GEOTHERMAL POTENTIAL OF THE TRIASSIC FORMATION WITHIN THE WEST NETHERLANDS BASIN

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1. INTRODUCTION

The West Netherlands Basin is an geological interesting area in the Western part of the Netherlands. Due to its deformation over time there is a tectonic complex structure in the subsurface. In the past many research projects were done in order explore hydrocarbons. The complexity of the fault structures creates a possible reservoir and seal structure, perfect for a potential hydrocarbon system. Exploration wells were drilled, seismics were shot and many field investigations were done. The West Netherlands Basin turned out to be suitable for the extraction of geothermal energy. Permeable sandstone layers that occur in the WNB in combination with a high reservoir temperature cause this area to be potentially suitable for the extraction of geothermal energy.

In Delft, a research project called the Delft Aardwarmte Project started several years ago. The DAP explores the possibility for geothermal extraction in the early Cretaceous layers.
In this project, deep sandstone layers from the Triassic are used to heat up water. Due to its greater depth the temperature is higher and a higher conversion of energy is targeted. This is a process that would work if the parameters of each sandstone layer would be the same. However, this is not the case. The permeability, faults, porosity and other soil characteristics change with increasing depth. *Trias Westland* is a company that combines 47 greenhouses farmers and wants to use geothermal energy as their energy source their greenhouses.

In this project, the geothermal potential of the West Netherlands Basin is evaluated. The geothermal potential of a field is done by taking the seismic/geological results and investigate what aspects change the level of potential. For successful geothermal energy production, three key aspects are essential in order to create a lucrative geothermal system. These aspects are the temperature at the depth of the targeted reservoir, the amount of fluid present within this specific reservoir and finally, the amount of pass ways through which fluids can flow.

The final goal of this Bachelor End Product is to describe the geothermal potential of the Triassic formation. Seismic and geological interpretation of the dataset will contribute to finalize this project. This research project is split up into two parts, the seismic interpretation and the geothermal potential. The different parts have overlapping parts that apply to both parts.

2. REGIONAL GEOLOGY OF THE WEST NETHERLANDS BASIN

2.1 West Netherlands Basin

The West Netherlands Basin is located in the south-west part of the Netherlands. In the past, this area is extensively used to find oil and gas fields. These fields are located in the fault traps seen in figure 2 and figure 4. However, due to permeable sandstone layers in this basin, it is also suitable for the creation of geothermal energy. The specific geothermal layer of interest in this thesis is located inside the Triassic sediments.

The basin is bounded by geological structures in the North and South. In the southern part of the WNB the London-Brabant Massif creates the boundary. In the northern part of the WNB, the Central Netherlands Basin is located. Their boundary is the Zandvoort Ridge. On the North-West side of the WNB the Broad Fourteens Basin is located. In the South-East direction it lays along the Roer Valley Graben. The location of this system can be seen in the figure 1. [4]

The depositional history of the West Netherland Basin has gone through multiple geological stages. Several elements have continuously changed in response to changing tectonic conditions. Although the basin has been described as one basin, it is actually divided into smaller sub elements bounded by long, NW-trending faults. 'Van Balen et al'(2000) divided the depositional history, Late Carboniferous-Tertiary history of the WNB into four different stages. [2],[4]

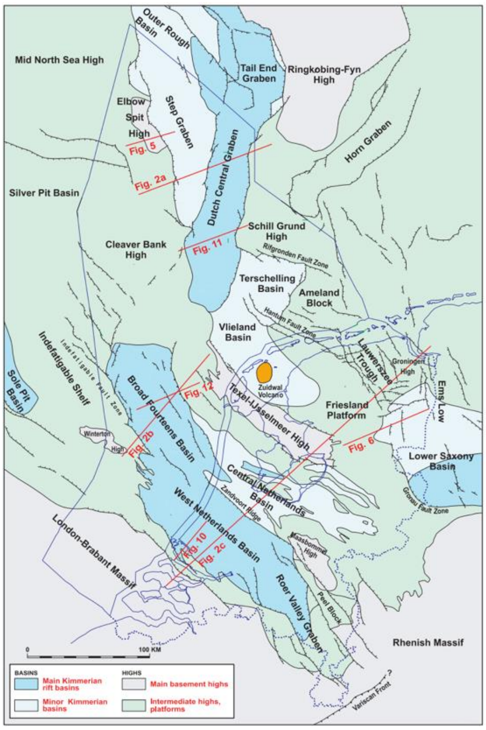


Figure 1 - Geological setting West Netherlands Basin [4]

2.2 Late Carboniferous-Early Permian Stage (318-271 Ma)

In the first period, the WNB developed upon the Campine Basin, which originated from the Variscan origin. During the Variscan orogeny, an uplift and erosion took place. The sediments that were uplifted and eroded originate from the Westphalian to the Early Permian. (Appendix 10.1). Especially in the northern Zandvoort Ridge a great uplift occurred. In the Late Carboniferous, the basin was filled with a predominantly fine-grained succession of shale and coal. As can be seen in figure 2, the northern part of the source rock was uplifted more than at the southern part. (Red layer) These shales and coals are later to be found as the source rock of several hydrocarbon explorations. [2]

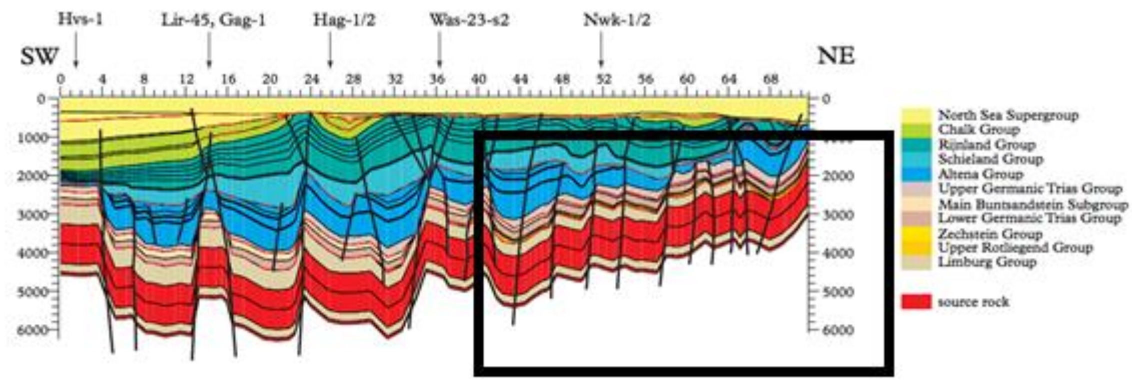


Figure 2 - cross section through the West Netherlands Basin [2]

2.3 'Pre-rift' Late Permian – Middle Jurassic (260-176 Ma)

In the Late Permian, the sedimentation continued. Sandstones from the upper Rotliegend group were deposited in the WNB. The sedimentary succession contained mainly fluvial and Aeolian sandstones from the Upper Rotliegend group, which is followed by clay-, siltstones from the Zechstein Group.

The Early Triassic is characterized by some regional subsidence. Subsidence caused the WNB to change into a North oriented basin. Fine grained lacustrine sediments are placed initially followed by a succession of sandy fluvial and aeolian depositions i.e. the Main Buntsandstein group. This porous sandstone increases fluid flow within the Triassic layer.

During the Hardegsen phase, at the early Triassic (245-235 Ma) the northern part of the WNB is uplifted. Erosion took place in this phase and the thickness of the Main Bundsandstein subgroup decreased to 180 m in the southern part and 45 m in the northern part. [2],[8]

2.4 'Syn-rift stage' Late Jurassic - Early Cretaceous (161-99.6 Ma)

The strong rift occurred during the Late Jurassic until the Early Cretaceous stage. The rifting caused the West Netherlands Basin to divide itself into two sub-basins, with different thicknesses. The difference in thickness is due to the syn-rift sedimentation combined with a continuous shift of depocentres. The distribution patterns of the basin were complex and diverse.

The syn-rift stage is the stage in which sediments deposit onto the normal fault. Since sedimentation took place during rifting, the layers from this period show a wedge shaped structure. The wedge shaped structure occurs when sediments deposit onto the fault plane. In fig.3 the syn-rift layers are indicated by the orange, grey and pink layers. [2],[8]

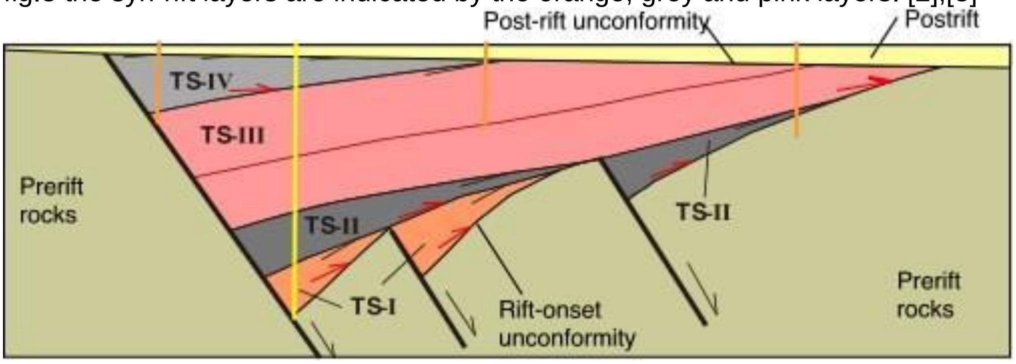


Figure 3 - Rift basin in an extension basin [9]

2.5 'Post-rift' and inversion stages Late Cretaceous - Quarternary (99.6 Ma- Now)

The syn-rift phase has stopped in this period. During the Upper Cretaceous (Santonian - Campanian) the WNB is located in the hinterland of the Alps. During this period, the alpine inversion creates a peak in its stresses that it converges to its hinterland. As a consequence, inversion occurs in the WNB. The subsurface therefore shows major reverse movements which are expressed by the occurrence of the so-called the flower faults. Also, this inversion resulted in the uplift of the layers. In marginal troughs in the North and South of the basin, sedimentation took place.

During the Maastrichtian-Danian period, the whole basin was covered with sediments. During inversion, faults from previous rifting activity are reactivated in a different direction. In fig. 4 it is seen that inversion takes place. The normal fault moves in the opposite direction relative to its original fault direction. The inversion ceased after the Maastrichtian-Danian period.

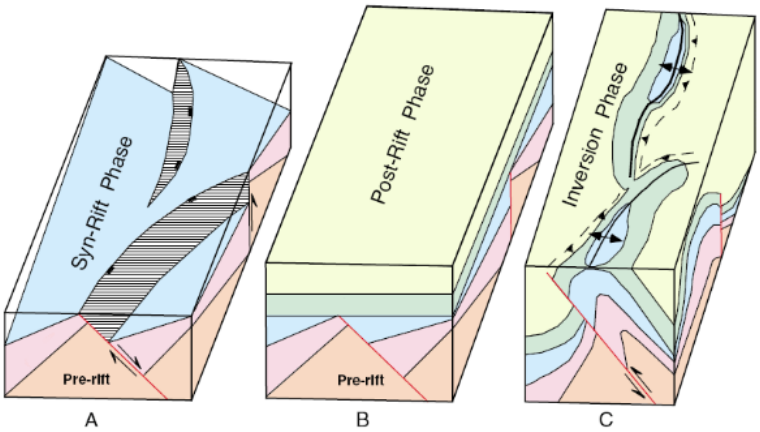


Figure 4 - Visualization, Syn-, Postrift and inversion phase [9]

In figure 5, all major faults in the WNB are displayed. Noticeable is that most of the faults are perpendicular to the NE-SW line. The inversion created so called flower structures as seen in figure 5. The post rift sediments are sediments that do not show a wedge shaped character anymore. However, they could be deformed due to the later inversion of the Alpine orogeny. The red circles in figure 5 indicate post rift sediments with the flower structures. The blue rectangle indicates an example of post rift sediments deformed by inversion. [2],[4]

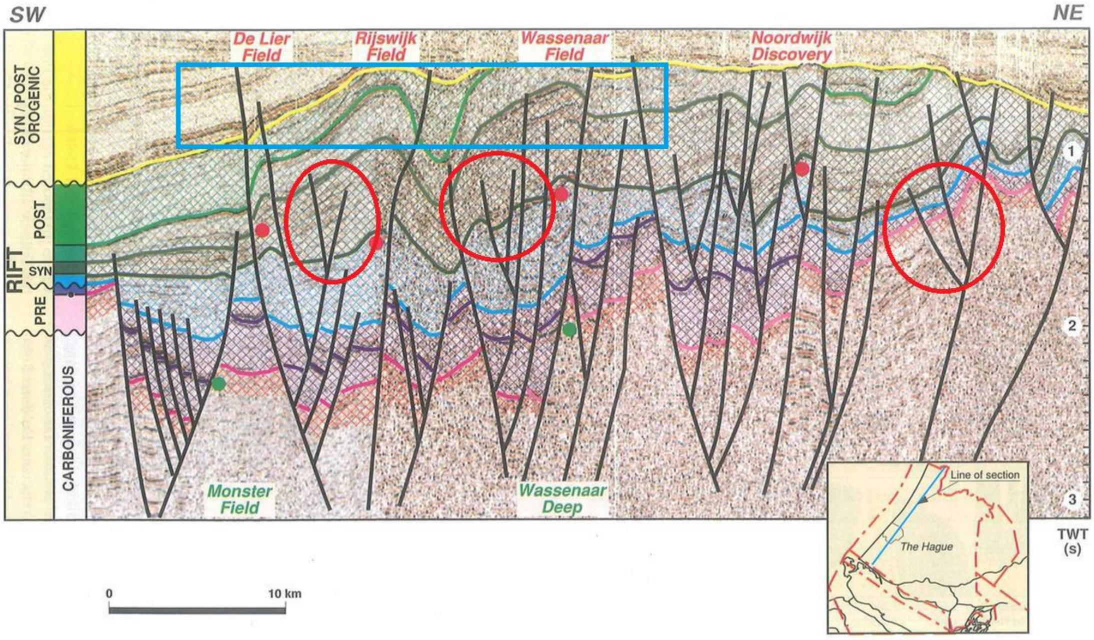


Figure 5 - Cross-section of the West Netherlands basin [2]

3. MATERIAL & METHODS

3.1 Materials

From the seismic data a model is made with which the Triassic potential of the West Netherlands Basin can be interpreted. The data contained a seismic data set and a well called LIR-45. The overview of the location can be seen in figure 6. In table 1 the well details are given. Full well interpretations from Nlog can be found in appendix 10.1 and 10.2.

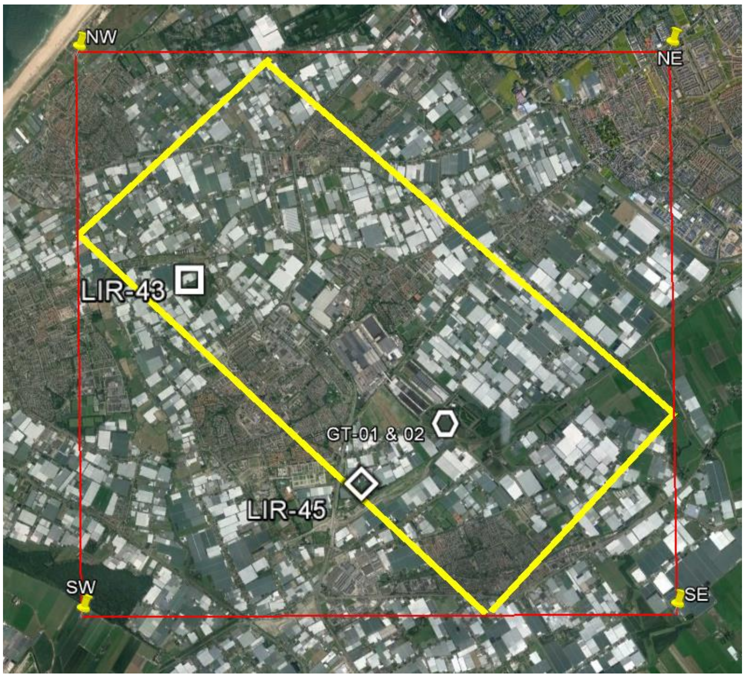


Figure 6 - Location of the projects. Yellow line shows the outer perimeter. [google earth]

Timeperiod	Well tops (meters)	Layername
Quartairy	0	Upper North Sea Group
Tertiary	507	Ieper Member
Cretaceous	692	Landen Clay Member
Jurassic	2433	Upper Werkendam Member
Triassic	2898	Dolomitic Keuper Member
Permian	3388	Zechstein Upper Claystone Formation
Carboniferous	3881	Maurits Formation

Table 1- Time period indication of the well LIR-45 [excel]

3.2 Methods

3.2.1 GEOLOGICAL AND GENERAL INTERPRETATION

After seismic interpretation, different layers within the geological setting are visualized and their relation to the rifting and inversion process, a colour is given to each layer. In this way it is easier to identify the layers and their corresponding rifting history. Colours that correspond to a specific period in time can be seen in figures 16 & 26 [3],[11] By looking at the structures and comparing them with the in advance research an interpretation and insight to the geothermal potential of the Triassic formation can be given.

3.2.2 PETREL

Petrel is a program used in interpret the seismic data. In petrel functions such as Ant-Tracking and Variance are important to interpret the fault structures and their geothermal potential.

3.2.3 FAULTS

Faults are mapped perpendicular to the inline or cross line. This is necessary for the eventual visualization of the faults. Different 3D cubes were realized called variance and ant tracking. The variance option reduces noise. Ant-Tracking is a powerful method for highlighting faults and horizons. First, a realized variance window is created and afterwards the ant-tracking window is created. An example of Ant-Tracking and Variance can be seen in figures 9 and 10.

Using Ant-Tracking, small faults are first of all interpreted. This was first done for the faults that were very clear and accurate. In the final product, the possibility of connecting smaller faults with each other was checked. In the process it becomes more clear that some faults do connect with each other and should be connected. [10],[11]

Figure 9 - screenshot AntTracking function Petrel without fault mapping [petrel]

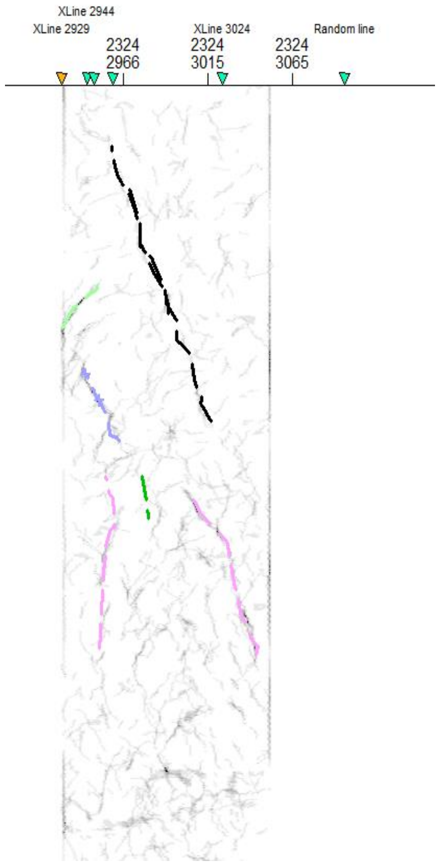


Figure 10 - screenshot AntTrackng function Petrel with fault mapping [petrel]

3.2.4 ADOBE ILLUSTRATOR

Adobe Illustrator is a program that is used in the project to display the structures nicely. In Adobe Illustrator the multiple layers are visualized and the thickness of the layers is shown. Figure 11 shows all the different options in this program.

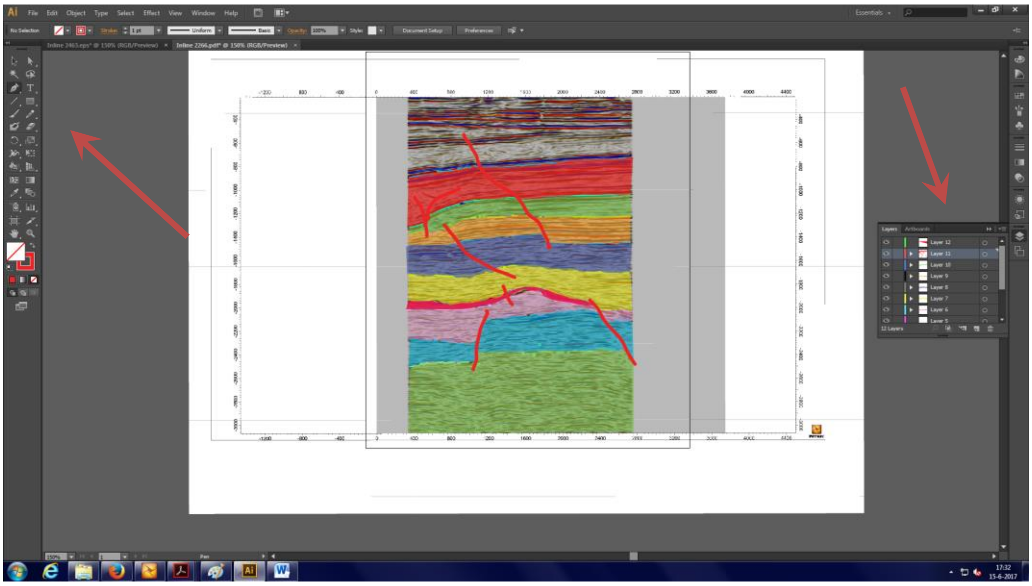


Figure 11 - Screenshot of Adobe Illustrator

3.3 Extensional structures

Specific structures are often seen in the subsurface when looking at an extensional basin and its geological background. In this chapter some of those structures that are likely to be seen are described. The structures have, next to the reservoir characteristics, a huge impact on the geothermal energy potential of the field.

3.3.1 HORST AND GRABEN

Horst and Graben structeres, seen in figure 12, have an influence on the geothermal potential of the field due to the fact that is described in 3.3.1, the anatomy of the fault. Horst and Grabens will occur in an extensional basin as the West Netherlands Basin. Horst Graben structures are formed when extension creates a planar fault. The uplifting of some areas creates horsten and grabens. When it is symmetrical called horst graben, when asymmetrical called a half graben. [10]

3.3.2 FAULT ZONE

An important aspect of the assessment of flow in a geothermal reservoir is the fault zone. Large faults do not occur in one straight line, but have small sub-faults around them. The level of brittle area around determines the flow and porosity of that area. As the area contains large amounts of almost impermeable rock (1-100 MD, Dr. N. Gholizadeh Doonechaly) the faults might just be the area through which water can flow. Displayed in fig. 13. [10]

3.3.3 RIFTING

As the West Netherlands Basin is an extension basin, rifting will occur. Rifting is the subsidence along normal faults caused by extension. It propagates along the fault plane and creates a wedge shaped character. As discussed before this has an increasing effect on the geothermal energy potential of the Triassic.

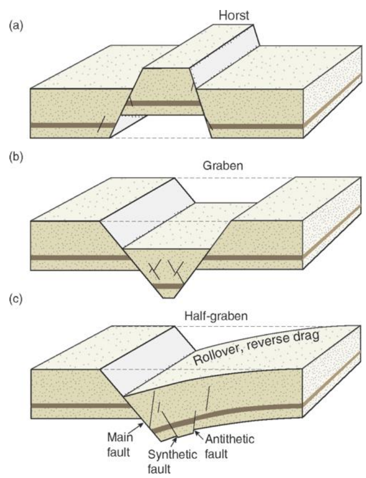


Figure 12 - Horst-Graben structures [google images]

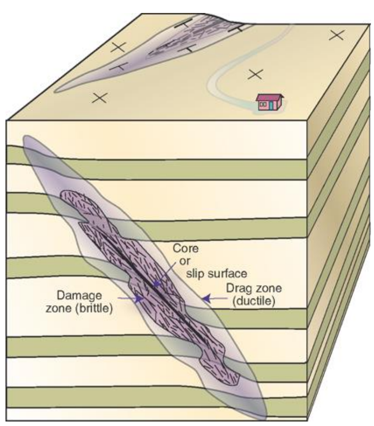


Figure 13 – fault atanomy [10]

3.3.4 FLOWER FAULTS

Due to the inversion a strike-slip fault at occurs at the cross section. The reactivation creates segments with a braided character that resemble a flower pattern. Fault zones with dominantly normal faulting (as in this project) are called negative shaped flowers. An example of positive flower faulting can be seen in figure 15. Flower structures are a form of inversion structures which can improve the permeability of a reservoir and thus the geothermal potential of it. [4]

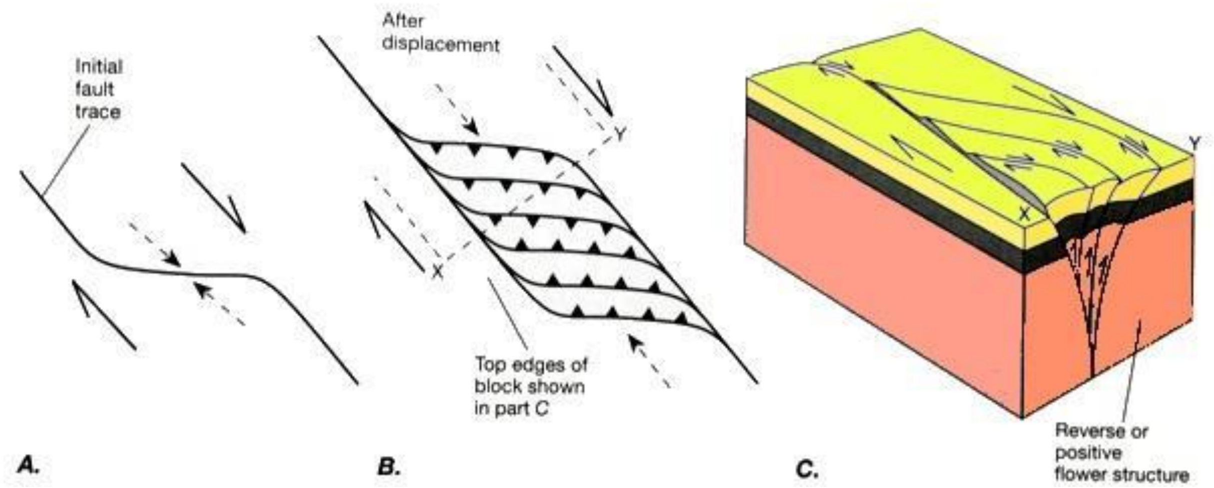


Figure 15 – Flower faulting [4]

4. GEOTHERMAL POTENTIAL OF THE WEST NETHERLANDS BASIN

Within this section the geometry, thickness changes and deformation of all formations will be described. The different formations have changed over time, they have been deformed by various occurred orogeny's. By interpreting the geometry, thickness variations and deformation of the adjacent layers of the Triassic, one can determine the volumetric characteristics of the whole Triassic formation. With these characteristics an insight into the geothermal potential of the Triassic formation can be made. In this section, the geometrical characteristics of the formations are described on the basis of the rifting periods. In table 3, the different thicknesses can be observed.

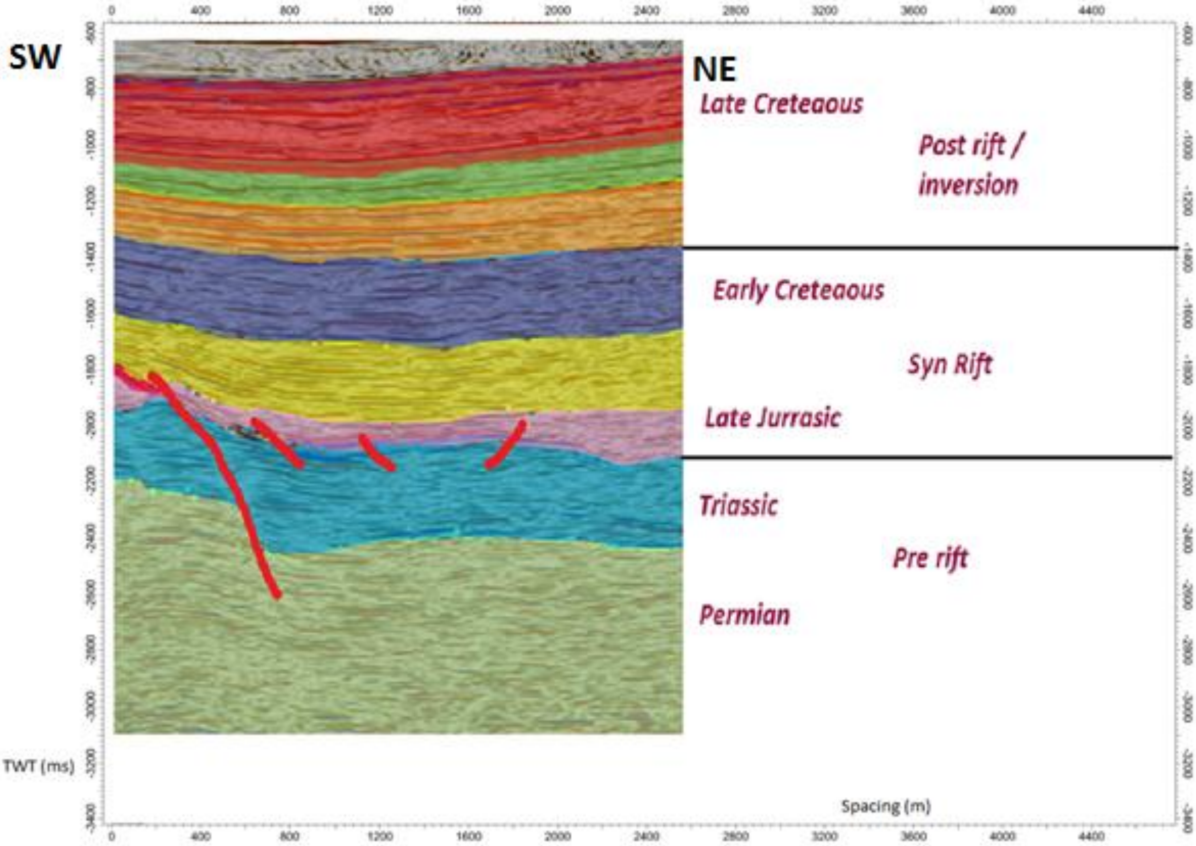


Figure 16 - Inline 2463 horizons with faults [Adobe Illustrator]

Depth (m)	Age	Formation	Average Thickness (m)	Minimal Thickness (m)	Maximum thickness(m)
735 1292	Cretaceous	Ommelanden formation	276	203	494
1662		Holland member	176	132	211
2084		De Lier Member	223	128	417
2471	Jurassic	Albasserdam Member	298	206	418
2550		Middle Werkendam	263	149	397
2600		Possidonia Shale	71	0	246
2898		Aalburg	172	15	376
3388	Triassic	Upper and Lower Germanic Trias Groups	318	200	440
	Permian	Zechstein	-	-	-

Table 3 - average-,minimal- and maximal thicknesses of the formations [excel]

4.1 Pre-rift

All sediments that are overlain by the Aalburg formation can be defined as pre-rift sediments. These formations are: the Zechstein and the Upper and Lower Germanic Trias. The Germanic Trias layers contain the bottom of the sandstone layer that is used for the extraction of geothermal energy in the dataset. (see figures 16-20) During the pre-rift period there was no active faulting. However, the zone of interest (Main Bundsandstein) was deposited. The thickness of the Germanic Triassic layer is on average 318 meters thick. (table 3 and figures 17-20).

Since the Trias is deposited in the Pre-rift period. The upper and lower boundary of the Triassic were not affected by the rifting during their deposit. Therefore, the thickness of the formation is fairly constant. The big variations of the Triassic thickness in table 3, is due to one small area in west-corner were the thickness has decreased. The overall thickness of the Triassic is fairly constant. The constant thickness of the Triassic layer is a very positive characteristic of the Triassic layer when looking at the geothermal potential of it.

4.2 Syn-rift

During the syn-rift period, the layers were deformed and bend towards the fault plane. This caused the syn-rift deposits to have a wedge shaped character. These are therefore all the sediments that have been deposited between the Late Jurassic and the Early Cretaceous. These are: the Aalburg, Posidonia Shale, Werkendam and Alblasserdam formations. The geothermal potential of the WNB increases in this timeperiod as the sandstone layer is covered by a non-conducting layer and deformation occurs. This layer with the deformation acts as a seal on top of the sandstone layer.

The rift evolves and the following aspects change. First of all, some individual normal faults grow and connect to each other. This can be seen in figure 21 to 23. Sedimentation follows the direction and orientation of the half grabens, North-East dipping. This is noticeable in figure 12 & 13. Since sedimentation, followed the direction of the fault plane, one can understand why the thickness of the Aalburg, Werkendam and the Alblasserdam formation is extremely variable. In table 3 the thicknesses of the different layers can be observed.

During the syn-rift period, different fault structures are seen. When extension starts, two opposite normal faults are formed. The created horst-graben structure is the outcome of two normal faults that lie in close proximity and have opposite dipping directions. (fig 23) The subsidence takes place at the hanging wall (graben) and in between the two foot walls, the horst is located. Faults structures might have a very important impact on the geothermal potential of a layer. This is due to the fact that faults might improve the permeability and passways of a reservoir. This will be further discussed in the next section.

The syn-rift phase also deformed the layers that were deposited in the pre-rift phase. Before the syn-rift, the pre-rift layers were deposited horizontally. During extension, the SW and the NE part of the pre-rift sediments subsided along the normal faults, as seen at the Triassic in figure 16 and 26. Therefore, it can be concluded that the syn-rift phase did not affect the thickness of the Triassic. This relative steady thickness of the Triassic layer can be seen in figure 19. However, the Triassic has been deformed due to subsidence, causing the depth of the top Triassic formation to be variable and the orientation to be shifted in a NW and SE direction. Therefore the syn-rift has a significant impact on the geothermal potential due to the creation of faults. These faults can influence the permeability of the reservoir and therefore increase the potential of geothermal energy. In figures 17 and 18 this faulting through the reservoir is displayed. It can be seen how a relatively huge fault runs throughout the whole reservoir.

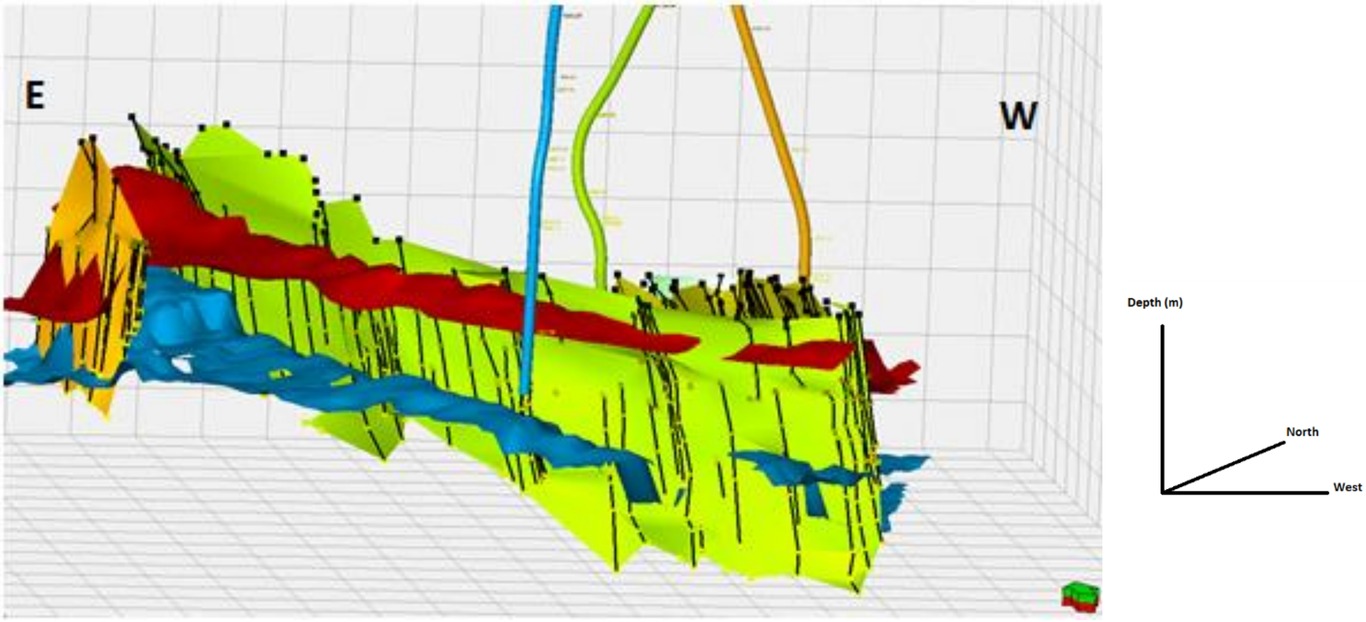


Figure 17 – Bottom and Top Trias are given in blue and red. Yellow fault crosses the entire section [Petrel]

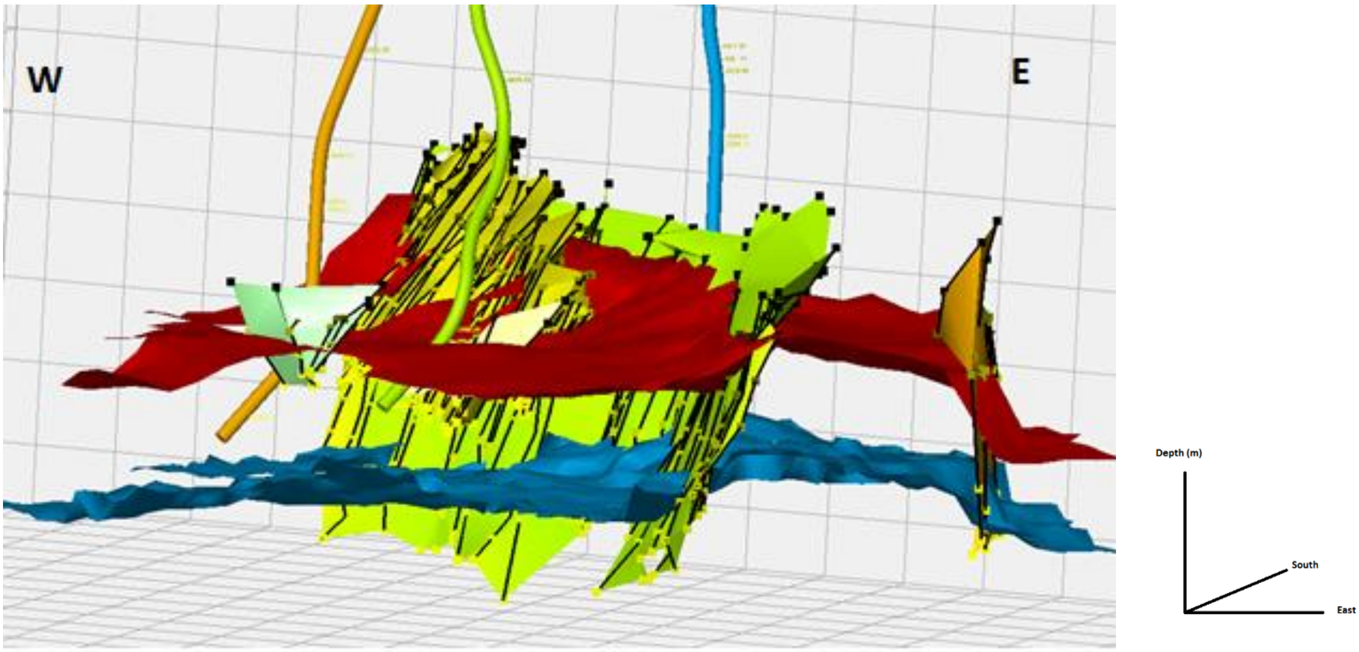
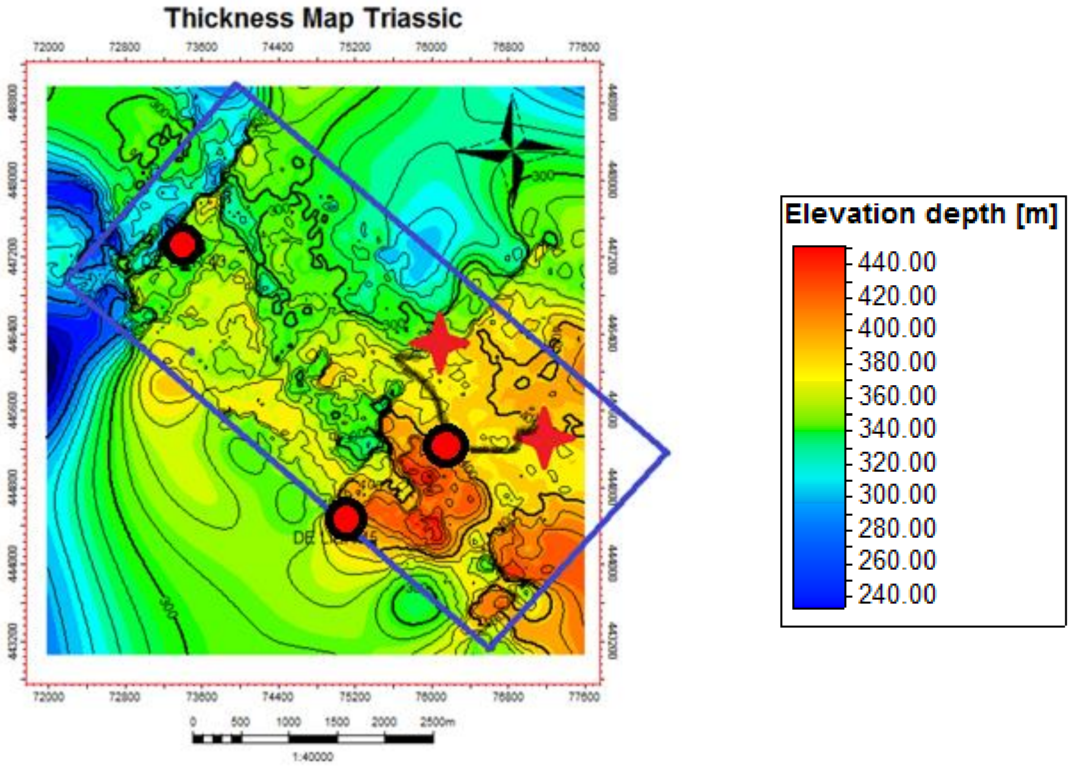


Figure 18 - Bottom and Top Trias are given in blue and red. Yellow fault crosses entire section [Petrel]



Figuur 18 - Thickness map of the Triassic formation [Petrel]

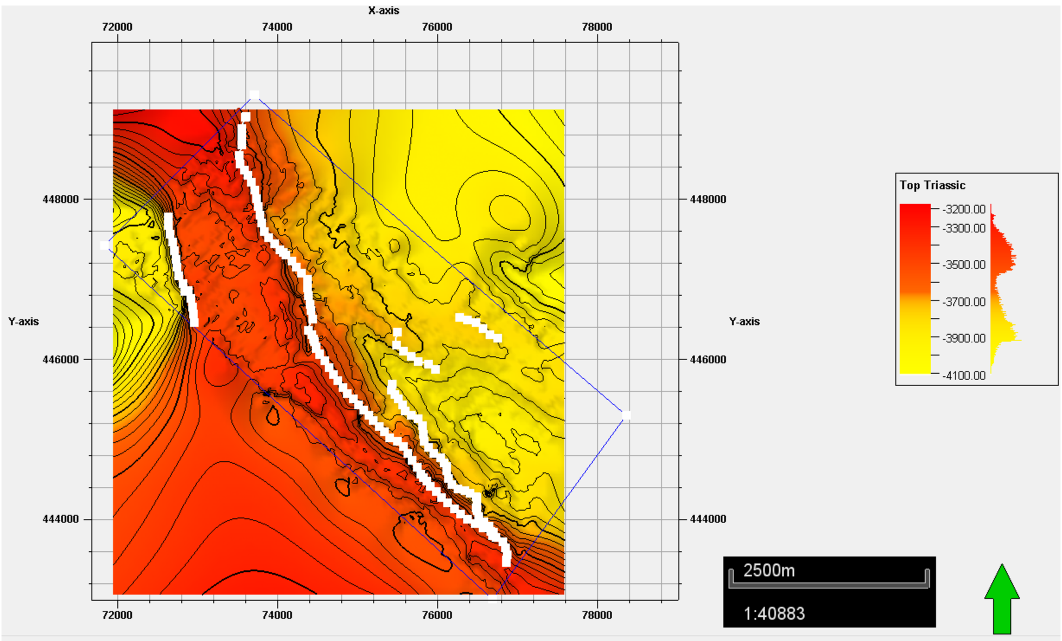


Figure 19 - Top visualization of the Top Triassic layer.

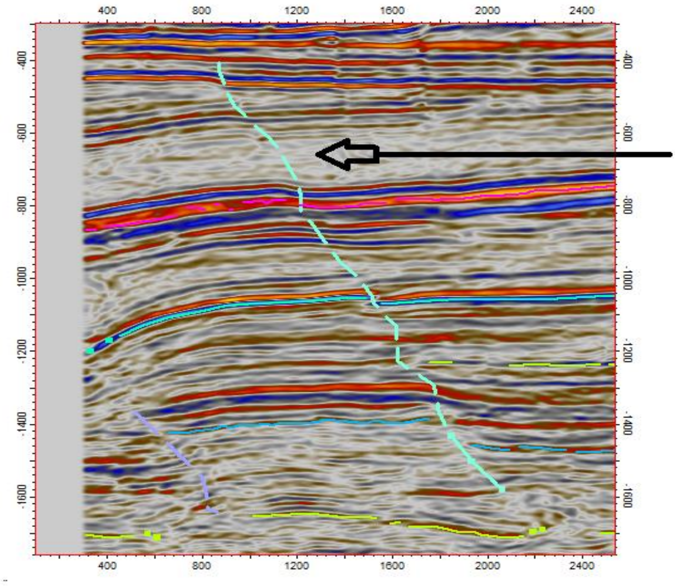


Figure 20 – Triassic thickness, red stars give well bottoms of GT-01 and GT02, The red dots indicate the surface locations. [Petrel]

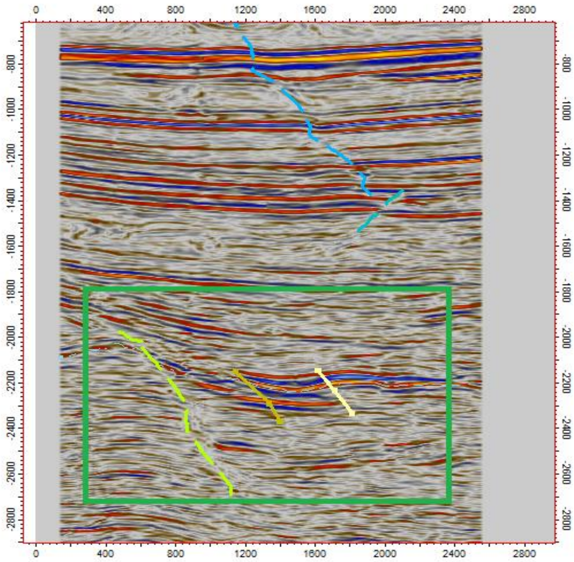


Figure 21 - Main Normal faults, originated from syn-rift period (NE-SW cross section) [Petrel]

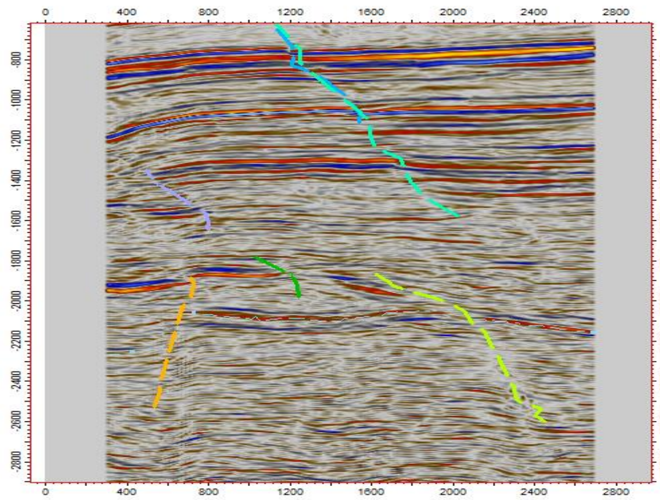


Figure 23 - Horst Graben structure, originated from syn-rift period
(NE-SW cross section) [Petrel]

4.3 Post-rift & Inversion

The post-rift and inversion stage have an importance when looking at the geothermal potential of the WNB and thus the Triassic layer. The later discussed reactivation of faults can influence path ways and permeability of the reservoir. In the post-rift period, the extension has fully stopped. This can be proved by figure 16 since these layers are all deposited in a fairly horizontal way. These are therefore all the layers that are underlain by the Alblasserdam Member. However, this period is characterized by another tectonic event, the inversion period.

The Alpine orogeny created convergent forces which caused the WNB to inverse. This inversion resulted in the uplift of post rift sediments. The subsurface therefore shows major reverse movements which are expressed by the occurrence of the so-called the flower faults. This means that inversion is the reason for all faults that are localized above the Alblasserdam Member. Interpreted flower structures can be seen in figures 24, 25 and 26.

Faults that were created during the syn-rift period are reactivated by the inversion causing opposite movement along the same fault. The opposite movement of the post rift sediments is the reason for the curved structure in for example the Holland and De Lier formations. This can be seen in fig 26. Different fault directions can be observed pointing out the inversion. This reactivation of the faults creates an

The reverse faulting in the Triassic layer causes the NE part of the Triassic layer to be uplifted again. This explains why the West part of the Triassic is located much deeper than the Eastern part.

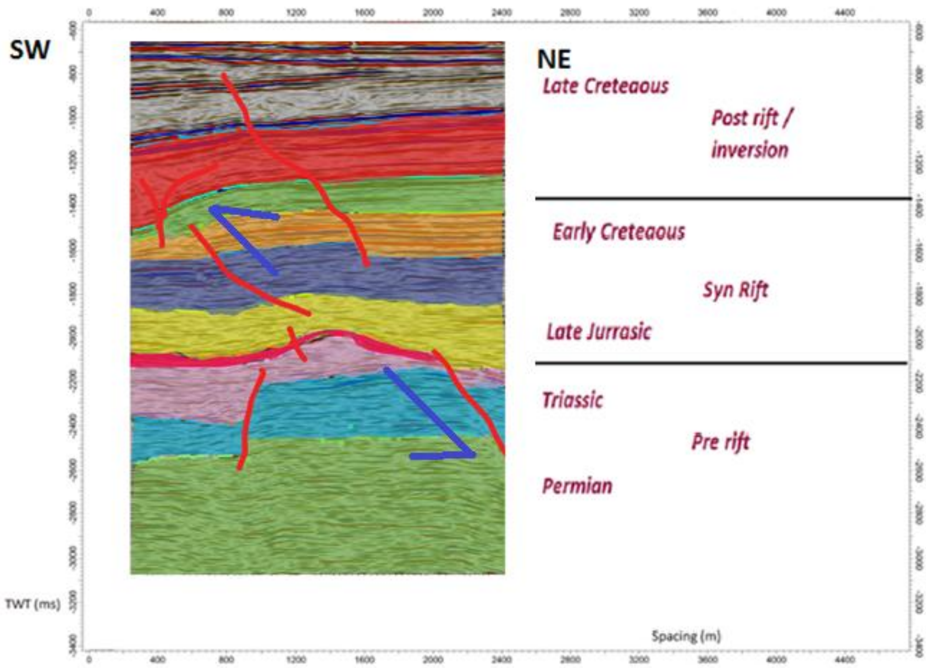


Figure 26 – Inversion faulting [Petrel]

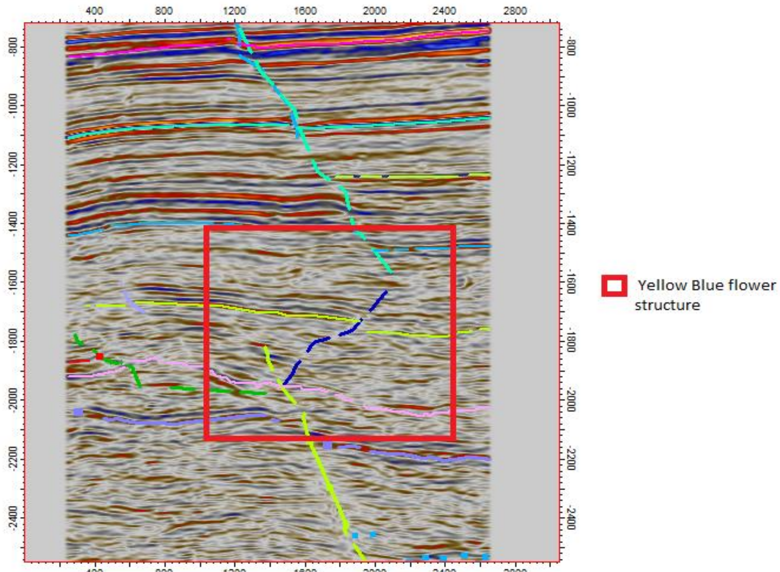


Figure 24 - flower faults, originated from inversion period (NE-SW cross section) [Petrel]

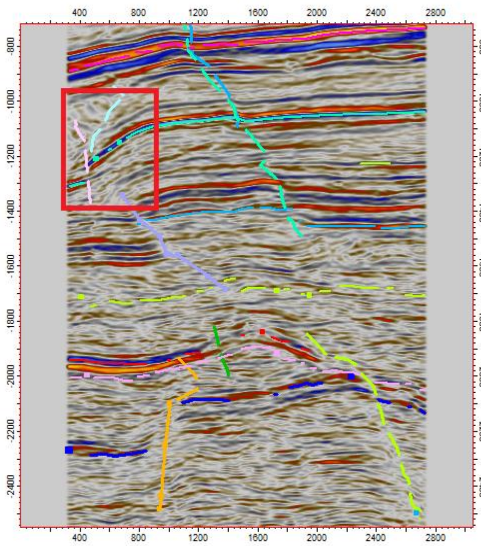


Figure 25 - flower faults, originated from inversion period (NE-SW cross section) [Petrel]

4.4 Geothermal potential of the Triassic layer

The Triassic is bounded by the Aalburg formation on top and the Zechstein formation at the base. In the borehole the Triassic layer is 318 meters thick. In the rest of the layer this thickness differs between 200 and 440 meters. In the figures 17-20 the geometry of the Triassic layer is displayed. The two geothermal wells are shown in figure 20 (indicated with the red star) Through the length (NW-SE direction) of the Triassic layer a fault has developed itself.

There are three aspects that are key for the success of a geothermal project. First of all the temperature of the reservoir must be high enough in order to create a big temperature difference. This project drills 4 kilometres underneath the subsurface where the average temperature is 140 degrees Celsius. This average temperature is a high enough to create the essential temperature difference.

Secondly, the fluids that are present are important for the flow capacity. In the reservoir a hydrostatic pressure regime is present, which is perfect for a geothermal reservoir.

The final aspect needed for a successful geothermal project are pass ways. The pass ways are the spaces in which the water can warm up and flow through to the extraction well. The pass way is dependent on the permeability and the fractures within the reservoir. According to Dr. N. Gholizadeh Doonechaly the permeability of the reservoir varies between 1 – 100 mD. These values are quite low, values up to 50mD would actually be on the low side for a geothermal energy reservoir. In order to increase the porosity three steps can be taken. These steps consist of stimulation methods: mechanical stimulation, thermal stimulation and chemical stimulation. Taking these steps will reduce the skim factor of the reservoir which means that more water can be pumped in under the same pressure difference. Mechanical stimulation consists of hydraulic stimulation with salt dissolutions. Thermal stimulation is done by injecting cold water. The temperature difference can create an increase in the porosity & permeability characteristics of the reservoir. The final approach is the chemical stimulation. This is done by injecting HCl or HFl. [N. Gholizadeh Doonechaly]

There is another aspect that can improve the amount of pass ways in a system. Faults that show conductive behaviour and therefore increase the permeability might improve the geothermal feasibility. However, if the fault creates a barrier in the reservoir it might show decreased permeability and will lower the geothermal feasibility. [12]

Faults do not occur in one straight line but have small sub-faults around them. The level of brittle area determines the flow and porosity of that area. In the reservoir, this brittle area is clearly witnessed around the fault. This can be seen in figure 27. This area of permeable brittle in the fault plane can just be the area in which the water flow will propagate

The presence of this fault, together with the brittle areas could potentially improve the conductive behaviour of the layer and therefore increase the feasibility of the geothermal project. [12]

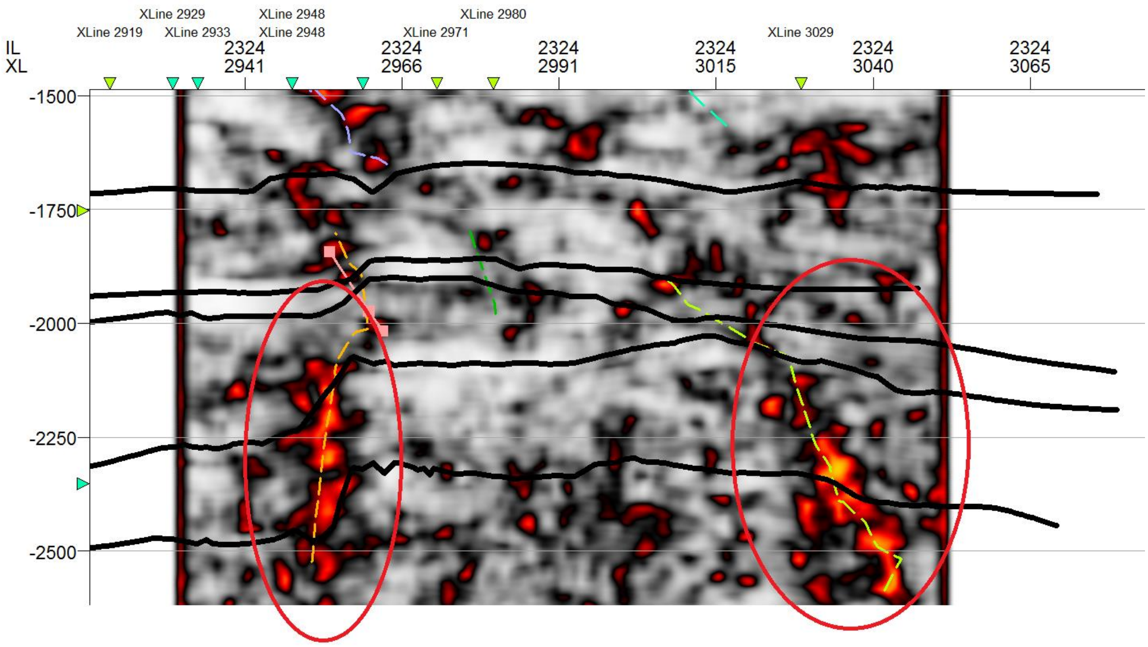


Figure 27 – Red zones show the brittle, fracture zone around a fault [variance, Petrel]

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5. UNCERTAINTY ESTIMATION

The uncertainty estimation of a reservoir located 3 to 4 km within the subsurface can be quite significant. It is important to find the boundaries of the uncertainty to generate the extreme scenarios for the volume and flow calculations. There are a couple of uncertainties that have to be taken into account. These are described in the following section.

5.1 Seismic uncertainty

The 3D seismic dataset has an uncertainty. The lines that are visualized on the seismic represent a bundle of 30 to 50 meters thick within the subsurface. Some layers in our project are almost 400 meters thick and are represented with only a few lines.

5.2 Uncertainty estimation of the Triassic layer thickness

The layer of interest is the Triassic layer. In order to determine the uncertainty in the Triassic layer, the difference in meters is calculated. This is done by looking at the location where the maximum deviation in the layer thickness is observed between the Top Trias and the Top Zechstein. Further indicators for the estimation of uncertainty, such as the standard deviation of the mean thickness can be found in Appendix 10.6.

CONCLUSION

In conclusion, the Triassic layer has been mapped using all of the techniques described in this paper. First, a literature study regarding the regional geology in the West-Netherland Basin was performed. This was essential to understand what geological structures could be present in the area and when tectonic movement took place in the geologic history.

Using Petrel, ant-tracking and variance cubes, all faults in the 3D-set were tracked. Characteristic structures present in the data related to either extension and inversion such as the horst-graben combination and flower faults were identified. This resulted into a better insight of the fault anatomy and therefore could give a better interpretation of the potential of geothermal energy production in the Triassic reservoir.

The clear visualization of the layers above and below the Triassic, gave the possiblity to map the thickness of the Triassic throughout the whole cube. Each layer was linked to either a pre-/syn- or post-rift period. Faults were described as either extensional faults or as faults caused by inversion.

Furthermore, all major faults in the Triassic are tracked which are necessary in order to construct an overall flow model of this geothermal potential layer. Since there is no information known about the overall permeability of the sandstone in the Triassic layer, the faults will have a very important role in the stimulation of the flow through the reservoir.

The reservoir shows to have a good potential for the use of geothermal energy. A few aspects have to be looked at to fully understand all the geothermal characterisitcs in the Triassic layer. These are the permeability, the porosity and the path ways.

At last, a summation of all possible uncertainties during this process was made. By estimating the maximum deviation in the Triassic layer thickness, an overall quality of the layer interpretation can be assigned to the final result.

All of the previous actions and choices regarding the overall interpretation of the three-dimensional dataset have eventually contributed to the final result, which is a 3D modelled interpretation of the potential geothermal Triassic layer.

RECOMMENDATIONS

Recommendations for the extraction of geothermal energy in the West Netherlands basin will be split into separate parts.

First of all, we advise *TriasWestland* to take a deeper look into the fault zone. As told by Dr. N. Gholizadeh Doonechaly the permeability range of the reservoir is very wide. From 1 up to 100 MD. 1 MD would mean there is no flow possible at all and the extraction would fail. However >60 MD is a good permeability value. According to Dr. N. Gholizadeh Doonechaly, it is possible that the faults and their brittle/breaking zone might just be the only path that the water will flow along. Doing an extra investigation into the fault zone of the area of interest might just give a belter estimation of the extraction level.

Moreover, we would advise to first do more research to the permeability of the specified layer as it is the most important factor to determine the flow model. By knowing if a reservoir has a constant higher permeability the uncertainty of the drillings, and thus the financial uncertainty, would go down.

Finally, important is to take a look into the risk management when applying methods for stimulation of the reservoir. If for example hydraulic stimulation is used, fault slippage might occur. Micro-seismic movements can occur and even create macro-seismic movements, which could lead to earthquakes. It is important to assess the mechanical stability of the reservoir, the stability of the fault and the interaction of the fault with the pressure system.

DISCUSSION

The findings made in this report contribute to the better understanding of the Trias layer in the West Netherlands Basin. As seen in the report of the contractor, the faults and layer interpretation in this report does deviate from the contractor report. This could indicate that there is an error margin in the report of the consulting company and would imply to take a good look at both reports before making the final decisions. Especially on the field of geology and fault/ horizon interpretation this report might be more informative than the one seen before.

By supplying this report, we hope one will get another view on the geology and model boundaries in order to create a better estimation for the final extraction model.

As discussed in the recommendations, further research into this matter will have to be done to conclude the conductivity of the fault, layer and seismics.

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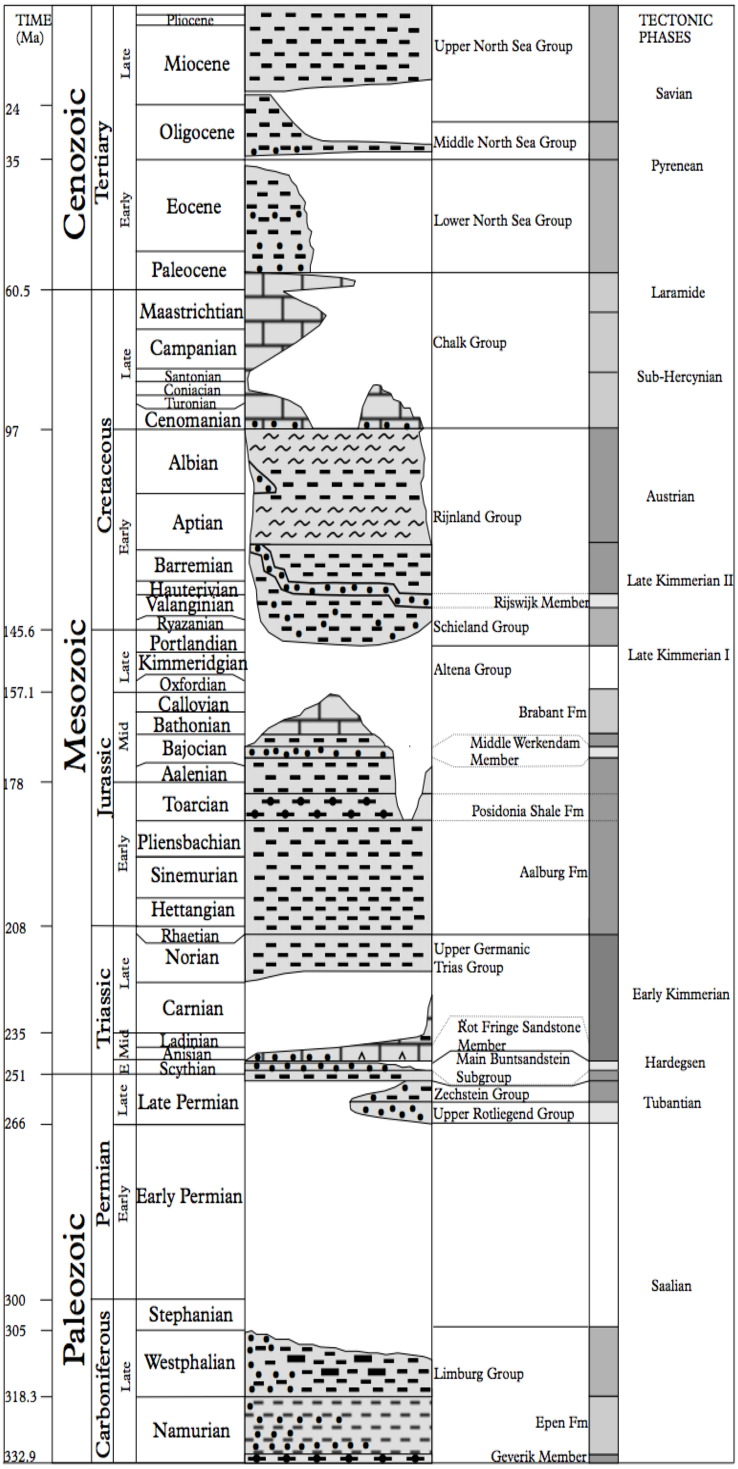
10. APPENDIX

10.1 Depositional history West Netherlands Basin



10.2 Borehole data LIR-45

Basisgegevens boorgat	
Naam :	DE LIER-45
Code :	LIR-45
Coördinaten (x, y in UTM31, ED50 formaat)	584186 , 5760229
Lat/Long (°)	51.98526773 , 4.22585304
Aangeleverde coordinaten	75134 , 444647 (RD)
Diepte in meter t.o.v. :	Rotary Table
Einddiepte (m) :	3915 M
Verticale positie van Rotary Table :	7.61 meter t.o.v. NAP
Vorm boortraject :	Gedevieerd
Deviatie in de x-richting :	-139.49
Deviatie in de y-richting :	-193.19
Werkelijke diepte (TVD) in m :	3899.62
Opdrachtgever :	NAM
Begindatum	19-12-1981
Einddatum	28-mrt-1982
Type boring :	Exploratie koolwaterstof
Resultaat van de boring :	Olie en gas
Status :	Abandoned

LIR-45 DATA	**Starting depth**	**Ending depth**
Upper North Sea Group	0	410
Rupel Formation	410	507
Ieper Member	507	680
Basal Dongen Sand Member	680	692
Landen Clay Member	692	735
Ommelanden Formation	735	1135
Texel Formation	1135	1173
Texel Greensand Member	1173	1183
Upper Holland Marl Member	1183	1292
Middle Holland Claystone Member	1292	1400
Holland Greensand Member	1400	1498

Lower Holland Marl Member	1498	1626
De Lier Member	1626	1709
Eemhaven Member	1709	1755
IJsselmonde Sandstone Member	1755	1770
IJsselmonde Claystone Member	1770	1855
Berkel Sandstone Member	1855	1900
Berkel Sand-Claystone Member	1900	2020
Rijswijk Member	2020	2084
Alblasserdam Member	2084	2433
Upper Werkendam Member	2433	2471
Middle Werkendam Member	2471	2485
Lower Werkendam Member	2485	2550
FAULT	2550	2550
Aalburg Formation	2550	2871
Sleen Formation	2871	2898
Dolomitic Keuper Member	2898	2926
Red Keuper Claystone Member	2926	2938
Upper Muschelkalk Member	2938	2940
Middle Muschelkalk Marl Member	2940	2954
Muschelkalk Evaporite Member	2954	2960
Lower Muschelkalk Member	2960	2993
Upper Röt Fringe Claystone Member	2993	3012
Röt Fringe Sandstone Member	3012	3028
Lower Röt Fringe Claystone Member	3028	3037

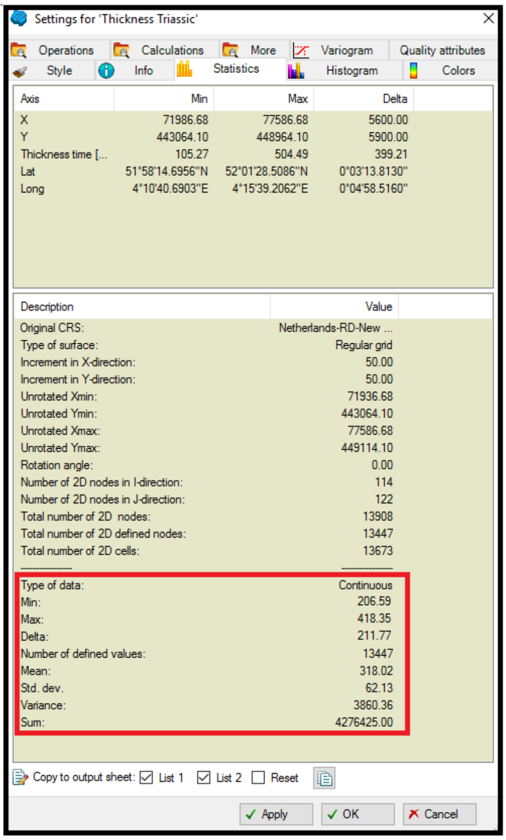
Solling Claystone Member	3037	3040
Basal Solling Sandstone Member	3040	3045
Hardegsen Formation	3045	3085
Detfurth Claystone Member	3085	3098
Lower Detfurth Sandstone Member	3098	3105
Upper Volpriehausen Sandstone Member	3105	3165
Lower Volpriehausen Sandstone Member	3165	3223
Rogenstein Member	3223	3312
Main Claystone Member	3312	3388
Zechstein Upper Claystone Formation	3388	3391
Slochteren Formation	3391	3400
Strijen Formation	3400	3766
Hellevoetsluis Formation	3766	3881
Maurits Formation	3881	3915

10.3 Velocity model data

Base		Correction		Model					
Surface	Top om	Well tops	Top om	V=V0+K*Z	V0: Constant	2358	K: Constant		-0.864
Surface	Top Hol	Well tops	Top Hol	V=V0+K*Z	V0: Constant	2120	K: Constant		-0.508
Surface	De Lier	Well tops	Top De	V=V0+K*Z	V0: Constant	2174	K: Constant		-0.441
Surface	Top Alb	Well tops	Top Alb	V=V0+K*Z	V0: Constant	2334	K: Constant		-0.635
Surface	Top We	Well tops	Top We	V=V0+K*Z	V0: Constant	2221	K: Constant		-0.738
Surface	Posido	Well tops	Top Po	V=V0+K*Z	V0: Constant	2221	K: Constant		-0.738
Surface	Top Aal	Well tops	Top Aal	V=V0+K*Z	V0: Constant	2221	K: Constant		-0.738
Surface	Top Tri	Well tops	Top Ke	V=V0+K*Z	V0: Constant	3143	K: Constant		-0.571
Surface	Top Ze	Well tops	Top Ze	V=V0=VInt	V0: Constant	3800			

Velocity model data [Petrel]

10.4 Indicators for the uncertainty estimation of the Triassic layer


Settings for 'Thickness Triassic'

Operations | Calculations | More | Variogram | Quality attributes | Style | Info | Statistics | Histogram | Colors

Axis	Min	Max	Delta
X	71986.68	77586.68	5600.00
Y	443064.10	448964.10	5900.00
Thickness time [...	105.27	504.49	399.21
Lat	51°58'14.6956"N	52°01'28.5086"N	0°03'13.8130"
Long	4°10'40.6903"E	4°15'39.2062"E	0°04'58.5160"

Description	Value
Original CRS:	Netherlands-RD-New ...
Type of surface:	Regular grid
Increment in X-direction:	50.00
Increment in Y-direction:	50.00
Unrotated Xmin:	71936.68
Unrotated Ymin:	443064.10
Unrotated Xmax:	77586.68
Unrotated Ymax:	449114.10
Rotation angle:	0.00
Number of 2D nodes in I-direction:	114
Number of 2D nodes in J-direction:	122
Total number of 2D nodes:	13908
Total number of 2D defined nodes:	13447
Total number of 2D cells:	13673
Type of data:	Continuous
Min:	206.59
Max:	418.35
Delta:	211.77
Number of defined values:	13447
Mean:	318.02
Std. dev.	62.13
Variance:	3860.36
Sum:	4276425.00

Copy to output sheet: List 1 List 2 Reset

Apply OK Cancel