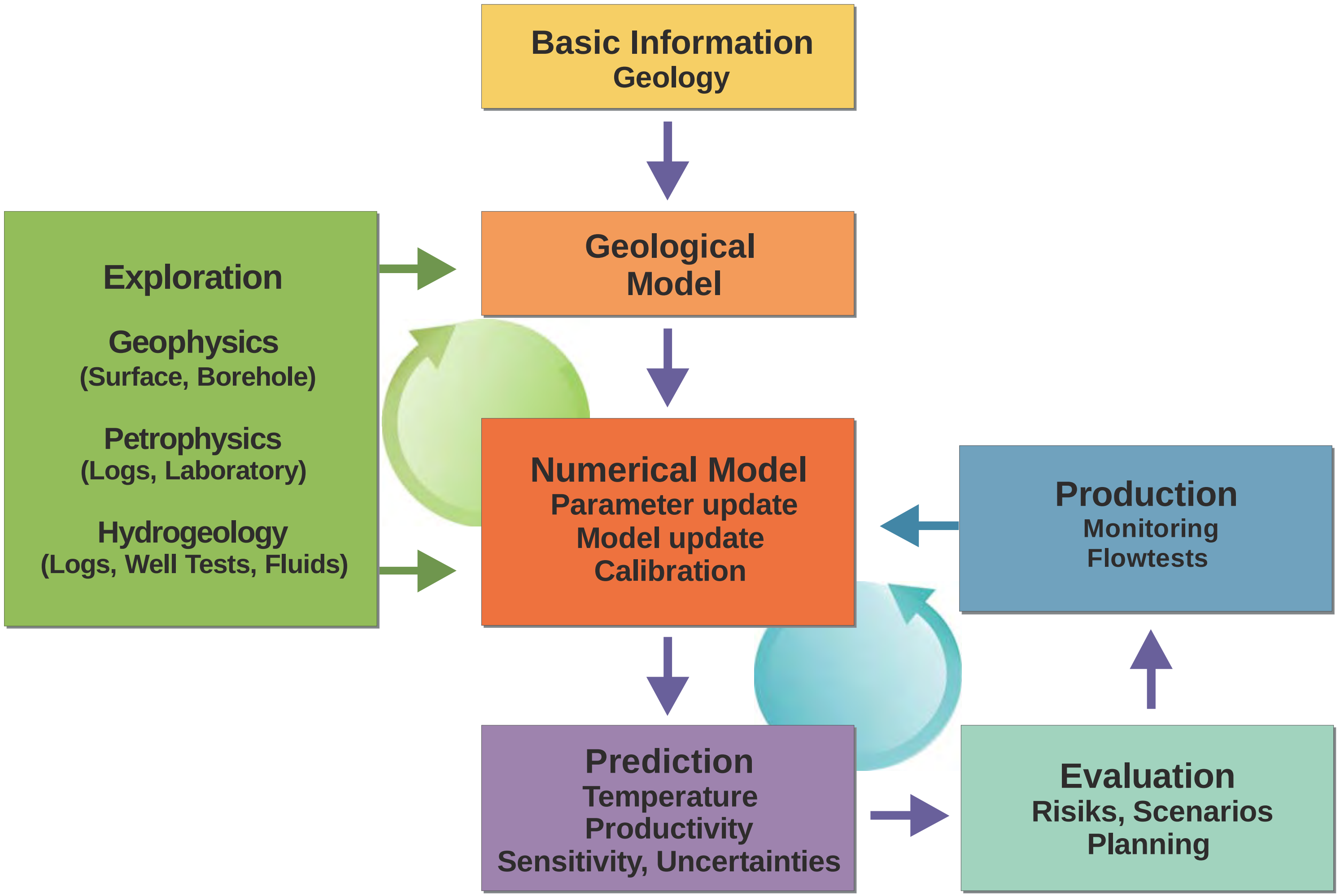
Geothermal Reservoir Characterization and Modelling

Methods and strategies to derive thermal properties from well data and to improve model input parameter

Dr. Renate Pechnig and Dr. Darius Mottaghy

GEOPHYSICA Beratungsgesellschaft mbH

Models - Key Position in Production and Exploration



GEOPHYSICA Beratungsgesellschaft mbH

Motivation

Challenges in deep geothermal projects

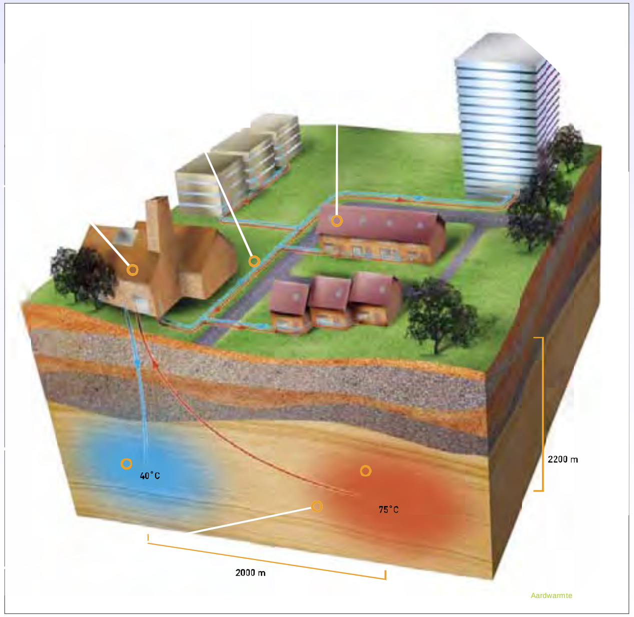
- ► **Precise identification of subsurface structures**
  (Layering, sequences, faults and fissures)
- ► **Detection of hydraulic pathways**
  (Porosity, permeability, hydraulic connectivity)
- ► **Reliable prediction of reservoir temperatures**
  (Temperature gradient, thermal conductivity, heat production)

GEOPHYSICA Beratungsgesellschaft mbH

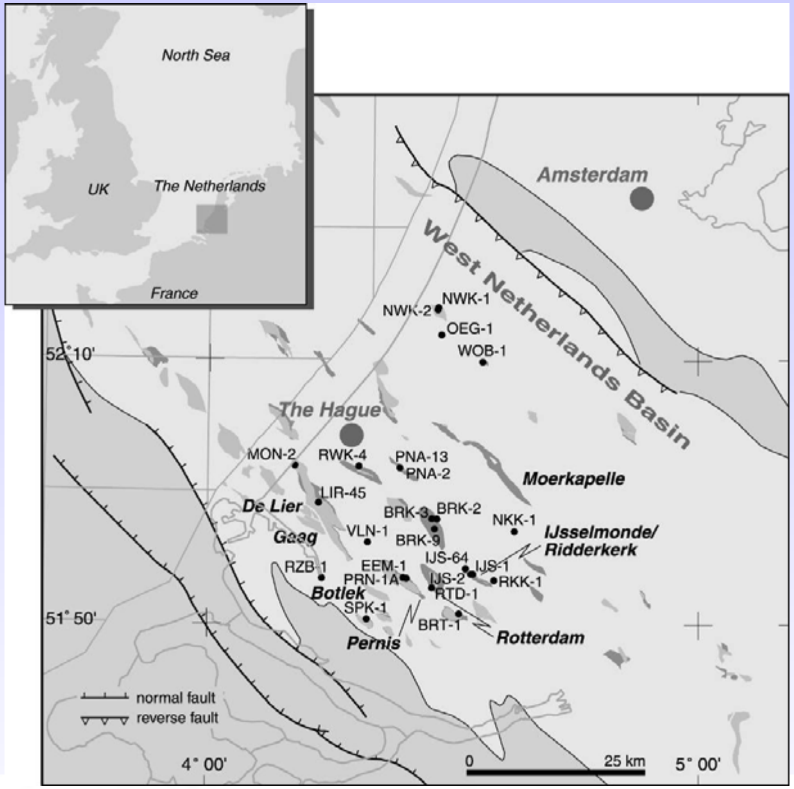
Case Study – Den Haag

Deep Geothermal Installation - Doublet System

- Heating for 6000 houses in the "Den Haag Zuidwest" district.
- Investors: Eneco Energy, E.ON Benelux, City of Den Haag and three housing companies Vestia, Staedion, Haagwonen.
- Thermal power geothermal doublet: ~ 5MWth
- Well depth: ~ 2200 m, deep sandstone reservoirs (Rijswijk and Delft)
- Required temperature: 75 °C
- Well flow: ~ 150 m³/h



Geological Setting

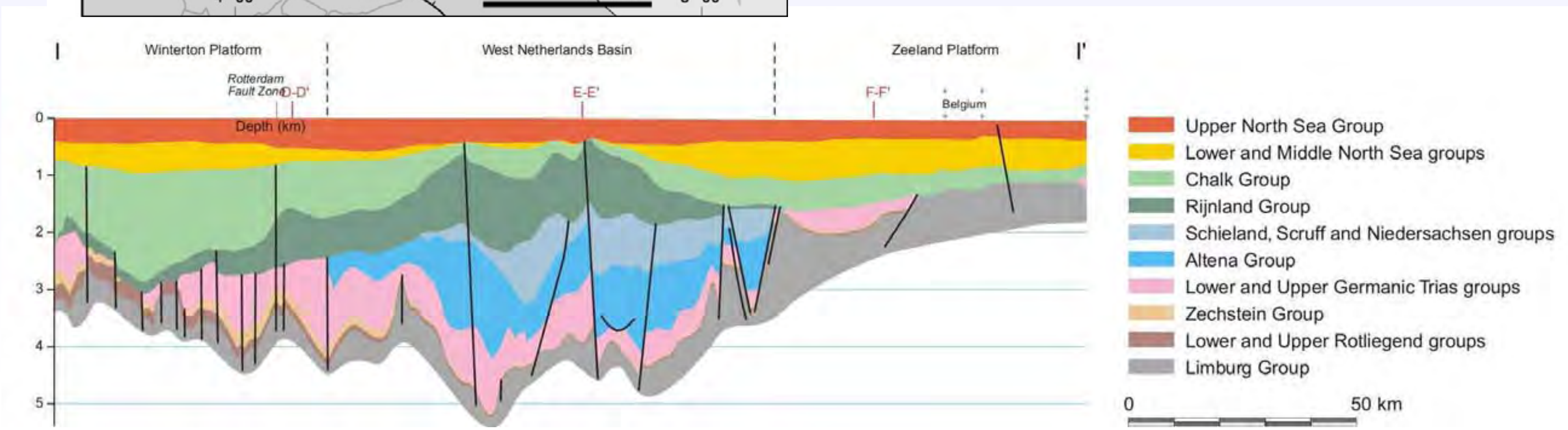


West-Netherland-Basin

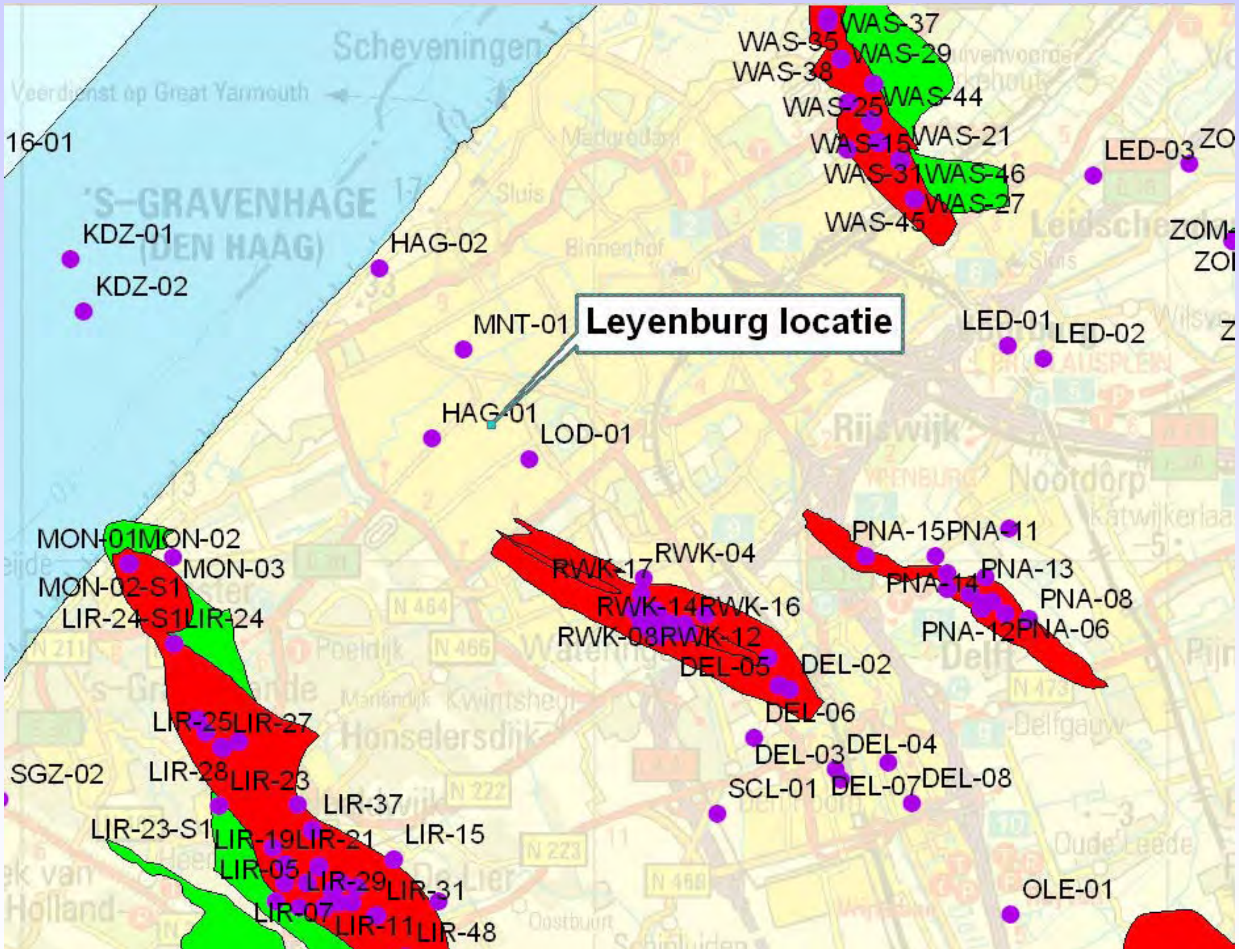
Late Jurassic/Early Cretaceous basin system.

Rifting formed half graben systems, filled with fluviatil sediments. Some of the sandstone members (Rijswijk, Berkel, Delft) are prominent reservoir rocks.

During the late Cretaceous the basin was inverted, resulting in horst and graben structures. Accumulation of oil and gas in the anticlines.



Well Locations



Exploration wells in the surrounding of the target area. Oil and gas drillings are all located at anticlines.

Target location of the geothermal drilling project is in a syncline position, where information is sparce.

GEOPHYSICA
Beratungsgesellschaft mbH

Seismic information

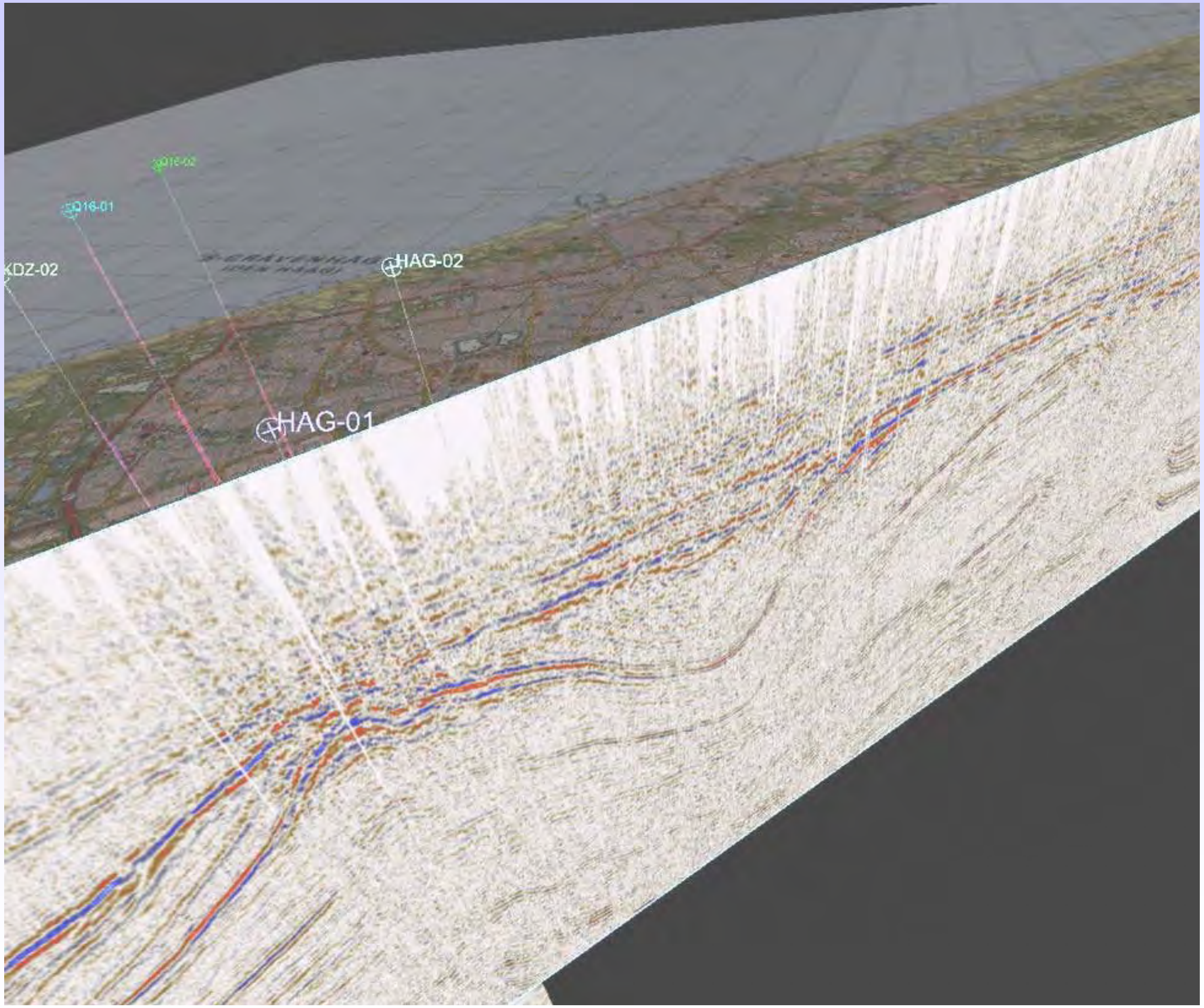


Diagram of 3-D seismic block. Visible are the exploration wells HAG-01 and HAG-02 in anticline position.

Motivation

The planning of the geothermal doublet requires a detailed knowledge of the subsurface geology and temperature conditions.

Well known

Subsurface geology and structures from oil and gas exploration activities - Seismic data and wells.

Not so well known

Temperature field – only sparse BHT data.

Targets:

Prediction of the steady-state temperature at reservoir depth considering the geometrical heterogeneity of the subsurface

Prediction of temperature evolution at producer well

GEOPHYSICA Beratungsgesellschaft mbH

Working stages

Built up of a 3-D Temperature Model (25 km x 25 km)

1. **Acquisition and compilation of basic data sets**
2. **Laboratory measurements on cuttings samples**
3. **Integration of log and laboratory data for prediction of thermophysical properties for the stratigraphic units**
4. **Set up and test of a 3-D numerical models and simulation runs**

GEOPHYSICA
Beratungsgesellschaft mbH

Key Well Selection

Boring	Yr	Analogue		Digital					Coredata
		SP	res	gr	dt	rhob	nphi	Res	
BRK-03	1955								
DEL-08	1994			gr	dt	rhob	nphi	Res	
HAG-01	1954	SP	Res						KNNSR
HAG-02	1955	SP	Res						KNNSR
KDZ-02	1986			gr	dt	rhob	nphi	Res	
LED-01	1956								KNNSR
LIR-45	1982			gr	dt	rhob	nphi	Res	KNNSR
MED-01	1958								KNNSR
MON-01	1956								KNNSR
MON-02	1982			gr	dt	rhob	nphi	Res	KNNSR
MON-03	1990			gr	dt	rhob	nphi	Res	
PNA-02	1955								KNNSR, SLDND
PNA-03	1955								KNNSR
PNA-04-S2	1981			gr		rhob	nphi		
PNA-07	1957								KNNSR
PNA-10	1957								KNNSR
PNA-14	1985			gr	dt	rhob	nphi		
PNA-15	1994			gr		rhob	nphi		
RTD-01	1984								SLDND
RWK-01	1953								KNNSR, SLDND
RWK-02	1953								KNNSR
RWK-03	1953								KNNSR
RWK-04	1954								KNNSR
RWK-05	1954								KNNSR
RWK-06	1954								KNNSR
RWK-07	1954								KNNSR
RWK-08	1955								KNNSR
RWK-09	1955								KNNSR
RWK-11	1956								KNNSR
RWK-14	1956								KNNSR
RWK-18	1954			gr	dt				
Q13-07-S2	1990			gr	dt	rhob	nphi	Res	
Q14-01	1984								KNNSR
Q16-01	1970			gr	dt			Res	KNNSR
Q16-02	1978			gr	dt	rhob	nphi	Res	
WAS-01	1956								KNNSR
WAS-02	1957								KNNSR
WAS-05	1957								KNNSR
WAS-23	1960			gr	dt	rhob	nphi	Res	KNNSR

Listing of the wells and and the availability of log data and core material.

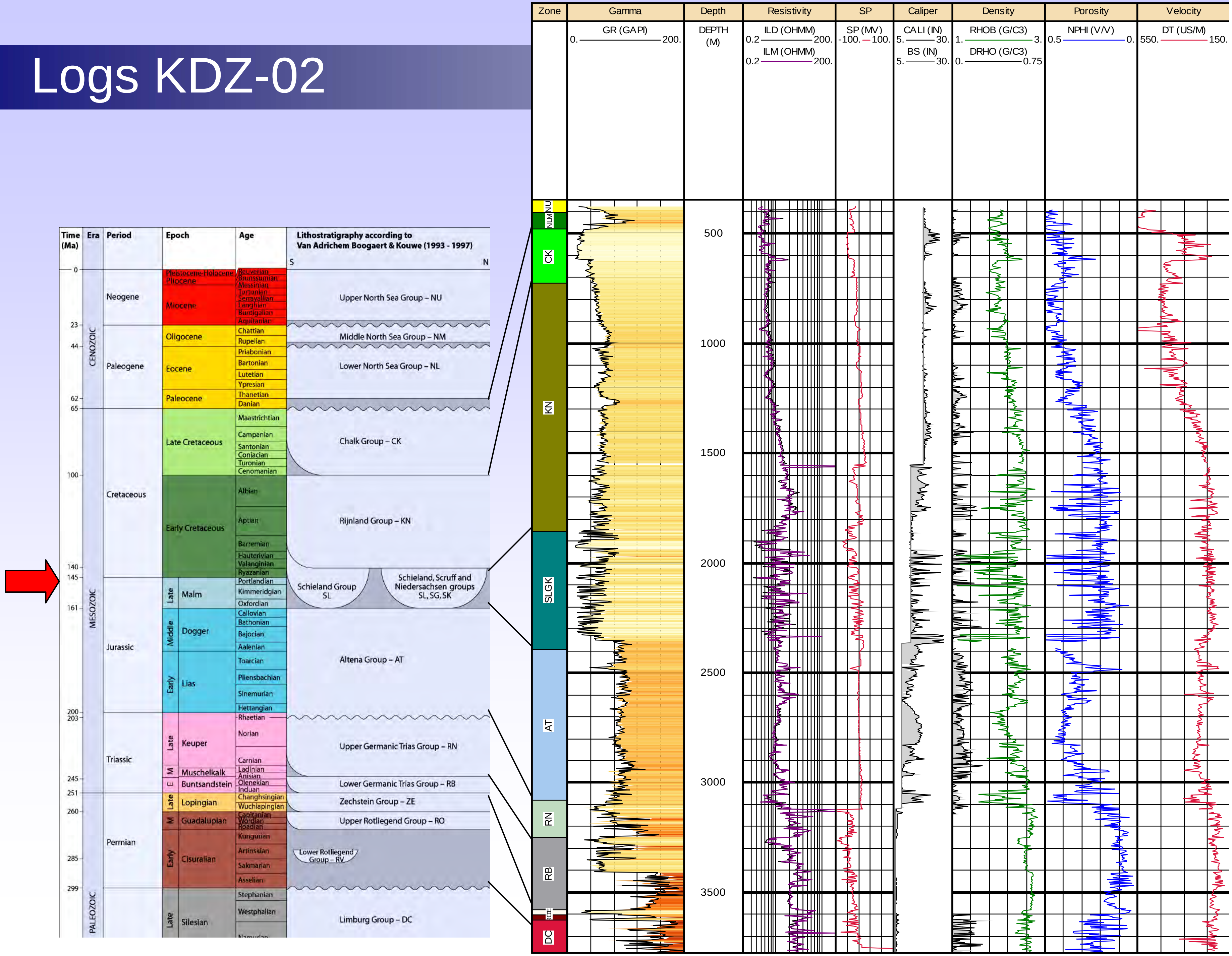
Cuttings available at repository in Zeist:

Q16-01
Q16-02
KDZ-02
WAS-23
MON-02

Cutting material per bag very limited at the Monster well (< 50 g per sample)

GEOPHYSICA
Beratungsgesellschaft mbH

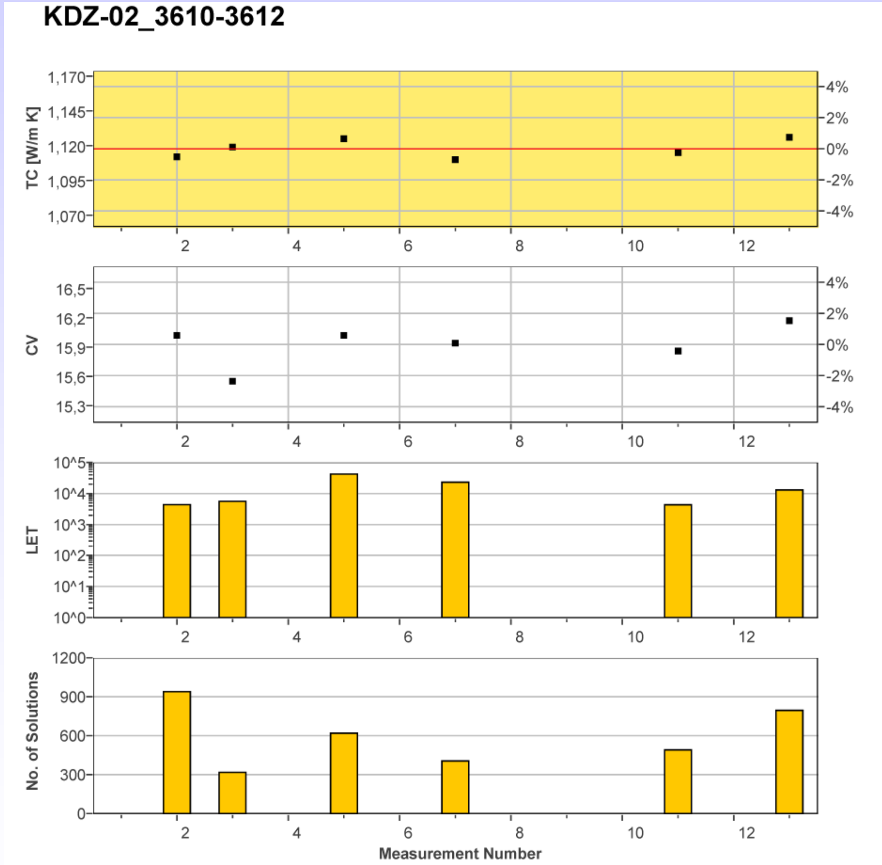
Logs KDZ-02



Time (Ma)
Era
Period
Epoch
Age
Lithostratigraphy according to Van Adrichem Boogaert & Kouwe (1993 - 1997)
S
N
CENOZOIC
MESOZOIC
PALEOZOIC
Neogene
Paleogene
Cretaceous
Jurassic
Triassic
Permian
Pleistocene-Holocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Late Cretaceous
Early Cretaceous
Malm
Dogger
Lias
Keuper
Muschelkalk
Buntsandstein
Lopingian
Guadalupian
Cisuralian
Silesian
Late
Middle
Early
Upper North Sea Group – NU
Middle North Sea Group – NM
Lower North Sea Group – NL
Chalk Group – CK
Rijnland Group – KN
Schieland Group SL
Schieland, Scruff and Niedersachsen groups SL, SG, SK
Altena Group – AT
Upper Germanic Trias Group – RN
Lower Germanic Trias Group – RB
Zechstein Group – ZE
Upper Rotliegend Group – RO
Lower Rotliegend Group – RV
Limburg Group – DC
Zone
Gamma
Depth
Resistivity
SP
Caliper
Density
Porosity
Velocity
GR (GAPI)
0.
200.
DEPTH (M)
ILD (OHMM)
ILM (OHMM)
0.2
200.
SP (MV)
-100.
100.
CALI (IN)
BS (IN)
5.
30.
RHOB (G/C3)
1.
3.
DRHO (G/C3)
0.
0.75
NPHI (V/V)
0.5
0.
DT (US/M)
550.
150.
NU
NLNM
CK
KN
SLGK
AT
RN
RB
ROE
DC
500
1000
1500
2000
2500
3000
3500

Laboratory Work

Thermal Conductivity Measurements / TK04



TC_{mean} : 1,118 W $m^{-1}K^{-1}$
TC_{min} : 1,110 W $m^{-1}K^{-1}$
TC_{max} : 1,126 W $m^{-1}K^{-1}$
Number of Measurements : 13
Measurement Date : 21.02.2008

Std. Deviation : 0,007 W $m^{-1}K^{-1}$
Std. Error : 0,003 W $m^{-1}K^{-1}$
Variation : ± 0,7%

Measurement of 50 cuttings samples.

Measuring a rock-water mixture with a half-space device.

Results: Rock matrix conductivtity

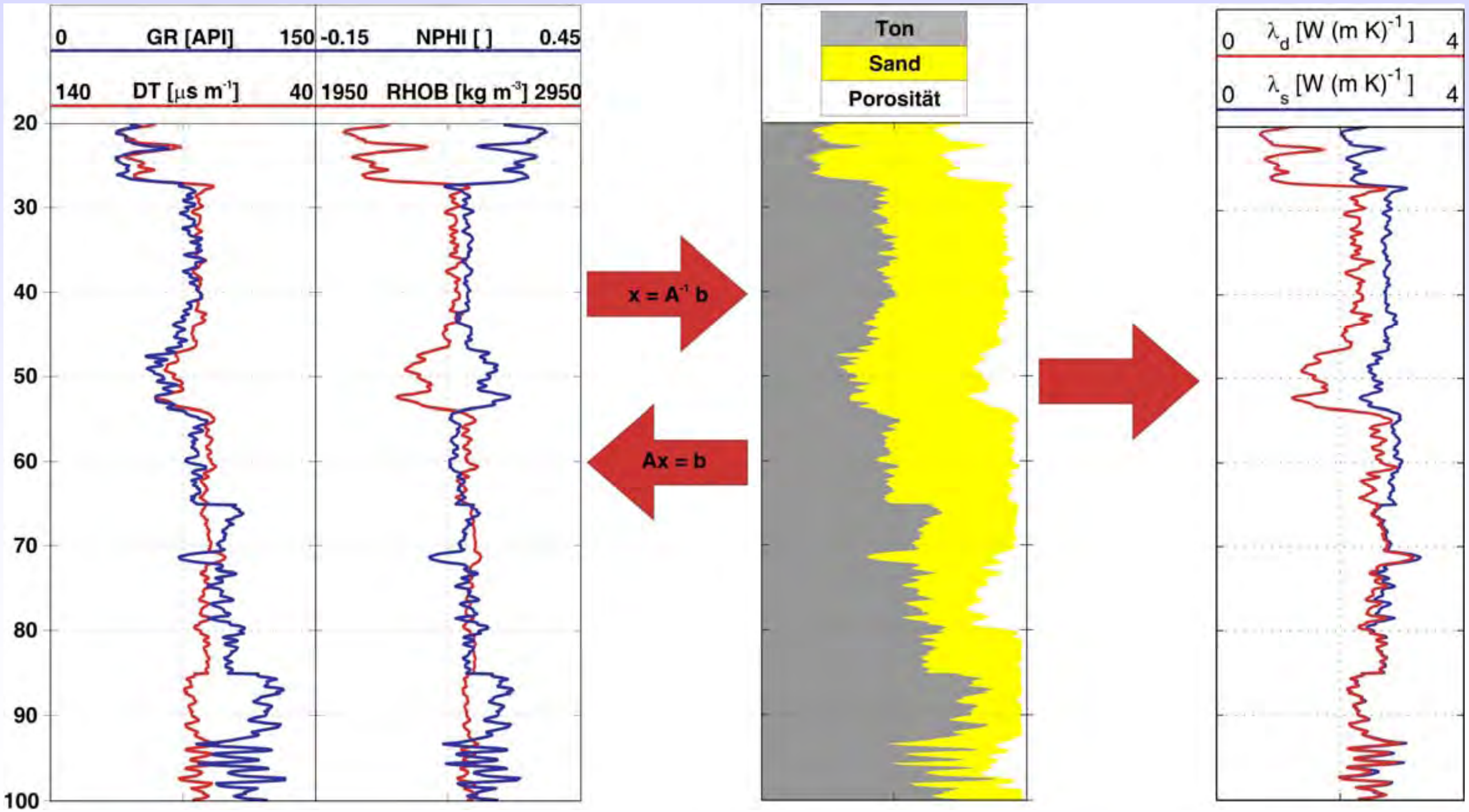
Log Analysis

Determination of thermophysical properties for the stratigraphic units

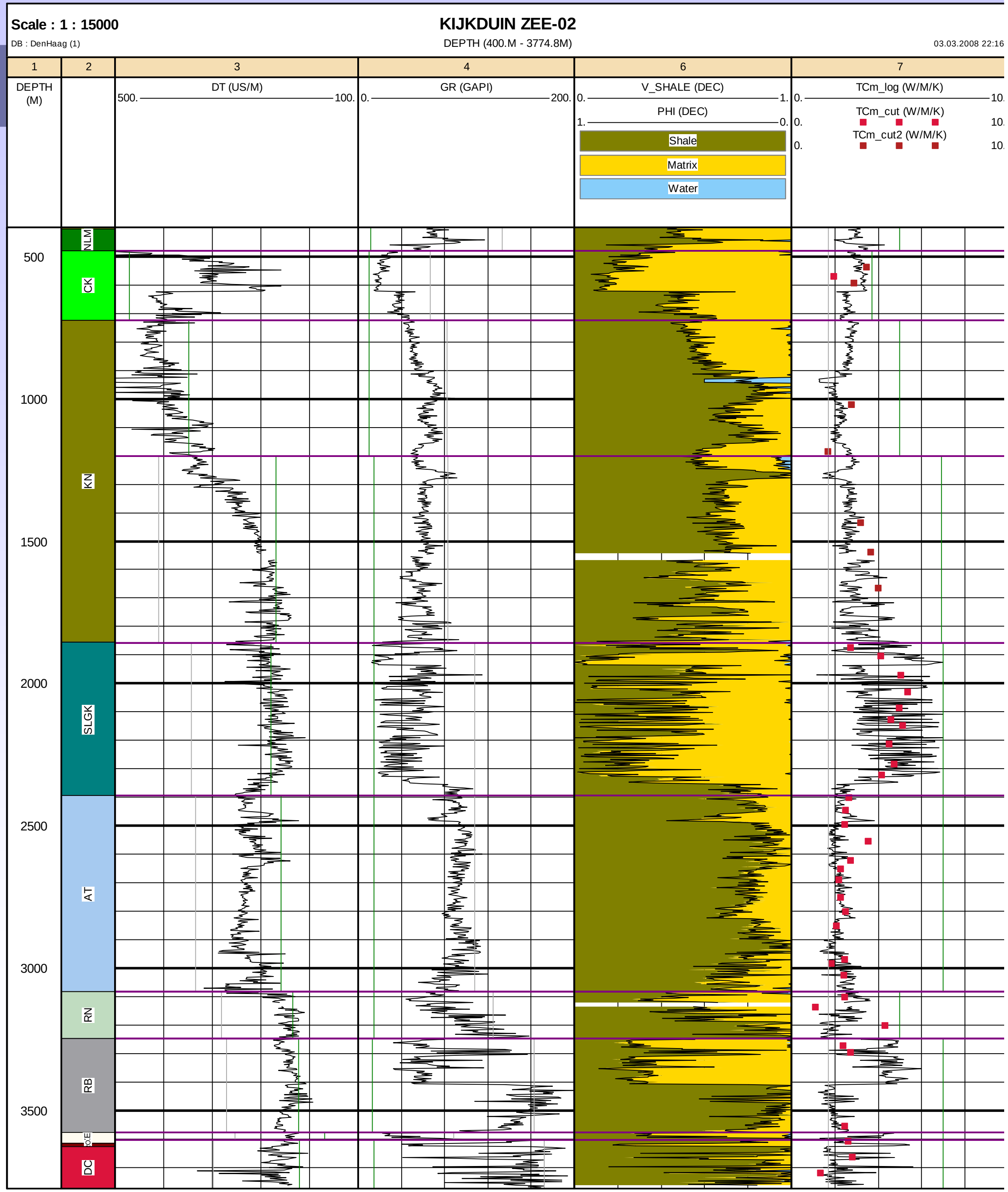
Rock matrix components, rock porosity

Thermal property prediction by logging data

Calibration of log data with laboratory measurements

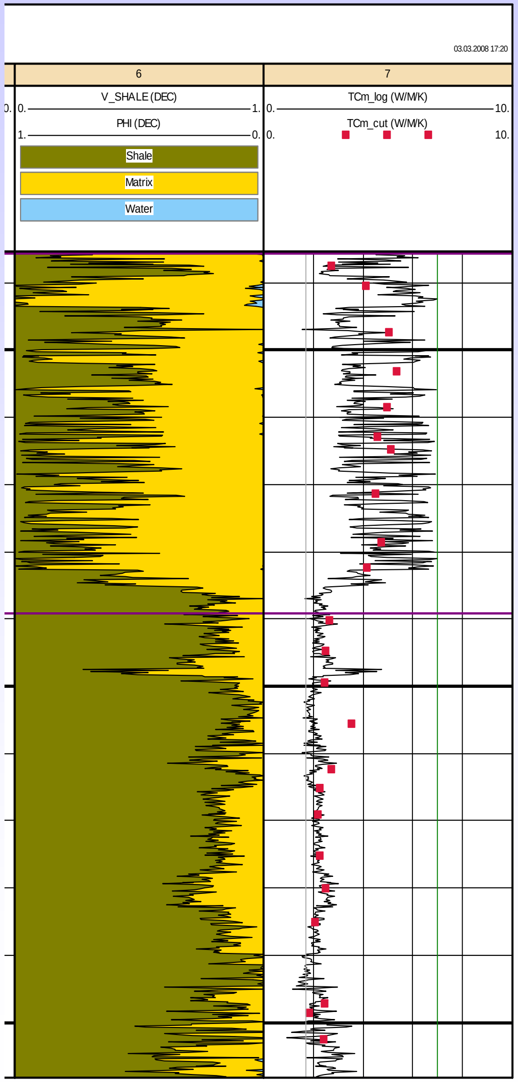


TC Rock Matrix



Comparison of measured thermal conductivities on cuttings and matrix conductivities calculated from logging data.

TC Rock Matrix and TC Effective



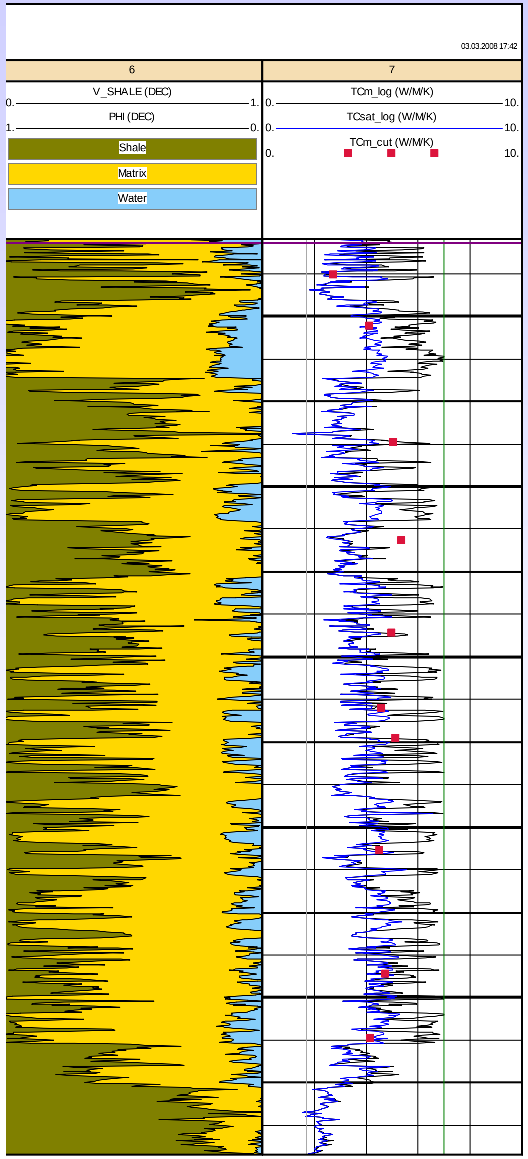
Siliciclastic sediments of the „SLGK - Jurassic Group“ and the „AT- Altena Formation“.

Average Values
TCmatrix

	SLGK	AT
TCm_log	*4.42*	*2.16*
TCm_cut	*4.54*	*2.46*

Calculation of effective thermal conductivities by considering rock porosity.

$$\lambda_s = \lambda_w^{\phi} \lambda_m^{(1-\phi)}$$



Beratungsgesellschaft mbH

3-D Model: Thermal Properties

Unit	Bulk Thermal Conductivity ($W\ m^{-1}\ K^{-1}$) Mean–Stdv. **Mean** Mean+Stdv.	Heat production ($\mu W\ m^{-3}$)
North Sea Supergroup (N)	**2.3**	1.05
Upper Cretaceous Supergroup (CK)	1.80 – **2.20** – 2.60	0.46
Lower Cretaceous Supergroup (KN)	1.94 – **2.51** – 3.08	0.92
Jurassic Supergroup (S)	2.75 - **3.75** – 4.57	0.75
Altena Group (AT)	1.81 – **2.17** – 2.53	1.44
Lower Germanic Trias Group (RB)	1.93 – **2.80** – 3.67	1.61
Permian Zechstein Group (ZE)	1.90 – **3.14** – 4.35	1.33
Rotliegend (RO)	**4.0**	0.75
Basement (DC)	**2.3**	2.30

3-D Model set up

Heat transport steady-state 3D-Simulation

9 Geological units: Base Layers from seismic survey (TNO)

Basal heat flow: 65 mW/m^2 , Surface temperature: 11 °C

Dimensions: 22.5 km x 24.3 km x 5 km, about 2.4 Mio nodes

Properties are functions of temperature

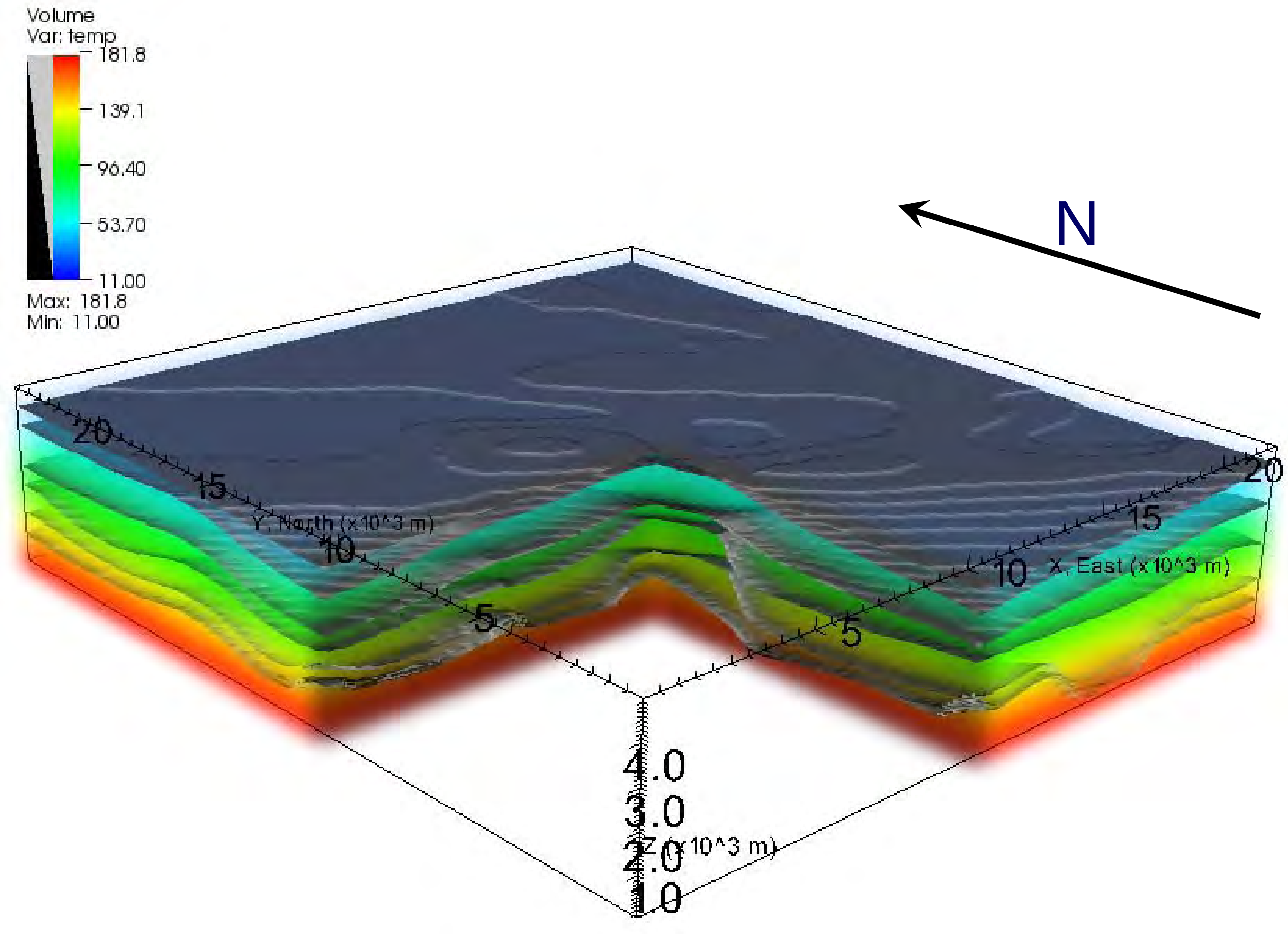
- **Motivation:**

  Temperature prediction at location

  Sensitivity analysis

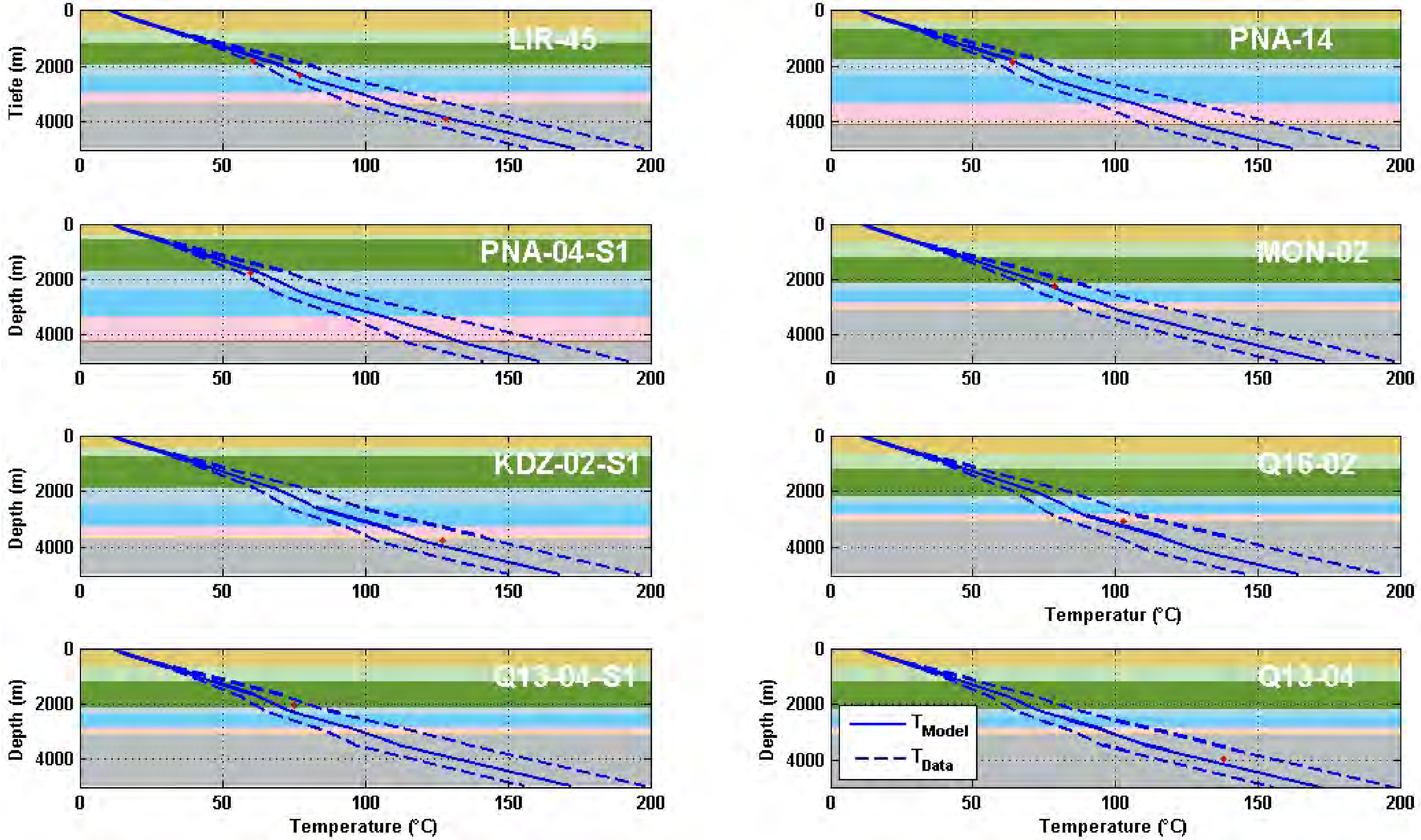
GEOPHYSICA
Beratungsgesellschaft mbH

3-D Model: Layers and Temperature Distribution

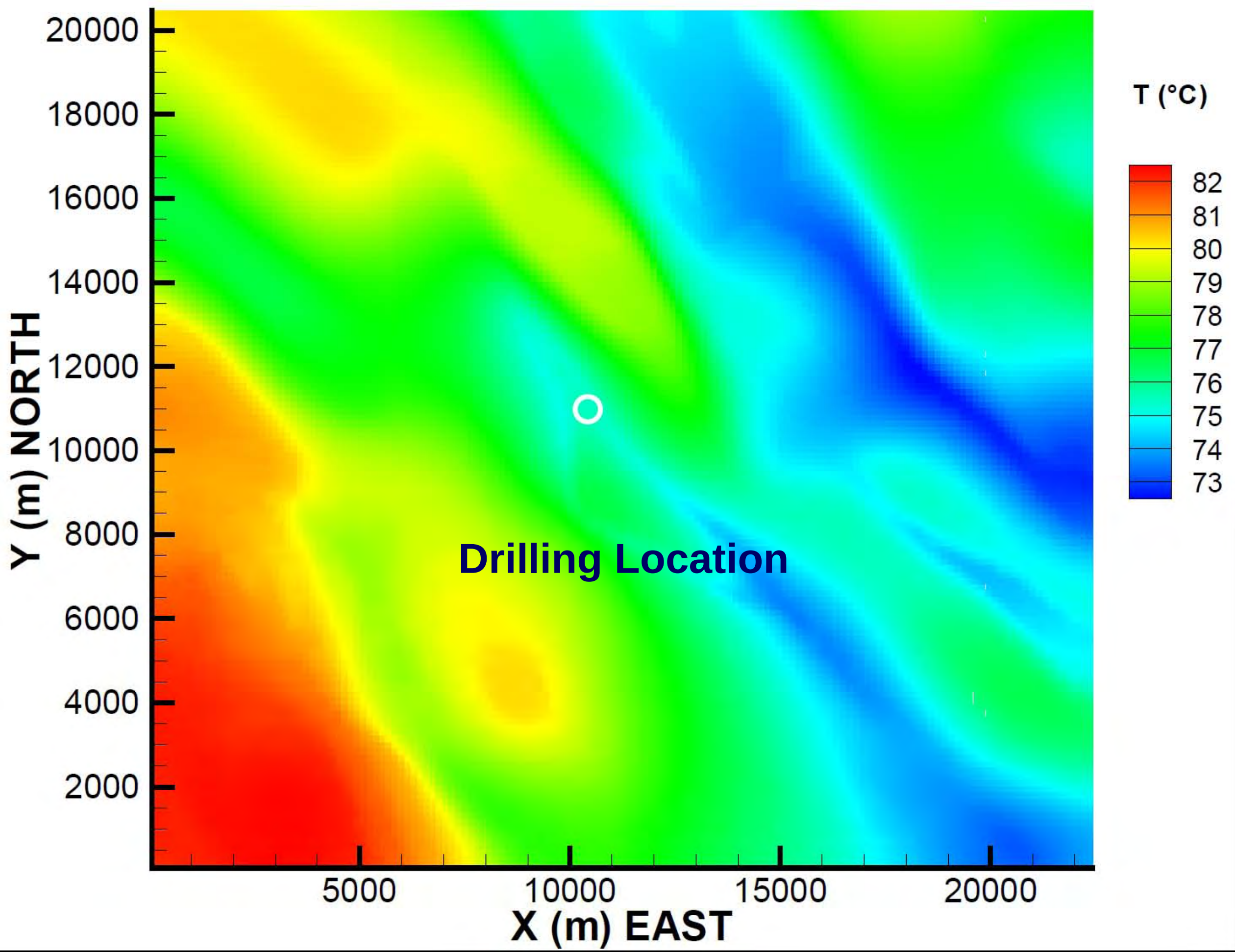


GEOPHYSICA Beratungsgesellschaft mbH

Comparison with BHT in the Area



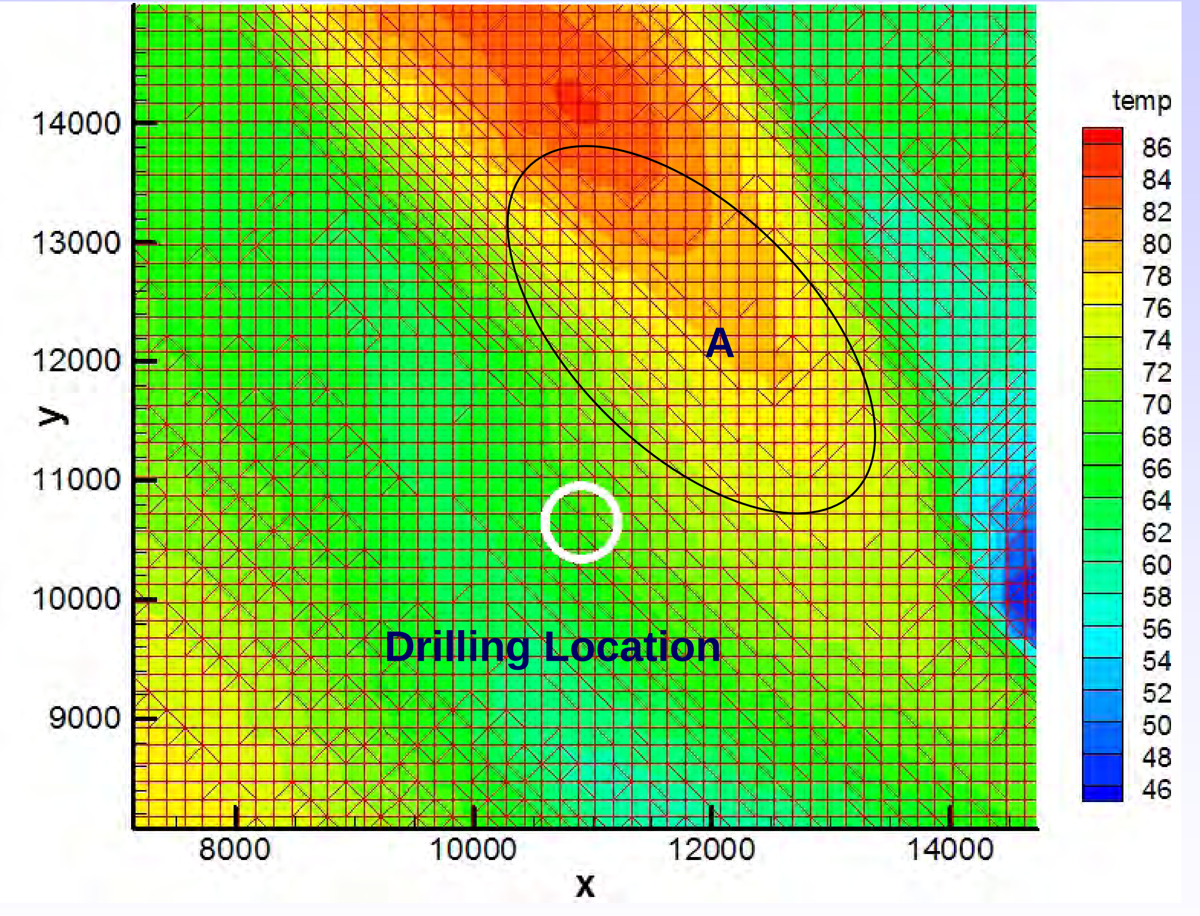
Cross section: z-plane / 2300 m Depth



Model reveals temperature variations of up to 9 °C within one depth as a result of the geometry of the layers and the corresponding thermal conductivity contrasts.

GEOPHYSICA Beratungsgesellschaft mbH

Iso slice: Top Unit 4, Reservoir



Production well reached target reservoir in September 2010.

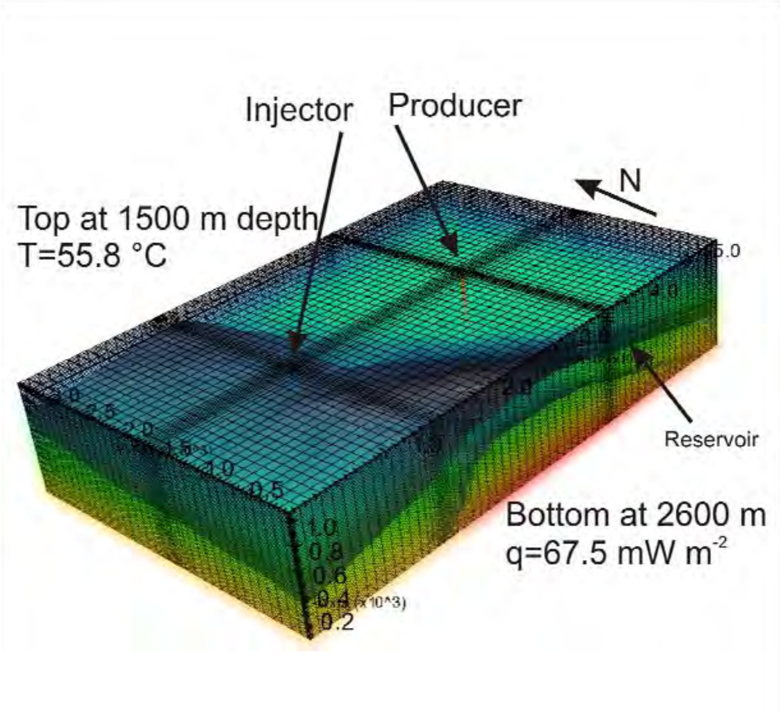
Prognosed temperatures of about 75°C were accounted.

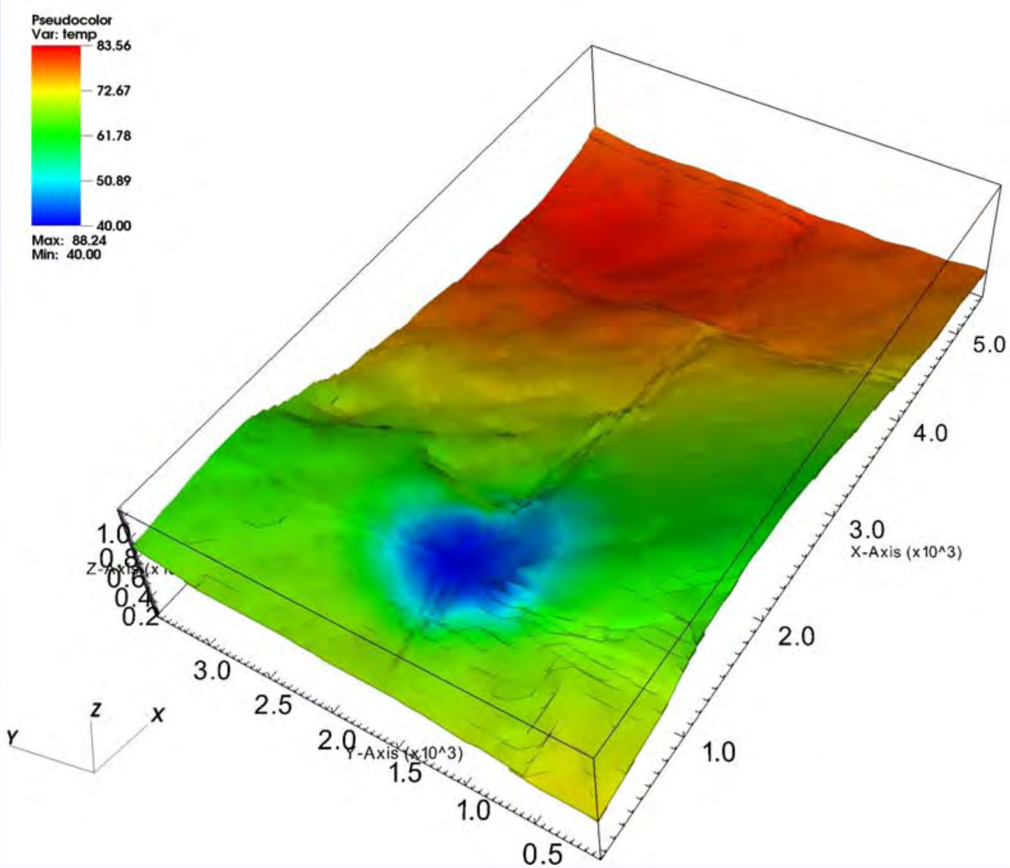
Temperature map calculated for the top of the reservoir. Based on this temperature information, the best position of the production well was chosen within a proposed target area A. This helped to save drillings costs and time.

GEOPHYSICA Beratungsgesellschaft mbH

Reservoir Simulations

Reservoir model for a deep geothermal dublette





Temperature (°C) prediction after 50 years of injection

GEOPHYSICA Beratungsgesellschaft mbH

Case Study – Hansestadt Hamburg

Client: Geologisches Landesamt Hamburg

Objective:

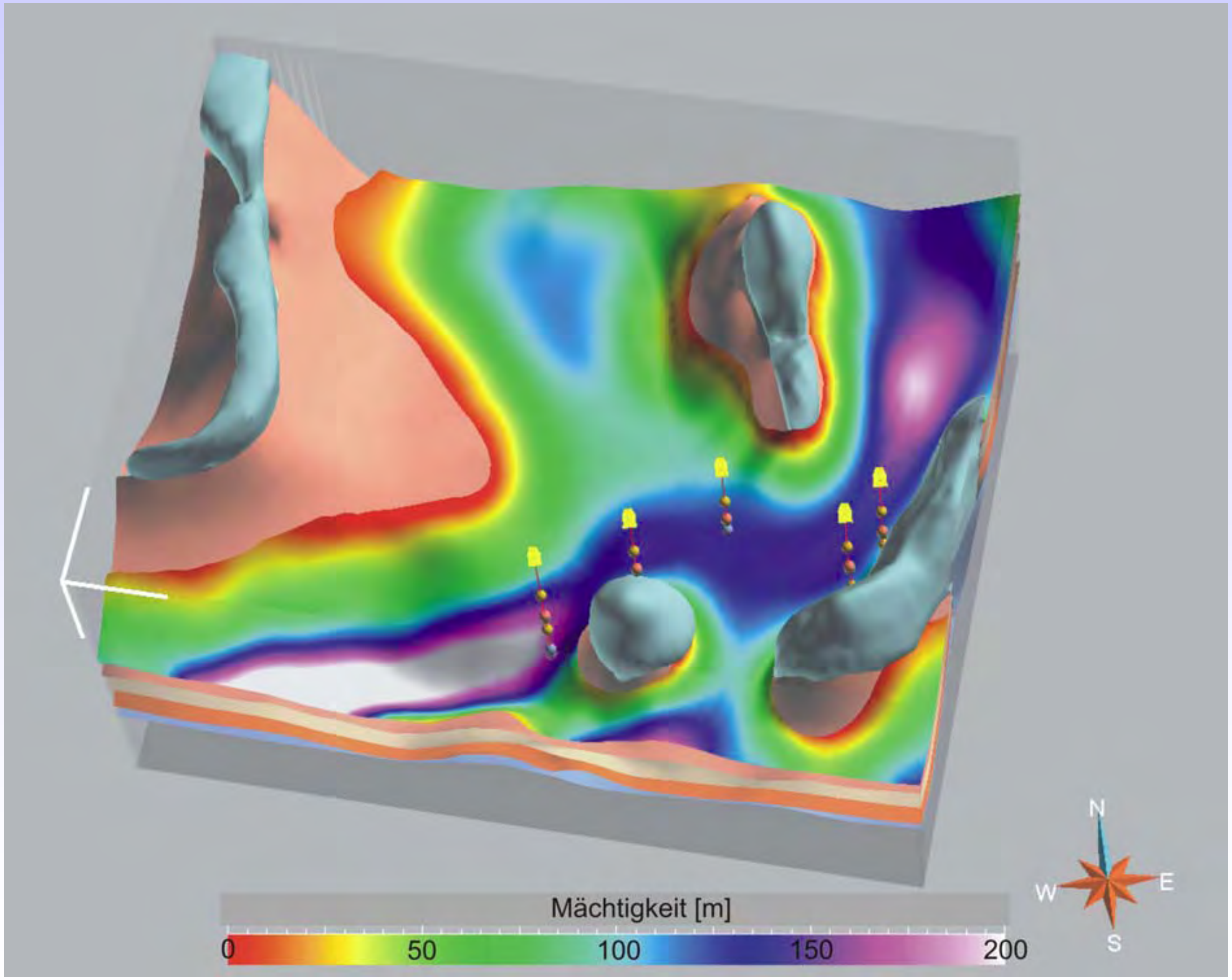
Large Scale Geothermal Model for the City of Hamburg and surrounding areas of Schleswig-Hostein.

Model size: 35,4 km x 28,4 km, depth 6 km

Model shall serve as information basis for future geothermal projects and shall give detailed information on subsurface structure and the related temperature field.

GEOPHYSICA
Beratungsgesellschaft mbH

Hamburg: Geological Model

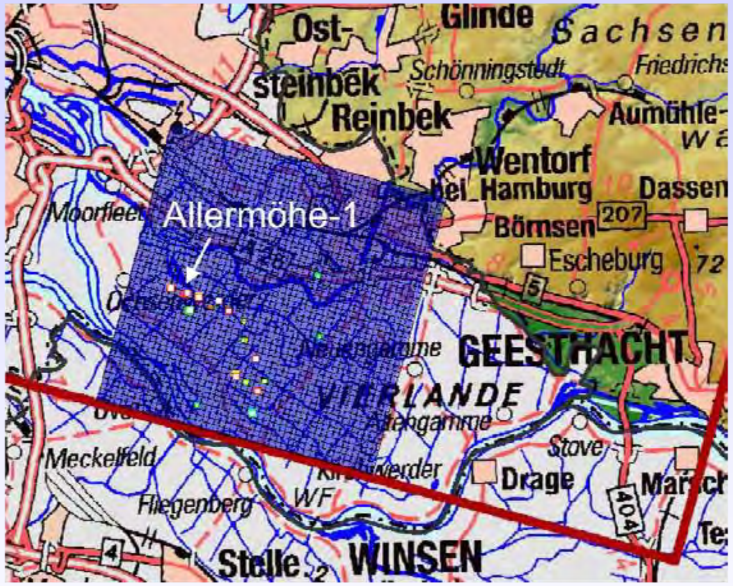


Model is based on GOCAD Geological Model provided by LLUR Schleswig-Holstein - Dezernat64

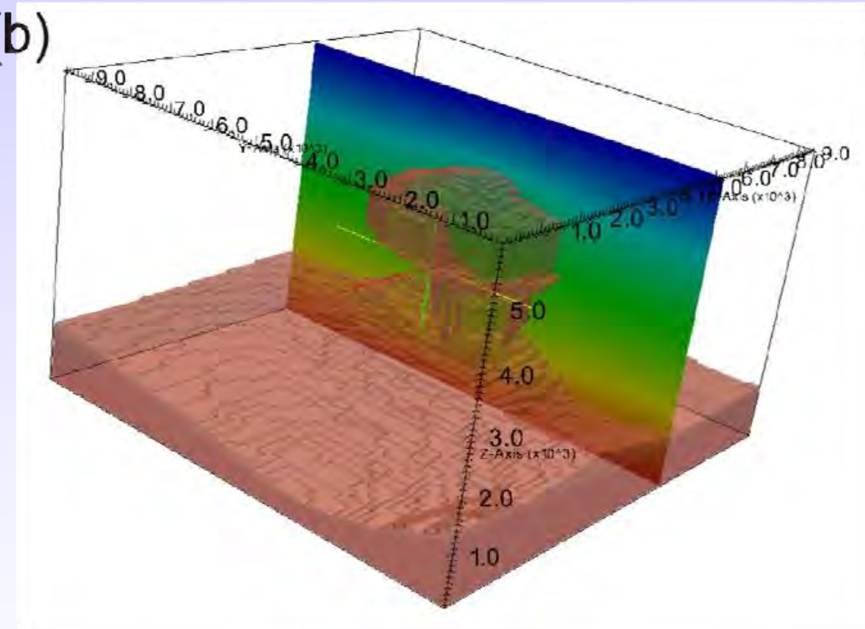
GEOPHYSICA
Beratungsgesellschaft mbH

Steady state simulations: inverse simulations

(a)

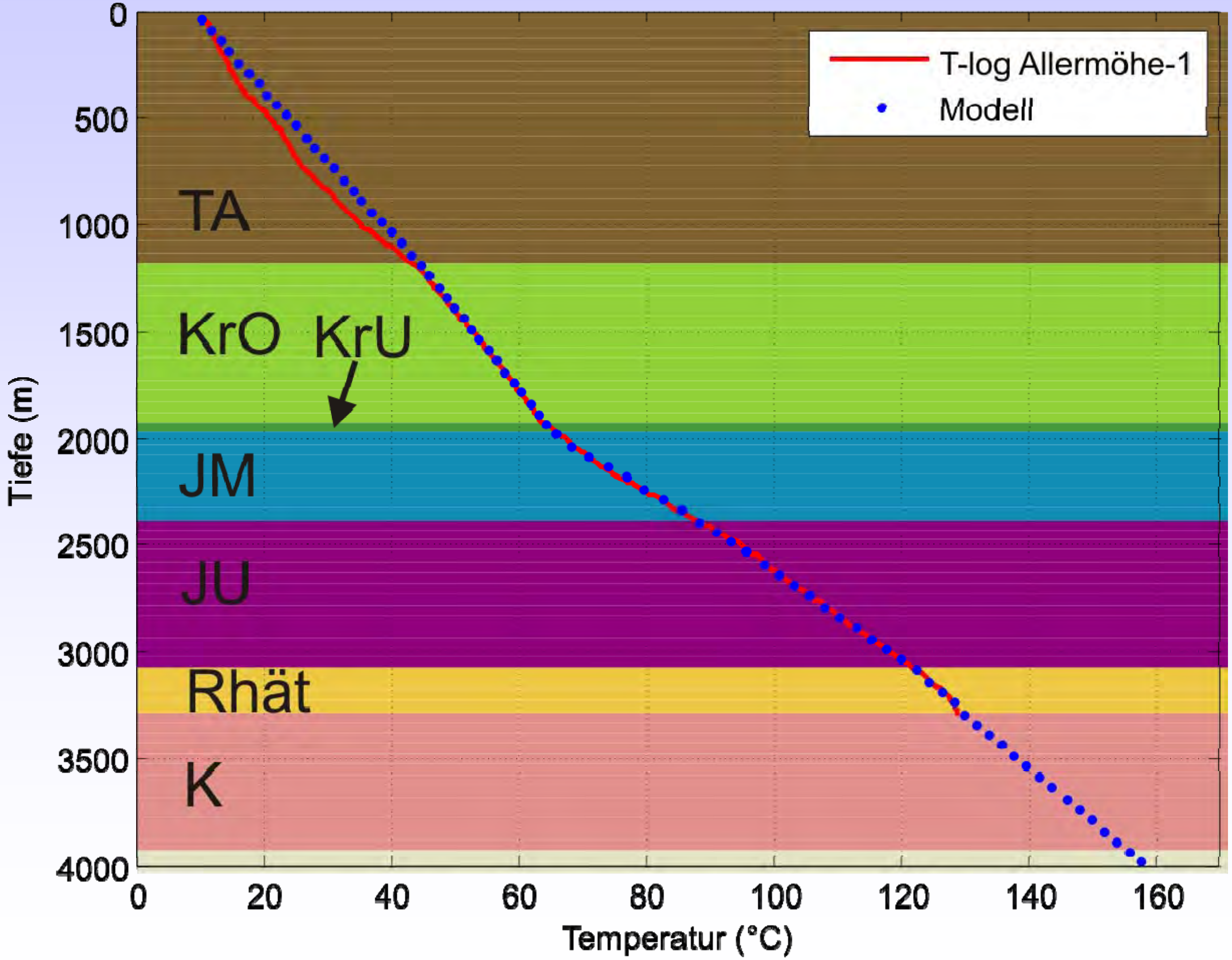


(b)



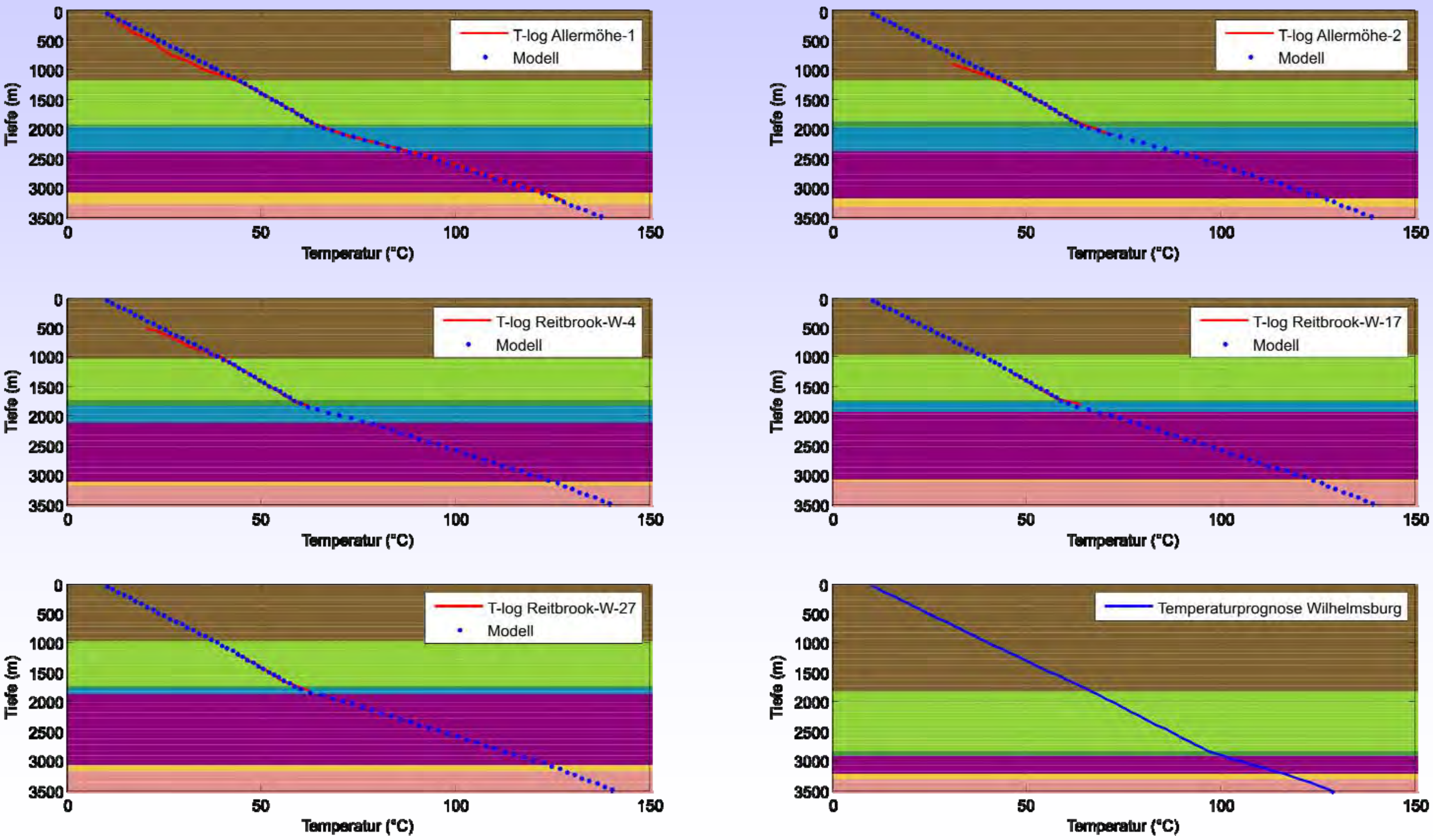
For inversion a small model was used, comprising temperture data from existing oil- and gas exploration wells in the sourrounding of a salt dome.

Steady state simulations: Temperature prediction



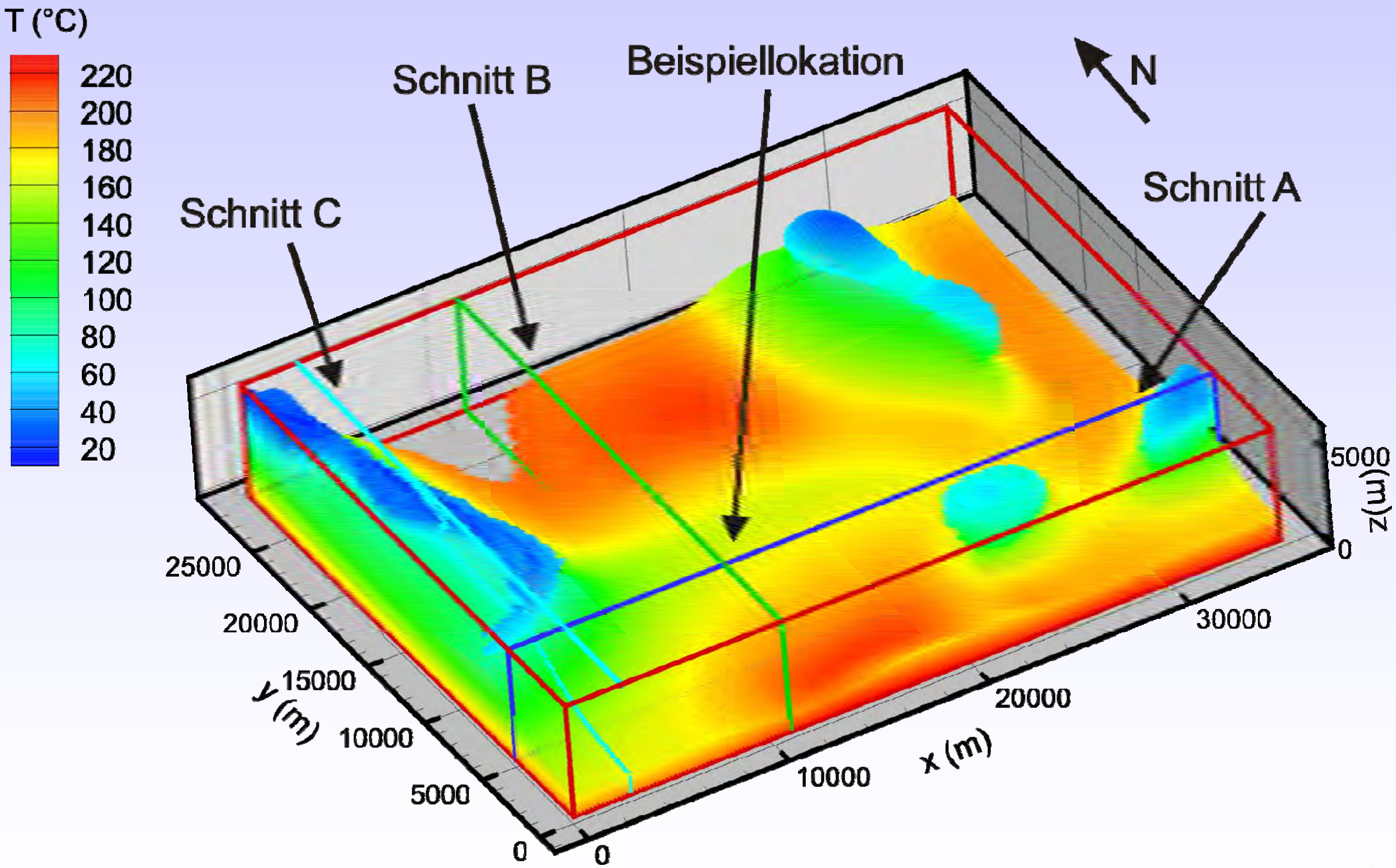
Temperature Log Data: LIAG, Hannover

Steady state simulations: Temperature prediction



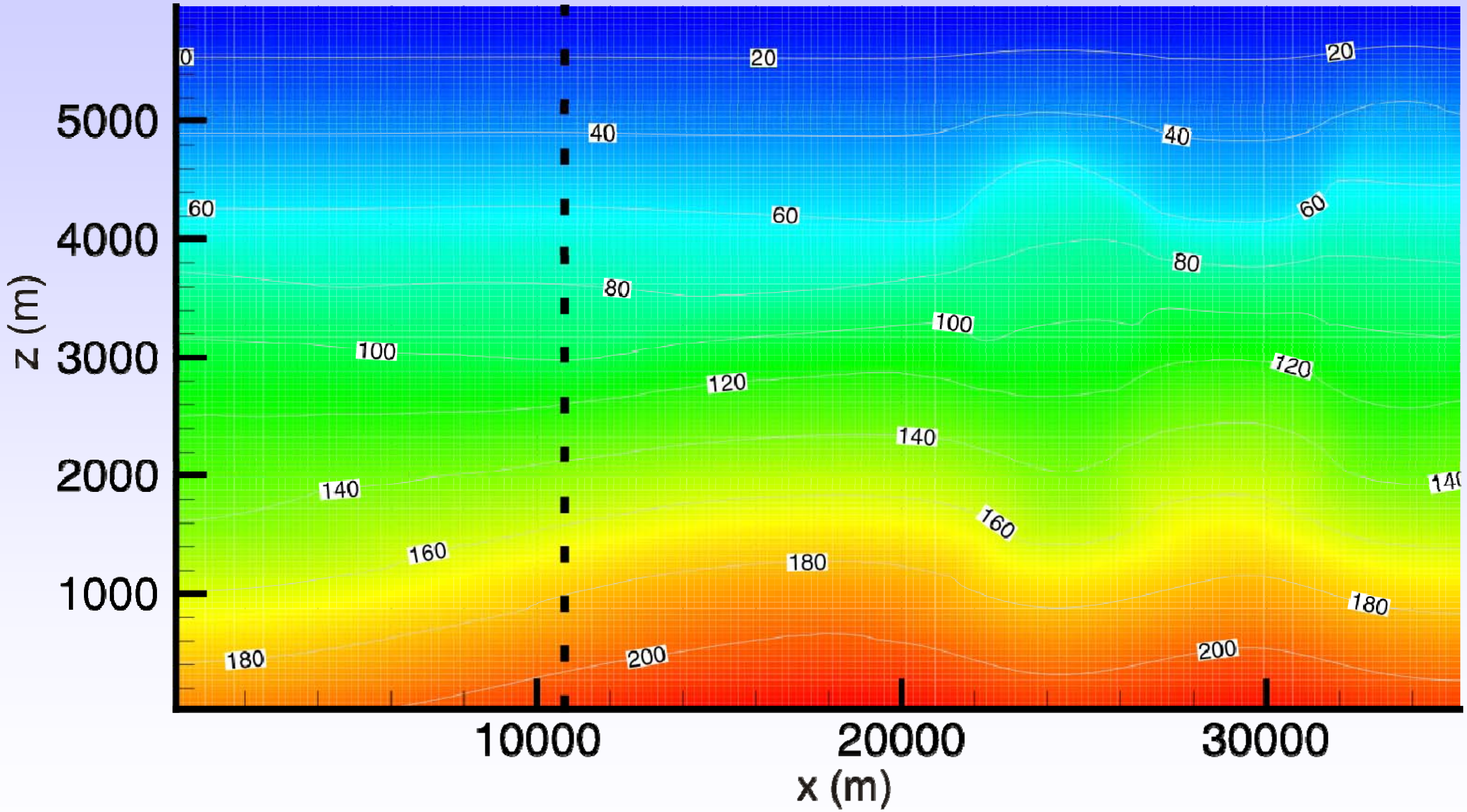
Temperature Log Data: LIAG, Hannover

Temperature distribution at Top Zechstein



GEOPHYSICA Beratungsgesellschaft mbH

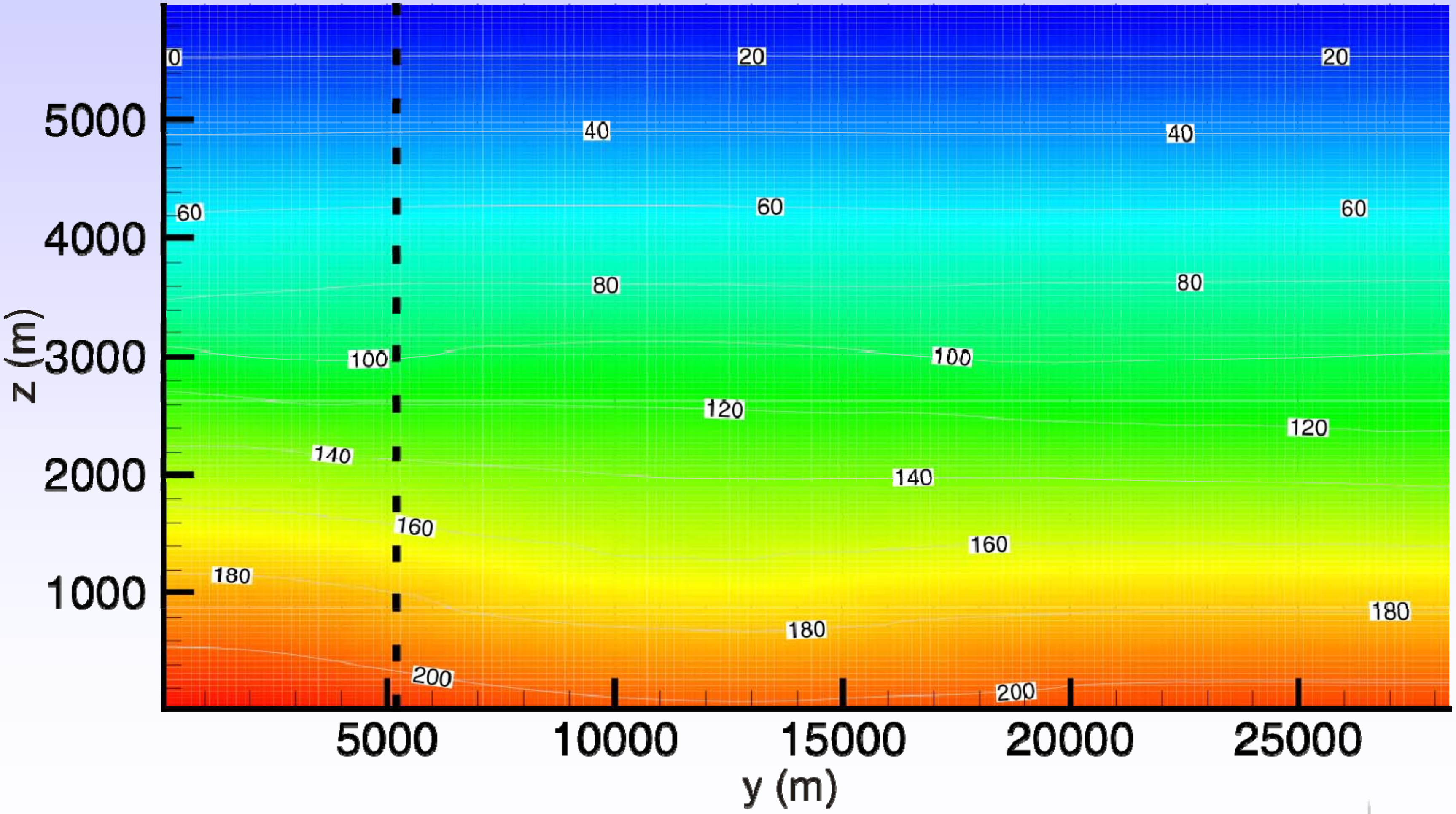
Temperature field, vertical section (A)



The model shows, that the salt structures strongly influence the temperature field. Isotherms are distorted in the surrounding of the salt domes and thermal gradients strongly change from place to place.

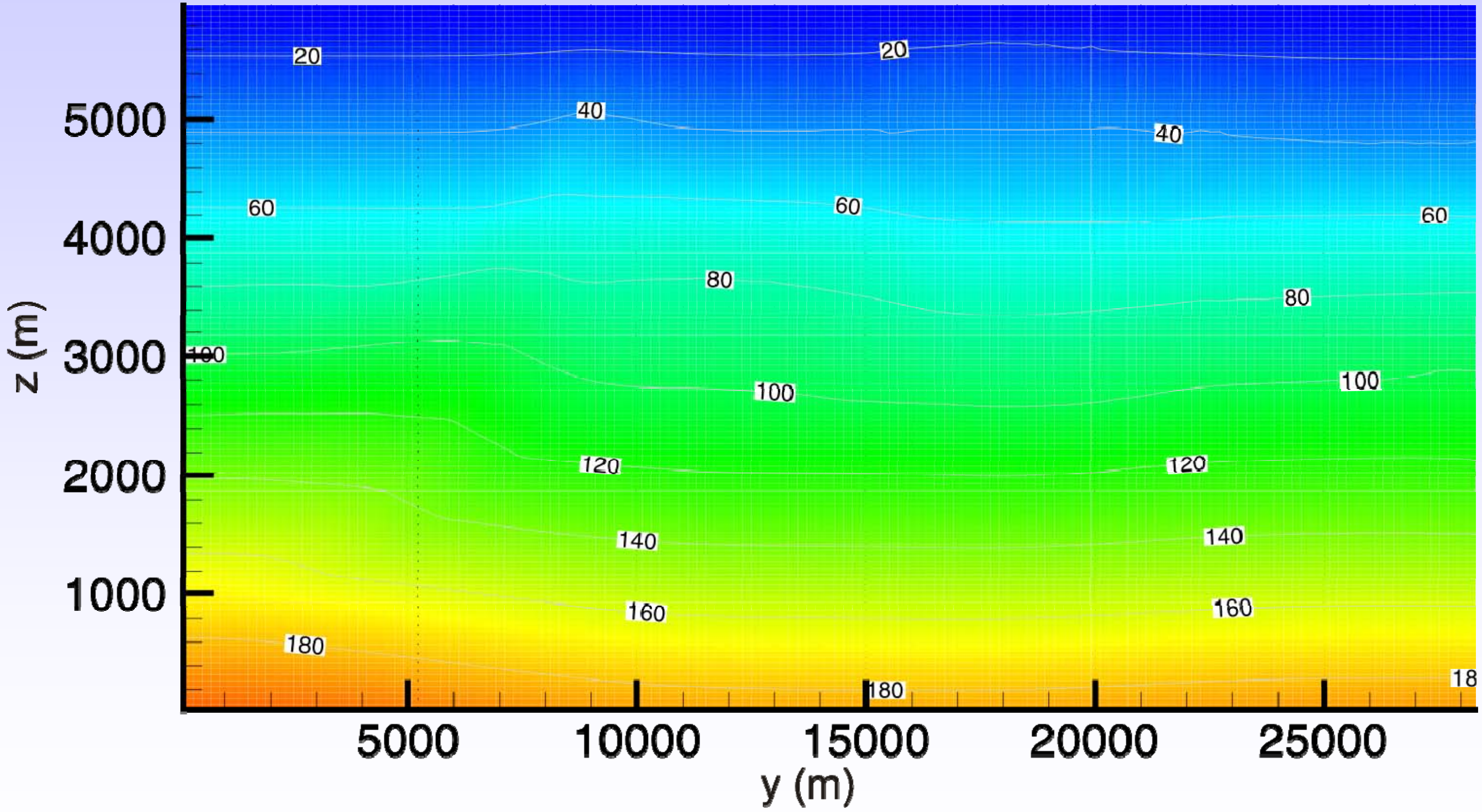
GEOPHYSICA
Beratungsgesellschaft mbH

Temperature field, vertical section (B)



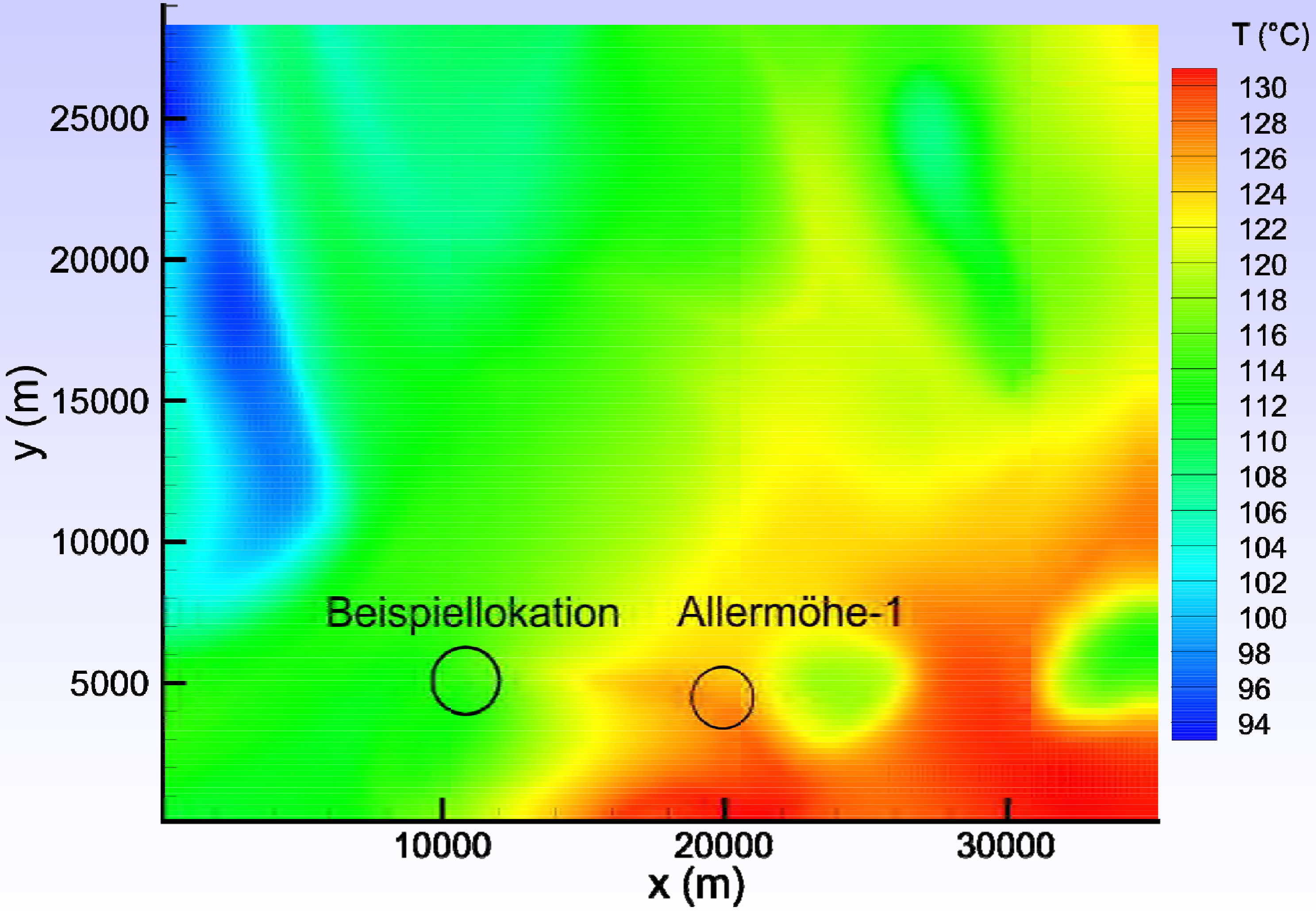
GEOPHYSICA
Beratungsgesellschaft mbH

Temperature field, vertical section (C)



GEOPHYSICA
Beratungsgesellschaft mbH

Temperature field, horizontal section z=3150 m



Model reveals temperature variations of more than 30°C in a depth of 3150 m, mainly as a result of the structure of the salt diapirs and the high thermal conductivity of the rock salt.

GEOPHYSICA Beratungsgesellschaft mbH

CONCLUSION

1. Combination of laboratory data, logging data and modeling allows a reliable prediction of reservoir temperatures and the future production behavior.
2. Numerical models can help to find optimal target locations and save drilling costs.
3. Long term reservoir simulations reduce risks in terms of economic and operating efficiency.
4. The cost of such studies are minor in comparison to seismic surveys and drillings.

Acknowledgements

Case Study – Den Haag
We thank IF Technology (Arnheim, the Netherlands) and TNO Built Environment and Geosciences (Delft, the Netherlands) for providing data and granting permission to publish results, as well as E.ON Benelux (Rotterdam, the Netherlands) for initiating and funding the districted heating project in The Hague, from which these data are derived.

Case Study – Hamburg
We thank the Geological Surveys of Hamburg and Schleswig-Holstein for providing data and granting permission to publish the results.

GEOPHYSICA
Beratungsgesellschaft mbH

References

.

Vogt, C., Mottaghy, D., Wolf, A., Rath, V., Pechnig, R. & Clauser, C. (2010): Reducing Temperature Uncertainties by Stochastic Geothermal Reservoir Modelling. Geophys. J. Int., 181, 1, 321-333, (DOI)10.1111/j.1365-246X.2009.04498.

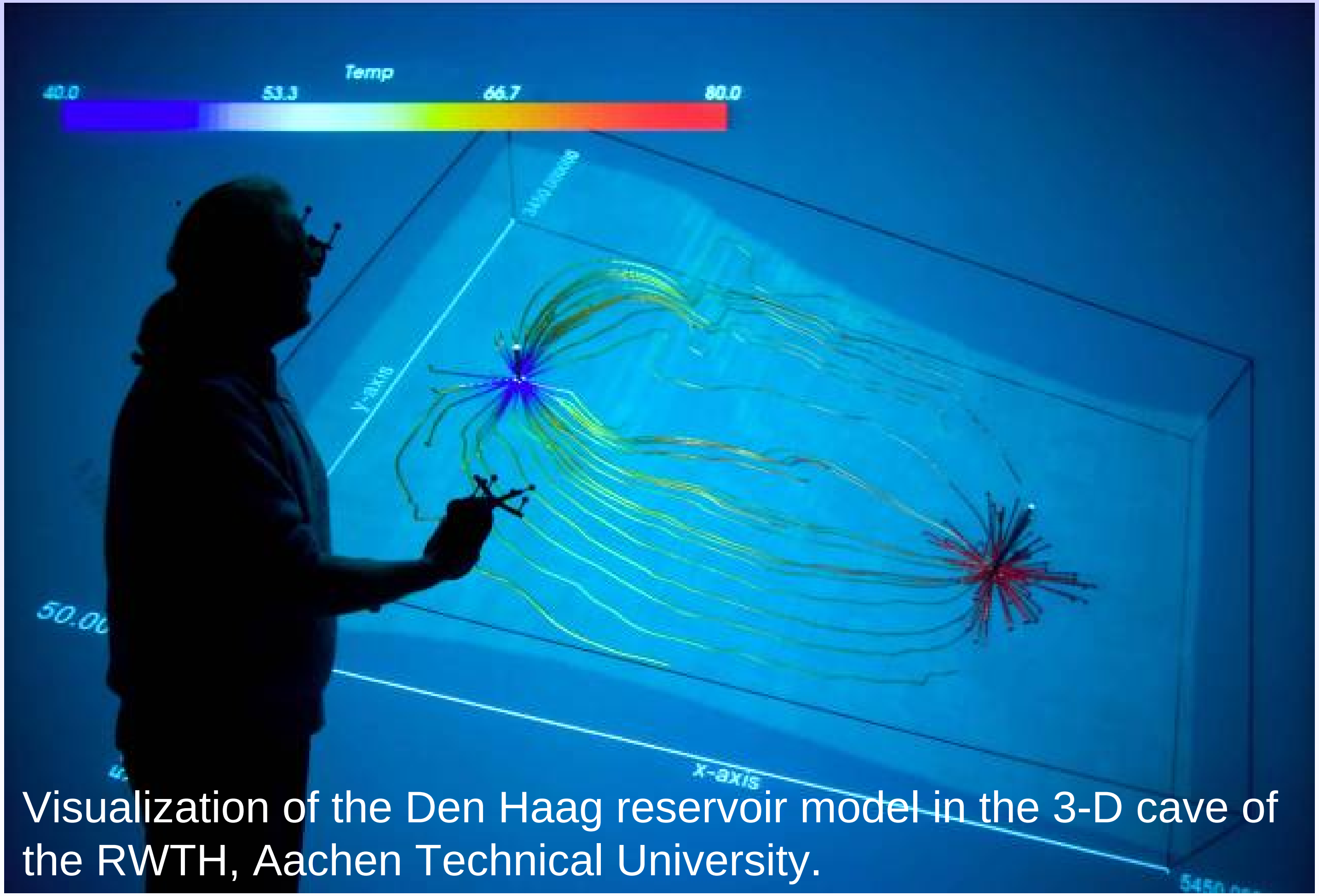
Mottaghy, D., Pechnig, R., (2010). Erstellung eines geothermischen Modells für Teile Hamburgs und anliegende Gebiete. BBR - Fachmagazin für Brunnen- und Leitungsbau, Jahresmagazin 12/2010

Mottaghy, D., Pechnig, R., (2009). Numerische 3-D Modelle zur Temperaturvorhersage und Reservoirsimulationen. BBR - Fachmagazin für Brunnen- und Leitungsbau, 60-10, 44-51

Hartmann, A., Pechnig, R. & C. Clauser, (2007): Petrophysical analysis of regional-scale thermal properties for improved simulations of geothermal installations and basin-scale heat and fluid flow. International Journal of Earth Sciences, DOI 10.1007/s00531-007-0283-y.

GEOPHYSICA
Beratungsgesellschaft mbH

Thank you for attention



Visualization of the Den Haag reservoir model in the 3-D cave of the RWTH, Aachen Technical University.

www.geophysica.de

GEOPHYSICA
Beratungsgesellschaft mbH