Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

# Feasibility for the Application of Geothermal Energy for Greenhouses in South-East Drenthe, the Netherlands, Results of a Multi-Disciplinary Study

Leonora J. Heijnen, Gerhard Diephuis, Peter Betts, Arnaud Huck, August Willemsen, Nick A. Buik

PO Box 605, 6800 AP Arnhem, the Netherlands

N.Heijnen@iftechnology.nl

**Keywords:** multi-disciplinary, 3D-seismic, acoustic impedance, geothermal, greenhouses, the Netherlands

**ABSTRACT**

The sub-surface potential has been evaluated in a multidisciplinary manner for application of geothermal energy for heating of greenhouses near Emmen in the northeastern part of the Netherlands. The zone of interest comprises two designated areas of greenhouse development sized 100 and 180 ha respectively. In this study 3D seismic data have been interpreted in conjunction with borehole data in order to obtain a detailed subsurface model in acoustic impedance. The results show that Triassic Volpriehausen and Detfurth sandstones of the Main-Buntsandstein constitute potential reservoirs for extraction of hot water. These reservoirs are present between depths of ca 2,000 – 4,000 m. Based on the local geothermal gradient the temperature at the top is estimated to be at least around 100 ºC. From interpreted 3D seismic data it could be inferred that the Volpriehausen and Detfurth sandstones have a combined thickness of ~ 45 m at the proposed locations. In the southern part of the area a fault zone is present where these sandstones most likely are grounded on underlying Zechstein salt deposits. This may complicate selection of the surface location and well-trajectories of the doublet-wells. Towards the north the target-reservoir appears to be less fractured as shown by extensive fault imaging on the 3D seismic. Optimal locations have been chosen on the basis of acoustic impedance data, allowing an estimation of porosity and thickness of the main target reservoir in the area – the Lower Volpriehausen Sandstone.

The uncertainty in productivity should be less than 10% in order to qualify for the Dutch guarantee fund (in founding). Flow rates have been calculated assuming a certainty of 90%. A potential flow rate of 100 m³/h is inferred, leading to an expected thermal power of 6 $MW_t$ to be delivered by one doublet-well. The application of a horizontal section in the well leads to an increased flow rate of 270 m³/h resulting in an expected thermal power of 16 $MW_t$. These results show that this project qualifies for the Dutch guarantee fund.

## 1. INTRODUCTION

The provincial town Emmen is located in the northeastern part of the Netherlands, near the border with Germany, see figure 1. The municipality of Emmen is designated to be one of top ten locations within the Netherlands for the development of greenhouses. The present zone of interest comprises two designated areas of greenhouse development sized 100 and 180 ha respectively. Greenhouse cultivation industry is interested in sustainable energy in order to reach the national climate aims by 2020. These aims include a reduction in greenhouse gas emissions of 30 % in 2020 when compared to 1990 and a percentage of 20 % of total energy supply that should be sustainable. Furthermore, exploiters of greenhouses are strongly dependent on energy price developments. Heating of the greenhouses by geothermal energy might therefore constitute an economic and environmental proposition. The application of geothermal energy for heating of greenhouses enjoys a broad support among which the Foundation “Glastuinbouw Emmen”, the Province of Drenthe and the municipality of Emmen.

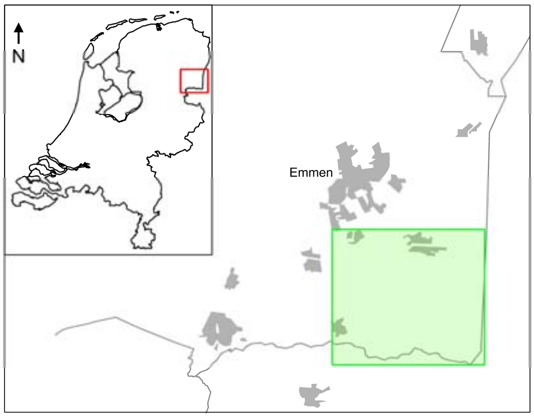


**Figure 1 the location of the research area near Emmen**

The first phase of the project, the geological investigation, has been completed by March 2009. In the following phases detailed reservoir engineering, well engineering, and energy harmonization will be carried out. In this paper the results of the geological investigation are reported. The questions raised during this investigation concerned the depth of the target formations, their properties and most importantly their potential of extracting geothermal energy for heating greenhouses. These questions can only be answered if a multi-disciplinary study takes places where geology, geophysics and petrophysics are integrated.

## 2. GEOLOGICAL SETTING

The Netherlands is located within the Northwest European Basin and its geological history has been influenced by sedimentation rates, tectonic phases and sea level changes. The region of southeastern Drenthe is located within the northeastern part of the Lower Saxony Basin. The area has undergone inversion during the Laramide and Subhercynian tectonic phases. The oldest penetrated sediments in the area are of Late Carboniferous age. The subsurface of the area consists of different types of sediments with several unconformities and NW-SE oriented faults. An overview of the different formations is given in table 1.

Results from an earlier general study showed four formations within the Germanic Trias Group with a high potential for a geothermal reservoir; the Solling Sandstone, the Hardegsen Formation, the Lower Detfurth Sandstone and the Lower Volpriehausen Sandstone. These are the formations on which this study is focused. Wells in the area showed thicknesses for the Hardegsen Formation of only a few meters. Furthermore, the formation is not present throughout the whole area. For these reasons, the Hardegsen Formation is not included in this study.

| chronostratigraphic name | age |
|---|---|
| North Sea Supergroup | Tertiary |
| Chalk Group | Upper Cretaceous |
| Rijnland Group | Lower Cretaceous |
| Altena Group | Jurassic |
| Germanic Triassic Group | Triassic |
| Zechstein Group | Permian |
| Lower-Rotliegend Group | Permian |
| Limburg Group | Carboniferous |

**Table 1 chronostratigraphy of southeastern Drenthe**

## 3. DATA

Figure 2 shows the wells that are used in this study and the extent of the 3D seismic data. The seismic data comprises the final depth and time-converted Pre-Stack Depth Migrated (PSDM) volumes, which have been made available by the local Shell/Esso Operating Company (NAM) for this study.

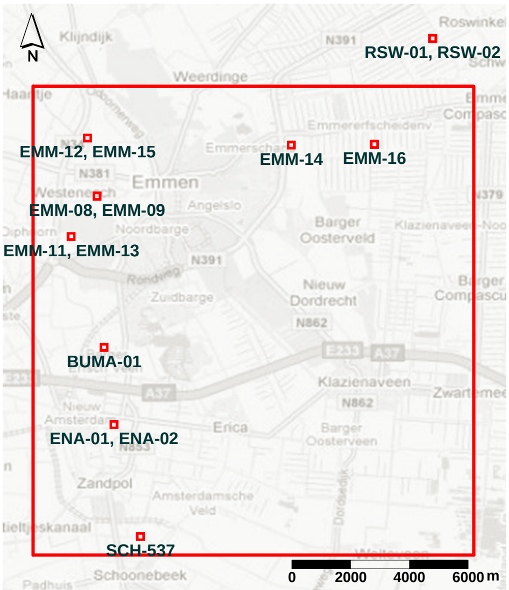


**Figure 2 Locations of wells and seismic used in the study**

## 4. PETROPHYSICS

A petrophysical evaluation has been carried out to determine the properties of the sandstones within the Germanic Triassic Group. The log data originate from wells, shown in figure 2. The wells have been drilled between 1976 and 1998 and had been logged with a fairly comprehensive logging suite over the sandstones of the Germanic Triassic Group even though the objectives of most wells were the deeper limestones of the Zechstein Group. The wells yielded enough log and core data which could be used as input for the evaluation. Well EMM-13 has not been evaluated as the formations where only logged with a cased-hole gamma ray.

The objectives of the petrophysical evaluation were to provide results in terms of porosity, permeability, lithology, net/gross etc. together with their uncertainty ranges.

### 4.1 Core Data Analysis

In RSW-01 the Lower Detfurth Sandstone and Lower Volpriehausen Sandstone members were cored which provided a calibration check on the porosity evaluation by logs. Porosity measurements are representative of the total porosity system. The mean grain density is 2.65 g/cm³, indicative of a primarly quartz matrix.

In RSW-02 plugs were taken with water as a lubricant. An additional set of samples were drilled from the center of the core with no lubricant. The water drilled samples indicate an average porosity of 25% and grain density of 2.65 g/cm$^3$. In contrast, the air drilled samples have an average porosity of 5 % and a grain density of 2.25 g/cm$^3$. This considerable difference can be explained due to the presence of halite in the pore space which has been flushed away in the samples drilled with water. Salt plugging can be easily recognized from the log response but a more involved multi-mineral probabilistic evaluation approach is necessary.

The core data have been correlated with porosity values derived from the logs. The compaction correction factor which is common for the Lower Volpriehausen Sandstone has been applied to the core data. The correction factor has been corroborated by the relationships developed by Juhasz, (1986). In figure 3, the comparison of stress corrected core porosity and log derived total porosity in well RSW-01 has been given.

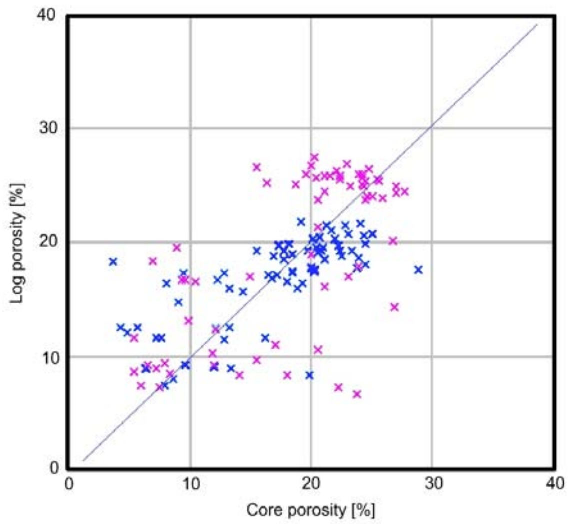


**Figure 3 Stress corrected core porosity vs log derived total porosity of the Lower Volpriehausen Sandstone (pink) and the Lower Detfurth Sandstone (blue) in RSW-01**

### 4.2 Probabilistic Evaluation

For a probabilistic evaluation, a mineral/fluid model has to be defined together with end points for each of the selected input logs. The number of log curves that can be usefully utilized in the analysis limits the number of minerals and fluids that can be accommodated in the model. Furthermore, the anticipated volume of a component should not be less than 2 % of the bulk volume. The components must have discernable log characteristics to be resolved during the analysis.

In 1985 a Thermal Decay Time (TDT) survey was performed within RSW-01, probably to check on the source of water production and salt deposition in the tubing. As this tool is particularly sensitive to the presence of salt, the model has been built for well RSW-01 by trial and error. During this process the validity of the chosen parameters was tested and the results were checked on any significant differences by including or excluding the TDT curve from the model. This was to ensure that the model could be applied in other wells where a TDT log had not been run and to be able to test for the presence of salt plugging in the Solling Sandstone and possibly within other sandstones. The conclusion of this analysis was that the original salt plugging is limited to the Solling Sandstone and the member shows similar characteristics in the other wells. However, from TDT data could be concluded that salt deposition has occurred in the Lower Volpriehausen Sandstone during gas production. This precipitation may well have consequences for the engineering of the geothermal project.

### 4.3 Permeability Prediction

For the permeability prediction a conventional porosity/permeability relationship was derived from core data. The resulting empirical relationship for the Lower Volpriehausen Sandstone is given in equation 1.

$$K = 10^{-0.7+23.9\phi-35.8\phi^2} \qquad (1)$$

Where K is the permeability in mD and φ the porosity expressed as fraction.

### 4.4 Formation Water Evaluation

In view of potential salt precipitation during production, a check was made as to variations in salinity in the study area based on available log data. For this review the apparent formation water resistivity ($R_{wa}$) has been calculated using Archie’s equation.

The salinity variation derived from Rwa values ranges from 210,000 to 300,000 ppm NaCl eq. with an average value of 270,000 ppm NaCl eq. This rather large range is as yet unexplained. Possible causes could comprise a lateral change in cementation factor, leading to erroneous salinity values, or possibly an error in tool calibration, as yet not identified. The possible problems and solutions which could arise due to the precipitation of salt should be investigated in the next stage of the project.

### 4.5 Uncertainty Analysis

An uncertainty analysis has been carried out using Monte Carlo simulations to quantify the uncertainty ranges on the calculated properties. For most parameters and log readings standard uncertainty ranges were assumed. 200 iterations were carried out over de sandstones in each well, resulting in the mean, P90, P50 and P10 averages. The P90 value represents the value where 90 % of the data has the same or a larger value.

## 5. GEOPHYSICS

To investigate the reservoir properties at the proposed locations, seismic interpretation has been carried out. Furthermore, the structures which may influence the location of the geothermal wells were identified.

### 5.1 Seismic Interpretation

Synthetic seismograms were made to correlate the seismic data to the wells. Nearly all the wells in the area are strongly deviated which makes it harder to make the correlation. In figure 4 the correlation of EMM-16 is given.(blue) with the seismic data (red).

Overall the correlation is fair after some stretching has been applied to the synthetic, but amplitudes do not correspond. This less than ideal well to seismic correlation can be explained by the application of large static corrections, in turn caused by the presence of peat in the shallow sub-surface as well as by the type of data (PSDM). Both can be responsible for the mismatch in amplitudes. From the synthetics, it can be concluded that neither Solling nor Lower Detfurth sandstones are visible individually as they are dissolved in the seismic data. As a consequence only the Lower Volpriehausen Sandstone has been interpreted in conjunction with stratigraphic important horizons. The results are shown in figure 5.

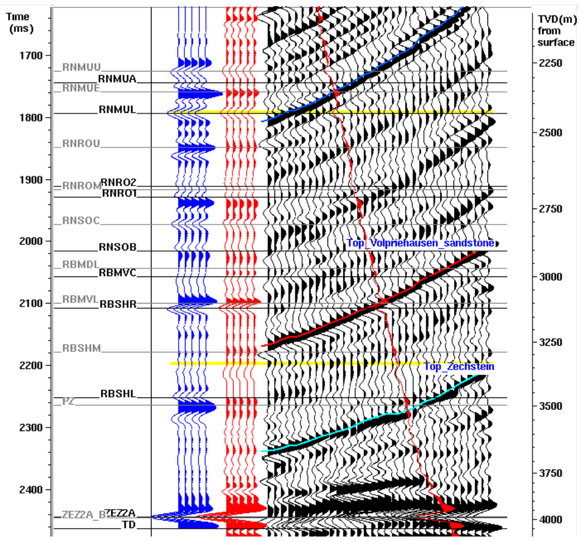


**Figure 4 Correlation synthetic seismogram of EMM-16**

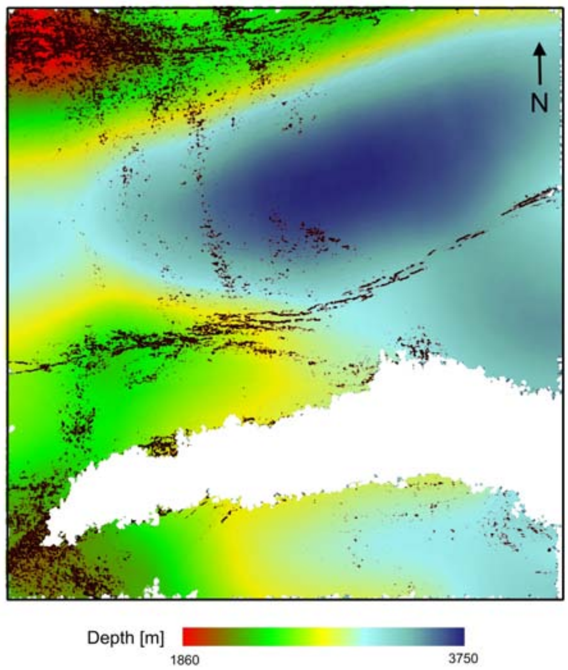


**Figure 5 Depth map of the top Lower Volpriehausen Sandstone including faults (black)**

In figure 5, a white area is shown. Within this area, the Lower Volpriehausen Sandstone was not as such recognizable. The interpretation in this area shows faults which extend downwards into the Zechstein salt. Due to the amount of displacement along the faults and assuming an equal thickness of the Triassic sediments, the reflection of the Lower Volpriehausen Sandstone should be positioned below the reflector of base Zechstein. It is not likely the Triassic sediments are thinner within the graben, rather the contrary. Therefore, it is assumed that lower parts of the

Triassic sediments, including the Lower Volpriehausen Sandstone, have been grounded within the graben. The chances for the presence of sandstones with a high porosity and permeability are rather low. The location of the faults may complicate selection of the surface location and well-trajectories of the doublet-wells. Towards the north, within the syncline, the target-reservoir appears to be less fractured as shown by extensive fault imaging on the 3D seismic.

### 5.2 Resolution

The resolution of the seismic wavelet determines which thicknesses form acoustic distinguishable units are be reliably represented (Kallweit & Wood, 1982). The temporal resolution of the seismic data, which equals the tuning distance, has been determined within the Triassic section. The wells in the area show thicknesses for the Lower Volpriehausen Sandstone near the tuning distance. Therefore, the amplitudes are not proportional to reflection coefficients and cannot be directly related to reservoir properties. The seismic reflectivity volume needs therefore to be inverted to acoustic impedance in order obtain representative values for the determination of thickness and reservoir properties.

### 5.3 Acoustic Impedance Inversion

To characterize the reservoir properties in the Lower Volpriehausen Sandstone, an acoustic impedance inversion has been applied to the seismic data. Several inversion algorithms are available to perform seismic inversion. In this study, a model-based inversion algorithm has been applied. It offers the most detailed control over the low frequency character of the inversion result which is essential for the determination of reservoir properties.

The model used requires an initial acoustic impedance model, which has been based on the available well data and interpreted horizons. In between well locations, the velocity and density data are interpolated along horizons using inverse-distance weighting. The density model was subsequently low-pass filtered with 10-15 Hz taper in order to eliminate insignificant details from the initial density model. The velocity information was derived from the sonic log of each well and interpolated in the same manner as density. Together they created a low frequency model. The character above 15 Hz is generated by the inversion process from the seismic data. Since the wavelet characteristically is poor in low frequency content, the results in this bandwidth were controlled almost exclusively by the initial model.

The model was built using the wells EMM-14, EMM-16 and SCH-537b as these wells showed the best correlation between the seismic data and well data. Amplitude mismatches between the synthetic and seismic traces should not impact on the low frequency model quality, except if they are caused by poor log quality. Since the latter is not the case, the inversion procedure was continued. The inversion was applied based on the matching parameters in the interval from top Muschelkalk Evaporite – 200 ms to top Zechstein + 100 ms. Outside this interval, the output volume was filled with the low frequency model.

The inversion to impedance comprises a four step iterative process. Firstly, the initial model of acoustic impedance is convolved with a selected wavelet. The resulting synthetic seismic volume is then compared with the seismic volume of which the output is called the derived synthetic seismic error. From the error a correction of absolute impedance is deduced for each block of the volume. The initial model is updated by adding the correction of impedance to the initial model. After a pre-defined number of iterations the final inverted acoustic impedance volume is produced. The relative inverted acoustic impedance is the subtraction of the inverted acoustic impedance and the low frequency model. The volume has been correlated first at position of the wells. The compared log-derived acoustic impedance from the wells shows a high correlation with the inverted impedance volume. Within the inverted impedance volume, lateral stratigraphic changes can be observed between the wells. This is shown in figure 6.

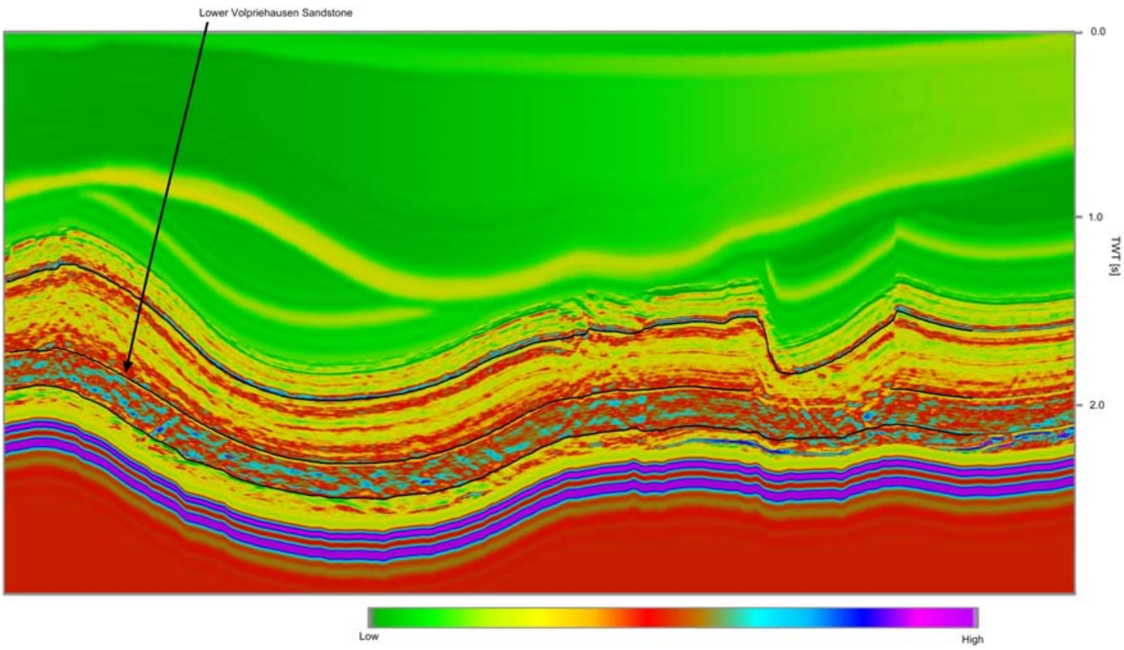


**Figure 6 Acoustic impedance at inline 9,198**

### 5.4 Integration of the Results

The results from the seismic interpretation have been used for the acoustic impedance inversion. The petrophysical results will next be integrated within the model in order to give an interpretation of the reservoir properties at the proposed project location.

As usual with the Lower Volpriehausen Sandstone, a direct relationship exists between the porosity and acoustic impedance. Low acoustic impedance corresponds with a high porosity and, likewise, high acoustic impedance corresponds with a low porosity. Before correlation of the relative acoustic impedance values from the seismic data with the results from the wells can be made, a correction has been applied for the clay volume. As the clay volume within the Lower Volpriehausen Sandstone is not uniform throughout the area, all values of the clay volume have been brought to 18 % with the use of the relationship from Eberhart-Phillips (1989). After the correction was done, the acoustic impedance has been correlated with the reservoir properties, i.e. average porosity. RSW-01 and RSW-02 have been included after a Gassmann substitution (Gassmann, 1951) to determine the acoustic response of equivalent water bearing reservoirs. The wells which have a thickness greater than the tuning distance have been used to determine the relationship between the acoustic impedance and porosity, displayed in figure 7.

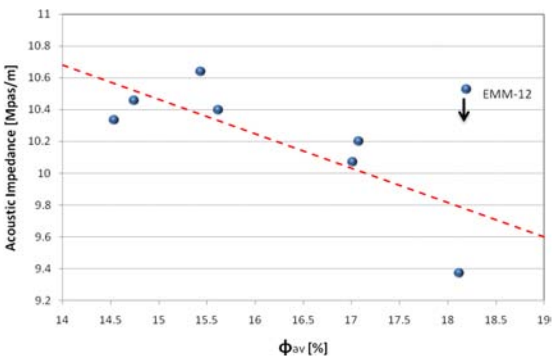


**Figure 7 Average porosity of the net thickness vs the acoustic impedance**

The results are not ideal which was more or less expected given the relatively poor well to seismic matches, nevertheless there is a clear correlation. EMM-12 is a clear exception at which location a lateral variation in acoustic impedance is visible in the data. Due to the mediocre correlation, it is not sensible to predict porosities outside the data range of 14-20 %. Other methods which are preferably used for non-linear relationships are also used to predict porosity. However, regional data shows a perfect linear relationship between the acoustic impedance and the average porosity for the Lower Volpriehausen Sandstone. The correlation between the values of the seismics and the wells remains less than average, even with the use of another method. This is again explained by the presence of peat in the shallow subsurface, leading to large statics, in turn causing local deviations from a true-amplitude nature.

The relationship of figure 7 has been applied to the Lower Volpriehausen Sandstone within the acoustic impedance volume. This resulted in a map of the average porosity within the Lower Volpriehausen Sandstone over the mapped area. The thickness has also been derived from the acoustic impedance volume combined with an assumed interval velocity of 3,500 m/s. The resulting values for thickness, in combination with the relationship between the average porosity and permeability, have been used to generate a map of the transmissivity. The results are shown in figure 8. Based on these maps, optimal locations for the wells have been chosen, allowing an estimation of porosity and thickness of the main target reservoir in the area – the Lower Volpriehausen Sandstone.

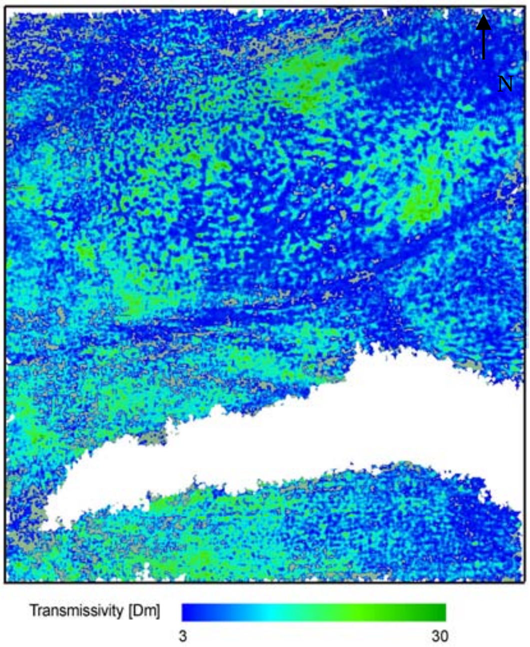


**Figure 8 Resulting transmissivity map of the Lower Volpriehausen Sandstone**

## 6. RESERVOIR PERFORMANCE

The results of the different disciplines have been used as input for an uncertainty analysis of the performance of the reservoir for geothermal use. The basic assumptions for this analyses follow from geological, geophysical and petrophysical data. Normal distributions for the porosity, the porosity-permeability relationship and the thickness are assumed. Regression coefficients are themselves stochastic variables with a standard deviation and are inversely related to each other. This has been accounted for within the simulations. Furthermore, a marginal dependency has been taken of porosity on thickness, based on a correlation coefficient of 0.25.

To every distribution a Monte Carlo simulation has been applied with 1,000 iterations. For each different location, the P90, P50 and P10 values of the transmissivity have been determined. A P90 value of 10 Dm, for example, shows a chance of 90% is present that the real transmissivity has a value of 10 Dm or higher. The P90 results show that the Lower Volpriehausen Sandstone has good quality for a geothermal reservoir. The distribution of the transmissivity of the syncline is shown in figure 9. This shows the assumption of a normal distribution was correct.

From the P90 values of the transmissivity, the P90 of the flow rate can be calculated. High values of formation fluid salinity have a relatively large impact on its viscosity. In turn, the viscosity of a fluid partly determines its potentiometric water level and resistance in the well. The flow which can be expected from a vertical well is approximately 100 $m^3$/h, depending on the coefficient of performance. This is somewhat lower than one may expect from the reservoir properties but can be explained by the high concentration of salt in the formation water. This results in a thermal power of 6 $MW_t$.

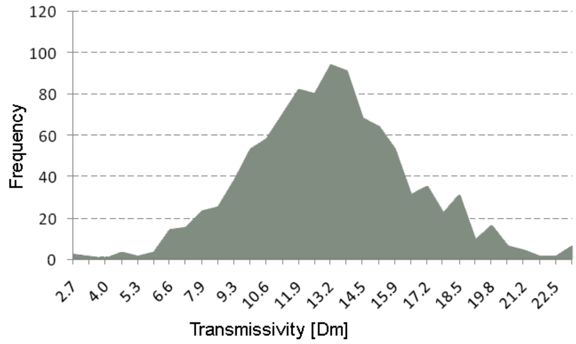


**Figure 9 Distribution of the transmissivity within the syncline**

The flow can be optimized by drilling a horizontal section of the well within the target formation. By doing so, the total flow towards the well will be improved. The flow rate within a horizontal well, for the same coefficient of performance is roughly 270 $m^3/h$. In this case, the thermal power increases to 16 $MW_t$.

The P90 value for both a horizontal as well as a vertical well indicates that projects within this area will qualify for the Dutch guarantee fund (in founding). The required thermal power of the greenhouses will in the end determine the final design of the wells.

## 7. CONCLUSIONS

The results from this interdisciplinairy study show that the Lower Volpriehausen Sandstone has good properties to be used as a geothermal reservoir. The petrophysical analysis shows a high concentration of salt within the formation water. This concentration has a relative large influence on the flow rate at which the formation water can be extracted. The flow rate can be optimized by applying a horizontal section of the well within the formation. The positioning of the wells is largely determined by maps showing reservoir geometry and properties. The position of the surface location limits the choice of locations for wells due to the presence of faults in their surrounding subsurface.

The integration of the different disciplines was needed to correctly evaluate the sandstone for the application of geothermal energy. The results will be used in the geological model for the detailed reservoir engineering in the next phase of the project. These results also show the project has large potential for the extraction of geothermal energy. Furthermore, the uncertainly analysis has shown that the P90 value for the transmissibility is sufficient for application to the Dutch guarantee fund.

## ACKNOWLEDGEMENTS

We would like to thank the Province of Drenthe for the financing of this study and for their permission to publish this paper. We would also like to thank the Nederlandse Aardolie Maatschappij (NAM) for the use of well and seismic data.

## REFERENCES

Eberhart-Phillips, D., Han, D-H. and Zoback, M.D., 1989, Empirical relationships among seismic velocity, effective pressure, porosity and clay content in sandstone, *Geophysics*, V **54**, pp 82-89

Gassmann, R., 1951, Elastic waves through a packing of spheres, *Geophysics*, **16**, 673-685

Juhasz, I., (1986), Conversion of routine air-permeability data into stressed brine-permeability data, Society of Professional Well Log Analysts, Aberdeen Chapter, 10th European Formation Evaluation Symposium Transactions, paper Y, 1-15

Kallweit, R.S. and Wood, L.C., 1982, The limits of resolution of zero-phase wavelets, *Geophysics*, **47**, 1035-1046