Deltares

Clarification Boom clay & Glauconitic sands Terneuzen

Clarification Boom clay & Glauconitic sands Terneuzen

Client	Ministerie van Economische Zaken en Klimaat
Contact person	
Project references	-
Keywords	-

Document information	
Version	1.0
Date	14-04-2026
Project number	11209639-013
Document ID	11209639-013-GEO-0005
Pages	17
Classification	
Status	Final

Introduction

In our report 11209639-013-GEO-0001, version 1.0 (dated 4 August 2025, referred to as Vermaas et al., 2025) an inventory of the subsurface conditions of the Terneuzen location is given. As the presently the amount of available local subsurface investigations is limited, this results in uncertainties regarding the subsurface conditions. For the site selection process Deltares was asked to provide an expert opinion regarding the possible variations with respect to the Rupel Formation layer (Boom clay) and the glauconite sand layer below it. The results of this expert opinion can be used to assess if the Terneuzen site contains geotechnical risks that differentiate this site from the other sites. The results of this expert opinion are therefore meant for preliminary geotechnical assessments and not for design purposes.

This report provides direction on the following questions:

1. What are potential uncertainties in presence and thickness of the Boom clay formation?
2. What are potential uncertainties in the stiffness parameters of the Boom clay formation?
3. What are potential uncertainties in the geotechnical characterization of the glauconite sand layers?

Chapter 1 and 2 describe the geological interpretations for the presence and thickness of the Boom clay formation in answer to question 1. Chapter 3 provides background information on the stiffness parameters of the Boom clay in answer to question 2. Chapter 4 provides additional information on the glauconite sand layers in answer to question 3. Chapter 5 summarizes the key findings.

Inhoud

1 Geological context Rupel Formation

Subsurface data at the Terneuzen sites is currently limited to shallow boreholes and a low number of CPTs. The limited data results in uncertainties related to the presence of units and the depth of unit boundaries, particularly at depths greater than NAP -10 m NAP (Dutch ordnance level). Most of the geological subsurface modelling at the Terneuzen site location is based on regional geological context as described in (Vermaas et al., 2025).

A key uncertainty is the presence and thickness of the Oligocene Rupel Formation. National models suggest its presence at depths between roughly NAP -20 m NAP and NAP -40 m, but with high uncertainty related to the lack of data at the site. Multiple arguments are important to consider in this context.

1.1 Regional geological context

- The Oligocene Rupel Formation (also referred to as Boom Formation, Rupel Clay Member or combinations of these terms) forms a clay-rich interval that is present in most of the Dutch subsurface (Figure 1). The Terneuzen site is located near the southernmost limit of preservation of this unit, which adds to the complexity of the interpretation of the local subsurface record.
- Where present, the Rupel Formation consists of fine-grained sediments. Clays and silts dominate in local grain-size measurements (Figure 2). The main lithology is dark greenish grey poorly calcareous to calcareous fat and stiff clays. Clayey sands with little mica and some glauconite of up to 1.5 m thick occur. The sediments of the Rupel Formation were deposited in open marine conditions.
- The top of the Rupel Formation in the Terneuzen region is formed by an important erosional unconformity (Figure 3, Figure 4). This erosive feature represents the main contact between poorly consolidated sediments above and better consolidated sediments (and sedimentary rocks) below. In most cases the erosive surface is directly overlain by Pleistocene or Holocene sediments. This represents an age gap with a duration of more than 25 million years. Multiple phases of erosion and deposition can be assumed to have shaped this surface. Erosion may have initiated early (e.g. during the Oligocene or Miocene), particularly because the regional context suggests an unconformity bounded stratigraphy within these marine deposits (Figure 4, Vandenberghe et al., 2014).
- Near the city of Terneuzen, local complete erosion of the Rupel Formation is proven (Albada Jelgersma et al. 2021). The glauconitic infill of this erosive feature suggests a Miocene or Pliocene age. In this case, a hole in the order of 200 m length was encountered within a clayey Rupel Formation with a thickness of about 20 m (Figure 5).
- The Western Scheldt Estuary is geologically a very young feature, and formed around the year 1300 AD. At present, this tidal estuary may reach depths of 60 m, showing the major erosive power of the constant tidal water movements. In this estuary, the Rupel Formation may form a hard-to-erode unit at places where the base of the estuary has been eroded down to the top of the unit. Other, younger, erosional-resistant layers in this estuary suggest that once locally the hard-to-erode layer has completely been eroded, a deep scour hole may form due to the underlying easier to erode unit destabilizing the overlying unit. The example at the city of Terneuzen suggest such a process, with local scour completely removing the Rupel Formation (Albada Jelgersma et al 2021).

2 Implications for the Terneuzen site

Taking the regional context into account, the following can be proposed on the subsurface buildup at the Terneuzen site.

- The Terneuzen site is located at the edge of the distribution area of the Rupel Formation (Figure 1, Figure 6). The nature of its thinning in this region, particularly whether this occurs gradually or rapidly, is unclear based on current data.
- The limited borehole and CPT data in the Terneuzen site vicinity suggests that when the unit is present, thickness is typically in the order of 15 to 20 m. Presence, thickness and lateral continuity at the site need to be determined from local measurements.
- The case near the city of Terneuzen indicates the possibility that locally at a scale of 100’s of meters the Rupel Formation may be entirely absent due to later erosion. Given the currently low data-coverage of the Terneuzen site, a local total absence of the Rupel Formation similar to this case should be considered an option. Additional future site investigations should be able to confidently identify any such features at the Terneuzen site if present. However, this is beyond the current scope of investigation.
- The national subsurface model GEOTOP contains significant uncertainty on these aspects (Figure 7). The base of the Rupel Formation (NMRU) in the GeoTOP national model rises gradually across the site towards the south. Additional data not used for the creation of this model suggests that the unit base remains stable at depths of about -40 m NAP. The depth of the top surface in this lower cross-section varies by approximately 15 m between -20 m and -35 m NAP. This fluctuation of the depth of the top surface represents erosional processes at the top of the layer.
- Overlying the Rupel Formation are likely late Pleistocene fluvial and continental sediments and/or Holocene marine to continental sediments. These may include early Holocene peat layers, and very young tidal channel infills from the past 500 years. These overlying units are poorly consolidated compared to the Rupel Formation and deeper units. Local subsurface data will need to be collected to determine lateral thickness variations in these units.
- Local variations in the presence and thickness of the Rupel formation over the project site is well possible. This poses the risk for uneven settlements of the project area and the building foundation. In case the Rupel formation is completely eroded these uneven settlements may occur within a short distance.

Figure 1 Map of the extend of the Rupel Formation in the Netherlands and Belgium (after Vis et al. 2016). The indicated locations in red are shown in the grain-size plots in the figure below, representing the nearest locations to the Terneuzen site.

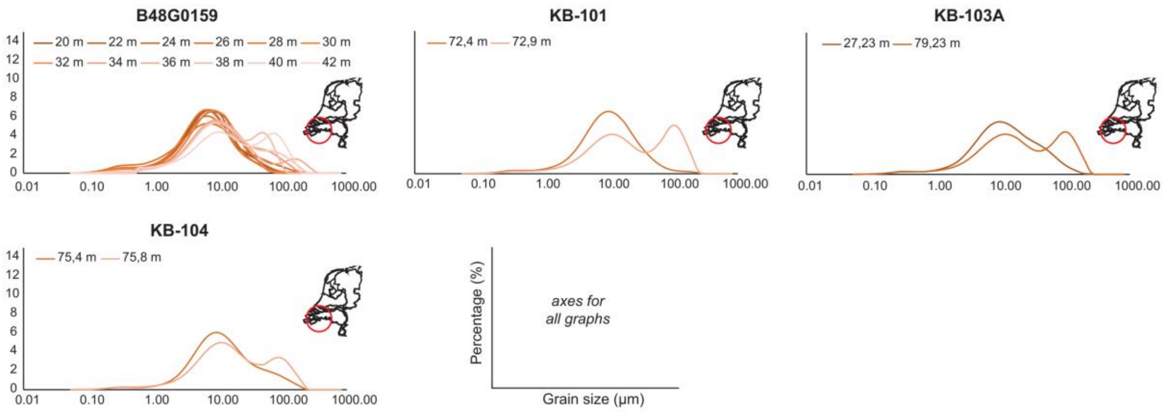

Figure 2 Grain-size distributions of analysed Rupel Formation samples from the Zeeland region (after Vis et al. 2016). All samples show a dominant peak around 10 µm, indicating clay to silt grainsize dominate with only a small contribution of (very fine) sand (i.e. >63 µm).

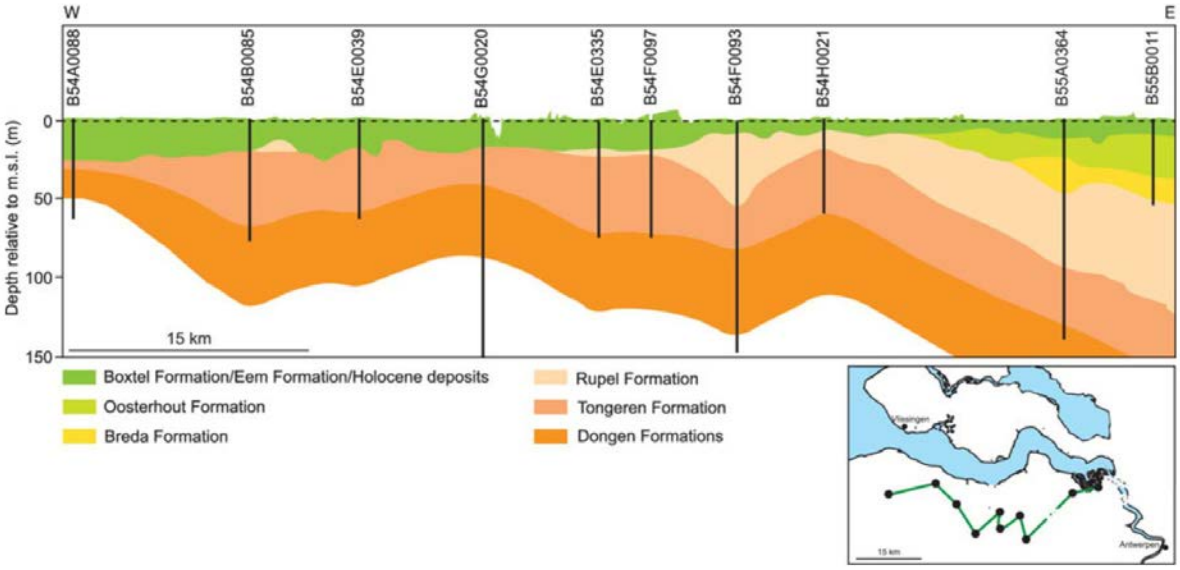

Figure 3 Schematised regional cross-section south of the Terneuzen site (After Vis et al. 2016). Green colour represent younger Pleistocene and Holocene sediments overlying a regional erosivie surface. The Rupel Formation is eroded by this. At the southernmost points of its presence thickness variations may occur, with both very thin presence (multiple meters) to tens of meters thickness possible.

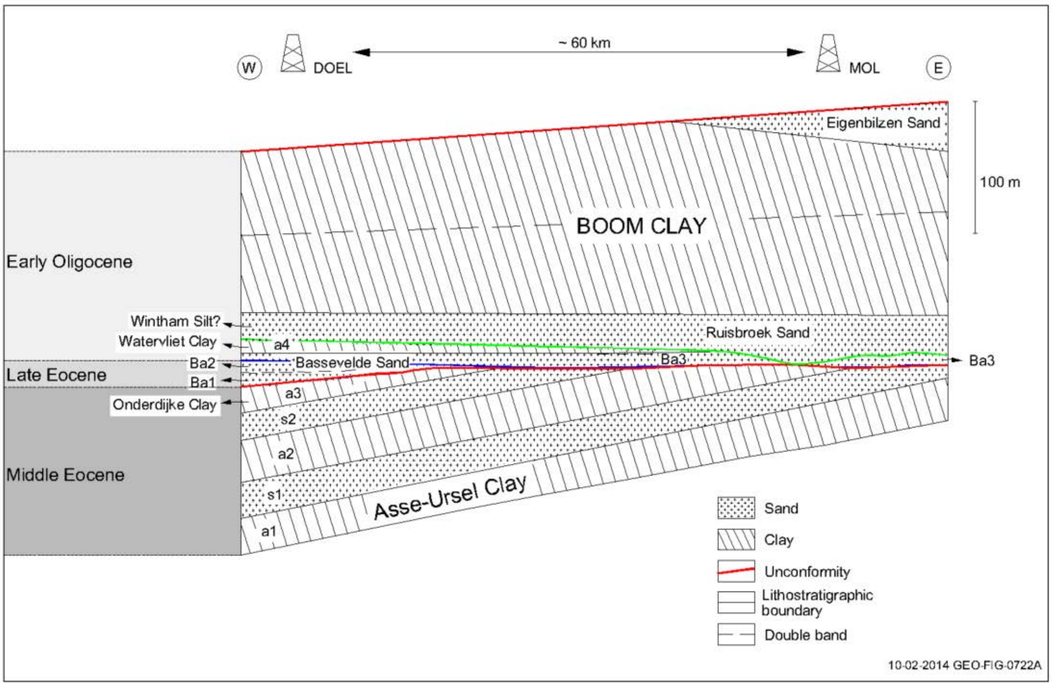

Figure 4 Schematic cross-section through the Upper Eocene to Lower Oligocene of northern Belgium (after Vandenberghe et al. 2014). This section represents the eastward continuation of the previous profile. The location on the westernmost end of this cross-section, Doel, is located on the border between Belgium and the Netherlands. The cross-section shows the thinning of the Boom clay (= Rupel Formation in the Netherlands) towards the west underneath the regional unconformity surface. The Ruisbroek Sand is referred to as NMTORU in the Terneuzen cross-sections, with the Watervliet Clay (NMTOWA) and Bassevelde Sand (NMTOBA) also present in the Terneuzen subsurface. The package containing Boom Clay (NMRUBO) and Ruisbroek Sand (NMTORU) is separated by an erosional unconformity (in green) from the Watervliet Clay (NMTOWA), which in turn is separated by an erosional unconformity (in blue) from the Bassevelde Sand (NMTOBA).

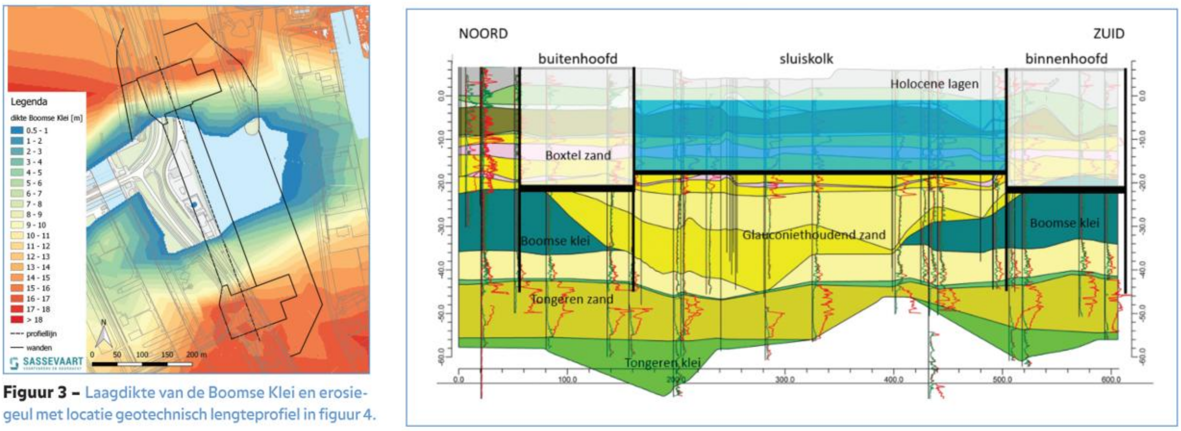

Figure 5 Left: Thickness map of the Rupel Formation at the city of Terneuzen (about 5 km east of the Terneuzen site) indicating an erosive gap in the Rupel Formation (Albada Jelgersma et al. 2021). Right: North-South cross-section across this structure interpreted as a channelised feature that locally completely eroded the Rupel Formation (in this figure referred to as 'Boomse klei'). The infill of this channel consists of glauconitic sands ('Glauconiethoudend zand'). Overlying this is a Late Pleistocene and Holocene succession. Depths and thicknesses of the Rupel Formation are similar to those expected at Terneuzen. This case shows that gaps in the presence of the Boom Clay with a size of multiple hundredths of meters may occur.

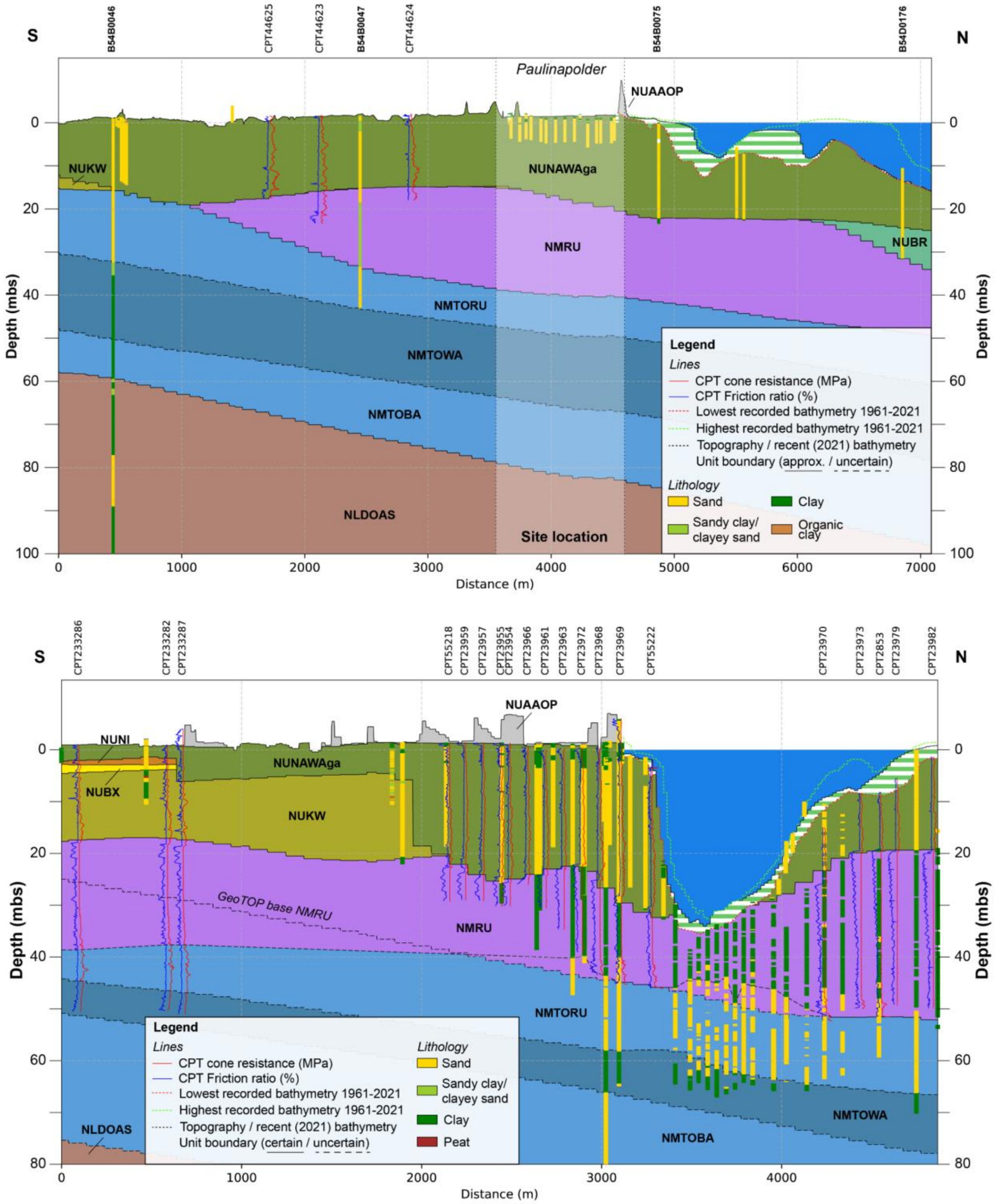

Figure 6 Two cross-sections, top across the Terneuzen site, bottom along the transect of the Western Scheldt Tunnel 5 km to the east of the site (after Vermaas et al., 2025). Units are largely based on national models, with small adjustments based on additional data in the profiles, particularly in the lower panel. The lower panel shows that while the base of the Rupel Formation (NMRU) in the GeoTOP national model rises gradually, additional data not used for the creation of this model suggests that the unit base remains stable at depths of about -40 m NAP. The depth of the top surface in this lower cross-section varies by approximately 15 m between -20 m and -35 m NAP. This fluctuation of the depth of the top surface represents erosional processes at the top of the layer.

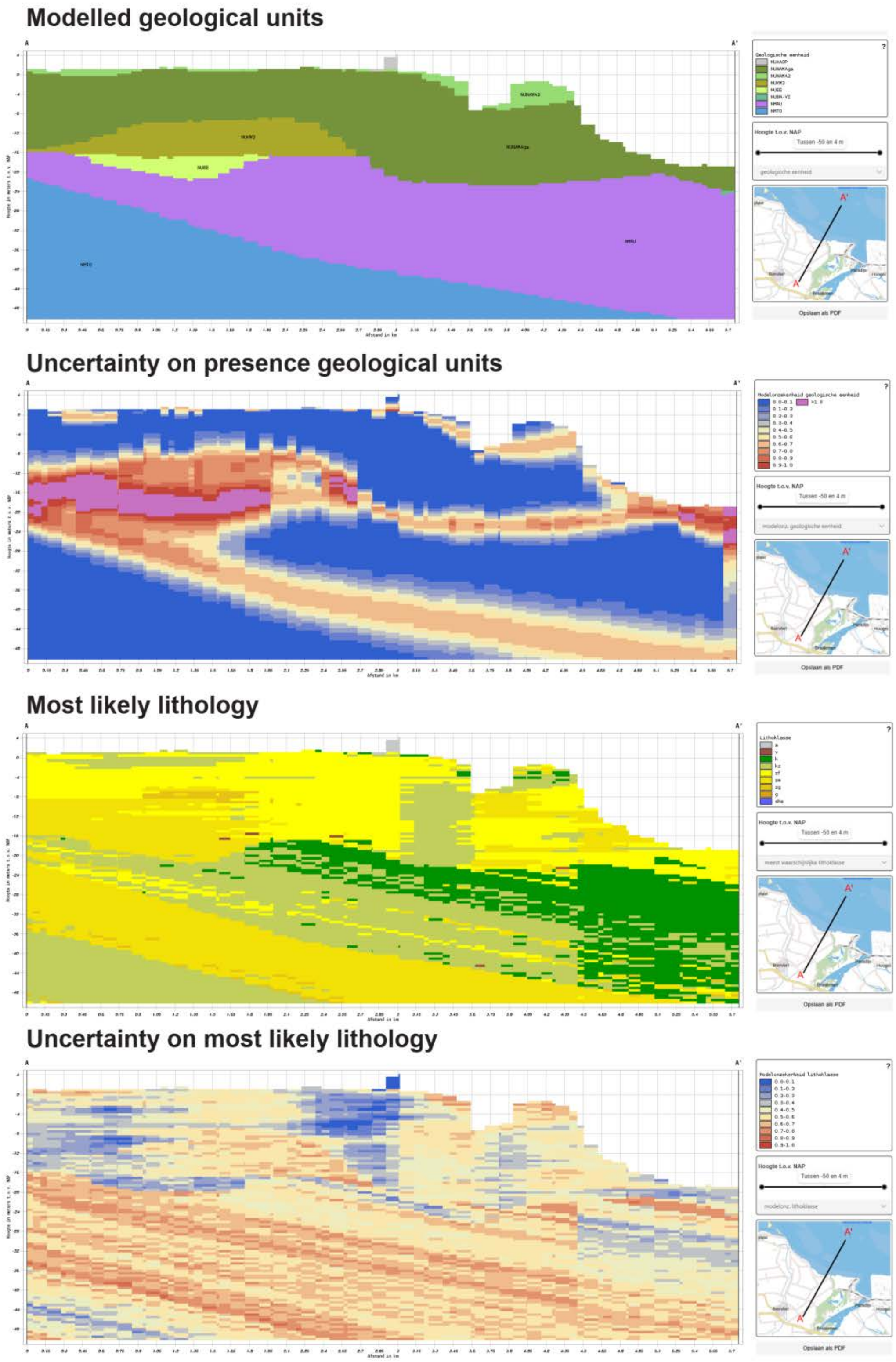

Figure 7 GEOTOP national model geological units, most likely lithology (yellow represents sand, green clay) and their uncertainties (blue is certain, red is uncertain). The main uncertainties on the presence of geological units is related to the interval -10 m to -20 m NAP, where above the regional unconformity at the top of the Rupel Formation multiple units may be present. Uncertainties in lithology are present throughout the record, but higher in the older units below the unconformity at -20 m NAP.

3 Stiffness of the Boom clay

For assessing the stiffness of the Boom clay available reports for the Western Scheldt tunnel, the Sluiskil tunnel and the Terneuzen sluice have been used. A thorough analyses of the data was considered to be outside the scope of the performed study. A first analysis showed that available data show a large scatter. Also, significant differences are observed from parameters derived from oedometer testing, triaxial testing and cone pressio meter testing. Table 6-4 of our report (Vermaas et al., 2025) shows this difference between the various methods. The value of E_{oed} ranges from 10 to 100 MPa.

The Boom clay is heavily overconsolidated. This implies that the stiffness is mainly determined by the preconsolidation pressure and hardly determined by the present stress level. As such, using a stress-dependent stiffness model for this layer was considered unrealistic. For this reason, no values for the stiffness of this layer were given in Table 6-7 of our report. Instead, recommended values, based on the observed range of values, are given in Table 6-8 of our report.

To illustrate the large variation in stiffness parameters the figure below shows the scatter in the oedometer stiffness, as derived from the oedometer tests for the Western Scheldt tunnel and the Sluiskil tunnel. As can be observed the scatter is large. No dependency of the stiffness with depth is present. Please note that these data are from projects at distances of 4 km to 7 km from the project location.

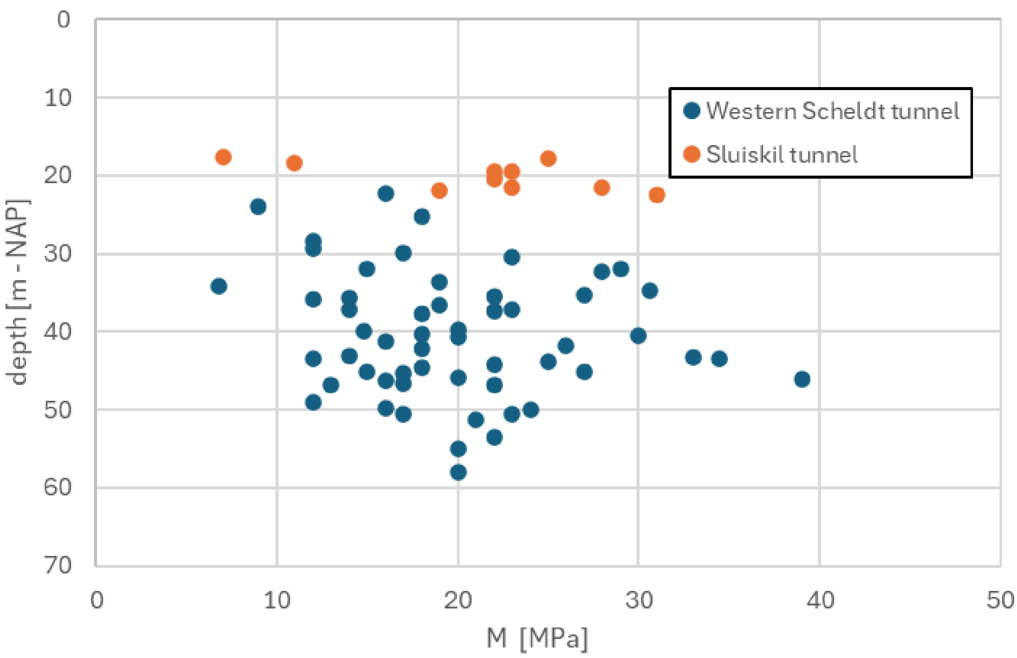

Figure 8 Laboratory data constrained modulus Boom Clay.

4 Parameters glauconitic sand underneath Rupel Formation

Parameters for the NMTORU layer (Glauconitic sand) are given in Table 6-7 of our report. Table 6-8 gives an estimated value for the stiffness. As with the Boom clay, Deltares indicates that using a stress dependent stiffness for this layer is not relevant given the high overconsolidation of this layer.

Some recent test results on glauconite sand from the region (Kattendijk, near Antwerp) is given in a paper by Konstantinou (Konstantinou et al., 2025). The used material is taken from shallow depth (TAW – 6 m, with TAW the Belgian ordnance level), which is about NAP – 8.33 m. This paper shows that the amount of glauconite may change the behaviour of the material from a sand-like behaviour to a clay-like behaviour. It also shows a decrease in stiffness and peak angle of internal friction.

In (Piedrabuena, A.R., 2024) model tests on driving piles in glauconite sand are performed. These tests show the crushable nature of glauconite sand.

5 Summary

This report provides direction on the following questions:

1. What are potential uncertainties in presence and thickness of the Boom clay / Rupel Formation?
   The limited current data indicates the likely presence of the Rupel Formation at the Terneuzen site, roughly at depths between NAP -20 m and NAP -40 m. Borehole and cone penetration test data surrounding the site indicate a presence of the unit in all directions around the site. Local erosional features in the order of 100's of meters where the unit is entirely absent are known from construction projects in the site vicinity. Until further subsurface data becomes available, this should be considered as a possibility at the Terneuzen site. Such differences may result in uneven settlements at short distances.

2. What are potential uncertainties in the stiffness parameters of the Boom clay / Rupel Formation?
   The available data on the stiffness of the Boom clay show a large scatter. Also the values obtained by different methods show large variations. The range of values for E_{oed} is about 10 to 100 MPa. This results in uncertainties with respect to the expected settlements.

3. What are potential uncertainties in the geotechnical characterization of the glauconite sand layers?
   Glauconitic soils are susceptibility to particle crushing. This transfers it's behaviour from a sand-like behaviour to a clay-like behaviour. One of the results is a decrease in stiffness and an increase in cohesion. Challenges during pile installation in this material are well known. Within the present scope it is not possible to quantify these effects.

A References

Albada Jelgersma, R., Cevaal, E., Bonnes, J., Varkevisser, A., Bevernaege, M., Vijlbrief, M., Verweij, A., Erdtsieck, T., 2021. Nieuwe Sluis Terneuzen: Diepe bouwkuipen van de sluishoofden (in Dutch). Geotechniek Special Nieuwe Sluis Terneuzen. P41-46.

Konstantinou, M., Piedrabuena, A.R., Hellebrekers, N., Elkadi, A.S., Mento, M., Gavin, K., 2025. Geotechnical Properties of a Glauconite Sand from Belgium. Proceedings of ISFOG 2025, 5th International symposium on frontiers in offshore geotechnics. P1-6.

Piedrabuena, A.R., 2024. First steps into the calibration chamber pile tests with glauconitic sands: On the behaviour of the sand fraction from glauconitic sand of the Kattendijk formation in Antwerp, Belgium. TU Delft MSc thesis, 101 pp.

Vandenberghe, N., De Craen, M., Wouters, L., 2014. The Boom Clay Geology, from sedimentation to present-day occurrence: A review. Memoirs of the Geological Survey of Belgium, N. 60. 76 pages.

Vermaas, T., Van Baak, C.G.C., Remmerswaal, G., Vermeulen, P.T.M., 2025. Terneuzen: Site evaluation: Geological and geotechnical characteristics and hazards. Deltares report 11209639-013-GEO-0001. 96 pages.

Vis, G-J., Verweij, H., Koenen, M., 2016. The Rupel Clay Member in the Netherlands: towards a comprehensive understanding of its geometry and depositional environment. Netherlands Journal of Geosciences - Geologie en Mijnbouw, 95-3, 221-251.

Deltares is een onafhankelijk kennisinstituut voor toegepast onderzoek op het gebied van water en ondergrond. Wereldwijd werken we aan slimme oplossingen voor mens, milieu en maatschappij.

Deltares

www.deltares.nl