Bolbro - Preliminary geological interpretations

03-09-2019
Anders Juhl Kallesøe, GEUS
Peter Sandersen, GEUS

1 Geomorphology

The Bolbro study area is located on the Late Weichselian Tinglev outwash plain in the southern part of Jutland (Figure 1), but small parts of the study area are located on glacial landscape remnants of pre-Weichselian age - called "hill islands". The Tinglev outwash plain is dominated by meltwater sand. The outwash plain surface has a gentle slope from east to west (see Figure 2).

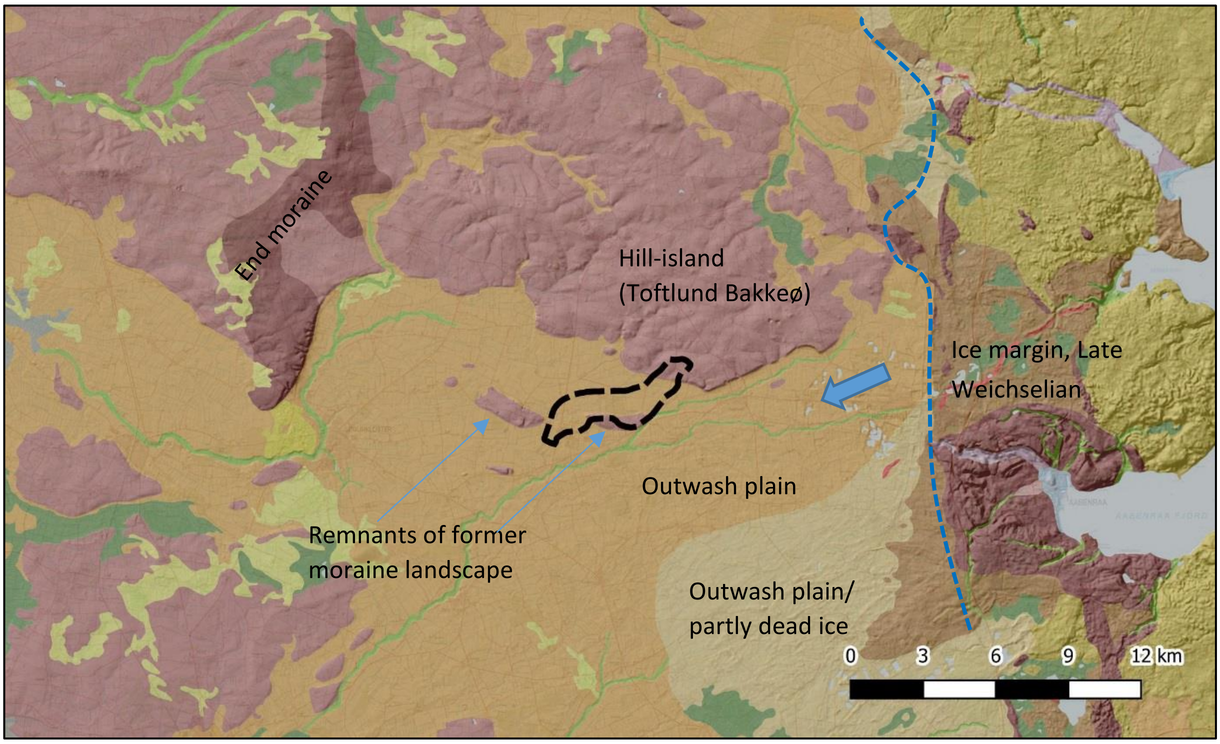

Figure 1: Morphological map. Study area marked with dashed black polygon and is primarily located on an outwash plain from the last glaciation (Weichselian) with the ice margin (Main Stationary Line; blue hatched line) approx. 10 km to the east (GEUS, 2018).

The main stationary line of the Late Weichselian ice sheet is located around 10 km east of the study area, representing the 'Main ice advance' from northeast (21 kyr BP). The younger 'East Jutland advance' and 'Belt-sea advance' from southeast (18-17 kyr BP) also drained meltwater through the study area, but did not reach as far west (Houmark-Nielsen, 2005).

In the northern part, on the hill island, the elevation reaches 50 m a.s.l., and from the rim of the hill island towards the outwash plain there is a relatively steep drop of 5-10 m. Elevations of the hills island indicate two plateaus – an upper plateau with elevations around 50 m, a middle plateau close to elevation 40 m before the transition to the outwash plain. The general east-west slope on the outwash plain in the study area is around 10 m - from elevation 35 m in east to elevation 25 m in west, see Figure 2. The small streams in the area are also shown on Figure 2. Most of the streams follow the dip in terrain slope towards west-southwest. The hill island remnants at the southern boundary show elevations up to approx. 40 m.

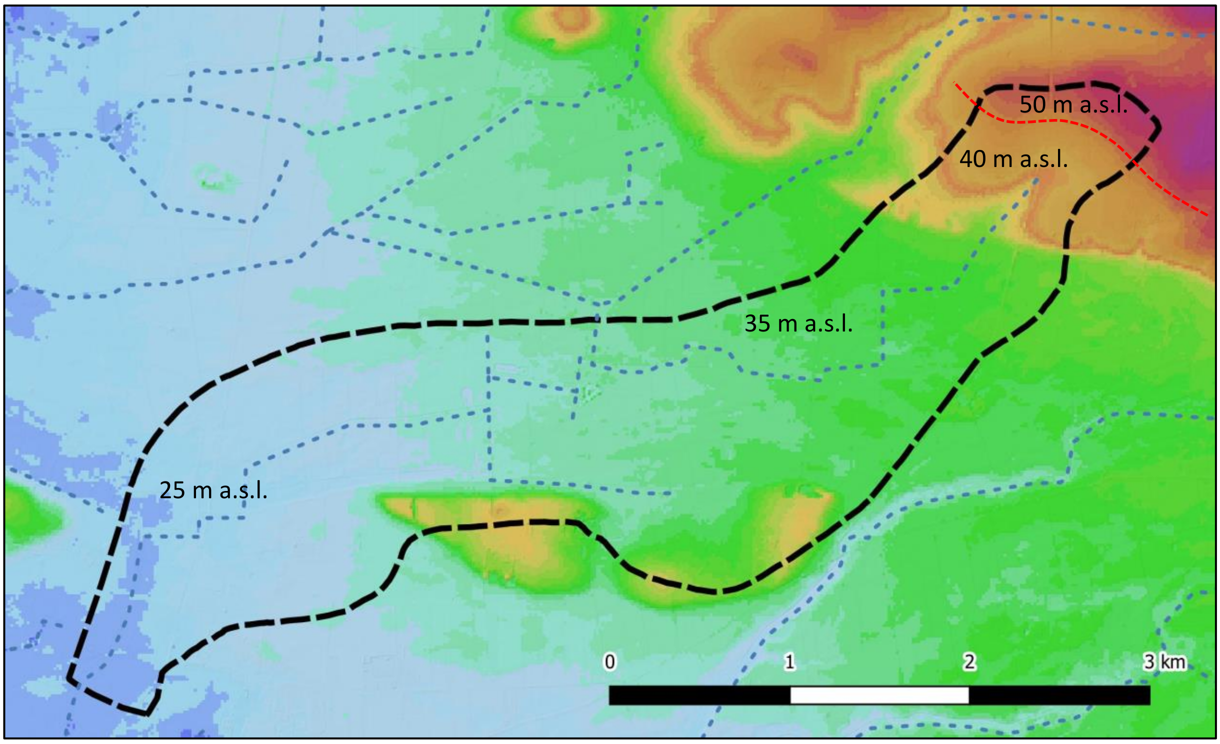

Figure 2. Digital elevation model (highest elevations: brown-red, lowest: blue). Blue dashed lines represent the small streams and channels in the area. The red line indicates two possible plateaus on the hill island

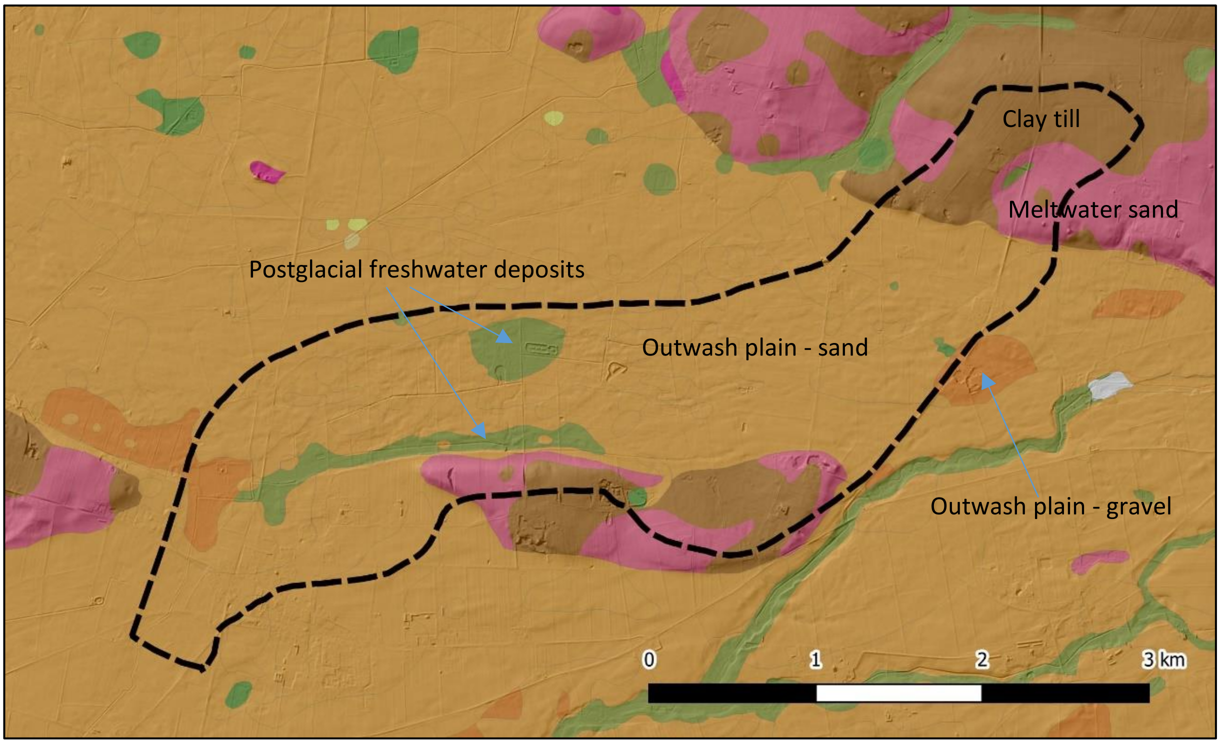

Figure 3. Soil types in the uppermost meter (Jakobsen et al. 2011). Brown colours: Tills; Red: Meltwater sand; Orange: Outwash sands/gravel; Green: Postglacial freshwater deposits.

A map of the soil types in the uppermost meter is shown on Figure 3. Outwash deposits (primarily sands) are the dominant soils in the study area, but to the north, in the highest parts of the terrain, occurrences of clay till and older meltwater sands deposits are found. Meltwater sands are found at the lower hill island plateau. Occurrences of postglacial freshwater deposits can be found locally in topographic lows.

2 Geophysical data and boreholes

Three types of geophysical data have been collected in and around the study area (Figure 4):

a. Tow-TEM data (tTEM) shown as red points
b. SkyTEM data (airborne Transient Electro Magnetic method) shown as purple points
c. MEP data (Multi Electrode Profiling) shown as green triangles/lines
d. The geological data comprise boreholes from the Jupiter database (black points).

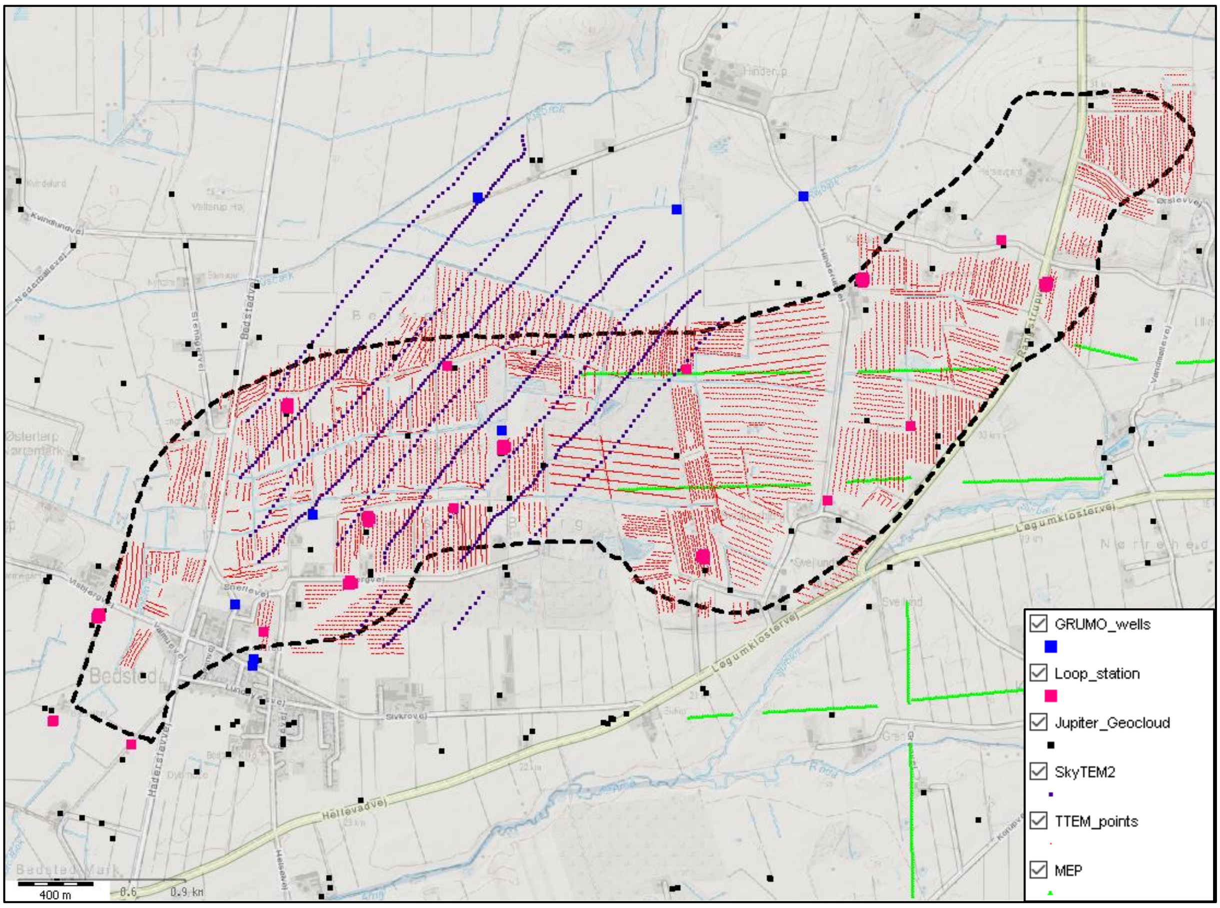

Figure 4. Boreholes (Jupiter and GRUMO) and geophysical datasets in the area. Legend is shown to the right.

Only approx. 15 boreholes are drilled deeper than 25 meters. Information from important stratigraphic boreholes at Løgumkloster (west), Hellevad and Rødekro (east) and Tinglev (south) have been used in the stratigraphic overview of the area, see under Stratigraphy (3).

3 Stratigraphy

Based on boreholes within the study area, the deepest parts of the subsurface comprise Miocene sequences of marine clay and sand. Deep tectonic fault systems have had structural impact on the Miocene deposits in the region, e.g. in the Tønder Graben towards the south (Rasmussen, 2010). The nearest stratigraphic borehole (Hellevad) and mapped fault lines are shown on Figure 5.

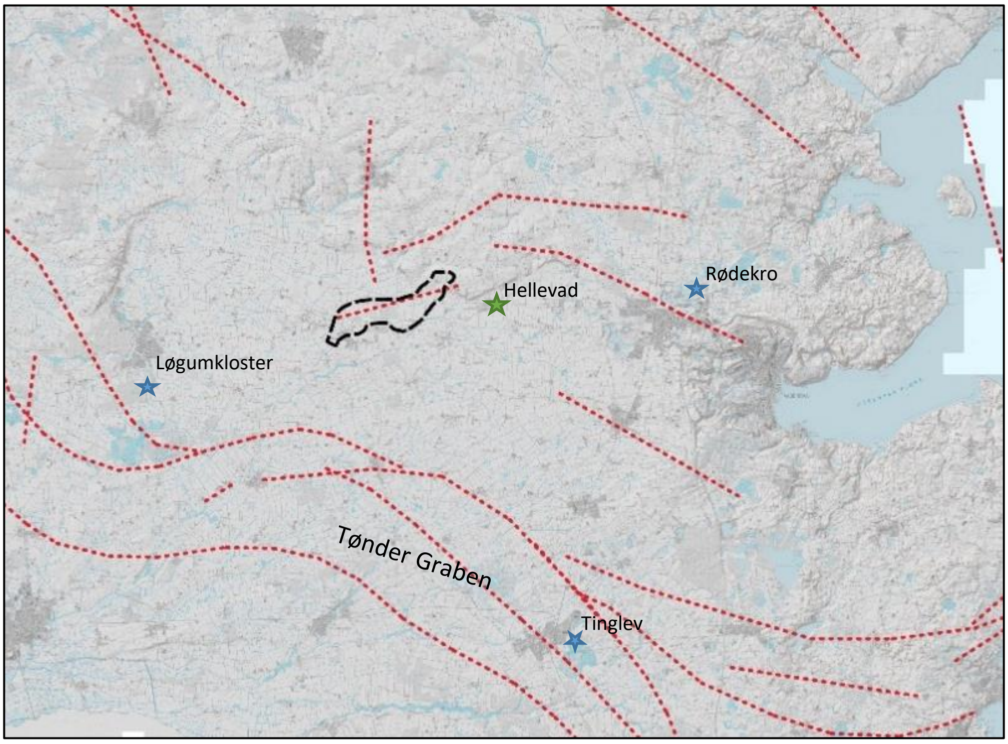

Figure 5. Stratigraphic boreholes Hellevad, Rødekro and Tinglev (from Rasmussen, 2010), and mapped deep fault lines in the region and the Tønder Graben (from Sandersen and Jørgensen, 2016).

The Hellevad Borehole (DGU nr. 160.1512) is located 4 km east of the study area and describes a Miocene sequence of sand and clay formations. The upper pre-Quaternary part of the deposits in the study area are thus expected to be represented by Miocene (mica-) sands and mica clays. Not many boreholes in the area give information of the Miocene deposits and the boundary between the Quaternary and pre-Quaternary sediments is not straightforward to map from the geophysical data due to lack of resistivity contrasts and significant geological heterogeneity. The Miocene marine clays have typically a high content of organic matter.

The Quaternary succession above consists of meltwater sand, meltwater gravel, clayey tills and occurrences of meltwater clay. The thickness of the Quaternary succession is interpreted to be thicker than approx. 40 m. Generally, the area has only a few deep boreholes, but still the lithological information from the boreholes gives a good impression of the sedimentary succession and fits well with the soil map (Figure 3). However, the very varying Quaternary sediments in depth makes the interpretation with tTEM resistivities challenging.

4 Buried tunnel valleys

Figure 6 below, shows the buried valleys mapped outside the study area. The buried valleys were formed as tunnel valleys underneath the ice sheets, they are generally between 1 and 2 km wide and some of them have depths of more than 100 m. As can be seen on the map, the valleys mostly have two preferred orientations, one around E-W/ENE-WSW and the other around NNW-SSE/N-S (Sandersen and Jørgensen, 2016).

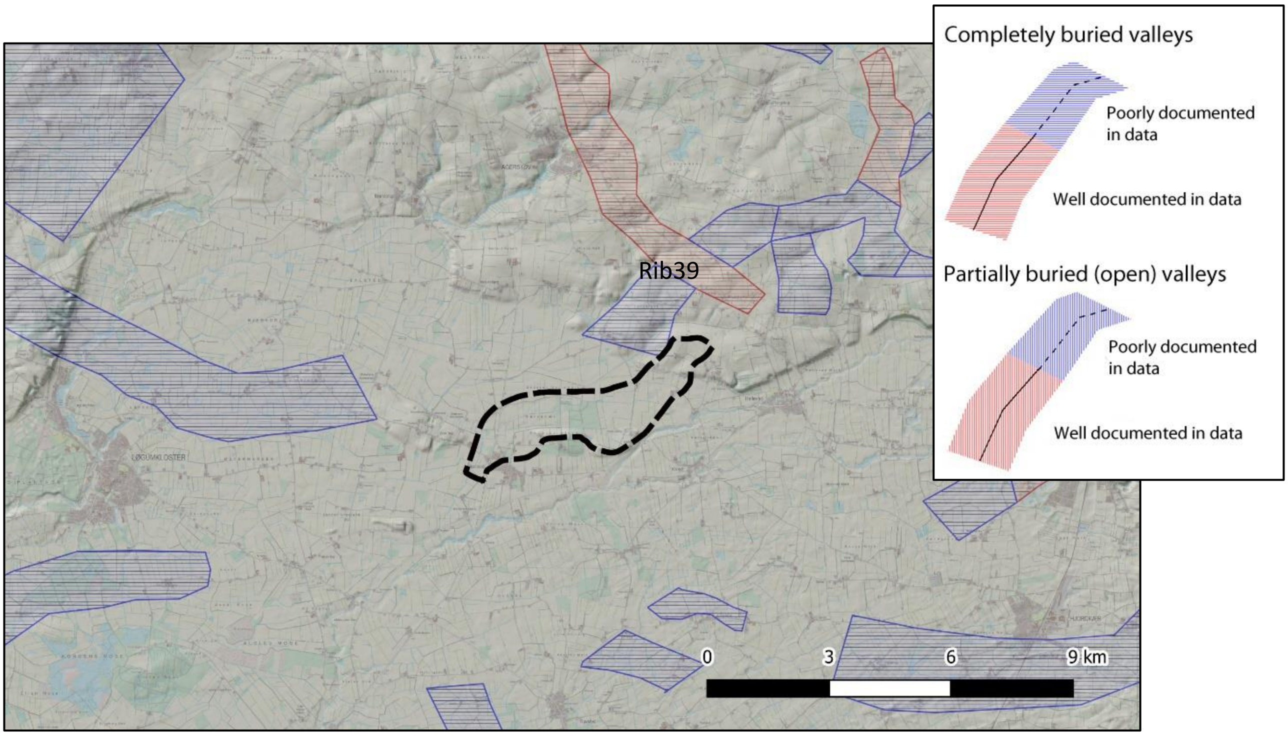

Figure 6. Mapped buried valleys close to the study area (shown with black hatched line). Legend for the map is shown above (Sandersen & Jørgensen, 2016) and on www.buried-valleys.dk)

The infill of the mapped valley system to the north (Rib39) is dominated by clayey sediments (clay till and meltwater clay). A continuation of this buried valley to the south has not been mapped (Sandersen and Jørgensen, 2016).

5 Geological interpretation of geophysical data

The tTEM cover is patchy and although the geology is very varied, the data gives valuable information of the geological setting. The SkyTEM-data is located in the central part north of Bedsted (Figure 4) and provide valuable information. The overlap makes a comparison of the two methods possible. MEP data are also included but are less useful in the interpretation, because the tTEM provides better resolution.

Cross-sections through the tTEM data and boreholes are shown on Figure 7, and a number of these profiles are shown in the following. SkyTEM data and MEP-profiles are included on selected profiles.

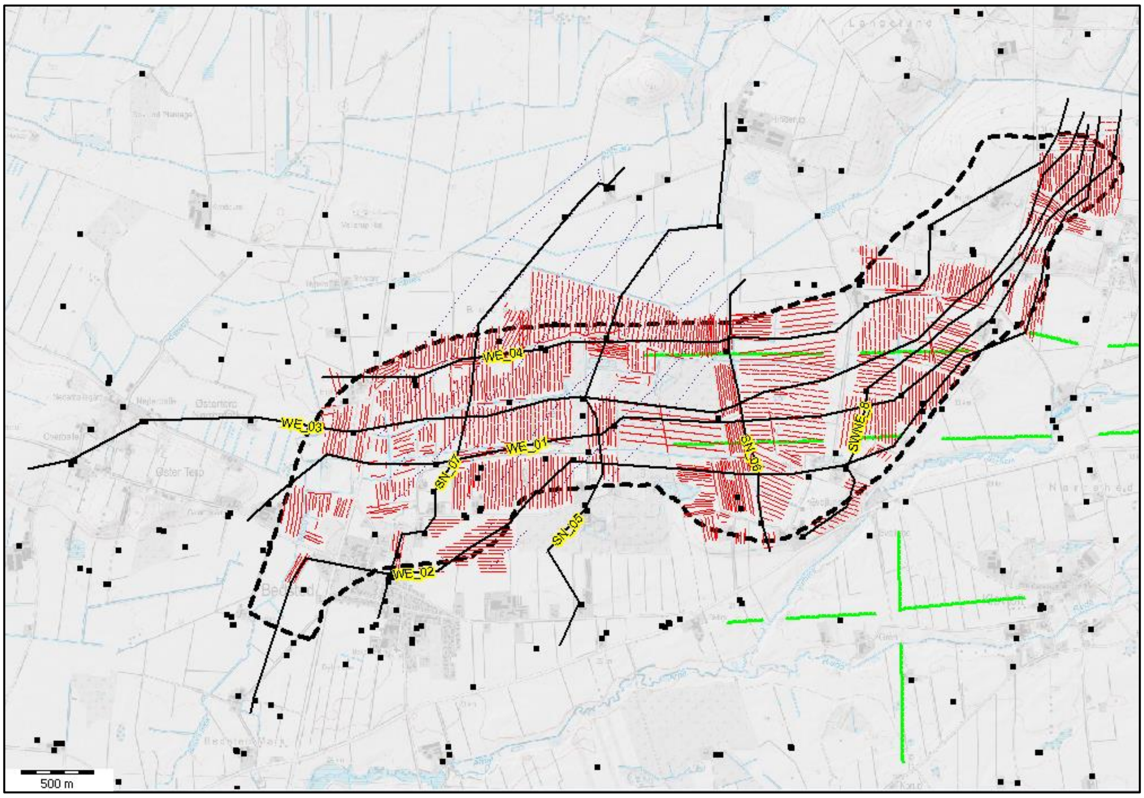

Figure 7. Cross-section overview. Profiles: Black lines, tTEM: red dots, SkyTEM: purple dots, MEP (ERT): green lines, Boreholes: black dots.

In the following, preliminary interpretations have been done on the representative cross-sections shown in Figure 7 and on selected 2D resistivity maps (Figure 8).

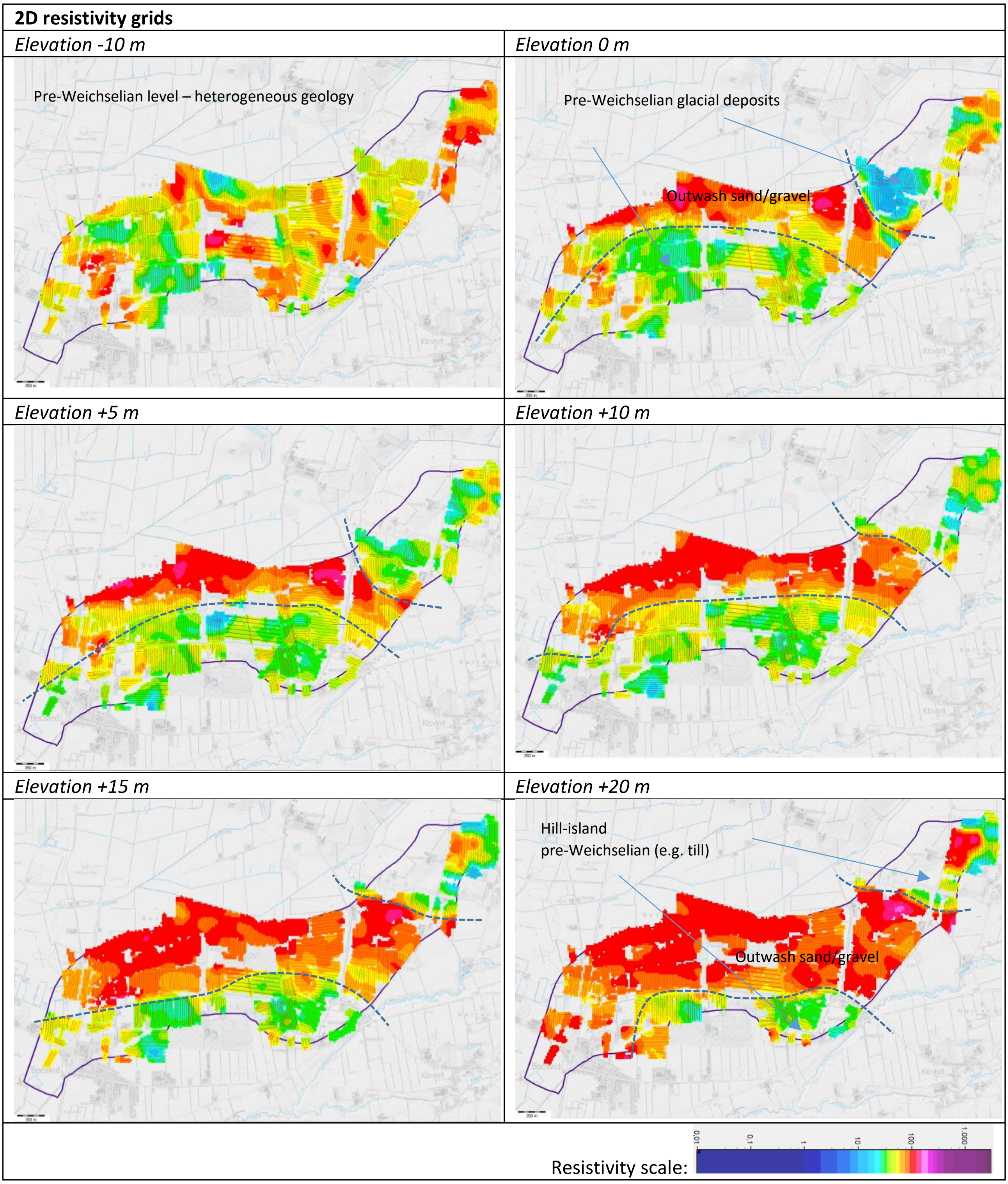

Figure 8. 2D resistivity grids of the tTEM dataset (tTEM smooth models, 30 layers)

Six slices of tTEM 3D resistivity grids are shown in Figure 8. The figure shows 1 m slices through elevation -10 m, 0 m, +5 m, +10 m, +15 m and +20 m. The slices give an overview of the boundaries between the "hill –island" (glacial) and the sandy outwash plain elements. The "hill-island" geology shows low to moderate resistivities (blue- green colours) revealing that it in the lower elevations extends beyond and beneath the mapped outwash plain.

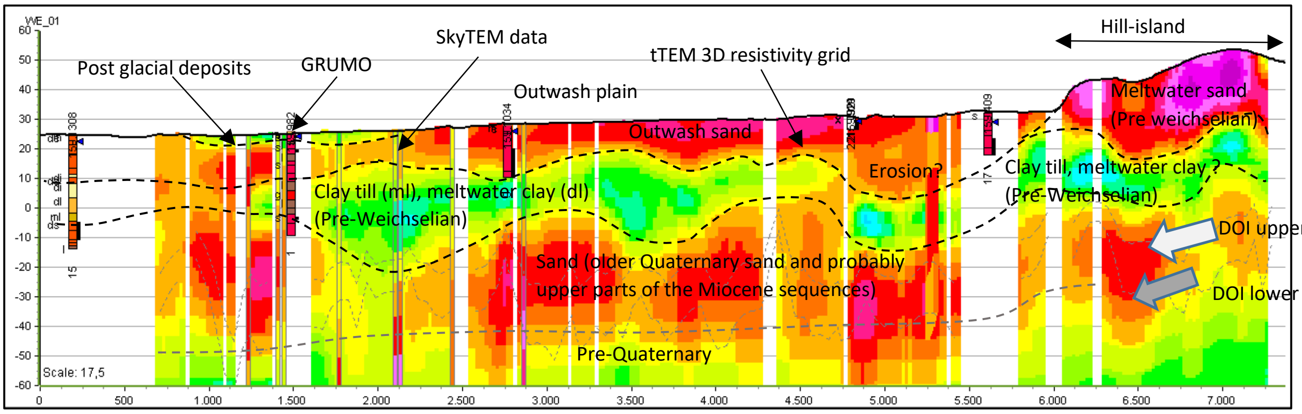

Figure 9. Cross section WE_01, W-ENE. For location, see Figure 7.TTEM data are shown as 3D resistivity grid and SkyTEM data are visualized as single sounding poles.

Cross section WE_01 (Figure 9), gives an overview of the study area from the west (outwash plain) to the northeast (hill island). Shown on the profile is a 3D resistivity grid of the tTEM dataset and overlapping SkyTEM soundings as single resistivity poles. The bottom of the outwash plain stands out quite clear in the geophysics - going from high resistivities (red colours) to moderate resistivities (green colours). As sketched at e.g. 5000 m on the cross section the pre-Weichselian surface is expected to have been exposed to erosion and/or glacial deformation). The present "hill-island" landscape is seen from 6000 m and further to the east. This part of the hill island is dominated by meltwater sand close to terrain and the deposits below this are presumed to be tills, and possibly meltwater clays. Thinner sand layers are likely to be present, but these cannot be resolved in the tTEM data. The moderate resistivities seem to correlate well throughout the profile at elevations below 20 m. The left side of the profile shows two boreholes (DGU no. 159.308 and DGU no. 159.982) that very well illustrate the varying quaternary geology found beneath the outwash plain.

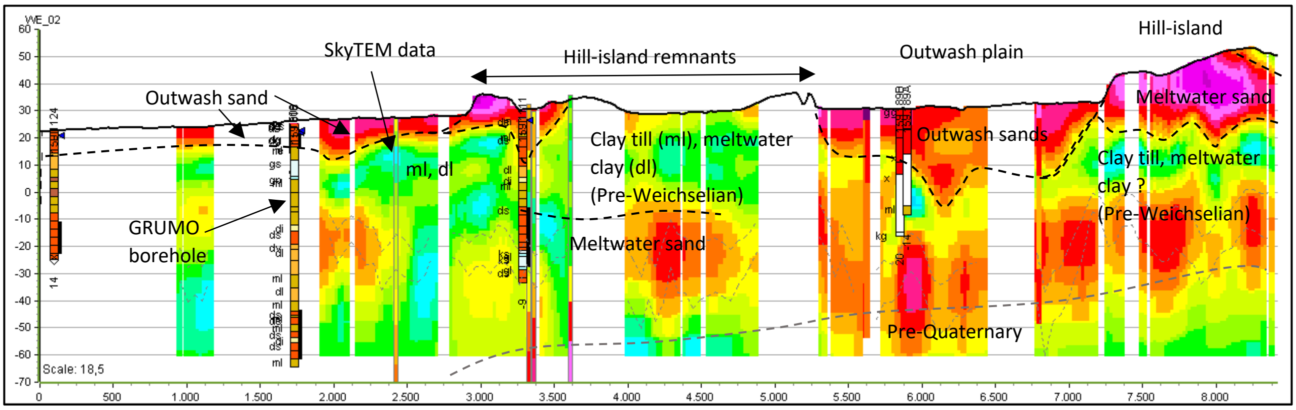

Figure 10. Cross section WE2, W-ENE. For location, see Figure 7. TTEM data are shown as 3D resistivity grid and SkyTEM data are visualized as single sounding poles.

The cross section in Figure 10 (WE_02) crosses both areas with hill-islands in the study area. The remnants of hill-islands in the terrain show an area with low resistivities reaching the surface. In boreholes, these deposits are described as clay tills. The outwash plain between the pre-Weichselian terrain elements indicate erosion into the lower fine-grained deposits. Borehole DGU no. 159.111, at 3300 m, describes meltwater clay and clay till from elevation +10 to -10 m, which correlates well with the low to moderate resistivities in tTEM. Beneath these sediments, a thick layer of meltwater sand is partly resolved in data by higher resistivities and validated in boreholes.

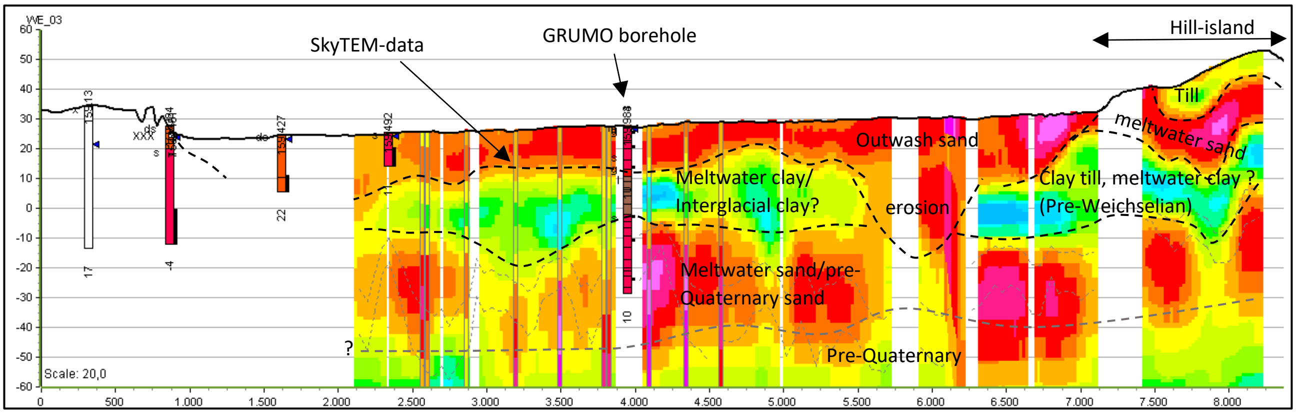

Figure 11. Cross section WE_03, W-ENE. For location, see Figure 7. TTEM data are shown as 3D resistivity grid and SkyTEM data are visualized as single sounding poles.

The cross section WE_03 in Figure 11 illustrates somewhat the same as the prior cross section WE_02. In addition, the data coverage gives a good understanding of the outwash plain and the upper parts of the hill island geology. At 4000 m, borehole DGU no. 159.983 describes clay from elevation +10 to -5 m with a description that could indicate an interglacial origin. The clay is described as being firm and containing gyttja, pointing to a pre-Saalian age. The tTEM data shows relatively low resistivities, which corresponds quite well to a possibly marine clay.

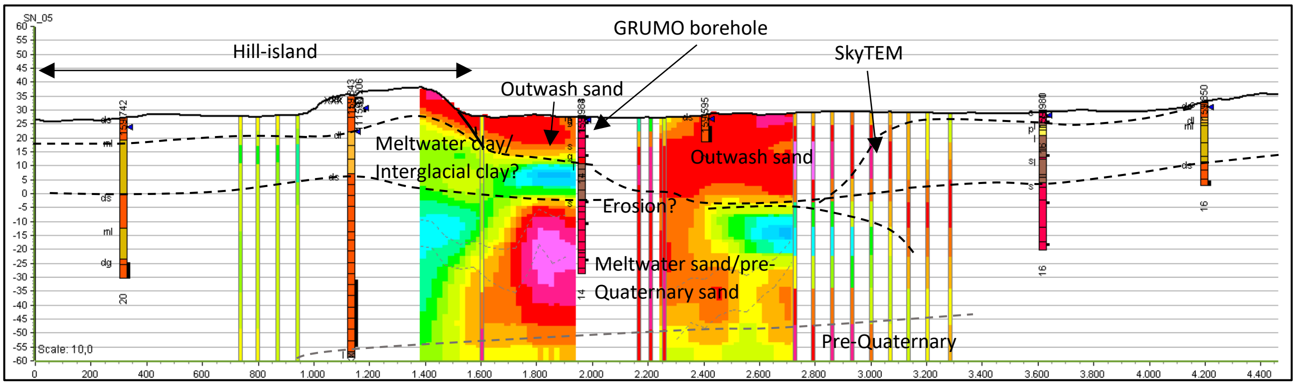

Figure 12. Cross section SN_05, S-N. For location, see Figure 7. TTEM data are shown as 3D resistivity grid and SkyTEM data are visualized as single sounding poles.

Cross section SN_05 crosses the study area from south to north in the central part. At 2000 m, the borehole DGU no. 159.983 as mentioned above is shown. SkyTEM data north of the tTEM survey shows the same pattern as tTEM going from high resistivities (outwash sands) to moderate to low (20-40 Ohmm) resistivities. North of the study area, the clay layer seems to be situated at lower elevations (below elevation -20 m).

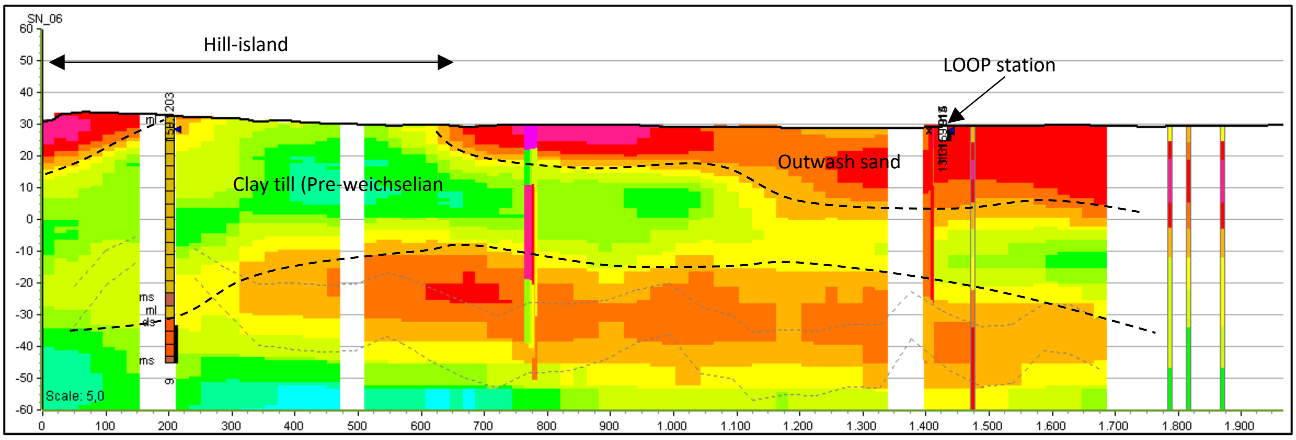

Figure 13. Cross section SN_06, S-N. For location, see Figure 7. TTEM data are shown as 3D resistivity grid and SkyTEM data are visualized as single sounding poles.

Cross section SN_06 (Figure 13) is oriented South-North about 1 km east of SN_05. Here the hill island area is dominated by moderate resistivities (30-50 Ohmm) which fits well to clay till found in borehole DGU no. 159.203. The borehole describes clay till from the surface to 56 m of depth. TTEM data to the north, having in mind the DOI, indicates a thinner clay layer below the outwash sands going from hill-island to outwash plain.

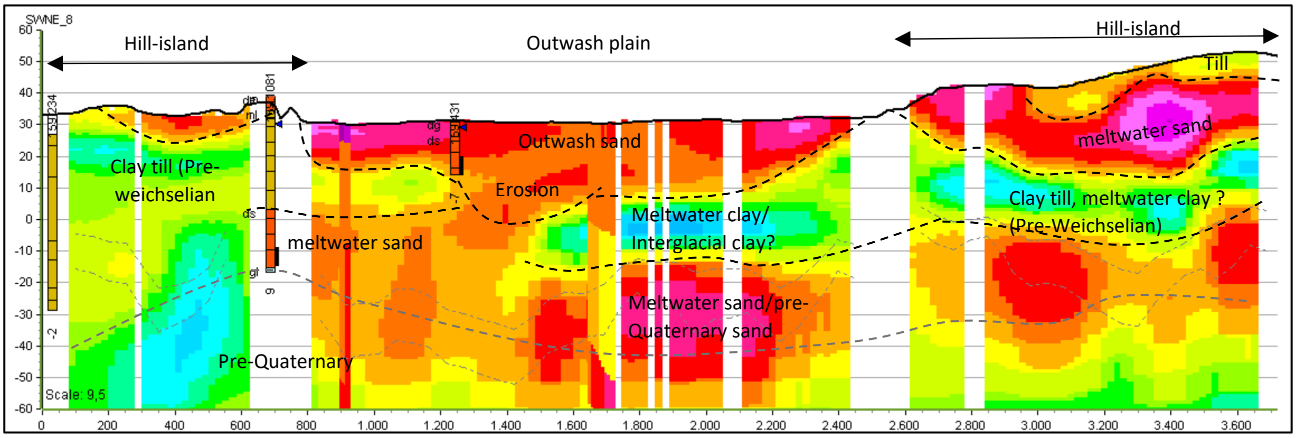

Figure 14. Cross section SWNE_8, SW-NE. For location, see Figure 7. TTEM data are shown as 3D resistivity grid and SkyTEM data are visualized as single sounding poles.

Cross section SWNE_8 (Figure 14) strikes SW-NE through the eastern part of the study area and illustrates the change in geological elements going from hill island to outwash plain and then again the Toftlund Hill Island to the north. TTEM data indicates possible erosion in the deeper part of the outwash plain; see profile at 1200 m to 1800 m. The western parts of the hill-island area shows a thick succession of clay till; see 0- 500 m (as shown on SN_06). Borehole DGU no. 159.1081 terminates in Miocene mica clay, but it is difficult to conclude if this is the actual boundary between the Quaternary and the Miocene successions or maybe disturbed layers from earlier glaciations (Saale or earlier).

Overall, the main five geological elements in the study area are identified as:

a. Outwash plain geology of Late Weichselian age with occurrences of Postglacial deposits in low-lying areas.

b. A pre-Weichselian glacial landscape affected by glaciers during the Saalian glaciation (or earlier). Sediments are clay tills, meltwater clays and meltwater sands.
   I. Upper till deposits on hill-islands
   II. Meltwater sand on hill-islands
   III. Fine-grained sequences of meltwater clay, clay till and possible interglacial clays mapped beneath the outwash sands and as deeper parts of the hill-island elements

c. Deeper successions of Quaternary deposits with a shift to the Miocene formations. A complex varying geology difficult to resolve from the datasets. The succession is presumably disturbed by deep faults, glacial erosion and glacial deformation.

It is further possible that interglacial marine clays are present in the area. These deposits would be found in prior low-lying areas/channel open in Holstein or Saale interglacial periods. A few kilometers west of the study area (near Løgumkloster) a sequence of interglacial clays are described in boreholes (e.g. DGU nr. 159.1254, see Sandersen and Jørgensen 2016. The interglacial deposits are found at approx. elevation -10 to -25 m.

Studies of the outwash plain topography at Løgumkloster to the west and Tinglev to the south propose neotectonic deformation due isostatic rebound (Sandersen and Jørgensen, 2015) which likely also could be the case in the Bolbro loop area. If so, this would have an impact on the deposits. At this level, a more thorough study is required to validate or invalidate the role of neotectonics, and is not done in the first preliminary interpretation.

6 Summary and conclusions

- **Geophysical mapping:** The area has a good but somewhat patchy coverage with geophysical data. The tTEM data has greatly improved the understanding of the geological setting. The tTEM provides a better resolution compared to the existing SkyTEM soundings, but the small SkyTEM survey in the area has been useful in the interpretation by adding information below the tTEM DOI.

- **Borehole information:** The information from boreholes are limited as many of the boreholes are shallow, but the general perception of the upper succession is fairly good. The Quaternary sequence is only penetrated by a few boreholes, thus the transition to the Miocene is difficult to map.

- **Geological elements:** The study area is predominately defined by an outwash plain of Late Weichselian age with occurrences of postglacial deposit in low-lying wet areas. The boundaries of the outwash plain are a pre-Weichselian glacial landscape affected by glaciers in the Saalian glaciation and earlier. Sediments are clay tills, meltwater clays and meltwater sands. The older glacial elements are visible in the topography as "hill-islands". The deeper succession of Quaternary deposits and the boundary to the Miocene formations are more complicated to interpret from the few deep boreholes and the geophysical datasets. It is likely though, that deep faults, glacial erosion and deformation has disturbed the pre-Weichselian succession.

- **Geological interpretation and correlation:** The preliminary interpretations of the data have revealed a good correlation between the terrain and the subsurface structures. The outwash plain can be distinguished from the older glacial geology, and the observations fit well into the current knowledge of the latest geological events in the area. Understanding the geology in the deeper parts is difficult at this preliminary stage, e.g. interpretation of the pre-Weichselian clays and the distribution of presumed interglacial deposits.

7 References

GEUS, 2018. Geomorphological map – Southern Denmark 1:200.000 (preliminary), Jakobsen, P. R.

Houmark-Nielsen M., Krüger J. Kjær K.H., 2005. De seneste 150.000 år – Istidslandskabet og naturens udvikling, Geoviden, geologi og geografi nr.2

Jakobsen, P. R., Hermansen, B., and Tougaard, L., 2011. Danmarks digitale jordartskort 1:25000 Version 3.1 Danmark og Grønlands Geologiske undersøgelser rapport no. 40: De nationale geologiske undersøgelser for Danmark og Grønland.

Sandersen, P.B.E. & Jørgensen, F., 2016. Kortlægning af begravede dale i Danmark. Opdatering 2010-2015. Vol- 1 and 2. GEUS Special Publication, ISBN 978-87-7871-451-0/452-7.

Sandersen, P. B. E. & Jørgensen, F. 2015: Neotectonic deformation of a Late Weichselian outwash plain by deglaciation-induced fault reactivation of a deep-seated graben structure. Boreas. Vol. 44, pp. 413–431. ISSN 0300-9483.

Rasmussen, E.S., Dybkjær, K., Piasecki, S., 2010. Lithostratigraphy of the upper Oligocene-Miocene session in Denmark. Geological Survey Denmark and Greenland Bulletin, 2010; 22:93.