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Evaluation of the geological, geophysical and hydrogeological conditions at Gideå

K Ahlbom
B Albino
L Carlsson
G Nilsson
O Olsson
L Stenberg
H Timje

Swedish Geological May 1983

SVENSK KÄRNBRÄNSLEFÖRSÖRJNING AB / AVDELNING KBS
Swedish Nuclear Fuel Supply Co/Division KBS
MAILING ADDRESS: SKBF/KBS, Box 5864, S-102 48 Stockholm, Sweden
Telephone 08-67 95 40

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Sveriges Geologiska AB

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by

Kaj Ahlbom, Björn Albino, Leif Carlsson, Göran Nilsson,
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SUMMARY

The Gideå study site has a flat topography, insignificant soil depth and a high percentage of outcrops. The dominating rock type in the area is veined gneiss of north-east structural strike and small dip. The veined gneiss contains sulphide minerals, primarily pyrite and pyrrhotite in the form of impregnations or as minor enrichments parallel with the gneiss structure. Economically valuable minerals are present in so small quantities that mining in the area is not realistic.

In conformity with the structure of the gneiss there are strata or irregular bodies of granite gneiss. The proportion of granite gneiss in the drill holes is 6%.

The fracture frequency in the rock mass is more than 4.0 fractures per metre down to a depth of 400 m. Below the 500 m level, the fracture frequency is 2.0 fractures per metre.
Outside the Gideå study site there are regional fracture zones towards the west-north-west and the north-west. These zones are 50-100 m wide, or more, and dip vertically. The regional zones delimit a plateau with an area of c. 100 km^2.

Within the study site there are defined local fracture zones at a mutual distance of 400-800 m. These local fracture zones delimit a triangular block of rock with a top surface of 1.8 km^2. This block is transversed by two local fracture zones, approx 4 m wide. Drill hole investigations indicate that the fracture zones in the study site have a mean width of c. 11 m and contain small portions of crushed and clay-altered rock. The fracture zones are steeply dipping with the exception of two sub-horizontal fracture zones in the northern and eastern parts of the area which are dipping outwards from the study site. Horizontal fractures of vast lateral extent can be found in the upper 100-200 metres. Under this level no horizontal fracture zones have been observed. Frequently occurring fracture minerals in the fracture zones are calcite, kaolinite, chlorite, laumontite, pyrite and the clay minerals illite and smectite.

Existing strata or bodies of granite gneiss have a higher hydraulic conductivity than the surrounding veined gneiss. At a depth of 500 m the granite gneiss has a hydraulic conductivity of 1.5×10^{-10} m/s, that of the surrounding bedrock being 2×10^{-11} m/s. This implies anisotropic hydraulic properties in the rock mass with a higher hydraulic conductivity horizontally.

The hydraulic conductivity in the veined gneiss and granite gneiss decreases substantially with increasing depth. In the rock mass as a whole, i.e. by forming the average of all data from both rock types, the hydraulic conductivity decreases from c. 4×10^{-9} m/s at 100 m depth to c. 2×10^{-11} m/s at a depth of 500 m.

The hydraulic conductivity in the local fracture zones at Gideå is 9×10^{-11} m/s at a depth of 500 m. The hydraulic conductivity in the fracture zones decreases with increasing depth in the same way as that of the rock mass. An interesting fact is that the hydraulic conductivity of the fracture zones is lower than in the granite gneiss.

The flat topography of the area implies that the hydraulic gradients in the bedrock are small. This has also been recorded by means of piezometric measurements.

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 project program, the so-called Standard Program (Brotzen, 1981, Thoregren, 1982).

Gideå is one of the study sites which have been investigated by means of deep drill holes in order to obtain better knowledge of the geological, hydrogeological and geochemical conditions at large depth in Swedish crystalline rock. The purpose of the investigation has been to bring forth the site-specific data required for a safety analysis for a storage of spent nuclear fuel. The investigations at Gideå began with the first drill hole in June 1981. The main part of the investigation was completed in February 1983.

1.2 Reporting of results

The present report constitutes a summary and evaluation of data from the Gideå study site. A detailed presentation of results from the area is made in the following reports:

- Albino, Nilsson & Stenberg, 1982:

  "Geological, tectonical and geophysical investigations at the Gideå study site."

  The report accounts for the geological and tectonical mapping of the study site with its surrounding region, and includes results from core logging, percussion drilled holes and geophysical surface investigations.

- Albino & Nilsson, 1982:

  "Summary of technical data on drill holes and fracture- and rock-type log."

The report accounts for drill core logging and technical data on drillings performed.

- Stenberg, 1983:

  "Borehole geophysical investigations at the study site Gideå."

  The report accounts for the geophysical loggings performed in the drill holes and an interpretation of fracture zones.

- Timje, 1983:

  "Hydrogeological investigations in study site Gideå."

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

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

2. THE SELECTION OF STUDY SITE GIDEÅ

Reconnaissance work carried out in 1981 resulted in Gideå being selected as one of the interesting sites. Gideå was chosen primarily on the following grounds:

- The site consists of migmatized veined gneiss. This rock type has been found suitable for the construction of rock caverns and tunnels due to low water inflow and has displayed low water capacities in rock-drilled wells.

- The area is of flat topography, thus the driving forces on the groundwater flow are small.

- Regional fracture zones delimit a 100 km^2 elevated plateau.

- The study site displays a low frequency of fracture zones interpreted from aerial photographs.

- The fracture frequency on outcrops is low at the study site.

- There is only one land-owner in the area.

The proportion of outcrops in the area is comparatively large, approx 15%, which facilitates the geological and tectonical interpretation of the area.

Geological field reconnaissance and geophysical profile measurements were made during spring and summer 1981. The profile measurements indicated that there were large parts of the area with few indications of fracture zones. Following these initial geological and geophysical investigations, the site was considered promising and a 700 m deep drillhole was made in order to study the characteristics of the bedrock towards deeper levels.

The results of the drilling indicated that the bedrock also at deeper levels consists of veined gneiss of low fracture frequency. The decision to initiate complete investigations was taken in the summer of 1981.

3. LOCATION AND TOPOGRAPHY

The Gideå site is situated in the northern part of Ångermanland county c. 30 km north-east of Örnsköldsvik, fig 3.1. The area is located in the Örnsköldsviks municipality and is reproduced on topographical map-sheet 19 J Husum NW.

The coastal areas of Ångermanland are located in the part of Sweden with the highest isostatic (land) uplift. The region is very hilly with high mountain peaks with valleys in between. Towards the north the hilly topography evens out, the Gideå study site being located on a flat plateau surrounded by major fracture valleys. The river Gideälven and the stream Husån partly follow these fracture valleys.

The level of the ground surface in the area varies between 80 and 130 m above sea level. A topographical profile of the site is shown in fig 3.2. The altitude characteristics of the site are illustrated by the hypsographic curve in fig 3.3.

The Gideå study site is forested interchanging with minor peat bogs. In the north-eastern part of the site there an is extensive peat bog system with its major part outside the area subjected to detailed investigations.

The quarternary deposits consist primarily of moraine, overlain in depressions by peat. The investigated area is 2 x 3 km.

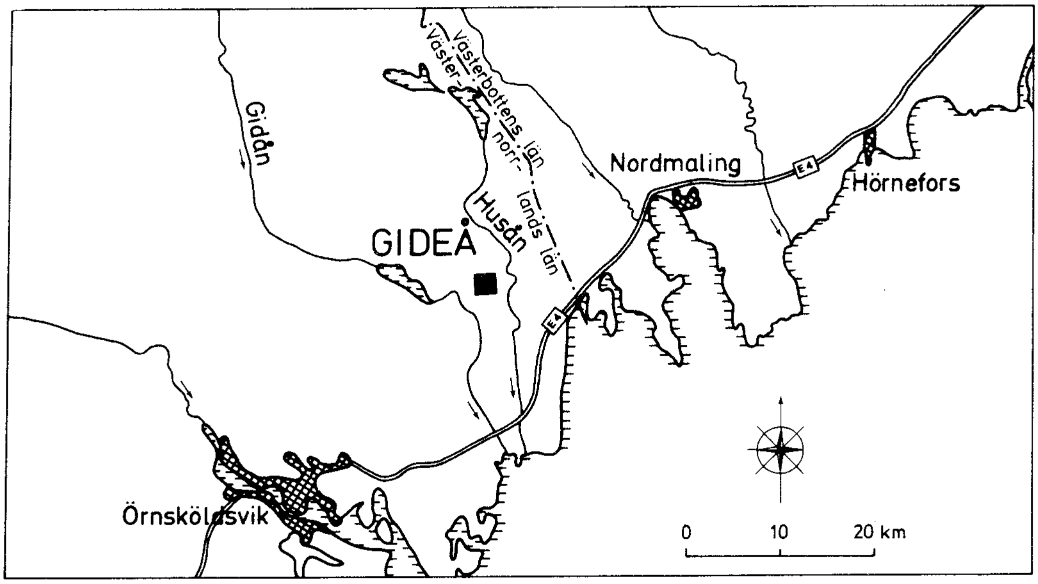


Figure 3.1 Locality map for site Gideå.

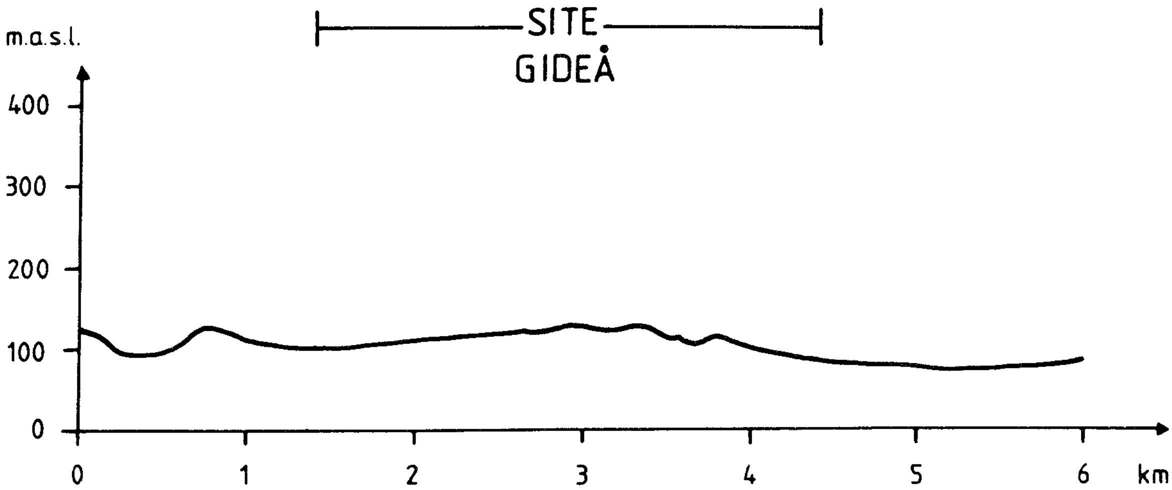


Figure 3.2 Topographical profile across site Gideå, location shown in fig. 5.1.

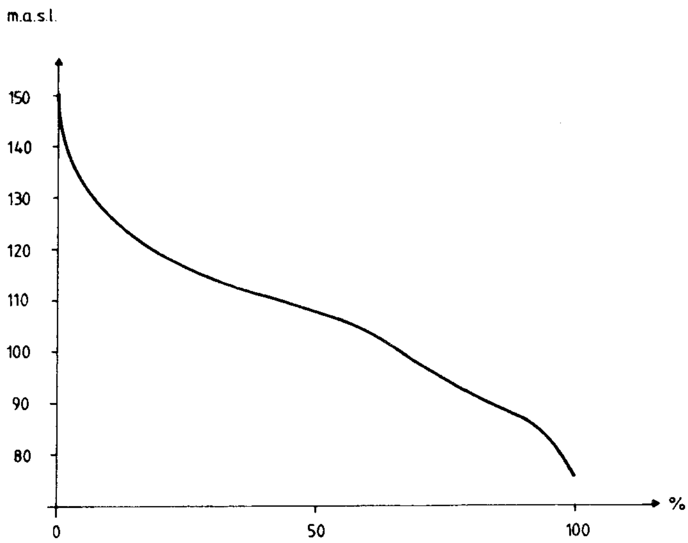


Figure 3.3 Hypsographical curve showing the altitude characteristics of the Gideå site.

4. BEDROCK GEOLOGY

4.1 Regional geology

The bedrock in the region consists mainly of rock types which have been part of the c. 1800-2000 mill. years old Sweco-Karelian mountain chain formation. These rock types today constitute various types of gneisses of vulcanic or sedimentary origin and of a series of granite gneisses. After the mountain chain formation granites intruded into the old bedrock. These granites are comparatively undeformed and are generally referred to as younger granites. The youngest rock types are dolerite of a probable age of 100 mill. years. Detailed descriptions of rock types and rock-type development are subject to publication (Lundqvist, in press).

The Husum NW map-sheet within which the Gideå site is situated, was recently mapped (Lundqvist, in press). The geological map is shown in fig 4.1. The map indicates that the bedrock consists of a large coherent body of veined gneiss of sedimentary origin. To the south there is a body of granite gneiss and to the west younger granite, so-called Revsund granite. There are also smaller bodies of amphibolites and ultrabasites. Dolerite constitutes the youngest rock type and has penetrated the old bedrock from the south.

The veined gneiss is present with a varying degree of migmatization. The migmatization took place c. 1800 mill. years ago when the bedrock was depressed to great depths (10 km) where it was exposed to high pressure and high temperature. This caused partial melting of the bedrock which resulted in new mineral combinations.

The veined gneiss is usually grey, although the colour varies with the biotite and feldspar content. Gneiss rich in biotite is greyish black whereas gneiss rich in feldspar is greyish white. In places the veined gneiss is porphyric with cm-sized

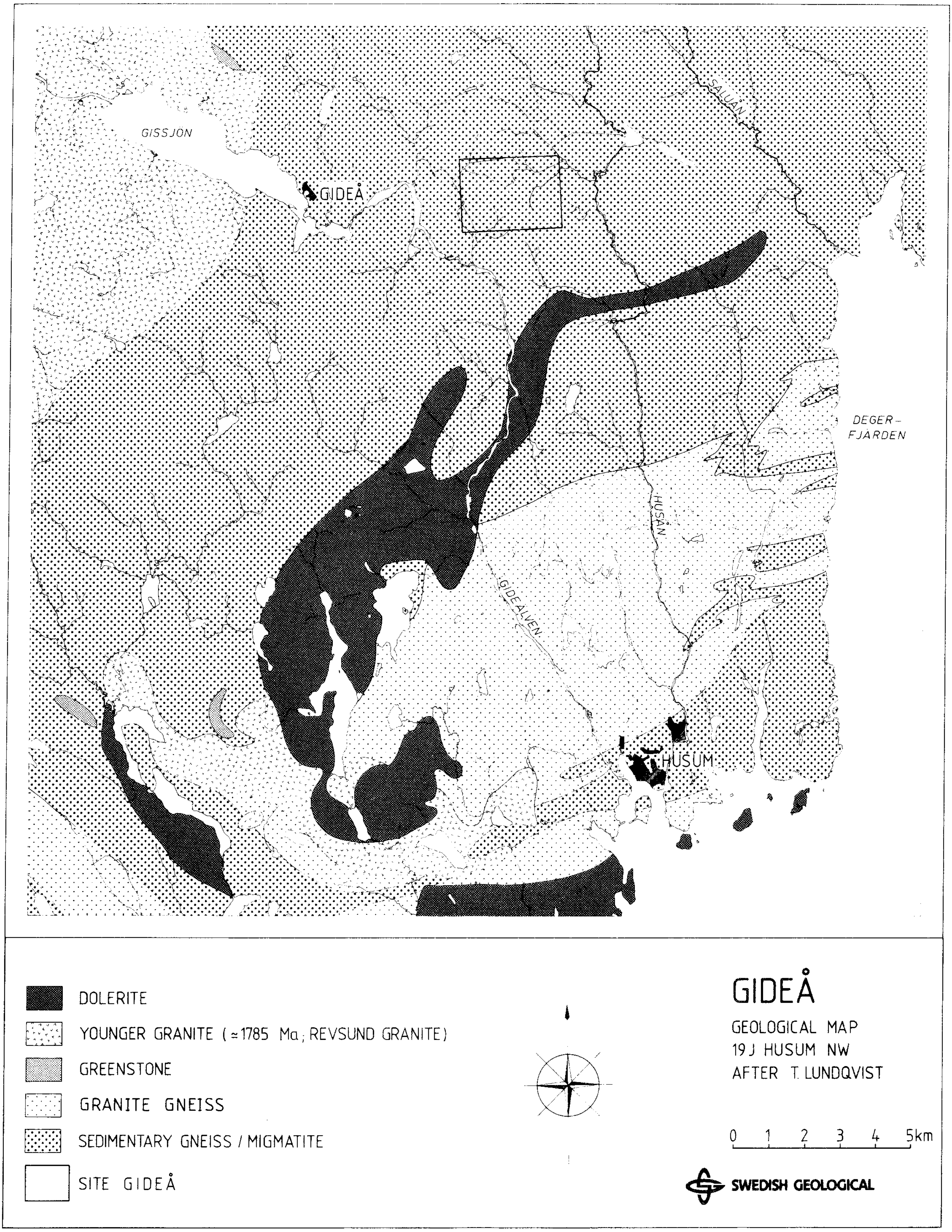


Figure 4.1 Regional geological map including site Gideå.

"eyes" of feldspar. There are minor streaks of amphibolite and sediment residues in the gneiss. The gneiss foliation structure is usually striking north-east with a small north-westerly dip.

Granite gneiss is present in a major massif south of the Gideå study site, fig 4.1. The granite gneiss is grey, medium-grained, usually porphyric with "eyes" of microcline and slightly foliated.

Younger granite, so-called Revsund granite, is found in the north-western part of the area. This granite is greyish-red, coarse-grained and porphyric with sometimes 1-5 cm large feldspar "eyes". Revsund granite is the dominating rock type in the inland of north Sweden (Norrland).

Amphibolite is present as minor bodies on the regional map. They are greenish-black and usually contain hornblende.

Dolerite, in the form of 10-500 m thick layers with a small dip towards the south-east is present south of the study site. The dolerite is greyish-black and fine- to coarse-grained. Dolerite also appears in metre-wide dikes of minor extension across the entire area, usually of east-westerly strike. This dolerite is in general greyish black, dense or fine-grained.

4.2 Bedrock in the study site

The Gideå study site is dominated by sedimentary gneiss of varying degrees of migmatization, fig 4.2. This variation is mainly due to differences in the composition of the original sediments. Local melting has resulted in the formation of irregular granitic bodies, migmatized granite, which are roughly following the regional structure of the bedrock. The boundary to the surrounding veined gneiss is well-fused, since the migmatized granite was formed in the bedrock environment where it is found today. No major coherent bodies of migmatized granite were found during the surface mapping.

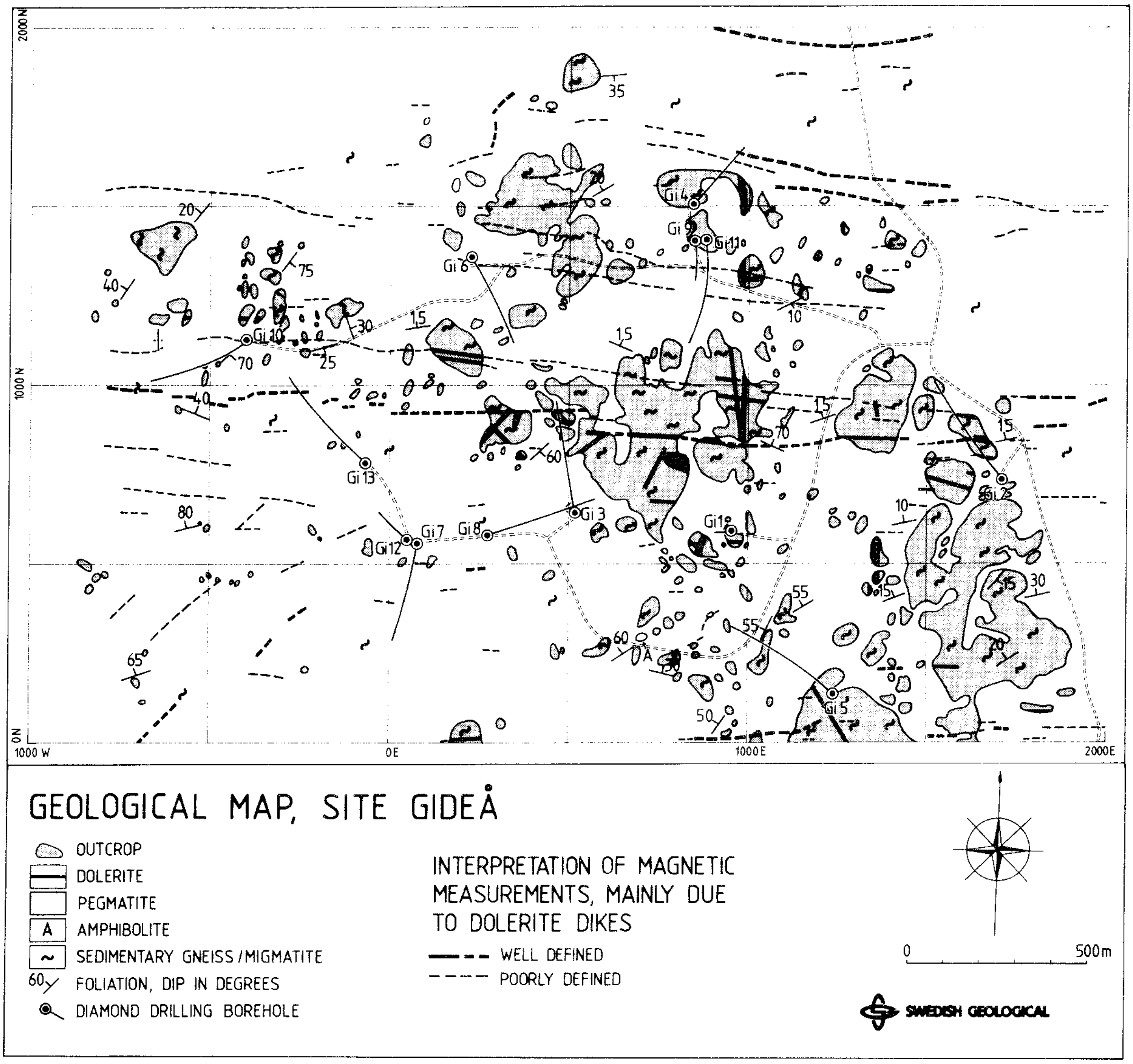


Figure 4.2 Geological map for site Gideå.

The veined gneiss is usually grey and fine- to medium-grained. The main minerals are quartz (56%), biotite (19%), plagioclase (13%) and microcline (6%). The veined gneiss contains sulphide minerals in small amounts, usually pyrrhotite and pyrite in the form of small mineral aggregates or fracture fillings.

The gneiss is characterized by veins and other irregular bodies of varying mineral compositions. Usually there are fragments of primary sediments in the form of extended lenses in the direction of the foliation. The lenses are 0.1-1.0 m long. In the granitic bodies there are usually parts with cmsized "eyes" of feldspar, so-called porphyroblasts. The schistosity varies with the degree of migmatization and appears as a parallel orientation of biotite. The foliation is in general north-easterly with a small dip, c. 10-30 degrees towards the north-west.

Granite gneiss appears in the drill holes as almost horizontal layers parallel with the veined gneiss structure. This rock type is grey and fine- to medium-grained and constitutes 6% (508 m) of a total core length of 8255 m.

In the area there is also pegmatite in the form of minor bodies and metre-wide dikes. The pegmatites are well-fused with the surrounding rock types.

Dolerite is present as dikes or thin layers of varying extension. The strike is in general east-westerly. The rock type is greyish black, dense- or fine-grained. In the widest dikes there is also medium-grained dolerite. Most dikes are less than 1 m wide. There are two c. 2-10 m wide dolerite dikes in the central part of the area. These display coarser texture and can be identified on the magnetic map, fig 4.3. The probable extension of the dolerites on the geological map, fig 4.2, has been interpreted on the basis of the magnetic map (Albino et al., 1982).

The main minerals in the dolerite are plagioclase (55%), pyroxene (25%), olivine (9%), biotite (3%), chlorite (3%) and opaque minerals (5%). There is no petrographic difference between the fine-grained and medium-grained dolerites. The dolerite probably belongs to the same generation as the so-called Ulvö dolerites, which have been dated back 1215 mill. years with the K-Ar method (Welin and Lundqvist, 1975).

Physical parameter measurements on rock samples from the study site indicate that there are a number of dolerite dikes of deviating magnetic remanence orientation, which may indicate the existence of different generations of dolerite dikes (Albino et al., 1982). Dolerite dikes of normal remanent magnetization (positive) usually stand out in blue colour on the magnetic map, fig 4.3. Dolerite dikes of deviating remanent magnetization (negative) show in faint red colour on the map.

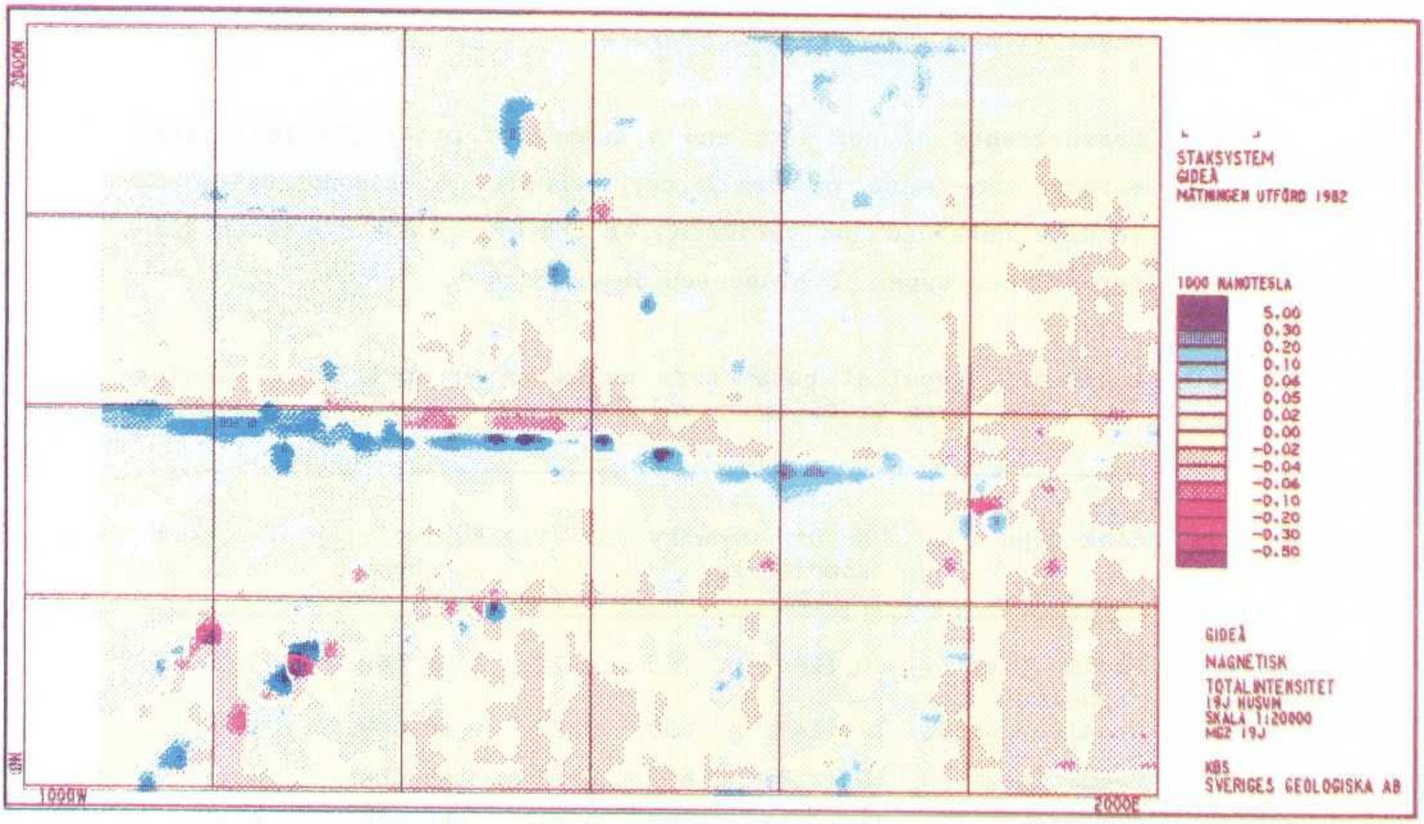


Figure 4.3 Magnetic field in Gideå.

As earlier mentioned, sulphide minerals occur over the entire area, primarily in the form of pyrrhotite and pyrite. The sulphide minerals are present in a dispersed fashion in the bedrock (disseminations) or appear as thin enrichments parallel with the structure of the gneiss. Large pointwise anomalies of lower resistivity and comparatively high induced polarization (IP) appear on the geophysical maps, indicating concentrations of pyrrhotite. In certain areas discolouration of the gneiss indicate the presence of sulphides. In the south-western corner of the magnetic map, there are two small, red and blue spots in connection with each other. These are probably caused by mineralizations of pyrrhotite. The content of economically valuable minerals is so small that mining in the area is not realistic.

4.3 Physical properties of the bedrock

Measurements of porosity and a number of other physical parameters were made on drill core samples. A compilation of results obtained and variation of characteristics between different rock types is presented in table 4.1.

Table 4.1 Physical parameters measured on drill core samples from Gideå (mean values).

Rock type	No of samples	Density kg/m^3	Porosity %	Resistivity ohmm	IP-effect %
Sedimentary gneiss	70 (28*)	2 720	0.21	8 080	3.2
Granite gneiss	17 (14*)	2 650	0.23	10 000	1.1
Pegmatite	10 (5*)	2 670	0.28	9 460	1.8
Dolerite	11 (8*)	3 000	0.03	544 000	9.8

*no. of porosity measurements

The mean porosity value for all rock types except dolerite is 0.22%. The porosity of dolerite is 0.03%.

Among the dolerite samples more than 50% have a resistivity in excess of 1 000 kohmm, which is the upper limit of the measuring equipment. This has made it inappropriate to compute a mean value for this rock type.

From the temperature measurements in all drill holes the mean temperature gradient for the area has been estimated at 15.9^{o}C/km. The temperature gradient is based on measurements between depth levels 400 and 600 m where the influence of climatological factors and drilling is of minor importance.

5. FRACTURE ZONES

5.1 Regional fracture zones

The Gideå study site is surrounded by regional fracture zones striking west-north-west and north-west, fig 5.1. The zones striking west-north-west are extensive and of widths greater than 100 m as estimated from geophysical data. The zones striking north-west are of a slightly smaller width, 50-100 m.

The interpretation of the regional fracture zones is based on aerial photographs and geophysical profile measurements. The results indicate a dip which is steep or steeply inclined towards the north-west. No drill holes penetrate the regional zones.

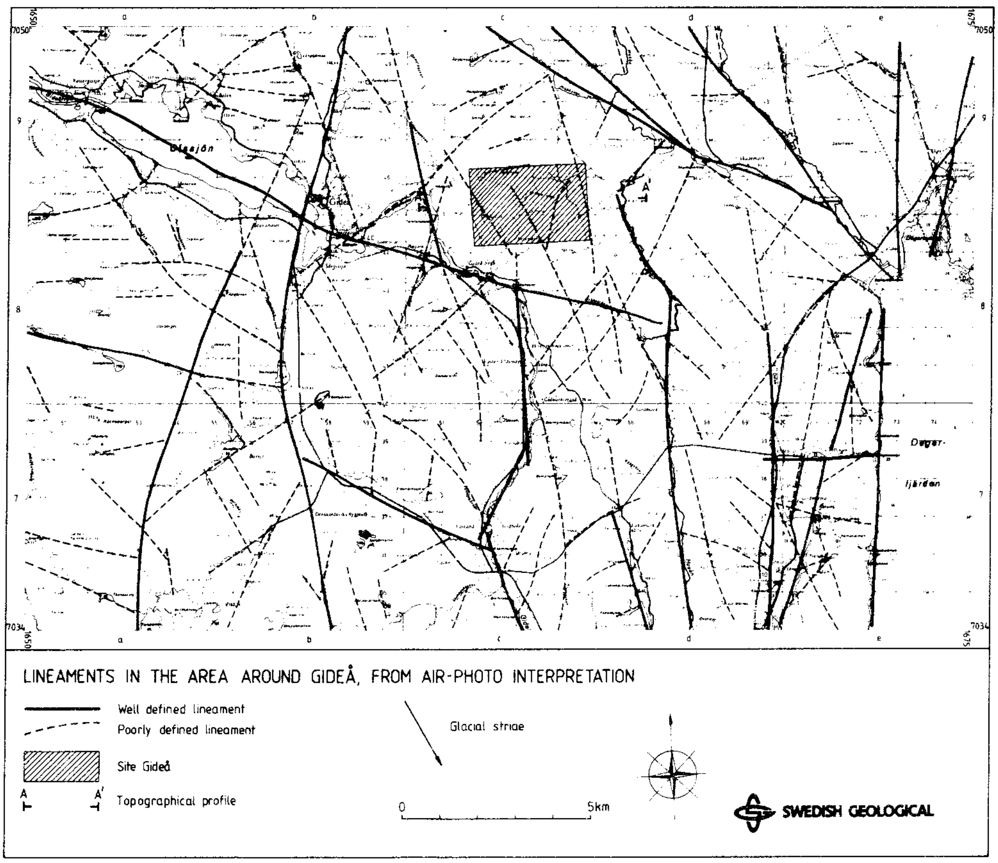


Figure 5.1 Interpreted lineaments around site Gideå.

5.2 Fracture zones within the study site

Within the Gideå study site there are only zones described as local fracture zones. These have been mapped by means of aerial photograph interpretation, geological mapping and geophysical ground measurements. The properties of the fracture zones have been examined by means of 13 core drill holes and 24 percussion drill holes. Geophysical as well as hydrological measurements have been performed in these drill holes. The position and depth of the drill holes as well as the total extent of the investigations performed are presented in Appendix. The positions of the core drill holes are illustrated in fig 5.3.

Fig 5.2 presents the results of the slingram (horizontal loop EM) measurements as well as a combined interpretation of fracture zones based on slingram and resistivity measurements on the ground surface. On the slingram anomaly map fracture zones, electric power lines and clay horizons are indicated in red. In the south-eastern corner of the map in fig 5.2, a power line stands out and in the north-eastern corner a peat bog superimposed on clay, both in red colour. Certain fracture zones (1 and 2) striking north-north-east are distinctly visible on the map. These zones are the largest fracture zones found in the area. Zones with an easterly and north-westerly strike have also been marked out in fig 5.3.

Indications of local fracture zones obtained from geophysical surface investigations and from topographical conditions have been examined by means of percussion drill holes. Water discharge and drill penetration rate have provided basic data for interpretation of the character of the zones.

The water capacity in the percussion drill holes varies. Many of the drill holes have nonmeasurable capacities. The highest capacity, 9000 l/h, was measured in a drill hole penetrating a major subhorizontal fracture zone (Zone 1). Drill holes close to each other may display a considerable variation in water capacity. The mean capacity is 2000 l/h and the median capacity is 240 l/h. The differences are due to the fact that 50% of the percussion drill holes have no measurable water discharge, whereas some exhibit great discharge rates.

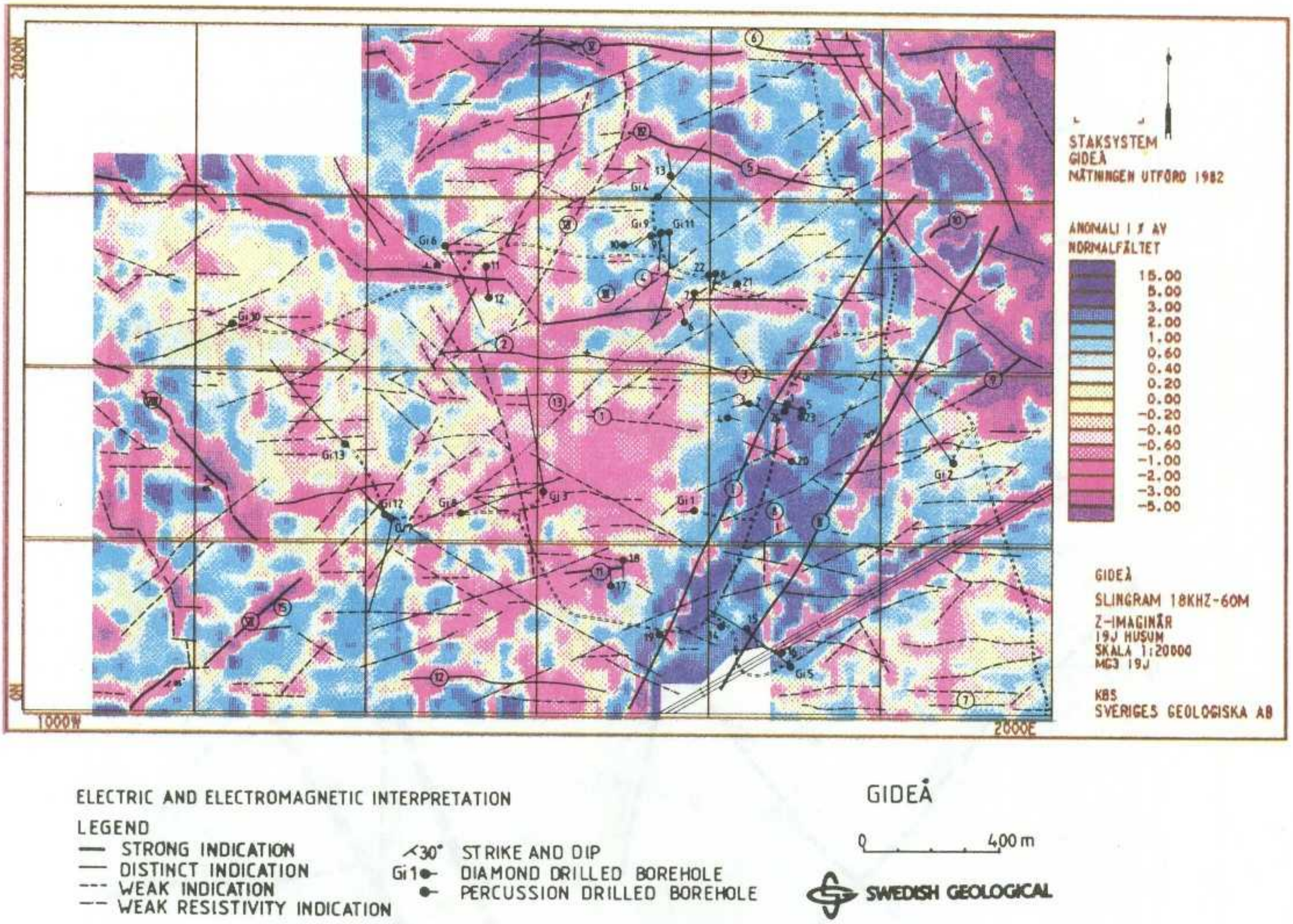


Figure 5.2 Slingram measurement showing areas with increased electric conductivity in Gideå mainly due to fracture zones.

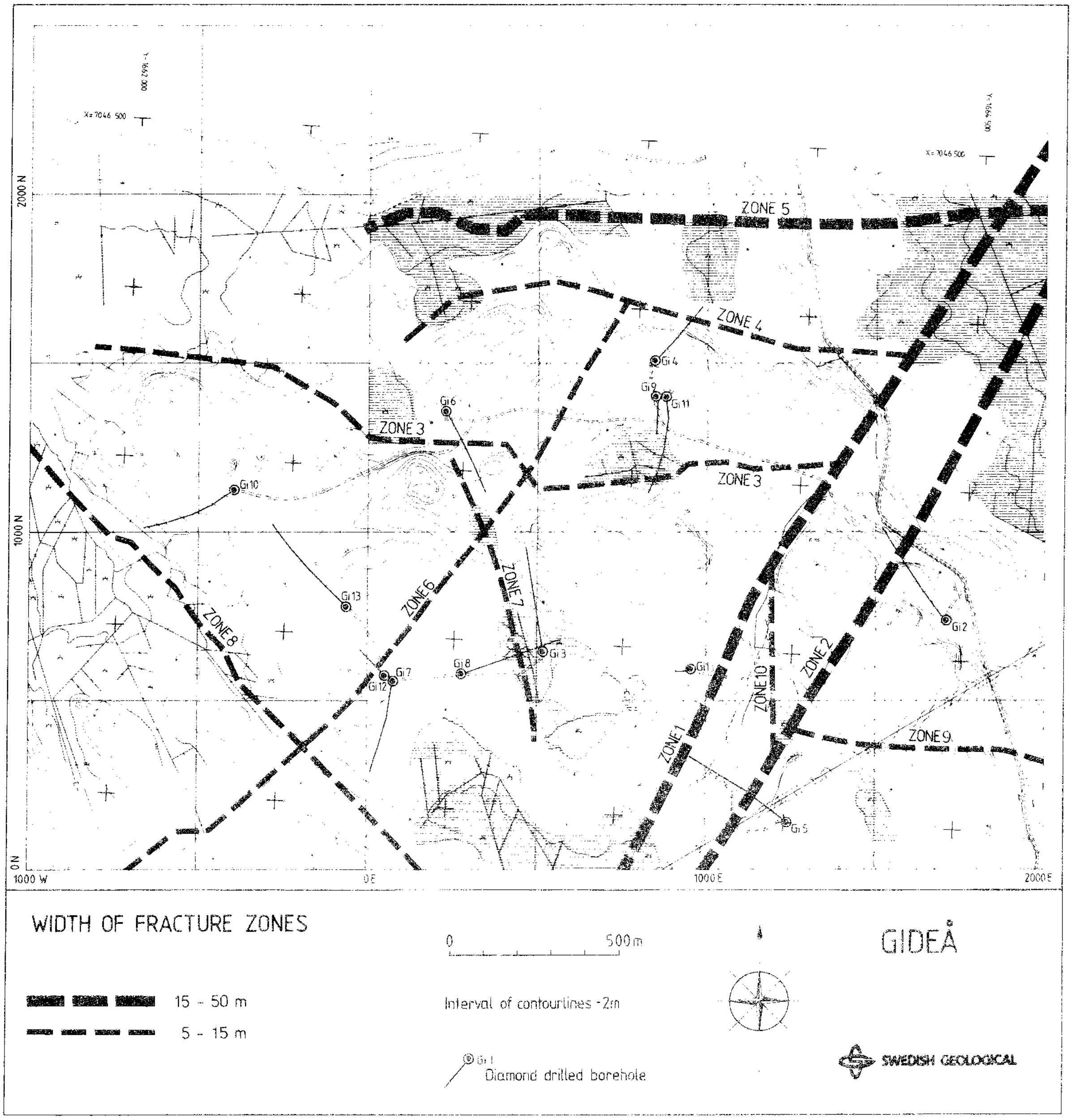


Figure 5.3 Fracture zones at the surface in site Gideå.

In the Gideå study site, eleven local fracture zones have been found. These have been examined by means of core drill holes in a total of 16 different locations, table 5.1. The positions of the fracture zones at the ground surface and at a depth of 600 m are shown in figs 5.3 and 5.4. The width of the fracture zones varies from 1 to 24 m with a mean width of 11 m. The width of the fracture zones has been determined in the drill holes from the point where the fracture frequency increases markedly to the point where it returns to its normal value. Also results from drill hole geophysical measurements have been taken into account. In order to calculate the actual widths of the fracture zones, a correction has been made for the angle of the drill hole to the fracture zone.

In drill hole geophysical measurements, the fracture zones stand out i.a. in the form of a reduction in bedrock resistivity. In the drill holes where differences in ground-water pressure occur, changes in water temperature along the drill hole show where in- and outflow of ground-water is taking place. Knowing the distribution of hydraulic conductivity along the drill holes, the in- or outflowing water value at different levels can be determined. Fig 5.7 shows results of geophysical measurements in drill hole Gi 4. The increased fracture frequency and the corresponding reduction in resistivity at drill hole lengths 217-259, 606-655 and 670-690 m relate to fracture zones 3A, 4 and 6, respectively. The water temperature curve below the 250 m level indicates a temperature in correspondence with the temperature of the bedrock, whereas the water temperature above this level is lower than that in the bedrock as such. The abrupt change in temperature indicates a waterflow from the upper part of the drill hole out through fracture zone 3A.

The local fracture zones are of less width and continuity compared to the regional fracture zones outside the study site. Differences in width and continuity exist between local fracture zones, which is evident from table 5.1 and fig 5.3. The mutual distance between the local zones is between 400 and 800 m.

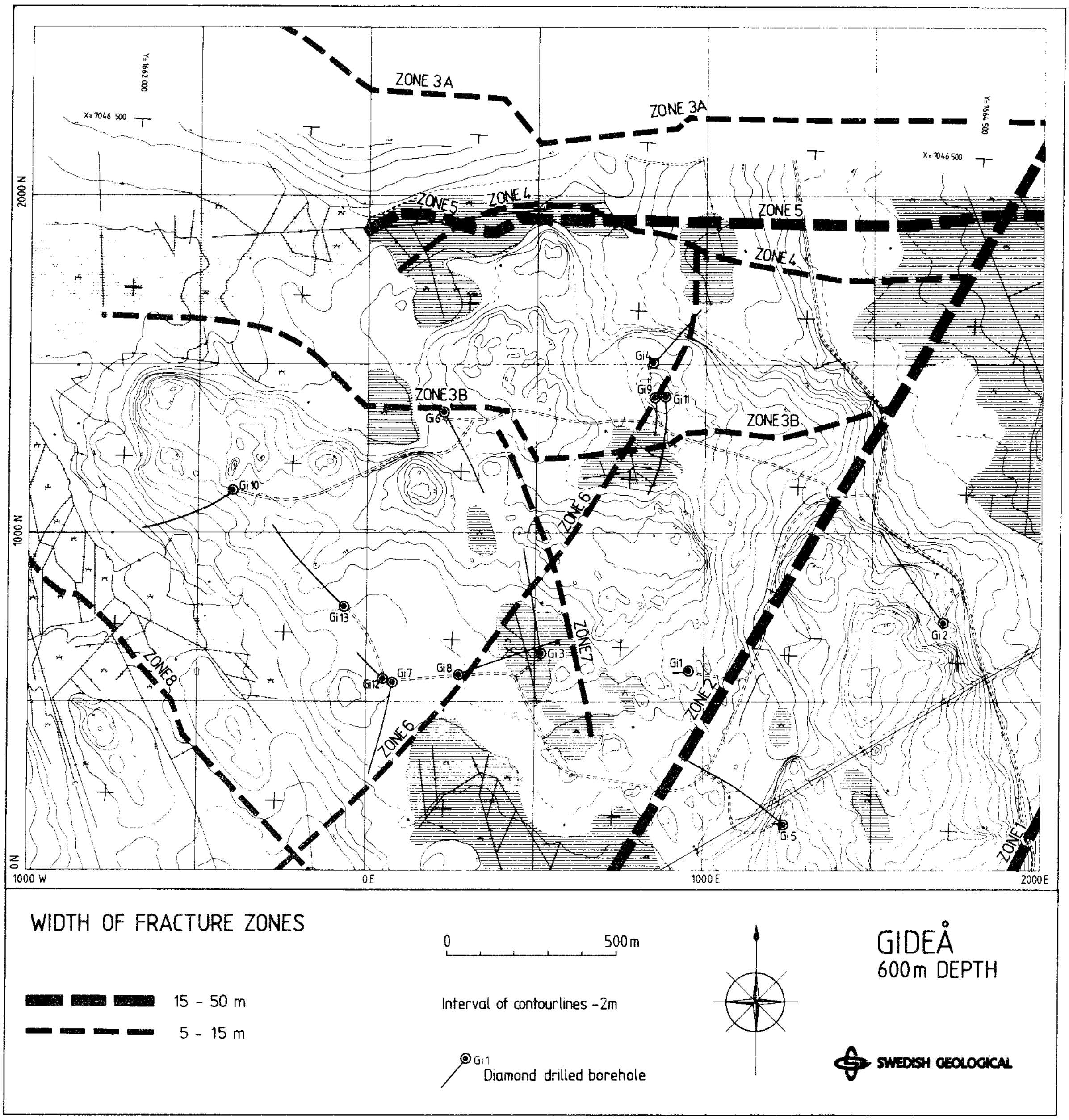


Figure 5.4 Fracture zones at 600 m depth in site Gideå.

Table 5.1 Summary of fracture zones in the Gideå study site.

Fracture zone	Position in drill hole (m)	Dip (degrees)	True width (m)	K-value (m/s)
1	Gi 2 (309-335)	40 SE	24	7×10^{-10}
	Gi 5 (210-232)	40 SE	22	3×10^{-6}
2	Gi 5 (520-567)	70 NW	11	$<5 \times 10^{-12}$
3A	Gi 4 (217-259)	30 N	20	2×10^{-7}
	Gi 6 (51- 80)	30 N	24	2×10^{-7}
	Gi 9 (129-146)	30 N	15	not measured
	Gi 11 (119-130)	30 N	10	1×10^{-9}
3B	Gi 6 (222-240)	80 N	9	7×10^{-12}
	Gi 11 (345-352)	80 N	4	7×10^{-11}
4	Gi 4 (606-655)	90	10	2×10^{-10}
5	-	80 N*	50 *	-
6	Gi 3 (622-629)	70 SE	4	5×10^{-9}
	Gi 4 (670-690)	70 SE	1	$<5 \times 10^{-12}$
	Gi 7 (362-397)	70 SE	3	2×10^{-11}
	Gi 12 (52- 61)	70 SE	8	not measured
7	Gi 3 (329-342)	75 E	7	7×10^{-11}
	Gi 6 (443-452)	75 E	1	7×10^{-10}
8	-	70 SW *	10 *	-
9	-	70 N *	5 *	-
10	-	90 *	5 *	-

* Calculated from geophysical information

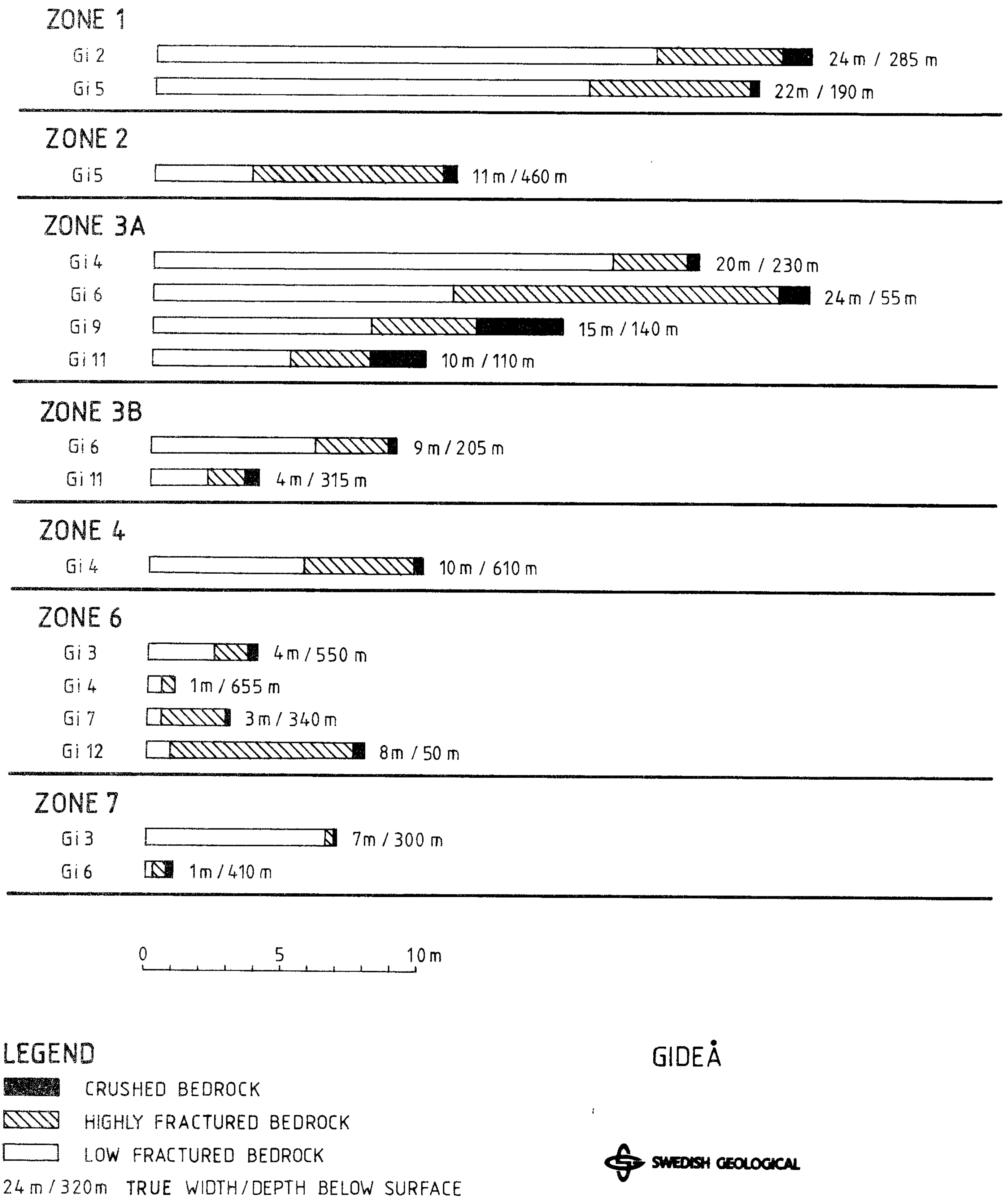


Figure 5.5 Percentage of crushed, highly fractured and low fractured bedrock in the fracture zones at Gideå. Fracture zone width and the depth where it is located in the drill hole are given after each bar.

Within the fracture zones there are as a rule, one or more crushed zones, generally one or a few dm wide. There are also parts characterized by a low fracture frequency in the fracture zones. A specification of the proportion of crushed and fractured rock in the fracture zones as well as rock of low fracture frequency is presented in fig 5.5. Crushed rock is defined in the drill core as rock-type fragments which cannot be combined into a complete drill core. Highly fractured rock in the drill core has a fracture frequency in excess of 10 fractures/m. Low fracture frequency corresponds to the normal fracture frequency at the level concerned. Core losses are defined in fig 5.5 as crushed rock. More detailed definitions of these concepts are provided by Ahlbom et al. (1983).

The zones are dipping 30-90 degrees to the horizontal plane. Down to the 100-200 metre level there are horizontal release joints. Deeper down in the bedrock no horizontal fracture zones have been observed.

Within the local fracture zones and in the dolerite dikes there are parts containing weathered and clay-altered rock. This has a sealing effect on the fracture zones and on the dolerites. Commonly occurring fracture minerals in the local fracture zones are calcite, chlorite, laumontite, pyrite and the clay minerals smectite and illite.

5.3 Rock mass fracturing

The fracturing of the rock mass has been mapped on outcrops and on drill cores. Fractures observed on the surface have two main orientations, viz. north and north-east. The latter direction is in accordance with the structure of the gneiss. The frequency of fractures longer than 0.5 m on the outcrops is 1.2 fractures/m.

The fracture frequency variation with depth in the rock mass, between the fracture zones, is indicated in fig 5.6. The fracture frequency is greater than 4.0 fractures/m down to the 400 m level. Below 500 m, the fracture frequency is 2.0 fractures/m. The higher fracture frequency of the drill cores as compared with the outcrop measurements is due to the fact that the frequency of horizontal fractures, release joints, has been underestimated in the outcrop mapping. The drill core fracture frequency also comprises all fractures irrespective of length, in contrast to outcrop mapping where fractures shorter than 0.5 m have not been included. The fracture frequency is shown in figs 7.1-7.5.

The total fracture frequency for the various rock types irrespective of depth, is the lowest in veined gneiss, 4.2 fractures/m, and granite gneiss with 7.4 fractures/m. In dolerite the fracture frequency is markedly higher, 20.6 fractures/m. In the fractures of the rock mass the same minerals are present as in the local fracture zones.

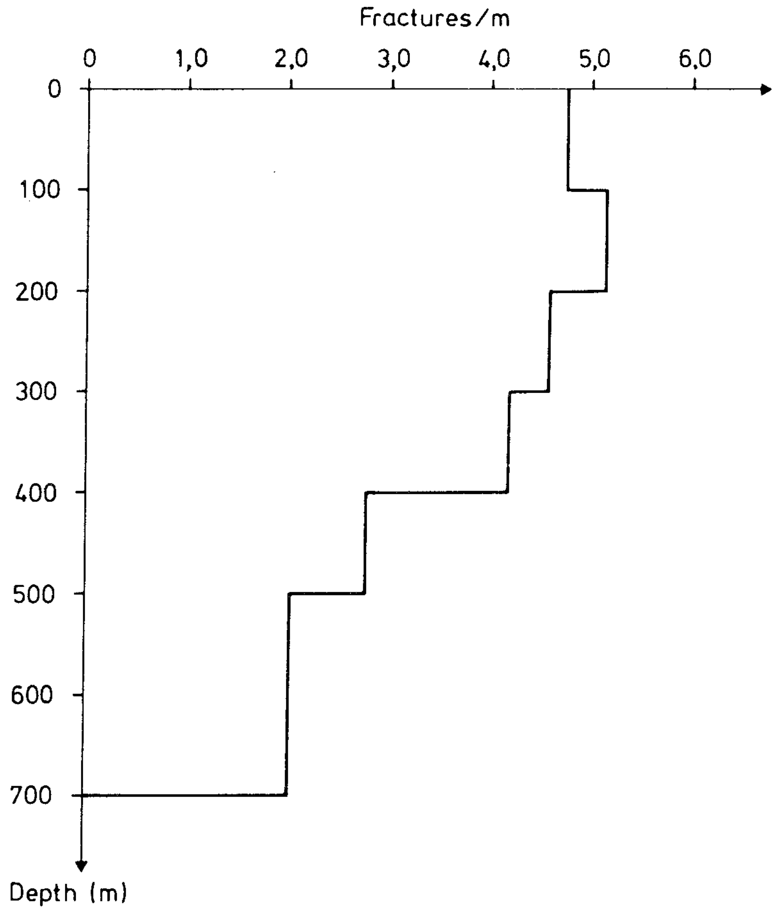


Figure 5.6 Fracture frequency in rock mass within site Gideå.

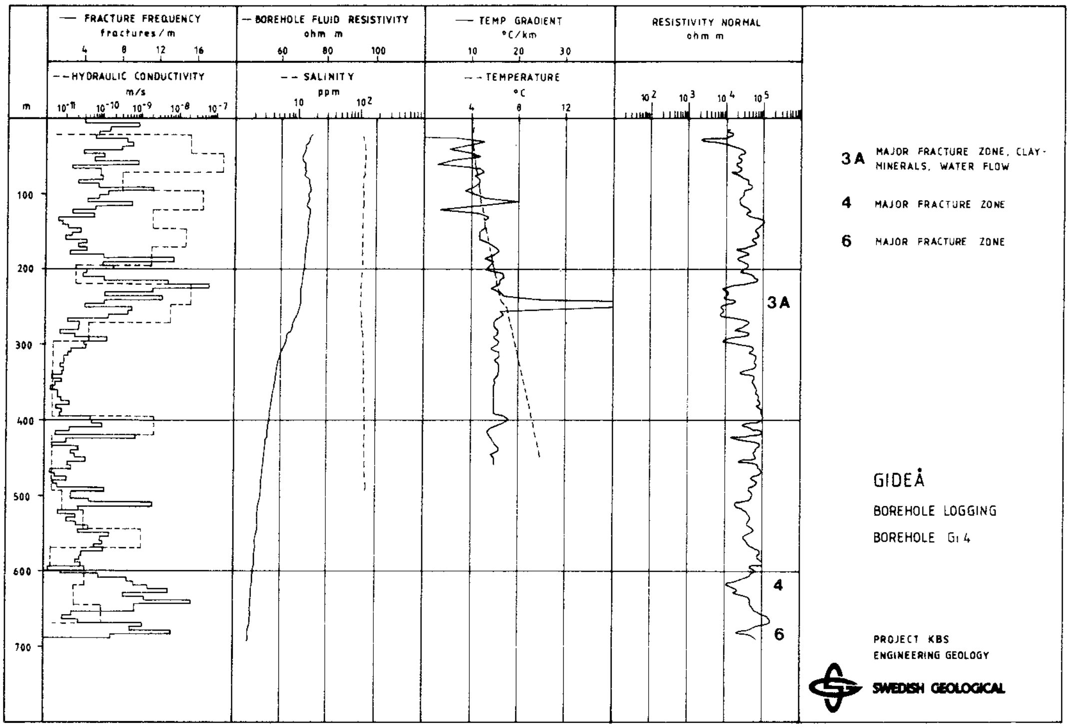


Figure 5.7 Results from logging of borehole Gi 4.

6. HYDROLOGICAL AND METEOROLOGICAL CONDITIONS

6.1 General

Hydrological and meteorological data and conditions in the Gideå study site are based on statistical information obtained from SMHI (the Swedish Meteorological and Hydrological Institute). The meteorological station at the Örnsköldsvik airport approx 10 km south-west of the Gideå study site has supplied meteorological information.

The Gideå study site is located on the water divide between two drainage areas. The northern part of the area is drained towards the north-east by small streams to the stream Husån. The remaining part of the area is drained towards the west by small streams to the river Gideälven. The stream Husån and the river Gideälven run into the Baltic after 19 and 16 km, respectively. There are no lakes in the study site. The total drainage area of the river Gideälven covers 3425 km^2 and that of the stream Husån 579 km^2. The comparatively elevated position of the study site in the terrain, in relation to its surroundings, implies that it can be regarded as a recharge area. Minor local discharge areas are found in low-lying parts, in most cases consisting of peat bogs.

6.2 Precipitation and temperature

In addition to the SMHI meteorological station (13824) at Örnsköldsvik airport, c. 10 km south-west of the Gideå study site, there are a number of meteorological stations in the vicinity of the Gideå site, which are listed in table 6.1.

Table 6.1 Meteorological stations in the vicinity of the Gideå study site

Station	nr	Distance from Gideå	Annual mean precipitation	Note
Ö-viks airport	13824	10 km	765 mm	adj
Nordmaling	13934	25 km	640 mm	unadj
Bjurvattnet	13871	45 km	645 mm	unadj
Norrfors	13847	32 km	548 mm	unadj
Hemling	13440	35 km	555 mm	unadj
Kasa	13920	17 km	619 mm	unadj
Ö-vik	13818	30 km	717 mm	adj
Mellansel	13826	35 km	518 mm	unadj

The Örnsköldsvik airport has been regarded as the station most representative of all with regard to the precipitation conditions in the Gideå area. Precipitation data have been registered there since 1971. The station is situated at a level which coincides well with the mean altitude of the local precipitation area at the Gideå site, 107 m above sea level. The mean monthly precipitation at Örnsköldsvik airport is specified in table 6.2.

Table 6.2 Estimated monthly mean precipitation at Örnsköldsvik airport.

Precipitation	J	F	M	A	M	J	J	A	S	O	N	D	Year
mm unadj	46	37	34	38	38	53	73	81	65	61	73	61	660
mm adj	55	45	41	46	46	62	73	92	74	73	87	71	765
% snow	92	92	87	37	2					12	54	70	

Of the annual mean precipitation, 33% is in the form of snow. Snow cover duration data have been obtained from measurement stations Mellansel and Nordmaling. At Mellansel, the ground is snow-covered for 160 days and at Nordmaling for 167 days. The duration of the ground frost period per annum is c. 143 days according to data from the Kasa meteorological station.

Table 6.3 Monthly mean temperature (^{o}C) at Örnsköldsvik airport, Hemling and Kasa

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Hemling	-10.7	-9.5	-5.1	0.3	6.3	12.3	13.9	12.4	7.5	1.9	-4.0	-7.8	+1.5
Kasa	-7.5	-7.8	-3.8	0.9	6.8	12.7	14.8	13.6	9.0	3.8	-1.8	-5.0	+3.0
Ö-viks airport	-8.5	-8.7	-4.4	0.5	7.0	13.2	15.1	13.7	8.8	3.3	-2.6	-5.8	+2.7

When estimating the temperature conditions at the study site, data from Örnsköldsvik airport, and the neighbouring stations Hemling and Kasa have been utilized. Table 6.3 shows monthly mean values. The annual mean temperature at Örnsköldsvik airport is c. +2.7^{o}C.

Measurement values from autumn 1981 until October 1982 relating to temperature, precipitation, and snow depth at Örnsköldsvik airport are detailed in the diagrams of figs 6.1 and 6.2.

6.3 Evaporation

Values of potential evaporation have been obtained from the Bredbyn and Vännäs meteorological stations. Values of the actual evaporation in the Gideå site have been interpolated from the isoline evaporation chart of Sweden (Eriksson, 1980). The potential evaporation amounts to 420 mm/year, the actual evaporation having been estimated at 410 mm/year in the Gideå area. Table 6.4 specifies potential and actual evaporation as monthly mean values.

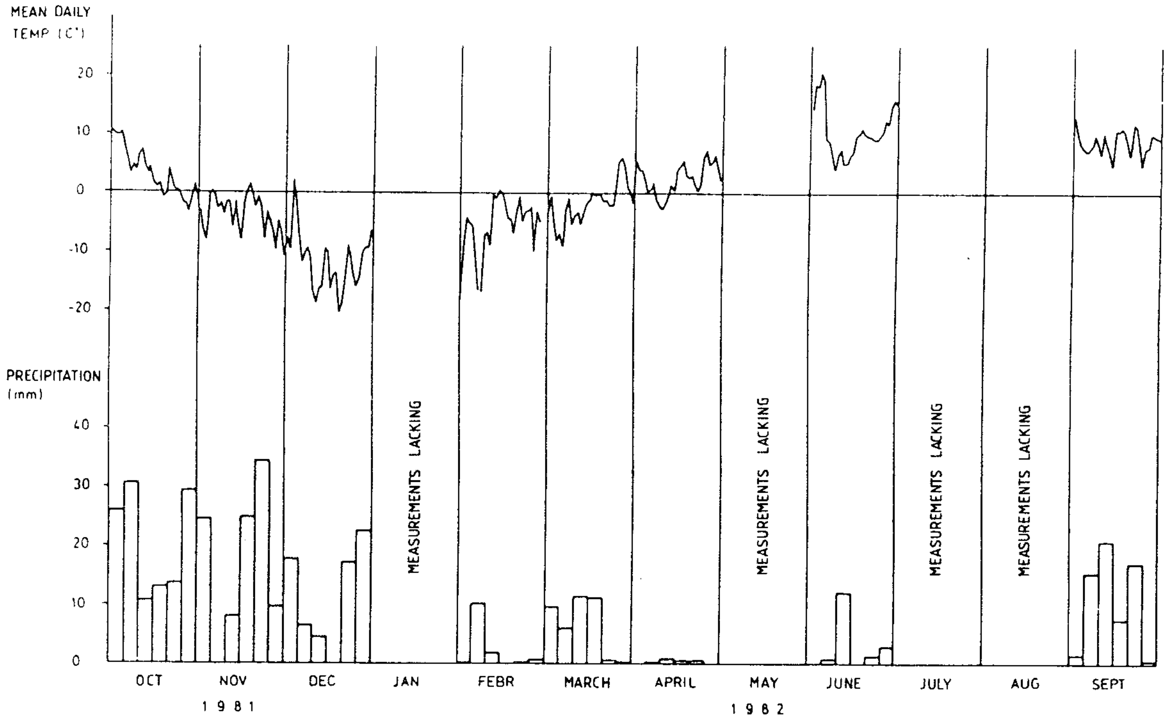


Figure 6.1 Mean daily temperature and the sum of five days' precipitation at Örnsköldsvik airport Oct. 1981 - Sept. 1982.

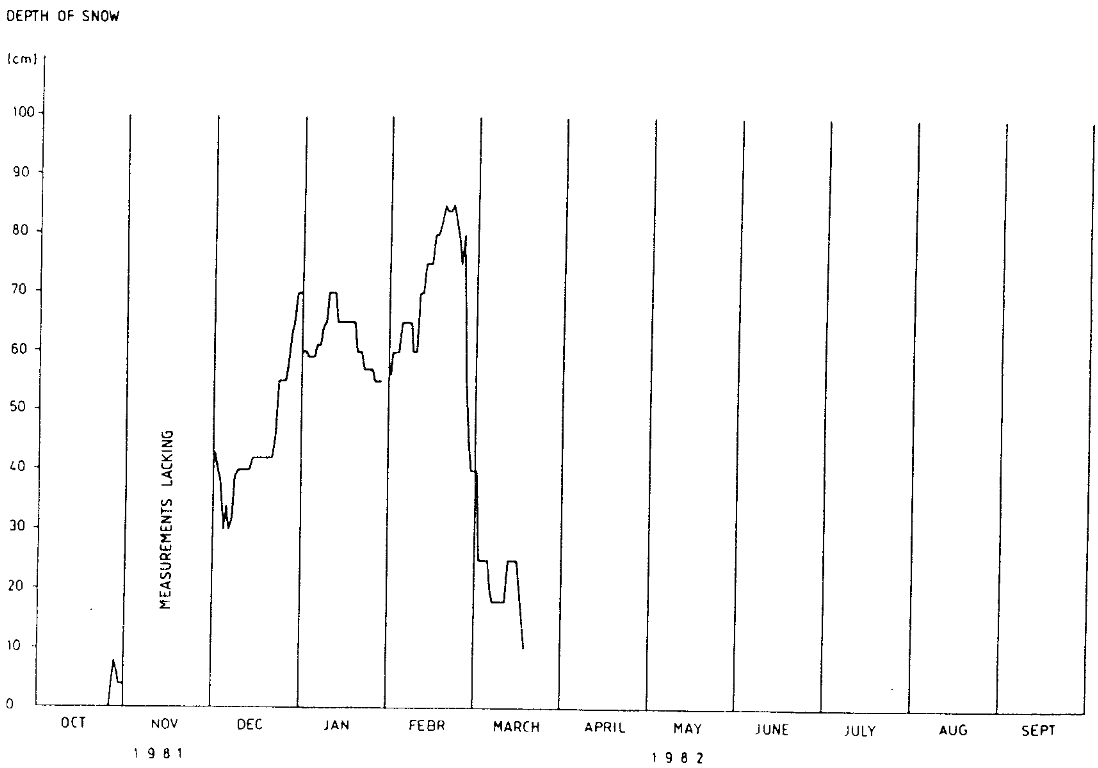


Figure 6.2 Depth of snow at Örnsköldsvik airport Oct. 1981 - Sept. 1982.

Table 6.4 Potential evaporation (mm) data from the Bredbyn and Vännäs stations, and estimated actual evaporation in the Gideå area.

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Potential													
Bredbyn	-1	1	5	22	79	122	104	73	30	6	-1	-1	420
Vännäs	0	1	6	19	70	112	102	68	31	9	1	0	416
Adjusted													
Gideå	0	0	5	20	75	110	100	65	28	7	0	0	410

6.4 Run-off

The Gideå study site is, as already mentioned, located on a plateau constituting the water divide between the stream Husån drainage area to the north-east and that of the river Gideälven to the west. Run-off data are available from water discharge measurements in the river Gideälven at Björna c. 25 km west-north-west of the Gideå site. The drainage area above Björna is 3017 km^2 whereof 5% is lake area. The mean discharge and the mean run-off indicated by observations made between years 1923 and 1975 have been estimated at 32 m^3/s, i.e. 10.5 $l/s\ km^2$.

There are no run-off observations for the Gideå study site, which has an area of 27 km^2. Setting out from observation data from other water courses with similar hydrological conditions the run-off pattern during a c. 50-year period have been simulated. Table 6.5 presents these estimated run-off values which should be regarded as approximate.

Table 6.5 Characteristic run-off values estimated for the Gideå study site

Highest flood run-off	300 $l/s\ km^2$
Mean flood run-off	130 "
Highest mean run-off	20 "
Mean run-off	11 "
Lowest mean run-off	4 "
Mean low water run-off	0,5 "
Lowest low water run-off	0,1 "
Drainage basin	c. 20 km^2
Proportion lake area	0%

Annual mean run-off amounts to 11 $l/s\ km^2$ (345 mm year). In table 6.6 estimated run-off per month is specified.

The run-off is low during the winter, in March and in August. Except for a peak, 50 $l/s\ km^2$, in May, the run-off is comparatively evenly distributed, between 8 and 12 $l/s\ km^2$, during the remaining part of the year.

Table 6.6 Monthly mean run-off ($l/s\ km^2$) for the Gideå study site

Monthly mean run-off	J	F	M	A	M	J	J	A	S	O	N	D	Year
$l/s\ km^2$	3	2	2	11	50	11	10	6	8	12	10	7	11

The distribution of the run-off over an individual year is indicated by the duration curve in fig 6.3.

6.5 Water balance

The water balance at the study site is determined by the following factors: precipitation, evaporation, run-off, change in storages and ground-water flow through the boundaries of the area. The precipitation amounts to the total of the other factors.

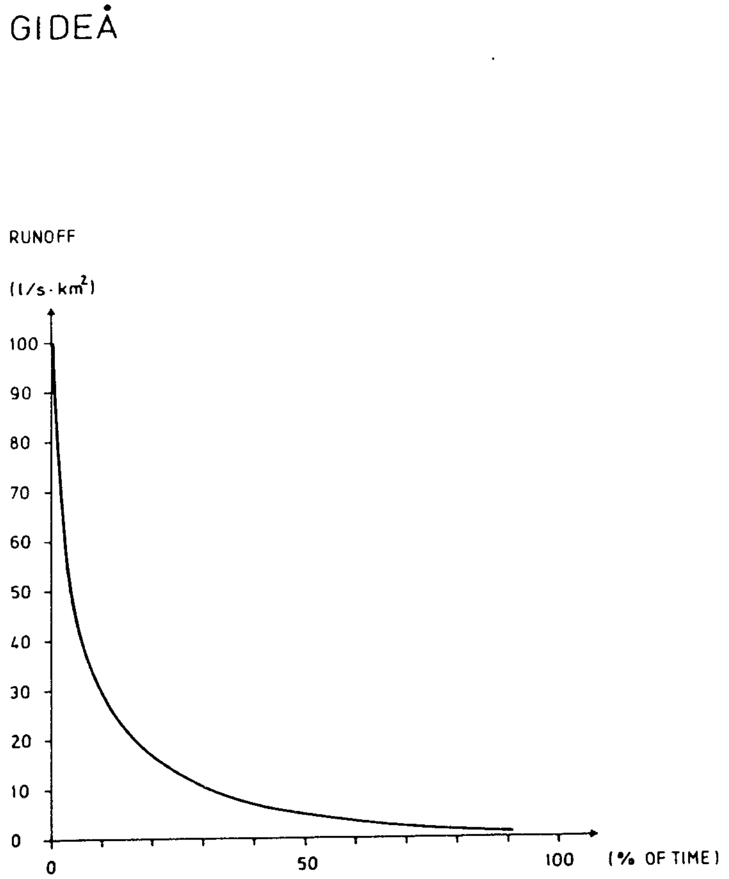


Figure 6.3 Duration curve for the Gideå site.

In Gideå, adjusted precipitation and actual precipitation have been estimated irrespectively of the run-off estimates. The values of precipitation and evaporation are subject to some uncertainty. The uncertainty of the annual values is probably of the magnitude 25 mm. The error in the annual run-off value is estimated at 10 mm. The water balance with respect to the Gideå site during the period 1951-80 will consequently be:

Adjusted precipitation	765 ± 25 mm/year
Actual precipitation	410 ± 25 mm/year
Run-off	345 ± 10 mm/year

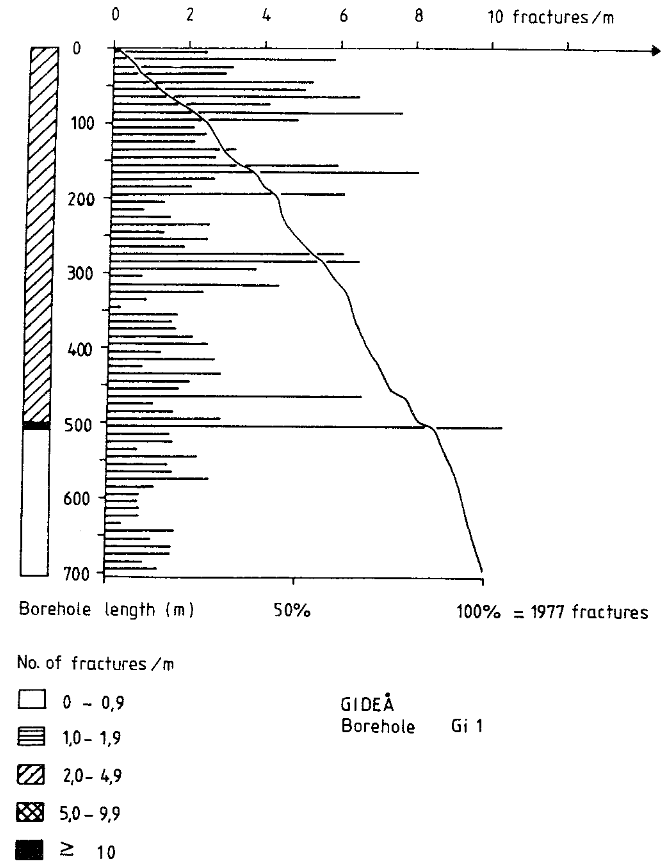
The difference between annual precipitation and evaporation plus run-off is 10 mm (0.32 l/s km^2), corresponding to c. 3% of the annual run-off. The difference may be caused by the uncertainty in the estimated basic values and should be regarded as acceptable. Thus, of the precipitation approx 55% will be accounted for by evaporation and 45% by run-off. The groundwater drainage through the boundaries of the site or via the bedrock is negligible.

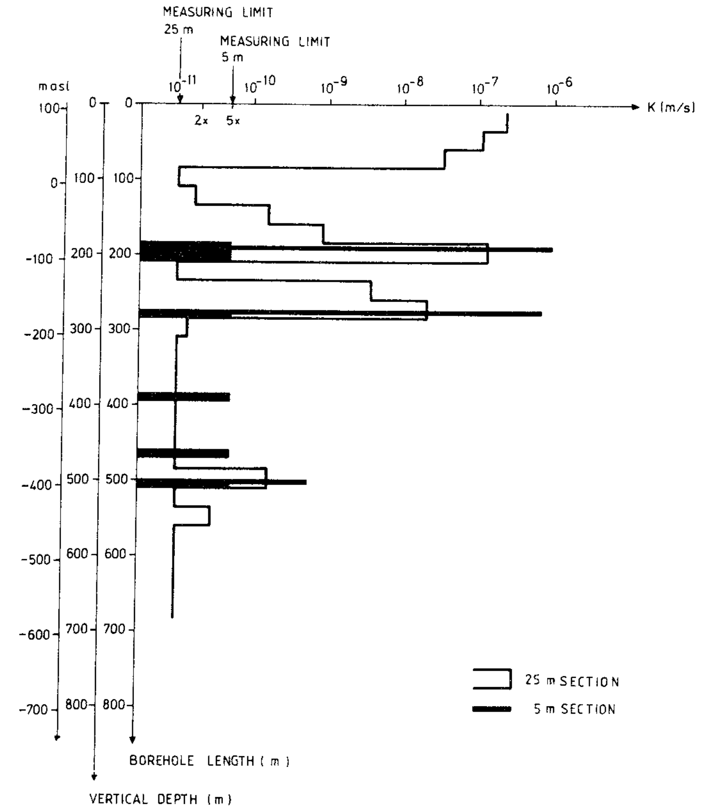
7. HYDRAULIC PROPERTIES OF THE BEDROCK

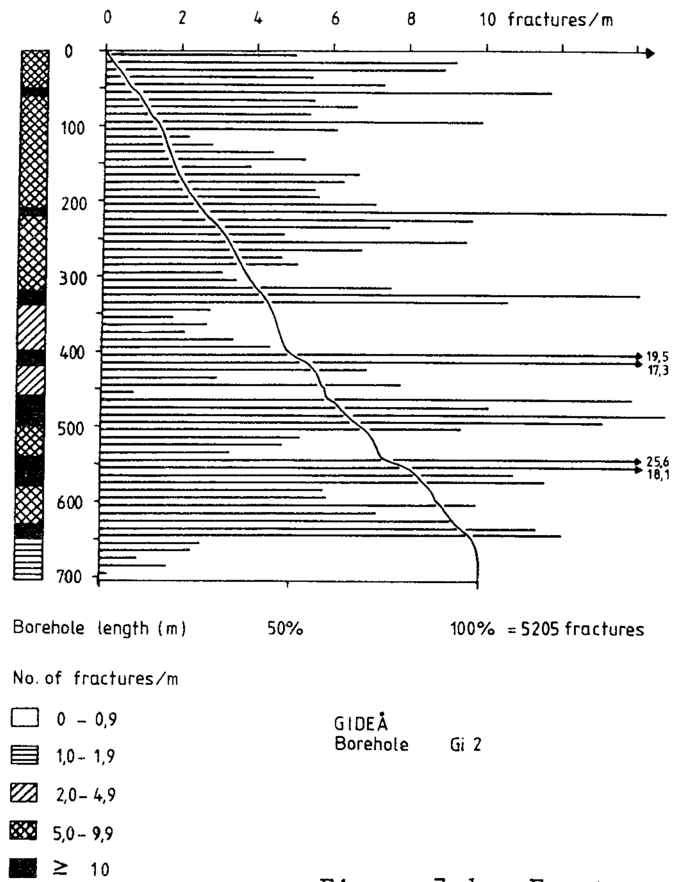
7.1 Hydraulic tests

The hydraulic conductivity (K) of the bedrock has been determined by means of water injection tests in core drill holes Gi 1 - Gi 13. These tests have been carried out in delimited 25 m sections in the drill holes, beginning at 10-30 m below the ground surface down to c. 10 m from the bottom of the drill hole. A total of 308 sections of 25 m have been tested. The tests were carried out under constant head (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 measurement section sometimes have higher K-values than longer sections containing several fractures. The hydraulic conductivity is specified in figs 7.1-7.7 together with the fracture frequency of the drill holes concerned.

In all core drill holes, with the exception of Gi 6, the injection tests have been supplemented with detailed measurements where the section length has been either 5 m or 10 m. The number of detailed measurements comprises 102 sections. These measurements were carried out in sections of high hydraulic conductivity for the purpose of delimiting the conductive parts of the individual 25 sections. The detailed measurements also constitute a way of checking the results from the 25 m sections. By comparing the transmissivity (T) (the hydraulic conductivity multiplied by the section length) from the measurements of different section lengths, an estimate is obtained of the reliability of the results. For the different sections, the relationship between the transmissivity of the 25 m and 5-10 m sections, respectively, have been specified in a way to make the result always greater than 1. The correspondence is satisfactory for the majority of the sections. Only in a few cases, the T-quotient is larger than 2. Of these cases, 50%, viz. the 3 highest T-quotients, are the result of one of the measurement sections having indicated a hydraulic conductivity







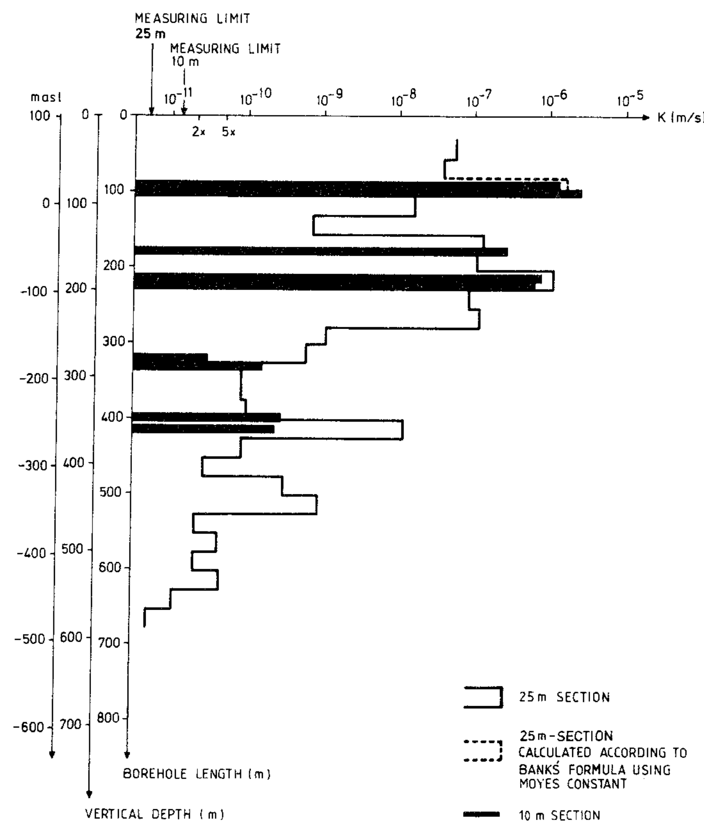
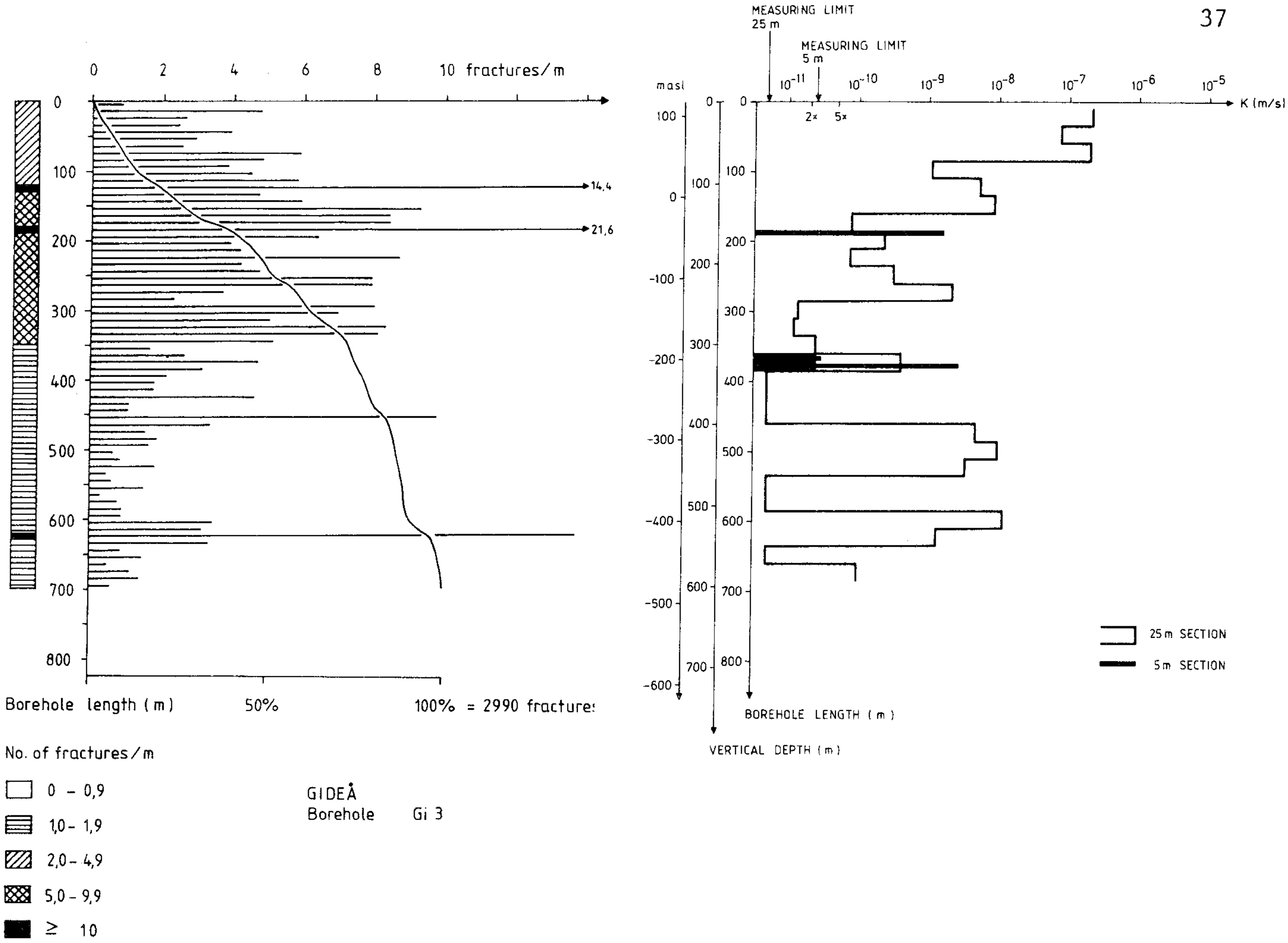
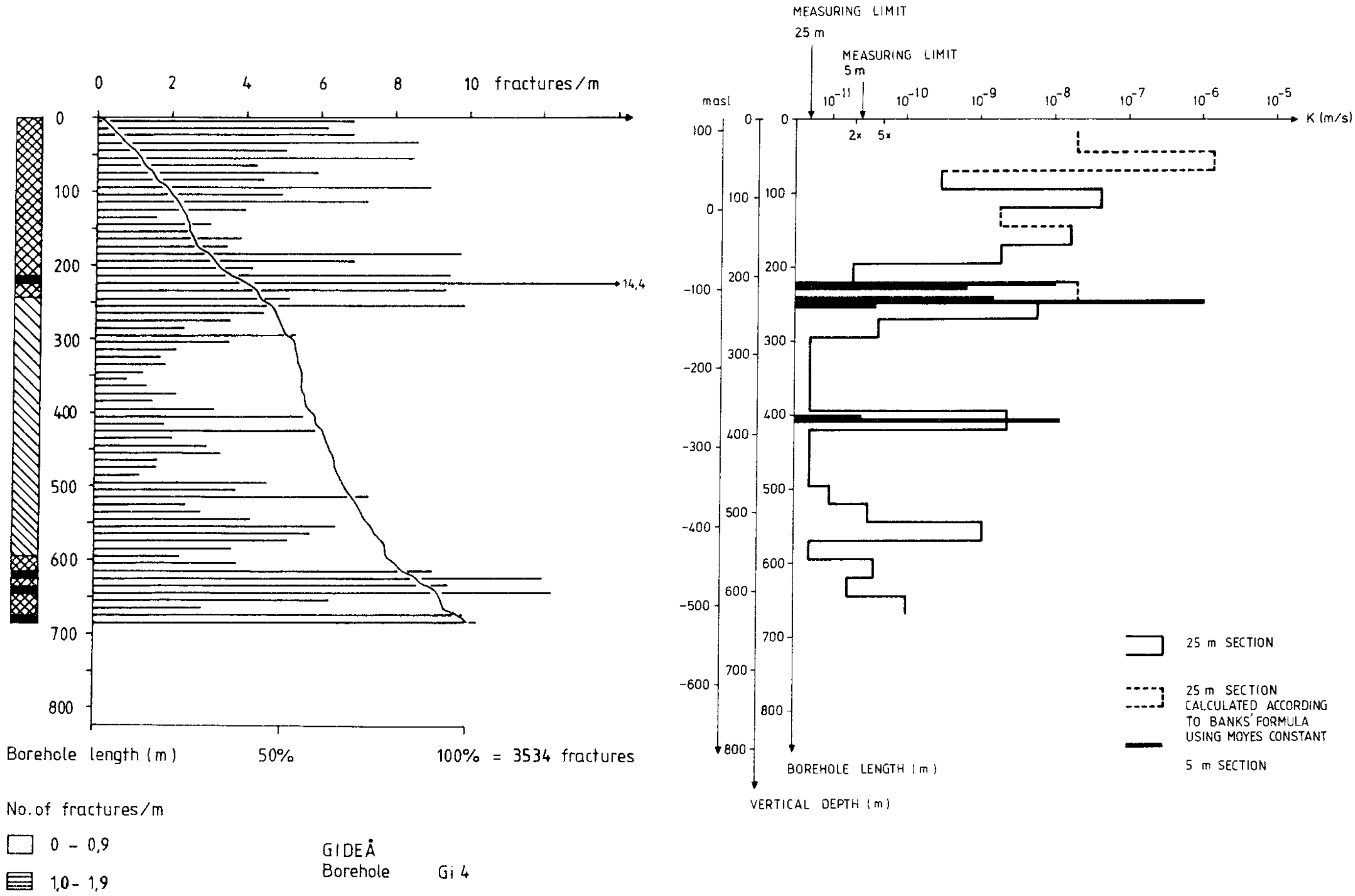


Figure 7.1 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, drill holes Gi 1 and Gi 2.





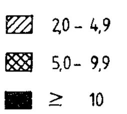
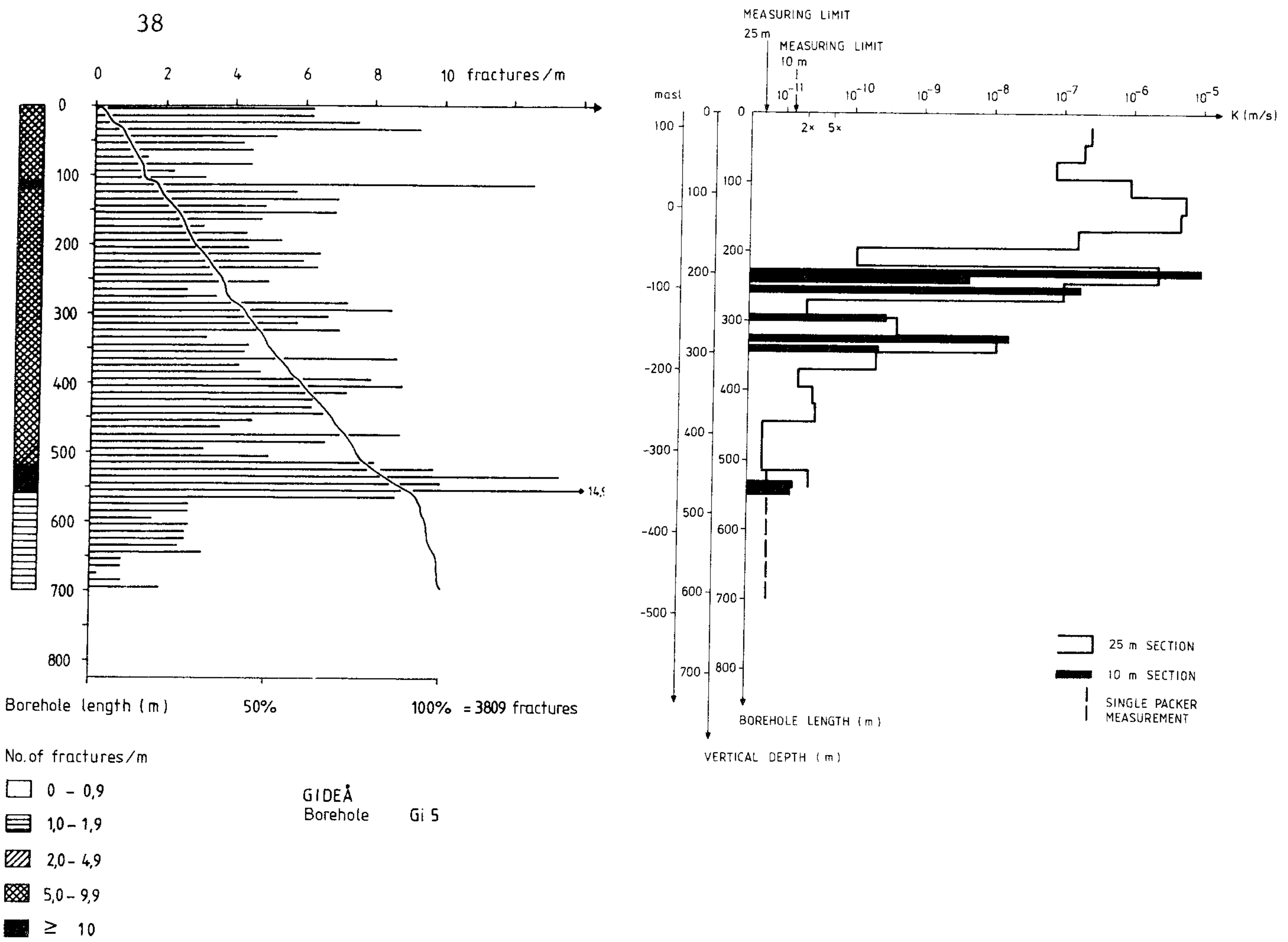
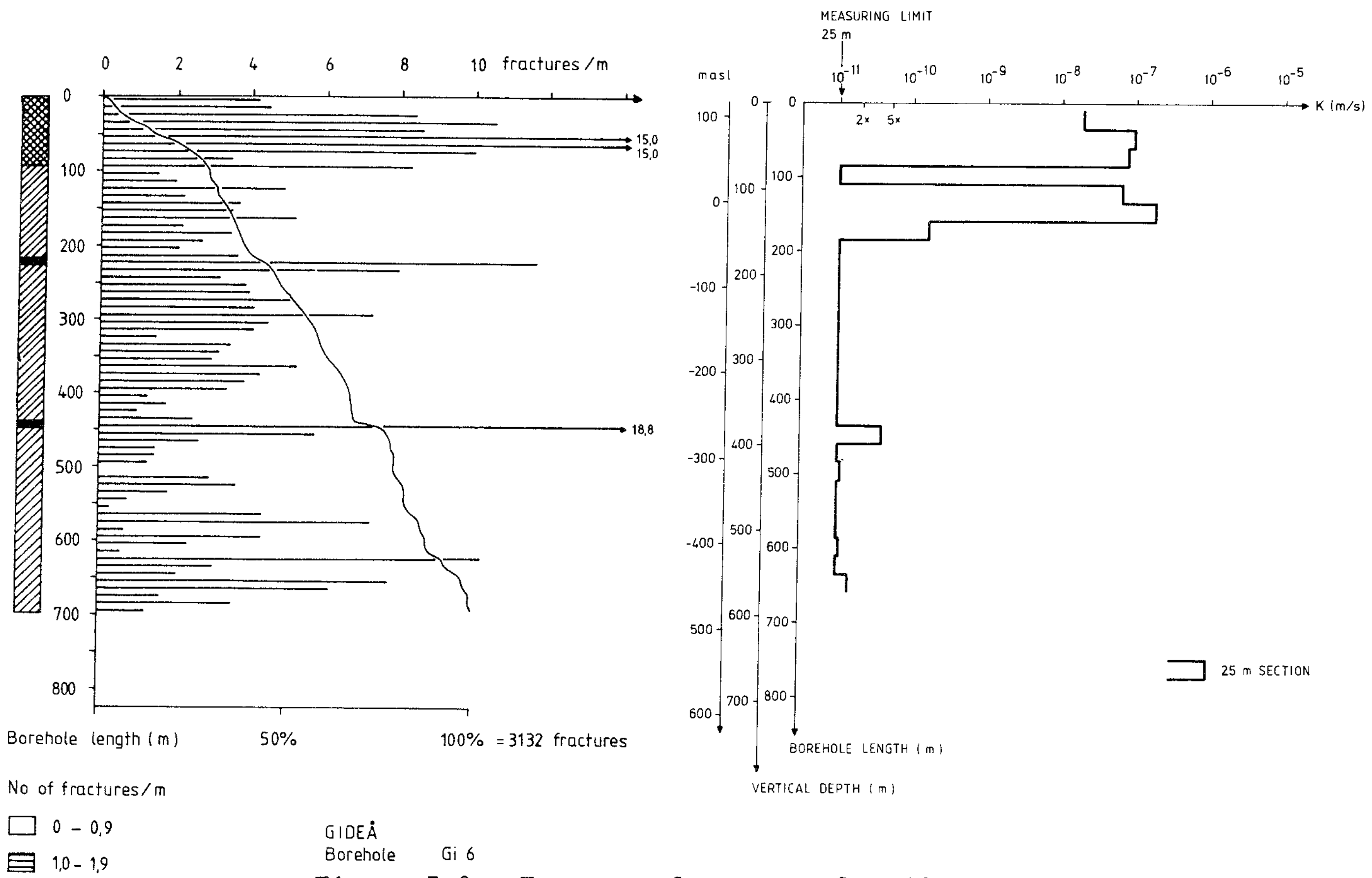


Figure 7.2 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, drill holes Gi 3 and Gi 4.





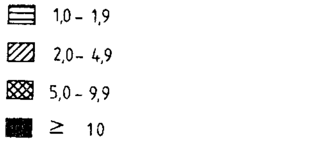
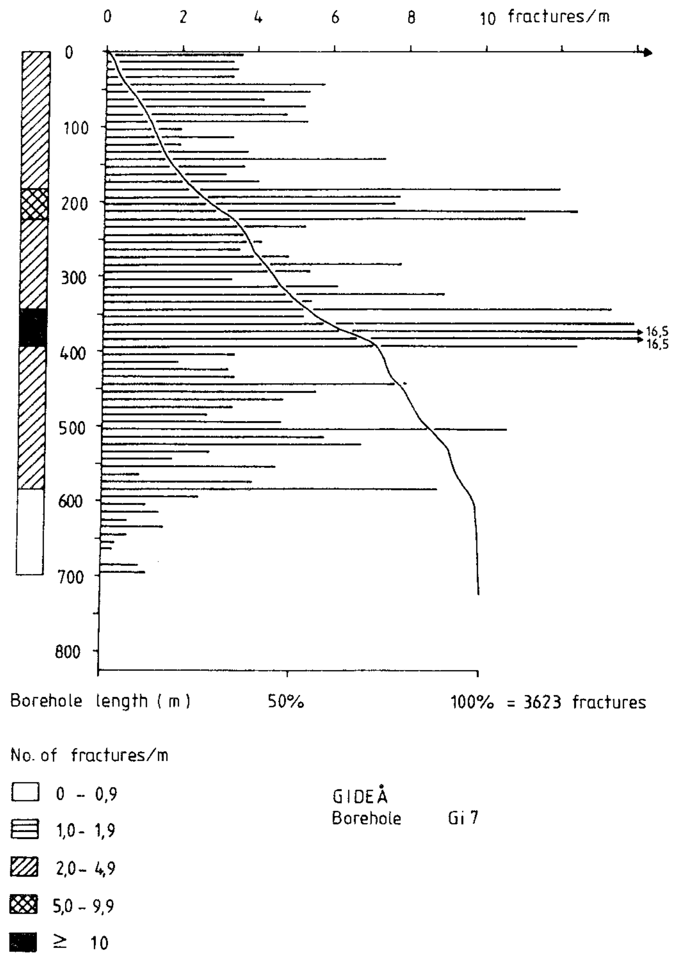
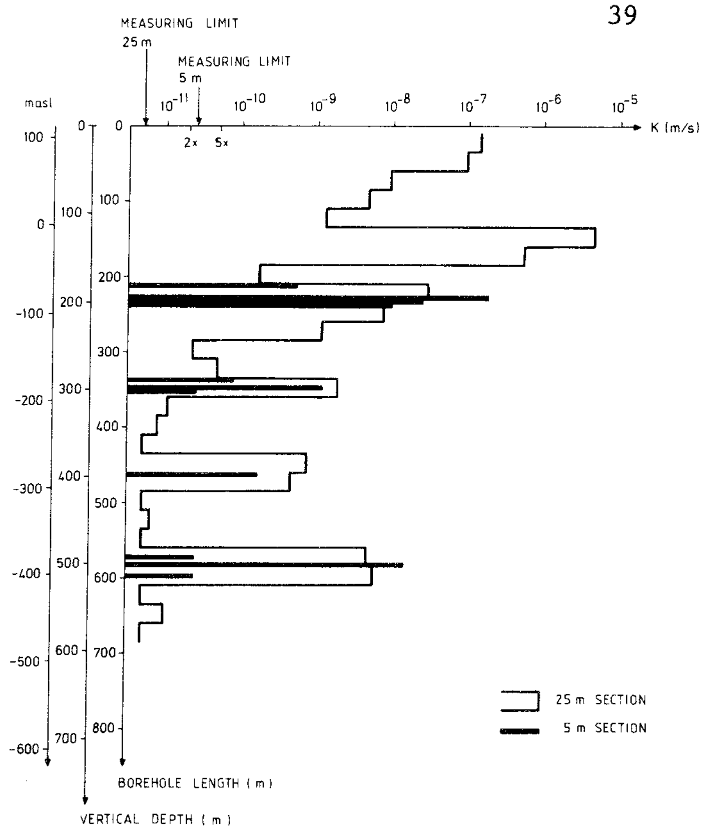
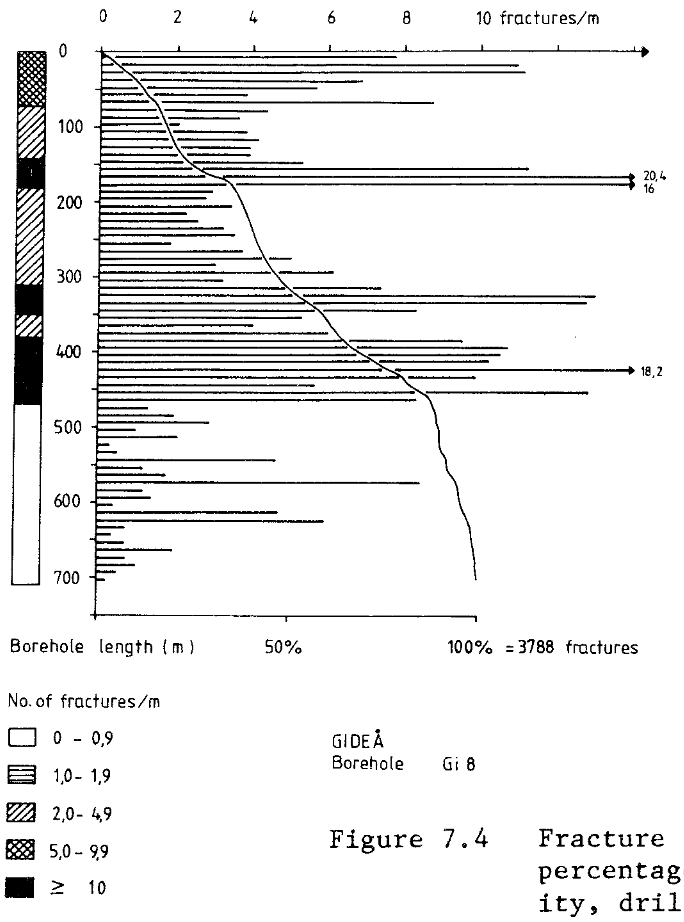


Figure 7.3 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, drill holes Gi 5 and Gi 6.







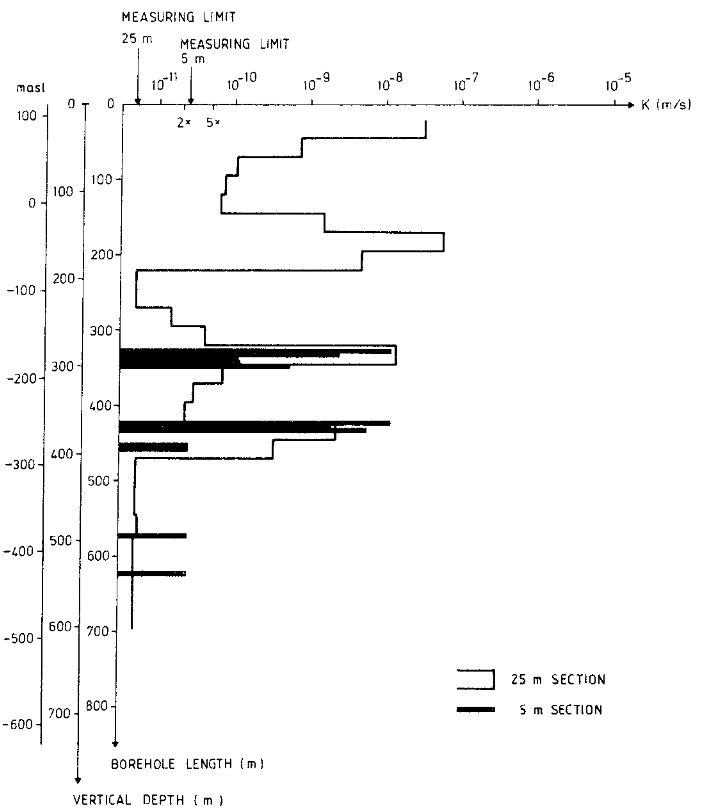
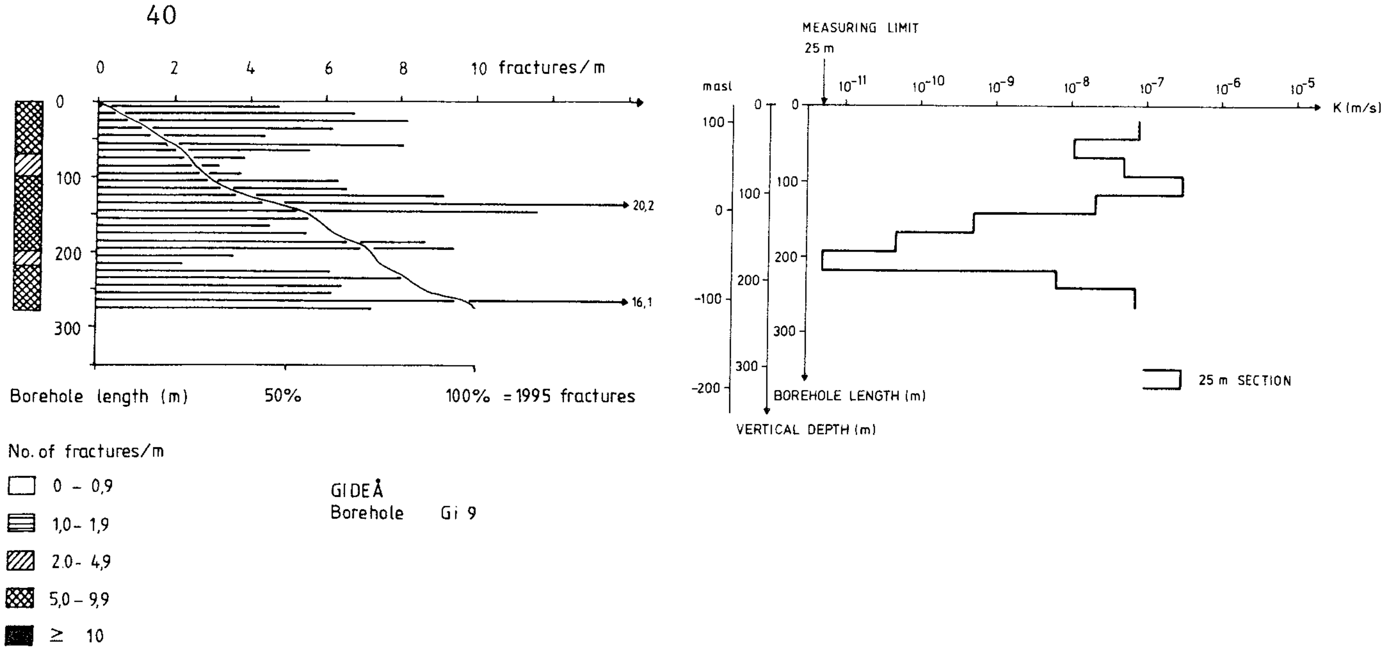


Figure 7.4 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, drill holes Gi 7 and Gi 8.



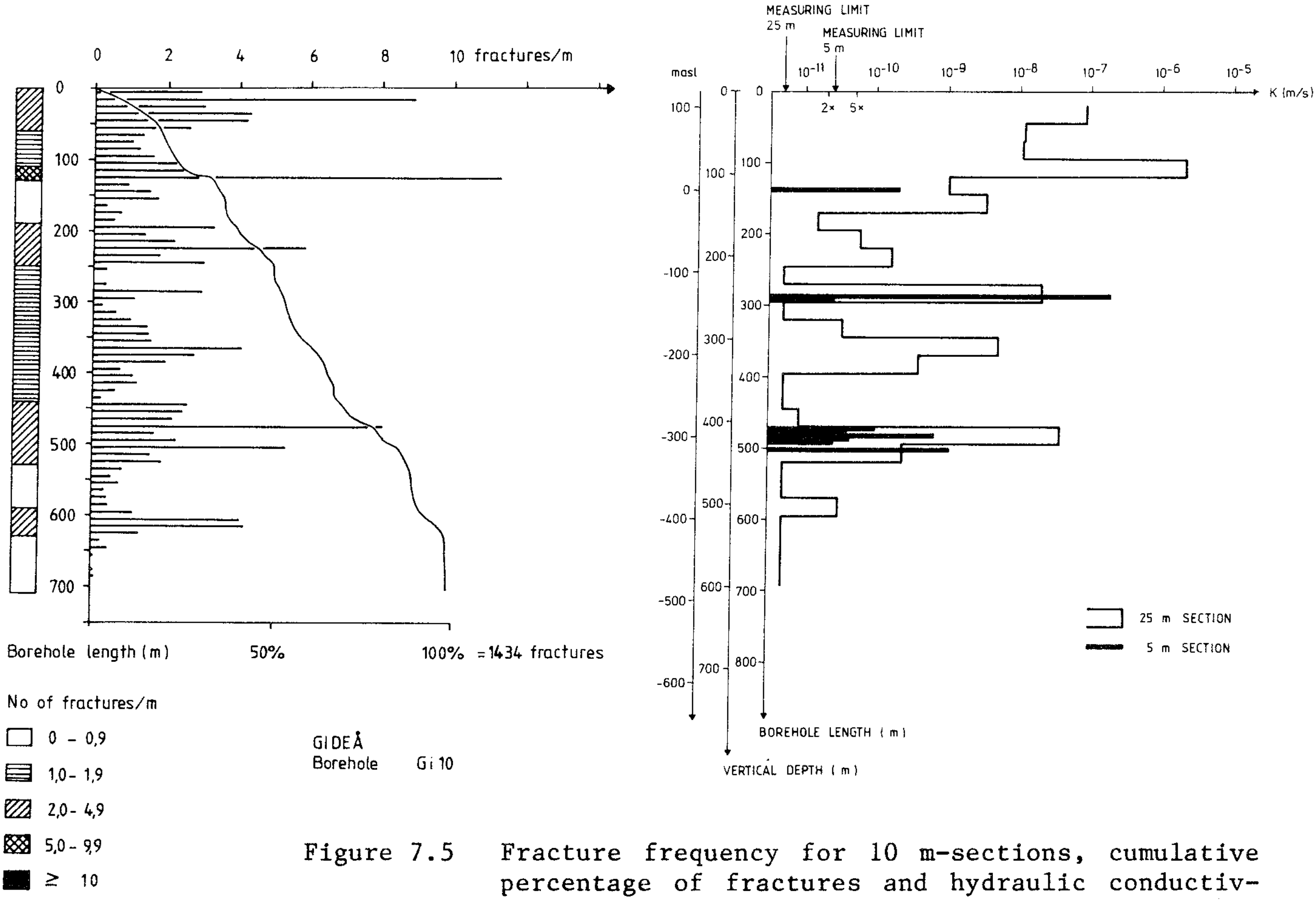
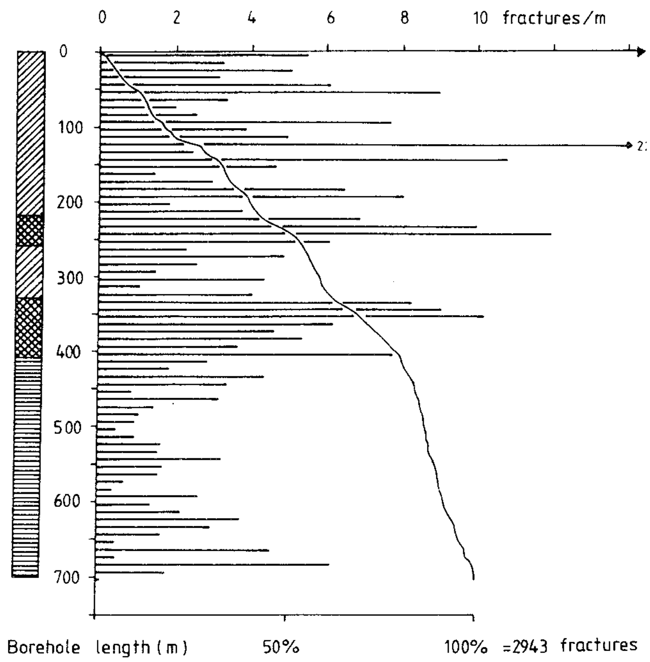
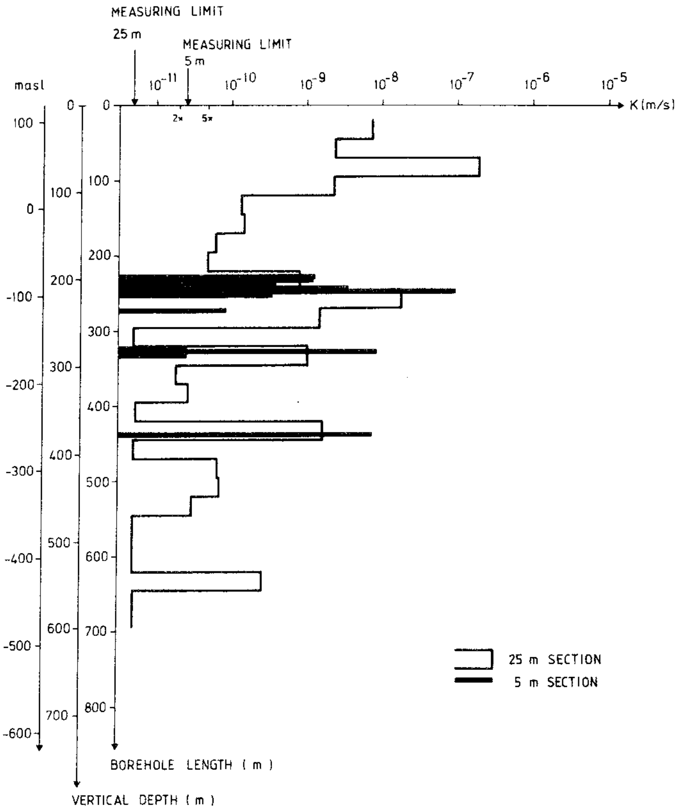


Figure 7.5 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, drill holes Gi 9 and Gi 10.

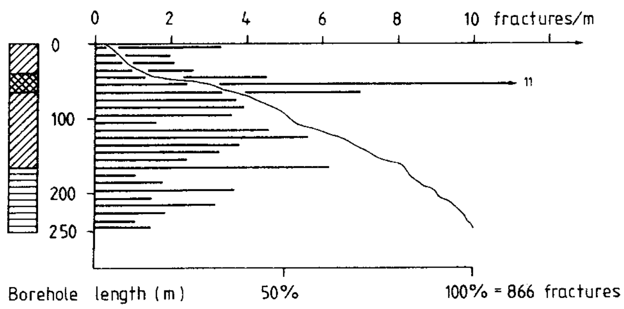


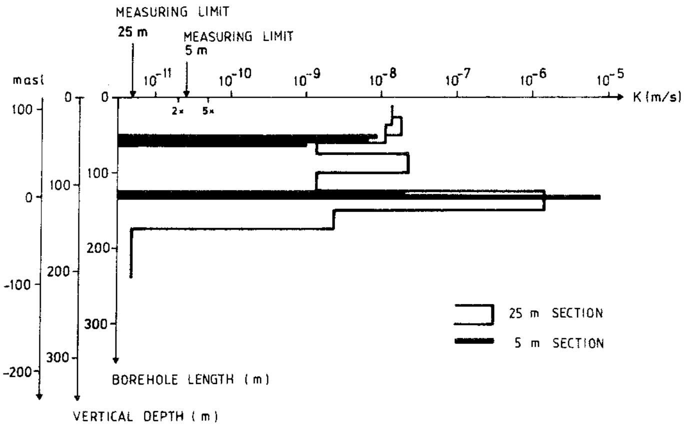


No. of fractures/m

- 0 - 0,9
- 1,0 - 1,9
- 2,0 - 4,9
- 5,0 - 9,9
- ≥ 10

GIDEÅ
Borehole Gi 11





No. of fractures / m

- 0 - 0,9
- 1,0-1,9
- 2,0-4,9
- 5,0-9,9
- ≥ 10

GIDEÅ
Borehole Gi 12

Figure 7.6 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, drill holes Gi 11 and Gi 12.

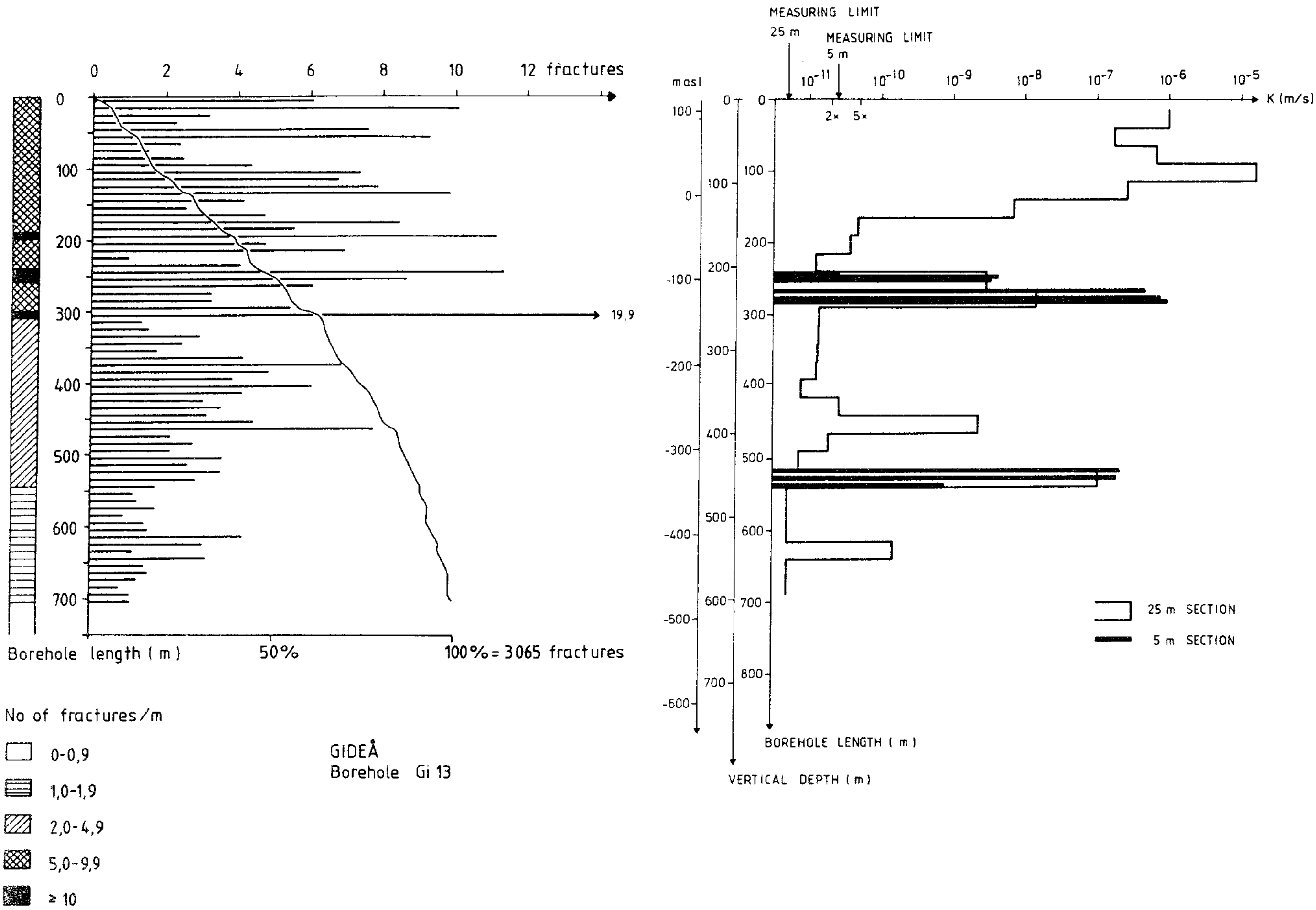


Figure 7.7 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, drill hole Gi 13.

lower than the measurement limit, which means that one of the values is the result of a leakage. The sections subjected to control measurement are given in table 7.1.

A test pumping was made in the central part of the study site in order to determine the hydraulic conductivity in fracture zone 1, fig 5.3. The zone is of north-easterly strike, dipping c. 40 degrees towards the south-east. The test pumping was performed in percussion drill hole HGi 24 for a duration of 18 days at a capacity of 2400 l/h (40 l/min). In addition to the measurements in the pump hole, variations in groundwater head were recorded in observation holes HGi 1, 5, 20, and 23, fig 8.1. All observation holes were sealed off with packers in three measurement sections. The middle section comprised the part estimated to be in contact with the fracture zone. After completed pumping, the recovery was measured for 17 days. The evaluation was made according to transient analysis methods.

7.2 Results

7.2.1 Hydraulic units

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

- rock mass
- local fracture zones

The classification is based on results from the geological and tectonic investigations which indicate the location and extension of existing local fracture zones. The occurrence of local fracture zones in the drill holes was determined on the basis of the drill core logs. The hydraulically tested 25 m sections not related to the zones represent the hydraulic conductivity in the rock mass. K-values from all core drill holes assigned to the rock mass are specified in fig 7.8.

GIDEÅ
Hydraulic conductivity (K)

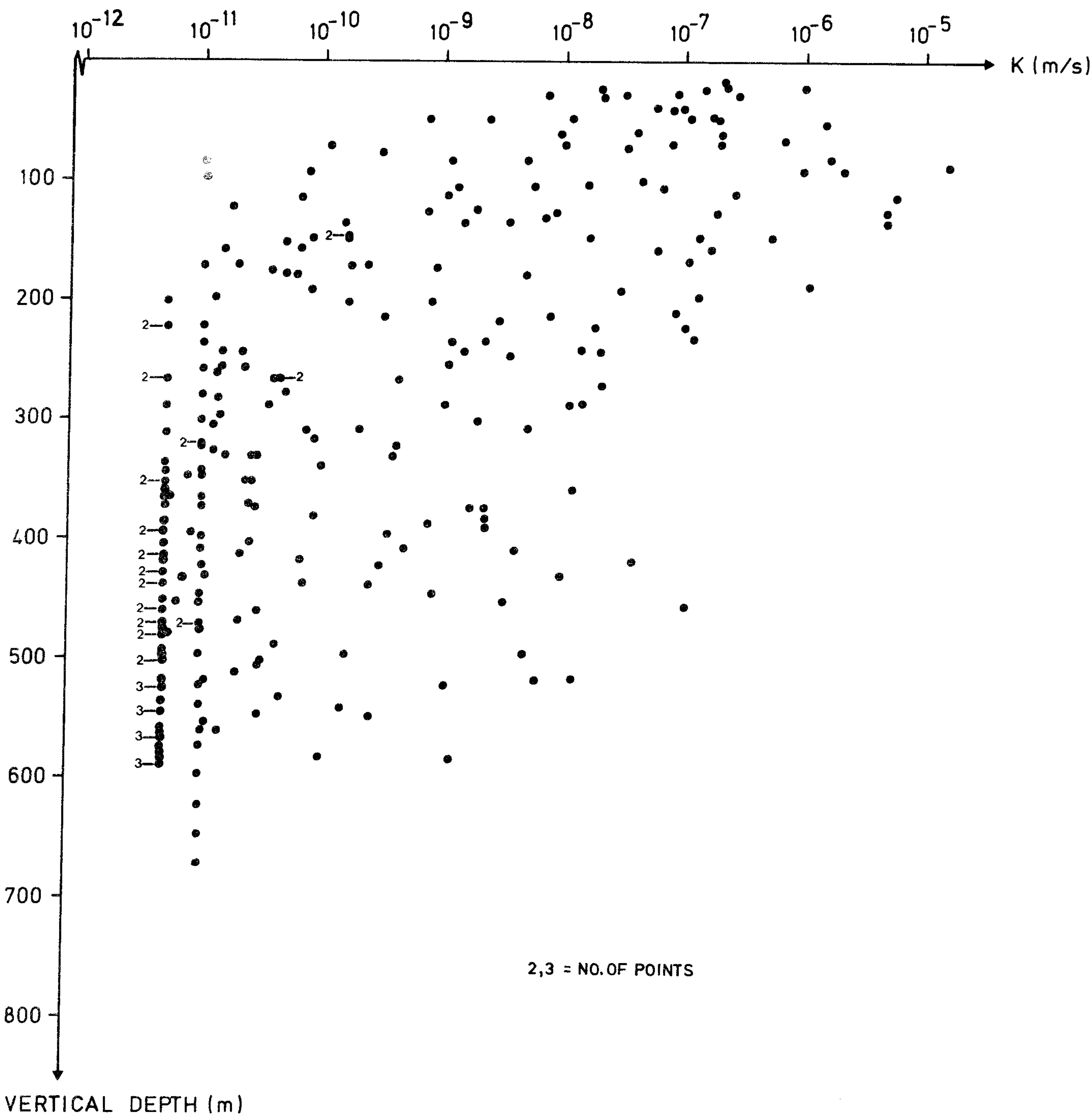


Figure 7.8 Hydraulic conductivity for rock mass (25 m-sections) in drill holes Gi 1 - Gi 8, Gi 10, Gi 11 and Gi 13.

Table 7.1 Comparison of the transmissivity between 25 m- and 5/10 m-sections in core drill holes at Gideå. The T-quotient defined to be greater than 1.

Drill holes 25 m section	T_{25} (m^2/s)	Parts with dominating flow	T_{DA} (m^2/s)	T-quotient 1	Notes
GI 1					T_{DA} = transmissivity in subparts
185-210	3.2 E-6	190-195	4.6 E-6	1.4	T_5 est acc Banks
260-285	5.4 E-7	275-285	3.4 E-6	6.3	
385-411	u.m.	385-395	u.m.	2	Control measurements
460-485	u.m.	460-470	u.m.	2	"
480-511	3.9 E-9	500-505	2.9 E-9	1.3	/u.m. = under measurement limits
Gi 2					
83-108	4.0 E-5	87.5-107.5	3.8 E-5	1.1	
158-183	3.3 E-6	175-185	3.7 E-6	1.2	
206-231	2.7 E-5	210-230	1.5 E-5	1.8	
328-353	2.1 E-9	327.5-337.5	1.6 E-9	1.3	
378-403	2.5 E-9	395-405	2.8 E-9	1.1	
Gi 3					
185-210	5.8 E-9	185-190	8.1 E-9	1.4	
360-385	1.0 E-8	375-380	1.3 E-8	1.3	
Gi 4					
395-420	5.7 E-8	405-410	5.9 E-8	1.0	
Gi 5					
220-245	5.8 E-5	225-235	9.3 E-5	1.6	
245-270	2.6 E-6	250-260	1.8 E-6	1.4	
320-345	2.8 E-7	320-330	1.7 E-7	1.7	
Gi 7					
210-235	7.2 E-7	225-235	1.1 E-6	1.5	
235-260	1.9 E-7	235-240	4.9 E-8	3.9	
560-585	1.2 E-7	580-585	7.8 E-8	1.5	
Gi 8					
345-370	1.8 E-9	345-350	2.8 E-9	1.6	
420-445	5.7 E-8	420-435	9.6 E-8	1.7	
570-595	u.m.	570-575	u.m.	1	Control measurements
629-546	u.m.	620-625	u.m.	1	"

Drill holes 25 m section	T_{25} (m^2/s)	Parts with dominating flow	T_{DA} (m^2/s)	T-quotient 1	Notes
Gi 10					
270-295	5.3 E-7	285-290	9.5 E-7	1.8	
495-520	6.3 E-9	500-505	5-4 E-9	1.2	
Gi 11					
220-245	2.0 E-8	240-245	1.7 E-8	1.2	
245-270	4.5 E-7	245-250	4.6 E-7	1.0	
320-345	2.6 E-8	325-330	4.2 E-8	1.6	
420-445	4.2 E-8	440-445	3.7 E-8	1.1	
Gi 12					
50- 75	3.4 E-8	50- 60	7.6 E-8	2.2	
125-250	4.1 E-5	130-135	4.0 E-5	1.0	
Gi 13					
240-265	7.1 E-8	245-255	3.8 E-8	1.9	
515-540	2.6 E-6	515-520			
		525-530	2.0 E-6	1.3	

In the upper part of the rock mass down to 200 m, the hydraulic conductivity is evenly distributed between 1 x 10^{-11} m/s and 1 x 10^{-5} m/s. Between 200-300 m, there are only 9 measured values in excess of 1 x 10^{-8} m/s. Below 300 m there are only three measured values higher than 1 x 10^{-8} m/s. The high K-values in the uppermost part of the rock mass are due to the bedrock being more fractured here than at greater depths. Statistical evaluation of the prevalence of fractures in the drill cores indicates a decreasing fracture frequency with depth. The proportion of open fractures is probably higher in the upper part of the rock due to the comparatively small vertical rock stresses.

Below 200 m depth, the rock load generates greater vertical stresses and the proportion of open fractures as well as the fracture frequency is lower. The low hydraulic conductivity values also depend on the continuity of the fractures being less at greater depths.

Existing granite gneiss strata in the rock mass usually have a higher hydraulic conductivity than the veined gneiss. There is no correlation between the hydraulic conductivity of the strata and their width. The granite gneiss does not display any markedly increased fracture frequency in comparison with the veined gneiss.

Hydraulic conductivity calculated in the 25 m and 10 m sections have been compared with the results of the core logging. In fig 7.9 and table 7.2 the K-values of the fracture zones have been summarized. Zones appearing in more than one drill hole have been connected. The diagram shows that the hydraulic conductivity decreases with depth. The highest conductivity values have been obtained in the widest zones. On the other hand, no correlation between the direction of the fracture zones and hydraulic conductivity has been noted.

Table 7.2 Hydraulic conductivity (K) for the fracture zones in the Gideå study site

Zone	Vertical depth (m)	Hydraulic cond. (m/s)	Found in drill hole	Estimated width (m)
1	191	2.7×10^{-6}	Gi 5	25
1	279	6.5×10^{-10}	Gi 2	25
3A	57	1.5×10^{-7}	Gi 6	12
3A	108	1.4×10^{-9}	Gi 11	12
3A	224	1.6×10^{-8}	Gi 4	12
3B	200	6.9×10^{-12}	Gi 6	10
3B	302	6.5×10^{-11}	Gi 11	10
4	592	1.5×10^{-10}	Gi 4	5
6	49	2.0×10^{-9}	Gi 12	5
6	329	2.1×10^{-11}	Gi 7	5
6	542	4.6×10^{-9}	Gi 3	5
7	291	7.1×10^{-11}	Gi 3	5
7	388	1.1×10^{-10}	Gi 6	5

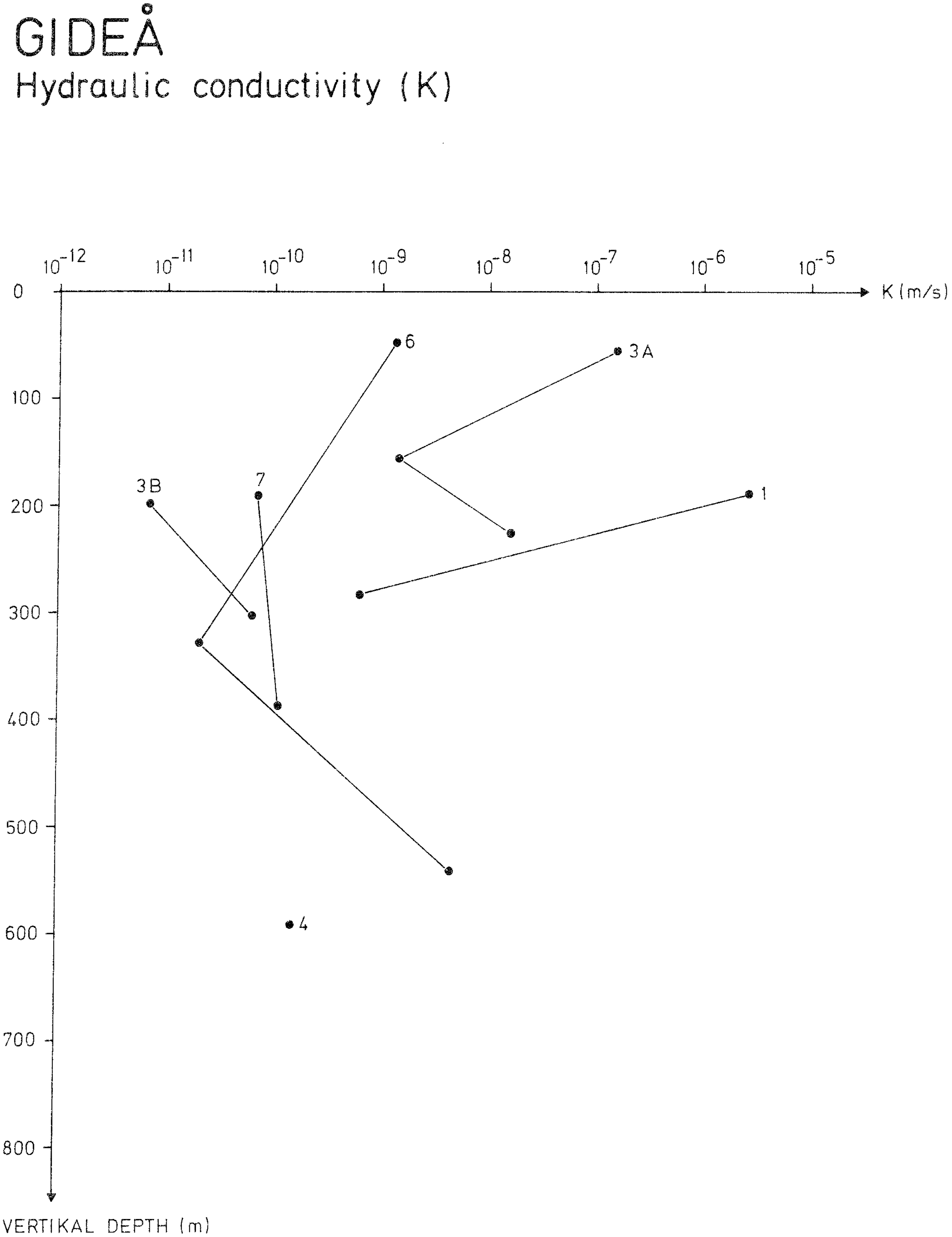


Figure 7.9 Hydraulic conductivity in local fracture zones penetrated by the drill holes Gi 2 - Gi 7, Gi 11 and Gi 12.

Results of the test-pumping of local fracture zone 1 indicate K-values between $5 \times 10^{-7} - 5 \times 10^{-6}$ m/s. This is well in accord with the results presented in chapter 7.3 where the hydraulic conductivity of local fracture zones down to 100 m depth fall within this interval.

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, respectively, has been calculated by means of regression analysis:

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

a,b = constants, z = depth

The power curve fit has given the best correlation. The results of the power curve regression are shown in figs 7.10-7.12. In the figures, a 95% confidence interval has also been indicated for the power curve relation, which means that there is a 95% probability that the curve is within the confidence limits.

In table 7.3 and fig 7.10 the obtained relations for the power curve are presented.

Table 7.3 The depth-dependence of the hydraulic conductivity for the hydraulic units of the bedrock

Hydraulic unit	Power curve	r^2	n
Rock mass	$K = 0.022\ xZ^{-3.33}$	0,46	264
Local fracture zones	$K = 0.085\ xZ^{-3.33}$	0,32	13

Z = depth in metres

The regression analysis indicates that the hydraulic conductivity in the local fracture zones is c. four times that of the rock mass.

As already mentioned, differences in hydraulic conductivity between different rock types have been confirmed. Granite gneiss strata in the dominating veined gneiss have, primarily at major depths, proved to have higher K-values than the surrounding gneiss. Veined gneiss or migmatite in connection to the granite gneisses also give higher K-values in relation to migmatite or veined gneiss without any granite gneiss elements. As a consequence, the rock mass has been divided into two hydraulic units, one representing the granite gneiss and one the remaining rock mass, mainly consisting of veined gneiss.

When calculating the hydraulic conductivity of the individual rock types, measured data from sections containing only veined gneiss, have formed the basis for the regression curve between depth and effective hydraulic conductivity. In the case of the measured sections containing granite gneiss and veined gneiss, the measured conductivity value has been reduced with the hydraulic conductivity value of the veined gneiss taken from the depth-conductivity relation obtained. Remaining hydraulic conductivity has been attributed to the granite gneiss according to the equation:

$$K_g = \frac{K_L \cdot L - K_v \cdot L_v}{L_g}$$

where

K_g = the granite gneiss K-value

K_L = K-value of 25 m section concerned

K_v = K-value of the veined gneiss at specified depth as obtained from the depth-relation, table 7.3

L_v = length of veined gneiss in the 25 m section

L_g = length of granite gneiss in the 25 m section

L = total length of section, 25 m

The result of the division into granite gneiss and veined gneiss is shown in table 7.4 and fig 7.13. Amphibolite and pegmatite are in this case included in the veined gneiss. The values obtained indicate that the hydraulic conductivity of the granite gneiss is c. two times higher than that of the local fracture zones at a depth of 500 m.

Table 7.4 Depth-dependence of the hydraulic conductivity in granite gneiss and veined gneiss

Hydraulic unit	Power curve	r^2	n
Granite gneiss	$K = 0.41 \times Z^{-3.49}$	0,28	85
Veined gneiss	$K = 0.026 \times Z^{-3.39}$	0,52	164

Z = depth in metres

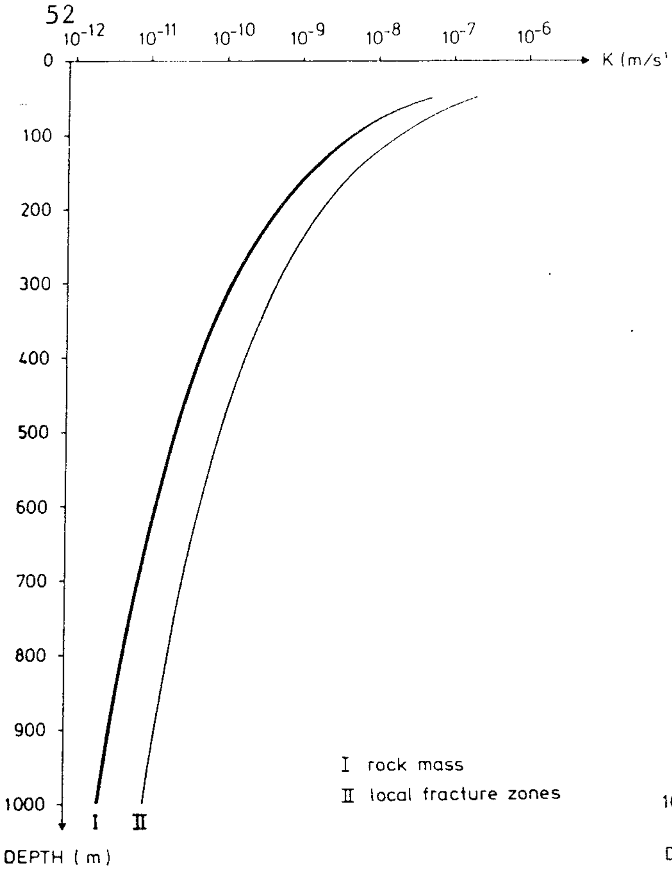


Figure 7.10 Relation between hydraulic conductivity and depth for different hydraulic units of the bedrock.

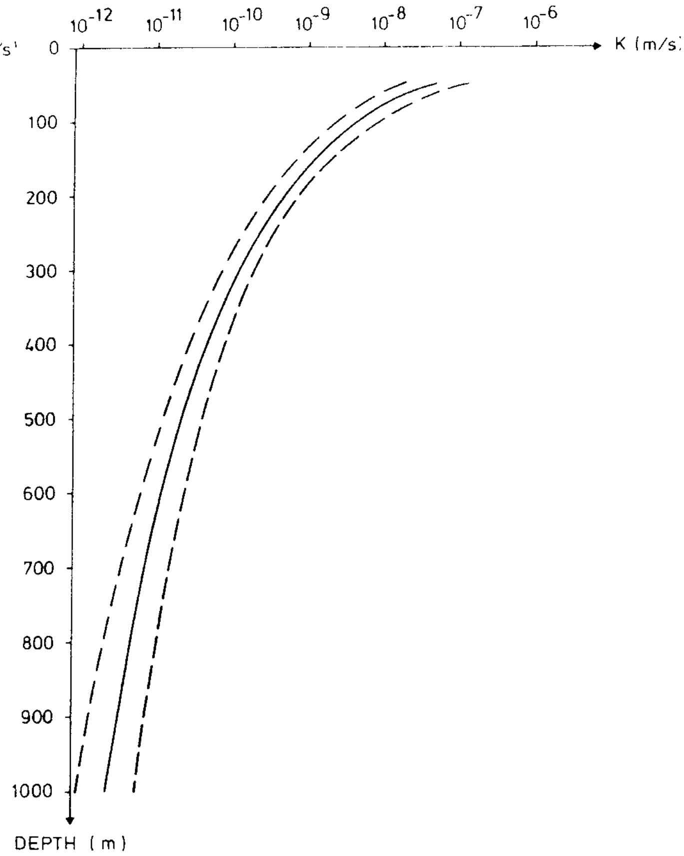


Figure 7.11 Relation between hydraulic conductivity and depth for the rock mass, 95% confidence interval.

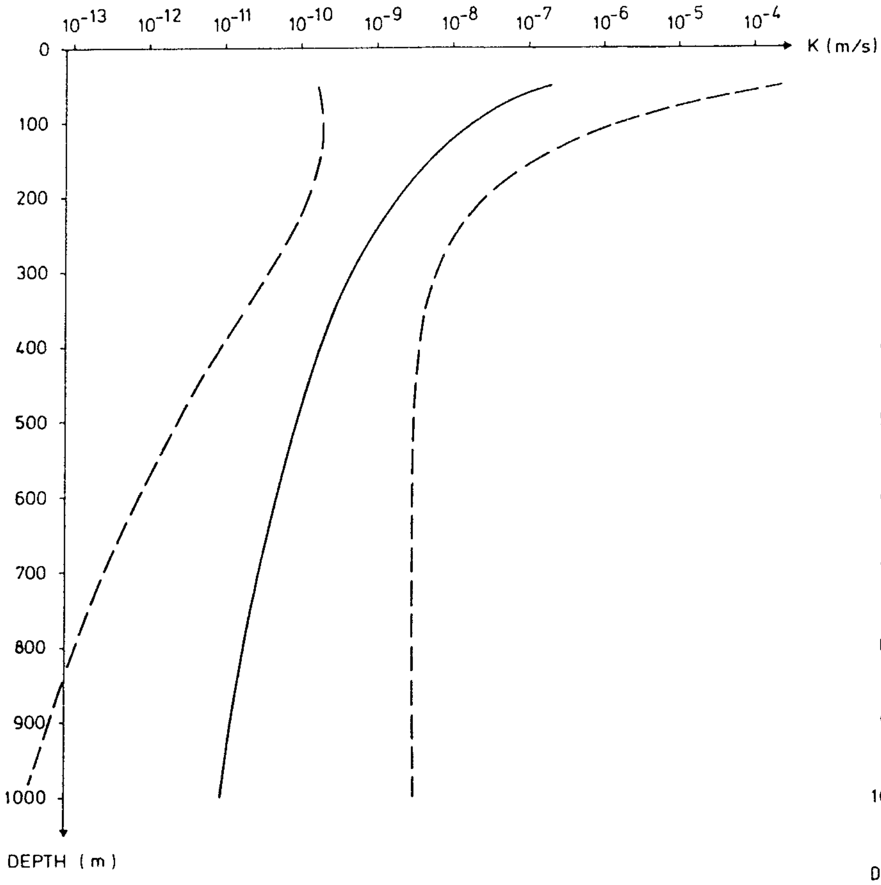


Figure 7.12 Relation between hydraulic conductivity and depth for the local fracture zones, 95% confidence interval.

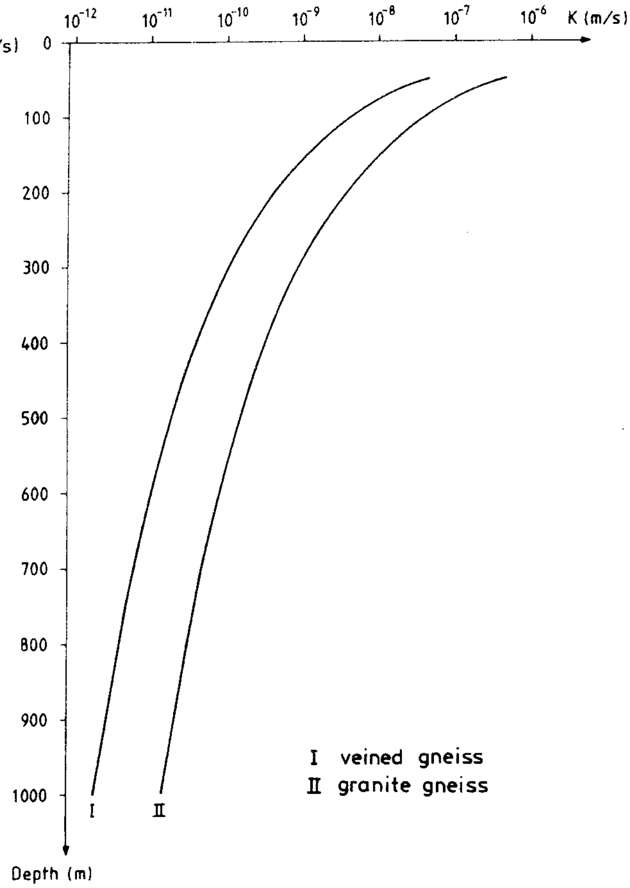


Figure 7.13 Relation between hydraulic conductivity and depth for different rock types.

8. GROUND-WATER CONDITIONS

8.1 General

The ground-water conditions within an area are characterized by the topographical, geological and climatological conditions. The geological conditions decide e.g. the size and variation of the water-transmitting and storaging properties. Geology and topography determine the conditions decisive for how much water the bedrock can transport. The climatological conditions are decisive on the amount of water available for transport.

Within the Gideå site, the existing ground-water conditions have been determined by measuring the hydraulic properties of the bedrock (chapter 7), and, by monitoring the ground-water table and the ground-water pressure at different depths in the bedrock. In addition, information on hydro-meteorological conditions has been collected (chapter 6). The data obtained have constituted the basis for the three-dimensional hydraulic model calculations of the site (Carlsson, Winberg and 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.

8.2 Registration of the ground-water table

The position of the ground-water table in the Gideå site has been registered in all 24 percussion drill holes as well as in 13 core drill holes, fig 8.1. The measurements were commenced in late November 1981 in the first percussion drill holes and successively in the remaining holes. In the present report, ground-water levels until the end of November 1982 are presented.

Three percussion drillholes were equipped with registering water-level gauges for continuous monitoring of the groundwater table. Observations of the ground-water level using sounding instruments have been carried out, with a few exceptions, once every second week. Longer interruptions have been necessary when other activities have been going on in the drill holes.

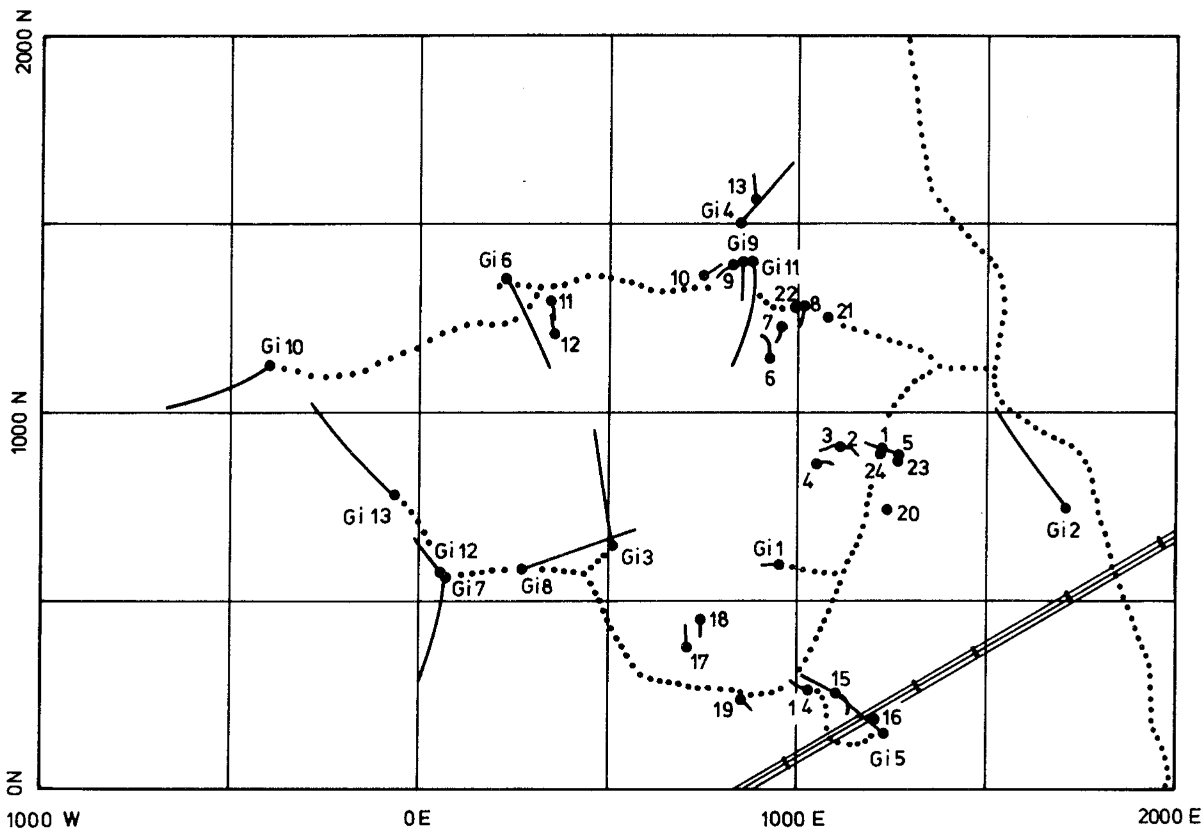


Figure 8.1 Locations of percussion drilled holes, HGi 1-24 and core drill holes Gi 1 - Gi 13.

During the period 811125-821124 the ground-water table in the Gideå bedrock has been situated between 103.7 and 118.5 m.a.s.l. The fluctuation of the ground water level in individual drill holes has varied between 0.2 and 3.9 m. The observation period for many of the drill holes is very short, and the annual variation amplitude has in many cases not been distinguished.

The position of the ground-water table is at it lowest in January through March. In conjunction with snow melting the ground-water table rises towards the end of March, reaching its maximum in April. During May through early August, the ground-water table continues to sink, even though there are a couple of minor recovery periods. In the middle and end of August there is a marked recovery and a new maximum is reached. After that, the ground-water table is highly situated and comparatively stable until the beginning of December, when it again starts to sink. The measurement results are well in accord with the normal annual variation of the ground-water table in southern Norrland, where there is, apart from the ground-water recharge in late spring, a secondary period of recharge during autumn (Knutsson and Fagerlind, 1977).

The distance from the ground surface to the ground-water table varies with the topographic locations. In general, the ground-water table is 1-3 m below the ground surface. Below small hills and in slopes the depth to the ground-water table can be more than 10 m. Ground-water discharge areas are found primarily at topographical low points. Consequently, the differences in level in the drill holes are as a result comparatively small. For the recharge areas, the situation is the opposite, the level variations in the drill holes being much greater. The greatest variation in ground-water level during the measurement period is found in drill holes in topographically high locations or located at steep slopes. In the area there are two artesian drill holes, Gi 2 and HGi 20. Gi 2 is located in a slope of a high rock section. Drill hole HGi 20 is situated at a low lovel in relation to the surrounding terrain.

In the beginning of June 1982, the upper part of 12 of the percussion drill holes were sealed off by means of rubber packers, in order to separate the ground water table in the upper part of the bedrock from the deeper ground-water. The sealings were placed 5-10 m beneath the actual ground-water level. Measurements of water pressure or water level were performed above, as well as below the packers. The drill holes thus sectioned-off were chosen in order to obtain an adequate spread as to area and altitude. In-flow and out-flow position, water capacity and fracture zones in the drill holes were also noted. In table 8.1 sectioned-off drill holes and measurement results are specified.

The results of the measurements in sectioned-off drill holes indicate that eight of the drill holes are located in recharge areas and two in discharge areas. In two drill holes, HGi 1 and HGi 15, the pressure gradient changed during the measurement period. In HGi 1, the inversion is due to water having been pumped from the nearby HGi 5 drill hole for water supply purposes in conjunction with the drilling work. The area around HGi 15 is a discharge area during summer and a recharge area in autumn. The pressure variations are greatest in the upper section of most of the drill holes due to a great influence of climatological factors. The smallest pressure differences appear in the low altitude drill holes.

8.3 Ground-water level maps

Two maps of the ground-water level in the bedrock at the Gideå site have been prepared. The regional map, fig 8.2, is of general character covering an area of c. 90 km^2. This area is bounded to the west by the river Gideälven and the north-south valley comprising lake Lill-Hudsjön. To the north-east, the boundary is constituted of the brook Flisbäcken, the stream Husån up to lake Västersjön, lake Skademarkssjön, and the valley from the latter down to bay Degerfjärden. The southern boundary is formed by the lowland area south of lake Hemsjön. The peat bog Degermyren and the valley at lake Fillingsjön on to the bay Degerfjärden and the Bottenhavet constitute the eastern boundary of the mapped area.

The local ground-water map, see fig 8.3, covers an area of 27 km^2 including the study site. The area is bounded to the west by the river Gideälven and to the east by stream Husån. To the north the peat bogs in a south-westerly direction from the Palltjärn to the river Gideälven and brook Flisbäcken constitute the area boundary. The lowland in connection to the brook Fräckenråbäcken constitutes the southern boundary of the area.

In the construction of the map, the ground-water table has been assumed to follow the topography. On the basis of observations in the area, the ground-water table in the upper parts of the bedrock has been assumed to be located 7-9 m below the ground surface on hills and in slopes and 1-3 m below the ground surface elsewhere. A morphological adaptation has also been made, to the effect that the ground-water level has been smoothed in the case of minor topographical deviations. Thus, the distance to the ground-water table is assumed to be greater below minor (isolated) hills than under larger higher parts of the terrain.

Table 8.1 Ground-water levels in sectioned-off percussion drill holes at Gideå during the period 820601-821124

Drill hole section		Ground-water level Highest m.a.s.l.	Lowest m.a.s.l.	Variation width (m)	Notes
HGi 1	o	105.19	103.37	1.82	
	b	105.23	103.06	2.07	ch
HGi 3	o	110.96	109.88	1.08	
	b	110.22	109.57	0.65	r
HGi 7	o	114.13	113.26	0.87	
	b	114.11	113.29	0.82	r
HGi 8	o	116.39	113.94	2.45	
	b	113.14	112.49	0.65	r
HGi 10	o	113.89	113.21	0.68	
	b	112.89	111.94	0.95	r
HGi 12	o	120.40	117.42	2.98	
	b	118.19	117.20	0.99	r
HGi 13	o	107.96	106.93	1.03	
	b	106.19	104.91	1.28	r
HGi 15	o	108.54	107.65	0.89	
	b	108.40	107.87	0.53	ch
HGi 16	o	112.09	108.84	3.25	
	b	108.39	107.86	0.53	r
HGi 18	o	114.10	113.50	0.60	
	b	112.49	111.61	0.88	r
HGi 19	o	112.56	111.42	1.14	
	b	112.57	111.72	0.85	d
HGi 20	o	107.45	107.12	0.33	
	b	108.02	107.54	0.48	d

o = over packer
b = below packer

ch = changes
r = recharge area
d = discharge area

mean variation o = 1.43 (standard deviation = 0.97)
b = 0.90 (standard deviation = 0.46)

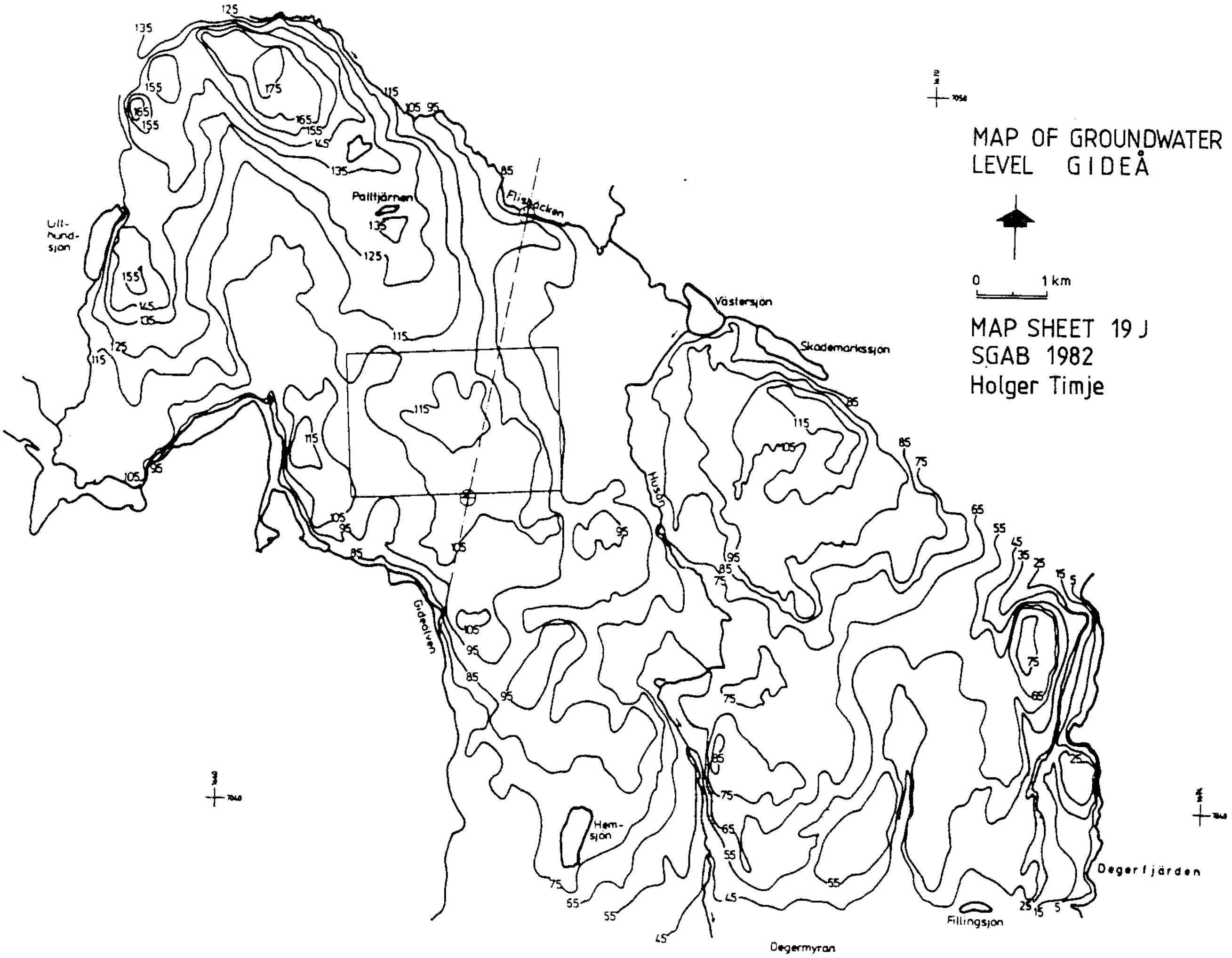


Figure 8.2 Regional map of ground-water level in the site Gideå.

Furthermore, the ground-water table is higher situated in narrow valleys than in wide ones. Lakes, streams and peat bogs indicate a ground-water level close to the ground surface and are assumed to be discharge areas for ground-water.

The regional ground-water map has been drawn in scale 1:25,000 and the local map in scale 1:10,000. They are reproduced in reduced size in figs 8.2 and 8.3. The levels represent an assumed mean level during the year, corresponding to a position of equilibrium between ground-water recharge, ground-water flow and ground-water discharge.

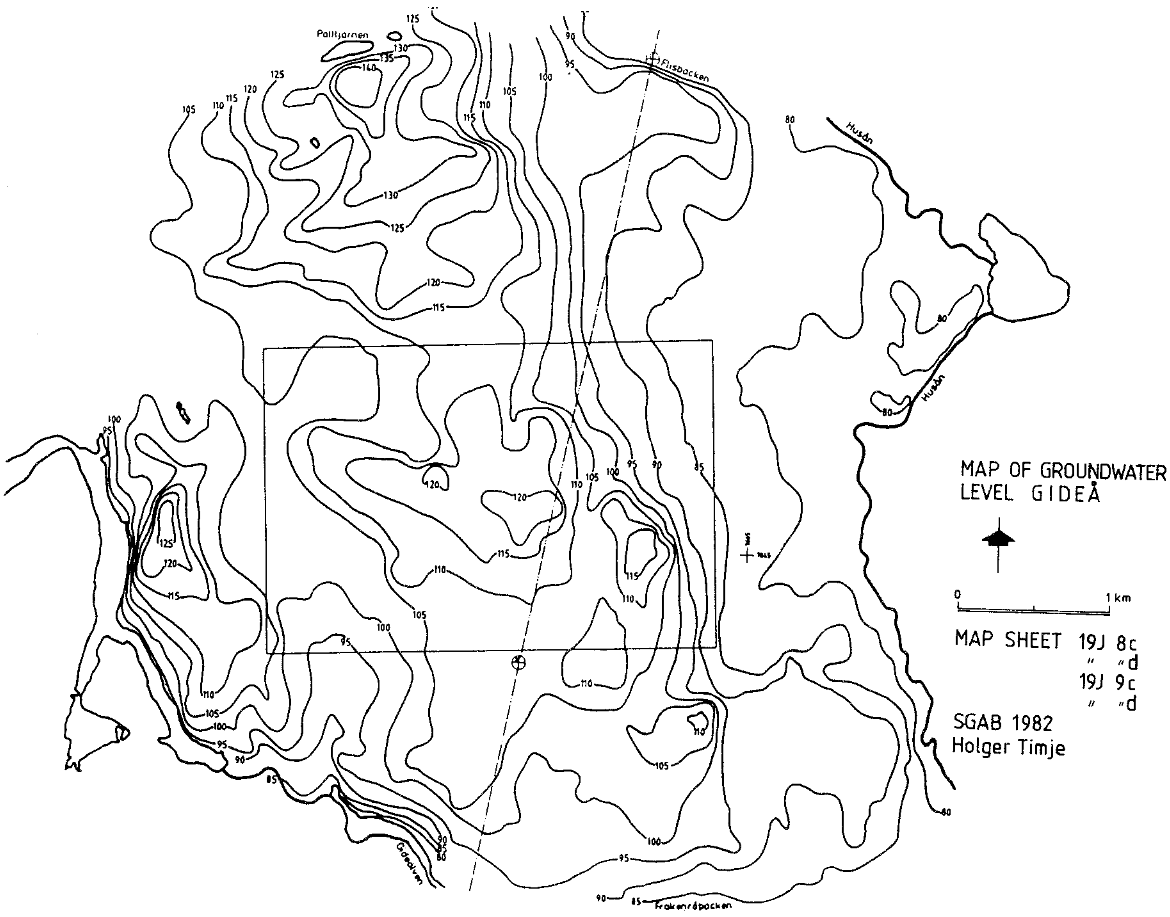


Figure 8.3 Local map of ground-water level in the site Gideå.

The central part of the study site mainly constitutes a recharge area for ground-water. A local discharge area is located in the lowland at fracture zones 1 and 2. The ground-water flow in the study site is primarily oriented towards the regional fracture zones following the river Gideälven to the west and south-west and stream Husån to the east.

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 high-pressure levels to low-pressure levels. In drill holes where the ground-water pressure increases with depth more than the hydrostatic pressure, discharge conditions are said to prevail. Conversely applies that recharge conditions are present when the ground-water is of higher presure in the upper parts of the drill hole than in the lower 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 phase (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. In the subsequent phase the flow is stopped and the pressure fall-off with time is registered. The original water pressure of the tested section is calculated on the basis of the results of the two phases, so-called Hornerplot (Carlsson et al., 1983). The ground-water pressure is indicated as over- and underpressure, respectively, in relation to the hydrostatic pressure in the drill hole at the corresponding level.

The majority of drill holes are characterized by overpressure in relation to the hydrostatic pressure in one or some of the measurement sections close to the surface, figs 8.4 and 8.5. In the deeper parts of the drill holes, there are generally lower water pressures than the hydrostatic pressures. In drill hole Gi 3 over- and underpressure are evenly distributed whereas the greatest over- and underpressure measured has been registered in Gi 4. In this drill hole, there is overpressure in the highest and lowest sections of the drill hole.

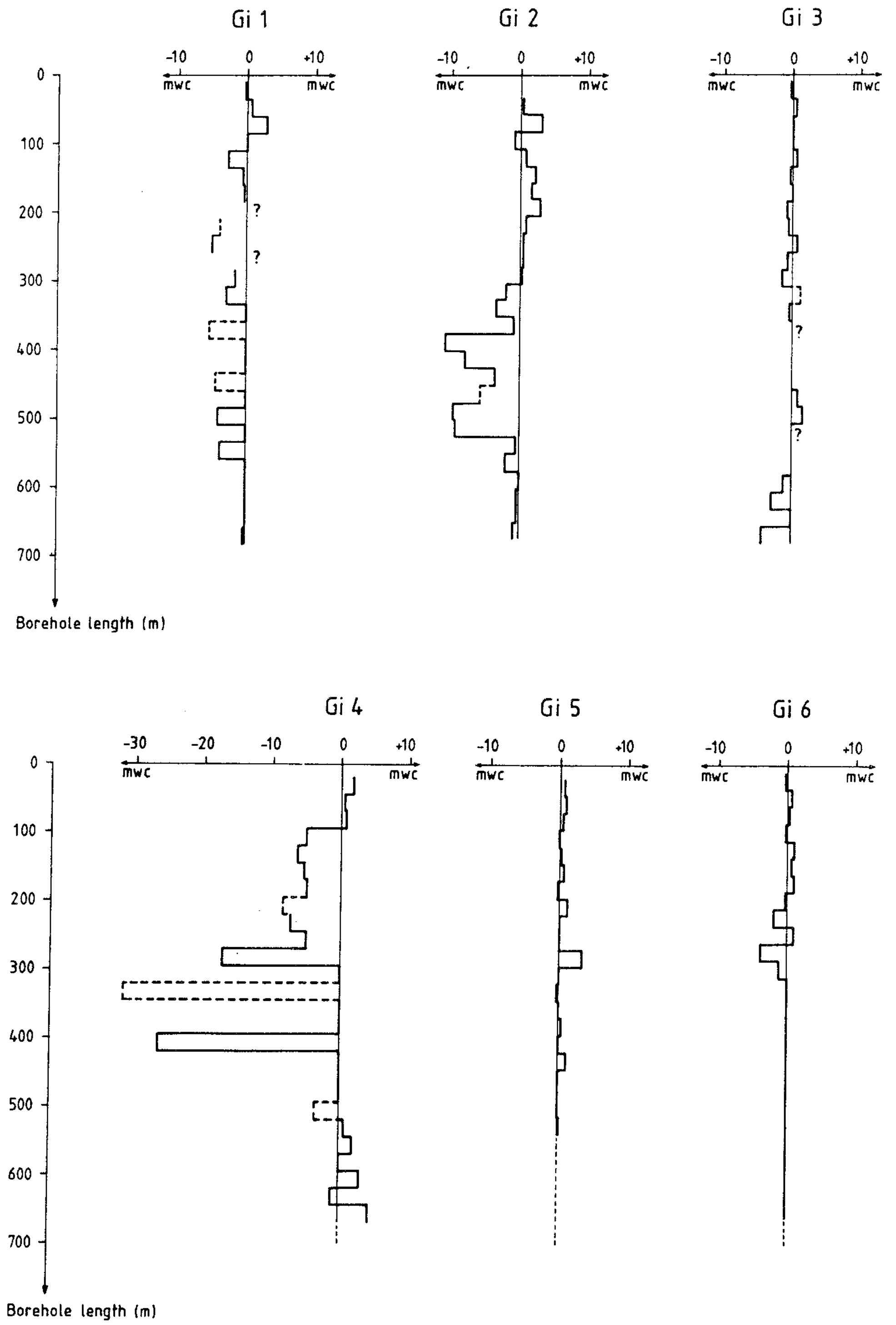


Figure 8.4 Pressure distribution (in metres of water column) in test sections of boreholes Gi 1 - Gi 6.

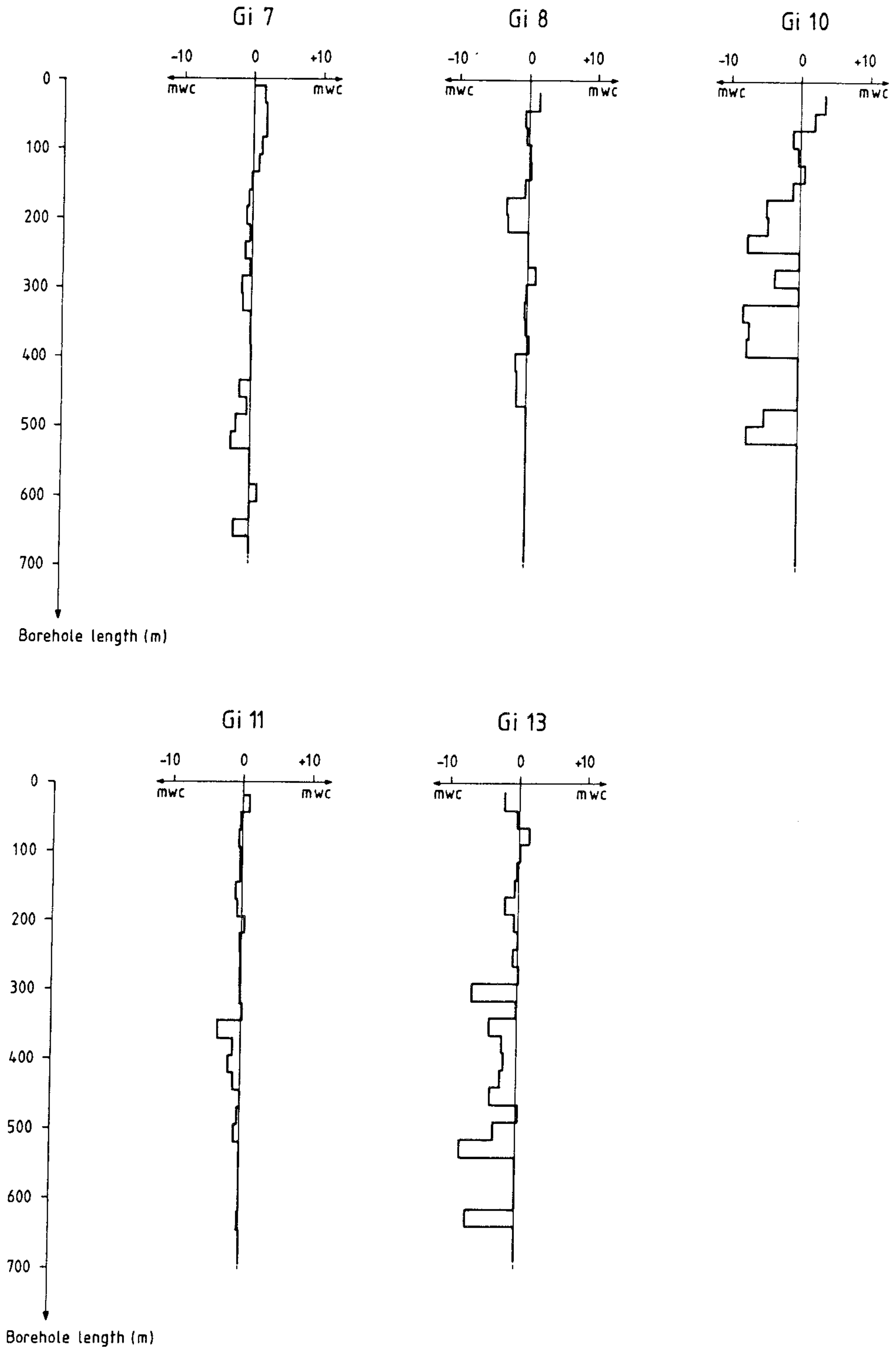


Figure 8.5 Pressure distribution (in metres of water column) in test sections of boreholes Gi 7, Gi 8, Gi 10, Gi 11 and Gi 13.

In the midsections underpressures of the magnitude 5-8 m water column have been registered. Many drill holes have a distinct recharge character with increasing underpressures with depth.

The section pressures obtained from the water injection tests are not necessarily representative of the natural ground-water pressure in the sections. The drill hole as such actually short-circuits the ground-water pressures from different levels.

By sealing off several levels in a drill hole the pressure equalisation caused by the drill hole can be avoided. During these so-called piezometric measurements as much as seven packers have been used and the ground-water pressure registered in five different sections, where one constitutes the free ground-water table. The ground-water pressure is specified as over- and underpressure, respectively, in relation to the hydrostatic pressure in the open drill hole at the corresponding level. The measurements have been performed during approx one month in drill hole Gi 7. The positioning of packers in this drill hole is illustrated in fig 8.6.

In drill hole Gi 7 there is underpressure in four of the sealed off sections, see fig 8.7. Only in the case of the uppermost section, viz. from the ground-water table down to 125 m, the presure is higher than the hydrostatic pressure existing before the drill hole was sectioned off. The deviation of the groundwater pressure from the hydrostatic pressure in the individual sections is small, c. 1 m water column. The pressure gradient in the drill hole is oriented downwards, which means that Gi 7 is situated in a recharge area. Fig 8.7 also specifies the ground-water pressure values obtained from the water injection tests (numbered rings). The correspondence is comparatively good between the values obtained from the tests.

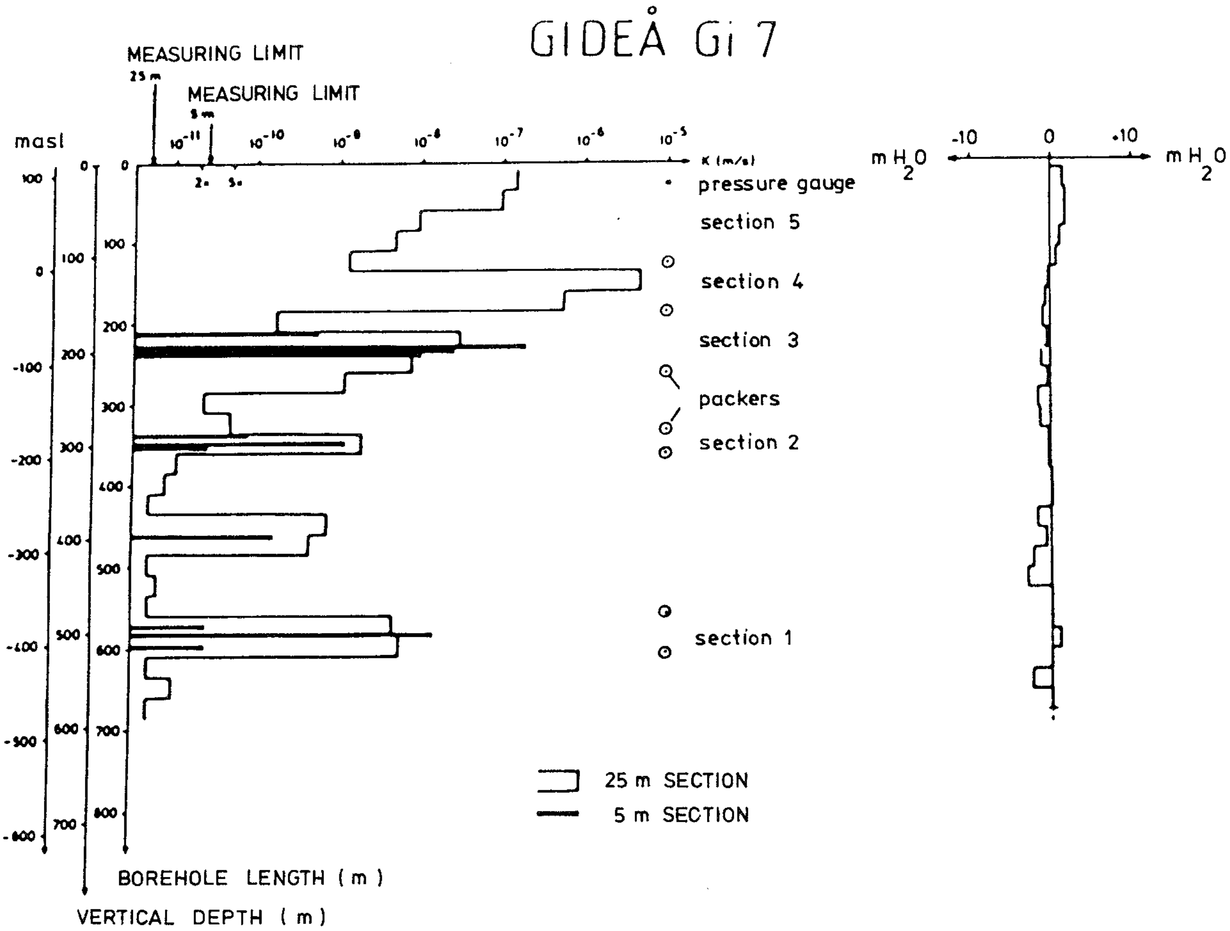


Figure 8.6 Location of packers and piezometric sections in borehole Gi 7.

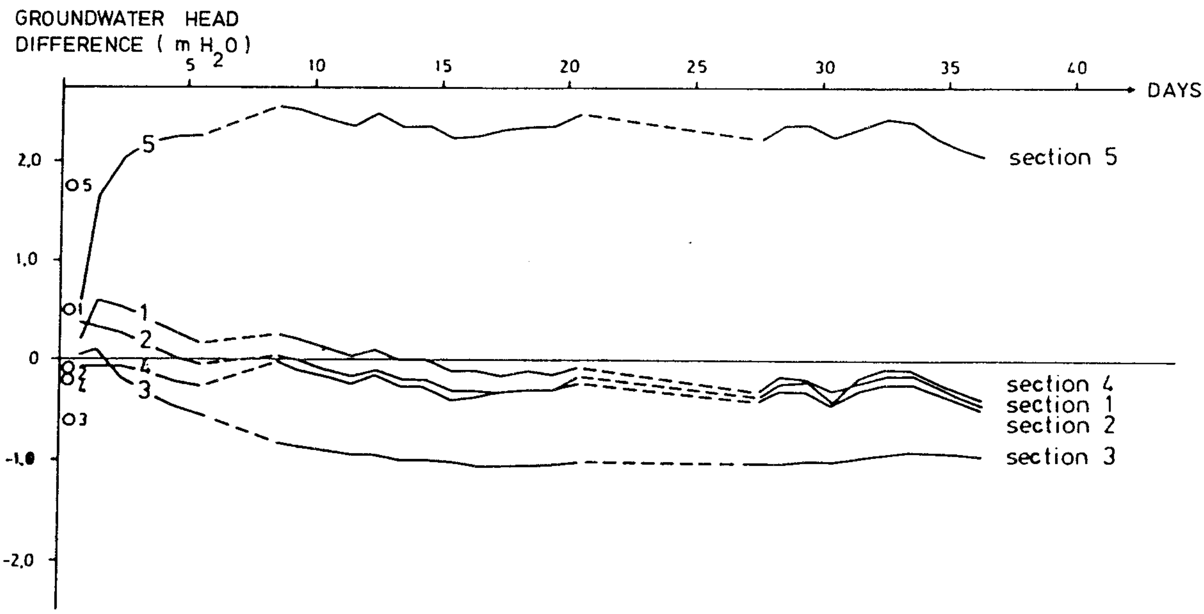


Figure 8.7 Ground-water pressure in sealed-off sections in drill hole Gi 7.

REFERENCES

AHLBOM, K., CARLSSON, L., OLSSON, O., 1983
Final Disposal of Spent Fuel - Geological, Hydrogeological and Geophysical Methods for Site Characterization.
Swedish Geological KBS TR 83-43.

ALBINO, B., NILSSON, G., 1982
Summary of Technical Data on Drillholes and Fracture-and Rock Type-Logs, Study Site Gideå. (in Swedish)
Swedish Geological

ALBINO, B., NILSSON, G., STENBERG, L., 1982
Geological, Tectonical and Geophysical Investigations at the Gideå Study Site. (in Swedish)
Swedish Geological.

ALMÉN, K-E., ANDERSSON, J-E., CARLSSON, L., HANSSON, K., 1982
Hydraulic Tests in Rock. Part 4: Comparative Studies of the Different Hydraulic Tests. (in Swedish)
Swedish Geological.

ALMÉN, K., HANSSON, K., JOHANSSON, B-E, NILSSON, G., ANDERSSON, O., WIKBERG, P., Åhagen, H., 1983
Final Disposal of Spent Fuel-Equipment for Site Characterization.
SKBF/KBS TR 83-44.

BROTZEN, O., 1981
Site Investigations for a Nuclear Waste Repository in Crystalline Rock. Proceeding of OECD/NEA Workshop on Siting of Radioactive Waste Repositories in Geological Formations.
France.

CARLSSON, L., WINBERG, A., GRUNDFELT, B., 1983
Model Calculations of the Groundwater Flow at Finnsjön, Fjällveden, Gideå and Kamlunge.
Swedish Geological, Kemacta Konsult AB, KBS TR 83-45.

ERIKSSON, B., 1980
Sweden's Water Balance. Annual Mean Values (1931-60) of Precipitation, Evaporation and Run-off. (in Swedish)
SMHI Report RMK 18.

KNUTSSON, G., FAGERLIND, T., 1977
Water Supplies in Sweden. (in Swedish)
SGU, Reports and Notice Nr. 9.

THOREGREN, U., 1982
Final Disposal of Spent Fuel - Standard Programme for Site Investigations.
Swedish Geological KBS TR 83-31.

SKBF/KBS, 1982
Radioactive Waste Management Plan, PLAN 82.
KBS TR 82-09.

STENBERG, L., 1983
Borehole Geophysical Investigations at the Study Site Gideå. (in Swedish)
Swedish Geological.

TIMJE, H., 1983
Hydrogeological Investigations in Study Site Gideå. (in Swedish)
Swedish Geological.

WELIN, E., LUNDQVIST, T., 1975
K-Ar Ages of Jotnian Dolerites in Västnorrlands County, Central Sweden.
GFF 97, pp 83-88.

APPENDIX: EXTENT OF INVESTIGATIONS AT THE GIDEÅ STUDY SITE

Surface investigations

Geological surface mapping

Detailed mapping — 6 km^2

Geophysical surface mapping

Surface mapping (point distance 40 x 20 m) — 5 km^2

Methods: Magnetic total intensity

Slingram (horizontal loop EM) 18 KHz-60 m

Resistivity

Induced polarization

Seismic profiles — 4 km

Depth investigations

Percussion drill holes

Nr	Coordinate x y	Levelling m.a.s.l.	Direction	Length (m)	Vertical depth (m)	Water Capacity (l/h)
1	902N/1224E	106.3	N70W/55	153	143	4000
2	903N/1112E	111.3	N90E/55	141	130	
3	902N/1109E	111.3	S70W/55	125	113	
4	862N/1051E	113.5	N90E/55	100	92	
5	886N/1268E	115.1	N70W/55	115	105	4000
6	1139N/ 925E	115.9	N /55	150	135	600
7	1230N/ 955E	116.2	S /55	150	139	2000
8	1283N/1016E	117.4	S /55	130	118	6000
9	1392N/ 826E	119.5	S60W/55	150	137	240
10	1361N/ 748E	115.3	N60E/55	150	142	480
11	1300N/ 347E	119.1	S /55	132	127	
12	1206N/ 351E	120.6	N /55	120	106	
13	1567N/ 880E	113.3	N5W /55	150	136	

Nr	Coordinate x y	Levelling m.a.s.l.	Direction	Length (m)	Vertical depth (m)	Water Capacity (1/h)
14	255N/1035E	111.4	N60W/55	125	107	480
15	247N/1110E	109.8	S60E/55	120	103	9000
16	179N/1212E	116.6	N60W/55	132	117	6000
17	372N/ 714E	117.6	N /55	120	107	
18	447N/ 750E	114.7	S /55	100	84	
19	232N/ 852E	112.8	S65E/55	100	87	
20	740N/1238E	107.5	90	100	99	6000
21	1251N/1080E	113.5	90	90	90	
22	1280N/ 995E	119.9	90	60	60	
23	870N/1266E	116.4	90	90	90	
24	894N/1219E	106.3	90	40	40	3000

Core drill holes

Nr	Coordinate x y	Levelling m.a.s.l.	Direction	Length (m)	Vertical depth (m)
1	593N/ 944E	117.0	90	704.3	701
2	737N/1709E	103.6	N40W/60	705.5	617
3	646N/ 514E	117.6	N20W/60	703.0	626
4	1505N/ 840E	116.0	N45E/70	690.7	657
5	140N/1240E	122.9	N60W/60	702.0	605 1)
6	1357N/ 225E	116.6	S30E/60	704.0	648
7	565N/ 74E	114.2	S /60	700.5	635
8	581N/ 281E	116.8	N70E/62	701.6	619
9	1400N/ 848E	120.7	S /67	281.9	250
10	1126N/ 392W	120.9	S70W/65	702.6	632
11	1399N/ 870E	118.4	S /60	701.5	632
12	570N/ 65E	114.3	N45W/61	249.8	218
13	780N/ 60W	114.5	N45W/61	704.5	616

1) Estimated depth due to slip in drill hole

Drill core investigations

Logged drill hole length	c. 8255 m
Chemical analyses	
Surface samples	5 pc
Drill core samples	
Bh depth	
Gi 2 30 m	1 pc
Petrophysical samples, evenly distributed in all drill holes and depths	111 pcs

Geophysical drill hole logging

Methods:	Drill hole deviation	1) 2)
	Natural gamma radiation	1) 2)
	Point resistance	1) 2)
	Resistivity, normal 1.6 m	2)
	Resistivity, lateral 1.65/0.1 m	2)
	Spontaneous potential	2)
	Temperature	2)
	Resistivity of drill hole water	2)
	Salinity	2)
	Induced Polarization	3)

1) Measurements performed in all percussion drill holes
2) Measurements performed in all core drill holes
3) Measurements performed in drill holes Gi 1 and Gi 4

Hydrological investigations

Water injection tests	Number of tests
25 m sections	308
10 m sections	17
5 m sections	85
3 m sections (Gi 9 and Gi 11)	81
2 m sections (Gi 7)	144
Single packer measurements	4

Piezometric measurements	Number of sections
Drill hole Gi 7	5

Interference tests	
Pump hole	HGi 24
Observation holes	HGi 1, 5, 20, 23

Groundwater level observations	Number of holes
Percussion drill holes HGi 1-24	24
Core drill holes Gi 1-12	12

List of KBS's Technical Reports

TR 83–11
Description of recipient areas related to final storage of unreprocessed spent nuclear fuel
Björn Sundblad
Ulla Bergström
Studsvik Energiteknik AB
Nyköping, Sweden 1983-02-07

TR 83–12
Calculation of activity content and related propeties in PWR and BWR fuel using ORIGEN 2
Ove Edlund
Studsvik Energiteknik AB
Nyköping, Sweden 1983-03-07

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