Quickscan for Potential of Inducing Seismicity

Koekoekspolder

IF Technology **Creating energy**

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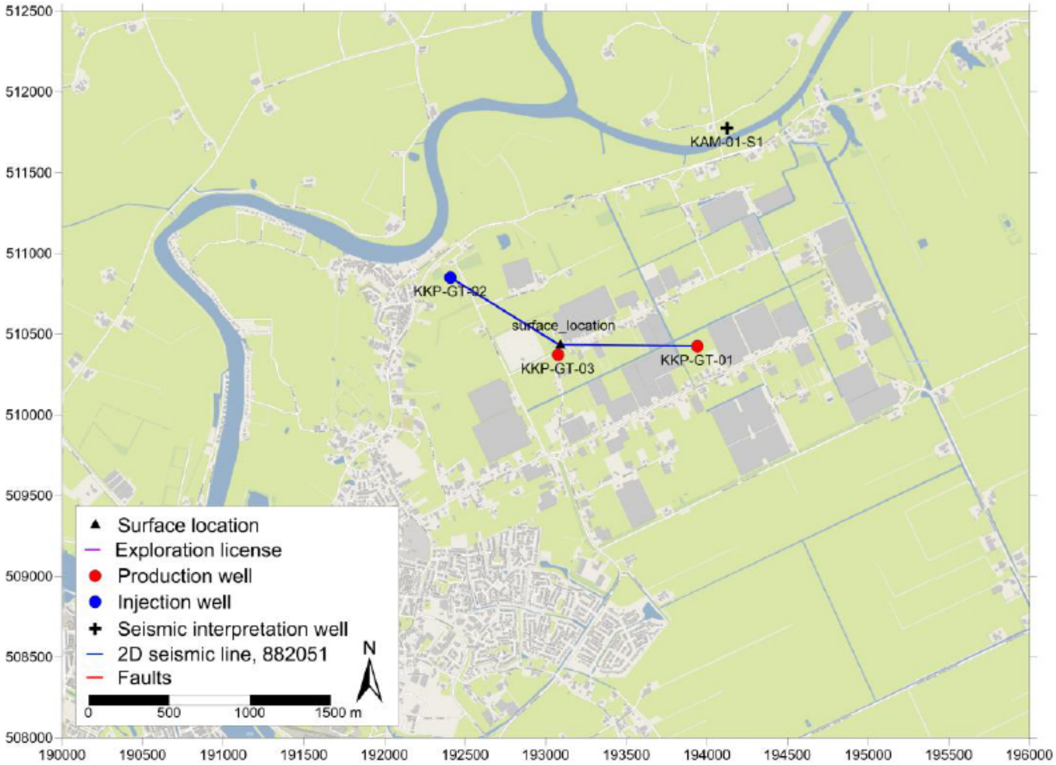
INHOUDSOPGAVE

1 Introduction

Aardwarmtecluster Koekoekspolder has requested IF Technology to determine the potential for inducing seismicity for a geothermal system. For this determination the quickscan method described in "Defining the framework for a seismic hazard assessment in geothermal projects" was used (Qcon en IF Technology 2016) in combination with the accessory addition by DAGO (M. van der Hout 2018). This is the next step into the realization of the geothermal system.

Figure 1.1 | The location of the geothermal system and proposed additional production well for Aardwarmtecluster Koekoekspolder. The surface location, well trajectories and sub-surface locations at top reservoir are indicated. Note that the location of KKP-GT-03 is not definite yet (2: Location second producer).



The geothermal system for Aardwarmtecluster Koekoekspolder is located within the exploration license of Kampen. The geothermal system targets the Slochteren Formation as the reservoir formation. It consists of one doublet and will be extended with an additional production well, see RNES application Koekoekspolder 2018 (IF Technology 2018). The existing doublet has been operative since 2012 and has a total produced volume of 5,824,146 m^3. No signs of induced seismicity have been reported during the operational time of the wells.

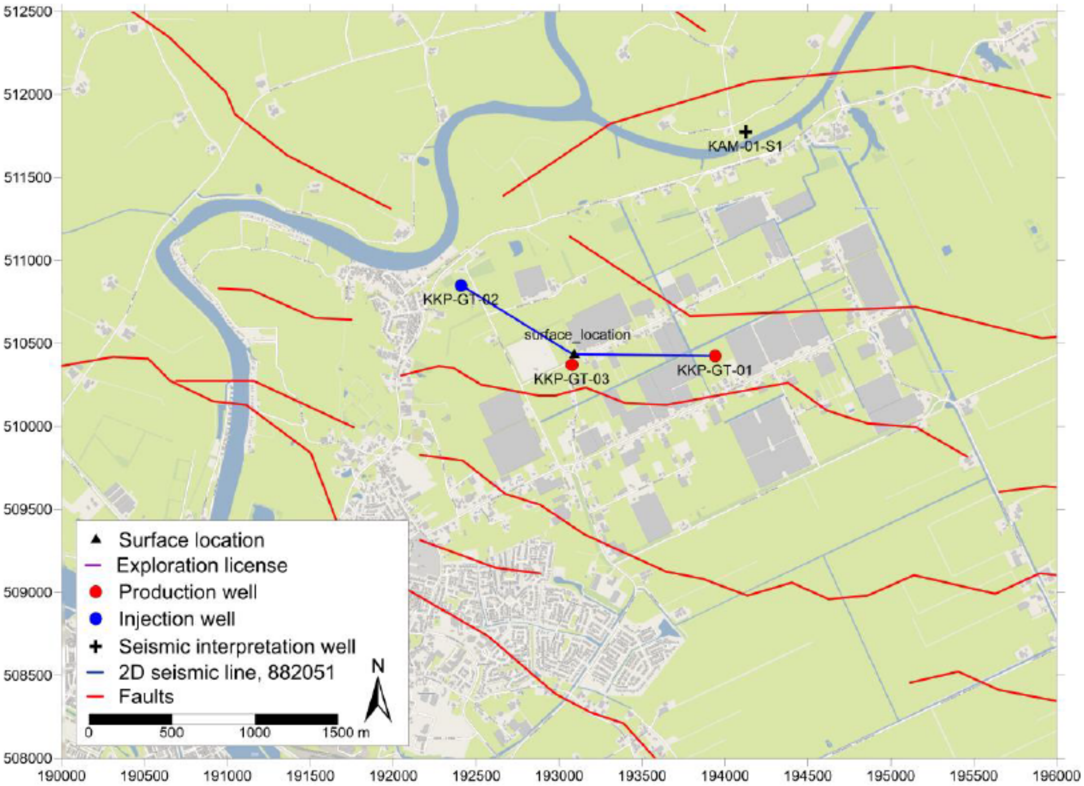
The current report consists of a quickscan of the potential for inducing seismicity for the to be drilled addition production well and the productive doublet. The potential for inducing seismicity is assessed for both the reservoir part of injection well and for the drilling of the new producer well trajectories.

2 Location second producer

2.1 INTRODUCTION

The exact location of this second producer with respect to the faults as interpreted by PanTerra (Panterra 2010) is presented in Figuur 2.1. When determining the well trajectory the distance to the existing two wells should be maximised. Also, the filter should enter the reservoir under an angle of approximately 20º (Well Engineering Partners 2019). These factors result in a preferred well trajectory azimuth of 194º. Yet, when drilling in this direction, the distance to the fault that seems to be located to the south of the surface location gets smaller. In order to gain a better understanding of this fault, the seismic sections and similarity maps have been reassessed.

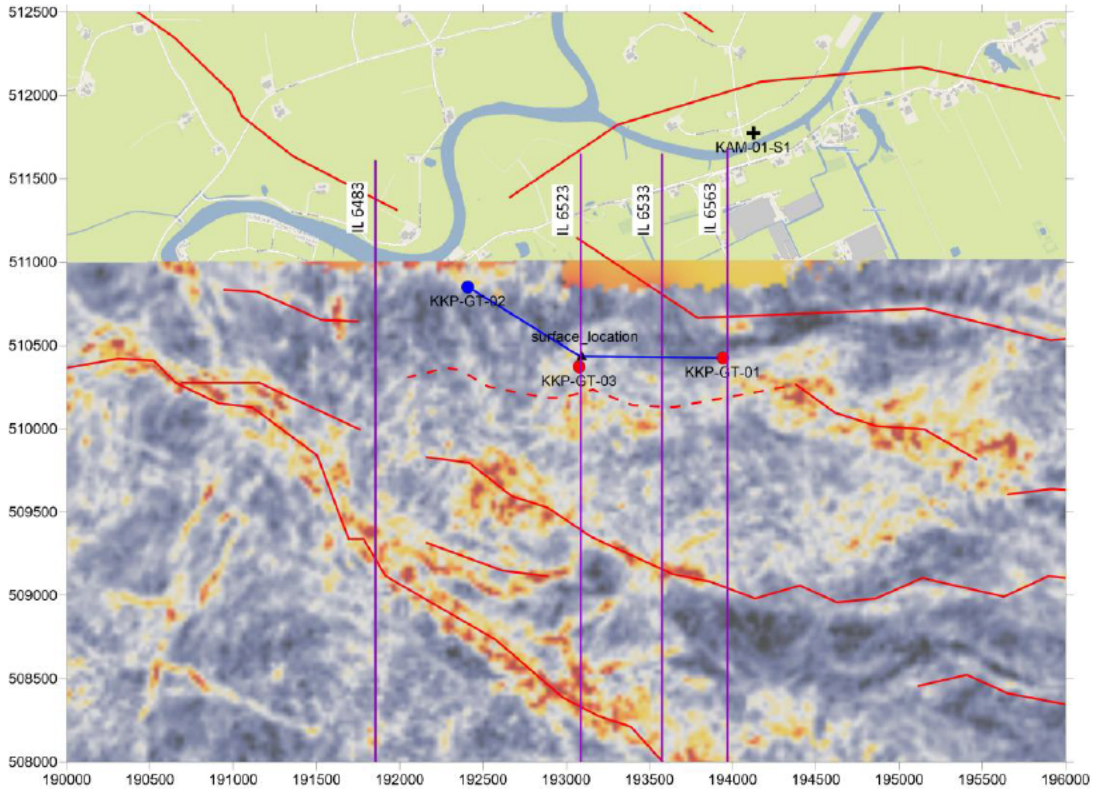
Figuur 2.1 | Well locations and proposed well location for KKP-GT-03 and faults at reservoir level as interpreted by PanTerra (2010).



2.2 REASSESEMENT OF SEISMIC DATA

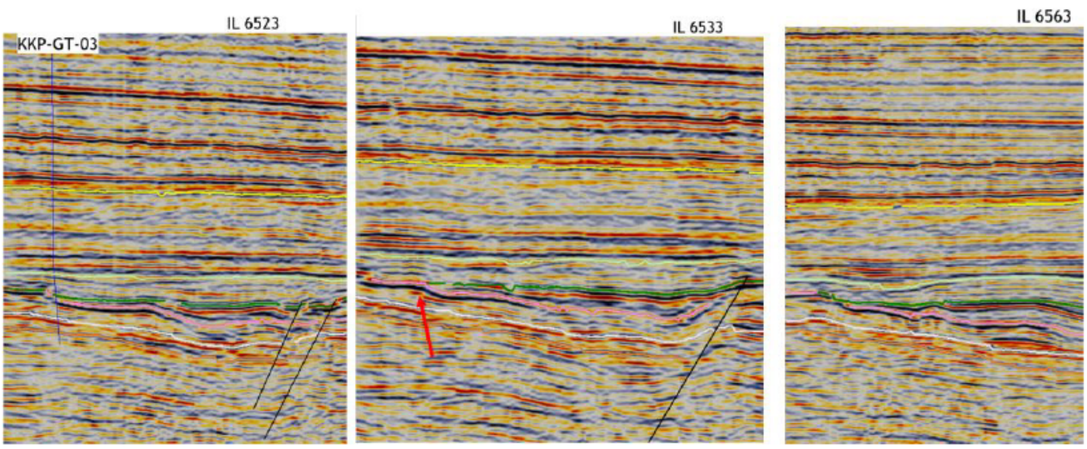
Reassessment of the similarity map of the top of the Slochteren reservoir (Figuur 2.2) shows very clear disturbances from the location of well KKP-GT-01 towards the east. Yet, in the part stretching from well location KKP-GT-01 towards the west, the disturbances are not that clear and do not point towards a clear fault.

Figuur 2.2 | Similarity map for the Slochteren reservoir. Inlines are depicted in purple, faults are depicted in red.

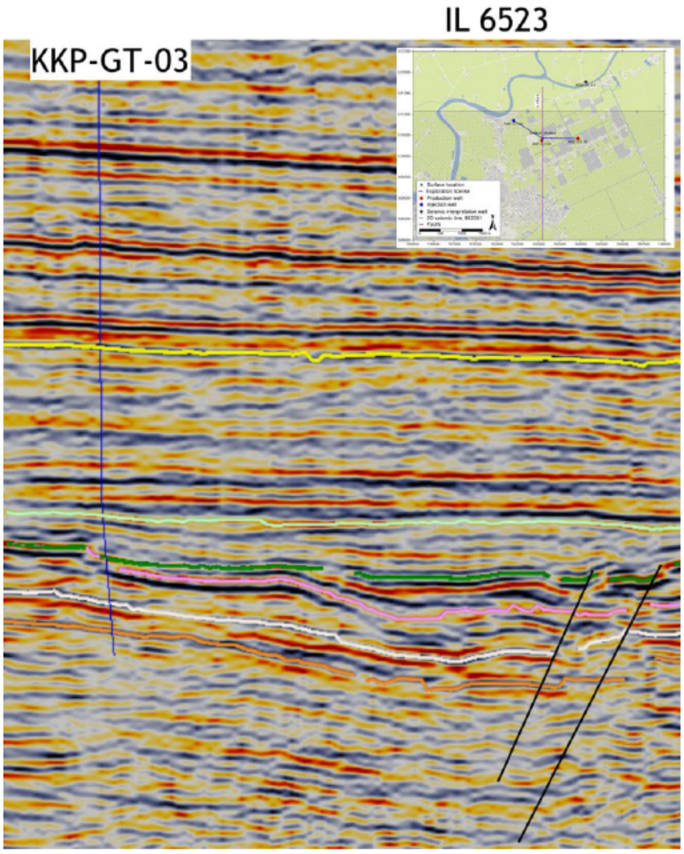


Four inlines (Figuur 2.2) of the seismic volume have been made to reassess the seismic interpretation. As Figuur 2.3 points out, the fault close to the surface location (dashed red line in Figuur 2.2) is not traceable on seismic sections. Figuur 2.4 provides a close-up of the inline crossing the surface location and the reservoir entry point for well KKP-GT-03.

Figuur 2.3 | Seismic sections for inlines 6523, 6533 and 6563. Inline 6523 is plotted along the well trajectory of KKP-GT-03. The black lines indicate the fault about 1000 m south of surface location. Note that no faults are distinguished at a distance of 200 to 300 m, where we would expect a fault (dashed in figure 2.2).



Figuur 2.4 | Seismic section of inline 6523.



2.3 CONCLUSION

Reassessing similarity maps and seismic sections for the area around the proposed well trajectory for well KKP-GT-03 resulted in the reconsideration of Panterra's (2010) fault interpretation. The fault 200 m south of the surface location, stretching from west to east, is most likely (partly) interpreted incorrectly and does not exist close to the entry point of well KKP-GT-03. This region is thus not anymore a boundary condition which should be kept in mind when considering well trajectories.

3 Quickscan

3.1 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 and the addition to this report as published by DAGO (M. van der Hout 2018). The decision tree for the three-level hazard and risk assessment procedure is shown in Figure 3.1.

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 concept is not based on circulation through existing faults
- The project location is not situated in the tectonically active Roer Valley rift system.
- The project location is not influenced by the Groningen gasfield.

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 3.2).

The scores of the different parameters are summed up, divided by the maximum possible score and subsequently compared to the categories in Figure 3.3. This result gives the potential for inducing seismicity category of the geothermal project and dictates which steps are needed next.

Figure 3.1 | Decision tree for the three-level hazard and risk assessment procedure.

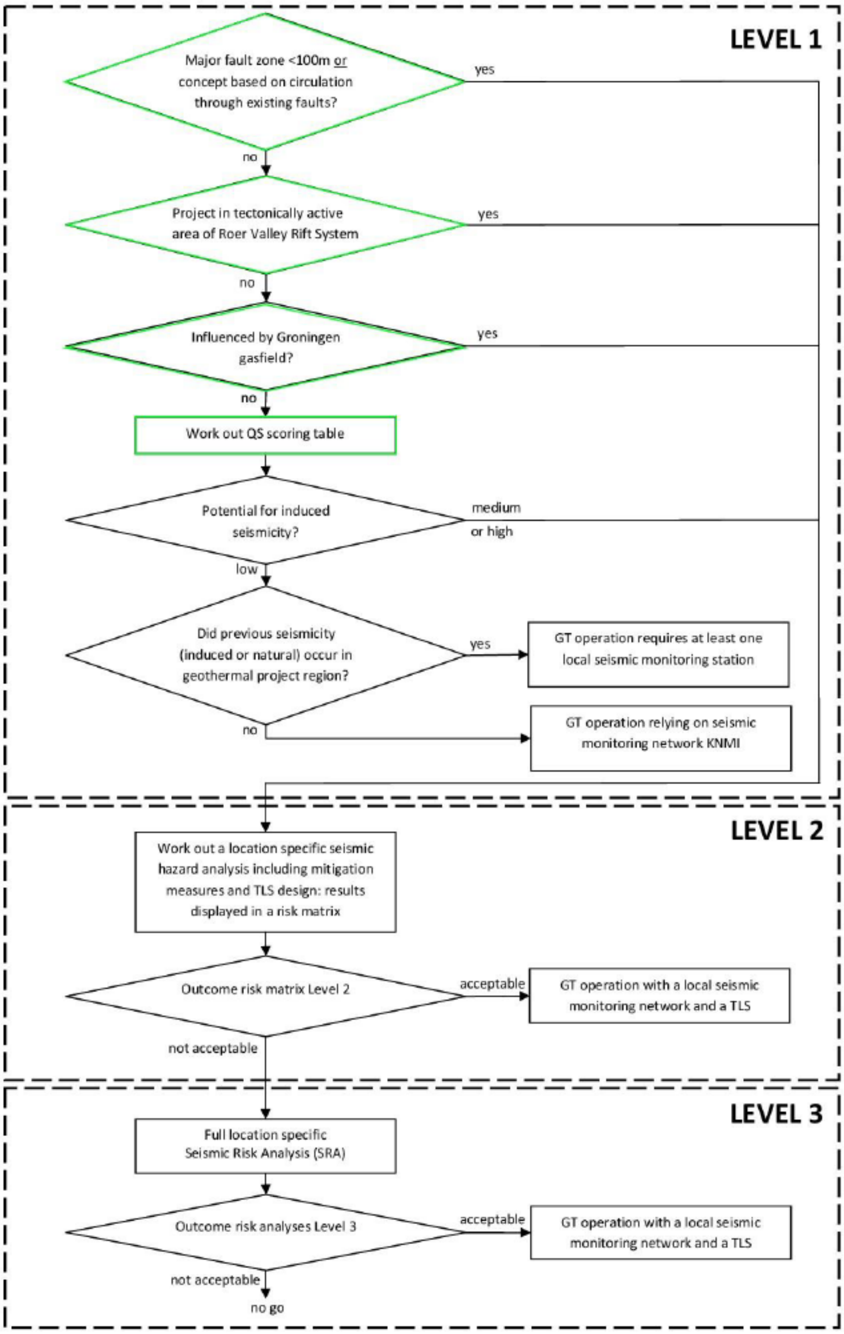
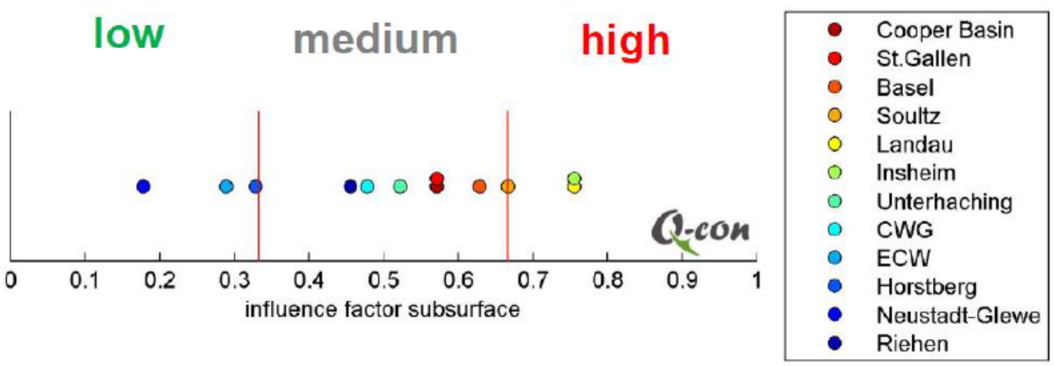


Figure 3.2 | From IF Technology and Qcon, 2016. Scoring scheme for the Quick/Scan. 'Basement connected' refers to a hydraulic connection between injection well and the crystalline basement (or rock mass with comparable properties). 'Inter-well pressure communication' refers to the hydraulic connection 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 3.3 | Translation of score to potential for inducing seismicity



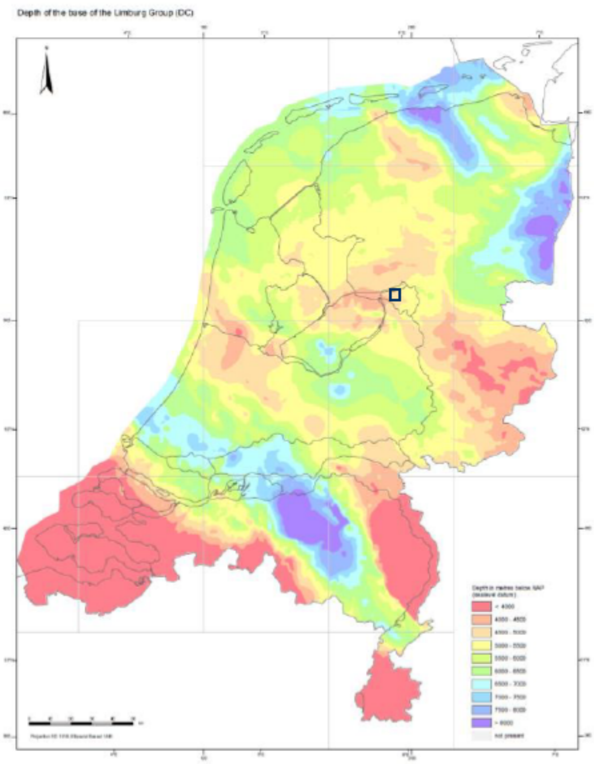
3.2 PARAMETERS

3.2.1 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 NAG-01 is located about 15 kilometres WNW from the geothermal project and has drilled to 4303 m TVD and ended in the top of the Devonian. The well didn't encounter basement rock. Since the top of the reservoir is found to be located at approximately 1800 m depth, the vertical distance from the geothermal reservoir to the basement is therefore more than 2.5 km. This is confirmed by Figure 3.4.

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 2.5 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. Yet, since the distance to the basement cannot be confirmed to be deeper than 3 km, a score of 3 is assigned.

Figure 3.4 | Map showing the depth of the base of the Limburg Group (DC) in the Netherlands. The project location is depicted with the black square. Modified after (M. van der Hout 2018).



3.2.2 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 at Koekoekspolder is designed such that the production and injection wells target the same strata with a horizontal distance of 1.600 m at reservoir level. Well test data shows that the reservoir is not locked by faults (Borst 2018). Therefore, inter-well pressure communication is deemed likely. According to the DAGO's report (M. van der Hout 2018) a score of 3 needs to be assigned to this parameter, since the largest distance between a producer and the injector is over 1 km.

3.2.3 Re-Injection Pressure

On May 3rd 2016, "Aardwarmtecluster 1 KKP BV" applied for a WABO in which was opted for a maximum injection pressure of 75 bar at an injection temperature of 35ºC. The desired flow rate is 260 m^3/h. This flow rate will result in a friction loss of 15 bar. The pore pressure is, including an overpressure of 4 bar, 196 bar. The water column of the injected water with a temperature of 35ºC results in a pressure of 206 bar at reservoir level. For these circumstances the given well head pressure of 75 bar results in a reservoir pressure of 74 bar. This coincides with a score of 10.

3.2.4 Circulation rate

The circulation rate for the entire system is 260 m^3/h. This results in a score of 7.

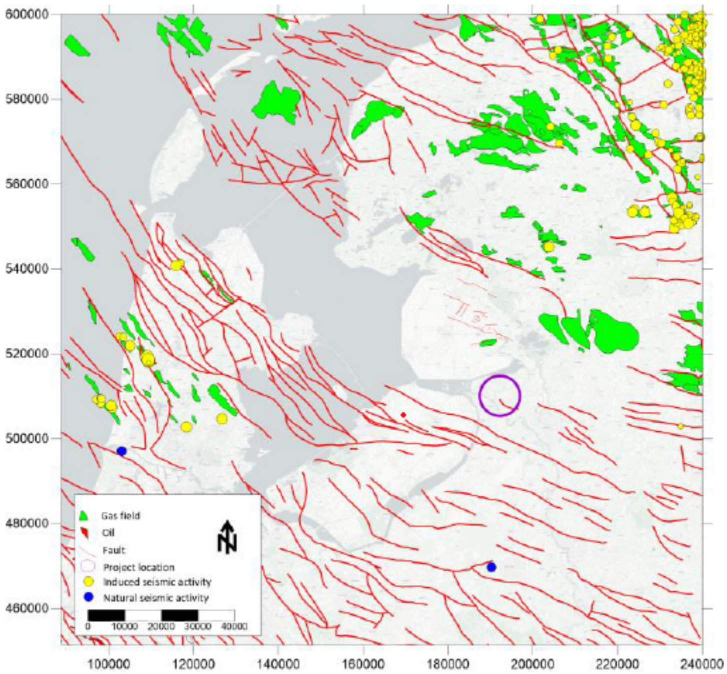
3.2.5 Epicentral distance to natural earthquakes

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 42 km, far more than 10 kilometres (see Figure 3.5). This results in a score of 0.

3.2.6 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 43 kilometres to the south (Figure 3.5). Since this is more than 10 kilometres, a score of 0 is applicable.

Figure 3.5 | The most recent earthquake catalogue by KNMI (yellow dots are induced seismic events and blue dots tectonic).

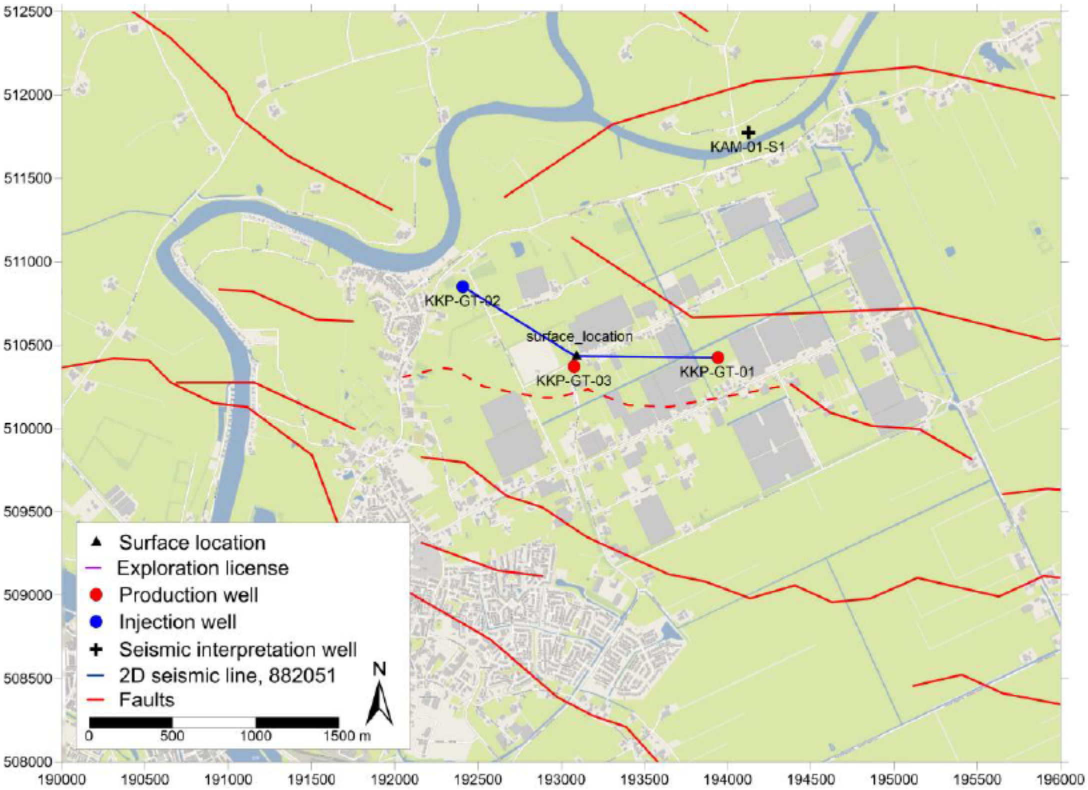


3.2.7 Distance to faults

The distance of the screens of the re-injection well 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. The shortest distance from a discontinuity is 500 m (

Figure 3.6). Since the quality of the seismic data is relatively high, this translates to a score of 3.

Figure 3.6 | Overview of the faults in the exploration licence area.



3.2.8 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 thesis of Mechelse (Mechelse E. 2017). This results in an orientation of 144° (error of 20.4º) 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 approximately 110 degrees. This orientation makes shearing possible.

A quick scan calculation of the slip and dilation tendencies shows that a pressure increase of at least 27 bar is needed at the faults within the reservoir to create critically stressed faults, and the minimum dilation tendency is 0.66. This means that shearing is unlikely and a score of 3 is applicable.

3.2.9 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.

3.3 SCORING RESULTS

The geothermal project scores are summarized in Table 3.1, resulting in a normalized score of 0.32. 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. Therefore no additional steps for quantifying the risk on inducing seismicity are necessary.

Table 3.1 | Scoring of the geothermal project mean case.

Score	Basement connected	Inter-well pressure communication	Re-injection pressure [MPa]	Circulation 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 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

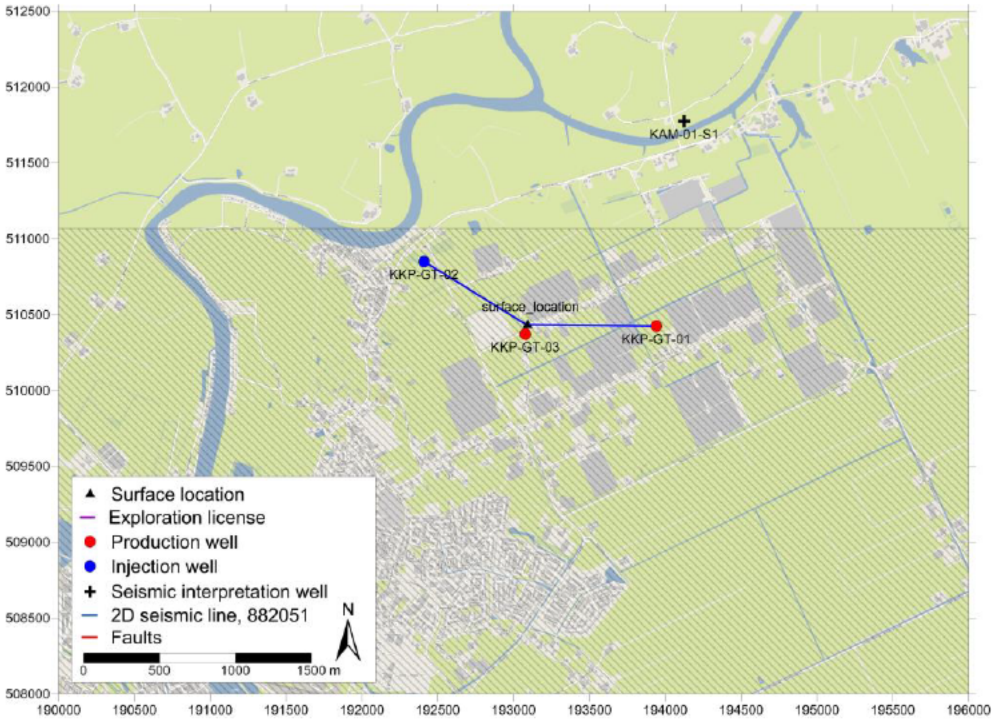
4 Well trajectories

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 trajectory for the new producer as proposed in paragraph 2 (Location second producer) is used for the current analyses. The well trajectory has been projected onto an inline of the nearest seismic volume (20121120) to establish whether any disturbances are visible along the well trajectories. The surface location of the seismic volume, line and wells as well as the wells sub-surface location at the top of the reservoir are indicated in figure 3.1.

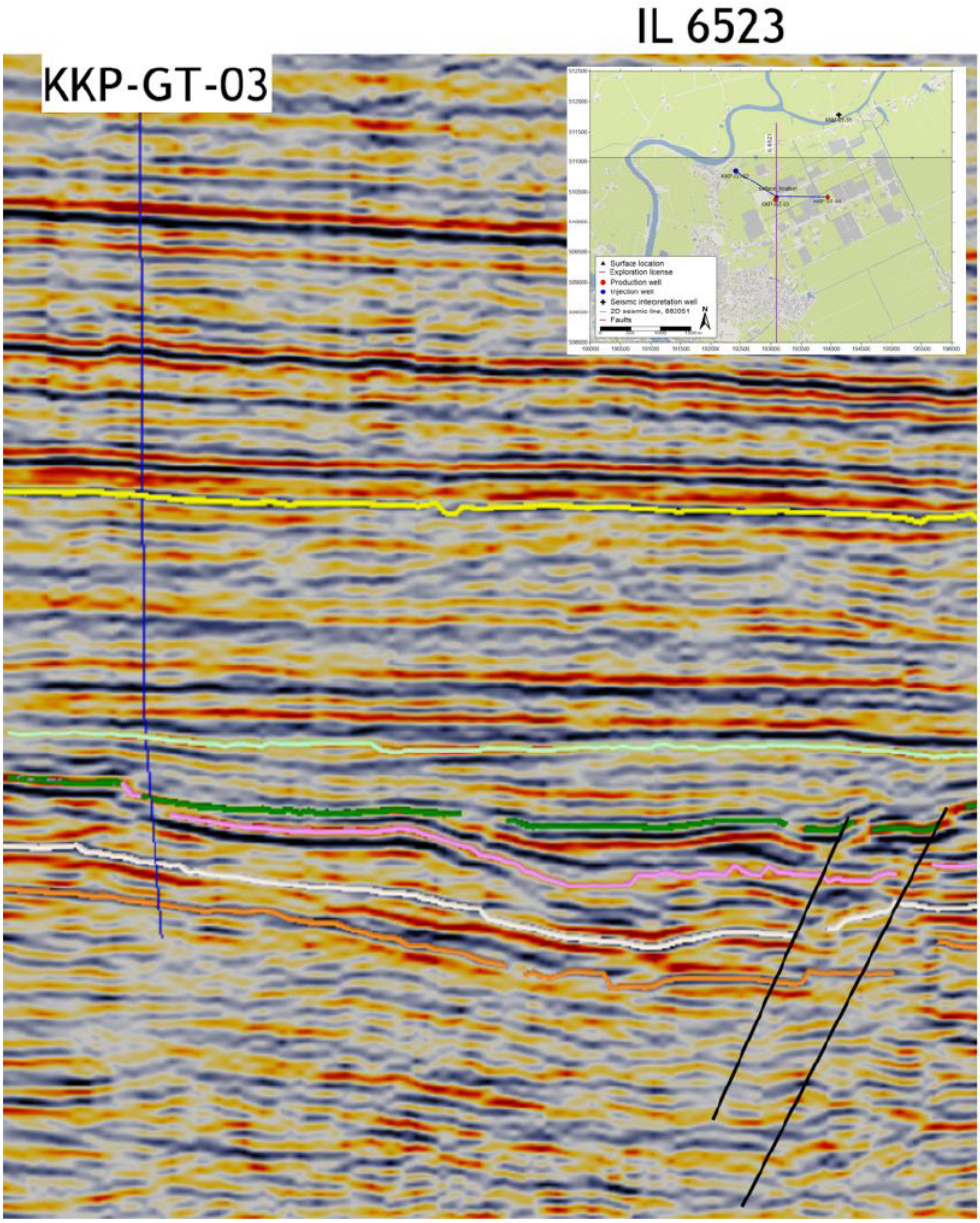
The well trajectory is determined based on a report by WEP (Well Engineering Partners 2019). Their proposed Kick Off Point is 1615 m, and the maximum inclination rate is 3°/30 m. The End of Build is 21° at a depth of 1840 m (Top Reservoir).

Figure 4.1 | Project and seismic locations.



The production well trajectory is projected on to an inline of the nearest seismic volume (IL 6523) (Figure 4.2). The seismic line shows no visible disturbances along the well trajectory.

Figure 4.2 | Projection of the new production well (KKP-GT-03) on seismic line 6523.In white: Base Slochteren (base reservoir), in pink: Base Zechstein, in green: Rijnland, in light green: Chalk, in yellow: Lower North Sea.



5 The Potential for inducing seismicity

5.1 QUICK SCAN RESULTS

The score of Aardwarmte Koekoekspolder 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.

5.2 WELL TRAJECTORY RESULTS

The projection of the proposed well trajectories on an inline of a 3D seismic volume shows no disturbances that coincide with the well trajectories. Therefore, no faults are expected along the well trajectories.

6 References

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Appendix 1

Well test interpretation from (Borst 2018).

6.1 TESTING FOR IRREGULARITIES IN THE RESERVOIR

In order to check whether there are irregularities such as faults present in a reservoir, a Horner analysis can be conducted. In this method wellbore static pressure or hydraulic head drawdown is plotted on the Y-axis against a logarithmic function of time on the X-axis ("Horner time", a way of writing time as a function of the change of time, with respect to the total pumping time before the start of the recovery test). Plotting the drawdown in a well against "Horner time" from the start of the recovery test shows whether the reservoir gets filled in gradually. If the reservoir fills in gradually the data points will follow a trend line. If the reservoir is not filled gradually steps will be noted in this graph.

Horner time is defined as $(T_t+T')/T'$. Tt is the total duration time of the pumping period. T' is the time since the start of the recovery test, i.e. the time since pumping stopped. Note that graphs must be read from right to left, since "horner time" lowers with time (Stetler 2010).

6.2 WELL TESTING KOEKOEKSPOLDER

The average flow rate during the pumping test preliminary to the recovery test is 56 m3/h for a duration of 18.6 hours. Filling in the formula for the radius of influence by (Bear 1979) shows that this pumping period has resulted in a radius of influence of 307 m (Main report: Methods, Well testing). Faults do exist within this radius (SRA:

Figure 3.6).

Well test data for well KKP-GT-01 is used to check whether or not these faults influence the conductivity of the aquifer. The recovery test shows that the drawdown responds to the flow rate in a discontinuous way (Figure 1), this could be a result of the faults which disrupt the conductivity of the reservoir. The underlying mechanism for this sealing capacity can be one of the following: the offset of the faults is so large that sand is no longer juxtaposed to sand, but to e.g. anhydrite. Another explanation could be that the faults act as seals due to e.g. clay smearing or cementation.

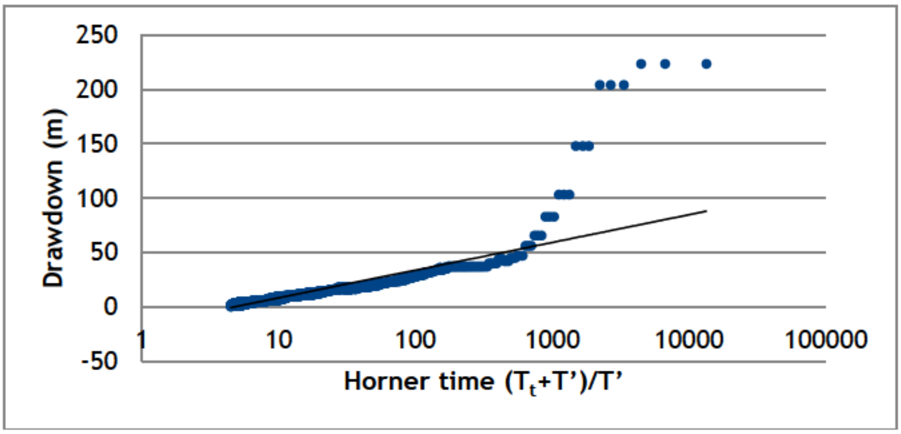

Figure 1 The drawdown response of the water level during the recovery test for KKP-GT-01. A clear step is visible in the data, implying an irregularity in the reservoir. Note that graphs must be read from right to left, since "horner time" lowers with time.

6.3 RELEVANCE FOR CURRENT SRA

For a Seismic Risk Assessment it is important to know if wells "communicate" with one another: does reservoir fluid flow from the production well to the injection well? If this wouldn't happen this could lead to an overpressure in the reservoir. The Horner plot in Figure 1 shows that the flow in the reservoir starts out fairly difficult, but a large step is visible after 10.000 $(T_t+T')/T'$. After this step the flow in the drawdown in the reservoir happens gradually. This could mean that there is an irregularity in the reservoir, but once the drawdown is high enough the seal has been abolished, after which the flow happens as if there had not been an irregularity.

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