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Evaluation of the geological, geophysical and hydrogeological conditions at Fjällveden

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SUMMARY

The Fjällveden study site has a flat topography and a high percentage of outcrops. The main type of rock in the area is veined gneiss with a north-east structural strike and vertical dip. The veined gneiss contains sulphide minerals, primarily pyrite and pyrrhotite, in the form of fracture minerals and as impregnations. The concentrations of economically valuable minerals are so small that mining in the area is not realistic. In conformity with the gneiss structure there are strata of granite gneiss. They have a mean width of 3 m and occur at a mean distance of 100 m. These strata are probably of greater continuity in the horizontal direction than in the vertical. The proportion of granite gneiss in the drill holes is 3 %.

The rock mass has a fracture frequency of 4.0 fractures per metre within the upper 100 metres. The frequency decreases with increasing depth and below the 300 m level it is 1.8 fractures per metre. The proportion of hydraulically conductive fractures is lower than the total fracture frequency.

The Fjällveden study site is delimited to the north-east and south-west by regional fracture zones, 80-90 m wide and dipping approx 75° towards the south-west. The fracture zones contain wide sections of crushed and clay-altered rock, mylonites and breccias. These zones are 1250 million years old or older.

The regional zones delimit a block at least 3 x 3 km large. This block contains only local fracture zones. Drill hole examinations indicate that the fracture zones are small and of a mean width of 5 m. They are steep and contain minor sections of crushed and clay-altered rock. Within the upper 100-200 metres horizontal fractures can be found. Below this level no horizontal fracture zones have been observed. Common fracture minerals in fracture zones are calcite, kaolinite, chlorite and illite. The extensive presence of kaolinite in the fracture zones and the bedrock as a whole indicates that Fjällveden is or has been subject to deeply extending weathering.

Existing granite gneiss strata possess higher hydraulic conductivity than the surrounding veined gneiss. At a depth of 500 m the granite gneiss has a hydraulic conductivity of 3×10^{-9} m/s, the corresponding value in the surrounding bedrock being 2×10^{-11} m/s. This gives the rock mass anisotropic hydraulic properties with a higher hydraulic conductivity in the north-easterly and vertical directions and a lower conductivity perpendicular to this.

The hydraulic conductivity in the veined gneiss and the granite gneiss decreases substantially with increasing depth. For the rock mass as a whole, i.e. by forming the average of all data from both rock types, the hydraulic conductivity decreases from approx 10^{-8} m/s at the surface rock to approx 10^{-11} m/s at a depth of 600 m.

The hydraulic conductivity in the local fracture zones in the Fjällveden area is 5×10^{-9} m/s at the 500 m level. In the case of fracture zones the hydraulic conductivity 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. Locally, there are low water pressures within granite gneiss strata at the 600 m depth level in the south-western part of the area. These strata are probably in hydraulic contact with the regionally delimiting fracture zone to the south-west.

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).

Fjällveden is one of the study sites which has been investigated by means of deep drill holes in order to obtain better knowledge of the geological, hydrogeological and geochemical conditions at large depths in Swedish crystalline rock. The purpose of the investigation has been to bring forth the site-specific data required for a safety analysis of the storage of spent nuclear fuel.

The investigations were initiated at Fjällveden, beginning with the first drill hole in June 1981. The main part of the investigations was completed in January 1983.

1.2 Reporting of results

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

- Carlsten, Duran & Kautsky, 1983:

  "Geological, tectonical and geophysical investigations at the Fjällveden study site". Available in Swedish only.

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

- Carlsten, 1983:

  "Summary of technical data on core drill holes and fracture- and rock-type log". Available in Swedish only.

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

- Carlsten, 1983:

  "Summary of technical data on percussion holes at Fjällveden". Available in Swedish only.

- Duran, 1983:

  "Borehole geophysical investigations at the study site Fjällveden". Available in Swedish only.

- Larsson, 1983:

  "Hydrogeological investigations at the study site Fjällveden". Available in Swedish only.

  The report accounts for the hydrological conditions at 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 Fjällveden investigations is described in the Appendix. A description of methods and instruments used for the different investigations is given by Ahlbom, Carlsson & Olsson (1983) and Almen, Hansson, Johansson, Nilsson, Andersson, Wikberg & Åhagen (1983).

2. THE SELECTION OF STUDY SITE FJÄLLVEDEN

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

- The site consists of veined gneiss. This rock type has been found suitable for construction of rock caverns and tunnels due to low water inflow and has displayed low water capacities in rock-drilled wells.
- The site is flat, thus the driving forces on the groundwater flow are small.
- Regional fracture zones at the site delimit a block of dimensions 3 km x 3 km, sufficient for a storage locations.
- The site displays a low frequency of fracture zones from aerial photographs.
- The fracture frequency on outcrops is low at the site.
- There is only one land-owner in the area.

The proportion of outcrops in the area is comparatively large, approx 10%, which facilitates the geological and tectonic interpretation of the site.

Geological field reconnaissance and geophysical profile measurements were made during spring and summer 1981. The measurements showed that the site was partly covered by electrically conductive clays and that between these there were extensive parts with few indications of fracture zones. Following these initial geological and geophysical investigations the site was considered promising, and a 700 m deep core drill hole was made in order to study the characteristics of the bedrock down 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 late in the summer of 1981.

3. LOCATION AND TOPOGRAPHY

The Fjällveden study site is located approx 80 km south-west of Stockholm and 20 km north-north-west of Nyköping in the Södermanland county, fig 3.1. The area is situated in the Nyköping municipality and reproduced on topographical map-sheet 9H Nyköping NW.

The Region is characterized by a flat topography with minor fracture valleys primarily in a north-westerly direction. The Fjällveden study site is situated between two such fracture valleys, the distance between them being 3 km.

The differences in altitude in the area are small and the relief within the site is low. The lowest point of the site is the lake Sågsjön, 38 m above sea-level. The highest point is at 76 m above sea-level. In the proximity of the depressions extending in a north-westerly direction, i.e. in the eastern and western limits of the site, the most broken relief is to be found. A topographical profile of the site is shown in fig 3.2. The altitude characteristics of the site are illustrated by the hypsographical curve in fig 3.3.

The Fjällveden study site is forested interchangingly with minor peat bogs. The quarternary deposits consist primarily of moraine, which is to a large extent covered by overlying glacial and post-glacial clays. These clay strata can be over 9 metres thick. The clays, particularly the post-glacial ones, are saline making them electrically conducting.

The study site investigated is 2.7 x 3.7 km. This comprises the area of 2 x 2 km investigated with detailed geophysical measurements as well as surrounding regional fracture zones, fig 5.4.

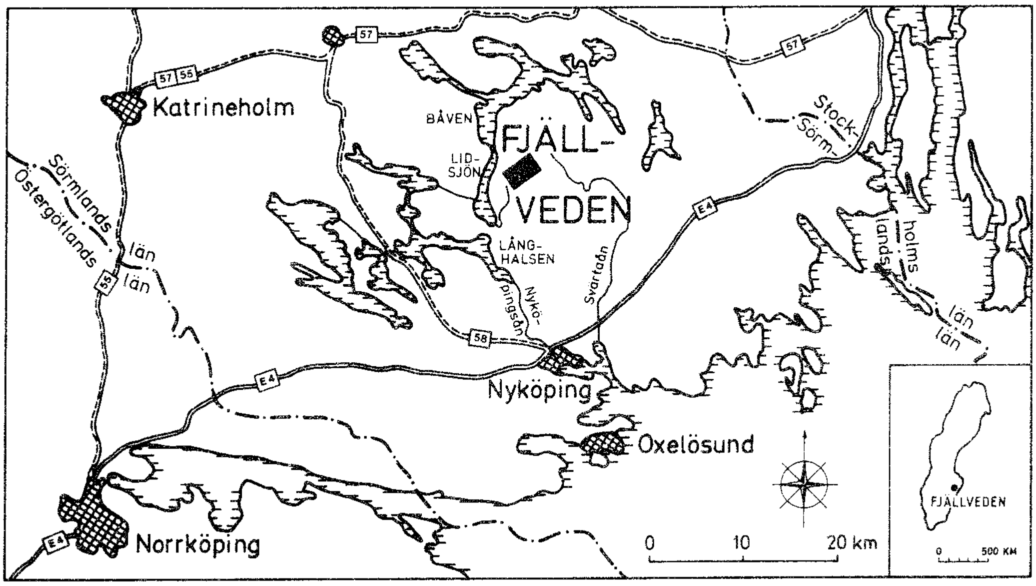


Figure 3.1 Locality map for site Fjällveden

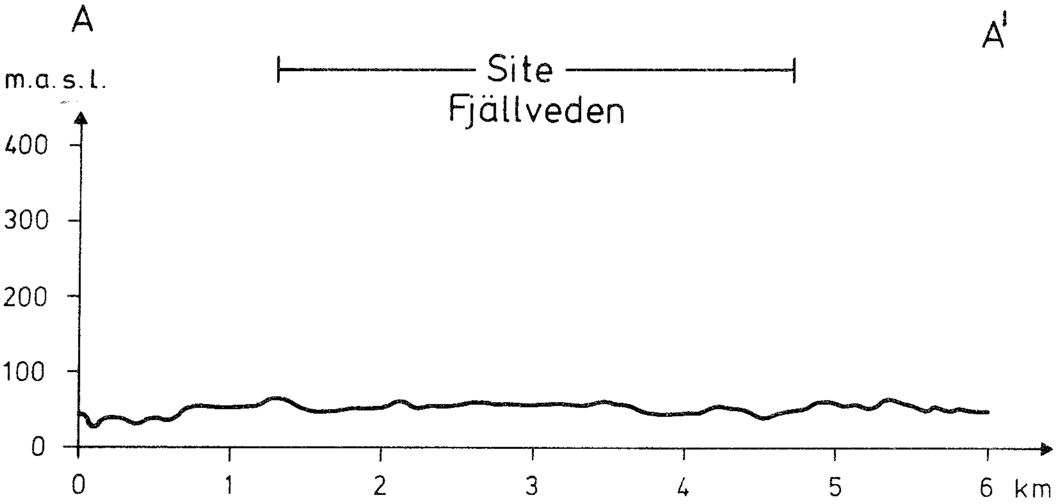


Figure 3.2 Topographical profile across site Fjällveden. Locations shown in figure 5.1.

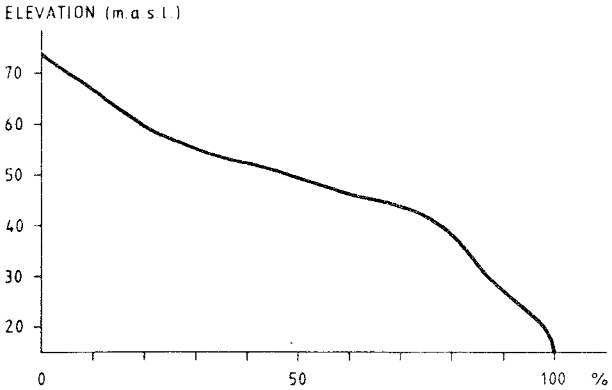


Figure 3.3 Hypsographical curve showing altitude characteristics in site Fjällveden.

4. BEDROCK GEOLOGY

4.1 Regional geology

The bedrock in this part of Sweden consists mainly of rock types which have been part of the approx 1800 - 2000 mill. years old Sweco-Karelian mountain chain formation. These rock types today constitute various types of gneisses of volcanic or sedimentary origin and of a series of granite gneisses. After the mountain chain formation granites were formed which penetrated into the old bedrock. These granites are comparatively undeformed and are generally referred to as younger granites. The youngest rock types are dolerite dikes of a probable age of 1200 mil. years. Extensive descriptions of rock types and geologic evolution of the area are to be found in the descriptions to surrounding geological map-sheets, e.g. Wikström 1979, Lundström 1976, and Stålhös 1975.

The region around Fjällveden was geologically mapped in 1882 and therefore does not meet contemporary requirements. A general mapping of a regional area around Fjällveden was therefore necessary. The map which is shown in fig 4.1 indicates that the bedrock to a major extent consists of veined gneiss of sedimentary origin and of granite gneiss. These rock types are present with a varying degree of migmatization. The bedrock was migmatized approx 1800 mill. years ago when the bedrock was depressed to a great depth (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 present is usually grey with greyish red and red streaks, depending on the varying presence of potash feldspar. Minor inclusions of greenstone and amphibolite are found conformal to the gneiss structure which is usually steeply dipping and with north-easterly strike.

Granite gneiss is present in several massifs at the Fjällveden study site, fig 4.1. The granite gneiss is as a rule grey to greyish red with slight foliation.

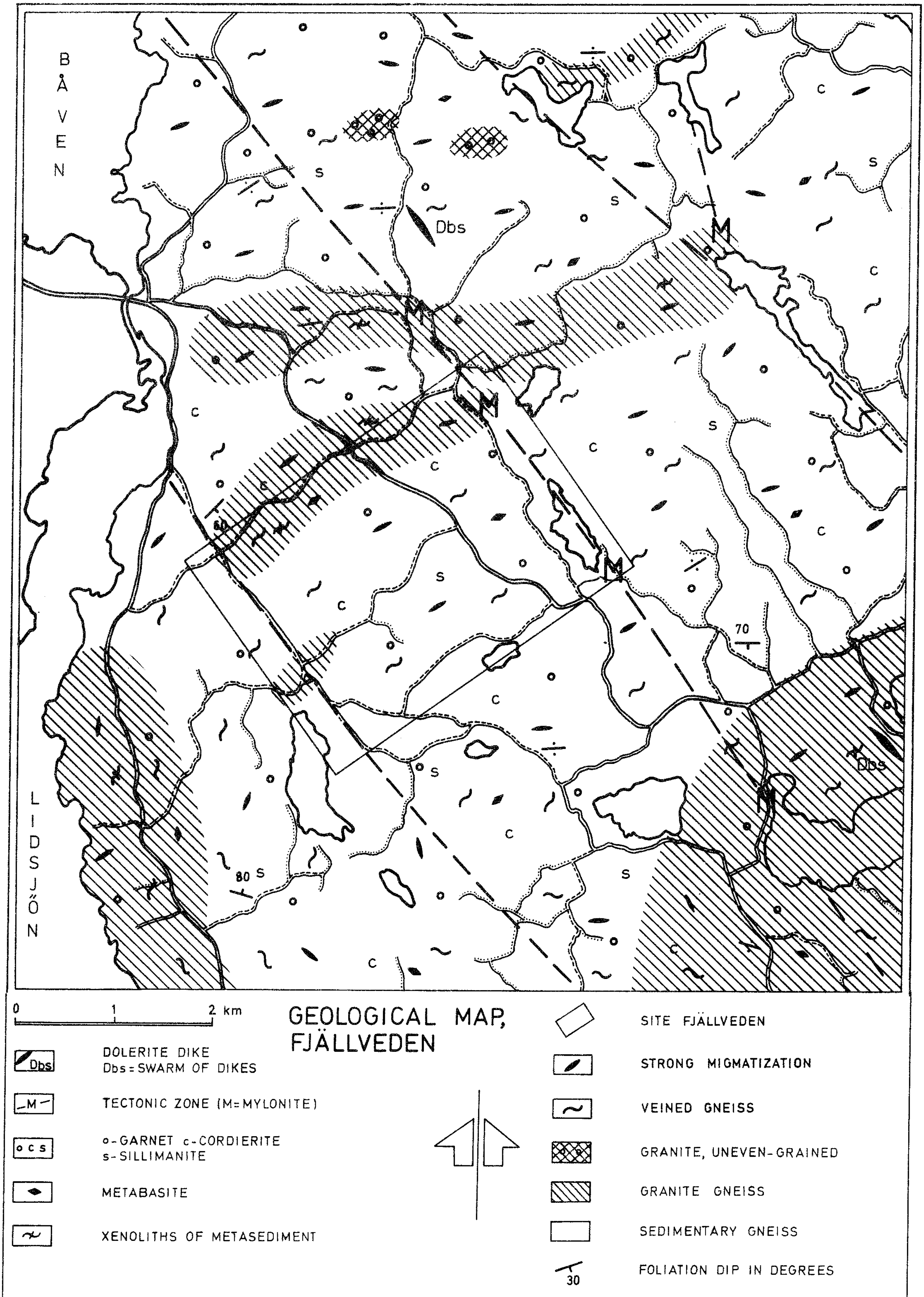


Figure 4.1 Regional geological map including site Fjällveden.

SWEDISH GEOLOGICAL

Within the regional area there are two minor bodies of younger granite (ref to fig 4.1). This granite is grey, of uneven granularity and only slightly foliated.

Dikes and irregular bodies of pegmatite are present throughout the regional area.

In the northern and south-eastern parts of the area numerous dolerite dikes have been found. This rock type is the youngest in the area. The dikes are frequently a metre wide and are present either separately or in clusters of approx ten parallel dikes, which in most cases have north-westerly orientation.

4.2 Bedrock at the study site

The Fjällveden area is dominated by veined gneiss of varying degree of migmatization, fig 4.2. This variation is mainly due to differences in the composition of the original sediments which later have been converted to veined gneiss. Local melting has resulted in the formation of irregular granitic bodies, migmatite granite, which are roughly following the regional structure of the bedrock. The boundary to the surrounding veined gneiss is as a rule well-fused, since the migmatite granite was formed in the bedrock environment where it is found today.

The veined gneiss is usually grey and fine- to medium-grained. The main minerals are quartz (50%), potash feldspar (25%), biotite (15%), and plagioclase (10%). Accessory minerals are i.a. cordierite, sillimanite, chlorite (after biotite), zircon and apatite. There are also sulphide minerals, usually in the form of pyrite and pyrrhotite.

The veins of the gneiss are white or to a minor degree light-red and mainly consist of quartz and feldspar. These two minerals have a low melting point. Thus, in combination with incomplete melting in the area, quartz and feldspar have been locally displaced and concentrated in veins in conjunction with the rock type formation. The veins are parallel with the foliation in the gneiss resulting in parallel-oriented biotite. Strike and dip of the foliation are generally of a north-easterly orientation and vertical but varies due to the fact that the bedrock has folded.

The veined gneiss usually contains small bodies of amphibolite.

The amphibolites are dark and fine-grained and occur as extended layers parallel with the foliation. The amphibolites mainly consist of amphibol feldspar and biotite. They are also usually garnet-bearing. The thickness of the amphibolite layers varies between decimetre- to metre-wide sections.

Fig 4.2 shows that granite gneiss has been found in a major part in the south-western sector of the area. The granite gneiss is grey and fine- to medium-grained and foliated in a north-easterly direction, i.e. the same direction as for the veined gneiss. Its mineralogical composition resembles that of the veined gneiss although with a lower quartz content. In older literature this type of granite gneiss is often referred to as "Old Granite".

Granite gneiss has also been found in 27 locations dispersed over the length of the drill cores. In total, granite gneiss constitutes 179 metres of a total drill hole length of 7 334 metres. Granite gneiss appears in this case as layers parallel to the foliation of the gneiss, which means that the layers are oriented in a north-easterly direction and with vertical dip. The width varies between 0.08 and 14.2 m, with a mean width of 3.1 m. The contact between granite gneiss and veined gneiss in the drill cores is well defined.

In the percussion-drilled holes the granite gneiss has been detected due to their slightly higher natural radiation level and higher resistivity. One example of geophysical anomalies due to granite gneiss is shown in fig 4.3. In fig 4.4 there is a projection to ground-level of granite gneiss strata found in core-drilled and percussion-drilled holes. The distance between the layers of granite gneiss varies from 20 up to 260 m, measured on a profile through the central part of Fjällveden. The mean distance between the layers is in this profile estimated to 100 m.

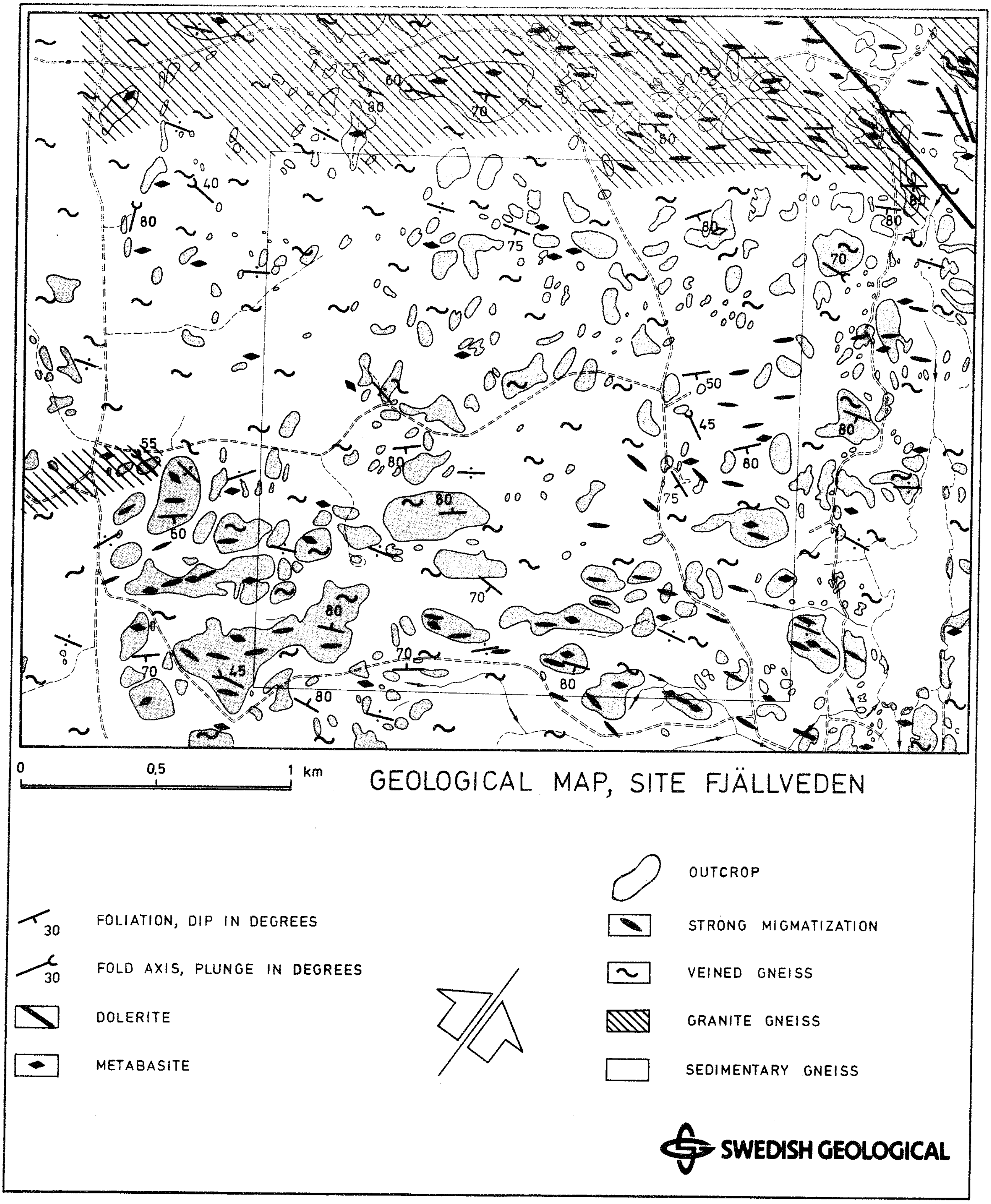


Figure 4.2 Geological map for site Fjällveden.

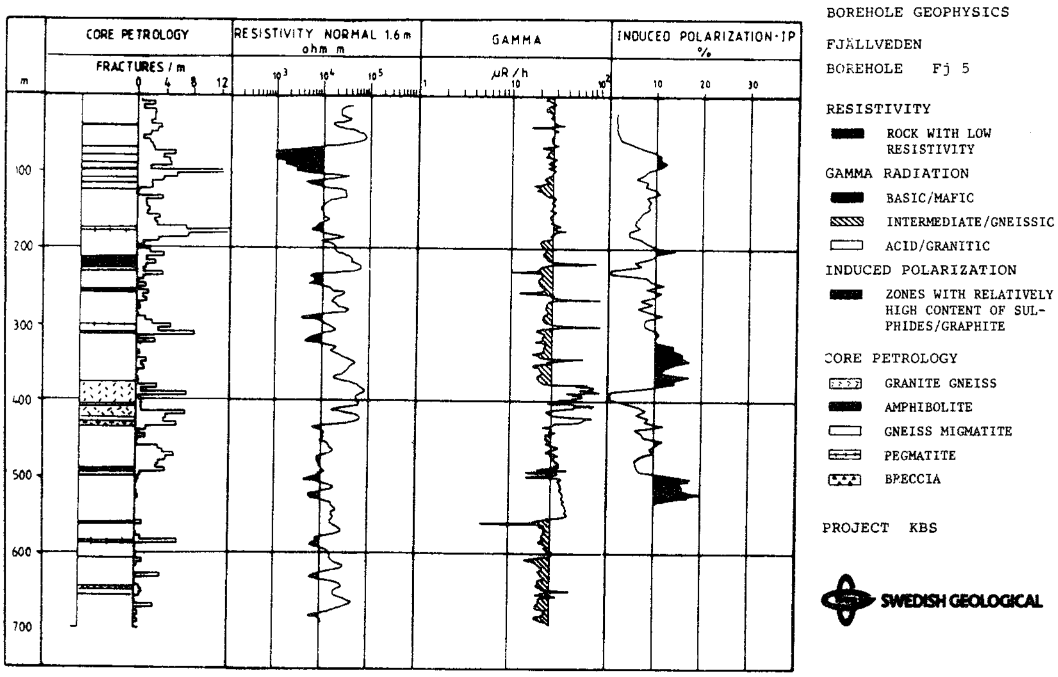


Figure 4.3 Results from logging of borehole Fj 5. Granite gneiss shows up as parts with higher natural radiation levels.

Drill-hole data indicate that the granite gneiss strata are more continuous in a horizontal direction as compared with the vertical. This can be explained by the fact that the granite gneiss and the veined gneiss have been folded isoclinically along horizontal fold axes causing the layers of granite gneiss to stretch and become thinner and be pulled apart at the fold limbs. The granite gneiss layers today remain as horizontal elongated bodies.

Pegmatite occurs throughout the study site in the form of dikes and minor massifs.

The youngest rock type in the area is dolerite which is present in the form of vertical dikes oriented in a north-westerly direction, i.e. perpendicular to the gneissic structure. These dikes are concentrated in the northern part of the site. The dolerite is grey to black and fine- to medium-grained. The dike width varies between 0.5 and 4 m.

As earlier mentioned there are sulphide minerals present throughout the site primarily in the form of pyrite and pyrrhotite. The occurrence of sulphide minerals results in low resistivity and comparatively high values of induced polarisation (IP) in the bedrock of the investigated area. Low resistivity values have been obtained in geophysical measurements on drill cores, in drill holes and on the ground surface. The sulphide minerals are dispersed in the bedrock (disseminations) and in the form of fracture veins and thin concentrations

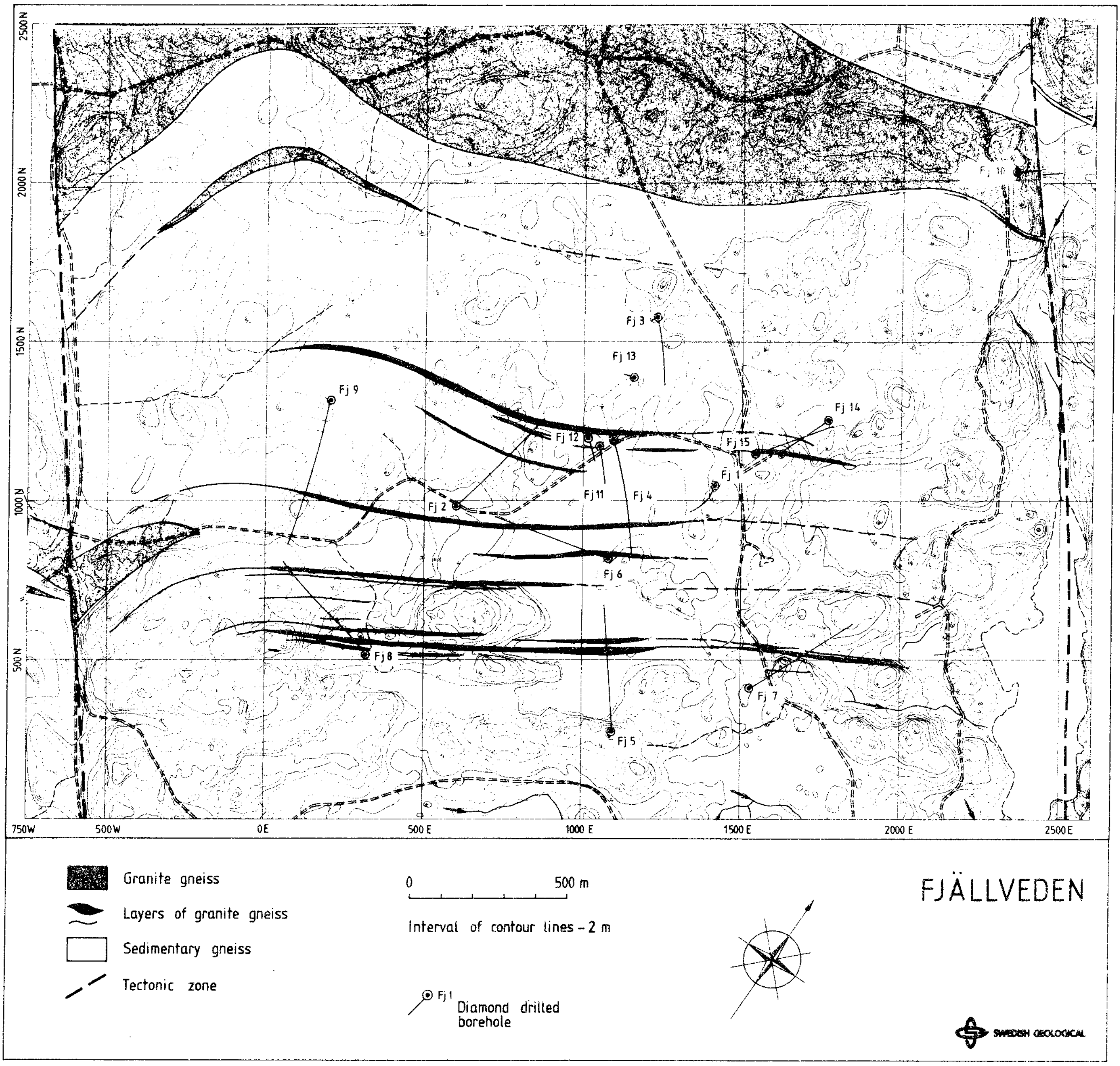


Figure 4.4 Projection at the surface of granite gneiss found in boreholes in site Fjällveden.

parallel with the gneiss structure. The granite gneiss is of comparatively higher resistivity and lower IP-effect which indicates a lower sulphide content. Due to overburden and the limited thickness of existing granite gneiss strata it has not been possible to utilise this circumstance for mapping the extension of the granite gneiss from the ground surface.

The geophysical maps indicate that pyrrhotite (which is magnetic) dominates the sulphite minerals in the north and pyrite in the south. The pyrrhotite in the north appears as an approx 300 m wide magnetic anomaly in blue on the magnetic map (ref to fig 4.5). This anomaly is coincident with a rock mass of low resistivity and high IP effect which indicates presence of sulphide minerals. Core drill hole Fj 13 was positioned in

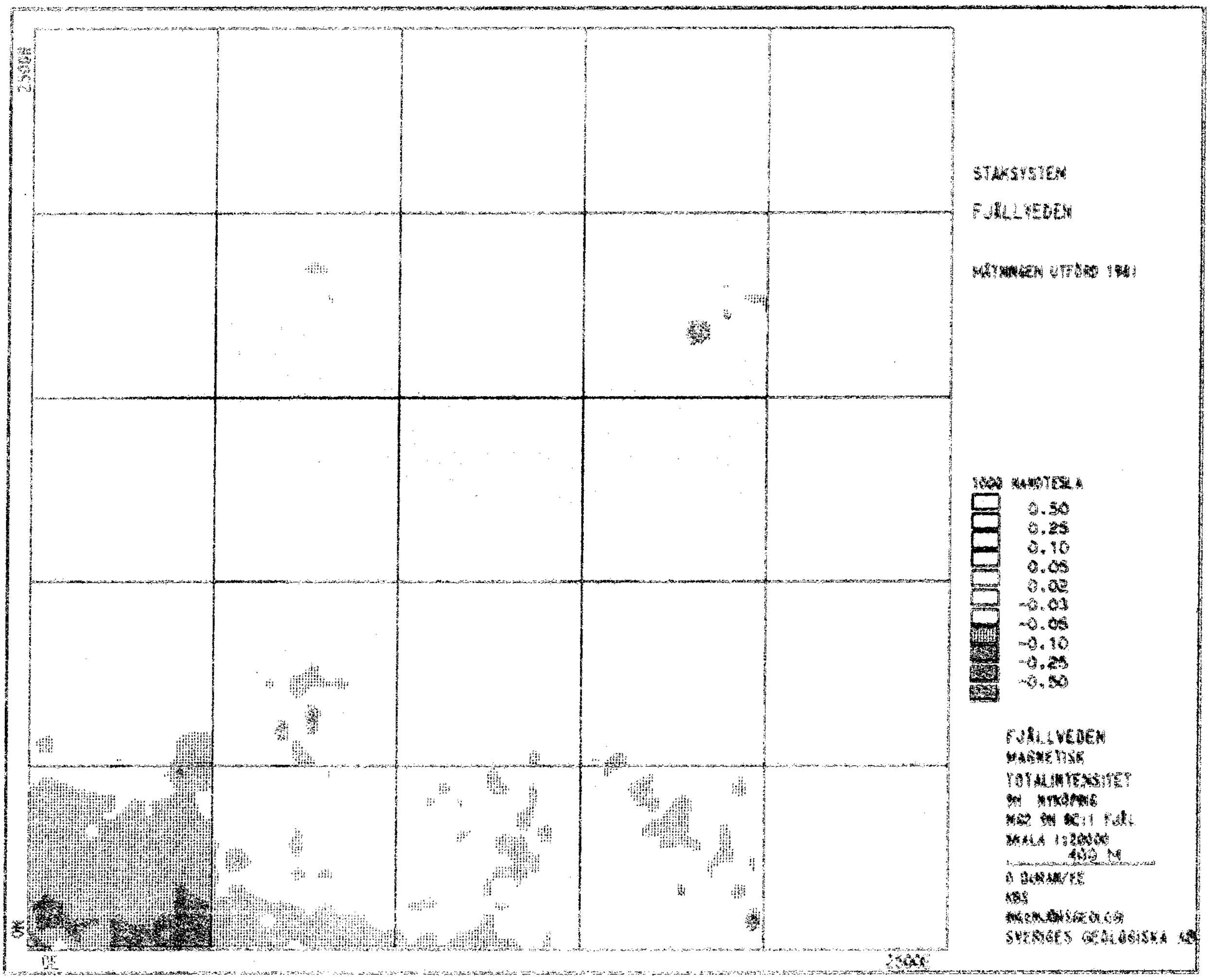


Figure 4.5 Magnetic field in Fjällveden. The blue colour indicates areas with higher content of pyrrhotite.

order to investigate this area. The drill core contains pyrrhotite, chalcopyrite and bornite, mainly between 60-117 m levels. In this section every 10th m has been sampled for analysis. These analyses display no high concentrations from mineral prospecting aspects, e.g. the highest copper concentrations in the analyses were 0.01%. In the south part of the area there are only minor concentrations of pyrrhotite.

4.3 Physical properties of the bedrock

Measurements of porosity and a number of other physical parameters were made on drill core samples. Results obtained and variation of characteristics between different rock types are shown in table 4.1.

Table 4.1 Physical parameters measured on drill hole samples from Fjällveden (average values)

Rock type	Density kg/m^3	Porosity %	Resistivity ohmm	IP-effect %
Sedimentary gneiss	2720	0.47	3 900	8.3
Granite gneiss	2680	0.28	10 500	4.4
Amphibolite	3010	0.03	158 000	8.5
Pegmatite	2630	0.34	4 200	1.9

The porosity of the amphibolites is considerably smaller than in other rock types. The difference in porosity is probably due to the fact that the amphibolite has a lower proportion of micro-fractures.

The difference in resistivity and IP-effect between the sedimentary gneiss and the granite gneiss is due to a lower sulphide mineral content in the granite gneiss.

From temperature measurements in all drill holes the average temperature gradient for the site is 15.6^{o}C/km.

5. FRACTURE ZONES

5.1 Regional fracture zones

The Fjällveden site is bounded to the north-east and south-west by regional fracture zones, fig 5.1. These regional fracture zones are oriented in a north-westerly direction and appear regularly at a relative distance of 2.5 - 3 km. When making the geological map-sheet Nyköping SO (Lundström, 1976) the observation was made that mylonite and breccia as well as jotnic dolerite are present in these zones. The presence of jotnic dolerite indicates that the zones are as old as jotnium or older, viz. approx 1,250 mill. years.

The regional fracture zone in the north-eastern part of Fjällveden was examined with the Fj 10 drill hole. In the fracture zone there are crushed sections, mylonite and breccia and an abundance of clay-filled fractures and indications of movements (shear indications). This means that movements in the bedrock have taken place along this zone, which is also evident from fig 4.4 where a lateral displacement across the fracture zone can be observed. The fracture zone is estimated to be 80-90 m wide and to be inclined 75 degrees in south-westerly direction, i.e. towards the study site.

The north-western fracture zone is assumed to be of the same orientation and magnitude as the north-eastern one.

5.2 Fracture zones within the study site

The fracture zones in the Fjällveden area have been mapped by means of aerial photograph interpretation, geological mapping and geophysical ground measurements. The properties of the bedrock at depth have been examined by means of 15 core drill holes and 49 percussion drill holes. In these holes, geophysical as well as hydrological measurements have been carried out. The position and depth of the drill holes as well as the total extent of the investigations performed are reported in the Appendix. The positions of the core drill holes are illustrated in fig 5.3.

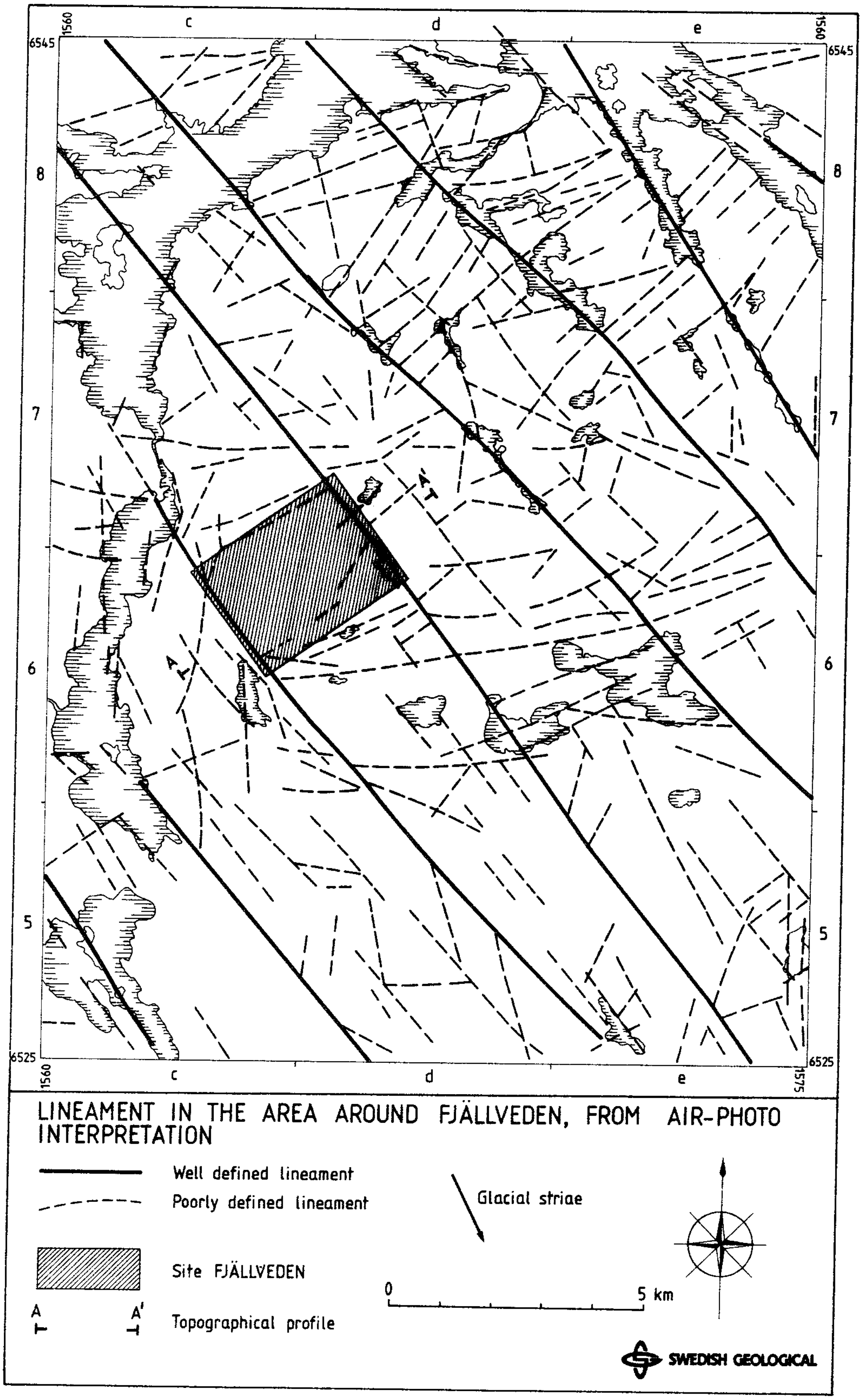


Figure 5.1 Interpreted lineaments around site Fjällveden.

Indications of local fracture zones obtained from geophysical surface investigations and from topographical conditions, have been examined by means of percussion drill holes. The indications have only in a few cases been verified as fracture zones in the drill holes. The indications have instead been caused by the presence of clays and sulphide minerals which make the geophysical measurements difficult to interpret. Clays and sulphides result in bigger anomalies than what can be expected from fracture zones. The results of the slingram (horizontal loop EM) measurements, fig 5.2, show the low-resistive areas in red colour. In general these represent areas with thicker clay layers than in the surrounding terrain. Certain fracture zones, however, stand out as clay-filled depressions, e.g. fracture

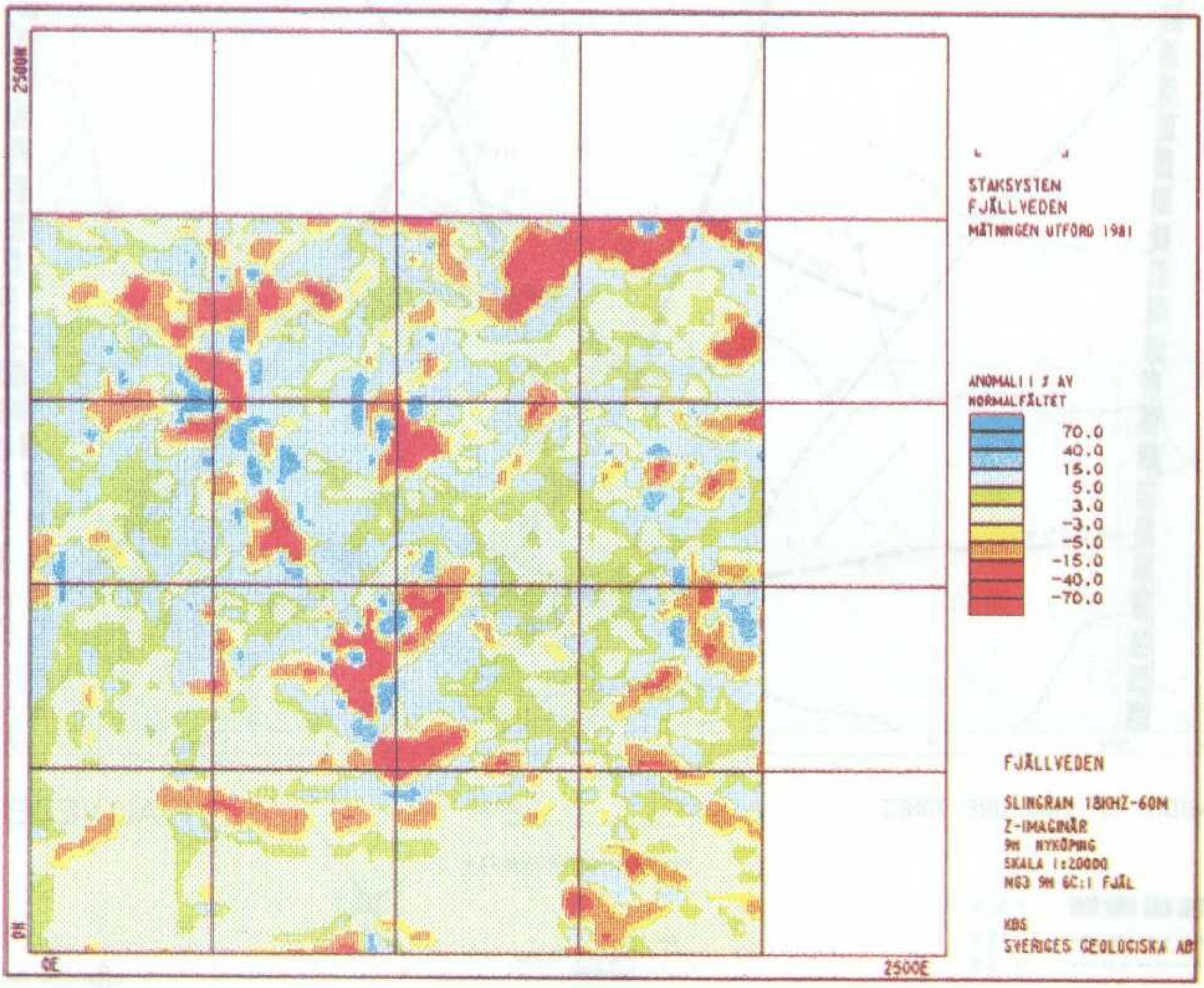


Figure 5.2 Slingram measurement showing areas with increased electric conductivity in Fjällveden mainly due to glacial clay.

zone 1. In the area there are depressions in a north-easterly direction which coincide with the strike of the gneiss. The majority of these depressions have proved to correspond to strata in the gneiss of varying resistance to weathering.

Percussion drill holes in general yield small water capacities. The median capacity of the percussion drill holes in the Fjällveden area is 350 l/h and the mean capacity 650 l/h.

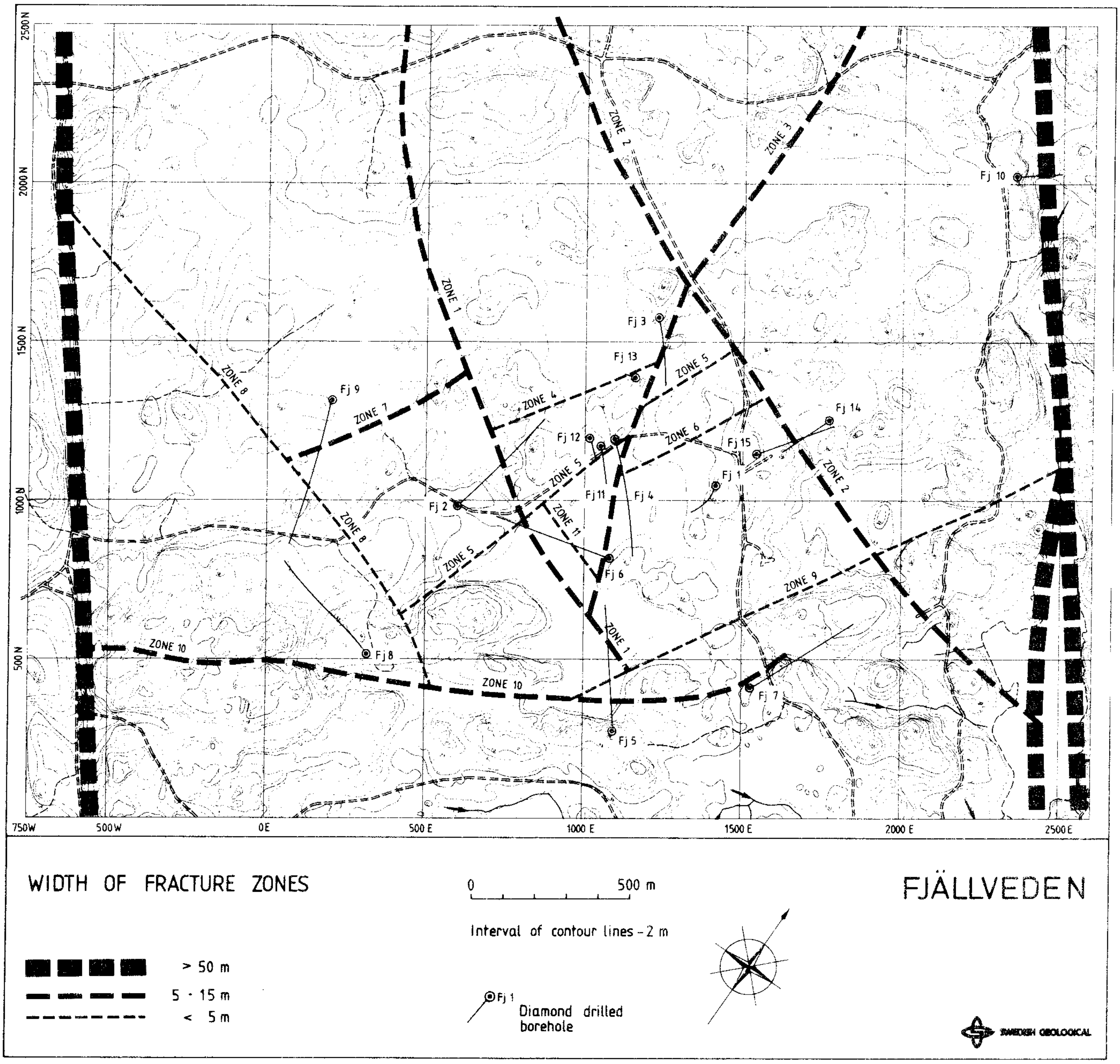


Figure 5.3 Fracture zones at the surace in site Fjällveden.

Within the study site, 11 local fracture zones have been found. These zones have been examined by means of core drill holes in a total of 21 different locations, table 5.1. The positions of the fracture zones at the ground surface and at a depth of 500 m are shown in figs 5.3 and 5.4. The width of the fracture zones varies from 0.2 to 14 m with a mean width of 5 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. In order to calculate the actual width of the fracture zone, a correction has been made for the angle of the drill hole to the fracture zone.

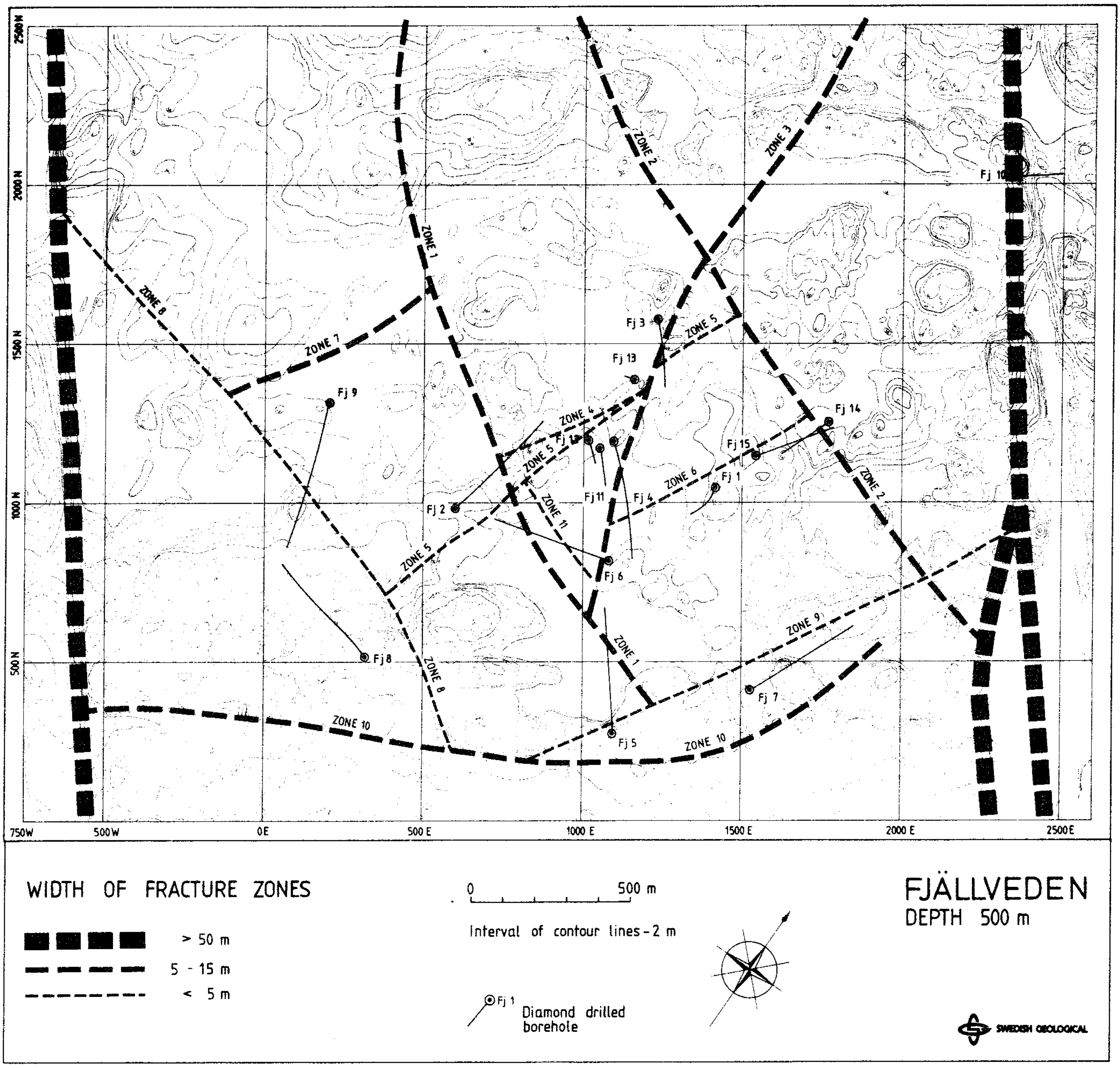


Figure 5.4 Fracture zones at 500 m depth in Fjällveden.

Table 5.1 Summary of fracture zones in study site Fjällveden

Fracture zone	Position in drill hole (m)	Dip (degrees)	True width (m)	K-value (m/s)
1	Fj 2 (340-354)	90	7	3 10-9
	Fj 5 (469-473)	90	1	2 10-9
	Fj 6 (479-486)	90	3	8 10-10
2	Fj 14 (115-134)	80 NE	12	not measured
	Fj 15 (304-321)	80 NE	9	not measured
3	Fj 3 (150-175)	90	5	3 10-7
	Fj 4 (140-192)	90	10	1 10-7
	Fj 6 (37- 59)	90	11	not measured
4	Fj 2 (596-600)	80 SE	1	7 10-9
5	Fj 4 (61- 63)	80 NW	1	1 10-6
	Fj 6 (610-611)	80 NW	0.5	1 10-11
	Fj 11 (64- 66)	80 NW	1	not measured
	Fj 12 (99-101)	80 NW	1	not measured
6	Fj 1 (674-676)	75 SE	0.2	1 10-10
7	Fj 9 (110-130)	60 NW	14	2 10-8
8	Fj 9 (424-433)	90	4.5	5 10-9
9	Fj 5 (173-185)	75 SE	5	5 10-7
	Fj 7 (685-731)	75 SE	5	1 10-10
10	Fj 5 (96-102)	70 SE	5	2 10-9
	Fj 7 (53- 89)	70 SE	6	not measured
11	Fj 6 (245-256)	90	3	not measured
Regional eastern zone	Fj 10 (70-165)	75 SW	90	1 10-6
Regional western zone	-	75 SW*	90	-

* Calculated from geophysical observations.

The local fracture zones are of less width and extension than the regional fracture zones delimiting the study site. These local fracture zones have proved to be of limited continuity as well as of little contrast to the surrounding rock mass in respect to water permeability. The distance between these zones is usually 300-900 m.

Within the fracture zones there are, as a rule, one or more crushed zones, in most cases one or a few dm wide. Within the fracture zone there are also parts of low fracture frequency. A specification of the proportion of crushed and fractured rock in the fracture zones as well as of rock of low fracture frequency is given 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, if any, are defined in the figure as crushed rock. More detailed definitions of these concepts are given by Ahlbom et al. (1983).

The zones are usually steep, the dip varying between 70° and vertical. Down to the 100-200 m level there are probably horizontal release joints. Deeper down in the bedrock no horizontal fracture zones have been observed.

Within the local fracture zones there are parts with brecciated, weathered and clay-altered rock. Commonly occurring fracture minerals are calcite, kaolinite, chlorite and illite. Crushed sections in the fracture zones have largely been sealed by the formation of clay minerals.

5.3 Rock mass fracturing

The fracturing of the rock mass has been mapped both on outcrops and on drill cores. The fractures observed on outcrops have two main directions, north-east and north-west, i.e. parallel with and perpendicular to the structure of the gneiss. The frequency of fractures longer than 0.5 m on outcrops is 0.9 fractures/m.

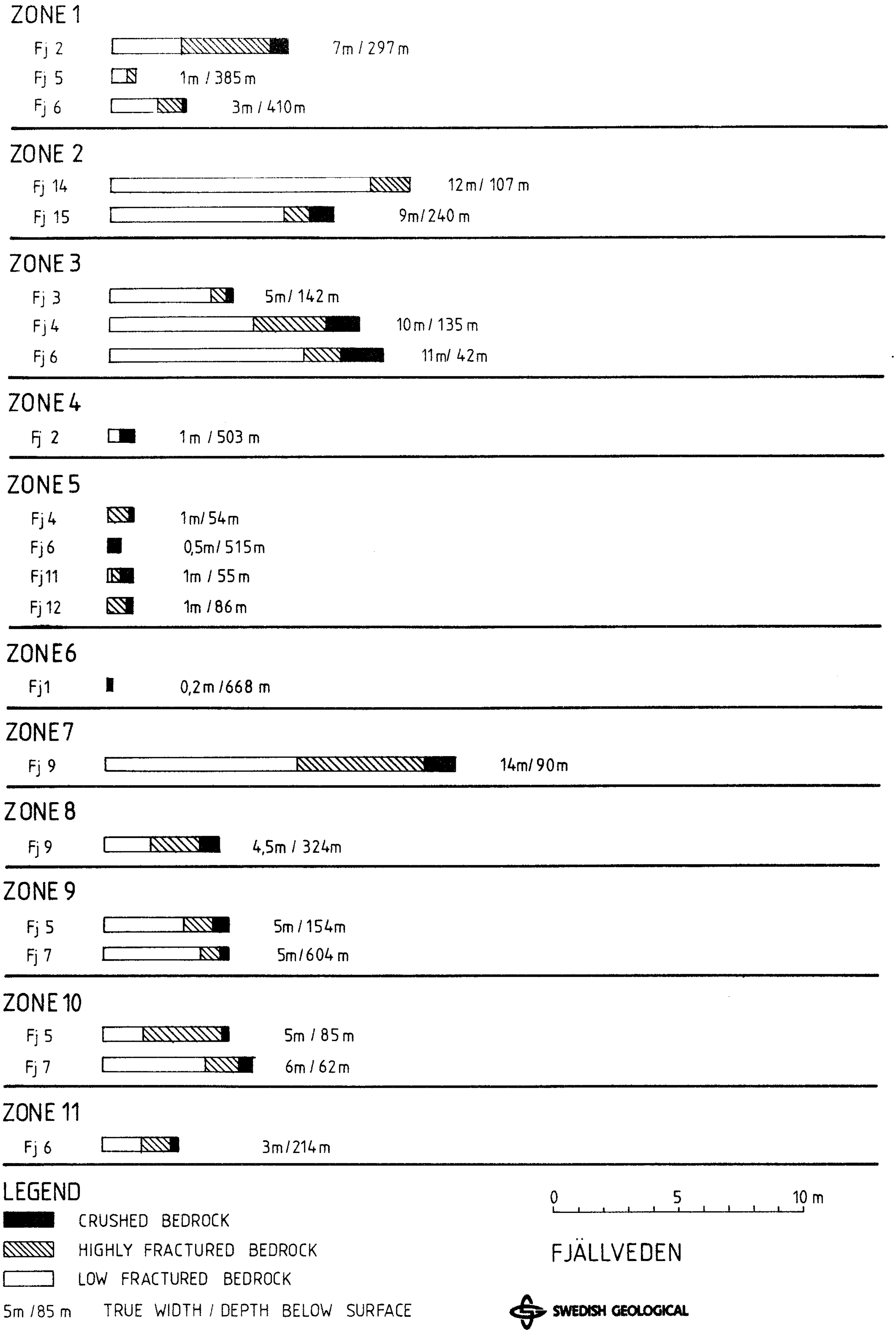


Figure 5.5 Percentage of crushed, highly fractured and low fractured bedrock in the fracture zones at Fjällveden. Fracture zones width given after each bar.

The variation of the fracture frequency with the depth of the rock mass between the fracture zones is shown in fig 5.6. The fracture frequency is the highest within the topmost 200 m. Deeper down in the rock mass the fracture frequency is 1.8 fractures/m. The higher fracture frequency of the drill cores as compared with the outcrop measurements is due to the frequency of horizontal fractures, release joints, having been underestimated in the outcrop mapping. The drill core fracture frequency also comprises all fractures irrespective of length in contrast to the outcrop mapping where fractures shorter than 0.5 m have not been included. The fracture frequency in the various drill holes is shown in figs 7.1 - 7.5.

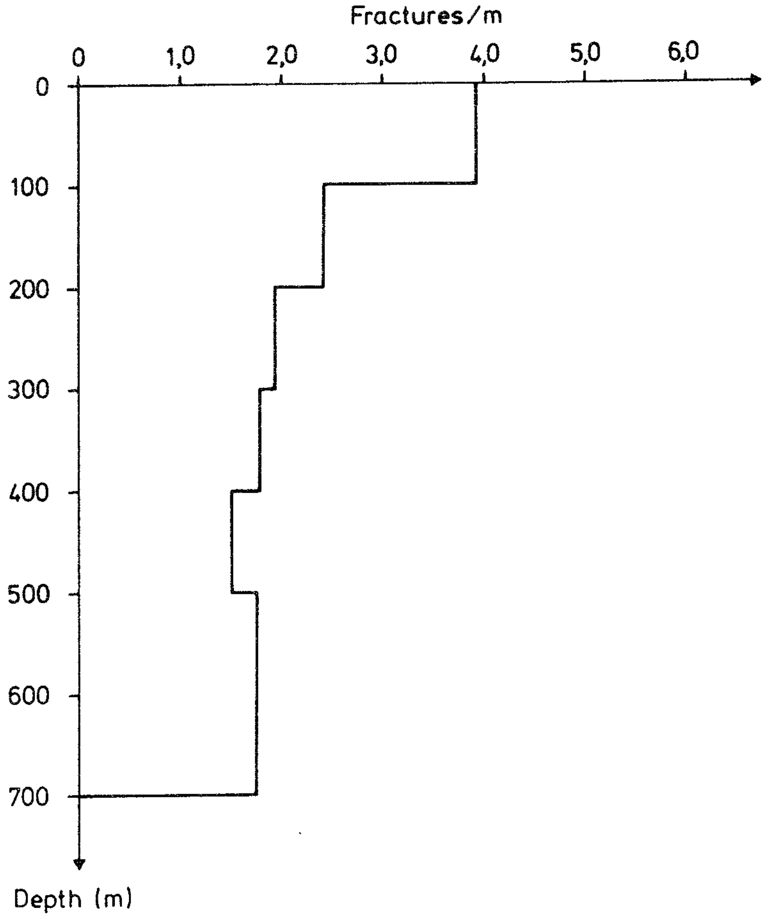


Figure 5.6 Fracture frequency in rock mass within site Fjällveden.

The surface fracture frequency of the different rock types display no differences. Migmatite as well as granite gneiss have the same value, viz. 0.9 fractures/m. The total fracture frequency for the various rock types, irrespective of depth in the drill cores, is lowest in migmatite, 2.8 fractures/m, followed by granite gneiss with 4.3 fractures/m and amphibolite with 5.9 fractures/m.

Common fracture filling minerals occurring in drill cores are calcite, chlorite, kaolinite, and pyrite. In addition, there are the clay minerals smectite, montmorillonite and illite. These clay minerals are frequently in-mixed with one another and difficult to separate. Some of the analysed clay samples indicate swelling ability. The presence of kaolinite indicates that the ground-water at Fjällveden has or has had chemical properties promoting alteration (weathering) of plagioclase into kaolinite.

6. HYDROLOGICAL AND METEOROLOGICAL CONDITIONS

6.1 General

Hydrological and meterological data and conditions in the study site Fjällveden are based on information obtained from SMHI. The information consists of mean values for the period 1951-80. Data from meterological stations with shorter observation series have been used when necessary.

The site Fjällveden is situated on the water divide between two drainage areas, fig 6.2. The western part is drained by the stream Nyköpingsån and the eastern part by the stream Svärtaån, fig 6.1. The Nyköpingsån drainage area covers 3623 km^2 and the Svärtaån drainage area 342 km^2. Both these streams flow into the Baltic after 20 km.

The location of the study site on the water divide means that it constitutes a recharge area. Low-lying parts of the area are local runoff areas for surficial ground-water. These parts usually coincide with peat bogs.

The study site is divided into local drainage areas, fig 6.2. The eastern part is drained towards lake Sågsjön and the stream south of it towards lake Kappstasjön. This drainage area is 12.4 km^2, 3 % being lakes. The north-western part drains the above-mentioned peat bogs via a stream falling into the northern part of lake Lidsjön. The drainage area is 4.8 km^2 and there are no lakes. The south-western part of the site is drained via the lake Morpasjön into lake Lidsjön. The drainage area is 3.5 km^2 at the Morpasjön outflow. The comparatively large lake Morpasjön, 0.4 km^2, makes the proportion of lake area reach 14 %. In all, the drainage areas cover 20.7 km^2 with a proportion of lake area of 4 %.

Data on the major lakes at the site are given in table 6.1.

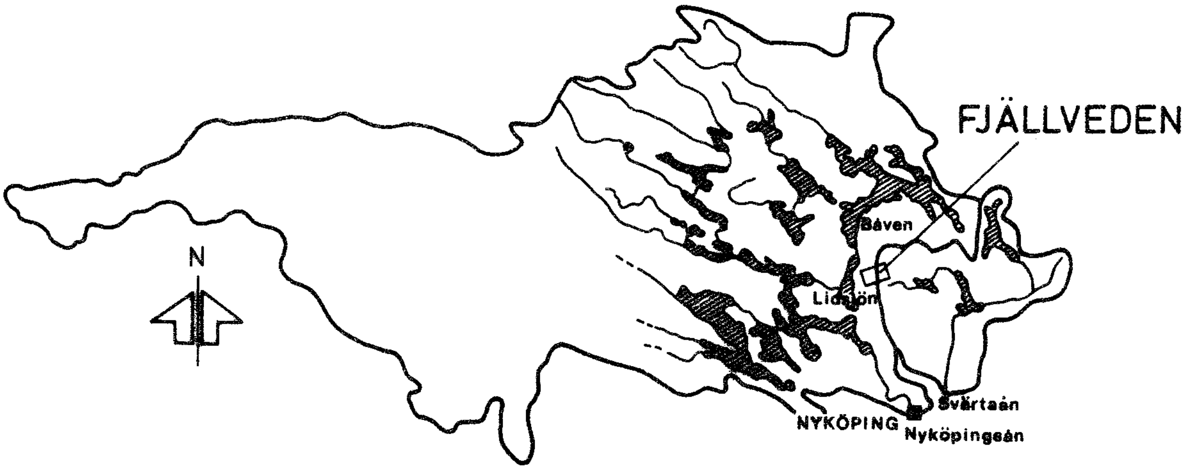


Figure 6.1 River basins connected with site Fjällveden

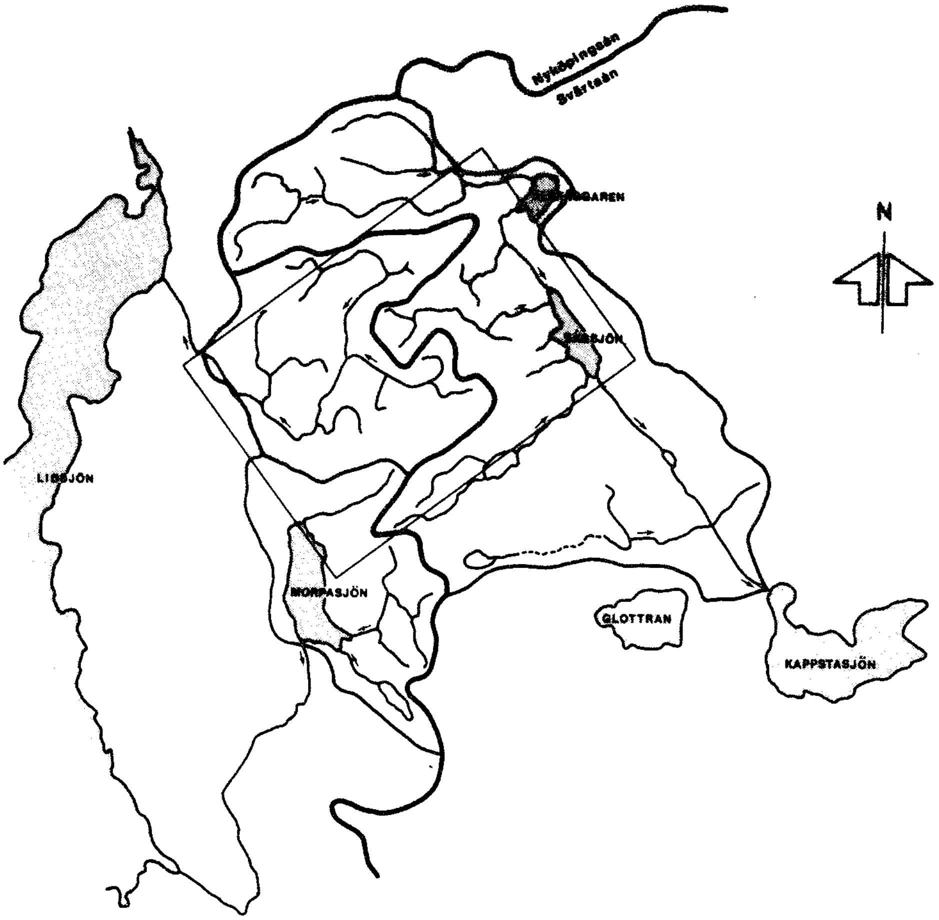


Figure 6.2 Local drainage basins within site Fjällveden

Table 6.1 Major lakes within and around the Fjällveden study site

Nyköping Stream drainage areas		Svärta Stream drainage areas	
<u>Lakes</u>		<u>Lakes</u>	
Båven	67.2 km^2	Eknaren	3.0 km^2
Lidsjön	8.9 "	Kappstasjön	1.0 "
Morpasjön	0.4 "	Glottran	0.4 "
		Sågsjön	0.18 "
		Älskäggaren	0.13 "

6.2 Precipitation and temperature

The temperature in the region around Fjällveden has been calculated using data from the meteorological stations listed in table 6.2.

Table 6.2 Data on the meteorological stations used to provide data for calculating the mean precipitation within the Fjällveden study site.

Station	Distance to site	Station altitude	Observation period	Adj. annual precipitation
Frändesta	10 km	30 m	1953-	654 mm
Stigtomta fpl	17 km	36 m	1937-60	624 mm
Ökna	14 km	20 m	1955-	669 mm
Lindö	7 km	18 m	1925-77	642 mm

The mean value for the four stations has been taken as an areal mean value for the study site. The adjusted annual precipitation is 647 mm and the adjustment factor 19 %.

The estimated precipitation distribution per month is shown in table 6.3.

Table 6.3 Calculated adjusted precipitation and monthly mean temperature for study site Fjällveden during the period 1951-80

Adj.	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Precipitation (mm)	48	37	36	39	44	52	72	76	62	58	64	59	647
% snow	71	75	70	25						3	15	43	21
Mean temp. (^{o}C)	-3.5	-4.2	-0.9	3.8	9.8	15.0	16.5	15.6	11.4	7.0	-2.2	-1.1	6.0

Of the annual precipitation 20 % falls as snow. During the period January - March snow constitutes more than 70% of the total precipitation. The ground is snow covered during the period 18/11 - 11/4. The durability is in average 105 days, varying for individual years between 154 and 26 days.

The duration of the frozen ground period has been regarded as the period during which the daily mean temperature is below zero. Ground freezing occurs during the period 12/12 - 27/3 corresponding to 106 days. At least a couple of weeks' time lag should be taken into consideration, however, before frozen ground has formed and also before it disappears.

The temperature conditions in the Fjällveden site are best represented by the Stigtomta values. The annual mean temperature is 6.0^{o}C. The monthly mean values are given in table 6.3.

6.3 Evaporation

The actual evaporation in the Fjällveden site has been calculated for the period 1951-80 based on the potential evaporation data relating to the Nyköping airport. In addition, the annual value of the actual evaporation in Fjällveden has been interpolated from the isoline evaporation chart (Eriksson 1980). The potential evaporation amounts to 596 mm/year, the actual evaporation having been estimated at 450 mm/year at the Fjällveden site. Table 6.4 specifies potential and actual evaporation as monthly mean values.

Table 6.4 Potential and actual evaporation in Fjällveden 1951-80

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Potential evaporation (mm)	2	5	19	54	102	134	120	92	49	18	2	0	596
Actual evaporation (mm)	1	3	10	35	75	110	95	75	35	10	1	0	450

6.4 Run-off

The Fjällveden study site is, as earlier mentioned, located on the water divide between the Nyköpingsån drainage area to the west and the Svärtaån drainage area to the east. Existing stations for run-off measurements in the area are located far down in the water system, thus the run-off data from the stations are not representative of the study site.

A better estimate of the run-off from the study site is obtained by comparing data from similar areas of the same size in the Stockholm region, and simulating the run-off in the Fjällveden area. The drainage area has for this purpose been set to

20 km^2 with a lake proportion of 4%. In table 6.5 the estimated monthly run-off is specified during the period 1951-80. The run-off has two peaks, one top peak in April during the spring flood and another in conjunction with the late autumn rains in November-December. In summer the run-off is insignificant during expended periods.

Table 6.5 Estimated monthly run-off in Fjällveden, 1951-80

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Run-off (l/s km^2)	6	6	9	16	10	2	1	2	3	6	9	8	6.5

The mean run-off during the year amounts to approx 6.5 l/s km^2 (=200 mm/year). The main part of the water volumn, however, is discharged during a comparatively limited part of the year. Thus more water is discharged during April than during the entire period June-October.

The distribution in time of the run-off is shown by the duration curve in fig 6.3. The duration is expressed in percent of time (year or period). From the figure is evident that the run-off is in excess of 6.5 l/s km^2 for only 30 % of the time. During half the year the run-off is on the average more than 3.5 l/s km^2.

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.

In Fjällveden, adjusted precipitation and actual precipitation have been estimated irrespectively of the run-off estimates. The adjusted values of precipitation and evaporation suffer from a certain uncertainty. The error for the annual value is probably about 25 mm.

The run-off error is estimated at 10 mm. The water balance with respect to Fjällveden during the period 1951-80 will consequently be:

Adjusted precipitation	647 ± 25 mm/year
Actual evaporation	450 ± 25 mm/year
Run-off	200 ± 10 mm/year

Of the precipitation, 70 % will consequently be evaporation and 30 % run-off. The ground-water run-off through the boundaries of the area or via the bedrock is negligible.

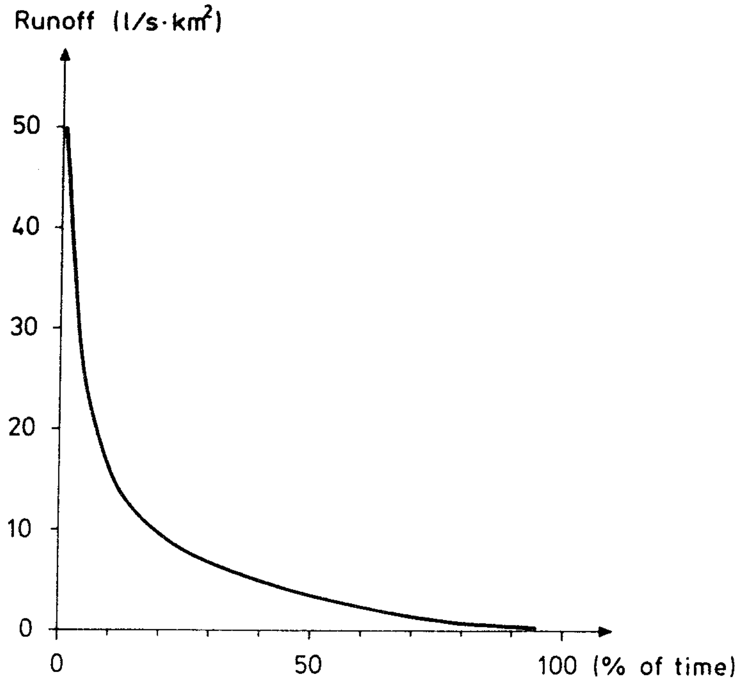


Figure 6.3 Mean duration of runoff at site Fjällveden during the period 1951-80.

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 holes Fj 1 - Fj 9. These tests have been carried out in 25 m sections sealed off by inflatable packers, beginning 15-25 m beneath the groundsurface, down to approx 10 m from the bottom of the drill holes. In all, 219 sections of 25 m have been tested. The tests were carried out under constant head (Almen et al. 1982), while the variation of the water-flow with time has been 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 together with the fracture frequency of the individual drill holes in figs 7.1 - 7.5.

In the majority of the drill holes the injection tests have been supplemented with detailed measurements where the section length has been 5 m or 10 m. The number of detailed measurements comprise 61 sections. The measurements were carried out 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 mean of checking the results obtained for the 25 m sections. By comparing the transmissivity (T) (the hydraulic conductivity multiplied by the section length) obtained 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 the 5 - 10 m section lengths, respectively, have been specified in a way to make the results 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. The three highest T-quotients are due to the measurement of a hydraulic conductivity lower than the measurement limit value, which means that one of the values is the result of a leakage. Data on all control-measured sections are given in Table 7.1.

In the centre of the study site, test-pumping has been carried out to examine the hydraulic conductivity in two of the fracture zones indicated by the geological and geophysical investigations. The text-pumping was carried out in percussion drill hole HFj 18 for 20 days at a capacity of 6000 l/h (100 l/min). In addition to the measurements in the pump hole, variations of the groundwater head were recorded in observation holes HFj 4, 13, 14, 21, 22, 23, 28 and 29, fig 8.1. All observation holes were sealed off with packers in three measurement sections. The middle section was chosen to represent the most water-conducting zone in the individual drill hole. After completed pumping, the recovery was measured for 19 days. The evaluation was made according to transient analysis methods.

Table 7.1 Comparison of transmissivity between 25 m and 5/10 m sections in core drill holes at Fjällveden. T-quotient defined 1.

Drill hole	Section (m)	T-quotient	Drill hole	Section (m)	T-quotient
Fj 2	340-365	1.08	Fj 7	425-450	4.04
	465-490	1.24		500-525	1.58
	590-615	1.04		525-550	2.83
				675-700	3.55
Fj 4	115-215	1.05			
	215-240	>24		725-750	1.39
Fj 5	165-190	1.59	Fj 8	645-695	1.68
	265-290	1.61		695-720	1.75
	290-315	1.07	Fj 9	215-265	1.11
	365-390	118.2		365-390	1.20
	490-515	1.12		415-440	1.81
	540-565	>4.40			
Fj 6	365-390	1.20			
	490-540	<1.77			

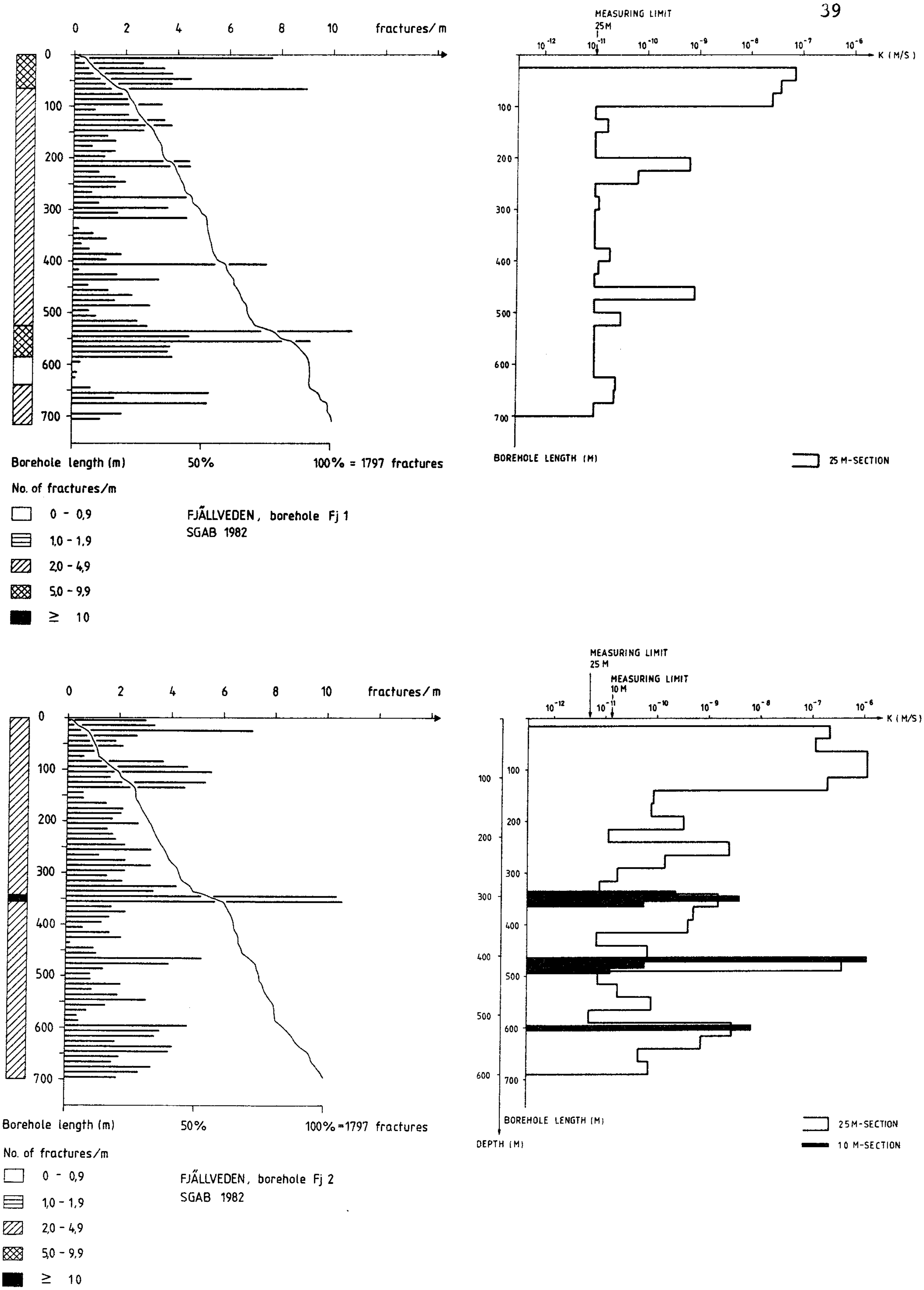


Figure 7.1 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, boreholes Fj 1 and Fj 2.

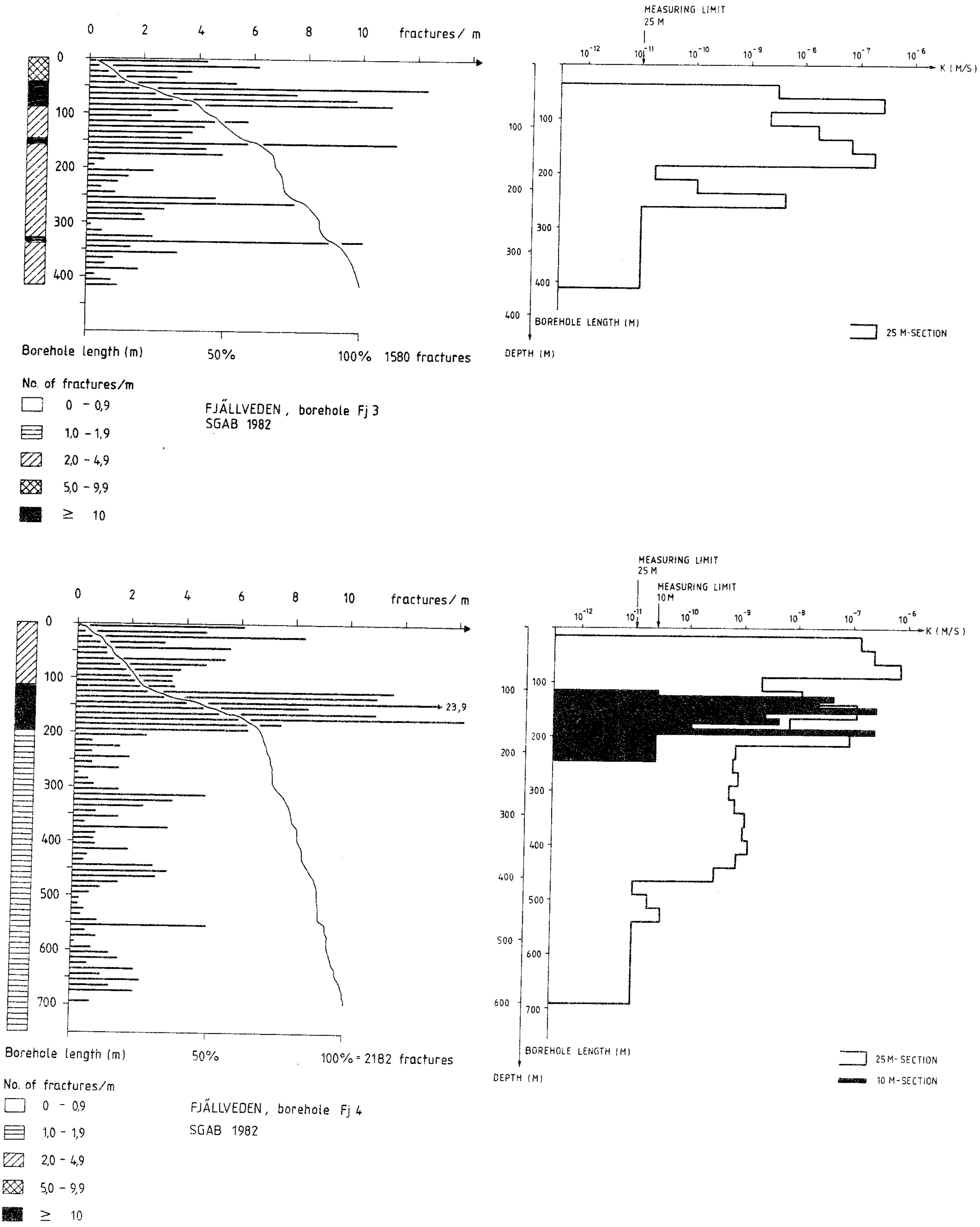


Figure 7.2 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, boreholes Fj 3 and Fj 4.

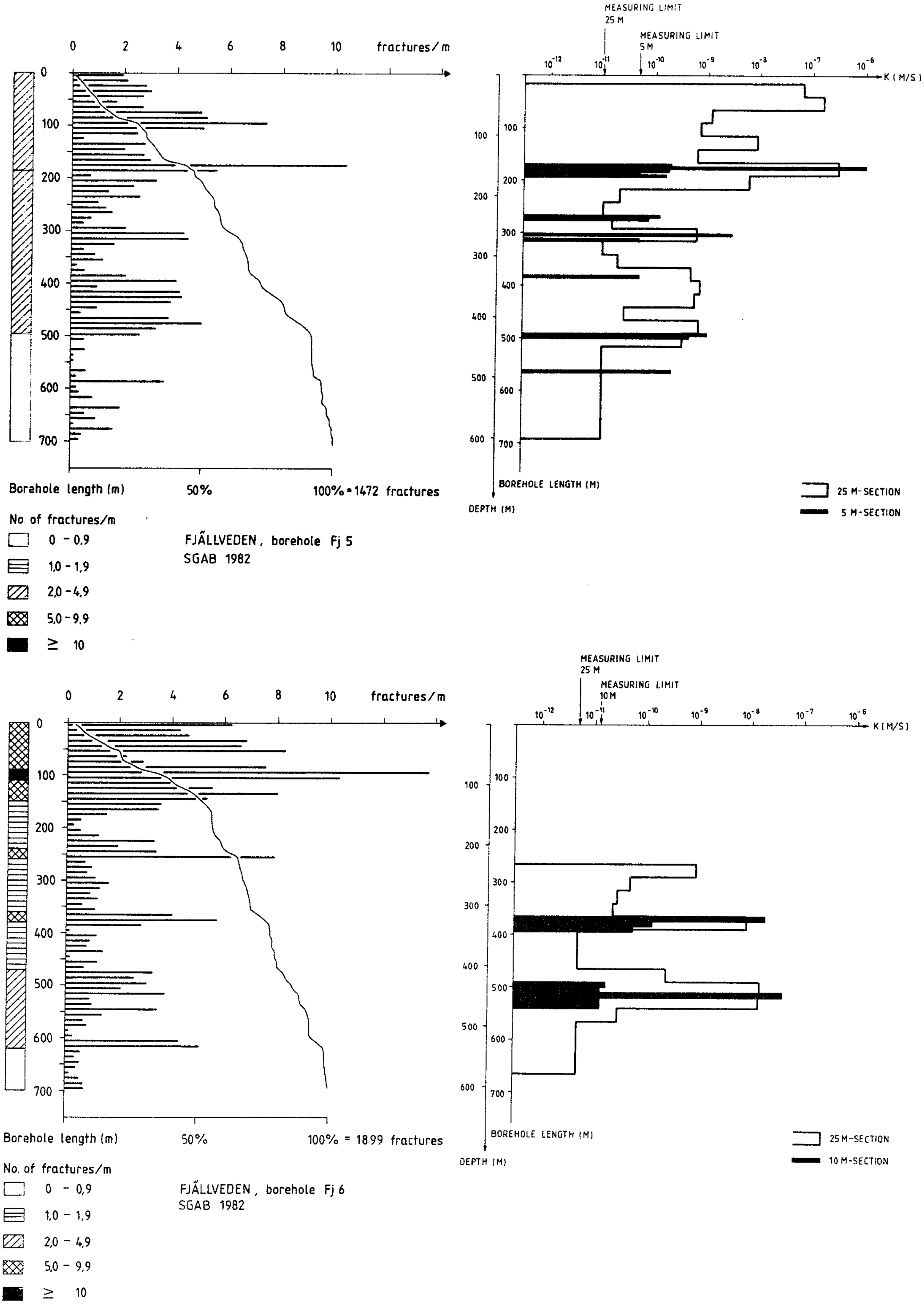


Figure 7.3 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, boreholes Fj 5 and Fj 6.

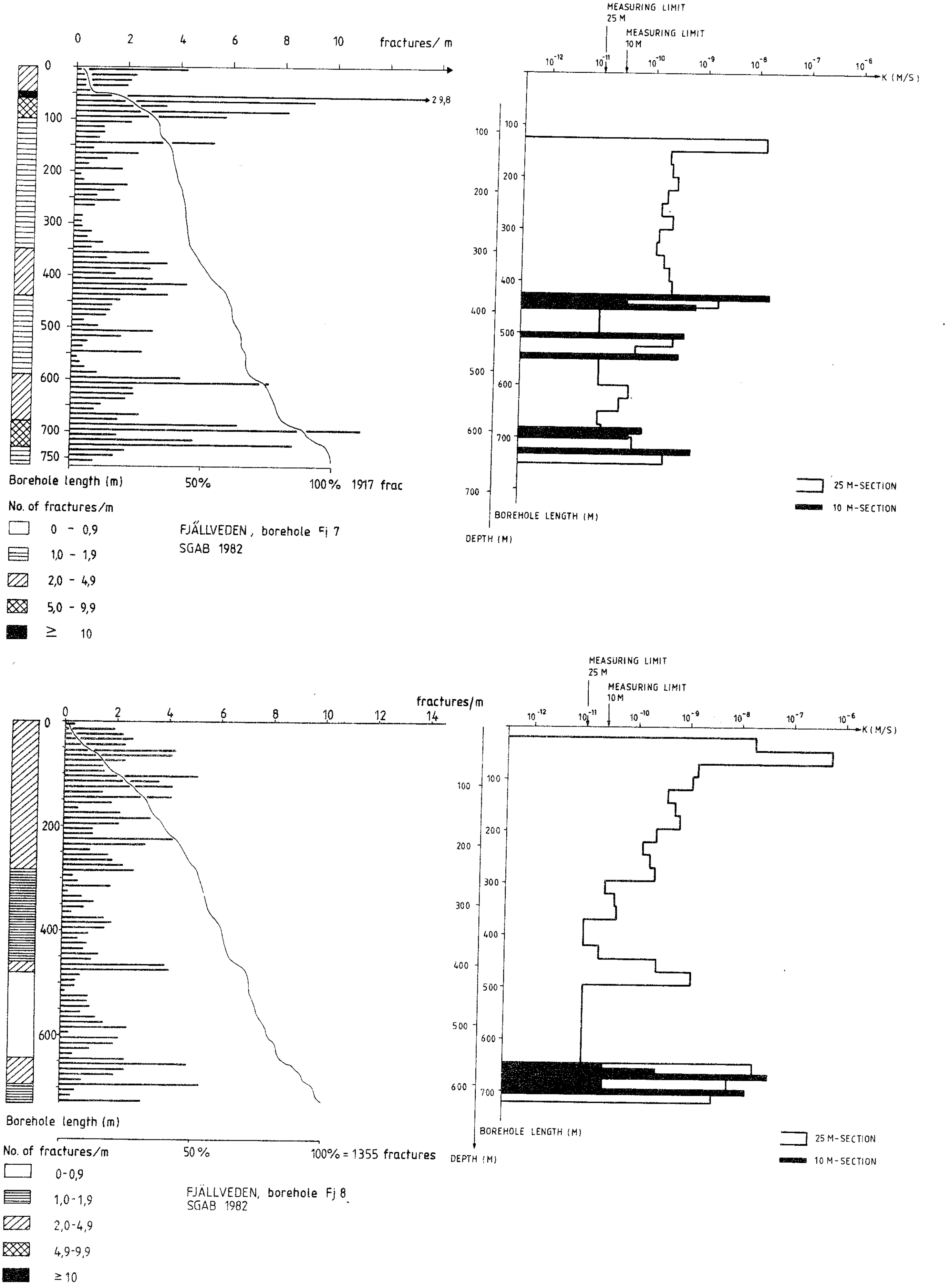


Figure 7.4 Fracture freqeuncy for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, boreholes Fj 7 and Fj 8.

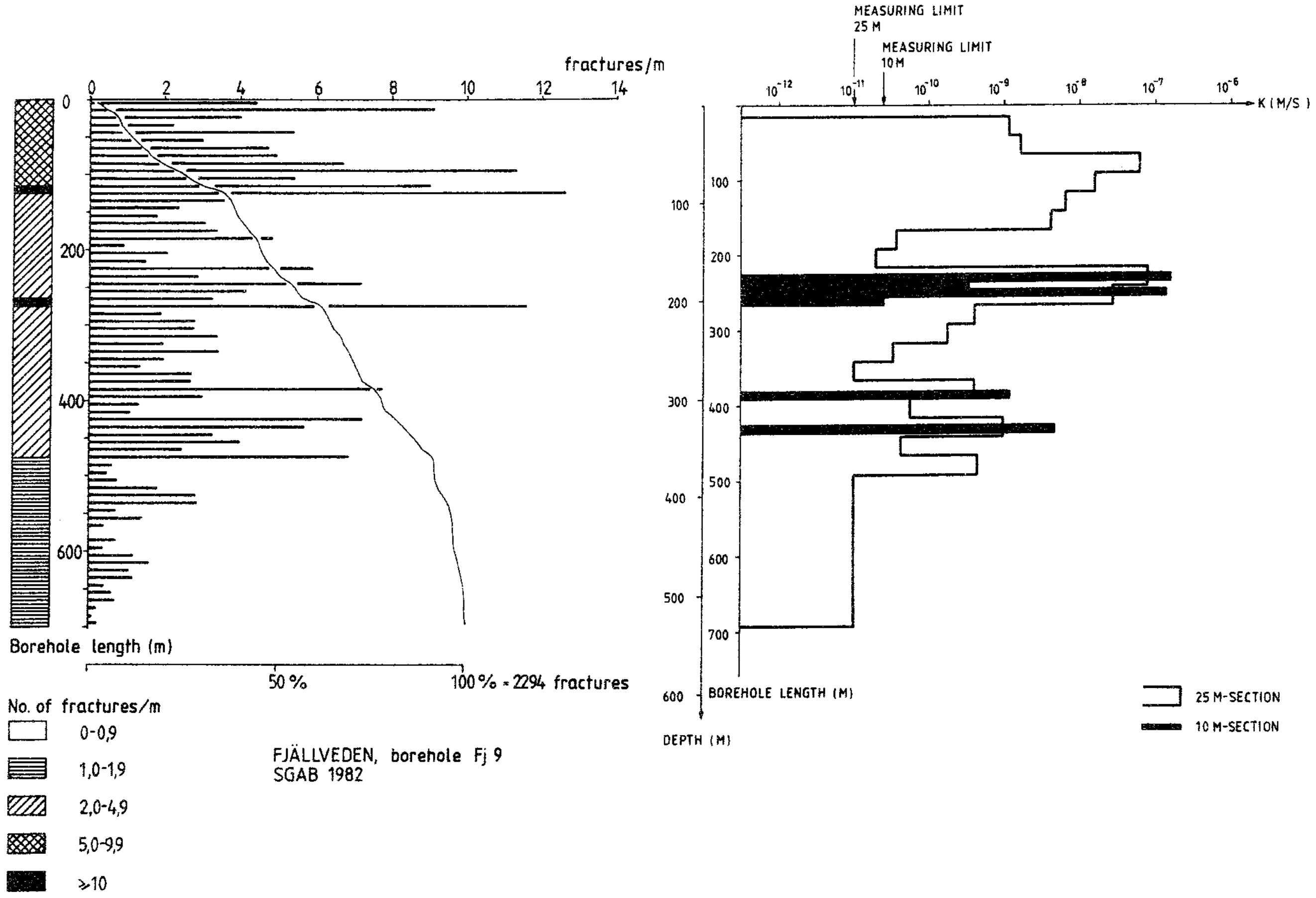


Figure 7.5 Fracture frequency for 10 m-sections, cumulative percentage of fractures and hydraulic conductivity, borehole Fj 9.

7.2 Results

7.2.1 Hydraulic units

The bedrock in the Fjällveden 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 area. The following three hydraulic units have been identified:

- rock mass
- local fracture zones
- regional fracture zones

This classification was based on results from the geological and tectonic investigations which indicate the location and extension of existing regional and local fracture zones. The occurrence of the local fracture zones in the drill holes has been determined on the basis of the drill core logs. The hydraulically tested 25 m sections not relating to the zones represent the hydraulic conductivity in the rock mass. K-values from all core holes relating to the rock mass are specified in fig 7.6.

The rock mass is divided into three parts with respect to hydraulic conductivity. An upper part extends down to 100 m, where the K-value varies between 1×10^{-9} m/s and 2×10^{-6} m/s. Between 100-200 m the range is wider, from the measurement limit 1×10^{-11} m/s to 2×10^{-7} m/s. Below 200 m depth the K-value is mainly less than 1×10^{-9} m/s. A few values up to 2×10^{-8} m/s, relate to sections of granite gneiss and pegmatite of higher fracture frequency than the surrounding rock (e.g. Fj 6 and Fj 8). Similar granite gneiss and pegmatite dikes, respectively, are present in several of the drill holes although the hydraulic conductivity does not increase.

At a depth below 400 m a K-value of $3,9 \times 10^{-7}$ m/s is observed, extremely high for these depths. The high K-value was measured in Fj 2. In the section concerned, 463-473 m drill hole length, both pegmatite and gneiss granite layers have been observed. Adjacent to the pegmatite there is also free crystallized pyrite, which indicates an open fracture. The K-value is the highest obtained below 200 m depth at the Fjällveden site.

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. The proportion of open fractures is probably higher in the upper part of the rock due to the comparatively small vertical rock stresses.

At depths greater than 200 m the rock load generates greater vertical stresses, the proportion of open fractures as well as the fracture frequency being lower. The low hydraulic conductivity values may also depend on the continuity of the fractures being less at great depths. The depth interval 100-200 m constitutes a transient zone between the other two.

Existing layers of granite gneiss in the rock mass usually have a higher hydraulic conductivity than the veined gneiss. No correlation was found between the hydraulic conductivities of the layers and their width. Thus, the highest K-values are found in two granite gneiss layers, the width of which are 1.3 and 4.4 m, respectively, whereas the thickest layers (approx 11-14 m) display K-values around 5×10^{-10} m/s. The granite gneiss does not show any markedly higher fracture frequency in comparison with the veined gneiss. No correlation between fracture frequency and hydraulic conductivity in the granite gneiss was found.

Hydraulic conductivity calculated in the 25 m and 10 m sections have been compared with the results of the core logging. For each fracture zone a K-value has been calculated for each drill hole where the zone was intersected. In fig 7.7 and table 7.2 the K-values of the fracture zones have been compiled. Zones appearing in several drill holes have been connected. Of the four zones detected in more drill holes than one, three have been observed at essentially different depths. The diagram shows that the hydraulic conductivity decreases with depth. On the other hand, no correlation between the width or the direction of the fracture zones and their hydraulic conductivity has been noted.

FJÄLLVEDEN Fj 1-9

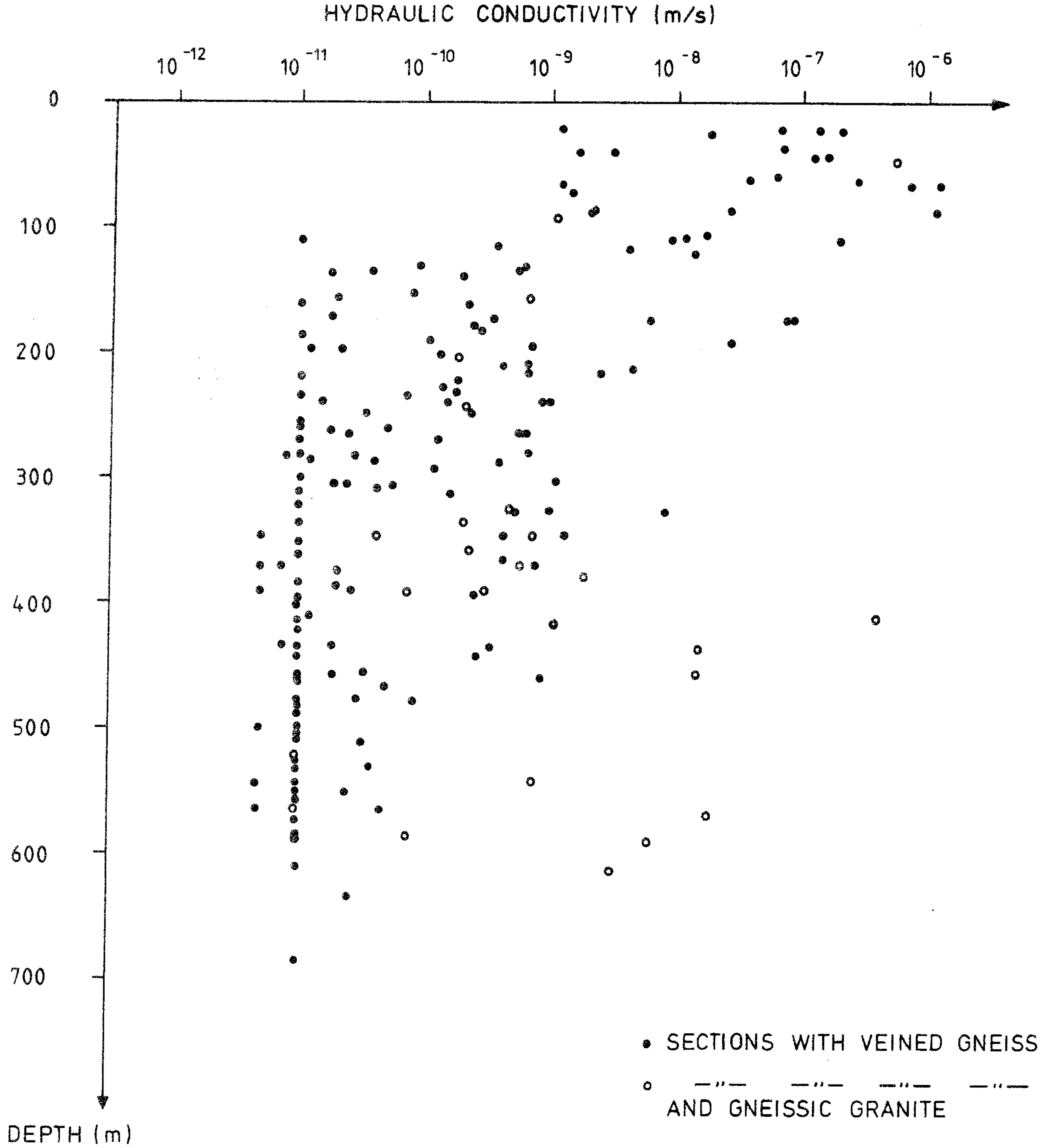


Figure 7.6 Hydraulic conductivity for the rock mass (25 m-sections) in boreholes Fj 1 - Fj 9.

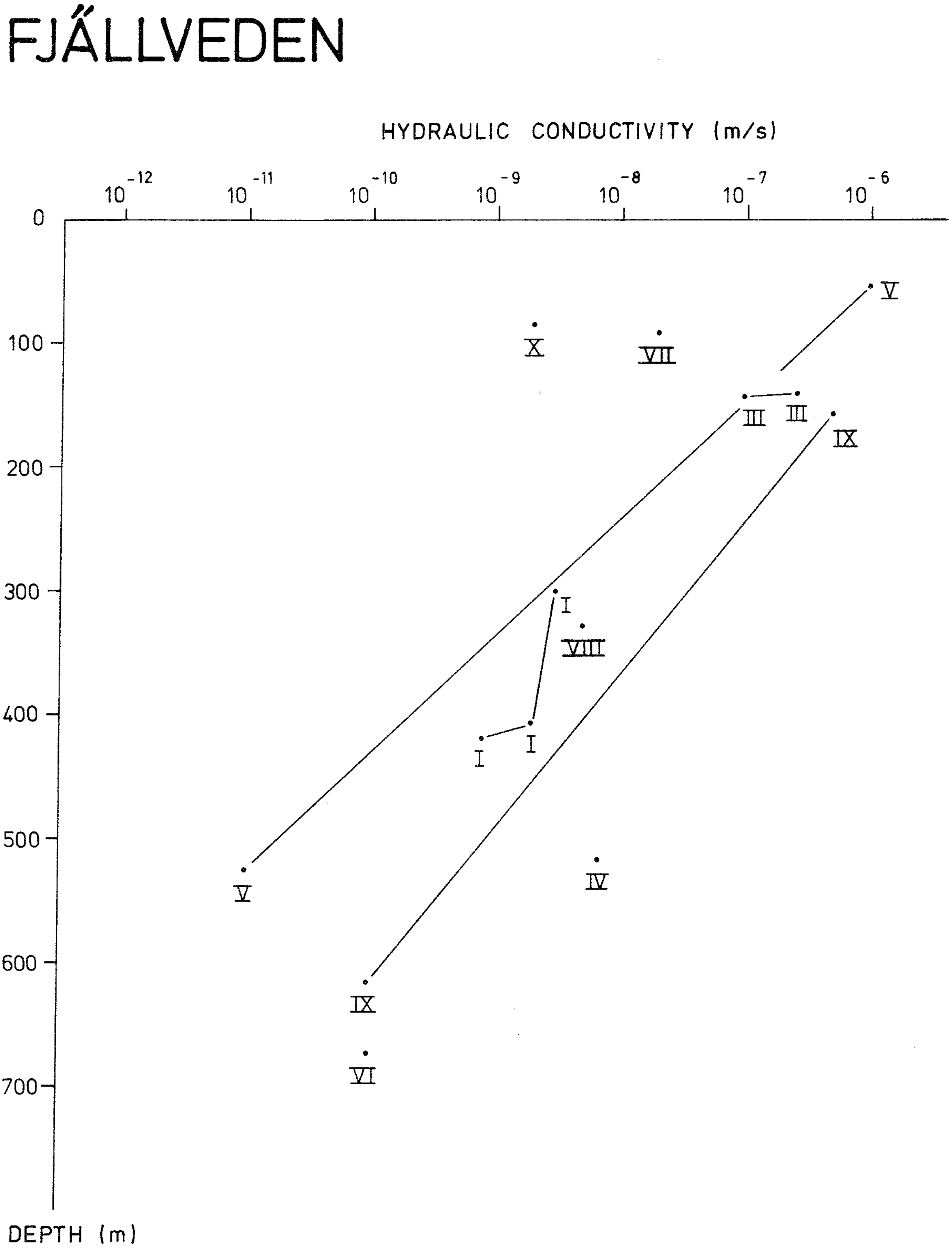


Figure 7.7 Hydraulic conductivity in local fracture zones penetrated by boreholes Fj 1 - Fj 9.

Table 7.2 Hydraulic conductivity (K) values for fracture zones at the Fjällveden study site

Zone	Zone width (m)	Observed in drill hole no	Length drill hole (m)	Length of crushed rock in zone (m)	K (m/s)
1	7	Fj 2	340-354	1.05	$3.0\ 10^{-9}$
	1	Fj 5	469-473	0.10	$2.0\ 10^{-9}$
	3	Fj 6	479-486	0.20	$8.0\ 10^{-10}$
3	5	Fj 3	150-175	0.92	$2.5\ 10^{-7}$
	10	Fj 4	140-192	6.26	$1.0\ 10^{-7}$
4	1	Fj 2	596-600	1.43	$7.1\ 10^{-9}$
5	1	Fj 4	61- 63	0.35	$1.0\ 10^{-6}$
	0.5	Fj 6	610-611	0.95	$1.0\ 10^{-11}$
6	0.2	Fj 1	674-676	0.38	$1.0\ 10^{-10}$
7	14	Fj 9	110-130	1.50	$2.0\ 10^{-8}$
8	4.5	Fj 9	424-433	0.96	$5.0\ 10^{-9}$
9	5	Fj 5	173-185	1.25	$5.0\ 10^{-7}$
	5	Fj 7	685-731	1.54	$1.0\ 10^{-10}$
10	5	Fj 5	96-102	0.15	$2.0\ 10^{-9}$

Results of test-pumping of two local fracture zones at the site, zone 3 and zone 4, indicate that their K-values vary between 1×10^{-6} m/s and 2.3×10^{-7} m/s. This is well in accordance with the results presented in chap 7.3 where the hydraulic conductivity of local fracture zones down to 100 m depth fall within this interval.

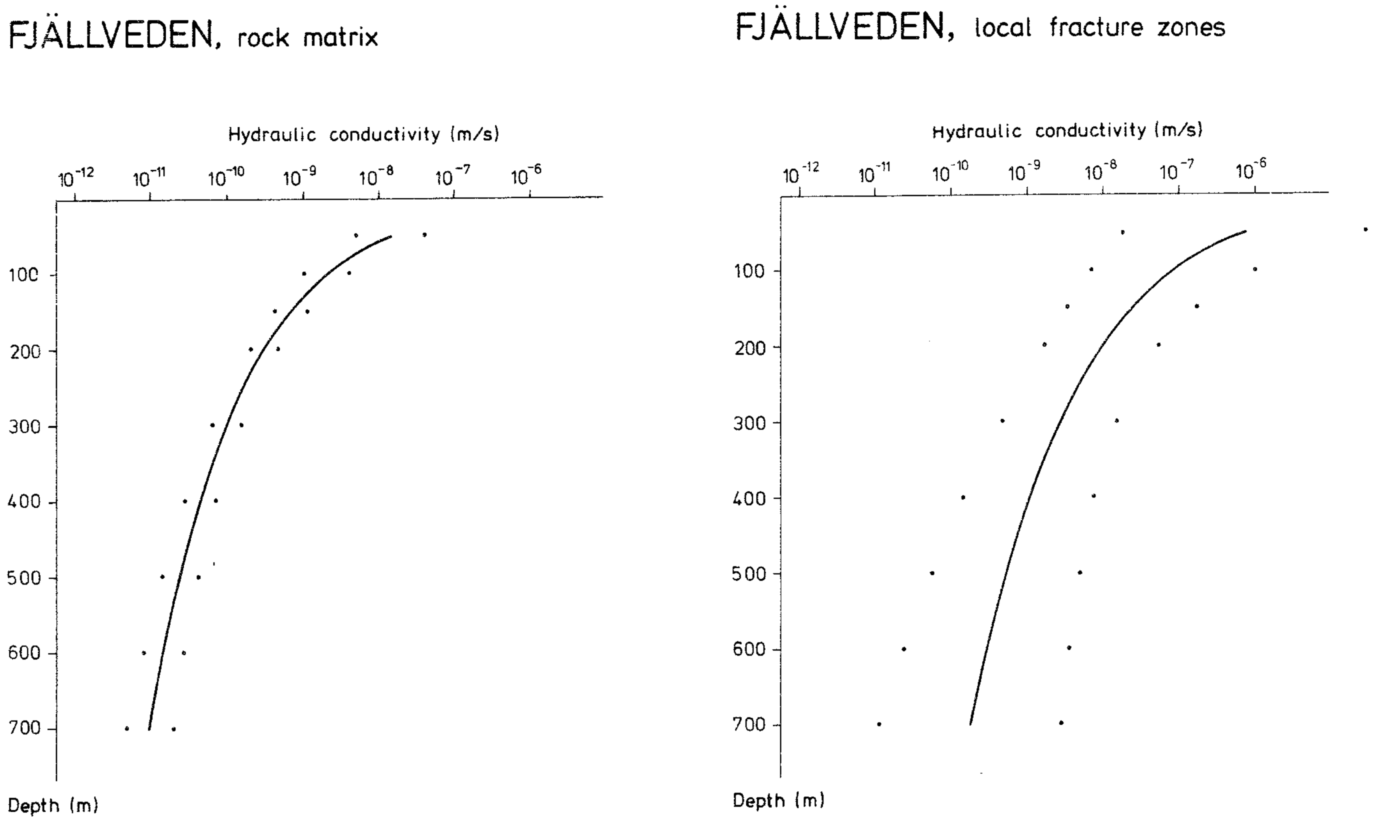


Figure 7.8 Relation between hydraulic conductivity and depth in the rock matrix and local fracture zones.

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.

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 " : $K(z) = a\,e^{b\,z}$

a,b = constants; z = depth

The power curve fit has given the best correlation. The results of the power curve regression are shown in fig 7.8. A 95 % confidence interval has also been indicated in the figures for the power curve, which means that there is a 95 % probability that the curve is within the confidence limits.

There are not many data relating to regional fracture zones at the Fjällveden study site and the experiences obtained at the Svartboberget study site have therefore been utilized in order to evaluate the depth dependence of the K-value. The Svartboberget results indicate that the K-value in the regional fracture zones is 10-20 times higher in the 100-800 m interval, than in the local fracture zones, and also that the decrease of hydraulic conductivity with increasing depth is slightly slower.

The resulting power curves are shown in table 7.3 and fig 7.9.

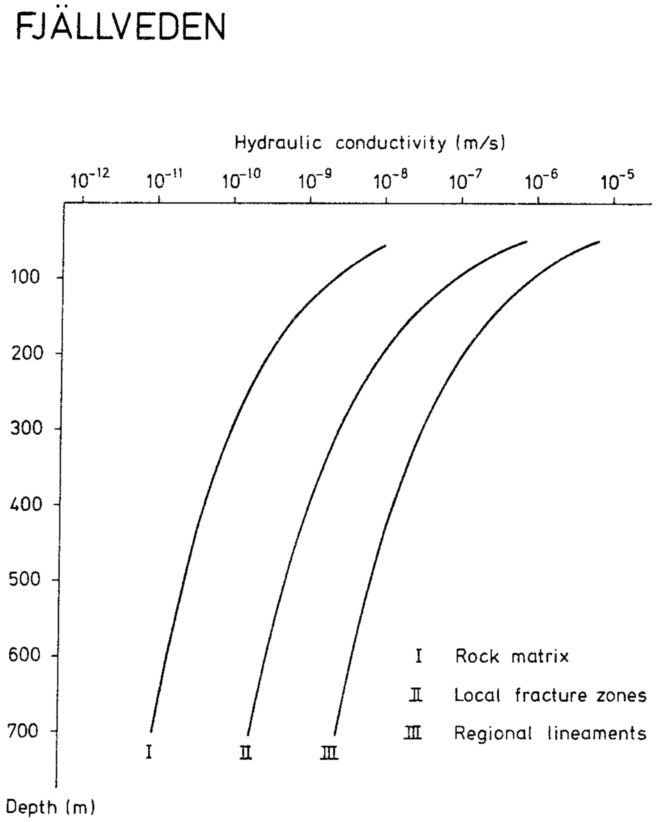


Figure 7.9 Relation between hydraulic conductivity and depth in different hydraulic units of the bedrock.

The regression analysis indicates that the hydraulic conductivity in the local fracture zones is between one and two orders of magnitude higher than in the rock mass. The difference is greatest in the uppermost parts and decreases with increasing depth. The hydraulic conductivity of the regional fracture zones is approximately ten times higher than for the local fracture zones.

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	$0.0008\ z^{-2.78}$	0.44	200
Local fracture zones	$0.17\ z^{-3.15}$	0.58	14
Regional fracture zones	$0.9\ z^{-3}$	-	1

Differences in hydraulic conductivity between different rock types have, as mentioned above, been confirmed. Layers of granite gneiss have, primarily at depths, proved to have higher K-values than surrounding gneiss. As a consequence, the rock mass has been divided into two hydraulic units, one representing the granite gneiss and one representing the remaining rock mass, mainly consisting of veined gneiss.

When calculating the hydraulic conductivity values of the individual rock types, measured data from sections containing only veined gneiss, have formed the basis for the regression curve between depth and the effective hydraulic conductivity. In the case of the measured sections containing granite gneiss and veined gneiss the measured conductivity value as 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 7.10. In veined gneiss, amphibolite and pegmatite is included. The values obtained indicate that the hydraulic conductivity of the granite gneiss is higher than that of the local fracture zones. At a depth of 700 m the difference is approximately one order of magnitude.

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

Hydraulic unit	Power curve	r^2	n
Granite gneiss	$0.003\ z^{-2.24}$	0.15	22
Veined gneiss	$0.003\ z^{-3.11}$	0.58	175

z = depth (m)

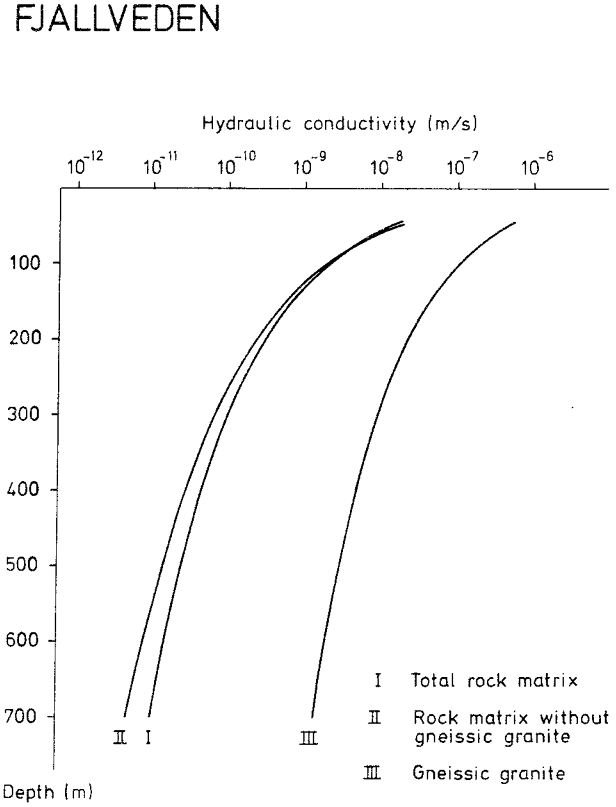


Figure 7.10 Relation between hydraulic conductivity and depth in different rock types within the rock mass

8. GROUND-WATER CONDITIONS

8.1 General

The ground-water flow within an area is characterized by the topographical, geological and climatological conditions. The geological conditions decide e.g. the size and variation of the water-permeable and storaging properties. Geology and topography determine the conditions decisive for how much water that can be transmitted through the bedrock. The climatological conditions are decisive for the amount of water available for recharge and ground-water flow.

Within the Fjällveden 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. Furthermore, information on hydro-meteorological conditions have been assembled (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 can be verified by measurement of ground-water pressure and by hydro-meteorological data.

8.2 Registration of the ground-water table

The position of the ground-water table at the Fjällveden site has been registered in all 49 percussion drill holes in and around the study site, and in 12 core drill holes, fig 8.1. The measurements were commenced in late January 1982 in the first 18 percussion drill holes, and successively in the remaining holes. In the present report, ground-water levels until the end of October 1982 are presented.

Three percussion drill holes were equipped with registering water-level gauges for continuous monitoring of the ground-water table.

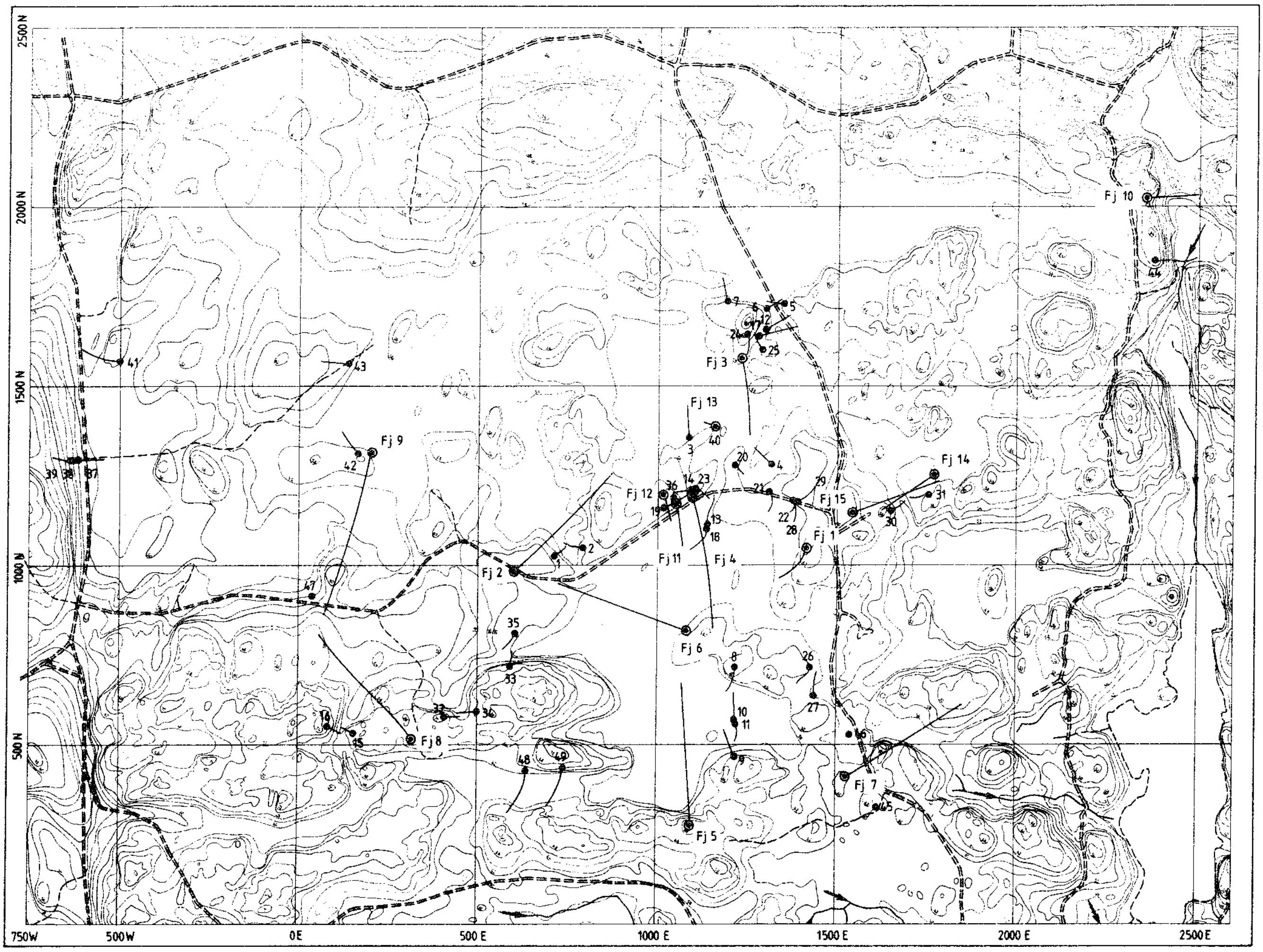


Figure 8.1 Boreholes for observation of ground-water levels in site Fjällveden.

Observations of the ground-water level using sounding instruments have been carried out, once weekly, with a few exceptions. Longer intervals have been necessary when other activities have been going on in the drill holes.

During the period 820121 - 821028 the ground-water table in the Fjällveden bedrock has been situated between 45.0 and 64.6 m.a.s.l. The fluctuation of the ground-water level in individual drill holes has varied between 0.5 and 4.8 m. The observation period for many drill holes is very short and the annual variation amplitude has in many cases not been distinguished. The annual variation of the ground-water table within the region (south and central Sweden) is characterized by rising ground-water levels in the fall whereas in late summer the lowest ground-water levels are registered. In the inland parts of the country a secondary maximum is observed in winters, whereas subsequent snow melting results in the highest ground-water levels during the year (Knutsson and Fagerlind, 1977).

Areas of ground-water discharge and runoff are primarily topographical low points. Here the variation in the ground-water level consequently is comparatively small. In the recharge areas the situation is the opposite, the level variations being much greater. The greatest variation in ground-water level during the measurement period has been noted in the highest located drill holes or those located on steep slopes. The distance from the ground level to the ground-water table varies with the topographic location. In general, the ground-water table is 1-3 m below the ground surface. Below minor hills and in slopes the depth to the ground-water can be more than 10 m.

In early June 1982, the upper parts of 11 percussion drill holes were sealed off with 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 approx 10 m beneath the actual ground-water level. Measurements of water pressure or water level were undertaken above, as well as below the packers. The drill holes thus sealed 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. Specifications of sectioned-off drill holes and measurement results are given in table 8.1.

The results of the measurements in sectioned-off drill holes indicates that 8 of the drill holes are in recharge areas and one in a discharge area and that in the case of two of the holes, the pressure gradient has changed several times during the measurement period. The pressure variations are greatest in the upper section of most of the drill holes, which is due to the greater influence of climatologic factors. The opposite conditions, however, were observed in HFj 10 which is located in a discharge area, and in HFj 31. The difference in level between the ground-water pressure above and below the packer has been calculated. The greatest difference in pressure was registered in drill holes at elevated positions, the difference amounting to max. 3.9 m. The smallest variations in level were noted in low altitude drill holes.

Table 8.1 Ground-water levels in percussion drill holes sealed off with packers at Fjällveden during the period 820604-821028.

Drill hole section	Ground-water level		Variation width (m)	Level difference		Note
	Highest m.a.s.l.	Lowest m.a.s.l.		Max	Min	
HFj 3 O	56.04	54.39	1.65			
B	55.23	53.97	1.26	0.81	0.28	Recharge area
HFj10 O	56.28	55.79	0.49			
B	56.33	55.64	0.69	0.15	0.03	Discharge area
HFj12 O	56.31	54.74	1.57			
B	58.18	55.51	0.67	0.78	0.01	Recharge area
HFj15 O	63.48	61.10	2.38			
B	62.28	60.69	1.59	1.36	0.05	Recharge area
HFj16 O	63.16	61.20	1.96			
B	62.23	60.79	1.44	1.04	0.04	Recharge area
HFj24 O	58.56	57.61	0.95			
B	55.94	55.20	0.74	3.03	1.93	Recharge area
HFj27 O	56.49	55.70	0.79			
B	56.27	55.53	0.74	0.33	0.05	Recharge area
HFj30 O	54.84	53.55	1.29			
B	54.63	53.75	0.88	1.75	0	Changing
HFj31 O	53.26	52.18	1.08			
B	52.91	51.38	1.53	0.80	0.29	Recharge area
HFj33 O	59.67	58.32	1.35			
B	59.64	58.29	1.35	0.05	0	Changing
HFj35 O	60.12	57.12	1.23			
B	56.89	55.66	1.23	3.91	2.60	Recharge area

O = over packer B = below packer

8.3 Ground-water level maps

Two maps of the ground-water level in the bedrock at the Fjällveden site have been prepared. The regional map is of general character covering an area of approx 90 km^2. This area is bounded by the lakes Lidsjön and Båven to the west and north, to the east by the NW-SE valley with the lake Samlingssjön, and to the south by the wide valley with the lake Kappstasjön. The local ground-water level map comprises the whole study site and an area south thereof. The size of the local area is 18 km^2.

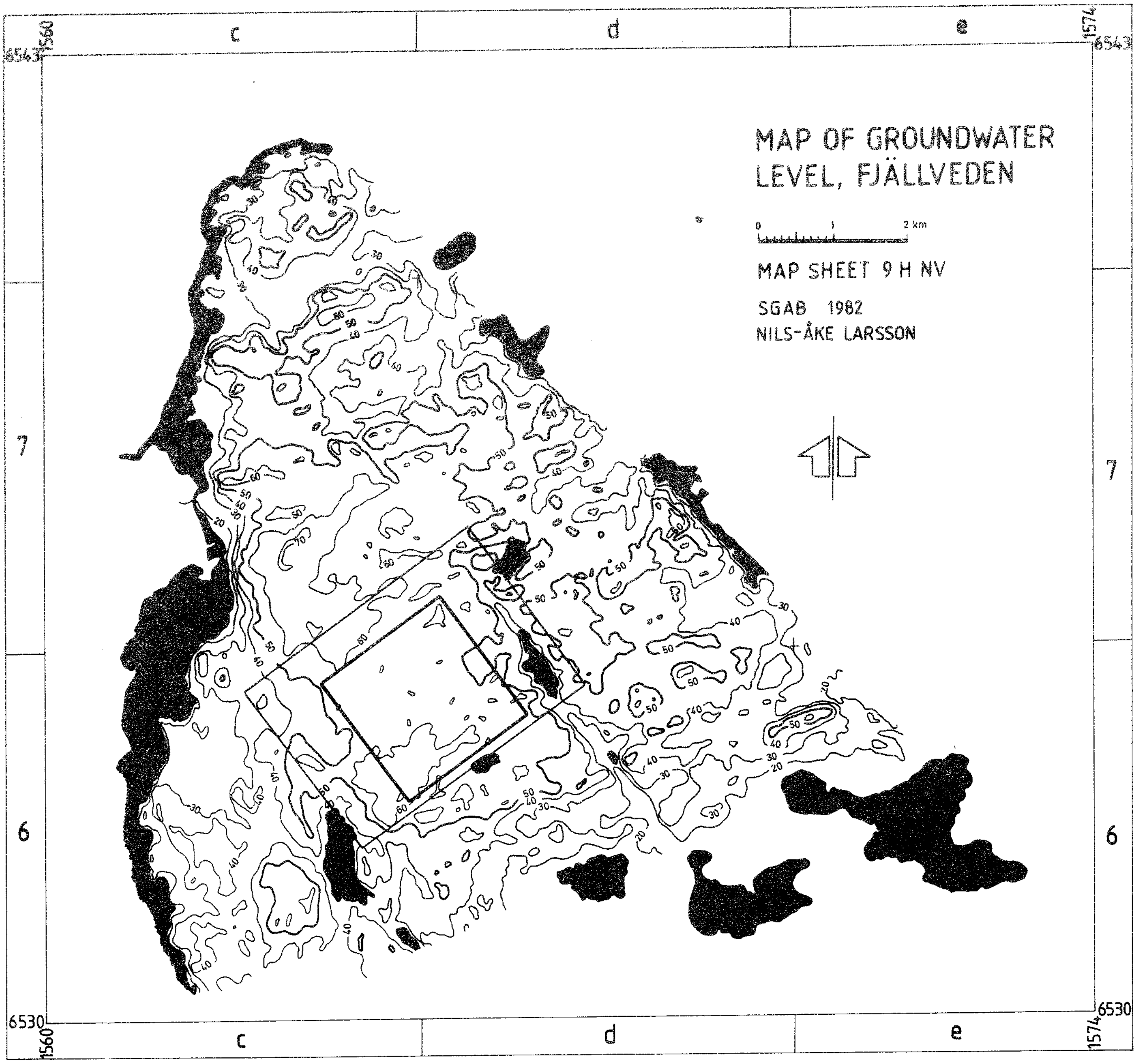


Figure 8.2 Regional map of groundwater level at site Fjällveden.

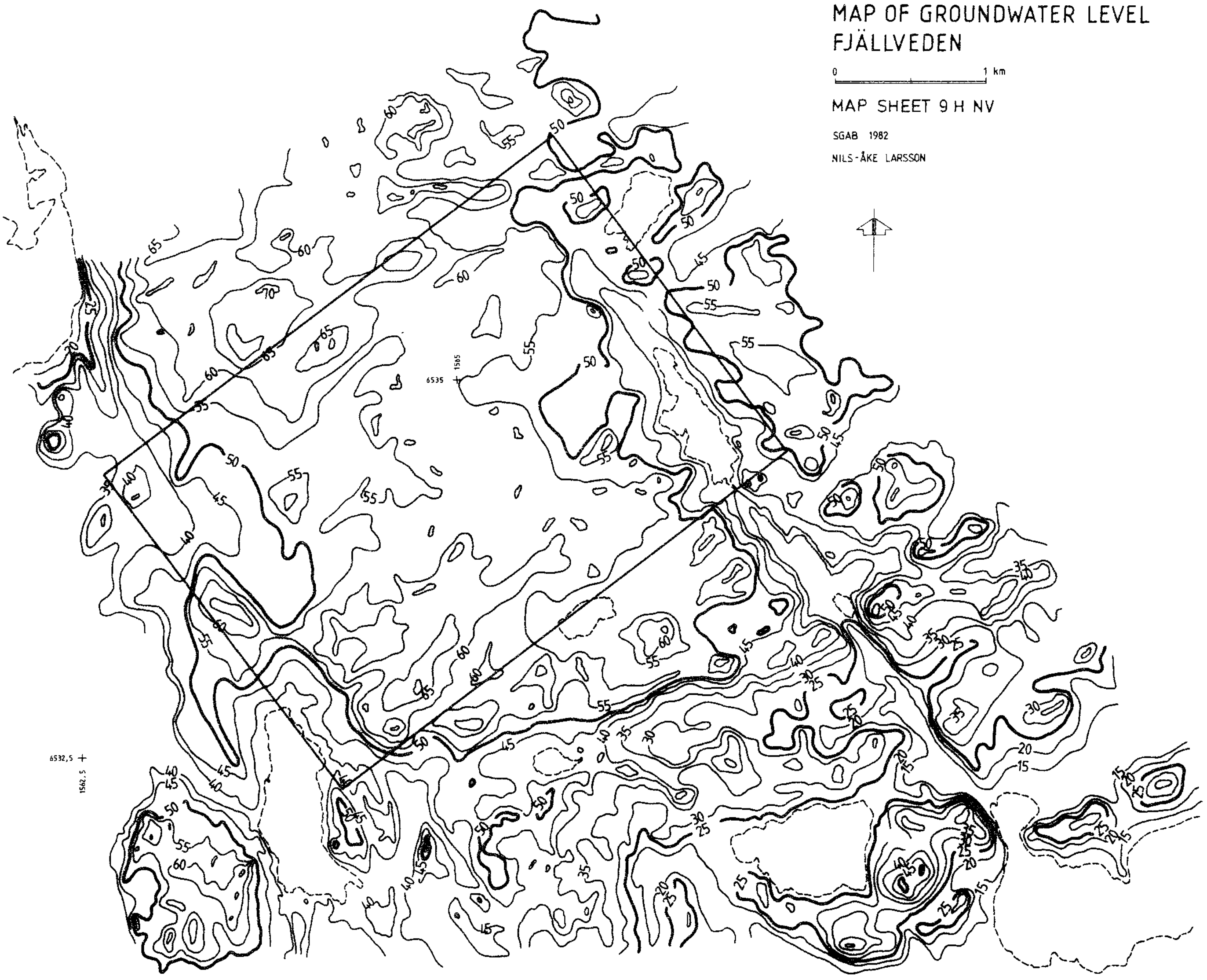


Figure 8.3 Local map of groundwater level at site Fjällveden.

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 in other parts of the area. 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 small (isolated) hills than under higher parts of the terrain. Furthermore, the ground-water table is more elevated 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 level 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.

The study site mainly constitutes a recharge area for ground-water. Small local discharge areas are found at lowly situated points. Major discharge areas are located to the west and south of the site where there are larger lakes. The ground-water flow at the study site is primarily oriented towards the regional fracture zones which delimit the site to the east and west, and to the south where the ground-water gradients are largest.

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 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 phase (Almen 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 under-pressure, respectively, in relation to the hydrostatic pressure in the drill hole at the corresponding level.

The ground-water head in the measured sections deviates in the majority of cases comparatively little from the hydrostatic pressures in the drill holes at corresponding levels. The highest over-pressure measured was obtained in FJ 2, +4 m wc (= meter water column) and the lowest, -8 m wc in Fj 9. Many drill holes displayed a distinct inflow character with rising negative pressures with increasing depth. Positive groundwater pressures are found primarily in the uppermost 100-200 m of the bedrock, fig 8.4.

In Fj 8 there are substantial under-pressures, -16 m wc at 700 m depth. These under-pressures are related to the presence of layers of granite gneiss. The layers probably have hydraulic connection wtih lower situated parts of the terrain, which is required for deviations of this magnitude. The layers of granite gneiss probably reach the western regional fracture zone of the study site.

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 equalization 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 under-pressure, respectively, in relation to the hydrostatic pressure in the open drill hole at the corresponding level.

The measurements have been performed during one-month periods in drill holes Fj 7 and Fj 8. The positioning of packers in these drill holes is illustrated in fig 8.5.

In drill hole Fj 7 there is under-pressure in four of the sections, fig 8.6. Only in the case of the uppermost section, viz. from the ground-water table down to 95 m, the pressure is higher than the hydrostatic pressure existing before the drill hole was sectioned-off. The deviation of the ground-water head from the hydrostatic pressure in the individual sections is small. The deviation is greatest in section 1, -2.5 m wc. The pressure gradient in the drill hole is oriented downwards, which means that Fj 7 is situated in a recharge area.

The situation in drill hole Fj 8 is the same as in Fj 7 even if the underpressures in the two deepest sections are considerably higher, fig 8.6. These under-pressures probably derive from the hydraulically conductive layers of granite gneiss which are found in these sections as referred to above. Fj 8 is located in a recharge area with a pressure gradient oriented downwards. Fig 8.6 also specifies the ground-water pressure values obtained from the water injection tests (numbered rings). In the case of both Fj 7 and Fj 8 the correspondence is comparatively good between the values obtained from the tests.

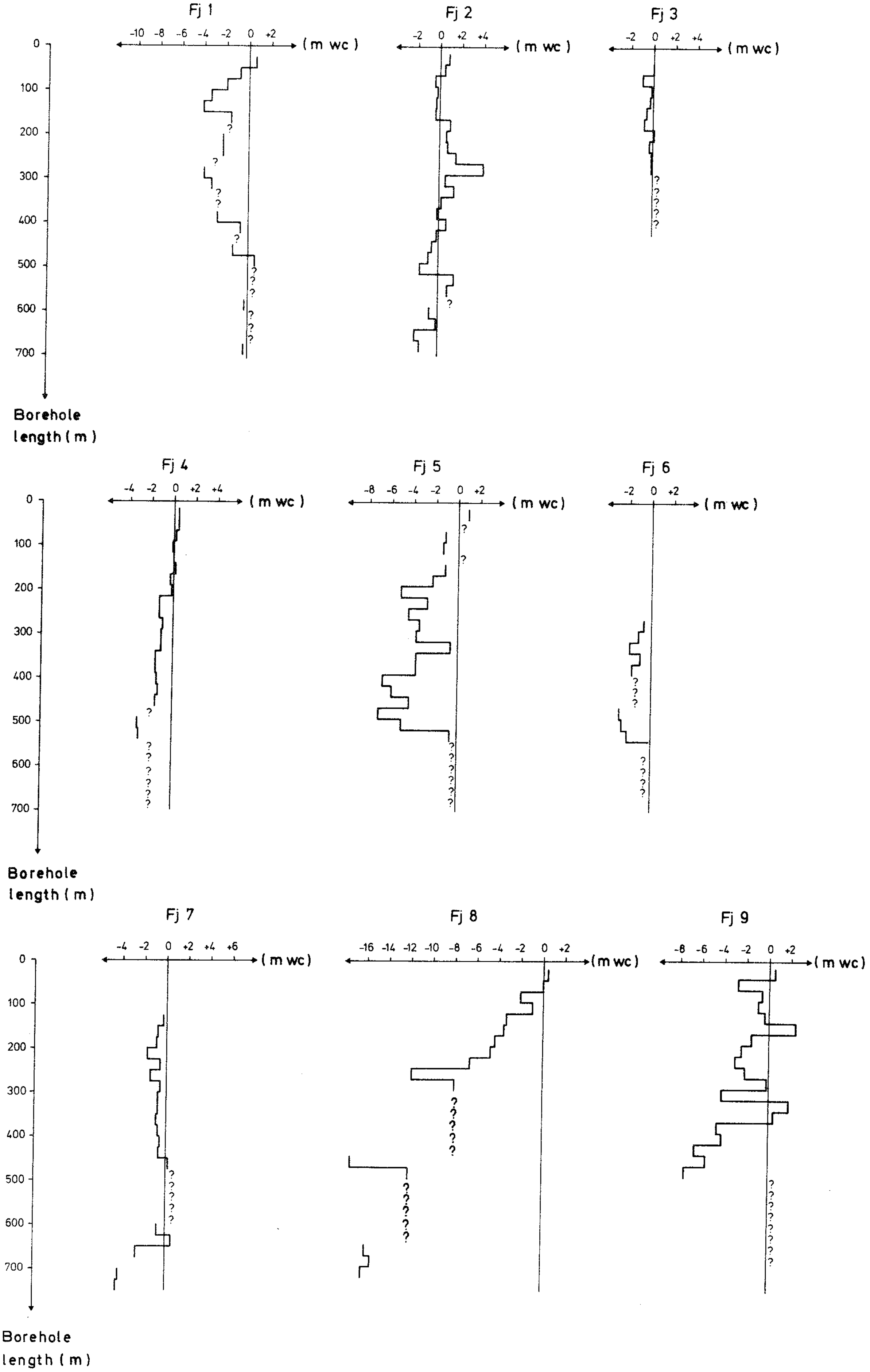


Figure 8.4 Pressure distribution in test sections of drill holes Fj 1 - Fj 9.

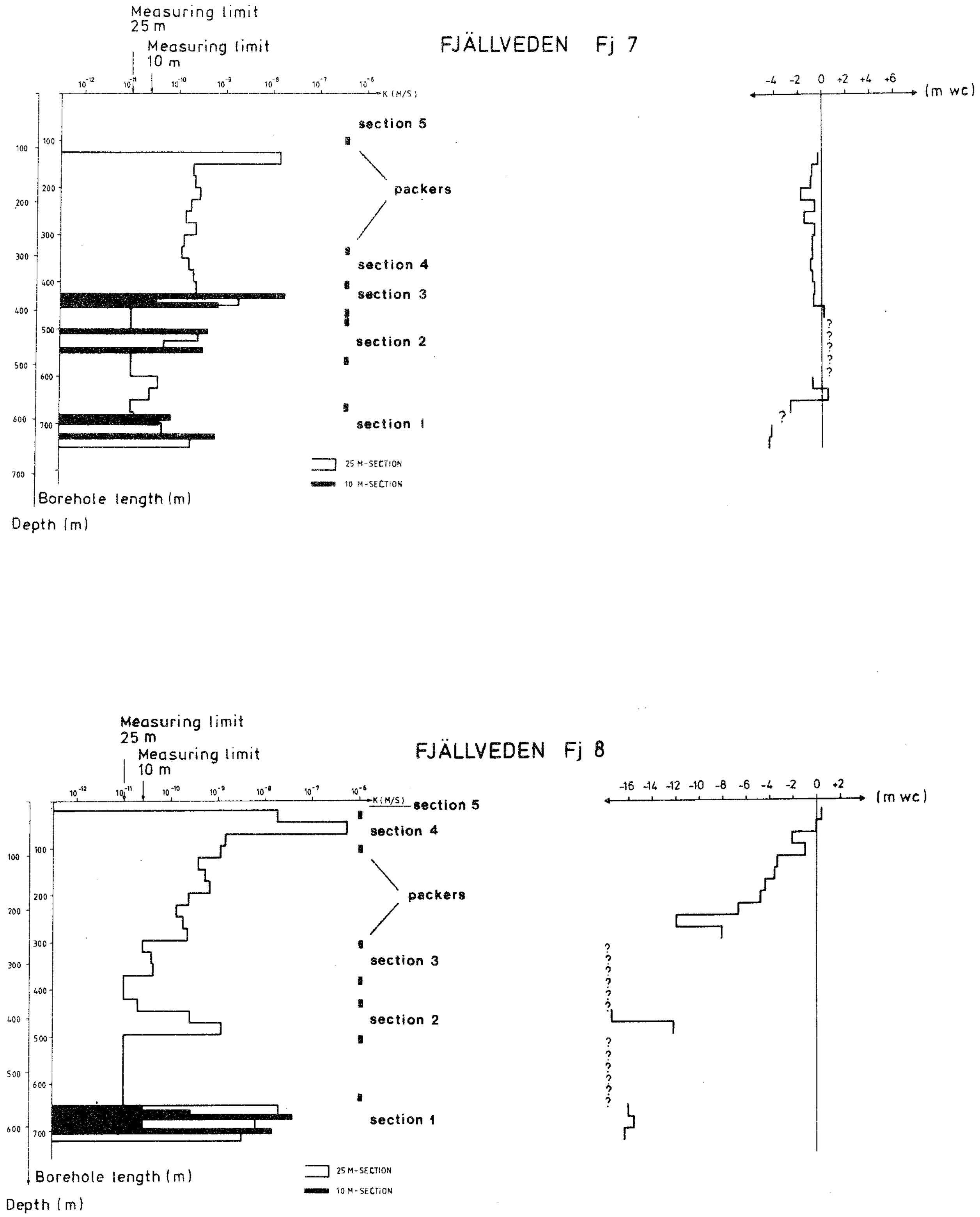
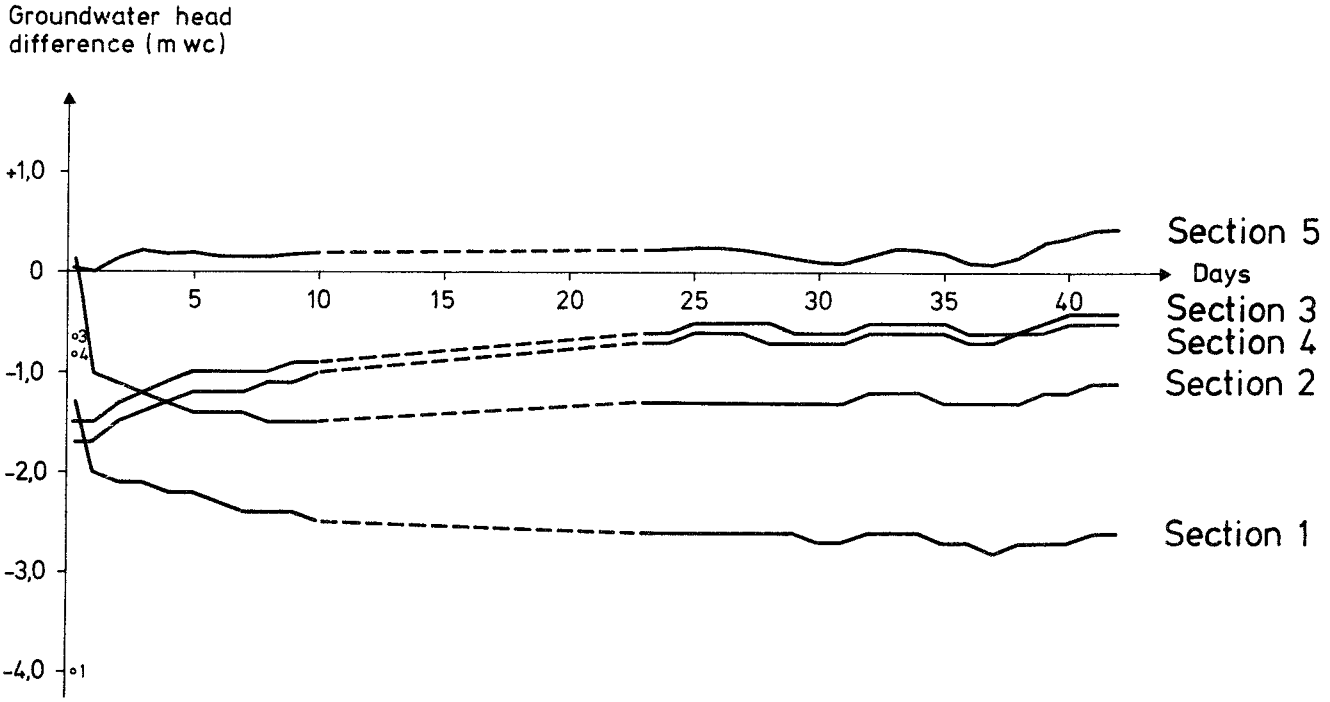


Figure 8.5 Positioning of packers and piezometric sections in drill holes Fj 7 and Fj 8.



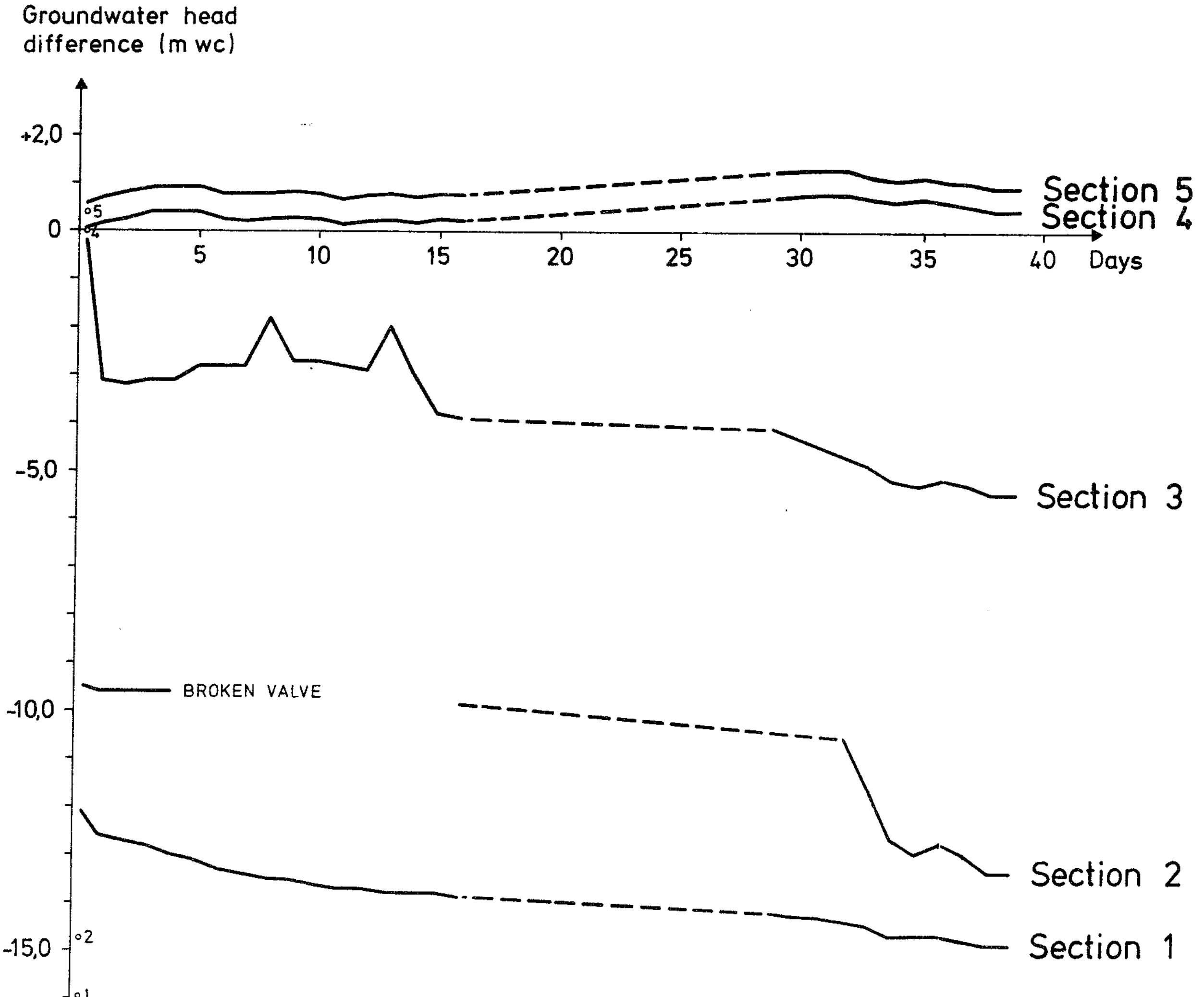


Figure 8.6 Piezometry. Groundwater head in sealed-off sections in drill holes Fj 7 and Fj 8. Ground-water pressure refers to hydrostatic pressure in the drill hole at respective levls.

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APPENDIX

EXTENT OF SITE INVESTIGATIONS AT FJÄLLVEDEN

Surface investigations:

Geologic surface mapping	
Regional mapping	90 km^2
Detailed mapping	10 km^2
Geophysical surface mapping	
Detailed surface mapping Magnetics, slingram, resistivity, IP	4 km^2
Refraction seismic profiles	6 km

Depth investigations

Core drill holes

No.	Coordinate	Altitude (m)	Direct.	Incl. (o)	Length (m)	Vert. depth (m)
1	1045 N /1415 E	63,25	S35E	85	711,4	695
2	890 N / 610 E	60,36	N10E	60	700,7	575
3	1560 N /1245 E	58,79	S50E	60	426,1	370
4	1195 N /1105 E	60,66	S42E	60	700,5	585
5	245 N /1080E	68,01	N35W	60	700,4	570
6	1010 N /1090 E	59,52	S70W	60	702,6	590
7	390 N /1530 E	61,38	N20E	60	760,4	647
8	510 N / 321 E	65,45	N76W	60	731,8	615
9	1308 N / 207 E	58,16	S18E	50	700,4	520
10	2015 N /2367 E	61,14	N50E	45	199,0	140
11	1173 N /1051 E	58,90	S45E	60	250,6	211
12	1189 N /1021 E	58,11	S54E	60	150,4	130
13	1383 N /1163 E	-	S74W	80	151,3	146
14	1255 N /1755 E	-	S20W	60	350,1	298
15	1145 N /1545 E	-	N35E	50	355,4	275

Percussion drill holes

No.	Coordinate	Altitude (m)	Direc.	Incl. (o)	Length (m)	Vert. (m)	Water capac. (l/h)
1	1030 N / 710 E	58,72	N25E	65	100	91	900
2	1085 N / 780 E	57,69	S25W	65	100	83	175
3	1350 N /1085 E	56,46	N30W	60	170	147	150
4	1270 N /1330 E	59,13	N85W	60	120	97	100
5	1720 N /1360 E	57,80	S42W	55	60	45	300
6	1705 N /1310 E	56,53	N35E	50	55	-	500
7	1730 N /1200 E	59,51	N45W	50	100	76	30
8	706 N /1220 E	64,13	S19E	59	160	143	100
9	460 N /1230 E	60,82	N55W	64	160	140	1300
10	570 N /1220 E	58,54	N38W	62	160	142	500
11	650 N /1220 E	58,86	S50E	60	120	108	100
12	1650 N /1305 E	58,52	N30E	50	105	64	5000
13	1090 N /1140 E	57,02	N40W	60	150	123	1100
14	1210 N /1100 E	59,23	S35W	60	120	98	800
15	520 N / 160 E	65,57	S70W	60	100	91	90
16	540 N / 90 E	72,11	N70E	60	100	89	500
17	1645 N /1280 E	58,44	N30E	50	140	109	700
18	1090 N /1140 E	56,98	S40E	60	141	114	3000
19	1160 N /1015 E	58,56	N30E	60	150	113	1100
20	1280 N /1225 E	57,69	N90E	60	150	-	1200
21	1204 N /1313 E	58,54	S75E	60	150	136	300
22	1180 N /1380 E	59,18	S70E	60	120	112	14000
23	1210 N /1105 E	59,22	N70E	60	140	131	550
24	1645 N /1250 E	62,79	S70E	60	100	82	250
25	1590 N /1300 E	58,81	N70W	60	100	87	1000
26	690 N /1430 E	59,13	S55E	60	100	83	0
27	600 N /1470 E	57,20	N55W	60	100	72	200
28	1179 N /1377 E	59,26	S70E	45	100	78	75
29	1179 N /1387 E	59,44	N25E	60	100	80	1200
30	1149 N /1652 E	56,36	N30E	60	100	86	1000
31	1193 N /1757 E	55,43	S30W	60	100	85	2000
32	576 N / 409 E	70,26	N50E	60	100	89	200
33	716 N / 593 E	66,12	N35W	60	100	86	800
34	593 N / 498 E	67,99	S40W	60	100	84	0

No.	Coordinate	Altitude (m)	Direc.	Incl. (o)	Length (m)	Vert. (m)	Water capac. (1/h)
35	811 N / 608 E	61,45	S35E	60	100	78	400
36	1171 N /1046 E	58,96	vertical		50	49	<100
37	1287 N / 610 E	52,32	N50E	60	150	129	1500
38	1287 N / 625 W	55,59	N50E	60	120	103	1000
39	1287 N / 626 W	55,75	N40W	60	120	105	30
40	1383 N /1163 E	-	S75W	80	58	57	-
41	1567 N / 497 W	47,83	S75W	50	175	133	600
42	1313 N / 171 E	57,20	N70W	62	150	126	100
43	1471 N / 143 E	54,48	S60W	58	150	125	600
44	1846 N /2382 E	62,84	N52E	45	150	105	100
45	324 N /1615 E	60,83	vertical		50	50	0
46	530 N /1542 E	57,75	vertical		50	50	200
47	914 N / 43 E	56,12	vertical		30	30	300
48	426 N / 640 E	63,54	S10E	35	150	88	0
49	435 N / 743 E	64,51	S14E	40	150	96	0

Investigations on drill cores

Total core length		7 533 m
Chemical analyses		
Bh	depth	
Fj 13	60-131 m	10 pcs.
Petrophysical samples 1)		237 pcs.

1) Evenly distributed on all core drill holes and depths.

Geophysical logging

Methods:		
borehole deviation	1)	2)
natural gamma radiation	1)	2)
single point resistance	1)	2)
resistivity		2)

self potential	2)
temperature	2)
salinity	2)
induced polarization	2)

1) Measurement in all percussion drill holes

2) " " " core drill holes except Fj 10.

Hydrological investigations

Water injection tests	Number
25 m-sections	219 pcs.
10 m	48 pcs.
5 m	13 pcs.
2 m	188 pcs. 1)

1) Only in Fj 2

Piezometric measurements	Number of sections
Drill hole Fj 7	5
Fj 8	5

Interference tests

Pump hole	HFj 18
Observation holes	HFj 4, 13, 14, 21, 22, 23, 28, 29

Ground-water level observations	Number
Percussion drill holes	49 pcs.
Core drill holes	12 pcs.

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