Geological evaluation for the seismic acquisition programme for SCAN areas F (Oost-Brabant and Noord-Limburg) and G (Zuid-Limburg)

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Authors:

Henk van Lochem (EBN/Argo), Marten ter Borgh (EBN) & Harmen Mijnlieff (TNO)

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Reviewers:

Stefan Carpentier (TNO), Nico Holleman (EBN), Bastiaan Jaarsma (EBN), Henk Koster (EBN), Kees van Ojik (EBN), Johan ten Veen (TNO), Hans Veldkamp (TNO) & Geert-Jan Vis (TNO)

Dit rapport is een product van het SCAN-programma en wordt mogelijk gemaakt door het Ministerie van Economische Zaken en Klimaat

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Inleiding en duiding

Voor u ligt één van de geologische evaluaties van het SCAN programma, zoals deze in juni 2019 is vastgelegd. Deze inleiding en duiding is later toegevoegd om de actualiteit te kunnen toevoegen en duiding te geven aan het rapport.

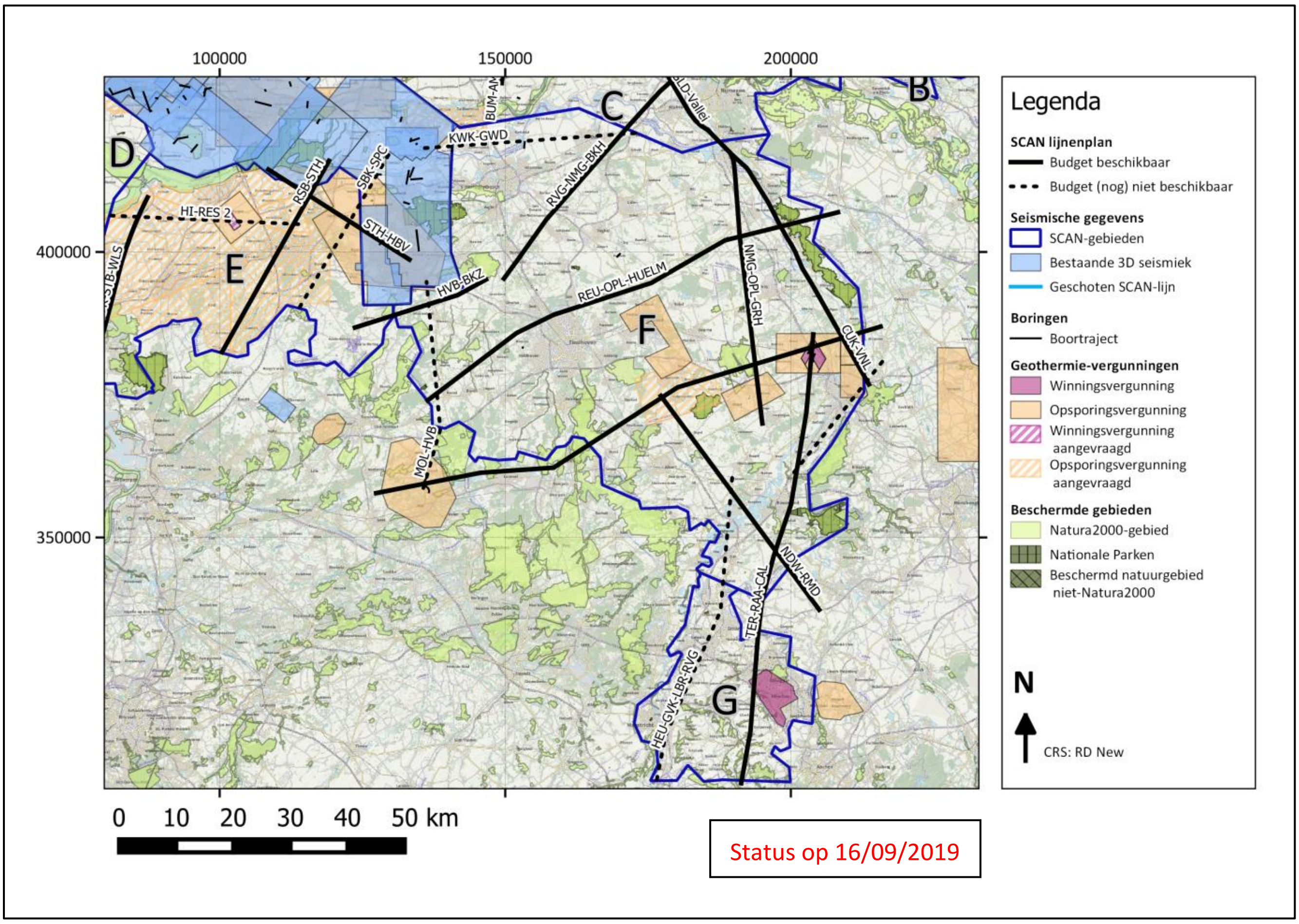
Om het acquisitieplan voor de SCAN 2D seismische lijnen te kunnen bepalen zijn door geologen en geofysici ondergrondevaluaties gemaakt van de verschillende SCAN-gebieden. Hierbij is gelet op welke delen van de ondergrond de beste kansen bieden voor geothermische projecten en welke informatie nog ontbreekt voor een goede evaluatie. Per (mogelijk) geothermische play is aangegeven welke gegevens en werkprogramma's nodig zijn om vast te stellen of de betreffende play al dan niet een interessant doel kan zijn voor geothermische boringen. Bij het opstellen van deze plannen en voorgestelde werkprogramma's is in eerste instantie vooral gekeken naar de technische bruikbaarheid en noodzakelijkheid, en minder naar een kosten-baten analyse van deze plannen. Voor elk SCAN-gebied (of combinatie van SCAN-gebieden) is op deze wijze een 2D seismisch lijnenplan gemaakt dat het beste de lacunes in de huidige 2D seismisch dataset, zowel in kwaliteit als kwantiteit, zou kunnen opvullen. Het rapport hierover en het voorgestelde acquisitieplan is vervolgens voorgelegd aan geologen en geofysici van EBN en TNO, die niet direct bij de evaluatie van het SCAN-gebied betrokken waren geweest. Op basis van de opmerkingen en aanvullingen van deze peer-reviewers zijn de plannen en rapporten waar nodig aangepast en afgerond. Het onderliggend rapport voor gebied F&G is het resultaat zoals dat op 28-06-2019 was afgerond. Om de informatie voor zoveel mogelijk geïnteresseerden toegankelijk te maken zijn de rapporten in het Engels geschreven, wat de meest gangbare taal is voor het geologische/geofysische vakgebied.

Nu alle rapporten en plannen afgerond zijn kan het totaal van de aanbevelingen hierin als "Best Technical Programme" worden gezien. Het Best Technical Programme is het acquisitieplan dat het meeste kans heeft om alle openstaande geologische vragen te beantwoorden. Echter, voor de 2D seismische acquisitie van het SCAN-project is er een beperkt budget beschikbaar bij het Ministerie van Economische Zaken en Klimaat. Op basis van de (veronderstelde) kosten van de seismische acquisitie is de verwachting dat voor het beschikbare budget niet het gehele "Best Technical Programme" kan worden uitgevoerd.

Om te bepalen welke seismische lijnen prioriteit hebben is een ranking van alle lijnen verricht. Deze ranking is onder andere gebaseerd op de volgende parameters: aantal mogelijk aanwezige primaire en secundaire plays, de dichtheid en kwaliteit van de seismische data in het gebied, de aanwezigheid van warmtevragers en de inpassing van lokale seismische initiatieven. Op basis van deze ranking wordt bepaald welke seismische lijnen met het beschikbare budget kunnen worden geacquireerd, terwijl de andere lijnen alleen zullen worden geacquireerd bij meevallende kosten of als aanvullend budget beschikbaar komt.

Na de acquisitie in het voorjaar van 2019 van een testlijn tussen Utrecht en Almere (deel van lijn EVD-UTR-BLA) om de acquisitieparameters in detail te bepalen, is besloten het programma verder te vervolgen in het oostelijk deel van SCAN gebied C. Op basis van de daar uitgevoerde terreinonderzoeken zijn enkele voorgestelde lijnen deels aangepast. Ook in sommige andere gebieden zijn er enkele kleinere aanpassingen gemaakt ten opzicht van het voorgestelde lijnenplan en ook in de toekomst zullen andere aanpassingen volgen nadat lokaal terreinonderzoek is verricht.

Op de kaart op de volgende bladzijde is de status van het lijnenplan van SCAN gebied F&G van heden weergegeven met inbegrip van de ranking van de lijnen. Op de website van SCAN (www.scanaardwarmte.nl) kan de status van de opname van de lijnen worden gevolgd.



Kaart met de status van het lijnenplan in de SCAN-gebieden F&G op 16/09/2019. Voor de lijnen die in doorgetrokken streep zijn weergegeven is met de huidige kostenverwachting budget voor acquisitie beschikbaar, voor lijnen die gestreept zijn weergegeven is met de huidige kostenverwachting geen budget beschikbaar.

Contents

1. Introduction to the SCAN project

In order to achieve the goals of the Paris Treaty and limit global warming a shift from fossil towards renewable energy resources is required. Geothermal energy is a proven and promising renewable energy resource. To successfully and safely plan, fund and execute geothermal projects subsurface data is essential. Presently producing geothermal projects in the Netherlands are generally located in areas where abundant subsurface data is available (Figure 1).

Although subsurface data availability in the Netherlands is excellent, the data is not well distributed over the country; data coverage is poor in roughly half of the country, including major residential and industrial areas with high heat demand (Figure 1). As a result, effective and economically feasible development of geothermal projects is not possible under the current circumstances in these areas. A framework study was carried out to identify what data acquisition is required to overcome this limitation (EBN–TNO-AGE, 2017). Subsequently, EBN and TNO-AGE have been asked by the Ministry of Economic Affairs and Climate to embark on a geothermal exploration program (SCAN: *'Seismische Campagne Aardwarmte Nederland'*) to decrease the subsurface uncertainty and hence shape the conditions needed for the successful development of geothermal projects in these areas.

The most important subsurface parameters that need to be known for the successful development of a geothermal project are permeability, thickness and depth of the aquifer. These parameters can be derived from seismic and well data (Table 1) (EBN – TNO-AGE, 2017). The SCAN project will therefore comprise acquisition of new 2D seismic data, reprocessing of vintage seismic data and drilling of new wells in areas with relatively low data availability. Nine such areas have been identified (Figure 1). The areas were prioritized based on the expected future heat demand. Area F, which comprises major urban centers such as Den Bosch, Eindhoven, Helmond, Weert, Venlo and Roermond, was identified as an area of the highest priority. Area G includes the cities of Maastricht, Sittard, Heerlen and Kerkrade, however, initial assessment prognosed a lower subsurface potential than area F. This report discusses both areas F and G, which have been evaluated together since their geological history and make-up is quite comparable. The combined area will be called 'Area F&G' in this report.

This document outlines the geological objectives and design criteria (position and orientation) for the 2D seismic acquisition ("Acquisitieplan" in the tentative planning, EBN, TNO-AGE, 2017, appendix 6). More potential future work other than the seismic acquisition is presented in this report. This includes geological and geophysical studies, seismic reprocessing and the drilling of exploration wells to test the stratigraphy and/or sedimentology. It should be noted that this work will be subject to further detailed review but is presented here only to give the proper setting for the 2D seismic acquisition plan.

Information	2D-Seismic data	3D-Seismic data	Well
Economical evaluation: presence and quality of aquifer, temperature			
Presence, continuity, depth and thickness aquifer	+	++	+++
Porosity	–	+/–	+++
Permeability (transmissivity)	– –	– –	+++
Temperature	+	+	+++
Safety, well planning and regional geological knowledge			
Regional geological model	++	+++	++
Presence of faults	+	+++	+/–
Character of overburden on well trajectory	+	++	+
Risk-assessment of presence of hydrocarbons	+	++	+/–
Water composition	– –	– –	++

Table 1 – data-acquisition methods and information resulting from these methods. Legend: –––: produces no or inaccurate information, +++: results in much, accurate information.

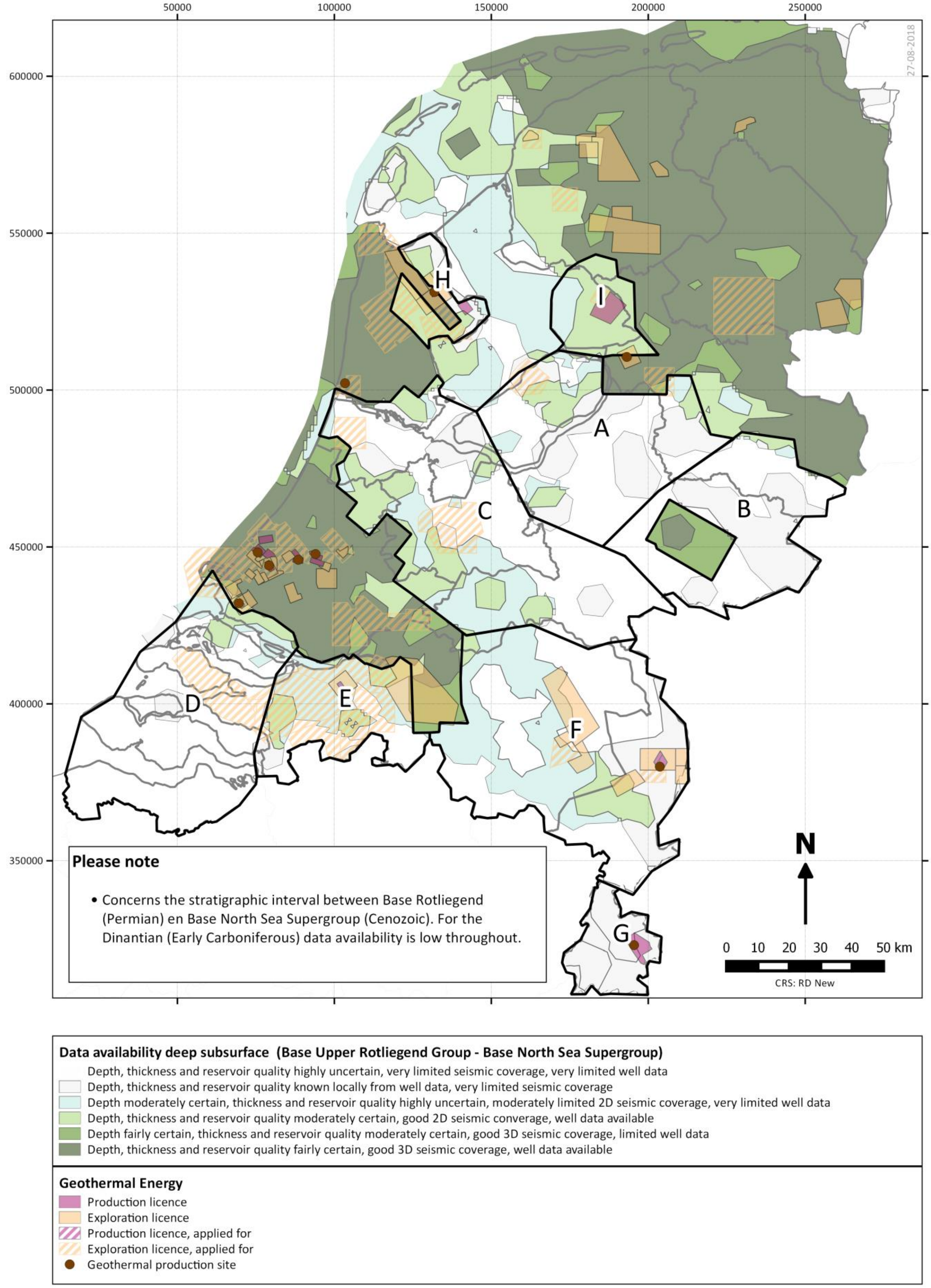


Figure 1 – SCAN areas, geothermal licences and producing geothermal installations (after EBN -TNO-AGE 2017).

2. Geological overview of SCAN area F&G

The stratigraphic interval of interest for geothermal purposes ranges from Lower Carboniferous (Dinantian) carbonates at a depth of approximately 4500–6000 m to Cenozoic sands as shallow as 300 m below ground level (excluding strategic ground water reservoirs). In the east and south of the province of Zuid Limburg even older Paleozoic rocks (Devonian and Cambro-Silurian) are relatively close to surface (NITG-TNO, 1999) and could form a potential target. The primary targets for geothermal projects in the area are provided by Lower Carboniferous carbonates and Triassic Röt and Buntsandstein sandstones (Figure 2). Cenozoic sands in the Roer Valley Graben may prove a primary target for low temperature geothermal systems and/or high temperature storage applications, whereas in the former coalmining area of Zuid Limburg water production from abandoned mines could take this role. Secondary targets include Upper and Lower Cretaceous sandstones, Upper Jurassic sandstones, Middle Jurassic limestones, Zechstein carbonates and the pre-Dinantian interval.

Within area F&G the following structural elements (Van Adrichem Boogaert & Kouwe, 1993–1997) can be distinguished for the Mesozoic–Cenozoic tectonostratigraphic evolution of the area (*Figure 3*):

- The central part of the Roer Valley Graben (RVG);
- The northern area is called the Peel-Maasbommel Complex (PMC);
- The area south of the Roer Valley Graben is the northern flank of the London-Brabant Massif, which is sometimes named in literature the Zeeland High (ZH) in the west or the Limburg High (LH) in east.

Another important structural element is the Paleozoic Campine Basin, in which a thick package of Upper Carboniferous sediments was deposited north of the London-Brabant Massif. During Upper Cretaceous the Roer Valley Graben was inverted and a period of non-depostion and/or erosion prevailed. Outside the Roer Valley Graben Upper Cretaceous deposits have been preserved, which include a large portion of siliciclastics next to the Roer Valley boundary faults. The Upper Cretaceous is especially thick on the Maasbommel High. The Paleogene Voorne Trough just extends into the west of area F, resulting in a thicker Lower North Sea Gp. in this area. Since the Oligocene onwards the Roer Valley Graben rapidly subsided along its boundary faults. Also, during this time, the Peel Block and Venlo Block were created, bounded by the Tegelen and Viersen Faults.

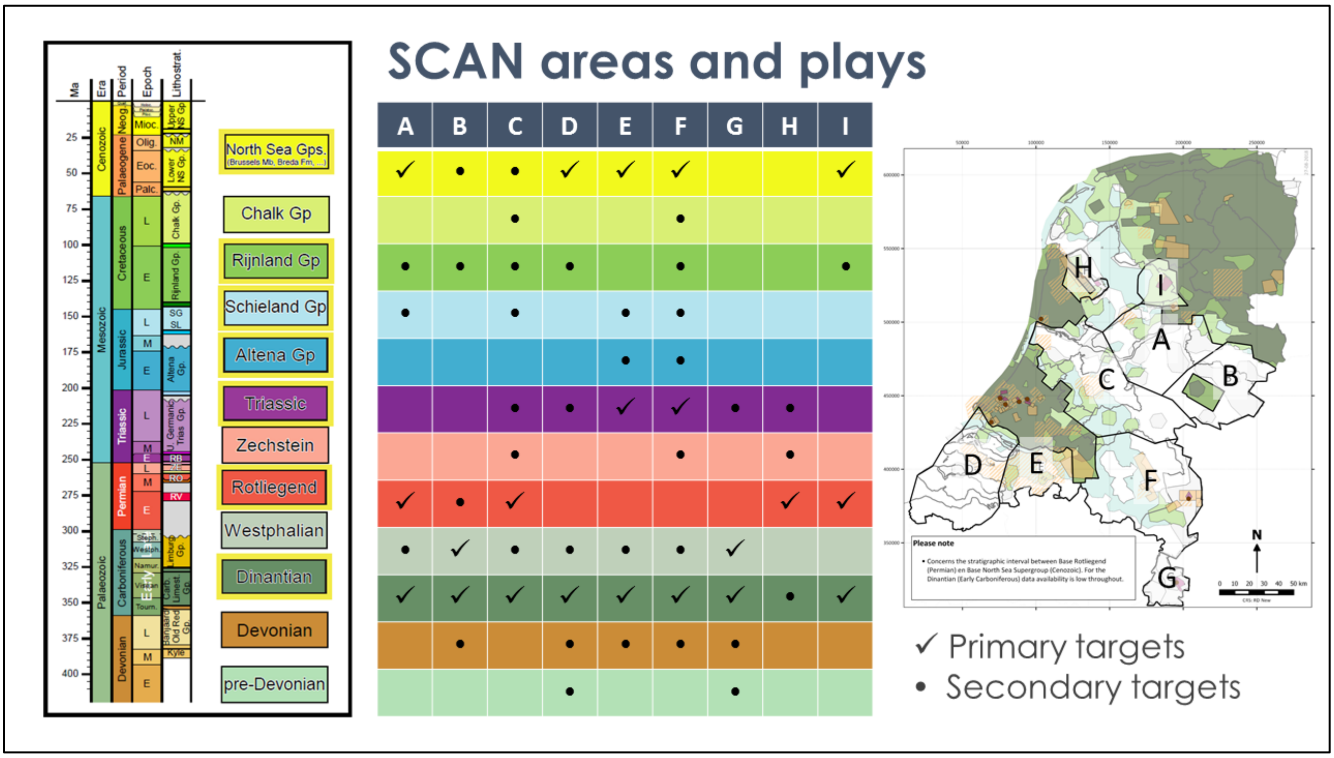


Figure 2 – Overview of the primary and secondary targets in the SCAN areas.

2.1 Stratigraphic Section

From old to young the stratigraphy relevant to geothermal projects in area F&G is expected to consist of:

- A thick Early Paleozoic section which consists of Cambrian to Silurian rocks (Figure 5; Cambro- Siluur), which form the core of the Brabant Massif. In Belgian outcrops and subsurface these rocks have a metamorphic character (Herbosch & Verniers 2015). The Cambro-Silurian is present at shallow depths (400-1500m) below the southern part of Zuid Limburg, from Maastricht to Vaals.
- Devonian (Figure 5; Devoon) sandstones and carbonate reefs are known to exist in Belgian outcrops. They directly overlie the Caledonian Unconformity. In the Californië (CAL-GT) wells, near Venlo and in well KSL-02 in Maastricht Devonian sandstones are found to be present in area F&G.
- Lower Carboniferous (Dinantian) carbonates (Figure 5; Kolenkalk) and shales. On the seismic data of area F&G the top of the Dinantian limestone can be recognized on some lines. The Dinantian is found in the Californië (CAL-GT) wells near Venlo at a depth of 1200-1600m, whereas the formation was encountered in wells at around 100m depth south of Maastricht to around 1000m in well GVK-01.
- An Upper Carboniferous siliciclastic sequence (sandstones, claystones and coal) (*Figure 4*; Limburg Groep, Figure 5; Dinkel, Caumer and Geul Subgroeps). The top of the Upper Carboniferous sequence was eroded during the Variscan orogeny resulting in a significant time gap between the Carboniferous and overlying Permian sediments represented by the Base Permian Unconformity. In the south and east of area F&G the Base Cretaceous Unconformity (BCU) cuts down into the Upper Carboniferous.

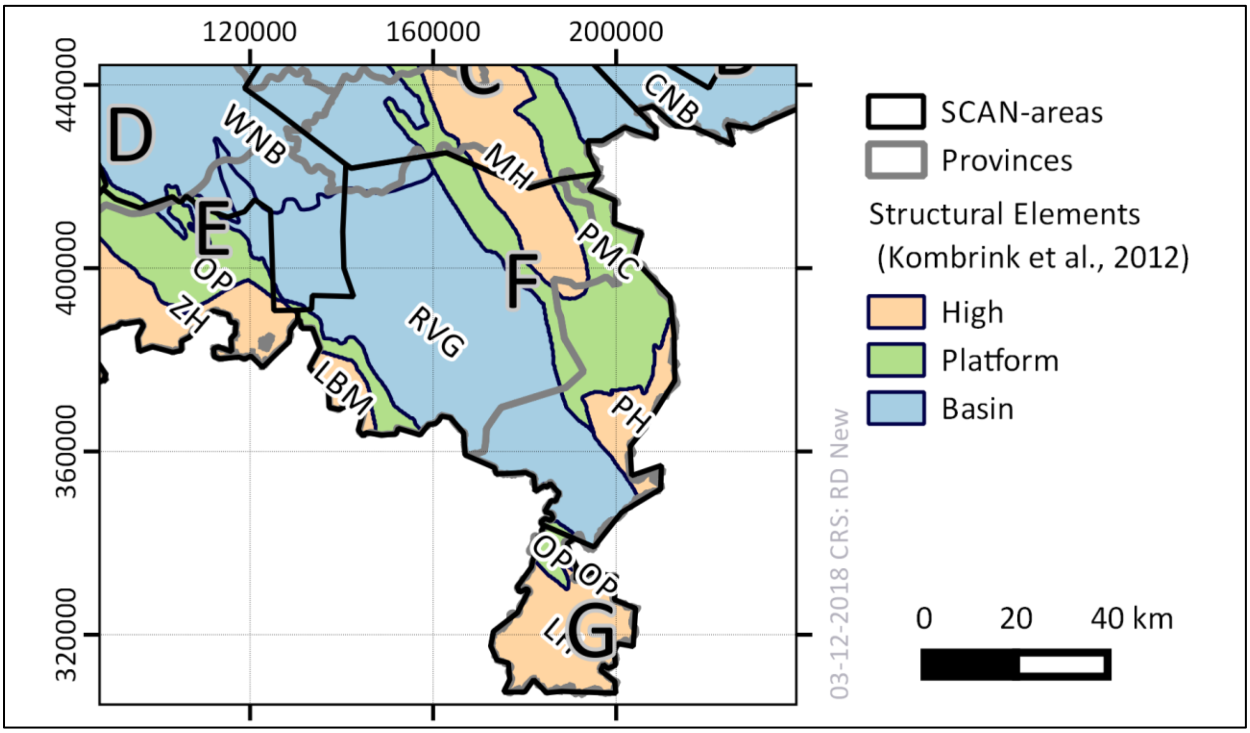


Figure 3 – Late Jurassic – Early Cretaceous structural elements in and around SCAN area F&G after Kombrink et al. (2012), CNB – Central Netherlands Basin, LBM – London–Brabant Massif, LH – Limburg High, MBH – Maasbommel High, OP – Oosterhout Platform, PH – Peel Block, PMC – Peel–Maasbommel Complex, RVG – Roer-Valley Graben, WNB – West Netherlands Basin, ZH – Zeeland High

- The Permian Rotliegend Slochteren Sandstone interval (*Figure 4*; Boven Rotliegend) overlies the BPU. In area F&G the Rotliegend sandstone is at the edge of the basin and, if present, only a few meters thick. Only in the north of area F in well KWK-01 a thickness of nearly 50m is reached.
- The Permian Zechstein interval (*Figure 4*) is a thin sequence, deposited at the fringe of the basin. Only around the Maasbommel High a thicker mixed lithology can be expected.
- The Lower Germanic Trias Group (*Figure 4* & Figure 5; Onder Germaanse Trias Groep) comprises the Lower Buntsandstein Formation and the Main Buntsandstein Subgroup. The Main Buntsandstein consists of a thick package of sandstones interbedded by thinner claystones. The Lower Buntsandstein, here located at the southern edge

of the Triassic basin, has a sandier facies compared to the common lacustrine claystone and thin oolitic limestones present further to the north.

- The Upper Germanic Trias Group (*Figure 4* & Figure 5; Boven Germaanse Trias Groep) comprises sandstones, claystones, carbonates and evaporites (predominantly anhydrites). The Röt interval does not contain evaporites, which characterize Rot sediments further towards the North, but here, at the basin fringe, a sandstone with good reservoir potential is found.
- The claystones of the Lower Jurassic Altena Group (*Figure 4* & Figure 5). In area F&G, they are only preserved in the Roer Valley Graben. In the northwestern corner of area F the limestone intervals in the Brabant Fm may have a geothermal reservoir potential.
- A thick package of Upper Jurassic Schieland Group sandstones and claystones (*Figure 4*). These are only present in the northwestern corner of area F in the Roer Valley Graben and unconformably overlie the Altena Gp. or older sections.
- The presence of the Lower Cretaceous Rijnland Group in area F&G (*Figure 4*) is limited to the Maasbommel High. However, since it has not been drilled, the presence of this formation and the lithology of the section is unknown.
- The Upper Cretaceous Chalk Group (*Figure 4* & Figure 5; Krijtkalk Groep). Despite its name, not only chalky limestone but, next to the tectonically inverting Roer Valley Graben, also siliciclastic sediments were deposited. In the Roer Valley Graben itself only a thin Danian Chalk interval is found. A thick package of Upper Cretaceous sediments is present on the Maasbommel High.
- The Lower and Middle North Sea Groups (*Figure 4* & Figure 5; Onder- en Midden-Noordzee Groep). This interval consists primarily of unconsolidated sands, sandstones and claystones and it thickens into the Roer Valley Graben and the southeastern extension of the Voorne Trough.
- The youngest sediments, the Upper North Sea Group (*Figure 4* & *Figure 5*; Boven-Noordzee Groep). These consist mainly of marine sands and claystones, but fluvial and estuarine sands and lignite can be found in the Roer Valley Graben as well. The interval is very thick (up to 1200m) in the Roer Valley Graben but is only a few hundred meters on the Peel and Venlo Blocks.

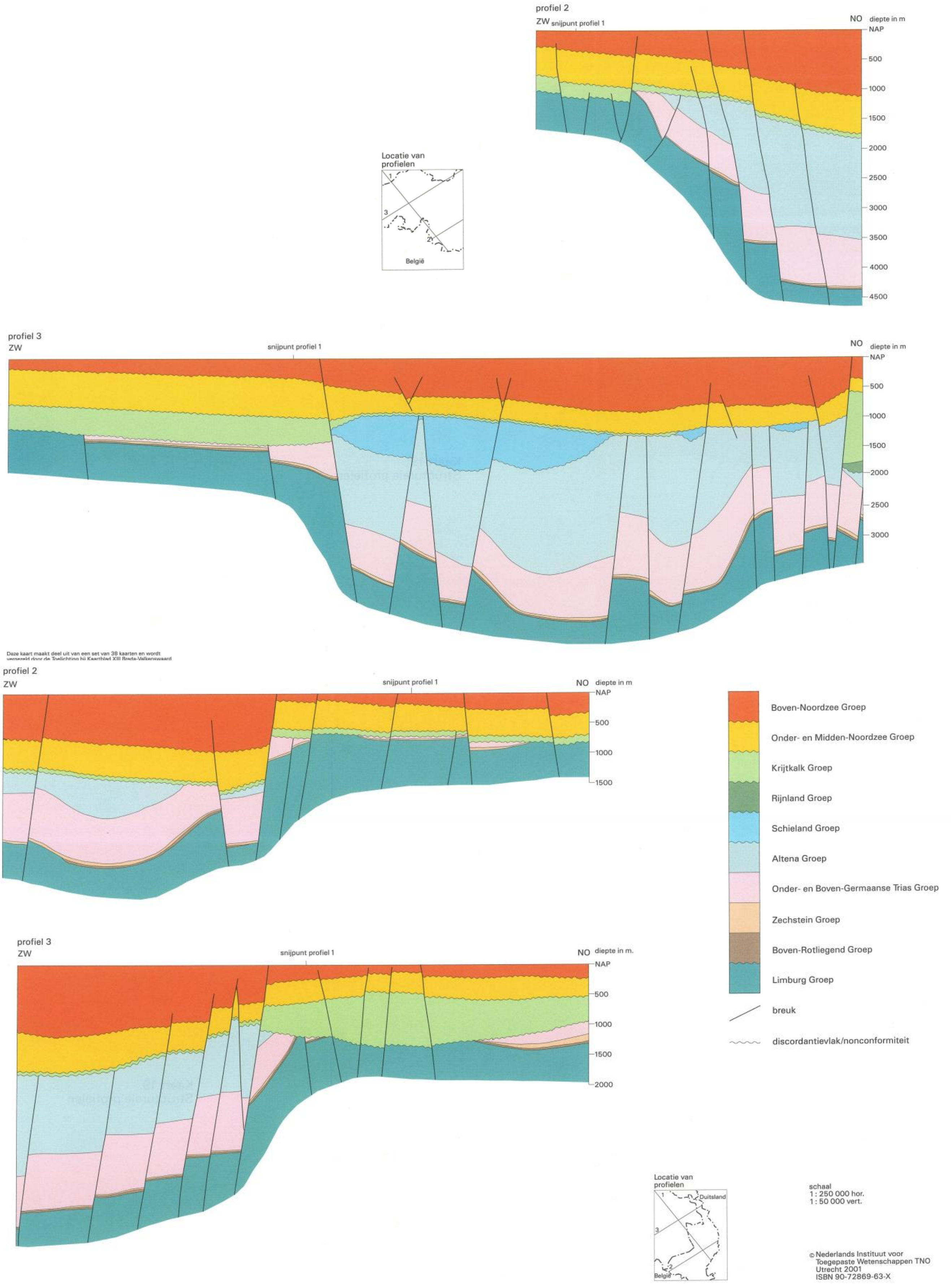


Figure 4 - Cross sections through area F (TNO-NITG, 2001).

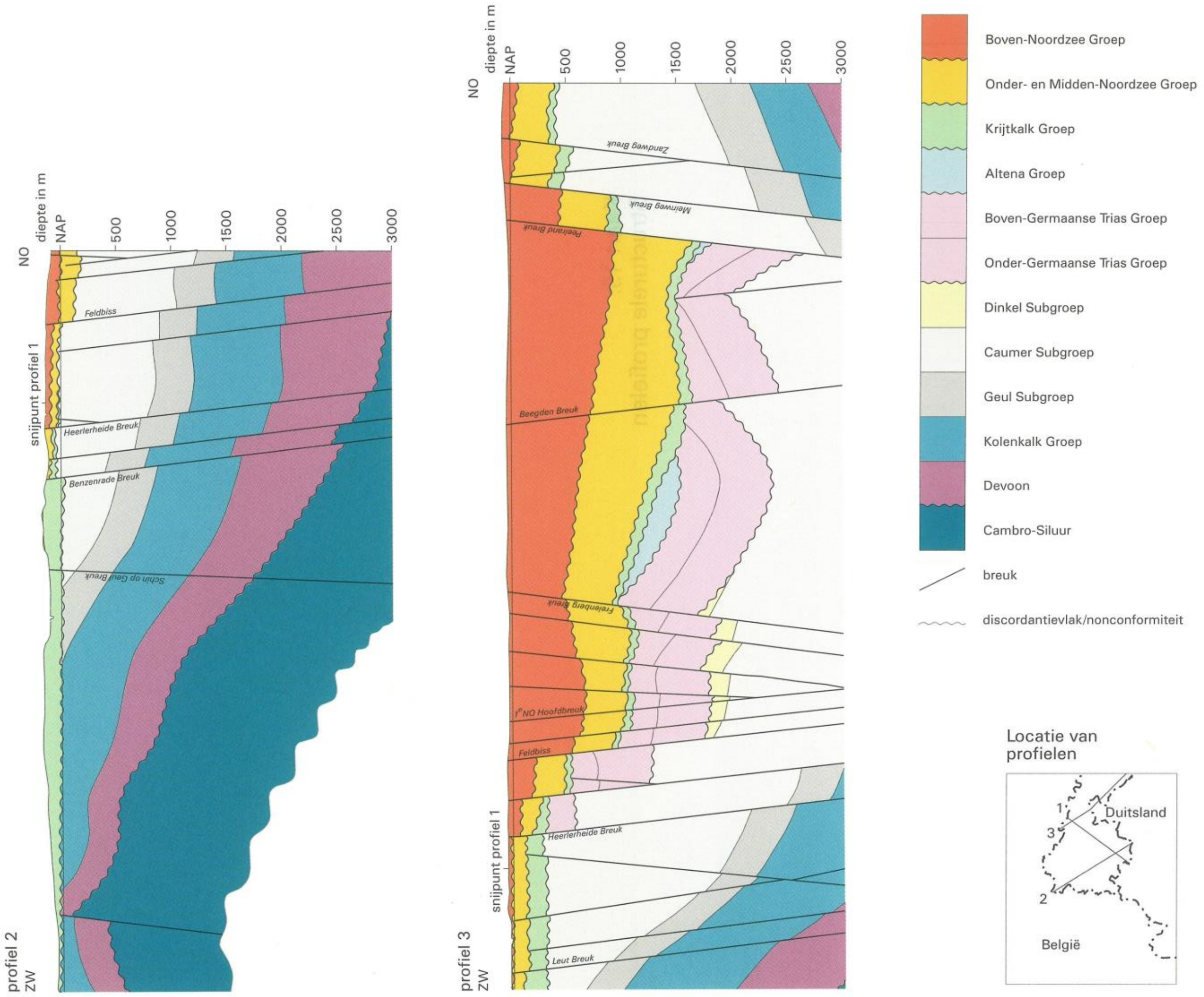


Figure 5 - Cross sections through area G (NITG-TNO, 1999).

2.2 Structure

The sequence of tectonic events, also applicable to area F&G, from Devonian times onwards is well summarised in De Jager (2007). The main NW-SE structural trend is interpreted to originate from the Caledonian tectonic event of mid-Palaeozoic times. The structural style at that time is considered to be a horst and graben configuration in an overall NE-SW extensional setting. The horsts and grabens were separated by major NW-SE trending normal fault systems with significant throw, which are expected to root in the basement.

These Caledonian fault systems were reactivated during Variscan and Alpine orogenic events, and in intermediate rifting events; each event under different stress-regimes: in orientation, strength and nature (compressive or extensional). For example, in the period from Mid/Late Jurassic until Late Cretaceous times, in the last phase of Pangean breakup, an extensional to transtensional regime resulted in the formation of the Mesozoic Basins (Broad Fourteens Basin, West Netherlands Basin, Roer Valley Graben) and intermediate platforms and/or highs. The subsequent Alpine tectonic events in which the Alpine stress regime forced oblique-slip movement along the old Caledonian faults resulted in, amongst others, thrust faults and flower structures in the Late Palaeozoic to Cenozoic sedimentary overburden.

For the development of geothermal systems and hazard assessment it is of utmost importance to have a good understanding of the structural evolution and architecture of the subsurface of area F&G, in an adequate detail. This requires a detailed interpretation of the structural and stratigraphic framework, for which control from seismic and well data is essential. These constraints are needed at least down to the top of the Dinantian, which is expected to be present at a depth of 1 to 6,5 km in area F&G.

From regional maps it appears that the structural architecture of area F&G is dominated by NW-SE trending horst and graben faults. However, the current fault mapping is simplified by the fact that correlating faults using only 2D data is difficult and is prone to aliasing.

From the 2D seismic data that is available in area F&G it can be inferred (*Figure 4* & Figure 5) that in this area:

1) The Cenozoic is faulted by large continuous NW-SE trending normal faults mostly stepping down to the axis of the Roer Valley Graben. North of the Roer Valley Graben the Peel Block is a horst created by these faults. On the southern flank of the Roer Valley Graben the faults appear to have a more anastomosing character. In the west the Roer Valley Graben is terminated by the N-S trending Rijen Fault. Here both the NW-SE and the N-S Rijen fault trends area present.
2) In the Jurassic to Upper Carboniferous interval a denser generally NW-SE trending fault system is present and more local horsts and grabens can be observed suggesting more faults with oblique orientations to the main trend. Again, near the Rijen Fault more N-S trending faults are seen, creating the Waalwijk structures.
3) Despite the inversion in the Roer Valley Graben no significant reverse faults are observed in the seismic sections, except potentially in the northernmost part of the Roer Valley Graben near KWK-01 and GWD-01, where evidence for compression/strike-slip is seen on seismic sections.
4) On the Maasbommel High the thickness of the Chalk seems to be influenced by folding and NW-SE trending faults.

2.3 Primary targets

2.3.1 Cenozoic sands

The sands in the Cenozoic section are a relatively new target for geothermal exploration and production. Since the Cenozoic is in general not buried deeper than 1.5 km the temperature in these sands is relatively low (30-45 ˚C). The application of this heat is called in Dutch: Lage Temperatuur Aardwarmte (LTA). An LTA doublet has recently been drilled in area E near Zevenbergen. The reservoir here is the Brussels Sand Mbr. of the Dongen Fm. at a depth of around -600m.

Since the Cenozoic was of nearly no interest to oil and gas exploration onshore The Netherlands very limited reservoir information is available. Additionally, the formation was usually not covered by an extensive logging suite in hydrocarbon exploration wells. The wells of the Zevenbergen doublet have not been released yet, however, some information is available on the website of the operator and in media coverage.

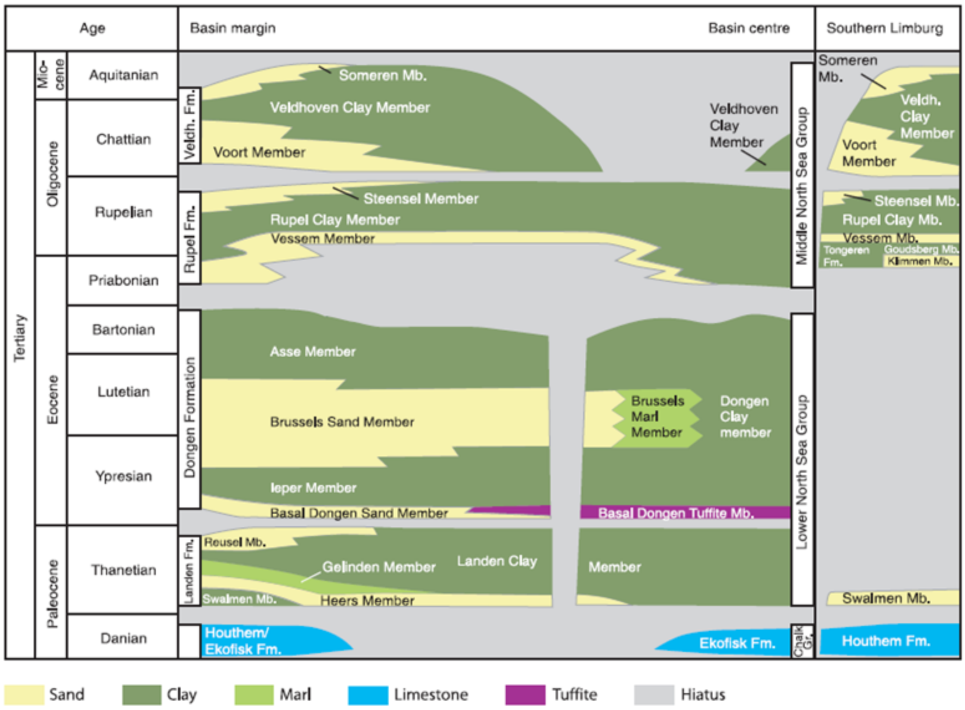


Figure 6 – Stratigraphic scheme of the Lower and Middle North Sea Groups in the Netherlands (Wong et al 2007).

The Lower North Sea Group (Figure 6) consists mainly of marine claystones with interbedded sandstones. In general, the thickest sand interval is the Middle Eocene Brussels Sand Mbr. of the Dongen Fm. Other Lower North Sea Gp. sand intervals are the Heers Mbr. at the base of the Landen Fm. and the Basal Dongen Sand Mbr. at the base of the Dongen Fm. However, in area F&G the Lower North Sea Group has only limited thickness and a large part of the section was either eroded or never deposited. The Brussels Sand Mbr. is absent in area F&G except in the south-eastern extension of the Voorne Trough near well HVB-01, where it is found erosionally truncated below the Middle North Sea Group. A quick-look seismic interpretation (*Figure 7*) shows that the Roer Valley Faults do not have a significant impact on the thickness distribution of the Lower North Sea Group. This seismic interpretation also shows that, contrary to what is indicated on Dinoloket, the Brussels Sands Mbr. is not present in well GWD-01. The Basal Dongen Sands Mbr. is present in the northern part of area F, whereas the Heers Mbr. is found nearly in every well in area F. Both reservoirs are, however, relatively thin (around 10m). Well SNM-GT-01, just north of area F, produces formation water from the Heers Mbr. for the local spa.

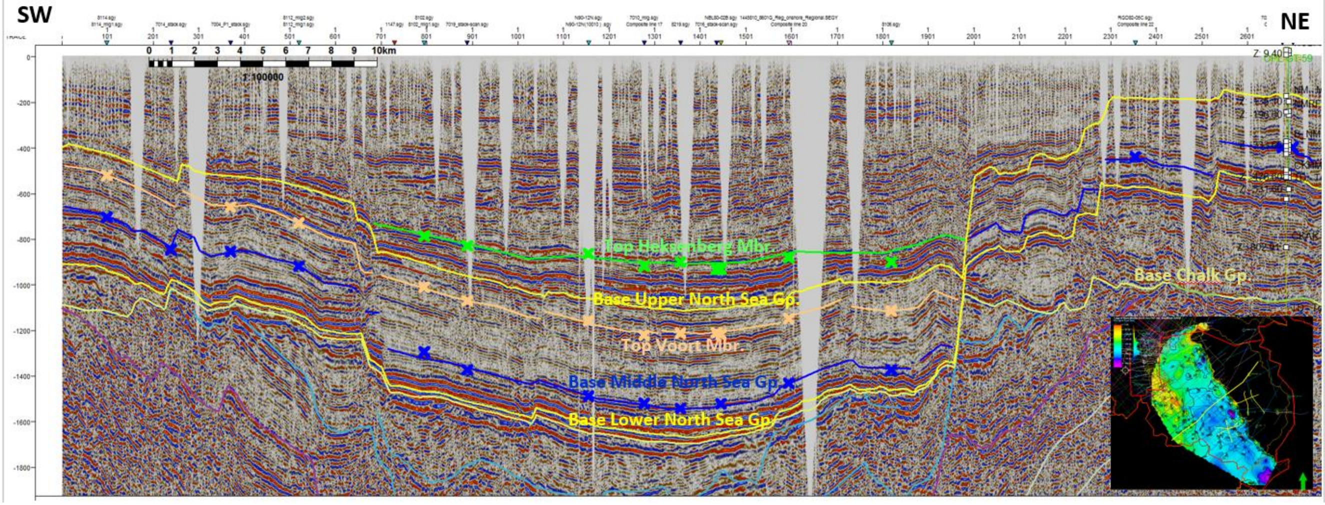


Figure 7 – Seismic section Roer Valley Graben with quick-look interpretation of Top Heksenberg to Base Lower North Sea Gp.

The Middle North Sea Group (Figure 6) consists of marine claystones with interbedded sands. In area F&G the Middle North Sea unconformably overlies the Lower North Sea Group, where the transgressive sands of the Vessem Mbr. of the Rupel Fm rest on the unconformity surface. The Vessem Mbr. may be another potential geothermal target. It has a thickness of 15-30m, is found over most of area F&G and does not seem to be influenced in thickness development by Roer Valley Faults. The reservoir has been cored in well AST-GT-02 at a depth of around -1480m, where a porosity between 30-38% and a permeability of 250-2500mD has been found. Another important sand interval in the Middle North Sea is the Voort Mbr. of the Veldhoven Fm. and the underlying Steensel Mbr. of the Rupel Fm. This sand interval only in present in the Roer Valley Graben (*Figure 7*) and can reach a thickness of more than 200m near well AST-GT-02, where an interval of 18m has been cored. The core plug porosities found are between 29-34% with core plug permeabilities between 6-100mD at a depth of around -1200m. The thickness distribution of the Upper Oligocene Voort interval is clearly influenced by the Roer Valley boundary faults, so the Upper Oligocene is the moment the Roer Valley Graben started to subside again.

Since the Roer Valley Graben subsided significantly during the Oligocene and the Neogene onwards, sand units of the Upper North Sea Group (Figure 7) have been buried to much larger depths (500-1200m) than in most of the Dutch onshore. The marine Breda Fm. and the intercalated estuarine Ville Fm. can have geothermal potential in the central part of the Roer Valley Graben. The Middle Miocene aged Ville Fm. contains lignite seams in the south of the Roer Valley Graben, which are mined in large open-pits in Germany. The sand/lignite interval of the Ville Fm. is called Heksenberg Mbr. (*Figure 8*) above and below the Heksenberg Mbr. sands of the Breda Fm. are present. The Lower Breda Mbr. is also called Kakert Mbr. in Zuid Limburg, whereas the Upper Breda Mbr. is there called Vrijherenberg Mbr. A 1.3m core in well AST-GT-02 in the Lower Breda Mbr. shows a core porosity range of 37-41% and a core permeability range of 1020-2220 mD at a depth of around -875m. The total sand package can reach a thickness of more than 500m in the centre of the Roer Valley Graben. It should be noted that at a depth of above -500m the water starts to be less saline and becomes of interest to the hydrogeological and drinking water community (Deckers et al 2014), as the Roer Valley contains a strategic reserve of fresh water. Geothermal projects in the Upper North Sea Gp. may thus be seen to interfere with drinking water use and protection. Another point to note is that, due to extensive groundwater extraction (*Figure 9*) in the lignite open pit mines in Germany, the pressure in the Cenozoic reservoir in the Roer Valley Graben has been depleted (TNO-NITG, 2001). This may influence the efficiency of geothermal projects in this area.

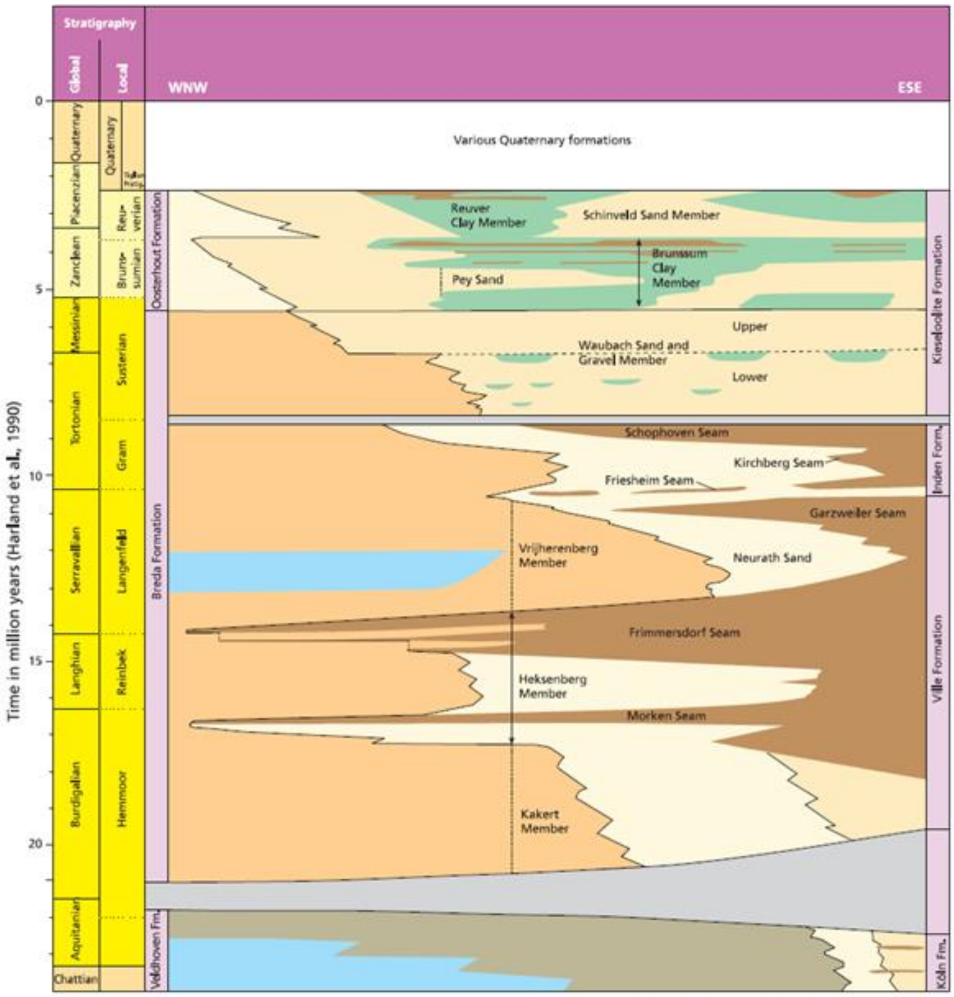


Figure 8 – Stratigraphic scheme of the Upper North Sea Group in the Netherlands (Wong et al 2007).

For a more comprehensive evaluation of the Cenozoic geothermal plays the following activities are recommended:

- Drill well to obtain good core and log coverage and well testing of the potential North Sea Gps. to evaluate the reservoir properties and sedimentological environments

In preparation of this well the following work could be done:

- Perform a petrophysical analysis of the North Sea reservoirs
- Study the impact of pressure depletion and drinking water claims on the feasibility of geothermal projects in the Cenozoic of the Roer Valley Graben
- Seismic reprocessing of relevant seismic data (if field data available)
- Perform a detailed seismic interpretation
- Use the new seismic data to be acquired for deeper targets to further refine the interpretation
- Test seismic inversion on North Sea reservoirs

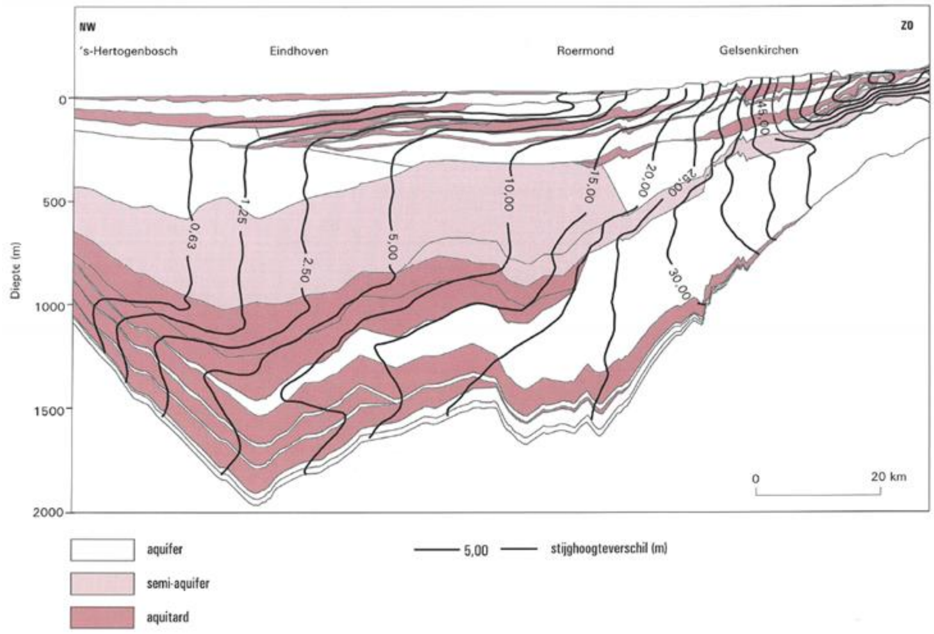


Figure 9 – Differences in hydraulic head in the Roer Valley Graben due to groundwater abstraction in the lignite mines in Germany (TNO-NITG, 2001)

2.3.2 Triassic sandstones

Triassic sandstones are the most obvious reservoirs in the Roer Valley Graben. Thick packages of sandstones are found in the Main Buntsandstein, additionally here, at the basin edge, the Röt Sandstone can also be an attractive reservoir. Even the Lower Buntsandstein interval is developed in a sandier facies, called the Nederweert Sandstone. Nearly everywhere in the Roer Valley Graben a more than 200m of gross sandstone interval is present in the Triassic. The more critical parameter for any geothermal project to succeed is the permeability distribution.

The Brabant Breed report (IF Technology 2012) provides a petrophysical and reservoir geological analysis of the Triassic reservoirs of the province of Brabant. In general, it shows that there is a large variation in porosity and especially permeability of the Triassic reservoirs. The Waalwijk area for example has an average porosity of 10% and an average permeability of 1mD. On the other end of the spectrum the STH-01 well north of Breda has an average porosity of 23% and an average permeability of 1000mD. According to the analysis of the Brabant Breed report reservoir quality may be related to burial depth, where a depth of -2800m is seen as a cut-off depth for sufficient reservoir quality (*Figure 10*). This results in a horseshoe-shaped distribution with good potential at the basin's western and eastern flanks and in the shallower centre of the basin near the AST-01 and NDW-01 wells.

However, comparing the petrophysical analysis in the Brabant Breed report with the available permeability data shows some important discrepancies:

- The mobilities obtained from formation pressures tests in well HVB-01 are a factor 10 to 100 lower than the calculated permeabities derived from the porosity-permeability transform function.
- In well KDK-01, which has a core section in the Röt sandstone, the observed core permeabilities are at least a factor 10 lower than the calculated permeability
- For well NDW-01 the core data of the Röt and Main Buntsandstein may not have been available for the analysis. The core permeability is seen to range between 0.1 to 1mD at locations where a permeability of over 100mD is calculated.

Based on these findings the conclusions of the report should be used with caution. Especially the good reservoir area in the centre of the Roer Valley Graben near the AST-01 and NDW-01 wells seems suspect. There are, however, certainly some wells which do have good reservoir quality, most of which are located at the basin's edge. One of the aspects which could determine the distribution of the reservoir quality in the Triassic is leaching, when the reservoir was exposed to fresh water influx during phases of uplift and erosion. Distance to the basin or erosion edge and hydrodynamic position could thus be an important factor. This would mean that, in general, Triassic intervals close to the erosion margins of the Roer Valley Graben and around the Maasbommel High stand the best chances to have a good permeability. However, since more hypotheses are possible more work is needed to test the various ideas.

For a geothermal project in the Triassic sandstones in area F&G the main uncertainty is reservoir quality. In order to reduce this risk, the following work program is proposed:

- A feasibility study to test seismic inversion to seismically determine areas of good porosity, this will include a comprehensive petrophysical evaluation of the Triassic reservoirs, building on existing work and a sedimentological and diagenetic study of the Triassic cores. Note: if seismic inversion test for the Triassic reservoir proves to not to be successful this may limit the acquisition of new 2D lines for the Triassic
- Reprocessing of the existing 2D seismic data (if field data available)
- Acquisition of new seismic lines connecting wells with good and poorer reservoir quality and the poorly covered Peel-Maasbommel Complex
- Use the new seismic data (and the reprocessed data) for seismic inversion to visualise and predict reservoir quality trends

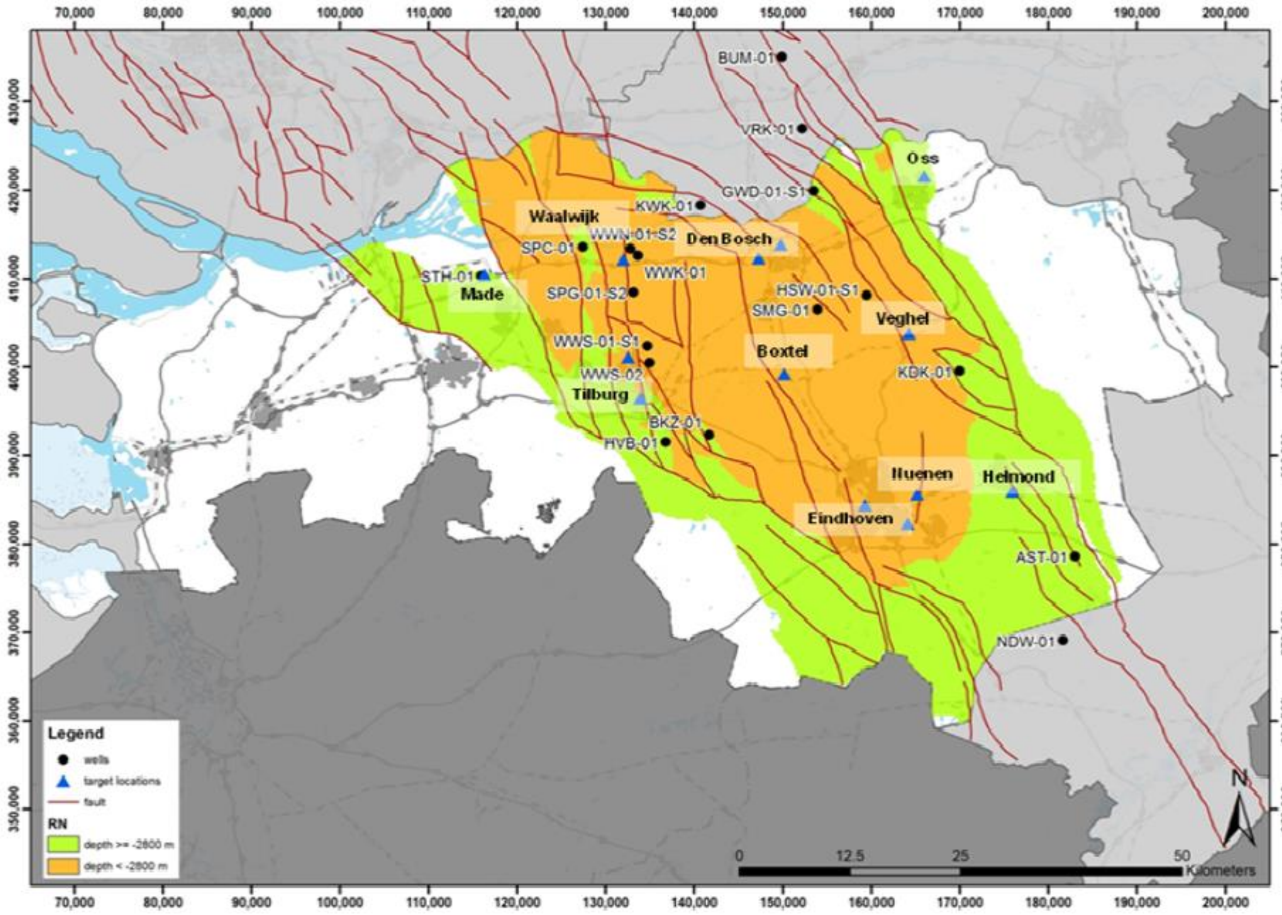


Figure 10 – Areas where a conventional geothermal system is possibly feasible in the Triassic (green) and where such a system is not most likely not feasible (orange). Also shown are the target locations (blue triangles). (IF Technology 2012)

2.3.3 Upper Carboniferous mine water

In the Heerlen area a geothermal project is based on the extraction and injection of water from now defunct and flooded coal mine galleries. Wells have been drilled vertically to a depth of 700m into a ~3m high gallery. A slotted liner was placed in the open hole section. Water with a temperature of ~28˚C is produced in winter time from one well and is used for heating office buildings, whereas in summer warm water obtained by cooling the buildings is reinjected into the second well. A separate shallow cold-water system provides water in summer time for cooling and receives spent heating water in winter.

Since more defunct mines are present between Sittard and Kerkrade duplication of this project can be envisaged in this specific area. Enough geological data to work on this play is expected to be present, based on the available wells and mining maps. It may involve a significant amount of work to digitize and vectorize the legacy data, however, this is beyond the scope of the SCAN project

2.3.4 Lower Carboniferous (Dinantian) carbonates

In area F&G some good information on the presence and thickness of the Lower Carboniferous (Dinantian) carbonates is available (Figure 13). The Californië geothermal project (CAL-GT) provides information of this reservoir on the Peel Horst, whereas in the south of Limburg several wells have penetrated the Dinantian at shallow depth. Also, Belgian wells, including the Balmat/Mol geothermal project, to the south of area F&G add to the knowledge of the Dinantian Geothermal play. Reijmer et al 2017 provide a good overview of the available data and reservoir facies interpretations. The top and base of the formation can be mapped with some confidence on seismic data over area F&G. Reijmer et al 2017 provide TWT maps of the top and base of the formation together with an isochron map of the Dinantian (*Figure 11*). However, in their view, the picking below the Roer Valley Graben was too uncertain, so the area was left blank in their maps.

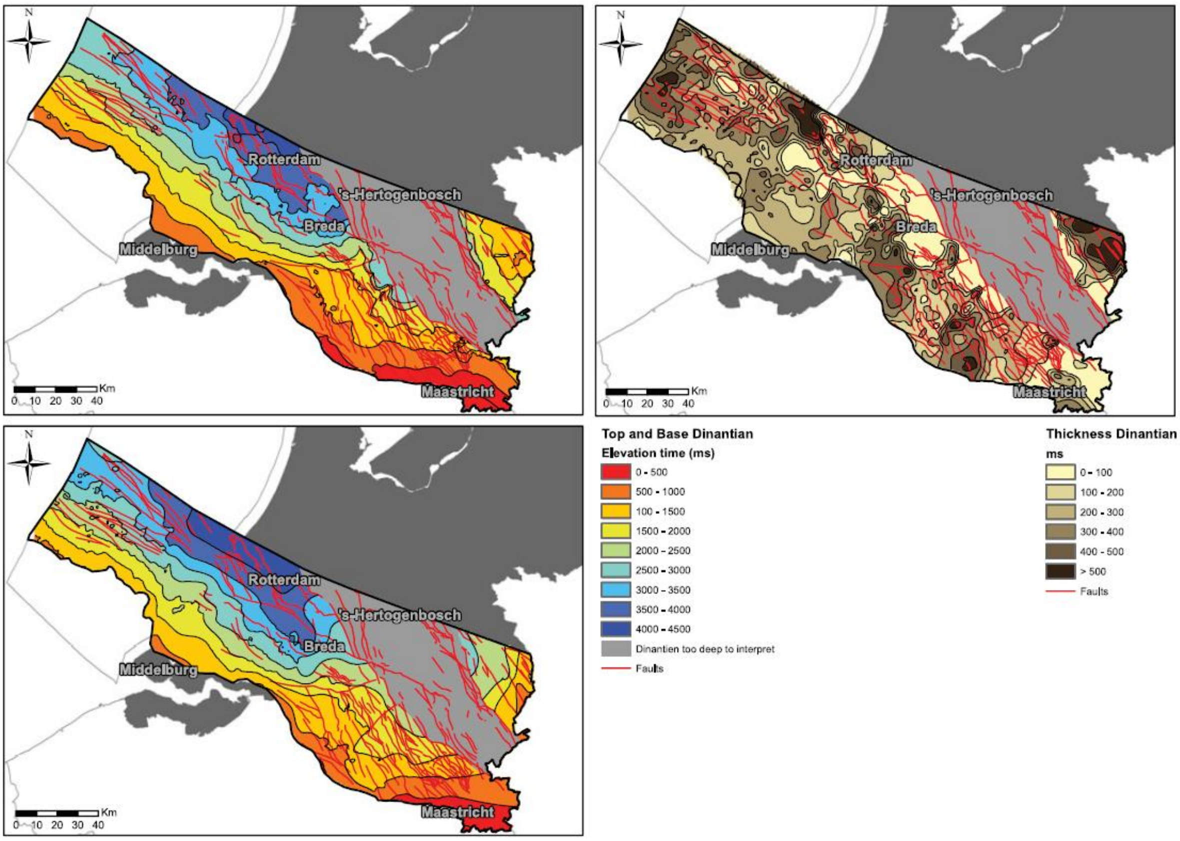


Figure 11 – Maps showing the elevation time of the interpreted top and base Dinantian horizons (top and bottom left, respectively) and the isochore thickness, both in ms. Note that in the centre of the Roer Valley Graben the top and base of the Dinantian cannot be interpreted in seismic data and are left blank. Fault lines (in red) represent those faults present that penetrate the top of the Dinantian; these include deep-seated syn-sedimentary faults as well as much younger ones. (from Reijmer et al 2017)

A TWT and depth map of Top Dinantian over area F&G is available from Dinoloket (TNO 2014). These maps do provide TWT and depth information of the Top Dinantian below the Roer Valley Graben. However, some concerns can be raised with respect to the depth conversion to this layer. Below the location of well NDW-01 in the Roer Valley Graben the top Dinantian is expected at a depth of around -5900m on the TNO depth map. Since well NDW-01 found the top of the Limburg Gp. at -2603m the expected isopach of the Limburg Group is 3297m. From the TNO TWT maps a Limburg isochron of 1075ms TWT can be calculated. From the isochron and isopach values an interval velocity of 6134m/s can be derived. This would seem unreasonably high for the clastic Limburg section, which more typically would have a 4200m/s velocity, as observed in the top of the Limburg drilled by well NDW-01. If TWT picking is correct the Top Dinantian could be 1km shallow at the NDW-01 location than indicated on the TNO depth map.

Recent experience with 2D seismic acquisition on a deep Dinantian target showed that this target may not be sufficiently imaged when using Vibroseis, especially if environmental constraints limit the sweep potential. Based on this experience and to avoid any soft near surface layers, seismic acquisition using shotholes drilled into water bearing sand layers is recommended for a deep Dinantian target.

Since the normal matrix permeability of Dinantian carbonates is very low, geothermal plays in this reservoir will depend on secondary permeability. Three subplays on enhanced permeability can be identified: related to faulting and fracturing (e.g. the Mol and Californië projects), karstification of the reservoir during the Dinantian/Namurian (e.g. Loenhout UGS in Belgium) and karstification below the Base Permian or Base Cretaceous Unconformity (e.g. KTG-01 well and the Californië project).

Based on the topographic expression of some major faults around the Roer Valley graben and the relatively large number of natural earthquakes it can be concluded that the area is currently under critical tectonic stress. At present (12-2018) the Californië geothermal project is closed-in as a precautionary measure, to investigate if a recent earthquake might have been induced by the production and injection process (*Figure 12*).

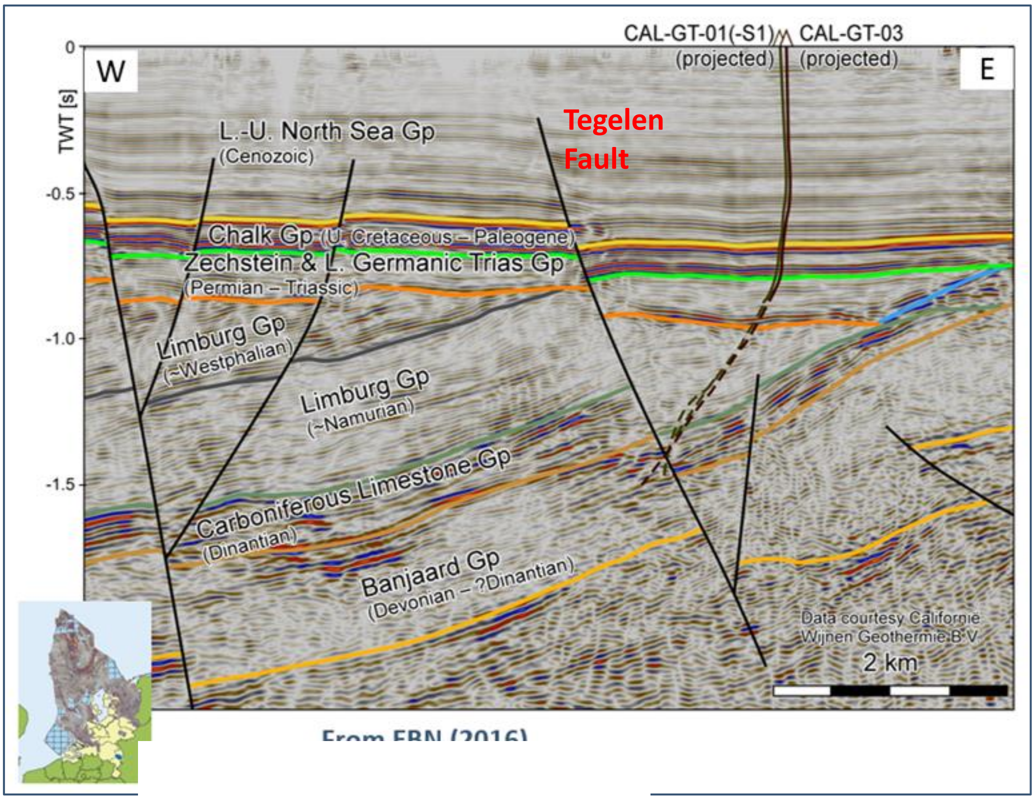


Figure 12 – Seismic section across the Californië geothermal project showing the picking of the Dinantian Limestone and the underlying Devonian. Note that the wells may cross the Tegelen Fault and that east of the wells the Dinantian subcrops below the Base Permian Unconformity and possibly even the Base Cretaceous Unconformity (from EBN 2017)

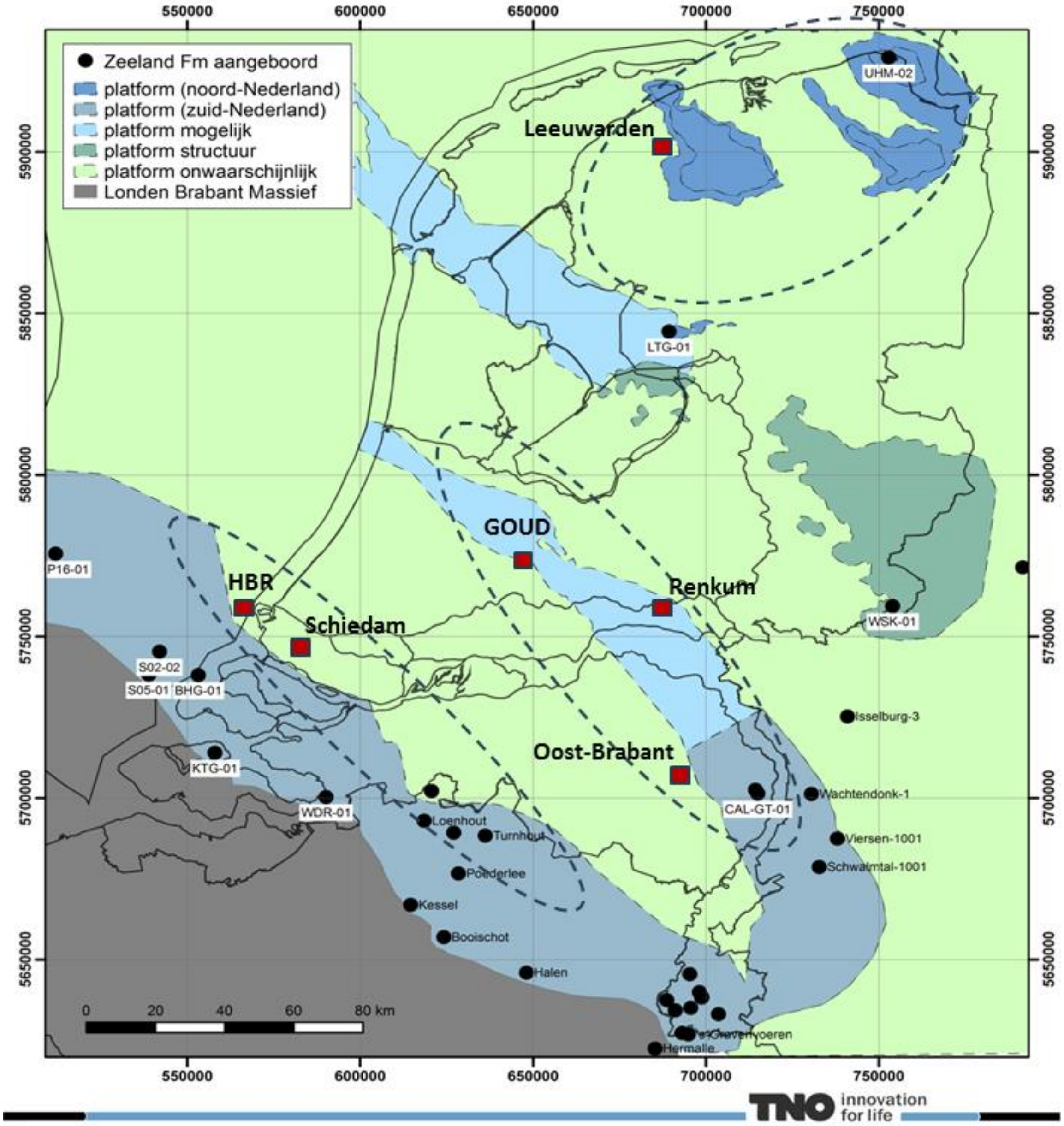


Figure 13 – Facies map of the Dinantian (Early Carboniferous) from Boxem et al. (2016). "Platform mogelijk": platform possible, "Platform structuur": platform structure, "Platform onwaarschijnlijk": platform unlikely, "Zeeland Formatie aangeboord": Zeeland Fm encountered in well. NB: This map may be outdated as it does not reflect the ongoing SCAN Dinantian work.

To reduce the risk of geothermal projects in the Dinantian of area F&G the following activities are proposed:

- A detailed seismic interpretation and depth mapping of the Dinantian (in progress, part of SCAN Dinantian)
- A reservoir study of the Dinantian (in progress, part of SCAN Dinantian)
- A seismicity study of geothermal projects (in progress, part of SCAN Dinantian)
- Acquisition of a seismic section connecting the Mol and Californië geothermal projects over the Roer Valley Graben
- Acquisition of new seismic sections with deep penetration in the Campine Basin, Peel Horst, Maasbommel High, Roer Valley Graben and Zuid Limburg
- A stress state study of the Roer Valley Graben and surrounding faults, including well Borehole Image Log measurements in new wells
- Reprocessing of existing seismic data (in field data available) to improve the seismic mapping

2.4 Secondary targets

2.4.1 Upper and Lower Cretaceous sandstones

In area F&G siliciclastic sediments are observed in the Upper Cretaceous section. In Zuid Limburg the siliciclastic Vaals and Aken Fms. (NITG-TNO, 1999) are well known from outcrops and wells. But also, north of the Roer Valley Graben on the Peel-Maasbommel Complex significant siliciclastic intervals are seen in the otherwise chalk bearing Upper Cretaceous (Gras 1995 and Gras & Geluk, 1999). In well OPL-16 more than 550m of sandy intervals were found below an upper Chalk package of around 100m thick. No reservoir information is available from this old well (spud 1911), but natural flow was observed from the top of the (fractured?) overpressured Chalk in this well. However, in well OPL-GT-59, which was drilled in 1986 next to the OPL-16 well, no overpressure was observed in the top of the Chalk, probably due to the ground water extractions related to mining activities in Germany.

North of the OPL-16 well on the Maasbommel High the thickness of the Upper Cretaceous interval increases to more than 1200m. The lithology of this interval is highly uncertain since the nearest well (MSB-01) is on the northern flank of the Maasbommel High. This well found the Upper Cretaceous mostly in Chalk facies.

Also, the presence, thickness and lithology of the Lower Cretaceous is highly uncertain on the Maasbommel High, since no well penetrated this interval south of MSB-01 and SNM-GT-01. In these wells a sandy marl was found in the Lower Cretaceous.

Proposed work for the Upper and Lower Cretaceous plays in area F&G:

- Acquisition of new seismic lines over the Maasbommel High, tie-in well OPL-16.
- Drill a well on the Maasbommel High to test the Cretaceous stratigraphy

2.4.2 Upper Jurassic sandstones

The Upper Jurassic interval found in the north-western part of the Roer Valley Graben may be as a prospective geothermal reservoir. The Schieland Group consists of fluvial sandstones interbedded with floodplain claystones. The N/G ratio is typically around 50%, which, for this type of facies, would mean the sandstone bodies are 3D spatially interconnected. The sandstones are found to have good reservoir properties in the cores of wells DON-01, WAP-01 and OIW-01. The core porosities range between 27-34% and the core permeabilities range between 200-5000mD. What is unclear at the moment is why in well HSW-01 the N/G is very low in the upper part of the Schieland section. Possibly this interval is incorrectly dated and belongs to the Altena Gp. which can be seen to be present in the footwall of the HSW structure. Since the play is located in only a small part of area F only a limited amount of work can be performed here.

Proposed work for the Upper Jurassic play in area F&G:

- Review age dating Schieland of HSW-01
- Acquire new seismic line over HSW-01 and the graben east of the west to confirm the presence of Schieland in this graben and to facilitate a detailed tie-in of the well

2.4.3 Middle Jurassic Brabant limestones

An internal study by EBN (Bussmann 2014) shows that locally the limestones of the Brabant Fm. may contain sufficient reservoir quality to be of interest as a geothermal reservoir. The best core permeabilities are found in wells AND-03-S2 and WED-01 located northwest of area F. The permeability of the Brabant limestones can be increased if the reservoir is leached below the Laramide Unconformity. East of well KWK-01 in the northwest corner of area F such a location was identified on the seismic data.

Proposed work for the Middle Jurassic Brabant play in area F&G:

- Acquire new seismic data over the subcrop lead in order to invert the seismic data to search for improved reservoir quality below the unconformity

2.4.4 Zechstein carbonates

Little pertinent data is available on the Zechstein of area F&G. The interval has been encountered in wells around the Maasbommel High and in wells in the neighbouring area in Germany. The Zechstein thickens to 135m in well Hülm-01 just across the border between the German towns of Goch and Weeze. The Zechstein shows a variety of lithologies; claystones, carbonates & anhydrites. Potentially the carbonate rocks can be leached below the Base Cretaceous Unconformity on the Maasbommel High and resulting in improved permeabilities. Well ARC-GT-01 produces warm water for the Arcen spa (Klein Vink) from a fault in the Zechstein carbonates. The higher than expected temperature and high salt level indicate that the water may originate from Dinantian carbonates (TNO-NITG 2001).

Proposed work for the Zechstein play in area F&G:

- Acquisition of new seismic lines around the Maasbommel High
- Obtain more reservoir information from nearby German wells

2.4.5 Neeroeteren Sandstone

In the Belgian Campine Basin fluvial-fan sandstones with a Westphalian D area are found below the Base Permian Unconformity. These braided channel sandstones are not yet found in The Netherlands due the absence of well penetrations in the Dutch part of the Campine Basin. The Belgian wells found the formation up to 300m thick at a depth of 650-900m, with a permeability up to 200mD (TNO, 2012). The reservoir quality may be less in the Dutch area, since it is located in a deeper part of the basin

Proposed work for the Neeroeteren play in area F&G:

- Acquisition of new seismic lines in the Campine area
- Drill a well to investigate the presence and reservoir quality of the Westphalian section of the Dutch Campine Basin

2.4.6 Pre-Dinantian interval

In the area F&G some information is available on the Pre-Dinantian intervals. In the wells of the Californië geothermal project (CAL-GT) sandstones and carbonates are found below the Dinantian carbonates (*Figure 12*). This potential reservoir interval is thought to have contributed to the production from the wells (Reith 2018), mainly from fracture and fault permeability. Also, in Zuid Limburg in well KSL-02 a sandy interval of the Bosscheveld Fm. in the Banjaard Gp. was found (Van Adrichem Boogaert & Kouwe, 1993–1997). Further south in Belgium and in Germany Devonian rocks are found in outcrop.

Below the Devonian the Cambro-Silurian of the Brabant Massif is expected to be present in Zuid Limburg (NITG-TNO 1999, Figure 5). This interval is proven by wells in Belgium and Germany. At the moment it is unclear if these rocks could have any geothermal potential. Most likely fractures, either natural or induced, are needed to obtain a sufficient production rate from this interval.

In the southern part of Zuid-Limburg the Devonian and Cambro-Silurian can be found at a depth of 200 to 1000m.

Proposed work for the Pre-Dinantian plays in area F&G:

- Acquisition of new seismic lines in Zuid Limburg over wells HEU-01, KSL-02 & GVK-01 and over the TNO wells near Terblijt and Eys. Sufficient testing of the acquisition parameters is needed since legacy lines show very poor results
- Use Belgian and German well and outcrop data to make a better prediction of the Devonian and Cambro-Silurian expected in Zuid Limburg
- Use gravimetry and magnetic data to predict the stratigraphy and structural configuration in Zuid Limburg
- Drill a well to test Cambro-Silurian reservoir potential of Zuid Limburg, conditional on favourable study results

3. Seismic survey design

In the previous chapter proposals were made for the further geological and geophysical evaluation of area D&E. These proposals have been reviewed and ranked on their respective potential impact of the play (w.r.t. expected areal extent and reservoir quality) and their estimated chance of success in delivering on the objectives of these projects. *Figure 14* graphically summarizes the most important proposed work items and their ranking. These considerations are the starting point for defining the location and goals for the planned seismic acquisition. Additionally, next to the geological objectives (3.1) the new seismic survey design should meet a number of essential technical criteria (3.2).

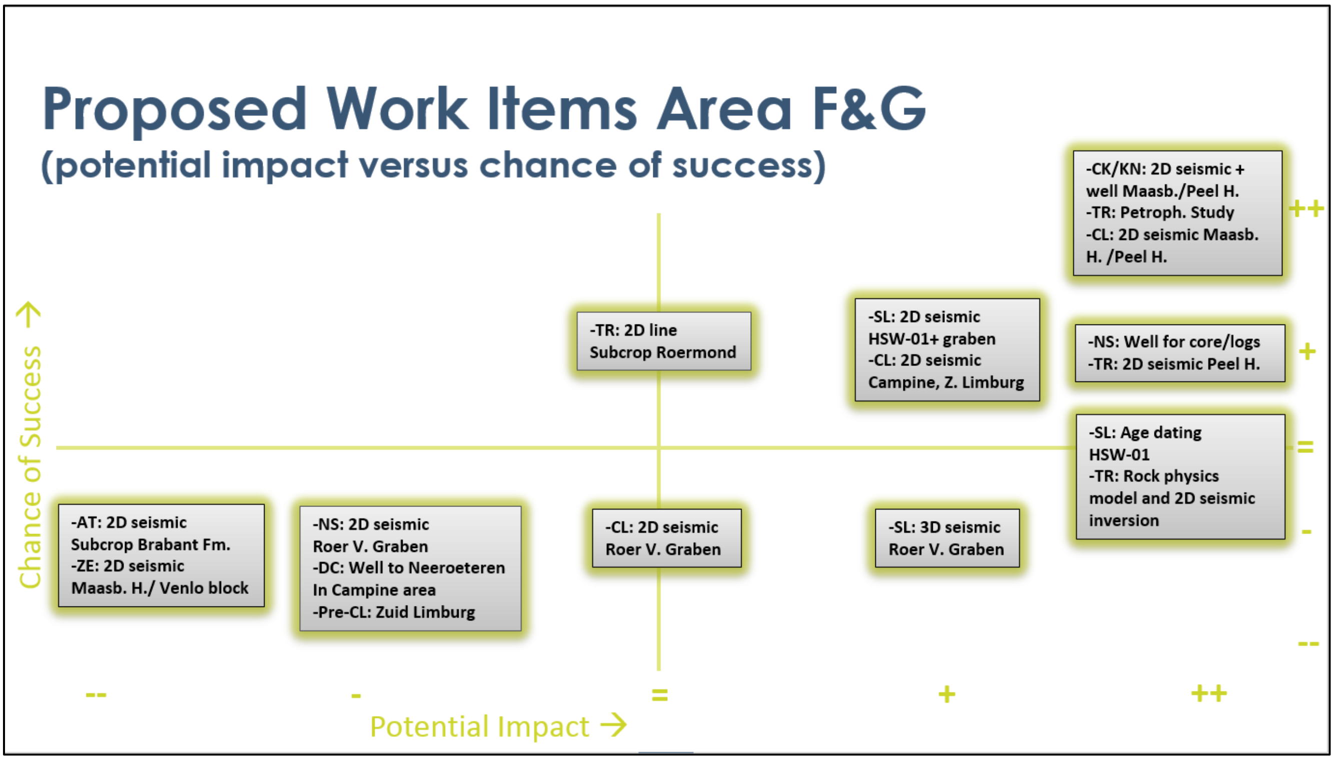


Figure 14 – Cartoon showing the main proposed work items for further evaluation of area F&G ranked according to potential impact of the play and estimated chance of success

3.1 Geological objectives of the seismic survey

The geological objectives of the seismic acquisition are summarized from high to low impact:

- Provide new high-quality seismic data over the Maasbommel High and Peel Horst since only a few seismic lines cover this area. There are potential reservoirs present in the Upper and Lower Cretaceous, Triassic, Lower Carboniferous and Devonian. Well ties can be provided by wells CAL-GT-01/05, OPL-16, a large number Peel Horst coal exploration wells and well Hülm just across the border in Germany. In this area the Zechstein can also be a potential reservoir, however, it is not expected that seismic acquisition will resolve this interval.
- Provide new high-quality seismic data to perform an inversion study on the Triassic to seismically predict the presence of good quality (leached?) reservoir. The 2D seismic lines tie to the wells HVB-01, BKZ-01, KDK-01 and GWD-01 with fair to good reservoir quality and wells KWK-01, AST-01 and NDW-01 with a poorer reservoir quality. Rock physics modelling will be performed before acquisition to test if seismic inversion can be successful and if so what the acquisition parameters are needed for this seismic inversion
- A 2D line crossing well HSW-01 is aimed to give a good tie of the well to the seismic, which may provide a better insight if a Jurassic low net/gross interval is correctly attributed to the Schieland Gp. This low net/gross ratio is downgrading the Schieland in the graben east of well HSW-01. This same graben will also be covered by a line crossing GWD-01. A line through HVB-01 will also provide a new tie to the thin Schieland in this area.
- Provide new high-quality seismic data for the Dinantian plays in the Campine area. In the Campine area the Dinantian is expected to be comparable to the Mol geothermal project to the south. An UDG seismic section will connect this project with the Dinantian Californië project over the Roer Valley Graben. In this way this line will also

investigate the presence or absence of the Dinantian carbonates below the Roer Valley Graben. Seismic sections on the west flank of the Roer Valley Graben investigating the Triassic play can also be used to image the Dinantian of the Campine Basin and the potential Neeroeteren play in this area.

- In Zuid-Limburg the Dinantian is relatively close to surface and drilled by several wells. Especially wells GVK-01, HEU-01 and Terziet-01 could provide a seismic tie. The seismic data could also provide information on the Devonian and deeper section. It should be noted that the current seismic coverage is very low and of poor quality.
- In part of the area F&G the Schieland could provide an interesting reservoir. A 3D survey may be helpful for the correlation of reservoir intervals from well penetrations. However, since the area relatively small and nearby in the Waalwijk area sufficient 3D data is available to test this play in a comparable setting, no 3D acquisition is proposed here.
- Just east of Roermond, near Heinsberg in Germany, the Triassic is expected to subcrop below the Base Cretaceous Unconformity. Leaching may have improved the reservoir quality in this area. A seismic line into Germany can be tied to well NDW-01 in the Roer Valley Graben. This line can also give information on the thickness and architecture of the North Sea reservoirs in the southern part of the Roer Valley Graben.
- The subcrop lead of the Brabant Formation is not seen as an attractive play for seismic acquisition, however, a line acquired for the Triassic between KWK-01 and GWD-01 will also illuminate this play to some extent.

3.2 Criteria for design of the seismic survey

The position and orientation of the lines of the survey were planned to meet as many of the criteria listed below as possible.

- De-risk of the geological issues and uncertainties described in sections 2 and 3.1.
- Take into account heat demand and active geothermal projects.
- Perpendicular to the regional NW-SE structural trend, where possible.
- Straight, long (>20 km) lines.
- Well ties for wells penetrating stratigraphic levels deeper than the Lower Cretaceous, preferably by choosing the line trajectory over / nearby an existing well location.
- Tie to 2D line to 3D seismic data.
- Minimalize complications from near-surface geology: push moraines, swamps, lakes, etc.
- Individual lines of survey cross each other.
- Avoid Natura2000 and other protected areas.
- Avoid mixing of land and water seismic.
- Synchronized with data acquisition plans (local seismic surveys, project locations) of active projects.
- Budget and time planning.

The acquisition parameters of the survey should take into account the following geological objectives:

- Have sufficient recording time and penetration energy to properly image Dinantian limestones at 5 sec TWT
- Be acquired with parameters that results in good imaging of subtle details as unconformities and karst-zones and permits quantitative interpretation reservoir properties. This would mean prestack data with dense source and receiver sampling in time and space and with long offsets. With this data special seismic processing/analyses should be possible such as: AVO, seismic inversion, Full Waveform Inversion, diffraction imaging and broadband processing.

3.3 Survey design

Figure 15 shows the proposed line locations covering area F&G which do conform to the above listed geological objectives and design criteria. The geological goals for each of the lines are given in Table 2 and further highlighted per line in geological cross-sections in Appendix 5.1. A buffer of 2 km is drawn around the ideal trajectory to accommodate alternative routing; field scouting may lead to significant changes to the design.

In EBN& TNO-AGE (2017) the length of the lines required for area F was estimated at 388 km, whereas no seismic acquisition was foreseen in area G. The current design amounts to 592 km, 182km of which are conditional (Table 3). It is therefore plausible that it may not be possible to acquire all proposed lines and it is therefore necessary to decide which lines have the highest priority. To facilitate this, a scoring system has been developed to assess how well they meet the design criteria. To indicate how the 2D seismic acquisition fits within the overall planning of the SCAN project an indicative planning of the main activities in SCAN area F&G is given in Appendix 5.2. It is possible that if good results are obtained with seismic reprocessing, acquisition of some new lines may not be necessary.

Line	Goals
KWK-GWD	Image Triassic. De-risk Triassic reservoir quality, depth and thickness. Provide data for seismic inversion project in Triassic. Tie to wells GWD-01 and KWK-01. Depth, thickness and facies of Schieland east of GWD. Depth, thickness and reservoir improvement of Brabant subcrop play. Provide tie to line RVG-NMG-BKH of SCAN Area C and Waalwijk 3D.
HVB-BKZ-HSW	Image Triassic and Dinantian. De-risk Triassic reservoir quality, depth and thickness, Dinantian presence, facies and depth. Provide data for seismic inversion project in Triassic. Tie to wells HSW-01, BKZ-01 and HVB-01. Depth, thickness and facies of Schieland near of HVB and east of HSW. Continuation of line RVG-NMG-BKH of SCAN Area C.
REU-KDK-OPL-Hülm	Image Cretaceous, Triassic and Dinantian. De-risk Triassic reservoir quality, depth and thickness, Dinantian presence, facies and depth, Cretaceous depth, thickness and seismic facies. Focus on improved Triassic reservoir quality near KDK and western boundary of Roer Valley Graben, provide data for seismic inversion project in Triassic. Tie to wells KDK-01, OPL-16 and German well Hülm. Line will also provide depth, thickness and facies information on North Sea reservoirs in the Roer Valley Graben and the potential Neeroeteren play in the Campine Basin.
NMG-OPL-GRH	Image Cretaceous, Triassic and Dinantian. De-risk Triassic presence, depth and thickness, Dinantian presence, facies and depth. Cretaceous depth, thickness and seismic facies. Provide data for seismic inversion project in Triassic. Tie to well OPL-16. Continuation of line GLD_Vallei of SCAN Area C.
CUK-VNL	Image Cretaceous, Triassic and Dinantian. De-risk Triassic presence, depth and thickness, Dinantian presence, facies and depth. Cretaceous depth, thickness and seismic facies. Potentially image Zechstein reservoir.
MOL-CAL-DE	Image Triassic and Dinantian. De-risk Triassic reservoir quality, depth and thickness, Dinantian presence, facies and depth. Provide data for seismic inversion project in Triassic. Tie to wells Mol, AST-GT-02 and CAL-GT. Line will also provide depth, thickness and facies information on North Sea reservoirs in the Roer Valley Graben and the potential Neeroeteren play in the Campine Basin.
MOL-HVB	Image Triassic and Dinantian. De-risk Triassic reservoir quality, depth and thickness, Dinantian presence, facies and depth. Provide data for seismic inversion project in Triassic. Tie to wells Mol and HVB-01. Line over Campine Basin to connect 3 dip lines and connect to Waalwijk 3D. Line may also provide information on the potential Neeroeteren play in the Campine Basin.
SWM-VNL	Image Dinantian. De-risk Dinantian presence, facies and depth. Potential subcrop area of Dinantian below Base Cretaceous Unconformity.
NDW-RMD (conditional)	*Image North Sea and Triassic and to provide location of Triassic subcrop near Heinsberg Germany. De-risk Triassic reservoir quality, depth and thickness. Provide data for seismic inversion project in Triassic. Line also to provide depth, thickness and facies information on North Sea reservoirs. Line may image Dinantian below Roer Valley Graben. Tie to well NDW-01.*
TER-RAA-CAL	*Image Triassic and Dinantian. De-risk Triassic, depth and thickness in Roer Valley, Dinantian presence, facies and depth. Tie to wells Terziet-01, Eys-01, RAA-01, BEE-72 and CAL-GT. Line could possibly image reflectors below Dinantian in Zuid-Limburg and Peel Horst. Line also useful for TNO for ground water research and potential Einstein Telescope project.*
HEU-GVK-LBR-RVG	*Image Triassic and Dinantian. De-risk Triassic, depth and thickness in Roer Valley, Dinantian presence, facies and depth. Tie to wells HEU-01, GVK-01, and LBR-01. Line could possibly image reflectors below Dinantian and the potential Neeroeteren play in the Campine Basin*

Table 2 – Geological goals for the proposed lines

Line	Total Length (km)	Comment
KWK-GWD	37.4	
HVB-BKZ-HSW	39.8	Continuation of SCAN Line RVG-NMG-BKH
REU-KDK-OPL-Hülm	81.3	
NMG-OPL-GRH	50.1	
CUK-VNL	45.2	
MOL-CAL	94.4	UDG line
MOL-HVB	36.6	
SWM-VNL	25.4	
NDW-RMD	*46.6*	*Conditional, depending feasibility of North Sea Gps. geothermal project in Roer Valley Graben*
TER-RAA-CAL	79.9	
HEU-GVK-LBR-RVG	55.1	
Total length	591.8	

Status of 28/06/2019

Table 3 – Length of the proposed lines. ***Please note that line lengths may change if lines are updated***

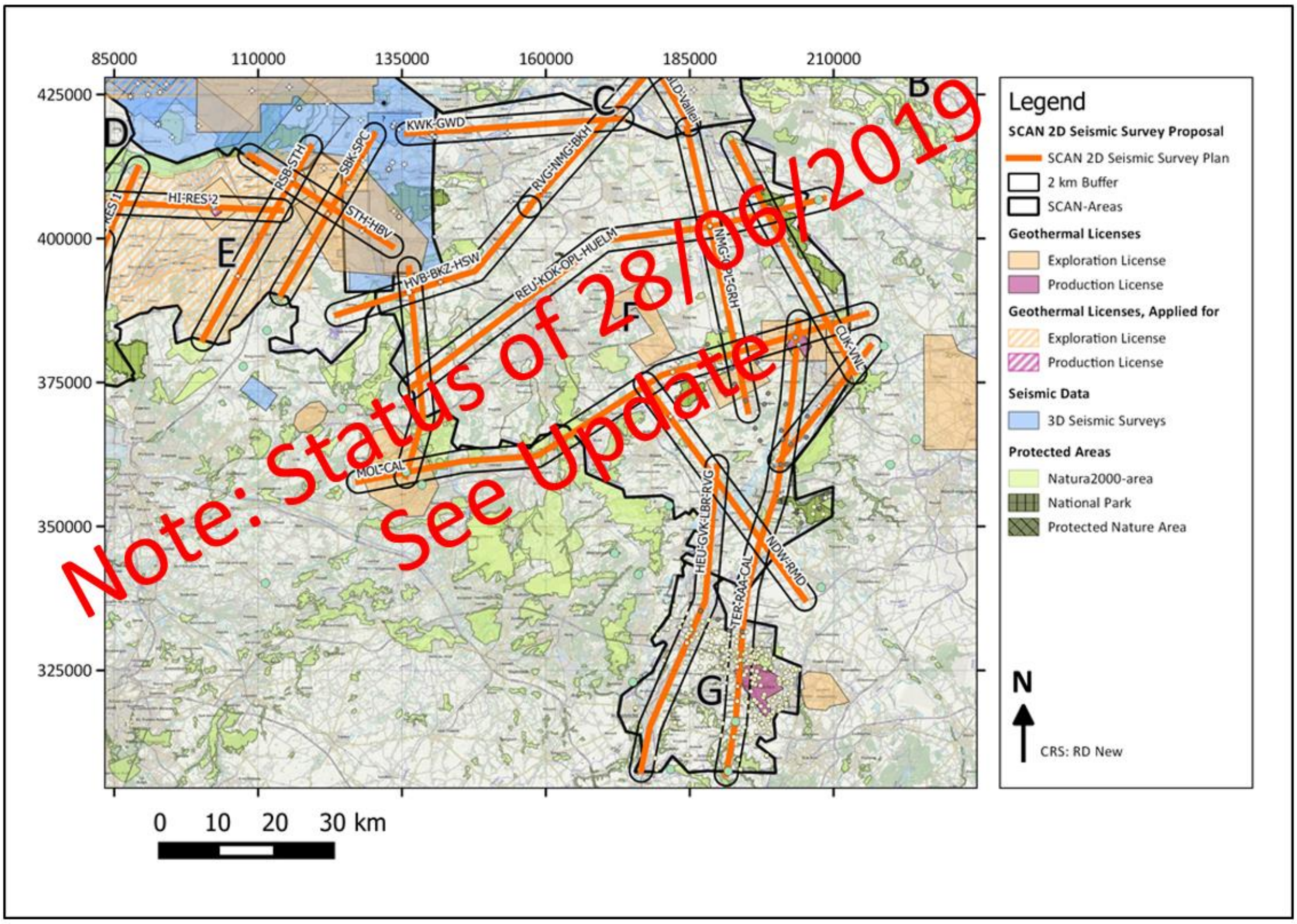


Figure 15 – Seismic survey design for SCAN area F&G. The outlines show the area where full-fold coverage is required. Note: the actual acquisition of these lines is subject to ranking and budget appropriation. **Please note that this figure displays the status of 28/06/2019, an updated map can be found on page 6 of this report**

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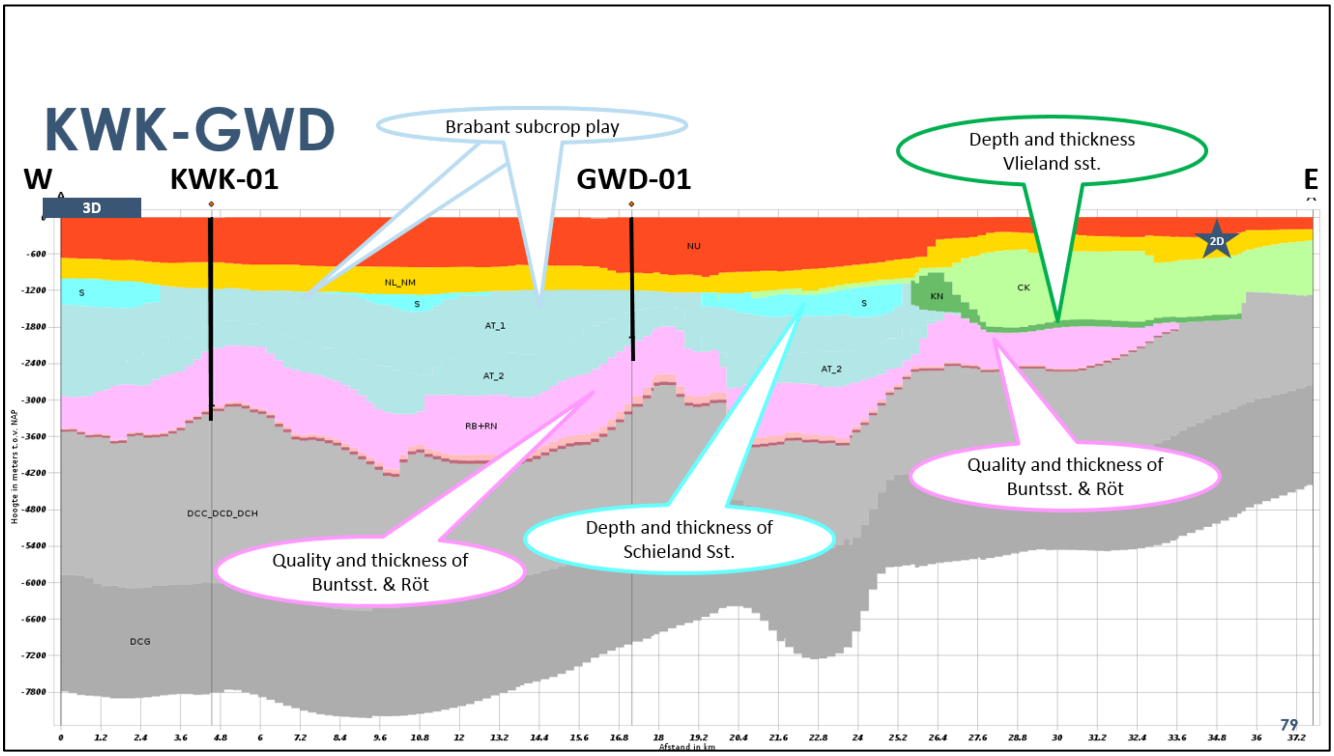
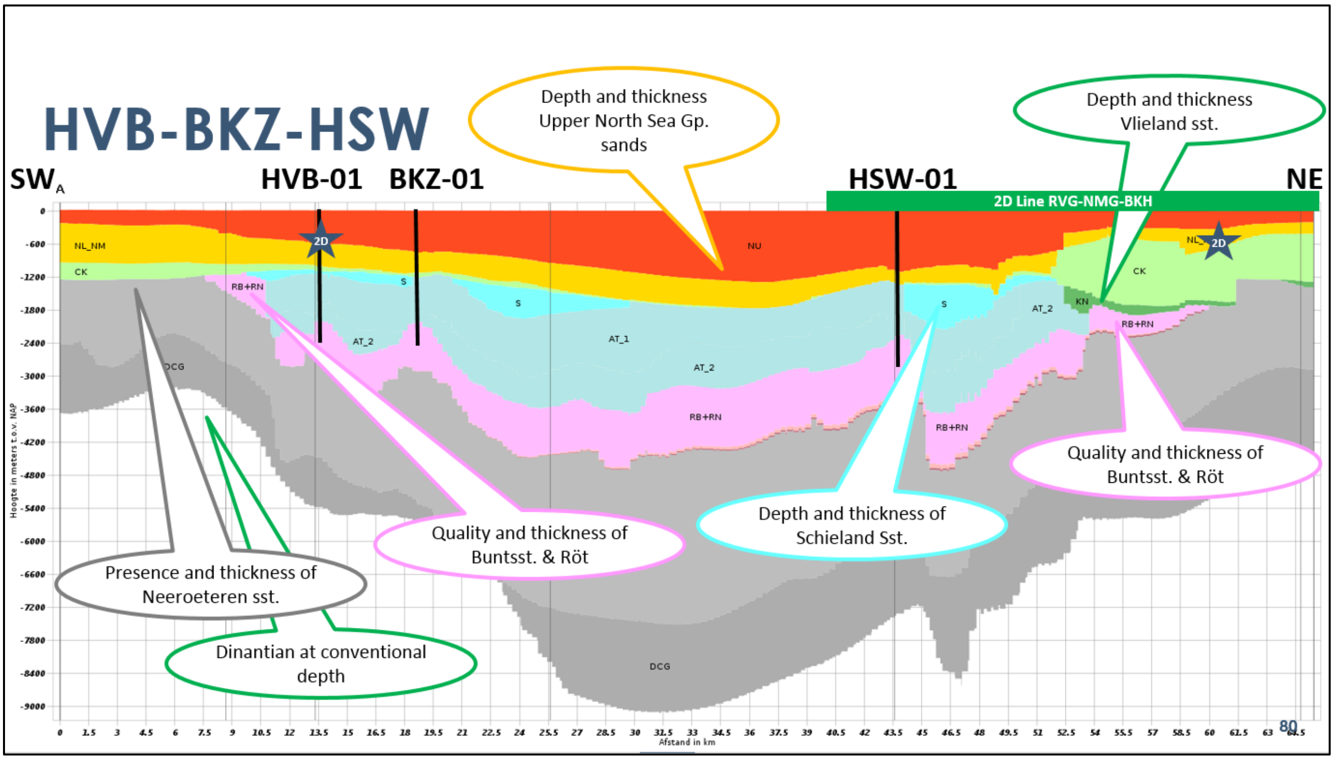
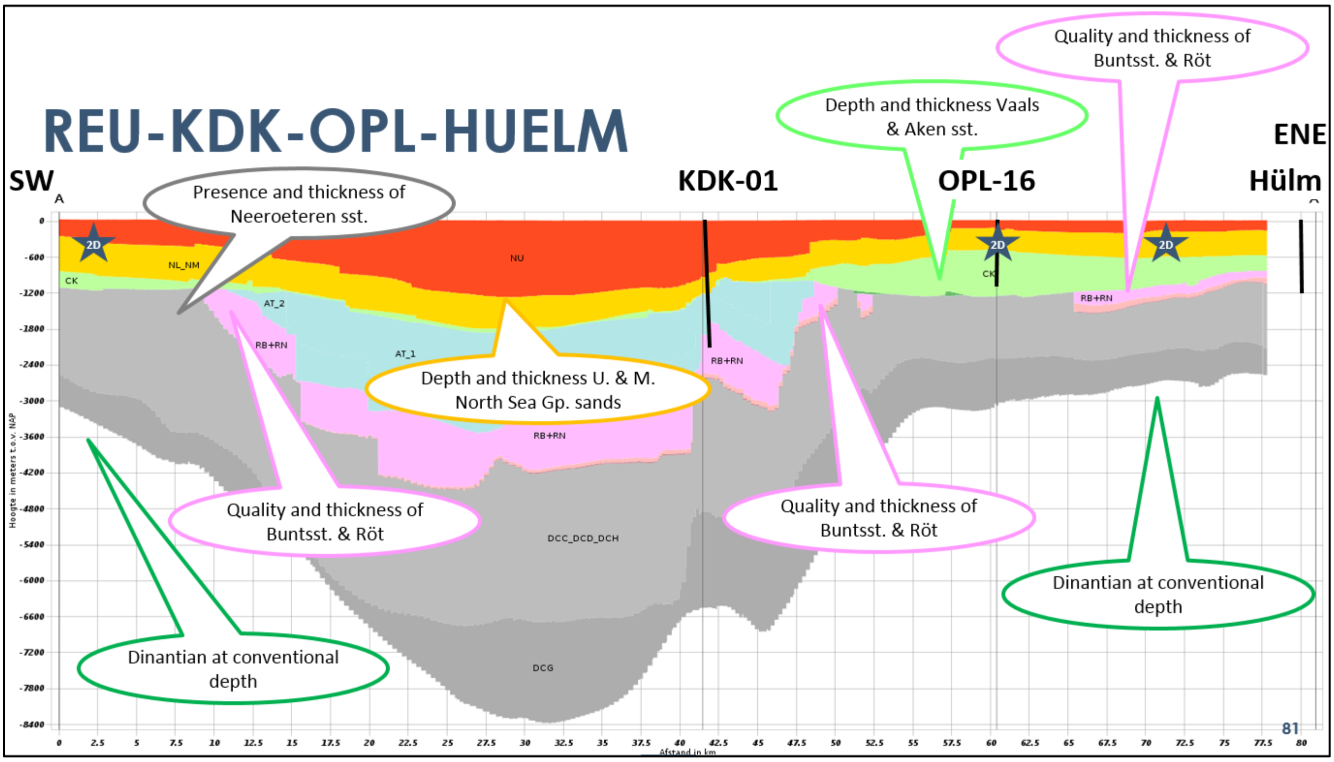
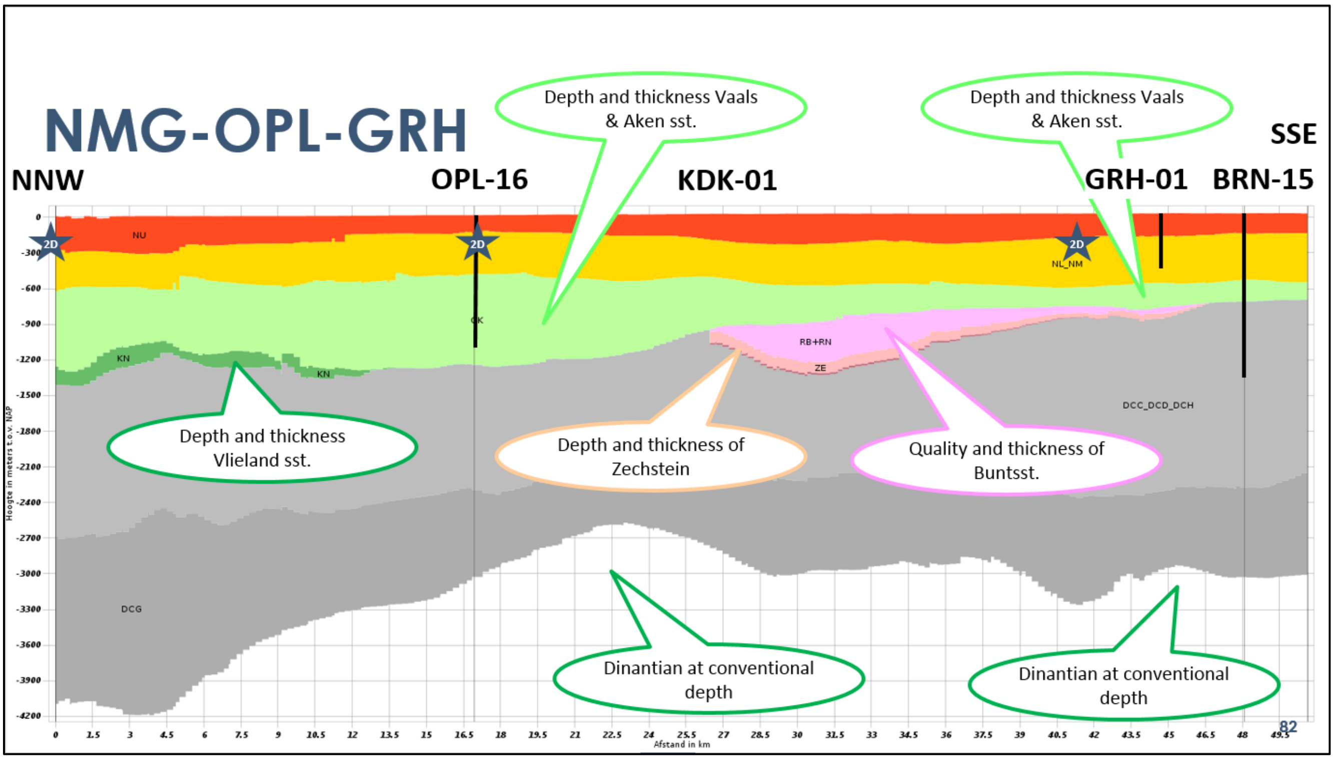
5. Appendices

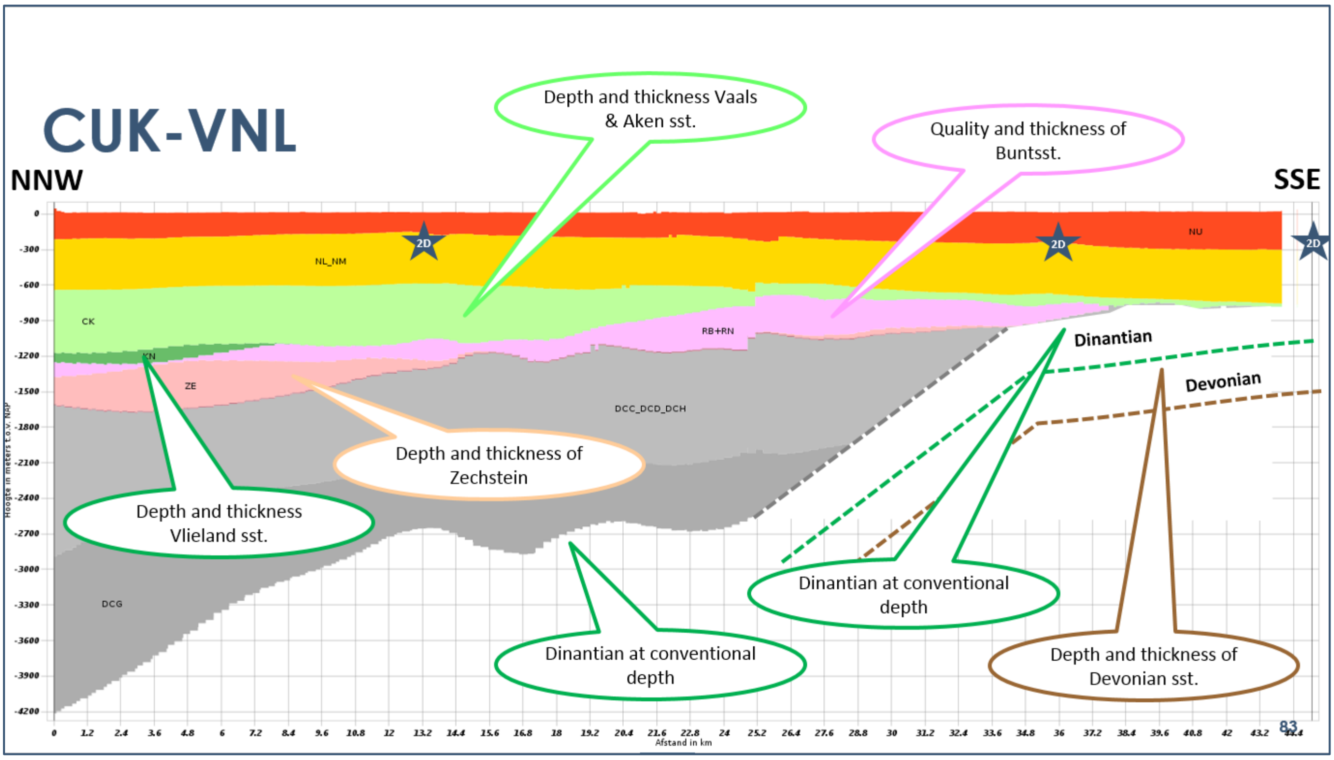
5.1 Depth sections from DGMdiep v4.0 in Dinoloket over proposed seismic sections area F&G

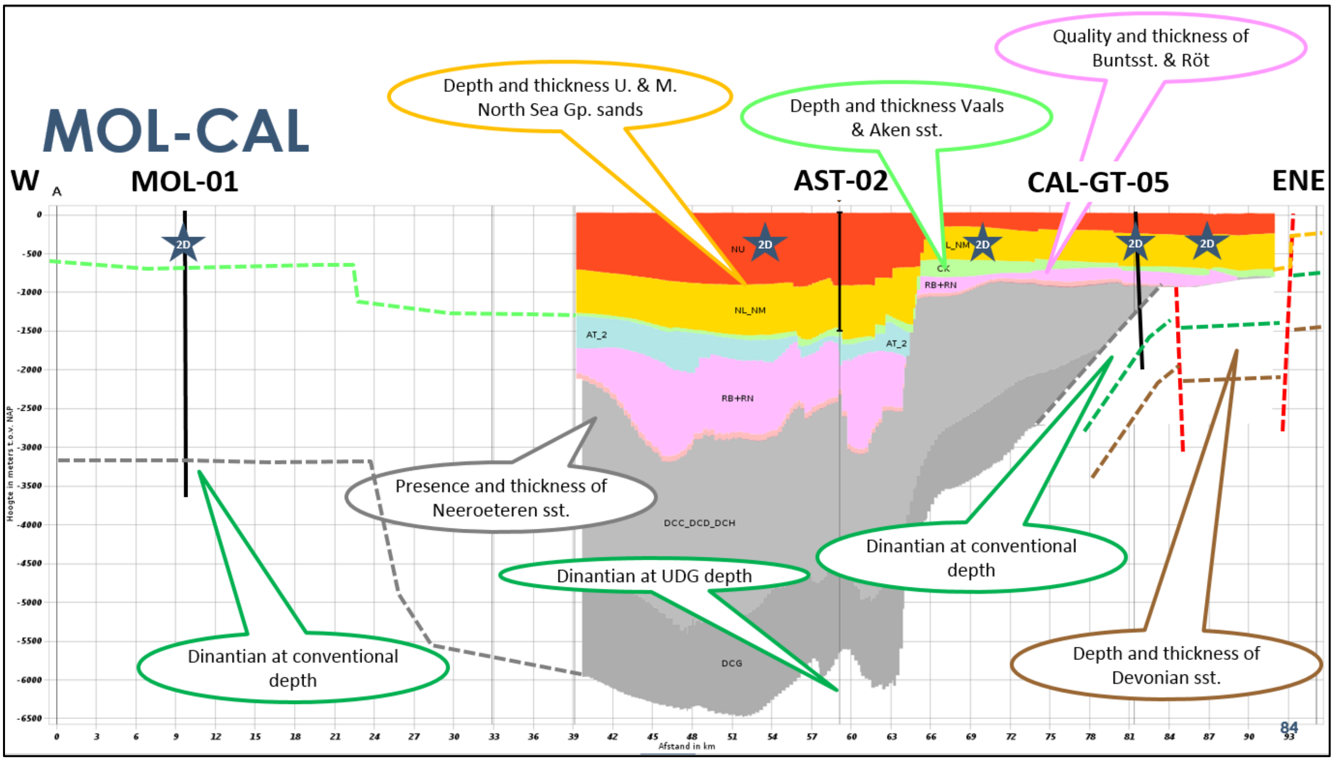


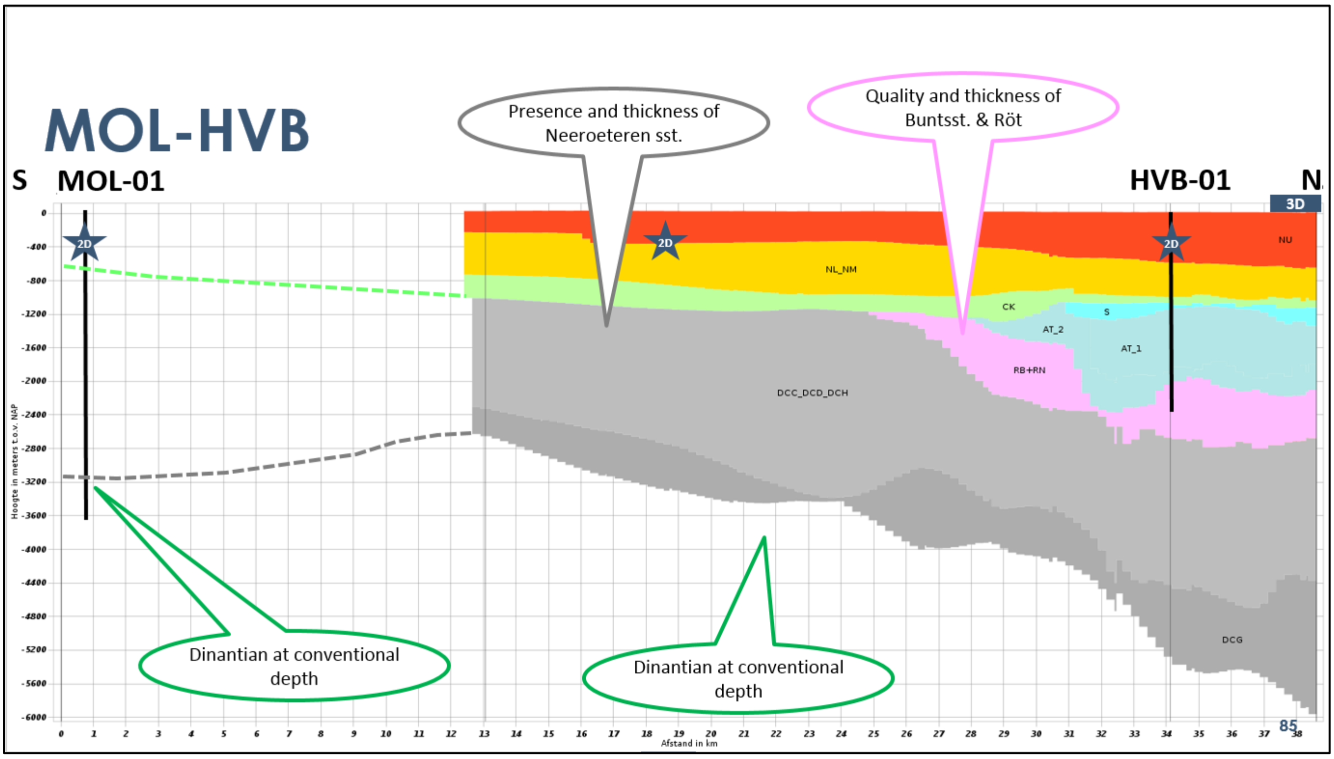


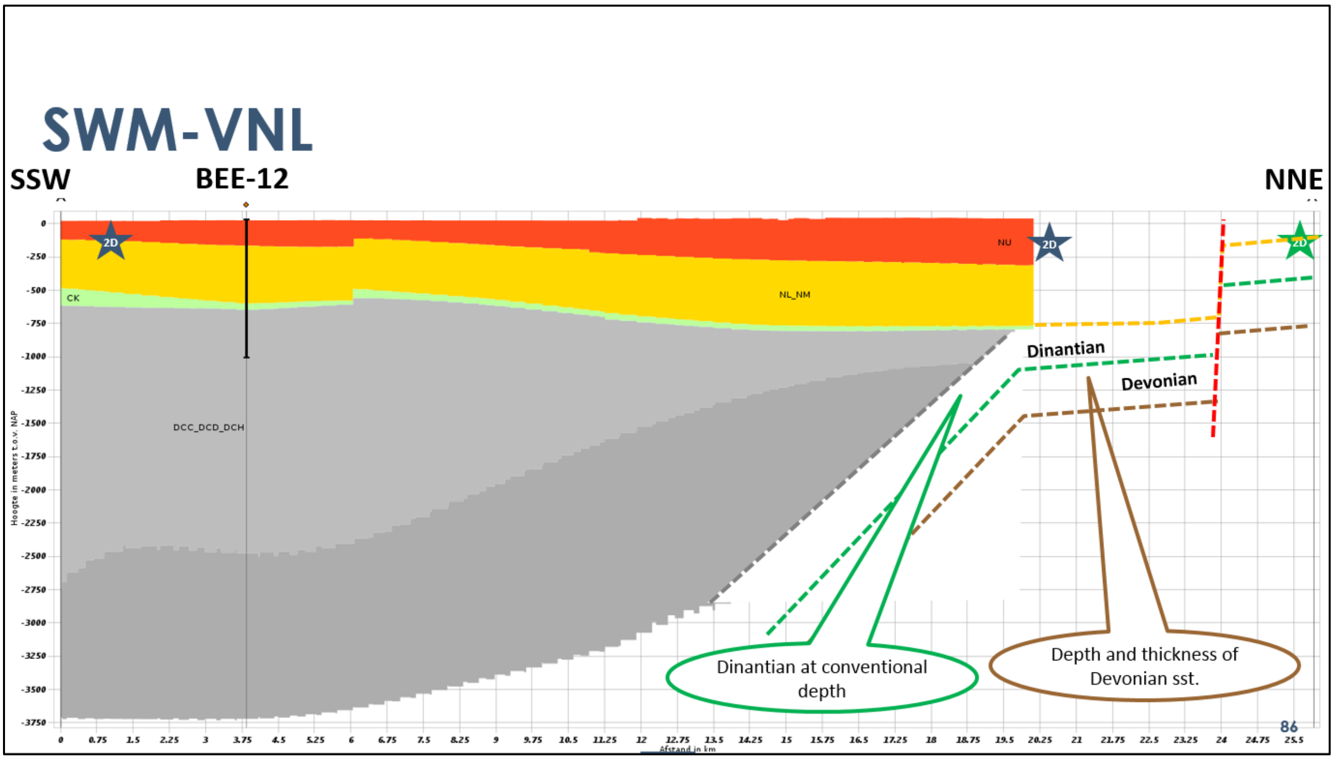

REU-KDK-OPL-HUELM
SW
ENE
KDK-01
OPL-16
Hülm
Presence and thickness of Neeroeteren sst.
Depth and thickness Vaals & Aken sst.
Quality and thickness of Buntsst. & Röt
Depth and thickness U. & M. North Sea Gp. sands
Quality and thickness of Buntsst. & Röt
Quality and thickness of Buntsst. & Röt
Dinantian at conventional depth
Dinantian at conventional depth
NU
NL_NM
CK
AT_2
AT_1
RB+RN
DCC_DCD_DCH
DCG
Hoogte in meters t.o.v. NAP
Afstand in km
81

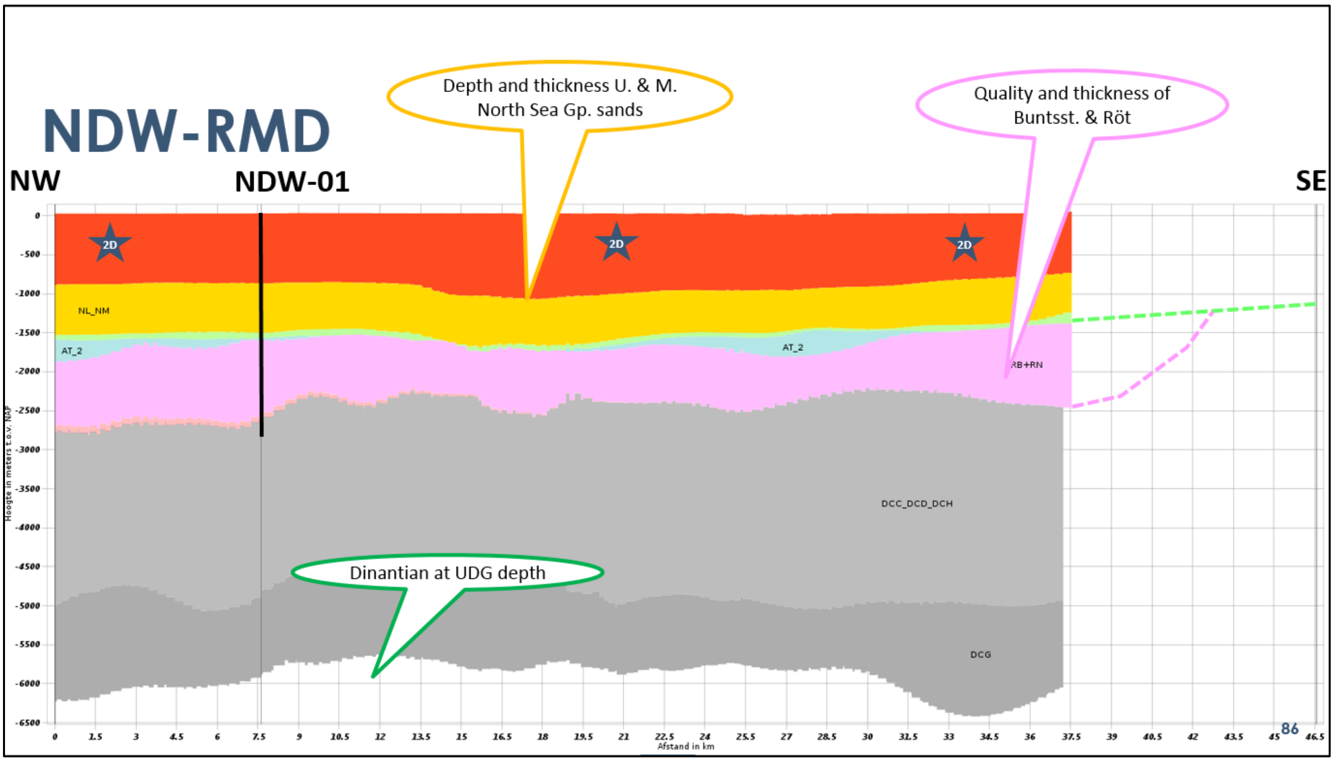

NMG-OPL-GRH
NNW
SSE
OPL-16
KDK-01
GRH-01
BRN-15
Depth and thickness Vaals & Aken sst.
Depth and thickness Vaals & Aken sst.
Depth and thickness Vlieland sst.
Depth and thickness of Zechstein
Quality and thickness of Buntsst.
Dinantian at conventional depth
Dinantian at conventional depth
NU
NL_NM
CK
KN
RB+RN
ZE
DCC_DCD_DCH
DCG
Hoogte in meters t.o.v. NAP
Afstand in km
82

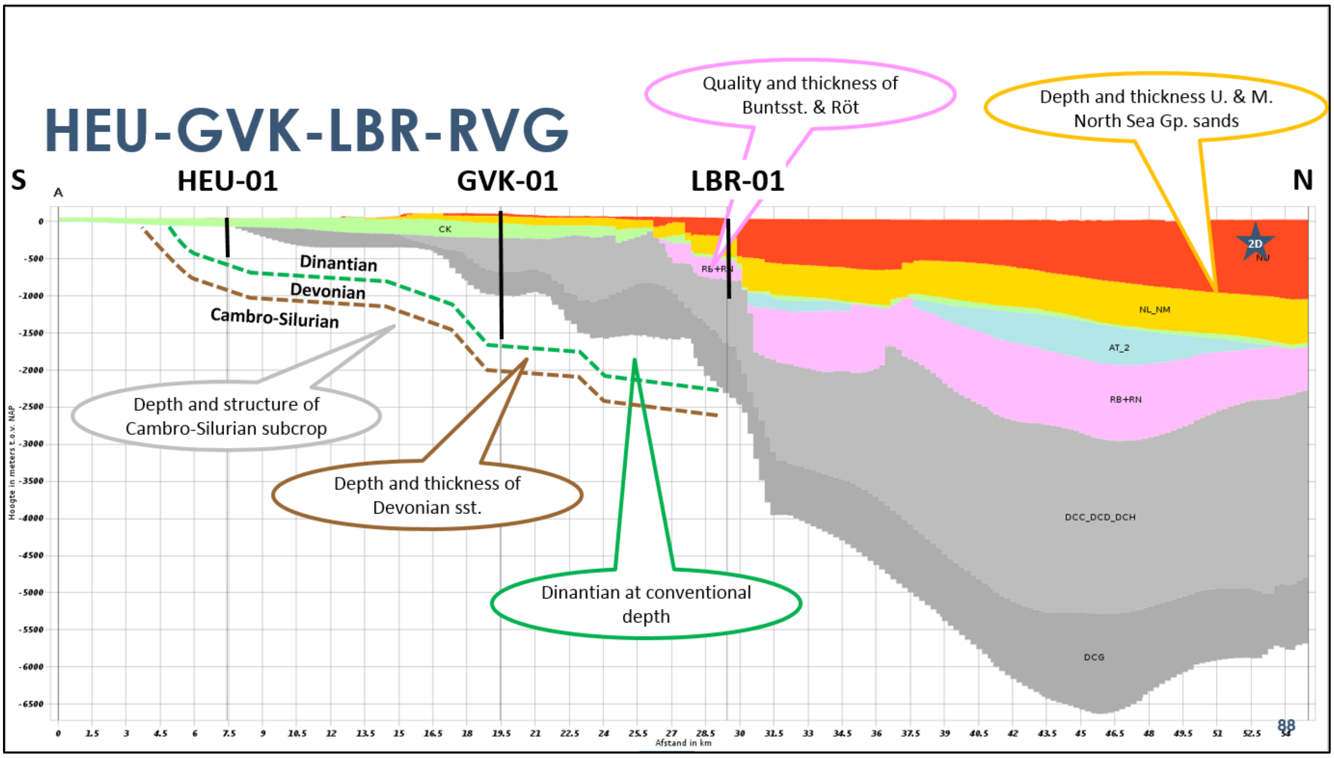

CUK-VNL
NNW
SSE
Depth and thickness Vaals & Aken sst.
Quality and thickness of Buntsst.
Dinantian
Devonian
Depth and thickness of Zechstein
Depth and thickness Vlieland sst.
Dinantian at conventional depth
Dinantian at conventional depth
Depth and thickness of Devonian sst.
NU
NL_NM
CK
KN
ZE
RB+RN
DCC_DCD_DCH
DCG
Afstand in km
83

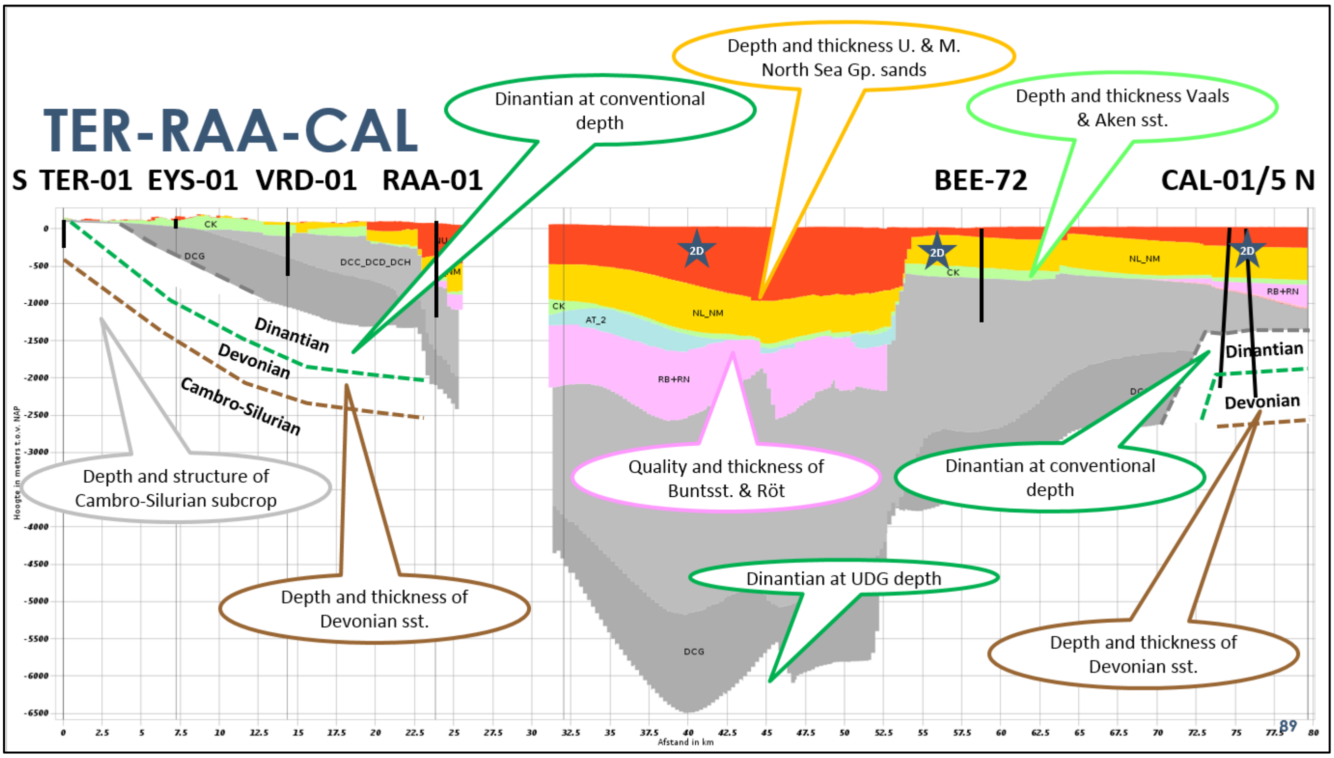

MOL-CAL
W
MOL-01
AST-02
CAL-GT-05
ENE
Depth and thickness U. & M. North Sea Gp. sands
Depth and thickness Vaals & Aken sst.
Quality and thickness of Buntsst. & Röt
Presence and thickness of Neeroeteren sst.
Dinantian at UDG depth
Dinantian at conventional depth
Dinantian at conventional depth
Depth and thickness of Devonian sst.
NU
NL_NM
AT_2
RB+RN
DCC_DCD_DCH
DCG
Afstand in km
84


MOL-HVB
S
MOL-01
HVB-01
N
3D
Presence and thickness of Neeroeteren sst.
Quality and thickness of Buntsst. & Röt
Dinantian at conventional depth
Dinantian at conventional depth
NU
NL_NM
CK
S
AT_2
AT_1
RB+RN
DCC_DCD_DCH
DCG
2D
Hoogte in meters t.o.v. NAP
Afstand in km
85


SWM-VNL
SSW
BEE-12
NNE
NU
NL_NM
CK
DCC_DCD_DCH
Dinantian
Devonian
Dinantian at conventional depth
Depth and thickness of Devonian sst.
2D
Hoogte in meters t.o.v. NAP
Afstand in km
86

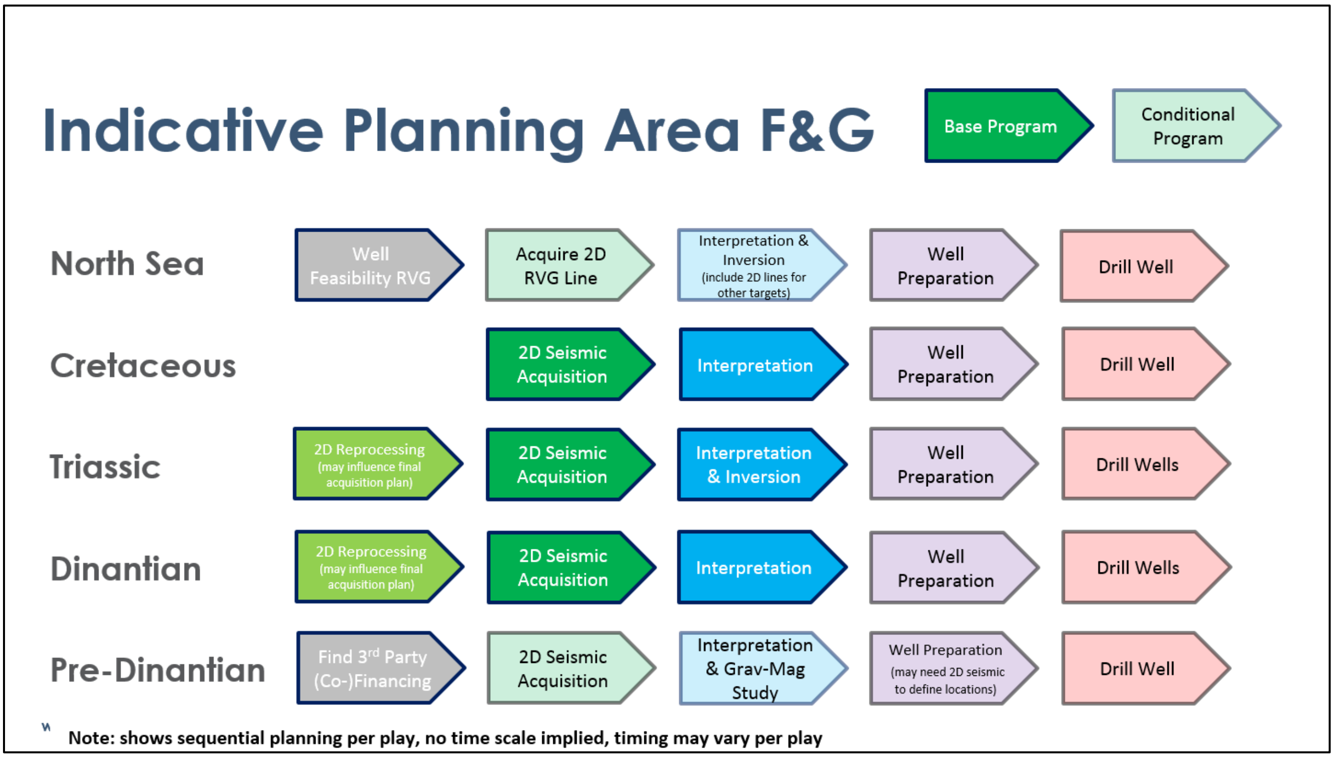

NDW-RMD
NW
NDW-01
SE
Depth and thickness U. & M. North Sea Gp. sands
Quality and thickness of Buntsst. & Röt
Dinantian at UDG depth
2D
NL_NM
AT_2
RB+RN
DCC_DCD_DCH
DCG
Afstand in km


HEU-GVK-LBR-RVG
S
HEU-01
GVK-01
LBR-01
N
Quality and thickness of Buntsst. & Röt
Depth and thickness U. & M. North Sea Gp. sands
Dinantian
Devonian
Cambro-Silurian
Depth and structure of Cambro-Silurian subcrop
Depth and thickness of Devonian sst.
Dinantian at conventional depth
CK
NL_NM
AT_2
RB+RN
DCC_DCD_DCH
DCG
Afstand in km



TER-RAA-CAL
S TER-01 EYS-01 VRD-01 RAA-01
BEE-72
CAL-01/5 N
Depth and thickness U. & M. North Sea Gp. sands
Dinantian at conventional depth
Depth and thickness Vaals & Aken sst.
Dinantian
Devonian
Cambro-Silurian
Depth and structure of Cambro-Silurian subcrop
Depth and thickness of Devonian sst.
Quality and thickness of Buntsst. & Röt
Dinantian at conventional depth
Dinantian at UDG depth
Depth and thickness of Devonian sst.
Dinantian
Devonian
Afstand in km

5.2 Indicative planning area F&G



Daalsesingel 1
3511 SV Utrecht
info@scanaardwarmte.nl
www.scanaardwarmte.nl

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