3D modelling of construction suitability in Espoo, Finland

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Abstract: A joint project between the Geological Survey of Finland (GTK) and the City of Espoo has been started, in a new development area in Espoo with the aim to investigate the geological history, which controls the geotechnical properties of fine-grained sediments.

The 2x3 km study area is situated on the southern coast of Finland. The lowest parts of the area lie less than 5 meters above sea level. The postglacial uplift in the area is today 0.2 meters/100 years, and the area has emerged from the Baltic Sea during the late Holocene.

The project includes a detailed sedimentological and geochemical study as well as basin analysis. Geophysical studies - electrical and electromagnetic (EM) tomography, both ground and airborne EM, gravity measurements and petrophysical laboratory studies of drilling samples will be used in compiling the 3D structural model, as well as the the construction suitability model.

The geotechnical drillhole database, already at hand, was extended with a series of new drillings and integrated with the sedimentological drillings, geophysical drill-core data and geophysical fieldwork. The data management is a combination of GIS- and CAD-technology.

Résumé: Modélisation en 3D de faisabilité de construction à Espoo, Finlande. Un projet conjoint au Centre national de la recherche géologique (GKT) et a la ville d'Espoo a été mis en place pour étudier l'histoire géologique qui détermine les propriétés géotechniques des sédiments à grain fin dans une nouvelle zone de développement à Espoo.

La zone d'étude de 2x3 km est située sur la côte sud de la Finlande. La partie inférieure de la zone d'étude est située à moins de 5 mètres au-dessus du niveau de la mer. L'élévation postglaciaire dans la zone est à l'heure actuelle de 0,2 mètres/100 ans et la zone a émergé de la mer Baltique durant la dernière holocène.

Le projet inclut une étude sédimentologique et géochimique détaillée et une analyse de la cuvette. Les moyens utilisées pour établir le modèle structurel en 3D ainsi que le modèle pour la faisabilité de construction ont été les études géophysiques – tomographie électrique et électromagnétique (EM), aéroportée et terrestre – les mesures de gravité et les études du laboratoire de pétrophysique des échantillons prélevés.

Les données géotechniques du trou de forage, déjà disponibles, ont été complétées par une série de forages intégrés aux forages sédimentologiques, par les données de la carotte géophysique et par le travail géophysique sur le terrain. La gestion des données se fait par une combinaison des technologies GIS (système d'information géographique) et CAD.

Keywords: drilling, geophysics, geotechnical engineering, sediments, site investigation, urban geosciences

GENERAL INFORMATION

The Suurpelto area is one of the main development areas in the Helsinki region (Figure 1). Already during 1999 the city of Espoo has started the land use planning (zoning). The size of the area is about 325 hectares and will include working, housing and services areas and also recreational and park areas. The aim is to provide housing for 7000 and workplaces for 8000 persons.

The Suurpelto area has formerly been mainly agricultural land and forests. The main recent change was the construction of the Kehä II (Ring II) highway through the eastern part of the area. The Lukupuro stream flows through the area from the northwest towards the southeast.

The foundation conditions in the area are already known to be challenging. The low initial bearing capacity of the often highly organic fine sediments and their difficult stabilization gives an impetus to study the sedimentology in order to help solving the problems of ground engineering.

The presented article gives the first results of a project carried out with the cooperating parties from the Geological Survey of Finland, Southern Finland Office (GTK), the City of Espoo, the Helsinki University of Technology (TKK) and the University of Helsinki, Department of Geography.

GEOLOGY

The Suurpelto area the crystalline bedrock mainly consists of Precambrian granites, gneisses and amphibolites. The bedrock topography is an ancient peneplain sloping towards south with a very low gradient. The relative bedrock topography is about 50 meters.

The Quaternary sediments directly overlying the unweathered bedrock in the Suurpelto area consist of a basal till unit in the lower parts of the area overlain by a glaciofluvial sand with an average thickness of one meter underlying varved glacial clays. On top of these varved sediments are the Yoldia, Ancylus and Litorina stage fine sediments. The uppermost sediments are more organic clay and silt gyttja (mud) deposits, especially in the most low-lying southern part of the basin. The thickness of the sediments can be as high as 25-30 meters in the Suurpelto sedimentary basin. On the slopes of the bedrock hills lie sand deposits that are related to the post-glacial shoreline processes (Figure 2).

The groundwater level is very near to thse urface throughout most of the Suurpelto area. In the lower parts of the basin there is practically no dry crust. Deeper down the hydrogeological conditions are influenced by the glaciofluvial sand unit below the fine sediments. The sand unit has a high water pressure, which was also identified during the piston core drilling.

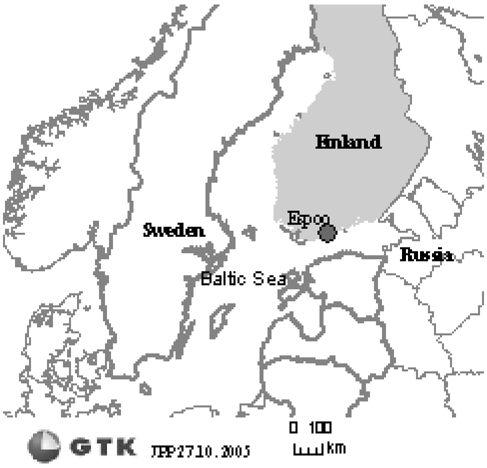

Figure 1. Location of the study area.

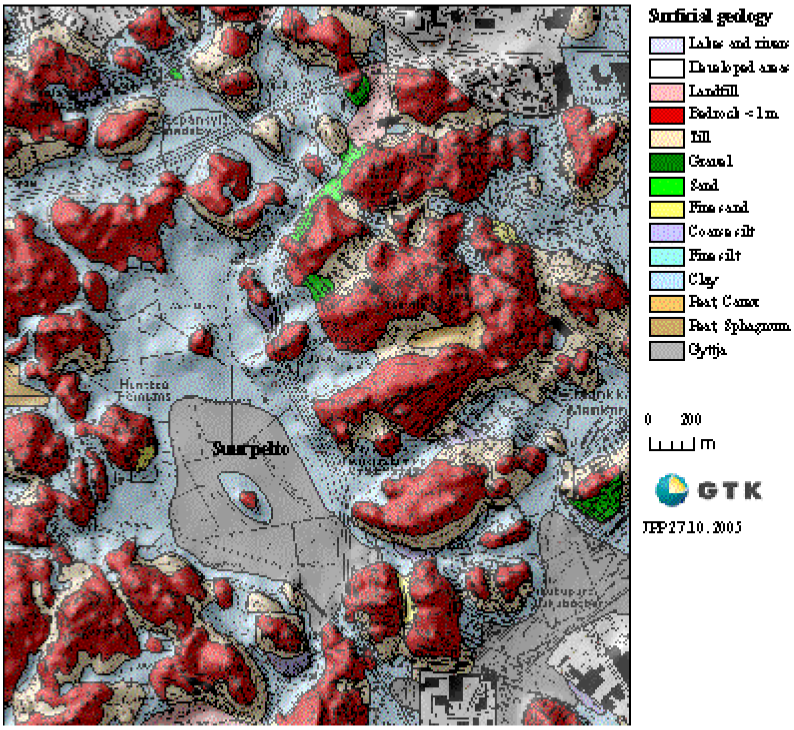

Figure 2. Surficial geology of the Suurpelto study area. Mapping information GTK Surficial Geology map 1:20 000. Base map copyright National Land Survey of Finland.

According to the Finnish varved clay chronology (Sauramo, 1923), the Suurpelto area was deglaciated ca. 1300 clay varve years before the drainage of the Baltic Ice Lake into the Yoldia Sea. This drainage has been dated at 11 590 ±100 calendar years ago (Saarnisto & Saarinen, 2001), meaning that the Suurpelto area was free from the continental ice sheet almost 13 000 years ago. After deglaciation, the Baltic Ice Lake waters were transgressing with the highest level at approximately 120 meters above the present sea level (a.s.l.) in Espoo area (Eronen, 1990). The emergence of the deglaciated areas proceeded rapidly during the Yoldia Sea phase, and the highest level of the Yoldia Sea is at 80 meters a.s.l. in Espoo area (Eronen, 1990). It was followed by Lake Ancylus stage (ca. 11 000-9000 years ago) and Litorina Sea stage (9000-) in the Baltic Basin history.

Most of the Suurpelto study area lies at an altitude of less than 10 meters a.s.l. and began to be exposed from beneath the receeding Litorina Sea waters at around 3000 years ago (Hyvärinen, 1999). However, the isolation threshold, representing the final isolation is situated in the SE corner of the study area at an altitude of 6 meters. Thereby, the final isolation of the study area took place ca. 2000 years ago (Hyvärinen, 1999), which also dates the formation of the Lukupuro stream over the isolation threshold. It is likely that prior to isolation the Suurpelto area was a sheltered bay of the Litorina Sea characterized by calm and stable sedimentation environment for hundreds if not thousands of years. The area is surrounded by a rolling relief of bedrock topography (with altitude of 30 to 50 m a.s.l.) in all directions, and has therefore been well sheltered from the wind and major wave activity during the bay stage (Figure 3).

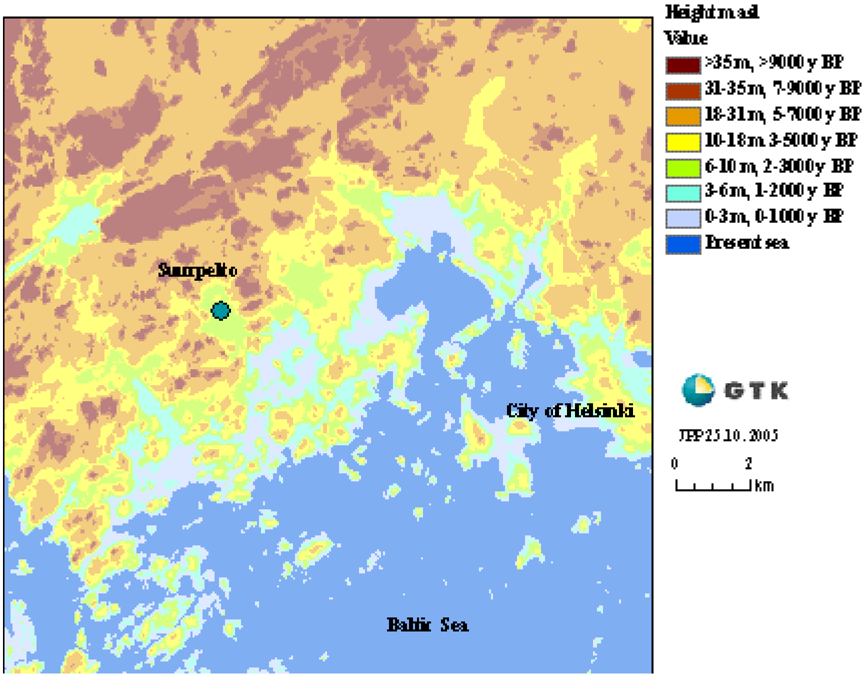

Figure 3. Shoreline changes during the Holocene on the coast of the Baltic Sea in the Helsinki area. Base map copyright National Land Survey of Finland.

GEOPHYSICAL SURVEYS

Airborne and ground geophysical techniques were used to characterize the geology and sedimentary deposits in the Suurpelto area. The airborne data includes electrical conductivity (Figures 5 and 6), magnetic and radiometric (earth's gamma radiation – total count, Th, K and U) maps. Airborne electrical conductivity is measured by a dual-frequency fixed-wing electromagnetic (EM) system (3.1 kHz & 14.4 kHz, vertical coplanar EM coils are mounted on the wingtips of the aircraft). A detailed description of the GTK's AEM system is given by Poikonen et al. (1998). Line spacing was 100 m and the nominal flight altitude 30 m. Multi-frequency (eight frequencies from 0.4 kHz to 56 kHz) ground EM (horizontal loop EM, HLEM) measurements, 2D electrical resistivity (ERT) soundings and gravity measurements were made at selected lines (see Figures 4 and 7). Spectral induced polarization (SIP) and the resistivity of core samples were measured in the laboratory.

Gravity data have been used to interpret the thickness of the sediments and the bedrock topography between the drilling sites (Figure 4). The airborne EM data will be inverted into the 3D model describing the subsurface electrical conductivity distribution. The conductivity model provides information about the total thickness of the sediments and the main sedimentological units. The ground EM and ERT data are used for the same purpose, for mapping the main sedimentological units between the drilling points. The conductivity distribution inverted from the ground data reveal, however, more detailed features than the airborne data alone.

The laboratory SIP and resistivity data are correlated with other laboratory chemical and geotechnical data to find out relations between the electrical conductivity and the geological and geotechnical parameters. The electrical conductivity model is then used for estimating the geological and geotechnical units between the drilling sites, i.e., to construct a 3D geological/geotechnical model for the Suurpelto area.

Even the raw airborne data, i.e. the low-frequency (3.1 kHz) in-phase maps in figure 4 and the high-frequency (14.4 kHz) in-phase map in figure 5, were found to be very useful. The Suurpelto area is characterized by a high electrical conductivity referring to saline and sulphide bearing clays. The preliminary laboratory electrical conductivity results (ρ=3-5Ωm) are very similar to the conductivity values measured for saline sulphide bearing Litorina Sea clays at the Kyrönjoki river valley in western Finland (Suppala et al., 2003, Vanhala et al., 2004). Comparison between the high-frequency (14.4 kHz) and the low-frequency conductivity (3.1 kHz) maps indicates that the clay beds are markedly thinner and less conductive in the northern part of the area than in the southern part. The maps also suggest that the saline clays beds are close to surface.

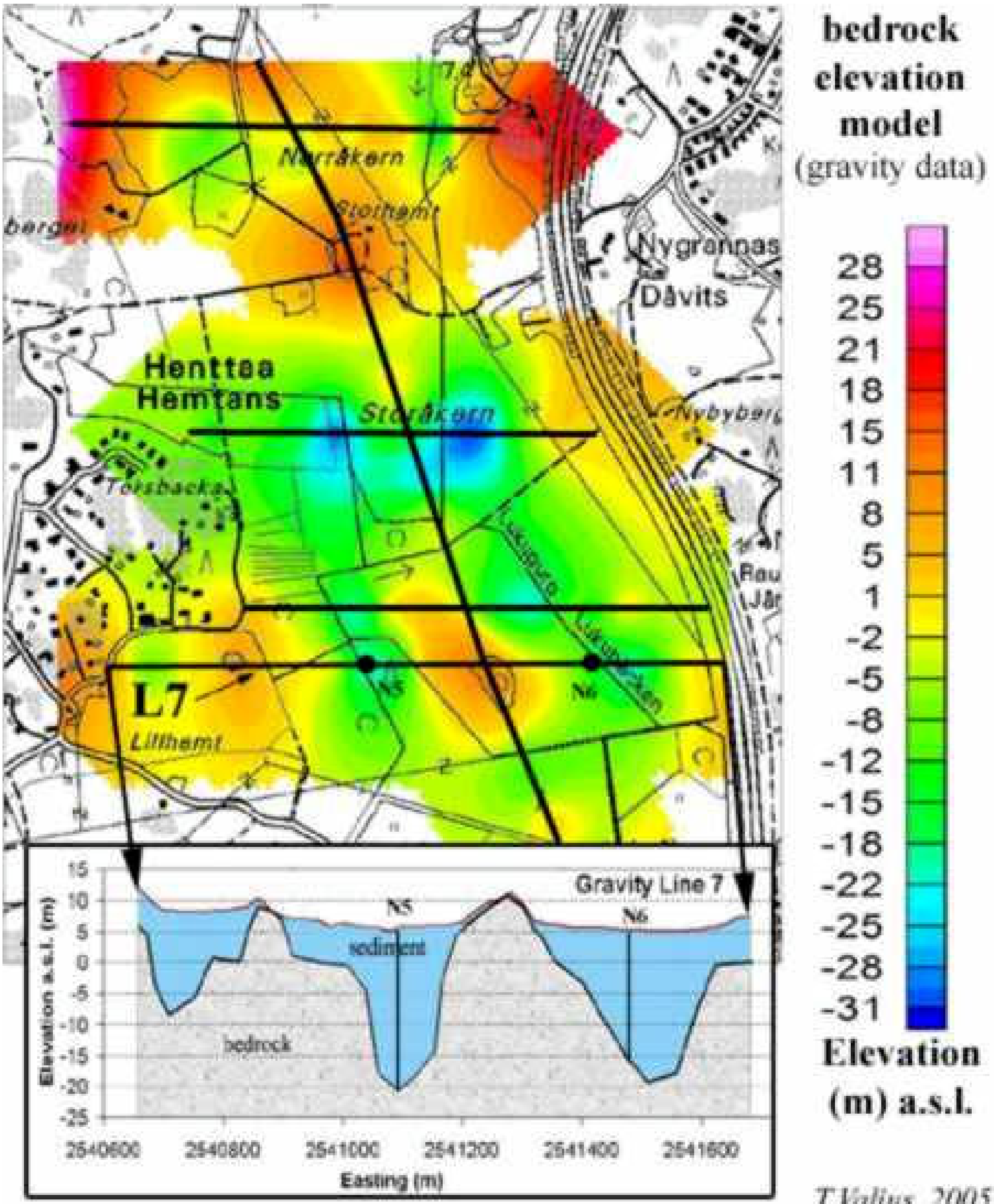

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Figure 4. Bedrock elevation model based on gravity interpretation. As an example, 2.5D profile interpretation from line 7 is given. Base map copyright National Land Survey of Finland.

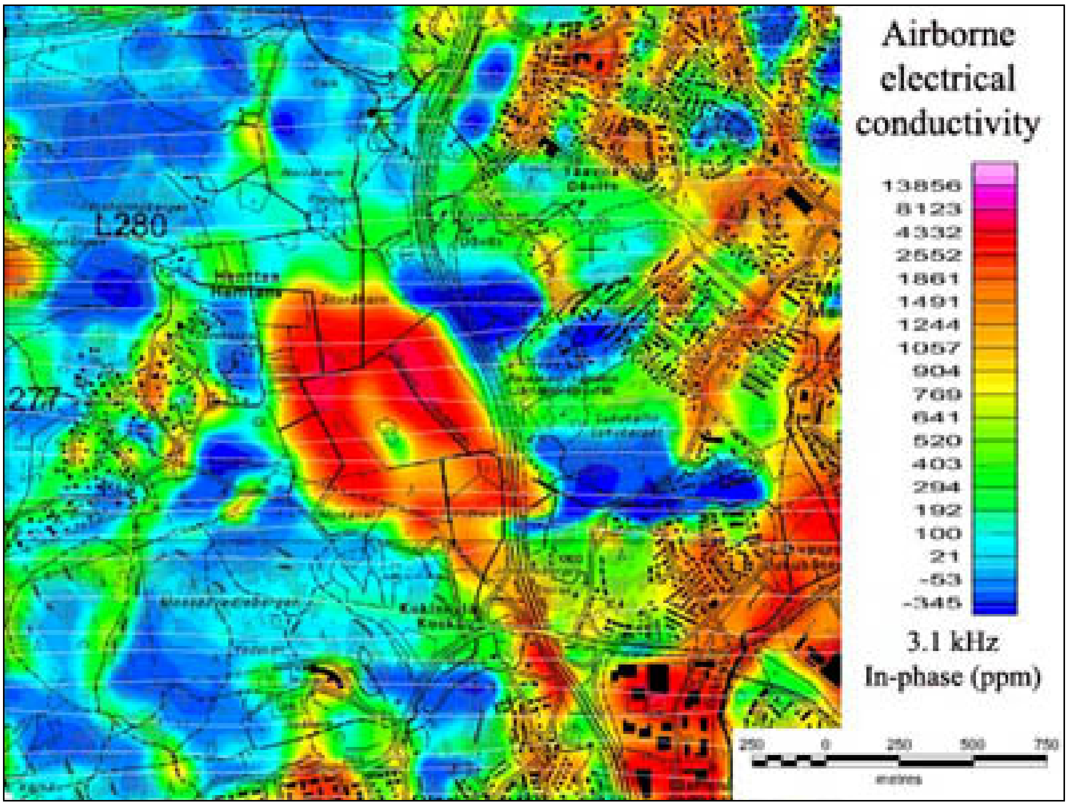

Figure 5. Airborne electrical conductivity – 3.1 kHz in-phase component. The low-frequency EM map is sensitive for good electrical conductors and has greater "depth penetration" than the high-frequency map. The thin E-W-trending white lines mark the flight lines. Base map copyright National Land Survey of Finland.

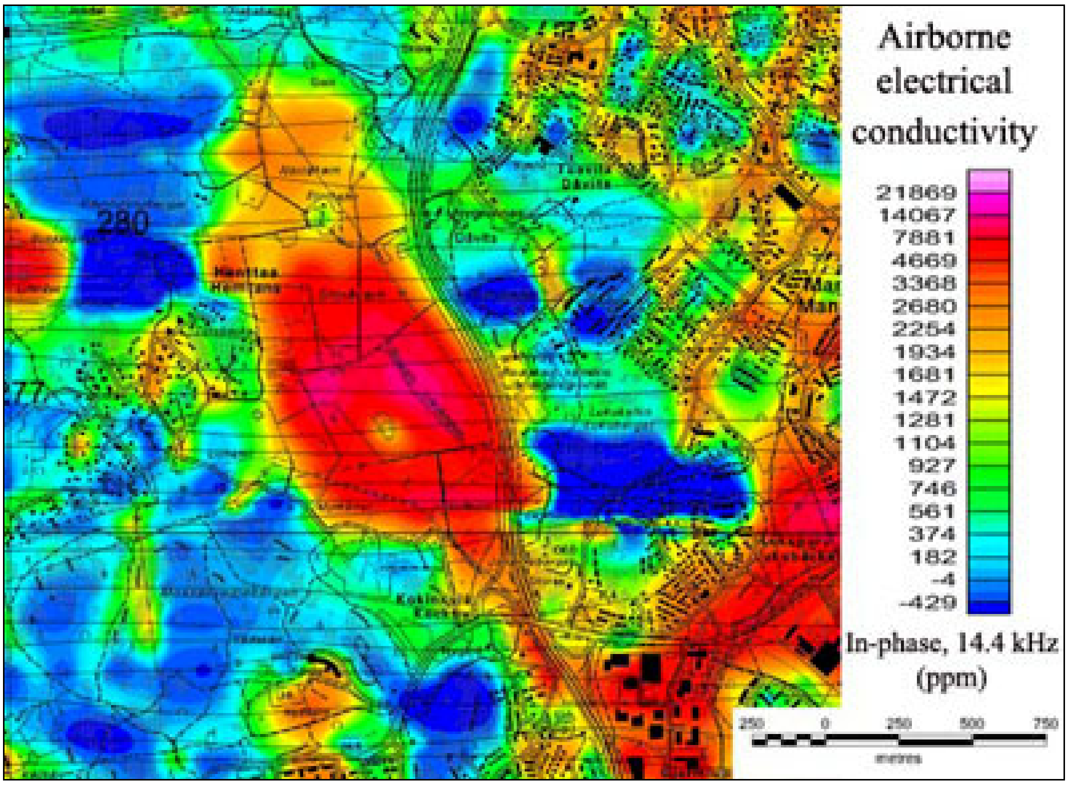

Figure 6. Airborne electrical conductivity – 14.4 kHz in-phase component. The thin E-W-trending black lines mark the flight lines. Base map copyright National Land Survey of Finland.

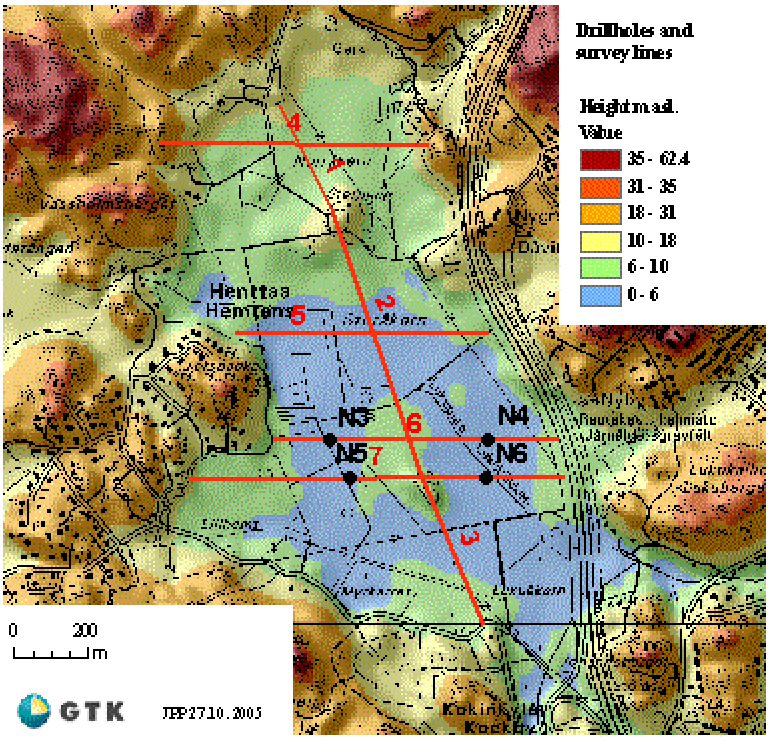

Figure 7. Suurpelto drillholes N3-N6 and geophysical survey lines. Base map copyright National Land Survey of Finland.

DRILLING

Coring of long sediment profiles was targeted on the basis of previous knowledge about the thickness of clayey deposits in the Suurpelto area. The selected four coring locations were also considered to best represent the long-term deposition of sediments in the Suurpelto depositional basin. Coring was carried out using a modification of the piston-type lake sediment corer (Putkinen & Saarelainen, 1998) for the purpose of retrieving clayey deposits into ca. 1-metre-long plastic tubes (sample tube inner diameter of 45 mm) for laboratory analysis. The corer was operated with a standard soil drilling equipment.

Altogether, 2060 cm (N3), 1700 cm (N4), 2100 cm (N5), and 1700 cm (N6) long and continuous sediment profiles were retrieved from the study locations. The cores were stored at a cold room temperature (+4 °C) prior to opening and analysis.

SEDIMENT STRATIGRAPHY

The study of sediment stratigraphy includes lithostratigraphical, geochemical and geophysical analyses carried out on the cored sediment samples. Sediment deposits are described in detail according to Troels-Smith classification (Troels-Smith, 1955) and logged for volume magnetic susceptibility (κ) using Bartington MS2C loop sensor and MS2E1 surface scanning sensor, water content (105 °C overnight) and loss on ignition (LOI, 550 °C for 2 hours) at 1 to 10 cm resolution. Additional mineral magnetic parameters, such as anhysteretic remnant magnetization (ARM) and saturation isothermal remnant magnetization (SIRM), will be used to investigate variations in quality and concentration of magnetic minerals. Physical parameters also include grain size analyses, specific surface analyses, and XRD analyses that will be targeted at suitable resolution based on sediment stratigraphy.

A volume specific sub-sampling technique will be applied in the physical and chemical investigations allowing calculations of water content and other substances as percentage by volume and/or weight per volume. Inductively coupled plasma atomic emission spectrometry (ICP-AES) and LECO CHN-600 element analyzer will be used to analyse basic elements such as Mn, Fe, K, Mg, S, P, Pb, Ti, and C, H, S, respectively. In addition, different sequential extraction methods (e.g. BaCl –extraction) will be used to determine cation and anion exchange capacity of the clayey deposits.

First measurements of volume magnetic susceptibility from the four sediment cores N3, N4, N5, N6 are presented in figures 8 and 9. These were logged at 20 mm intervals using a Bartington MS2C sensor (loop diameter of 70 mm) designed for studies of un-opened sediment tubes. Susceptibility varies between 3 and 95 SI $\times 10^{-5}$ units in all of the studied cores, and has a general increasing trend with depth. The highest values are found in the deepest deposits, indicating that the lowermost (i.e. the oldest) sediments have higher concentrations of magnetic minerals (probably magnetite and haematite). The results also suggest that there is a good correlation between all four studied cores in terms of magnetic susceptibility. Even some of the smaller-scale features of the susceptibility curves agree between two western cores N3 and N5, as well as between eastern cores N4 and N6. In addition, the values of susceptibility are much alike between all four cores, suggesting that the same physical sedimentary units representing different phases of geological development of the Suurpelto depositional basin are found in every core.

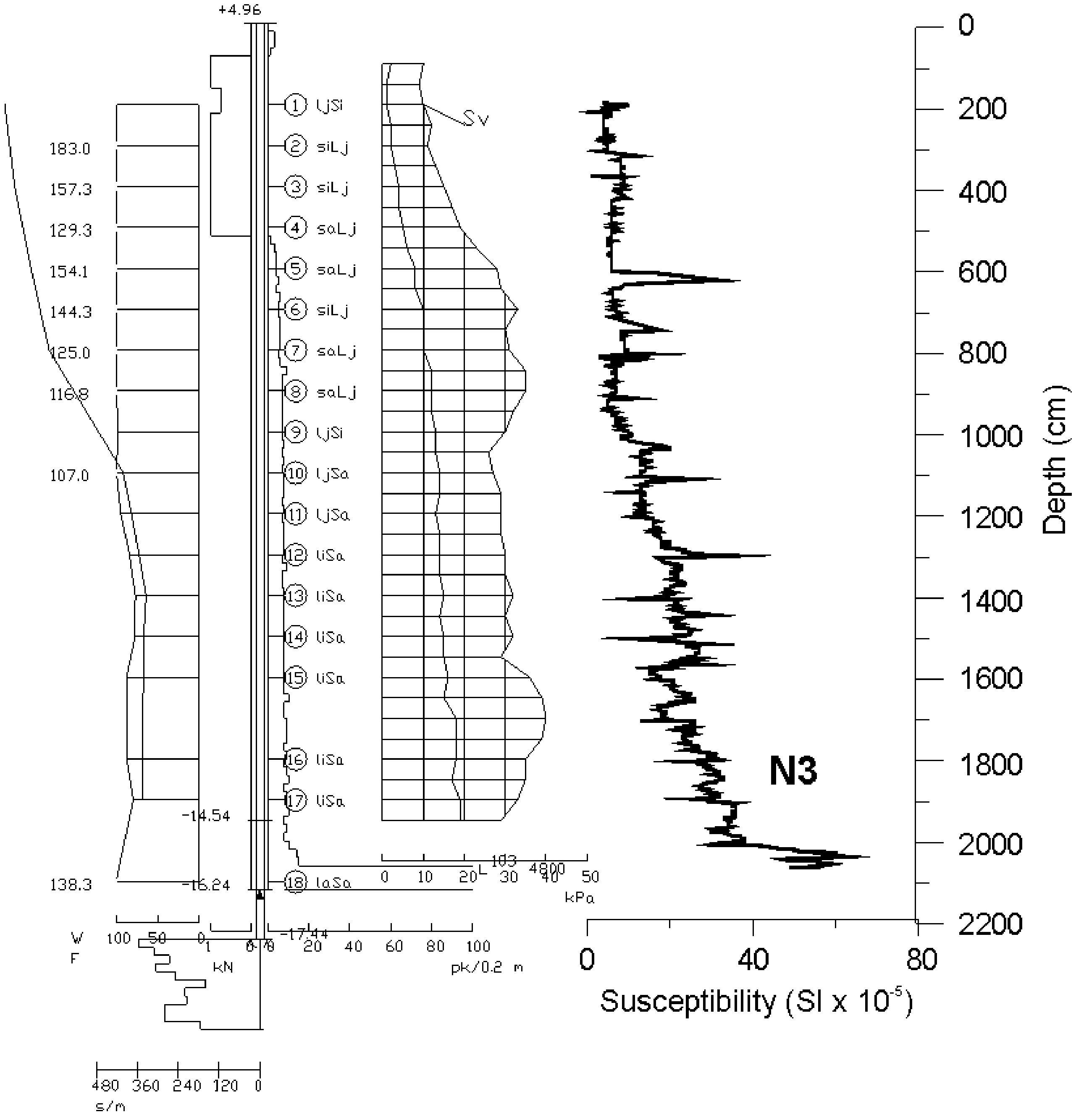

Figure 8. Drillhole and susceptibility profile data from point N3. Soil type explanations: ljSi or ljSa = silt or clay with organic content of 2-6 %, siLj, saLj = silty and clayey gyttjas respectively, liSa, clay with a clay fraction (<0.002 mm) higher than 50 %, laSa, clay with a clay fraction 30-50 %. Drillings include Swedish weight sounding test, vane test and percussion drilling with rods.

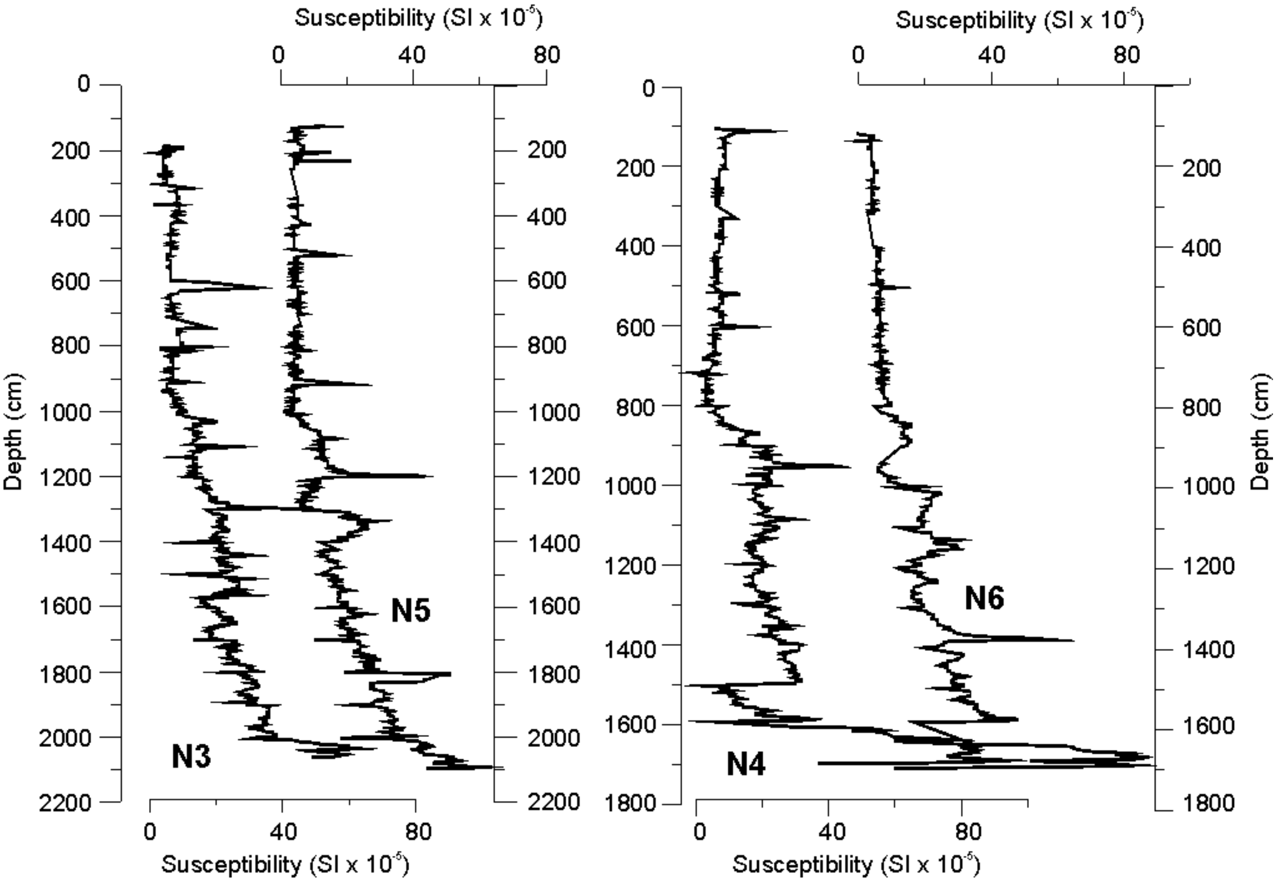

Figure 9. Magnetic susceptibility profiles from the drill-holes N3, N4, N5 and N6.A verification of this, however, requires opening of the cores and more detailed analysis, but if this is truly the case, it then gives us several advantages to begin with. Firstly, we can better characterize the geological and palaeohydrological history of the basin and combine these results with geophysical surveys (aerogeophysics, gravity methods, resistivity soundings) in order to provide a three-dimensional model of the sedimentary deposits in the study area. Secondly, we can select one of the cores for detailed analysis of physical and chemical measurements, and then generalize these results to other cores and eventually to entire sedimentary units within the basin. Core-to-core correlation will also allow us to investigate a single core with much better temporal resolution, and use the other cores only for replicate analysis to cross-check the quality of the analysis.

GEOTECHNICAL ENGINEERING

Geotechnical properties of the Finnish fine sediments have previously been studied especially by Gardemeister (1975). Gardemeister gives the background information on the strength and consolidation properties of the Finnish fine sediments linked to the Baltic Sea stages, and, on the other hand, to the clay fraction, organic (humus) and water contents of the sediments.

The geotechnical information from the Suurpelto area is beeing provided in three distinct phases. The first information component includes the previous drillings undertaken at the study site after the establishment of the City of Espoo geotechnical department. This material consists mainly of Swedish weight sounding test data but there are also Vane test and other drilling test data available. The City of Espoo geotechnical department has gathered the second and the most recent geotechnical information component used in this project since the beginning of the Suurpelto land use project was launched several years ago. Altogether, there are several hundreds of drilling logs available from the Suurpelto area. These include data from e.g. Swedish weight sounding tests, dynamic probing tests, and cone penetration tests. In addition, at the margin of the site, along the Kehä II highway thousands of drillings are available to be used in the present investigation. Other information provided by the City of Espoo from the Suurpelto area consists of various surveys, data from the recent detailed laser-scanning topographic survey, and a surficial geology mapping at a scale of 1:2,000. The first and the second type of information has been provided in digital format to the GTK by the City of Espoo. Both organizations use their respective relational databases for the management of the drilling and other ground information.

The third component of geotechnical data gathered from the Suurpelto area consists of several drilling and laboratory studies done for the specific purpose of interlinking with the studies done by the GTK in the four specific drilling locations (Figures 7 and 8). These include grain size analyses, water content and organic content measurements, fines number tests, undisturbed shear strength from fall cone tests and oedometer tests. These studies were undertaken by the City of Espoo and by the Helsinki University of Technology for the City of Espoo.

CONCLUSIONS

The present data collected by drillings, airborne geophysical methods and gravimetric profiling gives us the information on the minimum foundation depth (pile length) of the surveyed site. In Finland a depth of more than 13 meters has been found to be decisive from the point of view of rapidly rising foundation (pile) costs. In Suurpelto we are able to show that geophysics (gravimetric measurements and the aerogeophysics) allow us to delineate the excessively deep foundation condition areas. This methodology is perhaps most useful to employ in future new construction areas in accordance with sparse geotechnical drilling data.

The project has just begun, and yet the first results indicate that data from sedimentological and geophysical measurements and surveys enhance our understanding about the late-glacial/post-glacial history of the Suurpelto sedimentary basin. In line with geological history, sedimentological deposits in the Suurpelto area include evolutionary stages of the Baltic Basin history (Baltic Ice Lake, Yoldia Sea, Ancylus Lake, Litorina Sea). As investigated by Gardemeister (1975), different sedimentary units of the Baltic basin vary in terms of geotechnical properties. Using the methods mentioned above, their 3D distribution in the Suurpelto area can be traced and investigated. This provides valuable material for the land use planning.

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