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Hydrogeological investigations at the Klipperås study site

Bengt Gentzschein
Swedish Geological Company

Uppsala, June 1986

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HYDROGEOLOGICAL INVESTIGATIONS AT THE STUDY SITE KLIPPERÅS

Bengt Gentzschein

Swedish Geological Co, Uppsala

June 1986

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THE STUDY SITE KLIPPERÅS

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SUMMARY

The Klipperås study site is located in the south-east part of Sweden, c. 300 km south of Stockholm. The area has a flat topography with altitudes between c. 166 and 206 meter above sea level.

From water balance studies annual mean values for the study site was estimated:precipitation 760 mm, evaporation 508 mm and run-off 252 - 263 mm.

The ground-water table was registered in 21 boreholes within the study site. 17 boreholes were sealed-off by inflatable packers and the ground-water head above the packers was continously monitored. The measured ground-water levels in the boreholes at Klipperås varied between c. 196 m and 172 m above the sea level. The variation width of the ground-water levels were relatively small, less than 1 meter in most boreholes.

In seven of the boreholes, with depths varying between 564 m and 958 m, single-hole water injection tests were performed. The water injection tests resulted in relatively high values of hydraulic conductivity in the upper parts of the boreholes, generally between 10^{-9} m/s and 10^{-5} m/s. High conductivity values were also obtained at depths, but below 500 metres conductivity values from 10^{-11} to 10^{-9} dominate.

The bedrock in the Klipperås site was divided into two hydraulic units, rock mass and local fracture zones. The depth-dependence of the hydraulic conductivity in the two hydraulic units was calculated from regression analysis. The regression analysis shows that the hydraulic conductivity of the rock mass and the local fracture zones at 500 m depth are 4×10^{-10} m/s and 8×10^{-8} m/s respectively.

The topographic relief of the area implies that there is a low hydraulic gradient in the bedrock. This has also been confirmed by piezometric measurements in the boreholes. With the exception of one measurement section (of totally 241) the pressure differences obtained are lower than 5 m water column.

1. INTRODUCTION

1.1 Background

Investigations for the siting of a final repository for high-level radioactive waste are currently being conducted in the crystalline rock formations of Sweden. These investigations, which are performed in order to characterize different sites, are pursued in accordance with a general program, the so-called "Standard Programme" (Ahlbom et al. 1983).

In the Klipperås area,the investigations started in 1982 with reconnaissance studies for the selection of the site and geological mapping of the area. During 1982-83 surface geophysical investigations were performed within an area of 14 km^2. The depth investigations were started in April 1983 with the first cored and percussion borehole. During 1984 a more detailed ground surface geophysical investigation was conducted at the Klipperås study site. From June 1984 to April 1985 13 cored boreholes and 13 percussion boreholes were drilled. Geological mapping of the core and geophysical investigations in the boreholes were performed in accordance with the Standard Programme.

This report deals mainly with the hydrogeological investigations at the site. Water injection tests were performed in the seven deepest cored holes in September 1983 (borehole Kl 1) and during winter-spring 1985. The ground-water level of the boreholes was registered in 1984 and 1985.

The geological and geophysical investigations, concerning the Klipperås study site have been reported in the following reports:

- Geological and tectonic description of the Klipperås study site. SKB Technical Report TR 86-06. A. Olkiewicz and V. Stejskal. Swedish Geological Co, 1986.

- Geophysical investigations at the Klipperås study site.
  SKB Technical Report TR 86-07.
  S. Sehlsted and L. Stenberg.
  Swedish Geological Co, 1986.

- Geophysical laboratory investigations on core samples from the Klipperås study site.
  SKB Technical Report TR 86-09
  L. Stenberg
  Swedish Geological Co, 1986

- Fissure fillings from the Klipperås study site.
  SKB Technical Report TR 86-10
  E-L. Tullborg
  Swedish Geological Co, 1986

1.2 Location of the site

The Klipperås study site is located approx. 300 km south-southwest of Stockholm and 40 km west-northwest of Kalmar in Nybro commune, Kalmar county, Figures 1.1 and 1.2. The site is situated on the topographical map sheet 4 F Lessebo NE and the nearest village is Orrefors 4 km northeast of the area. The size of the study site investigated is 4 x 3 km, Figure 1.3.

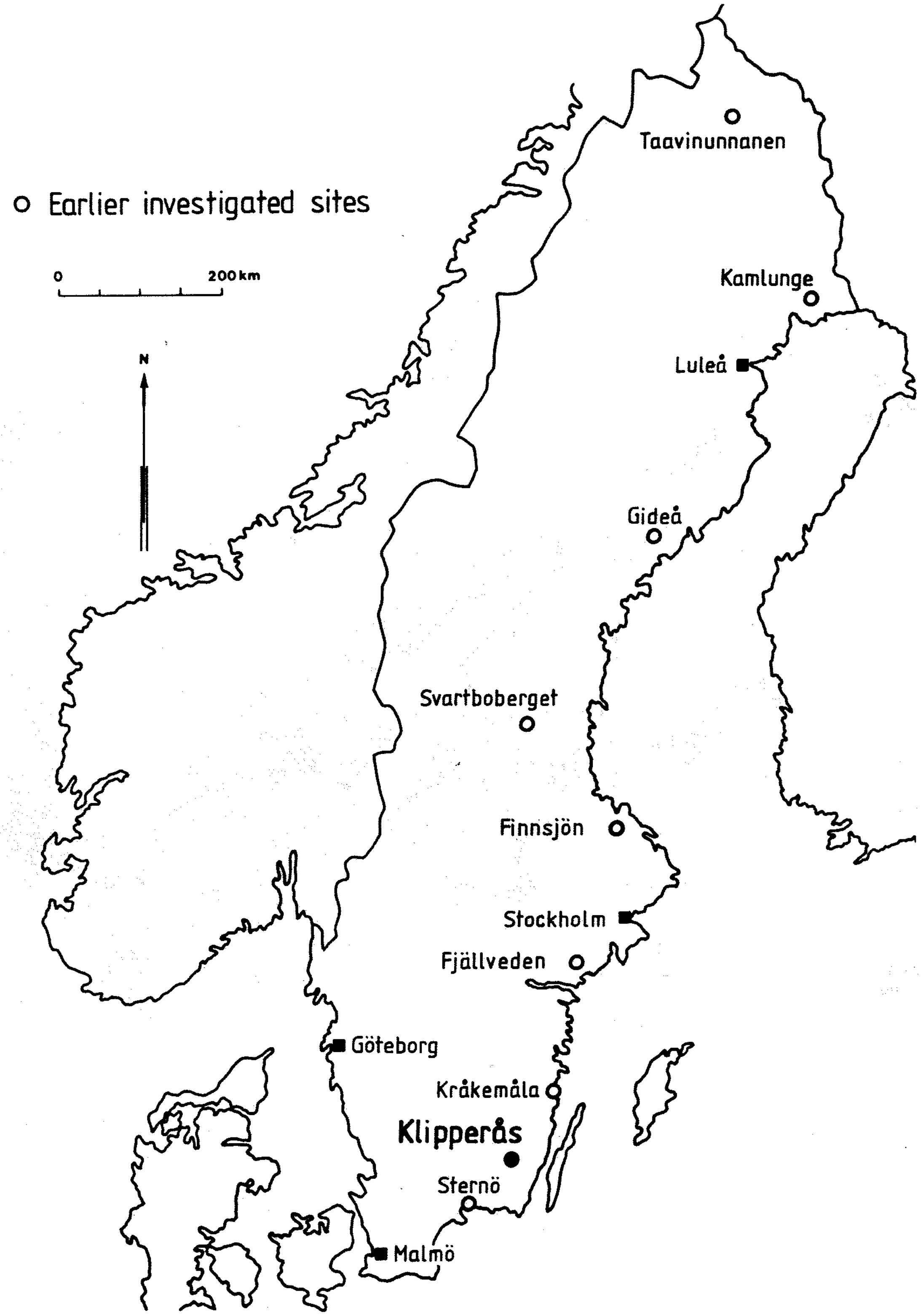

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Fig 1.1 The location of Klipperås and earlier investigated sites.

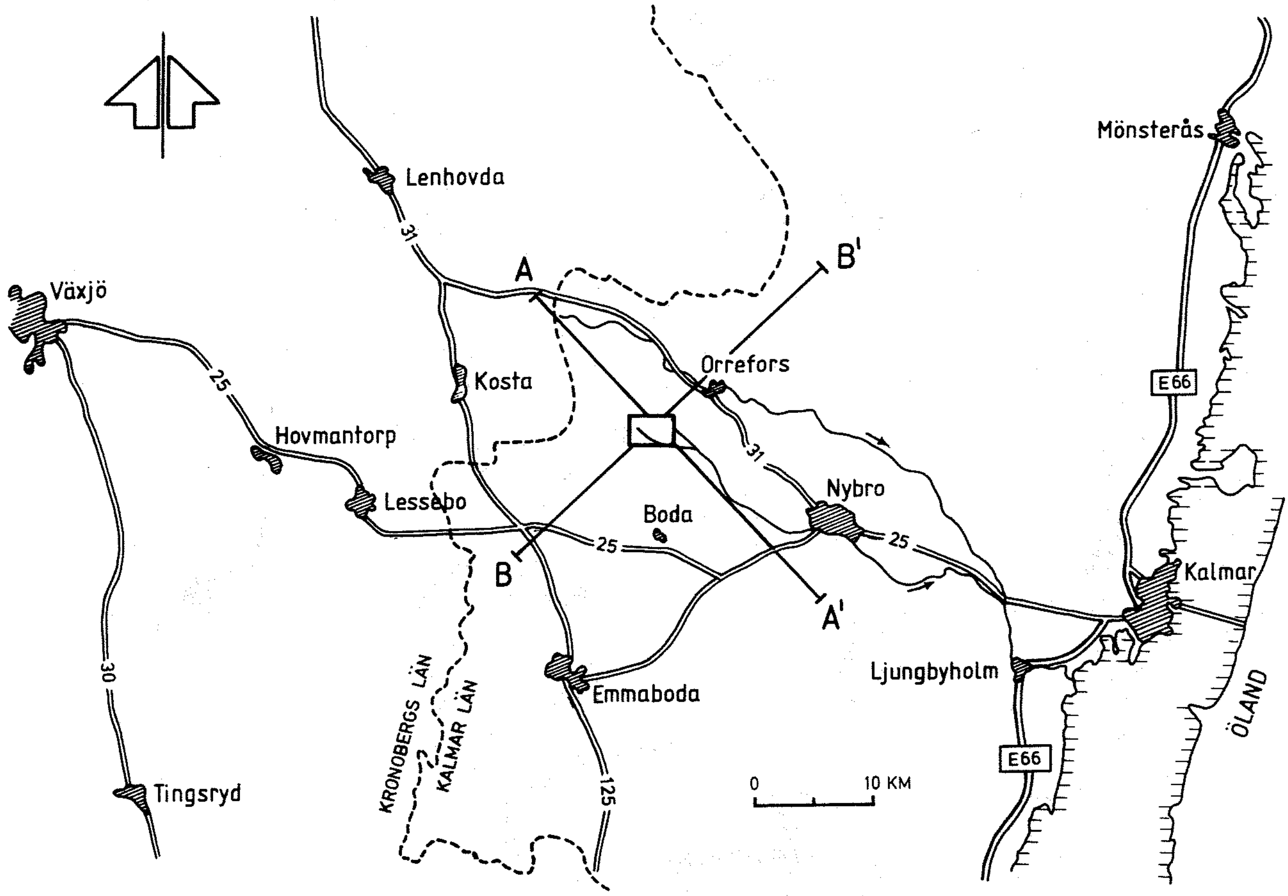


Fig 1.2 Locality map of the Klipperås site. Topographical profiles A-A′ and B-B′ are presented in Figure 2.2.

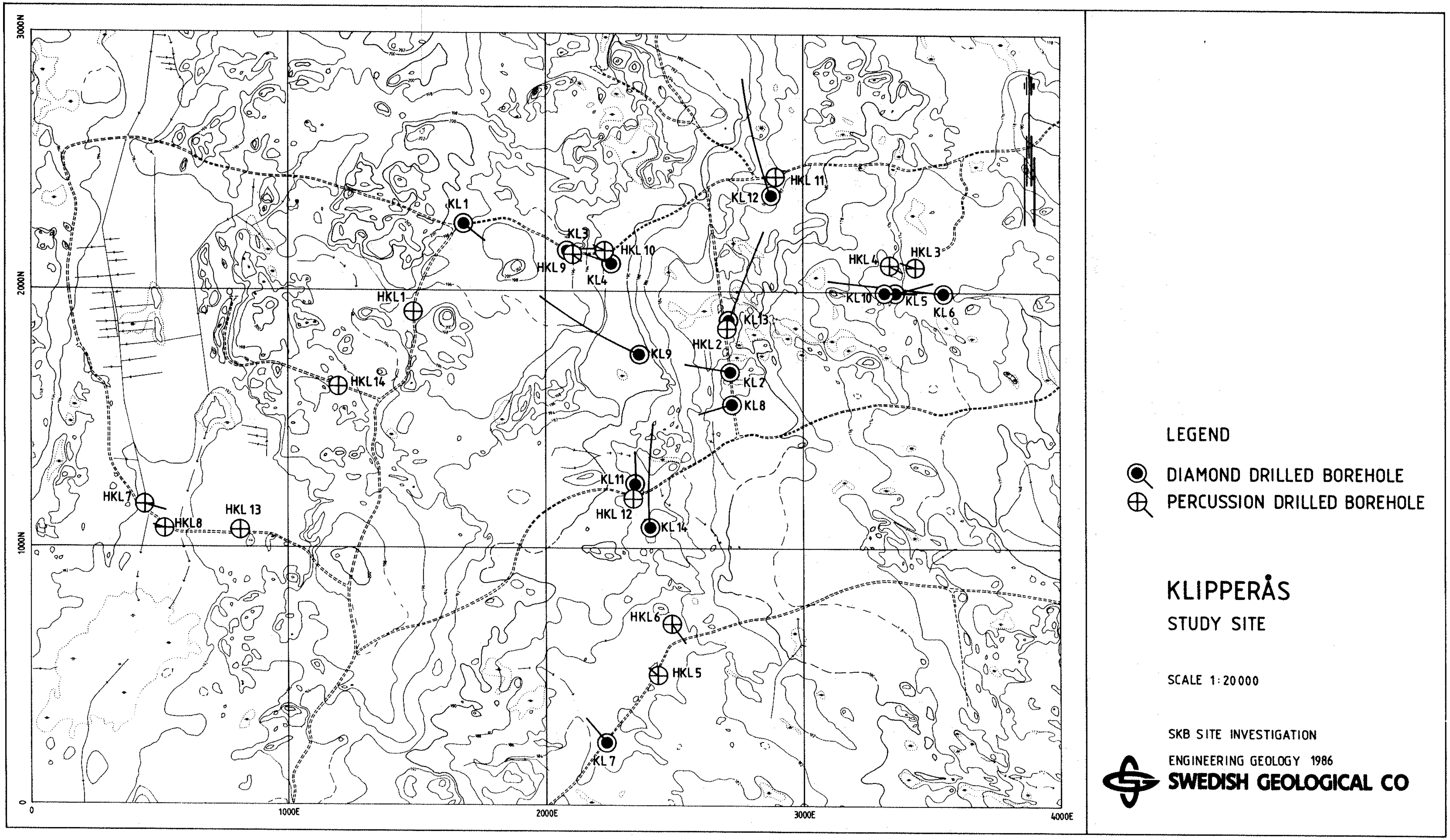


Figure 1.3 Map of Klipperås study site. Contour lines for every second meter.

2. SITE DESCRIPTION

2.1 Topography

The Klipperås study site is situated close to the south-east edge of the Småland Upland. Some 20 km west of the area the ground surface levels to c. 230 m above sea level. From Klipperås the surface gently slopes towards east-southeast and reaches a level of c. 100 m above sea level at a distance of 20 km from the site.

The differences in altitude in the area are relatively small, and the relief within the site is low. The lowest point of the site is found on the east boundary, c. 166 m above sea level. The highest point, c. 206 m above sea level, is situated on a vaguely indicated hill, elongating in the north-west direction in the west part of the site. Two topographical profiles of the area are presented in Figure 2.2. The altitude characteristics of the area are illustrated by the hypsographical curve in Figure 2.1.

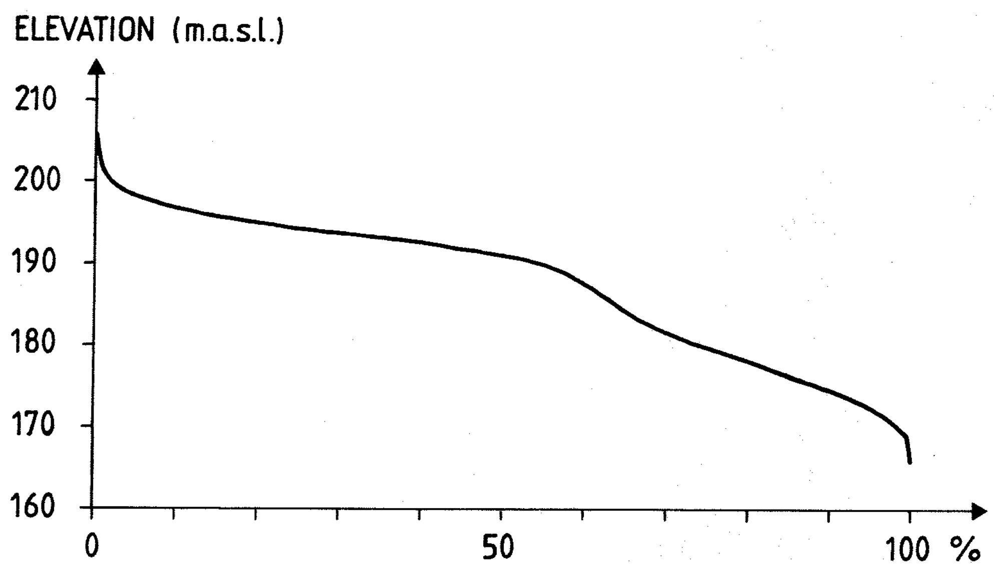


Fig 2.1 Hypsographical curve showing altitude characteristics in site Klipperås.

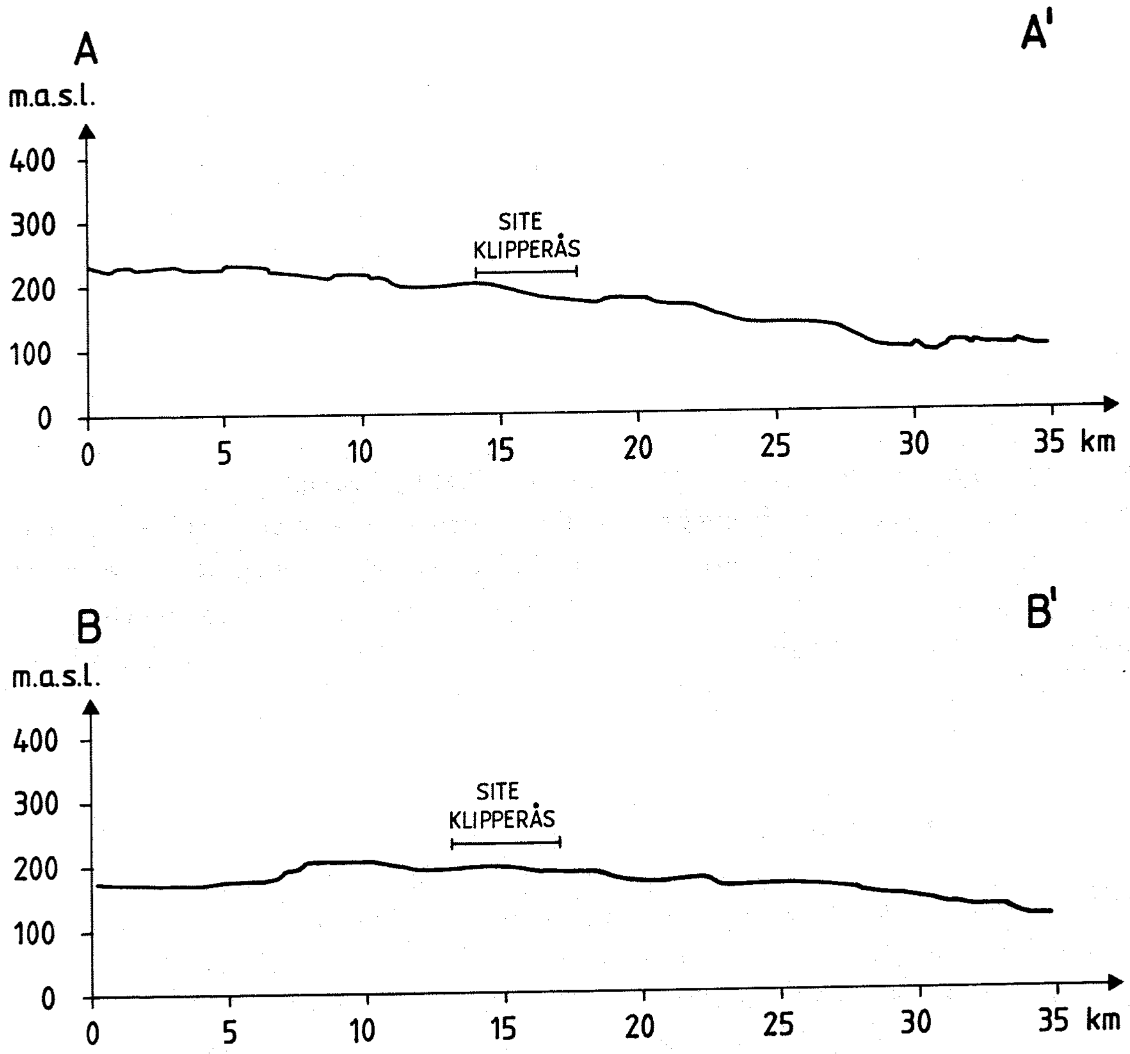


Fig 2.2 Topographical profiles across site Klipperås. The location of the profiles is shown in Figure 1.2.

2.2 Quaternary deposits

The percentage of outcrops within the site is very low, less than 0.5 percent. The Quaternary deposits consist primarily of moraine which is covered by overlying peat bogs in the depressions. In the western part of the site moraine with a high frequency of large boulders dominate. The boulder size decreases towards the central part and in the east the moraine consists primarily of small boulders and gravel.

The soil depth, measured in connection with the drilling of the

28 boreholes within the site, varies between 0.5 and 11 m, with a mean value of 4.2 m.

There are a number of eskers in the area. The largest of them is Nybroåsen. This extends along Orrefors and Nybro in a south-western direction down to Ljungbyholm, where it meets another esker from the north.

2.3 Land use

The Klipperås study site and its vicinity comprises a productive conferous forest. A few farms are also located in this area. The area close to the site is sparsely populated but within a radius of 30 km from Klipperås there are several municipalities, Figure 1.2. These communities get their water from wells drilled either in quaternary deposits or in the bedrock (Pousette et al 1981).

2.4 Lakes and rivers

The Klipperås study site is situated on the water divide between two drainage areas, Figure 3.1. The eastern part is drained by minor streams and ditches into the Ljungbyån stream. The western part is drained into the Hagbyån stream.

The largest lakes within the two drainage basins are as follows:

<u>Hagbyån</u>

Hultebräan	1,8 km^2
Örsjösjön	0,9 "
Dackebosjön	0,4 "
Mosjön	0,3 "
Gransjösjön	0,3 "
Madesjösjön	0,3 "
Storsjön	0,24 "

Ljungbyån

Orranässjön	1,2 km^2
Derasjö	0,6 "
Gillbondesjön	0,3 "
Stibbetorpssjön	0,2 "

Within the study site there are only 3 small meres which together comprise an area of less than 0,01 km^2. Instead there are several peat bogs. One of them, the former lake Deragårdssjön in the south-west, is relatively large. The portion of peat bogs within the site is 3.4 %.

3. HYDROLOGICAL AND METEOROLOGICAL CONDITIONS

3.1 General

Hydrological and meteorological data and conditions in the study site Klipperås are based on information obtained from SMHI (Swedish meteorological and hydrological institute). The information consists mainly of mean values from the period 1951-1980, but data from other periods has also been used.

The Klipperås site is situated on the water divide between two drainage areas, Figure 3.1. The eastern part, which includes all the diamond drilled boreholes, is drained by the Ljungbyån stream and the western part is drained by the Hagbyån stream. The Ljungbyån drainage area covers 750 km^2 with a lake portion of 0.8 % and the Hagbyån drainage area covers 447 km^2 with a lake portion of 3.6 %. These two streams flow into the Baltic after covering a distance of 40 km and 50 km respectively.

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

3.2 Precipitation and temperature

The precipitation in the region around Klipperås has been estimated on the basis of data from the meteorological stations listed in Table 3.1.

Table 3.1 Data on the meteorological stations used to provide data for calculating the mean precipitation within the Klipperås study site.

Station	Distance to site	Station altitude	Observation period	Adj. annual precipitation
Orrefors	5 km	170 m	1951-80	780 mm
Emmaboda	40 km	150 m	1951-80	725 mm
Grönåsen	12.5 km	215 m	1951-80	775 mm

The mean value for the four stations was taken as an areal mean value for the study site. The adjusted annual precipitation is 760 mm and the adjustment factor is 17 %. The estimated monthly distribution is shown in Table 3.2.

Table 3.2 Calculated adjusted precipitation and monthly mean temperature for study site Klipperås during the period 1951-80.

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Adjusted precip-ation (mm)	64	47	44	47	59	54	87	82	71	66	71	68	760
snow	55	47	39	21							8	37	15%
Mean temp °C	-3.1	-3.2	-0.7	3.8	9.2	14.0	15.1	14.5	10.6	6.4	2.0	-1.1	5.7

Of the total annual precipitation 15 % falls as snow. During the period January - March, snow constitutes 47 % of the total precipitation. On an average the ground is covered with snow during the period 25/11 - 30/3 (126 days).

Ground freezing has been estimated to occur during the period, 15/12 - 15/4 corresponding to 121 days.

The temperature conditions in the Klipperås site are represented by the Emmaboda values. The annual mean temperature is 5.7 °C. The monthly mean values are given in Table 3.2.

3.3 Evaporation

Evaporation is the most uncertain factor in the water balance of the area. The estimated evaporation-values, specified in Table 3.3, for the Klipperås site are based on data from surrounding meteorological stations and from the isoline evaporation map (Eriksson, 1980).

Table 3.3 Estimated potential and actual evaporation of the Klipperås site

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Potential evaporation (mm)	4	8	23	54	97	118	112	87	48	20	7	3	580
Actual evaporation (mm)	4	8	21	47	85	101	96	76	42	18	7	3	508

3.4 Run-off

The Klipperås site is, as mentioned earlier located on the water divide between two streams. The eastern part (70 % of the area) is drained by the Ljungbyån and the western part (30 %) by the Hagbyån. The only existing station for run-off measurements along two streams is 77 - 50091 Källstorp at Ljungbyån.

However, the Källstorp station is situated c. 30 km from the Klipperås area and its drainage basin does not include the site. The run-off data from Källstorp are not therfore 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 region. For this purpose the drainage area was fixed at 12 km^2 with a lake proportion of 0 %. In Table 3.4, the estimated monthly run-off is specified. The run-off has two peaks, one top peak in April during the spring flood, and another from the late autumn rains in November. In summer the runoff is small during extended periods.

Table 3.4 Estimated monthly run-off in Klipperås

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Run-off ($l/s x km^2$)	7.5	5.8	11.7	20.8	10.0	2.5	1.7	2.5	3.3	8.3	15.0	10.8	8.3

The mean run-off during the year amounts to approx. 8.3 l/s x km^2 (= 263 mm/year). The main part of the water volume, 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 Figure 3.2. The duration is expressed in percent of time (year or period). From the figure it is evident that run-off is in excess of 8.3 l/s x km^2 for only 30 % of the time. During half of the year the run-off is on the average more than 3.3 l/s x km^2.

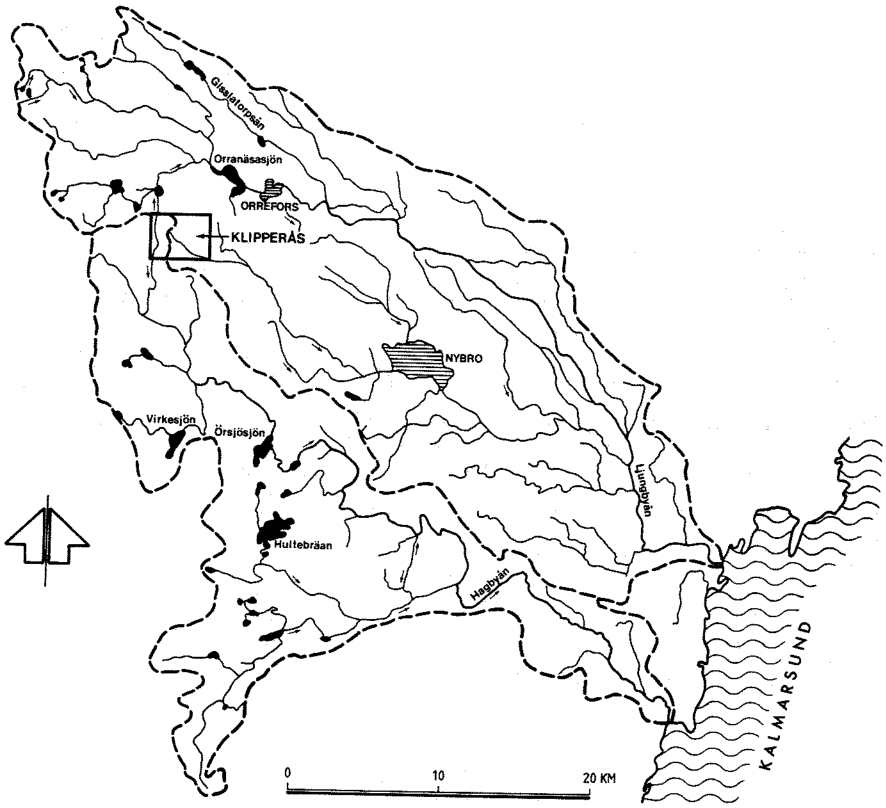


Fig 3.1 Dranaige areas of the two streams Ljungbyån and Hagbyån.

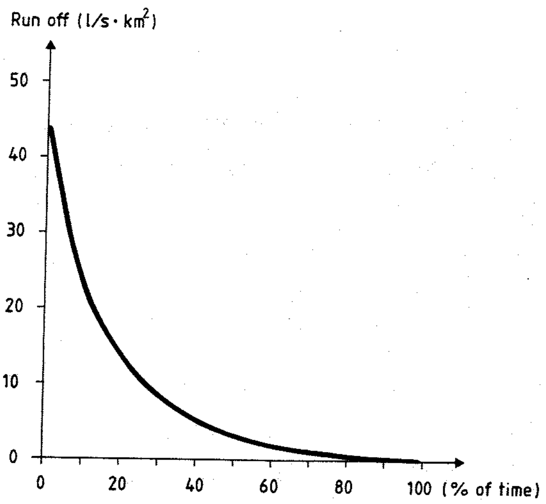


Fig 3.2 Estimated mean duration of run-off at site Klipperås.

In Table 3.5 estimated characteristic values of discharge and run-off are presented.

Table 3.5 Estimated characteristic values of discharge and run-off for the Klipperås site. Drainage area = 12 km^2, lake proportion = 0 %.

	m^3/s	$1/s \times km^2$
Maximum flood discharge/run-off	3	250
Mean flood discharge/run-off	1.0	83.3
Maximum mean discharge/run-off	0.20	16.7
Mean discharge/run-off	0.10	8.3
Lowest mean discharge/run-off	0.02	1.7
Mean low discharge/run-off	0.005	0.4
Minimum low discharge/run-off	0	0

The run-off can also be calculated as the difference of the estimated values of precipitation and evaporation. The annual run-off value will then be 760 - 508 = 252 mm. This is only 11 mm less than the run-off value (263 mm) independently estimated in the hydrological investigation above.

3.5 Water balance

The water balance at the study area is determined by the following factors: precipitation, evaporation, run-off, change in storages and ground-water flow through the boundaries of the area. Table 3.6 constitutes a summary of the water balance in the study area, based on long-term registrations. All input data has been obtained outside the Klipperås site. The maximum potential ground-water recharge within the area is, during an extended measurement period, composed of the run-off, since no changes in existing groundwater storages are assumed. The actual groundwater recharge is smaler.

Table 3.6 Estimated water balance for the Klipperås study site

	mm/year
Precipitation	760
Evaporation, potential	580
Evaporation, actual	508
Run-off	252-263

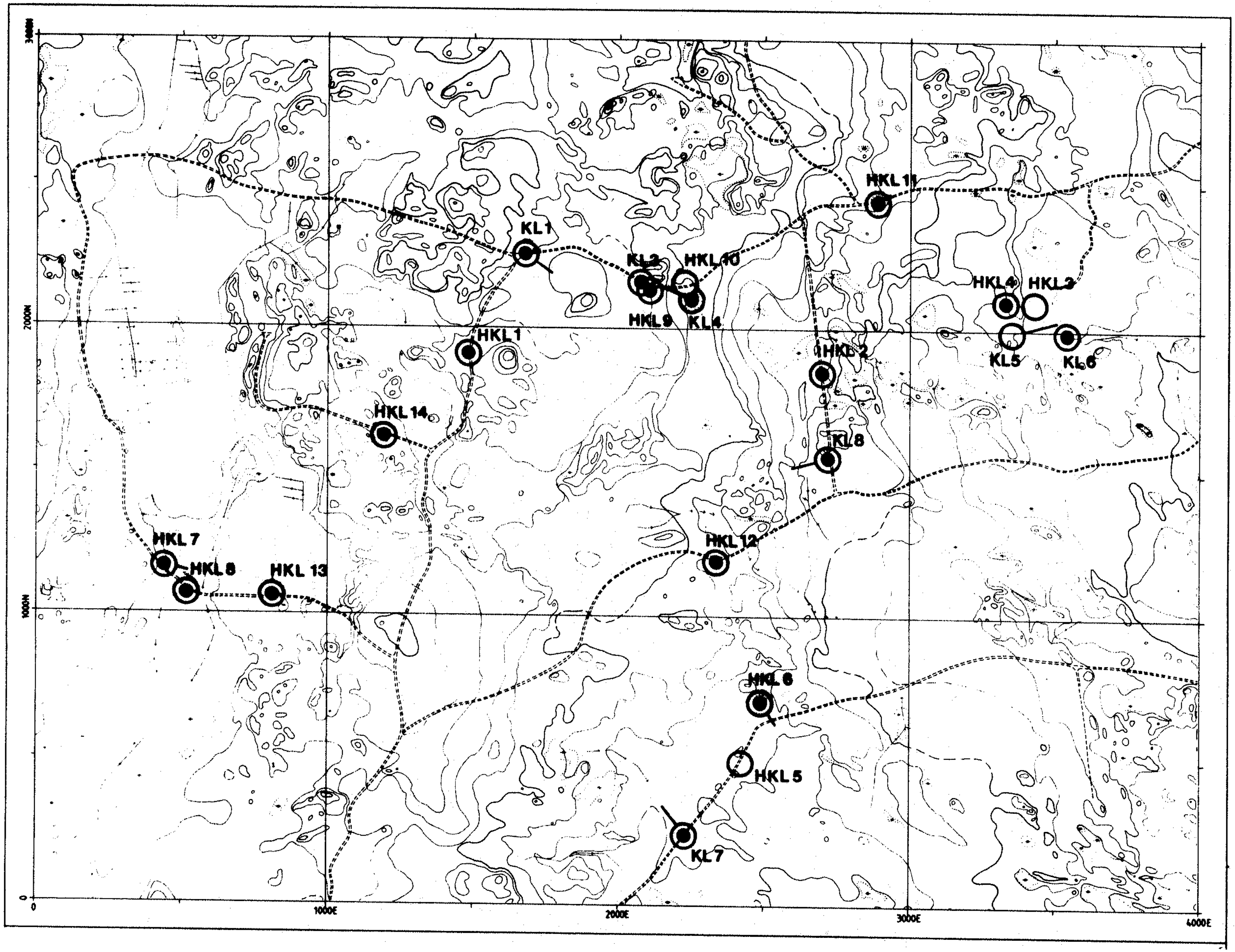
4. GROUND-WATER CONDITIONS

4.1 General

The ground-water flow within an area is determined by the topographical, geological and climatic conditions. The geological conditions, determine 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 climatic conditions de-determine the quantity of water available for recharge and ground-water flow.

During 1984 the position of the ground-water table within the Klipperås site was registered in 14 percussion boreholes and in seven of the cored boreholes, Figure 4.1. The measurements were commenced in late May in the first five percussion boreholes and then successively in the remaining holes. The ground-water table was registered by soundings, with varying intervals during spring and summer, and once a week during autumn.

Since the length of the boreholes at Klipperås vary considerably,the distribution of the ground-water level represents an integrated mean value of prevailing pressure conditions at different parts of the bedrock. To determine the ground-water pressure in the rock close to the ground surface, sections in totally 17 boreholes were sealed by inflatable packers, Figure 4.1. Above the packers, new equipment for continuous monitoring of the ground-water table were installed. These devices consist of a pressure transducer and a microcomputer unit, which allows storage of data. The ground-water pressure was stored in the memory of the unit if the ground-water table changed more than 25 mm. Smaller changes were stored every sixth hour. The memory of the unit had a storage capacity of 2096 registrations. Data was collected by a portable field computer. Data was collected within an interval of 2-3 months. Continuous monitoring of the ground-water table in sectioned-off holes commenced in March 1985.



LEGEND

OPEN BOREHOLES FOR GROUND-WATER OBSERVATIONS 1984

OPEN BOREHOLES DURING 1984 AND SECTIONED-OFF BOREHOLES DURING 1985

KLIPPERÅS

BOREHOLES FOR GROUND-WATER OBSERVATIONS

SCALE 1 : 20 000

Figure 4.1 Boreholes for observation of ground-water levels in site Klipperås

4.2 Variation of the ground-water level in open boreholes

During the period 840508-850123 the ground-water level in the Klipperås boreholes was situated between c. 196 m and c. 172 m above sea level, Table 4.2. The highest ground-water levels were measured in the western part of the site with maximum on the smooth ridge, extending in a north-south direction.
The registered ground-water levels decreased towards east and south-east, with minimum in the four boreholes penetrating the mafic dyke in the eastern part. The variation width of the ground-water level was relatively small. With the exception of three boreholes, it is less than 1 m during the period. There was no clear correlation between borehole altitude and variation width of the ground-water table. However, it should be noted that the measuring period was less than 8 months and that ocassionally the measuring frequency had been low.

The distance from the ground surface to the ground-water table was usually between 0.5 and 5 m in the high altitude boreholes. In lower situated areas this distance decreased to c. 0.1 - 1.2 m. In the three relatively highly situated boreholes in south-west, HKl 7, HKl 8 and HKl 13, the ground-water table was close to the ground surface and HKl 8 was artesian during periods.

During the measurement period the ground-water level had varied in a similar manner in all boreholes, appendix 1. The lowest ground-water levels were registered after the warm and dry period in July-August 1984. Maximum values were obtained after the heavy precipitation during autumn. The effect of snow melting during spring was not measured but should probably have resulted in a considerable increase in the ground-water levels.

Table 4.1 Borehole data, measuring period etc. for groundwater table registrations in open boreholes at Klipperås from 840508 to 850123.

Borehole	Borehole length (m)	Borehole depth (m)	Registration period	Comment
Kl 1	564.0	553.1	840605-841101	
Kl 3	250.0	218.9	840726-841121	
Kl 4	200.0	167.3	840726-841121	
Kl 5	246.4	204.2	840821-850123	Digging at the borehole 841101
Kl 6	266.9	227.0	840821-850123	
Kl 7	250.3	214.1	840911-850123	
Kl 8	266.1	223.7	841101-850123	
HKl 1	66.0	66.0	840509-850123	
HKl 2	150.0	150.0	840508-841219	
HKl 3	96.0	62.0	840508-841219	
HKl 4	99.0	63.0	840508-850123	
HKl 5	90.0	58.0	840508-840725	Borehole breakdown 0727
HKl 6	150.0	96.0	840605-850123	
HKl 7	99.0	63.0	840523-850123	
HKl 8	93.0	60.0	840523-850123	Artesian
HKl 9	77.0	50.0	840607-850123	
HKl 10	100.0	64.0	840705-850123	
HKl 11	100.0	100.0	840616-850123	
HKl 12	100.0	100.0	840607-850123	
HKl 13	100.0	100.0	840605-850123	
HKl 14	100.0	100.0	840605-850123	

Table 4.2 Registered extreme values of ground-water level in open boreholes during 840508-850123

Borehole	Borehole altitude m.a.s.l.	Groundwater level Highest m.a.s.l.	Lowest m.a.s.l.	Variation width (m)	Note
Kl 1	199.52	196.76	195.81	0.95	
Kl 3	197.25	192.57	191.87	0.70	
Kl 4	195.80	190.76	190.39	0.37	
Kl 5	175.77	174.81	172.28	2.53	
Kl 6	173.11	172.70	171.55	1.15	
Kl 7	185.97	184.97	184.79	0.18	
Kl 8	182.57	182.41	182.05	0.36	
HKl 1	197.12	195.86	195.21	0.65	
HKl 2	185.59	184.57	183.64	0.93	
HKl 3	172.86	172.28	171.69	0.59	
HKl 4	177.01	175.49	174.75	0.74	
HKl 5	186.80	183.96	183.81	0.15	
HKl 6	186.59	183.90	183.58	0.32	
HKl 7	192.55	191.59	191.43	0.16	
HKl 8	191.97	>191.65	191.54	>0.11	
HKl 9	197.08	193.41	191.64	1.77	
HKl 10	193.65	192.23	191.24	0.99	
HKl 11	185.84	182.40	181.79	0.61	
HKl 12	190.28	188.55	187.81	0.74	
HKl 13	192.63	191.98	191.70	0.28	
HKl 14	198.35	195.66	194.98	0.68	

4.3 Variation of the ground-water level in sectioned-off boreholes

Continuos registration of the ground-water table in the 17 sectioned-off boreholes at Klipperås was performed during the period March 1985 to November 1985, see Table 4.3. The registration commenced at different dates in the boreholes. Due either to other activities in the boreholes or to instrumental problems, breaks in the registrations did occure.

The measured ground-water levels in the sectioned-off boreholes varied between c. 196 m and c. 172 m above sea level, with maxima occuring in the western part of the area, see Table 4.4. The ground-water levels decreased towards the east and south-east. This pattern was about the same as observed from the measurements in the open boreholes during 1984. However the variation width of the ground-water levels was larger in the sealed-off boreholes than in the open ones, Table 4.4. Generally the largest variation width was found in the higher altitude boreholes, but there were exceptions.

In the sectioned-off boreholes the average distance from the ground surface to the ground-water table was between 0.5 m and 5.5 m in the high altitude boreholes. In lower altidude areas this distance descreased to c. 0.2 - 1.7 m. In Figure 4.2, the approximate mean ground-water levels (obtained from the registrations in the sectioned-off boreholes), are plotted versus the corresponding ground surfaces, respectively.

In appendix 2 the ground-water level in the 17 sectioned-off boreholes is presented. The observation period for the individual boreholes differs but some common features can be found. One of these is the increase of the ground-water level in March-May caused by snow melting. Then the curves usually smooth out and only minor peaks, from rainfall, can be noted. In some drill-holes (e.g. HKl 11) there is a falling trend in the ground-water table after the spring flood, in others (e.g. HKl 14) the ground-water level rises in the autumn.

Table 4.3 Borehole data, measuring period etc. for ground-water table registrations in sectioned-off boreholes at Klipperås during the period 850312 - 851111.

Borehole	Borehole inclination (°)	Distance to packer (m)	Registration start	Comment
Kl 1	80	39	850312	
Kl 3	60	16	850312	Break 24/4-20/5
Kl 4	60	16	850312	Break 17/4-20/5
Kl 6	60	19	850523	Packer out of order
Kl 7	60	13.5	850313	-"- Break 16/4-20/5
Kl 8	60	14.5	850314	Break 22/4-22/5
HKl 1	90	12.0	850313	Registrations up to 850906
HKl 2	90	12.0	850906	
HKl 4	50	14.0	850313	
HKl 6	50	15.0	850313	
HKl 7	50	14.5	850313	
HKl 8	50	13.5	850313	
HKl 9	50	18.0	850312	Registrations up to 851127
HKl 11	90	17.0	850603	
HKl 12	90	14.0	850523	
HKl 13	90	12.0	850313	
HKl 14	90	15.0	850313	

Table 4.4 Ground-water levels in sectioned-off drillholes at Klipperås during the period 850312-851111.

Borehole	Borehole altitude (m.a.s.l.)	Ground-water level Highest (m.a.s.l.)	Lowest (m.a.s.l.)	Variation width (m)
Kl 1	199.52	197.58	196.04	1.54
Kl 3	197.25	194.20	191.87	2.33
Kl 4	195.80	190.44	189.73	0.71
Kl 6	173.11	172.70	172.40	0.30
Kl 7	185.97	184.68	183.86	0.82
Kl 8	182.57	181.67	181.02	0.65
HKl 1	197.12	196.05	195.00	1.05
HKl 2	185.59	183.69	183.14	0.55
HKl 4	177.01	176.12	174.71	1.41
HKl 6	186.59	184.04	183.45	0.59
HKl 7	192.55	191.53	190.85	0.68
HKl 8	191.97	190.95	190.40	0.55
HKl 9	197.08	193.30	191.80	1.50
HKl 11	185.84	181.05	180.35	0.70
HKl 12	190.28	188.10	187.35	0.75
HKl 13	192.63	191.73	191.32	0.41
HKl 14	198.35	196.73	194.95	1.80

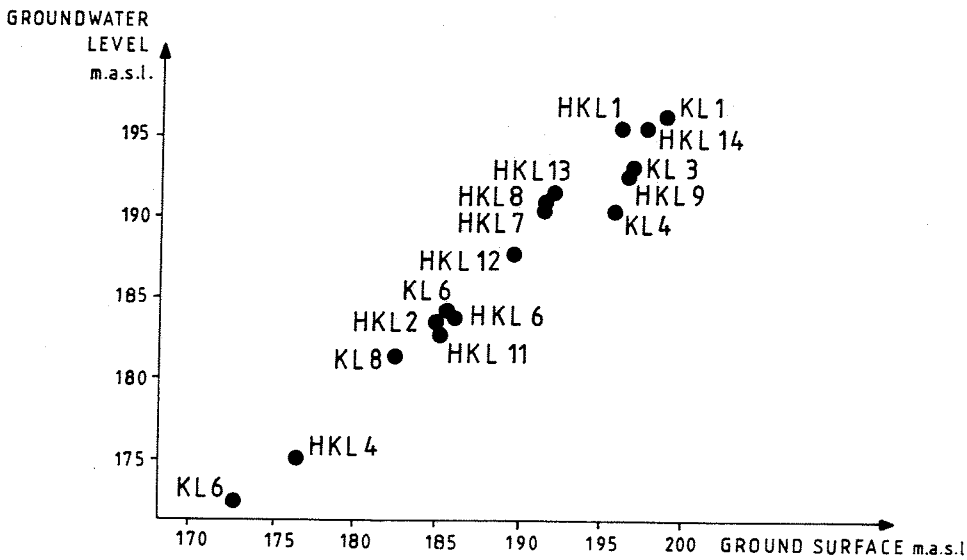


Figure 4.2 Mean ground-water level versus ground surface level in sectioned-off drillholes at Klipperås.

4.4 Ground-water level maps

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

The regional map in Figure 4.3 covers an area of c. 500 km^2 with the study site at its centre. The local map, Figure 4.4, has an acreage of 12 km^2 and includes the Klipperås study site.

In the construction of the map, the ground-water table has been assumed to follow the topography. On the basis of the observations in the area, with emphasis on the registrations in the sealed boreholes, the ground-water table in the upper parts of the bedrock has been assumed to be located 3-6 m below the ground surface on hills and in slopes and 0.5 - 1.5 m below the ground surface in the lower parts of the area. A morphological adjustment has also been made in the sense that the groundwater level has been "smoothed out" in the case of minor topographical differences. 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 elevation of the ground-water table is larger under narrow vallies than under 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 to a scale of 1:50 000 and the local map to a scale of 1:10 000. They are reproduced in reduced size in Figures 4.3 and 4.4. The levels represent an assumed mean level during the year, corresponding to a situation of equilibrium between ground-water recharge, ground-water flow and ground-water discharge.

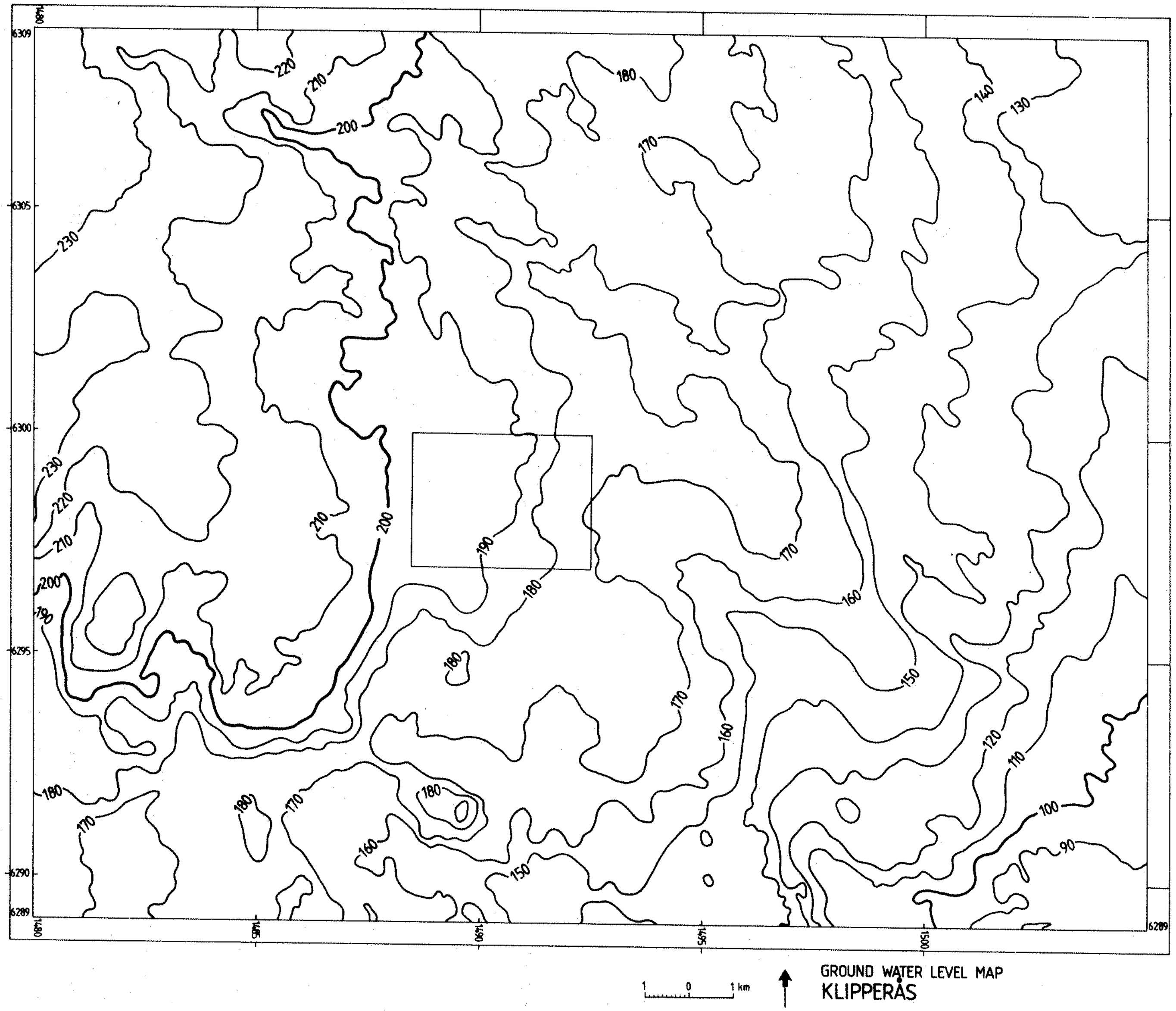


Figure 4.3 Regional map of ground-water level at site Klip-peras, contour lines for every tenth meter.

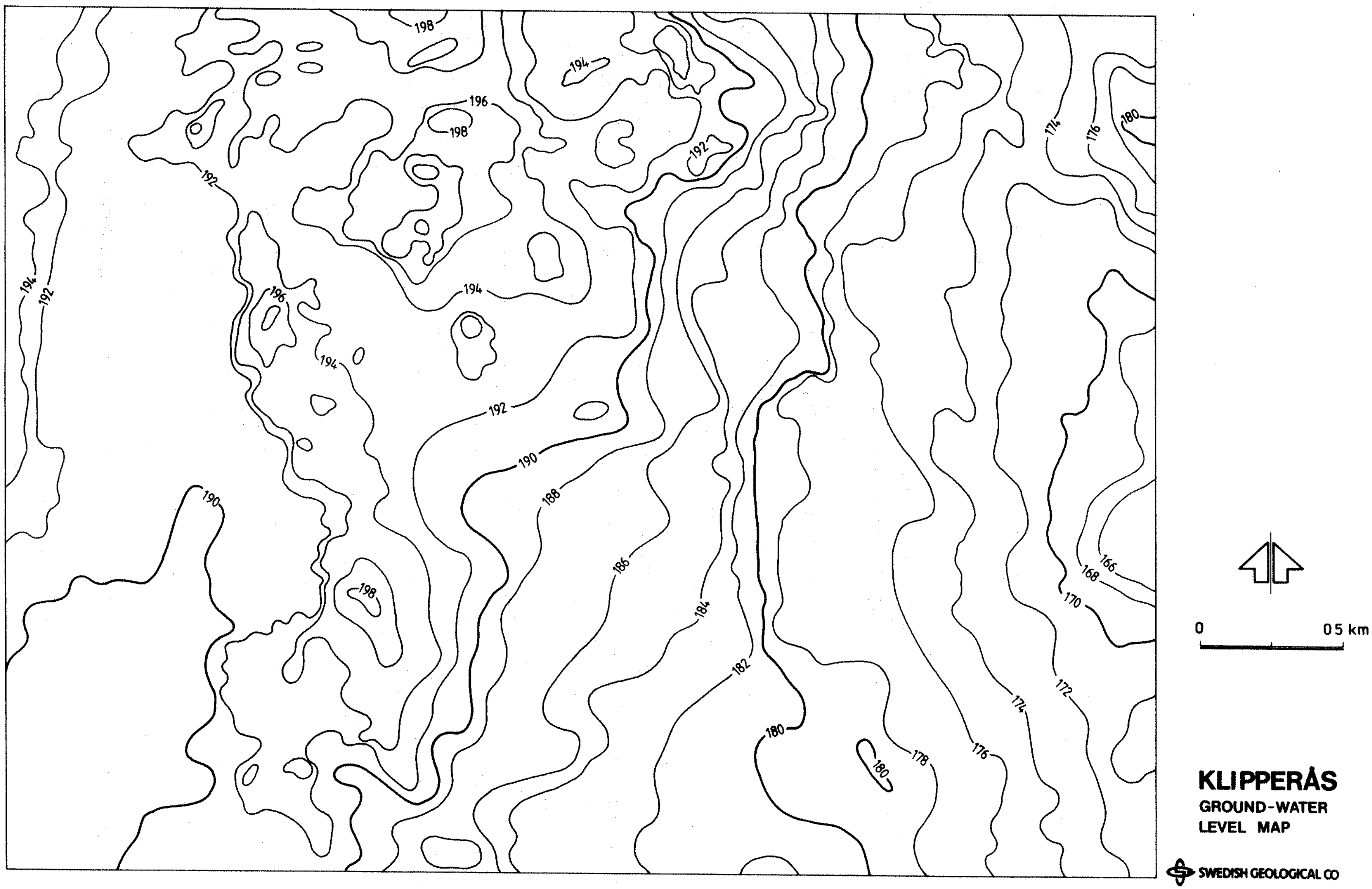


Figure 4.4 Local map of ground-water level at site Klipperås, contour lines for every second meter.

5. HYDRAULIC CONDUCTIVITY OF THE BEDROCK

5.1 General

The hydraulic conductivity (K) of the bedrock at Klipperås was determined from single-hole water injection tests in seven of the cored boreholes and from one interference test in the central part of the site.

The single-hole injection tests were performed in delimited 20 m or 25 m sections in boreholes Kl 1, Kl 2, Kl 6, Kl 9 and Kl 12-14, beginning 10-60 m beneath the ground surface down to c. 10 m from the bottom of the borehole, see Table 5.1. In all 241 sections of 20 m or 25 m were tested. In the deepest part of the boreholes single packer tests were performed, with section lengths varying between 8 m and 232 m.

In four boreholes the injection tests were supplemented with detailed tests where the section length was 5 m. The number of 5 m tests comprised 62 sections. These tests were performed in sections of high hydraulic conductivity so that the conductive parts of the individual 20 m/25 m sections could be delimited. The 5 m tests also make it possible to check the results obtained from 20 m/25 m sections. By comparing the transmissivity T (the hydraulic conductivity multiplied by the section length) obtained from tests with different section lengths, the reliability of the tests could be evaluated.

The supply water used in the injection tests was pumped from the percussion boreholes within the site. These boreholes were HKl 1 (supplied tests in Kl 1), HKl 2 (Kl 2, Kl 9 and Kl 13), HKl 3 (Kl 6), HKl 11 (Kl 12) and HKl 12 (Kl 14).

Before the water injection tests at the Klipperås site commenced, cuttings rock and drilling fluid, were removed from the boreholes. This was performed by introducing nitrogen gas down to the bottom of the holes through a plastic hose and then lifting the water and cuttings out of the borehole (air lift pumping). The procedure was repeated four times in the boreholes subjected to water injection tests.

During autumn 1985 an interference test was performed in the central part of the site for the purpose of investigating the geometry and the hydraulic properties of the highly permeable zone which intersect borehole Kl 2 at great depth. Water was injected in borehole Kl 2 at c. 790 m depth and ground-water level variations were registered in cored borehole Kl 8 as well as in borehole Kl 2. The two boreholes were sectioned off by rubber packers.

Table 5.1 Number of water injection tests and borehole data for the Klipperås cored boreholes.

	KL 1	KL 2	KL 6	KL 9	KL 12	KL 13	KL14
Borehole length (m)	564.0	958.6	808.0	801.8	730.1	700.1	705.2
Inclination (^{o})	80	80	60	60	55	60	60
Vertical depth (m)	555	943	700	694	598	606	610
Altitude (m)	199.5	182.3	173.1	192.2	183.8	183.3	189.1
W.inj. tested intervall (m)	31-564	60-958	20-808	30-801	20-730	10-700	20-705
Number of 25m-tests	21	-	-	-	-	-	-
Number of 20m-tests	-	44	38	37	35	33	33
Number of 5m-tests	6	16	-	20	-	20	
Number of single packer tests	2	1	2	1	1	3	1

5.2 Water injection tests

5.2.1 Test method

Equipment

The umbilical hose system was used for the water injection tests at the Klipperås site, Almén et al 1983. This equipment includes a test probe, control and recording instruments, hydraulic hoses and electrical cables, see Figure 5.1.

The test probe includes two rubber packers, infiltration pipe, test valve, relief valve, pressure transducers and temperature sensor. The length of the packers is 1 m and they are connected to the infiltration pipe at variable distances. The relief valve relieves the pressure in the test section, in such a manner that the generation of excessive pressure in the test section from expansion of the packers can be prevented. The test valve, like the relief valve, is a hydraulic operated valve. It permits instantaneous starting of the injection and fall-off phases under completely confined conditions.

The pressure in the test section is measured by two pressure transducers. This pressure, as well as the inflation pressure of the packers and the barometer pressure are registered continuously throughout the test. The water flow is measured by a flow metre. The range of measurement is 0.09 ml/min - 1455 l/min.

The test probe is connected to a multihose, which contains all the cables and hoses necessary for the test. The length of the umbilical hose is 1000 m. Its outside diameter is 47 mm. The internal diameter of the injection hose is 10 mm, while the other regulation hoses have an internal diameter of 4 mm.

The umbilical hose system is physically separated into three mobile units - measurement trailer, instrument trailer and diesel generator. In the measurement trailer, the equipment for injection, packer and valve operation is installed together with some of the measuring probes. The multihose is also installed in the measurement trailer.

All regulation and measuring functions, as well as storage of data from the tests are controlled and conducted from a micro-computer system in the instrument trailer. With a second micro-computer, all data diagrams needed for the evalutation of the test can be plotted immediately after the test is completed.

Test procedures

The single hole water injection tests at Klipperås were carried out as constant head tests performed in three consecutive phases (Figure 5.2), as follows:

- Phase I, packer sealing (30 min)
- Phase II, water injection (120 min)
- Phase III, pressure fall-off (120 min)

I

During the packer sealing the packers were tightened against the borehole wall by pressurizing the packer inflation fluid from the ground surface. To avoid excess pressure in the test section the relief valve was open during the first 25 minutes of the packer sealing phase. During the last 5 minutes, the relief valve was closed and the pressure increased/decreased towards the natural piezometric pressure of the test section. The tightness of the entire injection system, down to the test valve, was checked during the packer sealing phase. The flow rate measurement was checked by a cannula test.

II

An instantaneous opening of the test valve starts the injection phase. The differential pressure of the test section was increased as rapidly as possible to c. 200 kPa and was maintained at this level throughout the injection phase by automatic regulation of the water flow rate. In highly permeable test sections, it was not possible to obtain a differential pressure of 200 kPa due to friction losses in the injection hose. In these cases, the injection pressure was kept constant at a lower level. In very low-permeable test sections, the flow quickly decreased to the measuring limit, and the duration of the test may than be limited to approx. 20 minutes after injection start

III

The closing of the test valve ends the injection phase. The fall-off phase starts simultaneously. The injection pressure in the section declines towards the natural piezometric pressure of the test section under confined conditions. Normally, the fall-off period (2 hours) is too short to reach the natural piezometric pressure of the section.

The tightness of the system was also checked during the fall-off phase. A second cannula test was performed and was compared with the first one. The water injection test was completed by releasing the packer pressure and stopping the data registration.

5.2.2 Evaluation methods

The data from the single hole injection tests have been plotted on various graphs to identify different flow regimes i.e. linear, radial and spherical flow. The graphs also allow identification of outer boundary conditons from the test response.

The reciprocal flow rate (1/Q(t)) and flow rate (Q(t)) during the injection have been plotted versus time (t) on semilogarithmic and logarithmic graphs. 1/(Q(t)) has also been plotted versus the fourth root of time on linear graphs to detect linear flow periods. During the fall-off phase, the residual pressure was plotted on a Horner-diagram. The pressure change, related to the actual pressure at injection stop, was plotted versus time on a logarithmic graph.

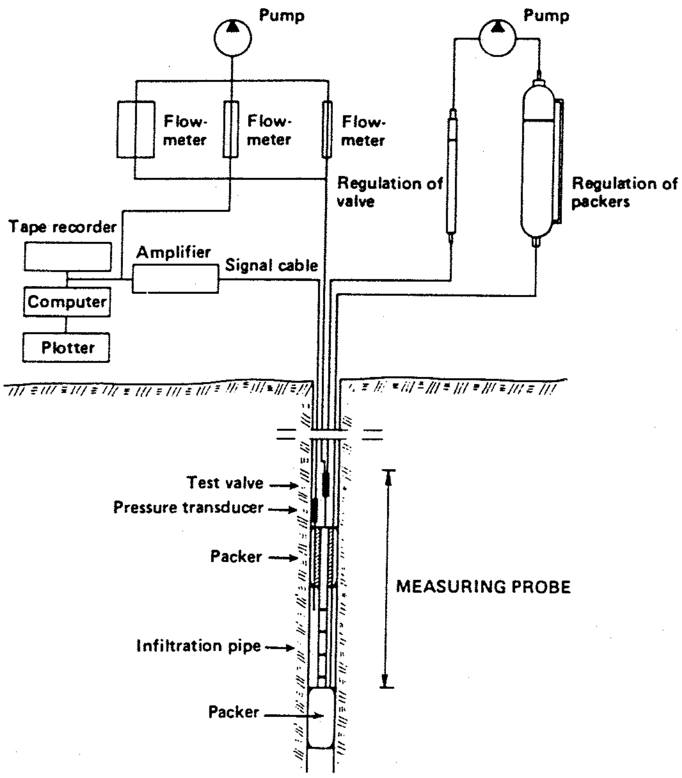


Fig 5.1 General configuration of water injection test equipment.

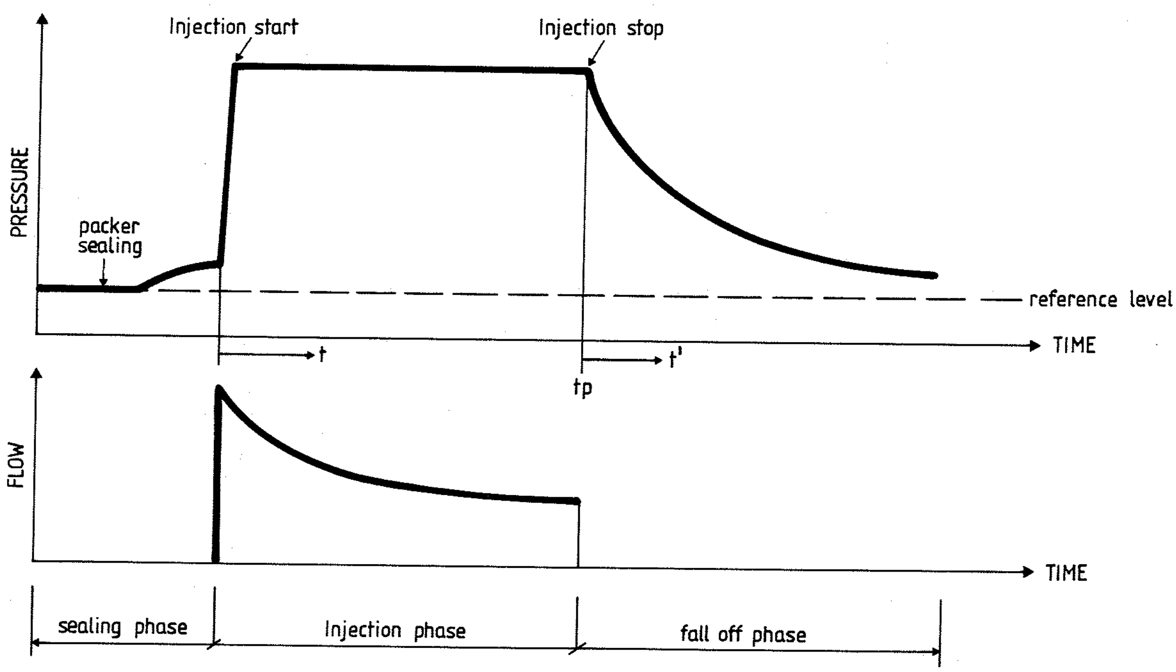


Fig 5.2 The different phases of a water injection test.

The transient analysis of the single-hole test is based on the the continuum approach, using porous media theory. The hydraulic conductivity of most sections of the rock has been determined from the slope of the straight line in the semilogarithmic diagrams. Here radial or pseudoradial flow is assumed. From the injection phase, the conductivity is calculated from the following equation:

$$K = \frac{0.183 \times p_w \times g}{dp \times L \times (1/Q)} \qquad (5.1)$$

K	=	hydraulic conductivity	(m/s)
p_w	=	density of water	(kg/m^3)
g	=	acceleration of gravity	(m/s^2)
dp	=	injection pressure in the test section	(Pa)
L	=	length of the test section	(m)
$(1/Q)$	=	flow change during a logarithmic time decade	(s/m^3)

The hydraulic conductivity can also be calculated from a steady-state analysis according to Moye (1967):

$$K = \frac{Q_p}{L \times H_o} \times C \qquad (5.2)$$

where H_o = head of water in the test section (m of water)
Q_p = flow rate at the end of injection phase (m^3/s)

The borehole constant C can be written in the form

$$C = (1 + \ln (L/d))/ 2\pi$$

where d = borehole diameter (m)

In equation (5.2) steady-state conditions are assumed. Transient conditions prevail during the injection phase, but the change of water flow at the end of the injection phase is often so small that the assumption above is a good approximation. For a number of reasons, the K value calculated above may differ from the K value obtained from transient evaluation. For example, in a steady-state evaluation skin effects or the precence of hydraulic boundaries, are not considered.

Some test sections, which show an approximate steady-state response, are evaluated from equation 5.2. Equation (5.2) has also been used in the evaluation when the flow regime of the test section has been identified as spherical.

From the fall-off phase the hydraulic conductivity has in general been calculated from the Horner-diagram. Here radial flow is assumed. The following equation is used:

$$K = \frac{0.183 \times Q_p \times p_w \times g}{\Delta(dp') \times L} \qquad (5.3)$$

where Q_p = the flow rate at the end of the injection phase (m^3/s)

$\Delta(dp')$ = pressure change during a logarithmic time decade (Pa)

The Horner-diagram also enables determination of the natural piezometric head of the test section, see chapter 6.

Sources of error related to the water injection tests are discussed by Ahlbom et al 1983. Briefly the principal instrumental errors are caused by resolution and accuracy of the pressure transducers and the flow meter and also due to variations of the injection pressure during the injection phase. The latter error is especially critical in highly permeable test sections, where it is difficult to maintain a constant injection pressure. A rough estimate of the test error related to the equipment is less than 20 %. This estimate does not include the effect of leakage around the packers, which sometimes occurs, especially in highly fractured rock.

The lower measurement limit for hydraulic conductivity in the water injection tests depends on the lowest measurable flow rate, the differential pressure and the section length, see equations (5.1)-(5.3). With the equipment used, the lower measurement limit of K has been determined to be 1.0×10^{-11} m/s for 20/25 m sections and 4.0×10^{-11} for 5m sections.

The size of the rock volume around the borehole that is tested can be estimated from the following expression:

$$r_e = (135 \times K \times t / S_s)^{1/2} \qquad (5.4)$$

where r_e = the radius of the influenced volume (m)
t = testing time in minutes
S_s = specific storage coefficient

Table 5.2 shows the radius of influence for different values of K. The specific storage coefficent has been estimated to be 10^{-5} for $K>10^{-7}$ m/s and 10^{-6} for $K<10^{-7}$ m/s.

Table 5.2 The influence radius (r_e) in water injection tests of 120 minutes duration for different values of the hydraulic conductivity (K) and for the above estimated values of specific storage.

K (m/s)	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}
r_e (m)	0.4	1.3	4.0	12.7	12.7	40.2

5.2.3 Cored borehole Kl 1

The hydraulic conductivity (K) obtained from the water injection tests is shown in Figure 5.3 and appendix 3(1).

25 m sections and single packer tests.

Very high values of hydraulic conductivity were measured down to 331 m borehole length. The K-values exceed 10^{-6} m/s in 50 % of the sections and only one is lower than 10^{-8} m/s. However, an increase in the ground-water level during the injection phase indicates leakage around the packers in the three uppermost sections. The K-values evaluated are therefore likely to be too high in these sections.

Below 331 m the hydraulic conductivity is very low. In only one section, 431-456 m, the K-value exceeds the measurement limit. The single packer test from 331 m down to the bottom of the borehole resulted in a K-value of 2.2×10^{-8} m/s - too high compared with the 25 m-tests and the single packer test from 556 m. The transmissivity of the single packer test from 331m is almost three orders of magnitude higher than the sum of the transmissivity of the 25 m-tests and the single packer test from 556 m. The reason for this discrepancy is not confirmed. However it is probably caused by leakage around the packers during the single packer injection test.

5 m sections.

Only one of the six 5 m tests resulted in a K-value higher than the measurement limit, 6.6×10^{-10} m/s in the section 433-438 m. The 5 m tests correspond fairly well to the 25 m tests. The sum of the transmissivity (T) obtained from the 5 m sections is only 1.18 times higher than the T-value obtained from the corresponding 25 m section. Ideally,this quotient should be one, but deviation from the assumed geometry and flow patterns may cause situations where this is not the case.

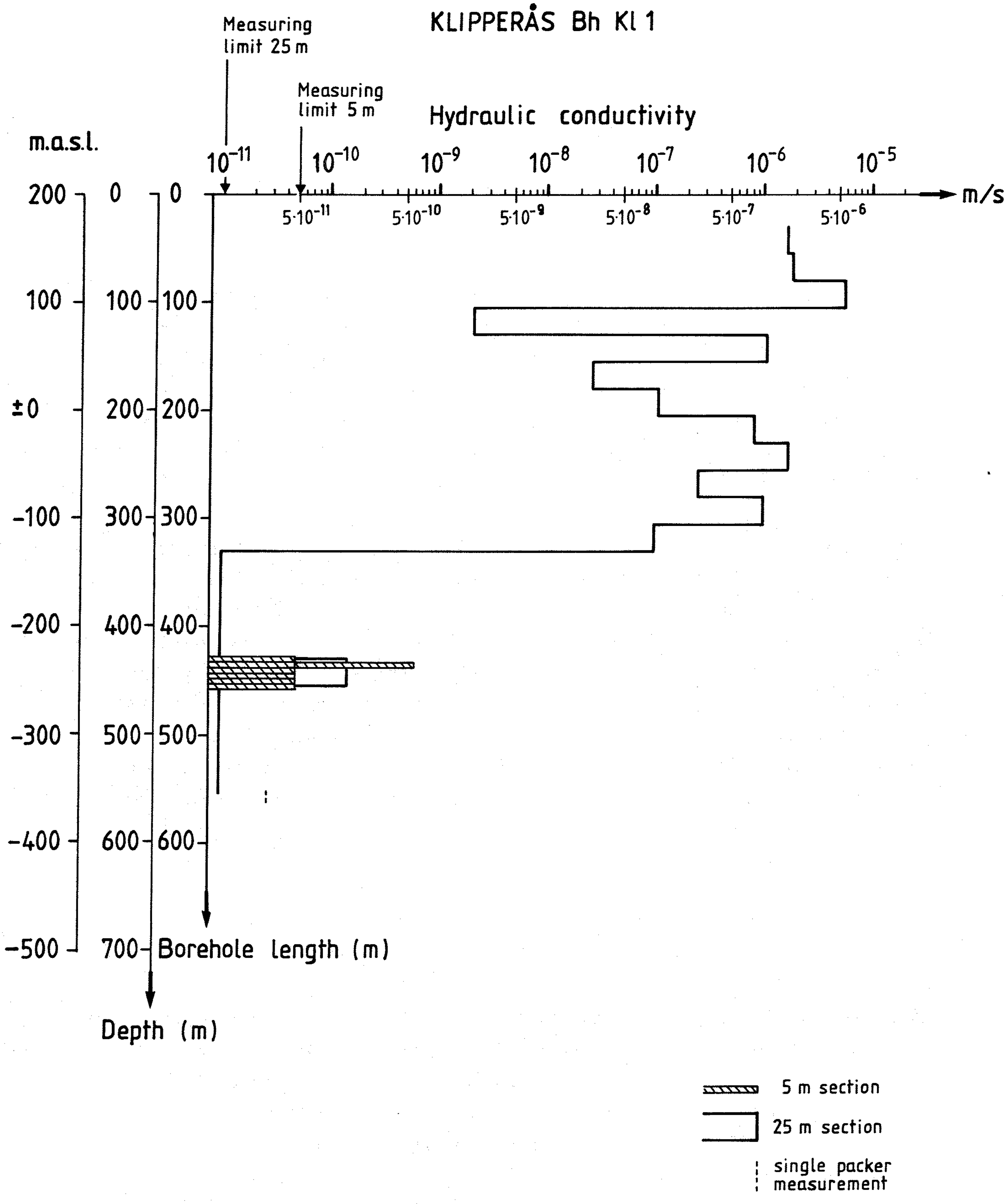


Fig 5.3 Hydraulic conductivity obtained from cored borehole Kl 1.

Fracture zones.

From geological surveying and surface geophysical measurements, thirteen fracture zones have been mapped within the Klipperås area, see Figure 5.10. One of these zones, zone10, is penetrated by borehole Kl 1.The calculated hydraulic conductivity is shown in Table 5.3.

Table 5.3 Fracture zone penetrated by cored borehole Kl 1 and its hydraulic conductivity (K).

Fracture zone	Length borehole (m)	Strike/Dip (degrees)	Width (m)	Vertical depth (m)	K (m/s)
10	280-310	N45E/85NW	10.5	290.5	9.3×10^{-7}

5.2.4 Cored borehole Kl 2

The hydraulic conductivity (K) obtained from the water injection tests is shown in Figure 5.4 and appendix 3(2).

20 m sections and single packer tests.

Low hydraulic conductivity values were determined in most sections and 27 of the 44 20 m tests resulted in K-values lower than the measurement limit. The high values obtained are found above 140 m borehole length (the arithmic mean is 3.8×10^{-8} m/s) and in the interval 740-810 m (the arithmetic mean is 3.1×10^{-7} m/s). The highest K-value of this borehole, 1.2×10^{-6} m/s, was determined in the section 790-810 m.

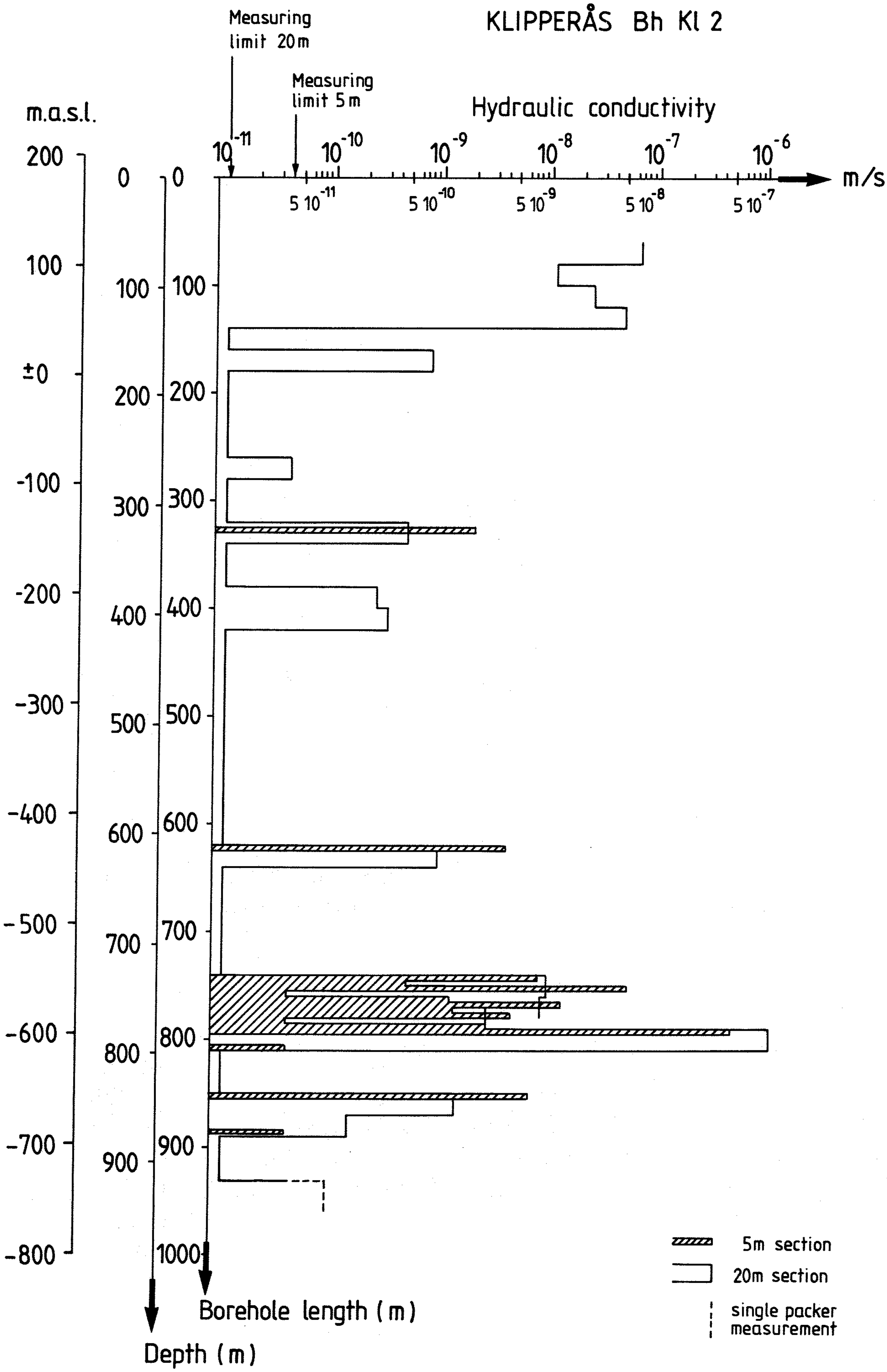


Fig 5.4 Hydraulic conductivity obtained from cored borehole Kl 2.

5 m sections.

Sixteen 5 m sections were tested in the most permeable parts at borehole depths exceeding 180 m. The highest value (5.3×10^{-7} m/s) is found in section 790-795 m. Table 5.4 shows a comparison of transmissivity between 20 m and 5 m sections. The T-quotient in the table is defined as the ratio of the transmissivity of the 20 m section (T(20 m)) to the sum of the transmissivities of corresponding 5 m sections (Σ T (5m)) or reciprocally in such a manner that the T-quotient is greater than unity.

As mentioned in chapter 5.1 the 5 m tests make it possible to check the results of the 20 m tests. If the detailed measurements cover the whole 20 m section and the K-values obtained are correct, the T-quotient should in the ideal case not diverge significantly from unity. Table 5.4 shows that this is indeed the case with six of the eight sections subjected to detailed tests.

The most permeable part of the borehole, 795-805 m, was not tested because of risk of packer collapse. This could explain the high T-quotient obtained from the 790-810 m interval.

The section 884-889 m covers a greenstone dyke. It was however impermeable, which accounts for the discrepancy in transmissivity in the interval 870-890 m.

Table 5.4 Comparison of transmissivity (T) between 20 m and 5 m sections in cored borehole Kl 2. The T-quotient is defined to be ≥ 1.

20m section (m)	T (20m) (m /s)	5m section (m)	T (5m) (m /s)	Σ T(5 m) (m /s)	T quotient
320-340	9.4xE-9	325-330	9.4xE-9	9.4xE-9	1.0
620-640	1.9xE-8	620-625	2.1xE-8	2.1xE-8	1.1
		740-745	4.1xE-8		
		745-750	2.5xE-9		
		750-755	2.8xE-7		
740-760	2.2xE-7	755-760	<2.0xE-10	3.2xE-7	1.5
		760-765	6.3xE-9		
		765-770	6.9xE-8		
		770-775	6.7xE-9		
760-780	1.8xE-7	775-780	2.4xE-8	1.1xE-7	1.7
		770-775	6.7xE-9		
		775-780	2.4xE-8		
		780-785	<2.0xE-10		
770-790	5.8xE-8	785-790	1.5xE-8	4.6xE-8	1.3
		790-795	2.7xE-6		
790-810	2.4xE-5	805-810	<2.0xE-10	2.7xE-6	9.0
850-870	2.9xE-8	865-870	3.5xE-8	3.5xE-8	1.2
870-890	3.0xE-9	884-889	<2.0xE-10	<2.0xE-10	14.2

Fracture zones.

None of the near-vertical fracture zones shown in Figure 5.10 intersects borehole Kl 2. However, at a depth of c. 800 m the borehole penetrates the subhorizontal fracture zone H 1. The calculated K-value of the zone is presented in Table 5.5.

Table 5.5 Fracture zone penetrated by cored borehole Kl 2 and its hydraulic conductivity.

Fracture zone	Length in borehole (m)	Strike/Dip (degrees)	Zone width (m)	Vertical depth (m)	K (m/s)
H 1	792-804	subhorizontal	12	785.9	2.0xE-6

5.2.5 Cored borehole Kl 6

The hydraulic conductivity (K) obtained from the water injection tests is presented in Figure 5.5 and appendix 3(3). No detailed tests were performed in this borehole.

20 m sections and single packer tests.

The water injection tests resulted in high conductivity values in large parts of the borehole. Above 560 m borehole length, the hydraulic conductivity varies between 4.5×10^{-9} m/s and 9.9×10^{-6} m/s with the majority of the K-values exceeding 1.0×10^{-7} m/s. The maximum value was calculated in the section 240-260 m.

The interval 560-660 m is somewhat less permeable, with a conductivity varying between 1.1 and 5.3×10^{-8} m/s, while the bottom of the borehole (below 660 m) has K-values close to the measuring limit.

Fracture zones.

Borehole Kl 6 does not penetrate any of the fracture zones mapped within the Klipperås study site, Figure 5.10. However the borehole intersect a dyke in the eastern part of the site. The dyke was first belived to be a fracture zone, but was later interpreted to be the same ultramafic dyke as in boreholes Kl 5 and Kl 10, Olkiewicz et al 1986. An estimate of the hydraulic

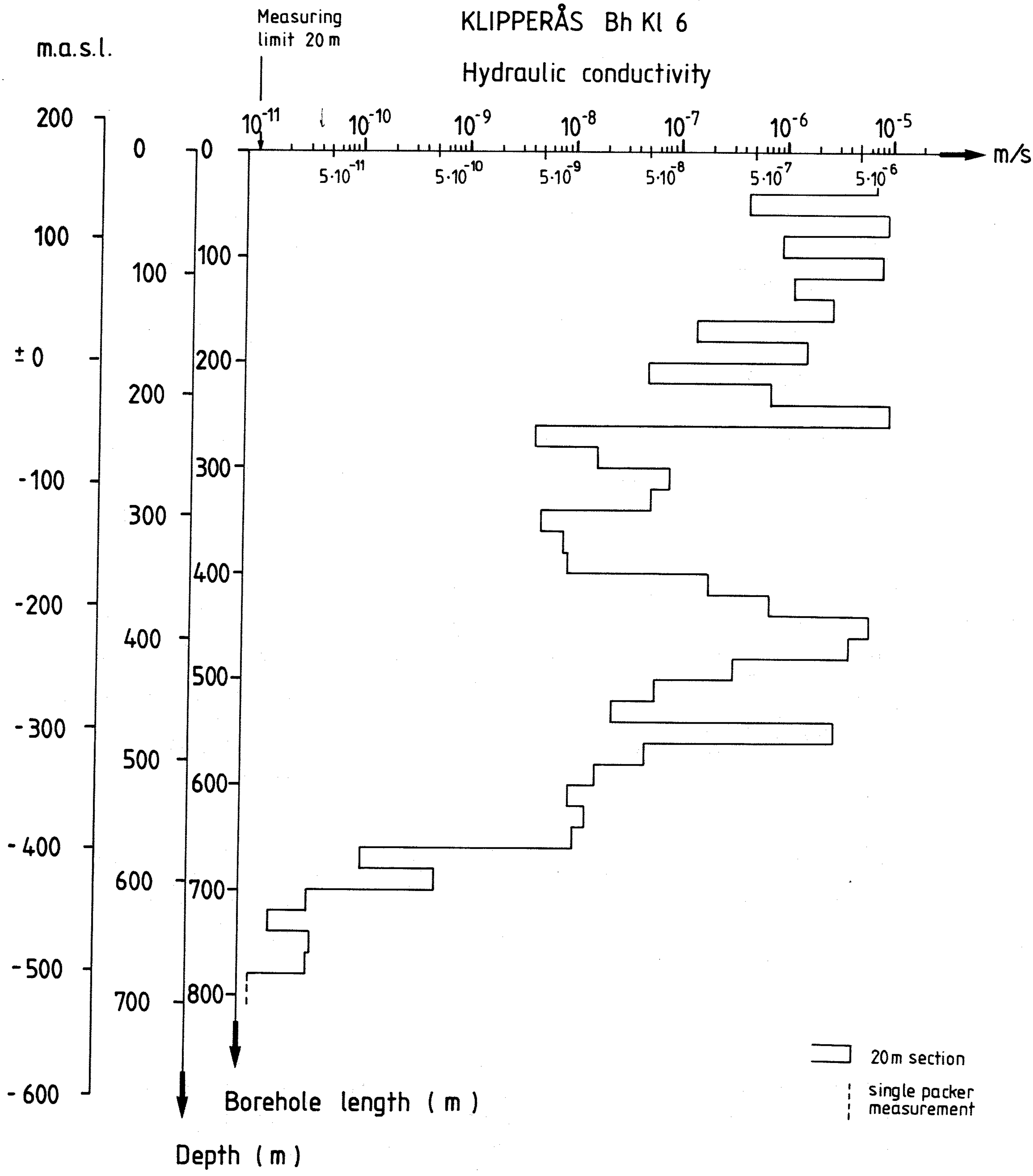


Fig 5.5 Hydraulic conductivity obtained from cored borehole Kl 6.

conductivity of the dyke is presented in Table 5.6

Table 5.6 Data for the ultramafic dyke penetrated by cored borehole Kl 6.

Length in borehole (m)	Strike/Dip (degrees)	Dyke-width (m)	Vertical depth (m)	K (m/s)
338-372	N-S/90	17	307.2	4.1xE-8

5.2.6 Cored borehole Kl 9

The hydraulic conductivity (K) obtained from the water injection tests is shown in Figure 5.6 and appendix 3(4).

20 m sections and single packer tests.

The 20 m tests resulted in high K-values above 430 m borehole length. With the exception of two sections at the measurement limit,they vary between 1.7×10^{-9} m/s and 2.2×10^{-5} m/s, and in this part of the borehole 50 % of the conductivity-values exceed 1.0×10^{-7} m/s. Between 430 m and 670 m the rock is less permeable ($K<3.7\times10^{-10}$ m/s). High K-values were again determined in the interval 670 m - 750 m with the maximum value, 5.1×10^{-7} m/s, in the section 690-710 m.

5 m sections.

20 5 m sections were tested in borehole Kl 9. They completely cover five 20 m sections. In Table 5.7, the transmissivities obtained from the two section lengths respectively are compared. The correspondence is satisfactory for the interval 370-430 m but not for the interval 670-710 m. Between 670-690 m borehole length the 5 m tests resulted in a much higher trans-

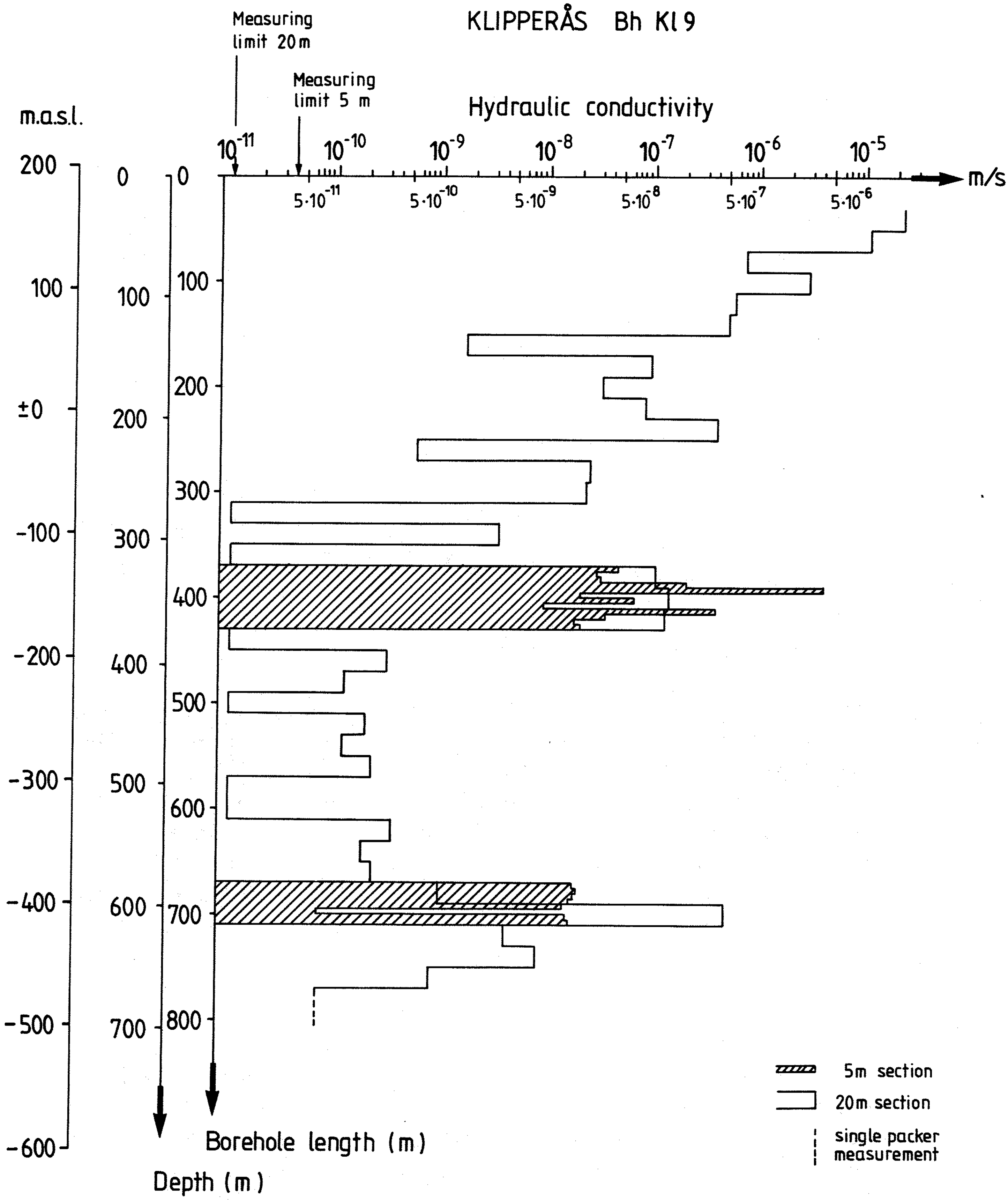


Fig 5.6 Hydraulic conductivity obtained from cored borehole Kl 9.

missivity than those obtained from the corresponding 20 m test. Between 690 m and 710 m, the opposite is true. This discrepancy is difficult to explain. It is possible that it is caused by leakage around the packers but this has not been confirmed.

Table 5.7 Comparison of transmissivity (T) between 20 m and 5 m sections in cored borehole Kl 9. The T-quotient is defined to be ≥ 1.

20m section (m)	T(20m) m /s	5m section (m)	T(5m) m /s	Σ T(5m) m /s	T-quotient
		370-375	2.3xE-7		
		375-380	1.5xE-7		
		380-385	1.6xE-7		
370-390	2.1xE-6	385-390	1.1xE-6	1.6xE-6	1.4
		390-395	5.7xE-6		
		395-400	9.0xE-8		
		400-405	3.3xE-7		
390-410	2.9xE-6	405-410	4.5xE-8	6.1xE-6	2.1
		410-415	2.0xE-6		
		415-420	1.8xE-7		
		420-425	8.9xE-8		
410-430	2.6xE-6	425-430	9.8xE-8	2.4xE-6	1.1
		670-675	9.4xE-8		
		675-680	1.0xE-7		
		680-685	9.4xE-8		
670-690	2.0xE-8	685-690	8.3xE-8	3.7xE-7	18.8
		690-695	7.5xE-8		
		695-700	<2.0xE-10		
		700-705	8.2xE-8		
690-710	1.6xE-6	705-710	8.5xE-8	2.4xE-7	42.2

Fracture zones.

Two of the fracture zones within the Klipperås study area, see Figure 5.10, are penetrated by borehole Kl 9. The data is presented in Table 5.8.

Table 5.8 Fracture zones penetrated by cored borehole Kl 9 and its hydraulic conductivity (K).

Fracture zone	Length in borehole (m)	Strike/Dip (degrees)	Zone-width (m)	Vertical depth (m)	K (m/s)
1	615-665	N30E/90	29	554.3	3.1xE-10
2	120-160	N30E/90	22	121.2	5.4xE-7

5.2.7 Cored borehole KL 12

The hydraulic conductivity (K), obtained from the water injection tests is shown in Figure 5.7 and appendix 3(5). No detailed tests were performed in borehole Kl 12.

20 m sections and single packer tests.

The single hole water injection tests resulted in high conductivity values down to 520 m borehole length. With the exception of three less permeable sections the K-values vary between 1.1×10^{-8} m/s and 3.1×10^{-6} m/s. Between 520 m and 620 m, the hydraulic conductivity ranges from the measurement limit to 2.0×10^{-8} m/s. The tests in the bottom of the borehole gave K-values at, or close to, the lower measuring limit.

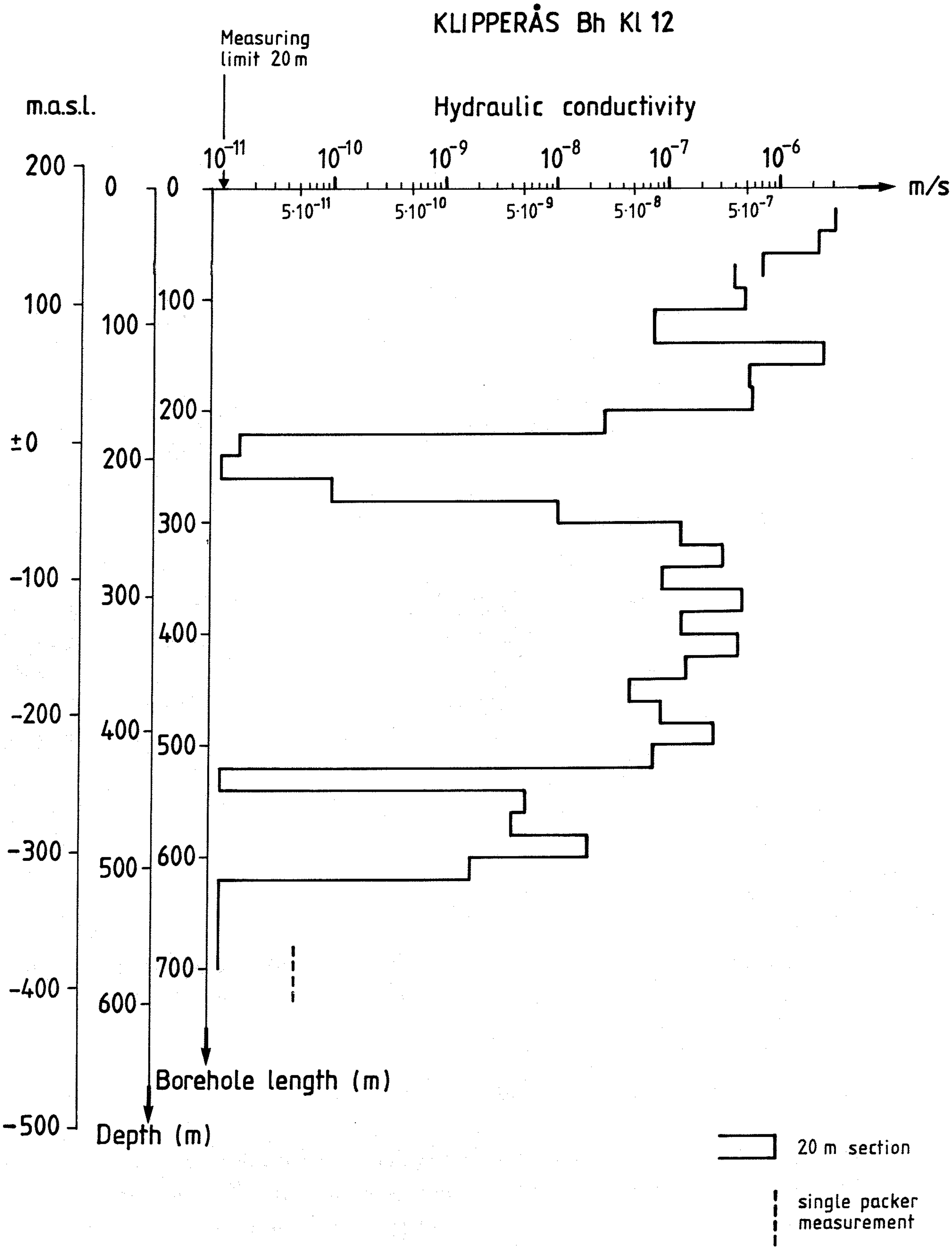


Fig 5.7 Hydraulic conductivity obtained from cored borehole Kl 12.

Fracture zones.

Cored borehole Kl 12 penetrates five of the fracture zones which were found within the study site, see Figure 5.10. The data is presented in Table 5.9.

Table 5.9 Fracture zones penetrated by cored borehole Kl 12 and their hydraulic conductivity (K).

Fracture zone	Length in borehole (m)	Strike/Dip (degrees)	Zone-width (m)	Vertical depth (m)	K (m/s)
2	595-630	N15E/85	13	501.7	9.6xE-9
7	288-306	N65E/80S	13.5	257.2	2.5xE-7
6	70-88	N75W/75S	12.5	64.7	4.4xE-7
8	312-347	N85W/75S	28	285.4	3.2xE-7
9	362-384	N60E/75S	17.5	323.0	5.5xE-7

5.2.8 Cored borehole Kl 13

The hydraulic conductivity (K) obtained from the water injection tests is presented in Figure 5.8 and appendix 3(6).

20 m sections and single packer tests.

The 20 m tests resulted in relatively high conductivity values above 190 m borehole length, between $4.4x10^{-8}$ m/s and $1.4x10^{-6}$ m/s. The interval 190-610 m has a much lower permeability. The hydraulic conductivity ranges between the measuring limit and $6.4x10^{-9}$ m/s. Only two K-values exceed $3.1x10^{-10}$ m/s.

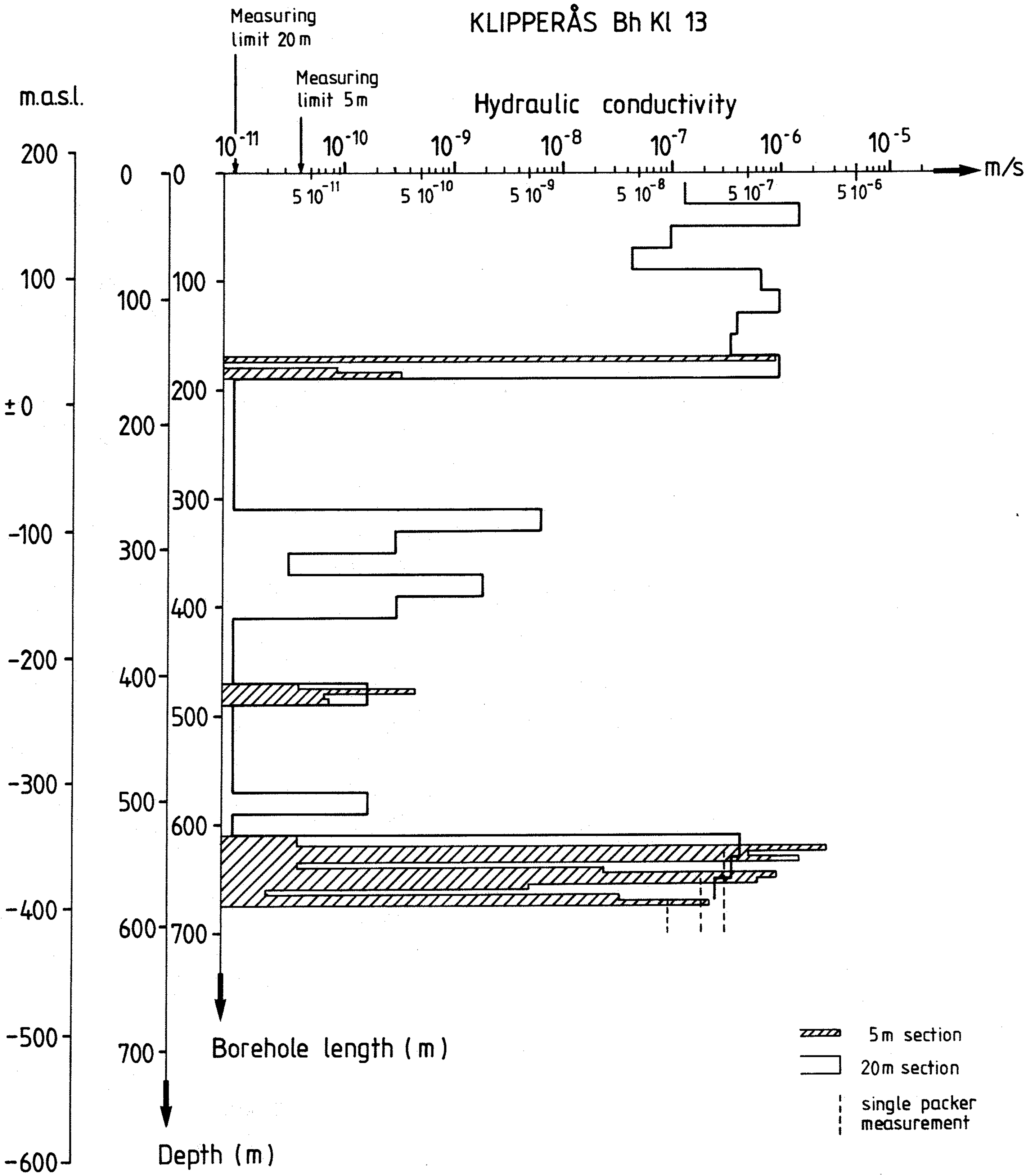


Fig 5.8 Hydraulic conductivity obtained from cored borehole Kl 13.

The three 20 m tests in the interval between 610 and 670 m again resulted in high K-values, c. 4×10^{-7} m/s. Three single packer measurements from 630 m, 650 m and 670 m respectively were performed in borehole Kl 13. They correspond relatively well to the 20 m tests and indicate that the bottom of the borehole (below 670 m) is permeable.

Table 5.10 Comparison of transmissivity (T) between 20 m and 5 m sections in cored borehole Kl 13. The T-quotient is defined to be ≥ 1.

20m section (m)	T(20m) (m /s)	5m section (m)	T(5m) (m /s)	Σ T(5m) (m /s)	T-quotient
		170-175	4.7xE-6		
		175-180	not measured		
		180-185	3.8xE-10		
170-190	2.0xE-5	185-190	1.7xE-9	4.7xE-6	4.1
		470-475	<2.0xE-10		
		475-480	2.3xE-9		
		480-485	3.0xE-10		
470-490	3.5xE-9	485-490	3.8xE-10	3.1xE-9	1.1
		610-615	<2.0xE-10		
		615-620	<2.0xE-10		
		620-625	1.4xE-5		
610-630	8.9xE-6	625-630	2.6xE-6	1.7xE-5	1.9
		630-635	7.9xE-6		
		635-640	<2.0xE-10		
		640-645	1.3xE-7		
630-650	7.5xE-6	645-650	4.9xE-6	1.3xE-5	1.7
		650-655	3.2xE-6		
		655-660	2.6xE-8		
		660-665	9.6xE-11		
650-670	5.4xE-6	665-670	1.7xE-7	3.4xE-6	
670-700*	2.9xE-6	670-675	1.2xE-6	1.2xE-6	2.4

* (single packer test)

5 m sections.

20 5 m sections were tested. 16 of them completely cover four 20 m sections. In these four sections, the calculated transmissivity of the two section lengths (respectively) correspond satisfactorily, see table 5.10.

The section 175-180 m was not tested because of the risk of packer collapse in this highly fractured part of the borehole. The high T-quotient in the interval 170-190 m indicate that the mentioned section has a high hydraulic conductivity (>10^{-6} m/s).

Fracture zones.

One of the fracture zones within the Klipperås site (Figure 5.10) is penetrated by borehole Kl 13. The calculated conductivity value of the zone is presented in Table 5.11.

Table 5.11 Fracture zone penetrated by cored borehole Kl 13 and its hydraulic conductivity (K).

Fracture zone	Length in borehole	Strike/Dip (degrees)	Zone-width (m)	Vertical depth	K (m/s)
5	152-188	N80W/75S	23	147.2	7.5xE-7

The high hydraulic conductivity values in the bottom of Kl 13 correspond to a moderate increase in fracture frequency in the core (Olkiewicz et al 1986) and to several low resistivity peaks from the borehole geophysical measurements (Sehlstedt and Stenberg 1986). However no correlation between this part of Kl 13 and the other Klipperås boreholes or with the local fracture zones mapped in Figure 5.10 has been confirmed.

5.2.9 Cored borehole Kl 14

The hydraulic conductivity (K) obtained from the water injection tests is presented in Figure 5.9 and appendix 3(7). In this borehole, detailed tests were not performed.

20 m sections and single packer tests.

High conductivity values were determined along the entire borehole. The most permeable sections were found above 560 m borehole length ($5.0 \times 10^{-9} < K < 1.1 \times 10^{-6}$ m/s). In this interval the arithmetic mean of the hydraulic conductivity is 1.5×10^{-7} m/s.

Below 560 m the K-values obtained are somewhat lower. They vary from 1.9×10^{-11} m/s to 5.2×10^{-9} m/s and the arithmetic mean of the K-values below 560 m is 3.2×10^{-9} m/s.

Fracture zone.

Borehole Kl 14 penetrates one of the fracture zones found at the Klipperås study site, Figure 5.10. The calculated conductivity of the zone is presented in Table 5.12.

Table 5.12 Fracture zone penetrated by cored borehole Kl 14 and its hydraulic conductivivty (K).

Fracture zone	Length in borehole (m)	Strike/Dip (degrees)	Zone width (m)	Vertical depth (m)	K (m/s)
4	368-410	N85E/80	27	354.2	3.9xE-7

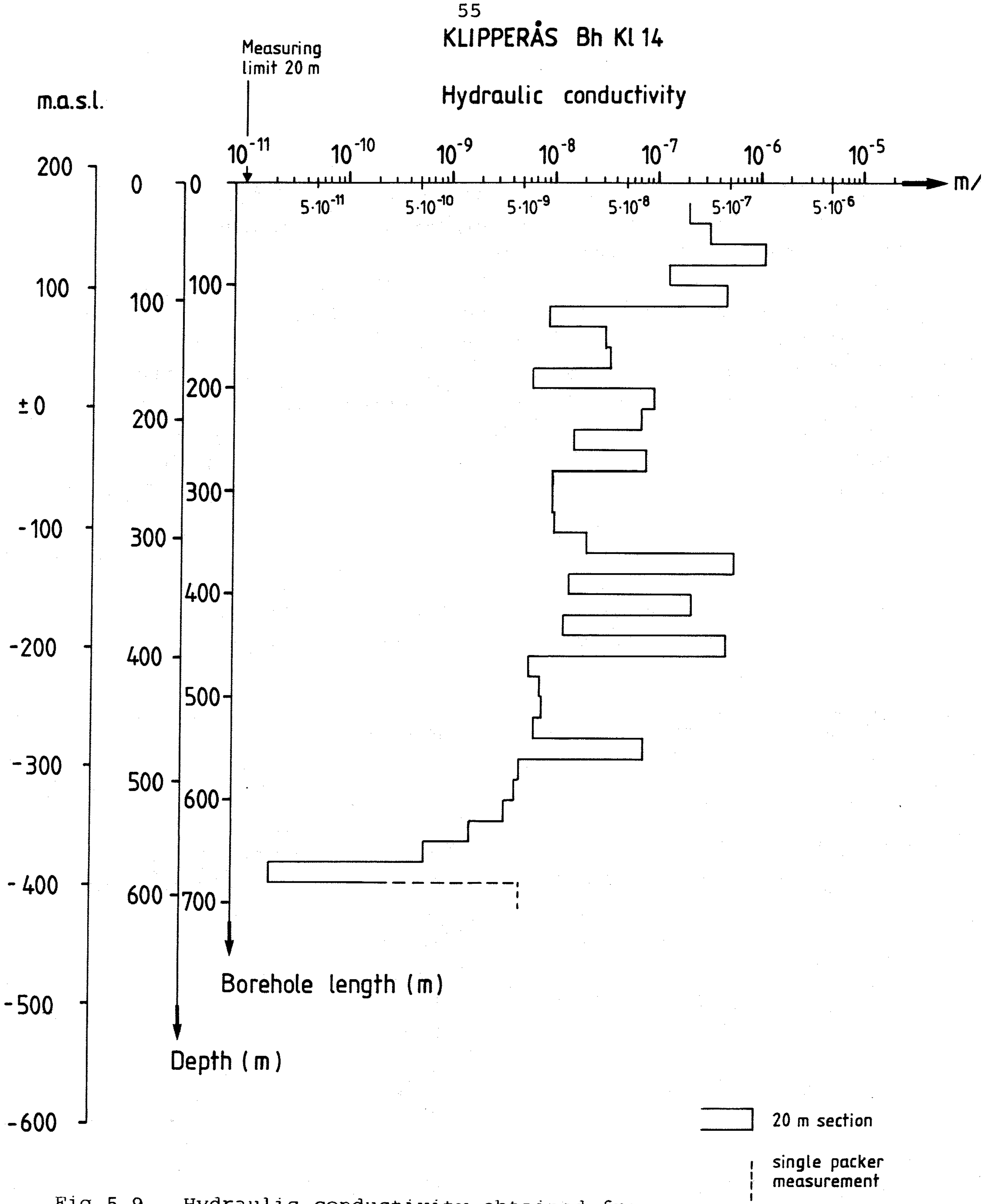


Fig 5.9 Hydraulic conductivity obtained from cored borehole Kl 14.

5.3 Interference test

5.3.1 General

During december 1985, an interference test was performed in the central part of the site. The purpose of the test was to investigate whether the fracture zone found at the depth of c. 800 m in borehole Kl 2 was hydraulically connected with surrounding boreholes. Water was injected over a ten days period in an isolated section covering the fracture zone in borehole Kl 2. During the injection period, as well as the successive recovery period, the pressure change was registered both in the injection section and also in a number of test sections in drill holes Kl 02 and Kl 08. The sections were sealed off by inflatable rubber packers. Section lengths are presented in Table 5.13.

Table 5.13 Measurement sections in boreholes Kl 2 and Kl 8 during the interference test at Klipperås.

Borehole/ section		Length in borehole	Section length	Note
Kl 2	MS1	809.3 - 958.2	148.9	Bottom of Kl 2
	MS2	783.0 - 808.3	25.3	Injection section
	MS3	705.2 - 782.0	76.8	
	MS4	0 - 54.4	54.4	
Kl 8	MS1	157.8 - 266.1	108.3	Bottom of Kl 8
	MS2	100.8 - 156.8	56.8	
	MS3	86.8 - 99.8	13.0	
	MS4	18.8 - 85.8	67.0	
	MS5	0 - 17.8	17.8	

The purpose of the interference test was also to investigate if there is any hydraulic connection between the zone in Kl 2 and the bottom of Kl 13. However, Kl 13 was blocked, and the measurement equipment could not be installed in the borehole.

5.3.2 Results

The interference test at Klipperås has at this date (June 1986) not yet been finally evaluated. Results will be presented in a separate report. Preliminary results, however, show that a hydraulic connection between the fracture zone injected in borehole Kl 2 and borehole Kl 8 is not present. This is one reason for classifying the fracture zone as a "subhorizontal zone", see Table 5.12. Furthermore, preliminary results showed an increase in ground-water pressure in the sections, adjacent to the injection section in borehole Kl 2, during the injection. This pressure increase indicates an interconnection between these sections.

5.4 Hydraulic properties of the bedrock

5.4.1 Hydraulic units

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

- o rock mass
- o local fracture zones

The classification was based on results from geophysical, geological and tectonic investigations which indicate the location and extension of existing zones. These zones are described in SKB technical report 86-06 (Olkiewicz and Stejskal,1986) and they are indicated on the map in Figure 5.14. Fracture zones 1-13 have been characterized as local fracture zones.

The fracture zones observed on the ground surface were correlated to fractured and crushed parts of the boreholes. In this manner the dip and strike of the fracture zones were fixed. Table 5.13 shows the depth at which the zones and the boreholes intersect.

The rock mass was defined as the bedrock excluding the local fracture zones.

5.4.2 Hydraulic conductivity of the hydraulic units

The water injection tested 25/20 m sections, which do not intersect the local fracture zones, represent the hydraulic conductivity values of the rock mass. K-values from all the cored boreholes related to the rock mass are specified in Figure 5.11

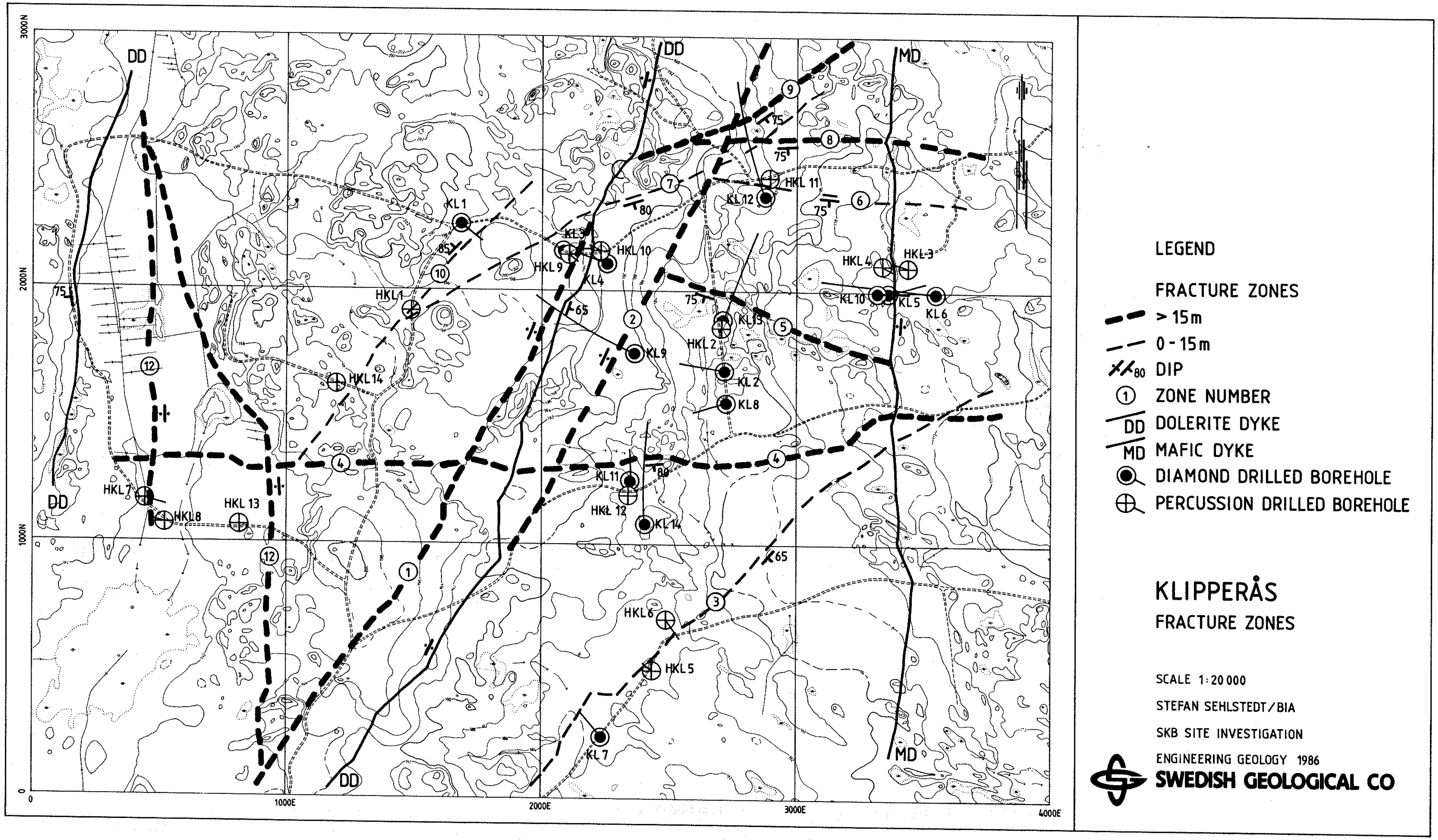


Figure 5.10 Fracture zones at the surface within the Klipperås site.

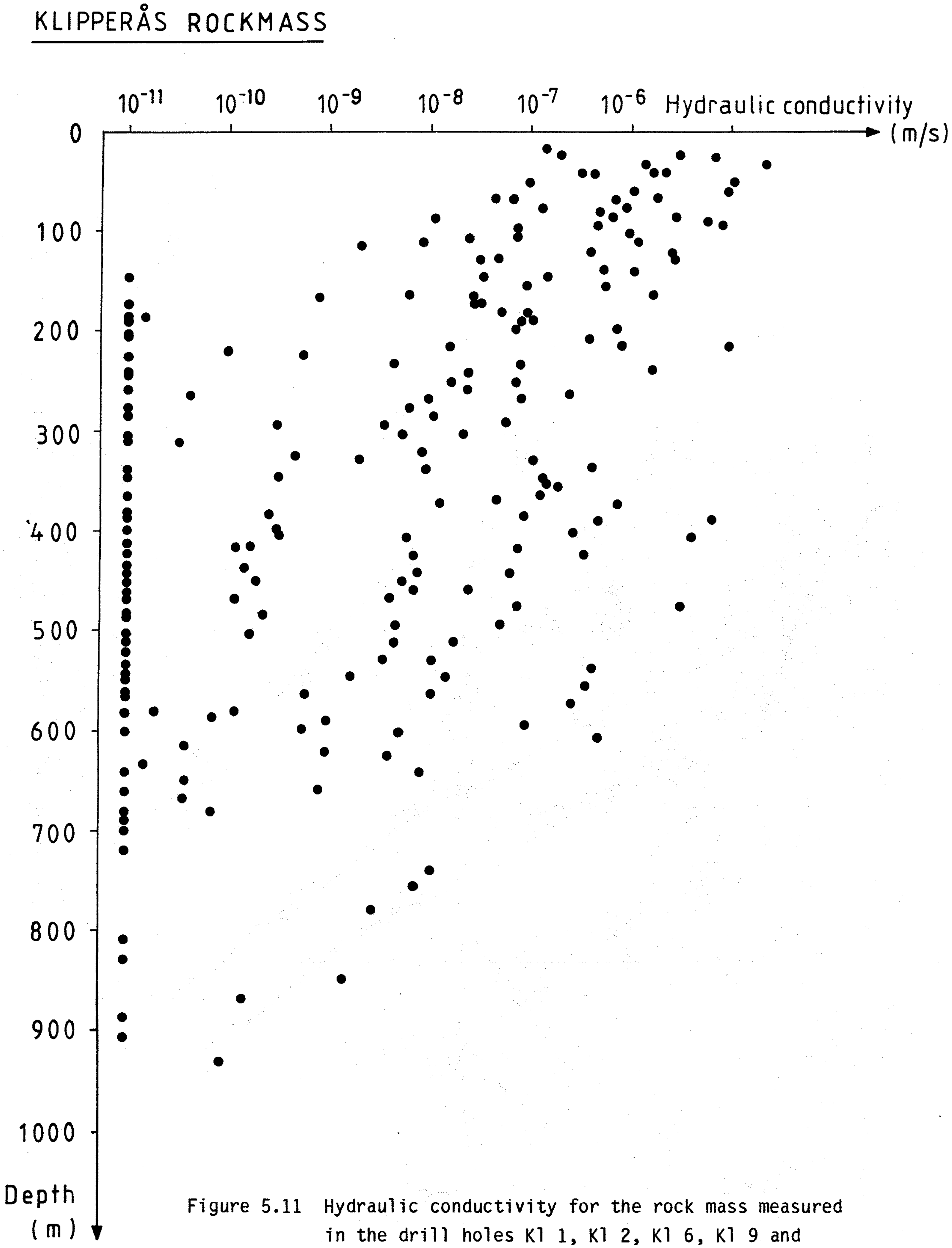


Figure 5.11 Hydraulic conductivity for the rock mass measured in the drill holes Kl 1, Kl 2, Kl 6, Kl 9 and Kl 12 - Kl 14.

The uppermost 150 m of the rock mass is highly conductive. The K-values vary between 2 x 10^{-9} m/s and 2 x 10^{-5} m/s. Below 150 m, down to c. 600 m, the range of variation of the hydraulic conductivity is larger. There are many K-values at the lower measuring limit, but most sections have conductivity values between 10^{-10} m/s and 10^{-6} m/s in this interval. Below 600 m,the results of the water injection tests indicate that the rock mass is less permeable. The majority of the K-values are at the lower measurement limit, but conductivity values up to 1.0 x 10^{-8} were found.

Hydraulic conductivity values calculated from the 25 m, 20 m and 5 m sections were compared with the results of the core logging and the borehole geophysical measurements. Each fracture zone has been assigned a K-value in each borehole where it is intersected, based on the different values obtained. In Figure 5.12 and Table 5.14 the K-values of the local fracture zones have been compiled. Zones appearing in more than one borehole have been connected.The diagram shows that the majority of the K-values range between 10^{-7} m/s and 10^{-6} m/s. The highest hydraulic conductivity (2.0 x 10^{-6} m/s) of the local fracture zones at Klipperås was measured in the horizontal zone which intersects borehole Kl 2 at a depth of c. 800 m.

The depth-dependence of the hydraulic conductivity in the rock mass and in the local fracture zones was calculated from a regression analysis. A "power curve" was used fitted to the results. The results of the power law curve regression are shown in Figures 5.13 and 5.14. A 95 % confidence interval has also been indicated for the relation curves in the figures, which means that there is a 95 % probability that the curves are within the confidence interval. The relationship for the power curves are displayed in Table 5.15 and Figure 5.15.

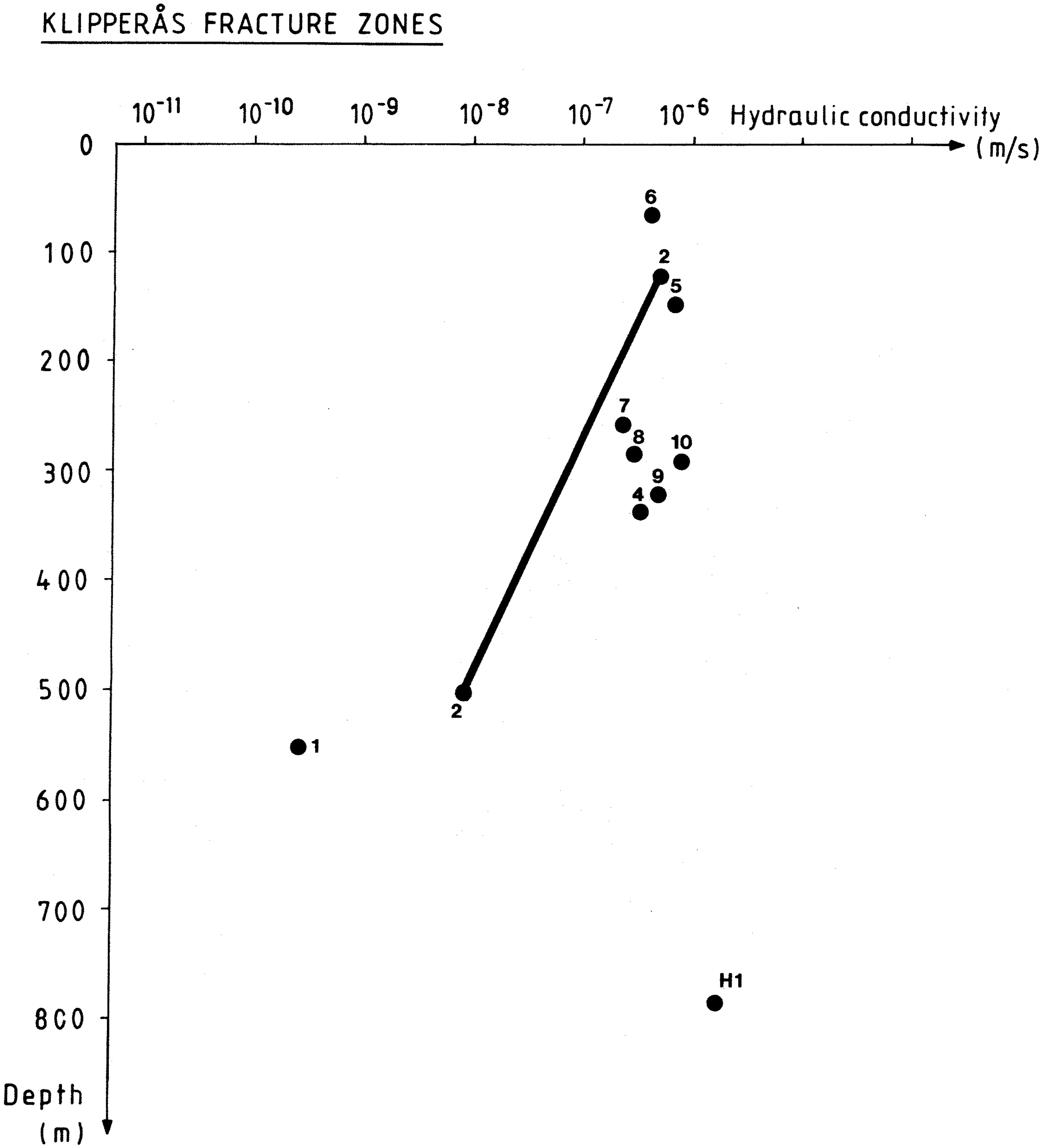


Figure 5.12 Hydraulic conductivity in local fracture zones penetrated by boreholes Kl 1, Kl 2, Kl 6, Kl 9 and Kl 12 - Kl 14.

Table 5.14 The hydraulic conductivity (K) of the local fracture zones in the Klipperås area.

Zone	Position in borehole (m)	Vertical depth (m)	Strike/Dip (degrees)	True width (m)	K (m/s)
1	Kl 3 (140-195)	145.1	N-S /90	28	not tested
	Kl 4 (110-180)	125.6	N20E/90	36	"
	Kl 9 (615-665)	554.3	N30E/90	29	$3.1\text{x}10^{-10}$
2	Kl 9 (120-160)	121.2	N30E/90	22	$5.4\text{x}10^{-7}$
	Kl12 (595-630)	501.7	N15E/85E	13	$9.6\text{x}10^{-9}$
3	Kl 7 (115-130)	106.1	N35E/65S	12	not tested
4	Kl11 (108-148)	98.1	N75E/90	23	"
	Kl14 (368-410)	336.9	N85E/80	27	$3.9\text{X}10^{-7}$
5	Kl13 (152-188)	147.2	N80W/75S	23	$7.5\text{x}10^{-7}$
6	Kl12 (70- 88)	64.7	N75W/75S	12.5	$4.4\text{X}10^{-7}$
7	Kl12 (288-306)	257.2	N65E/80S	13.5	$2.5\text{X}10^{-7}$
8	Kl12 (312-347)	285.4	N85W/75S	28	$3.2\text{x}10^{-7}$
9	Kl12 (362-384)	323.0	N60E/75S	17.5	$5.5\text{x}10^{-7}$
10	Kl 1 (280-310)	290.5	N45E/85NW	10.5	$9.3\text{X}10^{-7}$
H1	Kl 2 (792-804)	785.9	subhorizontal	12	$2.0\text{X}10^{-6}$
11-13					not tested

Table 5.15 The depth-dependence of the hydraulic conductivity for the hydraulic units of the bedrock.

Hydraulic unit	Power curve	r^2	n
Rock mass	$0.24 \times z^{-3.24}$	0.33	222
Local fracture zones	$1.86\ 10^{-4} \times z^{-1.22}$	0.12	11

z = depth (m)

The regression analysis shows that the hydraulic conductivity of the local fracture zones at 100 m and 700 m vertical depth are c. 13 and 380 times respectively larger than the conductivity of the surrounding rock mass.

The rock mass at Klipperås consists mainly of granite. The granite is not homogeneous however. For instance, several intervals of the cores contain other rock types, dykes and/or xenolits of greenstone being the most common. Dyke porphyre are also frequent. These two rock types are often related to higher fracture frequencies. The rock mass has therefore been divided into two additional hydraulic sub units, one representing greenstones and one representing porphyres. The hydraulic conductivity of the two sub units are represented by the K-values of the 20/25 m sections intersected by these two sub units respectively. A power curve regression has been calculated. The results are shown in Table 5.16 and Figure 5.16. For comparision, the regression curve of the rock mass is also shown in Figure 5.16.

Table 5.16 Depth-dependence of the hydraulic conductivity in greenstones and porphyres.

Hydraulic unit	Power curve	r^2	n
Greenstones	$20.89 \times z^{-4.06}$	0.34	84
Porphyres	$36.31 \times z^{-4.02}$	0.14	31

The result of the regression analysis shows that porphyres are somewhat more permeable than the total rock mass in the upper parts of the bedrock. However at depth this difference diminishes considerably, Figure 5.16 and Table 5.17. Greenstones are also more permeable in the upper parts but are c. 2-3 times less permeable in the deeper parts of the bedrock, compared with the total rock mass. All differences are, however, relatively small. This indicates that there are no significant difference in hydraulic conductivities of different rock types in the bedrock of the Klipperås site.

Table 5.17 Hydraulic conductivity at depth in different hydraulic units at Klipperås.

Depth (m)	Hydraulic unit/Hydraulic conductivity (m/s) Total Rock mass	Greenstones	Porphyres
100	8.0×10^{-8}	1.6×10^{-7}	3.2×10^{-7}
300	2.3×10^{-9}	1.8×10^{-9}	3.6×10^{-9}
500	4.4×10^{-10}	2.3×10^{-10}	4.5×10^{-10}
700	1.5×10^{-10}	5.8×10^{-11}	1.1×10^{-10}

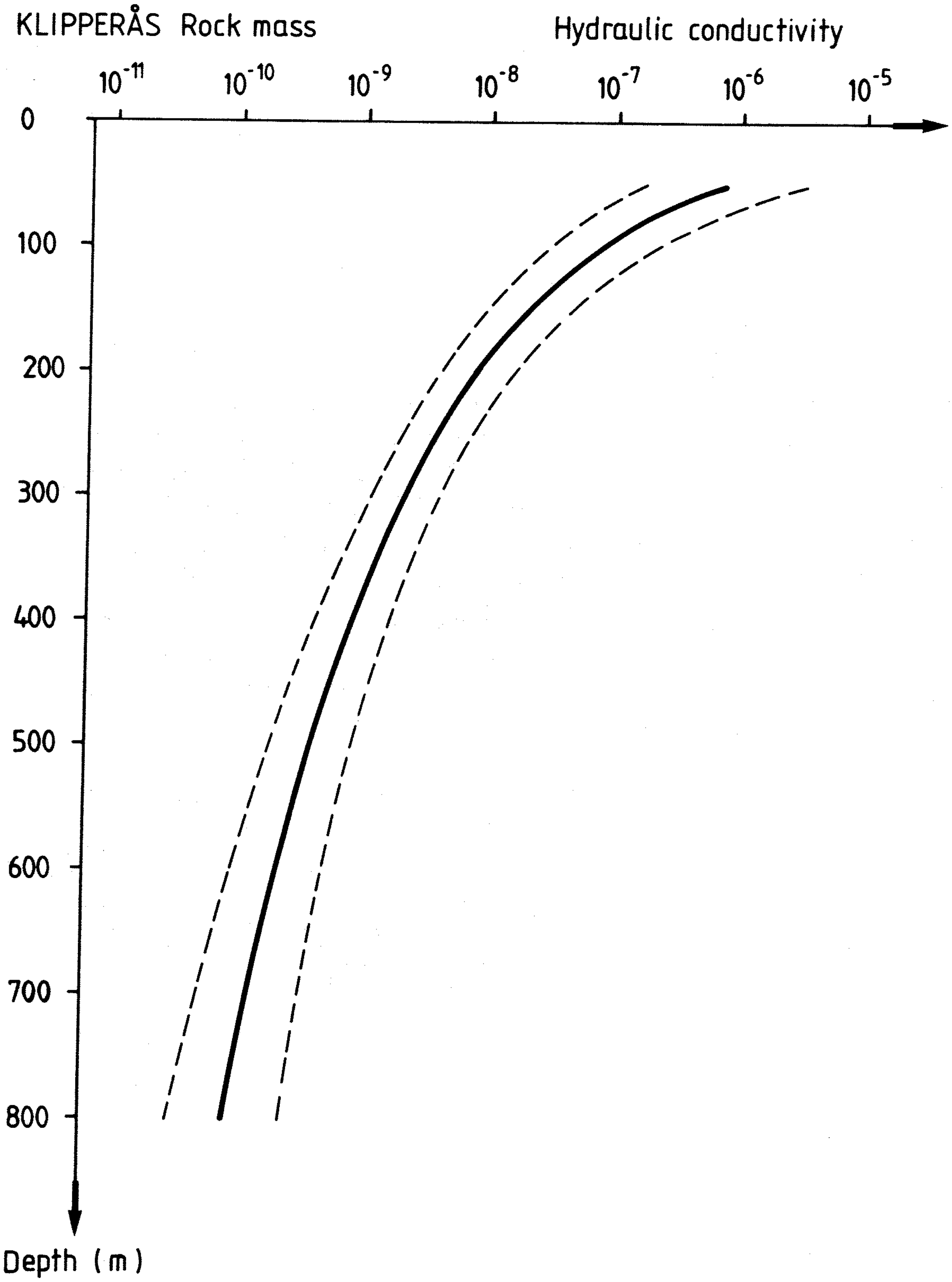


Figure 5.13 Relationship between hydraulic conductivity and depth in the rock mass.

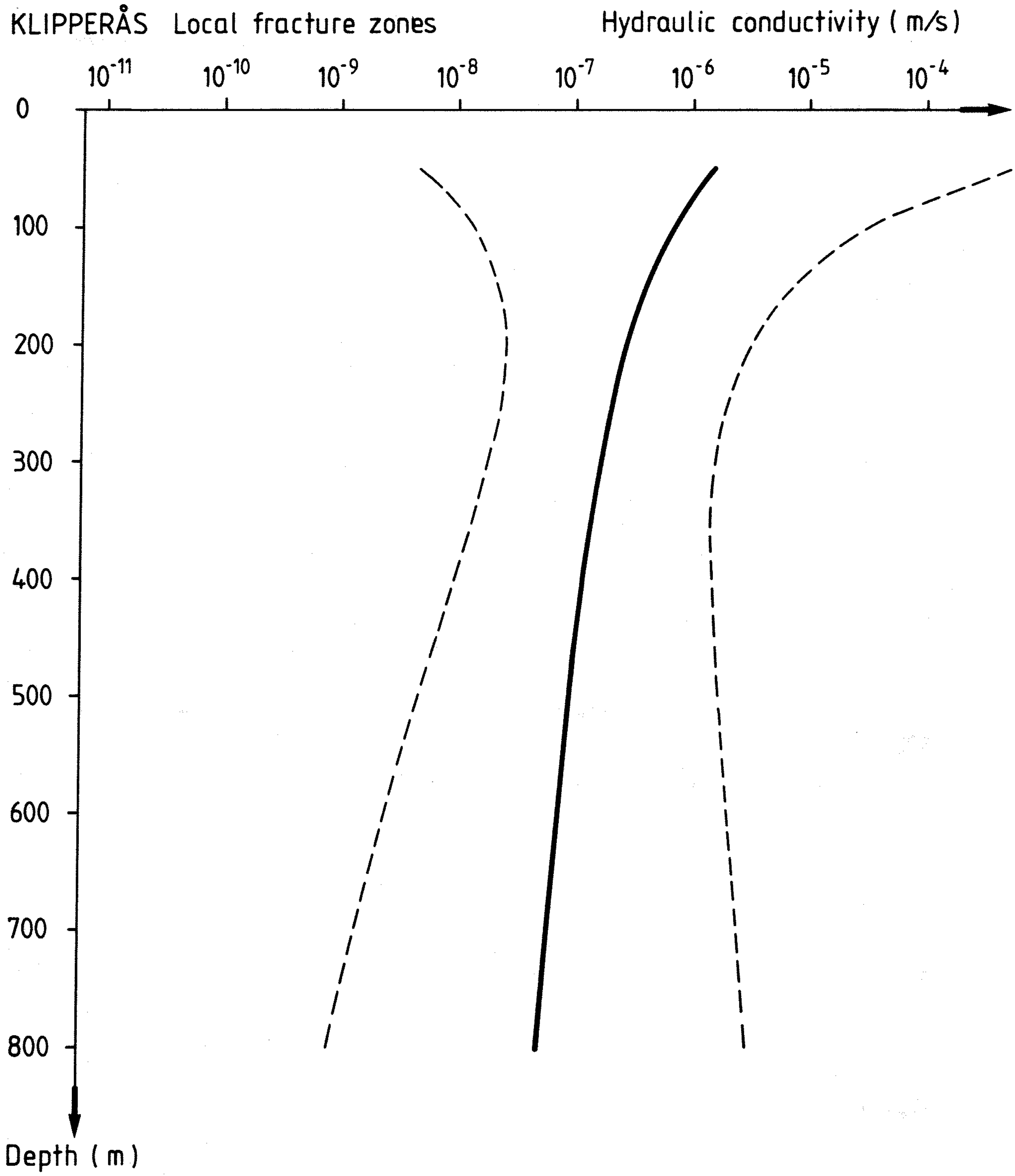


Figure 5.14 Relation between hydraulic conductivity and depth in local fracture zones.

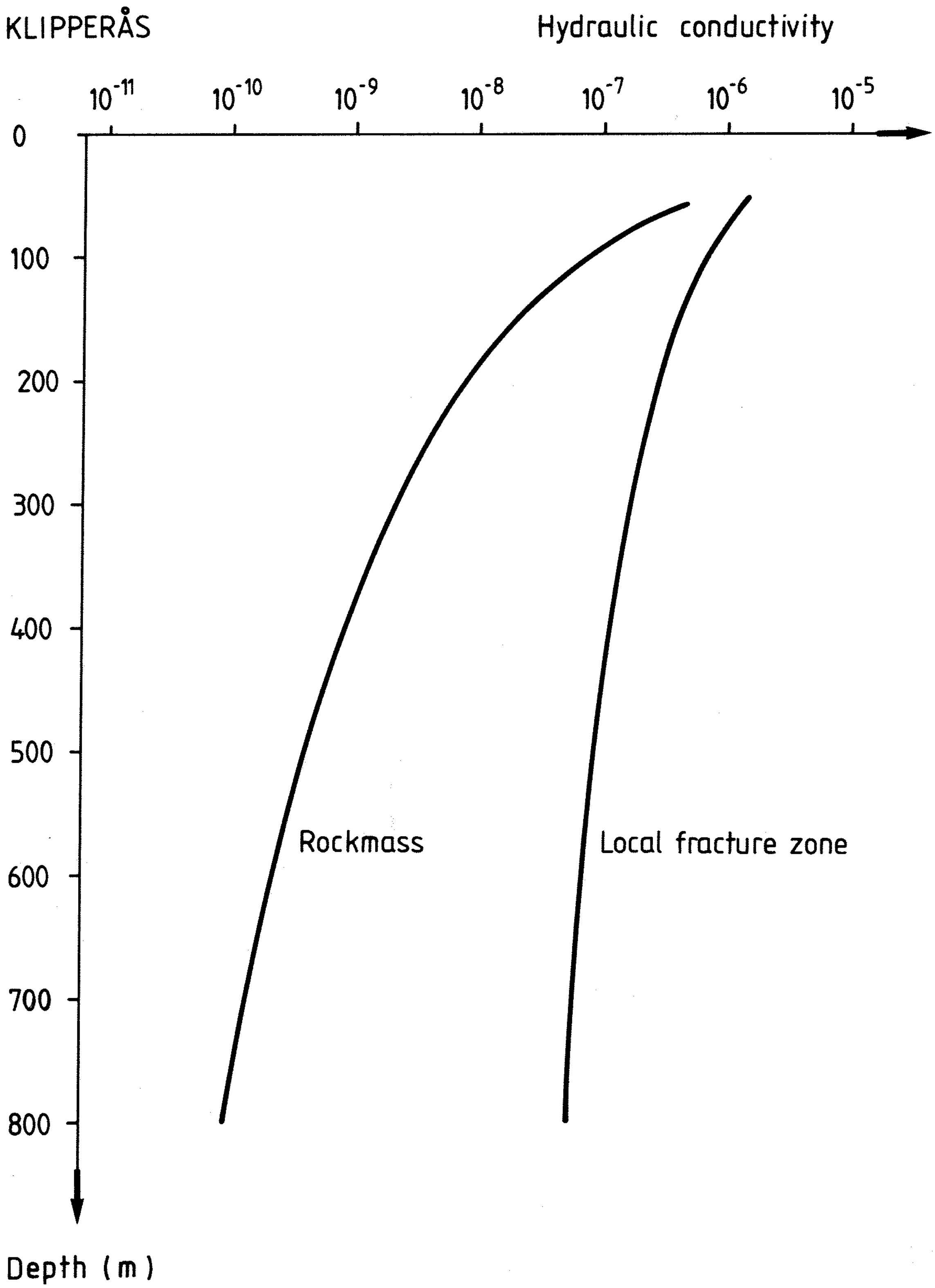


Figure 5.15 Relationship between hydraulic conductivity and depth in different hydraulic units of the bedrock at Klipperås.

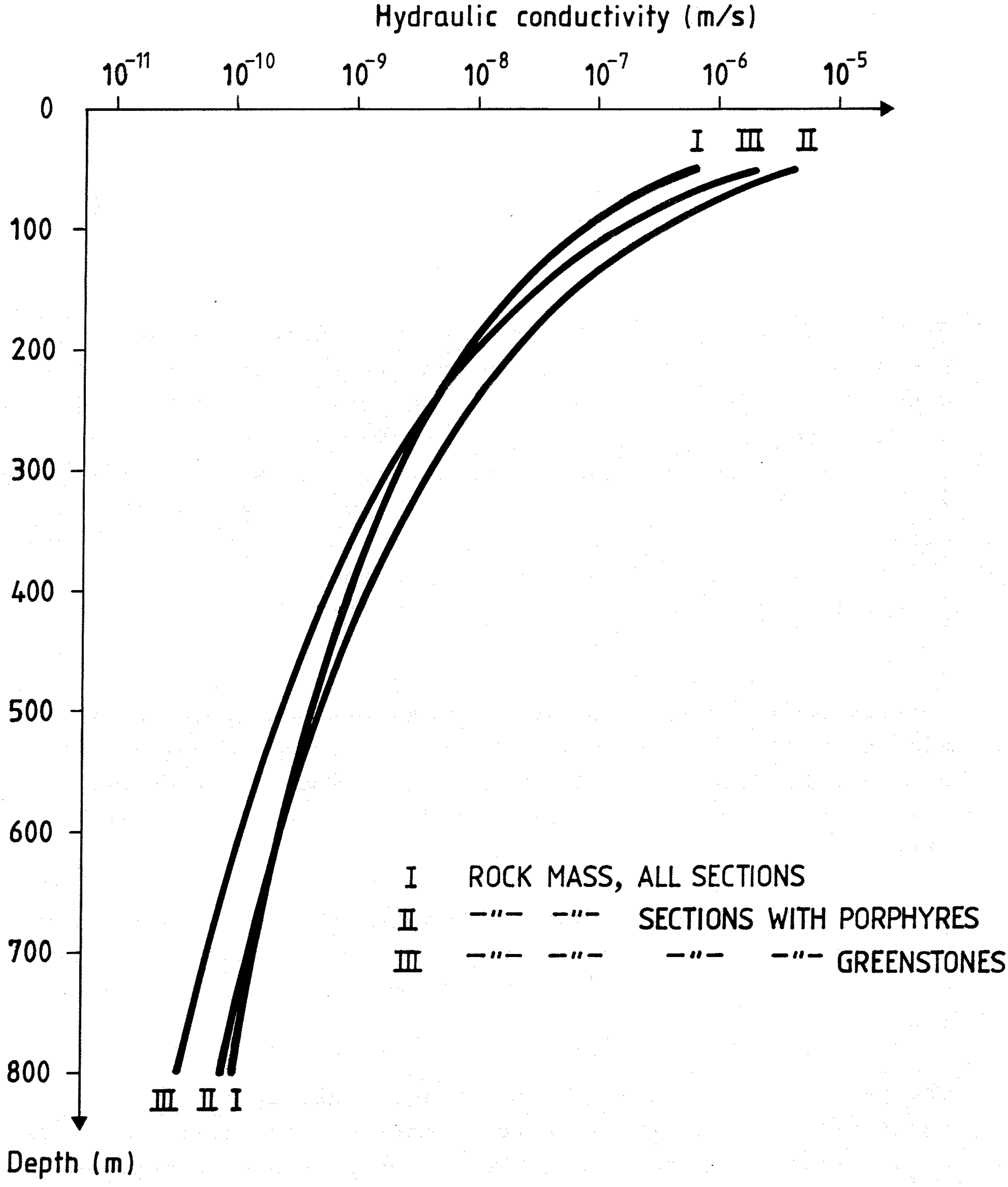


Figure 5.16 Relation between hydraulic conductivity and depth in different rock types within the rock mass at Klipperås.

6. PIEZOMETRIC MEASUREMENT AT DEPTHS

6.1 General

The piezometric pressure distributions (see Figures 6.1, 6.2) at different intervals of the boreholes will determine the natural groundwater conditions, such as recharge and discharge areas.

From the fall-off phase in the hydraulic tests the piezometric pressure of the rock surrounding the test section can be determined from different methods. If the duration of the preceeding injecton phase is sufficiently long, Horner's method (see chapter 5.3) also enables the piezometric pressure of the test section to be determined. This is achieved by extrapolating the straight line in the Horner-plot to infinite time, i.e. when $(t'/tp+t')=1$ on the time axis - tp is the duration of the injection phase, and t′ is the current time after injection stop.

In very low-permeable sections, with K-values close to the measurement limit the pressure fall-off is usually very low and some uncertainty in the value of the piezometric pressure obtained then exists. In these sections, the pressure-values obtained are, in general, too high.

In some sections the pressure decreases towards an approximately constant value. In such cases, this constant pressure is taken to be the natural piezometric pressure of the test section.

The packer sealing phase also permits a qualitative estimate of the piezometric pressure, after closure of the test valve. This occurs after 25 minutes and causes the pressure to increase/-decrease towards the piezometric pressure of the test section. This estimate provides a qualitative check of the reliability of the piezometric pressure obtained from the fall-off phase.

From the borehole geophysical investigations, i.e. the temperature measurements, inflow and outflow of ground-water in the borehole from the surrounding rock, can be determined (Sehlstedt and Stenberg, 1986). Inflow should then correspond to an over-pressure of the water in the bedrock compared with the pressure of the borehole water and outflow should correspond to an under-pressure of the water in the surrounding rock.

6.2 Results from fall-off tests

The ground-water pressure in cored boreholes Kl 1, Kl 2, Kl 6, Kl 9 and Kl 12 - Kl 14 has been calculated from the ground surface to the borehole bottom. The sections giving an unsatisfactory pressure fall-off registration and also those sections penetrating impermeable rock,were excluded from consideration. The ground-water pressure is indicated as an over- or underpressure in metres of water relative to the hydrostatic pressure in the borehole at the corresponding level, Figures 6.1 and 6.2.

In borehole Kl 1 the deviation of the ground-water pressure from the hydrostatic pressures at corresponding levels is very small (<1.1 m of water) with the exception of two test sections. However, the two test sections mentioned have K-values at the measuring limit, and the pressure values obtained are therefore uncertain.

Interpretation of temperature logging gives an inflow of water at 81 m and an outflow of water at 309 m. This is not in accordance with the piezometric measurements. In the section 306-331 m a small over-pressure was obtained, which would imply an inflow of water to the borehole at 309 m. In the sections 56-81 m and 81-106 m negative and zero differential pressures respectively were registered.

Borehole Kl 2 penetrates impermeable rock and the values of the ground-water pressures were not obtained in most of the sections. At borehole depths not exceeding 900 m, under-pressures < -3.5 m wc were usually registered. In the single packer section in the bottom of the borehole, an extremely low under-pressure, -38.4 m wc, was observed. This was the lowest under-pressure ever registered within the Klipperås site.

According to the geophysical investigations (Sehlstedt and Stenberg, 1986) an outflow of water occur at the depth of 804 m. A negative piezometric pressure, registered in the section 790-810 m support this interpretation.

In borehole Kl 6 the ground-water pressure in the test sections deviate less than 3.6 m wc from the hydrostatic pressure at corresponding levels. Under-pressures are found in the upper part, while over-pressures dominate at depth, indicating that recharge conditions prevails.

The temperature measurements shows indications of inflow at the depths 558 and 570 m and outflow of water at 244 m. This correlates well with the piezometric measurements in Kl 6. The temperature log also indicates inflow of water at three levels between 420 and 480 m. The corresponding sections gave, however, unsatisfactory pressure fall-off registrations and the piezometric pressures are therfore uncertain.

Borehole Kl 6 was first drilled down to 267 m, and later the drilling commenced down to 808 m. When the borehole was deepend it became artesian. This fact support the interpretation that recharge condition prevails in the borehole and it also support the interpretation of the temperature log (Sehlstedt and Stenberg, 1986).

In borehole Kl 9 over-pressures dominate above 150 m and at depths exceeding 370 m. In the interval between these depths, relatively small under-pressures were registered. The two relatively large over-pressures measured at depths of c. 500 m and 600 m respectively, are measured in very low-permeability sections, and the values obtained are therefore probably too high.

The geophysical measurement indicates an inflow of water to the borehole at the depth of 698 m. An over-pressure in the highly permeable section 690-710 m support this interpretation.

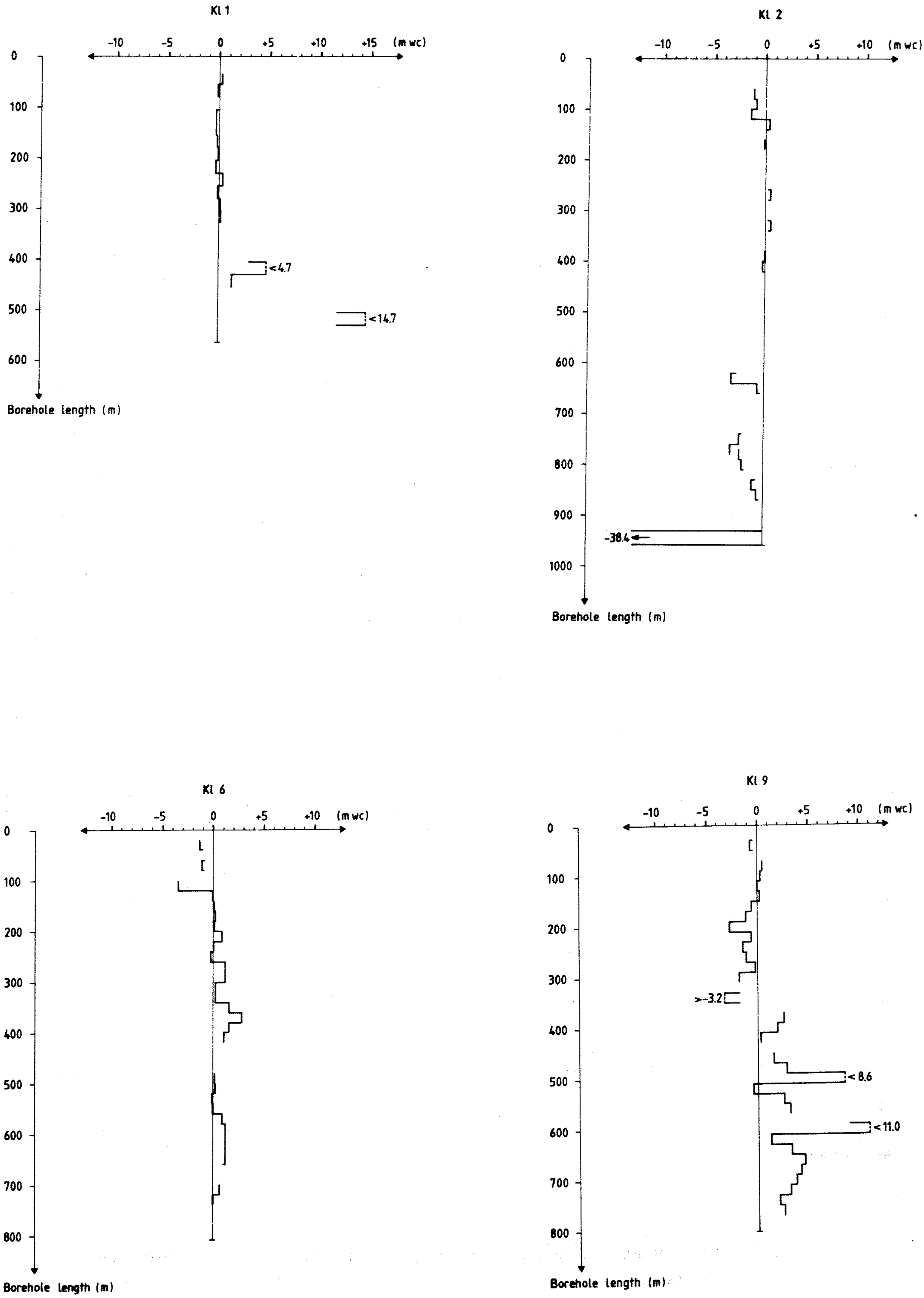


Figure 6.1 Piezometric pressure distribution in test sections of boreholes Kl 1, Kl 2, Kl 6 and Kl 9, calculated from the fall-off phase.

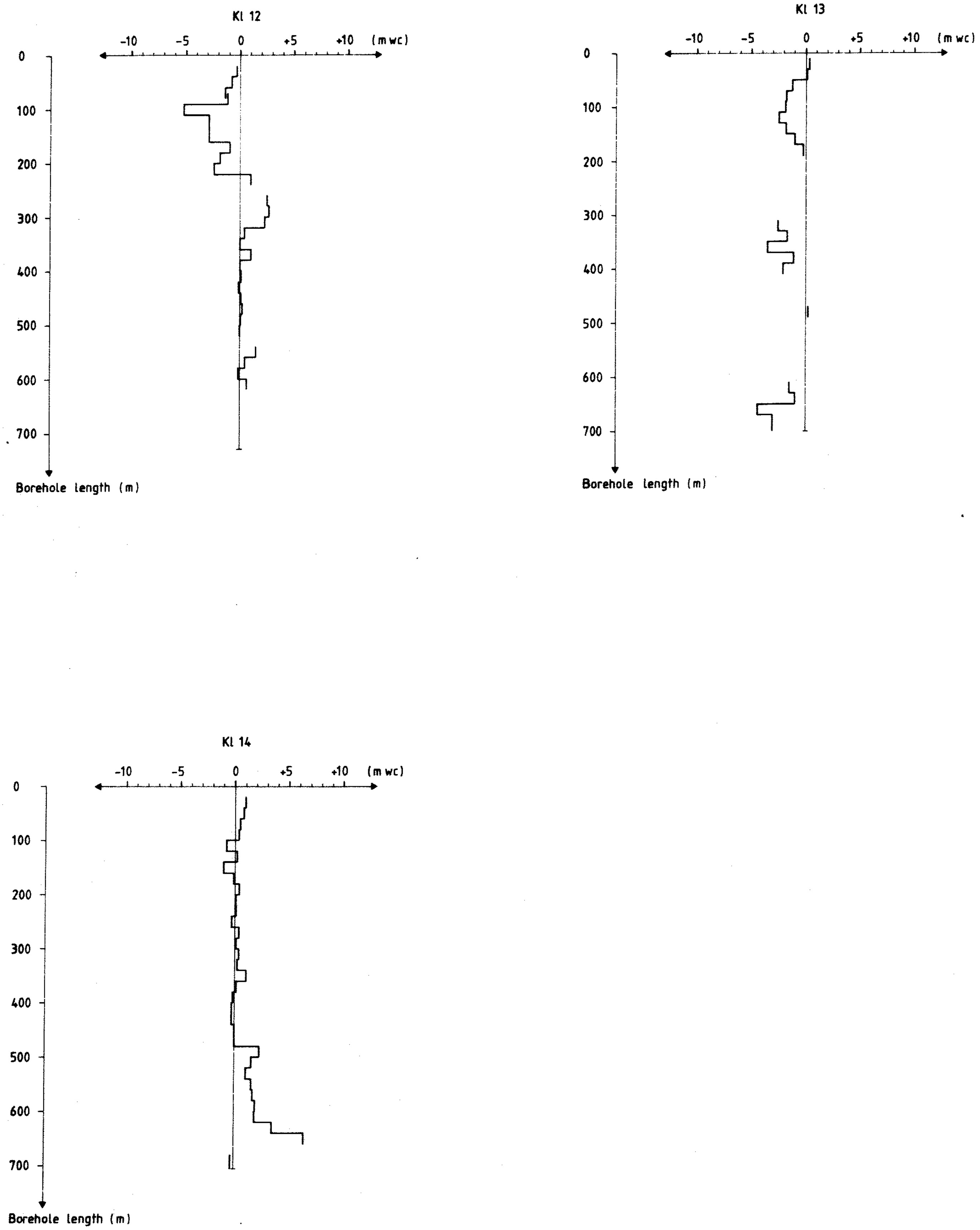


Figure 6.2 Piezometric pressure distribution in test sections of boreholes Kl 12 - Kl 14, calculated from the fall-off phase.

In borehole Kl 12 under-pressures between -0.3 and -5.2 m wc were registered above 220 m. At depths exceeding 220 m positive ground water head or values close to zero were observed in the test sections.

Interpretation of the temperature logging gives inflows of water to the borehole at depths of about 303, 323 m and 373 m. The piezometric measurements resulted in an over-pressure in the corresponding sections, which would support the interpretation above.

Drillhole Kl 13 penetrates impermeable parts of the bedrock. Only a small number of section ground-water pressures, were obtained. Under-pressures dominate. A weak trend of decreasing values with depth can be detected.

Interpretation of the borehole geophysical investigation imply an inflow of water downwards along the borehole and anoutflow of water at 624 m. An under-pressure in the sectioin 610-630 m support this interpretation.

In borehole Kl 14 low over-pressures above 140 m and relatively high over-pressures at depths exceeding 480 m were registered. Between 140 m and 480 m alternating,small values, in over- and under-pressures are found .

The temperature logging displays an inflow of water at 380 m and an outflow of water at 446 m. This is not entirely supported by the piezometric measurements. A small over-pressure was obtained in the section 360-380 m and in the section 380-400 m a sligth under-pressure was registered. In the section 440-460 m a differential piezometric pressure equal to zero was registered.

6.3 Water-flow balance of the cored boreholes

When the hydraulic conductivity and the ground-water head difference for the test sections are known, the approximate quantity of ground-water entering or leaving each section may be calculated by application of the following equation (Carlsson and Carlstedt, 1976):

$$Q = a \times K \times L \times s \qquad (6.1)$$

Q	= flow of water	(m^3/s)
s	= piezometric pressure in one section of the borehole	(m.w.c)
K	= hydraulic conductivity	(m/s)
L	= length of one borehole section	(m)
a	= parameter describing time and geometry	(= 1)

The approximate quantities of water flowing in to or out of each section of the Klipperås cored boreholes are presented in Figures 6.3 and 6.4. Results from sections containing impermeable rock and sections having unsatisfactory fall-off registrations are not plotted. These latter sections are distinguisheded by a question mark in the plots.

Under ideal conditions, when the ground-water level in the borehole is constant, the quantity of water recharging into the borehole should balance to the quantity discharging from the borehole. From Table 6.1 it can be seen that this is not the case in most boreholes. This discrepancy may arise from three causes:

I Even very small errors in the calculation of the piezometric pressure in permeable sections will have a very large effect on the results obtained from the flow calculation.

II No measurements are performed in the upper parts of the borehole, where the hydraulic conductivity is, in general, relatively high.

III In some sections of high hydraulic conductivity no piezometric pressures were calculated since the fall-off registration was unsatisfactory .

Table 6.1 The water balance in seven boreholes at the study site Klipperås

Drillhole	Recharge m^3/s	Recharge $m^3/year$	Discharge m^3/s	Discharge $m^3/year$
Kl 1	2.93 E-5	924	2.56 E-5	807
Kl 2	4.00 E-7	13	5.68 E-5	1 741
Kl 6	1.73 E-5	546	1.07 E-3	33 744
Kl 9	8.24 E-5	2 599	3.18 E-4	10 170
Kl 12	2.09 E-5	659	3.25 E-4	10 249
Kl 13	5.13 E-5	1 618	1.67 E-4	5 267
Kl 14	2.34 E-5	738	9.88 E-6	312

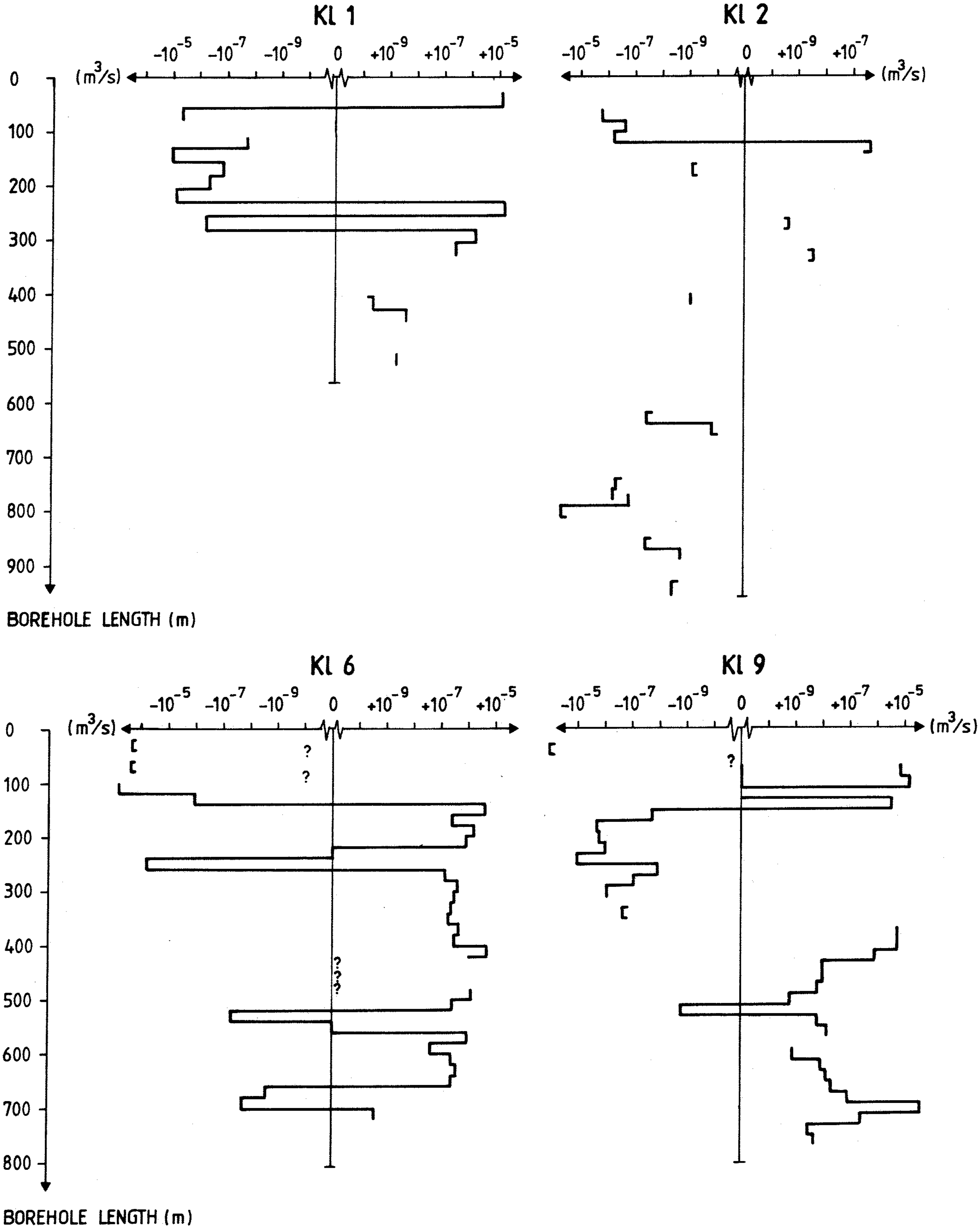


Figure 6.3 Water flow balance of the cored boreholes Kl 1, Kl 2, Kl 6 and Kl 9.

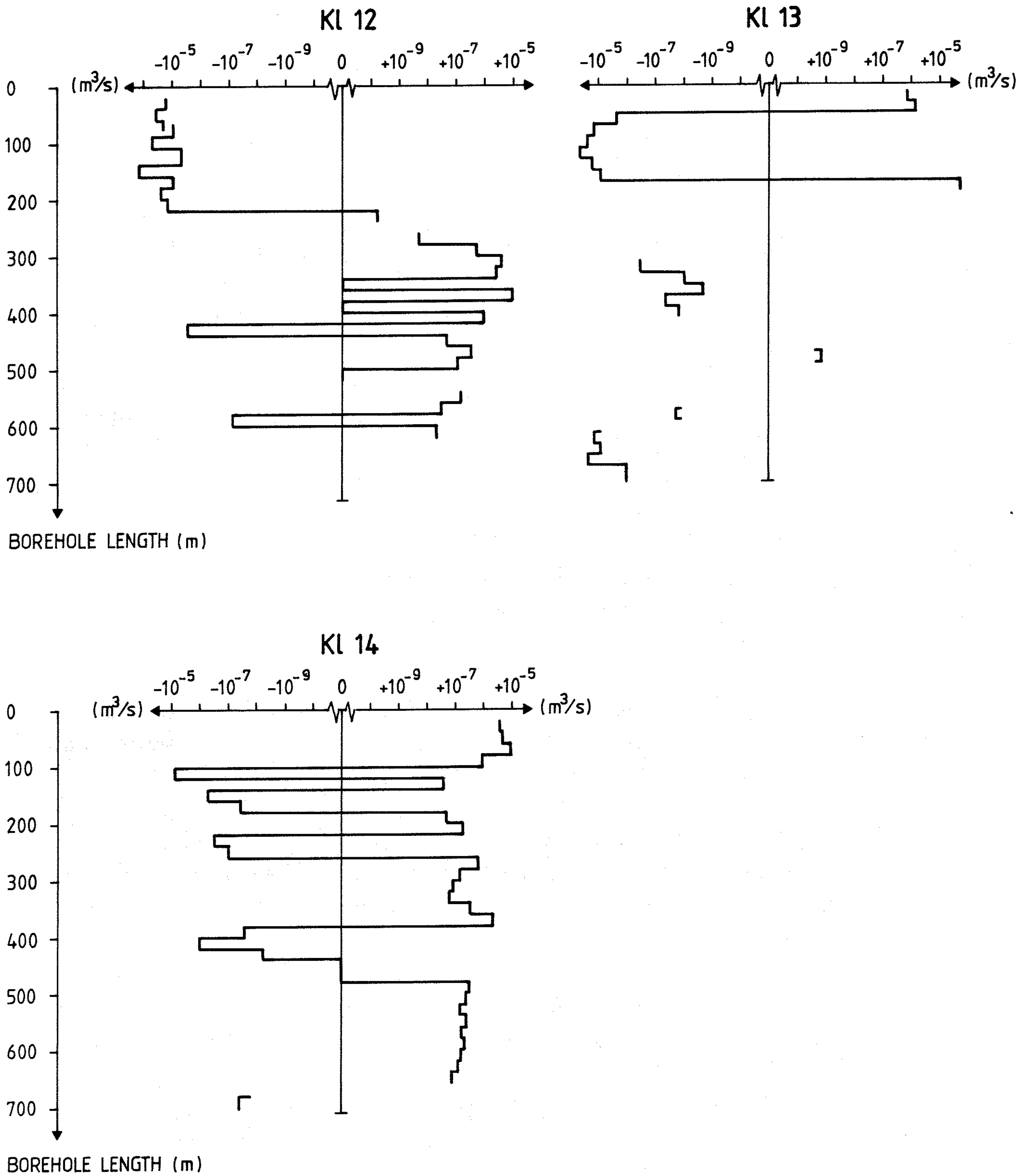


Figure 6.4 Water flow balance of the boreholes Kl 12 - Kl 14.

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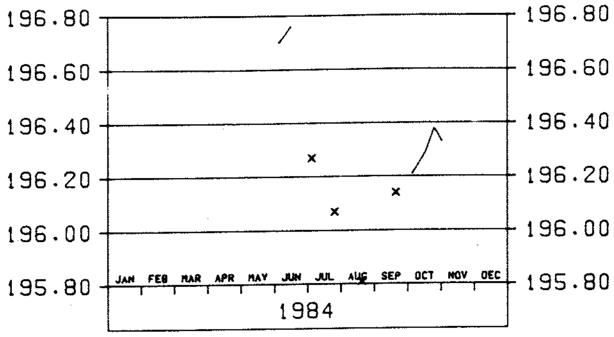

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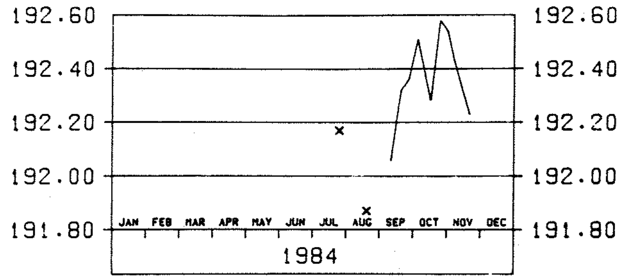

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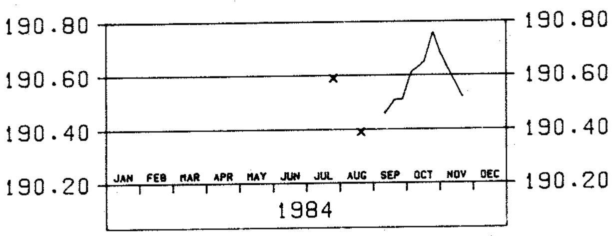

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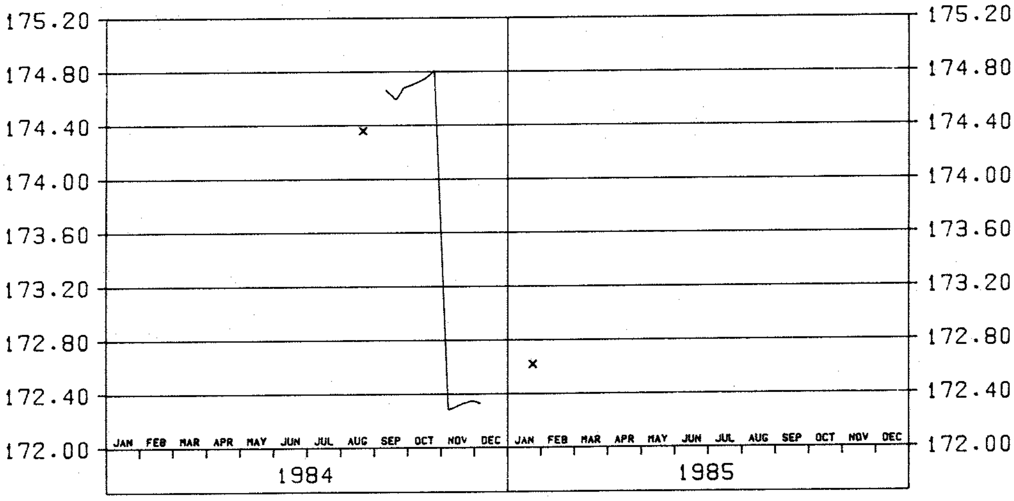

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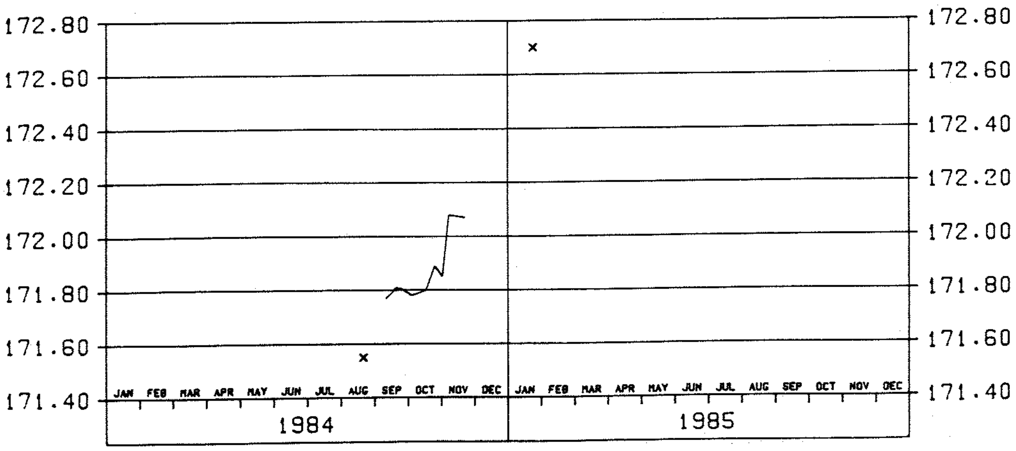

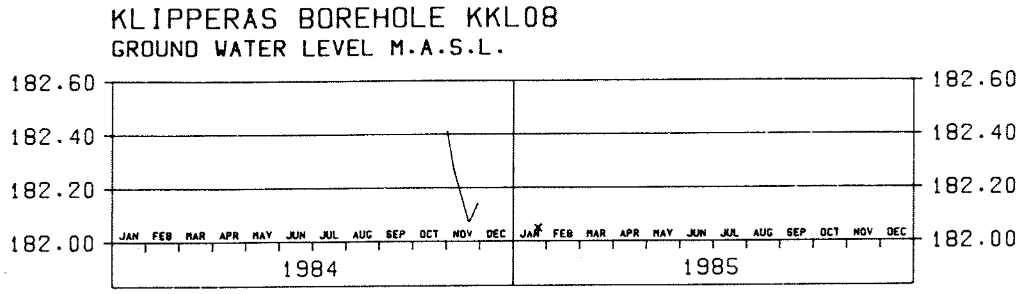
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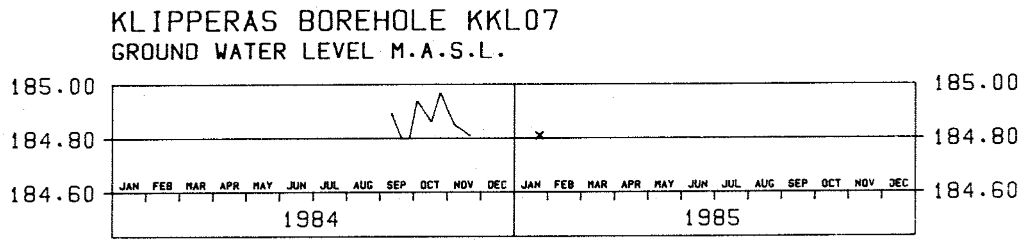
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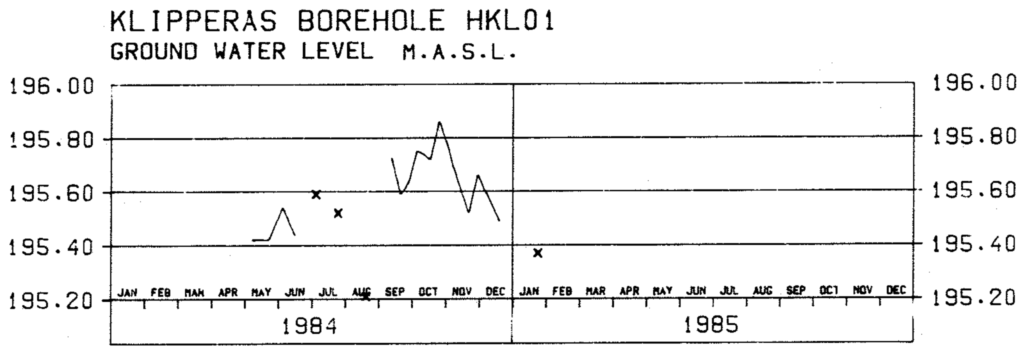
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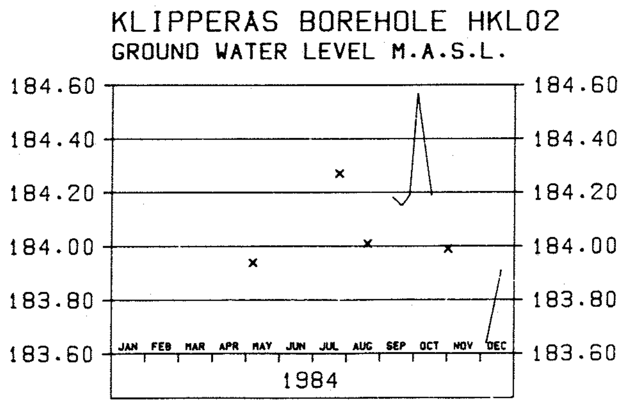
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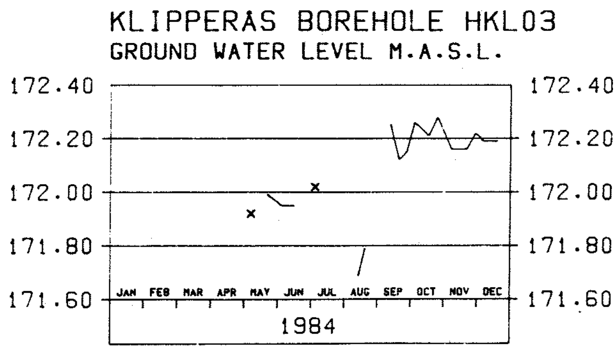
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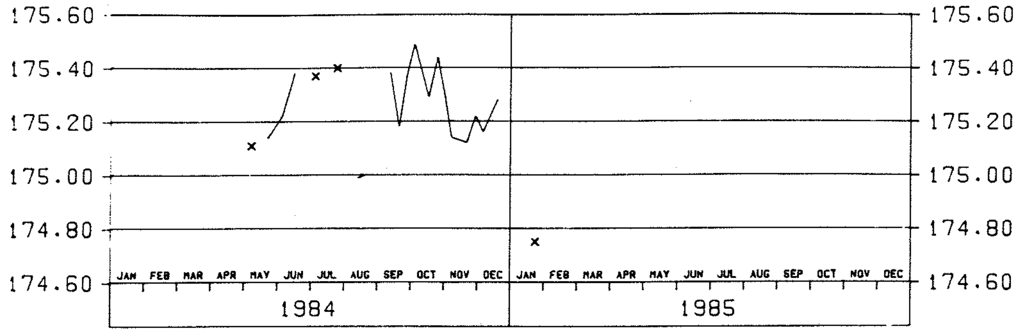

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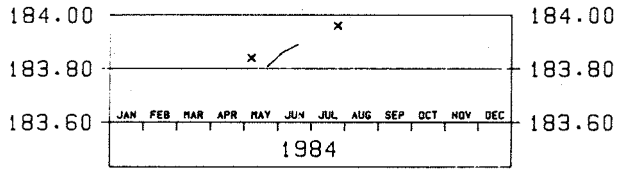

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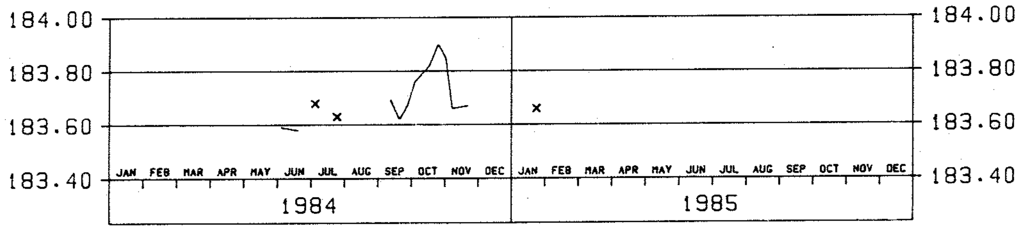

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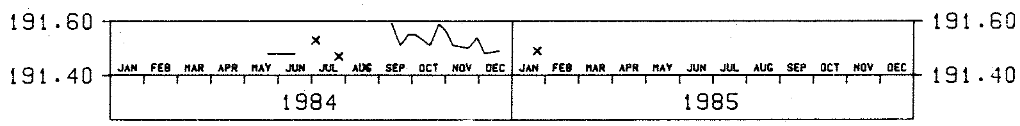

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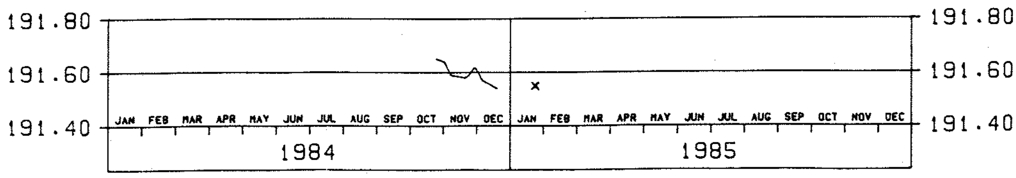

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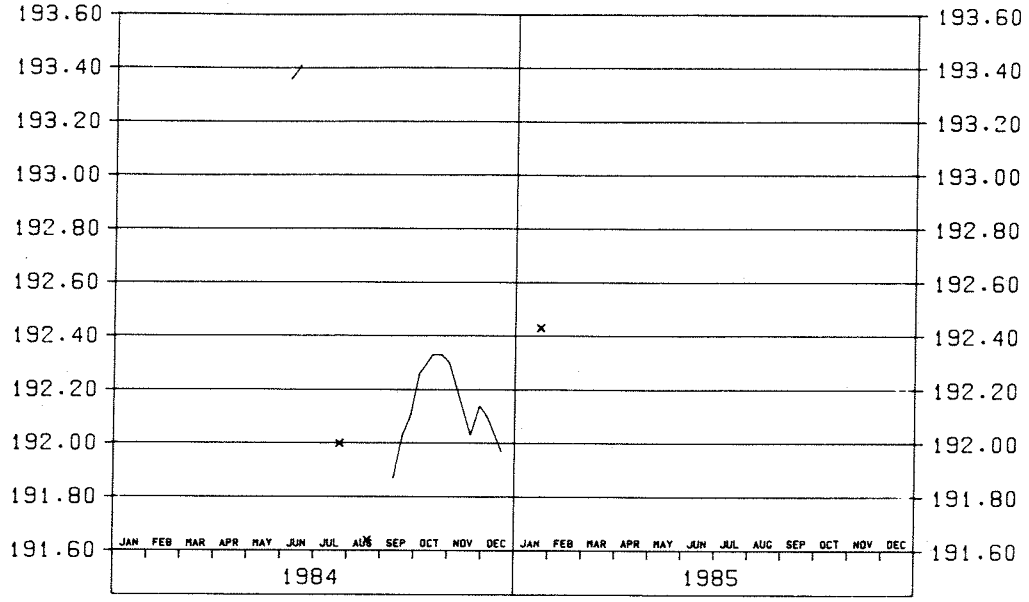

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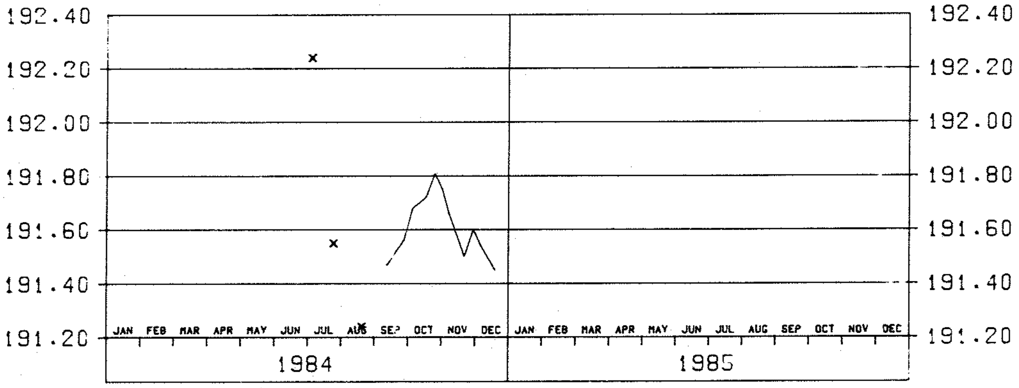

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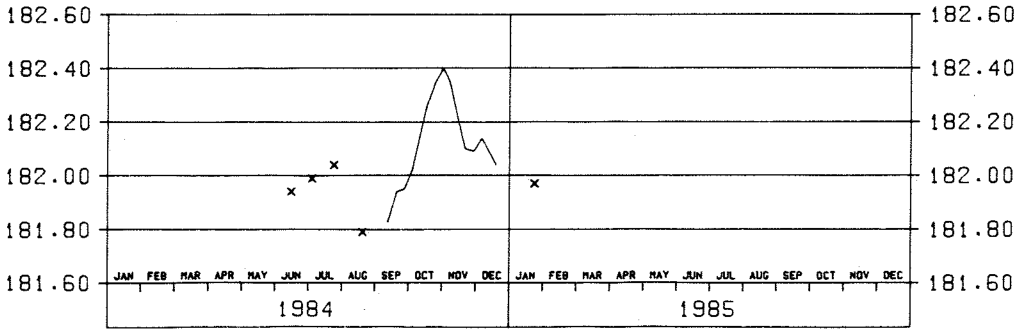

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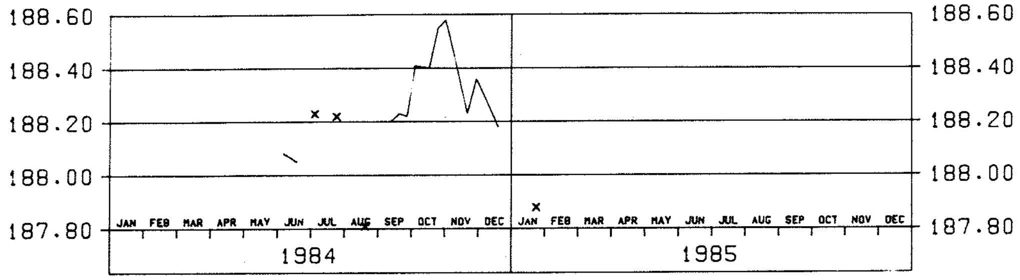

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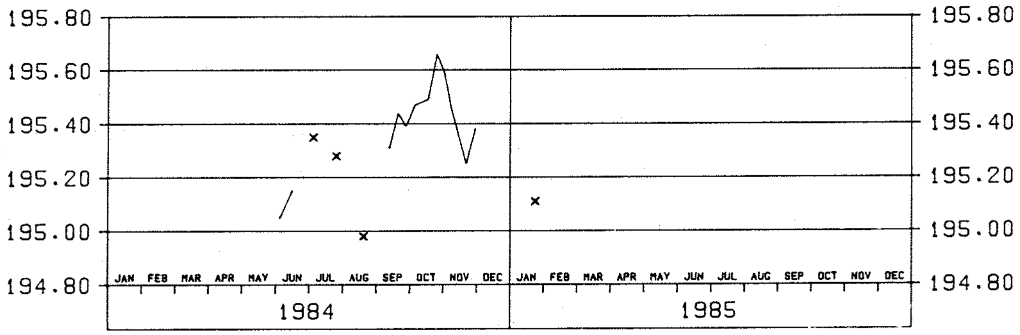

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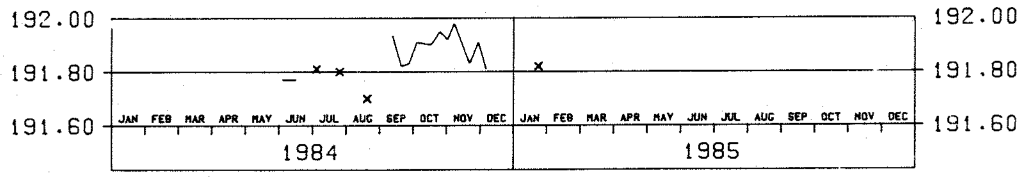

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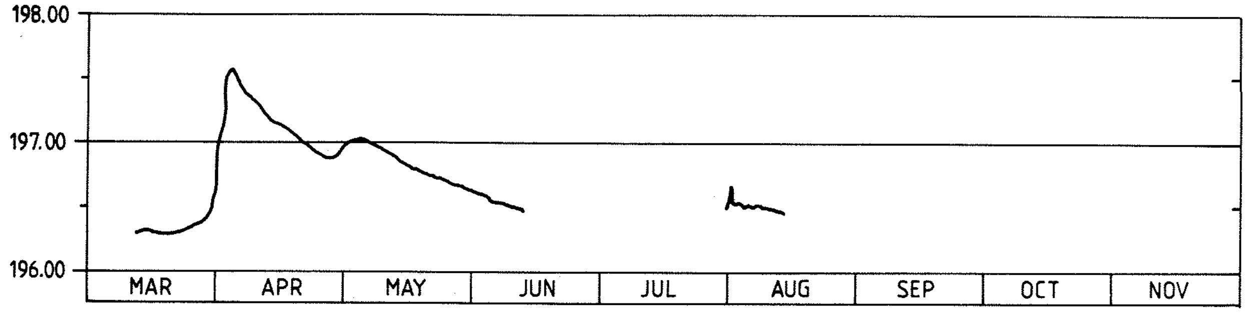

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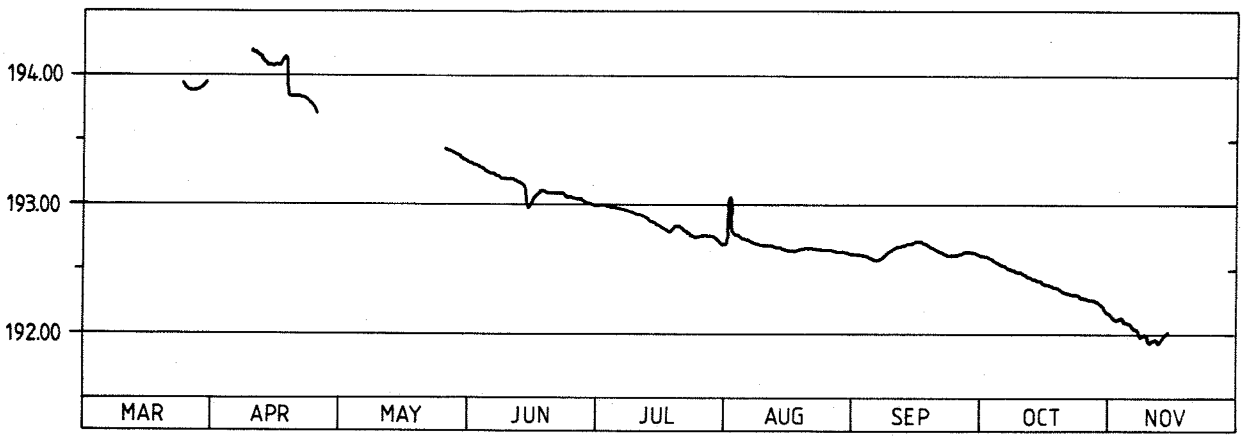

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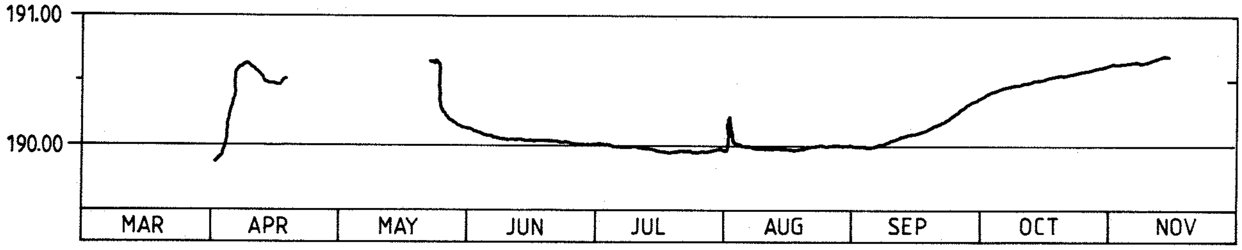

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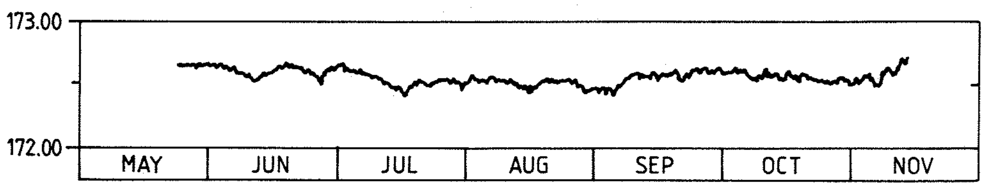

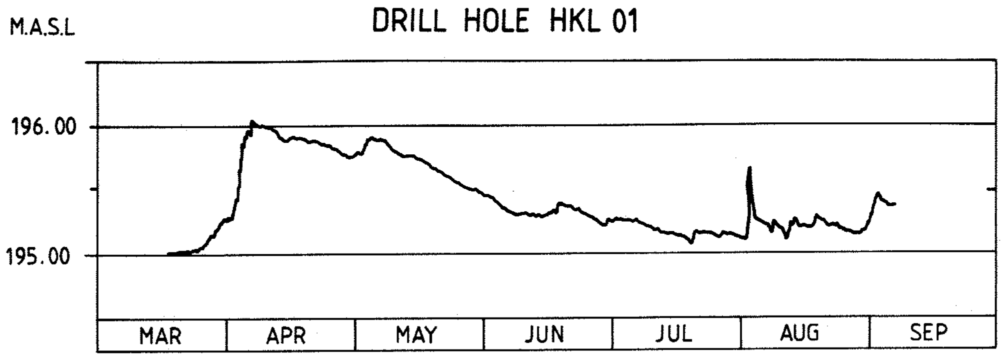
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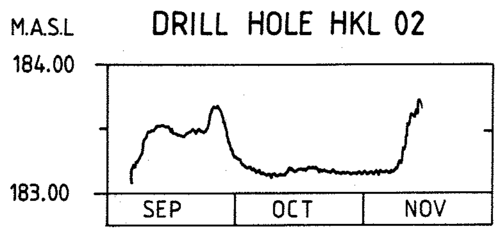
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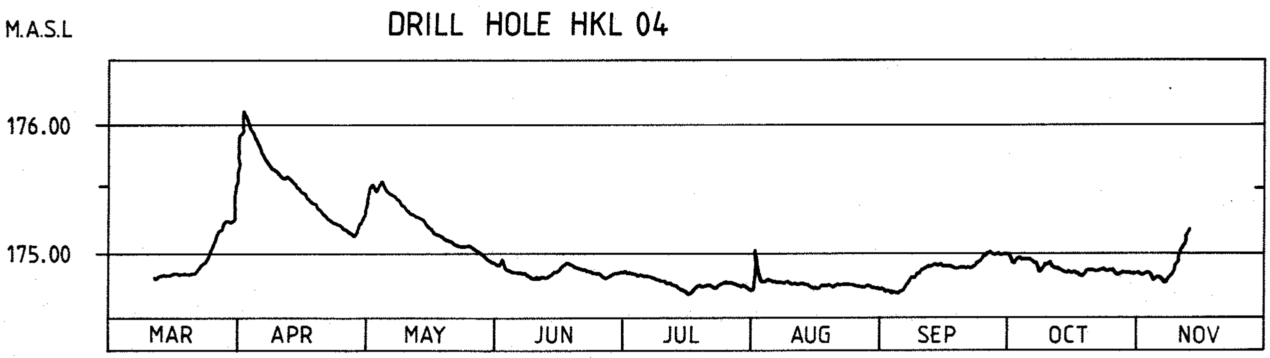
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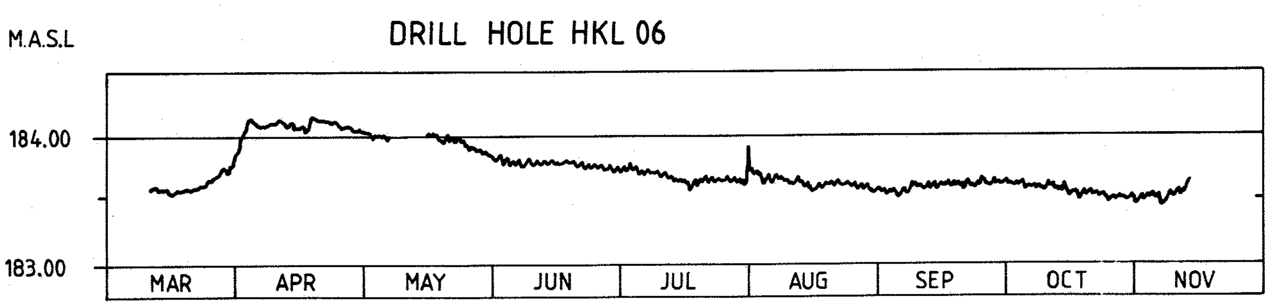
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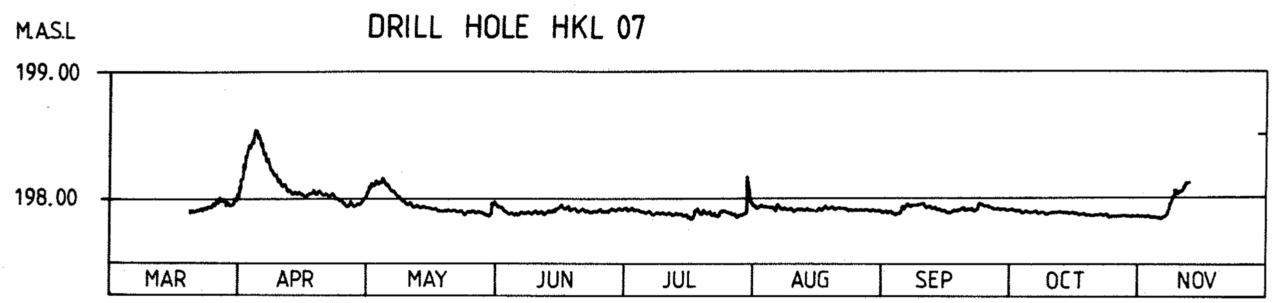
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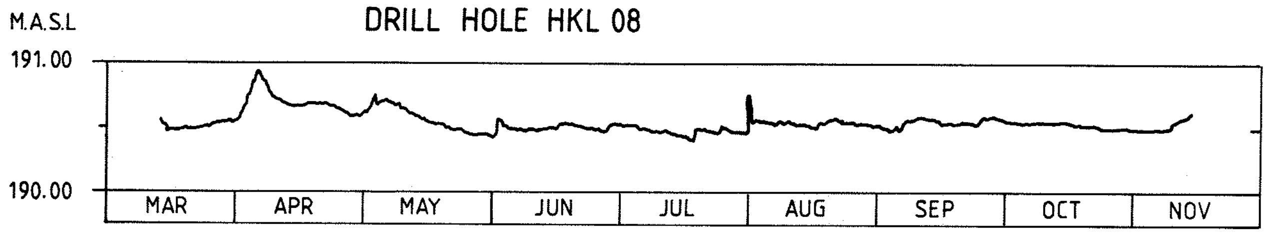
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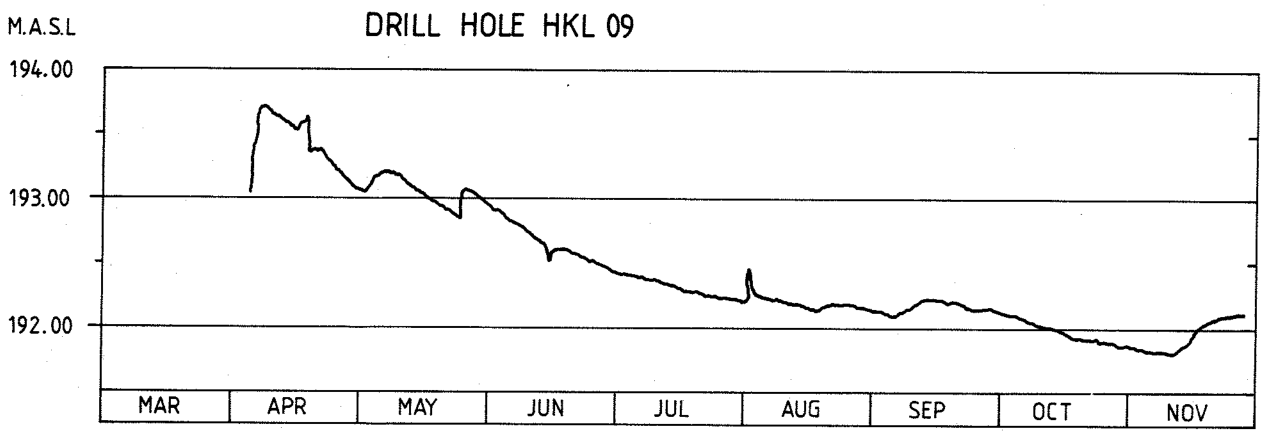
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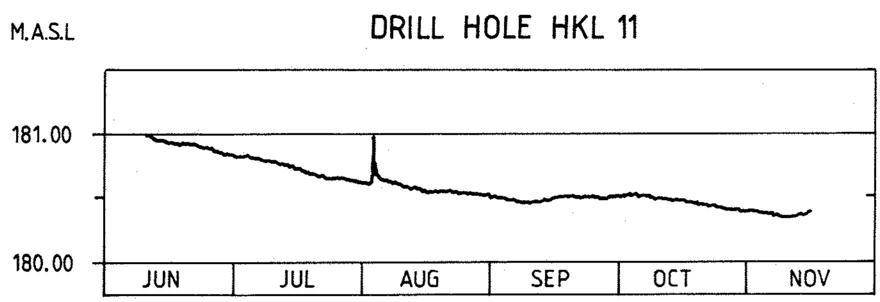
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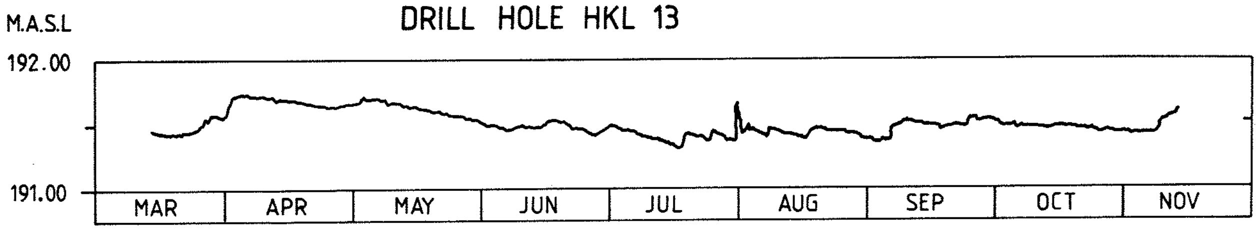

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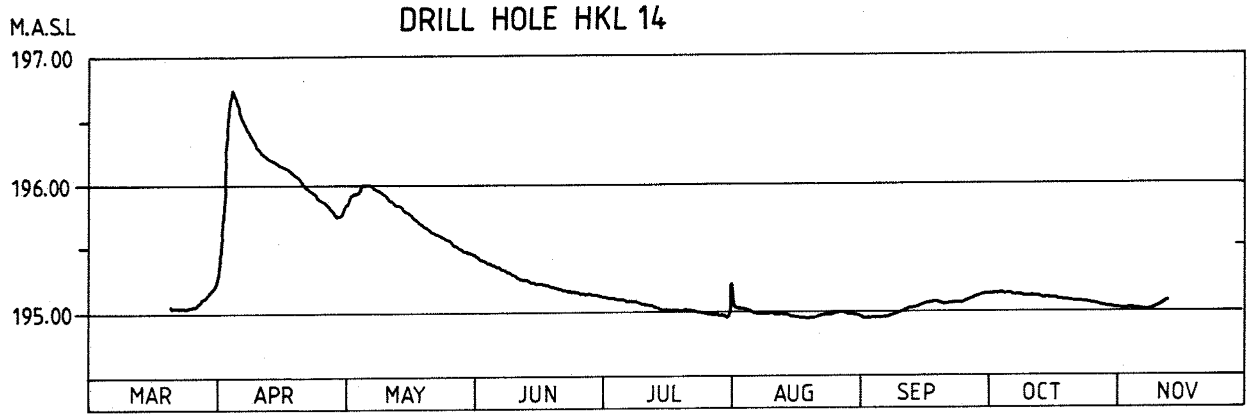

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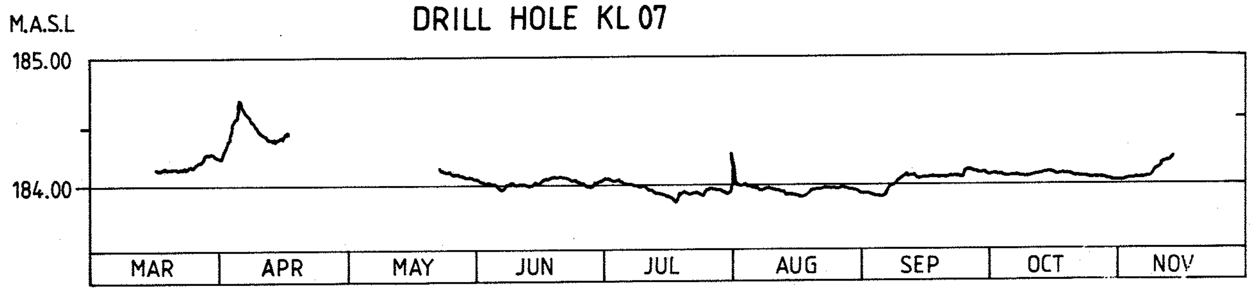

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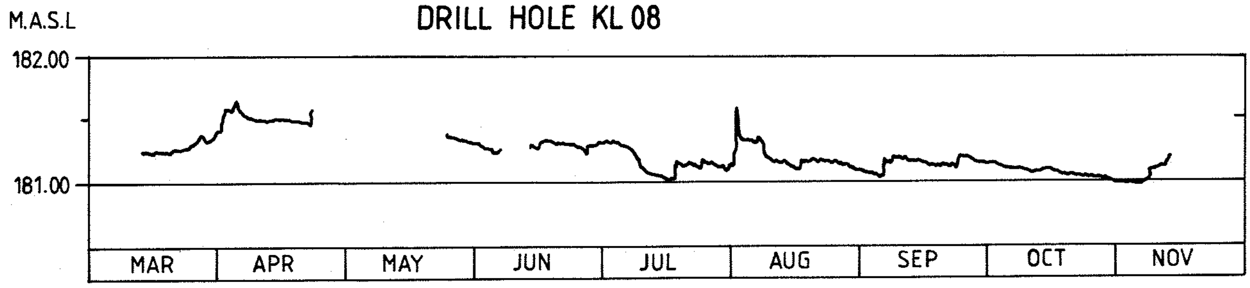

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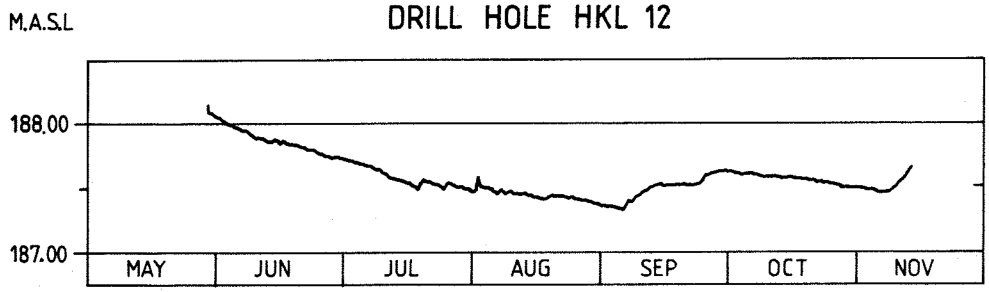

Cored borehole Kl 1
Hydraulic conductivity (K)

Section (m)	K (m/s)	Section (m)	K (m/s)
31- 56	1.7×10^{-6}*	**331-563.95	2.2×10^{-8}
56- 81	1.9×10^{-6}*	**556-563.95	2.8×10^{-11}
81-106	5.8×10^{-6}*		
106-131	2.1×10^{-9}		
131-156	1.1×10^{-6}*	428-433	$<5.0 \times 10^{-11}$
156-181	2.7×10^{-8}	433-438	6.6×10^{-10}
181-206	1.1×10^{-7}	438-443	$<5.0 \times 10^{-11}$
206-231	8.4×10^{-7}	443-448	$<5.0 \times 10^{-11}$
231-256	1.7×10^{-6}	448-453	$<5.0 \times 10^{-11}$
256-281	2.5×10^{-7}	453-458	$<5.0 \times 10^{-11}$
281-306	1.0×10^{-6}*		
306-331	1.0×10^{-7}		
331-356	$<1.0 \times 10^{-11}$		
356-381	$<1.0 \times 10^{-11}$		
381-406	$<1.0 \times 10^{-11}$		
406-431	$<1.0 \times 10^{-11}$		
431-456	1.5×10^{-10}		
456-481	$<1.0 \times 10^{-11}$		
481-506	$<1.0 \times 10^{-11}$		
506-531	$<1.0 \times 10^{-11}$		
531-556	$<1.0 \times 10^{-11}$		

* Steady-state evaluated ** Single packer test

Cored borehole Kl 2
Hydraulic conductivity (K)

Section (m)	K (m/s)	Section (m)	K (m/s)
60- 80	6.8×10^{-8}	680-700	$<1.0 \times 10^{-11}$
80-100	1.1×10^{-8}*	700-720	$<1.0 \times 10^{-11}$
100-120	2.5×10^{-8}	720-740	$<1.0 \times 10^{-11}$
120-140	4.9×10^{-8}	740-760	1.1×10^{-8}
140-160	$<1.0 \times 10^{-11}$	760-780	9.0×10^{-9}
160-180	7.9×10^{-10}	770-790	2.9×10^{-9}*
180-200	$<1.0 \times 10^{-11}$	790-810	1.2×10^{-6}*
200-220	$<1.0 \times 10^{-11}$	810-830	$<1.0 \times 10^{-11}$
220-240	$<1.0 \times 10^{-11}$	830-850	$<1.0 \times 10^{-11}$
240-260	$<1.0 \times 10^{-11}$	850-870	1.5×10^{-9}
260-280	4.1×10^{-11}	870-890	1.5×10^{-10}
280-300	$<1.0 \times 10^{-11}$	890-910	$<1.0 \times 10^{-11}$
300-320	$<1.0 \times 10^{-11}$	910-930	$<1.0 \times 10^{-11}$
320-340	4.7×10^{-10}	930-958	9.9×10^{-11}**
340-360	$<1.0 \times 10^{-11}$		
360-380	$<1.0 \times 10^{-11}$	325-330	1.9×10^{-9}
380-400	2.6×10^{-10}*	620-625	4.1×10^{-9}*
400-420	3.3×10^{-10}	740-745	8.2×10^{-9}
420-440	$<1.0 \times 10^{-11}$	745-750	5.1×10^{-9}*
440-460	$<1.0 \times 10^{-11}$	750-755	5.6×10^{-8}
460-480	$<1.0 \times 10^{-11}$	755-760	$<4.0 \times 10^{-11}$
480-500	$<1.0 \times 10^{-11}$	760-765	1.3×10^{-9}
500-520	$<1.0 \times 10^{-11}$	765-770	1.4×10^{-8}
520-540	$<1.0 \times 10^{-11}$	770-775	1.4×10^{-9}
540-560	$<1.0 \times 10^{-11}$	775-780	4.8×10^{-9}
560-580	$<1.0 \times 10^{-11}$	780-785	$<4.0 \times 10^{-11}$
580-600	$<1.0 \times 10^{-11}$	785-790	2.9×10^{-9}
600-620	$<1.0 \times 10^{-11}$	790-795	5.3×10^{-7}
620-640	9.7×10^{-10}*	805-810	$<4.0 \times 10^{-11}$
640-660	1.0×10^{-11}	865-870	6.9×10^{-9}
660-680	$<1.0 \times 10^{-11}$	884-889	$<4.0 \times 10^{-11}$

* : Steady-state evaluated   ** : Single packer test

Cored borehole Kl 6 | Appendix 3(3)

Hydraulic conductivity (K)

Section (m)	K (m/s)	Section (m)	K (m/s)
20- 40	7.1×10^{-6}*		
40- 60	4.4×10^{-7}*		
60- 80	9.6×10^{-6}*	680-700	5.6×10^{-10}
80-100	9.1×10^{-7}*	700-720	3.7×10^{-11}
100-120	8.3×10^{-6}*	720-740	1.5×10^{-11}
120-140	1.2×10^{-6}*	740-760	3.9×10^{-11}
140-160	2.9×10^{-6}*	760-780	3.7×10^{-11}
160-180	1.5×10^{-7}		
180-200	1.7×10^{-6}	700-808	** 1.9×10^{-11}
200-220	5.2×10^{-8}	780-808	** $<1.0 \times 10^{-11}$
220-240	7.6×10^{-7}		
240-260	9.9×10^{-6}		
260-280	4.5×10^{-9}		
280-300	1.7×10^{-8}		
300-320	8.3×10^{-8}		
320-340	5.6×10^{-8}		
340-360	5.4×10^{-9}		
360-380	8.5×10^{-9}		
380-400	9.3×10^{-9}*		
400-420	2.0×10^{-7}		
420-440	7.7×10^{-7}*		
440-460	6.8×10^{-6}*		
460-480	4.3×10^{-6}*		
480-500	3.5×10^{-7}*		
500-520	6.5×10^{-8}		
520-540	2.5×10^{-8}		
540-560	3.3×10^{-6}*		
560-580	5.3×10^{-8}		
580-600	1.8×10^{-8}		
600-620	1.1×10^{-8}		
620-640	1.5×10^{-8}		
640-660	1.1×10^{-8}		
660-680	1.2×10^{-10}		

*: Steady-state evaluated

**: Single packer test

Cored borehole Kl 9
Hydraulic conductivity (K)

Section (m)	K (m/s)	Section (m)	K (m/s)
30- 50	2.2×10^{-5}*	710-730	4.1×10^{-9}
50- 70	1.1×10^{-5}*	730-750	8.4×10^{-9}
70- 90	7.2×10^{-7}*	750-770	8.3×10^{-10}
90-110	2.9×10^{-6}	770-801**	7.1×10^{-11}
110-130	5.7×10^{-7}		
130-150	5.0×10^{-7}*	370-375	4.6×10^{-8}
150-170	1.7×10^{-9}	375-380	3.0×10^{-8}
170-190	9.4×10^{-8}	380-385	3.2×10^{-8}
190-210	3.3×10^{-8}*	385-390	2.1×10^{-7}
210-230	8.3×10^{-8}	390-395	1.1×10^{-6}
230-250	4.0×10^{-7}	395-400	1.8×10^{-8}
250-270	5.6×10^{-10}	400-405	6.5×10^{-8}*
270-290	2.5×10^{-8}	405-410	9.1×10^{-9}
290-310	2.4×10^{-8}*	410-415	4.0×10^{-7}
310-330	$<1.0 \times 10^{-11}$	415-420	3.6×10^{-8}
330-350	3.6×10^{-9}	420-425	1.8×10^{-8}
350-370	$<1.0 \times 10^{-11}$	425-430	2.0×10^{-8}
370-390	1.1×10^{-7}	670-675	1.9×10^{-8}
390-410	1.4×10^{-7}	675-680	2.0×10^{-8}
410-430	1.3×10^{-7}	680-685	1.9×10^{-8}
430-450	$<1.0 \times 10^{-11}$	685-690	1.7×10^{-8}
450-470	3.1×10^{-10}*	690-695	1.5×10^{-8}
470-490	1.2×10^{-10}	695-700	$<4.0 \times 10^{-11}$
490-510	1.0×10^{-11}	700-705	1.6×10^{-8}
510-530	1.9×10^{-10}	705-710	1.7×10^{-8}
530-550	1.2×10^{-10}		
550-570	2.3×10^{-10}		
570-590	$<1.0 \times 10^{-11}$		
590-610	1.0×10^{-11}		
610-630	3.6×10^{-10}		
630-650	1.8×10^{-10}		
650-670	2.3×10^{-10}		
670-690	9.9×10^{-10}		
690-710	5.1×10^{-7}		

* : Steady-state evaluated
**: Single packer test

Cored borehole Kl 12 Appendix 3(5)

Hydraulic conductivity (K)

Section (m)	K (m/s)	Section (m)	K (m/s)
20- 40	3.1×10^{-6}*	660-680	$<1.0 \times 10^{-11}$
40- 60	2.3×10^{-6}	680-700	$<1.0 \times 10^{-11}$
60- 80	7.2×10^{-7}*	680-730 **	4.3×10^{-11}
70- 90	4.0×10^{-7}*		
90-110	4.9×10^{-7}*		
110-130	7.5×10^{-8}		
120-140	7.5×10^{-8}		
140-160	2.6×10^{-6}*		
160-180	5.5×10^{-7}		
180-200	5.7×10^{-7}		
200-220	2.9×10^{-8}		
220-240	1.5×10^{-11}		
240-260	$<1.0 \times 10^{-11}$		
260-280	1.0×10^{-10}*		
280-300	1.1×10^{-8}		
300-320	1.4×10^{-7}		
320-340	3.2×10^{-7}		
340-360	9.1×10^{-8}		
360-380	4.7×10^{-7}		
380-400	1.4×10^{-7}*		
400-420	4.3×10^{-7}		
420-440	1.5×10^{-7}		
440-460	4.8×10^{-8}		
460-480	9.1×10^{-8}		
480-500	2.8×10^{-7}		
500-520	7.7×10^{-8}		
520-540	$<1.0 \times 10^{-11}$		
540-560	5.5×10^{-9}		
560-580	4.1×10^{-9}		
580-600	2.0×10^{-8}		
600-620	1.8×10^{-9}		
620-640	$<1.0 \times 10^{-11}$		
640-660	$<1.0 \times 10^{-11}$		

*: Steady-state evaluated

**: Single packer test

Cored borehole Kl 13 Appendix 3(6)

Hydraulic conductivity (K)

Section (m)	K (m/s)	Section (m)	K (m/s)
10- 30	1.4×10^{-7}	170-175	9.5×10^{-7}
30- 50	1.4×10^{-6}	180-185	7.6×10^{-11}
50- 70	9.8×10^{-8}	185-190	3.4×10^{-10}
70- 90	4.4×10^{-8}	470-475	$<4.0 \times 10^{-11}$
90-110	6.6×10^{-7}	475-480	4.7×10^{-10}
110-130	9.6×10^{-7}*	480-485	6.1×10^{-11}
130-150	4.1×10^{-7}*	485-490	7.5×10^{-11}
150-170	3.7×10^{-7}	610-615	$<4.0 \times 10^{-11}$
170-190	9.8×10^{-7}	615-620	$<4.0 \times 10^{-11}$
190-210	$<1.0 \times 10^{-11}$	620-625	* 2.8×10^{-6}
210-230	$<1.0 \times 10^{-11}$	625-630	* 5.3×10^{-7}
230-250	$<1.0 \times 10^{-11}$	630-635	1.6×10^{-6}
250-270	$<1.0 \times 10^{-11}$	635-640	$<4.0 \times 10^{-11}$
270-290	$<1.0 \times 10^{-11}$	640-645	2.6×10^{-8}
290-310	$<1.0 \times 10^{-11}$	645-650	9.7×10^{-7}
310-330	6.4×10^{-9}*	650-655	* 6.4×10^{-7}
330-350	3.1×10^{-10}	655-660	* 5.3×10^{-9}
350-370	3.2×10^{-11}	660-665	1.9×10^{-11}
370-390	2.0×10^{-9}	665-670	3.4×10^{-8}
390-410	3.2×10^{-10}	670-675	2.4×10^{-7}
410-430	$<1.0 \times 10^{-11}$		
430-450	$<1.0 \times 10^{-11}$		
450-470	$<1.0 \times 10^{-11}$	630-700 **	3.4×10^{-7}
470-490	1.7×10^{-10}	650-700 **	2.0×10^{-7}
490-510	$<1.0 \times 10^{-11}$	670-700 **	9.6×10^{-8}
510-530	$<1.0 \times 10^{-11}$		
530-550	$<1.0 \times 10^{-11}$		
550-570	$<1.0 \times 10^{-11}$		
570-590	1.7×10^{-10}		
590-610	$<1.0 \times 10^{-11}$		
610-630	4.4×10^{-7}*		
630-650	3.8×10^{-7}*		
650-670	2.7×10^{-7}*		

*: Steady-state evaluated

**: Single packer test

Cored borehole Kl 14 Appendix 3(7)

Hydraulic conductivity (K)

Section (m)	K (m/s)	Section (m)	K (m/s)
20- 40	$2.0x10^{-7}$	680-705 **	$5.2X10^{-9}$
40- 60	$3.2x10^{-7}$		
60- 80	$1.1x10^{-6}$*		
80-100	$1.3x10^{-7}$		
100-120	$4.8x10^{-7}$		
120-140	$8.8x10^{-9}$*		
140-160	$3.1x10^{-8}$		
160-180	$3.5x10^{-8}$		
180-200	$6.3x10^{-9}$		
200-220	$9.6x10^{-8}$		
220-240	$7.2x10^{-8}$*		
240-260	$1.6x10^{-8}$		
260-280	$8.1x10^{-8}$		
280-300	$1.0x10^{-8}$*		
300-320	$1.0x10^{-8}$*		
320-340	$1.1x10^{-8}$*		
340-360	$2.2x10^{-8}$		
360-380	$5.7x10^{-7}$		
380-400	$1.5x10^{-8}$*		
400-420	$2.3x10^{-7}$		
420-440	$1.3x10^{-8}$*		
440-460	$4.9x10^{-7}$*		
460-480	$6.0x10^{-9}$		
480-500	$7.1x10^{-9}$		
500-520	$7.8x10^{-9}$		
520-540	$7.0x10^{-9}$		
540-560	$7.7x10^{-8}$		
560-580	$4.8x10^{-9}$		
580-600	$4.6x10^{-9}$		
600-620	$3.6x10^{-9}$		
620-640	$1.7x10^{-9}$		
640-660	$6.0x10^{-10}$		
660-680	$1.9x10^{-11}$*		

*: Steady-state evaluated

**: Single packer test

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