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REPORT**

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**Description of geophysical data in
the SKB Database GEOTAB
Version 2**

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DESCRIPTION OF GEOPHYSICAL DATA IN THE SKB DATABASE
GEOTAB - VERSION 2

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

Information on SKB technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01), 1985 (TR 85-20), 1986 (TR 86-31), 1987 (TR 87-33), 1988 (TR 88-32) and 1989 (TR 89-40) is available through SKB.

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DATA IN THE SKB DATABASE
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PREFACE

This is the second edition of this report. In most chapters minor changes were made. New parts were included such as Chapter 5, Appendix E and Appendix F.

The text document was transferred to WP 5.0 format. Most figures are attached to the text document as plot files and are presented simultaneously when making a printout with a laser printer.

ABSTRACT

For the storage of different types of data collected by SKB a database called Geotab has been created. The following data is stored in the database:

- Background data
- Geological data
- Geophysical data
- Hydrogeological and meteorological data
- Hydrochemical data
- Tracer tests

This report describes the data flow for different types of geophysical measurements. The descriptions start with measurements and end with the storage of data in Geotab. Each process and the resulting data volume is presented separately. The geophysical measurements have been divided into the following subjects.

- Geophysical ground surface measurements
- Geophysical borehole logging
- Petrophysical measurements

Each group of measurements is described in an individual chapter. In each chapter several measuring techniques are described and each method has a data table and a flyleaf table in Geotab.

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INTRODUCTION

Since 1977 Swedish Nuclear Fuel and Waste Management Co, SKB, has been performing a research and development program for the final disposal of spent nuclear fuel. The purpose of this program is to gain knowledge and acquire data on radioactive waste. Measurements for the characterization of geological, geophysical, hydrogeological and hydrochemical conditions are performed in specific site investigations as well as for geoscientific projects.

Large volumes of data have been produced since the start of the program, in the form of both raw data and results. During the years this data has been stored in various formats by different institutions and companies that performed the investigations. It was therefore decided that all data from the research and development program should be gathered in a database. The database, called GEOTAB, is a relational database. It is based on a concept from Mimer Information Systems. It has been developed further by Ergodata. The hardware is a VAX 750 computer located at KRAB (Kraftverksbolagens Redovisningsavdelning AB), in Stockholm.

The database is composed of six main groups of data. These may be listed as follows:

- Background data
- Geological data
- Geophysical data
- Hydrogeological and meteorological data
- Hydrochemical data

In the database, background information from investigations and results are stored on-line on the VAX 750, while raw data is stored either on-line or on magnetic tapes.

This report deals with geophysical data and describes the data flow from the measurements at the study sites to the result tables in the database. All of the geophysical investigations were conducted by Swedish Geological Survey, SGU, before 820701, and by Swedish Geological Co, SGAB, after that date. However only SGAB has been cited in the geophysical flyleaf information, since all personnel involved and all filed material may now be found at SGAB.

The geophysical investigations have been divided into the following three subjects.

- Geophysical ground surface measurements
- Geophysical borehole logging
- Petrophysical measurements

Data corresponding to each subject is stored separately in the database.

At SGU/SGAB, the geophysical data was stored on-line on a PRIME 750 computer or on an inactive disc. During

1986-1987 the data files were transferred from SGAB to data files on the VAX computer and then loaded into Geotab. The flyleafs (tables containing measurement background data) were also punched, transferred and loaded into the database.

In the following chapters the dataflow for each of the four subjects is described separately.

In this report each chapter (2-6) deals with a given subject and also usually describes several measuring methods. In each chapter a graph shows the processes and data volumes in the data flow for the subject considered. An example of the graphic presentation is shown in Figure 1.1. The list of contents for each chapter has the same structure as the graph and these can be used separately. It is helpful to make a copy of the data graph and look at the copy while reading the report. It is then easy to localize a process/data volume of interest and also to read the description in the chapter.

Status of the different geophysical tables in Geotab is published elsewhere (Sehlstedt, 1990).

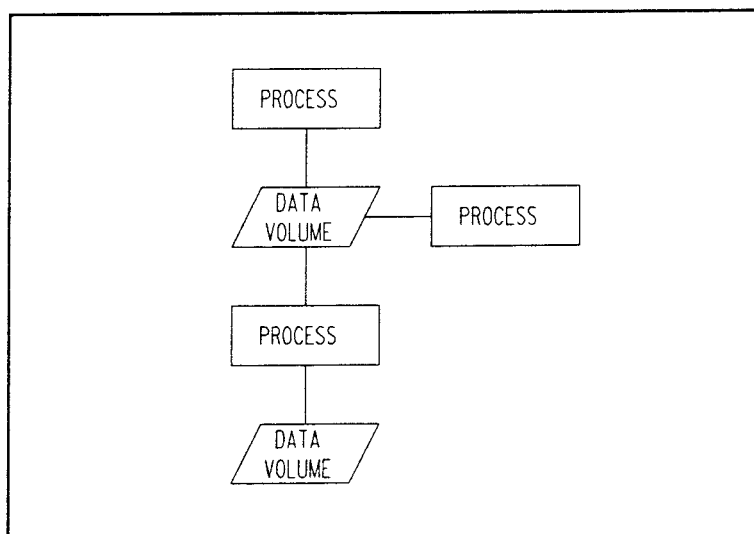


Figure 1.1 Example of graphic presentation of processes and data volumes.

2 GEOPHYSICAL GROUND SURFACE MEASUREMENTS - PROFILE MEASUREMENTS

During the reconnaissance work for new study sites profile measurements were made. The purpose was to localize regional fracture zones. This information can be used to define a grid net for more detailed measurements.

The measurements may be made as single profiles in any desired direction or in a spaced grid net. The profile length varies, but 3-10 km is most commonly used. Reading separation along the profiles is usually 20 m. However, 5-10 m is used when the total magnetic field is measured.

2.1 MEASURING EQUIPMENT

Instruments used for the measurements are listed in Table 2.1. Data on the equipment is found in SKB Technical Report TR.86-16.

Table 2.1 Instruments used

Method	Instrument	Manufacturer
Magnetic measurements	GSM-8 Proton	GEM-Systems, Canada
Horizontal Loop EM (HLEM)	18kHz 60m	SGAB, Sweden
Induced Polarization	RIPT-400	SGAB, Sweden
Resistivity	RIPS-2	SGAB, Sweden
	RIPT-400	SGAB, Sweden
VLF	RIPS-2	SGAB, Sweden
	EM-16	Geonics, Canada
Gravimetry	P 420 T	Sodin Ltd, Canada
	Model G	La Coste & Romberg Inc, USA
Seismic	Terraloc	ABEM, Sweden
Field computer	Geomac II	SGAB, Sweden

2.2 ROUTINES FOR DATA ACQUISITION AND PROCESSING

Collected data, forms/note books, cassette tapes and maps, are sent to the SGAB office in Luleå for processing. Data is transferred to a PRIME 750, where data processing and correction is performed. Since 1988 the processing is made on PC for the methods registered with Geomac II, Table 2.2 and 3.1.

Table 2.2 Registration media for different methods

Method	Form/note book	Geomac II
Tot. Magnetic Field	x*	x
Horizontal Loop EM	x*	x
VLF	x*	x

* older measurements

2.3 DESCRIPTION OF PROCESSES AND DATA VOLUMES IN FIGURE 2.1

2.3.1 Measurements

Short method descriptions and type of gained information from measurements have been published in SKB TR.86-16. Further information on magnetic and horizontal loop EM measurements is published in SKB TR.86-07.

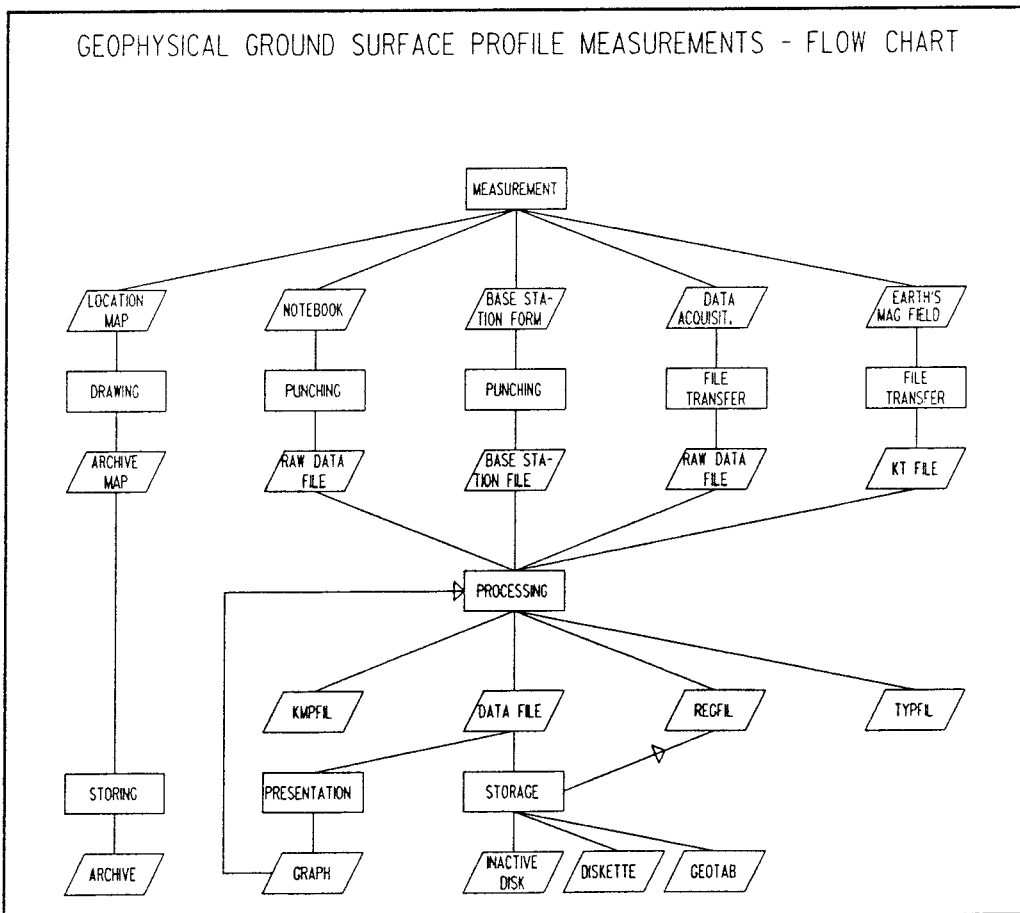


Figure 2.1 Data flow chart for geophysical ground surface profile measurements

2.3.2 Registration and data transfer

2.3.2.1 Location map

The profiles are normally drawn on an economic map sheet (1:10 000 or 1:20 000) in the field. Start and stop coordinates are marked on the map, as well as length and orientation points.

Drawing / Archive map

An archive map is drawn from the location map.

The archive map is stored in an archive at SGAB in Luleå.

2.3.2.2 Note book

Measured values are noted in note books. All but the magnetic measurements have been registered in this manner. During 1987 it became possible to register measured values with the Geomac II field computer for Horizontal Loop EM (slingram) and VLF also.

Punching / Raw data file

Notebook data are punched twice by two different persons. The files are crosschecked to eliminate punching errors.

The raw data file from punched note books are specially designed to fit the programs used for processing. In general, these consist of profile length and measured values.

2.3.2.3 Base station form

In measurements with the Horizontal Loop EM method (slingram), registrations must be made at a fixed base station. It is then possible to correct for instrumental drift. The instrument must be transported to the base station four times a daily.

Punching / Base station file

The form is punched as described in section 2.3.2.2.

The base station file contains the date, time and measured values.

2.3.2.4 Data acquisition

Since 1987 measurements are collected with a manually operated field computer, Geomac II, which registers the

measured value, the time and the coordinate. Earlier measurements were usually registered in note books.

File transfer / Raw data file

The measured data collected with the Geomac II field computer is dumped to a portable PC in the field. The diskettes are sent to the office at Luleå.

2.3.2.5 Registration of Earth's magnetic field

Variations in the earth's magnetic field are registered at a base station. This station consists of a fixed measuring instrument and a Geomac II which automatically registers the total magnetic field at preset time intervals. Occasionally, when measuring profiles, registrations from the station at Lovön are used. This information is needed to correct measurements for variations in the earth's magnetic field, which always occurs.

File transfer / KT file

The registrations of the earth's magnetic field are first compressed by choosing a fixed gradient interval between the readings on the Geomac II field computer. Values within such an interval are skipped, thus reducing the quantity of data stored. This compressed file is called a KT file. The file is transferred to a magnetic cassette tape and sent to the SGAB office in Luleå.

2.3.3 Processing / Data file

2.3.3.1 Prime

Each measurement is transferred to one file using a profile number to separate the profiles. The processing is then performed by using a program called BOK.P. In this the method to be calibrated is selected. The file is then transferred to a central file directory. Simultaneously, the profiles are registered in a register file called REGFIL. During the registration, the programs use two help files called TYPFIL and KMPFIL. The content of the register file and the help files is presented in Appendix A.

If errors are detected while the measurements are plotted, these are corrected. The geophysicist concerned recommends what corrections should be made. The processing personnel then follows his instructions. The new data file can be plotted again. The data file content and an example are found in Appendix A. Examples of file names and profile codes are also presented in the Appendix.

During processing work on an active disc, the following storage is used:

REGFIL	TYPFIL	KMPFIL	Measuring file
			Measuring file
			Measuring file
			...
			...

2.3.3.2 PC

Variations in the Earth's magnetic field is registered with a base station. To reduce measured magnetic data for these variations a program called MAGSEC is used.

To compensate Horizontal Loop EM measurements for instrumental drift, registrations are made at a check point several times a day. The compensation is made with a program called SRMSEC.

For IP/Resistivity measurements calculated values are delivered from the Geomac.

2.3.4 Presentation / Graph

Plotting is made from the Prime.

Data may be presented as single profiles or as maps. Single profile plots are made on a Calcomp plotter using a program called TX-CC. To construct a map plot, one uses the command files described under Presentation in section 3.3.1.3, using the program PRO.

Plotted graphs are used for a final check of the measurements. The correct graph is used for evaluation and report.

2.3.5 Data storage

Storage / Inactive disc

Data files are stored on an inactive disc at SGAB, Luleå. While storing the data, a registration of the disc name is made in REGFIL.

Data processed on PC are also stored on diskettes.

Storage / Geotab

The files are edited to fit in the Geotab tables. This is done by adding some key columns to make each measured value unique in Geotab. After editing the data files, they may be taped. The tapes are then sent to KRAB, Stockholm. Tape files are transferred to the VAX and loaded into Geotab. Another way to do this is to transfer the edited files from the Prime to the VAX

using the program KERMIT. Only small files are transmitted in this way.

In the database Geotab, each measuring method is stored in its own table under the subject GSGPHYS. Each method also has a flyleaf table which contains data on the measurement, date, field crew etc. The tables are listed in Table 2.3.

Table 2.3 Profile tables in Geotab.

Measuring method	Method	Created tables	
Total Magnetic Field Measurements	PROTMF	PROTMFF	PROTMFD
Horizontal Loop EM	PROH	PROHF	PROHD
VLF	PVLF	PVLFF	PVLFD
Induced Polarization/Resistivity	PROIPR	PROIPRF	PROIPRD
Gravimetric Measurements	PROG	PROGF	PROGD
Seismic Refraction Measurements	PRORS	PRORSF	

3 GROUND SURFACE GEOPHYSICAL MEASUREMENTS - GRID NET MEASUREMENTS

For more detailed studies of fracture zones and rock type, distribution measurements are made on grid nets. The grid net is oriented so that the optimal measuring direction is used. This is usually perpendicular to interesting features. In the net, a line separation of 40 m is used. Usually the reading separation is 20 m. However, 5-10 m is used for magnetic measurements. Interpretations made from these measurements are important when drilling programs are planned.

3.1 MEASURING EQUIPMENT

This has been described in section 2.1.

3.2 ROUTINES FOR DATA ACQUISITION AND PROCESSING

This has already been described in section 2.2.

Table 3.1. Registration media for different methods.

Method	Form	Geomac II
Total magnetic field	x*	x
Horizontal Loop EM	x*	x
VLF	x*	x
Induced Polarization	x*	x
Resistivity	x*	x

* old measurement

3.3 DESCRIPTION OF PROCESSES AND DATA VOLUMES IN FIGURE 3.1.

3.3.1 Measurements

Measurements are taken with the instruments listed in Table 2.1. The magnetic and HLEM measurements have been described in SKB TR.86-07.

3.3.2 Registration and data transfer

3.3.2.1 Grid net map / Measurement plan

The grid net map is normally drawn on an economic mapsheet (1:10 000 or 1:20 000) in the field. This is done while the terrain grid net is established. Easily determined locations in the terrain are marked on the map and their local coordinates are noted on the

backside of the map.

While the measurements are taken the field crew draws a measurement plan. This plan shows each line in the grid net. The start and stop coordinates, and the date and time of each measured profile is marked on the plan.

Drawing / Archive map

An archive map is made from the field grid net map. The origin of coordinates of the measured area are taken from the location map.

Storage / Archive/database table

Both the grid net map and the location plan are stored in an archive in Luleå.

The RAK coordinates (National Map System) of the origin in the grid net and the orientation of the net are stored in a database, STAKDB, on the Prime computer at SGAB in Luleå. This information is also stored in Geotab, in the table called Area.

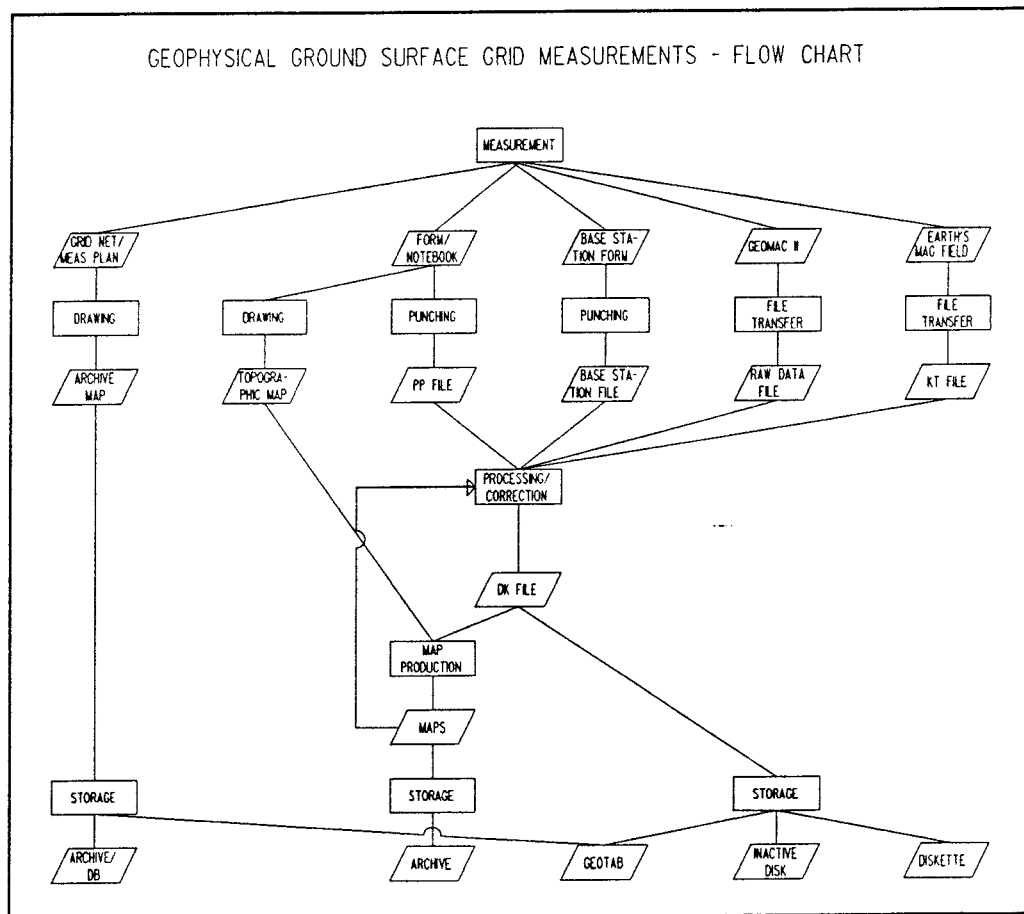


Figure 3.1 Data flow chart for geophysical ground surface grid net measurements

3.3.2.2 Form / Note book

Measured values are noted in forms or in special notebooks. Examples of the forms used are presented in Appendix B. The magnetic measurements have been registered in forms or with the Geomac II field computer. During 1987 it became possible to register measured values for all methods with Geomac II.

Drawing / Topographic map

A simplified topographic map is drawn from notes in notebooks or on forms. Fences, bob wires, telephone lines, power lines, ditches and marshes or other items which may influence the measurements are drawn on this map.

Punching / PP file

The appearance of the punched raw data file from forms/note books, also called the PP file depends on what measurement method is used. In general, the file contains coordinates and measured values. When Horizontal Loop EM (slingram) or VLF is measured, the measured values are given in the correct units. When IP and Resistivity is measured the punched values must be calculated to give the correct units.

3.3.2.3 Base station form

This has been described in section 2.3.2.3.

Punching / Base station file

This has been described in section 2.3.2.3.

3.3.2.4 Geomac II

This has been described in section 2.3.2.4.

Earlier registrations were made on special forms.

File transfer / Raw data file

The measured data, collected with the Geomac II field computer are dumped on to a portable PC in the field. Diskettes with data are sent to the office at Luleå.

The raw data file consists of unsorted profile measurements.

3.3.2.5 Registration of earth's magnetic field

This has been described in section 2.3.2.5.

File transfer / KT file

This has been described in section 2.3.2.5.

3.3.3 Processing / DK file

3.3.3.1 Prime

After initial processing, which includes calibration of the measurements, we have a DK file. A number of programs are required both for the calibration and for the creation of the DK file. The programs differ between the methods. A list of programs and their functions is presented in Table 3.2.

We now have a preliminary DK file. As a check on the measurements, a profile map is constructed. The geophysicist decides whether any corrections should be made. After the necessary corrections have been made, we have the final DK file.

Table 3.2 Processing programs and their function for data registered on forms

Method	Program name	Calibration	Create DK file
Total Magnetic Field	DKBM2	X	X
Horizontal Loop EM	SLIRA	X	X
Induc. Pol./Resistivity	IPXEL	X	
Induc. Pol./Resistivity	IPD		X
VLF	IPD		X

To reduce the storage space required for the measured data the data file is coded to an internal binary format and stored in matrix form. Normally one matrix contains data from an area of 400x400 m². To reduce the data to be stored further, only the upper left coordinate of the matrix is given. For each matrix information on the area name, method, component, line and reading separation etc are given. These files are called DK files. An example of a DK file is presented in Appendix B.

If data is collected with the Geomac II, processing will be made on a PC. The files are then transferred to DK format on the Prime using a program called ASC-DKB.

Sometimes profiles differ in background level from surrounding profiles. These profiles are localized by using the measuring plan made by the field crew and a map plotted from one of the programs PRO or RUT (section 3.3.3.1). If necessary, the geophysicist will recommend that this must be corrected. This is a

'subjective' change of data and must be done with great caution. Corrections are applied by using EDKB, which is an editor for the DK files. Background levels for single profiles or for areas may be changed or tilted.

3.3.3.2 PC

This has been described in section 2.3.3.2

3.3.4 Map production / Maps

Maps are plotted from the Prime.

To produce a map, a command language file is made. This standard file is used to run different programs. To run another program, one only has to change a row with the program name in the standard file. To make maps the following programs are used in the order shown.

- HISTO gives a histogram of the measured data. This is used to select the colour scale for coloured maps.
- PRO creates a plot file for a profile map and puts the file in a plot queue to a Calcomp plotter. The map is used to localize measured profiles or areas which differ from surrounding profiles in background level.
- RUT creates a plot file for a coloured square map and puts the file in a plot queue for a coloured inc plotter. The file is taped and taken to the plotter band station for plotting. The map is used to localize measured profiles or areas which differ from surrounding profiles in background level. The map is used for preliminary evaluation.
- ISO.F creates a plot file for a coloured isomap and puts the file in a plot queue for a coloured inc plotter. The file is taped and taken to the plotter band station for plotting. The map is used for evaluation and presentation.
- SIF creates a plot file for a figure map where each measured value is presented at its coordinate. The file is put in a plot queue to a Calcomp plotter.

The figure map and the topographic map are compiled on a transparent film.

Storing / Archive

The plotted coloured maps and a transparent film with the values at each coordinate are stored in a geophysical archive at SGAB in Luleå.

3.3.5 Data storage

3.3.5.1 Storage / Inactive disc

The data files are stored on an inactive disc at the SGAB Prime computer in Luleå. While these are stored on an inactive disc, a register file is updated with the new information. Contents and examples from the register file are presented in Appendix B. All DK files from one area are saved under the same directory (UFD). The storage structure appears as follows:

```
REGFIL          AREA UFD AREA UFD
                DK file DK file
                DK file ...
                ...     ...
```

If data is processed on a PC the data is also saved on diskettes.

3.3.5.2 Storage / Geotab

The DK files are converted to ASCII format. This is done with a program called DKB-ASC.

The ASCII files are edited to be compatible with the Geotab tables. Some key columns are added to make each measured value unique. The ASCII files are read from the Prime to tape. This is sent to KRAB, Stockholm. The files on the tape are read to the VAX computer and stored in the GEOTAB database tables.

In the Geotab database each measuring method is stored in its own table under the subject GSGPHYS. Each method also has a flyleaf table which contains data on the measurement, date, field crew etc. The tables are listed in Table 2.2.

Table 3.3 Grid net measurement tables in Geotab.

Method name	Method	Created tables	
Total Magnetic Field Measurements	TMAGF	TMAGFF	TMAGFD
Horizontal Loop EM, out-of-phase component	HLEMO	HLEMOF	HLEMOD
Horizontal Loop EM, in-phase component	HLEMI	HLEMIF	HLEMID
VLF, in-phase component	VLFIPH	VLFIPHF	VLFIPHD
VLF, quadrature component	VLFQA	VLFQAF	VLFQAD
VLF, resistivity	VLFR	VLFRF	VLFRD
VLF, phase angle	VLFPH	VLFPHF	VLFPHD
Induced Polarization	GSIP	GSIPF	GSIPD
Resistivity	GSR	GSRF	GSRD

4 GEOPHYSICAL BOREHOLE LOGGING

Geophysical borehole logging is used to localize and identify fracture zones, magnetic dikes or other geological boundaries found during the ground surface measurements. It is also possible to indicate water movements in the borehole.

Distances between measuring points vary from 1 m to 5 m, depending on what method is used. However, most methods are measured continuously.

4.1 MEASURING EQUIPMENT

Normally, a borehole logging system consists of the following items:

- a winch with a logging cable
- a regulated power supply
- a measuring wheel with a digital counter
- sondes
- a Boremac A2 analogue recorder
- a digital cassette recorder

This type of instrumentation is used for continuous registration. Methods measured at points with fixed separation have different types of analogue instruments and measured values are recorded manually. The type of registration for each method is given in table 4.1.

The equipment is transported in a logging van. Further information and data of the equipment is published in Almén et al (1986).

The same cable and winch is used for most methods. However special cables are required for both Radar and Sonic measurements.

Normally one sonde is used for each method measured. However, some sondes measure two components:

- Temperature / Borehole Fluid Resistivity
- Induced Polarization (IP) / IP-resistivity
- Resistivity -normal / Resistivity -lateral

4.2 ROUTINES FOR DATA ACQUISITION AND PROCESSING

Measurements made by the field crew produces forms or chart records and tapes. Collected data is sent to SGAB, Luleå. Data is transferred to a Prime computer and the data operator performs the processing. Final results are presented graphically or pictorially. Approved data is stored in the Geolis database or on an inactive disc at SGAB and in Geotab at SKB.

Table 4.1 Registration media for different logging methods.

Method	Form chart	Strip	Diskette	Tape
Borehole deviation	x			
Diffr. Resistance	x			
Gamma-gamma	x	x		
IP/IP-resistivity	x			
Nat. Gamma Rad.	x	x		
Neutron-neutron		x	x	
Radar			x	
Res.-norm 1.6 m	(x)	x		x
Res.-lateral 1.6-0.1m	(x)	x		x
Temperature/ Borehole Fl. Res.	x			
Self Potential		x	x	
Single Point Res.	x	x		
Slingram	x			
Sonic	x	x		
Susceptibility	x	x		
Tube Wave	x	x		
VLF	x			

(x) older type of registration

4.3 DESCRIPTION OF PROCESSES AND DATA VOLUMES IN FIGURE 4.1

In Figure 4.1 the processes and data volumes for borehole logging are shown. To the right of the figure the data flow chart for each method are presented. The methods registered with a chart recorder are listed in Table 4.1. These methods are usually also registered by a tape recorder.

4.3.1 Measurements

Borehole length is set to zero when the end of the sonde is at the top of the casing. This is marked on the strip chart or noted on forms. In continuous measuring the borehole length is corrected every 50 metres by marks on the cable. This is marked on the strip chart.

Normally, measurements are taken both downwards and upwards in the borehole.

Sonde / Signal

The sonde is connected to the logging cable. Some sondes are calibrated in the field, while others are calibrated in the laboratory. Sonde descriptions for each method are found in Appendix C.

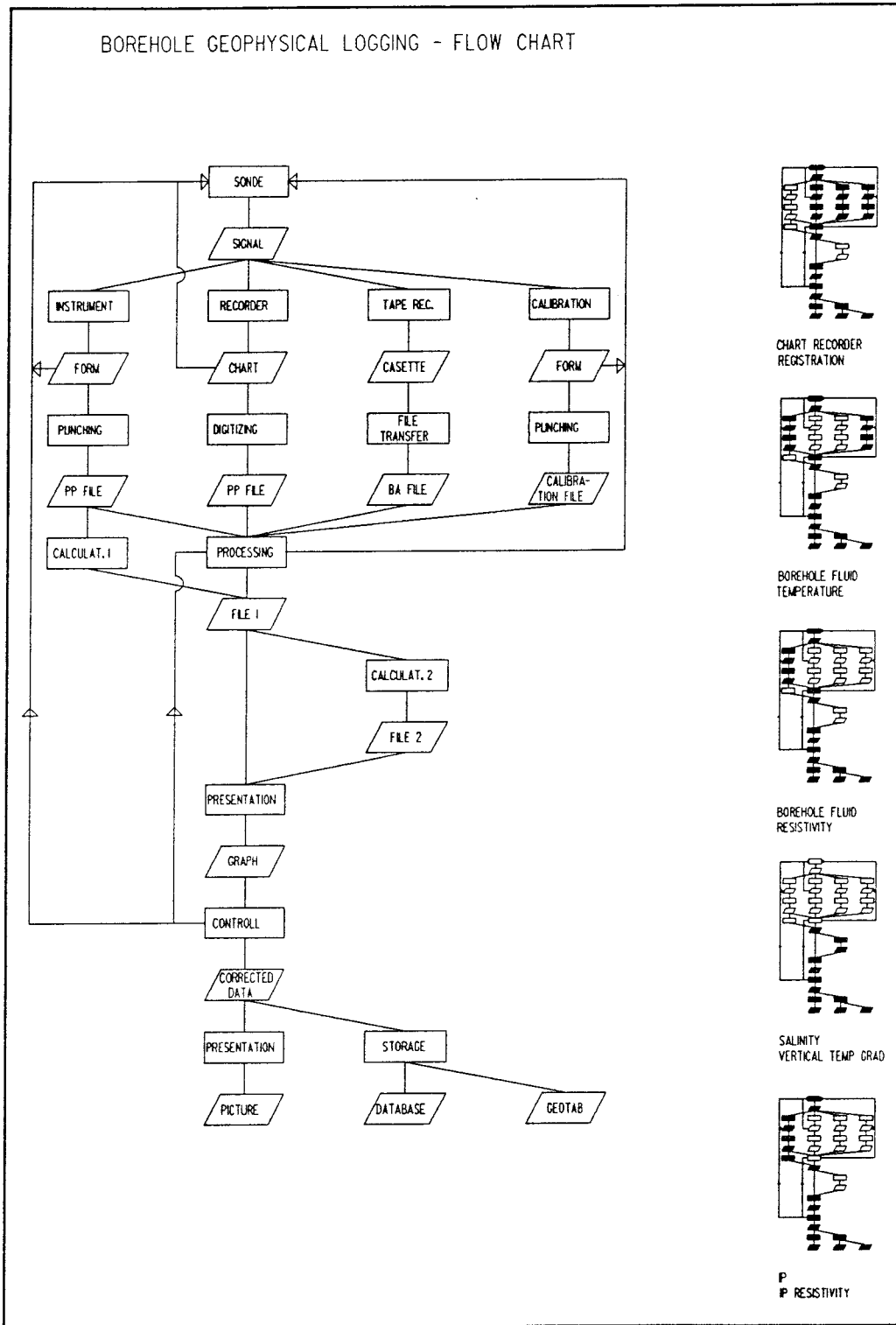


Figure 4.1 Data flow chart for geophysical borehole logging

A signal from the sonde is transmitted through an electric conductor in the logging cable. The signal, a variable voltage, constitutes the input signal for the registration equipment on the ground. In the borehole radar system, the same principle applies but the signal is transmitted in an optical fibre as light pulses.

The resolution of the input signal to the registration equipment is presented in Appendix C.

4.3.2 Registration and data transfer

4.3.2.1 Analogue instrument

Analogue instrument / Forms

Some methods are registered by analogue instruments. Measured values are observed and noted on forms by the operator. Methods registered this manner are presented in Table 4.1.

The form consists of a form heading and table. The table heading contains information on the method used, borehole measured, logging date, operator signature and equipment used. The form called "BORRHÅLSLOGGNING" is used for Temperature/Borehole Fluid Resistivity measurements and was used also earlier for Resistivity-normal and -lateral measurements. A different form is used for Induced Polarization (IP)/ IP resistivity measurements. Examples of the forms are found in Appendix C.

The forms are subsequently stored in an archive at SGAB, Uppsala.

Punching / PP file

Measurements registered on forms are punched. Before punching the data, the operator and the geophysicist check the protocols. If the geophysicist finds that the measurements are incorrect he will give instructions for new measurements to be made. To avoid punching errors, the forms are punched twice by different persons, and then cross checked.

After punching of measured data we get a raw data file. This is called a PP file. Methods registered on forms have more than two columns. The offset and number of positions for each column is listed in Appendix C.

4.3.2.2 Chart recorder

Chart recorder / Chart

A Boremac A2 analogue recorder is used here. A

technical description is found in SKB TR 86-16.

The measurements are registered for the methods mentioned in Table 4.1, on a chart from the chart recorder.

The length scale is usually set to 1:100.

The operator notes the method measured, logging date, chart recorder number, sonde number and logging crew signatures on the chart.

The charts are filed in the archive at SGAB, Uppsala.

Digitizing / PP file

Usually measurements are performed both upwards and downwards in the borehole. The geophysicist selects the best measurements for digitization. The calibration is checked with the measurement before digitization. If an error is detected in the measurement, a new calibration or measurement can be ordered.

Digitization of a chart graph gives a raw data file. This is called a PP file. Registrations made by chart recorder usually contains two columns, borehole length and measured values.

4.3.2.3 Tape recorder

Tape recorder / Cassette tape

A technical description of the equipment is found in SKB TR 86-16.

Registrations on cassette tapes are often made simultaneously with strip chart registration. The borehole length and the voltage signal from the sonde are sampled at a rate of 10 values/m. The logging cable is marked every 50 metres, and a signal is registered on the tape at each mark. This information is used to calibrate for tension in the logging cable.

After the processing is completed and the results have been approved, the tapes are erased.

File transfer / BA file

Measurements registered on cassette tapes are read to the SGAB Prime computer.

The raw data file from a registration on a cassette tape is called a BA file. The file format is found in Appendix C.

4.3.3 Calibration

Calibration / Calibration form or chart

To translate the value registered in mm or mV (chart recorder) or in mV (tape recorder) to physical units, it is necessary to calibrate the measurements. The calibration may be performed either in the field or in the laboratory, depending on calibration routines for the different methods. More detailed information on calibration routines is found in Appendix C. Calibration values can either be noted manually or registered on a strip chart.

Depending on the type of registration used, the output from the calibration might either be a protocol or a chart.

Punching / Calibration file

Calibration values are punched giving a calibration file.

Calibration files consist of two columns. The content of the first column depends on the type of registration used. Different file types are listed in Table 4.3. The unit in the second column is the corresponding calibrated value in physical units. Form registered methods are usually calculated from the registered values, with one exception. The calibration program reads this file in free format, so no specific format is required.

Table 4.2 Column content for different calibration files

Type of registration	column 1	column 2
chart record	mm or mV	value (physical unit)
cassette tape	mV	value (physical unit)
form	temperature	calibrated temperature

4.3.4 Processing

Processing / Data file 1

Raw data files, PP and BA files, must be processed to give result files. Depending on the type of registration, the processing might differ between the methods measured.

Methods registered on chart records, Table 4.1, and temperature measurements are handled the same way. The

processing includes calibration and correction. Calibration is performed by the program KAL. A length correction, for sonde length and casing length above ground, is also performed by the program.

The PP file for temperature/borehole fluid resistivity consists of one length column and two result columns. With the program KAL, these columns are split into two result files, temperature and borehole fluid resistivity.

One of the methods, SP, is measured in its proper physical unit mV and needs no calibration. Length correction, for sonde length and casing length above ground, is performed by the program DJUPKORR.

Methods registered on cassette tapes are length corrected, for tension in the logging cable, by the program BANDKORR. The geophysicist decides which of the up or down hole measurements should be used. The part of the raw data file selected is then calibrated by the program KAL.

After processing, we have a result file. This file comprises a borehole length column and a value column. The formats for the files are found in Appendix C.

Calculation 1 / Data file 1

Punched PP files are used for calculation of data files. Older resistivity (-normal and -lateral) measurements and Induced Polarization/IP resistivity are treated in this way. The calculations are performed by a program called RESIP on the Prime computer. To perform resistivity calculations it is necessary to specify a geometric factor, k, which depends on the electrode separation. This factor is calculated by the geophysicist responsible. The formulae used in the program RESIP are as follows:

$$\text{Resistivity} = \frac{\text{reading} * \text{scale} * k}{\text{current}} \quad \text{ohm-m}$$

$$\text{IP} = \frac{\text{IP reading} * \text{IP scale} * 100}{\text{RP reading} * \text{RP scale}} \quad \%$$

$$\text{IP resistivity} = \text{RP reading} * \text{RP scale} \quad \text{ohm-m}$$

After calculation, a length correction for sonde length and casing length above the ground surface is applied by the RESIP program.

After calculation, we have a result file. This file comprises a borehole length column and a value column. The formats of the files are found in Appendix C.

Calculation 2 / Data file 2

In some cases, it is possible to use the first data file (data file 1) as input for further calculations of new parameters. From temperature measurements, the vertical temperature gradient is calculated. Using temperature and borehole fluid resistivity, it is possible to calculate the salinity, as equivalent NaCl concentration (ppm) of the borehole fluid. The formulae used are found in Appendix C, under method descriptions. The format of these new data files is the same as that of the temperature data file.

4.3.5 Presentation / Graph

A result file can be presented on a graphic data screen using the program RITA. If the result is satisfactory, the file is saved as a DIS file. The program TX-CC is used to send this file to a Calcomp plotter.

The result files are presented as separate graphs, which are used for final control of the data.

4.3.6 Control / Corrected data file

The graphs plotted are checked by the geophysicist. If errors are detected, they are corrected or new measurements are made. When the measurement is approved, the corrected file is ready for final presentation and storing.

4.3.7 Presentation / Picture

The final presentation is often in the form of a picture with several methods. This is done by the program COMPLIT. The picture drawn on the screen is saved as a GKS file. The file is then sent to the Calcomp plotter by the program PLOTTF.

4.3.8 Data storage

Storage / Database

The corrected file is stored as an ASCII file on an inactive disc or in the Geolis database at SGAB, Luleå. The structure of the files stored in the Geolis database is described in the Geolis manual. Other measurements are stored as ASCII files on inactive disc. The structure of these files are as follows:

B(area name)		B(area name)	
Hole no	Hole no	Hole no	Hole no
Meas file	Meas file	Meas file	Meas file
Meas file	..	Meas file	..
Meas file

Example:

BKAMLUNGE		BKLIPPERAS
KM1	KM2	KL1
GAMMA*KM1*831210	GAMMA*KM2*821209	GAMMA*KL1*860513
SP*KM1*831204	SP*KM2*821203	SP*KL1*860512
NORMAL1.6*KM1*821007	NORMAL1.6*KM2*821007	NORMAL1.6*KL1*860513
...
...

Storage / Geotab

The ASCII files at the SGAB Prime computer are edited to be compatible with the Geotab tables. This is done by adding some key columns which makes each measured value unique in Geotab. All data files are in E format. To fit in Geotab this format must be edited as shown in Table 4.3. The files are then transferred to magnetic tapes, which are sent to KRAB, Stockholm. The tape files are transferred to the VAX 750 and the files are loaded into the database tables.

Table 4.3. E-format for data files

Prime	Geotab
E 01	E+01
E 03	E+03
E-01	E-01

In Geotab, each measuring method is stored in its own table under the subject BHGPHYS. Each method also has two flyleaf tables. The first contains background data about the measurement, date, field crew etc, while the second can be used to comment a specific section in the borehole. The tables are listed in Table 4.4.

Table 4.4. Geophysical borehole logging tables in Geotab

Method name	Method	Table names		
Borehole Fluid Resistivity	BFRES	BFRESF1	BFRESF1	BFRESF1
Borehole Fluid Salinity	BFSAL	BFSALF1	BFSALF2	BFSALD
Borehole Fluid Temperature	BFTEMP	BFTEMPF1	BFTEMPF2	BFTEMPD
Borehole Deviation	DEVANGLE	DEVF1		DEVANGLE
Differential Resistance	DIFFRES	DIFFRF1	DIFFRF2	DIFFRD
Natural Gamma Radiation	GAMMA	GAMMAF1	GAMMAF2	GAMMAD
Gamma-Gamma	GG	GGF1	GGF2	GGD
Inductive Conductivity	ICON	ICONF1	ICONF2	ICOND
Induced Polarization (IP)	IP	IPF1	IPF2	IPD
IP Resistivity	IPR	IPRF1	IPRF2	IPRD
Lateral Resistivity	LRES	LRESF1	LRESF2	LRESD
Magnetic Susceptibility	MSUS	MSUSF1	MSUSF2	MSUSD
Neutron-Neutron	NN	NNF1	NNF2	NND
Normal Resistivity	NRES	NRESF1	NRESF2	NRESD
Radar	RADAR	RADARF1	RADARF2	
Slingram	SLING	SLINGF1	SLINGF2	SLINGD
Sonic	SONIC	SONICF1	SONICF2	SONICD
Self Potential (SP)	SP	SPF1	SPF2	SPD
Single Point Resistance	SPRES	SPRESF1	SPRESF2	SPRESD
True Resistivity	TRES	TRESF1	TRESF2	TRESD
Tube Wave	TUBEW	TUBEWF1	TUBEWF2	
VLF	VLF	VLFF1	VLFF2	VLFD
Vertical Temperature Gradient	VTG	VTGF1	VTGF2	VTGD

5 GEOPHYSICAL BOREHOLE LOGGING 1989-

Since 1989 a new data acquisition system, called Acquire System, have been in use in the logging van. All processing of data is made on PC.

All methods are measured continuously.

5.1 MEASURING EQUIPMENT

Normally, a borehole logging system consists of the following items:

- a winch with a logging cable
- a regulated power supply
- a measuring wheel with a digital counter
- sondes
- electronic surface equipment
- PC with Acquire system

This type of instrumentation is used for continuous registration. Data is registered on 3.5" diskettes.

The equipment is transported in a logging van. Further information and data of the equipment is published in Almén et al (1986).

The same cable and winch is used for most methods. However special cables are required for both Radar and Sonic measurements.

Normally one sonde is used for each method measured. However, some sondes measure two components:

- Temperature / Borehole Fluid Resistivity
- Induced Polarization (IP) / IP-resistivity
- Resistivity -normal / Resistivity -lateral

5.2 ROUTINES FOR DATA ACQUISITION AND PROCESSING

Measurements made by the ABEM field crew produces data files on diskettes. After pre-processing collected data is sent to SGAB, Luleå or is handled by processing personnel in the field. All processing is made on PC. Final results are plotted. Approved data is stored in the SKB database Geotab.

5.3 DESCRIPTION OF PROCESSES AND DATA VOLUMES IN FIGURE 5.1

In Figure 5.1 the processes and data volumes for borehole logging are presented.

5.3.1 Measurements

Borehole length is set to zero when the end of the sonde is at the top of the casing. In continuous

measuring the borehole length is corrected every 50 metres by marks on the cable. This is marked in the raw data file during the measurement.

Normally, measurements are taken from the bottom and upwards in the borehole. A shorter check measurement is made in the lower part of the borehole while lowering the sonde to the bottom.

Sonde / Signal

The sonde is connected to the logging cable. Some sondes are calibrated in the field, while others are calibrated in the laboratory. Sonde descriptions for each method are found in Appendix C.

A signal from the sonde is transmitted through an electric conductor in the logging cable. Electronic surface units transform the signal to a variable voltage or to cps, used as input signal for the registration equipment on the ground. In the borehole radar system, the same principle applies but the signal is transmitted in an optical fibre as light pulses.

5.3.2 Registration and data transfer

5.3.2.1 Acquire system

PC / Raw data file (*.DA0)

The registration of measuring data is made on a PC and is handled by a software package called Acquire System. Registrations are stored in a raw data file. The file is structured as follows

```
col 1    length
col 2    velocity
col 3    value 1
(col 4)  value 2
```

Raw data is presented in real time on a screen or on a printer. This enables the field crew to judge if measurements run smoothly or if something is wrong.

Length correction / *.DB0

During the measurements a mark is registered in the raw data file at each 50 m mark on the cable. Registered borehole length from the measuring wheel is corrected versus the 50 m marks in the raw data file. The corrected file is named *.DB0.

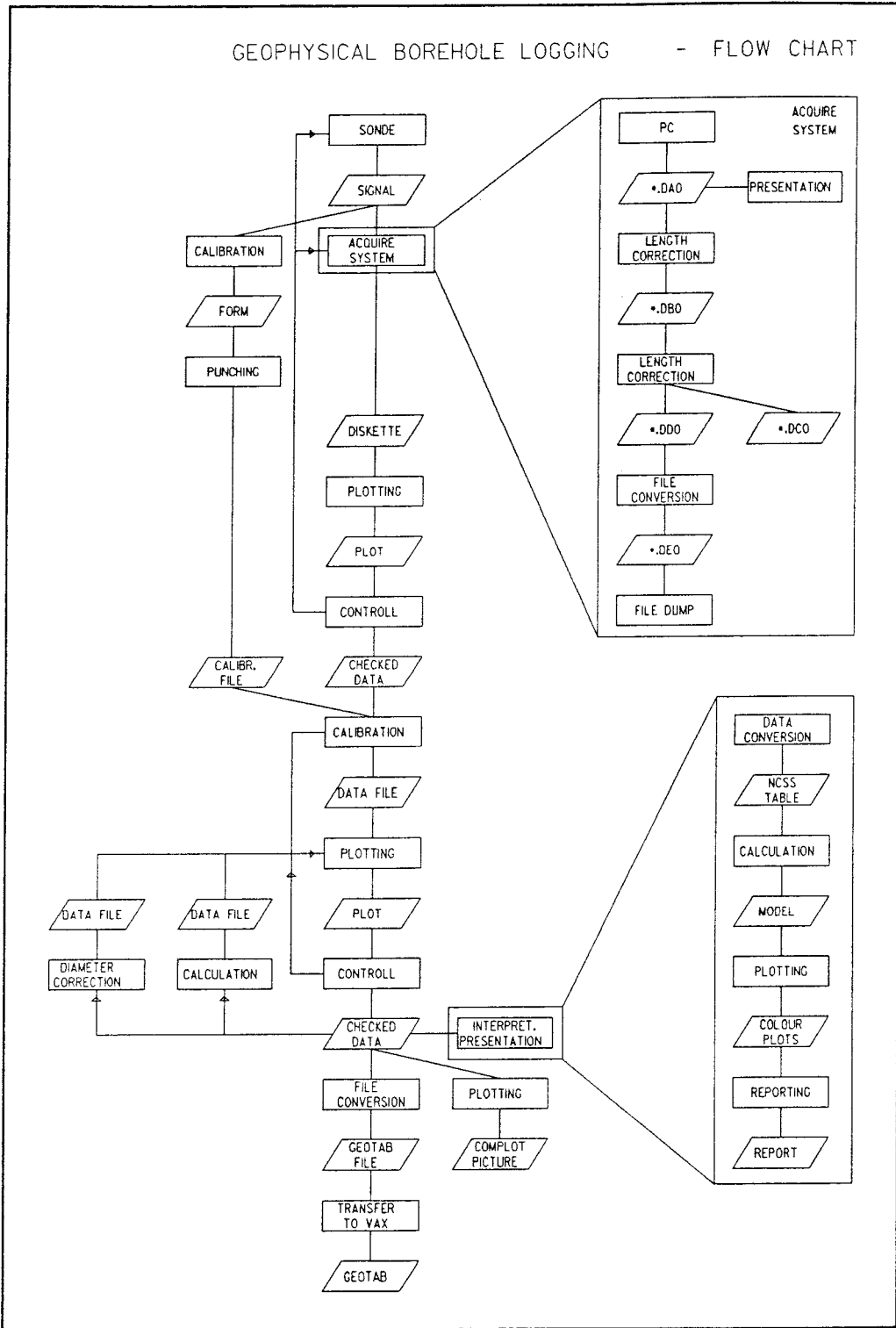


Figure 5.1 Data flow chart for geophysical borehole logging

Length correction / *.DC0 and *.DD0

Corrections for top of casing and measuring point in the sonde is made. Then the file is splitted in two files.

	*.DC0	*.DD0
col 1	length	length
col 2	velocity	value 1
(col 3		value 2)

File conversion / *.DE0

Usually the first registered value in the file is from the bottom of the borehole. If so the file is reversed. Then the *.DD0 file is converted to a special E-format used for plotting, further processing and database storage. This file is named *.DE0. An example of a value in this format looks like this: 1.150000E+003

File dump / Diskette

The *.DE0 file is dumped to a 3.5" diskette.

5.3.2.3 Plotting / Plot

The non calibrated data in the *.DE0 file is plotted using a program called PCCP and a HP plotter.

5.3.2.4 Control / Checked data

The plots are checked by a geophysicist. If errors are found the measuring crew is consulted. Data might be processed in Acquire once more or if necessary new measurements may be done.

5.3.3 Calibration

Calibration / Calibration form

To translate the value registered in cps or mV to physical units, it is necessary to calibrate the measurements. The calibration may be performed either in the field or in the laboratory, depending on calibration routines for the different methods. More detailed information on calibration routines is found in Appendix C. Calibration values can either be noted manually or registered on a strip chart.

Depending on the type of registration used, the output from the calibration might either be a protocol, a chart or a file.

Punching / Calibration file

Calibration values are punched giving a calibration file.

Calibration files consist of two columns. The content of the first column depends on which sonde is used. The unit in the second column is the corresponding calibrated value in physical units. The calibration program reads this file in free format, so no specific format is required.

Calibration / Data file

The checked data file and the calibration file are used by the program CAL to make the calibration. A data file with the actual physical unit of the measuring method is achieved.

5.3.4 Plotting / Plot

A result file can be presented on a graphic data screen using the program PCCP. If the result is satisfactory, the file is saved as a HPGL plot file. The plot file is sent to a HP plotter.

The result files are presented as separate graphs, which are used for final control of the data.

5.3.5 Control / Checked data

The plotted graphs are checked by the geophysicist. If errors are detected, they are corrected or new measurements are made. When the measurement is approved, the correct data file is ready for final interpretation, presentation and storing.

In some cases new types of data is calculated as described in Chapter 5.3.6 and 5.3.7.

5.3.6 Calculation / Data file

Checked temperature data is used to calculate the vertical temperature gradient. The calculation is made with the program TEMPGRAD.

Checked temperature and fluid resistivity data is used to calculate the salinity. The calculation is made with the program SALIN.

The new data files are then plotted, controlled etc.

5.3.7 Diameter correction / Data file

Many geophysical methods will be influenced if the borehole diameter changes. Magnetic susceptibility and

gamma-gamma measurements might be diameter corrected if necessary. This correction is made with a program called LOGCORR.

The new data files are then plotted, controlled etc.

5.3.8 Interpretation and presentation

Data conversion / NCSS table

The logs needed for interpretations are length corrected with the drill core as reference. Then data is loaded into NCSS (Number Cruncher Statistical System) tables.

Calculation / Model

Different calculations and statistical work is made in NCSS. The final result, a model, consists of several types of classifications which describes rock types, alteration, fracture classes and rock porosity. These classifications are dumped to ASCII files.

Plotting / Colour plots

To plot the results from the interpretation the ASCII files are loaded into the Petrocore Mapping System. In Appendix F a copy of a colour interpretation plot is presented.

Reporting / Report

The different colour plots are compiled to a report.

5.3.9 Plotting / Complot picture

The approved data is used to generate HPGL files. These files are compiled to so called Complot pictures. This is done with the drawing program PCCP. The HPGL plot files are sent to a HP 7475 plotter. A complot picture is presented in Appendix E.

5.3.10 Data storage

File conversion / Geotab file

The ASCII files are edited to be compatible with the Geotab tables. This is done with a program called LOG2DB which adds some key columns, which makes each measured value unique in Geotab.

Transfer to VAX / Geotab

Diskettes with data files are sent to SKB, Stockholm and transferred to the VAX750 at KRAB, Stockholm. Then the files are loaded into the database tables.

In Geotab, each measuring method is stored in its own table under the subject BHGPHYS. Each method also has two flyleaf tables. The first contains background data about the measurement, date, field crew etc, while the second can be used to comment a specific section in the borehole. The tables are listed in Table 4.4.

6 PETROPHYSICAL MEASUREMENTS

Petrophysical measurements are those in which the physical properties of a rock sample are measured. Petrophysics is a link between geology and geophysics. The measured values are used to correlate anomalies from the geophysical ground surface measurements with rock types observed by the geologist. The parameters measured are as follows:

- density
- porosity
- magnetic susceptibility
- magnetic remanence
- Q-value
- induced polarization
- resistivity

6.1 MEASURING EQUIPMENT

The equipment used for these measurements is as follows:

- a Mettler Precision Scales and a vacuum chamber (density, volume and porosity)
- an Oerstedtmeter (magnetic susceptibility, magnetic remanence and Q-value)
- a RIPS-3 instrument (resistivity and induced polarization)

6.2 ROUTINES FOR DATA ACQUISITION AND PROCESSING

Sampling is performed on the drill site or where the geological core mapping is done. The sampling is performed by the geophysicist or the geologist. The samples are sent to the SGAB laboratory in Malå. All samples are cut with a diamond saw, to fit in the RIPS-3 instrument, by the instrument operator. During the measurements the measured values are noted on different forms. These forms are sent to Luleå for further processing. The data on the forms are punched, processed and stored in a database at the SGAB Prime computer. Data is transferred to Geotab.

6.3 DESCRIPTION OF PROCESSES AND DATA VOLUMES IN FIGURE 6.1

6.3.1 Sampling / Prepared samples

Sections of the drill core are taken as samples. Sampling strategy is planned by the person responsible for the evaluation. It must always be borne in mind that samples must be representative for their rock type. Samples should also be uniformly distributed throughout the borehole, so that the influence of depth may be evaluated. Extra samples should be taken in those sections of most interest, such as fracture zones

or dykes.

All samples are marked with a borehole code and a borehole length. The sample is also given a rock type code by the geologist.

The collected samples, about 10 cm in length, are dispatched to the SGAB laboratory in Malå. Before the measurements are taken the samples must be cut into appropriate pieces. This is done in the laboratory with a diamond saw. The pieces cut from the samples usually then measure approximately 42 mm in diameter and 40 mm in length.

6.3.2 Measurements / Forms

Measuring procedures have been described in SKB TR86-09.

Three different protocols are used. Calculated parameters in brackets.

- Measurement protocol RIPS-3 (resistivity and IP)
- Measurement protocol Porositetsmätning (density and porosity)
- Oerstedtmeter form (magnetic susceptibility, magnetic remanence and Q-value)

Examples of the forms can be found in Appendix D.

Sample storage

After the measurements are completed the samples are sent to the SKB Drill Core Storage at Uppsala. The samples are returned to their drill core boxes.

6.3.3 Punching / Raw data file

The protocols are punched.

The format for the punched files is described in Appendix D.

6.3.4 CPL-routines / Database/Lists/Plots

Three CPL-routines (Command Procedure Language) are used to handle the parameter measurements, one for each protocol type. These have the following names:

- VIKT.CPL
- OERST.CPL
- IP.CPL

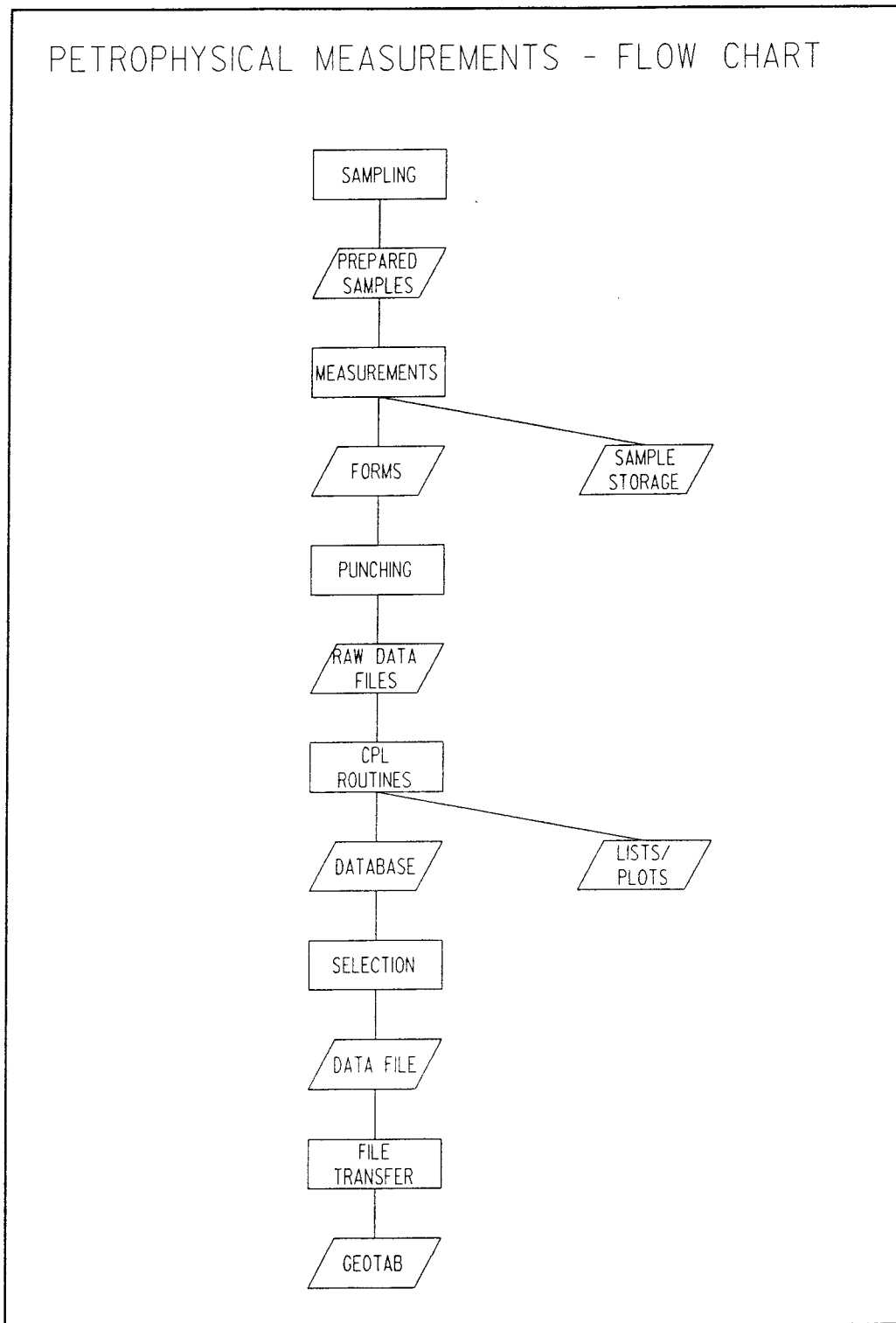


Figure 6.1 Data flow chart for petrophysical measurements

CPL-routines are used to process the punched files as follows:

- reads the punched files into the database
- makes all parameter calculations
- stores the final values in the database
- prints lists and plots

The CPL-routines print out a number of standard lists.

Some standard plots are plotted automatically by the CPL-routine OERST.CPL, magnetic susceptibility versus density, magnetic remanence versus density and magnetic susceptibility versus magnetic remanence. Other plots may be obtained from the Minitab program package.

6.3.5 Selection / Data file

A program called VALJENG is used to read data from the SGAB database to a print file.

The data file from the SGAB database contains the following columns:

- Borehole ID code
- Borehole length
- Rock type code
- Density
- Porosity
- Magnetic susceptibility
- Magnetic remanence
- χ value
- Induced polarization
- Resistivity

6.3.6 File transfer / Geotab

The data files are transferred to the VAX 750 using a program called Kermit and then loaded into the Geotab database.

In the Geotab database all measurements are stored in one table under the subject PETRO. Each method also has a flyleaf table which contains data on measurement, date, measuring operator etc. The tables are listed in Table 5.1.

Table 6.1. Petrophysical tables in Geotab.

Method	Method	Created tables	
Petrophysical measurements	PETRO	PETROF	PETROD

REFERENCES

- Almén, K-E., Andersson, O., Fridh, B., Johansson, B-E.,
Sehlstedt, M., Gustavsson, E., Hansson, K.,
Olsson, O., Nilsson, G., Axelsen, K. and
Wikberg, P. 1986: Site investigation.
Equipment for geological, geophysical,
hydrological and hydrochemical
characterization. SKB TR.86-16.
- Eriksson, E. and Olsson, O. 1984: Genomgång av
geofysiska data från SGAB:s verksamhet för
SKB/KBS. SGAB IRAP 84125.
- Gentzschein, B. 1986: Description of hydrogeological
data in SKB's database Geotab. SKB TR.86-22.
- Sehlstedt, S. 1990: Status of geophysical tables in
the SKB database Geotab. SKB AR 90-02.
- Sehlstedt, S. and Stenberg, L. 1986: Geophysical
investigations at the Klipperås study site.
SKB TR.86-07
- Stenberg, L. 1986: Geophysical laboratory
investigations on core samples from the
Klipperås study site. SKB TR.86-09.

APPENDICES

Appendix A (1)

Geophysical ground surface measurements - profile measurements

Data file

Content:

X co-ordinate		4 positions
Value 1 - magnetic, HLEM , VLF, IP		4 positions
Value 2 - HLEM , VLF, IP		4 positions
Value 3 - IP		4 positions

Example from a Horizontal Loop EM (slingram) data file:

20	-8	-4
40	-20	-6
60	-23	8
80	-10	7
100	-15	-18
120	-18	-15

REGFIL

Regfil is a register file for profile measurements. It contains the following columns:

Grid net, area or map sheet	20 positions
Profile code	10 positions
Type of measurement (code+number)	6 positions
File name data file	8 positions
UFD name (if stored on inactive disc)	6 positions

Example from REGFIL

KLIPPERÅS	P4F9H:P1	VLF-00	PS002340	SVEPRO
KLIPPERÅS	P4F9H:P2	VLF-00	PS002341	SVEPRO
KLIPPERÅS	P4F9H:P3	VLF-00	PS002342	SVEPRO
KLIPPERÅS	P4F9H:P1	VLF-01	PS002343	SVEPRO
KLIPPERÅS	P4F9H:P2	VLF-01	PS002344	SVEPRO
KLIPPERÅS	P4F9H:P3	VLF-01	PS002345	SVEPRO

The profile code with file name P4F9H:P3 contains the following information:

P	Profile measurement
4F	National map sheet code
9H	Square in map sheet
P3	Profile no 3 starting in this square

Appendix A (2)

KMPFIL

This is a fixed help file, used during the processing work. It contains information on the physical units for each method.

Method (code)	4 positions
Component no	1 position
Component text	16 positions
Unit	4 positions
Unit	10 positions

File content:

PROT 1	1 NANOTESLA
SLIN 1 Z-REELL	1 PROMILLE
SLIN 2 Z-IMAGINARY	1 PROMILLE
IP2E 1 IP/RP	1 PERCENT
IP2E 2 RESISTIVITY	1000 OHMMETER
IP2E 3 SP	1 MILLIVOLT
IP3E 1 IP/RP	1 PERCENT
IP3E 2 RESISTIVITY	1000 OHMMETER
IP3E 3 SP	1 MILLIVOLT
IP4E 1 IP/RP	1 PERCENT
IP4E 2 RESISTIVITY	1000 OHMMETER
IP4E 3 SP	1 MILLIVOLT
VLF- 1 REELL	1 PROMILLE
VLF- 2 IMAGINARY	1 PROMILLE

TYPFIL

The file named TYPFIL, having fixed content is used during the processing work. It contains the following columns:

Type of measurement (code+no)	6 positions
Number of components	1 positions
Type of measurement	20 positions

Content of TYPFIL:

PROT00 1 TOLTAL MAGNETIC FIELD
 SLIN00 2 SLINGRAM 18 KC 40M
 SLIN01 2 SLINGRAM 18 KC 60M
 SLIN02 2 SLINGRAM 3.6 KC 40M
 SLIN03 2 SLINGRAM 3.6 KC 60M
 SLIN04 2 SLINGRAM 3.6 KC 20M
 GRAV00 1 GRAVIMETER
 IP2E00 3 IP GRADIENT
 IP3E00 3 IP 3-EL.
 IP4E00 3 IP 4-EL. 20 WENNER CONFIG
 IP4E01 3 IP 4-EL. 40 WENNER CONFIG
 IP4E02 3 IP 4-EL. 20-40 SCHLUNBERGER
 DIPO00 3 IP DIPOL 4, 5
 DIPOL-DIPOL
 VLF-00 2 VLF GBR
 VLF-01 2 VLF JXZ
 VLF-02 2 VLF NAA

Appendix A (3)

Data file to Geotab

Example: Total magnetic field

Column	Content	Example
1*	Area code	KL
2*	Profile code	A
3*	Start date for measurement	851012
4*	Length along profile	40
5	Total magnetic field (nT)	51420

* Key column in Geotab

Appendix B (1)

Geophysical ground surface measurements - grid net measurements

Name conventions for data files

Position	Content
1- 4	type of measurement: ex SLIN, PROT, ASKA etc
5	*
6 -7	type of data: ex PP, KT, MM
8	*
9-28	area name

Ex. SLIN*PP*KLIPPERAS

Type of measurement:

PROT	Proton magnetometer (total magn. field)
ASKA	Askania magnetometer (total magn. field)
SLIN	Horizontal Loop EM
VLF-	VLF
IP2E	IP 2 electrode
IP3E	IP 3 electrode
IP4E	IP 4 electrode

Type of data file:

PP	Raw data
DK	Result file
KT	Earth's magnetic field
MM	Raw data file from data collection system (Geomac II)

REGISTER FILE

Position	Content
1-21	Grid net
11-42	Area name
43-46	Method
47-52	No of DK matrix (example at next page)
53-60	Update information
61-77	Date

Example:

```

KLIPPERAS KLIPPERÅS PROT 405 TILLÄGG THU DEC 15 1983
KLIPPERAS KLIPPERÅS PROT 40 UPPDAT THU DEC 15 1983
KLIPPERAS KLIPPERÅS SLIN 240 TILLÄGG FRI DEC 16 1983
KLIPPERAS KLIPPERÅS VLF- 440 TILLÄGG MON DEC 19 1983
KLIPPERAS KLIPPERÅS VLF- 324 TILLÄGG FRI FEB 17 1984
KLIPPERAS KLIPPERÅS SLIN 176 TILLÄGG THU FEB 23 1984
KLIPPERAS KLIPPERÅS PROT 311 TILLÄGG THU FEB 23 1984
KLIPPERAS KLIPPERÅS VLF- 62 TILLÄGG FRI FEB 24 1984
KLIPPERAS KLIPPERÅS PROT 78 TILLÄGG TUE SEP 18 1983

```

Appendix B (2)

Example from DK file (one punched form stored as a matrix)

```

KLIPPERÅS           : area name
MAGNETOM.PROTON    : type of measurement (code)
WNES               : measuring direction
  400              : form area width
  40  10           : line and reading separation
-2800  0           : co-ordinates for upper left corner
1000.009 N-TESLA   : unit
840917            : processing date

```

1	2	3	4	5	6	7	8	9	10
1	0.04	0.00	0.06	0.09	0.17	0.05	0.03	-0.01	-0.04
2		-0.02	0.08	0.05	0.15	0.09	-0.01	-0.03	0.01
3		-0.04	0.10	0.09	0.11	0.09	-0.01	-0.03	0.01
4		0.00	-0.06	-0.09	0.17	0.07	0.03	-0.01	-0.04
5		0.02	0.08	0.05	0.15	0.09	-0.06	-0.03	0.01
6		0.04	-0.10	0.09	0.11	0.09	-0.01	-0.03	0.01
7		0.00	0.06	0.09	0.17	0.05	0.03	-0.01	-0.04
8		-0.02	0.08	0.05	0.15	0.09	-0.01	-0.03	0.01
9			0.10	0.09	0.11	0.09	-0.01	-0.03	0.01
10			-0.06	-0.09	0.17	0.07	0.03	-0.01	-0.04
11			0.08	0.05	0.15	0.09	-0.06	-0.03	0.01
12			-0.10	0.09	0.11	0.09	-0.01	-0.03	0.01
13			0.06	0.09	0.17	0.05	0.03	-0.01	-0.04
14			0.08	0.05	0.15	0.09	-0.01	-0.03	0.01
15			0.10	0.09	0.11	0.09	-0.01	-0.03	0.01
16			-0.06	-0.09	0.17	0.07	0.03	-0.01	-0.04
17			0.08	0.05	0.15	0.09	-0.06	-0.03	0.01
18			-0.10	0.09	0.11	0.09	-0.01	-0.03	0.01
19			0.06	0.09	0.17	0.05	0.03	-0.01	-0.04
20			0.08	0.05	0.15	0.09	-0.01	-0.03	0.01
21			0.10	0.09	0.11	0.09	-0.01	-0.03	0.01
22				-0.09	0.17	0.07	0.03	-0.01	-0.04
23				0.05	0.15	0.09	-0.06	-0.03	0.01
24				0.09	0.11	0.09	-0.01	-0.03	0.01
25				0.09	0.11	0.09	-0.01	-0.03	0.01
26				-0.09	0.17	0.07	0.03	-0.01	-0.04
27				0.05	0.15	0.09	-0.06	-0.03	0.01
28				0.09	0.11	0.09	-0.01	-0.03	0.01
29				0.09	0.17	0.05	0.03	-0.01	-0.04
30				0.05	0.15	0.09	-0.01	-0.03	0.01
31				0.09	0.11	0.09	-0.01	-0.03	0.01
32				-0.09	0.17	0.07	0.03	-0.01	-0.04
33				0.05	0.15	0.09	-0.06	-0.03	0.01
34				0.09	0.11	0.09	-0.01	-0.03	0.01
35				0.09	0.17	0.05	0.03	-0.01	-0.04
36				0.05	0.15	0.09	-0.01	-0.03	0.01
37				0.09	0.11	0.09	-0.01	-0.03	0.01
38				-0.09	0.17	0.07	0.03	-0.01	-0.04
39				0.05	0.15	0.09	-0.06	-0.03	0.01
40				0.09	0.11	0.09	-0.01	-0.03	0.01

Appendix B (3)

File for Geotab

Total magnetic field

Column	Content	Example
1*	Area code	KL
2*	Measuring direction	E-W
3*	Start date of measurement	851025
4	x-co-ordinate (local net)(m)	2000
5	y-co-ordinate (local net)(m)	20
6	Total magnetic field(1000 nT)	0.210

* Key columns in Geotab

Appendix C-1 (1)

Geophysical borehole logging

Noted columns at different forms:

Temperature/Borehole Fluid Resistivity:

Column 1 borehole length
 Column 2 resistivity
 Column 3 temperature

Resistivity -normal and -lateral:

Column 1 borehole length
 Column 2 reading
 Column 3 scale
 Column 4 current

Induced Polarization (IP)/ IP resistivity:

Column 1 borehole length
 Column 2 RP reading
 Column 3 RP scale
 Column 4 IP reading
 Column 5 IP scale
 Column 6 current

File specifications for raw data files

PP files:

Chart recorder:	offset	pos
Column 1 borehole length	1	9
Column 2 value (mm)	10	15

Temperature/Borehole Fluid

Resistivity	offset	pos
Column 1 borehole length	1	6
Column 2 resistivity	7	6
Column 3 temperature	13	6

Resistivity -normal and -lateral:	offset	pos
Column 1 borehole length	1	4
Column 2 reading	6	3
Column 3 scale	10	6
Column 4 current	17	5

Induced Polarization/IP resistivity:

Column 1 borehole length
 Column 2 RP reading
 Column 3 RP scale
 Column 4 IP reading
 Column 5 IP scale
 Column 6 current

BA file	offset	pos
Column 1 borehole length	1	9
Column 2 value (mV)	10	15

PP files are originally registered on forms or by chart recorders. BA files are registered on cassette tapes.

Appendix C-1 (2)

File specifications for result files

Chart recorder registration and temperature/borehole fluid resistivity:			
		offset	pos
Column 1	borehole length	1	7
Column 2	value	8	13

Resistivity -normal/-lateral and Induced Polarization/IP resistivity:			
		offset	pos
Column 1	borehole length	1	7
Column 2	value	9	8

Data file to Geotab

Example: Natural gamma radiation

Column	Content	Example
1*	Borehole ID code	KKL02
2*	Logging date	851025
3*	Length along hole (m)	10.1
4	Gamma intensity (micro R/h)	0.350000E02

* Key column in Geotab

Appendix C II

Sonde descriptions

Borehole Fluid Resistivity

The probe is manufactured by Swedish Geological Co. The resistivity of the borehole fluid and the temperature are measured simultaneously by the same probe.

The resistivity of the borehole fluid is measured by a system of five electrodes. These electrodes are positioned in a plastic tube open at both ends. Plastic insulation is necessary to eliminate the influence of the bedrock on the measurements. The current (C) and the potential (P) electrodes in the probe are arranged as follows:

Electrode	C ₁		C ₂	P ₁		P ₂	C ₃
Separation (mm)		160		40		80	40

The result is expressed in ohm-m. Using temperature and resistivity data, the salinity of the borehole water can be calculated as equivalent ppm NaCl. The fluid resistivity is also used for corrections while calculating the true resistivity of the bedrock from the normal or lateral resistivity. Water flow along the borehole might also be indicated by this method, especially when this is correlated with temperature measurements.

Measurements are usually performed with a reading separation of five metres and the results are noted on forms.

Calibration is undertaken in the laboratory where the probe is lowered into a tank filled with salt water solution having variable salinity.

Borehole Fluid Salinity

The salinity of the borehole fluid is calculated from the borehole fluid resistivity and temperature. It is presented as equivalent concentration NaCl (ppm). The following formulae is used:

$$S(x) = \frac{1}{r(x) * s(25 \text{ }^\circ\text{C}) * (1 + b * (T(x) - 25 \text{ }^\circ\text{C}))}$$

r(x) = measured resistivity * borehole length
 T(x) = measured temperature * borehole length
 s(25 °C) = salinity coefficient = 0.00022 mho/m/ppm NaCl
 b = temperature coefficient = 0.022/°C

Borehole Fluid Temperature

The probe is manufactured by Swedish Geological Co. The temperature and the resistivity of the borehole fluid are measured simultaneously by the same probe.

The temperature (degrees Centigrade) is measured by a thermistor. From the measurements, the vertical temperature gradient (degrees Centigrade/km) is calculated.

From the measurements, information on water transport in the borehole is obtained.

Measurements are taken at discrete points with a separation of one metre. Earlier measurements were taken at a separation of 5 m. Measured values are noted. Calibration is undertaken both in the laboratory and in the field, using a very accurate quartz thermometer.

Borehole deviation

The probe is manufactured by Swedish Geological Co. This probe measures the borehole direction in the vertical plane, the inclination, by a pendulum. The direction in the horizontal plane, the declination, is measured by a compass needle. Both the direction of the compass and the position of the pendulum are measured electrically. A drawback with the use of a compass needle is that it is sensitive to magnetism. In magnetic rock types the direction of the needle will be incorrect.

The declination is measured in a 360 degree clockwise system, where 0 and 360 degrees is north. The inclination is measured in a 90 degree system, where 0 degrees is horizontal and 90 degrees is vertical.

The measuring point distance is 10 metres, and measured values are noted at forms. From the measurements coordinates in three directions, x, y and z, are calculated by trigonometric calculation for each measured point.

The pendulum is calibrated with a protractor while the compass needle is calibrated with a compass at the laboratory.

Differential resistance

The probe is manufactured by Swedish Geological Co. This probe measures the resistance between two electrodes separated by an insulator 12 mm in thickness. The upper and lower electrodes have lengths of 140 mm and 10 mm respectively. The insulator fits tightly in the borehole. This forces the current

between the electrodes to pass through the rock if the borehole wall is smooth. A fracture will make the borehole a little wider and the current will tend to flow in the borehole fluid which gives a lower resistance between the electrodes.

Differential resistance will indicate small fractures which increase the diameter of the borehole. This log works as an electric caliper in the absence of conducting minerals. The measurements are quite similar to those for a single point resistance, which is often used.

Natural Gamma Radiation

The probe is manufactured by Swedish Geological Co. It contains a scintillation detector. The active part is a 1.5 inch NaI crystal (gammalog) or a 4 inch NaI crystal (litolog) connected to a photomultiplier. This transforms the light pulses created in the crystal to electric signals proportional to the incoming gamma radiation. Most of the measurements were taken with the smaller crystal.

This probe will measure the natural gamma radiation (micro-Roentgen/h) of the bedrock. The results will provide information on the total radioactivity of the rock, i.e. the summation of potassium, uranium and thorium content. Variation in these elements will normally correspond to mineralogical changes in the rock.

The recording is performed either continuously with a strip chart recorder, or digitally on a cassette tape.

A radioactive source with a well known activity is used for calibration. Recently (1986) a calibration camp with three different calibration models was ready for calibration.

Gamma-Gamma (density)

This tool is manufactured by Mount Sopris. It has a 300 mCi Cs-137 source. A gamma-ray detector (NaI crystal) is positioned at a distance of 250 mm from the source. The gamma-gamma (density) tool is used to determine the rock density. In crystalline rock environments the tool is used, mainly, for lithology determinations.

The gamma-rays emitted will lose energy by Compton scattering collisions and other effects on their way through the formation. All these effects give a proportionally lower gamma ray reading in higher density formations. The intensity of the gamma rays received is exponentially proportional to the electron density of the formation. Since there is a close relation between the electron density and the bulk density of the formation, a log of the density

variation along the borehole is obtained.

The measuring results, continuously recorded along the borehole length, are registered both digitally and analogically on a strip chart recorder.

The tool is calibrated in environments with known density. The system is calibrated in a water tank, in a laboratory borehole with well determined densities and on an aluminum block. In the field the system response is checked with an aluminum block and in water. The density obtained in a borehole at the specific site, is also controlled against laboratory measurements performed on rock samples from the same borehole.

Inductive Conductivity

This physical property can be measured with the magnetic susceptibility probe. However this is possible only for very low resistivity (high conductivity), usually found in sedimentary rocks. The method has not yet been used by SGAB (nov 1987).

Induced Polarization (IP)

The probe is manufactured by Swedish Geological Co. Normally a three electrode array is used in the borehole and one current electrode is positioned on the ground. The separation between the electrodes is usually five metres, and copper-sulphate electrodes are used as potential electrodes. A square wave current with a frequency of 0.25 Hz is transmitted by a regulated power supply.

The induced polarization is expressed as a percentage of the voltage transmitted and indicates the presence of disseminated sulphide and graphite.

Measured values are noted on forms and the results are calculated by computer.

Calibration is not required.

IP-resistivity

These measurements are performed with the IP sonde. Data is collected and handled the same way.

Lateral resistivity

The probe is manufactured by Swedish Geological Co. Both lateral and normal resistivity is measured with this tool. The lateral array consists of one current electrode and two potential electrodes in the probe and one current electrode on the ground surface at some distance of the borehole. The separation of the current and upper potential electrode in the probe is 1.6 m,

while the potential electrode separation is 0.1 m. Usually a 1 mA current with a frequency of 11 Hz is transmitted into the bedrock.

The resolution of the lateral array is better resolution than that of the normal array. However, the normal resistivity is closer to the true resistivity of the rock. When passing through a zone of conductive material, such as a fracture zone, the lateral array shows an asymmetric anomaly. When a zone intersects the borehole at an angle less than 30 degrees to the borehole axis the anomaly will become symmetric.

With this configuration, the apparent resistivity (ohm-m) of the bedrock is measured. The true lateral resistivity might be calculated from the lateral resistivity and borehole fluid resistivity.

Measured values may be recorded by a number of different methods. Earlier forms were completed manually for each measured potential value with a fixed measuring point distance, usually one metre. Knowing the current used, the measured potential and the geometric factor, it is simple to calculate the resistivity. Today a continuous recording is made with a strip chart recorder and the measurements may be taped simultaneously.

The measurements are calibrated in the field by connecting a variable resistor to the system, thus calibrating the response to a known resistance.

Magnetic susceptibility

The probe, TH-3, is manufactured by Geoinstruments Oy. The measurements are based on the electromagnetic induction in two coils in the probe. An alteration of the susceptibility in the rock surrounding the borehole gives rise to a measurable change in the inductance in the coils.

The magnetic susceptibility gives information on the presence of magnetic minerals in the rock. In crystalline bedrock, the most common magnetic mineral is magnetite. Knowing the susceptibility of a rock, the magnetite content might be calculated. Rock types often differ in magnetite content and can thus be separated.

Measurements are continuous and recorded with a strip chart recorder. The data can also be stored on a cassette tape simultaneously. Two sets of probe diameters are available, 42 or 52 mm, depending on the borehole diameter. The measured values are dimensionless and given in SI-units.

Calibration is performed with calibration pads of known susceptibility in the field, or at a calibration camp, using the three different susceptibility models constructed for this purpose.

Neutron-Neutron (Porosity)

This probe is manufactured by Comprobe Co. The neutron-neutron tool contains a radioactive source of 5 Ci AmBe-241, which emits high energy neutrons into the formation. Two neutron detectors (He-3) are positioned at a distances of 260 mm and 520 mm from the source respectively. The radius of investigation around the borehole is approximately 1 to 2 times the source-detector or detector-detector spacing (Saksa, 1985). The result is presented as the ratio of the number of counts at the near detector to that of the number at the far detector.

The high energy neutrons will be slowed down by collisions with matter (scattering effect). The loss of energy increases as the difference between the masses of the target and the neutrons decreases. The mass of a hydrogen atom is approximately the same as the mass of a neutron. Thus, the retardation of the neutron is primarily a function of the quantity of hydrogen in the formation. But potassium, chlorine, nitrogen, iron and nickel are examples of elements that are efficient in scattering (Alexander et al. 1981). After a few micro seconds, the neutrons will slow down to what is called the thermal energy level. At this energy level, these thermal neutrons are captured by an atom, such as chlorine. Boron, iron, manganese and cadmium are examples of elements which are very efficient in the process of absorption (Alexander et al. 1981).

In crystalline rock environments, elements like potassium, chlorine and iron are quite common in the minerals. Thus, the tool will act also as a lithologic log. For example, a mafic dyke will appear stronger or almost as strong as a water bearing fracture zone. However, a mafic dyke has a larger density while a fracture zone has a lower density compared with the surrounding rock. Thus a gamma-gamma density log will help to discriminate between these two features.

Registrations are made with a strip chart recorder and may be recorded on a cassette tape simultaneously.

Since the neutron-neutron tool has been used mostly within sedimentary rock environments the calibration facilities are designed for these applications. The tool used in Sweden is calibrated in three models at the university of Lund with porosity values of 27.2 %, 32.4% and 39.8 %. For crystalline rock applications calibration models for low porosity values are not yet available. For measurements in crystalline rock, the system has been used mainly for relative measurements. In the field the system response is checked by using two plastic boxes.

Normal resistivity

The probe is manufactured by Swedish Geological Co.

Both lateral and normal resistivity are measured with this tool. The normal array consists of two current electrodes and two potential electrodes. One current and one potential electrode are situated in the probe, with a separation of 1.6 m (64"), sometimes called long normal. The other two electrodes are situated on the ground surface at some distance from the borehole. Usually a 1 mA current with a frequency of 11 Hz is transmitted into the bedrock.

With this configuration, the apparent resistivity (ohm-m) of the bedrock is measured. The normal resistivity log will indicate zones with anomalous resistivity such as fracture zones, conducting minerals or mineralizations. It is possible to determine the width and resistivity of such sections. In many types of rock it is possible to find a direct relation between resistivity and porosity.

From the apparent normal resistivity and the borehole fluid resistivity, it is also possible to calculate the true resistivity.

Measured values can be recorded in a number of different ways. Earlier forms were completed manually for each measured potential value with a fixed measuring point distance, usually one metre. Knowing the current used, the measured potential and the geometric factor it is simple to calculate the resistivity. Today, a continuous registration is made with a strip chart recorder and the measurements can be taped simultaneously.

The measurements are calibrated in the field by connecting a variable resistor to the system, thus calibrating the response to a known resistance.

Radar

The probe is manufactured by Swedish Geological Co. In the radar technique, electromagnetic waves are transmitted through the rock in order to obtain information on structures, such as fracture zones, in the rock mass. These features can be detected at larger distances from the borehole than is possible with most other borehole methods. The radar method takes advantage of the wave nature of an electromagnetic field. This gives the radar a high resolution, which is of the order of meters. In combination with investigation ranges of 100-150 m this makes the radar a unique instrument for mapping structures rock masses. The borehole radar uses frequencies in the range 20 to 60 MHz, which corresponds to wavelengths of 2 to 6 m in rock masses.

In a single hole reflection measurement the transmitter and receiver are lowered into the same hole and the distance between them is kept constant. As the measurements are taken, the results are displayed on a monitor and the data is stored on a diskette. The

distance to a reflecting object is determined by measuring the difference in arrival times between the direct wave and the reflected pulse. As the radar is lowered stepwise into the borehole, the time difference will vary in a characteristic manner, typical of the geometry of the reflector. From a radar measurement it is possible to determine the angle of intersection between the hole and a fracture plane and also the point of intersection.

Previous experience in the use of the radar method at Stripa and other sites indicates that the most clearly defined reflectors seen in the radar diagrams correspond to fracture zones and basic dykes. Reflections have also been observed from man made objects such as boreholes and drifts. The range of investigation which has been obtained in granitic and gneissic rocks has varied from about 50 m to 150 m.

Velocity calibrations are made by so-called VRP measurements (Vertical Radar Profile). These measurements are usually made with one antenna on the ground surface and one in the borehole.

Borehole slingram

The probe is manufactured by Swedish Geological Co. The equipment consists of an electromagnetic transmitter coil and a receiver coil in the borehole. The coils are coaxial and separated by a distance of 5-40 m. Usually a frequency of 18 kHz is used.

Due to electromagnetic induction, the transmitted primary field will, in the presence of a conductor, cause a secondary field of opposite direction, and the resulting field will be measured. The signal received will be divided into a real component, in-phase with the primary field, and an imaginary component, 90 degrees out-of-phase with the primary field. Measured signals are expressed as fractions of the transmitted signal (%).

The log is used to detect electrical conductors in the vicinity of the borehole. It will also indicate whether a good or poor electric conductor is present. In low resistivity formations, it may also be used to measure the resistivity.

Registrations are made with a strip chart recorder.

This method no longer used.

Sonic (Acoustic)

The probe is manufactured by Simplec. The probe uses an acoustic transmitter of a magnetostrictive type to generate an elastic wave. The frequency of the transmitter is of the order of 20 000 Hz and is transmitted in short pulses with a firing rate of 15

Hz. The distance between the transmitter (T) and the near receiver (R_n) is three feet (915 mm) and the distance between the two receivers is usually one or two feet (305 or 610 mm). The receivers mounted above the transmitter trigger and register the incoming wave when the amplitude exceeds a preset amplitude threshold.

The sonic velocity probe records the time for a compressional elastic wave to travel a defined length, e.g. the distance between the two receivers in the formation surrounding the borehole. Fractured sections and rock types with different elastic properties will be detected.

The result may be presented as a travel time (microseconds/metre) or as a rock velocity (metres/second).

These measurements are continuous and recorded with a strip chart recorder, and may also be stored simultaneously on cassette tape. The measurements dependent on the probe geometry, and a very accurate timing is therefore required. Field calibration is unnecessary. Nevertheless, it is recommended to do a check up in the casing.

Self potential (SP)

The probe is manufactured by Swedish Geological Co.

Two non-polarizing electrodes are used, one in the borehole and one on the ground surface at some distance from the borehole. The electrodes consist of a copper wire in a saturated copper-copper sulphate solution, which is in contact with the borehole fluid through a porous wooden plug.

This device can be used to measure the natural potential of the rock (V or mV). Natural potentials arises from redox processes, ionic diffusion or kinematic processes. Thus, the SP-log provides information on conducting minerals, variations in ionic concentration and groundwater flow in or out of the borehole. In crystalline rock, the principal use of this log is in the diagnosis of conducting minerals.

Continuous recording is made with a strip chart recorder and the measurements can be stored simultaneously on cassette tapes.

Single Point Resistance

This probe is manufactured by Swedish Geological Co. It consists of a plastic tube, one metre in length, with metallic electrode of a length of 50 mm in the middle. This electrode serves both as a current and a potential electrode. Another electrode is placed on the ground surface approx 50 m from the borehole. The diameter of

the electrode in the borehole might be 53 or 73 mm depending on the borehole diameter. The resistance may be measured at any of four different frequencies, 3, 11, 33 or 110 Hz. 11 Hz is the most commonly used frequency.

With this probe the contact resistance (ohm) of the bedrock is measured. The small electrode gives a high resolution. Conducting minerals and individual fractures or cavities in the borehole wall will be detected.

A continuous registration is made with a strip chart recorder and the measurements can be taped simultaneously on a cassette.

The measurements are calibrated in the field by connecting a variable resistor to the system, thus calibrating the response to a known resistance.

True Resistivity

The resistivity measured with the normal and lateral sonde is called apparent. If the measurements are corrected for the resistivity of the borehole water and the diameter of the sonde and the borehole, we get a true resistivity. This has not yet been done (nov 1987).

Tube Wave

The probe is manufactured by Mark Products.

In an unbounded, homogeneous medium, elastic waves propagate in the form of longitudinal P-waves and transverse S-waves. A fluid can only support P-waves. However, a borehole can support guided surface waves propagating along the surface of the borehole with very little attenuation. Such waves are called 'tube waves' or Stoneley waves.

A small charge of dynamite is detonated in a shallow shothole at an offset distance of 20-40 m from the well head. The seismic wave train is recorded with a hydrophone array (Mark Products Ltd), using 12 pressure sensitive hydrophones. The distance between each hydrophone is 1.06 m. The data is recorded digitally on a 12 or 24-channel signal enhancement seismograph, Nimbus E1210-F, and then transferred to a cassette tape on a desk top computer. After each shot, the device is lowered one metre and the procedure is repeated. Subsequent data can then be transferred to a main frame computer for permanent storage and subsequent analysis.

In general, there is a good correlation between tube wave sources and sections of high or increased hydraulic conductivity in the borehole. In general terms, it appears that tube waves may be detected from zones with a hydraulic conductivity exceeding 10^{-10} m/s

(Stenberg and Olsson, 1985).

VLF

The probe is manufactured by Swedish Geological Co. The equipment consists of a VLF antenna in the borehole and a reference antenna on the ground surface. The signal from a distant radio transmitter, GBR, Rugby, England, with a frequency of 16 kHz is used.

Transmitted electromagnetic signals have a vertical electric and a horizontal magnetic component. For this purpose, the latter is used. When disturbed by the presence of an electric conductor, the magnetic field is tilted as a result of electromagnetic induction. The borehole antenna measures the magnetic component along the borehole.

This method is used to indicate the presence of electrical conductors in the vicinity of the borehole. Good conductors may be detected at a considerable distance from the borehole. Conductors crossing the borehole may be separated from those which do not. However the orientation of a conductor will determine if whether or not it is detectable. Sheetlike conductors which are horizontal or vertical ones perpendicular to the direction of the transmitter station will not be detected.

This method no longer used.

Vertical Temperature Gradient

The vertical temperature gradient is calculated from temperature and borehole fluid resistivity and borehole deviation logging. A formula from linear regression analysis based on the least squares method is used for the calculation. Each gradient value is calculated from nine temperature values.

$$TG = \frac{1000 * (9 * \text{SUM}(L * T) - \text{SUM}(L) * \text{SUM}(T)) * \text{SIN}(FI)}{9 * \text{SUM}(L^2) - (\text{SUM}(L))^2} \quad ^\circ\text{C}/\text{km}$$

where L = borehole length
 T = temperature
 FI = borehole inclination

Small temperature anomalies will easily be discovered from gradient curves.

Appendix D (1)

Petrophysical measurements

Raw data files

The format of the punched files is described below.

<u>Oerstedt form</u>	offset	pos
Instrument constant:		
Column 1 always '1'	9	1
Column 3 instrument constant	14	5
Column 4 earth's magnetic field	19	5
Instrument scale:		
Column 1 always '2'	9	1
Column 3 instrument scale	14	5
Measurement:		
Column 1 GDA-code	1	9
Column 3 Measured value 1	14	5
Column 4 Measured value 2	19	5
Column 5 Measured value 3	24	5
Column 6 Measured value 4	29	5
Column 7 Measured value 5	34	5
Column 8 Measured value 6	39	5

<u>RIPS-3 form</u>	offset	pos
Column 1 GDA-code	1	9
Column 3 instrument number	10	4
Column 4 measuring date	18	6
Column 5 borehole GDA-number	24	9
Column 6 borehole length	33	7
Column 7 sample length (mm)	40	4
Column 8 contact area	44	4
Column 9 RP reading	48	3
Column 10 RP scale	51	5
Column 11 IP reading	56	3
Column 12 IP scale	59	5
Column 13 current	64	5
Column 14 always '1'	69	1

<u>Density and porosity form</u>	offset	pos
Column 1 GDA-code	1	9
Column 3 weight, dry surface (for porosity)	14	8
Column 4 weight, soaked (for porosity)	22	8
Column 5 weight	30	8
Column 6 weight in water	38	8

Appendix D (2)

Data file from SGAB database to Geotab (no editing necessary)

Column	Content	Example
1	Borehole id code/sample number	AKKL09030
2	Borehole length (m)	200.60
3	Rock type code	PSE
4	Density (g/cc)	2.65
5	Porosity (%)	0.27
6	Susceptibility (cgs)	0.000042
7	Q value	0.3576
8	Remanence (cgs)	0.000007
9	Resistivity (kohm-m)	13.40
10	IP (%)	2.07

Appendix E

Geophysical borehole logging. Complot picture.

Appendix F

Geophysical interpretation of borehole logging. Copy of colour plot.

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Description of geological data in SKB's database GEOTAB

Version 2

Stefan Sehlstedt, Tomas Stark

SGAB, Luleå

January 1991