R-05-54

Depth and stratigraphy of Quaternary deposits

Preliminary site description Laxemar subarea – version 1.2

Helena Nyman, SWECO Position AB

September 2005

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Keywords: Quaternary deposits, Overburden, Regolith, GeoEditor.

Summary

This report aims at describing the modelled Quaternary deposits (QD) depth according to six layers with different geological and hydrological properties in the Simpevarp regional model area.

The program used in the modelling of QD depths is the GeoEditor, which is an ArcView3.3-extension.

The input data used in the model consist of 102 boreholes and 328 observation points. As input is also a large number of observation points interpreted from geophysical investigations used; 1,087 points based on refraction seismic measurements (distributed in 31 profiles), 22 points from electrical soundings (VES) and 19,237 points from seismic and sediment echo sounding data. The outer part of the area has a low data density. Some of the used points are generally not very deep and do not describe the actual bedrock elevation. They do, however, describe the minimum QD depth at each location. A detailed topographical Digital Elevation Model (DEM), the maps of Quaternary deposits and outcrops were also used.

The model is based on a three-layer-principle where each layer can be given similar properties. The uppermost layer, Z1, has been influenced by the impact from surface processes, e.g. roots and biological activity. The bottom layer, Z3, is characterized by contact with the bedrock and is corresponding to a till layer. The middle layer, Z2, is corresponding to a clay layer and assumed to have different hydraulic qualities than Z1 and Z3. Besides those layers, another three layers are also modelled; M1 corresponds to a peat layer, M2 answers to a glaciofluvial sediment layer and M3 corresponds to a layer with artificial fill. All layers can have thickness zero.

The resulting model clearly shows the valleys with thicker depths of QD, surrounded by areas with thinner or no depths. The esker near Fårbo (Tunaåsen) is also distinctly marked in the south-western area. The northern and central part of the model area are characterized by numerous bedrock outcrops.

The maximum depth of QD in the model is about 50 m, and the average depth in this area is 2.1 m with outcrops included and 3.0 m with outcrops excluded.

Sammanfattning

Föreliggande rapport syftar till att beskriva det modellerade jorddjupet i Simpevarps regionala modellområde. Modelleringsprinciperna har varit en indelning av jordprofilen i sex huvudsakliga lager med olika geologiska och hydrologiska egenskaper.

Modellsystemet som använts vid modelleringen av jorddjup och sediment är GeoEditor, ett grafiskt verktyg i ArcView-miljö.

Indata till modellen har varit 102 borrhål och 328 provgropar eller observationspunkter. Som indata har också ett stort antal värden tolkade från geofysiska undersökningar använts; 1 087 punkter baserade på refraktionsseismiska mätningar (fördelade på 31 profiler), 22 punkter från elektriska sonderingar (VES) och 19 237 punkter från de maringeologiska undersökningarna. De yttre delarna av modellområdet har en lägre datadensitet än övriga delar. En del av de observationspunkter som använts är generellt grunda och når inte ner till bergöverytans nivå. Dessa observationer har ändå använts för att säkerställa ett minsta djup till berg. En detaljerad topografisk DEM (digital höjdmodell), jordartskartor, hällkarta och maringeologiska undersökningar har också använts i modelleringen.

Modellen har baserats på en trelagersprincip vid beskrivningen av de geologiska formationerna i området. Det översta lagret, Z1, har påverkats av ytliga processer, t ex rötter och biologisk aktivitet. Det understa lagret, Z3, karakteriseras av morän i kontakt med bergöverytan. Det mellersta lagret, Z2, motsvarar ett lerlager och antas ha annorlunda hydrogeologiska egenskaper än Z1 och Z3. Utöver dessa lager, har ytterligare tre lager modellerats; M1 som motsvarar ett torvlager, M2 som motsvarar ett lager med isälvssediment och M3 som beskriver ett lager med fyllnadsmaterial. Alla lager kan ha mäktigheten noll.

Den resulterande modellen visar tydligt de för området karaktäristiska dalgångarna med stora jorddjup, omgivna av områden med mindre eller inget jorddjup. Likaså isälvsavlagringen vid Fårbo (Tunaåsen) är tydligt markerad i den sydvästra delen av området. Norra delen karaktäriseras av hällmark.

Det största jorddjupet i modellen är ca 50 m, och medelvärdet för jorddjupet i området är 2,1 m med hällar inkluderade och 3,0 m beräknat utan hällar.

Contents

1 Introduction

SKB performs site investigations for localisation of a deep repository for high level radioactive waste. The site investigations are performed at two sites, Forsmark in Östhammar municipality and Simpevarp in Oskarshamn municipality, see Figure 1-1.

At the Simpevarp site, numerical and descriptive modelling are being performed both for the bedrock as well as for the surface systems. As input to the hydrology modelling, and over all understanding, the surface geology and Quaternary deposits (QD) depth to the bedrock surface area are important parameters. The hydrological modelling in the area as well as the need for a general view of the observations that has been performed led to the need for a QD depth model.

QD is the loose deposits overlying the bedrock and is often referred to as overburden or regolith. All known overburden in the Simpevarp regional model area was formed during the Quaternary period, after or during the latest glaciation. The term QD is therefore used for the overburden in the Simpevarp area.

This report presents a model that describes the estimated QD depth according to six layers characterized by different geologic and hydraulic properties in the Simpevarp regional model area. Available data from boreholes, observation points, seismic data, seismic and sediment echo sounding data and maps of QD area used as input data to the model.

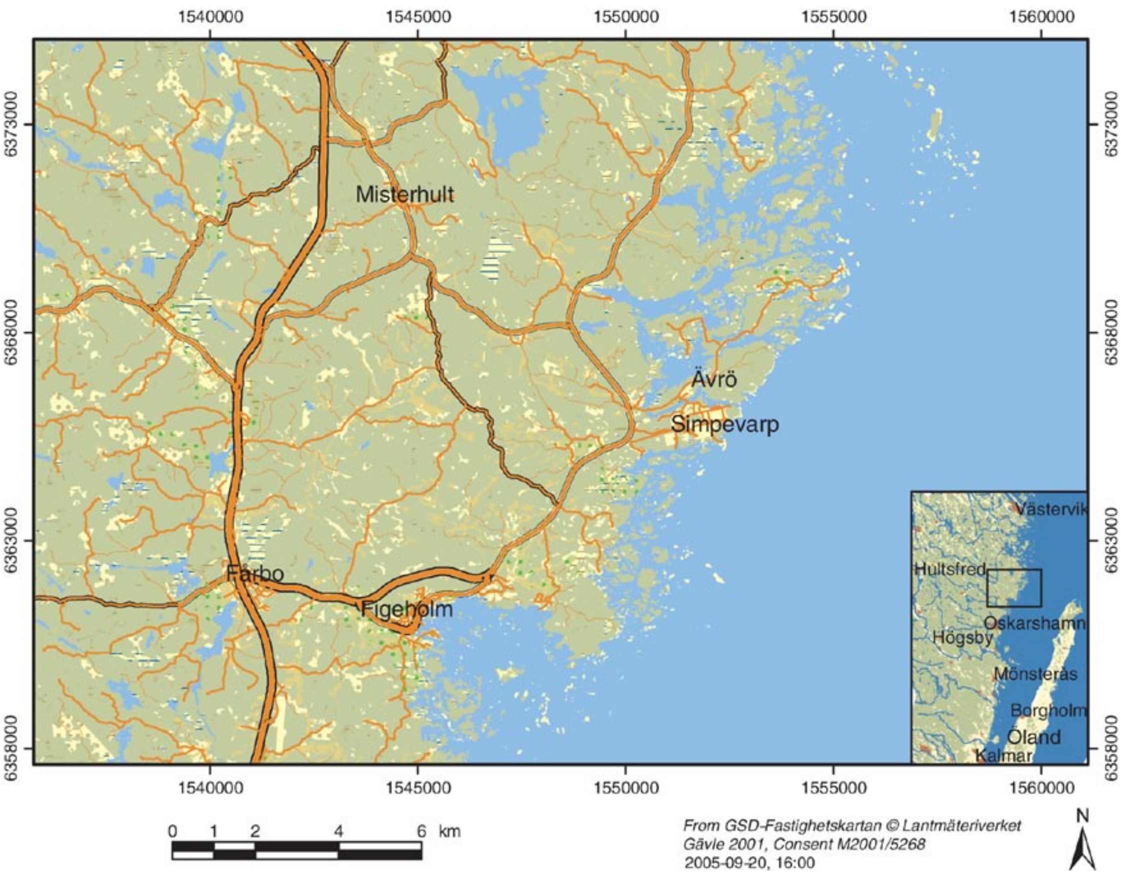

Figure 1-1. *Map showing the Simpevarp area.*

The resulting interpolated surfaces are presented in a GIS-environment and delivered on two CD's separate from this report, one with data that are classified as free and one with data classified as strictly secret. In chapter 5.1 the differences between the data sets are described. The CD's can be found at the SKB archive in Stockholm respectively in the SKB archive at the Äspö Hard Rock Laboratory, under media ID C097.

The model will be used in hydrological and transportation modelling of the area and to visualize the spatial distribution of the Quaternary cover. It will also identify areas with a low density of data. The model provides a close link between basic geological and geophysical data, conceptual interpretation and model representation.

1.1 The model area

The model area is a modified Simpevarp regional model area, shown in Figure 1-2. The regional model area is in the western part enlarged to contain the hole catchment area of the river Laxemarsån.

The area is characterized by long narrow valleys with larger QD depth than in the surrounding areas. The topography is relatively flat and has a slope towards the east. The whole area is situated below the highest coastline /Rudmark, 2004; Rudmark et al. 2005/. The topography is shown in Figure 3-1.

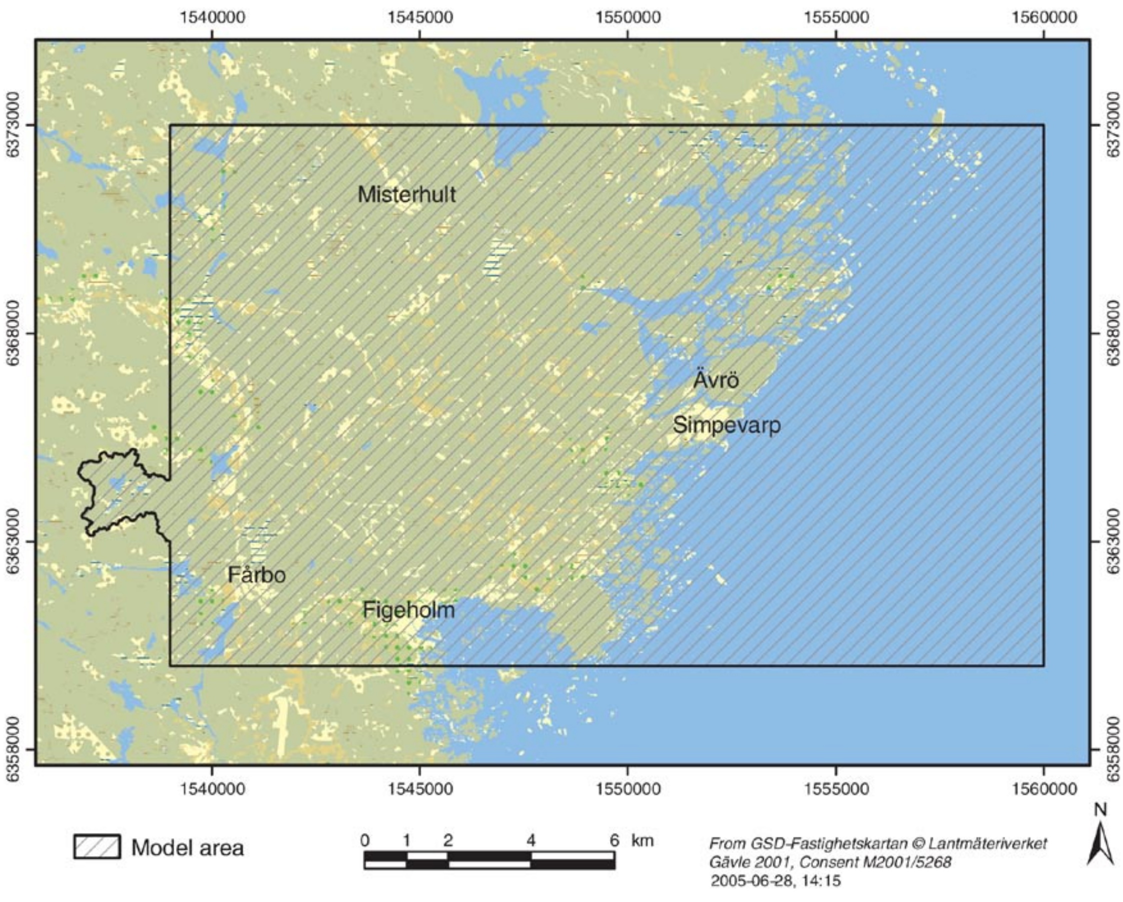

Figure 1-2. Model area for modelling of QD depth in the Simpevarp area.

2 Methodology

The program used in the modelling of QD depths at the Simpevarp site is the GeoEditor, a graphical tool for geological modelling and editing in a GIS-environment (ArcView3.3) /DHI Water & Environment, 2001/. The GeoEditor provides a close link to the hydrological modelling tool MIKE SHE, which is being used for the near-surface groundwater modelling at the Simpevarp site. Input files for the hydrological model can be prepared in the GeoEditor and results from the MIKE SHE model can be imported and presented in the GeoEditor-environment.

The GeoEditor can also be used explicit in a GIS-environment giving a general view of the observation points, boreholes etc in the area and giving the user the possibility of extracting profiles of geological formations for a general understanding of the geology in the area.

2.1 Description of the tool

The GeoEditor is a graphical tool for geological modelling and editing in a GIS-environment /DHI Water & Environment, 2001/. The modelling tool provides facilities to develop and test geological models based on borehole data and geophysical data. GeoEditor provides a close link between basic geological and geophysical data, conceptual interpretation and model representation.

The concept of the GeoEditor is to provide a simple GIS-based model in which the user can view existing observation data (boreholes, observation pits, seismic and geophysical data etc), interpolate geological formations based on the observation points, evaluate and adjust the interpolated layers and present the results as layers and in profiles.

The GeoEditor can be used as a database storing information, and for viewing the information stored for each observation point. The model can also include observations such as groundwater levels, pumping and transmissivity.

Based on experience of geologists, hydrologists and modellers two alternative approaches have been implemented. These are based on specifying either overall geological structures in a vertical profile mode, or zonations of characteristic aquifer properties in a depth interval mode. Both of the approaches are divided in a three-phase approach where selection of data is followed by geological interpretation. In this project the so called vertical profiles approach has been used, where a geological model, consisting of geological layers interpolated from discrete points, is developed.

The overall geological structure is specified in terms of layers by stepwise sweeping through a number of predefined geological profiles. For each profile discrete points used in the layer interpolation are digitized using the stratigraphy of each borehole covered by the profile. In the third step the discrete values are interpolated into a 3-dimensional geological model. The interpolation methods available in the GeoEditor are Inverse Distance Weighted (IDW), spline and trend interpolation.

The resulting geological model is, subsequently, evaluated. If necessary, the geological model can be modified until acceptance. Then the model can be transferred to ASCII-files, ESRI grids or input files to the groundwater modelling system MIKE SHE.

3 Input data

3.1 Data used in the model

The input data used in the model, see Table 3-1, is based on the information available at the data freeze 1.2 in Simpevarp, October 2004.

The DEM over the area is undulating with narrow valleys situated at bedrock-weakened zones /Brydsten and Strömgren, 2005/. The relatively flat topography has a slope towards the east (see Figure 3-1).

Figure 3-2 shows the distribution of observation points within the model area. The outer parts of the area have a low data density. The observation points are in many cases shallow and do not describe the actual bedrock elevation (Figure 3-3). They do, however, describe the minimum QD depth at each location.

The termination of the 20,776 observation points are distributed as shown in Table 3-2.

Table 3-1. Data used in the QD depth model.

Data	Description
DEM	The DEM used in the model is based on the existing DEM from the Swedish national land survey (LMV), the SKB DEM, nautical chart and depth soundings. The DEM has a resolution of 10 m and describes land surface, sediment levels at lake bottoms, and sea bottoms. The method for construction of the DEM and the bathymetry is described in /Brydsten and Strömgren, 2005/.
QD maps	The map of QD on land is a combination of detailed survey and regional mapping /Rudmark et al. 2005/. At sea, two maps of Quaternary deposits have been used /Ingvarson et al. 2004/ and /Elhammer and Sandkvist, 2005/ respectively.
Refraction seismic measurement data	Data included 31 profiles /Lindqvist, 2004a,b,c/. Each observed point has coordinates, a surface elevation and an estimated smoothed bedrock elevation. The total number of observation points is 1,087.
Boreholes and observation points	102 boreholes with an estimated bedrock elevation as well as 328 (mostly shallow) observation points with detailed stratigraphy is used /Bergman et al. 2005; Johansson and Adestam, 2004a; Johansson and Adestam, 2004b; Rudmark, 2004; Rudmark et al. 2005/.
Vertical electrical soundings (VES)	22 points from vertical electrical soundings (VES) with a estimated depth to bedrock is used /Thunehed and Pitkänen, 2003/.
Seismic and sediment echo sounding data	Data contains estimated depth to bedrock and stratigraphy from 19,237 sites /Elhammer and Sandkvist, 2005/.

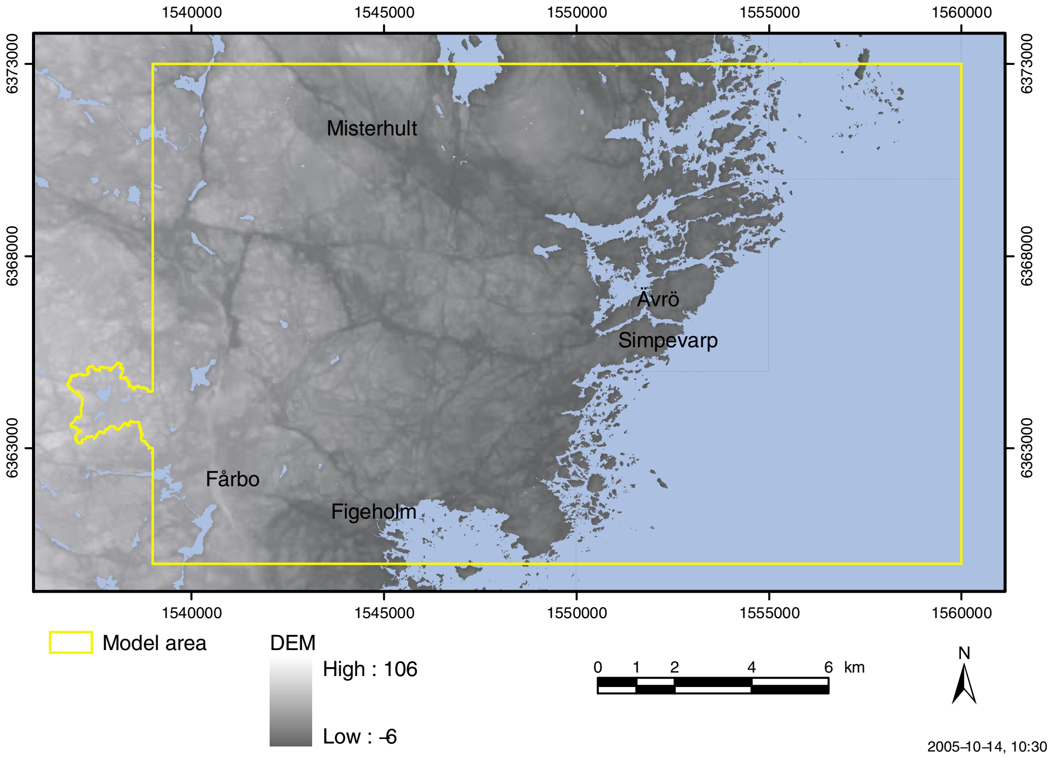

***Figure 3-1.** Topography (DEM) in a 10 m resolution /Brydsten and Strömgren, 2005/. The yellow line represents the model area. The DEM exist in the hole model area, but the depth in the sea are classified as strictly secret and can therefore not be shown in this report.*

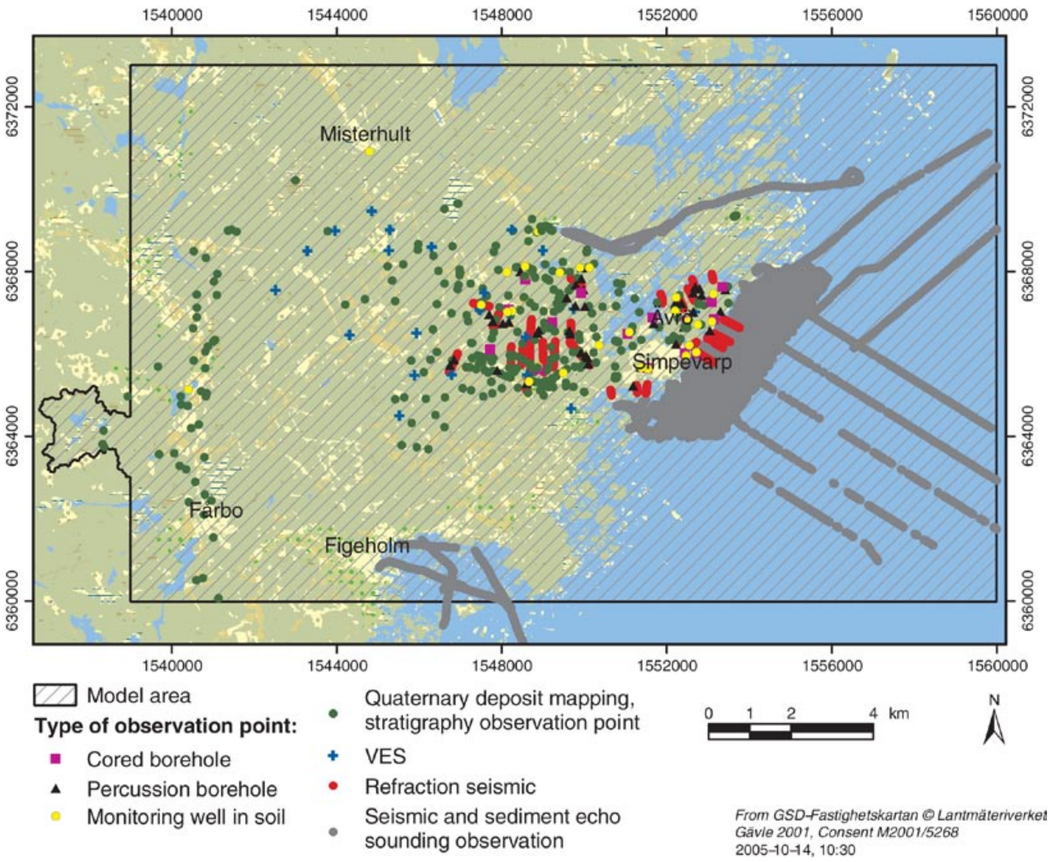

***Figure 3-2.** Map showing the distribution of observation points within the model area and the density of the various data sources. The black line represents the model area.*

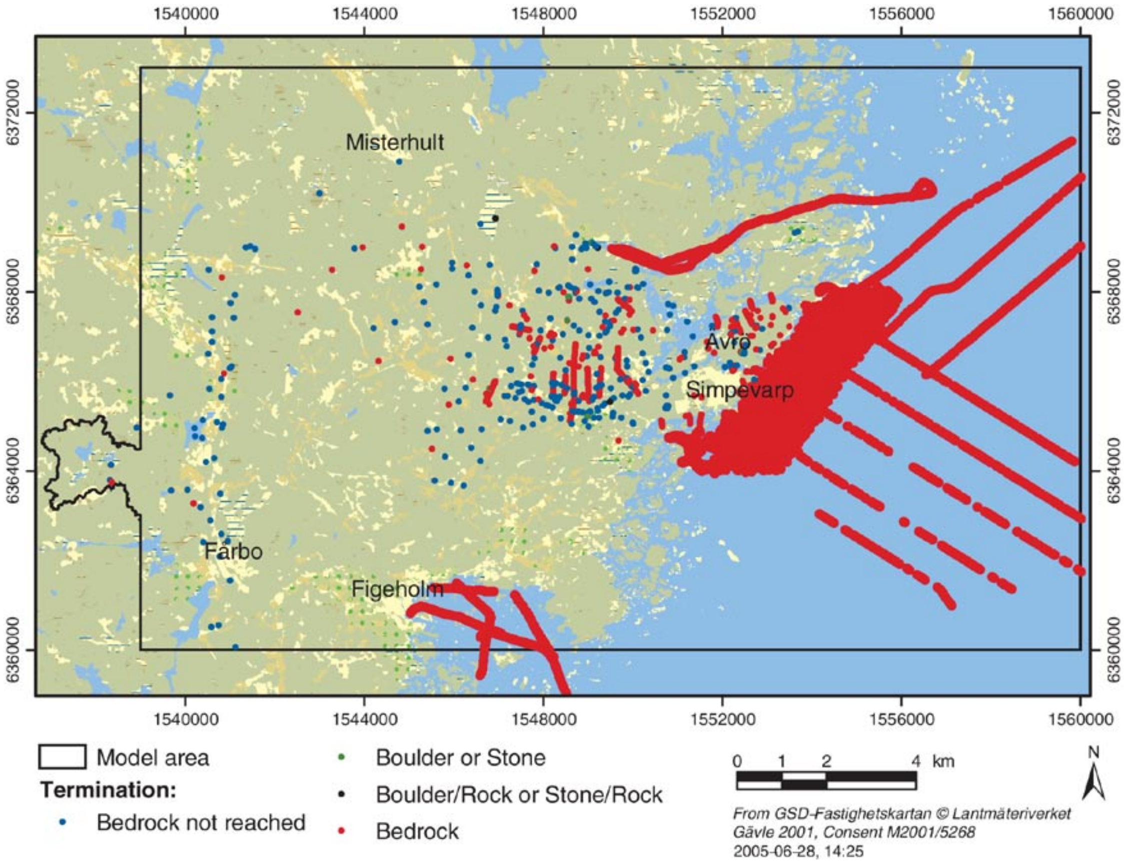

Figure 3-3. *Data density in the model area. The point colour indicate if the observation has reached bedrock or not.*

Table 3-2. Termination in observation points.

Type of termination	Number
Bedrock not reached	300
Termination against boulder/stone	9
Termination against boulder/rock or stone/rock	9
Termination against bedrock	20,458

3.2 Description of the Quaternary geology in the model area

The map of Quaternary deposits on land is a combination of detailed survey and regional mapping /Rudmark et al. 2005/. At sea, two maps of Quaternary deposits exists and have been used /Ingvarson et al. 2004/ and /Elhammer and Sandkvist, 2005/ respectively. Figure 3-4 and 3-5 show the QD maps and the different type of mapping methods that have been used in the area. The marine QD map from SGU /Elhammer and Sandkvist, 2005/ has a larger part of bedrock outcrops and a smaller part till, than the other QD maps. The discrepancies in the mapping methods e.g. interpretation of bedrock outcrops, affect the depth model since the QD maps are the basis when average values are assigned to the model.

Both the marine and terrestrial parts of the investigated area are characterised by a relatively flat bedrock surface with numerous fissure valleys, which in many cases can be followed for several kilometres. The highest topographical areas are dominated by till and bedrock outcrops. The valleys constitute areas, which have been sheltered from wave erosion and coastal streams. These low topographical areas have therefore during long time periods been favourable environments for sedimentation of clay. In the terrestrial part of the model area the groundwater level is high in the valleys. As a consequence of that, a layer of peat often covers the clay. Clay sediments are currently being deposited in the bays along the present coast. Exposed areas have been, and at some sites still are, subjected to wave washing, which have caused erosion and redeposition of some of the QD. Sand and gravel is currently being transported at the bottom of the most exposed parts of the sea. A sand and gravel layer therefore often covers the valleys at the sea bottom /SKB, 2005/.

The thickest QD occurs in the valleys whereas the QD thickness is generally low in other areas. There are, however, some exceptions from this. The glaciofluvial deposit in the western part of the model area, Tunaåsen, is an esker, which demonstrates among the largest thickness of QD in the model area, over 20 metre (data from SGUs well archive, Brunnsarkivet) /SGU, 2005/. There are also areas, especially in the south-western part of the regional model area, which are characterised by a coherent, probably relatively thick, till cover and few bedrock outcrops.

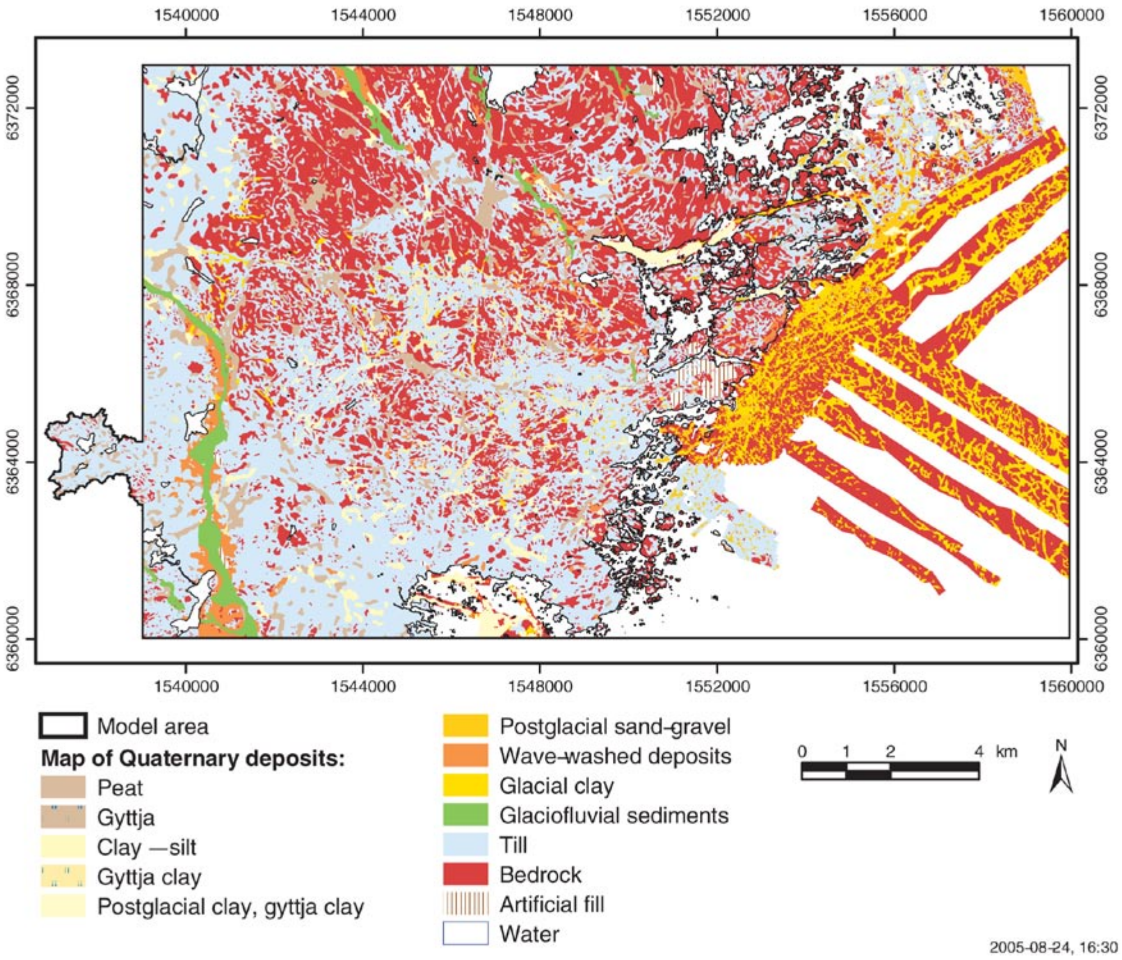

Figure 3-4. *Map showing the distribution of the Quaternary deposits in the Simpevarp area /Rudmark et al. 2005; Ingvarson et al. 2004; Elhammer and Sandkvist, 2005/.*

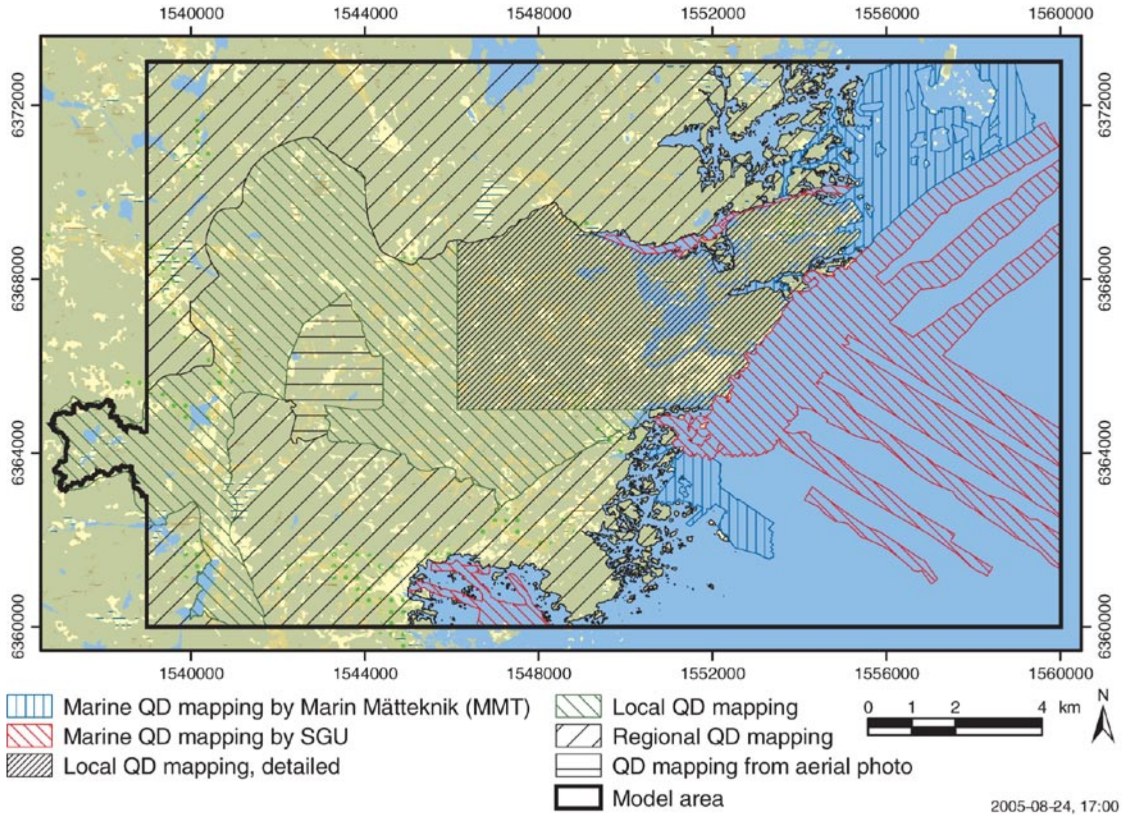

Figure 3-5. *Map showing the different QD mapping methods used in the Simpevarp area. All mapping, except from the marine mapping from MMT /Ingvarson et al. 2004/, is made by SGU /Rudmark et al. 2005; Elhammer and Sandkvist, 2005/.*

The QD in the Simpevarp area have the same stratigraphy as commonly occur below the highest coastline in other parts of Sweden. The following general stratigraphy was observed from the ground surface: peat, gyttja clay, sand, clay and till (Table 3-3). There are, however exceptions from this stratigraphy. In the broad valley west of Mederhult, three metre of sand was observed in between the clay and till. This sand layer may be of importance for the hydrological modelling of the area /SKB, 2005/.

Table 3-3. The stratigraphical distribution of QD in the Simpevarp regional model area.

Quaternary deposit	Relative age
Bog peat	Youngest
Fen peat	↑
Gyttja clay/clay gyttja	
Sand/gravel	↑
Glacial clay	
Till	↑
Bedrock	Oldest

4 Execution

The model has been built up and evaluated using the GeoEditor /DHI Water & Environment, 2001/. For the interpolation and some adjustments of the surfaces, tools in ArcGIS8 have also been used.

4.1 Conceptual model

4.1.1 Geological classes in the model area

The model is based on six layers where each layer is assumed to have similar geological and hydrological characteristics. The hydrological properties are described in /Werner et al. 2005/. The uppermost layer, Z1, is covering the whole area except from peat areas. Peat areas are not covered by Z1 since the total average depth for peat areas are thinner than Z1 and therefore are modelled as M1. Z1 is characterized by the impact from surface processes, such as roots and biological activity. The bottom layer, Z3, is characterized by contact with the bedrock and is corresponding to a till layer. The middle layer, Z2 is corresponding to a clay layer. Besides those layers, another three layer are also modelled; M1 corresponds to a peat layer, M2 answers to a glaciofluvial sediment layer and M3 corresponds to a layer with artificial fill. All layers can have thickness zero.

The principle for the definition of the six layers is illustrated in Figure 4-1. Observe that the layer thicknesses are shown in a principle way in the figure. It should also be noted that the layers are constructed in the model and does not represent real/actual stratigraphical units.

In the data files used by GeoEditor, a simplified code is used for each geological unit. The codes for each deposit according to the six layers are shown in Table 4-1.

4.1.2 Stratigraphy classes for observation points

The detailed stratigraphy classes and simplified codes for the observation points used in the model are shown in Table 4-2. Combinations of the classes and codes exist. This detailed information has not been used in the creation of the layers, but is shown as additional information.

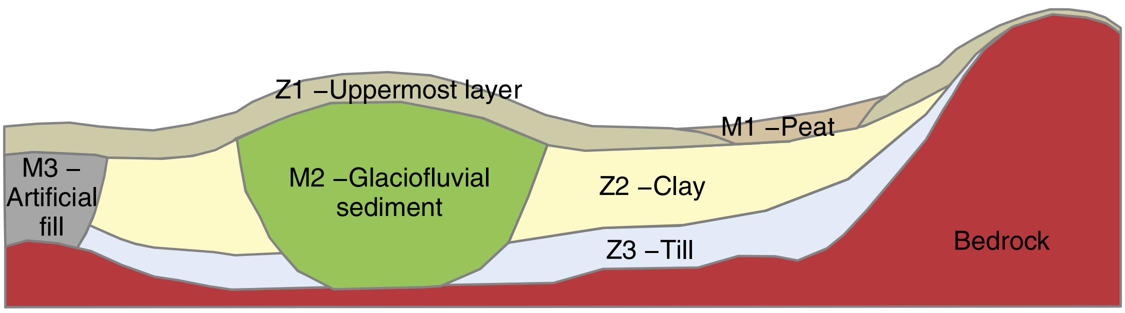

***Figure 4-1.** Conceptual model of the QD depth model. The principle of the six layers modelled in the area.*

Table 4-1. Deposits, simplified codes and occurrence for the six layers.

Deposit	Simplified code	Occurrence
Surface process affected layer	Z1	Exists in the whole area, except from peat areas.
Middle layer (clay layer)	Z2	Only exists where the map of Quaternary deposit shows peat, glacial/postglacial clay or postglacial sand-gravel at the surface.
Bottom layer (till layer)	Z3	Exists in the whole area, except where the map of Quaternary deposit shows bedrock, glaciofluvial sediment or artificial fill at the surface.
Peat layer	M1	Exists only where the map of Quaternary deposit shows peat at the surface.
Glaciofluvial sediment layer	M2	Exists only where the map of Quaternary deposit shows glaciofluvial sediment at the surface.
Artificial fill layer	M3	Exists only where the map of Quaternary deposit shows artificial fill at the surface.

Table 4-2. Deposit and simplified code for the detailed stratigraphy.

Quaternary deposit	Simplified code
Bog (peat)	B
Fen (peat)	F
Peat	Pe
Gyttja	Gy
Clay	Cl
Silt	Si
Sand	Sa
Gravel	Gr
Till	Ti
Stones	St
Boulder	Bo
Rock	Ro
Sediment	Sed
Calcareous	Calc
Material	Mtr
Fluvial	Fl
Fine	Fi
Glacial	Gl
Glaciofluvial	GlF
Postglacial	Po
Not known (QD)	NoKo

4.2 Data handling

Each observation point within the area has, regardless of the method for data collection, been handled as a borehole in the model approach. This means that coordinates, ID, method, surface elevation and stratigraphy has been set to each point. Additional information has been set to the observation points where it is available in input data, such as depth of observation.

The flow chart in Figure 4-2 shows how the model is constructed. Each step is also described later on in this chapter.

4.2.1 Data files

The information from each observation point is stored in two databases in dbf4-format. One database contains administrative information such as observation ID, surface elevation, observation method, x- and y-coordinate and observation depth. The second database contains the stratigraphy of each observation. The databases are imported to and interpreted in the GeoEditor. The databases are stored at SKB's GIS database /SDEADM.POS_SM_GEO_2594; SDEADM.POS_SM_GEO_2595/.

4.2.2 Elevation of boreholes and other data

A number of observation points lack surface elevation. They were therefore given surface elevations manually through the DEM of the topography. This had to be done for the observation points, seismic and sediment echo sounding data, electric soundings and some boreholes. The elevation of each borehole and other observation points are stored at SKB's GIS-database /SDEADM.POS_SM_GEO_2594/, under the column KOTE.

4.2.3 Average values for depth of Quaternary deposits

Since there are large parts of the modelling area without any observation points or only few observation points, the model is built up mostly from average values of different deposits, calculated from input data. The average values are then assigned to different areas in the model in relation to the map of QD. Table 4-3 shows the average values applied to the model.

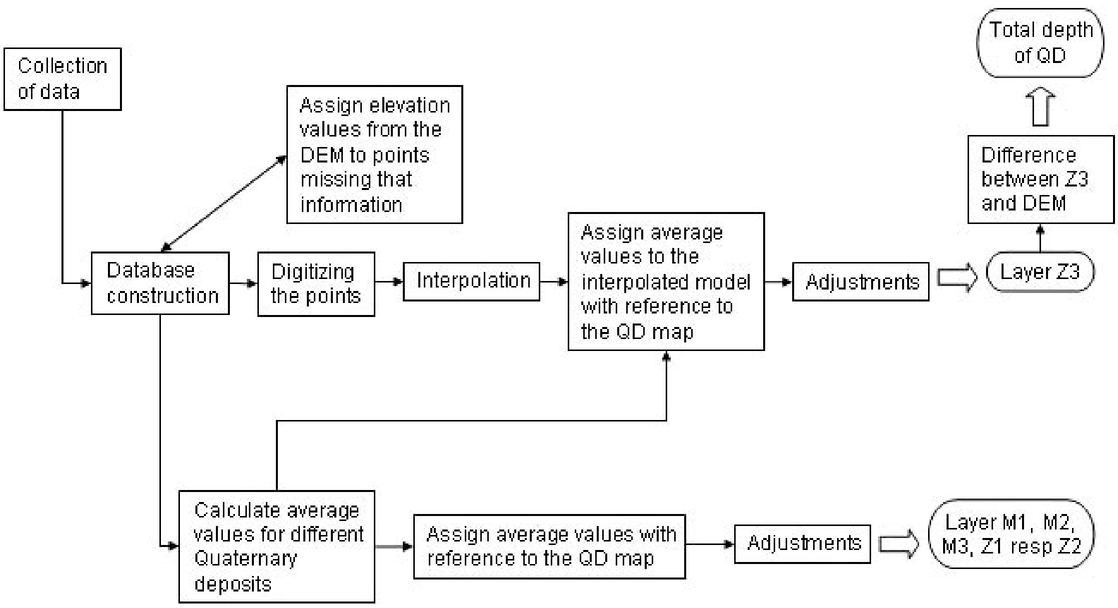

Figure 4-2. *Flow chart of the data handling.*

Table 4-3. Average values for depth of different QD in the Simpevarp area.

Quaternary deposit/area	Average value of depth (m)	Standard deviation of average value of depth (m)	Average value of total QD depth (m)	Source for calculationg average values
Peat	0.9	± 0.5	8.3	/Rudmark et al. 2005/
Glaciofluvial sediment (near Fårbo)	15	To small data set for calculating standard deviation	15	Assumed from /SGU, 2005/
Glaciofluvial sediment (other)	5	To small data set for calculating standard deviation	5	Assumed from /SGU, 2005/
Artifical fill	4	–	4	Assumed from site characerisation
Glacial clay	2.6	± 2.3	6.2	/Elhammer and Sandkvist, 2005/
Postglacial clay, including lakes and some bays	1.2	± 0.8	7.4	/Elhammer and Sandkvist, 2005/
Till (on land)	2	–	2	Assumed from site characerisation
Till (in the sea)	1	–	1	Assumed from site characerisation
Till (covered by clay/peat)	3.6	± 2.6	Depending on the covered QD	/Elhammer and Sandkvist, 2005/
Sea (not included by the maps of Quaternary deposits)	–	–	1.2	/Elhammer and Sandkvist, 2005/

4.3 Creating the bedrock surface (lower level of the Z3 layer)

4.3.1 Digitizing of points at bedrock surface

When defining a geological layer in the model, a point theme having the same name as the layer is generated. Digitized points describing the lower level of the layer are saved to the point theme. This will enable the user to see the horizontal location of the discrete values while these are digitised in the vertical view.

Since the geological layers can be defined differently from the stratigraphy defined in each borehole or observation, discrete points describing the lower level of each geological layer must be digitized manually. This also enables the user to digitize additional points, separate from the ones defined in boreholes and observations, which can be used in interpolation of layer surfaces. This also means that vertical profiles shows the actual stratigraphy in observation points that are more detailed than the modelled layer.

When digitizing discrete points in the Simpevarp model area, 135 profiles have been made from which the bedrock surface has been digitized. The profiles have been defined in order to cover all observation points and are shown in Figure 4-3.

No free digitizing (e.g. manually interpreted points) has been made for the overall QD depth; each discrete point has a reference in input data and observations. Both observations with estimated depth to the bedrock surface and shallower observation points have been used for the overall model.

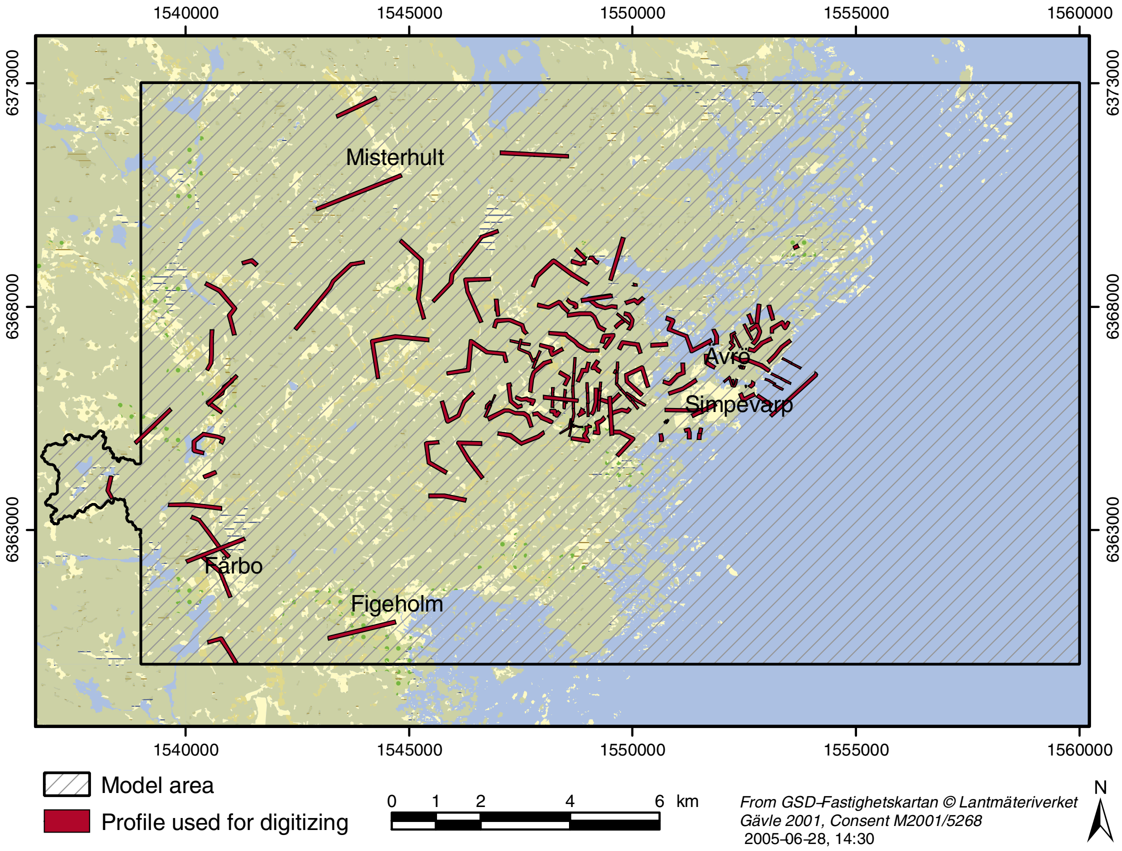

Figure 4-3. *Profiles covering all input data points used for digitizing the Z3 lower layer surface.*

In order to take areas of bedrock outcrop into account, the polygons describing bedrock in the map of QD on land were converted into points and elevations were assigned from the DEM. These points were added to the layer with digitized discrete points and used in the interpolation. For the same reason the seismic and sediment echo sounding data were added to the layer with digitized discrete points and used in the interpolation. These points were also assigned elevations from the DEM.

4.3.2 Interpolation of bedrock surface

The interpolated grid describing the bedrock surface elevation (the same as lower level of the Z3 layer) has a resolution of 10 m over an area of about 270 km^2. The model origin, grid size and model extension are shown in Table 4-4 and are valid for all grids in the resulting model.

The interpolation method used is Natural Neighbour. Since this method does not exist in the GeoEditor, the interpolation was done in ArcGIS8 with the extension 3D-Analyst.

Natural Neighbour is a weighted-average interpolation method. The interpolation creates a Delauney Triangulation of the input points and selects the closest nodes that form a convex hull around the interpolation point, then weights their values by proportionate area. This method is appropriate where sample data points are distributed with uneven density. It is a good general-purpose interpolation technique and has the advantage that you do not have to specify parameters such as radius, number of neighbours, or weights.

Table 4-4. Origin and extension of model grids.

Description	Value
Origin, x-coordinate (RT90 2.5 gon V)	1,536,785
Origin, y-coordinate (RT90 2.5 gon V)	6,359,995
Cell size of model grid	10 m
Number of cells in x-direction (east-west)	2,321
Number of cells in y-direction (north-south)	1,300

4.3.3 Adjustment of interpolated surface

Primary adjustments are:

- Adjust bedrock surface not to exceed topography.
- Adjust bedrock surface to at least correspond to average values of QD depths.
- Assign average values in areas where QD map is lacking.
- Ensure a Z1 depth of 0.1 m at bedrock outcrops.

The first adjustment was with respect to the topography, e.g. the bedrock elevation was corrected not to exceed the topography at any point. The problem occurs when the measured elevation at an observation point exceeds the interpolated DEM. In the same way, the total QD depth can be overestimated in cases when the measured elevation of an observation point is lower than the DEM. No adjustment has been made for the overestimated QD depths since the bedrock elevation is set to the correct measured elevation.

The second adjustment was made because most areas have a very low data density. The interpolation showed a total QD depth less than 0.5 metres in some areas where the map of Quaternary deposits showed a layer thickness of at least 0.5 m. Therefore the QD depth was adjusted down to average values (see Table 4-3) in the whole model area. This means that even if there exists an observation saying that the QD depth is less than the average value, the average value is used. On the other hand, in some areas observation points have made the QD depth larger than the average values, and in those cases the observed QD depth is kept in the model.

In large parts of the sea area there are no observation points, no map of Quaternary deposits and the DEM is less reliable than in other areas. In sea areas a total QD depth of 1.2 m is used. This means that the lower level of Z3 was corrected to have that depth in those areas. This average depth is calculated from the result of the interpolation in the sea area where SGU have made dense seismic and sediment echo sounding investigations.

An adjustment was also made to ensure a Z1 depth of 0.1 m in areas where the map of Quaternary deposits showed bedrock (this was included by discrete points in the interpolation but was adjusted to be exactly 0.1 m in areas where the interpolation showed a slightly smaller or larger Z1 depth). This thin layer on bedrock outcrops correspond to organic material that can affect the hydrology in the area.

Finally, the Z3 layer was clipped to just contain values inside the model area boundary. The adjustments were almost exclusively made in ArcGIS8, with the extension Spatial Analyst. The resulting minimum layer thickness is shown in Table 4-5.

Table 4-5. The resulting minimum layer thickness of Z3 in the model for different types of QD.

Quaternary deposit/area	QD depth on land (m)	QD depth at sea (m)
Peat/Glacial clay/postglacial sand/postglacial gravel/postglacial clay/lakes	3.6	3.6
Till	1.0	0.5
Glaciofluvial sediment	0.0	0.0
Artificial fill	0.0	0.0
Bedrock outcrop	0.0	0.0
Other (unknown area at sea)	–	0.7

4.4 Creating the lower level of the M1, M2 and M3 layer

M1, M2 and M3 just exist in areas of peat, glaciofluvial sediment and artificial fill. The M3 layer is exclusively made out of estimated values for the depth of the deposits (Table 4-6) and M1 and M2 are made out of average values, instead of interpolated from observation points.

Starting from the map of QD, converted into raster format with the same grid size and origin as the DEM, the cells corresponding to peat where selected in the DEM and lowered 0.9 m to create the lower level of the M1 layer. The rest of the cells kept the same value as the DEM, which gives the layer no thickness in those cells.

In the same way were all cells corresponding to glaciofluvial sediment selected and the elevation in those cells where lowered 5 and 15 m respectively, to create the lower level of the M2 layer. For creating the lower level of M3, all cells corresponding to artificial fill were lowered 4 m.

Finally the M1, M2 and M3 grids were cut to just contain values inside the model area boundary. The three grids were exclusively created in ArcGIS8, with the extension Spatial Analyst but some adjustments were made in the GeoEditor.

4.5 Creating the lower level of the Z1 and Z2 layer

4.5.1 Z1

Z1 is covering the whole model area, except peat areas where it has no thickness. On bedrock outcrops Z1 has a depth of 0.1 m, at the sea 0.5 m and on other areas on land 1 m (Table 4-7). Z1 is in other words not created from observations but from estimated values.

Starting from the map of QD, converted into raster format, cells corresponding to bedrock where selected in the DEM and lowered 0.1 m. Cells in the sea that are not corresponding to bedrock was lowered 0.5 m compared to the DEM and the rest of the cells where lowered 1 m to create the lower level of the Z1 layer.

Then the lower level of Z1 is adjusted not to exceed the lower level of M1 (peat layer) at any point.

4.5.2 Z2

Z2 only exists in areas where the map of QD does not show bedrock outcrop, till, artificial fill or glaciofluvial sediments. Z2 is built up from average values of clay depth, and not at all from observations (Table 4-8).

Starting from the map of QD, converted into raster format, cells corresponding to peat where selected in the Z1 layer and lowered 3.8 m to create the lower level of Z2. Cells corresponding to glacial clay was lowered 1.6 m, cells that answer to postglacial clay and lakes was lowered 2.8 m. All other cells kept the Z1 value, which means in those areas Z2 does not exist. Consequently areas with postglacial clay at the surface have in the model a total depth that is 1.2 m larger than areas with glacial clay at the surface.

In the area where SGU has made seismic and sediment echo sounding investigations the same average values for Z2 has been used. But since this area has not been adjusted to average values in the Z3 layer, the lower level of the Z2 layer has to be corrected. Otherwise Z2 will fall below the lower level of the Z3 layer and then lie directly on the bedrock, which is inaccurate. The Z2 layer must also be adjusted so that the Z3 has a thickness of at least 1 m and that the Z2 lower level not exceeds the Z1 lower level.

Finally both the Z1 and Z2 grids were cut to just contain values inside the model area boundary. The two layers were exclusively created in ArcGIS8, with the extension Spatial Analyst but some adjustments were made in the GeoEditor.

Table 4-6. Layer thickness of M1, M2 and M3 in the model.

Layer	QD depth on land (m)	QD depth at sea (m)
M1	0.9	–
M2	5.0/15.0	–
M3	4.0	–

Table 4-7. Layer thickness of Z1 in the model for different types of QD.

Quaternary deposit/area	QD depth on land (m)	QD depth at sea (m)
Peat	0.0	–
Bedrock outcrop	0.1	0.1
Lake	0.5	–
Other	1.0	0.5

Table 4-8. Layer thickness of Z2 in the model for different types of QD.

Quaternary deposit/area	QD depth on land (m)	QD depth at sea (m)
Peat	3.8	3.8
Glacial clay	1.6	1.6
Postglacial clay/lakes	2.8	2.8
Till	0.0	0.0
Glaciofluvial sediment	0.0	0.0
Artificial fill	0.0	0.0
Bedrock outcrop	0.0	0.0
Other (unknown area at sea)	–	0.0

5 Results

The average and median QD depth of the interpolated and adjusted model is shown in Table 5-1. Table 5-2 below shows the average value and median QD depth, based on input data from the different data sources. Generally, input data shows higher average and median QD depths than those derived from the interpolated results that are affected by areas of bedrock outcrop (i.e. a QD depth of 0.1 m). The reason for this is that the observations have been done at sites with large deposits depth. On the other hand, the average QD depth from the model excluding bedrock outcrops agree approximately with the average values from the input data.

In the near coastal area where SGU has made marine geological mapping (Figure 3-2) and in the bay Granholmsfjärden, Z3 can have a thinner thickness than what is specified in Table 4-5 since no average value adjustment of the Z3 layer is done in these areas. The interpolated bedrock elevation is preserved in this area and can therefore lie closer to the ground elevation in some areas. That is also valid for the Z2 layer in this area. The average values are used to set the thickness for Z2 in this area, just as it is in the whole model. But since the interpolated bedrock elevation is preserved in this area and therefore can lie closer to the ground elevation than the average values, Z2 in some areas have been adjusted to have a thinner thickness than the average values in Table 4-8.

The maximum QD depth in the model is about 50 m, in the bay Getbergsfjärden.

Table 5-1. Average and median QD depth calculated from the interpolated and adjusted model.

Type of data	Average QD depth (m)	Standard deviation of average QD depth (m)	Median QD depth (m)
Whole model (including bedrock outcrops)	2.1	2.7	1.2
Whole model except bedrock outcrops	3.0	2.8	2.0

Table 5-2. Average and median QD depth calculated from different sources of input data.

Type of data	Number of observations	Average QD depth (m)	Median QD depth (m)
Refraction seismic data	1,087	3.9	2.9
Electrical soundings (VES)	22	1.8	0.6
Point observation	328	2.1	1.5
Borehole	102	2.5	2.3
Seismic and sediment echo sounding data	19,237	2.8	2.2
Total	20,776	2.8	2.2

The northern and central parts of the model area are dominated by bedrock outcrops. In the south eastern part, the QD depth is generally higher. This is due to few bedrock outcrops and a large esker (Tunaåsen).

In large parts of the sea area there are no observation points and no QD data available. In these areas the value 1.2 m have been used as total QD depth. This average depth value is calculated from the result of the interpolation in the near costal sea areas where SGU have made seismic and sediment echo sounding investigations /Elhammer and Sandkvist, 2005/.

The QD depth model is probably most reliably in the area where SGU have made the seismic and sediment echo sounding investigations. In this area the density of observation points is very high and no average values for the total QD depth are therefore applied. Figure 5-1 and 5-2 show the total modelled QD depth in the whole model area and in the central area respectively.

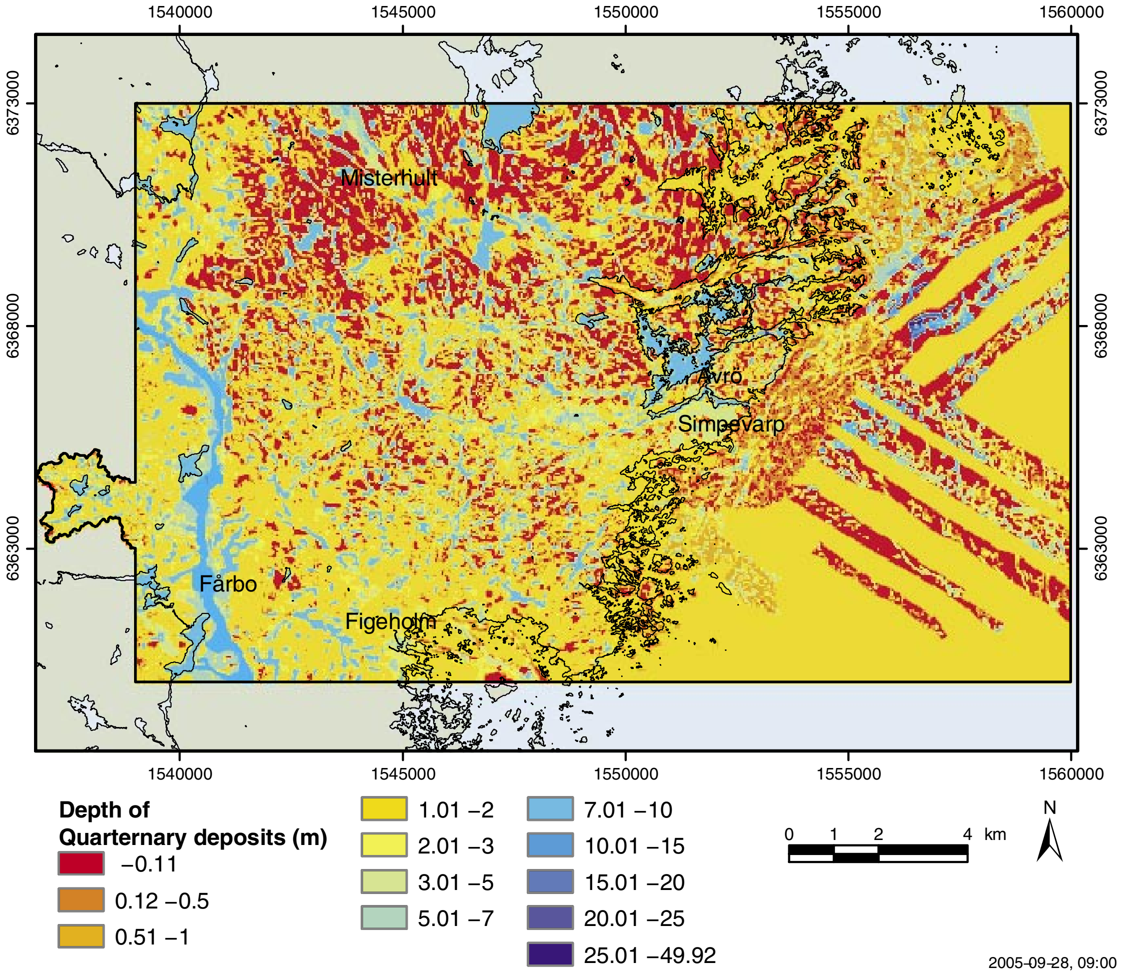

Figure 5-1. *Total modelled QD depth.*

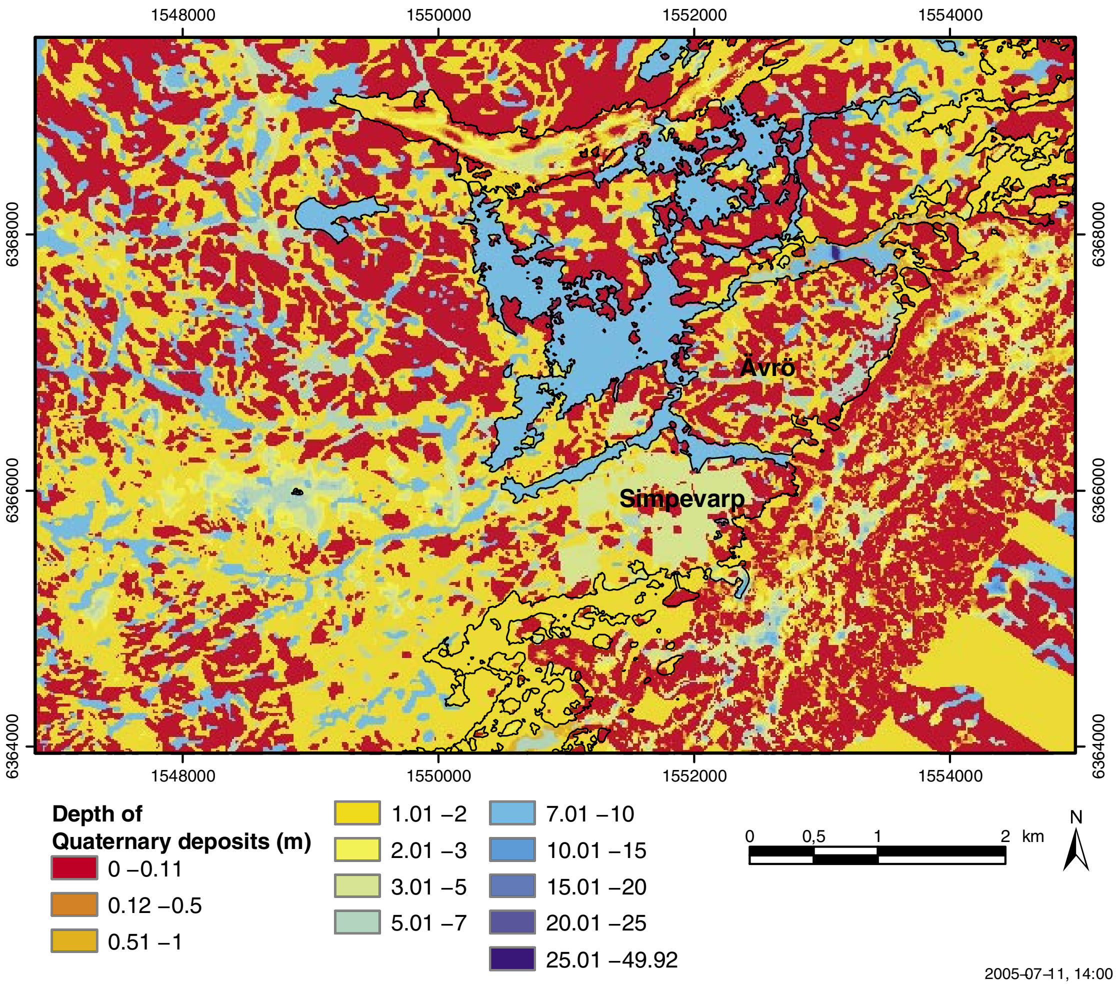

Figure 5-2. Total modelled QD depth in the central area.

5.1 Resulting files

Since bathymetry in areas deeper than –6 m is classified as strictly secret, the lower level layer resulting files are delivered to SKB in two ways. One set of data is cut to just contain information that is classified as free, that means areas that in the DEM lies above –6 m below sea level. This dataset is to be found in the SKB's GIS database /SDEADM.POS_SM_GEO_2656 to SDEADM.POS_SM_GEO_2661/. The other data set contains information for the whole model area and therefore stored in a safe at Äspö Hard Rock Laboratory /Media ID C097/.

The grid for the total depth of QD is not secret and a data set containing data for the whole model area is therefore to be found in the SKB's GIS database /SDEADM.POS_SM_GEO_2655/.

5.2 Profiles

A number of vertical profiles within the model area are presented in this chapter and Appendix 3, the horizontal views of the profiles are shown in Figure 5-3. To generate the vertical profiles the GeoEditor tool is needed.

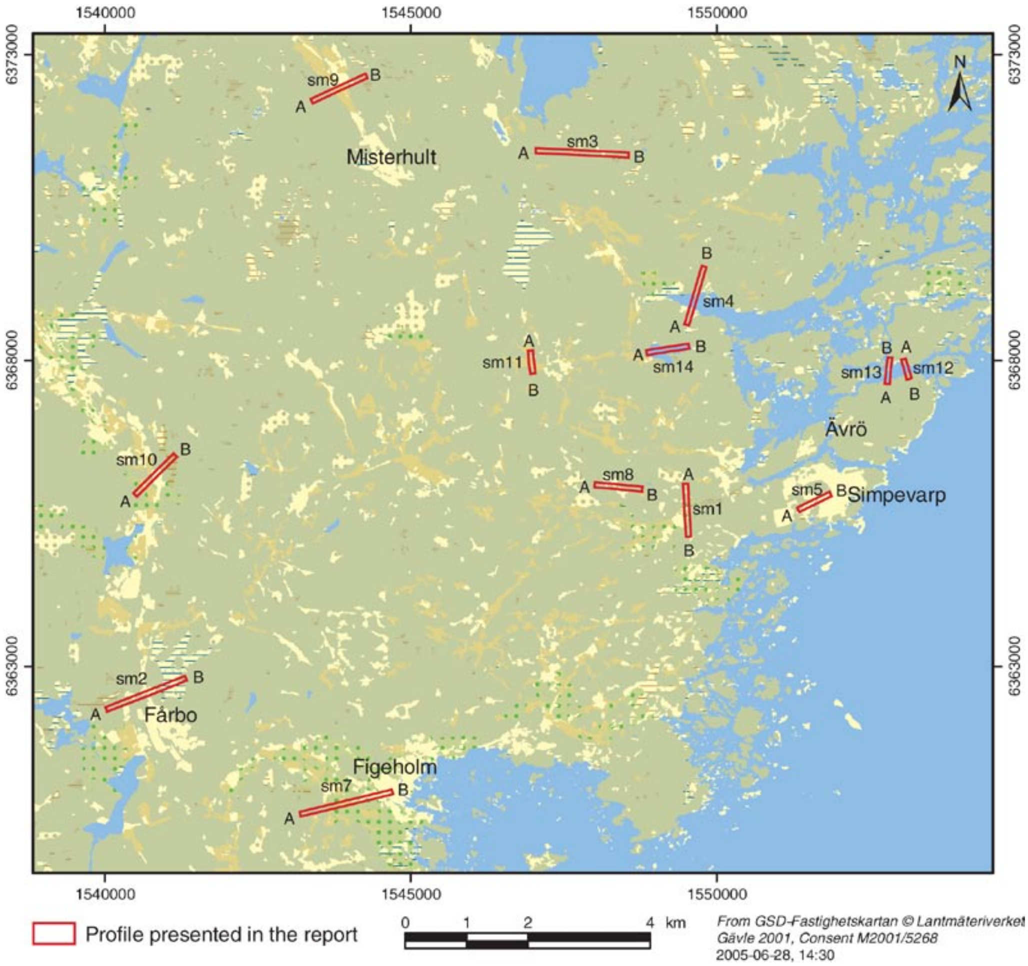

Figure 5-3. *Profiles from which model results are shown in the report. The names of general profiles refer to names of profiles shown in chapter 5.2 and Appendix 3. The labels A–B show the direction of the profile and can be found above the illustrated vertical profiles in Figure 5-4, Figure 5-5 and Appendix 3.*

It should be noted that the profiles are drawn along manually defined lines, in the centre of each profile in Figure 5-3, from which the modelled QD depth in each model grid point is illustrated. The profiles also show all observation points that fall within a 40 m band width of the profile projection line. This means that boreholes and observation points situated up to 20 m from the projection line in either direction, where the topography and layer elevations are illustrated, will be included. In some illustrated profiles, the elevations of observation points and depths of geological units may therefore differ from the modelled layers displayed in the profiles.

Figures 5-4 and 5-5 show typical profiles through the area. In Appendix 3, additional profiles are presented. The extension of the profiles are shown in the horizontal view, and also in Figure 5-3 in a smaller scale. Each profile is also marked with A–B to show the direction. The observation points are included in the illustrated profile and the distance from each point to the projection line is presented above each interpreted profile. The formations are listed in the legend but are also represented within each interpreted profile.

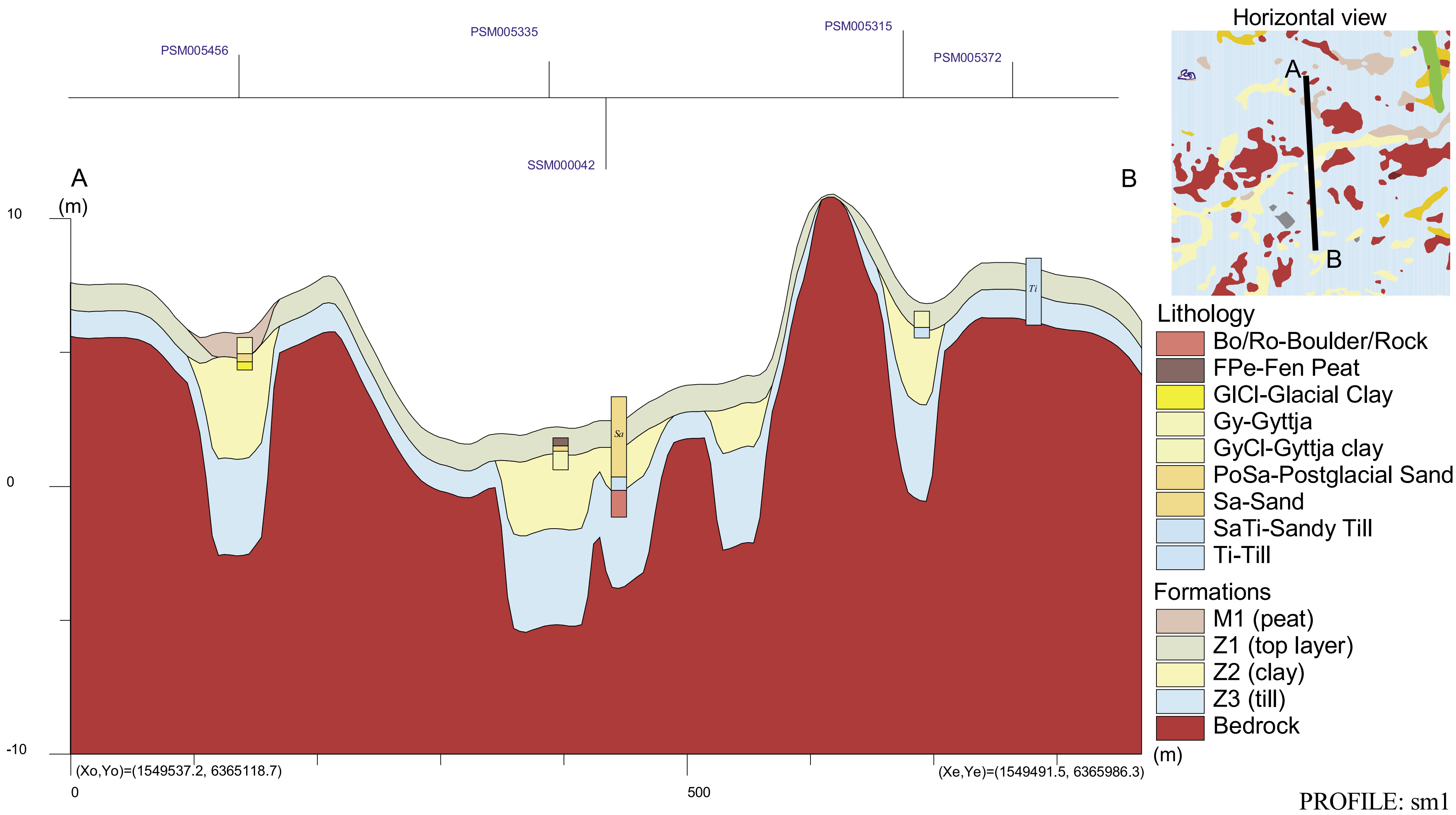

Figure 5-4. *Formations of M1, Z1–Z3 and total QD depth along profile sm 1 in Simpevarp. The observation points included are displayed above the profile. For location of the profile, see Figure 5-3.*

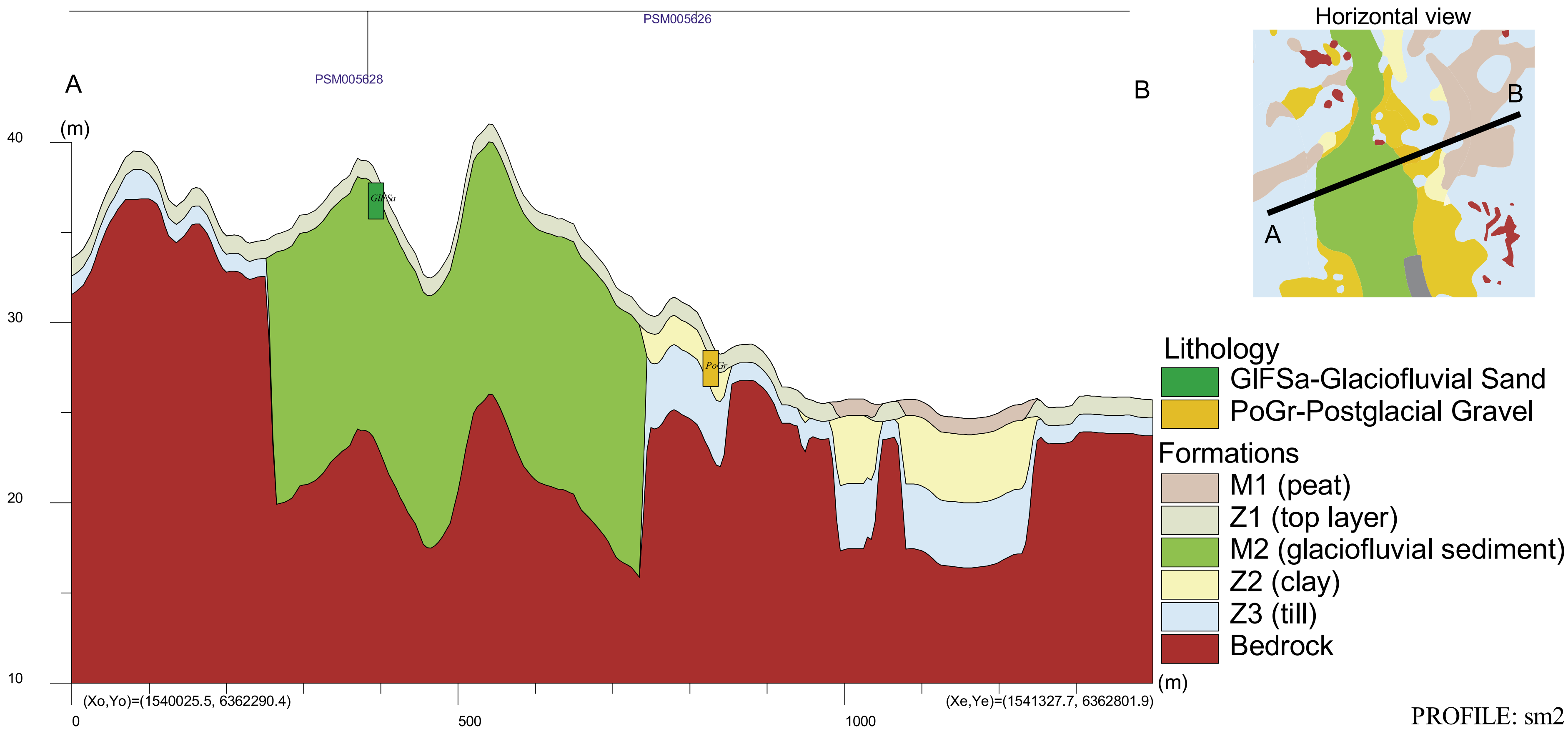

Figure 5-5. *Formations of M1, M2, Z1–Z3 and total QD depth along profile sm 2 in Simpevarp. The observation points included are displayed above the profile. For location of the profile, see Figure 5-3.*

6 Summary and discussion

The resulting model clearly shows the valleys with thicker QD depths, surrounded by areas with thinner or absent QD depths. The esker in the south-western part of the model area (Tunaåsen) is also distinctly marked. The northern part is characterized by numerous of bedrock outcrops.

The maximum QD depth in the model is about 50 m, in the bay Getbergsfjärden, and the average QD depth in model is 2.1 m (outcrops included). The modelled average QD depth is affected from areas with bedrock outcrop and from the average values adjustment that have been done and are included in the calculation. The total average QD depth calculated directly from input point data is 2.8 m. That is more comparable with the average QD depth of 3.0 m, calculated from the model when bedrock outcrops are excluded.

It should be noted that the model consists mainly of average values, which in most cases are calculated from observation points in the marine areas. The only area that is not at all affected by average values is the area where SGU have made detailed seismic and sediment echo sounding investigations (see Figure 3-2). In most parts of the sea areas there are no data available. In these areas the value 1.2 m has been used as total QD depth. That QD depth is divided into 0.5 m for the Z1 layer and 0.7 m for Z3. This means that the model contains no Z2 in these areas, and neither any bedrock outcrops.

6.1 Uncertainties and further developement of the model

6.1.1 Primary uncertainties

- The model use a simplified layer model.
- The data density is unevenly distributed over the area.
- Some observations are shallow and do not include depth to bedrock.
- There are differences between elevations in observation points and in the DEM.

It should be noted that the model presented in this report is a first simplified model version of the Simpevarp site where some generalisations have been necessary. The simplifications mainly consist of the definition of the three main layers where a more detailed resolution of formations may be applied. As the model develops further, the uncertainties and simplifications can be reduced.

The data density is shown in Figure 3-3. Sites where the bedrock surface has not been reached and areas of a generally low data density have the highest uncertainty.

The topographical DEM is very detailed but might be further improved by taking the measured elevation at each observation point into account when interpolating the DEM. This will reduce the number of points where the total QD depth is overestimated or where corrections have to be made to avoid layers above surface elevations. Overestimation of total QD depth can occur when the elevation of the observation is lower than the topography (which can appear in accurately surveyed observation points), as the layers are interpolated through fixed values in observation points and not in relation to surface elevations. In the same way the QD can be underestimated if the elevation in an observation point is higher than the topography.

6.1.2 Possible development

- Include more observation points.
- Incorporate manual digitizing.
- Improve model layer.
- Use measurements to interpolate the Z2 layer instead of using average values.

Improvement of the model can decrease the uncertainties. The first obvious improvement could be to include more observation points in the area, preferably deep enough to encounter the bedrock surface.

If manual digitizing was performed between observation points along profiles with poor data density the number of discrete point used in the interpolation of surfaces would increase, resulting in a better interpolation. Manual digitizing will give the option of manual interpretation of QD depth from other types of input data, such as estimation of areas with low respectively high QD depth, based on e.g. the QD at the surface or lineaments.

The geological formations used in the model (Z1, Z2 and Z3) may also be modified to ensure layers with correct geologic and hydraulic properties. For example, the layer affected by surface processes, vegetation and biological activity (Z1) might be thinner than one metre or Z2 could be divided into two layers (glacial and postglacial deposits).

In the area where SGU have made seismic and sediment echo sounding investigations it would be possible to use the result from the measurements to interpolate the Z2 layer instead of using average values like in this model.

6.2 Known errors in the model

- Wrong average QD depth for some watercourses.
- Possibly thinner clay depth in areas that lie higher above the present sea level.
- Larger QD depth in the southern part of the model area.
- The extrapolations in the sea sometimes give larger QD depth in between the transect lines than the actual measured QD depth along the lines.
- Small peat and clay areas probably have thinner QD depth than larger areas with the same QD.
- In the model the Z2 (clay) and Z3 layer (till) appear beneath the outer edge of the M2 layer, it should be the reverse relation.

In some areas (i.e. in the north-western part of the model area) the average QD depth for lakes (se Table 4-3) has also been used for watercourses, which might give a too large depth. In the next version of the model, the QD depth in the surroundings of the watercourse should be used.

It is possible (even probable) that the clay in general is thinner in the areas that lie higher above the present sea level. However, in this model the same average values for clay depth has been used in the whole model area.

In the model, the esker in Misterhult has a lower QD depth than the surrounding sand and clay areas. Since glaciofluvial sediment normally is thicker than surrounding deposits, the model is probably incorrect in this area i.e. the clay layers should most likely be thinner on this level above the sea.

The QD depth in the till areas in the bay south of Figeholm is less than in the land areas north of the bay. Possibly a larger QD depth should be used in this bay. Also, the area north and west of the bay have very few outcrops, which indicate that the QD depth may be larger than in the northern part of the model area.

In the outer part of the model area at the seaside, the seismic and sediment echo sounding investigations made by SGU only include a few transects with measured QD depths. The extrapolations made from these lines sometimes gives larger QD depth in between the lines than the actual measured QD depth along the lines. It might be possible to adjust this in the next version of the model.

The small peat and clay areas in the existing model have the same QD depth as the larger areas with the same deposits. Probably should a thinner QD depth be used for those smaller areas. The assumption in this model that all the peat areas are underlain by clay may also be wrong.

The appearance of the M2 layer (glaciofluvial sediment) in the model is not fully reliable. In the model, the Z2 (clay) and Z3 layer (till) appear beneath the outer edge of the M2 layer (see Figure 4-1 and Figure A3-5). In reality it may rather be the reverse relation.

6.3 Further use of the model

The databases and model can be updated when more data is available. The model presented in this report is a first version that can be further developed and thus more detailed.

The geological model can be used as a general description of the deposits in the area. Description of sediment layers and geological formations can be used in studies of for example biology, geochemistry and transport mechanisms. The model will be used as input for hydrogeological modelling.

A well built model is also an excellent tool for providing pedagogical presentation material of geological formations, as well as of other types of model results.

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Resulting data files stored in SKB's GIS-database.

Filename	Content of file	Reference
Admfil_laxemar	Administrative database of observations	SDEADM.POS_SM_GEO_2594
Litfil_laxemar	Stratigraphy database of observations	SDEADM.POS_SM_GEO_2595
ny_djup	Modelled total depth of Quaternary deposits	SDEADM.POS_SM_GEO_2655
ny_m1_kl	Modelled lower level of geological layer M1	SDEADM.POS_SM_GEO_2656
ny_m2_kl	Modelled lower level of geological layer M2	SDEADM.POS_SM_GEO_2657
ny_m3_kl	Modelled lower level of geological layer M3	SDEADM.POS_SM_GEO_2658
ny_z1_kl	Modelled lower level of geological layer Z1	SDEADM.POS_SM_GEO_2659
ny_z2_kl	Modelled lower level of geological layer Z2	SDEADM.POS_SM_GEO_2660
ny_z3_kl	Modelled lower level of geological layer Z3	SDEADM.POS_SM_GEO_2661

Resulting data files stored in SKB's archive at the Äspö Hard Rock Laboratory.

Filename	Content of file	Reference
ny_m1	Modelled lower level of geological layer M1	Media ID C097
ny_m2	Modelled lower level of geological layer M2	Media ID C097
ny_m3	Modelled lower level of geological layer M3	Media ID C097
ny_z1	Modelled lower level of geological layer Z1	Media ID C097
ny_z2	Modelled lower level of geological layer Z2	Media ID C097
ny_z3	Modelled lower level of geological layer Z3	Media ID C097

Appendix 1

Administrative database of observations

The administrative database used in the GeoEditor, admfil_laxemar.dbf, is stored in SKB's GIS-database /SDEADM.POS_SM_GEO_2594/.

Appendix 2

Stratigraphy database of observations

The stratigraphy database used in the GeoEditor, litfil_laxemar.dbf, is stored in SKB's GIS-database /SDEADM.POS_SM_GEO_2595/.

Profiles with interpreted geological layers

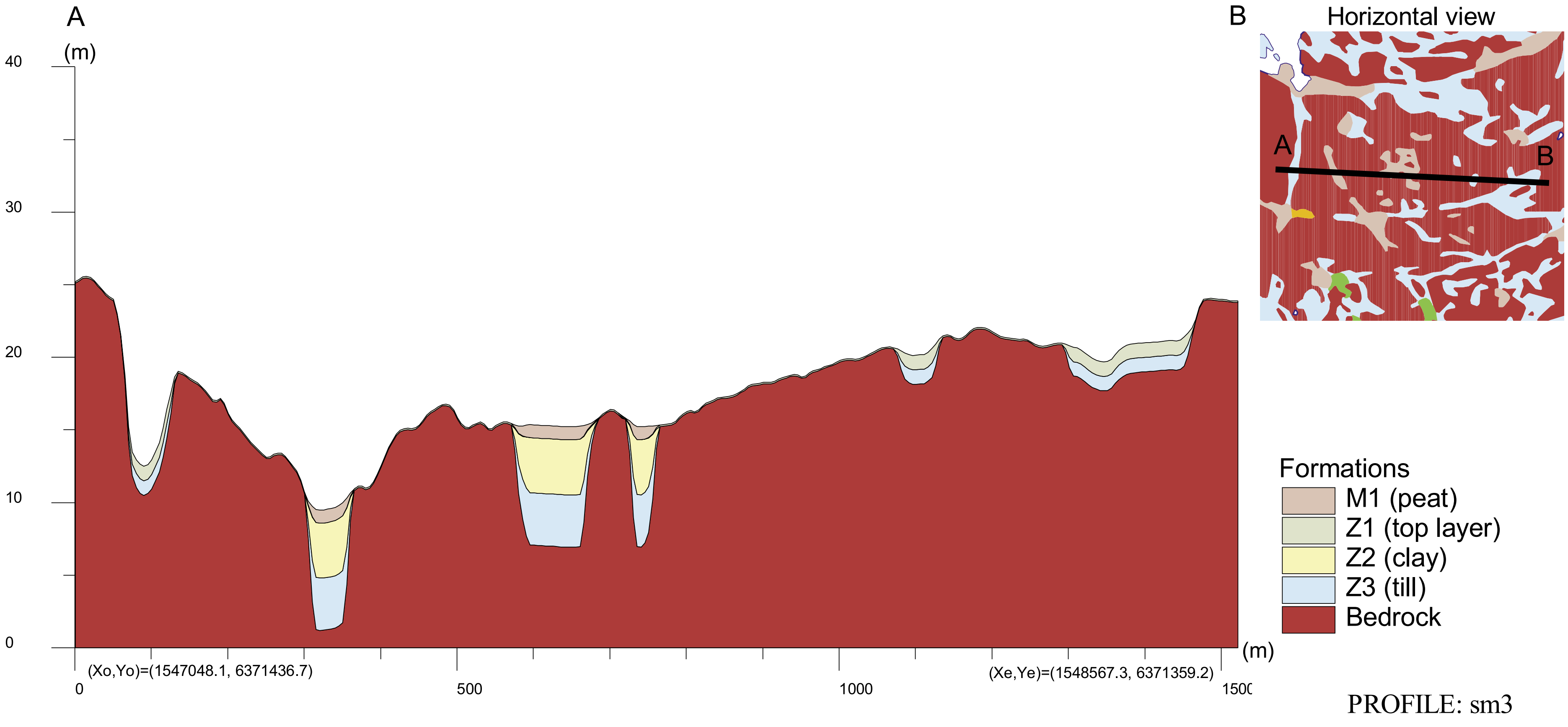


Figure A3-1. *Formations for profile sm 3. This profile does not include any observation points. For location of the profile, see Figure 5-2.*

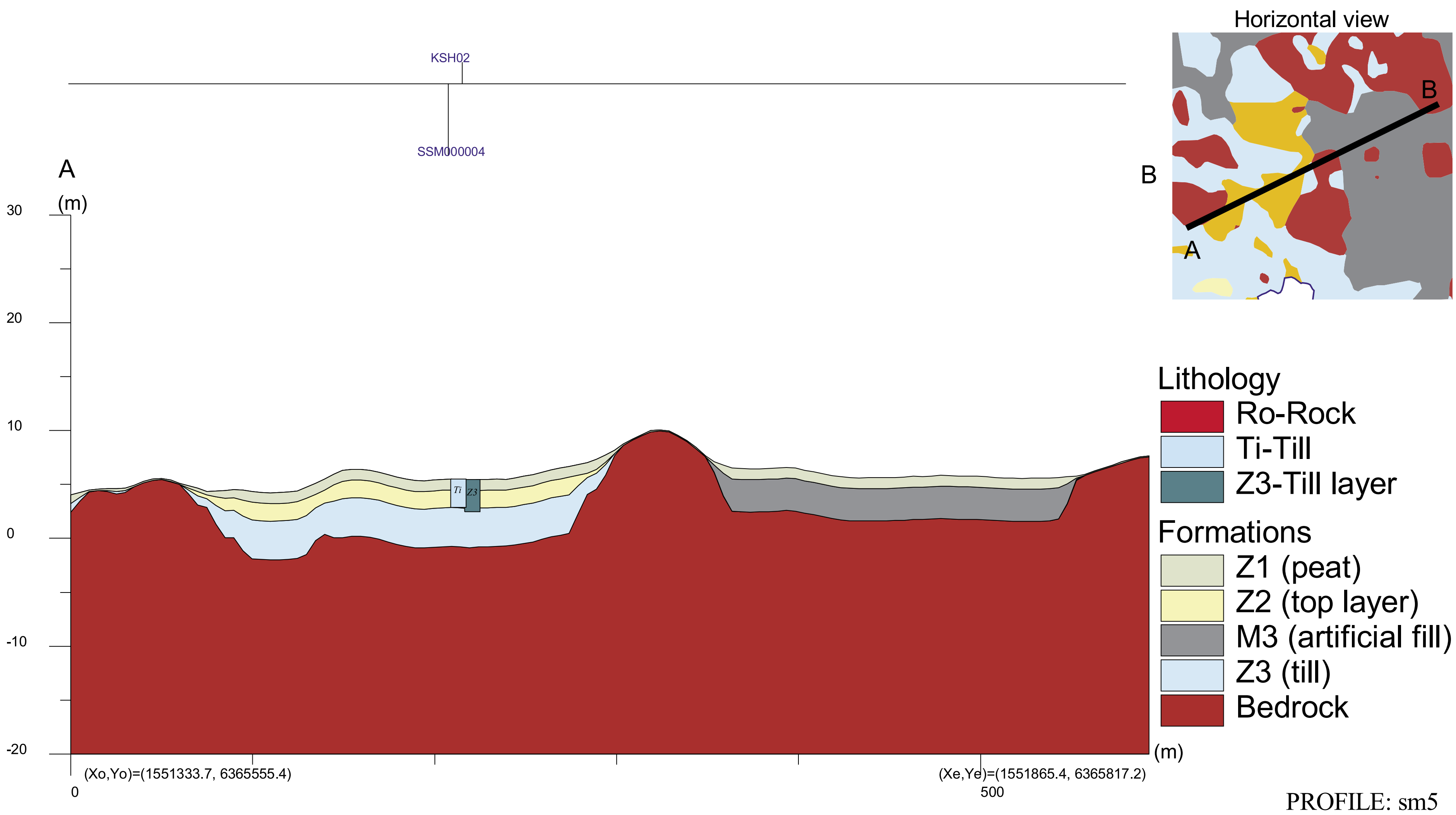


Figure A3-2. *Stratigraphy and formations for profile sm 5. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

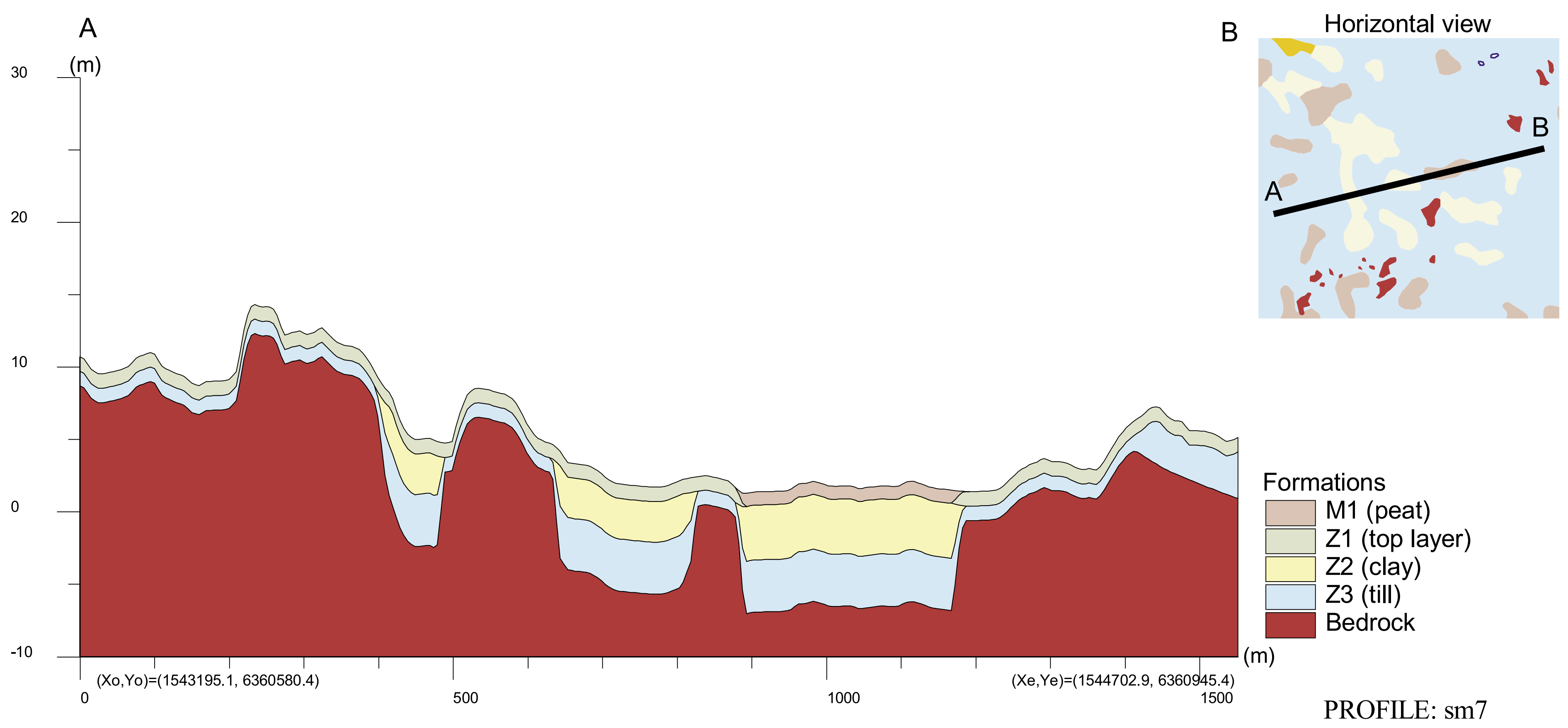
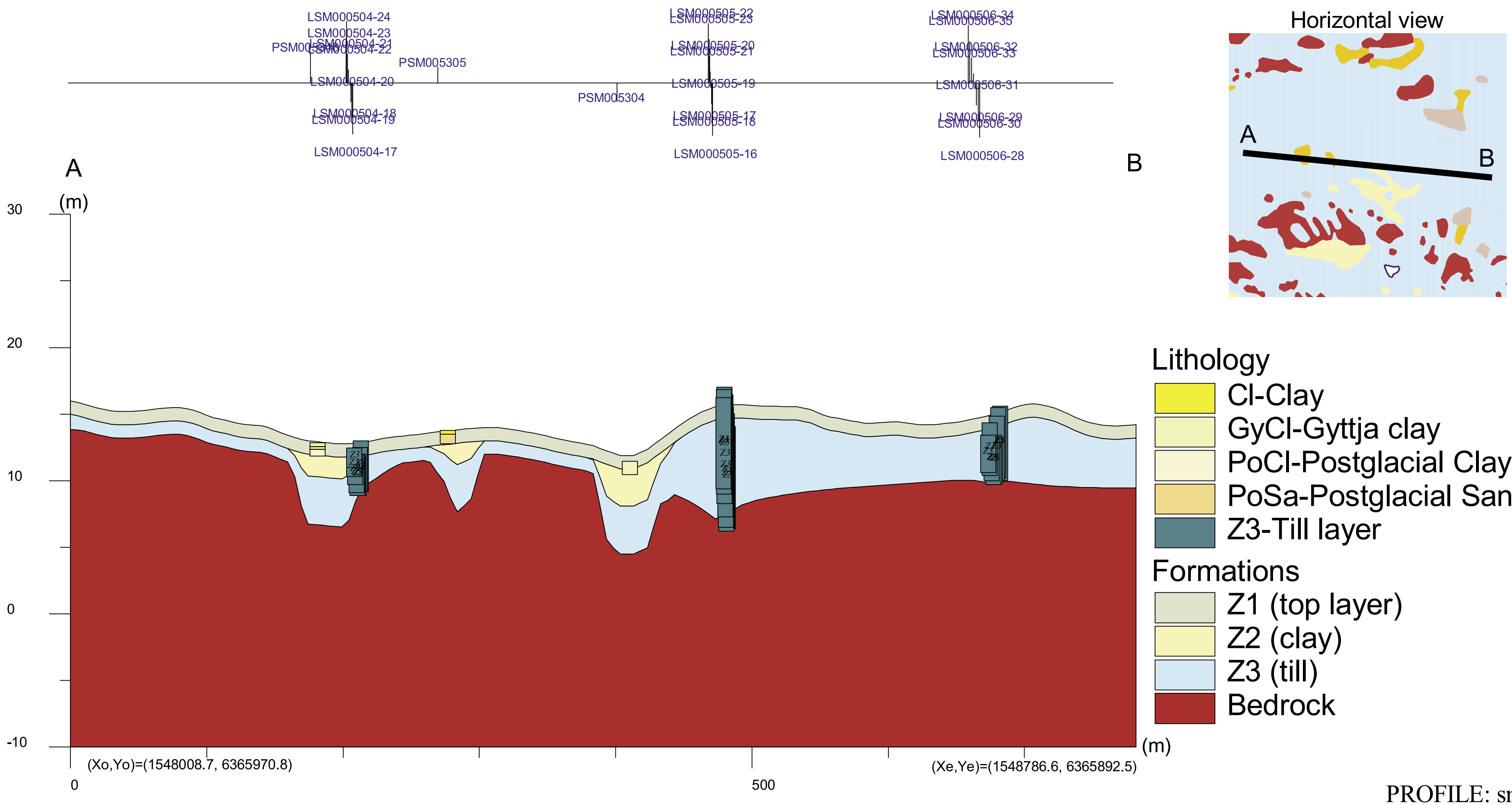


Figure A3-3. *Formations for profile sm 7. This profile does not include any observation points. For location of the profile, see Figure 5-2.*



PROFILE: sm8

Figure A3-4. *Stratigraphy and formations for profile sm 8. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

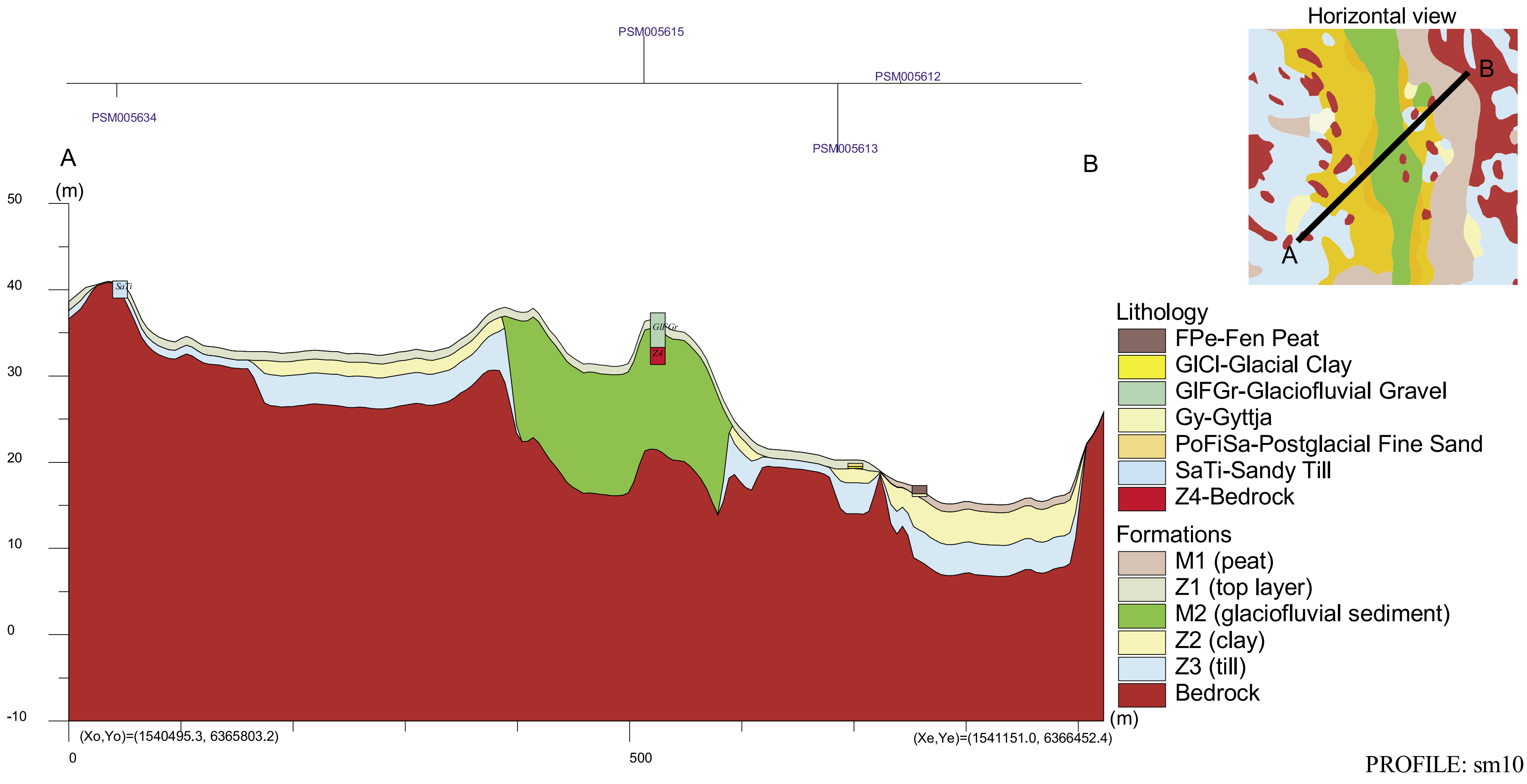


Figure A3-5. *Stratigraphy and formations for profile sm 10. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

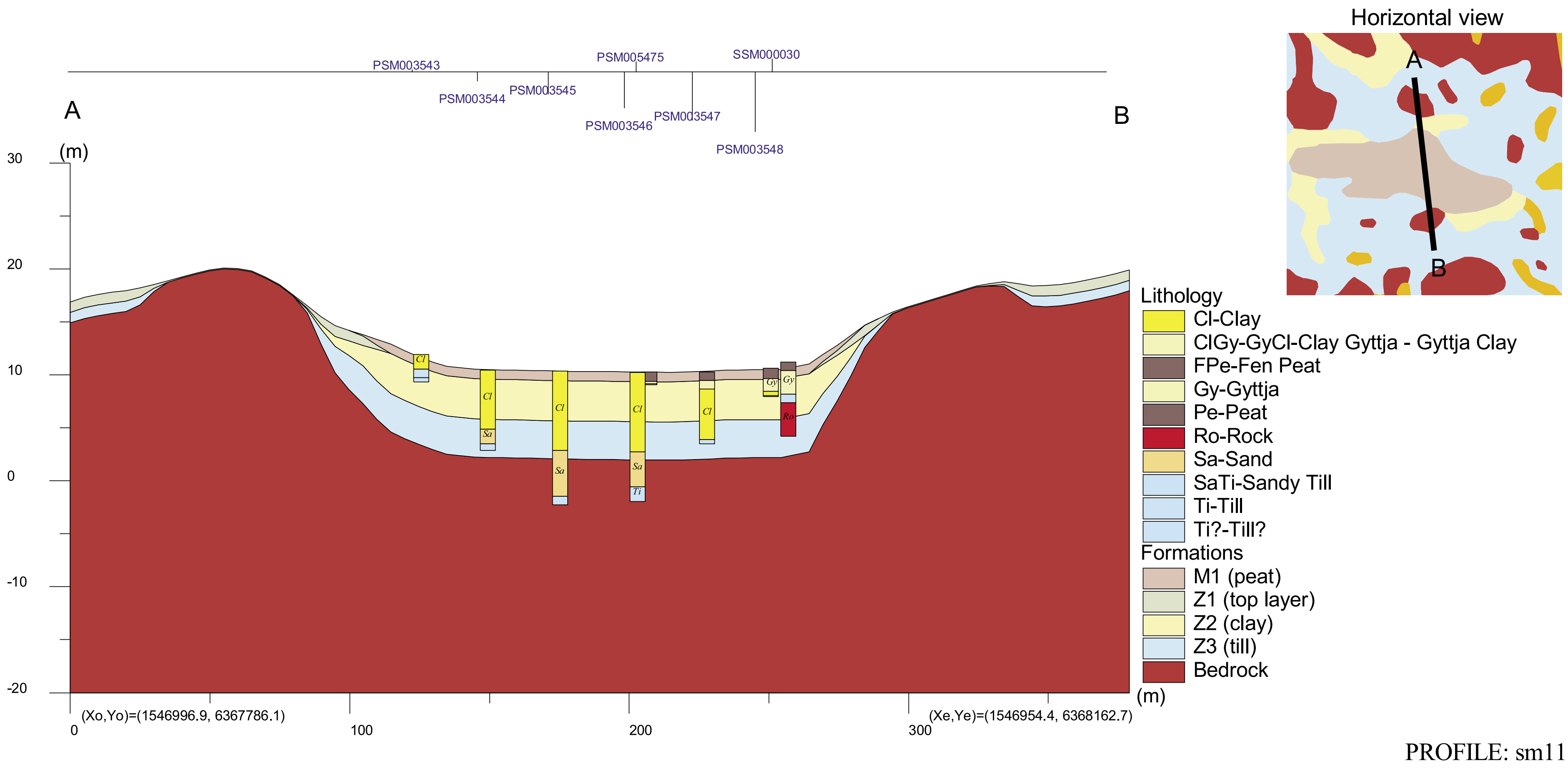


Figure A3-6. *Stratigraphy and formations for profile sm 11. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

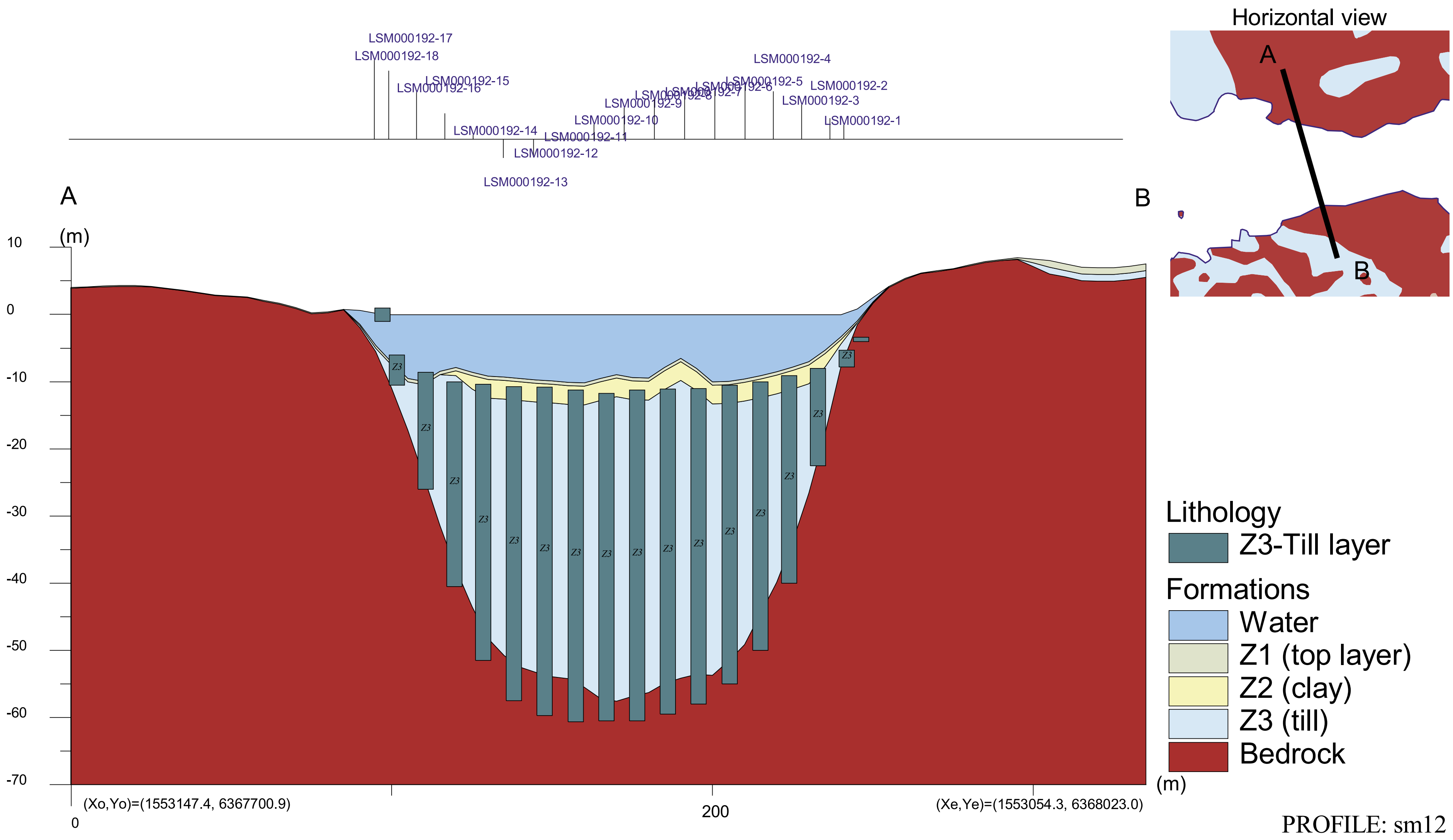
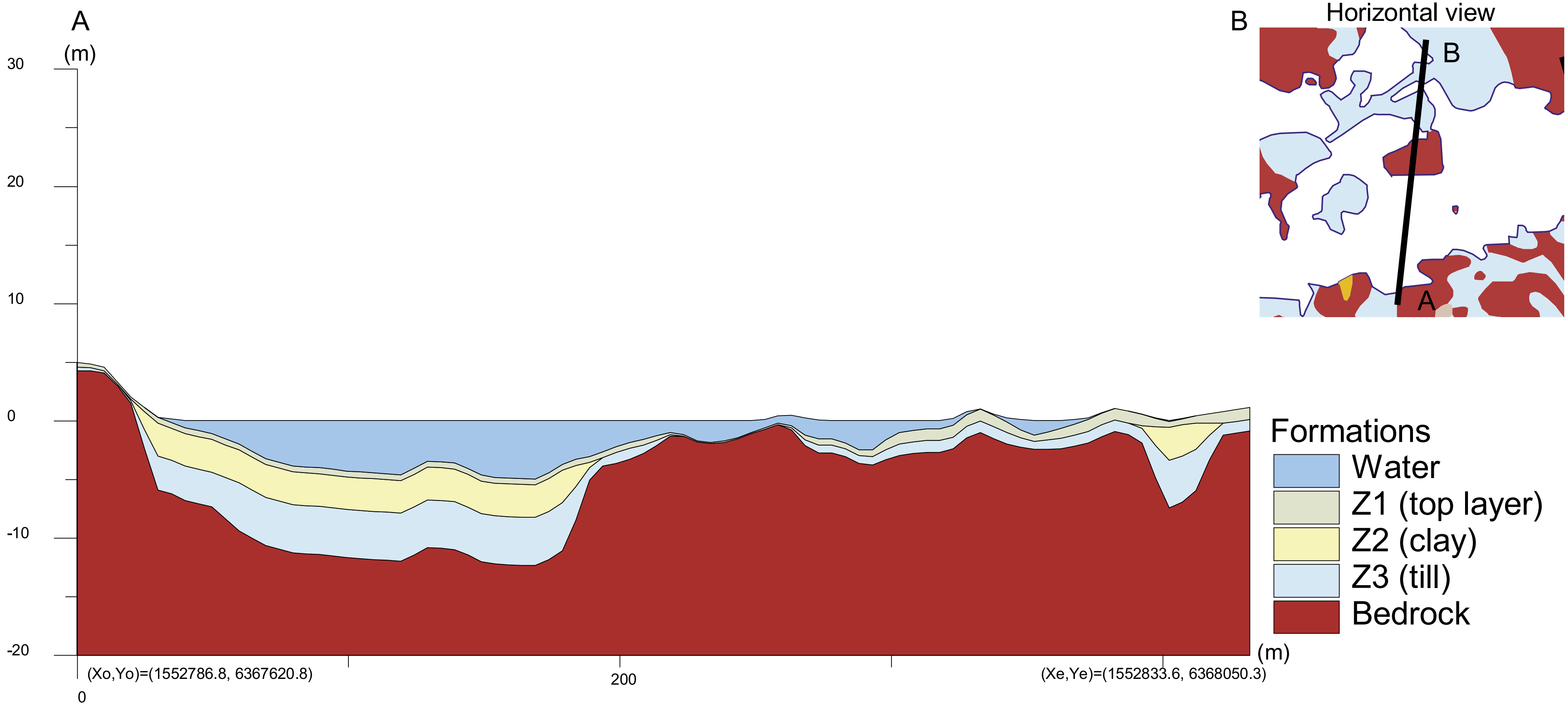


Figure A3-7. Stratigraphy and formations for profile sm 12. The observation points included are displayed above the profile. This profile shows the largest QD depth in the model area, the bay Getbergsfjärden. For location of the profile, see Figure 5-2.



PROFILE: sm13

Figure A3-8. *Formations for profile sm 13. This profile does not include any observation points. For location of the profile, see Figure 5-2.*

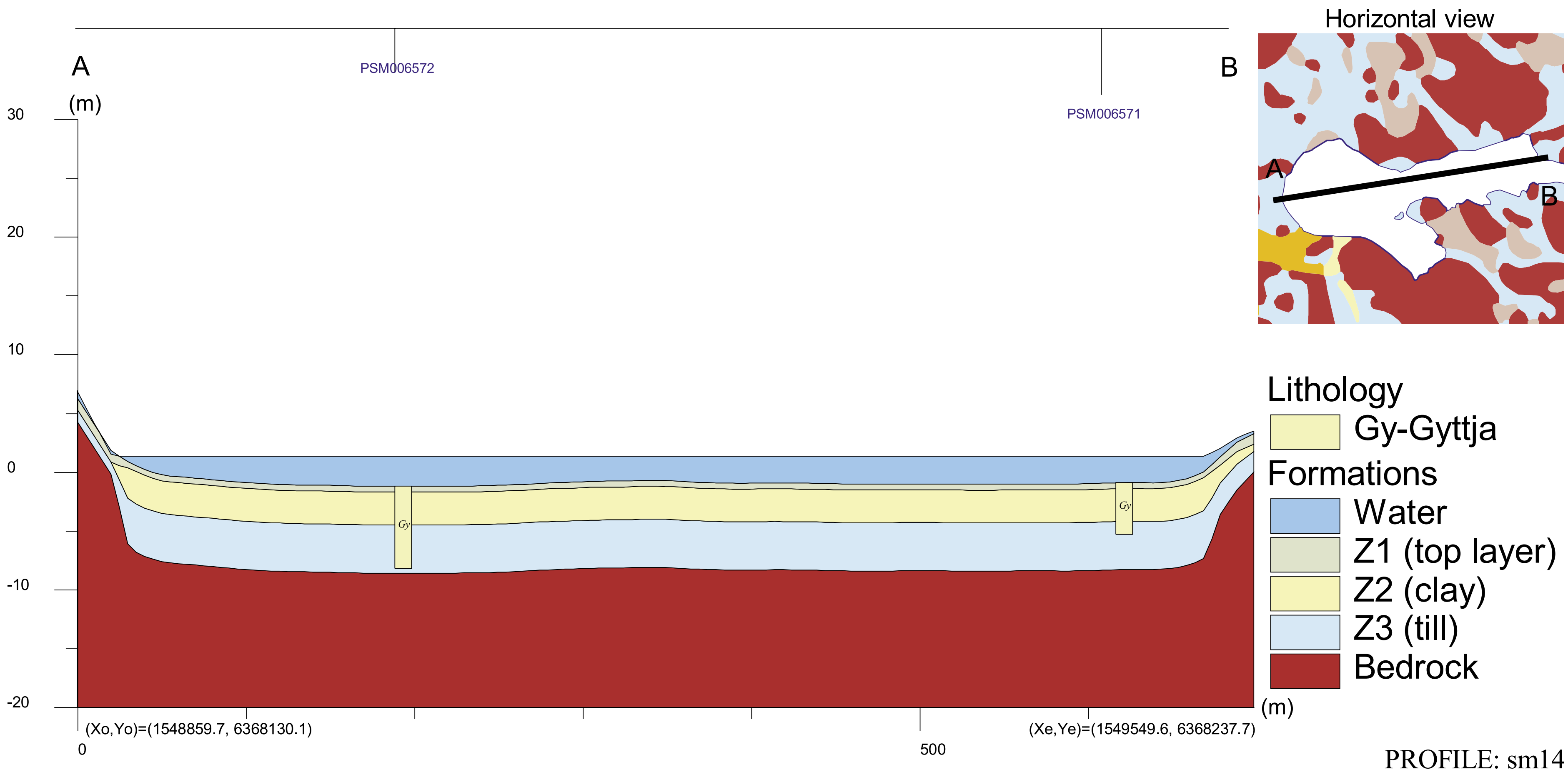


Figure A3-9. *Stratigraphy and formations for profile sm 14. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

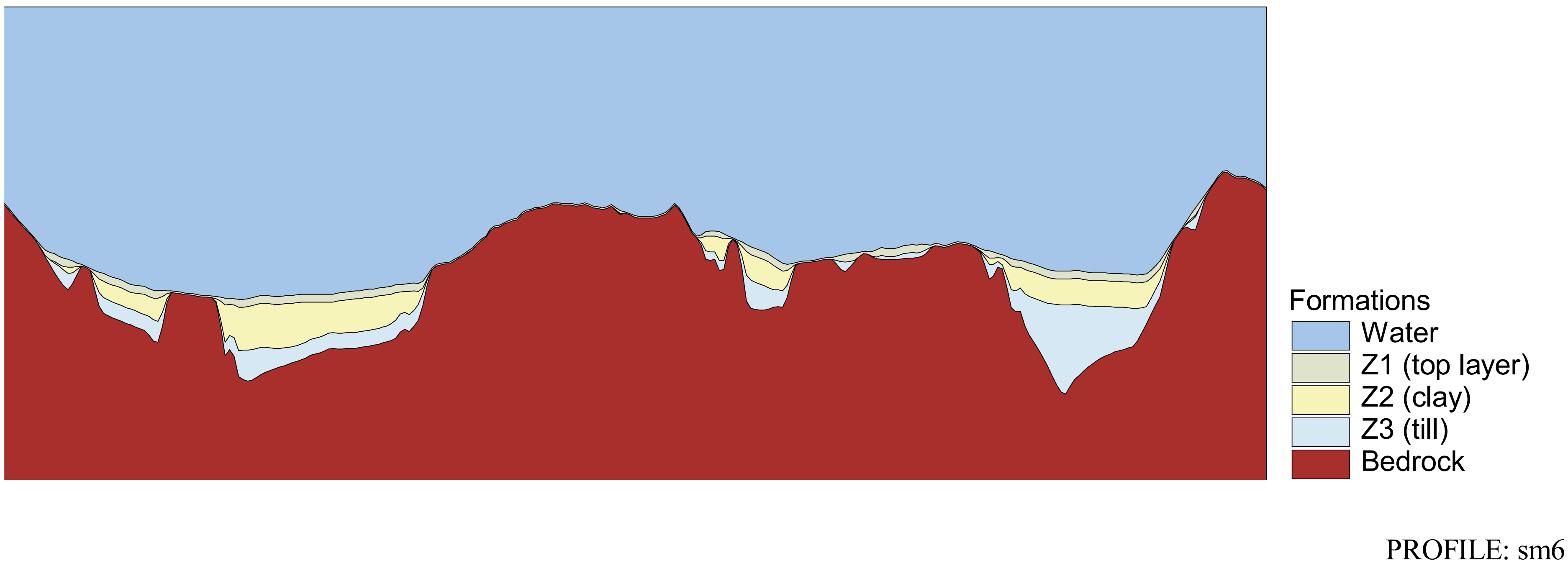


Figure A3-10. *Formations for profile sm 6. Since depth information at sea deeper than six metre are classified as strict secret, this report nor can show any profiles with depth or scale either the location of the profile. However, this figure shows how it can look like at sea.*

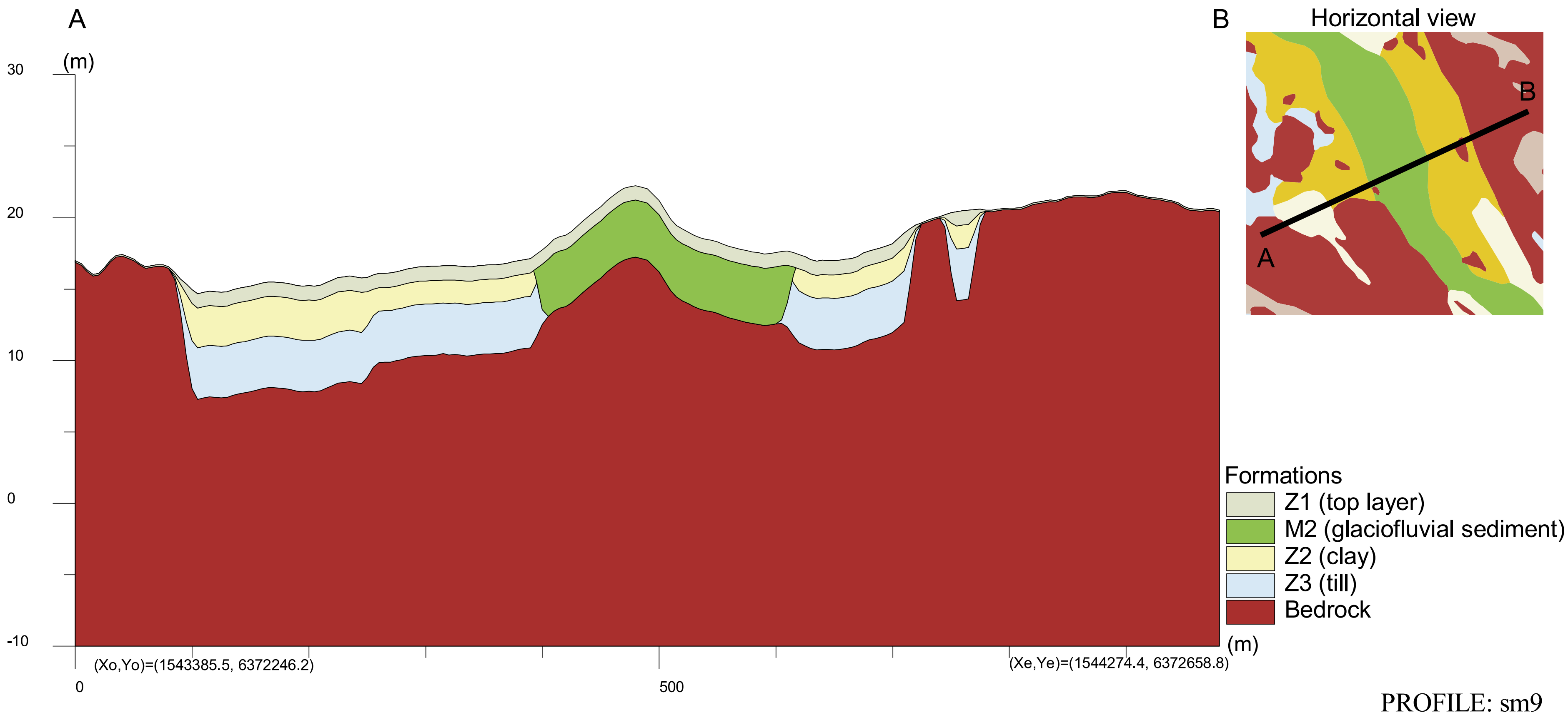


Figure A3-11. *Formations for profile sm 9. This profile does not include any observation points. The model are not reliable in the hole model area. This profile shows an example of that, glaciofluvial sediment normally not lies where the bedrock raises. For location of the profile, see Figure 5-2.*

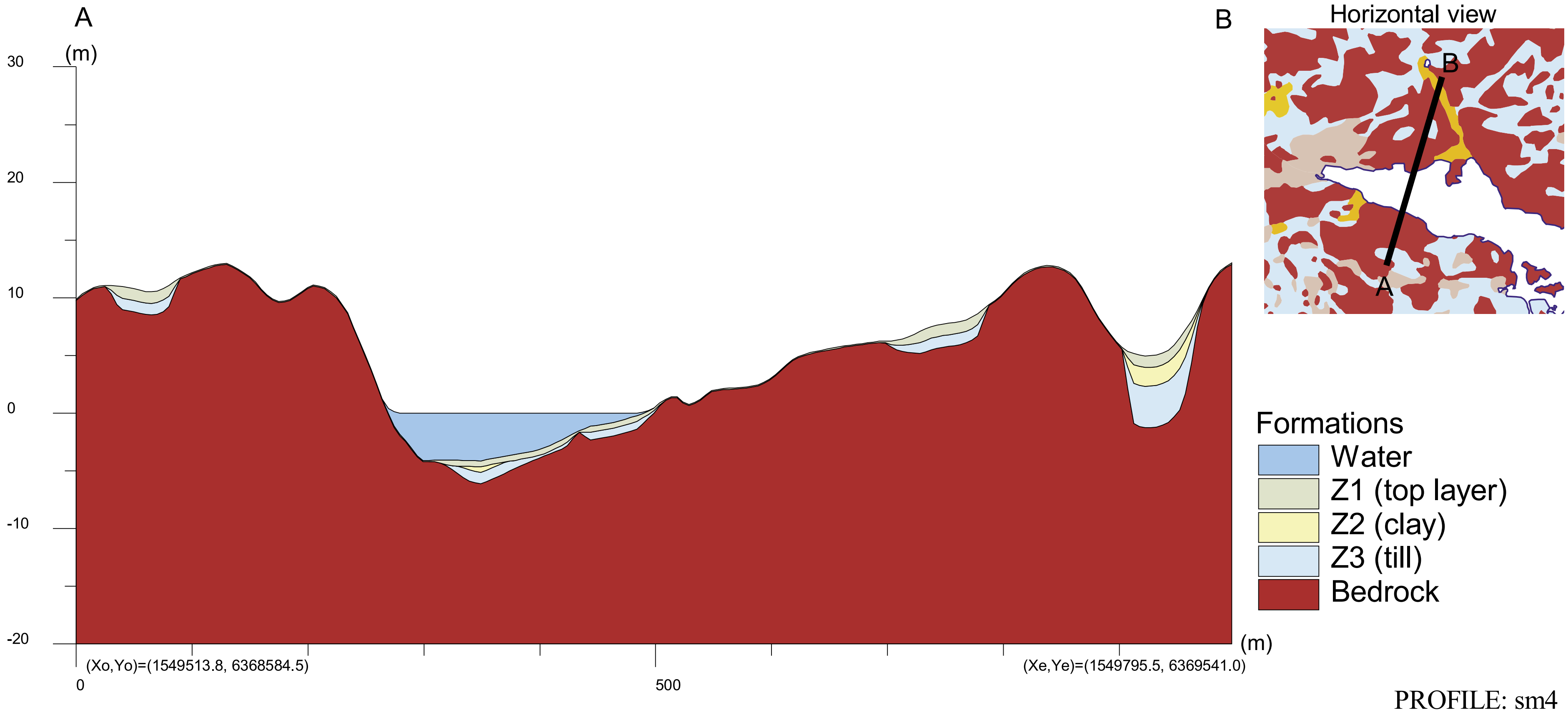


Figure A3-12. *Formations for profile sm 4. This profile does not include any observation points. The model are not reliable in the hole model area. This profile shows an example from the area where the seismic and sediment echo sounding observations not always measured QD depth down to bedrock, probably because of gas pockets in the clay. For location of the profile, see Figure 5-2.*