EBN Internship Report

Anja Dijkhuizen
3026051

Part I:
Basin analysis of Tertiary deposits in the Gorredijk concession using 3D seismics and well data

Part II:
Extra Work

Supervision:
Maarten-Jan Brolsma, Guido Hoetz, Fokko van Hulten; EBN
Prof. Dr. Chris Spiers; UU

EBN
September – November 2011

Part I:

Basin analysis of Tertiary deposits in the Gorredijk concession using 3D seismics and well data

Basin analysis of Tertiary deposits in the Gorredijk concession using 3D seismics and well-data

EBN-Internship
Anja Dijkhuizen

The 1000m thick Tertiary sequence present in the Dutch onshore subsurface can hold prospective reservoirs of shallow gas. In this report, an inventory of Tertiary reservoirs is made for the Gorredijk concession (Friesland, northern Netherlands). By using well, log and seismic data, the structural elements of the studied area are investigated. Thickness maps of the three Tertiary groups show a thickening trend towards the west. However, individual differences exist within the groups, implying basin shifts through the Tertiary Period. Gas migration would therefore be to the east, but timing is important due to the differences within each group. Indications of an erosive surface in the lower Tertiary Brussels Sand Member give more insight in the different Alpine phase pulses during the Tertiary. A large erosive event during the Miocene has eroded parts of the Upper Tertiary deposits. The associated angular unconformity, the 'Mid Miocene Unconformity', is shown not to be of tectonic but of sedimentary origin. Large Neogene delta foresets from the Eridanos deltaic system onlap on the Mid Miocene Unconformity. These delta deposits are so far only described to be found offshore. No closures from structural maps of key well tops and related seismic reflectors are found within the Tertiary deposits. The only prospective formation is the Lower Tertiary 'Basal Dongen Tuffite Member', which is known as a producing formation in areas around the studied area.

1. Introduction (Aims and Goals)

Since the discovery of hydrocarbons in the 1960's, the Netherlands and the North Sea area have been extensively studied. Seismic surveys, exploration and production well, log data and samples provide the information which is needed to understand the Dutch subsurface, both offshore and onshore. The Gorredijk concession (totally covering an area of 50x40 km in southern Friesland, see Figure 1) has been drilled over the last few years by the Canadian company Vermilion and unexpected gas bearing sands were found in the Cretaceous Vlieland Sandstone deposits (P.M. Gorissen, EBN report 2011). To extend this detailed seismic study of the Gorredijk concession the thick (about 1000 meter) Tertiary deposits present in this part of the Dutch subsurface are studied and an inventory of Tertiary reservoirs is made in this study. The alternation of clays and sands which characterize the Tertiary deposits in this area, hold several prospective shallow gas reservoirs. Seismic interpretation, well and log data are used to perform a detailed basin analysis to unravel the structural development of the Tertiary in the area around the Friesland Platform. Migration paths of gas which can be present in the underlying formations are reconstructed with this information. With the use of seismic structural maps, isochrons, seismic profiles, well interpretation and known geological data from the literature a detailed description of the structural elements for each important group in the Dutch Tertiary Period is given.

2. Geological Setting

2.1 Main overview

The Gorredijk concession is located on the Friesland Platform in the North of the Netherlands. The Friesland Platform is surrounded by the Vlieland Basin, the Lower Saxony Basin, the Groningen High and the Texel-IJselmeer High (see Figure 1). A complete stratigraphic sequence is present, except for the Triassic and Jurassic deposits which are very thin or not present at all.

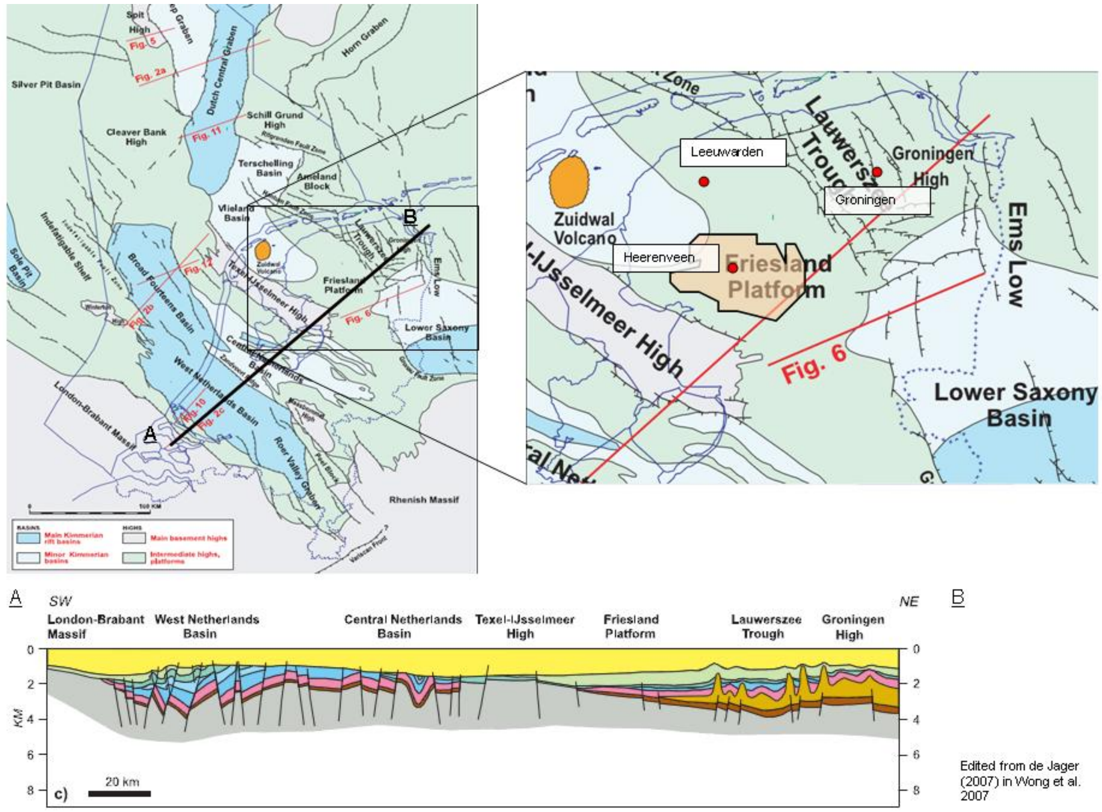


Figure 1: Location map of the studied area (outline indicated in orange) in the Friesland Platform. Surrounding structural elements are indicated in bold. Geological profile A-B runs from the SW to NE showing the presence of Zechstein salt (orange formation in the profile) at the northern side of the Texel-IJselmeer High. Jurassic deposits (blue) are not present at the Friesland Platform and Triassic (pink) deposits are relatively thin.

On the Friesland Platform the Permian deposits are relatively thin (100-200 meters) compared to the Lower Saxony Basin in the east. Movements of Zechstein salt, mainly during the Tertiary, caused this thinning of younger deposits. Several salt domes and ridges occur over the entire northern Netherlands, influencing the overlying strata. In the Friesland Platform area the Zechstein is generally directly overlain by Cretaceous deposits (see profile A-B in Figure 1). The Variscan orogeny caused origination of fault systems affecting the Carboniferous and Permian layers with a NW-SE trend (Geluk, 2007). These systems were reactivated during later tectonic phases. Normal faulting as a result from extension characterizes the Kimmerian deformation phase (break-up of the supercontinent Pangea), which episodic character led to several unconformities. Several smaller depocenters formed such as the Broad Fourteens Basin, The Central Netherlands Basin, the Lower Saxony Basin and the Vlieland Basin. Uplift of the basins occurred during the Alpine phase, which is related to at least three inversion pulses in the Netherlands (de Jager, 2007).

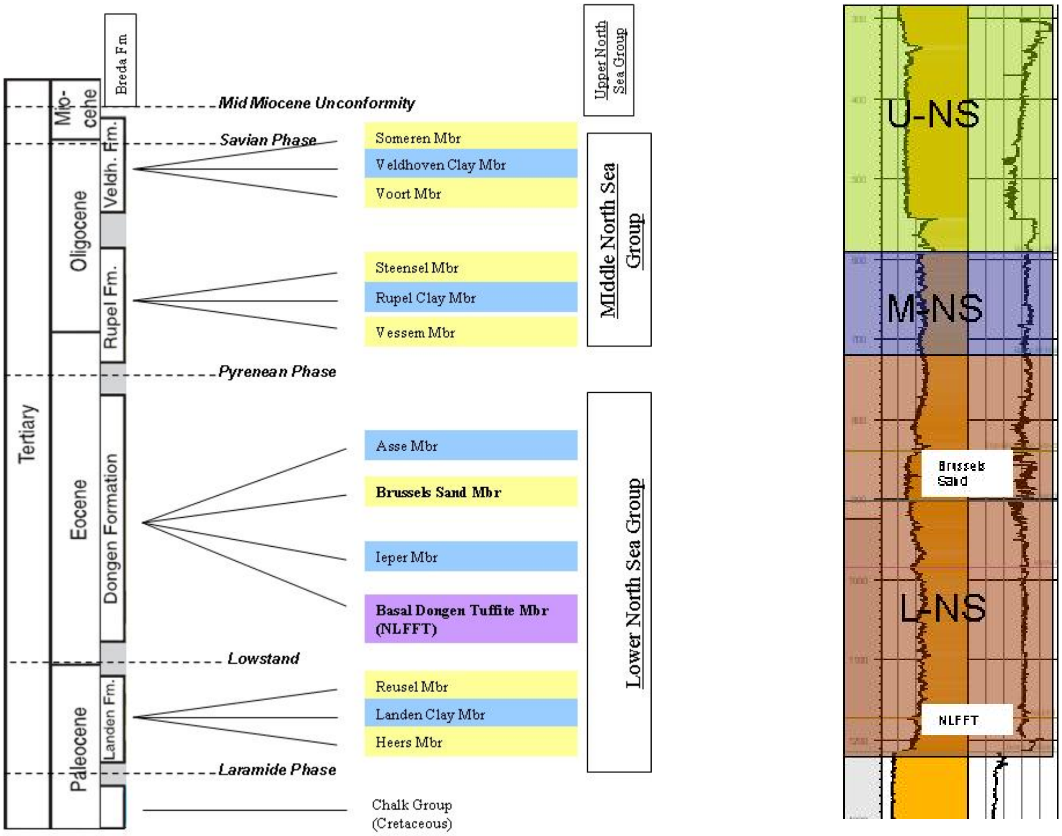


Figure 2: Chronostratigraphy of Tertiary formations around the Friesland Platform at the left. Blue formations consist mainly of clay, yellow formations of sand. Member NLFFT is indicated in purple. Unconformities of interest are indicated. Edited from Wong (2007) and Van Adrichem Boogaert & Kouwe (1997). Right: GR (in yellow) and DT (black line) logs from Petrel of well STN-01 showing the three Groups and two important elements in the L-NS. Top of U-NS (and Pleistocene deposits) is not included in this log. Same log will be placed in section 4 next to each Group description.

2.2 Tertiary setting

The Tertiary deposits in the Netherlands are divided in three groups: the Lower North Sea Group (L-NS), the Middle North Sea Group (M-NS) and the Upper North Sea Group (U-NS) (Van Adrichem Boogaert & Kouwe, 1997, see Figure 2). The base of the L-NS is separated from the underlying Chalk Group by the first Alpine pulse in the Tertiary: the Laramide unconformity. This unconformity characterizes the erosion of formations part of the late Chalk Group (Danian, Houthem and Ekofisk Formations). A lowstand is followed by a tuffite which can be easily recognized in well and log data. This Basal Dongen Tuffite Member (NLFFT) is a known gas reservoir around the studied area in the field Marknesse and De Wyk (personal communication F.F.N. van Hulten, public data ‘nlog’). The main part of the Dongen Fm deposited after the NLFFT, consists of clay material with some regression events (mainly in the Ieper Mbr). A major drop in sea level caused deposition of a thick sandstone member: the Brussels Sand Member. More distal this member has a more marly composition. The Pyrenean phase, the second Alpine pulse in the Tertiary, has eroded parts of the Brussels Sand Member in the SW offshore part of the Netherlands (de Lugt, 2007). In the area of interest of this study, this sandstone member is present and good to recognize on seismic data. Base of the M-NS is associated with the Pyrenean phase at the Eocene-Oligocene boundary. Consequently the Vessem Member, at the base of the

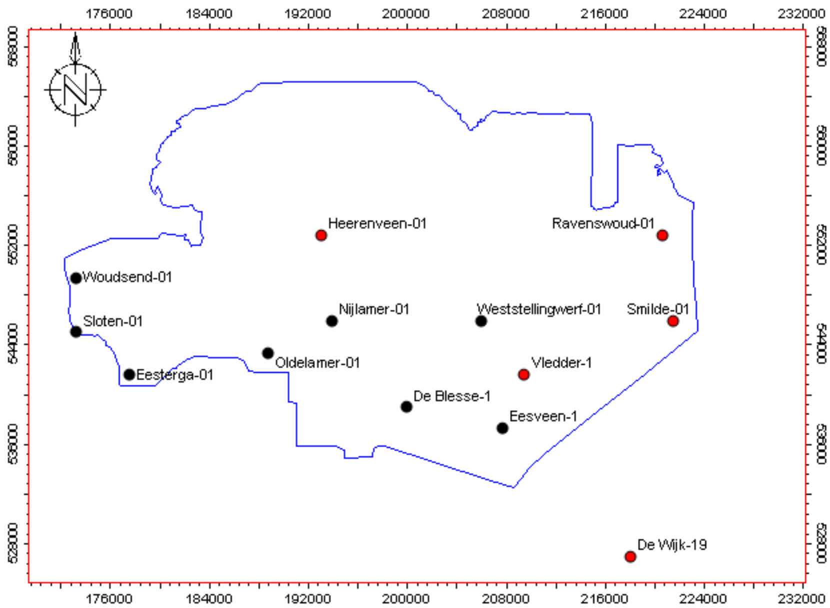


Figure 3: Map of the outline of the seismic cube of the studied area. Coordinates are indicated around the box. Used wells are shown with in black the wells used in Petrel and in red the wells of which the composite logs have been used for correlation.

M-NS, is generally not deposited (de Lugt, 2007). Regional uplift and a globally low sea level resulted in erosion of the Veldhoven Formation at the end of the Oligocene. Subsidence during the Neogene caused erosion during the Savian phase, which characterizes the base of the U-NS. No significant inversion can be demonstrated in the Netherlands (de Jager, 2007). However, de Lugt (2007) suggests movements during the Savian phase in the Broad Fourteens Basin. In the southern part of the Netherlands, the U-NS Breda Formation is characterized by delta foresets, deposited in a shallow-marine environment. This formation unconformable overlies the older strata (Wong et al., 2007) but is hardly present in the studied area. Associated with the Savian phase is the 'Mid Miocene Unconformity'(MMU), a sequence boundary visible on seismic data of the Netherlands (de Lugt, 2007). This angular unconformity at the MMU suggests a tectonic cause, however, Wong et al. (2007) note that the MMU is an onlap surface for Neogene deltaic sediments. These deltaic systems are possibly part of the Eridanos fluvio-deltaic system located in the north, which is of big influence on the North Sea Basin during the Neogene (Overeem et al., 2001). See extra work at the end of this report for a short discussion on these Neogene delta deposits.

3. Methods

For 3D seismic interpretation an in-house Petrel project is used (Gorissen, 2011) with data from both EBN and TNO projects (Figure 3). Interpreted Tertiary reflectors are shown in the x-line cross section of Figure 4. Interpretation is done by tying correlated well tops to the seismic cube. This is based on the assumption that reflectors follow bedding planes which are isochronous. Therefore reflectors represent time lines. From interpreted reflectors surfaces are created within Petrel and a smoothing is performed to exclude errors introduced during 'autotracking'. Several check loops resulted in high quality maps for each reflector. Well logs, headers and deviations in the existing project are gathered from public data (NLOG), TNO projects and from Vermilion. It is beyond the scope of this study to focus on any time-depth relations; this must be taken into account and reflectors are all near well top representations. To extent the existing data composite logs from public data (NLOG) are analyzed by hand. These are used to support the well correlation performed in Petrel. Supporting geological knowledge of the Tertiary is gained during personal sessions at EBN.

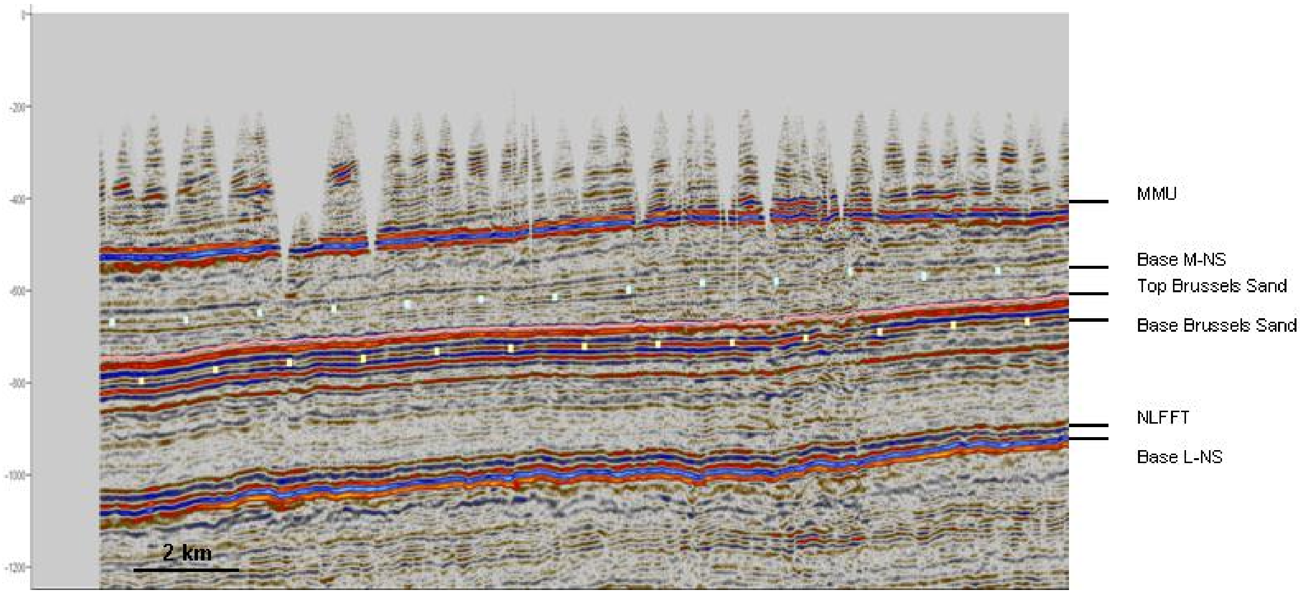
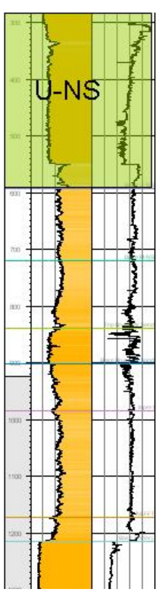


Figure 4: Seismic x-line cross section (W-E) showing the interpreted reflectors with their near correlating well tops.

4. Results

The reflector which is defined as the base Tertiary is mapped throughout the whole seismic cube within the studied area. Figure 5 shows the structural map constructed from this reflector. The inverse of this map gives the isochron for the base Tertiary from which the thickness of the whole Tertiary sequence can be found (Figure 6). In Figure 4 it is clear that the Pleistocene is not visible on seismics. The assumption is made that the Pleistocene deposits are not of influence on the total Tertiary thickness. A thickening trend of the Tertiary towards the west is reflected in the intensity of the brown colors in Figure 6. In the following sections each group of the Tertiary is described to find possible differences in structures and thicknesses for individual units, compared to the total Tertiary.



4.1 Upper North Sea Group

The structural map from the reflector which is correlated with the Mid Miocene Unconformity (Figure 7) shows a deepening trend towards the west: the reflector is present at deeper levels in the west than in the east. Presence of closures in the U-NS (seen as closed contour lines in the structural map) is not likely. The gradual trend of the structural map indicates no large influence of faults or halokinesis on the MMU. Well data combined with seismic data indicate that the base of the U-NS is defined by the MMU for almost the entire area. Therefore this reflector is used as lower boundary for the isochron map for the U-NS (Figure 8). This map does not show any large deviations from the isochron map of the total Tertiary. In the SW a small amount of U-NS strata is present below the MMU. This can be seen from the structural map of the base U-NS (Figure 9): the reflector is not present in most parts of the area. At the eastern end of this structural map the MMU overlies the reflector which is named base of the U-NS (Figure 10). Neogene delta lobes onlapping the MMU can be clearly recognized in Figure 10.

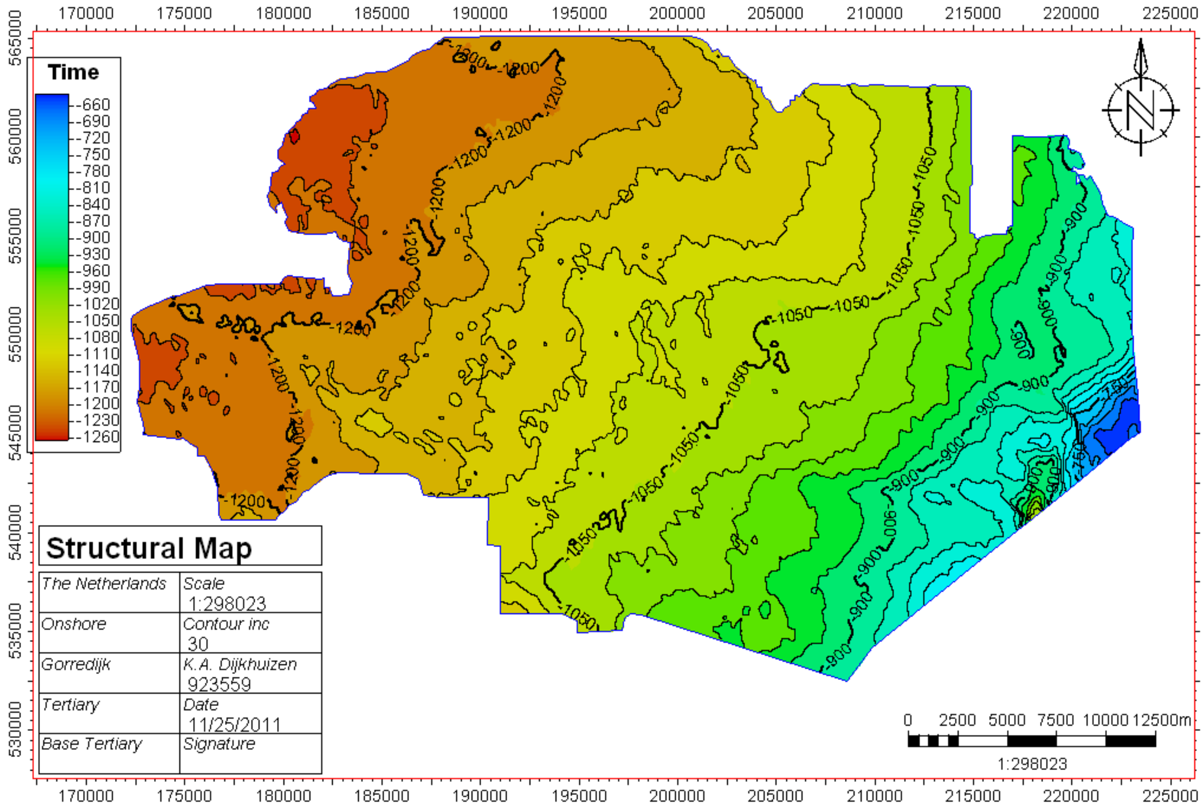


Figure 5: Structural map composed of the base Tertiary based on seismics. Smoothing has been applied to exclude interpretation and seismic errors. Values are in time.

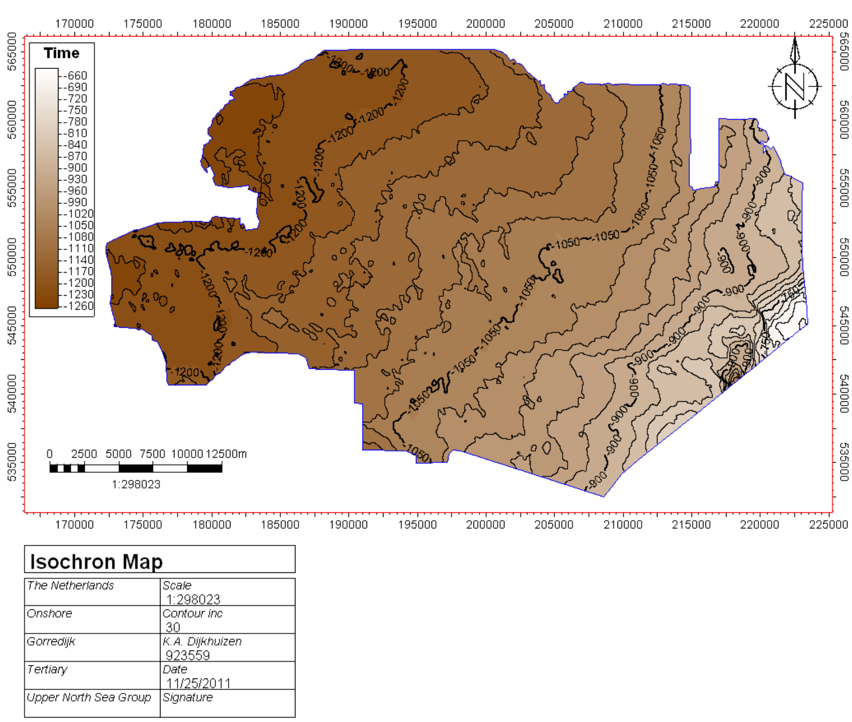


Figure 6: Total Tertiary thickness map (in time). Note the negative values due to using base Tertiary reflector as only input of the map. Thick deposits are in brown, thin in white. A clear thickening trend to the west can be recognized. Maximum value is 1260 ms.

Pleistocene deposits, when present, are included in this map.

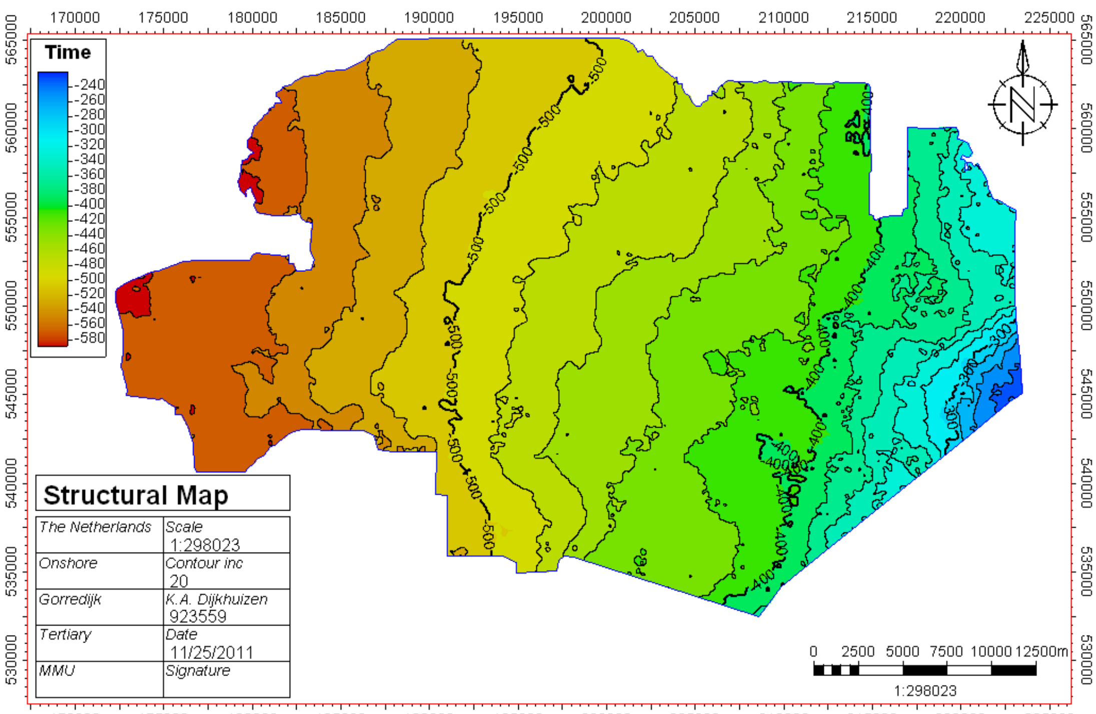


Figure 7: Structural map composed of the Mid Miocene Unconformity based on seismics. Smoothing has been applied to exclude interpretation and seismic errors. Values are in time.

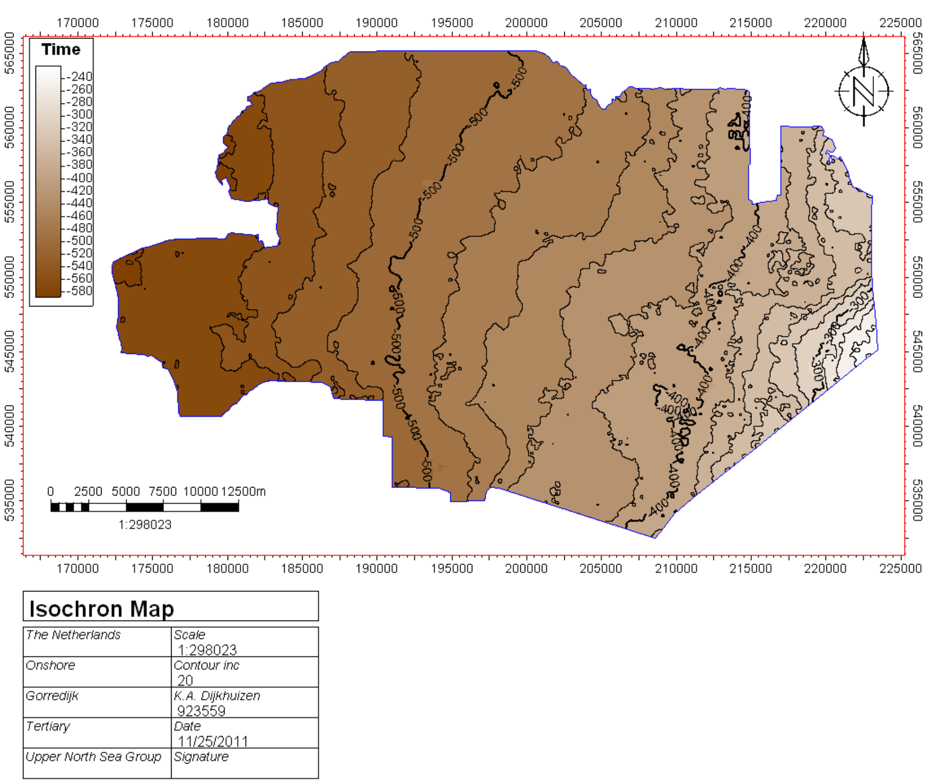


Figure 8: MMU thickness map (in time). Note the negative values due to using MMU reflector as only input of the map. Thick deposits are in brown, thin in white. The thickening trend is the same as for the total Tertiary: to the west. This suggests a strong influence of the U-NS Group on the total Tertiary characteristics. Maximum value is 580 ms (including Pleistocene deposits, if

present).

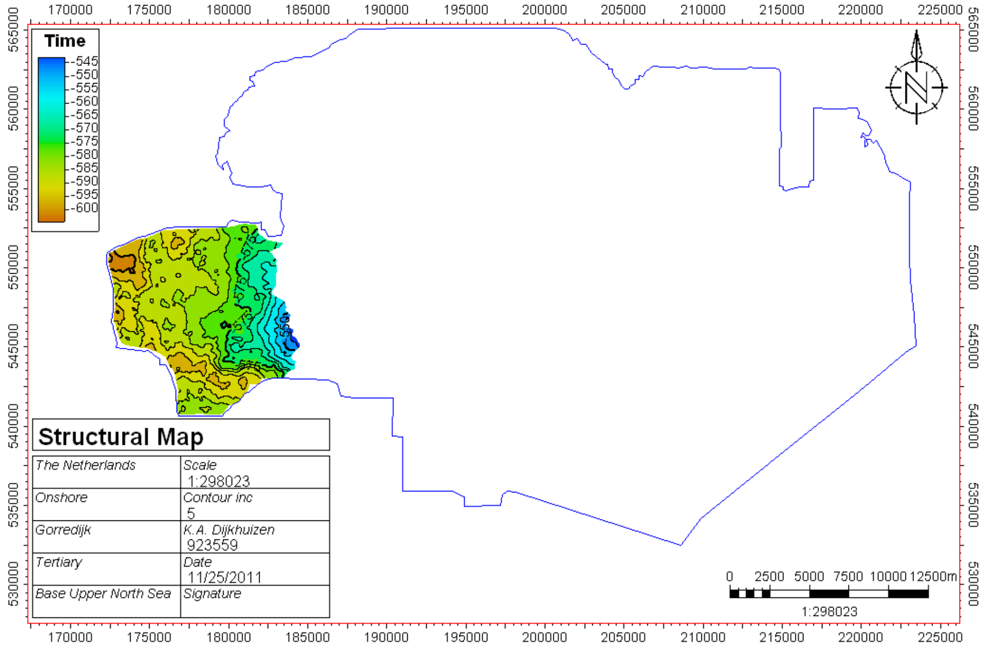
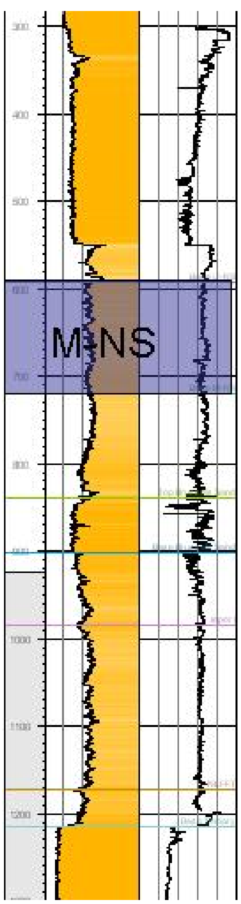


Figure 9: Structural map composed of the base U-NS based on seismics. Smoothing has been applied to exclude interpretation and seismic errors. Values are in time. Reflector is only present in the western part of the seismic cube.



4.2 Middle North Sea Group

The Middle North Sea Group has a more uniform character with thicker deposits on the southern and southwestern boundaries of the study area (Figure 11). From a NE-SW seismic profile (Figure 12) through the western part of the area, it is clear that a thickening occurs at the SW boundary of the area, while the strata are mainly parallel: the Middle North Sea deposits are 114 m thick in the NE, and 165 m in the SW. However, it must be noted that the upper boundary in this case is the MMU, not the base U-NS. In the SE-part, the top M-NS is not defined by the MMU reflector but extra reflectors are present. When the Base U-NS is used as the upper boundary for the M-NS a thickness of 120 m is found in the SW part of the area. This implies a difference of only 6 m between the NE and SW in the Middle North Sea Group and it can be considered as a flat uniform layer. Figure 13 shows the structural map of the base M-NS. The trend of the total Tertiary can still be recognized with some minor differences. It must be noted that in the eastern part of the area a small trough is present indicated by the deeper presence of the reflector compared to the area nearby. This trough is related to the high presence of the reflector at the most eastern side (indicated by the dark blue colors). It is known from other studies that a salt dome is present in this part; more salt domes are reported more to the east (see for example map IV of Veendam-Hoogeveen of TNO, 2000 on NLOG, Appendix 1). In the U-NS this character is not found as clearly as in the M-NS, from which a maximum reach of the influence of the salt dome can be stated. See Figure 14 for an example of the salt dome in this seismic cube with related faults.

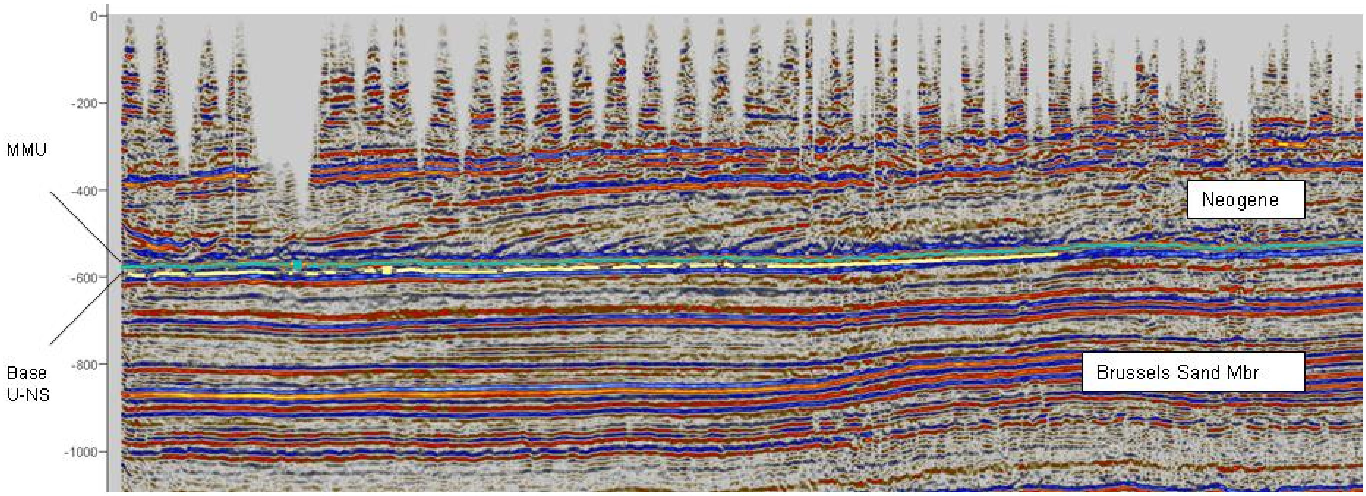


Figure 10: Seismic x-line cross section (W-E) showing MMU reflector (green line) overlying base U-NS reflector(yellow line). Delta lobes in the Neogene can be clearly recognized.

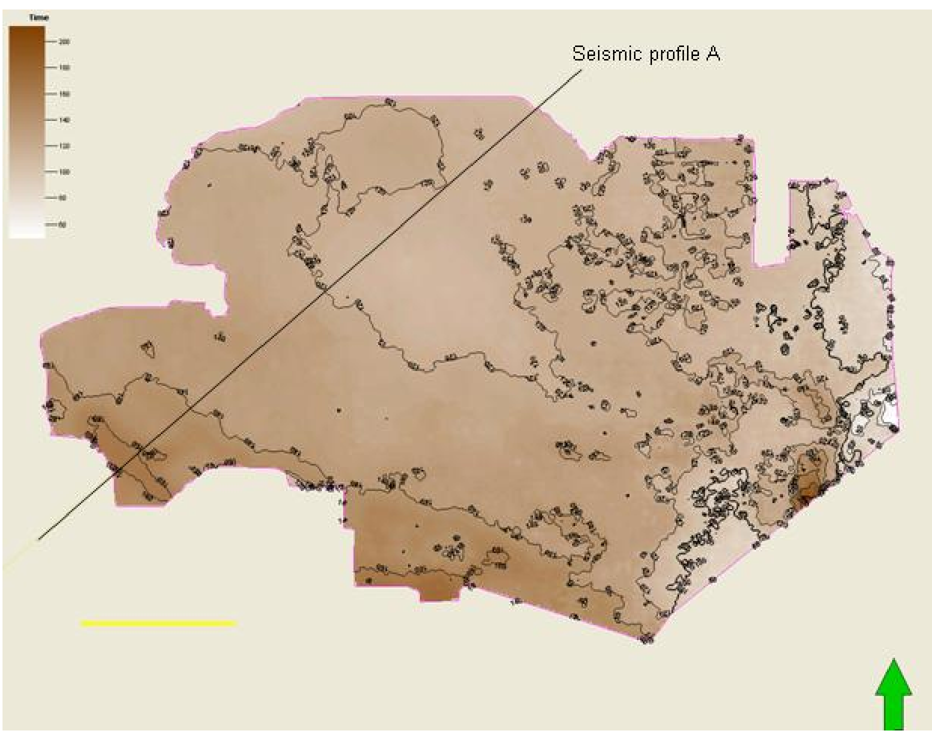


Figure 11: M-NS thickness map (in time). Values are positive due to extracting values of base U-NS from base M-NS to construct the map. Thick deposits are in brown, thin in white. Thickening occurs to the south and near the salt dome in the east, see text for further explanation. Seismic profile A is shown in Figure 12. Maximum value is 200 ms.

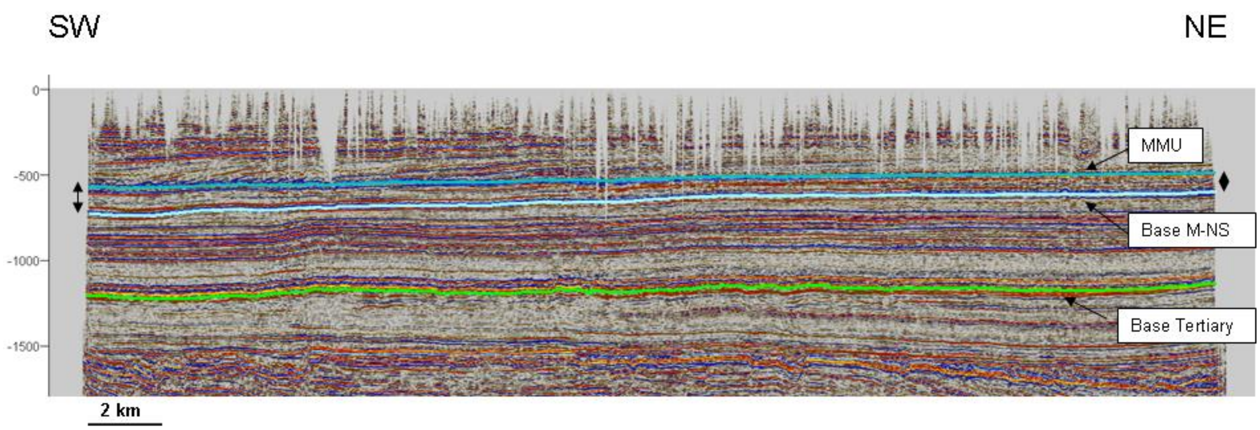


Figure 12: Seismic profile from SW to NE through Tertiary deposits. M-NS Group is situated between MMU and Base M-NS. One can see that the western end (arrow symbol) is thicker than the eastern end (check symbol).

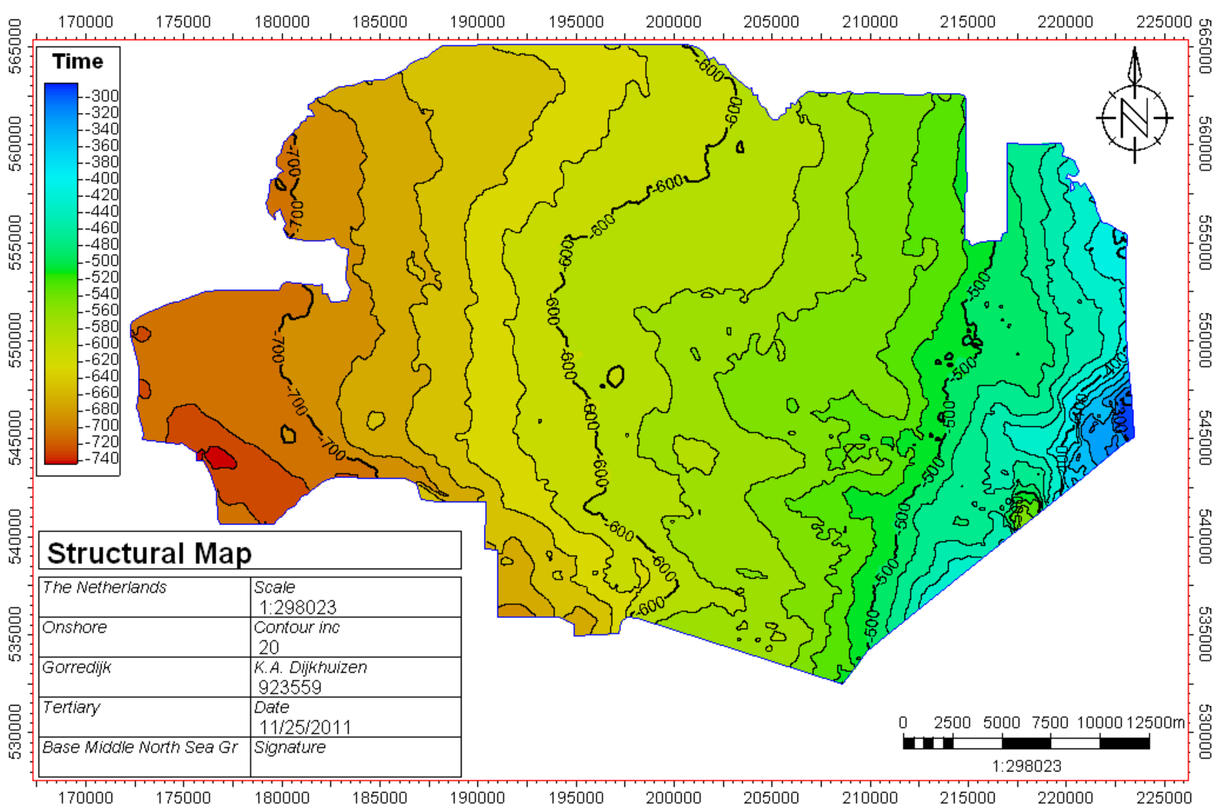


Figure13: Structural map composed of the base M-NS based on seismics. Smoothing has been applied to exclude interpretation and seismic errors. Values are in time.

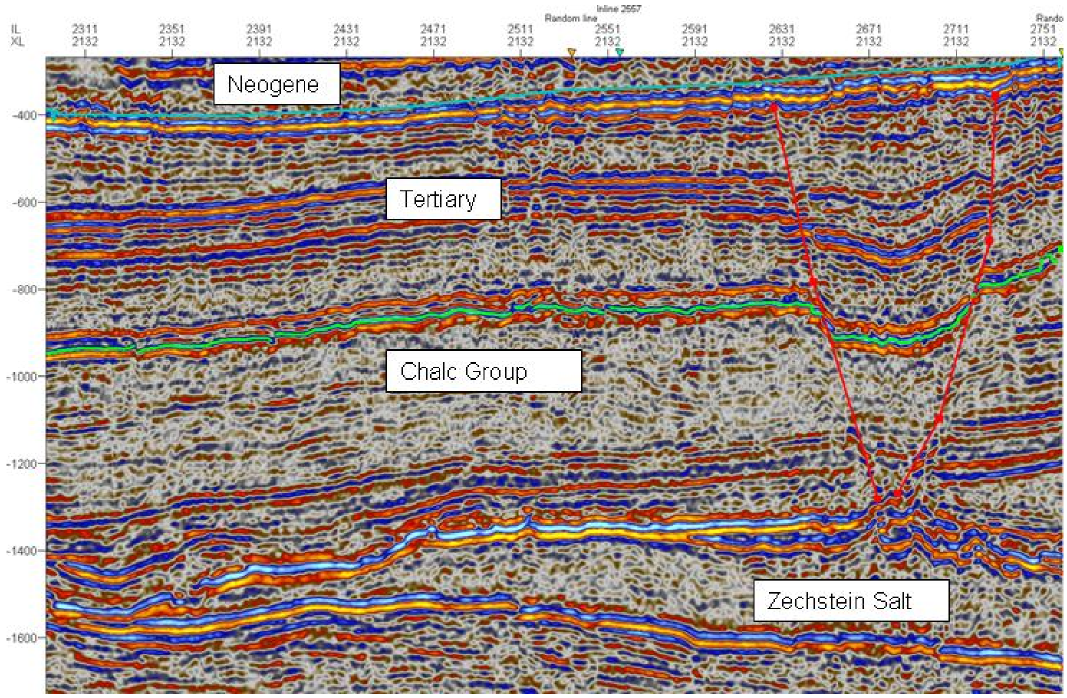
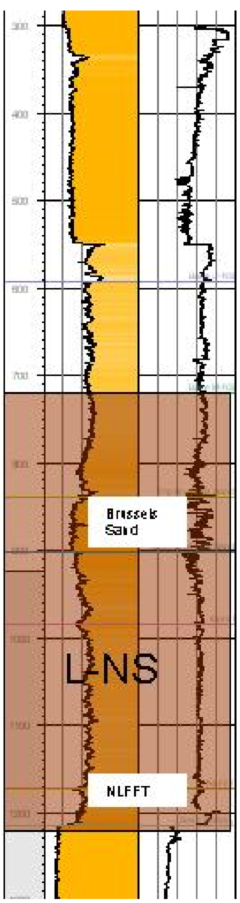


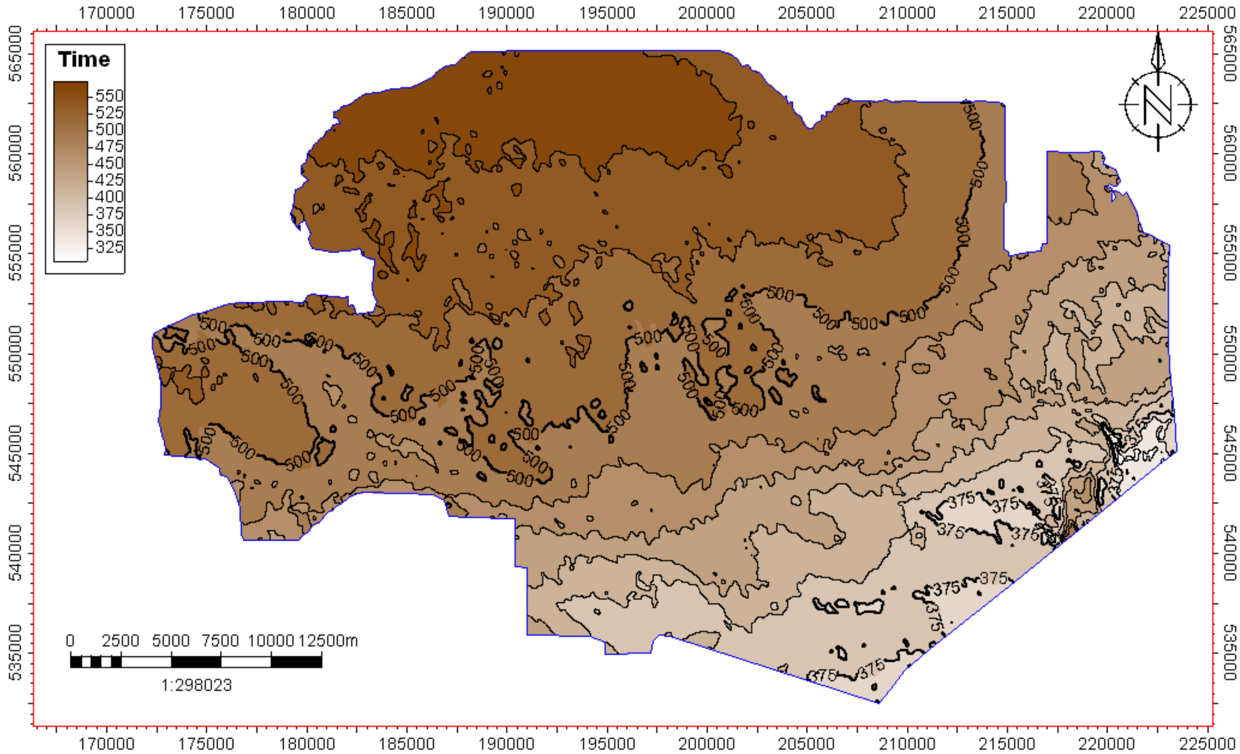
Figure 14: Seismic image (x-line, W-E cross section) of the eastern salt dome with two faults originating at the top of the dome. Smilde Low is situated in between the faults in the Tertiary deposits. Smilde High is located more to the east.



4.3 Lower North Sea Group

In the Lower North Sea Group thick deposits are present in the northwestern part of the studied area: almost twice as thick as in the southeastern part (Figure 15). This implies a small shift compared with the Upper and Middle North Sea Groups. The L-NS is the thickest group in the Tertiary and several important reflectors are interpreted (Figure 16). Individual isochrons of the different formations of the Lower North Sea Group show a shift of the main depocenter through the Lower Tertiary. In the following part these are shown from the base of the L-NS to the top.

The deposits of the Landen Fm show a small, gradual thickening to the west, while the Ieper Mbr sediments (including the tuffite NLFFT) thicken towards the north (Figure 17). In the lower part of the Brussels Sand Mbr no outstanding features are present and the sediments are relatively uniform in thickness. At the top part of the Brussels Sand Mbr however, several isolated areas of accumulated sediments can be distinguished from the isochron (Figure 18). A thin band of deposits exist at the southern boundary, and the thickest package of sediments is present in the SW. This is due to the presence of a high (called here the ‘Oldelamer High’). Two seismic profiles verify this (Figure 19). The total Brussels Sand Mbr isochron is clearly influenced by the upper part, with an overall thickening to the west (Figure 20). The isochron map of the most upper Asse formation of the L-NS is comparable with the isochron of the total Brussels Sand Mbr (Figure 21). All the isochrons of the L-NS members contain the trough and high in the SE above the salt dome. These will be called in this report the ‘Smilde Low’ and ‘Smilde High’, named after well Smilde-01 located near these structures. The Smilde High and Low and the Oldelamer High can all be



Isochron Map	
The Netherlands	Scale 1:298023
Onshore	Contour inc 25
Gorredijk	K.A. Dijkhuizen 923559
Tertiary	Date 11/25/2011
Lower North Sea Group	Signature

Figure 15: L-NS thickness map (in time). Values are positive due to extracting values of base M-NS from base L-NS to construct the map. Thick deposits are in brown, thin in white. During this period of sedimentation the depocenter seems to be positioned in the north where the deposits are thickest. Maximum value is 550 ms .

recognized in the structural maps of both the top and base of the Brussels Sand Mbr (Figure 22). The deepening of the Brussels Sand Mbr towards the NW can be verified with a more detailed look at the reflectors in this member. It is recognized that several reflectors are introduces in the NW part of the area. The first reflector being introduces in the Brussels Sand Mbr has been mapped and the structural map of this reflector is shown in Figure 23. This reflector is not present in the SE part of the area, explaining the thickness differences in this member.
One reflector of big interest is the Basal Dongen Tuffite Member (NLFFT) which is a producing formation in areas around the studied area. Unfortunately no clear closures can be seen in the structural map of this reflector (Figure 24), besides one small prospective closure (Figure 24) which is bounded by faults as can be seen on the seismic data. An amplitude map of the NLFFT shows no highlight at the location of the prospective closure, which is no positive indication for present gas (Figure 26).
.

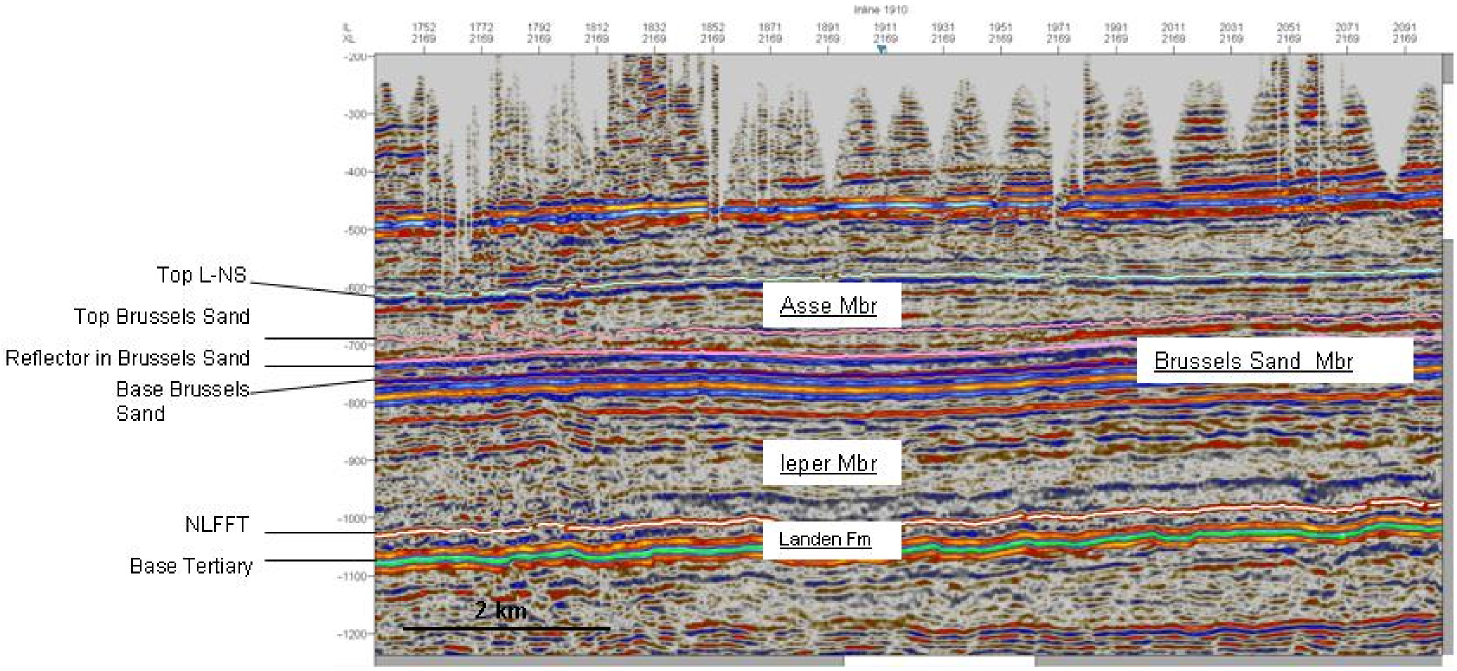


Figure 16: Seismic W-E profile showing mapped L-NS reflectors and main formations and members within the L-NS.

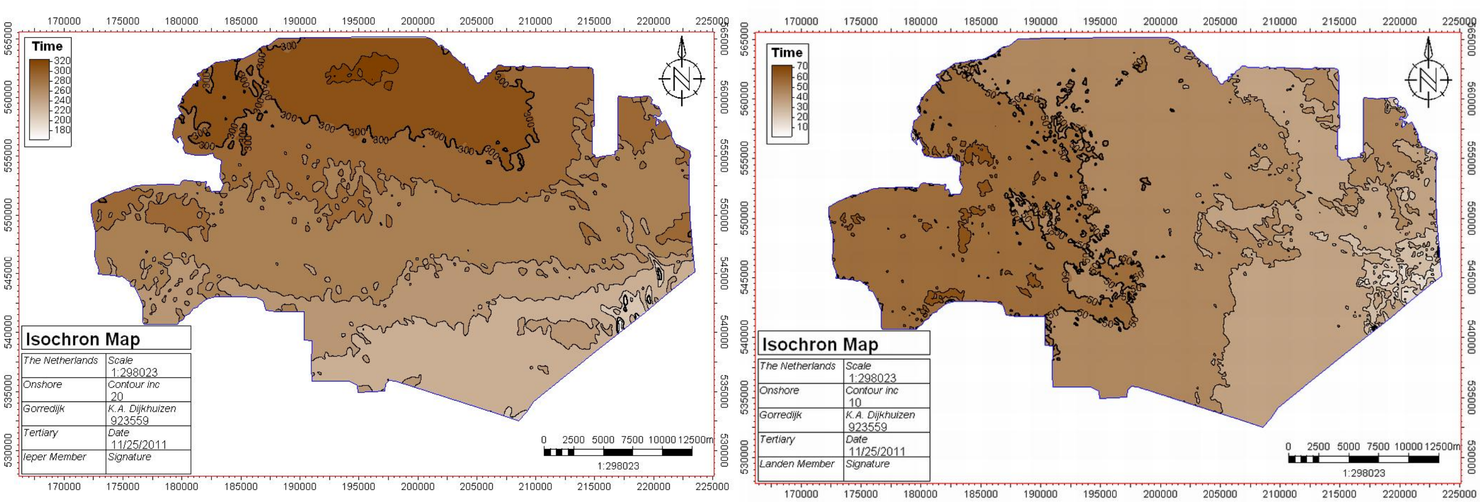


Figure 17: Left: isochron of Ieper Member of the L-NS, showing the same thickening towards the north as seen for the total L-NS. Right: ischron of the Landen Member of the L-NS, showing a shift of the depocenter to the west. Both show positive values due to extraction of reflectors to construct the maps.

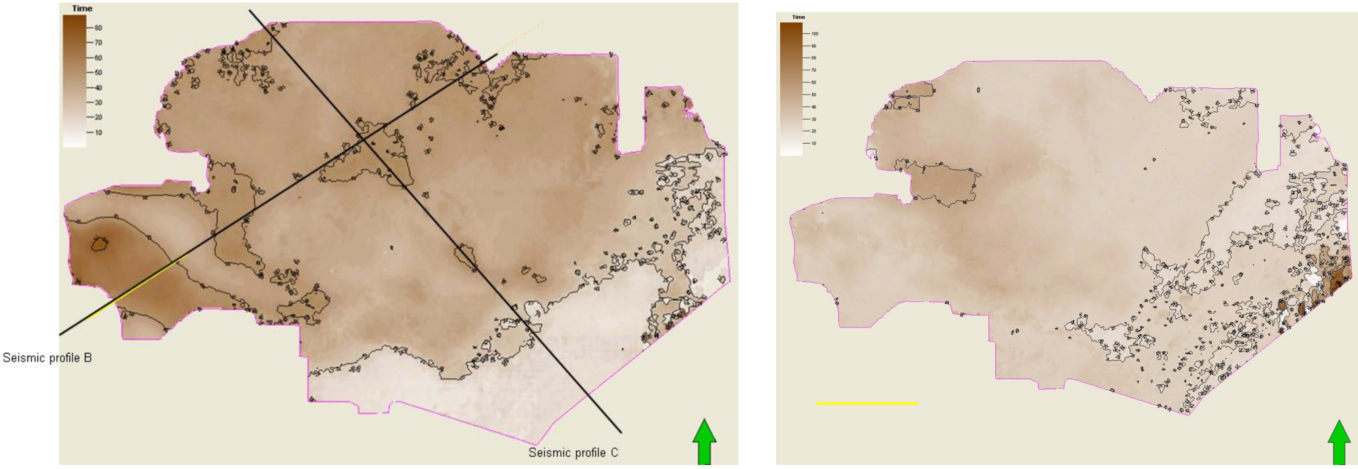


Figure 18: Left: isochron of top part of the Brussels Sand Mbr showing a thickening towards the SW . Right: ischron of the basal part of the Brussels Sand Mb with a more uniform character. Both values are positive due to extraction of reflectors to construct the maps. Positions of seismic profiles B and C are indicated in the left figure.

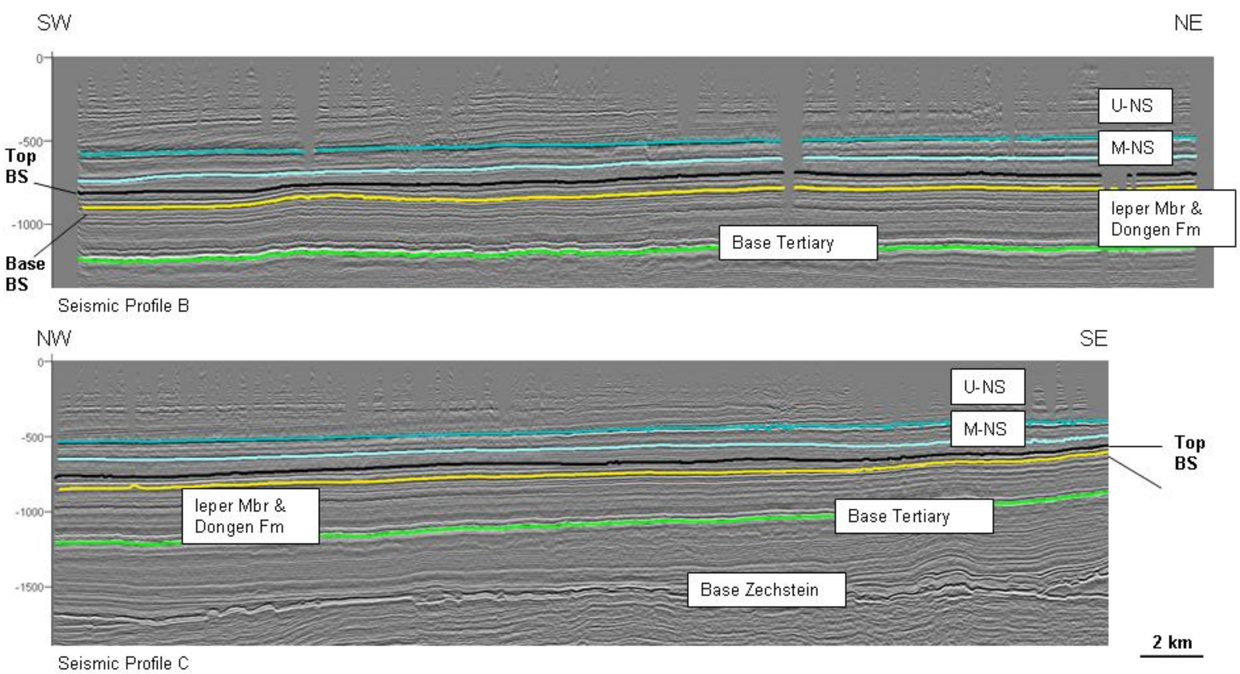


Figure 19: Seismic profiles B and C from Figure 18. In profile B the Oldelamer High is visible up to the Base Tertiary (bright green reflector). In profile C at the SE side the start of t he salt dome is visible in the lower part of the profile and thickening in the middle part of the profile (Oldelamer High) seems only visible in the Brussels Sand (between the yellow and black lines).

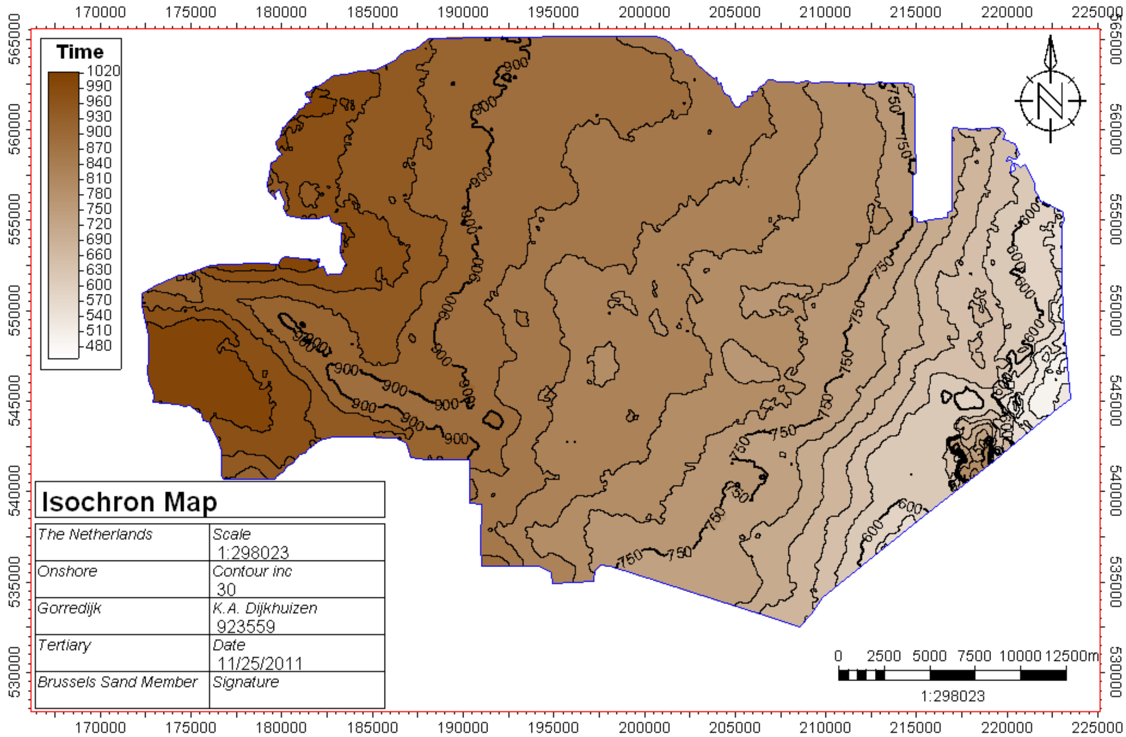


Figure 20: Total Brussels Sand thickness map (in time). Values are positive due to extracting values of base from top Brussels Sand to construct the map. Thick deposits are in brown, thin in white. For the total Brussels Sand Mbr a thickening towards the west is visible with influence from the salt dome in the east.

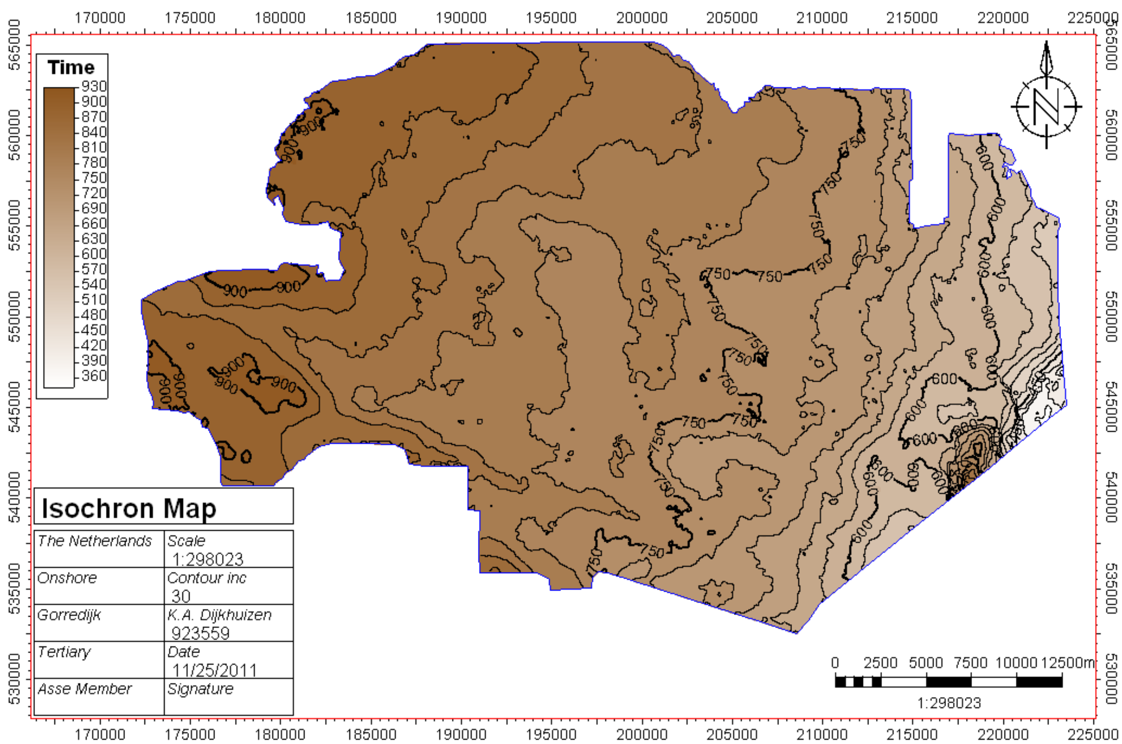


Figure 21: Asse Member thickness map (in time). Values are positive due to extracting values of base from top of the member to construct the map. Thick deposits are in brown, thin in white. The same thickening trend towards the west is visible in this map.

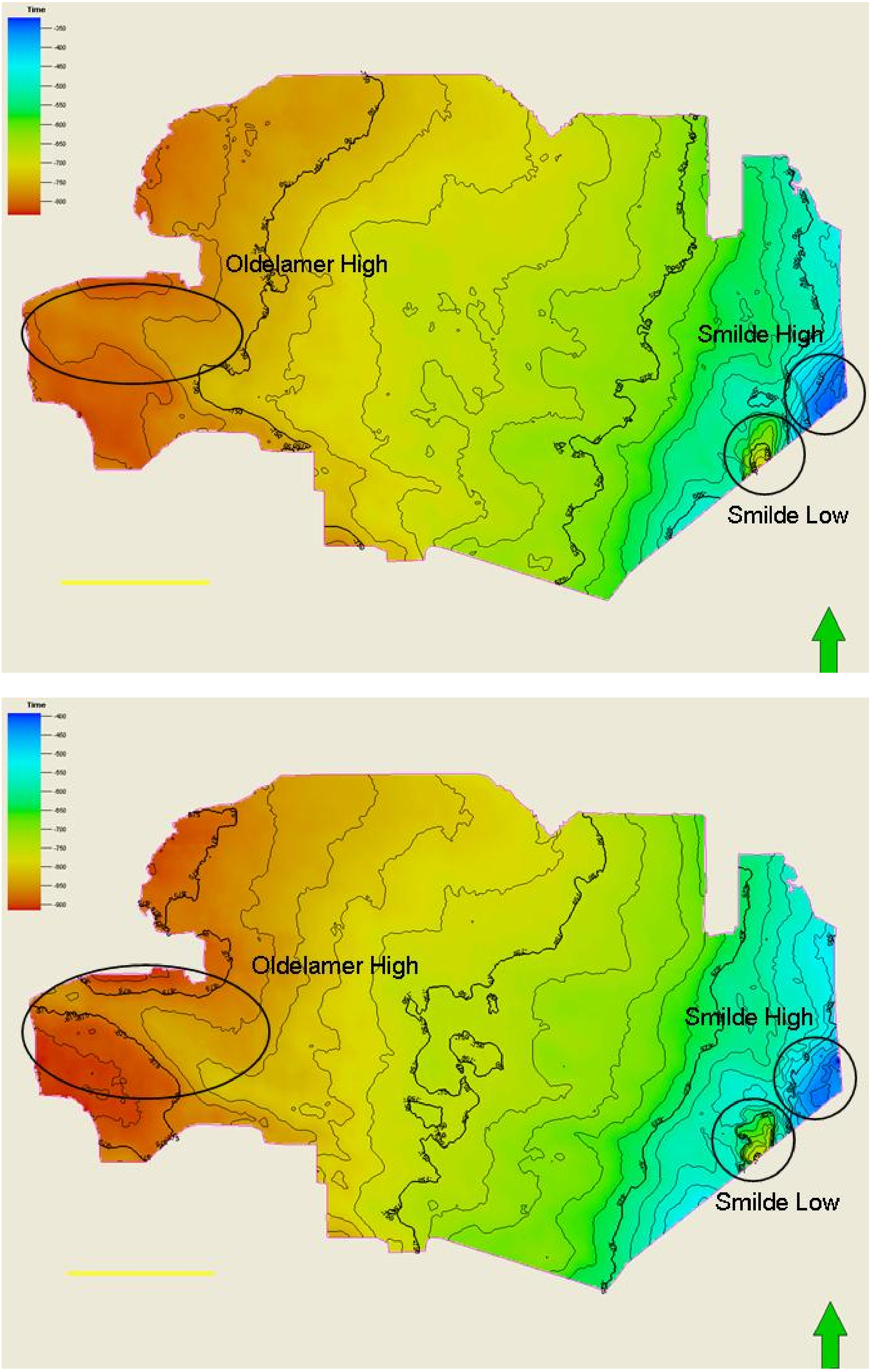


Figure 22: Structural maps of top Brussels Sand Member (top) and base Brussels Sand Member (below) based on seismics. The Oldelamer High in the west and the Smilde High and Low in the east are indicated. Values are in time.

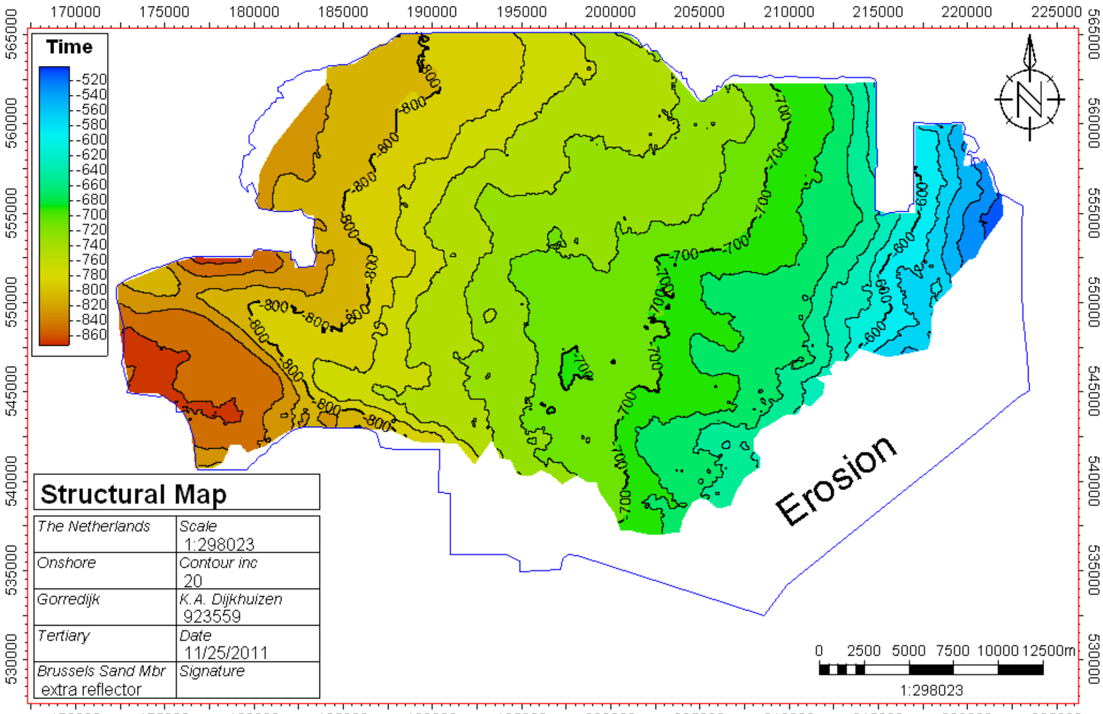


Figure23: Structural map composed of first extra reflector in the Brussels Sand Mbr based on seismics. Smoothing has been applied to exclude interpretation and seismic errors. Values are in time. White area represents area of erosion, here no extra reflectors are present in the seismic data.

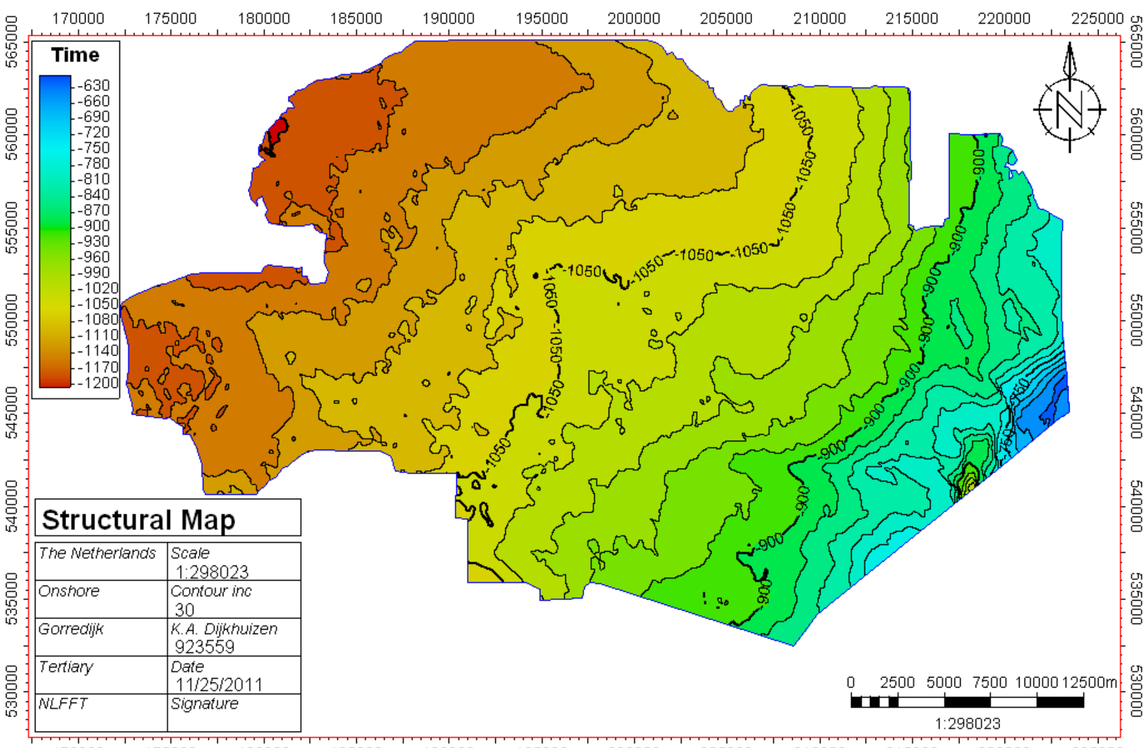


Figure24: Structural map composed of the NLFFT on seismics. Smoothing has been applied to exclude interpretation and seismic errors. Values are in time.

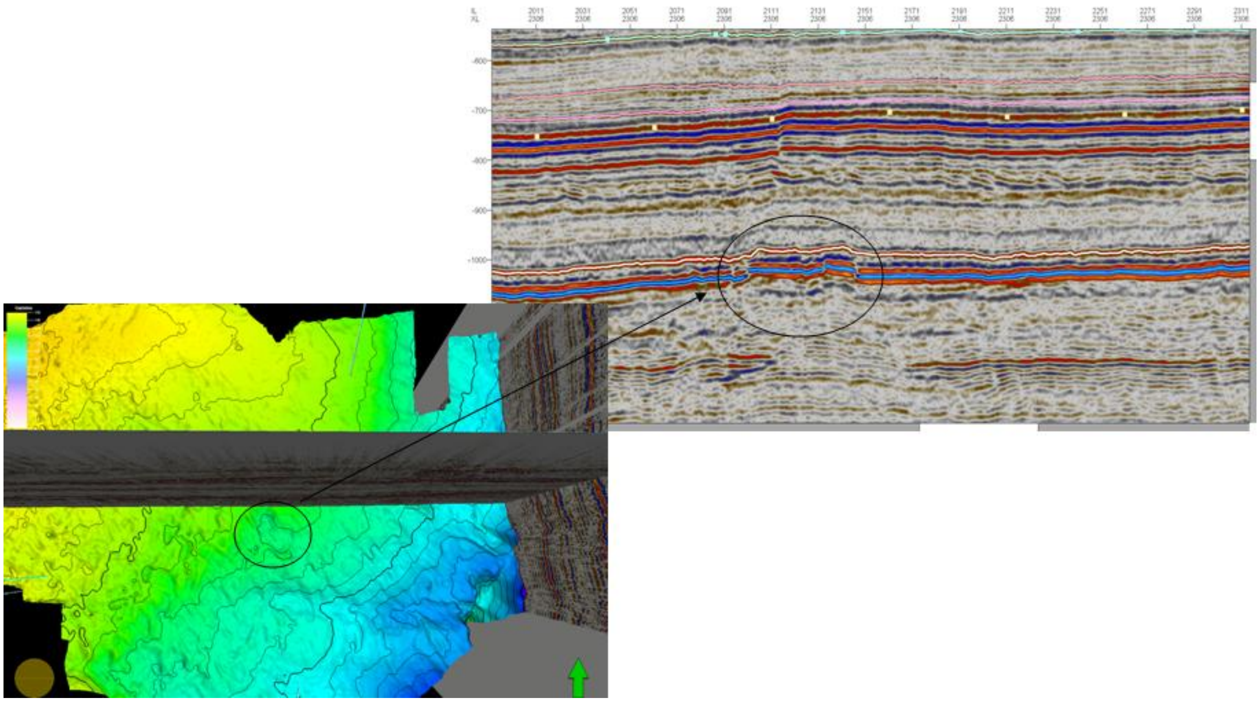


Figure 25: Prospective closure in NLFFT indicated on the structural map and on a seismic cross section (x-line). Two faults bound the small closure which can be sealing if this closure appears to be a reservoir.

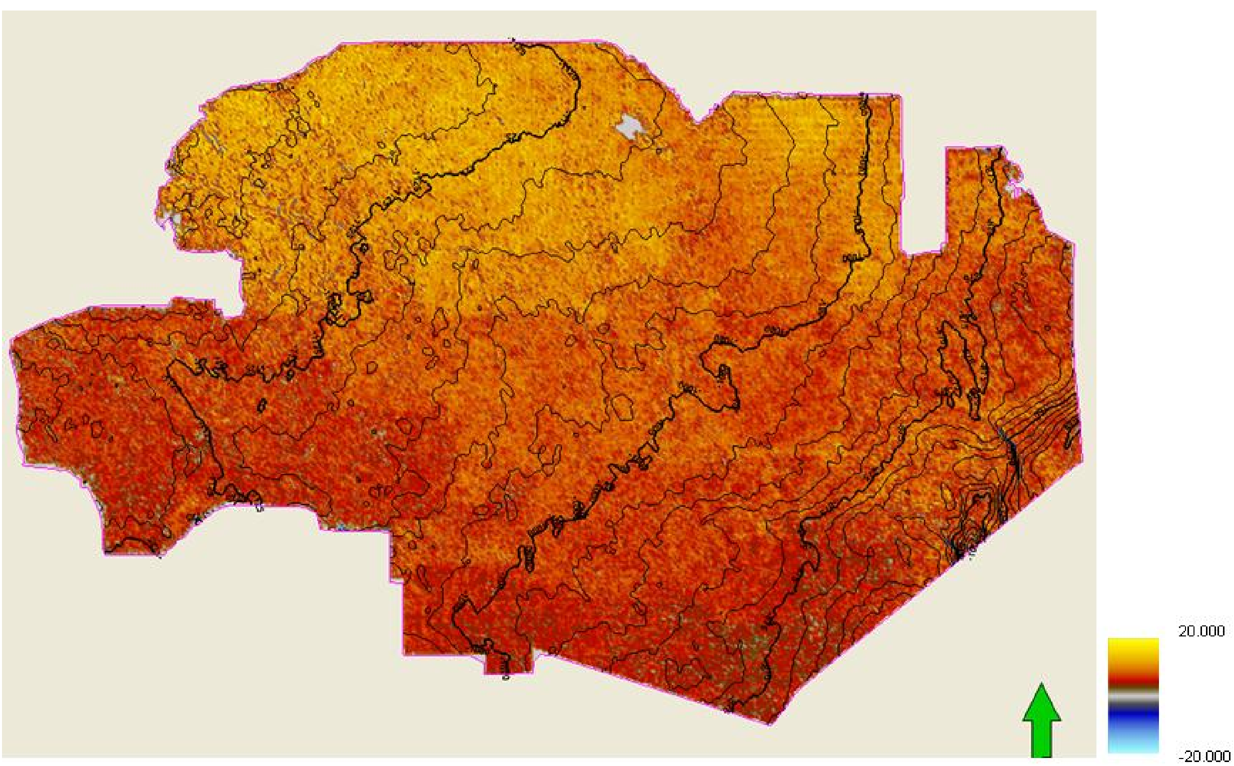


Figure 26: Amplitude map of NLFFT reflector. Yellow colors indicate higher amplitude values, red lower. No clear structures are visible (like for example channels).

4.4 Well correlation

To support the findings from seismic data two methods of well correlation are used: one using log data in Petrel and one by hand using composite logs. Figure 27 shows the position of the wells used in Petrel at a seismic x-line (W-E cross section). The Tertiary deposits can be recognized by using the gamma ray (GR) logs indicated with yellow colors. The base Tertiary is characterized by an increase in GR values. Top Tertiary is not indicated because the thick U-NS sequence is similar to the base at the top.

When looking at the deposits up to the base of the U-NS a thinning from west to east is very clear from the logs. The same trend is shown from the composite logs in Figure 28, with the same scale for every log. The erosive character of the M-NS Group is clearly recognizable from the thickness differences of this group in the logs. At one well (RVW-01) the complete M-NS Group has been eroded and is not present at all. In Appendix 2 well correlation of composite logs are shown with extra wells in an extended area. It must be noted that correlation is taken from public data. For some correlations an own interpretation is suggested where question marks were placed by studying the composite logs.

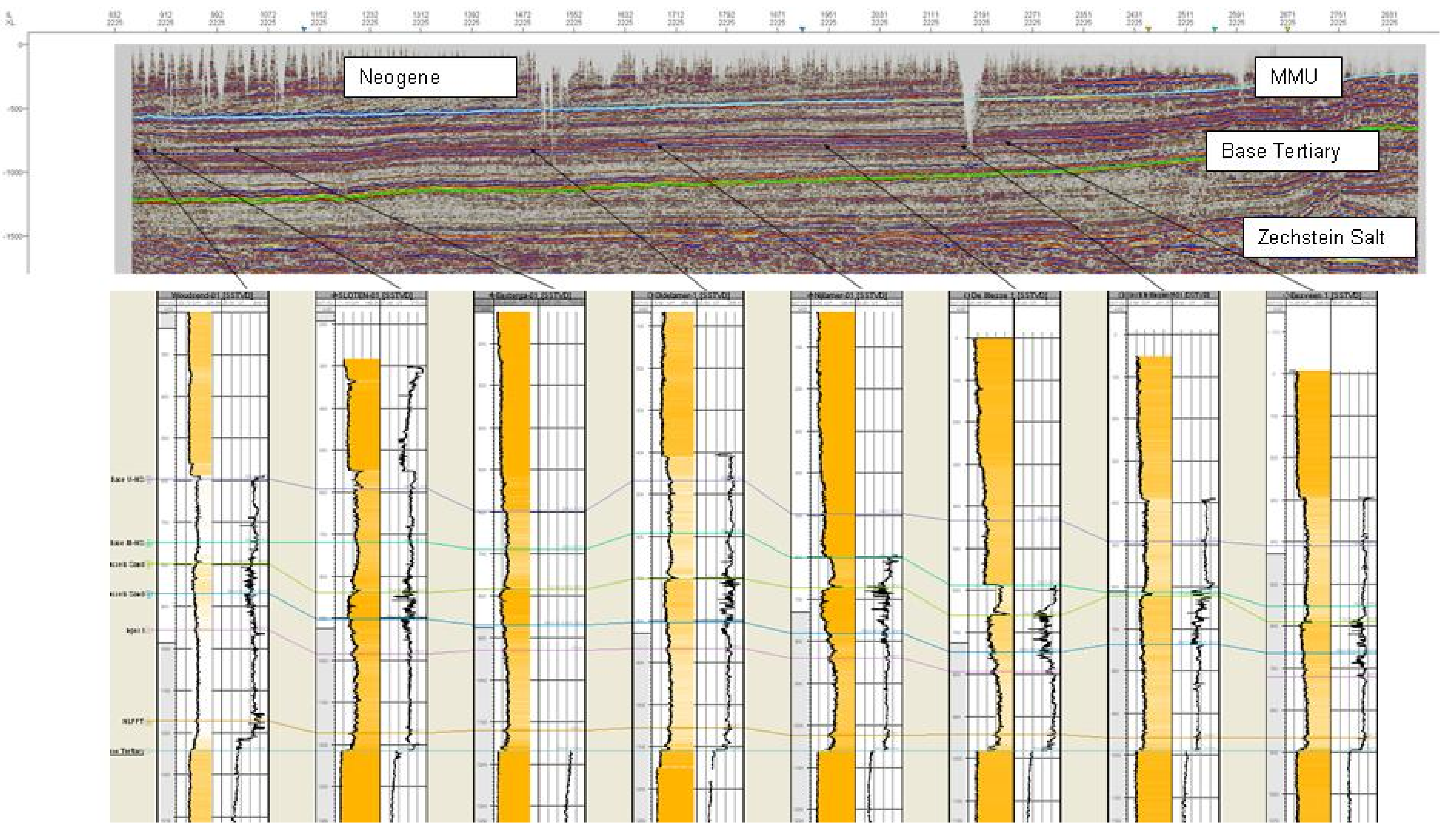
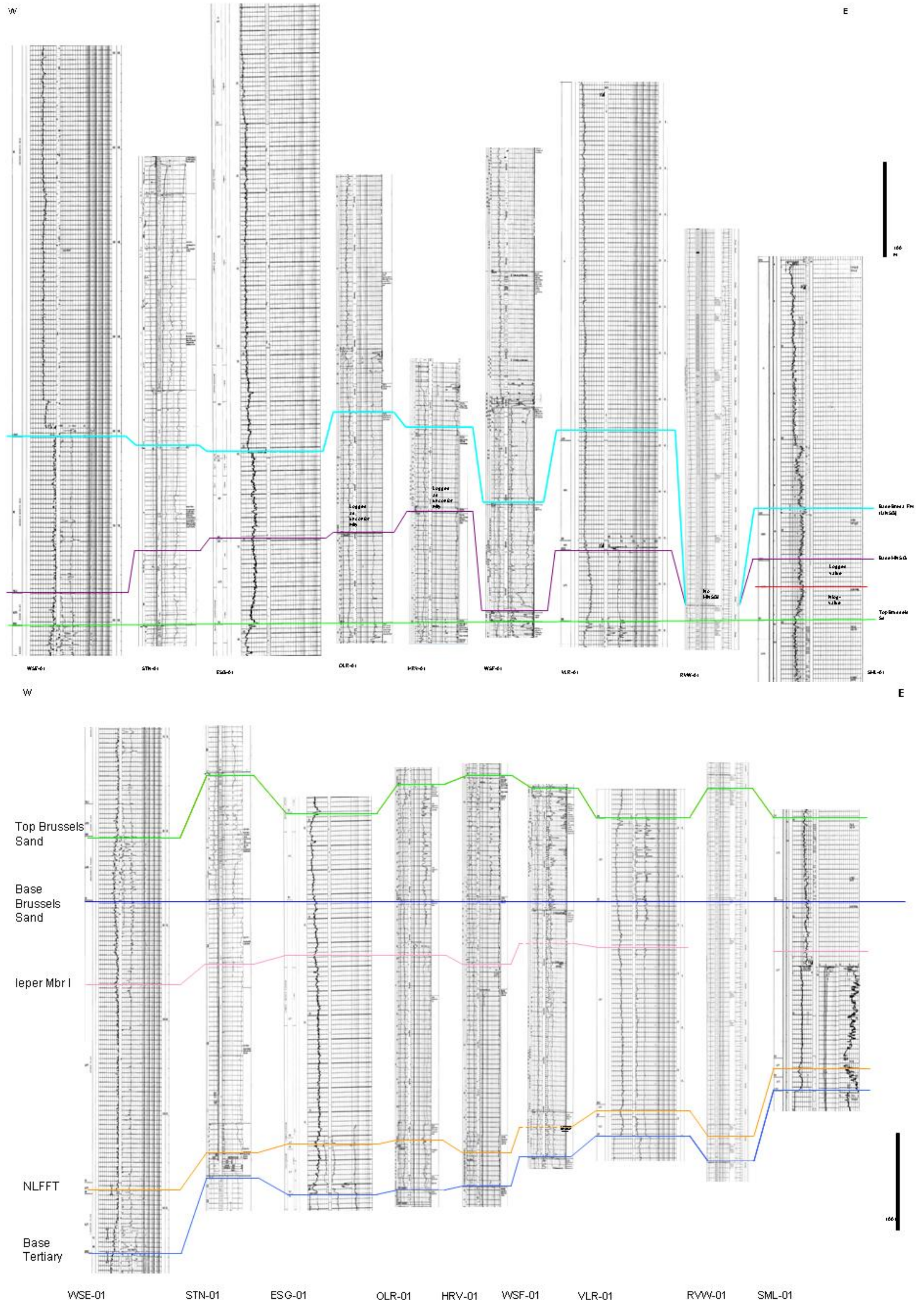


Figure 27: Relative position of 8 key wells in a seismic W-E (x-line cross section). Reflectors from base Tertiary to base U-NS are correlated and interpreted, base Tertiary well top is used as horizontal for all wells.. Highlighted reflectors are base Tertiary (green) and MMU (blue).



Source: www.nlog.nl

Figure 28: Two W-E cross sections through the studied area showing wells: WSE-01, STN-01, ESG-01, OLR-01, HRV-01, WSF-01, VLR-01, RVW-01 and SML-01 (see Figure 3 for positions). Black bars indicate 100 m in the logs. In the upper correlation the green line corresponds with the top Brussels Sand Mbr, purple with base M-NS and light blue with base U-NS. For the lower correlation the lines are named. Red line is alternative (own) correlation for base M-NS.

5. Discussion

5.1 Neogene

Tertiary deposits in the studied area show a semi-parallel character up to the Neogene deposits. At this point in time delta foresets come in from the (north) east and are deposited on the older Tertiary deposits. From Overeem et al. (2001) it is known that most deltaic sediments were transported to the large depocentre of the southern North Sea Basin. Study on seismic data from our onshore area however indicates a reach more to the south of the deltaic system than indicated in previous studies. Sorensen et al. (1997) suggested several phases which represent the prograding delta. From this study we can correlate the delta deposits present in the onshore Dutch subsurface to sequence 7 from Sorensen et al. (1997, see figure 19 of this article), implying an upper Pliocene age. The younger sequences are only locally present as very thin toes of the delta foresets. As known for other parts of the Netherlands, seismic data of the studied area show clearly the presence of the Mid Miocene Unconformity. In this area its erosive character is good to recognize in the western part where it overlies the lowest strata of the Upper North Sea Group. Therefore the MMU acts as the base of the U-NS in most part of the studied area. The most recent tectono-stratigraphic chart of the Netherlands (TNO, 2011) indicates a certain amount of deposits of the Breda Formation in the area more to the north (see Appendix 3). From this study no clear presence of Breda Formation has been found, possibly only in the western part of the area where the MMU is not interpreted as the base U-NS.

5.2 Pyrenean phase

The thickness of the total Tertiary sequence in this area shows a thickening toward the west. This is a gradual trend which the Upper North Sea Group follows. The two younger groups show shifts in depocenters and even individual formations and members show different thickening directions of the deposits. The relatively thick Lower North Sea Group shows a change in thickening direction of the sediments up to the Brussels Sand Member. This Brussels Sand Mbr is a thick sandstone member in which extra reflectors are introduced in the main part of the area, implying a higher sedimentation rate and/or subsidence of the Friesland Basin. It must be noted that a difference exists in the definition of the Brussels Sand Member in Dutch literature and in Belgium literature. See Appendix 4 for a comparison between the two from the literature. All the extra reflectors are cut-off by the top of the Brussels Sand Mbr, indicating this reflector as the representative of an erosive surface. During deposition of the Tertiary deposits, influence of the Alpine phase affected the Netherlands and therefore our study area. This Alpine phase occurred in pulses (de Jager, 2007) and one of these pulses could be related to the erosive event at the end of the Brussels Sand deposition. The Pyrenean compressive phase is not limited to the end of the Eocene. De Jager (2007) suggests the main tectonic pulse at the end of the Eocene, however de Lugt (2007) notes that compression is already active during the deposition of the Brussels Sand Mbr (see Figure 29 and 30). It must be said that both studies did not include our research area, and data needs to be correlated to fully understand the influence of the Pyrenean phase on the Dutch Tertiary deposits. From our data we can say at least that clearly an erosive event occurred at the top of the Brussels Sand Mbr, but it is not eroded completely. Other (local) erosive events could be the cause of the shifts in thickening direction for the other formations. Detailed study on deposition environment and local tectonics is needed to give a complete explanation for this shift in thickening direction.

5.3 Changing structural regime

It can be concluded from the above that during deposition of the Brussels Sand Mbr the area was under influence of tectonics and deformation. To find a time constrain for the main structural influence on the Tertiary deposits the seismic data were flattened on several reflectors. This means that an interpreted reflector is corrected to horizontal and the other seismic data is shifted, imitating the environment during deposition of the flattened reflector. In Appendix 5 seismic profiles (x-line projections: W-E profiles) of the six important reflectors are shown. The profiles for MMU, base M-NS and top Brussels Sand Mbr all show the thickening of Tertiary deposits towards the west as found from the isochrons earlier in this report. One point of interest is to see on the profile of the top Brussels Sand: above the flattened reflector thickening in the western part (as expected) can be seen, however, below the reflector a small increase in thickness is recognized towards the east. This is no longer visible at the profile for the flattened base Brussels Sand reflector; here the older strata are roughly parallel with irregular patterns in the younger strata. Flattening on both NLFFT and base Tertiary shows the main thickening towards the west of the total Tertiary sequence. This all emphasizes that during the deposition of the Brussels Sand Mbr the structural and depositional regime changed in this area. This can be of influence on the development of prospective reservoirs in the sands of the Tertiary deposits and must be taken into account in further studies.

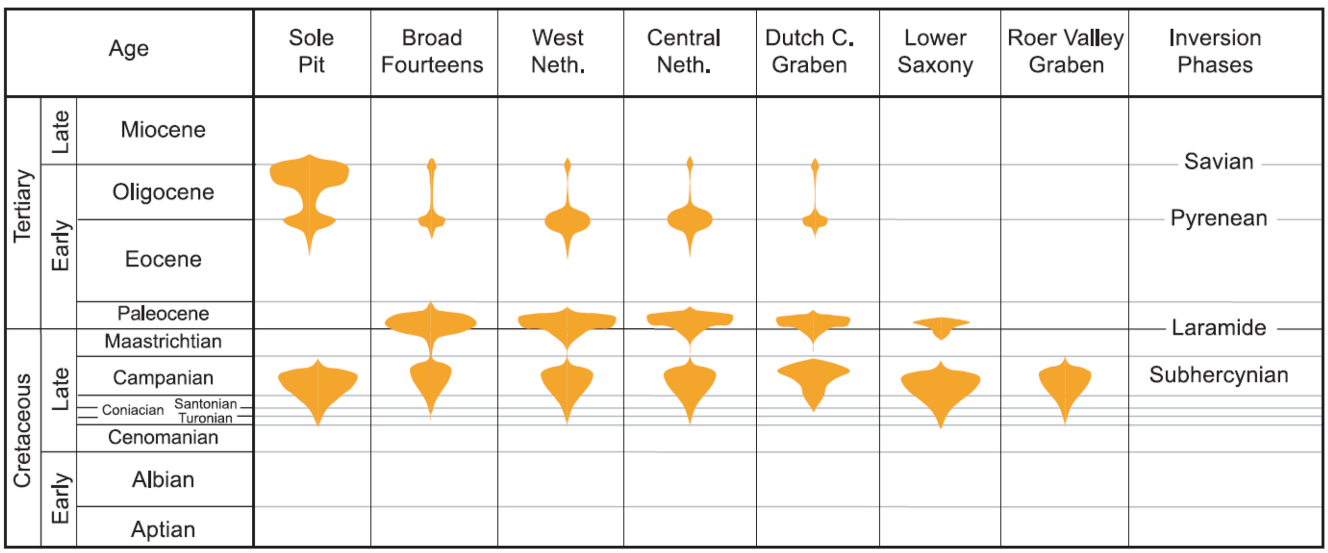


Figure 29: Timing and relative intensity of Alpine phase pulses. Friesland Platform is not included, use Central Neth. as reference. Pulse of interest is the Pyrenean, here placed at the Eocene-Oligocene boundary. From de Jager (2007).

5.4 Halokinesis

The presence of the Smilde High and Low is associated with a large salt dome due to halokinesis situated below these structures. From seismic data the salt dome can be clearly recognized with corresponding onlap of younger reflectors around it. From other studies it is known that in the area more to the east more salt domes are present (Appendix 1). Highs and lows in the Tertiary deposits there would be suggested with this study as analog.

The Oldelamer High is not situated on top of a salt dome or high, so its presence cannot be explained in terms of halokinesis. During deposition of the Brussels Sand Member a paleotopography is suggested as cause of this high.

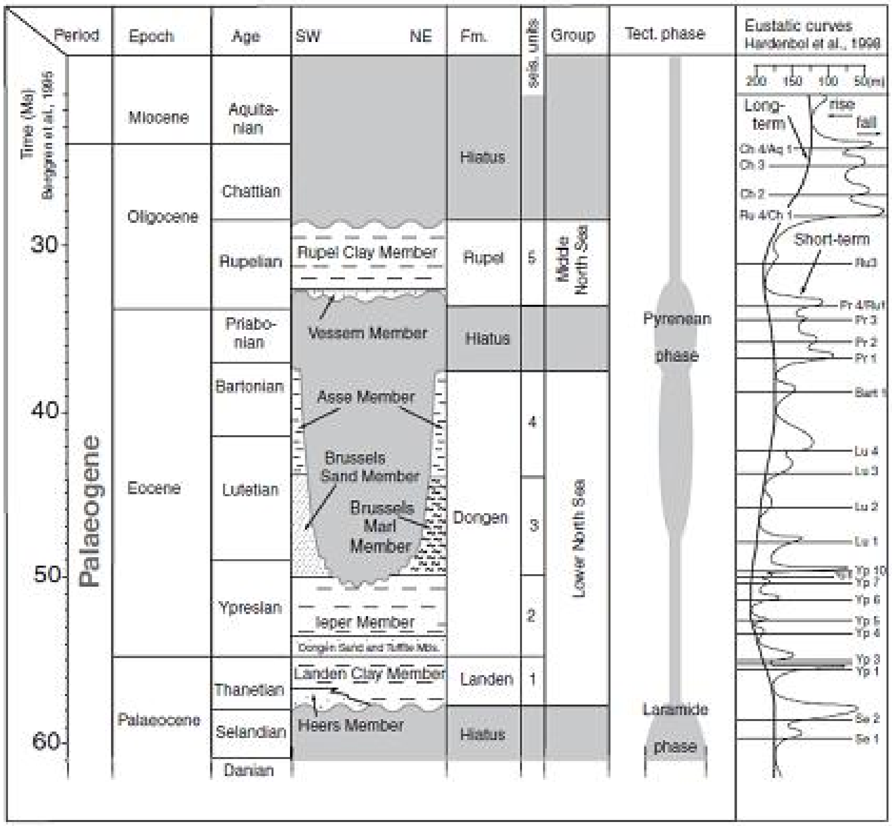


Figure 30: Schematic scheme adapted from de Lugt (2007) showing a longer time interval for the Pyrenean phase. Area used here is offshore western Netherlands and as indicated parts of the Brussels Sand Member are eroded in this area.

5.5 Closures and prospective reservoirs

No large closures have been found during seismic interpretation of the main Tertiary reflectors. Some small scale closed contour lines in the structural map correspond with small irregularities in the seismic data. These irregularities could be caused by movement in the shale layers which alternate with the sand layers (Loseth et al., 2011). More detailed study on the prospective NLFFT shows a small closure in the middle part of the area. Looking at the seismic data it is found that this closure is bound by two faults, suggesting a high prospectivity for this member. Unfortunately no high amplitudes are found around this prospective closure, which lowers the change of finding large gas volumes here. Future work on the Gorredijk concession should focus on more detailed mapping of faults in the NLFFT to find possibly small scale reservoirs.

5.6 Gas migration

Gas molecules in rocks have the tendency to travel upwards because of density contrast with the surrounding rock. Therefore, isochron and thickness maps can be used to produce forecasts on the presence of large gas volumes, with the assumption that a good reservoir and a seal are present. The main observation of the Tertiary deposits from this study is the thickening towards the west. This is at least visible in the U-NS and the M-NS. Gas migration would therefore occur from the west to the east, and the focus to find prospective reservoirs should be in the eastern part of the studied area. Unfortunately no clear closures are present in this part of the studied area so no suggestion for any prospective reservoirs can be made on the results so far.

6. Conclusions

Onshore Tertiary deposits in the Dutch subsurface show, despite a semi-parallel character of the strata, an interesting structural history. Several tectonic and erosional phases have affected the formations with the Pyrenean phase as being the phase of largest impact in the studied area. Halokinesis has affected the eastern part of the area, which is expressed as the Smilde High and Low which are recognized from isochrons from this study.
The only formation which holds an example of a closure is the Basal Dongen Tuffite Member, a producing formation in the area south of the Gorredijk concession. From study of the constructed isochrons, possible gas migration would have taken place from the west to the east. From this study no clear reservoirs have been proposed, more detailed study on timing and sealing of prospective reservoirs could result in new proposals for wells in the Gorredijk concession.

7. Acknowledgments

Special thanks are for Fokko van Hulten for his regular sessions on the Tertiary geology and his advice during the whole project. I would also like to thank Guido Hoetz and Martijn Gorissen for their help with the geophysics and Petrel. Maarten-Jan Brolsma is thanked for his advice and interest in my project. All my other colleagues at EBN are thanked for their inspiration and talks during this project. Last but not least my gratitude goes out for Prof. Chris Spiers for his patience and quick responses to all my questions.

References

Geluk, M.C., de Jager, J.; 2007. " Petroleum Geology" in Geology of the Netherlands. Edited by Th.E. Wong, D.A.J. Batjes & J. de Jager. Royal Netherlands Academy of Arts and Sciences, pp 241-264.

Gorissen, P.M; 2011. Vlieland Sandstone Prospectivity and Distribution. In-house EBN report

Haq, B.U., Hardenbol, J., Vail, P.R.; 1988. Mesozoic and Cenozoic Chronostratigraphy and cycles of sea-level change. In "Sea-Level Changes – An Integrated Approach" SEPM Special Publication No. 42.

Houthuys, R.; 2011. A Sedimentary Model of the Brussels Sands, Eocene, Belgium. Geologica Belgica, No. 14/1-2, pp 55-74.

Løseth, H., Wensaas, L., Gading, M.; 2011. Deformation structures in organic-rich shales. AAPG Bulletin, vol. 95, No. 5, pp 729-747.

De Jager, J.; 2007. "Geological Development" in Geology of the Netherlands. Edited by Th.E. Wong, D.A.J. Batjes & J. de Jager. Royal Netherlands Academy of Arts and Sciences, pp 5-26.

De Lugt, I. R.; 2007. Stratigraphical and structural setting of the Palaeogene siliciclastic sediments in the Dutch part of the North Sea Basin. Geologica Ultraiectina, No. 270.

Overeem, I. Weltje, G.J., Bishop-Kay, C., Kroonenberg, S.B.; 2001. The Late Cenozoic Eridanos delta system in the Southern North Sea Basin: a climate signal in sediment supply? Basin Research, vol. 13, pp. 293-312.

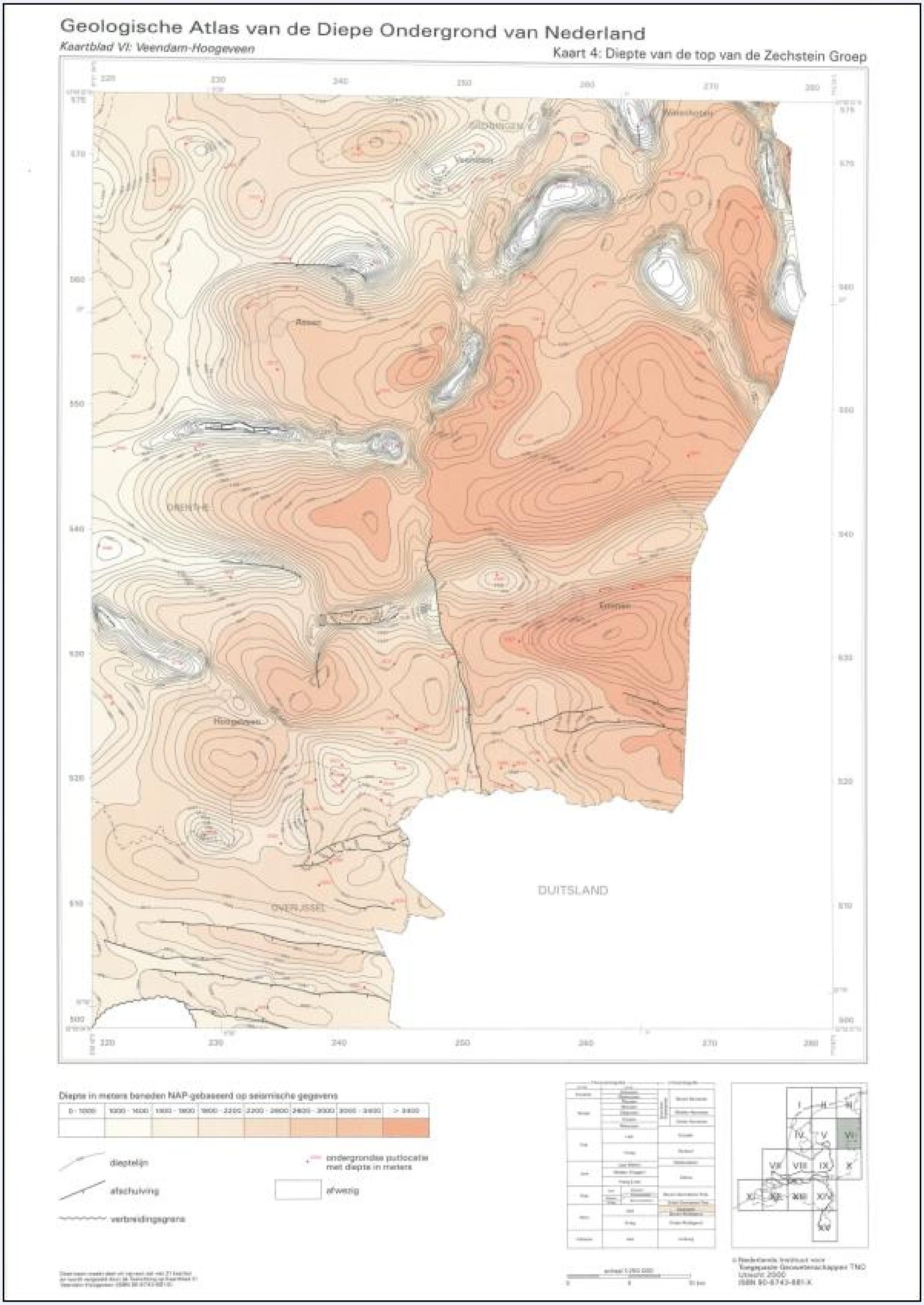
Sorensen, J.C., Gregersen, U., Breinier, M., Michelsen, O.; 1996. High-frequency sequence stratigraphy of Upper Cenozoic deposits in the central and southeastern North Sea areas. Marine and Petroleum Geology, vol. 14, pp. 99-123.

Van Adrichem Boogaert, H.A. & Kouwe, W.F.P. (eds); 1997. Stratigraphic nomenclature of the Netherlands, revision and update by RGD and NOGEPA. Mededelingen Rijks Geologische Dienst 50, Section I.

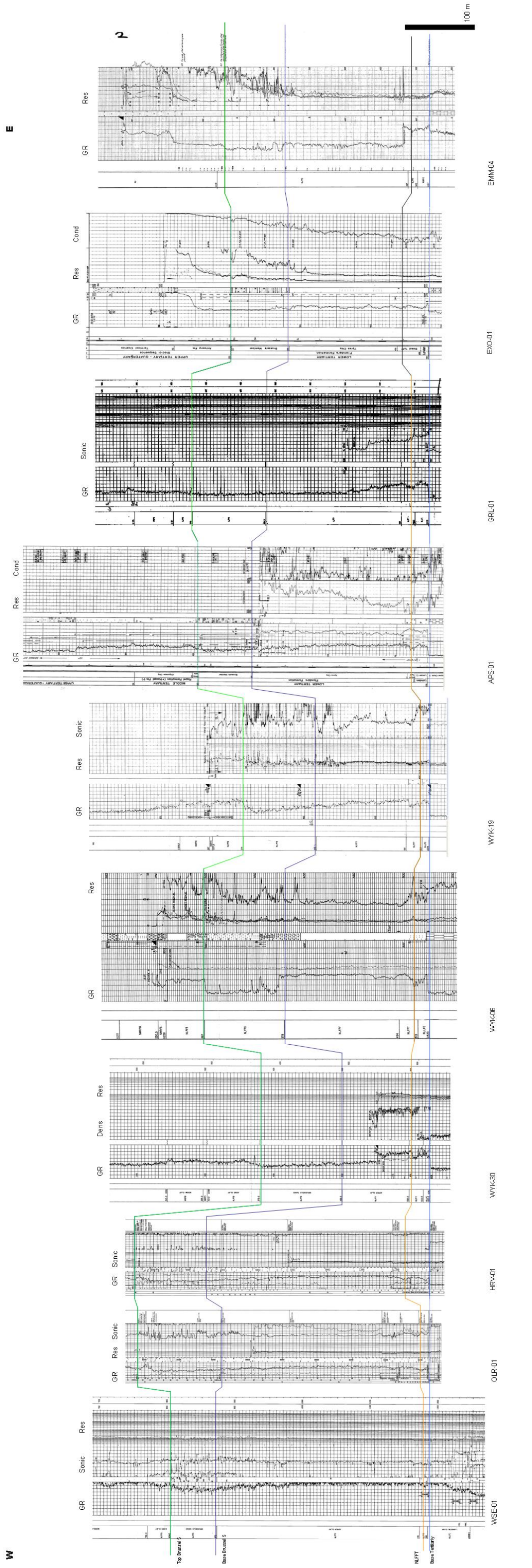
Wong, Th. E., de Lugt, I.R., Kuhlmann, G., Overeem, I.; 2007. “Tertiary’ in Geology of the Netherlands. Edited by Th.E. Wong, D.A.J. Batjes & J. de Jager. Royal Netherlands Academy of Arts and Sciences, pp 151-171.

Sources well data, Appendix 1,2 and 3: www.nlog.nl (public datasets from TNO)

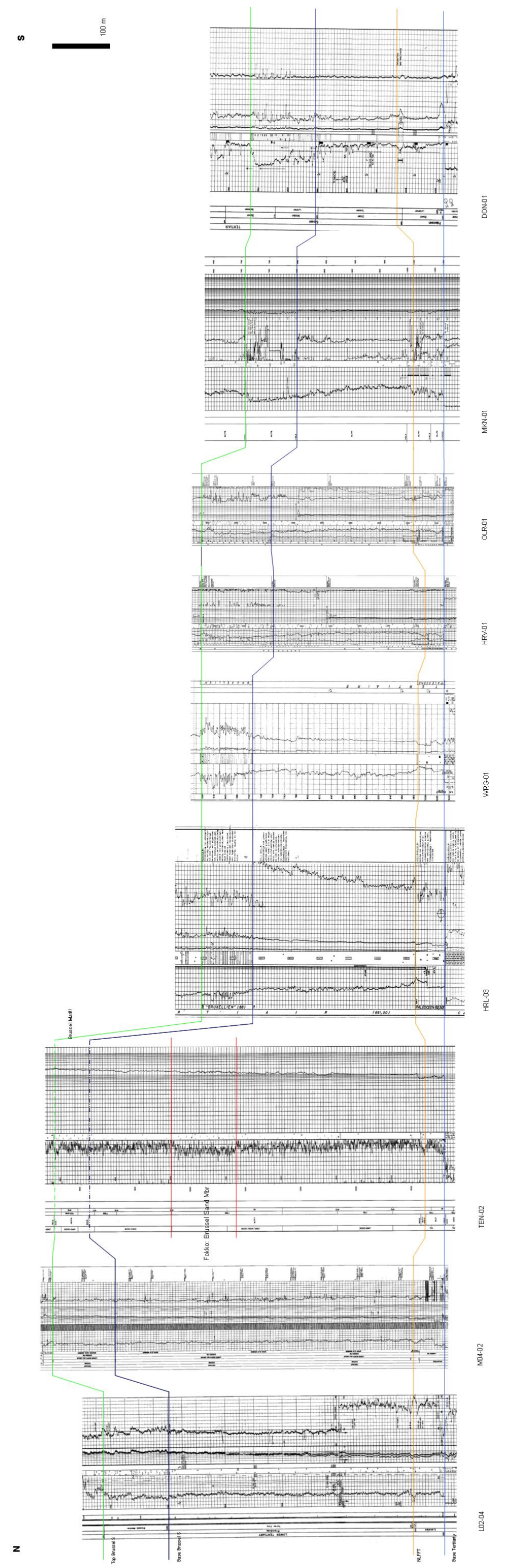
Appendix 1: Map fragment of Geological Atlas of the deep subsurface of the Netherlands (TNO)



Appendix 2: Correlation of composite logs of Tertiary well tops (data from www.nlog.nl)



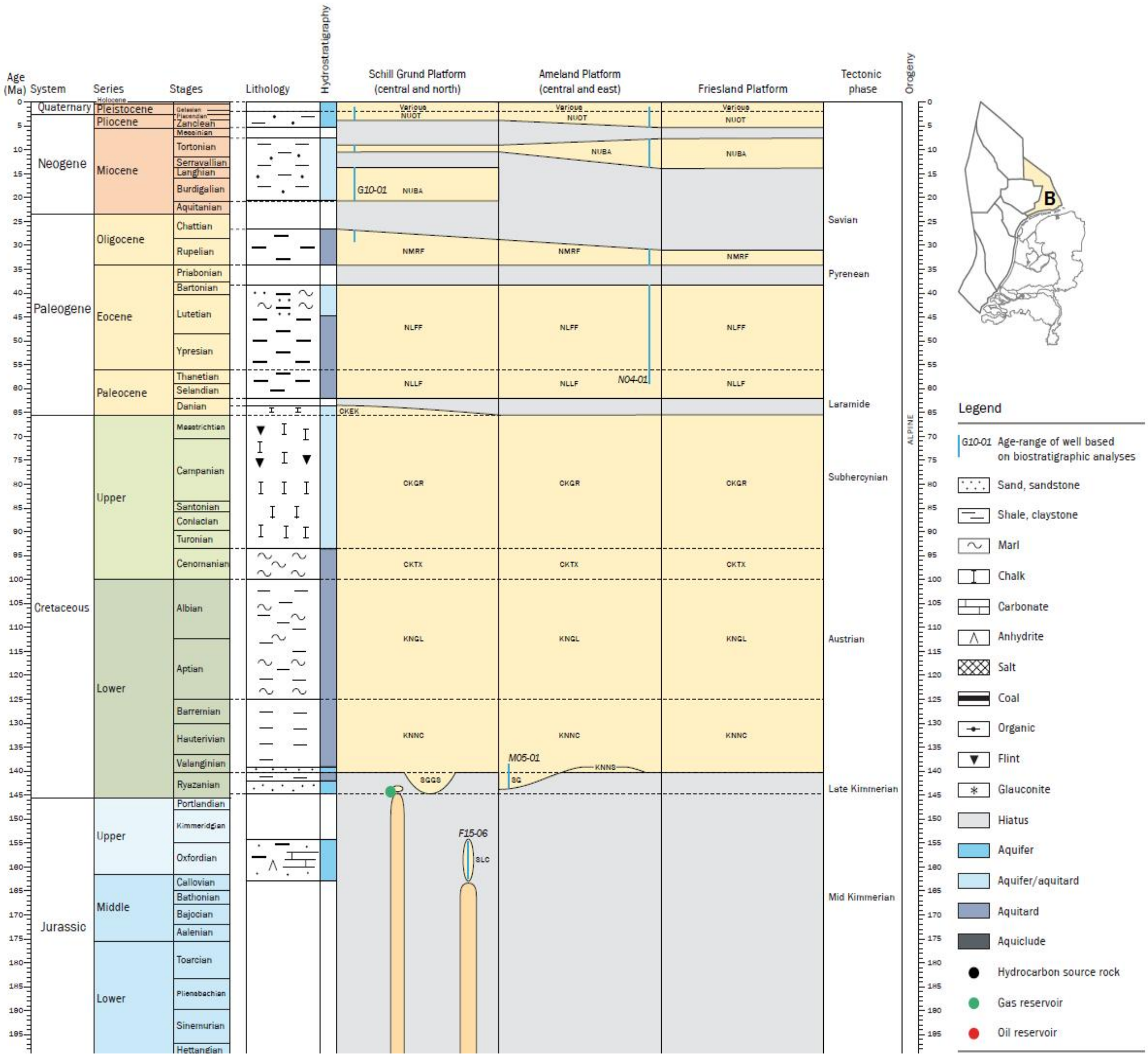
A



B

Composite logs up to top Brussels Sand Mbr selected on location and quality of log data. Correlated markers are from bottom to top: Base Tertiary (blue), NLFFT (yellow), base Brussels Sand (dark blue) and top Brussels Sand (green). **A)** Used wells from W to E: WSE-01, OLR-01, HRV-01, WYK-30, WYK-16, WYK-19, APS-01, GRL-01, EXO-01 and EMM-04. **B)** Used wells from N to S: L02-02, M04-02, TEN-02, HRL-03, WRG-01, HRV-01, OLR-01, MKN-01 and DON-01.

Appendix 3: Tectono-stratigraphic chart of Schill Grund, Ameland and Friesland Platforms (TNO, February 2011)



Various Quaternary formations

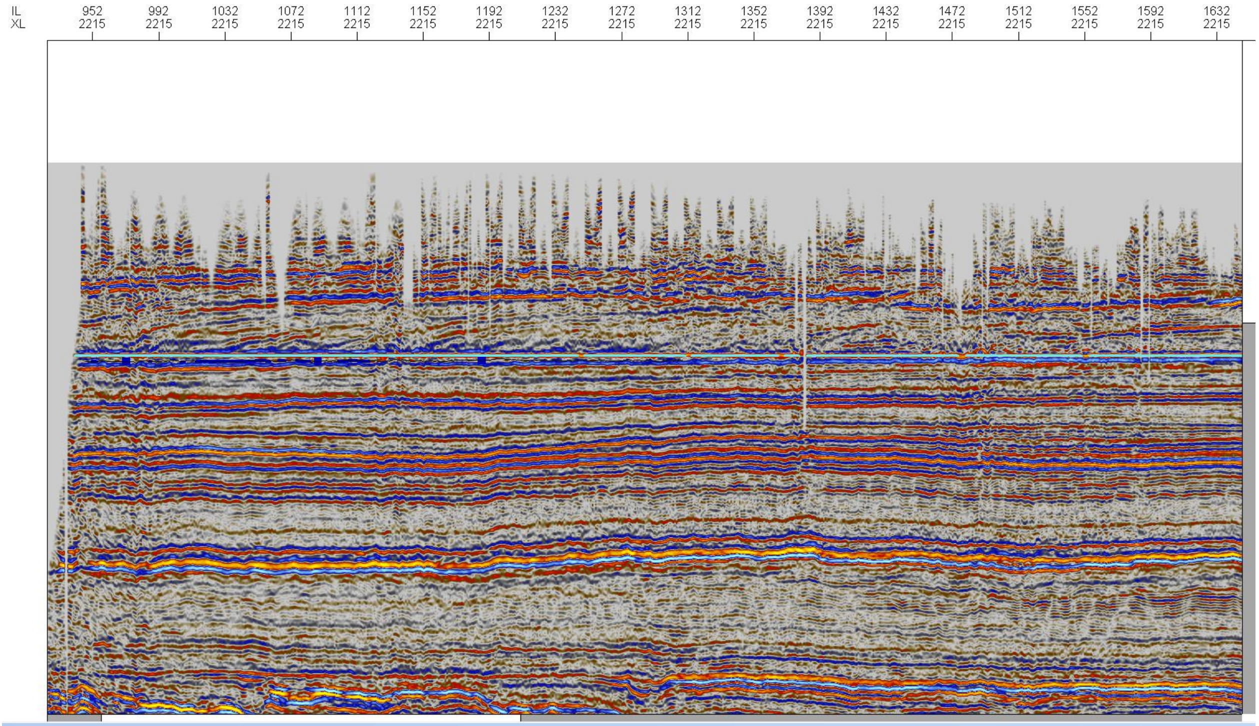
NU	Upper North Sea Group
NUOT	Oosterhout Formation
NUBA	Breda Formation
NM	Middle North Sea Group
NMRF	Rupel Formation
NL	Lower North Sea Group
NLFF	Dongen Formation
NLLF	Landen Formation
CK	Chalk Group

Appendix 4: Brussels Sand Member defined in Dutch literature vs. Belgium literature

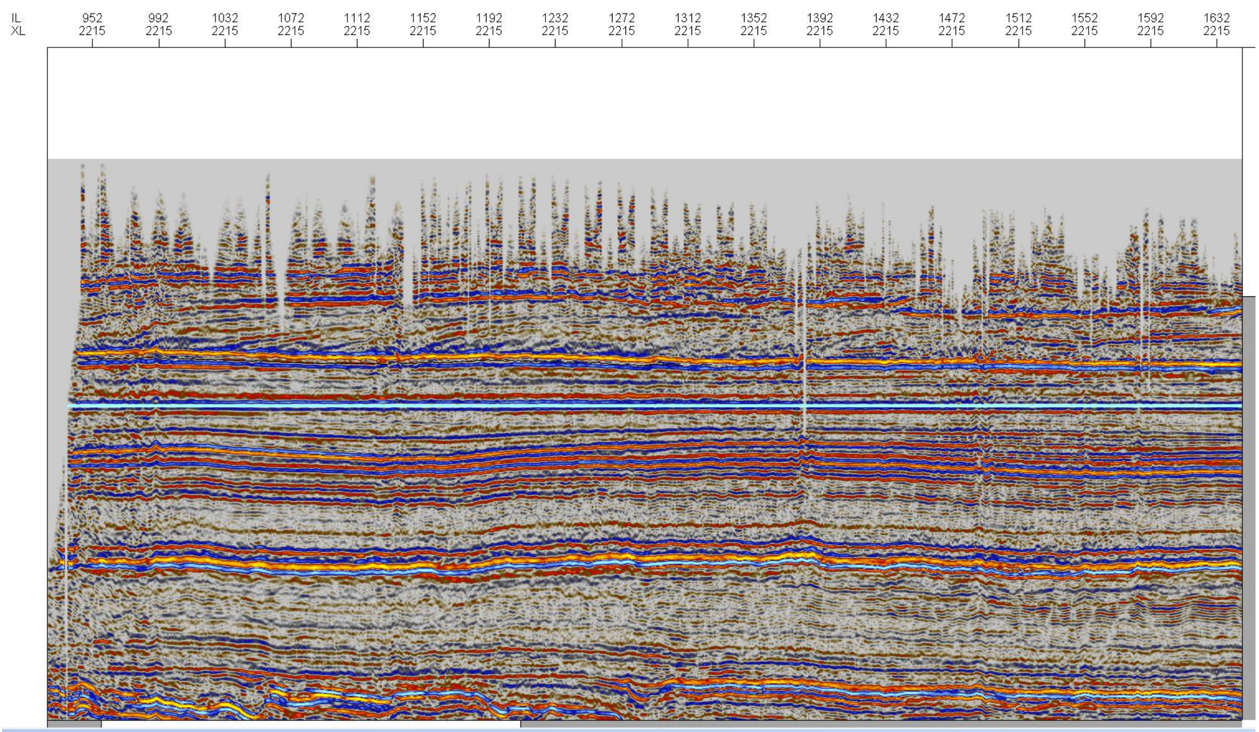
	NL	BE
Name correlation *(Stratigraphic nomenclature, 1997)*	Brussels Sand Member	Lede Formation Aalter Formation Brussel Formation Gent Formation
Definition	Succession of glauconitic, very fine grained sand with hard calc. ss layers. *(Stratigraphic nomenclature, 1997)*	Fine, medium and locally coarse sand characterized by the presence of hard siliceous ss concretions. *(Houthuys, 2011)*
Eustatic sequences	*Hardenbol (1998)*: Yp9/10 – Lu2 *Haq (1988)*: TA2.7 – TA3.4 (from *de Lugt, 2007; Stratigraphic nomenclature, 1997*)	*Hardenbol (1998)*: Yp10 – Lu1 *Hacq (1988)*: (from *Houthuys, 2011*)
Sedimentary environment	(Shallow) marine, inner-neritic to near-shore. Water depth was shallowing upwards.	Transgressive, estuarine to marine paleovalley fill
Paleo-environment		Tropical, shallow, mangrove fringed, marine bay with rapid sedimentation nearby land surface with humid forests. *(Houthuys, 2011)*
Depositional cycles	3 (Brussels Marl Member) *(de Lugt, 2007)*	1 *(Houthuys, 2011)*
Extra information	Not present on paleo-coastline and paleo-highs due to non-deposition and erosion. *(Stratigraphic nomenclature, 1997)*	*Vandenberghe, 2004*: Brussel sand facies found on top of younger Aalter sands and in Northern France at Lu2. This suggests comparable younger Brussel sand facies which covered the whole area to the South.

Appendix 5: Seismic profiles (W-E cross sections, x-lines) flattened on different horizons

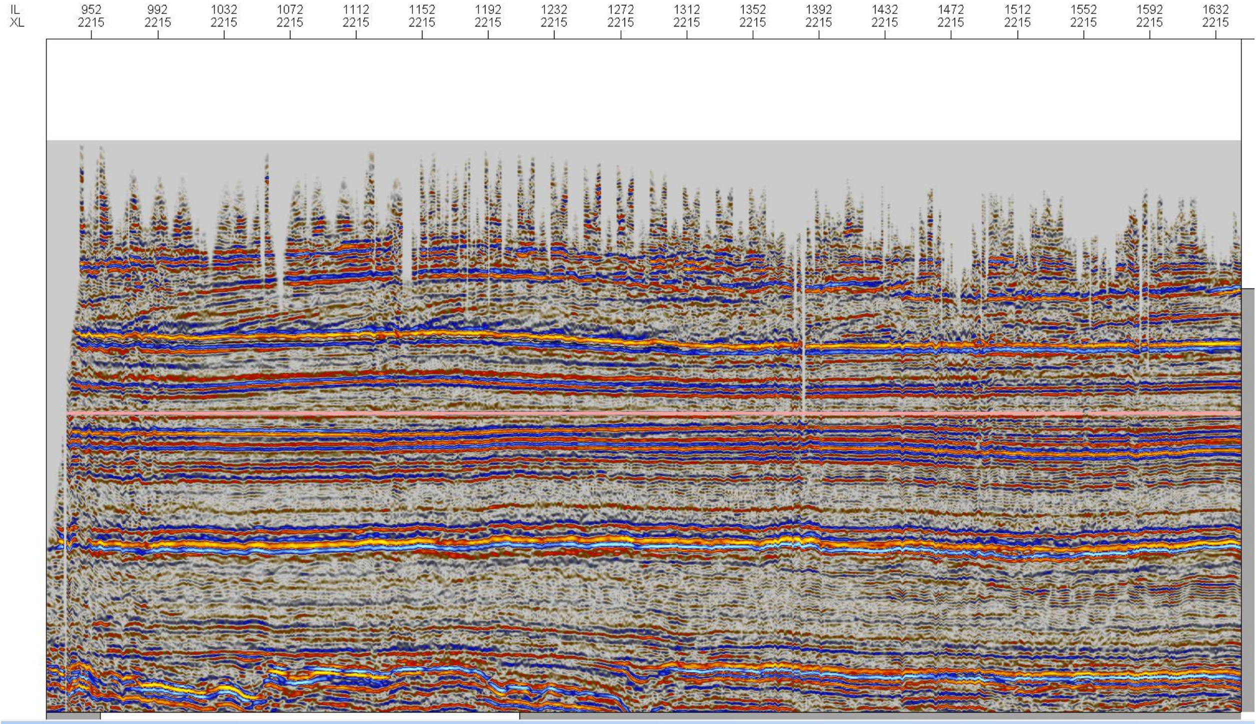
Flattened on MMU



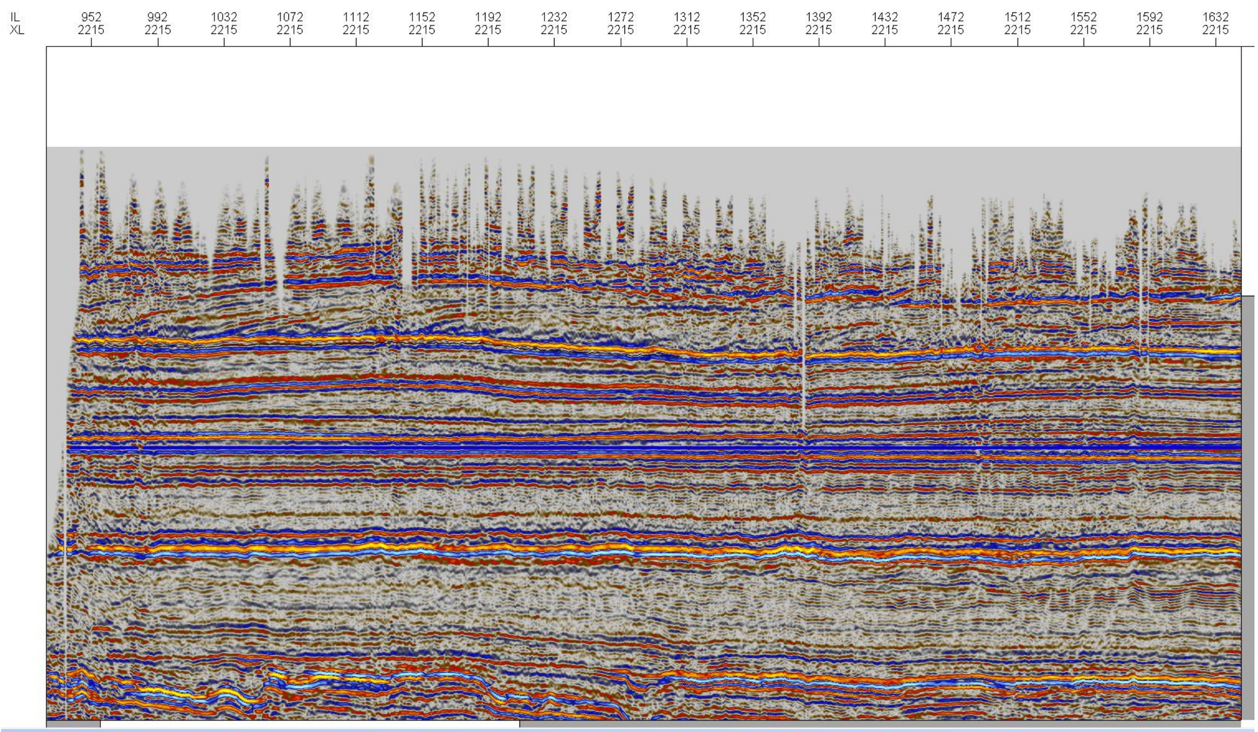
Flattened on base Middle North Sea Group



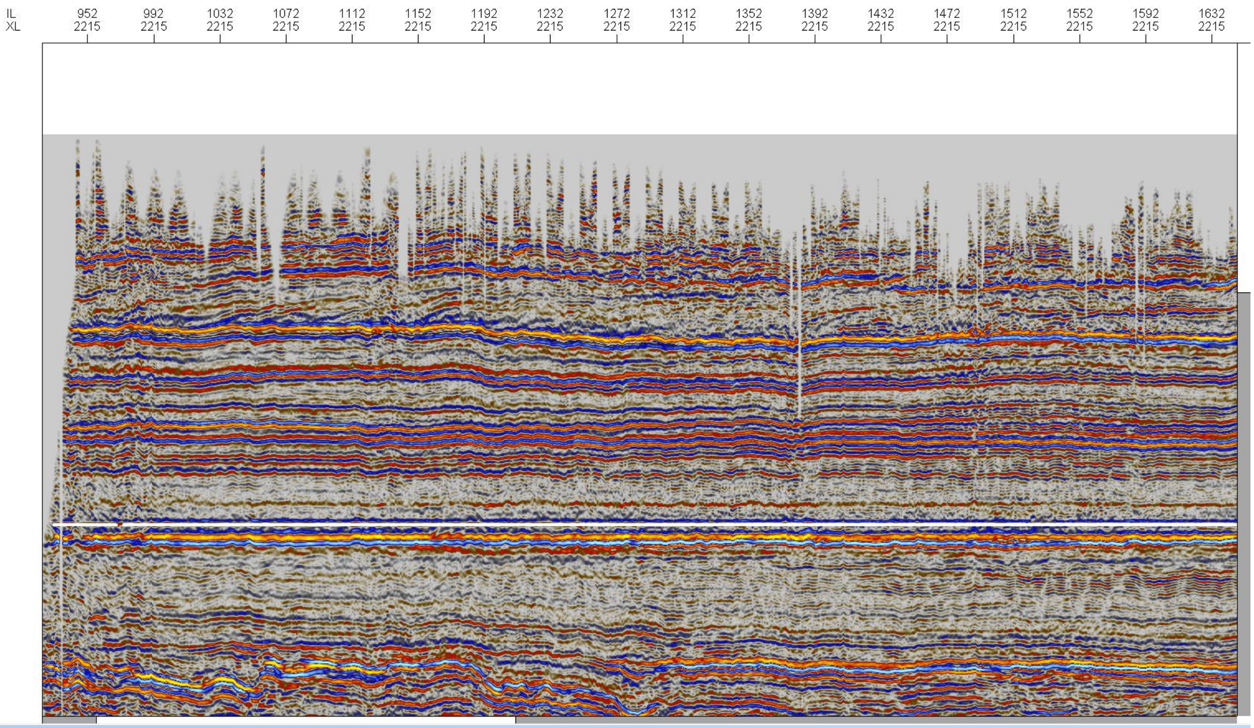
Flattened on top Brussels Sand Member



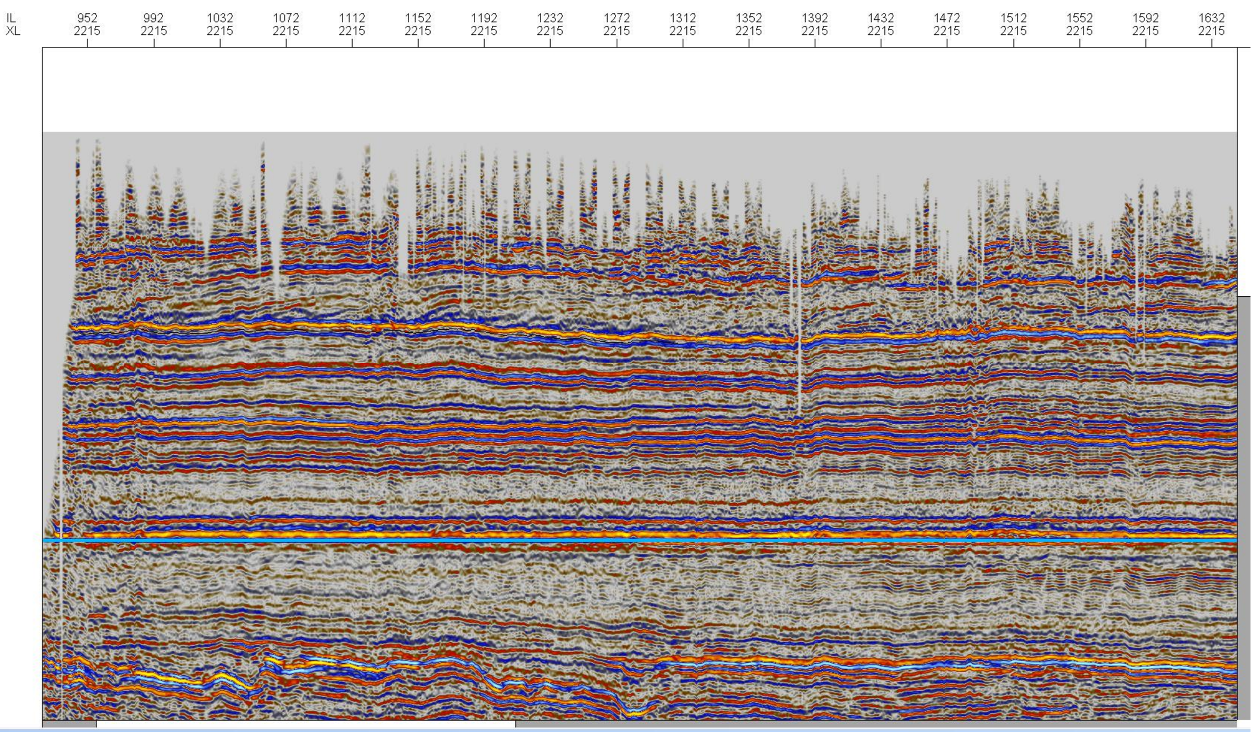
Flattened on base Brussels Sand Member



Flattened on NLFFT (Basal Dongen Tuffite Member)



Flattened on base Tertiary



Part II: Extra Work

Content

1. ***Shale gas in the Aalburg Formation***

2. ***Gorredijk concession***
    a. ***Polygonal faulting Chalk Group***
    b. ***Zechstein salt structures***
    c. ***Carboniferous reef***
    d. ***Neogene delta deposits***
    e. ***Geological features in 3D seismic data***

1. Shale gas in the Aalburg Formation

1.1 Introduction

At the start of my internship in September I worked on well data from the West Netherlands Basin and the Roer Valley Graben. Aim was to look at the Lower Jurassic Altena Group which has a high potential of finding shale gas. Gas plays in the Posidonia Shale are found at many locations in the Dutch subsurface, and now the focus is on the older Aalburg Formation (ATAL). This formation is much thicker (up to 1000 meter).
During 3 weeks I organized all the available well data (from public data on www.nlog.nl) and selected wells which show similar characteristics in the lower part of the Aalburg Formation in order to be able to propose a new formation: the 'Lower Aalburg Formation'. To prepare myself to the '3D seismic to exploit hydrocarbons' course I followed in Rijswijk I had a first look at the program Petrel and read background literature on hydrocarbon exploration.
Below an overview of my results from the data research on the Aalburg Formation. After the 3D seismic course I started to work on the Gorredijk project. My work on the Aalburg Formation was a good introduction to EBN, the workflow of finding hydrocarbons, well and log data and Petrel.

1.2 Methods

- Select wells on several criteria: is a mudlog available, is there any limestone present in the lower part, is the formation thick (over 50 meter) and good preserved. A description of every available well is made.
- Group available wells in four groups: no log data, bad log data, disputable data, good data
- Select prospective wells and order them on gas content peaks (> 1%, 0.5-1%, 0.1-0.5% + <0.1%)
- Construct maps of wells on gas content
- Propose most prospective wells on log data selection (gas content described above plus density, resistance, sonics and gamma ray logs) and on limestone content (important feature to distinguish lower part from upper part of the formation). This can be used in the future to select a seismic covered area for seismic research.

1.3 Results

	A	B	C
1	BOORGAT	CODE	FORMATION
3	ANDEL-06	AND-06	ALTENA
7	BROEKZIJDE-01	BKZ-01	ALTENA
10	BRAKEL-01	BRAK-01	ALTENA
13	BARENDRECHT-01	BRT-01	ALTENA
14	BARENDRECHT-02-SIDETRACK1	BRT-02-S1	ALTENA
15	BARENDRECHT-02-SIDETRACK2	BRT-02-S2	ALTENA
17	BARENDRECHT ZIEDEWIJ-02-SIDETRACK3	BRTZ-02-S3	ALTENA
19	BOSKOOP-01	BSKP-01	ALTENA
21	BUURMALSEN-01	BUM-01	ALTENA
28	GAAG-01	GAG-01	ALTENA
29	GAAG-02-SIDETRACK1	GAG-02-S1	ALTENA
32	GAAG-05	GAG-05	ALTENA
33	GEWANDE-01	GWD-01	ALTENA
34	GEWANDE-01-SIDETRACK1	GWD-01-S1	ALTENA
40	HILVARENBEEK-01	HVB-01	ALTENA

	A	B	C	D
1		ATAL		Thickness
2	**CODE**	**top**	**bottom**	**whole ATAL**
3	BKZ-01	1886	2127	241
4	BRT-01	2422	2927	505
5	BRT-02-S1	2565	2763	198
6	BRT-02-S2	2783	2861	78
7	BSKP-01	1439	1959	520
8	BUM-01	897	1147	250
9	GAG-02-S1	2885	2886	1
10	GAG-05	3314	3922	608
11	GWD-01	1614	1746	132
12	GWD-01-S1	1449	1606	157
13	IJS-64	2630	2711	81

Table 1

Colors of formations table1:
Red – not used
Yellow – bad log data
Orange – disputable log data
Green – good log: *prospective well*
Purple – thickness formation is below 50m

Well	total thickness (m)	Gas content peak [m before end fm]	Gas content peak (ppm)
GAG-05	608	100	281000
GAG-05	608	50	58000
BRAK-01	319	60	44000
GAG-05	608	0	42000
PRW-04	124	whole fm	3500-4000
BSKP-01	520	250	20000
OBLZ-01	97	0	19000
BRAK-01	319	0	18000
WWN-03	689	50	18000
WWN-03	689	45	18000
WWN-03	689	20	18000
BRAK-01	319	120	14000
BSKP-01	520	25	12000
SPG-01	54	45	11500
MSG-03	735	90	11005
BSKP-01	520	150	11000
MSG-03	735	75	10533
RDK-01	200	0	9762
MRK-01	411	180	9630
OBLZ-01	97	30	9000
SPG-01	54	25	9000
MSG-03	735	0	7111
WED-03	359	50	7000
MSG-03	735	30	5363
KDK-01	105	70	5000
RDK-01	200	100	5000
RKK-32-S3	423	35	5000
SPL-01-S1 - upper	484	10	5000
SPL-01-S1 - lower	641	80	5000
MRK-01	411	70	4708
SPG-01	54	0	4500
MRK-01	411	0	4000
RKK-32-S3	423	200	4000
WWK-01	572	70	4000
RKK-32-S3	423	100	3000
WED-03	359	15	3000
MSG-02	560	50	2585
MSG-02	560	0	2500
WWK-01	572	40	2500
SPL-01-S1 - lower	641	0	2000
WWK-01	572	0	1750
STW-01	212	0	1600
STW-01	212	140	1540
VRK-01	139	40	1500
KDZ-02-S1	406	120	1300
KDZ-02-S1	406	25	1200
STW-01	212	50	1100
BSKP-01	520	75	750
BRT-02-S1	198	60	704
KDZ-02-S1	406	55	600
BRT-02-S1	198	0	250

Table 2
Green: > 1%
Blue: 0.5-1%
Yellow: 0.1-0.5%
Orange: < 0.1%

All available wells selected on their gas content.

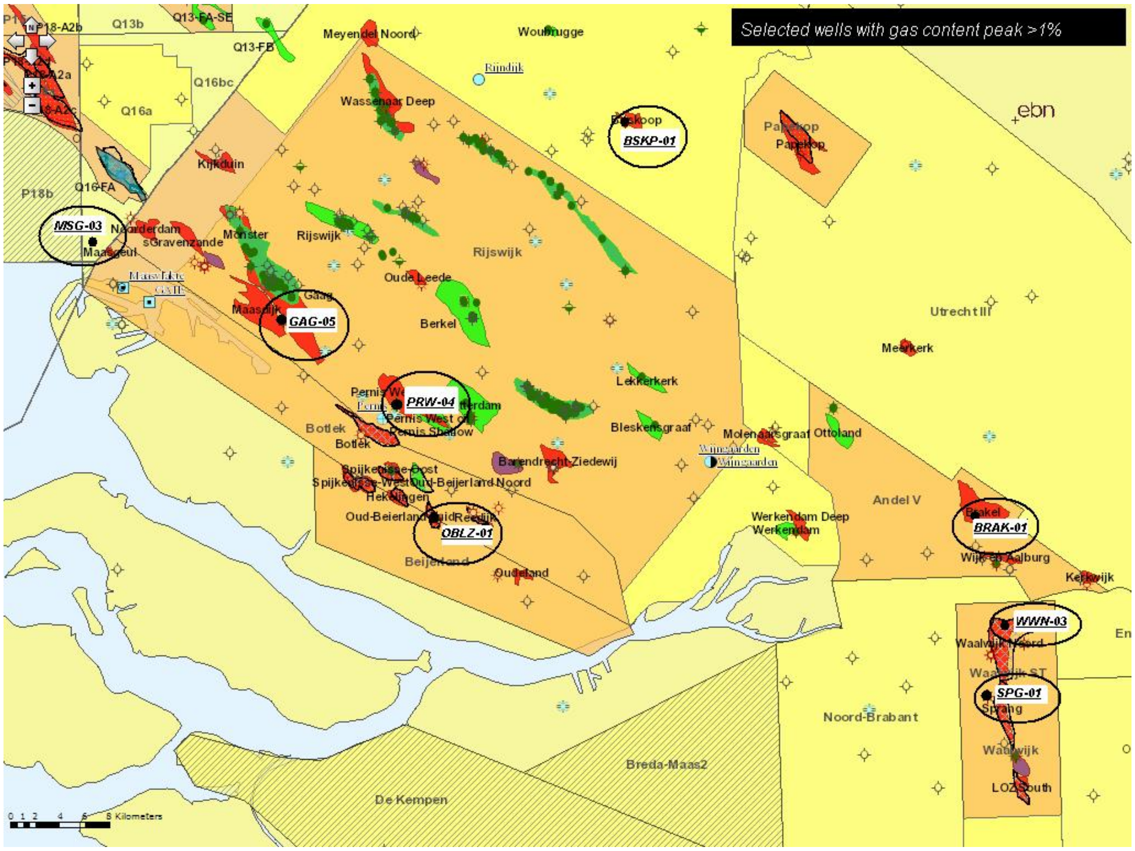
Overview prospective wells:

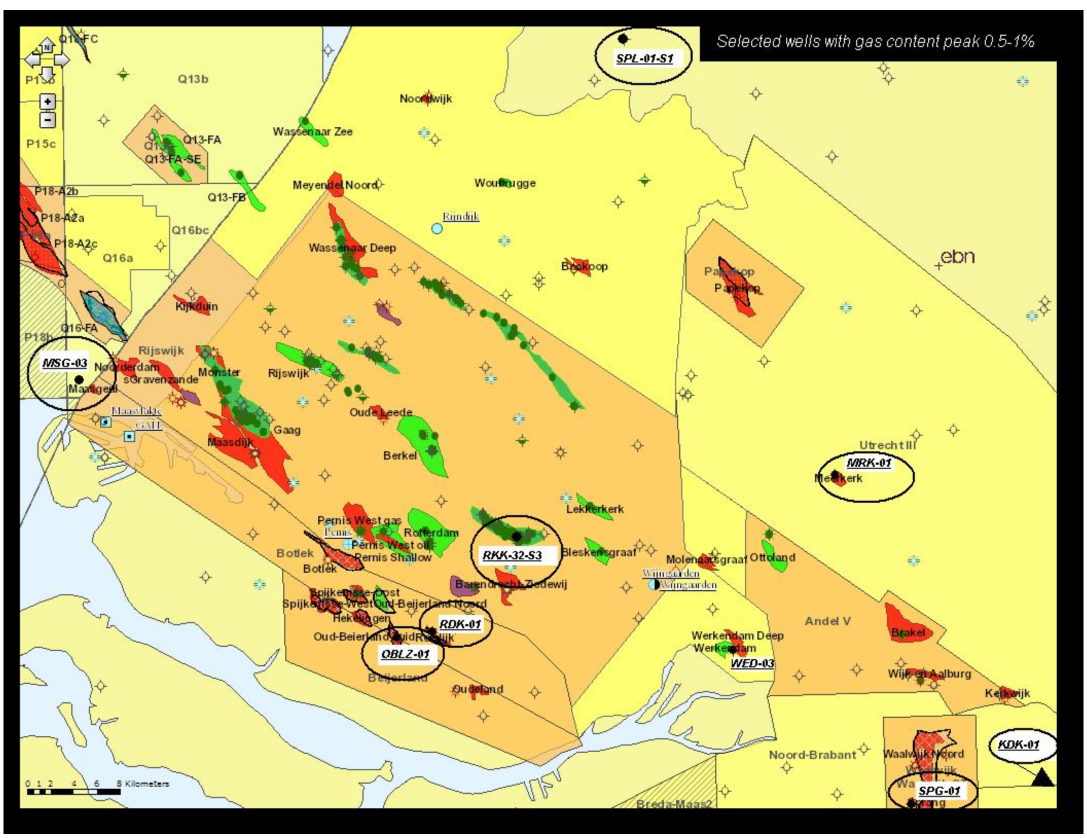
Well	total thickness (m)	start limestone [m before end fm]	Gas content peak [m before end fm]	Gas content peak (ppm)
BRAK-01	319		120	14000
BRAK-01			60	44000
BRAK-01			0	18000
BRT-02-S1	198	35 - end	60	704
BRT-02-S1			0	250
BSKP-01	520		250	20000
BSKP-01			150	11000
BSKP-01			75	750
BSKP-01			25	12000
GAG-05	608	50 - end	100	281000
GAG-05			50	58000
GAG-05			0	42000
KDK-01	105	30 - end	70	5000
KDZ-02-S1	406	120 - 100	120	1300
KDZ-02-S1			55	600
KDZ-02-S1			25	1200
MRK-01	411	40 - end	180	9630
MRK-01			70	4708
MRK-01			0	4000
MSG-02	560	50	50	2585
MSG-02		20 - end	0	2500
MSG-03	735	86	90	11005
MSG-03		65 - end	75	10533
MSG-03			30	5363
MSG-03			0	7111
OBLZ-01	97	35 - end	30	9000
OBLZ-01			0	19000
PRW-04	124		whole fm	3500-4000
RDK-01	200	40 - end	100	5000
RDK-01			0	9762
RKK-32-S3	423	35 - end	200	4000
RKK-32-S3			100	3000
RKK-32-S3			35	5000
SPG-01	54		45	11500
SPG-01			25	9000
SPG-01			0	4500
SPL-01-S1 - upper	484	50	10	5000
SPL-01-S1 - lower	641	100	80	5000
SPL-01-S1 - lower		75 - end	0	2000
STW-01	212	spots	140	1540
STW-01			50	1100
STW-01			0	1600
VRK-01	139	60 - end	40	1500
WED-03	359	180	50	7000
WED-03		end	15	3000
WWK-01	572	80	70	4000
WWK-01		65	40	2500
WWK-01		40 - 15	0	1750
		end		
WWN-03	689	170	50	18000
WWN-03		60 - end	45	18000
WWN-03			20	18000

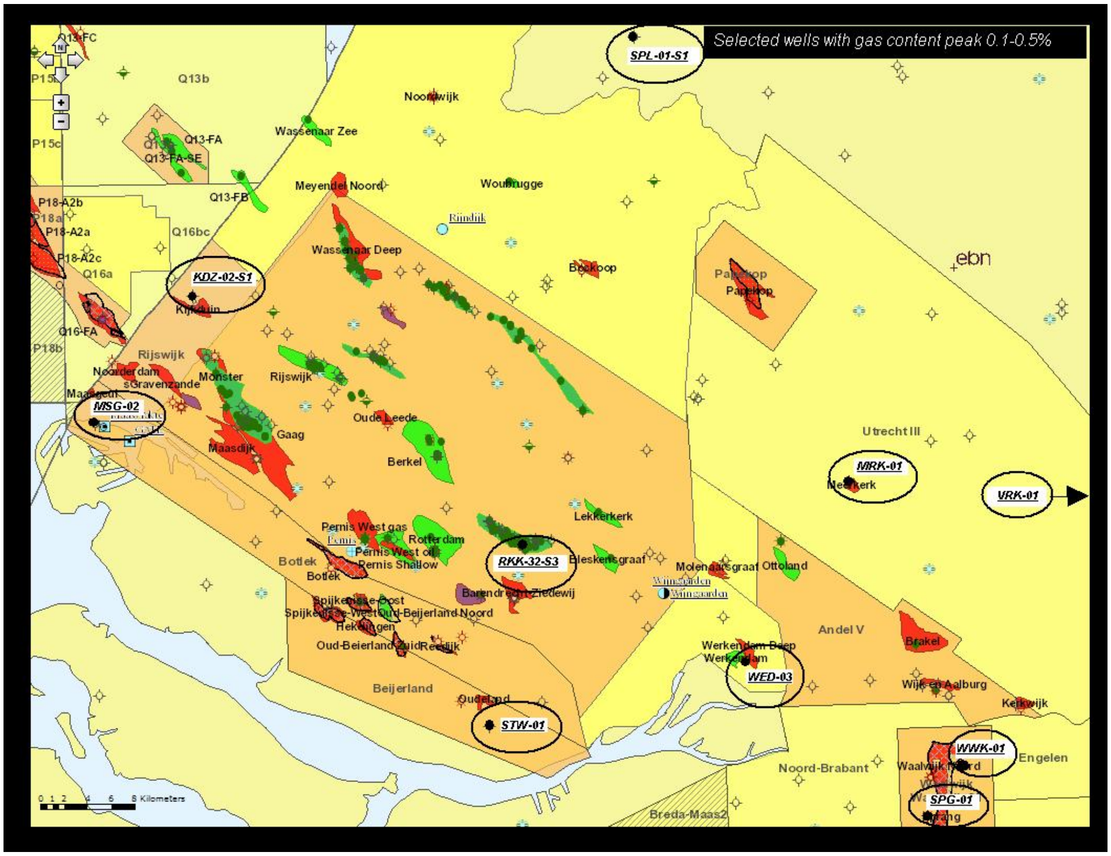
Table 3

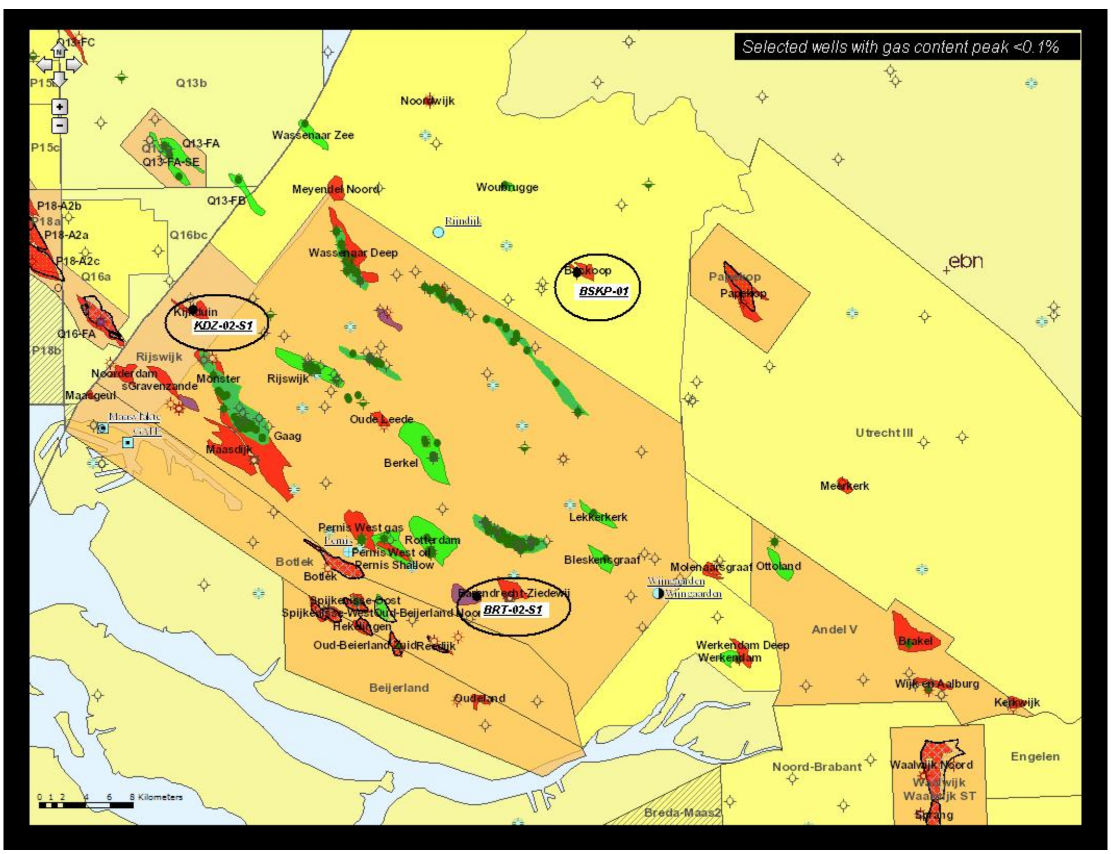
In the table above the prospective wells are subdivided in parts based on the gas content peaks present in the mudlog. This is done to find a consistent thickness for the proposed Lower Aalburg Formation.

Maps (from in-house WebGIS) with wells selected on present gas content peaks in the log data:






Selected wells with gas content peak 0.1-0.5%
SPL-01-S1
KDZ-02-S1
MSG-02
RKK-32-S3
MRK-01
VRK-01
WED-03
STW-01
WWK-01
SPG-01
Q13b
Noordwijk
Wassenaar Zee
Q13-FA
Q13-FA-SE
Q13-FB
Meyendel Noord
Woubrugge
Q16bc
Wassenaar Deep
Boskoop
Papekop
Rijswijk
Monster
Gaag
Oude Leede
Berkel
Maasdijk
Utrecht III
Lekkerkerk
Pernis West gas
Rotterdam
Pernis Shallow
Botlek
Bleskensgraaf
Molenaarsgraaf
Ottoland
Barendrecht-Ziedewij
Andel V
Brakel
Oud-Beijerland Noord
Oud-Beijerland Zuid
Beijerland
Werkendam Deep
Werkendam
Wijk en Aalburg
Kerkwijk
Engelen
Noord-Brabant
Breda-Maas2
ebn
0 1 2 4 6 8 Kilometers


Selected wells with gas content peak <0.1%
KDZ-02-S1
BSKP-01
BRT-02-S1
Q13b
Noordwijk
Wassenaar Zee
Q13-FA
Q13-FA-SE
Q13-FB
Meyendel Noord
Woubrugge
Q16bc
Wassenaar Deep
Boskoop
Papekop
Rijswijk
Monster
Gaag
Oude Leede
Berkel
Maasdijk
Utrecht III
Meerkerk
Lekkerkerk
Pernis West gas
Rotterdam
Pernis Shallow
Botlek
Bleskensgraaf
Molenaarsgraaf
Ottoland
Andel V
Brakel
Beijerland
Oudeland
Werkendam Deep
Werkendam
Wijk en Aalburg
Kerkwijk
Engelen
Noord-Brabant
Waalwijk Noord
Waalwijk ST
Sprang
Breda-Maas2
ebn
0 1 2 4 6 8 Kilometers

1.3 Conclusions

Only three wells show gas content peaks of >1% and 0.5-1% and are called prospective:
MSG-03
SPG-01
OBLZ-01

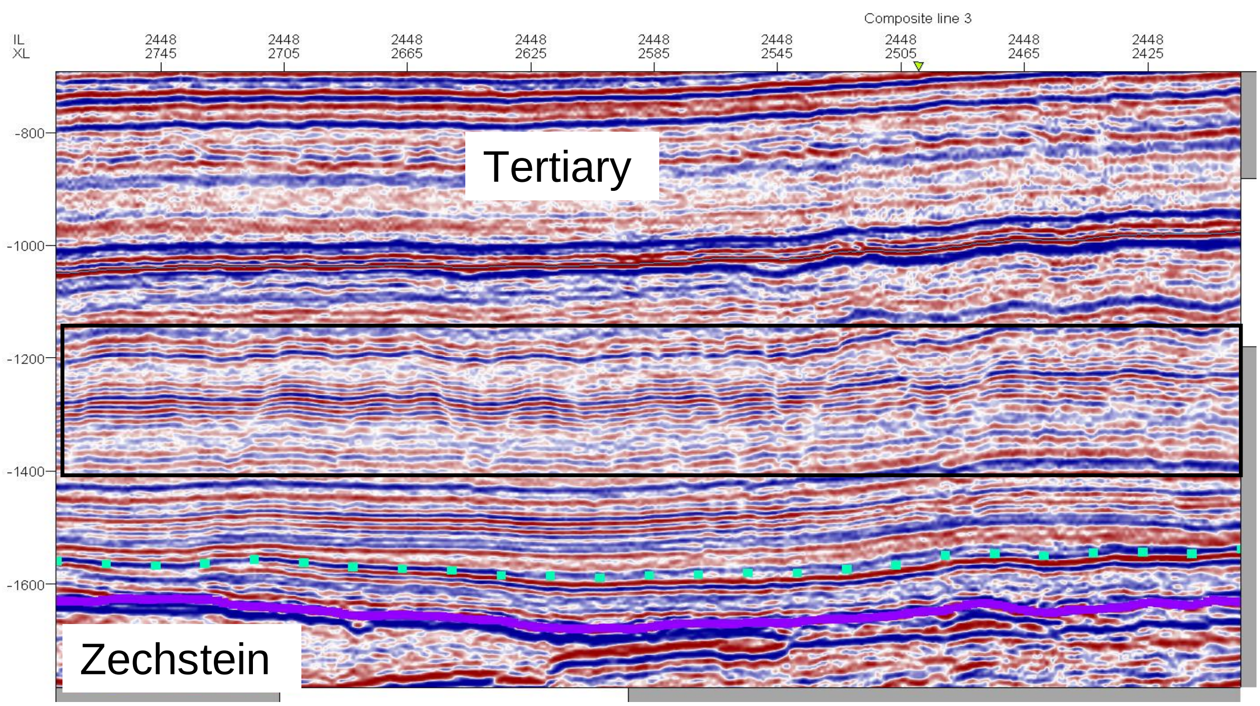
Unfortunately these wells are not located in the same seismic survey block. In order to perform a good seismic study other wells have to be included to have enough data available. A future study on the Aalburg Formation should take into account that good well data is sparse and therefore good knowledge on seismic interpretation is needed to deal with this.

Another consequence of the bad quality and quantity of the well data is that there are not enough indications to propose a completely new formation for the lowest part of the Aalburg Formation. There are some characteristics found (high gas content peaks, limestone present) and a more detailed study on other log data can be positive. However, in the three weeks I worked on this project there was not enough time to go into detail on this, so opportunities still exists on this proposal for a new formation.

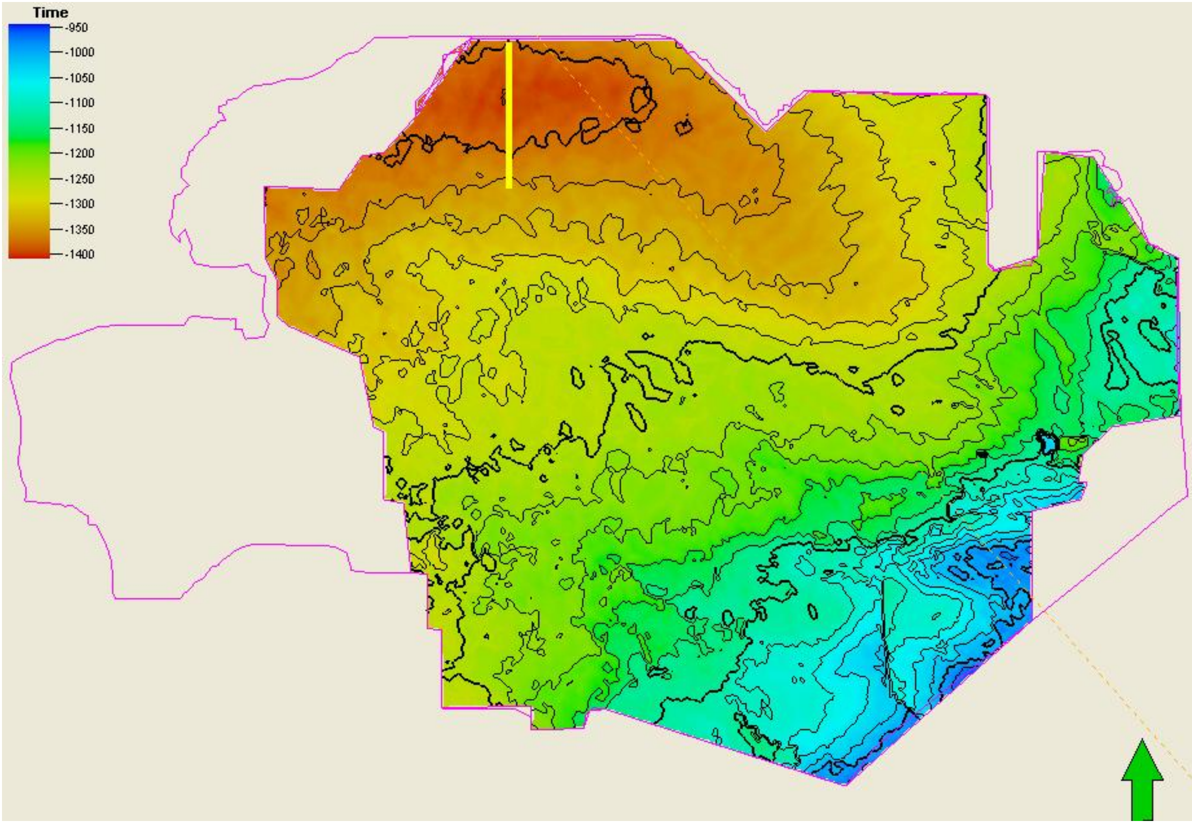
2. Gorredijk concession

2.a Polygonal faulting in the Chalk Group

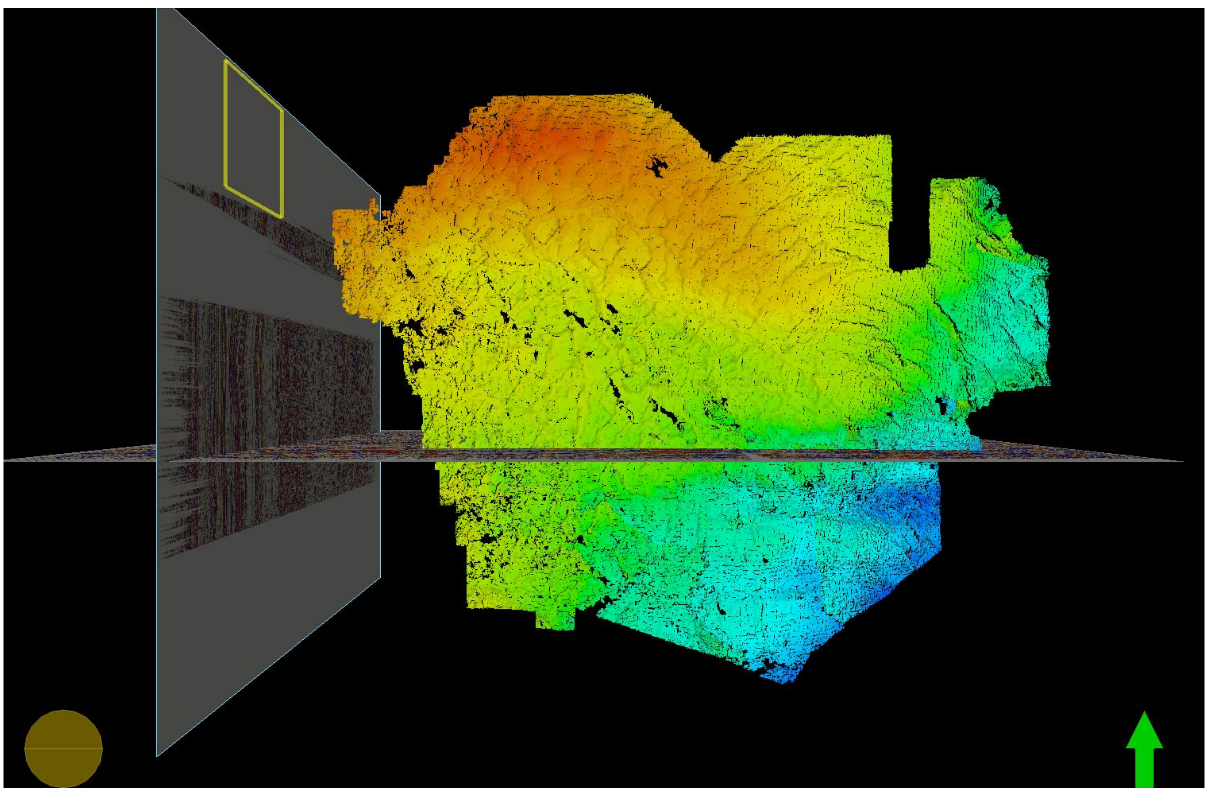
During scanning of the seismic data of the Gorredijk concession for the Tertiary study I noticed several normal faults in the formation below. Remarkably this faulting is only present in this formation which is the Cretaceous Chalk Group. Formation or layer bound normal faults could be polygonal faults. In map view the faults should have a polygonal pattern.
Because the Chalk Group is out op scope of the main study of my internship I only performed a short study to find out of this faulting is indeed polygonal faulting. With use of 'autotracking' in Petrel I made a surface of one of the bright reflectors in the Chalk Group which is faulted. From Cartwright et al. (2003) the constructed map is compared with their proposal for typical plan form patterns. From this small research I conclude that polygonal faulting is present in the Chalk Group which indicates an extensional stress regime during the Cretaceous. It is known from Herngreen & Wong (2007) that during deposition of the Chalk Group strong inversion and erosion of the Jurassic depocenters took place concordant with regional differential subsidence. From the presence of polygonal faults in the Gorredijk concession it can be concluded that a (regional) extensional regime, possibly with subsidence, affected this area. The physical process of the formation of these large scale structures can be compared with the formation of mud cracks in a dry lake. However, one must take the scale into account, which is much larger for these polygonal faults. For a better understanding of the direction of the polygonal faults, 'ant tracking' is performed in Petrel on a clear reflector in the Chalk Group. This shows a clear NE-SW main trend of the faults.



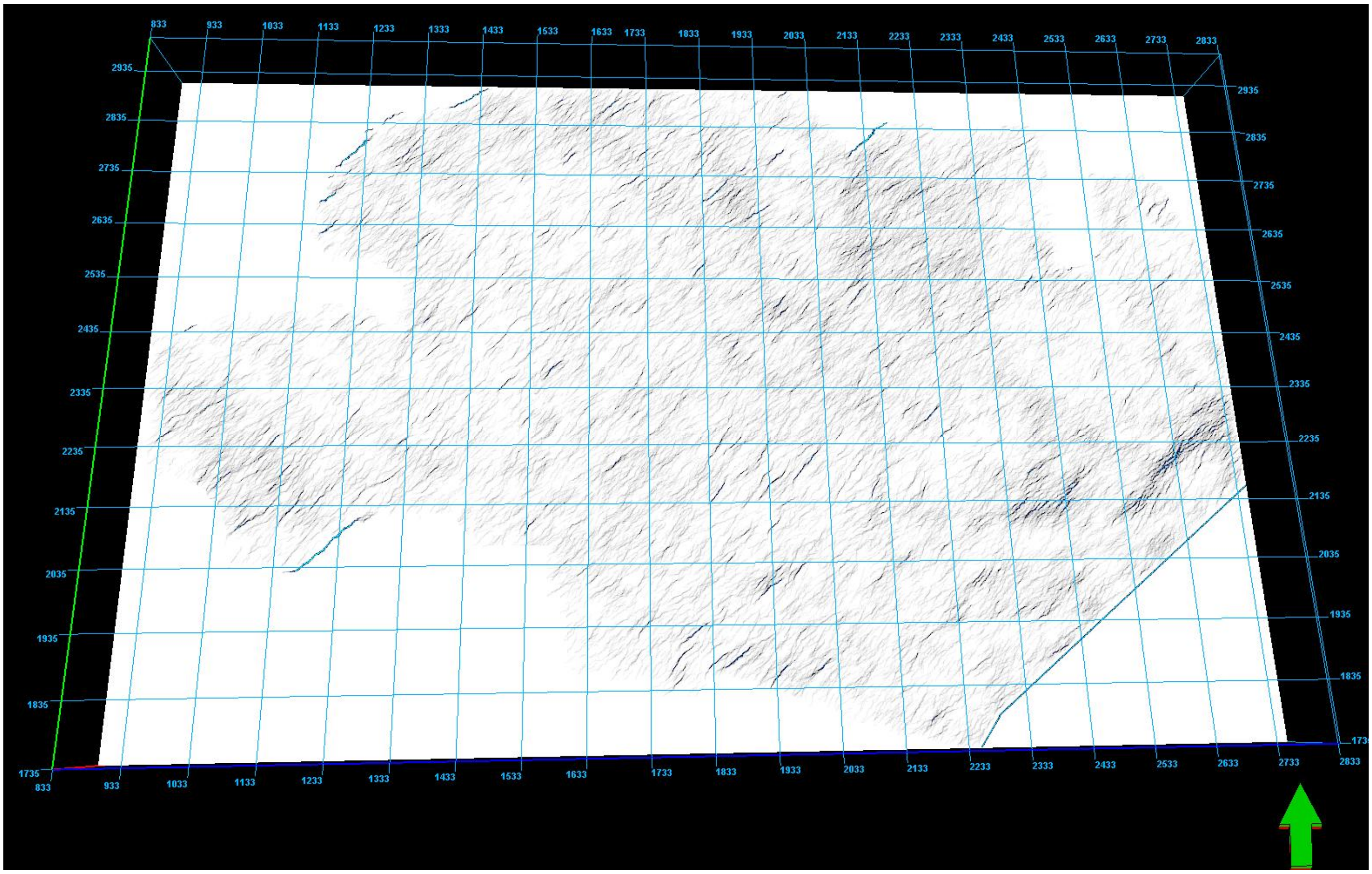
In the box the recognized faulted pattern in the Chalk Group(N-W in-line seismic cross section).



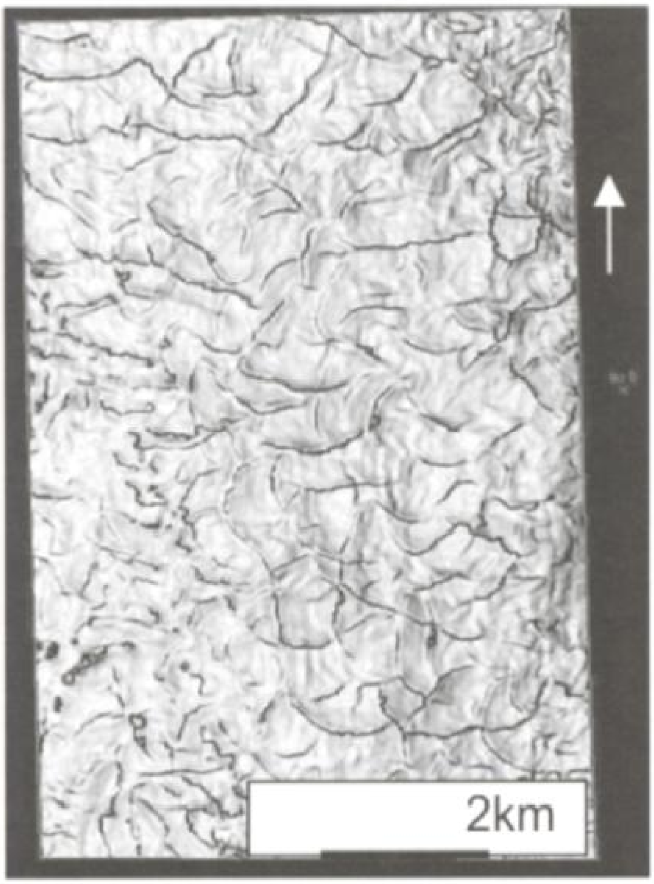
Mapped surface of a faulted Chalk reflector. The reflector is not present in the western part of the seismic area. The spiked appearance of the contour lines is due to faulting.



Interpreted surface of the faulted Chalk reflector. The curved fault pattern can be recognized from the elevation differences of the mapped surface.



Top view of an 'ant tracked' Chalk Group inra-reflector. This procedure shows irregularities in the seismic signal, which is an indication for faults. The main direction is NE-SW.



Adapted from Cartwright et al. (2003): Typical curved plan form pattern of a polygonal fault system. This patterns is very similar to the pattern recognized in the mapped Chalk reflector.

References

Cartwright, J., James, D., Bolton, A.; 2003. The genesis of polygonal fault systems: a review. Geologocial Society, London, Special Publications, vol. 216, pp 223-243.

Herngreen, G.F.W. & Wong, Th. E.; 2007. "Cretaceous' in Geology of the Netherlands. Edited by Th.E. Wong, D.A.J. Batjes & J. de Jager. Royal Netherlands Academy of Arts and Sciences, pp 127-150.

2.b Zechstein salt structures

From the seismic interpretations of the Tertiary reflectors in the Gorredijk concession, influence of a salt dome in the east is found. This is expressed in the 'Smilde' High and Low (see report on Tertiary, Figure 22). Zechstein salt is of big importance for the Dutch hydrocarbon exploration, since it acts as both a seal and reservoir.
A study from van de Sande et al. (1996) shows that thickness differences in the Zechstein 2 carbonate cycle can be linked with slope analysis. For the area east of the Gorredijk concession they proposed a structural model for this area in terms of basin configuration (see figure below).

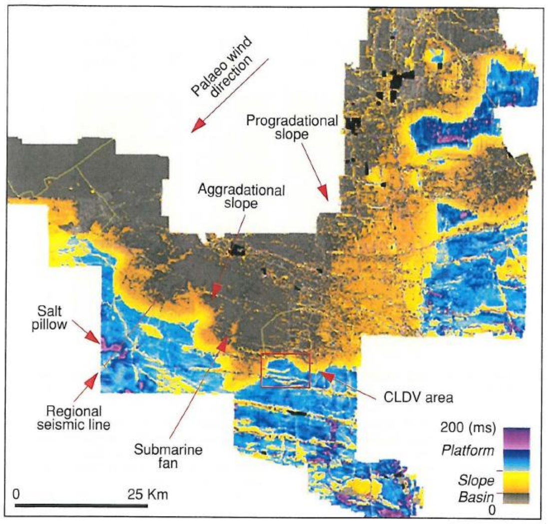


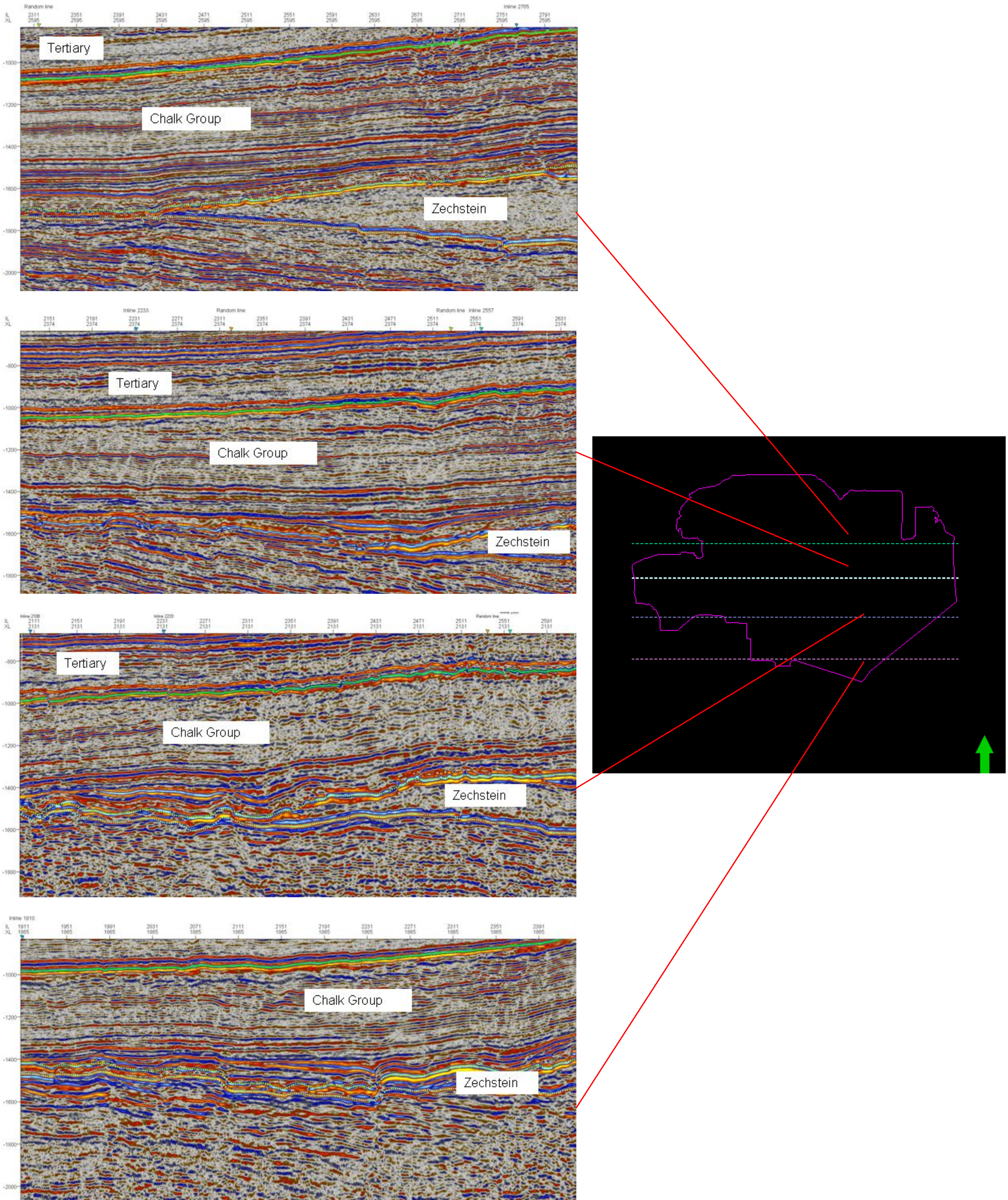
Figure 9 from van de Sande et al. (1996) showing a time isochore map of the Basal Zechstein Unit (which includes Z1 anhydrite, Z2 carbonate and Z2 Anhydrite) with indicated the platform, slope and basin as interpreted from the salt structures.

The relation between thickening of the Zechstein 1 and 2 cycles and the position of the basin slope can be expected in the study area of this report as well. Besides the salt dome found in the east of the Gorredijk concession, no clear thickness differences are found in the seismic data. The figure on the next page shows some seismic cross sections (W-E, x-line) through the seismic data (positions indicated in the outline figure to the right).
Since no clear thickening features are found it can be concluded that the slope of the basin is situated more to the SE. More detailed mapping of the different Zechstein units can give more insight, this was however beyond the scope of the internship since mapping of the Zechstein is very difficult and time consuming.

EDIT: Below you can find a short workflow description for mapping of the Z1 in the Gorredijk area.

References

van der Sande, J.M.M., Reijers, T.J.A., Casson, N.; 1996. Multidisciplinary exploration strategy in the northeast Netherlands Zechstein 2 Carbonate play, guided by 3D seismic. In: Rondeel et al. (eds), Geology of gas and oil under the Netherlands, pp 125-142, 1996.

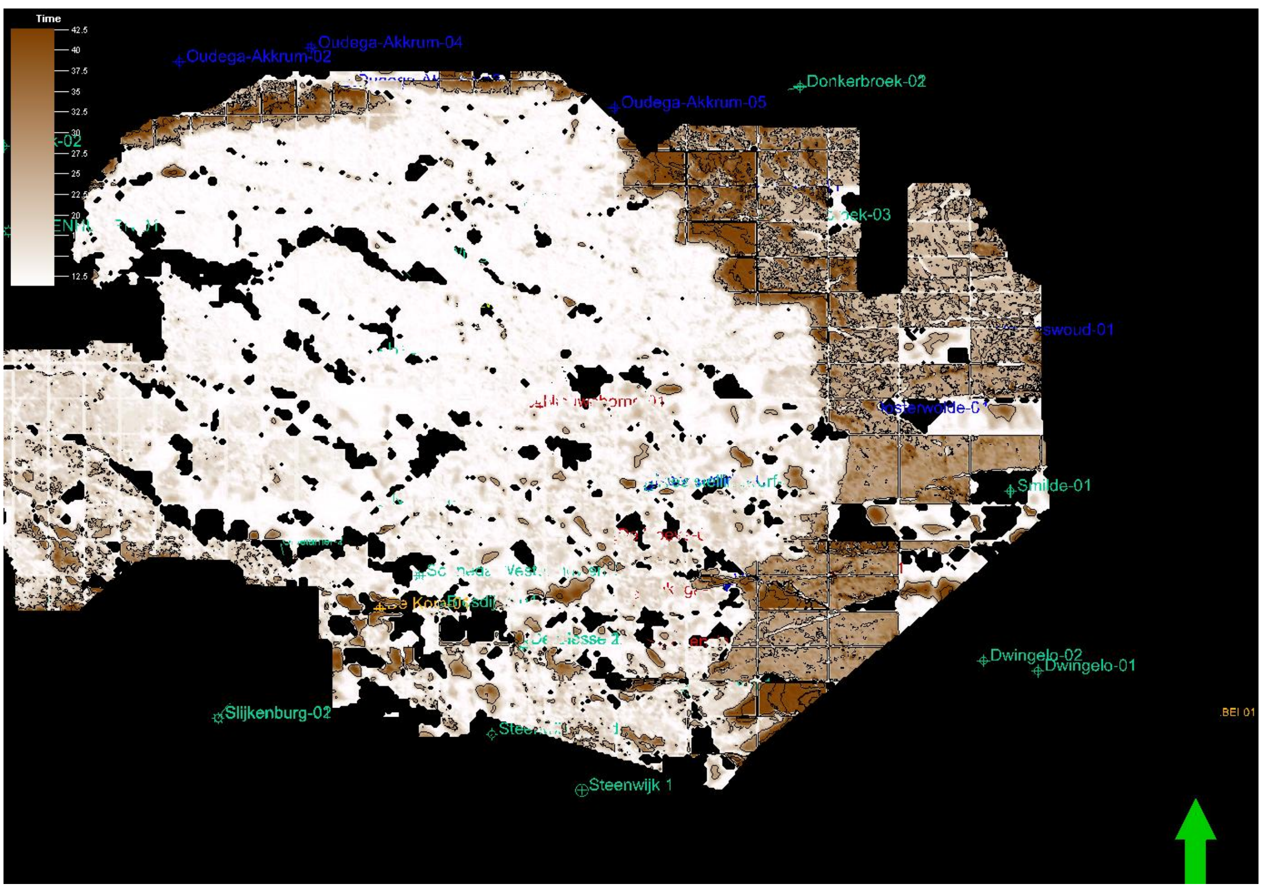

Tertiary
Chalk Group
Zechstein
Tertiary
Chalk Group
Zechstein
Tertiary
Chalk Group
Zechstein
Chalk Group
Zechstein

Mapping of the Z1

From well data a thickness map is constructed by Annemiek Asschert for the Z1-cycle. This map in meters is converted to TWT in Petrel as follows:

A copy of the Base Zechstein map is used as a basis. With the calculator function the new surface is calculated with with the formula Time = Distance / Speed. Time is here the resulting map, Distance is the thickness map from Annemiek, and for the Speed a value of 6000m/s is used on advice of Guido Hoetz.

The calculated TWT map is used as a guidline for the interpretation of the top Z1. It appeared that the top Z1 is in between a red and a blue marker, therefore the function Z-crossing is used during autotracking. Best seismic color-scheme to use is red-white-black. In the subfolder constraints of autotraking the top and bottom boundaries for the interpreted marker are used to guide the tracking. For top the top Zechstein (shifted 13 ms down) is used and for base the base Zechstein (shifted 10 ms up). The result is shown below. QC is needed in the areas of the Zechstein salt, here a wrong marker is taken during tracking. Thickening of Z1 is very subtle and values are on the boundary of the seismic resolution, making it very hard to get clear results.



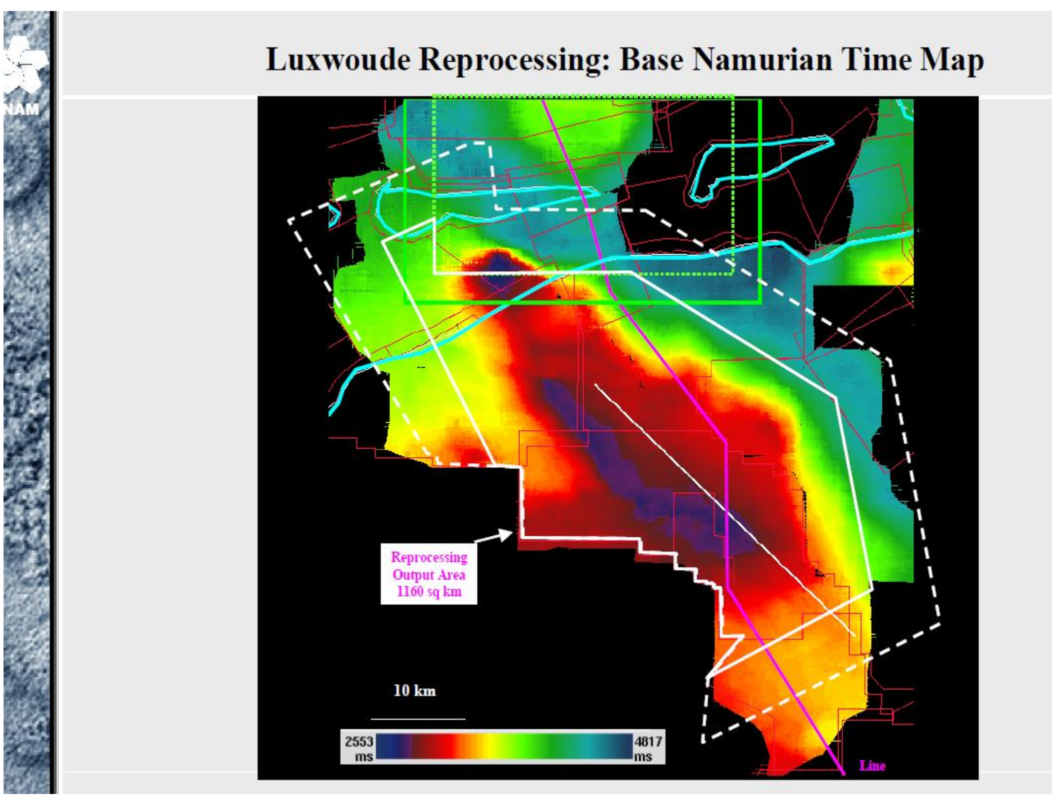
Thickness map (in time) of Z1. Range is from 12.5 (white) to 42.5 (brown). Discard the area in the east, this must be checked. The area in the south shows a small thickening, this is in the area with the main producing wells.

2.c Carboniferous reefs (Petrel project: G:\TZ\Projecten Utr\Gorredijk\Projecten\Project AD\Petrel/Gorredijk-Follega_AD.pet)

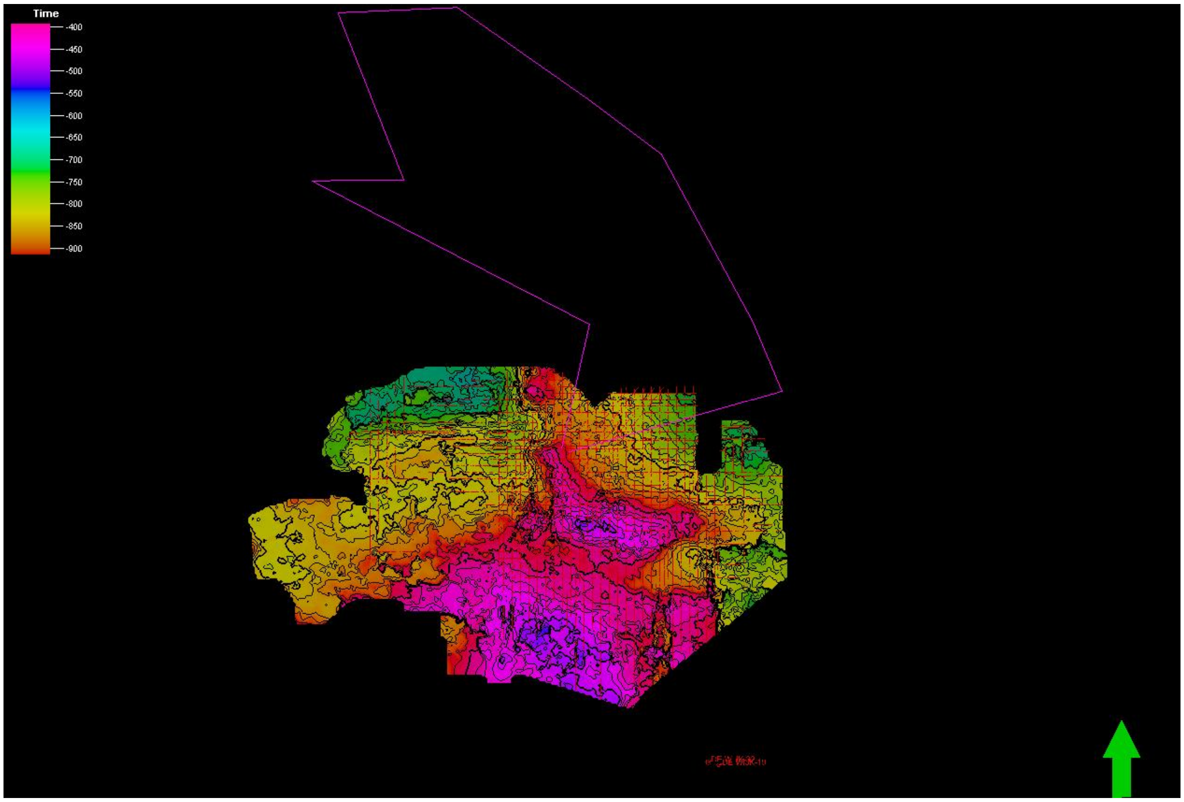
From different studies, both offshore and onshore, the presence of large Carboniferous reefs is known in the Dutch subsurface. A study from Kombrink et al. (2008) shows the outline of a large reef in the area around the Gorredijk area. From the Groningen area good seismic images are known from which the reef structure can be clearly recognized. North of the Gorredijk area a study from NAM (Luxwoude area/ 'Dokkum') visualizes a large reef as well.

In the Gorredijk area the same structure is recognized in the subsurface. However, it must be noted that with a lack of well data and seismic processing no age constrain can be given. The interpreted marker is therefore suggested to represent the Carboniferous reefs from the studies mentioned above. Because of the large scale of the structure interpreting in detail is not performed. To construct a seismic surface ('structural map') of the reef a manual grid is build in Petrel, using step sizes of 10 in the area thought to represent the rim and larger steps in the east and west. Below the constructed map is shown plus some seismic intersections showing the onlapping of sediments on top of the reef and a thick wedge underneath the Friesland platform. From this map it can be concluded that no large reef is present in the south part of the area: when the seismic lines would be corrected for the tilt (clearly seen in the overlying sediments) a basin structure would appear. In the north the rim of a narrow reef is visible, this can be the extension of the Luxwoude reef. To study this, the seismic data must be extended (using the in-house available 'Terra Cube').

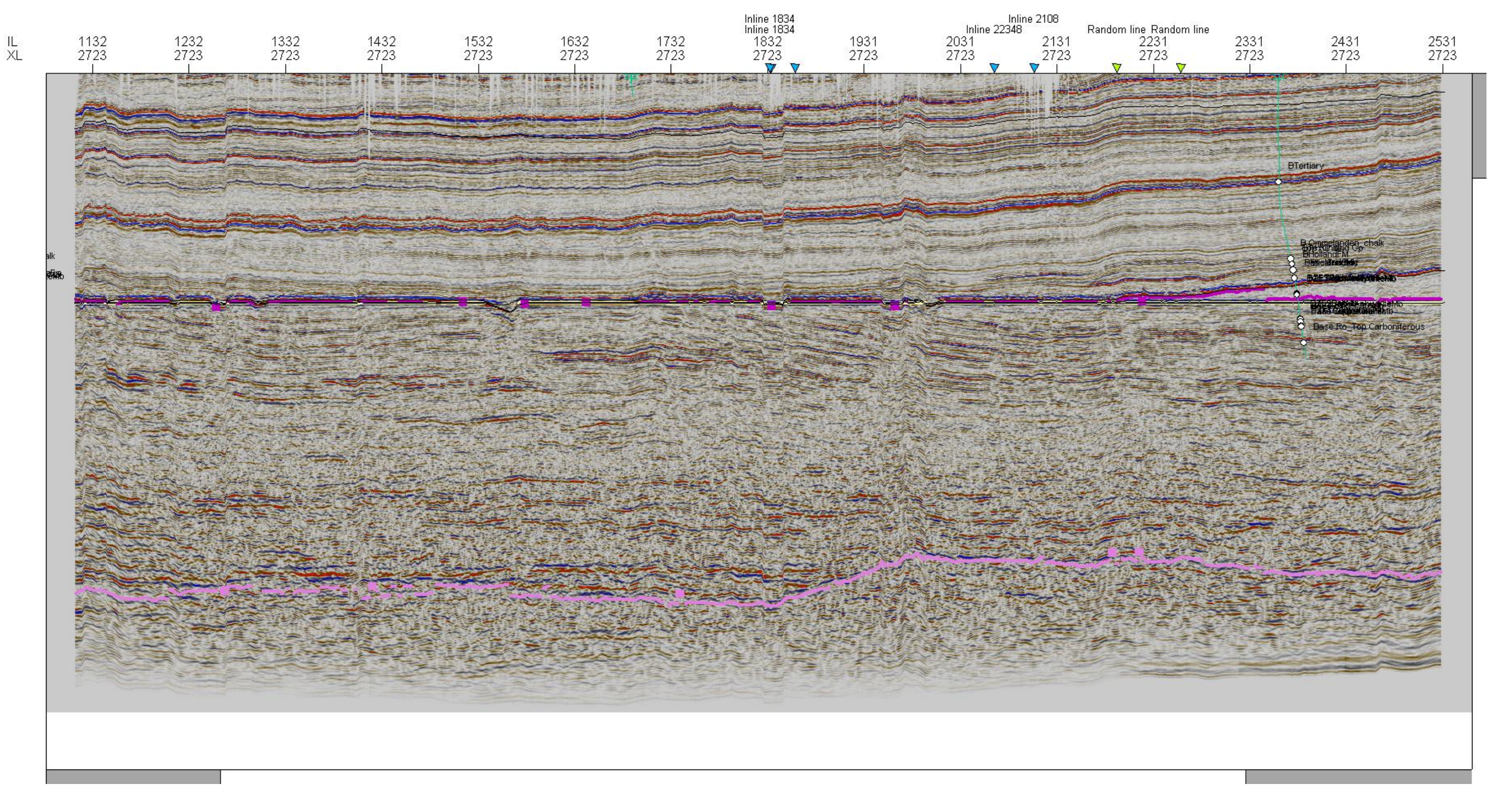
Part of improvement is the area in the east, underneath the Zechstein salt. Here the seismic data is blurry which makes it hard to follow the right seismic horizon. More time must be spent on this part for a better understanding of the reef in this part.



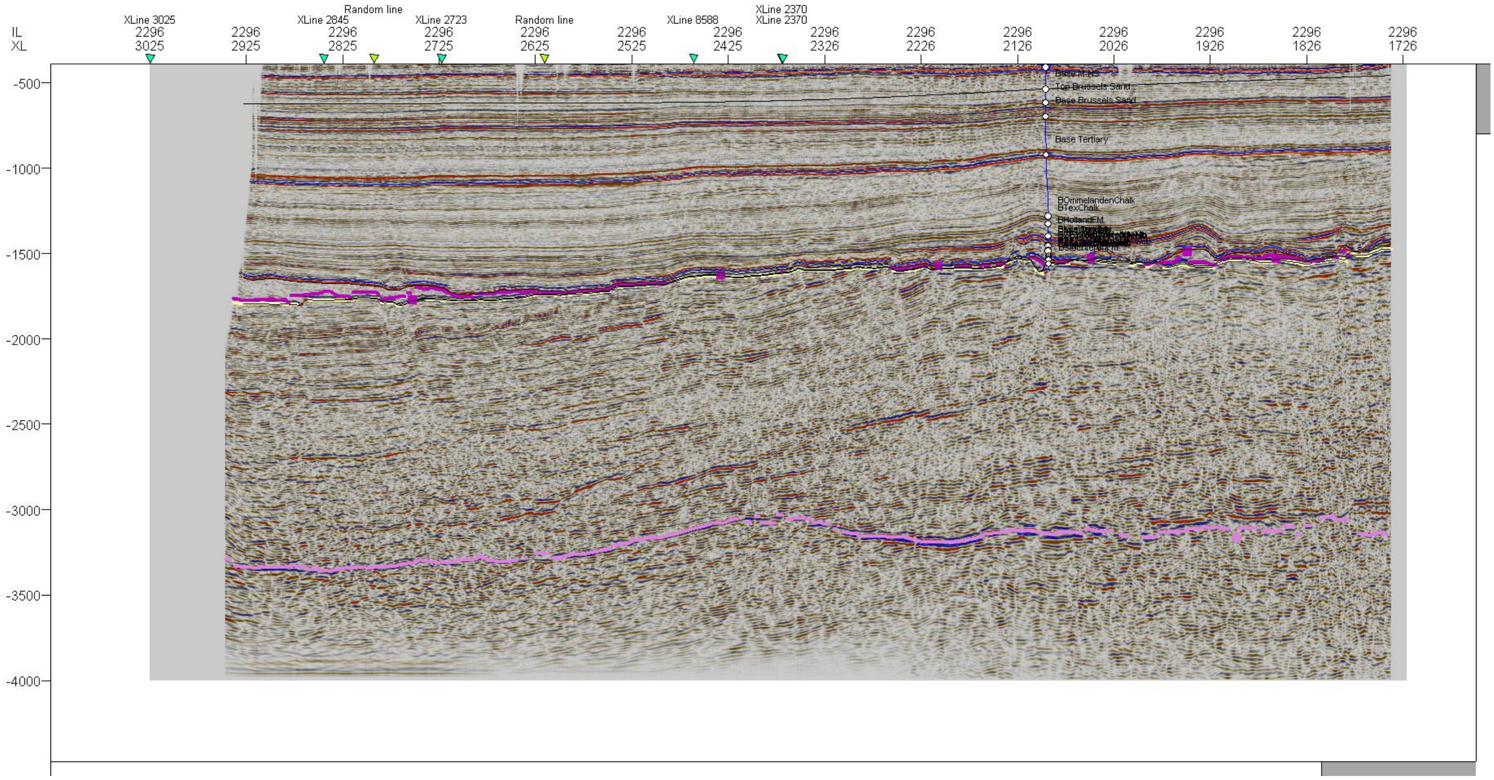
Structural map from NAM of the Luxwoude reef. Blue/red colors indicate a high presence of the mapped marker, green a low presence of the marker. Outline of the reef (red colors) is roughly copied and pasted in the figure below (purple outline).



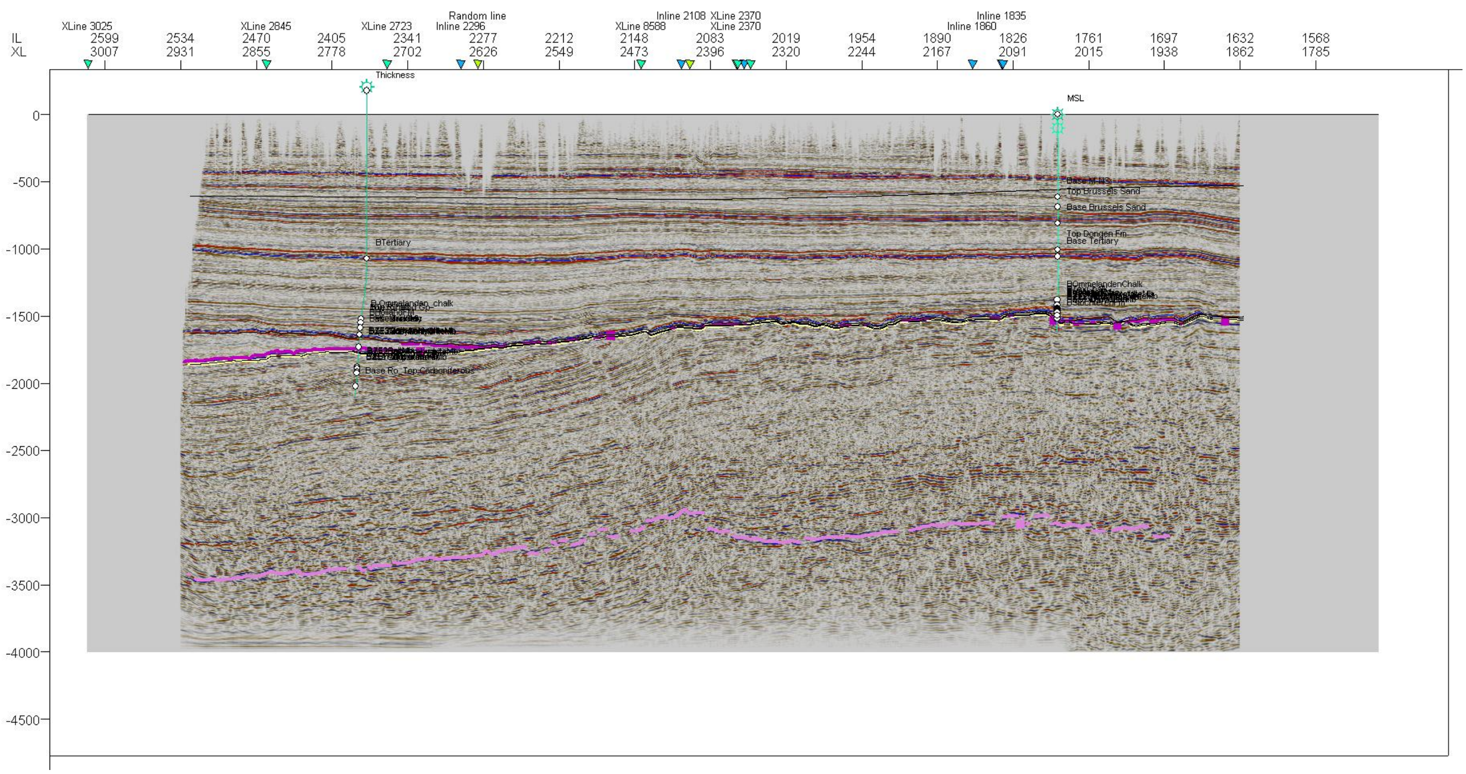
Structural map of a Carboniferous marker in the Gorredijk area, showing reef structures. Colors are roughly similar to figure above. Purple outline shows the margins of the Luxwoude reef from NAM. It can be seen that this reef extends into the Gorredijk area and bends to the east.



W-E seismic intersection of x-line 2723 (northern part of the area). Pink line represents the interpreted horizon, showing in the middle of the image clear onlapping on the reef structure. Seismic is flattened on base Zechstein marker.



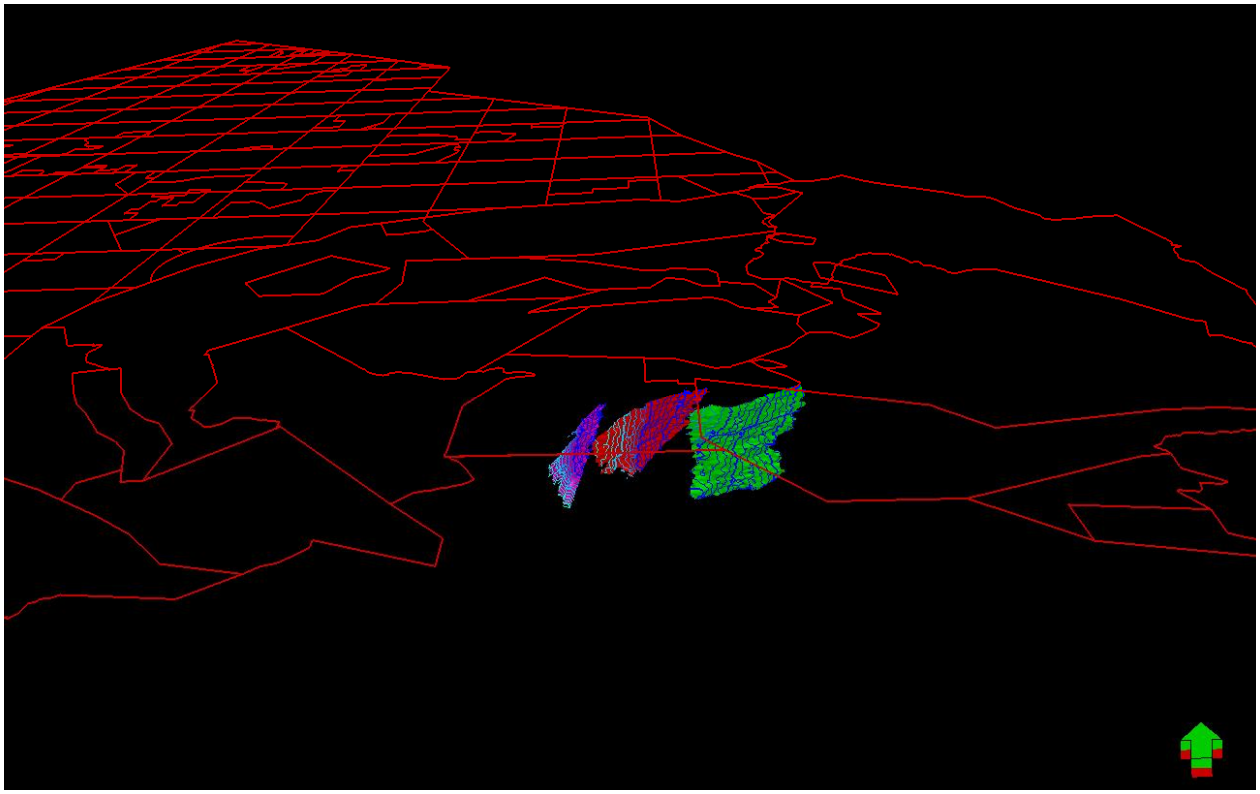
Seismic intersection (N-S, inline 2296) without flattening of the seismics. A clear thickening in the south part is visible and no reef structure is present there.



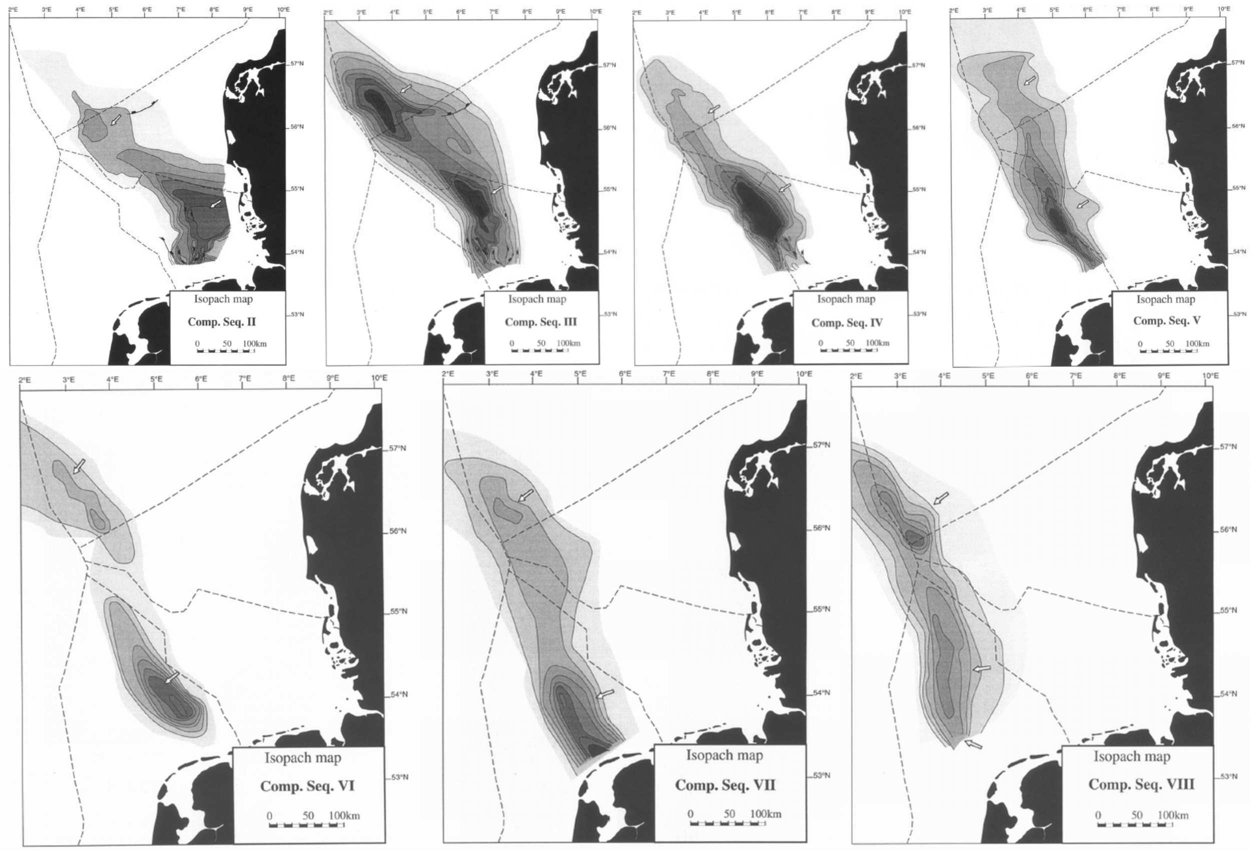
NE-SW seismic intersection through the reef and Friesland platform. No reef is present underneath the Friesland platform, instead a basin structure with wedging sediments on top can be seen (right part of the figure). The rim of the reef at the northern side is clearly visible in the structural map as well.

2.d Neogene delta deposits

As described in the report, deltaic lobes are recognized in the seismics of the studied area which onlap on the Mid Miocene Unconformity (see Figure 10 from report). It is suggested that these lobes are part of the Eridanos fluvio-deltaic system, which is located in the North. Here, a Petrel snapshots of the studied deltaic lobes is shown, visualizing the sediment supply from the East. Figures 14-20 from Sorensen et al. (1996) are included as well to show the possible extrapolation of the Eridanos delta to onshore Netherlands. The Rhine-system is an option to keep in mind as supply for the delta deposits found in the studied area. However, other studies (see for example 'Ondergrond van Nederland', TNO) show an after-glacial shift from the east to the south, implying the cut-off of the eastern Eridanos supply by the ice sheets from the north during the first extensive glacial, which gives rise to the supply from the south of the Rhine-system.



Snapshot from Petrel showing three mapped top of Neogene delta lobes. It is clear to recognize the supply direction from the East. In red outline of the Nl concesions (straight squares are offshore).



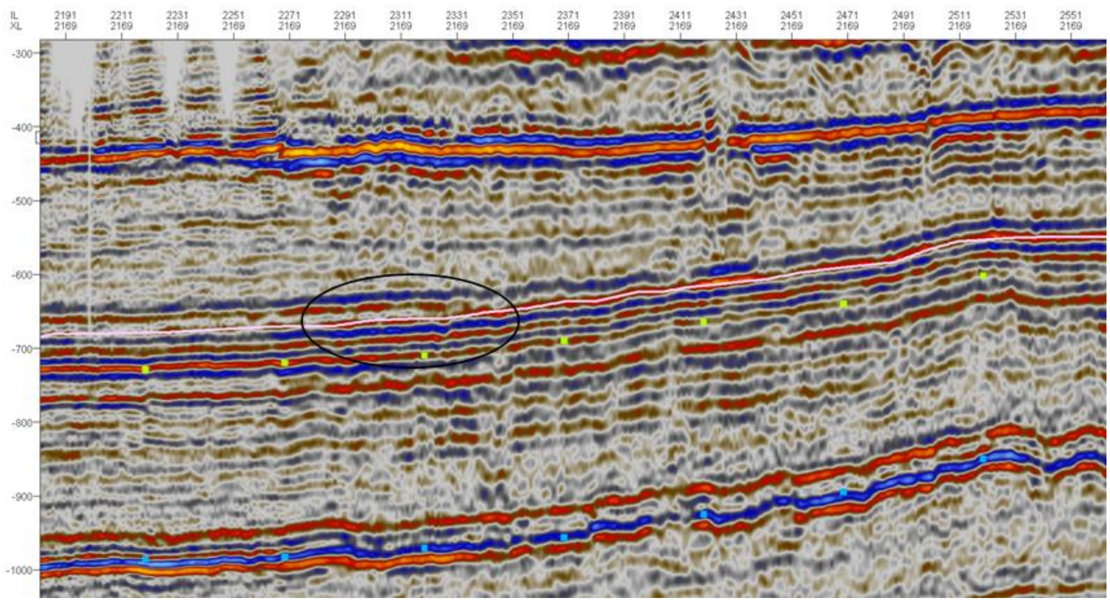
Isopach maps of composite sequences II-VIII (from top left to bottom right) from the Eridanos delta offshore Netherlands. Dark colors represent deeper presence in the subsurface indicating bigger depocenters. Arrows show the dominant direction of progradation. Adapted from Sorensen et al. (1996). Composite Sequence VII shows a cut-off of the depocenter. Extension of this depocenter to onshore Netherlands points to the studied area.

2.e Geological features in 3D seismic data

During seismic interpretation of Tertiary reflectors for the main part of this report, several geological features are recognized. Below a short overview of the found features (which are not described in the previous sections) with their geological meaning can be found. This is to show how seismic data can help to understand the subsurface (of the Netherlands).

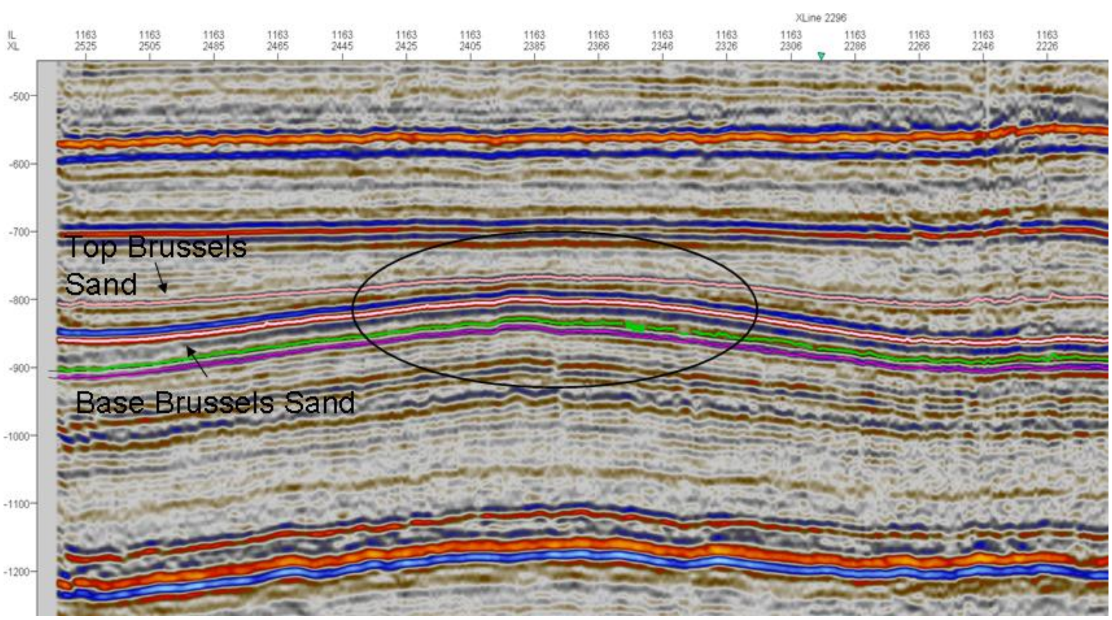
Onlap in the Brussels Sand Member:

Correlated with the introduction of extra reflectors in this member as described in the Tertiary report.



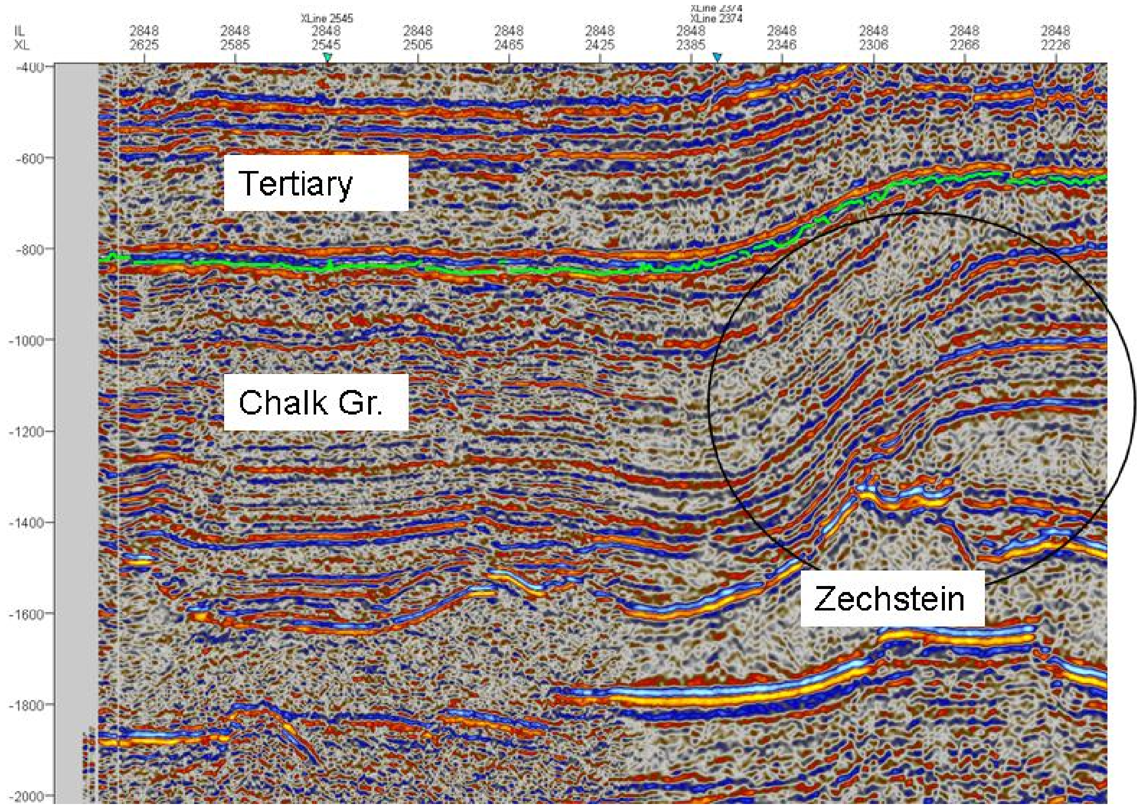
Cross-line (W-E) seismic cross section

No sedimentation/erosion on top of a topograghic high (Brussels Sand Member):



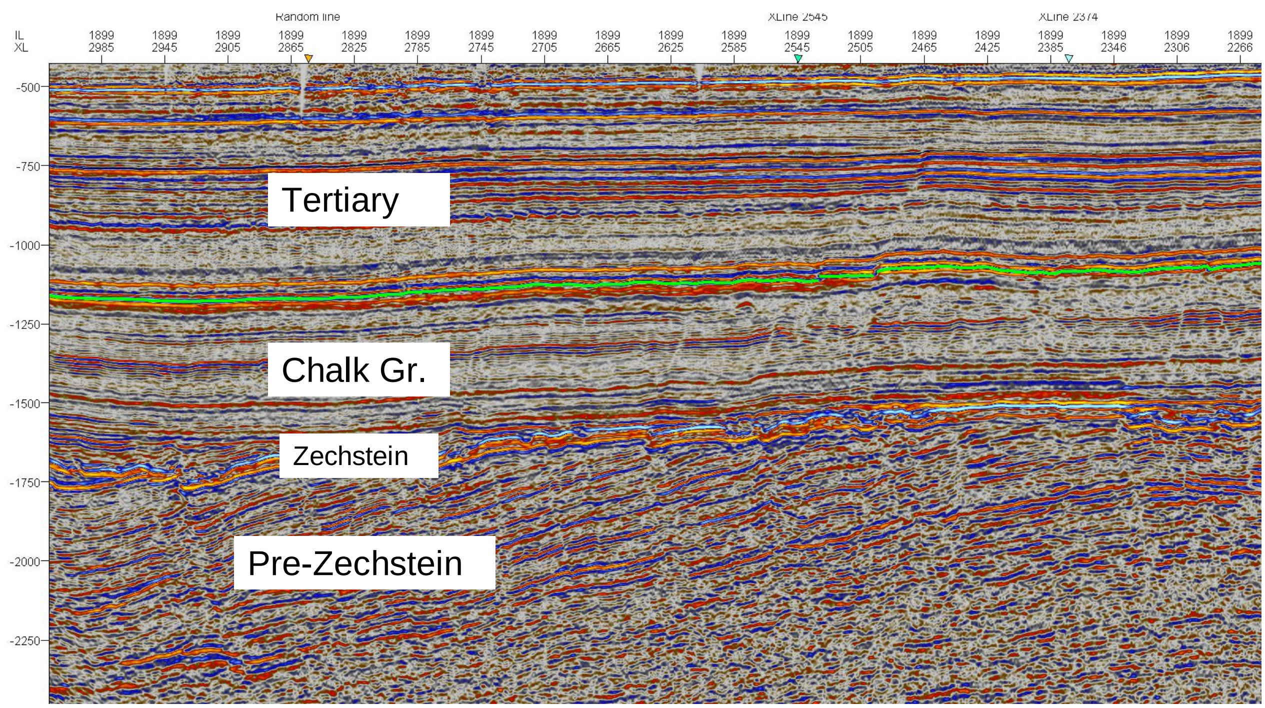
Cross-line (W-E) seismic cross section

Deformation effects above salt dome: Onlap of layers up to Tertiary:



In-line (N-S) seismic cross section

Tilting of Pre-Zechstein deposits: Angular unconformity with younger, semi-parallel deposits:



In-line (N-S) seismic cross section