R-05-07

Modelling of soil depth and lake sediments

An application of the GeoEditor at the Forsmark site

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DHI Water & Environment AB

February 2005

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ISSN 1402-3091
SKB Rapport R-05-07

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Keywords: Quaternary deposits, Soil depth, GeoEditor, Glacial till, Peat, Lake sediments.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

Summary

This report aims at describing the modelled soil depth according to three layers with different hydrogeolocical properties at the Forsmark site, based on available data from boreholes, observation points, seismic data and radar profiles.

For the lakes in the area, the sediment has been modelled according to six layers of the most common deposits in the area. The peat layer at Stenrösmossen has also been visualized.

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

The input data used in the model consist of 1,532 points based on seismic measurements, 31 profiles of interpreted ground penetrating radar data, 119 boreholes and 472 observation points. The western and south eastern part of the area has a low data density. In the southern parts the data density with respect to estimated bedrock elevation is low. Observation points in this area are generally not very deep and do not describe the actual bedrock elevation. They do, however, describe the minimum soil depth at each location. A detailed topographical DEM, bathymetry and map of Quaternary deposits were also used.

The model is based on a three-layer-principle where each layer is assumed to have similar hydrological characteristics. The uppermost layer, Z1, is characterized by the impact from surface processes, roots and biological activity. The bottom layer, Z3, is characterized by contact with the bedrock. The middle layer, Z2, is assumed to have different hydraulic qualities than Z1 and Z3. The lake sediments have been modelled according to six classes of typical deposits.

The modelled soil depths show a relatively high bedrock elevation and thus small total soil depth in the major part of the area. The median soil depth has been calculated to 1.9 m, based on model results in areas with higher data density. The maximum modelled soil depth is about 13 m, just north of Lake Stocksjön.

Generally, the sediment layers in the lakes of the area consists of a bottom layer of glacial and postglacial clay, covered by sand and gravel and number of nested layers of gyttja in different fractions. Lake Bolundsfjärden show a different sediment structure than most of the other lakes as the bottom layer of clay is missing in major parts. The lakes are shallow with sediment layers from a few decimetres to around 8 m.

Sammanfattning

Föreliggande rapport syftar till att beskriva och modellera jorddjupet i Forsmark baserat på tillgängliga data från borrhål, provgropar och observationspunkter, seismisk data samt markradarprofiler. Modelleringsprinciperna har varit en indelning av jordprofilen i tre huvudsakliga lager med olika hydrogeologiska egenskaper.

För sjöarna i området har sedimenten modellerats enligt en indelning i sex för området typiska lager. Torvformationen vid Stenrösmossen har även modellerats specifikt.

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

Indata till modelluppbyggnaden har varit 1 532 punkter med seismiska mätningar, 31 markradarprofiler, 119 borrhål samt 472 provgropar eller observationspunkter. De västra och sydliga delarna av modellområdet har en lägre datadensitet än övriga delar. De observationspunkter som finns i dessa områden är generellt grunda och når inte bergöverytans nivå. Dessa observationer har ändå använts för att säkerställa ett minsta djup till berg. En detaljerad topografisk DEM, bottengeometri i sjöar samt jordartskarta har också använts i modelleringen.

Modellen har baserats på en trelagersprincip vid beskrivningen av de geologiska formationerna i området. Det översta lagret, Z1, karakteriseras av ytliga processer, rötter och biologisk aktivitet. Det understa lagret, Z3, karakteriseras av uppsprucken morän i kontakt med bergytan. Det mellersta lagret, Z2, antas ha något annorlunda hydrogeologiska egenskaper än Z1 och Z3. Sjösedimenten har delats in i sex typiska grupper av avlagringar.

Modelleringen visar på en relativt ytligt liggande bergöveryta, det vill säga ett litet jorddjup i stora delar av modellområdet. Medianvärdet av beräknat jorddjup är 1,9 m, baserat på resultat från områden med högre datadensitet. Det största modellerade jorddjupet är ca 13 m, strax norr om Stocksjön.

Sjösedimenten består generellt av ett undre lager av glacial och postglacial lera, ovanlagrat av ett lager postglacialt sand eller grus samt ett antal varviga lager av gyttja i olika sammansättningar. Bolundsfjärden har en avvikande sedimentstruktur i jämförelse med övriga stora sjöar i området, då det undre lagret av lera i stort sett saknas. Sjöarna i området är relativt grunda med ett sedimentdjup mellan några decimeter till runt 8 m.

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 Kommun and Simpevarp in Oskarshamn Kommun.

At the Forsmark site, numerical modelling is being performed both for the bedrock as well as for the shallow ground water aquifer above the bedrock surface. For the shallow groundwater modelling, the surface geology and soil depth to the bedrock surface is an important parameter. 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 soil depth model covering the Forsmark site catchment.

This report presents a model which describes the estimated soil depth for the Forsmark site catchment. The report also includes modelling of lake sediments. The resulting interpolated surfaces are presented in a GIS-environment and delivered on a CD separate from this report. The CD can be found at the Forsmark archive, under field note no Forsmark 433.

This report aims at describing the modelled soil depth according to three layers characterized by different hydraulic properties at the Forsmark site, based on available data from boreholes, observation points, seismic data and radar profiles.

For the lakes in the area, the sediment has been modelled according to six typical layers. The peat layers at Stenrösmossen have also been visualized.

The model will be used in hydrological modelling of the area and to visualize the spatial distribution of the Quaternary cover. The model 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.

2 Methodology

The program used in the modelling of soil depths at the Forsmark site is the GeoEditor, which is a graphical tool for geological modelling and editing in a GIS-environment (ArcView3.3) /DHI Water & Environment, 2002/. The GeoEditor provides a close link between the hydrological modelling tool MIKE SHE, which is being used for the shallow groundwater modelling at the Forsmark site /DHI Water & Environment, 2003b/. 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, 2002/. 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, transmissivity.

Based on experience of geologists, hydrogeologists 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 then specified in terms of layers and lenses by stepwise sweeping through a number of predefined geological profiles. For each profile discrete points used in the layer interpolation are digitized using the lithology of each borehole covered by the profile. In the third step the discrete values are interpolated into a 3-dimensional geological model.

The interpolation method used in the GeoEditor is by default Inverse Distance Weighted (IDW), power of 2, no barriers, using the values of the 12 nearest neighbouring points without a maximum distance

/DHI Water & Environment, 2002/. The number of neighbouring points and the power exponent can be changed manually, and a fixed radius can be specified instead of a number of neighbouring points. The spline interpolation method and the trend interpolation method can be chosen manually instead of IDW.

The resulting geological model is, subsequently, evaluated. If necessary, the geological model can be modified until acceptance. When the geological model is accepted it can be transferred to Asci-files, ESRI grids or input files used in the groundwater modelling system MIKE SHE /DHI Water & Environment, 2003b/.

3 Input data

The input data used in the model is based on the information available at the datafreeze 1.2 in Forsmark, June 2004.

The model area is the Forsmark site catchment, shown in Figure 3-1. The model area corresponds to the area covered by the hydrological modelling of the shallow groundwater with MIKE SHE /Johansson et al. 2005/.

The Digital Elevation Model (DEM) used in the project was interpolated and delivered by SKB in December 2004, and is based on detailed flight observations. The DEM has a resolution of 10 m. The DEM contains mean water level in the lakes in the area. The topography is relatively flat and has a slope towards the east. The area is characterized by a number of lake and wetlands. The whole area is situated below the highest coastline /Sohlenius et al. 2004/. The topography is shown in Figure 3-2.

The method for construction of the DEM and the bathymetry is described in /Brydsten, 2004/.

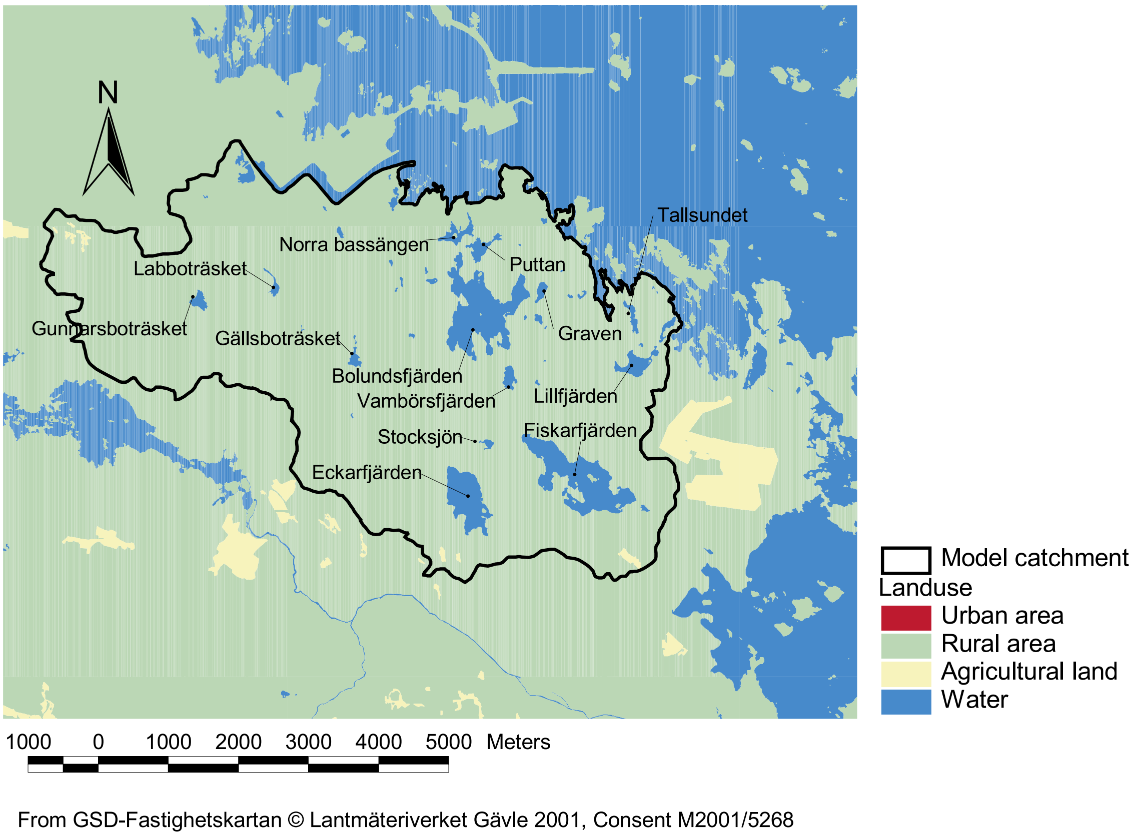

Figure 3-1. *Model area and lakes within the model catchment.*

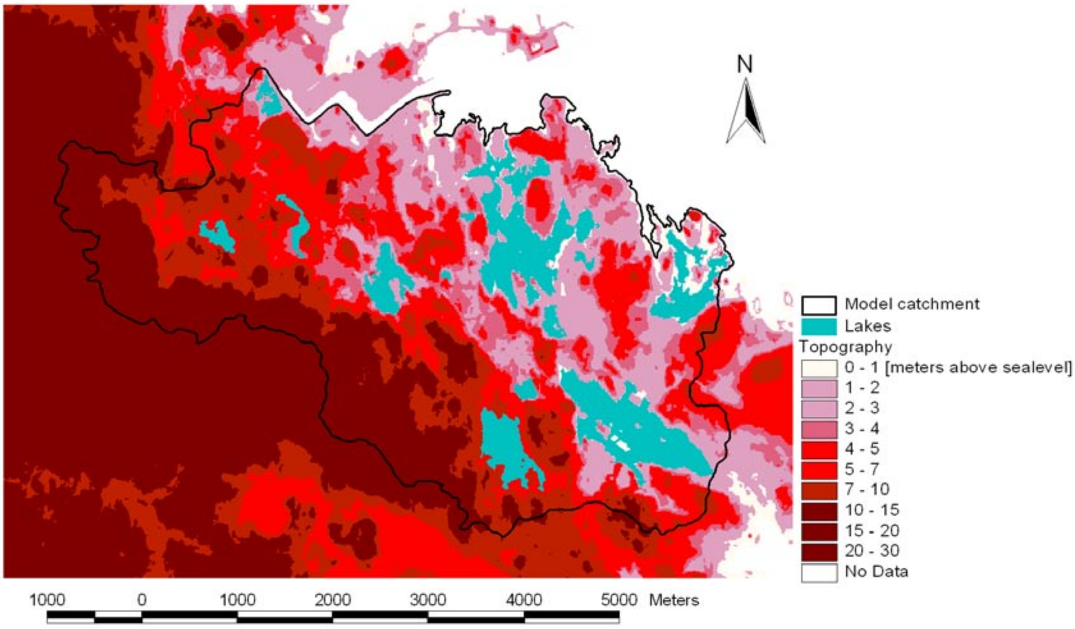

Figure 3-2. *Topography in a 10 m resolution. The black line represents the Forsmark site catchment which is the model area.*

Seismic data was delivered in excel-format and included five profiles across the area /Bergman et al. 2004/. Each observed point had coordinates, a surface elevation and an estimated smoothed bedrock elevation that was used in the model. The total number of observation points was 1,532.

Interpreted ground penetrating radar data was delivered for 31 profiles, with a total number of observations of 1,158. For each point the coordinates, surface elevation and bedrock surface elevation was represented /Marek, 2004/.

119 boreholes with an estimated bedrock elevation were delivered as well as 472 observation points with detailed lithology /Johansson, 2003; Sohlenius and Rudmark, 2003; Hedenström, 2004 a,b; Hedenström et al. 2004/.

Figure 3-3 shows the distribution of observation points within the model area. The western and south eastern part of the area has a low data density. In the southern parts the data density with respect to estimated bedrock surface elevation is low. Observation points in this area are generally not very deep and do not describe the actual bedrock elevation. They do, however, describe the minimum soil depth at each location.

The map of Quaternary deposits is a combination of a detailed survey within parts of the model catchment and a regional map elsewhere, see Figure 3-4. About 5% of the area where detailed geological mapping has been performed consists of bedrock cover. The most common quaternary deposit is glacial till, which covers approximately 75% of the investigated area /Sohlenius et al. 2004/.

The lakes in the area are shown in Figure 3-1.

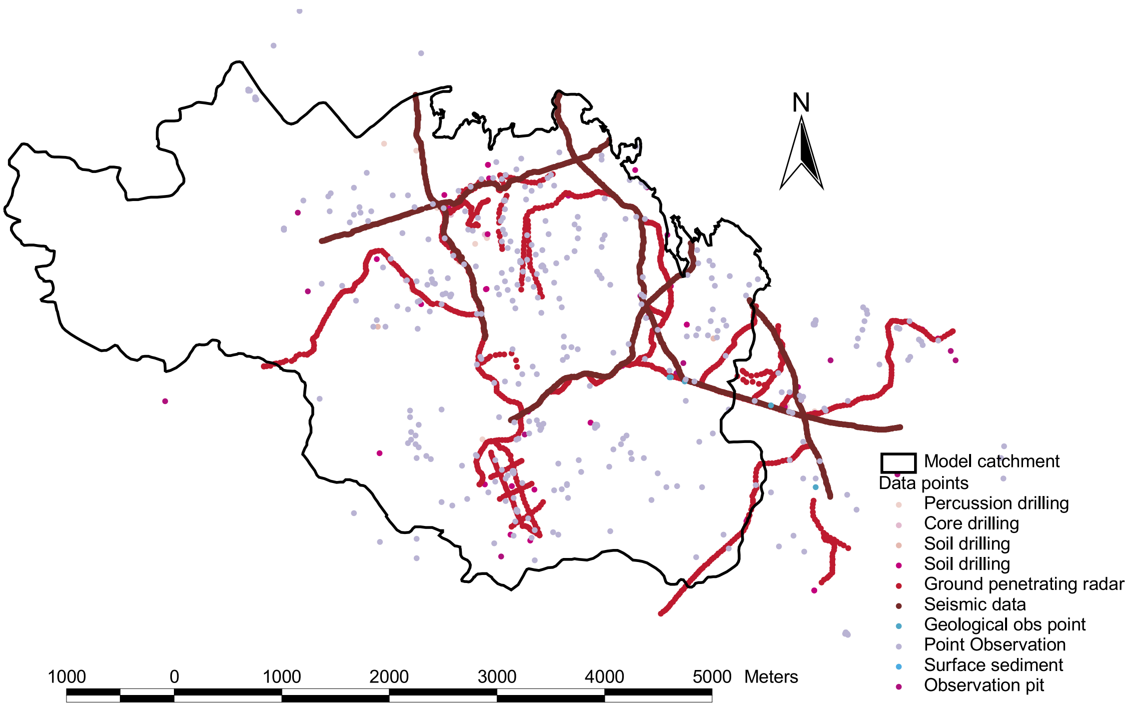

***Figure 3-3.** Map showing the distribution of observation points within the model area and the density of the various data sources. Observation points with measured and estimated bedrock surface elevation have a pink to red tone colour and shallow observations giving a minimum depth to bedrock are marked with a blue to purple tone. The black line represents the Forsmark site catchment which is the model area.*

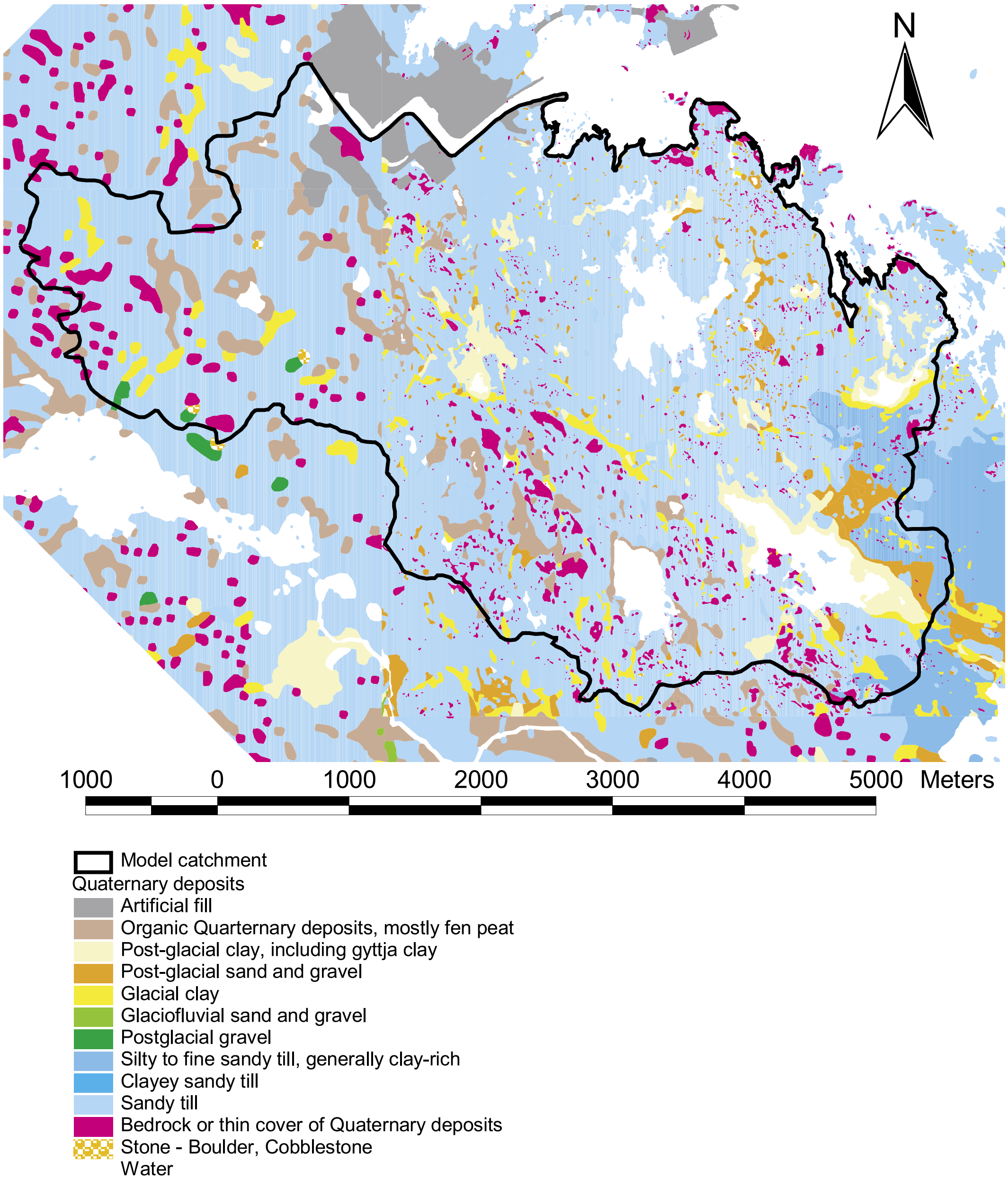

Figure 3-4. *Map showing the distribution of the Quaternary deposits in the Forsmark area. The black lines represent the sub catchments in the area. The black line represents the Forsmark site catchment which is the model area.*

4 Execution

The model has been built up and evaluated using the GeoEditor. For the adjustment of interpolated surfaces (see Chapter 4.5), a tool for handling and editing two-dimensional grid data in the geo-hydrological modelling system MIKE SHE has also been used, the dfs2-editor /DHI Water & Environment, 2003a/.

4.1 Data Handling

Each observation point of any kind within the area has been handled as a borehole in the model approach. This means that coordinates, ID, method, surface elevation and lithology has been set to each point. Additional information has been set to the observation points where it was available in input data, such as depth of observation and estimated hydraulic conductivities. The hydraulic conductivities were determined through slug tests at each location /Werner and Johansson, 2003/.

4.1.1 Elevation of boreholes and other data

A number of observation points were given surface elevations manually through the digital elevation model (DEM) of the topography. The elevation of each borehole and other observation points are stored at SKB's GIS-database /SDEADM.DHI_FM_GEO_2476/, under the column KOTE.

4.1.2 Geological classes in the model area

The model is based on three-layers where each layer is assumed to have similar hydrological characteristics. The uppermost layer, Z1, is characterized by the impact from surface processes, roots and biological activity. The bottom layer, Z3, is characterized by contact with the bedrock. The middle layer, Z2, is assumed to have different hydraulic properties than Z1 and Z3.

The principle for the definition of the three-layers is illustrated in Figure 4-1. Observe that the layer thicknesses fro each layer are shown in a principle way. It should also be noted that the three layers are constructed in the model and does not represent real/actual lithological 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 three layers are shown in Table 4-1 below.

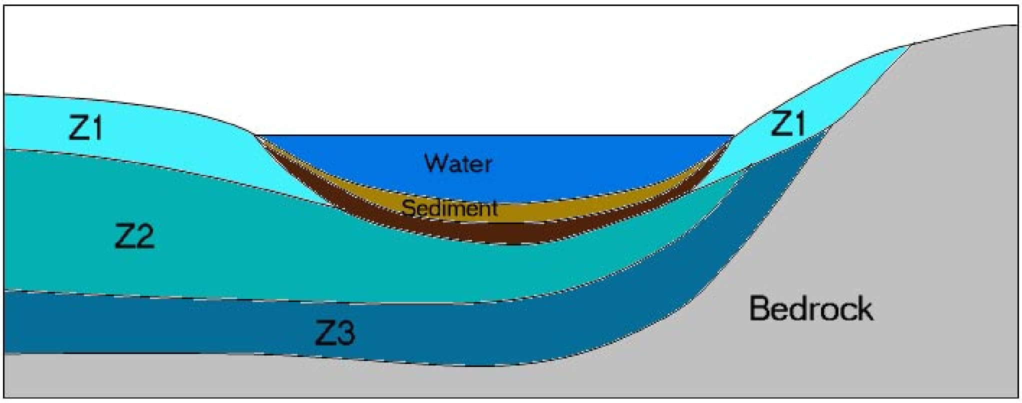

Figure 4-1. The principle of the three layers modelled in the area.

Table 4-1. Deposit and simplified code for the three layer principle.

Deposit	Simplified code
Surface process affected layer	Z1
Middle layer	Z2
Bottom layer	Z3
Bedrock	Berg

The layer thickness and thus the lower levels of the different layers have been calculated based on the total soil depth in each observation point. When the total soil depth is larger than 2 meters (e.g. the bedrock elevation is less than or equal to two meters below surface elevation), the layer thickness of Z1 is set to one meter, the layer thickness of Z3 one meter and the layer thickness of Z2 the remaining soil depth.

In the case of a total soil depth less than two meters (e.g. the bedrock elevation is less than or equal to 2 m below surface elevation), the layer thickness of Z1 is set to one meter and the layer thickness of Z3 is set to the remaining soil depth. The layer thickness of Z2 is set to zero.

In the case of a total soil depth less than one meters (e.g. the bedrock elevation is less than or equal to 1 m below surface elevation), the layer thickness of Z1 is set to the total soil depth. The layer thickness of Z2 and Z3 is subsequently set to zero.

4.1.3 Lithology classes for information boreholes and sediments in lakes

The detailed lithology-classes and simplified codes for the observation points used in the model are shown in Table 4-2 below. The simplified codes were defined based on the first letters of each deposit's name. These have not been used in the interpolation of the three layers, but are shown as additional information.

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

Quaternary deposit	Simplified code	Quaternary deposit	Simplified code
Algal Gyttja	AlGy	Gravel	Gr
Artificial fill	ArtFi	Gravelly Sand	GrSa
Bedrock	Br	Gravelly Till	GrTi
Bedrock fragment	BrFrg	Gyttja	Gy
Boulder Clay	BoCl	Microbial Mat	MiMa
Calcareous Gyttja	CalcGy	Peat	Pe
Clay	Cl	Postglacial Clay	PoCl
Clay Gyttja - Gyttja Clay	ClGy-GyCl	Postglacial Gravel	PoGr
Clay, flow earth	Cl,fe	Postglacial Gravelly Sand	PoGrSa
Clayey Sandy Silty Till	ClSaSiTi	Postglacial Sand	PoSa
Clayey Sandy Till	ClSaTi	Postglacial Sandy Gravel	PoSaGr
Clayey Till	ClTi	Postglacial Sediment	PoSed
Clay - Silt, flow earth	Cl-Si,fe	Postglacial Silt	PoSi
Coarse Silt - fine Sand	cSi-fSa	Postglacial Silty-Sand	PoSi-Sa
Detrius	Dt	Postglacial Stone	PoSt
Fen Peat	FPe	Postglacial Stony Gravel	PoStGr
Fractured Bedrock	FrcBr	Postglacial Stony Sand	PoStSa

For modelling of lake sediments, the detailed lithology as shown above has been used in the interpolation of surfaces. The lake sediments have been modelled according to six classes of typical deposits, Table 4-3 /Hedenström, 2004a/.

Table 4-3. Classification of lake sediments.

Lake sediment	Included deposit
Gyttja	Algal gyttja
	Gyttja
	Detrius
	Microbial mat
Calcareous gyttja	Calcareous gyttja
Clay gyttja - gyttja clay	Clay gyttja - gyttja clay
Postglacial sand and gravel	Postglacial sand
	Postglacial gravel
	Postglacial sandy gravel
	Postglacial stony gravel
Postglacial clay	Postglacial clay
Glacial clay	Glacial clay
	Glacial clayey silt
	Glacial silt
	Glacial silty sand

4.2 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, observation depth and hydraulic conductivities. The second database contains the lithology of each observation. The databases are imported to and interpreted in the GeoEditor. The databases are stored at SKB's GIS database /SDEADM.DHI_FM_GEO_2475; SDEADM.DHI_FM_GEO_2476/.

4.3 Digitizing of layer surfaces

When defining a geological layer in the model, a point theme, having the same name as the layer, is generated. Digitised points describing the lower level of the layer will be 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 lithology 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.

When digitizing discrete points in the Forsmark model area, 86 profiles have been made from which the three-layer principle has been digitized. The profiles have been defined in order to cover all observation points from the input data and are shown in Figure 4-2.

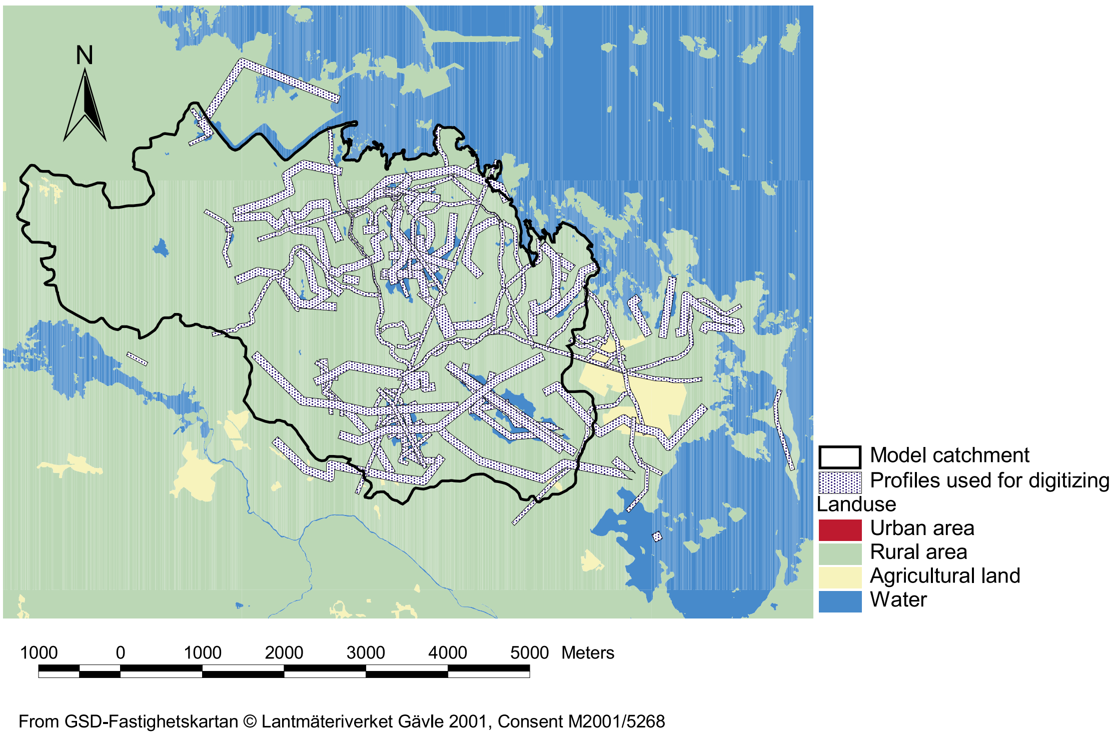

***Figure 4-2.** Profiles covering all input data points used for digitizing the three layers. The black lines represent the Forsmark site sub-catchments.*

In lakes and in the peat formation Stenrösmossen additional profiles have been made in which lenses of peat and lake sediments have been interpolated.

No free digitizing (e.g. manually interpreted points) has been made for the overall soil depth; each discrete point has a reference in input data and observations. Only observations with estimated depth to the bedrock surface, thus with a three-layer interpretation, have been used for the overall model. In case of sediments in lakes and the peat formation at Stenrösmossen, observation points with more detailed lithology have been used, and additional points have been digitized to ensure a smooth layer bottom where there is low data density.

In order to take areas of bedrock outcrop into account, the polygons describing bedrock in the map of Quaternary deposits were converted into points and elevations were assigned from the DEM. These points were added to each layer with digitized discrete points and used in the interpolation.

4.4 Interpolation of surfaces and lenses

The interpolated grids describing each lower layer elevation has a resolution of 10 m over an area of about 60 km^2. The model origin, grid size and model extension are shown in Table 4-4.

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

Origin, x-coordinate	1626720
Origin, y-coordinate	6695610
Cell size of model grid	10 m
Number of cells in x-direction	950
Number of cells in y-direction	600

The lake sediments and the peat formation at Stenrösmossen are described as lenses with a limited extension.

4.5 Adjustment of interpolated surfaces

The interpolated surfaces have been adjusted with respect to three different factors.

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 soil 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 soil depths since the bedrock elevation is set to the correct measured elevation.

The second adjustment was made in areas with a low data density. The interpolation in these areas could show a total soil depth less than 0.5 m in areas where the distribution of Quaternary deposits showed a layer thickness of at least 0.5 m. In these areas the soil depth was adjusted to the median modelled soil depth of the area, 1.9 m (with bedrock outcrop excluded). An adjustment was also made to ensure a soil depth of zero 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 zero in areas where the interpolation showed a very small soil depth).

The third correction was with respect to the layer thickness applied in the definition of the three layers. Adjustments were made to ensure that the layer thickness of Z1 and Z3 never exceeded one meter.

The lake sediment lenses have been adjusted according to layer order (the lower levels of each lens cannot exceed the layer above). An adjustment has also been made to ensure smooth layers without unrealistic layer thicknesses of zero in areas where this is most unlikely. The adjustments were made by manually setting the layer thicknesses at the shorelines of the lakes to zero, under the assumption that the lenses would have the same horizontal extension as the lake itself. By choosing the grid cells where the interpolation from the discrete points in the GeoEditor showed a layer thickness of zero, and re-interpolating them with respect to the shoreline and remaining layer thicknesses of the lens, a new adjusted sediment lens was created. The total soil depth (Z1–Z3) was set to the median soil depth under the lake sediments in areas where no information of the depth to bedrock was available.

The corrections with respect to the map of Quaternary deposits and final layer thickness were made using the grid-editor in MIKE SHE /DHI Water & Environment, 2003a/.

5 Results

The results show a median soil depth of 1.9 m, based on the interpolated result in areas of higher data density that showed a soil depth greater than 0.5 m where the map of Quaternary deposits showed deposits other than bedrock or water. In the western part of the model area, the de<nsity of input data is low, thus the median soil depth of 1.9 m is used (except for areas of bedrock outcrop). The medium soil depth is also used as a minimum depth under lakes in the area.

Table 5-1 below show the mean value and median soil depth based on input data from the different data sources. The input data show a generally higher median soil depth than the one derived from the interpolated results that are affected by areas of bedrock outcrop, e.g. a soil depth of zero.

The maximum modelled soil depth is about 13 m, just north of Lake Stocksjön. Measurements in observation points north of Lake Fiskarfjärden have shown a soil depth of around 16 m observations were not included in input data, and the modelled maximum soil depth around Lake Fiskarfjärden is around 10 m. For positions of lakes in the area, see Figure 3-1.

In the eastern parts of the area, the soil depth is generally higher. This area has also a higher data density than the western parts. Figure 5-1 shows the total modelled soil depth in the area.

Profiles from which results are shown in Chapter 5.1, 5.2, Appendix III and Appendix IV are shown in Figure 5-2.

Table 5-1. Mean value and median soil depth from input data.

Type of data	Number of observations	Mean soil depth	Median soil depth
Seismic data	947	4.07	2.73
Ground penetrating radar	1,014	3.33	3.13
Point observation	16	3.64	1.88
Soil drilling	45	4.42	4
Core drilling	5	6.04	7.10
Percussion drilling	18	4.97	4
Total	2,045	3.72	3.01

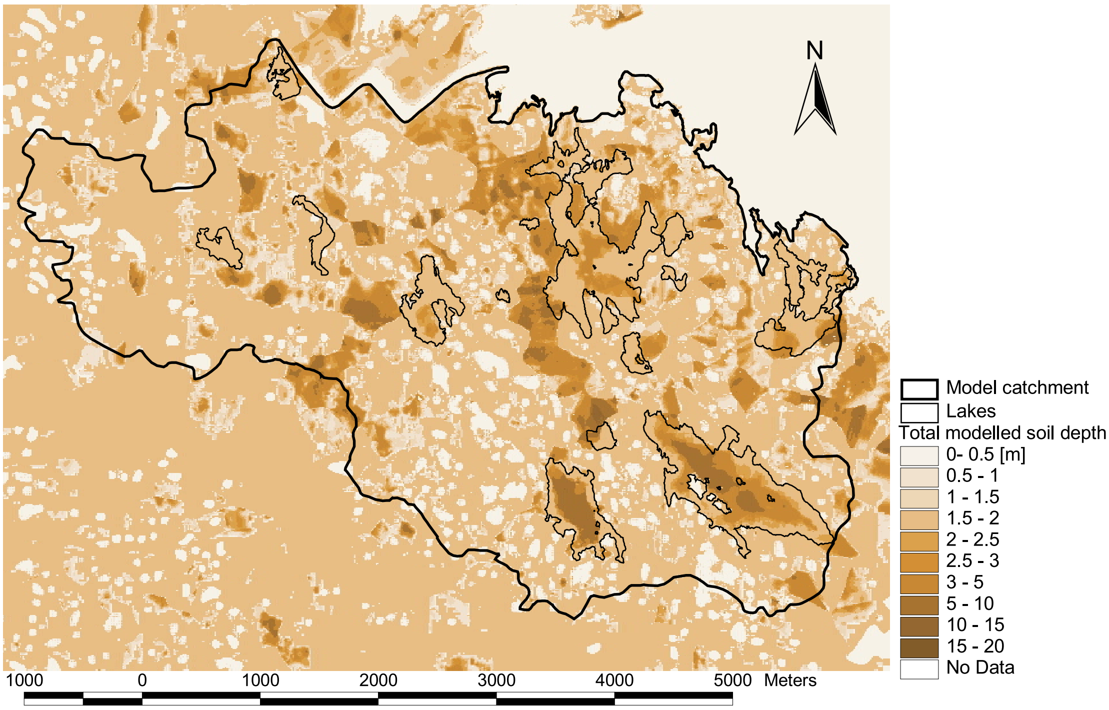

Figure 5-1. *Total modelled soil depth on land, Z1–Z3.*

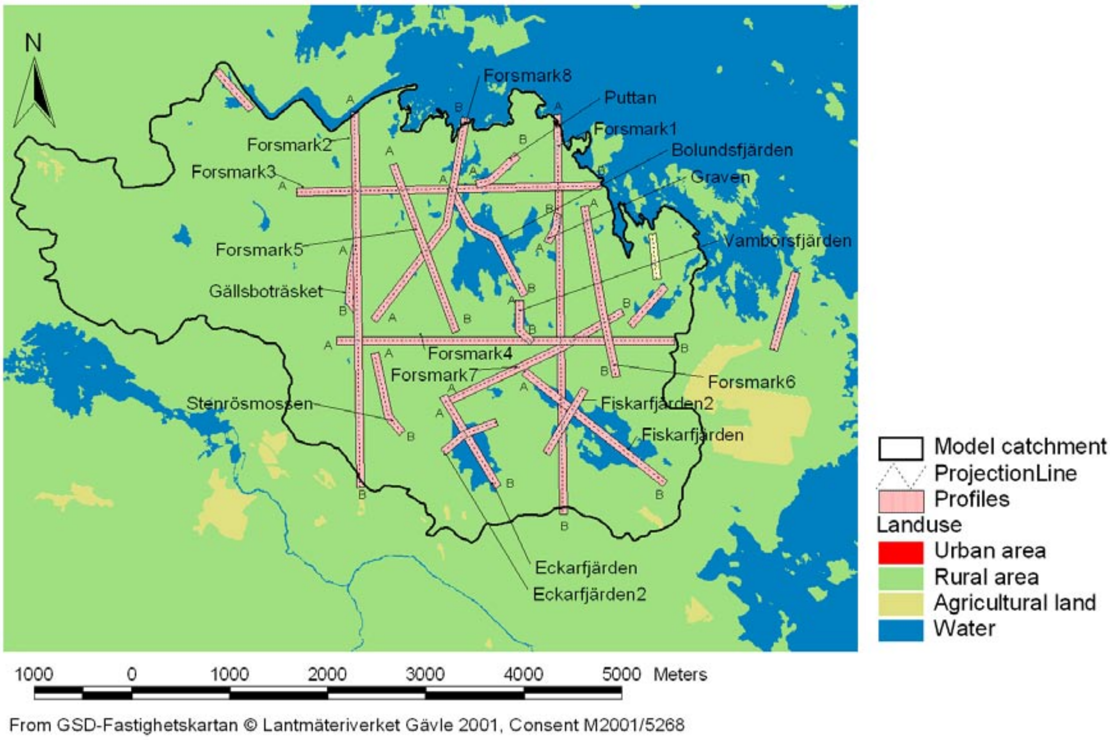

Figure 5 -2. *Profiles along the model from which results are shown in the report. The names of general profiles refer to names of profiles shown in Chapter 5.1, 5.2 and Appendix III and IV. The labels A–B show the direction of the profile and can be found above the illustrated vertical profiles in Figure 5-4 to 5-8 and Appendix III and IV.*

5.1 Profiles

A number of profiles within the model area are presented in the following chapter and Appendix III and IV.

It should be noted that the profiles are drawn along a manually defined line, shown as the projection line for each profile in Figure 5-2, from which the modelled soil 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 observations that actually are situated up to 20 m from the projection line where the topography and layer elevations are illustrated will be included. In some illustrated profiles, the elevations of observations points and depths of geological units differ from the modelled layers displayed in the profiles. This can be an effect of the 40 of observation points situated up to 20 m from the profiles projection line and thus the surface elevation and geological layers represented along that line.

Figure 5-3 and 5-4 show a typical profile through the area. In Appendix IV, additional profiles are presented. The horizontal view shows the extension of the profile, each profile is highlighted and is marked with A–B. The observation points 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. The formation Z4 in the profile represents the bedrock.

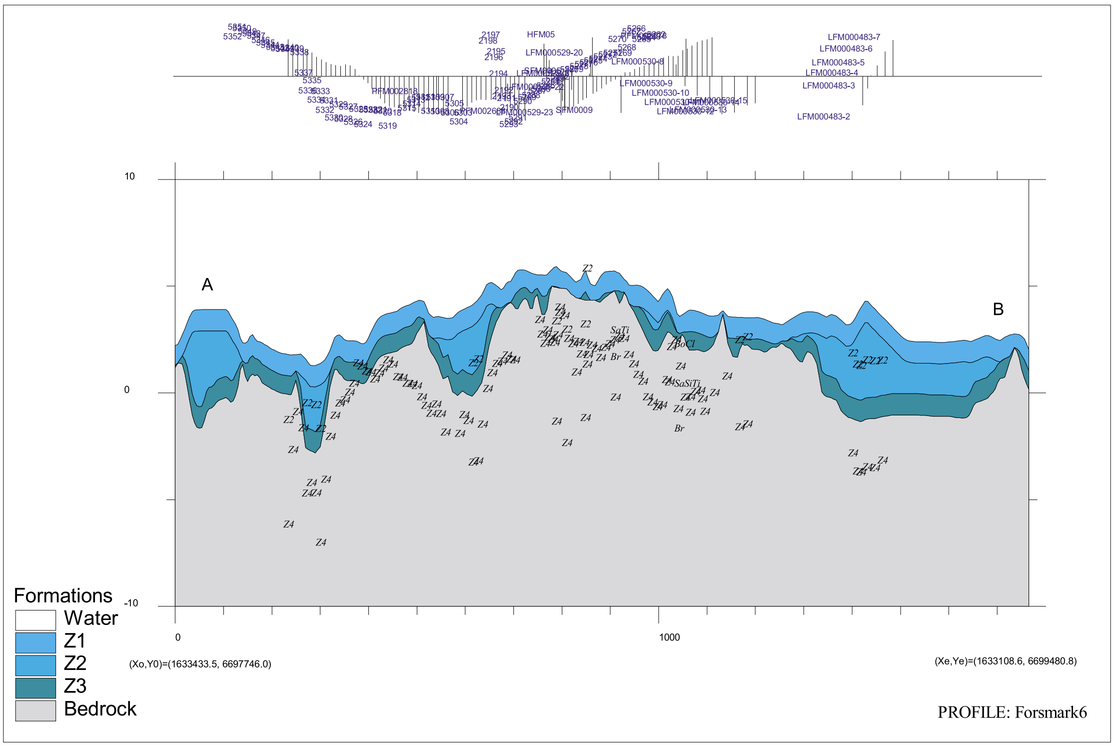

Figure 5-3. *Formations of Z1–Z3 and total soil depth along profile 6 in Forsmark. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

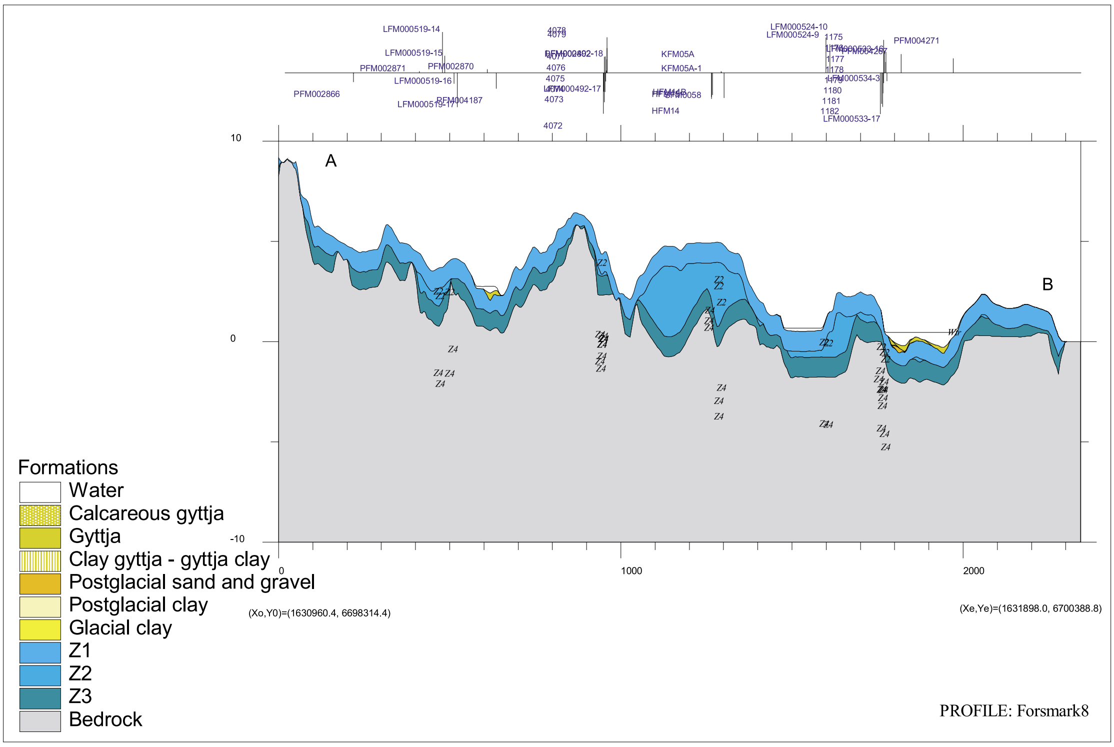

__Figure 5-4.__ Formations of Z1–Z3 and total soil depth along profile 8 in Forsmark. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.

5.2 Lake sediments

The lakes in the model area have been investigated through sediment analyses and modelled according to the six layers described in Chapter 4.1.3. Generally, the sediment layers consist of a bottom layer of glacial and postglacial clay, covered by sand and gravel and a number of nested layers of gyttja in different fractions /Hedenström, 2004a/. Lake Bolundsfjärden show a different sediment structure than most of the other lakes as the bottom layer of clay is missing in major parts. The lakes are shallow with sediment layers from a few decimetres to around 8 m.

This chapter shows the modelled lake sediments for the largest lakes in the area, Lake Eckarfjärden, Fiskarfjärden and Bolundsfjärden.

Lake Eckarfjärden is the oldest lake within the model area, isolated from the Baltic c 850 years ago /Hedenström, 2004a/. A bottom layer of glacial clay with an extension corresponding to the area of the lake is found. The clay layer has a maximum measured layer thickness of about 2 m. Postglacial clay is found in parts of the area. The clay layers are covered by postglacial sand and gravel throughout the lake. The sand is covered by nested layers of clayey gyttja, gyttja and calcareous gyttja. These layers were simplified as one consistent layer of clay gyttja-gyttja clay covered by one consistent layer of gyttja in the model.

Figure 5-5 shows a profile through Lake Eckarfjärden.

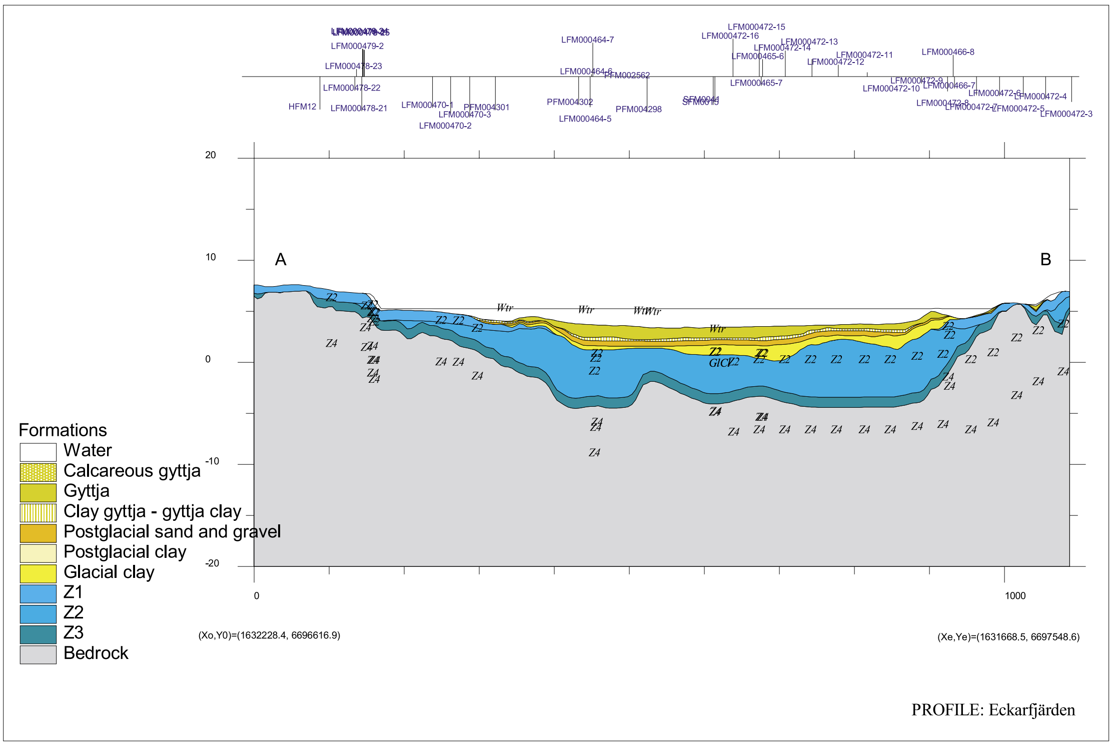

Figure 5-5. *Lake sediments and total soil depth along a profile through Lake Eckarfjärden. The observation points included are displayed above the profile. For location of the profile, see the Figure 5-2.*

Lake Fiskarfjärden generally has deeper sediments than Lake Eckarfjärden, with a maximum total sediment depth of about 8 m, not including the water column or till. The lowest layer of glacial clay is covered by a rather thick layer of postglacial clay. A thin layer of postglacial sand and gravel covers the clay layers. The sand is covered by nested layers of clayey gyttja and gyttja.

Figure 5-6 shows a profile through Lake Fiskarfjärden.

The layer structure in Lake Bolundsfjärden differs from Lake Eckarfjärden and Lake Fiskarfjärden. There is only one layer consisting of algae-gyttja covering the major parts of the lake. The layer of gyttja covers lower layers of clayey gyttja and postglacial sand and gravel. The lowest layer of glacial clay is not present in the major part of observations from Bolundsfjärden.

Figure 5-7 shows a profile through Lake Bolundsfjärden.

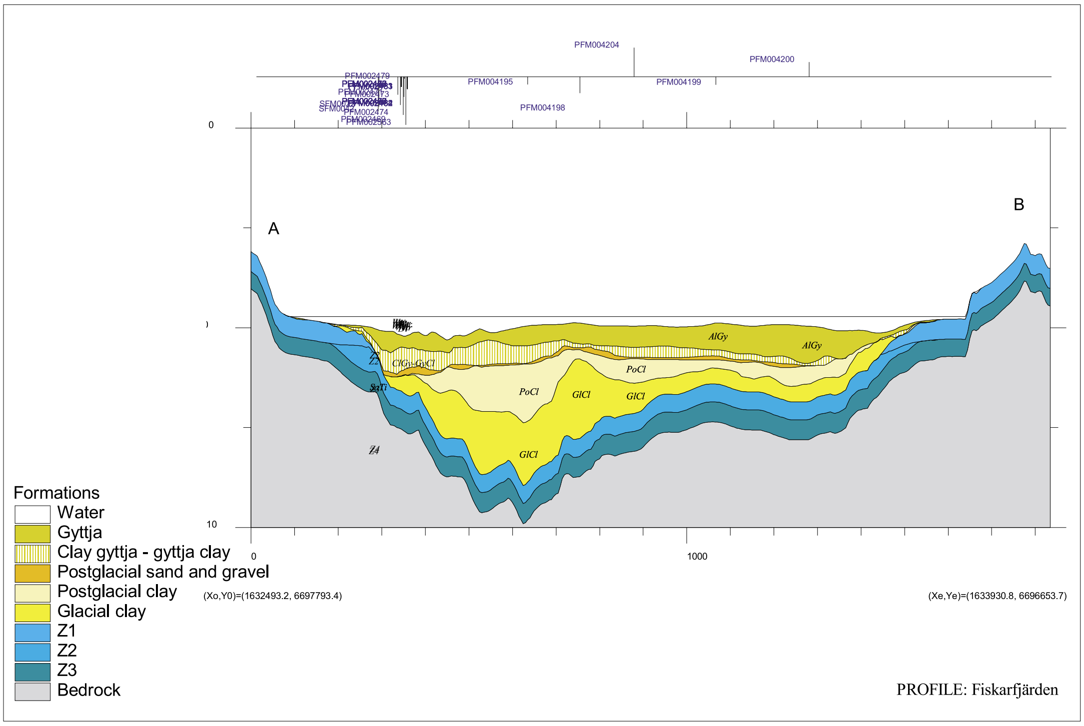

__Figure 5-6.__ Lake sediments and total soil depth along a profile through Lake Fiskarfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.

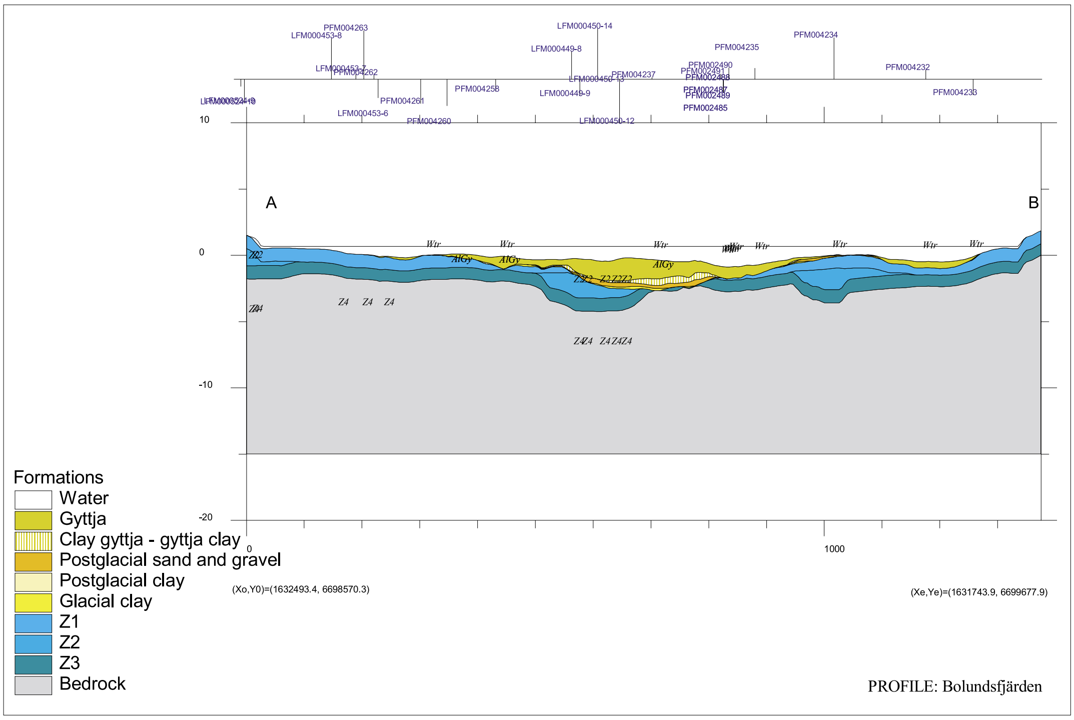

__Figure 5-7.__ Lake sediments and total soil depth along a profile through Lake Bolundsfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.

Additional profiles of lake sediments are presented in Appendix IV.

5.3 Peat at Stenrösmossen

Figure 5-8 shows a profile through the peat formation Stenrösmossen. The peat formation covers a layer of clayey gyttja that is not illustrated in the profile below.

The stratigraphy and chemical composition of the peat in Stenrösmossen has been described by /Fredriksson, 2004/.

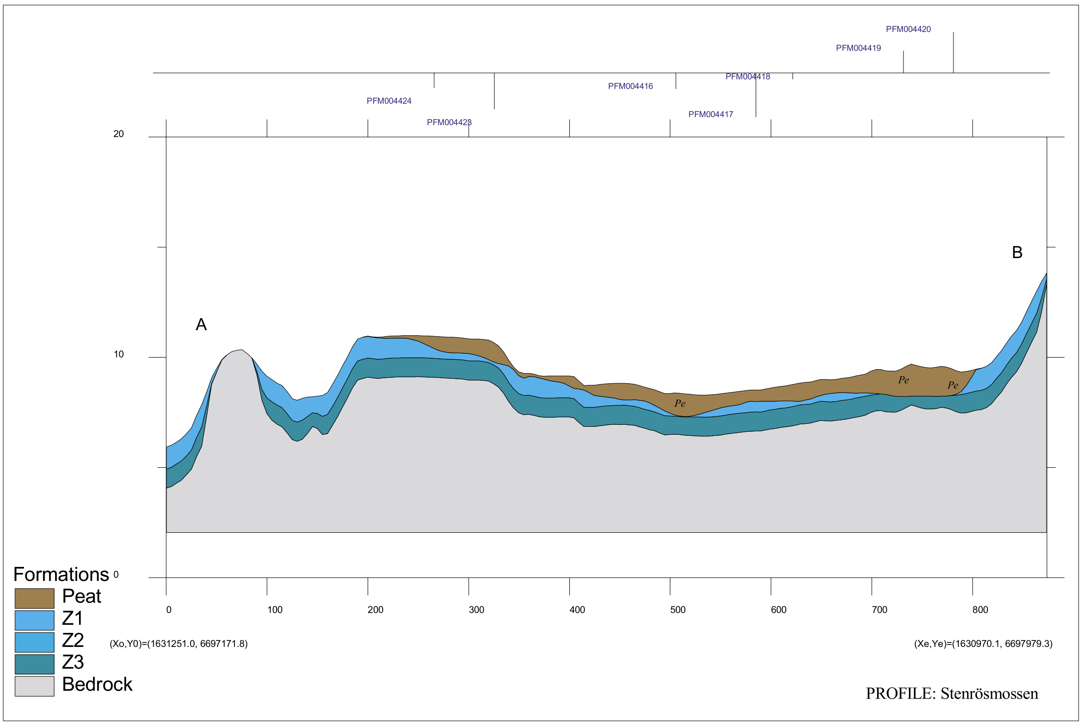

Figure 5-8. *Peat formation in a profile through Stenrösmossen. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

6 Summary and discussion

The modelled soil depths show a relatively high bedrock surface elevation and thus small total soil depth in the major part of the area. The median soil depth has been calculated to 1.9 m, based on interpolated model results in areas with higher data density. The modelled median soil depth is affected from areas with bedrock outcrop that have been included in the interpolation. The total median soil depth calculated directly from input data is 3.03 m.

The maximum modelled soil depth is about 13 m, just north of Lake Stocksjön.

The sediment layers in lakes generally consist of a bottom layer of glacial and postglacial clay, covered by sand and gravel and number of nested layers of various kinds of gyttja. Lake Bolundsfjärden show a different sediment structure than most of the other lakes as the bottom layer of clay is missing in major parts.

The lakes are shallow with sediment layers from a few decimetres to around 8 m.

6.1 Uncertainties and furher development of the model

It should be noted that the model presented in this report is a first simplified model version of the Forsmark site where some generalisation and simplifications 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 more limited.

The data density is shown in Figure 6-1. Areas dominated by shallow observation points and areas of a generally low data density have the highest uncertainty. Areas of low data density with respect to actual bedrock surface are marked with red rectangles in the figure below.

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.

The calculated median soil depth from input data is around 1 m larger than the modelled median soil depth. The lower result from the interpolated results is due to the impact of bedrock outcrop in the model area. Using the median soil depth based on input data instead of the modelled median soil depth may give a better description of the deposits in the area. If different zones of different characteristic median soil depth can be defined, the model can be upgraded to use specific median soil depths in different areas.

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 decrease the number of points where corrections have to be made to avoid layers above surface elevations or where the total soil depth is overestimated. Overestimation of total soil depth can occur when the elevation of the observation is lower than the topography, as the layers are interpolated through fixed values in observation points and not in relation to surface elevations.

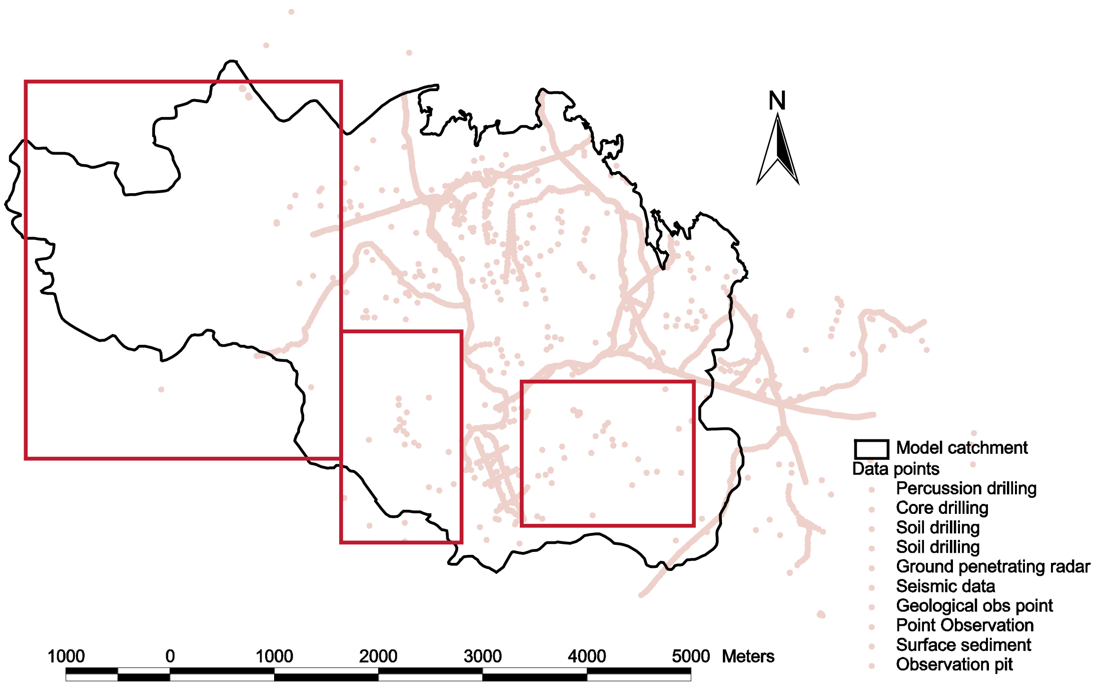

Figure 6-1. *Data density marked with areas of higher uncertainties in the results.*

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 soil depth from other types of input data, such as estimation of areas with low respectively higher soil depth, based on e.g. the Quaternary deposits 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 hydraulic properties. For example, the layer affected by surface processes, vegetation and biological activity might be smaller than one meter.

The model can also be updated with actual geological formations that include the distribution from the map of Quaternary deposits in the area.

6.2 Further use of the model

The model and databases can be updated as more data is available. The model presented in this report is a first simplified 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, geo chemistry and transport mechanisms.

The model may be used as input data for hydrogeological modelling of the area. The model and modelling system can also be used for result presentation from groundwater models and is especially compatible with MIKE SHE.

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

7 References

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Datafiles stored in SKB's GIS-database

Filename	Content of file	Reference
litfil1	Lithology database of observations	SDEADM.DHI_FM_GEO_2475
newadm2	Administrative database of observations	SDEADM.DHI_FM_GEO_2476
ll_calcgy	Modelled lower level of lake sediment calcareous gyttja	SDEADM.DHI_FM_GEO_2477
ll_clgy-gycl	Modelled lower level of lake sediment calcareous clay gyttja-gyttja clay	SDEADM.DHI_FM_GEO_2478
ll_glacclay	Modelled lower level of lake sediment calcareous glacial clay	SDEADM.DHI_FM_GEO_2479
ll_gyttja	Modelled lower level of lake sediment calcareous gyttja	SDEADM.DHI_FM_GEO_2480
ll_peat	Modelled lower level of peat at Stenrösmossen	SDEADM.DHI_FM_GEO_2481
ll_posagr	Modelled lower level of lake sediment postglacial sand and gravel	SDEADM.DHI_FM_GEO_2482
ll_postglclay	Modelled lower level of lake sediment postglacial clay	SDEADM.DHI_FM_GEO_2483
ll_z1	Modelled lower level of geological layer Z1	SDEADM.DHI_FM_GEO_2484
ll_z2	Modelled lower level of geological layer Z2	SDEADM.DHI_FM_GEO_2485
ll_z3	Modelled lower level of geological layer Z3	SDEADM.DHI_FM_GEO_2486

Appendix I

Administrative database of observations

The administrative database used in the GeoEditor, newadm2.dbf, is stored in SKB's GIS-database /SDEADM.DHI_FM_GEO_2476/.

Appendix II

Lithology database of observations

The lithology database used in the GeoEditor, litfil1.dbf, is stored in SKB's GIS-database /SDEADM.DHI_FM_GEO_2475/.

Appendix III

Profiles with interpreted geological layers

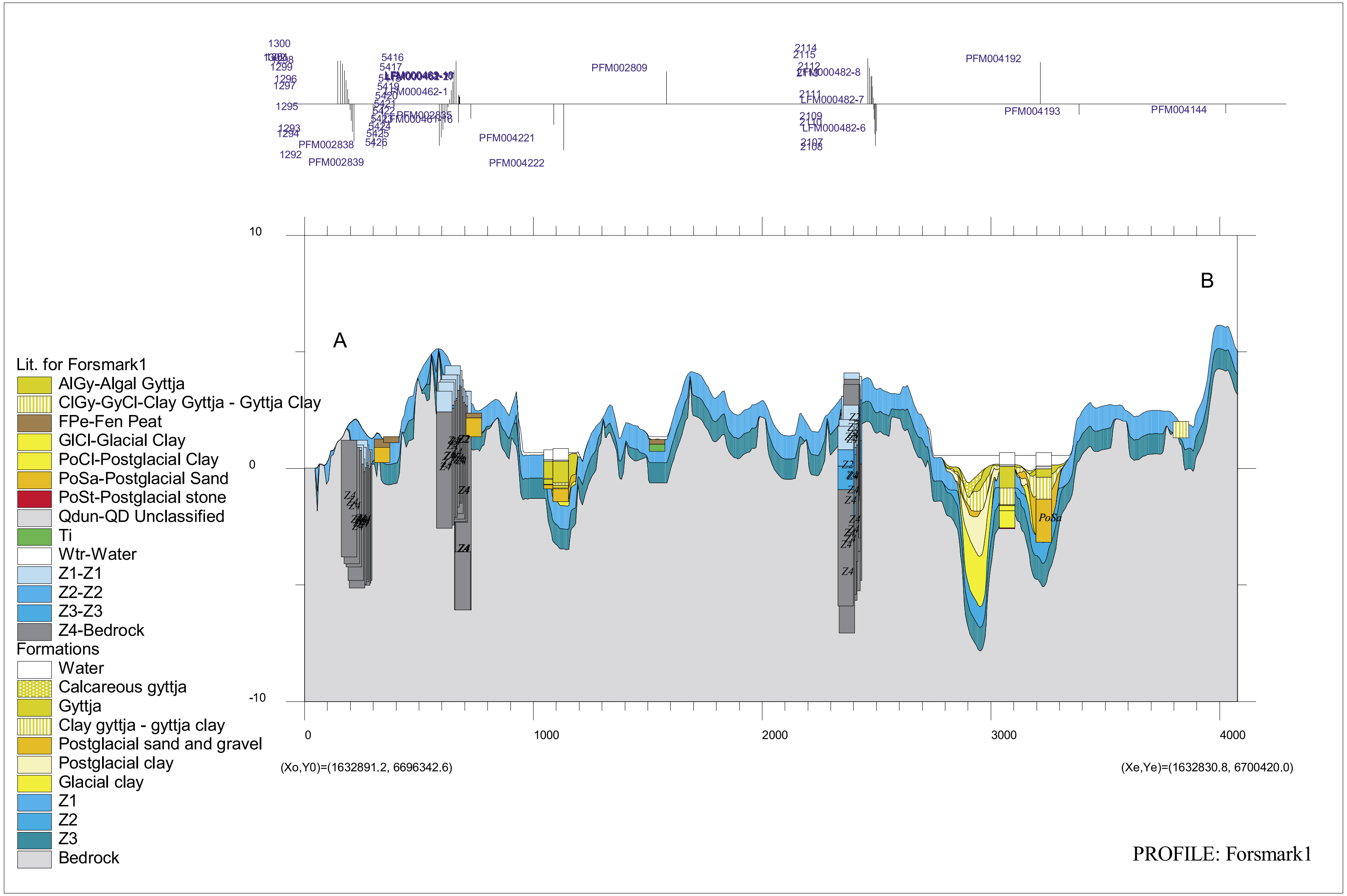

Figure III-1. *Lithology and formations for profile Forsmark 1. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

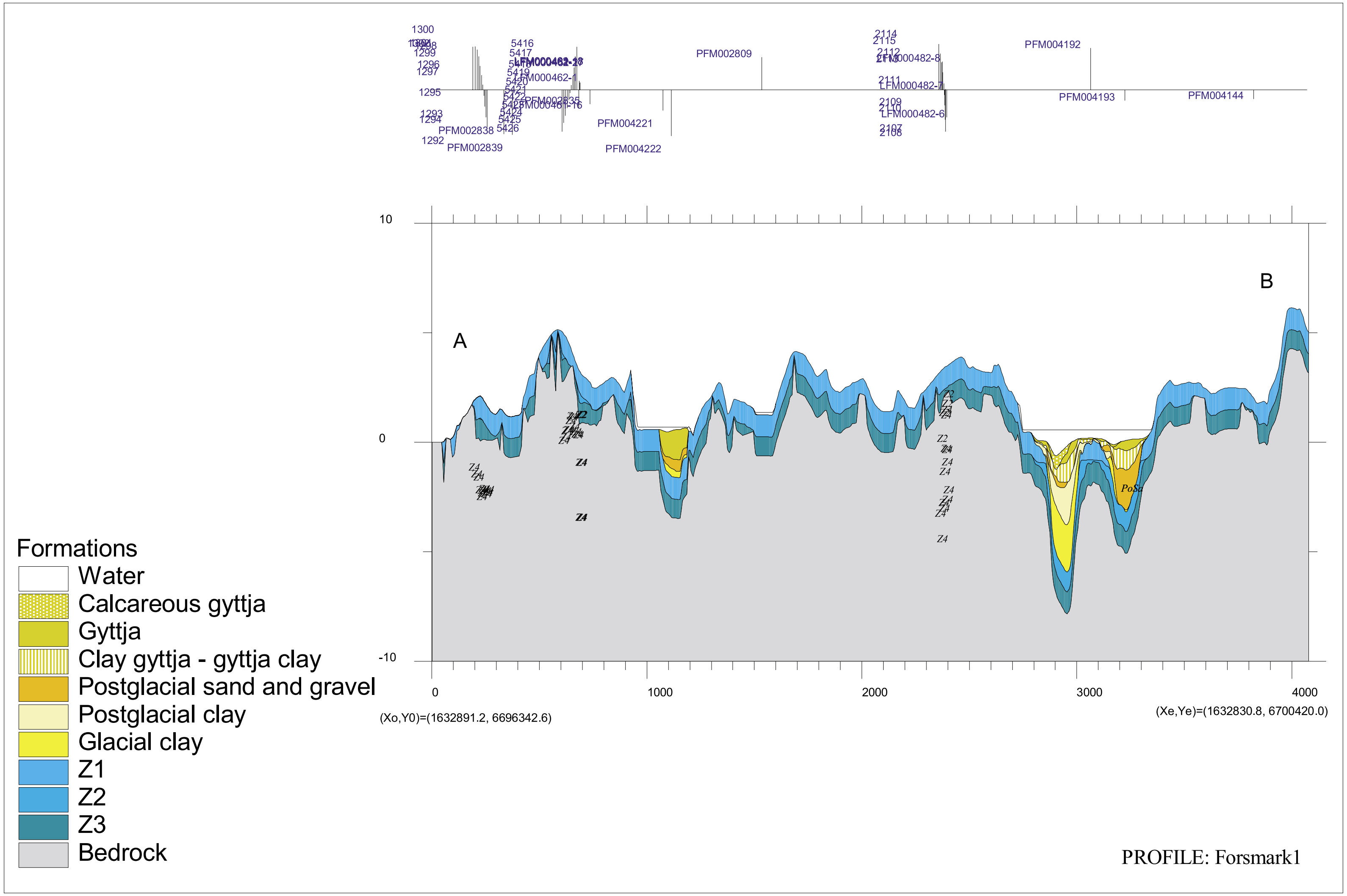

Figure III-2. *Formations for profile Forsmark 1. The observation points included are displayed above the profile. For location of the profile, Figure 5-2.*

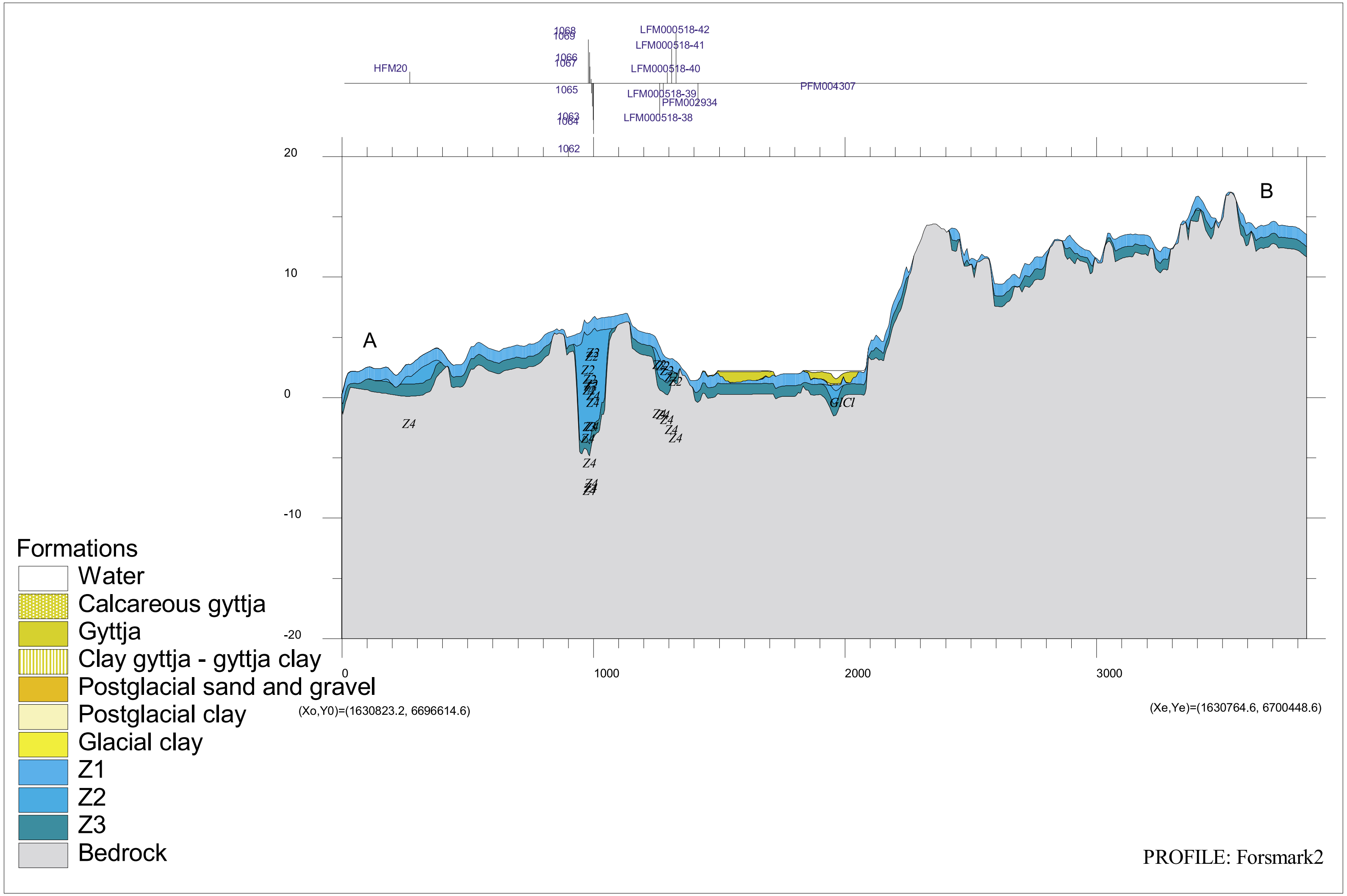

Figure III-3. *Lithology and formations for profile Forsmark 2. The observation points included are displayed above the profile. For location of the profile,see Figure 5-2.*

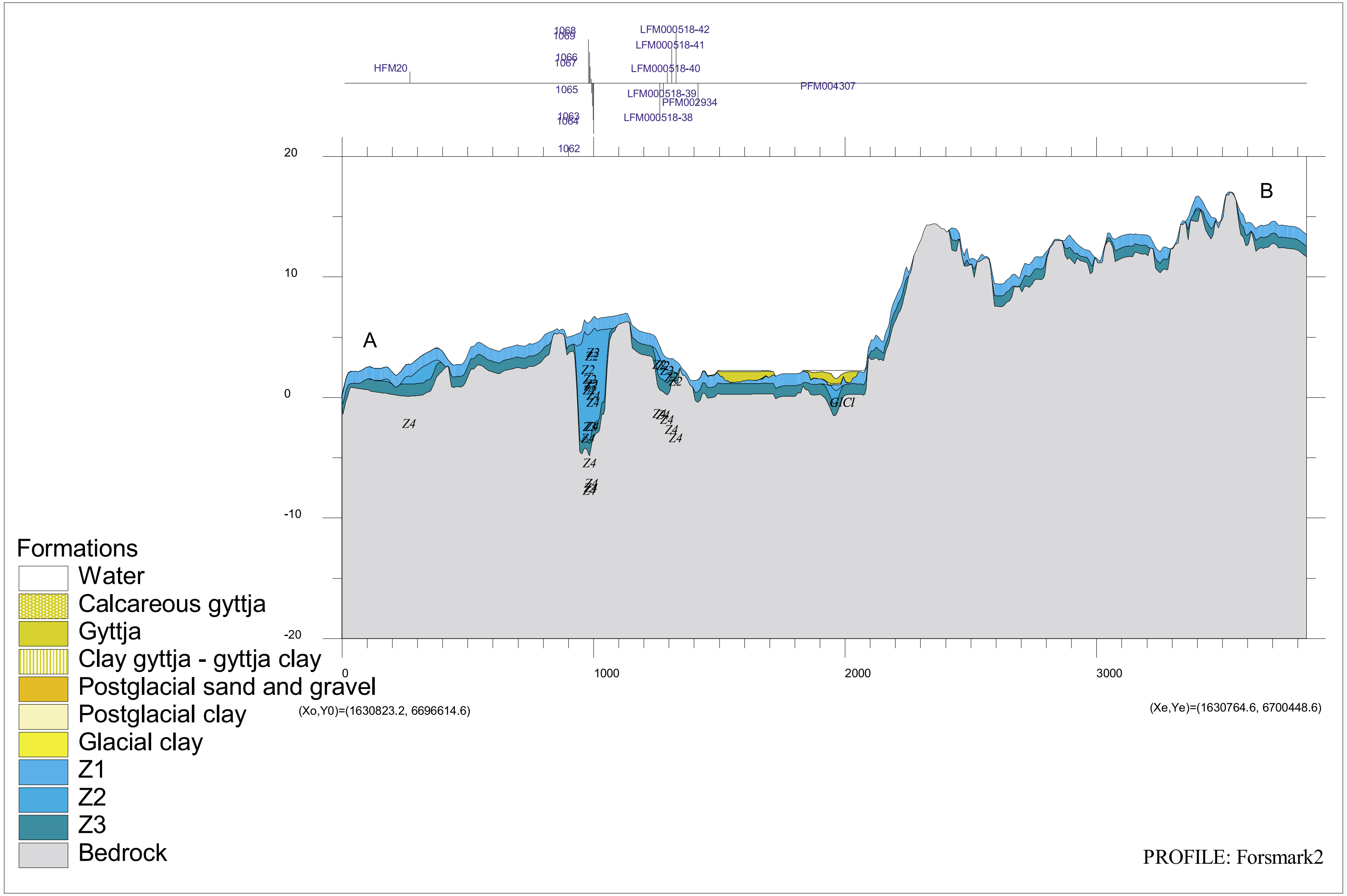

Figure III-4. *Formations for profile Forsmark 2. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

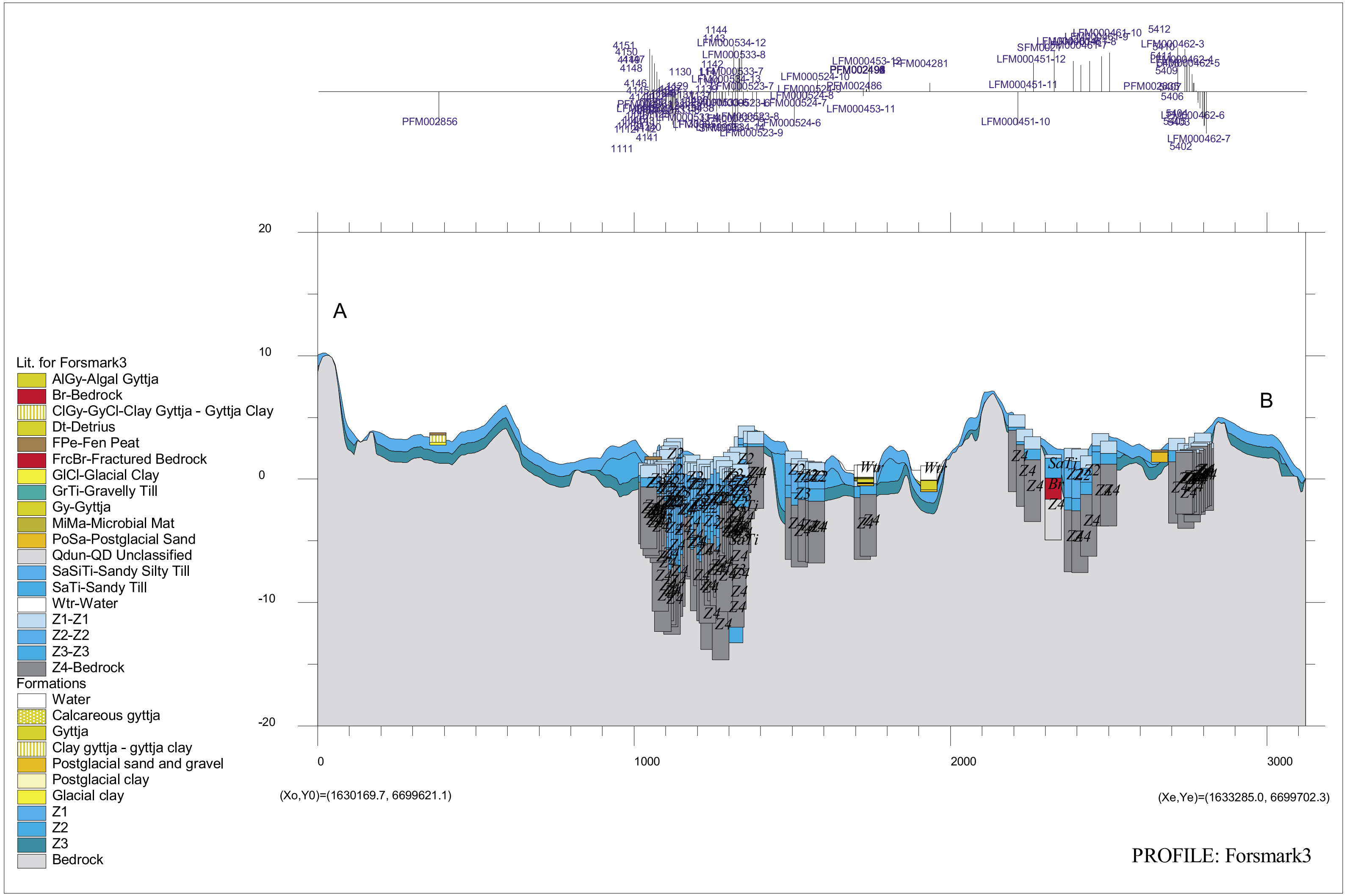

Figure III-5. *Lithology and formations for profile Forsmark 3. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

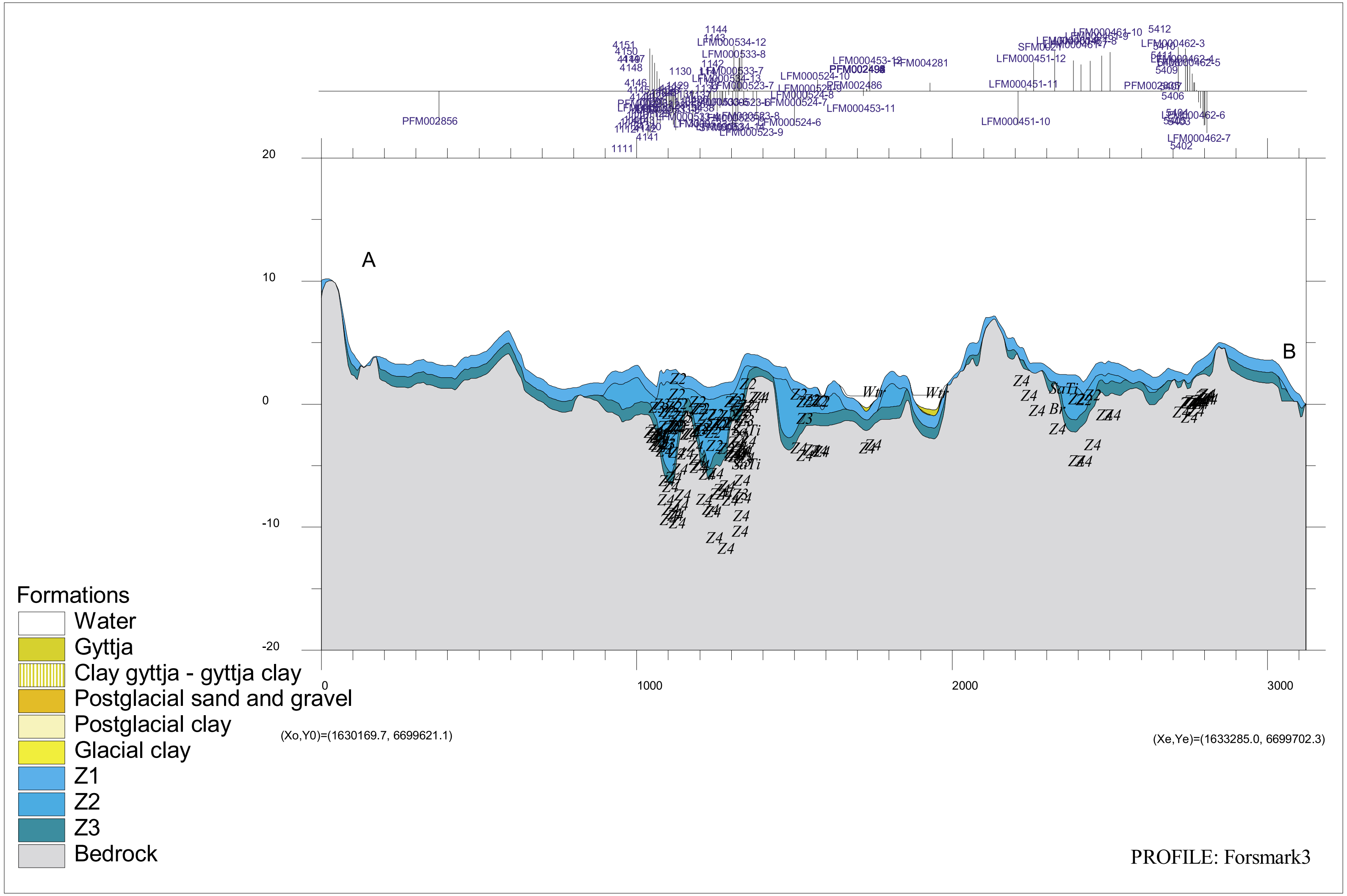

Figure III-6. *Formations for profile Forsmark 3. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

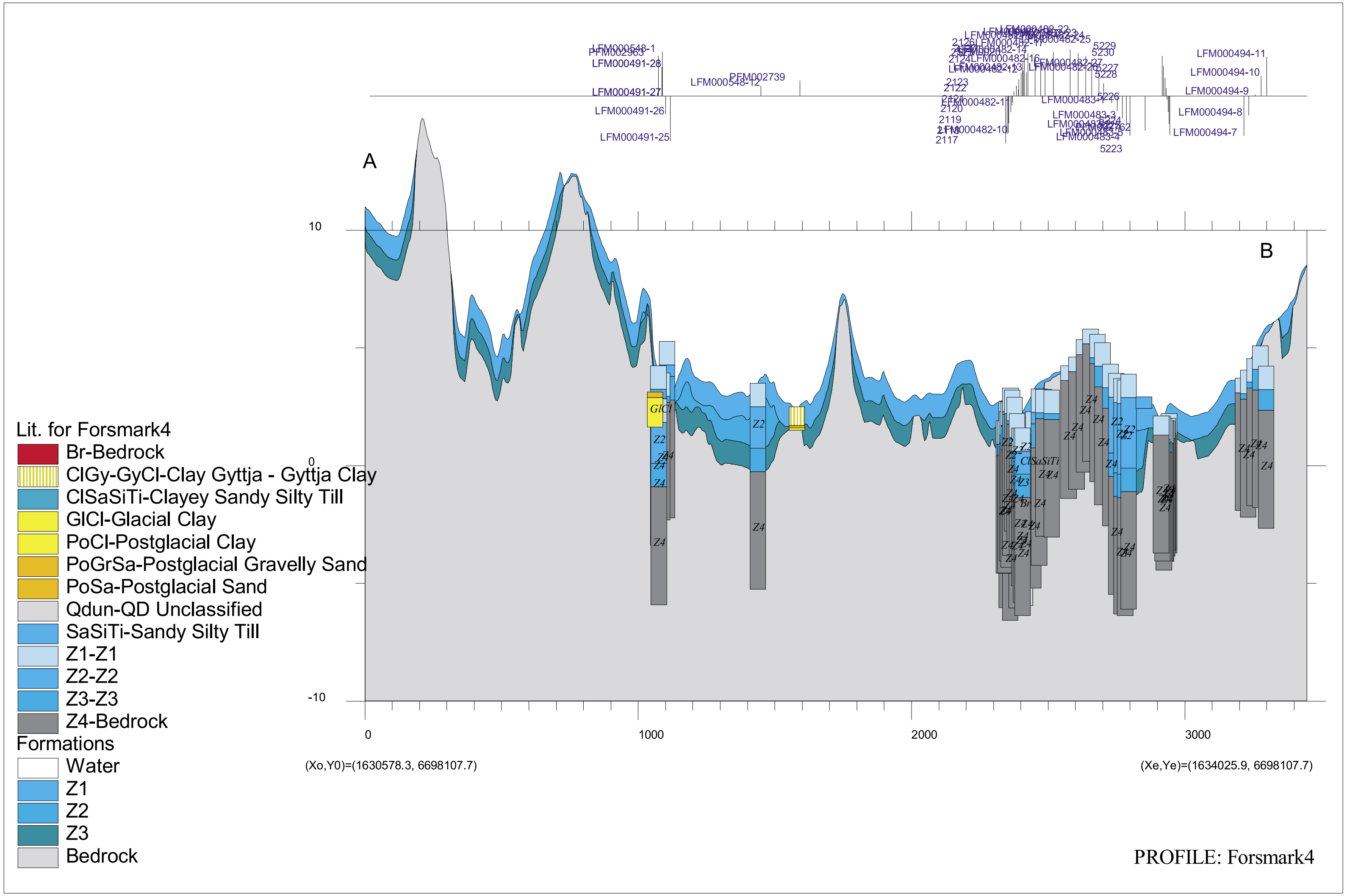

Figure III-7. *Lithology and formations for profile Forsmark 4. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

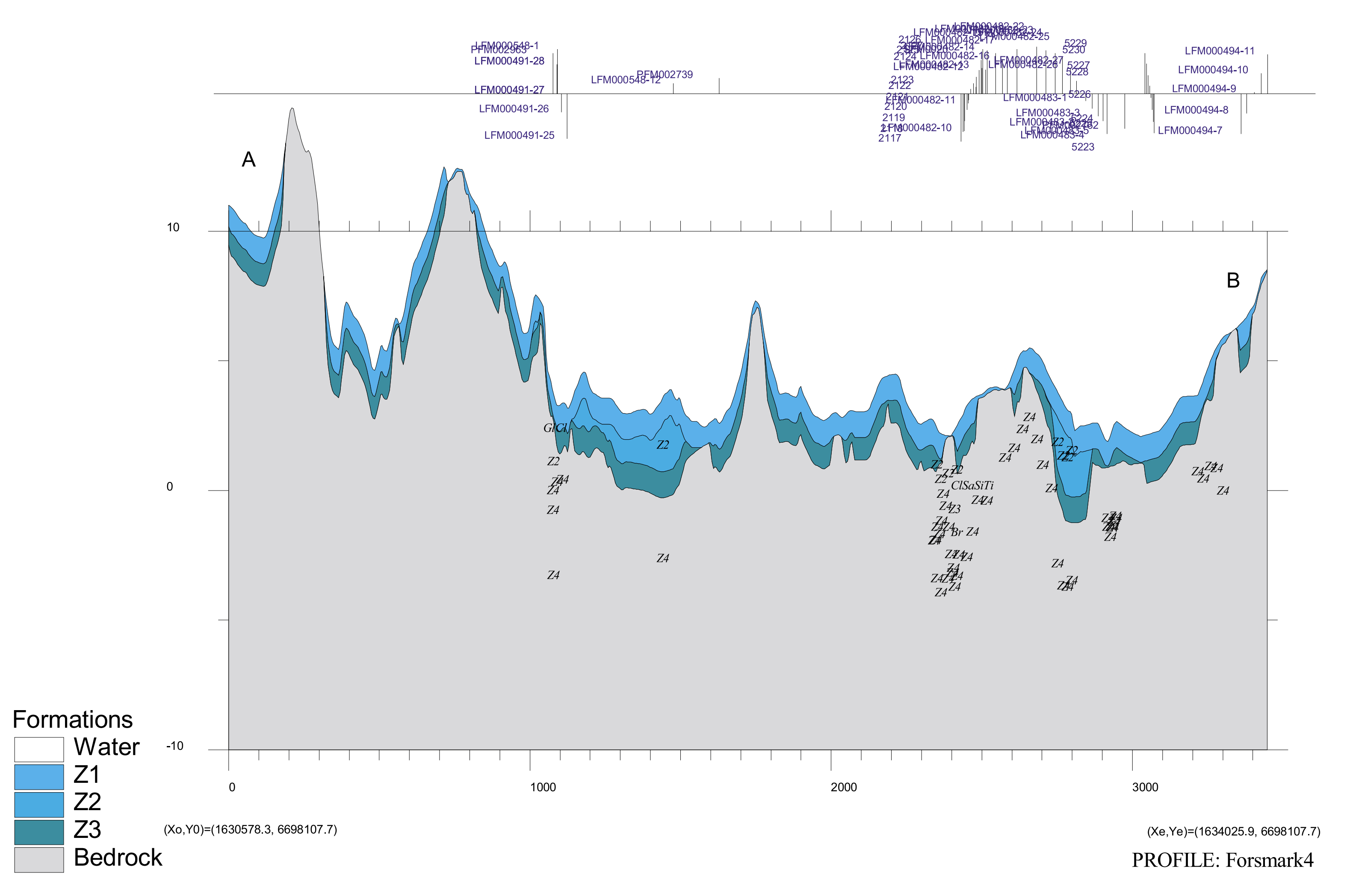

Figure III-8. *Formations for profile Forsmark 4. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

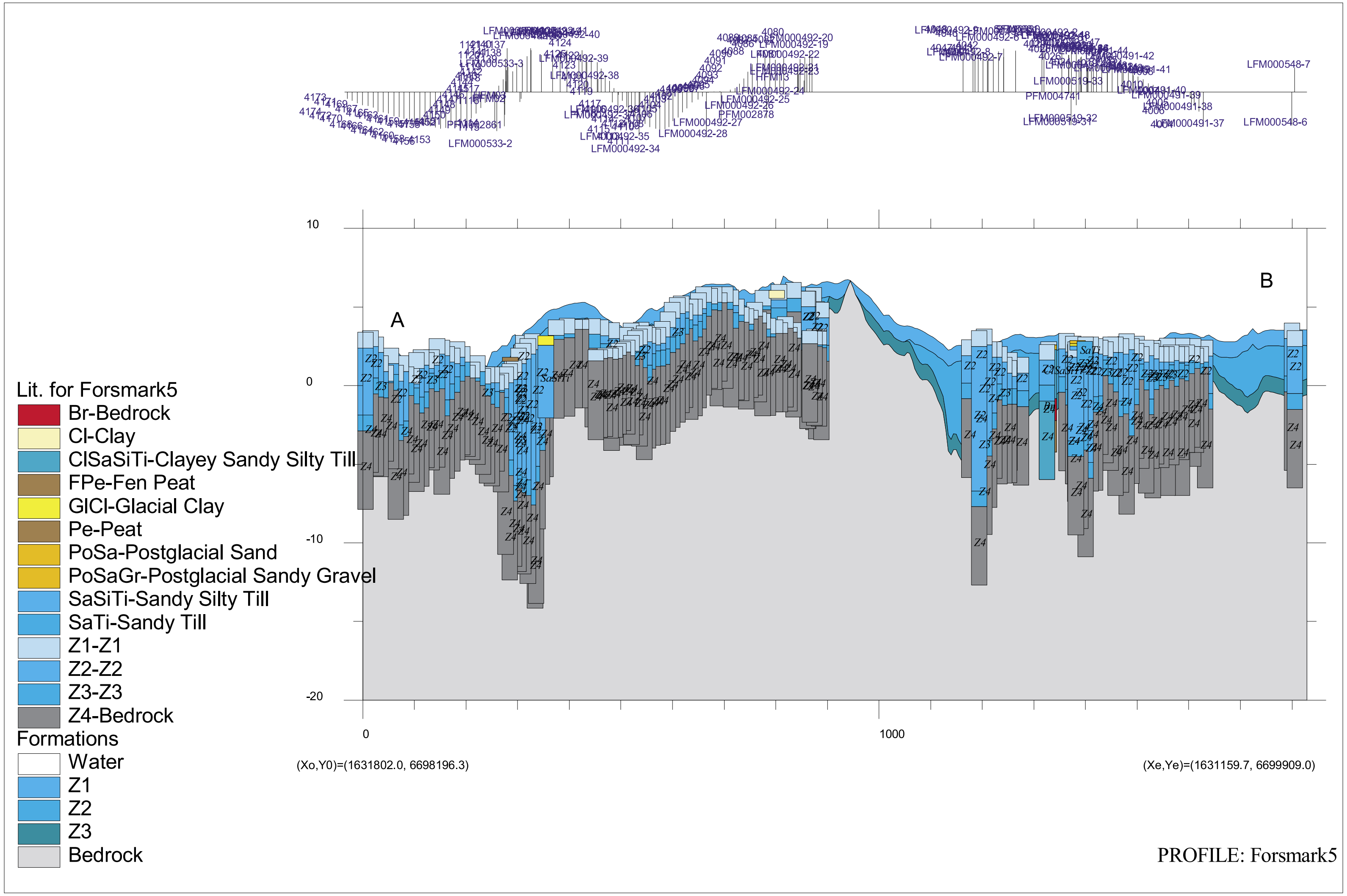

Figure III-9. *Lithology and formations for profile Forsmark 5. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

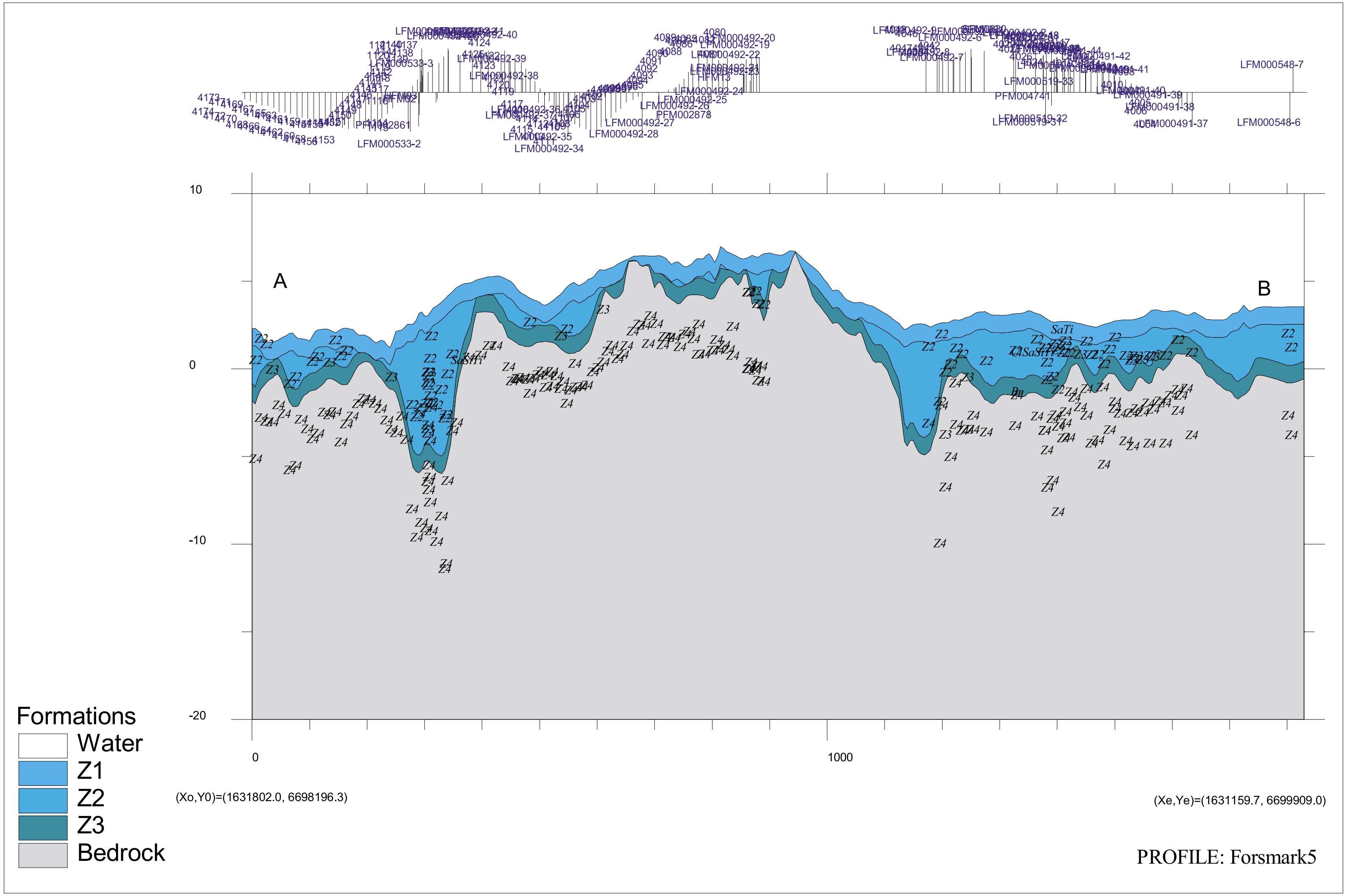

Figure III-10. *Formations for profile Forsmark 5. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

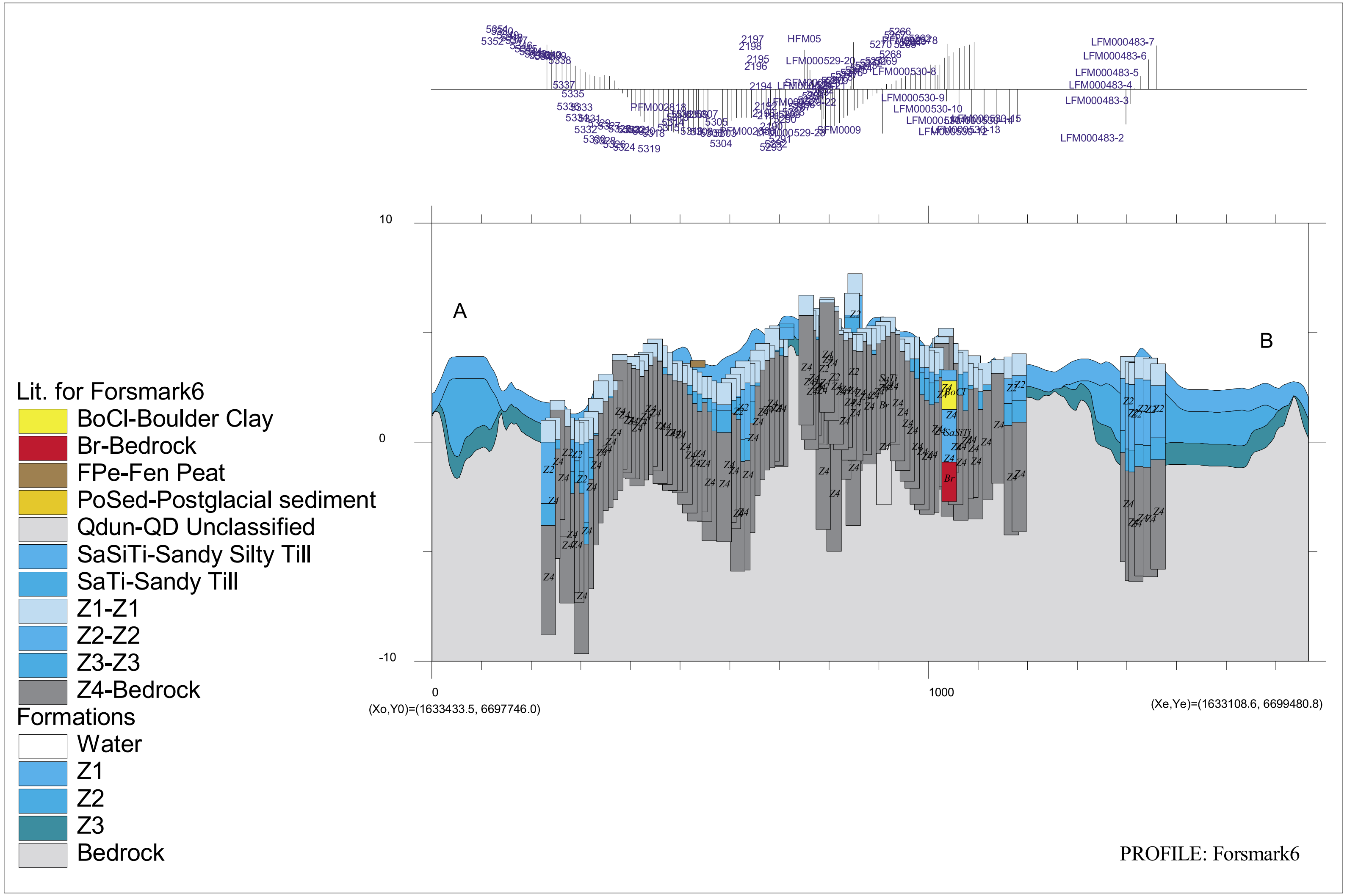

Figure III-11. *Lithology and formations for profile Forsmark 6. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

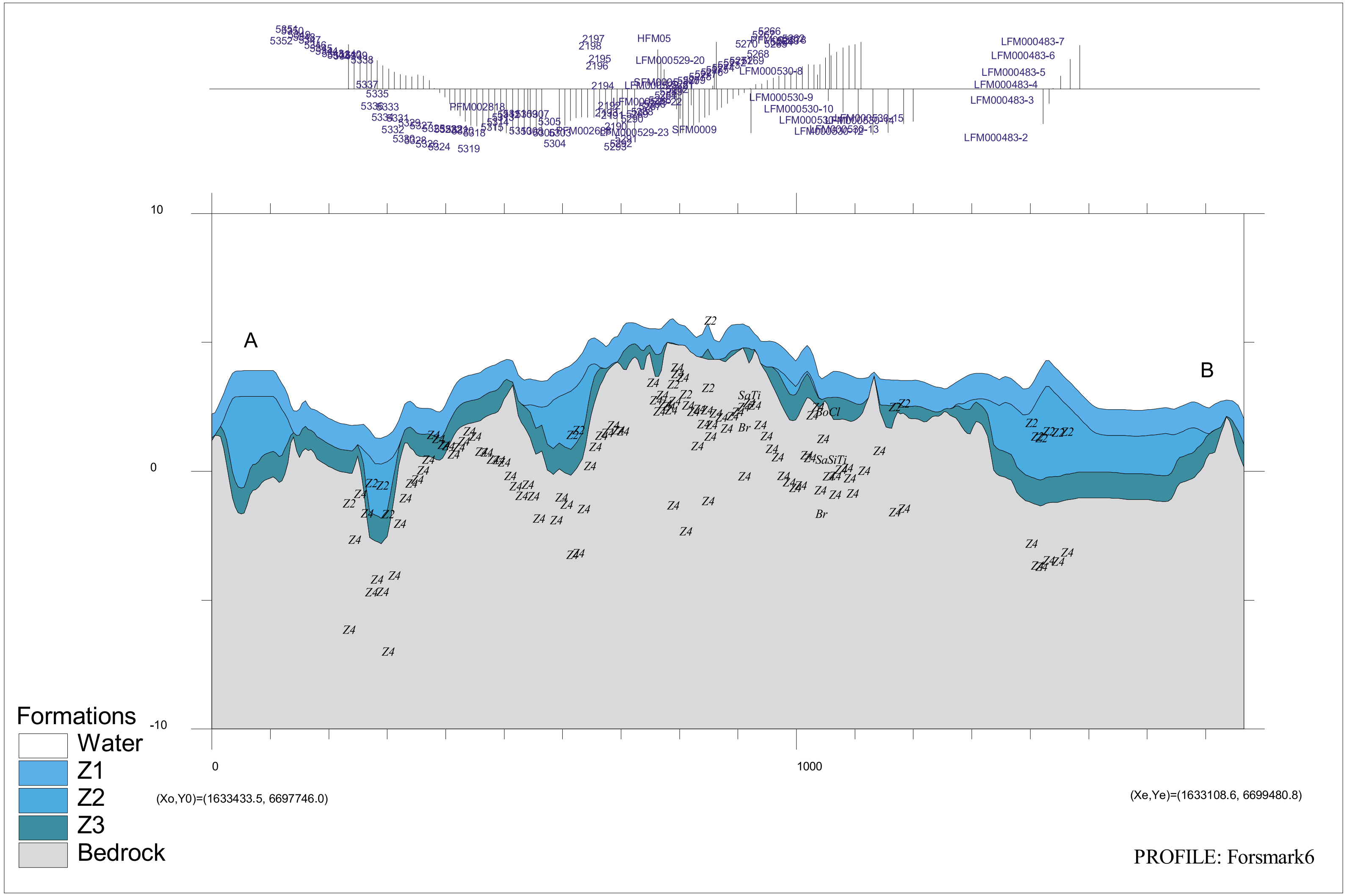

Figure III-12. *Formations for profile Forsmark 6. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

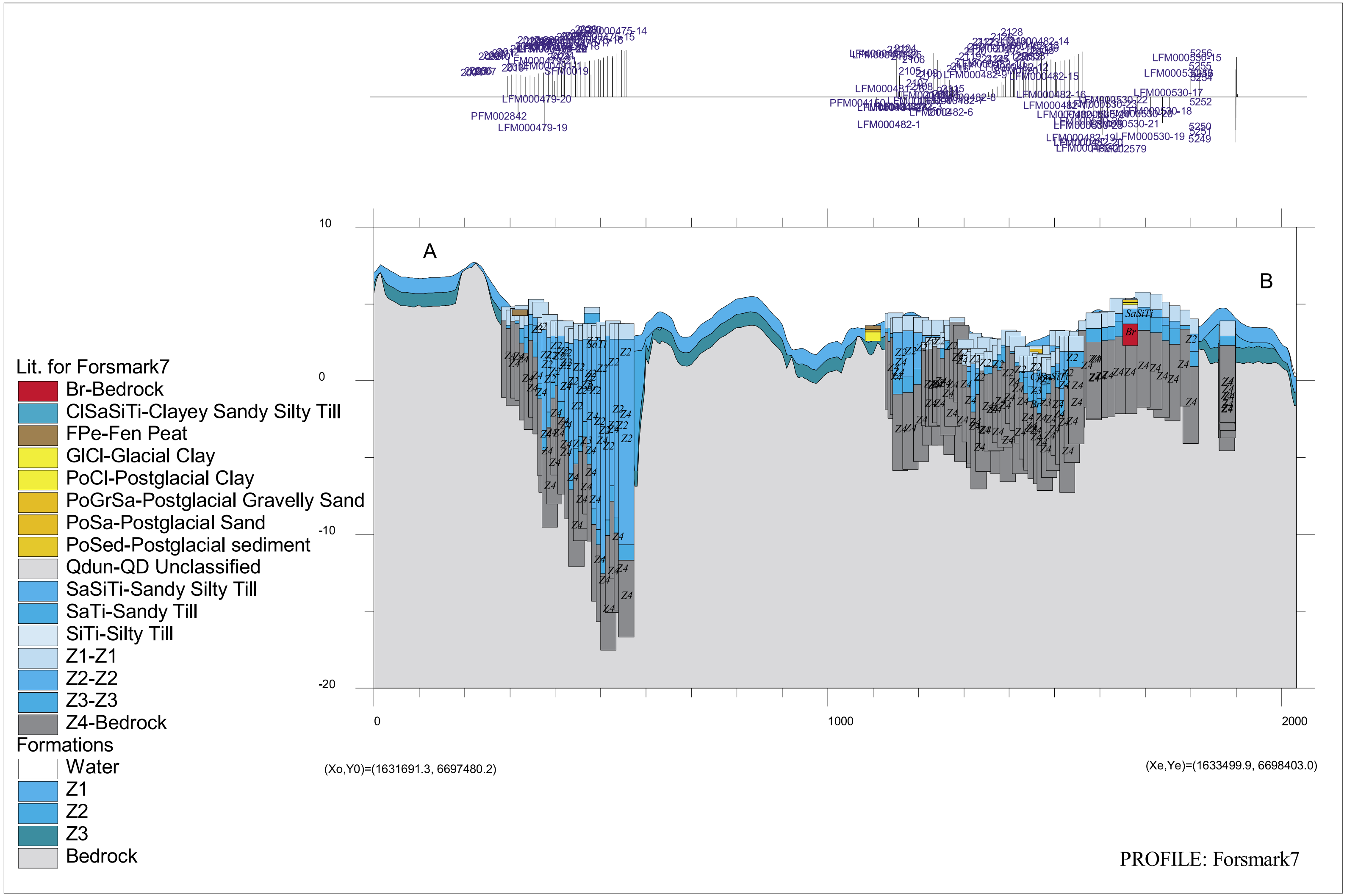

Figure III-13. *Lithology and formations for profile Forsmark 7. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

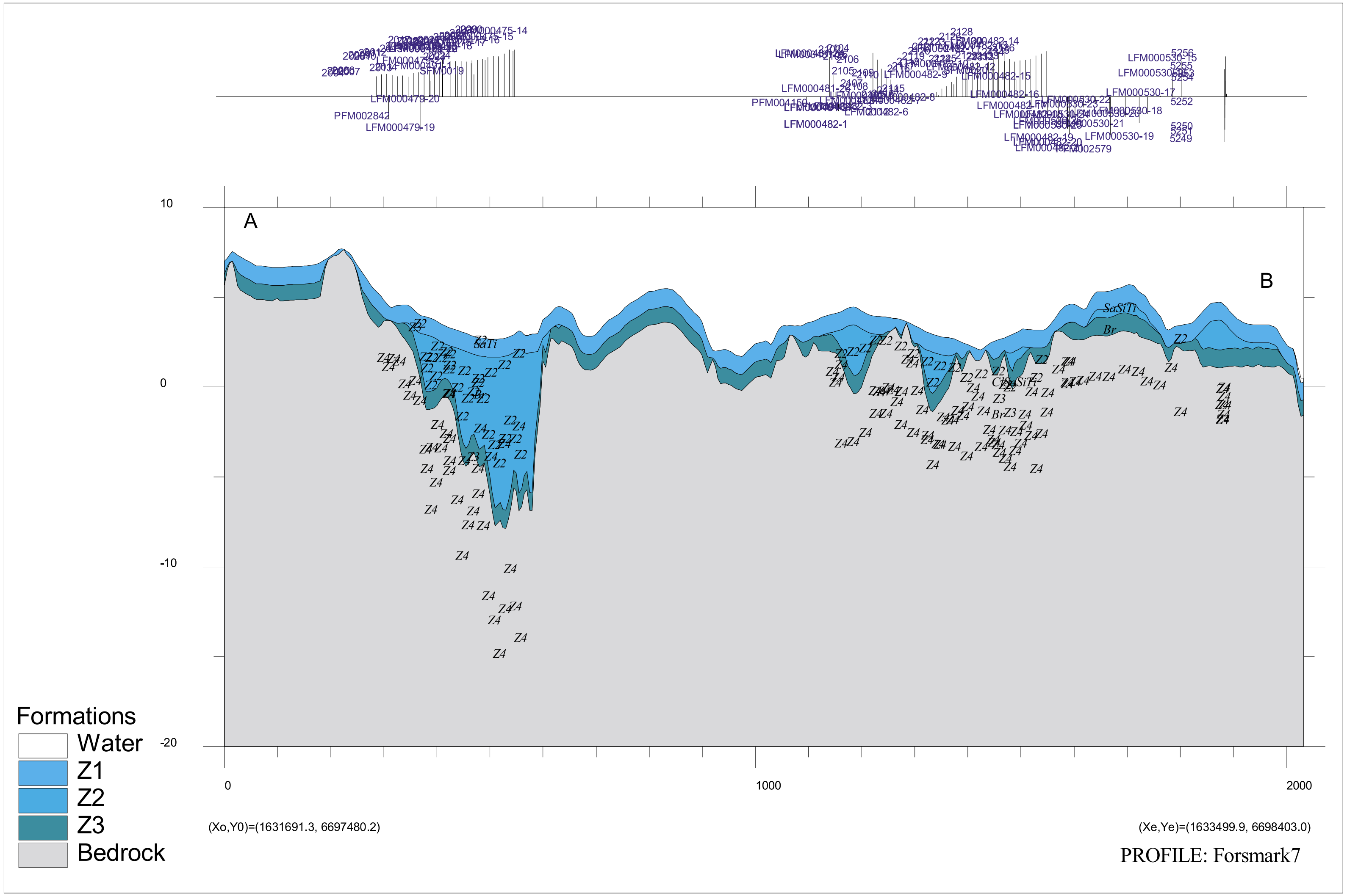

__Figure III-14.__ Formations for profile Forsmark 7. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.

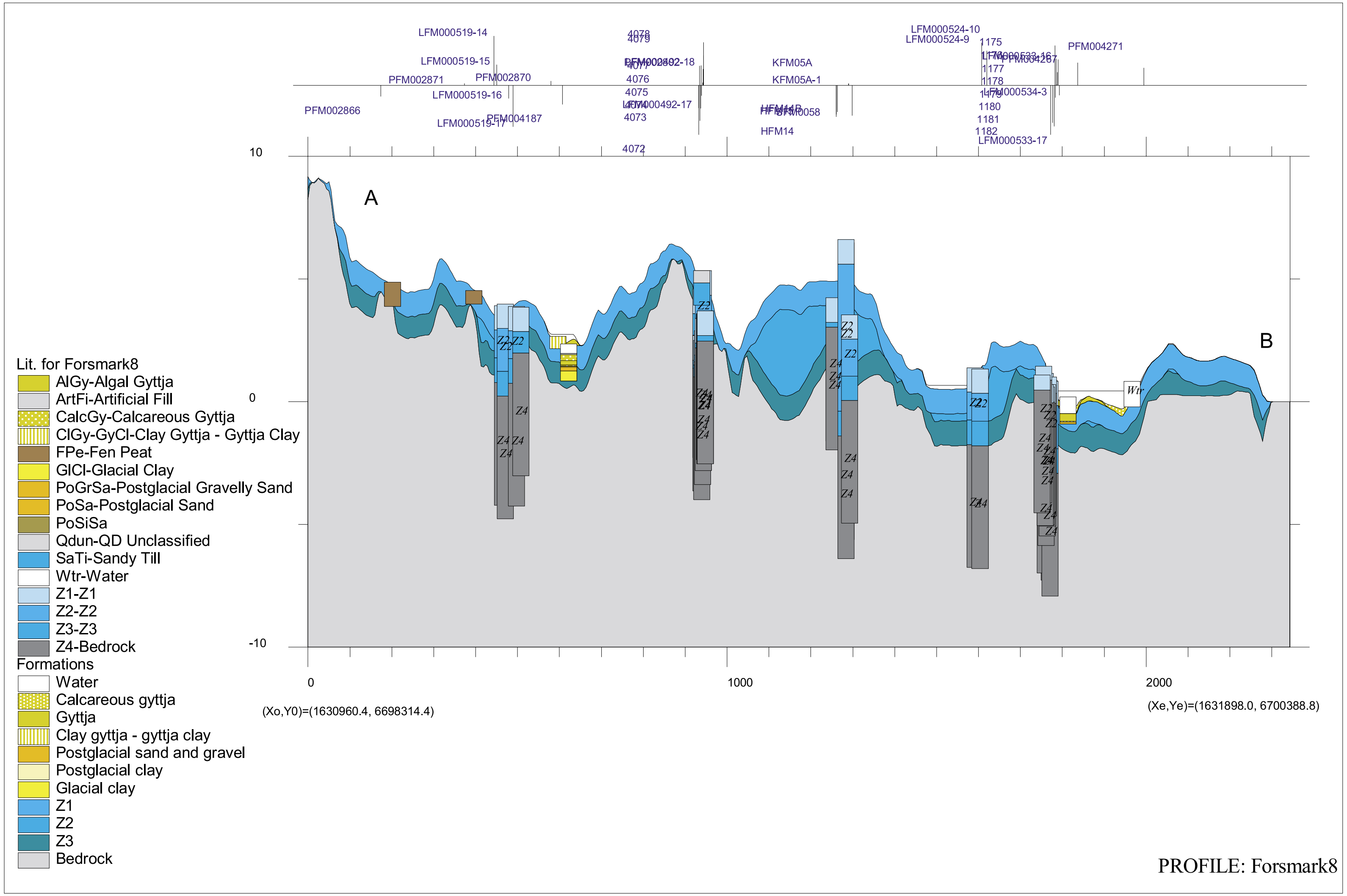

Figure III-15. *Lithology and formations for profile Forsmark 8. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

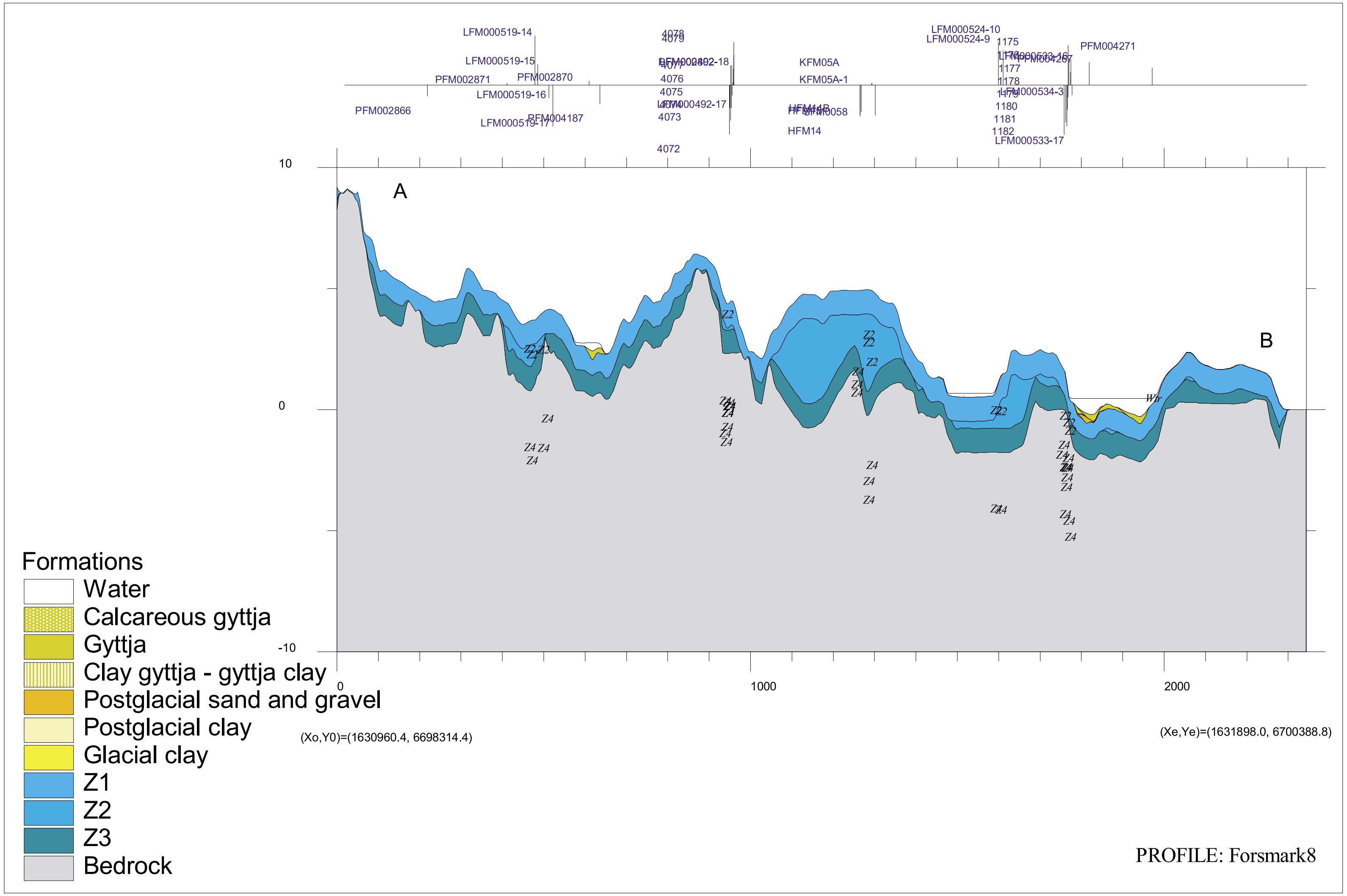

Figure III-16. Formations for profile Forsmark 8. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.

Appendix IV

Profiles with interpreted lake sediments

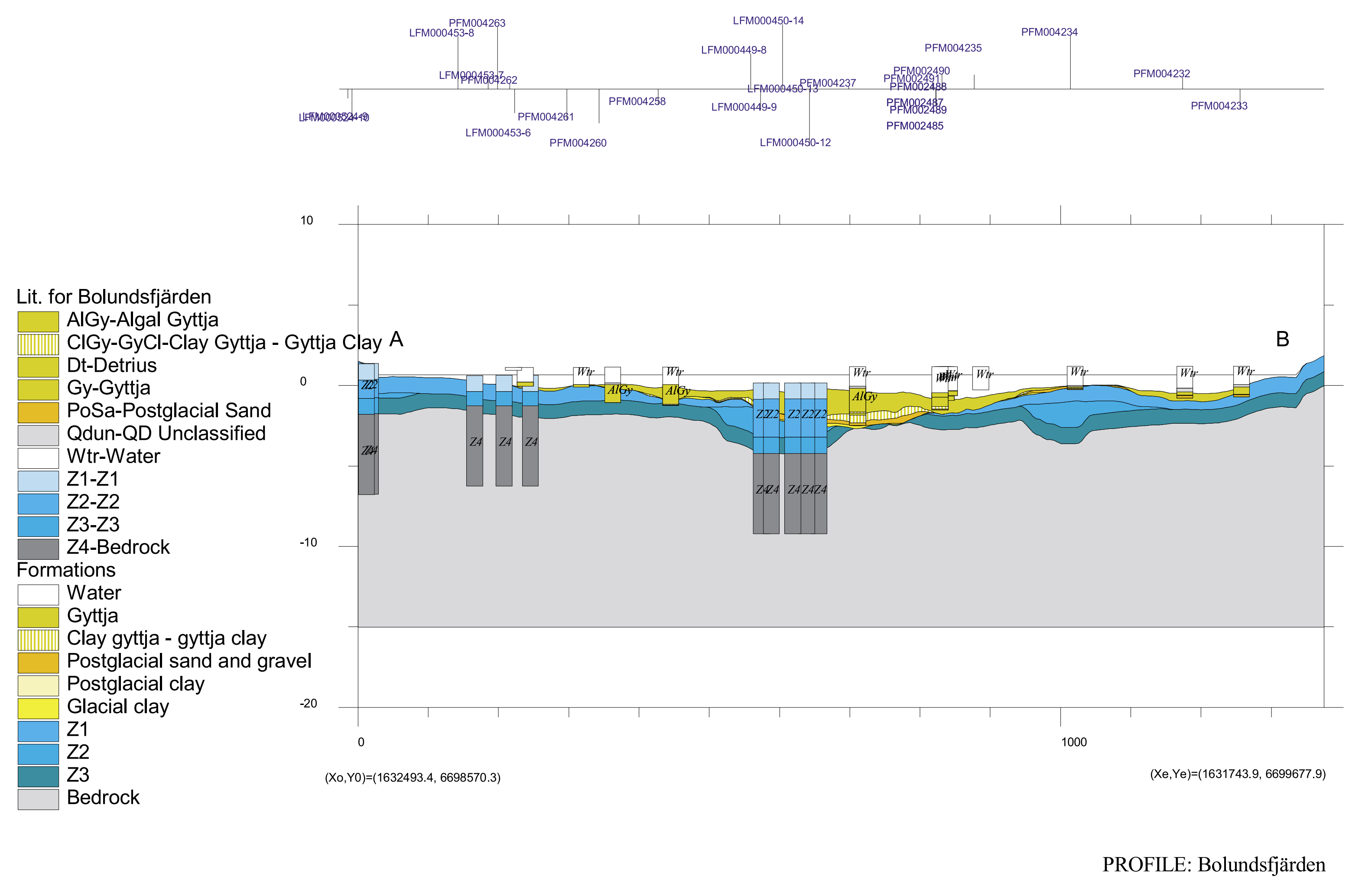

Figure IV-1. *Lithology and interpreted layers of sediment in a profile through lake Bolundsfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

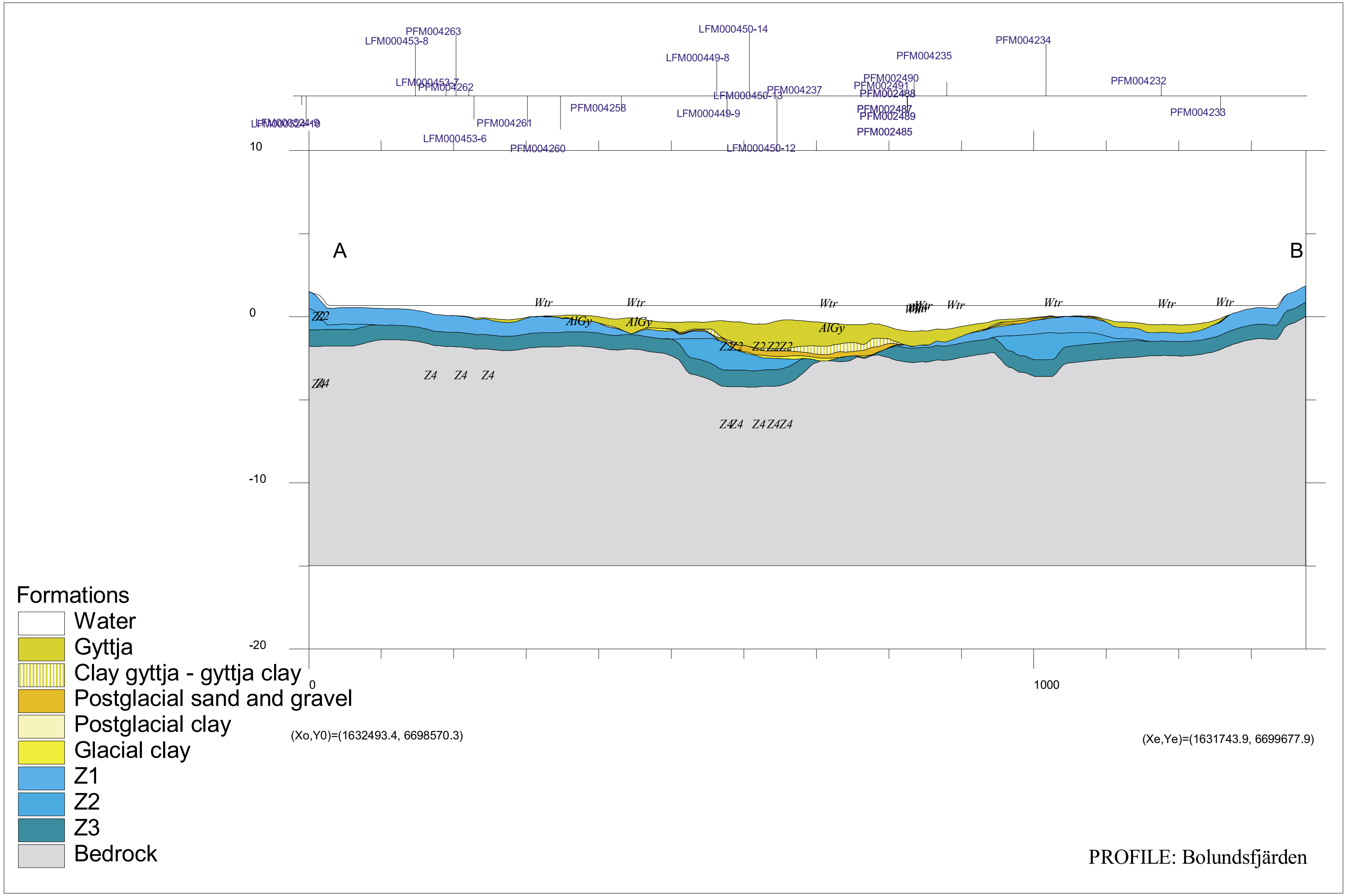

Figure IV-2. *Layers of sediments in a profile through lake Bolundsfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

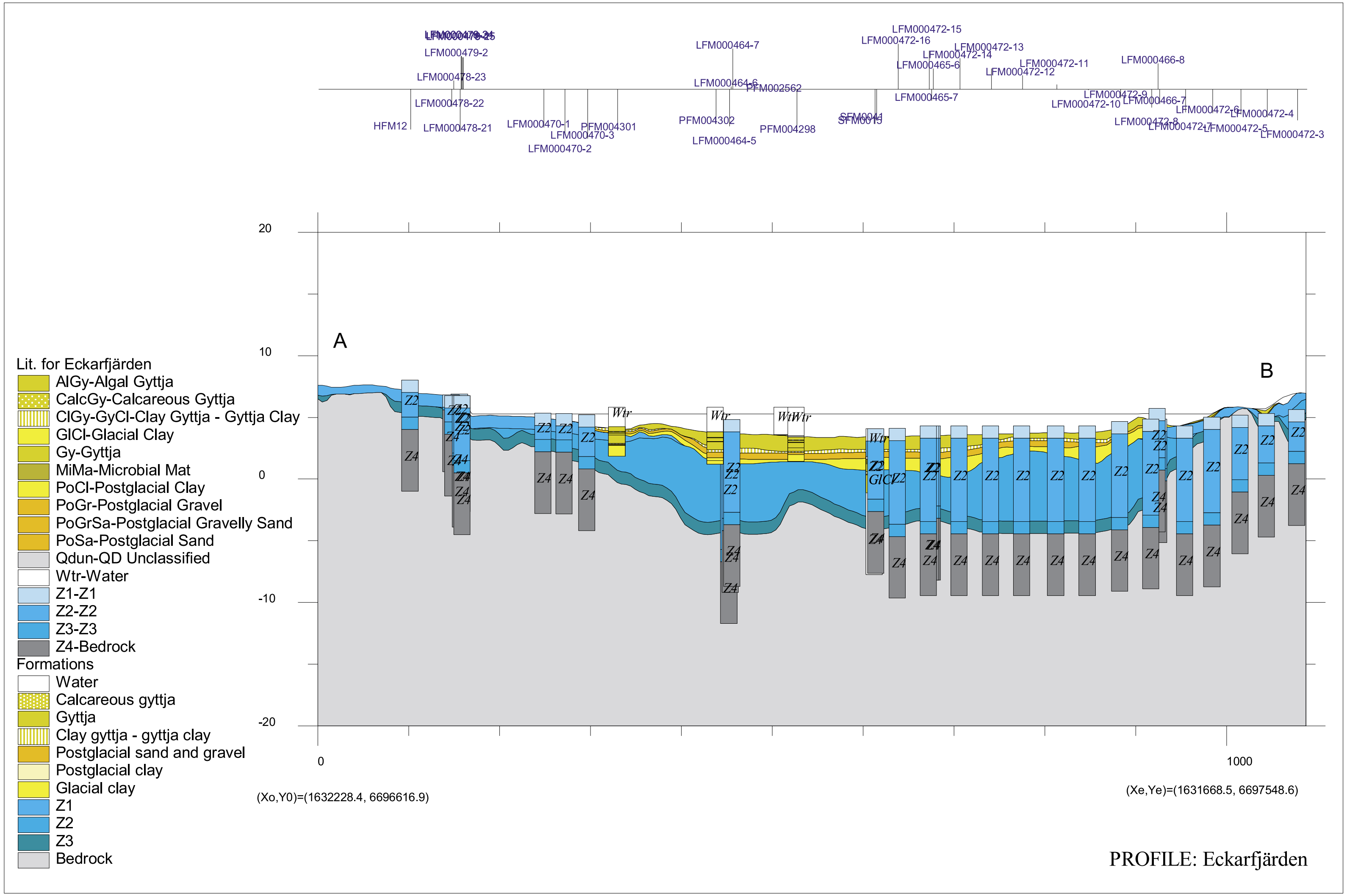

Figure IV-3. *Lithology and interpreted layers of sediment in a profile through lake Eckarfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

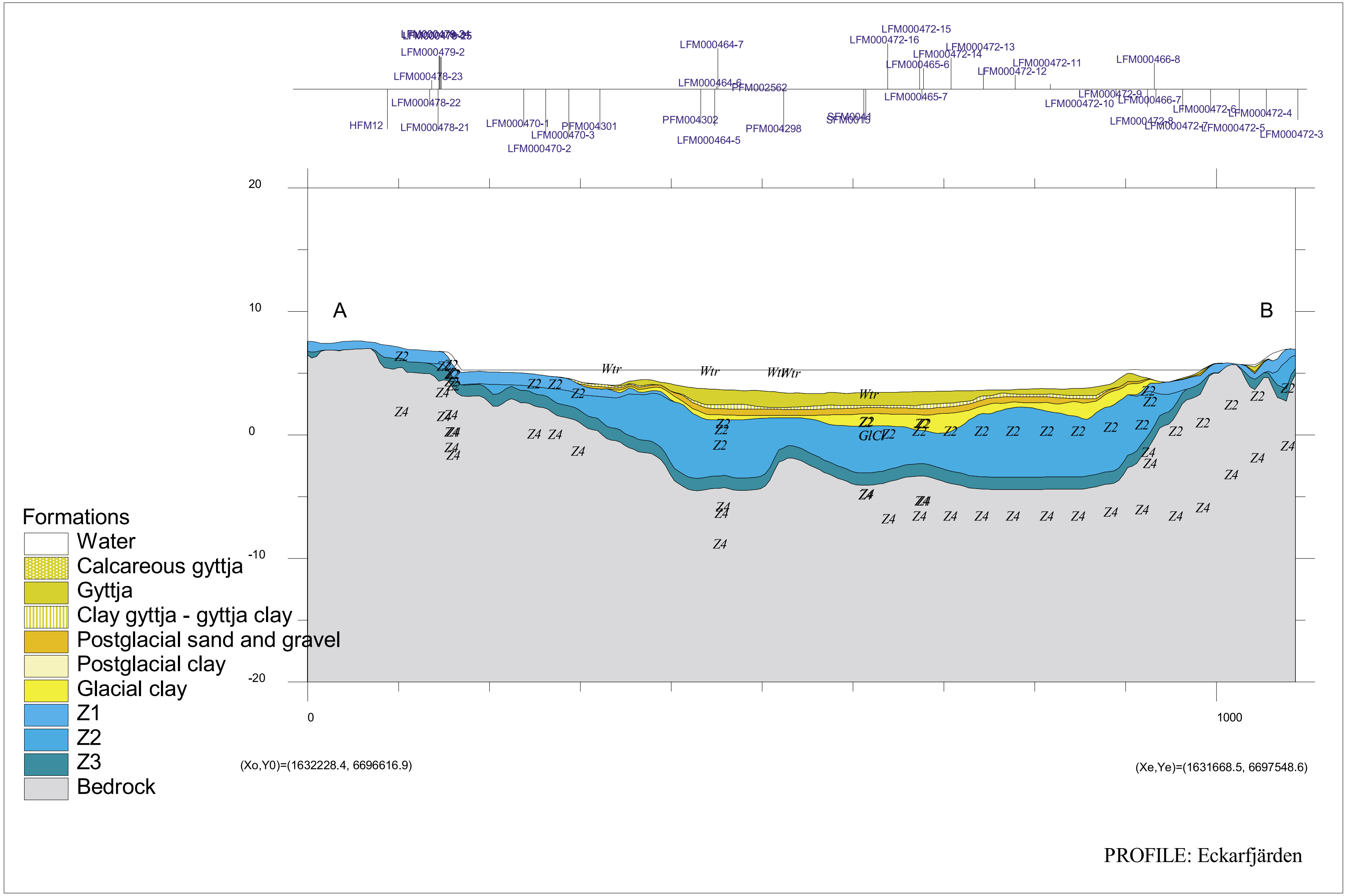

Figure IV-4. *Layers of sediment in a profile through lake Eckarfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

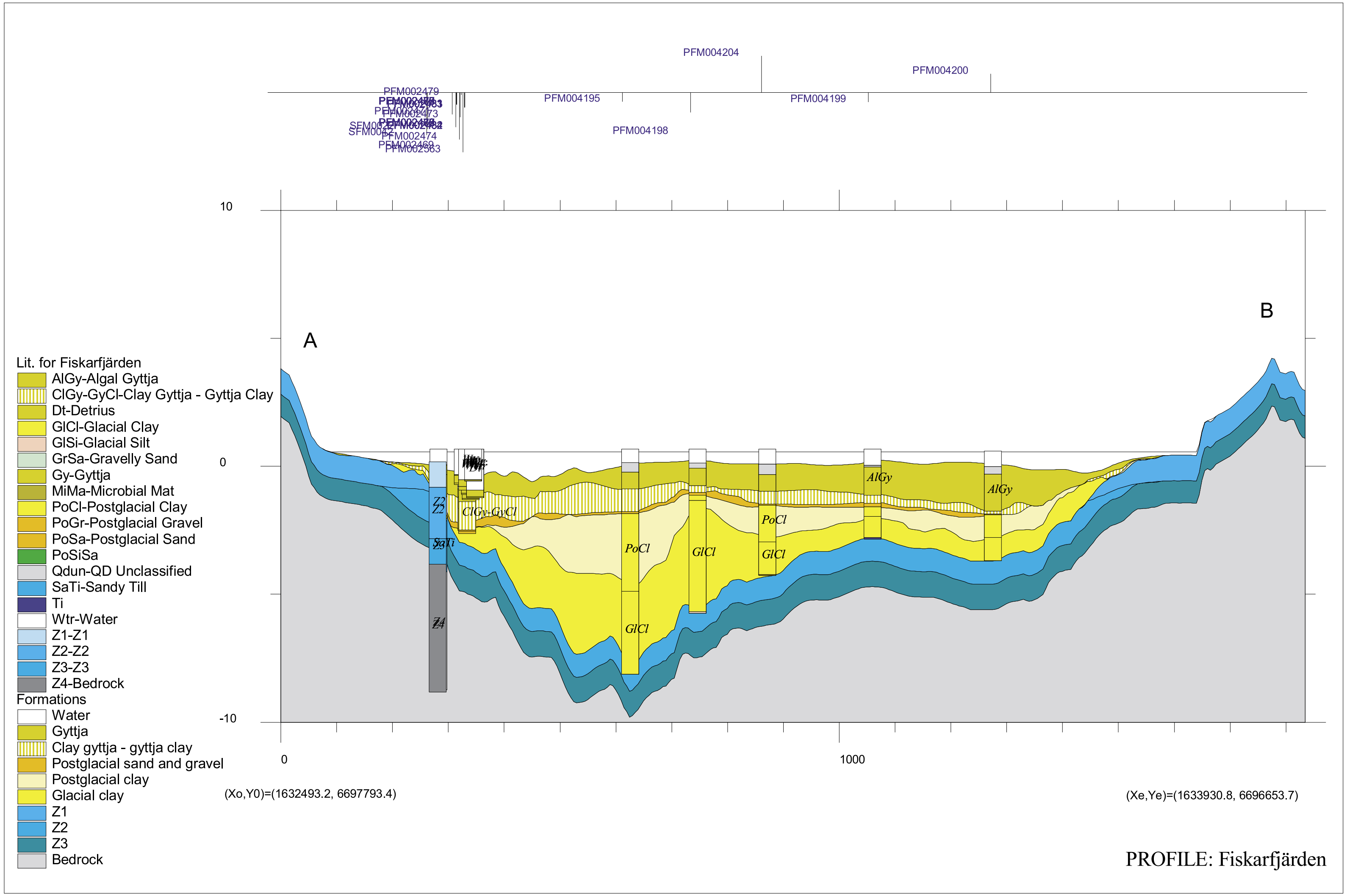

Figure IV-5. *Lithology and interpreted layers of sediment in a profile through lake Fiskarfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

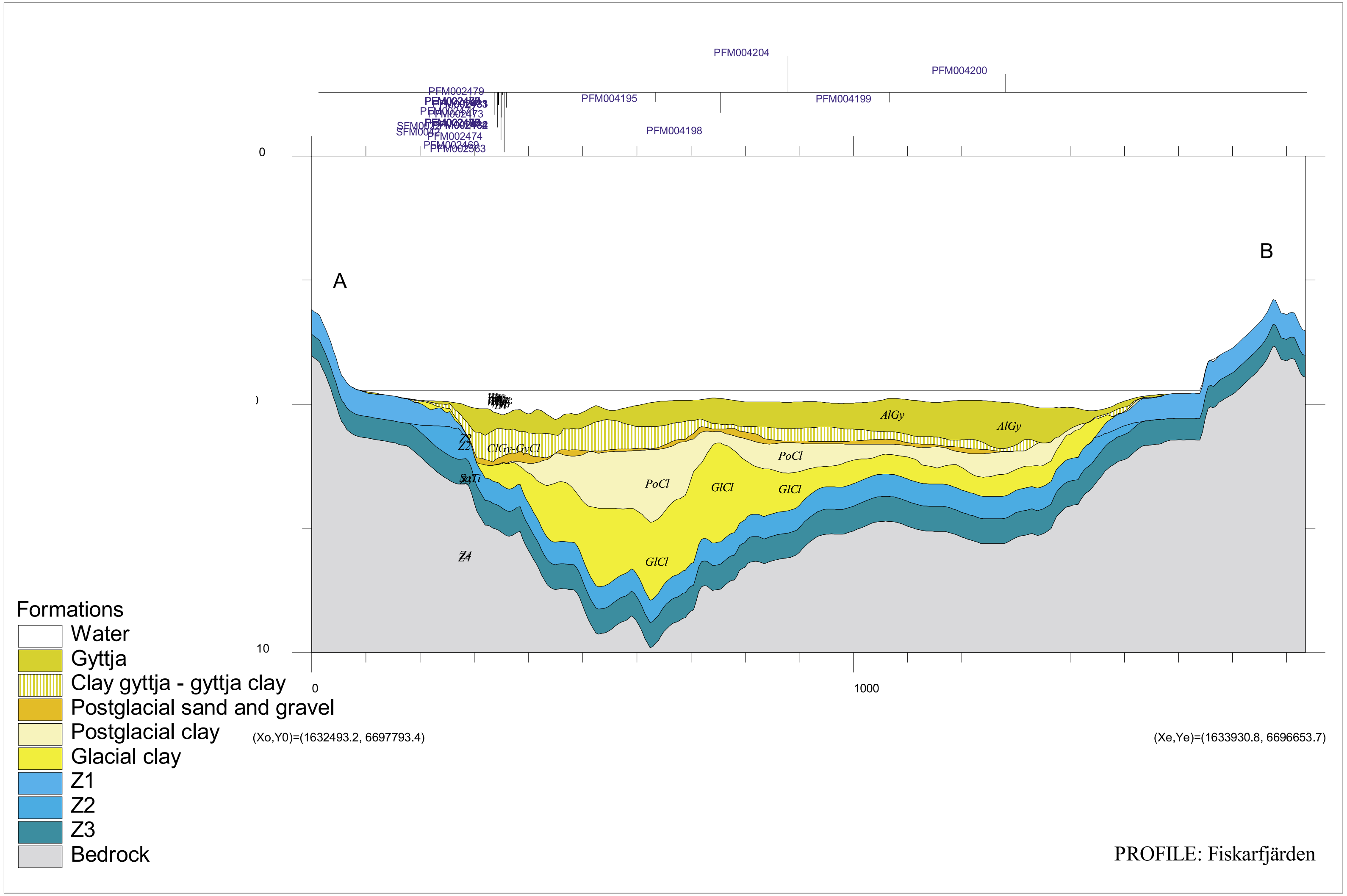

Figure IV-6. *Layers of sediment in a profile through lake Fiskarfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

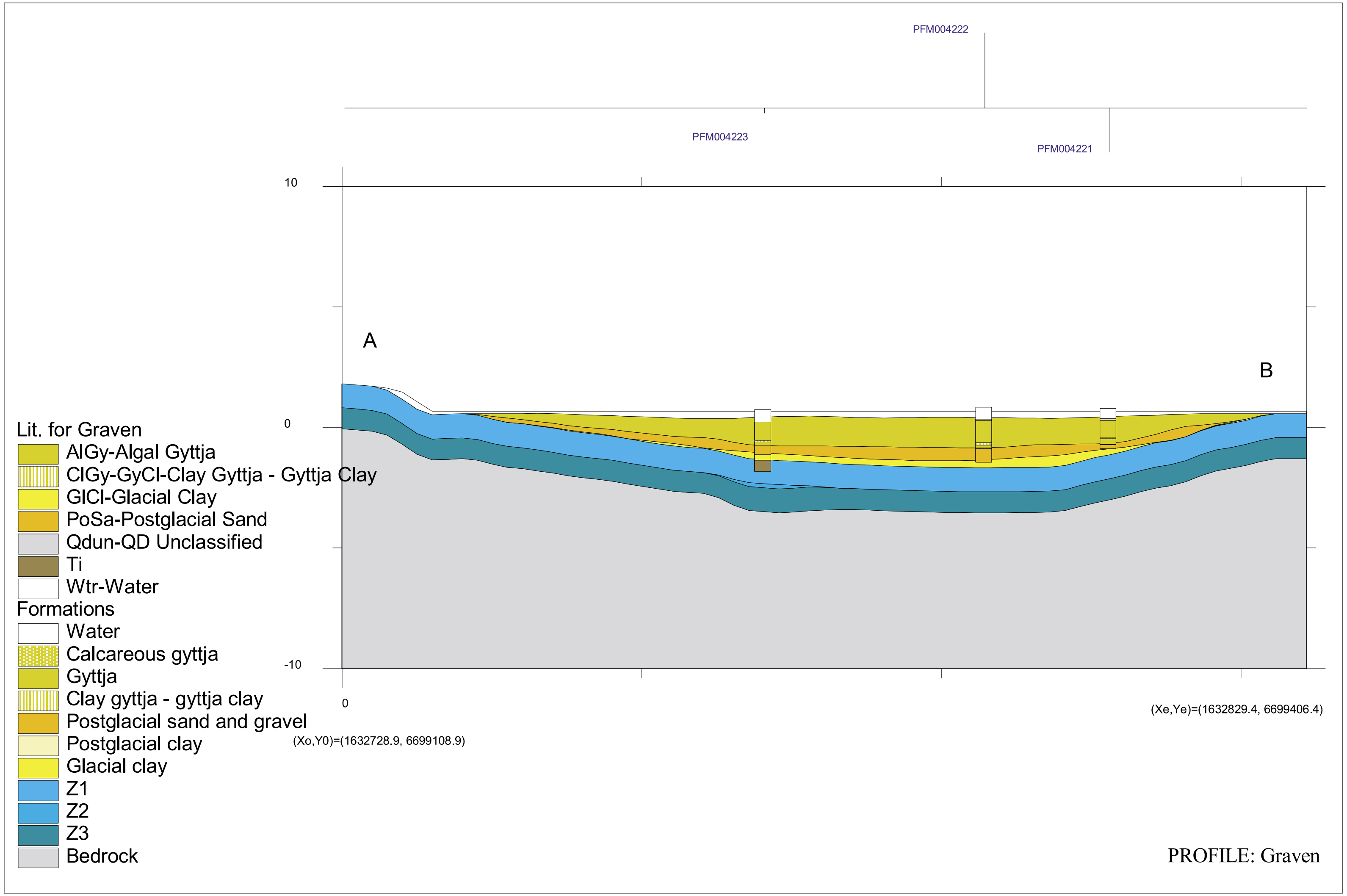

Figure IV -7. *Lithology and interpreted layers of sediment in a profile through lake Graven. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

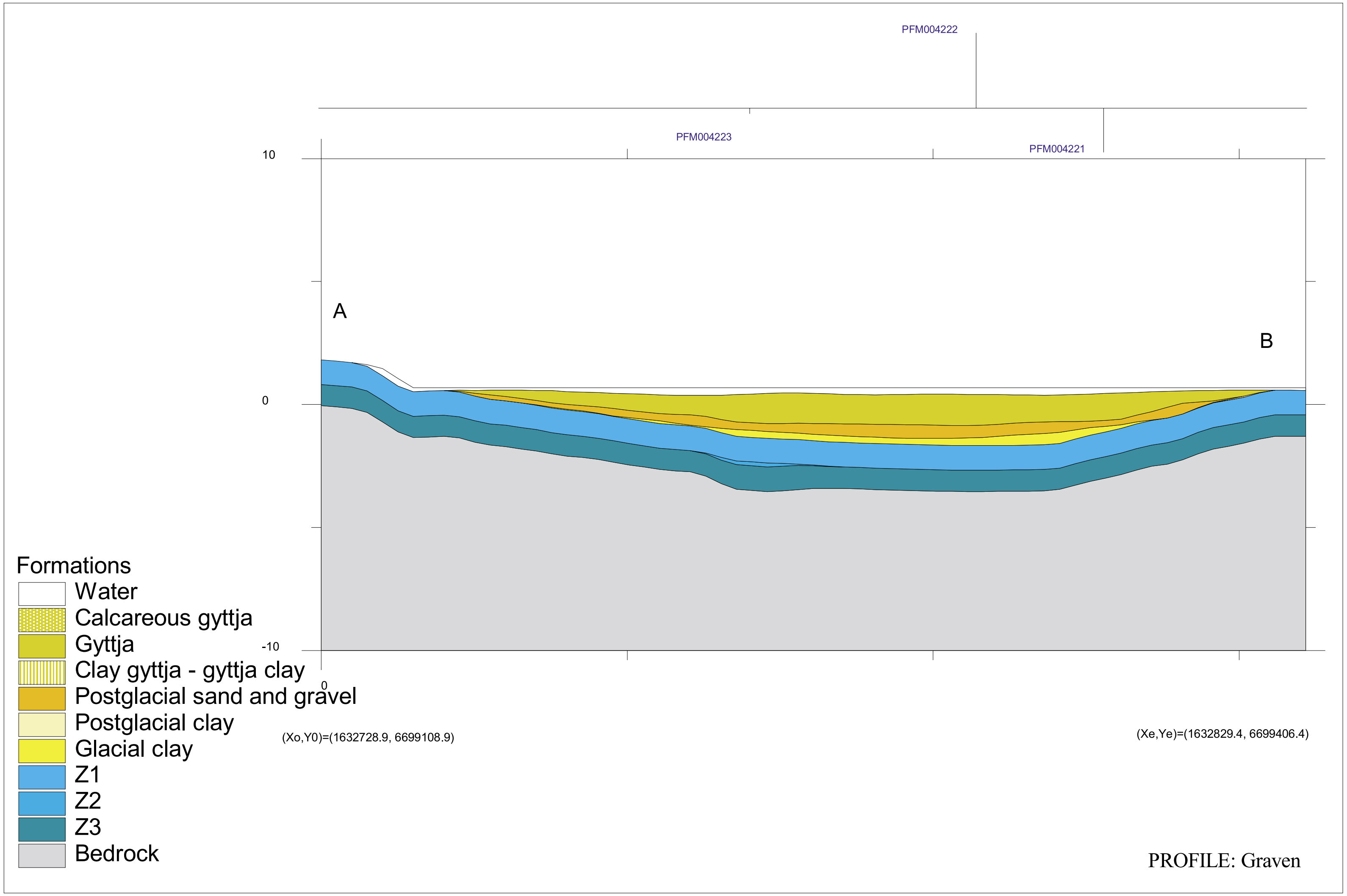

Figure IV-8. *Layers of sediment in a profile through lake Graven. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

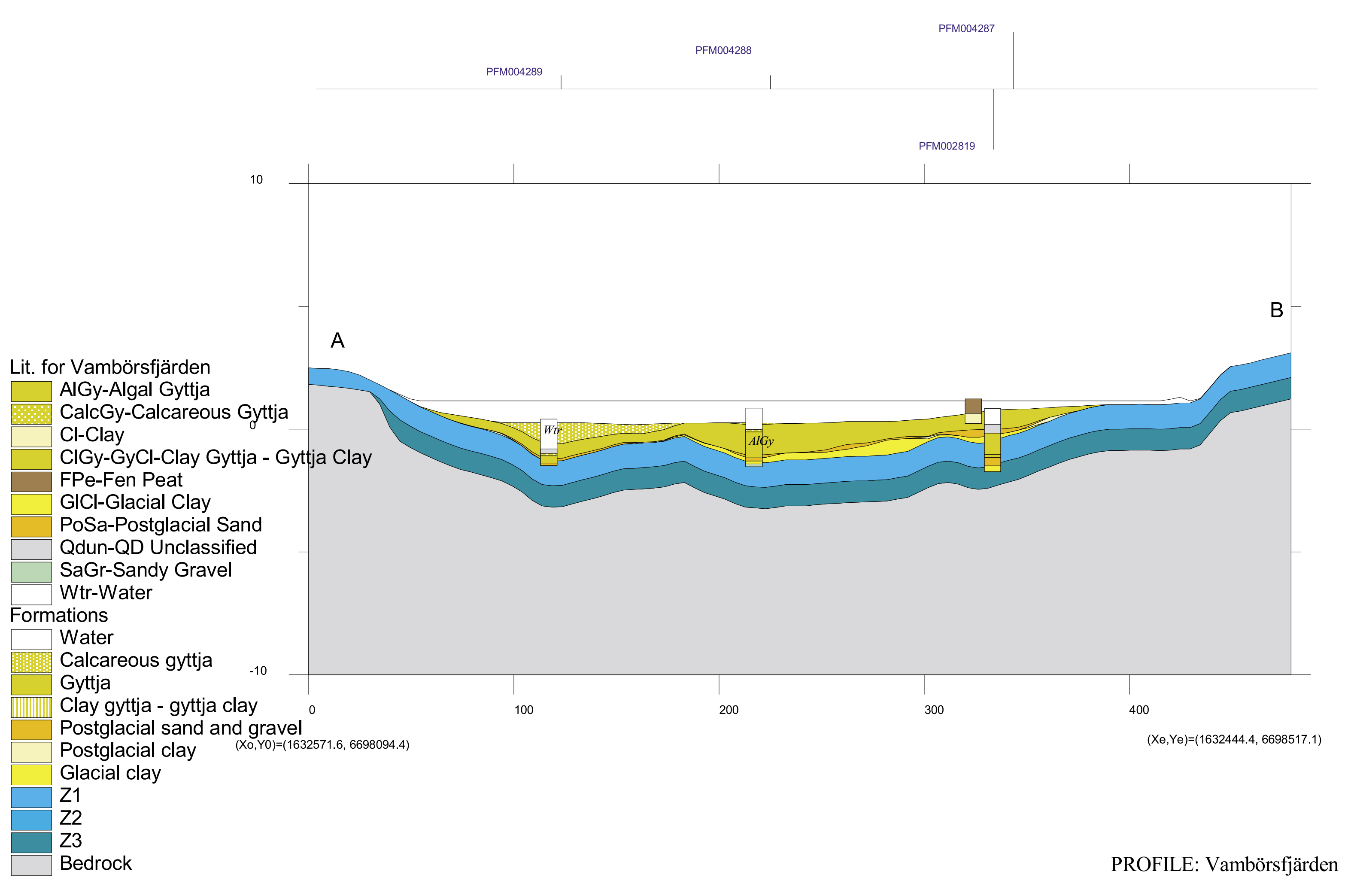

Figure IV-9. *Lithology and interpreted layers of sediment in a profile through lake Vambörsfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

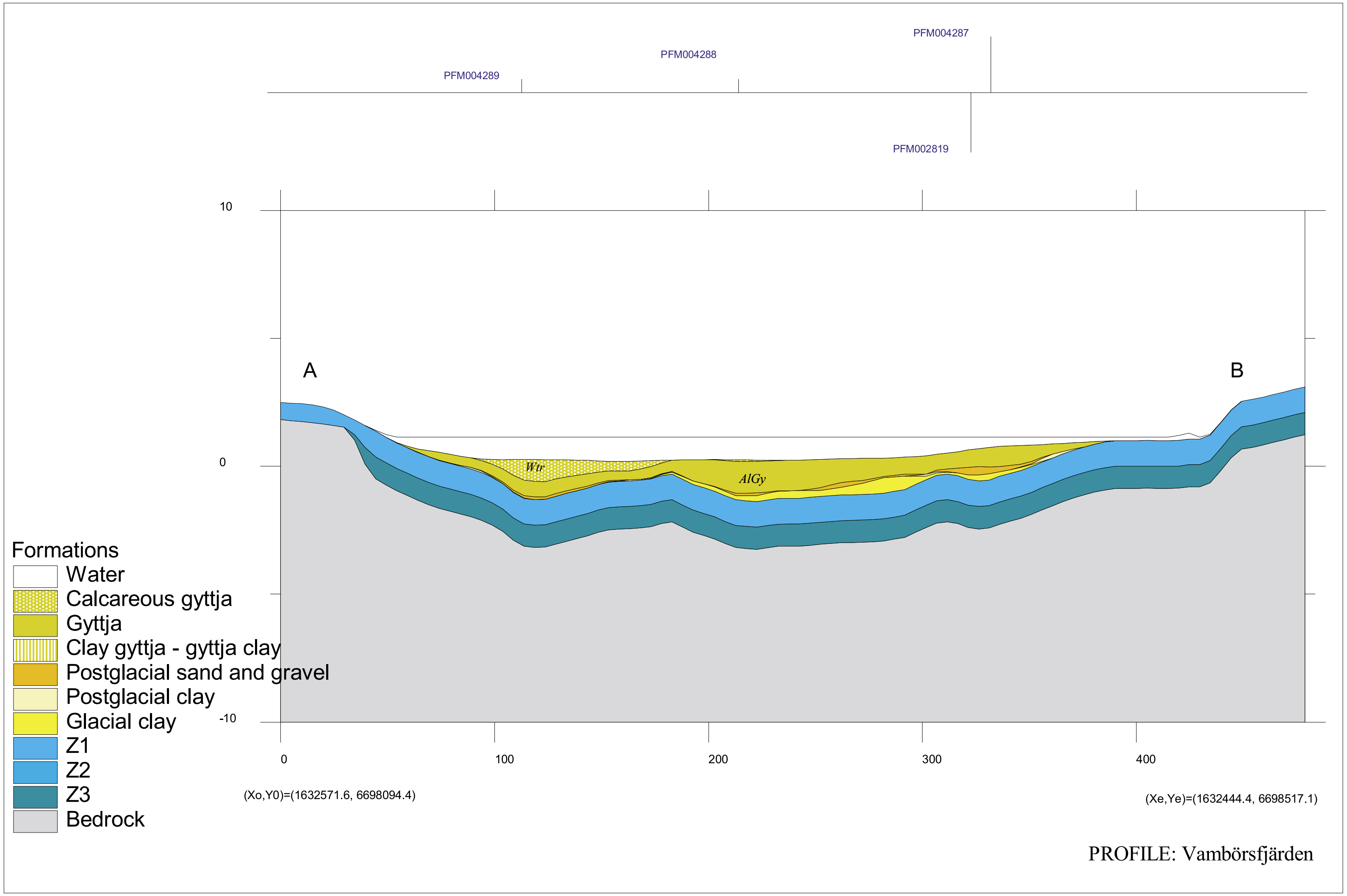

Figure IV-10. *Layers of sediment in a profile through lake Vambörsfjärden. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

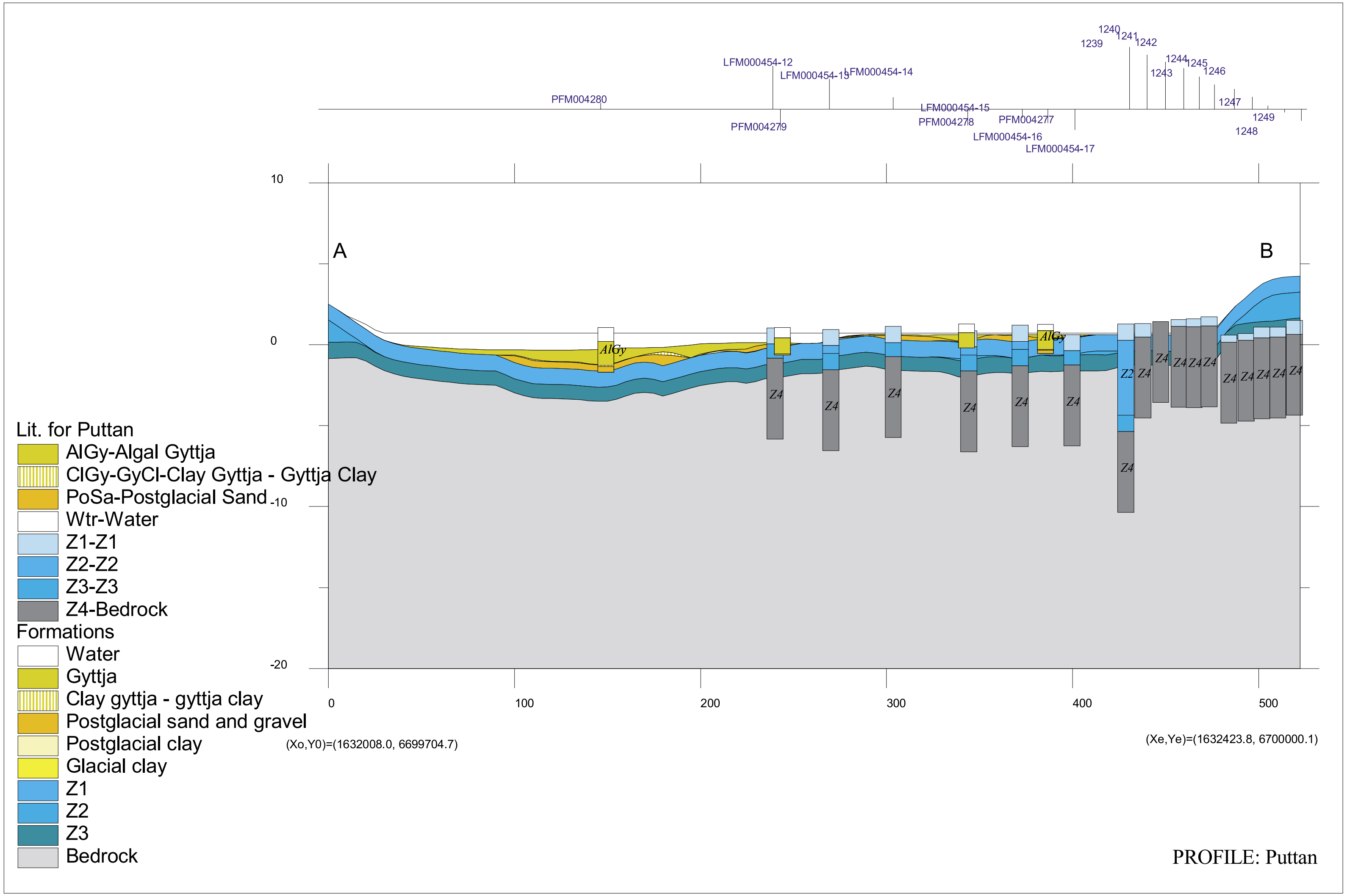

Figure IV–11. *Lithology and interpreted layers of sediment in a profile through lake Puttan. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

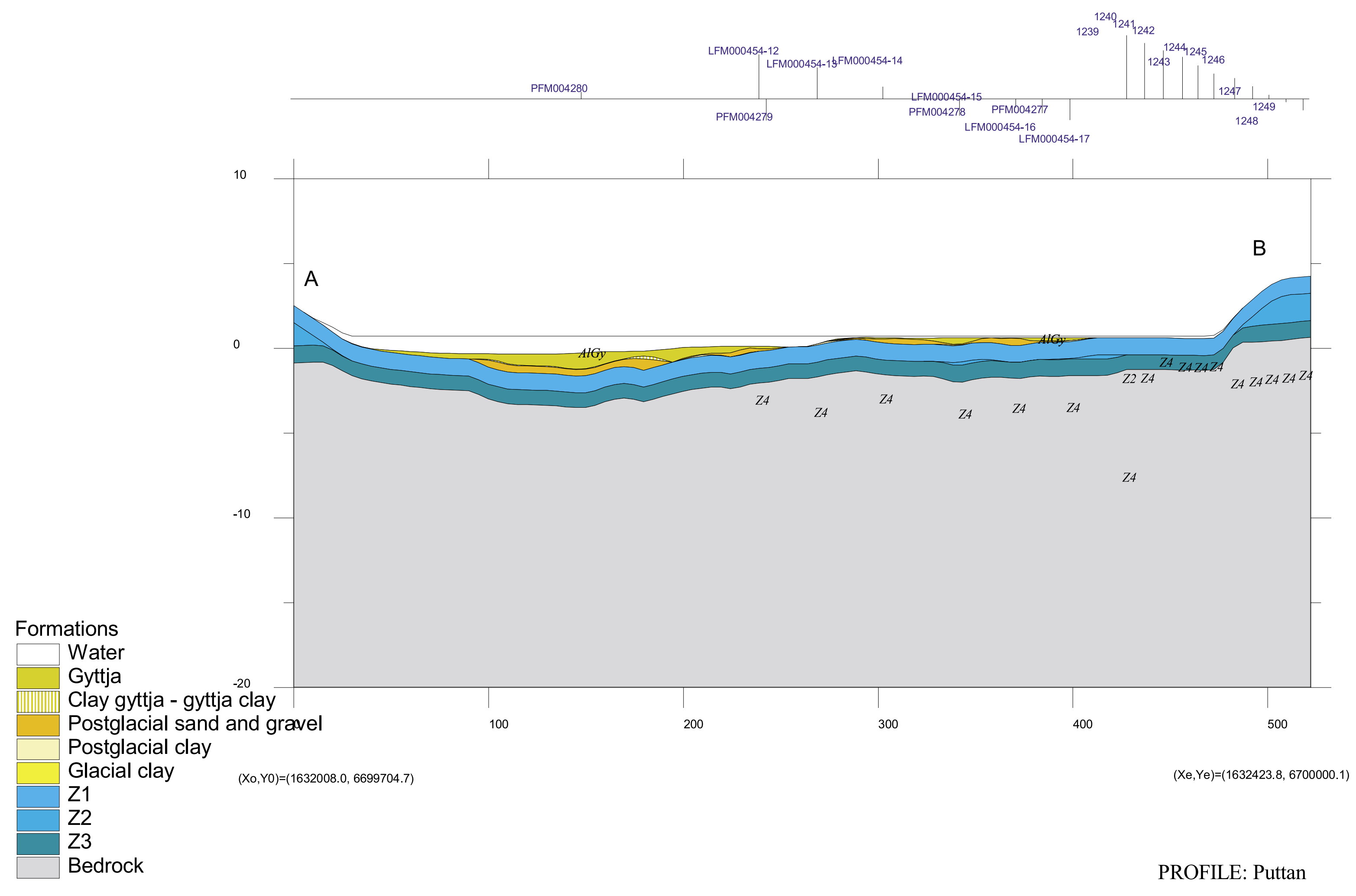

Figure IV-12. *Layers of sediment in a profile through lake Puttan. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

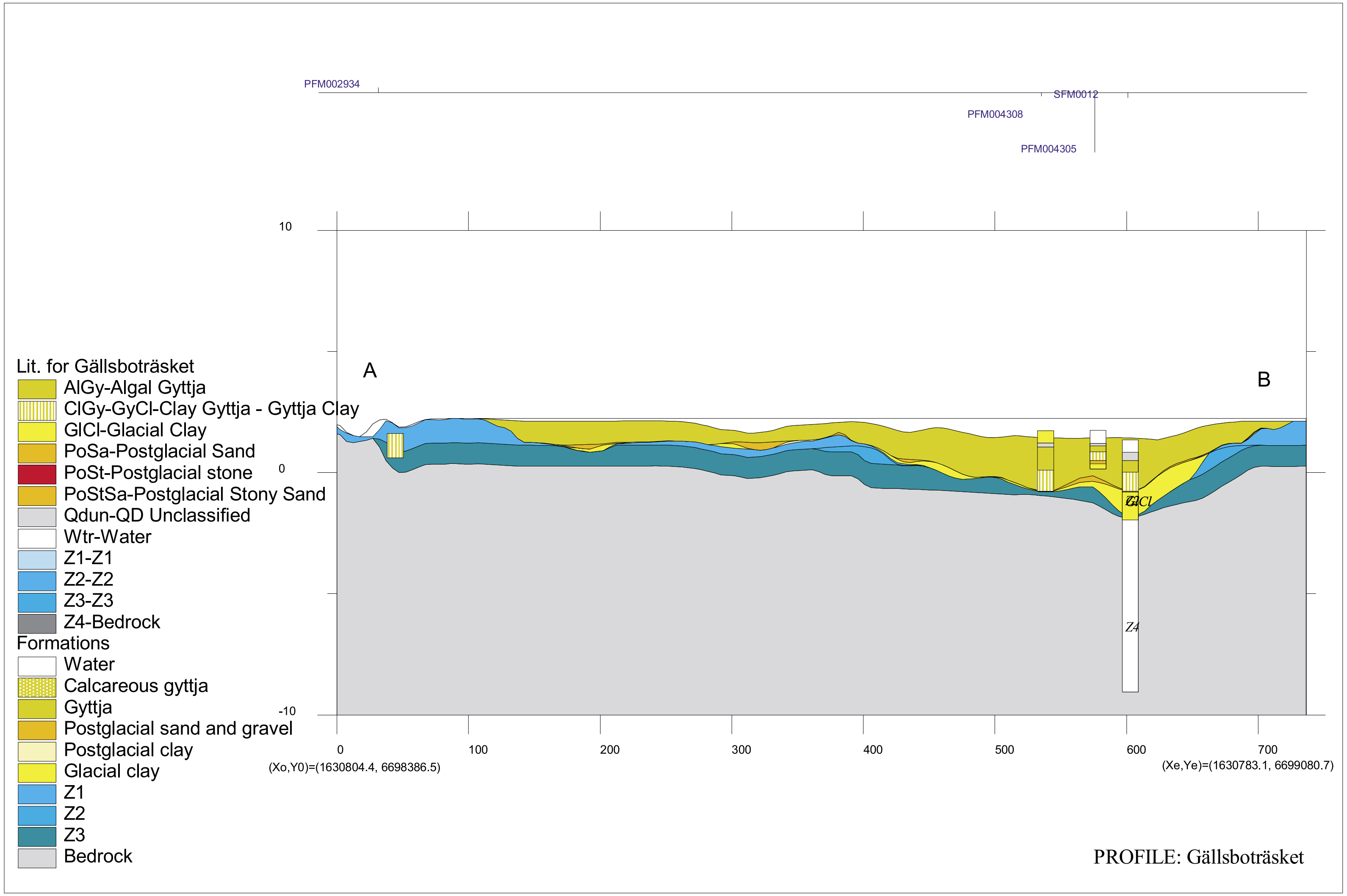

Figure IV-13. *Lithology and interpreted layers of sediment in a profile through Gällsboträsket. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*

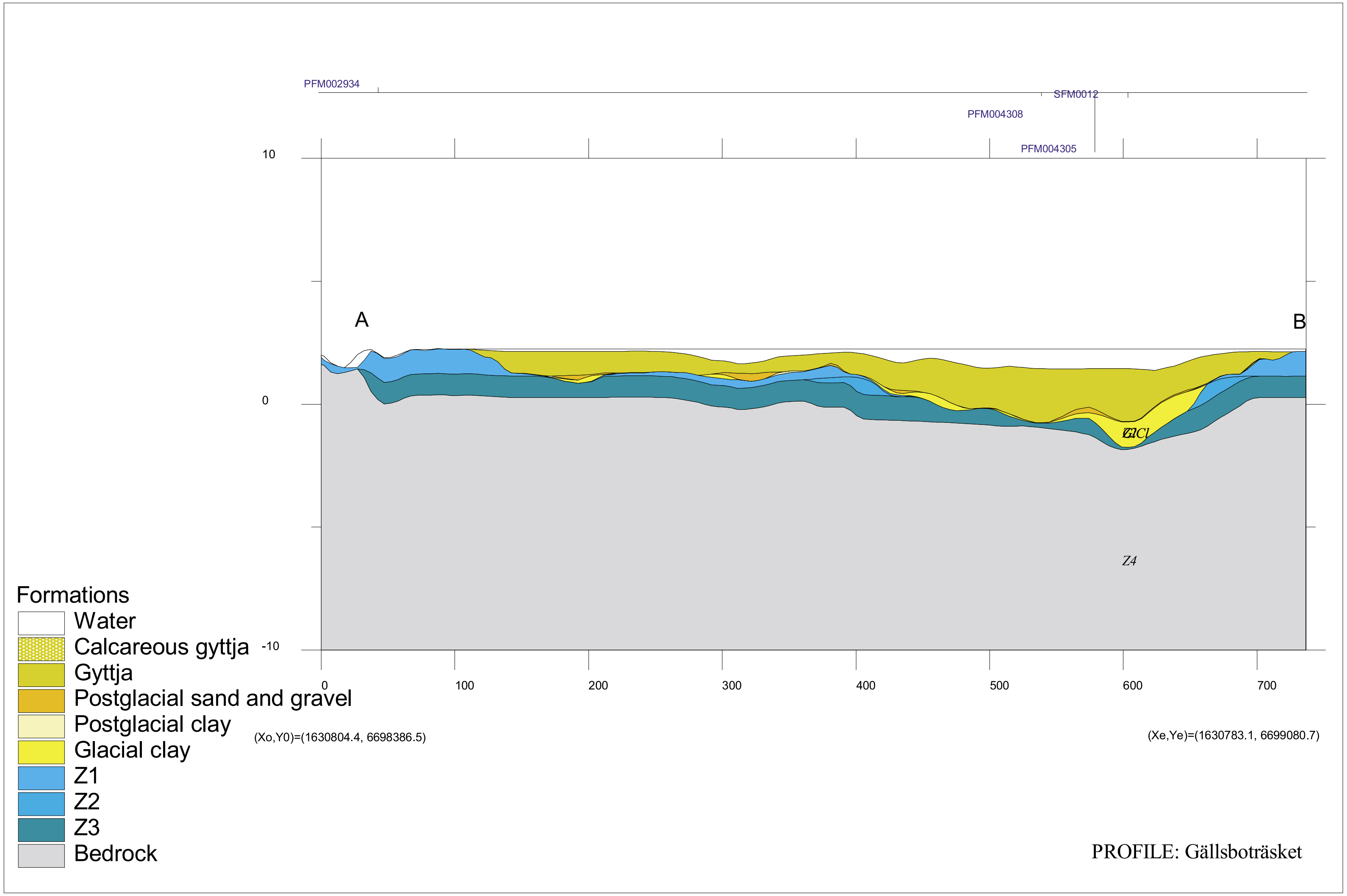

Figure IV-14. *Layers of sediment in a profile through lake Gällsboträsket. The observation points included are displayed above the profile. For location of the profile, see Figure 5-2.*