Novel concepts to construct cost effective geothermal wells with Electro Pulse Power Technology

Characterization of target formation and well design requirements

Deliverable D1.1

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Executive summary

A revolutionary drilling technology is developed in the DEEPLIGHT project and that uses electric power instead of mechanical and hydraulic forces. As a first step to establishing system requirements for Electro Pulse Power (EPP) drilling technology, geological, operational, and cost data for local scenarios in Turkey, Iceland and the Netherlands were gathered. This data has been represented in several Excel sheets and is a mix of public and confidential data, and therefore the sheets are only available within the DEEPLIGHT project consortium. A summary and discussion on the gathered data has been generated and serves as public deliverable D1.1 for the project. The collected data in the confidential sheets form together with this public report deliverable D1.1 and serve as input for the definition of the (commercial) EPP system requirements (deliverable D1.2), which. This report provides an initial list of observations to guide the next steps of the DEEPLIGHT project on the system requirements. From this report, it is concluded that, on the one hand, significant differences can be predicted between the geological formations to be drilled. On the other hand, it is concluded that there are several similarities for the drilling environment for these formations. These similarities concern the need for directional drilling, the typical hole size of 8-1/2”, and the general use of Water Based Mud. An overview of the formations for the local scenarios provides further background on the various geologies and demonstrates the potential significance of applying EPP drilling technology.

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1. Introduction & Scope

1.1. Introduction

The DEEPLIGHT consortium consists of a broad range of parties from different countries with different focus and expertise. In order to align all the expertise to reach the main project goal, development of a Electro Pulse Power (EPP) drilling technology, as much realistic data as possible from the local end users is required. For instance, to let de project develop EPP technology fulfilling market requirements, i.e., making the right steps to enable building a commercially viable system.

1.2. Scope

The present document presents a summary of collected data on drilling conditions and geology in Iceland, Turkey and the Netherlands. To this end, a predefined questionnaire has been prepared and distributed within different country referents.

The specific geological data could be used as a baseline for future (laboratory) tests. The query includes the most common drilling conditions and their related drilling complexities. Information on drilling conditions, the different bottom well assemblies, drill sections, and drill sizes can guide developers in improving drilling operations.

In addition, this document is intended to be the basis for initial conditions to be considered as the minimum operative requirements for a successful EPP technology that can be deployed in future tests and operations. A dedicated section of the data collection is intended to describe drilling sludge used in drilling operations and rock samples collected during drilling that are crucial to define future laboratory tests. In addition, the information collected here will be used as a basis for future cost and time savings (as part of Deliverable 1.2.).

2. Process description

2.1. Description of work and methodology

The present report presents the first results related to the Task 1.1 formation/geology/reservoir characterization that was carried out by Well Engineering Partners in collaboration with Zorlu Enerji, ÍSOR and Iceland Drilling Company.

The objective of this deliverable is to gather information required to define the Electro Pulse Power system specifications and to build on real cases a technical-economical model for subsequent pilots or commercial use.

The following steps were followed:

1) A template (Excel) was drafted and used as questionnaire to capture a complete set of data that can be used to compare the inputs from the different parties.
2) Zorlu Enerji for Turkey, ISOR and Iceland Drilling for Iceland and WEP were asked to fill in the questionnaire for targeted scenarios were EPP technology is expected to be beneficial.
3) Received data was analyzed and further clarifications were made. This data is part of the D1.1 deliverable and to be used as input for further DEEPLIGHT project activities.
4) Report on the performed work including main geological and operational findings.

The general scope of the DEEPLIGHT D1.1 deliverable can be summarized as follows:

- Geological aspects,
- Generalities on well design and operations for current drilling projects but also for potential future applications,
- Economics.

2.2. Background of collected parameters.

The significance of the parameters to be gathered is explained in this section to understand their relevance better. An essential part of the data collection is focused on drilling fluid (drilling mud) since this is the direct environment of the drilling system. Gathering the drilling fluid itself can be beneficial, but a clear plan of action and benefits must accompany it. The drilling fluid carries the newly produced cutting material from the drill/cut zone to the surface. That is an essential requirement for building a well effectively.

The drilling mud properties, the annulus geometry, and the pumping rate define the drag forces exerted on the cuttings. The fluid properties necessary to lift cuttings should not deteriorate the hole stability conditions and should be light enough to be pumped. Drilling fluids are thoroughly engineered and continuously conditioned to keep them in specifications. Furthermore, a proper balance between mud properties and mud rate assures cutting being removed from the bottom hole. If cuttings are not small enough, these are being re-grinded and consumes more energy. The future EPP tooling should be capable of producing cuttings that do not exceed the drag capacity of the drilling fluid used.

In addition to the stabilizing functions, drilling fluid is expected to convert hydraulics into mechanical energy, cooling, and well control (as it serves as a primary barrier). The drilling fluid also carries the data from the drilling assembly to the surface using pressure pulses. Additionally, the fluid used should have a minimal impact on the drilled formations and mitigate or prevent drilling problems such as stuck pipes or losses. Therefore, the chosen fluid system must be adapted to the formations to be drilled. This also applies to the complete well design, e.g., casing shoe depths and well trajectory selection. The mud system, including all handling, cleaning, and disposal, is a significant part of the total well construction costs.

In general, the parameters that mainly determine the cost of drilling a well are the volume of rock to be removed and the amount of materials used to finish the well. The volume of rock to be removed from the drill hole is calculated based on the drill hole diameter represented by the bit size and the drill hole section to be drilled. The energy required to convert the rock into transportable rock cuttings is directly related to the rock's properties, such as unconfined compressive strength (UCS), porosity, density, rock heterogeneities, and fluids contained therein. The environmental conditions of the boreholes can be derived from the temperature gradient, salinity, and formation inclination.

The energy applied to create cuttings from a rock is defined by the specific mechanical energy (MSE) [20]. This MSE is the amount of mechanical work exerted to extract a unit volume of rock (i.e., rock cuttings). The MSE has been effectively quantified in laboratory settings to evaluate the drilling efficiency of drill bits [21]. Various modifications have been proposed to describe the relationship between the MSE and the input energy delivered by the drill rig and where the latter is a function of Weight on Bit, Revolutions per Minute, hydraulics and drilling torque, and the drilling rate or Rate of Penetration (ROP). The maximum drilling efficiency is attained when the MSE is at its lowest value. The lowest value of MSE corresponds to the rock's confined compressive strength (CCS). The limited CCS and associated UCS can be measured from acquired cores or estimated from borehole logging. To better understand the amount of energy effectively used to produce cuttings, it is also necessary to calculate the amount of energy positioned to place the drill through the drill string and the lost pressure to remove produced cuttings from the bottom hole. As a standard in the drilling industry, drilling logs provide UCS and CCS values. However, it is a well-known technique, but precise comparisons of the drilling performance of different drill holes are challenging and require complex algorithms [22].

Therefore, using MSE, UCS, or CCS should be carefully performed when creating tool specifications and predicting ROP, mainly when using different drilling methods.

2.3. Case scenarios and applications

As was mentioned in a previous chapter, representants per country were asked to describe the expected best applications they found for the to-be-developed EPP tooling. The distributed Excel template aims to capture the initial conditions and data for techno-economical investigations. Essentially it contains the following information:

- Scenario description with expected added value
- Rig daily costs rates
- Drilling problems.

3. Collected data.

3.1. Overview

All data that was gathered is available via confidential Excel sheets within the DEEPLIGHT project consortium. The reader will find in this document a general summary of the formation characterization and drilling requirements data in Table 1 and Table 2 below. The full and confidential Excel sheets are available for detailed project investigations, while the summaries in this document are used to guide the general tooling development. Seven user scenarios found in Table 1 were provided by the parties from the three targeted countries. Similar data is listed together in the tables below to better understand the differences and similarities between the various user cases.

Table 1: Summary on characterization of target formations (with [references] added to some of the data) and information

Country	Scenarios	Fm. Name	Difficulties	Expected benefits	Age	Rock Density [g/cm³]	Target Fm. UCS [MPa]	Fm. Pore pressure [kg/cm²]	Fm. Temperature [°C]	Fm. Salinity [ppm]	Fm. Porosity [%]	Inter-bedded	During drilling problems	Final trip-out of hole response	Casing running response
Netherlands [8]	Standard geothermal well (complete well) [3]	North Sea Gr. Chalk Gr. Kolenkalk Gr.(target)	The Carbonaceous Zeeland Fm (Kolenkalk Gr.) has mud losses from partial to total	No need to change drill bits (time savings)	Quaternary to Carboniferous	~2.37 Chalk up to ~2.7 Kolenkalk [3,4]	78\148 [5,6,7]	~140 Chalk up to ~220 Kolenkalk [5]	>90 [5]	<80000 >100000 <80000 [10-12]	0.5 - >25 (even karst) [6]	Yes	Erratic torque and drag responses	Loss circulation events	Casing pulled due to inability to run to depth
Netherlands	CwD to drill deep hole section [3]	Kolenkalk Gr.	IDEM	More accurate reservoir completion (optimized depth and temperature)	Cretaceous to Carboniferous	~2.7 Kolenkalk	148 [5,6,7]		>90 [5]	>100000 <80000 [11,12]	0.5 - >20 (even karst) [6]	Yes	IDEM	IDEM	IDEM
Netherlands	Very deep wells [2]	North Sea Gr. Chalk Gr. Kolenkalk Gr.(target)	IDEM	Higher production temperatures (industrial resource)	IDEM	~2.37 Chalk up to ~2.7 Kolenkalk	148 [5,6,7]	~140 Chalk up to ~220 Kolenkalk [5]	>110 [5]	<80000 >100000 <80000 [10-12]	0.5 - >20 (even karst) [6]	Yes	IDEM	IDEM	IDEM
Netherlands	CwD to drill top hole section [1]	North Sea- and Chalk Gr.	Shallow gas \ hard formation	Faster drilling operations (reduction in operative hours)	Quaternary to Cretaceous	~2.37 Chalk	78 [5,6,7]	~140 Chalk [5]	>60 [5]	<80000 [7]	0.5 - >25	Yes	IDEM	IDEM	Expected drag-level responses

Turkey [11]	Reduction of bit trips	Menderes Metamorphics	PDC bounces and provokes downhole motor failure or MWD signal problems.	Time savings and therefore cost savings	Pre - Miocene	2810 (Quartzite) 2670 (Micaschist)	N\A	N\A	2400 m - 210 °C 3000 m - 230-245 °C	2400 m - 2.7 3000 m - 2.8	1.71 (Quartziteschist) 8.52 (Micaschist)	Yes	Erratic torque and drag response	Loss circulation event + overpulls	Joint wiped to reduce elevated drag levels
Iceland [9]	Reduction of bit/motor trips	Crystalline basalt \ Hyaloclastite	Service hours on motors are limited to 150 hrs; often, the BHA can only be tripped halfway through the production section	24-36 hrs on this trip and premature bit/motor failures.	Quaternary	2.7 \ 3.3	10 - 70	N\A	0 - 340	N\A	0 - 50	Yes	Near stuck pipe incidents	Transient tripping out problems	
	Reusable/Repairable Bit	IDEM.	Swapping electrode heads to use the same set for all possible hole sizes	Savings on motor rentals, bits, and logistics	Quaternary	2.7 \ 3.3	2 - 6	N\A	0 - 340	N\A	7 - 35	Yes	IDEM.	IDEM.	

Table 2: Summary on well design requirements (with [references] added to some of the data) and information

Country	Scenarios	Fm. Name	Drill bit type	Section Ø [in]	PDM [y\m]	Starting Depth [m]	Well inclination [°]	Length to be drilled with EPP [m]	Total Well depth (TVD) [m]	Mud type	Mud Name	Mud salinity [ppm eq \mg/l]	Max. Flowline Temperature [°C]
Netherlands [16]	Standard geothermal well (from conductor to TD)	Kolenkalk Gr.	TCB \ PDC	17.5 \ 12.25 \ 8.5	y	150	>40	Top Hole 1000 \ Deep Hole 1000	>2500	WBM	KCL/Polymer		~30
Netherlands [16]	CwD to drill deep hole section	Kolenkalk Gr.	TCB \ PDC	12.25 x 8.5	y	1200	>40	1000	>2500	WBM	KCL/Polymer	~50000	~30 (no circulation)
Netherlands [16]	Very deep wells	Kolenkalk Gr.	TCB \ PDC	12.25 \ 8.5	y	3000	>40	> 3000 [8]	>4500 [11]	WBM	KCL/Polymer		~30
Netherlands [15]	CwD to drill top hole section	North Sea- and Chalk Gr.	TCB \ PDC	12.25 x 17.5	y	150	<10	Top Hole 1000	<1200	WBM	KCL/Polymer	~16000	~50
Turkey [8]	Reduction of bit trips	Menderes Metamorphics	PDC	8.5	y	N\A	N\A	>880	>1100 [12]	WBM	Lime/gypsum/lignosulphonate	N\A	~80
Iceland [9]	Reduction of bit/motor trips \ Reusable/Repairable Bit	Crystalline basalt \ Hyaloclastite	IADC 627 Tricone Bit (Reservoir section)	12.25	y	N\A	N\A	1000 \ 400	>1800	WBM	Gel-Polymer (pure water if losses are severe) \ low concentrated polymer or pure water over reservoir interval	N\A	60

4. Description of potential locations and their geological settings

The data collected in this chapter is based on geological surveys focusing on the most relevant geological formations and their prospective drilling conditions. This information is only valid regionally and cannot be considered representative of the total extent of a country. Through the figures and maps in this chapter the reader learns more about the subsurface and the geothermal potential of the three countries for those specific regions.

4.1. Iceland

Brief description.

The DEEPLIGHT partner companies ISOR and Iceland Drilling have provided subsurface and drilling-related data of a project in the South close to Nesjavellir, in the Southern Peninsula close to Reykjanes, the Northeast region close to Krafla, see Figure 1.

A summary of the importance of these sites is presented below as taken from [9].

Reykjanes

The Reykjanes Peninsula is the landward extension of the Reykjanes Ridge and encompasses a high-temperature hydrothermal system in a "ridge-crest" graben system. The depth to the oceanic layer 3 (lower crust) is unknown, but a volcanic eruptive fissure zone of late Holocene age is targeted at 3-5 km depth and/or the center of the graben. The last volcanic eruption was in 1226 AD. The geothermal fluid is derived from seawater.

Nesjavellir

The Nesjavellir high-temperature hydrothermal system is associated with a relatively young central volcanic complex on the mid-Atlantic ridge system in SW-Iceland. During drilling in 1986 temperatures above 380°C were met at 2.2 km depth in well NJ-11 adjacent to a volcanic eruptive fissure zone. Because of a blow-out, the well was plugged up to 1.6 km depth (and this hostile situation has not been dealt with since). The geothermal fluid is of meteoric origin.

Krafla

The Krafla high-temperature system lies in an evolved central volcanic complex on the mid Atlantic ridge system in NE-Iceland, involving a caldera and a large cooling magma chamber at shallow depth under an exploited drill field. Magmatic gases released during a volcanic episode from 1975-1984 seriously affected the well field and disturbed the exploitation. A cooling magma chamber is believed to lie at a depth of 3-5 km depth. The geothermal fluid is of meteoric origin.

Most locations with geothermal potential follow a trend through the country's geography and share similar geologic conditions, see Figure 1.

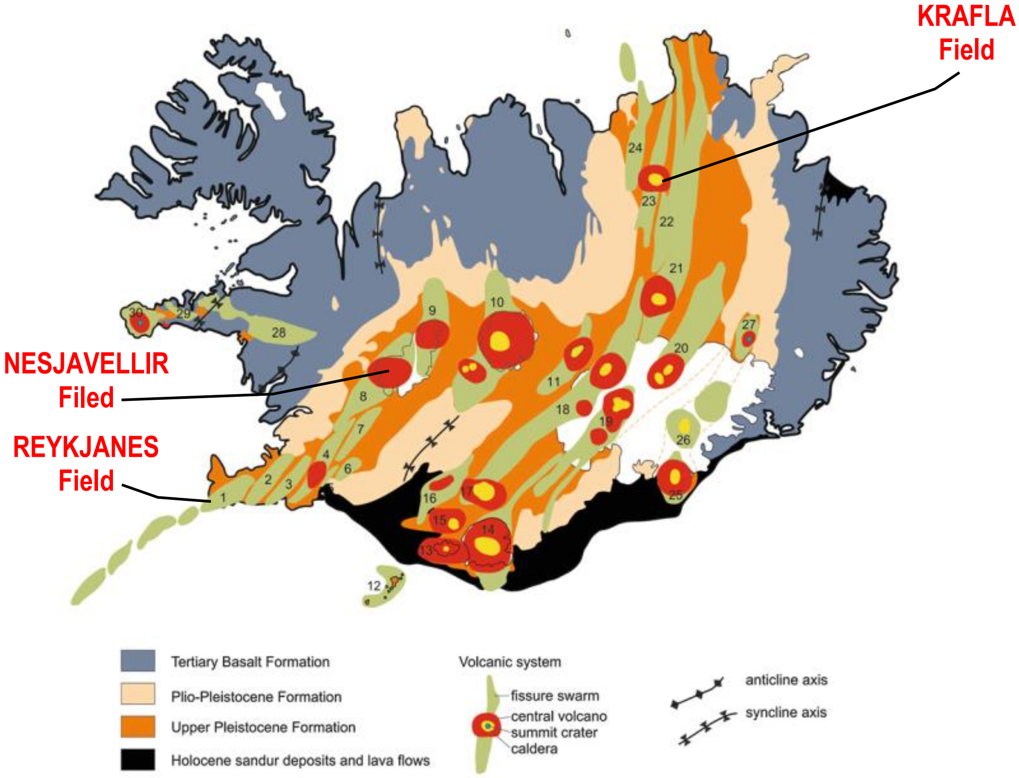


Figure 1: Distribution of active volcanic systems among volcanic zones and belts in Iceland. Numbers indicate each volcanic system [9].

4.1.1. Geological settings - Reykjanes Field

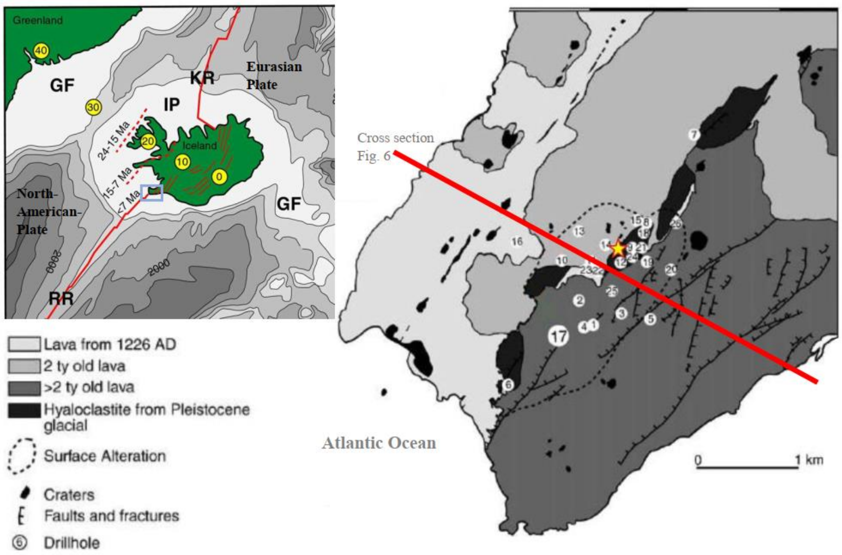


Figure 2: Upper left: Bathymetric map around Iceland Plateau. The wandering of the Iceland plume in Ma to its actual position is tracked with yellow circles. The plume transected two ocean ridge segments: the Reykjanes Ridge (RR) and the Kolbeinsey Ridge (KB). Active and inactive rifting and the related time frame is indicated by solid and dotted red lines(GF concerns the Greenland-Færöy-Ridge). The bluish rectangular shows the Southern Reykjanes Peninsula, as enlarged in the right picture: The legend on the lower left describes the surface expressions and the lithology. The numbers in the right picture represent already drilled wells [10].

From the red line of Figure 2., a cross-section showing the type of rock is presented in Figure 3, whereas Figure 4 describes the color code used to describe the lithology.

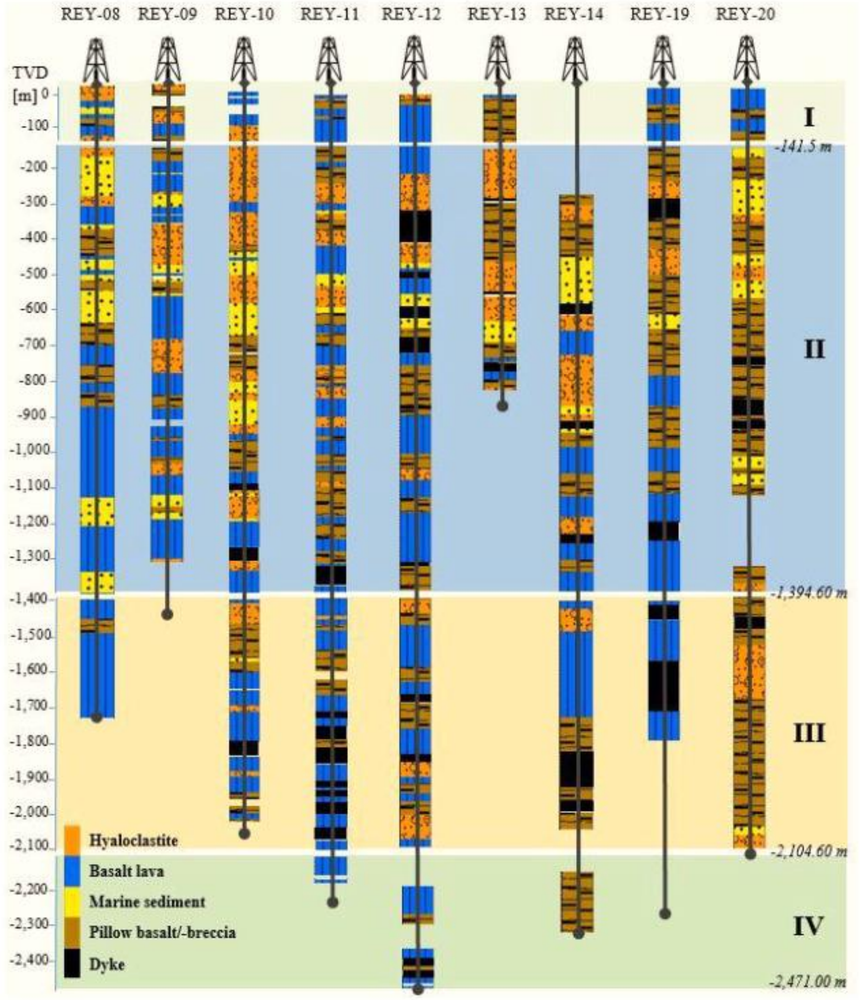
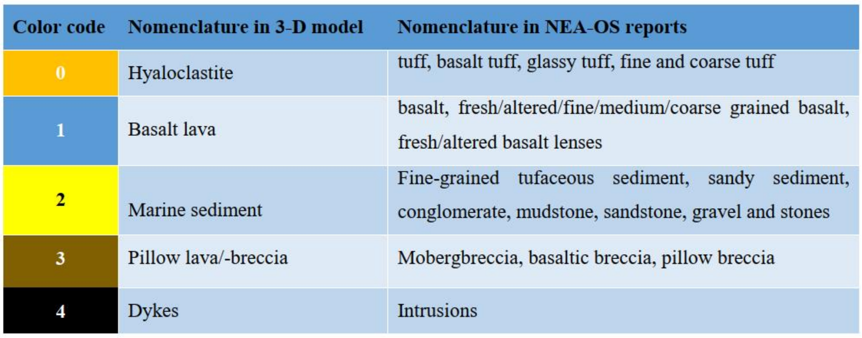


Figure 3: Cross section (red line, see Figure 2) between wells 8 to 20, showing lithology logs used for 3-D modeling.



Color code	Nomenclature in 3-D model	Nomenclature in NEA-OS reports
0	Hyaloclastite	tuff, basalt tuff, glassy tuff, fine and coarse tuff
1	Basalt lava	basalt, fresh/altered/fine/medium/coarse grained basalt, fresh/altered basalt lenses
2	Marine sediment	Fine-grained tufaceous sediment, sandy sediment, conglomerate, mudstone, sandstone, gravel and stones
3	Pillow lava/-breccia	Mobergbreccia, basaltic breccia, pillow breccia
4	Dykes	Intrusions

Figure 4: Listing of the color codes as used for modeling. The nomenclature of lithologies was correlated with similar lithology expressions in NEA-OS reports [9].

4.1.2. Geological settings - Nesjavellir Field

The Nesjavellir site, also located in the country's southwest, is geologically characterized by eruptive units. Several wells provide valuable information about this geological environment, see Figure 5.

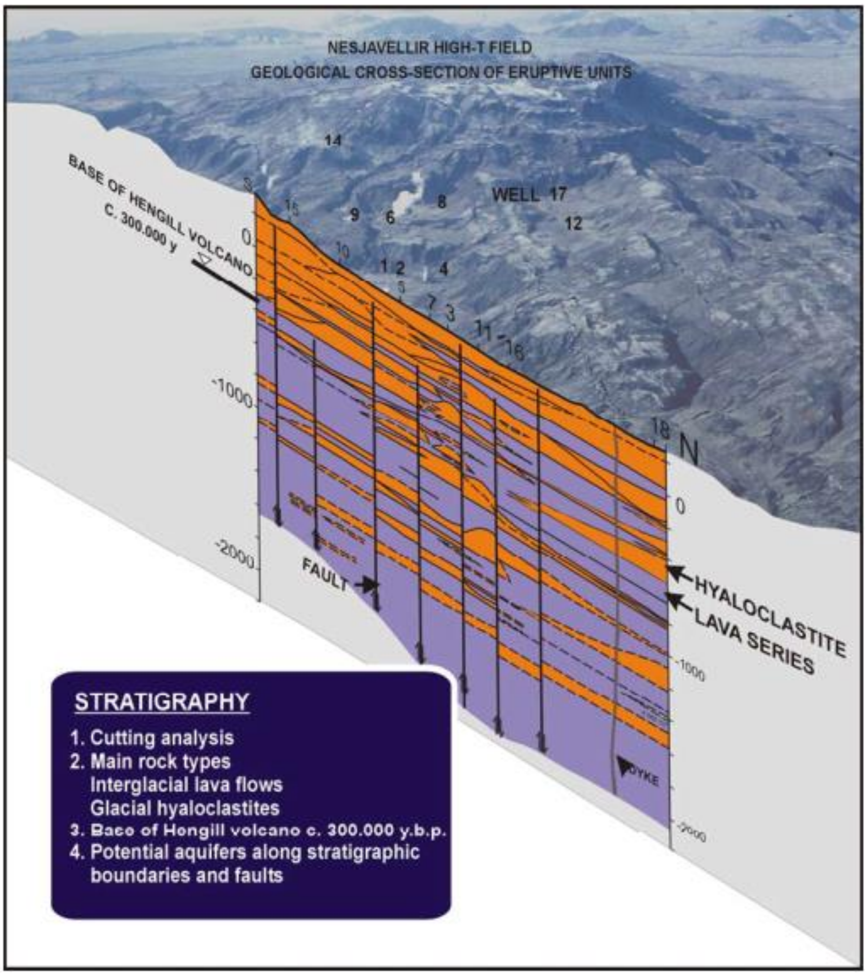


Figure 5: Simplified geological cross-section through the Nesjavellir drill field [9]

The base of the Hengill volcanic is set at some 300.000 years, below which depth sub glacially formed hyaloclastites become less abundant, but subaerial lava flows more so, forming several discrete series. Also shown are all the main faults detected within the field. Some faults reach the surface, while others are buried and inferred from drill cutting data by comparing lithological sections between wells [9].

4.1.3. Geological settings - Krafla Field

The Krafla field is in the northeast of the country. Recovered from the last volcanic eruption in the 1970s, intensive drilling campaigns at the end of the last century ensured the realization of this geothermal project.

The plan view in Figure 6 shows the location of the existing wells, and two cross-sections in Figure 7 show the complexity of the geology.

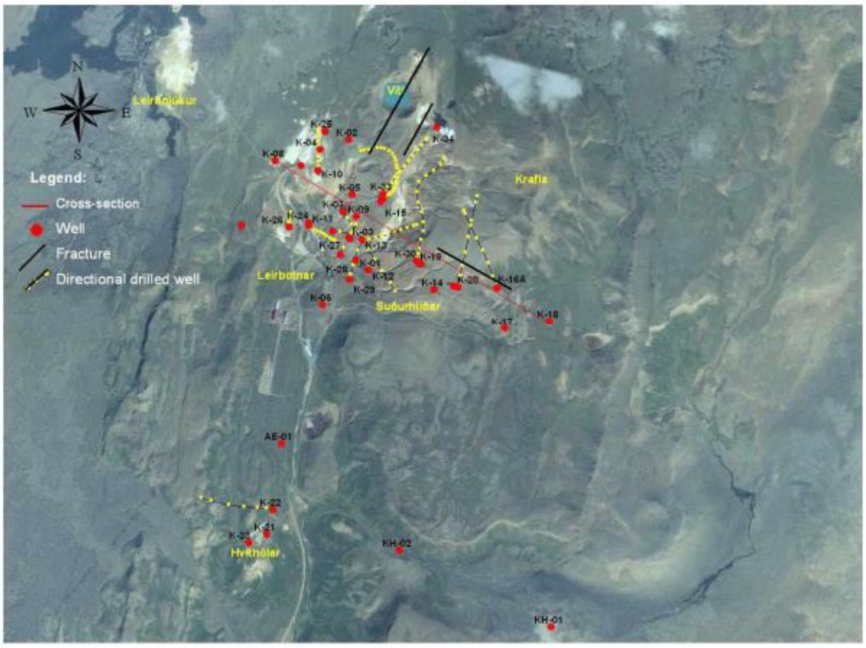


Figure 6: Location map of drill holes at Krafla. Trajectories for inclined wells are indicated. The cross-section location from well KJ-8 across the field to KJ-18 is shown. More information is in [9].

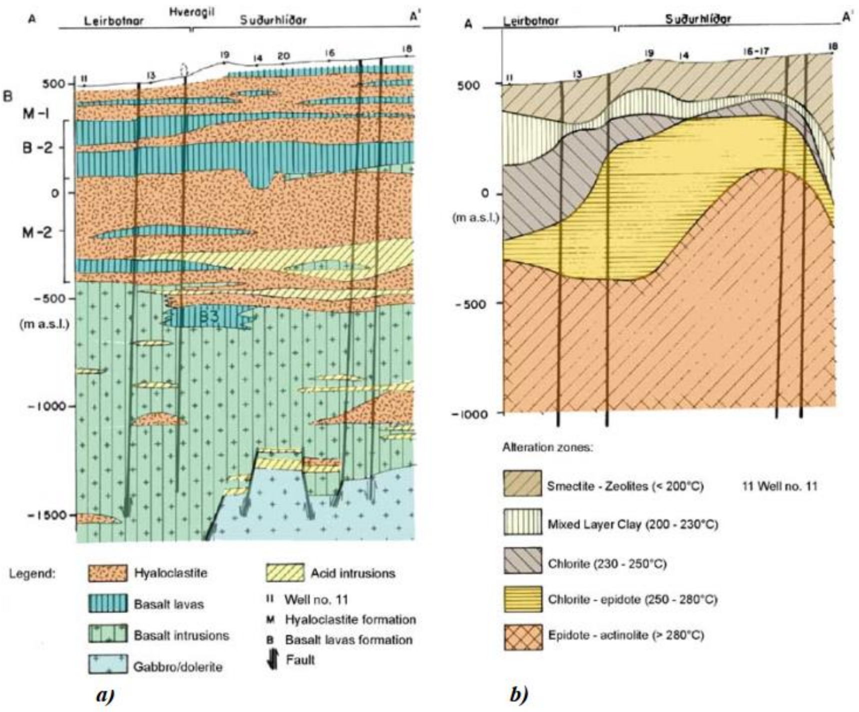


Figure 7: Geological (a) alteration (b) profiles across the Krafla drill field from west to east. The cross-section line is shown in red in Figure 6 (note the changes in scales).

4.2. Turkey

4.2.1. Kizildere field

The Kizildere (Denizli) geothermal field is situated in a tectonically active area, part of the Neogene graben structure of the Denizli Basin. See Figure 8 and Figure 9.

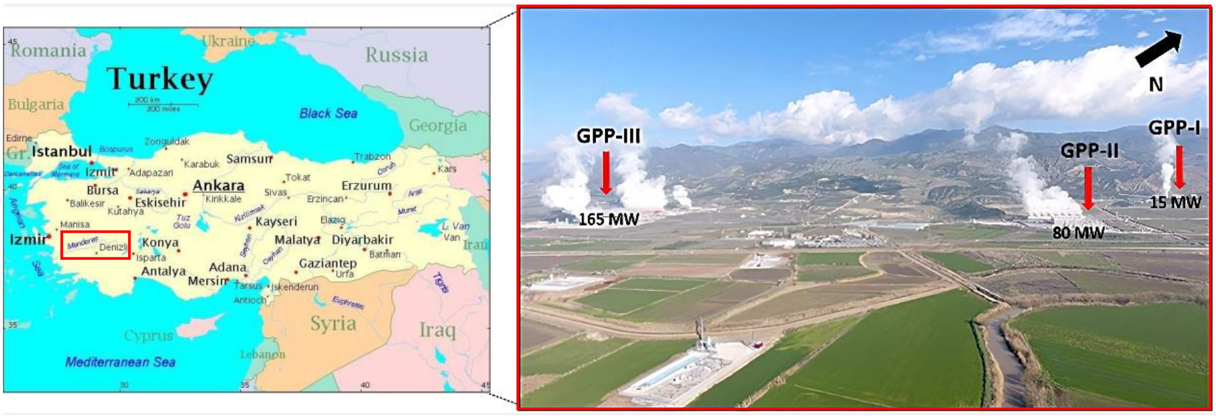


Figure 8: The view of the Kızıldere-I, Kızıldere-II, and Kızıldere-III GPPs within the Kızıldere geothermal field.

Drilling through the Neogene graben structure of the Denizli Basin can be challenging due to its geological complexity, see Figure 10. The graben structure is composed of various rock formations with different mechanical properties, making it difficult to predict the behavior of the rocks during drilling. In addition, the high temperatures and pressures in the geothermal reservoir can cause problems with drilling fluids and equipment and can lead to wellbore instability.

Figure 11 shows an approximation of the lithological column of the geothermal field Kızıldere. The lithological columns for Iceland (consisting mainly of altered basalts) and those for this specific Turkish basin allow the reader to understand the need to develop EPP tooling that could be versatile enough to drill through very different rock types.

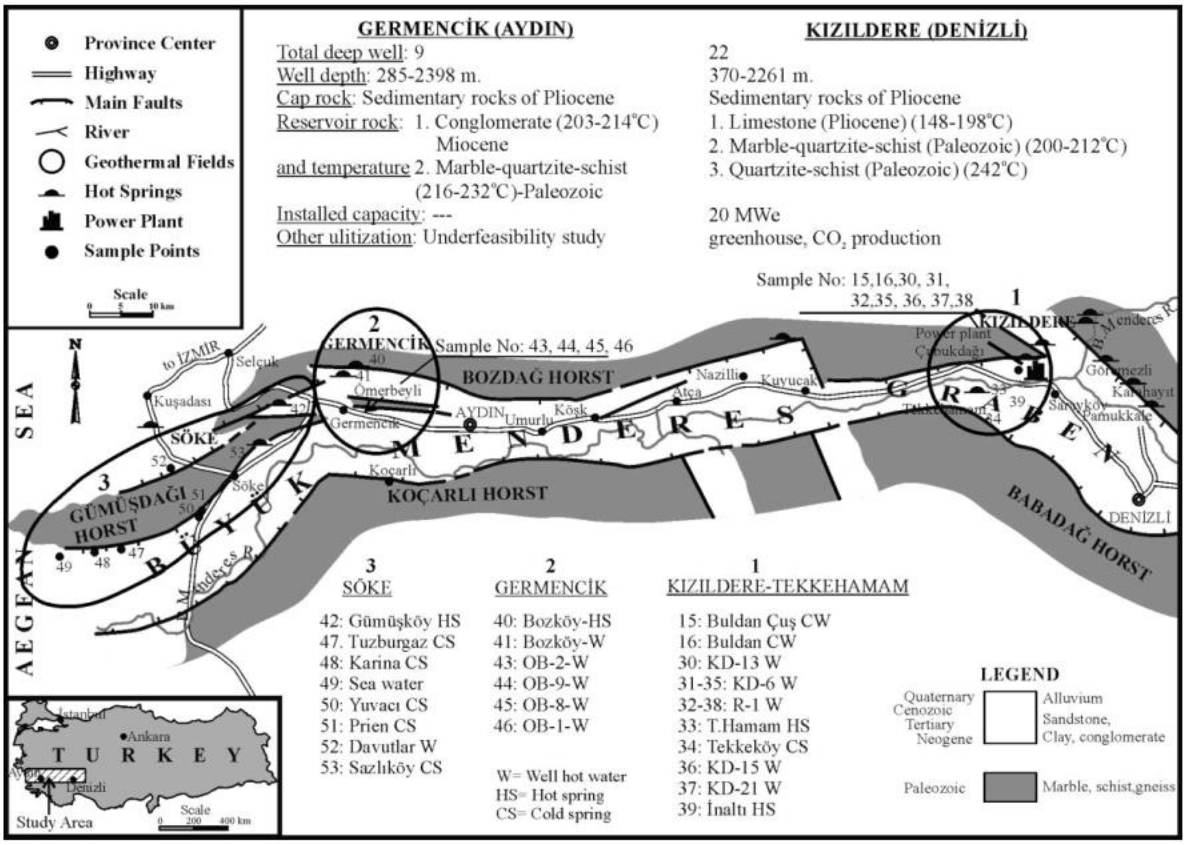


Figure 9: Main geothermal fields and sampling points of the study area, [13].

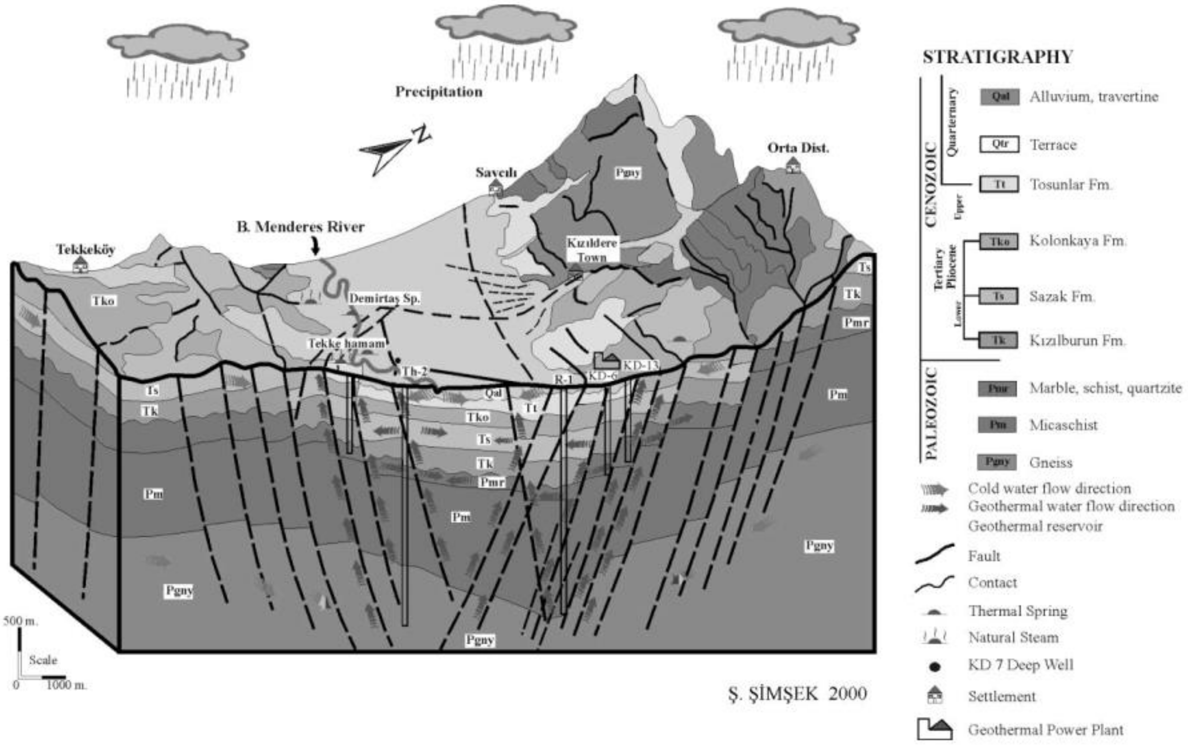


Figure 10: Block diagram of Denizli-Kizildere geothermal field, [12].

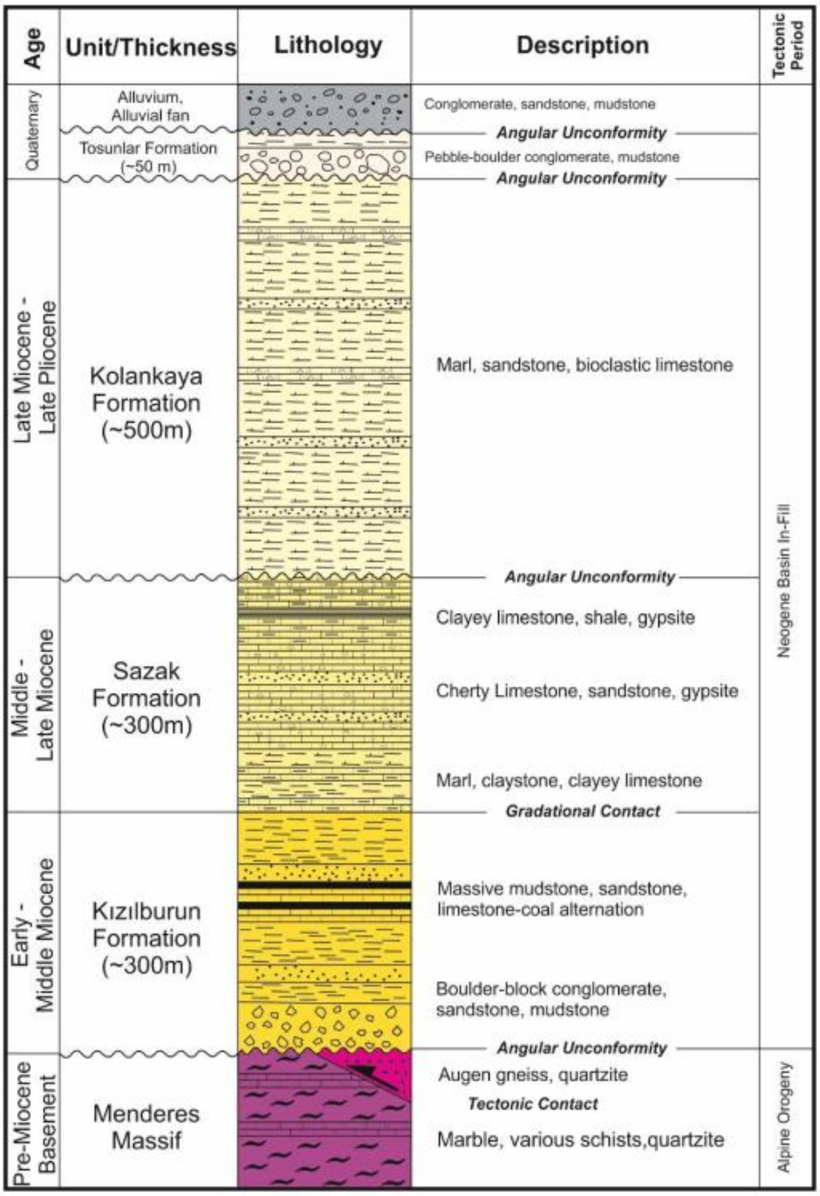


Figure 11: The generalized tectonostratigraphic column of the Denizli-Kizildere geothermal field area [12].

4.3. The Netherlands

A first impression of the Netherland's geography might suggest that not many challenges could arise from its geology. Although The Netherlands is in a tectonically quiet area, still, it is traversed by several faults, some of which have been active in the southern part of the country since the Oligocene, see Figure 12. Three of the 4 proposed scenarios pursue the Zeeland formation, also called the Kolenkalk, of the Lower Carboniferous period as the target reservoir of the 9 ⅝" or 7" deep hole section of the well. This formation can vary from zero meters to more than 1800 meters.

A general scenario was proposed: drilling top-hole wells in the Netherlands (through the North Sea Group and setting the casing shoe into the Chalk Group). These top holes are typically cased with 13 ⅜" casing.

4.3.1. Zeeland Formation (scenarios 1 to 3)

The Zeeland Formation (see Figure 13) is part of the Early Carboniferous, characterized by thick layers of limestone “Kolenkalk”. This limestone has a hard matrix, and in certain areas, the limestones are faulted, highly fractured, and have good permeability values. In addition, karst is present in these dense limestones in certain areas.

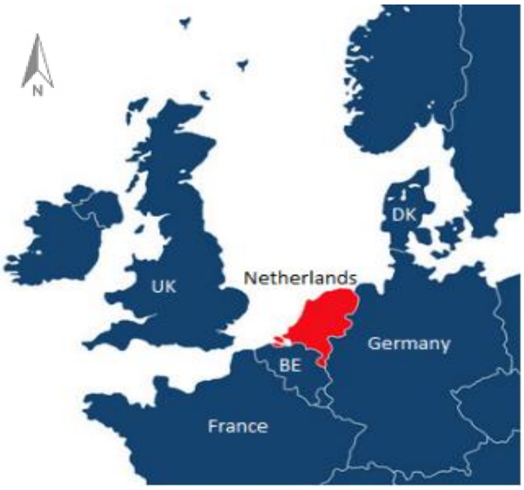


Figure 12: Map of the Netherlands

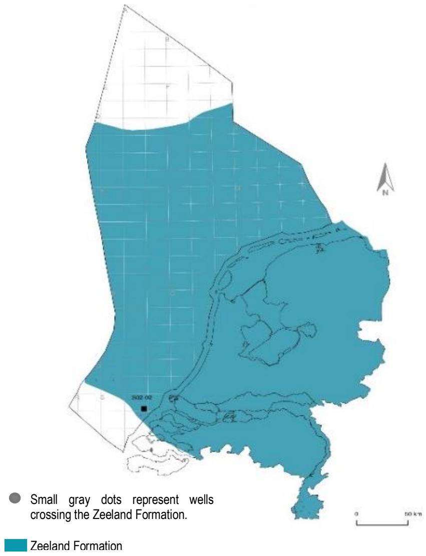


Figure 13: Extension of the Zeeland-formation [14] Geological setting

With focus on the southeastern portion of the Dinantian Limestones (Zeeland Formation) part of the active Roer Valley Graben system, its faulted and fractured nature provides pathways for hydrothermal fluids which have caused fault-related karstification, see Figure 14.

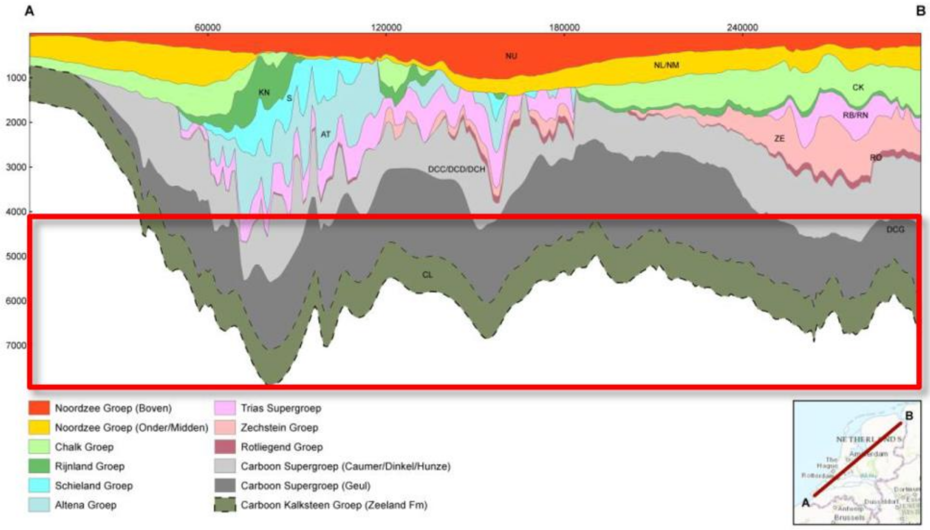


Figure 14: SW-NE cross-section of the Dutch subsurface. The Lower Carboniferous limestone is indicated by Carboon Kalksteen Groep (CL). Since the thickness of the Lower Carboniferous is uncertain, the formation is indicated by a dashed line [18].

Figure 15 provides a closer look at the zones drilled today targeting the differently aged Zeeland Formation. Note that the Zeeland Formation outcrops toward Belgium, the meteoric water infiltrated in this zone is conducted by the sub-cropping formation layer collaborating with the karstification process.

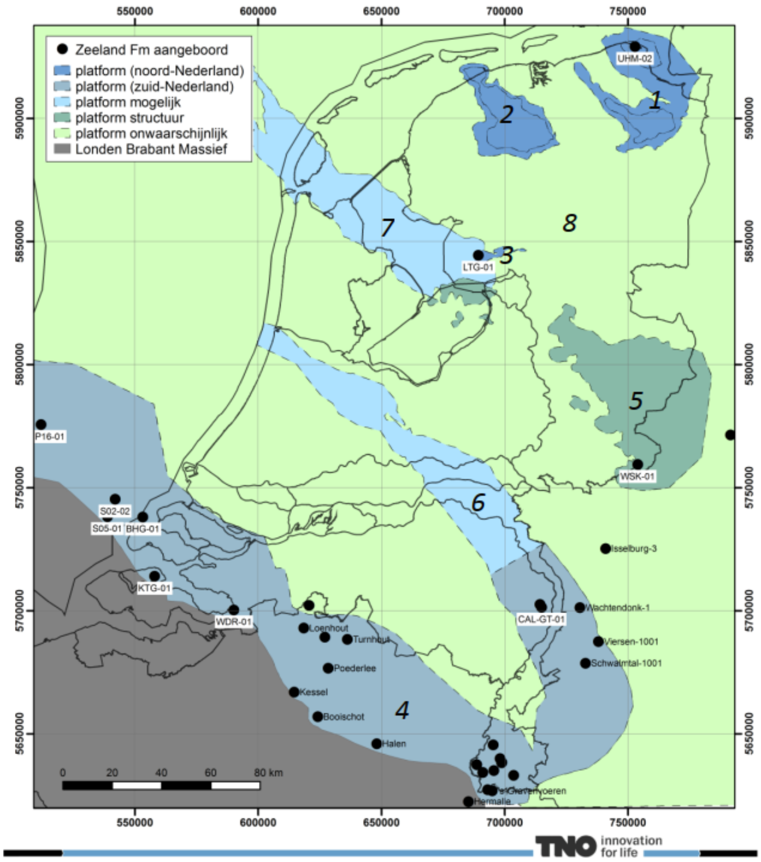


Figure 15: Subdivision of Dinantian-aged rocks in the Netherlands. The black dots are wells that drilled this Formation [4]

For details on the Stratigraphic Column of The Netherlands, the reader is referred to the official geological survey webpage [16]. Figure 16 provides details of the expected lithological column before reaching the Carboniferous system. Structural elements in this figure are compounds of stratigraphic groups that vary laterally along the geography of the Netherlands.

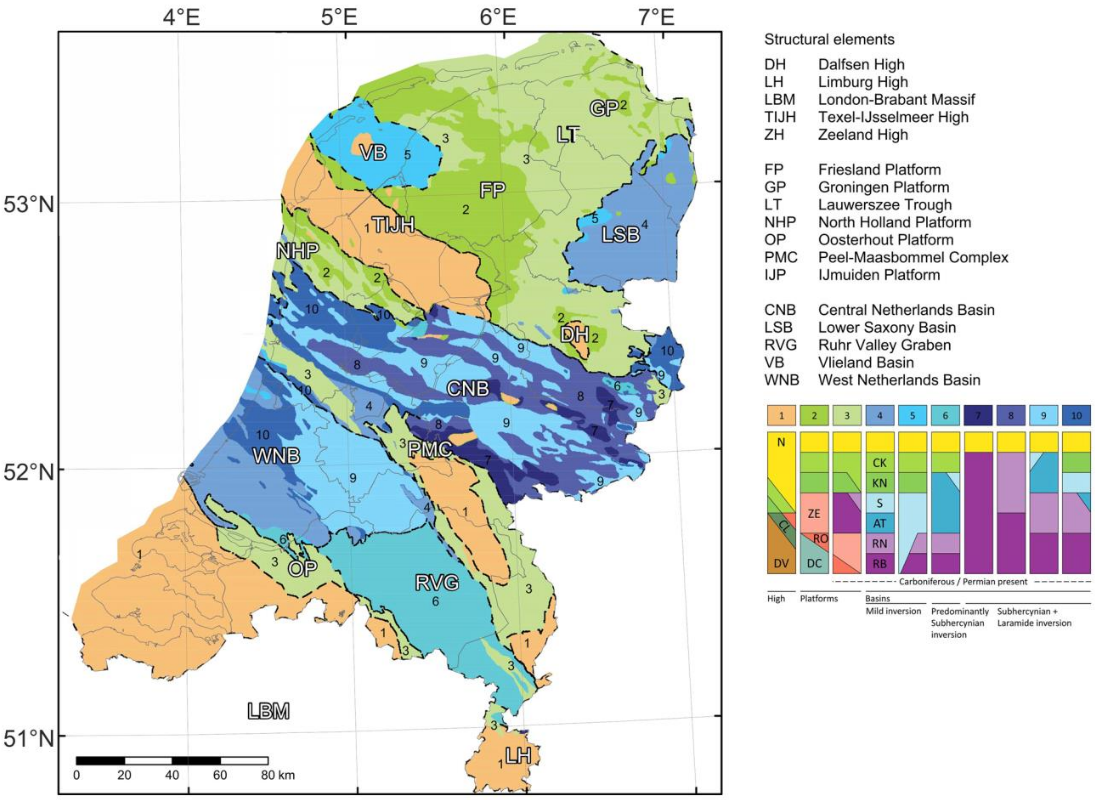


Figure 16: Early Carboniferous-Late Jurassic structural element of the Netherlands [18]. The color coding reflects the remaining sediment succession.

4.3.2. North Sea Group (and top Chalk) - Scenario 4

The North Sea Group (Figure 17) belongs to the Quaternary and Tertiary ages. This group is geologically characterized by a complex mixture of sedimentary rock formations, including sands-, silts- and claystone.

The underlying chalk (Figure 18) belongs to the Chalk Group of the Upper Cretaceous period. Only the Ekofisk formation belonging to the Tertiary age has chalk which is located just on top of the Ommelanden formation (Chalk Group)

The Chalk Group is a geological formation composed of soft, white, fine-grained limestone that is rich in the microscopic shells of ancient marine organisms. The Chalk is often interbedded with marl, a type of rock composed of clay and calcium carbonate. A standard practice in the drilling industry in the North Sea region is to put the casing shoe in the Ommelanden Formation. The thickness and composition of the Ommelanden formation can vary, but it is generally composed of soft to hard chalks and marls. The formation commonly contains bands or nodules of chert, which are very hard, siliceous material within a much softer chalk.

The Chalk Group is widespread across the Netherlands.

Location

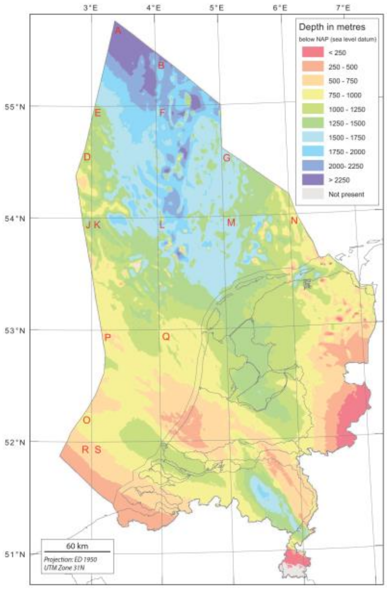


Figure 17: Depth of the base of the North Sea Supergroup (Paleogene) [18].

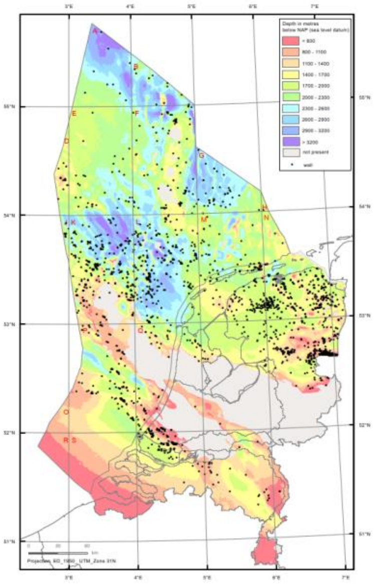


Figure 18: Depth of the base of the Chalk Group (Late Cretaceous), black dots are wells drilled in the Chalk Group.

Figure 19 represents the geothermal potential in the Netherlands by zones. The North Sea and Chalk Group are extensively drilled to get into geothermal reservoirs.

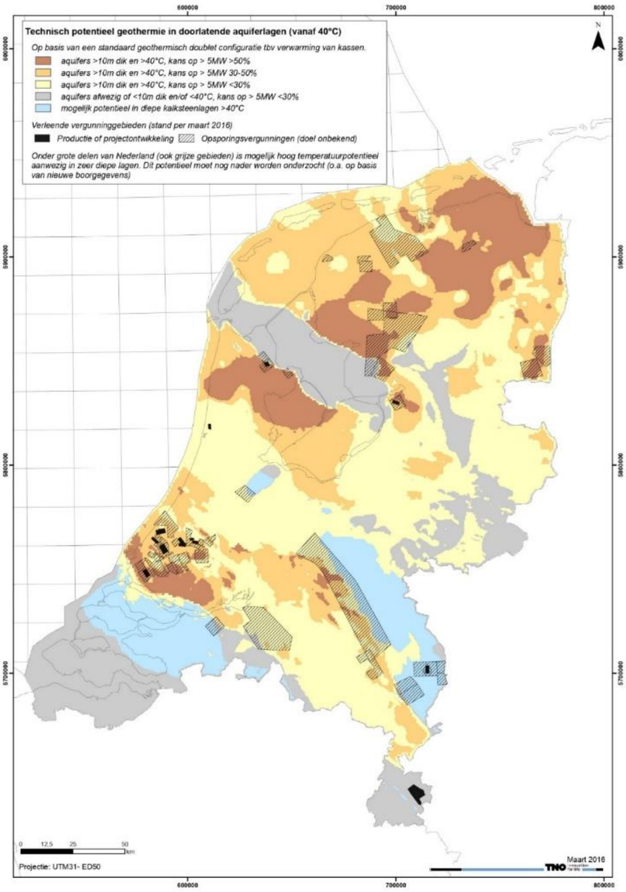


Figure 19: Map describing the geothermal potential in the Netherlands. Note the correspondence between the locations with geothermal potential and the geographic distribution of the North Sea Supergroup and the Chalk Group [19].

Geological setting

Figure 20 provides a general view of the Netherlands's salt domes and layers, mostly present in the northern and eastern parts of the Netherlands. These geological salt domes and layers represent additional complexities for drilling operations. Nevertheless, the drilling industry and its proven technologies have surpassed this inconvenience during drilling for decades. A tectonostratigraphic cross-section of the salt intrusions of the Zechstein Group can be expected, which is presented in Figure 21.

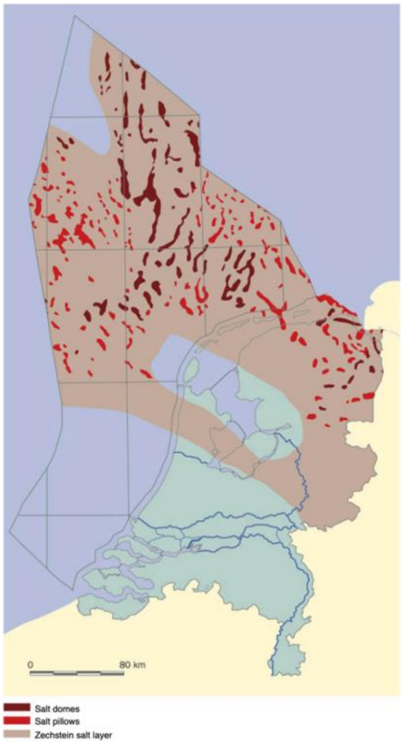


Figure 20: Map of salt domes and salt layers in the Netherlands [17]

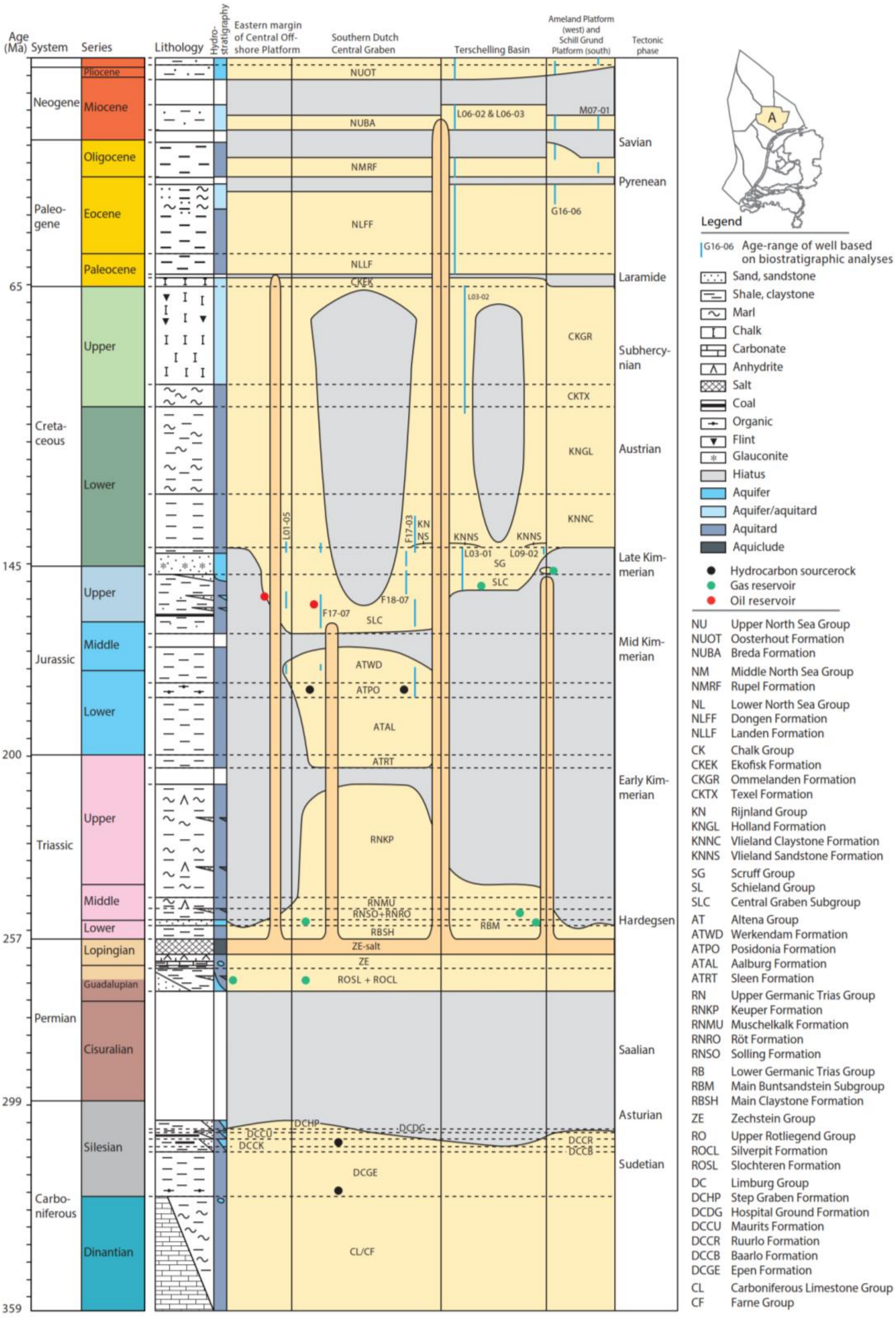


Figure 21: Tectonostratigraphic chart of the Terschelling Basin and surrounding platform areas. This overview of the Netherlands's lithostratigraphy can represent the geological complexities encountered in the Netherlands [18].

5. Observations

This chapter will summarize the initial observations used to guide the consortium in the various design options and create general understanding of technical requirements for the EPP tooling to be commercially viable. There are also several comparisons and suggestions noted. The data will be further analyzed for drafting all specifications for the EPP technology development (deliverable D1.2).

1. Seven scenarios were described: 1 in Turkey (TK), 2 in Island (IS), and 4 in the Netherlands (NL) (2 different formations, one of which is the top hole and 2 with casing-while-drilling (CwD)). One of the projects in NL is an opportunity (top hole), and another NL project (Ultra Deep) is currently under review/planned.
2. Main formations all are interbedded and show an extensive range of characteristics:
    a. TK: Menderes metamorphics; 210 °C to 245 °C; Porosity 2-9%
    b. IS: basalt; 0-340 °C; Porosity 0-50% UCS 2-70 MPa
    c. NL:
        i. Dinantian carbonates; 70 - 150°C; porosity 0.8%-28%; UCS 140 MPa
        ii. 1st casing section: sand, shales, chalk; ~40°C; porosity 0-20%; soft formations

    The data above could be used when building artificial formations for the drilling tests performed in the DEEPLIGHT project. Before preparing artificial formations, it is advised to document why it was decided to reproduce a specific type of rock.

3. Drilling assemblies (BHA's) are basic (directional) all including a downhole mud motor (PDM), a Measurement while Drilling (MWD) tool, stabilizers, and jars.
    a. BHA drill weight items to keep the drill string in tension and to prevent buckling as Drill Collars, Heavy Weight Drill Pipe can be reduced significantly with EPP drilling
    b. Jars are standard items to free the drilling assembly when stuck and will also be required with EPP assemblies. They generate a large shock force that an EPP system will need to survive.
4. The most chosen hole size is 8-1/2" (1x TK, 3x NL), followed by 12-1/4" by IS. Note that 2 Dutch applications require a reamer functionality (borehole enlargement tool). Hence, an electro head that can enlarge itself for CwD applications: it can drill a hole large enough for the casing plus annulus (open position). The tooling should fit through the casing (closed position) to do that. Another suggestion concerns a replaceable electro head to drill multiple hole sizes with the same tooling.
5. Most bits used are tri-cone which have a limited bearing life. Also, mud motors are replaced after 150 hrs in Iceland. Hence, there is the benefit of prolonging bit life (or drilling shoe to shoe).
6. Rigs in NL and Iceland can take power from the grid, while Turkish rigs use generators.
7. All mud systems are water-based muds to minimize drilling costs, as frequent losses occur. Casing running problems and stuck pipes are the results of these issues. In IS and NL freshwater is used when drilling with (total) losses. Otherwise, chlorides are present.
8. The maximum flow line temperature mentioned is 82°C. However, it will need to be further looked into what the MWD tool measures because all BHA's contained MWD tools. MWD temperature readings show the downhole circulating temperature what may be more realistic to the direct environment of an EPP drilling system.
9. The maximum depth mentioned is 3528m.
10. All wells are directional/deviated wells.
11. Most of the targeted sections are completed with liners. NL top-hole uses casing.
12. The shortest required run length is 870 m.

6. Conclusions

Sets of data were gathered for Iceland, Turkey, and the Netherlands on the downhole conditions using a standard and pre-defined questionnaire. Most relevant information could be gathered, although concrete geological data, such as formation strengths, are missing. Although the relevance of collecting mud and rock samples was initially proposed to be part of the scope of the task for deliverable D1.1, it remains open, and the complement or not of this task depends on the explicit requirement of the developers. These materials should be precisely addressed to be later searched for their existence, and when found, they should be prepared for laboratory tests to be executed within DEEPLIGHT. Nevertheless, the gathered drilling and formation data is expected to be sufficient for input for the EPP system specifications and requirements (DEEPLIGHT deliverable D1.2.). The gathered cost and time data can also be used in DEEPLIGHT activities targeted to quantify the various opportunities.

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