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Oskarshamn site investigation

Marine survey in shallow coastal waters

Bathymetric and geophysical investigation 2004

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Marin Mätteknik AB

October 2004

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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Abstract

In order to identify water depth, surface geology and upper substrata Marin Mätteknik AB has carried out acoustic marine investigations in the Simpevarp area. The data collected is divided in two groups based on water depths.

- In shallow water areas, with depths less than 3 m, single beam echo sounding has been performed collecting depth data. The collected data set gives a general description of the water depths in the shallow areas. The soundings were collected with the intention to follow the coastline and then add lines towards the deeper parts. The original line spacing was set to 80 m, but the recording of data was generally done with denser line spacing.
- In areas with depth more than 3 m multi beam echo sounding, side scan sonar and shallow seismic investigation have been used to collect depth data, acoustic seabed data and where possible, data from substrata. The survey lines were planned with a line spacing of 80 m and kept as straight lines. In parts, additional survey with multi beam has been performed to record full coverage for best results. It was possible to complete a large part of the gaps.

Sammanfattning

Med syfte att kartera bottendjup, ytgeologi och underliggande övre stratigrafi har Marin Mätteknik AB utfört undersökningar i den marina delen av Simpevarpsområdet. Den insamlade datan kan delas in i två grupper, baserat på vattendjup.

- I vattenområden grundare än 3 m användes singelstråleekolod för att samla in djupdata. Insamlad data ger en generell bild av vattendjupen i de grundare delarna. Djupdata samlades in genom att följa kustlinjen för att sedan mäta sig ut mot de djupare delarna. Den ursprungliga mätdefinitionen var ett linjeavstånd på 80 m, men data samlades ofta in med ett tätare linjeavstånd för att ge ett noggrannare resultat.
- I områden med vattendjup större än 3 m användes multistråleekolod och den geofysiska utrustningen bestående av side scan sonar och penetrerande ekolod. I dessa områden utfördes mätningen efter planerade raka linjer med ett linjeavstånd av 80 m. Efter uppmätning av de definierade linjerna kompletterades mätningen för att i valda delar kunna presentera en 100 % täckningsgrad med multistråledata.

Contents

1 Introduction

This document reports the data/results gained by the marine survey and seabed mapping, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-04-021. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	**Number**	**Version**
Sjömätning och sedimentkartering	AP PS 400-04-021	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för Maringeologisk undersökning	SKB MD -260.001	1.0
Metodbeskrivning för jordartskartering	SKB MD -131.001	1.0

The field activities were performed during 2004-08-10 to 2004-08-19.

The reporting and processing of data were performed from 2004-08-23 to 2004-10-11.

2 Objective and scope

The objective and scope of the performed activity are defined as follows.

The survey is a part of the investigation program for Site investigation conducted by SKB in the Simpevarp area with the purpose of determining the suitability for a deep repository of nuclear waste. The objectives include:

- Investigating water depth and structure of the seafloor.
- Defining the area distribution of geological regimes.
- Detecting and determine sediment substrata.

To measure and define the above the following survey activities have been performed

- Singlebeam echo sounding.
- Multi beam echo sounding.
- Side scan sonar investigation.
- Shallow seismic investigation.

3 Project parametres

3.1 Project Manual

Prior to the start of the survey a Project manual was produced to ensure the survey methodology and survey definitions throughout the survey.

3.2 Permits

The permit for the survey is given by the Headquarters of Swedish defence as stated (completed permit forwarded to SKB as a papercopy attached in report binder):

HKV id: 18 600: 711 43

Dated: 2004-08-09

HKV coordination: ÖvLt HB Fischhaber Försvarsmakten Högkvarteret GRO Mijö

3.3 Coordinate system

All data are reported in RT 90 2.5 gon west.

3.4 Height system

The water level reference during the survey was mean sea level (MSL) 2004. All presented data with regards to height system are correlated to RH70.

MSL related to RH70 –3 cm.

3.5 Water level correction

Water levels were obtained from SMHI:s water level station Oskarshamn, which presents the current value every hour.

3.6 Survey areas

The survey area (Figure 3-1) was divided into two types (Figure 3-2 and Figure 3-3).

The survey areas of the shallow waters are regarded as “areas”, meaning that the survey lines were defined on location to ensure the most suitable survey track with regard to the geographical conditions for the single beam survey

In the deeper areas a pre-defined set of straight survey lines was used for the Multi beam and geophysical survey.

The position and identity code of the survey lines are attached in Appendix 1.

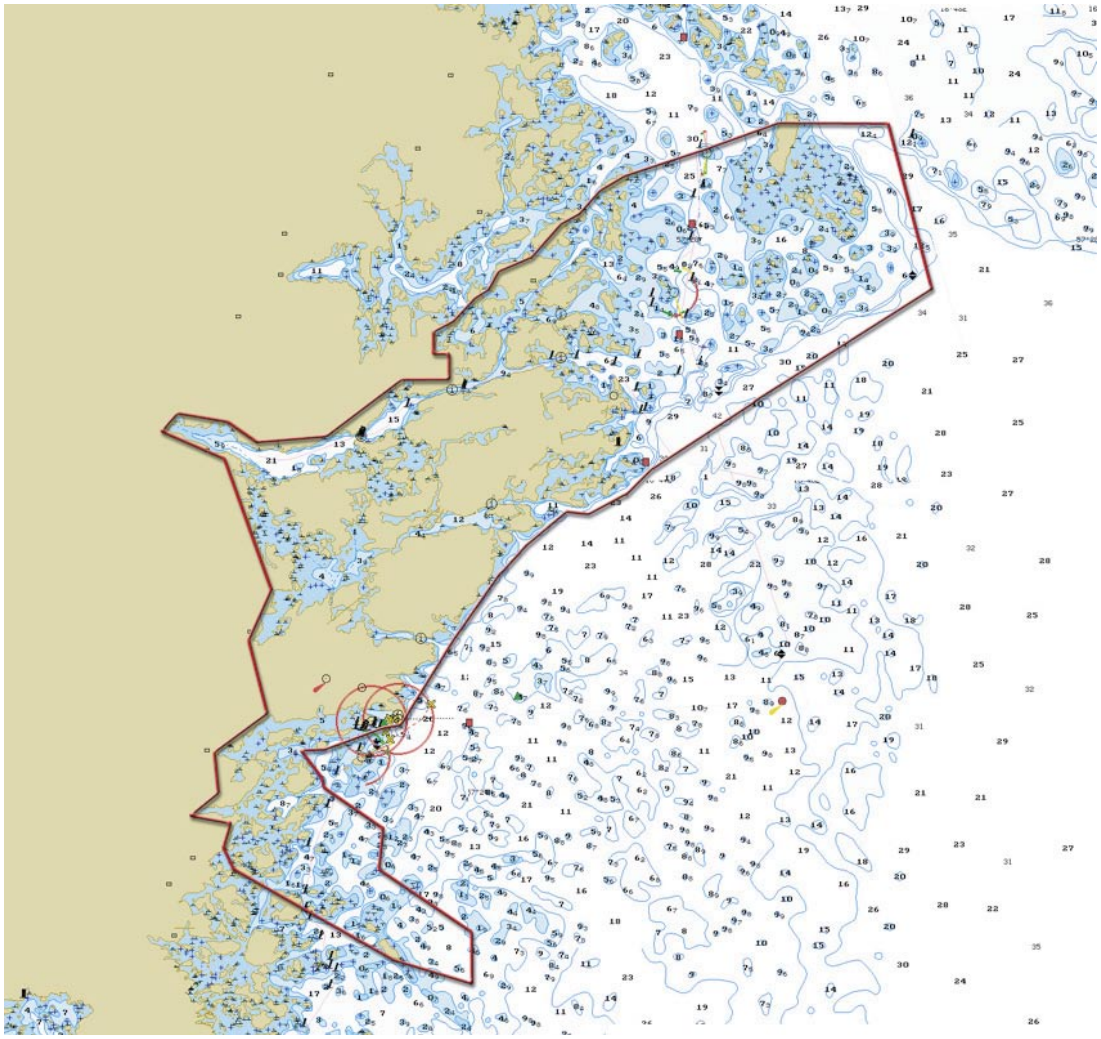

Figure 3-1. *The survey area is defined within the red line in the image above.*

Figure 3-2. *(Left) The areas for the survey of Pang (Figure 3-4), with single beam echo sounder in water depths less than 3 m. IDCODE GSM000013.*

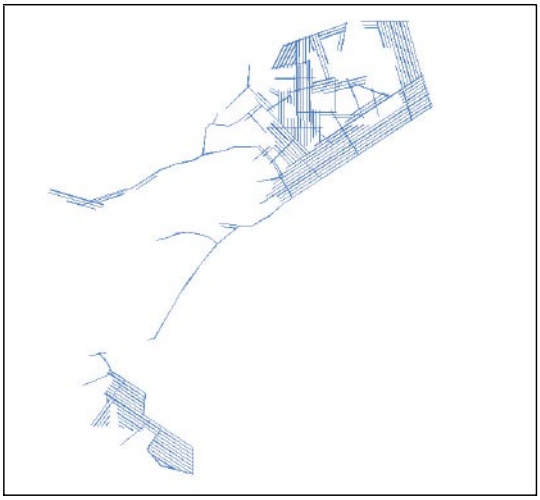

Figure 3-3. *(Right) The defined survey lines for Ping (Figure 3-5), with multi beam echo sounder and geophysics in water depths exceeding 3 m. IDCODE GSM000014.*

Figure 3-4. *(Left) Single beam vessel Pang.*

Figure 3-5. *(Rright) Multi beam and geophysical vessel MV Ping.*

4 Equipment

4.1 Description of equipment/interpretation tools

4.1.1 Shallow water vessel, 0–3 m water depth

To perform an efficient and high quality echo sounder survey in shallow waters, a small open vessel, a Mini Buster named Pang (Figure 4-1), was mobilised with the following equipment:

- Single beam echo sounder: Ceeducer with a top unit capable of storing recorded data (Figure 4-2).
- Differential GPS antenna.
- Navigation computer Laptop with TRANSAS navigational chart system.
- Power supply: Car batteries.

After installation the equipment was tested by measuring a defined line in two directions. The data was then compared to ensure accuracy. Soundings were also surveyed over a known depth, pre-measured by a ruler. After acceptance the vessel was ready to perform the survey.

Figure 4-1. *(Left) Svante and Olof ready to start the shallow water survey with Pang.*

Figure 4-2. *(Right) Navigation computer and top unit of the ceeducer single beam echo sounder used on the shallow survey vessel.*

4.1.2 Main vessel, water depths > 3 m

In areas with water depths exceeding 3 m, a fully equipped survey vessel was used (Figure 4-3).

The main instruments included:

- Multi beam echosounder Simrad EM 3000 300 kHz 256 beams.
- Sound velocity profiler: AML Smartprobe.
- Gyro Simrad SH50.
- DGPS Ashtech Z12.
- Navigation: TRANSAS Digital seacharts.
- Survey control and positioning system: ARON.
- Side scan sonar: Edgetech DF 1000 100/500 kHz.
- Sub-bottom profiler: Chirp CAP6000.
- Geophysical recording/processing system: Triton ISIS geophysical software.

The instrumentation in Ping is calibrated regularly at a location in Göteborg harbour where the area is known and previously used. At the survey location, function tests were performed prior to start of the survey. The function test includes control of the accuracy of the DGPS system, offsets of the Multi beam, Side scan sonar quality and positioning as well as the sub-bottom profiler data-quality.

Figure 4-3. *The survey set-up in Ping as monitored during survey.*

4.2 Processing tools

The listed software has been used to create the final data-sets, charts and interpretations included in this report.

4.2.1 Bathymetry

Cfloor from Roxar /4, 5/ : A software for processing, griding methods and presentation formats of the collected bathymetrical data.

Point edit: An in-house developed software for control and processing of raw data.

4.2.2 Geophysics

Triton ISIS geophysical software /1/: Software for recording and process the geophysical data from Side scan sonar and sub-bottom profiler. Apart from geological interpretation it is also used for positioning of obstacles, boundaries between geological features and digitising sub-bottom layers.

DelphMap: A side scan mosaic tool that produces side scan mosaic in geotiff format.

4.2.3 Charts and data presentations

AutoCAD2000 /3/: This software is the main tool for producing paper charts with the collected results.

ArcMap/View /2/: GIS software mainly used for controlling the conversion of various formats into usable formats for this GIS environment.

5 Execution

5.1 General

The fieldwork consisted of using two vessels, one for collecting depth soundings and geophysical survey in water depths exceeding 3 m and one vessel for water with less water depth than 3 m. Prior to start the areas for each survey task and the method to be used was agreed in the Project manual. The survey period included parallel activities for the 2 vessels during 9 effective days.

The survey in waters less than 3 m deep was first conducted along the coastline of the shallower areas and then offset lines were surveyed to make it possible to give a general depth of the area. The survey was performed in daylight in 10 to 12 hour operations each day. The survey progress went according to plan. Large parts of the areas included rocks not presented in any previous documentation (e.g. existing digital sea charts). To avoid unnecessary damage of the survey vessel and equipment the survey was performed with one surveyor as a lookout at the bow of the boat. Data was successfully collected to allow a general outline of the depths in the areas as well as detailed depth soundings along the survey tracks.

The survey in water depths exceeding 3 m was performed along lines defined prior to start of the survey. All parallel lines were planned with an offset of 80 m. A multi beam echo sounder was used to collect depth data with a swath of 6–7 times the water depth. In addition geophysical data was collected including side scan sonar and shallow seismic along the defined lines. Additional echo sounding was conducted in areas close to islands and shallow waters with the purpose to cover as much as possible with a 100% coverage of the sea floor. The results were successful according to the agreed limitations and the collected depth soundings present a detailed data collection in large parts.

The side scan sonar theoretically covers 50 m of the seafloor on both side of the survey line. From the results it is possible to define different surface geological regimes.

With the penetrating echo sounder a sediment profile was recorded along the survey lines. It should be noted that large sections include hard seabed of bedrock and till which does not allow any penetration of the sub-bottom profiler. The results focus on penetration of the sediments and depth to till and bedrock relief.

5.2 Preparations

5.2.1 Pre-planning

Prior to start of the survey the scope and methods were established with regard to the requirements. A discussion of limitations and most suitable methodology was conducted between Marin Mätteknik AB (MMT AB) and SKB.

5.2.2 Calibration and function tests

The calibrations of the instrument set up on Ping are performed in the vicinity of MMT office in Göteborg harbour. In this calibration procedure all offsets and corrections are controlled, and if needed, adjusted to ensure correct measurements.

After mobilisation and arrival at survey location in Simpevarp the vessels were function tested prior to start of survey.

The shallow survey vessel was function tested by recording data along a track two times in opposite directions. By comparing the lines it was concluded that the accuracy of the measurement and the positioning were correct. A second test was performed by measuring the depth with a ruler and then verifying it against recorded data from the echo sounder.

5.3 Execution of fieldwork

The fieldwork can be summarised in the table below.

Table 5-1. Activity table.

Date	Activity	Comment
2004-03-17	Tender and proposal delivered by MMT AB	
2004-06-14	Letter of intent from SKB	
2004-06-15	Permits sent to Headquarters	
2004-07-07	Production of a Project Manual	5 work days to complete
2004-08-05	Mobilisation of survey vessels	5 work days to complete
2004-08-09	Permit obtained from Headquarters of Swedish defence	
2004-08-10	Transportation and mobilisation in the Simpevarp area	
2004-08-11	Function test and start Survey area G and H + K2	
2004-08-12	Survey area G H C –D + K2	
2004-08-13	Survey area K1 and C	
2004-08-14	Survey area K3 and D–B	
2004-08-15	Survey area K3 and D–B	Extending Mb-survey towards islands.
2004-08-16	Survey area K3 and E–D–A	Extending Mb-survey towards islands.
	Brief progress meeting with SKB	
2004-08-17	Survey area K4 and E	Extending Mb-survey towards islands.
2004-08-18	Survey area K5 and Infills and extended survey for full coverage	Mb-survey towards islands and coverage of K6 as much as possible.
2004-08-19	Survey area K5 and Ping in C	
2004-08-20	Demobilisation	
2004-08-23	Start processing of data	
2004-09-16	Meeting to define data delviery	Main structure of the reports and data established
2004-10-09	Delivery of results to SKB	

5.4 Data handling/post processing

The following steps are performed in the processing of data.

5.4.1 Bathymery processing

Multi beam data

In brief the processing can be described by the following steps

1. Data is controlled and accepted onboard after every survey shift.
2. After completion of the survey all data is reviewed to ensure a complete collection of data sets.
3. Data is delivered to the office on hard discs and stored by a responsible processor on a server system.
4. Depth soundings are processed and corrected for water level changes during the time of the survey.
5. Depth soundings are filtered from noise and spikes by base criteria and manually in Point Edit.
6. The data-set is gridded with relevant grid cells of 5×5 m.
7. The grid is controlled and exported as contour lines (2 m), coloured bitmaps and ascii formats.

Single beam data

1. The recorded data is downloaded to a hard disc after every survey shift and reviewed in PointEdit.
2. After completion of the survey, the data is stored on server.
3. Depth soundings are corrected for tidal variations for each day.
4. The depth soundings are processed in PointEdit.
5. After control the data is accepted and stored as ASCII.
6. Contouring of the single beam data is set after evaluation of the data extension.

5.4.2 Geophysical processering

All the geophysical processing is performed digitally. The responsible survey operator performs the quality control on-line during survey

Side scan sonar data

1. The processing is performed by running the recorded files in playback mode. Various visual settings can be applied to enhance the interpretation possibilities.
2. The data is merged into areas and side scan sonar mosaic is then produced.
3. The merged mosaics are then the base for the digitalisation of the geological boundaries.
4. The interpretation of the data is performed, based on both the merged and the raw data files.

5. The focus of the interpretations are:
   – Type of seabed sediment.
   – Extension of bedrock at seabed surface.
   – Detection of objects on seabed surface.
6. The processing follows the following steps:
   – Evaluation and estimation of the geological regimes that are present in the area.
   – Decision on geological classes to be used. The classification aims to follow the 12 classes defined by Geological Survey of Sweden (SGU) /6/.
   – After classification the data is controlled and cross-checked to ensure correct interpretation.
   – Detection of objects and cables on seabed surface is performed.
   – The data is then converted into shape-files for further use in a GIS environment.

Sub-bottom profiler data

1. The processing is performed by running the recorded files in playback mode. Various visual settings can be applied to enhance the interpretation possibilities.
2. The different sub-bottom units are digitised based on the acoustic pattern.
3. All units are digitised with regards to the lower boundary, based on milliseconds The velocity in clays/silts and sand layers are set to 1,600 m/s. Based on this, the lower boundary is calculated.
4. Evaluation and estimation of the geological regimes that are present in the area.
5. Decision on geological units to be used. Focus is to determine the depth to hard relief, consisting of till and bedrock (lowest detected reflector).
6. Selection of representative profiles. Five selected profiles for detailed presentation.
7. After classification the data is controlled and cross-checked for any discrepancies.
8. The data is then converted into shape-files for further use in a GIS environment.

5.5 Analyses and interpretations

5.5.1 Bathymetry

The results are to be reviewed in charts and data sets. Two data sets are presented.

1. Multi beam and single beam data, gridded within measured boundaries.
2. An interpolated model including the measured depth soundings, the defined coastline and an estimation of shallow islets. The model is one example of interpolation of the collected data. It is important to note that there may be other ways.

5.5.2 Backscatter

The backscatter data is additional information obtained from the multi beam echo sounder. In general the measured reflectivity loss from each beam is dependent on the composition of the seabed. This provides a possibility to produce an index of the hardness of the seabed.

Colour code	Bottom index	Reflection	Typical sediments*
Red	Hard	Very strong reflection	Bedrock and till
Orange	Coarse	Strong reflection	Sand and gravel
Light green	Firm	Medium reflection	Silt and Sand
Grey	Soft	Weak reflection	Clays
Light grey	Soft to very soft	Very weak reflection	Gyttjaclays and loose sediments

*This method only provides a general indication of what seabed sediments are present. However, any geological interpretation should be performed with a side scan sonar and/or ground truth sampling.

5.5.3 Seabed surface geology

The interpretation is based on the acoustic pattern recorded, with the object to determine the seabed geology. The interpretation is based on the following:

1. Study of background information on what to expect generally in the area.
2. The acoustic pattern is interpreted by using general guidelines of each sediment's typical acoustic patterns and previous experience of acoustic patterns corresponding to a certain geological class. As an aid for the sonar interpretation the data from the sub-bottom profiler is used for cross validation.

The Triton ISIS-software allows the recorded data to be reviewed and includes a number of visual displaying options to enhance the view of data. The data can be scrolled back and forth over the screen and all information has position tags, which allows the geologist control of where the data was collected.

Objects on seabed surface are also detected through studying the acoustic pattern on the side scan sonar data.

5.5.4 Sub-bottom profiles

The interpretation is based on the acoustic pattern recorded, with the object to determine the sub-surface sediments. In general the focus is to determine the acoustic pattern in each digitised unit. The criterias for the interpretation are:

1. Acoustic penetration.
2. Distinct reflectors separating units.
3. Acoustic pattern in each unit.

The Triton ISIS-software allows the recorded data to be reviewed and includes a number of visual displaying options to enhance the view of data. The data can be scrolled back and forth over the screen and all information has position tags, which allows the geologist control of where the data was collected.

It is standard to correlate the interpretation from the side scan sonar and the sub-bottom profiler.

5.6 Nonconformities

5.6.1 Multi beam echo sounder

MMT AB proposed to use a multi beam echo sounder in water depths exceeding 3 m instead of the single beam echo sounder. The main arguments for this change are:

1. The Multi beam with 256 beams gives a much more detailed information in an area with an irregular seabed surface with large local variations due to bedrock outcrops.
2. The multi beam data can produce backscatter information, which is of use for determining seabed hardness.
3. The detailed depth information is a useful tool to enhance the quality of geological interpretation, current models, biological habitat mapping and more.

5.6.3 Water level station

At the time of the tender documents there was no available water level station in the area with continuous logging of water level changes. Therefore MMT AB suggested to place a water level station in the area. However at the time of the survey SMHI had opened a station at Oskarshamn. The recorded data from this station was used throughout the survey work.

5.6.3 Survey lines

The survey was conducted along all survey lines as defined prior to start of survey with the following exceptions:

1. Deviations of the lines due to shallow depth. Most of the lines were completed. In a few situations it was necessary to deviate from the line to avoid a shallow area or rock. Data was, however, recorded and the deviation visible in the track chart.
2. At the line C030a–C030f (SKB Id code LSM001146– LSM001151) it was not possible to pass into the inner bay. Therefore the survey line was moved to an alternative inlet to perform measurements.
3. Fishing gear was present in a few locations close to shore (Figure 5-1). This did not affect the survey apart from minor deviations of a few metres.

Figure 5-1. *Fishing gear in the water at Skärvarp.*

6 Results

6.1 General

The results from the marine surveys are best viewed in the presented data sets and charts included in this report. In the sections below the results are commented and briefly summarised.

6.2 Bathymetry

The inner parts consist of shallow areas where the water depth is between 0 and 4 m. Large areas are very shallow, less than 1 metre. In general the depth increases out in the middle of the marine areas. A number of very shallow passages are encountered connecting the marine systems with each other.

Another significant feature is the occurrence of large rocks or boulders. The boulders rapidly decrease the water depth but are not necessarily visible at the water line. This feature is mainly encountered in the shallow areas.

The outer areas are very irregular and the seabed is shaped by numerous local rises that partly extend to forming the archepelagic islands, submarine islets or rock. In between these the seabed is smoothed with sediment deposits, Figure 6-1.

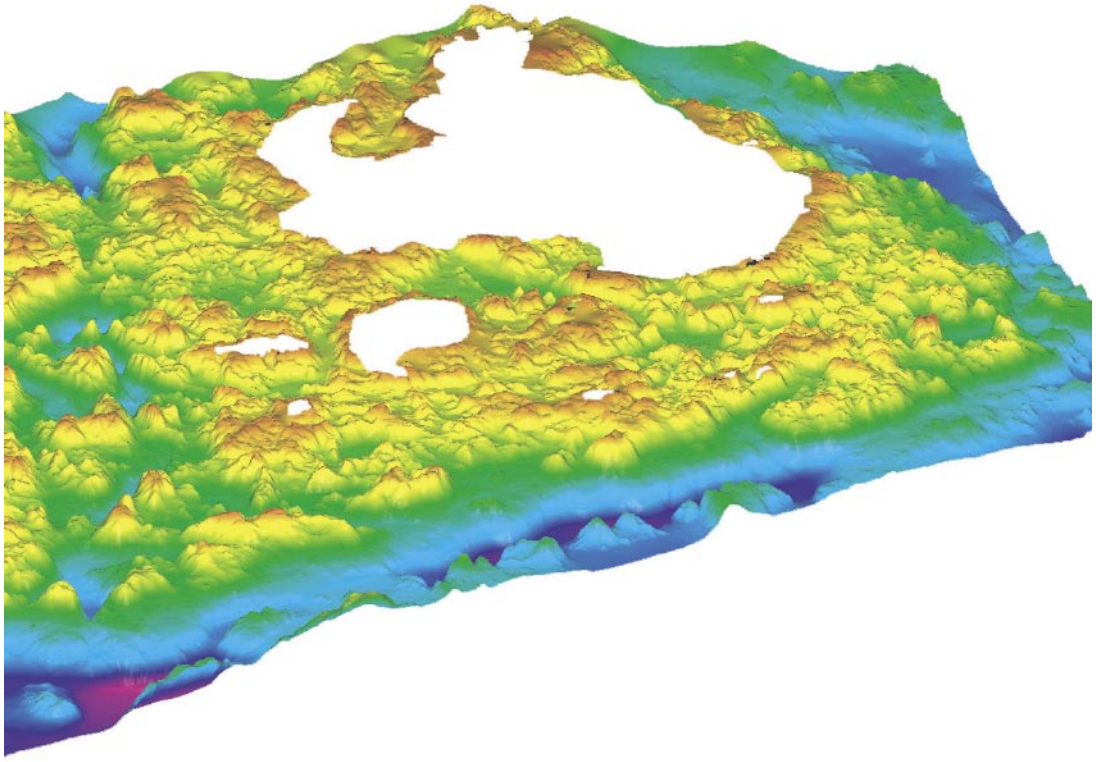

Figure 6-1. *3D View of the north eastern part of the area surrounding Boskär.*

6.3 Seabed surface geology

The seabed surface varies but generally a crystalline bedrock (granite) relief partly overlaid with till dominates the area.

South of Simpevarp only small areas of fine sediments are present and the till dominates the seabed together with exposed bedrock.

The till is also the dominating seabed feature in the archepelagic area west of Boskär and outside the coast of Simpevarp, Ävrö and Utlångö.

East of Boskär, southeast of Skärvarp and around Ljuskläppen the bedrock is to a large extent exposed and only covered by small areas of mainly sandy sediments.

Sandy sediments, such as fine sand and sand with gravel and stones, are present in the entire area and dominate in a depression east of Boskär and outside Enudden.

Soft clays are present in the inner, deeper parts of Granholmsfjärden and the embayment between Utlångö and Ävrö. An area reaching northeast from Enudden also displays soft clays at the seabed surface in between shallower hard seabed areas (Figure 6-2).

6.3.1 Exposed bedrock and seabed sediments

Crystalline bedrock

The crystalline bedrock is the dominant feature that forms the marine relief in the areas. In decreasing water depth close to islands and shallow waters the bedrock is often exposed at seabed surface, mostly surrounded by a till deposited with varying thickness. The largest bedrock outcrops are present in the vicinity around Boskär and around the islets southeast of Boskär and Ljuskläppen.

Till

Till is the dominant seabed type in vast parts of the areas (Figure 6-4). The till in the area shows varying boulder frequency and is partly reworked to include dominantly coarser fractions. The till is most dominant in the area south of Simpevarp and along the entire offshore coast of the area. The archipelago between Marsö and Boskär is also dominated by till. The till is also indicated to extend south and east of the surveyed area.

In parts large to very large single boulders are present in the till (Figure 6-5). Height above the surrounding seabed more than 2.5 m have been measured.

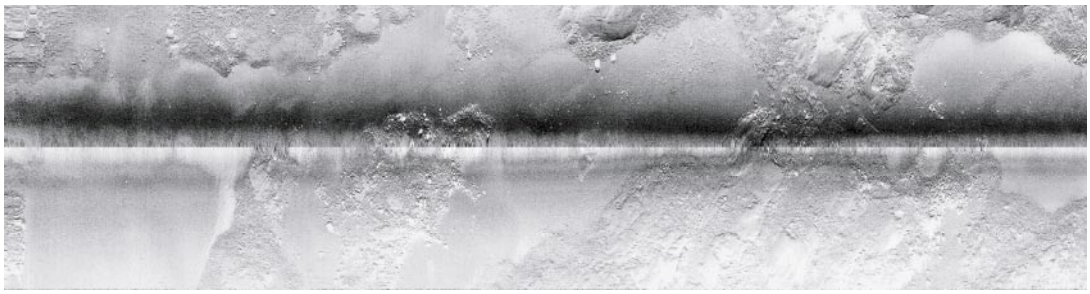

Figure 6-2. *Side scan sonar strip showing a swath of 100 m width. In the image the vessel direction is left to right. The seabed in the image varies with areas of clays in between outcrops of till and bedrock.*

Figure 6-3. *Sonar image of exposed bedrock.*

Figure 6-4. *(Left) Sonar images of typical till from the area.*

Figure 6-5. *(Right) Till with high frequency of boulders.*

Sand and Gravel

The sand and gravel in the area are mainly present in connection with the till and clay areas (Figure 6-6). The sandy sediments partly drape the slopes and the shallower areas. It is concluded that parts of the material originates from the till. The unit is often close to areas of fine sand. In parts the boundary between these units is transitional. Two extent areas of sand and gravel are present east of Enudden and in a depression east of the Boskär area. It should be noted that the ratio between sand and gravel in the area varies. In parts stones may be present in this unit.

Fine sand

In some deeper channels and infills fine sands and silt dominate the sediment (Figure 6-7). These areas are in general present in connection to areas with sand and gravel. In parts these sediments are thin and possibly mobile. The unit is dominant in deeper areas east and south east of Boskär and in the deeper parts in the archipelago. In the areas with fine-to medium sand areas of sand rippels are noted at several locations.

Postglacial clay

The postglacial clays are deposited in deeper areas and in larger channels. In parts the clays are soft and interpreted as gyttjaclay. The gyttjaclay is dominant in Granholmsfjärden. Larger post glacial deposits are also dominant in the outer southeastern part of the area (Figure 6-8).

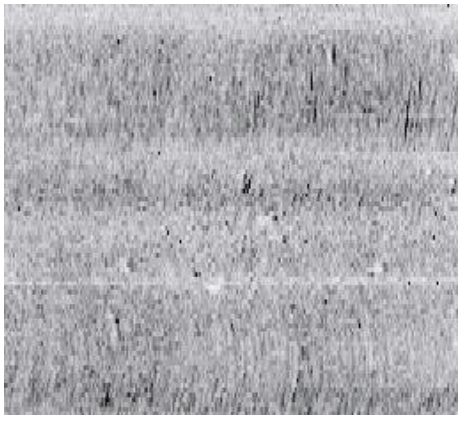

Figure 6-6. *Sonar image of sand and gravel.*

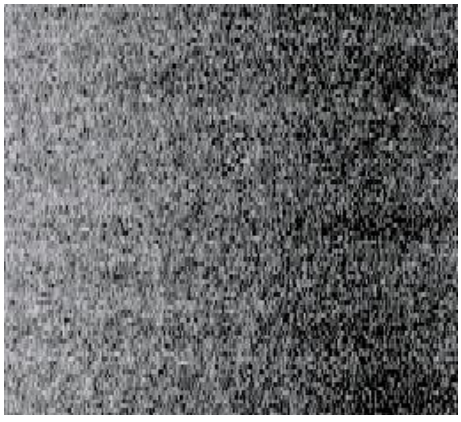

Figure 6-7. *Sonar image of silt and fine sand.*

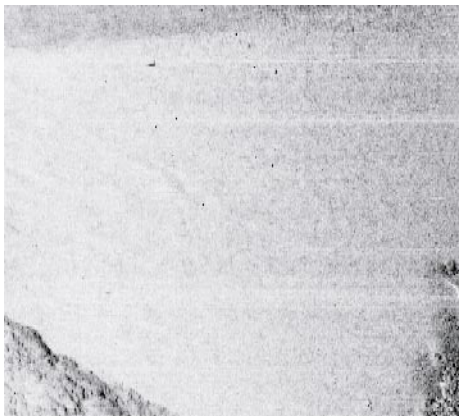

Figure 6-8. *Sonar image of postglacial clays*

6.4.1 General

A large part of the area includes a hard seabed with till and/or bedrock present at seabed surface. Gravel, sands and clays are deposited in pockets and channels in the hard seabed relief.

In smaller bathymetrical variations clays are present as pockets, in parts with surface veneers of gravel and sands. These pockets typically extend from 0.5 to 6–7 m.

In the deeper areas larger deposits of postglacial clays overlying glacial clays are detected. Veneers of sand and silt are often present draped over the sediment pockets.

In the deepest parts the sediment deposits are generally thicker, but bedrock and till are still occasionally present at seabed surface.

The type of sediment areas can be generally divided below.

6.4.2 Areas with dominantly hard seabed

South of Simpevarp the area is dominated by till and bedrock (Figure 6-9). As a result the few sediment pockets present are relatively shallow. The situation is similar in the surveyed area east of Ävrö and Utlångö.

6.4.3 Areas with hard seabed and pocket infills

A large part of the area between Utlångö and Boskär has an irregular seabed (Figure 6-10). In the depressions, pockets of sediments are deposited. In general clays overlaid by veneers of coarser sediments dominate the pockets. The thickness of the pockets varies from 0.5 m to 6–7 m.

6.4.4 Areas with larger sediment deposits

In the deeper parts east of Boskär and east of Kråkelund, thick deposits of clays overlay the undulating hard seabed relief (Figure 6-11). In these sections it is possible to define underlying glacial clay overlaid by a postglacial unit. In parts veneers of coarser sediments are deposited at seabed surface.

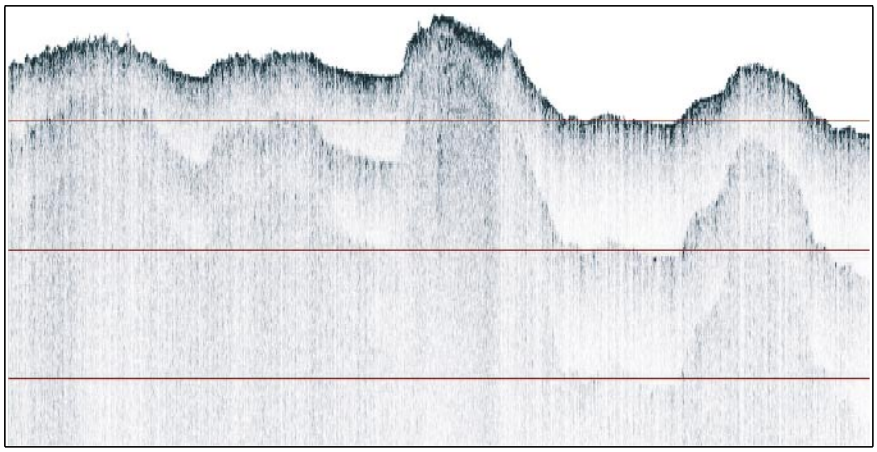

Figure 6-9. *Geophysical image of a typical hard seabed area. The upper seabed presents a strong surface reflection from the till and partly exposed bedrock. Red lines indicate 10 m interval.*

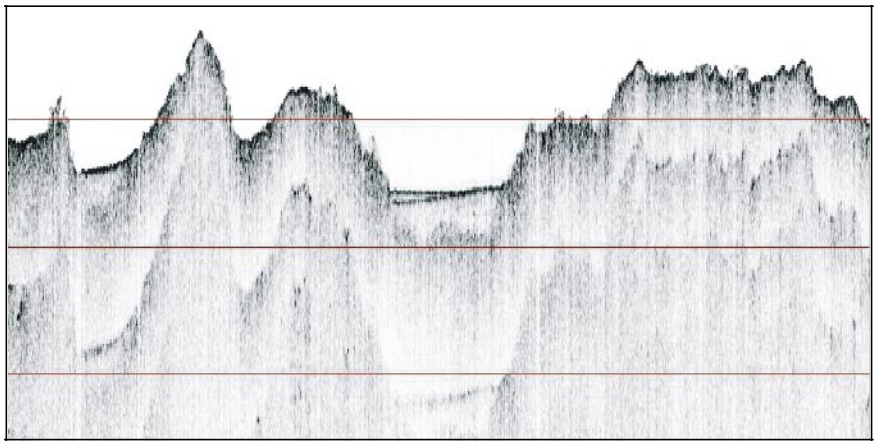

Figure 6-10. *Geophysical profile presenting an area with an undulating hard seabed relief with pockets of more fine grained sediments of clay. Often with a surface veneer of sand.*

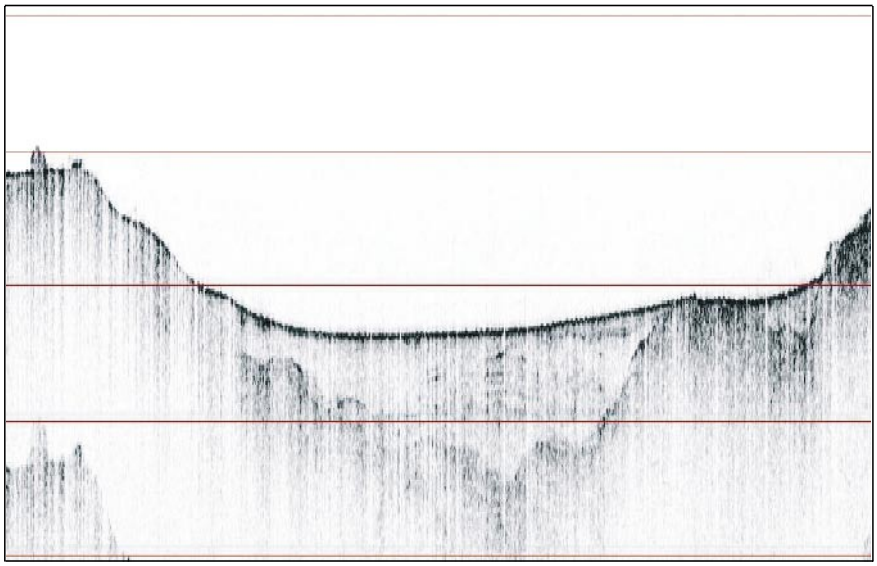

Figure 6-11. *Geophysical profile that illustrates larger deposit of clays in the underlying seabed relief.*

6.4.5 Areas with gas charged sediments

In the areas of Granholmsfjärden and adjacent channel the sediment deposition of clays is extensive. However, in vast parts the sediments are gas charged (Figure 6-12), hence the thickness of the clay unit is not known.

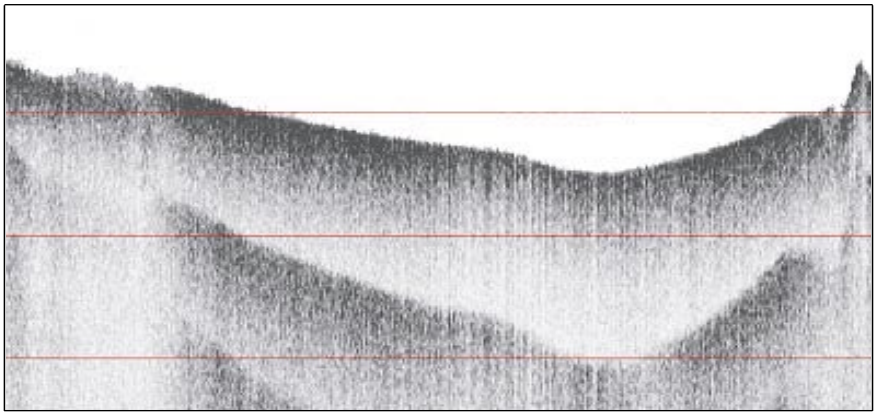

Figure 6-12. *Geophysical profile showing a soft gas charged sediment of Gyttjaclay. Although the sediments are very soft the gas cause "acoustic blanking" of the acoustic signal and no further data can be achieved.*

7 Summary and discussions

The marine survey has established an overview of the bathymetrical and geological situation of the seabed in the investigated area. A considerable amount of both depth and acoustic seabed data have been recorded, processed, presented and stored for further use.

All data has been processed by MMT AB.

The bathymetry data has been delivered as accepted points and as grid nodes of 5 x 5 m, thus allowing SKB to work with any modelling as desired. MMT AB has chosen to present all as contour lines and ESRI grid for use in GIS system, as well as in colour in paper charts.

The geophysical results have been processed and evaluated by MMT AB geologists. The presented data illustrates the distribution of present sediment composition at seabed surface based on the interpretation of the Side scan sonar. Objects detected on the seafloor have also been presented. The interpretation is presented in both paper charts and digitally for use in GIS systems.

The shallow seismic recorded in the area has been presented as a penetration chart indicating the thickness of sediment deposits in the area. 5 profiles have been presented in detail to present a typical situation. It was concluded that a grid of the sediment pockets covering the entire area would not be accurate with the present line spacing.

From the bathymetry data the shape of the hard seabed relief is distinct and the frequent local variations are clearly visible. From this data combined with recorded geophysical data the extension of the fine-grained sediment deposit can be further evaluated.

The geophysical raw data may be reviewed if further evaluation should be of interest.

Finally, the collected data set is considered to be very useful for evaluation of the area.

References

Post processing reference

/1/ Triton ISIS and Delphmap http://www.tritonelics.com/content/products/isis_sonar_suite.htm

/2/ ArcView http://www.esri.com/software/arcgis/arcview/index.html

/3/ ACAD http://www.autodesk.se/adsk/servlet/index?siteID=440386&id=4013250

/4/ cfloor http://www.cfloor.no/index.asp?page=Product

Grid methodology

/5/ Cfloor user guide version 6.0 from Roxar

Charting

/6/ Legend colour setting SGU, Maringeologiska kartan, 1989

Appendix 1

A.1 Defined survey lines and line codes

Table A-1. Survey lines in waters deeper than 3 m.

MMT Code	Start East	Start North	Stop East	Stop North	SKB idcode
A001	1557624	6373261	1558819	6373261	LSM001106
A002	1557676	6373181	1558051	6373181	LSM001107
A003	1557723	6373101	1558074	6373101	LSM001108
A004	1558217	6372601	1558022	6373283	LSM001109
A005	1558302	6372596	1558105	6373283	LSM001110
A006	1558387	6372590	1558189	6373283	LSM001111
A007	1558915	6370745	1558523	6372115	LSM001112
A008	1558755	6371597	1558272	6373283	LSM001113
A009	1558825	6371642	1558355	6373283	LSM001114
A010	1558895	6371688	1558438	6373283	LSM001115
A011	1558965	6371734	1558522	6373283	LSM001116
A012	1559035	6371780	1558605	6373283	LSM001117
A013	1559105	6371826	1558688	6373283	LSM001118
A014	1559408	6371057	1558771	6373283	LSM001119
B015	1559210	6371895	1556439	6370078	LSM001120
B016	1557380	6370600	1555715	6369507	LSM001121
B017	1559233	6371815	1558593	6371395	LSM001122
B018	1557524	6370598	1555381	6369193	LSM001123
B019	1559256	6371734	1558627	6371322	LSM001124
B020	1555387	6369101	1557676	6370602	LSM001125
B021	1558668	6371252	1559279	6371654	LSM001126
B022	1555359	6368987	1557828	6370606	LSM001127
B023	1558705	6371181	1559302	6371573	LSM001128
B024	1555207	6368792	1559325	6371492	LSM001129
B025	1555059	6368599	1559348	6371412	LSM001130
B026	1555481	6368780	1559371	6371331	LSM001131
B027	1555547	6368728	1559394	6371251	LSM001132
B028	1555579	6368653	1559418	6371170	LSM001133
C029a	1552209	6365107	1552357	6365157	LSM001134
C029b	1552357	6365157	1552842	6366000	LSM001135
C029c	1552842	6366000	1553000	6366284	LSM001136
C029d	1553000	6366284	1553240	6366626	LSM001137
C029e	1553240	6366626	1553514	6367023	LSM001138
C029f	1553514	6367023	1553938	6367541	LSM001139
C029g	1553938	6367541	1554519	6368035	LSM001140
C029h	1554519	6368035	1554809	6368010	LSM001141
C029i	1554809	6368010	1555302	6368293	LSM001142
C029j	1555302	6368293	1555611	6368578	LSM001143
C029k	1555611	6368578	1555673	6368619	LSM001144
C029l	1555673	6368619	1559438	6371088	LSM001145
C030a	1552423	6367670	1552687	6367725	LSM001146
C030b	1552687	6367725	1552939	6367829	LSM001147

MMT Code	Start East	Start North	Stop East	Stop North	SKB idcode
C030c	1552939	6367829	1553205	6367864	LSM001148
C030d	1553205	6367864	1553549	6367798	LSM001149
C030e	1553549	6367798	1553765	6367718	LSM001150
C030f	1553765	6367718	1553968	6367566	LSM001151
C031	1554063	6368008	1554436	6367965	LSM001152
C032	1554000	6368096	1554519	6368035	LSM001153
D033	1557259	6373224	1555625	6372633	LSM001154
D034	1557242	6373133	1556548	6372882	LSM001155
D035	1557225	6373042	1556574	6372806	LSM001156
D036	1556050	6372808	1556093	6370114	LSM001157
D037	1556130	6372837	1556175	6370031	LSM001158
D038	1556209	6372866	1556254	6370079	LSM001159
D039	1556309	6372902	1556316	6372477	LSM001160
D040	1556417	6372517	1556310	6372839	LSM001161
D041	1556749	6371772	1556366	6372923	LSM001162
D042	1556827	6371791	1556442	6372950	LSM001163
D043	1556782	6372179	1556517	6372977	LSM001164
D044	1557128	6373007	1557031	6372517	LSM001165
D045	1557256	6373245	1557111	6372510	LSM001166
D046	1556299	6372270	1556332	6370190	LSM001167
D047	1556382	6372052	1556393	6371419	LSM001168
D048	1556937	6371819	1556388	6371683	LSM001169
D049	1557046	6371764	1555752	6371442	LSM001170
D050	1557756	6371857	1556391	6371518	LSM001171
D051	1557743	6371772	1556392	6371436	LSM001172
D052	1557730	6371686	1556670	6371423	LSM001173
D053	1556992	6370944	1555993	6370944	LSM001174
D054	1557638	6370864	1556561	6370864	LSM001175
D055	1556647	6370544	1555248	6370544	LSM001176
D056	1556399	6371003	1556410	6370300	LSM001177
D057	1556479	6371003	1556489	6370356	LSM001178
D058	1556559	6371003	1556572	6370165	LSM001179
D059	1556406	6370543	1556908	6370098	LSM001180
D060	1556947	6371805	1556947	6370944	LSM001181
D061	1556857	6371003	1557561	6369857	LSM001182
D062	1556917	6370804	1557400	6370804	LSM001183
D063	1557685	6370805	1557267	6371790	LSM001184
D064	1557400	6371687	1558353	6371333	LSM001185
D065	1558070	6370839	1557898	6371558	LSM001186
D066	1558226	6371441	1557346	6370864	LSM001187
D067	1558321	6371408	1557229	6370692	LSM001188
E068	1555673	6372672	1555351	6372034	LSM001189
E069	1555782	6372711	1555447	6372047	LSM001190
E070	1555892	6372751	1555544	6372061	LSM001191
E071	1555972	6372732	1555640	6372074	LSM001192
E072	1555974	6372559	1555736	6372087	LSM001193
E073	1555977	6372387	1555832	6372100	LSM001194
E074	1555376	6372084	1556300	6372231	LSM001195
E075	1555971	6372780	1556012	6370196	LSM001196

MMT Code	Start East	Start North	Stop East	Stop North	SKB idcode
E076	1555434	6371799	1556473	6371816	LSM001197
E077	1555905	6371880	1555918	6371087	LSM001198
E078	1555923	6370780	1555931	6370278	LSM001199
E079	1555831	6371531	1555836	6371178	LSM001200
E080	1555843	6370781	1555849	6370360	LSM001201
E081	1555751	6371510	1555756	6371198	LSM001202
E082	1555763	6370779	1555768	6370442	LSM001203
E083	1555672	6371489	1555672	6370539	LSM001204
E084	1555592	6371469	1555592	6370620	LSM001205
E085	1555512	6371510	1555512	6370701	LSM001206
E086	1555230	6370986	1555833	6371372	LSM001207
E087	1555330	6371560	1555512	6371447	LSM001208
E088	1555278	6371498	1555512	6371353	LSM001209
E089	1554995	6371451	1555414	6371027	LSM001210
E090	1554697	6371639	1555357	6370971	LSM001211
E091	1554930	6371289	1556308	6369896	LSM001212
E092	1555376	6370725	1556240	6369852	LSM001213
E093	1555329	6370658	1556172	6369807	LSM001214
E094	1555282	6370592	1556620	6369240	LSM001215
E095	1555235	6370525	1556035	6369717	LSM001216
E096	1555442	6370203	1555967	6369673	LSM001217
E097	1555448	6370083	1555899	6369628	LSM001218
E098	1555375	6370043	1555830	6369583	LSM001219
E099a	1555035	6370085	1555404	6369691	LSM001220
E099b	1555404	6369691	1555606	6369340	LSM001221
E100	1554969	6369152	1555659	6369279	LSM001222
E101	1555298	6369632	1555941	6370268	LSM001223
E102	1555136	6369819	1555386	6370042	LSM001224
E103	1554875	6369695	1555279	6370054	LSM001225
E104	1554750	6370916	1555200	6370414	LSM001226
E105	1555101	6371113	1554658	6370730	LSM001227
E106	1554174	6371034	1554789	6371630	LSM001228
E107	1554768	6372141	1554738	6371597	LSM001229
F108	1550129	6368663	1550847	6368457	LSM001230
F109	1549654	6368882	1551018	6368492	LSM001231
F110	1549710	6368950	1551053	6368565	LSM001232
F111a	1550506	6368555	1551762	6368979	LSM001233
F111b	1551762	6368979	1552490	6369458	LSM001234
F111c	1552490	6369458	1552925	6369623	LSM001235
F111d	1552925	6369623	1553292	6369690	LSM001236
F111e	1553292	6369690	1553393	6369727	LSM001237
F111f	1553393	6369727	1553624	6369860	LSM001238
F111g	1553624	6369860	1554181	6369973	LSM001239
F111h	1554181	6369973	1554389	6370056	LSM001240
F111i	1554389	6370056	1554711	6370057	LSM001241
F111j	1554711	6370057	1554977	6370060	LSM001242
F111k	1554977	6370060	1555355	6369655	LSM001243
F111l	1555355	6369655	1555876	6368752	LSM001244
F112	1550705	6368664	1551654	6368984	LSM001245

MMT Code	Start East	Start North	Stop East	Stop North	SKB idcode
F113	1550875	6368616	1551584	6368855	LSM001246
F114	1552405	6369306	1551888	6368966	LSM001247
F115a	1555048	6371174	1554502	6370700	LSM001248
F115b	1554502	6370700	1554257	6370591	LSM001249
F115c	1554257	6370591	1553789	6370628	LSM001250
F115d	1553789	6370628	1553734	6370603	LSM001251
F115e	1553734	6370603	1553677	6370537	LSM001252
F115f	1553677	6370537	1553589	6369840	LSM001253
F116	1553833	6370625	1553959	6370890	LSM001254
G117	1551127	6364772	1550684	6364699	LSM001255
G118a	1551274	6364290	1551136	6364533	LSM001256
G118b	1551136	6364533	1550934	6364783	LSM001257
G119	1551196	6364342	1552120	6363726	LSM001258
G120	1551167	6364265	1552112	6363635	LSM001259
G121	1551311	6364073	1552105	6363544	LSM001260
G122	1551267	6364006	1552098	6363453	LSM001261
G123	1551223	6363940	1552091	6363361	LSM001262
G124	1551178	6363873	1552083	6363270	LSM001263
G125	1551134	6363806	1553343	6362334	LSM001264
G126	1551317	6364259	1550544	6363940	LSM001265
G127	1551134	6363806	1551166	6363495	LSM001266
G128	1550736	6362921	1551600	6364073	LSM001267
G129	1550819	6362898	1551330	6363580	LSM001268
G130	1550904	6362879	1551219	6363298	LSM001269
G131	1551005	6362880	1551204	6363145	LSM001270
G132	1551127	6362909	1551189	6362992	LSM001271
G133	1552120	6363726	1552076	6363179	LSM001272
G134	1551414	6363235	1552053	6362809	LSM001273
G135	1551427	6363131	1551990	6362756	LSM001274
G136	1551447	6363021	1551795	6362789	LSM001275
G137	1551454	6362920	1551573	6362841	LSM001276
G138	1552255	6363060	1551491	6362391	LSM001277
H139	1551088	6363741	1553343	6362238	LSM001278
H140	1551282	6363516	1553343	6362142	LSM001279
H141	1551402	6363340	1553343	6362046	LSM001280
H142	1552355	6362608	1553343	6361950	LSM001281
H143	1552311	6362541	1553343	6361854	LSM001282
H144	1552267	6362475	1553343	6361757	LSM001283
H145	1552223	6362408	1553343	6361661	LSM001284
H146	1552178	6362341	1553117	6361716	LSM001285
H147	1552239	6362204	1552872	6361783	LSM001286
H148	1553343	6361654	1553343	6362334	LSM001287
H149	1552521	6361880	1553343	6361654	LSM001288
H150	1552157	6362300	1552521	6361880	LSM001289
H151	1552168	6362287	1552551	6362862	LSM001290

A.2 Data delivery

The following data has been delivered to SKB

In paper 3 copies

Text report

P-report (This document)

Charts Extended A0 format Scale 1:10,000

SKB-001 Survey lines
Presentation of the theoretical survey lines used for GSM000014 and definition of area GSM00014 and GSM00013

SKB-002 Survey tracks
Presentation of the actual track of the survey vessels

SKB-003 Bathymetry Gridded data
Presentation of the gridded bathymetric data with 5 x 5 m

SKB-004 Bathymetry Interpolated data
Interpolation of all recorded bathymetry data including the coastline and shallow areas

SKB-005 Backscatter (Bottom reflection)
A grid presentation of a seabed hardness

SKB-006 Side scan sonar Mosaic
Side scan mosaic with resolution 0.4 m

SKB-007 Interpreted seabed geology (Based on the SGU classification table)
Interpreted geo boundaries as cloured polygons

SKB-008 Sub –bottom profile data Grided depth to bedrock or till
Chart showing thichness of finegrained sediments deposited on bedrock or till

SKB-009 Detailed profiles
Chart showing 5 selected profiles with detailed interpretation.

Digital data sets

Text report

Text report pdf

Lines

Theoretical LSM001106–LSM001290 shape

True survey track shape

Multi beam data

Accepted points		ASCII xyz
Grid nodes	5 x 5 metre	ASCII xyz and ESRI grid
Backscatter	10 x 10 metre	ASCII xyz
Contour lines		Shape files

Single beam data

Accepted points	ASCII xyz and ESRI grid

Geophysical data

Raw Side scan data	in XTF format
Raw Chirp data	in XTF format
Side scan sonar mosaic	Geotiff with ref tfw.files divided in EKORUTOR 6G3j 6H2a 6H3a 6H4a 6H3b 6H4b
Geoboundaries Contours	Shape files
Sonar contacts	as tiff images positions in shape files
Sub-bottom profile data as penetration	Shape files
5 detailed sedimentsections	ASCII XYZ

A.3 Calibration and function test

Differential Navigation System GPS

System:

Ashtech GG24 with differential Starlink RTCM 104 receiver.

Differential Station: Göteborg at freq 296.5 Hz and 100 bps.

Calibration:

Check of position when moored alongside a surveyed position in harbour.

The positions of GPS antenna as well as offset points are measured using a theodolite.

The measured positions are compared to those from the GPS system (Figure A-1). Both raw data from the GPS input as well as projected positions in the vessels reference point and offset points.

Position accuracy over 100 readings established to:

X:____0.09__m and Y:___0.18_____m

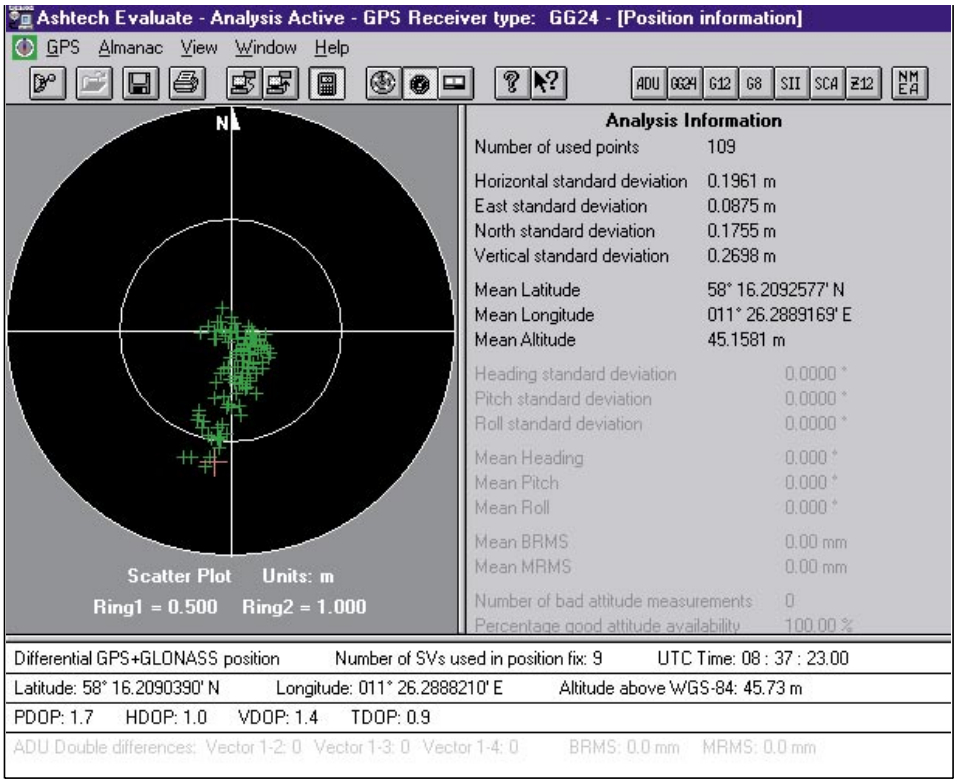

Figure A-1. *Image of the DGPS software display for view of the results.*

Side Scan Sonar – DF1000 100/500 kHz

001 Deployment of tow-fish.

002 Unfasten and move tow-fish with crane for deployment.

003 Lower tow-fish astern of vessel.

004 Check fish active and trigger on.

005 Hand-rub both sides of the fish and check for incoming signal in the display.

006 Check true water depth with echo sounder.

007 Fish lowered to necessary height over seabed. Fish need to be at less than 25 m height before bottom tracking can be performed properly.

008 When bottom track is established the fish is lowered to desired depth above seabed e.g. 15 m.

009 Check settings.

010 Set Sound velocity according to SVP.

011 Check display of seabed both 100 and 500 kHz. Quality check resolution e.g. boulders and other distinct features on seabed.

012 Survey two lines back and forth in parallel lines. 1 km each way.

013 Logging data on chosen media.

Results function test:

Sound velocity according to SVP set to:	__1,499_m/s_____
Seabed tracking:	__Controlled_____
Readings from Port and Starboard transducers:	__Observed._____
500/100 kHz frequencies:	__Received and logged_____
Gain functions:	__Controlled._____
Quality check image display:	__Verified_____

The calibration of the Side scan system was performed, by surveying two lines in opposite directions, and the position of the target was compared. The figures below illustrate the surveyed lines and the red mark in the figures is on the detected target.

Target position line 1 (Figure A-2):	X:__644396.7__	Y:__6459522.7__
Target position line 2 (Figure A-3):	X:__644395.2__	Y:__6459522.1__
Target position deviation:	X:__ 1.5____metre	Y:__0.6 metre___

Figure A-2. *(Left) Image from the calibration target line 1.*

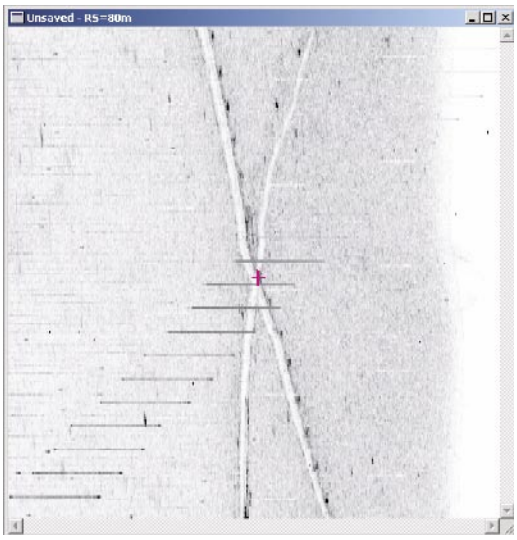

Figure A-3. *(Right) Image from the calibration target line 2.*

Results:

The test of the Side scan sonar is performed to make sure that the system works correctly. The required accuracy in the contract is ± 5 m and the Side scan sonar system is accepted.

Sub-bottom Profiler – Chirp CAP-6000

Calibration and adjustment

All adjustments are pre-set at the factory and should not require any modification in the field unless certain mechanical and/or electrical components are changed or the adjustment is inadvertently altered.

Signal to noise ratio shall be minimized and background acoustic noise shall be monitored after deployment.

Function test

001 Deployment of tow-fish.

002 Unfasten and move tow-fish with crane for deployment.

003 Lower tow-fish astern of vessel.

004 Check fish active and trigger on.

005 Listen for outgoing signal (Chirp).

006 Check true water depth with echo sounder.

007 Fish lowered to necessary height over seabed.

008 When bottom track is established the fish is lowered to desired depth above seabed.

009 Select setup files, set configuration and eventually name setup file.

010 Set Sound velocity according to expected sediment types.

011 Check display of signal in. Establish penetration depth.

012 Display test for quality and annotation.

013 Survey two lines back and forth in parallel lines. 1 km each way.

Results function test:

Sound velocity according to sediment set to:	1,600 m/s
Seabed tracking:	Controlled
Penetration	Observed
Data	Received and logged
Gain functions:	Controlled
Paper printout:	Verified
Quality check image display	Visualized
Comparison between both lines	Accepted

Calibration:

The calibration of the Chirp CAP-6000 system was performed by surveying two lines in opposite directions, and the position of the target was compared (Figures A-4 and A-6).

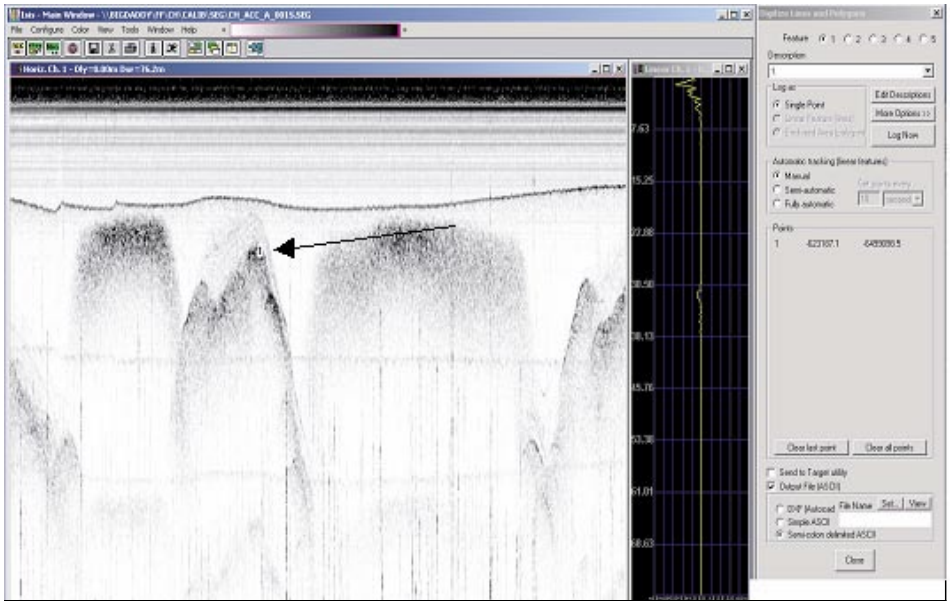

Figure A-4. *Image from the calibration targets line 1.*

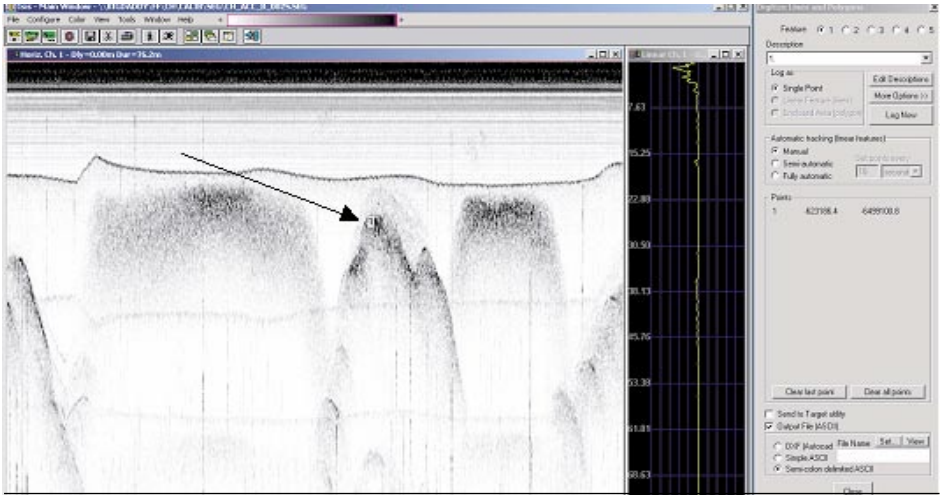

Figure A-5. *Image from the calibration targets line 2.*

Results:

Target position line 1:	X:__623187.1__	Y:__6499098.5__
Target position line 2:	X:__623186.4__	Y:__6499100.8__
Target position deviation:	X:__ 0.7___metre	Y:__2.3 metre__

The test of the Chirp is performed to make sure that the system works correctly. The required accuracy is ± 5 m and the Chirp system is accepted.

A.4 Detailed interpretation of five geological profiles

General

Five profiles were chosen for detailed interpretation of the sub-bottom profiles.

The detailed results below are based on the interpretation of the recorded acoustic reflector patterns from the sub-bottom profiler. In addition, verification of surface veneers has been made from acoustic data recorded by the side scan sonar.

Reference to kp in the text refers to kilometre distance from start of line (kp 0).

A014 (LSM001119)

The A014 profile intersects an area with an alternating surface geology with pockets of soft fine-grained sediments in between outcropping bedrock and till. The till unit may in parts be thin.

In the southernmost part, between kp 0.2–0.4 a 5 metre deep pocket of soft clay covered by a veneer of fine sand is present.

At kp 0.7–0.9 there is a pocket of clay approximately 5 m thick covered by a veneer unit of sand/gravel.

The northern part is outlined by a large soft-sediment pocket between kp 1.3–1.9.A thin surface layer of fine sand overlies a 10–11 m thick clay deposit. At approximately 6–7 m depth there is a distinct boundary, indicating the top surface of stiffer clay, presumably glacial clay.

B026 (LSM001131)

The surface sediments of profile B026 vary in composition and consist of fine sand, sand/gravel, soft clay and in parts till covering the underlying bedrock. Bedrock outcrops locally.

Between kp 0.2–0.3 a 4-metre thick deposit of clay overlain by fine sand is present as an infill in the dominating bedrock relief.

Further east between kp 0.6–0.9 a deposit of clays with a distinct boundary between the upper soft clay and the lower stiff clay are present. The deposit varies in thickness due to the irregularities in the bedrock relief.

Between kp 1.15–1.3 a relatively thin unit is deposited as an infill (max 2 m thick) consisting of soft clay overlain by a veneer of fine sand.

The sediment deposit between kp 1.4–1.9 is interpreted as a stiff clay overlain by soft clay.

Between kp 2.1–2.4 there is a sediment deposit, about 3 m thick, draped of the underlying relief consisting of an upper unit of soft clay and a lower unit of stiff clay presumable late glacial.

Between kp 2.5–2.9 the sediment deposit is one of the thicker fine-grained units in the surveyed area. The deposit is 10 metre thick holding stiff clay overlain by soft clay.

A continuous surface layer of soft clay is present between kp 2.1–2.9 with varying thickness, in parts only present as a surface veneer draped over the underlying bedrock.

Veneers of sediments mainly till and fine sand covering the underlying relief dominate the eastern part of the section.

D038 (LSM001159)

The section is dominated by the present bedrock and till relief. Sediment infills are present but are generally thin. The infills contain a mix of clay and sands.

D051 (LSM001172)

The bedrock relief dominates the section. Till is partly present as a surface layer. The infills of clay are relatively steep and narrow but reach 7 m of depth.

B015 (LSM001120)

The B015 section is characterised by thinner pockets of clayey sediments scattered over the area between the bedrock and till outcrops. The sediment composition of the pockets varies, but is considered to contain sand to some extents.

At kp 0.9 a 3–4 metre thick deposit of clay overlain by a veneer of sand/gravel is present.

At kp 1.2 a sand/clay deposit 2 metre thick is present. Similar deposits are found at kp1.8, overlain by a veneer of sand and gravel, and at kp 2.3 overlain by a veneer of fine sand.