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Kamlunge study site. Scope of activities and main results

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KAMLUNGE STUDY SITE
SCOPE OF ACTIVITIES AND MAIN RESULTS

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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 anyone of the study sites will be selected as a site for detailed characterization. Other sites with geological and/or socio-economical characteristics judged more favourable may very well be 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 Kamlunge 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), Thomas Ittner (groundwater chemistry), Peter Andersson (solute transport) and Christer Ljunggren (rock mechanics).

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1. ASSESSMENT OF THE KAMLUNGE STUDY SITE

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

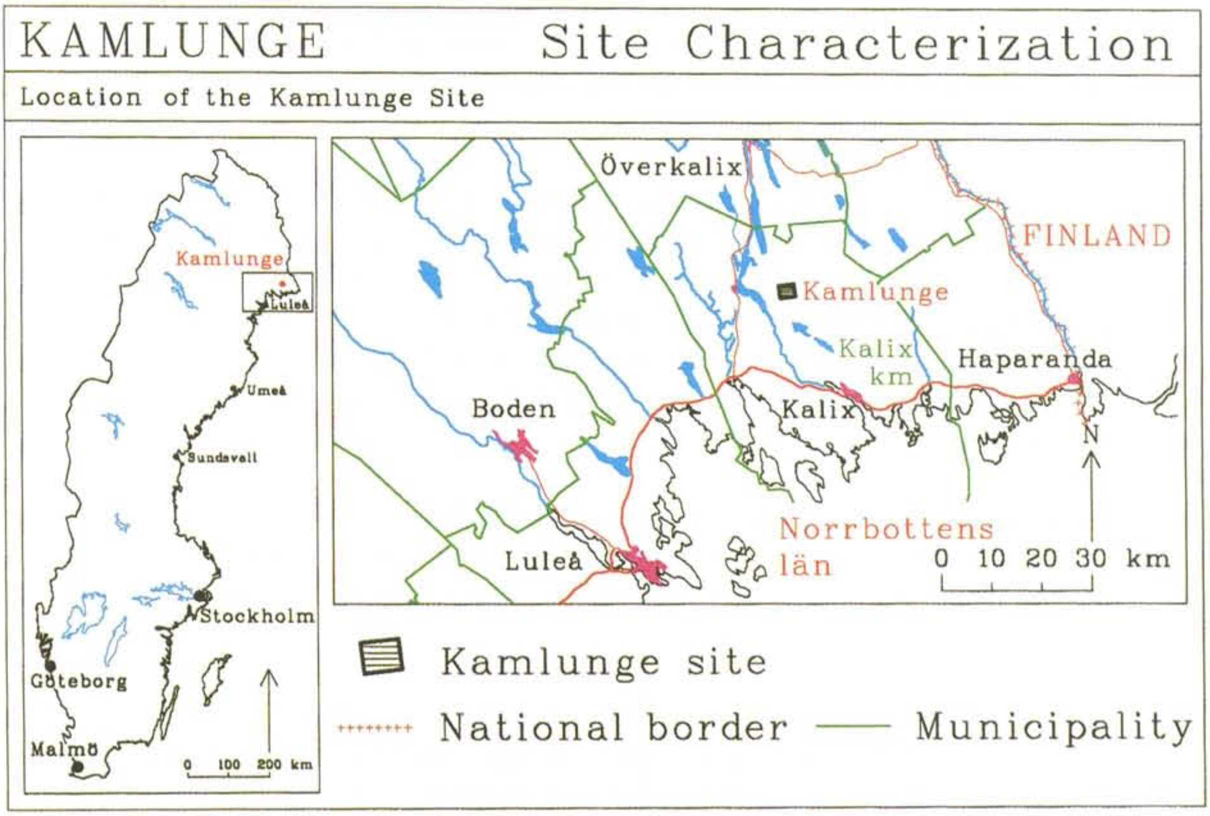


Figure 1. Location of the Kamlunge study site.

1.1 Main characteristics and uncertainties

Rock type distribution

The Kamlunge study site is situated in a region characterized by metamorphic rocks of magmatic and sedimentary origin. Apart from some younger dykes, the rocks in this region are between 1565-2700 Ma (million years old). The older rock in this region is represented by Archean granite gneiss, which is also a part of the oldest bedrock sequence in Sweden.

Two types of metasedimentary rocks occur in the Kamlunge study site, quartzitic gneiss and biotite gneiss. These are the oldest rocks within the site, 1900-2500 Ma. Other main rock types are Lina granite, granodiorite-diorite and amphibolite. These five rock types occur in separate large bodies irregularly intermixed with each other. Based on their occurrence in the drill cores Lina granite with associated pegmatites is the dominating rock type, constituting (40 %) of all drill cores. The proportions of the other rock types are: biotite gneiss (26 %), quartzitic gneiss (14 %), diorite-granodiorite (13%) and amphibolite (7 %). In addition, a small ultrabasic rock body consisting essentially of hornblende and pyroxene is found in two boreholes. The orientation of the layering in the quartzitic gneiss and in the biotite gneiss, as well as the schistosity in the rocks have a predominant northeasterly strike and a steep dip towards the northwest.

The Lina granite is 1560-1800 Ma, greyish red and fine to medium-grained. The granite dominates in the southern parts of the site. The main minerals are quartz, potash-feldspar, plagioclase and biotite. The biotite gneiss is usually greyish-black and fine to medium-grained. The main minerals are quartz, biotite and plagioclase. The rock has a distinct schistosity with a preferred orientation of biotite. Sulphides occur sparsely, as disseminated pyrite or as fracture fillings.

The quartzitic gneiss is grey and fine-grained. The main minerals are quartz, potash feldspar, plagioclase and biotite. The rock type occurs in 100 m wide sections in the drill cores and is banded or massive with irregular coarse-grained quarts-feldspar streaks.

The granodiorite is light brown with 2-5 cm large plagioclase grains in a matrix rich in biotite. This gives the rock type a porphyric appearance. The main minerals are biotite, plagioclase and amphibole. It is often schistosed and is locally folded. During the geological mapping no differentiation was made between granodiorite and diorite, although small bodies of diorite have been reported.

Amphibolite occurs as small bodies. The rock is dark grey and the main minerals are amphibole, biotite and plagioclase.

The overall fracture frequency is low in the Kamlunge site. Depending on rock types, scan-line surveys on outcrops and fracture mapping of drill cores show mean fracture frequencies between 1.1-1.3 fr/m and 3.6-4.7 fr/m, respectively.

One cause for the higher fracture frequency in the drill cores, compared with fractures in outcrops, is probably a high frequency of horizontal sheet fractures in the upper part of the bedrock. These fractures are commonly observed in vertical rock exposures, but they are not recorded in the scan-line surveys. The occurrence of such fractures in the upper part of the bedrock is also indicated by the strong decrease in fracture frequency with depth in the borehole cores. In the upper 100 m the mean fracture frequency is 5.5 fr/m, while below 200 m the frequency is 2.5 fr/m.

The scan-line survey shows a strong dominance of fractures trending WNW (N70W). Another, but far less expressed, fracture group are fractures trending ENE (N70E). Sealed fractures are mainly trending north-south.

Uncertainties: Rock types representing a wide petrographic spectrum, including a large variation in ages, are present at the site. This makes Kamlunge the most heterogenous of all SKB study sites with respect to rock types. The great variability of rock types most likely influence the groundwater flow system, the groundwater chemistry and the rock mechanical properties. Because of the complicated distribution of rock types no 3D model of rock type distribution has been made.

Fracture zones

Interpreted fracture zones at Kamlunge are primarily based on results from ground geophysical surveys anomalies (electrical and seismic methods), subsequently tested by shallow percussion boreholes and deep cored boreholes.

All together seven steeply dipping zones and one horizontal fracture zones have been identified within the study site. Common trends of the steeply dipping fracture zones are NW and NE. The width of the fracture zones varies from 1 to 14 m, with a mean width of 6 m. Spacings between zones varies between 500 to 1500 m.

The steeply dipping zones are often weathered and contain brecciated and crushed rock. Core losses when drilling through the zones are common. Common fracture minerals are chlorite, calcite, laumontite, smectite and various iron oxides.

The horizontal fracture zone, Zone H1, is identified in four cored boreholes at a depth of 550 m. The zone is permeable to water and its width varies between 4 and 14 m. It is less crushed and weathered compared to the steeply dipping fracture zones.

Uncertainties: Most interpreted fracture zones within the Kamlunge site are uncertain. Only three out of the eight interpreted zones are classified as "certain" or "probable" zones (c.f. SKB-nomenclature of fracture zones, Bäckblom, 1989). Other five fracture zones are uncertain because they have not been drilled to test their existence. They were included in the model based on topographical or geophysical indications only and they might be dismissed if tested by drilling or by excavated trenches.

At the same time there are several fractured sections in the boreholes that have not been assigned to any specific fracture zone. Since many of these sections occur in the upper 100 m, and since no indication of a fracture zone was found in the overlying outcrops, it is probable that at least some of these sections represent subhorizontal fracture zones.

Hydrology

The Kamlunge site is located on a topographical plateau with steep slopes towards the surrounding low-land. There is a difference in altitude of about 100 m between the plateau and the surrounding valleys. On the plateau the groundwater table is rather flat.

The strong topographical relief implies that the shallow groundwater flow is directed from the plateau towards the surrounding valleys. The plateau thus constitutes a major recharge area for groundwater. Minor, local discharge areas on the plateau are found in low-lying parts, covered by peat bogs.

Uncertainties: The strong topographical relief implies little doubt in the orientation of the shallow groundwater flow system, and where the major discharge areas are located. However, no data exist regarding the influence of a regional flow system at greater depths, especially below Zone H1.

Hydraulic units

The main hydraulic units included in the conceptual model of the Kamlunge site are the rock mass and the local fracture zones. The horizontal Zone H1, at 550 m depth, is treated as a separate unit.

Uncertainties: As discussed above the large variation in rock types implies that it is probably too simplistic to use "rock mass" as the only hydraulic unit for the "sound rock", i.e. the bedrock excluding the fracture zones. There are also obvious uncertainties with the assigned hydraulic properties of the fracture zones as most of them have not been drilled and hydraulically tested.

Hydraulic conductivity

The average hydraulic conductivity of the rock mass is low, about 10^{-11} m/s at 500 m depth. The number of measurements in the fracture zones is very few but indicates an almost linear decrease of hydraulic conductivity with depth and a conductivity of about 10^{-9} m/s at 500 m depth. The applied conductivity-depth relationships for the rock mass and the fracture zones implies that only small differences exist for the two units down to 100 m. At this depth both the fracture zones and the rock mass are assumed to have a hydraulic conductivity of about $5 \cdot 10^{-9}$ m/s. The hydraulic conductivity of the horizontal zone is assumed to be 10^{-8} m/s.

The conductive fracture frequency in the rock mass at Kamlunge is estimated to about 0.04 - 0.06 fr/m, based on all tested 25 m sections.

Uncertainties: The derived hydraulic conductivity functions versus depth for the different hydraulic units are uncertain, partly due to the uncertainties involved in the separation of data into fracture zones or rock mass, and partly due to the analysis technique based on regression analysis. For example, the few tested sections in interpreted fracture zones make any derived hydraulic conductivity function for this unit inherently uncertain. Another example is the uncertainties involved in the regression analysis which implies that an equally possible 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 or in the lower parts of the bedrock.

Groundwater flow rates at repository depth

The existence of a hydraulically conductive horizontal fracture zone at 550 m depth implies that a repository should preferably be located at least 100 m below such a zone. However, since no data were available regarding geologic and hydraulic conditions at that depth, a depth of 450 m were chosen to represent repository depth in the model calculations.

Two cases were modelled. In the first case the rock mass and the local fracture zones were treated as separate isotropic continua, but the horizontal zone was not included. The second case was identical to the first case, except that the horizontal zone was included. A decrease of hydraulic conductivity of the rock mass and fracture zones (except the horizontal zone) with depth was assumed for both cases. The horizontal zone was modelled as a separate hydraulic unit with constant properties.

The calculated groundwater flow rates at 450 m depth ranged between 15-30 ml/m^2/year in the first case and between 20-60 ml/m^2/year in the second case. Immediately below the horizontal zone, at 570 m depth, the corresponding flow rates were 8-20 ml/m^2/year and 4-10 ml/m^2/year, respectively. The effect of the horizontal zone was thus to increase the groundwater flux above the zone and decrease the flux below the zone.

Uncertainties: The modelling was made using the assumption of a porous media composed of two overlapping continua (rock mass and fracture zones) together with a third continuum (the horizontal zone). This generalization implies a large uncertainty in the groundwater flow calculations. The modelling shows that Zone H1 has a large influence on the groundwater flow. In the modelling it is assumed that the zone continues laterally until it meets the vertical regional fracture zones bounding the Kamlungekölen plateau. However, the lateral extension of the zone is not known outside the drilled area. Another uncertainty is whether additional horizontal fracture zones exist or not.

Solute transport

No specific models of solute transport at the Kamlunge site exist. There are only a few model simulations of groundwater travel times from a repository at 450 m depth. The reported travel times vary from 250 to 94 000 years in the local scale model where fracture zones are included. In the regional model, not including fracture zones, travel times are considerably longer, from 2 000 to 200 000 years. This demonstrates the importance of hydraulic structures, especially the horizontal fracture zone, for the solute transport at Kamlunge.

Uncertainties: The boundary conditions are of great importance for the solute transport. In the Kamlunge model, no sensitivity analysis have been made of the impact of different boundary conditions. Also, the existence, location and connectivity of fracture zones are important for the solute transport. These factors have not been varied to any extent. Lastly, to determine the actual fluid velocity through the Kamlunge site, knowledge of the kinematic porosity is important and no such data exist from the site.

Groundwater chemistry

A total of three boreholes and seven borehole sections have been sampled at Kamlunge. The samples indicate groundwater of varying ages, but with no depth dependence. The general groundwater chemistry indicate an environment common in Swedish crystalline bedrock. The groundwater are generally of a reducing character. None of the sampled sections was considered representative for the depth sampled.

Uncertainties: The groundwater chemistry conditions in general in the site is as a main uncertainty, as none of the sampled sections were considered representative for the depth sampled. The redox measurements are especially uncertain. In fact, the spatial variation of the groundwater chemistry is essentially unknown.

Another uncertainty involves the existence of saline groundwater at depth, as indicated by borehole resistivity logging in the lowermost part of some boreholes. The groundwater sampling programme failed to obtain any such water.

Rock mechanics

The rock mechanical investigations at Kamlunge only includes measurements of thermal parameters on core samples. These measurements showed a wide variation in thermal properties for the bedrock, reflecting the various rock types.

1.2 Suggestions for complementary studies

Conceptual geologic models

As discussed earlier the large variation in rock types at the Kamlunge study site probably influence the groundwater flow system, the groundwater chemistry and the radionuclide transport properties. The large variation in mechanical and thermal characteristics of the various rock types probably also influence the thermomechanical response of the rock mass to the heat generated from a repository. The distribution in 3D of the various rock types at Kamlunge should therefore be reinterpreted, using existing geological and geophysical maps as well as existing core logs and geophysical logs. As a complement to these data borehole radar surveys are suggested.

The existence of additional horizontal fracture zones should be investigated possibly by an integrated programme consisting of a renewed geologic/tectonic interpretation, borehole radar measurements, borehole VSP (vertical seismic profiling) measurements and hydraulic interference tests. The latter applies especially for possible horizontal fracture zones down to the maximum depth of "standard" percussion drilling (ca 150 m).

There exist some geophysical anomalies at the Kamlunge site that are questionable whether they represent fracture zones or not (e.g. the northeasterly extension of Zone 1). To resolve these questions excavation of trenches across these anomalies should be considered, thus providing a direct possibility for bedrock mapping.

Data from the Kamlunge study site is available down to about 600 m depth. However, as discussed earlier the hydraulic and mechanical influence of the horizontal fracture Zone H1 at 550 m depth implies that the preferable repository depth is at least 650 m. Since no data exist for the preferred repository bedrock there is an obvious need to investigate the bedrock at greater depths. This will involve a large drilling and testing programme including new boreholes, and deepening of existing ones, down to 1000 m depth.

Conceptual geohydrological models and data sampling

A first step to improve the conceptual hydraulic model at Kamlunge is to identify the types of conceptual models which might be utilized in the modelling, e.g. continuum models, fracture network models or stochastic continuum (parametric and non-parametric) models. This process should be based on experiences from the SKB-91 study and the Äspö Laboratory. Depending on the selected model(s) additional data sampling might be necessary.

The results of the regional groundwater flow model in the Kamlunge area should be tested by sensitivity analyses to determine the overall groundwater flow circulation on a regional scale. The primary goal of this investigation is to establish an improved conceptual model of the regional groundwater flow, aiming at identifying regional hydrological factors that have a major influence on the local flow system. This should include testing of the influence of fracture zones, especially horizontal ones, on the regional groundwater flow system. Furthermore, the sensitivity of the boundary conditions should be tested, including the upper boundary condition, on the groundwater flow conditions in the local area.

The regional study will require drilling of at least one deep borehole in the regional area. In this borehole combined logging of temperature and salinity, together with a spinner survey, should be performed both during natural and pumping conditions to measure the vertical flow under open borehole conditions and to identify water 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.

The boundary conditions of the local model, including the upper boundary condition, should be further investigated. Improved definition of the location and type of the outer boundary conditions of the local model is required. This task implies renewed geological and hydrogeological characterization of fracture zones, together with the investigations and conceptualization of the regional groundwater flow pattern outlined above.

The hydraulic properties of different rock types should be investigated. This could probably be made using existing data from hydraulic tests together with a new geological model, as suggested above. The study should also include new analyses of depth dependence of the hydraulic conductivity of different rock types, together with alternative analyses (models) of the hydraulic conductivity data, taking account of the variance of the measured data.

Improved definition and identification of major hydraulic conductors, such as fracture zones, including their location, extension and hydraulic properties and depth dependence is needed. As discussed above, each fracture zone should possibly be modelled as a separate hydraulic unit. An improved geometric and hydraulic characterization is especially important for the horizontal Zone H1 because of its hydraulic importance. The groundwater flow modelling suggests a decrease in groundwater flow below the zone. Similar to the regional flow study the modelling results should be tested by tracer dilution measurements carried out above, within and below the horizontal zone. In addition, the tracer dilution measurements should also include hydraulic head measurements and water sampling in isolated borehole sections.

As a final test of the validity of the (revised) conceptual model of the Kamlunge 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 observation boreholes within the site. The observed drawdowns 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

Since the available hydrochemical data is not representative there is a need for new samples. This should primarily be made in new boreholes. The new sampling rounds 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 from Kamlunge has been evaluated thoroughly, except the analyses from one shallow percussion borehole, there might be possible 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.

Within the discussed seven sampled sections it would be of special interest to study the origin of the groundwater in the very low part of borehole KKM13, 556-564 m. The surface characteristics of the water in the horizontal Zone H1 makes it interesting to evaluate its origin.

The large variability of rock types makes Kamlunge a good site for studies regarding the interaction between groundwater chemistry, bedrock chemistry and fracture minerals. For example, an increase in the sulfate concentration were observed in groundwater collected from an amphibolite. Also the influence of rock type on the oxidation-reduction potential is a near related research field of importance, which may be studied.

Solute transport

To improve the knowledge of the solute transport conditions at the Kamlunge site, the following factors are the 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 to 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. The major practical steps to achieve such improvement are listed under the heading "Conceptual geohydrological models" in this chapter.

Sorption coefficients including estimates of sorptive surface, and reaction coefficients are of next greatest importance to improve the 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 solute transport in 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

The rock at the Kamlunge study site has only been investigated for its thermal properties. However, as discussed earlier the heterogenous bedrock will probably affect the overall thermomechanical performance of the site when applying a heat load from a repository. To provide a basis for thermomechanical modelling and for overall mechanical assessment of the site it is therefore recommended that at least a few very basic mechanical parameters are determined for each rock type, such as the uniaxial compressive strength, the tensile strength, Young's modulus and the Poisson's ratio.

It also strongly recommended to investigate the stress state from the surface down to maximum borehole depth. It is especially important to investigate the stress state in connection to Zone H1.

2. BACKGROUND

2.1 Objectives

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

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 sites.

One of the investigated sites is Kamlunge. This study site was investigated during the years 1981 -1983 with the main objective to provide site-specific data for the performance assessments for the KBS-3 report (SKBF/KBS, 1983). The purpose of this report was to demonstrate that a safe repository for spent nuclear fuel can be located in Sweden.

When the scope of site investigations at Kamlunge 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. In addition, the investigations should be able to define the available area of "sound rock" for a repository at about 500 m depth.

To obtain the data needed to evaluate the importance of these key factors at Kamlunge, 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 Kamlunge study site

The Kamlunge study site is located in the southeastern part of Norrbotten county, Kalix municipality, about 65 km NE of Luleå, Figure 2. The site is located on a plateau, Kamlungekölen, which rises 100 m above the surrounding valleys. The size of the plateau is approx. 16 km^2. The size of the study site is 2.5 x 3 km. However, most surveys have been made within an area of 2.5 x 2 km, located in the central part of the site (Figure 5).

Kamlunge was selected as a result of the 1981 year reconnaissance studies (unpublished). These studies included air-photo interpretation, geological reconnaissance mapping and geophysical profile measurements. These preliminary studies showed that Kamlungekölen is well exposed, with low fracture frequency in outcrops and with few fracture zones.

To confirm favourable conditions, a 674 m deep borehole was drilled during the summer of 1981 in the central part of the Kamlunge site. Although several rock types were encountered, the degree of fracturing in the cores was low. The result of the borehole investigation was regarded favourable and a decision to initiate a complete site investigations was taken in the spring of 1982.

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

* Regional fracture zones delimit a 16 km^2 large plateau.
* The plateau consists of well exposed bedrock, which facilitates geological studies.
* Low frequency of fractures in outcrops.
* A low frequency of fracture zones, interpreted from aerial photographs and geophysical profile measurements.
* Easy accessible and favorable land ownership (Domänverket).

Two conditions were considered potentially unfavourable, the heterogenous bedrock of the Kamlungekölen and the high hydraulic gradient between the plateau and the surrounding valleys. However, since hydraulic measurements in the reconnaissance borehole did not indicate any variability in hydraulic conductivity with respect to rock types, and since generic modelling showed that the increased hydraulic gradient had only a small effect at 500 m depth, it was decided to complete the site investigations.

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 1982-1983. With the exception of some minor research project and some tests of methods and instruments, there has been no further activities in the site.

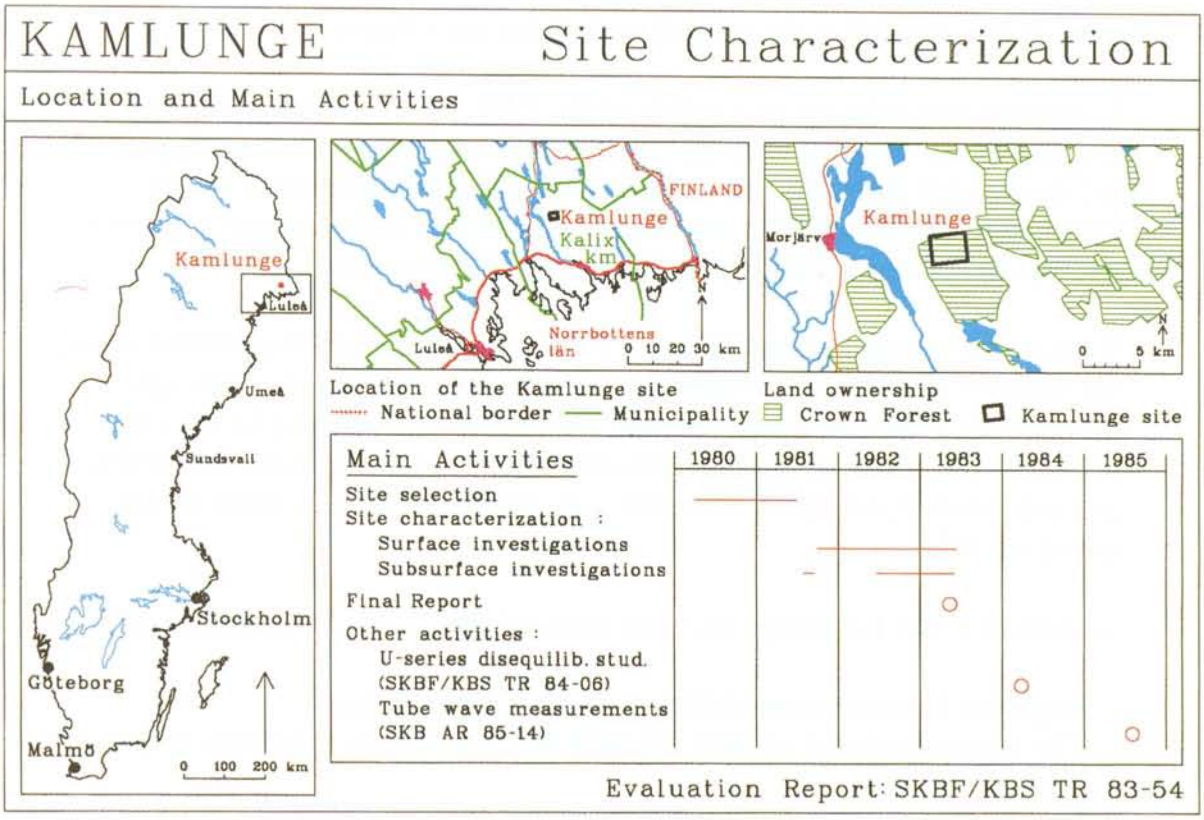


Figure 2. Location of the Kamlunge study site. Administrative borders and land ownership are shown. Main activities refer to the KBS-3 studies. Other activities refer to activities after the KBS-3 report.

3. SCOPE OF ACTIVITIES

3.1 Reconnaissance

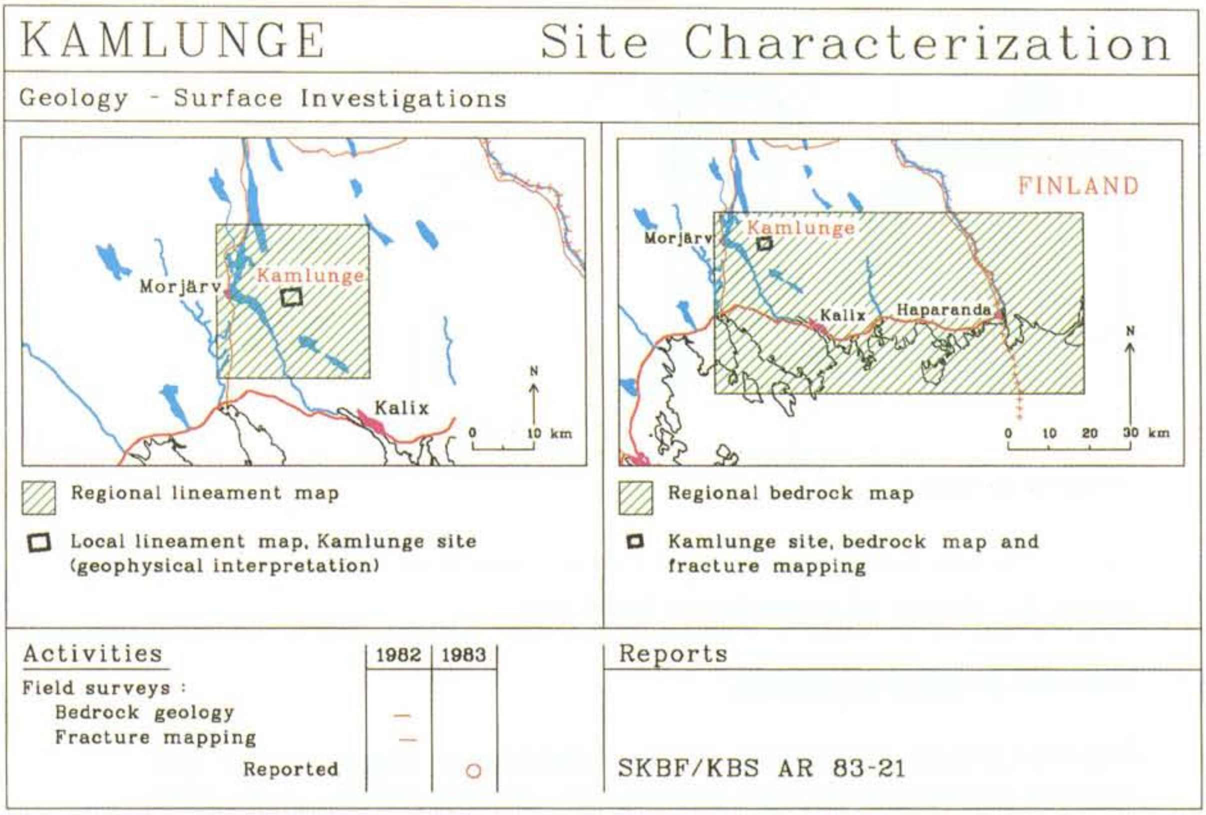
The Kamlunge site was selected in 1981 as a result of reconnaissance studies in the counties of Västerbotten and Norrbotten (unpublished). The reconnaissance phase included studies of geological and geophysical maps, literature review, lineament interpretation based on aerial photos and topographical maps and brief field checks. These checks included observation/estimates regarding rock types and degree of rock exposure, as well as degree of fracturing and other tectonic characteristics.

The counties of Västerbotten and Norrbotten have for a long period been subjected to extensive mineral prospecting activities. To facilitate these activities the Geological Survey of Sweden (SGU) produced modern geological and geophysical maps which cover most parts of the counties. For the Kamlunge study site unpublished airborne magnetic and radiometric maps were available, as well as a preliminary and unpublished geological map.

3.2 Surface investigations - regional area

Geology

The regional geologic setting are described in several Swedish and Finnish large-scale geologic maps and publications (e.g. Ödman, 1957, Kresten et al., 1977, Lundqvist, 1979, Pertunen, 1980, Simonen, 1980 and Welin et al., 1970. A modern geologic overview is presented by Lundqvist, 1991). In addition, there exist a large and mainly unpublished geological database for the region that has been produced during ore prospecting activities. The regional geological map of the Kamlunge study site and its surroundings (Figures 3 and 11) has been made in connection with such activities.



Activities	1982	1983
Field surveys :		
Bedrock geology	—	
Fracture mapping	—	
Reported		○

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 Kamlunge site.

Lineaments

Lineaments were interpreted (Albino et al., 1983a) from aerial photos and topographical maps of an 625 km^2 area, Figure 3.

Hydrology

Based on data from SMHI:s stations the hydrometerological conditions of the Kamlunge region was compiled (Danielsson, 1983). This compilation included temperature, precipitation, evaporation, water run-off, and gross water budget. The report by Danielsson also include a map of the groundwater level at Kamlungekölen and its closest surroundings. The areal extent of the map is shown in Figure 4.

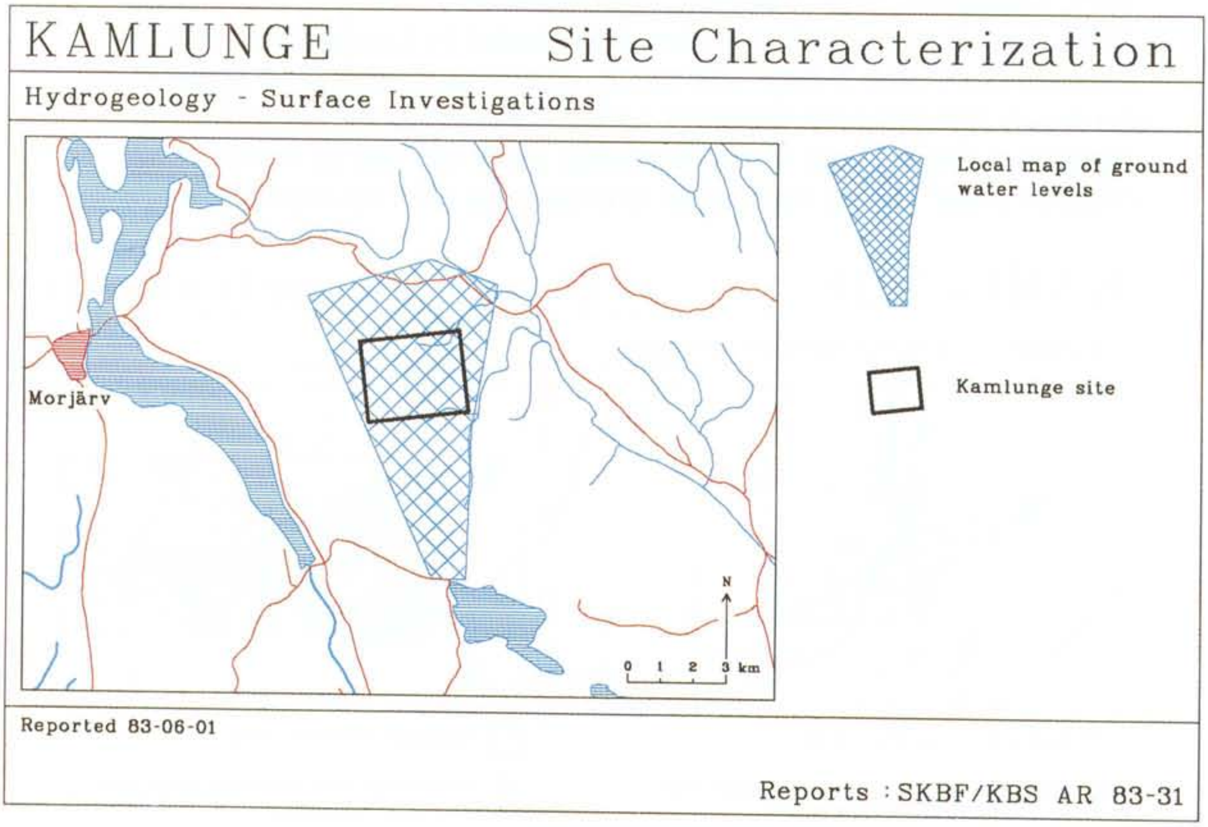
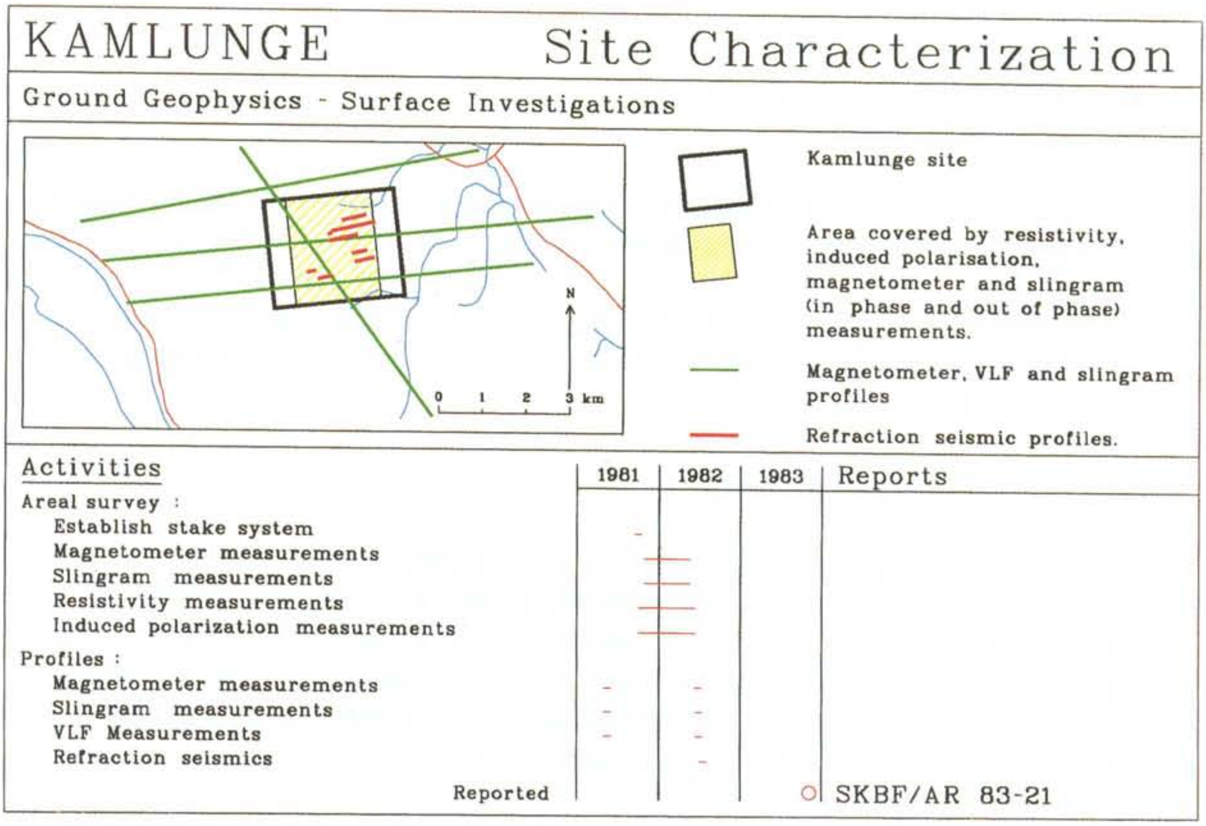


Figure 4. Extent of groundwater level map.

Regional geophysical profiles

Regional ground geophysical profiles consisting of magnetic, VLF and slingram measurements were made in four profiles (Albino et al., 1983a). Three of the profiles were oriented E-W, one was oriented NW-SE (Figure 5). The objective was to identify regional fracture zones and lithological boundaries and to provide some estimates regarding their character (mainly dip and width). The total length of these profiles is 38 km.



KAMLUNGE Site Characterization

Ground Geophysics - Surface Investigations

□	Kamlunge site
▨	Area covered by resistivity, induced polarisation, magnetometer and slingram (in phase and out of phase) measurements.
—	Magnetometer, VLF and slingram profiles
—	Refraction seismic profiles.

Activities	1981	1982	1983	Reports
Areal survey :				
Establish stake system	–			
Magnetometer measurements	–	–		
Slingram measurements	–	–		
Resistivity measurements	–	–		
Induced polarization measurements	–	–		
Profiles :				
Magnetometer measurements	–	–		
Slingram measurements	–	–		
VLF Measurements	–	–		
Refraction seismics		–		
Reported			○	SKBF/AR 83-21

Figure 5. Extent of ground geophysical measurements.

3.3 Surface investigations - Kamlunge site

Geology

The geological survey of the Kamlunge site included mapping of rock types and scan-line fracture studies at 48 localities within the site. The size of the geological surface mapping was 6 km^2. Petrographical studies and chemical whole-rock analyses were made on all together 10 samples (Albino et al., 1983a) representing five rock types.

Geophysical surface surveys

Detailed geophysical surveys were made within a 5 km^2 large square, Figure 5, located in the central part of the site (Albino et al., 1983a). The objective was to map lithological boundaries and to identify fracture zones. The surveys were made in a grid system with a separation of 40 m between survey lines and 20 m between measurement points. The orientation of the measurement lines was close to E-W. The methods included the following (see Figure 5):

- protonmagnetometer
- slingram 18 Khz
- resistivity (gradient method)
- induced polarization

In addition, 8 profiles of seismic refraction measurements were made, Figure 5. These profiles have a total length of 4 km.

The quality of all geophysical data was judged good and consequently the results was used with confidence to identify fracture zones and, to some extent, rock type boundaries.

3.4 Percussion boreholes

Percussion drilling were drilled to investigate possible fracture zones interpreted from geophysical measurements and from lineament studies. In addition, the percussion boreholes were used for measurements of the groundwater level, for hydraulic interference tests and for providing flushing water for the cored drilling. In total 22 percussion boreholes were drilled with borehole lengths varying between 50-182 m, see Table 1.

Identification of fracture zones intersected by the percussion boreholes were partly made from anomalies in drilling rates and from locations of major groundwater inflows. Data regarding these factors are found in Albino et al. (1983a) and Nilsson (1983).

A map showing the locations of the percussion boreholes is presented in Figure 6. The figure also presents activities, including time-tables, in these boreholes.

Borehole geophysical logging

More than half of the percussion boreholes in the Kamlunge site was logged geophysically with the following methods; natural gamma radiation, and single point resistance. For borehole HKM09 no gamma log was made and for boreholes HKM 04,11,13,15,17,19,21 and 22 no geophysical logging what so ever was made. Borehole deviation data are available from boreholes HKM 01,02,05,06, 08,10,14,18.

Borehole HKM20, which was drilled to investigate the character of the interpreted regional fracture zone in the valley west of the Kamlungekölen, was measured with the gamma log, SP-log, normal and lateral resistivity logs, temperature log and borehole fluid resistivity log.

Table 1. Percussion boreholes at the Kamlunge site. Water capacity refers to total capacity for the borehole. Zero water capacity refer to a "dry borehole" or only insignificant inflow. Major inflow refer to location of individual strong inflows (borehole lengths). Mainly from Nilsson (1983).

No (HKM)	Direction/Dip		Length/Depth (m)		Water capacity l/h	Major inflow (m)
01	S60E	/55	100	/82	6000	72
02	N60W	/55	107	/88	3000	46,83
03	S60E	/55	100	/82	6000	18,33,62,85
04	N60W	/55	100	/82	1800	13
05	N65W	/55	106	/87	0	
06	S65E	/55	115	/94	3000	20,98
07	N50E	/55	115	/94	300	61,81
08	S50W	/55	120	/98	350	
09	S	/55	120	/98	0	
10	N45W	/55	100	/82	9000	76
11	S45E	/55	120	/98	0	
12	S30W	/55	100	/82	900	20
13		/55	100	/100	720	4
14	S55E	/55	100	/82	1500	34
15		/90	50	/50	60	
16		/90	50	/50	600	13
17		/90	50	/50	0	
18		/90	100	/100	120	
19	S65E	/55	100	/82	180	86
20		/90	174	/	30000	84-174
21		/90	100	/100	780	31
22		/90	60	/60	1800	

The geophysical logging data were only to a minor extent used for identification and geometrical character of fracture zones. They have not been reported but are stored in the SKB database Geotab.

Hydraulic tests/measurements

The percussion boreholes were used to monitor the variations in the groundwater table for the period Nov. 1982 - April 1983 (Danielsson, 1983). For most boreholes this was made in open holes. However, in 8 percussion boreholes a packer was installed about 10 m below the groundwater level.

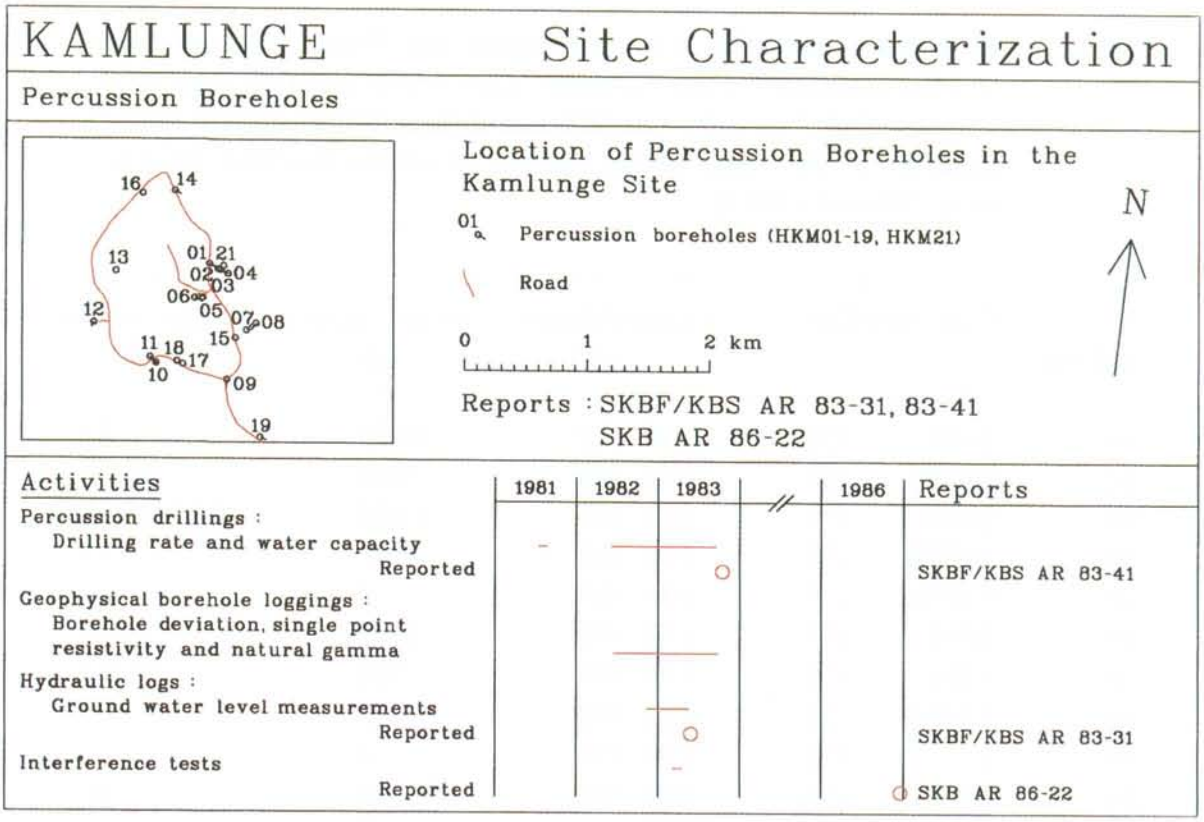


Figure 6. Location and activity periods of percussion boreholes. Borehole HKM20 is located outside the site in the regional fracture zone bounding the site to the west.

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 part. An interference test was also performed using percussion boreholes to evaluate the hydraulic characteristics of Zone 2. Pumping hole was HKM21 and observation boreholes were HKM01-04. The total time for the test, including the recovery phase, was 39 days. The result of the test is reported by Andersson and Hansson (1986).

3.5 Cored boreholes

A total number of 16 cored boreholes have been drilled at the Kamlunge site (Figure 7) down to a maximum vertical depth of 670 m. All boreholes except one are drilled inclined, 60 degrees from the horizontal. The borehole lengths varies between 104-701 m (Table 2). The main objectives was:

- to test and improve the preliminary tectonic model obtained from the surface investigations,
- to obtain data of the hydraulic characteristics of different hydraulic units (rock mass, rock types and fracture zones), and
- to obtain groundwater samples from different depths.

Table 2. Cored boreholes at the Kamlunge site.

No (KKM)	Direction/Dip	Length (m)	Depth (m)
01	N /85	674,0	670
02	S65E /60	701,3	566
03	S28N /60	700,2	583
04	N70E /60	700,1	577
05	S30E /60	251,4	210
06	S30E /60	104,5	89
07	N65W /60	249,0	208
08	N90E /60	251,3	208
09	S30E /60	449,3	366
10	N50W /60	287,0	205
11	S60E /60	700,4	546
12	S70E /60	801,9	636
13	S70E /60	703,1	582
14	S20W /60	700,2	579
15	S60E /60	251,2	210
16	N60W /60	252,6	211

To fulfil these objectives most of the boreholes were directed to intersect interpreted fracture zones or dykes at depth (Albino et al., 1983a, Ahlbom et al., 1983). 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.

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 Kamlunge amounts to 7777 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 1:40 is available in three borehole reports (Albino et al, 1983b, 1983c and 1983d). Generalized results concerning fracture frequency and rock types are presented in scales of 1:5 000 and 1:2 000 (Albino et al., 1983a). The data files (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

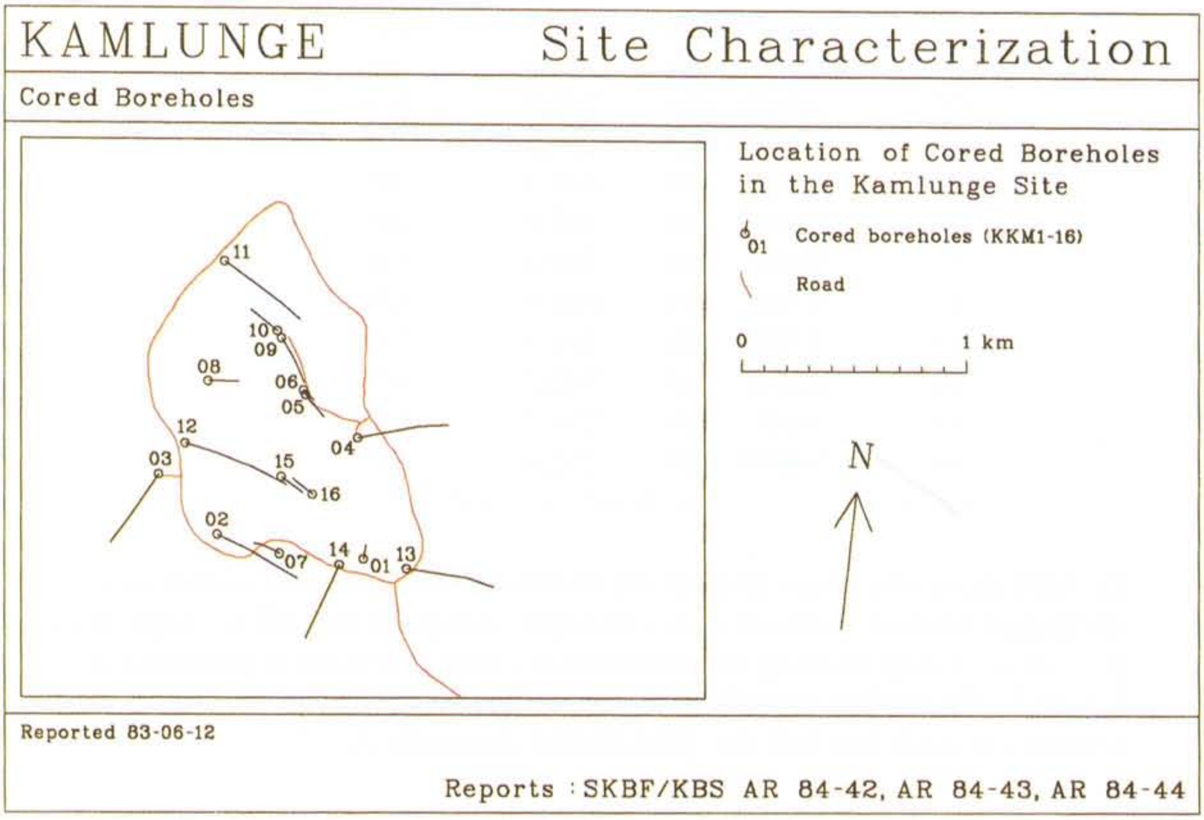


Figure 7. Location of cored boreholes at the Kamlunge site.

Core samples for petrophysical measurements (in total 121 samples) were taken at regular intervals below 200 m depth from the boreholes KKM02,03,04,09,11,12,13,14 (Sehlstedt, 1984a). The samples were measured with respect to:

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

In addition, 60 samples were measured with respect to 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).

Thermal properties (thermal conductivity, diffusivity and heat capacity) was determined using the "transient hot strip" method (Gustavsson et al., 1979) on 15 core samples from 300-700 m depth in borehole KKM01 (Ahlbom and Karawacki, 1983).

3.7 Geophysical logging

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

- borehole deviation
- natural gamma radiation
- point resistance
- resistivity, normal 1.6 m
- resistivity, lateral 1.65 m
- spontaneous potential
- temperature
- resistivity (salinity) of borehole water

In addition, several boreholes were logged with a prototype geochemical log for determining the redox-conditions of the deep groundwater. Due to suspected measurements errors these data have not been published nor stored in the SKB database. Two borehole (KKM02 and KKM09) were also measured with an induced polarization log.

The results from the geophysical logging are reported in the scale 1:5000 (Lindholm et al., 1983). The geophysical loggings made in each of the cored borehole are presented in Appendix A.

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. The majority of these measurements were made in 25 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, 230 sections with a length of 25 m were tested, c.f. Table 5. To obtain detailed information in crushed and fractured parts of the bedrock totally 98 measurements in 10 and 5 m section length were made. Furthermore, borehole KKM02 were tested between 300 m and 648 m borehole length in 2 m sections to obtain data on the conductive fracture frequency. These data are unpublished but available from the SKB database GEOTAB. In addition, 42 single packer tests were made to measure the average hydraulic conductivity from the packer to the bottom of the borehole.

Most tests were transient constant head injection tests. An exception is the steady state injection tests in 2 m sections performed in borehole KKM02 (Appendix A) for calculating the conductive fracture frequency. The results from the injection tests are presented in Danielsson (1983) and in Ahlbom et al. (1983). 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.

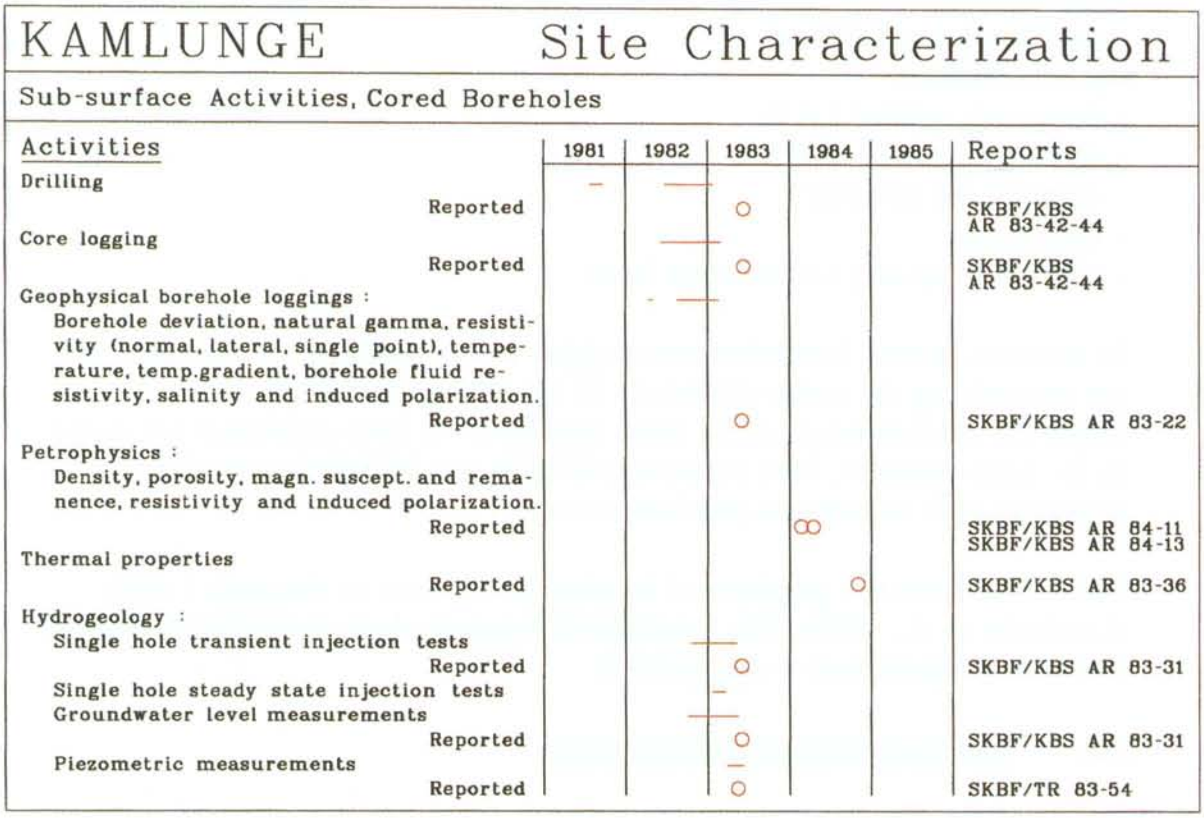


Figure 8. Activity periods - drilling, core logging, geophysical logging, petrophysical and thermal properties on samples from the cored boreholes hydraulic tests and monitoring.

Groundwater head measurements

The location of the groundwater table was measured during Nov. 1982 - April 1983 in the cored boreholes. The groundwater head in 25 m sections in the deeper parts of the bedrock was estimated from the pressure recovery phase of the water injection tests. In two boreholes, KKM03 and KKM12, piezometric measurements were also made in five isolated sections in each borehole for 20 and 60 days, respectively.

3.9 Groundwater sampling

Groundwater sampling was made in borehole KKM03 (two sampled sections), KKM08 (one sampled section) and KKM13 (four sampled sections). The sampling was made from 2.7 m long sections sealed-off by rubber packers. The sampling procedure normally included 14 days of sampling from each section. The chemical characteristics of the groundwater sampled in these sections are presented by Laurent (1983) and in Wikberg et al. (1983) and Smellie et al. (1985). Locations of sampled sections and chemical characteristics are discussed in Chapter 7. Activity periods and reporting of the groundwater sampling programme is presented in Figure 9. In addition, some groundwater samples were also obtained from the percussion borehole HKM20 (Laurent, 1983).

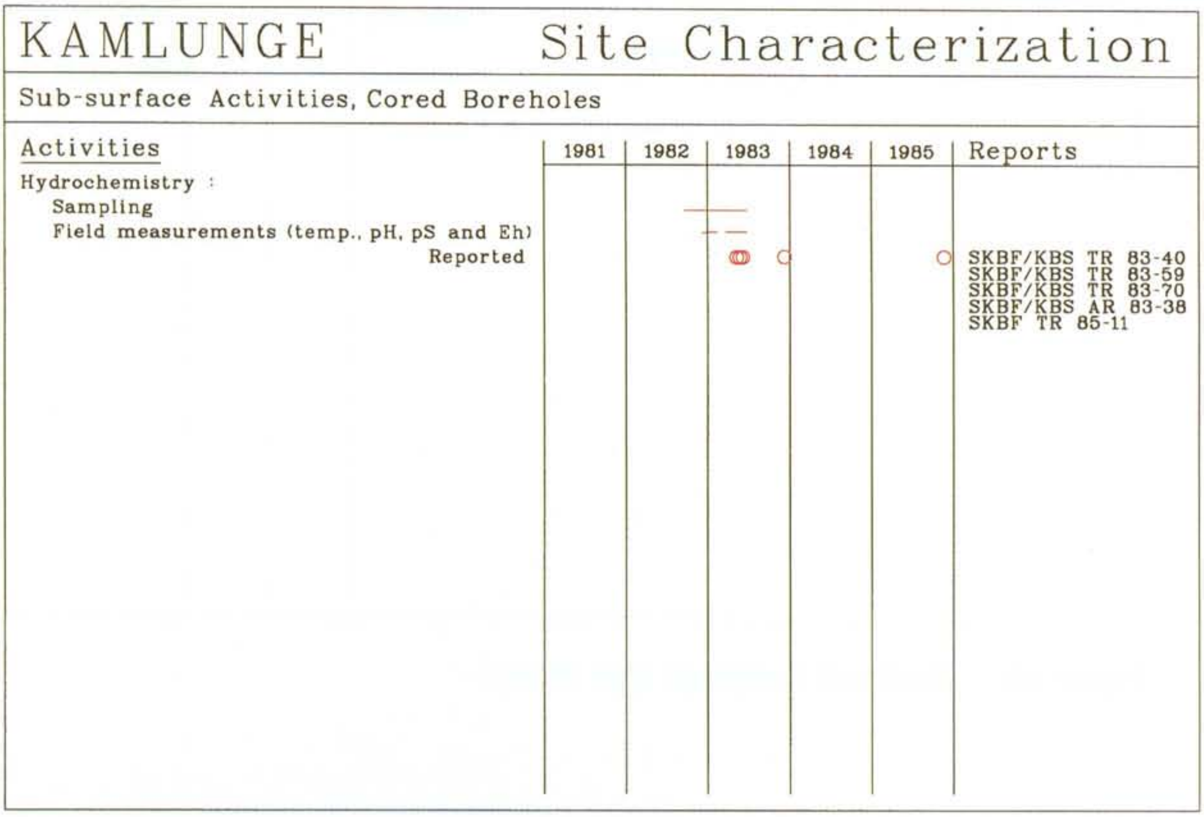


Figure 9. Activity periods - groundwater sampling in the cored boreholes.

3.10 Studies in the Kamlunge site since KBS-3

After the main investigations for the KBS-3 report were terminated in 1983, two boreholes KKM02 and KKM11 were during 1985 used for testing of a geophysical instrument, tube-wave (Stenberg and Olsson, 1984). With the exception of that study SKB has commissioned no other surface nor borehole studies at the Kamlunge study site. The boreholes has however been used on some occasions by the Luleå University of Technology for temperature measurements and for testing of equipment for rock stress measurements. These measurements have not been published.

Studies regarding uranium mobilization in different geochemical environments have been made on cores from borehole KKM03 (Smellie, 1984). One of these cores has subsequently been used to study the influence of oxidizing groundwater on the redox conditions in a single fracture and in the surrounding bedrock (Smellie et al., 1989). The studies made at the Kamlunge study site on contract from SKB are shown in Figure 10.

KAMLUNGE Activities after KBS-3 in the Kamlunge Study Site

Sub-surface Activities, Cored Boreholes

Activities	1984	1985	Reports
Uranium series disequilibrium studies of drillcore KKM03 Reported	○		SKBF/KBS TR 84-06
Tube wave measurements, KKM02 and KKM11 Reported	-	○	SKB AR 85-14

Figure 10. Studies at Kamlunge after KBS-3.

4. STORAGE OF INFORMATION IN THE SKB DATABASE

Data from surface surveys

With the exception of the refraction seismic survey, all geophysical surface measurements are stored in the SKB database GEOTAB. The database also includes data from the fracture survey. Other "surface data", such as geological maps, lineament interpretations, depth of overburden, hydrometerological data and groundwater level maps, are not stored.

Data from borehole surveys/tests

Most data from the geological and geophysical surveys, hydrological tests and water sampling in the cored boreholes are stored in GEOTAB. This includes borehole geometrical data (coordinates, length, dip, deviation etc), core logging, "standard" geophysical logs, petrophysical measurements and single hole hydraulic packer tests. Also stored are chemical analyses of sampled groundwater from the cored boreholes, as well as from the percussion borehole HKM20.

For the percussion boreholes the database includes geometrical data, geophysical logs, borehole deviation measurements, groundwater level monitoring and interference tests. A description of stored data from surveys in each borehole are presented in Appendix A (under the heading GEOTAB in Figures A2-A14).

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

Percussion boreholes. No drilling rates or data regarding drilling debris are stored. Furthermore, the data base does not contain any information regarding the locations of major inflows and total water capacities.

Geological analyses. No chemical analysis of whole rock samples nor analyses of fracture minerals is stored. This also applies to data concerning mineralogical compositions (thin sections).

Geophysical measurements. The database does not include thermal parameters measured on core samples. This also applies to results from the tube-wave survey.

5. GEOLOGIC MODELS

5.1 Regional geologic models

Geology

The region surrounding Kamlunge is characterized by metamorphic rocks of Precambrian age. The region has been relatively stable for long periods of geological time. The oldest rock in the region is basement Archean granite gneiss. In Finland and further north in Sweden, similar basement rocks reveal ages ranging from 2600-2800 Ma (Welin et al., 1971; Perttunen, 1980). Overlying and disconformable with the Archean basement are the younger Svecokarelian rock groups. The Svecokarelian is initially represented by metasediments and metavolcanics. These are followed by the Haparanda series of deep intrusives comprising granodiorite and gabbro which have been dated by Rb-Sr to circa 1840 Ma (Welin et al., 1971). The earlier metasediments and metavolcanics are thus considered to be within the range of 1900-2500 Ma. Metamorphism in the region culminated during the Svecokarelian epoch at approximately 1800 Ma resulting in widespread migmatization. Coeval with metamorphism, and forming large-scale intrusions in the region, is the Lina granite which indicated a range of Rb-Sr ages from 1565-1800 Ma (Welin et al., 1971). The youngest rock types are ultrabasic dikes with a probable age of 1140 million years (Kresten et al., 1977). Descriptions of rock types and geological evolution in the Norrbotten County are published by Ödman (1957) and Lundqvist (1991).

The Kalix NV map-sheet, within which the Kamlunge site is located, has not been geologically mapped by the geological survey in modern time. Compilation of existing data, together with minor mapping activities, have however been made as a part of the regional ore prospecting activities. The geological map of the region, Figure 11, has been produced as a part of those activities. No geologic profile showing the vertical distribution of different rock bodies exist for the Kamlunge region.

Lineaments

The Kamlunge region is characterized by extensive and well marked NW-trending lineaments, Figure 12, oriented parallel to the dominant southeasterly direction of the ice-movement. The spacing between these lineaments varies between 1-3 km. Lakes and rivers largely follow this direction. Lineaments also occur trending NNE (N10E) and NE (N30E).

The plateau, Kamlungekölen, is bounded towards the west by an extensive and NW trending lineament (Figure 12). The soil depth is large in the valley constituting the lineament as shown by seismic measurements and one percussion borehole (HKM20). At the location of the borehole, which is not the deepest part of the valley according to the seismic interpretation, the soil depth is 72 m. The percussion borehole shows that the underlying bedrock is fractured and highly permeable to water. The estimated groundwater yield was 30 000 l/h (Nilsson, 1983). The width of the fracture zone is uncertain, the seismic data suggests several low-velocity zones over a total width of 550 m (Albino et al., 1983a). In the reports the fracture zone is assumed to have a steep dip. Steep dips are also assumed for the regional fracture zones interpreted to limit Kamlungekölen towards the north and east.

No tectonic 3D model of brittle and plastic deformation have been made for the region surrounding the Kamlunge site.

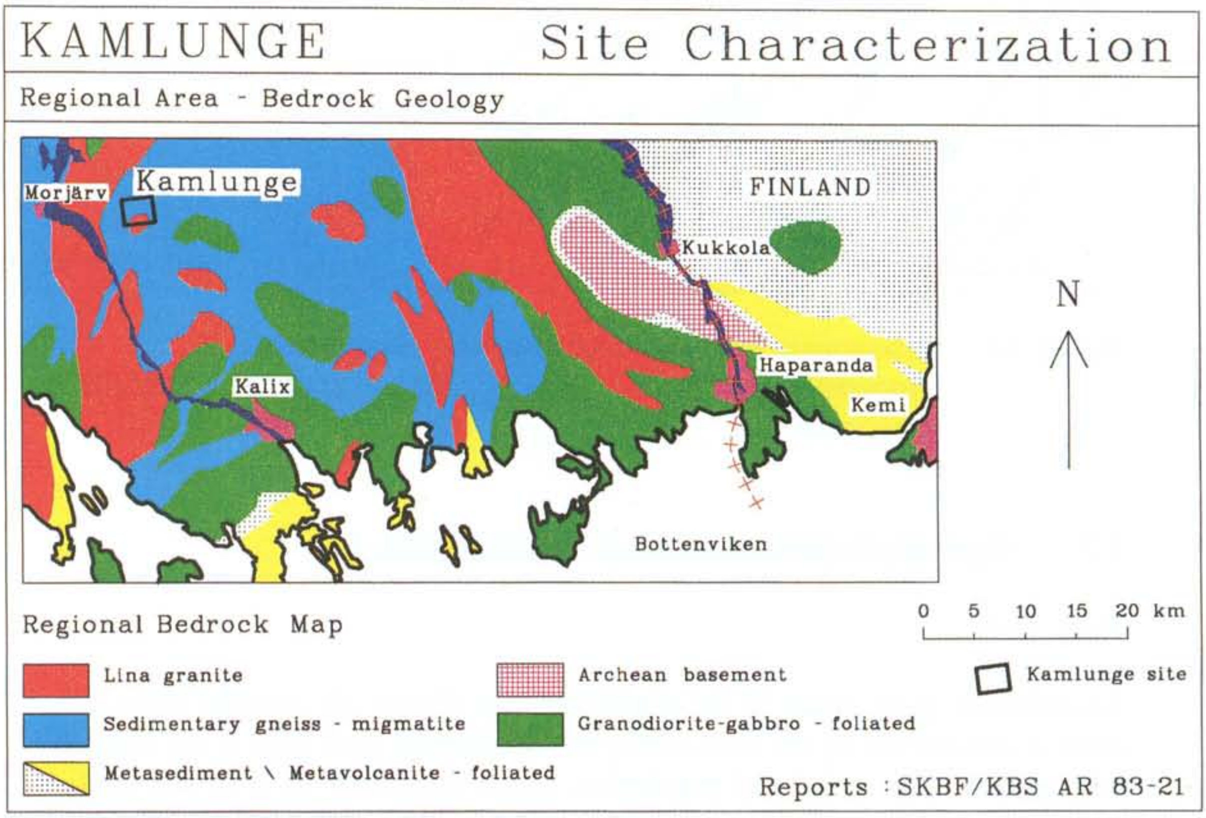


Figure 11. Distribution of rock types in the Kamlunge region (from Albino et al., 1983a).

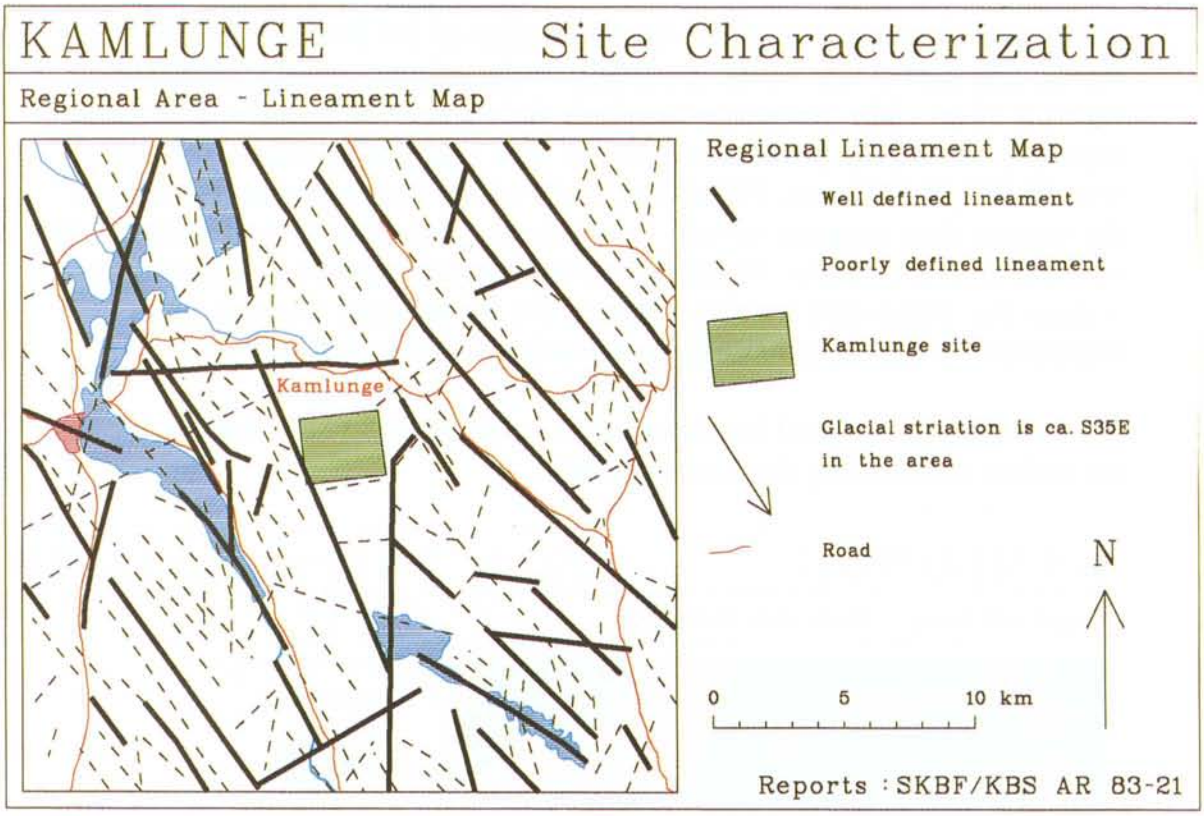


Figure 12. Lineaments in the Kamlunge region interpreted from topographical maps in scale 1:50 000 and geophysical profile measurements.

5.2 Geological characteristics of the Kamlunge site

Rock types

Several rock types occur in the Kamlunge site, Figure 13. Judging from their relative occurrence in the drill cores, the dominating rock type is the reddish Lina granite with associated pegmatites, which constitute 40 % of the total length of all drill cores. Diorite-granodiorite constitute 13 %, while biotite gneiss constitute 26 %, quartzitic gneiss 14 % and amphibolite 7 %. In addition, an ultrabasic rock body, consisting essentially of hornblende and pyroxene, was found in two boreholes (54 m in KKM09 and 12 m in KKM12). The orientation of the layering in the gneisses, as well as the schistosity, show a predominance of a northeasterly strike and a steep dip towards the northwest.

The Lina granite is a greyish red and fine to medium-grained rock type. Transitions to pegmatite and thereby coarser grain size take place gradually.

The granite is 1560-1800 Ma (Welin et al., 1971) and dominates in the southern parts of the site. The main minerals are quartz, potash-feldspar, plagioclase and biotite.

The biotite gneiss is usually greyish-black and fine to medium-grained. The main minerals are quartz, biotite and plagioclase. Thin bands of skarn are often found in the biotite gneiss. The rock has a distinct schistosity, which consist of parallel-orientated mica flakes. Bands rich in quartz and feldspar alternating with mica-rich bands also occur. Sulphides occur sparsely primarily as pyrite in the form of small mineral enrichments or fracture fillings.

The quartzitic gneiss is grey and fine-grained. The colour varies with the biotite content. The main minerals are quartz, potash feldspar, plagioclase and biotite. The rock type occurs in several 100 m wide belts and is usually unevenly grained, banded or massive with irregular course-grained quartz-feldspar streaks.

The granodiorite to diorite series constitute a series of intermediary and basic rock types belonging to the Haparanda series (ca 1880 Ma, Lundqvist, 1991). The granodiorite is light brown with 2-5 cm large plagioclase grains in a matrix rich in biotite. This gives the rock type a porphyric appearance. The main minerals are biotite, plagioclase and amphibole. Magnetite is an accessory mineral, its presence revealed by measurements of magnetic parameters. The rock type is therefore outlined in part on the magnetic map. Granodiorite and diorite is often schistose and has been folded in places. Diorite is subordinated in terms of volume and occurs as isolated lenses. The rock type consists mainly of amphibole and plagioclase, often with grains of magnetite.

Amphibolite occurs in the form of small bodies in the gneisses. The rock type is dark grey and the main minerals are amphibole, biotite and plagioclase. The schistosity increases with increasing biotite content.

Fractures

Orientations and characteristics of fractures have been mapped on outcrops along scan-lines. This fracture mapping method mainly measures steeply dipping fractures, why flat-lying fractures are strongly underestimated. The observed horizontal fractures in vertical rock exposures at Kamlunge are therefore strongly biased in the scan-line data.

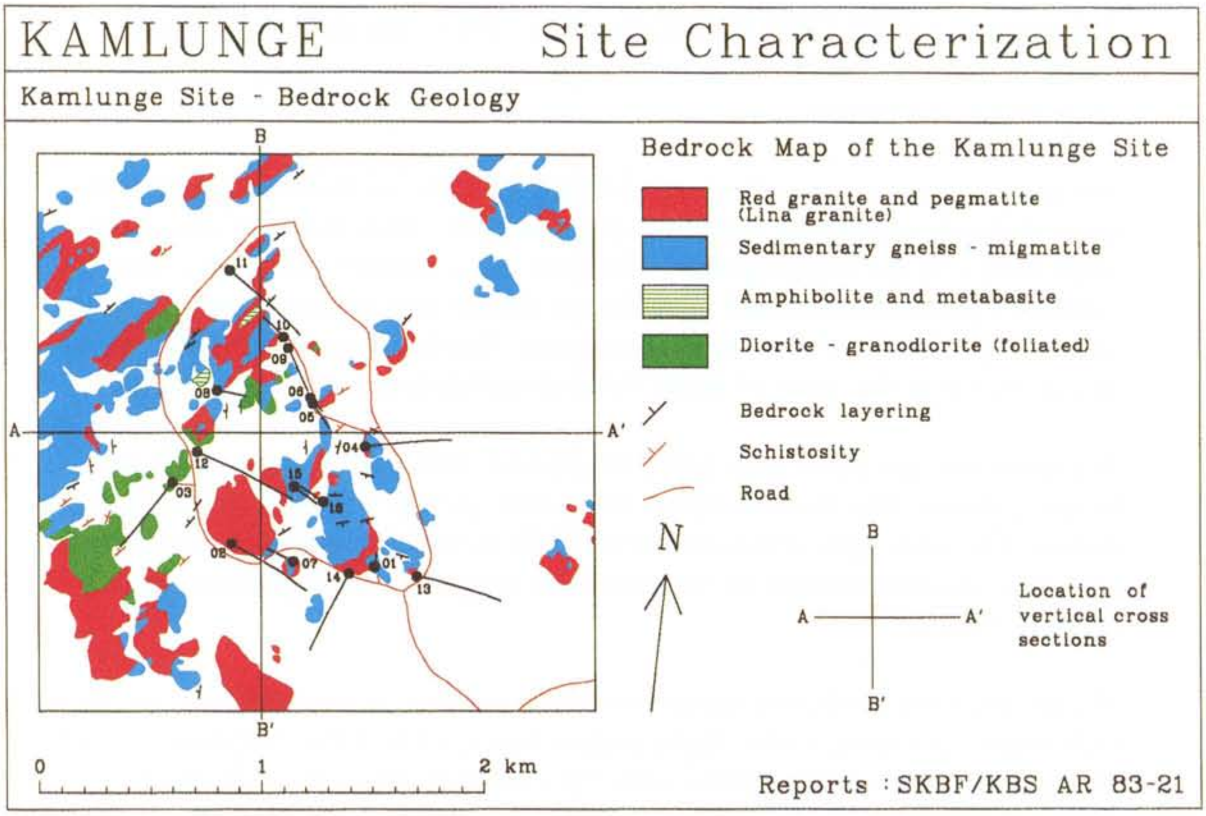


Figure 13. Bedrock map of the Kamlunge site.

The results of the fracture survey shows a strong dominance of fractures trending WNW (N70W), i.e. more or less perpendicular to the schistosity. To a minor extent there is also a dominance of ENE (N70E) trending fractures. Sealed fractures are mainly trending north-south.

The fracture frequency in the gneisses is 1.3 fr/m, while the dioritic, granodioritic and granitic rock types have a fracture frequency of 1.1 fr/m (for fractures longer than 0.5 m).

Results from the core mapping show that the average fracture frequency, in the upper 100 m of all drill cores, is 5.5 fr/m. The fracture frequency decreases with depth until 200 m. From 200 m and down to 700 m the average fracture frequency is more or less constant, about 2.5 fr/m.
The location of sections with high fracture frequency in each of the cored boreholes are presented in Appendix B.

The average fracture frequency for various rock types, irrespective of depth in the drill cores, is lowest for biotite gneiss, 3.6 fr/m, followed by Lina granite 3.9 fr/m, quartzitic gneiss 4.0 fr/m, granodiorite with 4.1 fr/m and amphibolite with 4.7 fr/m. The highest fracture frequency, 10.0 fr/m, is recorded for the ultrabasic rock type found in boreholes KKM09 and KKM12.

One reason for the higher fracture frequency of the drill cores when compared with the outcrop measurements is the underestimation of horizontal fractures in the outcrop mapping. This is also indicated by the strong decrease in fracture frequency with depth in the borehole cores. Another reason for a higher fracture frequency in the borehole cores is the fact that all fractures in the drill cores are recorded, regardless of length, whereas the outcrop mapping does not include fractures shorter then 0.5 m.

Common fracture minerals in the drill cores are chlorite, calcite and laumontite. Iron oxides are present in the form of hematite and goethite. In some altered sections the clay minerals illite, montmorillonite and smectite have been found. A few occurrences of sulphide minerals, mainly galena and pyrite, have also been mapped.

5.3 Fracture zones

Possible locations of fracture zones have been interpreted from aerial photographs (scale 1:20 000), detailed contoured topographical map, geological mapping and geophysical ground measurements. In general, this interpretation was regarded reliable due to the thin or absence of overburden which facilitates lineament interpretation. There are also no conductive clays in the overburden which at other sites have disturbed the electrical geophysical surveys.

In the central part of the site interpreted lineaments/geophysical anomalies were tested by shallow percussion boreholes to determine the existence and characteristics, including dip, of fracture zones. The result of the drilling programme was however, for several of the tested fracture zones, somewhat uncertain, as the highest groundwater inflows in many boreholes was not related to the interpreted fracture zones. According to Albino et al. (1983a) the high inflows might instead be an effect of a water conductive horizontal sheet fractures.

The water capacity in the percussion boreholes varies widely. The highest capacity is 9000 l/h, excluding borehole HKM20 which is located outside the site. Many boreholes are completely dry. In general, the percussion boreholes yield rather small water capacities. Excluding borehole HKM20, the median capacity is 720 l/h and the mean capacity 1300 l/h.

After the geometrical characteristics of the fracture zones in the upper part of the bedrock were determined, cored boreholes were directed to intersect the zones at deeper levels. In this way information regarding the continuation of the fracture zones was obtained, as well as quantitative data regarding geologic characteristics and hydraulic properties of fracture zones at deeper levels.

The surface and borehole studies resulted in the identification of seven steeply dipping zones and one horizontal zone within the study site (c.f. Appendix C). These zones have been examined by means of cored boreholes in a total of 14 different locations. The width of the fracture zones varies from 1 to 14 m, with a mean width of 6 m. Spacings between fracture zones varies between 500-1500 m.

The steeply dipping zones are often weathered and contain brecciated and crushed rock. Core losses, when drilling through the zones, are common. Commonly occurring fracture minerals are chlorite, calcite, laumontite, smectite and various iron oxides.

The horizontal fracture zone, Zone H1, is interpreted to occur in four boreholes at a depth of 550 m. In three of these the zone was tested hydraulically showing that the zone is permeable to water. Its width varies between 4 and 14 m. It is less crushed and weathered than the steeply inclined fracture zones. In two boreholes, KKM01 and KKM13, the zone is fractured and reddened through alteration and precipitation of the iron mineral hematite. Chlorite formed after hematite is present. The other two boreholes, KKM02 and KKM14, show only a moderate increase in fracture frequency at this level. The lateral extent of this zone has not been established, but it is not found in KKM12, for example (Figures 14 and 16).

The locations of interpreted fracture zones at the ground surface are shown in Figure 14, while the locations at 450 m depth is shown in Figure 15. The fracture zones are usually steep, the dip varying between 70° and vertical. North-south and east-west cross-sections are shown in Figure 16. The interpreted locations of each fracture zone in individual boreholes are presented in Appendix B.

A summary of all interpreted fracture zones, together with some of their properties, are presented in Table 3. Descriptions of each interpreted fracture zone are presented in Appendix C. This includes general geological characteristics for each zone, as well as basis for interpretation and reliability (c.f. Bäckblom, 1989).

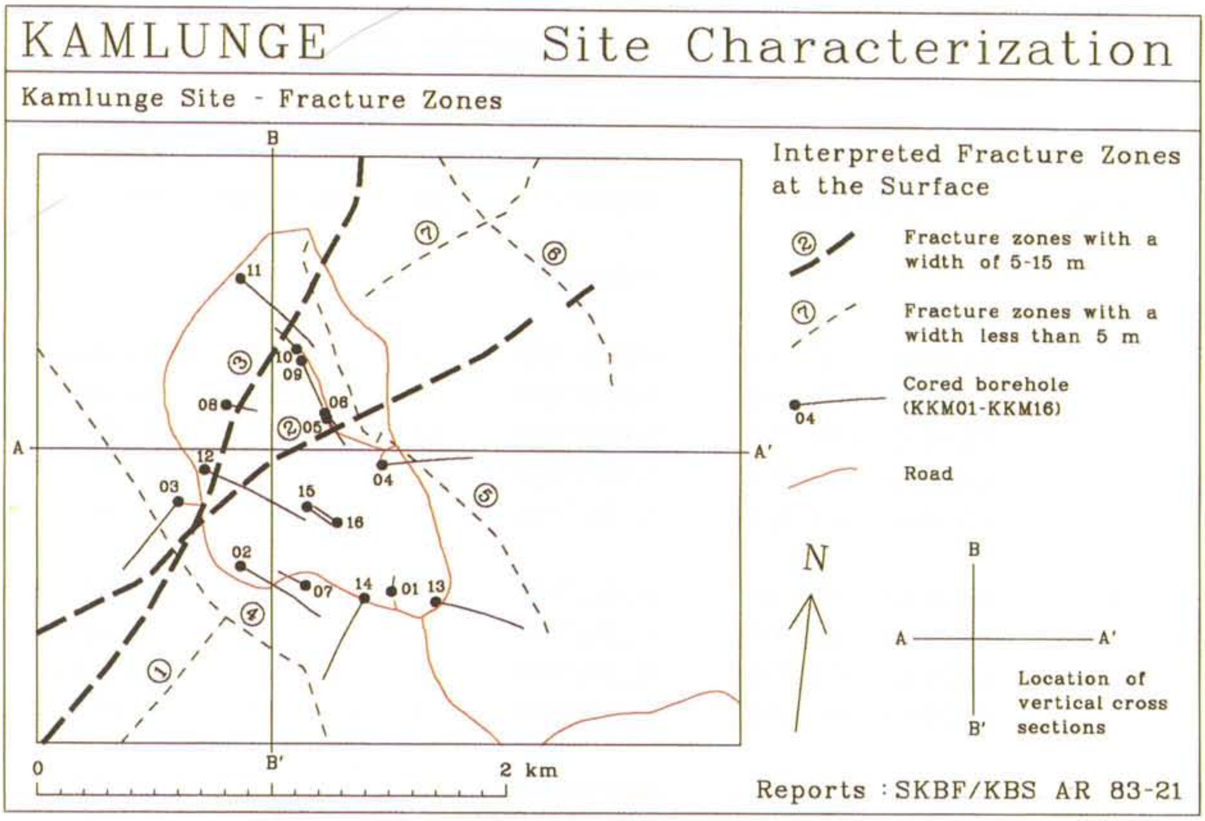


Figure 17. Interpreted fracture zones at the ground surface.

5.4 Validity of models

Rock type distribution

The well exposed bedrock at the Kamlunge site facilitates and reduces uncertainties in the geological mapping. It is therefore most likely that the geological map presented for the Kamlunge study site (Albino et al., 1983a) well represent the rock type distribution at the ground level.

Data regarding surficial distribution of rock types is also found on the magnetic and electrical maps. Towards depth, the core logs and the geophysical logs provide an good description of the rock type distribution. In spite of these data sets, no attempts have been made to compile the geological data into a 3D geological model of rock type distribution, probably because of the complicated rock distribution.

Table 3. Geometrical data, hydraulic conductivities and fracture frequencies for interpreted fracture zones, Kamlunge study site.

Fracture zone	Position in borehole (m)	Strike/Dip (degrees)	Width (m)	Fracture freq.(fr/m)	K-value (m/s)
1	- -	N40E/90*	3*	-	-
2	KKM05 (47- 53)	N55E/70W	5	32	no data
	KKM06 (86- 94)	N55E/70W	6	41	no data
	KKM12 (195-210)	N55E/70W	12	27	$2 \cdot 10^{-7}$
	KKM03 (313-317)	N55E/70W	4	12	$7 \cdot 10^{-11}$
	KKM09 (414-425)	N55E/70W	9	19	$2 \cdot 10^{-9}$
3	KKM12 (52- 60)	N25E/70W	7	15	$4 \cdot 10^{-9}$
	KKM08 (63- 69)	N25E/70W	4	19	no data
	KKM11 (324-335)	N25E/70W	10	9	no data
	KKM03 (441-450)	N25E/70W	1	22	$3 \cdot 10^{8}$
4	KKM03 (504-517)	N45W/80W	4	5	$4 \cdot 10^{-11}$
5	-	N45W/60E*	4*		
6	-	N45W/85E*	3*		
7	-	N55E/75W*	3*		
HI	KKM01 (544-560)	Horizontal	14	4	no data
	KKM14 (667-673)	Horizontal	5	8	$6 \cdot 10^{-9}$
	KKM13 (669-674)	Horizontal	4	19	$1 \cdot 10^{-8}$
	KKM02 (676-684)	Horizontal	7	8	$4 \cdot 10^{-9}$

*Calculated from geophysical information

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 an 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 presented, including main geologic and tectonic characteristics in the 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. As seen in Table 4 there are four fracture zones that are "certain" or "probable" and four zones that only should be regarded as "possible" implying a large uncertainty in the interpretation of fracture zones.

Table 4. Reliability of interpreted fracture zones mainly according to the nomenclature of Bäckblom (1989).

Fracture zone	Reliability
Zone 1	Possible
Zone 2	Certain
Zone 3	Certain
Zone 4	Possible
Zone 5	Possible
Zone 6	Possible
Zone 7	Possible
Zone H1	Probable

The main reason for the low reliability for many of the interpreted fracture zones at Kamlunge is simply that no boreholes have been drilled to test their existence. In the case where borehole have been drilled through the fracture zones there are in all cases fractured and altered bedrock at the interpreted location of the zones, leaving little doubt that these sections really represent fracture zones.

Regarding the question of additional zones there is several indications in the cores and in the geophysical logs that such zones exists. One example is a 15 m section of crushed bedrock at 40 m depth in borehole KKM11. Since no lineament nor geophysical anomalies exist in the borehole surroundings it is likely that this section represent a subhorizontal zone. Also at other localities the well exposed bedrock at the Kamlunge site and the detailed geophysical surveys makes the existence of undetected steeply dipping zones unlikely. Instead, it is more likely that those shallow and fractured borehole sections represent additional subhorizontal or gently dipping fracture zones.

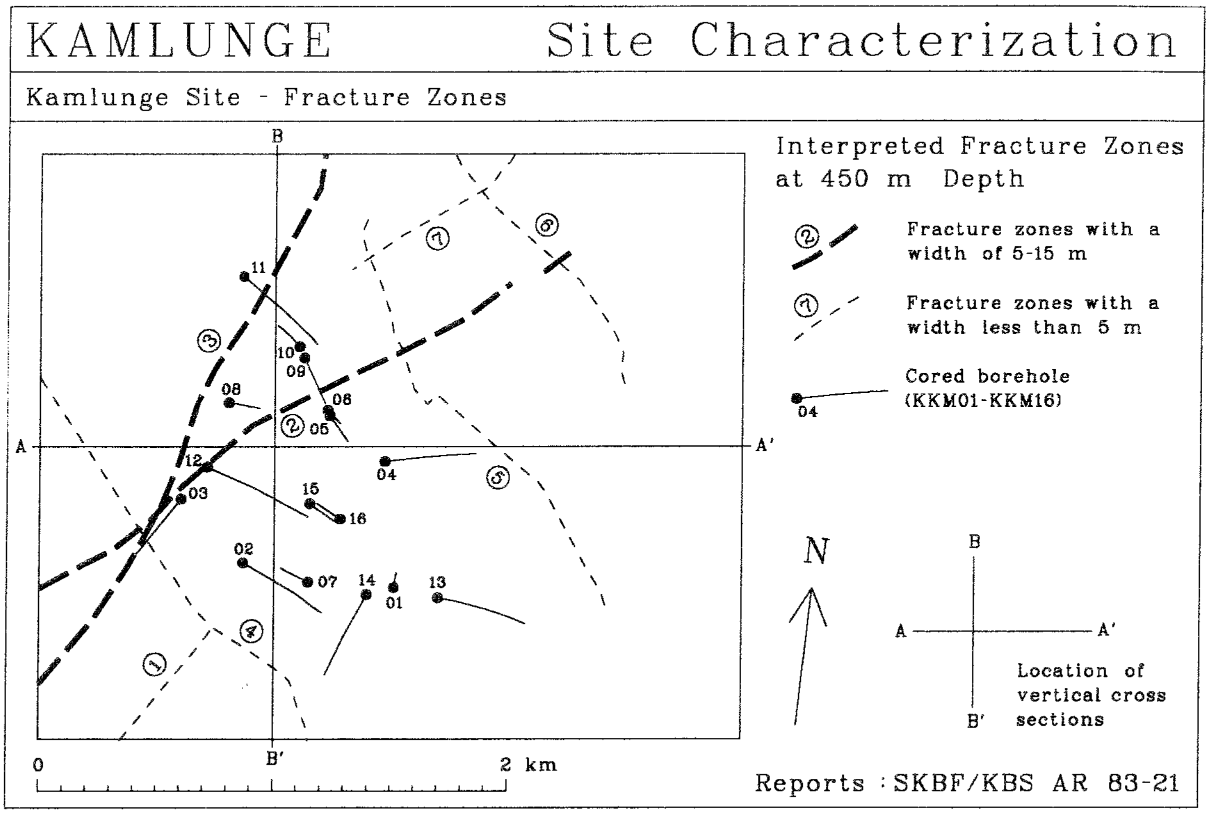


Figure 15. Interpreted fracture zones at 450 m depth.

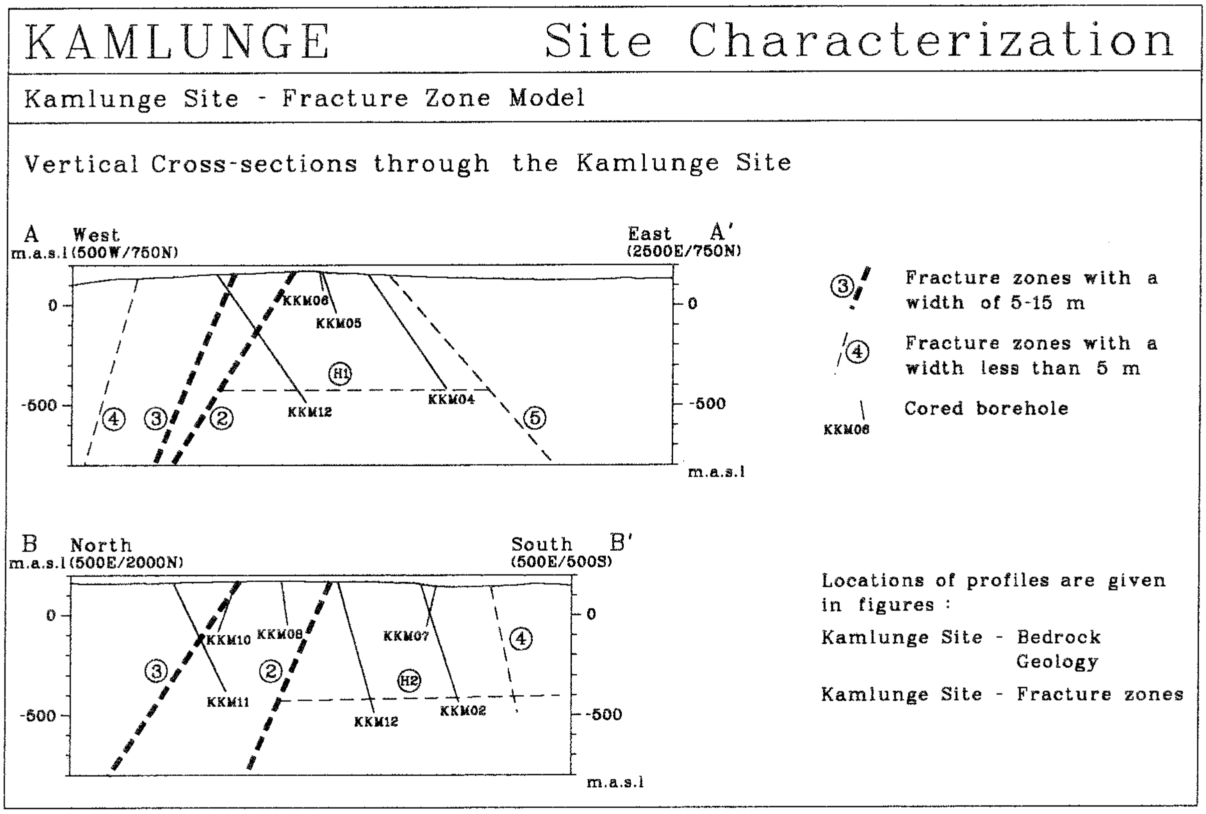


Figure 16. Vertical cross-sections through the Kamlunge site. Locations of sections is indicated in Figures 13, 14 and 15.

6. GEOHYDROLOGICAL MODELS

6.1 Available data and numerical model

The geoinformation used for hydraulic modelling at Kamlunge consist of the conceptual model of fracture zones, distribution of rock types in outcrops and in drill cores, hydrological and meteorological data, contour maps of the groundwater table, hydraulic conductivity data (both from single hole tests and one interference test in the upper part of the bedrock) and estimated piezometric head values in sections along some of the boreholes. All background data are presented in Ahlbom et al. (1983). The results from the interference test are presented by Andersson and Hansson (1986).

Table 5 presents the number of single hole water injection tests performed in the Kamlunge site. To provide an estimate on "investigation density" also the number of tests per km^2 of the local model domain (3.3 km^2) is presented. In total, 13 cored boreholes were tested hydraulically (cf. Appendix A). In one borehole (KKM08) only single-packer tests were carried out. The total borehole length covered by continuous double-packer tests (25 m sections) at Kamlunge is 5 750 m.

The geohydrological modelling at Kamlunge is presented by Carlsson et al. (1983). Steady-state groundwater flow calculations were performed using a three-dimensional model code based on the Finite Element Method described by Thunvik and Braester (1980) and Grundfelt (1983). The basic assumption in the type of model code used is that the bedrock can be represented by either one single continuum (porous media) or by several overlapping continua, e.g. rock mass and fracture zones. Modelling was performed both on a regional and local scale.

Model geometry and boundary conditions were obtained using geological and geophysical interpretations of fracture zones, hydrological data and groundwater table maps. The material properties, i.e. hydraulic conductivity, were derived from the single hole water injection tests and from the interference test. The hydrometeorological data were used in assessing the relevance of the model results.

Table 5. Number of borehole sections tested with different length together with number of tests per km^2 of the local model domain in the Kamlunge site.

Number of sections	Section length (m)	No of tests/km^2	Test type
230	25	70	double-packer
7	10	2	double-packer
91	5	27	double-packer
176	2	53	double-packer
42	26-651	13	single-packer
546		165	all sections

6.2 Regional model

Modelled domain and boundary conditions

A contour map of the regional (mean) groundwater table in the Kamlunge area is shown in Figure 17. The Kamlunge site is located on the top of a topographical plateau with relatively steep slopes towards the surrounding low-land. On the top of the plateau the topography of the groundwater table is rather flat but slopes steeply on the hill-sides. The top of the plateau mainly constitutes a recharge area for groundwater. Major discharge areas are found around the plateau area in lakes and streams, Figure 17.

The regional model domain is about 34 km^2 and comprises the whole plateau and the surrounding valleys, Figure 18. However, no regional influence beyond the surrounding valleys was considered, which implies that the regional model de facto should be regarded as an extended local model.

The groundwater table ranges from about 160 m above the sea level at the summit of the plateau to about 40-60 m in the surrounding valleys. A digitized contour map of the groundwater table, used as the upper boundary condition (zero prescribed head), is shown in Figure 18. A vertical section (A-A') of the groundwater table across the regional domain is also shown.

The vertical outer boundaries of the regional domain were treated as non-flow boundaries. They are located close to the steep hydraulic gradients along the plateau sides. A non-flow boundary condition was also applied at the lower boundary of the modelled domain at 1500 m depth. The total number of elements in the mesh of the regional model was 1884, distributed in

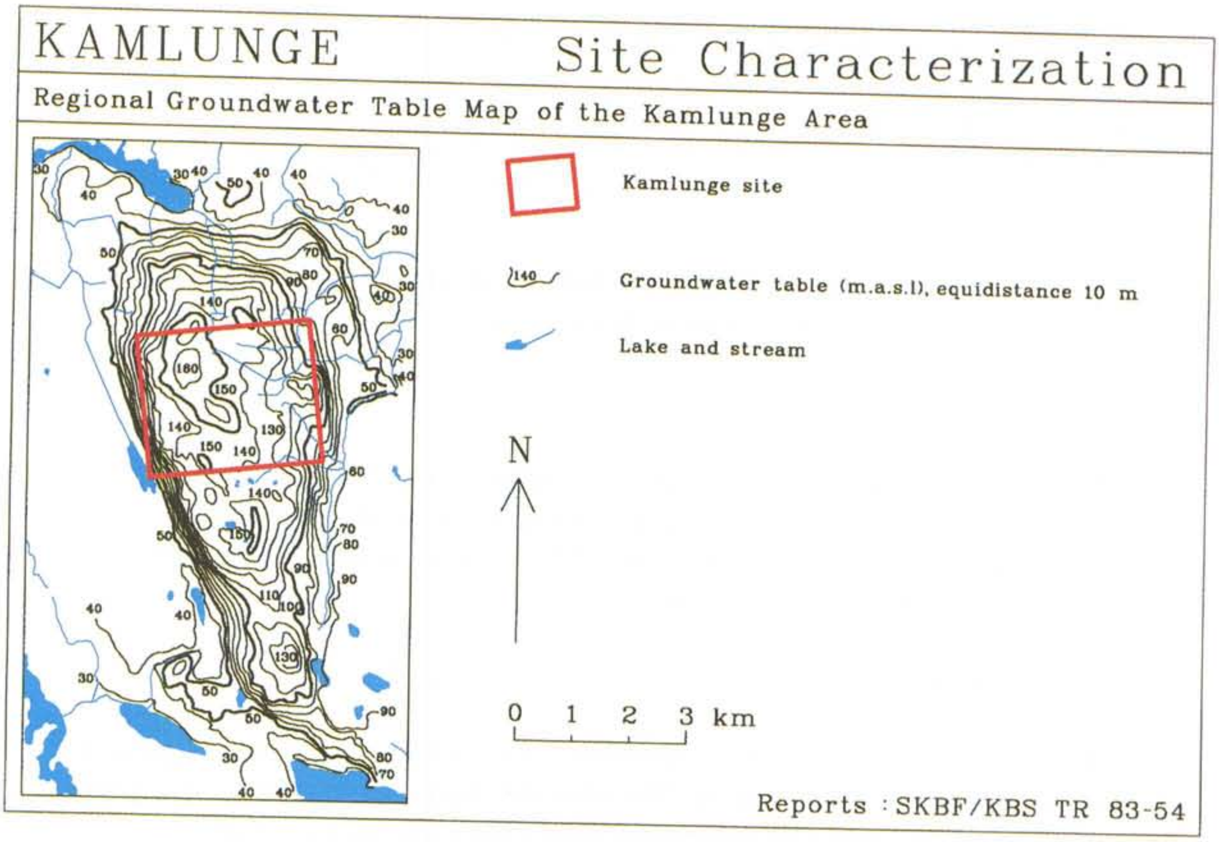


Figure 17. Regional groundwater table map in the Kamlunge area.

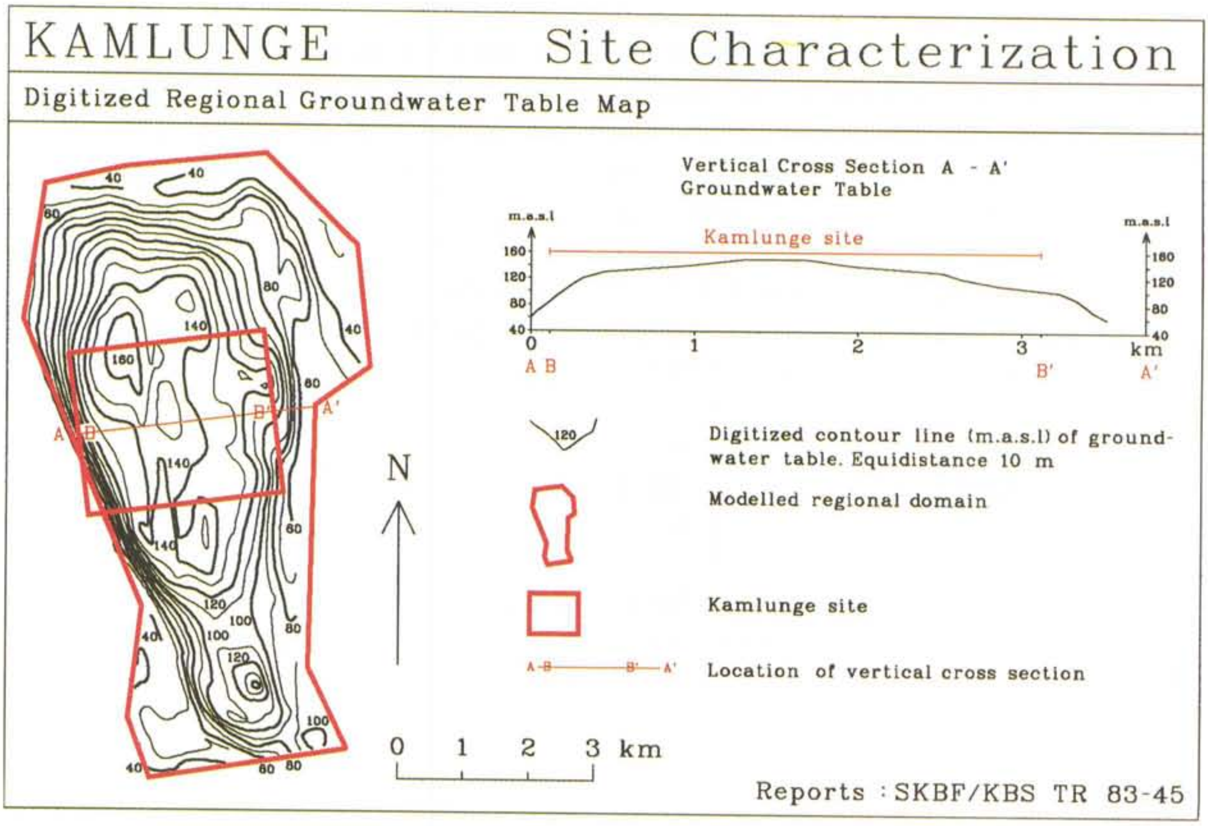


Figure 18. Regional groundwater table map used in the numerical modelling. The regional model domain and the Kamlunge site are outlined.

twelve layers extending down to a depth of 1500 m. The element mesh contained 8868 nodal points. The density of elements was higher in areas with steep gradients than in the relatively flat areas on the plateau.

Hydraulic units

The regional model only considered the bulk conductivity of the bedrock, thus no separation was made between fracture zones and rock mass.

Hydraulic conductivity

For the regional modelling a hydraulic conductivity function, based on a preliminary regression analysis of data from 25 m sections according to Eqn. (6.1), was applied to the rock mass. The regression curve is based on a power function of the following form:

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

where K_e is effective hydraulic conductivity, z is vertical depth below ground surface and A and b are constants. The effective hydraulic conductivity of the different hydraulic units was calculated from geometric means of all measured data in 100 m depth intervals, assuming a 3D flow geometry for the rock mass.

The hydraulic conductivity function applied to the rock mass in the regional model is shown in Table 6. The values on the constants A and b in Table 6 differ somewhat from the corresponding values in the local modelling (Table 8). This is because the conductivity function in the regional model was based on a preliminary analysis with fewer data.

Table 6. Constants A and b in Eqn. (6.1) representing the hydraulic conductivity function applied in the regional model at Kamlunge. From Carlsson et al. (1983).

Model	Rock mass	
	A	b
Regional	0.0014	2.93

Results

The distribution of the groundwater potentials was calculated in four horizontal planes at different depths. The calculations show that the topography of the hydraulic gradients is smoothed out with depth. For example, the local elevation of the groundwater table in the southern part of the regional area (Figure 18) totally disappeared at a depth of 750 m. The groundwater potentials and flow field were also calculated in six vertical cross sections. A similar pattern to that discussed above was obtained in these cases.

Not surprisingly, the steep gradient (about 10 %) of the groundwater table at the steep slopes of the plateau causes the strongest influence on the overall groundwater flow pattern.

Relevance of results

The value of the results of the regional modelling is limited. This is partly due to the fact that no fracture zones were included in the model, and partly because no regional influence beyond Kamlungekölens plateau was considered.

6.3 Local model

Modelled domain and boundary conditions

A detailed contour map of the (mean) groundwater table in the Kamlunge site, including the local model domain, is shown in Figure 19. The topography of the groundwater table in the local domain is relatively flat, ranging from about 135 m to 165 m above the sea level. The major part of the local area mainly constitutes a recharge area for groundwater. Local, minor discharge areas are found in low-lying parts within the area. The shallow groundwater flow is primarily directed from the top of the plateau towards the plateau sides.

The groundwater table was used as the upper boundary condition (zero prescribed head). The description of the groundwater table in the local model domain was derived from the digitized regional groundwater table map (Figure 18). The outer boundaries of the local domain are shown in Figure 20. They were treated as vertical boundaries with prescribed head in the modelling. Each nodal point at these boundaries were assigned the calculated head from the regional model at the corresponding coordinates. At the lower boundary of the modelled domain a non-flow boundary condition was applied at 1500 m depth.

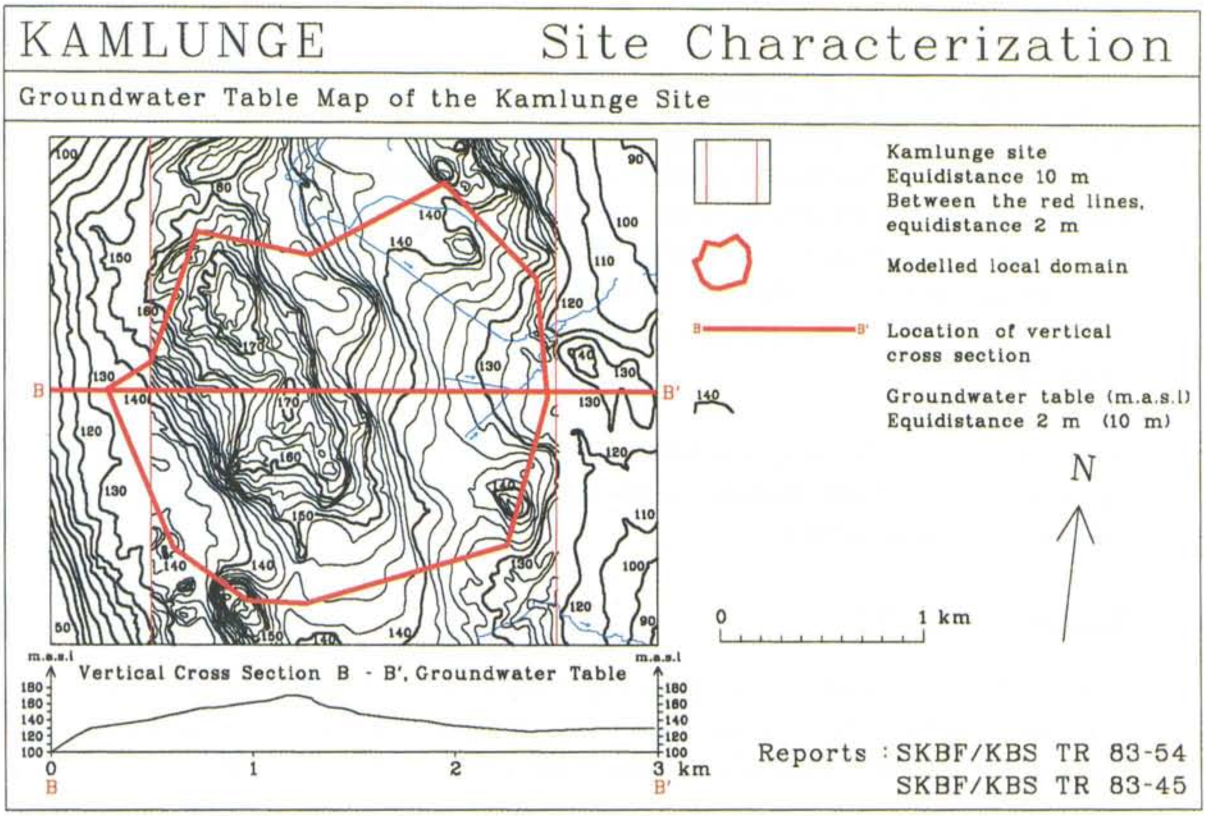


Figure 19. Groundwater table map. The local model domain and the groundwater table along cross section B-B' is outlined.

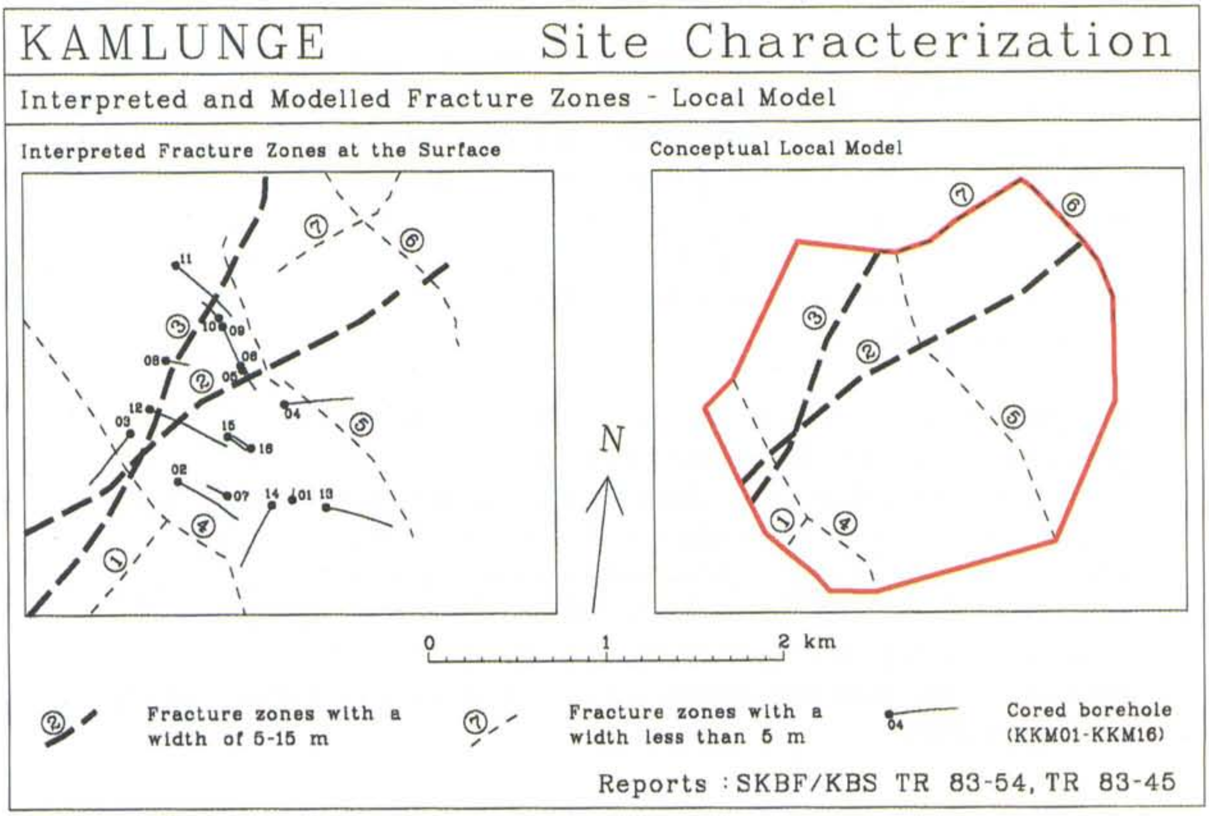


Figure 20. Interpreted and modelled fracture zones.

Two cases were modelled in the local domain. The cases were identical except for the horizontal fracture zone included in the second case. Both model meshes have the same areal distribution of elements except for one additional element layer representing the horizontal zone in the latter case. Since the topography of the groundwater level in the local model domain is rather flat, the elements were relatively evenly distributed over the domain.

The total number of elements in the first mesh was 2064, distributed in eight layers extending down to a depth of 1500 m with 8868 nodal points. The second mesh contains 2322 elements in nine layers with totally 10055 nodal points. The horizontal zone was represented by a 10 m thick element layer. The other fracture zones were modelled with one row of elements.

Hydraulic units

The main hydraulic units included in the model are 1) the rock mass (excluding all interpreted fracture zones), 2) local fracture zones (excluding the horizontal zone) and 3) the horizontal zone. No subdivision of the rock mass in different rock types was made. The surface locations and the width and strike of the interpreted and modelled fracture zones are presented in Figure 20 and Table 7, respectively. The intersections between boreholes and fracture zones are described in Table 3. As can be seen in Table 7 the majority of the fracture zones were modelled slightly wider than the interpreted widths due to numerical considerations.

Table 7. Interpreted and modelled fracture zone properties in the Kamlunge site. After Carlsson et al., (1983).

Fracture	Interpreted		Modelled	
zone	width (m)	dip(°)	width (m)	dip(°)
1	3	90	5	90
2	4-12	70NW	8	70NW
3	1-10	70NW	5	70NW
4	4	80SW	5	80SW
5	4	60NE	5	60NE
6	3	85NE	5	85NE
7	3	75NE	5	75NE
H 1	4-14	0	10	0

Hydraulic conductivity

Hydraulic conductivity functions versus depth were assigned to the hydraulic units defined in the model. Figure 21 shows all measured hydraulic conductivity data from the 25 m test sections versus depth in the Kamlunge site, both for the rock mass and the fracture zones. For these tests sections the lower measurement limit for the water injection tests corresponds to a hydraulic conductivity of 10^{-11} m/s.

Regression curves based on Eqn. 6.1 of effective hydraulic conductivity versus depth were made for the hydraulic units using all measured sections in the rock mass and fracture zones. The effective hydraulic conductivity of the different hydraulic units was calculated from geometric means of all measured data in 100 m depth intervals, assuming a 3D flow geometry for the rock mass and a 2D flow geometry for the fracture zones.

In the regression analysis of the fracture zones, the horizontal zone (H 1) was not included. Hydraulic conductivity values at or below the lower measurement limit were assigned the actual value of this limit.

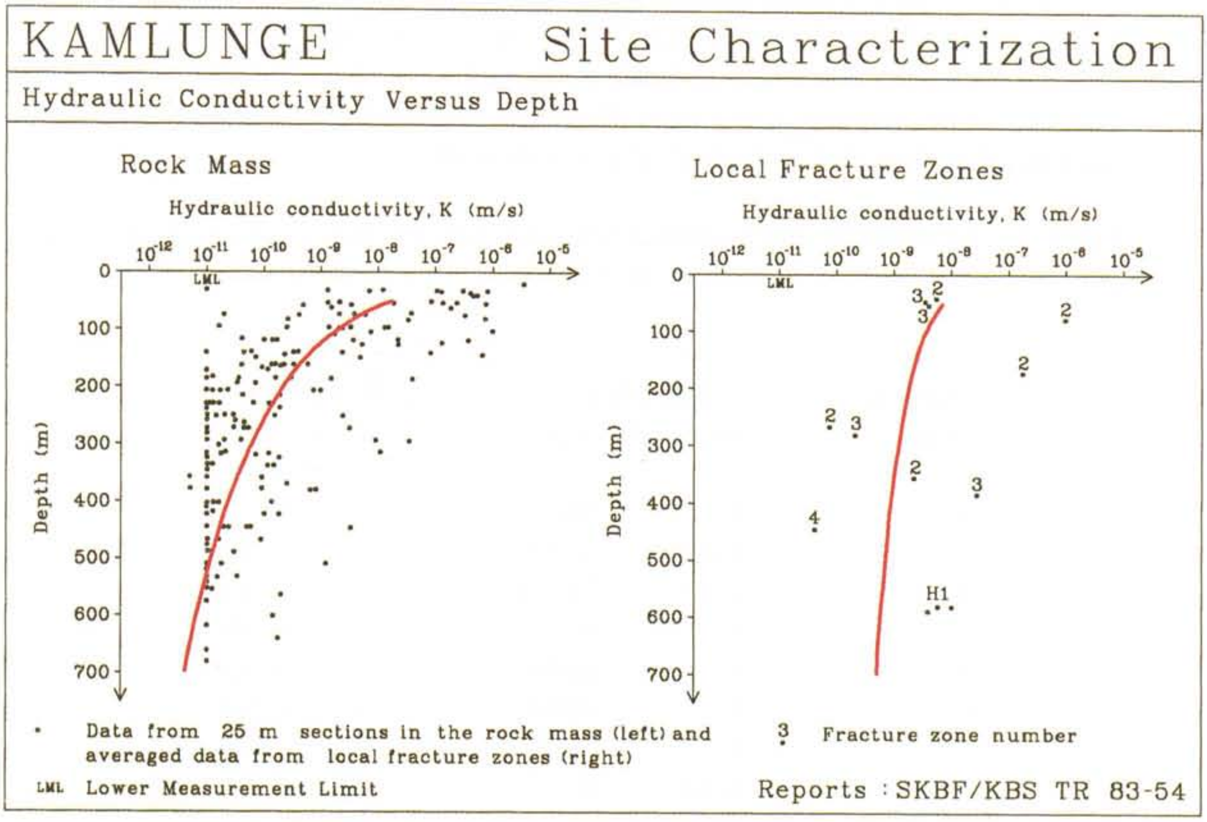


Figure 21. Hydraulic conductivity versus depth for rock mass (left) and for the local fracture zones (right) in the Kamlunge site.

Table 8 shows the derived constants A and b in Eqn. (6.1) from the regression analysis, expressing the hydraulic conductivity versus depth functions for the different hydraulic units together with the number of data used (n) and the regression coefficients (r^2).

The measured hydraulic conductivity of the horizontal fracture zone (H 1) ranges between $0.4\text{-}1 \cdot 10^{-8}$ m/s from single-packer tests in three boreholes.

The interference test in the upper c. 100 m of the bedrock in the Kamlunge site indicated an average hydraulic conductivity of about $2 \cdot 10^{-6}$ m/s (Andersson and Hansson, 1986). Although this value is uncertain due to technical problems during the test it differs significantly from the mean value of the hydraulic conductivity of the local fracture zones in this depth interval obtained from the regression analysis, see Figure 21.

Table 8. Constants A and b in Eqn. (6.1), number of data (n) and regression coefficients (r^2) for the different hydraulic units in the Kamlunge study site. From Carlsson et al., (1983).

Hydraulic unit	A	b	n	r^2
Rock mass	0.00791	3.17	227	0.54
Local fracture zones	$4.0 \cdot 10^{-7}$	1.02	8	0.10

The conductive fracture frequency (CFF) in the rock mass at Kamlunge was estimated by Osnes et al. (1991) by a probabilistic model using hydraulic conductivity data from all 25 m sections in the rock mass. The estimated range of CFF was 0.04-0.06 fr/m.

Model cases

Two cases were modelled on a local scale of the Kamlunge site in the KBS-3 study (Carlsson et al., 1983). In the first case the rock mass and local fracture zones (excluding the horizontal zone) were modelled as overlapping continua. In the second case also the horizontal zone was included. This zone was modelled as a separate hydraulic unit at 555-565 m depth extending over the entire domain. The zone was assigned a constant hydraulic conductivity of $K=1 \cdot 10^{-8}$ m/s. This corresponds to a contrast in hydraulic conductivity of about 800 times between the zone and the surrounding rock mass. The hydraulic conductivity functions applied for the rock mass and local fracture zones in both model cases are shown in Table 9.

Table 9. Constants A and b in Eqn. (6.1) representing the hydraulic conductivity functions applied to the rock mass and fracture zones in both model cases in the Kamlunge site. From Carlsson et al. (1983).

Model	Rock mass		Fracture zones	
	A	b	A	b
Local	0.00141	2.93	$1.2 \cdot 10^{-6}$	1.16

Results

The distribution of the groundwater potentials and groundwater flow rates in the rock mass was calculated in three horizontal planes at different depths for both model cases. These calculations show that the hydraulic gradient decreases with depth and that the horizontal components of the gradient is lowered by the presence of the horizontal fracture zone.

The groundwater flux was calculated at 450 m, 550 m and 570 m depth, i.e. 105 m above, 5 m above and 5 m below the horizontal zone, respectively. The distribution of the groundwater flux in the rock mass at 450 m depth with the horizontal zone included in the model is shown in Figure 22. The calculated ranges and representative values of the flow rates in the rock mass at these depths with and without the horizontal zone are shown in Table 10.

Table 10. Calculated groundwater flow rates (ranges and representative values) in the rock mass at different depths for the two model cases in the Kamlunge site. (From Carlsson et al., 1983).

	Groundwater flow rate (ml/m^2/year)			
	Without hor. zone		With hor. zone	
Depth(m)	Range	Repr. value	Range	Repr. value
450	15-30	20	20-60	50
550	8-15	10	15-30	25
570	8-20	10	4-10	6

Table 10 clearly shows that the presence of the horizontal zone increases the calculated groundwater flux above the zone with a factor of 2.5. Correspondingly, the presence of the zone decreases the flux below the zone with a factor of 2.

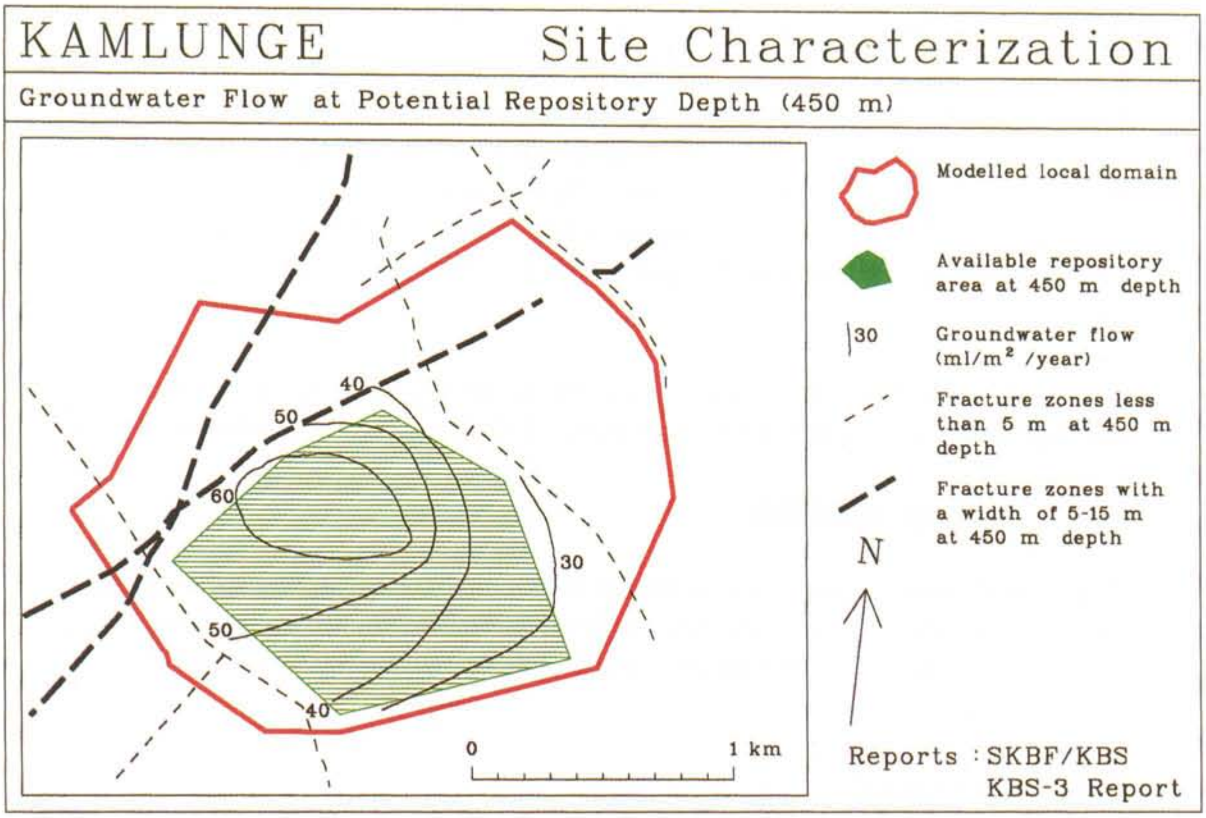


Figure 22. Groundwater flow at 450 m depth in the rock mass with the horizontal zone included (see text).

<u>Relevance of results</u>

The relevance of the numerical model was assessed from calculations of groundwater recharge and mass balance for the individual finite elements. The groundwater recharge at Kamlunge was estimated by Carlsson et al., (1983) from the regional and local model runs. The recharge rate was calculated as the total recharge across the top surface of the modelled domain divided by the area of the top surface.

The calculated recharge rates were about 20 mm/year and 1-2 mm/year, respectively, for the regional and the two local model runs. The recharge areas were estimated to about 14.5 and 1.7 km^2, respectively. The effect of the horizontal zone (and other fracture zones) on the recharge rate was small.

As pointed out by Larsson and Markström (1988) the calculated recharge rates mainly reflect the groundwater conditions and the hydraulic properties of the uppermost part of the bedrock including fracture zones and may have little influence on the groundwater flow conditions at repository depths. Thus, groundwater recharge calculations may be of limited use as a factor to assess the relevance of the model.

The mass balance was calculated for each element in the mesh to check the numerical quality of the solution. According to Carlsson et al. (1983) the proportion of elements deviating from mass conservation by less than 1% was 32 % and 27-28 % in the regional and local model runs, respectively. The proportion of elements deviating between 10-100 % was 20 and 21 %, respectively.

No comparison between observed and modelled groundwater potentials along the boreholes was made in the hydraulic modelling of the Kamlunge site.

6.4 Validity of models

The model results from the Kamlunge 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 groundwater flow and head conditions at the outer vertical boundaries of the regional model were assumed. Since non-flow boundaries were located close to the steep gradients along the plateau sides the groundwater near the boundaries is forced upward in the confined model box in contrast to the natural flow along the sides (Carlsson et al.,1983).

Furthermore, the regional groundwater table map is more or less an image of the topographical map which makes the upper boundary condition, i.e. the groundwater table, uncertain. It is however difficult to assess the uncertainties in the assumed boundary conditions and the effects of these in the local model domain without making sensitivity studies.

Local model

The outer vertical boundaries of the local model domain were treated as prescribed head boundaries, derived from the calculated heads in the regional model. Since the sensitivity of the latter heads to the actual boundary conditions in the regional model was not studied, the relevance of this assumption can not safely be assessed. Furthermore, the selection of the location of the outer boundaries of the local model domain is not described.

Hydraulic units

Regional model

The effects of not including fracture zones (including the horizontal zone) on the groundwater flow conditions in the regional area were not studied.

Local model

The division of the bedrock in the Kamlunge site in rock mass and local fracture zones should be considered as preliminary and uncertain. Furthermore, no subdivision of the rock mass into different rock type units has been made.

The great variability in geologic and hydraulic character of fracture zones may imply that each fracture zone should be regarded as an individual hydraulic unit, see below. However, due to the lack of data all fracture zones at Kamlunge (except the horizontal zone) were statistically treated as one hydraulic unit (c.f. Figure 21).

Hydraulic conductivity

The derived hydraulic conductivity versus depth functions of the rock mass, used in both the regional and local model, are uncertain due to the large scatter of the data, Figure 21. The averaging process also subdues extreme (high) values. Also the results of the statistical analyses of the hydraulic properties of the fracture zones are highly uncertain, particularly for the upper part of the bedrock.

For the Kamlunge site several mathematical functions were tested by the regression analysis of the hydraulic conductivity data, i.e. linear, power, logarithmic and exponential functions. The power function, which was found to give the best correlation, was selected in the regression analysis. As can be seen from Table 8, the correlation coefficients are generally rather low for the derived conductivity functions.

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 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 possibility of regional groundwater flow from topographically elevated areas beyond the modelled regional area has not been considered. For example, such a flow might be significant in the bedrock below the horizontal zone.

7. GROUNDWATER CHEMISTRY

7.1 Scope and reliability of samples

The groundwater chemistry data available form the Kamlunge study site was obtained during the KBS-3 investigations of 1981-1983. The results, including sampling methods, are presented by Laurent (1983), Wikberg et al. (1983) and Allard et al. (1983). Three boreholes were sampled, KKM03, KKM08 and KKM13. The sampled depths for each borehole is presented in Tables 11-14. Some groundwater samples were also obtained from the percussion borehole HKM20 located in the regional fracture zone bounding the Kamlungekölen plateau to the west. Since no evaluation of the representativity of these samples has been reported they are not included in this report. The data are however stored in the SKB database GEOTAB.

The results of the investigations are discussed and interpreted in detail for each sampled horizon by Smellie et al. (1985) 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 non 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 KBS-3 investigations 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).

7.2 Results

General chemistry

The general chemical composition of the samples from the different boreholes is shown in Table 11. The compositions indicates the presence of different water types as near-surface groundwater and intermediate to deep old groundwater. The major-ion chemistry generally show calcium as the dominating cation, while the anions are dominated to varying degrees by bicarbonate and sulphate/chloride, respectively. The two bottom sections in KKM13, as well as all sections in KKM03 and KKM08, are considered to be representative for a shallow groundwater with low concentrations of all dissolved species except for bicarbonate. Two sections deviates from this general pattern, and showing a major-ion composition characteristic for an older water. These sections occur in borehole KKM13 at depths of 197 m and 432 m and show significant higher concentrations for almost every measured species than for all other sampled horizons at Kamlunge. Both sections show chemical compositions that are characteristic for intermediate groundwater.

Table 11. General chemistry parameters at Kamlunge.

Sampled borehole	Depth m	pH	Conductivity 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
KKM03	106	7.9	12	5.7	13	2.8	1.3	65	3	4
KKM03	376	8.4	13	5.0	13	3.2	1.8	66	3	6
KKM08	198	6.3	4	0.8	2.1	0.6	0.2	7	1	5
KKM13	197	8.4	56	18	99	0.6	1.6	15	5	240
KKM13	432	8.6	108	23	232	3.3	6.2	19	20	520
KKM13	556	6.9	6	1.4	3.5	0.9	1.0	8	5	5
KKM13	564	7.0	6	1.0	3.0	0.5	0.7	9	1	6

There are no general trends with depth considering pH, electrical conductivity or the major-ion chemistry at the Kamlunge site. The odd phenomenon to have a shallow groundwater type (KKM13 at 556 m and 564 m) on a larger depth than more shallower sections (KKM13 at 197 m and 432 m) is probably due to the horizontal fracture zone that are penetrated by the lowermost part of borehole KKM13.

Redox-sensitive parameters

A summary of some of the redox-sensitive parameters is presented in Table 12. Of the samples collected in this study three out of six are reducing, as indicated by negative Eh-values. There are no apparent trends with depth in any of the redox parameters. However, large negative Eh-values are encountered at depth in KKM03 and KKM13. An exception is positive Eh values measured in the horizontal zone at the bottom of borehole KKM13.

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) show that Eh calculations based on the iron system does not explained the measured Eh values.

Table 12. Redox parameters at Kamlunge.

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
KKM03	106	+100	0.04	0.28	<0.01	0.48	0.006	0.016
KKM03	376	-150	0.86	1.0	<0.01	0.07	0.008	0.012
KKM08	198	+270	2.8	4	<0.01	1.11	0.002	0.008
KKM13	197	-70	0.51	0.48	0.03	0.07	0.041	0.016
KKM13	432	-100	0.72	0.83	0.02	0.10	0.009	0.008
KKM13	556	+50	6.8	8.1	<0.01	0.09	0.006	0.012
KKM13	564	+30	8.2	7.9	<0.01	0.10	0.006	0.012

Smellie (1983) concluded after a controlled field experiment in borehole KKM08, 238 m, that changes in the groundwater sampling pump flow rate resulted in significant variations in the physico-chemical parameters. High pump rate resulted in an increase in oxygen and low pump rate resulted in a groundwater of truly reducing character.

Uranium geochemistry

The measurements of uranium content and the activity ratio $^{234}U/^{238}U$ were performed in two different ways. Some samples were performed by high-resolution alpha spectrometry, while other measurements were performed by delayed neutron activation (DNA). The former method eventually became part of the hydrochemical programme.

As can be seen from Table 13, and which also is concluded by Smellie et al. (1985), there is a tendency to find relatively high uranium contents closer to the surface and relatively low concentrations in the deeper sections. The uranium isotope contents indicate widespread disequilibrium in the groundwater. The isotope ratios in KKM03 and KKM13, upper part, are relatively high, indicating that the groundwater have had long residence times in contact with the bedrock.

Table 13. Uranium geochemistry at Kamlunge.

Sampled borehole	Depth m	U ppb*	U ppb**	$^{234}U/^{238}U$ act. ratio
KKM03	106	24.3	11.94	2.8
KKM03	376	16.2	5.51	3.2
KKM08	198	0.04	-	2.4
KKM13	197	5.2	-	2.1
KKM13	432	10.2	-	1.8
KKM13	556	0.09	0.6	1.8
KKM13	564	0.04	-	1.8

*Analysis by high resolution alpha spectrometry.
**Analysis by delayed neutron activation (DNA).

Highly altered rock from fracture zones and samples from macroscopical fresh rock were sampled in borehole KKM03 for studies of the uranium decay series ^{238}U - ^{234}U - ^{230}Th. The fresh and unfractured rock generally appear to be at or near isotopic equilibrium. Samples from the highly conductive fracture zones (Zone 1 and Zone 2) general indicate depletions of ^{238}U and ^{234}U originating from the interactions of groundwater still marginally oxidizing, even at depths of 444 m. The investigated bedrock environment (100-600 m) is generally reducing, however, there is some evidence to indicate that rock/water interaction processes leading to the removal of total uranium has resulted from the presence of less reducing groundwater in large-scale fracture zones, hydraulical connected to the ground surface (Smellie, 1984).

Environmental isotopes

A summary of some of the analyses of the environmental isotopes from the KBS-3 investigations are presented in Table 14. No isotope data are available. The old age of KKM13, upper sections, is supported by ^{14}C data (6 500 - 7 400 years). Unfortunately, mixing with surface to near-surface waters has taken place (i.e. 10-18 TU and 0.07-0.10 mg/l oxygen), resulting in a significant amount of "dilution".

Table 14. Environmental isotopes at Kamlunge.

Sampled borehole	Depth m	Tritium TU	^{14}C years	$\delta^{18}O$ ‰ vs SMOW	$\delta^{2}H$ ‰ vs SMOW
KKM03	106	49	3575	-	-
KKM03	376	56	2985	-	-
KKM08	198	20	-	-	-
KKM13	197	10	7365	-	-
KKM13	432	18	6460	-	-
KKM13	556	39	1015	-	-
KKM13	564	25	800	-	-

7.3 Summary and relevance of results

A total of 3 boreholes and 7 different sections have been sampled. Smellie et al. (1985), presented an examination of all the seven sections sampled by considering geological, hydrological and chemical information in combination. They concluded that the results from the hydrological modelling agreed somewhat with measured piezometric pressures, except for KKM03, where no correlation was obtained. In fact, the groundwater modelling in this case is not likely to provide an accurate estimate of detailed flow conditions (hydraulic head distribution) at greater depths even if the local hydrogeology is described accurately, since there is a lack of consideration of any regional hydrological components. Thus, results from hydrological modelling did not provide a significant help in interpreting the hydrochemistry results.

Although it can be argued that the hydrological modelling did not provide accurate information about flow conditions at depth, the actual measurements of the piezometric pressures along each borehole could be utilized as an indication of whether water was flowing to or out from the sampled section of the borehole. Using this information, along with consideration of all other disturbing factors it was concluded by Smellie et al. (1985) that non of the seven sampled sections were representative for the depth sampled. Measurements of redox potentials are especially uncertain, but generally the redox measurements show that the groundwater are of a reducing character.

In borehole KKM03 and KKM08, the measurements reflect the composition of a shallow groundwater type, and they are very uniform in composition. Borehole KKM13 reveals groundwater of two varying types, although non of the sections can be considered representative for the sampled depths.
The two sampled water types are surface and near-surface waters in the two lowermost sections and intermittent to deep old groundwater, characterized by a high $CaSO_4$ content, in the uppermost two sampled sections. The near-surface waters in the lowermost section in KKM13 is interpreted to be caused by the horizontal Zone H1.

Drilling and sampling methods used for the investigations at Kamlunge were relatively "old". New techniques were developed and tested later on, and are described by Almén et al. (1983).

8. ASSESSMENT OF SOLUTE TRANSPORT

8.1 General considerations

No specific models of solute transport at the Kamlunge site exist. The report by Carlsson et al. (1983), however, describes a model of the groundwater system in which both a three-dimensional flow field and groundwater travel times from a repository at 450 m depth are shown. This model of the groundwater system at the site has been discussed in Chapter 6. A groundwater flow field is the essential basis of a groundwater solute transport model, and thus the implications for solute transport at the site 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 hypothetical repository located in a bedrock block at 450 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 modelling of the Kamlunge site was performed in two steps, in a regional scale and a local scale, as described in Chapter 6. The hydraulic boundaries of the regional Kamlunge model are placed so as to approximately enclose the topographically significant plateau with an area of about 34 km^2 and with depth of about 1.5 km. The local model covers an area of about 3.3 km^2 in the center of the regional model. For the regional model, a groundwater table following the topography with maximum relief of about 120 m is specified as the surface condition, whereas the four vertical sides and bottom are closed to flow. The boundaries are located close to the plateau sides. The depth to the bottom of the block was arbitrarily chosen. The head distribution determined from the regional model was then used to assign a head distribution along the vertical boundaries of the local model. The upper and lower surface boundary conditions were the same as for the regional model.

In model analyses for Kamlunge, no variations were carried out to examine the implications for flow and transport of the location and type of boundary conditions. The combination of boundary specifications used in the regional model may cause unnatural conditions of modelled solute transport through the repository level of these sites in two ways, both of which may strongly affect magnitude and direction of flow. First, because all vertical sides are closed, all water moving through the modelled region must enter and exit through the top surface. Second, some of the water entering through the top surface in the model region must reach the bottom of the model region no matter how deep the bottom is, and no matter what the hydraulic conductivity distribution is.

Under natural conditions, however, different flow fields would occur if water actually flowed across some of the vertical sides. In one situation, waters in the bottom portion of the modelled cube have their recharge area located at considerable distance outside of the field site in the direction of the regional topographic gradient. For example, such a situation could well exist below the horizontal fracture zone. In this case, waters actually recharging within the model area are limited to fill only the upper portion of the section down to the horizontal zone.

In another situation, waters recharging through the upper surface of the model region flow out of the model region through a vertical side and discharge to the surface at some considerable distance from the modelled region in a direction down the regional topographic gradient. Furthermore, all combinations of these two flow regimes are possible in reality with waters at various depths having different recharge and discharge areas that may or may not be within the site area.

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, as discussed in previous sections. 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. 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. In the local model of Kamlunge two different simulations, with and without a horizontal fracture zone, was made. These two simulations clearly demonstrates the effect of a horizontal structure on the head and flow distribution, c.f. Chapter 6.

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, except the simulations with and without the horizontal zone, were carried out to evaluate the implications for flow and transport of uncertainty in existence, location, and connectivity of conductive structures.

Hydraulic and transport parameter values

Knowledge of the spatial distribution of hydraulic conductivity is of direct importance to calculation of volumetric fluid flux (volume of fluid per cross-sectional area of rock per year) which is required to determine possible radionuclide source rates exiting the repository, as well as to determine the longevity of engineered barriers. No variations of hydraulic conductivity distributions were tested in the Kamlunge model.

Knowledge of both hydraulic conductivity and effective porosity for flow ("kinematic porosity") is important to determination of 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, it is not clear which value of the effective porosity that has been used, but most probably it has been held fixed at a value of 10^{-4}. 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-higher effective porosity on transport is simply a ten-times longer 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. Measurements in laboratory of porosity on rock samples are reported by Carlsson et al., 1983. The porosity values vary between $1\text{-}3 \cdot 10^{-3}$.

8.2 Transport Calculations

Groundwater flow fields showing fluid velocity vectors are presented for various cross-sections through the regional and local Kamlunge model blocks. Both models have decreasing conductivity with depth. The regional model has isotropic conductivity without fracture zones and the local model has isotropic conditions and fracture zones included. The influence of including a horizontal fracture zone at about 550 m depth is clearly demonstrated, c.f. Chapter 6.

Travel times for various paths to the surface (or more exact a hydraulic boundary), beginning at 450 m depth, i.e. above the horizontal fracture zone, are reported for both the regional and local model. The travel times for the regional model, without fracture zones, are considerably longer, 2 000 - 200 000 years, than in the local models, 250-94 000 years. There is also a marked difference between the two simulations in the local model where the travel times for some flow paths are decreased with a factor 100 in the presence of the horizontal fracture zone. This demonstrates the importance of conductive structures to transport paths at the Kamlunge site.

8.3 Implications of existing information for solute transport

The groundwater system analyses of the Kamlunge 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 450 m depth. Under the conditions studied, travel times are predicted within large ranges, from as little as few hundred to as much as a few hundred thousands of years. Travel times and paths are found to be most dependent on the existence of conductive fracture zones, but only one test varying structure and connectivity was carried out.

Boundary conditions are equally important to the transport predicted by the model analysis, but these were not varied either to test their impact. In fact, it is possible that the 450 m depth is within the realm of a deep regional groundwater system. Especially below the horizontal fracture zone it is possible that the groundwater flow and transport may have little, if anything, to do with the water-table topography within the site area. Flows at this depth may be driven by a more regional water-table gradient.

Considerations towards improving the transport predictions of the Kamlunge 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 wherein a repository would be situated. Boundary conditions appropriate to the surficial groundwater may not simply be projected downward to apply to deeper systems. Such an assumption, even when inappropriate, is decisive for the groundwater flow and transport that occurs at depth, and essentially overrides other considerations such as conductivity distribution. Further, information on conductive structures which control flow and transport that depends on structures which strike the ground surface is not likely sufficient to describe the connectivity at depth which may depend also on possible but not yet identified additional sub-horizontal zones that do no outcrop.

9. ROCK MECHANICAL CONDITIONS

None of the boreholes at the Kamlunge study site have been tested to determine the stress field in the area. Neither has the rock in the area been tested for its mechanical properties. The rock mechanical investigations conducted at the Kamlunge study site are limited to laboratory determination of the thermal properties on core samples.

9.1 Thermal properties of the bedrock

The properties thermal conductivity, diffusivity, heat capacity per unit volume and density were determined on core samples from borehole KKM01 using the transient hot strip method (Gustafsson et al., 1979). Samples from depths between 300-700 m were tested. The density of the samples were determined with the standard method of weighing the samples in air and in water. The results are presented in Table 15.

The thermal conductivity varies between 2.56 - 6.47 W/(m·K) (Ahlbom and Karawacki, 1983). Compared to the results from Gideå and Fjällveden the variation is greater for Kamlunge, reflecting the different rock types at the Kamlunge site. When compared to the compilation of rock properties on crystalline rocks, Tammemagi and Chieslar (1985), Sundberg (1988), one find that the mean values of conductivity and specific heat are within the 90% range of the compiled values. The mean value of the thermal diffusivity, however, is rather high. It should be pointed out that the compilation of thermal diffusivity results are based on few data.

Table 15. Thermal properties measured on core samples from borehole KKM01, Kamlunge. (Ahlbom and Karawacki, 1983).

Depth m	Thermal conductivity W/(m·K)	Thermal diffusivity m^2/s	Heat capacity J/kg·K	Density kg/m^3
300	6.47	$3.24 \cdot 10^{-6}$	700	2840
400	5.34	$2.34 \cdot 10^{-6}$	850	2690
450	2.65	$1.20 \cdot 10^{-6}$	800	2750
460	3.65	$1.84 \cdot 10^{-6}$	760	2610
470	3.05	$1.38 \cdot 10^{-6}$	790	2800
480	2.92	$1.43 \cdot 10^{-6}$	750	2720
490	3.66	$1.84 \cdot 10^{-6}$	750	2640
500	2.81	$1.32 \cdot 10^{-6}$	800	2660
510	3.63	$1.81 \cdot 10^{-6}$	740	2710
520	3.54	$1.74 \cdot 10^{-6}$	770	2630
530	3.55	$1.60 \cdot 10^{-6}$	840	2650
540	3.75	$1.78 \cdot 10^{-6}$	780	2720
550	3.68	$1.77 \cdot 10^{-6}$	790	2650
600	2.56	$1.15 \cdot 10^{-6}$	770	2900
700	2.95	$1.40 \cdot 10^{-6}$	760	2790
Mean:	3.61	$1.72 \cdot 10^{-6}$	777	2717

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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 is presented.

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-B3. Location of interpreted fracture zones are presented in Appendix C, Figure C1.

The present (Oct-91) availability of the cored boreholes have been studied by brief visits to each borehole. These inspections showed that all cored boreholes were locked and the borehole heads were undamaged. Problems with borehole stability or instrument blockage during the KBS-3 investigations are described in a report by Persson (1985). The obstacles reported by him are described in this Appendix.

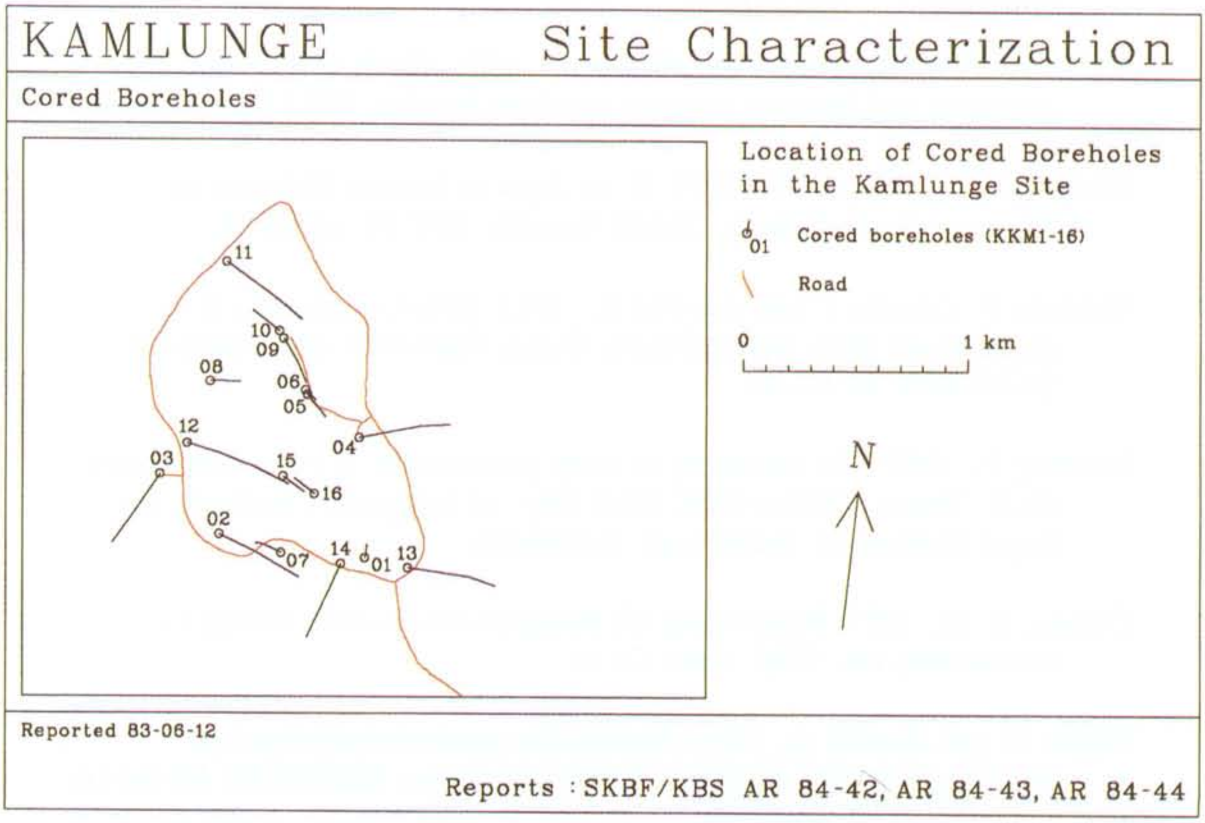


Figure A1. Locations of cored boreholes at Kamlunge study site.

Borehole KKM01

This borehole (Figure A2) is drilled vertical (85° to the horizontal). The borehole length is 674 m and the depth about 670 m. The borehole was drilled at an early stage of the site investigation programme to confirm favorable conditions at depth as was indicated by the reconnaissance surveys. Borehole coordinates and activities performed in the borehole are presented in Figure A2. Generalized results concerning rock types, fracturing and hydraulically conductive sections are presented in Appendix B, Figure B1.

The upper parts of the borehole is dominated by quartzitic gneiss, while the lower part is dominated by biotite gneiss, granite and pegmatite.

The only section with increased degree of fracturing occurs in a granitic section between 490-560 m. Other parts of the borehole display a low frequency of fractures. The horizontal Zone H1 is interpreted to occur in the lowermost part of the fractured section at 544-560 m. An increase in the salinity of the groundwater is indicated by the salinity log from 560 m and downwards (about 1 % equivalent salinity). Mean fracture frequency of the borehole is 2.9 fr/m (Albino et al., 1983a).

Borehole availability: The pipe-string equipment was dropped while testing the borehole at 450 m depth. During the rescue operation the equipment got stucked in the borehole. The borehole is now blocked at 231 m depth.

Borehole KKM02

This borehole (Figure A3) is 701 m in length and ends at a depth of about 570 m. It is drilled inclined 60° to the horizontal. The main purpose of the borehole was to obtain data regarding the bedrock conditions in the central part of the site and, more specifically, to investigate whether a geophysical lineament in the central part of the site represented a fracture zone or not.

The borehole is dominated by granitic rock down to 300 m. Below this depth quartzitic gneiss, granite and biotite gneiss occurs in equal proportions. No fractured section was identified in the cores that could be correlated with the geophysical lineament. The borehole is interpreted to intersect Zone H1 at 676-684 m borehole length.

The degree of fracturing is highest in the borehole from the surface down to 56 m depth. This is not interpreted to be caused by a fracture zone but as a result of local increased sheet fracturing in a granitic section. The mean fracture frequency of the borehole is 3.1 fr/m. Generalized results are presented in Appendix B, Figure B1.

Borehole availability: No known problems with borehole blockage.

Borehole KKM03

This borehole (Figure A4) is 700 in length and drilled inclined 60°, reaching a depth of about 530 m. The borehole is located in the western part of the site with the objective to investigate the general character of the bedrock close to a regional fracture zone, bounding the site towards the west, and more specifically, to study the character of Zone 4.

Granodiorite is the dominating rock type down to 400 m. Below this borehole length biotite gneiss and amphibolite dominates.

The borehole is the most fractured of all boreholes at the Kamlunge study site. The average fracture frequency is 4.6 fr/m. Sections with increased fracture frequency occurs commonly all along the borehole, although a slight decrease of fracturing could be observed with depth.

The borehole is interpreted to intersect not only Zone 4, but also Zone 2 and Zone 3. Zone 2 is penetrated between 313-337 m, where the cores display red stained and strongly foliated rock. Zone 3 is interpreted to occur between 441-450 m and Zone 4 between 504-517 m. Judging from the core mapping the relevance of a fracture zone intersecting the latter section is however questionable. Generalized results are presented in Appendix B, Figure B1.

Borehole availability: No known problems with borehole blockage.

Borehole KKM04

This borehole (Figure A5) has a length of 700 m and drilled inclined 60°, reaching a depth of about 580 m. The objective with the borehole was to characterize the peat-covered area bounding the central part of the site towards northeast and, more specifically, to investigate the characteristics of Zone 5.

The cores display a strong variability in rock types. Granite, biotite gneiss, quartzitic gneiss and diorite occurs in more or less equal proportions.

The fracture frequency is low with the exception of a pegmatite dyke at 155-160 m. Average fracture frequency is 2.5 fr/m.

Zone 5 was not encountered in the borehole, which implies that the zone must dip to the northeast, if it exist. Main results from borehole investigations are shown in Appendix B, Figure B1.

Borehole availability: No known problems with borehole blockage.

Borehole KKM05

This borehole (Figure A6) is inclined, 60°, with a length of 250 m and a depth of about 200 m. The borehole is, together with borehole KKM06, positioned to penetrate and characterize Zone 2.

Biotite gneiss dominates the cores down to 100 m. Pegmatite occurs between 100-150 m and amphibolite between 150-200 m. Below this depth and to the end of the borehole quartzitic gneiss is the dominating rock type.

Zone 2 is interpreted to occur between 47-53 m, where the rock is red stained, weathered, brecciated and highly fractured.

The fracture frequency of the borehole is high down to 200 m, and slightly lower between 200-250 m. The average fracture frequency of the borehole is high, 6.6 fr/m. This is partly due to Zone 2, but also partly due to the surficial location of the borehole. Main results from borehole investigations are shown in Appendix B, Figure B1.

Borehole availability: No known problems with borehole blockage.

Borehole KKM06

This borehole (Figure A7) has a length of 105 m. It is drilled inclined 60°, reaching a depth of about 90 m. It was drilled 25 m from and parallel to borehole KKM05 with the objective to investigate Zone 2. Dominating rock type is biotite gneiss.

Zone 2 is found between 86-94 m, where the rock is strongly red stained, weathered, brecciated and highly fractured. Several meters of core was not obtained in Zone 2 due to core loss. Mean fracture frequency is 10.7 fr/m.

Borehole availability: No known problems with borehole blockage.

Borehole KKM07

This borehole (Figure A8) has a length of 249 m. It is drilled inclined 60°, reaching a depth of about 210 m. The main purpose of the borehole was to investigate if a fracture zone, that was indicated by geophysical surveys, could be identified in the borehole.

The dominating rock type in the borehole cores is biotite gneiss. Granite and pegmatite occurs to a lesser degree. The fracture frequency is in general low with a mean frequency of 3.0 fr/m. One exception is a small fractured section in granite between 146-150 m. However, since this section does not cause any significant anomaly in the electrical logs it was not considered to represent a fracture zone. The borehole does not interpreted to intersect any fracture zone. Main results from borehole investigations are shown in Appendix B, Figure B2.

Borehole availability: No known problems with borehole blockage.

Borehole KKM08

This borehole (Figure A9) is 251 m in length and is drilled inclined 60°, reaching a depth of about 210 m. The borehole is located in the northern central part of the site with the objective to characterize Zone 3.

Biotite gneiss dominates in the upper part of the borehole, while granodiorite dominates from 100 m and downwards. The cores down to 100 m often display sections with red stained, weathered and brecciated rock as well as a high fracture frequency. Zone 3 is interpreted to be located within this section, although no precise location is presented in the reports. Several fractured sections also occur below 100 m borehole length, separated by low fractured bedrock. Mean fracture frequency of the cores from this borehole is 7.3 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B2.

Borehole availability: No known problems with borehole blockage.

Borehole KKM09

This borehole (Figure A10) is drilled 60° to the horizontal and has a length of 449 m, corresponding to a depth of about 370 m. The objective was to investigate the location and character of Zone 2 at a greater depth.

Because of problems with borehole instability the drilling was terminated at 449 m borehole length, although the planned length was 700 m.

The borehole is dominated by biotite gneiss. In addition, there are several large sections with granite and pegmatite. A highly fractured ultramafic rock occurs between 350-430 m. The average fracture frequency of the borehole is 5.1 fr/m. Zone 2 is interpreted to be penetrated between 414-419 m borehole length. Although judging from the core logs and the available section covered by geophysical logs, the fractured section is much larger, probably between 348-425 m. The fractured section is characterized by several subsections containing red stained and strongly weathered and fractured bedrock.

Borehole stability problems occurred in clay-altered rock between 414-416 m. Another section with increased fracturing occurs between 28-65 m borehole length. However, this is interpreted to be of local extension only.

Borehole availability: The borehole is blocked at 422 m borehole length where 6 m of drill-string is still left in the borehole due to borehole collapse. Because of the borehole instability no geophysical logging nor water injection test has been made below 400 m borehole length.

Borehole KKM10

This borehole (Figure A11) is 287 m in length and is drilled inclined 60°, reaching a depth of about 250 m. The borehole is positioned in the northern part of the site with the main purpose to confirm that Zone 3 does not dip towards southeast.

The borehole is dominated by granite, biotite gneiss and granodiorite down to 180 m borehole length, below this length the cores are dominated by biotite gneiss. There are several fractured sections in the cores between 50-100 m. However, since these sections only causes spike-like anomalies on the geophysical logs, no fracture zone has been interpreted in this part of the borehole. Below 100 m the fracture frequency is low implying sound rock. Thus the borehole strengthen the interpreted northwesterly dip of Zone 3. The mean fracture frequency for the borehole is 4.2 fr/m.

Borehole availability: No known problems with borehole blockage.

Borehole KKM11

This borehole (Figure A12) is inclined 60° and has a length of 700 m and a approximate depth of 550 m. This borehole was drilled in the northernmost part of the site with the objective to investigate the continuation and dip of Zone 3.

Granodiorite and granite dominates the bedrock down to 275 m. Biotite gneiss dominates from this depth and down to 470 m. From 470 m and down to the borehole end the bedrock is once again dominated by granodiorite.

Between 45-64 m there is a strongly crushed and weathered section of the core located in a pegmatite. This section is interpreted as caused by intense local horizontal sheet fracturing. No horizontal fracture zone has been assigned with this fractured section, although judging from the core logs this seems highly likely.

Zone 3 is reported to occur between 324-335 m, although the core logs and the geophysical logs indicate a wider zone, 282-374 m. The bedrock within the zone is foliated, red stained and highly fractured. Mean fracture frequency for the borehole is 3.9 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B3.

Borehole availability: No known problems with borehole blockage.

Borehole KKM12

This borehole (Figure A13) is located in the northwestern part of the site and drilled towards the central part. The borehole is inclined 60° and is 801 m in length, corresponding to a depth of about 640 m. The objective was to characterize Zones 2 and 3 and to characterize the "sound rock" in the central part of the site.

The cores from this borehole includes all the various rock types commonly found in the Kamlunge study site. The dominating rock types are the following: 0-190 m granodiorite, 190-360 m granite, 360-460 m biotite gneiss and 460-802 m granite. According to the core log the foliation increases below 63 m along with increasing tectonic influence on the cores. This influence culminates between 110 m and 112 m, where the rock is red stained, strongly foliated, mylonitized and brecciated. Another brecciated and weathered section occurs between 202 m and 220 m. The fracture frequency is generally high down to 240 m. Below this depth the fracture frequency is low. Mean fracture frequency of the cores from this borehole is 4.3 fr/m.

The borehole is interpreted to penetrate Zone 3 at 52-60 m and Zone 2 between 195-210 m. (Surprisingly has no fracture zone been assigned to the tectonically affected section between 110-112 m.) Main results from borehole investigations are shown in Appendix B, Figure B3.

Borehole availability: No known problems with borehole blockage.

Borehole KKM13

This borehole (Figure A14) has a length of 703 and is drilled inclined 60°, reaching a depth of about 580 m. The borehole is located in the southeastern part of the site with the general objective to characterize the bedrock in this area. Most rock types that occurs at Kamlunge are represented in the cores although the dominating rock type is granite.

The fracture frequency is low all along the borehole resulting in a mean fracture frequency for the borehole of 3.4 fr/m. One exception occurs between 669-674 m at the interpreted location of Zone H1. The rock is here red stained and altered. An increase in borehole fluid salinity is observed in the borehole water resistivity log at this section. Main results from borehole investigations are shown in Appendix B, Figure B3.

Borehole availability: After the drilling it was discovered that the borehole was contaminated with diesel oil. A percussion borehole was drilled nearby and pumped to remove the oil from the cored borehole. It is reported that this action cleaned, at least temporary, the borehole. No other problems with borehole blockage has been reported.

Borehole KKM14

This borehole (Figure A15) is 700 in length and drilled inclined 60°, reaching a depth of about 580 m. The objective was to characterize the bedrock in a peat covered area in the central-southwestern part of the site.

The borehole cores contains, in more or less equal amounts, granite, quartzitic gneiss, amphibolite and biotite gneiss. The fracture frequency is low for most parts of the borehole resulting in a mean frequency of 3.1 fr/m. Some small sections of increased fracturing occurs at 125 m and 305 m, however these are considered to be local.

Zone H1 is interpreted to occur between 667-673 m borehole length. Although a slight increase in degree of fracturing could be observed at this borehole length, the interpreted location of Zone H1 in this borehole is mainly a result of a high hydraulic conductivity in this particular section of the borehole together with extrapolation of Zone H1 from other boreholes. Main results from borehole studies are shown in Appendix B, Figure B3.

Borehole availability: No known problems with borehole blockage.

Borehole KKM15

This borehole (Figure A16) is 251 in length and drilled inclined 60°, reaching a depth of about 210 m. The main purposes of the borehole was, together with borehole KKM16, KKM02 and KKM07, to investigate if a geophysical lineament in the central part of the site represented a fracture zone or not.

The borehole is dominated, from top to bottom, by biotite gneiss, quartzitic gneiss and granite. The fracture frequency is somewhat increased down to 60 m. Below this borehole length the fracturing is low. Mean fracture frequency of the cores from this borehole is 3.9 fr/m.

No fracture zone was identified in the borehole. Main results from borehole investigations are shown in Appendix B, Figure B3.

Borehole availability: No known problems with borehole blockage.

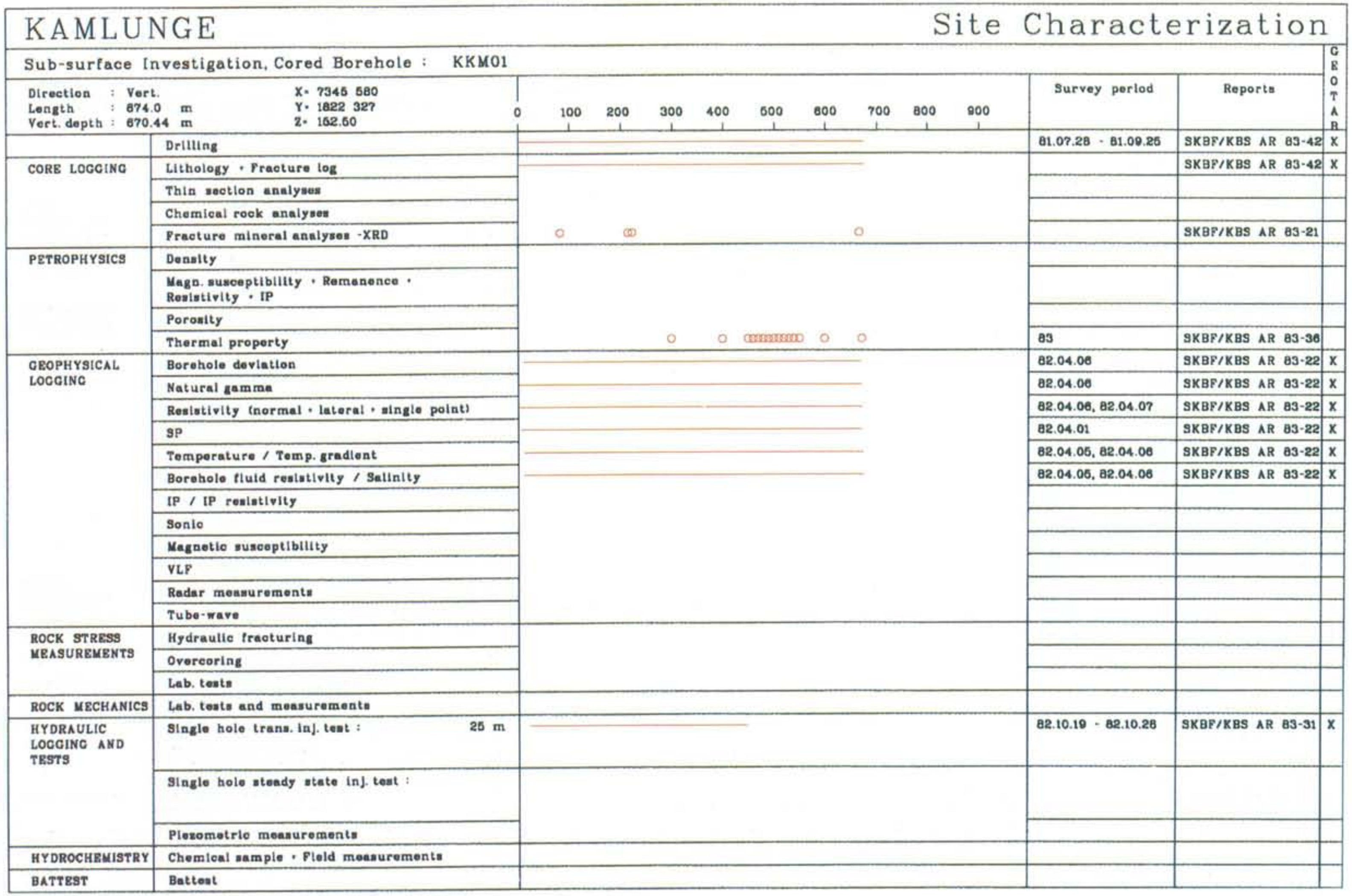
Borehole KKM16

This borehole (Figure A16) is 251 in length and drilled inclined 60°, reaching a depth of about 210 m. Similar to borehole KKM15 the main purposes of the borehole was to investigate if a geophysical lineament in the central part of the site represented a fracture zone or not.

Down to 50 m borehole length granite dominates. Below this borehole length quartzitic gneiss is the dominating rock type. The fracture frequency increases with depth reaching a maximum around 100 m. Below this depth the degree of fracturing decreases. Mean fracture frequency is 4.7 fr/m.

No fracture zone has been identified in the borehole. Main results from borehole investigations are shown in Appendix B, Figure B3.

Borehole availability: No known problems with borehole blockage.



KAMLUNGE Site Characterization

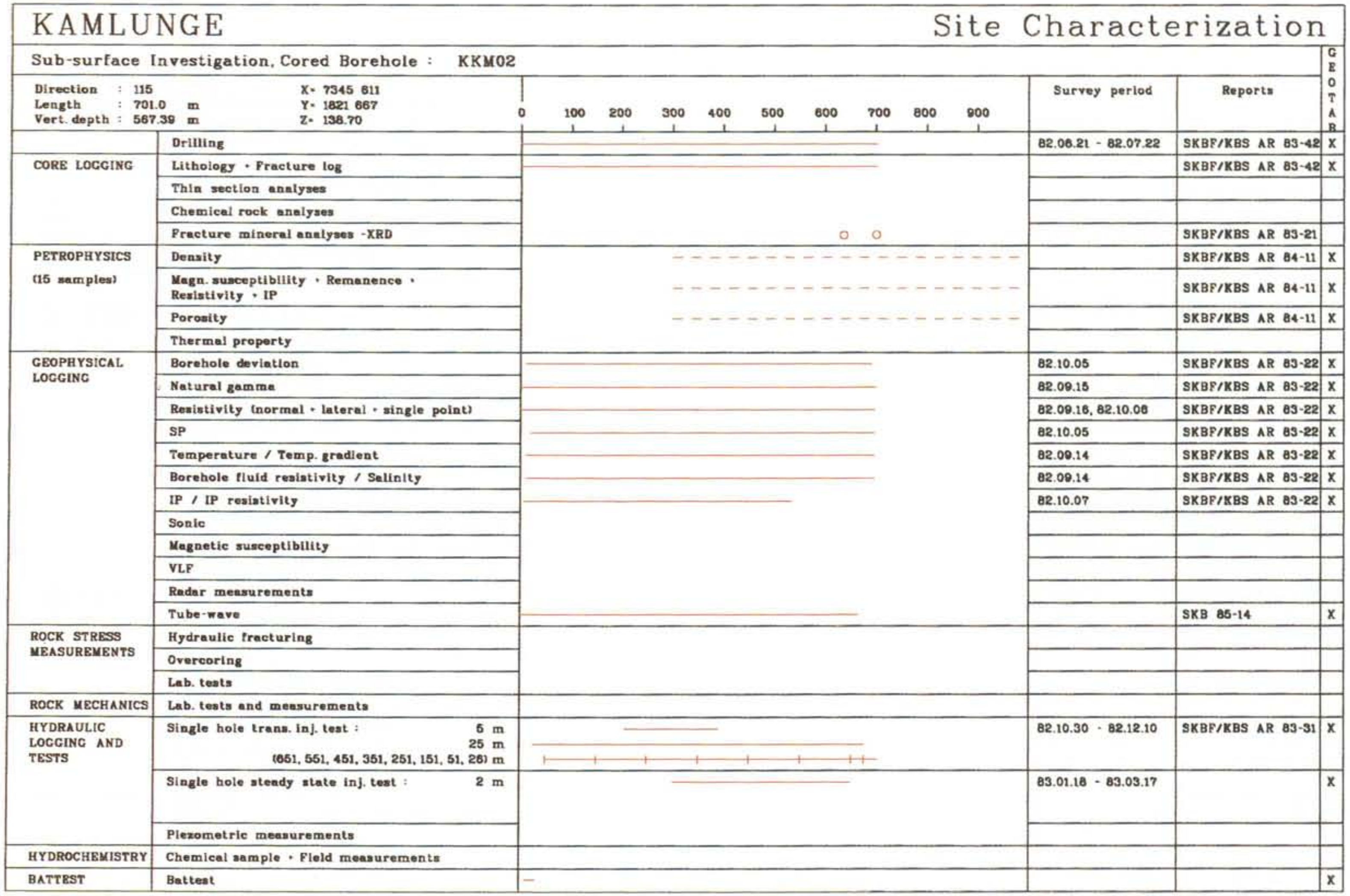
Sub-surface Investigation, Cored Borehole : KKM01

Direction : Vert.
Length : 674.0 m
Vert. depth : 670.44 m

X= 7345 580
Y= 1822 327
Z= 152.50

		Survey period	Reports	GEOTAR
	Drilling	81.07.28 - 81.09.25	SKBF/KBS AR 83-42	X
CORE LOGGING	Lithology · Fracture log		SKBF/KBS AR 83-42	X
	Thin section analyses			
	Chemical rock analyses			
	Fracture mineral analyses -XRD		SKBF/KBS AR 83-21	
PETROPHYSICS	Density			
	Magn. susceptibility · Remanence · Resistivity · IP			
	Porosity			
	Thermal property	83	SKBF/KBS AR 83-36	
GEOPHYSICAL LOGGING	Borehole deviation	82.04.06	SKBF/KBS AR 83-22	X
	Natural gamma	82.04.06	SKBF/KBS AR 83-22	X
	Resistivity (normal · lateral · single point)	82.04.06, 82.04.07	SKBF/KBS AR 83-22	X
	SP	82.04.01	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient	82.04.05, 82.04.06	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity	82.04.05, 82.04.06	SKBF/KBS AR 83-22	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 : 25 m	82.10.19 - 82.10.28	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :			
	Piezometric measurements			
HYDROCHEMISTRY	Chemical sample · Field measurements			
BATTEST	Battest			

Figure A2. Activities in borehole KKM01.



KAMLUNGE Site Characterization

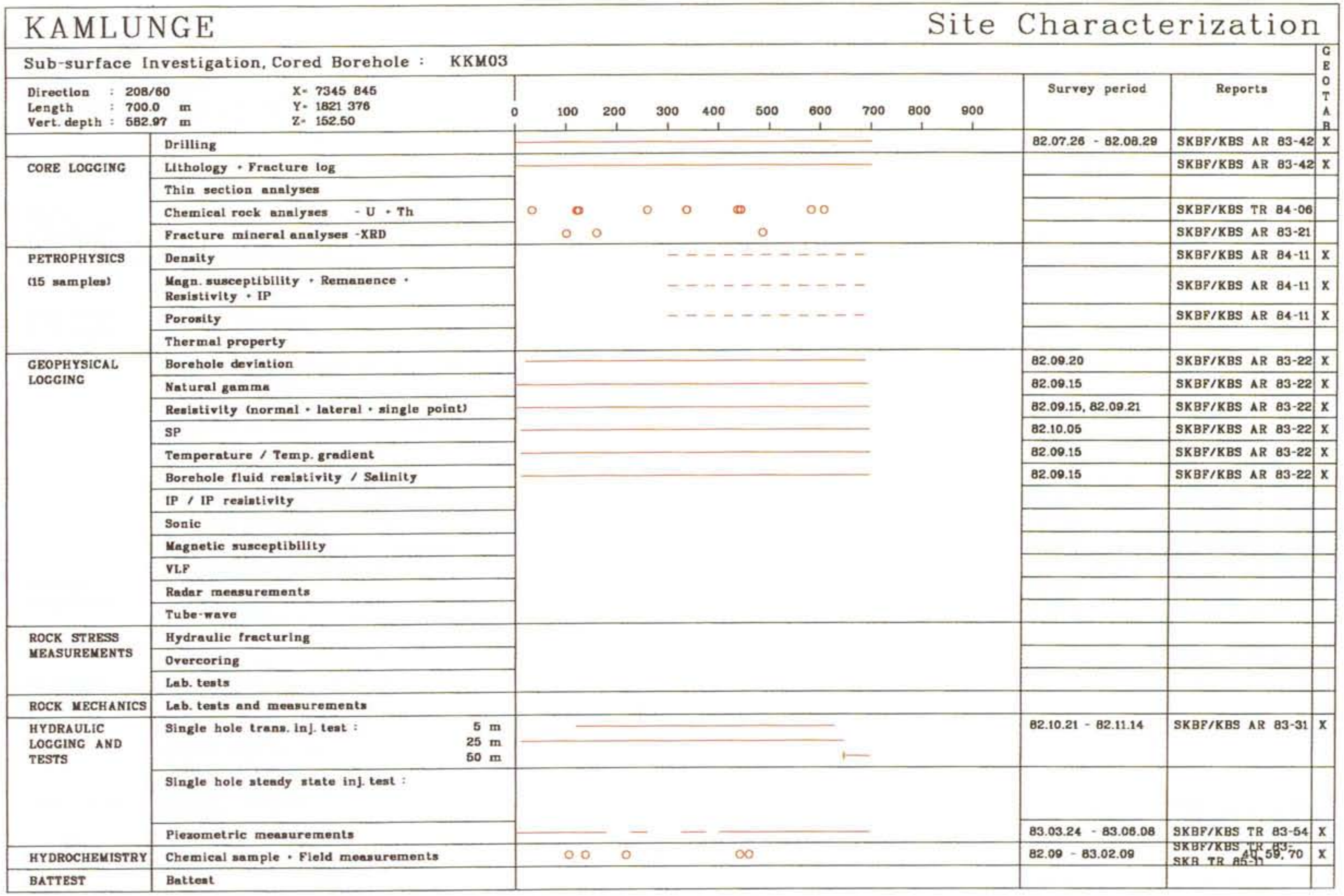
Sub-surface Investigation, Cored Borehole : KKM02

Direction : 115
Length : 701.0 m
Vert. depth : 567.39 m

X- 7345 611
Y- 1821 667
Z- 138.70

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.06.21 - 82.07.22	SKBF/KBS AR 83-42	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-42	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD	o o		SKBF/KBS AR 83-21	
PETROPHYSICS (15 samples)	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility • Remanence • Resistivity • IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.10.05	SKBF/KBS AR 83-22	X
	Natural gamma		82.09.15	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.09.16, 82.10.06	SKBF/KBS AR 83-22	X
	SP		82.10.05	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.09.14	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.09.14	SKBF/KBS AR 83-22	X
	IP / IP resistivity		82.10.07	SKBF/KBS AR 83-22	X
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements				
	Tube-wave			SKB 85-14	X
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 (651, 551, 451, 351, 251, 151, 51, 26) m		82.10.30 - 82.12.10	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test : 2 m		83.01.18 - 83.03.17		X
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				X

Figure A3. Activities in borehole KKM02.



KAMLUNGE

Site Characterization

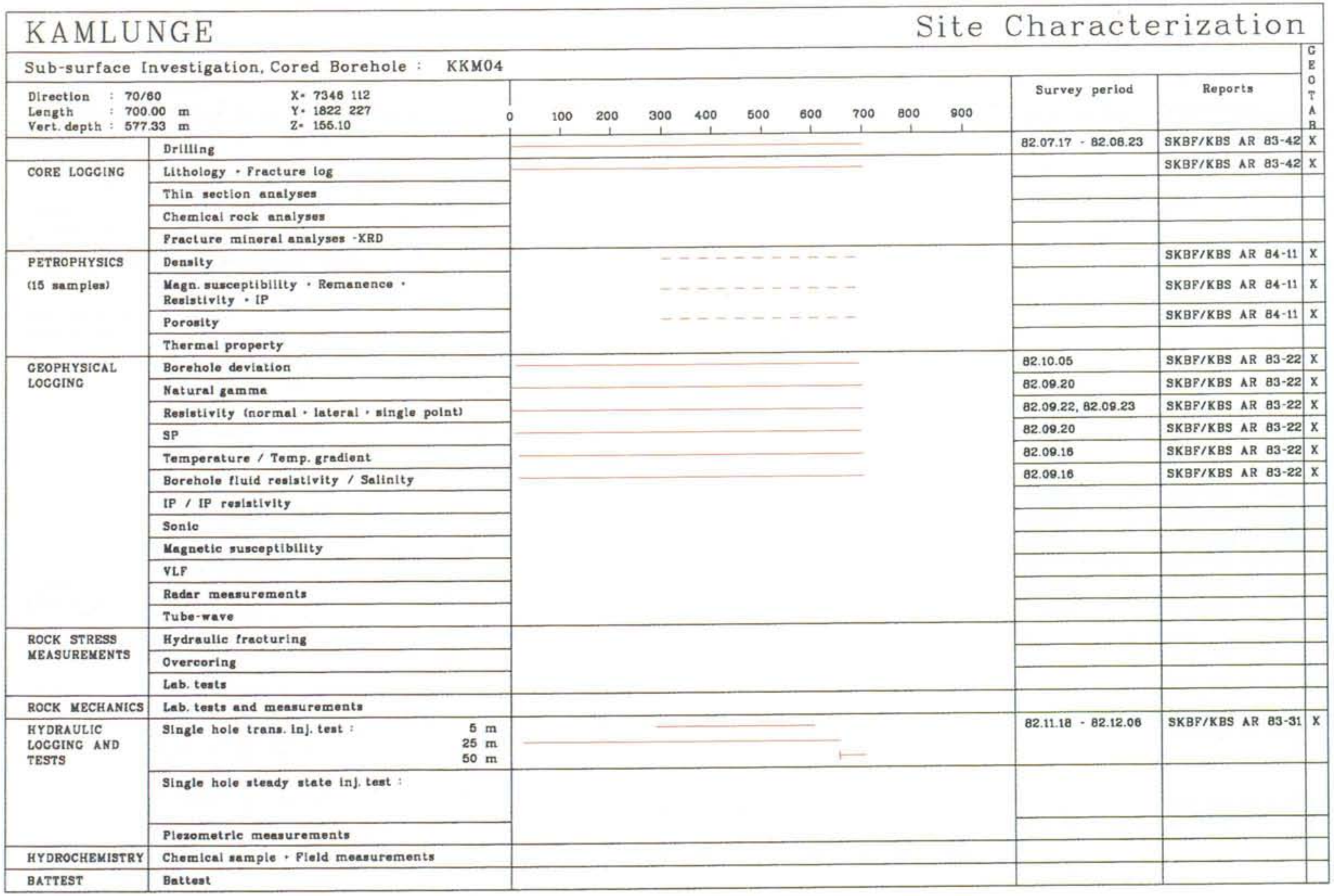
Sub-surface Investigation, Cored Borehole : KKM03

Direction : 208/60
Length : 700.0 m
Vert. depth : 582.97 m

X= 7345 845
Y= 1821 376
Z= 152.50

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.07.26 - 82.08.29	SKBF/KBS AR 83-42	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-42	X
	Thin section analyses				
	Chemical rock analyses - U • Th			SKBF/KBS TR 84-06	
	Fracture mineral analyses -XRD			SKBF/KBS AR 83-21	
PETROPHYSICS (15 samples)	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility • Remanence • Resistivity • IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.09.20	SKBF/KBS AR 83-22	X
	Natural gamma		82.09.15	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.09.15, 82.09.21	SKBF/KBS AR 83-22	X
	SP		82.10.05	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.09.15	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.09.15	SKBF/KBS AR 83-22	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 : 5 m 25 m 50 m		82.10.21 - 82.11.14	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements		83.03.24 - 83.06.08	SKBF/KBS TR 83-54	X
HYDROCHEMISTRY	Chemical sample • Field measurements		82.09 - 83.02.09	SKBF/KBS TR 83-40, 59, 70 SKB TR 85-11	X
BATTEST	Battest				

Figure A4. Activities in borehole KKM03.



KAMLUNGE

Site Characterization

Sub-surface Investigation, Cored Borehole : KKM04

Direction : 70/60
Length : 700.00 m
Vert. depth : 577.33 m

X= 7346 112
Y= 1822 227
Z= 155.10

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.07.17 - 82.08.23	SKBF/KBS AR 83-42	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-42	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS (15 samples)	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility • Remanence • Resistivity • IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.10.05	SKBF/KBS AR 83-22	X
	Natural gamma		82.09.20	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.09.22, 82.09.23	SKBF/KBS AR 83-22	X
	SP		82.09.20	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.09.16	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.09.16	SKBF/KBS AR 83-22	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 : 5 m 25 m 50 m		82.11.18 - 82.12.06	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

Figure A5. Activities in borehole KKM04.

KAMLUNGE — Site Characterization

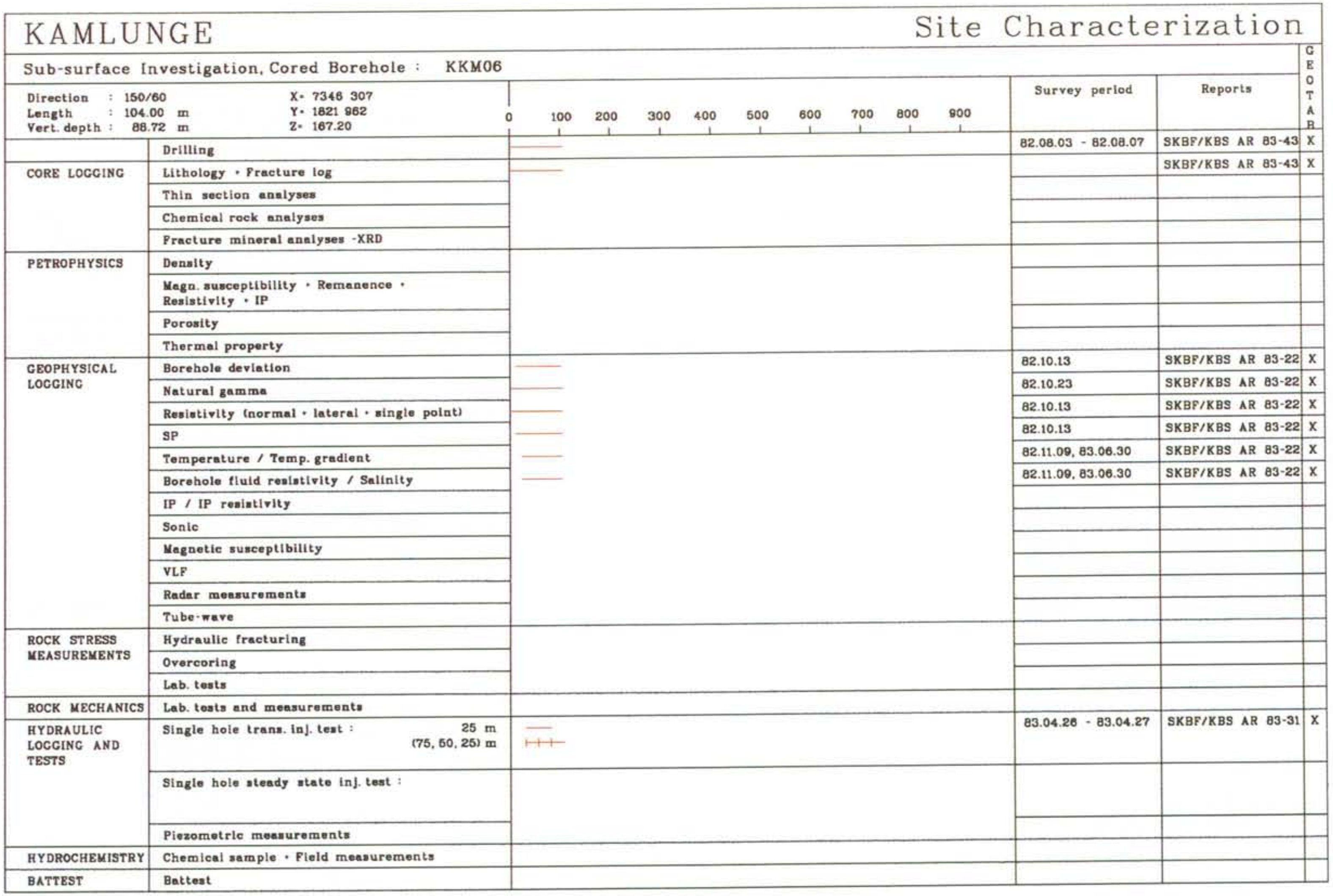
Sub-surface Investigation, Cored Borehole : KKM05

Direction : 140/60
Length : 251.00 m
Vert. depth : 211.44 m

X= 7348 283
Y= 1821 975
Z= 166.90

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.07.17 - 82.08.23	SKBF/KBS AR 83-43	X
CORE LOGGING	Lithology + Fracture log			SKBF/KBS AR 83-43	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.10.11	SKBF/KBS AR 83-22	X
	Natural gamma		82.10.11	SKBF/KBS AR 83-22	X
	Resistivity (normal + lateral + single point)		82.10.11, 82.10.12	SKBF/KBS AR 83-22	X
	SP		82.10.12	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.11.10, 83.06.28	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.11.10, 83.06.28	SKBF/KBS AR 83-22	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 : 10 m 25 m (220, 150, 45) m		83.04.13 - 83.04.20	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample + Field measurements				
BATTEST	Battest				

Figure A6. Activities in borehole KKM05.



KAMLUNGE

Site Characterization

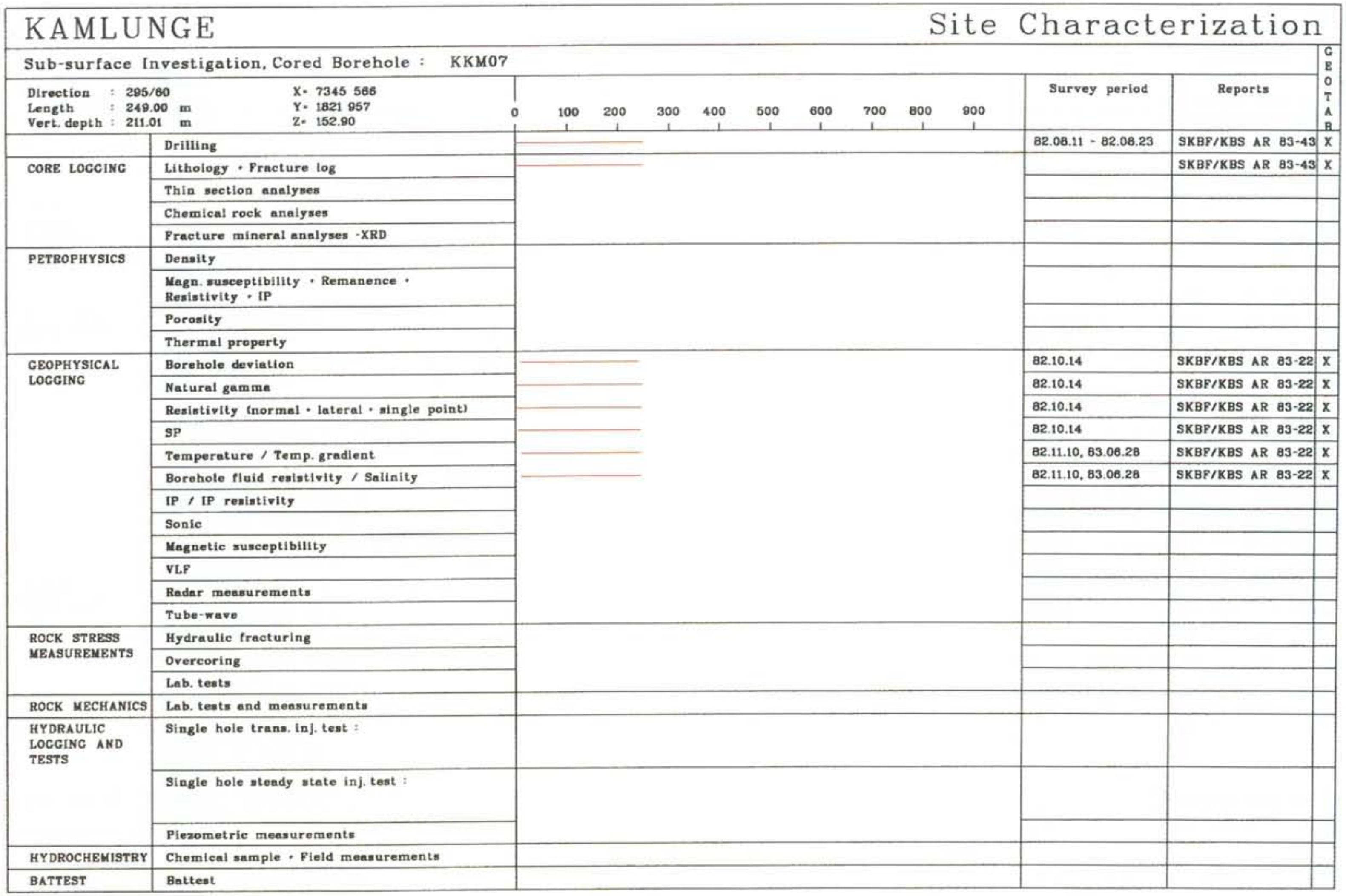
Sub-surface Investigation, Cored Borehole : KKM06

Direction : 150/60
Length : 104.00 m
Vert. depth : 88.72 m

X- 7346 307
Y- 1821 962
Z- 167.20

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.08.03 - 82.08.07	SKBF/KBS AR 83-43	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-43	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. susceptibility • Remanence • Resistivity • IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.10.13	SKBF/KBS AR 83-22	X
	Natural gamma		82.10.23	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.10.13	SKBF/KBS AR 83-22	X
	SP		82.10.13	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.11.09, 83.06.30	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.11.09, 83.06.30	SKBF/KBS AR 83-22	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 : 25 m (75, 50, 25) m		83.04.26 - 83.04.27	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

Figure A7. Activities in borehole KKM06.



KAMLUNGE

Site Characterization

Sub-surface Investigation, Cored Borehole : KKM07

Direction : 295/60
Length : 249.00 m
Vert. depth : 211.01 m

X= 7345 566
Y= 1821 957
Z= 152.90

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.08.11 - 82.08.23	SKBF/KBS AR 83-43	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-43	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. susceptibility • Remanence • Resistivity • IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.10.14	SKBF/KBS AR 83-22	X
	Natural gamma		82.10.14	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.10.14	SKBF/KBS AR 83-22	X
	SP		82.10.14	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.11.10, 83.06.28	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.11.10, 83.06.28	SKBF/KBS AR 83-22	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 :				
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

Figure A8. Activities in borehole KKM07.

Figure A9. Activities in borehole KKM08.

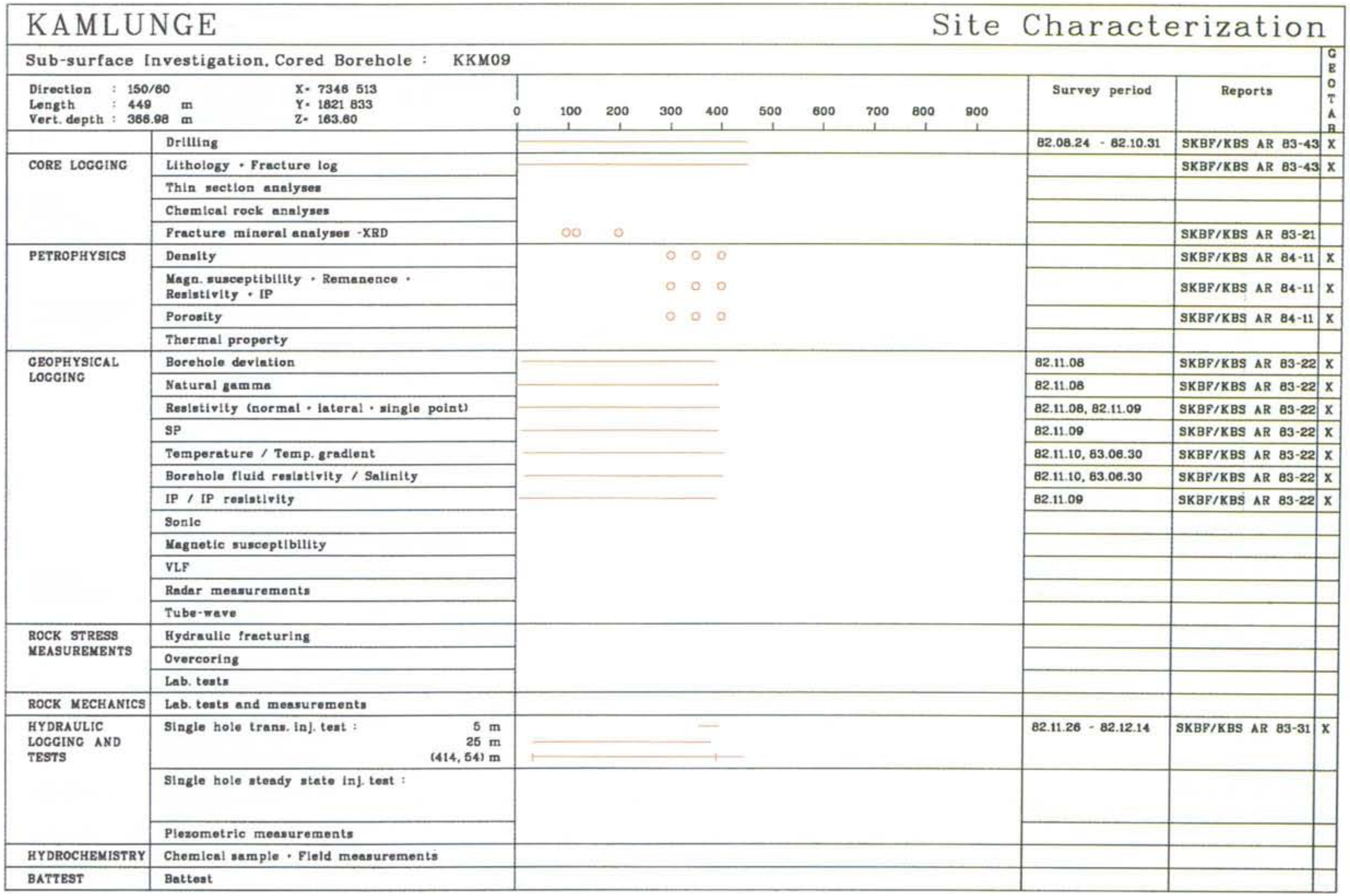
KAMLUNGE Site Characterization

Sub-surface Investigation, Cored Borehole : KKM08

Direction : 90/60
Length : 251 m
Vert. depth : 208.60 m

X• 7346 287
Y• 1821 539
Z• 162.85

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.08.24 - 82.09.04	SKBF/SKB AR 83-43	X
CORE LOGGING	Lithology • Fracture log			SKBF/SKB AR 83-43	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD	○ ○		SKBF/SKB AR 83-21	
PETROPHYSICS	Density				
	Magn. susceptibility • Remanence • Resistivity • IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		83.03.02	SKBF/KBS AR 83-22	X
	Natural gamma		83.02.22	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		83.01.31	SKBF/KBS AR 83-22	X
	SP		83.02.01	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		83.01.31, 83.06.30	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		83.01.31, 83.06.30	SKBF/KBS AR 83-22	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 : 10 m (226, 190, 180) m		83.03.21 - 83.03.28	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements	○ ○	83.05.16 - 83.06.07	SKBF/KBS AR 83-38 SKBF/KBS TR 83-70	X
BATTEST	Battest				



KAMLUNGE Site Characterization

Sub-surface Investigation, Cored Borehole : KKM09

Direction : 150/60
Length : 449 m
Vert. depth : 366.98 m

X= 7346 513
Y= 1821 833
Z= 163.60

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.08.24 - 82.10.31	SKBF/KBS AR 83-43	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-43	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD			SKBF/KBS AR 83-21	
PETROPHYSICS	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility • Remanence • Resistivity • IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.11.08	SKBF/KBS AR 83-22	X
	Natural gamma		82.11.08	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.11.08, 82.11.09	SKBF/KBS AR 83-22	X
	SP		82.11.09	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.11.10, 83.06.30	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.11.10, 83.06.30	SKBF/KBS AR 83-22	X
	IP / IP resistivity		82.11.09	SKBF/KBS AR 83-22	X
	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 : 5 m 25 m (414, 54) m		82.11.26 - 82.12.14	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

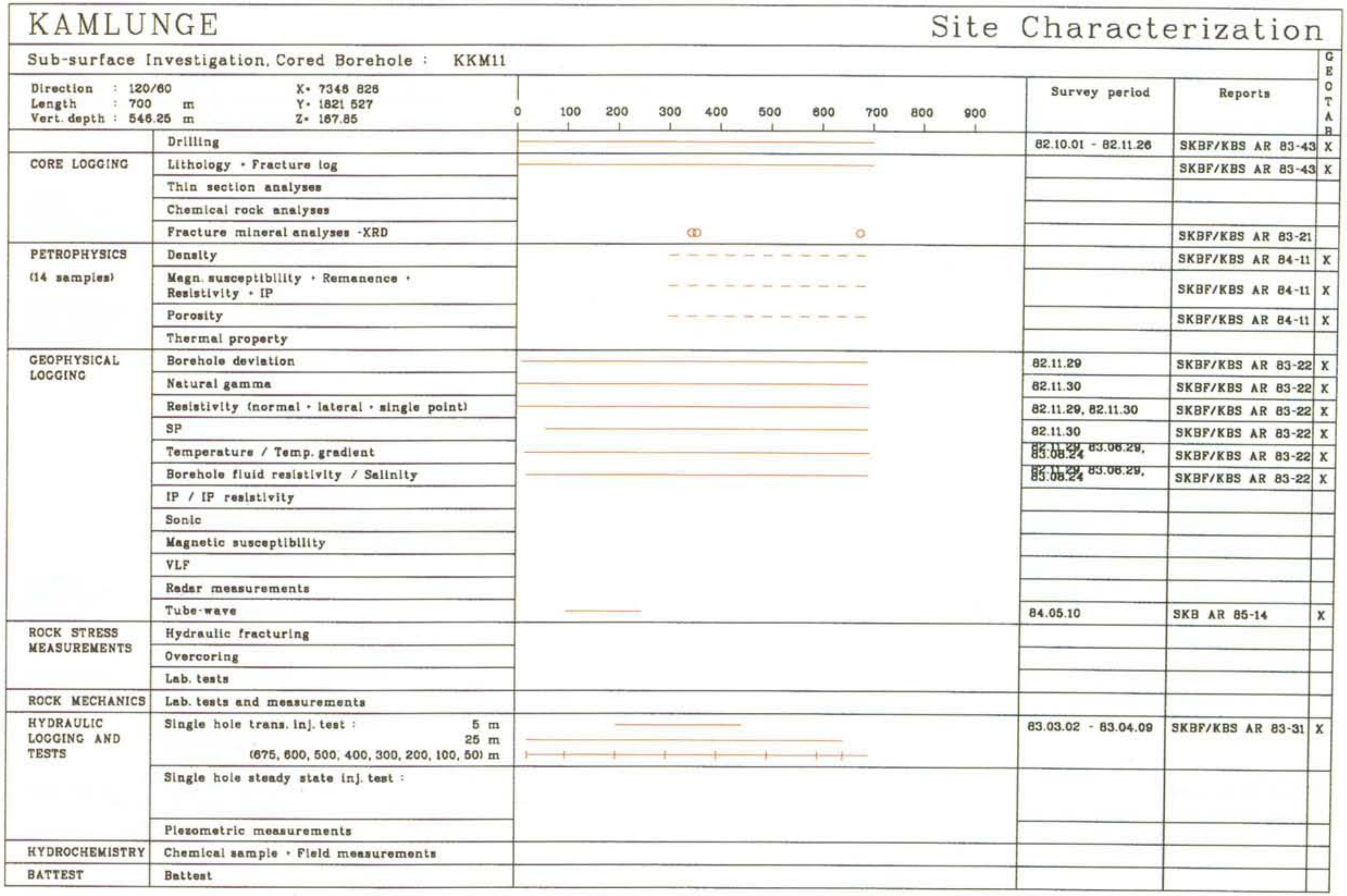
Figure A10. Activities in borehole KKM09.

KAMLUNGE Site Characterization

Sub-surface Investigation, Cored Borehole : KKM10

Direction : 310/60 Length : 287 m Vert. depth : 250.40 m	X= 7348 557 Y= 1821 807 Z= 162.60	0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.09.15 - 82.09.26	SKBF/KBS AR 83-43	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-43	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. susceptibility • Remanence • Resistivity • IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.10.19	SKBF/KBS AR 83-22	X
	Natural gamma		82.10.19	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.10.21, 82.10.25	SKBF/KBS AR 83-22	X
	SP		82.10.21	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.11.09, 83.06.29	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.11.09, 83.06.29	SKBF/KBS AR 83-22	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 : 5 m 25 m (259, 184, 84, 34) m		83.04.08 - 83.05.03	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

Figure A11. Activities in borehole KKM10.

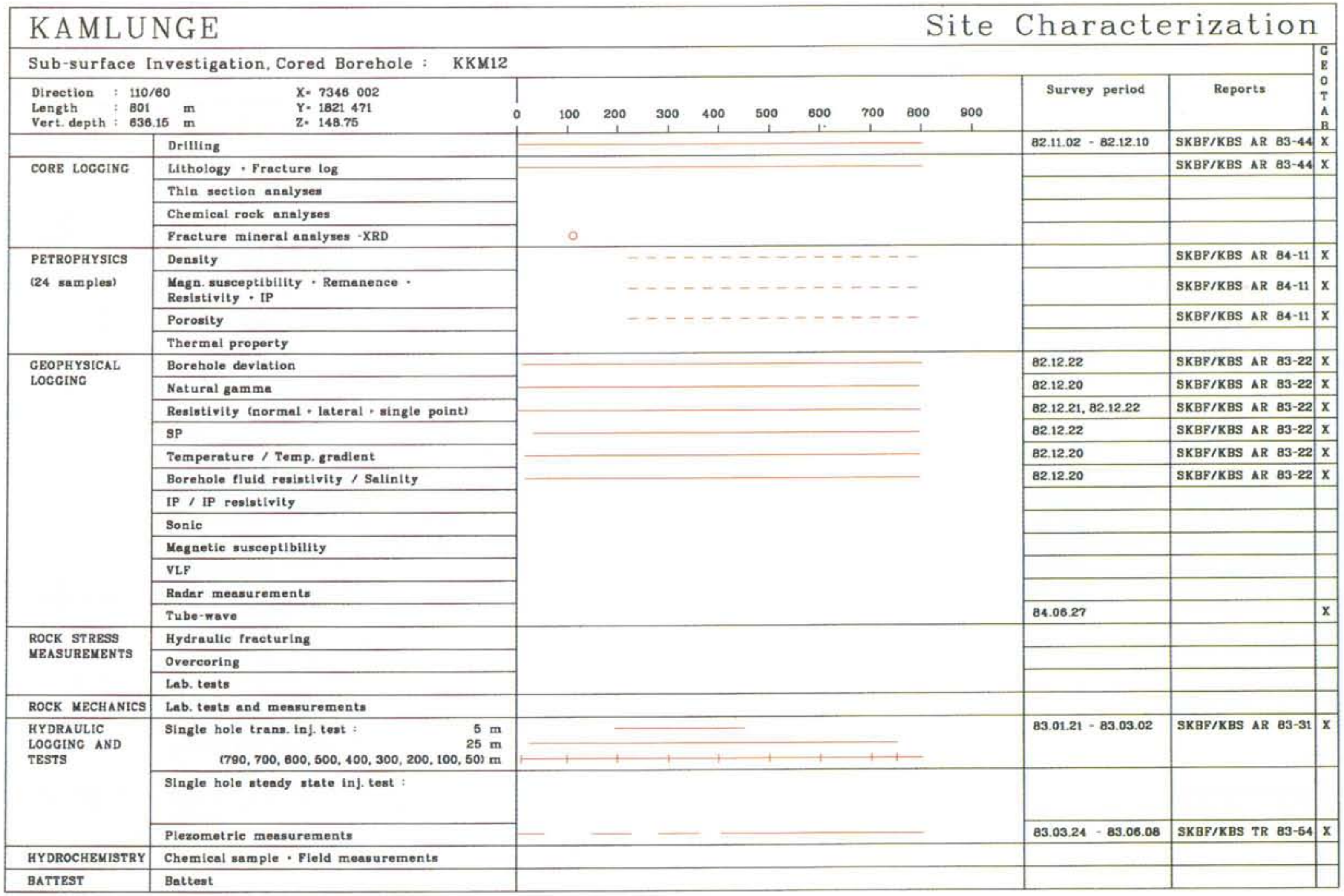


KAMLUNGE — **Site Characterization**

Sub-surface Investigation, Cored Borehole : KKM11

Direction : 120/60 Length : 700 m Vert. depth : 546.25 m	X• 7346 826 Y• 1821 527 Z• 167.85	0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.10.01 - 82.11.26	SKBF/KBS AR 83-43	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-43	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD			SKBF/KBS AR 83-21	
PETROPHYSICS (14 samples)	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility • Remanence • Resistivity • IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.11.29	SKBF/KBS AR 83-22	X
	Natural gamma		82.11.30	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.11.29, 82.11.30	SKBF/KBS AR 83-22	X
	SP		82.11.30	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.11.29, 83.06.29, 83.08.24	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.11.29, 83.06.29, 83.08.24	SKBF/KBS AR 83-22	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements				
	Tube-wave		84.05.10	SKB AR 85-14	X
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 (675, 600, 500, 400, 300, 200, 100, 50) m		83.03.02 - 83.04.09	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

Figure A12. Activities in borehole KKM11.



KAMLUNGE

Site Characterization

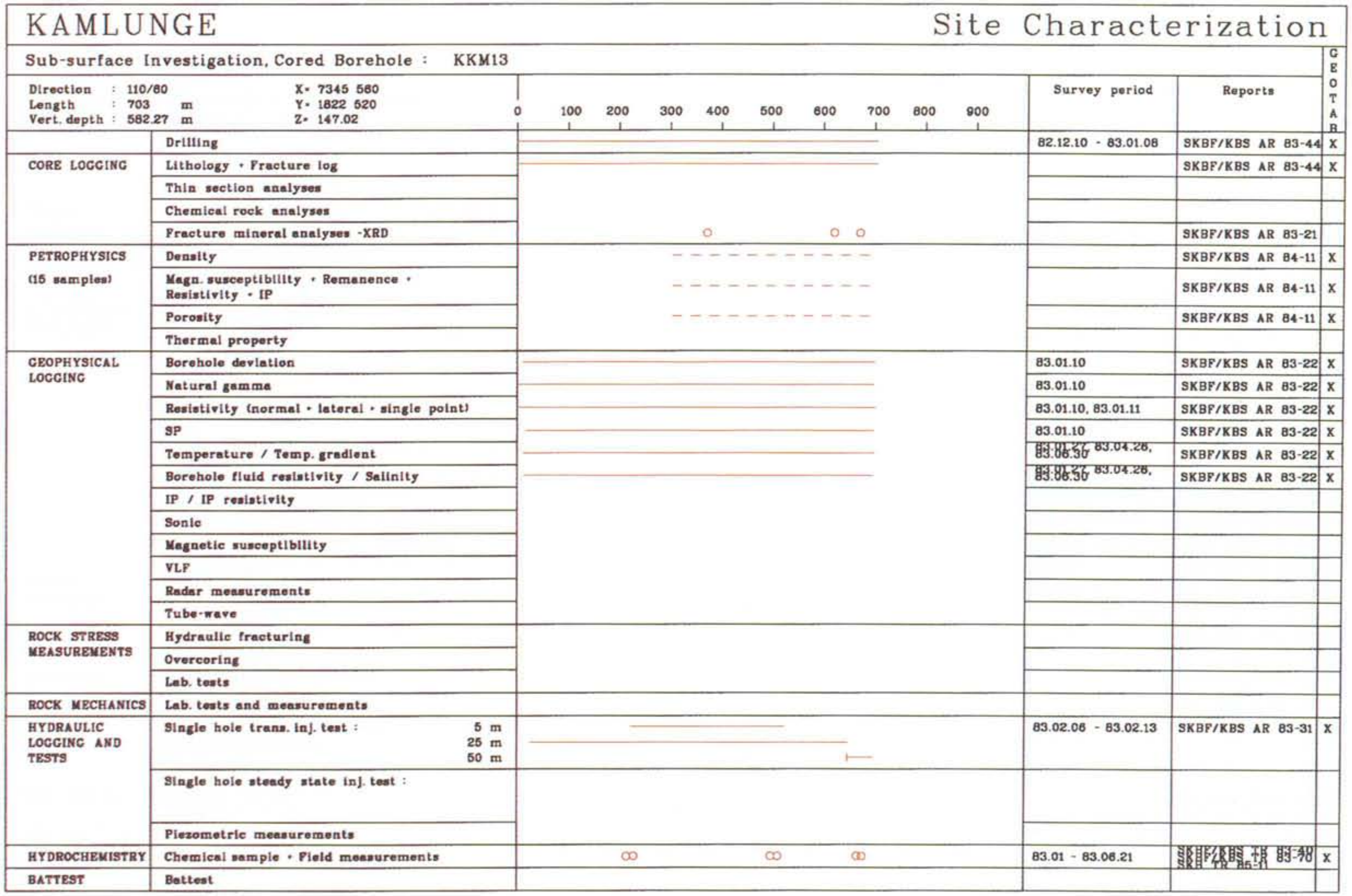
Sub-surface Investigation, Cored Borehole : KKM12

Direction : 110/60
Length : 801 m
Vert. depth : 636.15 m

X= 7346 002
Y= 1821 471
Z= 148.75

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.11.02 - 82.12.10	SKBF/KBS AR 83-44	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-44	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD	○			
PETROPHYSICS (24 samples)	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility • Remanence • Resistivity • IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.12.22	SKBF/KBS AR 83-22	X
	Natural gamma		82.12.20	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		82.12.21, 82.12.22	SKBF/KBS AR 83-22	X
	SP		82.12.22	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		82.12.20	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		82.12.20	SKBF/KBS AR 83-22	X
	IP / IP resistivity				
	Sonic				
	Magnetic susceptibility				
	VLF				
	Radar measurements				
	Tube-wave		84.06.27		X
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 (790, 700, 600, 500, 400, 300, 200, 100, 50) m		83.01.21 - 83.03.02	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements		83.03.24 - 83.06.08	SKBF/KBS TR 83-54	X
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

Figure A13. Activities in borehole KKM12.



KAMLUNGE Site Characterization

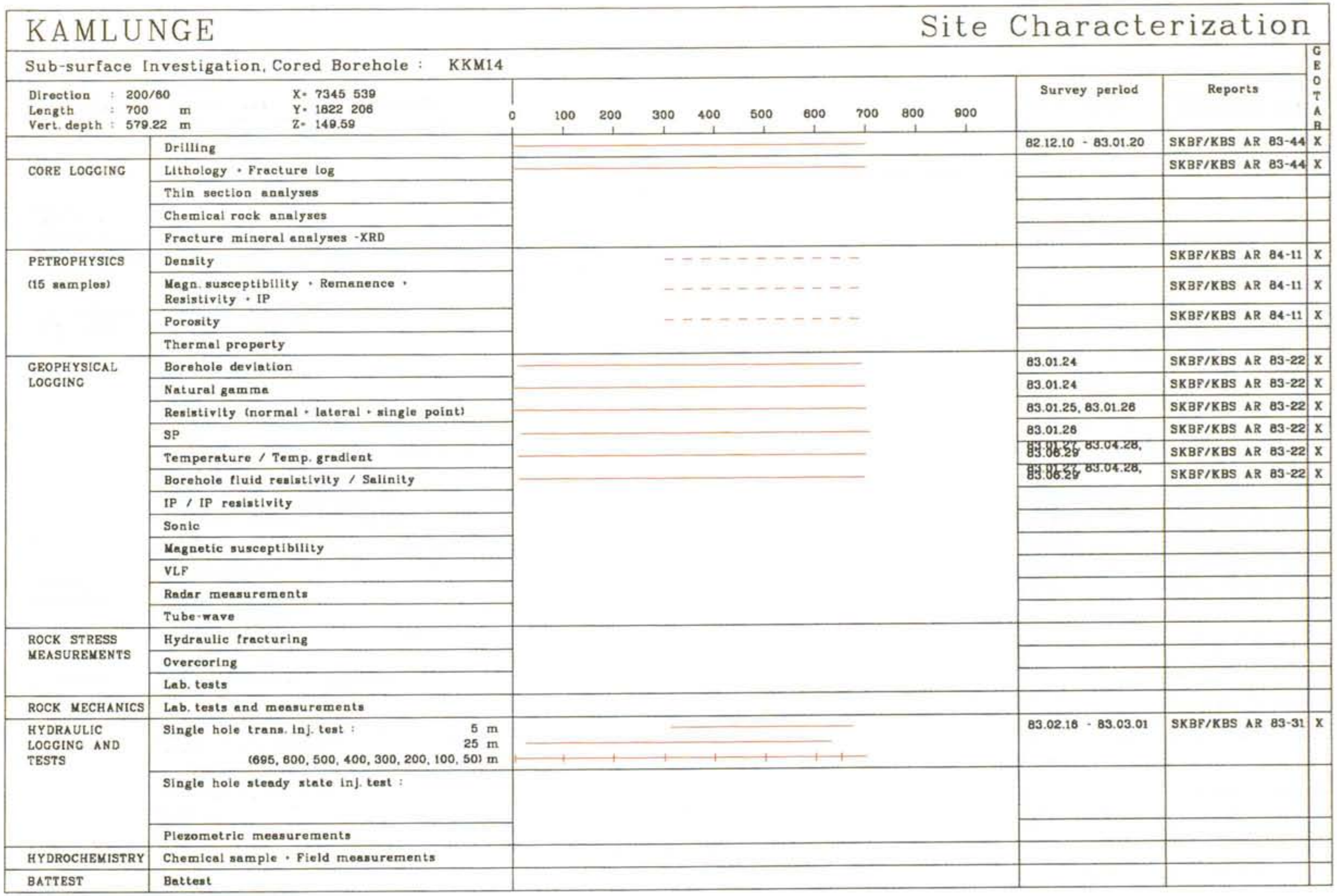
Sub-surface Investigation, Cored Borehole : KKM13

Direction : 110/60
Length : 703 m
Vert. depth : 582.27 m

X- 7345 560
Y- 1822 520
Z- 147.02

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		82.12.10 - 83.01.08	SKBF/KBS AR 83-44	X
CORE LOGGING	Lithology · Fracture log			SKBF/KBS AR 83-44	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD	○ ○ ○		SKBF/KBS AR 83-21	
PETROPHYSICS (15 samples)	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility · Remanence · Resistivity · IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		83.01.10	SKBF/KBS AR 83-22	X
	Natural gamma		83.01.10	SKBF/KBS AR 83-22	X
	Resistivity (normal · lateral · single point)		83.01.10, 83.01.11	SKBF/KBS AR 83-22	X
	SP		83.01.10	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		83.01.27, 83.04.26, 83.06.30	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		83.01.27, 83.04.26, 83.06.30	SKBF/KBS AR 83-22	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 : 5 m 25 m 50 m		83.02.06 - 83.02.13	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample · Field measurements	∞ ∞ ∞	83.01 - 83.06.21	SKBF/KBS TR 83-40 SKBF/KBS TR 83-70 SKB TR 85-11	X
BATTEST	Battest				

Figure A14. Activities in borehole KKM13.



KAMLUNGE Site Characterization

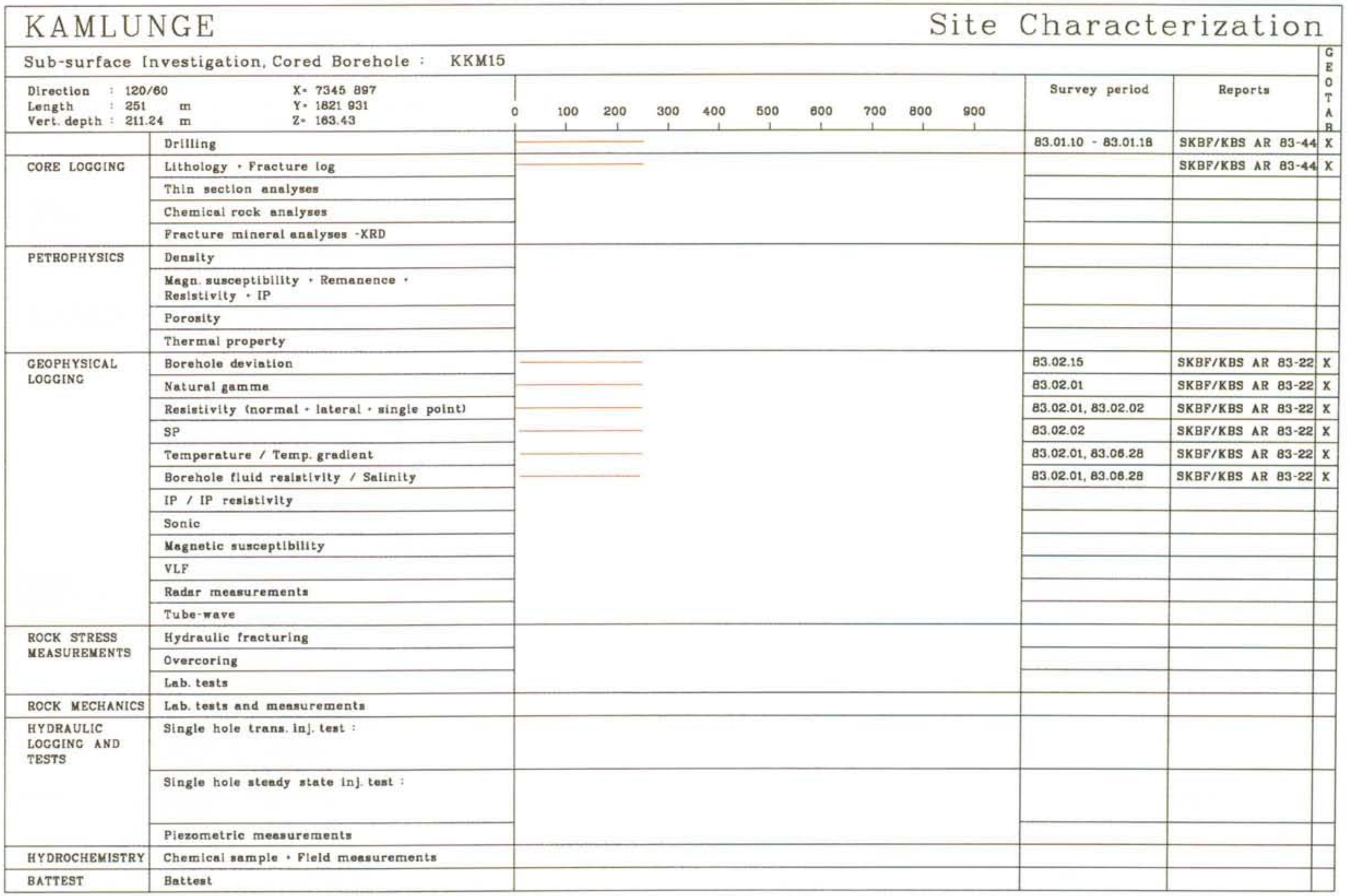
Sub-surface Investigation, Cored Borehole : KKM14

Direction : 200/60
Length : 700 m
Vert. depth : 579.22 m

X= 7345 539
Y= 1822 206
Z= 149.59

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAR
	Drilling		82.12.10 - 83.01.20	SKBF/KBS AR 83-44	X
CORE LOGGING	Lithology + Fracture log			SKBF/KBS AR 83-44	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS (15 samples)	Density			SKBF/KBS AR 84-11	X
	Magn. susceptibility + Remanence + Resistivity + IP			SKBF/KBS AR 84-11	X
	Porosity			SKBF/KBS AR 84-11	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		83.01.24	SKBF/KBS AR 83-22	X
	Natural gamma		83.01.24	SKBF/KBS AR 83-22	X
	Resistivity (normal + lateral + single point)		83.01.25, 83.01.26	SKBF/KBS AR 83-22	X
	SP		83.01.26	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		83.01.27, 83.04.28, 83.06.29	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		83.01.27, 83.04.28, 83.06.29	SKBF/KBS AR 83-22	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 : 5 m 25 m (695, 600, 500, 400, 300, 200, 100, 50) m		83.02.16 - 83.03.01	SKBF/KBS AR 83-31	X
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample + Field measurements				
BATTEST	Battest				

Figure A15. Activities in borehole KKM14.



KAMLUNGE Site Characterization

Sub-surface Investigation, Cored Borehole : KKM15

Direction : 120/60
Length : 251 m
Vert. depth : 211.24 m

X= 7345 897
Y= 1821 931
Z= 163.43

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		83.01.10 - 83.01.18	SKBF/KBS AR 83-44	X
CORE LOGGING	Lithology + Fracture log			SKBF/KBS AR 83-44	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. susceptibility + Remanence + Resistivity + IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		83.02.15	SKBF/KBS AR 83-22	X
	Natural gamma		83.02.01	SKBF/KBS AR 83-22	X
	Resistivity (normal + lateral + single point)		83.02.01, 83.02.02	SKBF/KBS AR 83-22	X
	SP		83.02.02	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		83.02.01, 83.06.28	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		83.02.01, 83.06.28	SKBF/KBS AR 83-22	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 :				
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample + Field measurements				
BATTEST	Battest				

Figure A16. Activities in borehole KKM15.

KAMLUNGE Site Characterization

Sub-surface Investigation, Cored Borehole : KKM16

Direction : 300/60
Length : 250 m
Vert. depth : 210.96 m

X- 7345 845
Y- 1822 065
Z- 164.59

		0 100 200 300 400 500 600 700 800 900	Survey period	Reports	GEOTAB
	Drilling		83.01.14 - 83.01.18	SKBF/KBS AR 83-44	X
CORE LOGGING	Lithology • Fracture log			SKBF/KBS AR 83-44	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. susceptibility • Remanence • Resistivity • IP				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		83.02.18	SKBF/KBS AR 83-22	X
	Natural gamma		83.02.22	SKBF/KBS AR 83-22	X
	Resistivity (normal • lateral • single point)		83.02.17	SKBF/KBS AR 83-22	X
	SP		83.02.22	SKBF/KBS AR 83-22	X
	Temperature / Temp. gradient		83.02.16, 83.06.29	SKBF/KBS AR 83-22	X
	Borehole fluid resistivity / Salinity		83.02.16, 83.06.29	SKBF/KBS AR 83-22	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 :				
	Single hole steady state inj. test :				
	Piezometric measurements				
HYDROCHEMISTRY	Chemical sample • Field measurements				
BATTEST	Battest				

Figure A17. Activities in borehole KKM16.

APPENDIX B

GENERALIZED RESULTS FROM BOREHOLE MEASUREMENTS

Generalized results from core mapping and borehole measurements/tests in the cored boreholes KKM01-KKM16 are presented in Figures B1-B4. For each borehole the following information is presented; 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. Quartzitic gneiss and biotite gneiss are collectively termed sedimentary gneiss - migmatite.

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 19 in Chapter 6). Highly increased hydraulic conductivity is noted where the conductivity in the borehole section is more than 100 times higher.

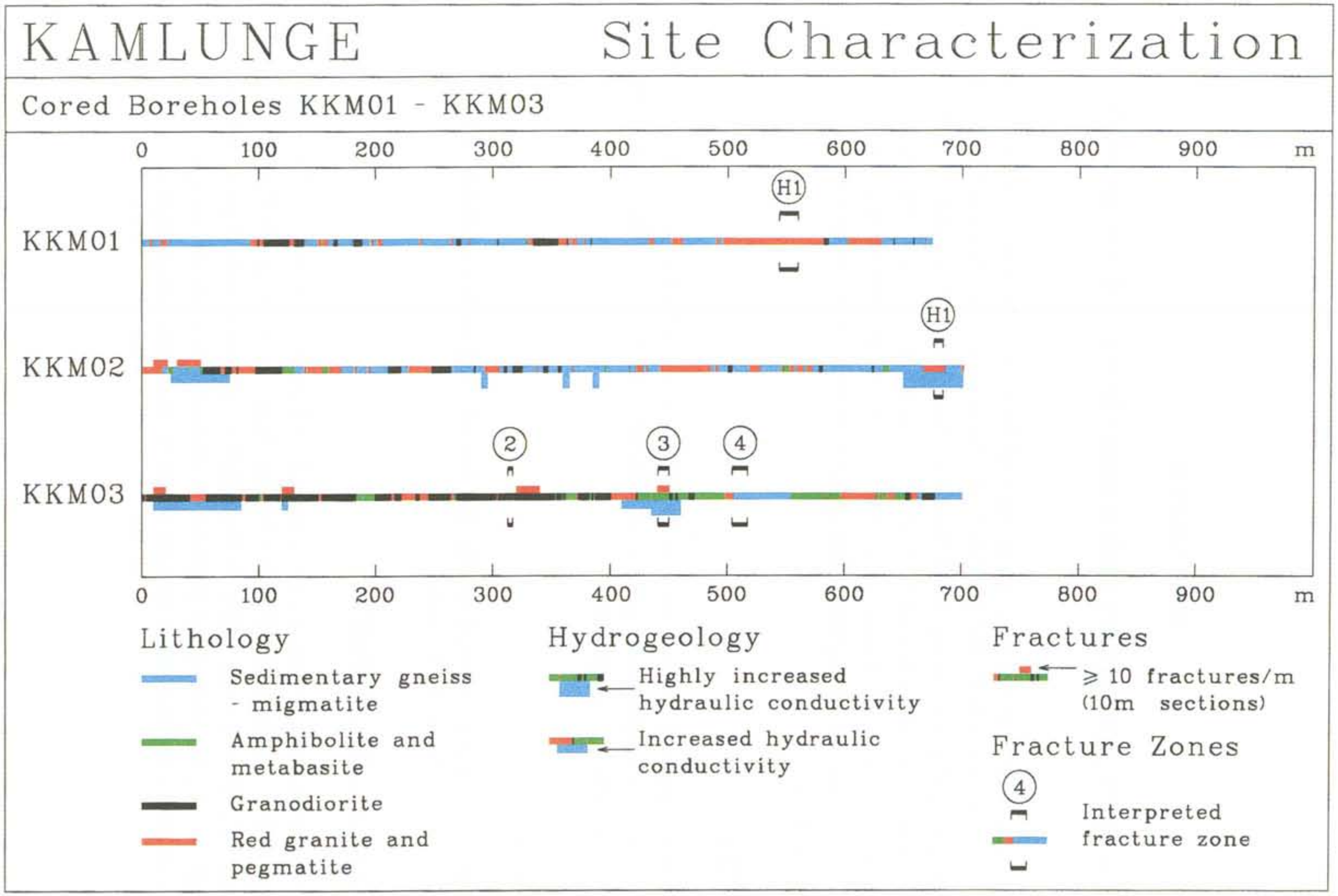


Figure B1. Results from borehole surveys in KKM01-KKM03. The horizontal axis represent borehole length.

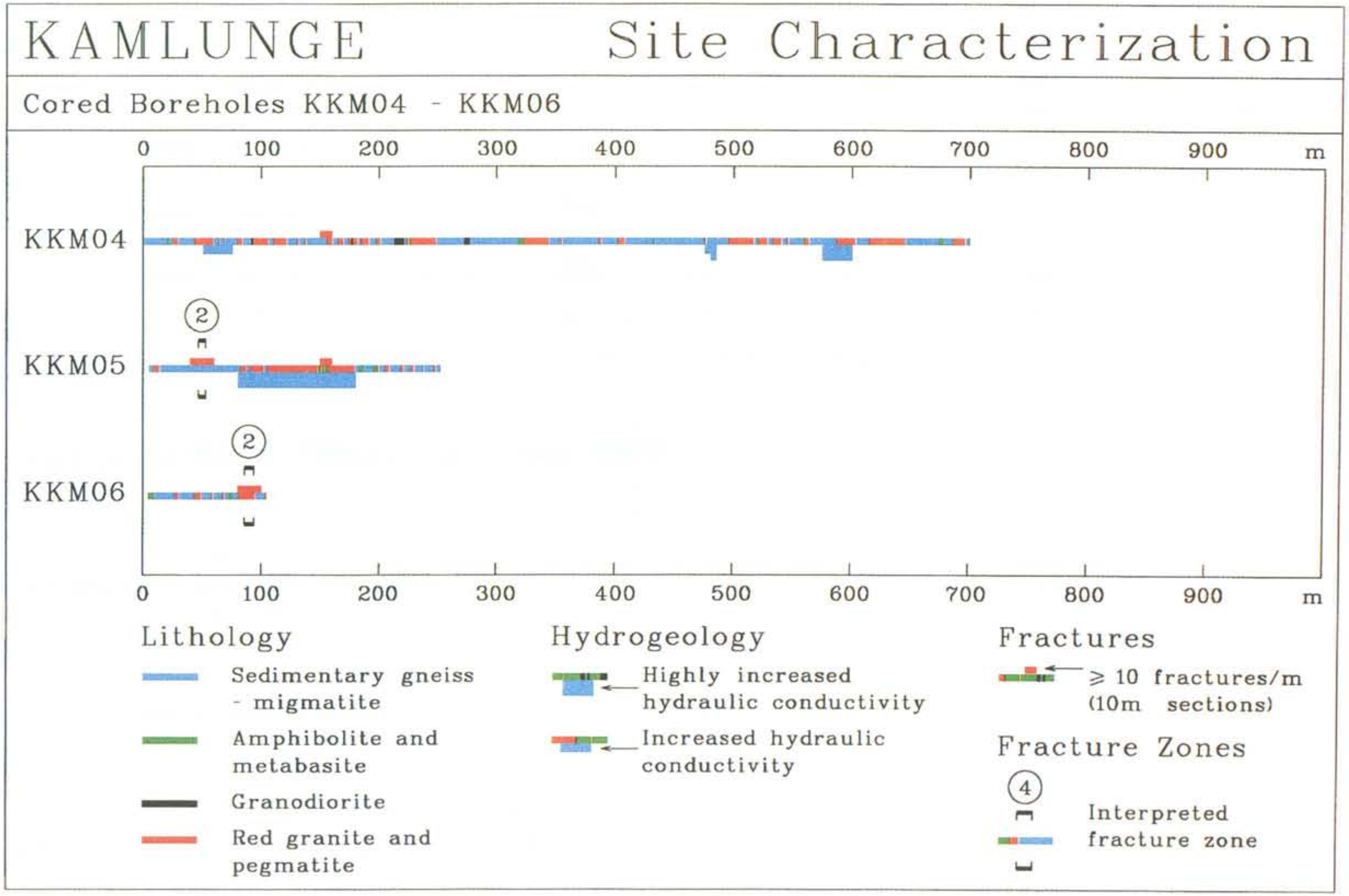


Figure B2. Results from borehole surveys in KKM04-KKM06. The horizontal axis represent borehole length.

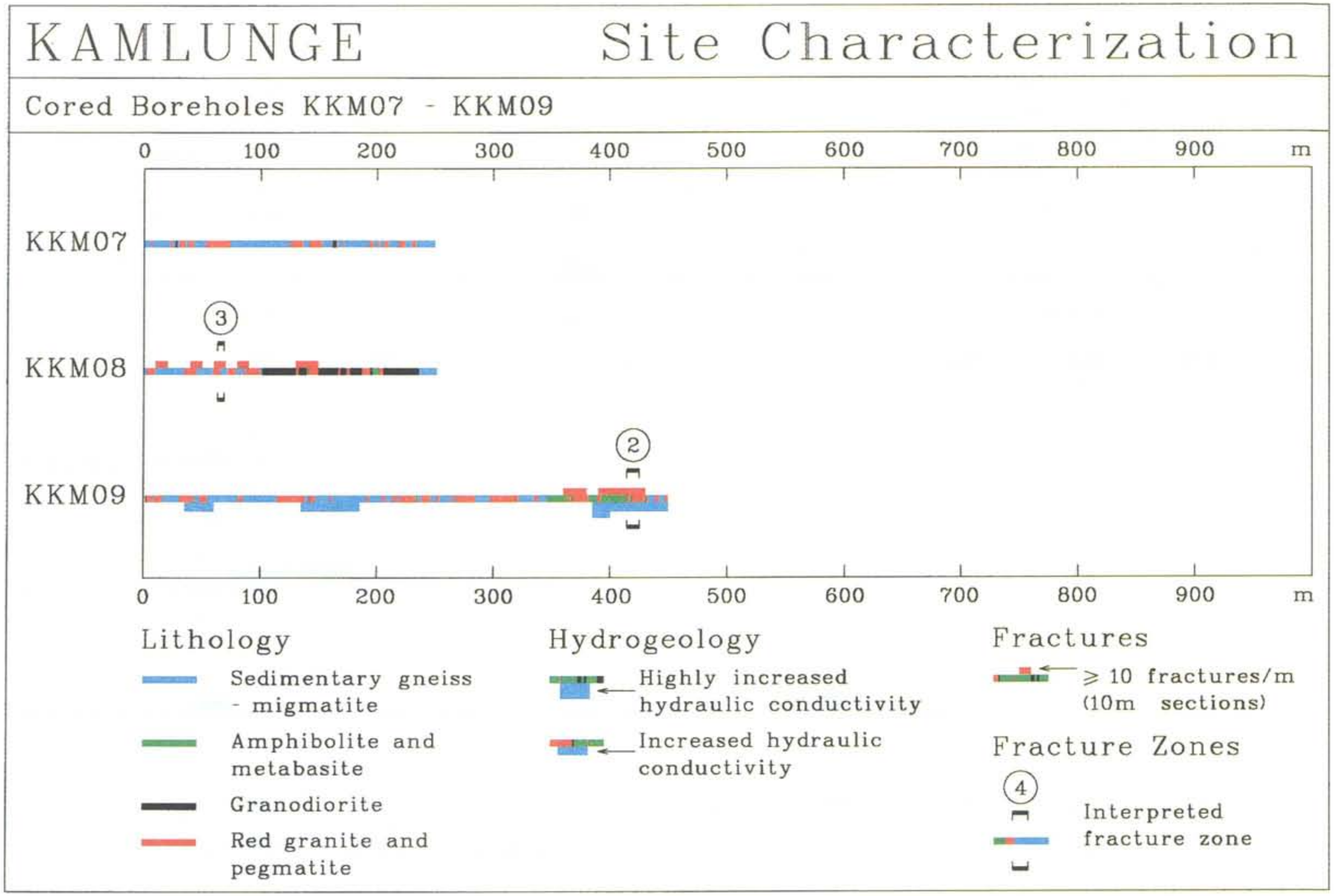


Figure B3. Results from borehole surveys in KKM07-KKM09. The horizontal axis represent borehole length.

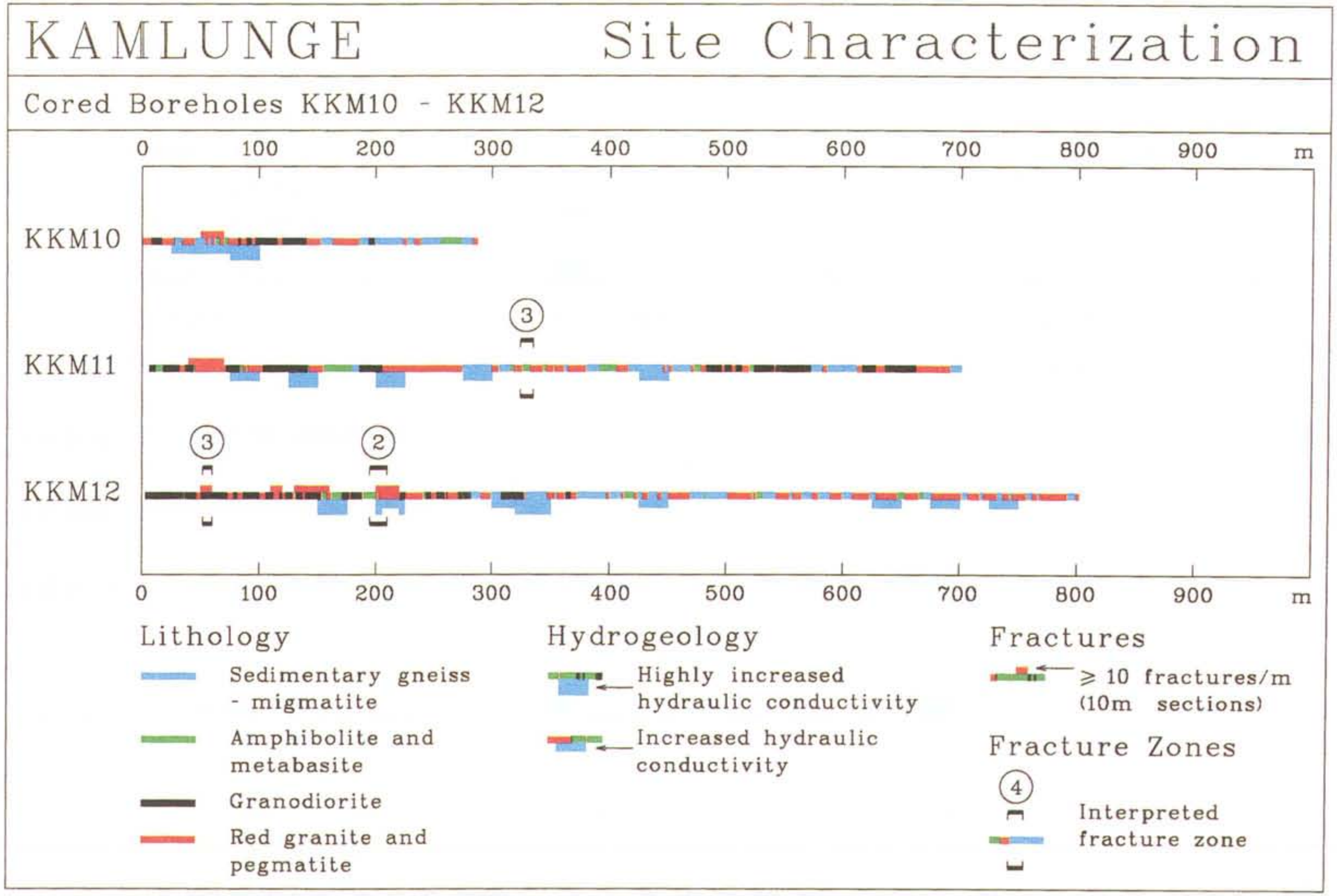


Figure B4. Results from borehole surveys in KKM10-KKM12. The horizontal axis represent borehole length.

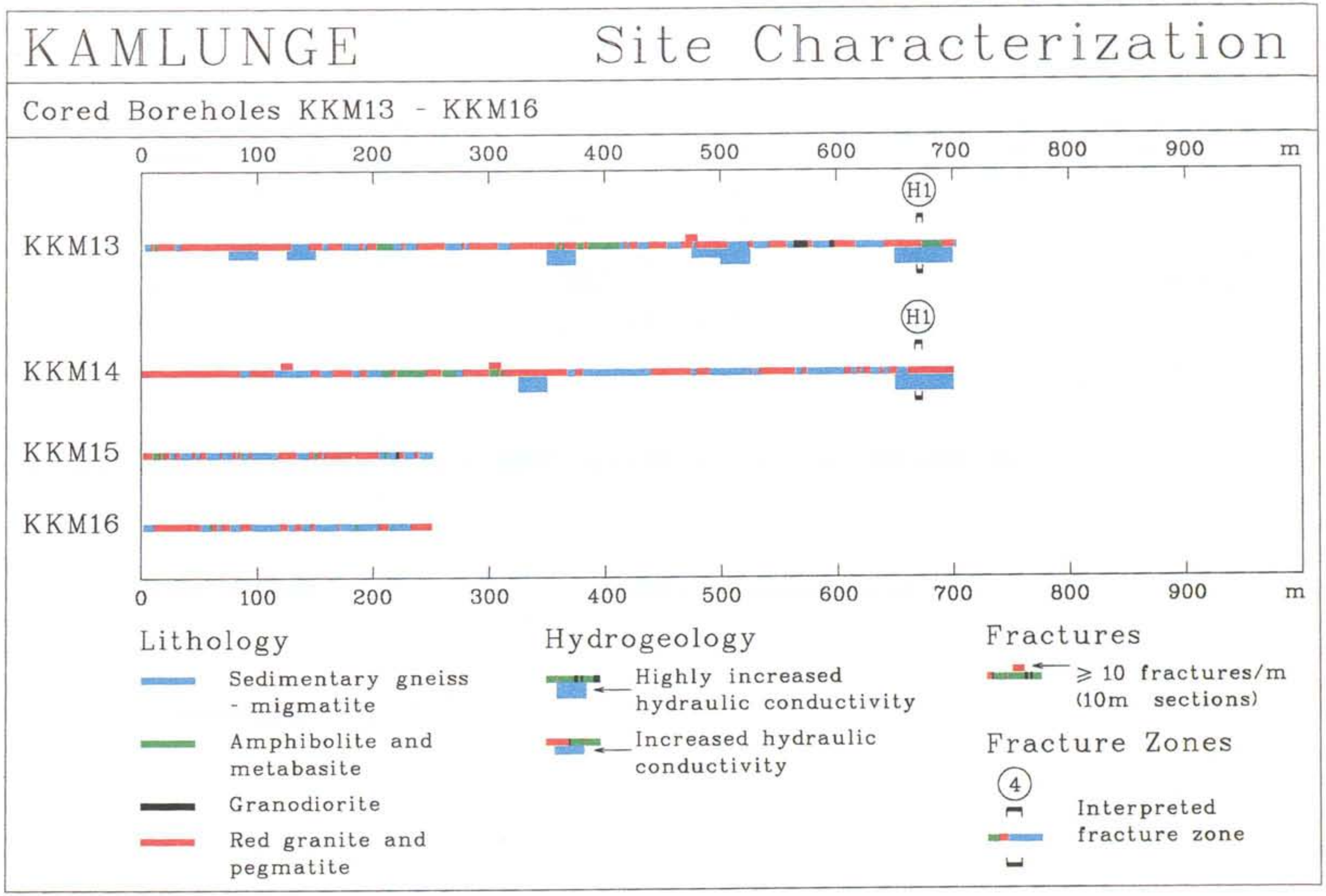


Figure B4. Results from borehole surveys in KKM13-KKM16. The horizontal axis represent borehole length.

APPENDIX C

DESCRIPTIONS OF EACH FRACTURE ZONE

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

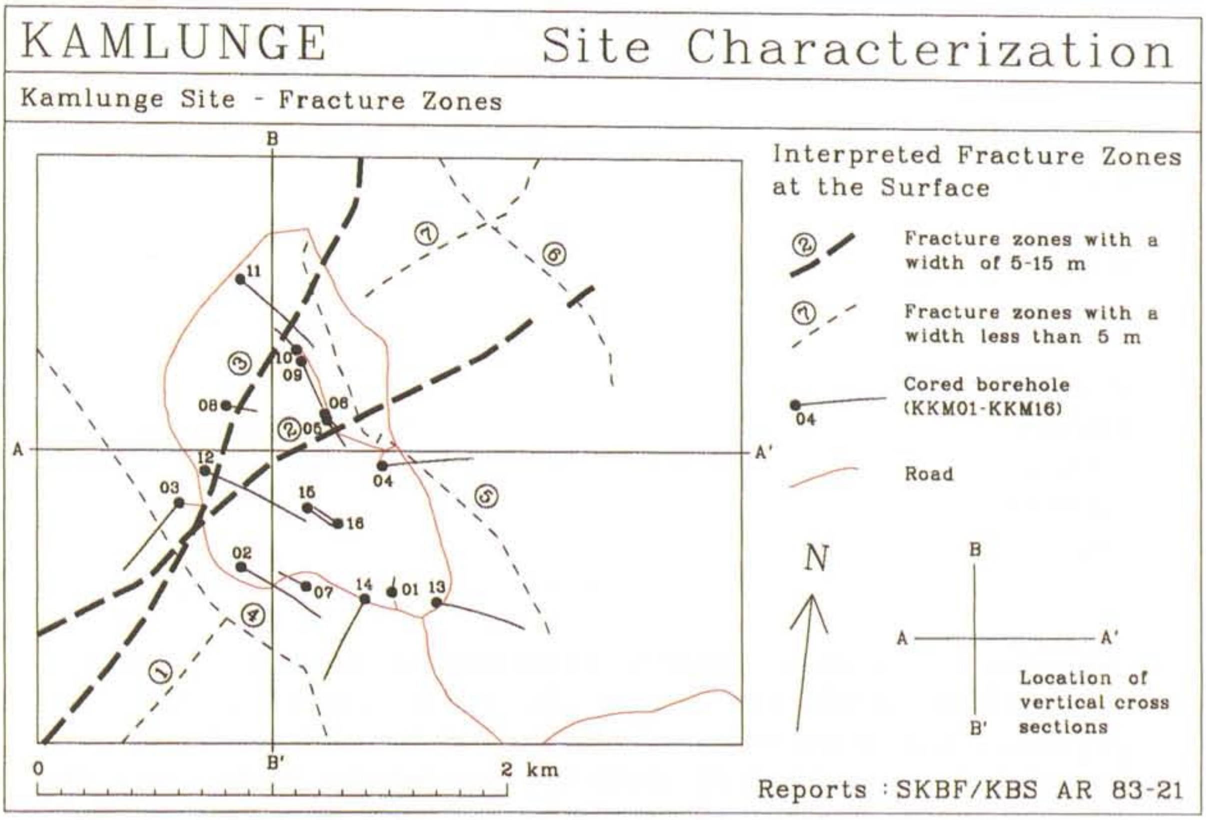


Figure C1. Map of interpreted fracture zones in the Kamlunge site.

ZONE 1

Zone 1 is interpreted to strike N45E and dip vertically. It appears as a weakly expressed lineament in the southeastern part of the site. The results from the electrical geophysical surveys strongly suggests that this zone continues across the central part of the site. Since such a central location of the zone would strongly affect the lay-out of a repository it was decided to make a thoroughly drilling programme to investigate its existence and, if so the character of the zone. The existence of the zone was tested in several boreholes (Table C1).

Table C1. Boreholes for investigating Zone 1.

	Interpreted location of Zone 1 in boreholes
Cored boreholes	
KKM02	---
KKM07	---
KKM15	---
KKM16	---
Percussion boreholes	
HKM05	---
HKM06	---
HKM10	---
HKM11	---

Two percussion boreholes (HKM06 and HKM10) showed high groundwater inflows (3000 and 9000 l/h), while the other boreholes were dry. The geometrical relationship between the locations of the inflows in the two boreholes and the geophysically interpreted zone did not however favour the existence of a fracture zone. The high inflows were therefore interpreted as a result of water conductive horizontal sheet fractures and not as an indication of a fracture zone. This interpretation is strengthen by the boreholes KKM07 and KKM02, in where no fracture zone was found at the proposed location of Zone 1.

The two cored boreholes KKM15 and KKM16 were drilled in the central part of the site to confirm that no fracture zone exists here. Since no increased degree of fracturing could be observed in these boreholes, at the possible locations of Zone 1, the zone was dismissed from the central part of the site. However, due to a weak lineament in the southeastern part of the site, were it has not been tested by boreholes, the existence of a fracture zone in this part was still regarded possible.

Reliability: Only the southeastern part of the zone is still interpreted to exist, although the existence of this zone is highly uncertain. According to the Bäckblom nomenclature the reliability level of the zone in this pare is "possible". The dismissal of Zone 1 in the central part of the site seems justified (although an explanation of the geophysical anomaly is still lacking).

ZONE 2

Zone 2 strikes N55E and dips 70° towards the northwest. The interpreted length of the zone is 3 km and its width is estimated to 8 m. The zone is well expressed on the electrical geophysical maps. The zone is also, at least partly, well expressed topographically. The existence of the zone was tested by drilling (Table C2).

Table C2. Boreholes for investigating Zone 2.

	Interpreted location (m) of Zone 2 in boreholes
Cored boreholes	
KKM03	313-337
KKM05	47-53
KKM06	86-94
KKM09	414-425
KKM12	195-210
Percussion boreholes	
HKM01	72
HKM02	46,83

Two percussion boreholes penetrates the Zone 2. Both boreholes show relative high groundwater inflows, 3000-6000 l/h, although no clear relation between the groundwater inflows and the proposed location of the zone was found. In the five cored boreholes the zone is characterized by high fracture frequency at all interpreted intersections with the zone and the bedrock is commonly red stained and brecciated. Sections with crushed bedrock are common. Main fracture minerals are chlorite, calcite and iron-oxides. Accessory minerals are epidot, biotite, laumontite and muscovite.

Zone 2 crosses a well exposed area in the southwestern part of the site. However, in spite of this no trace of the zone was possible to observe in the outcrops.

Reliability: The observation of Zone 2 in a large number of boreholes implies a "certain" reliability level for the zone, in spite of the absence of a conclusive observation of the zone in outcrops.

ZONE 3

Zone 3 strikes N25E and dips 70° towards the northwest. The interpreted length is 2.9 km and its width is estimated to 5 m. The zone is only weekly expressed in the geophysical measurements. This also applies for its topographical expression. The existence of the zone was tested by drilling (Table C3).

Table C3. Boreholes for investigating Zone 3.

	Interpreted location (m) of Zone 3 in boreholes
Cored boreholes	
KKM03	441-450
KKM08	63-69
KKM11	324-335
KKM12	52-60
Percussion borehole	
HKM14	34

In the cored boreholes the zone is characterized by weathered and brecciated bedrock, sections of crushed bedrock and relatively thick infillings of calcite, chlorite and laumontite. Other common fracture minerals are iron-oxides, epidote and biotite. One percussion borehole was drilled into the interpreted location of Zone 3. The water capacity of the borehole was 1500 l/h.

Reliability: Zone 3 is only weakly expressed geophysically and topographically at the surface. In boreholes, it is interpreted to occur as well defined fractured sections in four cored boreholes and, possibly, in one percussion borehole. The large number of boreholes makes the overall reliability level "certain", in spite of the its weak surface expression.

ZONE 4

Zone 4 is located in the western part of the site. It is interpreted to strike N45W and dip 80° towards the southwest. The zone is well expressed on the slingram and resistivity maps, as well as on the topographical map. The existence of the zone was tested by drilling (Table C4).

Table C4. Boreholes for investigating Zone 4.

	Interpreted location (m) of Zone 4 in borehole
Cored borehole	
KKM03	504-517

Borehole KKM03 is interpreted to intersect the zone. However, this is not strongly supported by the borehole fracture and geophysical logs. There are other and more fractured sections in the borehole. No percussion borehole were drilled to investigate the zone.

Reliability: The existence of Zone 4 is well indicated due to its appearance on geophysical and topographical maps. However, the result from borehole KKM03 does not conclusively confirm the dip. A reliability level of "possible" should therefore be assign to the existing interpretation.

ZONE 5

This zone is reported to trend N45W and dip 60° towards the northeast. It is located outside and bounding the central well exposed part of the site to the east. Geophysically, the zone is indicated on the slingram and resistivity maps, as well as topographically as a trend of peat bogs. The existence of the zone was tested by drilling (Table C5) and by four refraction seismic profiles.

The result of the seismic survey was rather ambiguous with thin (10-15 m) low-velocity sections in two of the profiles, while corresponding low-velocity sections were not observed on the other two profiles. Furthermore, no fracture zone could conclusively be interpreted from the two percussion boreholes that were drilled to investigate the existence and the dip of the zone. As a final test borehole KKM04 was drilled to investigate the existence of Zone 5. Since no fracture zone was found in the borehole it was concluded that, if Zone 5 exists, it must dip 60^0 or less to the northeast. Although the Kamlunge geology report (Albino et al., 1983a) expressed doubts regarding the existence of the zone, the Zone 5 was included in the reports.

Reliability level: "possible".

Table C5. Boreholes for investigating Zone 5.

	Interpreted location (m) of Zone 5 in boreholes
Cored borehole	
KKM04	---
Percussion boreholes	
HKM07	---
HKM08	---

ZONE 6

Zone 6 is located in the northeastern part of the site and is interpreted to strike N45W and dip 85° towards the northeast. The length of the zone is 1.3 km and its width is estimated to 3 m. The zone is well expressed on the slingram and resistivity maps, as well as on the topographical map.

No boreholes have been drilled to intersect the zone. The geometrical characteristics is estimated from geophysical anomalies only.

Reliability level: "possible".

ZONE 7

This zone is also located in the northeastern part of the site. It is interpreted to strike N55E and dip 75° towards northwest. The length is 1 km and its width 3 m. The zone is weakly expressed on the slingram and resistivity maps, which also applies to the topographical map.

No boreholes have been drilled to intersect the zone. The geometrical characteristics is estimated from geophysical anomalies only.

Reliability level: "possible" (at the most).

ZONE H1

The Zone H1 is located at about 550 m depth below the Kamlungekölen plateau. Its width varies between 4 and 14 m. Since the zone is only weakly indicated in the cores and in the geophysical logs it was not discovered until the hydraulic water injection tests were made. These tests showed consistent hydraulic conductivities of 10^{-8}-10^{-9} m/s in all boreholes but one at a depth of 550 m in the central part of the site. Also several geophysical borehole logs showed distinctive changes in salinity at that depth. The zone is interpreted to occur in the boreholes presented in Table C6.

Table C6. Boreholes penterating Zone H1.

	Interpreted location (m) of Zone H1 in boreholes
Cored boreholes	
KKM01	544-560
KKM02	676-684
KKM13	669-674
KKM14	667-673

In two boreholes, KKM01 and KKM13, the zone is fractured and reddened through alteration and precipitation of hematite. Chlorite formed after hematite is also present. In the other boreholes, KKM02 and KKM14, only an increased fracture frequency is apparent at this level. The lateral extent of this zone has not been established, but it is not found in KKM12, for example.

Reliability: The existence of fractured and water conductive sections in four out of five boreholes at the same depth in the central part of the site is a strong indication for the existence of Zone H1. However, before the existence of Zone H1 can be regarded "certain" the hydraulic connectivity between the boreholes should be proved. Thus the reliability level is "probable".

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GEOTAB. Overview
Ebbe Eriksson[1], Bertil Johansson[2], Margareta Gerlach[3], Stefan Magnusson[2], Ann-Chatrin Nilsson[4], Stefan Sehlstedt[3], Tomas Stark[1]
[1]SGAB, [2]ERGODATA AB, [3]MRM Konsult AB
[4]KTH
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TR 92-02
Sternö study site. Scope of activities and main results
Kaj Ahlbom[1], Jan-Erik Andersson[2], Rune Nordqvist[2], Christer Ljunggren[3], Sven Tirén[2], Clifford Voss[4]
[1]Conterra AB, [2]Geosigma AB, [3]Renco AB,
[4]U.S. Geological Survey
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Björn Lindbom, Anders Boghammar
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P J Henderson, J-O Österberg, B Ivarsson
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Johan Claesson
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Statistical inference and comparison of stochastic models for the hydraulic conductivity at the Finnsjön site
Sven Norman
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Description of the transport mechanisms and pathways in the far field of a KBS-3 type repository
Mark Elert[1], Ivars Neretnieks[2], Nils Kjellbert[3], Anders Ström[3]
[1]Kemakta Konsult AB
[2]Royal Institute of Technology
[3]Swedish Nuclear Fuel and Waste Management Co
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Description of groundwater chemical data in the SKB database GEOTAB prior to 1990
'Sif Laurent[1], Stefan Magnusson[2], Ann-Chatrin Nilsson[3]
[1]IVL, Stockholm
[2]Ergodata AB, Göteborg
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Björn Lindbom, Anders Boghammar
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Sven Norman
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Jordi Bruno[1], Patrik Sellin[2]
[1]MBT, Barcelona Spain
[2]SKB, Stockholm, Sweden
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Sven Follin
Department of Land and Water Resources, Royal Institute of Technology
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