



Seismic Hazard Analysis

Level 1 (Quick-Scan)

Doublet VDB-GT-05 / VDB-GT-06

May 2023

Version 1

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SUMMARY

For the development of the Bleiswijk 1b licence a Level-1 (Quick-Scan or QS) Seismic Hazard Analysis ("SHA") was performed to assess and quantify the risks of seismicity during geothermal development of doublet VDB-GT-05/ VDB-GT-06. This has been done on the basis of the protocol set up by IF Technology B.V. and Q-CON GmbH (Baisch et al., 2016). This SHA report describes the results as they have been established for producer-injector pair VDB-GT-05/ VDB-GT-06 on the basis of the current knowledge and adheres to the pre-mentioned guidelines. This doublet (referred to as "GT05/06" in this report) will be situated in the exploration license Bleiswijk 1b, where another doublet (VDB-GT-03 / VDB-GT-04) has been operational between 2010-2019. The operational settings used for this assessment are based on the high case scenario reported in the *Winningsplan aardwarmte Versie 2.0 Bleiswijk1b-VDB-GT-05/-06* compiled by *IPS Geothermal* in 2023. This scenario assumes a maximum flow rate of 359 m³ / hr and injection temperature of 15°C.

The IF/Q-CON framework describes a set of criteria that control seismic risk. For GT05/06, each of these parameters have been evaluated. The results are presented in a scoring table where the scores for the individual criteria are normalized (Table 1). The resulting weighted score is 0.29, which is associated with low risk, according to the IF/Q-CON framework.

Table 1 SHA scoring scheme for GT05/06. The applicable scores are highlighted in blue.

Score	Basement Connected	Inter-well pressure communication	Re-injection Pressure [Mpa]	Flow Rate [m ³ /h]	Epicentral distance to natural earthquakes [km]	Epicentral distance to induced seismicity [km]	Distance to fault [km]	Orientation of fault in current stress field	Net injected volume [1000m ³]	Sum of column scores	Normalized score
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		
Column Score	0	3	3	7	0	0	3	10	0	26	0,29

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 is established because a balance between the injected and produced volumes is maintained. If no seismicity has occurred during that initial stage, risk is greatly reduced. No observations have been made related to seismicity during operations of doublet VDB-GT-03/VDB-GT-04, while producing heat from the Delft reservoir in the same geothermal development license Bleiswijk 1b (2010-2019). Although the VDB-GT-05/VDB-GT-06 is planned to be producing from both the Delft and Alblaserdam reservoirs, the experience with VDB-GT-03/VDB-GT-04, indicates that seismicity risks are reduced here.

The risk of seismicity related to the thermos-elastic effects in geothermal applications has not been taken into account in the IF/Q-CON methodology and have therefore not been investigated in this report.

INTRODUCTION

A new geothermal development licence is prepared for Bleiswijk 1b licence area (Figure 1), situated in the municipality of Berkel en Rodenrijs and owned by 85 Degrees renewables 3 & 4 B.V. and IPS Geothermal Energy B.V.. This new doublet, consisting of producer VDB-GT-05 and injector VDB-GT-06, is planned to be drilled in the same area as former producer VDB-GT-03 and injector VDB-GT-04 and is also surrounded by several other existing geothermal doublets (PNA-GT, VDB-GT & LSL-GT). The target reservoir is the Nieuwerkerk Formation, consisting of combination of the Delft Sandstone and Alblasserdam Members, the first also being a main target of other doublets in this region.

The geological parameters in this analysis are based on the geological study performed by Panterra in 2021.

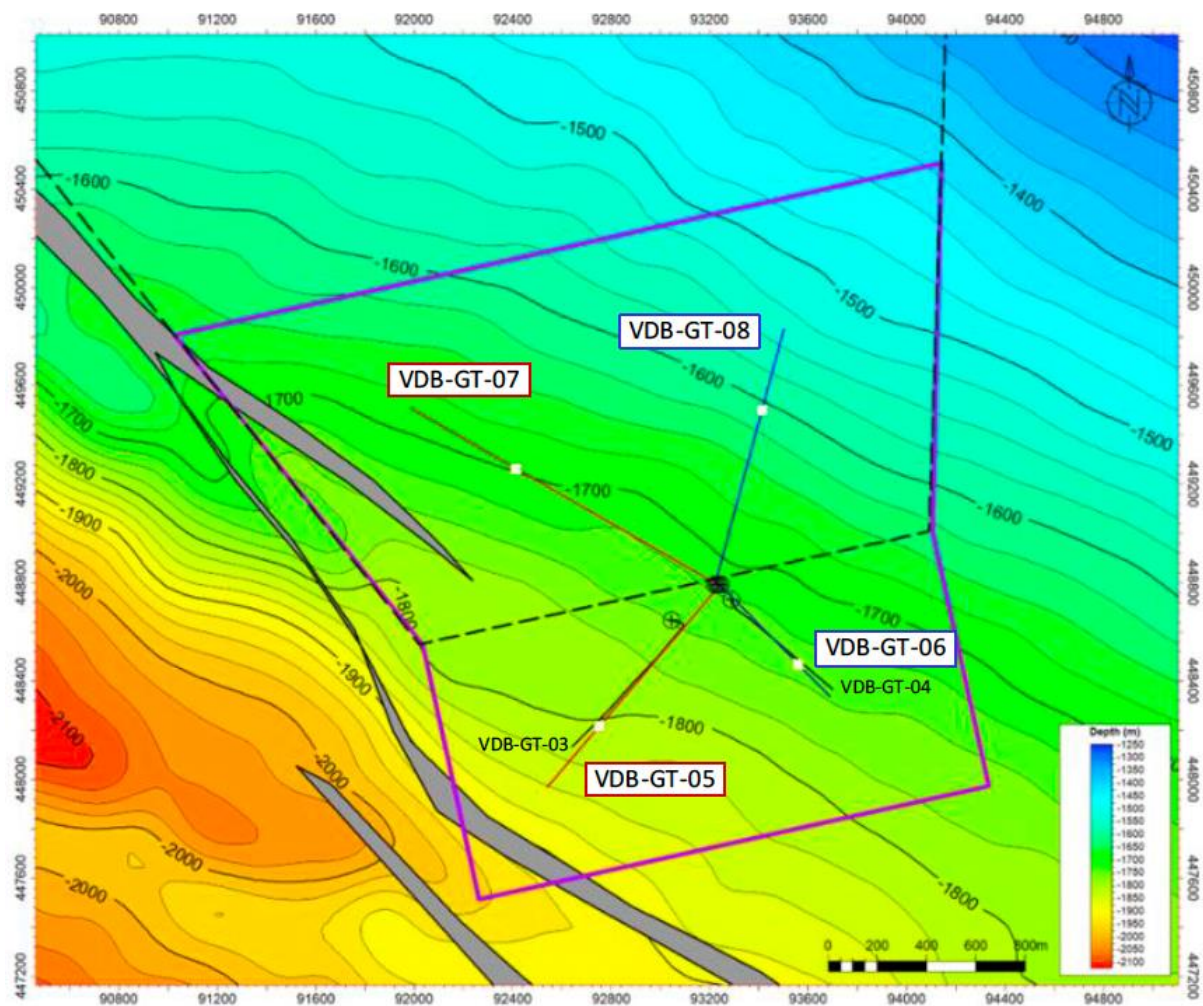


Figure 1. Dieptekaart van de top reservoir (Nieuwerkerk Fm.) met bestaande (VDB-GT-03 /-04) en geplande put (VDB-GT-05 t/m -08) inclusief penetratiepunten top reservoir. Het gebied van de Bleiswijk1b winningsvergunning & Zoetermeer II is aangegeven. 25 meter contour interval met Alblasserdam breuken (Panterra, 2021)

Guidelines for geothermal projects

To assess the risk of local seismicity as a result of the geothermal installation VDB-GT05/VDB-GT-06, the report "Defining the Framework for Seismic Hazard Assessment in Geothermal Projects V0.1" by IF/Q-CON was used (Baisch, et.al, 2016).

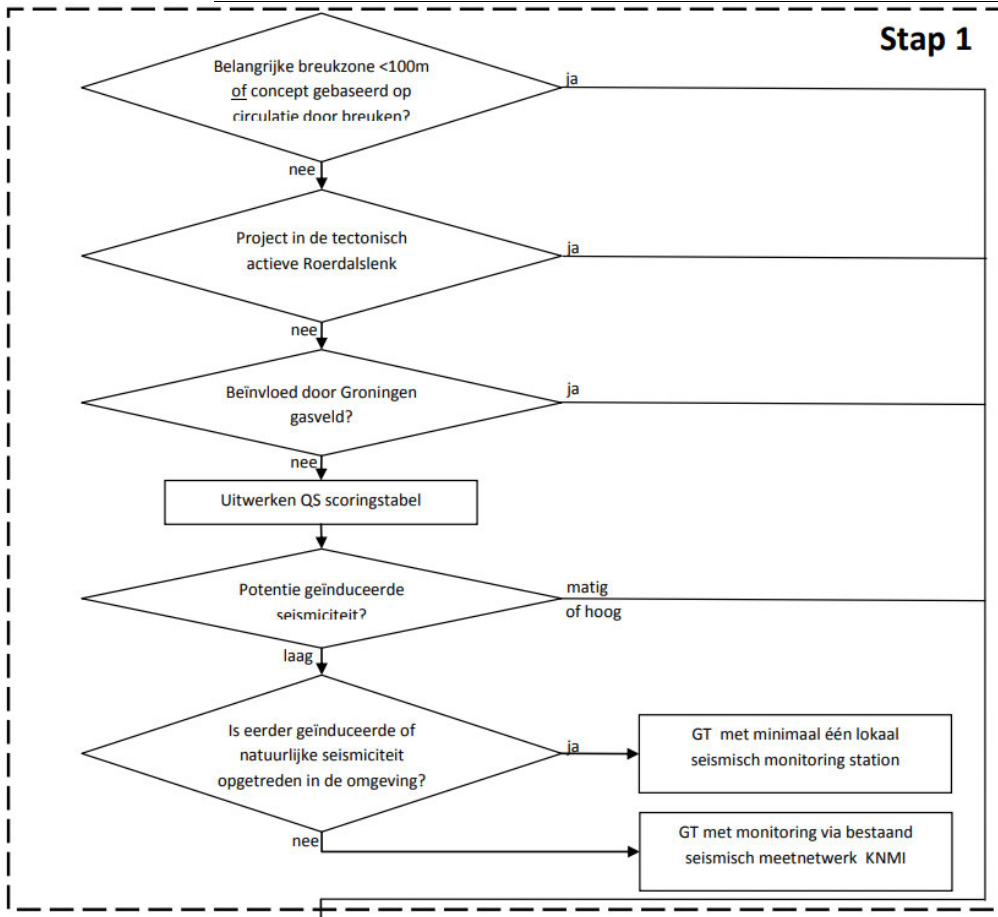


Figure 2. Decision Tree for Level 1 SHA according to the IF/Q-CON Guidelines

With the argumentation in Table 2 the first three questions in the IF/Q-CON decision tree (Figure 1) can be answered with ‘no’.

Table 2: Answers and argumentation for the first three question in the IF Q-CON decision tree leading to the Quicksan scoring.

Decision tree question	Answer Y/N	Argumentation or reference
Distance to major fault zone < 100 m?	No	Producer VDB-GT-05 will keep a minimum distancer of 200m from the nearest fault, whereas injector VDB-GT-06 nearest distance to a fault is 1330m (Panterra 2022)
Project tectonically active area of Ruhr Valley Graben?	No	Doublet VDB-GT05/06 is located in the West Netherlands basin, more than 50 km away from the nearest end of the Ruhr Valley Graben (De Jager, 2007)
Influenced by Groningen Field?	No	Location is 210 km away from e.g. Loppersum (area in middle of Groningen field), Our location is not influenced by the Groningen field.

Results

Seismic Hazard Analysis scoring scheme Quicksan (IF/Q-CON)

Table 1 shows the scoring IF/Q-CON scheme with answers in blue for GT05/06. Below the rationale for each score is discussed.

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 associated with geothermal activity in basement rock. In the Netherlands until this date, no geothermal project has been drilled into basement rock.

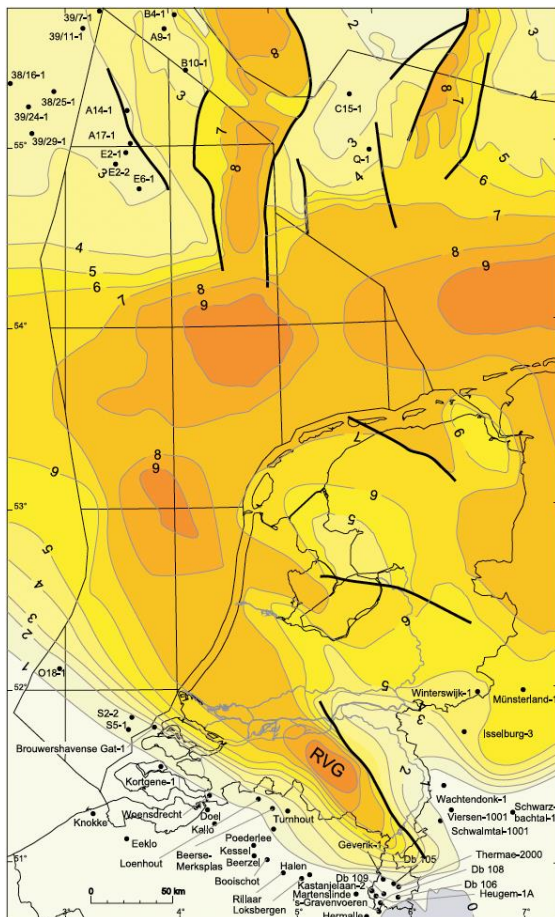


Figure 3 Schematic depth map in kilometres of the top of the pre-Silesian (Geluk et al. 2007)

The depth of the basement is poorly constrained in this area. An estimate of the depth of the basement can be derived from a map of the top of the pre-Silesian presented by Geluk et al. in 2007 (Figure 3). At GT05/06, the basement depth is estimated approximately 7-8 km, some 5 km below the target reservoir. A hydraulic connection between the basement and reservoir through faults cannot be assessed with the 3D seismic dataset at hand. Downward extension of major faults mapped at reservoir level cannot be completely ruled out given the quality loss of the seismic data at deeper levels. Either way, the present-day tectonic inactivity in conjunction with the ~5000m thick

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sedimentary package between basement and reservoir would render pressure communication by direct hydraulic connection highly unlikely. Therefore, this results in a score of "0".

Inter-well pressure communication

The geological study performed in 2021 by Panterra demonstrated that both wells will be drilled in the same fault block and that the maximum horizontal distance of 1074m between the wells is at their TD locations. The drilling trajectories (Figure 4) have a 945m horizontal distance at the Top Delft reservoir penetration points (Panterra, 2021).

The doublet VDB-03&VDB-04 has been producing heat from the same Delft reservoir for 7 years and the stable production pressures and flow rates demonstrated that the injector had good pressure communication with the producer over these years (Willems, 2012). All doublets in the region have demonstrated inter-well communication. As a result, injector-producer communication is therefore very likely, but not proven, for GT05/06 and a score of "3" is proposed.

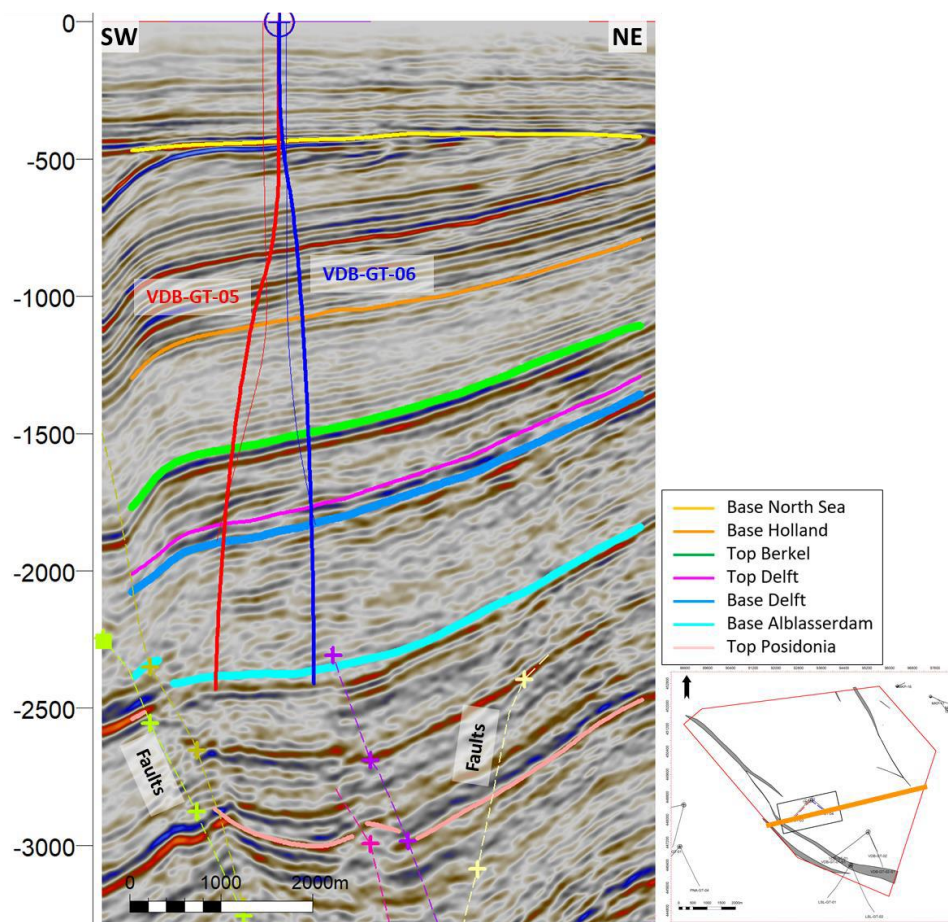


Figure 4 SW-NE seismic cross-section cutting through the TD locations of the planned producer (thick red line) and injector (thick blue line) wells (Panterra, 2021)

Re-injection pressure

The re-injection pressure and injector VDB-GT-06 will be kept to maximum of 40 bar (IPS Geothermal, 2023). This results in a score of "3" (1-4Mpa or 10-40bar).

Flow rate

For the high case scenario flow rate is kept to a maximum of 359m³/hour in (IPS Geothermal, 2023). This results in a score of "7" (180-360 m³/h).

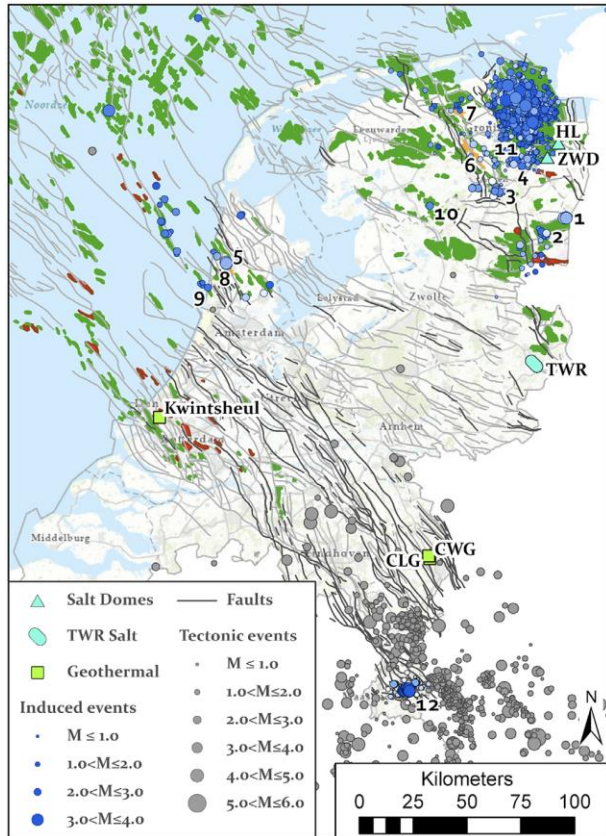


Figure 5 Overview of seismicity in the Netherlands (Muntendam-Bos et al., 2022). The natural seismicity is indicated by grey circles, induced seismicity as recorded by the national KNMI network by blue circles (www.knmi.nl, January 1, 2021). The dark grey lines indicate potentially tectonically active faults; the light grey lines indicate faults in the Permian formations (www.nlog.nl). Oil and gas fields are denoted in red and dark green, respectively; the underground gas storage (UGS) gas fields in orange (www.nlog.nl)

Seismicity in the area

Figure 5 shows the recorded natural and induced seismicity in the Netherlands (Muntendam-Bos et al., 2022). The nearest recorded seismicity (either induced or natural) is approximately 15 km away from the GT05/06 location. According to Muntendam-Bos et al. (2022) this event was recorded by a seismic array installed at the geothermal operation of Nature's Heat at Kwartsheul, the Netherlands. The event may have been induced by the geothermal operations, however, at this stage it cannot be ruled out that this event is tectonic either. The next closest tectonic event is 50 km away and the next closest induced event is 60 km away, both northwards from GLT05/06.

Based on these observations, the distance to an epicentre of a natural or induced earthquake is established to be more than 10 km and results in a score of "0".

Regional fault properties

GR05/06 is covered by 3D seismic data. Seismic interpretation and generation of depth and thickness maps was carried out in Petrel 2019 as part of the Zoetermeer study on the NAM reprocessed depth cube (2018) as described in the SDE++ Geological Study Bleiswijk 1b (Panterra 2021).

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A distance to faults study was subsequently carried out for GT05/06 (Panterra, 2022) and established that the planned well path of the producer VDB-GT-05 will reach its minimum distance of 200m to the nearest "F01-De Kievit" fault at the base of the Alblasterdam reservoir. The study showed that the injector VDB-GT-06 will only reach a minimum distance of 1330m from the same fault at the same stratigraphic level.

As the scoring is based on the injector (VDB-GT-06), which is located at a minimum distance of 1330m from faults, the resulting score in table 1 is "3" (distance between 0.5 and 1.5 km).

Current stress field

The map in Figure 6 shows the location of GT05/06 with respect to in-situ stress data from the World Stress Map (Heidbach et al., 2018), while a rose diagram from the Dutch Stress Map shows the horizontal stress direction of the Schieland group (Mechelse, 2017). These measurements represent the orientation of the maximum horizontal stress, S_H , interpreted from well data in several geological formations.

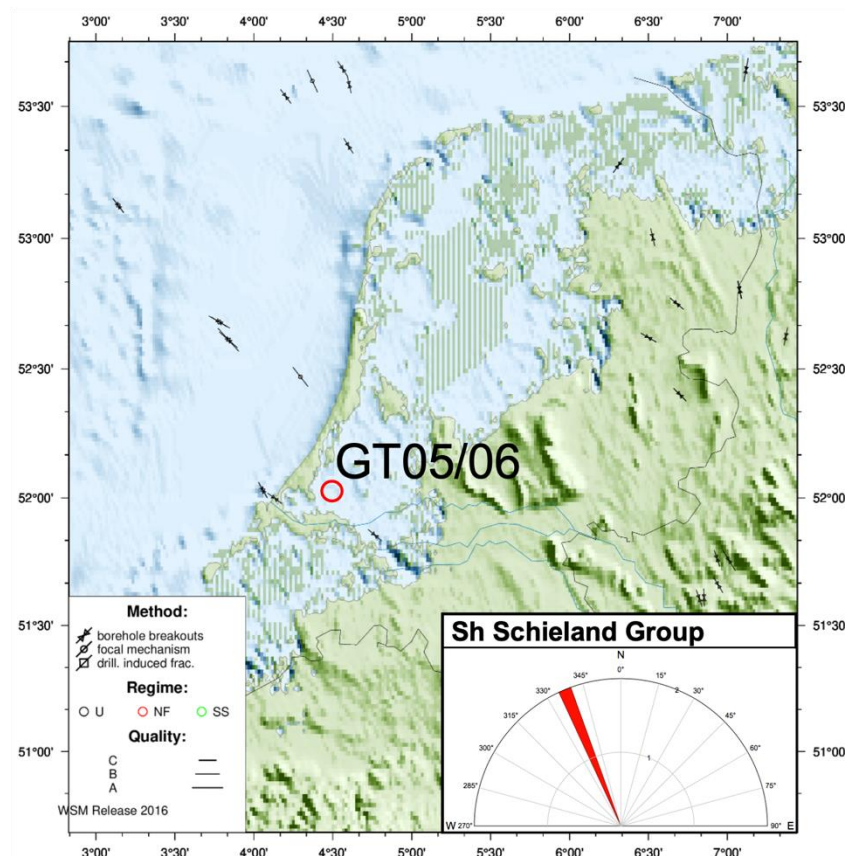


Figure 6 Stress map of Netherlands for all units. Map data is from the World Stress Map (Heidbach et.al, 2018). Rose diagram of Sh by Mechelse (2017).

A difference of 25-30° is noted between borehole breakouts nearest to the GT05/06 area (310°; world stress map) and the range of stresses recorded in the Schieland Group (335-340°; Dutch stress map).

The dominant orientation of the nearby faults varies from 300-330° (Figure 3), which in combination with the uncertainty range of the orientation in the current stress field could result in a favourable orientation for shearing

Net injected volume

Since the GT05/06 doublet will be based on mass-balanced fluid flow, the net injected volume is zero, yielding a score of “0” (<100 m3).

Additional argumentation

The suggested points below could further could lower the view on seismicity risks, and perhaps in future lower the score as more data becomes available.

- The doublet VDB-GT03/VDB-GT-04 has been in production with the Delft as reservoir between 2010 and 2019 and there are no known adverse effects;

Conclusions

This Seismic Hazard Analysis is focussed on the IF/Q-CON framework for geothermal projects. Based on this, the weighted score for the IF/Q-CON quickscan for the GT05/06 geothermal project is 0.28, which is associated with the low seismicity potential range (Table 1).

Nederlandse samenvatting

Voor de ontwikkeling van aardwarmte in de Bleiswijk 1b vergunning is een Level-1 (Quick-Scan of QS) Seismic Hazard Analysis ("SHA") uitgevoerd om de risico's van seismiciteit tijdens de geothermische ontwikkeling van doublet VDB-GT-05/ VDB-GT-06 te beoordelen en te kwantificeren. Dit is gedaan op basis van het protocol van IF Technology B.V. en Q-CON GmbH (Baisch et al., 2016). Dit SHA-rapport beschrijft de resultaten zoals deze zijn opgesteld voor doublet VDB-GT-05/ VDB-GT-06 op basis van de huidige kennis en houdt zich aan de eerdergenoemde richtlijnen. Het doublet bevindt zich in de opsporingsvergunning Bleiswijk 1b (in dit rapport aangeduid als "GT05/06"). De gebruikte operationele parameters zijn gebaseerd op het hoge productie scenario van het *Winningsplan aardwarmte Versie 2.0 Bleiswijk1b-VDB-GT-05/-06* (IPS Geothermal, 2023) met een debiet van 359 m/uur en een injectietemperatuur van 15°C.

Het IF/Q-CON protocol beschrijft een reeks criteria die seismische risico's kunnen veroorzaken. Voor GT05/06 is elk van deze criteria geëvalueerd. De resultaten worden gepresenteerd in een scoretabel waarin de scores voor de individuele criteria zijn genormaliseerd (tabel 1). De resulterende gewogen score is 0,29, wat in het laag risico gebeid valt.

Geïnduceerde seismiciteit wordt veroorzaakt door een verandering in de in-situ spanningstoestand. De spanningstoestand van een geothermisch reservoir wordt beïnvloed door poro-elastische en thermo-elastische effecten. De drukveranderingen gerelateerd aan poro-elastische effecten treden voornamelijk op in de buurt van de productie (afname) en injectie (toename) en nemen snel af weg van de putten. Na de eerste productie zal een evenwicht tot stand komen doordat er een evenwicht tussen de geïnjecteerde en de geproduceerde volumes wordt gehandhaafd. Als er in die beginfase geen seismiciteit is opgetreden, zijn de risico's sterk verminderd. Er zijn waarnemingen gedaan met betrekking tot seismiciteit tijdens de exploitatie van doublet VDB-GT-03/VDB-GT-04, waar warmte uit het Delft reservoir werd gewonnen in dezelfde winningsvergunning Bleiswijk 1b tussen 2010 en 2019. Hoewel de doublet VDB-GT-05/VDB-GT-06 zowel uit het Delft als het Alblasserdam reservoir zal produceren, geven de goede ervaringen met productie en injectie in het Delft reservoir met doublet VDB-GT-03/VDB-GT-04 extra vertrouwen om seismiciteitsrisico's hier als laag in te schatten.

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