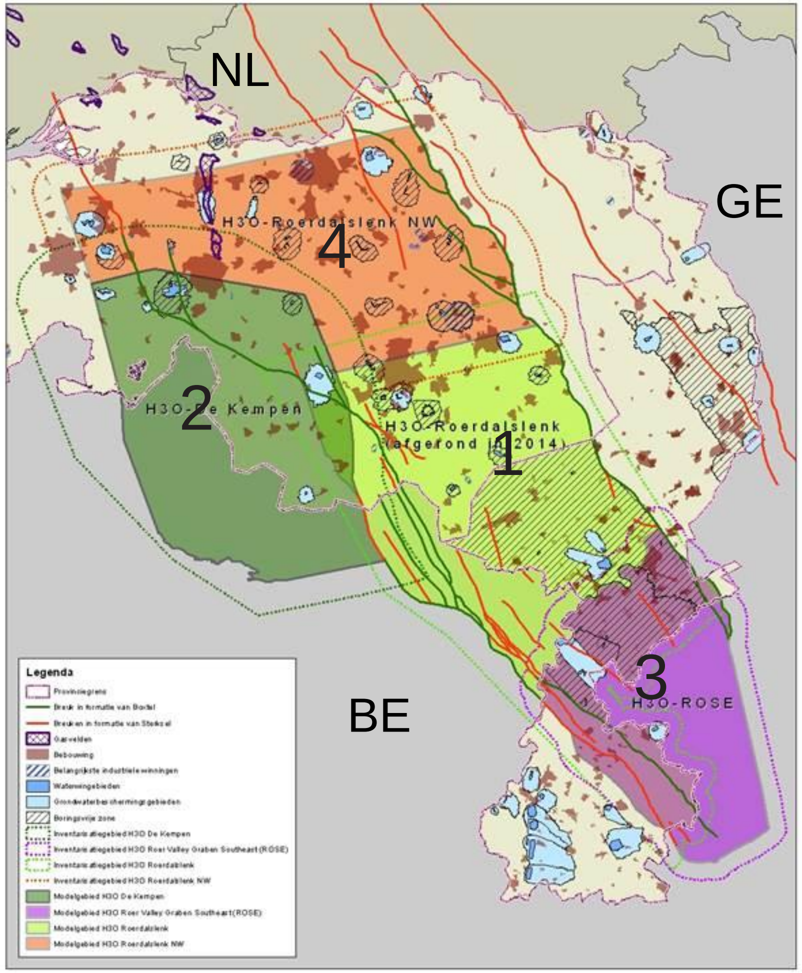
1985-2012 **Regional** mapping of the NL

regional → detail

2012	Start **detailed** mapping **onshore** more interest	
2012-….	SE of the NL:	H3O projects
2012-2018	NE of the NL:	DGM-NNL



H3O-PROJECTS



Aim: Building 3D hydro-geological models (crossborder, Cenozoic)

1.	Roervalley Graben	2012-2014
2.	De Kempen	2015-2017
3.	Roervalley Graben SE (ROSE)	2016-2018
4.	Roervalley Graben NW	2017-2019

Activities

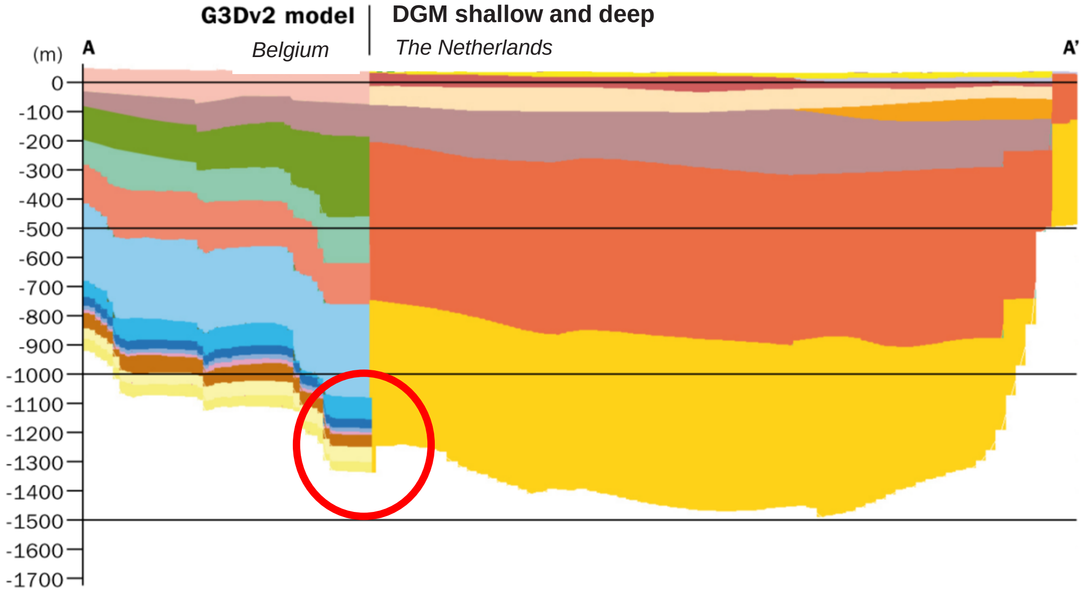
- Data inventarisation
- Lithostratigraphic and hydrological correlation chart
- Interpretation wells and seismics
- Modelling: shallow and deep
- Analysis and reporting

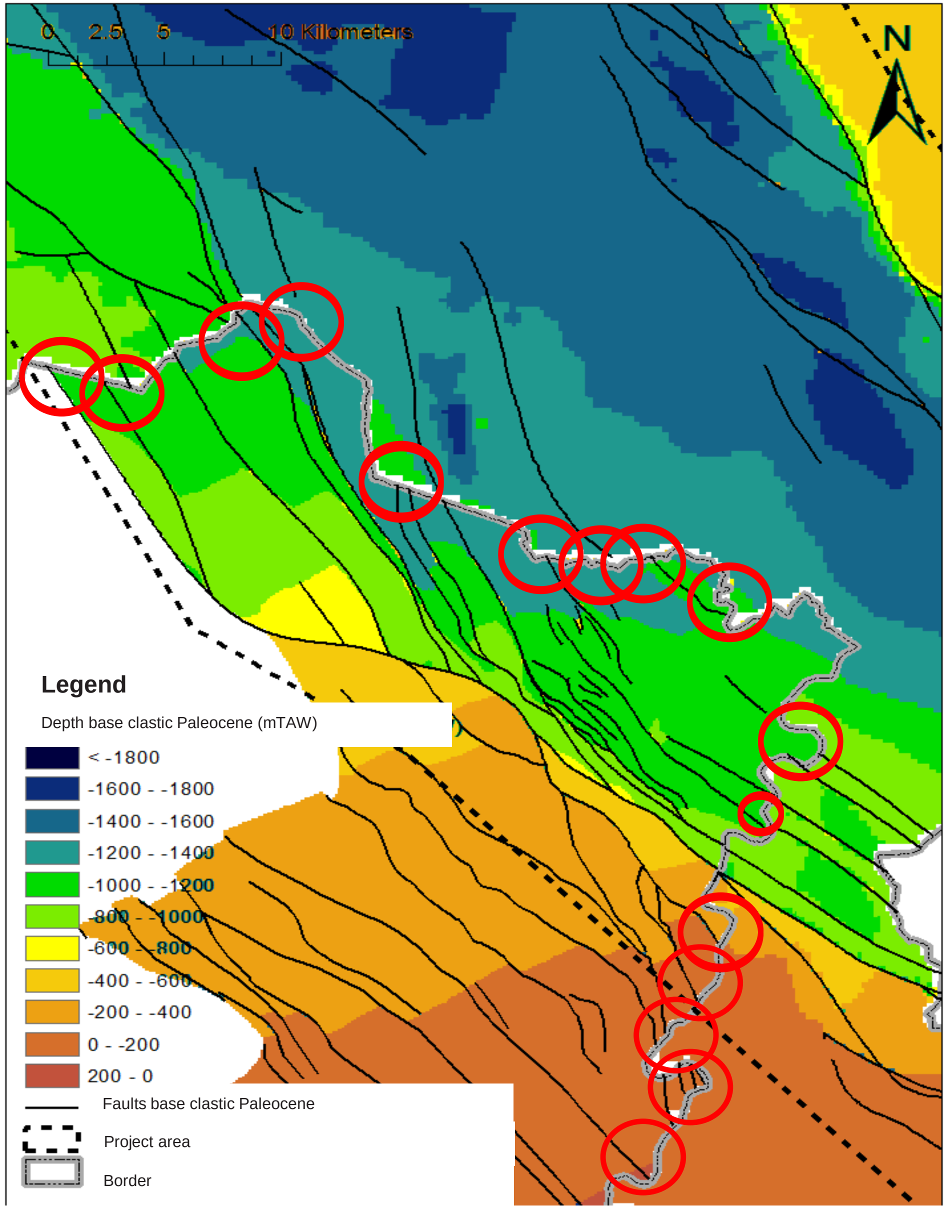
- Financed: Provinces, TNO (GIP), water companies
- Executed parties: TNO (NL), VITO+BGD (BE), GD NRW Krefeld (GE)

H3O-PROJECTS

Crossborder Inconsistencies

- Different (hydro)geological classification
- Different co-ordinates
- Non-matching of faults
- Depth and thickness
- Differences in level of detail
  - “To harmonise the geological and hydrogeological models (Cenozoic) of the NL, Flanders and Germany along the frontier

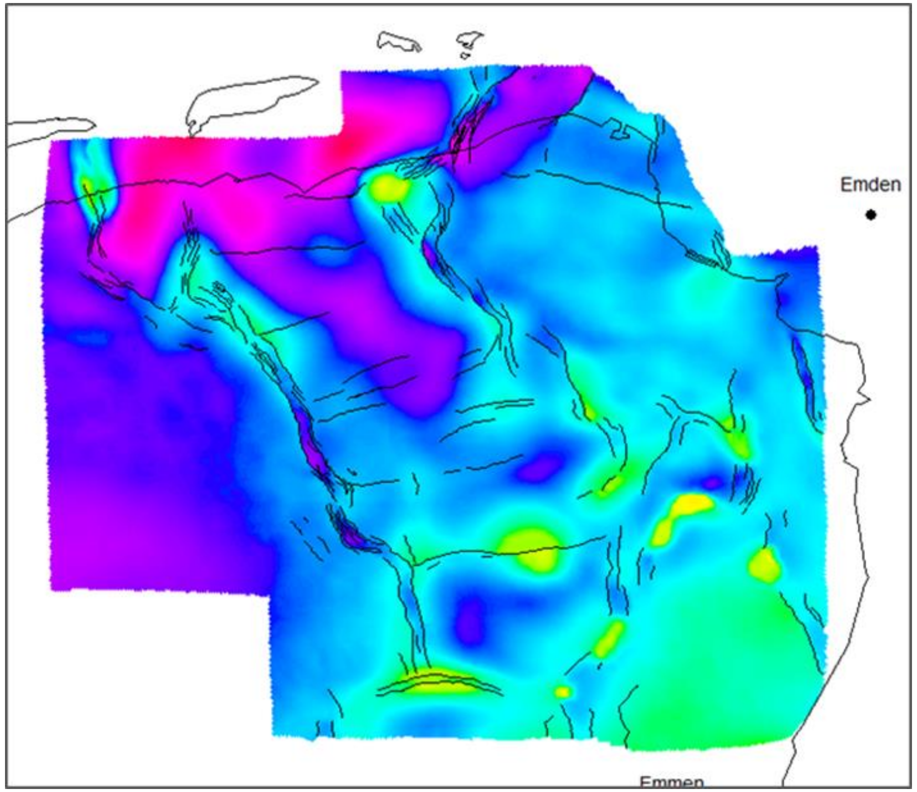


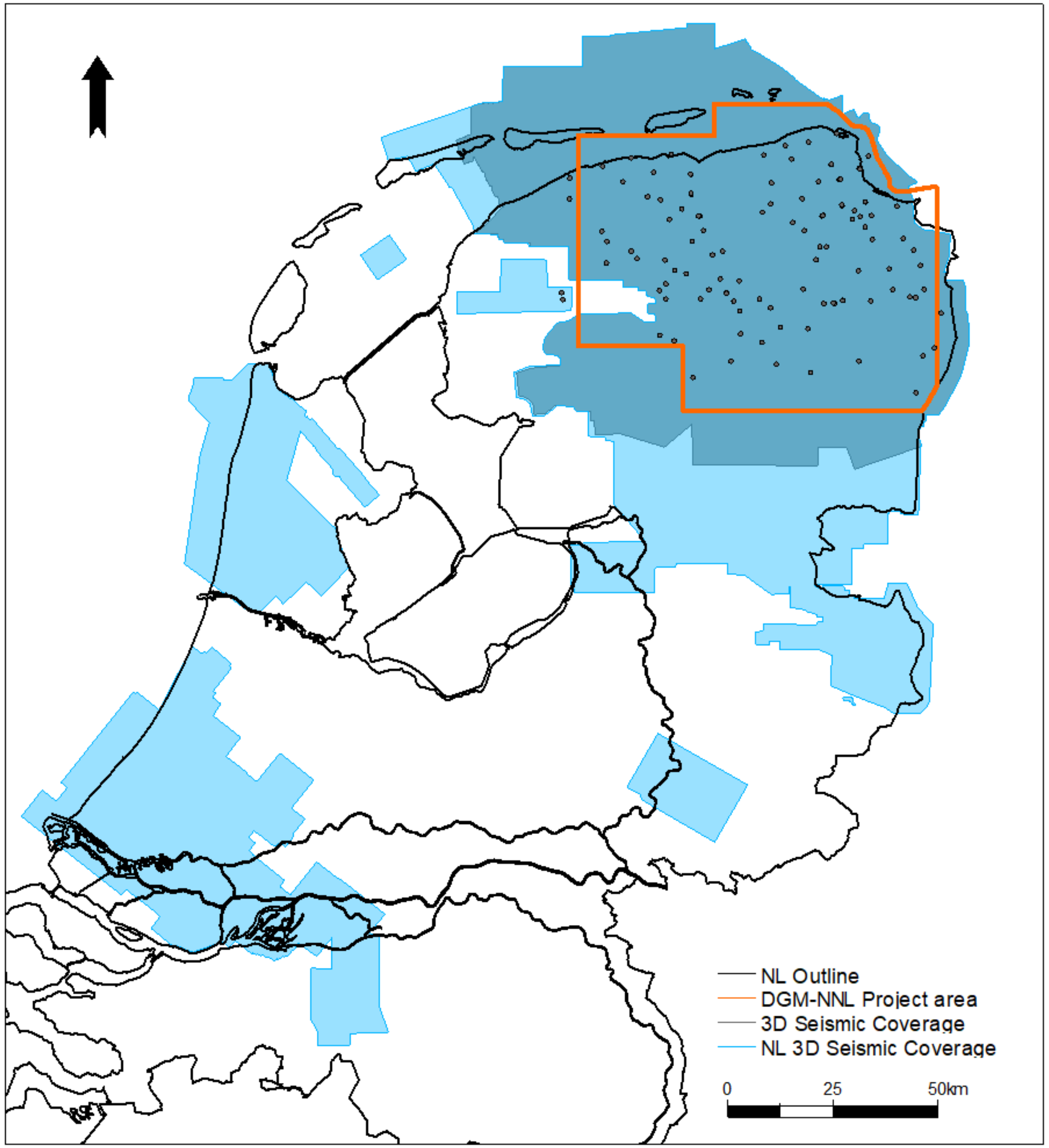


TNO innovation for life

Input-data

- completely covered with 3D seismic surveys
- Stratigraphical interpretation of layers (DINO)





DGM-NNL DGM NORTH NETHERLANDS

- Stratigraphic column with 67 modelled layers

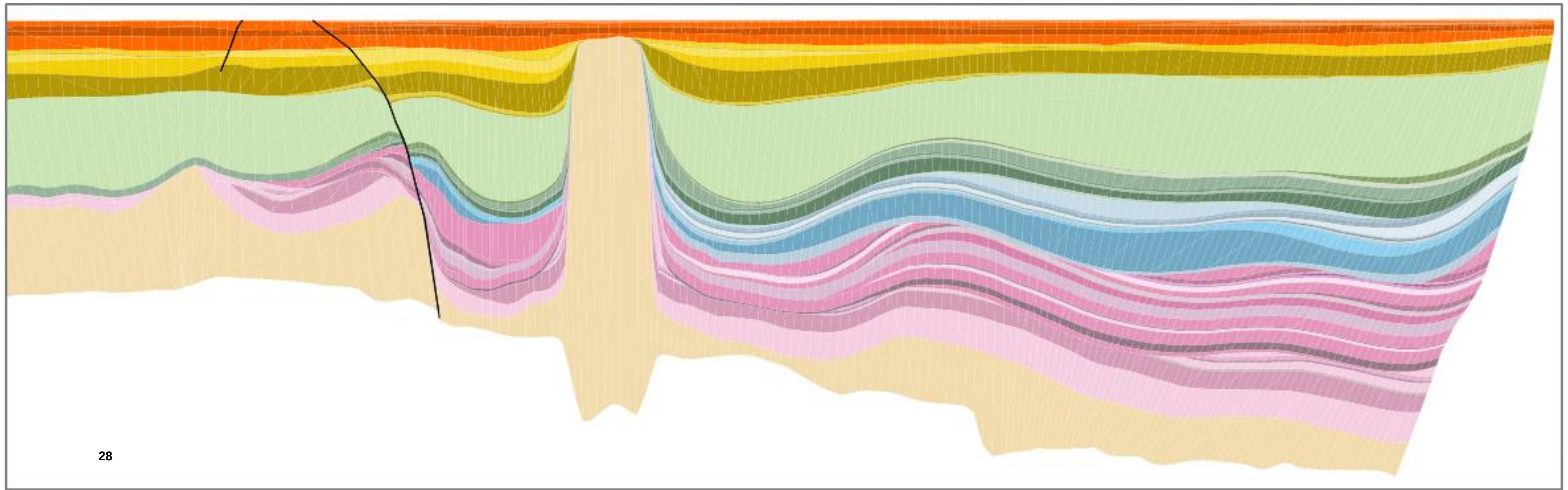
- **Seismic interpreted horizons:**
  - 9 horizons DGM-deep (NU,N,CK,KN,S,AT,RN,RB,ZE)
  - 4 horizons in Paleogene

Public in Q1 2019

DGM 2.2 (Naaldwijk – Oosterhout)

Neogene	Naaldwijk
	Boxtel
	Eem
	Drente
	Drachten
	Urk Tynje
	Peelo
	Urk
	Appelscha
	Peize
	Maassluis
	Oosterhout
	BREDA (BASE NU)
Paleogene	Rupel Clay
	VESSEM MEMBER
	ASSE MEMBER
	BRUSSEL MEMBER
	IEPER MEMBER
	Basal Dongen Tuffite
	LANDEN CLAY (BASE N)
Late Cretaceous	Ommelanden Formation
	Plenus Marl
	TEXEL FORMATION (BASE CK)
Early Cretaceous	Upper Holland Marl
	Middle Holland Claystone
	Lower Holland Marl
	Vlieland Claystone I
	Friesland Member
	Vlieland Claystone II
	BENTHEIM SANDSTONE (BASE KN)
Late Jurassic	Upper Coevorden
	Middle Coevorden
	Lower Coevorden
	Serpulite Member
	Weiteveen Upper Marl
	Weiteveen Upper Evaporite
	Weiteveen Lower Marl
	Weiteveen Lower Evaporite
	WEITEVEEN BASAL CLASTICS (BASE S)

Early and Middle Jurassic	Werkendam Formation
	Aalburg Formation
	SLEEN FORMATION (BASE AT)
Triassic	Upper Keuper Claystone
	Dolomitic Keuper
	Red Keuper Claystone
	Red Keuper Evaporite
	Middle Keuper Claystone
	Main Keuper Evaporite
	Lower Keuper Claystone
	Upper Muschelkalk
	Middle Muschelkalk Marl
	Muschelkalk Evaporite
	Lower Muschelkalk
	Upper Röt Claystone
	Upper Röt Evaporite
	Intermediate Röt Claystone
	Main Röt Evaporite
	SOLLING CLAYSTONE (BASE RN)
	Basal Solling Sandstone
	Hardegsen Formation
	Detfurth Claystone
	Lower Detfurth Sandstone
	Volpriehausen Clay-Siltstone
	Lower Volpriehausen Sandstone
	Rogenstein
	MAIN CLAYSTONE (BASE RB)
Permian	**ZECHSTEIN GROUP (BASE ZE)**

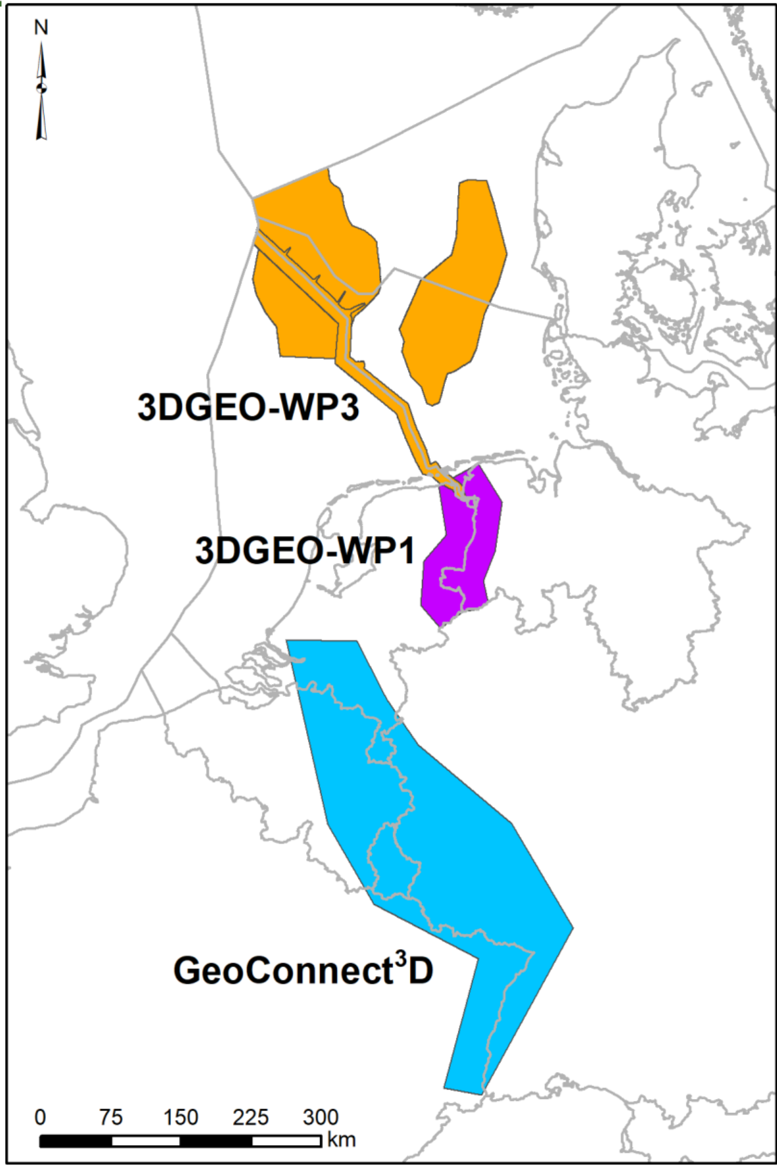


TNO's contribution to GeoERA

45 national and regional Geological Survey Organisations (GSOs) from 32 European countries

GeoEnergy projects

- HIKE > Induced Hazards & Impacts
- 3DGEO > Transnational 3D modelling
- HOTLIME > Geothermal Carbonate plays
- GeoConnect³D > 3D spatial planning: from 3D models towards policy support
- GARAH > Hydrocarbon plays and hydrates
- MUSE > Shallow geothermal in urban areas



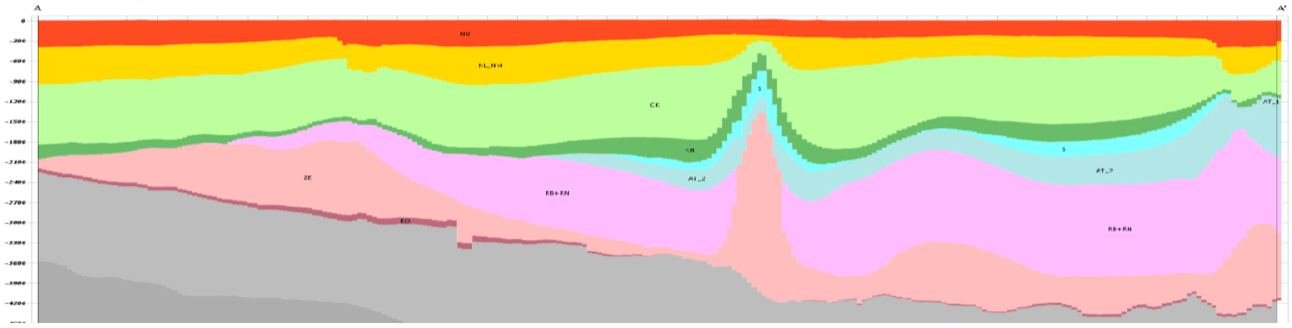
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166

Establishing the European **Geo**logical Surveys **R**esearch **A**rea to deliver a **Geo**logical Service for **E**urope

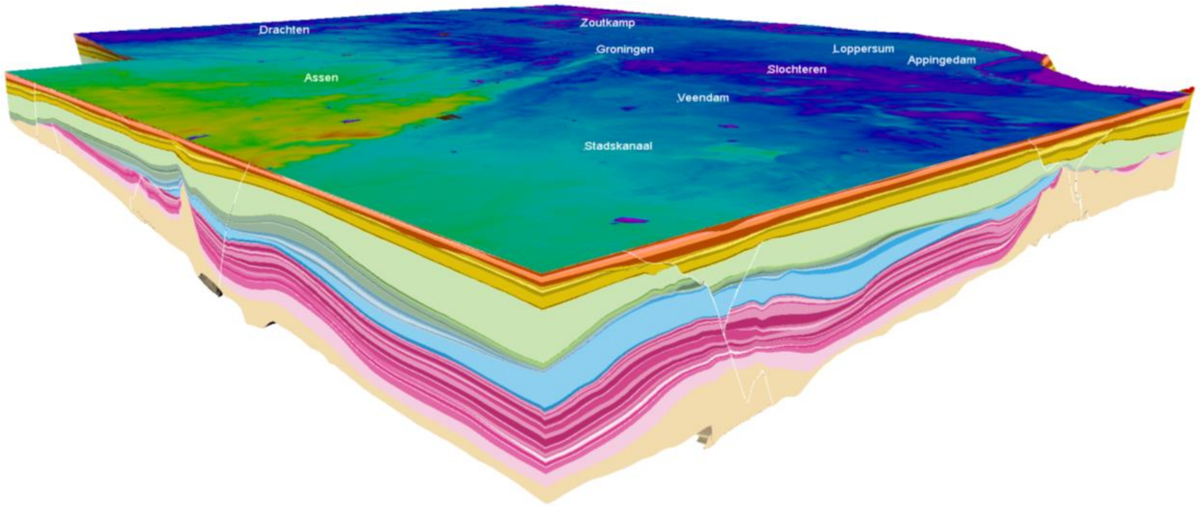
CONCLUSIONS

SHIFT OF FOCUS, MORE DETAIL, INTEGRATION

100 YEARS OF GEOLOGICAL MAPPING



DGM v4.0 (extraction from DINOloket): Stratigraphic Group level



DGM-NNL: Stratigraphic Member level >> public Q1 2019

- New produced models:
  - DGM-deep V5.0 — main layers
  - VELMOD-3.1, 4.0 — velocity
  - ThermoGIS V2.0 — properties, geoth.potential
  - H3O-projects — harmonisation, groundwater, detail
  - DGM NNL — layers, detail
  - GeoERA — harmonisation
- Subsurface data
  - synergy (re-use)
  - new data needed
- Subsurface models
  - unlock the potential of energy resources
  - subsurface planning
  - change in use and requirements of models

TNO innovation for life