Bijlage 2 - Quickscan for potential of inducing seismicity
Nederlandse samenvatting

HET POTENTIEEL VOOR HET OPWEKKEN VAN SEISMICITEIT

QUICK SCAN RESULTATEN
De score van het geothermie project van Bernhard in de Quick Scan is de categorie met een laag potentieel voor het opwekken van seismiciteit. Daarom zijn er geen aanvullende stappen nodig voor het kwantificeren van het risico op het opwekken van seismiciteit.

PUT TRAJECT RESULTATEN
De projectie van de voorgestelde puttrajecten op de dichtstbijzijnde seismische lijnen vertoont geen verstoringen / ongelijkheden die samenvallen met de puttrajecten. Daarom worden er geen breuken verwacht langs de boortrajecten. Er moet rekening mee worden gehouden dat we een beperkt aantal 2D-seismische lijnen hebben. Daarom kan de mogelijke aanwezigheid van breuken langs het boortraject niet worden uitgesloten. We zien echter geen indicatie van breuken langs de puttrajecten op de hierboven getoonde seismische lijnen.

Quickscan for Potential of Inducing Seismicity Bernhard Rozen Luttelgeest

IF Technology **Creating energy**

Datum 14 februari 2020
Referentie 20200214/63341/NB
Betreft Potential for inducing seismicity
Behandeld door [redacted]
Gecontroleerd door [redacted]
Versienummer 2.0

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INHOUDSOPGAVE

1 Introduction

Bram Bernhard has requested IF Technology to determine the potential for inducing seismicity for a geothermal system consisting of a triplet with one producer and two injectors. For the determination the quickscan method described in "Defining the framework for a seismic hazard assessment in geothermal projects" is used (Qcon en IF Technology 2016). This is the next step into the realization of the geothermal system.

In April 2012 a Masterplan Geothermal energy has been written for the Luttelgeest area (Panterra 2012). In 2015 a report was written by IF Technology for the SDE+ application for Bram Bernhard (IF Technology 2015). The SDE+ was granted in the spring of 2016. Also a report was written by IF Technology for a SDE+ application for Hoogweg Paprikakwekerijen (IF Technology 2017a). The SDE+ was granted in the spring of 2017. After the SDE+ was granted, additional questions by SodM about the possibility and consequences of compartmentalization have been asked. These questions were answered in a memo "Breukanalyse Hoogweg Luttelgeest" (IF Technology 2017b). Summer 2018 the wells at Hoogweg have been drilled and tested. Based on the well test results is it concluded that there is a good pressure communication between the wells at Hoogweg. It is expected that the geology at the location of Hoogweg and at the location of Bernhard is comparable (locations are 1.5 km apart), so that no risk on compartmentalisation is expected at the chosen well locations for Bernhard.

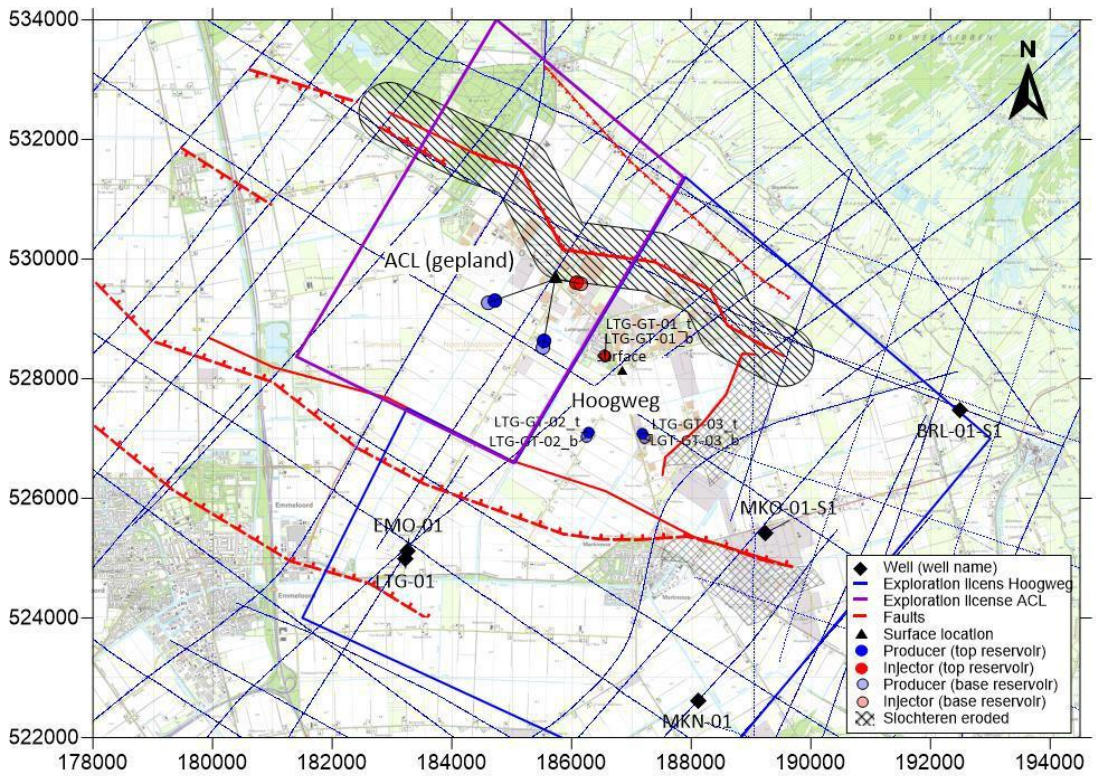


Figure 1.1 | The location of the proposed geothermal system for greenhouse owner Bram Bernhard (within the purple area). The surface location (black triangle) and sub-surface locations at top reservoir are indicated (blue dots injectors, red dot producer). In red the faults, in blue the seismic lines.

The proposed geothermal system for Bram Bernhard is located within the exploration license of Luttelgeest 2 (see Figure 1.2). The geothermal system targets the Slochteren Formation as the reservoir formation. The geothermal system consists of one triplet (one producer and two injectors), see Figure 1.1.

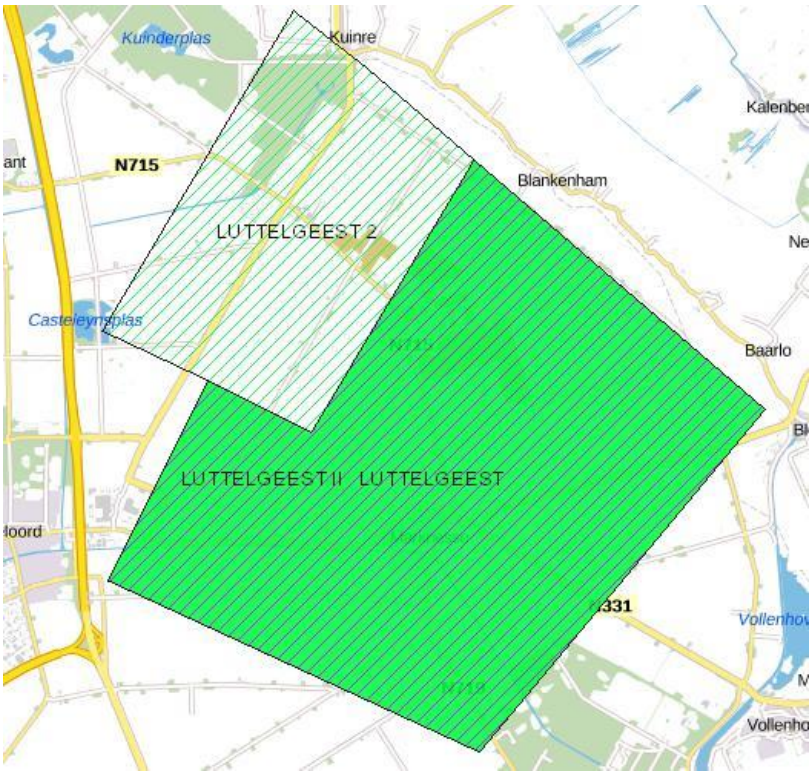


Figure 1.2 | Applied exploration licence Bram Bernhard: Luttelgeest 2.

The current report consists of a quickscan of the potential for inducing seismicity for the triplet system. The potential for inducing seismicity is assessed for both the reservoir part of the triplet configuration and for the drilling of the well trajectories. The available seismic lines have been interpreted structurally for this quick scan.

2 Quickscan

2.1 METHODOLOGY

The methodology used in the quickscan for the potential for inducing seismicity follows the guidelines as specified in the technical report "Defining the Framework for seismic hazard Assessment in geothermal Projects" as published by Qcon and IF Technology in 2016 (Qcon en IF Technology 2016). The decision tree for the three-level hazard and risk assessment procedure is shown in Figure 2.1.

Based on the decision tree a quickscan approach can be followed, because the answer to the first three questions is no:

- No major fault zones are present within 100 meters of the project location.
- The project location is not situated in the tectonically active Roer Valley rift system.
- The project location is not influenced by the Groningen gas field.

Therefore, the next step is to work out the quickscan scoring table. This is done in the current report.

The first step is a quickscan for induced seismicity potential. In the quickscan the potential for inducing seismicity is evaluated, by assigning scores for the project using several key parameters (Figure 2.2).

The scores of the different parameters are summed up, divided by the maximum possible score and subsequently compared to the categories in Figure 2.3. This result gives the potential for inducing seismicity category of the geothermal project and dictates which steps are needed next.

Figure 2.1 | Decision tree for the three-level hazard and risk assessment procedure.

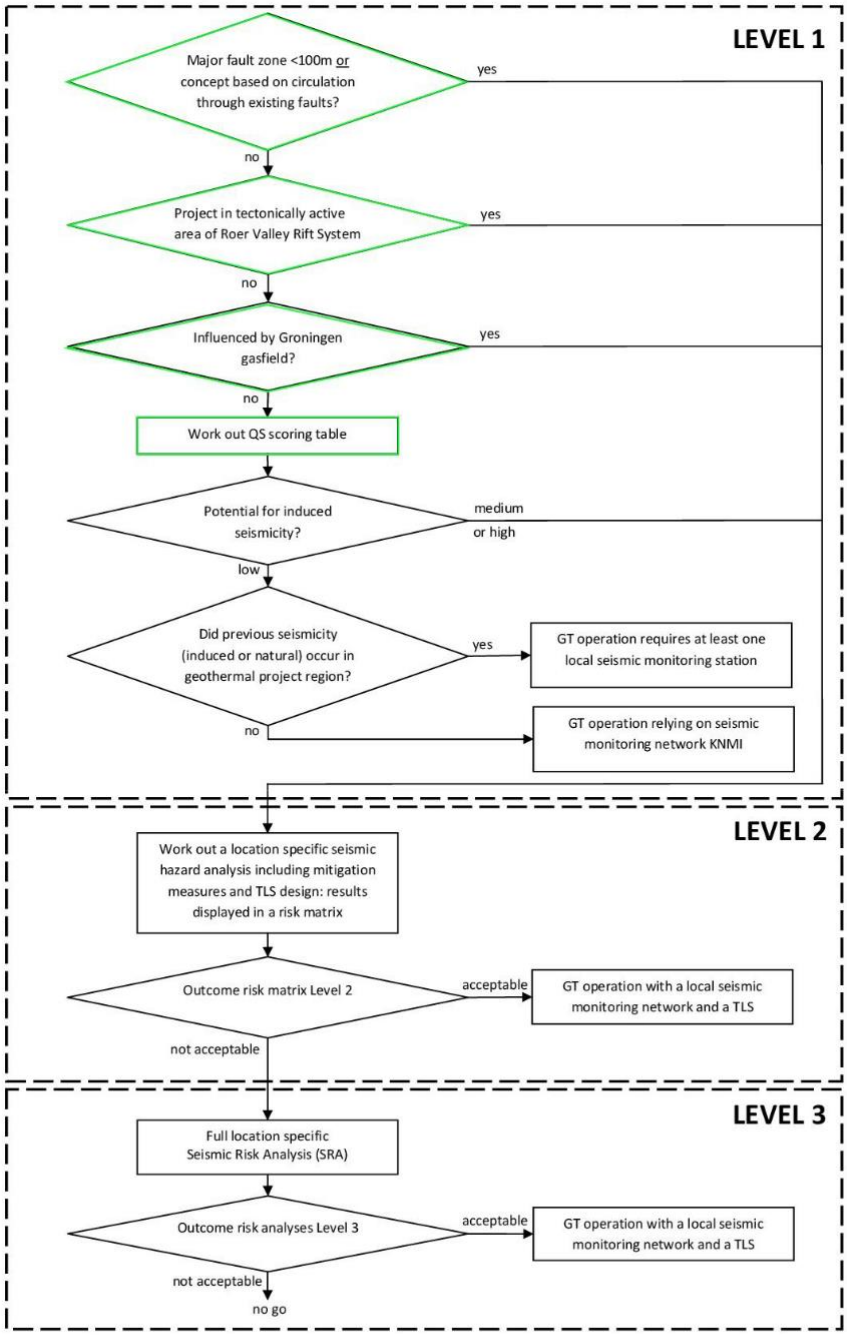
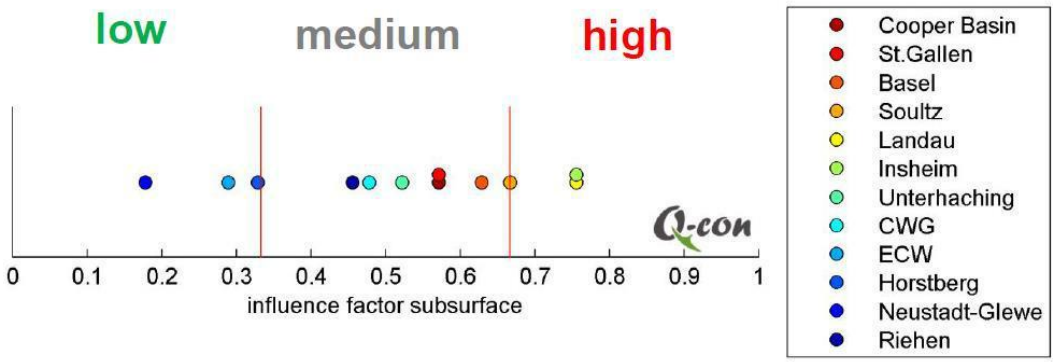


Figure 2.2 | From IF Technology and Qcon, 2016. Scoring scheme for the Quick/Scan. 'Basement connected' refers to a hydraulic connection between injection well and the crystalline basement (or rock mass with comparable properties). 'Inter-well pressure communication' refers to the hydraulic connection between the injection and production wells. 'Distance to fault' refers to the distance between the injection well and the nearest mapped fault. 'Orientation of fault in current stress field' refers to the orientation of the nearest mapped fault. 'Net injected volume' refers to the difference between injected and produced fluid volume (e.g. hydraulic fracturing or injection test).

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

Figure 2.3 | Translation of score to potential for inducing seismicity.



2.2 PARAMETERS

2.2.1 Basement connected

A key parameter is the hydraulic connection to the basement. With the term basement a crystalline rock or a rock mass with comparable hydraulic and mechanical properties is described. If a hydraulic connection between the open part (screens) of the wells and the basement is present, the potential for inducing seismicity is increased. This parameter was incorporated in the Quick-Scan because fluid injection into crystalline rock typically produces seismicity and the largest magnitude seismic events associated with geothermal activities in Europe consistently occurred in basement rock. Well LTG-01 is located about 10 kilometres to the southwest from the geothermal

project and has drilled to 5.115 m TVD and ended in the top of the Devonian. The well didn't encounter basement rock. The vertical distance from the geothermal reservoir to the basement is therefore more than 3 km (Figure 2.4).

There is the possibility of hydraulic connection between the Rotliegend reservoir and the basement through open permeable faults. This possibility cannot be fully excluded. However, the presence of faults that enable pressure communication between the injection well and the basement over a vertical distance of more than 3 kilometres is considered very unlikely. Especially since the carboniferous strata mainly consist of shales that exhibit ductile behaviour: faults would probably be sealed. Therefore, a connection to the basement is deemed very unlikely and a score of 0 is assigned.

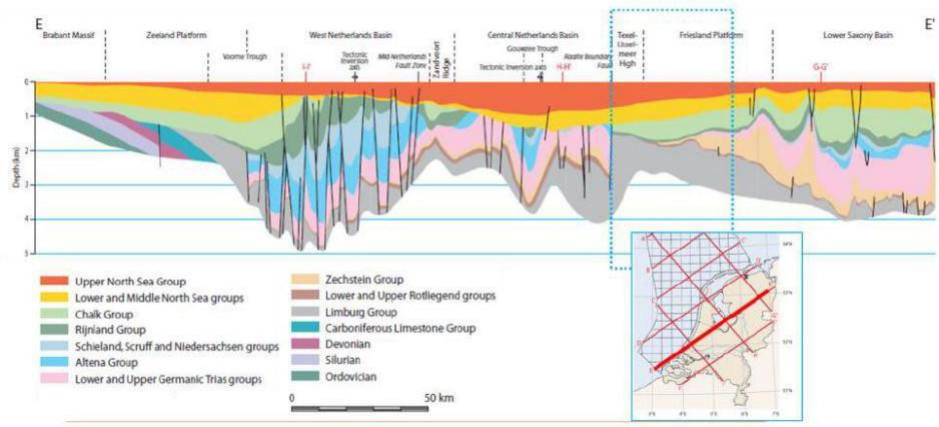
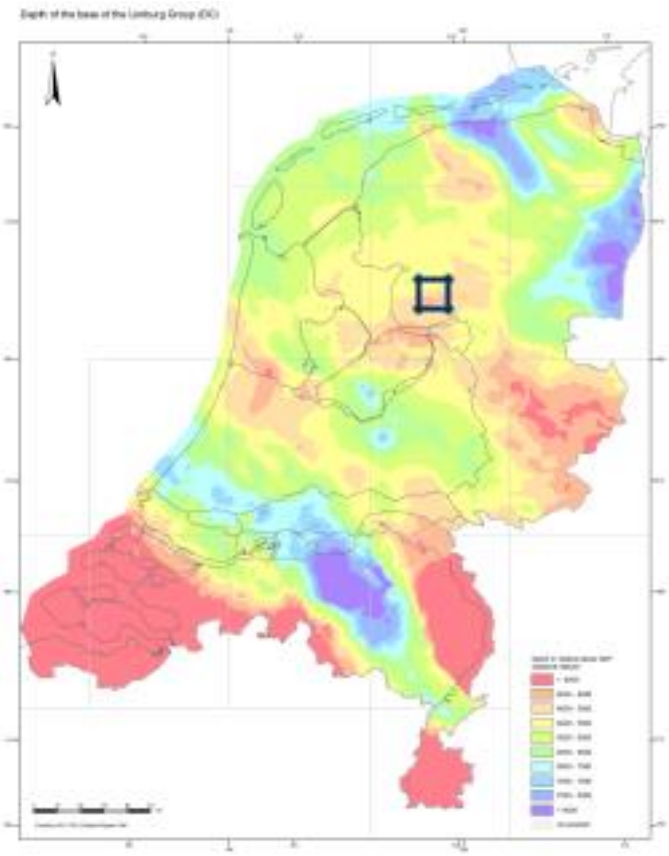


Figure 2.4 | Geological cross-section through the Netherlands with the Luttelgeest area indicated by the blue dotted box. The regional mapping has stopped at the Limburg group in the Luttelgeest area. The Carboniferous strata are situated below these strata, as is indicated by LTG-01. Source IF Technology, 2017.



Figuur 2.5 | Map showing the depth of the base of the Limburg Group (DC) in the Netherlands. The project location is depicted with the black square.

2.2.2 Inter-well pressure communication

The pressure differences created at the injection or production well propagate through the reservoir. Inter-well pressure communication can be blocked or hindered, when the injection and production wells are separated by a hydraulic barrier. This barrier can be a low permeability layer in the reservoir itself (when production and injection occur in different strata within the reservoir and a confining layer is present in between) or a (partly) sealing fault that separates the producer from the injection wells.

The geothermal system for Bram Bernhard is designed such that the production and injection wells target the same strata with a horizontal distance of max. 1600 m at reservoir level. The vertical distance is less than 100 m. Therefore a score of 0 is assigned.

2.2.3 Re-Injection Pressure

Based on the well test results of Hoogweg a reservoir model for both projects is setup. This reservoir model is used to calculate the pressure differences at the wells of Bernhard. According to the reservoir model the maximum pressure change at the injection wells is 62 bar (6.2 MPa). This pressure change is for an infiltration rate of 176 m^3/h per well and an injection temperature of 15°C. This results in a score of 7.

2.2.4 Circulation rate

The circulation rate for the entire system is 350 m^3/h. The critical point is at the re-injection well, where pressure is increased by the injection. Since the geothermal system has two re-injection wells, the circulation per re-injection well is 175 m^3/h. This is the circulation rate used in the quickscan scheme, which results in a score of 3.

2.2.5 Epicentral distance to natural earthquakes

The shortest distance between the screens of the re-injection wells to the nearest natural earthquake was determined using the most recent earthquake catalogue by KNMI. The distance to the nearest event in Apeldoorn is far more than 10 kilometres (see Figure 2.6). This results in a score of 0.

2.2.6 Epicentral distance to Induced seismicity

The shortest distance between the screens of the open part of either of the re-injection wells to the nearest induced seismicity event is determined using the most recent earthquake catalogue by KNMI. The nearest induced event is more than 23 kilometres to the northeast (Figure 2.6). Since this is more than 10 kilometres, a score of 0 is applicable.

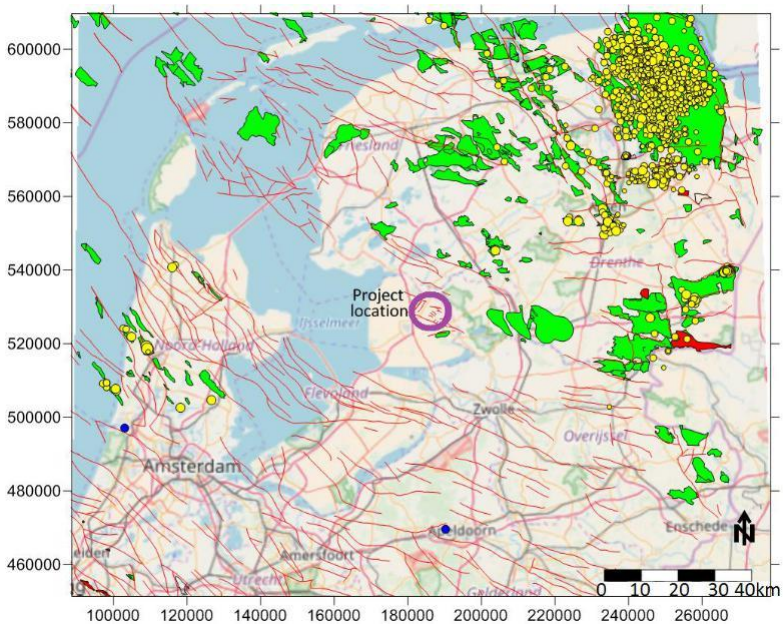


Figure 2.6 | the most recent earthquake catalogue by KNMI (yellow dots are induced seismic events and blue dots tectonic).

2.2.7 Distance to faults

The distance of the screens of the re-injection well(s) to faults is another key parameter to deduce the potential for inducing seismicity. The shorter the distance the larger the effect of the injection well at the concerning fault and the larger the potential for inducing seismicity. Both injection wells are projected in the middle of the graben structure. The distance between the injection wells and the nearest fault is more than 1000 m. This results in a score of 3.

2.2.8 Orientation of fault in current stress field

The quick scan score for the orientation of a nearby fault in the stress field is expressed as the likeliness of shearing of that fault based on the orientation of the fault in comparison to the stress field. Here the fault with the highest score is leading, for example: when the orientation of the nearest fault in the stress field is unfavourable for failure, it may be required to use another nearby fault with a more critical orientation (higher total score for "distance to fault" and "orientation of fault in current stress field").

The orientation of the stress field (Sv, SHmax, and Shmin) is determined using the world stress map (www.world-stress-map.org). This map indicates a direction of approximately 130° (between 120 and 140°) for SHmax. Shmin is oriented perpendicular to SHmax and Sv oriented in vertical direction. Most faults in the direct vicinity of the project location have a strike orientation of between 100 ands 150°. This orientation makes shearing possible. However, the faults have a steep inclination (a dip of 75 to 90 degrees), which makes shearing unlikely.

However, if purely the orientation of the faults is taken into account, a conservative score of 10 is applied.

2.2.9 Net Injected Volume

The geothermal system is configured to have a mass balanced fluid circulation. Therefore, the net injected volume is zero, which results in a score of 0.

2.3 SCORING RESULTS

The geothermal project scores are summarized in Table 2.1, resulting in a normalized score of 0.30. This is below the boundary of low to medium potential for inducing seismicity. Following the guidelines, the project classifies as a low potential for inducing seismicity.

Table 2.1 | Scoring of the geothermal project mean case.

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	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 Well trajectories

The potential for inducing seismicity by the geothermal system also depends on the seismicity potential during drilling of the wells to the sub-surface target locations. The potential for inducing seismicity during drilling is primarily defined by the location of the well trajectories relative to faults. If the well trajectory intersects faults, the potential for inducing seismicity will increase.

The well trajectories for the producer and the two re-injection wells are shown in Figure 3.1. The well trajectories have been projected onto the nearest seismic lines to establish whether any disturbances are visible along the well trajectories.

Please note that the trajectories shown are approximate as the trajectories do not plot directly onto the available 2D lines. The surface location of the seismic line and wells as well as the wells sub-surface location at the top of the reservoir are indicated in figure 3.1.

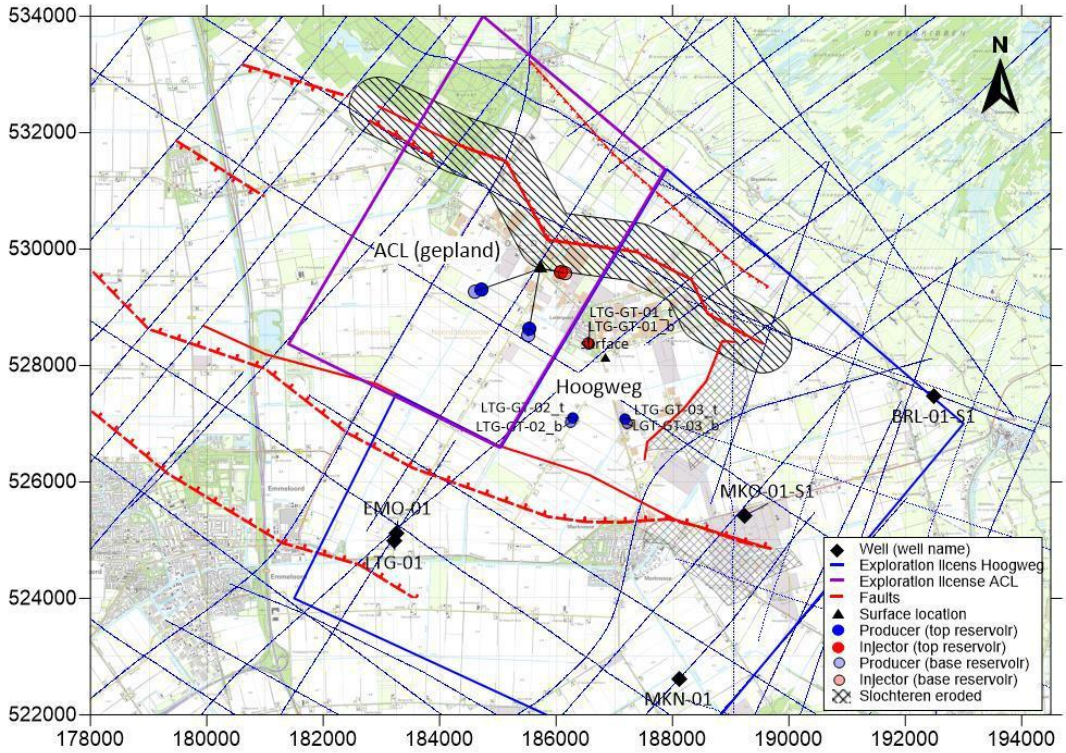


Figure 3.1 | Project- and seismic line locations.

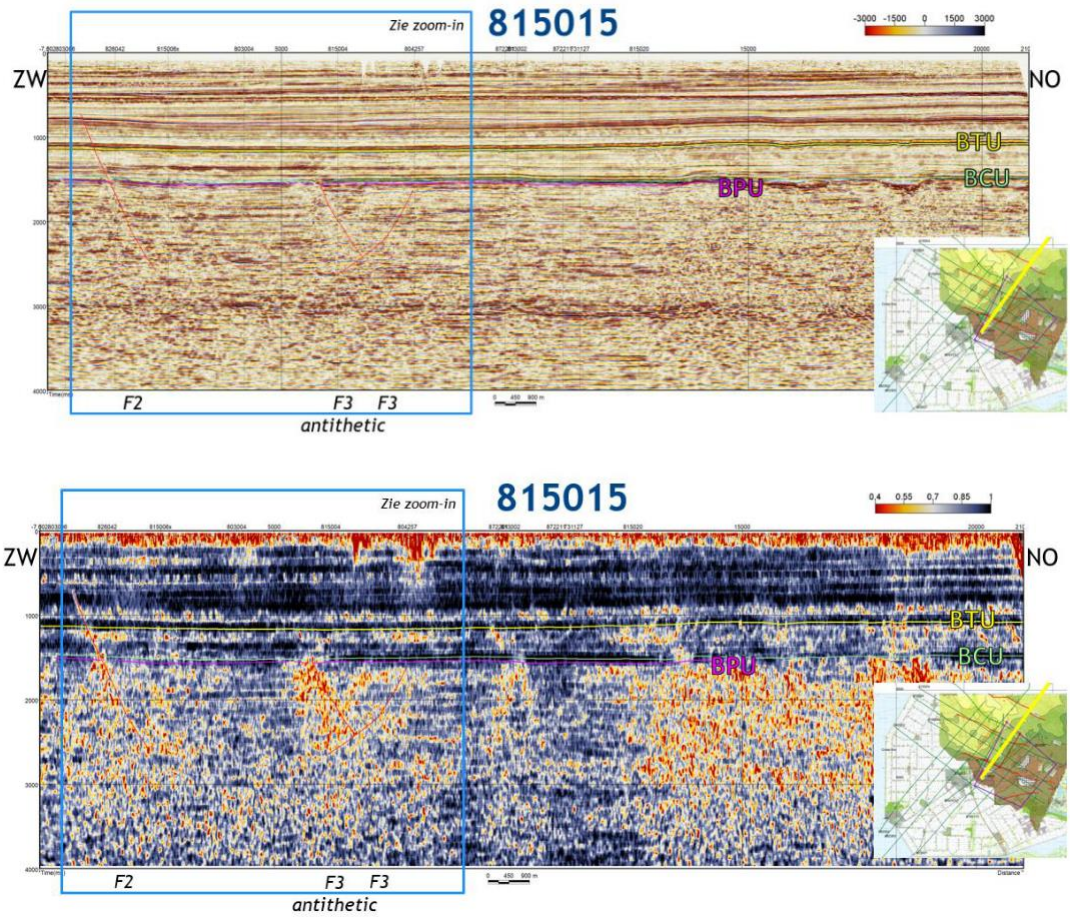
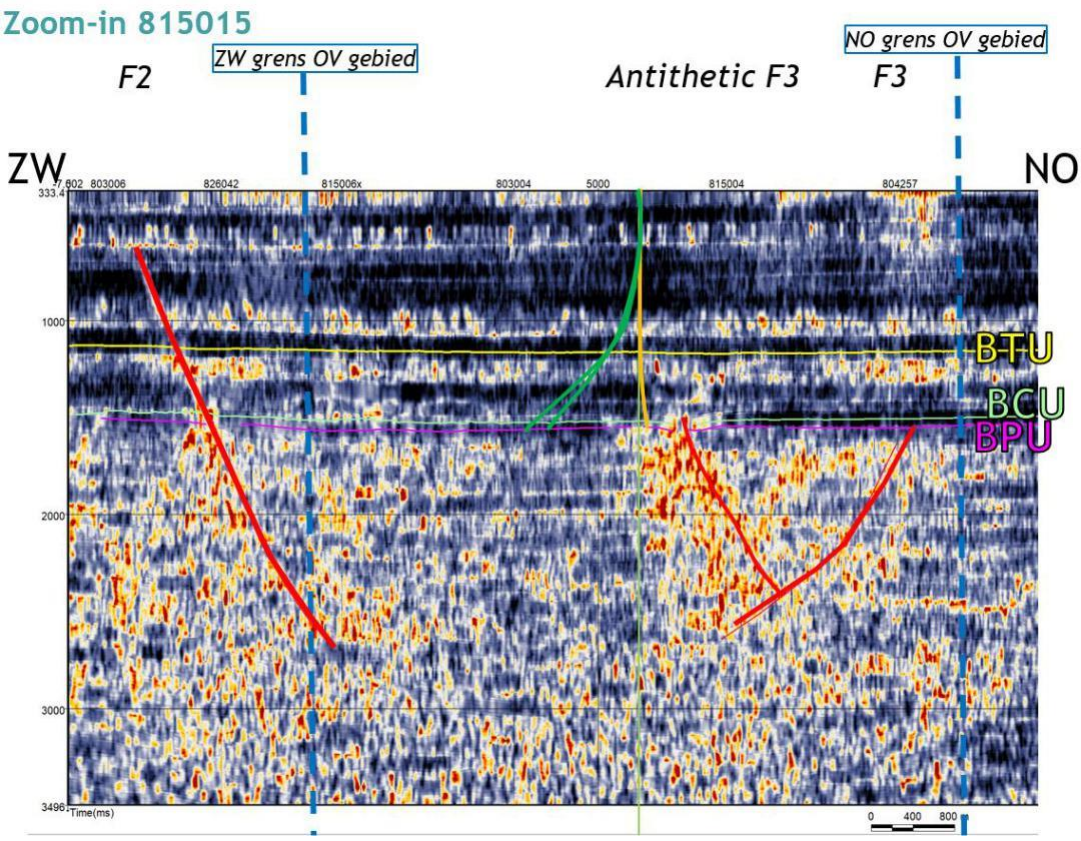
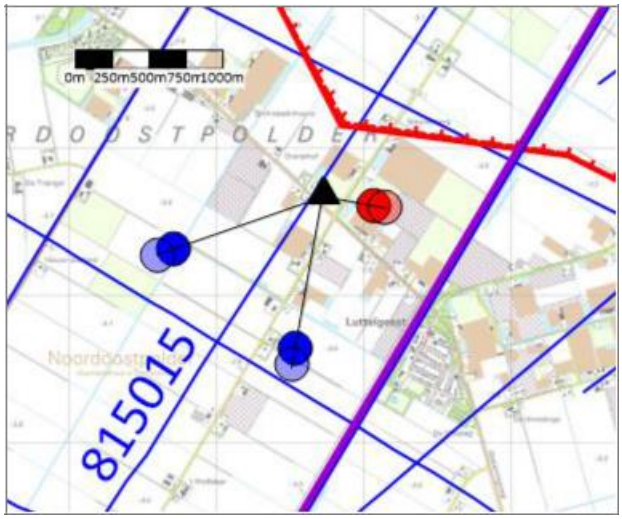


Figure 3.2 | The seismic section and the corresponding similarity of seismic line 815015, the zoom-in window for figure 3.3 and its location with respect to the exploration licence. BTU (Base Tertiary Unconformity) in yellow, BCU (Base Cretaceous Unconformity) in green and BPU (Base Permian Unconformity) in pink. The BPU is the base of the reservoir.



Figuur 3.3 | Projection of the proposed well trajectories of the two re-injection and one production well on seismic line 815015. The injection and producer well trajectories are in green and orange, respectively. See Figure 3.2 for the abbreviations. The surface location is ~50m from the line.

No disturbances/dissimilarities are visible along the projected well trajectories of the three planned wells. From Figuur 3.3 it seems as if the well trajectory of the production well (orange) is getting relatively close to the faults. In reality, the well trajectory is drilled towards the east of the surface location. On this location, the fault is located approximately 500 m north of the planned well (Figuur 3.4).



Figuur 3.4 | Zoom in of the planned well locations, geological structure and available seismic data.

4 The Potential for inducing seismicity

4.1 QUICK SCAN RESULTS

The score of Bernhard's geothermal project in the Quick Scan is the category low potential for inducing seismicity. Therefore, no additional steps for quantifying the risk on inducing seismicity are necessary.

4.2 WELL TRAJECTORY RESULTS

The projection of the proposed well trajectories on the nearest seismic lines shows no disturbances/dissimilarities that coincide with the well trajectories. Therefore, no faults are expected along the well trajectories. It must be kept in mind that we have a limited amount of 2D seismic lines. Therefore, the possibility of faults along the well trajectory cannot be excluded. However, we see no indication of faults along the well trajectories on the above shown seismic lines.

NL SUMMARY

4 HET POTENTIEEL VOOR HET OPWEKKEN VAN SEISMICITEIT

4.1 QUICK SCAN RESULTATEN

De score van het geothermie project van Bernhard in de Quick Scan is de categorie met een laag potentieel voor het opwekken van seismiciteit. Daarom zijn er geen aanvullende stappen nodig voor het kwantificeren van het risico op het opwekken van seismiciteit.

4.2 PUT TRAJECT RESULTATEN

De projectie van de voorgestelde puttrajecten op de dichtstbijzijnde seismische lijnen vertoont geen verstoringen / ongelijkheden die samenvallen met de puttrajecten. Daarom worden er geen breuken verwacht langs de boortrajecten. Er moet rekening mee worden gehouden dat we een beperkt aantal 2D-seismische lijnen hebben. Daarom kan de mogelijke aanwezigheid van breuken langs het boortraject niet worden uitgesloten. We zien echter geen indicatie van breuken langs de puttrajecten op de hierboven getoonde seismische lijnen.

5 References

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