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Klipperås study site.
Scope of activities and main results

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KLIPPERÅS STUDY SITE.
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Information on SKB technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01), 1985 (TR 85-20), 1986 (TR 86-31), 1987 (TR 87-33), 1988 (TR 88-32), 1989 (TR 89-40), 1990 (TR 90-46) and 1991 (TR 91-64) is available through SKB.

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PREFACE

During the period from 1977 - 1986 SKB (Swedish Nuclear Fuel and Waste Management Co) performed surface and borehole investigations of 14 study sites for the purpose of assessing their suitability for a repository of spent nuclear fuel. The next phase in the SKB site selection programme will be to perform detailed characterization, including characterization from shafts and/or tunnels, of two or three sites. The detailed investigations will continue over several years to provide all the data needed for a licensing application to build a repository. Such an application is foreseen to be given to the authorities around the year 2003.

It is presently not clear if any of the study sites will be selected as a site for detailed characterization. Other sites with geological and/or socio–economical characteristics judged more favorable may very well be the ones selected. However, as a part of the background documentation needed for the site selection studies to come, summary reports will be prepared for most study sites. These reports will include scope of activities, main results, uncertainties and need of complementary investigations.

This report concerns the Klipperås study site. The report has been written by the following authors; Kaj Ahlbom and Sven Tirén (scope of activities and geologic model), Jan–Erik Andersson (geohydrological model), Tomas Ittner (groundwater chemistry), Peter Andersson (assessment of solute transport), and Christer Ljunggren (rock mechanics).

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1. ASSESSMENT OF THE KLIPPERÅS STUDY SITE

This chapter summarizes characteristics and uncertainties of the Klipperås study site, Figure 1. Based on these descriptions the needs for complementary site characterization studies are outlined.

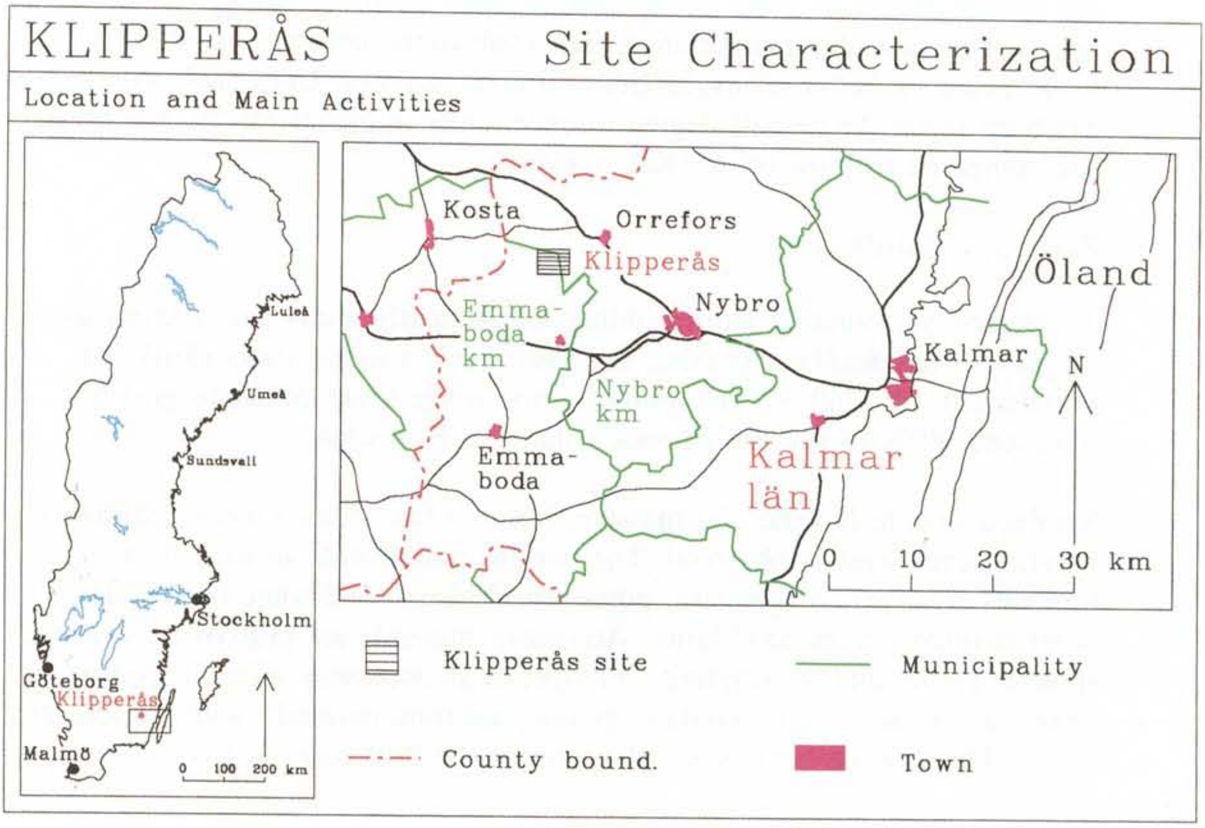


Figure 1. Location of the Klipperås study site.

1.1 Main characteristics and uncertainties

General

The Klipperås study site is located within the sub–Cambrian peneplain, implying a low topographical relief. The altitude only varies between 190 – 200 m a.s.l., for more than 50 % of the site. On the regional scale the ground surface is gently inclined, dipping 0.16° (equals to 0.5 %) towards the east–southeast. The low relief of the site, in combination with a several meters thick and evenly distributed moraine do not, with a few exceptions, permit the identification of fracture zones using lineament interpretations based on aerial photos.

Only a few small outcrops occurs within the 12 km^2 area constituting the Klipperås study site. The geological and tectonical models are therefore mainly based on results from cored drillings and surface geophysical surveys.

No report exists for the Klipperås site where all data are evaluated. Although the present report to some extent aims to serve such a purpose, the scope does not include the interpretations nor evaluations needed to resolve the inconsistencies between results from different surveys. Until such an effort has been made the overall degree of uncertainty is higher for the Klipperås site compared to most other SKB study sites.

Rock type distribution

The region surrounding and including the Klipperås study site is dominated by greyish red Småland granite, and associated volcanic rocks (Småland porphyries), of 1760 – 1810 million years in age (Ma). Småland granite represents 85% of the drilled rock volume at Klipperås.

Småland granite is generally massive, but in a few cases a weak schistosity trending east–west is observed. The normal composition of rock forming minerals is quartz, plagioclase, potassium feldspar, and some biotite. The latter is often altered to chlorite. Accessory minerals are muscovite, epidote, sphene, pyrite, and/or magnetite. Fluorite is an accessory mineral. Aplitic dykes, associated to the Småland granite, are thin, normally with a width of 0.5 m. The relative occurrence of aplites in the drill cores is 1 %.

Among subordinate rock types greenstones are most common constituting 7 % of the drill cores. They occur as basic xenoliths and metadolerites. The mineral assemblage is chlorite, plagioclase, quartz, and epidote.

Composite dykes containing Småland porphyries (older than 1620 Ma) and dolerites are common. These dykes trend between E–W and WNW–ESE and dip steeply to the south. The width is normally about 10 m. Their relative occurrence in the drill cores is 5.5 %.

The youngest rock in the area are dolerite dykes (900 Ma). They have well-preserved textures and are often magnetic. The width varies from some meter to almost 10 m. Their trend varies from N–S to NE–SW and they are steeply dipping. Their relative occurrence in the drill cores is 1.5 %.

Judging from the core logs, the overall fracture frequency is moderate–high for Klipperås, compared to other SKB study sites. The average fracture frequency for various rock types, irrespective of depth in the drill cores, is lowest for Småland granite with 4.3 fr/m, followed by aplite with 7.4 fr/m, dykes of Småland porphyries with 7.5 fr/m, greenstone with 10.0 fr/m, and dolerite dykes with 6.4 - 18.7 fr/m.

Uncertainties: The Klipperås study site differs from other SKB sites in its more or less lack of outcrops. Interpretation of rock type distribution therefore had to rely on borehole cores in combination with surface and borehole geophysical surveys. This implies uncertainties not encountered at other sites.

The lack of oriented cores implies uncertainties in the orientations of dykes and other lithological contacts, as well as in the interpretations of widths of dykes. In combination with the lack of surface data, this results in uncertainties in the rock type distribution even close to the boreholes. No attempt to present a 3D model of rock type distribution has been made.

Fracture zones

A total of 11 (local) fracture zones trending NNE, E–W and N–S, have been interpreted in the central part of the site. Their widths varies from 10 to 30 m. The zones were interpreted from surface geophysical surveys and later tested by boreholes. The boreholes showed that the bedrock within the zones generally are strongly tectonized. This includes a high degree of fracturing, sections with crushed rock and the presence of breccias and mylonites.

Uncertainties: A few strong linear geophysical anomalies occur in the large area constituting the Klipperås site. Sometimes they are accompanied by a weak lineament at the ground surface. These strong anomalies all proved to represent fracture zones. However, there are still uncertainties regarding their widths. Other interpreted fracture zones, less geophysically apparent, are all associated with uncertainties. Especially regarding widths and extensions.

The frequent occurrence of fractured and hydraulically conductive sections in the boreholes, which are not assigned to any specific fracture zone, is a strong indication for the existence of additional, unidentified fracture zones. This is also indicated by the "anomalous" large spacings between interpreted fracture zones. A rough estimate indicates this to be about twice as large for Klipperås compared to other SKB sites.

Hydrology

The Klipperås area represents a site with a gentle topography. The regional area, 85 km in length, is bounded in the west by a regional groundwater divide from where the ground surface gently dips towards the strait of Kalmarsund in the east. In the subregional area around the Klipperås site the groundwater table is relatively flat, ranging from about 230 m a.s.l. in the northwest to about 90 m a.s.l. in southeast, corresponding to an average hydraulic gradient of about 0.5 %, for the shallow groundwater. The regional groundwater flow is primarily directed from northwest to southeast. Local, minor discharge areas are found in low-lying parts within the area. Within the Klipperås site the elevation of the shallow groundwater table ranges between 200 - 170 m a.s.l.

Uncertainties: The uncertainty normally associated with groundwater flow modelling by assuming the groundwater table to be a direct image of the topographical map is probably not important in the Klipperås region due to the very large size and the gentle topography of the modelled areas.

Hydraulic units

The conceptual regional and subregional hydraulic models at Klipperås, used in the modelling, were based on strong generalizations incorporated only some interpreted fracture zones. Therefore, the modelled fracture zones should be regarded as generic (assumed). Furthermore, no division of the rock mass into different rock types was made.

Uncertainties: The inherent uncertainties in the generic approach.

Hydraulic conductivity

The effective hydraulic conductivity of the rock mass, calculated from statistical analysis of data from the Klipperås site, is significantly higher than other study sites. One probable reason is that few fractured sections in the boreholes could be assigned to any specific fracture zone. This in turn led to a very crude separation between fracture zones and rock mass, which probably have resulted in a erroneous high conductivity for the rock mass. For example, in the generic modelling of the subregional area a conductivity-depth function was used for the rock mass corresponding to a conductivity of about 10^{-9} m/s at 500 m depth. This is 40 - 50 times higher than the calculated hydraulic conductivity for the rock mass at 500 m depth at Fjällveden, Gideå and Svartboberget study sites, and about 80 times higher than that at Kamlunge study site.

The number of measurements in fracture zones are very limited, but also they indicate a high "average" hydraulic conductivity. The applied hydraulic conductivity function in the subregional model corresponds to a fracture zone conductivity of about 10^{-7} m/s at 500 m depth. This is between 100 - 1000 times higher than the calculated hydraulic conductivity of the fracture zones at 500 m depth at the above mentioned study sites.

In the regional model a generic horizontal zone was assumed at 300 m b.s.l. and extending over the total modelled area (85 km). In a preliminary modelling this zone was assigned a constant hydraulic conductivity of $3 \cdot 10^{-8}$ m/s. The large extension of the zone implies a variation in depth from the ground surface to the zone (from 550 m in the west to 300 m in the east). Later modelling therefore assumed a depth dependent conductivity corresponding to values of about $9 \cdot 10^{-9}$ and $8 \cdot 10^{-8}$ m/s, respectively. This should be compared to the measured hydraulic conductivity of the horizontal zone at Klipperås of $2 \cdot 10^{-6}$ m/s (800 m depth).

The average conductive fracture frequency in the rock mass at the Klipperås site was estimated to about 0.09 – 0.12 fr/m, based on all tested 20 m sections in the cored boreholes.

Uncertainties: The applied hydraulic conductivity functions versus depth for the different hydraulic units are uncertain and probably to high, partly due to uncertainties in the separation of data in hydraulic units, and partly due to the inherent uncertainty of the regression analysis. An alternative interpretation is that the upper 100 – 200 m of the bedrock has higher conductivity than the deeper bedrock and that no significant depth trend exists neither in the upper nor in the lower parts of the bedrock.

The same uncertainty applies to the high hydraulic conductivity assumed for the (vertical) fracture zones. This is probably not representative and may, at least partly, be explained by the fact that the data from the horizontal zone was included in the regression analysis. This zone should rather be conceptualized as an independent, deterministic hydraulic unit.

Groundwater flow rates at repository depth

Only generic hydraulic modelling on a regional and subregional scale was performed in order to analyze sensitivities in boundary conditions for a conceived model on a local scale. The site evaluation program was however terminated before any local groundwater flow modelling was made.

The regional and subregional generic modellings were made using crude estimates of hydraulic properties and assumed locations, widths and properties of fracture zones. They should therefore be regarded as scooping calculations with little or no relevance on reality.

Bearing this in mind, the calculated groundwater flow in the subregional model, and at 500 m depth, was 300 ml/m^2/year. This value is considerably higher than those calculated from other study sites, e.g. Fjällveden, Gideå and Kamlunge. One reason might be the higher hydraulic conductivity applied for the rock mass at Klipperås. The generic modellings showed that groundwater fluxes were insensitive to varying locations of generic fracture zones and/or outer boundary conditions.

Uncertainties: Some assumptions in the generic modelling are highly unrealistic, such as the presence in the regional model of a 85 km continuous horizontal fracture zone. This, and the fact that no "real" fracture zones were incorporated in the models, implies that the modelling results should only be regarded as indicative and of minor relevance on reality.

Groundwater chemistry

The results show that the groundwaters at Klipperås are of near-surface to intermediate in type. No deep saline water was encountered. The sampled sections show a very uniform chemical composition and there are no general trends with depth considering pH, electrical conductivity or the major-ion chemistry. All sampled sections are reducing in character.

Klipperås groundwaters differs from other study sites by the high ^{14}C ages in the deep sampled groundwaters, and its complete lack of saline waters at greater depths (even below a horizontal fracture zone at 800 m depth). The reason for this difference might be that the bedrock at Klipperås was never covered by the post-glacial sea, as was the case for the other sites. Thus the exchange from non-saline glacial groundwaters to marine saline water, which occurred during submergence for most sites, did not occurred at Klipperås. It is therefore possibly that the non-saline and "old" groundwaters encountered at great depths at Klipperås are in fact relict glacial meltwater.

Uncertainties: A total of 3 boreholes and 7 different sections have been sampled. The drilling and sampling methods that were used at the Klipperås site were considerably improved compared to the "KBS-3 sites" which has resulted in high accuracy measurements of redox potentials and several other parameters. However, considering the hydraulic parameters of the boreholes it was concluded by Smellie et al. (1985 and 1987) that only three out of the seven sampled sections were representative for the depth sampled.

Solute transport

No specific models of solute transport at the Klipperås site exist. However, included in the generic 2D and 3D groundwater flow models there are some simulations of the groundwater travel times from a generic repository at 500 m depth to the surface. Travel times varies between 6 000 - 40 000 years in the 2D regional scale model, while they are somewhat shorter in the 3D subregional scale model, 2 000 - 10 000 years.

Uncertainties: The generic approach implies inherent uncertainties. Results should therefore only be regarded as indicative for assumed hydraulic properties and conditions.

Rock mechanics

Rock mechanical investigations have not been performed at the Klipperås site. However, dynamic rock mass modulus and dynamic Poissons ratio have been calculated to 78 GPa and 0.25, respectively, using data from tube–wave measurements.

1.2 Suggestions for complementary studies

Conceptual geologic models

Only very generalized geological and tectonical models exists for the Klipperås study site. Most models describes minor subareas and profiles in the vicinity of the cored boreholes. Much more detailed and reliable models of rock types distribution and location and characteristics of fracture zones are needed. Especially important is to determine location, extension and properties of the subhorizontal zone at 800 m depth. Also the existence of additional such zones should be investigated. There is also a need for assessments regarding the "constructability" of the site. For example, no attempt has been made to estimate available area of "sound rock" at 500 m depth.

These needs could be meet by a thoroughly reinterpretation of existing data, including results from borehole radar measurements, which were performed after the main site characterization was terminated. Based on preliminary conceptual model(s) interesting core sections should be selected for remapping and, if possible, trenches should be made to expose the bedrock at interesting locations, both to obtain data and to test the model.

Conceptual geohydrological models and data sampling

As described above only very generalized geological models exists for the site and a detailed 3D model remains to be made. When such a model exists it will form the basis for a conceptual geohydrological site model.

Based on the type of hydraulic models chosen for the site, e.g. continuum models, fracture network models or stochastic continuum (parametric and non–parametric), the remapping and other complementary geological field work, see above, should include the data needs imposed by the chosen type of hydraulic models.

The results from the generic flow models, in those cases where hydrostatic boundaries are prescribed, indicate that the groundwater is horizontal at greater depths and thus the flow is regional in character. This should be investigated further aiming at identifying regional and local hydrological factors that have a major influence on the local flow system. At what depth the local flow system changes from being local to regional in character, and what hydraulic conditions that controls this change–over, are interesting questions. The long time stability of the flow systems are another.

The groundwaters at the Klipperås site are non–saline in character down to depths of about 1000 m. The compositions indicate waters of near–surface or intermediate in type. This is somewhat contradictory to the general picture of a slowly horizontally directed regional groundwater flow. As discussed earlier at least some of the deep groundwaters might represent relict glacial meltwater which infiltated the bedrock during deglaciation.

One explanation for the non–saline deep groundwaters at Klipperås might be that the site is situated close to, but above "highest coastline", i.e. above the highest level reached by the sea after the last inland ice. Thus no exchange from non–saline to marine waters occurred. In comparison, most other SKB study sites are located below "highest coastline" and were therefore covered by the post–glacial sea until some 3 000 - 10 000 years ago. This difference between sites should be utilized to study the implications the post–glacial sea level history have on groundwater flow and groundwater chemistry with time. Such a study is of importance for validating groundwater flow models, both generally and site specific.

The influence of a regional flow system might be studied by direct measurements in at least one new borehole at a "critical" location determined by hydraulical modelling based on a new conceptual geohydraulical model. Measurements in this borehole should include combined logging of temperature and salinity, together with a spinner survey, both during natural and pumping conditions to measure the vertical flow under open borehole conditions and to identify conductive structures in the borehole. Subsequently, tracer dilution measurements could be carried out to measure the natural flow through the borehole. In addition, head measurements and water sampling should be carried out in isolated borehole sections. Most of these measurements should also be carried out in some of the existing boreholes at Klipperås, notably KKL02.

As a final test of the validity of the established conceptual model of the Klipperås site, a long–term pumping test should be carried out in one of the deep boreholes, centrally located within the site. Observations of drawdown should be made in all available boreholes within the site. The observations should be compared with predicted ones. The pumping test should be combined with tracer and dilution tests by injecting tracers in some of the nearest observation sections before the test. Observations of changes of the water chemistry during pumping should also be made.

Groundwater chemical conditions

The region, in where Klipperås is located, can be characterized as a recharge area in regional scale. This is also indicated by the sampled groundwaters which are of near–surface to intermediate in type down to large depths. As discussed above, it is also possible that at least some of the deep non–saline groundwaters originate from glacial meltwater.

To resolve questions regarding origin of various groundwaters both in time and space, it is suggested to make in–situ flow measurements at earlier sampled sections to determine whether the water is stagnant or not. Another suggestion is to drill a deeper borehole or deepening of an existing one. The new sampling rounds in this new borehole should be designed to meet three objectives: to characterize the groundwater chemistry at depth, to assist in the interpretation of regional hydrology, and to assist in the interpretation of local hydrology.

Although the available chemistry data at Klipperås has been evaluated thoroughly, there might be a possibility to gain some further hints about hydrological conditions by complementary evaluation of existing data.

Firstly, one may attempt to compare the general chemistry characteristics of the different sections for all the boreholes. This would show to what extent the sampled sections can be categorized into distinct groups, and thereby possibly provide clues that can be used to interpret the geohydrology. Secondly, it may be worthwhile to do a careful examination of the time series of the chemistry data from some of the different sampled sections. The changes in the chemical composition in a particular section during the sampling period, may in some cases reflect changes in mixing conditions. It is possible that such additional analysis would help in the interpretation of where local or regional flow conditions prevails.

Solute transport

To calculate solute transport at the Klipperås site, the following factors would be most important; 1) investigation of the deep groundwater system (what boundary conditions would be appropriate for a local site model predicting flow and transport?) and, 2) investigation of geometry and connectivity of conductive structures if such exist (what are the major flow paths that need be considered in a model?). Once these facts are established, the point of next greatest importance would be determination of hydraulic conductivity distribution including possible depth dependence.

Sorption coefficients including estimates of sorptive surface, and reaction coefficients are of next greatest importance to improving knowledge of nuclide transport in both the conductive fractures and in bedrock blocks. In-situ tests to determine effective sorption coefficients, effective area and importance of matrix diffusion should be carried out.

Of least importance to a safety analysis is knowledge of pure parameters of transport, the effective porosity and the dispersivity, which only change the timing of nuclide mass arrival in the biosphere. Uncertainty in these parameters would likely be overshadowed by uncertainties in the boundary conditions, structures, conductivity distribution and sorptivity of nuclides.

Rock Mechanics

No rock mechanical investigations have been conducted at the Klipperås study site. Stress measurements should therefore be made down to the maximum depth of the boreholes. Furthermore, thermal properties should be measured as well as some basic mechanical properties using uniaxial compression and Brazilian disc tests.

2. BACKGROUND

2.1 Objectives

Geological investigations of study sites in the Swedish programme for disposal of spent nuclear fuel have until 1990 involved a total of 14 sites. For some of these sites, investigations have been limited to surface studies and/or only one deep borehole. Relatively extensive investigations have been carried out at eight study sites. The later performed site investigations have involved an extensive programme of surface geophysical surveys and geological mapping and several deep boreholes down to depths between 700 - 1000 m.

Over the years the scope of the investigations at the study sites has gradually extended due to a steady increasing demand of data for performance assessments. The amount of data available from the later investigated sites are therefore greater compared to the earlier study sites.

Klipperås was the last of the study sites investigated by SKB. The site was investigated during the years 1984–1985 and main results are reported in Olkiewicz and Stejskal (1986), Sehlstedt and Stenberg (1986), Gentzschein (1986), Tullborg (1986), Laurent (1986), and Wikberg et al. (1987). A brief summary of the Klipperås study is presented by Nilsson et al. (1987).

When the scope of site investigations at Klipperås was established it was considered most important to address those factors that have appreciable potential for rendering the site relatively unfavorable. Key factors in this respect are the groundwater flow system and the chemical conditions of the deep groundwater.

To obtain the data needed to evaluate the importance of these key factors at Klipperås, the site investigations had the following main objectives:

* Identify and characterize major and minor fracture zones, dykes and other lithological inhomogeneities.

* Identify and characterize "homogeneous" rock blocks.

* Determine groundwater heads, groundwater recharge and discharge areas and groundwater divides.

* Determine the chemical constituents and redox conditions of groundwater.

2.2 Selection of the Klipperås study site

The Klipperås study site is located in the southern part of Kalmar county, Emmaboda and Nybro municipalities, about 35 km WNW of Kalmar (Figure 1 and 2). The areal extent of the site is 3 x 4 km. However, there is a considerable variation in the areal extent covered by the various surveys (cf. Figure 3–5).

Klipperås was one of several alternative areas selected during the reconnaissance studies of 1982 - 1983 (Tirén and Magnusson, 1983). The purpose was to find areas within a region of flat topography implying a low regional hydraulic gradient. Geological reconnaissance studies and geophysical profile measurements were made during 1982 - 1983 and are presented by Tirén and Magnusson (1983).

The reconnaissance studies only identified a few minor lineaments at Klipperås, mainly because of the flat topography and the lack of surface information due to the extremely low degree of outcrops. To study bedrock conditions at depth a 564 m deep cored borehole was drilled during 1983. The drill core showed an altered bedrock (dominated by Småland granite) penetrated by a minute network of hairline fractures and a locally intensely sheared bedrock. Hydraulic tests in the borehole indicated however an extremely low conductive rock from a depth of 331 m to the bottom of the borehole, which was regarded favorable, and a decision to initiate complete site investigations was taken in 1984. At that time no major geologic or non-geologic factor was judged unfavorable for the Klipperås site. The only concern was the lack of surface data due to the existence of the thick and evenly distributed moraine layer. However, it was belived that this could be compensated by a detailed geophysical ground survey incorperating several methods.

In summary, the Klipperås study site was selected due to the following conditions:

* The site is dominated by one rock type, Småland granite.

* The Klipperås study site is located in a very flat region. The relief is very low and the ground surface is on a regional scale just slightly inclined eastwards, ca 0.5 %, inferring small local and regional hydraulic gradients.

* Easy accessible and favorable land ownership (Crown Forest).

2.3 Investigation periods

The time schedule for the main activities are shown in Figure 2. The main period of site characterization took place between 1984 – 1985. With the exception of a borehole radar survey, there has been no further activities at the site.

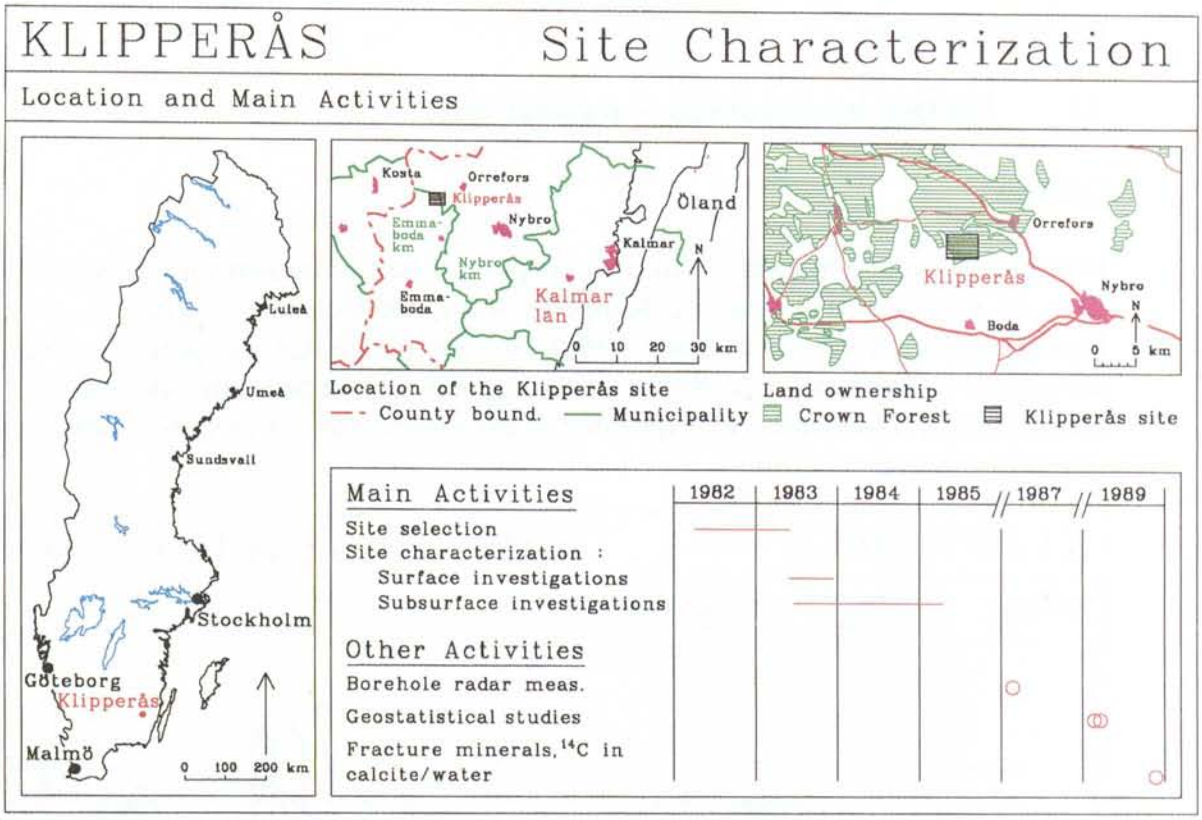


Figure 2. Location of the Klipperås study site. Administrative borders and land ownership are shown. Main activities refer to the site characterization studies. Other activities refer to activities after the main site characterization was terminated.

3. SCOPE OF ACTIVITIES

3.1 Reconnaissance

The Klipperås site was selected in 1982 as a result of reconnaissance studies (Tirén and Magnusson, 1983). The reconnaissance phase included studies of geological maps and literature, lineament interpretation based on aerial photos and topographical maps, brief field checks and ground geophysical profile measurements. The field checks included observations regarding rock types, rock type distribution and degree of rock exposure, as well as degree of fracturing and other general tectonic characteristics. Interpreted lineaments were inspected. The geophysical measurements included VLF and magnetic profiling (total profile length was 35 km within an area of 4 x 6 km). At 11 localities the thickness of the morain cover was investigated by hammer–seismic refraction measurements. Since no modern detailed geological maps were available the reconnaissance studies have to rely on old maps and modern small scale overview maps. The region also lacks airborne geophysical maps.

3.2 Surface investigations – regional area

Geology

Lineaments were interpreted from aerial photos and topographical maps of a 25 x 25 km large area with the Klipperås study site located in its centre, Figure 3 (Olkiewicz and Stejskal 1986). Surface geological mapping has been performed in an area of ca 90 km^2 including the Klipperås study site and its surroundings, The degree of exposures is extremely poor in this area, only some 70 outcrops are found.

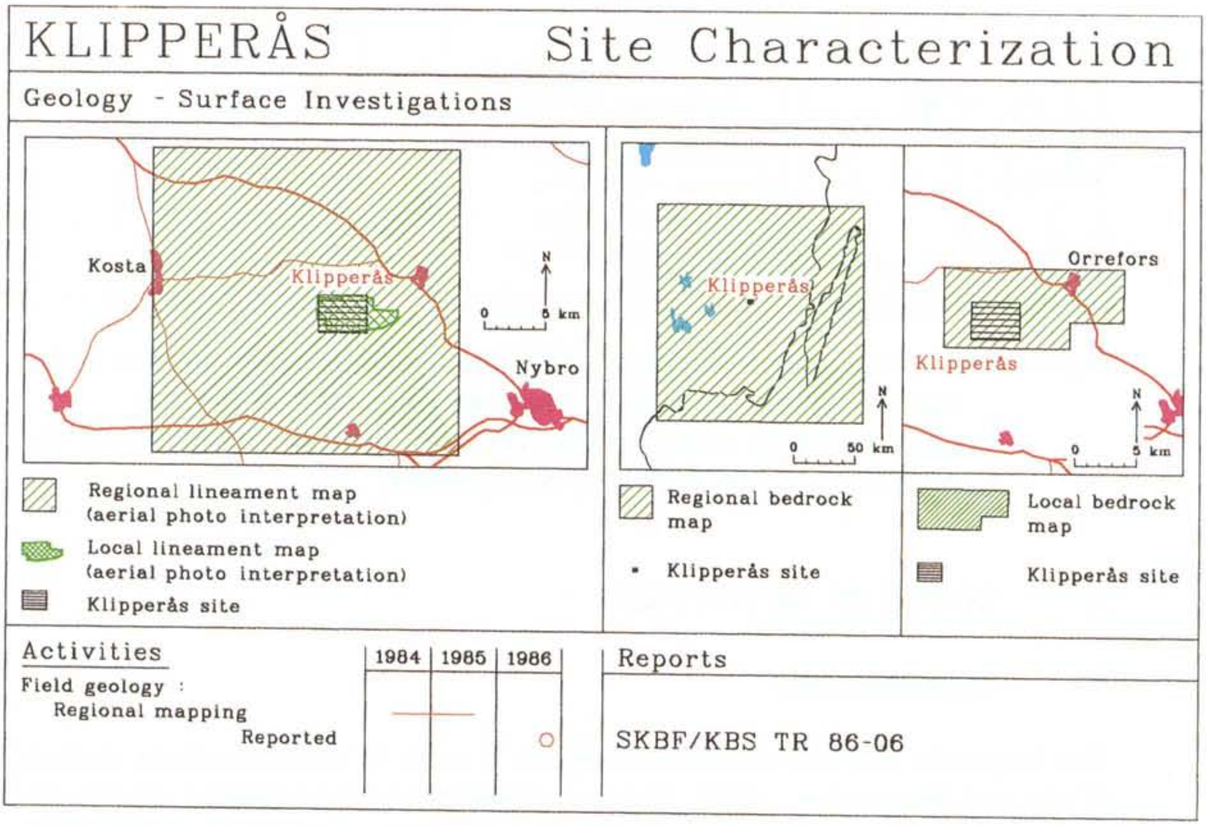
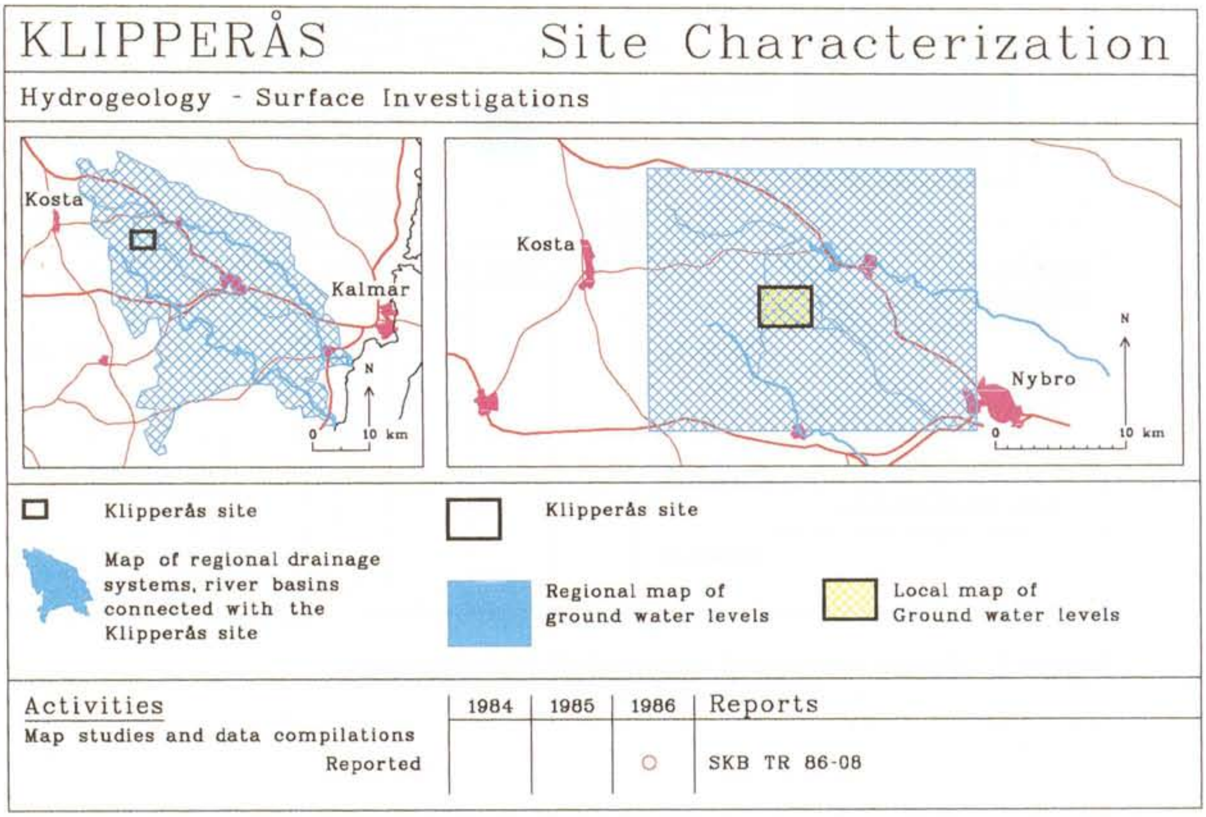


Figure 3. Regional geologic and tectonic studies. Left – area investigated for lineament analysis. Right – extent of the regional geologic map together with the areal extent of the Klipperås site.

Available geological maps for the Klipperås site and its surroundings are map sheets "Lessebo" (Holst, 1876) and "Lenhofda" (Holst, 1893) in the scale of 1: 200 000, and a geological map in the scale 1:200 000 covering the topographical map sheets "Lessebo", "Kalmar", "Karlskrona" and "Ottenby" (Hedström and Wiman, 1906). A recent compilation map in the scale of 1:250 000 exists for the Kalmar county (Bruun et al., 1991).

Hydrology

Based on data from SMHI:s stations the hydrometeorological conditions of the Klipperås region was compiled (Gentzschein, 1986). This compilation included temperature, precipitation, evapotranspiration, water run-off, and gross water budget. The report by Gentzschein (1986) also includes maps of regional and local drainage systems, as well as regional (500 km^2) and local (12 km^2) maps of groundwater levels. The areal extent of these maps is shown in Figure 4.



Activities	1984	1985	1986	Reports
Map studies and data compilations Reported			○	SKB TR 86-08

Figure 4. Left – regional and local maps of groundwater table. Right – extent of maps showing the regional and local drainage systems.

Geophysical subregional survey

A subregional survey, covering 14 km^{14} was made to locate the site for the detailed measurements. This survey consisted of ground geophysical magnetic, VLF and slingram measurements. The objective was to identify regional fracture zones and lithological boundaries and to provide some estimates regarding their character (mainly dip estimates). Systematic measurements were performed along E–W profiles with a line separation of 100 meters, and a distance of 20 meters (5 meters for the magnetometer measurements) between measurement points. In addition, the subregional survey included 14 N–S trending profiles.

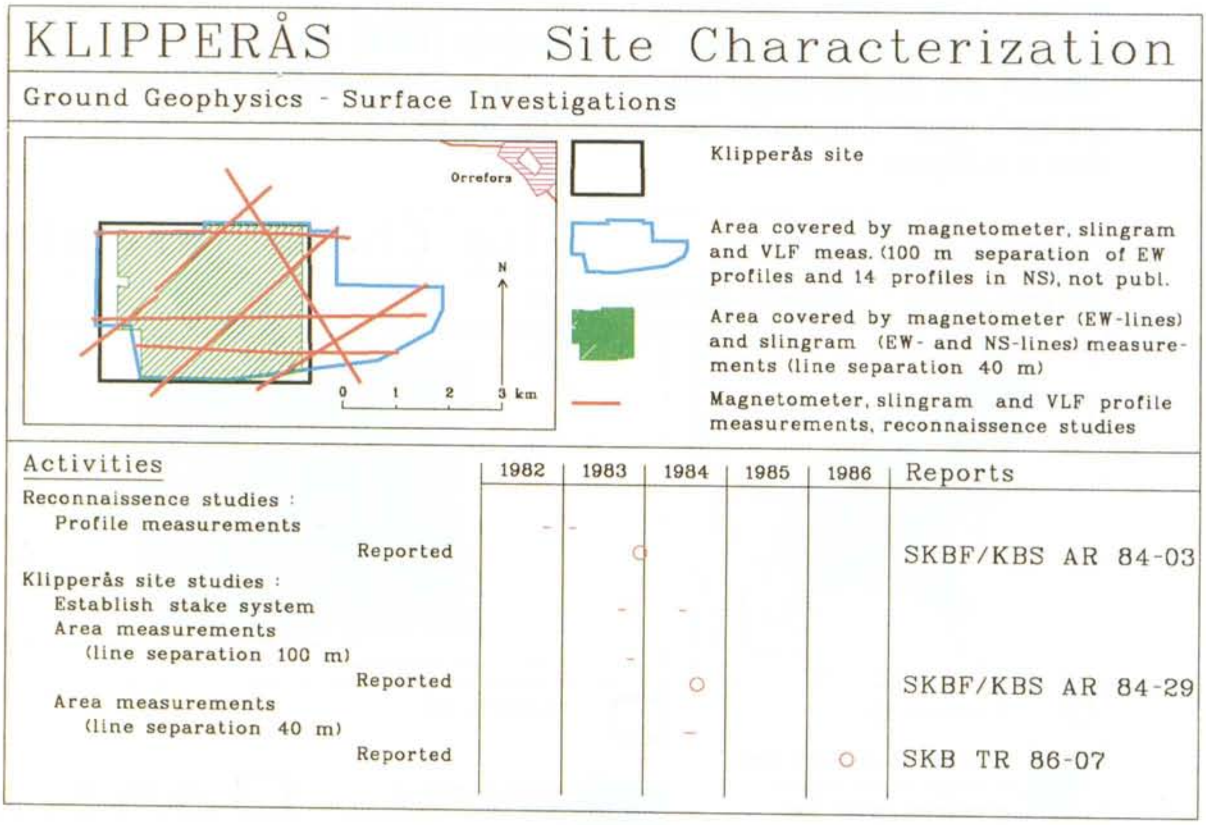


Figure 5. Extent of ground geophysical measurements.

3.3 Surface investigations - Klipperås study site

Geology

The exposed bedrock at Klipperås forms only a per mill of the study site. The bedrock mapping therefore only included data from less than 30 outcrops within the 3 x 4 km large study site (Olkiewicz and Stejskal, 1986).

Geophysical surface surveys

A detailed geophysical survey was made within a ca 9 km^2 square, Figure 5, located in the central part of the site (Sehlstedt and Stenberg, 1986). The objective was to map lithological boundaries and to identify fracture zones. The Klipperås study site is the first area where detailed electro-magnetical (Horizontal Loop EM) measurements have been performed in two perpendicular directions, in this case with measurement lines trending E-W and N-S. Magnetic measurements was performed along E-W trending lines. The surveys were made in grid systems with a separation of 40 m between survey lines and a station spacing of 10 and 20 m for the magnetical and electromagnetical measurements, respectively. The following type of geophysical instruments was used (see also Figure 5):

- protonmagnetometer
- slingram 18 Khz

The magnetic and electromagnetic data was judged good and consequently the results was used with confidence to identify magnetic rock types and fracture zones, using petrophysical characteristics of the different rock types (Stenberg, 1986).

3.4 Percussion boreholes

Percussion drilling were used to investigate possible fracture zones interpreted from geophysical measurements and from lineament studies. In total 14 percussion boreholes (Egerth, 1986) were drilled with borehole lengths varying between 66 - 150 m, Table 1. A map showing the locations of the percussion boreholes, including time-tables for activities in these boreholes, are presented in Figure 6.

Inflow and groundwater capacity

Identification of fracture zones intersected by the percussion boreholes were made from anomalies in drilling rates and from locations of major groundwater inflows (Gentzschein, unpublished data, SKB-archive).

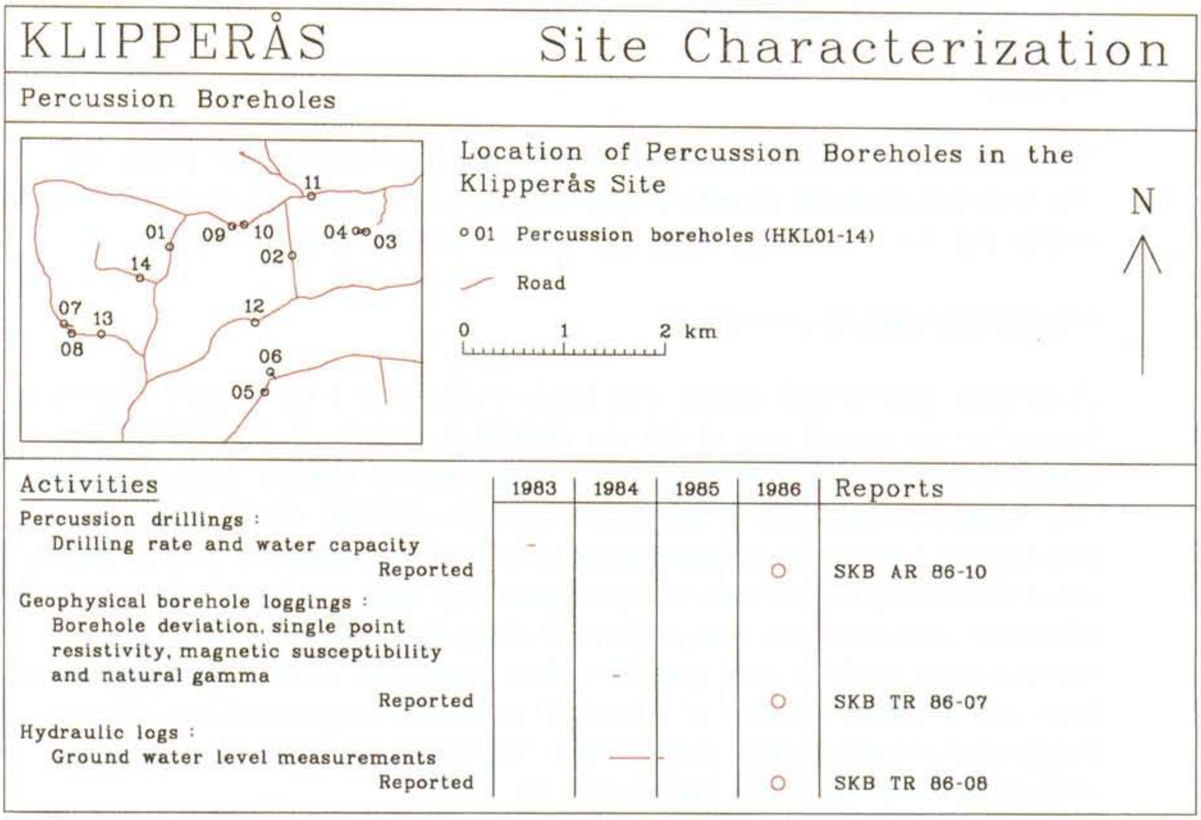


Figure 6. Location of percussion boreholes and activities.

Borehole geophysical logging

The percussion boreholes in the Klipperås site was logged with the following methods; borehole deviation, natural gamma radiation, single point resistance, and magnetic susceptibility. Data are not stored in the SKB database, see Chapter 4.

Sehlstedt and Stenberg (1986) presents a brief interpretation of the lithology and fracture zones in the percussion boreholes based on the geophysical logs. These results have been used in the geological and structural interpretation of the site (Olkiewics and Stejskal, 1986).

Hydraulic tests/measurements

The percussion boreholes were used to monitor the variations in the groundwater table for the period March–Nov. 1985 (Gentzschein, 1986). This was made in sectioned–off holes. In 11 percussion boreholes a packer was installed about 12 – 18 m below the groundwater level. This made it possible to monitor variations both in the groundwater table in the upper part of the bedrock and the groundwater head in the deeper groundwater.

Table 1. Percussion boreholes at the Klipperås site. Water capacity refers to total capacity for the borehole (Gentzschein, unpublished data). Zero water capacity refer to a "dry borehole" or only insignificant inflow. Major inflow refer to location of individual strong inflows.

No (HKL)	Direction/Dip		Length/Depth (m)		Water capacity l/h	Major inflow (m)
01		/90	66	/66	3 700	5,16,22,30,53,60
02		/90	150	/150	550	6,47
03	N90E	/50	96	/62	2 500	53
04	N90W	/50	99	/63	4–5 000	6,36,49,60
05	N40W	/50	90	/58	3 600	3,48,69,90
06	S40E	/50	150	/96	2 000	58,61,141,146
07	N90W	/50	99	/63	7 000	12,47,57,68
08	N90E	/50	93	/60	20 000	29,37,52,69
09	S70E	/50	77	/50	20 000	16,40,53,56,63
10	N70W	/50	100	/64	6 000	8,27
11		/90	100	/100	3 000	30
12		/90	100	/100	2 500	3,27,40,54,83
13		/90	100	/100	5 000	21,28,51,97
14		/90	100	/100	3 500	35,81

3.5 Cored boreholes

A total number of 14 cored boreholes have been drilled at the Klipperås site (Figure 7) down to a maximum vertical depth of 943 m. Most boreholes are drilled inclined (Table 2). The main objectives was:

- to test and improve the preliminary geological–tectonical model obtained from the geophysical surface survey
- to obtain data of the hydraulic characteristics of different hydraulic units (rock mass, rock types and fracture zones).
- to obtain groundwater samples from different depths and in different hydraulic environments.

To fulfil these objectives most of the boreholes were directed to intersect interpreted fracture zones or dykes at depth (Olkiewicz and Stejskal, 1986, Sehlstedt and Stenberg, 1986). A map showing the locations of cored boreholes is presented in Figure 7. The drilling periods is shown in Figure 8. Detailed break–downs of activities in each borehole are presented in Appendix A.

Table 2. Cored boreholes at the Klipperås site.

No (KKL)	Direction/Dip	Length (m)	Vertical depth (m)
01	S46E /80	564	553
02	N82W /78	959	940
03	N85E /60	250	219
04	N71W /59	200	168
05	N76E /56	246	204
06	N84W /56	808	667
07	N40W /57	250	214
08	S78W /58	266	225
09	N60W /56	801	664
10	N90E /49	203	153
11	N07W /57	251	210
12	N14W /50	730	560
13	N22E /55	700	570
14	N02E /55	705	572

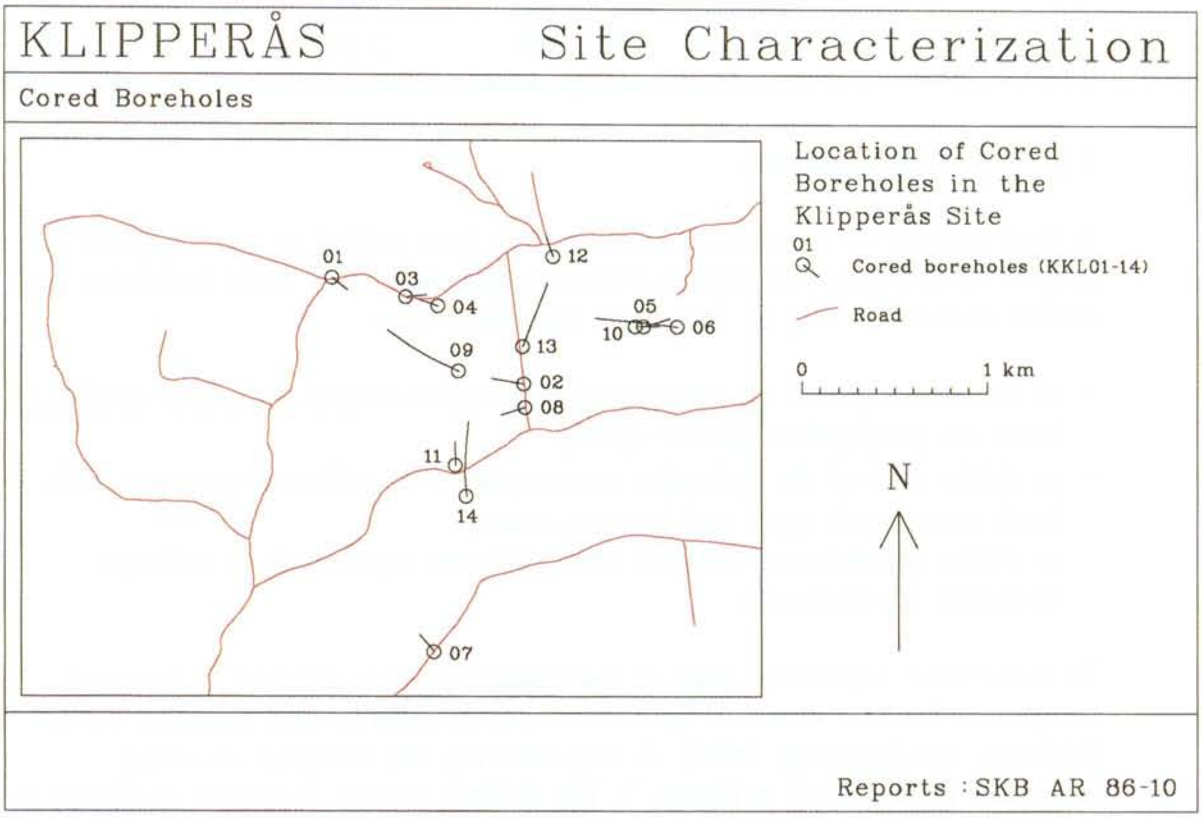


Figure 7. Location of cored boreholes.

3.6 Core logging and petrophysical measurements

The drill cores were mapped with respect to rock types, fractures and fracture minerals. In total, the drill cores from Klipperås amounts to 6 933 m. The core mapping data, except for descriptions of rock types, was stored on discs using a computerized system (Almén et al., 1983). Detailed print–outs in a scale of roughly 1:30 is available in borehole reports (Egerth, 1986). Generalized results concerning fracture frequency and rock types are presented in Olkiewicz and Stejskal (1986). The computerized storage (now transferred to the SKB database GEOTAB) include data on:

- rock type
- intersection angle between lithological contact and core axis
- type of fracture (sealed, fresh or coated)
- intersection angle between fracture and core axis
- fractured section (more than 10 fr/m)
- crushed section
- core loss
- fracture mineral
- short comment

Samples and analyses of fracture minerals from the cores was taken in order to reveal the tectonic history of the area, the effect of recharge water on the fracture minerals and the depth of recharge water influence in the bedrock and the fracture zones. Stable isotope analyses on calcite fillings was carried out and used as a tool to describe variations in the water circulation (Tullborg, 1986). Carbonate samples from open fractures in crystalline rock have been analyzed for their ^{14}C contents using accelerator mass spectrometry. The purpose was to get knowledge about water/mineral interactions along the groundwater flow paths and to what depth modern carbonate has been transported by the groundwater (Possnert and Tullborg, 1989).

Core samples for petrophysical measurements (in total 196 samples) were taken from boreholes KKL02 and KKL09 (Stenberg, 1986). The samples were measured with respect to:

- density
- magnetic susceptibility
- remanent magnetization
- resistivity
- induced polarization
- porosity

The density values were determined by weighing the sample in water and in air. Porosity values were obtained by weighing fully saturated samples and then re-weighing the samples after drying in an hot oven. A description of the methods used is presented by Öqvist and Jämtlid (1984).

3.7 Geophysical logging

The following "standard" set of geophysical logs were used in the cored boreholes at Klipperås (see Figure 8 and Appendix A):

- borehole deviation
- natural gamma radiation
- single point resistance
- resistivity, normal 1.6 m
- resistivity, lateral 1.65 m
- self potential
- temperature
- resistivity of borehole water (salinity)
- magnetic susceptibility
- sonic

The results from the geophysical logging are reported in the scale 1:5 000 (Sehlstedt and Stenberg, 1986). The extent of geophysical loggings made in each of the cored borehole are presented in Appendix A.

Tube-wave measurement was performed in borehole KKL02 in order to establish the location of permeable fractures for the in-situ hydrochemical sampling (Stenberg, 1984).

3.8 Hydraulic tests and monitoring

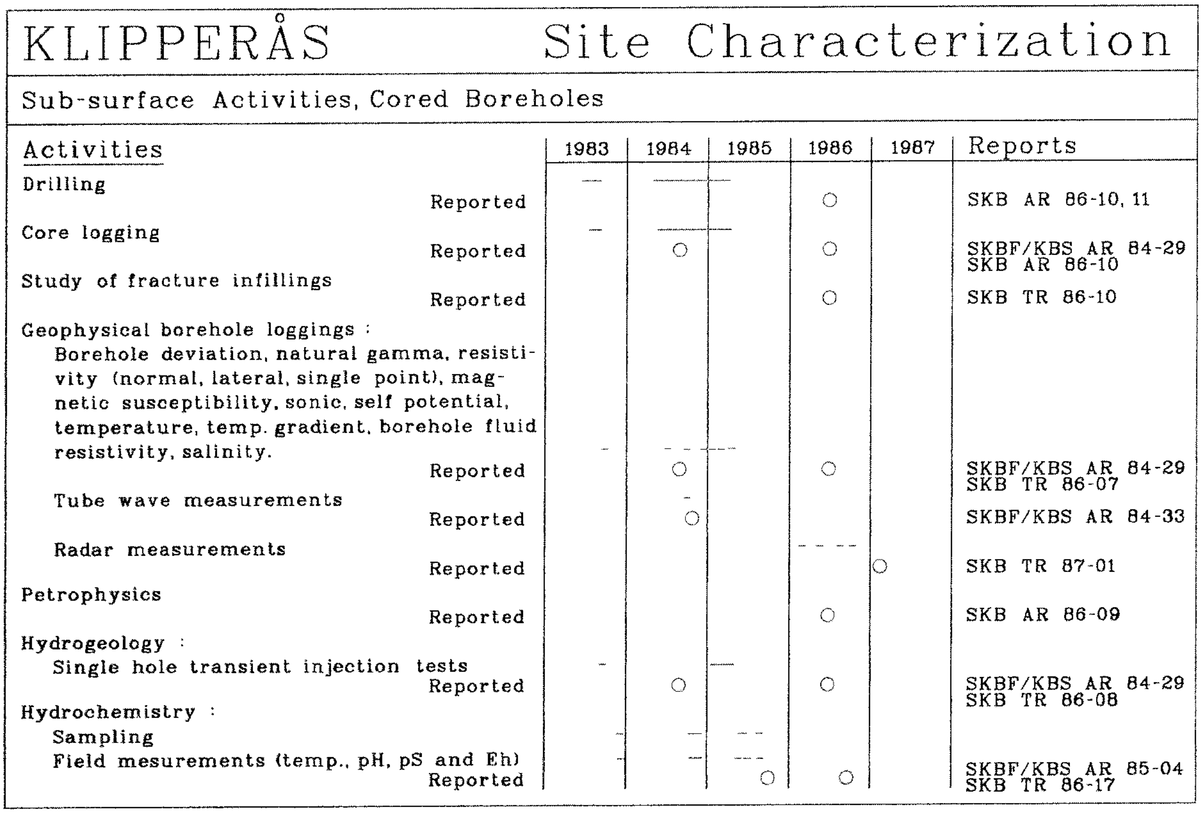
Water injection tests

The hydraulic conductivity of the bedrock has been determined by single hole water injection tests in packed-off sections in the cored boreholes, Figure 8. The majority of these measurements were made in 20 m sections throughout the boreholes from 10 - 30 m below the ground surface down to c. 10 m from the bottom of the boreholes. In total, 220 sections with a length of 20 m and 21 sections with a length of 25 m were tested, c.f. Section 6.1. To obtain detailed information in crushed and fractured parts of the bedrock totally 62 measurements in 5 m section length were made. Eleven single packer tests were also made to measure the average hydraulic conductivity from the packer to the bottom of the borehole.

All tests were transient injection tests at constant head, with a 2 hour injection period followed by a 2 hour recovery period. The hydraulic testing methods and results are presented in Gentzschein (1986). The activity periods for the hydraulic tests are presented in Figure 8. Scope of water injection tests in the different boreholes is presented in Appendix A.

Groundwater head measurements

The location of the groundwater table was measured during most part of 1985 in the cored boreholes. The groundwater head in sections in the deeper parts of the bedrock was estimated from the pressure recovery phase of the water injection tests.



KLIPPERÅS Site Characterization

Sub-surface Activities, Cored Boreholes

Activities		1983	1984	1985	1986	1987	Reports
Drilling	Reported				○		SKB AR 86-10, 11
Core logging	Reported		○		○		SKBF/KBS AR 84-29 SKB AR 86-10
Study of fracture infillings	Reported				○		SKB TR 86-10
Geophysical borehole loggings : Borehole deviation, natural gamma, resistivity (normal, lateral, single point), magnetic susceptibility, sonic, self potential, temperature, temp. gradient, borehole fluid resistivity, salinity.	Reported		○		○		SKBF/KBS AR 84-29 SKB TR 86-07
Tube wave measurements	Reported		○				SKBF/KBS AR 84-33
Radar measurements	Reported					○	SKB TR 87-01
Petrophysics	Reported				○		SKB AR 86-09
Hydrogeology : Single hole transient injection tests	Reported		○		○		SKBF/KBS AR 84-29 SKB TR 86-08
Hydrochemistry : Sampling Field mesurements (temp., pH, pS and Eh)	Reported			○	○		SKBF/KBS AR 85-04 SKB TR 86-17

Figure 8. Activity periods - drilling, core logging, geophysical logging and petrophysical measurements of core samples, hydraulic measurements, and groundwater sampling in cored boreholes.

3.9 Groundwater sampling

Groundwater sampling was made in one isolated section in borehole KKL01, six sections in KKL02, and one section in KKL09. The chemical characteristics of the groundwater sampled in these sections are presented by

Laurent (1986) and Smellie et al. (1985 and 1987). Locations of sampled sections and chemical characteristics are discussed in Chapter 7.

3.10 Extent of rock mechanics investigations

No rock mechanics investigations have been conducted at the Klipperås study site. Tube-wave measurements in borehole KKL02, Stenberg (1984), allowed a very crude estimate of the dynamic rock mass modulus and the dynamic Poisson's ratio.

3.11 Studies in the Klipperås study site after main site investigations

This section lists studies that were made at Klipperås or using data from Klipperås after the main site characterization was terminated in 1985.

- Borehole radar measurements (Carlsten et al., 1987) was performed in 10 out of the 14 cored boreholes at Klipperås.

- Representativity of groundwater chemical samples at various depths in relation to existing hydraulic conditions (Smellie et al., 1987).

- Correlations between hydraulic conductivities and fracture characteristics were studied using multivariate analysis by Andersson and Lindqvist (1989).

- Some results from the study above were included in a comprehensive evaluation of experiences gained from the borehole radar surveys (Carlsten et al., 1989). The latter study was performed as a comparison between borehole radar interpretations and multivariate analysis of geological, geophysical and hydrogeological borehole data.

- A ^{14}C study was performed by Possnert and Tullborg (1989) to study the interaction between groundwater and calcite in open fractures.

General results

The borehole radar investigation performed in the Klipperås study site (Carlsten et al., 1987) confirmed the existence of the previous interpreted fracture zone configuration. The survey also indicated the existence of a more densely configuration of minor radar reflectors, with a mean separation less than 100 m. Most radar detected structures in the Klipperås study site trend E-W and have vertical to subvertical dips. A large part of these structures are dolorite dykes and greenstones. This indicates that the greenstones form sheet-like structures and are not isolated fragments as assumed in the geological model of the site (cf. Olkiewics and Stejskal, 1986). Somewhat surprising, the borehole radar only identified some 25 % of the frequently occurring aplitic and Småland porphyry dykes mapped in the drill cores. A subhorizontal fracture zone (Zone H1, Figure 15) was indicated by the borehole radar measurements to trend N–S and dip 20° towards the west.

The results from the hydrochemical study are discussed in Chapter 7.

The statistical study by Andersson and Lindqvist (1989) showed that sub-horizontal fractures in granite generally have a high positive correlation to sections with increased hydraulic conductivity and that the hydrogeological properties of different rock types vary considerably within the site. They also found a positive correlation between the occurrence of fracture infillings of Fe–oxyhydroxides and increased hydraulic conductivity.

The majority of the radar reflecting structures in the Klipperås site are correlated with low resistivity borehole sections. Most radar reflectors (65 %) are associated with lithological contacts, others are associated with fractured zones.

The ^{14}C study (Possnert and Tullborg, 1989) indicates that there is an extensive downwards percolation of groundwater in the bedrock. The content of ^{14}C in the groundwater decreases rapidly at very shallow depths. This is especially accentuated across the calcite dissolution–precipitation transitional zone at a depth of 50–150 m. They also present an alternative explanation involving two separate aquifers: extensive circulating water down to 100 to 200 m and stagnant water below.

4. STORAGE OF INFORMATION IN THE SKB DATABASE

Data from surface surveys

All geophysical surface measurements are stored in the SKB database GEOTAB. Other "surface data", such as geological maps, lineament interpretations, depth of overburden, hydrometeorological data and groundwater level maps, are not stored in the database.

Data from borehole surveys/tests

Most data from the cored boreholes, such as geological and geophysical surveys, hydrological tests and hydrochemical investigations, are stored in GEOTAB. Stored data consist of borehole geometrical data (coordinates, length, dip, deviation etc), core loggings, petrochemical analysis, "standard" geophysical logs, petrophysical measurements, single hole hydraulic packer tests and chemical analyses from sampled groundwater. For the percussion boreholes the database also includes groundwater level monitoring.

A description of stored data from surveys in each cored borehole are presented in Appendix A (under the heading GEOTAB in Figures A2–A15).

The following borehole measurements/sampling/analysis are **not stored** in the database:

Percussion boreholes. Recorded drilling rates or data regarding drilling debris are not stored. The data base does not contain any information regarding the locations of major groundwater inflows and total yields in the boreholes.

Geological analyses. No analyses of fracture minerals are stored. This also applies to data concerning mineralogical compositions (thin sections) of the bedrock.

5. GEOLOGIC MODELS

5.1 Regional geologic models

Geology

The oldest rocks (about 2 000 Ma old) in the southeasternmost part of Sweden, i.e. central Småland, are strongly metamorphosed Svecokarelian metasediments, metavolcanics, and early granitoids. These rocks were between 1 650 - 1 810 Ma ago (Lundqvist, 1991) intruded by a suite of Småland granites and associated volcanic rocks which today compose the main part of the bedrock in the region (part of the Trans-Scandinavian Igneous Belt), Figure 9. The Småland granite suite has been intruded at a few localities, e.g. Karlshamn and along the coast at Oskarshamn (Blå Jungfrun to Götemar), by reddish massive and often coarse-grained 1 350 - 1 400 Ma old granites of Rapakivi type. The Götemar granite has an anomalous high U-Th content.

The Småland granites are intruded by several generations of dykes. Common are NW to NNW trending dykes of Småland porphyries older than 1 420 Ma and of granitic-granodioritic-monzonitic composition. In marginal areas these intrusions occur as composite dykes and contain also more basaltic intrusions. The later are represented by uralitic dolorites, some are often porphyritic. In the central and the eastern Småland such dykes trends NE to ENE.

The youngest intrusive rocks are N-S trending 960 - 980 Ma old dolerite dykes. These dykes have a regional appearance and are mappable from Blekinge in the south and in under the Scandinavian mountains in the central part of Sweden.

Southwestern Sweden, less than 75 km to the west of the Klipperås study site, was submerged and deformed during the Sveconorwegian orogeny (cf. the Grenvillian orogeny) for ca 1 200 - 900 Ma ago. Southeastern Sweden was at least in its border regions distorted by this tectonic episode. Rocks of the Almesåkra Group (see below) were thrusted eastwards. Subhorizontal faultplanes have also been identified further to the east.

The Småland suite of granitoids and volcanics was at least in its western part covered by sedimentary rocks of the Almesåkra Group; locally a more than 1 200 m thick sequence of 1 100 - 1 300 Ma old sediments dominated by feldspatic sandstones (Rodhe, 1987).

At about 700 - 850 Ma ago the Visingsö sediments, which at least in some parts are fault related (debris flows), were deposited west of the Almesåkra formation. These sediments are now found in the Vättern graben.

At the end of the Precambrian the region was extremely flat and had a relief less than 20 m; the sub-Cambrian peneplain was formed. During the Cambrian the sea transgressed and shallow sea sediments were deposited. The sedimentation continued at least into the Silurian. Minor synsedimentary faulting occurred during the Cambro-Ordovician periods. Clastic Cambro-Ordovician dykes trending ENE (dominant), NNE and N-S (subordinate) are reported (Nordenskjöld, 1944). During late Paleozoicum the bedrock was gently tilted towards the east. The sedimentary cover were then eroded and the present land surface comprises in large parts the sub-Cambrian peneplain. The base of the Paleozoic sediments is now found along the east coast.

Description of the regional geology are presented by, e.g. Magnusson et al. (1960) and Lundqvist (1991). Description of rock types are found in descriptions of geological map, e.g. Persson (1974), Lundegårdh et al. (1985), and Rodhe (1987). Geomorphological descriptions are presented by, e.g. Nordenskjöld (1944), Rudberg (1954), Elvhage and Lidmar-Bergström (1987), and Lidmar-Bergström (1988).

Lineaments

Lineaments visible on aerial photographs are shown in Figure 10. Two large lineaments of regional extension, oriented NW-SE, can be distinguished about 5 km northeast and 9 km southwest of the Klipperås study site. These lineaments are considered to be of regional importance. The existence of the northern regional lineament was confirmed by mylonites and slickensided granite in outcrops along the lineament.

There are a few distinct lineaments within the Klipperås study site. These coincide rather well with interpreted fracture zones and/or dolerite dykes (c.f. Figure 12 and 13).

Note that the lineament map used in the generic groundwater modelling described in Chapter 6 are simplified maps made by Lindbom et al. (1989). These maps are deduced by combining the lineament map presented by Olkiewicz and Stejskal (1987) and a regional lineament interpretation based on satellite information (Ehrenborg, 1977).

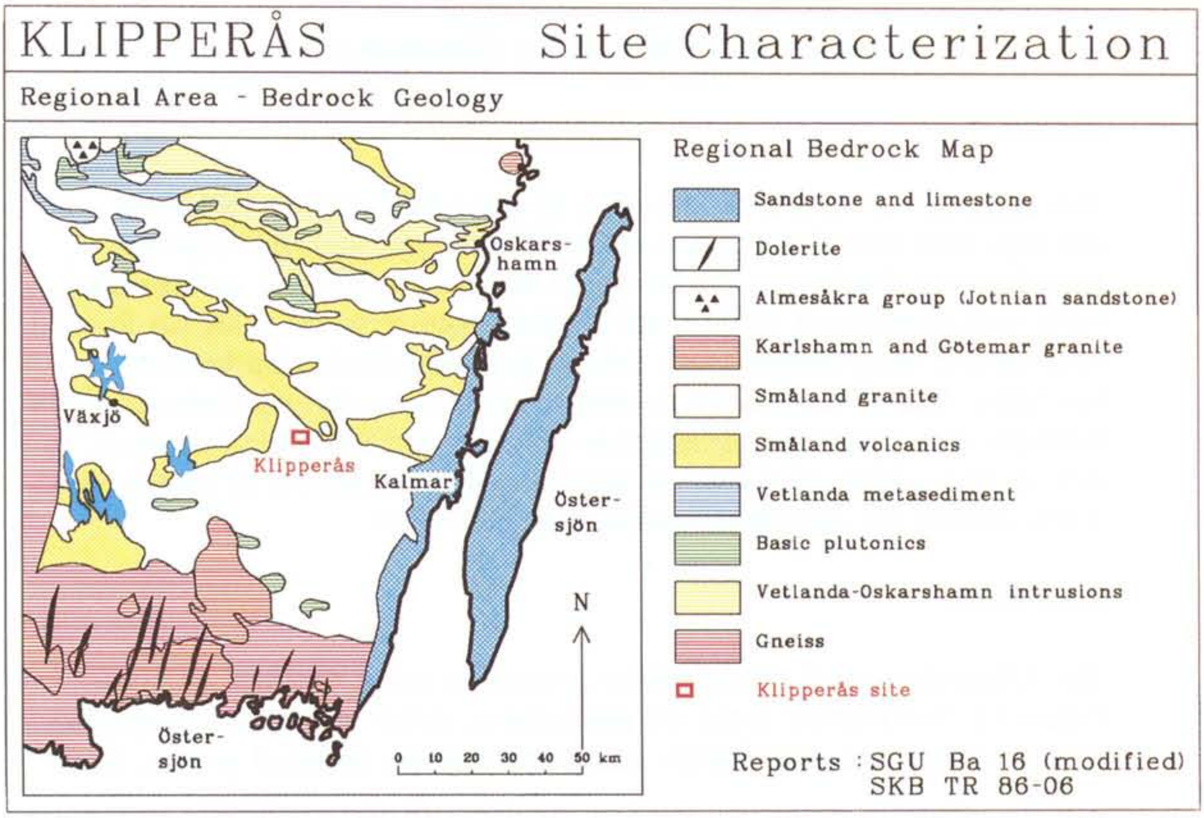


Figure 9. Distribution of rock types in the Klipperås region.

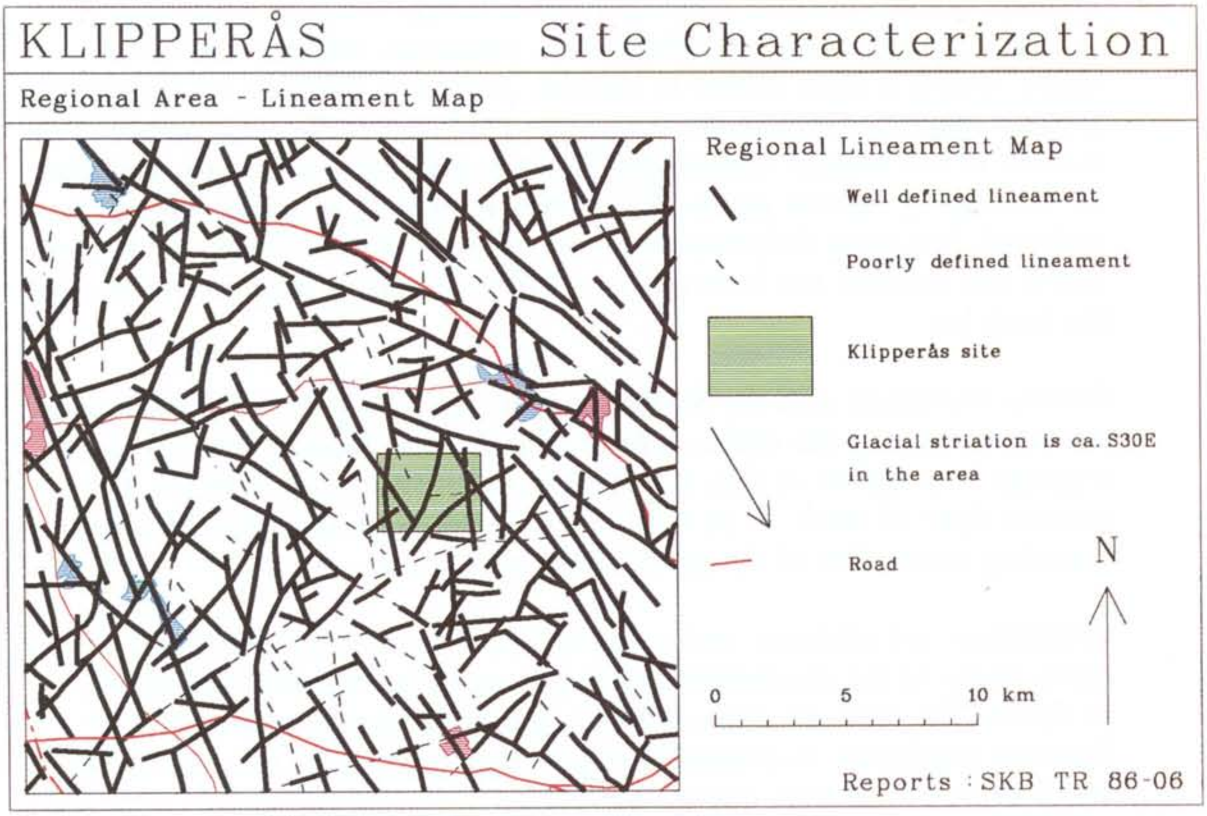


Figure 10. Lineaments in the Klipperås region interpreted from aerial photos (from Olkiewicz and Stejskal, 1986).

5.2 Geological characteristics of the Klipperås site

General

The Klipperås study site differs from all other SKB sites in its lack of outcrops (less than 30 outcrops in the 12 km^2 large site). Interpretation regarding the distribution of rock types therefore had to rely on borehole cores and geophysical surface and borehole measurements. This has implied considerable uncertainties when interpreting rock distribution between boreholes. Due to the lack of oriented cores there is also uncertainties in the borehole data concerning orientations of dykes and lithological contacts, as well as true widths of dykes. All these uncertainties should be kept in mind when reading the conceptual model presented below.

Rock types

The Klipperås area is dominated by granite, so called Småland granite, Figure 11. Subordinate rocks are greenstones, dykes of Småland porphyries, dolerite dykes, and aplite dykes associated with the Småland granite, Table 3.

The Småland granite is normally greyish red, medium-grained and massive, although a weak foliation trending E-W is locally observed. The rock forming minerals are quartz, plagioclase, potassium feldspar, and some biotite, which is often altered to chlorite. Accessory minerals are muscovite, epidote, sphene, pyrite, and/or magnetite. Fluorite was found as an accessory mineral in one sample. Quartz demonstrates undulatory extinction, common for secondarily formed grains. The granite is strongly magnetic when it is unaltered, but along deformation zones, e.g. semi-ductile zones and fracture zones, the wallrock has been oxidized and the magnetic character of the rock has been lost.

Closely associated with the Småland granite are light red, fine grained aplitic dykes, constituting the oldest dykes within the site. Judging from the core loggings they appear as thin, 0.5 m wide, dykes with sharp contacts. One extreme dyke of about 10 m width has however been identified. No data regarding orientation of the aplitic dykes is reported.

Greenstones are schistose and represent a number of originally different rock types. Some of the greenstones are considered to be xenoliths and others to be dykes. The latter are meta-dolerites and occur together with dykes of Småland porphyries as composite dykes. Main minerals in the greenstones are chlorite, plagioclase, quartz and epidote.

The dykes of Småland porphyries exhibit variable chemical compositions: granitic–granodioritic–monzonitic. As mentioned above, these dykes are associated with meta–dolerites and the contact between them is always sharp and often tectonically disturbed. The dykes of Småland porphyries are considered older than the meta–dolerites. The main minerals are phenocrysts of plagioclase, microcline, and locally quartz, in a groundmass of quartz and feldspar. Accessory minerals are chlorite, epidote, ore minerals, and apatite. The width of the dykes are usually about 10 m and they are oriented E–W to WNW with steep dips (75 - 90^0) towards the south.

The youngest rock encountered in the area are rather well–preserved dolerite dykes, about 900 Ma in age. They exhibit relatively well–preserved textures. Three types of dykes was encountered at the site, firstly a strongly magnetic dolerite, with the main minerals plagioclase, augite, and olivine. Secondly an uralite (i.e. altered) dolerite, with the main minerals plagioclase, amphibole, and biotite, and thirdly a strongly magnetic alkaline dolerite with the main minerals pyroxene, olivine, and biotite. The third type has a well preserved primary mineralogy and structure. The width of these dykes varies from about 1 m to 10 m. However, there is one exception, a 100 m wide dyke indicated by the geophysical surface measurements. This interpreted dyke has not been controlled by drilling. The orientation of the basic dykes varies from N to NE. Northerly oriented dykes are interpreted to dip 80 - 90^0 towards west, while northeasterly dykes dip 65 - 90^0 towards east. The location of interpreted dykes are presented in Figure 12.

Table 3. Distribution of rock types in the cored boreholes at the Klipperås site. Age of rocks decreasing upwards.

Rock type	% of the length of all drill cores
Dolerite dykes	1.5
Småland porphyry dykes	5.5
Aplite	1
Småland granite	85
Greenstone	7

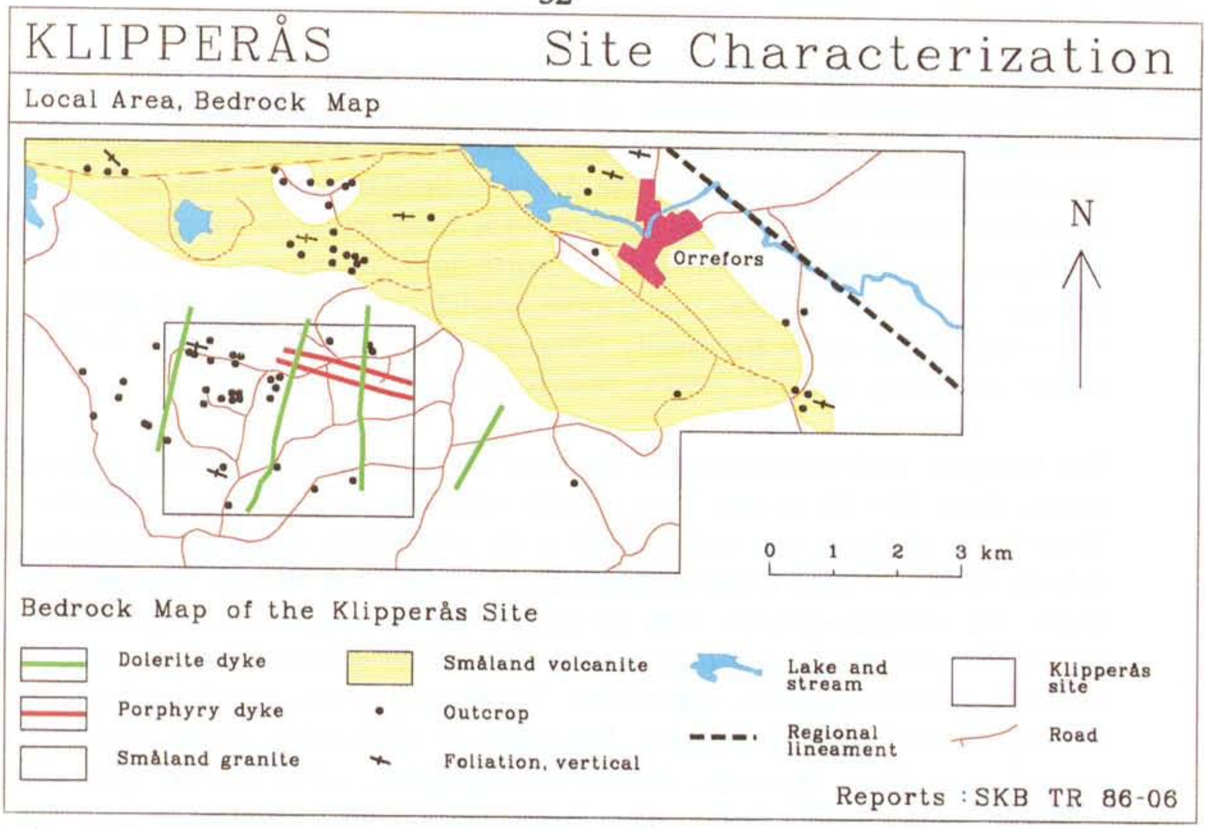


Figure 11. **Generalized map of the bedrock at the Klipperås study site and its surroundings.**

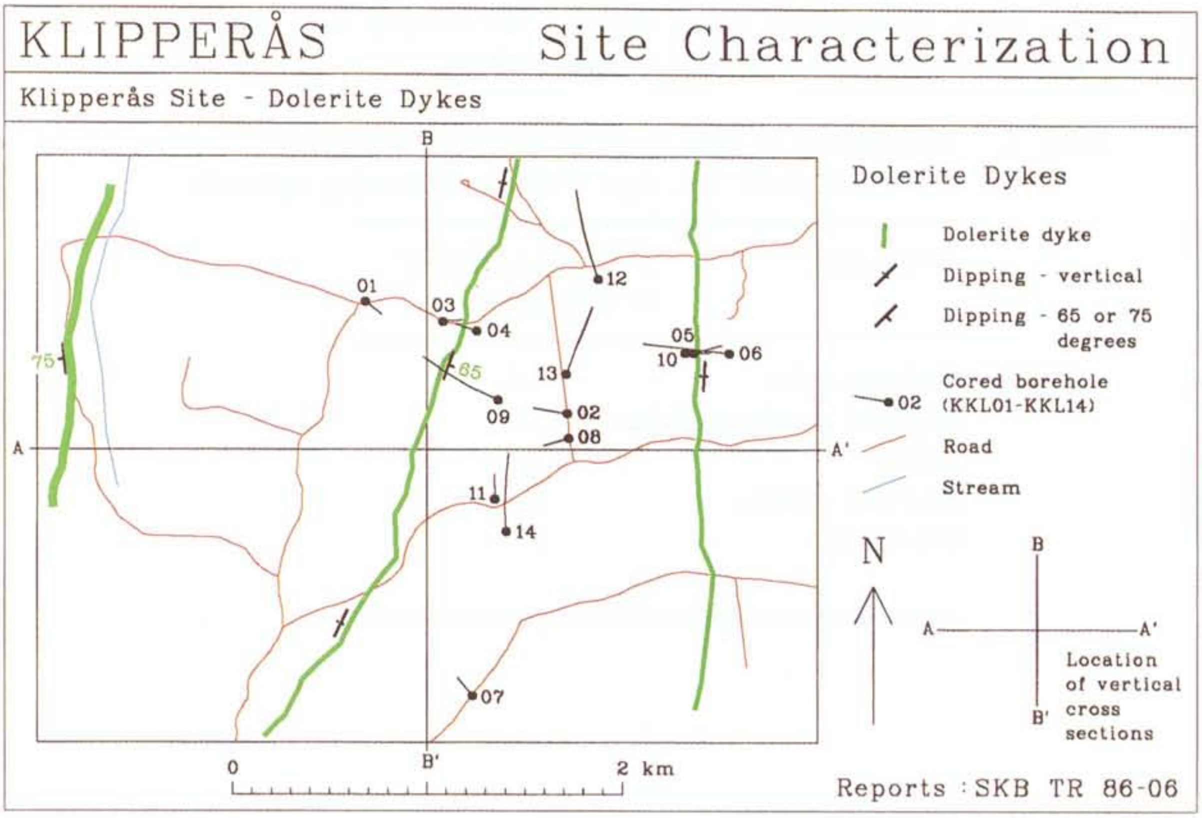


Figure 12. Dolerite dykes at the Klipperås site.

Fractures

The average fracture frequency for various rock types, irrespective of depth in the drill cores, is lowest for Småland granite with 4.3 fr/m, followed by aplite dykes with 7.4 fr/m, dykes of Småland porphyries with 7.5 fr/m, greenstone with 10.0 fr/m, and dolerite dykes with 6.4 - 18.7 fr/m.

The location of sections with high fracture frequency in each of the cored boreholes is presented in Appendix B.

Common fracture filling minerals in the cores are chlorite, epidote, hematite, calcite, muscovite/illite, quartz, adularia (alkali-feldspar), and pyrite. In the upper 100 m of the bedrock, dissolution of calcite has occurred and rust minerals (Fe-oxyhydroxides) have been precipitated (Tullborg, 1986). She also found that relative occurrence of calcite close to and within fracture zones are notably less than in the county rock away from the fracture zones. Infillings of Fe-oxyhydroxides in fracture zones are found down to depth of at least 400 m. In the greenstone and the dolerite dykes the clay mineral smectite has been identified together with calcite. The later is less affected by alteration than calcite in fractures in the Småland granite. The fracture infillings indicate that reactivation of fracture zones have occurred.

5.3 Fracture zones

Possible locations of fracture zones were interpreted from aerial photographs (scale 1:20 000), geological mapping and geophysical ground measurements. Fracture zones interpreted from these data were regarded as preliminary because of the flat topography in general, and because of the uncertainties due to the moraine cover and intense forestry.

Shallow percussion and cored boreholes were drilled to test interpreted zones. All interpreted fracture zones, associated with strong geophysical anomalies, were in these boreholes found to be either fracture zones or basic dykes or a combination of both. It should however be noted that the average spacing between the fracture zones, associated with these anomalies, are about twice as large as for other SKB sites. This might imply the existence of additional smaller fracture zones at Klipperås which has not been detected. This possibility is supported by the borehole radar measurements, see section 3.11.

The result of the surface and borehole studies in combination are 13 local fracture zones, Figure 13 and 15. Eleven zones have been examined by means of cored boreholes in a total of 15 different locations. A summary of all interpreted fracture zones, together with some of their properties, are presented in Table 4. Descriptions of each interpreted fracture zone are presented in Appendix C. This includes general geological characteristics for each zone, as well as the basis for the interpretation and its reliability (c.f. Bäckblom, 1989).

The fracture zones widths varies from 10.5 to 36 m, with a mean width of 20 m. The width was determined in the drill cores from the point where the fracture frequency increases markedly to the point where it returns back to its normal value. In order to calculate the actual width of the fracture zone, a correction has been made for the intersection angle between the borehole and the fracture zone.

Within the fracture zones there are, as a rule, one or more sections of crushed bedrock, generally one or a few decimetres wide, which often are clay altered and sealed. Red colouring of fracture surfaces due to oxidization is abundant. Commonly occurring fracture infilling minerals within the fracture zones are calcite, chlorite, clay minerals, epidote and quartz.

The locations of interpreted fracture zones at the ground surface are shown in Figure 13, while the locations at 500 m depth is shown in Figure 14. The fracture zones are usually steeply dipping, with the exception for one subhorizontal zone and one zone dipping 65° from the horizontal. North–south and east–west vertical cross–sections are shown in Figure 15. The interpreted locations of each fracture zone in individual boreholes are presented in Appendix B.

5.4 Validity of models

Rock type distribution

The geological map of the Klipperås site and its surroundings, Figure 11, should only be regarded as a generalized description of the rock type distribution. This is because the map is based on the very limited amount of outcrops correlated with ground geophysical measurements and to some extent borehole data.

Results concerning rock type distribution in boreholes have been compiled into 2D models of minor subareas and vertical profiles in the vicinity of the boreholes. However, these models have not been compiled into 2D or 3D models covering the whole site. This is because the distance between boreholes, and the lack of a detailed geological map of the site, do not permit interpolation of results between boreholes.

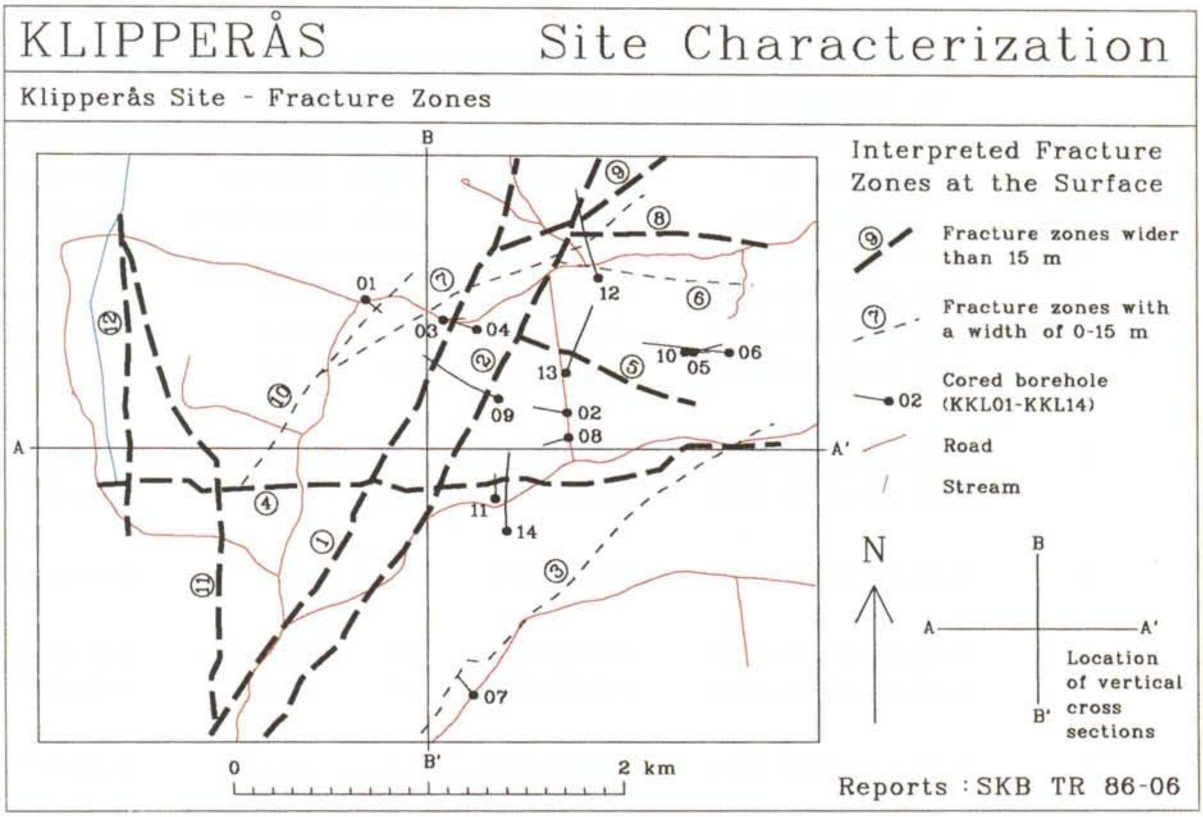


Figure 13. Interpreted fracture zones at the ground surface.

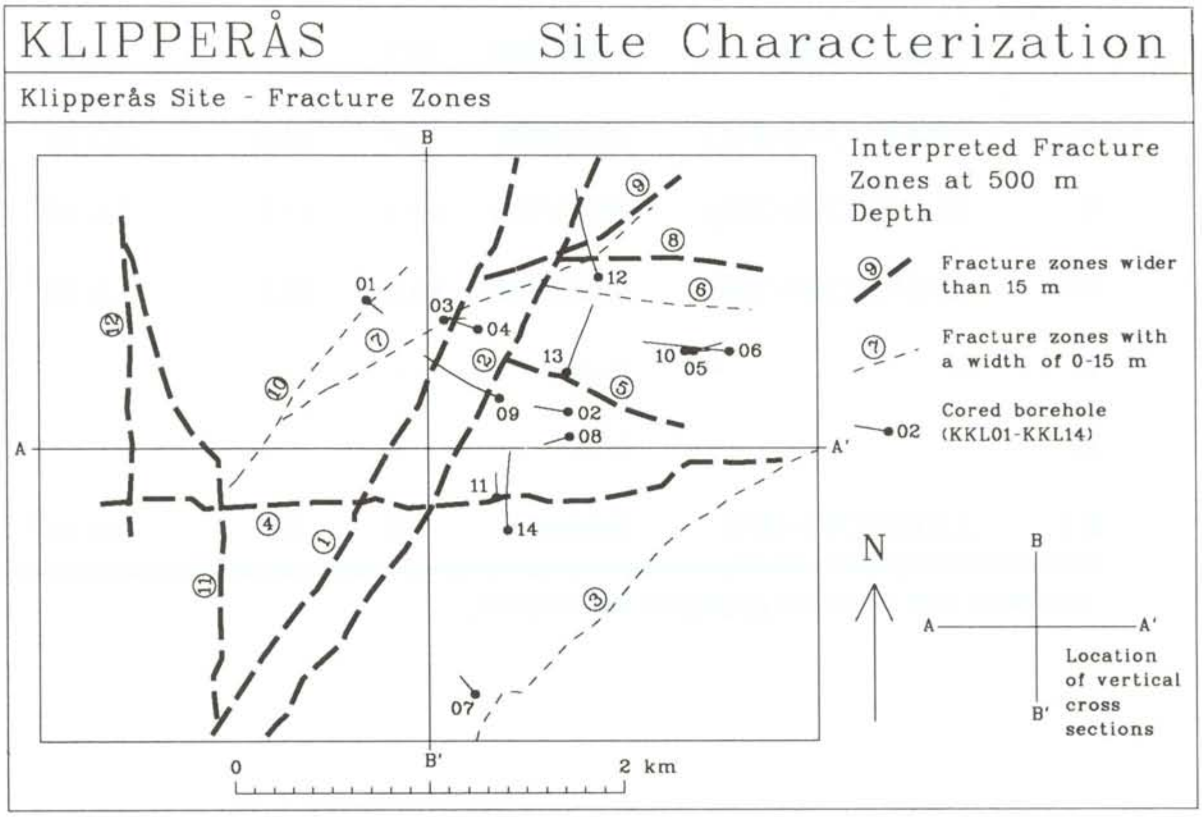


Figure 14. Interpreted fracture zones at 500 m depth.

Table 4. Geometrical data, hydraulic conductivities and fracture frequencies for interpreted fracture zones, Klipperås study site.

Fracture zone	Position in borehole (m)	Strike/Dip (degrees)	Width (m)	Fracture freq.(fr/m)	K–value (m/s)
1	KKL03 (140–195)	N–S/90	28	9.8	not tested
	KKL04 (110–180)	N20E/90	36	14.1	not tested
	KKL09 (615–665)	N30E/90	29	9.7	$3.1 \cdot 10^{-10}$
2	KKL09 (120–160)	N30E/90	22	8.2	$5.4 \cdot 10^{-7}$
	KKL12 (595–630)	N15E/85E	13	7.5	$9.6 \cdot 10^{-9}$
3	KKL07 (115–130)	N35E/65E	12	9.2	not tested
4	KKL11 (108–148)	N75E/90	23	12.4	not tested
	KKL14 (368–410)	N85E/80E	27	10.6	$3.9 \cdot 10^{-7}$
5	KKL13 (152–188)	N80W/75S	23	9.1	$7.5 \cdot 10^{-7}$
6	KKL12 (70–88)	N75W/75S	12.5	11.9	$4.4 \cdot 10^{-7}$
7	KKL12 (288–306)	N65E/80S	13.5	12.5	$2.5 \cdot 10^{-7}$
8	KKL12 (312–347)	N85W/90	28	10.6	$3.2 \cdot 10^{-7}$
9	KKL12 (362–384)	N60E/75S	17.5	13.2	$5.5 \cdot 10^{-7}$
10	KKL01 (280–310)	N45E/85W	10.5	10.2	$9.3 \cdot 10^{-7}$
11	– –	N–S*	–	–	–
12	– –	N–S*	–	–	–
H1	KKL02(792–804)	Subhoriz.	12	9.3	$2.0 \cdot 10^{-6}$

* Interpreted from the ground geophysical measurements.

The structural onprint on Småland granite and volcanites has generally been considered to be very insignificant. However, rather large parts of the rocks in the Klipperås site are altered, as indicated by ground magnetic measurements. The regional implication of this is not known.

The ground magnetic measurements also indicate block faulting. Rock blocks with different magnetic signature are separated by relatively broad zones of oxidized, low magnetic, rocks. The western part of the area shows a more homogeneous magnetic character, while the eastern part have an irregular pattern. This indicates that considerable amount of block faulting have occurred in the NNE trending zone intersecting the central part of the site.

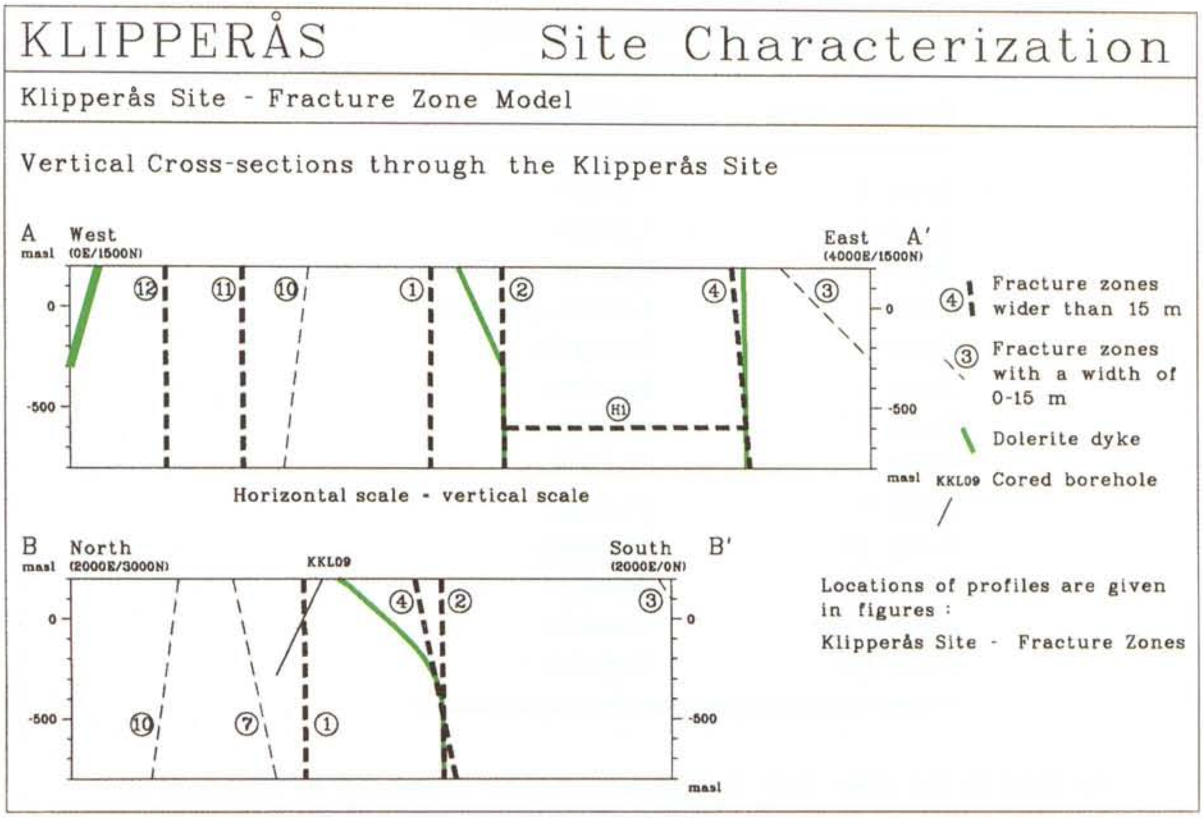


Figure 15. Vertical cross–sections through the Klipperås site. Locations of sections is indicated in Figures 12, 13 and 14.

Interpreted fracture zones

A description of each fracture zone is presented in Appendix C. This includes on what grounds the fracture zone has been interpreted, including a judgment regarding the reliability in the interpretation, mainly based on the nomenclature suggested by Bäckblom (1989). Also, intersections with interpreted fracture zones and boreholes are given, including main geologic/tectonic characteristics mapped in the drill cores or, for the percussion boreholes, amount of groundwater inflows. Three levels of reliability regarding the existence of each fracture zone are identified (from low to high reliability), possible, probable and certain, see Table 5.

Table 5. Reliability of interpreted fracture zones mainly according to the nomenclature of Bäckblom (1989).

Fracture zone	Reliability
Zone 1	Certain
Zone 2	Certain
Zone 3	Certain
Zone 4	Certain-possible
Zone 5	Probable
Zone 6	Possible
Zone 7	Possible
Zone 8	Possible
Zone 9	Possible
Zone 10	Probable
Zone 11	Possible
Zone 12	Possible
Zone H1	Probable

As seen in the table four interpreted fracture zones can be regarded as "certain", three can be regarded as "probable", and six are "possible" if one strictly follows the nomenclature by Bäckblom. However, the base information as revealed by the ground geophysical measurements, the core loggings, results from the percussion drillings, and especially the hydraulic tests performed in the cored boreholes indicates strongly that the geological-hydrological character of the site is not well understood and should be further investigated. For example, Zone 1 and Zone 2 most probably represent one 300 - 400 m wide zone which has been reactivated and Zone 1 and Zone 2 are the most deformed parts of the zone. This alternative interpretation might explain some of the discrepancy between many of the measured high conductivity values and the presented tectonic model of the site.

Average spacing of interpreted fracture zones at Klipperås is about twice as large as for other SKB study sites. The reason for this might be that available data only permits the geometrical definition of larger zones and that the smaller fractured sections in the boreholes therefore are omitted.

6. GEOHYDROLOGICAL MODELS

6.1 Available data and numerical model

The geoinformation used for hydraulic modelling at Klipperås consist of the conceptual models of lineaments and fracture zones on different scales, distribution of rock types in outcrops and in drill cores, hydrological and meteorological data, contour maps of the groundwater table and hydraulic conductivity data from single hole tests.

The geological and geophysical data from the Klipperås site are presented in Olkiewicz and Stejskal (1986) and Sehlstedt and Stenberg (1986), respectively, whereas the hydrogeological data are presented by Gentzschein (1986). The generalized interpretation of fracture zones and the conceptual models, used in the modelling, are presented in Winberg and Gentzschein (1987) and Lindbom et al. (1988 and 1989).

Table 6 presents the number of single hole water injection tests performed in the Klipperås site. To provide an estimate on "investigation density" also the number of tests per km^2 is presented in the table. Since no local domain was modelled at Klipperås the investigation density is in this case based on the area of the site (12 km^2). In total, 7 cored boreholes with vertical depths ranging from 553 m to 940 m were tested hydraulically (cf. Appendix A). The total borehole length covered by continuous double-packer tests (20 m and 25 m sections) at Klipperås is about 4900 m. In addition, double-packer tests in selected 5 m sections together with single-packer tests were carried out, see Table 6.

The geohydrological modelling at Klipperås is presented by Lindbom et al. (1988 and 1989). Steady-state groundwater flow calculations were performed using a model code based on the Finite Element Method described by Thunvik and Braester (1980) and Grundfelt (1983). A two-dimensional model of a regional section and a three-dimensional model of a subregional area were carried out. It should be observed that the regional and subregional areas used in the modelling do not coincide with the corresponding areas in the geological interpretation in Chapter 5. The basic assumption in the type of model used is that the bedrock can be represented by either one single continuum (porous medium) or by several overlapping continua, e.g. rock mass and fracture zones.

Model geometry and boundary conditions were obtained using hydrological data and topographical and groundwater table maps. Only more or less generic fracture zones were included in the groundwater flow model. The material properties, i.e. hydraulic conductivity, were derived from the single hole water injection tests.

Table 6. Number of borehole sections tested with different length together with number of tests per km^2 in the Klipperås site.

Number of sections	Section length (m)	No of tests* /km^2	Test type
21	25	1.7	double-packer
220	20	18.3	double-packer
62	5	5.2	double-packer
11	8-233	0.9	single-packer
314		26.2	all sections

* area of the site = 12 km^2

6.2 Regional model

Modelled section and boundary conditions

A topographical map of the regional area at Klipperås together with surface hydrology and interpreted regional fracture zones is shown in Figure 16. The size of the regional area is approximately 10 000 km^2. The subregional area and the Klipperås site is also marked in the figure. The regional area is bounded in the west by the eastern groundwater divide of the drainage basin of the Mörrumsån stream. The eastern boundary coincides with an interpreted lineament in the strait of Kalmarsund in the Baltic Sea. The northern and southern hydrological boundaries are not defined explicitly but approximately coincide with the northern divide of the Alsterån stream and the southern divide of the Hagbyån stream, respectively. The shallow groundwater is mainly drained towards the east to the strait of Kalmarsund.

The modelled section (C–C') in the regional area is shown in Figure 17. The section is parallel to the main regional topographical gradient. The extension of the section is approximately 85 km. The topography of the ground level along the section together with the conceptual regional model are shown in Figure 17.

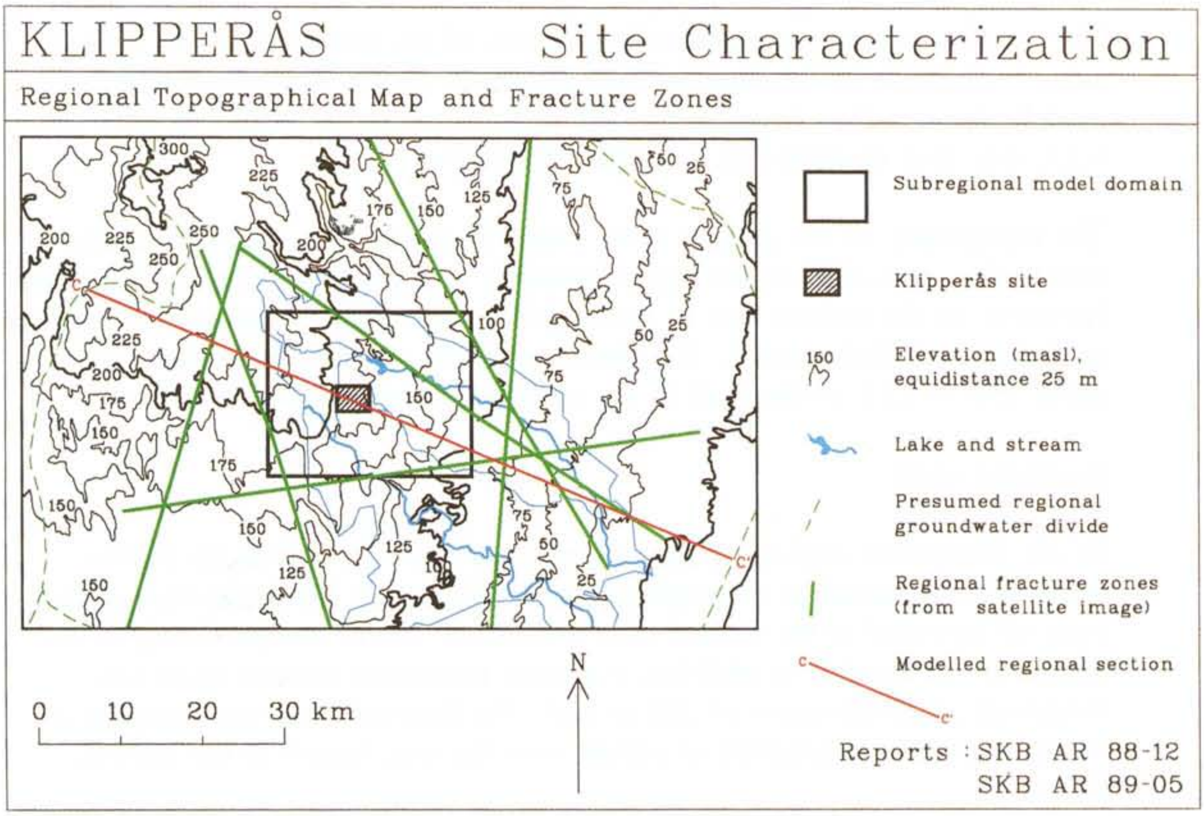


Figure 16. Regional topographical map and fracture zones selected from interpreted satellite images.

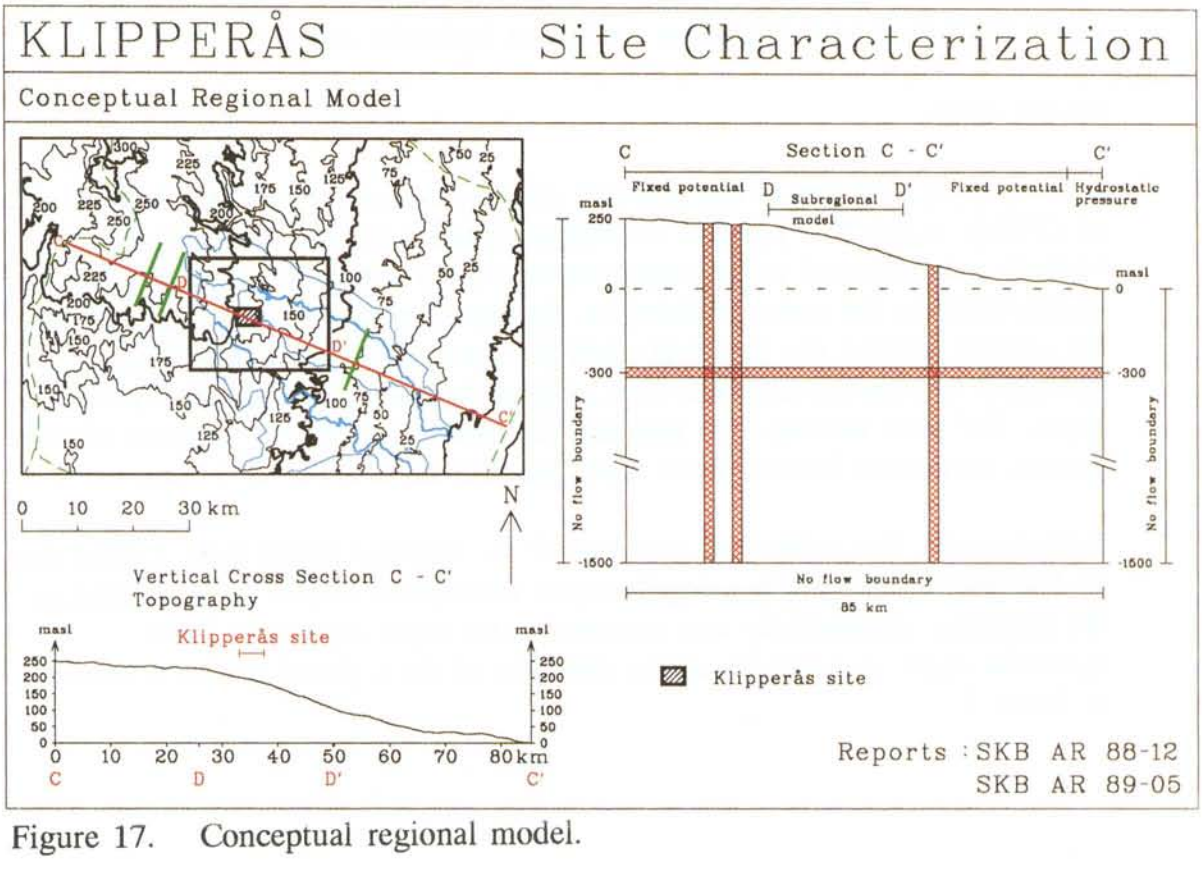


Figure 17. Conceptual regional model.

The vertical western and eastern boundaries of the section coincide with the outer boundaries of the regional area described above. They were both modelled as no-flow boundaries. The bottom boundary, located at 1500 m b.s.l., was also modelled as a no-flow boundary.

The topography of the ground level, assumed to coincide with the groundwater table, was used as the upper boundary condition (zero prescribed head). However, in the eastern part of the section a hydrostatic pressure was applied in the strait of Kalmarsund. The elevation of the top surface ranges from about 250 m a.s.l. in the west to the mean sea level in the east.

Hydraulic units

Of six interpreted regional fracture zones in Figure 16 only three fracture zones were included in the regional model, Figure 17. These fracture zones were all assumed to be vertical with a width of 100 m and persisting to the bottom of the model. In addition, a generic horizontal fracture zone was conceived at an elevation of 300 m b.s.l. The fracture zone was assigned a width of 30 m and assumed to persist over the total length of the section, Figure 17.

The remainder of the bedrock outside the fracture zones was treated as the rock mass hydraulic unit. In cases when no fracture zones were included, the entire bedrock was modelled as a separate hydraulic unit.

Model cases

Firstly, three subcases of the regional model were performed by Lindbom et al. (1988). In the first subcase no fracture zones were included and the bedrock was assumed to be homogeneous with a constant hydraulic conductivity in the entire domain, i.e. no depth dependence was applied. In the second subcase the rock mass and the vertical fracture zones were modelled as separate continua with constant hydraulic conductivity with depth. The third subcase was identical to subcase 2, with the addition of the generic horizontal fracture zone described above.

Subsequently, five additional subcases of the regional model were carried out by Lindbom et al. (1989) using the same conceptual model. In these subcases the hydraulic conductivity was assumed to be depth dependent in all hydraulic units. A summary of the subcases of the regional model is shown in Table 7.

The number of elements in the meshes of the regional model ranged from 1116 to 1270 for subcases 1–8 whereas the total number of nodal points ranged from 3615 to 4085 for the different subcases.

Table 7. Characteristics of the different modelled subcases of the regional model at Klipperås. After Lindbom et al. (1989). K_r and K_f denotes hydraulic conductivity of the rock mass and fracture zones, respectively.

Subcase	Hydr. conductivity		Rock mass	Fracture zones	
	Depth–dep.	Constant		Vertical	Horizontal
1		x	K_r	none	none
2		x	K_r	$10 \cdot K_r$	none
3		x	K_r	$10 \cdot K_r$	$10 \cdot K_r$
4	x		K_r	none	none
5	x		K_r	K_f	none
6	x		K_r	K_f	K_f
7	x		K_r	$10 \cdot K_r$	none
8	x		K_r	$10 \cdot K_r$	$10 \cdot K_r$

Hydraulic conductivity

A constant hydraulic conductivity with depth (Table 8) was assumed for all hydraulic units in subcases 1–3. In subcases 4–8 hydraulic conductivity functions (Table 9) were applied to the different hydraulic units (Figure 20). The hydraulic conductivity values at 50 m, 500 m and 800 m depth calculated from these functions are presented in Table 12. The same functions were also used in the subregional model (Chapter 6.3).

The generic horizontal zone was located at 300 m depth below sea level in the regional model, corresponding to a depth of the zone of about 550 m in the west to about 300 m below ground level in the east (Figure 17). In subcase 3 a constant hydraulic conductivity of $3 \cdot 10^{-8}$ m/s was assigned to the zone (Table 8), corresponding to a transmissivity of $9 \cdot 10^{-7}$ m^2/s. In subcases 6 and 8 a depth–dependent conductivity of the zone was assumed (Table 9).

It should be noted that by calculating the hydraulic conductivity versus depth in the modelling, the depth–coordinate (z) in Eqn. (6.1) was counted below a reference datum approximately coinciding with the highest elevation in the modelled domain. This is not strictly consistent with the definition of the z–coordinate in Eqn. (6.1) where z is defined as the depth below the ground level. This implies that the applied conductivity of the horizontal zone (and also of the rock mass at a certain depth below the reference datum) was constant along the modelled section although the ground level is sloping (Figure 17).

In subcase 6 the applied conductivity of the horizontal zone was about $8 \cdot 10^{-8}$ m/s, corresponding to a transmissivity of about $2 \cdot 10^{-6}$ m^2/s, implying a hydraulic conductivity contrast of about 85 to the surrounding rock mass. In subcase 8 the applied conductivity of the zone was about $9 \cdot 10^{-9}$ m/s, corresponding to a transmissivity of about $3 \cdot 10^{-7}$ m^2/s and a conductivity contrast of about 10 to the rock mass. The measured transmissivity of the horizontal zone at about 800 m depth was about $2 \cdot 10^{-5}$ m^2/s (Chapter 6.3).

Table 8. Hydraulic conductivities (m/s) of the hydraulic units used in subcases 1–3 of the regional model at Klipperås. After Lindbom et al. (1988). Bedrock denotes subcase when no distinction was made between fracture zones and rock mass.

Subcase	Bedrock	Rock mass	Fracture zones Vertical	Horizontal
1	$3 \cdot 10^{-9}$	none	none	none
2	none	$3 \cdot 10^{-9}$	$3 \cdot 10^{-8}$	none
3	none	$3 \cdot 10^{-9}$	$3 \cdot 10^{-8}$	$3 \cdot 10^{-8}$

Table 9. Constants A and b in Eqn. (6.1), see Chapter 6.3, representing the hydraulic conductivity functions applied to the hydraulic units in subcases 4–8 in the regional model at Klipperås. After Lindbom et al. (1989). FZ=fracture zones.

Subcase	Bedrock/Rock mass		Vertical FZ		Horizontal FZ	
	A	b	A	b	A	b
4	1.01	3.25	none		none	
5	0.98	3.29	$1.78 \cdot 10^{-4}$	1.22	none	
6	0.98	3.29	$1.78 \cdot 10^{-4}$	1.22	$1.78 \cdot 10^{-4}$	1.22
7	0.98	3.29	9.8	3.29	none	
8	0.98	3.29	9.8	3.29	9.8	3.29

Results

The calculated isopotential distribution within the regional domain indicated a predominantly horizontal groundwater flow field directed towards east in the central region and that the flow was mainly governed by the topography. The calculated groundwater potentials along the lateral boundaries of the sub-regional area indicated a very low decrease in head in the vertical direction. This implies that hydrostatic boundary conditions would be appropriate at these boundaries in the subregional model.

The calculated potentials and flow pattern were almost identical for all subcases. This indicates that the presence of both the vertical fracture zones and the horizontal zone had little effect on the potentials and the flow pattern on the regional scale, given the geometry of the fracture zones and the contrast of the hydraulic conductivity between the fracture zones and the bedrock/rock mass. On the other hand, the magnitude of groundwater flow rate and the flow rate distribution in the vertical direction is strongly affected by the assumed depth–dependence of hydraulic conductivity of the hydraulic units. In subcases 1–3 (constant hydraulic conductivity with depth) the flow rate was rather constant or increased slightly with depth in some places of the domain. In subcases 4–8 (decreasing conductivity with depth) the groundwater flow predominantly occurred in the upper part of the domain.

In subcases 1–3 the calculated groundwater flow rate in the bedrock/rock mass ranged between 60 - 300 ml/m^2/year within the modelled domain whereas the flow rate in the horizontal fracture zone was one order of magnitude higher (i.e. the hydraulic conductivity contrast). In subcases 4–8 the flow rate in the bedrock/rock mass ranged from about 0.3 ml/m^2/year in the lower part of the domain to about 300 - 3000 ml/m^2/year in the top. The average flow rate at 500 m depth was about 200 ml/m^2/year in the modelled domain.

Within the subregional area the regional model indicates a flow rate at 500 m depth of about 170 - 400 ml/m^2/year in the rock mass (subcases 1–3) and 40 - 160 ml/m^2/year (subcases 4–8).

6.3 **Subregional model**

Modelled domain and boundary conditions

A three–dimensional model was performed of the subregional area at Klipperås (defined in Figure 16). A contour map of the (mean) groundwater table within the subregional area including the site area is shown in Figure

18. The size of the subregional area is about 500 km^2. The groundwater table along the vertical cross section D–D', coinciding with the modelled regional section, is also shown in the figure.

The topography of the groundwater table in the subregional area is relatively flat, ranging from about 230 m a.s.l. in the northwest to about 90 m a.s.l. in southeast. This corresponds to an average hydraulic gradient of about 0.5 % for the shallow groundwater. Local, minor discharge areas are found in low-lying parts within the area. The shallow groundwater flow is primarily directed from northwest to southeast.

The groundwater table map of this area was digitized and used as the upper boundary condition in the model (zero prescribed head). The outer boundaries of the subregional model domain were treated as vertical boundaries. In the first phase of the modelling, prescribed head conditions were applied to these boundaries based on the results of the regional modelling. Subsequently, no-flow boundary conditions were applied to the outer boundaries as a sensitivity analysis. At the lower boundary of the modelled domain a no-flow boundary condition was applied at 1 500 m depth.

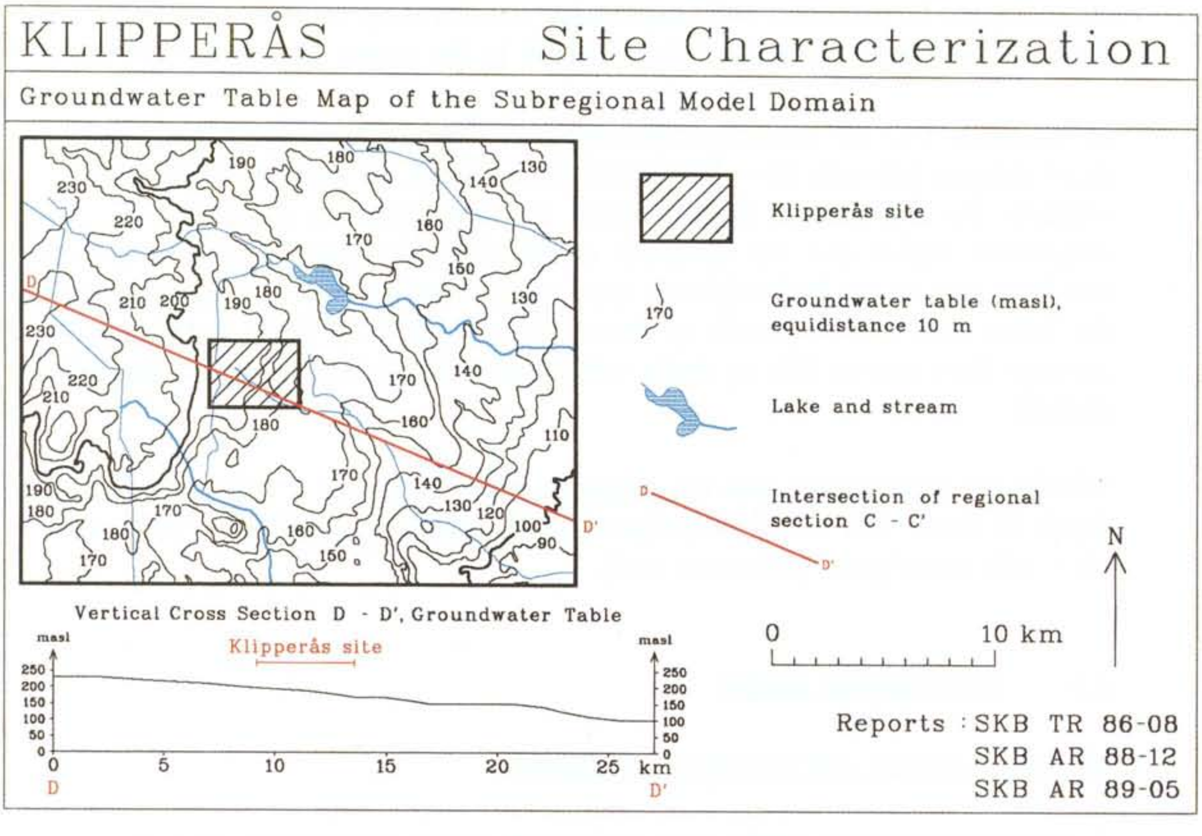


Figure 18. Groundwater table map of the subregional area at Klipperås.

The finite element mesh consisted of 10 104 nodal points and 2 086 elements distributed in seven layers of which five layers were located in the upper part of the domain (down to 700 m b.s.l.) and the remaining two layers in the lower part. The elements were kept as rectangular as possible in shape.

Hydraulic units

The hydraulic units included in the subregional model were derived from the borehole investigations and constitute 1) the bedrock (including all interpreted fracture zones), 2) the rock mass (excluding all interpreted fracture zones) and 3) the vertical fracture zones. The conceptualization of the interpreted vertical fracture zones in the subregional model is shown in Figure 19. Although some concern was taken to locate these zones at locations of lineaments the zones should be regarded as generic with little relevance on real conditions. The widths of the vertical fracture zones were assumed to 50 m and the zones were assumed to persist to the bottom of the model domain. No generic horizontal fracture zone was included in the subregional model.

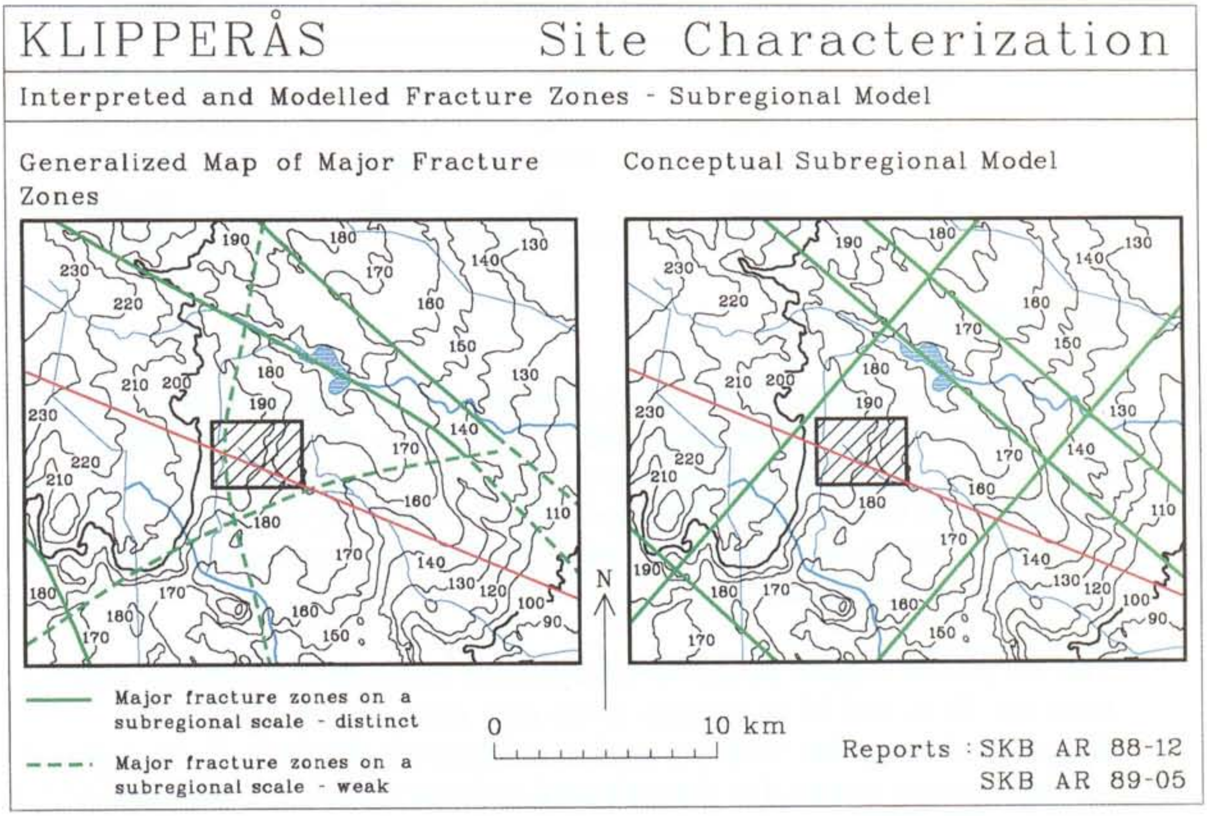


Figure 19. Interpreted major fracture zones and modelled fracture zones in the subregional model at Klipperås.

Model cases

Four subcases were modelled on the subregional scale (Table 10). In the first subcase the entire bedrock was modelled as a homogeneous, isotropic hydraulic unit. In the second subcase the bedrock was divided in two separate continua, i.e. the rock mass and the vertical fracture zones. The first two subcases were modelled with prescribed head conditions at the outer boundaries based on the results of the regional model. Subcases 3 and 4 were identical to 1 and 2, respectively but no-flow conditions were applied at the outer boundaries. The hydraulic conductivity functions applied to the hydraulic units in the different model cases are shown in Table 11.

Table 10. Characteristics of the different subcases of the subregional model at Klipperås. K_b, K_r and K_f denotes the hydraulic conductivity of the bedrock, rock mass and fracture zones, respectively.

Subcase	Bedrock	Rock mass	Fracture zones	Boundary conditions
1	K_b	none	none	Prescribed head
2	none	K_r	K_f	Prescribed head
3	K_b	none	none	No–flow
4	none	K_r	K_f	No–flow

Hydraulic conductivity

Hydraulic conductivity versus depth functions were assigned to the hydraulic units defined in the model. Regression curves of the effective hydraulic conductivity versus depth were calculated for the different hydraulic units (Winberg and Gentzschein, 1987) to assign the hydraulic properties of the hydraulic units in the subregional area. The regression curves were based on data from the Klipperås site.

The left part of Figure 20 shows all measured hydraulic conductivity data from the 20 m and 25 m sections in the rock mass versus depth in the Klipperås site together with the applied conductivity functions in the regional and subregional model. For the measured sections the lower measurement limit corresponds approximately to a hydraulic conductivity of 10^{-11} m/s. The right part of the figure shows the estimated hydraulic conductivity of the interpreted fracture zones within the site (Gentzschein 1986) together with the applied conductivity functions versus depth in the regional and subregional model.

The regression curves were based on a power function of the following form:

$$K_e = A \cdot z^{-b} \quad (z > 0) \qquad (6.1)$$

where K_e is effective hydraulic conductivity, z is vertical depth below ground surface and A and b are constants. The effective hydraulic conductivity versus depth functions of the different hydraulic units were calculated using all measured conductivity data, assuming a 3D flow geometry in the rock mass and a 2D flow geometry in the fracture zones. Measured data below the lower measurement limit were assigned the actual value of this limit. In the regression analysis for the fracture zones, the interpreted horizontal fracture zone (Zone H1) was also included, Figure 20.

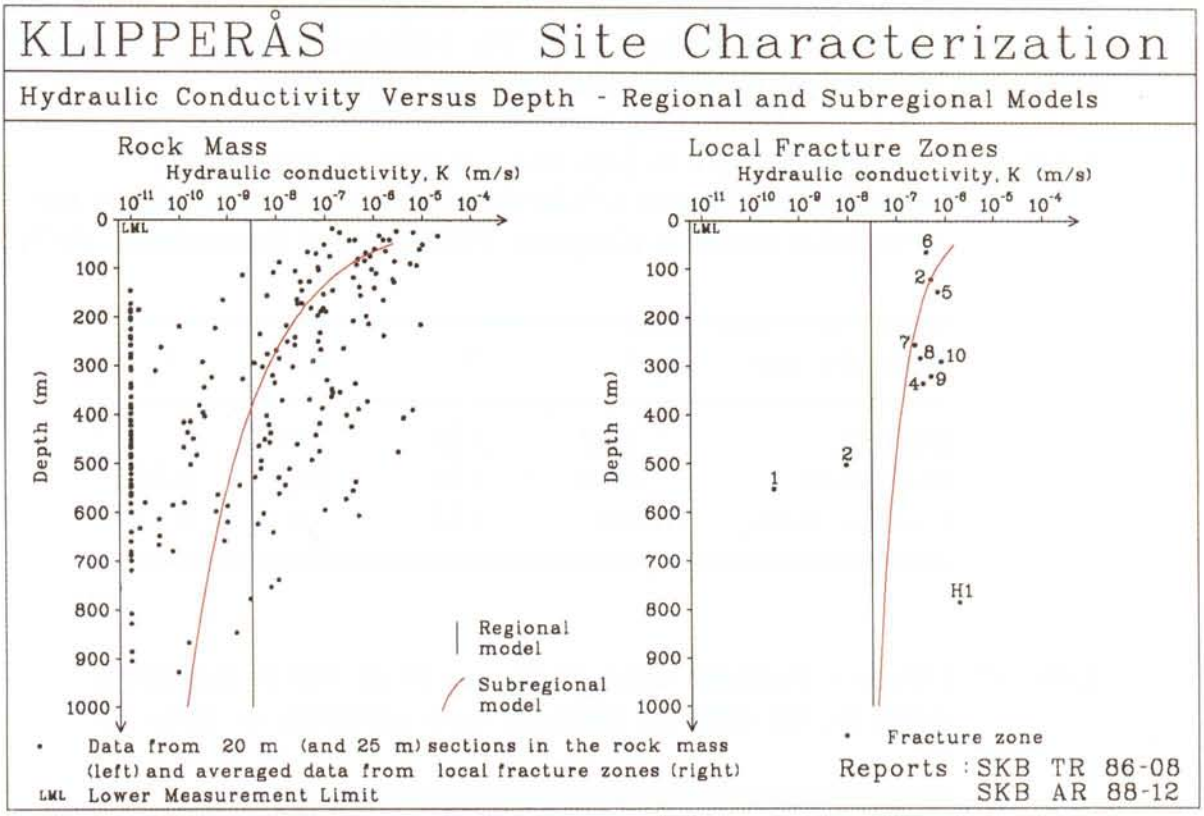


Figure 20. Measured hydraulic conductivity within the Klipperås site together with applied conductivity versus depth functions for the rock mass (left) and fracture zones (right) in the regional and subregional model.

Table 11 shows the derived constants A and b in Eqn. (6.1) from the regression analysis, expressing the effective hydraulic conductivity versus depth for the different hydraulic units in the subregional model. The number of data used in the regression analyses (n) and the regression coefficients (r^2) are also shown. Table 12 presents the corresponding effective hydraulic conductivities at 50 m, 500 m and 800 m depth. As seen, the conductivities of the bedrock and rock mass are similar at all depths. The contrast in hydraulic conductivities between fracture zones and rock mass is about 70 at 500 m depth, and about 180 at 800 m depth.

The measured hydraulic conductivity of the horizontal fracture zone (H1) at 800 m depth was $2 \cdot 10^{-6}$ m/s, as calculated from a double-packer test with a section length of 20 m. The interpreted width of the zone is 12 m (Gentzschein, 1986). These values correspond to a transmissivity of the zone of $2.4 \cdot 10^{-5}$ m^2/s.

The conductive fracture frequency (CFF) in the rock mass was estimated by Osnes et al. (1991) by a probabilistic model using hydraulic conductivity data from all 20 m sections in the rock mass. The estimated average value of CFF in the rock mass in the Klipperås site was 0.09 - 0.12 fr/m.

Table 11. Constants A and b in Eqn. (6.1), number of data (n) and regression coefficients (r^2) for the different hydraulic units in the subregional model at Klipperås. (Winberg and Gentzschein, 1987).

Hydraulic unit	A	b	n	r^2
Bedrock	1.01	3.25	233	
Rock mass	0.98	3.29	222	0.33
Fracture zones	$1.78 \cdot 10^{-4}$	1.22	11	0.12

Table 12. Effective hydraulic conductivities at 50 m, 500 m and 800 m depth for the different hydraulic units according to Table 10.

Hydraulic unit	K_{50}	K_{500}	K_{800}
Bedrock	$3.0 \cdot 10^{-6}$	$1.7 \cdot 10^{-9}$	$3.7 \cdot 10^{-10}$
Rock mass	$2.5 \cdot 10^{-6}$	$1.3 \cdot 10^{-9}$	$2.8 \cdot 10^{-10}$
Fracture zones	$1.5 \cdot 10^{-6}$	$9.1 \cdot 10^{-8}$	$5.1 \cdot 10^{-8}$

Results

The distribution of the groundwater potentials and the groundwater flow field was calculated for the subregional area in three horizontal planes at different depths below ground surface (top surface, 500 m and about 900 m) and along three vertical sections for all subcases. In addition, the flow fields and flow rates were calculated in more detail in a horizontal plane at a potential repository depth (500 m) within an area roughly corresponding to the site.

The potential distribution at the potential repository depth was almost identical in all four subcases. Figure 21 shows the calculated potential distribution in a horizontal plane at 500 m depth for subcase 4. Furthermore, both the positions of the isopotential curves, i.e. the hydraulic gradients, and the flow pattern were maintained from the top surface to this depth (and even to 900 m depth) for all subcases, c.f. the groundwater level map in Figure 18. This indicates that the model was insensitive to both the presence of the fracture zones (given their hydraulic conductivity) and the type of outer boundary conditions applied.

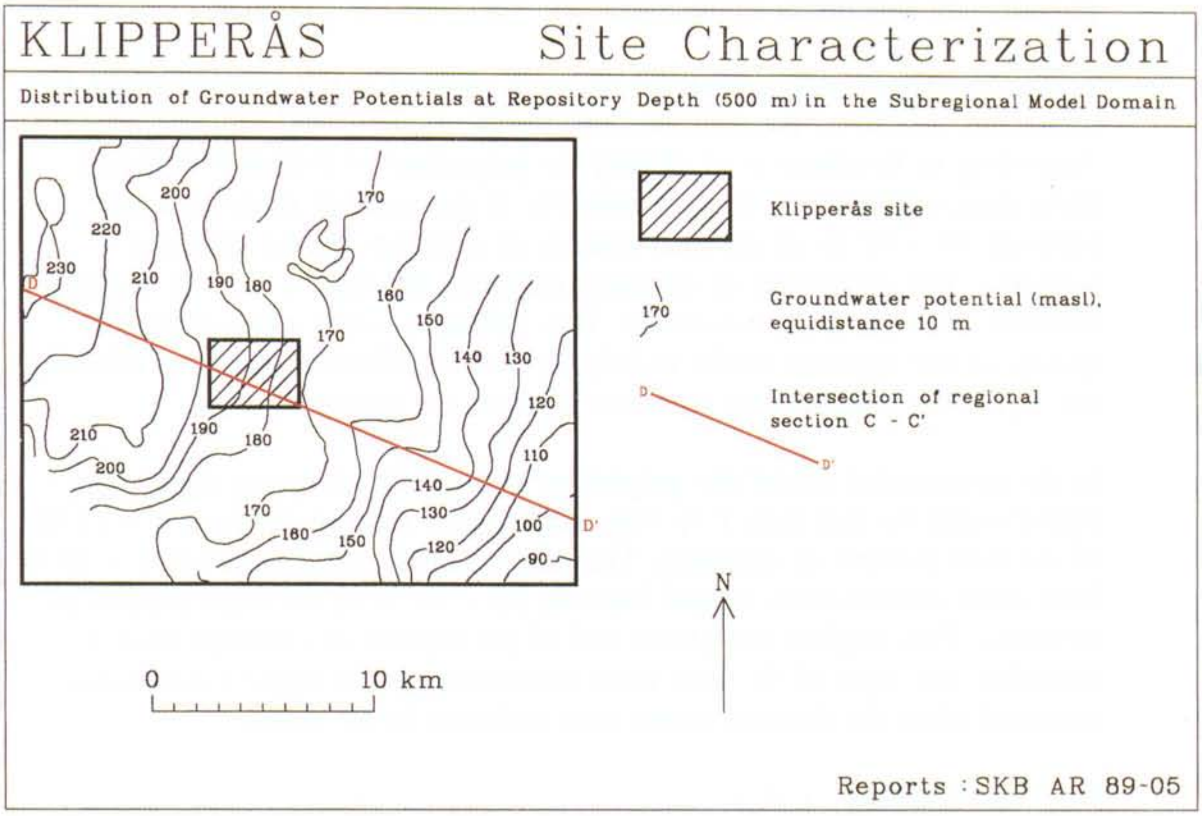


Figure 21. Calculated distribution of the groundwater potentials at repository depth (500 m) from the subregional model at Klipperås. After Lindbom et al. (1989).

The calculated average groundwater flow rate at 500 m depth in the rock mass in the subregional area was about 300 ml/m^2/year. When hydrostatic outer boundary conditions were applied (subcases 1 and 2) the flow pattern was horizontal whereas the flow pattern in general seems to be more governed by the modelled topography when no–flow boundaries were applied (subcases 3 and 4).

Also in the local area (the site) the flow pattern and magnitude of flow was almost identical for all subcases. The average flow rate in the rock mass at 500 m depth was again about 300 ml/m^2/year. At the intersections of fracture zones the flow rate was increased by a factor 50 – 70, corresponding to the applied hydraulic conductivity contrast.

Relevance of results

The relevance of the numerical models was assessed from calculations of the mass balance for the individual finite elements. No estimates of the groundwater recharge or comparisons of the measured and calculated groundwater potentials along boreholes were made at Klipperås.

The mass balance was calculated for each element in the mesh to check the numerical quality of the solution both for the regional and subregional model. According to Lindbom et al. (1989) the proportion of elements deviating from mass conservation by less than 1% in the regional model ranged between 70 – 87 % of the total number of elements for the different subcases. The proportion of elements deviating between 1 – 10 % ranged between 13 – 22 % in this model. This indicates a very good numerical quality of the regional model mainly due to high discretization and relatively low hydraulic conductivity contrasts between the hydraulic units.

In the subregional model the proportion of elements deviating from mass conservation by less than 1 % was much lower, ranging between 5 – 13 % of the total number of elements. The proportion deviating between 1 – 10 % from mass conservation ranged between 36 – 44 % of the total number of elements. This implies that about half of the number of elements have a deviation less than 10 % from mass conservation. The highest deviations occurred when the fracture zones were included in the model.

6.4 Local model

No local hydraulic modelling of the Klipperås site has been performed.

6.5 Validity of models

The model results from the Klipperås area can be assessed by examining some of the specific assumptions made by the conceptualization of the models in relation to existing geological and hydrogeological conditions within the area.

Boundary conditions

Regional model

The topography of the ground level, assumed to coincide with the regional groundwater table, was used as the upper boundary condition. This is clearly an approximation of prevailing conditions.
However, this source of error is probably not important in the Klipperås region due to the very large size and the gentle topography of the modelled areas. Since the calculated potential distribution in the regional (and subregional) model domain at depth was found to be largely governed by the upper boundary condition, the definition of this condition may be important. A sensitivity analysis should be made to assess the sensitivity of the assumed upper boundary condition on the model results and the effects in the subregional and local model domains.

Subregional model

The outer vertical boundaries of the subregional model domain were firstly treated as prescribed head boundaries, derived from the calculated heads in the regional model, and subsequently as no-flow boundaries. The transformation of the prescribed head boundaries from the regional model domain to the subregional domain is not clearly described. However, the model results proved to be quite insensitive to the type of outer boundary conditions applied. This may possibly be explained by the large size of the modelled domain in relation to the depth of the domain given the hydraulic gradient and material properties (Lindbom et al. 1989).

Hydraulic units

Regional model

The use of generic fracture zones in the regional model limits the validity of the model for estimating regional groundwater flow.

Subregional model

The division of the bedrock in rock mass and fracture zones are preliminary due to uncertainties in the structural interpretation. In general, a poor correlation between interpreted fracture zones and measured hydraulic conductivity distributions along boreholes is found at Klipperås. No comprehensive 3D geologic model exists for the Klipperås site.

No horizontal fracture zone was included in the subregional model although such a zone was identified at 800 m depth. Thus, the effects of such a zone on the groundwater flow conditions were thus not evaluated. In other study sites, notably Finnsjön and Kamlunge, horizontal zones have a strong influence on groundwater flow system.

At the time of groundwater flow modelling no subdivision of the rock mass into different rock types were made. Later studies by Gentzschein (1986) and Andersson and Lindqvist (1989) showed that the various types of dykes at Klipperås all have hydraulic conductivities that significantly differs from the granite.

Hydraulic conductivity

A constant hydraulic conductivity versus depth was assumed both for the rock mass and fracture zones in the first three subcases of the regional model. This assumption is unrealistic and probably leads to incorrect groundwater flow conditions at a potential repository depth. Furthermore, the derived hydraulic conductivity versus depth functions of the rock mass from statistical analysis, used in both the regional and subregional model, are uncertain both due to uncertainties in the division of the rock in hydraulic units and due to the large scatter of the data (Figure 20). The averaging process subdues extreme (high) values. The calculated hydraulic conductivity of the rock mass at depth at Klipperås is significantly higher than that calculated in the other study sites. This is likely to be a result of a poor separation of the bedrock into relevant hydraulic units.

The hydraulic conductivity function applied to the fracture zones, both in the regional and subregional model, is also highly uncertain. The available data are very few (often only one value from each zone) which, a priori, implies a high uncertainty. In the regression analysis the horizontal zone was included in the conductivity-depth analyses, although, from geological and hydraulical reasons, it should better be treated as a separate unit. The inclusion of the zone in the regression analysis resulted in a very high hydraulic conductivity applied to all vertical fracture zones at depth, which is probably not realistic.

Results

The calculated head and groundwater flow distributions at a potential repository depth in the crystalline rock should be regarded as average values in an equivalent formation composed of one single continuum or two overlapping continua (rock mass and fracture zones) within the bounded domain. The results of such models are rather insensitive to the hydraulic conductivity functions applied to the hydraulic structures (Larsson and Markström, 1988).

The modelling at Klipperås has also shown that the models may be insensitive to the type of boundary conditions applied to the outer model boundaries if the modelled domain is large.

The lack of sensitivity to the presence of the fracture zones may be due to the magnitude of the hydraulic conductivities applied to the bedrock/rock mass and the fracture zones. Table 12 shows that the applied hydraulic conductivity of the fracture zones at 50 m depth is in the same order of magnitude (or slightly lower) as that of the bedrock/rock mass. This implies that the infiltration of groundwater in the upper part of the bedrock should be similar both with and without fracture zones. At 500 m depth, however, the applied hydraulic conductivity of the fracture zones was about 70 times higher than that of the bedrock/rock mass at 500 m depth.

The calculated groundwater flow rates at a potential repository depth of 500 m do not appear entirely consistent between the regional and subregional models. From the regional model the average flow rate at 500 m depth within the subregional (and site) area was estimated to 40 - 160 ml/m^2/year for subcases 4–8 (with depth dependent hydraulic conductivity). According to the subregional model the average groundwater flow rate at 500 m depth was about 300 ml/m^2/year within the subregional (and site) area for all subcases. This is a higher flow rate than that calculated from the corresponding subcases of the regional model although the same hydraulic conductivity functions were applied in both cases (e.g. compare subcase 4 of the regional model with subcase 1 (and 3) of the subregional model). To some extent the difference might be a result of including a horizontal fracture zone in the regional model and not in the subregional model.

Finally, no estimates of the groundwater recharge or comparisons between observed and calculated groundwater potentials along boreholes were made from the models to assess the validity of the model results.

7. GROUNDWATER CHEMISTRY

7.1 Scope and reliability of samples

The groundwater chemistry data available form this site was partly obtained during the site characterization studies 1981 – 1983 (borehole KKL01) and partly from investigations during 1984 – 1985. The results, including sampling methods, are presented by Laurent (1986) and Smellie et al. (1987). Three boreholes were investigated, KKL01, KKL02 and KKL09. Sampled sections are in KKL01 one section at 406 m depth, in KKL02 five sections at 326, 741, 761, 777 and 860 m depths, and in KKL09 one section at 696 m depth.

The results are discussed and interpreted in detail for each sampled horizon by Smellie et al. (1985 and 1987) by considering chemistry, geology and hydrology. Measurements of hydraulic conductivity and piezometric pressures in each borehole were used, along with results from site specific groundwater flow modelling, in an attempt to put each sampled section in relation to local groundwater flow conditions. By considering the various sources of contamination it was concluded that only three of the seven sampled horizons was truly representative for the depth sampled.

In the following sections some of the most important results of the chemical analyses from the site characterization studies will be presented and commented on briefly. A division is made into general chemistry, redox-sensitive parameters, uranium chemistry and environmental isotopes. Such a division is somewhat arbitrary, and obviously some of the parameters overlap. Where not specifically referenced, the comments made are generally based on the extensive data analysis carried out by Smellie et al. (1985 and 1987).

7.2 Results

General chemistry

The chemical composition of the samples from the different boreholes at Klipperås is shown in Table 11. It indicates the presence of two water types: near-surface and intermedient groundwater. The major-ion chemistry generally shows calcium and sodium as the dominating cations, while the anions are dominated by bicarbonate. None of the sections is distinctly deviating. All sections show chemical compositions that are characteristic for shallow to intermediate groundwaters.

Table 11. General chemistry parameters at Klipperås.

Sampled borehole	Depth m	pH	Conduc- tivity mS/m	Na^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	K^+ mg/l	HCO_3^- mg/l	Cl^- mg/l	SO_4^{2-} mg/l
KKL01	406	8.3	31	47	14	2.3	1.0	80	45	1.5
KKL02	326	7.6	28	29	31	1.0	1.1	140	17	0.1
KKL02	741	8.2	27	38	16	1.0	1.6	97	21	0.1
KKL02	761	8.1	20	13	22	4.0	3.1	106	7	0.5
KKL02	777	8.2	21	15	22	4.0	3.1	103	8	0.2
KKL02	860	8.2	38	60	8.3	1.8	1.6	102	51	1.5
KKL09	696	7.6	23	15	29	3.0	1.3	120	5.9	4.3

The sampled sections show a very uniform chemical composition and there are no general trends with depth considering pH, electrical conductivity or the major-ion chemistry. No deep saline waters was encountered.

Redox-sensitive parameters

A summary of some of the redox-sensitive parameters is presented in Table 12. Generally, all samples collected at this site are reducing, as indicated by negative Eh-values. There are no apparent trends with depth in any of the redox parameters.

Redox parameters are especially sensitive to contamination by oxygen during sampling, by high pumping rates and drilling fluid residue. The samples in Table 12 were not filtered immediately after sampling, and this is likely to have yielded erroneously high Fe(III)-values (Nordstrom and Puigdomenech, 1986). Thus, iron can not be expected to fully reflect redox conditions in this case, although the mere presence of Fe(II) indicate reducing conditions. Wikberg et al. (1983) also show that Eh calculations based on the iron system does not explain the measured ones in this case.

Uranium geochemistry

The uranium contents were measured by high-resolution alpha spectrometry; the $^{234}U/^{238}U$ activity ratios were too few and considered unreliable. As can be seen from Table 13, and which also is concluded by Smellie et al. (1985 and 1987), there is a tendency to find relatively high uranium contents closer to the surface and relatively low concentrations in the deeper sections.

Later measurements of uranium content in the groundwaters (Landström and Tullborg, 1990) showed different values but similar trends (Table 15).

Table 12. Redox parameters at Klipperås.

Sampled borehole	Depth m	Eh mV	Fe(II) mg/l	Fe–tot mg/l	S(–II) mg/l	O_2 mg/l	NO_3^-–N mg/l	NH_4^+–N mg/l
KKL01	406	-300	0.008	0.010	0.09	–	0.005	0.01
KKL02	326	-290	0.13	0.14	0.10	–	0.02	0.08
KKL02	741	-360	0.08	0.09	0.36	–	0.02	0.03
KKL02	761	-310	0.33	0.35	0.05	–	–	–
KKL02	777	-320	0.20	0.21	0.05	–	–	–
KKL02	860	-300	0.04	0.04	0.11	–	0.01	0.02
KKL09	696	-270	0.09	0.10	0.01	–	0.02	0.02

Table 13. Uranium geochemistry at Klipperås.

Sampled borehole	Depth m	U ppb*
KKL01	406	0.01
KKL02	326	0.01
KKL02	741	0.07
KKL02	761	–
KKL02	777	–
KKL02	860	–
KKL09	696	0.04

*Analysis by high resolution alpha spectrometry.

Environmental isotopes

The analytical isotope data are few, but confirms that groundwaters from the Klipperås site are of meteoric origin and have not undergone any modification due to evaporation processes. A summary of analyses of environmental isotopes are presented in Table 14. An interesting fact is the high ^{14}C ages obtained from two sampled sections. Similar high ages have not been obtained from any other of the SKB study sites (Wikberg 1992).

Table 14. Environmental isotopes at Klipperås.

Sampled borehole	Depth m	Tritium TU	^{14}C years	$\delta^{18}O$ ‰ vs SMOW	$\delta^{2}H$ ‰ vs SMOW
KKL01	406	<3	28375	-11.90	-86.5
KKL02	326	3	-	-12.35	-
KKL02	741	13	-	-11.31	-
KKL02	761	25	-	-	-
KKL02	777	-	-	-	-
KKL02	860	-	-	-	-
KKL09	696	2	30795	-11.93	-

Additional analysis

During an evaluation of the mobility of trace elements in groundwater (Landström and Tullborg, 1990), three groundwater samples were analyzed. These samples were sampled during the field investigation presented above (Smellie et al., 1987) and have been acidified and stored in polytene bottles at low temperature and re-analyzed. The results are presented in Table 15.

7.3 Summary and relevance of results

A total of 3 boreholes and 7 different sections have been sampled. The drilling and sampling methods that were used at the Klipperås site were considerably improved compared to the "KBS-3 sites". Consequently, the measurements of redox potentials and several other parameters are of high accuracy. However, considering the hydraulic parameters of the boreholes it was concluded by Smellie et al. (1985 and 1987) that only three out of the seven sampled sections were representative for the depth sampled.

The results show that the groundwaters at Klipperås are of near-surface to intermediate in type. No deep saline water was encountered. The sampled sections show a very uniform chemical composition and there are no general trends with depth considering pH, electrical conductivity or the major-ion chemistry. All sampled sections are reducing in character.

Klipperås groundwaters differs from other study sites by the high ^{14}C ages in the deep sampled groundwaters, and its complete lack of saline waters at greater depths (even below a horizontal fracture zone at 800 m depth). The reason for this difference might be that the bedrock at Klipperås was never covered by the post–glacial sea, as was the case for the other sites. Thus the exchange from non–saline glacial groundwaters to marine saline water, which occurred during submergence for most sites, did not occurred at Klipperås. It is therefore possibly that the non–saline and "old" groundwaters encountered at great depths at Klipperås are in fact relict glacial meltwater.

Table 15. Main and trace elements in groundwater from Klipperås (neutron activation analyses).

Element		KKL01 406 m	KKL02 326 m	KKL09 696 m
Na	mg/l	46.5	40	17.5
Ca	"	17	42	33
Fe	"	0.011	0.14	0.11
Rb	µg/l	3.5	4.3	4.9
Sr	"	296	267	313
Cs	"	0.07	0.093	0.10
Ba	"	53	134	91
Co	"	0.027	0.076	0.02
Cr	"	<0.17	<0.3	–
Zn	"	7.5	6.9	2.9
Sb	"	0.2	0.017	0.02
Hf	"	–	0.01	–
Th	"	<0.02	<0.02	<0.02
U	"	3.2	4.6	0.66
Sc	"	0.004	0.0032	0.0032
La	"	<0.013	0.11	<0.13
Ce	"	0.25	0.24	0.25
Nd	"	–	–	–
Sm	"	–	0.033	–
Eu	"	0.0025	0.0021	0.0035
Tb	"	<0.015	0.0073	–
Yb	"	<0.050	0.024	<0.014
Lu	"	0.0028	0.0023	0.0032
Ta	"	–	<0.02	–

8. ASSESSMENT OF SOLUTE TRANSPORT

8.1 General considerations

No specific models of solute transport at the Klipperås site exist. The reports by Lindbom et al. (1988 and 1989), however, describes a model of the groundwater system in which both a two-dimensional and a three-dimensional flow field is shown. In addition, groundwater travel times from a generic repository at 500 m depth are shown for both flow fields. A groundwater flow field is the essential basis of a groundwater solute transport model, and thus the implications of the existing work for solute transport at the sites may be evaluated. All of the uncertainties that are relevant to the model of the groundwater system, described in Chapter 6, are relevant to the transport as well. These and additional considerations are reviewed here with emphasis on their impact on solute migration. Of greatest interest for transport are typical flow paths through a generic repository located in a bedrock block at 500 m depth which eventually reach either the surface or a conductive fracture zone which quickly leads flow to the surface. The discussion focuses on flow and transport along such paths through the repository as predicted by the existing model of the groundwater system.

Boundary conditions

The two-dimensional regional model of the Klipperås site covers a vertical cross-section with a length of 85 km. A groundwater table coinciding with the topography with maximum relief of about 250 m is specified as the surface condition, whereas the two vertical sides and bottom are closed to flow. The bottom of the cross-section was set to 1500 m below sea level. The western boundary coincides with a groundwater divide, while the eastern coincides with a satellite interpreted lineament in the strait of Kalmarsund. In the 2D-model analyses for Klipperås, no variations were carried out to examine the implications for flow and transport of the location and type of boundary conditions.

The aim of the two-dimensional regional model calculation was to determine the pressure distribution to be assigned as boundary conditions for the three-dimensional subregional model. The external boundaries of the subregional model enclose a block having sides of about 20 by 30 km and a depth of 1.5 km. The upper boundary is specified by the groundwater table in a way similar to the 2D-model, whereas the lateral boundaries were assigned hydrostatic pressures as determined by the regional 2D-model. The bottom boundary was set as a no-flow boundary. Included in the 3D-model analyses was a study of the effect on the flow and transport of changing the lateral boundaries to no-flow boundaries. The resulting flow rates and travel times were almost the same as with the hydrostatic pressure boundaries. The reason for this was probably that the areal extent of the model was so large that boundary effects were negligible.

Hydraulic structures

Any uncertainty in location and connectivity of hydraulically conductive structures such as fracture zones leads to mild uncertainty in the calculation of hydraulic potentials in the groundwater model. Such uncertainty, however, often can lead to extreme differences in details of predicted transport of solutes through the same model. Modelled groundwater heads may be of similar value whether or not fracture zones are distinctly included in a model, or whether their contribution to the local transmissivity is spread homogeneously through the model. This is shown by the parameter variations in Subcases 1, 2 and 3 for the 2D–analysis of the Klipperås site. In contrast, the location and direction of transport paths and fluid velocities along paths are exceptionally sensitive to the particular location and connectivity of conductive structures.

When conductivity contrasts of two or more orders of magnitude exist between conductive zones/layers and less–conductive bedrock blocks, then the spatial distribution and connectivity of the conductive zones, whether at model boundaries or within model bounds, have a major influence on groundwater flow and solute transport. However, in the model analyses, no variations were carried out to evaluate the implications for flow and transport of uncertainty in location and connectivity of conductive structures.

Hydraulic and transport parameter values

Knowledge of the spatial distribution of hydraulic conductivity is of direct importance to the calculation of groundwater flux which is required to determine possible radionuclide source rates exiting the repository, as well as to determine the longevity of engineered barriers. Eight variations of hydraulic conductivity distributions were tested in the 2D–model and two variations in the 3D–model of the Klipperås model. These consisted of mildly different depth–dependencies of hydraulic conductivity, as well as variations of the hydraulic conductivity in the fracture zones. Model results for transport through the site (flow direction and travel times), show that such parameter variations have limited effect on flow behavior. Rather, geometry and connectivity of conductive structures, as discussed above, may be the most important control on groundwater flow and transport to be studied by variations.

Knowledge of both hydraulic conductivity and effective porosity for flow ("kinematic porosity") is important to determine actual fluid velocity through a repository region. The effective porosity is important for transport of radionuclides that do not undergo strong chemical or surface retardation processes along flow paths to the surface, and together with hydraulic conductivity, controls travel times of such nuclides. In the model analysis, the effective porosity was held fixed at a value of 10^{-3}, which is a rather high value compared to values determined in field investigations. While this parameter was not varied in the simulations, it is merely a scaling value on fluid velocities and travel time, and the effect of ten–times–lower effective porosity on transport is simply a ten–times shorter travel time.

Dispersivities and sorption coefficients were not treated in the site model as these are parameters only of true solute transport models and not of groundwater flow models. Neither of these parameters have been measured at the site.

8.2 Transport Calculations

Groundwater flow fields showing fluid velocity vectors are presented for cross–sections through the Klipperås model block for each of eight variations in the 2D–model and four variations in the 3D–model.

The 2D–model is varied by either using fixed values for hydraulic conductivity and altering the conductivity distribution between rock mass and fractures (Subcases 1–3), or using a depth-dependent relation of the hydraulic conductivity and altering the conductivity distribution between rock mass and fractures (Subcases 4–8). The transport velocities at 500 m depth for the 2D–model are quite similar in the first three cases as are groundwater fluxes. However, at greater depths the influence of the depth–dependent hydraulic conductivity applied in Subcases 4–8 gives significantly lower transport velocities.

Travel times are given for particles released at four different points, two above and two below a horizontal fracture zone. These travel times ranged between 6 000 - 40 000 years. The shorter times are in most cases calculated from those cases were the horizontal fracture zone was included.

The 3D subregional model is varied by changing the boundary conditions from hydrostatic pressure levels (Subcases 1 and 2), to no–flow boundaries (Subcases 3 and 4), and by excluding fracture zones (Subcases 1 and 3) or not (Subcases 2 and 4). Only vertical fracture zones was included in this model.

The transport velocities at 500 m depth are almost identical for all cases. The reason for this is most probably the insensitivity imposed by the large areal domain of the model.

Travel times are given for particles released at four different points within an area corresponding to a possible repository site and at four different arbitrary chosen points. The travel times within the repository area are ranging between 2 000 - 10 000 years, and the variations between the different cases are very small. This result again demonstrates the insensitivity of the model to changes in boundary conditions and incorporation of fracture zones. However, no analysis was made of the sensitivity of the model to changes in properties and connectivity of the fracture zones. Results from other sites, notably Finnsjön and Kamlunge, show that horizontal fracture zones have a strong influence on groundwater flow and transport. Although a subhorizontal zone was identified at 800 m depth at Klipperås, no such zone(s) was incorporated in the model.

8.3 Implications of existing information for solute transport

The groundwater system model analyses of the Klipperås site is the primary basis for this evaluation of solute transport. In detail, little is actually known about transport paths or travel times from a repository at 500 m depth. Under the conditions studied, travel times are predicted within a relatively wide range, 2 000 - 60 000 years. Travel times and paths are found to be dependent on the existence of conductive fracture zones, but tests varying structure and connectivity were not carried out. Rather variations, concerned relatively minor changes to assumed hydraulic conductivities, resulting in relatively unimportant differences in predicted flow fields and groundwater behavior was carried out.

Boundary conditions are equally important to the transport predicted by the model analysis. The transport was found to be insensitive to the different boundary conditions applied in the 3D-model. However, both the 2D and the 3D-model covered a very large domain compared to the repository area which resulted in this insensitivity to changes in the boundary conditions. The more or less absence of local topographical relief at Klipperås implies that groundwater flow and transport through a generic repository may have little, if anything, to do with the water-table topography within the site area. Flows at depth is probably driven by the gently inclined hydraulic gradient of the regional groundwater table.

Considerations towards improving the transport predictions of the Klipperås site model must begin with improvements in the conceptual model of the groundwater system. Of particular importance is a clarification of flow regimes in the deeper regions of the site.

9. ROCK MECHANICAL CONDITIONS

No investigations concerning the rock mechanical conditions were performed at Klipperås. Thus there are no data concerning rock stress distribution towards depth. Data are also lacking on mechanical and thermal parameters.

There are however some indirect data from tube-wave measurements in borehole KKL02. These data allowed crude estimates of dynamic rock mass modulus and dynamic Poisson's ratio, which turned out to be 78 GPa, and 0.25, respectively.

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APPENDIX A
ACTIVITIES IN THE CORED BOREHOLES

This appendix presents all activities that have been performed in the cored boreholes in separate activity schemes for each borehole. Each scheme contains information on activities/surveys for the particular borehole with reference to depths or intervals. Also borehole coordinates, survey periods, references to reports and information on storage in the SKB database GEOTAB are presented in Figures A2–A15.

Locations of the cored boreholes are presented below in Figure A1. Intersections of fracture zones with boreholes are summarized in Table 3 and in Appendix B, Figures B1–B5. Generalized results concerning rock types, fracturing and hydraulically conductive sections are also presented in Appendix B, Figures B1–B5. Brief descriptions of interpreted fracture zones are presented in Appendix C, and location on surface in Figure C1.

The availability of the cored boreholes have been studied by brief visits to each borehole (Sep–91). These inspections showed that all borehole locks at Klipperås were intact. Problems with borehole stability or instrument blockage during investigations, as described by Persson (1986), are incorporated in this appendix.

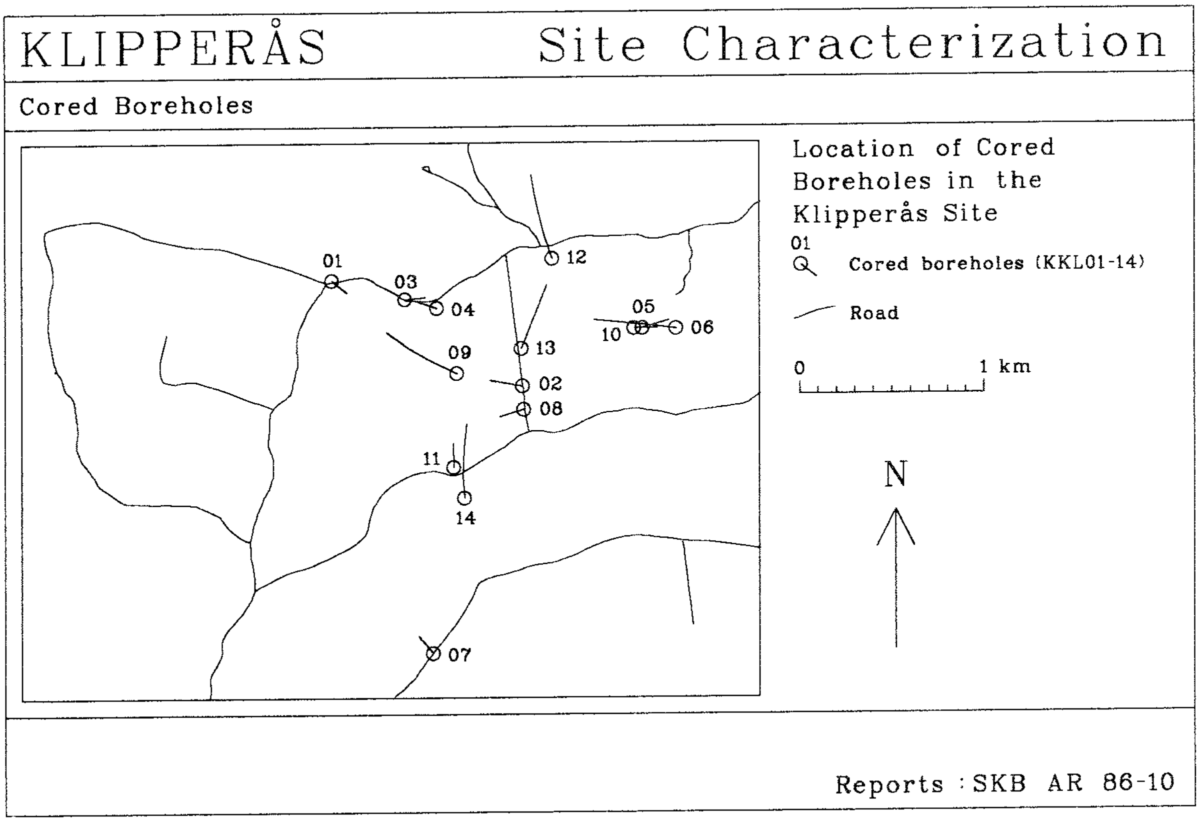


Figure A1. Locations of cored boreholes at Klipperås study site.

Borehole KKL01

Borehole KKL01 is drilled with the direction 134° and the inclination 80° to the horizontal and the borehole length is 564 m (Figure A2). The borehole was drilled at an early stage of the site investigation programme to confirm favorable conditions at depth as indicated by the reconnaissance surveys. The borehole is interpreted to penetrate Zone 10 between 280 - 310 m borehole length. The estimated true width of Zone 10 in this borehole is 10.5 m. The mean value of fracture frequency in the borehole is 6.9 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B1.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL02

Borehole KKL02 is drilled with the direction 278° and the inclination 78° to the horizontal and the borehole length is 959 m (Figure A3). The purpose with the borehole was to penetrate the homogeneous bedrock in the central part of the site. The borehole intersects the subhorizontal Zone H1 between 792 - 804 m borehole length. However, the core from the section between 764.3 - 796.5 m is missing due to theft during the drilling campaign. The estimated true width of zone H1 in this borehole is 12 m. The mean value of fracture frequency in the borehole is 2.8 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B1.

Borehole availability: There are no known problems with borehole blockage. However, due to technical reasons during drilling, the drill bit and a 0.5 m long part of the core barrel was abandoned in the bottom of the borehole.

Borehole KKL03

Borehole KKL03 is drilled with the direction 85° and the inclination 60° to the horizontal and the borehole length is 250 m (Figure A4). The purpose with the borehole was to penetrate the interpreted Zone 1, which was intersected between 140 - 195 m borehole length. The estimated true width of Zone 1 in this borehole is 28 m. The mean value of fracture frequency in the borehole is 6.8 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B1.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL04

Borehole KKL04 is drilled with the direction 289° and the inclination 59° to the horizontal and the borehole length is 200 m (Figure A5). The purpose of the borehole was to investigate Zone 1 and a dolerite dyke located close to and parallel to the zone. The borehole intersects Zone 1 between 110 – 180 m and the dolerite dyke between 78 – 92 m borehole length. The estimated true width of Zone 1 in this borehole is 36 m. The mean value of fracture frequency in the whole borehole is 10.9 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B2.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL05

Borehole KKL05 is drilled with the direction 76° and the inclination 56° to the horizontal and the borehole length is 246 m (Figure A6). The purpose with borehole KKL05, as well as with KKL06 and KKL10, was to investigate the characteristics of an extensive N–S trending dolerite dyke. The core from the borehole confirmed the dyke at 19 – 29 m borehole length. The dyke is characterized by clay alteration and high fracture frequency. The borehole also intersects unaltered porphyric dykes. The granite is down to the bottom of the borehole sparsely fractured. The mean value of fracture frequency in the whole borehole is 5.5 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B2.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL06

Borehole KKL06 is drilled with the direction 276° and the inclination 56° to the horizontal and the borehole length is 808 m (Figure A7). The purpose with the borehole was to investigate the N–S–trending dolerite dyke, see above, at a deeper location and, generally, to obtain data on bedrock conditions at a greater depth. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B2.

The borehole intersects the dolerite dyke between 338 – 372 m borehole length, which indicates a vertical dip of the dyke. Increased fracturing and a 1.5 m long section with crushed rock, is associated with the dolerite. The granite on both sides of the dyke is only slightly fractured. The borehole also penetrates E–W trending porphyritic dykes. The granite is strongly sheared at the contacts to these dykes. The mean value of fracture frequency in the whole borehole is 5.1 fr/m.

Borehole availability: There are no known problems with borehole blockage. However, there have been difficulties with temporarily blockages in the borehole during different borehole measurements.

Borehole KKL07

Borehole KKL07 is drilled with the direction 320° and the inclination 57° to the horizontal and the borehole length is 250 m (Figure A8). The purpose with the borehole was to penetrate the interpreted Zone 3, which was intersected between 115 - 130 m borehole length. Between 116 - 127 m most of the rock is crushed and one meter of this section consists of unconsolidated, sandy and greyish–yellow fault breccia. The estimated true width of Zone 3 is 12 m. The mean value of fracture frequency in the borehole is 11.3 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B3.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL08

Borehole KKL08 is drilled with the direction 283° and the inclination 58° to the horizontal and the borehole length is 266 m (Figure A9). The purpose with the borehole was to investigate a distinct N–S trending electromagnetic anomaly. The borehole intersects a fractured bedrock between 91 - 95 m borehole length. Apart from increased fracture frequency the section is characterized by 1 m of a strongly sheared and crushed granite. However, this structure was not separated as a specific fracture zone in the conceptual model of the site. The mean value of fracture frequency in the borehole is 3.5 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B3.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL09

Borehole KKL09 is drilled with the direction 300° and the inclination 56°. The borehole length is 801 m (Figure A10). The purpose with the borehole was to investigate Zone 1 and Zone 2 and a dolerite dyke located in between the zones. The dyke was intersected between 356 – 369 m. In this section the fracture frequency were increased.

The borehole intersects Zone 2 between 120 – 160 m borehole length. This section is characterized by an increased fracture frequency and two sections of crushed granite, which are 0.5 m and 0.1 m wide, respectively. The section between 615 – 665 m represents Zone 1 which is characterized by schistose greenstone and deformed granite. In some places brecciation occurs along the contacts. The estimated true width of Zone 1 in this borehole is 29 m and Zone 2 is 22 m. The mean value of fracture frequency in the whole borehole is 4.5 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B3.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL10

Borehole KKL10 is drilled with the direction 90° and the inclination 49° to the horizontal and the borehole length is 203 m (Figure A11). The purpose with borehole KKL10, as well as KKL05 and KKL06, was to investigate the N–S trending dolerite dyke, see above. The borehole penetrates the dyke between 88 – 100 m borehole length. The dyke is less altered compared to borehole KKL05 but the fracturing is intense. The section includes a total of 0.8 m crushed rock. A porphyritic dyke occurs in contact to the dolerite.

The granite is low fractured all along the borehole (2.8 fr/m), however the mean fracture frequency for the whole borehole, incorporating both the granite and the dykes, is 4.4 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B4.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL11

Borehole KKL11 is drilled with the direction 353° and the inclination 57°. The borehole length is 251 m (Figure A12). The purpose with the borehole was, together with KKL14, to penetrate and characterize the interpreted Zone 4. The borehole intersects Zone 4 between 108 – 148 m borehole length. This section is highly fractured and the rock is tectonized. The estimated true width of Zone 4 in this borehole is 23 m. The mean value of fracture frequency in the whole borehole is 6.5 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B4.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL12

Borehole KKL12 is drilled with the direction 346° and the inclination 50° to the horizontal and the borehole length is 730 m (Figure A13). The purpose with the borehole was to investigate a low magnetic anomaly pattern indicating dykes and block faulting in the vicinity of Zone 2.

The general result from the borehole reveals a complex geological and tectonical environment with a number of porphyritic dykes and fracture zones (Zones 2, 6, 7, 8 and 9) with various orientations. The interpreted intersections of the fracture zones with the borehole are tabulated below.

Interpreted fracture zones in borehole KKL12.

Fracture zones	Interpreted location of fracture zones (m)	True widths (m)
Zone 6	70–88	12.5
Zone 7	288–306	13.5
Zone 8	312–347	28.0
Zone 9	362–384	17.5
Zone 2	595–630	13.0

The mean value of fracture frequency in the whole borehole is 5.0 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B4.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL13

Borehole KKL13 is drilled with the direction 22° and the inclination 55°. The borehole length is 700 m (Figure A14). The purpose of the borehole was to penetrate the interpreted Zone 5 and the deep bedrock to the north of the borehole. The borehole intersects Zone 5 between 152 – 188 m borehole length. The estimated true width of Zone 5 in this borehole is 23 m. The mean value of fracture frequency in the whole borehole is 3.4 fr/m.

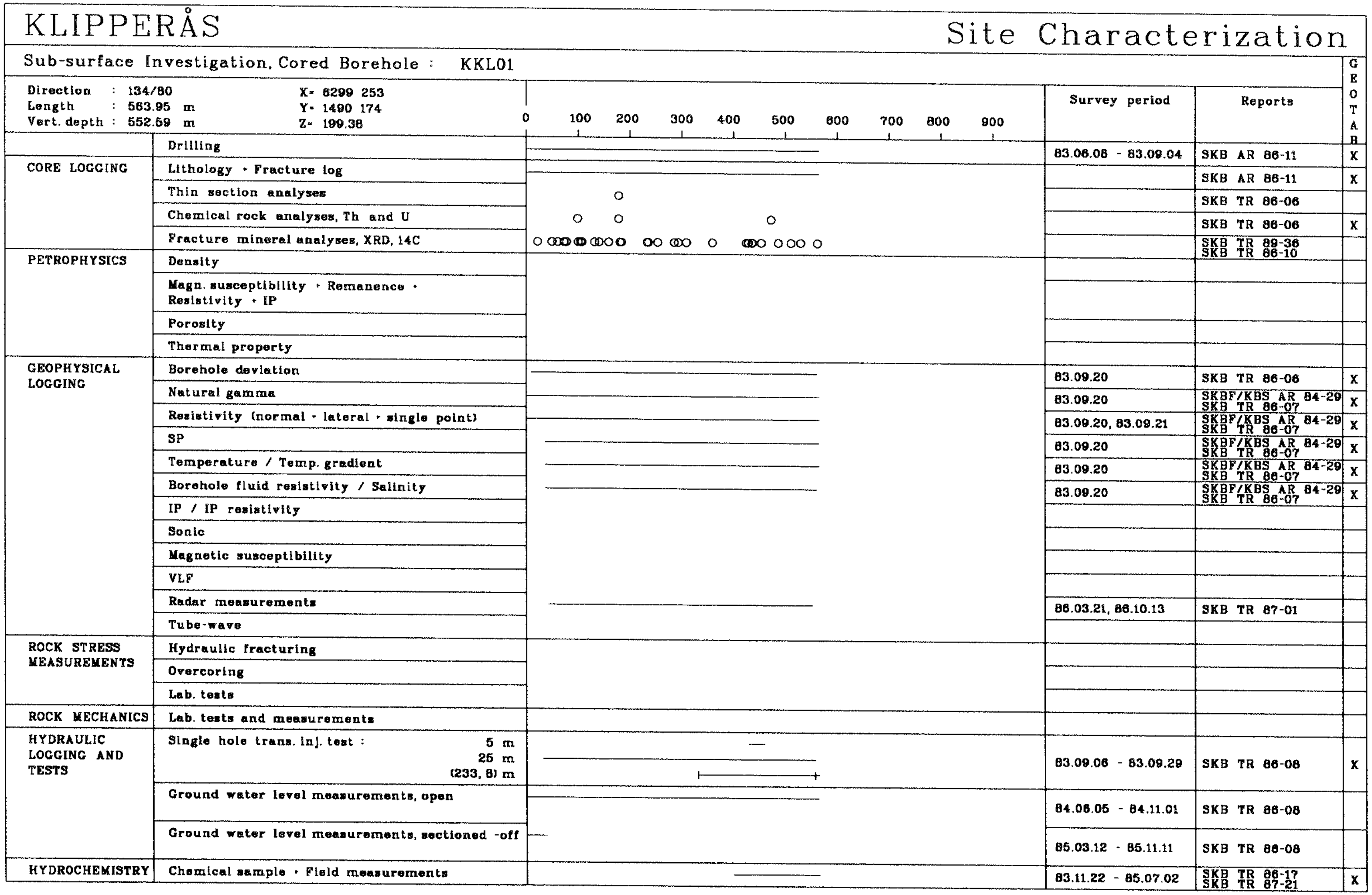
Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B5.

Borehole availability: There are no known problems with borehole blockage.

Borehole KKL14

Borehole KKL14 is drilled with the direction 2° and the inclination 55°. The borehole length is 705 m (Figure A15). The purpose with the borehole was, together with KKL11, to investigate Zone 4 and the bedrock the bedrock at a greater depth north of the zone. The borehole intersects Zone 4 between 368 - 410 m borehole length, in where the cores display an increased fracturing. The increased fracturing continues below the interpreted zone, possible due to an intersection with another, minor, fracture zone. The estimated true width of Zone 4 in this borehole is 27 m. The mean value of fracture frequency in the whole borehole is 4.1 fr/m. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B5.

Borehole availability: There are no known problems with borehole blockage.



KLIPPERÅS Site Characterization

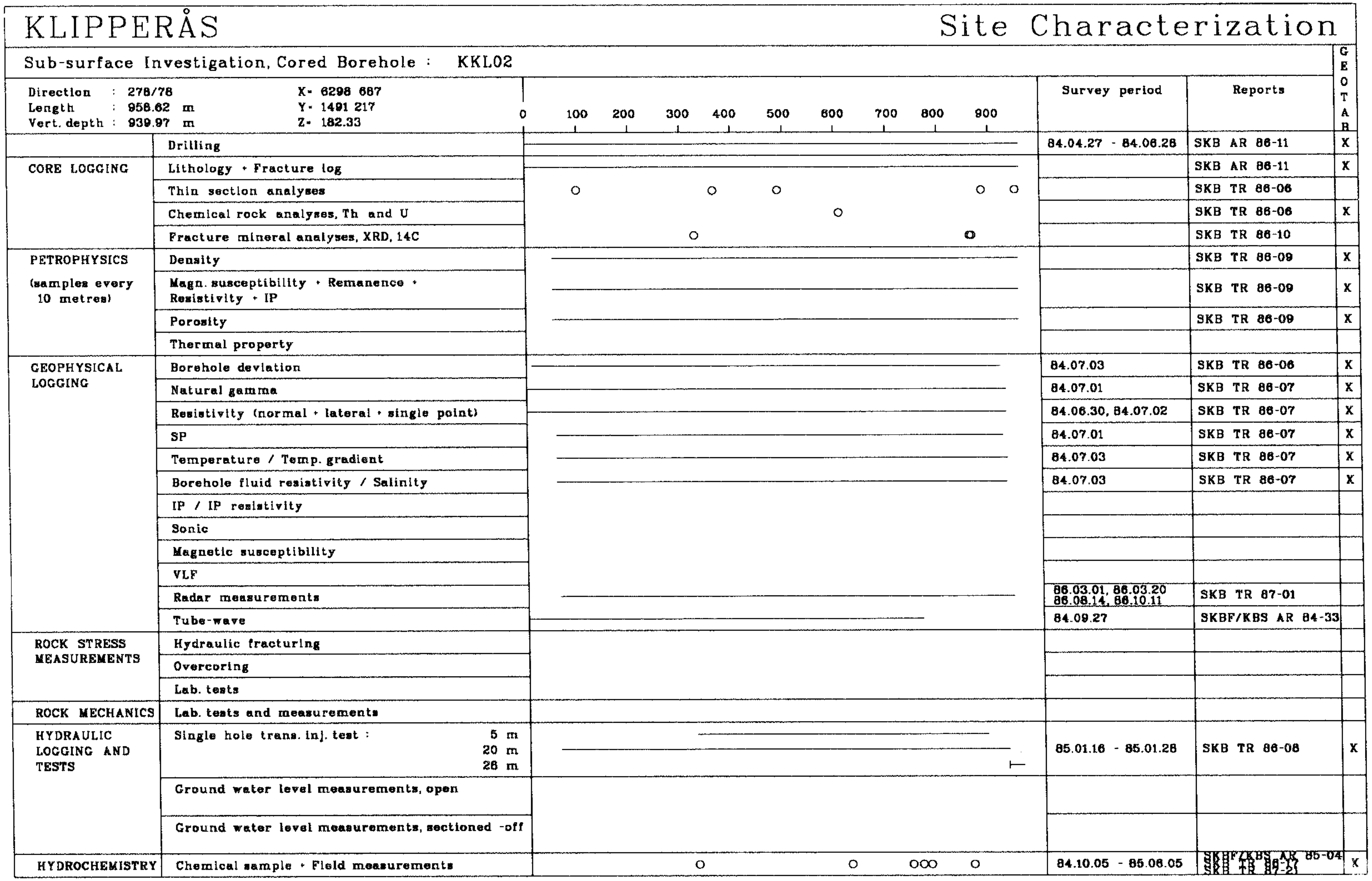
Sub-surface Investigation, Cored Borehole : KKL01

Direction : 134/80
Length : 563.95 m
Vert. depth : 552.59 m

X= 6299 253
Y= 1490 174
Z= 199.38

		Survey period	Reports	GEOTAB
	Drilling	83.06.08 - 83.09.04	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log		SKB AR 86-11	X
	Thin section analyses		SKB TR 86-06	
	Chemical rock analyses, Th and U		SKB TR 86-06	X
	Fracture mineral analyses, XRD, 14C		SKB TR 89-36 SKB TR 86-10	
PETROPHYSICS	Density			
	Magn. susceptibility + Remanence + Resistivity + IP			
	Porosity			
	Thermal property			
GEOPHYSICAL LOGGING	Borehole deviation	83.09.20	SKB TR 86-06	X
	Natural gamma	83.09.20	SKBF/KBS AR 84-29 SKB TR 86-07	X
	Resistivity (normal + lateral + single point)	83.09.20, 83.09.21	SKBF/KBS AR 84-29 SKB TR 86-07	X
	SP	83.09.20	SKBF/KBS AR 84-29 SKB TR 86-07	X
	Temperature / Temp. gradient	83.09.20	SKBF/KBS AR 84-29 SKB TR 86-07	X
	Borehole fluid resistivity / Salinity	83.09.20	SKBF/KBS AR 84-29 SKB TR 86-07	X
	IP / IP resistivity			
	Sonic			
	Magnetic susceptibility			
	VLF			
	Radar measurements	86.03.21, 86.10.13	SKB TR 87-01	
	Tube-wave			
ROCK STRESS MEASUREMENTS	Hydraulic fracturing			
	Overcoring			
	Lab. tests			
ROCK MECHANICS	Lab. tests and measurements			
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test : 5 m 25 m (233, 8) m	83.09.06 - 83.09.29	SKB TR 86-08	X
	Ground water level measurements, open	84.06.05 - 84.11.01	SKB TR 86-08	
	Ground water level measurements, sectioned -off	85.03.12 - 85.11.11	SKB TR 86-08	
HYDROCHEMISTRY	Chemical sample + Field measurements	83.11.22 - 85.07.02	SKB TR 86-17 SKB TR 87-21	X

Figure A2. Activities in borehole KKL01.



KLIPPERÅS Site Characterization

Sub-surface Investigation, Cored Borehole : KKL02

Direction : 278/78
Length : 958.62 m
Vert. depth : 939.97 m

X- 6298 687
Y- 1491 217
Z- 182.33

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling	———	84.04.27 - 84.06.28	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log	———		SKB AR 86-11	X
	Thin section analyses	○ ○ ○ ○ ○		SKB TR 86-06	
	Chemical rock analyses, Th and U	○		SKB TR 86-06	X
	Fracture mineral analyses, XRD, 14C	○ ○		SKB TR 86-10	
PETROPHYSICS (samples every 10 metres)	Density	———		SKB TR 86-09	X
	Magn. susceptibility + Remanence + Resistivity + IP	———		SKB TR 86-09	X
	Porosity	———		SKB TR 86-09	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation	———	84.07.03	SKB TR 86-06	X
	Natural gamma	———	84.07.01	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)	———	84.06.30, 84.07.02	SKB TR 86-07	X
	SP	———	84.07.01	SKB TR 86-07	X
	Temperature / Temp. gradient	———	84.07.03	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity	———	84.07.03	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements	———	86.03.01, 86.03.20 86.08.14, 86.10.11	SKB TR 87-01	
	Tube-wave	———	84.09.27	SKBF/KBS AR 84-33	
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test : 5 m 20 m 26 m	——— ——— ⊢	85.01.16 - 85.01.28	SKB TR 86-08	X
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements	○ ○ ○○○ ○	84.10.05 - 85.06.05	SKBF/KBS AR 85-04 SKB TR 86-17 SKB TR 87-21	X

Figure A3. Activities in borehole KKL02.

KLIPPERÅS Site Characterization

Sub-surface Investigation, Cored Borehole : KKL03

Direction : 85/60
Length : 249.96 m
Vert. depth : 216.58 m

X= 6299 160
Y= 1490 579
Z= 197.25

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		84.07.01 - 84.07.09	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log			SKB AR 86-11	X
	Thin section analyses				
	Chemical rock analyses, Th and U				
	Fracture mineral analyses, XRD, 14C				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		84.12.19	SKB TR 86-06	X
	Natural gamma		84.12.19	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)		84.12.19, 85.01.11	SKB TR 86-07	X
	SP		85.04.26	SKB TR 86-07	X
	Temperature / Temp. gradient		85.01.11	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity		85.01.11	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements				
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test :				
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A4. Activities in borehole KKL03.

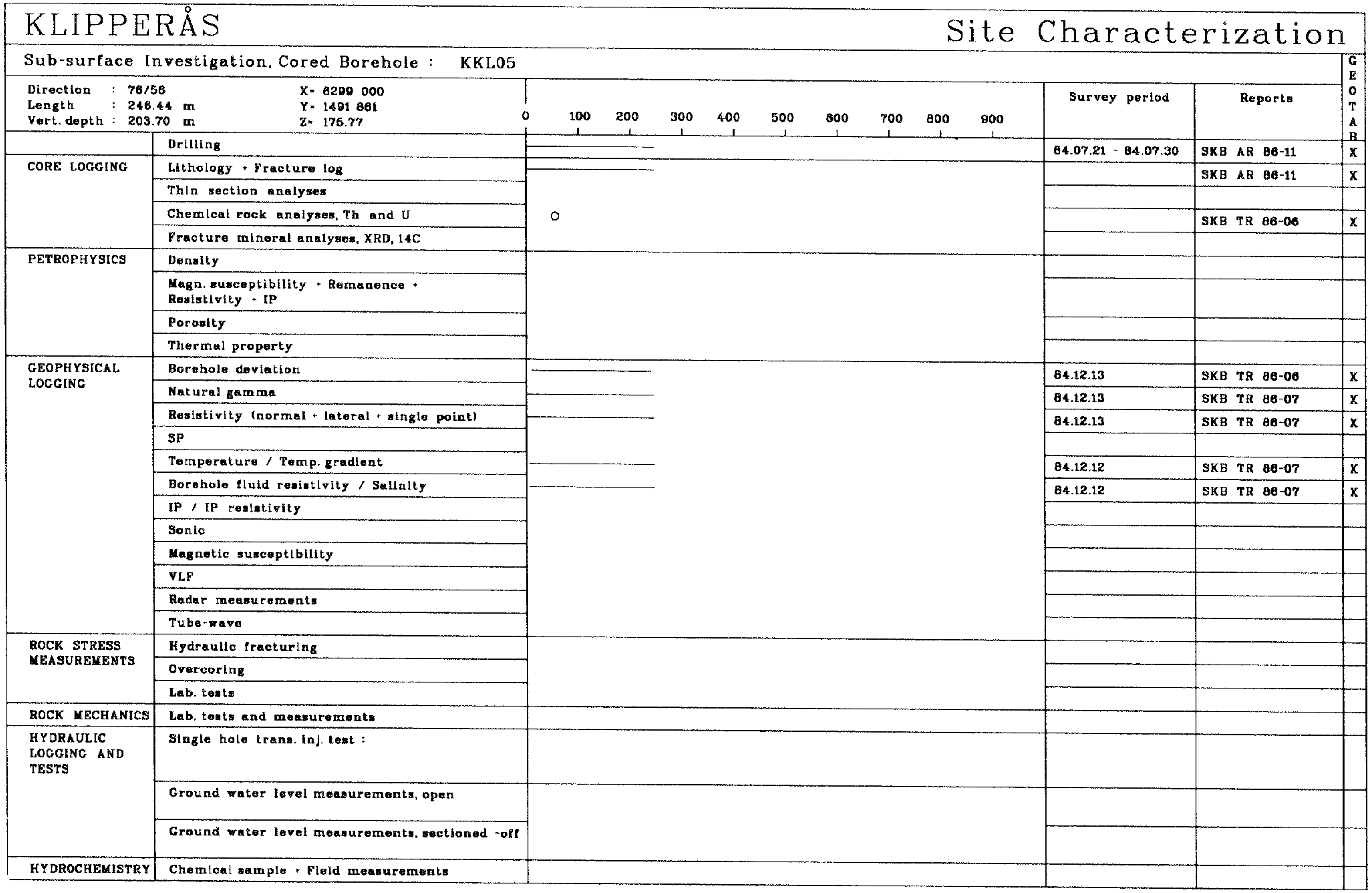
KLIPPERÅS Site Characterization

Sub-surface Investigation, Cored Borehole : KKL04

Direction : 289/59 X= 6299 110
Length : 200.01 m Y= 1490 743
Vert. depth : 167.63 m Z= 195.80

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling	——	84.07.10 - 84.07.18	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log	——		SKB AR 86-11	X
	Thin section analyses				
	Chemical rock analyses, Th and U				
	Fracture mineral analyses, XRD, 14C				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation	——	84.09.30	SKB TR 86-06	X
	Natural gamma	——	84.10.02	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)	——	84.10.01, 85.01.11	SKB TR 86-07	X
	SP	——	84.10.02	SKB TR 86-07	X
	Temperature / Temp. gradient	——	84.09.29	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity	——	84.09.29	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements	——	86.02.28	SKB TR 87-01	
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test :				
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A5. Activities in borehole KKL04.



KLIPPERÅS

Site Characterization

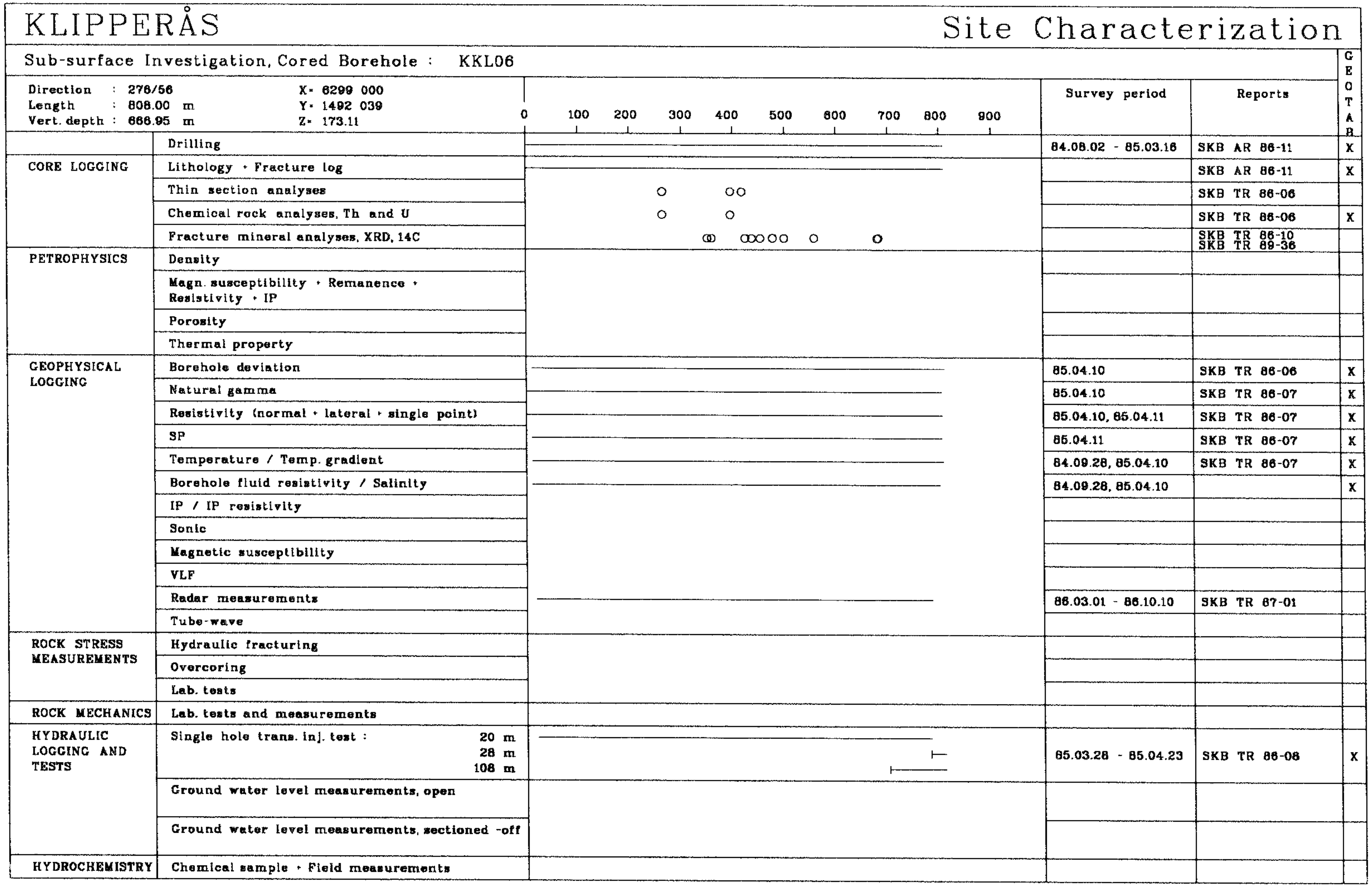
Sub-surface Investigation, Cored Borehole : KKL05

Direction : 76/56
Length : 246.44 m
Vert. depth : 203.70 m

X= 6299 000
Y= 1491 861
Z= 175.77

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		84.07.21 - 84.07.30	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log			SKB AR 86-11	X
	Thin section analyses				
	Chemical rock analyses, Th and U	○		SKB TR 86-06	X
	Fracture mineral analyses, XRD, 14C				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		84.12.13	SKB TR 86-06	X
	Natural gamma		84.12.13	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)		84.12.13	SKB TR 86-07	X
	SP				
	Temperature / Temp. gradient		84.12.12	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity		84.12.12	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements				
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test :				
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A6. Activities in borehole KKL05.



KLIPPERÅS Site Characterization

Sub-surface Investigation, Cored Borehole : KKL06

Direction : 276/56
Length : 808.00 m
Vert. depth : 666.95 m

X= 6299 000
Y= 1492 039
Z= 173.11

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling	———	84.08.02 - 85.03.16	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log	———		SKB AR 86-11	X
	Thin section analyses	○ ○○		SKB TR 86-06	
	Chemical rock analyses, Th and U	○ ○		SKB TR 86-06	X
	Fracture mineral analyses, XRD, 14C	○○ ○○○○○ ○ ○		SKB TR 86-10 SKB TR 89-36	
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation	———	85.04.10	SKB TR 86-06	X
	Natural gamma	———	85.04.10	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)	———	85.04.10, 85.04.11	SKB TR 86-07	X
	SP	———	85.04.11	SKB TR 86-07	X
	Temperature / Temp. gradient	———	84.09.28, 85.04.10	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity	———	84.09.28, 85.04.10		X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements	———	86.03.01 - 86.10.10	SKB TR 87-01	
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test : 20 m 28 m 108 m	——— ⊢ ⊢——	85.03.28 - 85.04.23	SKB TR 86-08	X
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A7. Activities in borehole KKL06.

KLIPPERÅS

Site Characterization

Sub-surface Investigation, Cored Borehole : KKL07

Direction : 320/57
Length : 250.28 m
Vert. depth : 213.80 m

X= 6297 253
Y= 1490 725
Z= 185.97

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling	——	84.08.14 - 84.08.23	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log	——		SKB AR 86-11	X
	Thin section analyses				
	Chemical rock analyses, Th and U				
	Fracture mineral analyses, XRD, 14C	O OO		SKB TR 89-36	
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation	——	84.10.02	SKB TR 86-06	X
	Natural gamma	——	84.10.02	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)	——	84.10.03, 85.01.14	SKB TR 86-07	X
	SP	——	84.10.02	SKB TR 86-07	X
	Temperature / Temp. gradient	——	84.09.29	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity	——	84.09.29	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements				
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test :				
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A8. Activities in borehole KKL07.

KLIPPERÅS Site Characterization

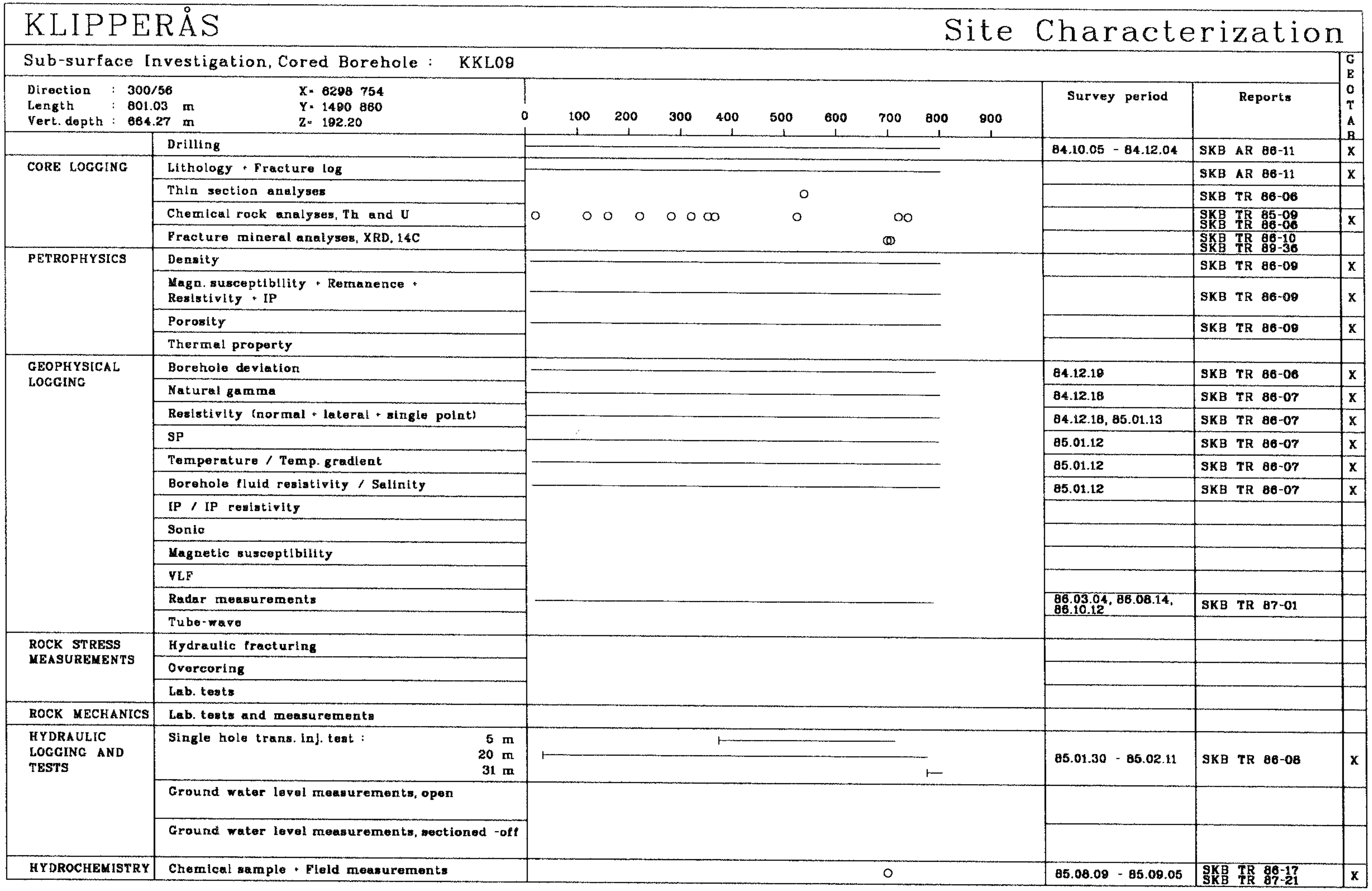
Sub-surface Investigation, Cored Borehole : KKL08

Direction : 258/58
Length : 286.11 m
Vert. depth : 224.51 m

X= 6298 557
Y= 1491 222
Z= 182.57

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		84.10.25 - 84.10.30	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log			SKB AR 86-11	X
	Thin section analyses				
	Chemical rock analyses, Th and U				
	Fracture mineral analyses, XRD, 14C				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		84.12.13	SKB TR 86-06	X
	Natural gamma		84.12.13	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)		84.12.13, 85.01.11	SKB TR 86-07	X
	SP		85.01.12	SKB TR 86-07	X
	Temperature / Temp. gradient		84.12.12	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity		84.12.12	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements		86.03.03, 86.10.09	SKB TR 87-01	
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test :				
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A9. Activities in borehole KKL08.



KLIPPERÅS — Site Characterization

Sub-surface Investigation, Cored Borehole : KKL09

Direction : 300/56 — X= 6298 754
Length : 801.03 m — Y= 1490 860
Vert. depth : 664.27 m — Z= 192.20

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		84.10.05 - 84.12.04	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log			SKB AR 86-11	X
	Thin section analyses	○		SKB TR 86-06	
	Chemical rock analyses, Th and U	○ ○ ○ ○ ○ ○ ○○ ○ ○○		SKB TR 85-09 SKB TR 86-06	X
	Fracture mineral analyses, XRD, 14C	○○		SKB TR 86-10 SKB TR 89-36	
PETROPHYSICS	Density			SKB TR 86-09	X
	Magn. susceptibility + Remanence + Resistivity + IP			SKB TR 86-09	X
	Porosity			SKB TR 86-09	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		84.12.19	SKB TR 86-06	X
	Natural gamma		84.12.18	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)		84.12.18, 85.01.13	SKB TR 86-07	X
	SP		85.01.12	SKB TR 86-07	X
	Temperature / Temp. gradient		85.01.12	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity		85.01.12	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements		86.03.04, 86.08.14, 86.10.12	SKB TR 87-01	
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test : 5 m 20 m 31 m		85.01.30 - 85.02.11	SKB TR 86-08	X
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements	○	85.08.09 - 85.09.05	SKB TR 86-17 SKB TR 87-21	X

Figure A10. Activities in borehole KKL09.

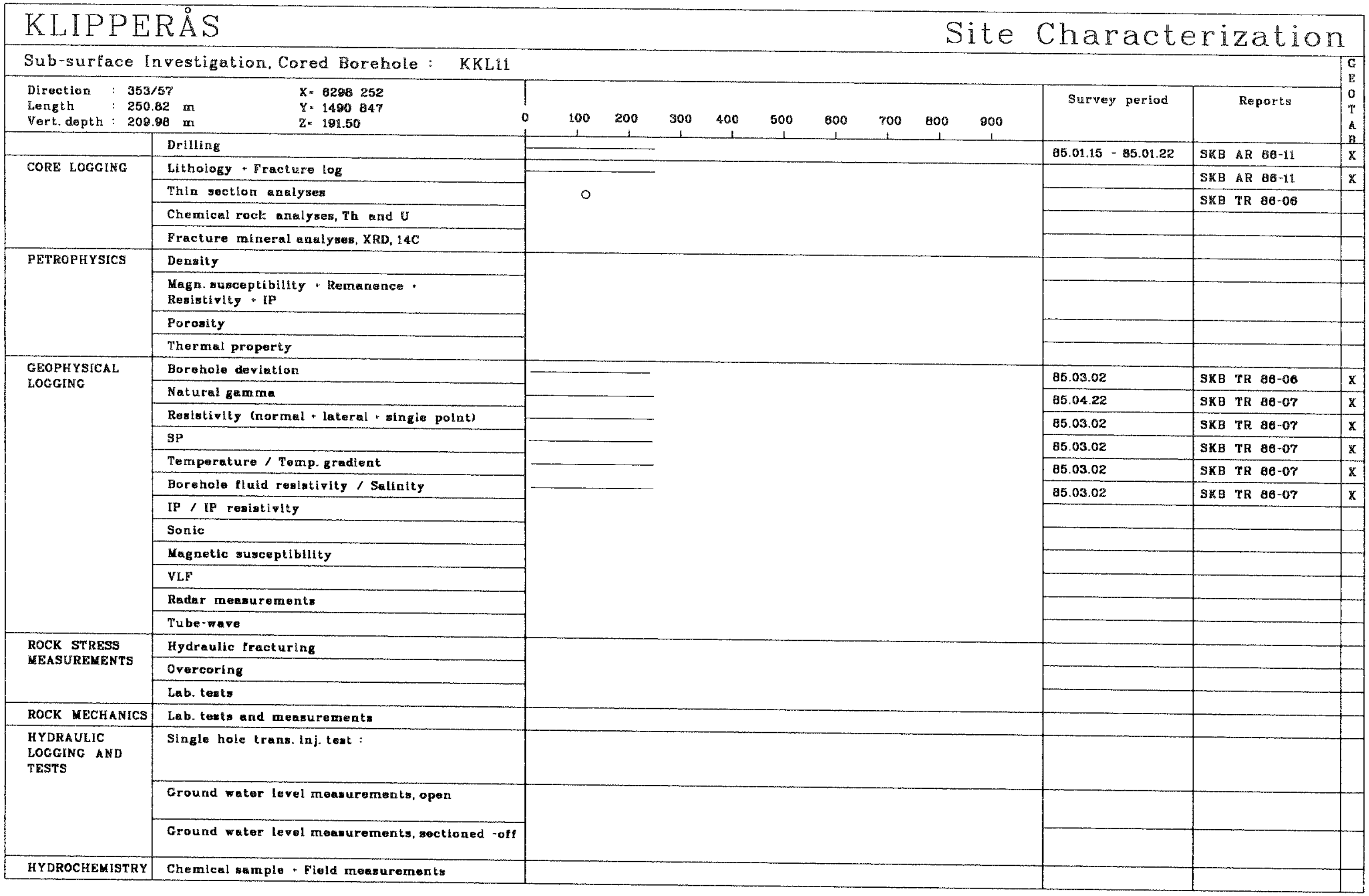
KLIPPERÅS Site Characterization

Sub-surface Investigation, Cored Borehole : KKL10

Direction : 90/49 X= 6299 000
Length : 202.88 m Y= 1491 810
Vert. depth : 153.27 m Z= 176.06

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling	—	85.01.05 - 85.01.14	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log	—		SKB AR 86-11	X
	Thin section analyses	○		SKB TR 86-06	
	Chemical rock analyses, Th and U	○		SKB TR 86-06	X
	Fracture mineral analyses, XRD, 14C	○○		SKB TR 86-10	
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation	—	85.02.27	SKB TR 86-06	X
	Natural gamma	—	85.04.13	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)	—	85.03.01	SKB TR 86-07	X
	SP	—	85.03.01	SKB TR 86-07	X
	Temperature / Temp. gradient	—	85.02.27	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity	—	85.02.27	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements	—	86.02.26, 86.10.10	SKB TR 87-01	
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test :				
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A11. Activities in borehole KKL10.



KLIPPERÅS

Site Characterization

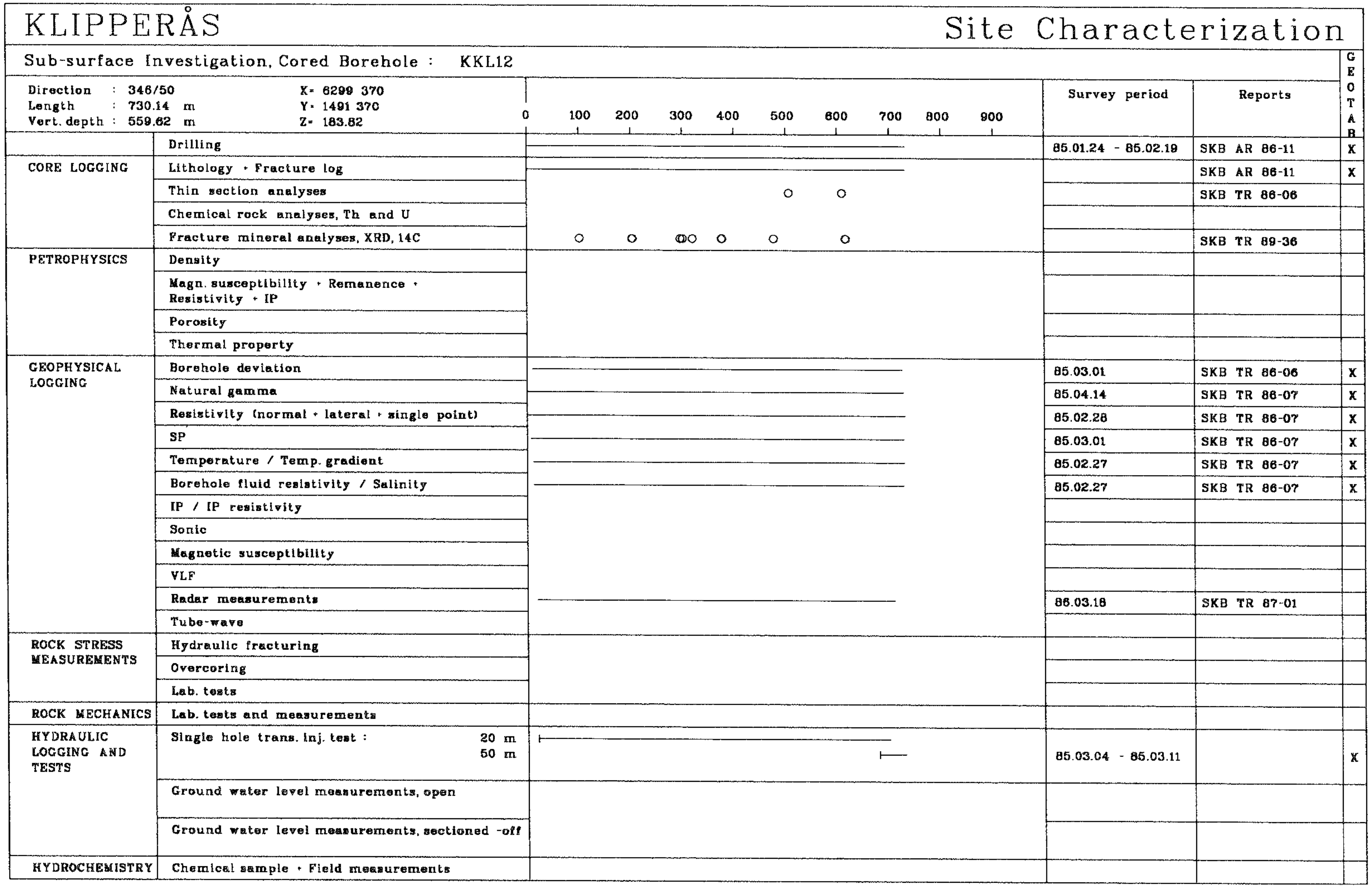
Sub-surface Investigation, Cored Borehole : KKL11

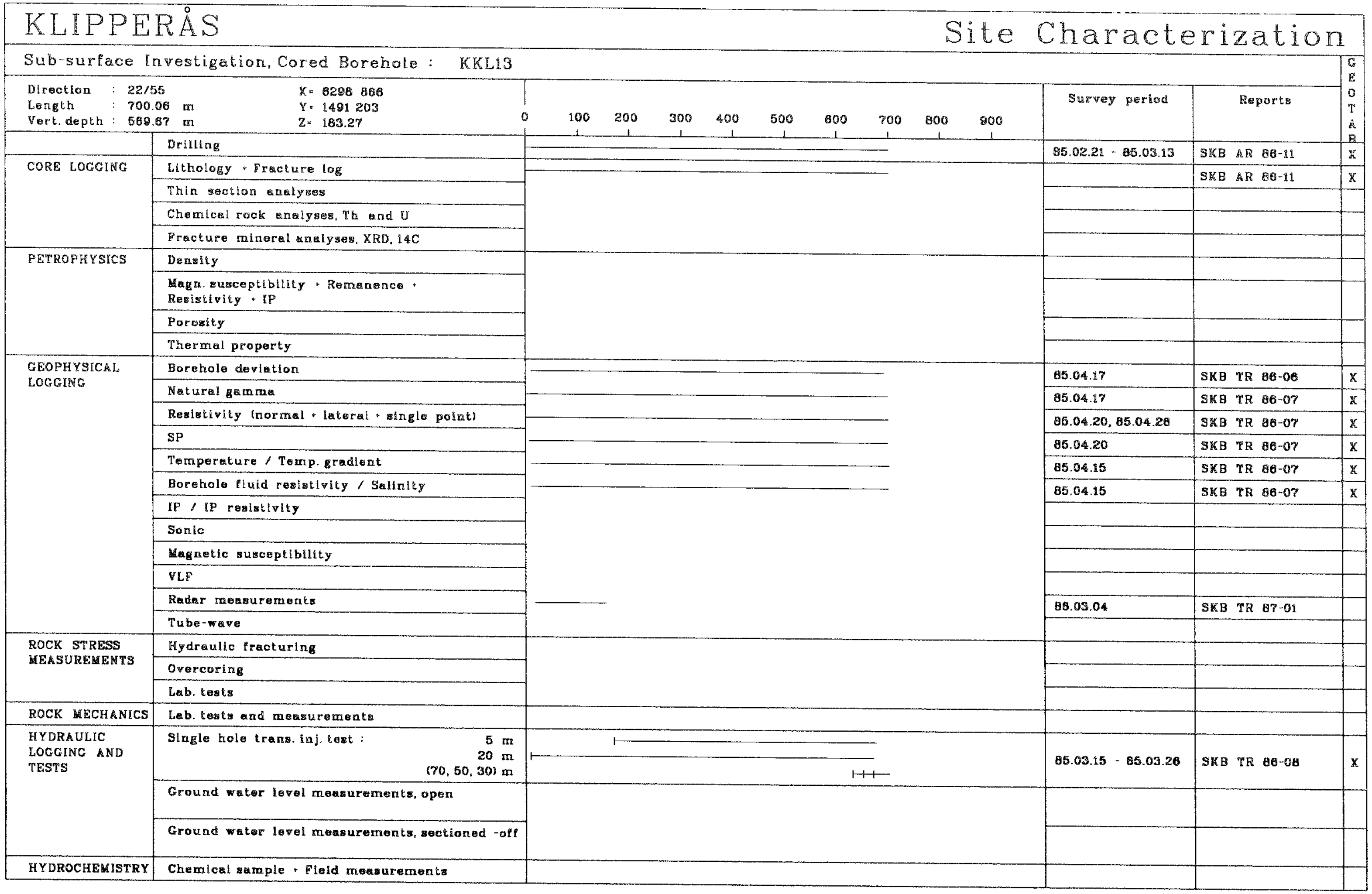
Direction : 353/57
Length : 250.82 m
Vert. depth : 209.98 m

X= 6298 252
Y= 1490 847
Z= 191.50

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		85.01.15 - 85.01.22	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log			SKB AR 86-11	X
	Thin section analyses	○		SKB TR 86-06	
	Chemical rock analyses, Th and U				
	Fracture mineral analyses, XRD, 14C				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		85.03.02	SKB TR 86-06	X
	Natural gamma		85.04.22	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)		85.03.02	SKB TR 86-07	X
	SP		85.03.02	SKB TR 86-07	X
	Temperature / Temp. gradient		85.03.02	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity		85.03.02	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements				
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test :				
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A12. Activities in borehole KKL11.





KLIPPERÅS Site Characterization

Sub-surface Investigation, Cored Borehole : KKL13

Direction : 22/55
Length : 700.06 m
Vert. depth : 569.67 m

X= 6298 866
Y= 1491 203
Z= 183.27

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		85.02.21 - 85.03.13	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log			SKB AR 86-11	X
	Thin section analyses				
	Chemical rock analyses, Th and U				
	Fracture mineral analyses, XRD, 14C				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		85.04.17	SKB TR 86-06	X
	Natural gamma		85.04.17	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)		85.04.20, 85.04.26	SKB TR 86-07	X
	SP		85.04.20	SKB TR 86-07	X
	Temperature / Temp. gradient		85.04.15	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity		85.04.15	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements		86.03.04	SKB TR 87-01	
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test : 5 m 20 m (70, 50, 30) m		85.03.15 - 85.03.26	SKB TR 86-08	X
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A14. Activities in borehole KKL13.

KLIPPERÅS Site Characterization

Sub-surface Investigation, Cored Borehole : KKL14

Direction : 02/55 Length : 705.22 m Vert. depth : 571.67 m	X= 6298 084 Y= 1490 900 Z= 189.12	0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling	————	85.03.19 - 85.04.08	SKB AR 86-11	X
CORE LOGGING	Lithology + Fracture log	————		SKB AR 86-11	X
	Thin section analyses	○ ○ ○ ○ ○		SKB TR 86-06	
	Chemical rock analyses, Th and U	○		SKB TR 86-06	X
	Fracture mineral analyses, XRD, 14C	○ ○ ○ ○ ○○○ ○ ○ ○ ○ ○ ○		SKB TR 86-10	
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation	————	85.04.17	SKB TR 86-06	X
	Natural gamma	————	85.04.18	SKB TR 86-07	X
	Resistivity (normal + lateral + single point)	————	85.04.16, 85.04.18	SKB TR 86-07	X
	SP	————	85.04.18	SKB TR 86-07	X
	Temperature / Temp. gradient	————	85.04.16	SKB TR 86-07	X
	Borehole fluid resistivity / Salinity	————	85.04.16	SKB TR 86-07	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements	————	86.03.19	SKB TR 87-01	
	Tube-wave				
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test : 20 m 25 m	———— ⊢	85.04.23 - 85.05.04	SKB TR 86-08	X
	Ground water level measurements, open				
	Ground water level measurements, sectioned -off				
HYDROCHEMISTRY	Chemical sample + Field measurements				

Figure A15. Activities in borehole KKL14.

APPENDIX B
GENERALIZED RESULTS FROM BOREHOLE MEASUREMENTS

Generalized results from core mapping and borehole measurements/tests in the cored boreholes KKL01–KKL14 are presented in Figures B1–B5. For each borehole the following information is presented: variation in rock types, location of fractured sections and locations of sections with increased hydraulic conductivity. For comparison, also intersections with interpreted fracture zones are shown in the figures. The generalizations have been made in the following way:

Rock types

Main rock types are shown, i.e. rocks with a width/extension along the core greater than 1 m. Amfibolitic bodies and other basic rock types are collectively described as "greenstone".

Fracturing

Increased fracturing is noted where the fracture frequency exceeds 10 fr/m over a 10 m section of the core.

Increased hydraulic conductivity

Increased hydraulic conductivity is noted for borehole sections where the conductivity is more than 10 times higher than the average hydraulic conductivity for the rock mass at the depth in question (see Figure 20 in Chapter 6). Highly increased hydraulic conductivity is noted where the conductivity in the borehole section is more than 100 times higher.

Comments on results shown in Figures B1–B5

In the 14 cored boreholes 11 fracture zones are identified. One zone is penetrated by three boreholes, two zones by two boreholes, and 8 zones are penetrated by single boreholes. Still there are several sections with highly increased hydraulic conductivity which do not coincide with the 11 fracture zones, as KKL01, KKL02, KKL09, and KKL12. Borehole KKL06 have many sections with highly increased hydraulic conductivity and high fracture frequency without any fracture zone assigned to these sections.

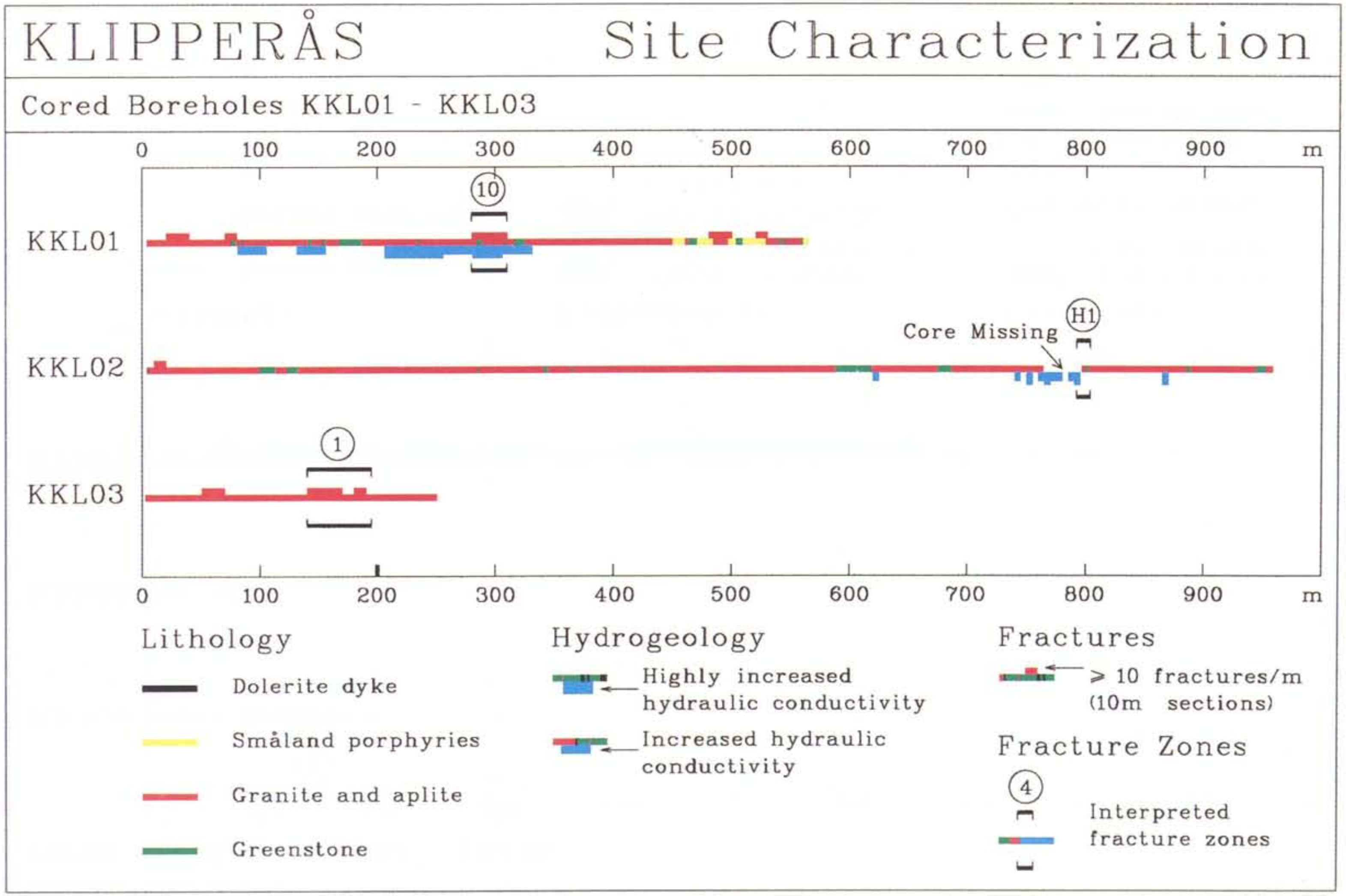


Figure B1. Results from borehole surveys in KKL01–KKL03. The horizontal axis represents borehole length.

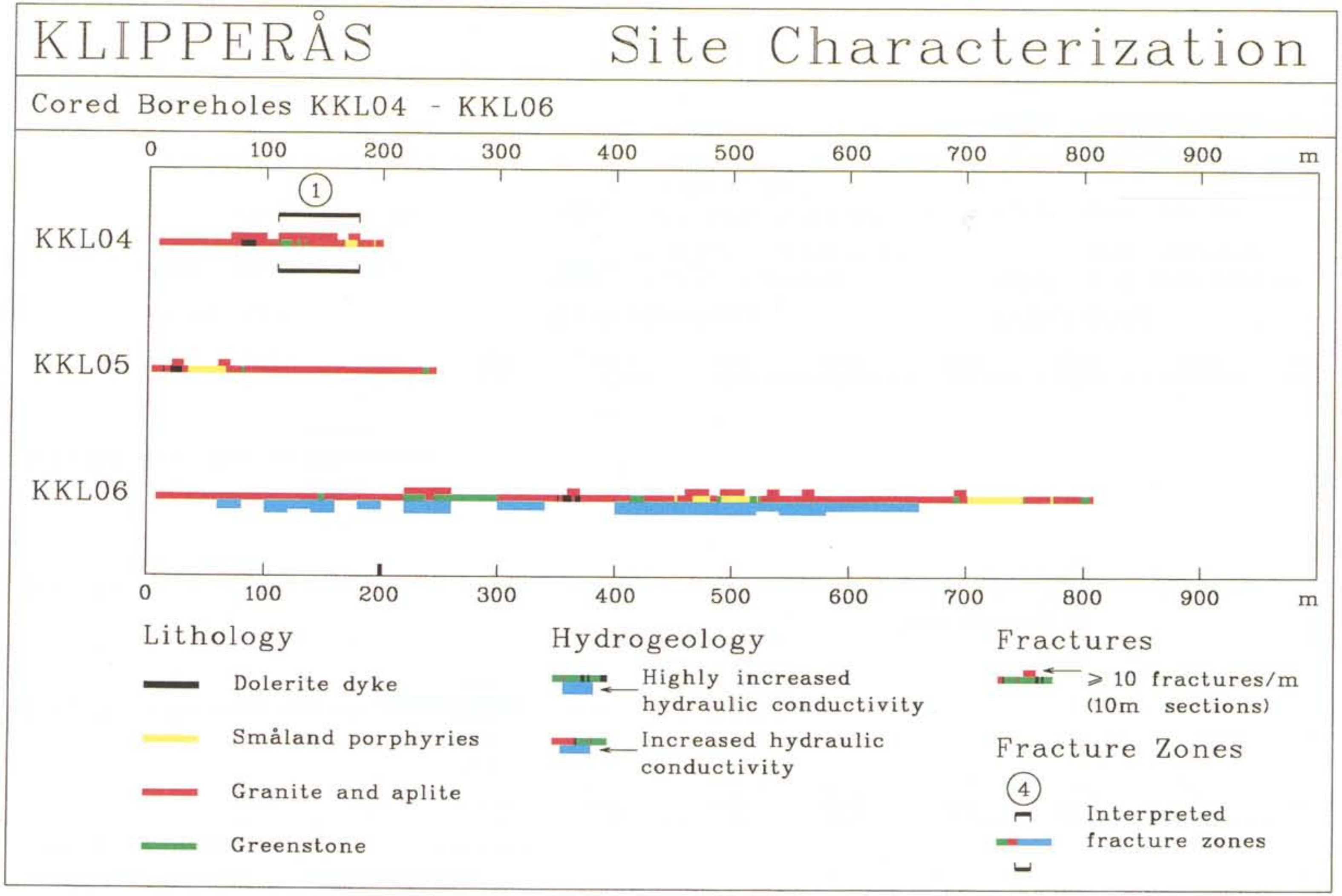


Figure B2. Results from borehole surveys in KKL04–KKL06. The horizontal axis represents borehole length.

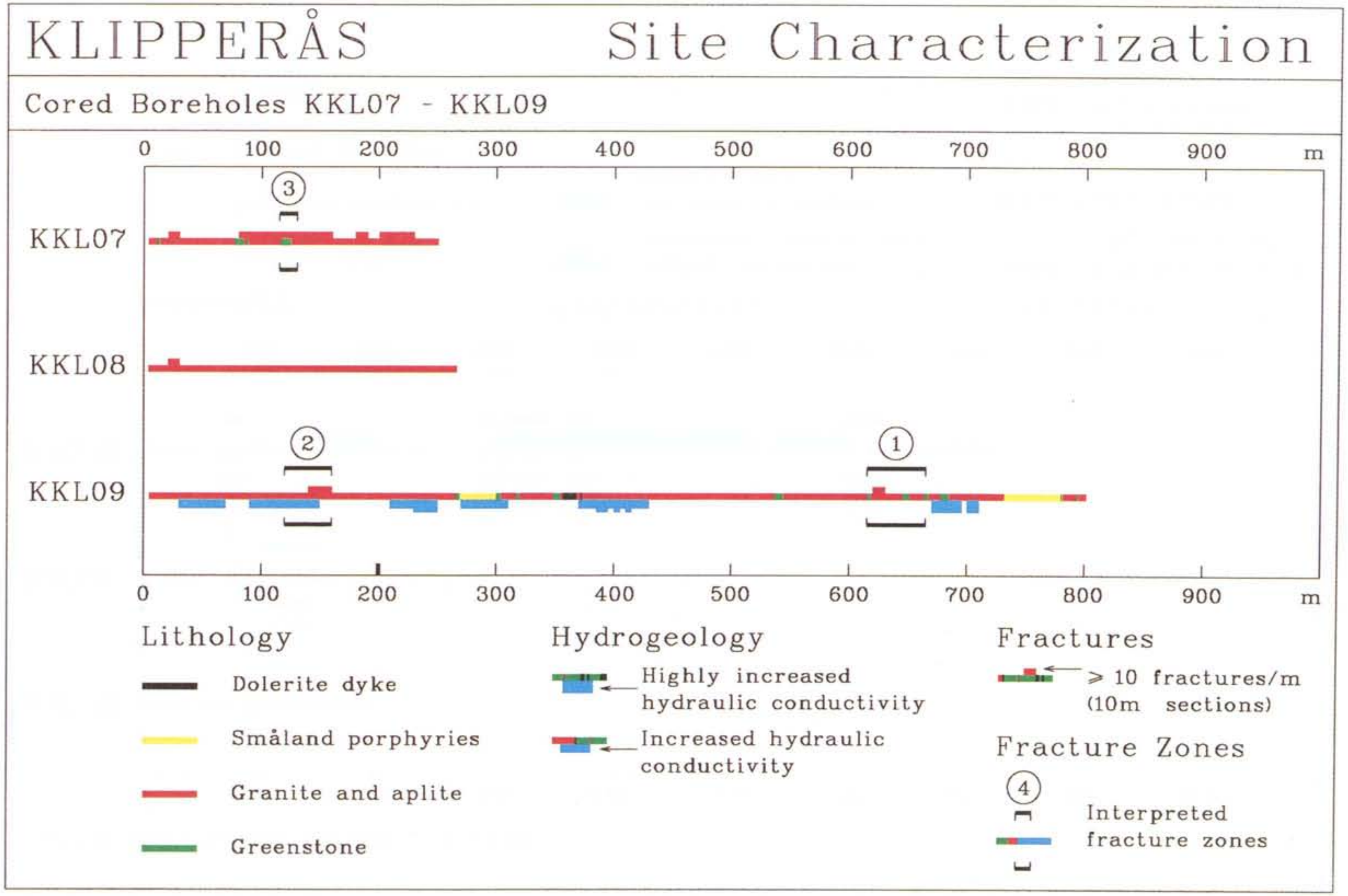


Figure B3. Results from borehole surveys in KKL07–KKL09. The horizontal axis represents borehole length.

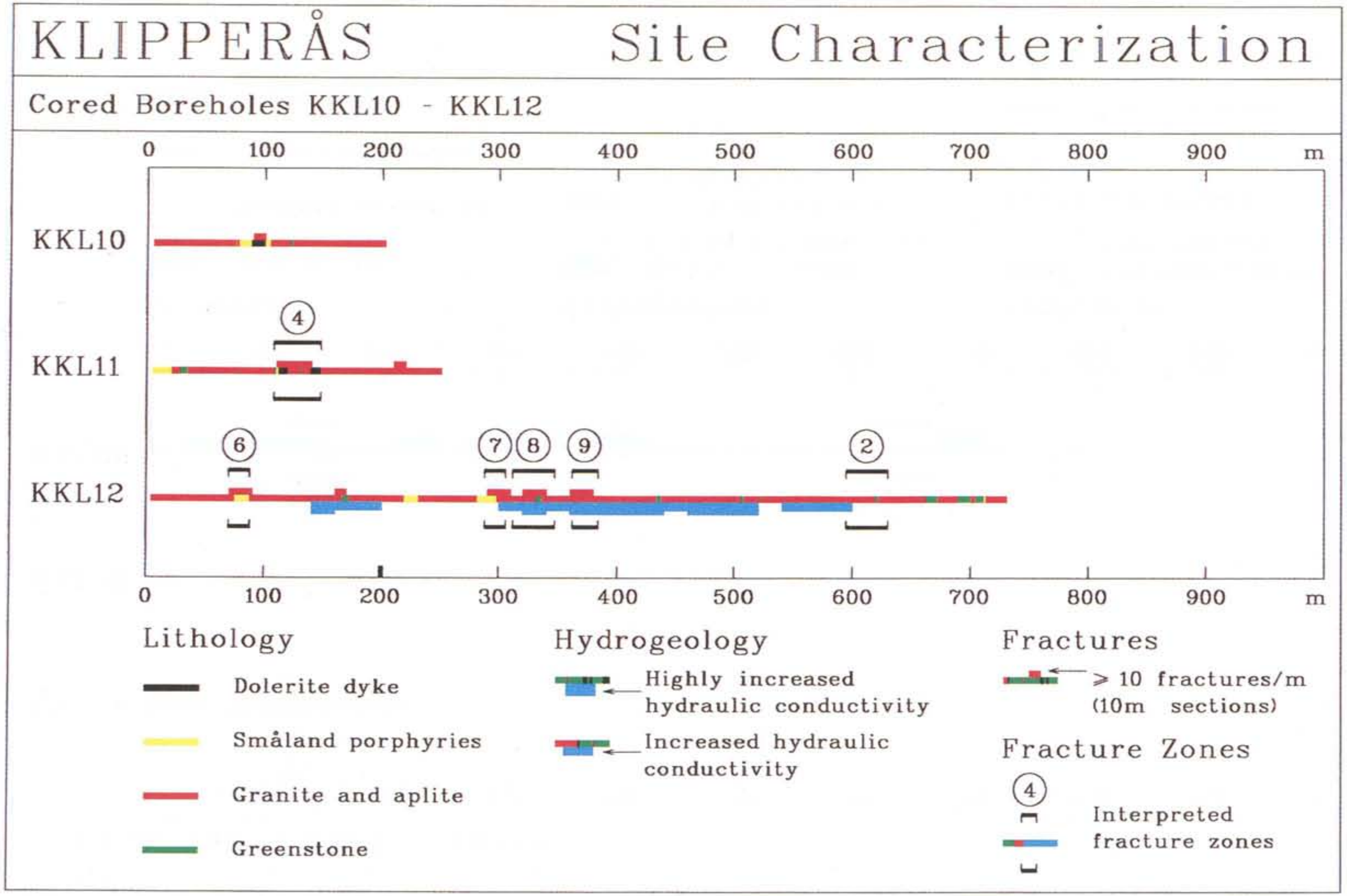


Figure B4. Results from borehole surveys in KKL10–KKL12. The horizontal axis represents borehole length.

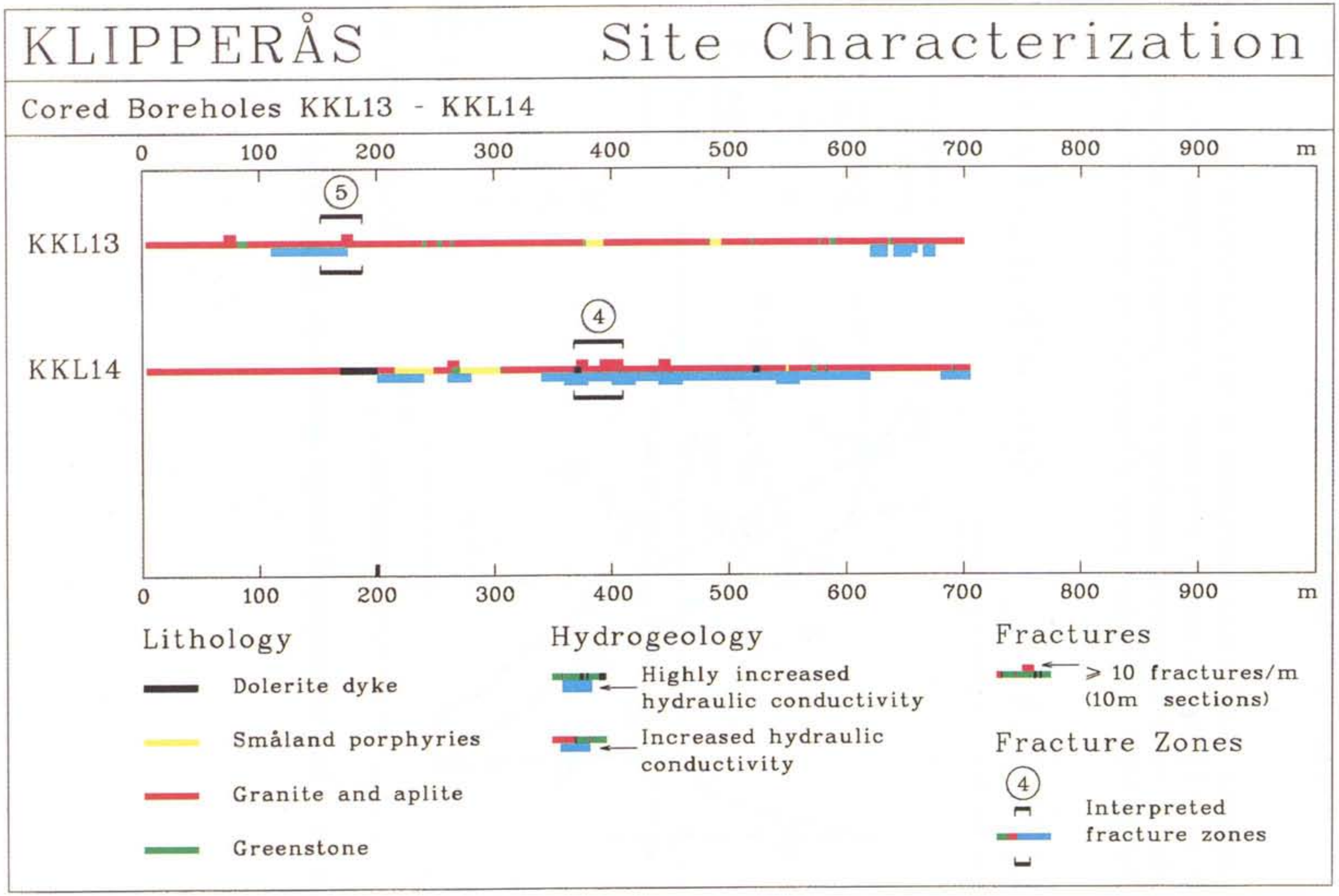


Figure B5. Results from borehole surveys in KKL13–KKL14. The horizontal axis represents borehole length.

APPENDIX C
DESCRIPTIONS OF EACH FRACTURE ZONE

This appendix presents brief descriptions of each interpreted fracture zone, displayed in Figure C1, together with general comments regarding the reliability of the interpretation, according to the nomenclature presented by Bäckblom (1989). The fracture zones at Klipperås are summarized in Section 5.4.

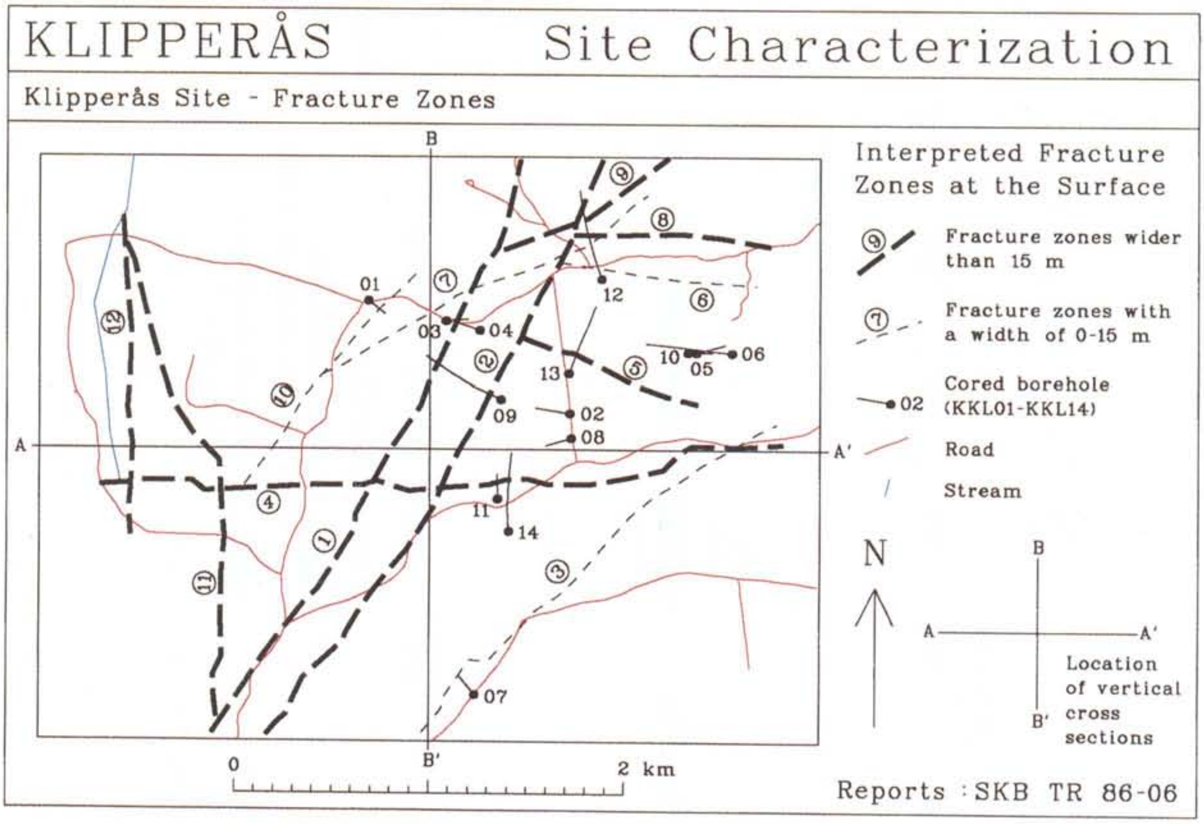


Figure C1. Map of interpreted fracture zones in the Klipperås site.

ZONE 1

The principal direction of Zone 1 is N25E and the dip is vertical. The average calculated true width is 30 m. The zone intersects the central part of the site and it is well indicated by the geophysical surface measurements and it has been intersected by three boreholes, KKL03, KKL04, and KKL09.

The geophysical surface measurements indicates that the northern part of the zone is intruded by a basic dyke, which width is approximately 10 m. All rocks within the zone are strongly brecciated and mylonitized with fissures sealed by quartz, epidote, or calcite.

The fracture zone is tested hydraulically in borehole KKL09 and in the percussion borehole HKL09. The results are ambiguous since hydraulic tests in the cored borehole did not showed any increased conductivity, while the percussion borehole yield a water capacity of 20 000 l/h.

Reliability: The core mapping, as well as the surface geophysical surveys, indicate a much wider zone compared to the present interpretation. This is strengthen by the high water capacity in borehole HKL10, located in the vicinity of the interpreted location of the zone. Presumably Zone 1, as well as Zone 2 (see below), are instead late reactivated parts of a ca. 200 - 300 m wide old oxidized shear zone. Furthermore, the high frequency of aplites and late dolerite dykes along this structure speaks in favour for a wider fracture zone. The change in width does not change the reliability of the present interpretation. Thus, the occurrence of Zone 1 in three boreholes, together with a strong geophysical anomaly results in a reliability level of "**certain**", according to the nomenclature of Bäckblom (1988).

ZONE 2

Zone 2 parallels Zone 1 at a distance of ca. 300 m to the east, i.e. its trend is N25E and the dip is vertical. The average calculated true width is 20 m. The zone is well indicated by the ground geophysical measurements, as a topographical lineament and it has been intersected by two boreholes, KKL09 and KKL12.

According to geophysical surface measurements is the southernmost part of the zone intruded by a dolerite dyke, whose width is approximately 10 m.

In borehole KKL09, Zone 2 is interpreted between 120 - 160 m borehole length. In the central parts of the zone, a fault gouge, 1.5 cm in width, is described. Long sections of the core are altered, brecciated and partly mylonitized. In KKL12, at 595 - 630 m borehole length, Zone 2 consists of breccias, mylonites and foliated bedrock. The core is interwoven by many epidote and quartz sealed fractures. Hydraulically, only a slight increase in conductivity is measured at the interpreted locations of the zone.

Reliability: Zone 2 is located in a wide zone of oxidized deformed Småland granite with inlayers of greenstone, aplite and dolerite. The zone has no increased significant hydraulic signature compared to the country rock. Zone 2 is most presumably a reworked easterly part of Zone 1, see above. Still, the reliability of Zone 2 is "**certain**" according to the Bäckblom classification.

ZONE 3

The main direction of Zone 3 is N35E and the dip is 65° to the east. The calculated true width is 12 m. Zone 3 is well indicated by ground geophysical measurements, as a 200 m wide zone of oxidation. The existence of the zone was investigated by borehole KKL07.

Borehole KKL07 is reported to intersect Zone 3 between 115 - 130 m. In the core logs, however, the highly fractured sections starts at 107 m and continues at least to 137 m. Between 116 to 127 m, most of the rock is crushed and one meter of the section consists of grey-yellow sand. A microscopy study shows that the sand is a product of crushing, presumably formed during faulting. The sharp edged grains, 0.1 - 1 mm, consist of small rock fragments (granite, greenstone, and porphyry) and is slightly clay altered. This indicates that Zone 3 is the reactivated part of an older zone containing a composite dyke. This indicates that Zone 3 is the reactivated part of an older zone containing composite dykes (Tullborg, 1986). A general observation is that the bedrock within and below the zone frequently exhibits old breccias, mylonites and fractures filled with quartz and epidote, probably indicating earlier repeatedly reactivations.

No hydraulic tests was performed in borehole KKL07. One percussion borehole, HKL05, drilled through the zone yield 3 600 l/h, while borehole HKL06, drilled in its vicinity yield 2000 l/h.

Reliability: **Certain**, however, Zone 3 is probably much wider than what is earlier reported.

ZONE 4

The main direction of Zone 4 is E-W and the dip is 80° to the south. The average calculated true width is 25 m. Zone 4 is well indicated by the electromagnetic surface measurements and as a topographical lineament. The zone has been intersected by two boreholes, KKL11 (108 - 148 m) and KKL14 (368 - 410 m).

The fracture frequency in KKL11 is high and the borehole contains three crushed sections. Hematitization is common and clay alteration occurs in two sections, 5 cm and 2 cm in thickness, respectively. Loss of drill water were recorded at four different depths. Old tectonic structures, such as breccias and sealed fractures occur mainly within and very close to Zone 4. Common fracture minerals are epidote, quartz, and calcite.

The core from KKL14 shows traces of earlier tectonic movements, not only within Zone 4, but also up to 70 m outside both sides of the zone. Schistosity, brecciation, mylonitization, and several epidote sealed fractures characterize this section of the core. The fracture frequency is very high, but only a small part of the core is crushed. Alteration is common and in two parts clay alteration occur in the rock. In one of the parts, a 0.40 m long section of clay alteration is observed. Loss of flushing water during drilling was observed within the zone.

Reliability: Zone 4 is strongly indicated, geophysically from Zone 2 and eastwards. Borehole KKL14 confirms the zone in this area. Westwards of Zone 2, the zone is only weakly indicated and is not tested by any borehole. The reliability should therefore be "**certain**" in its eastern part and "**possible**" in its western part.

ZONE 5

The principal direction of Zone 5 is N80W and the dip is 75° to the south. The zone is interpreted at 152 - 188 m, and its calculated width is 23 m. Zone 5 is indicated by the ground geophysical measurements and it has been intersected by borehole KKL13.

Losses of flushing water were observed at 173 m, 174 m, and 175 m. Hematitization, alteration, and clay alteration occur in the core. The rock within the zone is brecciated, mylonitized, and interwoven by epidote sealed fractures.

Reliability: Zone 5 has been interpreted to be intersected by borehole KKL13 in its most fractured part. However, alternative locations exists. The reliability of Zone 5 is "**probable**" according to the Bäckblom nomenclature.

ZONE 6

The main direction of Zone 6 is N75W and the dip is 75° to the south. The zone is interpreted at 70 – 88 m, and its calculated width is 13 m. Zone 6 is weakly indicated by the ground geophysical measurements and it has been intersected by borehole KKL12.

The core from KKL12 exhibits tectonic influences such as brecciation, mylonitization, foliation, and sealed fractures. Even below Zone 6, in the direction towards Zone 7, many narrow sequences of mylonitization and foliation can be found.

Reliability: Borehole KKL12 has been drilled into a tectonical complex area, as indicated by the ground geophysical measurements just east of Zone 2. The present interpretation is not unique why a "**possible**" reliability should be assigned to the zone.

ZONE 7

The main direction of Zone 7 is N65E and the dip is 80° to the south. The calculated true width is 13.5 m. Zone 7 is identified by ground geophysical electromagnetic measurements and it has been intersected by borehole KKL12 (288 - 306 m).

The section between 288 – 384 m in borehole KKL12 exhibits high fracture frequency, which is in accordance with the geophysical borehole logging. Nevertheless, in this disturbed section three separate and distinct zones, namely Zone 7, Zone 8, and Zone 9 has been distinguished. The core from 230 m to 400 m shows that the rock within, between, and outside the zones is tectonized, brecciated, mylonitized, and contains a large number of epidote sealed fractures and a smaller number of quartz sealed fractures.

Reliability: Zone 7 is considered as "**possible**" due to the tectonical complexibility of the area.

ZONE 8

The main direction of Zone 8 is N85W and the dip is vertical. The calculated true width is 28 m. Zone 8 is indicated by ground geophysical measurements and it has been intersected by borehole KKL12 (312 – 347 m). A general description is presented above.

Reliability: Zone 8 is considered as "**possible**" due to the tectonical complexibility of the area.

ZONE 9

The principal direction of Zone 9 is N60E and the dip is 75° to the south. The calculated true width is 17.5 m. Zone 9 is indicated by ground geophysical measurements and it has been intersected by borehole KKL12 (362 - 384). A general description is presented above.

Reliability: Zone 8 is considered as "**possible**" due to the tectonical complexibility of the area.

ZONE 10

The principal direction of Zone 10 is N45E and the dip is 85° to W. The calculated true width is 10.5 m. Zone 10 has been intersected by borehole KKL01 (280 - 310 m.)

A long section between 280 - 330 m, thus partly within the zone, shows signs of tectonic stress, brecciation, mylonitization, and foliation. Geological and geophysical observations indicate fault movements within the zone. Losses of flushing water was registered at 289 m. The zone also coincides with a section of increased hydraulical conductivity.

Reliability: "**possible**".

ZONE 11

The geophysical surface measurements show three strong linear anomalies in the western part of the site. No cored drilling was performed to investigate these anomalies, however, two the anomalies were supposed to represent fracture zones, Zone 11 is one of them, Zone 12 see below is the other. The direction of Zone 11 is about N-S. The width and dip of the zone is unknown.

Reliability: "**possible**".

ZONE 12

The direction of Zone 12 is about N-S. The width and dip of the zone is unknown, see description above. Two percussion boreholes HKL07 and HKL08, aimed to intersect Zone 2, both yielded great inflows of water, 20 000 and 7 000 l/h, respectively.

Reliability: Other percussion boreholes in the vicinity, not interpreted to penetrate fracture zones, yield equally high water capacities as the ones penetrating Zone 12. The relevance of the borehole results for interpreting Zone 12 is therefore uncertain why a reliability "**probable**" is assigned.

ZONE H1

At a section between 792 - 804 m in borehole KKL02 the resistivity log exhibits low values, indicating a fracture zone (Zone H1). Due to theft during drilling campaign the cores from most parts of this section is however not available. The remaining part of the core (8 m), related to the Zone H1, consists of highly fractured granite mixed with greenstone. Crushed rock comprises 0.5 m of the core. The rock is slightly altered and hydrate Fe-oxides cover fracture surfaces. Water transport has therefore occurred within the fractures. In one place, within the zone, at 802 m, loss of flush water during drilling was noted. The rock within the above mentioned section of the core contains epidote and calcite healed fractures.

All attempts to correlate the section with indications on surface or with some of the existing zones in other nearby boreholes were unsuccessful. A horizontal, or subhorizontal, orientation of zone H1 was therefore considered most probable. An interpretation of data obtained from borehole radar investigations performed 1986 confirms the existence of a subhorizontal zone. The orientation of zone H1, according to borehole radar measurements, is N-S and the dip is 20° to the west (Carlsten et al., 1986).

Reliability: Zone H1 is labelled "**probable**" according to the Bäckblom nomenclature, as if it is only found in one borehole. The hydraulic conductivity measurements suggests a wider zone, ca 50 m, than what is suggested above (i.e. at 740 - 805 m borehole length in KKL02).

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[1]Conterra AB, [2]Geosigma AB, [3]Renco AB,
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[1]MBT, Barcelona Spain
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