Ejer Bavnehøj – Preliminary geological interpretations

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1 Geomorphology

The Ejer Bavnehøj LOOP 3 study area is located in a hilly glaciated landscape in the eastern part of Jutland just east of the highest point in Denmark (Yding Skovhøj; Figure 1). The study area lies on the northeast-facing hillside (Figure 2). The terrain is predominantly clayey. To the north of the area and west of Skanderborg, a system of open tunnel valleys forms a low-lying area with several lakes (Figure 1).

In the southern part of the study area, the elevation reaches 170 m a.s.l. and to the northeast, it slopes down to around 40 m a.s.l. The terrain, as seen on Figure 2, is dominated by orientations perpendicular to the slope (VNV-ESE to N-S) seen as either valleys (blue arrow) or abrupt slope changes (black arrow). In a few places, erosional valleys parallel to the slope can be seen (WSW-ENE to SW-NE; yellow arrow).

Figure 1: Morphological map. Study area marked with black hatched line. Map width is approx. 28 km. (Map from Smed, 1978).

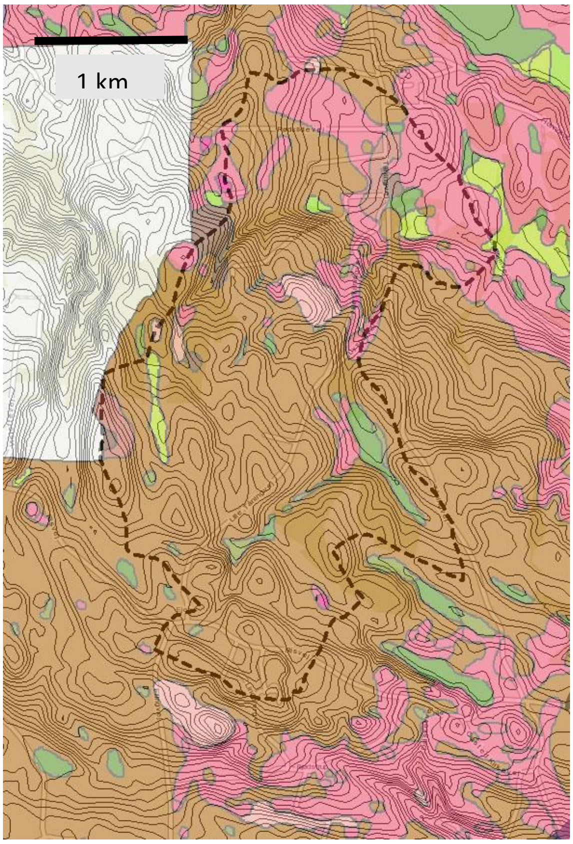


Figure 3: Soil types in the uppermost meter (Jakobsen et al. 2011). Brown colours: Tills; Red: Meltwater sand; Light red: Meltwater clay; Green: Postglacial freshwater deposits.

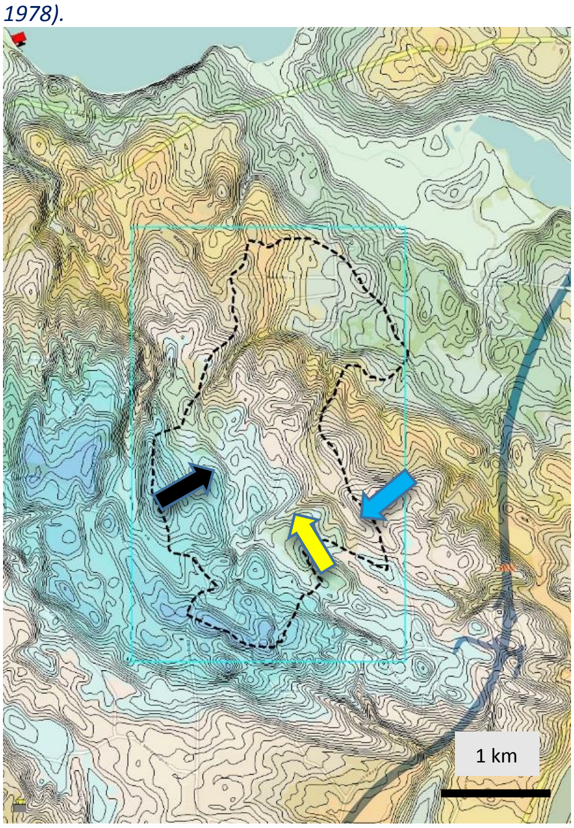


Figure 2: Digital elevation model (2½ m equidistance; highest elevations: blue, lowest: green)

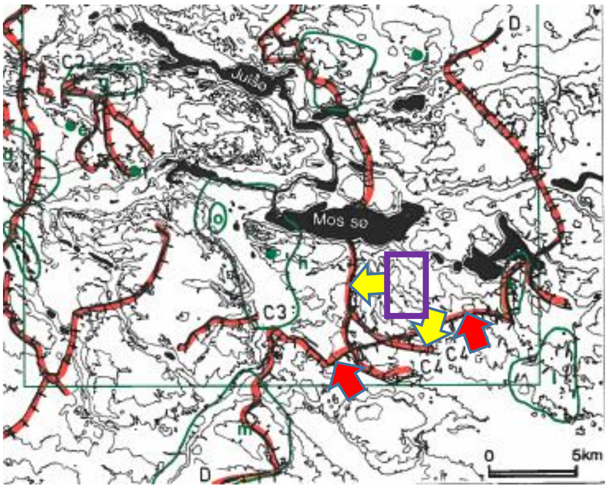


Figure 4: Ice-marginal positions (red colour). 'C'-positions: Main advance; 'D'-position: East Jutland advance. Study area marked with rectangle. Map detail from Larsen & Kronborg (1994).

A map of the soil types in the uppermost metre is shown on Figure 3. Clay tills dominate the study area, but to the north, in the lowest parts of the terrain, occurrences of meltwater sand are found. Occurrences of postglacial freshwater deposits can be found locally.

The two latest ice-advances that reached the area was the 'Main ice advance' from northeast and later on the 'East Jutland advance' from southeast (Larsen et al., 1979). The ice-advance from northeast had a temporary ice margin approximately at the culmination of the hills ('C4' on Figure 4; yellow arrows), whereas the ice from southeast stopped just short of the study area hills ('D' on Figure 4; red arrows).

2 Geophysical data and boreholes

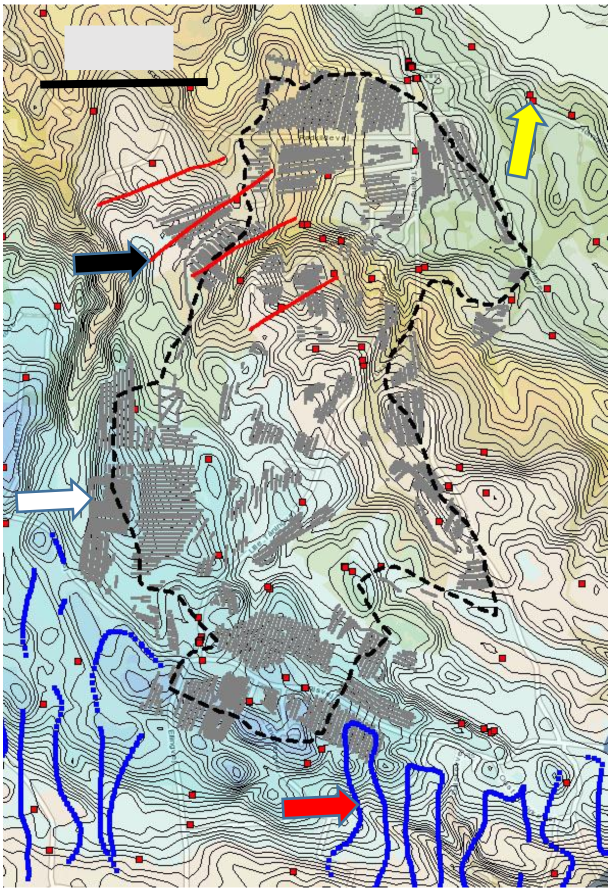


Figure 5: Geophysical data and boreholes. Except for the tTEM, data is downloaded from Gerda and Jupiter databases (www.geus.dk).

Three types of geophysical data have been collected in and just around the study area (Figure 5):

- tow-TEM data (tTEM) shown as grey lines (white arrow)
- Electrical Resistivity Tomography (ERT) shown as red lines (black arrow)
- SkyTEM data (airborne Transient Electro Magnetic method) shown in blue (red arrow)

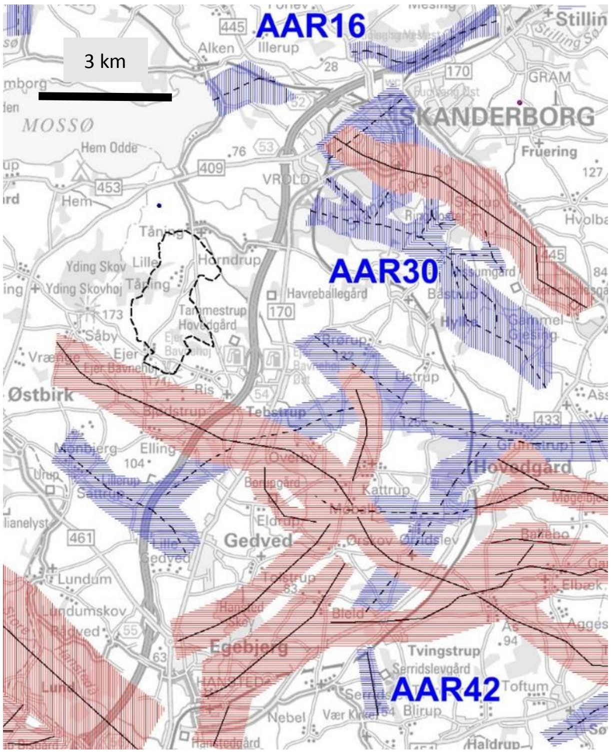
The geological data comprise boreholes from the Jupiter database (red dots; yellow arrow).

3 Stratigraphy

Based on boreholes within the study area, the deepest parts of the subsurface consist of grey to greenish sticky marine clay of Eocene age (e.g. DGU no. 98.457). Above this clay, scattered and thin occurrences of black mica clay (presumably Oligocene; e.g. DGU no. 98.80) can be found.

The Quaternary succession above consists of predominantly clayey tills, meltwater sand, meltwater gravel, and minor occurrences of meltwater clay. The thickness of the Quaternary succession is ranging from a few meters to more than 100 m. Isolated floes of pre-Quaternary sediments occur occasionally within the Quaternary succession suggesting glaciotectonic deformation. Generally, the area has only a few deep boreholes, but still the lithologic information from the boreholes gives a good impression of the sedimentary succession and fits well with the soil map (Figure 3). However, the freshwater sediments seen on the soil map have not been penetrated by any of the boreholes.

4 Buried tunnel valleys



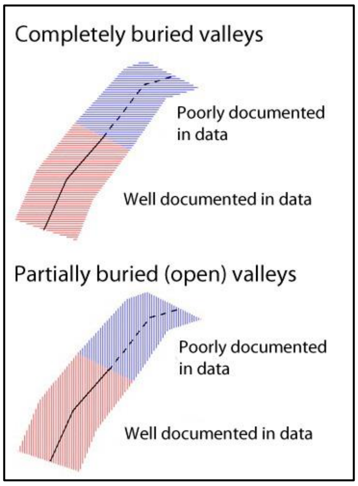


Figure 6:
Mapped buried valleys close to the study area (shown with black hatched line). Legend for the map is shown above; "AAR30" refers to locality numbers used in Sandersen & Jørgensen (2016) and on www.buried-valleys.dk.

Figure 6 above, shows the buried valleys that have been 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 WNW-ESE/NW-SE and the other around SW-NE/WSW-ENE. The WNW-ESE/NW-SE orientation is also clearly seen in the present-day terrain (see Figure 1).

The mapped valleys most probably represent several generations, but the two mentioned orientations match fairly well the orientations of the two youngest ice-advances mentioned above. Relative age-relationships of the valleys found by Sandersen & Jørgensen (2016) confirm that the VNV-ESE/NW-SE orientation is the youngest and therefore probably represents the East Jutland Advance.

5 Geological interpretation of geophysical data

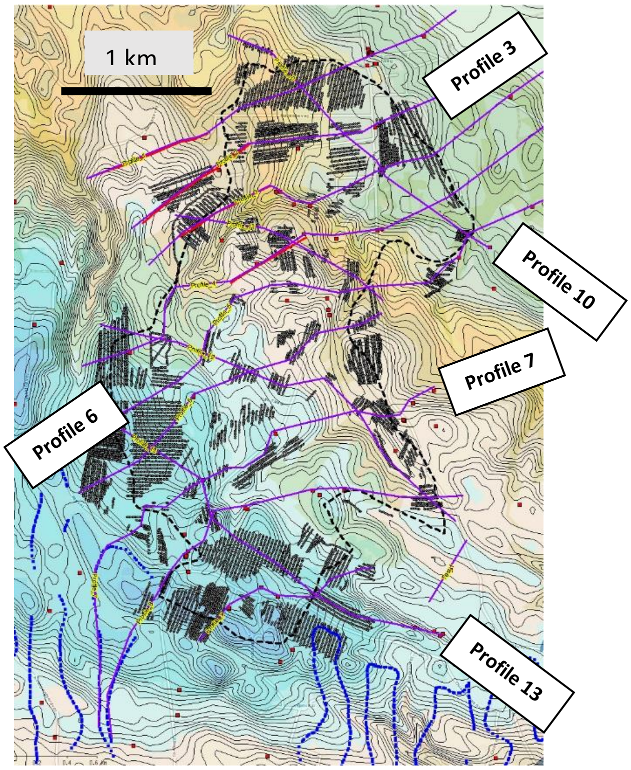


Figure 7: Location of selected profiles.

The tTEM cover is patchy and although the geology and the terrain is very varied, the data gives a very good impression of the geological setting. The four ERT-profiles at the northwestern edge of the area provide valuable information and a good possibility for comparing the two methods. The SkyTEM-data is located outside the study area, but it adds valuable information on the geological connections to the neighbouring areas to the south.

Profiles 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 ERT-profiles are included on selected profiles.

Two slices of a tTEM 3D resistivity grid are shown in Figures 8 and 9. Figure 8 shows a 5-m slice 50 m a.s.l. revealing that the southern and central parts of the area have low resistivities (blue) whereas the north-eastern part of the area has moderate to high resistivities (green to red). The 85 m a.s.l. slice in Figure 9 shows that at higher altitudes, bands of higher resistivities emerge in the low-resistivity sediments. Generally, the tTEM 3D grid in Figures 8 and 9 shows large variations of the elevation of the good conductor.

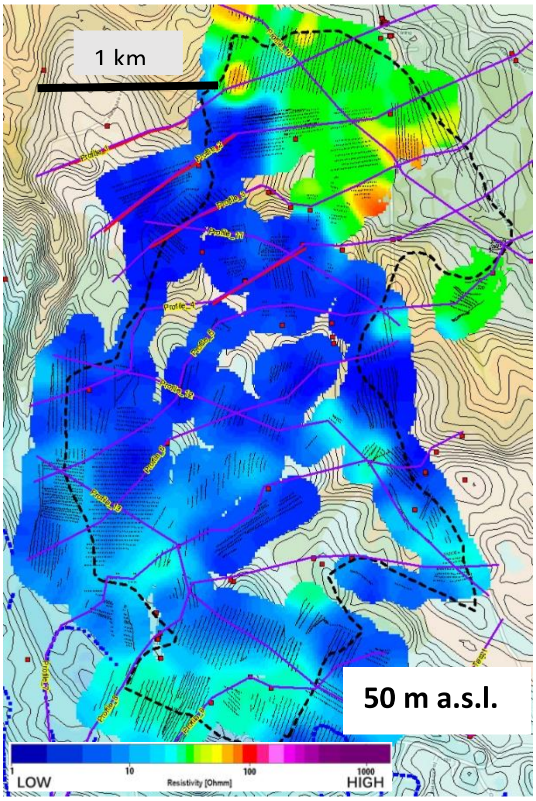


Figure 8: 3D-grid of tTEM data; slice 50 m a.s.l.

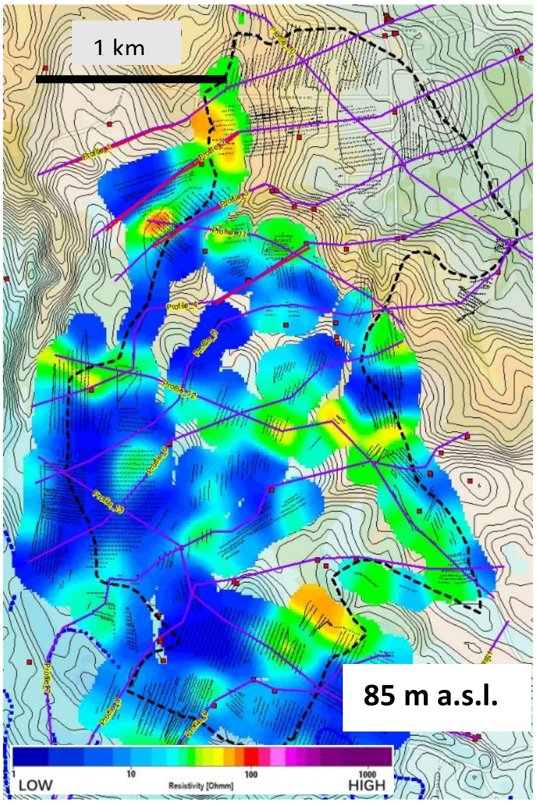


Figure 9: 3D-grid of tTEM data; slice 85 m a.s.l.

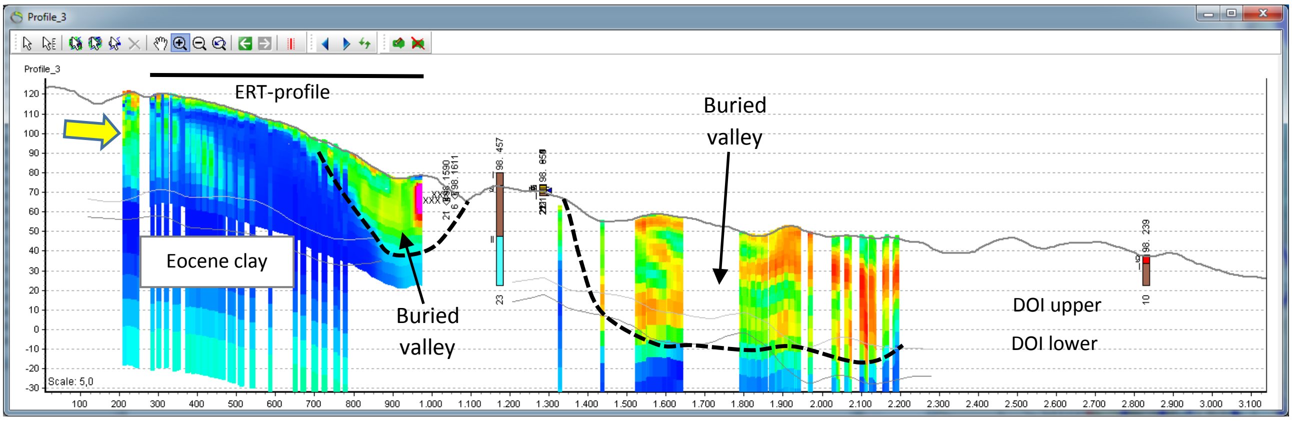


Figure 10: Profile 3; WSW-ENE. For location, see Figure 7.

In Figure 10, ERT data and tTEM data are shown with some overlap in the left side of the profile. The two data sets show agreement on the level of resistivity and depth to the good conductor, but the tTEM reveals slightly elevated resistivities at some depth below the low resistivity layer close to the surface (see yellow arrow). Apparently, the ERT method cannot penetrate the low-resistive layer as good as the tTEM method. The resulting picture of the subsurface is a low-resistivity slab covering layers of higher resistivity (between 200 and 550 m), pointing to a deformed sedimentary succession. The mapped layers are well above the tTEM DOI shown as grey lines on the profile. The low-resistivity layer is the sticky Eocene clay found for instance in borehole DGU no. 98.457 (blue bottom layer). To the right on the ERT data, a part of a valley-infill can be seen (bottom of valley is highlighted with a black hatched line).

The right side of the profile shows a more than 50 m thick, complex succession of moderate to high resistivities probably consisting of tills and sandy/clayey meltwater sediments. The succession appears deformed. The layers occur in the northern part of the study area (Figure 8) and probably constitute the infill of a NW-SE oriented buried valley. A genetic relation to the valleys farther to the southeast, as seen on Figure 6, is possible. The bottom of the valley, however, is not fully resolved by the tTEM.

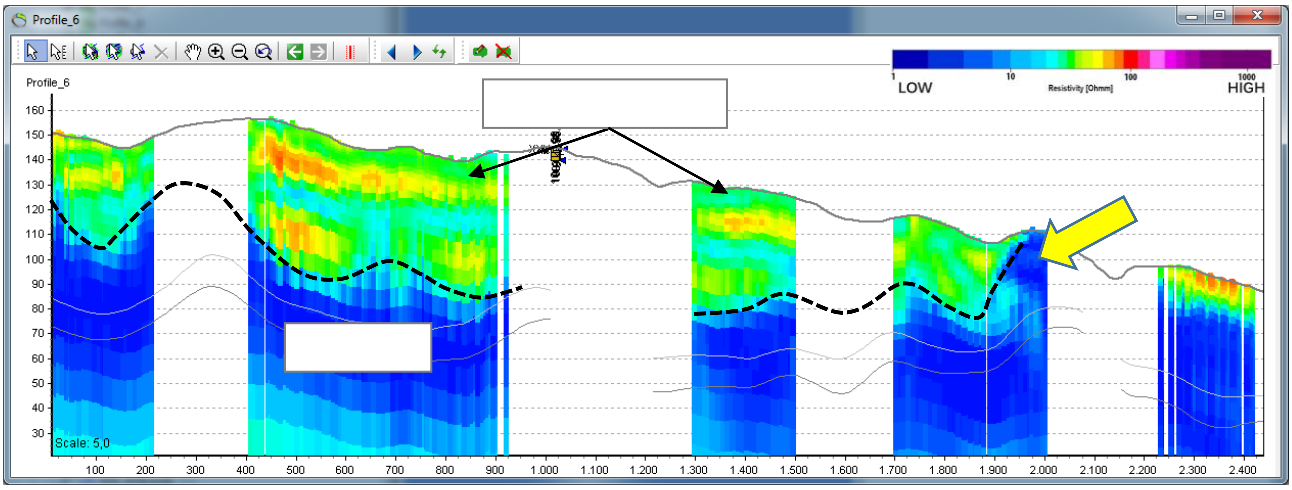


Figure 11: Profile 6; WSW-ENE. For location, see Figure 7.

The profile in Figure 11 crosses the high parts of the study area. The surface of the Eocene clay (blue; low resistivities) shows some variation and to the right a slab of a low-resistivity layer is seen over layers of slightly higher resistivity (yellow arrow; between 1900 and 2000 m). The layers of moderate to high resistivity (green to red) represent the Quaternary succession, and although other parts of the subsurface seem very deformed and complex, this part seems to be less deformed and fairly easy to correlate. The succession above the Eocene clay appears to consist of two high-resistivity layers each covered by a low-resistivity layer.

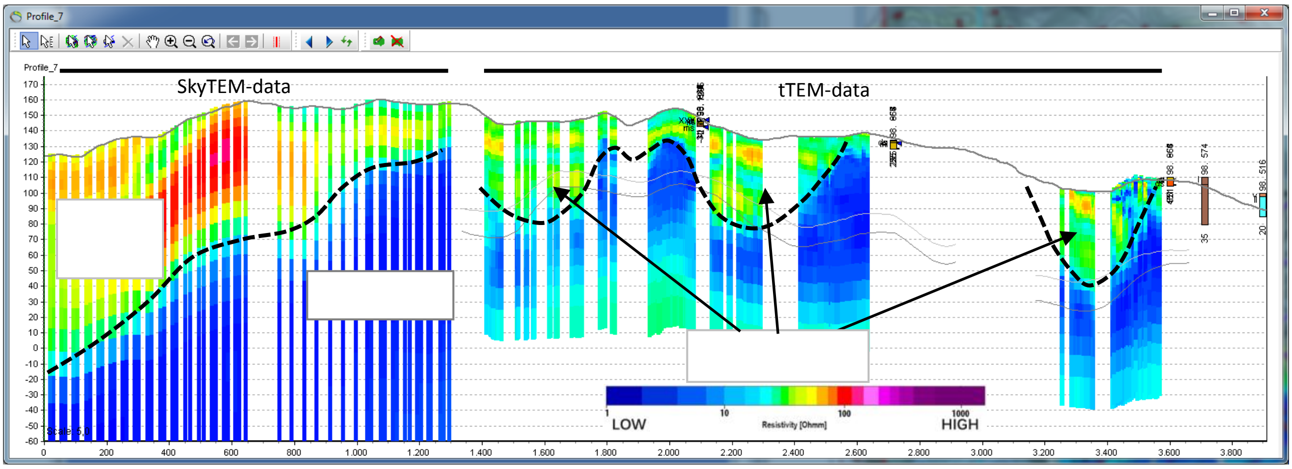


Figure 12: Profile 7; SW-NE. For location, see Figure 7.

The profile 7 in Figure 12 shows SkyTEM data on the left side and tTEM data on the right side. The two datasets show good correspondence despite the tTEM data does not penetrate as deep as the SkyTEM-data. To the left the SkyTEM data maps the deep buried valley shown on Figure 6 just south of the study area. In the middle of the profile, two smaller buried valleys are crossed at 1400-1800 m and 2100-2500 m. Apparently, the valleys have comparable infill, but there are, however, no boreholes to confirm this. To the far right, another buried valley is seen at 3200-3500 m. All three valleys mapped by the tTEM data show topographic lows above.

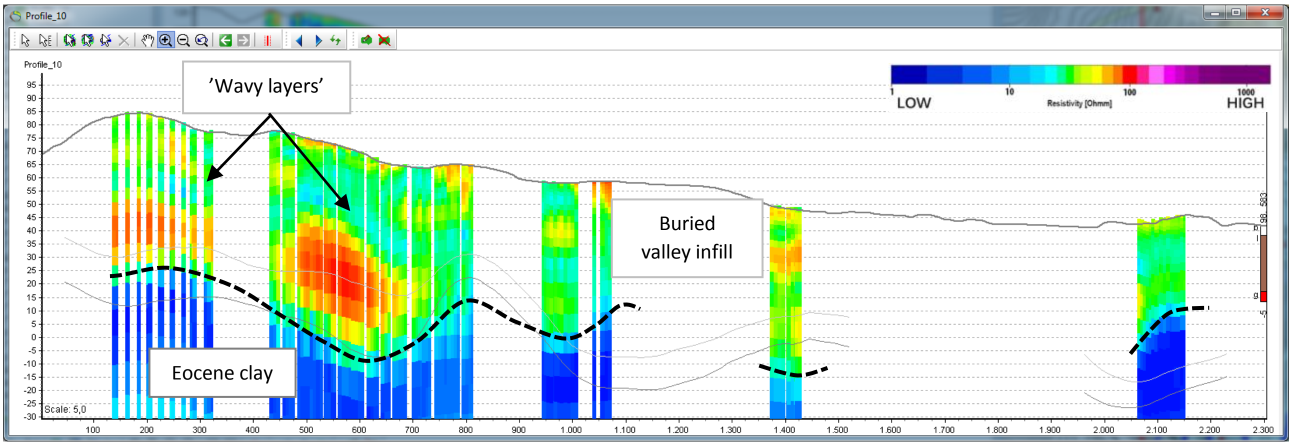


Figure 13: Profile 10; NW-SE. For location, see Figure 7.

Profile 10 in Figure 13 shows the infill of the broad buried valley to the northeast. Especially in the left side of the profile, the layers have a wavy appearance pointing to pronounced glaciotectonic deformation.

Profile 13, shown on Figure 14, gives a very clear picture of the valleys in the southernmost part of the study area, and just as it was seen on Figure 11 and 12, the valley infill seems to be rather undisturbed and apparently being of more or less the same type. This succession is presumably penetrated in the borehole DGU no. 98.942 just southeast of the study area. In this borehole, layers of meltwater sand and gravel are interlayered by clay tills and meltwater clay. The meltwater clay is most likely responsible for the relatively low resistivities in the middle of the Quaternary succession mapped by the tTEM (Figure 14; yellow arrow).

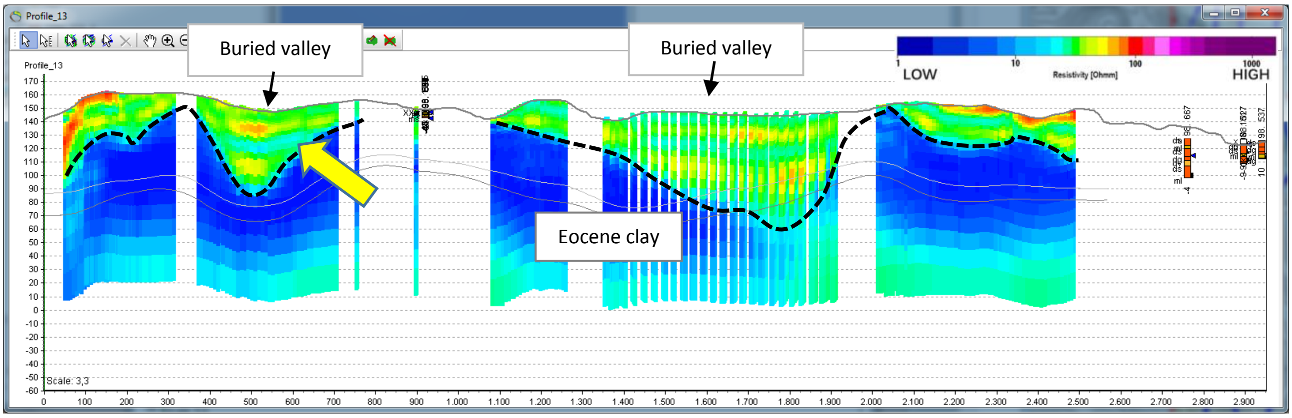


Figure 14: Profile 13; NW-SE. For location, see Figure 7.

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 good resolution of individual layers and the surface of the good conductor. In some cases, the tTEM manages to map slightly higher resistivities beneath slabs of the good conductor.
- **Borehole information:** The information from boreholes are limited as many of the boreholes are shallow, but the general perception of the succession is fairly good. The Eocene clays can be found in all of the study area showing very varied elevations; highest to the SW and lowest to the NE. Above the Eocene clay, a Quaternary succession consisting of tills, meltwater sands and clays and occasional occurrences of postglacial freshwater deposits. No boreholes, however, have penetrated the postglacial deposits.
- **Glaciotectonic deformations:** The effects of glaciotectonic deformation from northeast can easily be seen in the terrain as pronounced orientations of hill crests, slopes and erosional valleys. In the tTEM data, folded sedimentary successions and dislocated slabs of Eocene clay can be seen. The Main ice advance was probably responsible for the glaciotectonic deformation from the northeast, whereas the younger East Jutland advance from southeast probably did not override the study area.
- **Buried valleys:** The surrounding areas show buried valleys of varied size and with preferred orientations roughly around NW-SE and SW-NE. A large buried valley is found to the northeast within the study area and the tTEM-data shows signs of deformations of the valley infill. In the highest parts of the study area to the southwest, narrower buried valleys are found in the Eocene clay. These valleys are presumably filled with roughly the same type of sediments and because they seem to be more or less undeformed, they are probably filled with meltwater sediments from the youngest ice advance when it resided just southeast of the study area. The valleys could be either eroded by meltwater streams or formed as longitudinal lows formed between slabs of ice-pushed sediments. As such, they are *not* formed as tunnel valleys underneath the ice.
- **Geological interpretation and correlation:** The preliminary interpretations of the data have revealed a very good correlation between the terrain and the subsurface structures. These observations fit well into the current knowledge of the latest geological events in the area, thus providing good possibilities of making robust geological correlations between the geological and geophysical data.

7 References

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