InImpact Kennisagenda Radial Jetting

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G1345

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Versie 1

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Inhoudsopgave

1 Summary

PanTerra has performed a number of doublet performance calculations for a few of the major Dutch deep subsurface geothermal reservoirs. As such, the benefits of radial jetting have been assessed. The thermal yield is taken as the determining factor for an economically viable geothermal project. It is found that radial jetting has the potential to double the thermal yield and to significantly increase the depth and areal range in which geothermal doublets can be developed.

2 Introduction

InImpact has asked PanTerra to perform support for a Kennisagenda Aardwarmte project concerning radial jetting for Dutch geothermal doublets. As such, the applicability and effectivity of radial jetting has been evaluated for a number of geothermal reservoirs. These reservoirs comprise the most common reservoirs used for geothermal application in the Netherlands (see Figure 5-1);

- the Nieuwerkerk Formation (part of the Schieland Group, SL),
- the Triassic Bundsandstein (part of the Upper- and Lower Germanic Trias Group),
- the Slochteren Formation (part of the Upper Rotliegend Group) and
- the Lower Carboniferous Kolenkalk (part of the Carboniferous Limestone Group).

The study below presents the results of numerous doublet performance calculations based on varying reservoir property variations.

3 Methods

In order to demonstrate the potential effectiveness of radial jetting, reservoir performance (in terms of thermal yield) has been calculated for multiple scenarios. For each scenario, the porosity, permeability, temperature and well configuration changes with depth in accordance with regional porosity-depth relationships, porosity-permeability relationships and geothermal gradients. A doublet well system has been assumed.

To automate this process, the TNO DoubletCalc tool (version 1.4.3 on www.NLOG.nl) has been rebuild and modified to enable multiple runs for a pre-set series of input variables. As mentioned, some variables were varied such as depth, temperature, permeability and well design. However, to be able to compare the results for different reservoirs, some variables were fixed. These include variables such as nett reservoir thickness, salinity, injection temperature (35°C for all reservoirs), and casing diameters. Importantly, all scenarios were iterated until a Coefficient Of Performance (COP) of 20 was achieved. This is important as it ensures realistic results in terms of pump pressure differences and system efficiency.

For each of the reservoirs a thickness, nett to gross and salinity was chosen which is estimated to be characteristic of that reservoir within the Netherlands. The positive effect of radial jetting has been accounted for by applying a constant skin factor of -6. This factor is a rough estimate and will vary as a function of rock properties and is therefore currently under investigation.

4 Results

Below, the results are presented for the different reservoirs. A graph is presented for each reservoir which compares the doublet performance with and without radial jetting with respect to reservoir depth. Also shown in the graph is the change of the nett transmissivity, kH, with respect to depth. The nett transmissivity is calculated by multiplying nett thickness with permeability. All graphs presented below show an initial increase of the thermal yield with depth until an optimum has been reached followed by a decrease (except for the Kolenkalk). This is caused by the competing effects of increasing reservoir temperature with depths versus a decrease of porosity and permeability due to compaction and diagenesis. Important to note is the fact that, compared to standard case, radial drilling increases the yield progressively. However, it also increases the optimal reservoir depth and extends the depth range in which geothermal projects are viable. In general, a project is potentially viable (for a business case) when the expected yield exceeds 10 to 15 MWth. Note however, that a COP of 20 is quite high and that there have been a number of realised projects with COPs of 15 or lower.

For each reservoir maps have been made which show the lateral extent to which a minimal yield of 10 MWth can be achieved. Note however that thickness changes have not been taken into account in these maps. Additional calculations have to be made to account for the thickness variations in the reservoirs.

4.1 Nieuwerkerk Formation

For the Nieuwerkerk Formation the results of the calculations are presented in Figure 4-1. Figure 4-2 and Figure 4-3 show the depth and extent of the major sandstone member in the Nieuwerkerk Formation, the Delft Sandstone Member. The gross thickness assumed for the sands is 100 m which can be quite high for most of the peripheral regions. In Figure 4-4 the difference between systems with radial jetting and without is shown by plotting the extent to which a yield of 10 MWth can be achieved. Note that thickness variations have not been accounted for in this map.

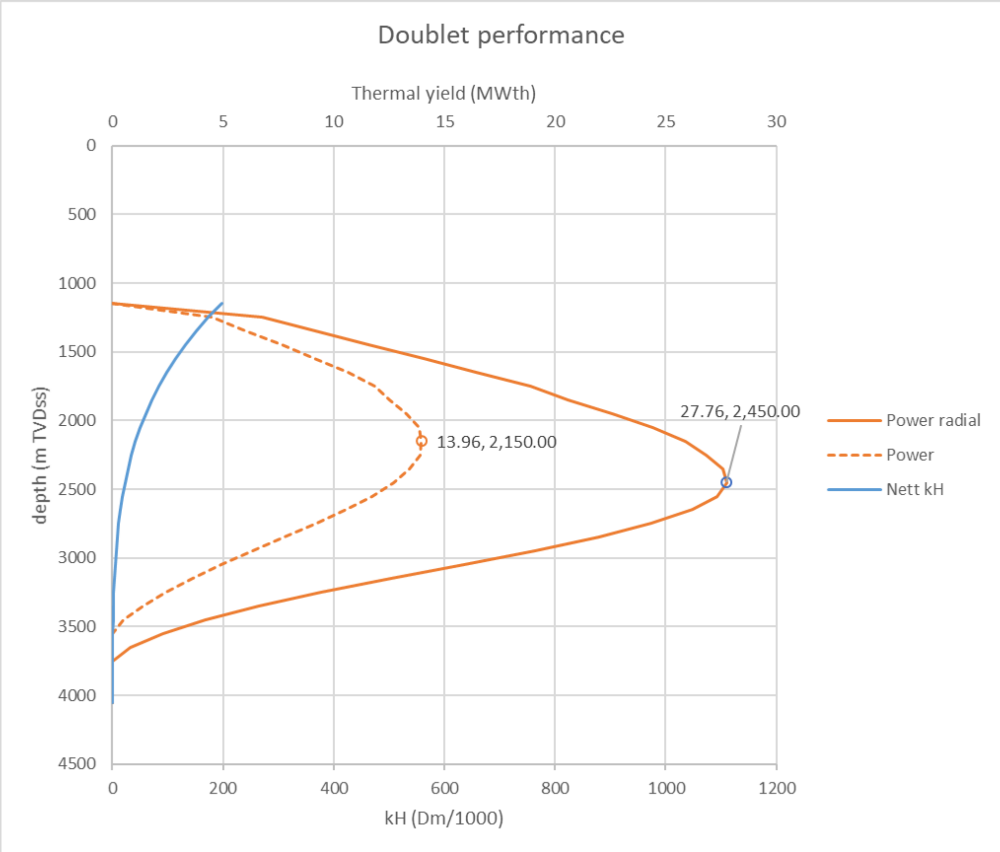

Figure 4-1: Doublet performance, in terms of thermal yield for the Nieuwerkerk Formation based on typical reservoir parameters corrected with respect to depth at a COP of 20. The thermal yield lines (orange) show that radial jetting (solid orange line) has the potential to significantly improve performance compared to the non-stimulated case (dotted orange line). Note that the optimum depth, signified by the annotated circle, increases when applying jetting. The nett transmissivity, kH, is represented by the blue line.

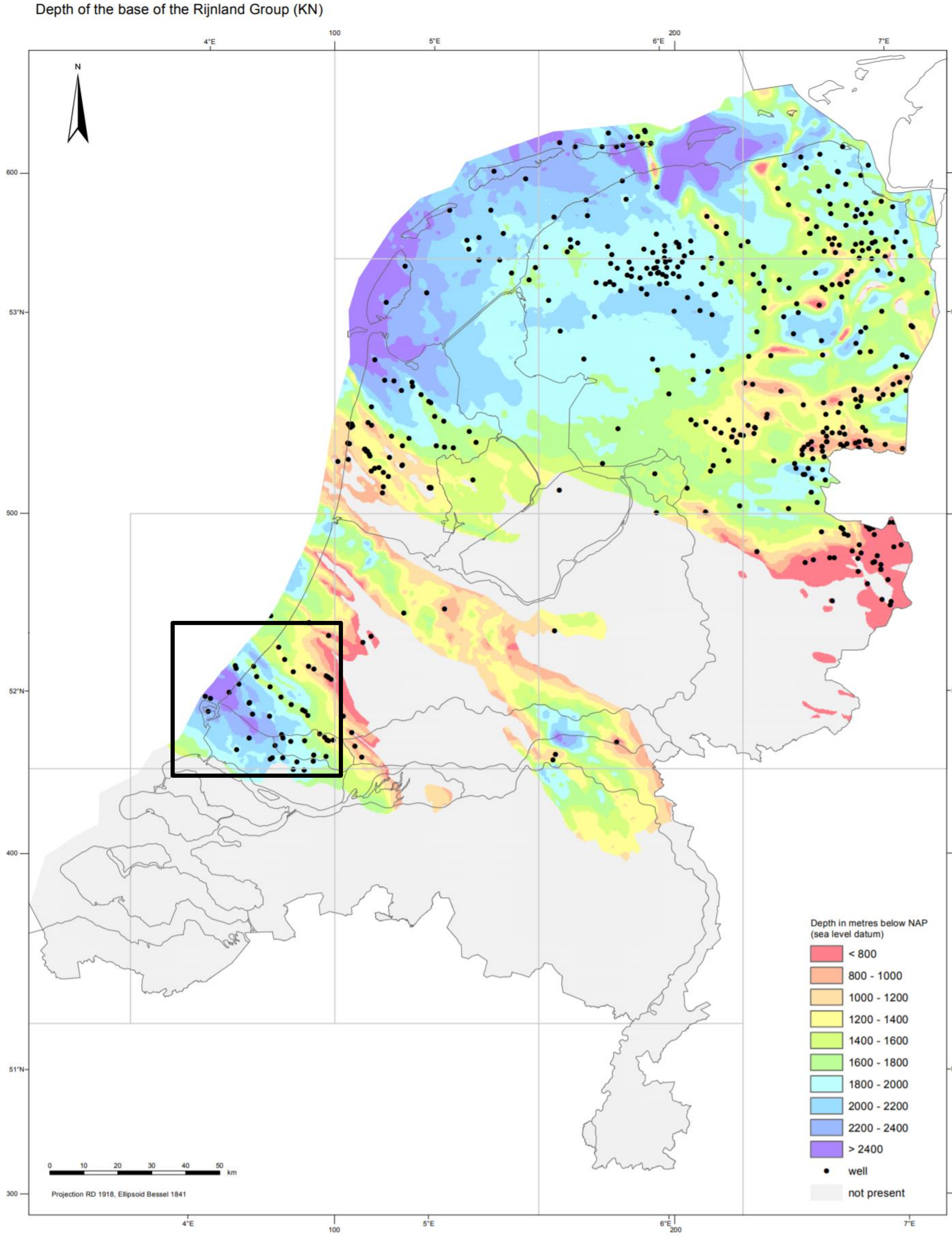

Figure 4-2: Depth map for the top of the Schieland Group which is close to the top of the Nieuwerkerk sandstones but extends further (from www.NLOG.nl). The extent according to TNO mapping of the major sandstone member in the formation, the Delft Sandstone, is presented in Figure 4-3. The black square outlines the map shown in Figure 4-3.

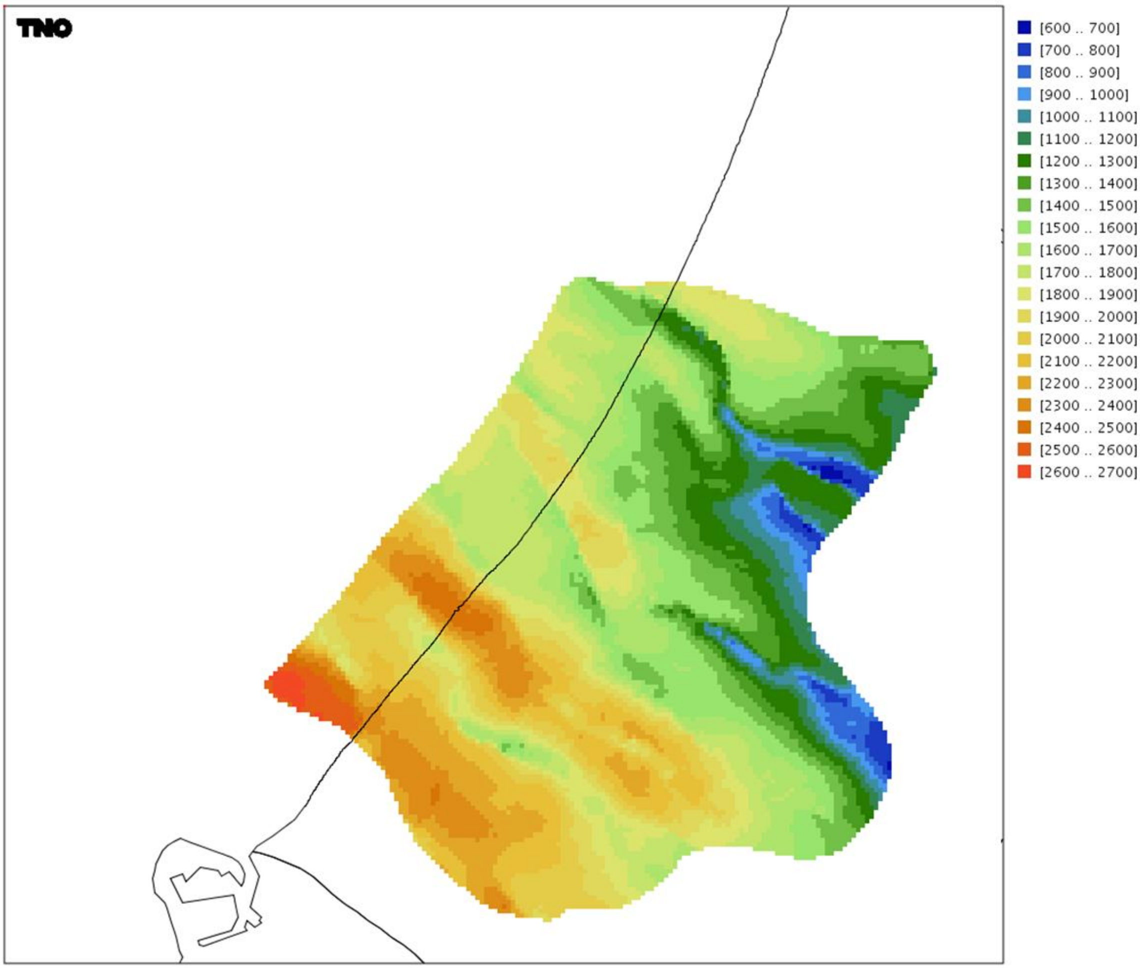

Figure 4-3: Depth map (and lateral extend) of the top of the Delft Sandstone Member which is generally the top of the sands in the Nieuwerkerk Formation (from ThermoGIS, www.NLOG.nl).

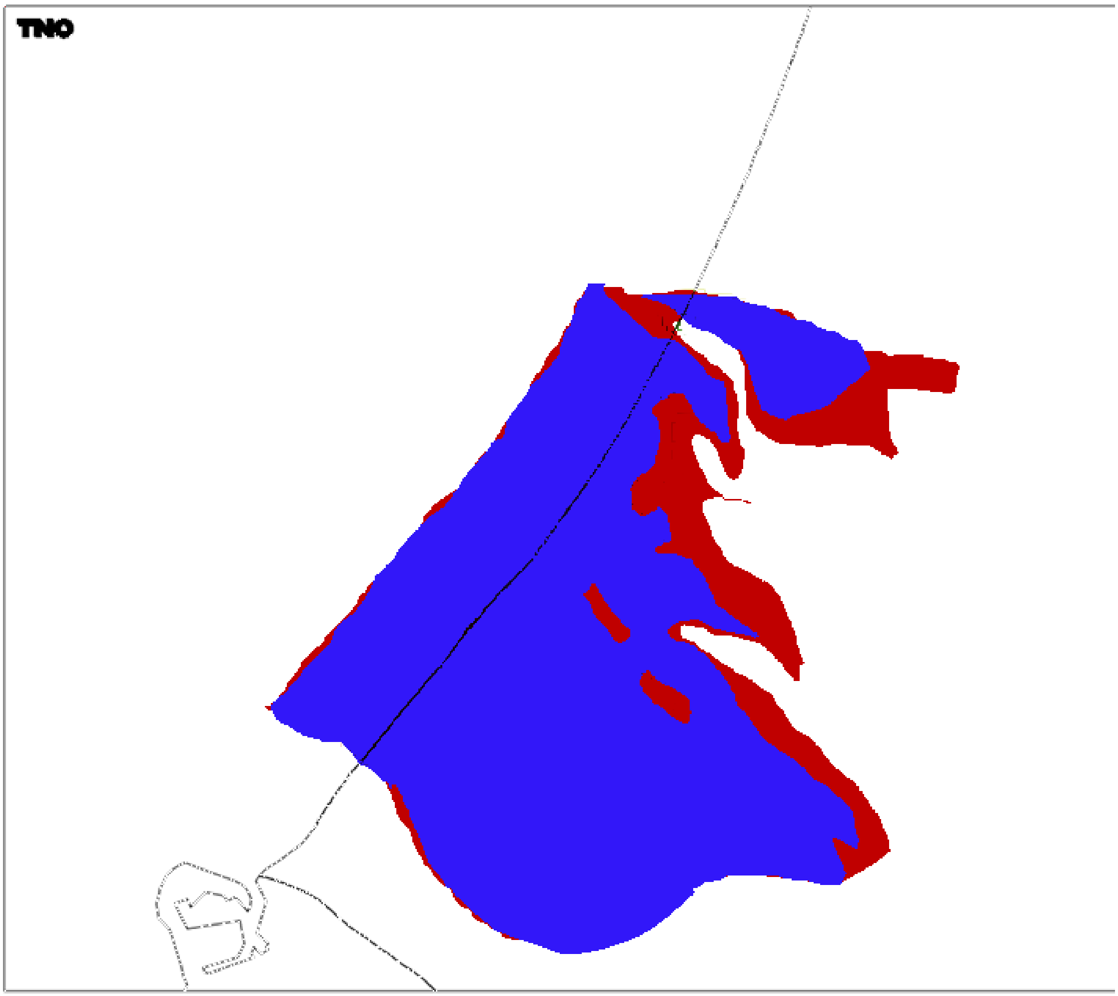

Figure 4-4: Lateral extend of the 10 MWth yield without radial jetting (blue area) and the extension when applying radial jetting (red area). Thickness variations have not been accounted for.

4.2 Triassic Bundsandstein

For the Triassic Bundsandstein the results of the calculations are presented in Figure 4-5. Figure 4-6 shows the depth and extent of the top of the stacked sandstones in the Triassic Bundsandstein. The gross thickness assumed for the sands is 180 m. In Figure 4-7 the difference between systems with radial jetting and without is shown by plotting the extent to which a yield of 10 MWth can be achieved. Note that thickness variations have not been accounted for in this map.

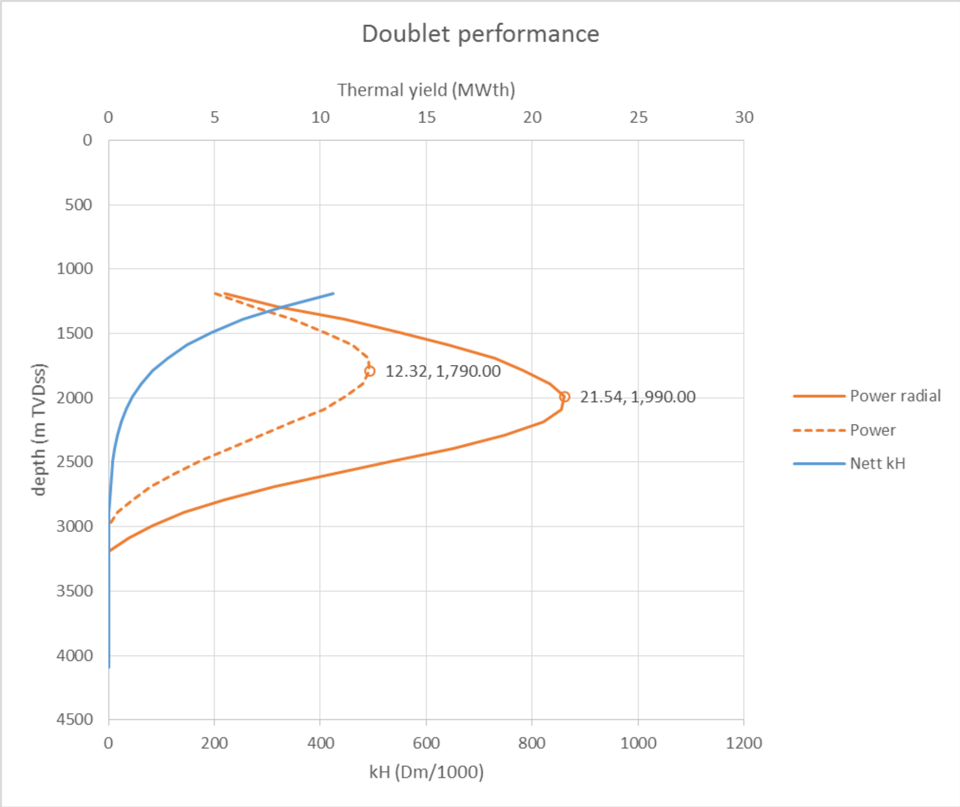

Figure 4-5: Doublet performance, in terms of thermal yield for the Triassic Bundsandstein based on typical reservoir parameters corrected with respect to depth at a COP of 20. The thermal yield lines (orange) show that radial jetting (solid orange line) has the potential to significantly improve performance compared to the non-stimulated case (dotted orange line). Note that the optimum depth, signified by the annotated circle, increases when applying jetting. The nett transmissivity, kH, is represented by the blue line.

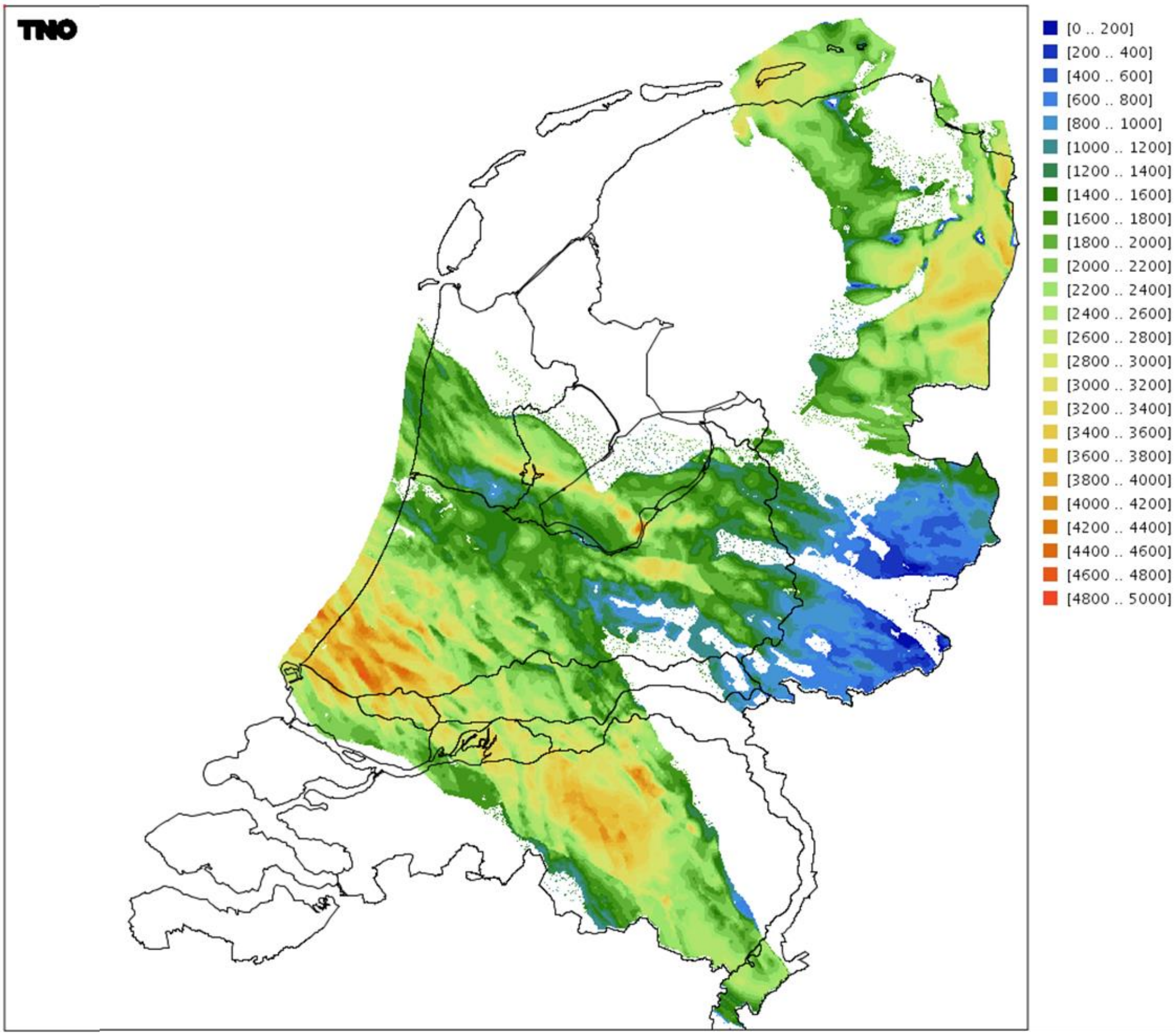

Figure 4-6: Depth map (and lateral extend) of the top of the stacked Triassic Bundsandstein (from ThermoGIS, www.NLOG.nl).

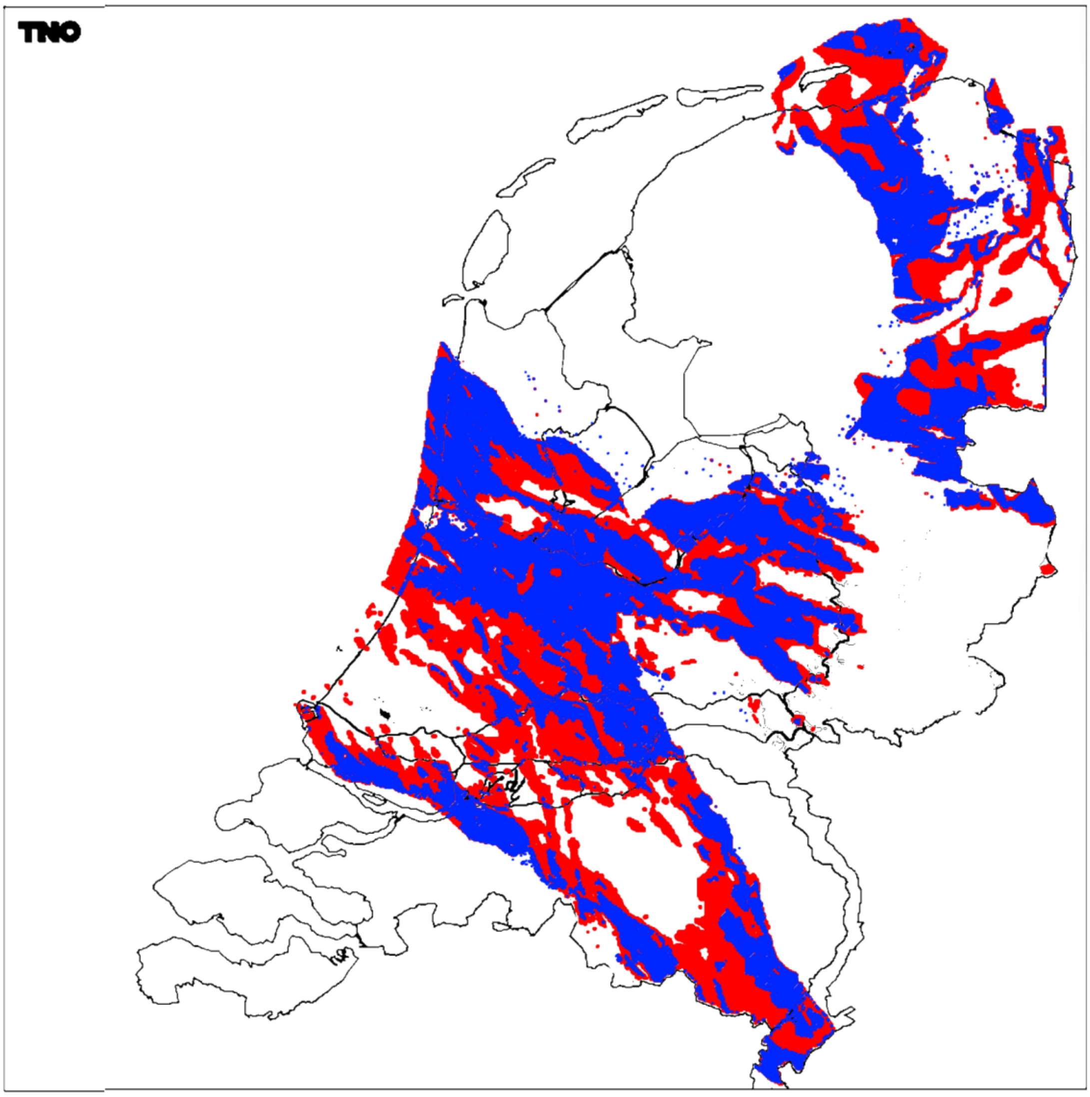

Figure 4-7: Lateral extend of the 10 MWth yield without radial jetting (blue area) and the extension when applying radial jetting (red area). Thickness variations have not been accounted for.

4.3 Slochteren Formation

For the Slochteren Formation the results of the calculations are presented in Figure 4-8. Figure 4-9 shows the depth and extent of the top of the stacked sandstones in the Triassic Bundsandstein. The gross thickness assumed for the sands is 175 m. In Figure 4-10 the difference between systems with radial jetting and without is shown by plotting the extent to which a yield of 10 MWth can be achieved. Note that thickness variations have not been accounted for in this map. Towards the southern Netherlands, there is a significant decrease in thickness in the Slochteren Formation.

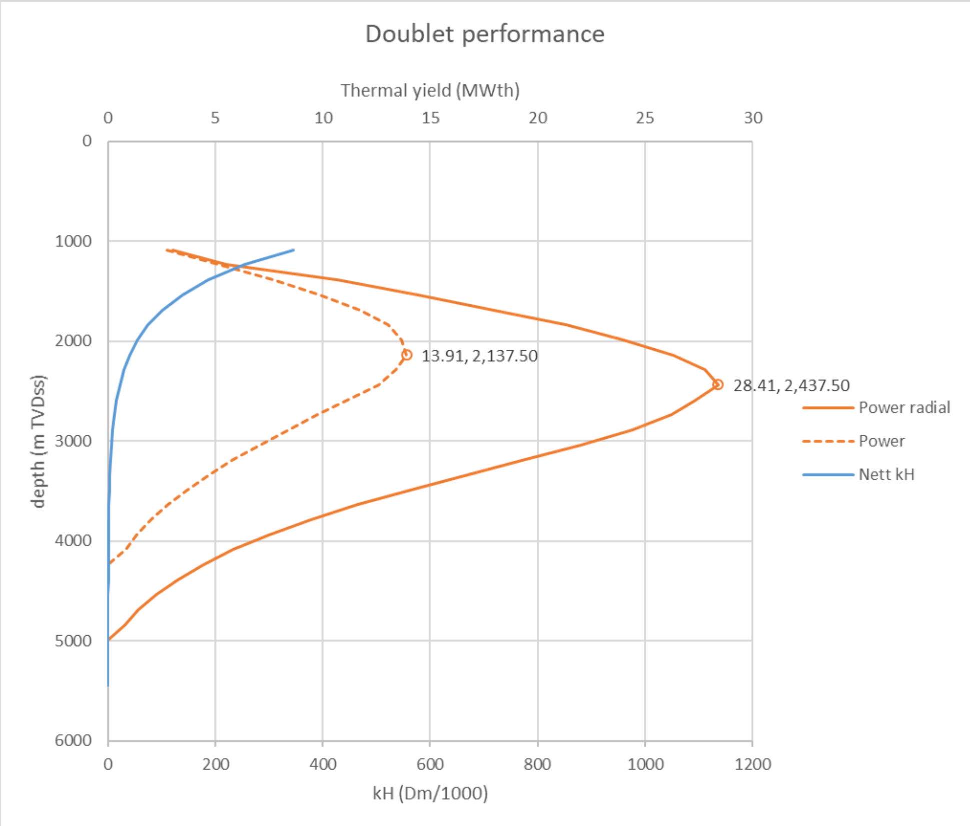

Figure 4-8: Doublet performance, in terms of thermal yield for the Slochteren Formation based on typical reservoir parameters corrected with respect to depth at a COP of 20. The thermal yield lines (orange) show that radial jetting (solid orange line) has the potential to significantly improve performance compared to the non-stimulated case (dotted orange line). Note that the optimum depth, signified by the annotated circle, increases when applying jetting. The nett transmissivity, kH, is represented by the blue line.

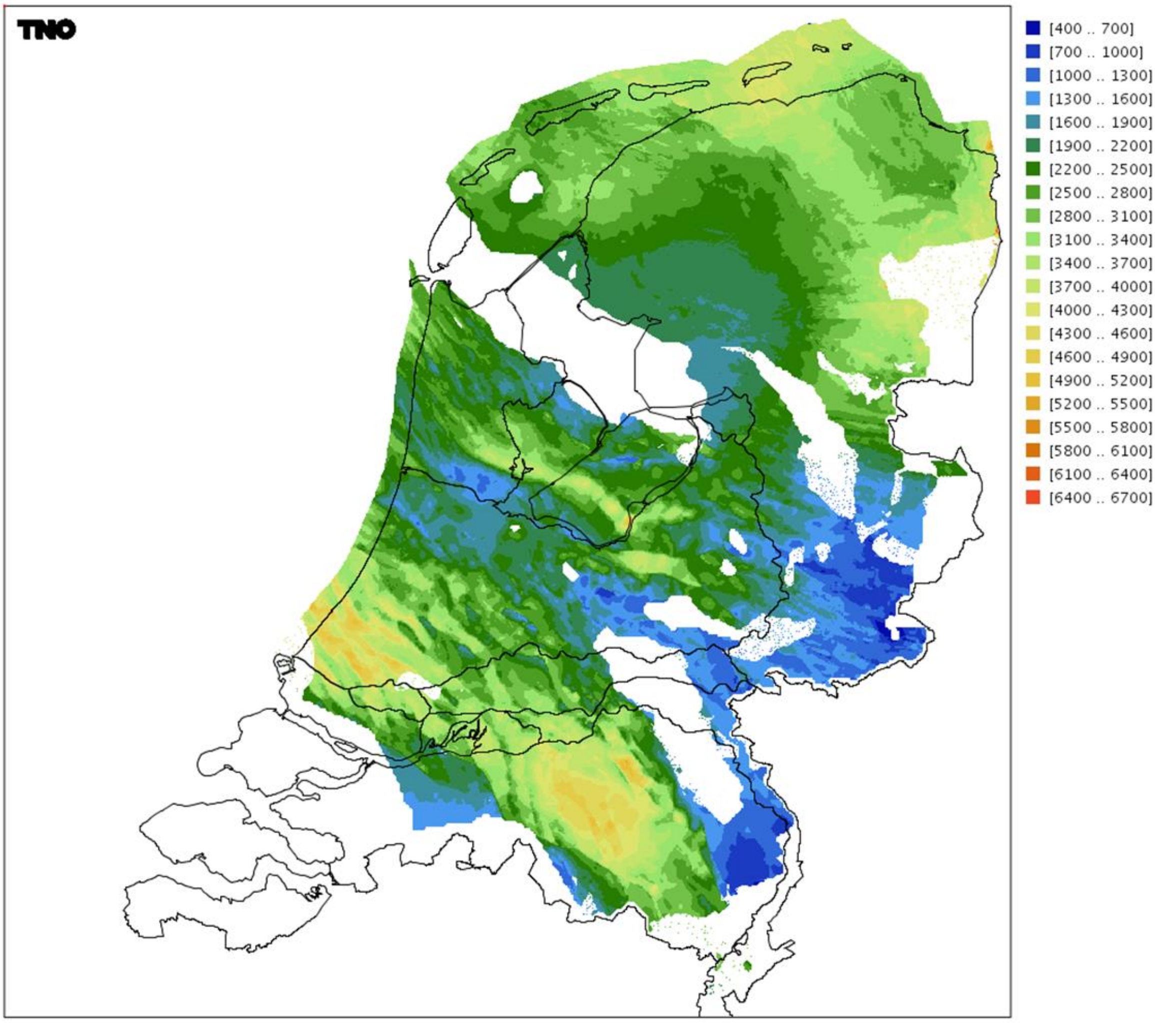

Figure 4-9: Depth map (and lateral extend) of the top of the Slochteren Formation (from ThermoGIS, www.NLOG.nl)

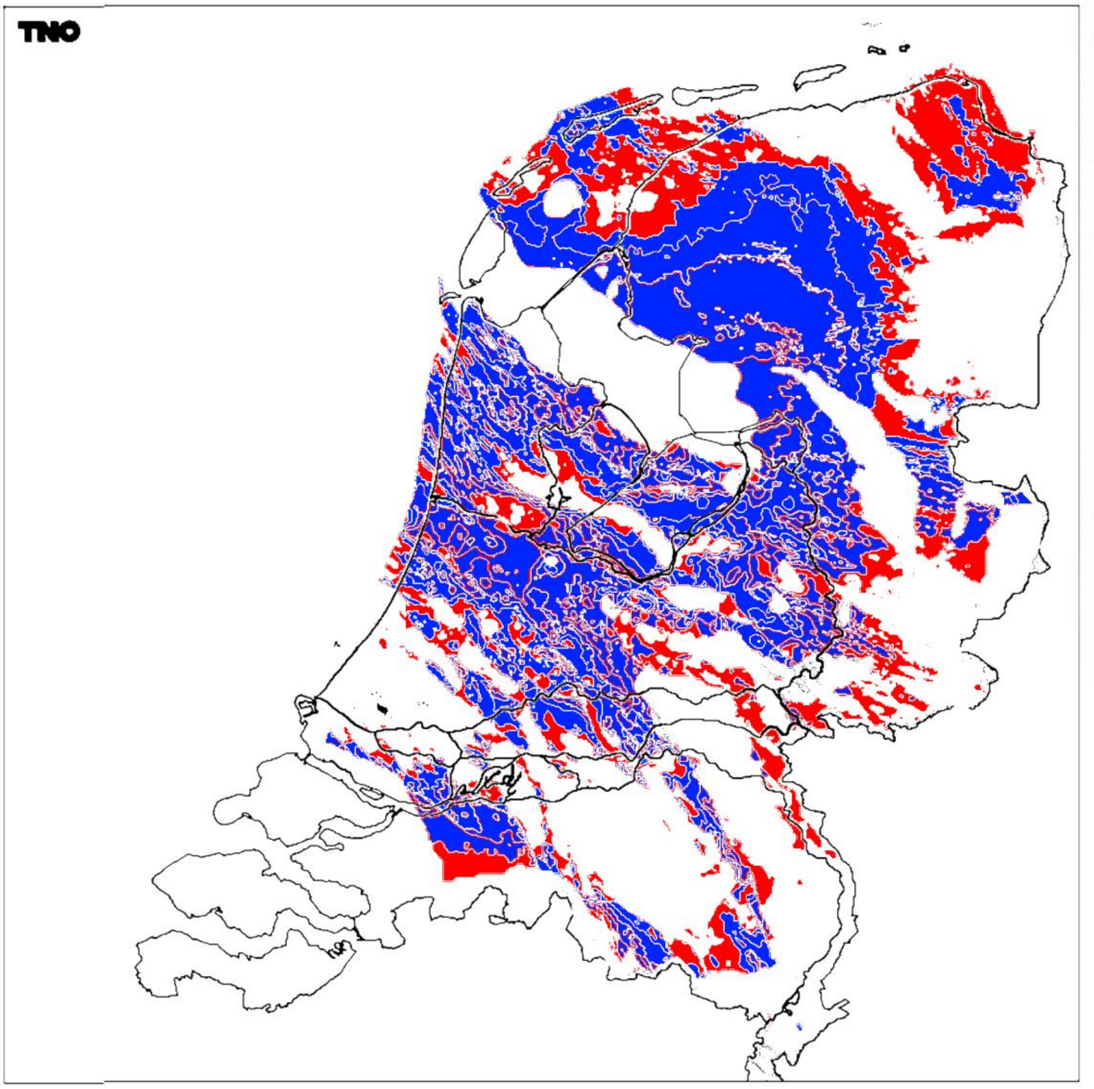

Figure 4-10: Lateral extend of the 10 MWth yield without radial jetting (blue area) and the extension when applying radial jetting (red area). Thickness variations have not been accounted for.

4.4 Carboniferous Kolenkalk

For the Kolenkalk the results of the calculations are presented in Figure 4-11. Contrary to the other reservoirs, an optimum depth is not found. Instead, the yield just increases with depth. This is due to the fact that the porosity and thus permeability is assumed constant (and very low). Technical limitations will restrict the realistic depths which can be accessed. For these calculation a lower depth limit of -6,200 m tvdss has been assumed. Figure 4-12 shows the depth of the base of the Limburg Group which is the top of the Kolenkalk. A nett thickness assumed of 400 m has been assumed for the limestones. In Figure 4-13 the difference between systems with radial jetting and without is shown by plotting the extent to which a yield of 10 MWth can be achieved. Note that, according to these results, only with radial jetting a thermal yield of more than 10 MWth can be achieved. Thickness variations have not been accounted for in this map. Importantly, there are a few restricted areas where the Kolenkalk is thought to be viable target based on deposition i.e. along former carbonate platforms. These areas have not been incorporated in the map.

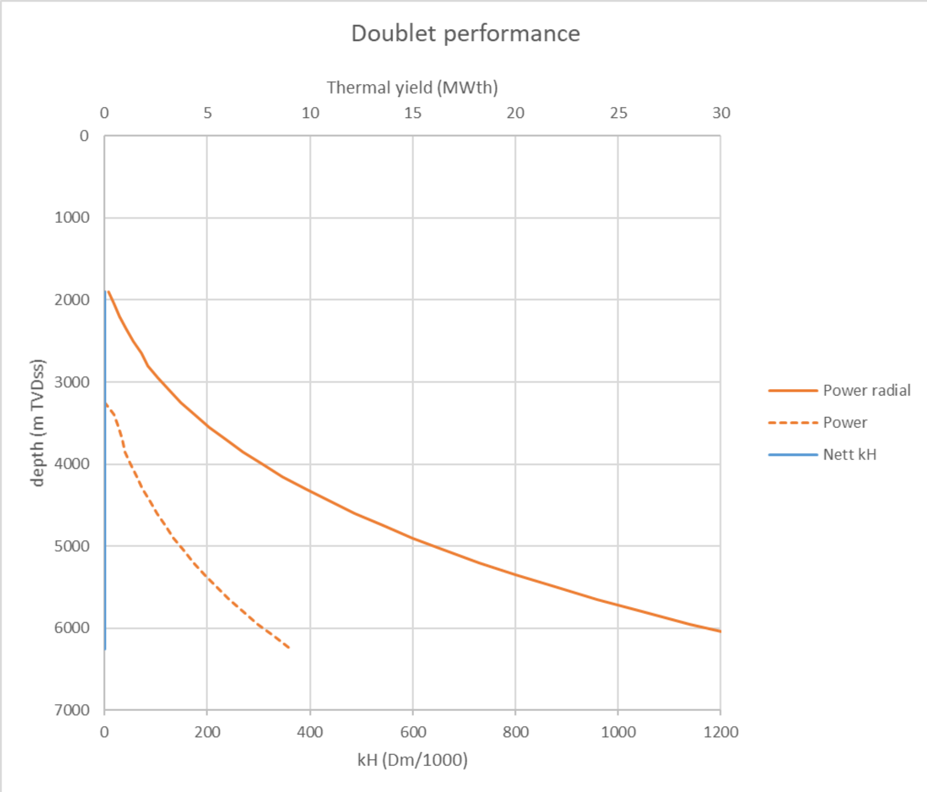

Figure 4-11: Doublet performance, in terms of thermal yield for the Carboniferous Kolenkalk based on typical reservoir parameters corrected with respect to depth at a COP of 20. The thermal yield lines (orange) show that radial jetting (solid orange line) has the potential to significantly improve performance compared to the non-stimulated case (dotted orange line). Note that the nett transmissivity (blue line), kH, is very small at all depths.

The calculation of Figure 4-11 is theoretical and it would suggest that with only radial jetting a viable thermal system in the Kolenkalk can be developed. We donot believe this result is representing the truth, but it does show that in radial jetting in the Kolenkalk in combination with natural fractures could give a good working system.

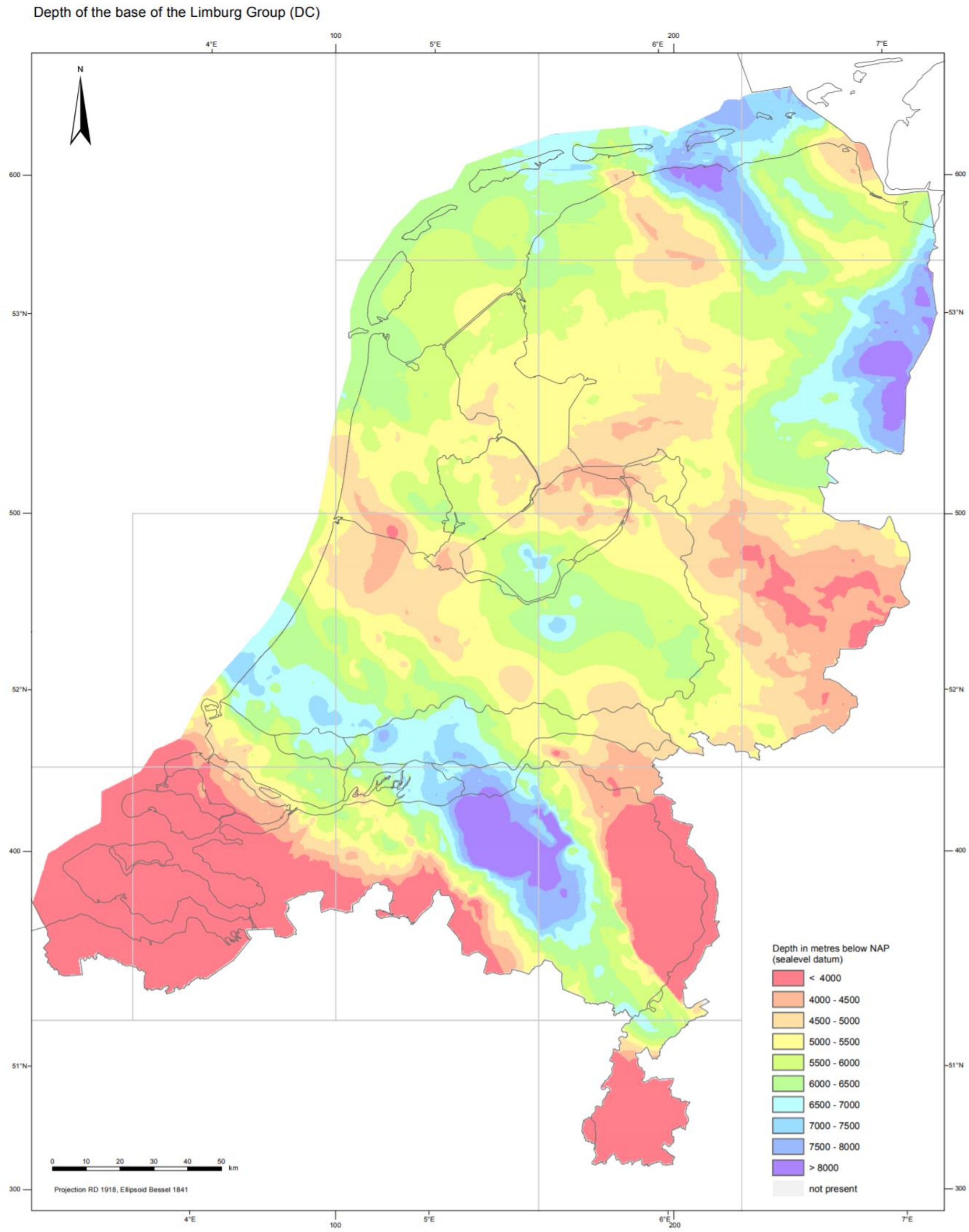

Figure 4-12: Depth map for the base of the Limburg Group (from www.NLOG.nl).

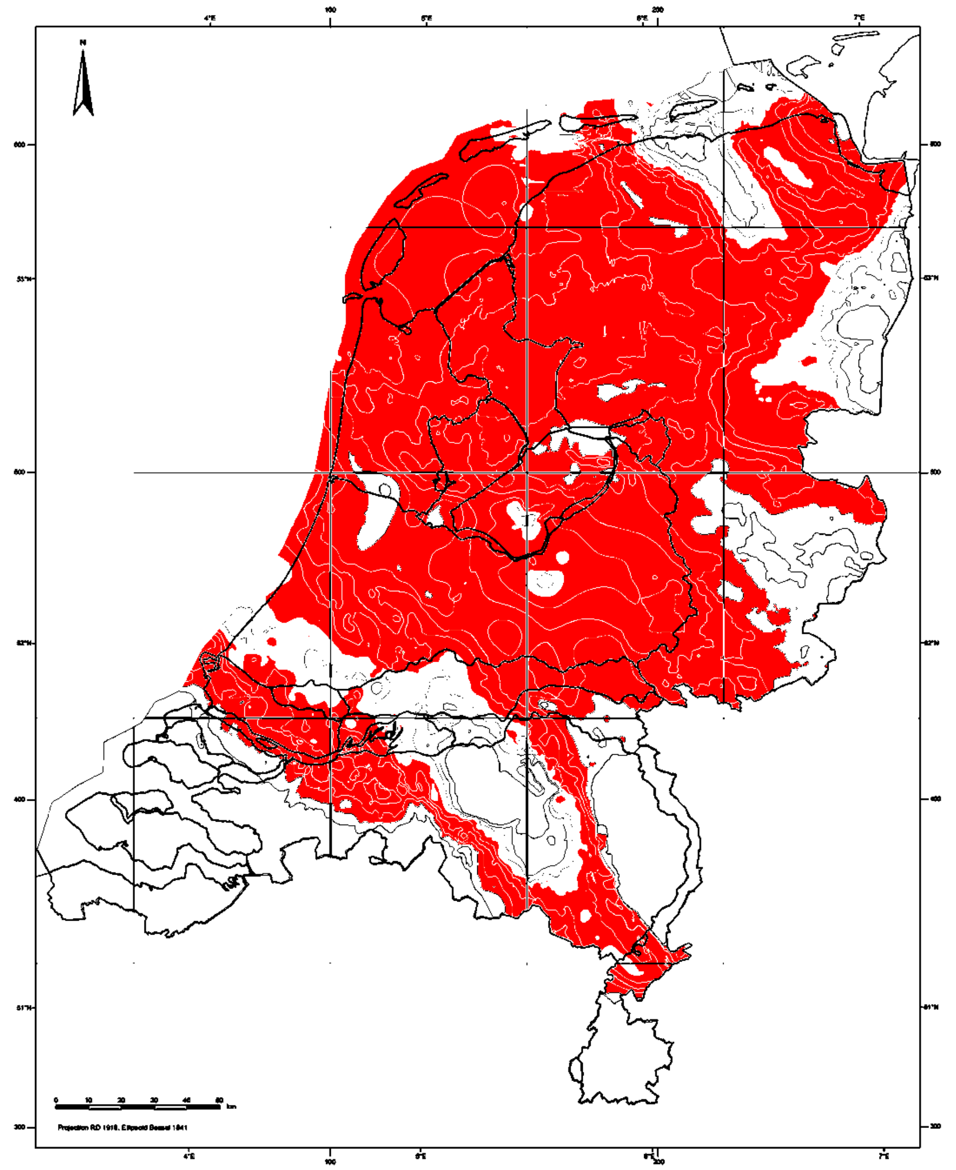

Figure 4-13: Lateral extend of the 10 MWth yield without radial jetting (blue area, not present) and the extension when applying radial jetting (red area). This map is purely based on the expected depth range of the Kolenkalk. Thickness variations and depositional facies changes like carbonate platforms have not been accounted for.

5 Stratigraphic Table Netherlands

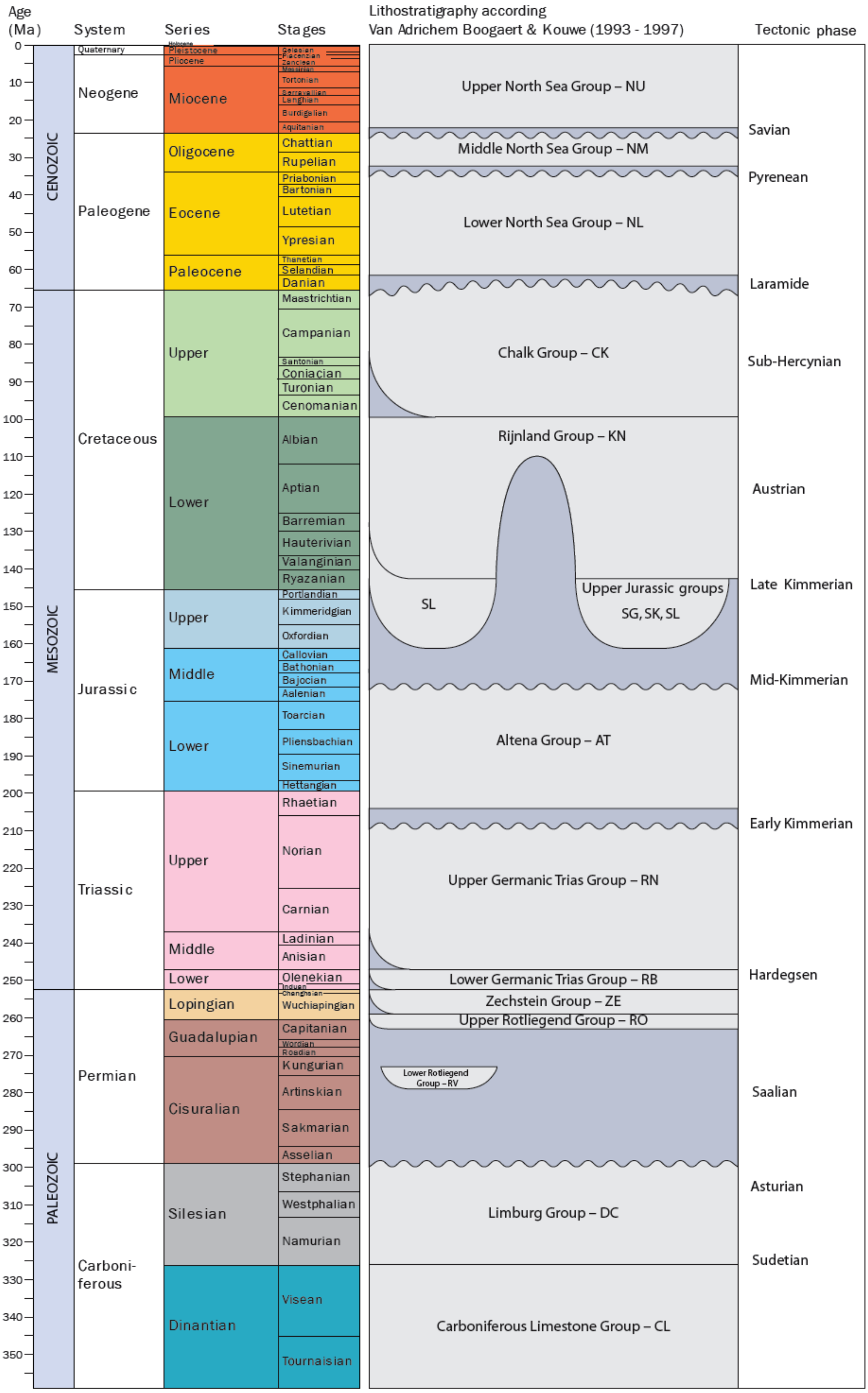

Figure 5-1: Stratigraphic Column for the deep Dutch subsurface (from www.nlog.nl)