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

A list of other reports published in this series during 1983 is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17) and 1982 (TR 82-28) is available through SKBF/KBS.

Sveriges Geologiska AB

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by

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SUMMARY

The Svartboberget study site is an elongate hill, approx 2.5 km wide and 5 km long. The difference in altitude between the upper part of Svartboberget and the adjacent valleys to the northeast and southwest is 85 and 75 m, respectively. The depth of the Quaternary sedimentary cover is small and the percentage of exposed rock is small. The main rock type is a migmatitic paragneiss with a great amount of neosome, granite, and subordinate veins. In the northern part of the area there is a 150 m thick layer of graphitic gneiss. The content of economic minerals within this gneiss is small but future mining could not be excluded.

The fracture frequency of the rock mass is 2.6 fractures per metre and the variation with depth is insignificant.

The Svartboberget study site is situated between two north-northwest orientated valleys which are defined by regional fracture zones. The thickness of these zones are from 10 to more than 250 m. They dip 30 to 40 degrees towards the southwest and can be traced over long distances. The fracture zones consist of discrete sections, locally more than 30 m thick, of highly fractured and subordinate crushed rock. These sections are separate from each other by c. 10-125 m wide sections of normally fractured rock.

The regional fracture zones delimit a rock plinth, approx 5 km^2 large, consisting of the actual hill Svartboberget. Within this plinth there are local fracture zones with a mutual distance of 100-500 m. In all, 17 local fracture zones with varying dip have been located. These fracture zones intersect each other at different depths. Drill hole investigations indicate that the fracture zones have a mean width of 16 m. They contain minor parts of crushed rock. Common infilling in the fracture zones are calcite, chlorite, illite and zeolite.

The hydraulic conductivity in the rock mass of Svartboberget decreases with depth. At 100 m depth, the conductivity is c. 4 x 10^{-9} m/s and at 500 m c. 5 x 10^{-11} m/s. The hydraulic conductivity of the local fracture zones in Svartboberget is at 500 m depth 8 x 10^{-10} m/s. In the fracture zones the hydraulic conductivity decreases with depth in a corresponding way.

The topographic relief of the area implies that there is a high hydraulic gradient in the bedrock. This has also been confirmed by piezometric measurements where i.a. pressure differences of a 30 m water column have been registered in a drill hole.

1. INTRODUCTION

1.1 Background

Within the scope of the long-range program for final disposal of spent nuclear fuel, investigations will be performed in a number of study sites (SKBF/KBS 1982). These investigations which are performed in order to characterize different sites are pursued in accordance with a general program, the so-called "Standard Programme" (Brotzen 1981, Thoregren 1982).

Svartboberget is one of the study sites which has been investigated by means of deep drilling in order to obtain better knowledge of the geological, hydrogeological, and geochemical conditions at great depths in the Precambrian crystalline rocks of Sweden. The purpose of the investigation has been to bring forth the site-specific data required for a safety analysis of the repository of spent nuclear fuel.

The investigations at Svartboberget were initiated with reconnaissance studies in autumn 1979. These studies resulted in a recommendation for detailed investigation of the Svarboberget study site. These were initiated in June 1980 with detailed geological mapping of Svartboberget and a regional mapping of the surrounding Voxna area. The depth investigations were started in December 1980 with the first drill hole; the main part of the investigation was completed in July 1982.

1.2 Reporting of results

This report constitutes a summary and evaluation of data from the Svartboberget study site. The results obtained in this area are accounted for in detail in the following reports:

Ahlbom, Henkel, Scherman and Tiren, 1981:
"Reconnaissance studies of potential study sites in middle and northern Norrland in 1979-1980." (Swedish language).

Gentzschein, 1983:
"Hydrogeological investigations within the Svartboberget study site, 15F Voxna SO." (Swedish language).

The report accounts for the hydrological conditions within the site, including ground water maps and results of water injection tests in the deep core drill holes.

Hesselström, 1982:
"A summary of physical parameter measurements and chemical analyses of core samples from Svartboberget." (Swedish language)

The report accounts for petrophysical properties of various rock types.

Hesselström, 1982:
"A regional study of magnetic dislocation in the Voxna area, central Sweden," and
"Model computation for the depth determination of the sediment migmatite at Svartboberget." (Swedish language)

The report accounts for a regional (75 x 75 km) interpretation of lineaments from airborne geophysical measurements and a model estimation of the thickness of migmatized sediments in Svartboberget.

Jämtlid, 1982:
"Drill hole geophysics in study site Svartboberget, map 15F Voxna SE." (Swedish language)

The report constitutes a summary of geophysical logging performed and an interpretation of fracture zones.

Skifte, 1982:
"Surface water conditions at Svartboberget." (Swedish language)

The report constitutes an introductory study of the surface water conditions in the Voxna area.

Tirén, Eriksson and Henkel, 1981:

"Geological, tectonical and geophysical investigations of the Voxna area including the study site Svartboberget." (Swedish language)

The report accounts for the surface-geological and surface-geophysical mapping of the Svartboberget study site and a regional (c. 375 km^2) geological and geophysical study of the area surrounding Svartboberget.

Tirén, 1982:

"Geological and tectonical depth investigations at the study site Svartboberget, 15F Voxna SE." (Swedish language)

The report accounts for the results from the investigation of geology at depth comprising bedrock petrography, petrochemistry and a three-dimensional interpretation of occurring fracture zones.

Tirén, 1982:

"A summary of technical data for the different drill holes with fracture and rock type logs, Svartboberget, 15F Voxna SE." (Swedish language)

The report presents the results of the drill core loggings and technical data from the drilling work.

The extent of the main elements of the investigations of Svartboberget is described in the Appendix. A description of methods and instruments used in the different investigations is given by Ahlbom, Carlsson & Olsson (1983) and Almén, Hansson, Johansson, Nilsson, Andersson, Wikberg, & Åhagen (1983).

2. THE SELECTION OF STUDY SITE SVARTBOBERGET

Reconnaissance work carried out in 1980 resulted in Svartboberget being selected as one of the interesting sites for further investigation. Svartboberget was chosen primarily on the following grounds:

- The bedrock of Svartboberget consists of migmatite. Water wells in this rock type have proved to yield low water capacities.
- The Svartboberget study site is located in a regional synform where migmatite is the dominating rock type in its central parts.
- Experience from the construction of rock caverns and tunnels in foliated migmatite is favourable: low water inflow and comparatively small stability problems.
- The region is covered by airborne geophysical measurements.
- The Svartboberget study site constitutes a rock plinth delimited by regional fracture zones.
- The Quaternary sedimentary cover of soft sediments is thin at Svartboberget which makes fracture zones appear topographically.
- There are few topographically well-defined lineaments at Svartboberget.
- The fracture frequency in outcrops is low in the study site.
- The major part of the area is owned by one land-owner.

The proportion of exposed rock in the site area is comparatively small, less than 1%. Regional mapping of the geological and tectonic conditions was therefore considered to be of utmost importance for the interpretation of the study site.

Geological field reconnaissance and geophysical profile measurements of Svartboberget was undertaken in 1980. The geophysical measurements indicated that major fracture zones are lacking at the site. Indications of fracture zones were obtained, however, when crossing the delimiting north-northwest orientated valleys.

In December 1980 a vertical, c. 800 m deep drill hole was drilled in the eastern part of the site in order to obtain information of thickness and variation in composition and fracture frequency of the migmatite. The results indicated that the thickness of the migmatite is in excess of 800 m and the composition of the rock varies to the same extent as on the surface. The fracture frequency in major sections of the drill core was high due to the location of the drill hole close to a regional fracture zone situated just north of the site. The results of the introductory investigations were considered promising and a decision to initiate further investigations was made in spring 1981.

3. LOCATION AND TOPOGRAPHY

Svartboberget is an elongate hill with a north-northwestesterly extension located in the Ovanåker commune in western Hälsingland, Gävleborg county, fig 3.1. The site is situated on the topographical map-sheet 15F Voxna SE. The nearest urban district is Edsbyn, located 12 km east of the area. Voxna, 5 km to the southwest, is the nearest village. The regional area surrounding the Svartboberget study site (375 km^2) is referred to as the Voxna area.

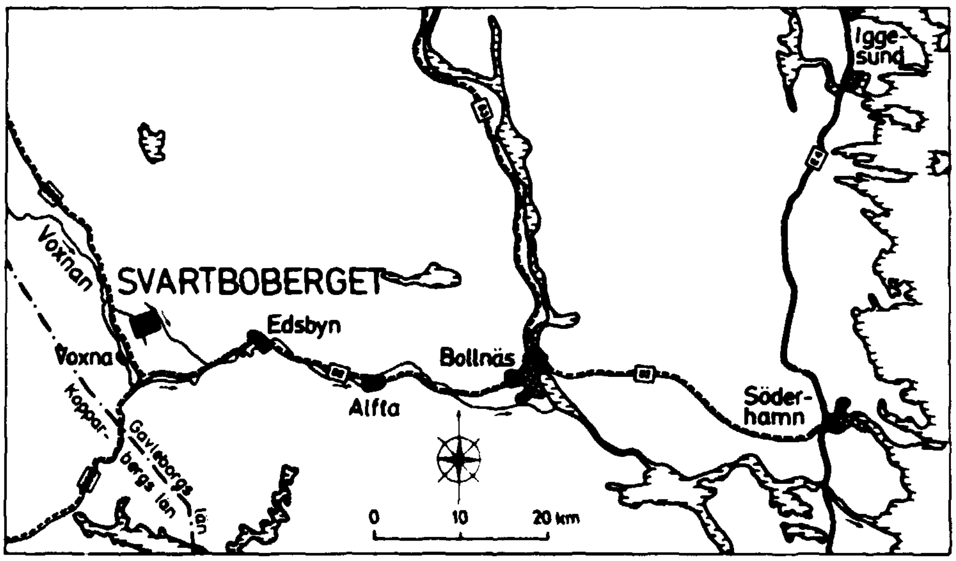


Figure 3.1. Locality map of site Svartboberget.

The topographically most prominent features in the region are north-northwesterly hills and valleys extending parallel to Svartboberget, fig 5.1. These valleys divide the southern central part of the Voxna area into three sub-areas, which are 2-2.5 km wide and more than 8 km long. Svartboberget, which is the centrally located sub-area, is constituted of a smoothly sculptured hill. The differences in altitude between the upper part of Svartboberget, c. 305 m above sea level, and the bottom of the eastern and the western valleys are 85 m and 70 m, respectively. Both these valleys are drained by small streams. The eastern stream flows in a southerly direction, whereas the western one flows to the north, fig 6.1.

The sub-area west of Svartboberget is slightly wider than Svartboberget and has a more broken topography. The Voxna river valley constitutes the western boundary of this sub-area.

The sub-area east of Svartboberget is elongate, approx 15 km, and consists of a number of smoothly sculptured hills of west-northwesterly orientation.

These sub-areas are bounded to the south by the river, Voxnan, which here flows in an easterly direction. North of the Svartboberget site, topographical features are oriented west-northwest. The southern-most of these is an open valley which constitutes the northern boundary of the Svartboberget site.

The Quaternary deposits at Svartboberget consist mainly of boulder-rich till. In connection with the drilling the soil depth has been measured in the area. On the upper part of Svartboberget the overburden is thin: 0-2 m. South and north of Svartboberget, the soil depth is greater, 6 and 8 m, respectively.

In the valley southwest of Svartboberget and south of the outflow of Södra Brynåssjön the soil depth is 2-3 m. The soil depth in the valley northeast of Svartboberget is not known. In this valley there are glacifluvial deposits. This may indicate a relatively greater thickness of the soil.

In the Voxna area there is a permanent population in Voxna, Ö. Älmesbo and along the Voxna valley. These homesteads are predominantly farms, with the exception of the village of Voxna. A large number of cottages are spread along the Älmån valley and around Loftsjön. Otherwise, the Voxna area comprises productive woodland.

A topographical profile of the area is presented in fig 3.2. The altitude characteristics of the area are illustrated by the hypsographical curve in fig 3.3. The area investigated with detailed geophysical measurements is 2 x 2 km, extending over 0-2000 E and 0-2000 N in the local coordinate system, fig 5.4.

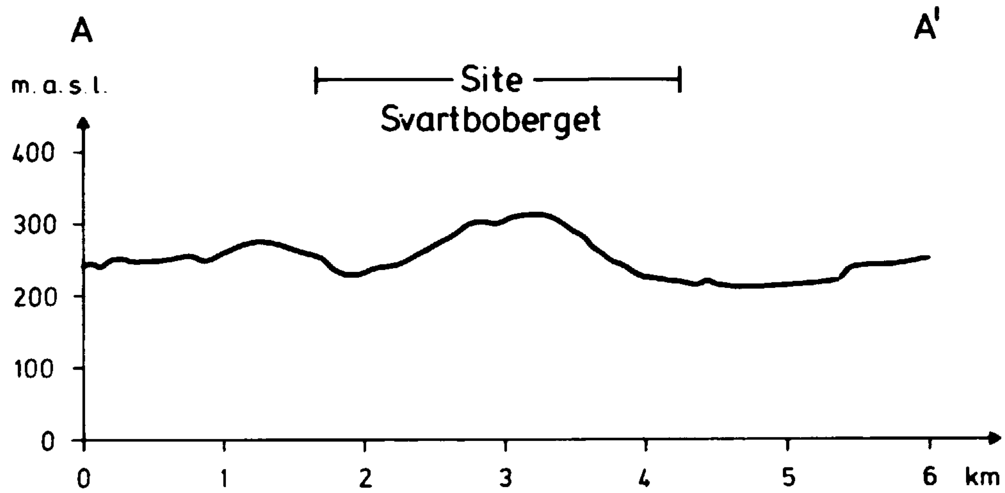


Figure 3.2. Topographical profile across site Svartboberget, location shown in Fig. 5.1.

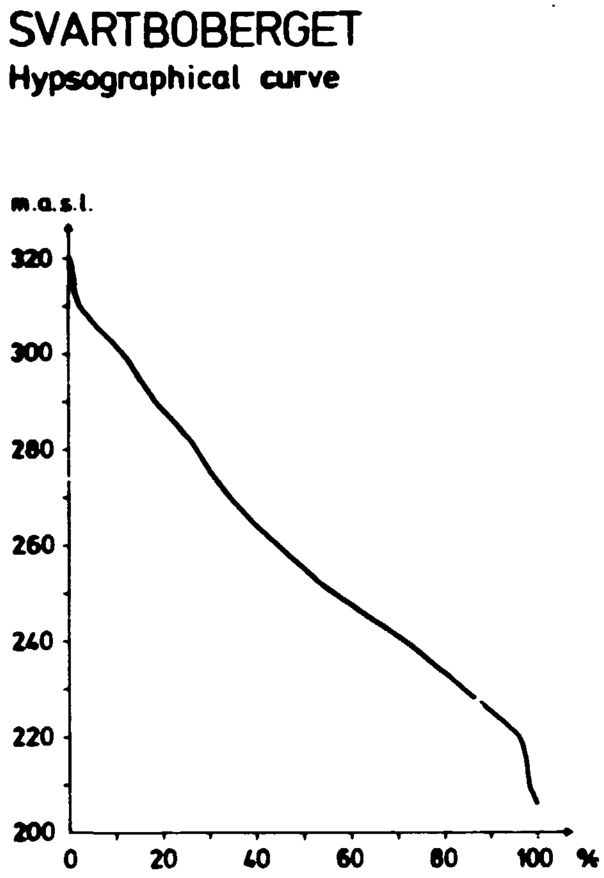


Figure 3.3. Hypsographical curve showing altitude characteristics in site Svartboberget.

4. BEDROCK GEOLOGY

4.1 Regional geology

The bedrock in the region mainly consists of rocks formed during the Svecokarelian orogeny, c. 1800-1900 mill. years ago. The oldest rocks are different types of migmatites, mainly of sedimentary origin, and gneisses. During a relatively early stage of the orogeny, granites and subordinate basic rocks penetrated older rocks. These igneous rocks, the so-called Old Granites (Old Granite suite), are today deformed and referred to as granite-gneiss. The migmatization took place during a phase of the orogeny when the rock complex was depressed to great depth, approx 10 km, where it was exposed to high pressure and high temperature. This resulted in partial melting and the formation of new mineral assemblages. The youngest rock is dolerite dykes of a probably age of c. 1200 mill. years. A detailed description of rock types and rock-type development is rendered by Lundegårdh (1967) and Tirén (1982). The geological evolution within the region is summarized in table 4.1.

Table 4.1 Geological evolution of the region around the site Svartboberget.

Geological event, rock type	Age (Ma)
Dolerite	1200 (?)
Migmatitization and folding	1800-1850
Old Granite suite	c 1900
Supracrustal rocks (clay-sandstone, quartzite, basic and acid intrusives and effusives)	c 2000

The geology of the region around the Svartboberget site is illustrated in detail in figs 4.1 and 4.2.

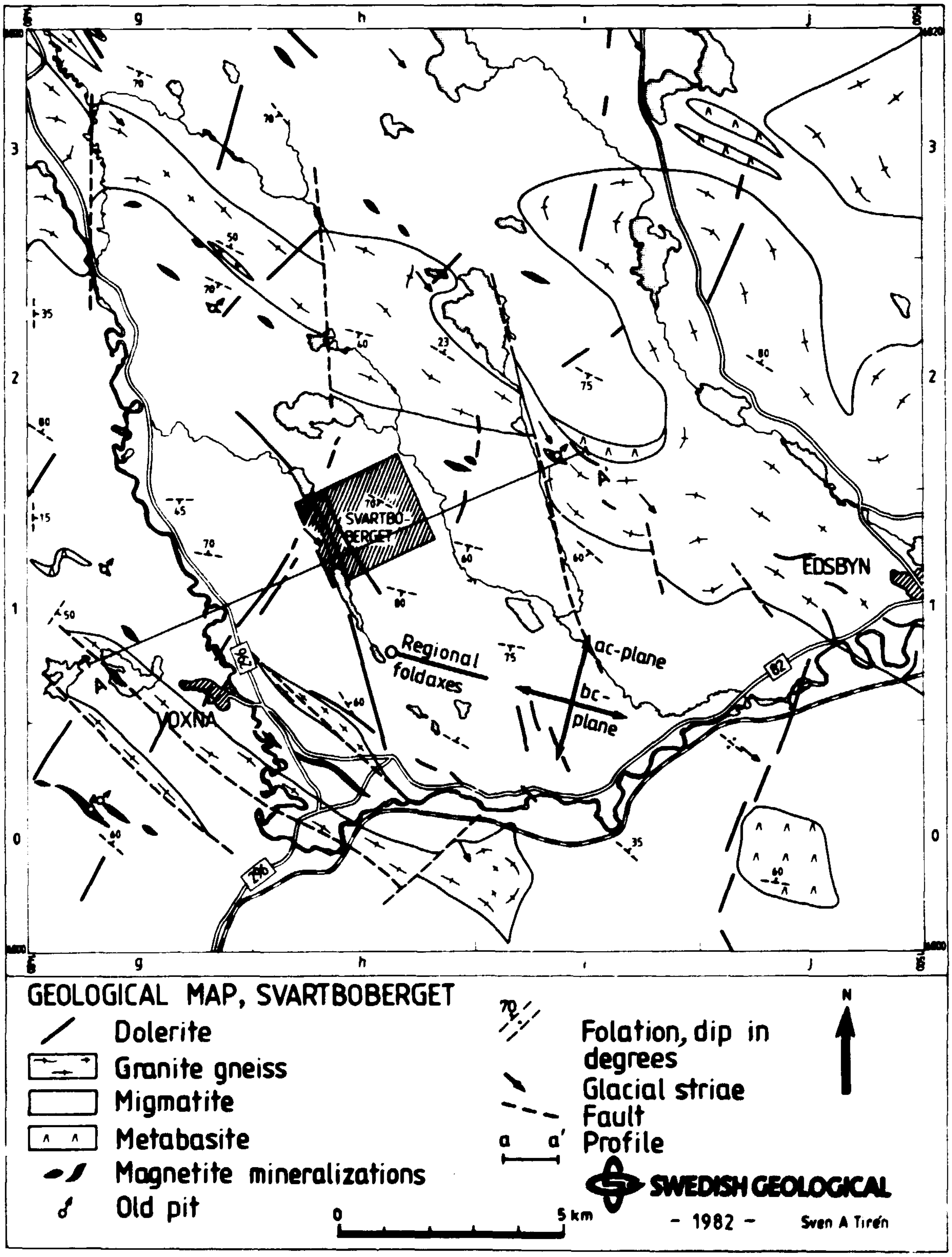


Figure 4.1. Regional geological map including site Svartbo-berget.

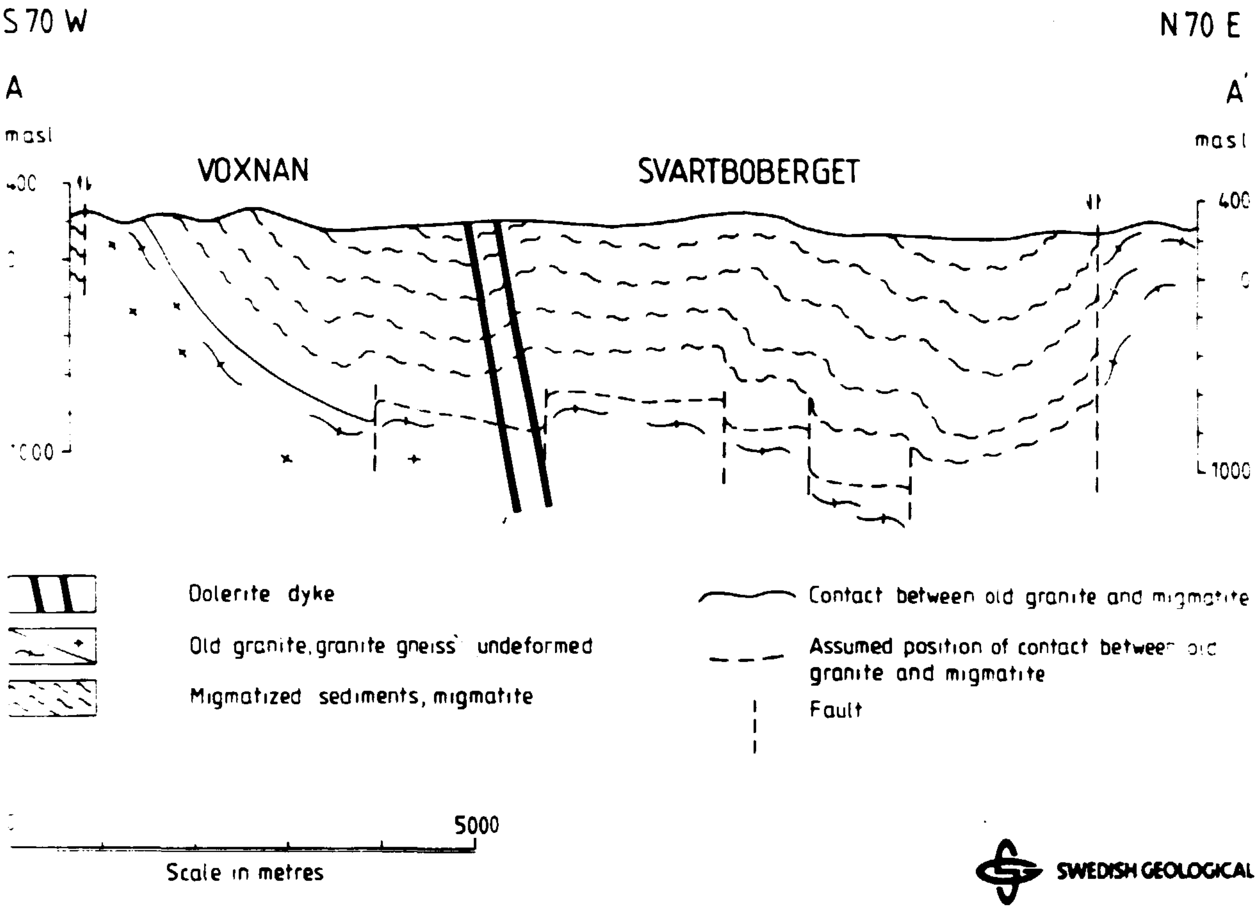


Figure 4.2. Geological profile through site Svartboberget, location shown in Fig. 4.1.

4.2 Geology of the study site

The bedrock of the Svartboberget study site mainly consists of migmatite, 95%. The thickness of the migmatite has been determined by drilling to be more than 800 m. The migmatite was formed from sediments which were originally pelite dominated with subordinate intercalated beds of quartzite. The metamorphosed fine-grained beds today appear as coarse-grained layers in the migmatite gneiss. The quartzite layers have been folded and disrupted and today occur as fragments in the gneiss.

Graphitic migmatite (9-13 weight % C) has been found in drill hole Sv 1. Several layers of various thickness of this migmatite are found in a c. 140 m thick sequence between 365-505 m depth. These layers dip very gently towards the southwest and are faulted in the northern part of the area. The fault plane strikes west-northwest and dips 80 degrees to the north.

The migmatite also contains a grey granitic component referred to as migmatite granite. This was formed during the migmatization and mainly conforms with the internal structure of the migmatite. The migmatite granite usually displays a gradual transition into the surrounding migmatite, but locally has sharp and straight contacts. This applies particularly when the migmatite granite is in direct contact with a brittle layer, e.g. preserved quartzitic bed. The migmatite granite appears as minor, irregular, medium-grained to coarse-grained bodies. The presense of these granitic bodies seems to have an annealing effect on the bedrock. No typical granitic fracture pattern has been observed.

The main minerals in the migmatite and the inherent migmatite granite are quartz, plagioclase, biotite and potash feldspar. Accessory minerals are white mica (alteration of plagioclase and sillimanite), cordierite, garnet, sillimanite, opaque minerals, chlorite (alteration of biotite), amphibole, pyroxene, epidote, zircon, sphene, calcite, rutile and apatite. Among the opaque minerals, pyrrhotite is the most prominent and appears locally in millimetre-thick veins. In the graphitic migmatite the main minerals are quartz, plagioclase and graphite. Other common minerals in this rock type are pyrrhotite, biotite and chalcopyrite.

Greenstones constitute 2-3% of the bedrock in Svartboberget. They appear in layers and lenses parallel to the foliation of the migmatite. The thickness of these layers is an average of less than 1 m. A greenstone of 15 m width has been penetrated in the eastern corner of the study site (drill hole Sv 3). This greenstone is a meta-gabbro and is, like other thicker greenstones, medium- to coarse-grained and slightly deformed.

The thinner greenstones, c. 1 m and thinner, are in general well-foliated fine- to medium-grained amphibolites. Greenstones appear, as a rule, evenly distributed in the bedrock. In the northwestern part of the site (drill hole Sv 7, 295-382 m) there is a c. 85 m sequence in which greenstones constitute 35% of the rock.

In the western part of the Svartboberget site the surface geophysical measurements indicate the presence of two steep dipping, persistent dolerite dykes oriented in a north-northwesterly direction. These dolerite dykes have been examined by drilling (Sv 4) and are less than 1 m wide, figs 5.4 and 5.5.

The dominating minerals in the dark (basic) rock types are plagioclase (locally strongly altered) and amphibole (usually hornblende). Foliated greenstones contain biotite, locally as the main mineral. Accessory minerals are opaque minerals, white mica, apatite, epidote and quartz.

Granite-gneiss constitutes less than 0.5% of the bedrock of the Svartboberget site and appears as decimetre-thick dykes and sills. It also appears as fragments in the migmatite. The composition of the granite-gneiss is dominated by plagioclase, quartz and biotite. Accessory minerals are potash feldspar, muscovite, opaque minerals, apatite, epidote, zircon and rutile.

4.3 Physical properties of the bedrock

Porosity and a number of other physical parameters have been measured on drill core samples. A summary of results obtained and variations in characteristics between different rock types is given in table 4.2.

The graphitic gneiss differs from other rock types with regard to electric properties due to its high content of electrically conductive graphite.

Measurements of temperature in all drill holes give an average temperature gradient for the area of 13.6^{o}/km.

Table 4.2. Physical parameters measured on core samples from Svartboberget (average values).

Rock type	Density km/m³	Porosity %	Resistivity ohmm	IP-effect %	No. of samples
Migmatite	2723	0.27	13 100	2.9	210
Graphitic migmatite	2892	0.38	60	83.0	16
Granite-gneiss	2716	0.26	13 100	3.0	10
Amphibolite	3001	0.21	17 700	5.5	44

4.4 Model calculations based on aero-geophysical measurements

The western part of Hälsingland is covered by geophysical aerial maps in scale 1:50,000. These maps have been used for detailed studies of the geological conditions (Tirén et al., 1981, Hesselström, 1982). Different rock types in the surroundings of Svartboberget display varying magnetic properties. The migmatite is in general non-magnetic, whereas the grey granite-gneiss is slightly magnetic. Thus the granite-gneiss appears as airborne magnetic measurement anomalies. The dolerite dykes appear on the geophysical maps as highly magnetic, distinct bands.

In and around the Svartboberget study site there are magnetic anomalies of low amplitude and long wavelength, which indicate the presence of magnetic material at great depth. This material is assumed to be a granite-gneiss of the same type as that found east of Svartboberget. The magnetic properties of the granite-gneiss occurring in outcrops have been measured in field and on drill core samples. The results have been used for the adaption of different models to the airborne magnetic measurements. The estimates have been compiled into a three-dimensional model of the top surface of the granite-gneiss in Svartboberget and its surroundings, fig. 4.3.

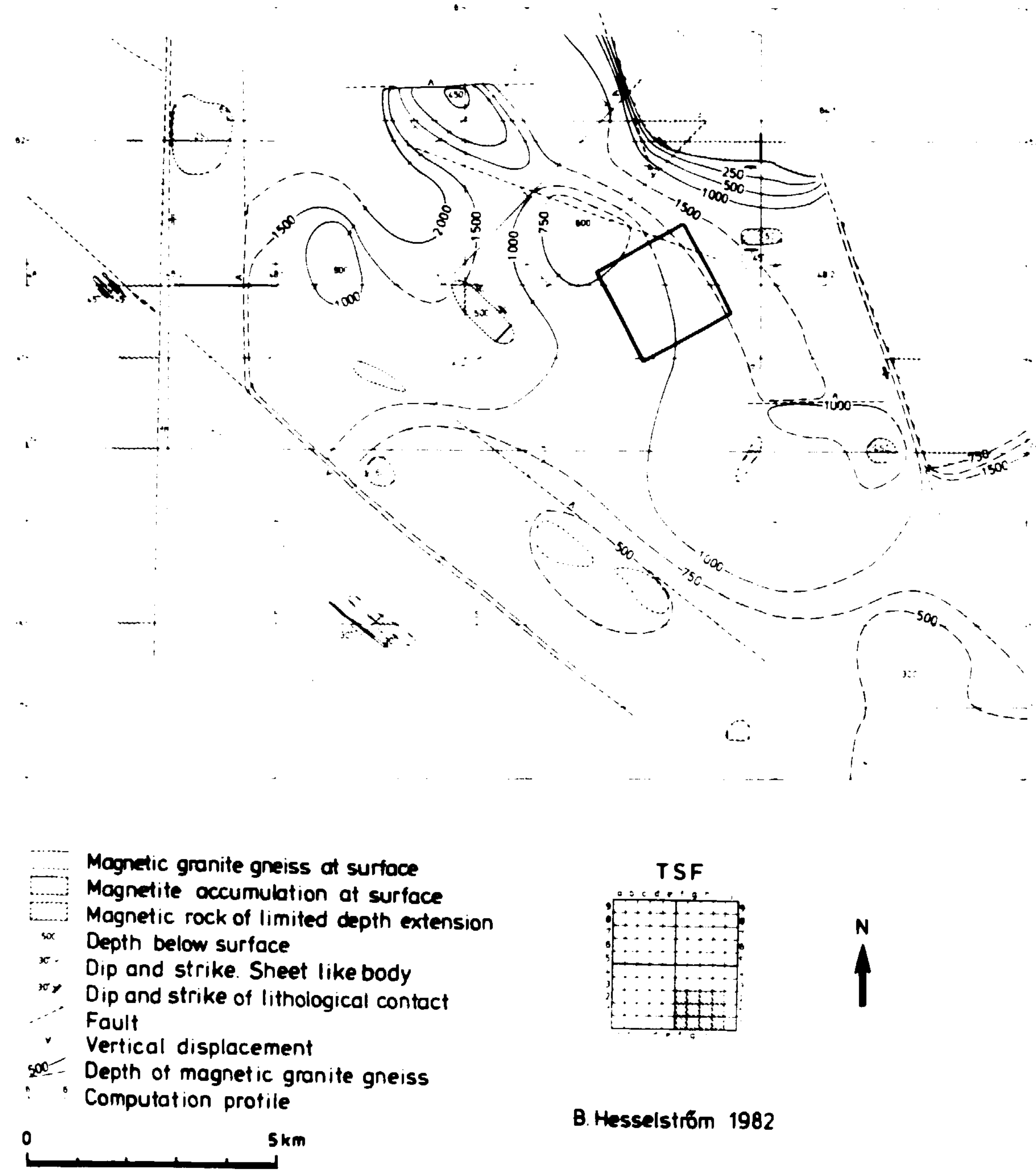


Figure 4.3 Tentative interpretation of the boundary between migmatite and granite-gneiss from aeromagnetic data.

4.5 Mineral potential

Mineralizations which have been subject to mining in the Voxna area are different types of iron ore, magnetite and hematite ores. The iron ore mineralizations are found in connection with thin greenstone layers and skarn bands.

The largest of the iron ore deposits is the Gymåsen mining area which comprises more than 20 pits. This area is located approx 8 km southwest of Svartboberget, fig 4.1. The main ore body is a 2 m wide quartz banded hematite ore and a 4 m wide magnetite ore. The mine was closed down prior to the beginning of the twentieth century (Lundegårdh, 1967) but the area is still subject to mining concessions.

Another mining activity in the Voxna area involves surface cuts (minor open pit mining, diameter 5-10 m). The location of these is specified in fig 4.1.

All the above mineralizations are outside the Svartboberget study site. Within the site a sequence of graphitic layers of 365-505 m depth have been recorded in drill hole Sv 1, section 4.2. The graphite content reaches c. 13 weight % C. The more graphitic layers usually have a high content of iron sulphides and some copper sulphides (copper content being less than 0.08 weight % Cu).

5. FRACTURE ZONES

5.1 Regional fracture zones

The Svartboberget study site is delimited to the northeast and southwest by valleys of a north-northwesterly orientation, both defined by regional fracture zones. The width of the valley bottom in these fracture-defined valleys varies between 10 and 250 m. The valleys are widest where they intersect minor north-westerly oriented valleys. The north-northwesterly striking fracture zones dip 30-40 degrees to the southwest and can be followed topographically for 10-15 km, figs 5.1 and 5.4. To the south, the fracture-defined valleys are bounded by fracture zones defining the Voxnan valley. To the north these zones change direction and become more northerly oriented.

The north-northwesterly zones have a parallel strike with regional features delimiting, to the east, an older, approx 1800 mill. years old, granite gneiss and migmatite region from a younger, 1400-1600 mill. years old, vulcanite and granite series to the west. This boundary runs c. 40 km west of Svartboberget. The vulcanite and granite series can be followed southwards down into Småland and to the north up to, and under, the Scandinavian Caledonides. In conjunction with the large-scale volcanic activity, the older, surrounding bedrock was exposed to major rock stresses. This resulted in the formation of lowangle faulting. The north-northwesterly fracture zones at Svartboberget were probably formed during this period.

West of the Voxnan river there occur gently dipping, undeformed dolerite dikes which have intruded along fracture zones similar to the ones described above. These dolerites are c. 1200 mill. years old, and the fracture zones thus must be older.

These regional fracture zones may have been reactivated approx 900-1200 mill. years ago in connection with the Sweconorwegian orogeny when the area was exposed to compression from west to east. When the Scandinavian Caledonides was formed c. 0.4 mill. years ago, these low-angle faults may have been reactivated again. Calculations made on the basis of the magnetic aerial measurements verify that vertical and lateral movements have occurred along the north-northwesterly fracture zones.

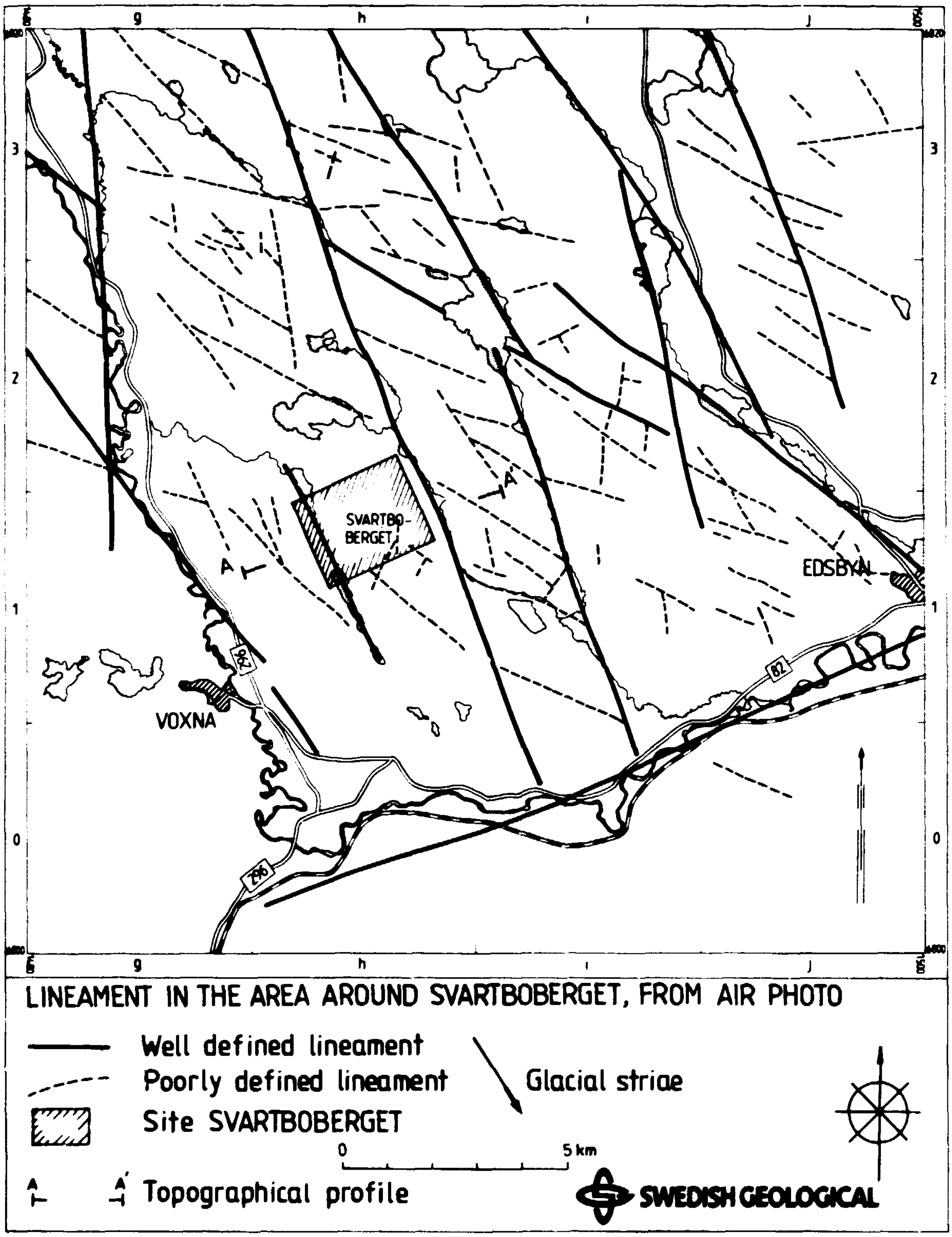


Figure 5.1. Interpreted lineaments around site Svartboberget.

The regional fracture zone northeast of Svartboberget (Zone 18), fig 5.4, was investigated by means of four surface-geophysical profiles. The zone dips 30-40 degrees to the southwest, and its upper parts were investigated by means of core drill holes Sv 1, Sv 2 and Sv 3. The southwestern zone (Zone 19) was investigated by means of eight surface geophysical profiles and five percussion drill holes. The two regional fracture zones contain parallel sets of fracture zones often with a central part of crushed rock (less than 5 m) surrounded by thinner sections of high fracture frequency. The thickness of these zones is locally more than 30 m. The central parts of these fracture zones are weathered and permeable to water. The water discharge rate is high in the upper parts of the fracture zones but decreases with depth, section 7.2.2. The rock sections in between these zones have a slightly increased or low fracture frequency (section 5.3). The distance between the fracture zones varies from 10 to 125 m. The position of the regional fracture zones in the Svartboberget study site is indicated in fig 5.4.

5.2 Fracture zones within the study site

The fracture zones within the Svartboberget study site have been mapped by aerial photograph interpretation, geological mapping and geophysical surface measurements. The properties of the bedrock, including fracture zones at depth have been investigated by seven core drill holes and 16 percussion drill holes and geophysical and hydrological measurements in these. The position and length of the drill holes and the total extent of the investigations performed are given in the Appendix. The position of the core drill holes and the fracture zones and their orientation are shown in fig 5.4.

Due to the topography and insignificant soil depth at Svartboberget, existing fracture zones appear clearly on topographical maps. Detailed surface geophysical measurements give clear and unambiguous indications of fracture zones. The accordance between topographically and geophysically indicated fracture zones is good.

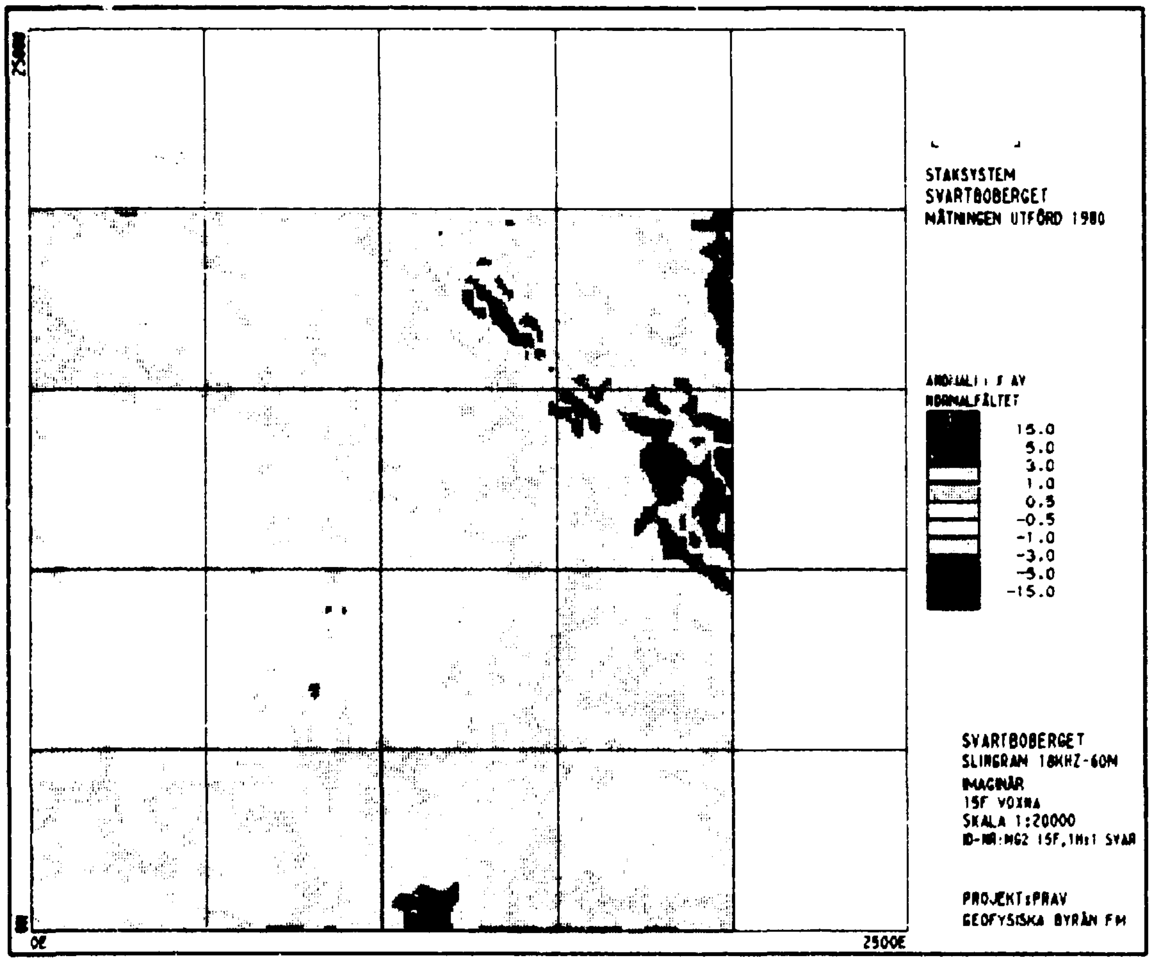


Figure 5.2. Slingram (horizontal loop EM) measurements at Svartboberget showing areas with increased electric conductivity.

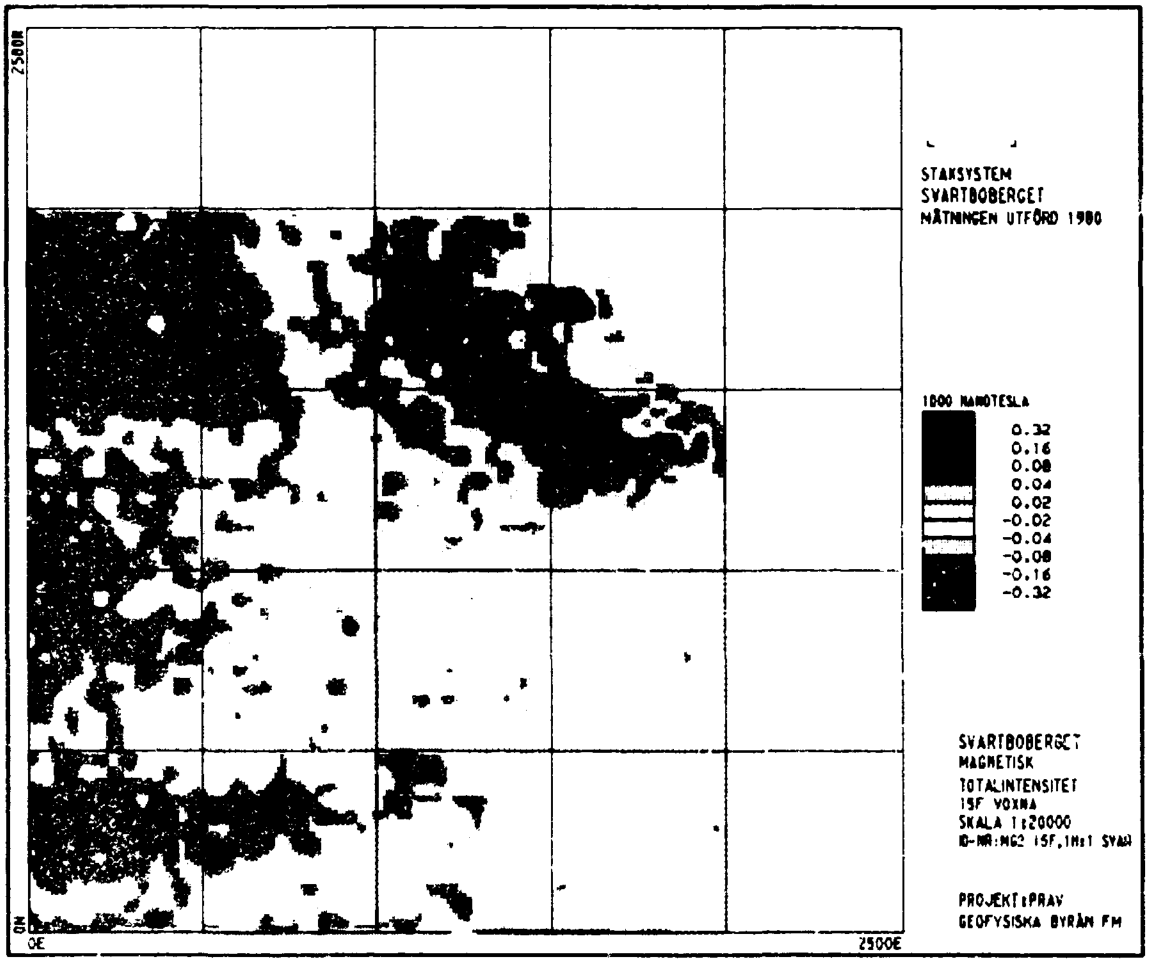


Figure 5.3. Magnetic field at Svartboberget.

The detailed surface geophysical measurements, e.g. slingram (horizontal EM-loop frame), indicate the occurrence of distinct fracture zones, fig 5.2. The surface magnetic mapping indicates changes in magnetic magnitude (the magnetic field) across certain zones, fig 5.3. In outcrop, these variations are reflected by a change in lithology; the low-magnetic side has a higher content of migmatite granite inclusion in the gneiss. In the northern part of the slingram map, there are two low-resistivity streaks striking west-northwest. These streaks also exhibit a high IP-effect and are interpreted to be graphitic layers rich in sulphides. These layers dip steeply to the north.

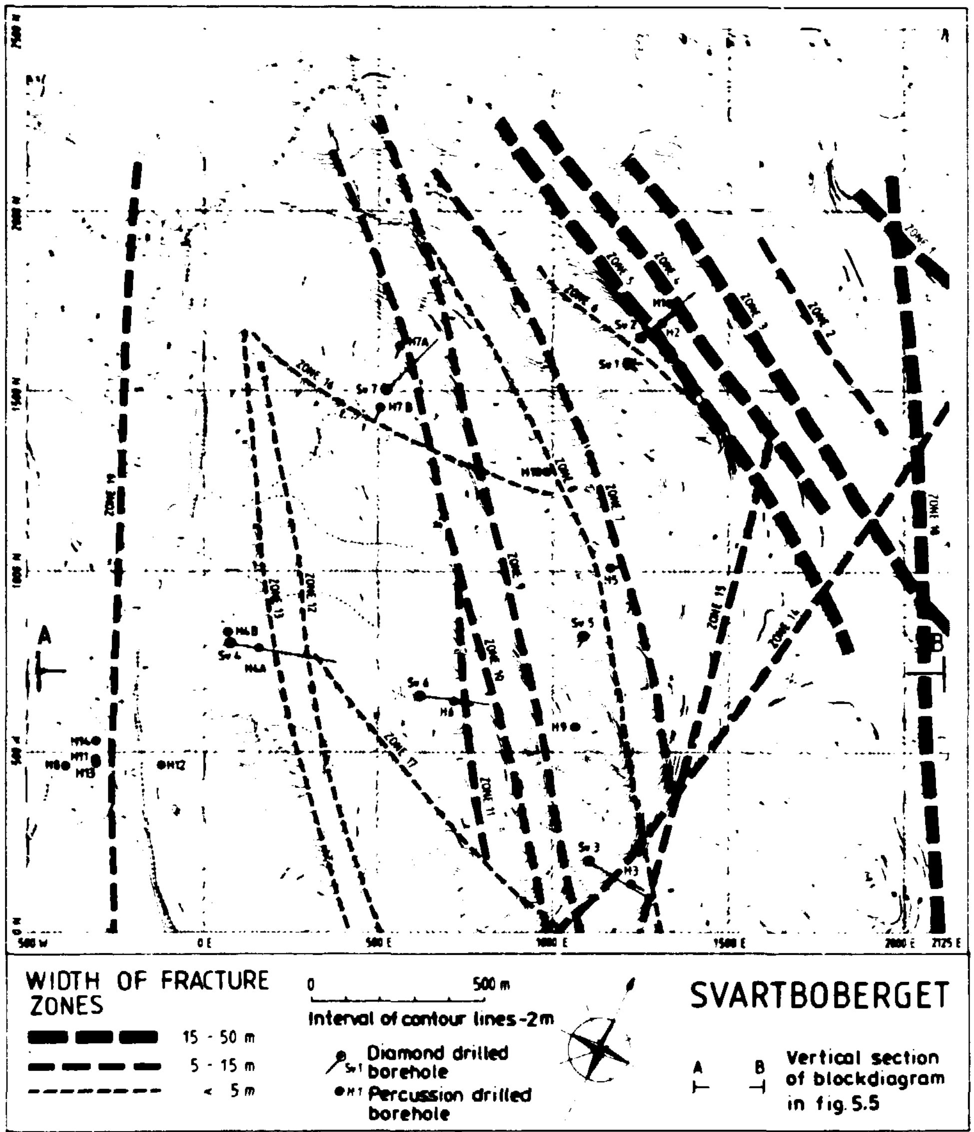


Figure 5.4 Fracture zones at the surface of site Svartboberget.

The fracture zones in the study site are of local character except the earlier described regional fracture zones. In all, 17 local and 2 regional fracture zones have been located within the study site. A compilation of the fracture zones is given in table 5.1. Differences in orientation between the local fracture zones imply that the zones intersect at depth, fig 5.5. Many of the local fracture zones have been penetrated by two or more drill holes, table 5.1. Within the fracture zones there are, as a rule, one or more sections of crushed rock, usually one or two decimetres thick. A summary of proportions of crushed rock, rock of high fracture frequency, and rock of low fracture frequency in the fracture zones is given in fig 6.5.

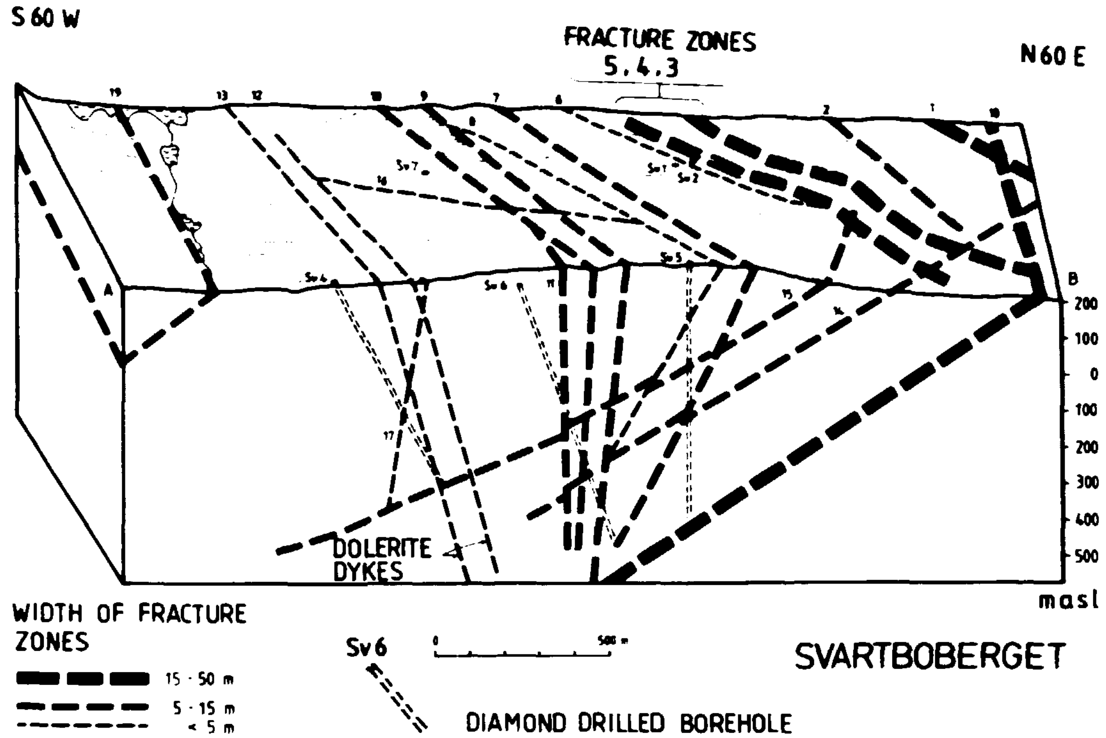


Figure 5.5. Block diagram, site Svartboberget.

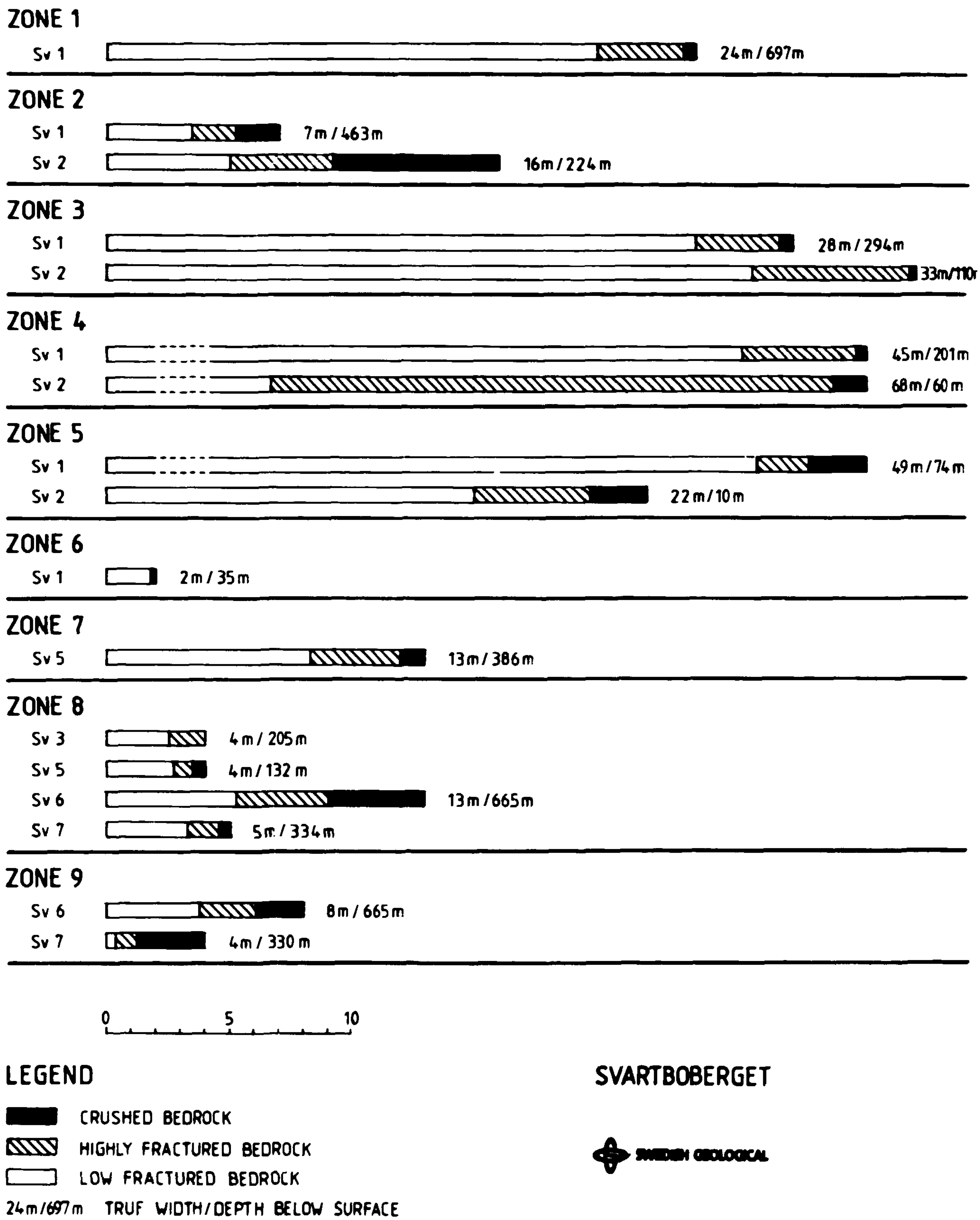


Figure 5.6. Percentage of crushed, highly fractured and low fractured bedrock in the fracture zones at Svartboberget. (2 figs.) Fracture zone width and the depth where it is located are given after each bar.

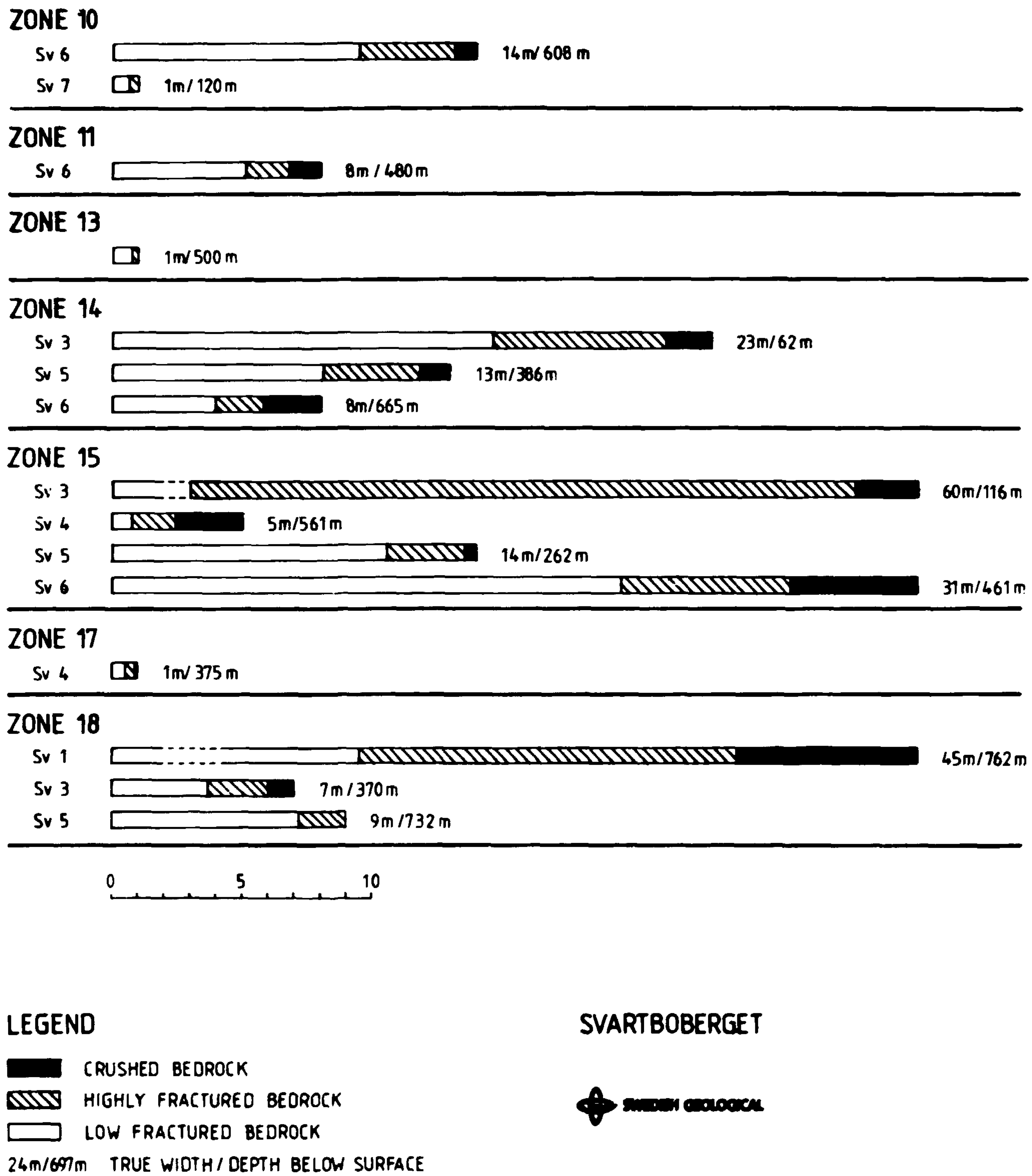


Figure 5.6 (continued). Percentage of crushed, highly fractured and low fractured bedrock in the fracture zones at Svartboberget. (2 figs.) Fracture zone width and the depth where it is located are given after each bar.

The positions of the fracture zones in different drill holes have been interpreted e.g. on the basis of geophysical drill hole measurements. Fig 5.7 displays results of geophysical measurements in drill hole Sv 4. For comparison, the fracture frequency of the drill core and the hydraulic conductivity, calculated on the basis of water injection tests in 25 m sections are shown.

Sections with reduced resistivity in the drill hole largely coincide with parts of increased fracture frequency. On the basis of tectonical studies and the geophysical measurements in the drill hole Sv4 indications (7), (8), and (9) in fig 5.7 have been interpreted as being local fracture zones.

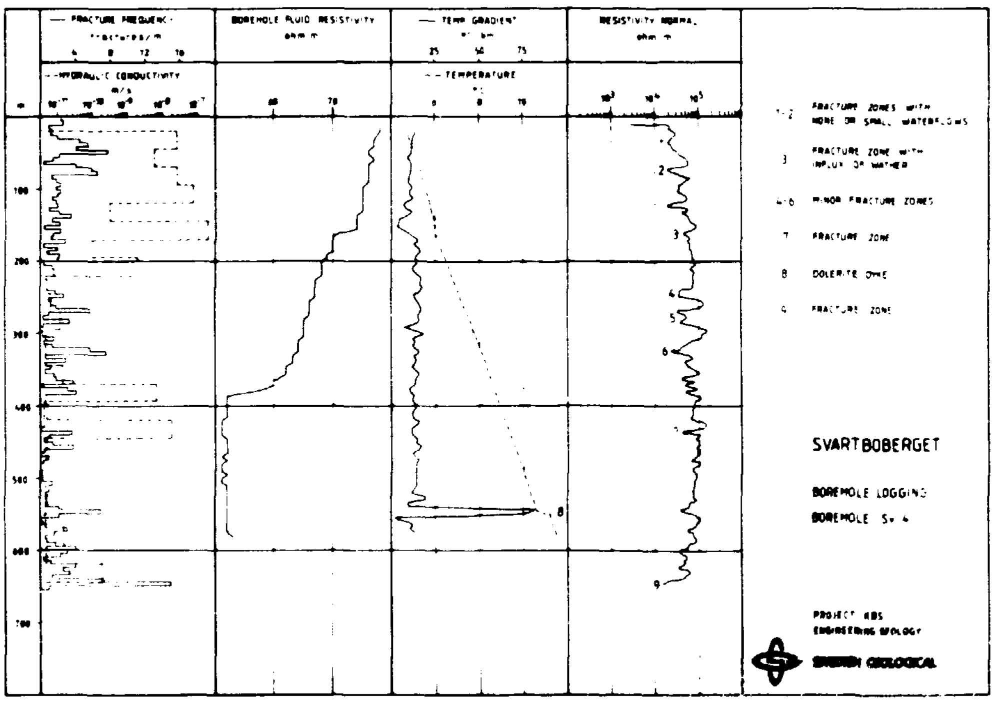


Figure 5.7. Result from logging of drill hole Sv 4, site Svartboberget.

The mutual distance between the local fracture zones are on surface generally 100-500 m. Marked local fracture zones are found in the northern part of the study site, zones 1-6. The width of these zones varies between 5-50 m and the mutual distance is 30-80 m. The remaining local fracture zones are from 2 and up to 15 m wide.

In the western part of the study site two dolerite dykes c. 1 m thick occur in fracture zones 12 and 13. The width of these fracture zones is less than 5 m.

Common fracture minerals in the regional and local fracture zones are calcite, chlorite, illite and zeolite minerals. The gently dipping fracture zones usually display signs of weathering. Indications of movements are common in the zones.

Table 5.1. Summary of fracture zones in site Svartboberget.

Fracture zone	Position in drill hole (m)	Dip (degrees)	True width (m)	K-value (m/s)
1	Sv 1 (682-713)	40 S	25	6 E-12
2	Sv 1 (458-467)	45 S	10	5 E-8
	Sv 2 (295-311)	45 S	15	not measured
3	Sv 1 (275-312)	45 S	25	5 E-8
	Sv 2 (144-177)	45 S	25	not measured
4	Sv 1 (169-223)	40 S	50	2 E-8
	Sv 2 (50-119)	40 S	50	not measured
5	Sv 1 (45-104)	30 S	40	4 E-7
	Sv 2 (0- 22)	30 S	20	not measured
6	Sv 1 (35- 37)	30 S	2	2 E-7
7	Sv 5 (371-401)	65 SW	10	5 E-10
8	Sv 3 (245-250)	60 SW	5	3 E-11
	Sv 5 (128-136)	60 SW	5	1 E-8
	Sv 6 (666-685)	60 SW	5	<8 E-11
	Sv 7 (383-390)	70 SW	5	4 E-9
9	Sv 6 (666-685)	80 SW	10	8 E-11
	Sv 7 (383-390)	85 SW	5	4 E-9

Fracture zone	Position in drill hole (m)	Dip (degrees)	True width (m)	K-value (m/s)
10	Sv 6 (591-633)	85 SW	10	2 E-10
	Sv 7 (140-142)	85 SW	5	<1 E-10
11	Sv 6 (475-506)	90	10	7 E-9
12		75 E*	5*	
13	Sv 4 (545-549)	75 E	4	<3 E-11
14	Sv 3 (58- 83)	40 W	25	2 E-7
	Sv 5 (371-401)	40 W	10	5 E-10
	Sv 6 (666-685)	40 W	10	<8 E-11
15	Sv 3 (100-170)	30 W	30	9 E-8
	Sv 4 (643-648)	30 W	5	2 E-9
	Sv 5 (254-270)	30 W	15	2 E-8
	Sv 6 (475-506)	40 W	10	7 E-9
16		75 N*	5*	
17	Sv 4 (435-437)	85 S	2	2 E-7
Regional zone 18	Sv 1 (736-788)	35 SW	>30	1 E-9
	Sv 3 (441-448)	35 SW	5	8 E-9
	Sv 5 (727-737)	35 SW	15	3 E-8
Regional zone 19		35*	>30*	

*Calculated from geophysical observations.

5.3 Fracture frequency of the rock mass

The fracture frequency of the rock mass has been measured on outcrops and on drill cores. The dominating strike of fractures in outcrop on Svartboberget is north to northeast, i.e. at high angle to the foliation in the migmatite. These fractures show no indications of movement and are probably tension fractures. The frequency of fractures longer than 0.5 m in outcrop is 1.0 fractures/m.

The fracture frequency in the rock mass, between the fracture zones, varies insignificantly with depth and is in average 2.6 fractures/m, fig 5.8. The rock mass in the western part of the area has a comparatively low fracture frequency, 1.6 fractures/m. In the eastern part, the fracture frequency of the rock mass is 2.7 fractures/m. The difference is due to the fracture zones outcropping in the eastern part and the fact that drill holes in the western part penetrate the fracture zones at major depths.

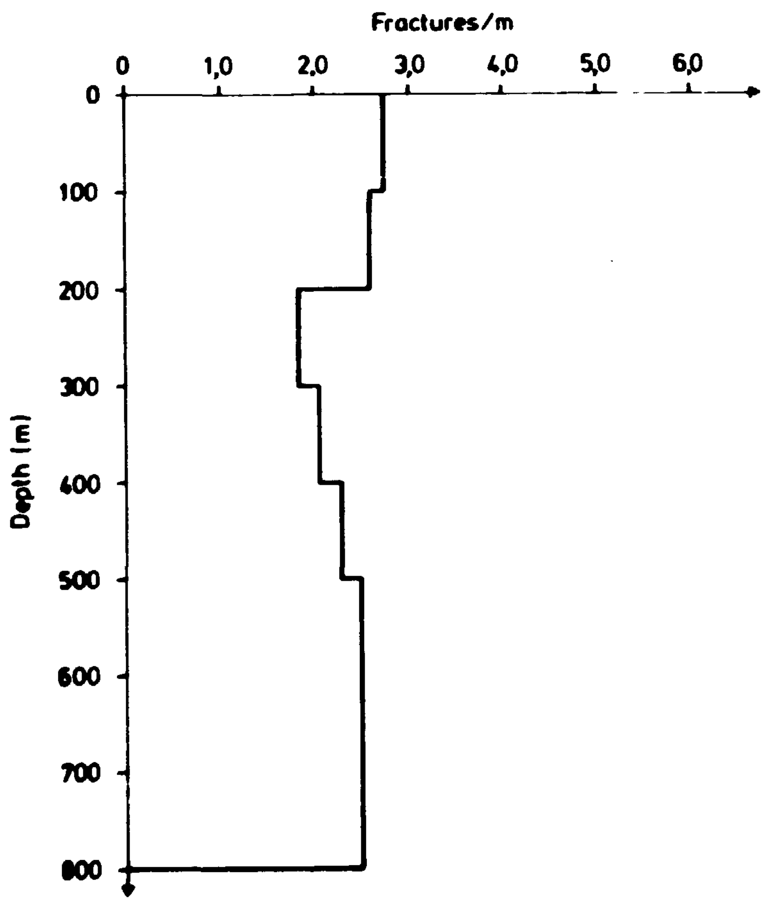


Figure 5.8 Fracture frequency in rock mass within site Svartboberget.

Common fracture minerals are chlorite, calcite and illite. Illite usually appears in the form of thick coatings up to 2 mm thick on slip surfaces. Otherwise, illite appears as a thin film on fracture surfaces. Chlorite is present especially on fracture surfaces parallel to the foliation.

6. HYDROLOGICAL AND METEOROLOGICAL CONDITIONS

6.1 General

Hydrological and meteorological data and conditions in the Svartboberget study site are based on information from the Swedish Meteorological and Hydrological Institute (SMHI). Data obtained have earlier been analyzed by Skifte (1981) and Gentzschein (1983).

The Svartboberget study site is situated in the Voxnan drainage area of 3708 km^2 whereof 6.1% constitutes lakes. The Voxnan river discharges its water into the Ljusnan river south of Bollnäs, some 40 km from the Voxna village. The Ljusnan flows into the Baltic at Ljusne, after an additional 40 km. The discharge area of river Ljusnan is at the outlet approx 20,000 km^2.

The topography of the Svartboberget site indicates the presence of a recharge area for groundwater. The limited lowland areas to the east and west constitute discharge areas for groundwater, also from the deeper parts of the bedrock.

The Svartboberget site and its immediate surroundings have been divided into three local discharge areas (fig 6.1) viz.:

I The stream Älmån upstream from the Loftsbäcken stream

II The Brynåsbäcken brook upstream from lake N Brynåssjön

III The Älmessjöbäcken brook upstream from the outlet in lake Älmessjön.

The size and topographical characteristics of the partial areas are displayed in table 6.1. The discharge areas have an aggregated area of 41.4 km^2, whereof 4.7% is lakes.

The major lakes in the area are located in the lowland areas surrounding the actual Svartboberget mountain. The size of the lakes is detailed in table 6.2.

Figure 6.1. Local drainage areas within site Svartboberget.

Table 6.1. Data on local discharge areas at the Svartboberget study site.

Site	Highest point (m.a.s.l.)	Lowest point (m.a.s.l.)	Mean altitude (m.a.s.l.)	Area (km^2)	% Lake
I	340	190-195	252	31.4	4.9
II	318	227	257	6.0	6.0
III	316	190	225	4.0	1.5

Table 6.2 Major lakes within and in the vicinity of the study site Svartboberget

Name	Area in km^2
Råttjärnasjön	1.1
Norra Brynåssjön	0.15
Södra Brynåssjön	0.25
Älmessjön	0.30

6.2 Precipitation and temperature

The precipitation in the region around the Svartboberget site has been estimated on the basis of data from the meteorological stations Lobonäs and Edsbyn. Lobonäs is located 19 km north-west of the study site at an altitude of 220 m above sea level. Edsbyn is situated 12 km east of Svartboberget at 161-189 m above sea level. The observations commenced in 1931 at Lobonäs and in 1941 at Edsbyn. Adjusted monthly mean values provided by both stations are listed in table 6.3.

Table 6.3. Calculated adjusted monthly and annual mean values of precipitation at stations Lobonäs and Edsbyn (mm)

Station	Period	J	F	M	A	M	J	J	A	S	O	N	D	Year
Lobonäs	1941-81	43	31	29	39	50	72	97	85	65	53	62	48	674
Edsbyn	1941-81	46	32	31	37	50	64	89	87	65	63	60	50	664

In order to calculate the precipitation in the three partial areas I, II and III, the following factors have to be taken into account. The orographical amplification of the precipitation and the dependence of precipitation on frequent wind directions. According to the SMHI, the major part of the precipitation falls in the eastern and southern parts of the Svartboberget site. The precipitation in the partial areas is estimated at:

Area I: 730 ± 50 mm
Area II: 685 ± 50 mm
Area III: 682 ± 50 mm

On the basis of results given above, the precipitation in the Svartboberget study site is estimated at 715 ± 50 mm. Of the annual mean precipitation at Edsbyn, 24% falls in the form of snow. On the top of Svartboberget which is more highly elevated, the proportion of snow is probably greater. The duration of the snow cover during a 30-year period varies between 101 and 184 days, the mean value being 152 days.

The temperature conditions at Svartboberget are probably best represented by the monthly mean temperature at Edsbyn which is given in table 6.4.

Table 6.4. Monthly mean temperature in °C during the period 1941-81 at the Edsbyn meteorological station

Jan.	-7.8	May	8.5	Sep.	9.3		
Feb.	-7.2	June	12.9	Oct.	4.2		
March	-2.6	July	15.3	Nov.	-1.6		
April	2.7	Aug.	13.8	Dec.	-5.2	Year	3.5

6.3 Evaporation

The mean value at Edsbyn of annual potential evaporation during the period 1961-1978 has been estimated at 528 mm. The variation range is 485-581 mm and the standard deviation 29 mm.

The annual evaporation in the area has been estimated by SMHI at 375 mm. The atmospheric radiation and wind exposure reach their highest values on the southern and western slopes of the Svartboberget site and consequently the evaporation should be higher there. The evaporation in the partial areas has been estimated at:

Area I: 375 ± 50 mm
Area II: 400 - 410 ± 50 mm
Area III: 400 - 410 ± 50 mm

The mean annual evaporation in the Svartboberget study site has been estimated at c. 390 mm.

6.4 Run-off

As is evident from fig 6.1, the western part of Svartboberget study site is drained (35% of the area) by the Brynåsbäcken brook which flows towards the northwest into the Voxnan river, c. 7 km upstream from the village of Voxna. The eastern part of the study site (65% of the area) is drained to the south by the Älmån stream which flows into the Voxnan c. 15 km downstream from the village of Voxna. There are two stations for run-off measurements along the Voxnan river, viz. (48-740) Nybro at Voxna and (48-1890) at the Alfta hydroelectric power plant. Table 6.5 specifies estimated or measured annual values of run-off in the Voxnan river.

Table 6.5. Water discharge in the river Voxnan

Run-off area	Period year	Discharge area km^2	Specific run-off $l/s\ km^2$ (mm)	Discharge rate m^3/s	Note
Upstream from Nybro	1914-25 1940-64	2 252	10.0 (315)	22.5	from measurement series
Upstream from Nybro	1951-64	2 252	10.1 (319)	22.7	from measurement series
Upstream from Alfta hydroelectric plant	1951-75	3 140	10.2 (322)	32.0	from measurement series
Upstream from Alfta hydroelectric plant	1951-64	3 140	9.9 (312)	31.1	from measurement series
Between Alfta & Nybro	1951-64	888	9.4 (296)	8.3	estimated
Upstream inlet of Älmån plus Älmån basin	1914-25 1940-64	2 410	10.0 (315)	24.2	estimated

The specific run-off for the three partial run-off areas, respectively, has been estimated as the difference between the precipitation and the estimated evaporation. The estimated annual run-off values for the individual partial areas are:

Area I:	Älmån (stream)	11.3 l/s km^2	(355 mm)
Area II:	Brynåsbäcken (brook)	8.7 l/s km^2	(274 mm)
Area III:	Älmessjöbäcken (brook)	8.6 l/s km^2	(271 mm)

For the study site Svartboberget the specific run-off has been estimated at 10.4 l/s km^2.

6.5 Water balance

The water balance at the study area is determined by the following factors: precipitation, evaporation, run-off storage and groundwater flow through the boundaries of the area. Table 6.6 constitutes a summary of the water balance in the study area, based on long-term registrations. Input data have throughout been obtained outside the Svartboberget site. The maximum potential groundwater recharge within the area is, during an extended measurement period, constituted of the run-off, since no changes in existing groundwater storages are assumed. The actual groundwater recharge is less.

Table 6.6. Estimated water balance for the Svartboberget study site

	mm/year
Precipitation	715 ± 50
Evaporation, potential	528
Evaporation, actual	390 ± 50
Run-off	285 - 320

7. HYDRAULIC PROPERTIES OF THE BEDROCK

7.1 Hydraulic tests

The hydraulic conductivity (K) of the bedrock has been determined by means of water injection tests in core drill holes Sv 1 and Sv 3–Sv 7. The tests have been performed in delimited 25 m sections in the drill holes, beginning 15-25 m beneath the ground surface down to c. 10 m from the bottom of the drill hole. In all, 147 sections of 25 m have been tested. The tests were carried out under constant pressure (Almén et al. 1982), while the variation of the water flow with time was registered. This procedure permits evaluation according to the theories of transient tests. The hydraulic conductivity determined in this way constitutes a mean value for the individual 25 m sections. Individual fractures within the respective test sections may have a higher K-value. The hydraulic conductivity is specified, together with the fracture frequency of the individual drill holes, in figures 7.1-7.3.

In the majority of the drill holes the injection tests have been supplemented with detailed measurements where the section lengths have been 5 or 10 m. The number of detailed measurements comprise 87 sections. These measurements were performed in sections of high hydraulic conductivity for the purpose of delimiting the conductive parts of the individual 25 m sections. The detailed measurements also constitute a means to check the results obtained from 25 m sections. By comparing the transmissivity T (the hydraulic conductivity multiplied by the section length) obtained from the measurements of different section lengths, the reliability of the results can be assessed. For the different sections, the relationship between the transmissivity of the 25 m and the 5-10 m lengths, respectively, have been specified in a way to make the result always be greater than 1. The correspondence is satisfactory for the majority of the sections. The T-quotient is less than 3 for most of the sections subjected to detailed measurements. In 15 of the 25 m sections, however, the transmissivity of the entire section has been found to be many times higher than the total of the partial sections. In these cases, the most permeable part must be located outside the boundaries of the partial sections. All control measured sections are detailed in table 7.1.

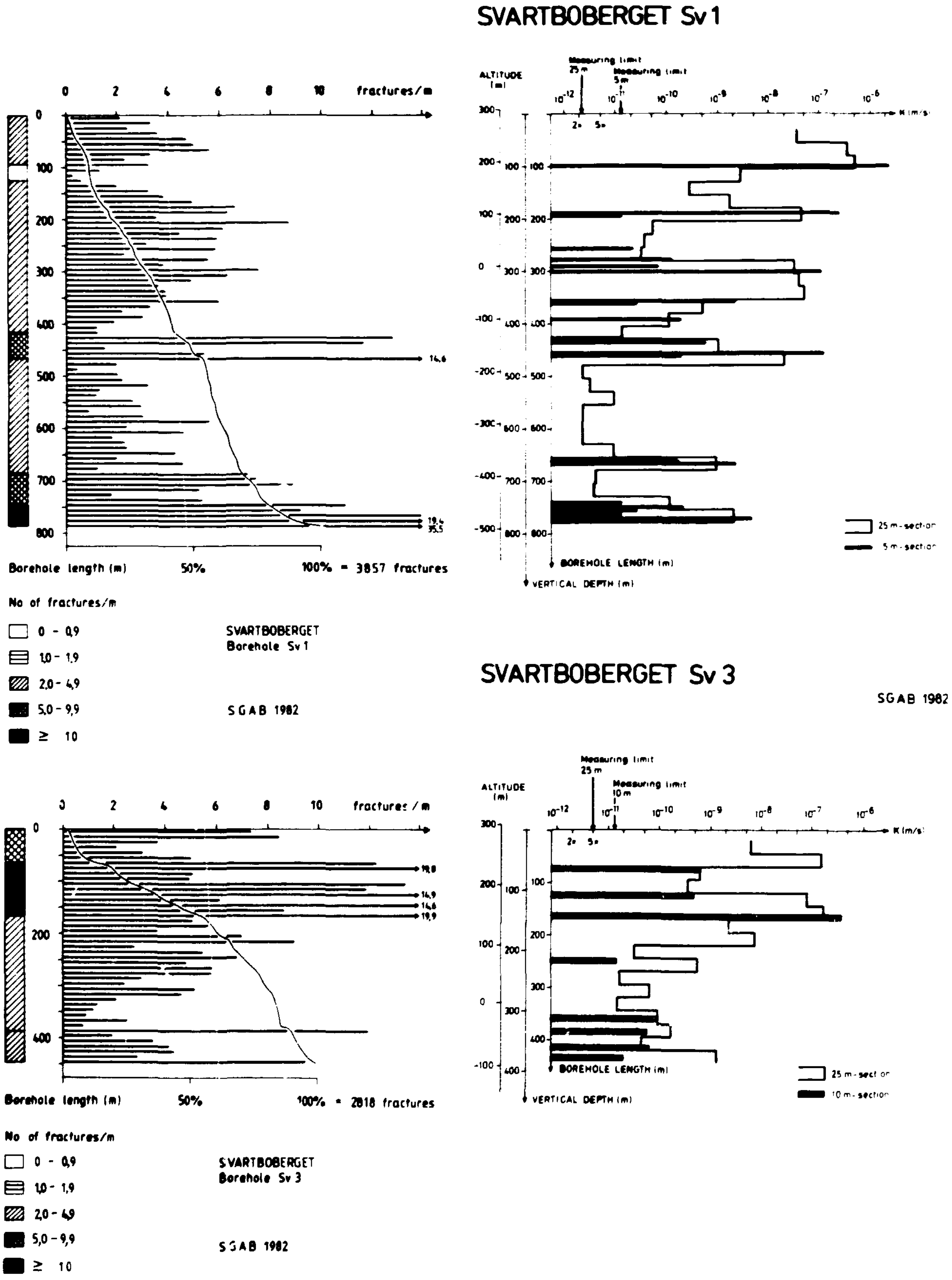


Figure 7.1. Fracture frequency for 10 m-sections, cumulative number of fractures and hydraulic conductivity, drill holes Sv 1 and Sv 3.

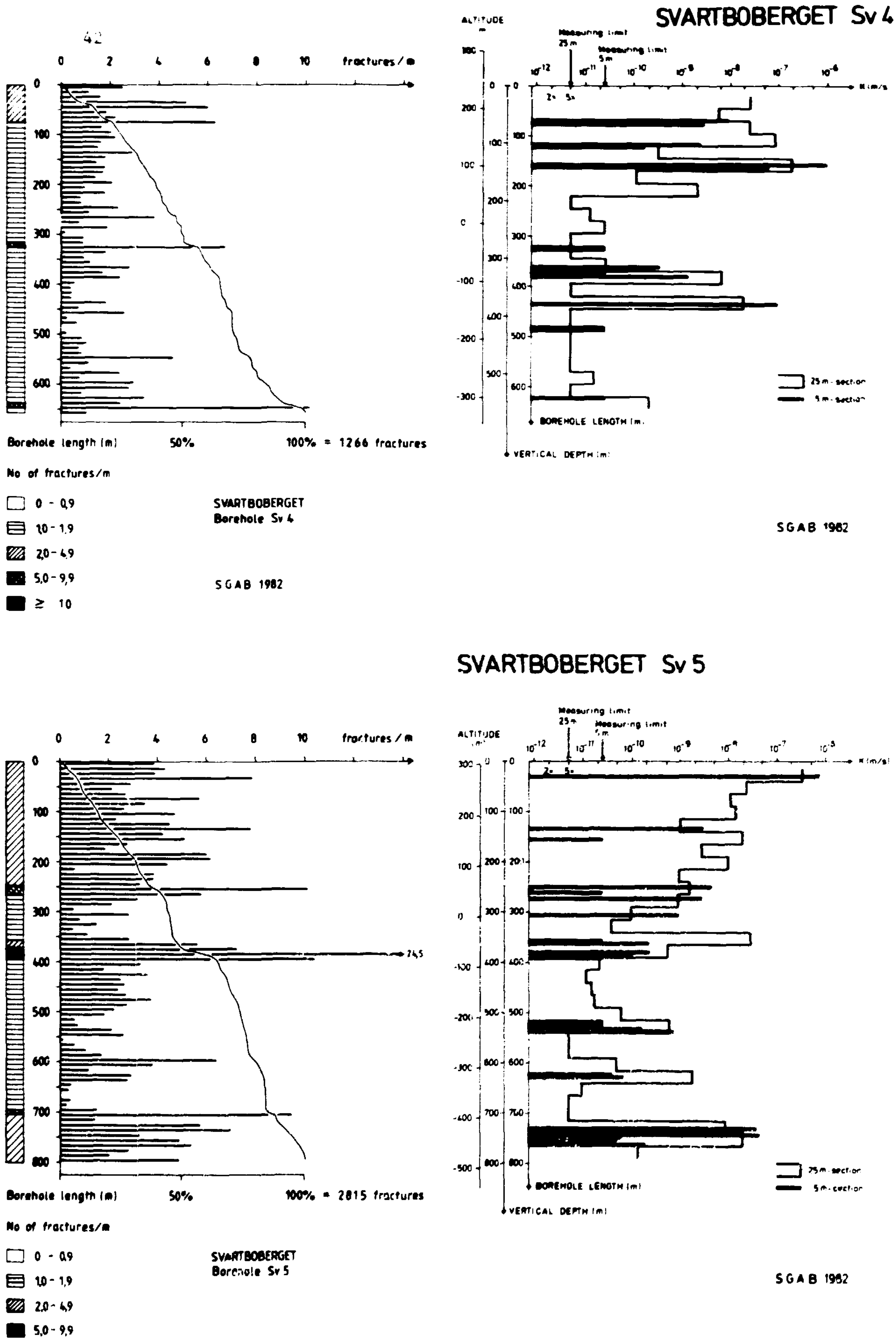
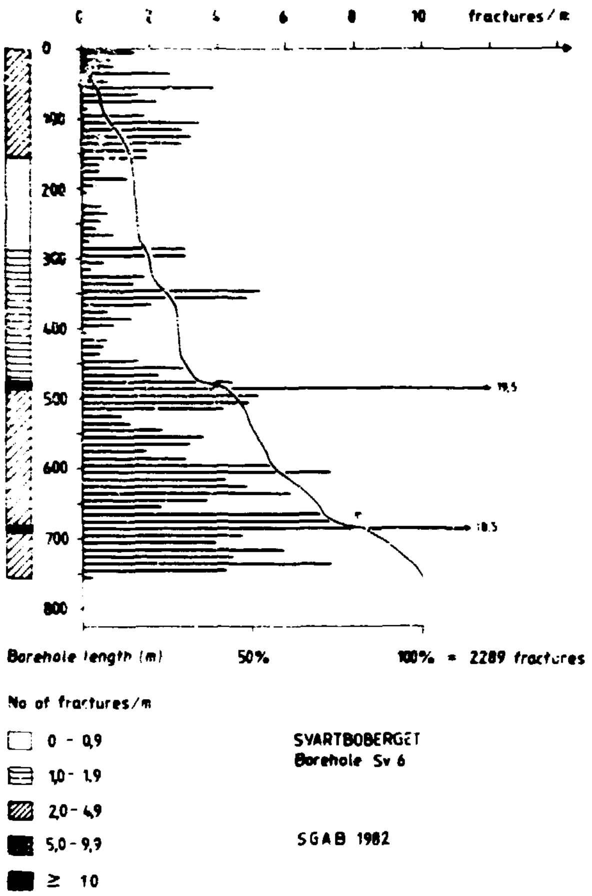
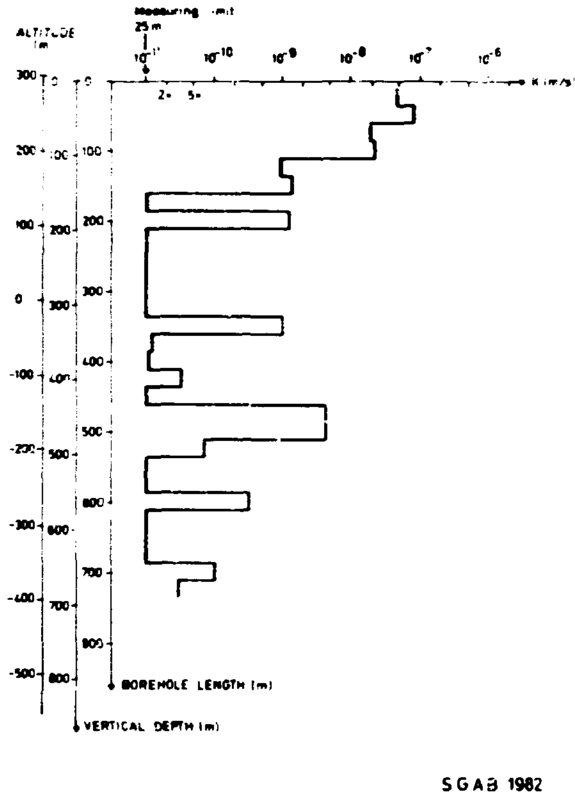


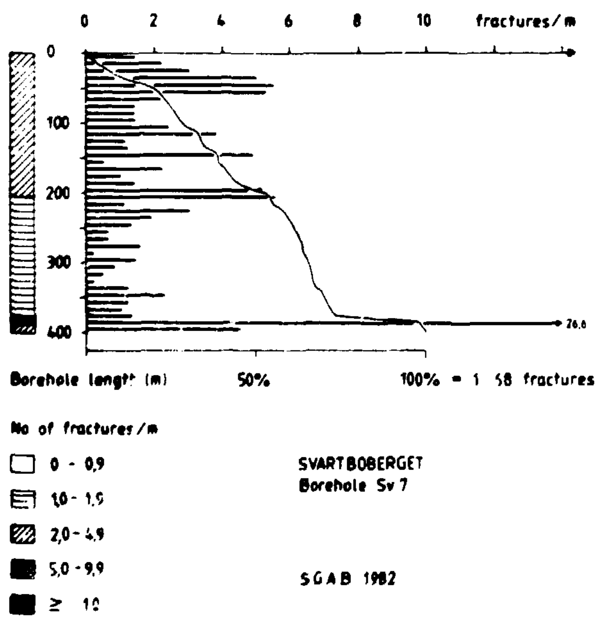
Figure 7.2. Fracture frequency for 10 m-sections, cumulative number of fractures and hydraulic conductivity, drill holes Sv 4 and Sv 5.

SVARTBOBERGET Sv 6





SVARTBOBERGET Sv 7



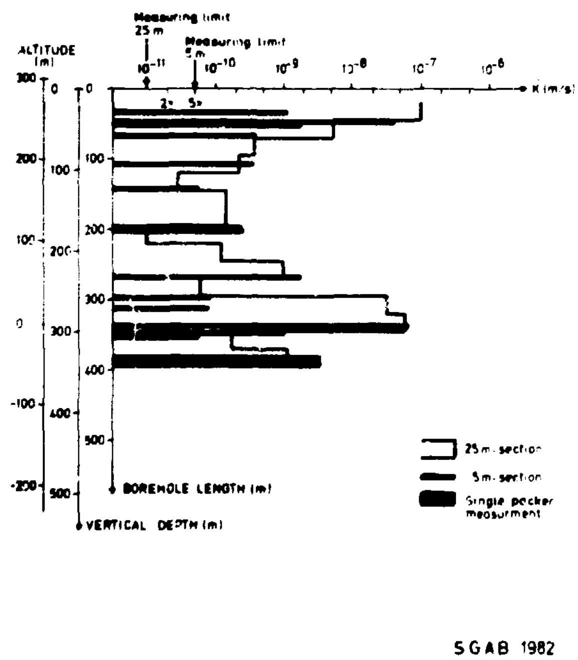


Figure 7.3. Fracture frequency for 10 m-sections, cumulative number of fractures and hydraulic conductivity, drill holes Sv 6 and Sv 7.

Table 7.1. Comparison of transmissivity between 25 m and 5/10 sections in core drill holes at Svartboberget study site. The T-quotient is defined ≥ 1.

Drill hole	25 m section (m)	Length of detailed measure-ments (m)	T-quotient	Drill hole	25 m section (m)	Length of detailed measure-ments (m)	T-quotient
Sv 1	80-105	5	1.1	Sv 4	370-395	8	4.8
	180-205	10	1.2		420-445	5	1.1
	255-280	10	1.1	Sv 5	15- 40	5	2.2
	280-305	10	1.5		115-140	5	1.8
	355-380	10	1.3		140-165	5	>1.9E+5
	380-405	5	2.9		240-265	10	1.6
	430-455	5	10.0		265-290	5	1.7
	455-480	10	1.3		290-315	5	1.9
	655-680	15	1.7		340-365	10	672.0
	730-755	10	2.3		365-390	10	7.6
	755-780	25	1.9		515-540	25	3.3
Sv 3	70- 95	10	2.5		615-640	10	83.0
	120-145	10	425.0		715-740	10	1.3
	145-170	10	1.2		740-765	25	2.2
	245-270	10	93.0	Sv 7	20- 45	5	357.0
	345-370	10	2.5		45- 70	15	1.6
	370-395	10	7.4		95-120	5	1.7
	395-420	10	1.8		120-145	10	2.8
	420-445	10	165.0		195-220	10	10.0
Sv 4	45- 95	10	13.7		245-270	5	2.6
	95-120	5	175.0		295-320	10	920.0
	120-145	5	9.1		320-345	5	4.4
	145-170	10	1.1		345-370	10	1.2
	345-370	7	2.5				

In the valley to the west of the Svartboberget site a test-pumping has been carried out for the purpose of determining the hydraulic conductivity in the regional fracture zone with surrounding rock mass, which presence has been indicated by the geological and geophysical investigations. The test pumping was carried out in percussion drill hole HSv 11 for a duration of 14 days at 6000 l/h (100 l/min) capacity. In addition to measurements in the pump hole, variations of the ground-water head was registered in observation holes HSv 8, 12, 13 and 14, fig 5.4. After completed pumping, the recovery was measured for a duration of 8 days. The evaluation was made according to transient analysis methods.

The regional fracture zone (number 19 in fig 5.4) dips 30-40 degrees to the west, according to surface geophysical investigations. Drill holes HSv 11, HSv 13 and HSv 14 have been positioned in a way to intersect the fracture zone at c. 50 m depth. The two latter drill holes have been sectioned off into three sections by means of packers in a way that the midsection includes the fracture zone. Drill holes HSv 8 and HSv 12 were positioned ot the west and east, respectively, of the assumed outgoing on the ground surface of the fracture zone. These drill holes were not sectioned off during the measurement period.

7.2 Results

7.2.1. Hydraulic units

The bedrock in the Svartboberget site has been divided into different units with respect to their hydraulic properties. This division is basic to the construction of a descriptive hydraulic model of the area. The following three hydraulic units have been identified:

- Regional fracture zones
- Local fracture zones
- Rock mass

The classification was based on results from the geological and tectonic investigations which indicate the location and extension of existing regional and local fracture zones. In section 5 the fracture zones within and in the vicinity of the Svartboberget site are described. These zones are indicated on the map in fig 5.4. Fracture zones 1-17 have been characterized as local fracture zones, and fracture zones 18 and 19 as regional fracture zones.

The appearance of the fracture zones has been determined by drill core mapping. The hydraulically tested 25 m sections not including fracture zones, represent the hydraulic conductivity of the rock mass. K-values from all core drill holes relating to the rock mass are specified in fig 7.4.

The rock mass is divided into three parts with respect to hydraulic conductivity (K). Above 100 m vertical depth high measurement values have been obtained, usually higher than 5×10^{-9} m/s. In the 100-200 m interval the K-values vary substantially, viz. between 1.0×10^{-11} m/s and 1.9×10^{-7} m/s. Below 200 m, the hydraulic conductivity is low, usually lower than 1×10^{-10} m/s. However, eight K-values higher than 1×10^{-9} have been registered. Two of these derive from a rock segment in core drill hole Sv 7 (295 m-345 m) where the fracture frequency is very low, but a number of greenstone bands interchanged with migmatite occur. Of the remaining five high K-values, three have been obtained in low to normally fractured migmatite, whereas the remaining two were obtained in a 25 m section where a few greenstone inclusions are observed in migmatite.

The high K-values in the uppermost part are caused by the bedrock being more fractured here than at greater depths. The number of open fractures is probably higher in the upper part of the bedrock due to the relatively small vertical rock stresses.

Below 200 m, the rock load generates greater vertical stresses and the proportion of open fractures as well as the fracture frequency is less. The low hydraulic conductivity may also depend on the continuity of the fractures being less at greater depths. The 100-200 m sector constitutes a transient zone between the other two.

Occurring rock types have a similar hydraulic conductivity. As earlier mentioned, greenstone bands have been found in highly permeable test sections. However these bands are also found in rock mass sections of normal conductivity and in impermeable rock mass. Additionally, there is no difference in hydraulic conductivity between migmatite granite and migmatite gneiss.

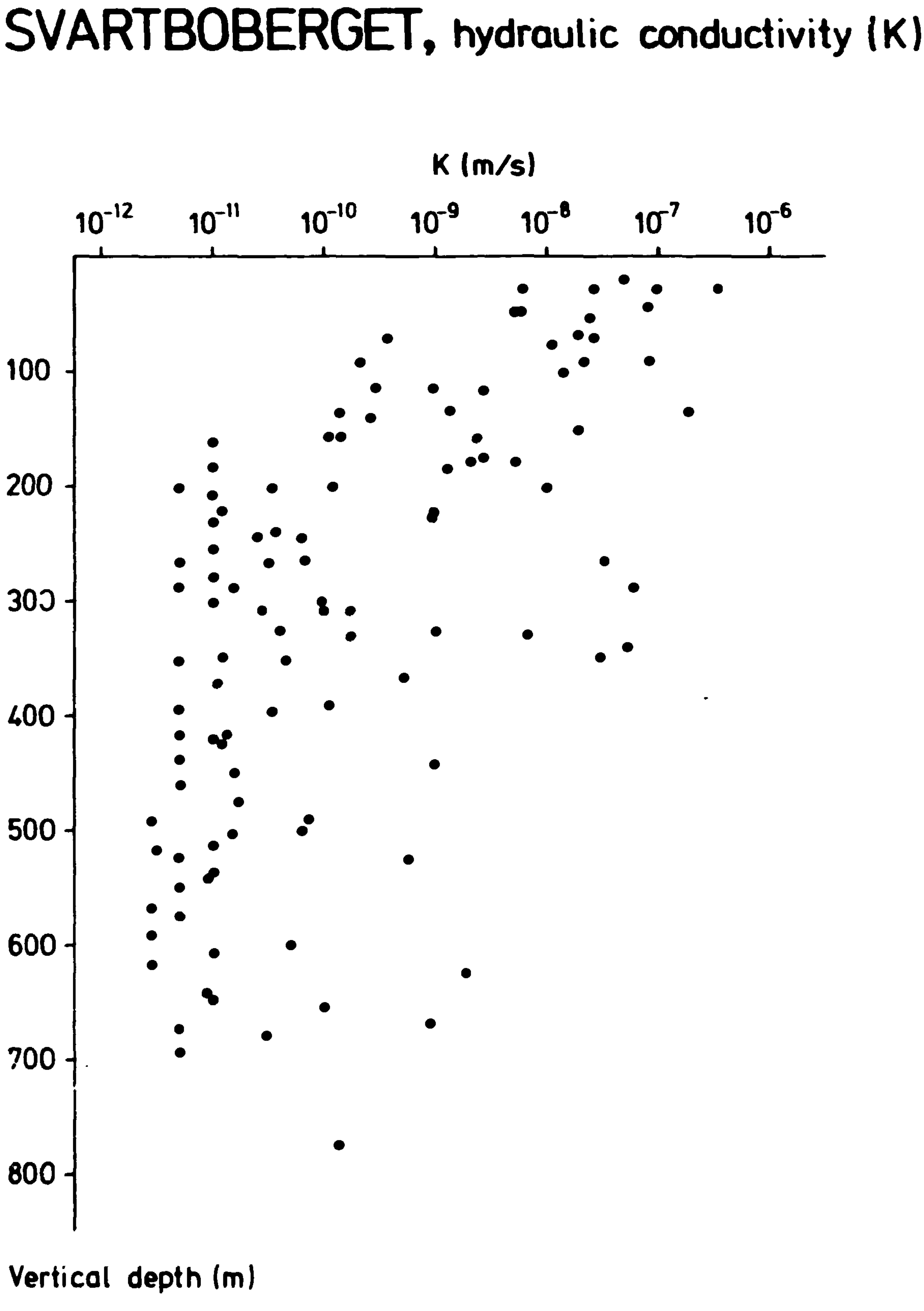


Figure 7.4 Hydraulic conductivity for the rock mass in the drill holes Sv 1, Sv 3-Sv 7 (25 m sections).

Hydraulic conductivity values calculated from 25 m, 10 m and 5 m sections have been compared with the results of the core logging. Each fracture zone has been attributed a K-value in each drill hole where it is intersected, based on the different values obtained. In fig 7.5 and table 7.2 the K-values of the local fracture zones are indicated. Zones appearing in more drill holes than one have been connected. The diagram shows that the hydraulic conductivity decreases with depth. On the other hand, no correlation between width or orientation and the hydraulic conductivity of the fracture zones has been noted. As for Zone 8, the conductivity increases substantially between 214.3 and 334.7 m in Sv 7. This may be caused by an intersection between Zones 8 and 9 in this interval.

Test-pumping results support the interpretation of a fracture zone dipping towards the west (Zone 19, fig 5.4) indicated by the geophysical investigations. The central part of the fracture zone is represented by the middle sections of percussion drill holes HSv 13 and HSv 14, fig 5.4. In these sections a hydraulic conductivity of 1.8 - 2.9 x 10^{-6} m/s was obtained, table 7.3. Also in the other sections and in drill hole HSv 8 high K-values were obtained (5.8 x 10^{-7} - 1.0 x 10^{-6} m/s), indicating that the entire area to the west of the fracture zone is of high fracture frequency and highly permeable to water. In drill hole HSv 12 no significant influence by the test-pumping in HSv 12 was found. This drill hole is situated outside to the east of the examined fracture zone.

Only three values of hydraulic conductivity in the regional fracture zones have been obtained during water injection tests in the core drill holes. The K-values have been extracted in a way analoguous with the method applied to local fracture zones. A compilation of data is presented in table 7.3.

Table 7.2. The hydraulic conductivity (K) of the local fracture zones in the Svartboberget study area.

Zone	Zone width (m)	Found in drill hole	Length in drill core (m)	Length of crushed rock (m)	K (m/s)
1	25	Sv 1	682 - 713	0.62	6.4 E-12
2	10	Sv 1	458 - 467	4.04	5.3 E-8
3	25	Sv 1	275 - 312	0.25	4.9 E-8
4	50	Sv 1	169 - 233	1.35	1.9 E-8
5	40	Sv 1	45 - 109	3.04	4.4 E-7
6	<5	Sv 1	35 - 37	0.13	1.7 E-7
7	ca 10	Sv 5	371 - 401	2.50	4.5 E-10
8	5	Sv 5	128 - 136	0.91	1.2 E-8
8	5	Sv 3	245 - 250	0.08	3.0 E-11
8(9)	5 (<10)	Sv 7	383 - 390	4.90	4.4 E-9
8	<10	Sv 6	666 - 685	4.61	7.9 E-11
9(8)	<10 (5)	Sv 7	383 - 390	4.90	4.4 E-9
9	<10	Sv 6	666 - 685	4.61	7.9 E-11
10	5-10	Sv 7	140 - 142	0.00	<1.3 E-10
10	-	Sv 6	591 - 600	2.23	2.0 E-10
11	<10	Sv 6	475 - 506	5.00	7.0 E-9
13	5	Sv 4	545 - 549	0.10	<3.1 E-11
14	ca 10	Sv 3	58 - 83	1.69	1.5 E-7
14	-	Sv 5	371 - 401	2.50	4.5 E-10
14	<10	Sv 6	666 - 685	4.61	7.9 E-11
15	5-15	Sv 3	100 - 170	2.70	9.4 E-8
15	-	Sv 5	254 - 270	0.36	1.6 E-8
15	-	Sv 6	475 - 506	5.00	7.0 E-9
15	-	Sv 4	643 - 648	2.70	1.7 E-9
17	<5	Sv 4	435 - 437	0.30	2.1 E-7

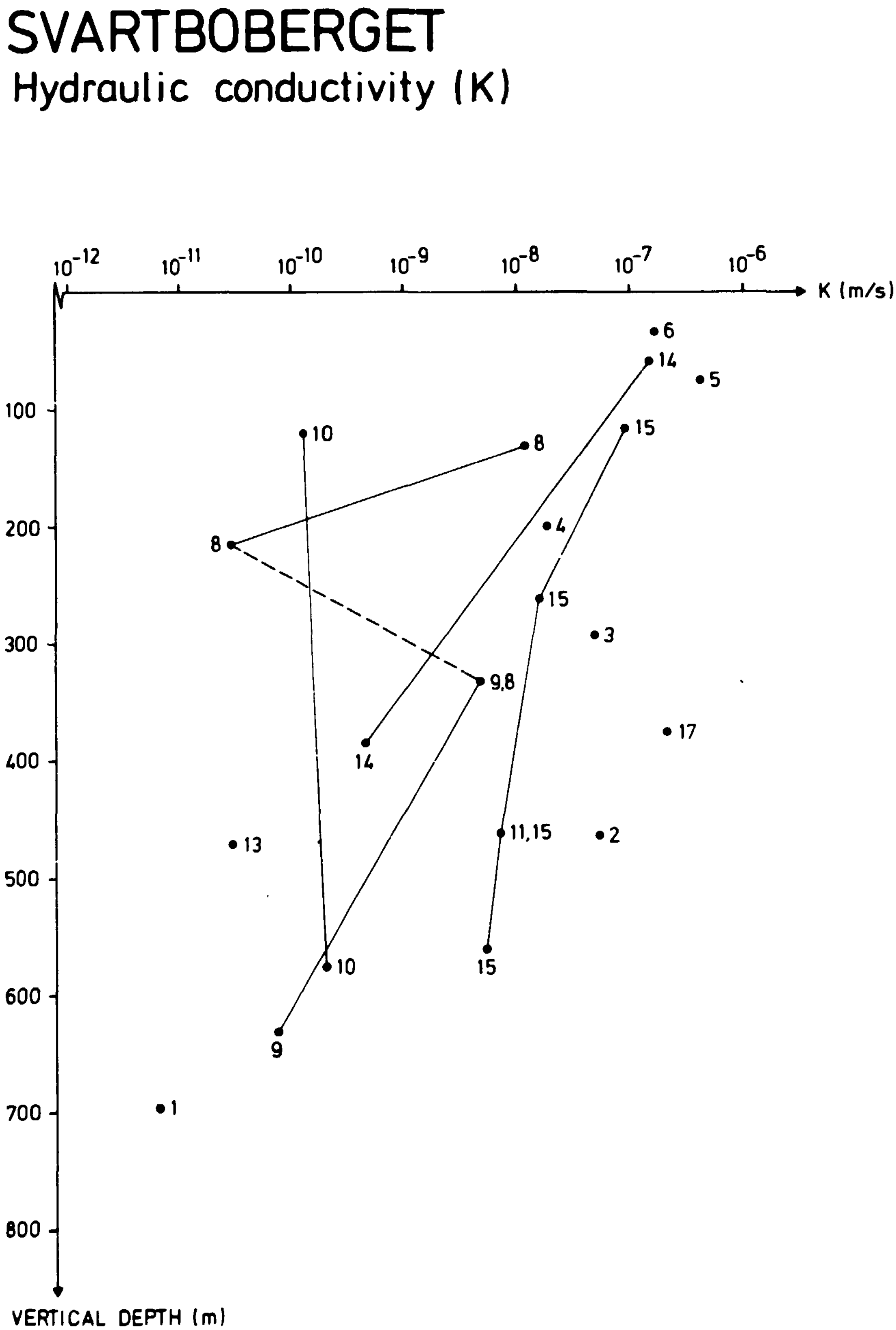


Figure 7.5. Hydraulic conductivity in local fracture zones penetrated by the drill holes Sv 1, Sv 3-Sv 7.

Table 7.3. Hydraulic conductivity of regional fracture zones in the Svartboberget study area

Zone	Zone width (m)	Found in drill hole	Length in drill core (m)	Length of crushed rock (m)	K (m/s)
19	10	HSv 11	-	-	2.0 E-6
19	10	HSv 13	-	-	1.8 E-6
19	10	HSv 14	-	-	2.9 E-6
18	5	Sv 3	441 - 448	1.15	8.1 E-9
18	15-30	Sv 1	762 - 788	9.90	1.1 E-9
18	15	Sv 5	727 - 737	0.04	3.0 E-8

7.2.2 Depth-dependence of the hydraulic conductivity

The depth-dependence of the hydraulic conductivity in the rock mass and in the local fracture zones has been calculated by means of regression analysis as follows:

1. Linear function regression: $K(z) = a + b z$
2. Power curve regression: $K(z) = a z^b$
3. Logarithmic regression: $K(z) = a + b \ln z$
4. Exponential regression: $K(z) = a e^{bz}$

a, b = constants, z = depth

The power curve function fit has throughout given the best correlation. The results of the calculations are shown in figs 7.6-7.8. A 95% confidence interval has also been indicated for the relation curves in the figures, which means that there is a 95% probability that the curves are within the confidence interval. The relationships for the power curves are displayed in table 7.4 and fig 7.9.

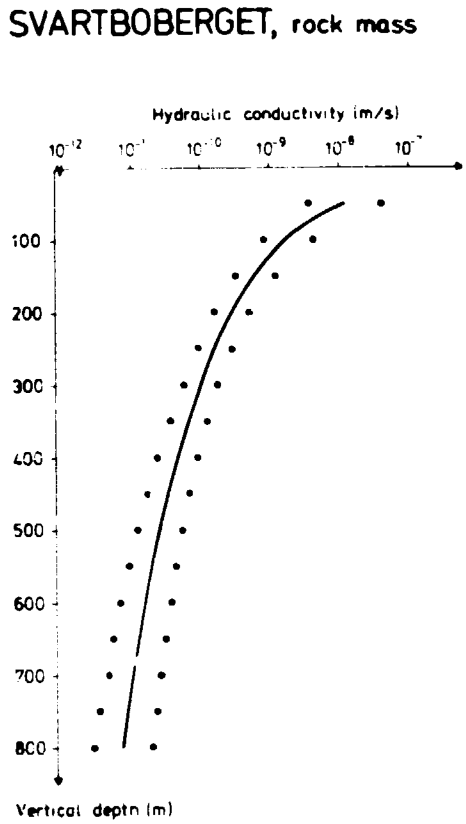


Figure 7.6. Relationship between hydraulic conductivity and depth in the rock mass.

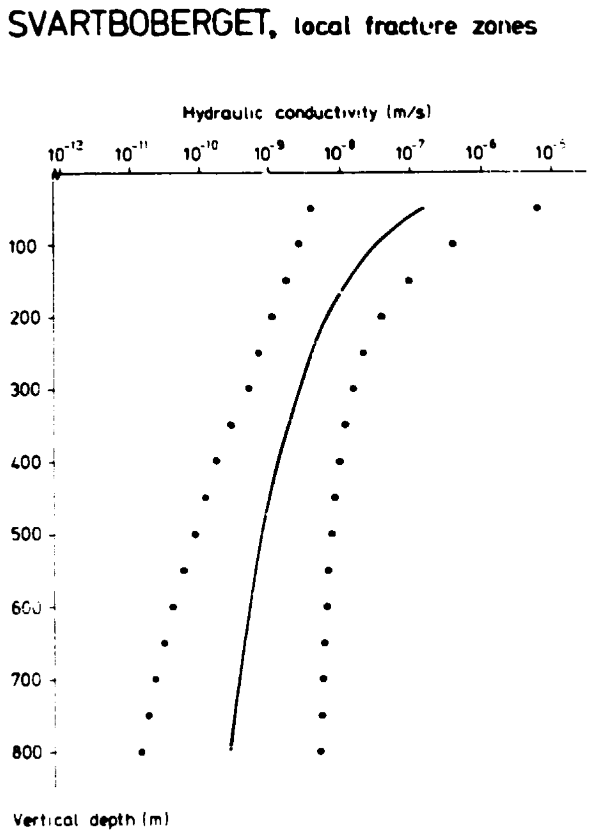


Figure 7.7. Relationship between hydraulic conductivity and depth in local fracture zones.

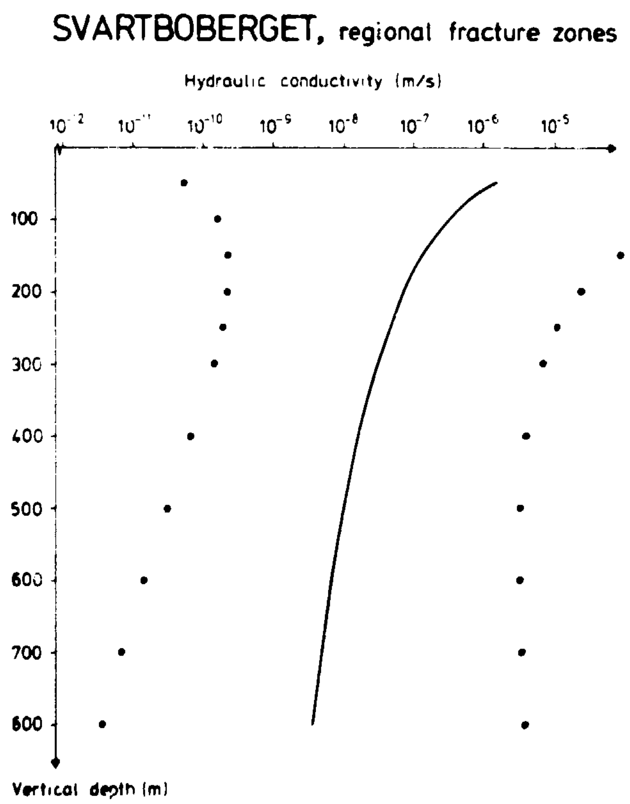


Figure 7.8. Relationship between hydraulic conductivity and depth in regional fracture zones.

Table 7.4. Depth-dependence of the hydraulic conductivity in different units of the bedrock. r = coefficient of determination, n = number of K-values.

Hydraulic unit	Relationship	r^2	n
Rock mass	$K = 4.79 \times 10^{-4} \times z^{-2.70}$	0.48	109
Local fracture zones	$K = 1.30 \times 10^{-3} \times z^{-2.31}$	0.31	19
Regional fracture zones	$K = 7.08 \times 10^{-3} \times z^{-2.17}$	0.80	4
z = depth (m)			

The regression analysis shows that the hydraulic conductivity of the local fracture zones at 100 m and 800 m vertical depth are c. 17 and 38 times, respectively, larger than the conductivity of the rock mass. The hydraulic conductivity of the regional fracture zones are c. 10 and 14 times, respectively, larger than the conductivity of the local fracture zones at mentioned depths.

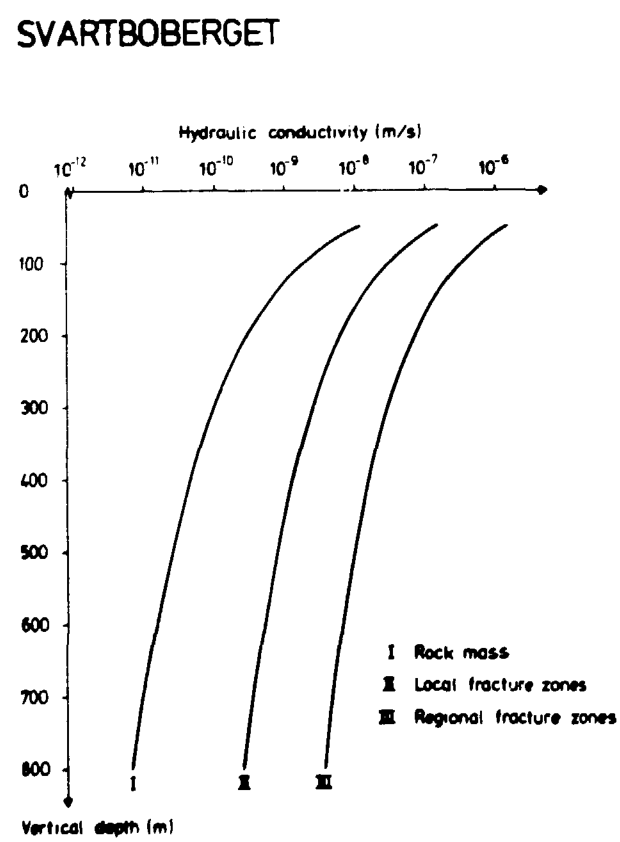


Figure 7.9. Relationship between hydraulic conductivity and depth in different hydraulic units of the bedrock.

8. GROUND WATER CONDITIONS

8.1 General

The ground water flow within an area is characterized by the area's topographical, geological and climatological conditions. The geological conditions decide i.a. the size and variation of the water-conducting and water-storaging properties. Geology and topography determine the conditions decisive for how much water the bedrock can transport. The climatological conditions are decisive for the amount of water available for recharge and ground water flow.

The ground water conditions at the Svartboberget site have been determined by measuring the hydraulic properties of the bedrock, chapter 7, as well as by monitoring the position of the ground water table and the ground water pressure at different depths in the bedrock. In addition, information has been assembled on hydro-meteorological conditions, chapter 6. The data obtained have constituted the basis for the three-dimensional hydraulic model calculations of the site (Carlsson, Winberg, Grundfelt, 1983). The results of these calculations describe the ground water conditions within the entire investigated area. The calculations can be verified by measurements of ground water pressure and by hydro-meteorological data.

The ground water table in an individual drill hole represents a mean value of prevailing pressure conditions in different parts of the penetrated formation. The drill holes at Svartboberget vary considerably in length. Their ground water levels are not directly comparable since they represent different ground water tables. In order to obtain an estimation of the ground water pressure in the parts of the rock close to the ground surface, six drill holes were sectioned off by means of inflatable packers during different periods of time. The packers were placed c. 10 m vertically below the ground water table.

8.2 Registration of the ground water table

The position of the ground water table at Svartboberget has been registered in seven core drill holes and six percussion drill holes as from 811029. The ground water table has been registered by means of soundings once every week. During April 1982 an additional ten percussion drill holes were successively included in the measurement program after completed drilling, fig 5.4. In three holes, registering water-level gauges were installed for continuous monitoring of the ground water table. During periods when other activities were carried out in the drill holes, no ground water soundings have been performed.

During the period 811029-821030 the ground water table on the Svartboberget ridge was situated between 261-310 m above sea level. In the Brynåsbäcken valley the ground water level was c. 231 m.a.s.l. The distance from the ground surface to the ground water table is usually between 5 and 15 m in the high-altitude drill holes. In lower situated areas this distance decreases to c. 0.5-1 m. The ground water level in the highly situated drill holes HSv 6 and Sv 6 deviates from this pattern. HSv 6 is artesian and the ground water level of Sv 6 is close to the ground surface (0.2 m-1.1 m). This deviation is probably due to the fact that the drill holes are in hydraulic connection with the highly elevated parts south-east of Sv 6. In the drill holes which are located on slopes (Sv 1-Sv 3, HSv 2 and HSv 3), the greatest distance to the ground water table has been indicated, viz. at 15-26 m.

During the measurement period the ground water table has varied, largely in the same way in all drill holes. The lowest ground water levels have been registered before snow melting or after the warm and dry period in July 1982. Maximum values have been obtained after snow melting and after the heavy precipitation in August and September. This is in accord with the normal seasonal variation of the ground water in southern Norrland where there is, apart from the ground water recharge during the latter part of the spring, a secondary period of ground water recharge during autumn (Knutsson and Fagerlind 1977).

In the higher situated drill holes, the ground water level fluctuates more, the amplitude being 2.6–9.3 m. After heavy rain, the ground water level rises substantially but falls rapidly during dry periods. Drill holes Sv 6 and HSv 6 are in this case exceptions. The drill holes in low-lying parts of the study site and in the Brynåsbäcken valley have smaller level variations, the amplitude being c. 0.3–1.5 m and the response to precipitation is less.

In the drill holes sectioned-off with packers, table 8.1, the upper section usually exhibits a higher ground water level than the lower. Also in this case, percussion drill hole HSv 6 constitutes an exception. In HSv 6 the lower section is artesian, whereas the ground water level in the upper section is below the ground surface. In the upper section the ground water level variation is greater, which is to be expected, since it is influenced more directly by prevailing climatological conditions.

Drill hole HSv 4A is located in a discharge area. The ground water level in the upper and lower sections are in close correspondence ($\leq$0.1 m) during the entire measurement period. Also HSv 6 is located in a discharge area, the distance between the ground water tables of the individual sections being less than 1.06 m.

The four remaining sectioned-off drill holes are located in recharge areas. They have the highest ground water pressure above the packer. The greatest difference in ground water level has been registered in drill hole HSv 7B, which lower part intersects a fracture zone.

Table 8.1 Ground water levels in sectioned-off drill holes at Svartboberget during the period 811029-821030.

Drill hole section		Ground water levels Highest m.a.s.l.	Lowest m.a.s.l.	Variation width (m)	Difference in levels (m) Max	Min	Note
Sv 3	O	285.00	283.32	1.68			Recharge
	B	276.32	274.81	1.51	10.19	8.42	area
HSv 3	O	269.85	263.94	5.91			
	B	261.00	259.83	1.17	6.96	3.28	-
HSv 4A	O	244.12	242.59	1.53			Discharge
	B	244.16	242.64	1.52	0.10	0.01	area
HSv 5	O	290.60	290.18	0.42			Recharge
	B	290.11	289.13	0.98	1.49	1.05	area
HSv 6	O	298.76	298.42	0.34			Discharge
	B	299.47	298.54	0.93	1.05	0.01	area
HSv 7B	O	283.19	280.53	2.66			Recharge
	B	272.91	269.37	3.54	11.50	8.05	area

O = over packer B = below packer

8.3 Ground water level maps

Two maps of the ground water level in the bedrock have been prepared to cover the area at and around the Svartboberget site. The maps are intended to indicate the overall ground water flow within the area and to constitute a basis for numerical calculations of the ground water conditions.

The regional map in fig 8.1 covers an area of c. 120 km^2 delimited by the Voxnan river to the south and south-west and by an imaginary north-westerly line through lake Loftssjön to the east. The local area has an acreage of c. 10 km^2 and comprises the Svartboberget study site.

The ground water level maps are based partly on the above-reported ground water level observations and partly on certain assumptions based primarily on relations between ground water level and topography obtained from these ground water level observations. These assumptions may be summarized as follows:

- Below isolated elevated parts the distance between the ground surface and the ground water table is between 10 and 15 m;
- The ground water levels at and below the lakes in the area are assumed to coincide with the lake surface;
- The Brynåsbäcken and Älmån water courses are assumed to be discharge areas for ground water;
- Major peat bogs are assumed to be discharge areas for ground water;
- Major regional fracture zones are assumed to exhibit a local lowering of the ground water table in higher situated parts, when compared with the surrounding rock mass.

The ground water level maps in scale 1:5,000 and 1:50,000, respectively, are shown in reduced size in figs 8.1 and 8.2. The levels represent an assumed mean level during an individual year, which corresponds to an equilibrium between ground water recharge, ground water flow and ground water discharge.

The highly elevated central part of the study site mainly constitutes a recharge area for ground water. A local discharge area is located at drill holes HSv 6 and Sv 6. The peripheral parts of the study site to the west, north and east are discharge areas. Major discharge areas with concentrations of lakes and peat bogs are located south and south-west of Svartboberget and at lake Råttjärnasjön to the north.

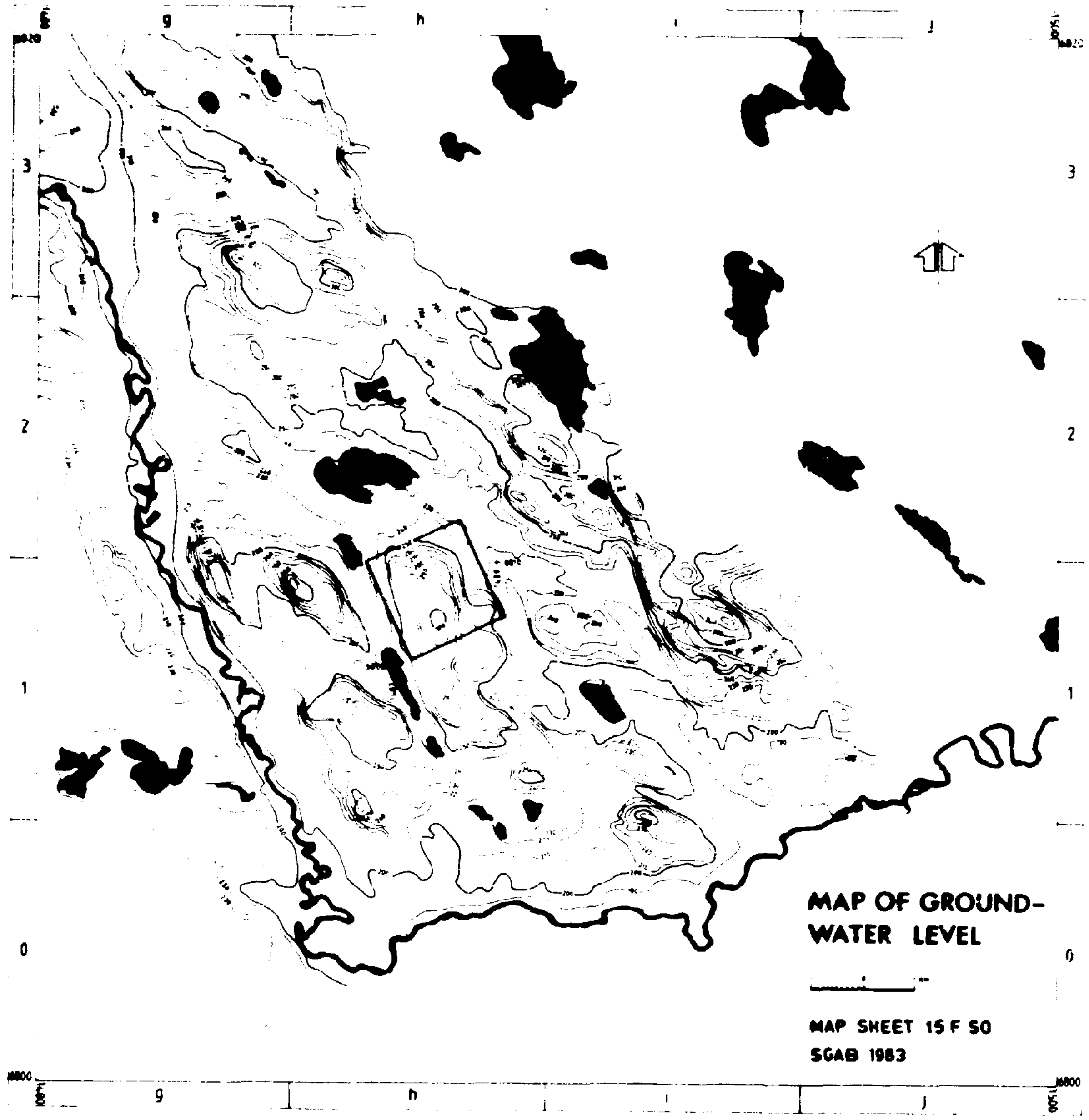


Figure 8.1. Regional map of ground water level at site Svart-
boberget.

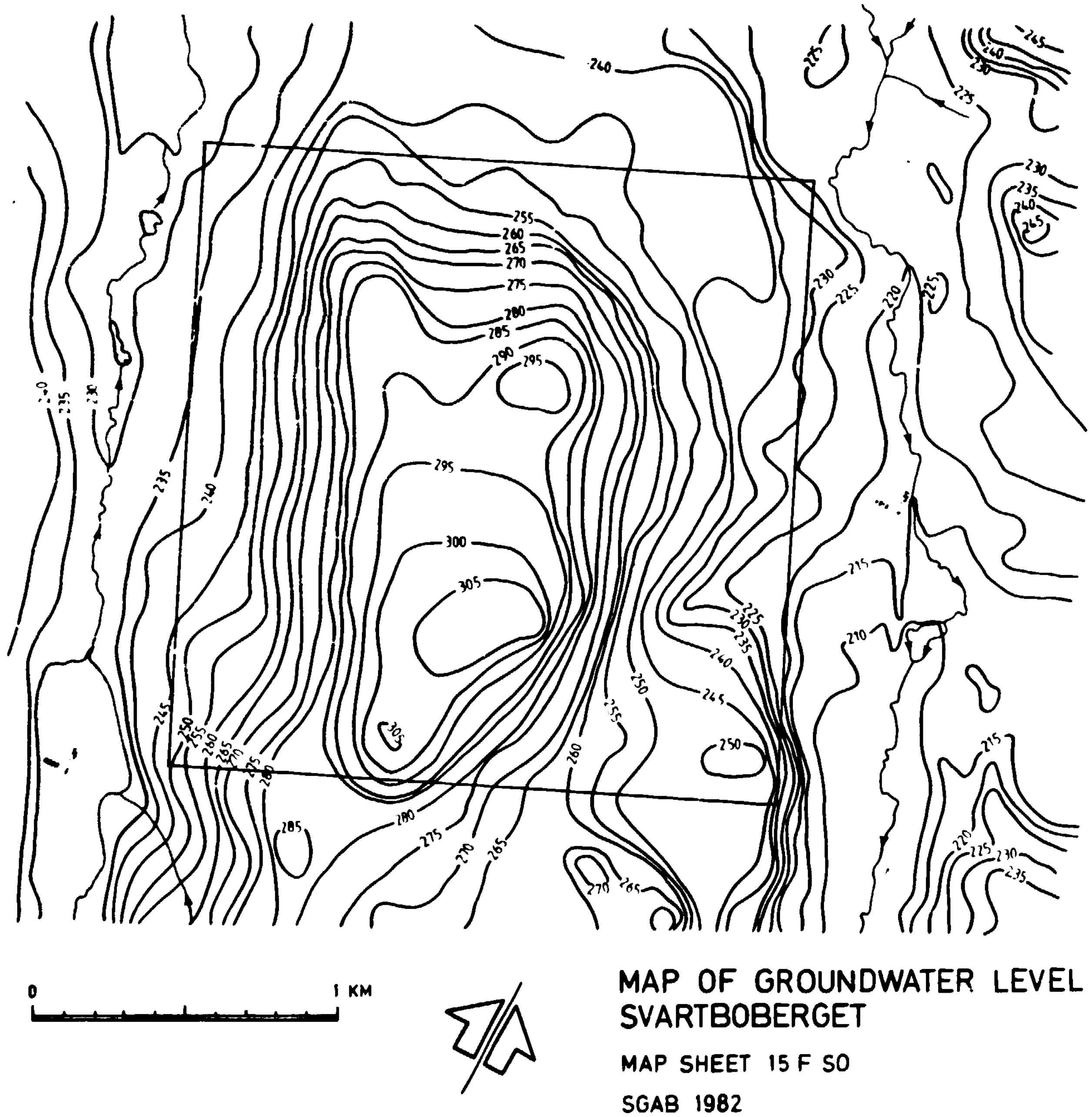


Figure 8.2. Local map of ground water level at site Svartbo-berget

The ground water flow in the study area is primarily oriented towards the regional fracture zones running along the valleys of the Brynåsbäcken and Älmån streams to the west and east, but also in a northerly direction towards lake Råttjärnasjön. From a regional aspect, the ground water flow is apparently oriented towards Voxnan in the south and southwest where the low-lying parts of the area are located.

8.4 Ground water head at different depths in the bedrock

The ground water pressure in the bedrock varies both laterally and vertically. The ground water moves from levels with high pressure to levels with lower pressure. In drill holes where the difference between the ground water presure and the hydrostatic pressure increases with depth, discharge conditions are said to prevail. Conversely applies that recharge conditions are present when the ground water is of higher pressure in the upper parts of the drill hole than in the lower situated parts.

The ground water pressure at different levels in the bedrock has been determined according to the following two methods:

- Calculation based on the results of water injection tests with subsequent pressure fall-off period (Almén et al., 1982);

- Continuous registration in separate sealed-off sections using pressure gauges.

The water injection tests are carried out in two phases. During the first phase a constant injection pressure is maintained and the injected flow volume registered. During the second phase the flow is stopped and the fall-off of the pressure with time registered. The original water pressure of the tested section is calculatd on the basis of the results of the two phases, so-called Horner plot (Almén et al., 1982).

The ground water pressure in core drill holes Sv 1 and Sv 3-Sv 7 has been calculated from the ground surface to the drill hole bottom. Excluded are sections comprising impermeable rock and sections with unsatisfactory pressure fall-off registration. The ground water pressure is indicated as over- and under-pressure in metres of water in relation to the hydraulic pressure in the drill hole at the corresponding level, fig 8.3.

The ground water pressure in the measurement sections in many cases deviate substantially from the hydrostatic pressures in the drill holes at the corresponding levels (fig 8.3). The deviation is generally negative. Very low under-pressures, less than -30 m of water, have been registered below the 345 m level in core drill hole Sv 3 and in Sv 5 between 290 m and 640 m. Low under-pressures have also been registered in drill hole Sv 1 below 205 m borehole length. The over-pressures obtained are usually registered in the upper parts of the core drill holes. They are, however, of low magnitude.

In the above-mentioned drill holes, the pressure decreases with depth, which means that recharge conditions prevail. The reverse condition can be noted in drill hole Sv 4 which indicates discharge conditions.

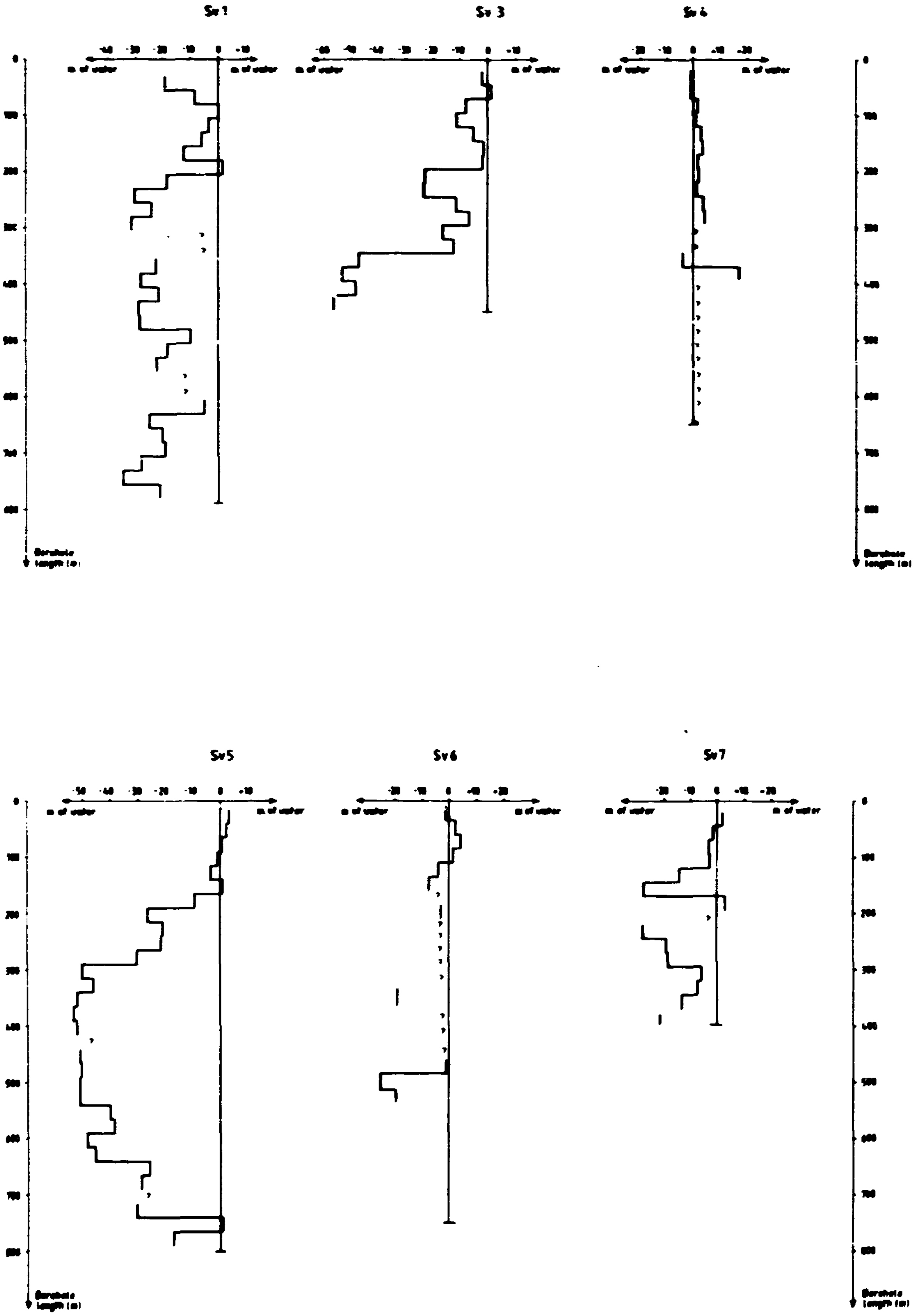


Figure 8.3. Pressure distribution (in metres of water column) in test sections of drill holes Sv 1, Sv 3-Sv 7.

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APPENDIX I: SCOPE OF STUDY SITE INVESTIGATIONS AT SVARTBOBERGET

Surface investigations

Geological surface mapping		
Regional mapping	375 km^2	
Detailed mapping	6 km^2	
Geophysical surface mapping		
Surface measurement	4 km^2	Magnetic field
		Slingram (horizontal loop indicator)
		Resistivity
		IP
Geophysical profiles outside the study site (slingram (horizontal loop EM))	29 km^2	

Depth investigations

Core drill holes

No.	Coordinate	Levelling (m)	Direct.	Incl. (o)	Length (m)	Vert. depth (m)
1	1574 N/1214 E	290.05	-	90	788.0	788.0
2	1644 N/1250 E	281.58	N 26 E	60	400.0	346.4
3	201 N/1097 E	290.66	W - E	60	450.0	389.7
4	806 N/ 69 E	240.63	N 80 E	60	651.0	563.8
5	826 N/1080 E	307.01	S 10 E	85	801.0	798.0
6	660 N/ 616 E	293.30	N 75 E	70	750.0	704.8
7	1504 N/ 522 E	288.25	N 30 E	60	397.0	343.8

Percussion drill holes

No.	Coordinate (rod system)	Levelling (m)	Direc.	Incl. (o)	Length (m)	Vert. depth (m)	Water capac. (1/h)
1	1730 N/1340 E	257.34	-	90	22	22	?
2	1683 N/1309 E	263.81	N26E	60	104.5	90.5	200
2B	1683 N/1309 E	264.20	N26E	60	60.0	52.0	?
3	132 N/1223 E	275.19	W -E	60	100.0	86.6	45
4A	785 N/ 163 E	246.24	N80E	60	100.0	86.6	200
4B	828 N/ 72 E	240.57	-	90	120.0	120.0	200
5	1011 N/1169 E	303.41	N62E	60	70.0	60.6	530
6	649 N/ 693 E	298.77	N75E	70	100.0	94.0	700
7A	1624 N/573.5E	284.86	S25W	60	70.0	60.6	1600
7B	1451 N/ 515 E	286.86	S25W	45	70.0	49.5	1700
8	462 N/ 385 W	232.56	-	90	51.0	51.0	2000
9	568 N/1068 E	314.23	-	90	50.0	50.0	100
10	1273 N/ 983 E	295.62	-	90	50.0	50.0	480
11	478 N/ 301 W	231.65	-	90	100.0	100.0	3600
12	463 N/ 190 W	234.56	-	90	100.0	100.0	8800
13	467.5N/ 301 W	231.71	-	90	150.0	150.0	4400
14	529 N/ 302 W	231.18	-	90	100.0	100.0	7300

Drill core mapping

Mapped drill hole length 4 238 m

Chemical Analyses

Drill hole	Depth (m)	No. of samples	Drill hole	Depth (m)	No. of samples
Sv 1	384.50	1	Sv 4	125.00	1
Sv 1	391.09	1	Sv 4	452.40	1
Sv 1	392.53	1	Sv 4	555.47	1
Sv 1	451.07	1	Sv 4	575.45	1
Sv 1	493.45	1	Sv 4	589.75	1
Sv 2	226.05	1	Sv 5	84.61	1
Sv 2	267.70	1	Sv 5	103.87	1
Sv 2	309.10	1	Sv 5	236.40	1
Sv 3	136.63	1	Sv 5	575.45	1
Sv 3	310.30	1	Sv 5	577.36	1
Sv 4	25.75	1	Sv 5	587.15	1

Petrophysical samples 1) 280 pcs

1) Evenly distributed on all core drill holes and depth

Thin sections 22 pcs

Geophysical logging

Methods:

- Borehole deviation measurements 2) 3)
- Natural gamma radiation 1) 2)
- Point resistance 1) 2)
- Resistivity 2)
- Differential resistance 2)
- Spontaneous Potential (SP) 2)
- Temperature 2)
- Salinity 2)
- Induced Polarization (IP) 2)

1) Measurements performed in all percussion drill holes except HSv 1, HSv 8

2) Measurements performed in all core drill holes except Sv 2

3) Measurement performed in percussion drill holes HSv 2, HSv 3, HSv 4A, HSv 6

Hydrological investigations

Water injections tests	Number of tests
25 m sections	147 pcs
10 m sections	8 pcs
5 m sections	79 pcs

Piezometric measurements	Number of sections
Drill hole Sv 4	5 pcs 1)
Drill hole Sv 5	5 pcs 1)

1) Measurements not yet completed

Interference tests

Pump hole	HSv 11
Observation holes	HSv 8, 12, 13, 14

Groundwater level observations	Number
Percussion drill holes	16 pcs
Core drill holes	7 pcs

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