# Seismic Hazard Analysis (Quick-Scan)
# Polanen

SHA

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1900011-C-01

# SHA Polanen

# 1900011-C-01

Version 1

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# Inhoudsopgave

# 1 Samenvatting

Energie Transitie Beheer B.V. ("**ETP**") heeft PanTerra Geoconsultants B.V. ("**PanTerra**") gevraagd een Level-1 (Quick-Scan of **QS**) Seismic Hazard Analysis (**SHA**) uit te voeren waarin de risico's op seismiciteit bij geothermische exploratie worden omschreven en gekwantificeerd. Dit wordt gedaan op basis van het protocol ontwikkeld door IF Technology B.V. en Q-con GmbH ("Defining the Framework for Seismic Hazard Assessment in Geothermal Projects 5 V0.1") en de leidraad opgesteld door SodM in 2016 ("Methodiek voor risicoanalyse omtrent geïnduceerde bevingen door gaswinning, tijdelijke leidraad voor adressering"). Dit rapport beschrijft de resultaten uitgerekend voor één doublet MON-GT, en volgt de bovengenoemde methodieken op basis van de huidige kennis. Het doublet staat gepland om geboord te worden in de opsporingsvergunning Monster 2 ("**Polanen**").

Het IF/Q-CON protocol beschrijft een aantal criteria die bepalend zijn voor seismisch risico. Deze parameters zijn voor Polanen beoordeeld en zijn een score toegewezen. In de scoringsmatrix, gepresenteerd in Table 2-1, staan de resultaten. De genormaliseerde score is 0.30 en wordt geassocieerd met een laag risico. Ook op basis van de leidraad van SodM kan worden geconcludeerd dat het risico voor Polanen laag is en geen locatie-specifieke SHA nodig is.

Geïnduceerde seismiciteit wordt veroorzaakt door een verandering in de lokale stress (druk) situatie. Deze stresssituatie wordt beïnvloed door poro-elastische en thermo-elastische effecten. De drukverandering gerelateerd aan de poro-elastische effecten treedt voornamelijk op nabij de productieput (drukafname) en de injectieput (druktoename), en neemt snel af naarmate de afstand tot de putten groter wordt. Na initiële productie treedt een equilibrium op omdat de geïnjecteerde en geproduceerde volumes gelijk zijn. Als tijdens deze initiële periode geen seismiciteit optreedt, is het geassocieerde risico zeer klein geworden. Voor het doublet MON-GT moeten de boringen nog plaatsvinden, maar binnen de gestelde productierichtlijnen van SodM, worden geen problemen verwacht. De effecten van de afkoeling van het reservoir, de thermo-elastische effecten zoals compactie, zijn niet meegenomen in de methodieken van IF/QCON en SodM en als zodanig niet onderzocht in deze studie.

Voor Polanen is het noodzakelijk massabalans (gelijke injectie en productie) te handhaven en om het doublet seismisch te monitoren gedurende productie. Hiervoor is nog geen infrastructuur aanwezig. Daarnaast is het van belang om de nieuwe putten zo ver mogelijk van de gekarteerde breuken te plannen en om na boring interferentietests uit te voeren. Hiermee kan worden bepaald of er mogelijk onvoorziene drukverschillen in het reservoir kunnen optreden.

# 2 Summary

Energie Transitie Beheer B.V. ("**ETP**") heeft PanTerra Geoconsultants B.V. ("**PanTerra**") to perform a Level-1 (Quick-Scan or **QS**) of the Seismic Hazard Analysis ("**SHA**") to assess and quantify the risks of seismicity during geothermal exploration. This has been done on the basis of the protocol set up by IF Technology B.V. and Q-CON GmbH ("Defining the Framework for Seismic Hazard Assessment in Geothermal Projects 5 V0.1") and the guideline provided by SodM in 2016 ("Methodiek voor risicoanalyse omtrent geïnduceerde bevingen door gaswinning, tijdelijke leidraad voor adressering"). This SHA report describes the results as they have been established for one doublet MON-GT on the basis of the current knowledge and adheres to the pre-mentioned guidelines. The doublet is planned to be drilled in the exploration license Monster 2 (referred to as "**Polanen**" in this report).

The IF/Q-CON framework describes a number of criteria which control seismic risk. For Polanen, each of these parameters have been evaluated. The results are presented in a scoring table where the scores for the individual criteria are normalised (Table 2-1). <u>The resulting weighted score is 0.30 which, according to the IF/QCON framework is associated with low risk. Similarly, the SodM criteria indicate low risk and do not warrant further investigation.</u>

Induced seismicity is triggered by a change in the in-situ stress state. The stress state of the geothermal reservoir is affected by poro-elastic and thermo-elastic effects. The pressure changes related to poro-elastic effects occur mainly near the production (decrease) and injection (increase) well and decreases rapidly away from the wells. After initial production an equilibrium will be established because there is a balance between the injected and produced volumes. If no seismicity has occurred during that initial stage, risk is greatly reduced. The MON-GT wells have not been drilled yet, but operation within the guidelines set by SodM is not expected to result in problems.

The risk of seismicity related to the thermoelastic effects in geothermal applications has not been taken into account in the IF/QCON and SodM methodologies and have therefore not been investigated in this report.

It is key for Polanen to maintain mass balance as to not build up or reduce reservoir pressure and to monitor the doublet for seismic activity during production. There is no monitoring infrastructure present yet. It also of importance to plan the new wells as far separated from mapped faults as possible and to perform well tests. Well tests can show whether intra-well communication is good (which avoids pressure differentials). It is recommended to carry out an interference test when the new wells are drilled.

Table 2-1 SHA scoring scheme for Polanen. The applicable scores are highlighted in red.

| Score | Basement connected | Inter-well pressure communication | Re-injection pressure [MPa] | Flow rate [$m^3$/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 $m^3$] |
|---|---|---|---|---|---|---|---|---|---|
| **10** | Yes | No | >7 | **>360** | <1 | <1 | <0.1 | Favourable | >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** |

# 3 Introduction

The Monster 2 exploration licence (Figure 3-1), owned by ETP, is situated in the municipality of Westland. The planned doublet, consisting of producer MON-GT-01 and injector MON-GT-02, is located within this exploration licence, northwest to several other geothermal doublets (HON-GT, PLD-GT). The target reservoir is the Delft Sandstone Member, which is the main target of other doublets in this region.

A geological study of the subsurface of Polanen was performed in 2018 (PanTerra, G1421), based on which an SDE+ subsidy application was performed and approved. This SHA is based on the geological data and interpretations documented in the geological report. The well trajectories and downhole targets have changed (as per April 2020 v5).

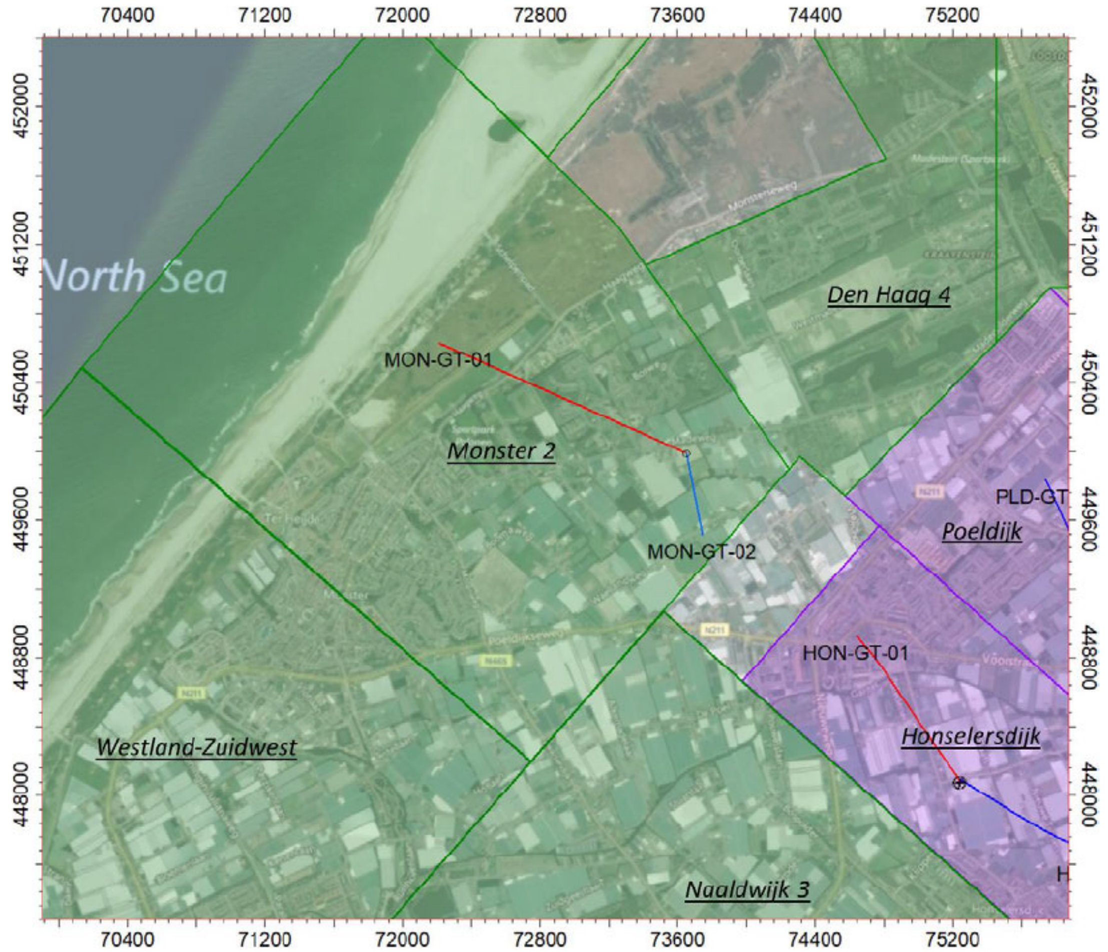


**Figure 3-1. Location of planned wells with reference to geothermal licences (purple: production licence, green: exploration licence) and nearby geothermal doublets (producers in red, injectors in blue).**

## 3.1 Guidelines for geothermal projects

A decision tree has been made by IF/Q-CON which is presented in Figure 3-2. The decision tree contains three levels where the highest level 3 is applicable to the highest risk category. Level 1 and 2 are here referred to as **SHA** or *Seismic Hazard Analysis,* of which Level-1 is considered the "Quick-Scan" SHA. Level 3 is referred to as **SRA** or *Seismic Risk Analysis*, which is a full location-specific risk analysis. This report will touch upon all the aspects described under Level 1 of the SHA. In case the conclusion of this report would warrant a progression to Laevel 2, further work is needed.

The first three considerations described in level 1 do not need special attention: no major fault zones are present within 100 m of the doublet (Figure 3-3 and Figure 4-6), the Roer Valley Graben (RVG) and the Groningen gas field are far away and no natural or induced seismicity has occurred in the target area (Section 4.1.5).

The QS scores (Table 2-1) are individually substantiated in section 4.1.

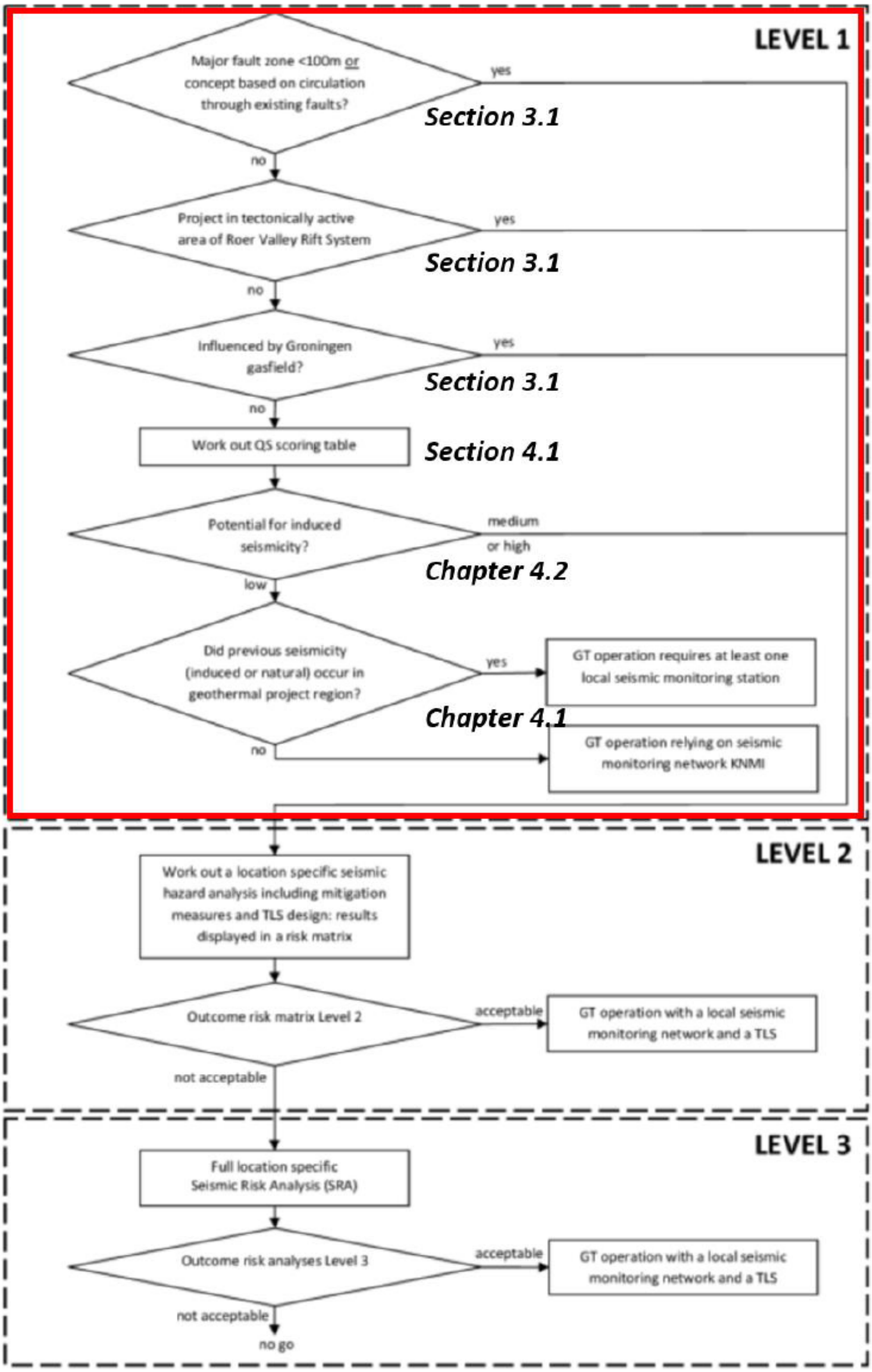


**Figure 3-2. Decision tree as presented in the report by IF/Q-CON. In this report only Level 1 (red outline) is covered. The sections in which each of the elements are discussed are added in the figure. TLS stands for Traffic Light System.**

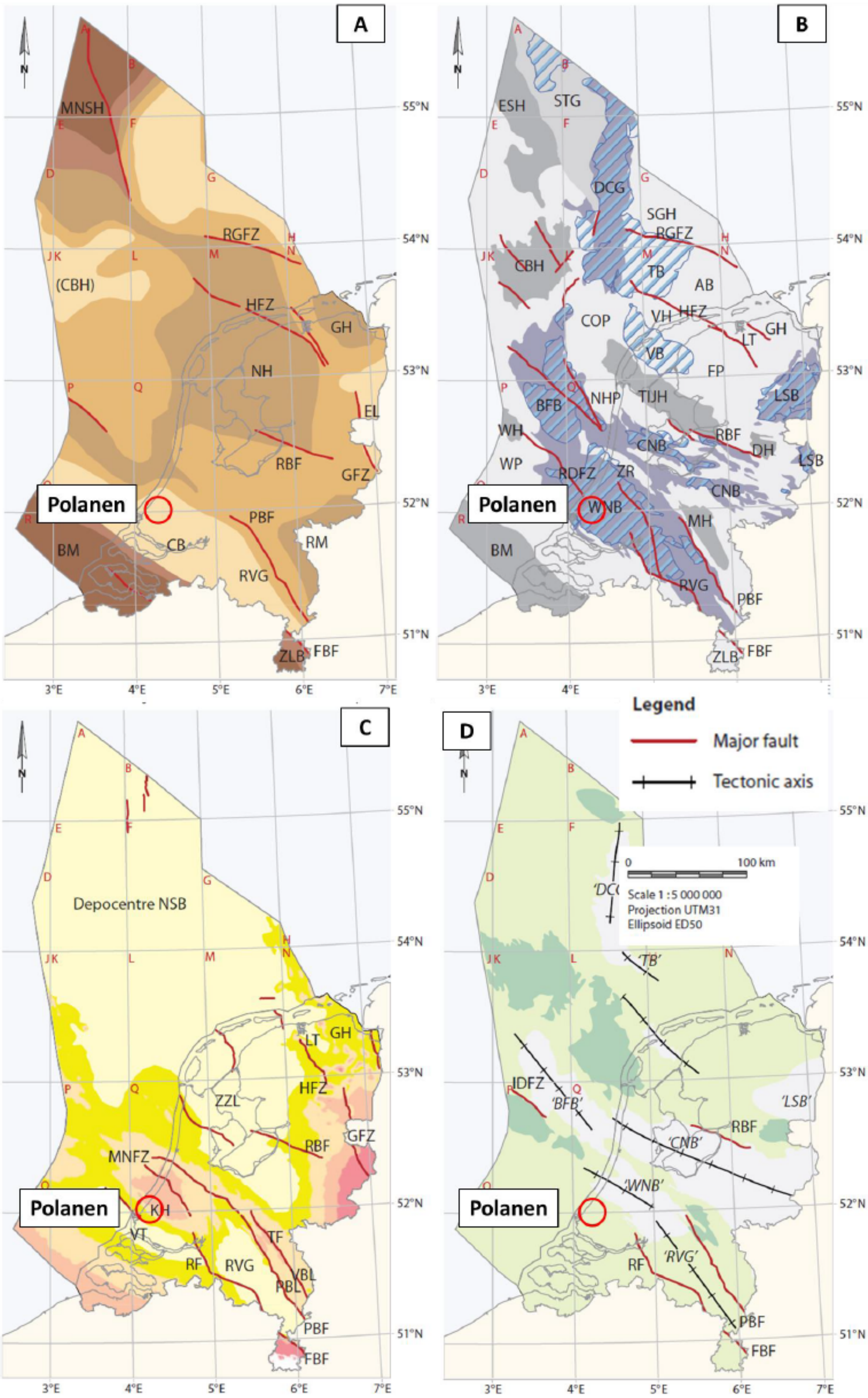


**Figure 3-3. Structural elements and major fault zones as present during the Variscan (A), Late Jurassic-Early Cretaceous (B), Late Cretaceous-Early Tertiary (C) and Cenozoic (D) (from Duin et al., 2006).**

## 3.2 Guidelines for gas production (SodM)

**The guidelines published by SodM in February 2016 address the risks associated with gas production. As such, the guidelines include the effects of (future) gas production on the reservoir. Since this is not applicable to Polanen, only step 1 of the SodM guidelines and decision tree (Figure 3-4) is discussed in this report.**

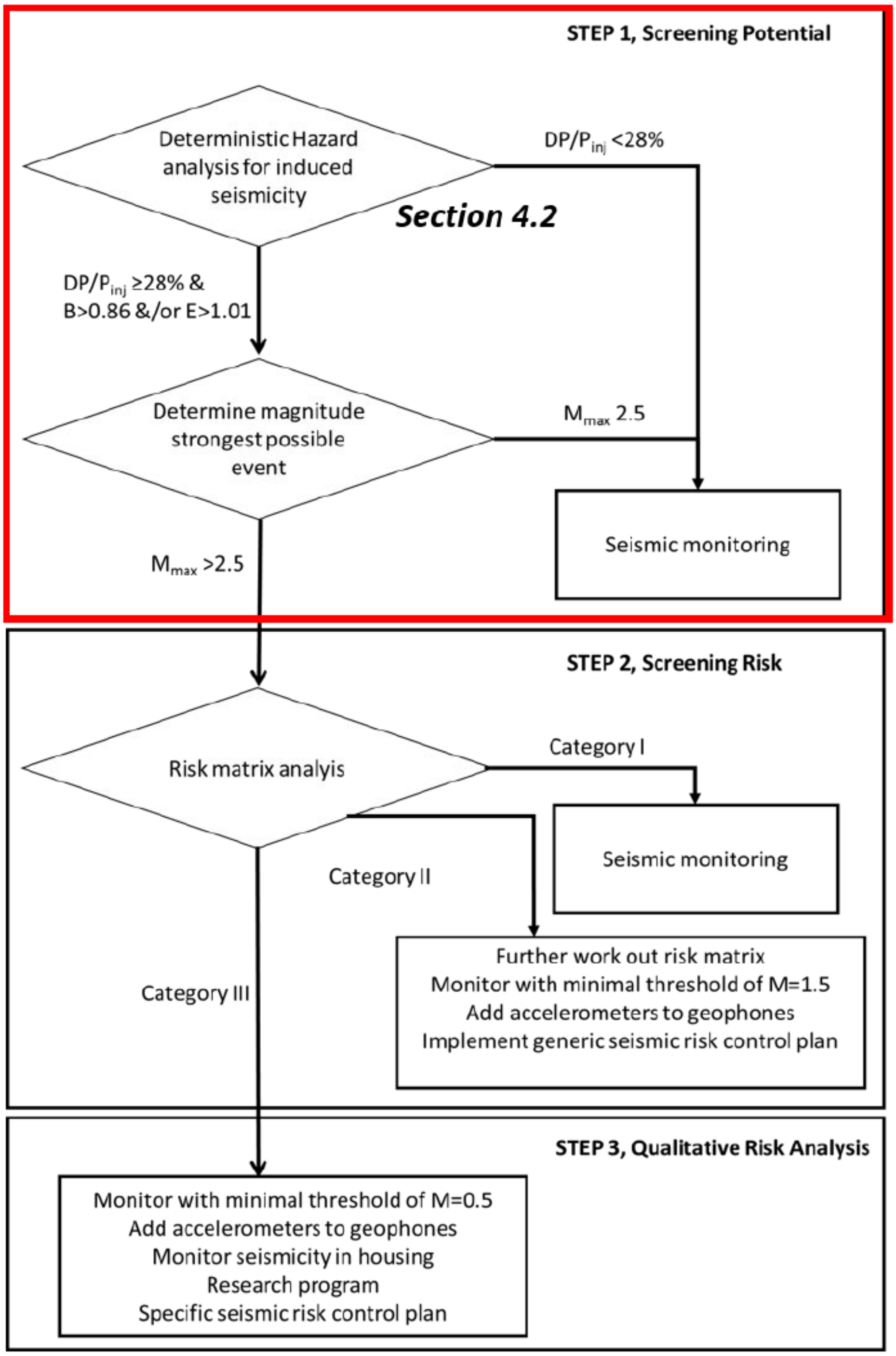


**Figure 3-4. Adapted decision tree based on the document published by SodM. In this report only Level 1 (red outline) is covered. The sections in which each of the elements are discussed are added in the figure. The definitions of the parameters are discussed in section 4.2.**

# 4 Results

## 4.1 SHA scoring scheme (IF/QCON)

### 4.1.1 Basement connection

Since the basement (crystalline crust) is indicated as being in a critical stress state by various authors, a hydraulic connection between the geothermal reservoir and the basement would be hazardous. As described in the framework from IF/Q-CON the largest magnitude seismic events in Europe are connected to geothermal activity in basement rock.

In the Netherlands until this date, no geothermal project has been drilled into basement rock. Also, the depth of the basement is poorly constrained. An estimate of the depth of the basement is derived from a map of the top of the pre-Silesian presented by Geluk et al. in 2007 (Figure 4-1). At Polanen, the basement is present at a depth of approximately 7 km, more than 4.5 km below the target reservoir. A hydraulic connection between the basement and target reservoir through fault(s) is not observed on the 3D seismic dataset (Figure 4-7). However, the presence of such fault(s) cannot be ruled out given the quality of the seismic data at deeper levels (e.g. Carboniferous). In case that deep basement fault(s) are present, the >4500 m separation between the reservoir and the basement and inactivity of the fault(s), makes pressure communication via a direct hydraulic connection unlikely. Polanen scores "0" on basement connection (Table 5-1).

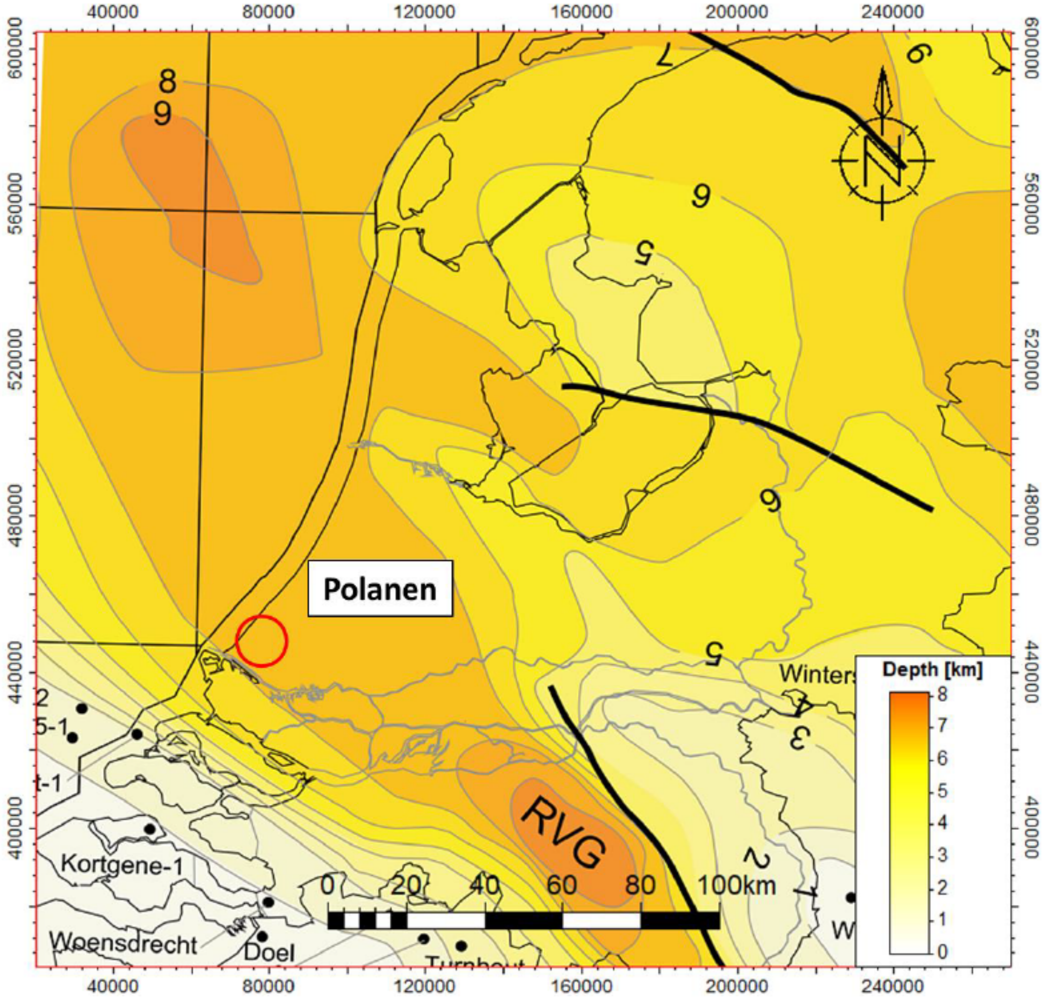


Figure 4-1. Depth map of top of the pre-Silesian in km (from Geluk et al., 2007).

#### 4.1.2 Inter-well pressure communication

MON-GT-01 and -02, target the Delft Sandstone Member and both will perforate the entire reservoir at approximately 2300 m depth. The wells are oriented parallel to the main fault direction, approximately 1800 m apart. No faults are observed between the two wells. Possible subseismic faults are unlikely to be sealing since the reservoir thickness is greater than the seismic resolution.

The target reservoir is permeable (550 mD) and is estimated to have a high net to gross ratio of 93%. All wells in the fault block have drilled the reservoir. Connectivity between reservoir sands in MON-GT-01 and MON-GT-02 is therefore expected to be excellent. All doublets in the region have demonstrated inter-well communication.

Pressure communication is vital for the planned doublet. In case that there is no pressure communication between the wells, the project would not be viable. According to the scoring guidelines, the inter-well pressure communication is scored as “yes” (0, see Table 5-1).

#### 4.1.3 Re-injection pressure

The expected injection pressure at Polanen is calculated with DoubletCalc. Based on an average flow rate of 456 $m^3$/hr (410 $m^3$/hr when including 10% downtime), the pressure difference at the injector is approximately 52 bar. This corresponds to an injection gradient of approximately .125 bar/m, which is below SodM protocol (SodM, 2013). Based on the calculated pressure difference at the injector, Polanen scores a 7 on the re-injection category (4-7 MPa, Table 5-1).

## Geotechnics (Input)

| Property | min | median | max |
|---|---|---|---|
| aquifer permeability (mD) | 330.0 | 550.0 | 1000.0 |
| aquifer net to gross (-) | 0.9 | 0.93 | 0.98 |
| aquifer gross thickness (m) | 60.0 | 70.0 | 90.0 |
| aquifer top at producer (m TVD) | 2055.0 | 2283.0 | 2511.0 |
| aquifer top at injector (m TVD) | 2065.0 | 2294.0 | 2523.0 |
| aquifer water salinity (ppm) | 120000.0 | 140000.0 | 160000.0 |

| Property | value |
|---|---|
| number of simulation runs (-) | 1000.0 |
| aquifer kh/kv ratio (-) | 4.0 |
| surface temperature (°C) | 10.0 |
| geothermal gradient (°C/m) | 0.0325 |
| [ 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) | 35.0 |
| distance wells at aquifer level (m) | 1750.0 |
| pump system efficiency (-) | 0.7 |
| production pump depth (m) | 800.0 |
| pump pressure difference (bar) | 89.0 |
| outer diameter producer (inch) | 12.41 |
| skin producer (-) | 0.0 |
| skin due to penetration angle p (-) | -0.88 |
| pipe segment sections p (m AH) | 800.0,2941.0 |
| pipe segment depth p (m TVD) | 800.0,2283.0 |
| pipe inner diameter p (inch) | 7.92,11.75 |
| pipe roughness p (milli-inch) | 0.4,2.0 |
| outer diameter injector (inch) | 8.68 |
| skin injector (-) | 0.0 |
| skin due to penetration angle i (-) | 0.0 |
| pipe segment sections i (m AH) | 2351.0 |
| pipe segment depth i (m TVD) | 2294.0 |
| pipe inner diameter i (inch) | 8.25 |
| pipe roughness i (milli-inch) | 2.0 |

## Geotechnics (Output)

| Monte Carlo cases (stochastic inputs) | P90 | P50 | P10 |
|---|---|---|---|
| aquifer KH net (Dm) | 28.23 | 37.23 | 54.39 |
| mass flow (kg/s) | 111.27 | 136.2 | 171.55 |
| pump volume flow (m³/h) | 373.0 | 456.2 | 575.6 |
| required pump power (kW) | 1317.2 | 1611.3 | 2032.9 |
| geothermal power (MW) | 19.03 | 24.1 | 30.95 |
| COP (kW/kW) | 13.8 | 15.0 | 16.1 |
| aquifer pressure at producer (bar) | 220.51 | 234.14 | 248.26 |
| aquifer pressure at injector (bar) | 221.92 | 235.53 | 248.76 |
| pressure difference at producer (bar) | 21.4 | 24.66 | 26.74 |
| pressure difference at injector (bar) | 45.1 | 51.99 | 56.33 |
| aquifer temperature at producer * (°C) | 81.3 | 85.39 | 89.48 |
| temperature at heat exchanger (°C) | 80.42 | 84.39 | 88.46 |

| base case (median value inputs) | value |
|---|---|
| aquifer KH net (Dm) | 35.81 |
| mass flow (kg/s) | 132.1 |
| pump volume flow (m³/h) | 442.6 |
| required pump power (kW) | 1563.1 |
| geothermal power (MW) | 23.38 |
| COP (kW/kW) | 15.0 |
| aquifer pressure at producer (bar) | 234.23 |
| aquifer pressure at injector (bar) | 235.33 |
| pressure difference at producer (bar) | 25.0 |
| pressure difference at injector (bar) | 52.66 |
| aquifer temperature at producer * (°C) | 85.33 |
| temperature at heat exchanger (°C) | 84.37 |
| pressure at heat exchanger (bar) | 51.88 |

* @ mid aquifer depth

**Figure 4-2. DoubletCalc calculations with expected flow rate indicate a pressure increase of 52 bar at the injector.**

### 4.1.4 Flow rate

The expected average flow rate of the doublet is 410 $m^3$/hr, based on 90% uptime. Actual flow rate is prognosed to be 456 $m^3$/hr (Figure 4-2). During the summer, the flow rate will be significantly less, during the winter possibly higher. According to the SHA guidelines, these flow rates result in the maximum score of 10. It should be noted that this score might be too high. The scoring guidelines are based on Figure 4-3 which reflects the possible trend between flow rate and seismicity of existing projects. This trend is based on projects that produce from basement rocks, whereas Polanen will produce from sediments. Most projects that produce from sediments have not encountered any seismicity and plot below the trend line. Two projects resulted in seismicity with magnitude >1, but below the 2.5 magnitude threshold set by SodM (Figure 3-4). Polanen scores a 10 on the flow rate category (>360 $m^3$/h, see Table 5-1).

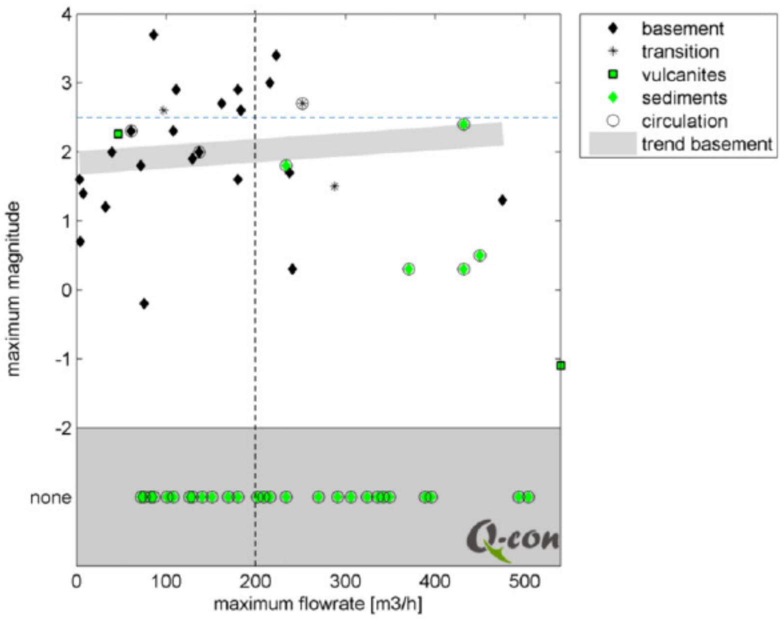


**Figure 4-3. Maximum magnitude of induced events as a function of the (re-)injection rate for geothermal projects. Rock type of the target formation is indicated according to the legend. Symbols in circles denote flow operations, open symbols denote fluid injection. Trend line was fitted to basement data points by IF/QCON (light grey). Data points with no seismicity were discarded for fitting trend line (from IF/QCON, 2016). The blue dashed line highlights the M 2.5 threshold from SodM.**

### 4.1.5 **Seismicity in the area**

Figure 4-4 shows the recorded natural and induced seismicity in The Netherlands. The nearest recorded seismicity (either induced or natural) is approximately 50 km away from Polanen.

Polanen is located near several oil and gas fields. According to the operator of the nearest fields, NAM, the chance of induced seismicity related to the Monster gas field is 19% (±5%), the chance of seismicity due to production of the De Lier field is negligible. According to TNO, there is a chance of 20 to 30% of induced seismicity Figure 4-5. The possible induced seismicity is related to depletion of the gas reservoir. There is no relation to the geothermal project in Polanen.

The closest seismic measuring station is installed in 2019 and situated about 15km away in Vlaardingen (not displayed in Figure 4-4), other stations are or are currently being installed in Spijkenisse, Barendrecht and Wassenaar, situated up to 30 km away. Prior to 2019, the approximate detection limit was about 1.5-2.0 in magnitude on the Richter scale (Dost et al., 2012). The stations installed in 2019, together with two more planned stations in 2020 (Zoetermeer and Monster) should improve the detection limit to < 1.0 for the Westland area.

Based on the IF/QCON scoring scheme, Polanen scores a 0 on seismicity (> 10 km distance to induced and natural seismicity, Table 5-1).

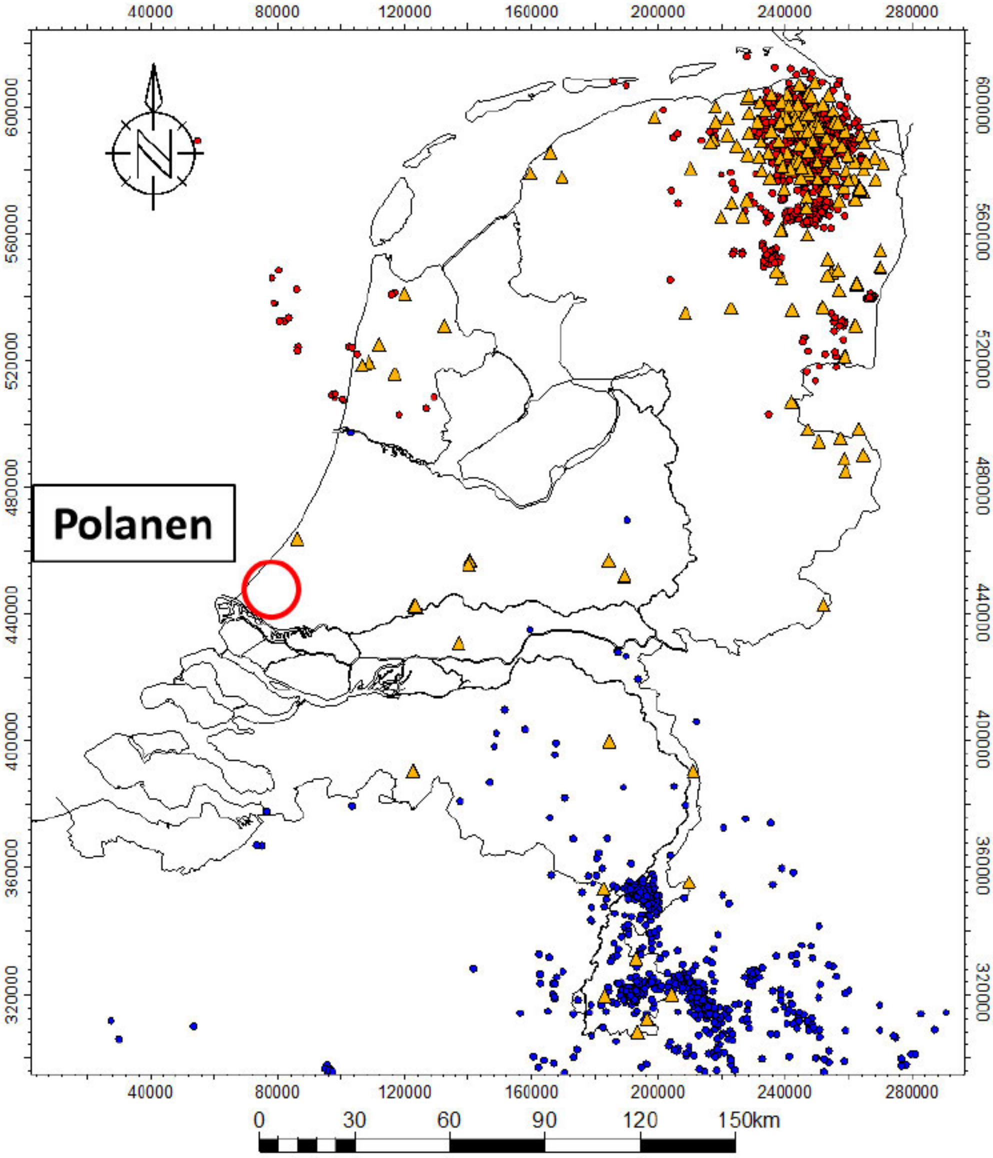


**Figure 4-4. Map showing the epicentres of the seismicity in The Netherlands per December 2019 (red circles, induced seismicity and blue dots natural seismicity) and the measuring stations (orange). No induced or natural seismicity has been recorded in the proximity of Polanen.**

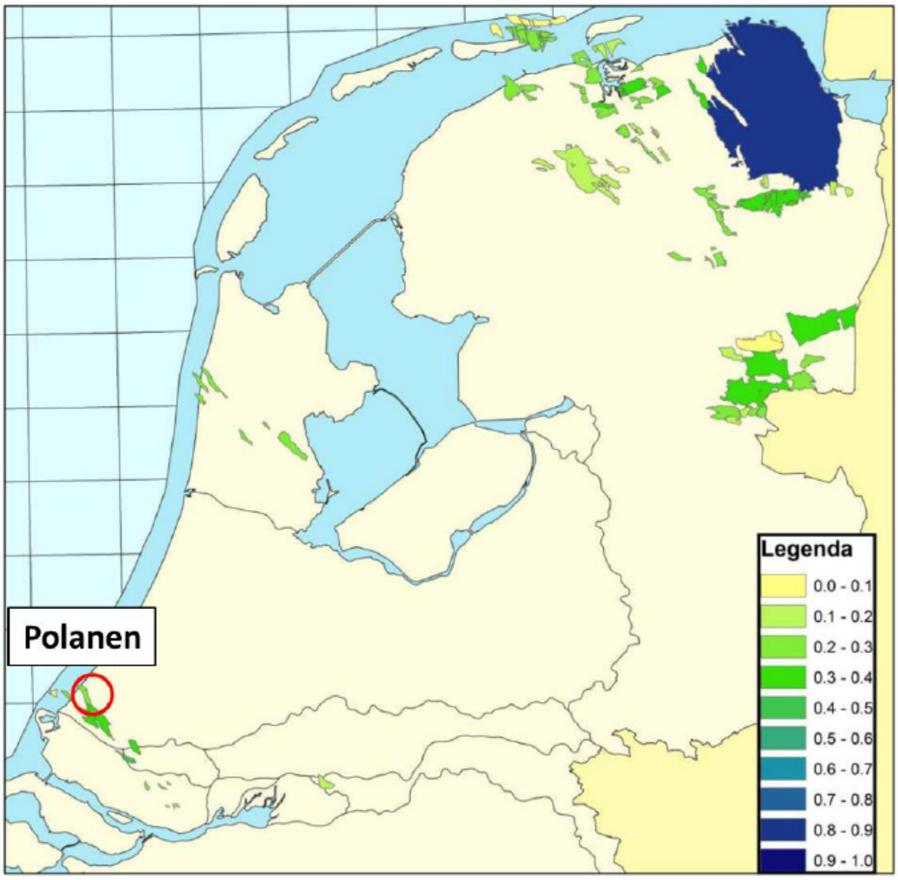


**Figure 4-5. Probability of induced seismicity related to gas fields (TNO, 2016).**

### 4.1.6 Regional fault properties

Polanen is covered by 3D seismic data. Seismic interpretation was performed on time cube L3NAM1990c (documented in SDE+ geological report G1421, PanTerra, 2018). The quality of the seismic data is average. The top reservoir map with mapped faults is displayed in Figure 4-6, Figure 4-7 and Figure 4-8 show seismic cross section along the wells. At reservoir level injector MON-GT-02 is located approximately 700 to 800m away from faults (Figure 4-6 and Figure 4-8). The closest fault to producer MON-GT-01 is a N-S oriented fault west of the well. The distance between fault and well at reservoir level is approximately 400. Due to the average quality of the seismic data there is some uncertainty on the exact location of the fault. Minimal distance is approximately 200 m. Based on Doubletcalc2D modelling, the cold water from of the injector does not reach any of the faults (Figure 4-9).

The scoring is based on the distance between MON-GT-01 and the N-S fault west of the well, which is approximately 400m, at least 200m. All other faults are >500 m away from the planned wells. The resulting score is a 7 (distance between 0.1 and 0.5 km, see Table 5-1).

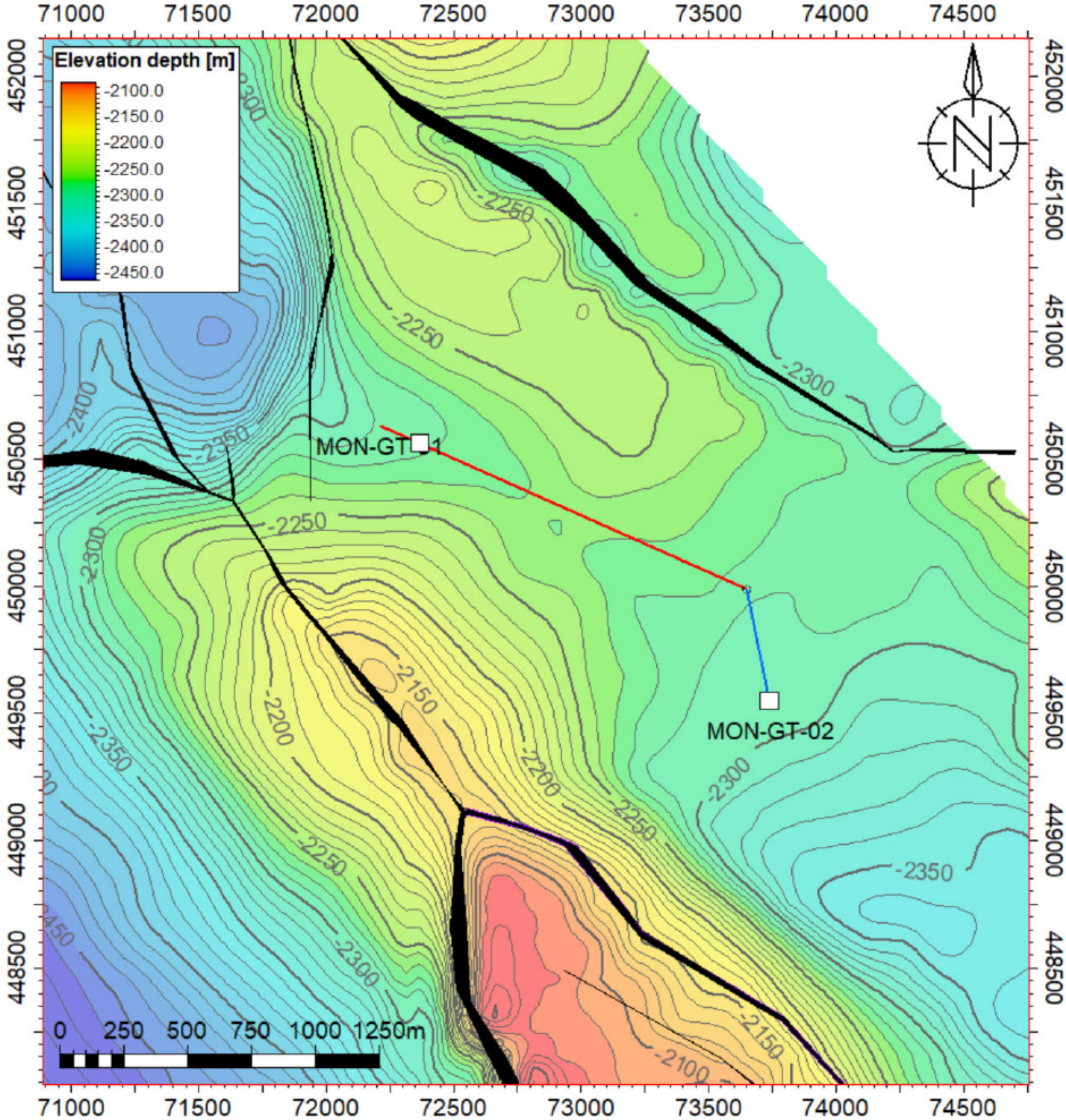


**Figure 4-6. Top reservoir depth map of the target area, showing the planned wells. Penetration points are indicated by white squares, faults in black.**

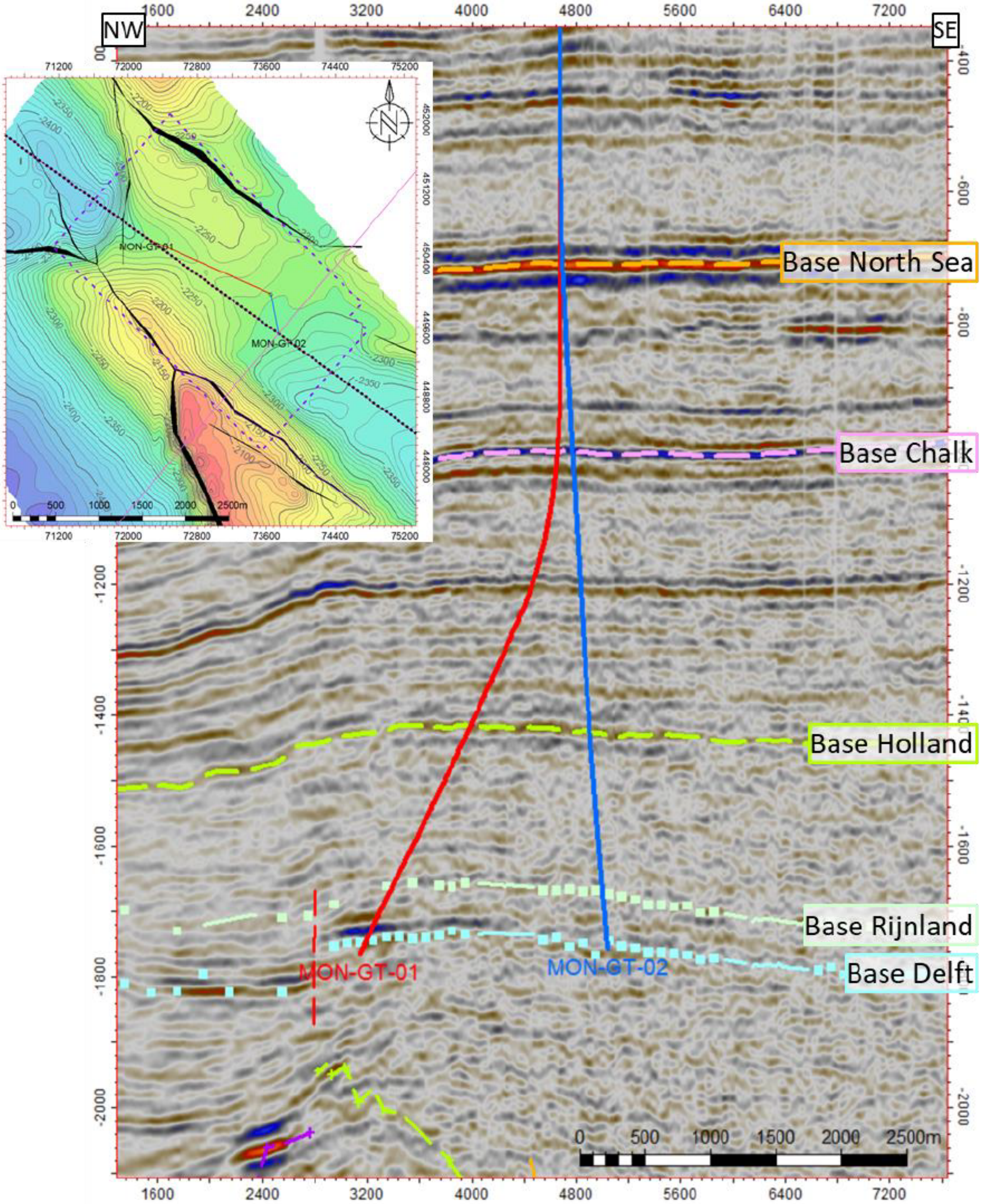


**Figure 4-7. Projection of the production and injection well on a seismic cross section. The horizontal axis is in meters, the vertical axis is in milliseconds two-way travel time. The location of the crossline is indicated by the black dashed line on the map.**

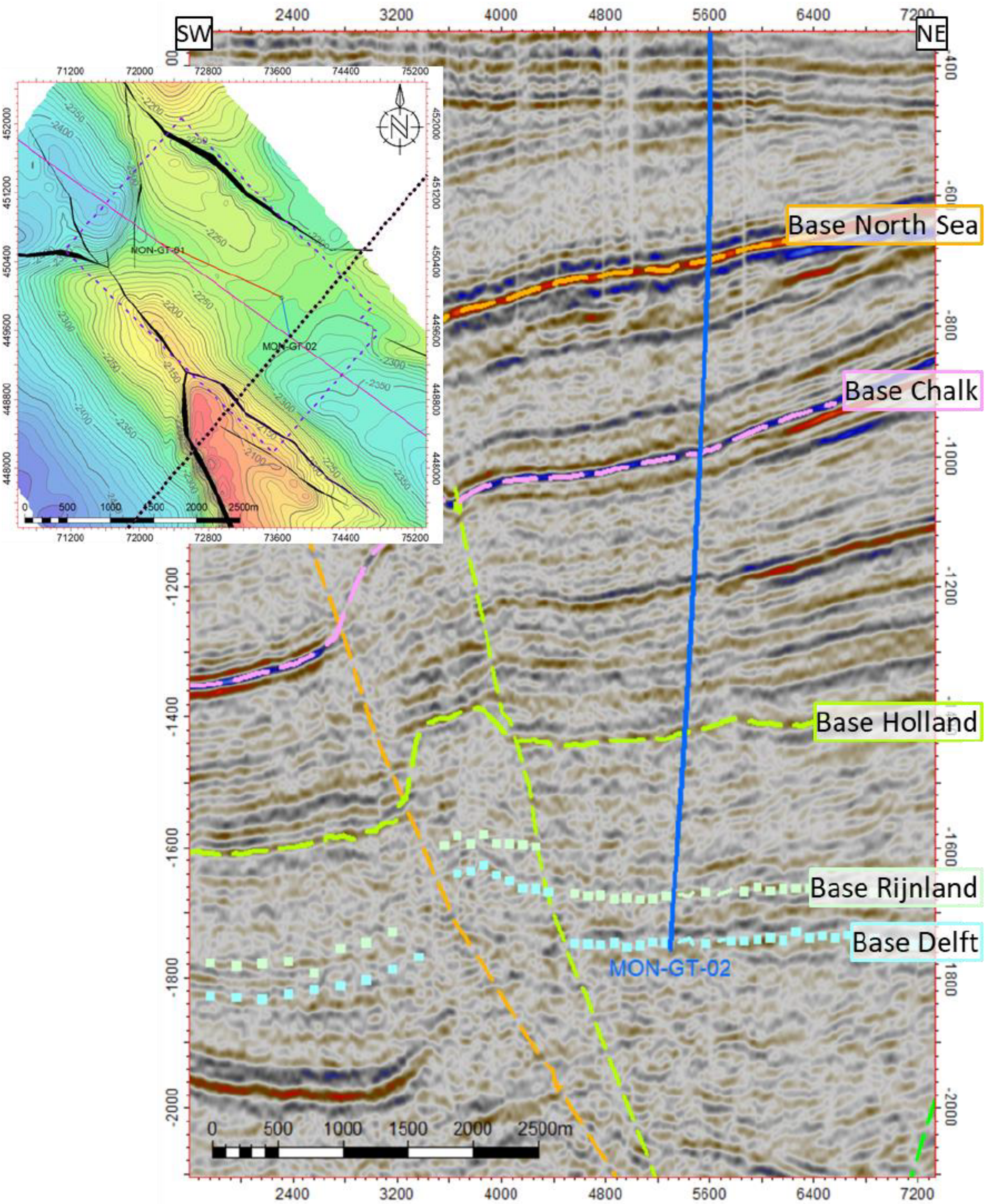


**Figure 4-8. Projection of the injection well on a seismic cross section. The horizontal axis is in meters, the vertical axis is in milliseconds two-way travel time. The location of the crossline is indicated by the black dashed line on the map.**

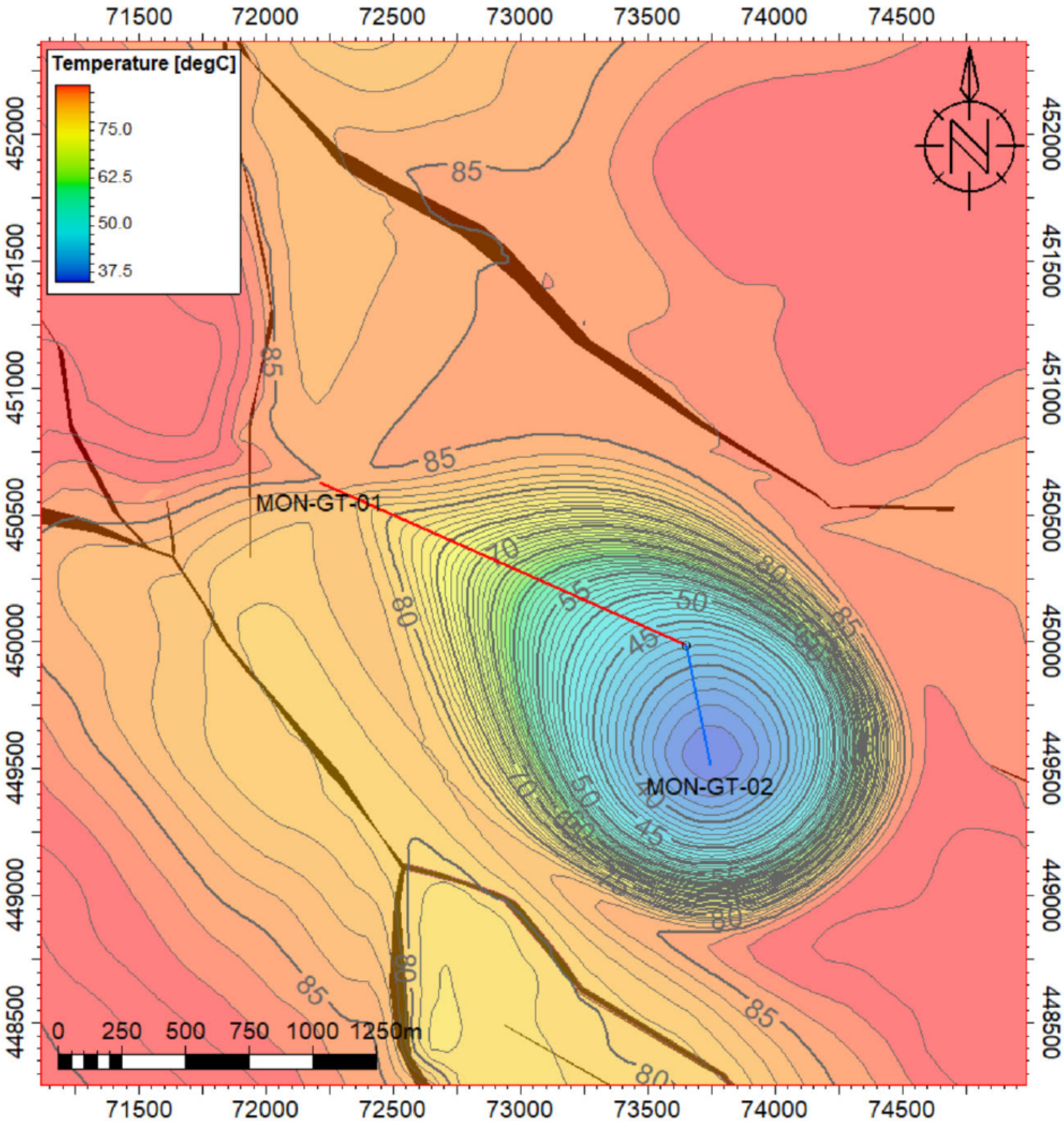


**Figure 4-9: Reservoir temperature after 30 years of production, based on Doubletcalc2D modelling. Faults are indicated in black..**

### 4.1.7 Current stress field

The map in Figure 4-10 shows the location of Polanen with respect to in-situ stress data from the World Stress Map and Dutch Stress Map. These measurements represent the orientation of the maximum horizontal stress, $S_H$, interpreted from well data in several geological formations. Most in-situ stress data from the Schieland Group indicate an $S_H$ of approximately 335°. It should be noted that there is a slight discrepancy between the data from the world stress map and the Dutch stress map. An accurate assessment of the local stress field could be analysed from the new wells by study of e.g. borehole breakouts, drilling induced tensile fractures or well tests.

The dominant orientation of faults in the region is 310° (Figure 4-6), which in combination with the current stress field makes shearing possible (score of 7). The nearest fault (N-S fault west of MON-GT-01, see Section 4.1.6) has a different orientation. It is almost orthogonal to the orientation of $S_H$, making shearing unlikely. As this fault is closest to the doublet and controls the scoring of the category "Regional fault properties" (Section 4.1.6), the scoring on this category is based on the same fault. The cold water front will not reach the 310° faults. Polanen scores a 3 (Shearing unlikely, see Table 5-1) on the category 'stress field versus fault orientation'.

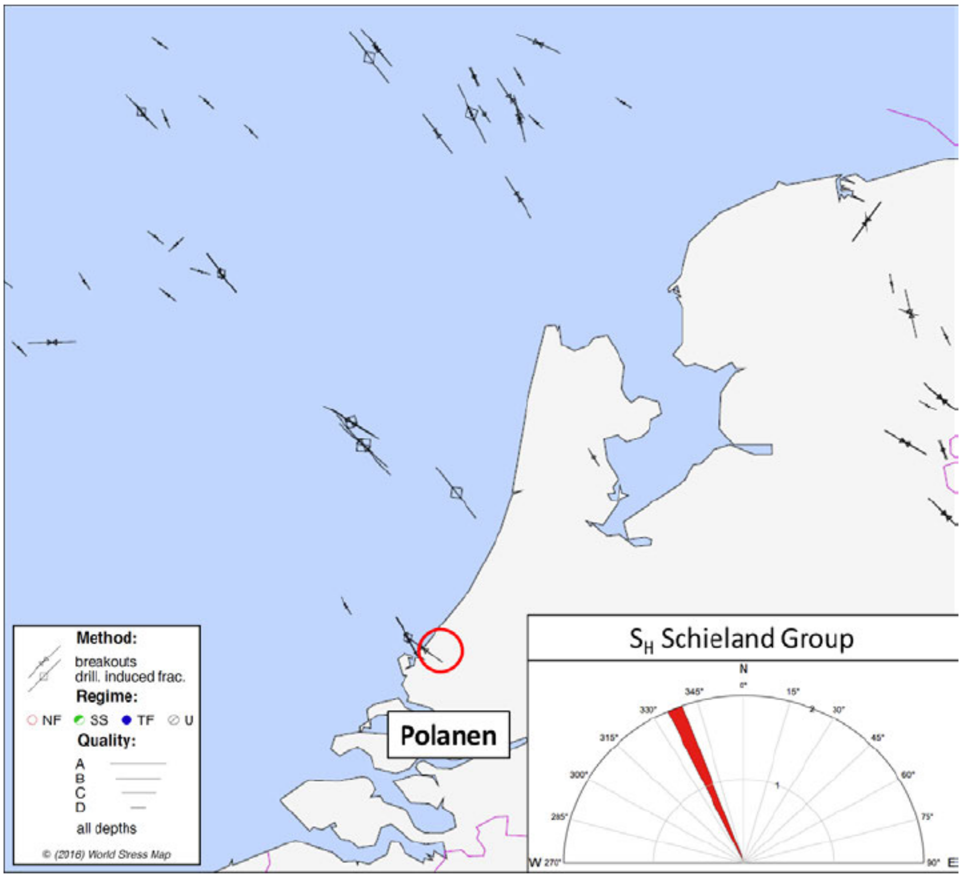


**Figure 4-10. Stress map of the south-western Netherlands for all units Map data is from the World Stress Map (Figure adapted from Heidbach et al., 2016), rose diagram of is from the Dutch Stress Map (Mechelse, 2017), showing slightly different stress directions for the Schieland Group as in the World Stress Map for the area around Polanen.**

#### 4.1.8 Net injected volume

Since the Naaldwijk doublets are based on mass-balanced fluid flow, the net injected volume is zero. Other doublets in the Netherlands have demonstrated good pressure communication between producer and injector well. The volumes related to degassing, and the addition of inhibitor are negligible. Therefore, the net injected volume criteria is given a score of 0 (<100 m$^3$, see Table 5-1).

## 4.2 Deterministic hazard analysis for induced seismicity (SodM)

The SodM guidelines for risk analysis of induced seismicity have been written specifically for gas exploration and is focussed on depletion and compaction. Therefore, the application for geothermal projects is limited. However, the cooling of the reservoir due to geothermal activity also results in compaction and could give scenario similar to depletion (Brouwer et al., 2005; Fokker & van Wees, 2014)

The SodM guidelines are partially based on the probability class system made by TNO (TNO, 2012) (see Table 4-1). In this table the parameters mentioned are:

- DP/Pini: The ratio of the pressure difference (DP) and initial pressure (Pini) in the reservoir at a given moment in time;
- E: The ratio between the Young's moduli of the overburden and the reservoir rock;
- B: A measure of the reservoir fault intensity.

B is defined as follows:

$$B = \frac{fault\ surface\ area^{3/2}}{gross\ rock\ volume} = \frac{l_b{}^{3/2}\, h^{1/2}}{A}$$

Where h is the maximal thickness of the gas column, $l_b$ is the total length of the intra-reservoir faults and bounding faults and A is the surface area of the accumulation.

Table 4-1. probability class system made by (TNO, 2012), part of the SodM guidelines.

| Seismicity has already ocurred | |
|---|---|
| $DP/P_{ini} \geq 28\%$ | B > 0,86 en E ≥ 1,34: $P_h$ = 0.42 ± 0.08 |
| | B > 0,86 en 1,01 ≤ E ≤ 1,33: $P_l$ = 0.19 ± 0.05 |
| | B < 0,86 en/of E < 1,01 Risk Negligible |
| $DP/P_{ini} < 28\%$ | Risk Negligible |

The reservoir pressure difference which occurs during geothermal production at Naaldwijk is expected to be small. This is mainly due to the fact that the produced and injected volumes are equivalent, inter-well communication is expected to be excellent (Section 4.1.2). The expected pressure difference is in the order of 10 bar, initial reservoir pressure is approximately 235 bar. Resulting DP/Pini is approximately 4%, significantly lower than the 28% threshold documented in the SodM guidelines (Table 4-1). Therefore, based on the SodM guidelines, the seismicity risk is negligible.

# 5 Conclusions

This Seismic Hazard Analysis is primarily focussed on the IF/QCON framework for geothermal projects and to a lesser extend the SodM guidelines for gas exploration. Based on these, the seismicity risk associated to the Polanen geothermal project is low (see Figure 5-1). The weighted score for the IF/QCON quickscan is 0.30 which is on the low end of the classification (see Figure 5-2). The SodM criteria do not warrant further investigation since the deterministic hazard analysis gives a negligible risk (see Figure 5-3).

It is key for Polanen to maintain mass balance as to not build up or reduce reservoir pressure significantly. In case well trajectories are changed, the distance to faults should be an important parameter to consider. It is recommended to retain a minimum distance of 100 m, preferable 200 m. This is most critical for the injector.

It is recommended to carry out an interference test when the new wells are drilled. An interference test tests the intra-well communication, which is critical for the risk of seismicity (and performance of the doublet). Based on the drilling and well test results of the new doublet, the SHA scoring scheme and weighted SHA score should be adjusted accordingly.

Despite the low seismicity potential, it is recommended to monitor the wells during the entire lifespan of the doublet.

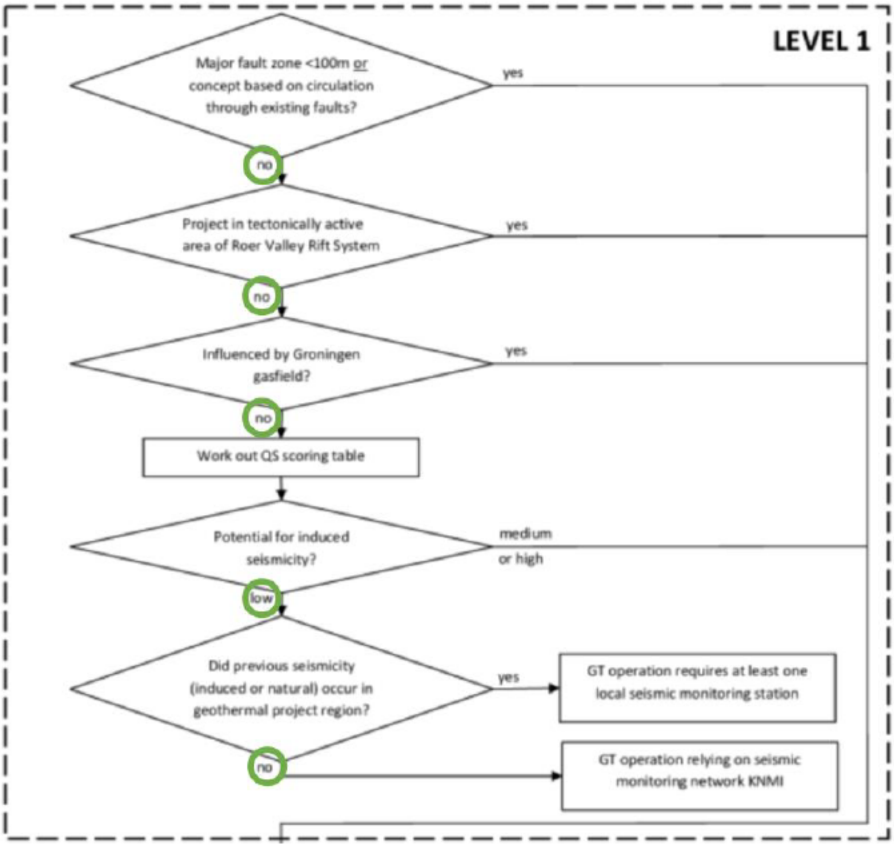


Figure 5-1. Level 1 SHA assessment for Polanen based on the IF/QCON guidelines.

Table 5-1 SHA scoring scheme for the Polanen doublet. The applicable scores are highlighted in red.

| Score | Basement connected | Inter-well pressure communication | Re-injection pressure [MPa] | Flow 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 | Favourable | >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** |

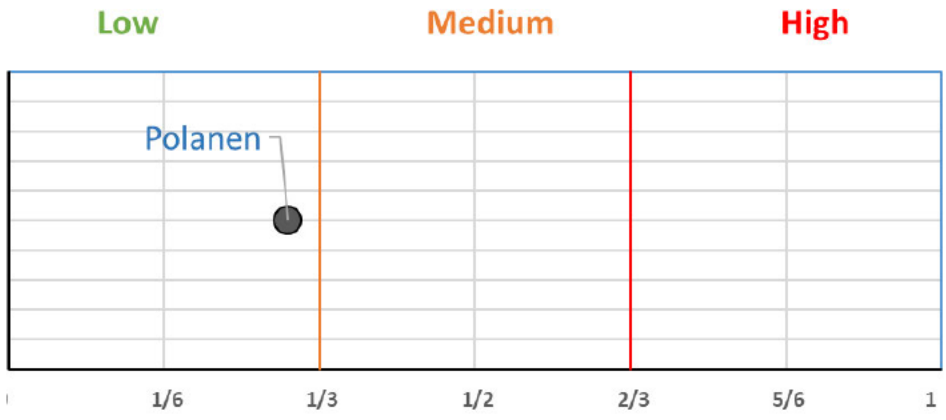


Figure 5-2. Result of the SHA quickscan based on the IF/QCON guidelines.

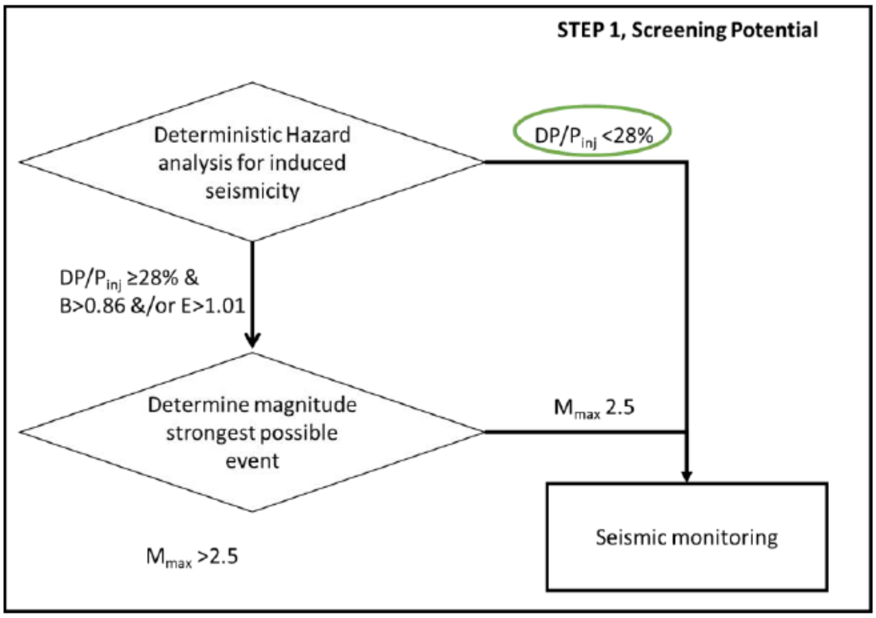


Figure 5-3. Step 1 SHA assessment for Polanen based on the SodM framework.

# 6 References

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