Forsmark site investigation

Detailed marine geological survey of the sea bottom outside Forsmark

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SKB

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Abstract

This document reports the findings gained through a detailed marine geological survey of the sea bottom adjacent to the Forsmark site investigation area.

The survey comprised detailed hydro-acoustic mapping controlled by sediment sampling and comprised approximately 410 km survey lines. 47 bottom inspections with video camera were carried out and, where possible, sediment sampling was done at these locations.

The data delivery to SKB includes digital data on survey lines, sample points, sampling results, sonar mosaics, map of sea floor material, bottom topography and a terrain model of the Crystalline rock surface.

It should be noted that the bathymetric model and the terrain model of the Crystalline bedrock surface are classified for military defence reasons.

Sammanfattning

Denna rapport beskriver resultaten av en detaljerad maringeologisk undersökning i anslutning till platsundersökningsområdet Forsmark.

Undersökningen omfattade hydroakustisk kartläggning längs totalt cirka 410 längdkilometer i kombination med sedimentprovtagning. 47 lokaler filmades med videokamera och där så var möjligt togs sedimentprover vid dessa lokaler.

Dataleveransen till SKB omfattar digitala data rörande mätlinjer, provtagningspunkter, provtagningsresultat, sonar mosaiker, karta över bottenmaterial, bottentopografi och bergytans topografi.

Det skall noteras att informationen rörande bottentopografi och bergytans topografi är hemligstämplad av försvarsmakten.

Contents

1   Introduction

This document reports the findings gained through a "Detailed marine geological survey outside Forsmark" of the sea bottom adjacent to the Forsmark site investigation area. The survey, which is one of the activities within the site investigation at Forsmark, was commissioned by the Swedish Nuclear Fuel and Waste Management Co (SKB) and carried out by the Geological Survey of Sweden (SGU) in close collaboration with Geosigma AB and the University of Stockholm as sub consultants.

The survey comprised detailed hydro-acoustic mapping controlled by sediment sampling. The work was performed in accordance to "Metodbeskrivning för maringeologisk undersökning" (SKB MD 260.001) and following the activity plan AP PF 400-02-27 (SKB internal controlling document) during the period September 2002 to May 2003.

2   Objective and scope

The main aims of the marine geological survey were to map:

- The morphology of the sea bottom.
- The morphology of the underlying bedrock surface.
- The horizontal and vertical extension of the sediments.
- Indications of neotectonic bedrock displacements.

The survey area, see Figure 2-1, includes a near-shore primary survey area investigated with a line spacing of 100 m and a more distant secondary survey area which was investigated with a line spacing of 1,000 m.
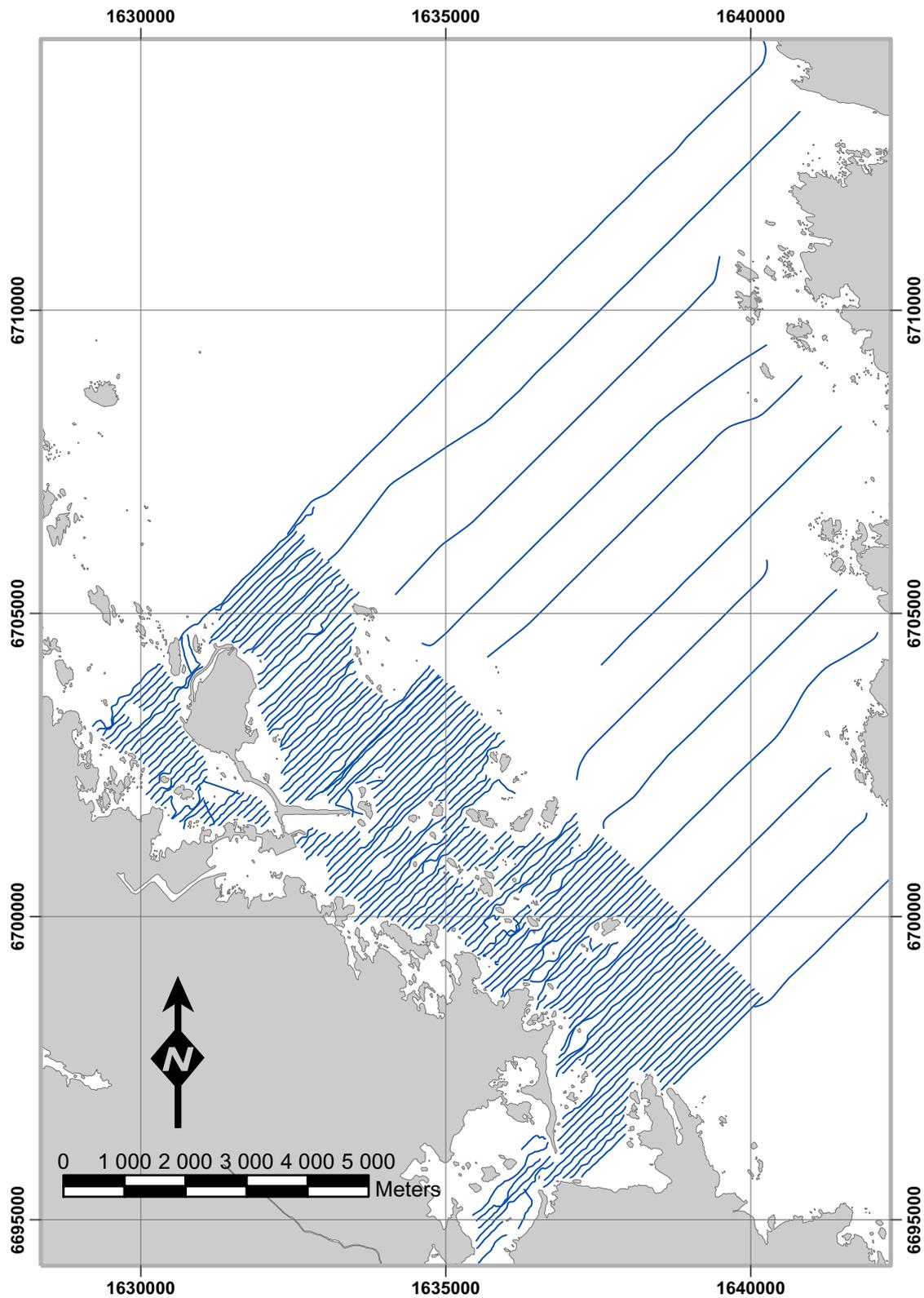
Figure 2-1. *The Forsmark marine geological survey area. The near-shore primary area was surveyed along lines spaced 100 m, whereas the more distant secondary area was surveyed along lines spaced 1000 m. Permissions: Lantmäteriverket 2001, M2001/5268 and Sjöfartsverket, 010305-H30/04-04-17597.*

3 Equipment

3.1 Survey principles

3.1.1 Seismic reflection profiling

Instrumentation for seismic reflection profiling in the range above c 10 kHz are mostly referred to as echo sounders, whereas those in the range 3–10 kHz are called sediment sounders or sub bottom profilers. Technically they are very similar, using ceramic transmitters which usually also serve as receivers. Below c 3 kHz it becomes necessary to use other types of transmitters; air guns, water guns and various types of high voltage transmitters. These low frequency instruments, referred to as seismic profilers, also require separate receivers in the form of hydrophone arrays.

The sediment sounders (sub bottom profilers) are capable of penetrating mud, clay and sand, under favourable conditions down to more than 50 m below the seafloor. They rarely penetrate till, however. Chirp sounding constitutes transmission of a computer-controlled frequency sweep, and a computer decoding of the echoed sweep. The chirp technology is an efficient way to increase the energy output while keeping rather low transmission amplitudes. In the present case the chirp soundings provided clear records of the uppermost mud sediments and the glacial varved clays. Exceptions were those areas where the mud sediments were gas-charged.

A high-resolution reflection seismic system was used to acquire information about the subsurface geology down to the bedrock. The system is built up of a seismic source producing a low-frequency pulse, a 6-channel hydrophone streamer and acquisition hard- and software. Compared to the sub bottom profiler this system enables better penetration but with decreased vertical resolution as trade-off. Two different types of seismic sources were used; an electromechanical "Boomer" source (500–1,500 Hz) and a "Bubble-pulser".

3.1.2 Side scanning sonar

Side scanning sonar (SSS) equipment is used to obtain information about the seabed surface. The ship tows the SSS transducer and the survey coverage is normally a few hundred metres across track. The intensity of the reflecting sound corresponds to different sediments and seabed textures. Data from SSS are converted into images, which in turn are used by the geologist for interpreting the surficial geology of the seabed.

3.2   Survey equipment

Two sets of field survey equipment were used, one set for water depths greater than six metres and one for water depths ranging between six and three metres. Areas with water depths less than three metres were not investigated.

Water depths greater than six metres, primary survey area:

- Survey vessel: S/V Ocean Surveyor.

- Positioning, survey monitoring and depth logging: LEICA MX 12 channel DGPS receiver, EPOS RDS corrections, EIVA NaviPac survey computer system.

- Echo sounding: Simrad EA 200, 200 kHz.

- Sub bottom profiler: Edo Western HiPac 7 kHz/GeoAcoustic SE2000S datalogger.

- Reflection seismics: EG&G Uniboom, Marshall Acoustic six channel Trout streamer, Triton-Elics Delph Seismic six channel data logger.

- Side scanning sonar: Klein 500 kHz/Triton-Elics ISIS data logger.

- Sediment samplers: 1 m gravity corer, 6 m piston corer, heavy grab sampler and Gemini corer.

- Under water video camera.

Water depths greater than six metres, secondary survey area:

As above except

- Side scanning sonar: Benthos SIS 1000.

Water depths between six and three metres, primary survey area only:

- Survey vessel: A water jet powered 6.5 m survey launch.

- Positioning, survey monitoring and depth logging: ASHTECH differential GPS receiver, EPOS RDS corrections, Meridata survey computer system.

- Echo sounding: Foruno/Reson 200 kHz.

- Sub bottom profiler: EdgeTech Chirp Profiler 3–9 kHz/Meridata Multi-mode Sonar System.

- Reflection seismics: Benthos Bubble Pulser one channel/Meridata Multi-mode Sonar System.

- Side scanning sonar: Klein 500 kHz/Meridata Multi-mode Sonar System.

- Sediment samplers: Small grab sampler and Gemini corer.

3.3   Interpretation software

The equipment for analysis and interpretation consists, in short, of:

- Software for survey planning, data interpretation, geometric correction, production and delivery of spatial databases, mainly Micro Station/Intergraph MGE 5.07, IRAS-C 8.0, ESRI ArcView 3.2 and software specially developed for SGU.

- Software for handling and storing sediment sample descriptions, mainly Microsoft Access 97.

4 Execution

4.1 General description

The assignment was performed according to the specifications set up in the method description (SKB MD 260.001), with the exemption of the secondary survey area line spacing, which was increased to 1,000 m (instead of 100 m).

Within the primary area, surveying of sub-areas with water depths greater than 6 m was conducted from the survey vessel S/V Ocean Surveyor. Within sub-areas with water depths 3 to 6 m a smaller boat was used. The surveying was performed along pre planned survey lines and included echo sounding, sediment echo sounding, reflection seismic and side scanning sonar.

In the secondary area, a long-range side scanning sonar was used instead of the high-resolution sonar used for the detailed investigation. In areas where the actual water depth was much shallower than the depths given by the nautical charts, the line planning was adjusted according to the physical conditions. The systems were used parallel, with digital recording of all data and position of each system. All survey lines were noted in a protocol and the work with each profile was followed up. Changes and/or problems were also noted in the protocol. After quality control of each survey line, the data were converted and the profile preliminary interpreted. At this stage, possible sampling points were selected.

Sampling was done to verify the geological interpretation of the acoustic data and to solve interpretation problems. Different types of sampling methods were applied: In soft sediments 1 and 6 m corer were used. The 6 m cores also gives a stratigraphical model of the sampling point. Coarser sediments were sampled with a grab sampler. Before sampling the sea bottom, the sampling site was filmed with an under-water video camera and notations were made in a protocol. The camera position aboard the ship is the same as the piston corer station. Grab samples, gravity cores and Gemini cores are taken through the moon pool in the centre of the ship. Each sample is described in a database. The database contains a main table for technical data, positions, water depth, time and sampling method etc. To this table are linked tables containing sediment description data, sub sample data including sub sample weight etc. Normally the samples are photographed.

4.2 Preparations

The data are used qualitatively rather than quantitatively and no special calibration is made. Exceptions are positioning and water depth measurements.

The positioning equipment is checked against a fix point on land.

Echo sounding measurements are checked against known water depths. Sound velocity in water is measured with a specially designed CTD-probe. Information from an automatic water level gauge situated within the survey area, supplied by the Swedish meteorological and hydrological institute (SMHI) was used to monitor the water level in the area during the survey.

4.3   Execution of measurements

4.3.1   Positioning and coordinate system

Positioning was performed using LEICA and ASHTECH differential GPS receivers. The navigational data were recalculated from the receivers NMEA-strings in longitude/latitude to the Swedish RT-90 2.5 V map projection and also adjusted for the location of the towed sensors.

From April 1, 2000 the built in error in the GPS system was decreased from about +/– 50 m to the metre level. This means that the quality of the receiver is now the dominant factor for accurate positioning, and also that the use of differential receivers is less important. However, the use of differential receivers may help to reduce atmospheric disturbances. The differential 12 channel ASHTECH G12 and LEICA sensors used for the present survey are regarded as accurate to the meter level. The differential corrections were based on the EPOS system.

4.3.2   Sound velocity

The sound velocity in the water at the time of the survey is essential for the evaluation of the seismic records. The required data; depth, salinity and temperature may either be determined by measurements performed exclusively for the purpose or achieved from oceanographical observations. The essential parameter for calculation of the sound velocity in water bodies is the temperature, which was measured during the present survey. For the evaluation of the recordings a water velocity of 1,460 m/s was used.

4.3.3   System parameters

The data acquisition parameters are presented in Table 4-1 and 4-2 for the Ocean Surveyor and the smaller survey launch, respectively.

Table 4-1. Data acquisition parameters used for surveying with R/V Ocean Surveyor.

Instrument type	Channel/ Instrument	Record length (ms)	Frequency range (kHz)	Pulse length (ms)	Trigger rate (ms)	Sampling rate (kHz)
Reflection seismic	Uniboom	250	0.5–1.5	0.5	500	5
Sub-bottom profiler	EDO Western	250	3.5/7	0.2	500	20
Echo sounding	Simrad	N/A	200	0.05	N/A	N/A
Side-scanning sonar	Klein Sonar	100	500	0.02	100	16
Side-scanning sonar	SIS 1000	1,000	100–120	5	1,000	8

Table 4-2. Data acquisition parameters used for surveying with the smaller survey launch.

Instrument type	Channel/ Instrument	Record length (ms)	Frequency range (kHz)	Pulse length (ms)	Trigger rate (ms)	Sampling rate (kHz)
Reflection seismic	Bubble-pulse	150	No filter	2.0	150	16
Sub-bottom profiler	Chirp	150	3–9.5	30	150	16
Echo sounding	Foruno/ Reson	N/A	200	0.05	N/A	N/A
Side scanning sonar	Klein Sonar	125	500	0.02	175	16

Depth data from the instruments were stored in separate computer files, and GPS positional data in a separate file. Before storage, the positional data strings (NMEA – GPGGA) were converted to X/Y-coordinates in RT90 2.5 V. Furthermore, the 3-dimensional layout of the instruments during the survey was recorded in order to facilitate coordinate calculation of positions and instrument depth for each shotpoint.

4.4   Data handling, analyses and interpretation

4.4.1   Water depth measurements

The water depths along the survey lines were measured using an echo sounder and data (x, y, z, time and date) were stored in ASCII-format. Depths along the survey lines in the secondary area were derived from the sub-bottom profiler measurements. As the sub-bottom profiler works at a lower frequency than the ship echosounder, depth measurements in the secondary area are slightly less accurate. Information from an automatic water level gauge situated within the survey area, supplied by SMHI, was used to correct the measured data for changes in sea water level during the survey. The depth measurements were used to make a digital terrain model over the area. Data from the sea chart and the geological map were used to correct the model for differences between the survey lines.

4.4.2   Seismic and sediment echo sounding data

Data are primarily stored in SEG-Y format. After conversion to image raster format, each file is quality controlled and accepted or, if rejected, data is collected again along this survey line. After quality control, the resulting position file is filtered. Position data and line number from each survey line are collected in a graphic file, which is transformed to Arc View shape format.

The survey data are transformed to image format and the seismic and sediment echo sounding data are interpreted simultaneously to graphic data. The acoustic stratigraphy is interpreted to geological lithology. The information from the sediment sampling is used in the interpretation. The quality of this work depends to a high degree on the experience and skill of the interpreting geologist. Knowledge of the local geology and sedimentology are important.

The interpreted sections are transformed to ASCII files containing x-, y- and z-coordinates and a geological code. These time based files are recalculated to meter based sections in the same format. Information about the sound velocity in different materials is based on literature studies. From these sections a graphical data set is produced, showing the geological material at the sea bottom along the survey lines.

Table 4-3 presents a few rows of data from a seismic section. Columns 1–10 represents the following variables; shot number, easting (RT90 2.5V), northing (RT90 2.5 V), number of stratigraphic units, code for 1:st seismic unit, depth below sea level, code for 2nd seismic unit, depth below sea level, basement code, depth below sea level.

Data was then re-arranged to fit into a format suitable for the SKB-SICADA database. An Id-code referring to SKB's internal project documentation was added to each seismic line. Each row in Table 4-4 corresponds to one stratigraphic unit. The values in the marin_seis_code column were translated into the soil_c and genes_c codes, according to SKB standards. One explanatory column was also added; marin_seis_text.

A digital terrain model (DTM) describing bedrock topography was produced from the interpreted geological sections in ASCII-format. Where the geological sections occurred more sparsely, some supportive iso-lines were manually drawn to strengthen the DTM. At locations where bedrock outcrops at sea-bottom is evident from the geological interpretation/side scanning sonar images, data from the more accurate ship echo sounder were used. From this data a Triangulated Irregular Network (TIN) was created and in turn converted to a USGS DEM raster through a tension spline function.

Table 4-3. Example data from seismic section.

1	1633074.82	6705875.34	3	6	−16.4989	76	−18.6815	99	−50.524
2	1633077.25	6705877.28	3	6	−16.1821	76	−18.5062	99	−51.1702
3	1633079.68	6705879.22	3	6	−15.8653	76	−18.3312	99	−51.8162
4	1633082.11	6705881.16	3	6	−15.5483	76	−18.1563	99	−52.4631

Table 4-4. Marine seismic stratigraphy adapted to the SICADA database format.

(Idcode)	shot_point_ID (number)	depth_from (m)	depth_to (m)	soil_c (code)	genes_c (code)	marin_seis_c (code)	marin_seis_text (text)
LSM000325	1	0.00	15.35		42	6	Vatten
LSM000325	1	15.35	21.12	12	3	66	Moränlera
LSM000325	1	21.12				99	Kristallin berggrund
LSM000325	2	0.00	16.25		42	6	Vatten
LSM000325	2	16.25	17.3	29	8	19	Glacial lera
LSM000325	2	17.3	23.55	12	3	66	Moränlera
LSM000325	2	23.55				99	Kristallin berggrund

4.4.3 Side scanning sonar

Sonar data are primarily stored in SEG-Y format. After conversion to image raster format, each file is quality controlled and accepted or, if rejected, data is collected again along this survey line. After quality control, the resulting position file is filtered. Acoustic data are corrected for slant range and geographically positioned in registered raster strip files. The resulting strip files are mosaiced together in 2.5×2.5 km squares, each representing one fourth of an economical map sheet, for the primary survey area and in 5×5 km squares in the regionally measured area. The mosaics are named according to the system used by the Swedish Land Survey. They are transferred to geo referenced tiff images with 25 cm pixel size for the primary survey area and the pixel size 1 m for the secondary survey area. The mosaics are interpreted to produce a geological map of the bottom sediments. To support the interpretation, data from the seismic and sediment echo sounding, sediment sampling, water depths and other background data are used. The interpretation is based on the different responses from different geological materials. Bedrock shows up as dark and rough areas while unconsolidated sediments give a pale and "soft" impression. Important factors for an accurate geological mapping are the understanding of how the sonar signal interacts with the morphology and geology of the sea bottom, the effect of "shadowing", and an overall knowledge about the geology in the area.

4.4.4 Seabed samples

Sample data are first stored in an MS Access database. Relevant tables were exported and re-mapped according to SKB lexicon tables sampling_equipment_c, soil_c, soil_prefix_c and genes_c. In general, re-mapping of values was carried out in the same manner as the seismic stratigraphy. Two data-sets were delivered to SKB, one with the activity codes and one containing the sample data. An explanatory column ("kommentar") was added to the latter.

5　Results and data delivery

The fieldwork resulted in approximately 410 km survey lines (Figure 2-1), whereof about 335 km were measured from the smaller boat and the remaining 75 km from the R/V Ocean Surveyor. In addition to this, 47 bottom inspections with video camera were carried out. Where possible, sediment sampling was also done at these locations. Four piston core samples, 5 Gemini samples (where of 3 from the small boat) and 30 samples with the large grabber were taken. The sampling points are shown in Figure 5-1.

The survey line information is delivered in Arc View line shape format ("linjer"), with the line number as attribute data. The information from the sediment sampling is stored in an Access database with geographical, technical and geological data. A subset of the information in this database is also delivered in Arc View point shape format ("prov"), with attribute data on id, x, y, z, date, sampling platform, sampling method, penetration and short geological description of the sample.

Each site sampled from R/V Ocean Surveyor were filmed with an under-water video camera and stored on VHS tape. A copy of the tape has been delivered. Data about the film sequences (start/stop time, Id nr and short notations on what can be seen) are noted in a form.

The sonar mosaics, Figure 5-2, are delivered in Geotiff format. Each mosaic is named after the geographical position on the economical map sheet according to the Swedish Land Survey. The sections with interpreted geological stratigraphy are delivered as two ASCII files named line_surveying_forsmark.txt and stratigraphy_data_forsmark.txt.

The map-themes describing the bottom material, bomatr (main bottom material), tunt (thin layers) and ripples (areas with sand ripples) are delivered in ArcView shape format. They have furthermore been combined to produce a marine geological map, Figure 5-3. In the outer, regionally mapped area the data sets have the suffix "reg", and in the inner detailed area the suffix "det" (e.g. bomatr_reg.shp).

The bottom topography, Figure 5-4, is delivered as a 5 m equidistant ArcView line shape set and a terrain model in USGS DTM and ArcInfo grid format. The terrain model of the Crystalline bedrock surface, Figure 5-5, is delivered as 5 m equidistant ArcView line shape set and a terrain model in USGS DTM and ArcInfo grid format.

It should be noted that the bathymetric model and the terrain model of the Crystalline bedrock surface are classified for military defence reasons.
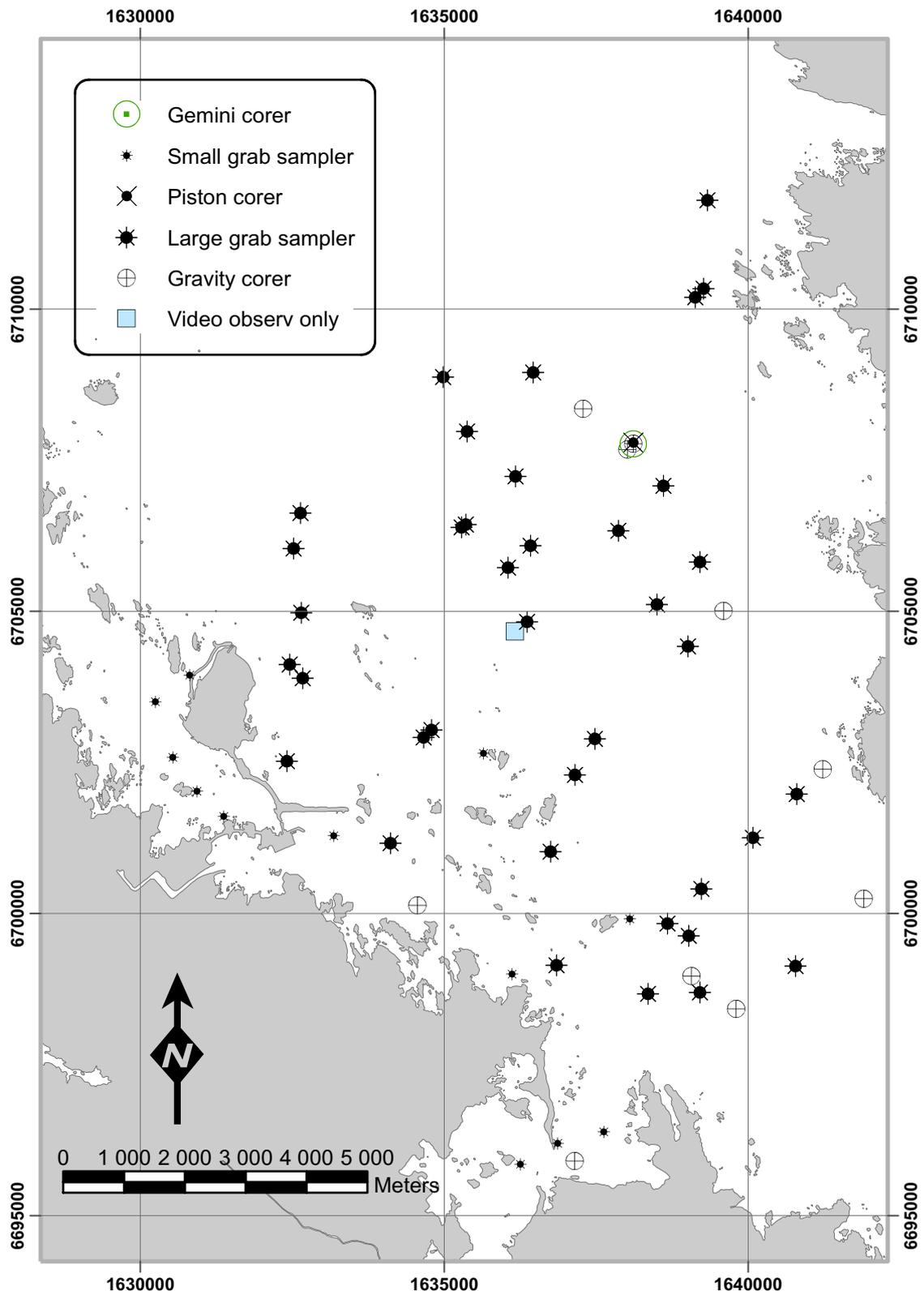
Figure 5-1. *Forsmark marine geological survey. Sampling sites. Permissions: Lantmäteriverket 2001, M2001/5268 and Sjöfartsverket, 010305-H30/04-04-17597.*
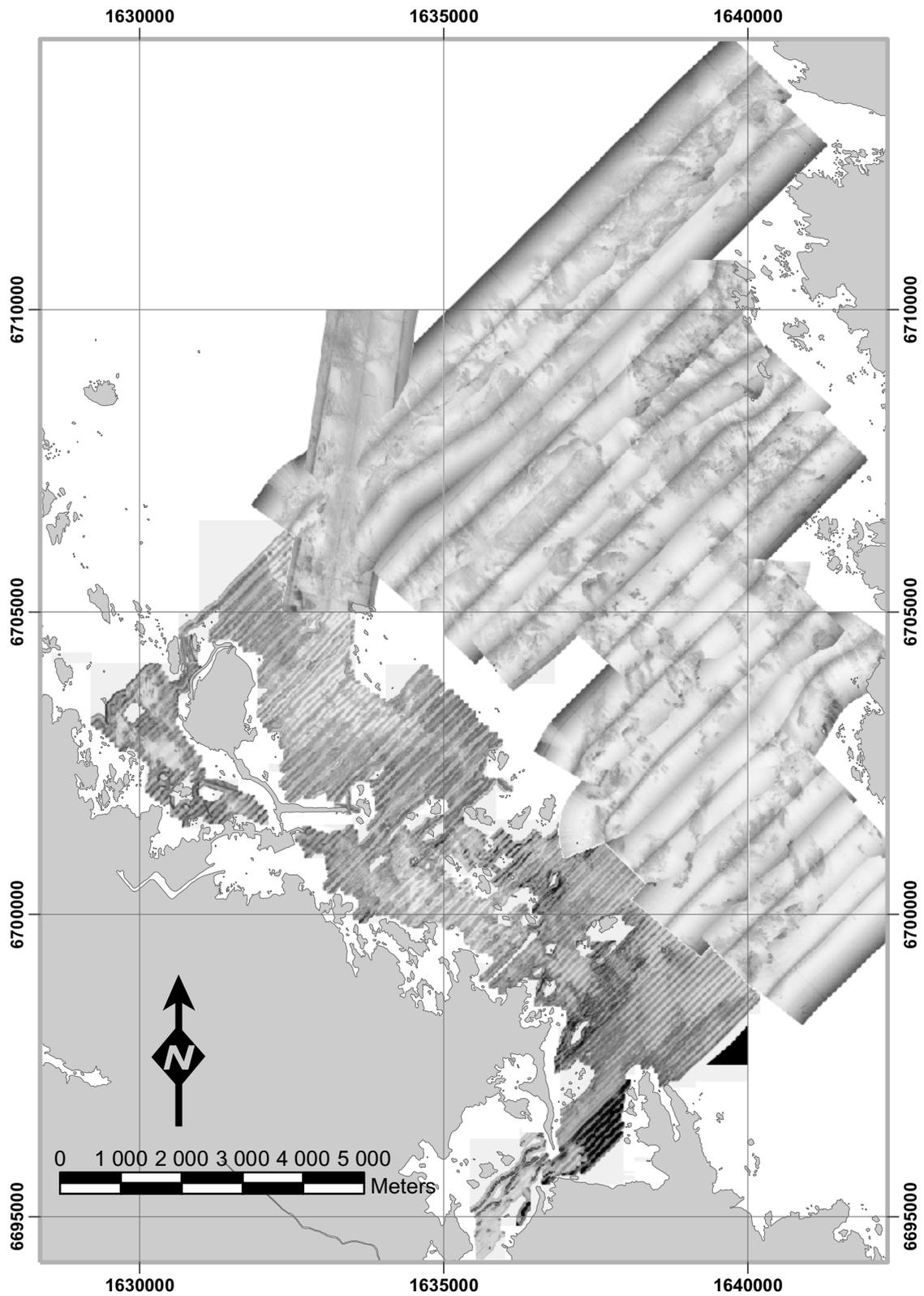
Figure 5-2. *Forsmark marine geological survey. Sonar mosaics. Permissions: Lantmäteriverket 2001, M2001/5268 and Sjöfartsverket, 010305-H30/04-04-17597.*
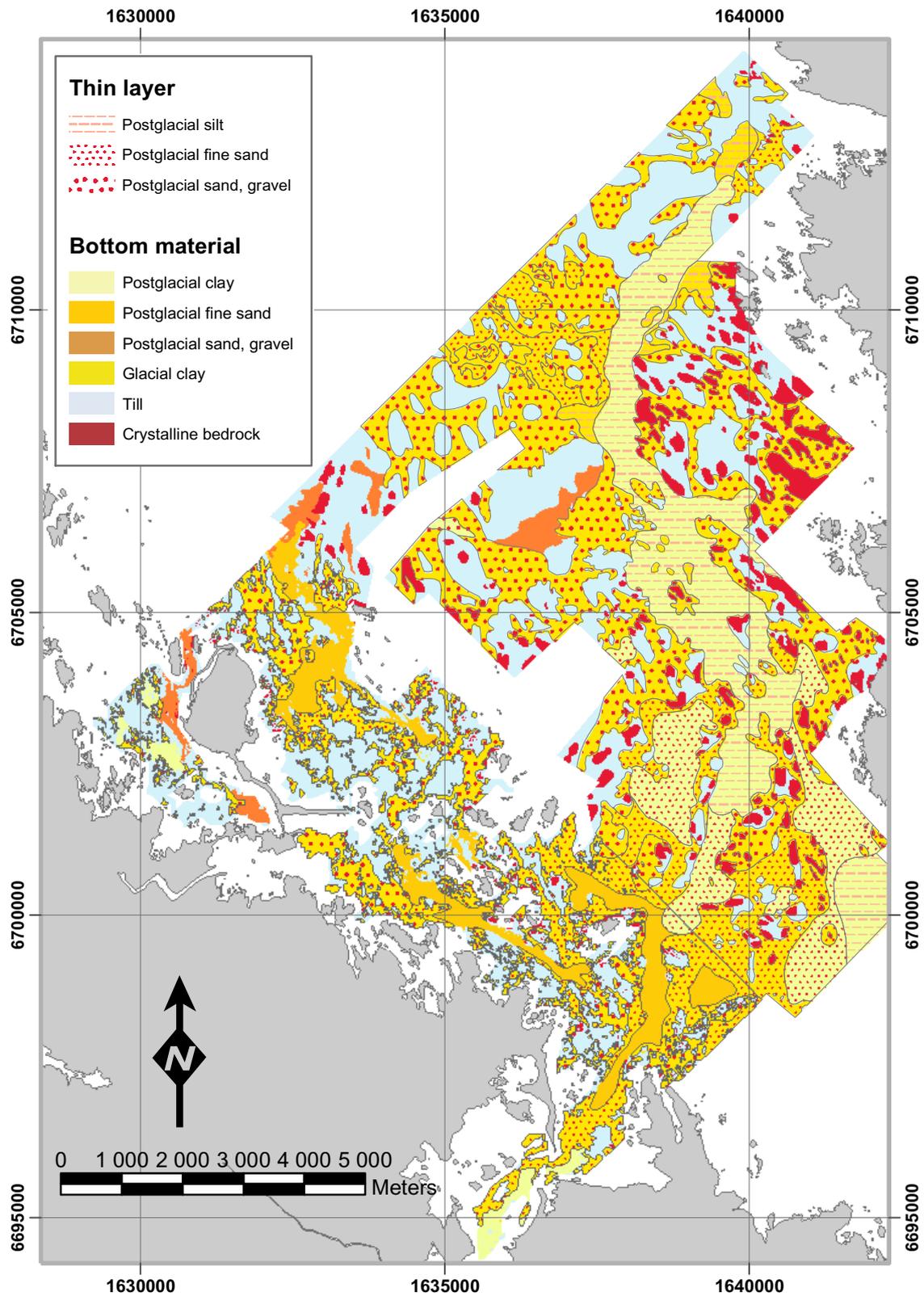
Figure 5-3. *Forsmark marine geological survey. Marine geological map. Permissions: Lantmäteriverket 2001, M2001/5268 and Sjöfartsverket 010305-H30/04-04-17597.*
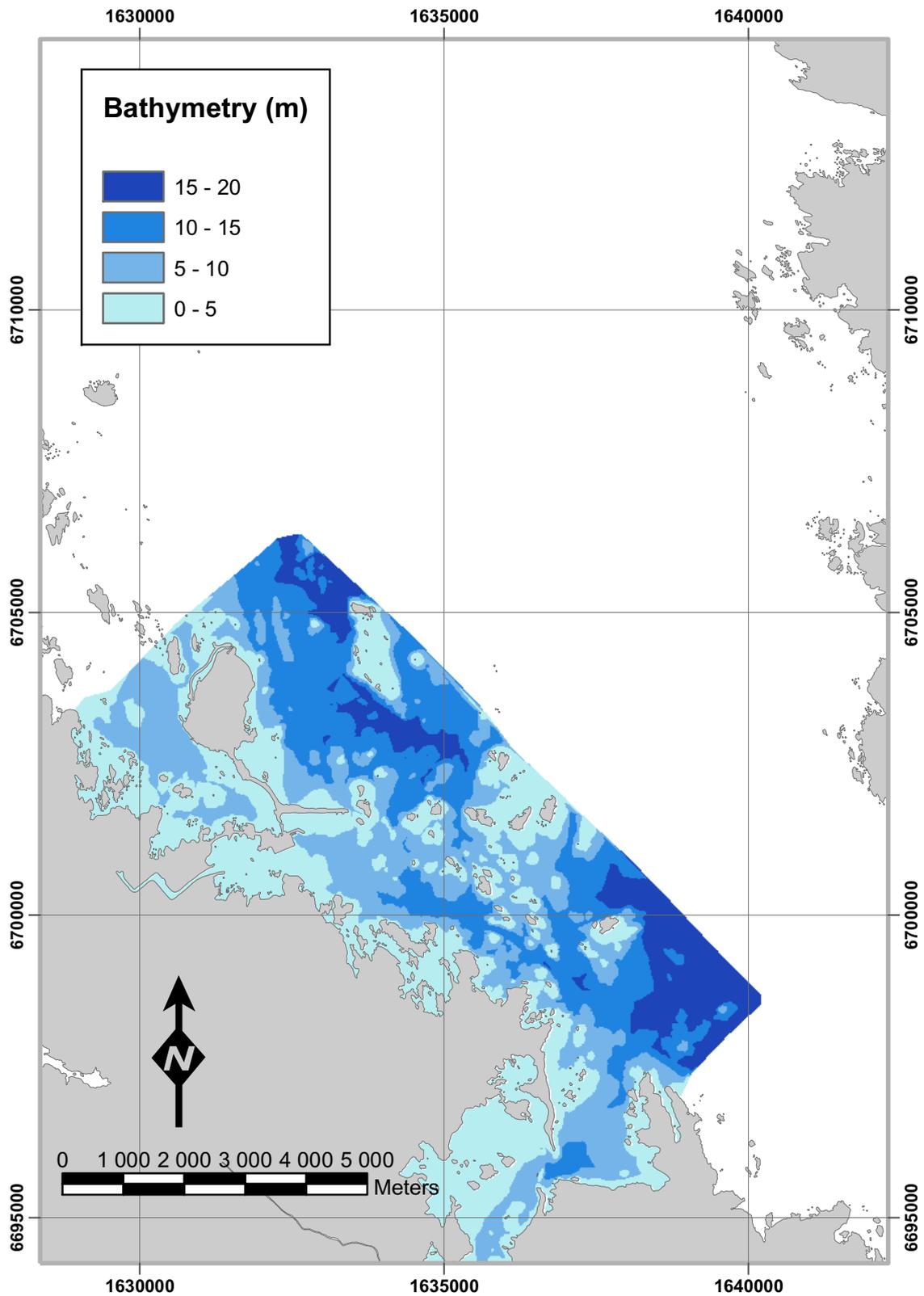
Figure 5-4. *Forsmark marine geological survey. Bathymetric model. Permission to publish: Sjöfartsverket 010305-04-17297:22.*
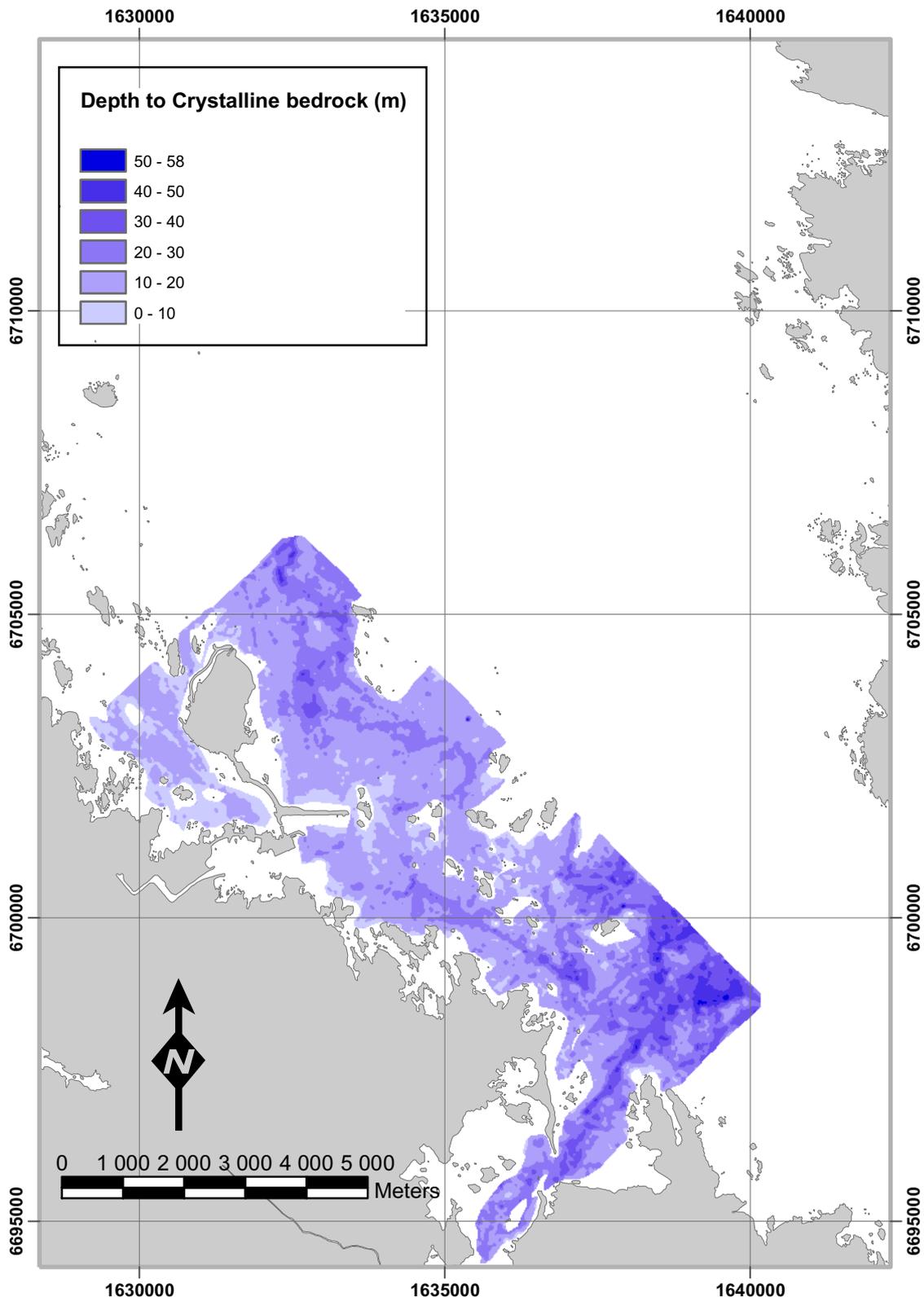
Figure 5-5. *Forsmark marine geological survey. Terrain model of the Crystalline bedrock surface. Permission to publish: Sjöfartsverket 010305-04-17297:22.*