ULTRA DEEP GEOTHERMAL PROGRAM IN THE NETHERLANDS

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ABSTRACT

Dinantian Carbonates form the target geothermal reservoir for active and future geothermal projects for the onshore Netherlands and therefore also for the Dutch Ultra Deep Geothermal (UDG) program. This reservoir is, like most carbonates, heterogeneous in many ways having different characteristics at different scales. Unfortunately, the seismic and well datasets for the reservoir are relatively sparse and of variable quality. Learning from geological analogues is therefore of key importance to be able to predict flow performance. Furthermore, proper and consistent assessment and mitigation of the technical risks is important to support business cases at different locations in the Netherlands, represented by six consortia in this UDG program, and to execute UDG projects at these locations in a safe and sustainable way. This requires continuously generating new learnings and taking account of learnings from elsewhere.

Large variations in depth, thickness, temperature, stress field and reservoir permeability of the Dinantian Carbonates can be expected at the different locations of the six UDG consortia. In addition, reservoir properties vary enormously, as a result of initial differences in facies and post-depositional differences in fracturing and diagenesis. To study the entire range of possibilities that would prove the feasibility of these carbonates for UDG development, these consortia closely work together to utilize synergies to jointly lower the shared risks of UDG development. For this, 2D/3D seismic data acquisition and (re-)processing will be performed. Large (basin-)scale mapping and structural analysis will take place and conceptual reservoir models will be built. Best-practices and templates for technical risk analyses (including induced seismicity) and for well and stimulation design will be developed jointly to assure that assessments in the projects are optimal and comparable. Subsequently, the different consortia, in locations close to each other, will apply and refine the results of the first stage at a regional scale. Finally, detailed local models and conceptual well and stimulation designs are developed by the individual consortia to mitigate risks and support the local business cases. This research should point out the technical and economic feasibility of Ultra Deep Geothermal energy as a new source of renewable energy for the Netherlands as to provide high temperature heat.

1. INTRODUCTION

To achieve the substantial decrease in CO2 emissions defined in the Paris Agreement to mitigate climate change, the Dutch national energy supply needs to increase in level of sustainability. At this moment there are successful geothermal projects already in production that replace fossil fuel heating as a sustainable alternative. However, the application of geothermal energy in existing projects in the Netherlands is not sufficient for the provision of high-temperature heat for, as an example, the process industry where temperatures over 130°C are required. It is anticipated that Ultra Deep Geothermal (UDG) energy can potentially make a substantial contribution to the transition towards a sustainable heat supply. To reach these temperatures in the Netherlands, geothermal reservoirs at depths over 4 km are required. The Dutch subsurface at these depths has not been explored extensively until now and is therefore relatively unknown.

At the beginning of 2016, the Ministry of Economic Affairs and Climate, EBN and TNO (more specifically the energy unit known as 'ECN part of TNO')embarked on a collaboration to explore the possibilities for the development of UDG in the Netherlands. Based on the (still limited) amount of subsurface data and knowledge of the Dutch subsurface at greater depths, the Dinantian Carbonates play was identified by studies of EBN and TNO as the most promising play in terms of matching heat demand while having repetitive potential to exploit for Ultra Deep Geothermal energy (Boxem et al., 2016). The goal of the UDG program is to investigate its potential by identifying the best exploration pilot projects for heat production that can be developed in the near future. From geological and technological perspective, these pilot projects are complex and will require innovative methods.

2. DINANTIAN CARBONATES

2.1 Geology

The understanding of the Dinantian play and its geological history is important for the determination of the most important parameters, such as porosity and permeability, that determine the technical feasibility of UDG and that make up the business case for a consortium.

The Early Carboniferous Dinantian carbonate platforms developed on the flanks of the London-Brabant Massif (LBM) and to the North of this structure. The geometries and facies of these platforms vary from South to North (Jaarsma et al., 2018), see Figure 1 and 2. In the South, the platforms developed during Tournaisian and Visean times and are progressively onlapping the LBM. Reijmer et al. (2017) confirmed the presence of three successive carbonate facies types in this area, while exhumations resulted in porosity-enhancing meteoric karstification. Indications for this type of karstification are found in seismic data and in data from wells drilled in this area.

To the North of the LBM, the Dinantian strata deepen and are mostly poorly imaged by the current seismic data available. A geothermal well, drilled just to the North of the LBM, found clear indications for severe hydrothermal dolomitisation and karstification of a (yet) unknown timing. The largest part of the central Netherlands, including the region on which the UDG consortia GOUD and Renkum concentrate, has currently too poor seismic coverage to allow for seismic mapping of the Dinantian strata. Therefore, new seismic data will be acquired in the coming years to fill in the blank spots.

Further to the North of the LBM, distinctive, isolated carbonate platforms developed during the Visean as described by Kombrink (2008) and Van Hulten (2012) and mapped and described in more detail by Hoornveld (2013). These platforms bear resemblance in age, dimension and shape to isolated platforms in the Caspian Sea such as Kashagan and Tengiz. Only two wells were drilled into the Dinantian strata in this area and they encountered (largely) tight limestones of Visean age before TD in Devonian. However, Tournaisian limestones may be present in between the Visean platforms, as proposed by Kombrink (2008). Diagenetic processes including karstification in the platform margins, described for Caspian Sea carbonate platforms by Collins et al. (2014), may have taken place here as well.

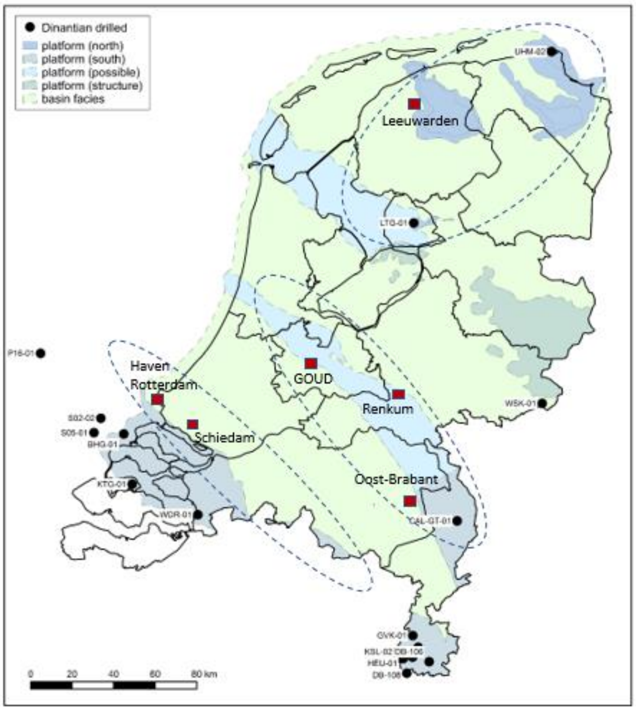

Figure 1: Map of the Netherlands with the locations of the 6 consortia (squares) and the three regions (ellipses) (modified after Boxem et al. 2016).

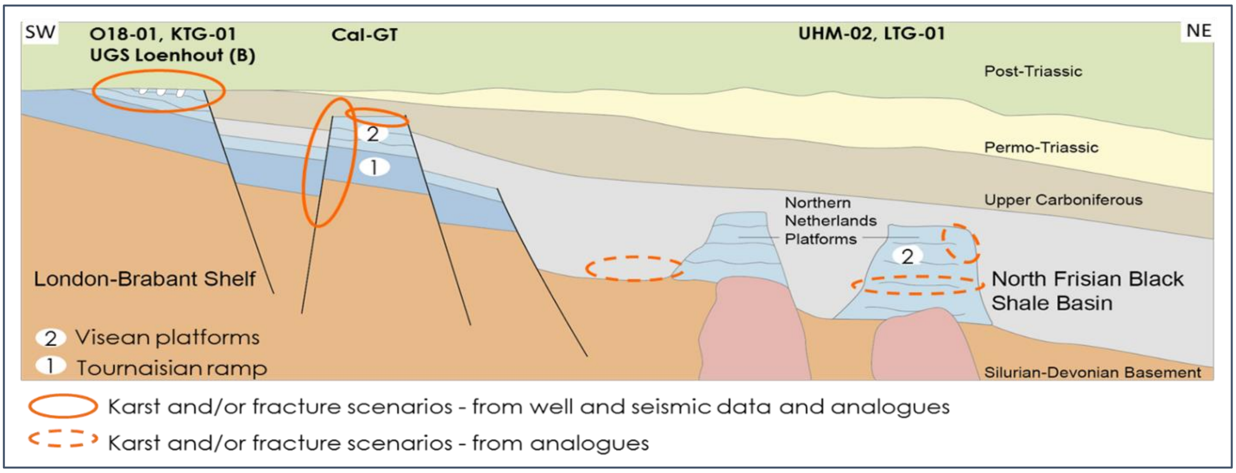

Figure 2: Conceptual diagram showing the different Dinantian carbonate platforms in the Dutch subsurface, from South to North (Jaarsma et al., 2018).

2.2 Geothermal projects with Dinantian carbonates reservoir

Two geothermal doublets with five wells in total were drilled in the northern part of the Dutch province Limburg. So far, these doublets are the only geothermal projects in the Netherlands that are within a Dinantian carbonates reservoir. Unfortunately, the too sparse seismic and well datasets do not allow for a proper understanding of the reservoir geometry nor for a conclusive modelling of production and injection in these projects, as demonstrated by Reith, 2018. However, the knowledge gained in these projects is of great value for a better understanding of the play and have increased the knowledge of the Dinantian reservoir. This also holds for the Balmatt project in Belgium that also greatly contributed to the knowledge of the geothermal reservoir behaviour of the Dinantian (Bos et al. 2018). The UDG Program will learn from them and in its turn can contribute to answering the remaining questions in the three projects.

3. UDG PROGRAM

During several workshops in 2016, the Ministry of Economic Affairs and Climate, EBN and TNO, together with industry consortia , screened the present status of UDG in the Netherlands. In this process seven UDG initiatives with a consortium were identified. These consortia, consisting of several companies, were all in the same phase of project development, i.e. the formation of the consortium, the knowledge of the potential reservoir, identification of potential customers and their requirements. As a result of this process, the Green Deal UDG was signed by the six UDG consortia labelled in Figure 1 and by EBN, TNO, the Ministry of Infrastructure and Water Management and the Ministry of Economic Affairs and Climate (Green Deal 217 – Green Deal UDG, 2017).

The ambition of the Green Deal UDG parties is the safe and sustainable realization of one or more pilot UDG projects, ideally divided among the three regions indicated in Figure 1. The realization of these pilot projects should provide insight into the feasibility of further geological and technological risk reduction and safe, sustainable and cost-effective development of UDG in the Netherlands. Because of the anticipated differences in reservoir characteristics at Dinantian level in the Dutch subsurface, it is expected that the realisation of more than one project is required to determine the feasibility and contribution of UDG to the sustainable energy supply across the Netherlands.

The consortia have committed themselves cooperate to increase, share and apply the knowledge required for UDG activities in the Netherlands. The consortia are spread across the country, each of them consisting of different parties with a demand for high temperature energy, such as the process industry (producing amongst others paper, beer, cheese or candy bars), utility companies, hospitals, district heating network, etc. The consortia work together not only on the exploration and development of the subsurface, but also on subjects like stakeholder management and integration of the subsurface heat into the surface facilities.

The UDG program, developed jointly by the consortia, EBN and TNO, consists of the following two main pillars; 1) the Knowledge and Expertise Program (KEP) and 2) the Exploration Work Program (EWP). The KEP aims at developing and sharing knowledge between the different consortia, whereas within the EWP the subsurface exploration activities for the projects of the consortia are defined.

4. KNOWLEDGE AND EXPERTISE PROGRAM

The knowledge and expertise program forms the basis for the build-up and sharing of know-how between the consortia in order to increase the success rate of safe and responsible developments of UDG (pilot) projects. Based on an integrated project development approach, activities have been identified to further co-develop these projects within the UDG context. The activities of this broad UDG knowledge and expertise program (KEP) are grouped together in eight different themes, being integrated project development, exploration and static model, dynamic subsurface modelling, development concepts, communication & stakeholder engagement, business case analysis & financing, heat demand surface and operational project management. Within KEP knowledge and expertise is shared between the consortia via joint workshops and working groups that take place during the full program period.

The three KEP themes exploration and static model, dynamic subsurface modelling and development concepts together are the topics of the EWP. Since all activities are related to one another, an integrated approach is required for a successful UDG program. Integrated project development is considered a key factor to assure the safe and responsible development for the projects of the consortia.

5. EXPLORATION WORKPROGRAM

The projects of the six UDG consortia are all currently at a similar stage, where more detailed exploration activities are required to understand the subsurface in more detail. This is necessary to be able to develop the first UDG exploration project(s) in a safe and sustainable manner. The work is, whenever possible, combined across the UDG projects, with the goal to enhance the quality of the overall results, to avoid duplication of work and to reduce costs for all parties involved. At the end of the EWP each project will build a well-founded business case using the results of the EWP. The business case together with the exploration strategy for the pilot wells will form the basis on which a consortium can decide whether or not to continue with the realization of a pilot. The drilling of the pilot wells is not part of the EWP.

Fundamental research questions may be identified during the programs progress, but these are out of the scope of the current UDG program. These questions can be subject of (international) research projects or programs that are already running or that may run in the near future.

5.1 Value of information

The geological complexity in the Dutch subsurface and the expected variations in reservoir properties of the Dinantian carbonates require in-depth understanding of the associated risks and opportunities as well as knowledge of the relationships between all activities performed during the exploration and production lifecycle of an UDG project. In the pre-drill exploration phase the risks and uncertainties in the subsurface may be reduced by applying exploration activities such as, seismic acquisition, reprocessing and interpretation, and the study of analogues. The activities of this exploration phase aim to lay a foundation for several successful UDG projects in the Netherlands and result in the following value of information for integrated project development:

- Subsurface data and information to determine the right drilling location and target, the well trajectory, to assess overburden risks, and to identify the technologies that could be used;
- A basis for risk management during the entire lifetime of the project so it can be realised and produced in a verifiably safe and sustainable manner;
- A reduction in the uncertainties of the input subsurface parameters for the business case;
- Information on the rock properties to help in developing an optimal approach for safe and effective reservoir stimulation (if needed);
- Increase of the probability of success for the pilot wells that will be drilled after completion of the EWP;
- Information that will help to identify alternative solutions and make decisions during realisation of the project;
- Combining the results from the first (UDG) wells with all other information obtained as to further optimise the placement of subsequent wells of a project;
- A basis for adequate reservoir management during the decades of production;
- Data and information on the Dutch subsurface to reduce risks and uncertainties for follow-up projects in the same subplay - so-called ‘play development’ (Veldkamp et al., 2019).

All activities of the EWP are expected to have a large value of information compared to its costs, both in terms of safe and sustainable development and on de-risking of the economics of the projects involved.

5.2 Structure of the EWP

The activities of the EWP aim at laying the foundations of successful ultradeep geothermal projects, as such they are arranged in three main pillars, see Figure 3; 1) national activities, which represent activities that are relevant for all geothermal initiatives in the Dinantian Carbonates (i.e. the UDG consortia and other initiatives), 2) activities at a regional level that are relevant for consortia which are located in the same geological region, and 3) activities at a local level that are specific for a single consortium. Data management, model integration and seismic acquisition and (re)processing are two work packages in this work program that are executed on all three scales, hence they both cover all three pillars.

The EWP has a strong link to another Dutch geothermal exploration program, called SCAN (Seismic Campaign Geothermal Netherlands). Figure 3 shows the EWP work packages which are fed with results of SCAN.

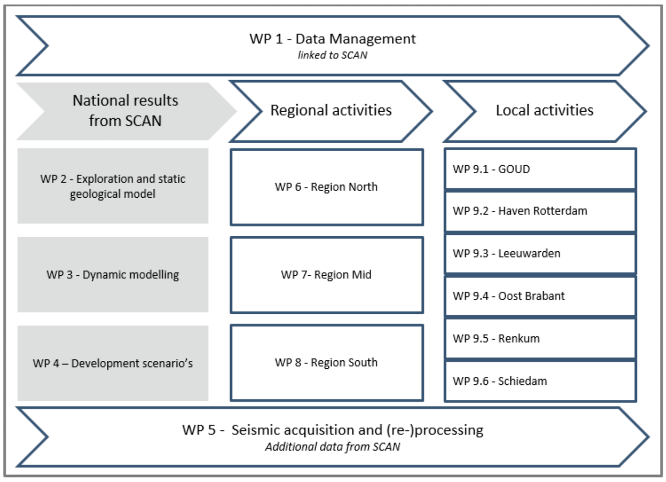

Figure 3: The activities of the EWP are arranged in three main pillars with the two transcending work packages.

5.3 Data management

A vast amount of relevant data and information about the Dinantian carbonates exists in the public domain, including a large amount from neighbouring countries. By sharing, storing and maintaining existing and newly developed data and knowledge on a central location, this work package will ensure that all consortia will work on the latest data and information and on the best available and suitable methodologies.

5.4 National activities

The national activities of the EWP result in an improved understanding of a number of key subsurface parameters: the presence, depth, thickness and facies of the Dinantian strata, the temperature distribution and the present-day reservoir quality (porosity and permeability) as a result of fracturing and diagenesis. From the enhanced insights from these activities the uncertainty of the reservoir parameters is reduced. This implies that, prior to drilling, the geothermal power can be estimated with a higher degree of certainty and the business case for projects can be better defined . Results comprise among others national scale maps and an atlas of (conceptual) reference reservoir models that can be used to predict the distribution of the Dinantian carbonate reservoir and the relevant reservoir properties. Methodologies to assess the chance and associated risks of induced seismicity will be developed. Also, reference conceptual reservoir (natural) flow models of Dinantian carbonate reservoirs, including geochemical and geomechanical rock-fluid interaction will be developed. Testing and validation of these models takes place by data and experience from field analogues (from oil/gas and geothermal). This is considered critical as data and models from geothermal projects with Dinantian carbonate reservoirs are available to a limited extent only.

A range of stimulation options will be assessed, along with a technical risk inventory and a conceptual (generic) well design that can be adjusted to local project situations in a later stage.

The insights, models and best practices that result from the national activities will be applied by the consortia in the subsequent regional and local activities.

5.5 Seismic acquisition and (re)processing

At national to regional scale, a sufficient good seismic dataset is required to better understand the larger-scale distribution of the reservoir and to gain insights into the geological development impacting reservoir quality in multiple ways (fractures, diagenesis). This is also required to improve analyses on induced seismicity at project scale. The overall objective is to get the best possible seismic dataset serving different purposes at different scales and locations.

At regional to local scale, a proper seismic dataset is required to understand the smaller-scale distribution of the reservoir and the variations in reservoir properties, the presence and dimensions of faults, and also to determine the target location for wells.

Within the EWP, the seismic work package comprises the acquisition and (re)processing of 2D and 3D seismic data at local, regional and national scale. The Dinantian strata are the primary target; however, fall-back options at shallower (e.g. Triassic or Permian/Rotliegend) or deeper (Devonian) levels have to be kept in mind. Depending on the project location and the available datasets, the work within the seismic work package ranges from reprocessing of existing 3D seismic in some areas to acquisition of new 2D seismic in other areas.

5.6 Regional activities

The tasks of the work packages that form the regional activities are aimed at getting a better understanding of the regional structure of the different platforms and basins at Dinantian level for the projects that are in the same geological region. The regional work forms a necessary step in developing the subsurface model, which in its turn is the input for the 3D reservoir model on which eventually the right drilling target can be identified and used during the 30 years of production.

The activities comprise regional interpretation and depth conversion of seismic and other geophysical data, develop a conceptual model for the reservoir quality of the different platforms, evaluate the regional stress regime and consider shared geological, drilling and other risks.

5.7 Local activities

During the local activities of the EWP, the national and regional scale static, dynamic and geomechanical (reference) models will be used to determine the subsurface location of the first pilot well with the highest probability of success the lowest risk and the highest value of information. The models will also be used for evaluating the well after drilling, and are updated when necessary. This may lead to necessary adjustments of the location or well design of the next well. Once the geothermal system starts production, the updated reservoir and geomechanical models will be used for monitoring purposes so the system can be optimized and operated in a safe and sustainable way. The conceptual design will give crucial input for the business case since it will deliver a cost estimation of the project sufficient to make a reliable final investment decision.

5.8 Planning & budget

It is estimated that the complete program will cover approximately 2.5 to 3 years, starting at the beginning of the fourth quarter of 2018. The planning takes into account the project phasing where the work is done in sequence from large (national) scale to regional to local scale. Within this period of 2.5 to 3 years there will be five go/no-go moments. Consortia can decide to leave the program only at these five points in time. These moments are defined as follows:

1. After (re)processing and interpretation of seismic data and after completion of the shared program at the national level (1st "pillar");
2. After completing the work on the regional level (2nd "pillar");
3. After completing the local static geological model (as part of the 3rd "pillar");
4. After completing the local dynamic model (as part of the 3rd "pillar");
5. After completing the local conceptual well design (as part of the 3rd "pillar").

The total budget of the EWP amounts up to over 22 million Euro including a contingency of 20% based on the benchmarking from EBN from similar studies in the hydrocarbon industry.

The national activities (first pillar) are performed as part of the government-sponsored SCAN project. For almost all the other EWP activities the related costs are supported via a subsidy of 50%. The results of the activities for which subsidy is granted will be made publicly available as this is one of the conditions as stated by the Green Deal. Costs for each consortium will depend on the beneficiary of the activity. For the activities that are beneficial to all, 50% of the costs will be carried by the Ministry of Economic Affairs and Climate (via EBN). The consortia will bear the remaining 50%. For activities beneficial to a region, the consortia in that region are accountable for the remaining 50% together.

3. CONCLUSIONS

The urgency of increasing the sustainability of the high temperature heat demand and the high exploration risks involved has resulted in the UDG program for the Netherlands. Via an integrated project development, a strong collaboration with knowledge and data sharing, the combination with the play based portfolio approach, the defined program aims for a safe and sustainable development of pilot UDG projects using the Dinantian carbonates reservoirs for high temperature heat production.

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