

Bijlage 1

GEO THERMIE DELFT

Geologische evaluatie t.b.v. Geothermie Delft Doublet
SDE++ 2020

Chapters 1-2, 7-10, Appendices F-L

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1 Summary

This report describes the geology of the subsurface of Delft, in particular the Delft Sandstone Member reservoir, with the aim to highlight the geothermal potential. Based on this study a new doublet is planned at the Delft University of Technology. The doublet will consist of two wells, producer DEL-GT-01 and injector DEL-GT-02 (Figure 1). The produced heat will be used for district heating. The report will be used to support the SDE++ application of this doublet.

1.1 Planned doublet

The project location is located within the exploration license of Pijnacker-Nootdorp 6A ([Staatscourant 2019, nr 49060](#)). The location of the planned wells and their surface location are presented in Figure 1 and Table 1.

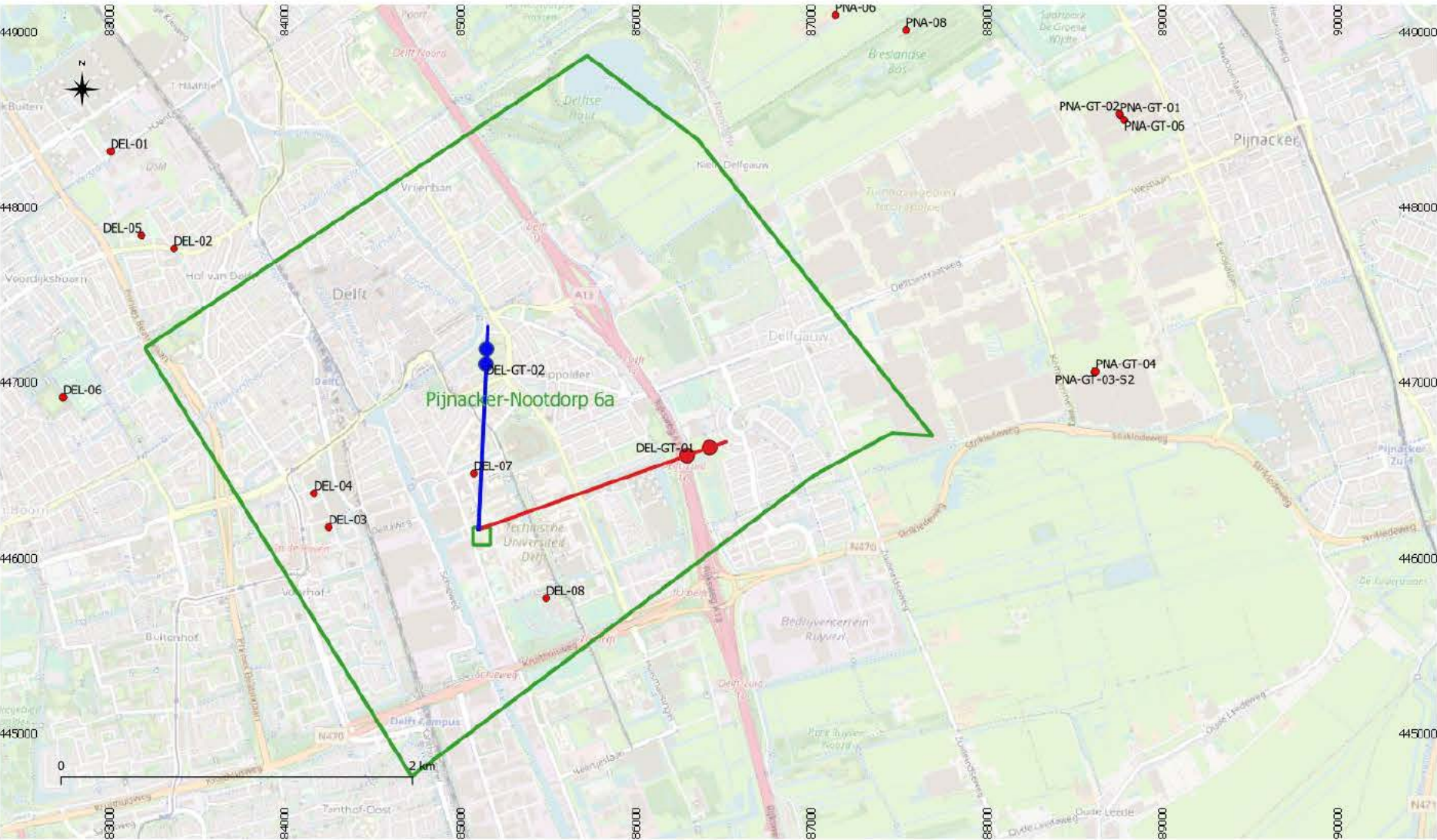


Figure 1: Map view of the study area and planned doublet. The Pijnacker-Nootdorp 6a exploration license is outlined in green and the surface location is shown as a green square. The well trajectories of the producer (DEL-GT-01) is shown in red and the well trajectory of the injector (DEL-GT-02) is shown in blue. The red and blue dots on the well trajectories indicate the penetration points at the top and the bottom of the reservoir. The red dots show other wells in the vicinity of the project location.

Table 1: Rijkswijkdriehoek (RD) coordinates of the geothermal wells and the expected top and base of the reservoir in the injection and production well

	X (RD) m	Y (RD) m
DEL-GT-01		
Surface	85106	446165
Top Reservoir Delft Sst	86285	446583
Base Reservoir Delft Sst	86412	446628
DEL-GT-02		
Surface	85100	446163
Top Reservoir Delft Sst	85142	447105
Base Reservoir Delft Sst	85145	447188

1.2 Applied parameters

The target reservoir is the Delft Sandstone Member, at a depth of approximately 1900-2200mTVDSS. The doublet performance has been calculated with DoubletCalc1.4.3 (Figure 2). Input parameters are provided in Table 2, Table 3, Table 4, Table 5, Table 6. The information used to determine these input parameters are based on seismic data and neighboring well information, especially on information from the geothermal wells that have already been drilled or are already operational in the same graben (PNA-GT-01→06).

Table 2: Geological parameters with corresponding min, median, and max values

Reservoir characteristics	Min	Median	Max	Unit
Permeability	250	600	1300	mD
Net/Gross	0.62	0.72	0.85	-
Gross thickness	92	123	154	m TVD
Depth top production well	1946	2162	2378	
Depth top injection well	1761	1957	2153	m TVD
Aquifer water salinity	105.000	130.000	150.000	ppm

Table 3: Geological parameters without standard deviation

Aquifer characteristics	Value	Unit
Kh/Kv ratio	5	-
Surface temperature	10	°C
Geothermal gradient	0.0315	°C/m

Table 4: Non-geological parameters (pump and aquifer properties)

Well and pump properties	Value	Unit
Injection temperature	20	°C
Distance between producer and injection wells at aquifer level	1321	m
Pump system efficiency	0.7	-
Production pump depth	600	m
Pump pressure difference	63	bar

Table 5: Production well (DEL-GT-01) specifics used in DoubletCalc1D

Production well specifics	Value	Unit
Outer diameter at aquifer	8.5	Inch
Penetration angle producer	45	°
Skin due to deviation	-0.44	-
Pipe segment sections	600, 750, 790, 2600, 2650 600, 749, 787, 2130, 2165	m AH m TVD
Pipe inner diameter	9.850, 12.390, 8.681, 8.681, 5.921	inch
Pipe roughness	1.97, 1.97, 1.97, 2.75, 2.75	milli-inch

Table 6: Injection well (DEL-GT-02) specifics used in DoubletCalc1D

Production well specifics	Value	Unit
Outer diameter at aquifer	12.25	Inch
Penetration angle producer	42	°
Skin due to deviation	-0.3	-
Pipe segment sections	2300 1963	m AH m TVD
Pipe inner diameter	8.681	inch
Pipe roughness	2.75	milli-inch

Geotechnical input

A) Aquifer properties

Property	min	median	max
aquifer permeability (mD)	250	600	1300
aquifer net to gross (-)	0.62	0.72	0.85
aquifer gross thickness (m)	92	123	154
aquifer top at producer (m TVD)	1946.0	2162	2378.0
aquifer top at injector (m TVD)	1761.0	1957	2153.0
aquifer water salinity (ppm)	105000	130000	150000

Property	value
aquifer kh/kv ratio (-)	5
surface temperature (°C)	10.0
geothermal gradient (°C/m)	0.0315
[mid aquifer temperature producer (°C)]	0.0
[initial aquifer pressure at producer (bar)]	0.0
[initial aquifer pressure at injector (bar)]	0.0

B) Doublet and pump properties

Property	value
exit temperature heat exchanger (°C)	20
distance wells at aquifer level (m)	1321
pump system efficiency (-)	0.7
production pump depth (m)	600
pump pressure difference (bar)	63

C) Well properties

calculation length subdivision (m)

Producer				
outer diameter producer (inch)		8.5		
skin producer (-)		0		
penetration angle producer (deg)		45		
skin due to penetration angle p (-)		-0.44		
Segment	pipe segment sections p (m AH)	pipe segment depth p (m TVD)	pipe inner diameter p (inch)	pipe roughness p (milli-inch)
1	600	600	9.850	1.97
2	750	749	12.390	1.97
3	790	787	8.681	1.97
4	2600	2130	8.681	2.75
5	2650	2165	5.921	2.75
6				
7				
8				

Injector				
outer diameter injector (inch)		12.25		
skin injector (-)		0		
penetration angle injector (deg)		42		
skin due to penetration angle i (-)		-0.3		
Segment	pipe segment sections i (m AH)	pipe segment depth i (m TVD)	pipe inner diameter i (inch)	pipe roughness i (milli-inch)
1	2300	1963	8.681	2.75
2				
3				
4				
5				
6				
7				
8				

Figure 2: DoubletCalc1D 1.4.3 input screen

1.3 Expected geothermal power

The geothermal power estimates that result from the used input parameters are presented in Figure 3. The P50 geothermal power estimate is 25.59MW. The P90 power estimate is 18.44MW. The related DoubletCalc1D probability plots and fingerprinting plots are presented in Figure 4 and Figure 5.

Geotechnics (Input)

Property	min	median	max
aquifer permeability (mD)	250.0	600.0	1300.0
aquifer net to gross (-)	0.62	0.72	0.85
aquifer gross thickness (m)	92.0	123.0	154.0
aquifer top at producer (m TVD)	1946.0	2162.0	2378.0
aquifer top at injector (m TVD)	1761.0	1957.0	2153.0
aquifer water salinity (ppm)	105000.0	130000.0	150000.0

Property	value
number of simulation runs (-)	1000.0
aquifer kh/kv ratio (-)	5.0
surface temperature (°C)	10.0
geothermal gradient (°C/m)	0.0315
[mid aquifer temperature producer (°C)]	0.0
initial aquifer pressure at producer (bar)]	0.0
[initial aquifer pressure at injector (bar)]	0.0
exit temperature heat exchanger (°C)	20.0
distance wells at aquifer level (m)	1321.0
pump system efficiency (-)	0.7
production pump depth (m)	600.0
pump pressure difference (bar)	63.0
outer diameter producer (inch)	8.5
skin producer (-)	0.0
skin due to penetration angle p (-)	-0.44
pipe segment sections p (m AH)	600.0,750.0,790.0,2600.0,2650.0
pipe segment depth p (m TVD)	600.0,749.0,787.0,2130.0,2165.0
pipe inner diameter p (inch)	9.85,12.39,8.68,8.68,5.92
pipe roughness p (milli-inch)	1.97,1.97,1.97,2.75,2.75
outer diameter injector (inch)	12.25
skin injector (-)	0.0
skin due to penetration angle i (-)	-0.3
pipe segment sections i (m AH)	2300.0
pipe segment depth i (m TVD)	1963.0
pipe inner diameter i (inch)	8.68
pipe roughness i (milli-inch)	2.75

Geotechnics (Output)

Monte Carlo cases (stochastic inputs)	P90	P50	P10
aquifer kH net (Dm)	34.93	54.45	90.12
mass flow (kg/s)	87.73	119.65	157.05
pump volume flow (m³/h)	295.2	403.7	527.9
required pump power (kW)	737.9	1009.3	1319.8
geothermal power (MW)	18.44	25.59	33.94
COP (kW/kW)	23.9	25.4	27.0

aquifer pressure at producer (bar)	208.57	221.64	235.0
aquifer pressure at injector (bar)	188.94	200.48	211.58
pressure difference at producer (bar)	13.19	16.69	19.13
pressure difference at injector (bar)	28.07	35.39	40.48
aquifer temperature at producer * (°C)	76.25	80.07	83.85
temperature at heat exchanger (°C)	75.47	79.07	82.86

base case (median value inputs)	value
aquifer kH net (Dm)	53.14
mass flow (kg/s)	117.75
pump volume flow (m³/h)	396.5
required pump power (kW)	991.3
geothermal power (MW)	25.21
COP (kW/kW)	25.4

aquifer pressure at producer (bar)	221.81
aquifer pressure at injector (bar)	200.36
pressure difference at producer (bar)	16.86
pressure difference at injector (bar)	35.75
aquifer temperature at producer * (°C)	80.04
temperature at heat exchanger (°C)	79.13
pressure at heat exchanger (bar)	32.48

* @ mid aquifer depth

Figure 3: Output screen from DoubletCalc1D based on the input as presented in Figure 2.

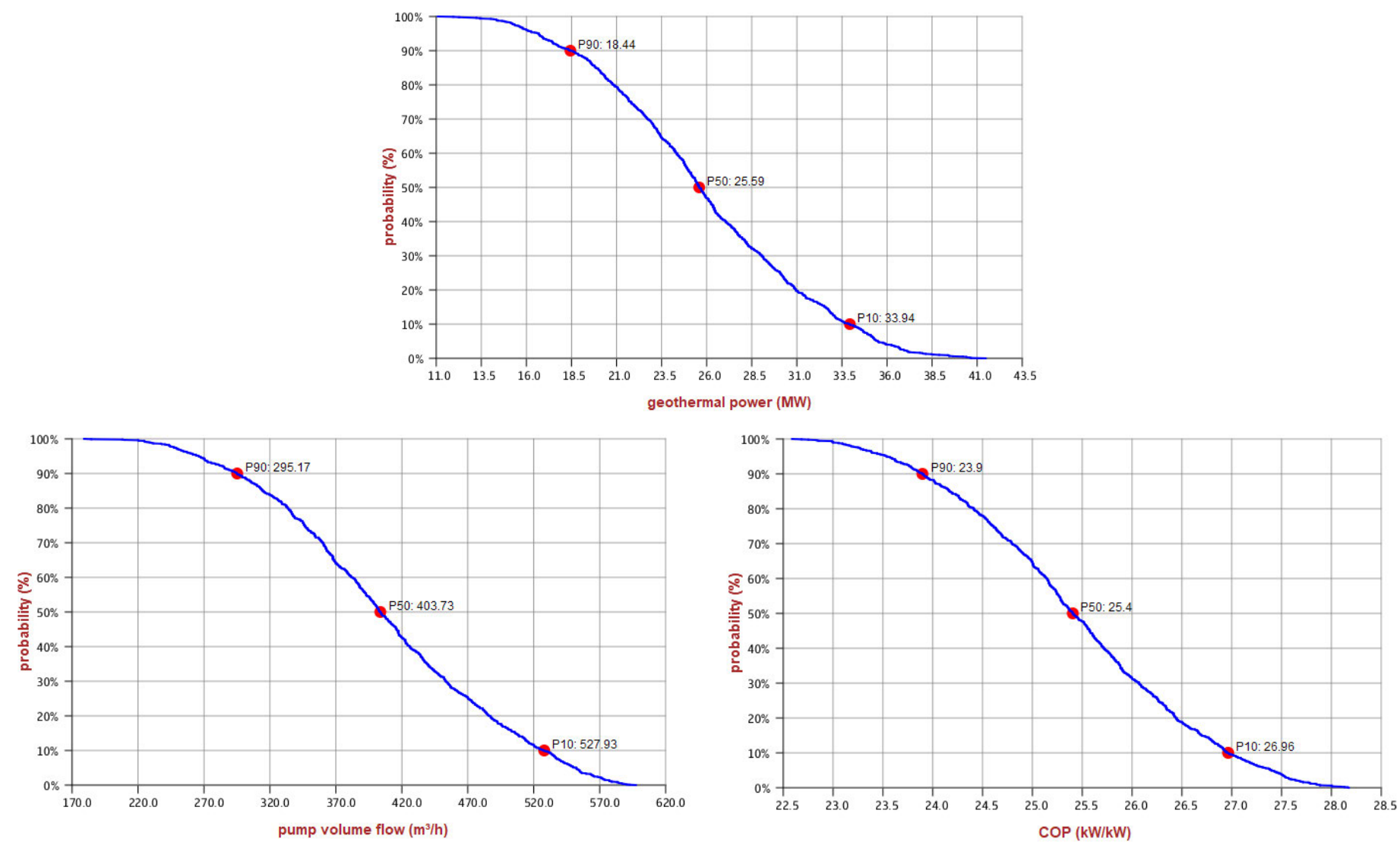


Figure 4: Probability of geothermal power, pump volume flow, and COP of the calculations as presented in Figure 3.

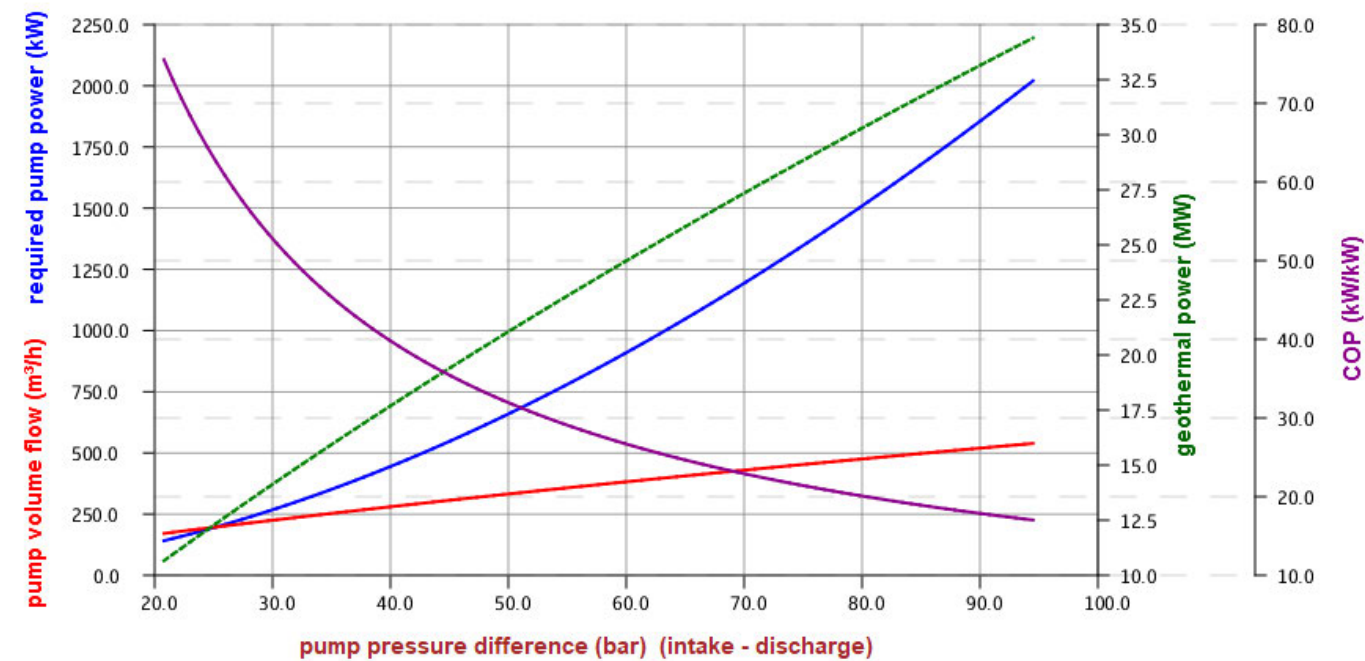


Figure 5: Fingerprinting plot of the calculations as presented in Figure 3.

2 Location and wells

2.1 Project location

The surface location of the planned doublet is located in the City of Delft (in the Province of Zuid-Holland) at the campus of the Delft University of Technology. De planned doublet is located within the Pijnacker-Nootdorp 6a exploration license area ([Staatscourant 2019, nr 49060](#)), which is situated within the municipalities of Delft and Pijnacker-Nootdorp (Figure 6). The neighboring geothermal licenses in the area are the two exploitation licenses Pijnacker-Nootdorp 4 and Pijnacker-Nootdorp 5 and the exploration license Ypenburg (Figure 7).

2.2 Wells

This application is for a doublet system, consisting of a production well and an injection well. The production well will be drilled with an outstep of approximately 1420m. The outstep of the injection well will be approximately 1040m. The distance between the wells at mid-aquifer level will be approximately 1321m.

- Delft-GT-01 (DEL-GT-01), production well (red in Figure 6)
- Delft -GT-02 (DEL-GT-02), injection well (blue in Figure 6)



Figure 6: Map view of the study area and planned doublet. The Pijnacker-Nootdorp 6a exploration license is outlined in green and the surface location is shown as a green square. The well trajectories of the producer (DEL-GT-01) is shown in red and the well trajectory of the injector (DEL-GT-02) is shown in blue. Municipality boundaries are indicated by steel blue.

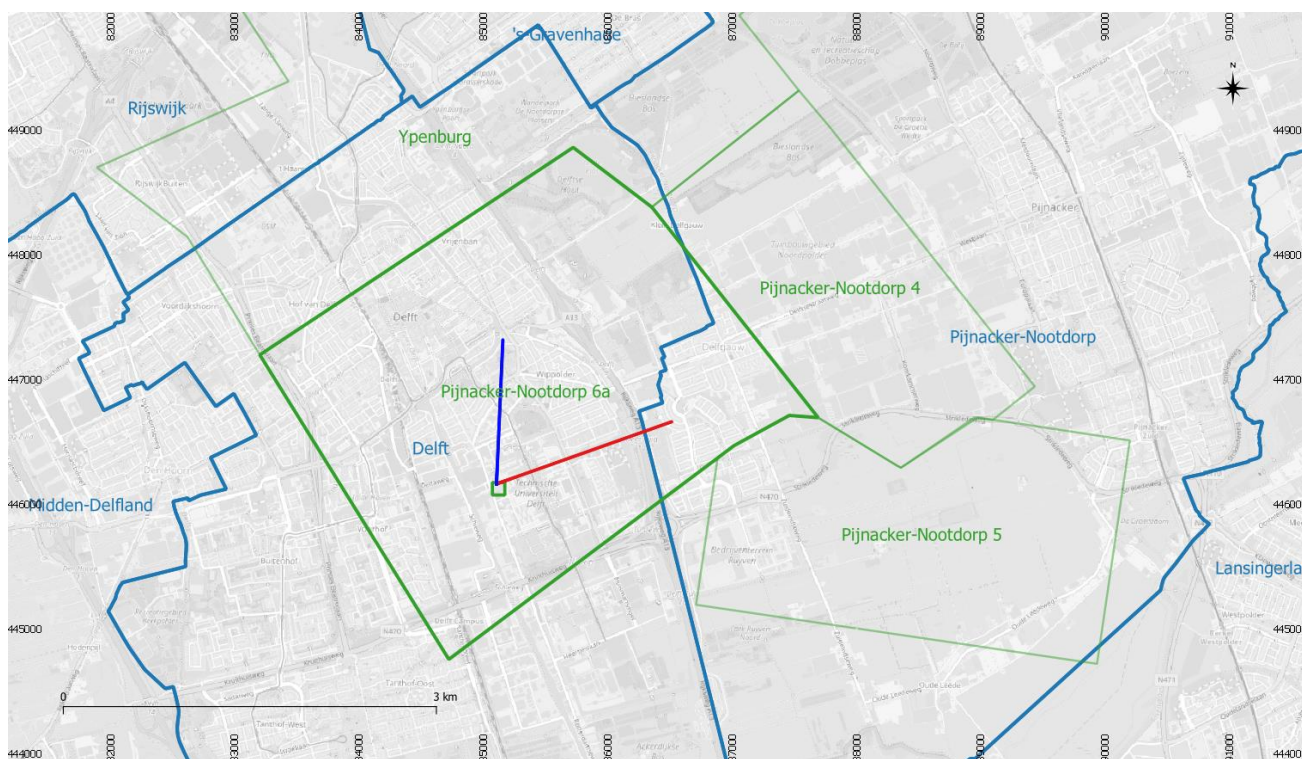


Figure 7: Map view of the larger area around the planned doublet. The geothermal licenses in the area are outlined in green. Municipality boundaries are indicated by steel blue. The well trajectories of the producer (DEL-GT-01) is shown in red and the well trajectory of the injector (DEL-GT-02) is shown in blue.

3 Geological Setting

3.1 Regional Geology

The Geothermie Delft exploration license area is located in the Late Jurassic-Cretaceous West Netherlands Basin. A precursor of this basin is the much larger Carboniferous-Triassic North Sea basin.

The geology of the West Netherlands Basin has been described by Racero-Baena & Drake (1996), its hydrocarbon habitat by De Jager et al (1996). The basin originated by rifting in the latest Jurassic and Early Cretaceous and is characterized by divergent strike-slip faulting creating a NW-SE trending block-faulted basin. The basin inverted during the Late Cretaceous and Early Tertiary. During inversion pre-existing normal faults were reactivated and narrow anticlinal structures were formed. One of these narrow and long inversion anticlinal structures is at the west side of the Geothermie Delft exploration license study area (Figure 8); here it is called the Rijswijk structure. The IJsselmonde, Berkel, Oude Leede and Rijswijk oil and gas accumulations are located on this structure. Seismic data show that prior to the main inversion phases in the Late Cretaceous and Early Tertiary relatively weak pulses of compressional tectonic activity occurred during the Early Cretaceous.

On Figure 8 the location of the Geothermie Delft geothermal exploration license has been indicated; the exploration license is officially named Pijnacker-Nootdorp 6a. The south-western part of the Geothermie Delft exploration license is over this Rijswijk structure. North-East of the Geothermie Delft exploration license is the relatively small Pijnacker structure with the former Pijnacker oil field. This structure has been described as a pop-up anticline by Racero-Baena & Drake (1996). In between the Pijnacker and the Rijswijk structure is a syncline (Figure 8) for which in some reports the name Vrijenban syncline has been used.

Figure 9 is a published seismic section illustrating the Rijswijk and Pijnacker anticlines. The anticlines are inversion structures formed during the inversion phases in the late Cretaceous and Early Tertiary. During these phases earlier strike-slip faults with an extensional component were reactivated with a compressional component resulting in anticlinal structures, so called pop-up structures and flower structures. These are characterized by complex faulting including normal and reverse faults. This has been illustrated by Racero-Baena & Drake (1996) for the Pijnacker structure. The Rijswijk structure is similar but possibly less complex in the area of the Geothermie Delft exploration license. Important for the Delft project is that reverse and normal faults do exist and may occur with displacements at the seismic scale and the sub-seismic scale.

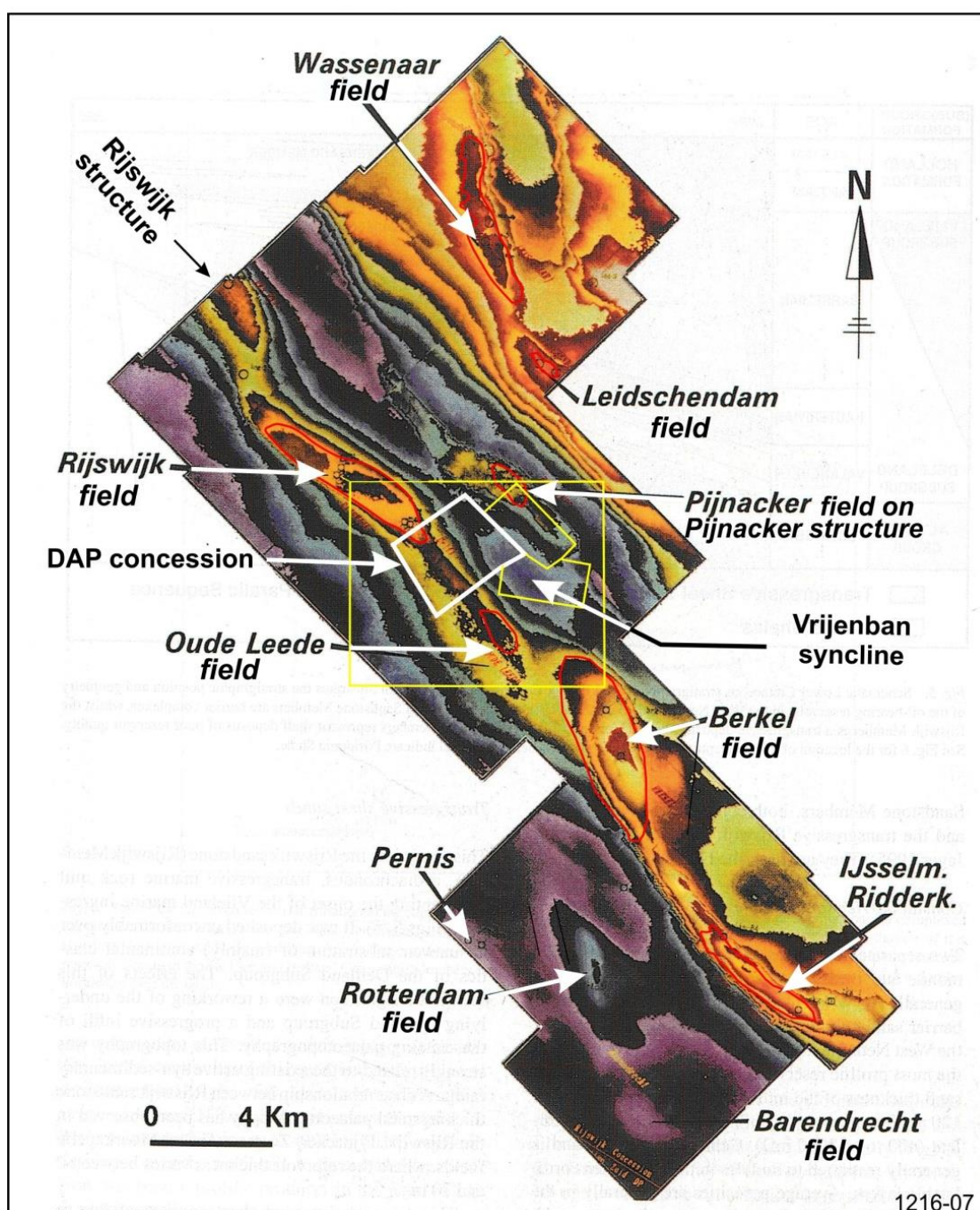


Figure 8 Map showing the top Vlieland Formation in TWT time. Light colours are structural highs, dark colours are structural lows. The figure is taken from Racero-Baena & Drake (1996) and slightly modified. The map shows the long and narrow anticlines (the Rijswijk structure). The IJsselmonde, Berkel, Oude Leede and Rijswijk oil accumulations are part of this structure. The figure illustrates "the continuity of the central NW-SWE oriented inverted anticlinal trend which reflects the continuity of the rift faults". Colour code ranges from 700 (red) to 1700ms TWT (dark purple)". The approximate position of the Delft (=Pijnacker-Nootdorp 6a) exploration license is indicated with a white outline.

Figure 10 is a depth map of Base Nedersaksen (SK) and Schieland (SL) Groups (Base Albasserdam (SLDNA)) of a large part of the basin. This map is based on TNO DGM-deep V5 model (2019). It shows the long Rijswijk anticline through the centre of the figure and the small Pijnacker anticline with the Vrijenban syncline in between. The map shows the locations of PNA-GT doublets (PNA-GT-01/-02, PNA-GT-03/-04 and PNA-GT-05/-06). In addition, the two VDB doublets (VDB-GT-01/-02 and VDB-GT-03/-04) and the LSL doublet (LSL-GT-01/-02) further to the east are shown. HAG-GT doublet (HAG-GT-01/-02) and other wells relevant for the study (PNA-13, DEL-03, DEL-08) are indicated as well.

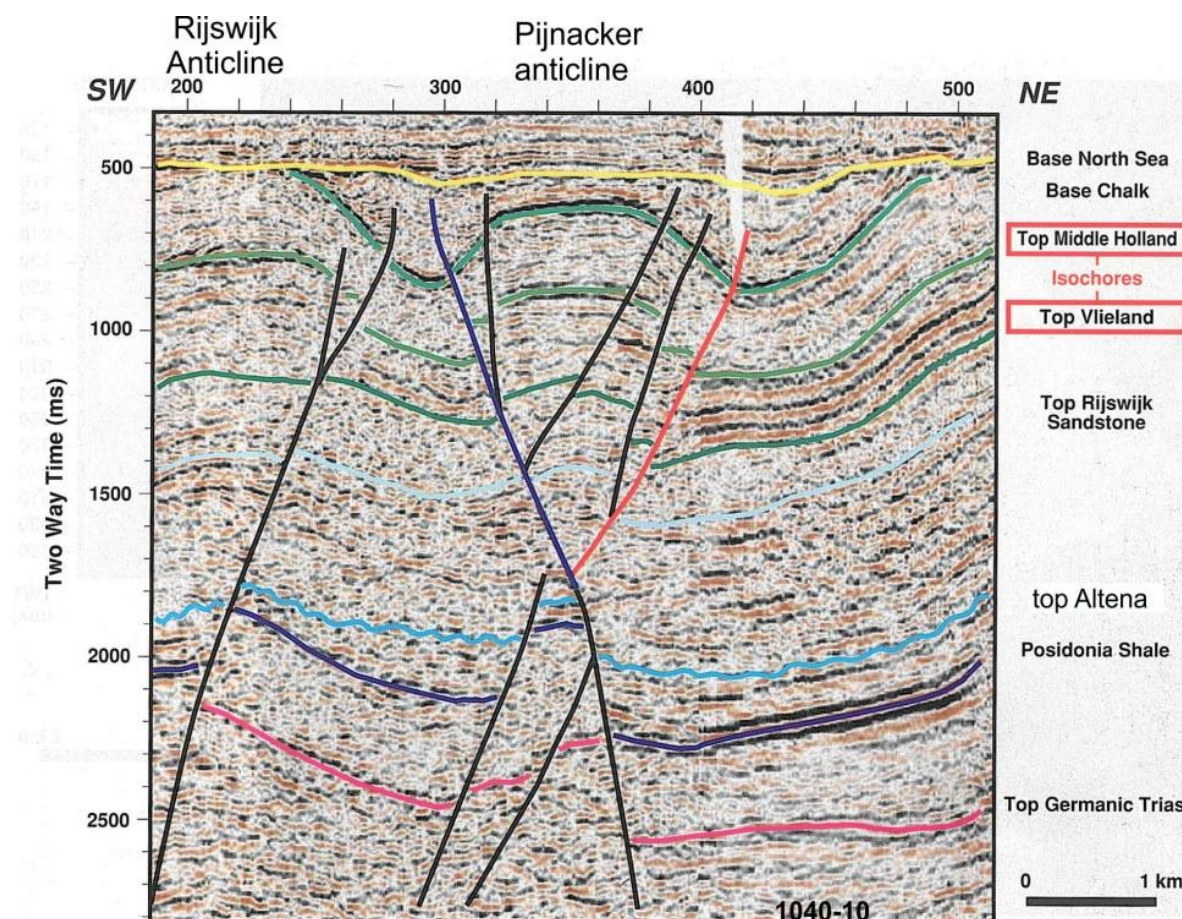


Figure 9 Published seismic section showing the Rijswijk and Pijnacker anticlines. The figure was published by Racero-Baena and Drake (1996). The section is located in or near the saddle between the Pijnacker and Rijswijk structures. Toward the SE the Vrijenban syncline between Rijswijk and Pijnacker further develops and deepens.

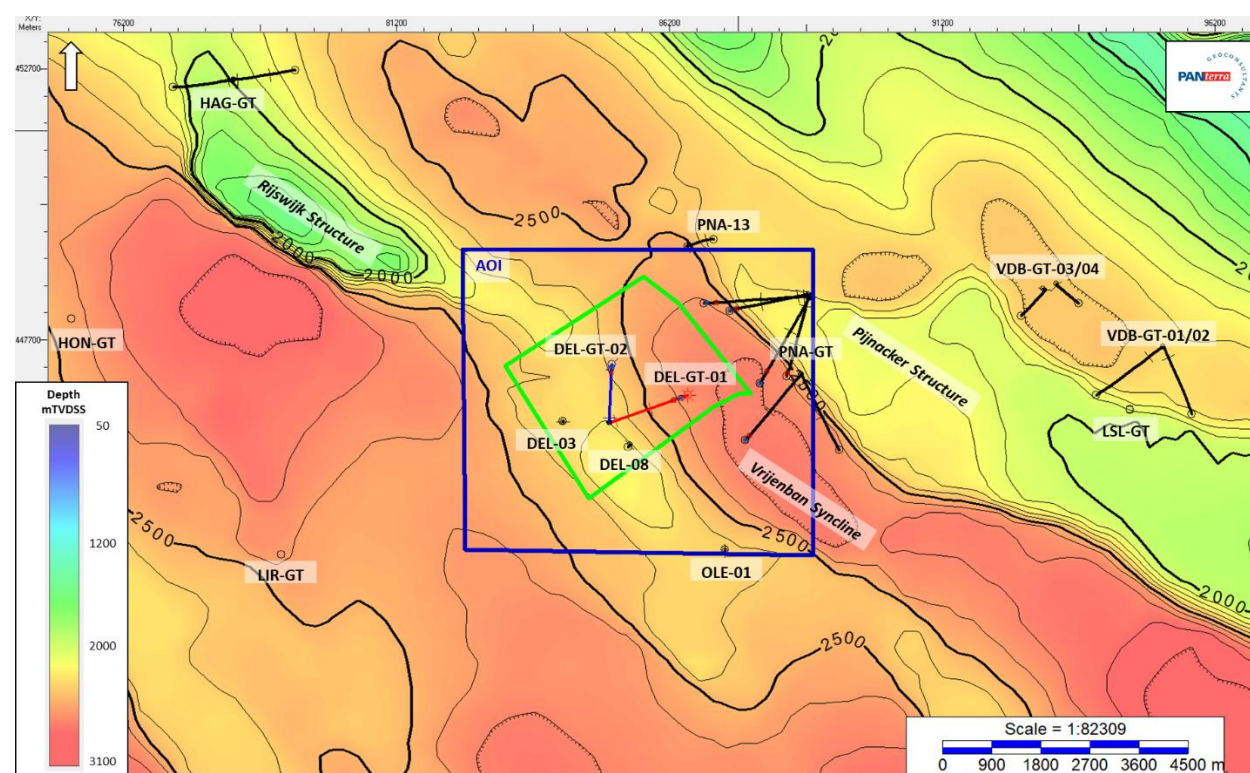


Figure 10 Depth map of base Nedersaksen and Schieland groups (TNO DGM-deep V5 model, 2019). The map shows the location of the main Rijswijk structure and the small Pijnacker structure. The Geothermie Delft planned well trajectories (DEL-GT-01/-02), exploration license boundaries (green line), area of interest (AOI, dark blue line) and relevant wells and doublets have been indicated.

3.2 Hydrocarbon occurrences in the vicinity of the project area

The study area is in a basin with a mature oil and gas source, the Posidonia Formation (De Jager et al. 1996) that has generated and still is generating large quantities of oil and gas. Many oil and gas fields are present in close proximity to the proposed doublet (Figure 11). Hydrocarbons can be present in two forms: 1) oil and gas accumulations or 2) gas dissolved in formation water and oil dispersed in formation water.

3.2.1 Traps with accumulations of free oil and/or gas

The Rijswijk Member is an oil productive reservoir in the Rijswijk and Pijnacker Fields near the town of Delft (Figure 11). The Berkel Member is productive in the Berkel field. In Oude Leede gas is present in the argillaceous sandstones of the De Lier Member. The De Lier Member has produced some oil and gas in the former Delft field. DEL-07 drilled in 1955 and abandoned probably in 1968 is located close to the project. It was perforated and tested in the De Lier Member. DEL-08 drilled in 1994 has oil shows in the De Lier Member and minor shows in the Rijswijk Member.

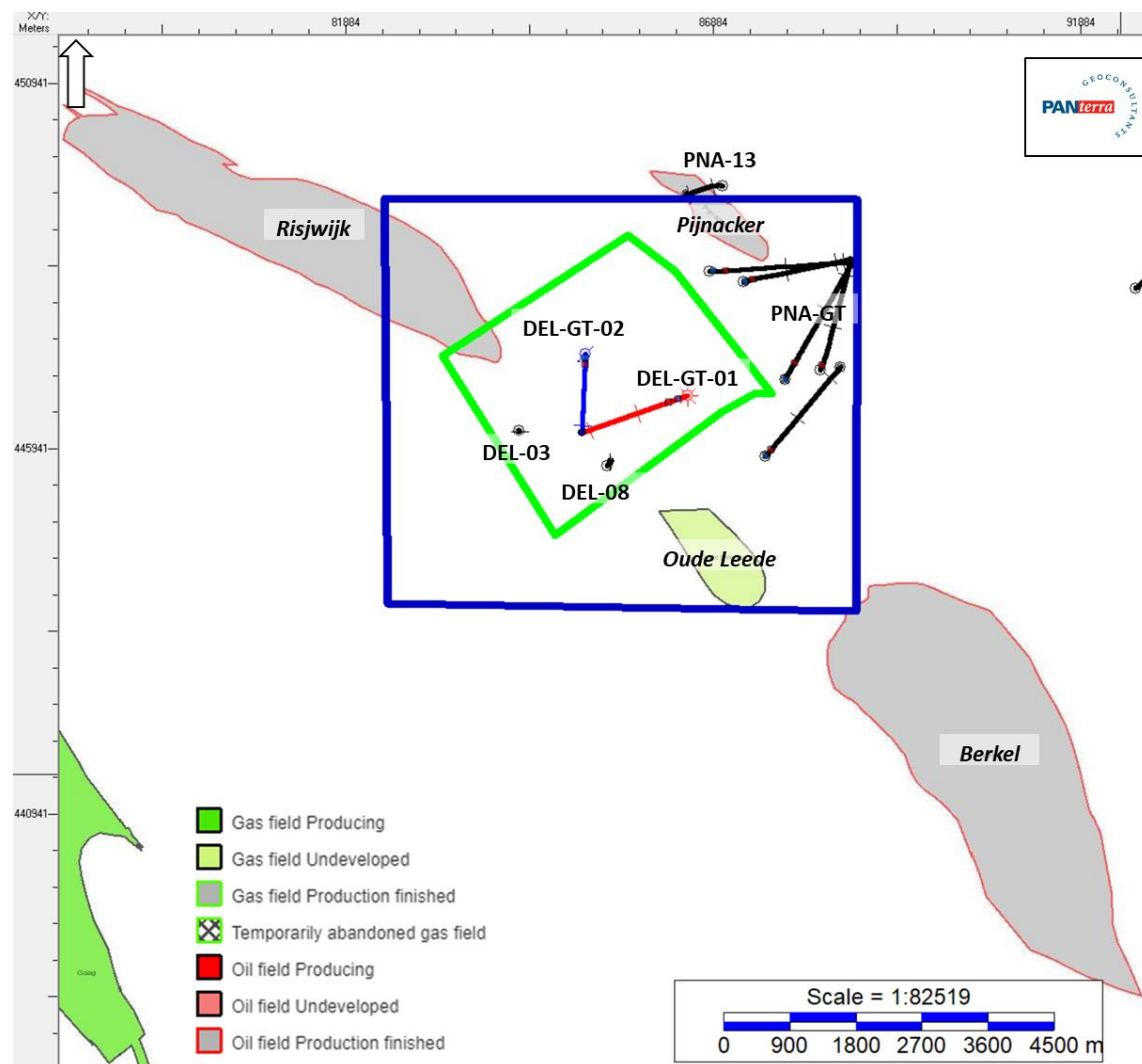


Figure 11 Location of the exploration license (green line) and AOI (blue line) with respect to oil and gas fields (from www.nlog.nl). Pijnacker is the abandoned oil field in the Rijswijk Sandstone Member on the crest of the Pijnacker structure. The Rijswijk field is the abandoned oil field that produced from the Rijswijk Sandstone on the crest of the Rijswijk structure. Oude Leede is an undeveloped gas accumulation in the De Lier Member. The Berkel oil field produced from the Berkel Sandstone Member, it is now abandoned.

The Delft Sandstone is not oil or gas productive in the West Netherlands basin, but may have some shows. Considering the presence of a mature source rock in the AOI and of hydrocarbon accumulations in nearby fields, the potential presence of gas pockets was checked with seismic data. Seismic lines along the planned well trajectories (Figure 12 and Figure 13) show the upper part of a potential gas cloud confined within the Delft Sandstone. This is also shown in map view (Figure 14) where the overlay of the 2000 m gas pocket boundaries with the Base Delft map suggests that gas follows the Delft structure. The gas pocket area is reduced at shallower depths and a shift toward NW is observed (Figure 14). This is likely due to gas leakage along the faults. As discussed in next section (0), even if presence of gas in the area is confirmed by readings of well DEL-08, the gas is likely to be in solution. No gas pockets intersect well traces.

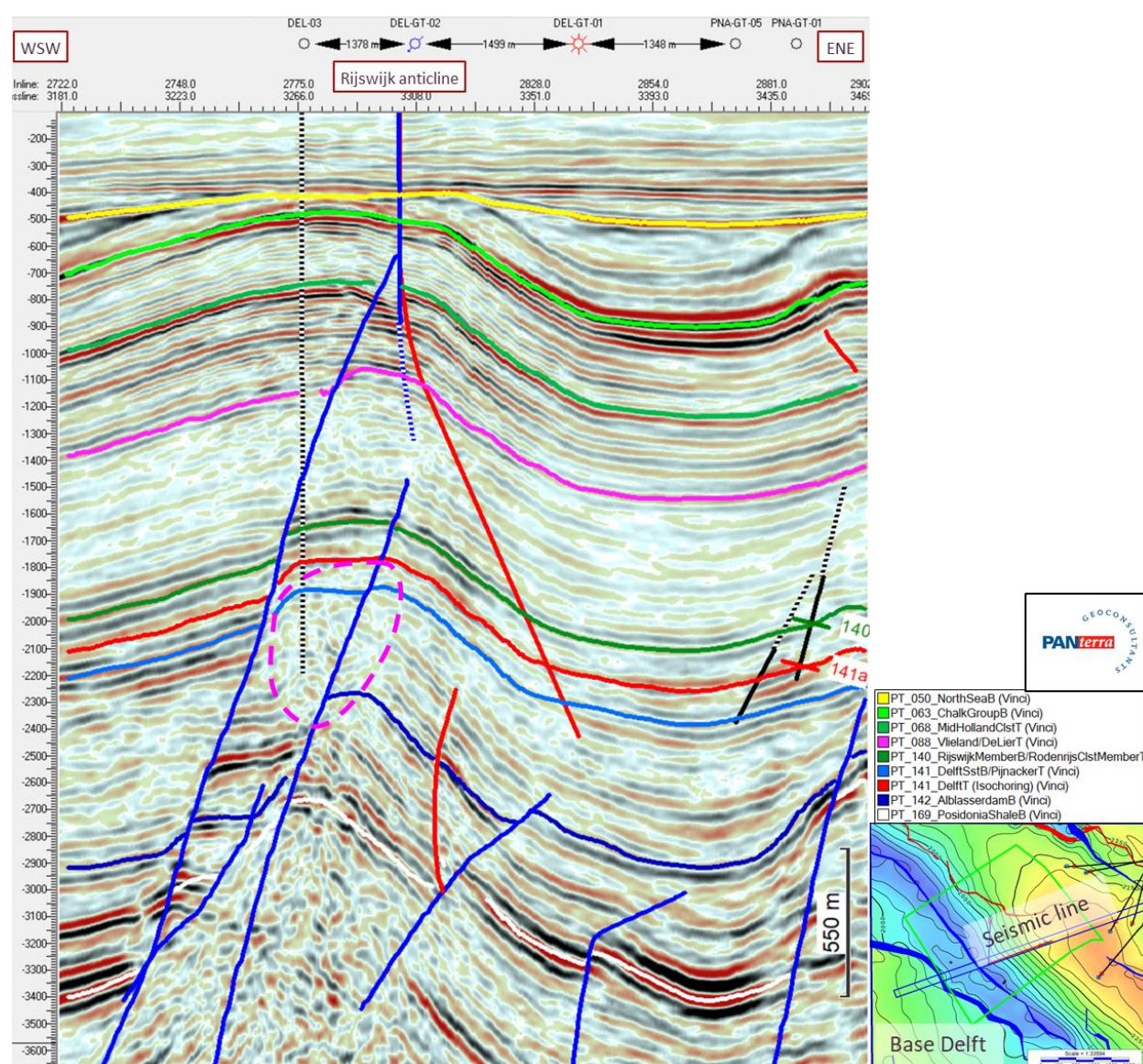


Figure 12 Seismic section along planned production well DEL-GT-01 (red trajectory). Pink dashed line indicates the potential gas pocket area. See insert for line trajectory. Depth in mTVDSS.

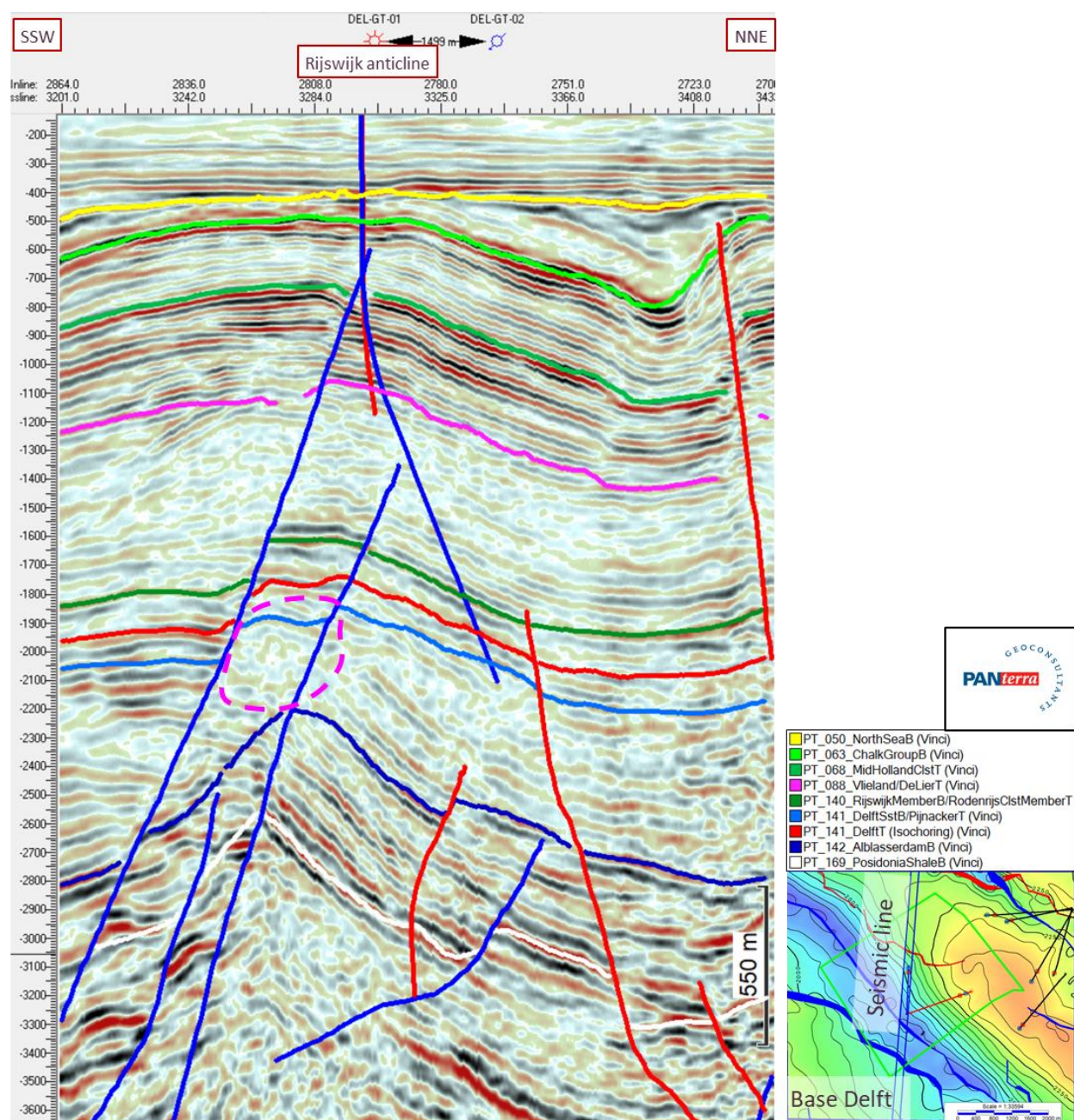


Figure 13 Seismic section along planned injector well DEL-GT-02 (blue trajectory). Pink dashed line indicates the potential gas pocket area. See insert for line trajectory. Depth in mTVDSS.

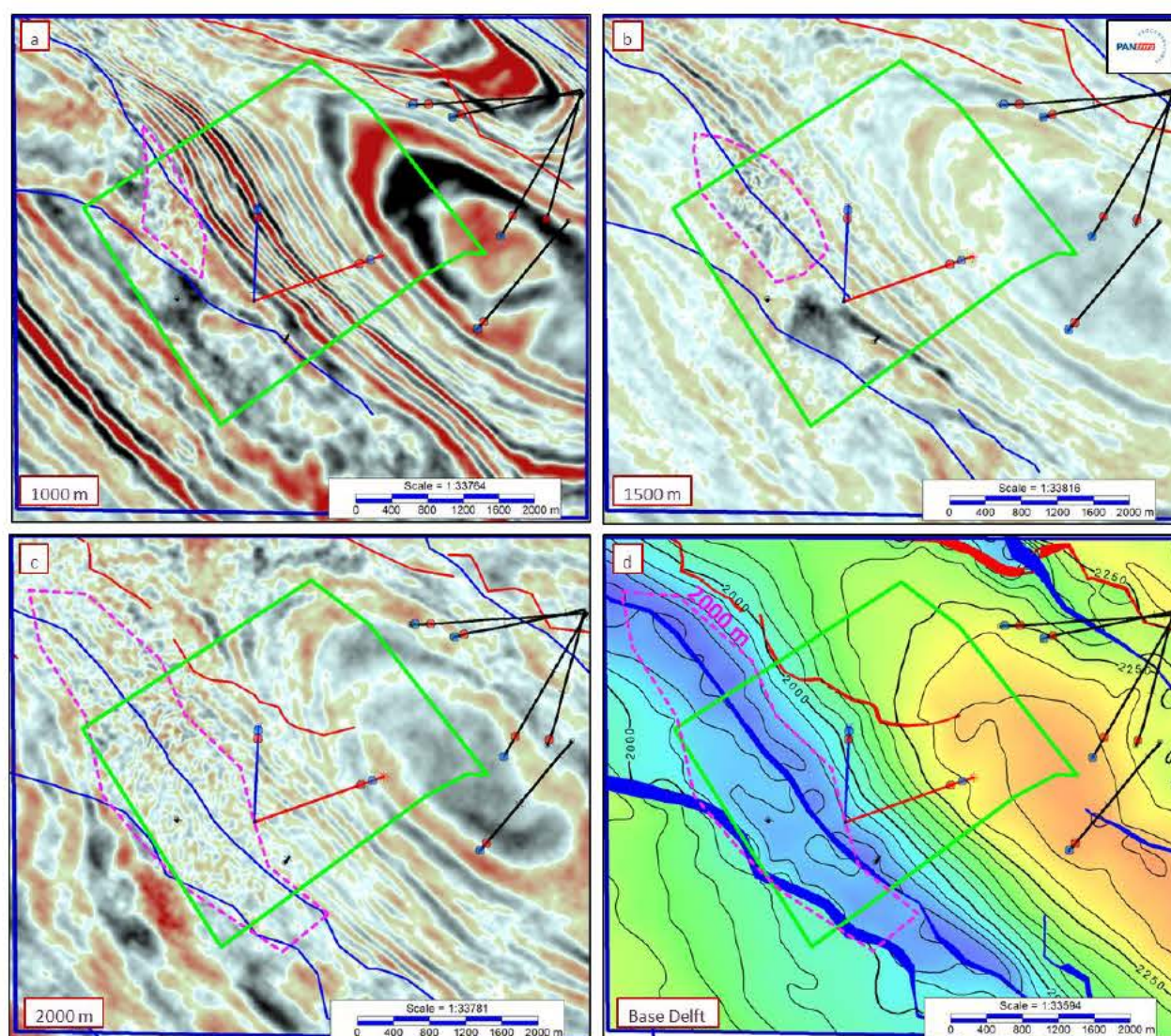


Figure 14 Seismic depth slices at 1000 (a), 1500 (b) and 2000 (c) mTVDSS showing potential gas pocket area (dashed pink line). Insert 'd' shows the overlap of gas pocket area at 2000 mTVDSS (dashed pink line) with base Delft.

3.3 Hydrocarbons dissolved dispersed in formation water

In most surrounding geothermal wells, oil and/or gas is present in the produced formation water from both the Rijswijk and the Delft Sandstone reservoirs. Apparently, the sandstones of the Delft and Rijswijk Members can be carrier beds for migrating hydrocarbons. Considering this, the chance that hydrocarbons are present in formation water in the planned DEL-GT-01 and -02 is considered high.

Evidence for active potential expulsion of hydrocarbons out of the Posidonia source rock is difficult to demonstrate and presence of possible carrier beds is below seismic resolution. Further, the amounts of hydrocarbons present in formation water are too low to be detected by wireline logs. Only by testing or producing large quantities of formation water presence of hydrocarbons can be shown. Thus, observation in geothermal wells is the single source that can be used to estimate the chance of occurrence and quantities of hydrocarbons. Five out of the eight doublets (listed in Table 7) coproduce gas in quantities between 1 and 1.5 Nm³ for each produced m³ of formation water. One of the eight had oil.

Table 7 Hydrocarbon observations in nearby geothermal doublets. Data from Bakker (2011) and other sources (including personal communication Ammerlaan).

Geothermal doublet	Normalized volume of gas per volume of produced water
HAG-GT	1.5 Nm ³ /m ³
PNA-GT-01 and 02	0.5 Nm ³ /m ³ ; small amounts of oil are present
PNA-GT-03 and -04	1 Nm ³ /m ³
PNA-GT-05 and -06	1 Nm ³ /m ³
VDB-01, -02, 03, 04	Traces
HON-GT-01 and -02	1 to 1.5 Nm ³ /m ³
LSL-GT-01 and -02	1 Nm ³ /m ³

4 Available well and seismic data

4.1 Selection of reference wells

The West Netherlands Basin has been the subject of many studies for the oil and gas and geothermal industry and relevant results are incorporated in this report. Reference is made only to the studies of direct importance for the Geothermie Delft project.

Reference wells are listed in Table 8. Relevant wells for the study were chosen based on proximity to the target area, data availability and quality, as well as reservoir characteristics.

Table 8 List of reference wells of wells in the project area.

Well	Year drilled	Notes
DEL-03	1953	
DEL-08	1994	TD in Rodenrijs member
HAG-GT-01	2010	
HAG-GT-02	2010	
HON-GT-02	2012	
LIR-GT-01	2014	
LIR-GT-02	2014	
LSL-GT-01	2017	
LSL-GT-02	2017	
OLE-01	1959	
PNA-13	1977	GR digitized
PNA-GT-01	2010	
PNA-GT-02	2010	No top and bottom depth of screen found in the data files
PNA-GT-03-S2	2010	
PNA-GT-04	2010	
PNA-GT-05	2018	Data not in public domain (nlog)
PNA-GT-06	2018	Data not in public domain (nlog)
VDB-01	2007	
VDB-02	2007	
VDB-03	2009	
VDB-04	2009	

4.2 Seismic data

The study area is fully covered by the 3D seismic survey R-2824, NAM depth migrated reprocessing cube of good quality released in 2018. Because of the depth processing, the need for time depth conversion of this cube is discarded.

The seismic surveys are displayed as SEG reverse, meaning that all seismic sections shown in this report are displayed such that a negative number (through or red colour) represents a hard kick (an impedance increase). The header of the R-2824 seismic survey with geometry information is given in Figure 15.

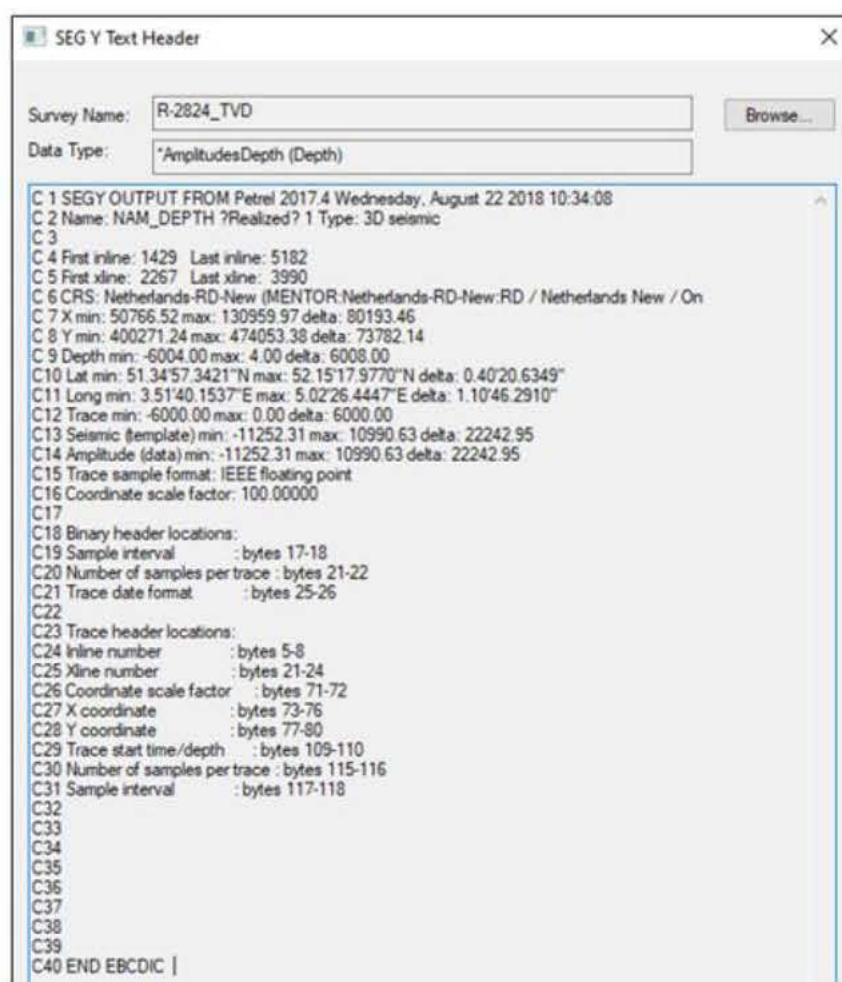


Figure 15 Geometry of the seismic depth cube (R-2824)

4.3 Coordinate system

The location of most data is in the new Netherlands National Triangulation System (Rijksdriehoekstelsel). Georeferenced data of different projection systems were converted to this system.

Name: Netherlands National System new: *Rijksdriehoekstelsel* new
Type: Double Stereographic
Central Meridian: 5.387638889
Origin Latitude: 52.156160556
Scale Factor: 0.999907900
False Northing: 463000.000000
False Easting: 155000.000000

Units: Meters

Datum: Netherlands
Ellipsoid: Bessel 1841
Prime Meridian: Greenwich
Transform Method: Molodensky
Delta x (m): 593
Delta y (m): 26
Delta z (m): 478

The units used in this report relate to the International System of Units (abbreviated SI from the French *Système International*). All distances are expressed in metres or in kilometres. Temperatures are expressed in degrees Celsius.

4.4 Additional data

GIS files (shapefiles and raster data) have been downloaded from the TNO portal in order to compare results and create maps:

- Well locations
- Seismic data
- Licences
- Oil and gas fields
- Faults (ref. TNO 2002)
- Depth maps (DGM 5.0)

All shapefiles and raster files have been transformed from the UTM 31, ED50 to the *Rijksdriehoekstelsel* coordinate system with the Netherlands datum if necessary.

5 Seismic Interpretation and Depth Model

5.1 Methodology

Seismic interpretation and generation of depth and thickness maps was carried out in IHS Kingdom 2019 on the NAM reprocessed depth cube (2018). This reprocessed cube shows better lateral continuity compared to the original time processed data and horizons are easier to pick. Especially faults are better visible, and their location is therefore more certain in comparison to the original time processed data. The pre-stack depth migration also ensures that faults are at the right location.

5.2 Additional data

According to the scope of this study, the seismic horizons listed in Table 9 were interpreted on the latest reprocessed seismic depth cube.

Table 9 Formation picks and reflector properties

Formation pick	Reflector type	Seismic Interpretation	Isochoring	Comment
Base North Sea	Trough	Yes	No	
Base Chalk Group	Peak	Yes	No	
Top Middle Holland Claystone	Peak	Yes	No	
Top Vlieland	Trough	Yes	No	Same as Top De Lier
Base Rijswijk Member	Trough	Yes	No	Same as Top Rodenrijs Claystone Member
Top Delft Sandstone	Not specified	No	Yes	Top of target interval, same as Base Rijswijk
Base Delft Sandstone	Trough	Yes	No	Bae of target interval, same as Top Alblasserdam
Base Alblasserdam	Trough	Yes	No	
Base Posidonia Shale	Trough	Yes	No	

All seismic sections shown in this report adhere to the seismic character given in Table 9. This means that negative seismic amplitudes representing a hard kick are red in colour, e.g. Base North Sea pick.

5.3 Well to seismic ties

The seismic interpretation was entirely performed on the NAM reprocessed depth cube (2018), and well tops fitted very well the seismic interpretation. Therefore, no well to seismic tie was needed.

5.4 Seismic interpretation

The seismic character of the different stratigraphic intervals played an important role in ambiguous situations and when additional information was unavailable. The Alblasserdam Member therefore provides a good reference due to its low intensity of the seismic amplitudes with a transparent “noisy” appearance as a result of increased shale content. The Delft is often recognized as a more reflective interval, sometimes with internal channel configurations or mounts. Additionally, the Base Delft is locally recognized as an unconformity which is a key reference for recognizing the Base Delft.

All horizons listed in Table 9 were interpreted on every 20th inline and crossline of the AOI (Figure 16). This resulted in a dense grid further used as input for creating depth maps and thus avoids additional uncertainties from an unconstrained interpolation algorithm.

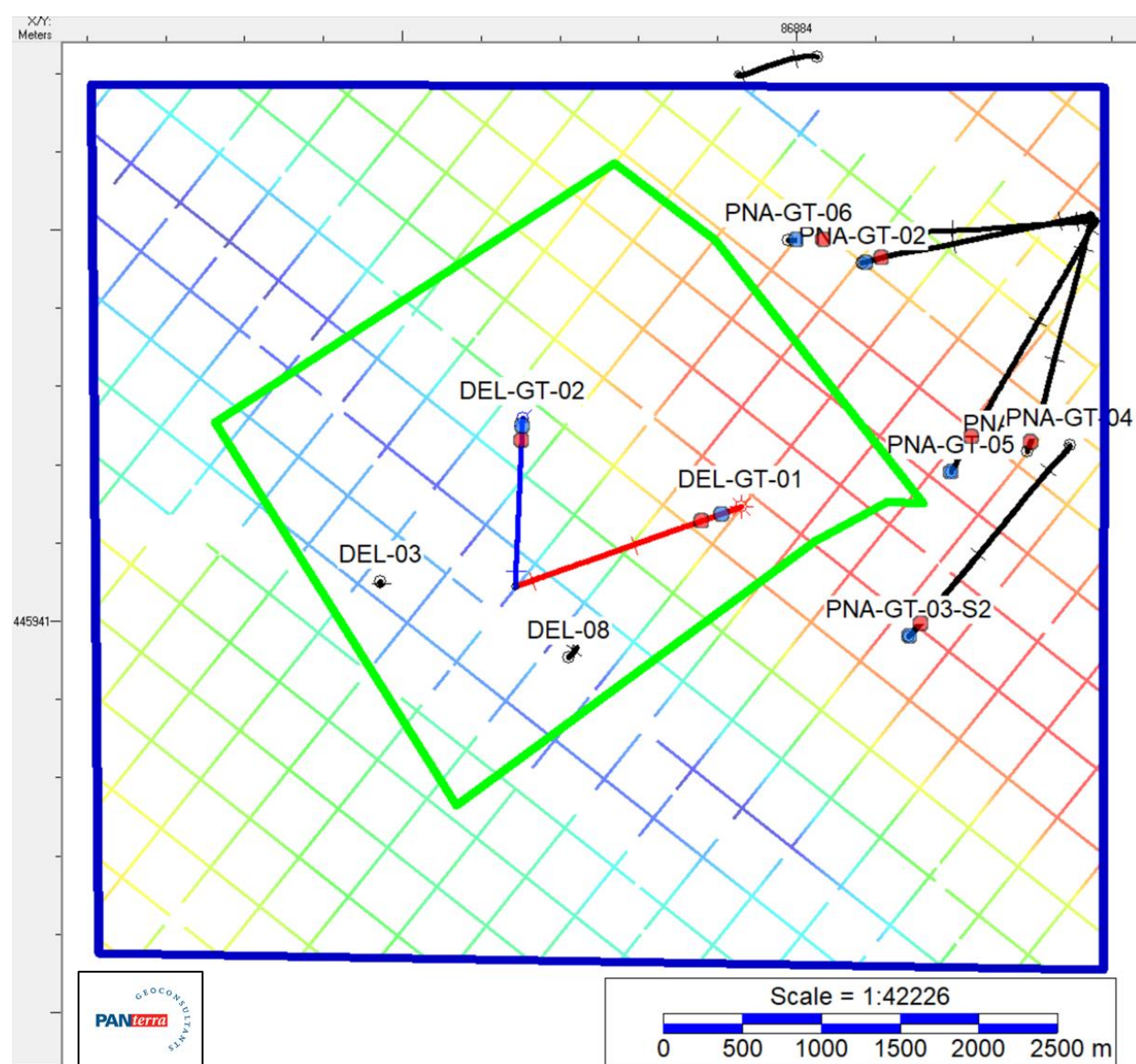


Figure 16 Seismic interpretation grid of Base Delft (every 20th IL/XL) and outlines of Pijnacker-Nootdorp 6a (green) and AOI (blue). Seismic inlines that exemplify structural complexity, reflector continuity and well top matches from NW to SE are displayed in from Figure 17 to Figure 20. Figure 21 shows a crossline showing thickness variations along the basin.

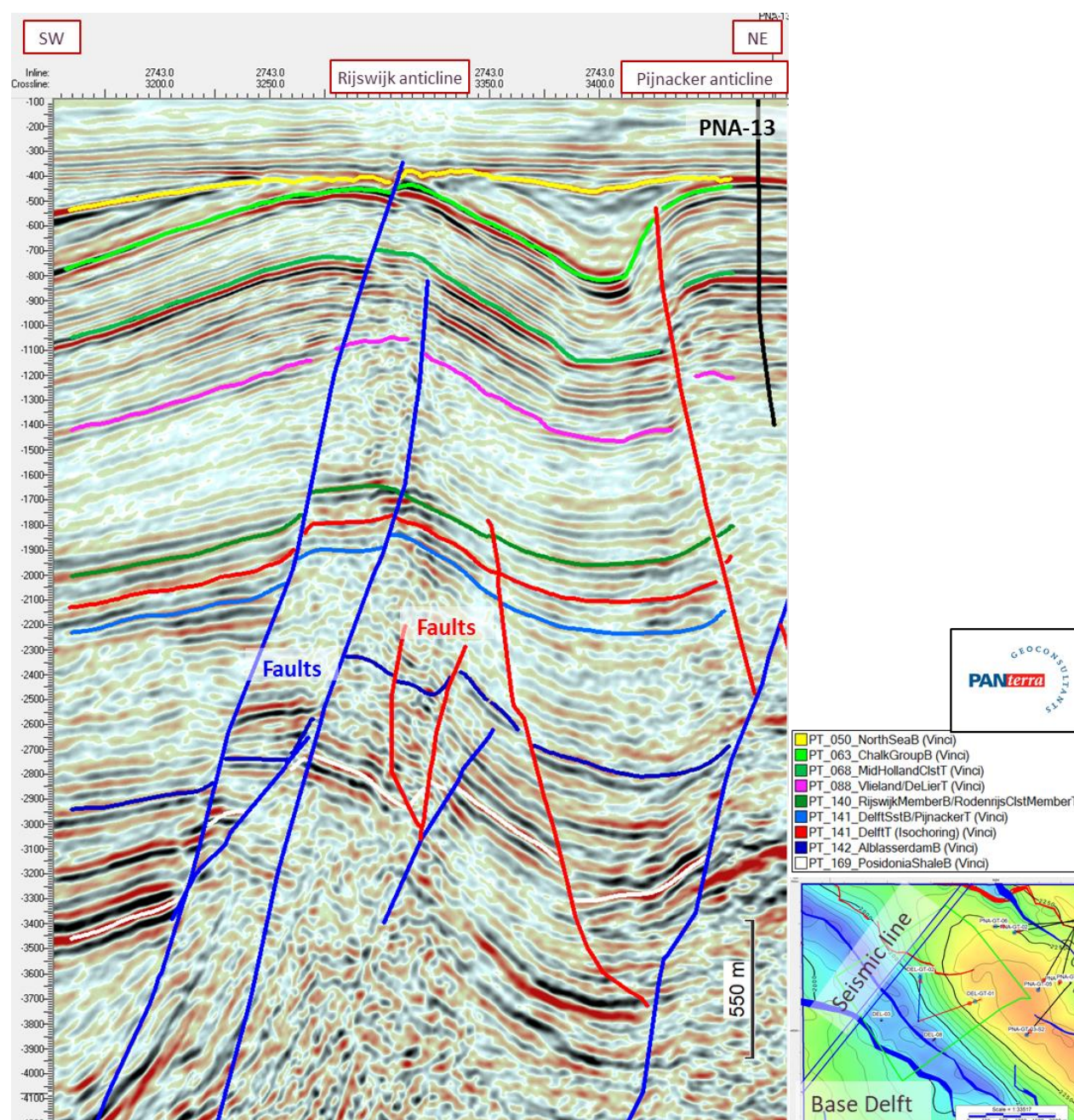


Figure 17 Seismic section along inline 2743. The figure shows the fault system, the anticlinal structures, interpreted reflectors and projected well PNA-13. See insert for line trajectory.

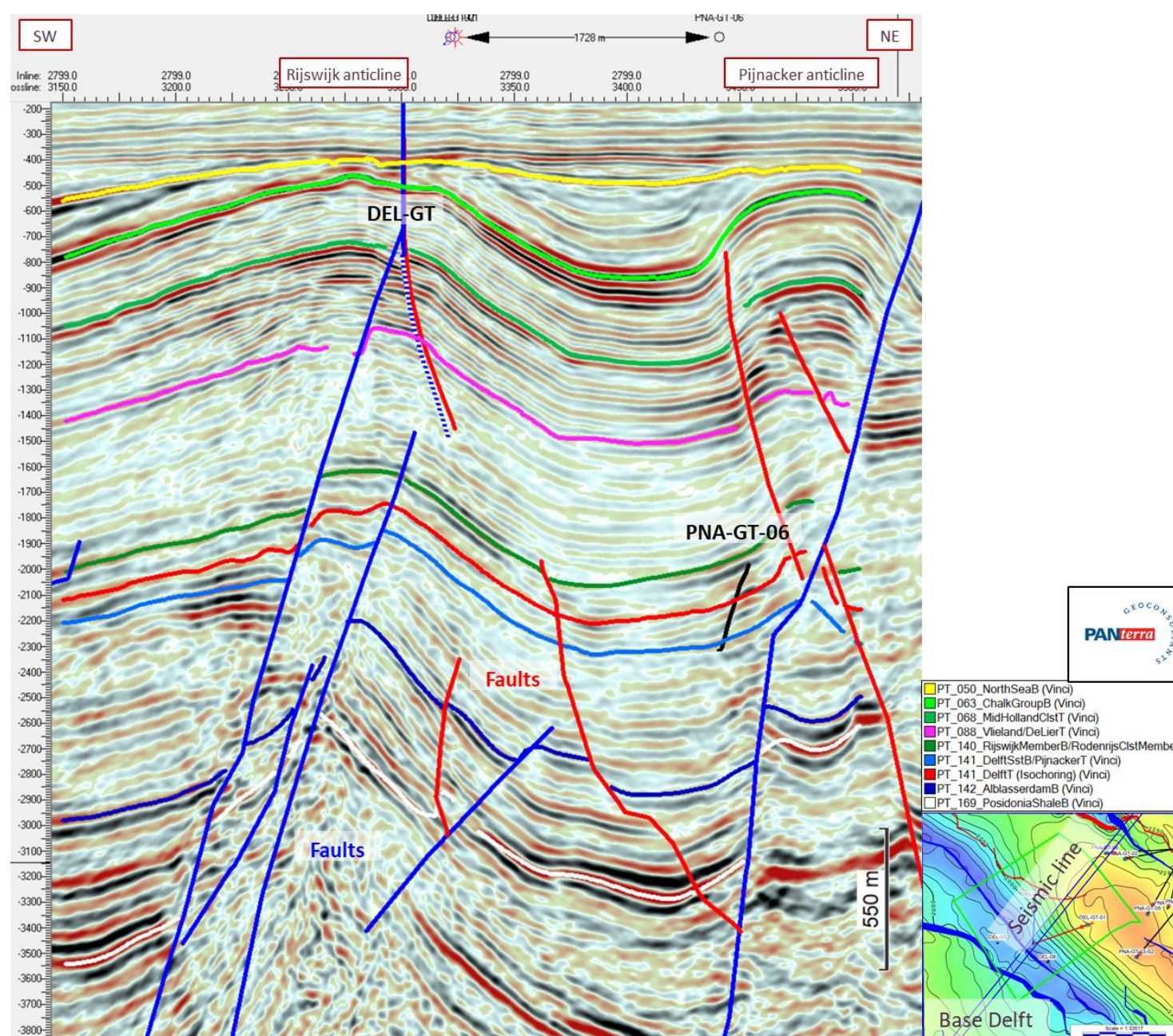


Figure 18 Seismic section along inline 2799. The figure shows the fault system, the anticlinal structures, interpreted reflectors, projected planned wells (DEL-GT) and part of projected well PNA-GT-06. See insert for line trajectory.

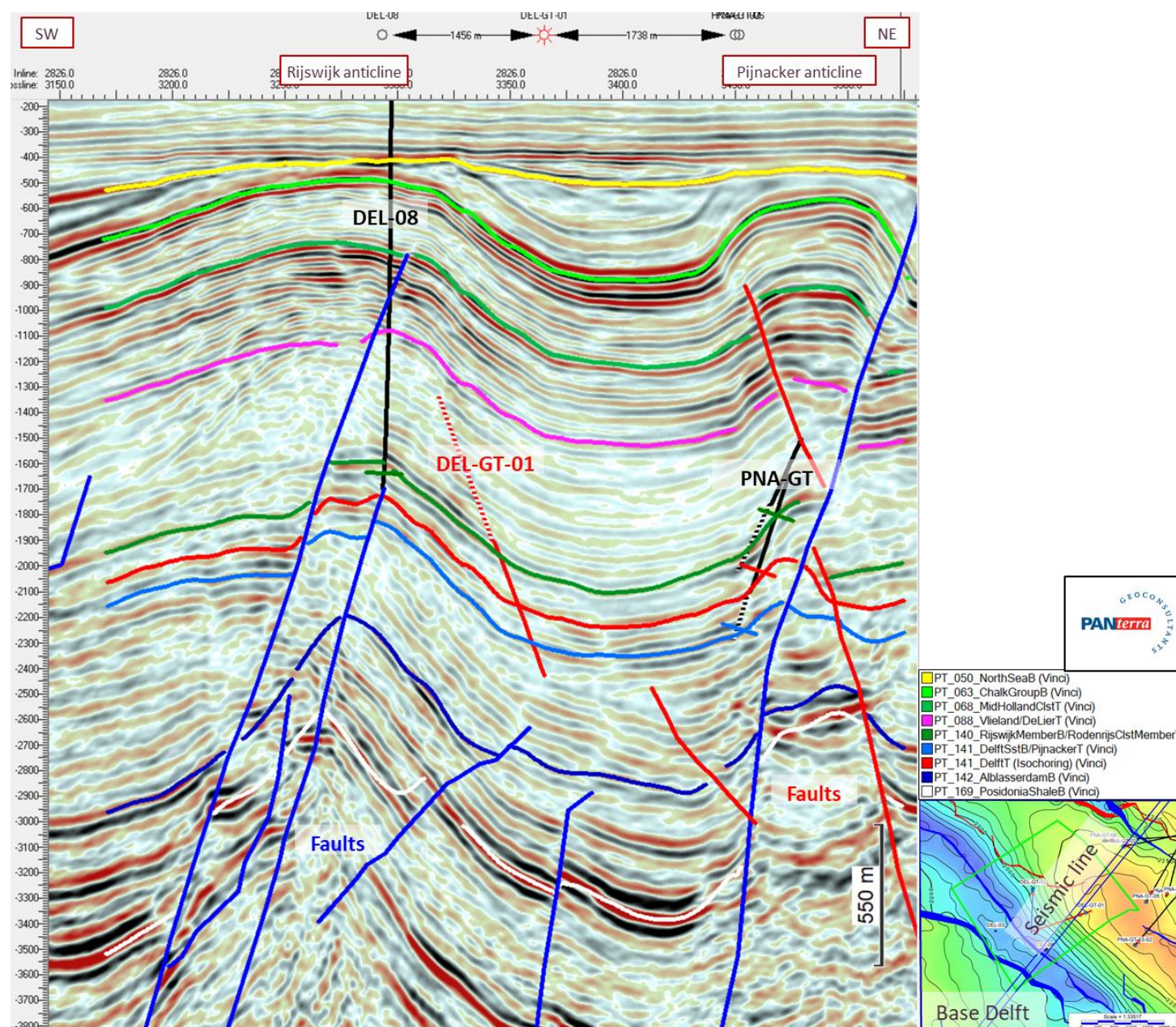


Figure 19 Seismic section along inline 2826. The figure shows the fault system, the anticlinal structures, interpreted reflectors, projected planned production well (DEL-GT-01) and part of projected wells DEL-08 and PNA-GT-02 Well tops used to tie seismic interpretation are projected along the borehole trajectories. See insert for line trajectory.

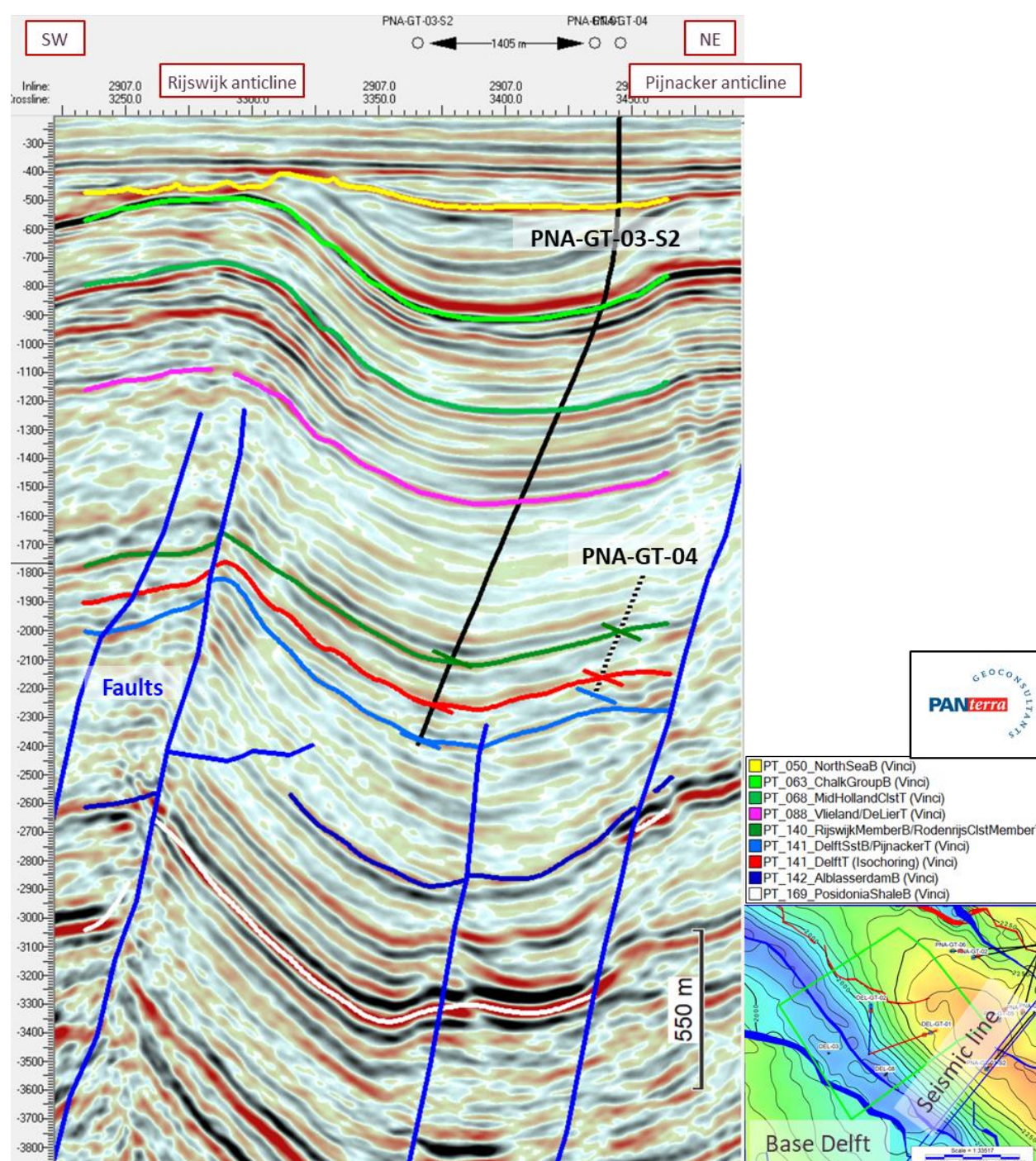


Figure 20 Seismic section along inline 2907, subparallel to PNA-GT-03-S2 trajectory. The figure shows the fault system, the anticlinal structures, interpreted reflectors, well PNA-GT-03-S2 and part of projected well PNA-GT-04. Well tops used to tie seismic interpretation are projected along the borehole trajectories. See insert for line trajectory.

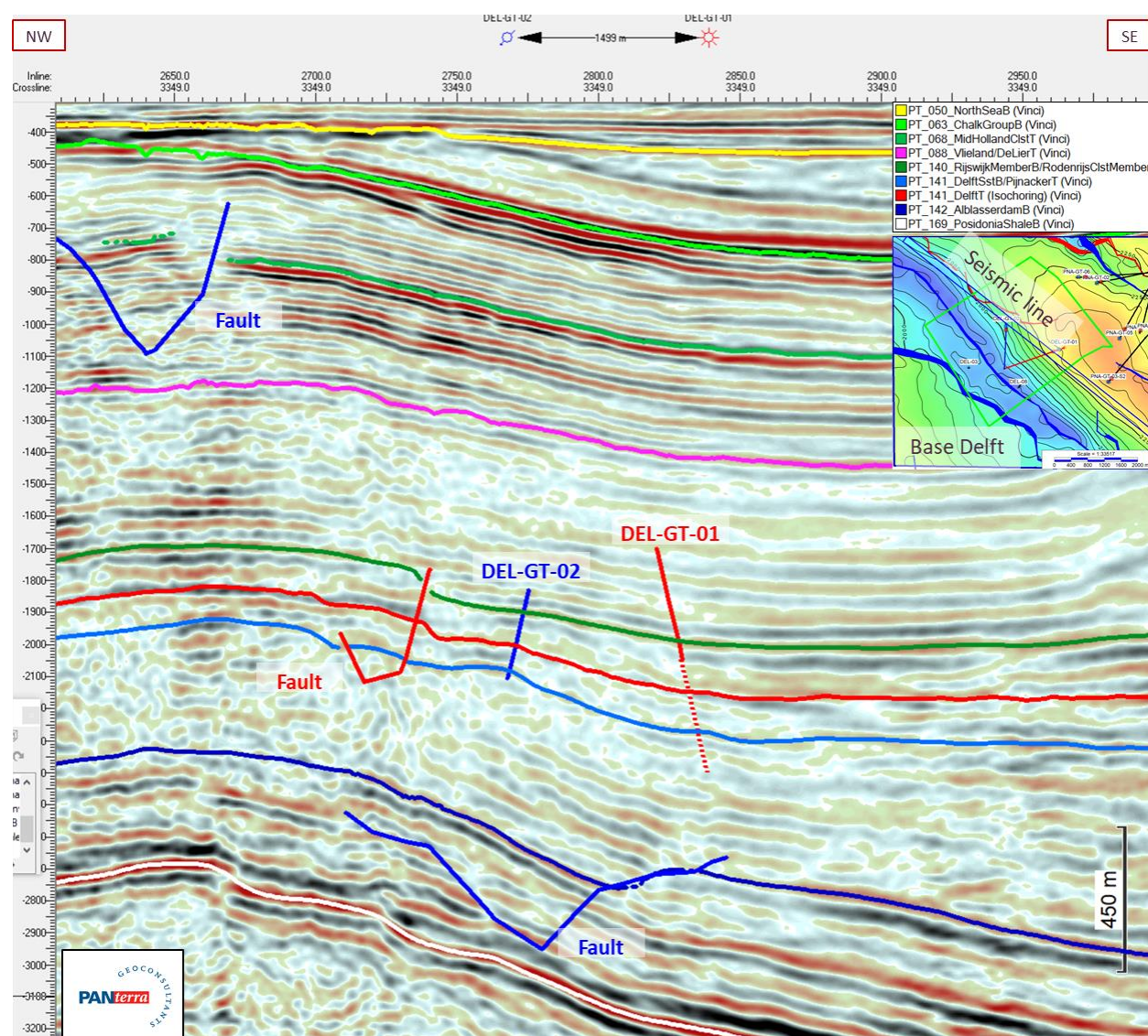


Figure 21 Seismic view along crossline 3349. The figure shows the fault system, interpreted reflectors and part of projected trajectories of planned doublet (DEL-GT-01 and DEL-GT-02). Note the reduced reflector continuity of Base Delft in the target area. See inset for line trajectory.

5.5 Gridding algorithm

Structural depth grids from interpreted seismic horizons were gridded at 40*40m cell size. Fault system was incorporated into the gridding process.

5.6 Depth and thickness maps of the Reservoir

The only reservoir of interest for this exploration license is the Delft Sandstone Member.

The Base Delft Sandstone depth map (Figure 22) is derived from the gridding of the interpreted horizon Base Delft, following the methods described from Chapter 5.1 to 5.5.

Due to the reduced lateral continuity of Top Delft sandstone reflector within the study area, the construction of an average Top Delft Sandstone map (Figure 23) was preferred to a map derived from seismic horizon interpretation. The Top Delft map is obtained by averaging the results of two distinct (Near-)Top Delft isochored grids (see Figure 24), both based on gridded seismic horizons: one referred to Top Rodenrijs (Figure 25) and another to Base Delft (Figure 22) map. To do so, the following workflow was applied:

Wells drilled within the Geothermie Delft AOI show an average thickness of the Rodenrijs Member of 180 mTVT (Table 10). Subtracting this value to the Top Rodenrijs grid (Figure 25), a first isochored (Near-)Top Delft grid was obtained. Similarly, the Delft Member average thickness value of 156 mTVT measured in wells within the Geothermie Delft AOI (Table 10) was added to the Base Delft grid to obtain a second isochored (Near-)Top Delft grid. Note that Delft Member thickness measured in PNA-GT-01 was not included into the average calculation since Base Delft is not reached by the well. Finally, the two (Near-)Top Delft isochored grids (one based on Top Rodenrijs and another on Base Delft) were averaged, producing the average Top Delft grid and map used in the study, shown in Figure 23. The Top Delft map obtained with this workflow minimize the uncertainties deriving from the two preliminary isochored depth maps and shows a good match with available well tops (see Figure 19, Figure 20 and Figure 24).

*Table 10 Rodenrijs and Delft Sandstone thickness values (mTVT) measured in wells within the AOI for the study. Averages were used for isochoring process. *Total thickness unknown, Base Delft not reached (value not included into the Average).*

Well	Thickness Rodenrijs (mTVT)	Thickness Delft (mTVT)
PNA-13	249	134
PNA-GT-01	158	>63*
PNA-GT-02	213	231
PNA-GT-03-S2	161	123
PNA-GT-04	151	136
DEL-08	147	na
Average	180	156

The depth maps of the Delft Sandstone reservoir show a dipping trend that reflects the NW-SE oriented anticline-syncline-anticline structure of the AOI. The east corner of the Geothermie Delft licence shows the deepest values both for Base (around 2350 mTVDSS) and Top (around 2250 mTVDSS) Delft. Shallower values are recorded along the Rijswijk anticline with around 1850 mTVDSS for the Base and 1750 mTVDSS for the Top Delft.

The depths estimated for the new doublet are given in Table 11.

Table 11 Estimated reservoir depths of the planned doublet

DEL-GT-01:	Depth (mTVD)	DEL-GT-02:	Depth (mTVD)
Top Delft	2162	Top Delft	1957
Base Delft	2297	Base Delft	2050

The Delft Sandstone was interpreted to have a relatively consistent thickness of about 100 to 150 m in most of the AOI (Figure 26). A significative thickening, up to almost 250 m, is recorded on the NE flank of the Vrijenban syncline. It occurs in proximity of the PNA-GT-01/-02 and PNA-GT-05/-06 wells, along the main fault of the Pijnacker anticline. A thinning of the reservoir is observed on the opposite flank of the syncline, locally with values of about 50 m. This NE to SW thinning is likely related to syn-sedimentary activity of faults.

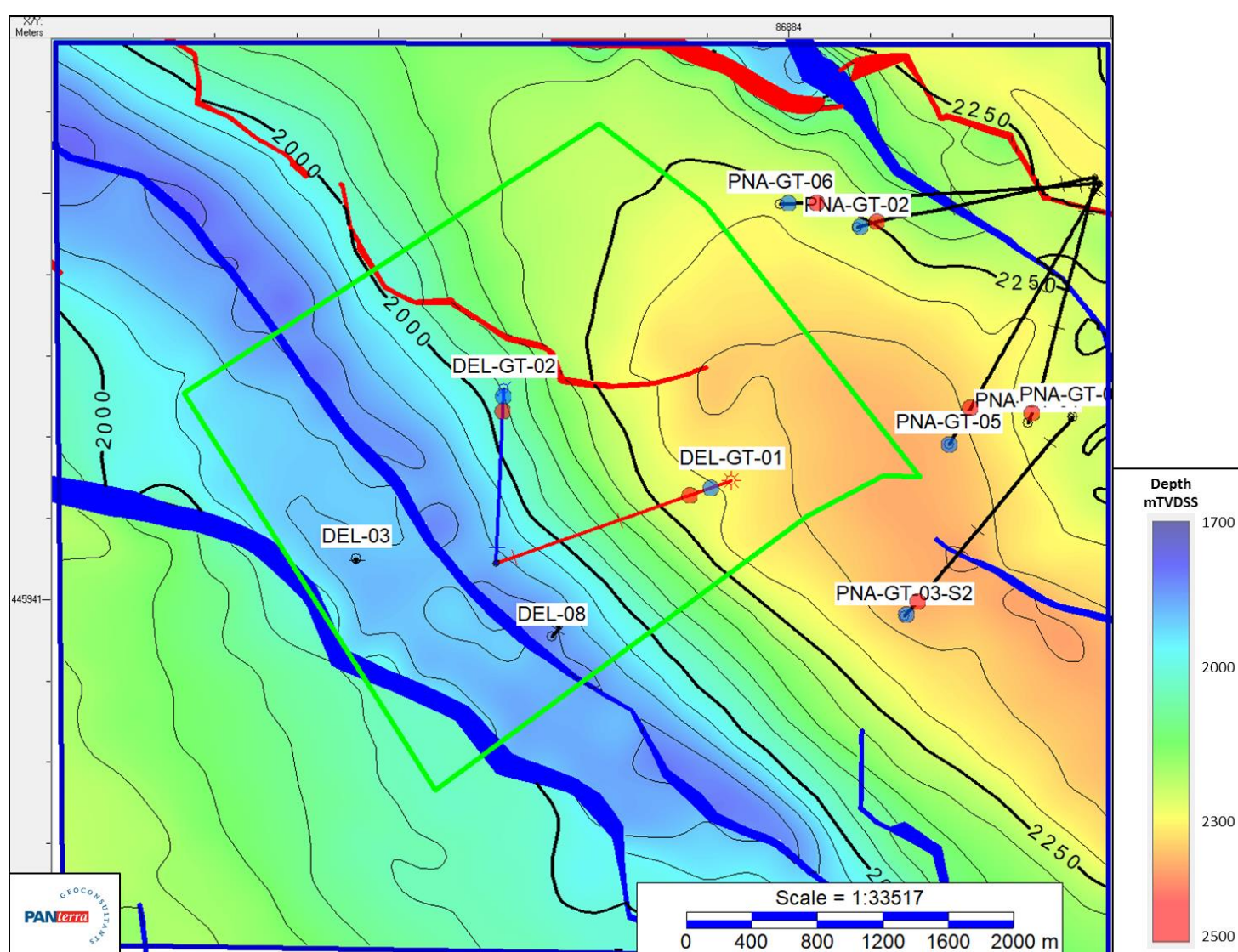


Figure 22 Base Delft depth map (base reservoir) with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green. Blue polygons are SW-dipping faults, red polygons are NE-dipping faults.

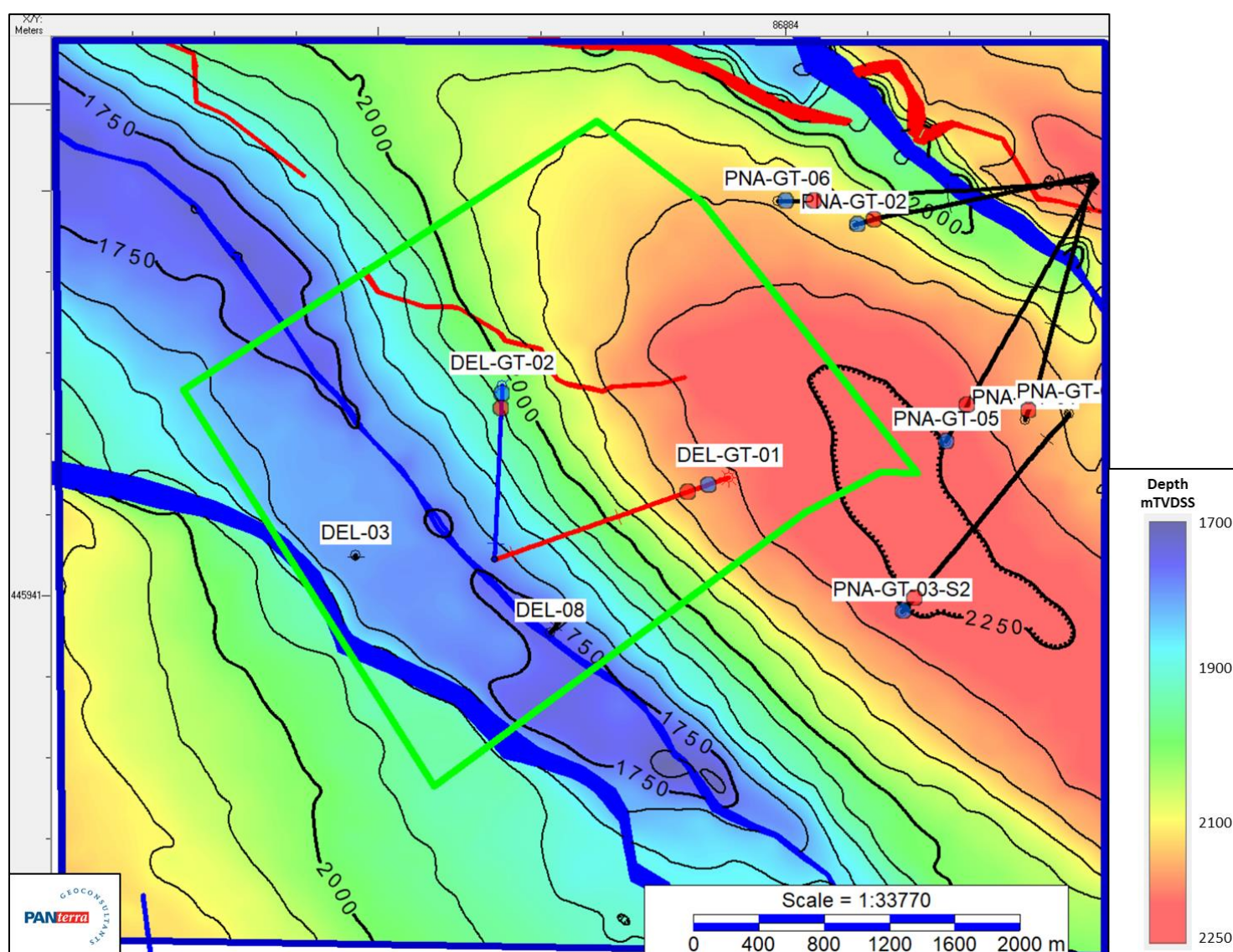


Figure 23 Average Top Delft isochore depth map (Top reservoir) with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green. Blue polygons are SW-dipping faults, red polygons are NE-dipping faults.

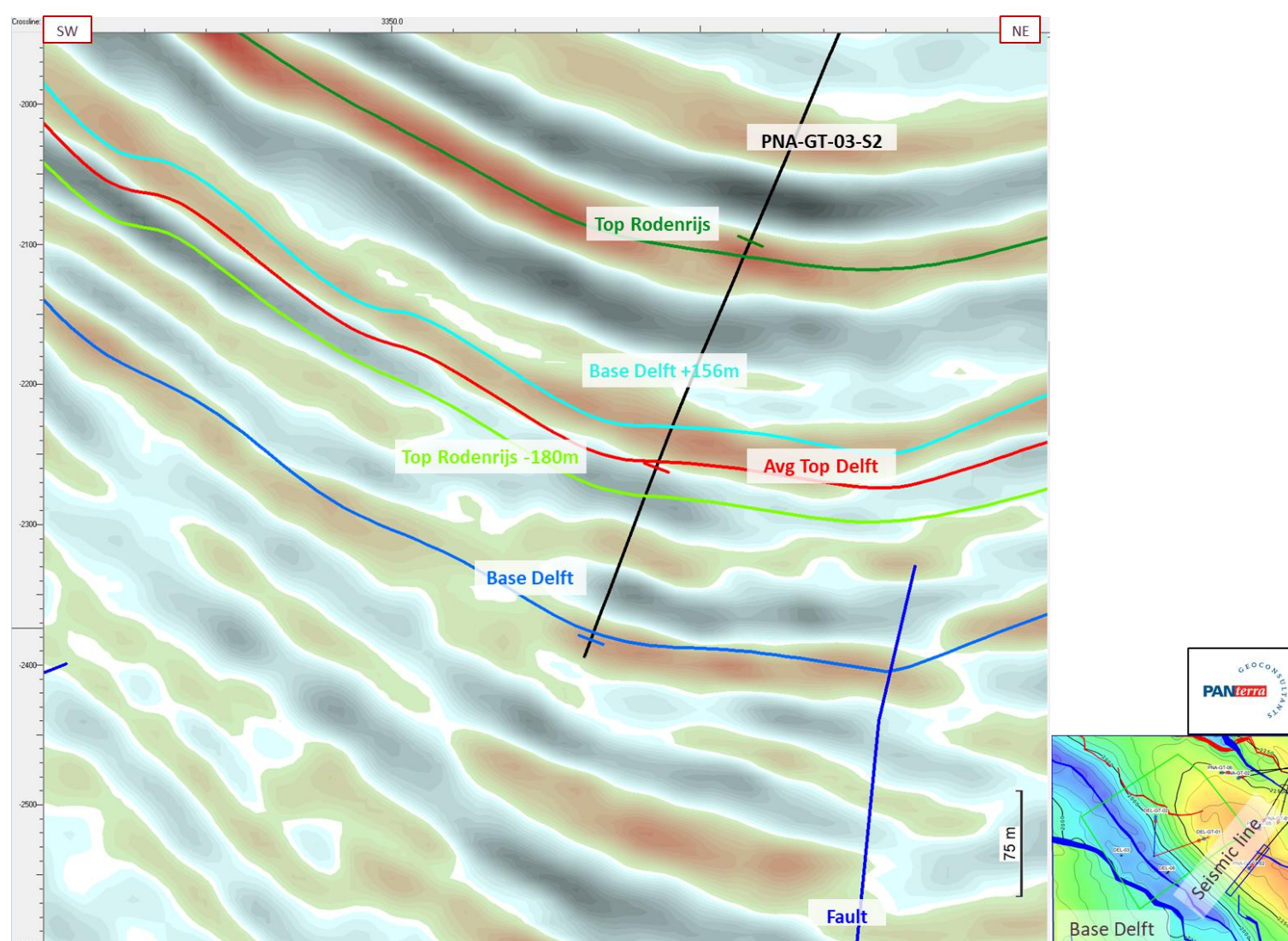


Figure 24 Detail of a seismic section along inline 2907, subparallel to PNA-GT-03-S2 trajectory. The figure shows the depth grids derived from seismically interpreted horizons (Base Delft and Top Rodenrijs), the (Near-)Top Delft isochored depth grids (Base Delft +156m and Top Rodenrijs -180) and the Average Top Delft depth grid. Note the good match of grids with well tops in PNA-GT-03-S2.

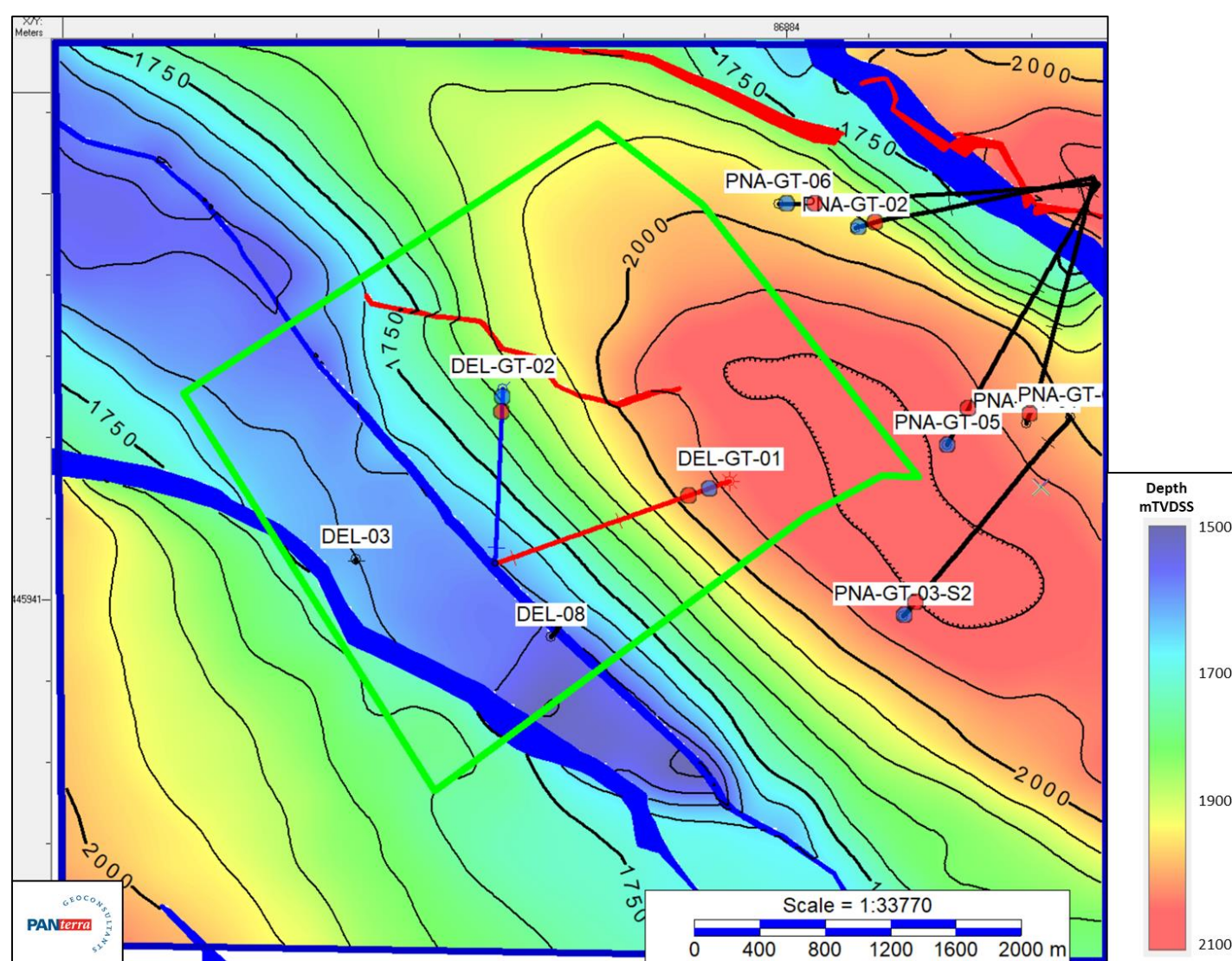


Figure 25 Base Rijswijk/Top Rodenrijs depth map with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green. Blue polygons are SW-dipping faults, red polygons are NE-dipping faults.

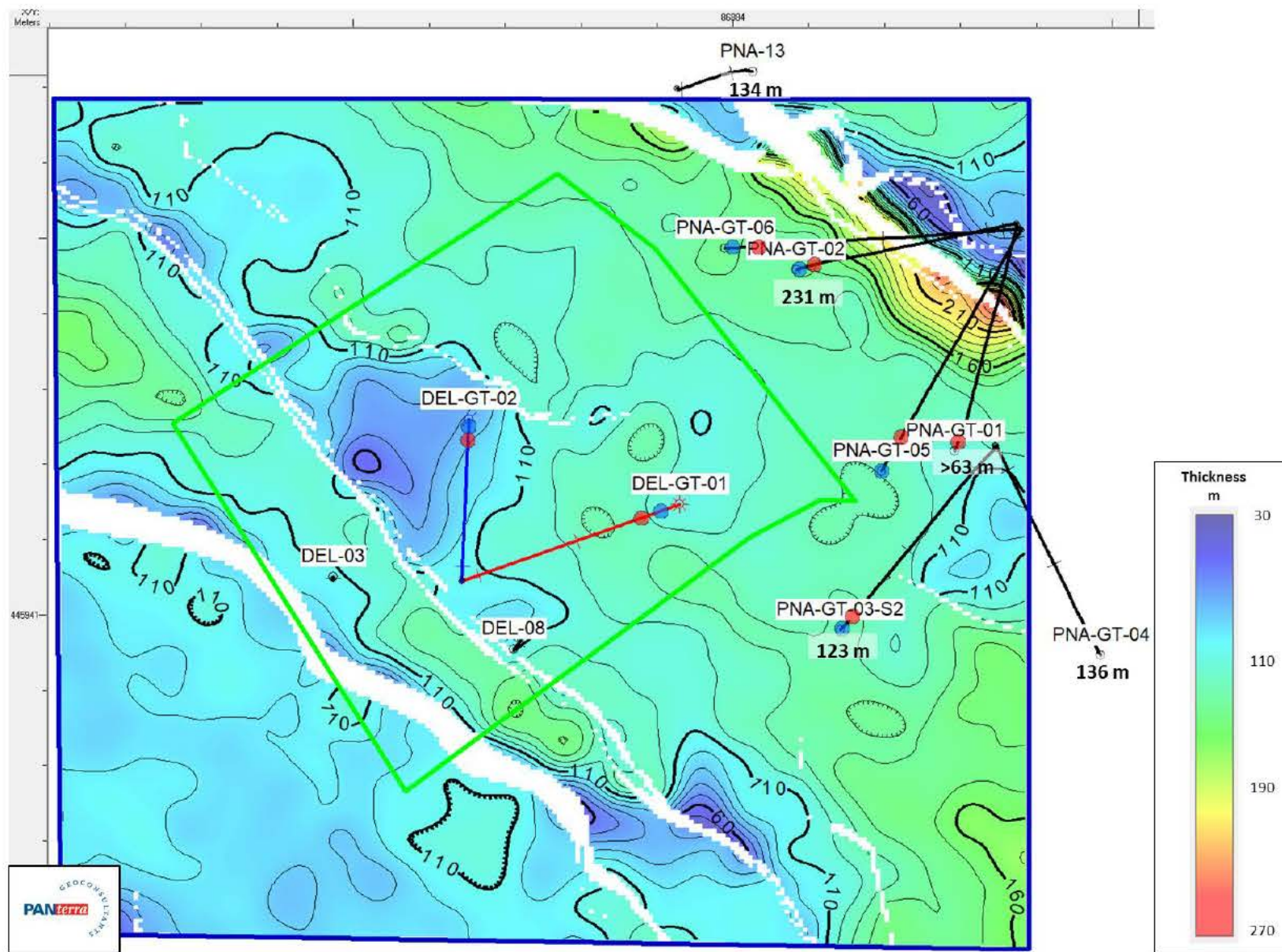


Figure 26 Delft Thickness map with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. Available Delft Sandstone Thickness (mTVT) according to available well tops is shown as well. The Geothermie Delft exploration license is outlined in green.

5.7 Uncertainty in the depth maps

The low residuals (Table 12) give confidence in the accuracy of the depth maps. The uncertainty of 10% used in DoubletCalc1D for power analysis is more than sufficient to cover the depth uncertainty range. The actual depth uncertainty of the interpretation within the AOI is around 1% on average, as listed in Table 12.

Table 12 Residual at wells

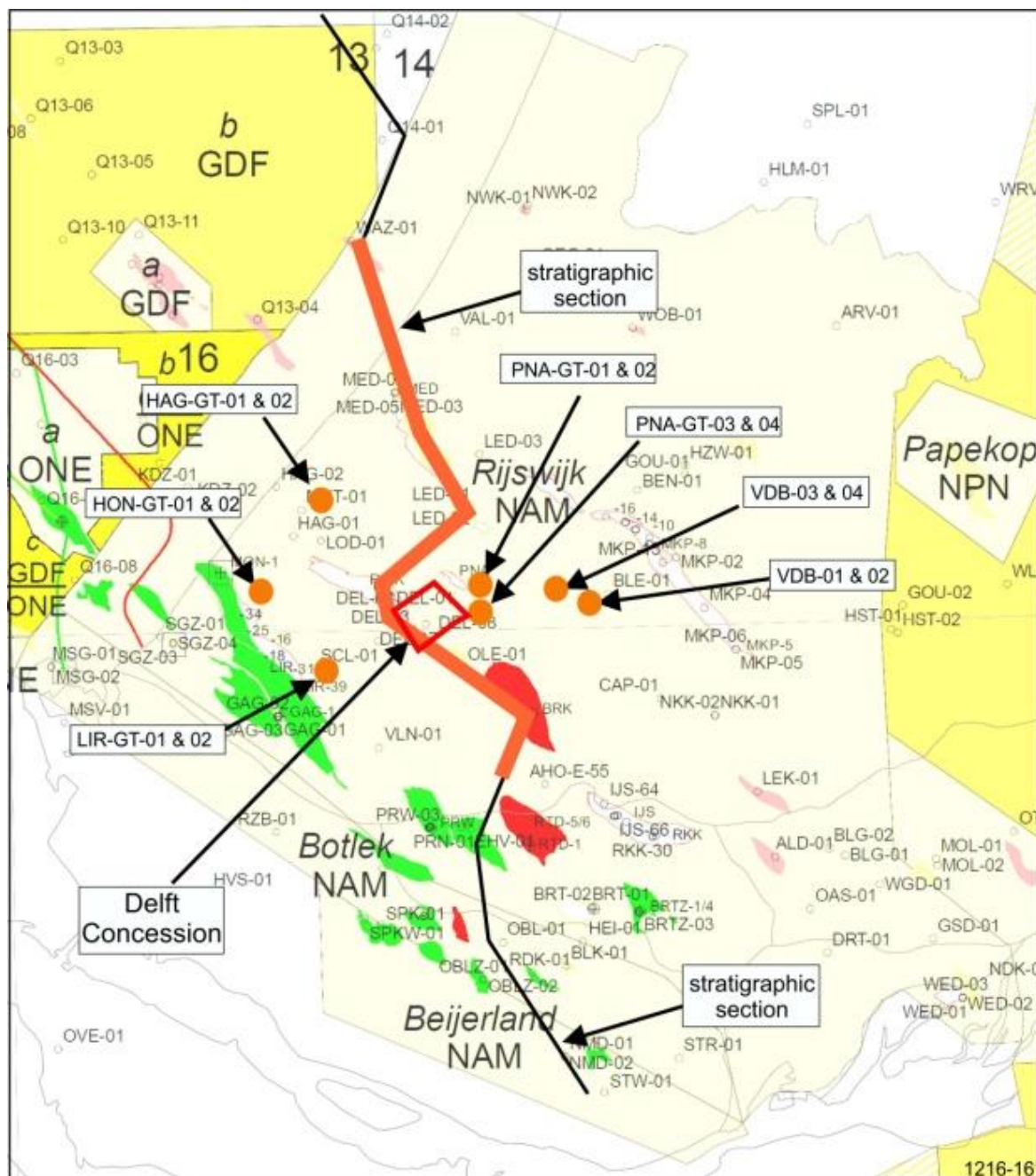
Well	Surface	Well Top Depth (mTVDss)	Depth map intersection (m TVDss)	Residual (m)	Residual (%)
DEL-08	Top Rodenrijs	1637	1591	46	2.9
PNA-GT-01	Top Rodenrijs	2005	2013	8	0.4
PNA-GT-02	Top Rodenrijs	1803	1803	0	0
PNA-GT-03-S2	Top Rodenrijs	2098	2109	11	0.5
PNA-GT-01	Top Delft	2163	2165	2	0.1
PNA-GT-02	Top Delft	2016	2088	72	3.4
PNA-GT-03-S2	Top Delft	2259	2255	4	0.2
PNA-GT-02	Base Delft	2247	2266	19	0.8
PNA-GT-03-S2	Base Delft	2382	2377	5	0.2

6 Characterisation and Model of the Reservoir

6.1 Stratigraphic correlation and lateral thickness variation of the aquifers

Relevant for geothermal purposes in the Delft area are the non-marine sediments of the Nieuwerkerk Formation (SLDN) that were deposited in subsiding half-grabens, while at places the adjacent highs were subjected to erosion. This formation is overlain by the marine Vlieland Sandstone Formation (KNNS) and this in turn is overlain by the marine Vlieland Claystone Formation (KNNC). Several members have been formally defined that are important in the Delft area (see Figure 27 and Figure 28) from top to bottom:

- The Berkel Member (KNNSB, Vlieland Sandstone Formation): sandstones deposited in coastal-marine settings. It is developed just south-east of the Delft area, see for its areal distribution Figure 29.
- The Berkel Sand-Clay Member (KNNSC, Vlieland Sandstone Formation): A package of shaley sands has been defined as the Berkel Sand-Claystone Member. It is the sea-marginal facies of the more massive sandstone of the Berkel Member. The Berkel Sand-Clay Member is often combined with the Berkel Member and together the two units are more or less informally named the Berkel Sandstone.
- Rijswijk Member (KNNSR, Vlieland Sandstone Formation): transgressive-marine sandstone with a more or less continuous distribution in the West Netherlands Basin (Figure 29).
- Rodenrijs Claystone Member (SLDNR, Nieuwerkerk Formation): non-marine claystone with at places thin coals and thin sands.
- Delft Sandstone Member (SLDND, Nieuwerkerk Formation): massive fluvial sandstones with minor clay intervals. This sandstone is observed in the centre of the West Netherlands Basin and is tens of meters thick. The distribution and thickness of this potential reservoir is discussed below.
- Alblasserdam Member (SLDNA, Nieuwerkerk Formation): fluvial sandstones and shales. In earlier reports by PanTerra the Alblasserdam Member is subdivided into two units:
 1. The Pijnacker unit (informal name) consisting of a thick non-marine interval with channel sandstones and claystones. This unit is variable in thickness: up to several hundreds of meters. The base of this unit is a subtle seismic unconformity. In some wells the lower part of the Pijnacker is sand-rich.
 2. Papekop unit (informal name); the unit is dominated by non-marine claystones with subordinate channel sands. The unit is variable in thickness. The base of this unit is at places a major seismic unconformity. Below the unconformity is the Jurassic Altena Group.



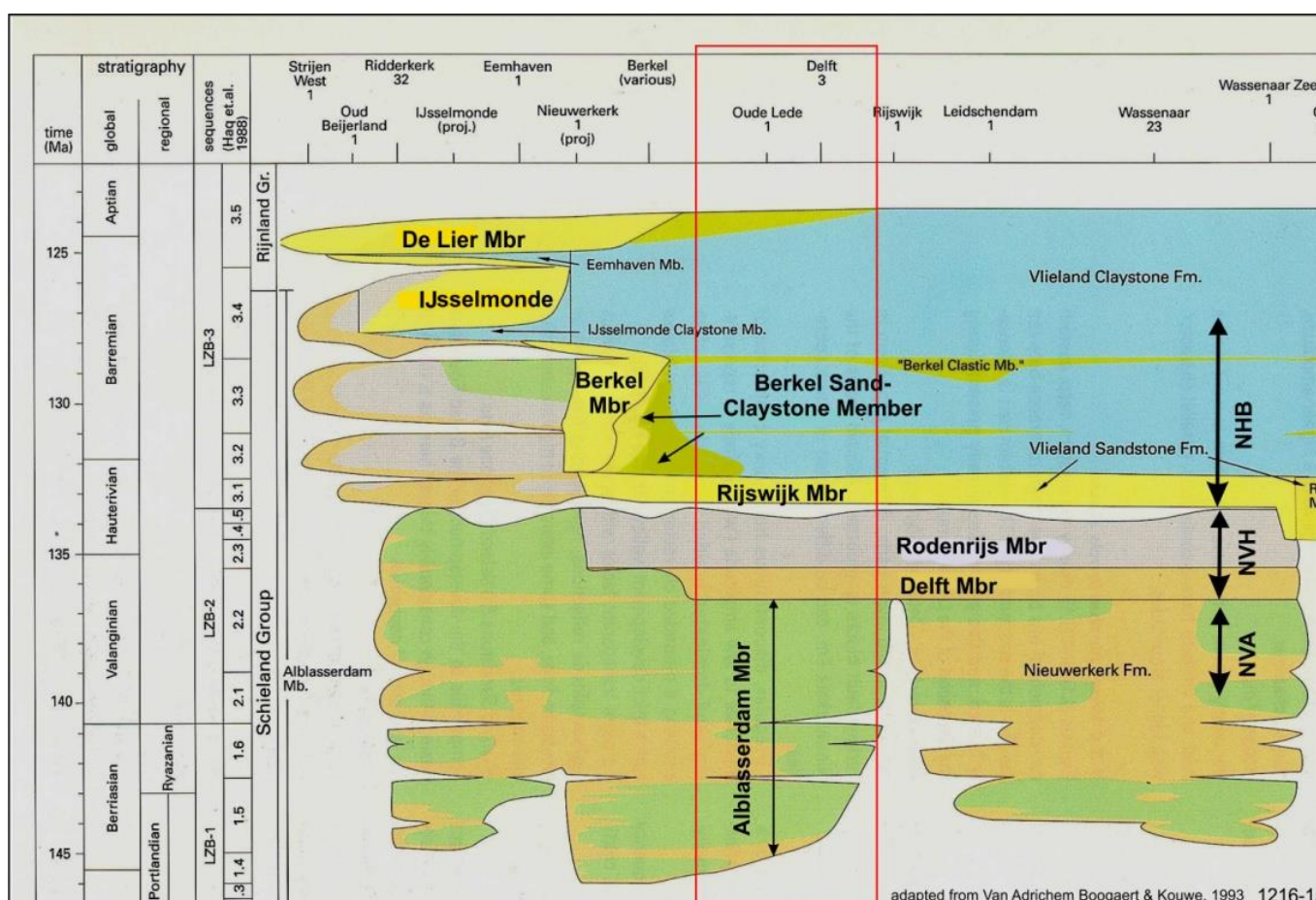


Figure 28 Stratigraphic scheme through the West Netherlands basin showing the members important for the area under discussion. The wells on which this scheme has been based are in the previous figure, exceptions are the IJsselmonde and Nieuwerkerk boreholes which are projected on the line of section of this scheme. The Delft area is indicated with a red box. Marine claystones are blue, marine sandstones are bright yellow, non-marine claystones are in green, non-marine sandstones are ochre. (Adapted from Adrichem Boogaert & Kouwe, 1993)

6.1.1 Potential reservoirs

The Delft Sandstone (SLDND) is the main target for geothermal wells in the West Netherlands basin and is the main aquifer targeted for this project. Other potential reservoirs are the Rijswijk Member (KNSNR) and to the south of the city of Delft the Berkel Sand-Claystone Members (KNSB, KNSC).

The Berkel Sand-Claystone Member is a package of clayey sands and clays. On logs it is characteristically thin bedded. It is interpreted as the seaward marginal facies of the massive sands of the Berkel Member. It is several tens of meters thick and pinching out toward the West and North-West. The map of Figure 29 shows that the Geothermie Delft area is located near the north-westerly limit of the Berkel unit which is confirmed by well data and seismic data. Figure 30 shows that the unit is developed in the southern wells and absent in the northern wells. The first geothermal doublet drilled in the West Netherlands basin, VDB-01 and -02 is completed in this interval together with the Rijswijk Member.

The Rijswijk Member is about 10-30 m thick and is well developed in PNA-GT-03-S2, PNA-GT-04 and DEL-01 (see Figure 30). In these three wells it is overlain by a package of shaley sands of the Berkel Sand-Claystone Member. The Rijswijk Member is thin (up to 10m) in PNA-GT-01 and -02. In the oil well PNA-13 the Rijswijk Member is well developed with almost 70m. This has been explained by the presence of a small and local pull-apart basin during the Early Cretaceous in which the Rijswijk Member is thick (Racero-Baena & Drake, 1996)

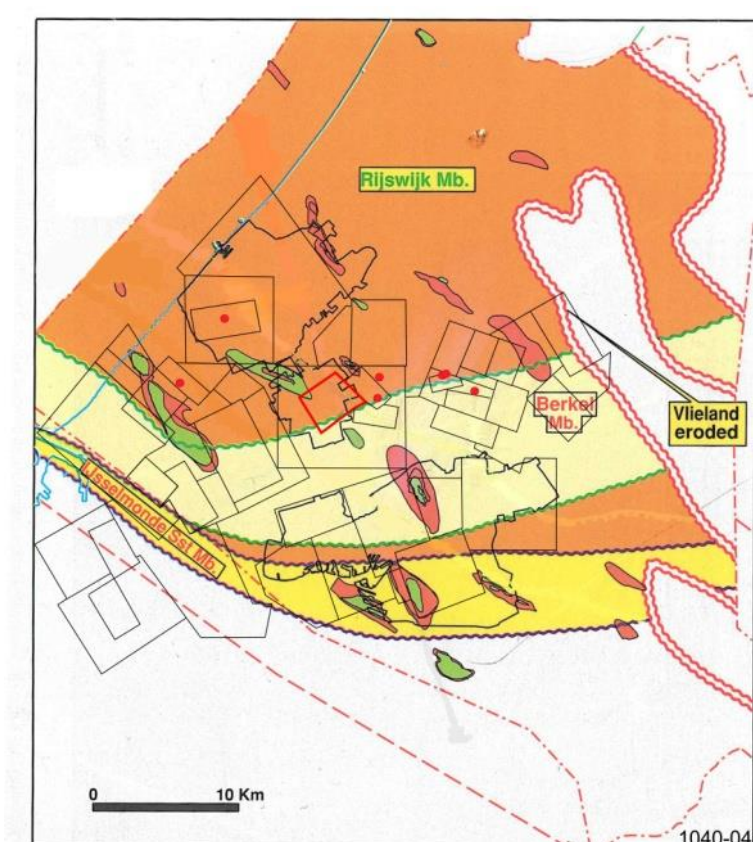


Figure 29 Map of the West Netherlands basin showing distribution of the Lower Cretaceous Rijswijk, Berkel and IJsselmonde Sandstones. Dark yellow is the area where the IJsselmonde sandstone occurs. Light yellow is the area where the Berkel Sandstone is present. Orange is the area where the Rijswijk Member sandstone is present; this sandstone is present as well below the Berkel. The map correctly predicted presence/absence of Berkel sandstones in all recently drilled geothermal wells (red dots). The location of the Delft exploration license is indicated in red. (Adapted from Racero-Baena & Drake, 1996)

In case well-developed Rijswijk Sandstone is present, the top of the Rodenrijs Claystone is easy to pick. However, if the Rijswijk is not well-developed some debate may be possible. The top of the Rodenrijs Member is characterized by black clays with a restricted lagoonal palyno-flora. Coals are probably well developed in the four Pijnacker geothermal wells but cannot be interpreted with confidence because of the absence of wireline logs.

Where the top Delft Sandstone is not well developed as a clean sandstone the position of the base Rodenrijs is subjective. Normal and reverse faults are both present in the Pijnacker and Rijswijk structures; PNA-13 has been interpreted by the operator to have crossed reverse and normal faults (see Figure 30). Presence of faults makes it difficult to interpret stratigraphic thicknesses, in particular with old wells that lack modern logs or new geothermal wells that do not have proper well logs. However, seismic suggests that away from the structural culminations major faults are not developed.

The thickness of the Rodenrijs is of importance for the estimate of the depth of the Delft sandstone reservoir using seismic data. Figure 30 shows a section through wells in the vicinity of the Geothermie Delft project. See Table 10 for Rodenrijs and Delft thickness values estimates.

If sandstones at the top of the Delft Member are well-developed, the base of the Rodenrijs Member is easy to define. The Delft Sandstone is variable in thickness (see Figure 26 and Figure 30). In the three of the four Pijnacker geothermal wells the base Delft Sandstone cannot be picked with certainty because these wells were not drilled deep enough. Therefore, the gross thickness of the Delft Member in three Pijnacker geothermal wells PNA-GT-01, PNA-GT-03S2, and PNA-GT-04 of about 150m can be considered a minimum thickness. PNA-13 suggests a thickness of 134 m, while PNA-GT-02 thickness may be 231 m.

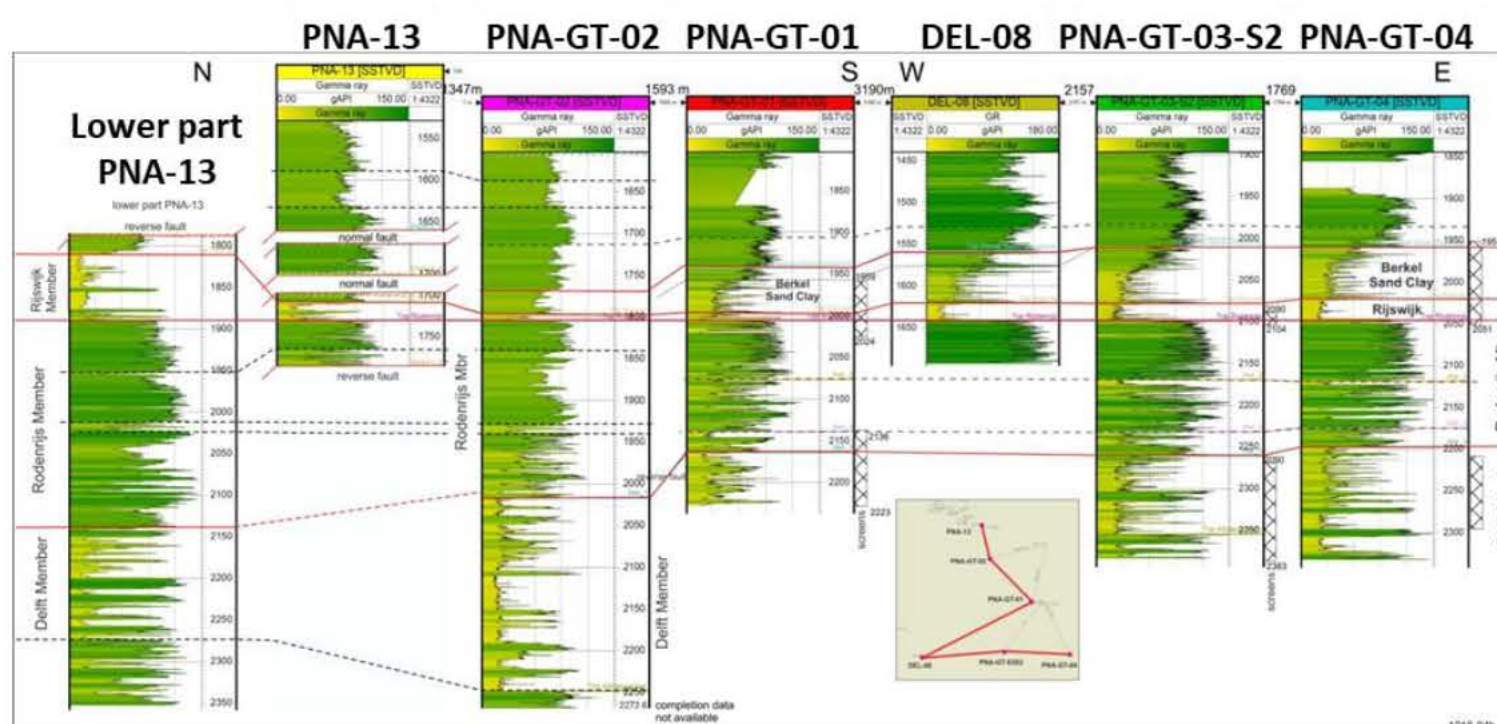


Figure 30 Section through the four Pijnacker geothermal wells, PNA-13 and DEL-08.

Wells DEL-07 and DEL-08 are close to the planned Geothermie Delft wells, unfortunately both wells did not penetrate the Delft Sandstone, nor did well Oude Leede-01 (OLE-01, see Figure 10). The nearest well on the Rijswijk structure that penetrated the Delft Sandstone and deeper section is DEL-03 (drilled in 1954). This well penetrated 106m section interpreted as Delft sandstone followed by a minimum of 308m Alblasserdam Member before TD in the Alblasserdam Member. The 108m of Delft Sandstone thickness is thinner than observed in the Pijnacker geothermal wells. The 1954 cuttings description does not suggest presence of well-developed sandstone, but fine-grained sandstone grading to siltstones.

Of the 14 wells on the Pijnacker structure only PNA-13 penetrated the Delft Member. A digital log of the GR was not available for the Delft Member but a digitized GR from a tiff image is included in Figure 30; the Delft Sandstone is relatively poorly developed in this well.

6.2 Petrophysical evaluation

For this project no new petrophysical analyses have been performed. For a few wells references have been made to analyses from earlier reports. Reason is that few wells are available with sufficient logs for a full petrophysical analysis and secondly, the general paucity of relevant core data needed to establish reliable poro-perm relations for the units under discussion. Of the recently drilled geothermal wells in the project area only GR logs are available. Using these, net sand of the reservoirs has been calculated with a 50% shale cut-off (Table 13).

Table 13 Thickness and N/G values of wells drilled within the Vrijenban syncline. *Base Delft not drilled.

Well	Top Delft (mTVD)	Base Delft (mTVD)	Thickness Delft (mTVD)	N/G Delft
PNA-GT-01	2164	2227	>63*	0.62*
PNA-GT-02	2017	2248	232	0.81
PNA-GT-03-S2	2260	2383	123	0.66
PNA-GT-04	2197	2333	136	0.72

For thickness and N/G values the wells drilled within the Vrijenban syncline (same as the planned doublet) are considered most important, these are the four wells of the two Pijnacker doublets (see Figure 30). PNA-GT-02 penetrated the longest section below the Rodenrijs Member and encountered 232m of sand-rich section (N/G = 0.81). The poorest section is that of PNA-GT-03-S2 with 123m gross Delft section with a N/G of 0.66. PNA-GT-01 has not reached the base of the Delft, therefore its thickness and N/G cannot be considered representative. Overall, the PNA/GT wells indicate a median N/G value of 0.66.

6.3 Well test evaluation

Well test data from a number of geothermal doublets situated within 10 km from the planned doublet are available and described hereunder.

6.3.1 Honselersdijk

A well test was performed for HON-GT-02 and evaluated by PanTerra in 2012 (described in *advies aanvraag Garantieregeling AARD03002 Geothermie De Lier* by TNO-AGE, 2013, found on www.rvo.nl) is publicly accessible. The evaluation concluded that the permeability of the Delft Sandstone Member is 1190 mD. The reservoir at HON-GT-02 is situated approximately 10 km from the target of DEL-GT-01 and -02.

6.3.2 De Lier

An analysis of the well tests for LIR-GT-01 and GT-02 is also published (*Analysis of Well test LIR-GT-01* and *Analysis of Well test LIR-GT-02* from August 2014 by Panterra, 2017a, on www.rvo.nl). These tests show that the average reservoir permeability of the Delft Sandstone Member is 1000 mD and 1300 mD for well -01 and -02 respectively assuming that the whole net sand contributes to flow. An interference test showed that the permeability between the wells is as high as 2000 mD. The reservoir at LIR-GT-01 and -02 is situated approximately 6.5 km from the target of DEL-GT-01 and -02.

6.3.3 HAL

An analysis of well tests for HAG-GT-01 and HAG-GT-02 performed and valued by HydrecoGeomec (2018) is published (*Analysis of Well test HAG-GT-01* and *Analysis of Well test HAG-GT-02*, available on www.nlog.nl). These tests show that the average reservoir permeability of the Delft Sandstone Member is 1400 mD and 2300 mD for well -01 and -2 respectively, assuming that the whole net sand contributes to flow. The reservoir at HAG-GT-01 and -02 is situated approximately 9 km from the target of DEL-GT-01 and -02.

6.3.4 Lansingerland

Also for well LSL-GT-01, results of a well test performed in 2017 (Lingen, 2017) are available (*Analysis of Well test LSL-GT-01*, found on www.rvo.nl). The test indicates an average permeability of 607 mD for the Delft Sandstone, considering 35m of net sand contributing to the flow. The reservoir at LSL-GT-01 is situated approximately 9.5 km from the target of DEL-GT-01 and -02.

Table 14 Well test data

Well	Top Delft (mTVD)	Base Delft (mTVD)	Delft Net Thickness (mTV)	N/G Delft	Average Permeability (mD)
HAG-GT-01	2195	2281	62.5	0.73	1400
HAG-GT-02	1761	1873	96	0.86	2300
HON-GT-02	2407	2544	116.5	0.85	1190
LIR-GT-01	2387	2528	70.5	0.5	1000
LIR-GT-02	2324	2418	63.9	0.68	1300
LSL-GT-01	1849	1904	35	0.63	607

6.4 Production data evaluation

Relevant production data is available for the Ammerlaan doublet (PNA-GT-01 and -02) and the Van den Bosch doublet (VDB-03 and -04). Results are summarized in Table 17.

6.4.1 Ammerlaan

As of February 2017, the Ammerlaan doublet produced 157 m³/h. The measured pressure at the ESP was 13.9 bar and the injection pressure was 41.3 bar. The production water had a temperature of 76.2 °C at the surface.

These numbers were used to make a back-calculation with DoubletCalc1D (PanTerra, 2017b). Note that the well diameter of the existing Ammerlaan doublet is small compared to standards used today. More importantly, the completion of the wells is far from optimal. According the correlation presented in Figure 30, the Rijswijk has only been completed in PNA-GT-01. Also, only the upper part of the Delft Sandstone has been completed in both PNA-GT-01 (approximately 80 m TVT) and PNA-GT-02 (approximately 32 m TVT). It is difficult to say whether the lower part of the Delft completed in PNA-GT-02 has communication with the upper (screened) part of the Delft in PNA-GT-01. The gamma ray shows that there are multiple shaley layers which separate the clean sands.

For the back-calculation, an average thickness of 65 m TVT has been assumed (the average screened thickness of the upper part of the Delft) and a N/G of 0.6 (slightly higher than the screened section in PNA-GT-01). The pump pressure difference is set to 70 bar which is the maximum pressure restriction for this doublet. A flow rate of 157.7 m³/h is calculated with a permeability of 620 mD.

6.4.2 Van den Bosch

The data available for the two Van den Bosch doublets are incomplete. There are no logs apart from GR logs of two wells and therefore tops and bottoms of the producing aquifers are imprecisely known, and porosity and permeability of the reservoirs cannot be derived. However, historical production and injection data are available for the two doublets. Willems (2012) has attempted to estimate permeabilities using the radial inflow equation and a Monte Carlo simulation of the unknown parameters in this equation. Using this method, it was possible to estimate upper and lower limits for the permeabilities of the two reservoir units. He further used a dynamic reservoir model to test sensitivities. The parameters which are used for this analysis are summarized in Table 15 and the results are shown in

Table 16. These calculations did not include reservoir damage (skin).

Table 15 Characterization of the aquifers from production data (Willems, 2012).

	VDB-03	VDB-04
Type of well	Producer	Injector
P _{pump} (bar)	11	26
P _{wf} (bar)	178	218
P _{res} (bar)	195	189
Delta P	17	29
Screen length	70	84
Prod/Inj. Indices (m ³ /h/bar)	8.8	5.2
Formation	Delft	Delft
Flow rate (m ³ /h)	150	150

Table 16 Permeabilities calculated by the radial inflow equation (Willems, 2012).

Reservoir	Well	Average permeability (mD)	Permeability range (mD)
Delft	VDB-03	424	300-600
	VDB-04	339	

Table 17 Well production data

Well	Reservoir	Average permeability (mD)	Flow rate (m ³ /h)
PNA-GT-01/-02	Delft Sandstone	620	157.7
VDB-03	Delft Sandstone	424	150
VDB-04	Delft Sandstone	339	150

6.5 Permeability from public information

No additional permeability data from the public domain was used other than explained in Chapters 6.3 and 6.4.

6.6 Reservoir parameters in the Geothermie Delft licence area

Reservoir parameter forecast for the Delft Sandstone has been updated from what was proposed in the previous Geothermie Delft geological study (PanTerra, 2016). New estimates are based on an updated seismic interpretation of the area on a reprocessed depth cube (Chapter 5), on petrophysical information (Chapter 6.2) and on most recent well test (Chapter 6.3) and production data evaluation (Chapter 6.4).

The sub-chapters below describe the reservoir parameter input distribution applied for the DoubletCalc1D calculation.

6.6.1 Gross Thickness

Refer to Chapter 5.6 'Depth and thickness maps of the Reservoir'.

Delft Sandstone: **92 m** (average thickness at well locations minus 25%) - **123 m** (average thickness at planned well locations) - **154 m** (average thickness at well locations plus 25%).

6.6.2 Net to Gross (N/G)

Refer to Table 13, petrophysical data from wells drilled into the Vrijenban Syncline. Note that PNA-GT-01 is not considered for N/G estimates because has not reached Base Delft.

Delft Sandstone: **0.62** (Min value observed in the Vrijenban wells minus 0.04) - **0.72** (Median value observed in the Vrijenban wells) - **0.85** (Max value observed in the Vrijenban wells plus 0.04).

6.6.3 Permeability

Refer to Chapter 6.3 and 6.4, evaluation of well tests and production data. Production data of Ammerlaan doublet are considered as the most representative data point for the planned Geothermie Delft doublet since it was drilled in the same basin (Vrijenban syncline), at a distance of 2 km only from the planned production well.

Delft Sandstone: **250 mD** (based on low case of VDB production data evaluation of 300 mD minus 50 mD, 17%) – **600** (based on Ammerlaan production data, rounded down) - **1300** (average value of well test permeabilities in Table 14, rounded up).

6.7 Anisotropy

Anisotropy of the reservoir can be expressed as the ratio between horizontal and vertical permeability; Kh/Kv. This ratio is usually relatively high when the reservoir is layered and low when the reservoir is homogeneous (in horizontal and vertical sense). The Delft reservoir usually has a relatively high anisotropy. Based on prior studies in the WNB, a Kh/Kv of 5 is used for the Delft reservoir.

Results and uncertainty discussion

Table 18 provides a summary of expected ranges in gross thickness (Chapter 6.6.1), net-to-gross ratio (Chapter 6.6.2) and average permeability (Chapter 6.6.3) for the Delft Sandstone in the Geothermie Delft area. Reservoir anisotropy (Chapter 0) and expected water properties (Chapter 7) are also included. Uncertainties are discussed in the respective chapters.

Highest risk is allocated to permeability of the reservoir. The uncertainty is reflected in the large data spread assigned to this property.

Table 18 Summary table of expected ranges in reservoir properties of the Delft Sandstone for the Geothermie Delft area.

Parameters		Min	Median	Max	Uncertainty
Delft Sandstone	N/G (dec)	0.62	0.72	0.85	-14%/+18%
	Gross thickness (m)	92	123	154	-25%/+25%
	Average Permeability (mD)	250	600	1300	-58%/+117%
	Salinity (ppm)	105,000	130,000	150,000	-19%/+15%
	Kh/Kv		5		
	Temperature Gradient (°C/100m)		3.15		

7 Formation water

7.1 Temperature

In order to determine the expected temperature for the Delft doublet, the temperature maps of the subsurface of the Netherlands from Bonté et al, 2012 are taken into account (Figure 31). These maps indicate that the subsurface temperature in the area of the Delft doublet is approximately 72°C at 2000m depth and 104°C at 3000m depth. This corresponds to a temperature gradient of approximately 0.310-0.0313°C/100m, assuming a surface temperature of 10°C. Figure 32 shows a comparison between the result of the Bonté et al 2012 model (best model) and the calibration values, which shows a similar gradient and surface temperature.

However, production temperatures from the neighboring PNA-GT-01 geothermal production well are expected to be more indicative for the local temperature at the location of the Delft doublet. During production in February 2017 a temperature of 76.2°C was measured at surface, before the heat exchanger. The back calculation in DoubletCalc1D suggests that the aquifer temperature at the producer should be 78.3°C (Appendix F), which corresponds to a gradient of 0.315°C/100m, assuming a surface temperature of 10°C:

$$T = 10 + 0.0315 \cdot d$$

Where °C and d is the depth in m.

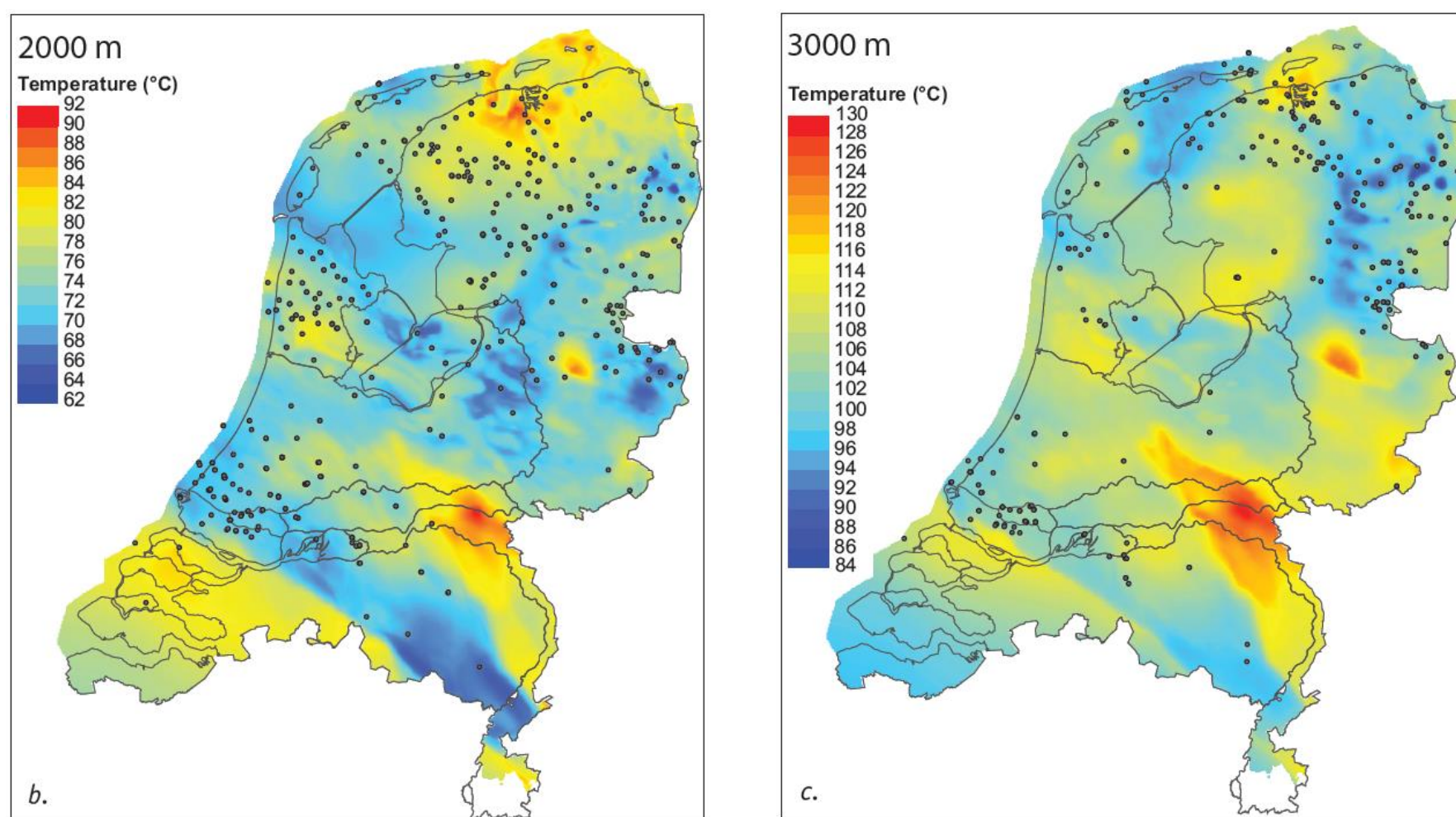


Figure 31: Subsurface temperature map of The Netherlands at 2000m and 3000m (Bonté et al, 2012). These maps are generated from thermal-tectonic forward modelling, calibrated with BHT measurement in wells (corrected for thermal perturbation during drilling) and few DST measurements in wells. Used wells are indicated by black dots.

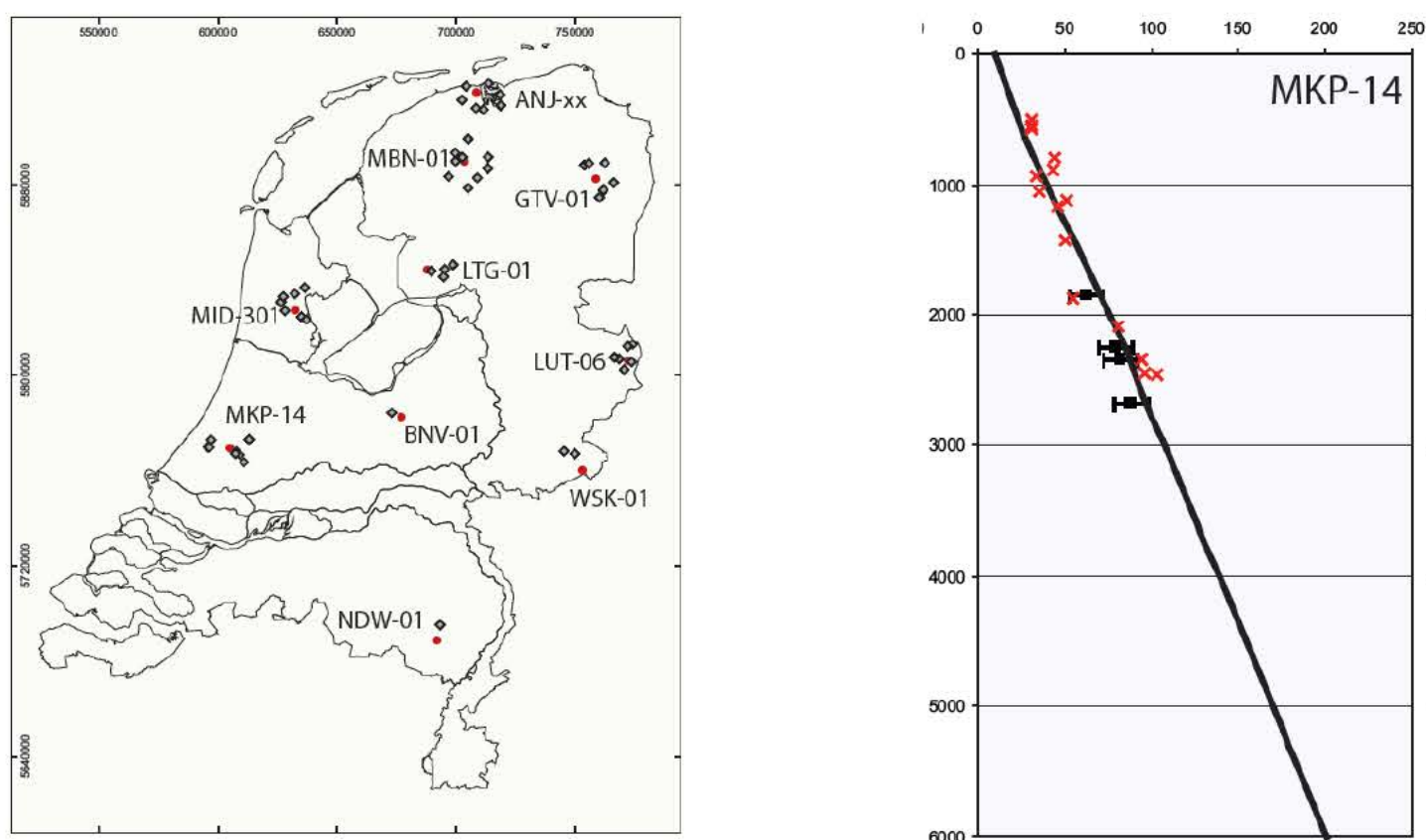


Figure 32: Left: Localities of wells selected to show the comparison between the result of the model (best model) and the calibration values. Red dots: wells represented and compared to the model result. Diamond: values of wells found within a diameter of 10km of the main well. Right: comparison between the values used as calibration and the modelled temperature (from the best model). Black square: BHTx_ICS values in the well. Black line: Temperature in the model. Red crosses: unspecified temperature values within 10km of the well. (Bonté et al, 2012).

7.2 Salinity

To determine the expected salinity for the Delft doublet, data from the neighboring PNA-GT-01 geothermal well is considered. Formation water was sampled during the production from PNA-GT-01. The analysis of the produced water (dd 10-01-2017) gave a TDS of 130.000mg/L. Therefore, the mean salinity of the formation water is determined to be 130.000ppm (Appendix H).

The minimum salinity of the formation water is determined based on the P10 salinity measured in the geothermal wells within a distance of approximately 15km from the proposed drilling location, which is 105.000ppm. The maximum salinity of the formation water is determined based on the P90 salinity measured in the geothermal wells within a distance of approximately 15km from the proposed drilling location, which is 150.000ppm.

Table 19: TDS measured in geothermal wells within a distance of approximately 15km from the proposed drilling location

Well	TDS (g/l)
HAG-GT-01	115
HON-GT-01	123
HON-GT-02	127
KHL-GT-01	153
PNA-GT-01	130
LIR-GT-01	155
LIR-GT-02	140
VDB-GT-03	104
VDB-GT-04	109
PLD-GT-01	115
PLD-GT-02	89
NLW-GT-01	120
NLW-GT-02	130
LSL-GT-01	121

Percentile	TDS(g/l)
P10	105
P90	150

Aquifer	Low	Mid	High
Salinity	105.000	130.000	150.000

7.3 Hydrocarbons

Information from the neighboring geothermal wells are used to determine the expected hydrocarbon content for the Delft doublet. After drilling and clean-out of the PNA-GT-05 -S1 well, the gas/water ratio was determined during two stable production intervals. This resulted in:

- 1,020m³ gas/m³ water (average water production 329m³/hr)
- 1,026m³ gas/m³ water (average water production 334m³/hr)

Appendix 0 shows the clean-out section of the end of well report of the PNA-GT-05-S1.

Appendix 57H shows the water analysis on the water in PNA-GT-05/06 system, including the mineral oil content.

7.4 Aquifer pressure

During the drilling of the wells PNA-GT-01 to -06, no indications of significant overpressure were recorded. The aquifer pressure at top reservoir is assumed to be hydrostatic. The reservoir pressure is expected to be 222 bar at the producer and 200 bar at the injector (Figure 40).

Table 20: Reservoir tops and expected local pressure at reservoir level

	Depth top (mTVD)	Pressure (bar)
Production well (DEL-GT-01)	2162	222
Injection well (DEL-GT-02)	1957	200

8 Doublet performance

8.1 Doublet configuration

The Delft doublet will consist of the DEL-GT-01 producer and DEL-GT-02 injector. Figure 33 shows the top of the reservoir with the planned locations of the wells at this level. The corresponding well locations are given in Table 21. The distance between the production well and injection well at mid-reservoir level is approximately 1321m. The geothermal system was positioned based on the information derived from the seismic interpretation study, including the fault trends. Seismic cross sections along the planned well trajectories are shown in Figure 34 and Figure 35.

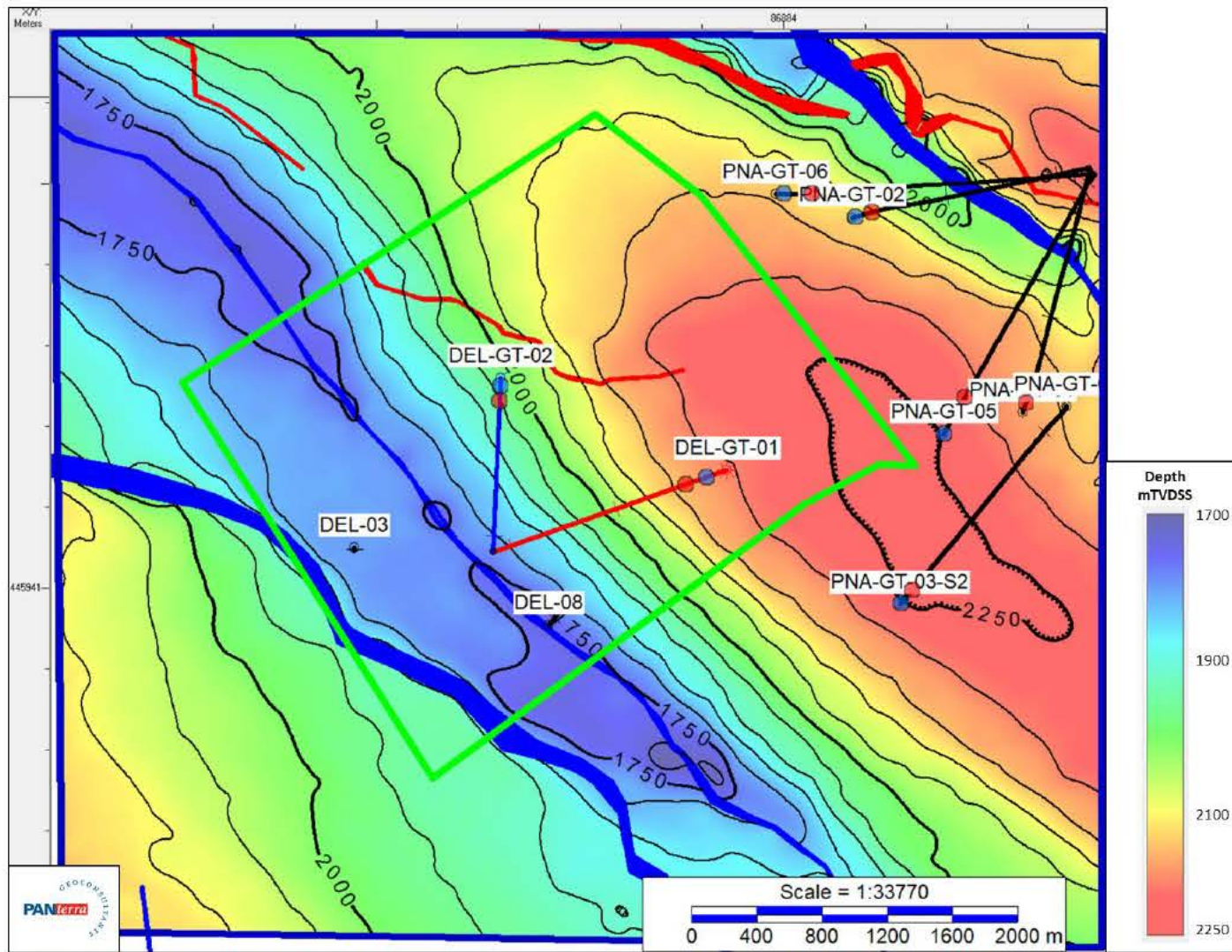


Figure 33: Average Top Delft isochored depth map (Top reservoir) with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green. Blue polygons are SW-dipping faults, red polygons are NE-dipping faults.

Table 21: Rijksdriehoek (RD) coordinates of the geothermal wells and the expected top and base of the reservoir in the injection and production well

	X (RD) m	Y (RD) m	Depth (m TVD)
DEL-GT-01			
Surface	85106	446165	
Top Reservoir Delft Sst	86285	446583	2162
Base Reservoir Delft Sst	86412	446628	2297
DEL-GT-02			
Surface	85100	446163	
Top Reservoir Delft Sst	85142	447105	1957
Base Reservoir Delft Sst	85145	447188	2050

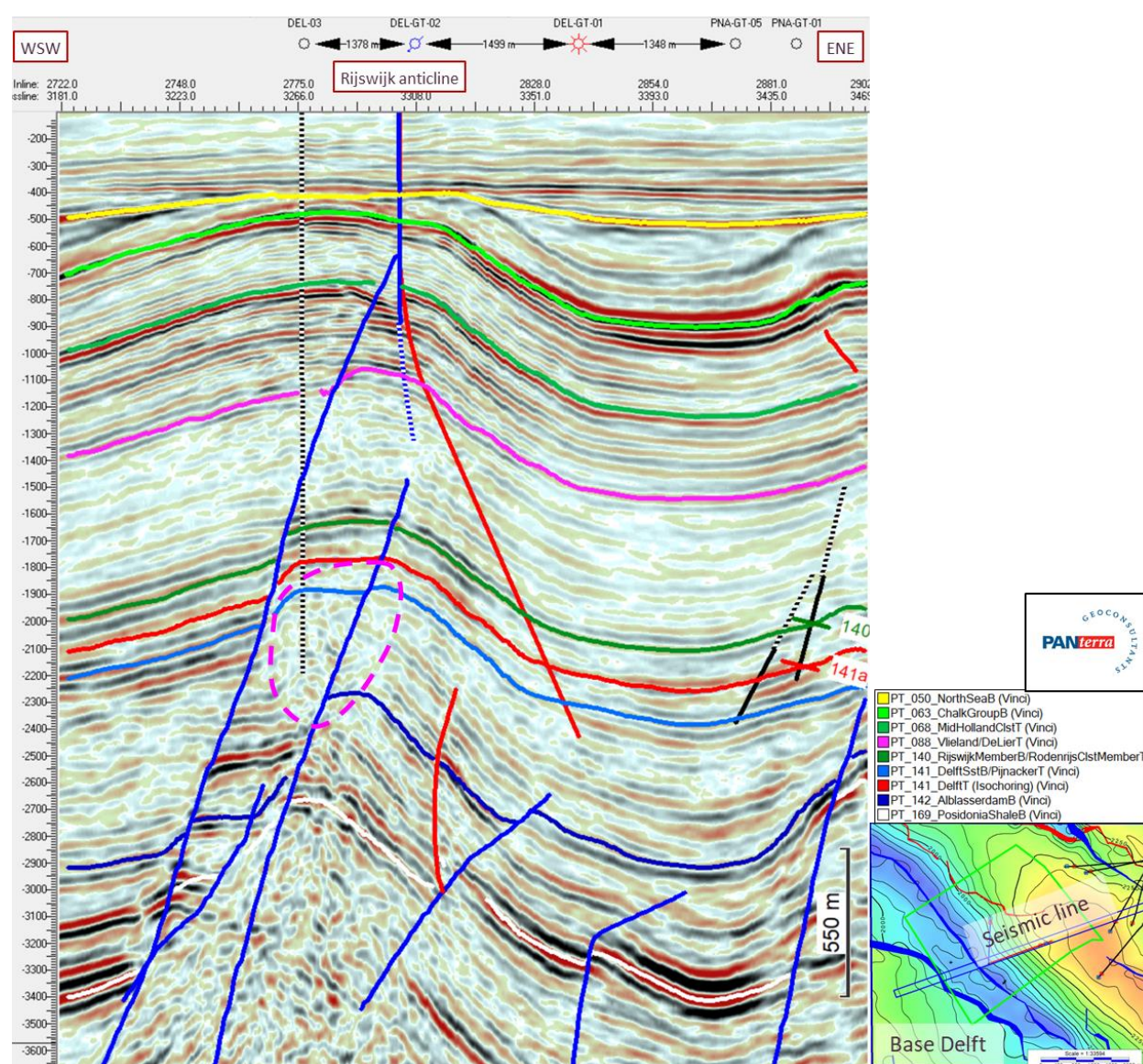


Figure 34: Seismic section along planned production well DEL-GT-01 (red trajectory). Pink dashed line indicates the potential gas pocket area. See insert for line trajectory. Depth in mTVDSS.

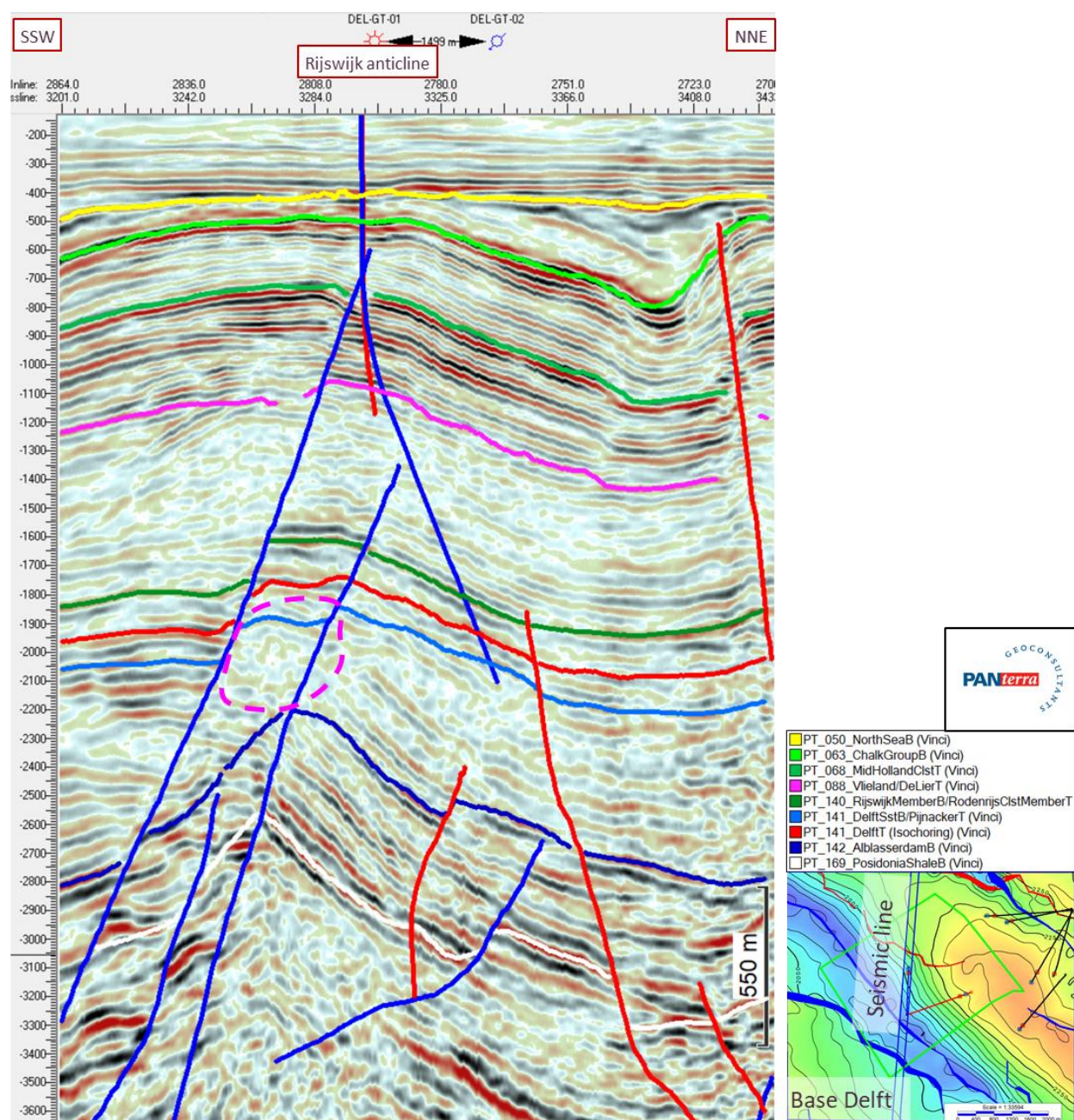


Figure 35: Seismic section along planned injector well DEL-GT-02 (blue trajectory). Pink dashed line indicates the potential gas pocket area. See insert for line trajectory. Depth in mTVDSS.

8.2 Well architecture

Conceptual casing schemes from wells DEL-GT-01 and DEL-GT-02 are shown in Figure 36 and Figure 37, respectively. The well trajectories are given in Appendix I.

The open hole diameter is 8.5 inch within the reservoir, which is completed with 6-5/8" wire wrapped screens. The inclination of the producer at reservoir level is 45°. Within the producer, the Electronic Submersible Pump (ESP) is located at a depth of 600mTVD. The ESP will be installed in combination with a shroud, which will provide a monitorable annular space at the surface casing. A fibre optic cable will be installed from surface to the reservoir section inside the screens as part of the Research & development plan for the TU Delft.

The open hole diameter of the injector is 12.25 inch within the reservoir, which is completed with 9-5/8" casing and perforations. The inclination of the injector at reservoir level is 42°. A fibre optic cable will be installed from surface to the reservoir section outside the cemented casing as part of the Research & development plan for the TU Delft.

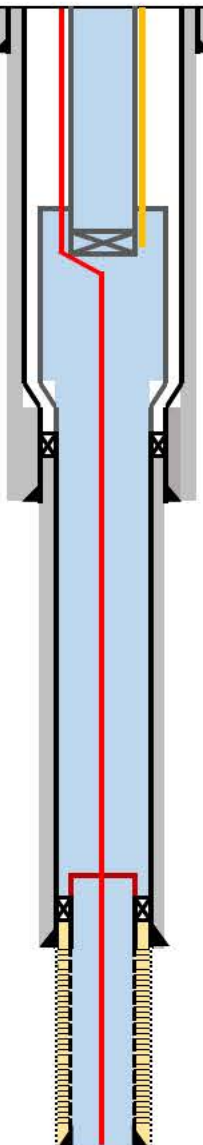
Casing items	Hole ID	Pipe OD	Collar OD	Pipe D	Pipe D	Depth GL		GTD-GT-01		Depth GL		Pipe OD	Collar OD	Pipe ID	Pipe ID	ESP / Shroud / Fibre Optics	Planned Coring interval mAHD / mTVD	Lithology top (mTVD)
	in	in	in	in	in	m	m	Producer: Internal Fiber Optics cable		m	m	in	in	in	in			
				(nom)	(drift)	tvd	ah			tvd	ah			(nom)	(drift)			
22" Conductor		22,000	welded		21,000	60	60											Quaternary
																		Oosterhout
																		Rupel
																		Chalk 405
																		U. Holland Marl 505
KOP (2.1'/30m)						580	580			580	580	10,750	11,488	9,850		10-3/4" 51# L80 Premium 10-3/4" x 13-3/8" Shroud ESP FO cable suspension X/O		
16" 84# L80 BTC, Surface casing 16" x 13-3/8" X/O	20,000	16,000	17,000	15,010						750	749	13,375	14,080	12,390		13-3/8" 68# L80 Premium 13-3/8" x 9-5/8" X/O		M. Holland Claystone 755
9-5/8" PBR 13-3/8" x 9-5/8" Liner Hanger						800	797			790	787	9,625	10,398	8,681		9-5/8" Seal Stem		
13-3/8" 68# L80 BTC, Shoe track	20,000	13,375	14,080	12,390		830	825											Holland Greensand 865
																		L. Holland Marl
EOB 45°						1220	1154											De Lier Sandstone 1120
																		Berkel Sandstone
																		Berkel Sand/claystone
																		Rijswijk Sandstone
9-5/8" x 7" Screen Hanger 9-5/8" 47# 13Cr L80 Liner Top 7" WWS with 6-5/8" 316 basepipe	12,250	9,625	10,398	8,681		2600	2130									FO cable centralizer	2620 / 2144	
						2650	2165											Delft Sandstone 2162
						2650	2165			2650	2165					FO DPS gauges over reservoir section	Total of 6 cores	
Bottom 7" WWS with 6-5/8" 316 basepipe TD	8,500	7,000		5,921		2940	2370			2940	2370					FO Cable bullnose	2920 / 2356	Alblasserdam 2297
						2970	2392											

Figure 36: Conceptual well design of producer DEL-GT-01

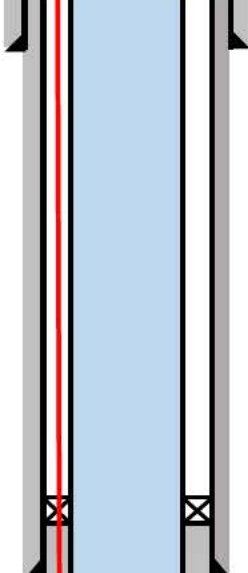
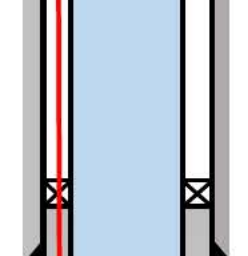
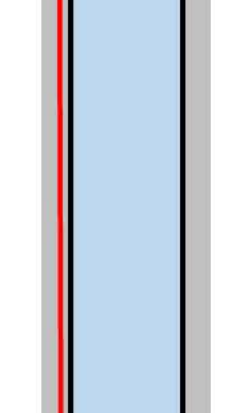
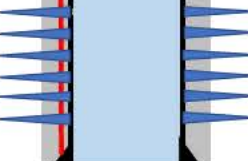
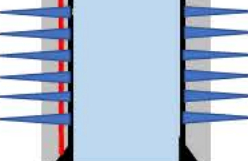
Casing items	Hole ID	Pipe OD	Collar OD	Pipe ID	Pipe ID	Depth GL		GTD-GT-02		Lithology
	in	in	in (nom)	in	in (drift)	m tvd	m ah	Injector: External Fibre Optics cable		top (mTVD)
20" Conductor		20,000	welded	19,000		60	60			Quaternary
										Oosterhout
										Rupel
										Chalk 405
										U. Holland Marl 505
KOP (2.1°/30m)						600	600			
13-3/8" x 9-5/8" Swell Packer						770	769			
13-3/8" 68# L80 BTC, Shoe track	17,500	13,375	14,080	12,390		820	817			
										Holland Greensand 845
										L. Holland Marl
EOB 42°						1200	1146			Core 7
										De Lier Sandstone 1090
										Core 8
										Vlieland Claystone
										Berkel Sandstone
										Berkel Sand/claystone
										Rijswijk Sandstone
										Core 9
										Rodenrijs claystone 1815
										Delft Sandstone 1957
Top of perforations						2300	1963			
Bottom of perforations						2410	2045			
9-5/8" 47# 13Cr L80 Liner	12,250	9,625	10,398	8,681		2440	2067			Alblasserdam 2050

Figure 37: Conceptual well design of injector DEL-GT-02

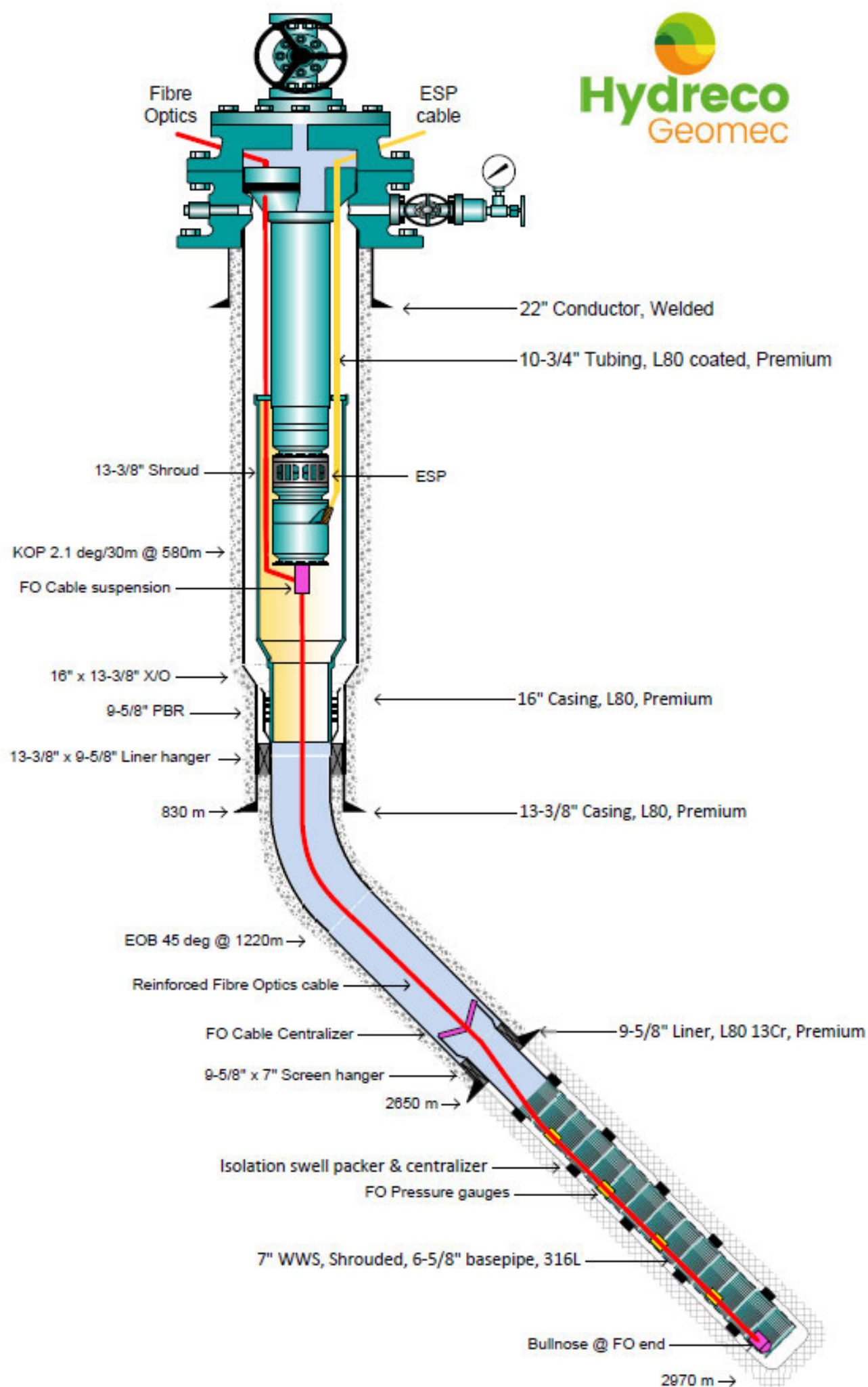
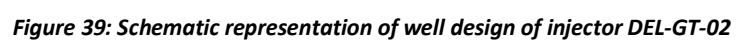


Figure 38: Schematic representation of well design of producer DEL-GT-01



8.3 Geothermal capacity

The geothermal capacity of the doublet is calculated using the TNO software DoubletCalc1D (Mijnlieff et al, 2012). A screenshot of the input and output data is shown in Figure 40. Probability plots of the geothermal power and the flow rate are presented in Figure 41.

Geotechnics (Input)

Property	min	median	max
aquifer permeability (mD)	250.0	600.0	1300.0
aquifer net to gross (-)	0.62	0.72	0.85
aquifer gross thickness (m)	92.0	123.0	154.0
aquifer top at producer (m TVD)	1946.0	2162.0	2378.0
aquifer top at injector (m TVD)	1761.0	1957.0	2153.0
aquifer water salinity (ppm)	105000.0	130000.0	150000.0

Property	value
number of simulation runs (-)	1000.0
aquifer kh/kv ratio (-)	5.0
surface temperature (°C)	10.0
geothermal gradient (°C/m)	0.0315
[mid aquifer temperature producer (°C)]	0.0
[initial aquifer pressure at producer (bar)]	0.0
[initial aquifer pressure at injector (bar)]	0.0
exit temperature heat exchanger (°C)	20.0
distance wells at aquifer level (m)	1321.0
pump system efficiency (-)	0.7
production pump depth (m)	600.0
pump pressure difference (bar)	63.0
outer diameter producer (inch)	8.5
skin producer (-)	0.0
skin due to penetration angle p (-)	-0.44
pipe segment sections p (m AH)	600.0,750.0,790.0,2600.0,2650.0
pipe segment depth p (m TVD)	600.0,749.0,787.0,2130.0,2165.0
pipe inner diameter p (inch)	9.85,12.39,8.68,8.68,5.92
pipe roughness p (milli-inch)	1.97,1.97,1.97,2.75,2.75
outer diameter injector (inch)	12.25
skin injector (-)	0.0
skin due to penetration angle i (-)	-0.3
pipe segment sections i (m AH)	2300.0
pipe segment depth i (m TVD)	1963.0
pipe inner diameter i (inch)	8.68
pipe roughness i (milli-inch)	2.75

Geotechnics (Output)

Monte Carlo cases (stochastic inputs)	P90	P50	P10
aquifer kH net (Dm)	34.93	54.45	90.12
mass flow (kg/s)	87.73	119.65	157.05
pump volume flow (m³/h)	295.2	403.7	527.9
required pump power (kW)	737.9	1009.3	1319.8
geothermal power (MW)	18.44	25.59	33.94
COP (kW/kW)	23.9	25.4	27.0

aquifer pressure at producer (bar)	208.57	221.64	235.0
aquifer pressure at injector (bar)	188.94	200.48	211.58
pressure difference at producer (bar)	13.19	16.69	19.13
pressure difference at injector (bar)	28.07	35.39	40.48
aquifer temperature at producer * (°C)	76.25	80.07	83.85
temperature at heat exchanger (°C)	75.47	79.07	82.86

base case (median value inputs)	value
aquifer kH net (Dm)	53.14
mass flow (kg/s)	117.75
pump volume flow (m³/h)	396.5
required pump power (kW)	991.3
geothermal power (MW)	25.21
COP (kW/kW)	25.4

aquifer pressure at producer (bar)	221.81
aquifer pressure at injector (bar)	200.36
pressure difference at producer (bar)	16.86
pressure difference at injector (bar)	35.75
aquifer temperature at producer * (°C)	80.04
temperature at heat exchanger (°C)	79.13
pressure at heat exchanger (bar)	32.48

* @ mid aquifer depth

Figure 40: Input and output of DoubletCalc1D

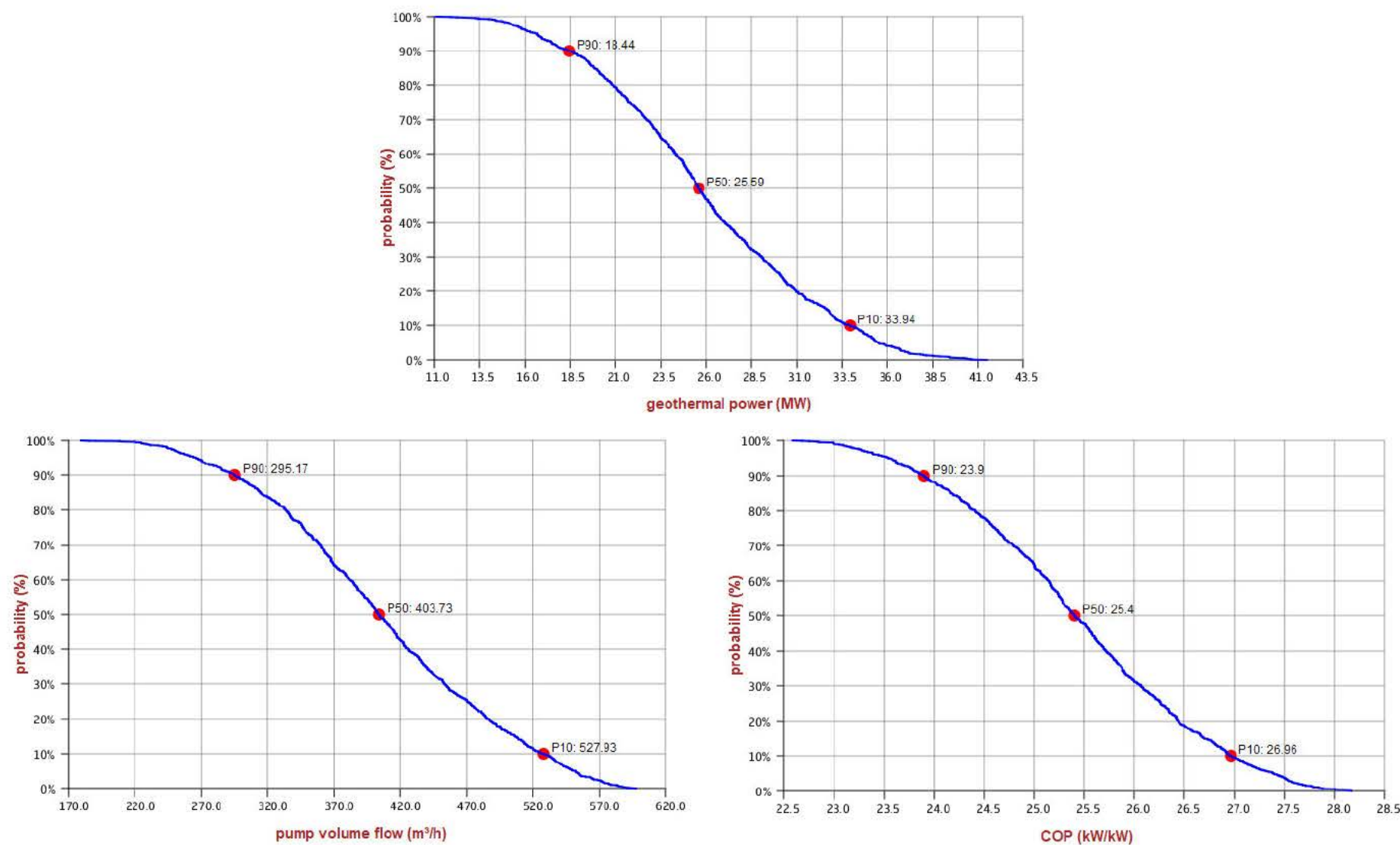


Figure 41: Probability of geothermal power, pump volume flow, and COP of the calculations as presented in Figure 40.

8.4 Operational settings

The DoubletCalc1D simulation shows that the injection pressure difference of the injection well at reservoir level is approximately 36 bar. An injection pressure difference of 36 bar results in a required well head pressure of 28 bar, due to the effective injection pressure of 8 bar as a result of the cold water in the injection well; the pore pressure at reservoir level is 200 bar and the pressure as a result of the weight of the cold water column is 208 bar.

According to the “Protocol bepaling maximale injectiedrukken bij aardwarmtewinning – versie 2”, SodM and TNO-AGE, 2013, a Tubing Head Pressure (THP) of around 57 bar is permitted when water of 35°C would be injected (see also Appendix J). For this project, the produced water will be re-injected with a temperature of 20°C. According to SodM, this colder injection temperature will reduce the allowed pressure change decrease with 15 bar (1 bar/°C cooling from 35°C). This takes into account the thermo-elastic effect as a result of the cold injected water, which results in a maximum allowed THP of 42 bar. Thus, the calculated required THP of 28 bar falls within the allowed THP @20°C of 42 bar. The geomechanical calculation in Appendix J also shows that the expected injection pressure at reservoir level is below the minimal horizontal stress (including the thermal effects).

Table 22: Comparison of the predicted and allowed changes in pressure. The effective pressure as a result of the weight of the cold-water column is incorporated in the calculation of the required THP.

Well	Code	Injection Temperature [°C]	Allowed THP (SodM) at 35°C [bar]	Allowed THP (SodM) at 20°C [bar]	Required pressure @ reservoir level [bar]	Effective pressure cold water column [bar]	Required THP [bar]
Injection well	DEL-GT-02	20	57	42	36	8	28

8.5 Interference

The Geothermie Delft doublet (DEL-GT-01/02) is planned in the Delft Sandstone reservoir within the Vrijenban syncline. Within this syncline there are already two doublets operational: the Ammerlaan doublet (PNA-GT-05/06) and the Duijvestijn doublet (PNA-GT-03/04). In order to evaluate the risk of interference between the new Geothermie Delft doublet and the Ammerlaan and Duijvestijn doublets, dynamic modelling within the reservoir has been performed. Figure 42 shows the pressure difference and Figure 43 shows the temperature difference after 35 years for the 3 doublets operating in the Vrijenban syncline. A comparison between the 3 doublets operating simultaneously and a stand-alone Geothermie Delft doublet can be found in Appendix K. Pressure wise, the doublets do influence each other slightly during the lifetime of the projects. Temperature wise, there is no breakthrough expected from one doublet to the other. However, the temperature decrease in the DEL-GT-01P starts slightly earlier in case of the 3 doublets operating simultaneously. Having said that; this is only in the order of 0.6 °C after 35 years.

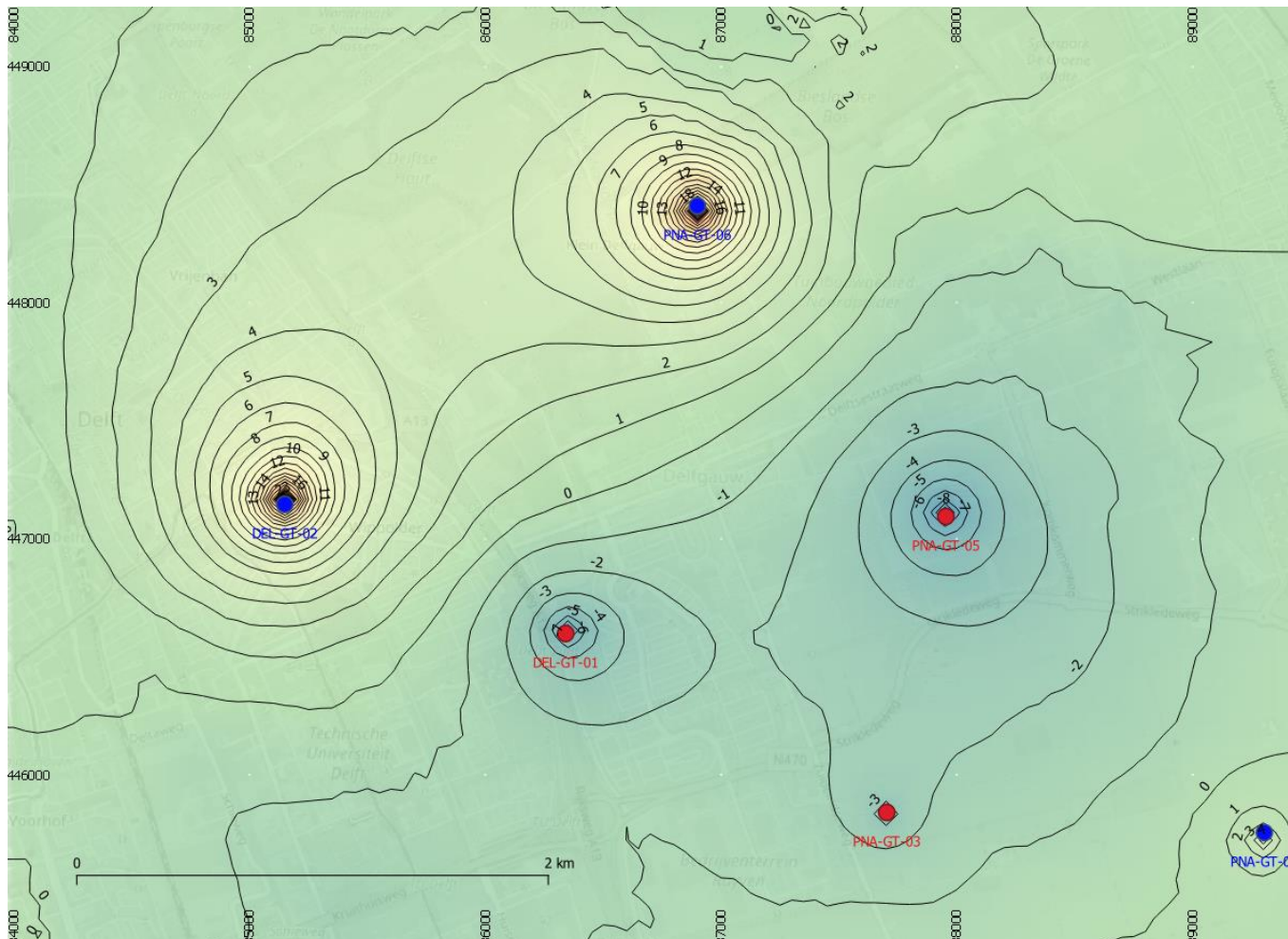


Figure 42: Pressure difference after 35 years for the 3 doublets operating in the Vrijenban syncline. Injectors in blue. Producers in red. DEL-GT-01/02: Delft doublet. PNA-GT-05/06: Ammerlaan doublet. PNA-GT-03/04: Duijvestijn doublet. See Appendix K for input parameters.

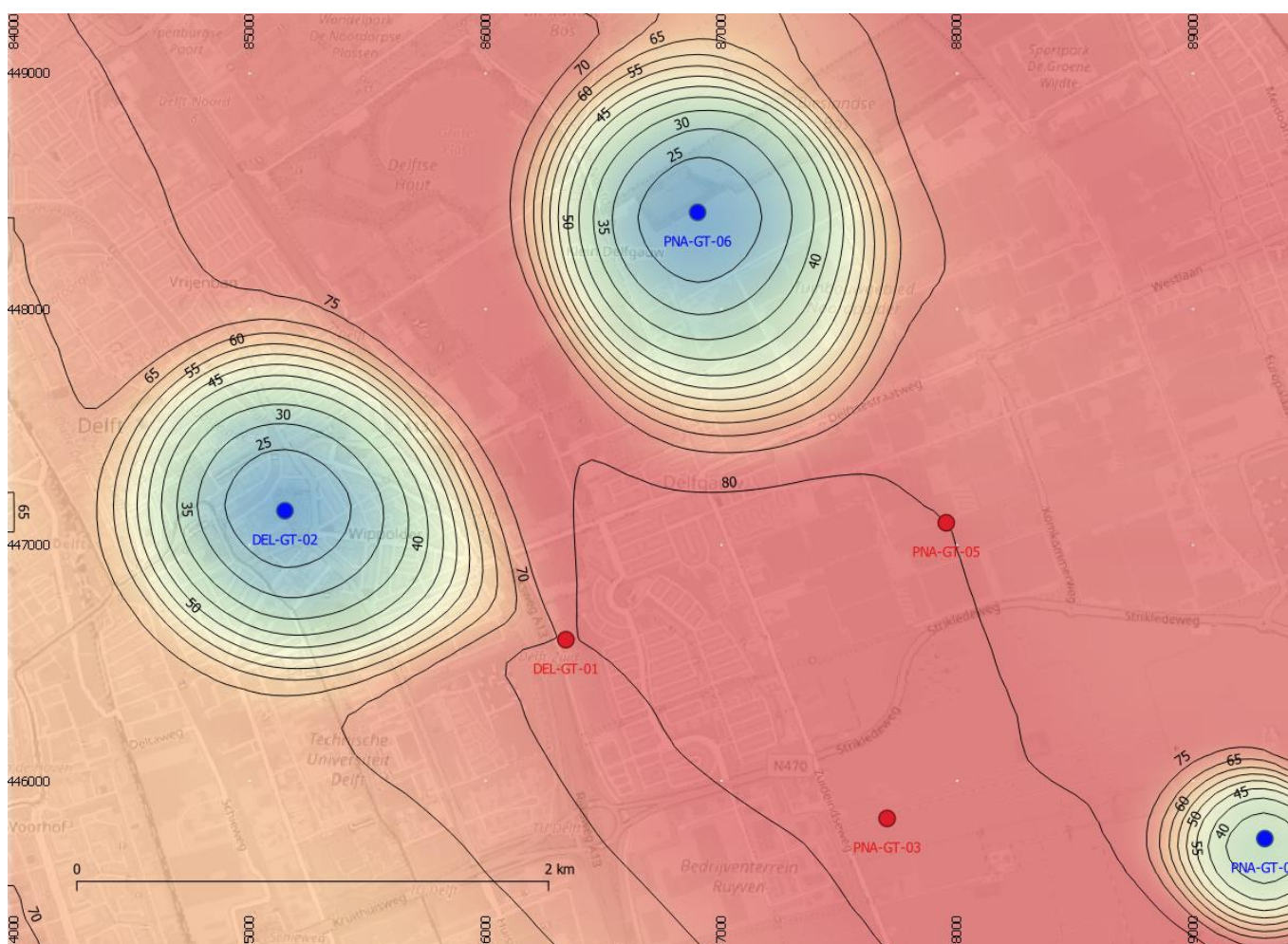


Figure 43: Temperature distribution after 35 years for the 3 doublets operating in the Vrijenban syncline. Injectors in blue. Producers in red. DEL-GT-01/02: Delft doublet. PNA-GT-05/06: Ammerlaan doublet. PNA-GT-03/04: Duijvestijn doublet. See Appendix K for input parameters.

8.6 Risks

This chapter lists the geological factors that could result in a risk for the project. The hazards described in this chapter include:

- drilling hazards
- operational hazards
- seismic hazards

Project hazards and risks like financial aspects, heat distribution, licenses and public acceptance have not been taken into account.

8.6.1 Geological drilling hazards

Depth of the reservoir formation

The depth of the formation depends on the seismic interpretation and the time-depth model. Top of reservoir was interpreted on the seismic data, which brings in an uncertainty due to the resolution of the data. The time-depth model also contains uncertainty, because only limited information in the study area is available on the time-depth relationship. As a result, the reservoir formation might be located at either greater or shallower depth than is expected according to the seismic interpretation. This results respectively in higher or lower costs for drilling and a delay in the drilling process. Nevertheless, the depth uncertainty has been largely reduced by the information from the PNA-GT-0 to 06 wells, which have been drilled in the same graben.

Lithological hazards

The lithological drilling hazards are shown in Table 23. The probable drilling hazards for the project location are based on experience with wells that have been drilled in the area (in particular PNA-GT-01 to 06). The formations in mentioned groups are known to introduce drilling hazards such as swelling clays, bit balling, swabbing, cavings and pack-offs. Well bore problems can occur due to low stabilization forces (Well bore break out, cavings due to low mudweight) or high mudweight (Borehole tensional failure and leak-off, losses). Problems can also occur due to limited chemical inhibition of clays (Swelling and break out) which is normally a lack of inhibition effect that increases over time. No salt swelling is expected in these wells.

Table 23 is based on previous wells and the risk mitigation for washouts are controlled flow rate and good fluid loss properties (filter cake building capacity) in the surface hole and use of Oil Based Mud in the intermediate hole section to prevent clay swelling and clay cavings (which are normally leading to swabbing effects and overpulls).

To further evaluate possible presence of the abovementioned formations across the DEL-GT-01 & 02 wells, the relevant offset wells have been studied for drilling issues. This overview is shown in the below table:

Table 23: Indicated drilling hazards

Formation	Issue	Wells
North Sea	Washout:	
	- Conductor drop, foundation failure	PNA-07, PNA-09
	- Large cement volumes - >100% excess	PNA-GT-01 to 04, DEL-08
Ommelanden	Losses	PNA-GT-03, PNA-GT-04
	Chert (up to 40% in base Ommelanden)	PNA-GT-01 to 04, DEL-08
Chalk	Tight hole	DEL-05, PNA-02, PNA-03, PNA-05
Holland claystone	Bit balling	DEL-08
U. Holland Marl	Bit balling	PNA-15
	Cavings	PNA-04
L. Holland Marl	Tight hole	PNA-04
De Lier	Losses	DEL-03
	Tight hole	PNA-04
Vlieland claystone	Swelling clays, tight hole, stuck pipe	PNA-04, PNA-05
	Losses (base Vlieland)	OLE-01, PNA-04
Rijswijk	High torque/friction	PNA-04
Rodenrijs	High torque/friction	PNA-04
	Losses	DEL-03
Delft sandstone	Losses	DEL-03
Alblasserdam	Tight hole	PNA-13

Casing points

The offset wells have a large variety in casing schemes, some have proven to be more successful than others. The following casing points have been found:

- Conductor: Conductor at ca. 50-60m (driven to refusal), and/or shallow surface casing to 150-250m
- Surface/Intermediate casing section before Drilling with BOP's: In the Chalk group, or upper Rijnland. Above the Holland Greensand.
- Production casing: Either in base caprock (Rodenrijs Claystone member) or top reservoir (Delft Sandstone member) For geothermal well DEL -GT 01 the intermediate casing will be placed in top reservoir. (Both Rodenrijs Claystone and Delft Sandstone are part of the Schieland group and Nieuwerkerk Formation.

This will lead to the following casing scheme for DEL-GT-01 and 02:

- Conductor 60 meters - satisfies foundation, sealing water zone
- Surface casing 850 meters - through the chalk, above the Holland Green Sand and providing a good shoe
- Intermediate casing Only producer: Casing shoe will be placed at top reservoir
- TD Inside top section Alblasserdam

Mud losses

When the well trajectory encounters faults, mud losses can occur. Mud losses may also be the result of the weight of the mud. This results in a delay in the drilling process and might even result in jammed drilling equipment, leading to higher drilling costs. When this occurs, the weight of the mud can be adjusted and the drilling continues. Too high mud weight can result in losses, so a fine balance is needed at all times. Smooth operations with low pressure fluctuations when starting and stopping pumps will increase the chance of success. It is also possible that a sidetrack is needed. The risk can be minimized by a good fault/fracture analysis and an analysis of the offset data.

Shallow gas

There are no bright spots on the seismic indicating shallow gas above the shoe of the surface casing (see also Chapter 3.2.1). The first sealing mechanism to trap shallow gas is the Middle Holland Claystone and in that formation the surface casing will be set. While drilling the surface hole, a mud weight will be used above the proven pressure gradient of the surface layers both for well bore stability and for well control purposes.

Formation gas

The reference wells of PNA-GT-05 & 06 have not shown any free gas after a full year of production. The Geothermie Delft wells are planned in the same compartment in the block and are not divided by seismic faults in a high permeability connected sandstone. There is no reason to assume a free gas cap for the producer, since it is drilled at similar depth as the PNA-GT-05 & 06 wells. For the injector, a maximum theoretical free gas cap could be assumed, which reflects its shallower position compared to PNA-GT-06 (injector) well. This will be taken into account in the detailed design phase to ensure kick tolerance and the planned mud weight will be sufficient.

8.6.2 Operational hazards

This section lists the operational risks that have an influence on the initial reservoir performance.

Hydrocarbons

Occurrences of dissolved gas have been encountered in other geothermal projects and are expected in this region. When dissolved gas is present, the anticipated maximum amount is estimated to be 1.02 Nm³/m³ formation water. The exact amount can only be determined after drilling. The possible occurrence of dissolved gas will be taken into account for the design of the system.

Uncertainty geological structure

Faults and fractures are determined based on the seismic data. Yet, due to the resolution of the seismic data, it could be possible that fractures or faults have been missed in the interpretation.

Scaling

Scaling results in a decrease in well/pipe diameters, which will in the end increase electricity costs for the system. Water sampling and analysis of these samples is needed to define possible measures, such as the addition of inhibitors to minimize the scaling. It will be monitored during production and will be taken into account during maintenance of the system.

Corrosion

Corrosion in the wells will be mitigated by the use of corrosion-resistant alloys for the casings and liners.

Unconsolidated sands

Sand production is possible, since the production rates will be relatively high. This will be mitigated by the installation of wire-wrapped-screens in the reservoir section of the production well.

8.6.3 Seismic Risk/Hazard Assessment

The companies Q-con and IF Technology (Baisch et al, 2016) analysed the main indicators for the probability of induced seismicity in geothermal projects and the associated risk/effect. Based on this, recommendations have been made for a methodology to give an insight into the seismic hazard/risk and to determine the associated mitigation measures. This methodology consists of the following three steps:

1. In Level 1, a QuickScan is performed on the basis of a number of indicators, which provides insight into the potential for the occurrence of induced seismicity. If it follows that the seismicity potential is low, then no further steps are required.
2. In case of moderate or high potential, the hazard analysis is expanded within Level 2. An important part of Level 2 is also to determine the mitigation measures to reduce the hazard of seismicity.
3. If Level 2 shows that the hazard is not acceptable (despite the mitigation measures) one will proceed to Level 3, which consists of a quantitative risk analysis. In this Level 3 the security risk and the risk of economic damage with the associated uncertainty will be quantified.

For GeoThermie Delft, the QuickScan of Level 1 has been carried out (see Appendix L). Since the outcome of the Level 1 SRA QuickScan is that the potential of induced seismicity is low (Table 24), Level 2 and Level 3 are not yet implemented. After the gathering of additional local information during the drilling phase, from the well tests and after further dynamic and mechanical modelling, it will be determined whether that the SRA should be extended further.

Table 24: SRA Level 1 QuickScan Scoring table for Geothermie Delft. The QuickScan Score is 27, which indicates a low seismicity potential.

score	basement connected	inter-well pressure communication	re-injection pressure [MPa]	circulation rate [m³/h]	epicentral distance to natural earth- quakes [km]	epicentral distance to induced seismicity [km]	distance to fault [km]	orientation of fault in current stress field	net injected volume [1000 m³]
10	yes	no	> 7	> 360	< 1	< 1	< 0.1	favorable	> 20
7	possible	unlikely	4 - 7	180-360	1 - 5	1 - 5	0.1 - 0.5	shearing possible	5 - 20
3	unlikely	likely	1 - 4	50-180	5 - 10	5 - 10	0.5 – 1.5	shearing unlikely	0.1 - 5
0	no	yes	< 1	< 50	> 10	> 10	> 1.5	locked	< 0.1

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A. Details used data

Table 25 List of reference wells of wells in the project area.

Well	Year drilled	Notes
DEL-03	1953	
DEL-08	1994	TD in Rodenrijs member
HAG-GT-01	2010	
HAG-GT-02	2010	
HON-GT-02	2012	
LIR-GT-01	2014	
LIR-GT-02	2014	
LSL-GT-01	2017	
LSL-GT-02	2017	
OLE-01	1959	
PNA-13	1977	GR digitized
PNA-GT-01	2010	
PNA-GT-02	2010	No top and bottom depth of screen found in the data files
PNA-GT-03-S2	2010	
PNA-GT-04	2010	
PNA-GT-05	2018	Data not in public domain (nlog)
PNA-GT-06	2018	Data not in public domain (nlog)
VDB-01	2007	
VDB-02	2007	
VDB-03	2009	
VDB-04	2009	

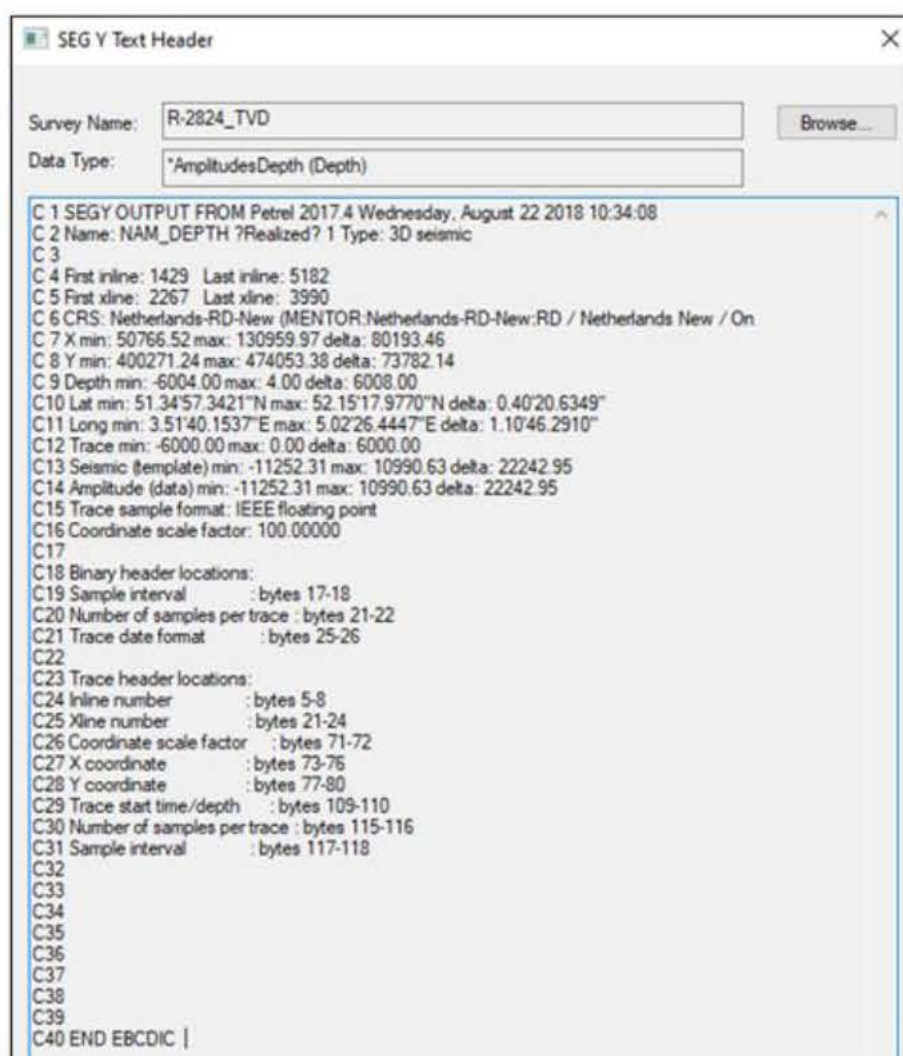


Figure 44 Geometry of the seismic depth cube (R-2824)

B. Details petrophysical evaluation

See Chapter 6.2, "Petrophysical evaluation".

Table 26 Thickness and N/G values of wells drilled within the Vrijenban syncline. *Base Delft not drilled.

Well	Top Delft (mTVD)	Base Delft (mTVD)	Thickness Delft (mTVT)	N/G Delft
PNA-GT-01	2164	2227	>63*	0.62*
PNA-GT-02	2017	2248	232	0.81
PNA-GT-03-S2	2260	2383	123	0.66
PNA-GT-04	2197	2333	136	0.72

C. List of well tests, details, and results of the evaluation.

See Chapter 6.3, "Well test evaluation"

Table 27 Well test data

Well	Top Delft (mTVD)	Base Delft (mTVD)	Delft Net Thickness (mTV)	N/G Delft	Average Permeability (mD)
HAG-GT-01	2195	2281	62.5	0.73	1400
HAG-GT-02	1761	1873	96	0.86	2300
HON-GT-02	2407	2544	116.5	0.85	1190
LIR-GT-01	2387	2528	70.5	0.5	1000
LIR-GT-02	2324	2418	63.9	0.68	1300
LSL-GT-01	1621	1980	88	0.47	565

D. List of production data, details, and results of the evaluation.

See Chapter 6.4, "Production data evaluation"

Table 28 Well production data

Well	Reservoir	Average permeability (mD)	Flow rate (m ³ /h)
PNA-GT-01/-02	Delft Sandstone	620	157.7
VDB-03	Delft Sandstone	424	150
VDB-04	Delft Sandstone	339	150

E. Depth and thickness maps

This appendix includes all depth and thickness maps produced for this study, see also Chapter 5.6.

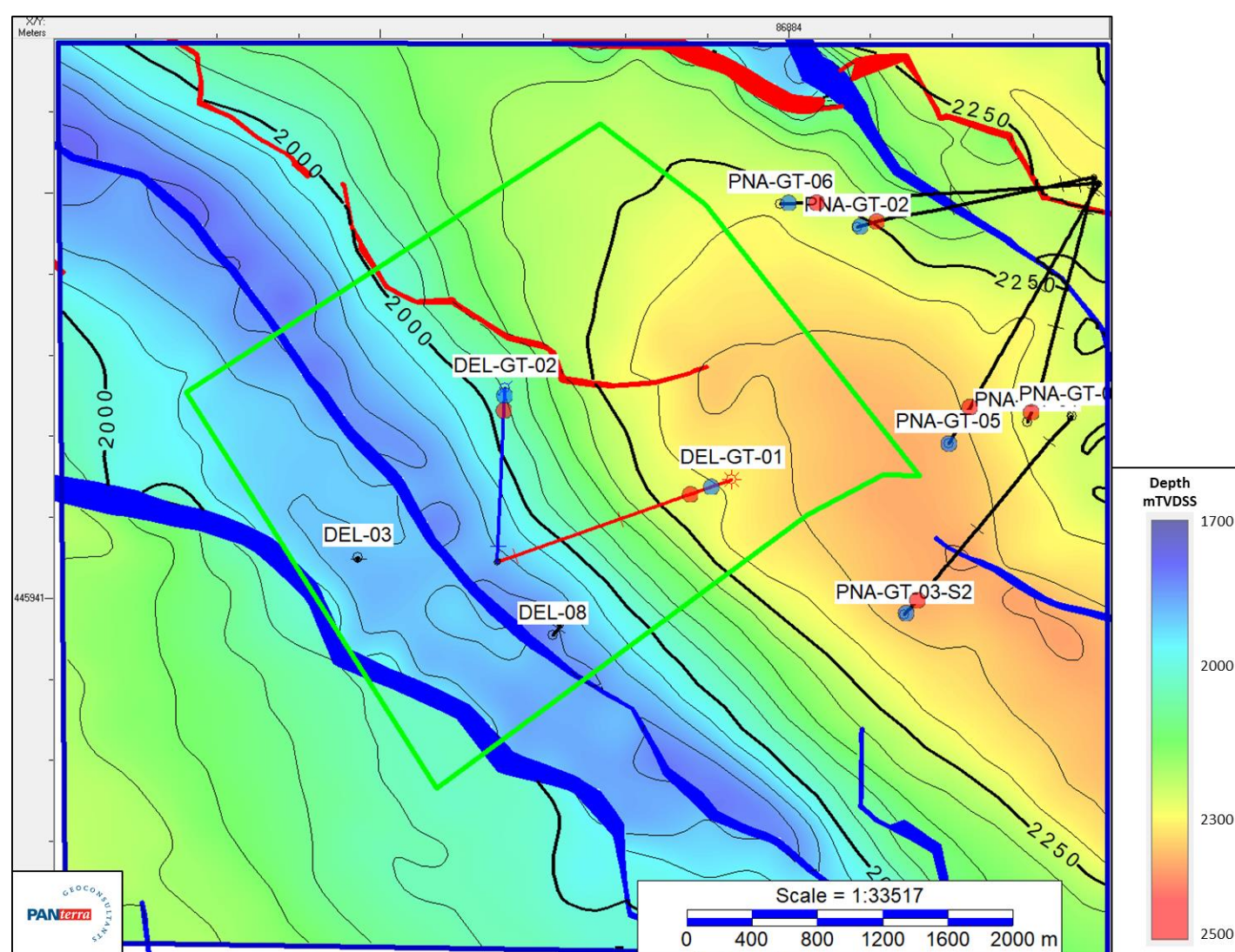


Figure 45 Base Delft depth map (base reservoir) with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green. Blue polygons are SW-dipping faults, red polygons are NE-dipping faults.

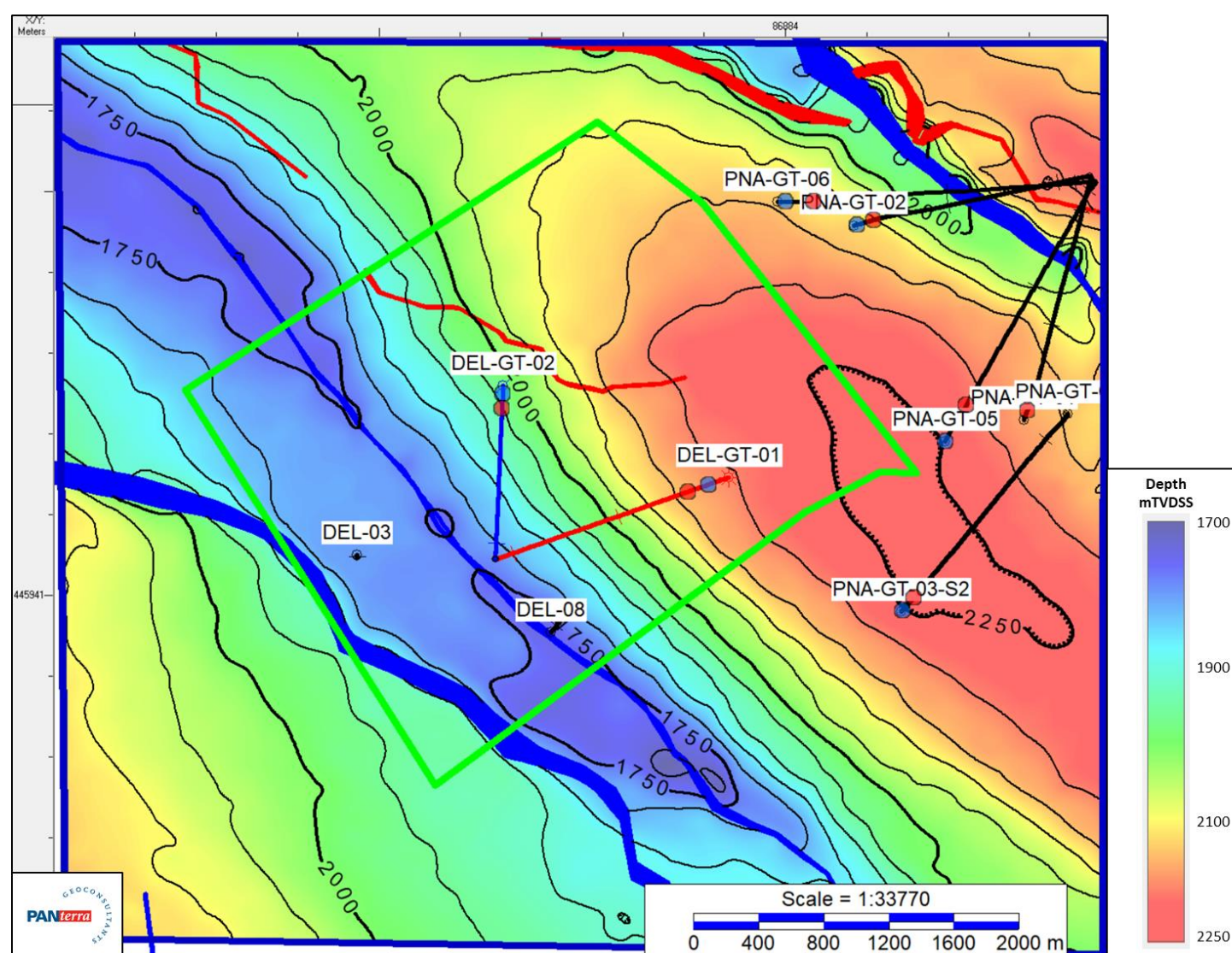


Figure 46 Top Delft isochored depth map (Top reservoir) with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green. Blue polygons are SW-dipping faults, red polygons are NE-dipping faults.

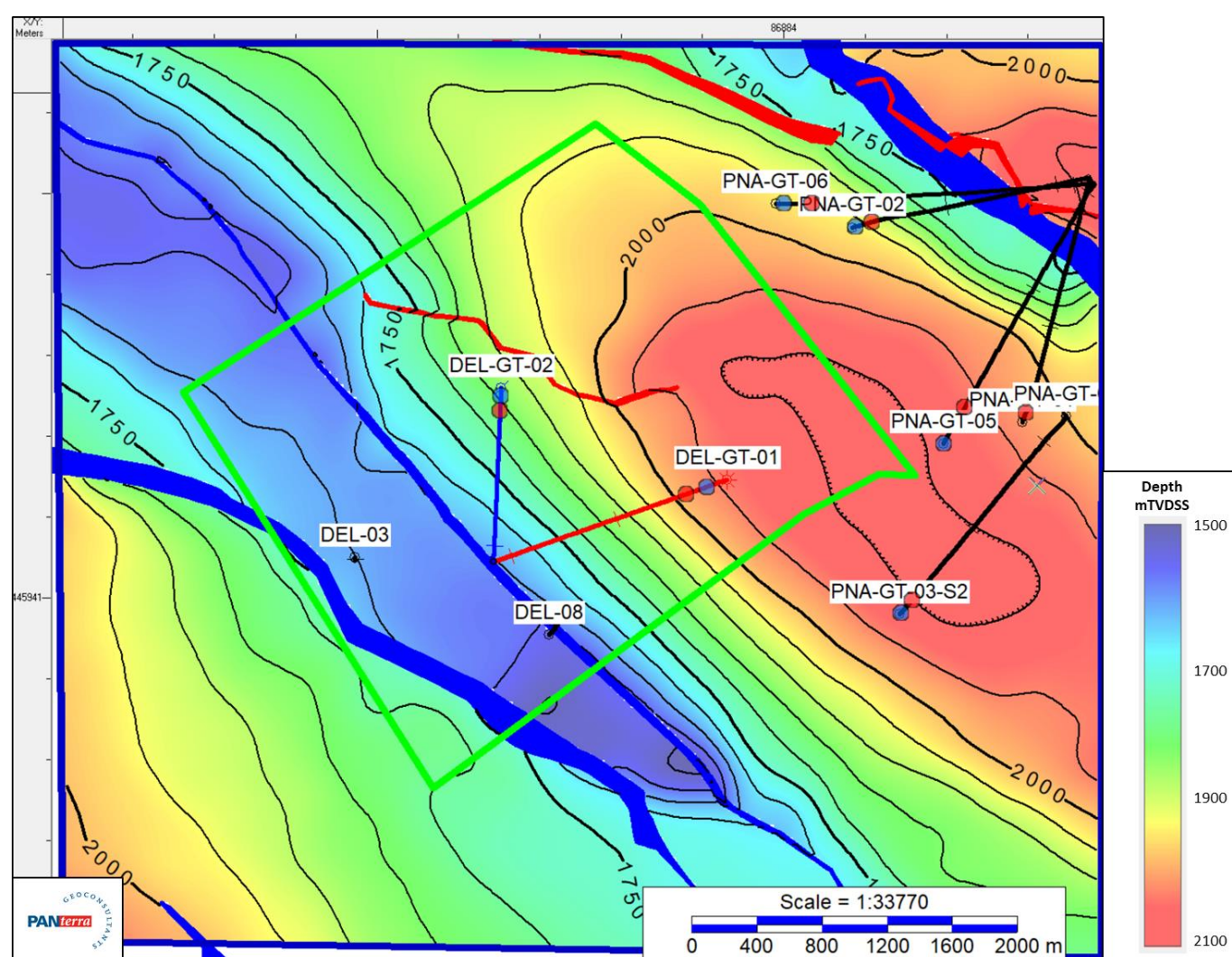


Figure 47 Base Rijswijk/Top Rodenrijs depth map with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green. Blue polygons are SW-dipping faults, red polygons are NE-dipping faults.

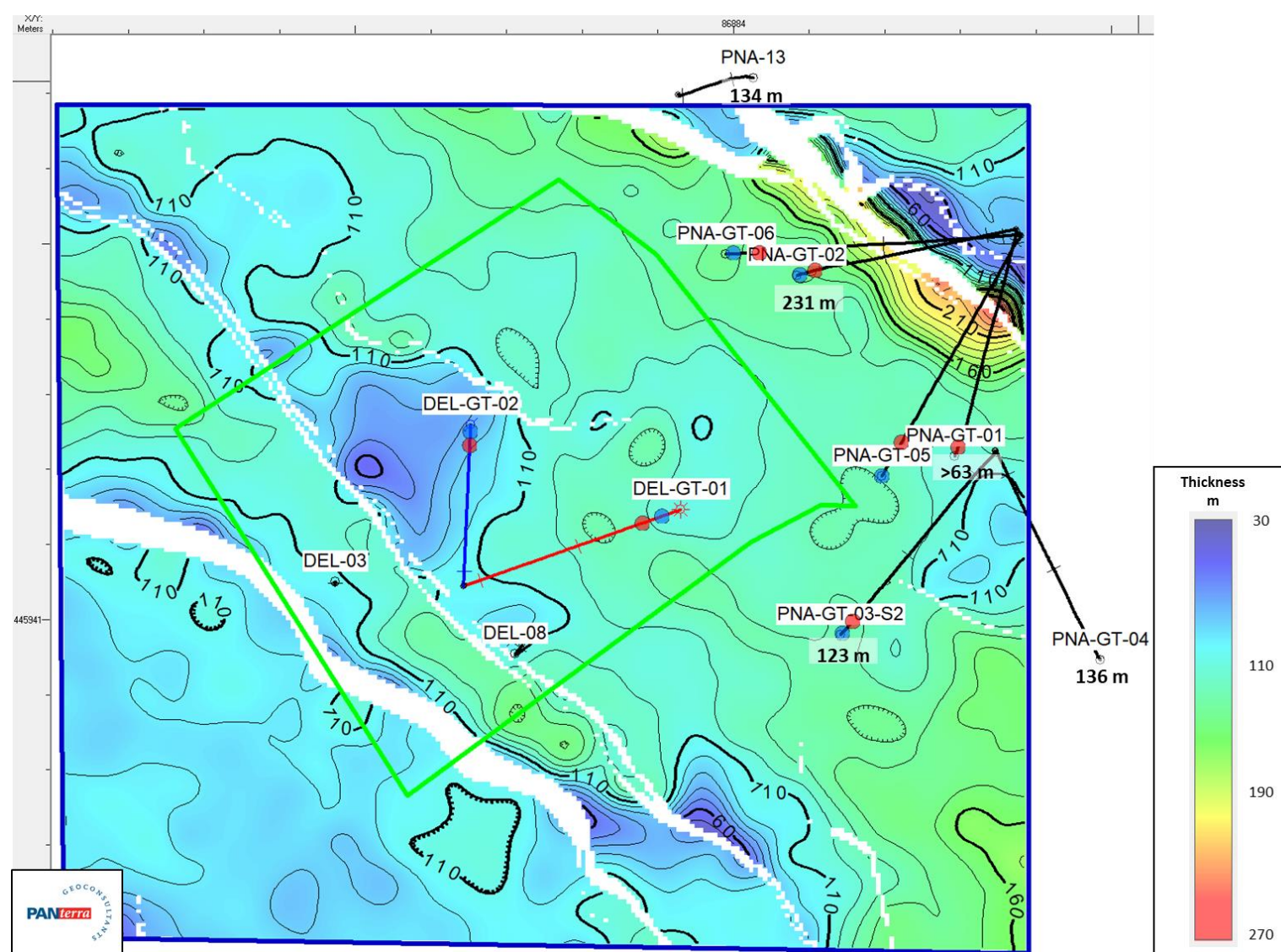


Figure 48 Delft Thickness map with planned producer (red) and injector (blue) wells. Red circles on well paths mark Top Delft penetration points, blue circles mark Base Delft penetration points. The Geothermie Delft exploration license is outlined in green.

F. Back calculation in DoubletCalc1D

Geotechnics (Input)

Property	min	median	max
aquifer permeability (mD)	500.0	620.0	700.0
aquifer net to gross (-)	0.58	0.6	0.62
aquifer gross thickness (m)	64.0	65.0	66.0
aquifer top at producer (m TVD)	1922.0	2136.0	2350.0
aquifer top at injector (m TVD)	1807.0	2008.0	2209.0
aquifer water salinity (ppm)	100000.0	130000.0	140000.0

Property	value
number of simulation runs (-)	1000.0
aquifer kh/kv ratio (-)	5.0
surface temperature (°C)	10.0
geothermal gradient (°C/m)	0.0315
[mid aquifer temperature producer (°C)]	0.0
inital aquifer pressure at producer (bar)]	0.0
[initial aquifer pressure at injector (bar)]	0.0
exit temperature heat exchanger (°C)	18.0
distance wells at aquifer level (m)	1500.0
pump system efficiency (-)	0.7
production pump depth (m)	500.0
pump pressure difference (bar)	70.0
outer diameter producer (inch)	6.0
skin producer (-)	0.0
skin due to penetration angle p (-)	-0.27
pipe segment sections p (m AH)	500.0,954.0,2304.0,2733.0
pipe segment depth p (m TVD)	500.0,907.0,1834.0,2136.0
pipe inner diameter p (inch)	6.18,8.53,6.18,4.0
pipe roughness p (milli-inch)	1.8,1.8,1.8,1.8
outer diameter injector (inch)	6.0
skin injector (-)	0.0
skin due to penetration angle i (-)	-0.24
pipe segment sections i (m AH)	978.0,2320.0,2475.0
pipe segment depth i (m TVD)	928.0,1887.0,2008.0

Geotechnics (Output)

Monte Carlo cases (stochastic inputs)	P90	P50	P10
aquifer kH net (Dm)	21.55	24.11	26.0
mass flow (kg/s)	43.93	46.68	48.56
pump volume flow (m³/h)	147.9	157.2	164.1
required pump power (kW)	410.9	436.6	455.7
geothermal power (MW)	8.98	9.83	10.73
COP (kW/kW)	21.3	22.6	23.9

aquifer pressure at producer (bar)	205.6	218.67	231.38
aquifer pressure at injector (bar)	193.42	204.99	216.68
pressure difference at producer (bar)	15.11	15.91	16.85
pressure difference at injector (bar)	33.55	34.95	36.73
aquifer temperature at producer* (°C)	74.59	78.32	82.03
temperature at heat exchanger (°C)	72.74	76.2	79.72

base case (median value inputs)	value
aquifer kH net (Dm)	24.18
mass flow (kg/s)	46.68
pump volume flow (m³/h)	157.1
required pump power (kW)	436.3
geothermal power (MW)	9.84
COP (kW/kW)	22.6

aquifer pressure at producer (bar)	218.73
aquifer pressure at injector (bar)	205.27
pressure difference at producer (bar)	15.88
pressure difference at injector (bar)	34.93
aquifer temperature at producer* (°C)	78.31
temperature at heat exchanger (°C)	76.23
pressure at heat exchanger (bar)	32.4

* @ mid aquifer depth

G. Well test information

	End of Well Report PNA-GT-05 / PNA-GT-05-S1	
	Revision No.	1.0
	Operator:	Ammerlaan Geothermie B.V.

8.22 Clean out operations

Started	:	09-08-2019 13:00 hrs
Finished	:	13-09-2019 17:00 hrs
Duration	:	100.00 hrs (4.16 days)
NPT	:	0 hrs (0 days)

8.22.1 Summary

The work platform was installed on the well and casing running equipment rigged up. Run in inhibitor line to 1675 m. After making up the ESP in the mousehole it was picked up and placed in work platform. Connected the Inhibitor line to the ESP. Run in hole ESP on 8 5/8" tubing, with dual inhibitor lines and ESP cable to 688.32 m (ESP Bullnose depth). Splice cable to penetrator, connect inhibitor lines to hanger and land hanger.

Install tubing head adaptor and X-mas tree, rigged up clean out equipment and connected piping to wellhead. ESP was started for the first clean out sequence (also see figure 14 & 15).

- 2 hr to reach and stabilize flow at 143 m³
- 0,5 hr to reach and stabilize flow at 240 m³
- 1,5 hr to reach and stabilize flow at 340 m³.
- 4,5 hr flow at 290 – 310 m³

Started ESP for second clean out sequence after injecting produced water into PNA-GT-02 from tanks through filtration system:

- 4,0 hr flow at max rate of 353 m³

Total water produced = 2770 m³

Total gas produced = 2613 m³

During 2 stable production intervals gas / water ratio is determined (see fig 16).

- 1,020 m³ gas / m³ water (average water prod. 329 m³/hr)
- 1,026 m³ gas / m³ water (average water prod. 334 m³/hr)

After stopping the ESP, the well was shut in, and produced water was injected into PNA-GT-02 from tanks through filtration system. After disconnecting all piping from the wellhead all clean out equipment was rigged down.

Figure 49: End of well report for Clean-out operations Ammerlaan PNA-GT-05-S1

H. Water analysis

Metals

(NEN6961/NEN 6966/C1)

- Aluminium, µg/l	<100
- Barium, µg/l	8500
- Cadmium, µg/l	<1
- Calcium, µg/l	5400000
- Chrome, µg/l	9.7
- Iron, µg/l	38000
- Lead, µg/l	110
- Magnesium, µg/l	840000
- Manganese, µg/l	1700
- Nickel, µg/l	38
- Potassium, µg/l	240000
- Silicium, µg/l	14000
- Sodium, µg/l	41000000
- Strontium, µg/l	330
- Zinc, µg/l	1200

Mercury, µg/l (ISO 12846)	<0.10
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<u>Bicarbonate as HCO₃</u> , mg/L (WAC/III/A/006)	40
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<u>Carbonate as CO₃</u> , mg/L (WAC/III/A/006)	<2.5
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PAH, µg/L (SGS 12-01)

- Naphthalene, µg/l	13
- Phenanthrene, µg/l	0.6
- Anthracene, µg/l	0.035
- Fluoranthene, µg/l	0.018
- Benz[a]anthracene, µg/l	<0.010
- Chrysene, µg/l	<0.010
- Benzo[k]fluoranthene, µg/l	<0.010
- Benzo[a]pyrene, µg/l	<0.010
- Benzo[ghi]perylene, µg/l	<0.010
- Indeno[1,2,3-cd]pyrene, µg/l	<0.010

Mineral Oil

(NEN-EN-ISO 9377-2)

-Total C10-C40, µg/l	120
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<u>pH</u> (ASTM E 70)	7.01
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Figure 50: Water analysis report injection water Ammerlaan PNA-GT-05/06, SGS 25-03-2020

I. Well trajectories

Table 29: Well trajectory of production well DEL-GT-01

Depth	Build Rate	Hole Angle	Depth2	X-coordinate	Y-coordinate	Formation
MD	DEGREES	DEGREES	TVD	RD	RD	
m	per 10 m	Total	m	m	m	
0	0	0	0	85106	446165	
10	0	0	10	85106	446165	
20	0	0	20	85106	446165	
30	0	0	30	85106	446165	
40	0	0	40	85106	446165	
50	0	0	50	85106	446165	
60	0	0	60	85106	446165	
70	0	0	70	85106	446165	
80	0	0	80	85106	446165	
90	0	0	90	85106	446165	
100	0	0	100	85106	446165	
110	0	0	110	85106	446165	
120	0	0	120	85106	446165	
130	0	0	130	85106	446165	
140	0	0	140	85106	446165	
150	0	0	150	85106	446165	
160	0	0	160	85106	446165	
170	0	0	170	85106	446165	
180	0	0	180	85106	446165	
190	0	0	190	85106	446165	
200	0	0	200	85106	446165	
210	0	0	210	85106	446165	
220	0	0	220	85106	446165	
230	0	0	230	85106	446165	
240	0	0	240	85106	446165	
250	0	0	250	85106	446165	
260	0	0	260	85106	446165	
270	0	0	270	85106	446165	
280	0	0	280	85106	446165	
290	0	0	290	85106	446165	
300	0	0	300	85106	446165	
310	0	0	310	85106	446165	
320	0	0	320	85106	446165	
330	0	0	330	85106	446165	
340	0	0	340	85106	446165	
350	0	0	350	85106	446165	
360	0	0	360	85106	446165	
370	0	0	370	85106	446165	
380	0	0	380	85106	446165	
390	0	0	390	85106	446165	
400	0	0	400	85106	446165	
			405	North Sea Base		
410	0	0	410	85106	446165	
420	0	0	420	85106	446165	
430	0	0	430	85106	446165	
440	0	0	440	85106	446165	
450	0	0	450	85106	446165	
460	0	0	460	85106	446165	
470	0	0	470	85106	446165	
480	0	0	480	85106	446165	
490	0	0	490	85106	446165	
500	0	0	500	85106	446165	
			505	Calk Base		
510	0	0	510	85106	446165	
520	0	0	520	85106	446165	
530	0	0	530	85106	446165	
540	0	0	540	85106	446165	
550	0	0	550	85106	446165	
560	0	0	560	85106	446165	
570	0	0	570	85106	446165	
580	0,2	0,2	580	85106	446165	
590	0,7	0,9	590	85106	446165	
600	0,7	1,6	600	85106	446165	
610	0,7	2,3	610	85107	446165	
620	0,7	3	620	85107	446166	
630	0,7	3,7	630	85108	446166	
640	0,7	4,4	640	85109	446166	
650	0,7	5,1	650	85110	446166	
660	0,7	5,8	660	85110	446167	
670	0,7	6,5	670	85112	446167	
680	0,7	7,2	680	85113	446168	

690	0,7	7,9	690	85114	446168
700	0,7	8,6	699	85115	446169
710	0,7	9,3	709	85117	446169
720	0,7	10	719	85119	446170
730	0,7	10,7	729	85120	446170
740	0,7	11,4	739	85122	446171
750	0,7	12,1	749	85124	446172
			755	Mid Holland Claystone Top	
760	0,7	12,8	758	85126	446172
770	0,7	13,5	768	85128	446173
780	0,7	14,2	778	85131	446174
790	0,7	14,9	787	85133	446175
800	0,7	15,6	797	85136	446176
810	0,7	16,3	807	85138	446177
820	0,7	17	816	85141	446178
830	0,7	17,7	826	85144	446179
840	0,7	18,4	835	85147	446180
850	0,7	19,1	845	85150	446181
860	0,7	19,8	854	85153	446182
			865	Holland Greensand Top	
870	0,7	20,5	863	85157	446183
880	0,7	21,2	873	85160	446184
890	0,7	21,9	882	85163	446186
900	0,7	22,6	891	85167	446187
910	0,7	23,3	900	85171	446188
920	0,7	24	910	85175	446190
930	0,7	24,7	919	85179	446191
940	0,7	25,4	928	85183	446192
950	0,7	26,1	937	85187	446194
960	0,7	26,8	946	85191	446195
970	0,7	27,5	955	85195	446197
980	0,7	28,2	963	85200	446198
990	0,7	28,9	972	85204	446200
1000	0,7	29,6	981	85209	446202
1010	0,7	30,3	989	85214	446203
1020	0,7	31	998	85219	446205
1030	0,7	31,7	1006	85224	446207
1040	0,7	32,4	1015	85229	446209
1050	0,7	33,1	1023	85234	446210
1060	0,7	33,8	1032	85239	446212
1070	0,7	34,5	1040	85244	446214
1080	0,7	35,2	1048	85250	446216
1090	0,7	35,9	1056	85255	446218
1100	0,7	36,6	1064	85261	446220
1110	0,7	37,3	1072	85267	446222
1120	0,7	38	1080	85273	446224
1130	0,7	38,7	1088	85278	446226
1140	0,7	39,4	1096	85284	446228
1150	0,7	40,1	1103	85290	446231
1160	0,7	40,8	1111	85297	446233
1170	0,7	41,5	1118	85303	446235
			1120	Vlieland / De Lier Mbr Top	
1180	0,7	42,2	1126	85309	446237
1190	0,7	42,9	1133	85316	446239
1200	0,7	43,6	1140	85322	446242
1210	0,7	44,3	1147	85329	446244
1220	0,7	45	1154	85335	446246
1230	0	45	1162	85342	446249
1240	0	45	1169	85349	446251
1250	0	45	1176	85355	446253
1260	0	45	1183	85362	446256
1270	0	45	1190	85369	446258
1280	0	45	1197	85375	446261
1290	0	45	1204	85382	446263
1300	0	45	1211	85389	446265
1310	0	45	1218	85395	446268
1320	0	45	1225	85402	446270
1330	0	45	1232	85409	446272
1340	0	45	1239	85415	446275
1350	0	45	1246	85422	446277
1360	0	45	1253	85429	446279
1370	0	45	1261	85435	446282
1380	0	45	1268	85442	446284
1390	0	45	1275	85449	446287
1400	0	45	1282	85455	446289
1410	0	45	1289	85462	446291
1420	0	45	1296	85469	446294
1430	0	45	1303	85475	446296

1440	0	45	1310	85482	446298
1450	0	45	1317	85489	446301
1460	0	45	1324	85495	446303
1470	0	45	1331	85502	446305
1480	0	45	1338	85509	446308
1490	0	45	1345	85515	446310
1500	0	45	1352	85522	446312
1510	0	45	1360	85529	446315
1520	0	45	1367	85535	446317
1530	0	45	1374	85542	446320
1540	0	45	1381	85549	446322
1550	0	45	1388	85555	446324
1560	0	45	1395	85562	446327
1570	0	45	1402	85569	446329
1580	0	45	1409	85575	446331
1590	0	45	1416	85582	446334
1600	0	45	1423	85589	446336
1610	0	45	1430	85595	446338
1620	0	45	1437	85602	446341
1630	0	45	1444	85609	446343
1640	0	45	1451	85615	446346
1650	0	45	1459	85622	446348
1660	0	45	1466	85629	446350
1670	0	45	1473	85635	446353
1680	0	45	1480	85642	446355
1690	0	45	1487	85649	446357
1700	0	45	1494	85655	446360
1710	0	45	1501	85662	446362
1720	0	45	1508	85669	446364
1730	0	45	1515	85675	446367
1740	0	45	1522	85682	446369
1750	0	45	1529	85689	446372
1760	0	45	1536	85695	446374
1770	0	45	1543	85702	446376
1780	0	45	1550	85709	446379
1790	0	45	1557	85715	446381
1800	0	45	1565	85722	446383
1810	0	45	1572	85729	446386
1820	0	45	1579	85735	446388
1830	0	45	1586	85742	446390
1840	0	45	1593	85749	446393
1850	0	45	1600	85755	446395
1860	0	45	1607	85762	446397
1870	0	45	1614	85769	446400
1880	0	45	1621	85775	446402
1890	0	45	1628	85782	446405
1900	0	45	1635	85789	446407
1910	0	45	1642	85795	446409
1920	0	45	1649	85802	446412
1930	0	45	1656	85809	446414
1940	0	45	1664	85815	446416
1950	0	45	1671	85822	446419
1960	0	45	1678	85829	446421
1970	0	45	1685	85835	446423
1980	0	45	1692	85842	446426
1990	0	45	1699	85849	446428
2000	0	45	1706	85855	446431
2010	0	45	1713	85862	446433
2020	0	45	1720	85869	446435
2030	0	45	1727	85875	446438
2040	0	45	1734	85882	446440
2050	0	45	1741	85889	446442
2060	0	45	1748	85895	446445
2070	0	45	1755	85902	446447
2080	0	45	1763	85909	446449
2090	0	45	1770	85915	446452
2100	0	45	1777	85922	446454
2110	0	45	1784	85929	446456
2120	0	45	1791	85935	446459
2130	0	45	1798	85942	446461
2140	0	45	1805	85949	446464
2150	0	45	1812	85955	446466
2160	0	45	1819	85962	446468
2170	0	45	1826	85969	446471
2180	0	45	1833	85975	446473
2190	0	45	1840	85982	446475
2200	0	45	1847	85989	446478
2210	0	45	1854	85995	446480

2220	0	45	1862	86002	446482	
2230	0	45	1869	86009	446485	
2240	0	45	1876	86015	446487	
2250	0	45	1883	86022	446490	
2260	0	45	1890	86029	446492	
2270	0	45	1897	86035	446494	
2280	0	45	1904	86042	446497	
2290	0	45	1911	86049	446499	
2300	0	45	1918	86055	446501	
2310	0	45	1925	86062	446504	
2320	0	45	1932	86069	446506	
2330	0	45	1939	86075	446508	
2340	0	45	1946	86082	446511	
2350	0	45	1953	86089	446513	
2360	0	45	1961	86095	446515	
2370	0	45	1968	86102	446518	
			1970			Rijswijk Base / Rodenrijs Clst Top
2380	0	45	1975	86109	446520	
2390	0	45	1982	86115	446523	
2400	0	45	1989	86122	446525	
2410	0	45	1996	86129	446527	
2420	0	45	2003	86135	446530	
2430	0	45	2010	86142	446532	
2440	0	45	2017	86149	446534	
2450	0	45	2024	86155	446537	
2460	0	45	2031	86162	446539	
2470	0	45	2038	86169	446541	
2480	0	45	2045	86175	446544	
2490	0	45	2052	86182	446546	
2500	0	45	2060	86189	446549	
2510	0	45	2067	86195	446551	
2520	0	45	2074	86202	446553	
2530	0	45	2081	86209	446556	
2540	0	45	2088	86215	446558	
2550	0	45	2095	86222	446560	
2560	0	45	2102	86229	446563	
2570	0	45	2109	86235	446565	
2580	0	45	2116	86242	446567	
2590	0	45	2123	86249	446570	
2600	0	45	2130	86255	446572	
2610	0	45	2137	86262	446575	
2620	0	45	2144	86269	446577	
2630	0	45	2151	86275	446579	
2640	0	45	2159	86282	446582	
2645			2162			Top Delft Sst
2650	0	45	2166	86289	446584	CASING POINT
2660	0	45	2173	86295	446586	
2670	0	45	2180	86302	446589	
2680	0	45	2187	86309	446591	
2690	0	45	2194	86315	446593	
2700	0	45	2201	86322	446596	
2710	0	45	2208	86329	446598	
2720	0	45	2215	86335	446600	
2730	0	45	2222	86342	446603	
2740	0	45	2229	86349	446605	
2750	0	45	2236	86355	446608	
2760	0	45	2243	86362	446610	
2770	0	45	2250	86369	446612	
2780	0	45	2258	86375	446615	
2790	0	45	2265	86382	446617	
2800	0	45	2272	86389	446619	
2810	0	45	2279	86395	446622	
2820	0	45	2286	86402	446624	
2830	0	45	2293	86409	446626	
2835			2297			Base Delft Sst/ Pijnacker
2840	0	45	2300	86415	446629	
2850	0	45	2307	86422	446631	
2860	0	45	2314	86429	446634	
2870	0	45	2321	86435	446636	
2880	0	45	2328	86442	446638	
2890	0	45	2335	86449	446641	
2900	0	45	2342	86455	446643	
2910	0	45	2349	86462	446645	
2920	0	45	2357	86469	446648	
2930	0	45	2364	86475	446650	
2940	0	45	2371	86482	446652	
2950	0	45	2378	86489	446655	

2960	0	45	2385	86495	446657	
2970	0	45	2392	86502	446659	TD
2980	0	45	2399	86508	446662	
2990	0	45	2406	86515	446664	
3000	0	45	2413	86522	446667	

Table 30: Well trajectory of injector well DEL-GT-02

Depth	Build Rate	Hole Angle	Depth2	X-coordinate	Y-coordinate	Formation
MD	DEGREES	DEGREES	TVD	RD	RD	
m	per 10 m	Total	m	m	m	
0	0	0	0	85100	446163	
10	0	0	10	85100	446163	
20	0	0	20	85100	446163	
30	0	0	30	85100	446163	
40	0	0	40	85100	446163	
50	0	0	50	85100	446163	
60	0	0	60	85100	446163	
70	0	0	70	85100	446163	
80	0	0	80	85100	446163	
90	0	0	90	85100	446163	
100	0	0	100	85100	446163	
110	0	0	110	85100	446163	
120	0	0	120	85100	446163	
130	0	0	130	85100	446163	
140	0	0	140	85100	446163	
150	0	0	150	85100	446163	
160	0	0	160	85100	446163	
170	0	0	170	85100	446163	
180	0	0	180	85100	446163	
190	0	0	190	85100	446163	
200	0	0	200	85100	446163	
210	0	0	210	85100	446163	
220	0	0	220	85100	446163	
230	0	0	230	85100	446163	
240	0	0	240	85100	446163	
250	0	0	250	85100	446163	
260	0	0	260	85100	446163	
270	0	0	270	85100	446163	
280	0	0	280	85100	446163	
290	0	0	290	85100	446163	
300	0	0	300	85100	446163	
310	0	0	310	85100	446163	
320	0	0	320	85100	446163	
330	0	0	330	85100	446163	
340	0	0	340	85100	446163	
350	0	0	350	85100	446163	
360	0	0	360	85100	446163	
370	0	0	370	85100	446163	
380	0	0	380	85100	446163	
390	0	0	390	85100	446163	
400	0	0	400	85100	446163	
			405	North Sea Base		
410	0	0	410	85100	446163	
420	0	0	420	85100	446163	
430	0	0	430	85100	446163	
440	0	0	440	85100	446163	
450	0	0	450	85100	446163	
460	0	0	460	85100	446163	
470	0	0	470	85100	446163	
480	0	0	480	85100	446163	
490	0	0	490	85100	446163	
500	0	0	500	85100	446163	
			505	Calk Base		
510	0	0	510	85100	446163	
520	0	0	520	85100	446163	
530	0	0	530	85100	446163	
540	0	0	540	85100	446163	
550	0	0	550	85100	446163	
560	0	0	560	85100	446163	
570	0	0	570	85100	446163	
580	0	0	580	85100	446163	
590	0	0	590	85100	446163	
600	0	0	600	85100	446163	
610	0,7	0,7	610	85100	446163	
620	0,7	1,4	620	85100	446163	
630	0,7	2,1	630	85100	446163	
640	0,7	2,8	640	85100	446164	
650	0,7	3,5	650	85100	446164	
660	0,7	4,2	660	85100	446165	

670	0,7	4,9	670	85100	446166
680	0,7	5,6	680	85100	446167
690	0,7	6,3	690	85100	446168
700	0,7	7	700	85100	446169
710	0,7	7,7	710	85100	446171
720	0,7	8,4	720	85100	446172
730	0,7	9,1	729	85100	446174
740	0,7	9,8	739	85100	446175
740			Mid Holland Claystone Top		
750	0,7	10,5	749	85100	446177
760	0,7	11,2	759	85100	446179
770	0,7	11,9	769	85100	446181
780	0,7	12,6	778	85101	446183
790	0,7	13,3	788	85101	446186
800	0,7	14	798	85101	446188
810	0,7	14,7	808	85101	446191
820	0,7	15,4	817	85101	446193
830	0,7	16,1	827	85101	446196
840	0,7	16,8	836	85101	446199
845			Holland Greensand Top		
850	0,7	17,5	846	85101	446202
860	0,7	18,2	855	85101	446205
870	0,7	18,9	865	85102	446208
880	0,7	19,6	874	85102	446212
890	0,7	20,3	884	85102	446215
900	0,7	21	893	85102	446219
910	0,7	21,7	902	85102	446222
920	0,7	22,4	912	85102	446226
930	0,7	23,1	921	85103	446230
940	0,7	23,8	930	85103	446234
950	0,7	24,5	939	85103	446238
960	0,7	25,2	948	85103	446242
970	0,7	25,9	957	85103	446247
980	0,7	26,6	966	85104	446251
990	0,7	27,3	975	85104	446256
1000	0,7	28	984	85104	446261
1010	0,7	28,7	992	85104	446265
1020	0,7	29,4	1001	85104	446270
1030	0,7	30,1	1010	85105	446275
1040	0,7	30,8	1018	85105	446280
1050	0,7	31,5	1027	85105	446286
1060	0,7	32,2	1035	85105	446291
1070	0,7	32,9	1044	85106	446296
1080	0,7	33,6	1052	85106	446302
1090	0,7	34,3	1060	85106	446308
1100	0,7	35	1069	85106	446313
1110	0,7	35,7	1077	85107	446319
1120	0,7	36,4	1085	85107	446325
1127			1090	Vlieland / De Lier Mbr Top	
1130	0,7	37,1	1093	85107	446331
1140	0,7	37,8	1101	85107	446337
1150	0,7	38,5	1108	85108	446343
1160	0,7	39,2	1116	85108	446350
1170	0,7	39,9	1124	85108	446356
1180	0,7	40,6	1131	85108	446363
1190	0,7	41,3	1139	85109	446369
1200	0,7	42	1146	85109	446376
1210	0	42	1154	85109	446383
1220	0	42	1161	85110	446389
1230	0	42	1169	85110	446396
1240	0	42	1176	85110	446403
1250	0	42	1184	85111	446409
1260	0	42	1191	85111	446416
1270	0	42	1198	85111	446423
1280	0	42	1206	85111	446429
1290	0	42	1213	85112	446436
1300	0	42	1221	85112	446443
1310	0	42	1228	85112	446449
1320	0	42	1236	85113	446456
1330	0	42	1243	85113	446463
1340	0	42	1250	85113	446469
1350	0	42	1258	85114	446476
1360	0	42	1265	85114	446483
1370	0	42	1273	85114	446490
1380	0	42	1280	85114	446496
1390	0	42	1288	85115	446503
1400	0	42	1295	85115	446510
1410	0	42	1302	85115	446516

1420	0	42	1310	85116	446523
1430	0	42	1317	85116	446530
1440	0	42	1325	85116	446536
1450	0	42	1332	85117	446543
1460	0	42	1340	85117	446550
1470	0	42	1347	85117	446556
1480	0	42	1354	85117	446563
1490	0	42	1362	85118	446570
1500	0	42	1369	85118	446576
1510	0	42	1377	85118	446583
1520	0	42	1384	85119	446590
1530	0	42	1392	85119	446596
1540	0	42	1399	85119	446603
1550	0	42	1407	85119	446610
1560	0	42	1414	85120	446617
1570	0	42	1421	85120	446623
1580	0	42	1429	85120	446630
1590	0	42	1436	85121	446637
1600	0	42	1444	85121	446643
1610	0	42	1451	85121	446650
1620	0	42	1459	85122	446657
1630	0	42	1466	85122	446663
1640	0	42	1473	85122	446670
1650	0	42	1481	85122	446677
1660	0	42	1488	85123	446683
1670	0	42	1496	85123	446690
1680	0	42	1503	85123	446697
1690	0	42	1511	85124	446703
1700	0	42	1518	85124	446710
1710	0	42	1525	85124	446717
1720	0	42	1533	85125	446724
1730	0	42	1540	85125	446730
1740	0	42	1548	85125	446737
1750	0	42	1555	85125	446744
1760	0	42	1563	85126	446750
1770	0	42	1570	85126	446757
1780	0	42	1577	85126	446764
1790	0	42	1585	85127	446770
1800	0	42	1592	85127	446777
1810	0	42	1600	85127	446784
1820	0	42	1607	85128	446790
1830	0	42	1615	85128	446797
1840	0	42	1622	85128	446804
1850	0	42	1629	85128	446810
1860	0	42	1637	85129	446817
1870	0	42	1644	85129	446824
1880	0	42	1652	85129	446830
1890	0	42	1659	85130	446837
1900	0	42	1667	85130	446844
1910	0	42	1674	85130	446851
1920	0	42	1681	85131	446857
1930	0	42	1689	85131	446864
1940	0	42	1696	85131	446871
1950	0	42	1704	85131	446877
1960	0	42	1711	85132	446884
1970	0	42	1719	85132	446891
1980	0	42	1726	85132	446897
1990	0	42	1733	85133	446904
2000	0	42	1741	85133	446911
2010	0	42	1748	85133	446917
2020	0	42	1756	85133	446924
2030	0	42	1763	85134	446931
2040	0	42	1771	85134	446937
2050	0	42	1778	85134	446944
2060	0	42	1786	85135	446951
2070	0	42	1793	85135	446957
2080	0	42	1800	85135	446964
2090	0	42	1808	85136	446971
2100			1815		Rijswijk Base / Rodenrijs Clst Top
2100	0	42	1815	85136	446978
2110	0	42	1823	85136	446984
2120	0	42	1830	85136	446991
2130	0	42	1838	85137	446998
2140	0	42	1845	85137	447004
2150	0	42	1852	85137	447011
2160	0	42	1860	85138	447018
2170	0	42	1867	85138	447024

2180	0	42	1875	85138	447031	
2190	0	42	1882	85139	447038	
2200	0	42	1890	85139	447044	
2210	0	42	1897	85139	447051	
2220	0	42	1904	85139	447058	
2230	0	42	1912	85140	447064	
2240	0	42	1919	85140	447071	
2250	0	42	1927	85140	447078	
2260	0	42	1934	85141	447084	
2270	0	42	1942	85141	447091	
2280	0	42	1949	85141	447098	
2290	0	42	1956	85142	447105	
2292			1957			Top Delft Sst
2300	0	42	1964	85142	447111	
2310	0	42	1971	85142	447118	
2320	0	42	1979	85142	447125	
2330	0	42	1986	85143	447131	
2340	0	42	1994	85143	447138	
2350	0	42	2001	85143	447145	
2360	0	42	2008	85144	447151	
2370	0	42	2016	85144	447158	
2380	0	42	2023	85144	447165	
2390	0	42	2031	85145	447171	
2400	0	42	2038	85145	447178	
2410	0	42	2046	85145	447185	
			2050			Base Delft Sst/ Pijnacker
2420	0	42	2053	85145	447191	
2430	0	42	2060	85146	447198	
2440	0	42	2068	85146	447205	TD
2450	0	42	2075	85146	447211	
2460	0	42	2083	85147	447218	
2470	0	42	2090	85147	447225	
2480	0	42	2098	85147	447232	
2490	0	42	2105	85147	447238	

J. Geomechanical analysis

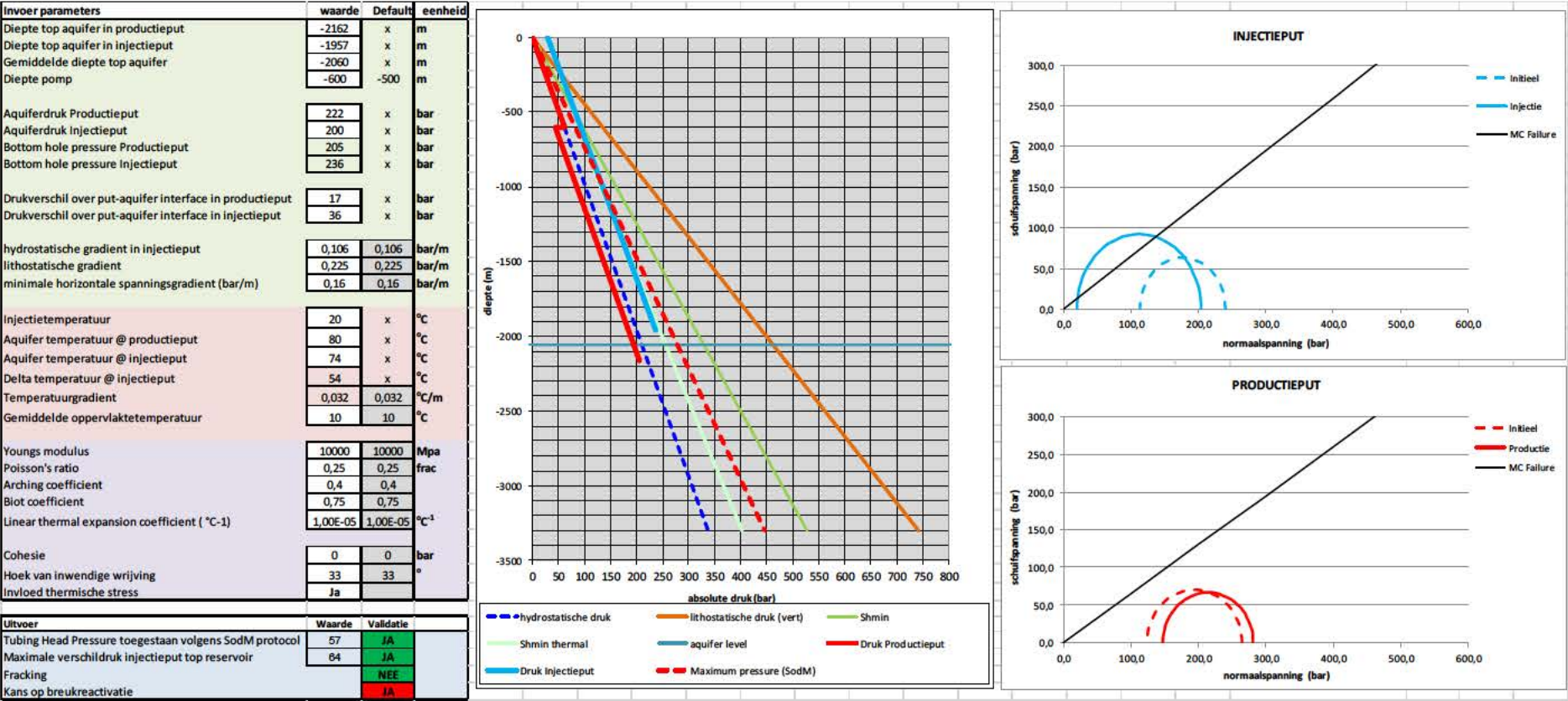


Figure 51: Geomech2D calculation (TNO), using the input/output from DoubletCalc1D (Figure 40)

K. DoubletCalc2D input parameters interference model

REGION OF INTEREST

xmin

83975.0

m

nx

111.0

-

xmax

89525.0

m

ny

100.0

-

ymin

444472.2222213

m

ymax

450027.7847213

m

grid geometry

depth_50m.grd

use values

view

AQUIFER PROPERTIES

initial temperature

78.0

C

temp_50m.grd

use value

view

aquifer depth

2100.0

m

depth_50m.grd

use value

view

(cell) thickness

128.0

m

thickness_50m.grd

use value

view

porosity

0.17

-

none

use grid

view

net to gross

0.72

-

none

use grid

view

actnum

1.0

-

none

use grid

view

permeability in xdir

600.0

mDarcy

none

use grid

view

permeability in ydir

600.0

mDarcy

none

use grid

view

water salinity

130000.0

ppm

CALCULATION SETTINGS

time end production

35.0

yrs

time end analysis

35.0

yrs

output interval

1.0

yrs

output/calculation interval after production

100.0

yrs

Figure 52: DoubletCalc2D input – Aquifer.

name	Well 0	Well 1	Well 2	Well 3	Well 4	Well 5	
x	86348.0	85144.0	87960.0	86920.0	87680.0	89300.0	m
y	446606.0	447147.0	447115.0	448372.0	445850.0	445750.0	m
well diameter	8.5	12.25	12.25	12.25	6.0	6.0	inch
well skin	0.0	0.0	0.0	0.0	0.0	0.0	-
well excess pressure	30.0	-30.0	30.0	30.0	30.0	30.0	bar
well (inj) temperature	-1.0	20.0	-1.0	20.0	-1.0	35.0	C
well flow rate	-400.0	400.0	-450.0	450.0	-160.0	160.0	m3/h
pressure constraint	no						

Figure 53: DoubletCalc2D input – Input wells.

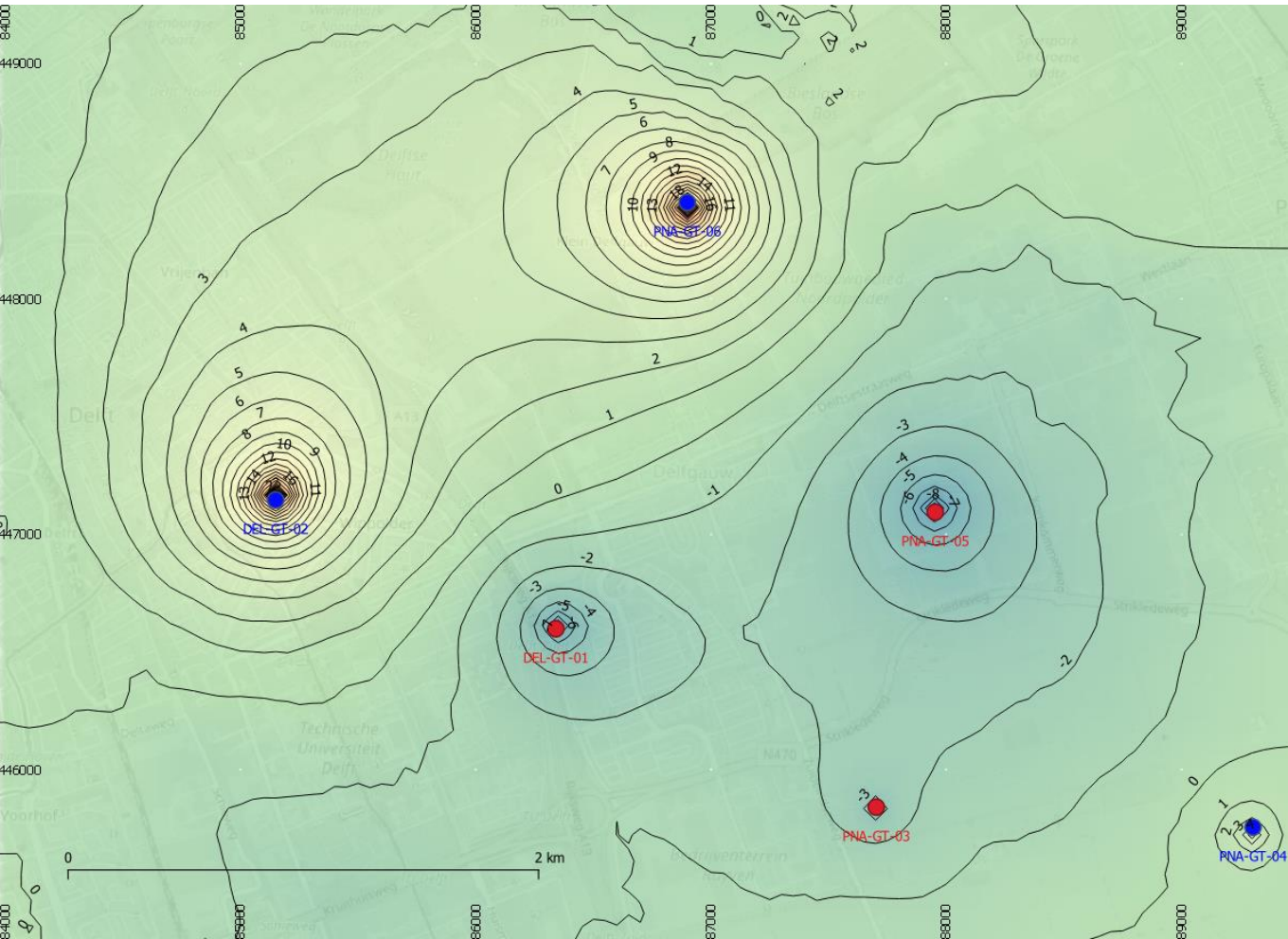


Figure 54: Pressure difference after 35years for the 3 doublets operating in the Vrijenban syncline. Injectors in blue. Producers in red. DEL-GT-01/02: Delft doublet. PNA-GT-05/06: Ammerlaan doublet. PNA-GT-03/04: Duijvestijn doublet.

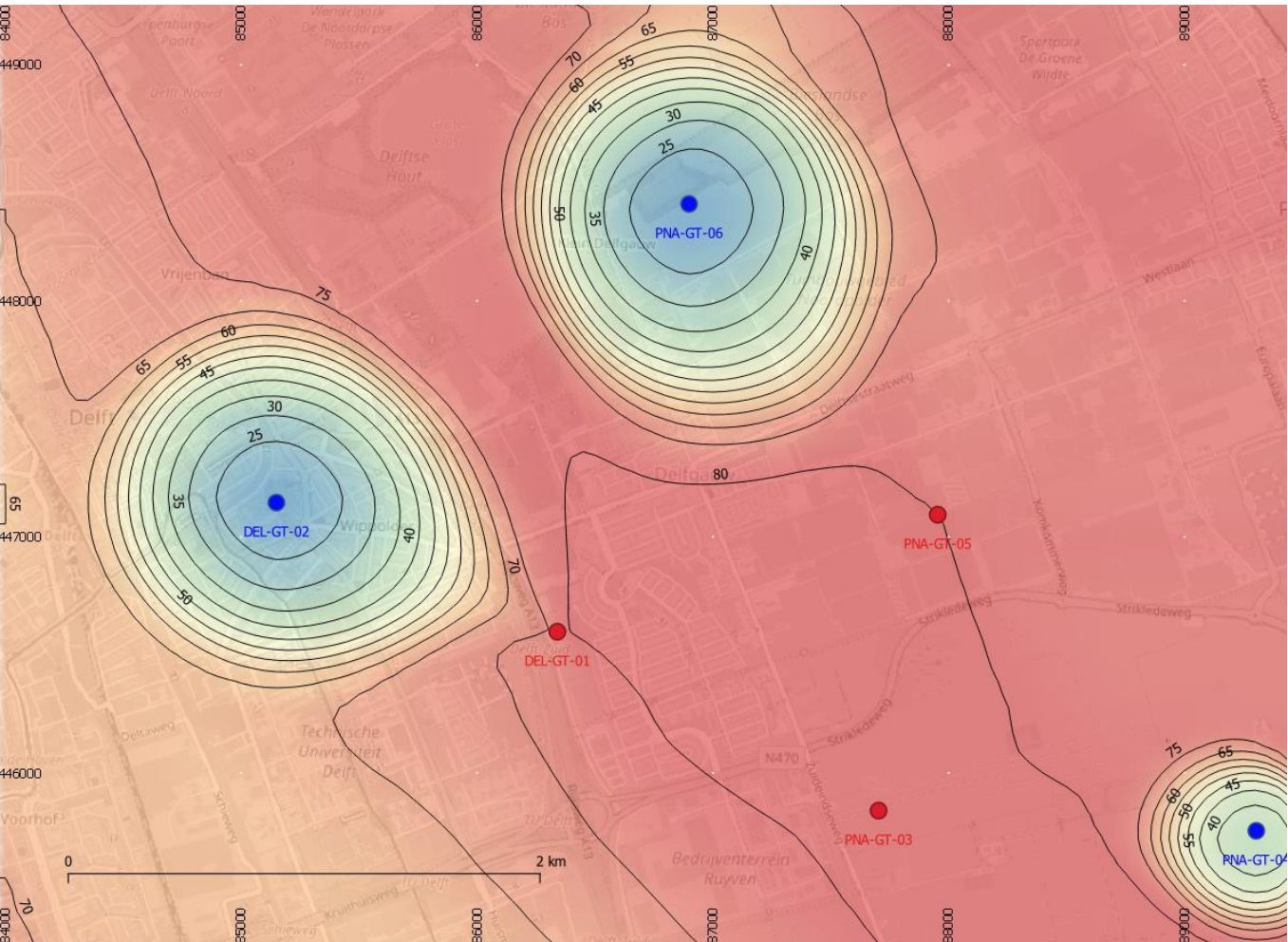


Figure 55: Temperature distribution after 35years for the 3 doublets operating in the Vrijenban syncline. Injectors in blue. Producers in red. DEL-GT-01/02: Delft doublet. PNA-GT-05/06: Ammerlaan doublet. PNA-GT-03/04: Duijvestijn doublet.

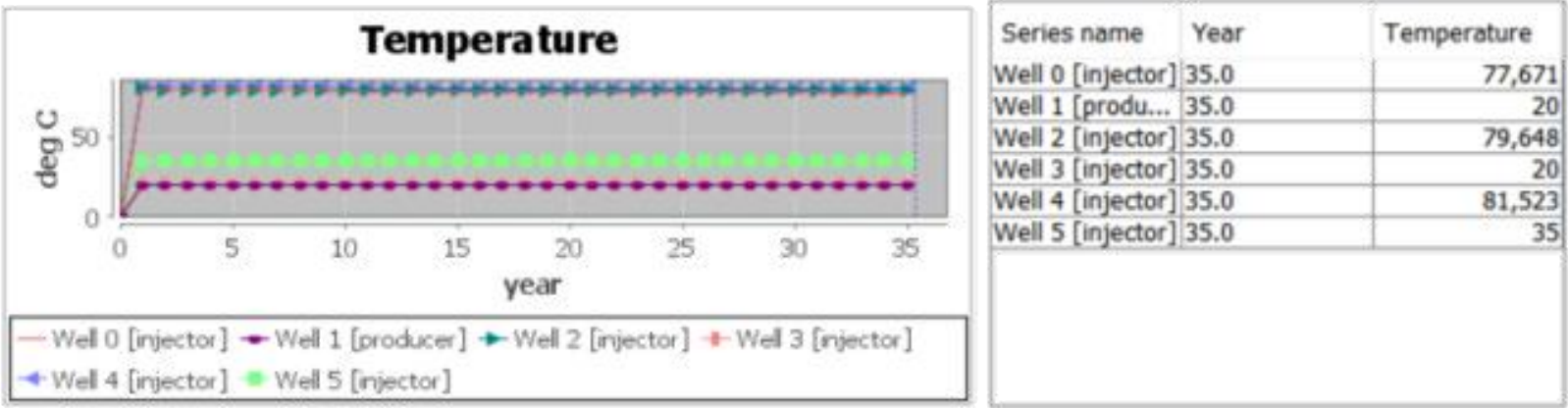


Figure 56: Pressure, Temperature, Flow-rate over 35 years for the 3 doublets operating in the Vrijenban syncline.

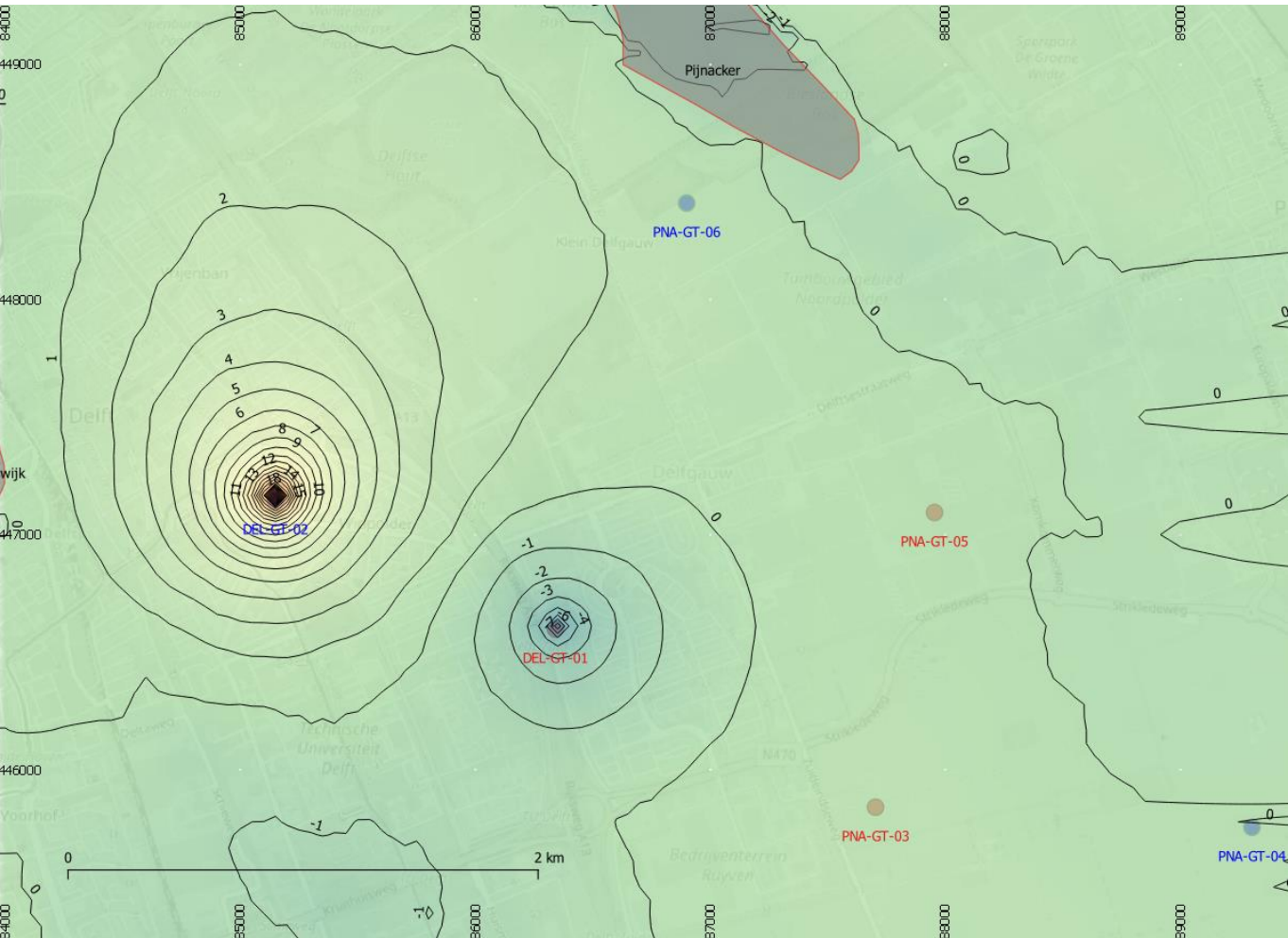


Figure 57: Pressure difference after 35years for the Delft doublet only. Injectors in blue. Producers in red. DEL-GT-01/02: Delft doublet.

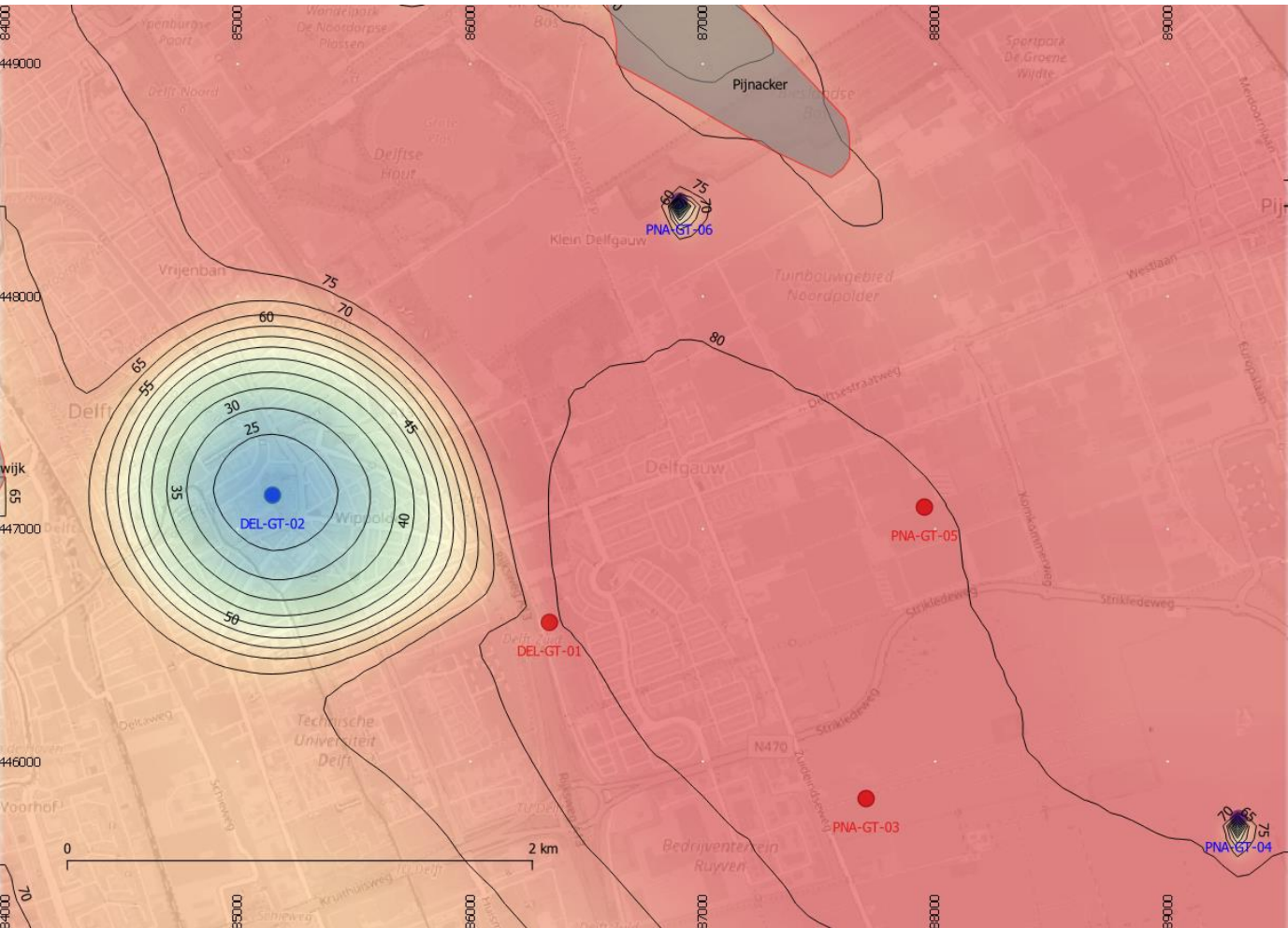


Figure 58: Temperature distribution after 35years for the Delft doublet only. Injectors in blue. Producers in red. DEL-GT-01/02: Delft doublet.

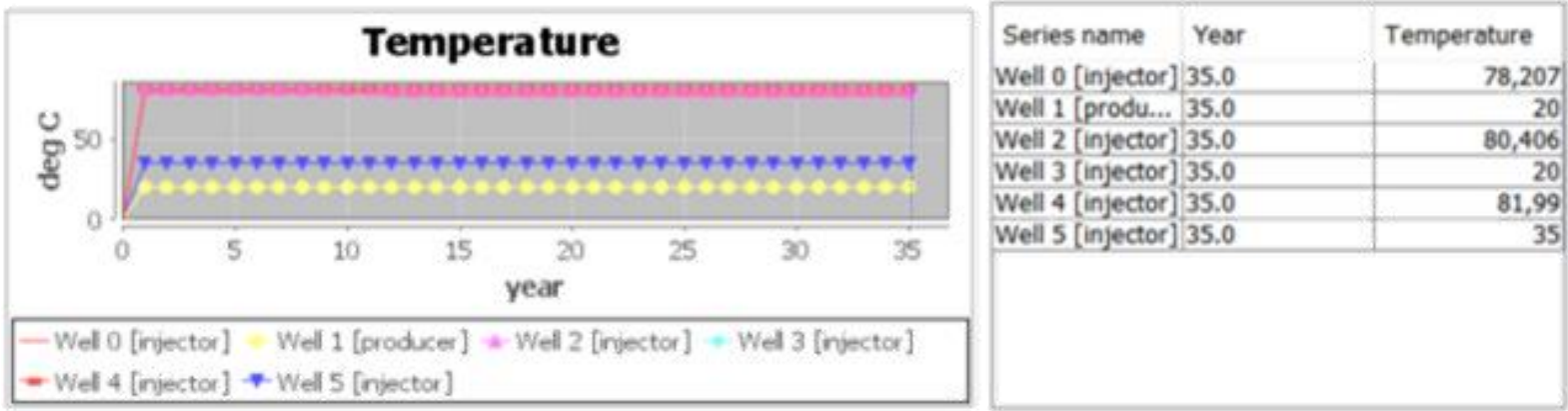


Figure 59: Pressure, Temperature, Flow-rate over 35 years for the Geothermie Delft doublet only.

For a more elaborate study on the effects on pressure and temperature interference within the Vrijenban syncline, please refer to Reinhard (2019).

For a more elaborate study on the expected breakthrough times within de Delft Sandstone Geothermal Reservoir, please refer to Perkins (2019).

L. Seismic Risk Analysis

Introductie

Om te bepalen wat het risico van geïnduceerde seismiteit door geothermie winning bij het GeothermieDelft project is, zal er een Seismische Risico Analyse (SRA) uitgevoerd worden. Hierin worden de risico's in kaart gebracht en het juiste vervolgtraject bepaald met betrekking tot monitoring en verdere analyse van risico's en gevaren.

Een geothermisch project kan veilig gerealiseerd worden door ervoor te zorgen dat de injectie- en productieputten binnen één geologisch blok liggen, zodat er een goede hydraulische connectie is. Daarnaast dienen de putten op veilige afstand van bestaande breuken geplaatst te worden. Een goede basis van de geothermische project planning en de SRA wordt gevormd door een goed begrip van de ondergrond, zoals gedetailleerde kartering van bestaande breuken en analyse van het ondergrondse stress regime.

Monitoring

In Zuid Holland wordt al decennia lang olie en gas gewonnen uit de ondergrond. De regio is niet bekend met natuurlijke of geïnduceerde seismiteit. Echter, een deel van de velden in Zuid Holland valt in de categorie met een niet verwaarloosbare kans op aardbevingen. In een in 2016 gepubliceerde tijdelijke leidraad voor de risicoanalyse voor door gaswinning geïnduceerde bevingen door Staatstoezicht op de Mijnen wordt aangegeven dat bij deze gasvelden een minimale cataloguscompleteheid van $M=1.5$ gevraagd wordt. Om de drempelwaarde van $M=1.5$ te bereiken is het KNMI momenteel bezig een permanent monitoring netwerk te realiseren in Zuid Holland. Hierdoor kunnen de juiste metingen gedaan worden en kan, als er beweging geregistreerd wordt, met betrouwbare plaatsbepaling bepaald worden waar de oorsprong ligt. Met het voorgestelde plan zouden de belangrijkste gasvelden en geothermie locaties in Zuid Holland in de toekomst gedekt zijn. De eerste stations van deze uitbreiding zijn reeds geïnstalleerd (NL-ZH01, Vlaardingen, NL-ZH02 in Zoetermeer, NL-ZH03 in Delfgauw, NL-ZH06 in Naaldwijk <https://www.knmi.nl/nederland-nu/seismologie/stations>). De verwachting is dat de verdere uitbreiding van het seismische monitoring netwerk in het komende jaar gerealiseerd zal worden.

Afhankelijk van de bevindingen van de SRA en de staat van het KNMI monitoringnetwerk, zal de aanvrager indien nodig ook zelf monitoring apparatuur installeren voor de ontwikkeling van GeoThermie Delft.

Seismische Risico Analyse (SRA)

Er is door de firma's Q-con en IF Technology (Baisch et al, 2016) een analyse gemaakt van de belangrijkste indicatoren voor de kans op geïnduceerde seismiteit bij aardwarmteprojecten en het bijbehorende risico/effect. Op basis hiervan zijn aanbevelingen opgesteld voor een methodiek om de seismische risico's inzichtelijk te maken en de bijbehorende beheersmaatregelen te bepalen. Dit protocol heeft de vorm van een stappenmethode:

1. In Level 1 wordt op basis van een aantal indicatoren een QuickScan uitgevoerd, die inzicht geeft in de potentie voor het optreden van geïnduceerde seismiteit. Als hieruit volgt dat de potentie laag is, dan zijn geen verdere stappen nodig (Figure 60).
2. Bij een matige of hoge potentie wordt in Level 2 de gevarenanalyse uitgebreid en worden ook de mogelijke gevolgen - en daarmee het mogelijke risico - inzichtelijk. Een belangrijk onderdeel van Level 2 is tevens het bepalen van de beheersmaatregelen om het risico te beperken (Figure 61)
3. Als uit Level 2 blijkt dat het risico niet acceptabel is (ondanks de beheersmaatregelen) kan er overgegaan worden tot Level 3. Level 3 betreft een kwantitatieve risico analyse: het kwantificeren van het veiligheidsrisico en het risico op economische schade met de bijbehorende onzekerheid (Figure 61).

Voor GeoThermie Delft is de QuickScan van Level 1 uitgevoerd. Hierbij is gebruik gemaakt van de score tabel in Figure 62.

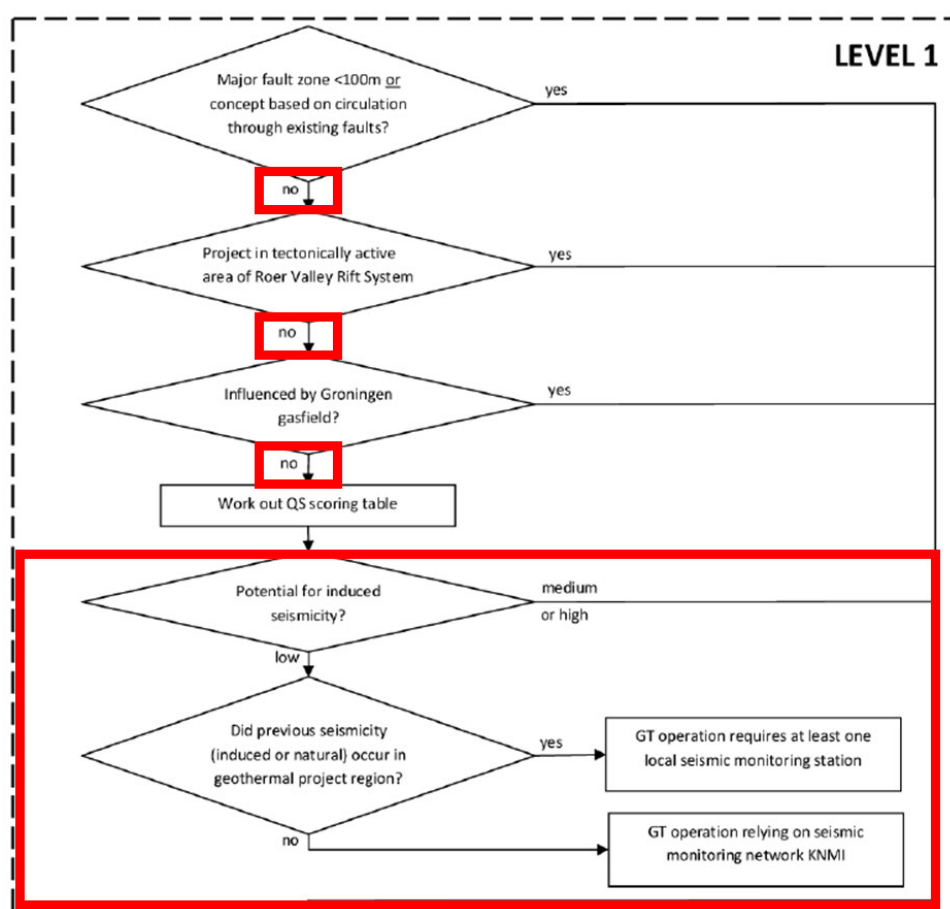


Figure 60: SRA Level 1 (Baisch et al, 2016)

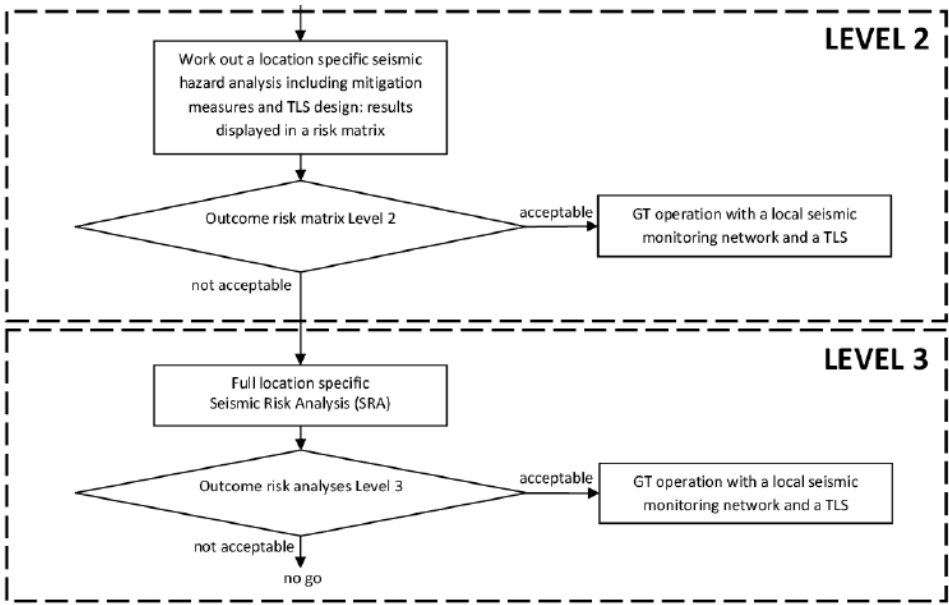


Figure 61: SRA Level 2 & Level 3 (Baisch et al, 2016)

score	verbinding met kristallijnen basis	afstand [km] tot bestaande breuken	oriëntatie van de breuk in heersende stressveld	netto geïnjecteerd volume [x1.000 m³]	drukcommunicatie tussen de putten	injectiedruk [bar]	systeemdebiet [m³/uur]	afstand [km] tot natuurlijke aardbevingen	afstand [km] tot geïnduceerde seismiteit
10	ja	< 0,1	gunstig (voor bezwijken)	> 20	nee	> 70	>360	< 1	< 1
7	mogelijk	0,1-0,5	bezwijken mogelijk	5-20	niet waarschijnlijk	40-70	180-360	1-5	1-5
3	niet waarschijnlijk	0,5-1,5	bezwijken niet waarschijnlijk	0,1-5	waarschijnlijk	10-40	50-180	5-10	5-10
0	nee	> 1,5	bezwijken vrijwel onmogelijk	< 0,1	Ja	< 10	<50	> 10	> 10

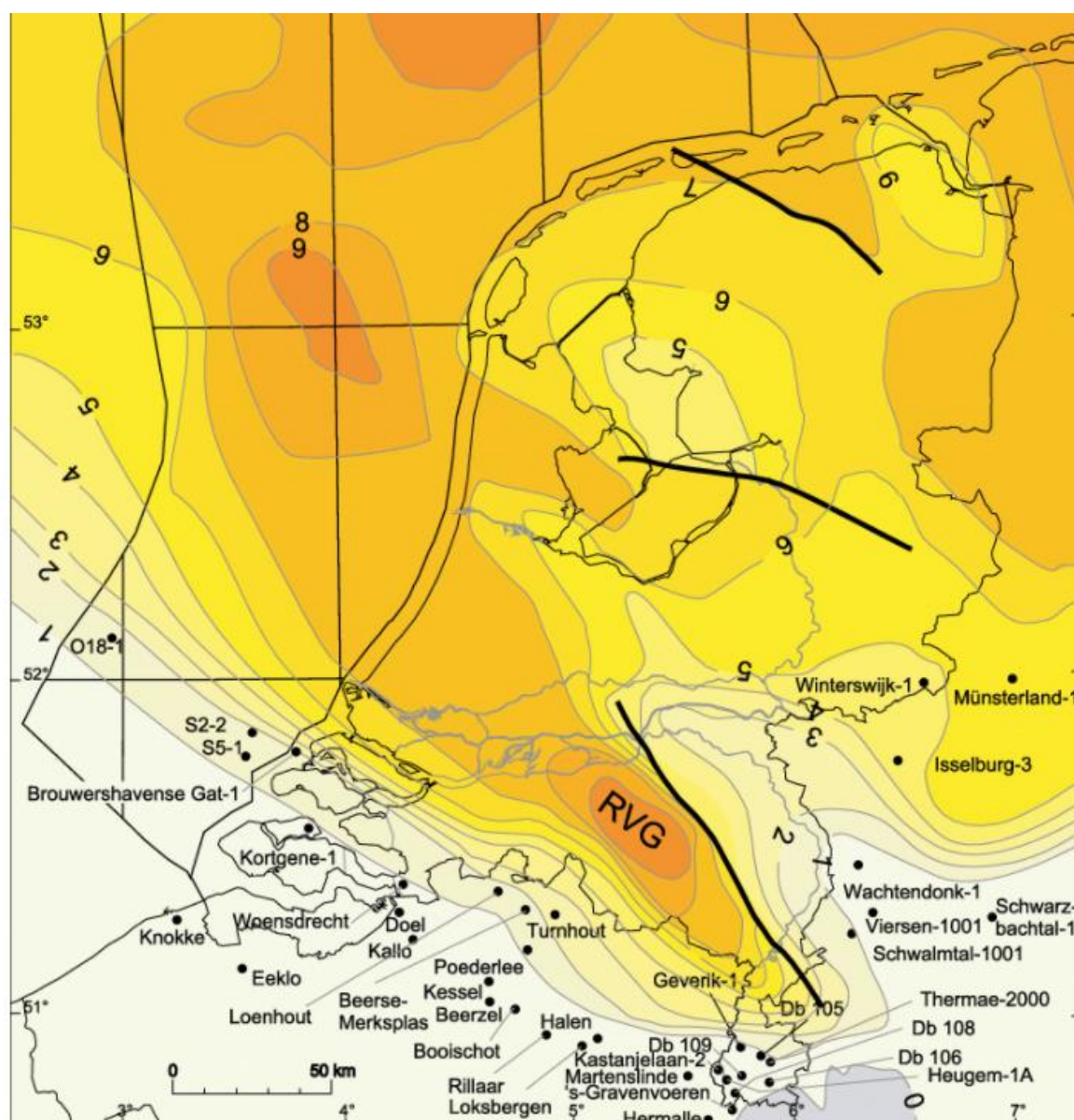
Figure 62: Scoringsschema voor QuickScan SRA (Baisch et al, 2016).

Level 1: QuickScan SRA

Voor het GeoThermie Delft project is gekeken naar de 9 criteria in de score tabel in Figure 62. Hieronder wordt per criterium besproken wat de score is.

1. Verbinding met kristallijnen basement: Score 0

Er is geen verbinding met kristallijnen basement. Het basement wordt meer dan 7 km diep verwacht, dat is 5 km dieper dan het doel-aquifer voor GeoThermie Delft (Figure 63 en Figure 64). Op basis hiervan wordt een **SCORE:0** gegeven.



Schematic depth map in kilometres of the top of the pre-Silesian. For the southern Netherlands and adjacent parts of Belgium and Germany, maps of Bless et al. (1976), Legrand (1968) and NITG (2001) have been used. In other areas, the top of the pre-Silesian has been constructed by adding regional isopachs of the Silesian (Van Buggenum & Den Hartog Jager, this volume) to the depth of the base Permian surface (Lokhorst, 1998). The map further gives an overview of wells which encountered the pre-Silesian. RVG: Roer Valley Graben.

Figure 63 :Top van het pre-Silesian (Geluk et al, 2007). De contouren representeren kilometers diepte

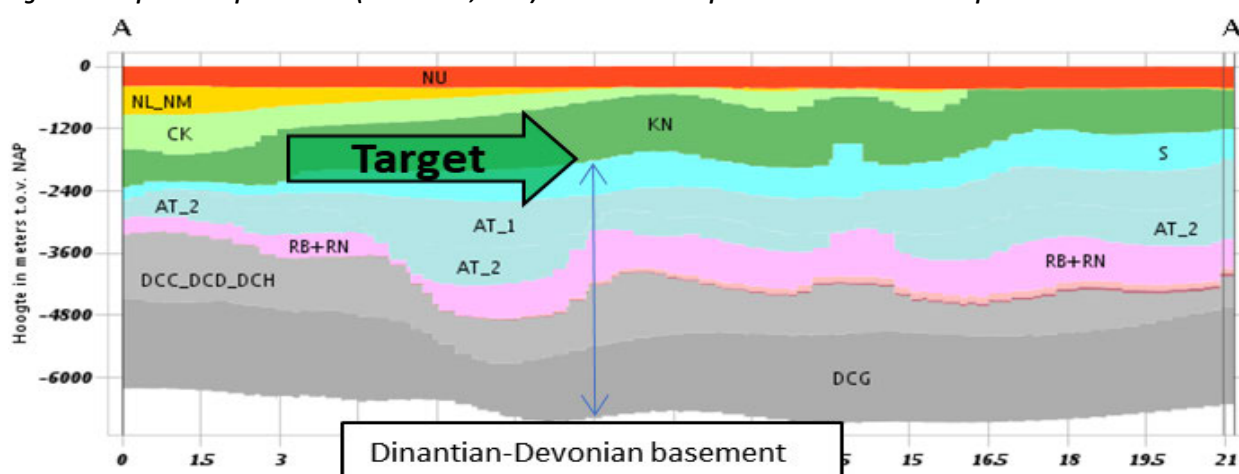


Figure 64: Diepte van het GeoThermie Delft target (Schieland groep is blauw) versus diepte van de Limburg groep (Carboon= donkergrijs). Onder de Limburg groep ligt nog het Dinantiaan, Devoon, en daaronder wordt pas het basement verwacht (DGM deep v4)

2. Afstand tot bestaande breuken: Score 7

De afstand tot bestaande breuken staat weergegeven in Figure 65. De breuken zijn weergegeven op de Top Delft Zandsteen. De afstanden tot de randbreuk van het Rijswijk Hoog (oranje stippel lijn) zijn:

- DEL-GT-01: ± 1.225 m
- DEL-GT-02: ± 750 m
- De afstanden tot de Secundaire breuk bij injector (blauwe lijn)
 - DEL-GT-01: ± 380 m
 - DEL-GT-02: ± 680 m

De afstand tot deze breuken is op Basis Delft niveau groter dan bovenstaande getallen. In Figure 66 en Figure 67 wordt het (minimale) verzet lang de secundaire breuk aangegeven.

Op basis van de bovenstaande afstanden wordt een **SCORE:7** gegeven.

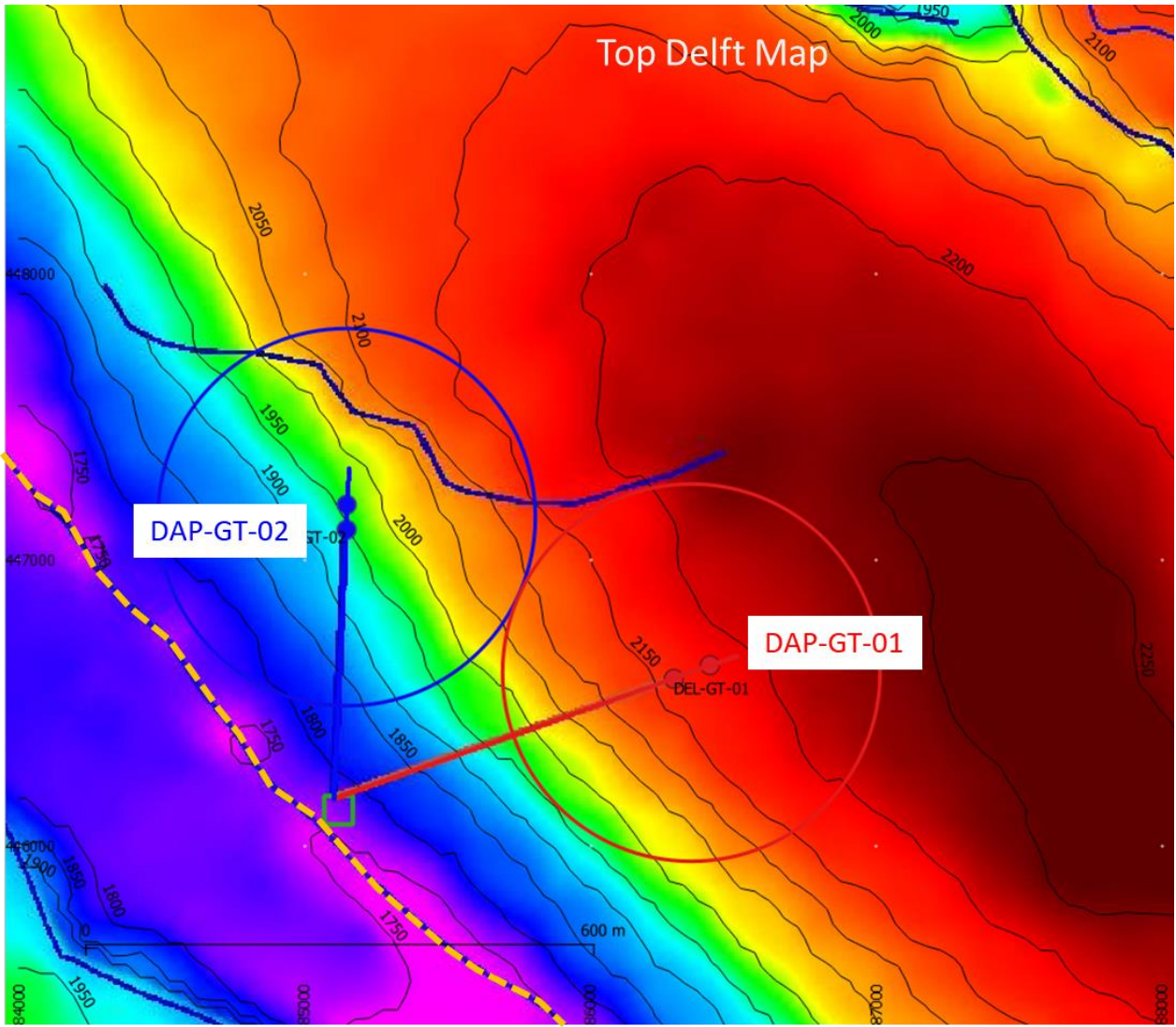


Figure 65: Diepte van de top Delft Zandsteen, inclusief breukinterpretatie in rood

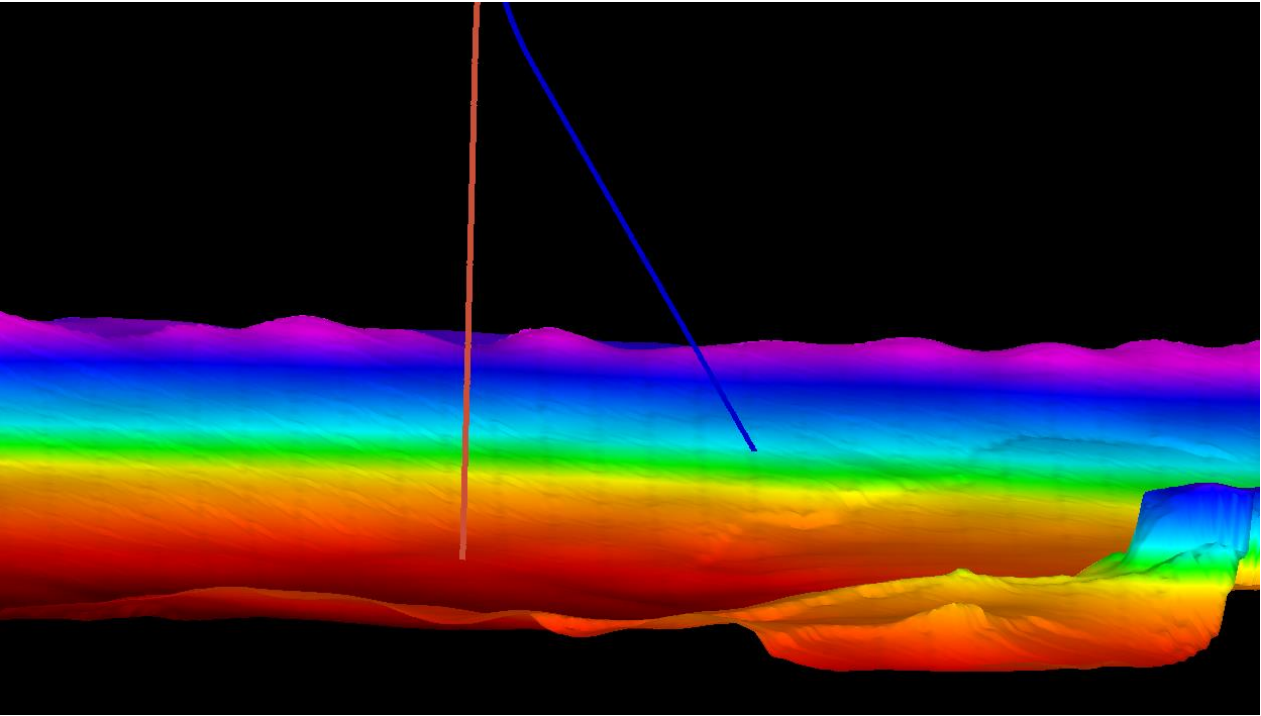


Figure 66: Top Delft Zandsteen met secundaire breuk

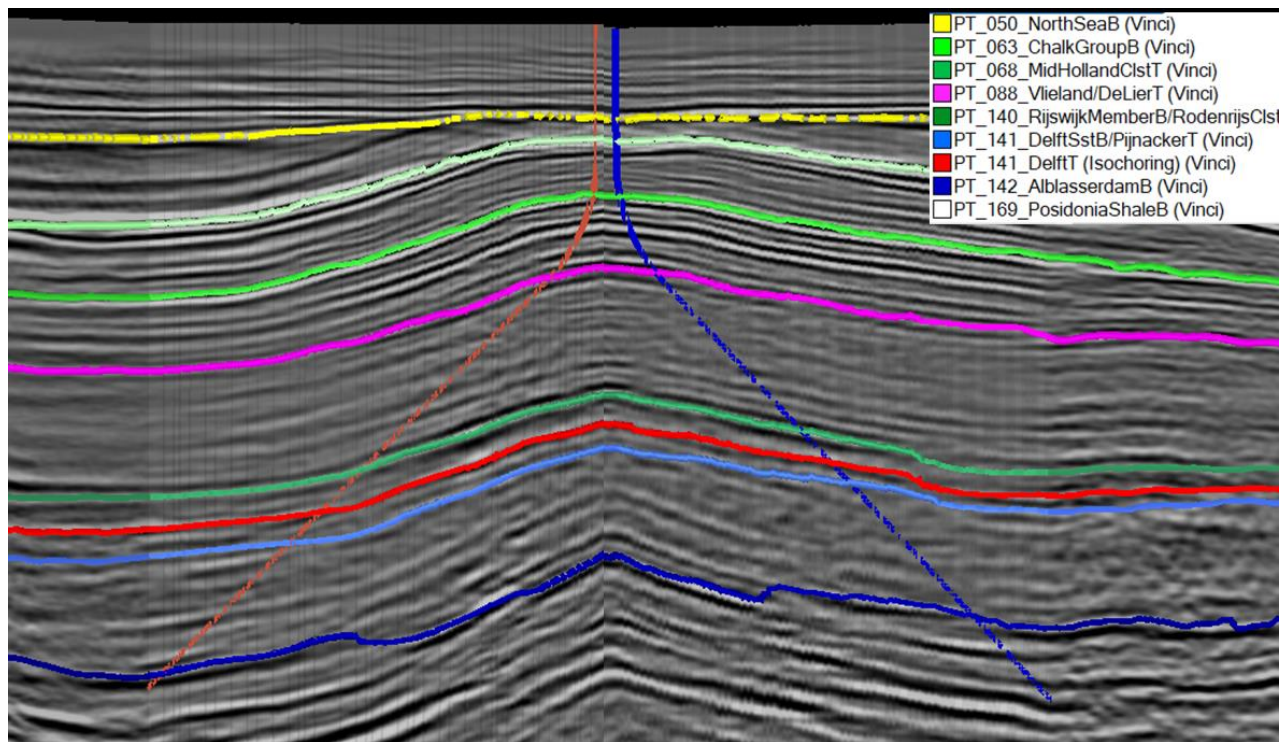


Figure 67: Seismische secties langs well trajectories. De secundaire breuk ligt rechts van de injector. Top reservoir is in rood aangegeven

3. Oriëntatie van breuken in heersende stressveld: Score 7

Regionale stress metingen duiden op een NW-ZO georiënteerde maximale horizontale stress (Figure 68). In een strike-slip stress regime geldt dat breuken parallel aan S_{Hmax} (maximale horizontale stress) het meest waarschijnlijk worden gereactiveerd, en breuken loodrecht op S_{Hmax} het minst waarschijnlijk. Figure 69 laat het lokale stressveld zien samen met de oriëntatie van de breuken. Letterlijk genomen is de oriëntatie van de breuken *gunstig voor bezwijken*.

Aanvullende informatie kan gevonden worden in de richting van extensie tijdens het Neogeen (Figure 70). Deze kaart toont actieve breuken in het quartair (doorgetrokken zwarte lijnen; zie legenda inzet). Er bevinden zich geen actieve breuken in de buurt van de projectlocatie. Het West Nederlands Bekken toont geen geomorfe indicaties voor breuk activiteit. De uniforme Neogene-Quartaire bodemdaling gaat niet gepaard met breukvorming. Het West Nederlands Bekken is seismisch inactief. Dit wordt bevestigd door het feit dat ondanks een decennialange geschiedenis van olie- en gaswinning er geen geïnduceerde seismiteit gemeten is. Op basis hiervan zou de conclusie getrokken kunnen worden dat *bezwijken niet waarschijnlijk* is.

Op basis hiervan wordt in de QuickScan een **SCORE: 7** gegeven, passend bij de gradatie 'bezwijken mogelijk' (zie Figure 62).



Figure 68: World Stress Map, Heidbach, Oliver; Rajabi, Mojtaba; Reiter, Karsten; Ziegler, Moritz; WSM Team (2016): World Stress Map Database Release 2016. GFZ Data Services.[doi:10.5880/WSM.2016.001](https://doi.org/10.5880/WSM.2016.001).

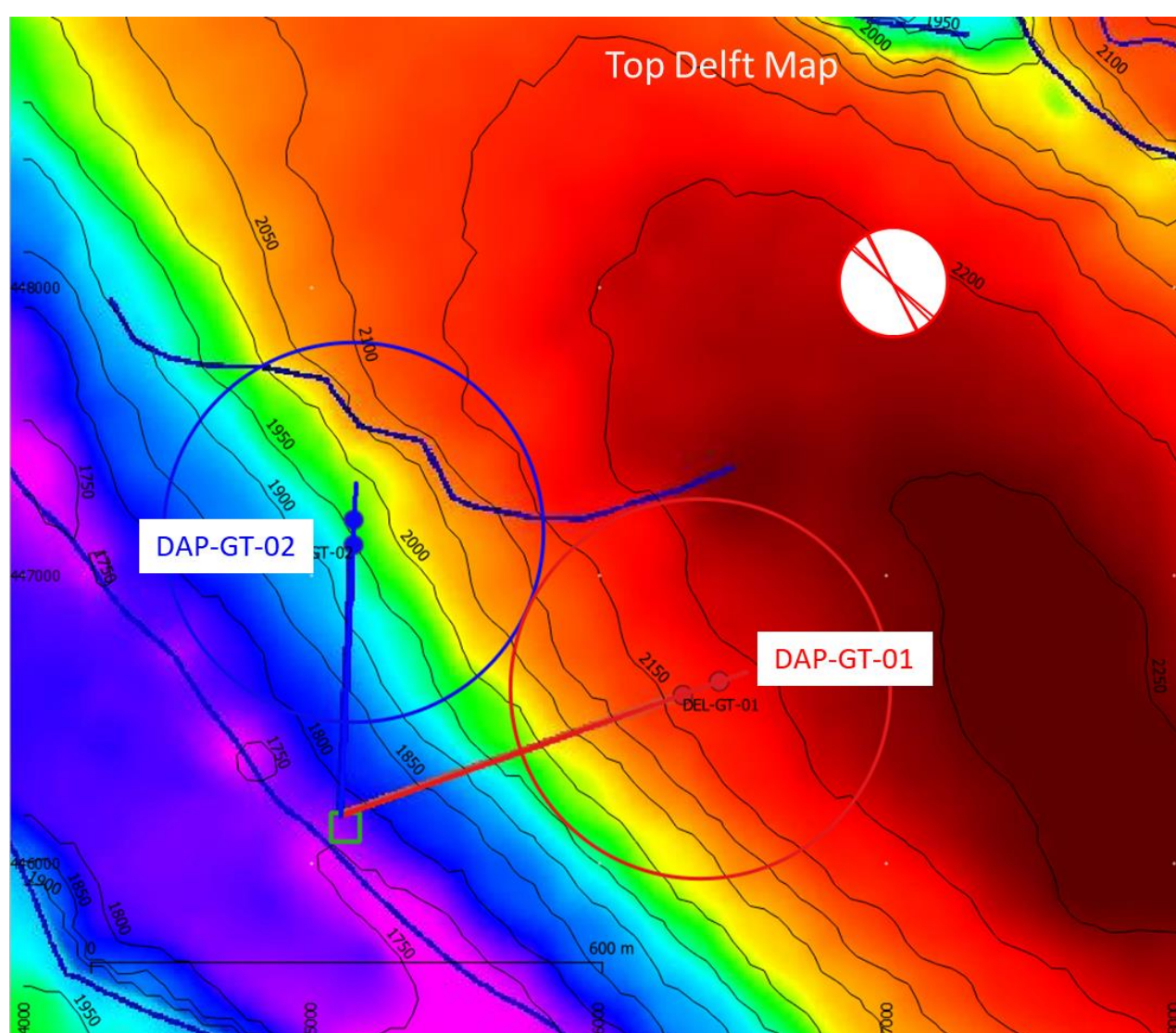


Figure 69: Witte cirkel met rode lijnen: regionaal gemeten oriëntaties van SHmax.

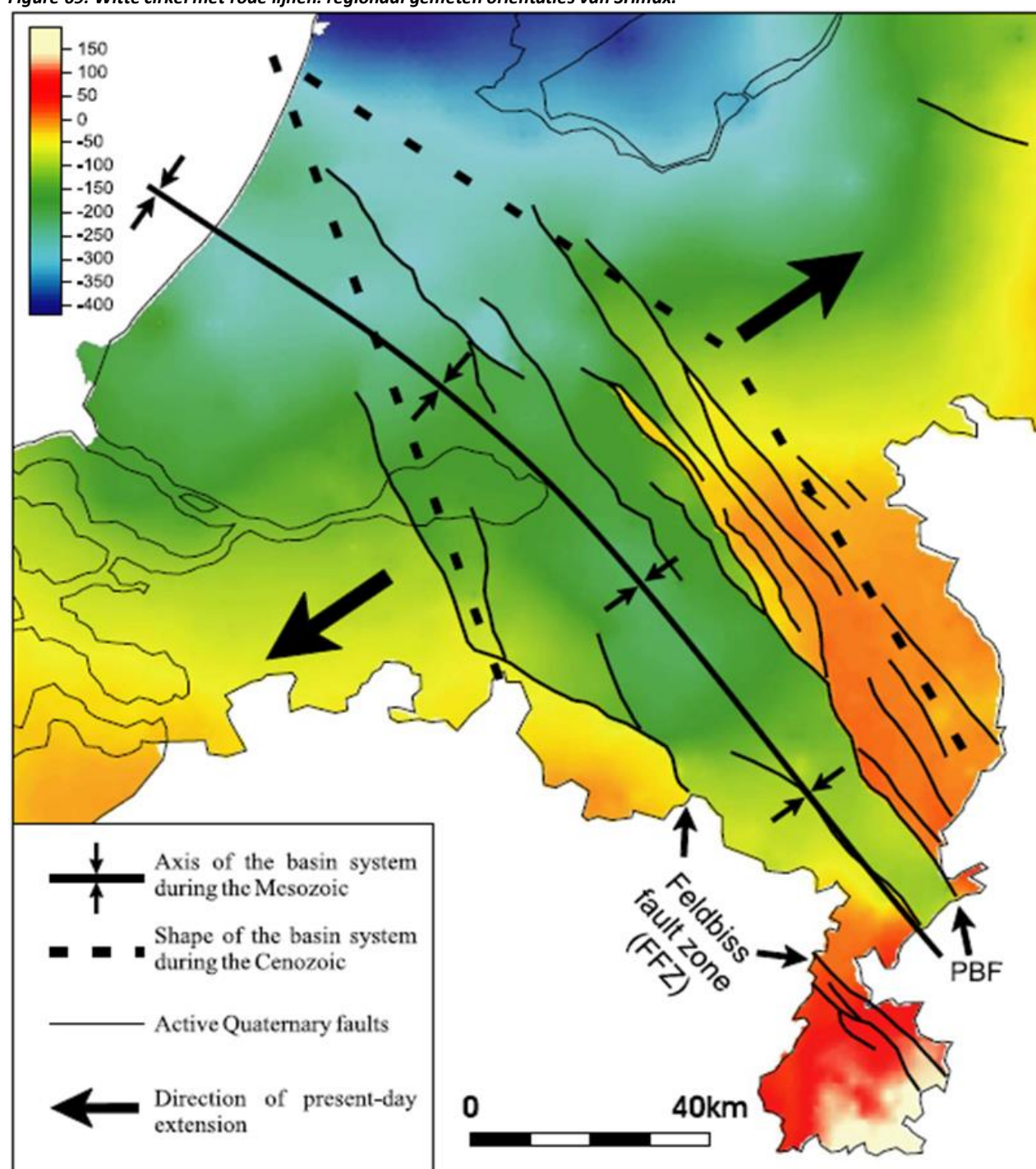


Fig. 5. Depth map of the base Quaternary horizon. Active Quaternary faults are indicated (PBF).

Figure 70: De richting van extensie tijdens het Neogeen (Worum et al, 2005). De kleurenschaal duidt de dikte van het Kwartair. Actieve Mio-Pliocene breuken zijn weergegeven in zwart.

4. Netto geïnjecteerd volume: Score 0

Het volledige geproduceerde watervolume wordt ook weer geïnjecteerd. Op basis hiervan wordt een **SCORE:0** gegeven

5. Drukcommunicatie tussen putten: Score 0

Productie en injectie vinden beiden plaats uit en in Delft Zandsteen. Op de 3D seismiek zijn er geen breuken geïnterpreteerd tussen de producer en de injector en wordt er drukcommunicatie verwacht tussen de injector en de producer. Daarmee wordt de **SCORE: 0**.

Puttesten zullen uiteindelijk deze drukcommunicatie moeten bevestigen.

6. Injectiedruk: Score 3

Het drukverschil op aquifer niveau tussen de put en het aquifer is berekend op ongeveer 36 bar voor een debiet van 400m³/u. De score die bij deze drukken hoort is **SCORE: 3**.

Puttesten zullen uiteindelijk deze injectiedruk op reservoirniveau moeten bevestigen.

7. Systeemdebiet: Score 10

Het P50 systeemdebiet voor GeoThermie Delft is 400m³/uur; dit hoge debiet worden haalbaar geacht met relatief lage verwachte drukverschillen (zie ook punt 6 hierboven). Desondanks wordt de **SCORE:10** (volgens Figure 62).

8. Afstand tot natuurlijke aardbevingen: Score 0

Er zijn in Zuid-Holland geen natuurlijke bevingen gerapporteerd (Figure 71).

9. Afstand tot geïnduceerde seismiteit: Score 0

Er zijn in Zuid-Holland geen geïnduceerde bevingen gerapporteerd (Figure 71).

De conclusie van de QuickScan is een score van 27 (Figure 72). Hieruit volgt dat de potentie van geïnduceerde seismiteit laag is.

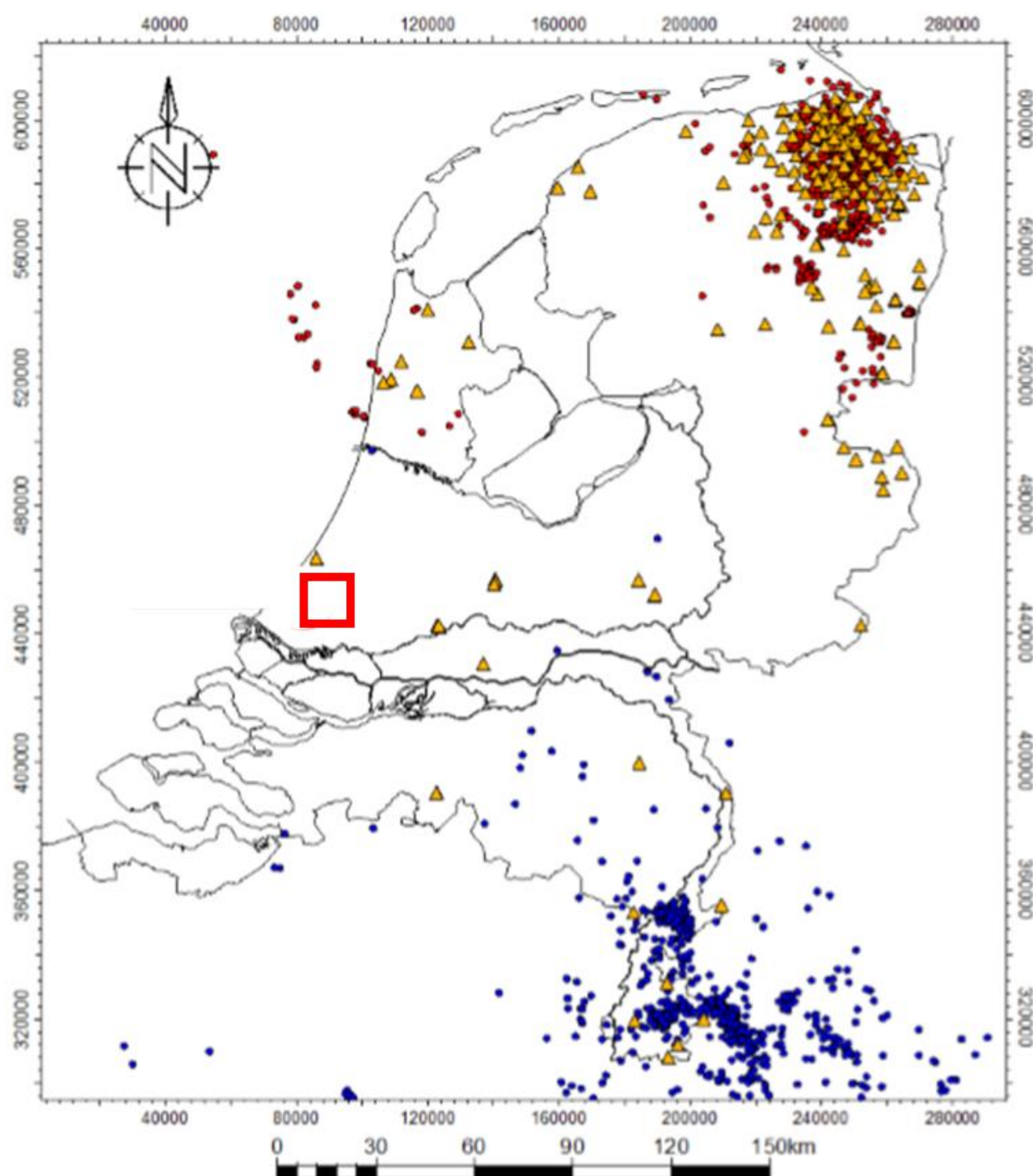


Figure 71: Kaart met epicentrum van seismiteit in Nederland (November 2018). Rode cirkels geïnduceerde seismiteit. Blauwe punten natuurlijke seismiteit en de meetstations in oranje. Rode vierkant geeft projectlocatie weer.

score	verbinding met kristallijnen basis	afstand [km] tot bestaande breuken	oriëntatie van de breuk in heersende stressveld	netto geïnjecteerd volume [x1.000 m ³]	drukcommunicatie tussen de putten	injectiedruk [bar]	systeemdebiet [m ³ /uur]	afstand [km] tot natuurlijke aardbevingen	afstand [km] tot geïnduceerde seismiciteit
10	ja	< 0,1	gunstig (voor bezwijken)	> 20	nee	> 70	>360	< 1	< 1
7	mogelijk	0,1-0,5	bezwijken mogelijk	5-20	niet waarschijnlijk	40-70	180-360	1-5	1-5
3	niet waarschijnlijk	0,5-1,5	bezwijken niet waarschijnlijk	0,1-5	waarschijnlijk	10-40	50-180	5-10	5-10
0	nee	> 1,5	bezwijken vrijwel onmogelijk	< 0,1	Ja	< 10	<50	> 10	> 10

Figure 72: Scoringsschema uit Figure 62, uitgewerkt voor GeoThermie Delft

Level 2: locatie-specifieke gevarenanalyse (Seismic Hazard Analysis, SHA)

In Level 2 wordt een uitgebreide en locatie-specifieke gevarenanalyse (Seismic Hazard Analysis, SHA) gedaan. De mogelijke gevolgen van de risico's worden inzichtelijk gemaakt. De uitkomst van een SHA is de waarschijnlijkheid dat geïnduceerde seismiciteit van een bepaalde magnitude gaat optreden. Deze verwachte seismiciteit wordt omgezet in een vibratie niveau aan maaiveld en zo wordt de bovengrondse impact bepaald. In deze stap wordt een lokaal seismisch meetnetwerk ontworpen en mitigerende maatregelen vastgelegd volgens een verkeerslichtmethode (Traffic Light System; TLS). Een belangrijk onderdeel van het TLS zijn de responstijden die horen bij het meetsysteem, het effectueren van de maatregelen en de bijbehorende communicatie met SodM en alle betrokken partijen.

Worden risico's na Level 2 acceptabel geacht, dan kan overgegaan worden op realisatie van het systeem met bijbehorende beheersmaatregelen. Geothermie wordt dan ontgonnen met een lokaal seismisch meetnetwerk (te installeren door de aanvrager met gebruikmaking van een professionele onafhankelijke partij) en TLS.

Level 3 locatie-specifieke risicoanalyse (Seismic Risk Analysis, SRA)

Zijn de risico's ondanks beheersmaatregelen niet acceptabel, dan is Level 3 nodig. Level 3 betreft een locatie specifieke SRA, waarin kwantificering van de veiligheidsrisico's nodig is. Indien het resultaat na de werkzaamheden van Level 3 nog steeds onacceptabel wordt geacht, dan zal het winnen van geothermie niet worden doorgezet.

Conclusies

Aangezien de uitkomst van de Level 1 SRA QuickScan is dat de potentie van geïnduceerde seismiciteit laag is, worden Level 2 en Level 3 vooralsnog niet uitgevoerd. Na het vergaren van lokale informatie tijdens de boring en uit de puttesten en na verdere dynamische en mechanische modellering zal bepaald worden of dat de SRA alsnog verder uitgebreid dient te worden.