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Geological model of the Hanko aquifer

Prepared by
Samrit Luoma

Prepared for:
ELY Centre Uusimaa,
Hanko City and
Hanko Water and Waste Water Work

Centre for Economic Development, Transport and the Environment

HANGON KAUPUNKI
HANGÖ STAD

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Geological Survey of Finland **Summary**

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Tekijät Samrit Luoma	Raportin laji Investigation report
	Toimeksiantaja ELY Centre Uusimaa, Hanko City and Hanko Water and Waste Water Work
Raportin nimi Geological model of the Hanko aquifer.	

Tiivistelmä

This study was carried out as part of the POAKORI project with the aim to investigate detailed characteristics and distributions of the First Salpausselkä ice-marginal deposit in the Hanko groundwater area. The geological model was constructed based on the available geological, geophysical and hydrogeological data. The interpretation was done for the bedrock topography and the distributions of the Quaternary deposits with the confirmation of the sediments from 429 drilled boreholes where 46 boreholes drilled into the bedrock. The bedrock surface elevation varies between -49.0 and +31.0 m a.s.l. The deepest bedrock surface with the elevations between -49.0 and -30.0 m a.s.l. were found in the areas between Lindnäsudden, south to south-east of Fermion Oy, and south to south-east of Motocross-rata. The shallower bedrock topography was found in the Hanko town and south to south-east of the study areas. The Quaternary deposit lies between the bedrock and ground surface with the thickness varies from zero to more than 40 m. The Quaternary deposit in the study area consists of glacial till, coarse-grained sediments of the ice-marginal primary deposit, the fine-grain sediments (silt and clay) of the glaciolacustrine and the coarse-grained sediments of the littoral deposit. The glacial till overlain the bedrock surface throughout the study area with the average thicknesses of 1-2 m. The primary deposit of the ice-marginal sediments consists of various grain sizes from very fine-sand to boulder and spatially distributed throughout the study area with the general trend of the coarser grains accumulated in the proximal area in the north to the finer grains of the distal area in the south and south-east. The First Salpausselkä ice-marginal formation in the study area could probably formed in several phases. At least three main parallel ridges of the ice-marginal formations are observed. A narrow esker or a tunnel filled coarse-grained materials was observed from the drilled borehole data in the areas between Hopearanta (Kart 1 and Kart 2) and south of Neste D oil station. However, there is not clear whether these coarse-grained units are connected and continued as a long esker from north to south or only confined in a short distance in front of the local ice-marginal ridges.

The fine-grained unit consists of the layers of silt and clay overlaid the primary deposit with the thickness varies between zero and 37 m. The thick fine-grained unit accumulated in the areas between Lindnäsudden, south of Fermion Oy and south to south-east of Motocross-rata with the maximum thickness of 37 m. The fine-grained layer seems to disappear in the areas between south ETNA and the Baltic Sea shoreline. If it did exist, it could probably be deformed by the wave action during the isostatic land uplift. The littoral deposit consists of sand and gravel from the littoral process. LiDAR-DEM reveals landforms of the First Salpausselkä formation and remnants of the littoral processes from wave action along the ancient shoreline during the submerged terrain

was uplifted to the shore level due to the isostatic land uplift and changes of water levels in the Baltic basin. The maximum ancient shoreline in the Hanko area lying between 12-14 m a.s.l. at the present depth. The littoral sediments (sand and gravel) are, therefore, expected to be found in the areas between the maximum ancient shorelines and the coastlines.

The Hanko groundwater area is separated from the Sandö-Grönvik groundwater area in the east and the Hanko town in the west by the elevated bedrock surface. The thick fine-grained unit lying in the NW-SE direction from Lindnäsudden in the northern coast of the Baltic Sea to south and south-east of Fermion Oy, and south of Motocross-rata, separated the Hanko groundwater area into two main aquifers; the east and the west aquifers. The east aquifer is unconfined with the groundwater levels vary between zero and 12 m a.s.l. The west aquifer consists of two main groundwater levels; the perched- and the main (lower) groundwater levels. The perched groundwater is accumulated above the fine-grained unit in the northern part of the west aquifer and has groundwater levels very between 1.51 and 11.58 m a.s.l., which is similar water levels to the east aquifer. The main groundwater level in the west aquifer is semi-confined with partly bounded by the fine-grained unit. The groundwater levels vary between less than zero and 6.70 m a.s.l., approximately 1.24-7.64 m lower than the perched water level.

The results from this study provide useful information of the geological framework for the groundwater flow and solute transport modelling, and also for the vulnerability and risk assessments of the groundwater area for land use planning and water supply management in the future.

Asiasanat (kohde, menetelmät jne.)
Groundwater, 3D geological model, ice-marginal deposit, Hanko, the First Salpausselkä

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Contents

1 INTRODUCTION

The shallow groundwater is an important water resources for water supply to the municipalities in Finland. However, groundwater areas are at risk from the results of human activities and contaminations from various sources and groundwater risk sites. In addition, the coastal aquifers such as in Hanko, are facing the additional risks and threats from contamination of salt-water intrusion at present and in future sea level rise. For the sustainable water resources management, it is important to understand the geological and hydrogeological characteristics of the aquifers, to be able to identify the vulnerable groundwater areas to the contaminations in order to provide protection to those groundwater areas. To be able to identify the extents of the pollution area, the chemical characteristics, the movements and directions of the contaminants, for the areas that have already been contaminated, and to provide information for the risk assessment and the remediation plans.

Within the POAKORI project (Kemiallisesti huonossa tilassa olevien pohjavesialueiden kokonaisvaltainen riskinhallinta), the Pirkanmaa- and the South Savo ELY Centres in collaboration with the Uusimaa ELY Centre, the Finnish Environment Institute (SYKE), the Geological Survey of Finland (GTK), WaterHope Oy and Ramboll Finland Oy, aim to develop an operating model that can be used as a tool for risk assessments of groundwater contamination sites and for prioritization of risk management measures in the vulnerable groundwater areas to ensure that the greatest risk to groundwater areas are first to be cleaned up and/or protected. The operating model consists of the investigations of geological and hydrogeological characteristics of aquifer bodies, flow and solute transport models, sensitivity, vulnerability and risk analysis, in order to create a new comprehensive approach to risk managements for the wellhead protection areas of the water intake wells and the whole groundwater area.

This report summarize the results of detailed investigation of the geological characteristics and distributions of the Quaternary sediments of the shallow groundwater aquifer in the Hanko case study area, and to construct the 3D geological model and visualization of the aquifer by utilizing all available geological and geophysical data. The results from this study provide geological framework not only for the groundwater flow and solute transport modelling, but also for the vulnerability and risk assessments of the groundwater area for land use planning and water supply management in the future.

2 STUDY AREA

The study area is located in the western part of the Hanko Peninsula in southern Finland, covers total area of 61 km^2, which consists of the Hanko main groundwater area (#0107801), the Täktom groundwater protection area class II (#107807), and the Hanko town (Fig. 1). The aquifer in the Hanko area is underlain by the basement of the Precambrian crystalline igneous and metamorphic rock and covered by the Quaternary deposits. The Precambrian bedrock, which mainly consists of granite, quartz diorite and granodiorites, forms a sharp contact with the Quaternary deposits, with some rock exposed in the area (Kielosto et al. 1996). The aquifer

in the study area is situated in the First Salpausselkä ice-marginal formation deposited during the Weichselian and Holocence deglaciation of the Scandinavian Ice Sheet (Fyfe 1991, Saarnisto et al. 1994, Kielosto et al. 1996). The First Salpausselkä ice-marginal formation consists of glacial till, gravel, sand and clay, together with postglacial littoral gravel, sand and clay (Figs. 2 - 4). The primary ice-marginal formation in Hanko was formed in deep water with a low narrow ridge (Fyfe 1991). When the ice sheet withdrew from the area, this formation was covered by fine-grained sediments, silt and clay layers of the Ancylus Lake and Littorina Sea. The sea level has been regressive since the glacial period due to isostatic land uplift. The primary deposit of the First Salpausselkä formation was exposed to sea waves and also to wind (Kielosto et al. 1996). The topographic landform varies between 10–14 m a.s.l. along the northern ridge of the First Salpausselkä ice-marginal formation and its elevation decreases to less than two metres along the northern and southern coastlines, while in the south and southeast the elevation gradually decreases to 5–7 m a.s.l. The area is partly covered by wetlands and peatlands. In many parts of the aquifer, the groundwater level is close to the ground surface, and water intake areas are located along the coastline, where the groundwater level may often fall below the sea level.

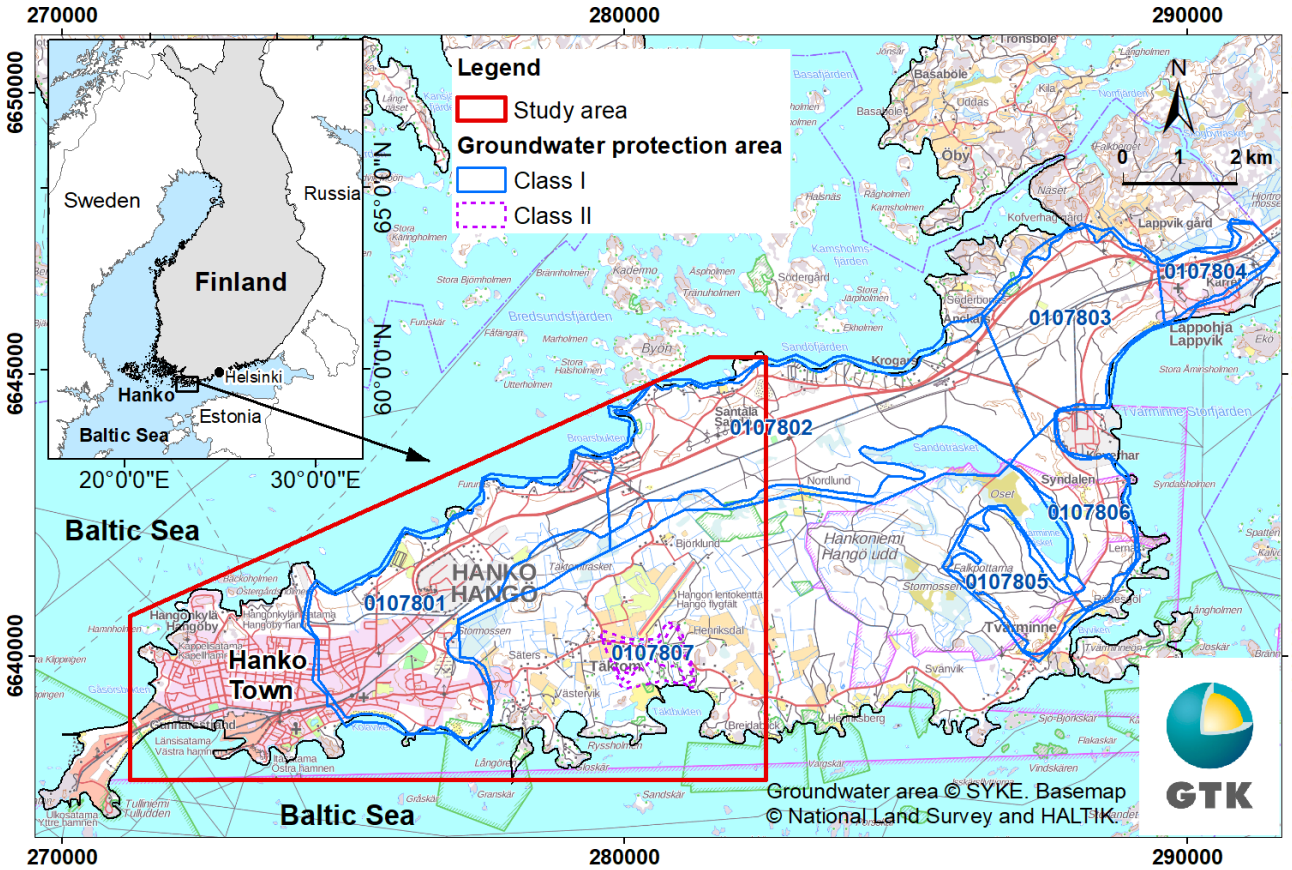


Fig. 1 Location map of the study area.

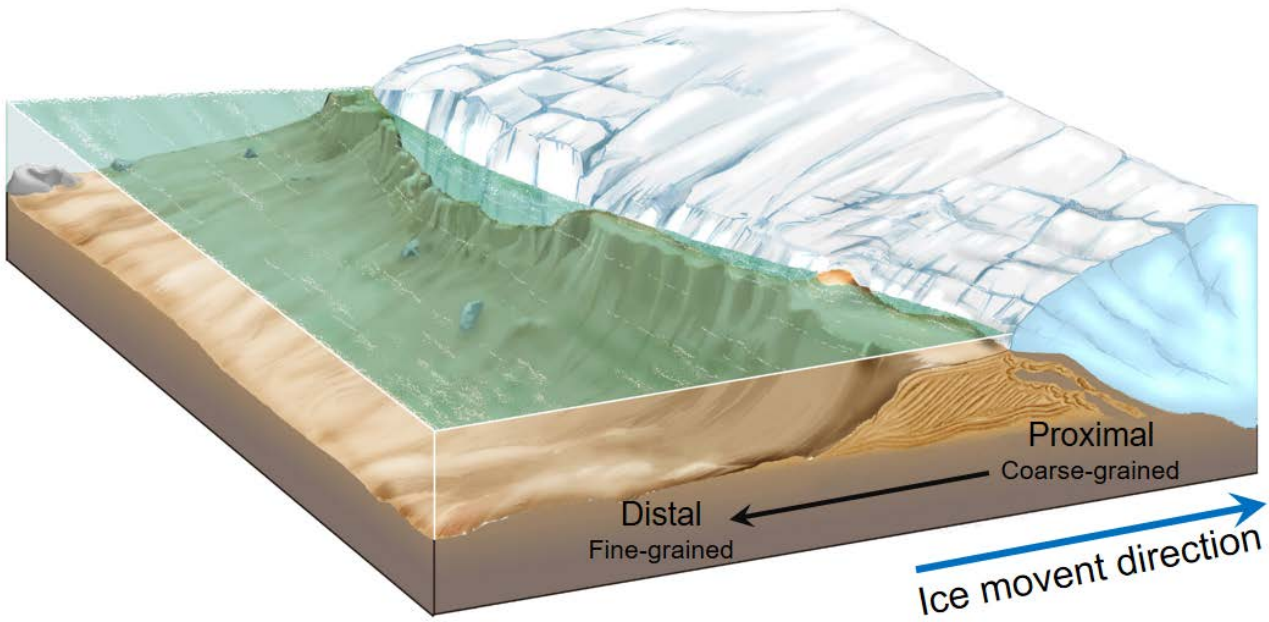


Fig. 2 Conceptual model of the Salpausselkä ice-marginal deposit. The subglacial melted sediments deposited as a ridge in front of the ice-margin. Figure: GTK/Harri Kutvonen.

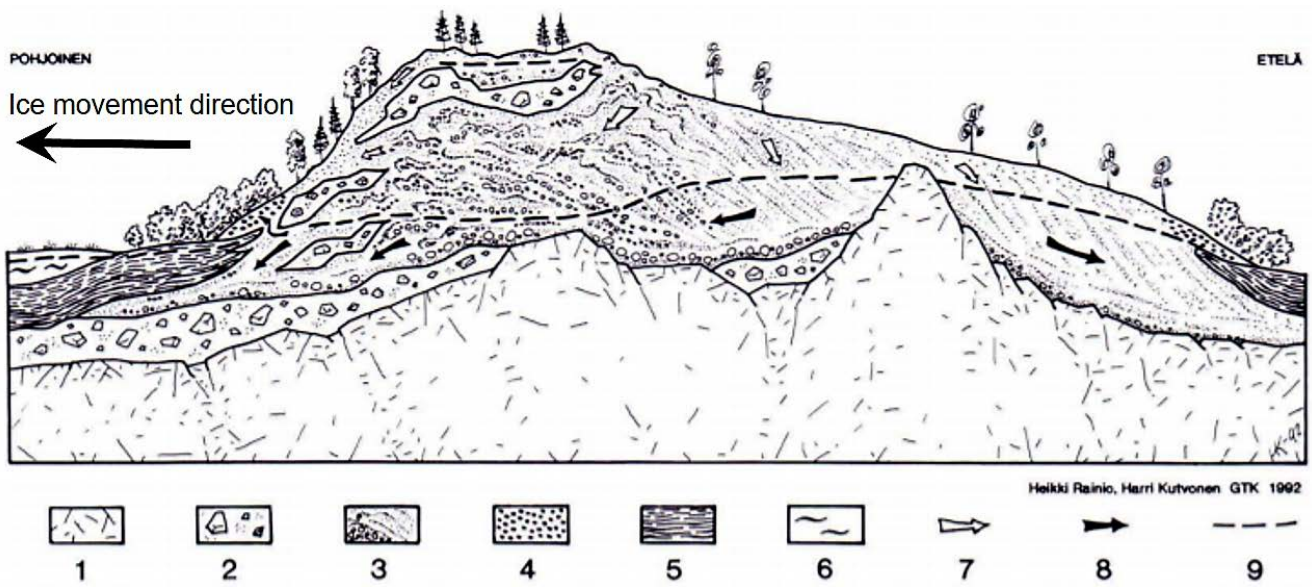


Fig. 3 Schematic drawing of the First Salpausselkä formation in the Kasarminmäki, Kouvola. Legend captions consist of 1 bedrock, 2 glacial till, sand and gravel of the primary ice-marginal deposit, 4 sand and gravel of littoral deposit, 5 fine-grained (silt and clay) of glaciolacustrine, 6 peats, 7 unsaturated zone, 8 saturated zone, and 9 groundwater level (After Saarnisto et al. 1994).

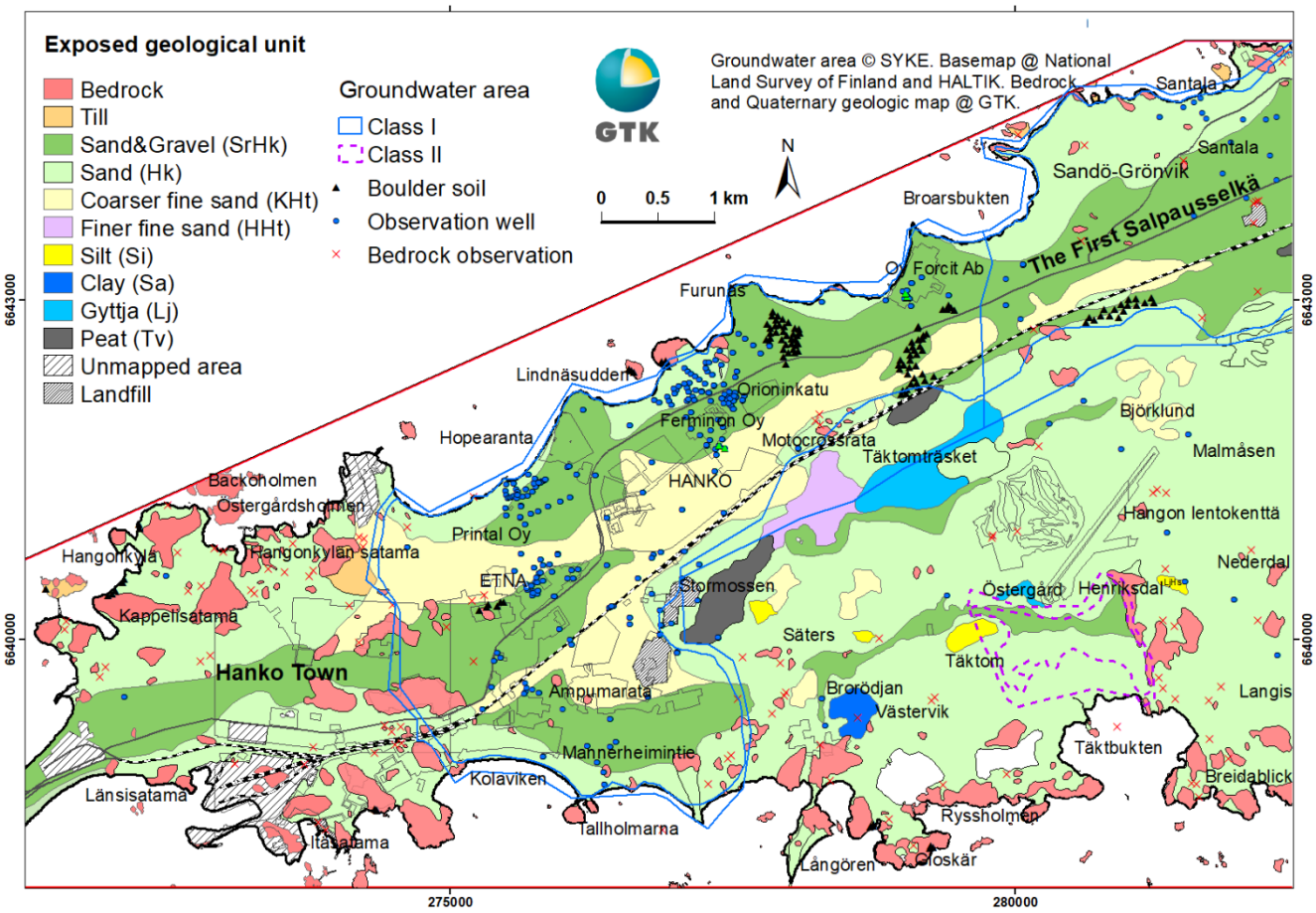


Fig. 4 The Quaternary geological deposit map of the study area.

3 DATA AND METHODS

3.1 Data

Geological model of the Quaternary deposit in the Hanko area was constructed in order to provide the geological framework for the groundwater flow and solute transport modelling. Data used in this study consists of all available geological, geophysical and hydrogeological data gathered from various projects from GTK and other studies that took place in this area. The detailed sedimentary distributions of the First Salpausselkä ice-marginal formation in the Hanko groundwater area has been mostly full-filed with new data with the contributions from Esko Nylander (ELY Uusimaa) and Eeva Teräsvuori (ELY Uusimaa) with their great efforts in searching for the hydrogeological data from missing reports and updating the POVET database, which provided valuable data for 3D geological modelling and calibration data for 3D groundwater flow modelling. Some parts of data remain unpublished, therefore, only the interpretations of the results of those data were used for the modelling. Data used in this study are shown in Fig. 5 and in the lists below:

- Total 429 drilled boreholes data with 46 boreholes drilled into the bedrock from various sources including the GTK database, Pohjatutkimus database, the descriptions of the drilled boreholes from the ELY-Uusimaa and the Hanko City's reports.
- Reports of the studies in the ETNA area from the ELY-Uusimaa and the Hanko City.
- Bedrock surface depths from gravimetric surveys during 1997-2009 from GTK.
- Ground-penetrating radar (GPR) data during 2005-2006 from GTK and the interpretation data of the study in the Stormossen landfill area in 2016 from the Hanko City's report.
- Groundwater levels from 200 observation wells from the POVET-database (SYKE 2018).
- Top bedrock data from the seismic survey in 2017 in the Baltic Sea between Hopearanta and Furunäs coastal areas from the BONUS-SEAMOUNT project, GTK.
- LiDAR Digital Elevation Model data from the National Land Survey (NSL, 2018).
- Bedrock and Quaternary geologic map scale 1:20 000 from GTK.

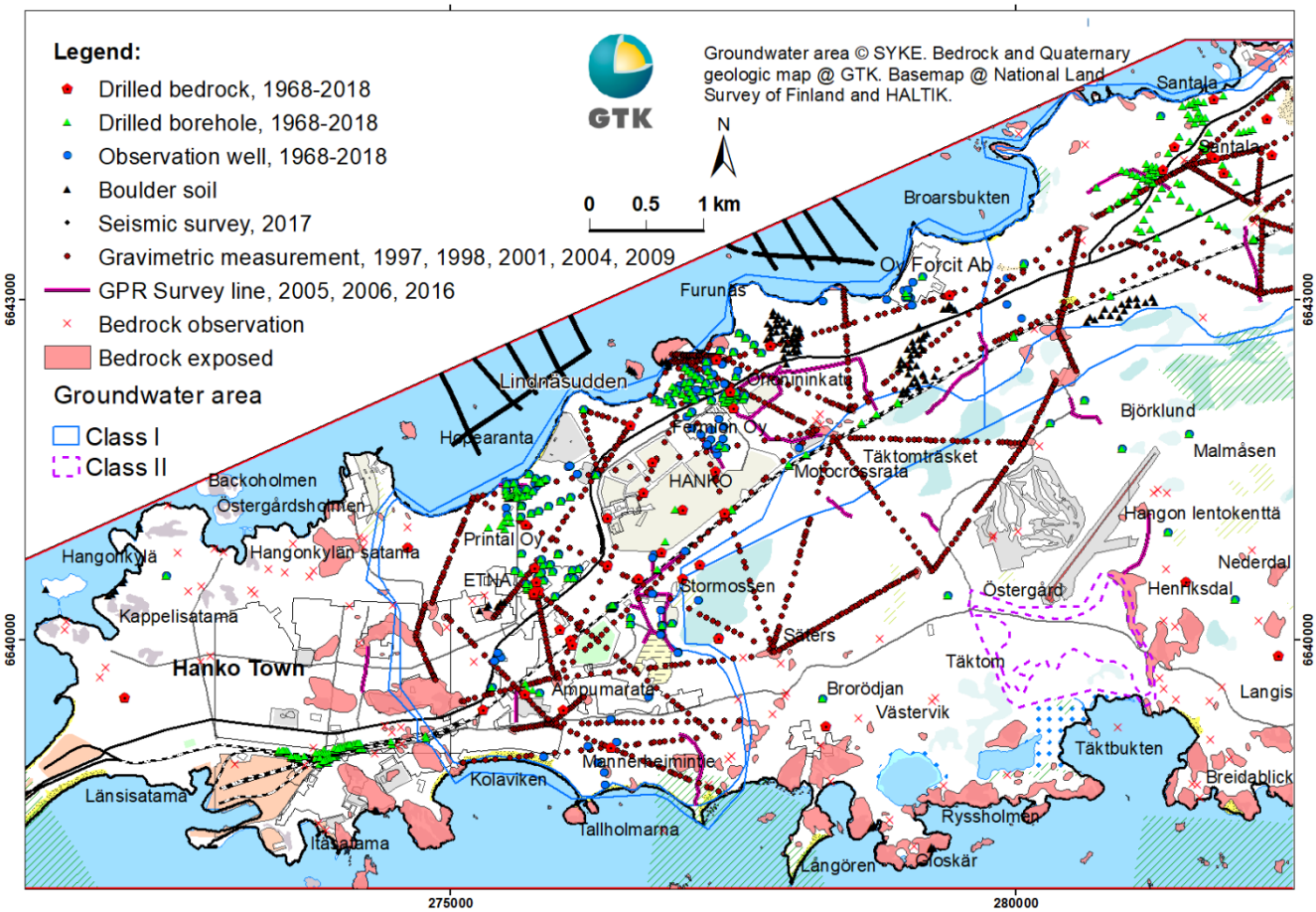


Fig. 5. Locations of data used for the interpretation.

3.2 Methods

Distribution of the Quaternary deposit is constrained by ground surface and bedrock surface. The interpretation was carried out by first identifying the bedrock surface and then the distributions of the Quaternary sediments. LiDAR - Digital Elevation Model (LiDAR-DEM) (NSL, 2018) was utilized as a ground surface data and also for the identification of the ancient geologic landforms such as the location of the highest shoreline following deglaciation, which could support the interpretation and prediction of the sediment types and its distributions in this area. The software used was an integration of ArcGIS/ArcMap (version 10.4) for the spatial analyst and GMS (version 10.3) for the 3D geological modelling.

3.2.1 Bedrock surface interpolation

The bedrock surface interpolation was conducted in 2 steps. First, all available bedrock elevation data were prepared as point data and were interpolated into a 5m x 5m grid map by using kriging interpolation method in the ArcGIS/ArcMap. The interpolated bedrock surface grid map was calibrated with all data points, including boreholes those did not reach the bedrock. In the area that the interpolated bedrock surface was shallower than those data points, 5 m deep was added to those boreholes. Then all data points were re-interpolated by using the Topo-to-Raster method and re-calibrated until the interpolated bedrock surface grid map was in good calibration with the data points.

3.2.2 Quaternary deposit

The total thickness of Quaternary deposit was calculated by subtracting the bedrock topographic map from the LiDAR – DEM map. The distribution of the Quaternary deposits were based on the descriptions of the sediments from drilled boreholes. In the area that GPR profile available, the internal structures and the distributions of sediments were interpreted based on the reflection patterns of the GPR profiles which were calibrated with the sediments from drilled boreholes. In the area that lack of those mentioned data, the correlations between boreholes and the Quaternary geologic map were used to support the interpretations. The uncertainty of the interpretation, hence, based entirely on those data, until the new data is available for the update.

The Quaternary sediments of the First Salpausselkä ice-marginal deposit are complex and high heterogeneities, cause difficulties correlating the sediments between the nearby wells. Based on the grain sizes and its sequences from drilled boreholes descriptions from bottom to top, the sediments were grouped into four main units represent the dominant sediments found in those intervals: 1) glacial till; 2) coarse-grained sediments (sand, gravel, stone (pebbles, cobbles, boulders)) from the primary deposit of the ice-marginal formation; 3) fine-grained (silt and clay) unit from glaciolacustrine; and 4) littoral deposit (sand and gravel).

3.2.3 Groundwater levels

Most of the groundwater levels data used for the interpretation obtained from the POVET-database (SYKE, 2018). Groundwater levels vary spatially and temporally. To study the groundwater flow directions, the distribution maps of groundwater levels were produced from the groundwater levels data at more or less the same time as possible. However, not all data

points were available at a time, the missing data were obtained from the correlation of groundwater levels from the available nearby wells. In this reports, grid maps of groundwater levels were interpolated from the majority of observation data measured during May-June 2017. In some areas such as the areas around ETNA Oy, Printal Oy, Stormossen landfill and Motocross-rata (Fig. 4), two groundwater levels were observed as the perched groundwater in the upper part and the main groundwater in the deeper part of the aquifer. These perched groundwater levels have been monitored with the periods of times and the existences are reliable. Perched groundwater zones could possibly be found locally in many places in different levels above the fine-grained layers. For the mapping and geological modelling purpose, only one perched groundwater level was mapped following the main interpreted fine-grained unit.

4 RESULTS AND DISCUSSION

4.1 Bedrock surface topography

The bedrock surface topography of the Hanko groundwater area is presented in Fig. 6. The bedrock surface elevation varies between -49.0 and +31.0 m a.s.l. The deepest trench-feature of the bedrock surface with the elevations between -49.0 and -30.0 m a.s.l. were found in the areas between Lindnäsudden, south to south-east of Fermion Oy, and south to south-east of Motocross-rata. The shallower bedrock topography was found in the Hanko town and south to south-east of the study areas.

4.2 Quaternary deposits

The total thickness of the Quaternary geological deposit varies from zero meter in the bedrock exposed area, to more than 40 m in the areas between Lindnäsudden, south to south-east of Fermion Oy, and south to south-east of Motocross-rata - the deepest trench area of the bedrock surface as shown in Fig. 7. Based on the descriptions of the drilled boreholes, the Quaternary sediments in the study area composed of the basal till, the coarse-grained sediment (sand, gravel, coarser-grained gravel or stone (as it is also called “kivi” in Finish in the drilled description) of the ice-marginal primary deposit, the fine-grain sediment (silt and clay) of the glaciolacustrine deposit and the coarse-grained sediments of the littoral deposit (Fig. 8). The cross-sections of the selected locations showing the bedrock topography, the groundwater levels, sediments at the drilled boreholes and the screen intervals are presented in Figs. 9 and 10. The distributions of the main Quaternary sediments from the bottom to the top parts are described in the following sections.

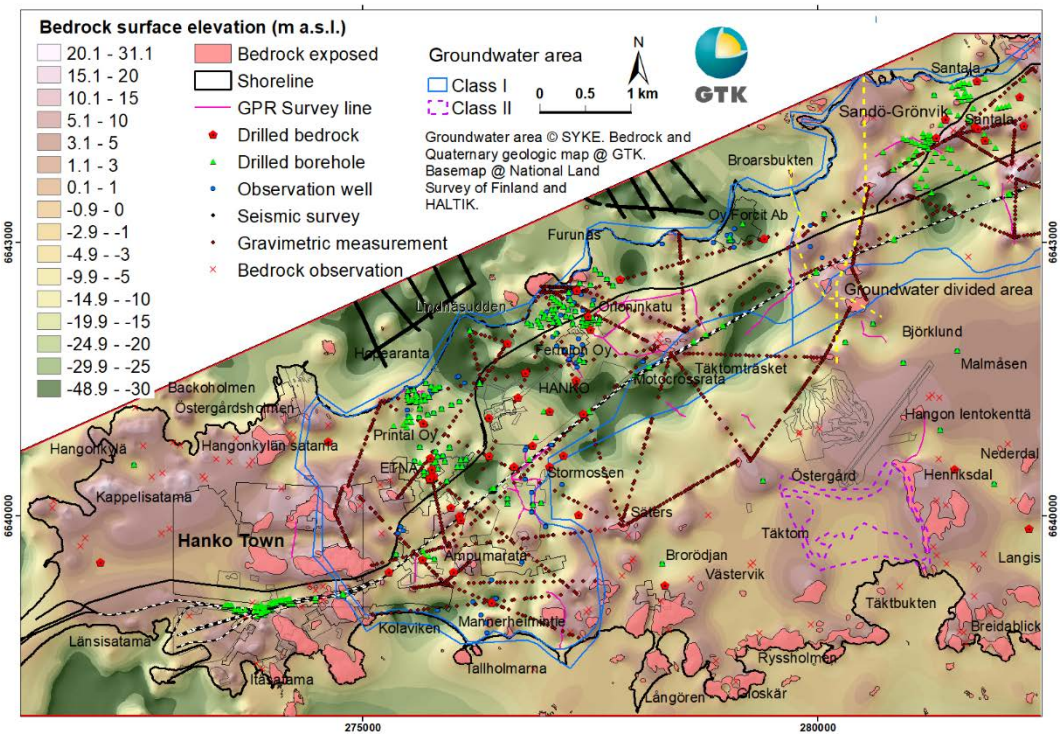


Fig. 6 Interpolated map of the bedrock surface elevation in the study area.

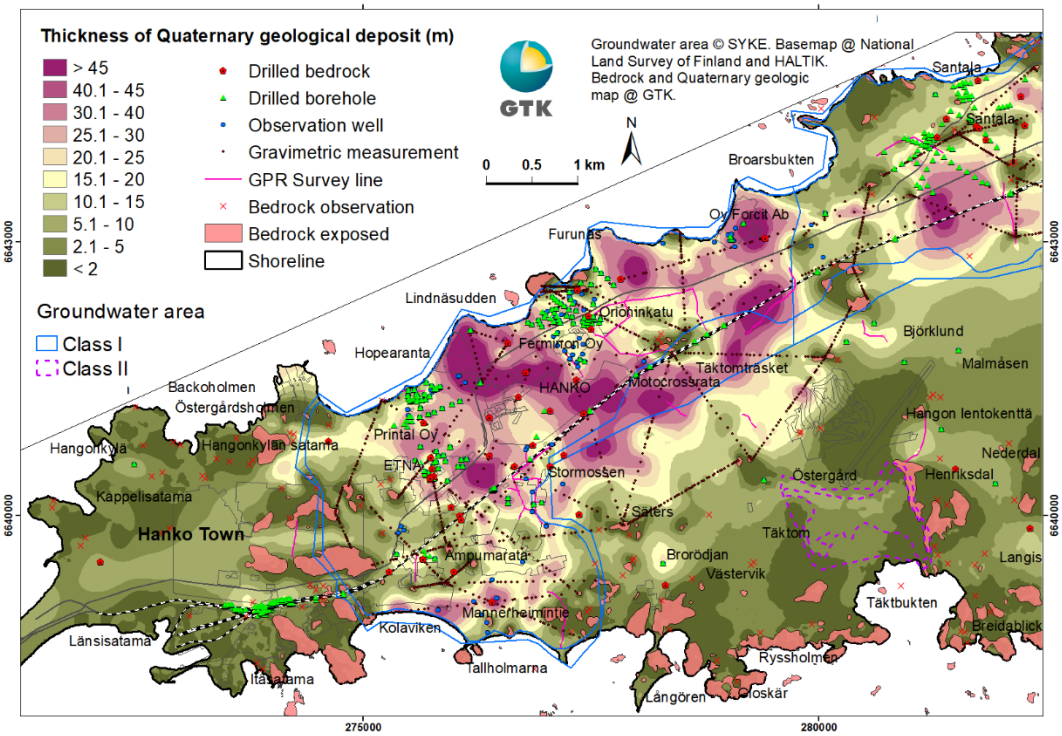


Fig. 7 Thickness map of the Quaternary geological deposit.

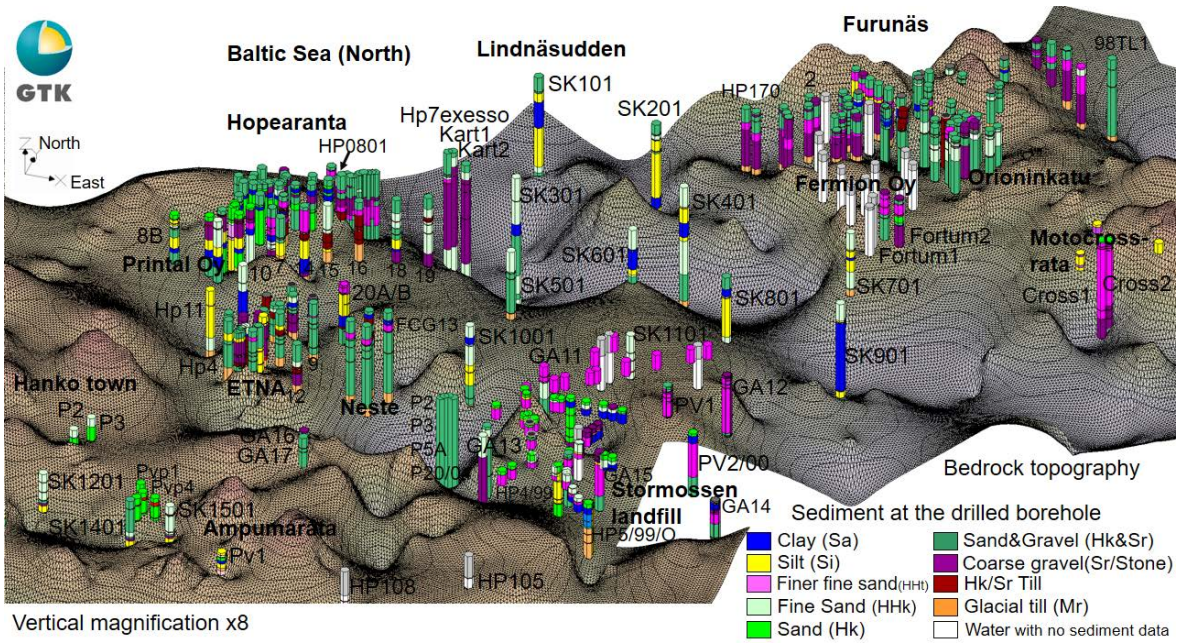


Fig. 8 Distributions of drilled boreholes in the areas between the Hanko town (left) and the Orioninkatu (right) with the background of bedrock surface.

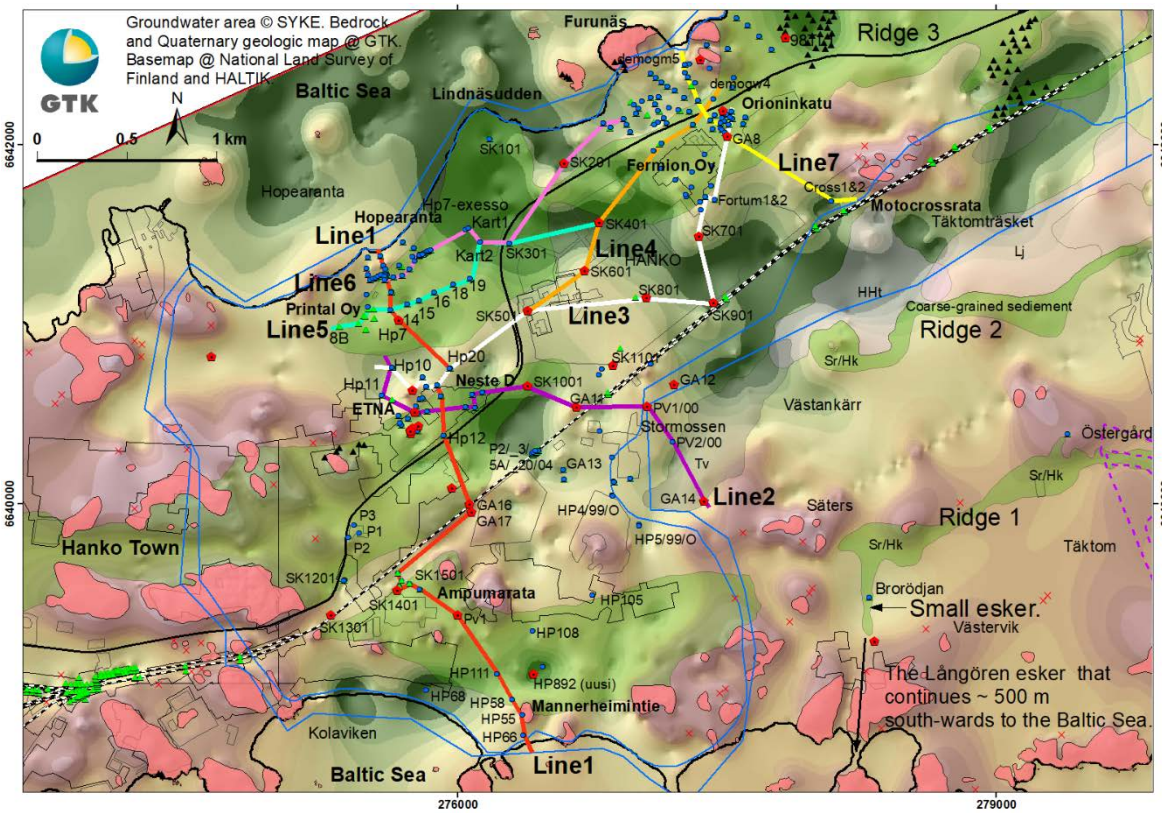


Fig. 9. Map showing locations of cross-sections and boreholes in the Hanko area.

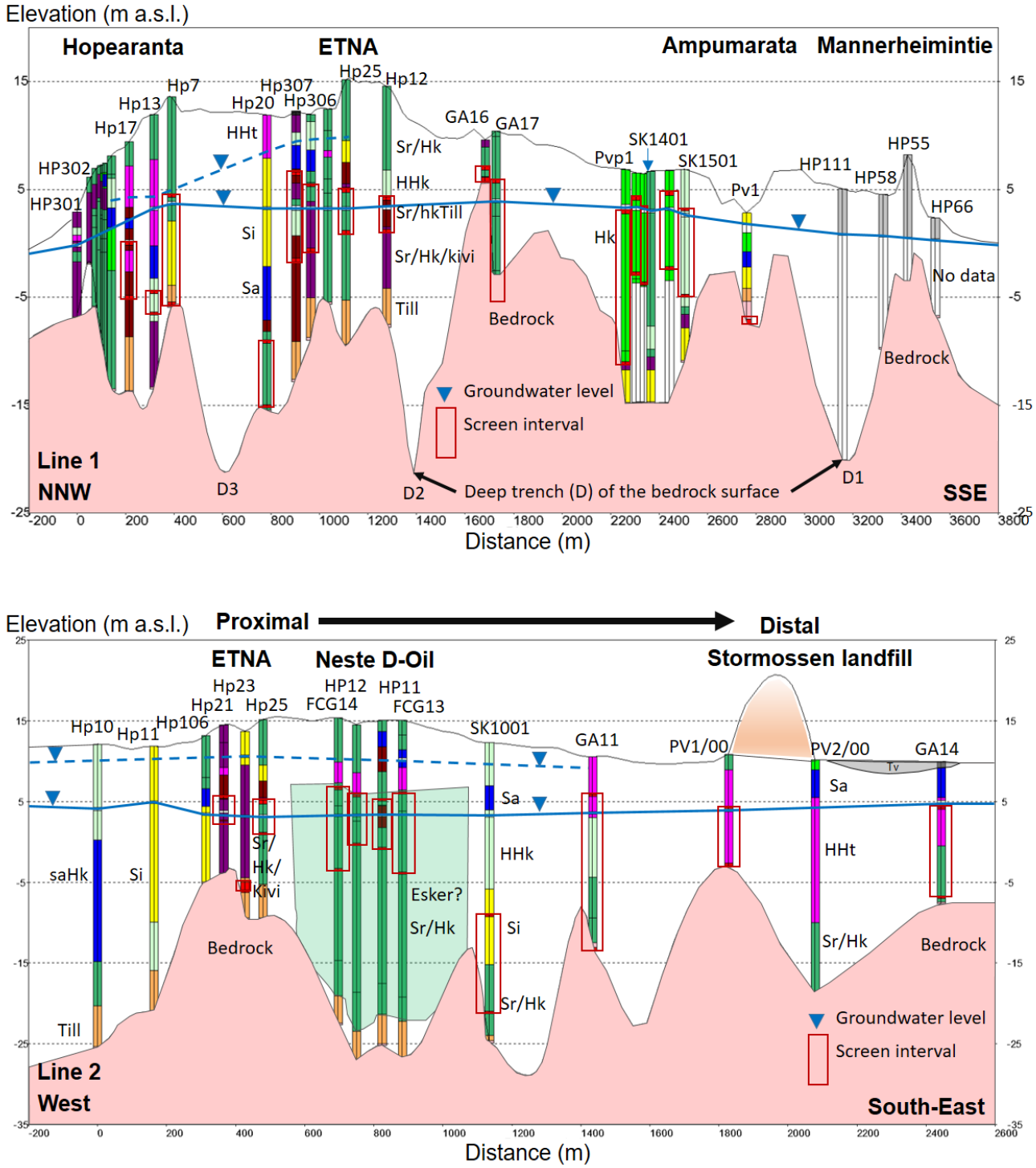
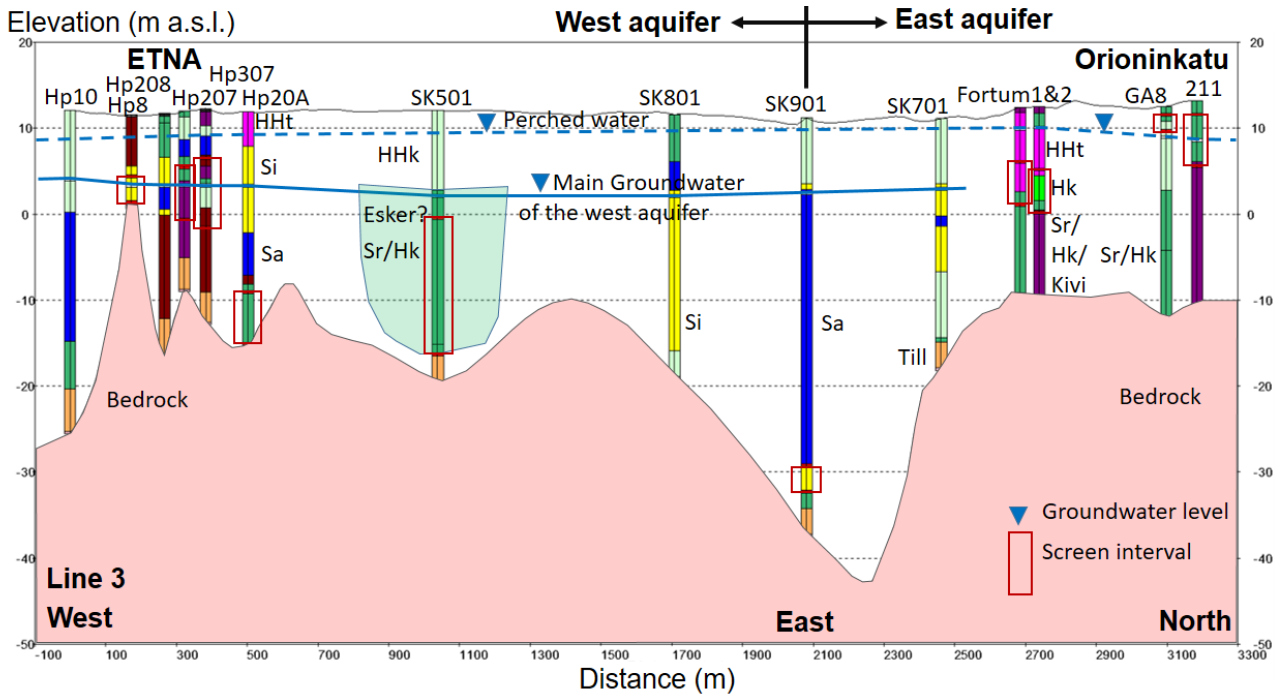


Fig. 10a Cross-sections along lines 1 & 2 showing the bedrock topography, the groundwater levels and sediments at the drilled boreholes.



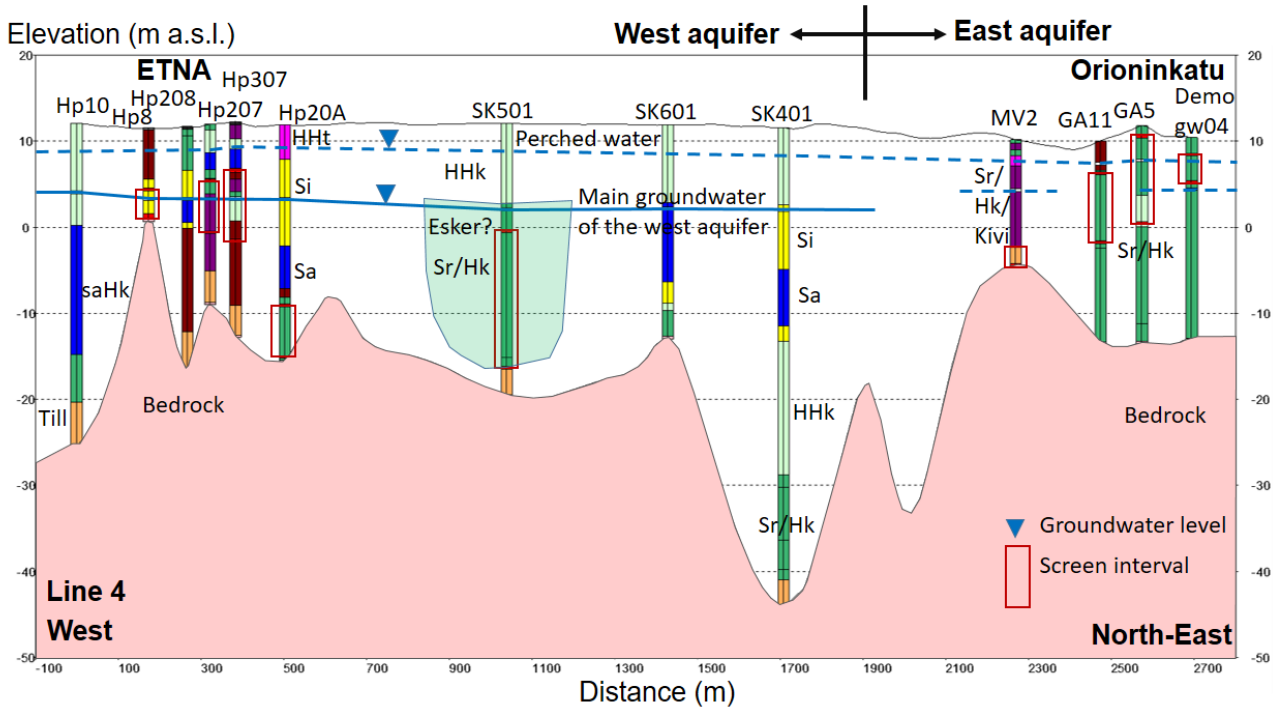
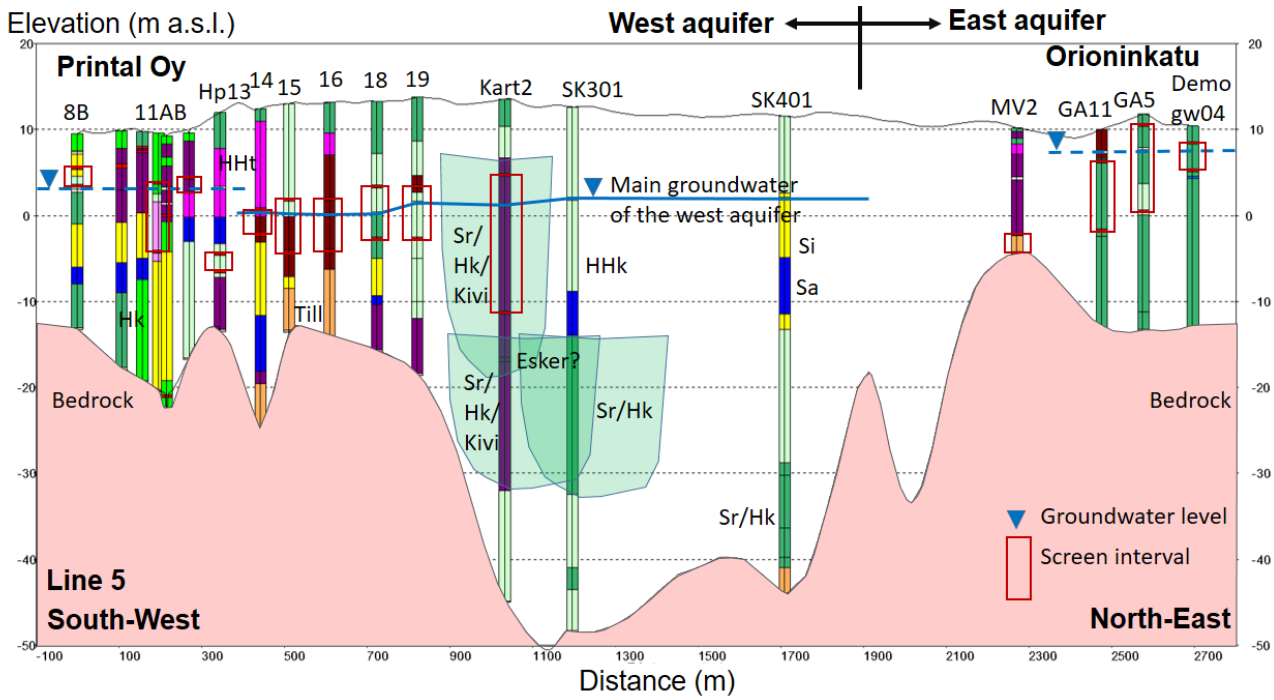


Fig. 10b Cross-sections along lines 3 & 4 showing the bedrock topography, the groundwater levels and sediments at the drilled boreholes.



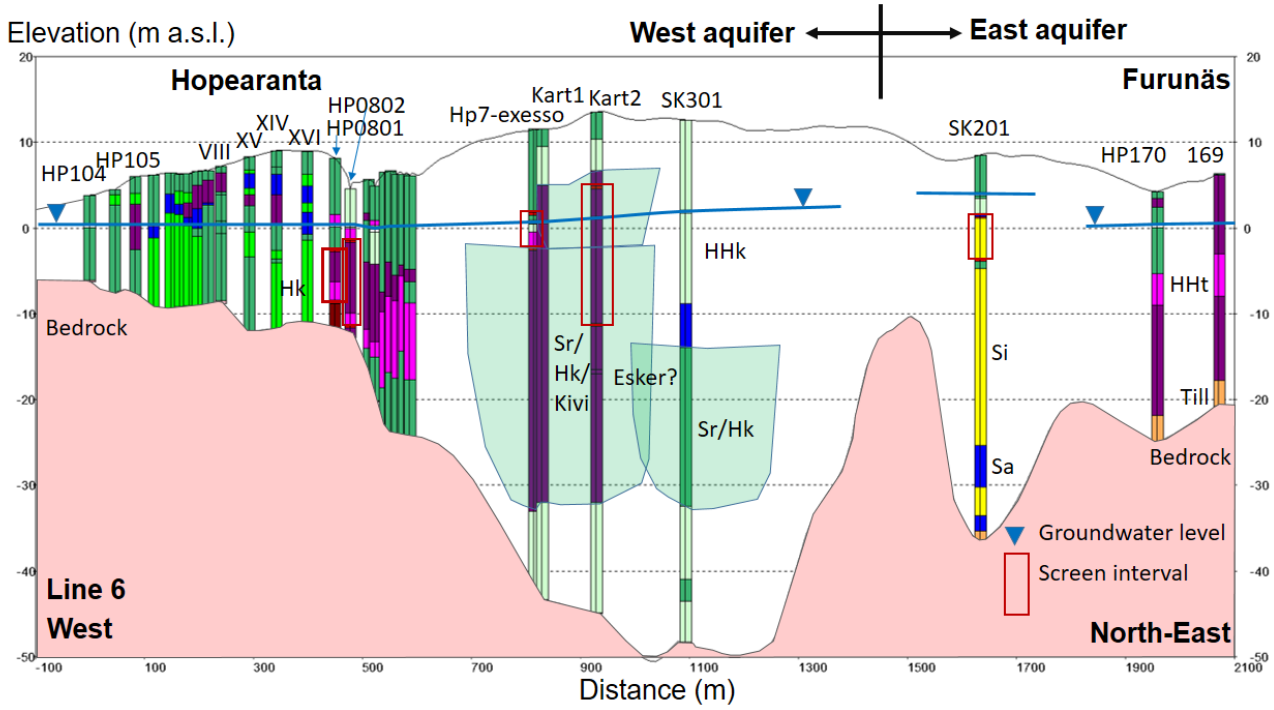


Fig. 10c Cross-sections along lines 5 & 6 showing the bedrock topography, the groundwater levels and sediments at the drilled boreholes.

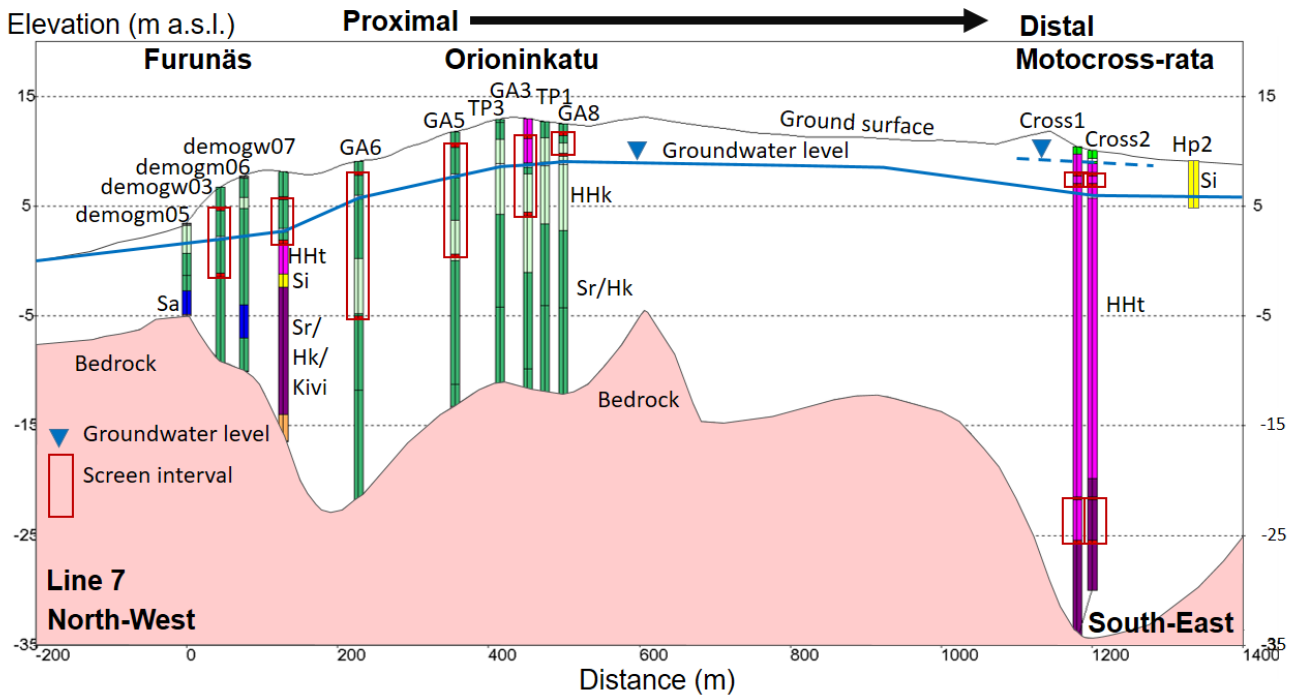


Fig. 10d Cross-sections along line 7 showing the bedrock topography, the groundwater levels and sediments at the drilled boreholes.

Glacial till

Fig. 11 presents top depth and thickness maps of glacial till. The glacial till overlain the bedrock surface throughout the study area with the average thicknesses of 1-2 m. In the southern area of Oy Forcit Ab has no drilled borehole data available. The interpretation was done based on the data from GPR profiles and the Quaternary geological map. The large areas of the boulders found in this area indicate the proximal deposit of the First Salpausselkä formation and the glacial till is commonly found filling the bedrock surface in the proximal areas. In some areas, the glacial tills were described as sandy or gravelly till and deposited in the middle of the primary deposit. These till layers were grouped in to the primary deposit. The glacial till in this study, hence, represented only the till layer that overlain the bedrock surface.

Primary deposits

The primary deposit of the ice-marginal sediment is found between the glacial till and the fine-grained units. It consists of various grain sizes from very fine-sand to boulder and spatially distributed throughout the study area with the general trend of the coarser grains accumulate in the proximal area in the north to the finer grains of the distal area in the south and south-east. Based on the Quaternary geologic map, the mixed of coarse-grained and boulder (>256 mm) soils are found spatially along the First Salpausselkä ridges such as in the western of ETNA and the areas between Furunäs and south of Oy Forcit Ab (Fig. 2). These boulders can be observed clearly in the field in those areas. Sand and gravel are found in large parts

including the areas around the south and south-east of ETNA, Ampumarata and Mannerheimintie along the coastline in the south, the Hopearanta, Fermion Oy and Orioninkatu. Fine and very fine-sand are found mainly in the south and south-east in the areas between the Stormossen landfill and south and east of Motocross-rata, and the area between ETNA and Printal Oy.

The First Salpausselkä ice-marginal formation in the study area could probably formed in several phases. At least three main parallel ridges of the ice-marginal formations (Ridges1-3, Fig.9) and the deep trenches of the bedrock surface (Fig.10a-Line1) were observed. The first south-most ridge of the Täktom ice-marginal formation, which the eastern part is classified as the Täktom groundwater area class II. The second ridge has a smaller size, formed between the first and the third (the main First Salpausselkä ridge). The fine-grained sediments were observed in the areas between those ridges. Some parts of the primary ice-marginal deposits were well preserved and some parts were deformed by the wave action in areas between the present and ancient shorelines. In the western side of the Täktom ice-marginal formation ridge, a small and narrow esker was clearly observed from the LiDAR-DEM landform (Fig. 13). This esker is in the same trend with the Långören esker that continues around 500 m south-wards to the Baltic Sea. The similar small and narrow eskers could possibly formed in front of the ice-marginal ridges in some other areas, e.g. from ETNA-Neste Oil-D station formed southwards direction to the Baltic Sea. This can be observed from the observation wells NesteHP11, NesteFCG13, NesteHP12, NesteFCG14, P2/04, P3/04, P5A/04 and P20_04 at the Eläinten hautausmaa and GA13, west of Stormossen. In the Hepearanta area around the observation wells Kart1 and Kart2, Hp7-exesso, SK301 and SK501. The sediments in these observation wells show a trend of thick sand and gravel or stone approximately 25-30 m thick with the absence of silt layer, discontinued from the nearby wells (Fig. 10). It could probably be a hidden esker or tunnel filled coarse-grained materials that cut through the fine-grained layers during the ice-marginal deposit. However, there is not clear evidence whether these coarse-grained units are connected and continued as a long esker from north to south or only confined in a short distance in front of the local ice-marginal ridges. Moreover, the deep observation well HP892 (uusi) was recorded in the POVET-database with the top of the bedrock surface of -40.28 m a.s.l., but no description of the drilled hole is available. This well is in the same trend with those “hidden eskers”, the description of the drilled borehole could validate the continuity of the esker.

Fine-grained unit

The fine-grained unit consists of the silt and clay layers overlaid the primary deposit. Fig. 12 presents top depth and thickness maps of the fine-grained unit. In the Hanko groundwater area, thick fine-grained unit accumulated in the areas between Lindnäsudden, south of Fermion Oy and south to south-east of Motocross-rata with the maximum thickness of 37 m. Fine-grained layers are absent in the areas between Fermion Oy and Orioninkatu, where the drilled boreholes and the GPR profile indicated thick layers of coarse-grained (gravel and sand). Fine-grained layers are found in the areas nearby the coastline in Furunäs and Oy Forcit Ab. However the extent of these fine-grained layers are not clear, due to the insufficient data as many drilled boreholes are quite shallow and did not reached the bedrock surface.

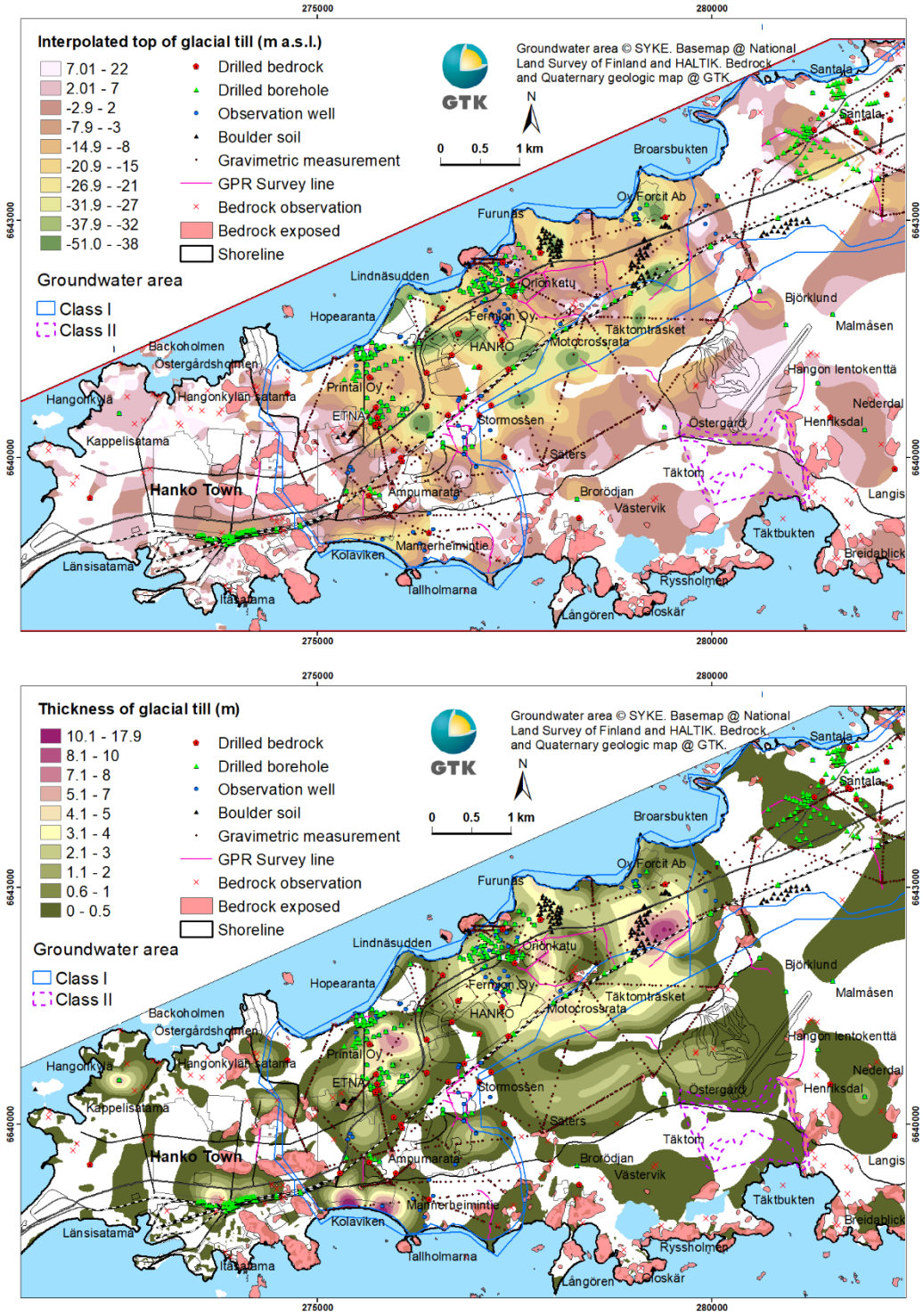


Fig. 11 Interpolated maps of a) top depth and b) thickness of glacial till.

Most parts of the areas between south ETNA and the Baltic Sea shoreline in the south did not encounter the fine-grained layers, except drilled boreholes in the area around the Ampumarata water intake well, where the approximately 1.4 m of clay and 2.0 m of silt layers lay beneath the thick sand and gravel and overlaid the glacial till. Also in the Hopearanta water intake wells area, the fine-grained (mainly clay) was disappeared in the areas below the ancient shoreline around wells HP0801 and HP0802, and some parts of the “hidden eskers” areas (Fig.12). The fine-grained layer could probably be deformed by the wave action during the isostatic land uplift or cut off by the younger coarse-grained sediments. The cross-sections showing the sediments at the drilled boreholes between ETNA and Hopearanta is presented in Fig. 10.

Littoral deposits

LiDAR-DEM reveals landforms of the First Salpausselkä formation and remnants of the littoral processes from wave action along the ancient shoreline during the submerged terrain was uplifted to the shore level due to the isostatic land uplift and changes of water levels in the Baltic basin. The maximum ancient shoreline in Hanko lying between 12-14 m a.s.l. at the present depth (Fig. 13). The littoral sediments (sand and gravel) are, therefore, expected to be found in the areas between the maximum ancient shorelines and the coastlines. Based on the description of drilled borehole, the thickness of littoral deposit varies between 2 –5 m.

Based on the above mentioned data, two additional maps were produced:

1. A Net Coarse-grained (NC) map derived from the subtraction of the fine-grained thickness from the total thickness of Quaternary deposit (a net gross (NG)), is shown in Fig. 14a.

   NC = NG – Thickness of fine-grained (1)

2. A Net Sand (NS) – represents a thickness map of sand and gravel derived from the subtraction of the thickness of fine-grained and glacial till units from the total thickness of Quaternary deposit is presented in Fig. 14b.

   NS = NG – Thickness of fine-grained – Thickness of glacial till (2)

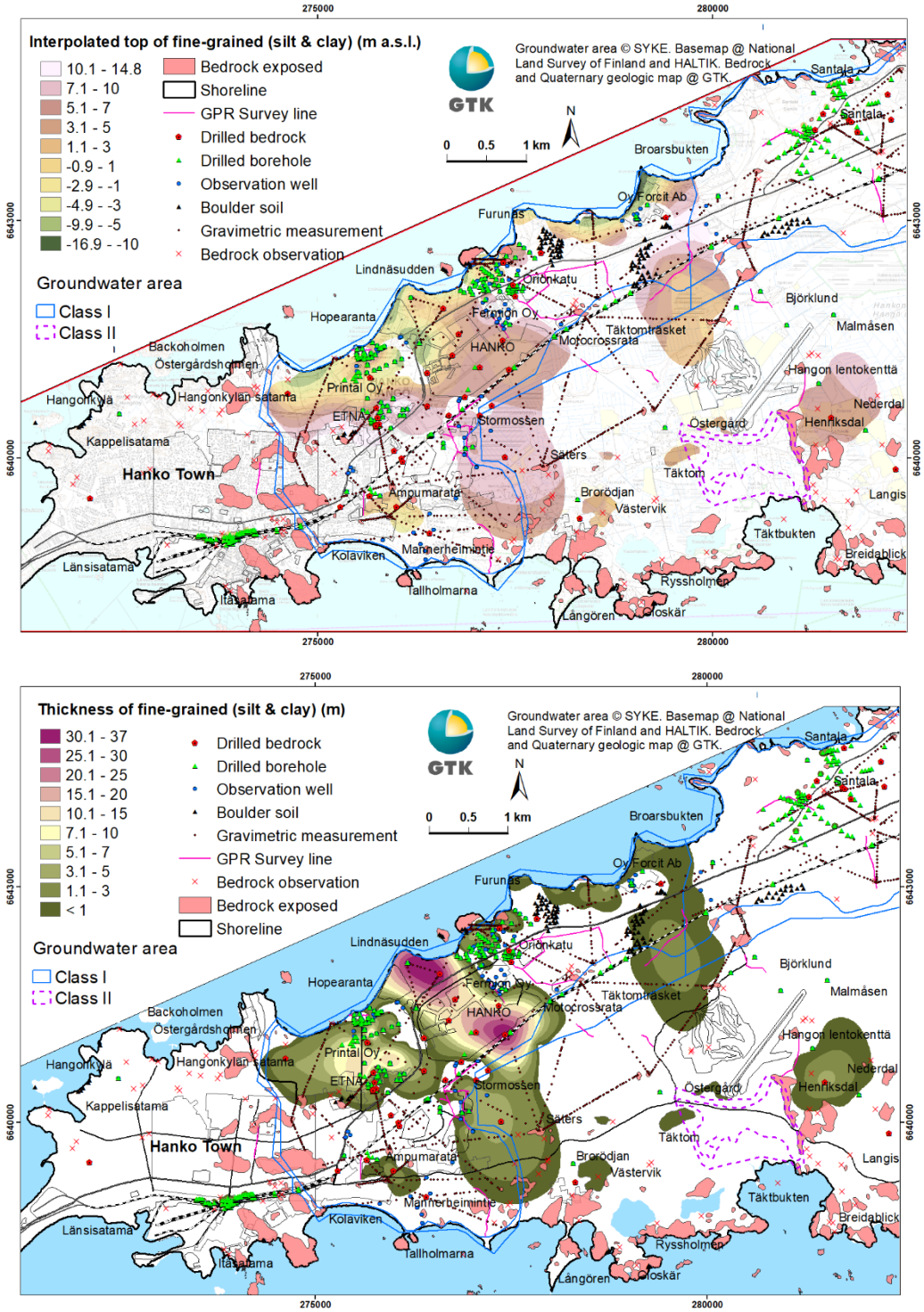


Fig. 12 Interpolated maps of a) top depth and b) thickness of fine-grained (silt and clay) unit.

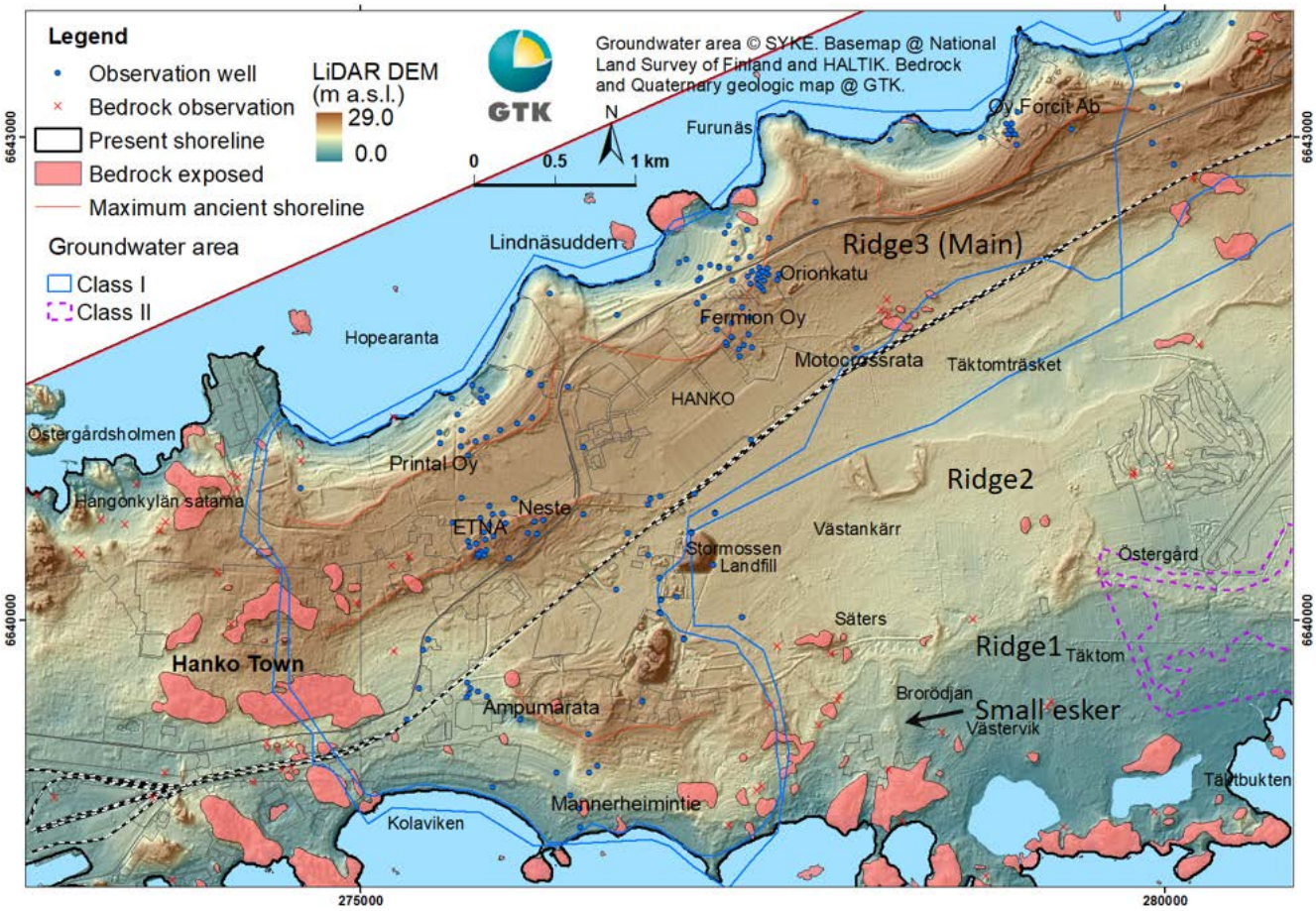


Fig. 13 Hillshaded LiDAR-DEM showing the ancient shorelines (beach ridges) in the Hanko area. The maximum ancient beach ridges (red line) lying between 12 and 14 m a.s.l.

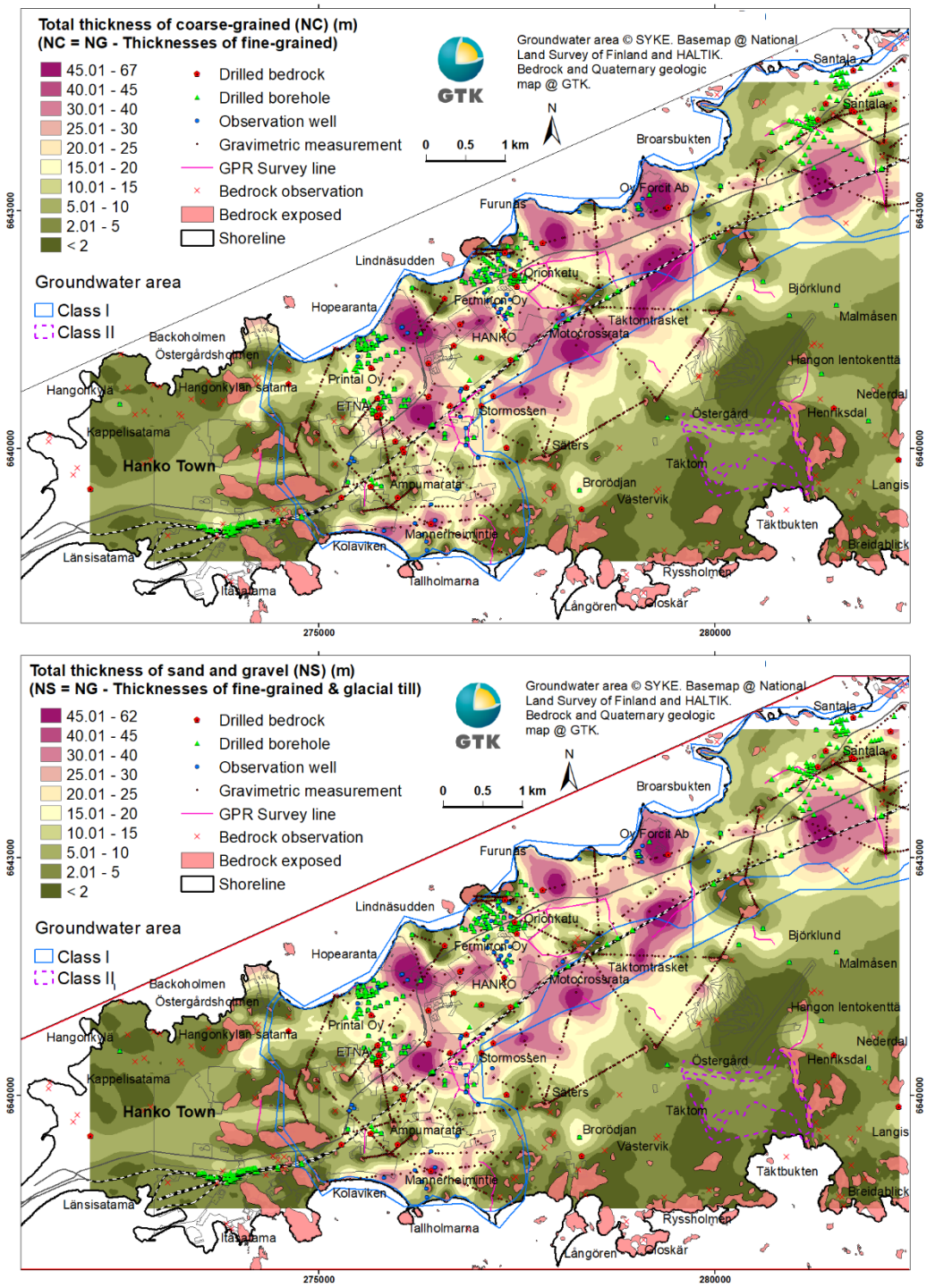


Fig. 14 Total thickness maps of a) Net Coarse-grained and b) Net Sand.

4.3 Groundwater levels

The Hanko groundwater area consists of two main aquifers, which are separated from each other by a thick fine-grained unit in the NW-SE direction from Lindnäsudden to south of Fermion Oy and south of Motocross-rata (Fig. 12). These two aquifers, hereafter referred to as the east and the west aquifers, for the aquifers located in the eastern side and the western side of the thick fine-grained unit, respectively, have differences of groundwater levels and are separated from each other. In the west aquifer more than one groundwater levels have been observed; the perched groundwater accumulates in the upper part of the aquifer, above the fine-grained layers, and the main groundwater accumulates in the lower part of the aquifer or beneath the fine-grained layers. While in the east aquifer, only one main groundwater level was observed from the drilled boreholes, except the locally perched groundwater found in the Motocross-rata area.

4.3.1 Perched groundwater

Perched groundwater is found in four main areas: Printal Oy, ETNA, Stormossen landfill area and Motocross-rata (Figs 15 and 16). The perched groundwater levels vary between 1.51-11.58 m a.s.l., 0.5-7.8 m below the ground surface and 1.24-7.64 m differences from the main groundwater level (Figs.15 - 19). Perched groundwater levels in the west aquifer are similar to the main groundwater level in the east (Fermion Oy – Furunäs – Orioninkatu - Oy Forcit Ab) as shown in Fig.16, a combined map of perched groundwater level in the west and the main groundwater level in the east. Fig. 17 presents the total thickness of the aquifers in the perched groundwater area in the west and the main groundwater area in the east. Fig. 18 the thickness maps of the unsaturated and saturated zones of the perched groundwater in the west aquifer and the main groundwater in the east aquifer.

4.3.2 Main groundwater table

Fig. 20 presents the distribution maps of the main groundwater levels from both aquifers. The main groundwater in the west aquifer (Hopearanta – ETNA - Ampumarata) is semi-confined with the groundwater levels vary between less than zero metre in the Hopearanta water intake wells and 6.7 m a.s.l.in the middle of the aquifer area. The aquifer in the northern part is confined by the thick fined-grained unit. Fig. 20a presents a map of groundwater level with pressured, and Fig. 20b a map of groundwater level beneath the fine-grained layer in the confined area. The groundwater levels are observed decreasing and are below the fine-grained unit in some areas, so the actual confined area is probably smaller than as it is presented in this map. Fig. 21 presents thickness map of the unsaturated zone of the main aquifer. Two saturated thicknesses maps of the main aquifers beneath the fine-grained layer were computed: 1) bounded by top glacial till, and 2) bounded by bedrock surface as shown in Fig. 22. The East aquifer (Furunäs – Orioninkatu - Oy Forcit Ab) is unconfined with the groundwater level varies between zero meter in the coastal area and 10-12 m a.s.l. in the middle of the aquifer. The interpolated groundwater level remains high uncertainty in the boundary area between the Hanko and the Sandö-Grönvik groundwater areas, due to insufficient groundwater levels data points.

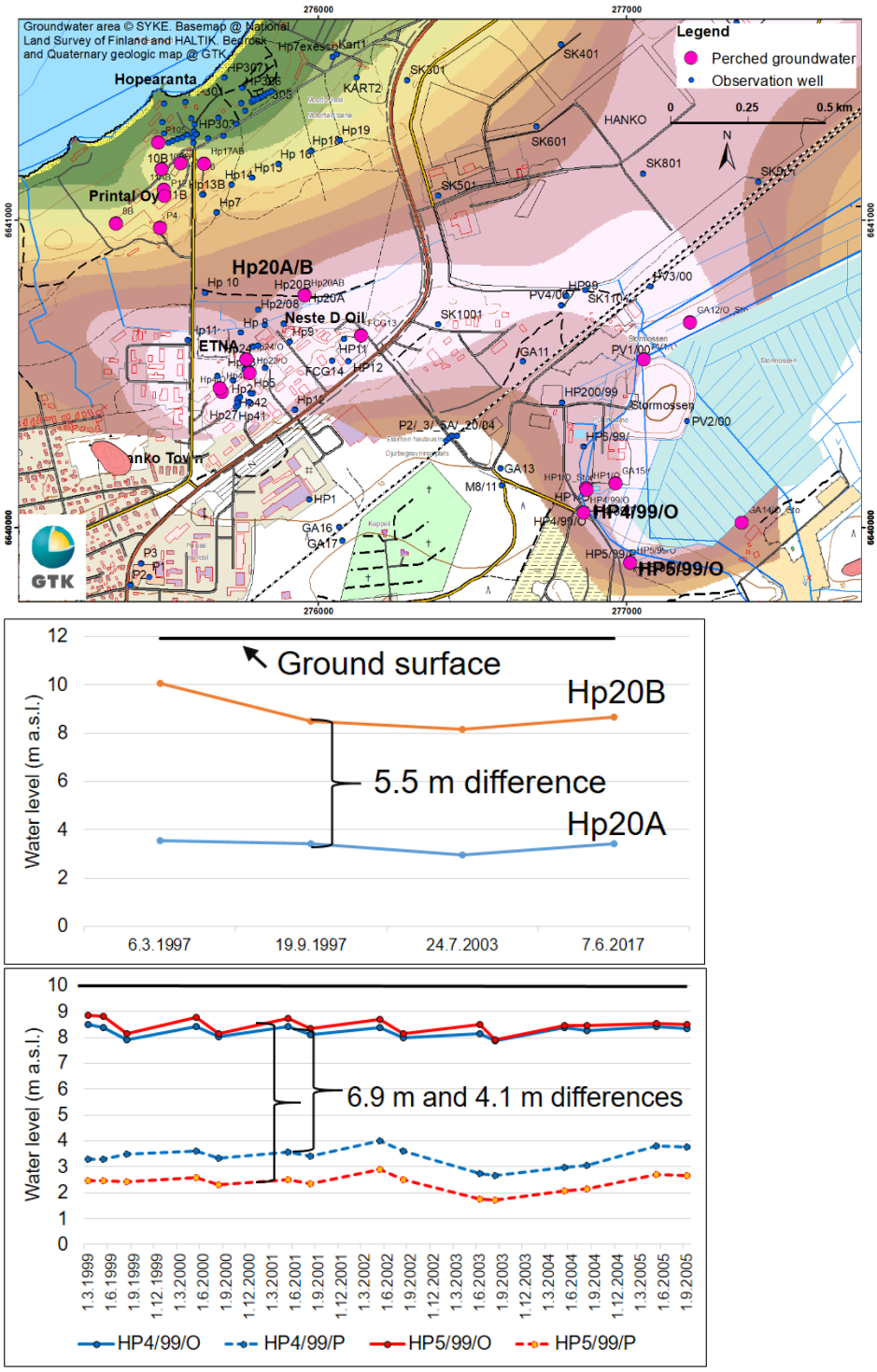


Fig. 15. Graphs showing the groundwater levels of the perched groundwater (upper) and the main groundwater (lower) from the POVET database during 1997-2017.

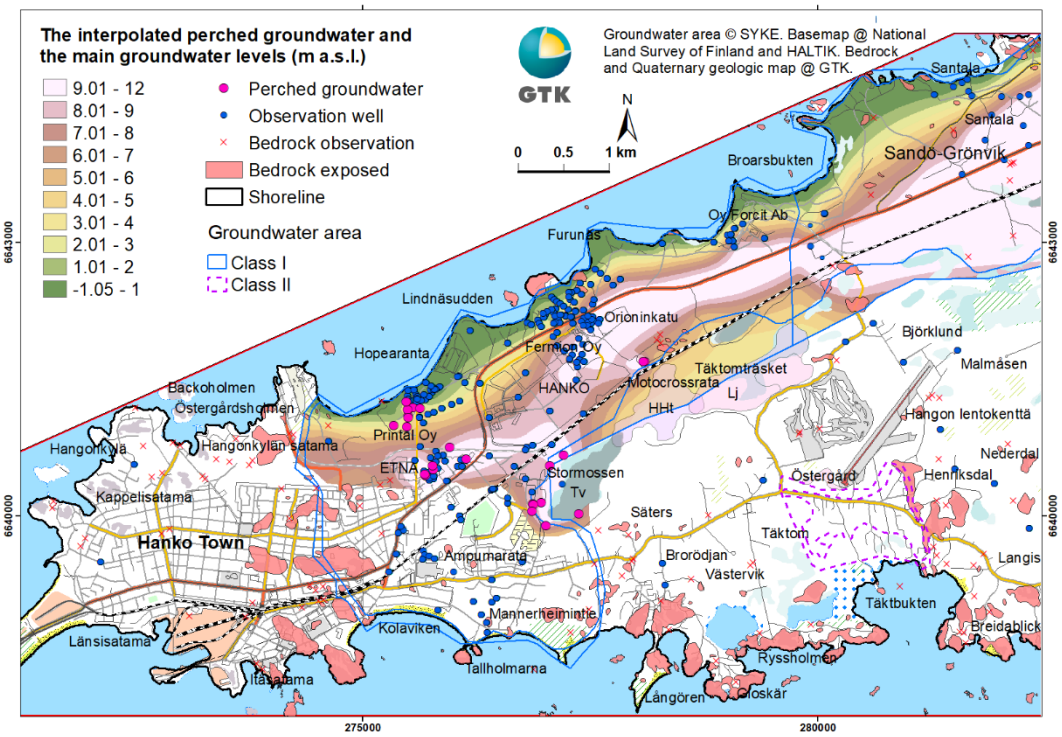


Fig. 16. Map of the perched- and the main groundwater levels.

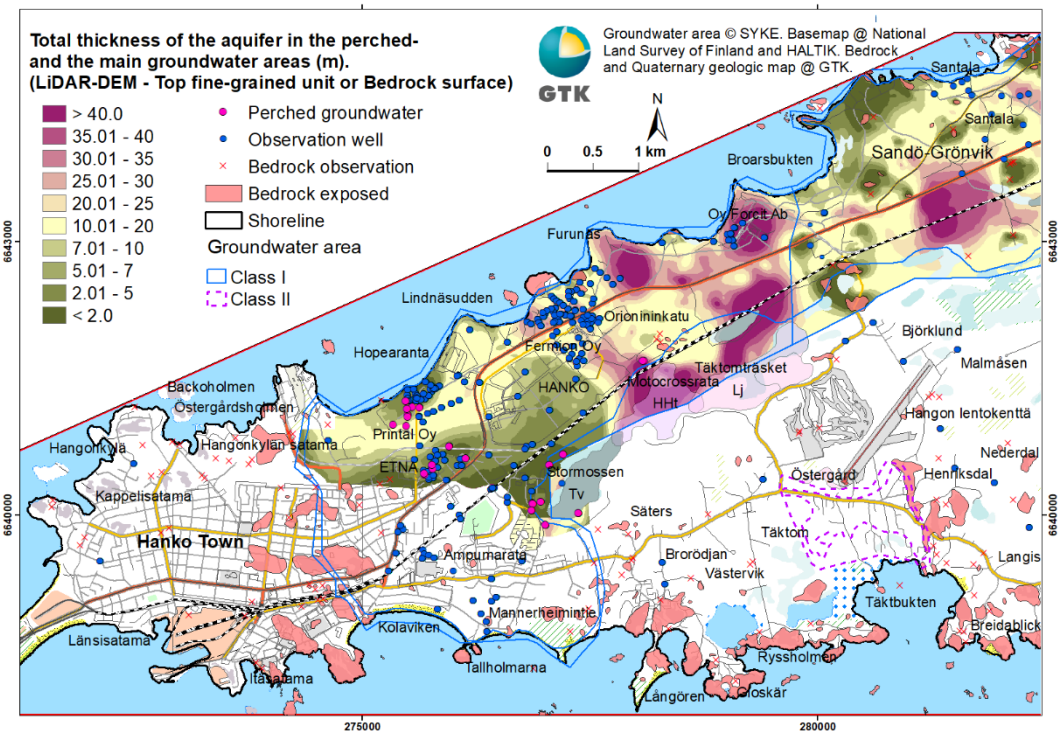


Fig. 17 Total thickness map of the aquifers in the perched- and the main groundwater areas.

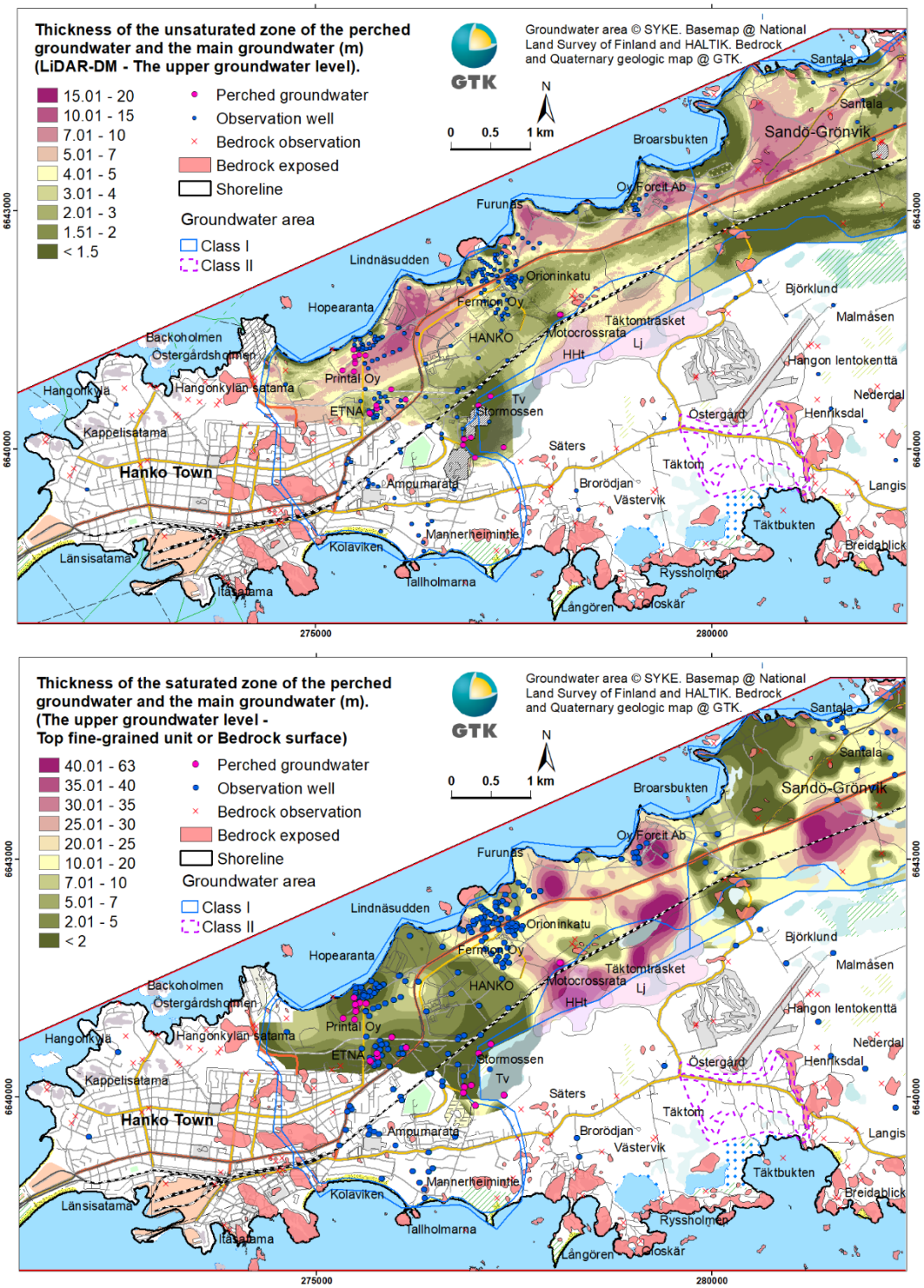


Fig. 18 Thicknesses of a) the unsaturated and b) saturated zones of the perched groundwater in the West aquifer and the main groundwater in the East aquifer.

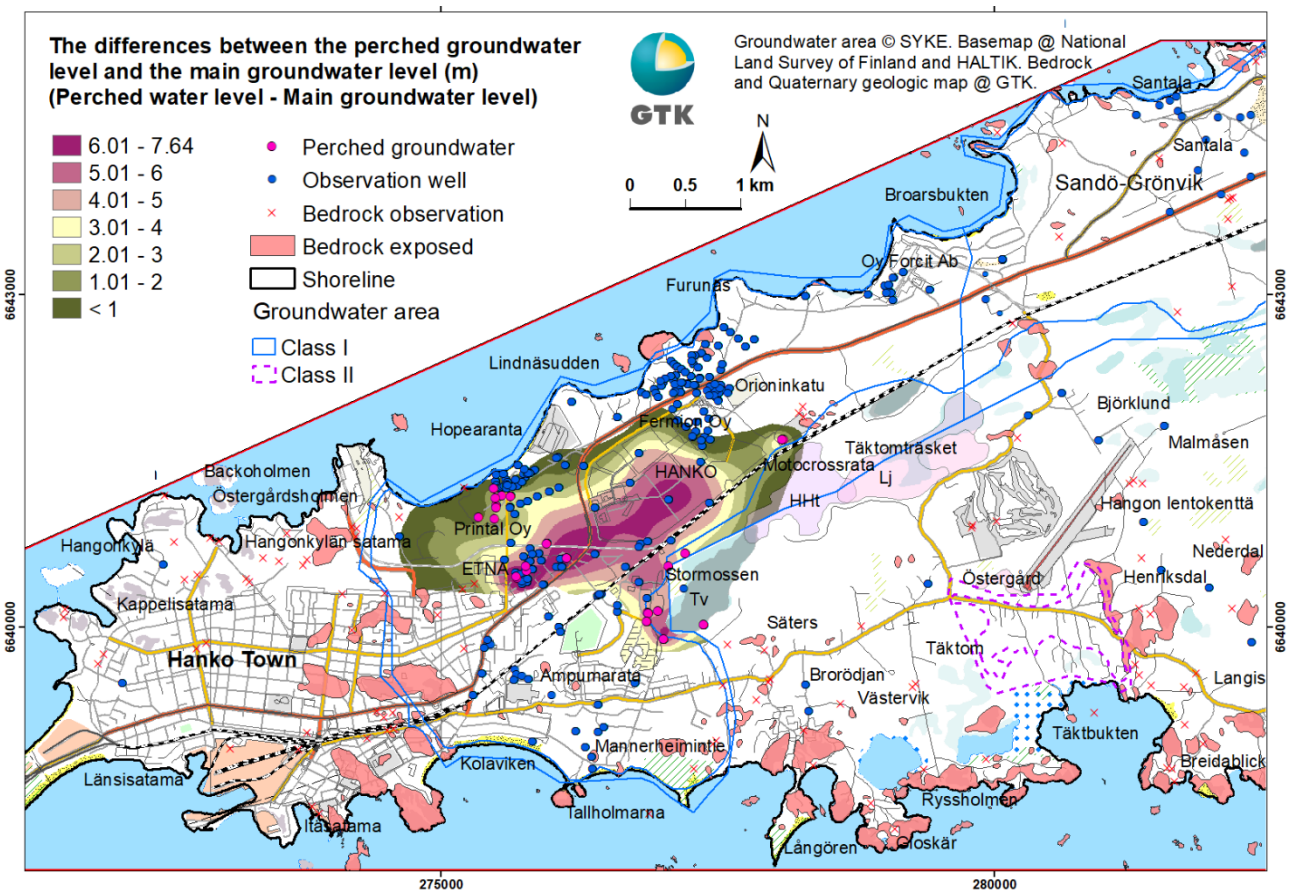


Fig. 19 Map of head differences between perched groundwater and the main groundwater.

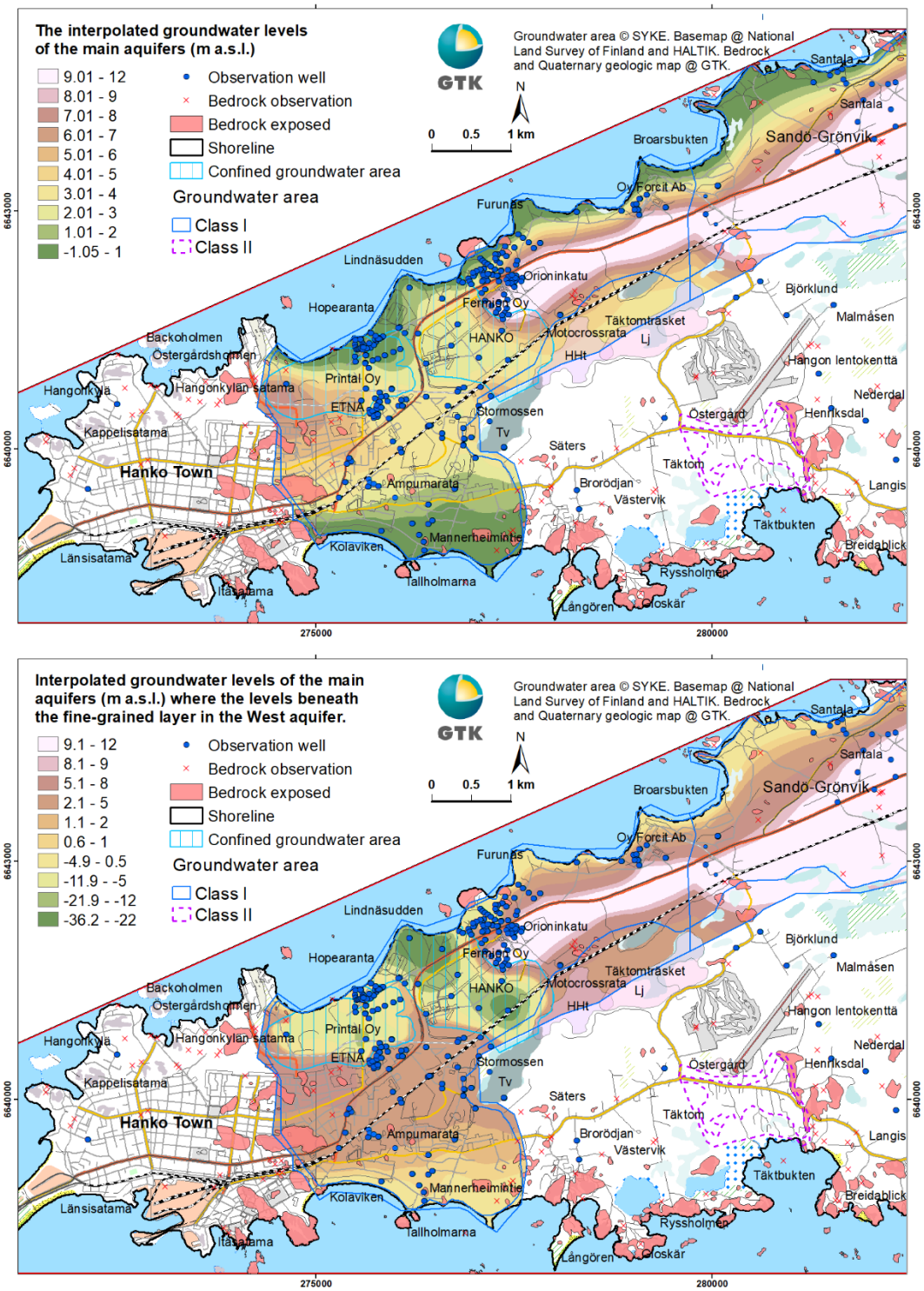


Fig. 20 Distribution maps of a) the main groundwater levels including the level under pressured; and b) the level beneath the fine-grained layer in the confined area.

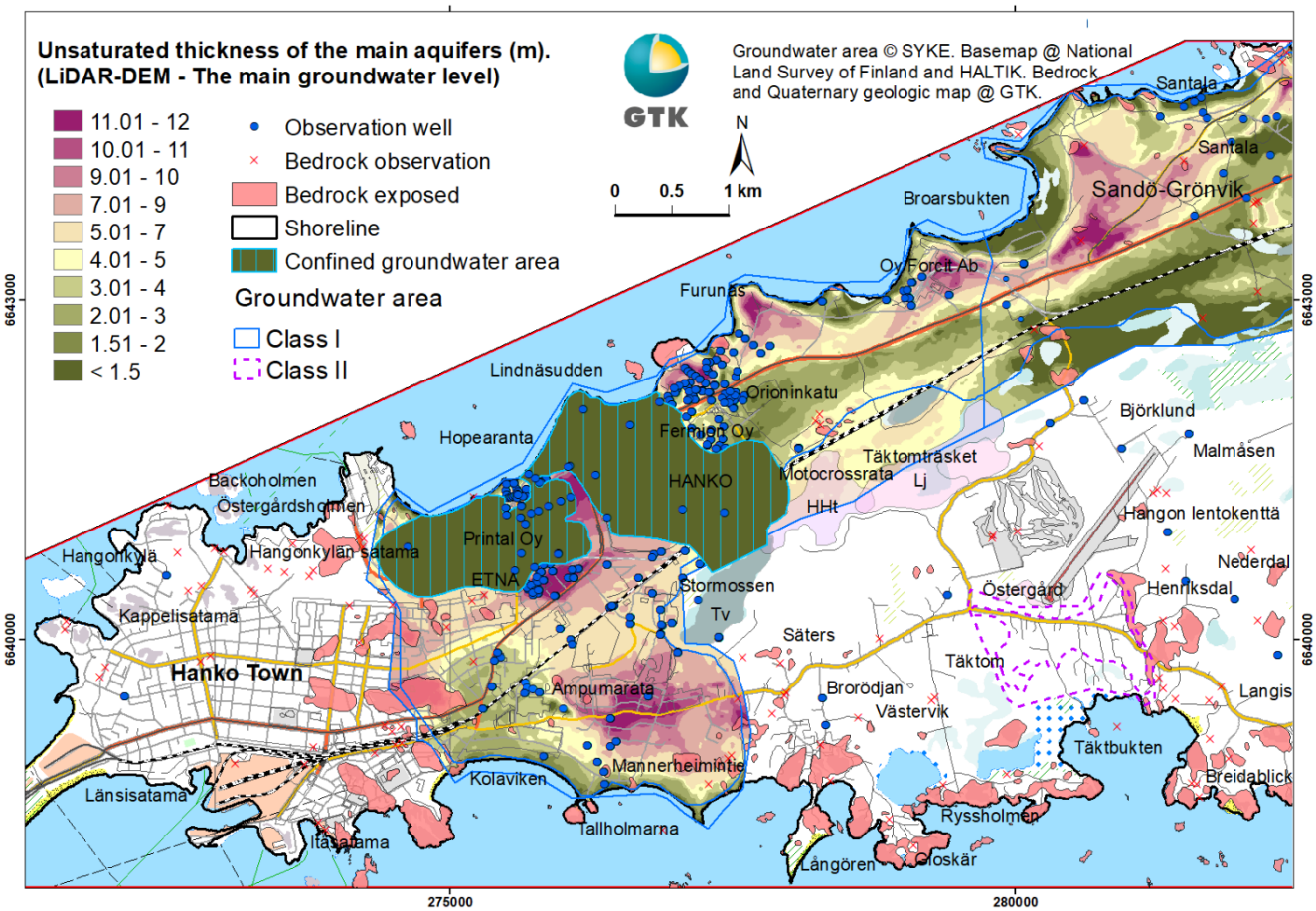


Fig. 21 Thickness map of the unsaturated zone of the main aquifer.

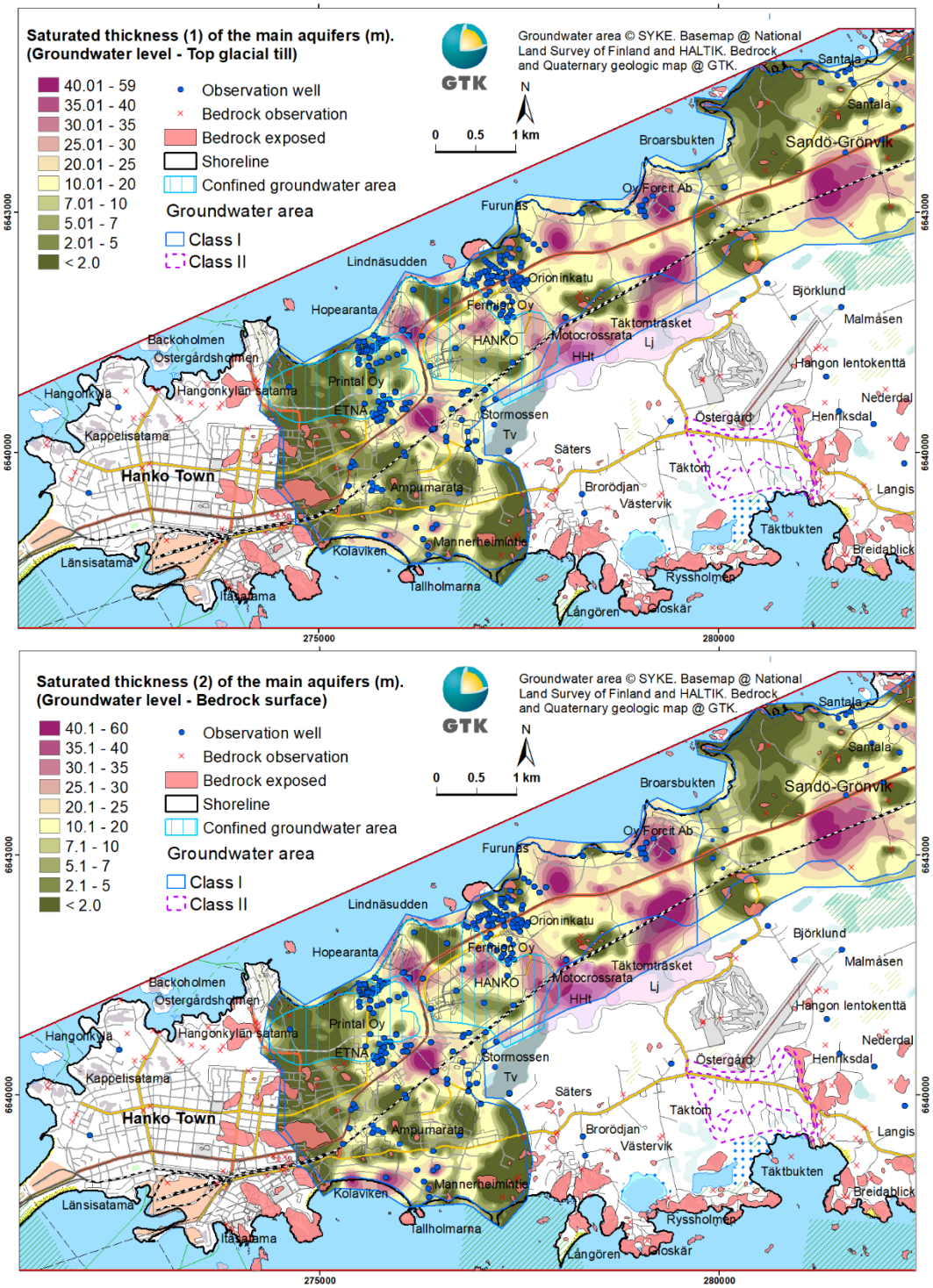


Fig. 22. Saturated thicknesses of the main aquifer beneath the fine-grained layer: a) bounded by top glacial till, and b) bounded by bedrock surface.

5 CONCEPTUAL GEOLOGICAL MODEL OF THE HANKO AQUIFER

The aquifer materials in study area are highly heterogeneous with variety of aquifer materials including glacial till, coarse-grained of sand, gravel, cobble and boulder of glacial outwash, glaciolacustrine of silt and clay, and sand and gravel of littoral deposit. A conceptual geological model of the Quaternary geological deposits, as shown in Fig. 23, consists of 5 main units from bottom to top of the deposits as described below:

Unit 1: Bedrock – is relatively impermeable. Some fractures were observed in the rock exposed area in the Hanko area, however due to insufficient data, the influence of fracture is not discussed in this study. Bedrock topography are variable from low elevation terrains to deep trench or depression of kettle hole. Three deep trenches of the bedrock surface were observed in the NE-SW direction, following the general trend of the First Salpausselka ice-marginal formation. These could act as the ground-line of the ice-marginal controlling the deposition of the sediments, e.g. the high elevation of the bedrock surface areas were often found associated with the coarse-grained sediments (boulder soil area) deposit in the proximal area close to the ice-marginal ground-line. The deep trenches or kettle-holes were often filled with the fine-grained sediments.

Unit 2: Glacial till – consists of mostly silts and clay and some sand and gravel, with the average thickness of 1-2 m overlain the bedrock surface.

Unit 3: Primary deposit of the ice-marginal formation – consists of coarse-grained sediments with spatially variations both in the vertical and horizontal directions. As mentioned earlier that the bedrock topography controlled the depositional patterns of the sediments where the coarse-grained sediments accumulated in the proximal area close to the ice-marginal ground-line and finer-grained sediments deposit in the more distal area. The sediments that found in between those three ridges (Ridge 1-3, e.g. Ampumarata-ETNA-Hopearanta) are possibly poorly connected by the intervention of the fine-grained unit. However, some parts of the primary deposit were deformed by wave action during the isostatic land uplift and could enhance the connectivity of those coarse-grained sediments.

Unit 4: Fined-grained unit of the glaciolacustrine deposit – consists of silt and clay, deposited in the deep water, therefore in the area that has no deformation or rework of waves, the fine-grained sediments could be found everywhere. Thick fine-grained unit was found in the deep trench of the bedrock surface. This could formed after buried ice lobs or ice blocks melted and created depression surface which later on were filled with fine-grained sediments.

Unit 5: Littoral deposit - consists of sandy and gravelly littoral sediments. The highest ancient shorelines from LiDAR - DEM landforms lying between 12-14 m a.s.l. The sediments which are the products of the rework from the littoral process deposit between the ancient shoreline and the nowadays coastlines both in the south and the north with the average of 2-5 m. In the south, the areas between the south of ETNA and the Baltic Sea shoreline did not encountered the fine-grained layers and perched groundwater. If the fine-grained sediment was existed, it could possibly be removed by the littoral process.

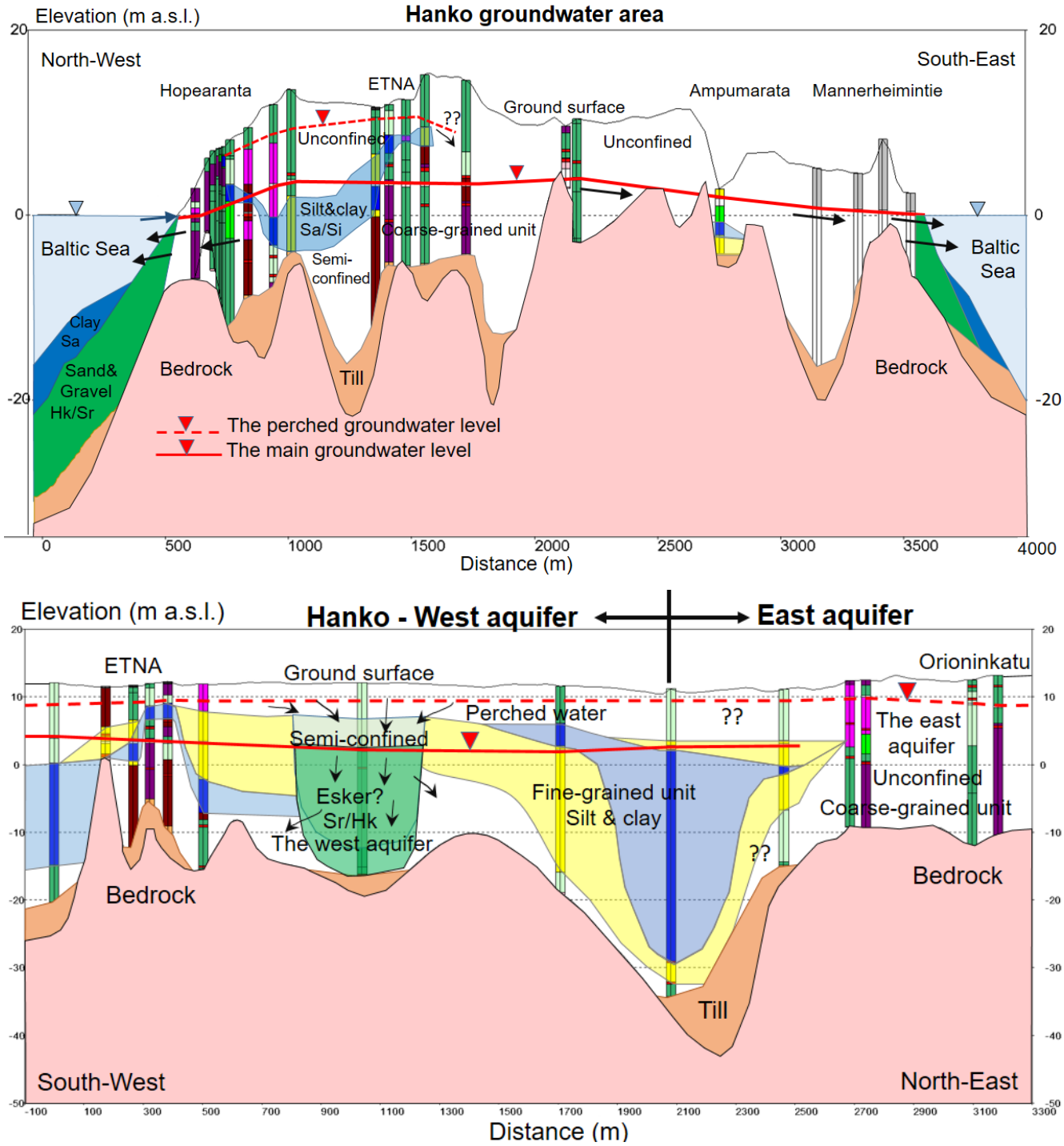


Fig. 23. Conceptual cross-sections of the Hanko groundwater area showing the sediments at the drilled boreholes and groundwater levels.

6 LIMITATIONS OF THE MODEL

The geological model was interpreted and constructed based on the available data and geological background of the study area. The bedrock topography is highly variable and difficult to predict and also the glaciogenic of the sediments in the study area is high heterogeneous, although the data used in this study are quite intensive, there are still rooms for the uncertainties, especially in the areas that have sparse drilled boreholes. Moreover the soil descriptions from the drilled boreholes were obtained from different studies. This causes some inconsistencies of the descriptions from different drilling operators. The model was constructed to represent the main geological units and could not covered all details of the smaller sediment units in some areas.

7 CONCLUSIONS

The detailed geological and hydrogeological characteristics of the bedrock topography and the Quaternary deposit of the shallow aquifer in the Hanko groundwater area was intensively investigated based on all available geological, geophysical and hydrogeological data. The First Salpausselkä ice-marginal deposits in the study area are complex and contain heterogeneous materials. The depositional sequences of the First Salpausselkä ice-marginal formation of the Hanko groundwater area consist of five main units from bottom to top: 1 bedrock, 2 glacial till, 3 primary deposit of the ice-marginal sediments, 4 fine-grained deposits of the glaciolacustrine, and 5 the littoral coarse-grained deposits.

The Precambrian crystalline bedrock surface formed a sharp contact with the Quaternary deposits. The bedrock topography are variable from low elevation terrains to deep trench or depression of kettle hole. Three deep trenches of the bedrock surface were observed in the NE-SW direction, could act as the ground-line of the ice-marginal controlling the deposition of the sediments. The high elevation of the bedrock surface areas were often found associated with the coarse-grained sediments deposit in the proximal area close to the ice-marginal ground-line. The deep trenches or kettle-holes were often filled with the fine-grained sediments. The glacial till overlain the bedrock surface throughout the study area with the average thickness of 1-2 m. The primary deposit of the ice-marginal formation consists of coarse-grained sediments with high spatially variations where the coarse-grained sediments accumulated in the proximal area close to the ice-marginal ground-line and finer-grained sediments deposit in the more distal area. The sediments that found in between those three deep trenches are possibly poorly connected with the interbeded of the fine-grained unit from the glaciolacustrine deposit. Some parts of the primary- and glaciolacustrine deposits were deformed by the wave action due to the isostatic land uplift and the littoral process, which could improve the connectivity of the coarse-grained unit.

Based on geological and hydrogeological data, the Hanko groundwater area is separated from the Sandö-Grönvik groundwater area in the east and the Hanko town in the west by the elevated bedrock surface. The thick fine-grained unit lying in the NW-SE direction from Lindnäsudden in the northern coast of the Baltic Sea to south and south-east of Fermion Oy,

and south of Motocross-rata, separated the Hanko groundwater area into two main aquifers; the east and the west aquifers. The east aquifer is unconfined with the groundwater levels vary between zero and 12 m a.s.l. The west aquifer consists of two main groundwater levels; the perched- and the main (lower) groundwater levels. The perched groundwater is accumulated above the fine-grained unit in the northern part of the west aquifer and has groundwater levels very between 1.51 and 11.58 m a.s.l., which is similar water levels to the east aquifer. The main groundwater level in the west aquifer is semi-confined with partly bounded by the fine-grained unit. The groundwater levels vary between less than zero and 6.70 m a.s.l., approximately 1.24-7.64 m lower than the perched water level.

8 ACKNOWLEDGEMENTS

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