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Gideå study site. Scope of activities and main results

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

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PREFACE

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

It is presently not clear if 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 the ones selected. However, as a part of the background documentation needed for the site selection studies to come, summary reports will be prepared for most study sites. These reports will include scope of activities, main results, uncertainties and need of complementary investigations.

This report concerns the Gideå 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), Rune Nordqvist (groundwater chemistry), Clifford Voss (assessment of solute transport) and Christer Ljungren (rock mechanics).

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CONTENTS cont.

1. ASSESSMENT OF THE GIDEÅ STUDY SITE

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

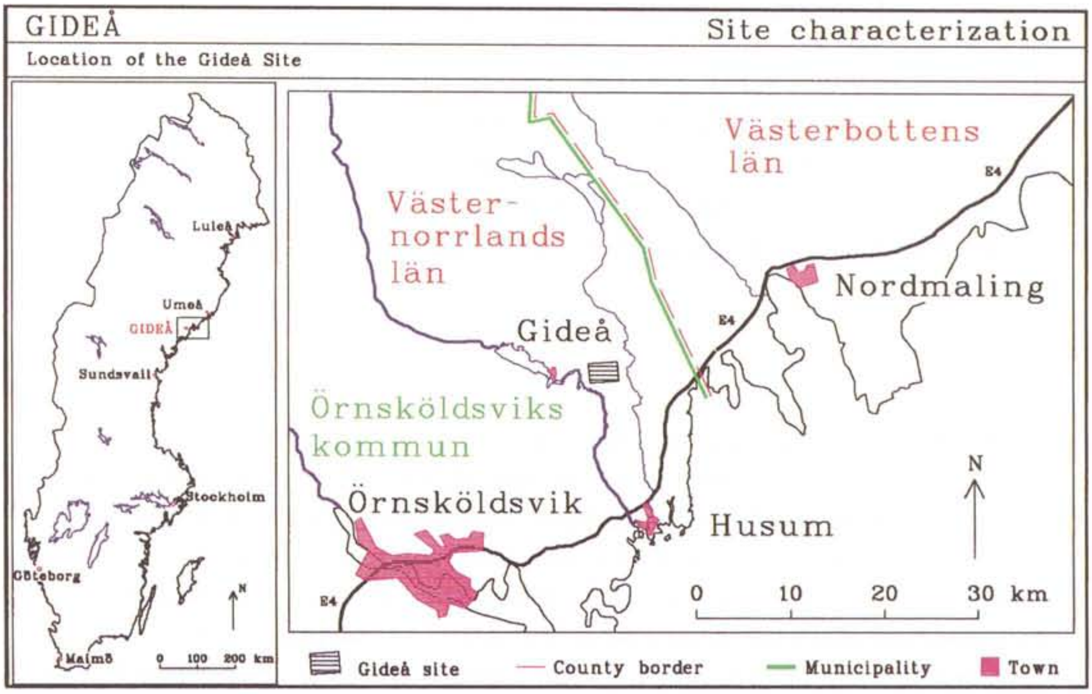

Figure 1. Location of the Gideå study site.

1.1 <u>Main characteristics and uncertainties</u>

Rock type distribution

The Gideå study site is located within a large region of migmatized veined gneiss of sedimentary origin. The migmatization of the sediments has resulted in two rock types; veined gneiss (main rock type) and migmatite granite (subordinate rock type). These rocks were during the late phase of the Svecokarelian orogeny (c. 1 800 milj. year) intruded by granitic dykes. The deformation during this orogeny has resulted in a foliation of the granitic dykes, as well as the migmatite granite and veined gneiss. The granites were during this time transformed to granite gneiss. The foliation at Gideå generally trends northeast with dips commonly varying between 10–30 degrees towards northwest. Other orientations of the foliation has also been measured which implies folding. The granitic dykes probably follow the foliation, i.e they are interpreted as subhorizontally or gently dipping.

During the Jotnian time (1 215 milj. years) east–westerly oriented and vertical doleritic dykes intruded the bedrock at Gideå. With the exception of two 2–10 m wide dykes in the central part of the site, the width of the dolorite dykes are less than 1 meter. The magnetic survey suggests an average distance between the dolerite dykes of 200–300 m. Outside the site there is a gently dipping Jotnian dolerite sheet of several hundered meter thickness. Pegmatite occurs in the form of minor bodies and meter–wide dykes.

Uncertainties: No model describing the 3–D distribution of rock types exist for the Gideå site. Thus, there is no interpretation regarding the lateral and vertical extension of the granitic and doloritic dykes, in spite of their probable influence on the groundwater flow and on the groundwater chemistry.

Fracture zones

Interpretation of data indicating zones at the Gideå site has led to the definition of 11 fracture zones. The interpretations are primarily based on results from ground geophysical surveys anomalies (electrical and seismic methods), subsequently tested by shallow percussion boreholes. Common orientations of fracture zones are NE–SW and E–W. The widths of the fracture zones, estimated from borehole data, varies between 1–24 m. The bedrock within the fracture zones are commonly strongly clay altered. This might explain the generally low hydraulic conductivity measured in these zones (see below).

Uncertainties: A frequent occurrence of fractured sections in the drill cores make interpolations difficult/uncertain between boreholes, as well as between surface and boreholes. Most interpreted fracture zones should therefore be regarded as more or less uncertain. There are also many fractured sections in the boreholes that are not assigned to any specific fracture zones. The gently dipping foliation in general and the occurence of a gently dipping dolerite sheet outside the site indicate that there might be unidentified gently dipping structures within the site. It is therefore possible that additional studies will disclose additional fracture zones, probably both steeply and gently dipping.

Hydrology

The central part of the Gideå site constitutes a recharge area for groundwater whereas a local discharge area is located in the lowland towards the east. The shallow groundwater flow is mainly directed towards the regional lineaments coinciding with the river Gideälven in the southwest and the river Husån in the east. A local elevated area is located to the west of the Gideå site. The topography of the groundwater table within the site is rather flat, ranging from about 80 m to 125 m above the sea level.

Uncertainties: No study of the regional groundwater flow pattern has been performed in the Gideå area. Consequently, it is not known whether the waters at repository depth belong to a shallow local groundwater system or a regional flow system.

Hydraulic units

The main hydraulic units included in the conceptual model of the Gideå site are the rock mass and local fracture zones. The rock mass was subdivided into veined gneiss and granite gneiss in the modelling. The latter strata was assumed to be continuous and subhorizontally layered, thus implying anisotropic conditions in the rock mass.

Uncertainties: The assumed continuous and subhorizontal layering of the granite gneiss strata have not been tested. Also, the dolerite dykes have not been included in the hydraulic modelling.

Hydraulic conductivity

The average hydraulic conductivity of the veined gneiss is low, about 10^{-11} m/s at 500 m depth, while the hydraulic conductivity of the granite gneiss is about one order of magnitude higher. The number of measurements in the fracture zones are very limited but, with one or two exceptions, the measured conductivities are generally low, in the same order as the granite gneiss. The fracture zones thus have no or only minor influence on the groundwater flow in the modelling. The hydraulic properties of the dolerite dykes have not been fully evaluated, but in general the hydraulic tests indicate low conductivity.

The conductive fracture frequency was estimated to 0.4 – 1.5 fr/m from 2 m tests in borehole KGI07 and to 0.04 – 0.06 fr/m from 25 m tests in all core boreholes at the site.

Uncertainties: The derived hydraulic conductivity functions versus depth for the different hydraulic structures are uncertain, partly due to uncertainties in the division of data in hydraulic structures from the geological interpretation, and partly due to the analysis technique based on regression analysis. An alternative interpretation of the hydraulic conductivity data is that the upper 100–200 m of the bedrock has higher conductivity than the deeper bedrock and that no significant depth trend exists in neither upper or lower parts of the bedrock.

Groundwater flow rates at repository depth

Two cases were modelled in the Gideå site. In the first case both the rock mass and the local fracture zones were modelled as separate isotropic continua. In the second case the rock mass was assumed to have uniform anisotropic hydraulic properties parallel and perpendicular to the granite gneiss strata. A smooth decrease of hydraulic conductivity with depth was assumed for both cases. The calculated groundwater flow rates at a potential repository depth of 600 m ranged between 5–15 ml/m^2/year in the first case and between 2–4 ml/m^2/year in the second case.

Uncertainties: The calculated groundwater flow rates should be regarded as average values in an equivalent formation composed of two overlapping continua (rock mass and fracture zones). Discrete flow paths with high hydraulic conductivity have not been included in the modelling.

Groundwater chemistry

A total of ten borehole sections in two boreholes were sampled. The samples indicate groundwaters of varying ages, but no particular depth dependence was noted. The general groundwater chemistry indicate an environment common to Swedish crystalline bedrock. The groundwaters are generally of a reducing character. Only samples from two of the sections were considered representative for the depth sampled. These sections represented relatively shallow groundwaters.

Uncertainties: As only two of the sampled sections were considered to be representative samples, the groundwater chemistry conditions in general at the site remains as a main uncertainty. In fact, the character of the deeper groundwaters is essentially unknown. The redox measurements are especially uncertain.

Rock mechanics

The rock mechanical investigations at Gideå includes measurements of mechanical and thermal parameters on core samples and rock stress measurements down to 500 m by the hydraulic fracturing technique. The overall result is that no anomalous mechanical properties has been discovered and thus, taking into account the measured state of stress, it is concluded that no major stability problem is foreseen for a repository at 600 m depth.

The orientation of the maximum horizontal stress is oriented N67°E, with a standard deviation of ± 19°. This is not in accordance with the NW–SE trend generally found in Sweden.

Uncertainties: The data are rather scattered for the orientation of the maximum horizontal stress. The rock stress measurements also included some few points which gave orientations in the NW–SE direction. One possible explanation for the resulting average NE–SW orientation, apart from the stresses, can be that the induced fractures by the hydraulic fracturing have been influenced by foliation planes in the gneissic rock.

1.2 Suggestions for complementary studies

Conceptual geologic models

It is strongly suggested to develop three–dimensional conceptual models of rock type distribution for the Gideå site, both on regional and on site scale. For the regional scale gently dipping doleritic sheets at greater depths should be considered to be included in the models. For the site scale, the model should describe the vertical and lateral extension of the doloritic and granite dykes, as well as the bodies of migmatite granite. This might require some remapping of outcrops and drill cores. The new models are foreseen to be used in hydraulic models of regional and local groundwater flow, and for influence of different rock types on groundwater chemistry.

The frequent occurrence of doloritic dykes could also have an substantial influence on the "constructability" of the site, as these dykes often are strongly fractured and clay altered. This influence should be evaluated.

It is probable that a several hundred meter thick doloritic sheet have intruded in the, now eroded, bedrock above the site. This intrusion caused a substantial thermal influence on the surrounding bedrock for thousands of years (probably much higher than any possible influence by a repository). What effect this heating had on the bedrock at Gideå should to be evaluated.

To reduce uncertainties in location and extension of interpreted fracture zones a comparison between tectonic characteristics of fractured sections in drill cores should be made. This will include remapping of tectonized sections and analysis of fracture minerals and other characteristics. Data obtained, in connection with other results, such as borehole radar measurements, would probably substantially improve the basis for interpreting fracture zones.

It should also be considered to perform a reflection seismic survey to obtain data regarding subhorizontal fracture zones and gently dipping bodies of migmatite granite and granitic dykes. The reflection seismic survey would also provide data regarding the possible occurrence of gently dipping doleritic sheets at greater depths.

Conceptual geohydrological models and data sampling

A first step to improve the conceptual hydraulic model at Gideå 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) additionel data sampling might be necessary.

The regional groundwater flow, within a larger area around the Gideå site, should be investigated qualitatively to determine the overall groundwater flow circulation on a regional scale. The primary goal of this investigation is to establish a general conceptual model of the regional groundwater flow, including possible flow paths from a repository to the biosphere. The outer boundary conditions of the local model should be defined after analyzing the regional flow field. This analysis should include modelling of the regional groundwater hydrology, aiming at identifying regional hydrological factors that have a major influence on the local flow system.

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 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 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, including dolerite dykes and granitic dykes, should be further 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 and fracture zones, together with alternative analyses (models) of the hydraulic conductivity data, taking account of the variance of the measured data.

In some of the boreholes high hydraulic conductivities have been measured at great depths. In spite of this, no strong hydraulic conductor have so far been identified/located at Gideå. Since the occurrence of such conductors is of importance for the performance of a repository, it should be considered to further study the possible occurrence of such conductors.

As a final test of the validity of the (revised) conceptual model of the Gideå 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 sufficient for a proper characterization of chemical conditions at the Gideå site, there is a need for additional sampling. 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 at Gideå has been evaluated thoroughly, 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 were local or regional flow conditions prevails.

Solute transport

To improve knowledge of transport at the Gideå site, the following factors would be most important; 1) investigation of the deep groundwater system (what boundary conditions would be appropriate for a local site model predicting flow and transport?) and, 2) investigation of geometry and connectivity of conductive structures if such exist (what are the major flow paths that need be considered in a model?). Once these facts are established, the point of next greatest importance would be determination of hydraulic conductivity distribution including possible depth dependence. 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 improving knowledge of nuclide transport in both the conductive fractures and in bedrock blocks. In-situ tests to determine effective sorption coefficients, effective area and importance of matrix diffusion should be carried out.

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

Rock Mechanics

The rock stress measurements have only been conducted to 500 m below surface (the anticipated repository level). It might be suggested to investigate the stress state from 500 m depth down to the bottom of borehole KGI01 at 700 m depth to ensure the stresses are continuous. These measurements would then also allow to check the somewhat scattered orientation of the calculated maximum horizontal stress.

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 later investigated sites is Gideå. 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, 1983). The purpose of this report was to demonstrate how and where a safe repository for spent nuclear fuel can be located in Sweden.

When the scope of site investigations at Gideå 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 groundwaters. In addition, data was required on available area of "sound rock" at 500 m depth that is potentially suitable for a repository.

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

* Identify and characterize major and minor fracture zones, dykes and other lithological features.
* 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 Gideå study site

The Gideå site is located in the northern part of Västernorrland county, Örnsköldsviks municipality, about 30 km north–east of Örnsköldsvik, Figure 2. The areal extent of the site is 2 x 3 km. The site was one of several alternative areas presented in a reconnaissance study of the Västernorrland county (Ahlbom & Olkiewicz, 1981). Detailed geological reconnaissance studies and geophysical profile measurements were made during spring of 1981. These studies indicated promising conditions at the Gideå site. To confirm favourable conditions, a 700 m deep borehole was drilled the same year in the central part of the Gideå site. The cores indicated sound rock (veined gneiss of low fracture frequency) to the end of the borehole, with the exception of some minor fractured sections. The result of this borehole was regarded favorable and a decision to initiate complete investigations was taken at the end of summer of 1981.

The Gideå site was selected due to the following conditions:

* The site consists of migmatized veined gneiss. Regional well surveys show low water capacities for this rock type.
* Experience from excavating rock caverns and tunnels in this type of gneiss has been favorable.
* The Gideå study site and its surrounding have a flat topography, inferring small hydraulic gradients.
* Regional fracture zones delimit a large (100 km^2), slightly elevated plateau in which the Gideå site is situated.
* A low frequency of fracture zones, interpreted from aerial photographs.
* Well exposed bedrock, about 15 %, facilitates geological studies.
* Low frequency of fractures in outcrops in the study site.
* Easy accessible and favorable land ownership (a forest company).

The only factor that was considered unfavourable was a high frequency of steeply dipping doleritic dykes in the site.

2.3 Investigation periods

The time schedule for the main activities (phases of investigations) are shown in Figure 2. The main period of site characterization took place between 1981–1983. After this period the site has been used intermittently for R&D projects and for testing of new instruments for site characterization.

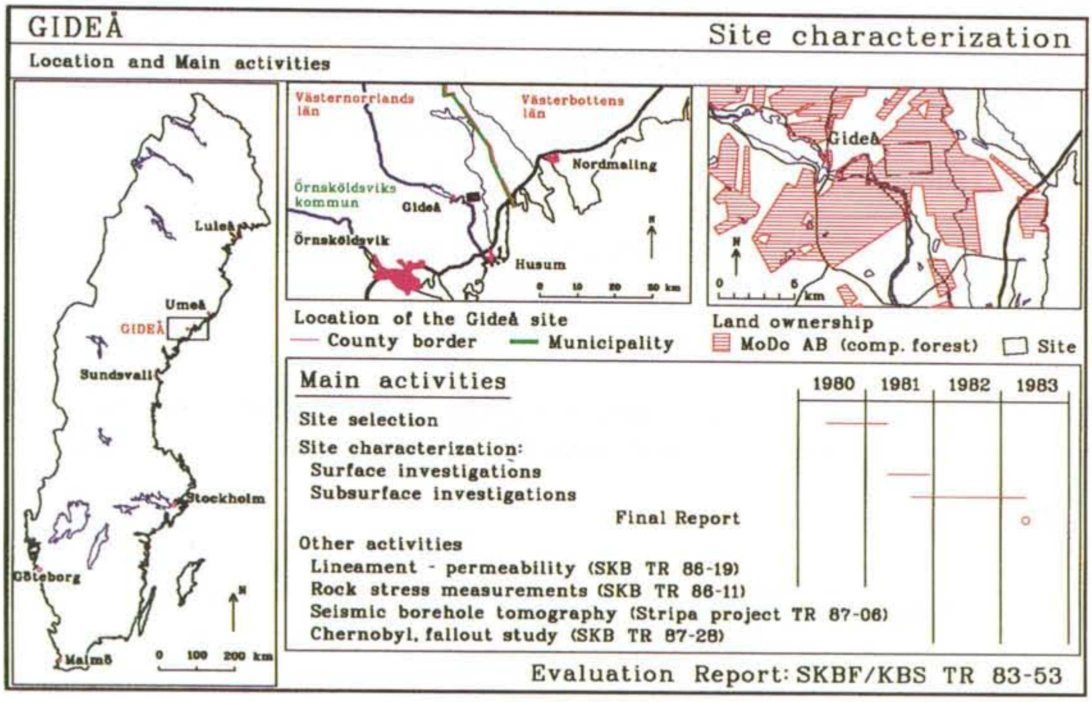

Figure 2. Location of the Gideå study site. Administrative borders and land ownership are shown in the central and right parts. Main activities (lower part) refer to the KBS–3 investigations. Other activities refer to R&D projects at the Gideå site after the KBS–3 report.

3. SCOPE OF ACTIVITIES

3.1 Reconnaissance

The Gideå site was selected in 1981 as a result of reconnaissance studies of the Västernorrlands county during 1980–1981 (Ahlbom & Olkiewicz, 1981).

The reconnaissance phase included studies of geological maps and literature, air–photo interpretation of lineaments and brief field checks. The latter included estimates of rock exposure, degree of fracturing and distribution of fracture zones. As a result of the reconnaissance studies three potential favourable sites were selected. All of these consist of migmatite and were located within a 9 x 7 km^2 area, about 30 km northeast of Örnsköldsvik, Figure 2. A survey of land–ownership showed that two of the selected sites were owned by several small land owners, while a forest company owned the land of the third site. This site, the Gideå site, was due to the this reason selected for preliminary studies.

Geological mapping, by the Swedish Geological Survey (SGU), of the bedrock in the Västerbotten county was in progress at the time of the reconnaissance for study sites in this region. From this mapping project unpublished base maps in the scale of 1:50 000 were used for the reconnaissance work. The different maps has later been compiled into a published map of the Västernorrlands county at a scale of 1:200 000 (Lundquist, 1987, 1991).

Airborne geophysical measurements has not been made for the region. This is also the case for gravimetric grid-measurements. Thus no regional geophysical maps were available during the reconnaissance.

The SGU data base of water capacity in wells "brunnsarkivet" was used to obtain general hydraulic characteristics of different rock types in northern Sweden.

3.2 Surface investigations - regional area

Geology

The regional distribution of rock types was obtained from the geological base map 19J Husum NV, Figure 3, discussed above. Lineaments were interpreted from air-photos of an 400 km^2 area including the Gideå site. Fracture surveys were performed at 5 localities outside the Gideå study site at a distance of 1-8 km from the Gideå site, Figure 3. All fracture surveys were located in migmatized gneiss, except for one in a dolerite dyke.

Hydrology

Based on data from SMHI:s stations the hydrometerological conditions of the Gideå region was compiled (Timje, 1983). This compilation included temperature, precipitation, evapotranspiration, water run-off, and gross water budget. The report by Timje (1983) also presents two groundwater level maps; a regional map (70 km^2) and a semi-regional map (27 km^2). The areal extent of these maps is shown in Figure 4.

Geophysical profiles

Ground geophysical profile measurements were made outside the site to map regional fracture zones. The survey consisted of 6 profiles (Figure 5) with a total length of about 19 km. For most profiles the measurements included magnetometer, slingram and VLF surveys.

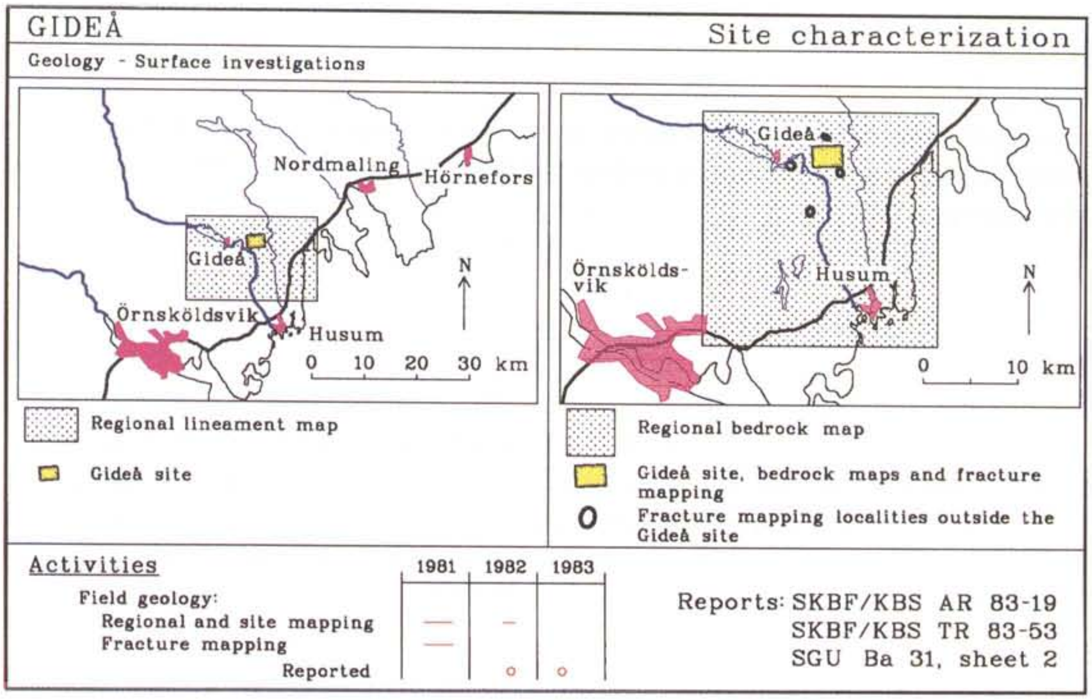

Figure 3. Regional geologic and tectonic studies. Left – area for lineament analysis. Right – extent of the regional geologic map together with localities for fracture surveys outside the Gideå site.

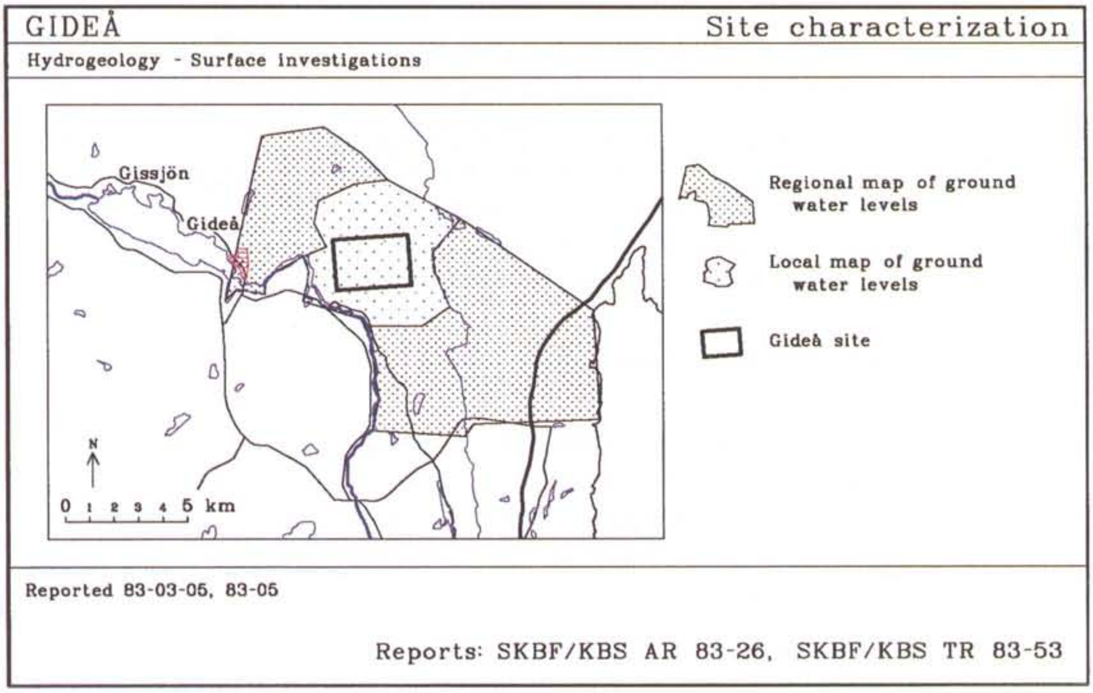

Figure 4. Extent of regional and local maps of groundwater table.

3.3 Surface investigations - Gideå site

Geology

The geological survey at the Gideå site included mapping of outcrops, mapping of rock types and scan-line fracture studies within the 6 km^2 large site. Petrographical studies were made on 7 thin-sections and chemical whole-rock analyses made on 6 samples (Albino et al., 1983).

Geophysical surveys

Detailed geophysical surveys were made for the main part (5 km^2) of the site (Albino et al., 1983). The objective was to identify fracture zones and doloritic dykes. 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 N-S. The methods included the following (see also Figure 5):

- protonmagnetometer
- slingram, 18 kHz
- resistivity (gradient method)
- induced polarization

In addition, 10 N-S and 6 E-W VLF-profiles were measured within the site to determine the dip of fracture zones. Also, 2 profiles of seismic refraction measurements were made, Figure 5. The profiles had a total length of 4 km.

For the main part of the site, the quality of the geophysical data was judged good and consequently the results was used with confidence to identify fracture zones and magnetic rock types (mainly dolerites). However, in areas covered by thick peat layers the electrical conductive surficial peat layer effectively shielded information from the underlying bedrock.

Petrophysical measurements of surface samples

Petrophysical measurements were made on 38 samples from dolerite dykes. The objective was to obtain data on natural remanent magnetization to be used in the interpretation of magnetic anomalies. In addition to remanence also density, susceptibility, Q-value, IP-effect and resistivity were measured on these samples (Albino et al., 1983).

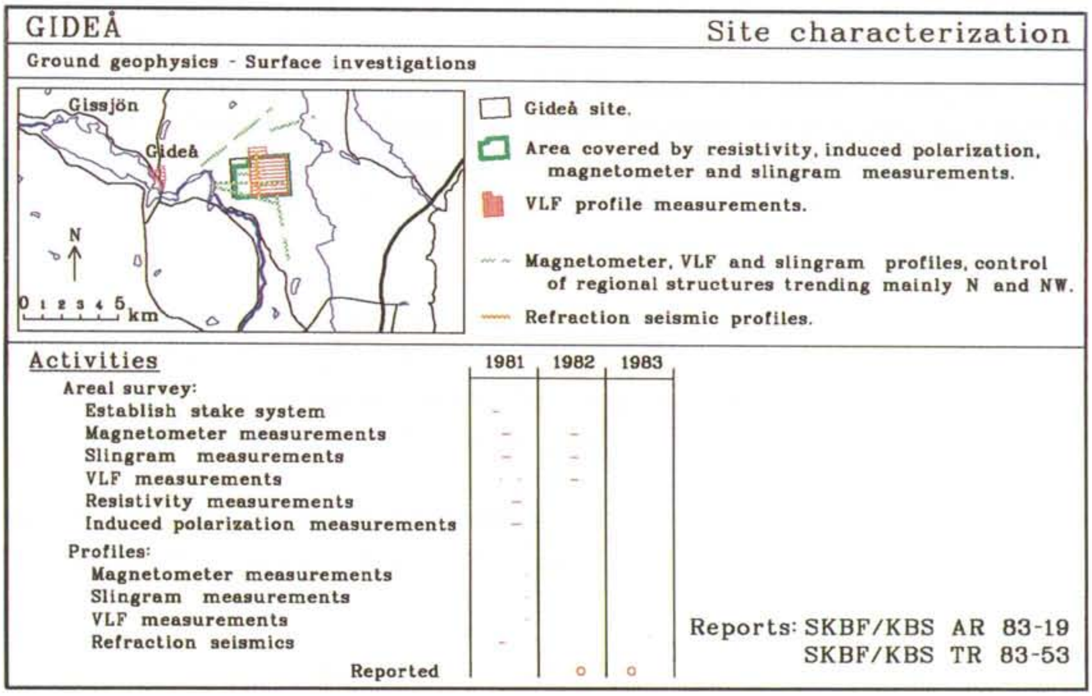

Figure 5. Extent of ground geophysical measurements.

3.4 Percussion boreholes

Percussion drilling were used to investigate possible fracture zones interpreted from geophysical measurements and from lineaments. In total 24 percussion boreholes were drilled with borehole lengths varying between 40–153 m, Table 1. A map of percussion boreholes is presented in Figure 6, while Figure 7 presents activities, including time-tables, in these boreholes.

Inflow and groundwater capacity

Identification of fracture zones intersected by the percussion boreholes (Albino et al., 1983) were made from anomalies in drilling rates and from locations of major groundwater inflows (Albino & Nilsson, 1982).

Borehole geophysical logging

The percussion boreholes in the Gideå site was logged with the methods; borehole deviation, natural gamma radiation and single point resistance. Data from these measurements have not been reported and evaluated (data are, with the exception of borehole deviation data, stored in the SKB database).

Hydraulic tests/measurements

The percussion boreholes were used to monitor the groundwater table (Timje, 1983) and also for one interference test (Andersson and Hansson, 1986). The latter test involved the boreholes HGI01, 05, 20, 23 and 24. Data on the groundwater head in the surficial part of the bedrock was obtained by positioning a packer at 5–10 m below the groundwater table in 12 percussion boreholes. The groundwater table above the packer and the groundwater head below the packer was recorded during a period of one year (1982).

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

No (HGI)	Direction/Dip		Length/Depth (m)	Water capacity l/h	Major inflow (m)
01	N70W	/55	153/143	4000	28
02	N90E	/55	141/130	0	–
03	S70W	/55	125/113	0	–
04	N90E	/55	100/92	0	–
05	N70W	/55	115/105	4000	48
06	N	/55	150/135	600	4
07	S	/55	150/139	2000	28,32
08	S	/55	130/118	6000	44
09	S60W	/55	150/137	240	46
10	N60E	/55	150/142	480	–
11	S	/55	132/127	0	–
12	N	/55	125/106	0	–
13	N05W	/55	150/136	0	–
14	N60W	/55	125/107	480	–
15	S60E	/55	120/103	9000	116
16	N60W	/55	132/117	6000	124
17	N	/55	120/107	0	–
18	S	/55	100/84	0	–
19	S65E	/55	100/87	0	–
20		/90	100/99	9000	95
21		/90	90/90	0	–
22		/90	60/60	0	–
23		/90	90/90	0	–
24		/90	40/40	3000	2,10,14,22

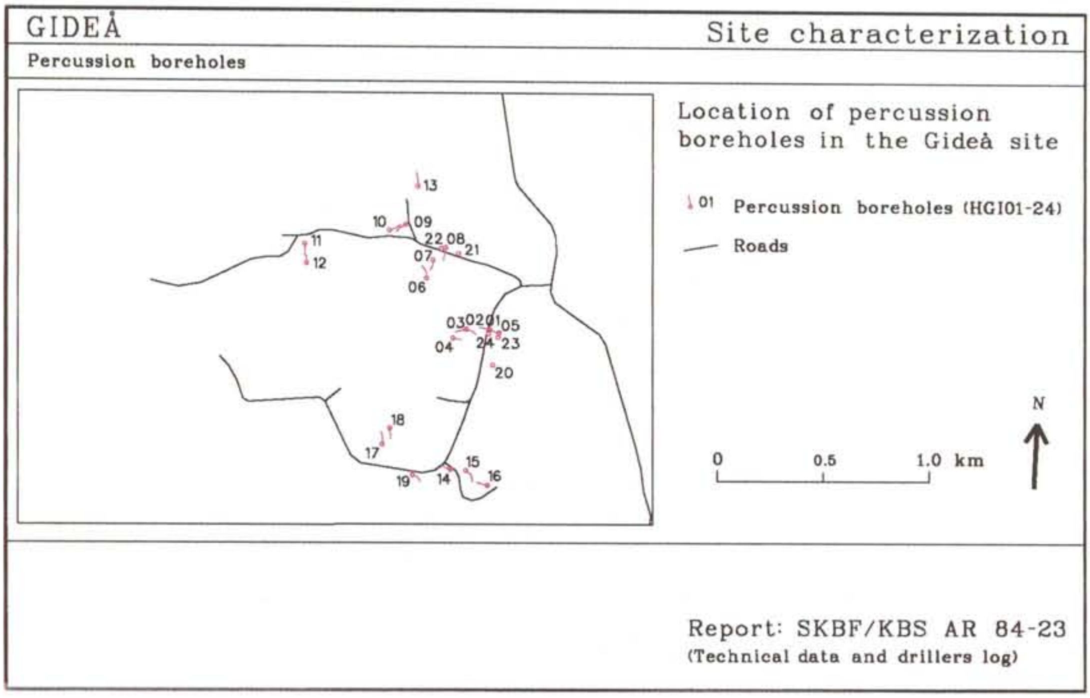

Figure 6. Location of percussion boreholes.

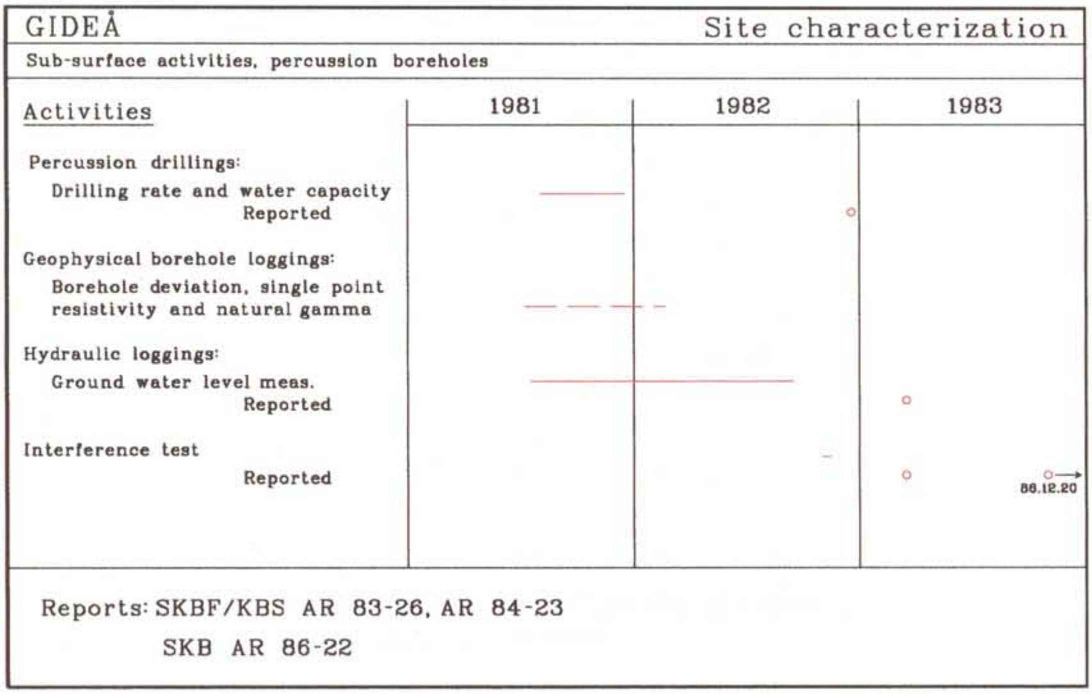

Figure 7. Activity periods – percussion boreholes.

3.5 Cored boreholes

A total number of 13 cored boreholes have been drilled in the Gideå site (Figure 8) down to a maximum depth of 701 m. Most boreholes are drilled inclined, 60 degrees from the horizontal and with a borehole length of ca 700 m (Table 2). The main objectives was:

- to test and improve the preliminary geological model obtained from the surface investigations.
- to obtain data on the hydraulic characteristics of different hydraulic units (rock mass, rock types and fracture zones).
- to obtain groundwater samples from different depths and in different hydraulic environments (discharge and recharge areas).

To fullfil these objectives most of the boreholes were directed to intersect interpreted fracture zones or dykes at depth (Albino et al., 1983). A map showing the locations of cored boreholes is presented in Figure 8. The drilling periods is shown in Figure 9. Detailed break-downs of activities in each borehole are presented in Appendix A.

Table 2. Cored boreholes at the Gideå site.

No (KGI)	Direction/Dip	Length (m)	Depth (m)
01	/90	704.3	701
02	N40W /60	705.5	617
03	N20W /60	703.0	626
04	N45E /70	690.7	657
05	N60W /60	702.0	605
06	S30E /60	704.0	648
07	S10W /60	700.5	635
08	N70E /62	701.6	619
09	S /67	281.9	250
10	S70W /65	702.6	632
11	S /60	701.5	632
12	N45W /61	249.8	218
13	N45W /61	704.5	616

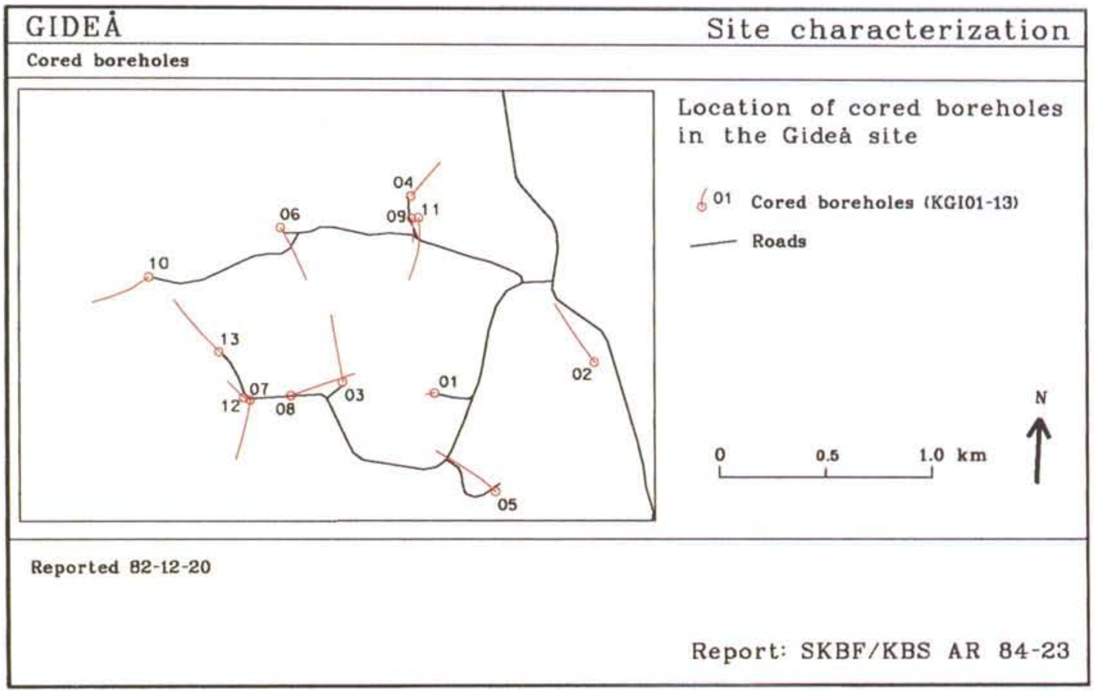

Figure 8. Location of cored boreholes at the Gideå site.

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 at Gideå amounts to 8 255 m. The core mapping data, except for descriptions of rock types, was stored on discs using a computerized system (Almén et al., 1983). Detailed print–outs in a scale of roughly 1:30 is available in borehole reports (Albino & Nilsson, 1982). Generalized results concerning fracture frequency and rock types are presented in scales of 1:5 000 and 1:2 000 (Albino et al., 1983). The computerized storage (now transfered 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)
- angle between fracture and core axis
- fractured section (more than 10 fr/m)
- crushed section
- core loss
- fracture mineral
- short comment

Core samples for petrophysical measurements (in total 111 samples) were taken at evenly intervals from all cores (Albino, 1984). The samples were measured with respect to:

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

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 in Öqvist & Jämtlid (1984).

In addition, 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 KGI01 (Ahlbom and Karawacki, 1983).

3.7 Geophysical logging

The following "standard" set of geophysical logs were used in the cored boreholes at Gideå (see Figure 9 and Appendix A):

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

The results from the geophysical logging are reported in the scale 1:5 000 (Stenberg, 1983). In addition to the "standard" methods above, boreholes KGI01 and KGI04 was measured with an induced polarization log (Stenberg, 1983) and boreholes KGI02 and KGI03 with an electrochemical log (pH, Eh and pS^{2-}) (Duran, 1984). The geophysical loggings made in each of the cored borehole are presented in Appendix A.

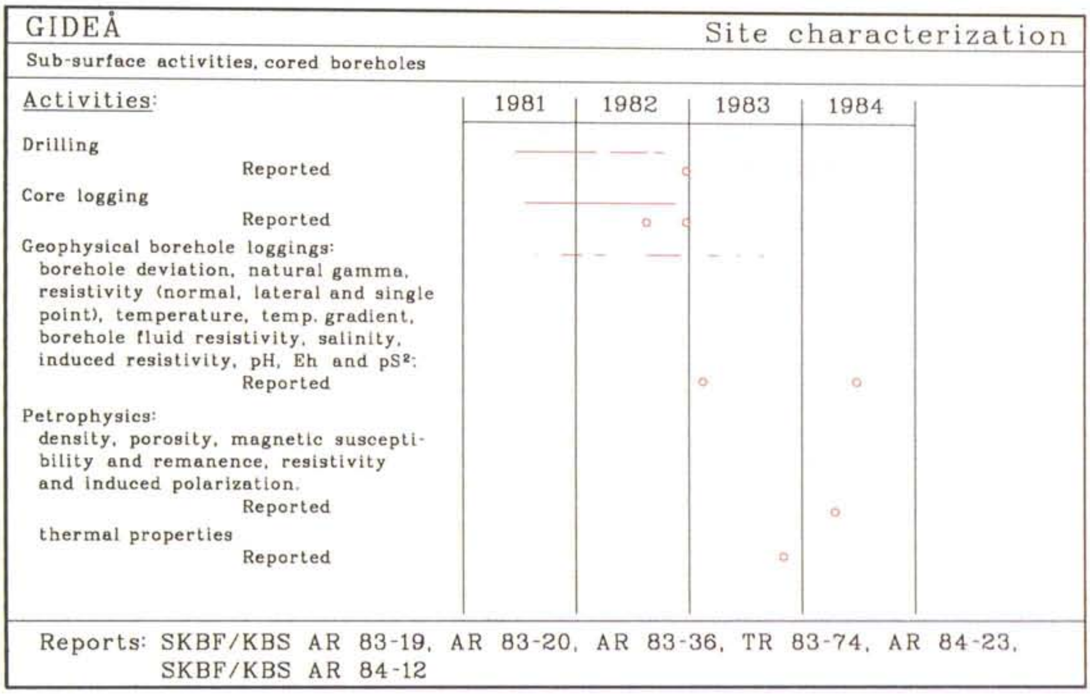

Figure 9. Activity periods – drilling, core logging, geophysical logging and petrophysical measurements on samples from the cored boreholes.

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, 308 sections with a length of 25 m were tested. To obtain detailed information in crushed and fractured parts of the bedrock also 10 and 5 m sections were used. Furthermore, 2 m and 3 m sections were made to obtain data on conductive fracture frequency. Four tests were also made with a single packer to measure the average hydraulic conductivity from the packer to the bottom of the borehole.

Most tests were transient injection tests at constant head. An exception is the steady state injection tests in 2 m and 3 m sections performed in boreholes KGI07 and KGI09 (Appendix A) for calculating the conductive fracture frequency. With the exception of the 2 and 3 m sections, the hydraulic testing methods and results are presented in Timje (1983) and in Ahlbom et al. (1983). The activity periods for the hydraulic tests are presented in Figure 10. Scope of water injection tests in the different boreholes is presented in Appendix A.

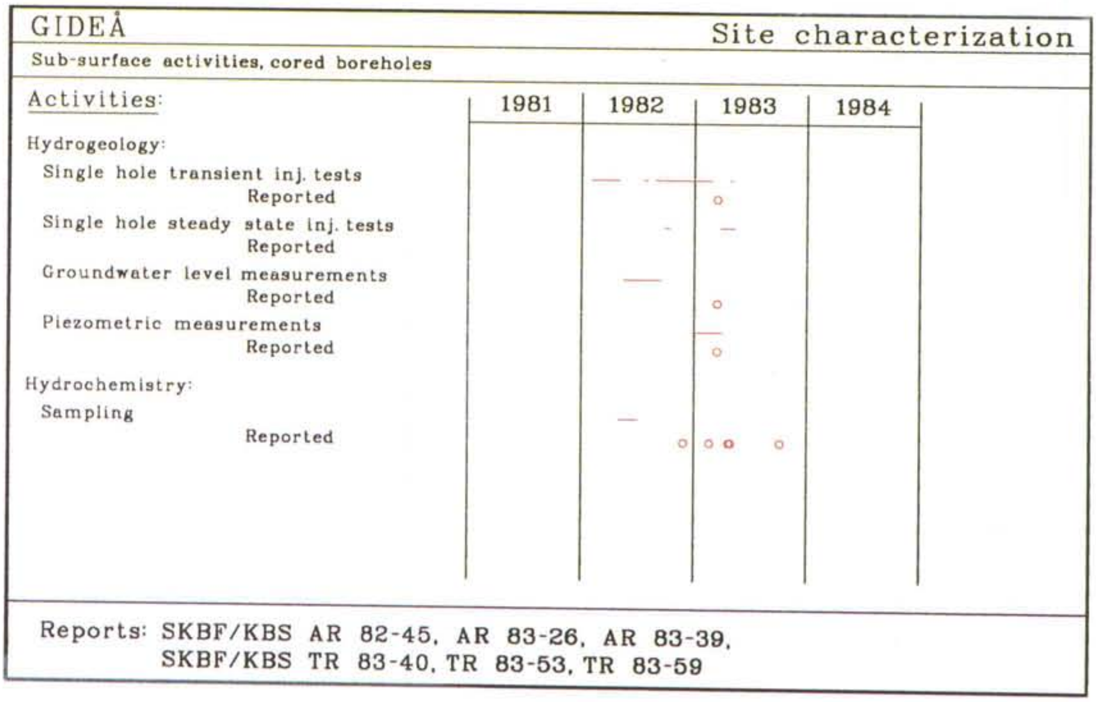

Figure 10. Activity periods – hydraulic measurements and groundwater sampling in the cored boreholes.

Groundwater head measurements

The location of the groundwater table was measured during most part of 1982 in the cored boreholes. The groundwater head in deeper parts of the bedrock was estimated from the pressure recovery phase of the water injection tests. In one borehole, KGI07, piezometric measurements were also made in five isolated sections for about one month.

3.9 Groundwater sampling

Groundwater sampling was made in five isolated sections in each of the boreholes KGI02 and KGI04. The chemical characteristics of the groundwaters sampled in these sections are presented in Laurent (1983) and in Wikberg et al. (1983). Locations of sampled sections and chemical characteristics are discussed in Chapter 7.

3.10 Studies at the Gideå Site since KBS-3

After the main investigations for the KBS-3 report, which were terminated in 1983, the Gideå site have been used for different research projects or for testing of new instruments. The activity periods for these studies are shown in Figure 11. The studies have involved:

1. Testing of a tubewave instrument in boreholes KGI07 and KGI11 (Stenberg and Olsson, 1984).

2. Testing of the mise-á-la masse method for orientation of fracture zones Magnusson, 1985.

3. Testing of seismic borehole tomography in boreholes KGI 01, 02 and 11. These investigations were a part of the Stripa project (Phil et al., 1987).

4. Rock stress measurements by hydraulic fracturing in borehole KGI01 (Bjarnason and Stephansson, 1986). Rock stresses were measured at 31 points between 15-501 m depth. Six points were rejected, the data of remaining 25 points are considered reliable.

5. Rock mechanical tests on core samples from four depths in borehole KGI01 (Ljunggren et al., 1985). The tests included:

   - sound velocity measurements
   - uniaxial compression tests with acoustic emission recording
   - brazilian tests
   - three point bending tests

6. Borehole radar measurements in KGI01 (Ljunggren and Raillard, 1986). The objective was to determine if the hydraulically induced fractures (see above) could be identified by the radar.

7. Correlation between lineaments and permeability values (Ericsson and Ronge, 1986). This study included extensive fracture surveys within the Gideå site and in its surroundings. The fracture/lineament data was compared with K-values obtained from the deep cored boreholes. The study includes a statistical evaluation of well data from the region.

8. Radionuclide deposition and migration within the Gideå site originated from the Chernobyl accident (Gustafsson et al., 1987). This study is presently in progress and includes identification of discharge and recharge areas within the site, gamma spectrometric surface measurements, activity distribution in vegetation, soil profiles, sediments and on rock samples

from outcrops. Also measured are the activity of surface waters, groundwaters (artesian water from borehole HGI20 and from several sections down to about 100 m in borehole KGI02).

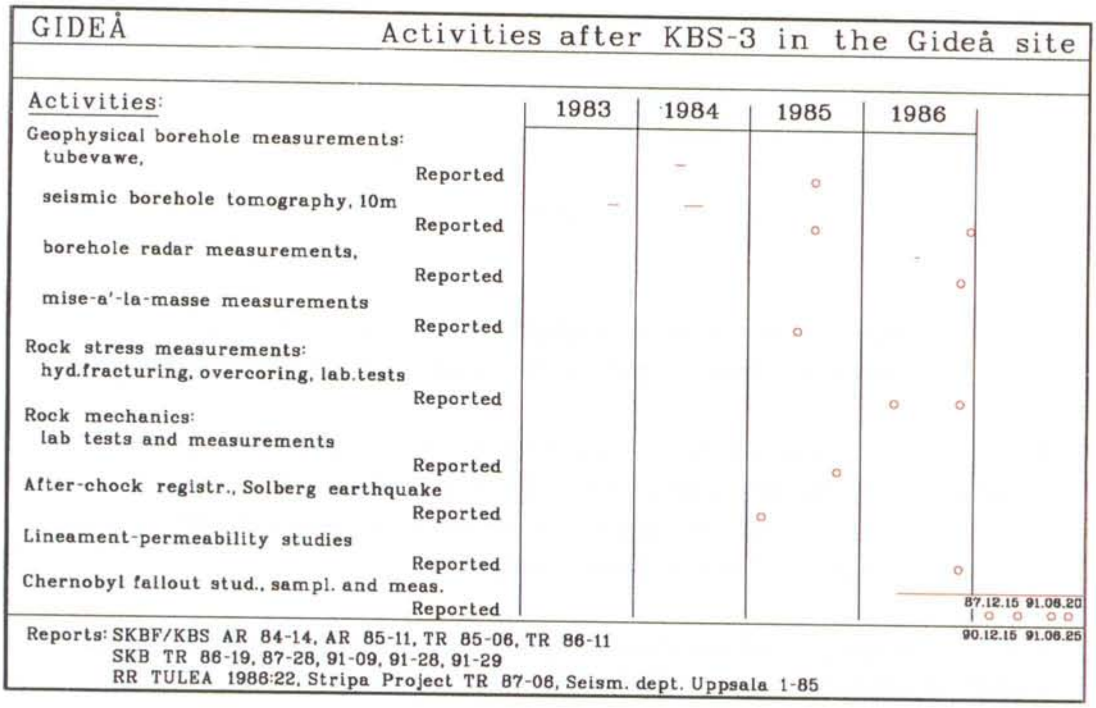

Figure 11. Activity periods for borehole investigations since KBS-3.

4. STORAGE OF INFORMATION IN THE SKB DATABASE

Data from surface surveys

With the exception of results from the refraction seismic survey, all results from the geophysical surface measurements are stored in the SKB database GEOTAB. The database also includes data from the fracture surveys, performed both by SGAB and VIAK. Other "surface data", such as geological maps, lineament interpretations, hydrometerological data and groundwater level maps, have not been stored in GEOTAB.

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 the database. Apart from borehole geometrical data (coordinates, length, dip, deviation etc), this includes results from 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. For the percussion boreholes the database also includes 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).

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

Percussion boreholes. No drilling rate data or data regarding drilling debris are stored. Also, there is no information stored in the data base regarding borehole deviation data, nor locations of major inflows and total water capacities.

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

Geophysical and mechanical measurements. The database does not include: thermal and mechanical parameters measured on core samples and borehole radar, seismic tomography and tube–wave measurements. This is also the case for the mise–á–la–masse measurements and the stress measurements by hydraulic fracturing.

5. GEOLOGIC MODELS

5.1 Regional geologic models

Geology

The regional geologic map, Figure 12, show that the bedrock surrounding the Gideå site consists of a large coherent body of migmatized sedimentary, veined gneiss of Svecokarelian age (c. 1 800 milj. years). To the south there is a body of granite gneiss and to the west younger granite, the so-called post-orogenic Revsund granite. Dolerite constitutes the youngest rock type and has penetrated the old bedrock from the south. The Gideå site is located at the central part of the veined gneiss region. The large areal extent of the veined gneiss also implies a large depth extent. Because of this, no regional 3D models of lithological boundaries were made.

A regional geologic event that have affected the Gideå site was intrusions of the Jotnian dolerite dykes at 1 215 million years ago (Welin and Lundqvist, 1975). The dykes commonly appear as frequent, east-west oriented dykes and as thick gently dipping sheets. The vertical dykes are commonly between 0.5-15 m wide, while the dolerite sheets might be between one hundred to several hundred meters thick, lopolithic and semi-circular (Larson, 1980). The sheets dip eastwards towards central points outside the coastline, where the feeder dykes are assumed to be located. The northern part of one of these doloritic sheets is located in the region south to southeast of the Gideå site (colored green on the regional geologic map, Figure 12). Depending on assumed dip, the width estimates for this sheet varies between 100-300 m. The sheet was probably located in the now eroded bedrock above the Gideå site, and it affected the surrounding bedrock by heating. However, no study of this effect on the bedrock at the Gideå site has been made.

Lineaments

Regional lineaments have been interpreted from topographical maps in the scale 1:50 000. The resulting map is presented in Figure 13. No regional tectonic 3D model was made regarding block faulting nor regarding plastic deformation (folding).

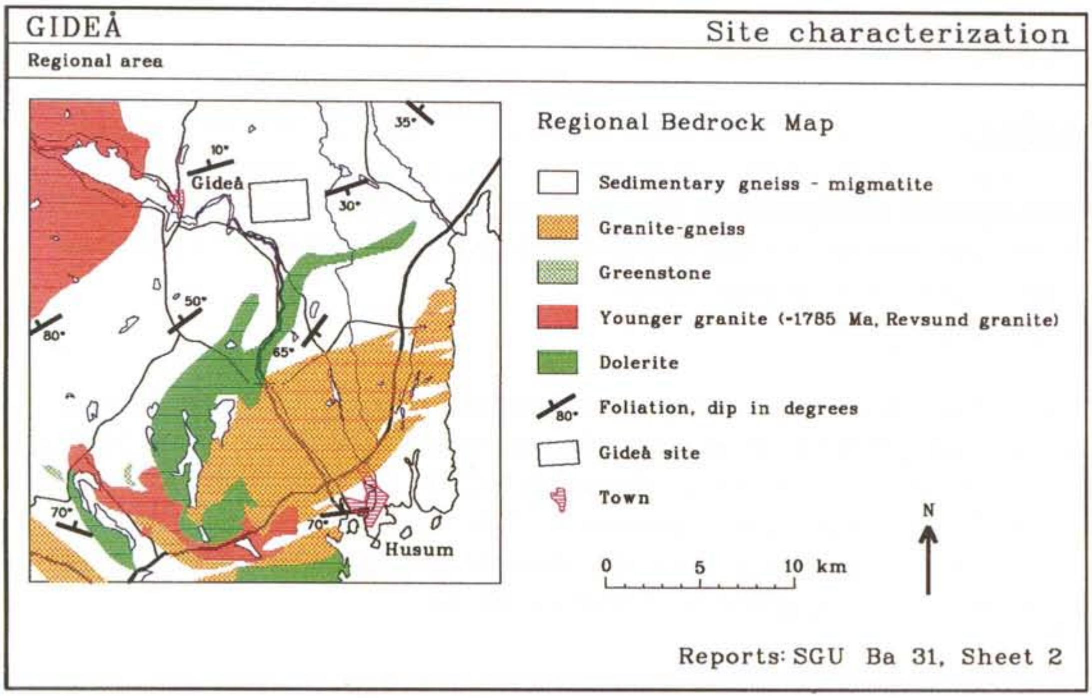

Figure 12. Distribution of rock types in the Gideå region (from Lundqvist, 1987).

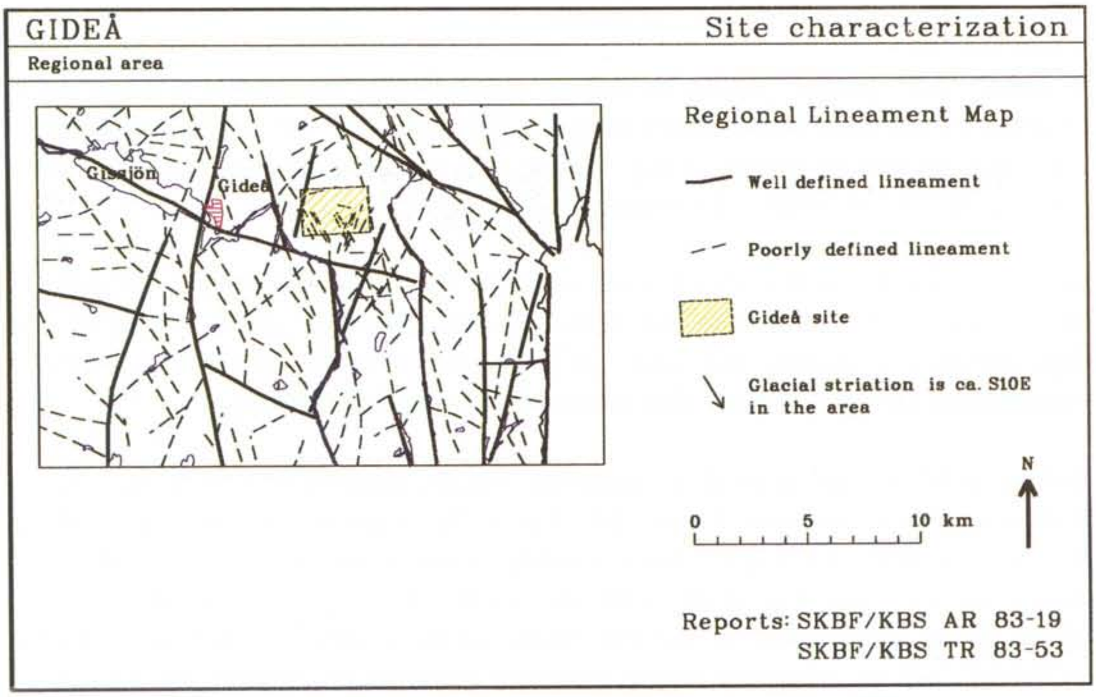

Figure 13. Lineaments in the Gideå region interpreted from topographical maps in scale 1:50 000 and air–photos in scale 1:20 000.

5.2 Geological characteristics of the Gideå site

Rock types

Migmatized sediments dominates the bedrock at the Gideå site, Figure 14. The migmatization of the sediments has resulted in two rock types; veined gneiss (main rock type) and migmatite granite (subordinate rock type). These rocks were intruded by late Sveco-karelian granitic dykes (c. 1 800 milj. years) and Jotnian doleritic dykes (1 215 milj. years).

The veined gneiss is grey and fine to medium grained. The rock forming minerals (determined on four samples) are quartz (39–76 %, mean 56%), biotite (5–35 %, mean 19%), plagioclase (2–24 %, mean 13%), microcline (2–11 %, mean 6%) and muscovite (0–7 %, mean 4 %). The gneiss contains sulphide minerals in small amounts, usually pyrrhotite and pyrite in the form of small aggregates or fracture fillings.

Partial melting of the metasediments during the migmatization has resulted in the formation of irregular granitic bodies, migmatite granite, which are roughly conform with the gneissic structure of the rock. The granitic bodies contains cm–sized feldspar porphyroblasts. The contacts to the surrounding veined gneiss are well–welded. No major coherent body of migmatite granite was found during the surface mapping.

Svecokarelian granitic dykes of mainly granodioritic composition have been mapped in the drill cores. Since they are foliated they are described in the core logs as granite gneiss. They occupy 6% of the total core length. They are interpreted to follow the regional foliation.

All the rocks described above were affected by the Svecokarelian orogeny and as a result they are foliated. This foliation generally trends northeast with dips commonly varying between 10–30 degrees towards northwest. Other orientations of the foliation also occur which implies folding.

Jotnian dolerites are present as frequent, steeply dipping dykes of varying thickness and extensions, Figure 14. The strike is generally east–west. They are grayish black with grain sizes varying between fine to medium. Most dykes are less than 1 m wide, with the exception of two c. 2–10 m wide dykes in the central part of the site. Some of the doloritic dykes are possible to identify on the magnetic maps, and thus possible to identify for longer distances. According to the interpretation of the magnetic survey an average distance between the dykes are 200–300 m.

Pegmatite occurs as minor bodies and as meter–wide dykes. The pegmaties are well–welded to the surrounding bedrock. Detailed information of the distribution of rock types in each of the cored boreholes is presented Appendix B.

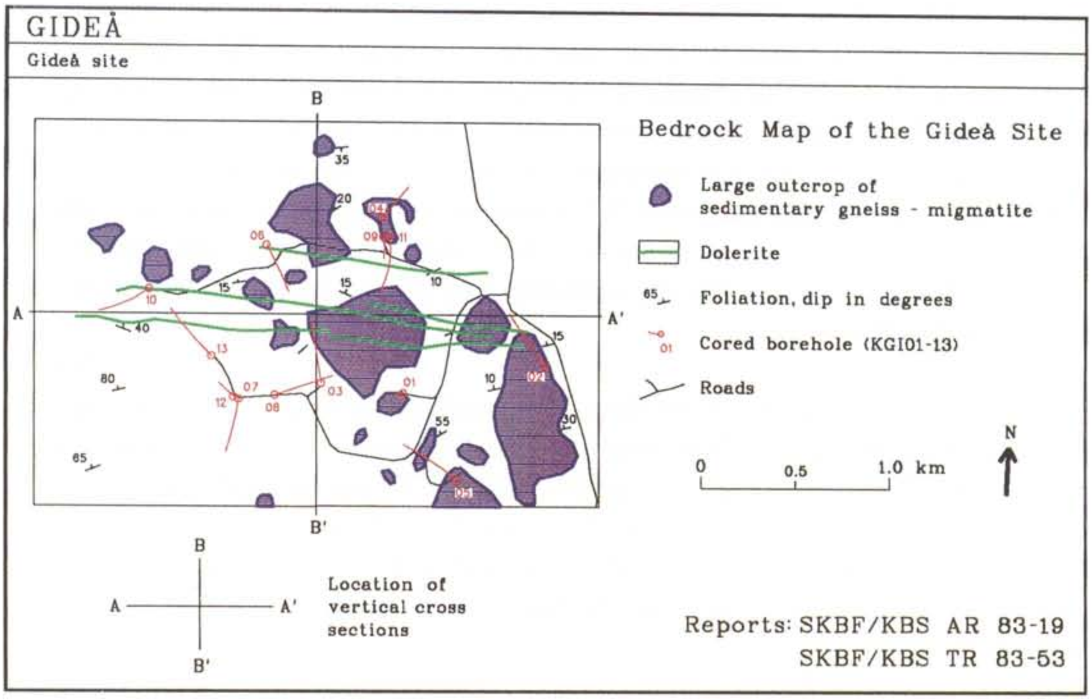

Figure 14. Bedrock map of the Gideå site.

Fractures

Fractures have been mapped on outcrops by a scan–line technique. The fractures have two main orientations, viz. north and northeast. The latter direction is in accordance with the foliation. The fracture frequency determined by these scan–line surveys is 1.2 fr/m (for fractures longer than 0.5 m). Based on a fracture mapping of the Gideå site and its surroundings, including the Gissjö hydropower tunnel, Ericsson and Ronge (1986) found four main fracture directions north–south (tension), east–west (tension), N30°E (shear) and N60°W (shear).

Down to 400 m depth the average fracture frequency in the drill cores is rather high; 4.0 fr/m. However, below this depth the fracture frequency decreases to about 2.0 fr/m below 500 m depth. The location of sections with high fracture frequency in each of the cored boreholes are shown in Appendix B.

The average fracture frequency for veined gneiss in the drill cores is 4.2 fr/m and for granite gneiss 7.4 fr/m. In dolerite the fracture frequency is markedly higher, 20.6 fr/m.

5.3 Fracture zones

Fracture zones have mainly been interpreted from geophysical maps and profiles. In addition, lineaments interpretated on air–photos and topographical maps have been used to some minor extent. The physical conditions at the Gideå site is well suited for geophysical measurements, due to the high degree of outcrops and restriced thin cover of moraine. This setting is ideal for electrical measurements as no electrical conductive layer will disturb the information from the underlying bedrock. The setting is also well suited for seismic refraction surveys.

Most interpreted fracture zones from the geophysical maps have been tested by percussion boreholes. Disturbances in the drilling rate and/or large inflows was regarded as indications of fracture zones. The information from the percussion boreholes was used to; 1) check if the geophysical anomaly represent a fracture zone, and 2) estimate a dip of the zone and 3) obtain qualitative information regarding its degree of fracturing and hydraulic properties.

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.

All together, 11 fracture zones have been defined at the Gideå site. The properties of these zones have been examined by 13 cored boreholes and 24 percussion boreholes. Seven of the fracture zones have been examined by cored boreholes at 16 locations. A summary of all interpreted fracture zones are presented in Table 3. The locations of interpreted fracture zones at the ground surface are shown in Figure 15, while the locations at 600 m depth is shown in Figure 16. North–south and east–west cross–sections are shown in Figure 17.

The fracture zones at Gideå are dipping 30–90 degrees from the horizontal. No subhorizontal fracture zones have been identified, although there are indications of horizontal release joints down to 100–200 m depths.

Within the fracture zones there are, as a rule, one or more sections of crushed bedrock, generally one or a few dm wide. Generally, the fracture zones also contains parts with low fracture frequency. Commonly occurring fracture minerals in the local fracture zones are calcite, chlorite, laumontite, pyrite and the clay minerals smectite and illite.

Fracture zones and dolerite dykes commonly contains parts with clay–altered rock. This alteration is thought to be the main reason for the low hydraulic conductivity commonly found for both the fracture zones and the dolerite dykes at the Gideå site. Table 3 presents geometrical data for interpreted fracture zones together with data regarding their hydraulic conductivities and fracture frequencies. The latter has been calculated from core logs.

Appendix B presents for each borehole the main results regarding rock types, degree of fracturing, sections with increased hydraulic conductivity and intersections with fracture zones.

Descriptions of each interpreted fracture zone are presented in Appendix C. The descriptions include on what basis each fracture zone has been interpreted, as well as general comments regarding the reliability of the interpretation. Also, general geological characteristics for each zone are presented.

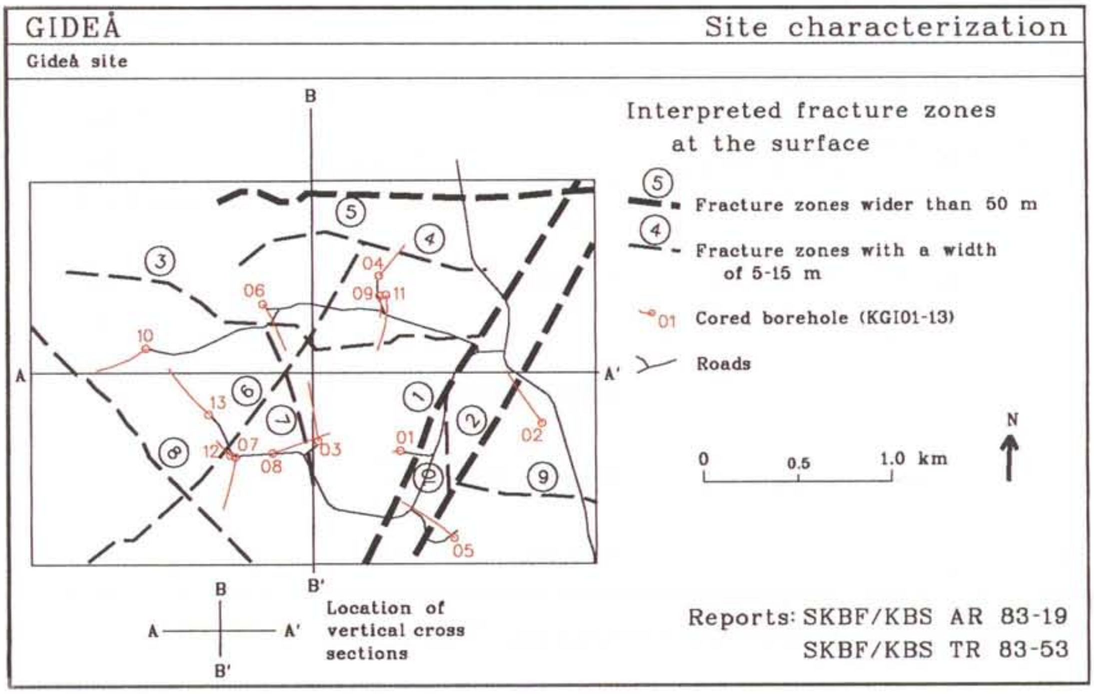

Figure 15. Interpreted fracture zones at the ground surface.

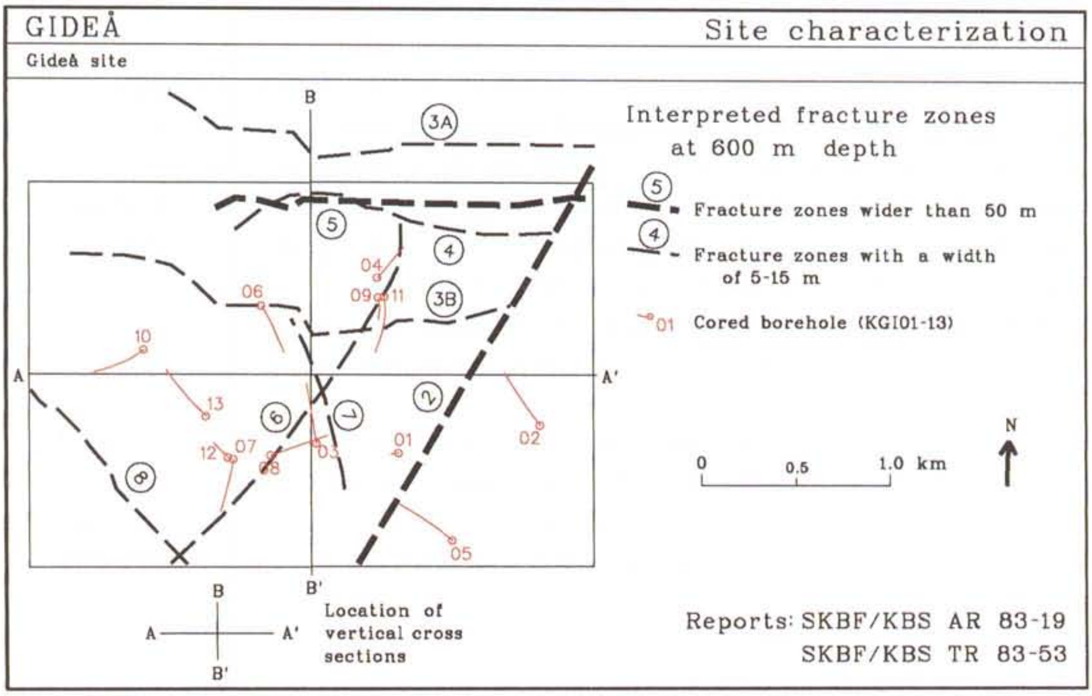

Figure 16. Interpreted fracture zones at 600 m depth.

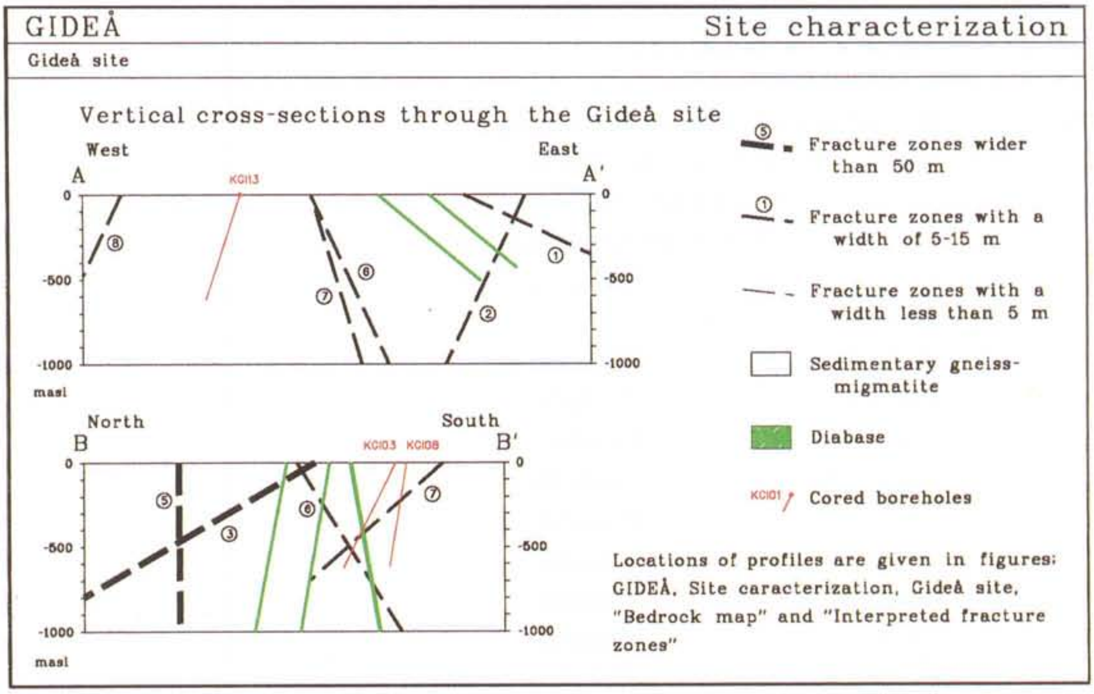

Figure 17. Vertical cross–sections through the Gideå site. Locations of sections is indicated in Figures 13 and 16.

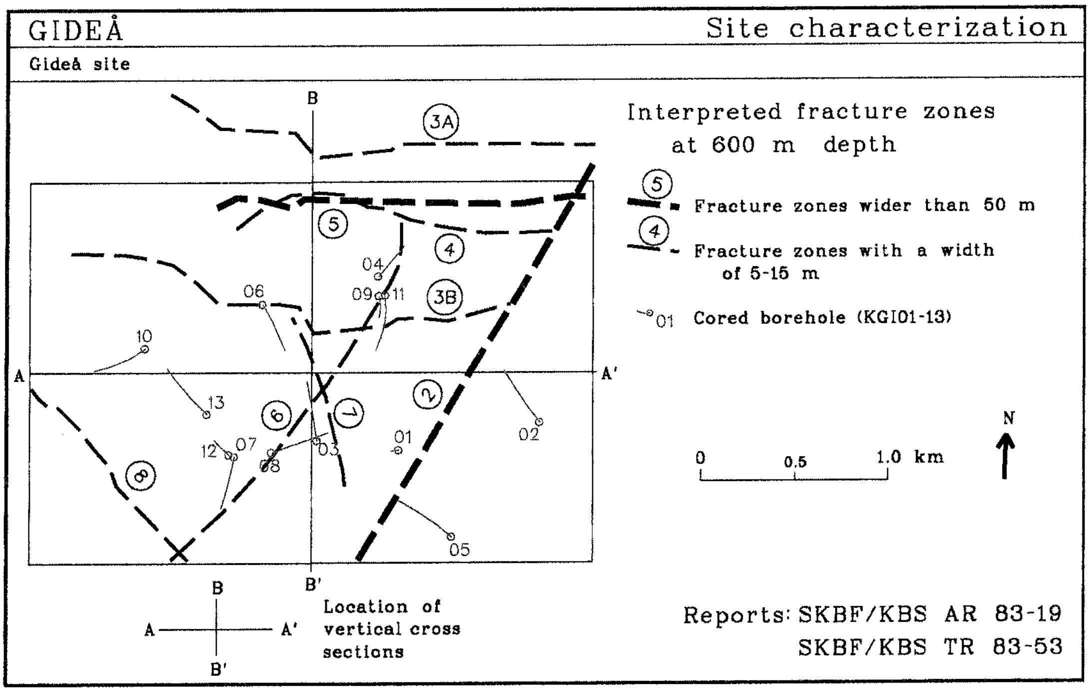

Figure 16. Interpreted fracture zones at 600 m depth.

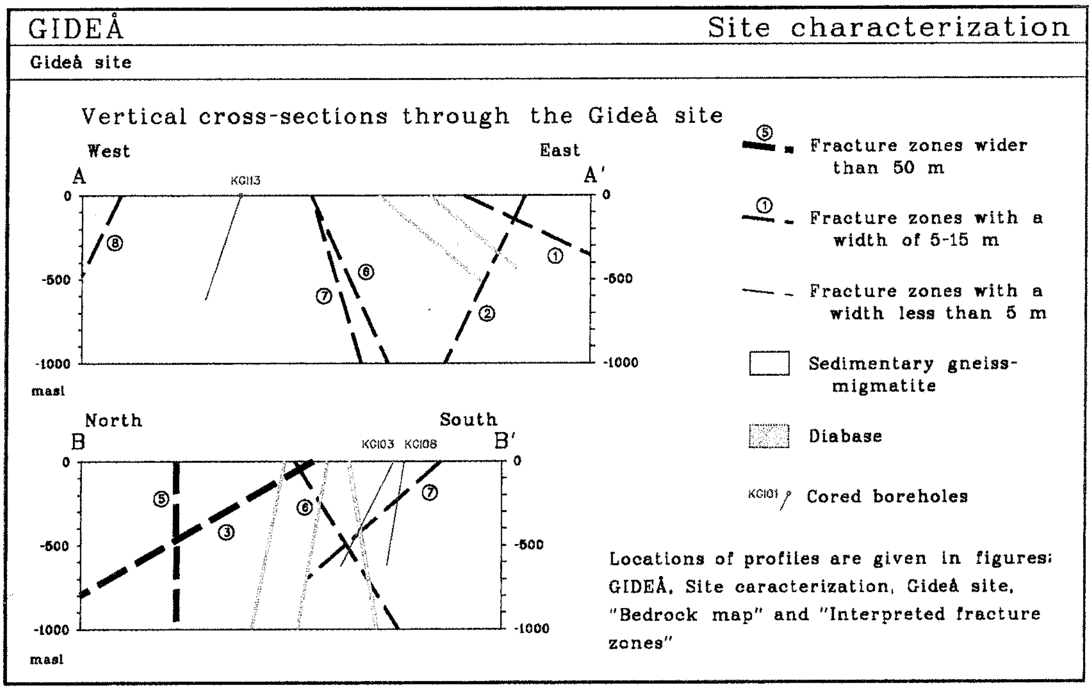

Figure 17. Vertical cross-sections through the Gideå site. Locations of sections is indicated in Figures 13 and 16.

5.4 Validity of models

Rock type distribution

The outcrop and core mapping at the Gideå site and its surroundings have not been compiled into 3D geological models of rock type distribution. It was not considered necessary at the time of geologic mapping. Later borehole measurements showed however, that although veined gneiss is the main rock type at Gideå, other rock types, mainly steeply dipping doleritic dykes and granitic dykes (granite gneiss), may have a substantial influence on groundwater flow and possible also on groundwater chemistry due to different hydraulic properties and chemical composition.

The existing core mapping does not well distinguish between migmatite granite and granitic dykes. Before a 3D model is made some remapping of cores will therefore be necessary. A subhorizontal orientation is presumed for the granite gneiss, but this has not been demonstrated.

Interpreted fracture zones

The nomenclature suggested by Bäckblom (1989) are used here to describe the "level of reliability" for each interpreted fracture zone, see Table 4. Three levels are identified (from low to high reliability), possible, probable and certain. Reasons for classification of fracture zones in different "reliability levels" are discussed in Appendix C.

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

Fracture zone	Reliability
Zone 1	Probable
Zone 2	Probable
Zone 3A	Certain
Zone 3B	Probable
Zone 4	Possible
Zone 5	Possible
Zone 6	Possible
Zone 7	Possible
Zone 8	Possible
Zone 9	Possible
Zone 10	Possible

As seen in Table 4, the reliability of most interpreted fracture zones are rather low. With the exception of Zone 3A, fracture zones at Gideå should be regarded as "possible" or "probable" zones.

One explanation to this uncertainty is the rather high fracture frequency (4 fr/m) generally found in most boreholes. This make it difficult to distinguish the fracture zones from the "background fracture noise". The high fracture frequency also permits many alternative interpretations of fracture zones.

It should also be noted that during the KBS-3 studies a conservative approach were taken when interpreting fracture zones. To avoid discussions of possible additional fracture zones, all suspected fracture zones were included in the model, even if the indications were weak. Also, if alternative dips were possible the most unfavourable for a repository was selected.

Regarding the possible occurrence of subhorizontal fracture zones it was considered conservative to not include such zones in the model since generic modelling showed that a conductive subhorizontal fracture zone in the bedrock above a repository would substantially reduce the groundwater flow at repository level. Because of this reason, and also because of the general lack of time for detailed analysis during KBS-3, it was decided not to investigate the possibility of subhorizontal fracture zones at the Gideå site.

In conclusion, most interpreted fracture zones at the Gideå site should be regarded as uncertain. The general tectonic character of the Gideå site also implies that further work on detailed correlation between boreholes and between surface and borehole data might identify additional fracture zones. In particular, this is the case for gently dipping and subhorizontal fracture zones.

6. GEOHYDROLOGICAL MODELS

6.1 Available data and numerical model

The geoinformation used for hydraulic modelling 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. To provide an estimate on "investigation density" also the number of tests per km^2 is presented in the table. In total, 13 cored boreholes were tested hydraulically (cf. Appendix A).

The geohydrological modelling of the Gideå site 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). Model geometry and boundary conditions were obtained using geological and geophysical interpretations of fracture zones, hydrological data and a map of the groundwater table. The core mapping were used for the division in different rock types. The material properties, i.e. hydraulic conductivity, were derived from the single hole water injection tests and from the interference test. The hydrometeorological data and piezometric head 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 in the Gideå site.

Number of sections	Section length (m)	No of tests/km^2	Test type
308	25	51	double-packer
17	10	3	double-packer
85	5	14	double-packer
81	3	14	double-packer
144	2	24	double-packer
4	107-287	0.7	single-packer
639		107	all sections

The total number of elements in the mesh of the model was 2464, distributed in eight horizontal layers of which two layers represent fracture zone intersections. The element mesh contained 10751 nodal points. The fracture zones was modelled with one row of elements. At intersections between fracture zones a 20 m thick element layers was introduced. 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.

6.2 Regional model

No regional hydraulic modelling of the Gideå area has been performed.

6.3 Local model

Modelled domain and boundary conditions

A contour map of the (mean) groundwater table in the Gideå area is shown in Figure 18. The central part of the area mainly constitutes a recharge area for groundwater, whereas a local discharge area is located in the lowland towards the east. The shallow groundwater flow is primarily directed towards the regional lineaments coinciding with the river Gideälven in the west and the stream Husån in the east. A local elevated area is located to the west of the Gideå site.

The modelled domain extends somewhat outside the Gideå site, see Figure 19. Within this area the topography of the groundwater table is rather flat, ranging from about 80 m to 125 m above the sea level. The modelled domain is in the north bounded by Zone 5. In northwest, southwest and south the outer boundaries coincide with topographical groundwater divides, see Figures 18 and 19. The eastern boundary is considered as a symmetric discharge boundary, corresponding to the existing local discharge area at Zones 1 and 2, see Figure 20.

The upper boundary condition on the top of the modelled domain corresponds to the elevation of the groundwater table, i.e. zero prescribed pressure. The applied upper boundary condition within the modelled domain in digitized form is shown in Figure 19 as a contour map and as a vertical cross-section. The minor elongated area with increased density of contour lines towards NW in the contour map (a local sink of about 10 m) is most likely an artefact stemming from the interpolation routines used in the modelling. It does however not affect the results of the modelling since the area is very limited and the head change is small in relation to the total head changes within the area.

At the northern boundary of the modelled domain a non-flow boundary condition is applied on the northern side of Zone 5 (c.f. Figure 20). Non-flow boundary conditions were also applied along the topographical groundwater divides in NW, SW and S and along the discharge boundary in the east. At the lower boundary of the modelled domain a non-flow boundary condition is applied at 1500 m depth.

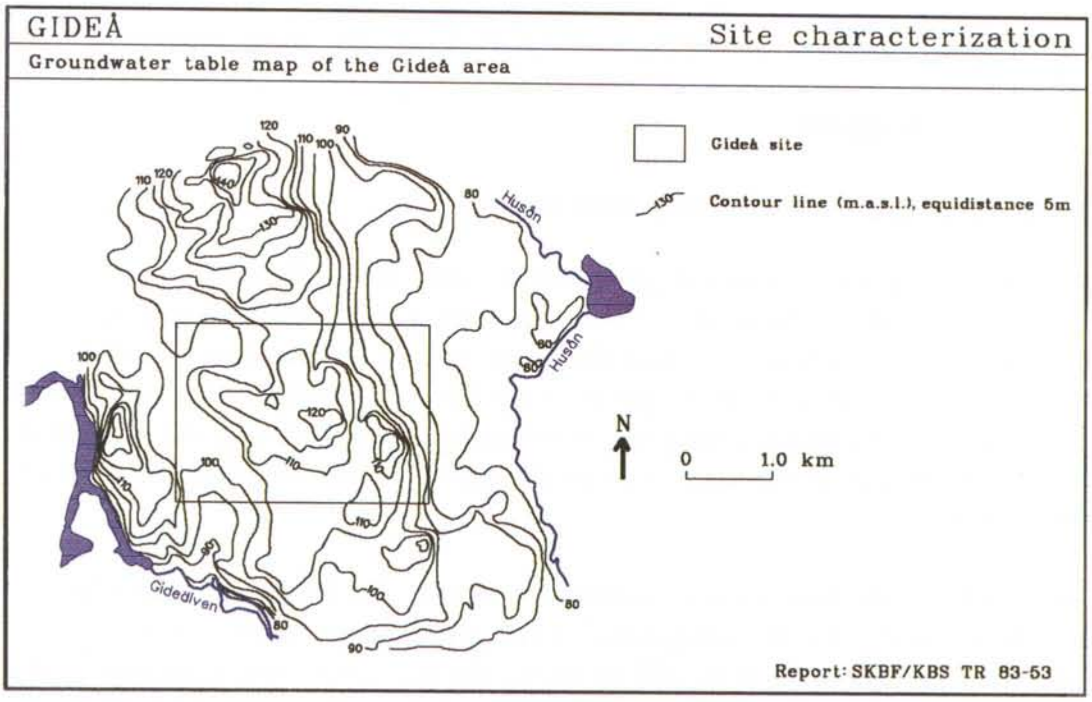

Figure 18. Groundwater table of the Gideå site and its surroundings.

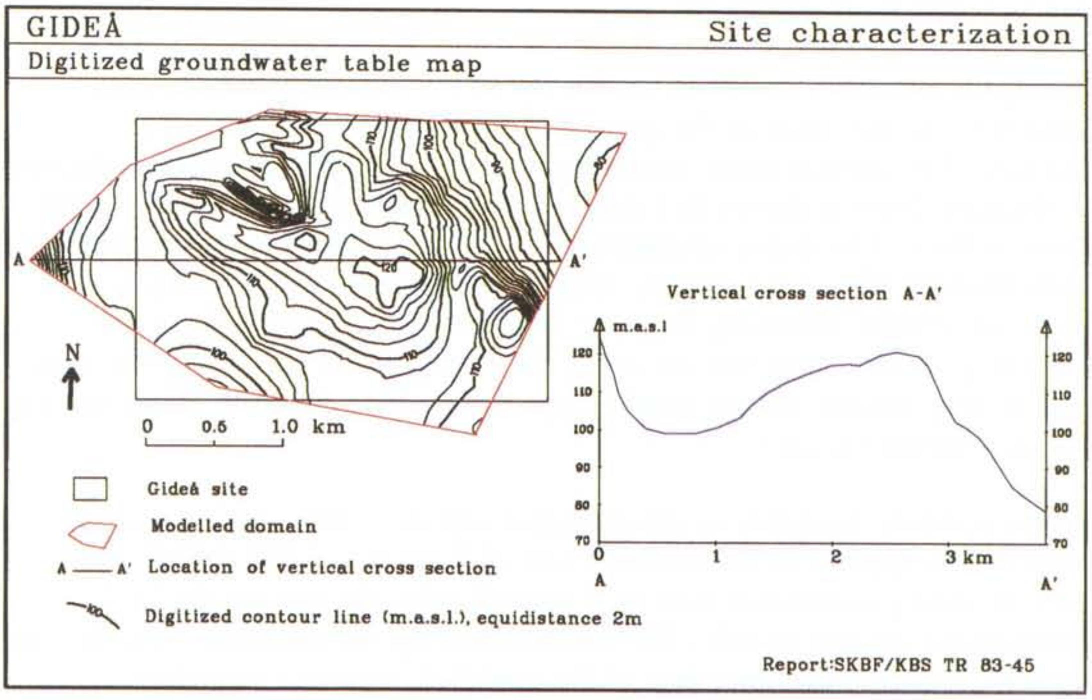

Figure 19. Digitized map of the groundwater table at the Gideå site used in the numerical modelling. Also the modelled domain is outlined.

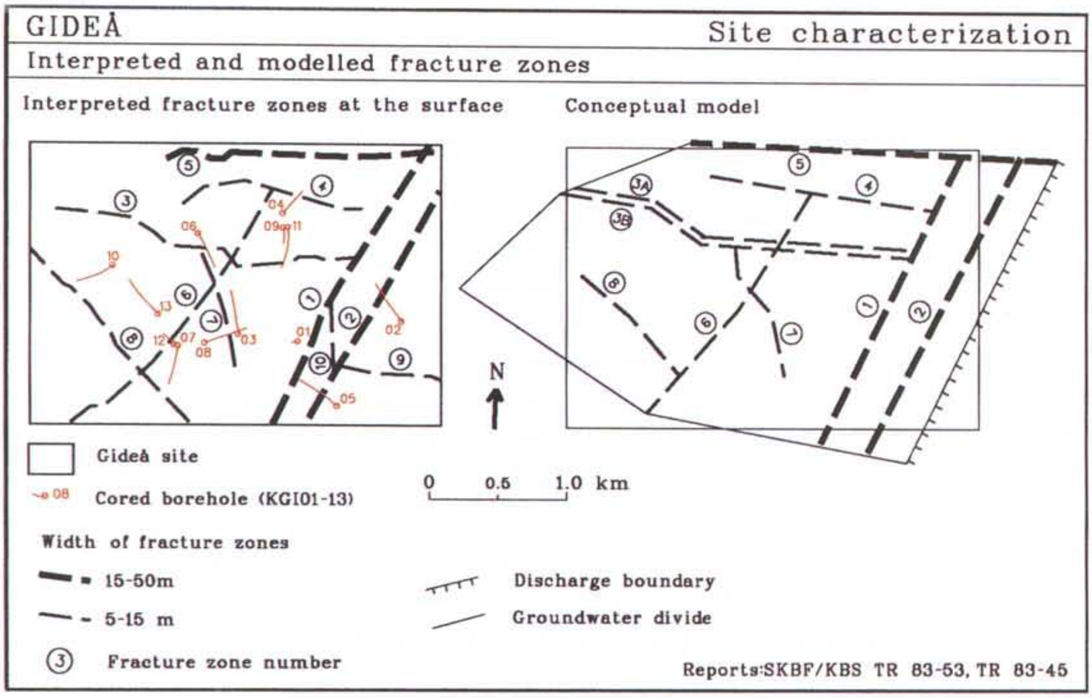

Figure 20. Interpreted and modelled fracture zones at the surface at the Gideå site.

Hydraulic units

The main hydraulic units included in the model are 1) the rock mass (excluding interpreted fracture zones), and 2) the local fracture zones. The surface locations and the width and strike of the interpreted and modelled fracture zones are presented in Figure 20 and Table 6, respectively. The intersections between boreholes and fracture zones are described in Table 3.

Zones 3A and 3B are assumed to intersect at the surface. Several of the other fracture zones are inclined and intersect at depth. The moderately dipping Zone 1 and the steeply dipping Zone 2 intersect at a depth of about 125 m. Also the gently dipping Zone 3A and the vertical Zone 4 intersect at this depth. Zones 1 and 3A also cut through the vertical outer model boundaries in the east and north, respectively, at a depth of about 500 m. As seen in Table 6 the deviations between the interpreted and modelled fracture zones are small.

Table 6. Interpreted and modelled fracture zone properties in the Gideå site. After Carlsson et al., (1983).

Fracture zone	Interpreted width (m)	Interpreted dip(°)	Modelled width (m)	Modelled dip(°)
1	22–24	40SE	25	40SE
2	11	70NW	15	70NW
3A	10–24	30N	12	30N
3B	4–10	80N	10	80N
4	10	90	5	90
5	50*	80N*	50	90
6	1–8	70SE	5	70SE
7	1–7	75E	5	75E
8	10*	70SW*	10	70SW

* Interpreted from geophysical information

The rock mass in the Gideå site is composed of veined gneiss with intercalated layers of granite gneiss (granitic dykes). At the time of the modelling, the granitic strata were assumed to be subhorizontally layered and continuous over long distances. Therefore, it was decided to divide the rock mass into two hydraulic substructures, i.e. veined gneiss and granite gneiss. However, as discussed in section 5.4, the subhorizontal distribution of the granite gneiss, assumed in the modelling, should be regarded as uncertain.

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 at the Gideå 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.

The rock mass were subdivided into sections with only veined gneiss and sections with both veined gneiss and granite gneiss rocks (almost no section consisting of only granite gneiss was found). This subdivision in rock types was made from the core mapping. Regression curves of effective hydraulic conductivity versus depth were made for these two rock types and also for all measured sections regardless of rock types (curves I–III in Figure 21).

The regression curve for the granite gneiss (curve III) was calculated as the difference between the total section transmissivity and the estimated transmissivity for the interval consisting of veined gneiss (from regression Curve II). The resulting transmissivity was divided by the assumed length of granite gneiss in the section (Carlsson et al., 1983). The regression curves are based on a power function of the following form:

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

where K_e is effective hydraulic conductivity, z is vertical depth below ground surface and A and b are constants. The effective hydraulic conductivity of the different hydraulic units was calculated from geometric means of all measured data in 25 m sections, assuming a 3D flow geometry for the rock mass and a 2D flow geometry for the fracture zones. Measured data below the lower measurement limit were assigned the actual value of this limit.

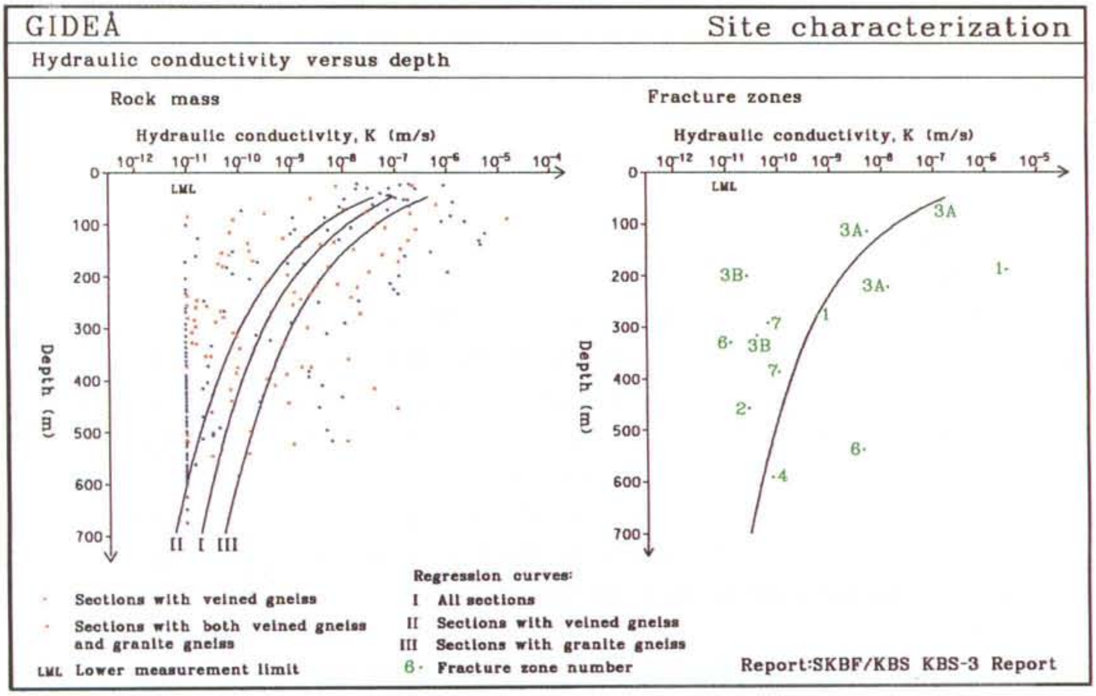

Figure 21. Hydraulic conductivity versus depth for rock mass (left) and for fracture zones (right).

Table 7 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 structures and rock types together with the number of data used (n) and the regression coefficients (r^2). In the table also the calculated anisotropic hydraulic conductivities are presented.

Table 7. Constants A and b in Eqn. (6.1), number of data (n) and regression coefficients (r^2) for the different hydraulic structures and rock types together with calculated anisotropic hydraulic conductivities in the Gideå site. After Carlsson et al., (1983).

Hydraulic structure	A	b	n	r^2
Rock mass	0.0532	3.33	264	0.46
Veined gneiss	0.0263	3.39	164	0.52
Granite gneiss	0.4000	3.49	85	0.28
K_e parallel to structure	0.0470	3.43		
Local fracture zones	0.0846	3.33	24	0.32

Figure 21 shows that the estimated hydraulic conductivity of the granite gneiss is significantly higher than that of the veined gneiss and even higher than the conductivity of the local fracture zones. This fact justifies the treatment of the granite gneiss as a separate hydraulic unit.

The assumed occurrence of alternating strata of veined gneiss and granite gneiss implies that anisotropic hydraulic conditions would prevail in the rock mass. Consequently, in directions parallel to the orientation of the granite gneiss strata the hydraulic conductivity of the rock mass was represented by the arithmetic mean of the two rock types in the modelling. Perpendicular to the orientation of the strata the hydraulic conductivity was represented by the harmonic mean. The effective hydraulic conductivities in the two directions were weighted in proportion to the occurrence of the two rock types as described by Carlsson et al. (1983). In the Gideå site the granite gneiss was assumed to constitute about 6 % of the rock mass.

The measured hydraulic conductivity of the fracture zones is, at least for depths greater than 200 m, very low, see Figure 21. As discussed in Chapter 5, one explanation might be fracture sealing by clay alteration.

One interference test in a fracture zone in the upper 100 m of the bedrock (Anderson and Hansson, 1986) resulted in an hydraulic conductivity of $0.6–9.3 \cdot 10^{-7}$ m/s, which is in good agreement with the mean value of the hydraulic conductivity of the local fracture zones in this depth interval, see Figure 21.

The conductive fracture frequency (CFF) in the rock mass was estimated from statistical analysis of K–values from 2 m tests in borehole KGI07 (Carlsson et al., 1983). The conductive fracture frequency in the rock mass ranges from 0.38–1.53 fr/m in the (vertical) depth interval 200–600 m of this borehole. Subsequently, Osnes et al. (1988) estimated the CFF by a probabilistic model using hydraulic conductivity data from 25 m tests in all boreholes at the Gideå site. From these tests the CFF in the rock mass was estimated to 0.043–0.055 fr/m.

Model cases

Two cases were initially modelled in the Gideå site in the KBS–3 study (Carlsson et al., 1983). In Case 1 both the rock mass and fracture zones were modelled as separate isotropic continua with hydraulic conductivity versus depth functions according to Table 8. In Case 2 the rock mass was assumed to have uniform anisotropic hydraulic properties parallel and perpendicular to the postulated subhorizontal granite gneiss strata. The hydraulic conductivity functions applied for the rock mass and local fracture zones in the modelling are shown in Table 8.

Table 8. Constants A and b in Eqn. (6.1) representing the hydraulic conductivity functions applied for the rock mass and fracture zones in the different model cases in the Gideå site. From Carlsson et al. (1983).

Model case	Rock mass		Fracture zones	
	A	b	A	b
1 Isotropic	0.050	3.33	0.00138	2.79
2 Anisotropic				
horizontally	0.047	3.43		
vertically	0.026	3.40	0.08460	3.33

Results

The distribution of the groundwater potentials and groundwater flow rates were calculated in a number of horizontal planes at different depths for the isotropic and anisotropic case. The calculated ranges and representative values of the groundwater flow rates in the rock mass at 400 m, 500 m and 600 m below the ground level for the two cases are shown in Table 9. The most significant effect of the anisotropy is a lowering of the hydraulic gradients in the horizontal plane in the latter case. This results in a decrease in the flow rate with a factor of about 2–3, compared to the isotropic case.

The calculated hydraulic gradients decrease faster with depth in Gideå than e.g. in the Fjällveden site, both for the isotropic and anisotropic case. This is probably due to that the intersecting inclined and vertical fracture zones in Gideå relieve the gradients more effectively (Carlsson et al., 1983).

The groundwater flow distribution in the rock mass at a potential repository depth of 600 m for the isotropic case is illustrated in Figure 22. The general groundwater flow pattern at depth in the Gideå site is largely governed by the surficial recharge at the central plateau from which groundwater flows radially in all directions.

Table 9. Calculated groundwater flow rates (ranges and representative values) in the rock mass at different depths for the two model cases in the Gideå site (From Carlsson et al., 1983).

	Groundwater flow rate ($ml/m^2/year$) Isotropic case		Groundwater flow rate ($ml/m^2/year$) Anisotropic case	
Depth(m)	Range	Repr. value	Range	Repr. value
400	10–50	40	10–50	20
500	10–20	15	5–15	5
600	5–15	10	2–4	3

Relevance of results

The relevance of the numerical model was assessed from calculations of groundwater recharge and mass balance for the individual finite elements. Furthermore, calculated groundwater potentials along boreholes were compared with measured piezometric heads in the tested sections.

The groundwater recharge in the Gideå site was estimated by Carlsson et al., (1983) for the isotropic and anisotropic case. 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 111 mm/year and 73 mm/year, respectively, for the isotropic and anisotropic case.

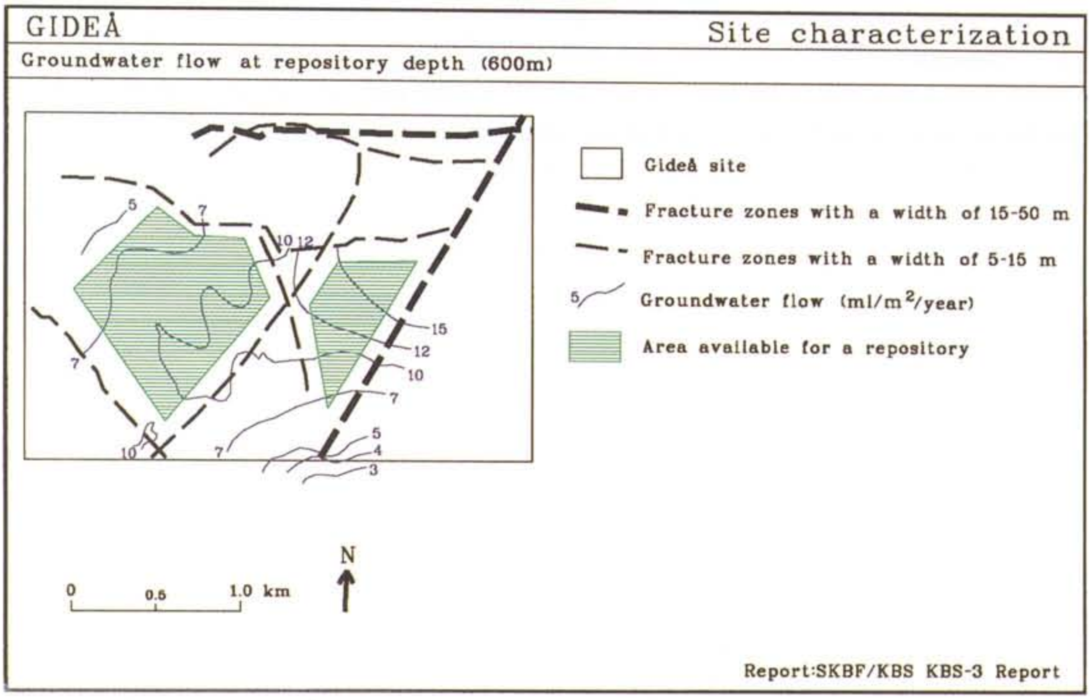

Figure 22. Groundwater flow at 600 m depth for isotropic hydraulic conductivity of the rock mass (see text).

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 29 % and 24 % for the isotropic and anisotropic case, respectively. Elements with high deviations are located close to the top surface and fracture zones. Particularly fracture zone intersections (both horizontal and vertical) appear to affect the solution negatively.

The groundwater potentials were calculated along lines coinciding with the boreholes KGI03, KGI07 and KGI08 for the isotropic case by Carlsson et al., (1983), see Figure 23. In the figure also the estimated piezometric heads in conjunction with the injection tests in the 25 m long test sections are shown together with the potential at the top of the boreholes.

It should be observed that the measured data generally represent short–time measurements of piezometric head and may thus be uncertain, particularly in low–conductive sections. The data from borehole KGI07 are considered as less uncertain since these data are obtained from long–term piezometric measurements. Although the trends of the measured and modelled potentials are similar, as can be seen in Figure 23, the correlation is not perfect.

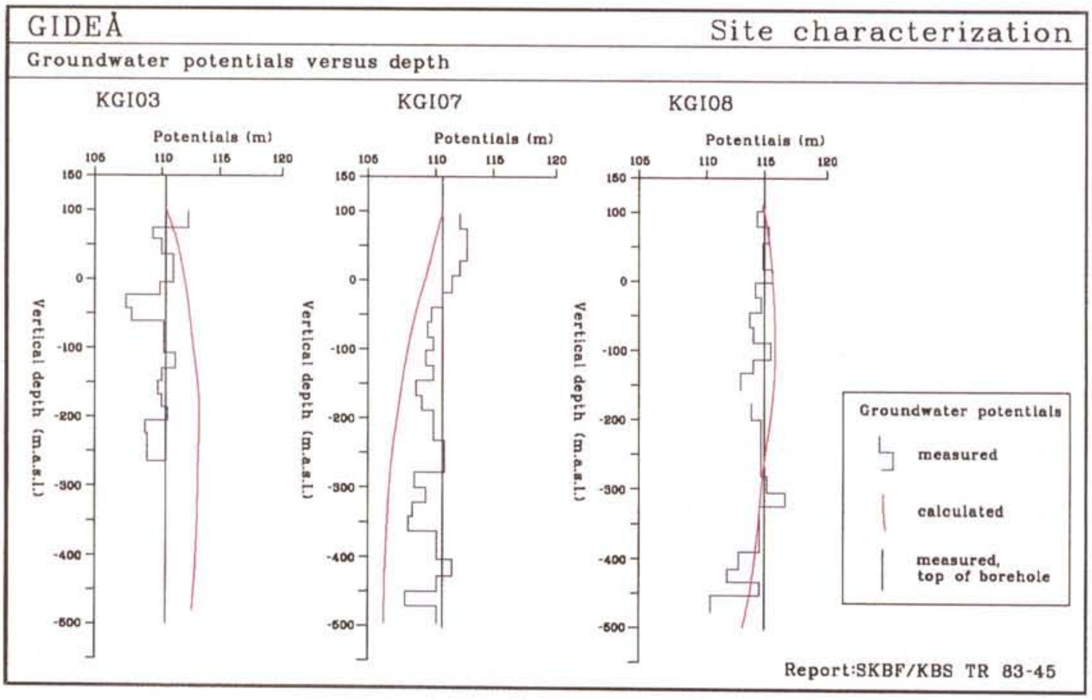

Figure 23. Groundwater potentials in 25 m sections versus depth for boreholes KGI03, KGI07 and KGI08.

6.4 Validity of models

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

Boundary conditions

Since no modelling on a regional scale was performed of the Gideå site, the groundwater flow and head conditions at the outer boundaries of the local model were assumed. It is however difficult to assess the uncertainties in these assumptions without making sensitivity studies.

There also exist some uncertainties in the geological interpretation of the fracture zone bounding the modelled domain in the north (Zone 5) since it is not penetrated by any boreholes. Thus, the non-flow boundary condition applied for this zone in the model may be critical. The non-flow boundary conditions applied along the topographical groundwater divides in NW, SW and S, and along the discharge boundary in the east, are also considered as uncertain since they are based on surface-near conditions which may not be applicable at depth.

Hydraulic units

The division of the bedrock in the Gideå site in: 1) rock mass, and 2) local fracture zones should be considered as highly preliminary and uncertain. As described earlier no 3D geologic model exists. Thus, the subdivision of the rock mass into different rock type units is speculative, especially concerning the geometrical assumptions. Also the results of the statistical analyses of the hydraulic properties of the fracture zones are highly uncertain. 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. However, due to the lack of data all fracture zones at Gideå were statistically treated as one hydraulic unit (c.f. Figure 21).

Hydraulic conductivity

The derived hydraulic conductivity versus depth functions are uncertain due to the large scatter of the data, Figure 21. The averaging process also subdues extreme (high) values. For the Gideå 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 7, the correlation coefficients are generally rather low for the derived conductivity functions. Other uncertainties are assumed flow geometries in the calculation of the effective hydraulic conductivity, and how to treat data which are below the lower measurement limit.

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).

7. GROUNDWATER CHEMISTRY

7.1 Scope and reliability of samples

The groundwater chemistry data from the Gideå site was obtained during the KBS-3 investigations 1981-1983. These results, including sampling methods, are presented by Laurent (1983) and Wikberg et al. (1983). The groundwater was sampled in five sections in each of the boreholes, KGI02 and KGI04. The sampled sections in borehole KGI02 were 157, 288, 353, 478 and 528 m while the sampled sections in KGI04 were 91, 212, 385, 498 and 596 m.

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 by Smellie et al. (1985) that only two of the eight sampled sections at the Gideå site was considered relevant for the sampled depth, see Table 8.

Table 8. Groundwater sampling in boreholes KGI02 and KGI04. "Representativity" refers to if a sample is considered as representative for the section sampled (Smellie et al., 1985).

Borehole	Sampled section	Representativity
KGI02	178-180	Yes
KGI02	328-330	No
KGI02	400-402	No
KGI02	544-546	No
KGI02	602-604	No
KGI04	96-98	No
KGI04	222-224	Yes
KGI04	404-406	No
KGI04	512-514	No
KGI04	616-691	No

7.2 Results

General chemistry

The chemical composition of the samples from the two boreholes at Gideå is shown in Table 11. The compositions indicate the presence of several main water types: near-surface and shallow groundwaters, intermediate to deep old groundwater (non-saline), and deep to very old groundwater (saline). 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. Two sections very distinctly deviates from this general pattern, and showing a major-ion composition characteristic for an old, saline water (but not marine). These sections are two sections in borehole KGI04 at depths 385 and 596 m, respectively. Here, the dominating ions are sodium and chloride, and the electrolytical conductivity values are significantly higher than for all other sampled horizons at this site.

The two sections that are considered representative for the depth sampled are relatively shallow and consists of the uppermost section in KGI02 at a depth of 157 m, and in KGI04 at a depth of 212 m. Both of these sections show chemical compositions that are characteristic for shallow to intermediate groundwaters, with pH-values around 9 and amounts of the major ions that would be normal for non-saline groundwaters in Swedish crystalline rocks.

Table 11. General chemistry parameters at Gideå, sampled in cored boreholes.

Sampled borehole	Depth m	pH	Conduc-tivity mS/m	Na^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	K^+ mg/l	HCO_3^- mg/l	Cl^- mg/l	SO_4^{2-} mg/l
KGI02	157	8.8	26	50	10	3.3	2.1	161	4.8	3.3
KGI02	288	8.8	27	49	10	2.4	2.2	163	4.7	0.3
KGI02	353	8.6	27	53	10	2.2	1.9	160	5.4	0.2
KGI02	478	8.8	27	51	10	2.2	2.2	160	5.0	0.1
KGI02	528	8.7	27	50	11	2.0	2.2	158	4.6	0.1
KGI04	91	7.9	24	11	33	4.6	2.5	141	1.5	3.3
KGI04	212	9.0	25	49	9	0.9	0.8	133	7.9	0.2
KGI04	385	9.3	68	105	21	1.0	2.1	18	178	0.1
KGI04	498	8.8	23	5	30	4.4	2.7	121	2.2	8.0
KGI04	596	8.0	115	145	58	0.9	3.0	50	260	0.7

There are no general trends with depth considering pH, electrolytical conductivity or the major–ion chemistry at the Gideå site. This is the case especially for KGI02 where all sampled sections show a very uniform chemical composition, typical for shallow to intermediate groundwaters. This is interpreted to be caused by a very dominating hydraulic structure in the uppermost section, with artesian water, influencing all the other sampled sections in the borehole.

Redox–sensitive parameters

A summary of some of the redox–sensitive parameters is presented in Table 12. Generally, the samples collected at this site are in most cases reducing, as is indicated by negative Eh–values. There are no apparent trends with depth in any of the redox parameters in Table 12. However, large negative Eh–values are encountered at depth in borehole KGI04.

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

Table 12. Redox parameters at Gideå, sampled in cored boreholes.

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
KGI02	157	-90	0.14	0.15	0.02	0.02	0.009	0.066
KGI02	288	-60	0.59	0.59	0.03	-	0.005	0.062
KGI02	353	-40	0.47	0.59	0.04	0.10	0.015	0.062
KGI02	478	-90	0.78	0.82	0.02	0	0.015	0.043
KGI02	528	-90	0.63	0.71	0.03	0.01	0.008	0.019
KGI04	91	10	0.75	1.6	<0.01	0.04	0.010	0.058
KGI04	212	-60	0.25	0.28	0.04	0.05	0.012	0.004
KGI04	385	10	0.05	0.10	<0.01	0.25	0.009	0.012
KGI04	498	-50	7.3	8.5	<0.01	0.01	0.007	0.012
KGI04	596	-290	-	0.9	–	0	–	–

Nordstrom and Puigdomenech (1986) also argued that dissolved sulfide is the dominant redox-determining species in groundwaters from Gideå. They also point to the possibility of organic carbon contents being important for redox conditions in Swedish groundwaters. Further, they state that measurements of dissolved sulfide by ion-sensitive electrode at Gideå are not reliable.

Uranium geochemistry

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

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 ground-waters. The isotope ratios in KGI02 are relatively high, indicating that the groundwaters have had long residence times in contact with the bedrock.

Table 13. Uranium geochemistry at Gideå.

Sampled borehole	Depth m	U ppb*	U ppb**	$^{234}U/^{238}U$ act. ratio
KGI02	157	0.23	0.20	7.7
KGI02	288	0.12	1.34	5.4
KGI02	353	-	<0.27	-
KGI02	478	-	<0.31	-
KGI02	528	0.06	0.15	5.9
KGI04	91	-	1.02	-
KGI04	212	0.67	0.98	6.7
KGI04	385	0.06	<0.2	2.8
KGI04	498	0.44	<0.2	2.4
KGI04	596	0.02	<0.1	2.0

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

Environmental isotopes

A summary of some of the analyses of the environmental isotopes from the Gideå site is presented in Table 14. The isotope data generally indicate a predominately meteoric origin to the groundwaters. There are no particular trends with depth. It can be noted that the two sections in borehole KGI04 (385 and 596 m) that showed deviating general chemistry features also show deviating oxygen and hydrogen isotope data.

Table 14. Environmental isotopes at Gideå, sampled in cored boreholes.

Sampled borehole	Depth m	Tritium TU	^{14}C years	$\delta^{18}O$ ‰ vs SMOW	$\delta^{2}H$ ‰ vs SMOW
KGI02	157	3	-	-12.62	-90.1
KGI02	288	3	6445	-12.57	-90.1
KGI02	353	<3	6570	-12.68	-91.4
KGI02	478	<3	6720	-12.44	-89.5
KGI02	528	<3	6435	-12.73	-92.7
KGI04	91	36	-	-12.93	-93.4
KGI04	212	5	11895	-12.55	-89.7
KGI04	385	8	-	-13.63	-99.4
KGI04	498	49	3850	-12.94	-94.1
KGI04	596	10	-	-13.81	-100.8

7.3 Summary and relevance of results

A total of 2 boreholes and 10 different sections have been sampled. Smellie et al. (1985), presented a careful and thorough examination of all the 10 sections sampled by considering geological, hydrological and chemical information in combination. Measurements of piezometric pressure along each borehole were used together with hydraulic modeling of the site in order to consider the effect of groundwater flow patterns on the groundwater chemistry. However, the results from the hydrological modelling generally did not agree well with measured piezometric pressures. As discussed in Chapters 5 and 7, this could partly be explained by the lack of consideration of any regional hydrological components. Consequently, results from the hydraulic modelling might not provide significant help in interpreting the hydrochemistry results.

In spite of limited knowledge regarding flow conditions at depth the actual measurements of the piezometric pressures along each borehole can 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 other disturbing factors Smellie et al. (1985) concluded that only two out of ten sampled section were representative for the depth sampled. Both these sections show chemical compositions that are characteristic for shallow to intermediate groundwaters, with pH–values around 9 and amounts of the major ions that would be normal for non–saline groundwaters in Swedish crystalline rocks. In borehole KGI02, all the sampled sections are reflecting the composition of the most shallow section, and are thus very uniform in composition. Borehole KGI04 reveals groundwaters of more varying types, although the only section considered representative for this borehole also show a water of shallow to intermediate origin. Thus, truly representative samples exist only for shallow to intermediate waters at this site, while deeper groundwaters are still not characterized.

Drilling and sampling methods used for the main part of the investigations at Gideå were relatively "old". New techniques were developed and tested later on, and are described by Almén et al. (1983). Measurements of redox potentials are especially uncertain, but generally the redox measurements show that the groundwaters are of a reducing character.

Although most samples are not representative for the depth sampled, some general observations regarding chemical composition can be made. The sampled groundwaters indicate a variety of waters with different ages. Due to the non–representativity of most samples, no conclusions regarding depth dependencies can be made. However, the two samples in borehole KGI04 indicate that old, relatively saline groundwaters do exist at greater depths.

8. ASSESSMENT OF SOLUTE TRANSPORT

8.1 General considerations

No specific model of solute transport at the Gideå site exists. However, a model of the groundwater system at the site does exist and has been discussed in Chapter 6. The report by Carlsson et al. (1983), describes a model of the groundwater system at the Gideå site in which both a three–dimensional flow field and groundwater travel times from a repository at the –500 m level are shown. A groundwater flow field is the essential basis of a groundwater solute transport model, and thus the implications of the existing work for solute transport 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 the −500 m level, 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 external boundaries of the model are placed so as to approximately enclose a block having sides of 2.5 km, including the region of the site. A groundwater table with maximum relief of 40 m is specified as the surface condition, whereas the four near-vertical sides and bottom are closed to flow. Of the four sides, only the north side is positioned along an inferred conductive fracture zone. The eastern side is placed along a low in the groundwater table. It is implied that no flow crosses this line because it is a discharge area. The other sides are placed below groundwater table divides. The depth to the bottom of the block was arbitrarily chosen. In model analyses for the site, 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 may cause unnatural conditions of modelled solute transport through the repository level of the site 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. In this case, waters actually recharging within the model area are limited to fill only the upper portion of the section. In another situation, waters recharging through the upper surface of the model region flow out of the model region through a near-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.

Finally, the choice of a groundwater divide or discharge area as a no–flow boundary extending to considerable depth in the model may be questionable. As the flow field is three–dimensional rather than two–dimensional, the divide or discharge point may be applied with certainty only to the uppermost groundwater flow cell and not necessarily to a deep regional flow system.

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. This is shown by the parameter variations in Case 1 and Case 2 for the Gideå site. In contrast, the location and direction of transport paths and fluid velocities along paths are exceptionally sensitive to the particular location and connectivity of conductive structures. Thus predicted transport in the site is subject to uncertainty stemming from wrong or missing connections of known structures, and from missing structures such as sub–horizontal conductive zones not discovered at the time of transport modelling.

When conductivity contrasts of two or more orders of magnitude exist between conductive zones 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 analysis, no variations 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. Two variations of hydraulic conductivity distributions were tested in the Gideå model. These consisted of mildly different depth–dependencies of hydraulic conductivity as well as mild anisotropy (ten times or less differences among principal values). Model results for transport through the sites (flow direction and travel times), show that such parameter variations have limited effect on flow behavior. Rather, geometry and connectivity of conductive structures, as discussed above, may be the most important control on groundwater flow and transport to be studied by variations.

Knowledge of both hydraulic conductivity and effective porosity for flow ('kinematic porosity') is important to 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 all model analyses, the effective porosity was 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. Laboratory measurements on drill cores of porosity and diffusivity are reported by Skagius (1986). Two samples, one consisting of granite and one of gneiss, from approximately 500 m depth were analyzed.

8.2 Transport Calculations

Groundwater flow fields showing fluid velocity vectors are presented for various cross–sections through the Gideå model block for each of two variations. Both have decreasing conductivity with depth in both fracture zones and in bedrock blocks. One has isotropic conductivity (Case 1) and one has anisotropic conductivity in the blocks (Case 2) with vertical conductivity about half of horizontal conductivity. The fracture zones at the Gideå site are not all near–vertical and have various dips such that a number of them intersect at various depths below the surface. The transport velocities at the –500 m level are quite similar in both cases as are volumetric fluid fluxes. Patterns are similar and actual values differ by less than one order of magnitude at most points.

Travel times for various paths to the surface, beginning at the -500 m level, are reported only for one case, Case 1. The travel times are from about one thousand years to three-hundred thousand years. Due to the minor difference in variations Case 1 and Case 2, it should be expected that travel time for Case 2 would be similar to those presented for Case 1.

A single actual travel time has been measured at the Gideå site following the April 1986 Chernobyl nuclear power plant accident. Ru-106 appeared in artesian groundwaters at a depth of 100 m in borehole KGI02 in February 1987 (Gustafsson et al., 1987). While no detailed path interpretation has been made, this indicates a swift travel time of less than one year in conductive structures that lead from the surface to a depth of 100 m.

8.3 Implications of existing information for solute transport

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

Boundary conditions are equally important to the transport predicted by the model analysis, but these were not varied to test their impact. In fact, it is entirely possible and even likely that the -500 m level at each site is within the realm of a deep regional groundwater system. The groundwater flow and transport through the repository may have little, if anything, to do with the water-table topography within the site area. Flows at depth may be driven by a more regional water-table gradient, a possibility that is excluded by the choice of closed vertical boundaries in the model.

Considerations towards improving the transport predictions of site models 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 at 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 outcrop at the ground surface is not likely sufficient to describe the connectivity at depth, which may depend also on sub-horizontal zones that do no outcrop.

9. ROCK MECHANICAL CONDITIONS

At the Gideå study site the horizontal rock stresses have been determined by hydraulic fracturing tests in one borehole. The cores from two different rock types at Gideå have been tested with regard to their mechanical properties. The thermal properties were determined on core specimens in one borehole between depths 300 - 700 m.

9.1 Mechanical and thermal properties of the rock

For the Gideå rock the following laboratory tests were conducted on core samples from borehole KGI01 to determine the mechanical properties:

- sound velocity measurements
- uniaxial compression tests
- brazilian disc tests
- triaxial compression tests
- three point bending tests

All together, 12 rock samples were tested with each method (except for triaxial compression tests were only gneiss was tested). Of these, 6 samples were migmatitic gneiss (migmatite) and 6 samples migmatitic granite (aplite granite). Migmatitic gneiss is the dominating rock type. Samples were taken from depths 370 m, 425 m, 510 m and 600 m.

Sound velocity measurements

From the sound velocity measurements on the gneiss the compressional wave velocity was determined to be 5000 ± 545 m/s, the shear wave velocity 3350 ± 128 m/s, the dynamic Young's modulus 65.4 ± 10.2 GPa and the Poisson's ratio 0.12 ± 0.1. The ratio between the compressional- and shear wave velocity of 0.67 indicate a moderate content of microfractures.

For the granite the compressional wave velocity was determined to 4816 ±148 m/s, the shear wave velocity 3055 ± 100 m/s, the dynamic Young's modulus 55.8 ± 55.8 GPa and the Poisson's ratio 0.135 ± 0.05. The ratio between the compressional- and shear wave velocity of 0.65 indicate a moderate content of microfractures.

Uniaxial compressive tests

The uniaxial compressive tests on the gneiss gave a uniaxial compressive strength of 128.2 ± 15.5 MPa, a static Young's modulus of 56.4 ± 4.0 GPa and a static Poisson's ratio of 0.24 ± 0.05.

For the granite the uniaxial compressive strength was determined be 201.0 ± 15.6 MPa, the static Young's modulus 64.3 ± 6.0 GPa and the static Poisson's ratio 0.32 ± 0.05. The reported values of the Young's modulus and Poisson's ratio have been determined at a load level corresponding to 50% of the failure load of the specimens.

Brazilian disc test

The brazilian disc tests gave a tensile strength of 18.1 ± 3.2 MPa for the gneiss and 12.3 ± 1.7 MPa for the granite.

Triaxial compression test

The triaxial compression tests were performed with confining pressures of 5, 10 and 25 MPa. The tests show a rock behavior which correlates with hard brittle rocks. The results show a high increase in failure stress as the confining pressure is increased from 10 to 25 MPa. Table 13 presents the results from each test.

Table 13. Results from controlled triaxial tests on core specimens from borehole KGI01, Gideå.

Rock type	Confining pressure (MPa)	Failure stress (MPa)	Young's modulus (GPa)
Gneiss	5	147.2	61.4
Gneiss	5	162.4	59.8
Gneiss	10	240.4	63.8
Gneiss	10	181.9	64.2
Gneiss	25	357.2	68.4
Gneiss	25	295.6	66.7

Three point bending tests

The three point bending tests on the gneiss gave a fracture toughness of 1.86 ± 0.5 MN/m and a Young's modulus of 51.2 ± 12.8 GPa.

For the granite the fracture toughness was 2.52 ± 0.5 MN/m and the Young's modulus 52.1 ± 10.8 GPa.

Thermal properties

The properties thermal conductivity, diffusivity, heat capacity per unit volume and density were determined on core samples from borehole KGI01 using the transient hot strip method (Gustafsson et al., 1979). The results are presented in Table 14 below. The thermal conductivity varies between 3.14 – 5.51 W/(m·K) (Ahlbom and Karawacki, 1983). This reflects the inhomogeneity of the veined gneiss at the site.

Table 14. Thermal properties measured on core samples from borehole KGI01, Gideå. (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	4.09	$1.75x10^{-6}$	880	2660
400	3.69	$1.53x10^{-6}$	880	2750
450	3.73	$1.63x10^{-6}$	840	2720
460	3.87	$1.69x10^{-6}$	850	2710
470	3.64	$1.43x10^{-6}$	930	2740
480	4.00	$1.76x10^{-6}$	850	2670
490	3.66	$1.64x10^{-6}$	830	2690
500	4.41	$1.85x10^{-6}$	890	2690
510	3.72	$1.62x10^{-6}$	860	2660
520	5.51	$2.32x10^{-6}$	850	2800
530	3.14	$1.31x10^{-6}$	880	2740
540	3.51	$1.54x10^{-6}$	840	2710
550	3.95	$1.58x10^{-6}$	940	2670
600	3.32	$1.35x10^{-6}$	900	2720
700	3.59	$1.45x10^{-6}$	900	2740
Mean:	3.86	$1.63x10^{-6}$	875	2710

9.2 Rock stress measurements

The rock stress measurements were conducted in the vertical borehole KGI01. Measurements were conducted at 25 test sections, from the ground surface to a maximum depth of 500 m.

The results is presented in Figure 24. It show moderate rock stresses and no extreme values were recorded. The minimum horizontal stress increases with depth at a rate close that of the theoretical vertical stress (ρgz), representing a stress field close to isotropic in the vertical plane containing the minimum horizontal stress and the theoretical vertical stress. The minimum horizontal stress show a slight decrease in stress gradient with depth. It may be represented as a bi-linear stress increase with depth where the inflexion point is at approximately 300 m. It is, however, not possible to find a geological correlation to such an interpretation. Between 300 m and 400 m depth the fracture frequency decreases quite markedly and the hydraulic conductivity decreases drastically at 280 m. These facts, however, do not support the bi-linear interpretation discussed above. Hence, the stress gradient for the minimum horizontal stress should be interpreted as slowly decreasing from surface down 500 m depth. At surface, the minimum horizontal stress is around 2 MPa and at 500 m depth 11.5 MPa.

For the maximum horizontal stress a clear scatter in magnitude can be seen as measuring points close to each other are compared. This scatter is partly due to the evaluation technique. The maximum horizontal stress also show a tendency of decreasing magnitude gradient with depth. At surface, the maximum horizontal stress is around 3 MPa and at 500 m depth 19 MPa. The ratio of maximum horizontal stress/minimum horizontal stress is fairly stable, around 1.6, throughout the measured borehole interval.

The orientation of the maximum horizontal stress has been determined to N67°E. This orientation is based on a total of 11 reliable imprints of initiated hydrofractures. No rotation of the orientation with depth can be found. The standard deviation on the orientation is ± 19°.

9.3 Evaluation

Based on the rock mechanical tests conducted at Gideå nothing anomalous is found. The rock stress measurements report moderate stress magnitudes. A slight, not distinct, decrease in stress gradient with depth can be found. The difference in magnitude between the maximum and minimum horizontal stress is, based on experience from other measurements, normal to low for

Sweden. That is, the stress anisotrophy in the horizontal plane is normal to low which is preferred for the construction of any underground facility.

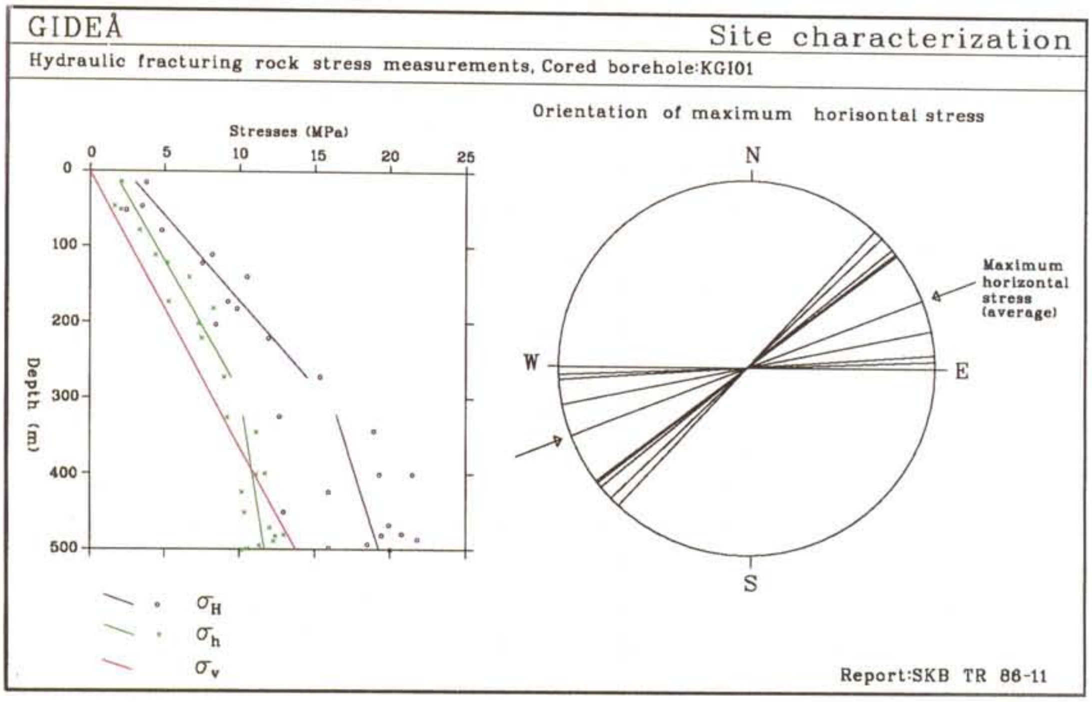

Figure 24. Evaluated stress field at the Gideå study site from measurements in borehole KGI01.

The standard deviation of the stress orientation is somewhat high. The orientation of the maximum horizontal stress at Gideå does not coincide with the NW–SE trend found in Sweden (Müller et al., 1991, Stephansson and Ljunggren, 1989). As can be seen in Figure 24 the data are rather scattered for the orientation of the maximum horizontal stress. The rock stress measurements also included some few points which gave orientations in the NW–SE direction. One possible explanation for the resulting average NE–SW orientation, apart from the stresses, can be that the induced fractures have been influenced by foliation planes in the gneissic rock. This phenomena is believed to have occurred when hydrofracturing measurements were conducted in the borehole at the campus at the Luleå University of Technology (Ljunggren and Bjarnason, 1990).

Rock burst is a phenomena that has to be considered since the repository is intended to be located at a considerable depth. Taking into account the stress state at Gideå and the uniaxial compressive strength values of the gneiss and granite the risk for rock burst is small. Minor rock burst may occur in the gneiss below 300 m depth.

The majority of the mechanical properties have to be considered as very normal for crystalline rocks when compared to the compilation of rock properties on crystalline rocks by Tammemagi and Chieslar (1985). A few exceptions are for the gneiss a very high tensile strength (18.1 MPa) and a slightly low uniaxial compressive strength (128.2 MPa). The latter can be due to a rather high mica content. If the data is compared to the strength- and modulus ratio classification by Deere and Miller (1966) it obtains a high quality designation.

No significantly low quality mechanical parameter has been discovered, and taking into account the evaluated stress state the rock shouldn't create any stability problems in the construction of a repository at 600 m depth.

The thermal properties for Gideå rock are normal to high as judged by the compilation on crystalline rocks by Sundberg (1988).

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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 borholes have been studied by by brief visits to each borehole. These inspections showed that all boreholes at Gideå were locked and the borehole heads were undamaged. Problems with borehole stability or instrument blockage during earlier surveys are described in a report by Persson (1985). Based on that report the main obstacles for future borehole surveys are described in this Appendix.

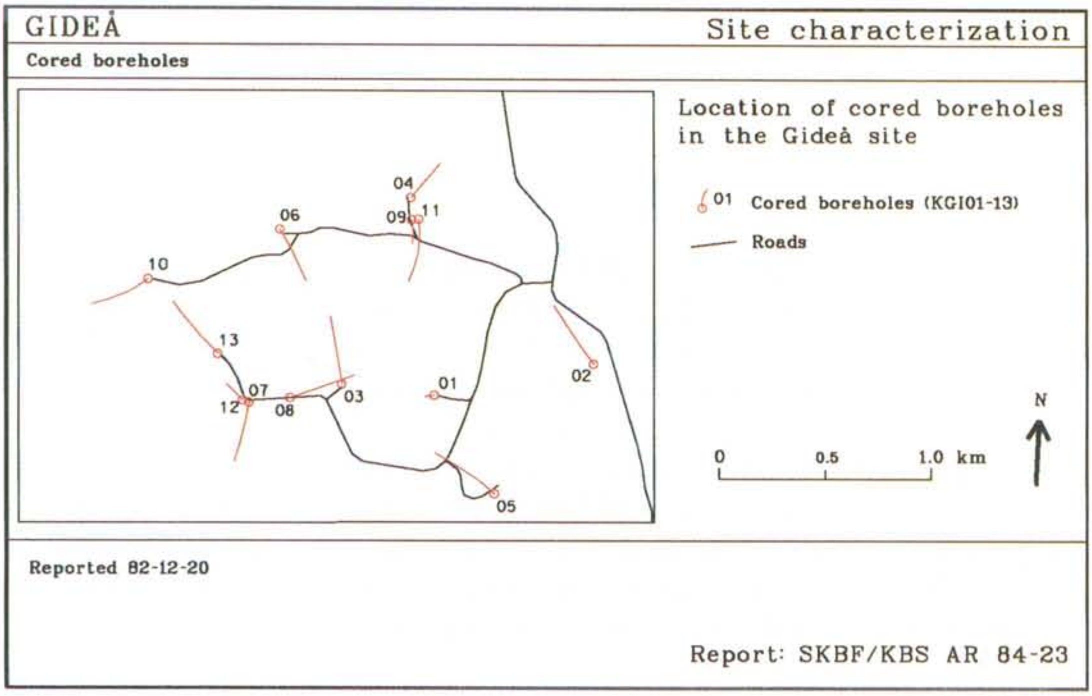


Figure A1. Locations of cored boreholes at Gideå study site.

Borehole KGI01

Borehole KGI01 (Figure A2) is vertical and is 701 m deep. The borehole was drilled at an early stage to confirm favourable conditions at depth as 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 borehole does not penetrate any of the interpreted fracture zones. Mean fracture frequency of the borehole is 2.8 fr/m.

Availability: The borehole is blocked at 695 m by a packer and at 540 m by a borehole collaps. The latter occured in 1984 due to the use of explosives in a seismic tomography survey.

Borehole KGI02

Borehole KGI02 (Figure A3) is 706 m in length and ends at a depth of 617 m. It is drilled inclined 60° to the horizontal. It is located in a fractured part of the site with the objective to study the characteristics of Zone 1. The zone is interpreted to be penetrated by the borehole between 309–335 m borehole length. The cores from this borehole has the highest mean fracture frequency, 7.4 fr/m, of all boreholes at the Gideå site. Generalized results are presented in Appendix B, Figure B1.

Availability: The borehole is blocked at 300 m by a 2 m long sond.

Borehole KGI03

Borehole KGI03 (Figure A4) is 703 m in length and drilled inclined 60°, reaching a depth of 626 m. The borehole is located in the central and low fractured part of the site with the objective to investigate a possible fault, as indicated by the geophysics, and to obtain geologic and hydraulic characteristics of an extensive doleritic dyke. No fault was found at the location predicted by the geophysics. However, the borehole intersects Zones 7 and 6 at 329–342 m and 622–629 m borehole length, respectively. The extensive doleritic dyke was found at 454–463 m. The dolerite is strongly fractured. Mean fracture frequency of the cores from this borehole is 4.2 fr/m. Generalized results are presented in Appendix B, Figure B1.

Availability: The borehole is blocked at 685 m by parts of a pipe string equipment.

Borehole KGI04

Borehole KGI04 (Figure A5) is 691 m in length and drilled inclined 70°, reaching a depth of 657 m. The borehole is positioned to intersect a major fracture zone (Zone 4). The zone is interpreted to be penetrated by the borehole between 606–655 m borehole length. The borehole also penetrates Zone 3A (217–259 m) and Zone 6 (670–690 m). The mean fracture frequency is 5.1 fr/m. Borehole coordinates and activities performed in the borehole are presented in Figure A5. Main results from borehole investigations are shown in Appendix B, Figure B1.

Availability: The borehole is blocked at 220 m due to damage caused by explosives used in a seismic tomography survey.

Borehole KGI05

Borehole KGI05 (Figure A6) is inclined, 60°, with a length of 702 m and a depth of 605 m. The borehole is positioned to penetrate and characterize two major fracture zones (Zones 1 and 2) that constitute the eastern boundary of a major low fractured rock block. The borehole is interpreted to penetrate Zone 1 at 210–232 m and Zone 2 at 520–567 m borehole length. Mean fracture frequency is 5.4 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B1.

Availability: The borehole is blocked at 540 m due borehole collaps.

Borehole KGI06

Borehole KGI06 (Figure A7) has a length of 704 m. It is drilled inclined 60°, reaching a depth of 648 m. The objective was to penetrate a geophysically indicated fracture zone (Zone 3) and to characterize at depth the central rock block. The results indicated that Zone 3 consisted of two fracture zones 3A and 3B. These zones were penetrated at 51–80 m (3A) and 222–240 (3B), respectively. Also Zone 7 is interpreted to intersect the borehole at 443–452 m borehole length. Mean fracture frequency is 4.5 fr/m. Generalized results are presented in Appendix B, Figure B2.

Availability: The borehole was earlier blocked by a umbilical-hose. By injecting 200 l of hydrocloric acid in the lowermost part of the borehole the umbilical-hose was released and the borehole is now open.

Borehole KGI07

Borehole KGI07 (Figure A8) has a length of 700 m. It is drilled inclined 60°, reaching a depth of 635 m. The objective was to investigate the southern part of the central rock block where there is limited surface data due to lack of outcrops and low resolution of the ground geophysical measurements. The borehole intersect Zone 6, at 362-397 m. Mean fracture frequency is 5.2 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B2.

Availability: There are no known problems with borehole blockage.

Borehole KGI08

Borehole KGI08 (Figure A9) is 702 m in length and is drilled inclined 62°, reaching a depth of 619 m. The borehole is located in the southern part of the central rock block. The objective was to investigate a possible fracture zone, as indicated by a trace of peat bogs, and to obtain data of the rock mass between boreholes KGI07 and KGI03. No fracture zone was found. Mean fracture frequency of the cores from this borehole is 5.4 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B2.

Availability: There are no known problems with borehole blockage.

Borehole KGI09

The drilling of borehole KGI09 (Figure A10) was terminated at 282 m borehole length, due to drilling difficulties. The borehole has a dip of 67° and reaches a depth of 250 m. The objective was to identify the dip of Zone 3. Due to the termination of the borehole this objective was only partly achieved. Instead another borehole, KGI11, was drilled 20 m east and parallel to KGI09. The borehole KGI09 however intersect Zone 3A between 129-146 m. Mean fracture frequency of the cores from borehole KGI09 is 7.1 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B2.

Availability: There are no known problems with borehole blockage.

Borehole KGI10

Borehole KGI10 (Figure A11) is 703 m in length and is drilled inclined 65°, reaching a depth of 632 m. The borehole is located in the western part of the site with the objective to investigate the dip and character of Zone 7 and to extend the investigated area to the west. Since no fracture zone was found in the borehole it was assumed that Zone 7 dips to the SW, that is away from the borehole. Mean fracture frequency in the cores of this borehole is 2.0 fr/m, i.e. it is the less fractured borehole in the site. Main results from borehole investigations are shown in Appendix B, Figure B2.

Availability: No known problems with borehole blockage.

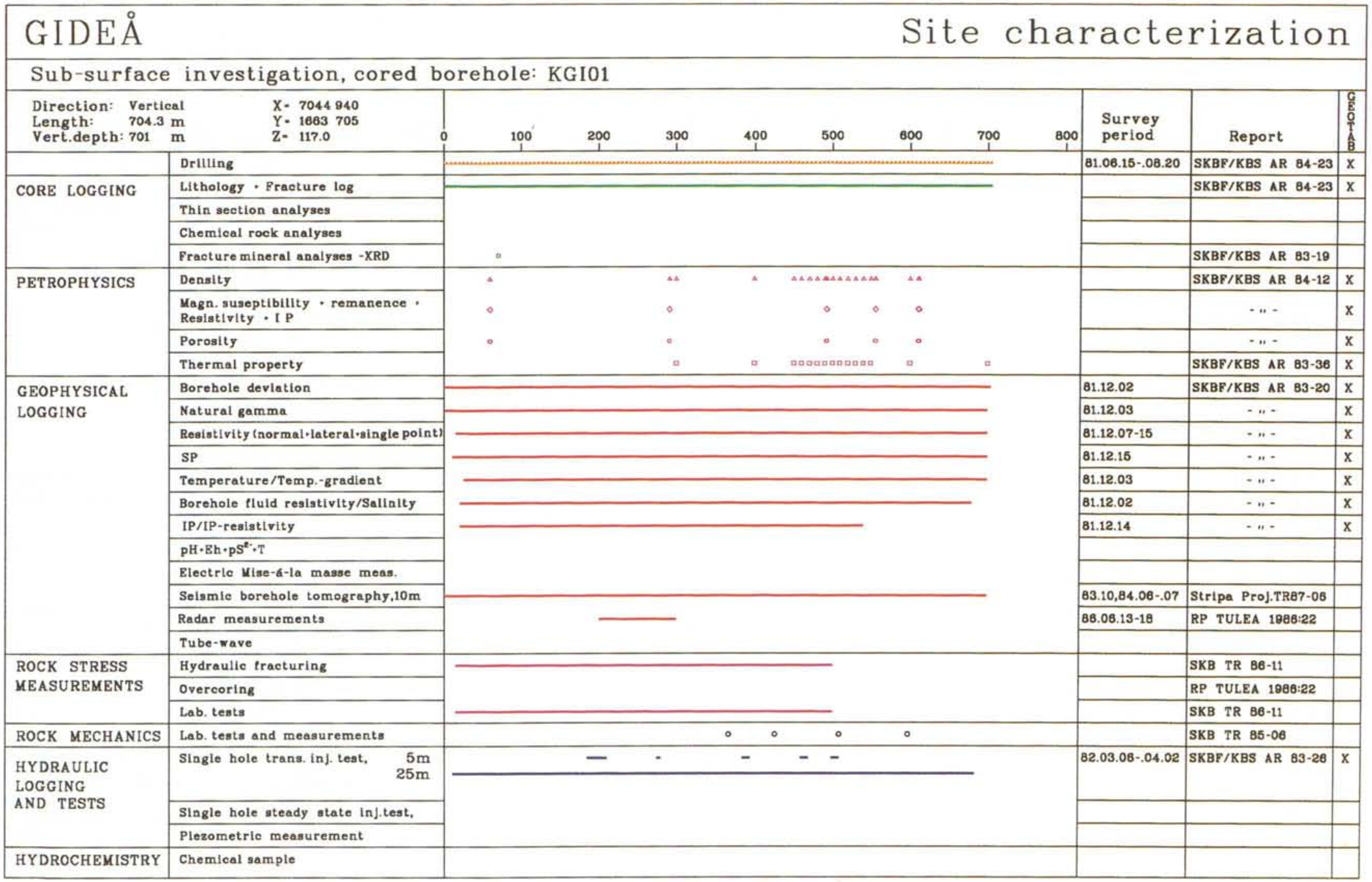
Borehole KGI11

Borehole KGI11 (Figure A12) is inclined 60° and has a length of 702 m and a depth of 632 m. This borehole was drilled to replace borehole KGI09 that was terminated due to technical difficulties. Thus, there exist two boreholes, 20 m apart down to 250 m depth. Below this depth only KGI11 continues. The objective of the borehole was to locate Zone 3 and determine its dip, and to characterize doleritic dykes and the rock mass in general at depth in the central rock block. Zone 3A was found between 119–130 m and Zone 3B between 345–352 m. Mean fracture frequency of the cores from this borehole is 4.2 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B3.

Availability: There is no known problems with borehole blockage. However, the borehole was earlier contaminated by diesel oil. To clean the borehole and the surrounding bedrock a short percussion borehole was drilled near borehole KGI10. After some time most of the oil was recovered by puming in the percussion borehole. If there is any remaining damage today is not known.

Borehole KGI12

This borehole (KGI12, Figure A13) is drilled inclined 61° and is 250 m in length, corresponding to a depth of 218 m. The objective was to locate Zone 6 and to determine its dip. The borehole was interpreted to intersect Zone 6 between 52–61 m. Mean fracture frequency of the cores from this borehole is 3.5 fr/m. Main results from borehole investigations are shown in Appendix B, Figure B3.



GIDEÅ

Site characterization

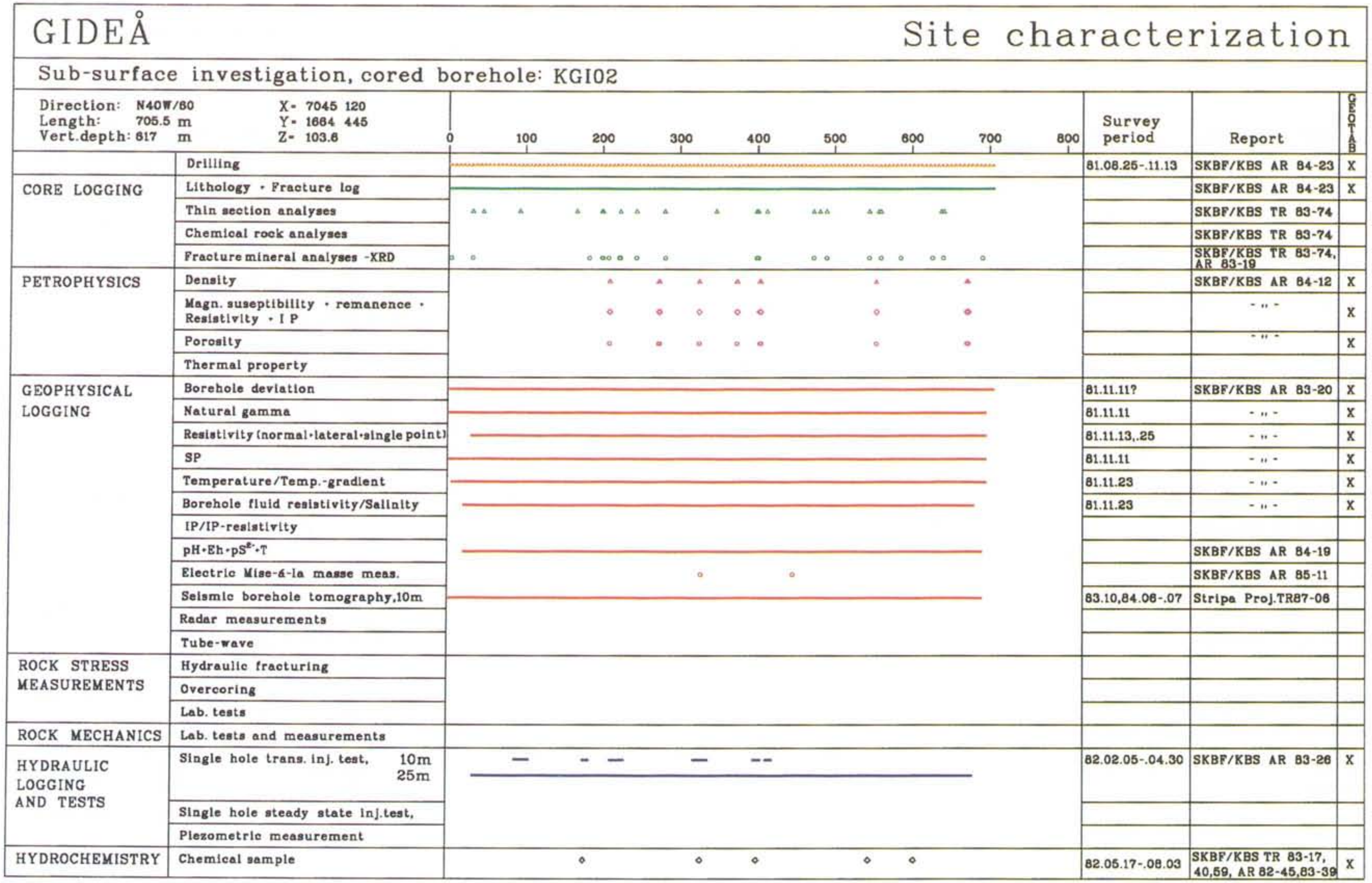
Sub-surface investigation, cored borehole: KGI01

Direction: Vertical
Length: 704.3 m
Vert.depth: 701 m

X- 7044 940
Y- 1663 705
Z- 117.0

		Survey period	Report	GEOTAB
	Drilling	81.06.15-.08.20	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses			
	Chemical rock analyses			
	Fracture mineral analyses -XRD		SKBF/KBS AR 83-19	
PETROPHYSICS	Density		SKBF/KBS AR 84-12	X
	Magn. suseptibility · remanence · Resistivity · I P		- " -	X
	Porosity		- " -	X
	Thermal property		SKBF/KBS AR 83-36	X
GEOPHYSICAL LOGGING	Borehole deviation	81.12.02	SKBF/KBS AR 83-20	X
	Natural gamma	81.12.03	- " -	X
	Resistivity (normal·lateral·single point)	81.12.07-15	- " -	X
	SP	81.12.15	- " -	X
	Temperature/Temp.-gradient	81.12.03	- " -	X
	Borehole fluid resistivity/Salinity	81.12.02	- " -	X
	IP/IP-resistivity	81.12.14	- " -	X
	pH·Eh·pS^{2-}·T			
	Electric Mise-á-la masse meas.			
	Seismic borehole tomography,10m	83.10,84.06-.07	Stripa Proj.TR87-06	
	Radar measurements	86.06.13-18	RP TULEA 1986:22	
	Tube-wave			
ROCK STRESS MEASUREMENTS	Hydraulic fracturing		SKB TR 86-11	
	Overcoring		RP TULEA 1986:22	
	Lab. tests		SKB TR 86-11	
ROCK MECHANICS	Lab. tests and measurements		SKB TR 85-06	
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test, 5m 25m	82.03.06-.04.02	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test,			
	Piezometric measurement			
HYDROCHEMISTRY	Chemical sample			

Figure A2. Activities in borehole KGI01.



GIDEÅ

Site characterization

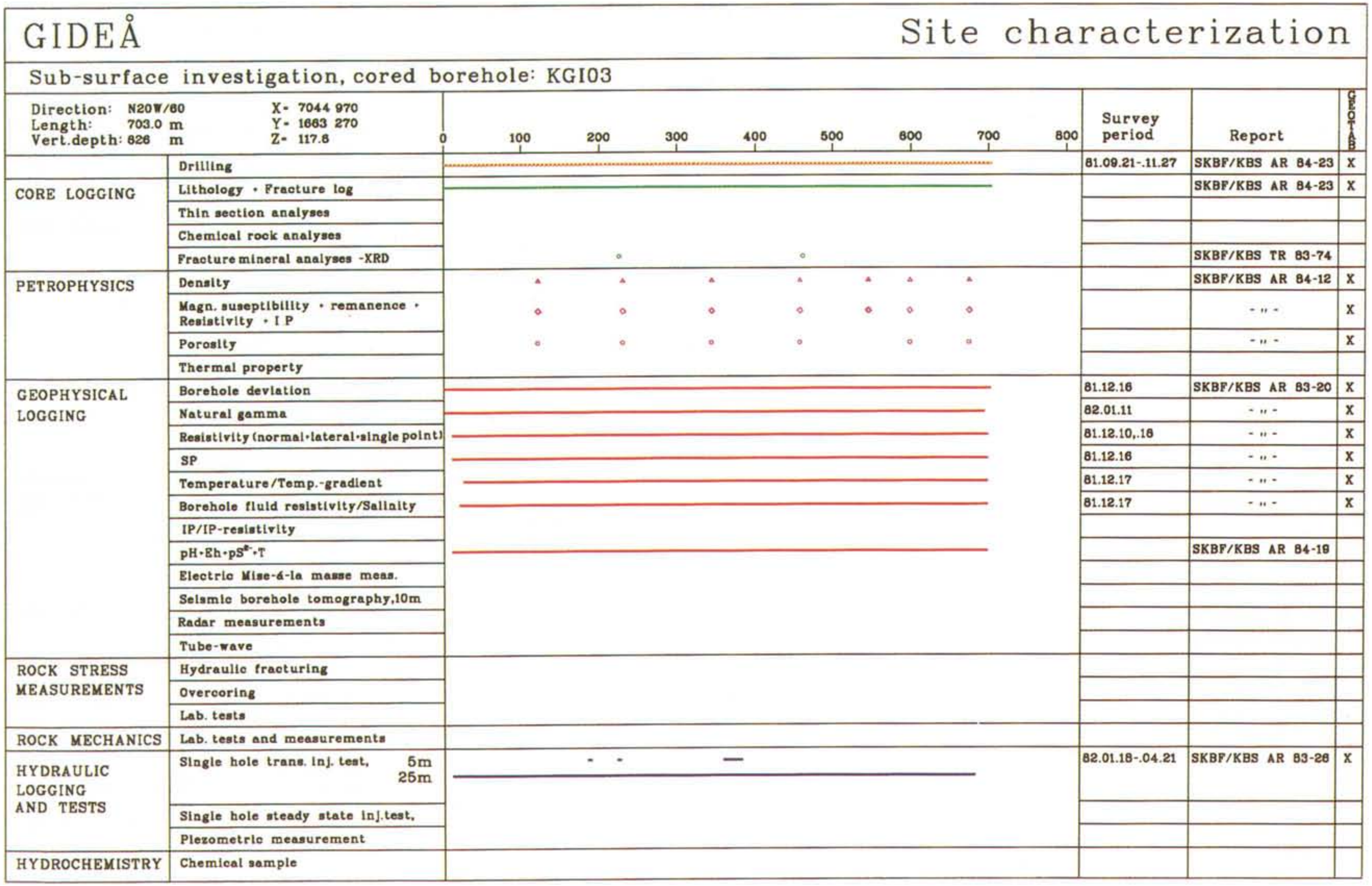
Sub-surface investigation, cored borehole: KGI02

Direction: N40W/60
Length: 705.5 m
Vert.depth: 617 m

X- 7045 120
Y- 1664 445
Z- 103.6

		Survey period	Report	GEOTAB
	Drilling	81.08.25-.11.13	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses		SKBF/KBS TR 83-74	
	Chemical rock analyses		SKBF/KBS TR 83-74	
	Fracture mineral analyses -XRD		SKBF/KBS TR 83-74, AR 83-19	
PETROPHYSICS	Density		SKBF/KBS AR 84-12	X
	Magn. suseptibility · remanence · Resistivity · I P		- " -	X
	Porosity		- " -	X
	Thermal property			
GEOPHYSICAL LOGGING	Borehole deviation	81.11.11?	SKBF/KBS AR 83-20	X
	Natural gamma	81.11.11	- " -	X
	Resistivity (normal·lateral·single point)	81.11.13,.25	- " -	X
	SP	81.11.11	- " -	X
	Temperature/Temp.-gradient	81.11.23	- " -	X
	Borehole fluid resistivity/Salinity	81.11.23	- " -	X
	IP/IP-resistivity			
	pH·Eh·pS^{2-}·T		SKBF/KBS AR 84-19	
	Electric Mise-á-la masse meas.		SKBF/KBS AR 85-11	
	Seismic borehole tomography,10m	83.10,84.06-.07	Stripa Proj.TR87-06	
	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, 10m 25m	82.02.05-.04.30	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test,			
	Piezometric measurement			
HYDROCHEMISTRY	Chemical sample	82.05.17-.08.03	SKBF/KBS TR 83-17, 40,59, AR 82-45,83-39	X

Figure A3. Activities in borehole KGI02.



GIDEÅ

Site characterization

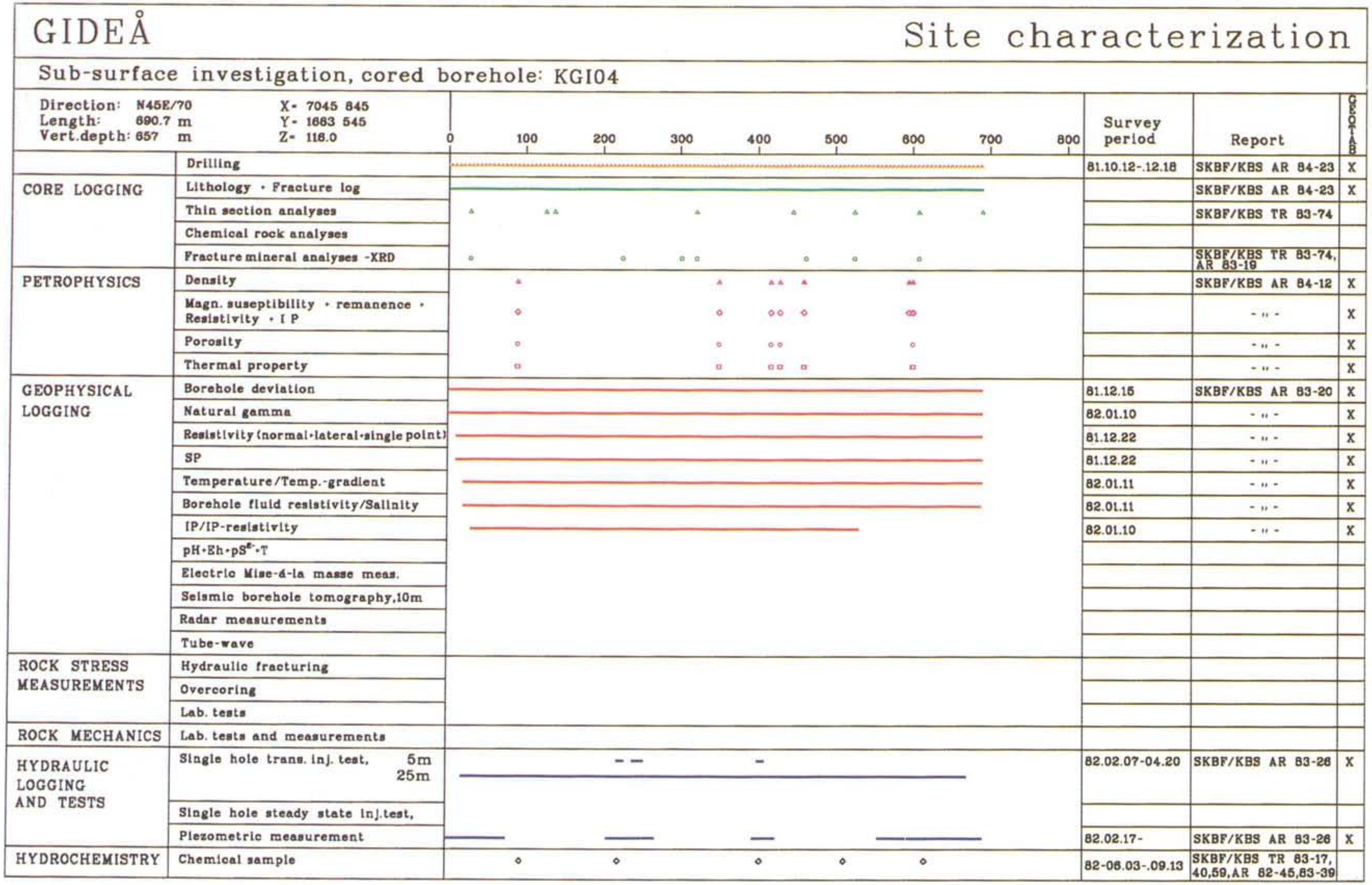
Sub-surface investigation, cored borehole: KGI03

Direction: N20W/60
Length: 703.0 m
Vert.depth: 626 m

X- 7044 970
Y- 1663 270
Z- 117.6

		Survey period	Report	GEOTAB
	Drilling	81.09.21-.11.27	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses			
	Chemical rock analyses			
	Fracture mineral analyses -XRD		SKBF/KBS TR 83-74	
PETROPHYSICS	Density		SKBF/KBS AR 84-12	X
	Magn. suseptibility · remanence · Resistivity · I P		- " -	X
	Porosity		- " -	X
	Thermal property			
GEOPHYSICAL LOGGING	Borehole deviation	81.12.16	SKBF/KBS AR 83-20	X
	Natural gamma	82.01.11	- " -	X
	Resistivity (normal·lateral·single point)	81.12.10,.16	- " -	X
	SP	81.12.16	- " -	X
	Temperature/Temp.-gradient	81.12.17	- " -	X
	Borehole fluid resistivity/Salinity	81.12.17	- " -	X
	IP/IP-resistivity			
	pH·Eh·pS^{2-}·T		SKBF/KBS AR 84-19	
	Electric Mise-á-la masse meas.			
	Seismic borehole tomography,10m			
	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, 5m 25m	82.01.18-.04.21	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test,			
	Piezometric measurement			
HYDROCHEMISTRY	Chemical sample			

Figure A4. Activities in borehole KGI03.



GIDEÅ

Site characterization

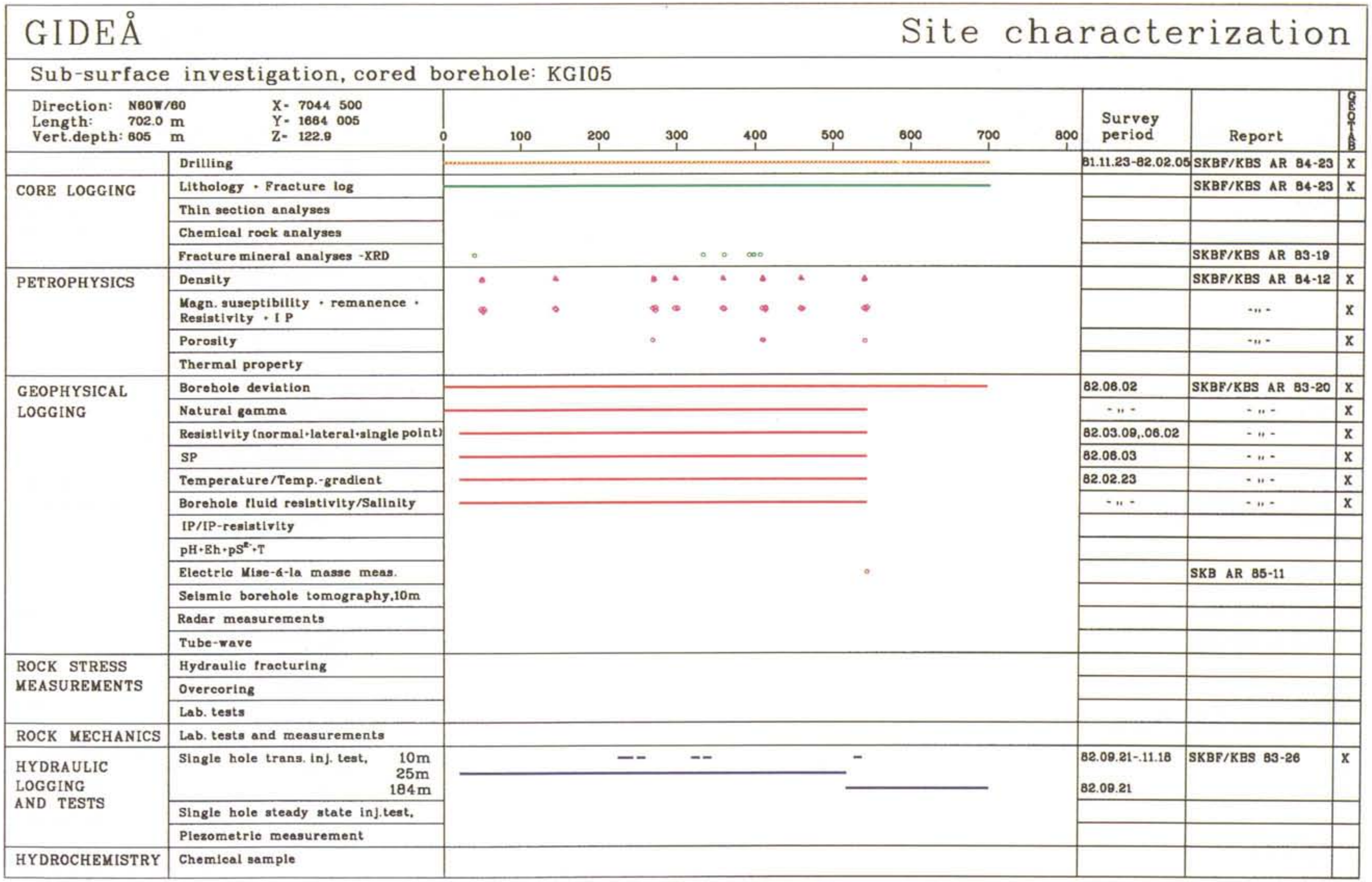
Sub-surface investigation, cored borehole: KGI04

Direction: N45E/70
Length: 690.7 m
Vert.depth: 657 m

X- 7045 845
Y- 1663 545
Z- 116.0

		Survey period	Report	GEOTAB
	Drilling	81.10.12-.12.18	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses		SKBF/KBS TR 83-74	
	Chemical rock analyses			
	Fracture mineral analyses -XRD		SKBF/KBS TR 83-74, AR 83-19	
PETROPHYSICS	Density		SKBF/KBS AR 84-12	X
	Magn. suseptibility · remanence · Resistivity · I P		- " -	X
	Porosity		- " -	X
	Thermal property		- " -	X
GEOPHYSICAL LOGGING	Borehole deviation	81.12.15	SKBF/KBS AR 83-20	X
	Natural gamma	82.01.10	- " -	X
	Resistivity (normal·lateral·single point)	81.12.22	- " -	X
	SP	81.12.22	- " -	X
	Temperature/Temp.-gradient	82.01.11	- " -	X
	Borehole fluid resistivity/Salinity	82.01.11	- " -	X
	IP/IP-resistivity	82.01.10	- " -	X
	pH·Eh·pS^{2-}·T			
	Electric Mise-á-la masse meas.			
	Seismic borehole tomography,10m			
	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, 5m 25m	82.02.07-04.20	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test,			
	Piezometric measurement	82.02.17-	SKBF/KBS AR 83-26	X
HYDROCHEMISTRY	Chemical sample	82-06.03-.09.13	SKBF/KBS TR 83-17, 40,59,AR 82-45,83-39	

Figure A5. Activities in borehole KGI04.



GIDEÅ

Site characterization

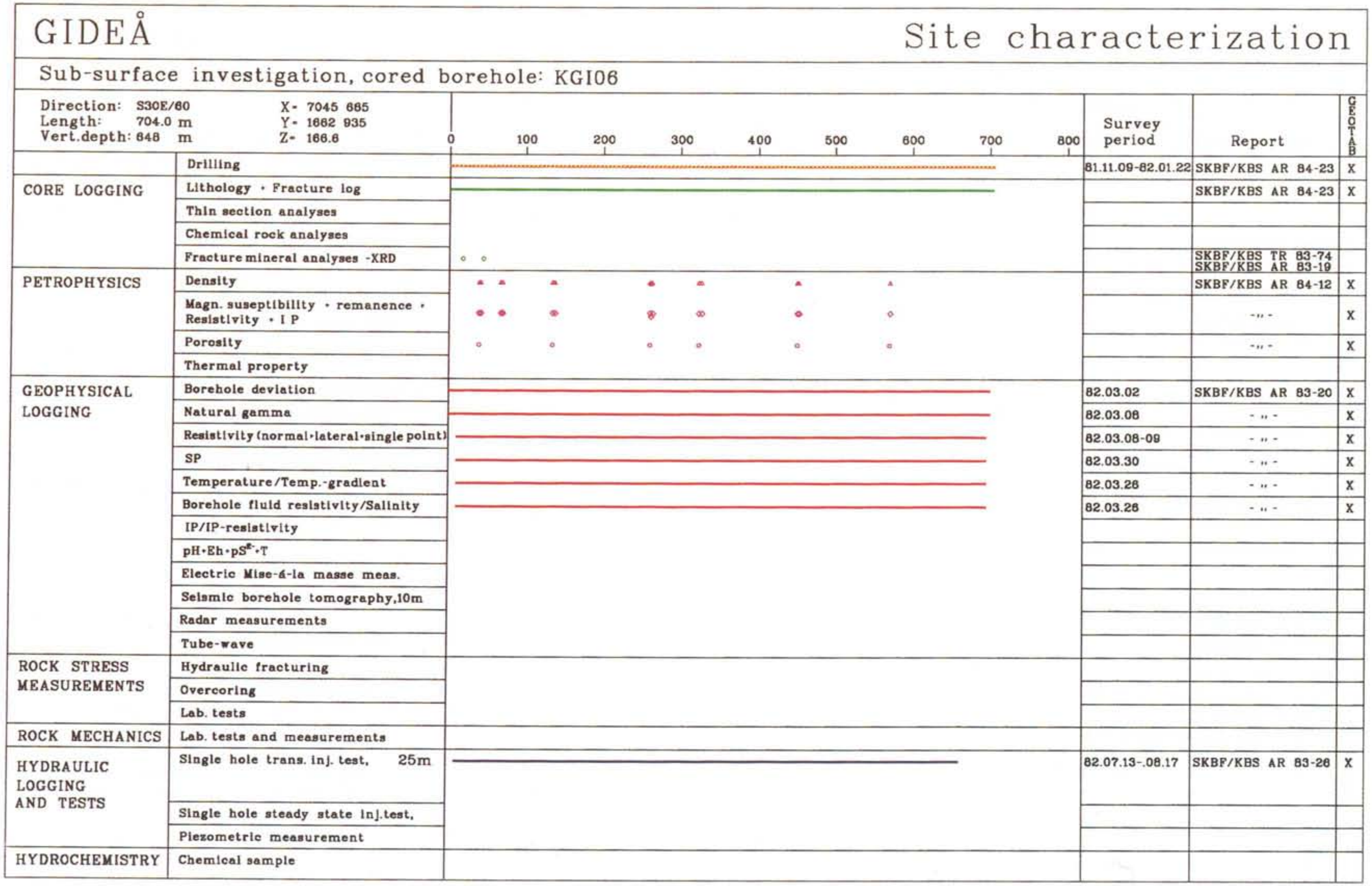
Sub-surface investigation, cored borehole: KGI05

Direction: N60W/60
Length: 702.0 m
Vert.depth: 605 m

X- 7044 500
Y- 1664 005
Z- 122.9

		0 100 200 300 400 500 600 700 800	Survey period	Report	GEOTAB
	Drilling		81.11.23-82.02.05	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log			SKBF/KBS AR 84-23	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD			SKBF/KBS AR 83-19	
PETROPHYSICS	Density			SKBF/KBS AR 84-12	X
	Magn. suseptibility · remanence · Resistivity · I P			-"-	X
	Porosity			-"-	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.06.02	SKBF/KBS AR 83-20	X
	Natural gamma		- " -	- " -	X
	Resistivity (normal·lateral·single point)		82.03.09,.06.02	- " -	X
	SP		82.06.03	- " -	X
	Temperature/Temp.-gradient		82.02.23	- " -	X
	Borehole fluid resistivity/Salinity		- " -	- " -	X
	IP/IP-resistivity				
	pH·Eh·pS²⁻·T				
	Electric Mise-á-la masse meas.			SKB AR 85-11	
	Seismic borehole tomography,10m				
	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, 10m 25m 184m		82.09.21-.11.18 82.09.21	SKBF/KBS 83-26	X
	Single hole steady state inj.test,				
	Piezometric measurement				
HYDROCHEMISTRY	Chemical sample				

Figure A6. Activities in borehole KGI05.



GIDEÅ

Site characterization

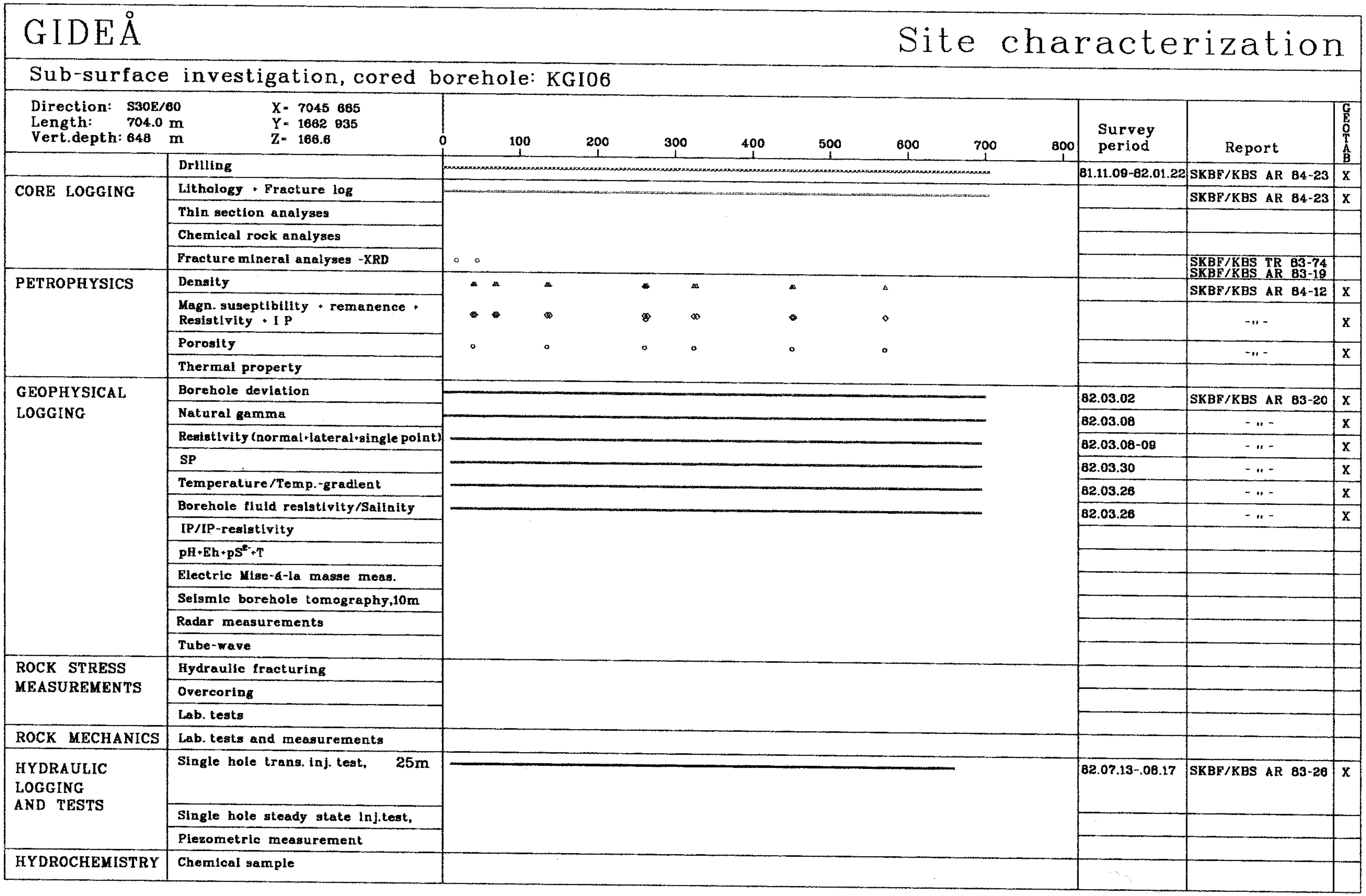
Sub-surface investigation, cored borehole: KGI06

Direction: S30E/60
Length: 704.0 m
Vert.depth: 648 m

X- 7045 665
Y- 1662 935
Z- 166.6

		Survey period	Report	GEOTAB
	Drilling	81.11.09-82.01.22	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology • Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses			
	Chemical rock analyses			
	Fracture mineral analyses -XRD		SKBF/KBS TR 83-74 SKBF/KBS AR 83-19	
PETROPHYSICS	Density		SKBF/KBS AR 84-12	X
	Magn. suseptibility • remanence • Resistivity • I P		-„-	X
	Porosity		-„-	X
	Thermal property			
GEOPHYSICAL LOGGING	Borehole deviation	82.03.02	SKBF/KBS AR 83-20	X
	Natural gamma	82.03.06	- „ -	X
	Resistivity (normal•lateral•single point)	82.03.06-09	- „ -	X
	SP	82.03.30	- „ -	X
	Temperature/Temp.-gradient	82.03.26	- „ -	X
	Borehole fluid resistivity/Salinity	82.03.26	- „ -	X
	IP/IP-resistivity			
	pH•Eh•pS^{2-}•T			
	Electric Mise-á-la masse meas.			
	Seismic borehole tomography,10m			
	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, 25m	82.07.13-.08.17	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test,			
	Piezometric measurement			
HYDROCHEMISTRY	Chemical sample			

Figure A7. Activities in borehole KGI06.



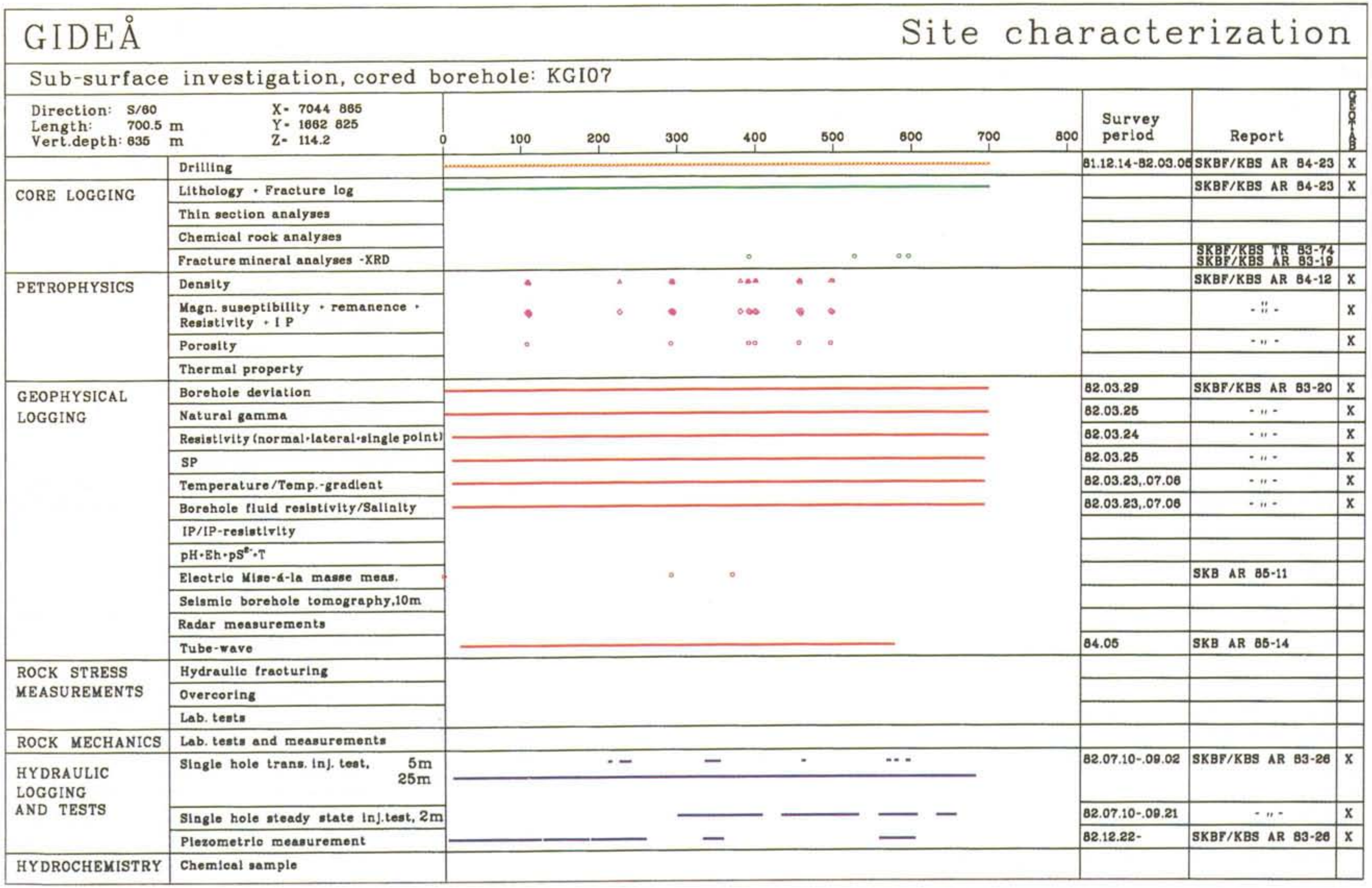
GIDEÅ Site characterization

Sub-surface investigation, cored borehole: KGI06

Direction: S30E/60 X- 7045 665
Length: 704.0 m Y- 1662 935
Vert.depth: 648 m Z- 166.6

		0 100 200 300 400 500 600 700 800	Survey period	Report	GEOTAB
	Drilling		81.11.09-82.01.22	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology + Fracture log			SKBF/KBS AR 84-23	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD			SKBF/KBS TR 83-74 SKBF/KBS AR 83-19	
PETROPHYSICS	Density			SKBF/KBS AR 84-12	X
	Magn. suseptibility + remanence + Resistivity + I P			-״-	X
	Porosity			-״-	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.03.02	SKBF/KBS AR 83-20	X
	Natural gamma		82.03.08	- ״ -	X
	Resistivity (normal+lateral+single point)		82.03.08-09	- ״ -	X
	SP		82.03.30	- ״ -	X
	Temperature/Temp.-gradient		82.03.26	- ״ -	X
	Borehole fluid resistivity/Salinity		82.03.26	- ״ -	X
	IP/IP-resistivity				
	pH+Eh+pS²⁻+T				
	Electric Mise-á-la masse meas.				
	Seismic borehole tomography,10m				
	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, 25m		82.07.13-.08.17	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test,				
	Piezometric measurement				
HYDROCHEMISTRY	Chemical sample				

Figure A7. Activities in borehole KGI06.



GIDEÅ Site characterization

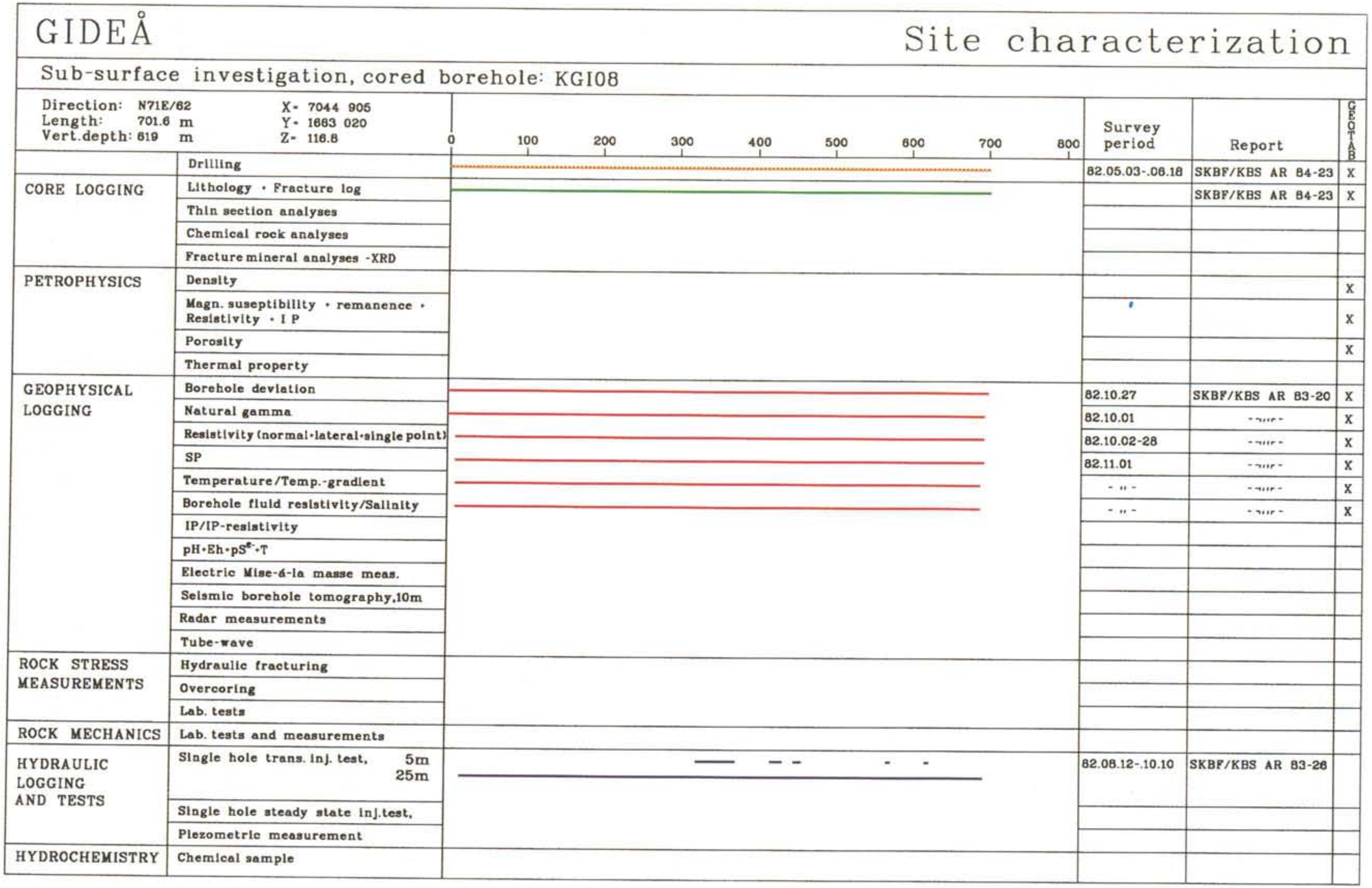
Sub-surface investigation, cored borehole: KGI07

Direction: S/60
Length: 700.5 m
Vert.depth: 635 m

X- 7044 865
Y- 1662 825
Z- 114.2

		0 100 200 300 400 500 600 700 800	Survey period	Report	GEOTAB
	Drilling		81.12.14-82.03.06	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log			SKBF/KBS AR 84-23	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD			SKBF/KBS TR 83-74 SKBF/KBS AR 83-19	
PETROPHYSICS	Density			SKBF/KBS AR 84-12	X
	Magn. suseptibility · remanence · Resistivity · I P			- " -	X
	Porosity			- " -	X
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.03.29	SKBF/KBS AR 83-20	X
	Natural gamma		82.03.25	- " -	X
	Resistivity (normal·lateral·single point)		82.03.24	- " -	X
	SP		82.03.25	- " -	X
	Temperature/Temp.-gradient		82.03.23,.07.06	- " -	X
	Borehole fluid resistivity/Salinity		82.03.23,.07.06	- " -	X
	IP/IP-resistivity				
	pH·Eh·pS^{2-}·T				
	Electric Mise-á-la masse meas.			SKB AR 85-11	
	Seismic borehole tomography,10m				
	Radar measurements				
	Tube-wave		84.05	SKB AR 85-14	
ROCK STRESS MEASUREMENTS	Hydraulic fracturing				
	Overcoring				
	Lab. tests				
ROCK MECHANICS	Lab. tests and measurements				
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test, 5m 25m		82.07.10-.09.02	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test, 2m		82.07.10-.09.21	- " -	X
	Piezometric measurement		82.12.22-	SKBF/KBS AR 83-26	X
HYDROCHEMISTRY	Chemical sample				

Figure A8. Activities in borehole KGI07.



GIDEÅ

Site characterization

Sub-surface investigation, cored borehole: KGI08

Direction: N71E/62
Length: 701.6 m
Vert.depth: 619 m

X- 7044 905
Y- 1663 020
Z- 116.8

		Survey period	Report	GEOTAB
	Drilling	82.05.03-.06.18	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses			
	Chemical rock analyses			
	Fracture mineral analyses -XRD			
PETROPHYSICS	Density			X
	Magn. suseptibility · remanence · Resistivity · I P			X
	Porosity			X
	Thermal property			
GEOPHYSICAL LOGGING	Borehole deviation	82.10.27	SKBF/KBS AR 83-20	X
	Natural gamma	82.10.01	-"-	X
	Resistivity (normal·lateral·single point)	82.10.02-28	-"-	X
	SP	82.11.01	-"-	X
	Temperature/Temp.-gradient	- " -	-"-	X
	Borehole fluid resistivity/Salinity	- " -	-"-	X
	IP/IP-resistivity			
	pH·Eh·pS^{2-}·T			
	Electric Mise-á-la masse meas.			
	Seismic borehole tomography,10m			
	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, 5m 25m	82.08.12-.10.10	SKBF/KBS AR 83-26	
	Single hole steady state inj.test,			
	Piezometric measurement			
HYDROCHEMISTRY	Chemical sample			

Figure A9. Activities in borehole KGI08.

GIDEÅ

Site characterization

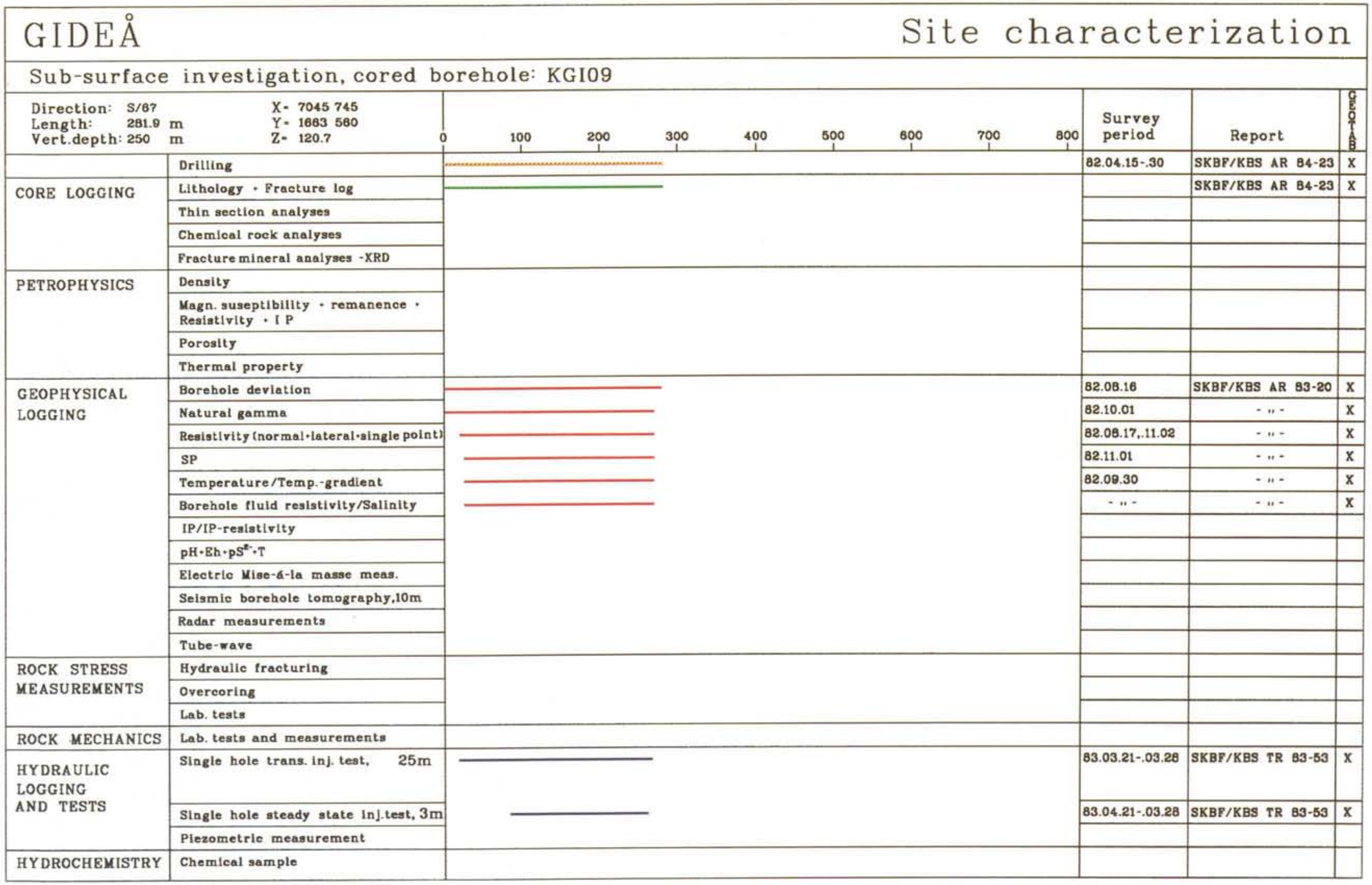
Sub-surface investigation, cored borehole: KGI09

Direction: S/67
Length: 281.9 m
Vert.depth: 250 m

X- 7045 745
Y- 1663 560
Z- 120.7

		0 100 200 300 400 500 600 700 800	Survey period	Report	GEOTAB
	Drilling		82.04.15-.30	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology + Fracture log			SKBF/KBS AR 84-23	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. suseptibility + remanence + Resistivity + I P				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.08.16	SKBF/KBS AR 83-20	X
	Natural gamma		82.10.01	- " -	X
	Resistivity (normal+lateral+single point)		82.08.17,.11.02	- " -	X
	SP		82.11.01	- " -	X
	Temperature/Temp.-gradient		82.09.30	- " -	X
	Borehole fluid resistivity/Salinity		- " -	- " -	X
	IP/IP-resistivity				
	pH+Eh+pS^{2-}+T				
	Electric Mise-á-la masse meas.				
	Seismic borehole tomography,10m				
	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, 25m		83.03.21-.03.28	SKBF/KBS TR 83-53	X
	Single hole steady state inj.test, 3m		83.04.21-.03.28	SKBF/KBS TR 83-53	X
	Piezometric measurement				
HYDROCHEMISTRY	Chemical sample				

Figure A10. Activities in borehole KGI09.



GIDEÅ

Site characterization

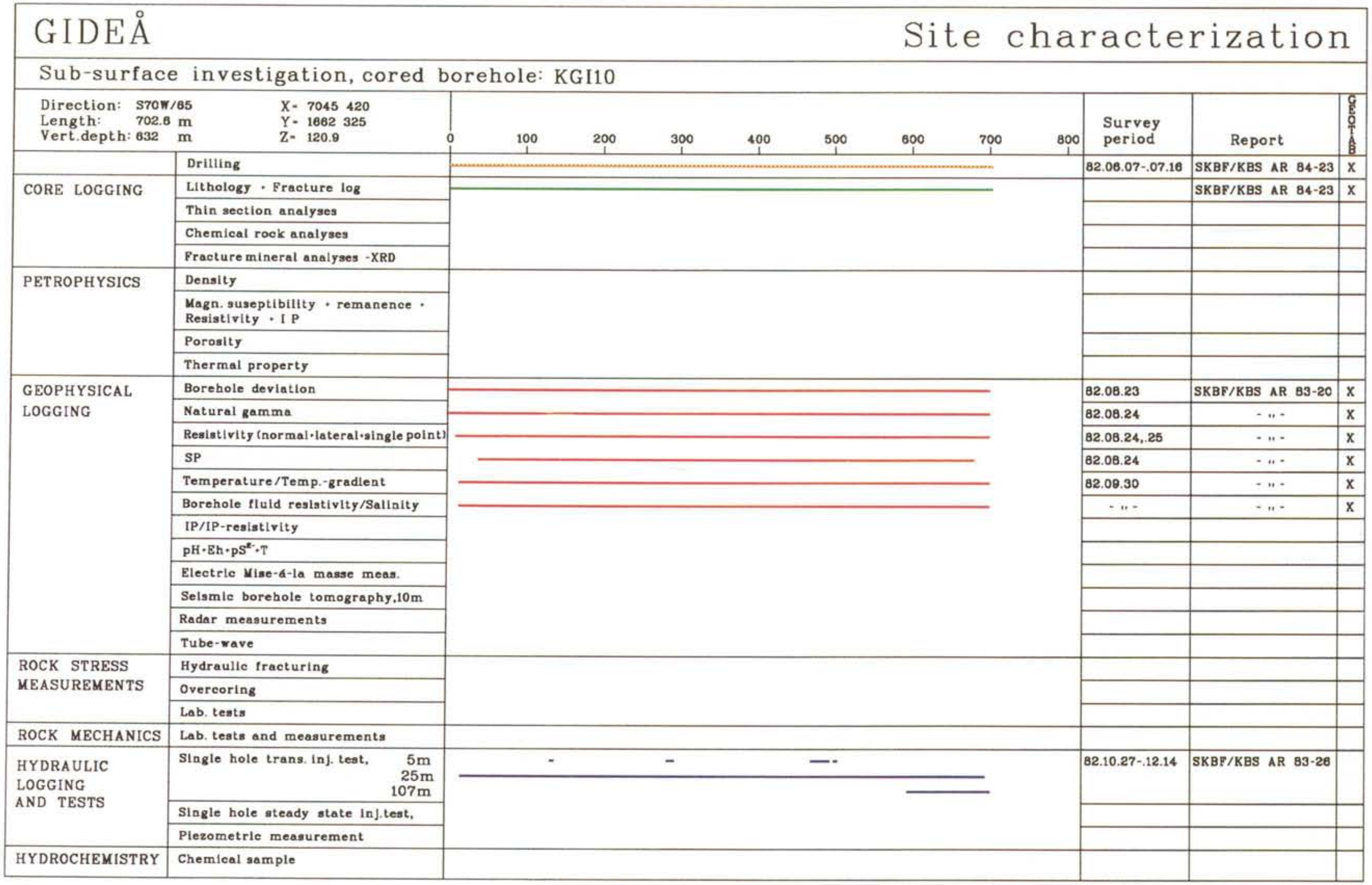
Sub-surface investigation, cored borehole: KGI09

Direction: S/67
Length: 281.9 m
Vert.depth: 250 m

X- 7045 745
Y- 1663 560
Z- 120.7

		Survey period	Report	GEOTAB
	Drilling	82.04.15-.30	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses			
	Chemical rock analyses			
	Fracture mineral analyses -XRD			
PETROPHYSICS	Density			
	Magn. suseptibility · remanence · Resistivity · I P			
	Porosity			
	Thermal property			
GEOPHYSICAL LOGGING	Borehole deviation	82.08.16	SKBF/KBS AR 83-20	X
	Natural gamma	82.10.01	- " -	X
	Resistivity (normal·lateral·single point)	82.08.17,.11.02	- " -	X
	SP	82.11.01	- " -	X
	Temperature/Temp.-gradient	82.09.30	- " -	X
	Borehole fluid resistivity/Salinity	- " -	- " -	X
	IP/IP-resistivity			
	pH·Eh·pS^{2-}·T			
	Electric Mise-á-la masse meas.			
	Seismic borehole tomography,10m			
	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, 25m	83.03.21-.03.28	SKBF/KBS TR 83-53	X
	Single hole steady state inj.test, 3m	83.04.21-.03.28	SKBF/KBS TR 83-53	X
	Piezometric measurement			
HYDROCHEMISTRY	Chemical sample			

Figure A10. Activities in borehole KGI09.



GIDEÅ

Site characterization

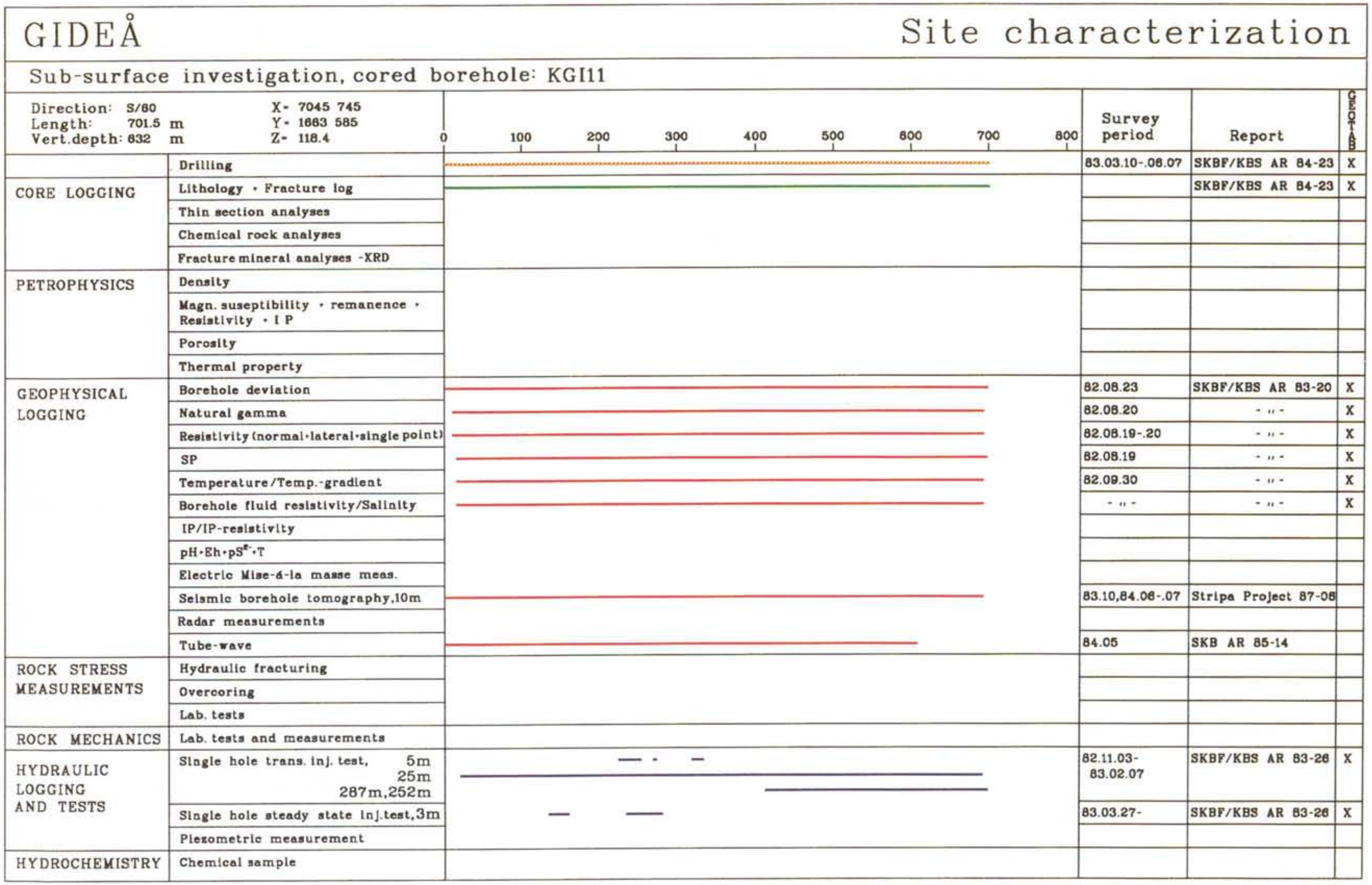
Sub-surface investigation, cored borehole: KGI10

Direction: S70W/65
Length: 702.6 m
Vert.depth: 632 m

X- 7045 420
Y- 1662 325
Z- 120.9

		0 100 200 300 400 500 600 700 800	Survey period	Report	GEOTAB
	Drilling		82.06.07-.07.16	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology · Fracture log			SKBF/KBS AR 84-23	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. suseptibility · remanence · Resistivity · I P				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.08.23	SKBF/KBS AR 83-20	X
	Natural gamma		82.08.24	- " -	X
	Resistivity (normal·lateral·single point)		82.08.24,.25	- " -	X
	SP		82.08.24	- " -	X
	Temperature/Temp.-gradient		82.09.30	- " -	X
	Borehole fluid resistivity/Salinity		- " -	- " -	X
	IP/IP-resistivity				
	pH·Eh·pS^{2-}·T				
	Electric Mise-á-la masse meas.				
	Seismic borehole tomography,10m				
	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, 5m 25m 107m		82.10.27-.12.14	SKBF/KBS AR 83-26	
	Single hole steady state inj.test,				
	Piezometric measurement				
HYDROCHEMISTRY	Chemical sample				

Figure A11. Activities in borehole KGI10.



GIDEÅ

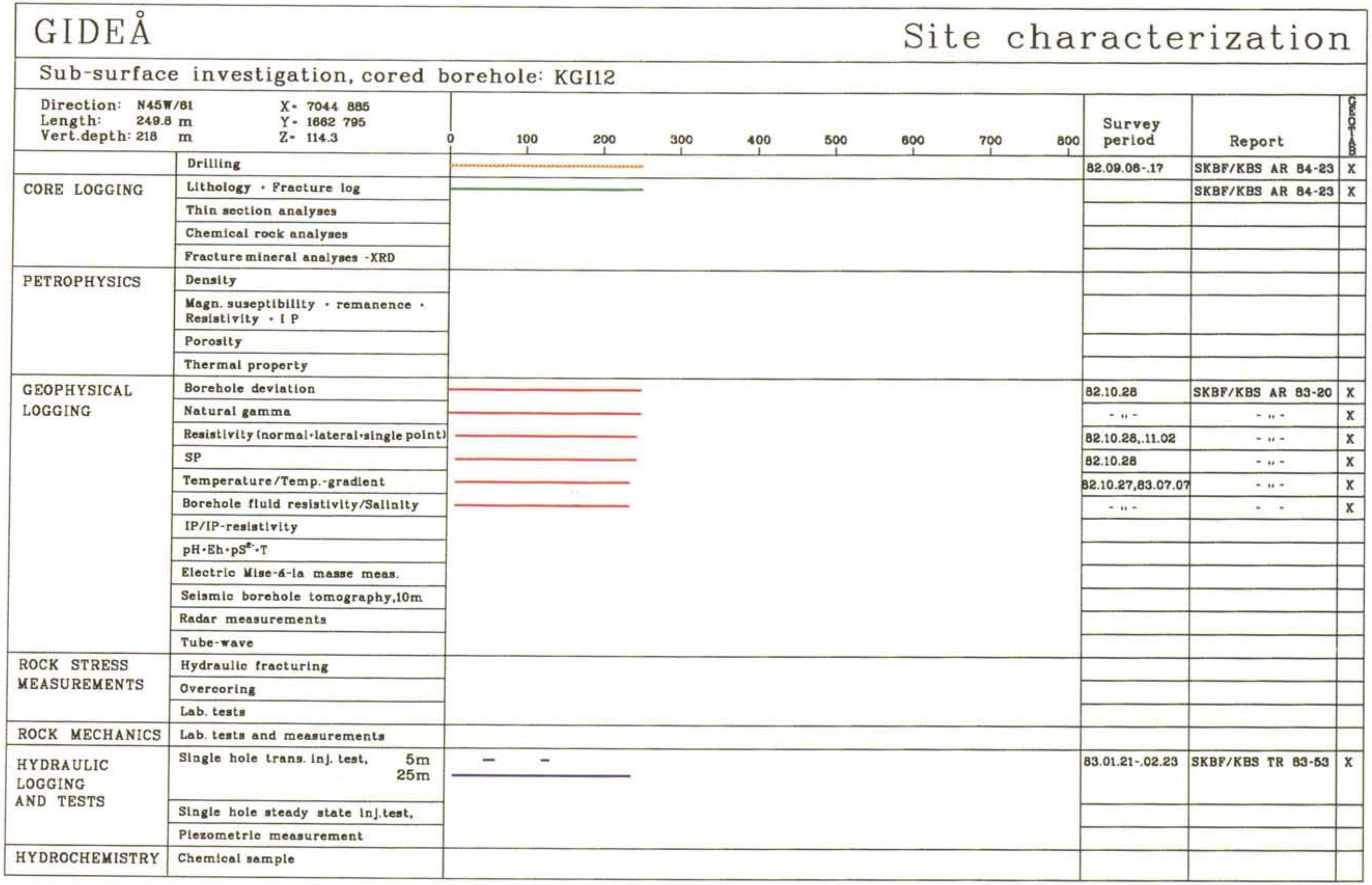
Site characterization

Sub-surface investigation, cored borehole: KGI11

Direction:	S/60
Length:	701.5 m
Vert.depth:	632 m
X-	7045 745
Y-	1663 585
Z-	118.4

		Survey period	Report	GEOTAB
	Drilling	83.03.10-.06.07	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology + Fracture log		SKBF/KBS AR 84-23	X
	Thin section analyses			
	Chemical rock analyses			
	Fracture mineral analyses -XRD			
PETROPHYSICS	Density			
	Magn. susceptibility + remanence + Resistivity + I P			
	Porosity			
	Thermal property			
GEOPHYSICAL LOGGING	Borehole deviation	82.08.23	SKBF/KBS AR 83-20	X
	Natural gamma	82.08.20	- " -	X
	Resistivity (normal-lateral-single point)	82.08.19-.20	- " -	X
	SP	82.08.19	- " -	X
	Temperature/Temp.-gradient	82.09.30	- " -	X
	Borehole fluid resistivity/Salinity	- " -	- " -	X
	IP/IP-resistivity			
	pH+Eh+pS^{2-}+T			
	Electric Mise-á-la masse meas.			
	Seismic borehole tomography,10m	83.10,84.06-.07	Stripa Project 87-06	
	Radar measurements			
	Tube-wave	84.05	SKB AR 85-14	
ROCK STRESS MEASUREMENTS	Hydraulic fracturing			
	Overcoring			
	Lab. tests			
ROCK MECHANICS	Lab. tests and measurements			
HYDRAULIC LOGGING AND TESTS	Single hole trans. inj. test, 5m 25m 287m,252m	82.11.03- 83.02.07	SKBF/KBS AR 83-26	X
	Single hole steady state inj.test,3m	83.03.27-	SKBF/KBS AR 83-26	X
	Piezometric measurement			
HYDROCHEMISTRY	Chemical sample			

Figure A12. Activities in borehole KGI11.



GIDEÅ

Site characterization

Sub-surface investigation, cored borehole: KGI12

Direction: N45W/61
Length: 249.8 m
Vert.depth: 218 m

X- 7044 885
Y- 1662 795
Z- 114.3

		0 100 200 300 400 500 600 700 800	Survey period	Report	GEOTAB
	Drilling		82.09.06-.17	SKBF/KBS AR 84-23	X
CORE LOGGING	Lithology + Fracture log			SKBF/KBS AR 84-23	X
	Thin section analyses				
	Chemical rock analyses				
	Fracture mineral analyses -XRD				
PETROPHYSICS	Density				
	Magn. suseptibility + remanence + Resistivity + I P				
	Porosity				
	Thermal property				
GEOPHYSICAL LOGGING	Borehole deviation		82.10.28	SKBF/KBS AR 83-20	X
	Natural gamma		- " -	- " -	X
	Resistivity (normal-lateral-single point)		82.10.28,.11.02	- " -	X
	SP		82.10.28	- " -	X
	Temperature/Temp.-gradient		82.10.27,83.07.07	- " -	X
	Borehole fluid resistivity/Salinity		- " -	- -	X
	IP/IP-resistivity				
	pH-Eh-pS^{2-}-T				
	Electric Mise-á-la masse meas.				
	Seismic borehole tomography,10m				
	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, 5m 25m		83.01.21-.02.23	SKBF/KBS TR 83-53	X
	Single hole steady state inj.test,				
	Piezometric measurement				
HYDROCHEMISTRY	Chemical sample				

Figure A13. Activities in borehole KGI12.

APPENDIX B

GENERALIZED RESULTS FROM BOREHOLE MEASUREMENTS

Generalized results from core mapping and borehole measurements/tests in the cored boreholes KGI01–KGI13 are presented in Figures B1–B4. For each borehole the following information is presented; variation in rock types, location of fractured sections and locations of sections with increased hydraulic conductivity. For comparison, also intersections with interpreted fracture zones are shown in the figures. The generalizations have been made in the following way:

Rock types

Main rock types are shown, i.e. rocks with a width/extension along the core greater than 1 m. Doleritic dykes and other basic rock types are collectively described as "greenstone". Late orogenic granite refers to the Svecokarelian granitic dykes discussed in Section 5.2.

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 21 in Section 6.3). Highly increased hydraulic conductivity is noted where the conductivity in the borehole section is more than 100 times higher.

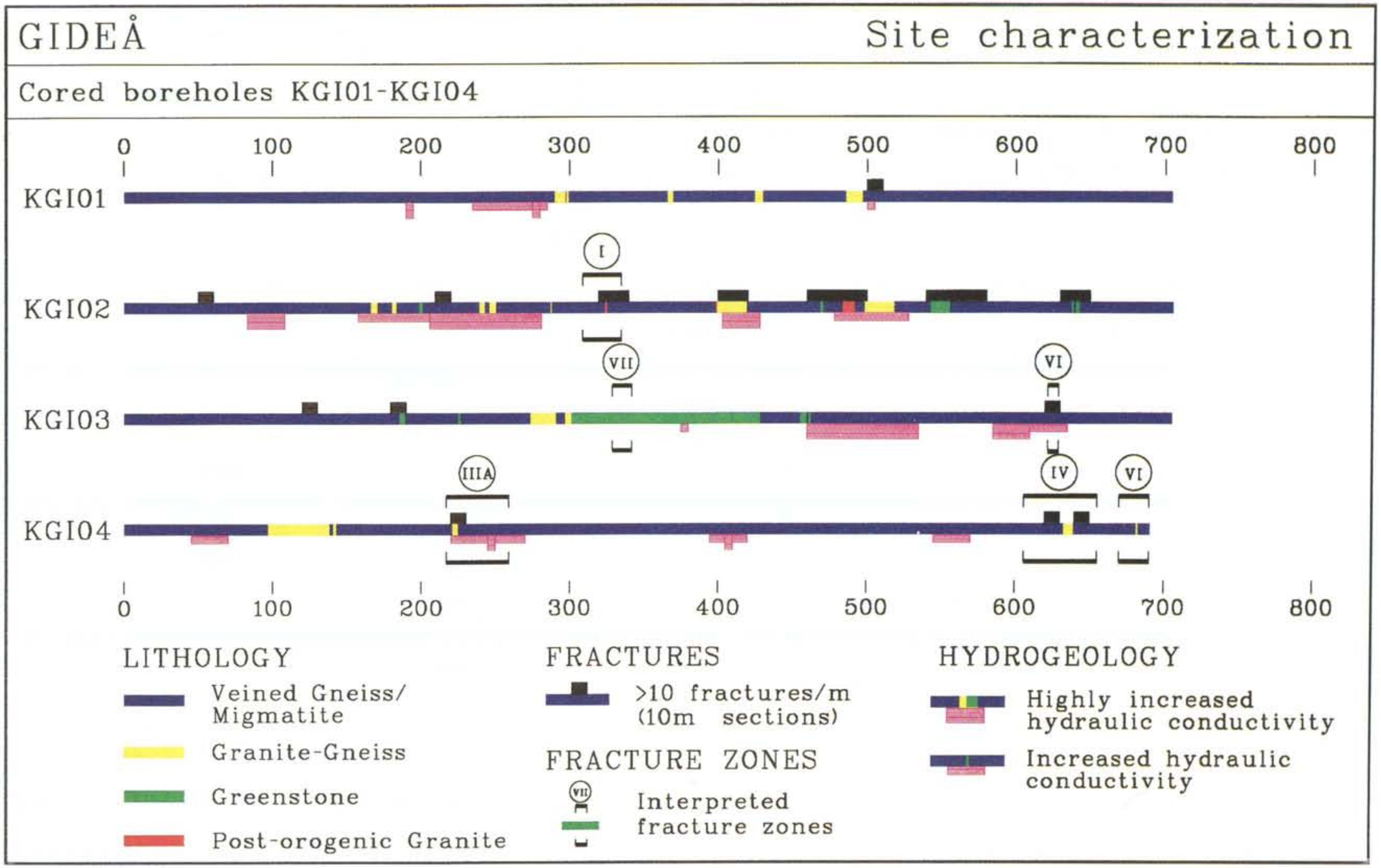
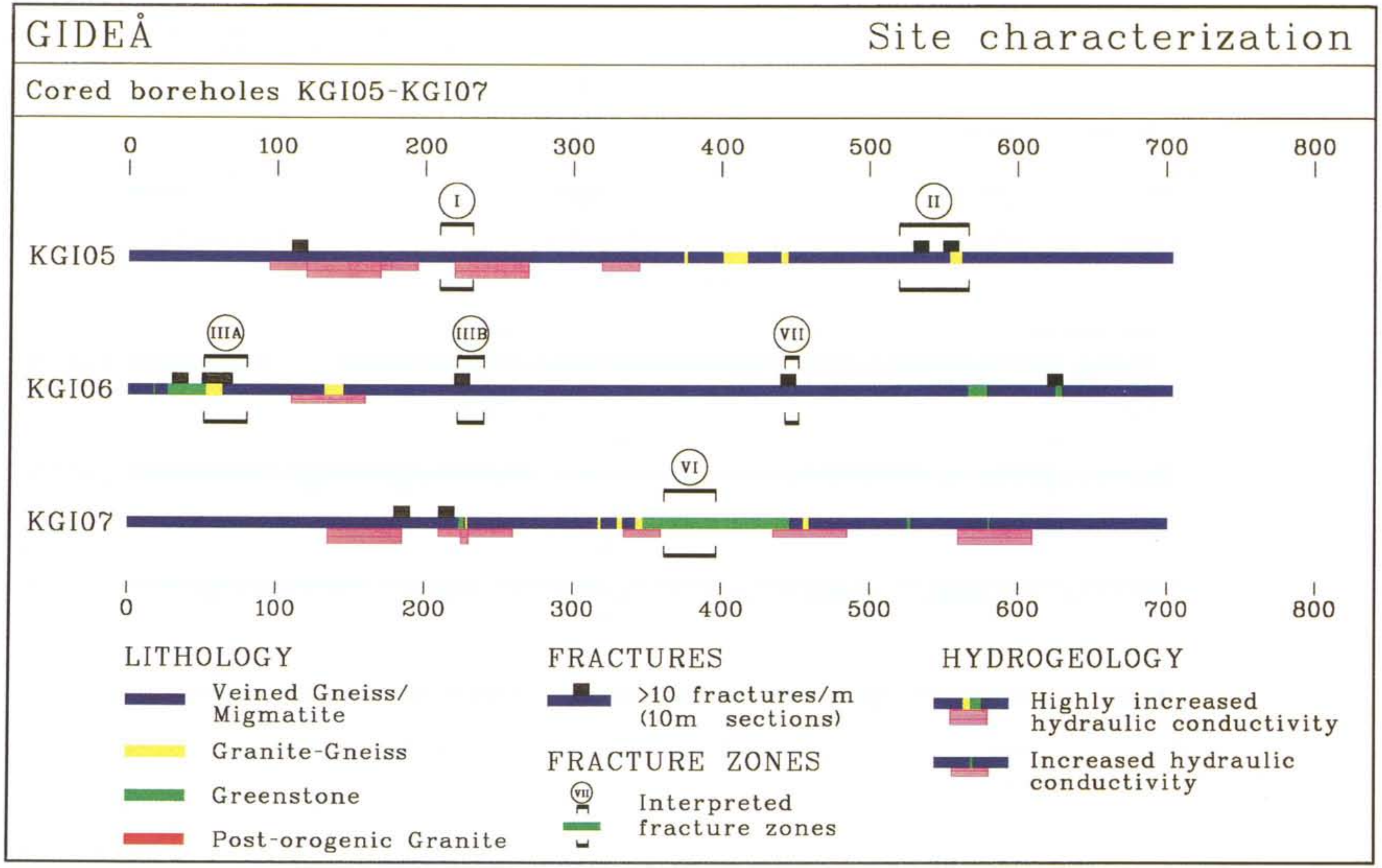


Figure B1. Results from borehole surveys in KGI01–KGI04. The horizontal axis represent borehole length.

Figure B2. Results from borehole surveys in KGI05–KGI07. The horizontal axis represent borehole length.



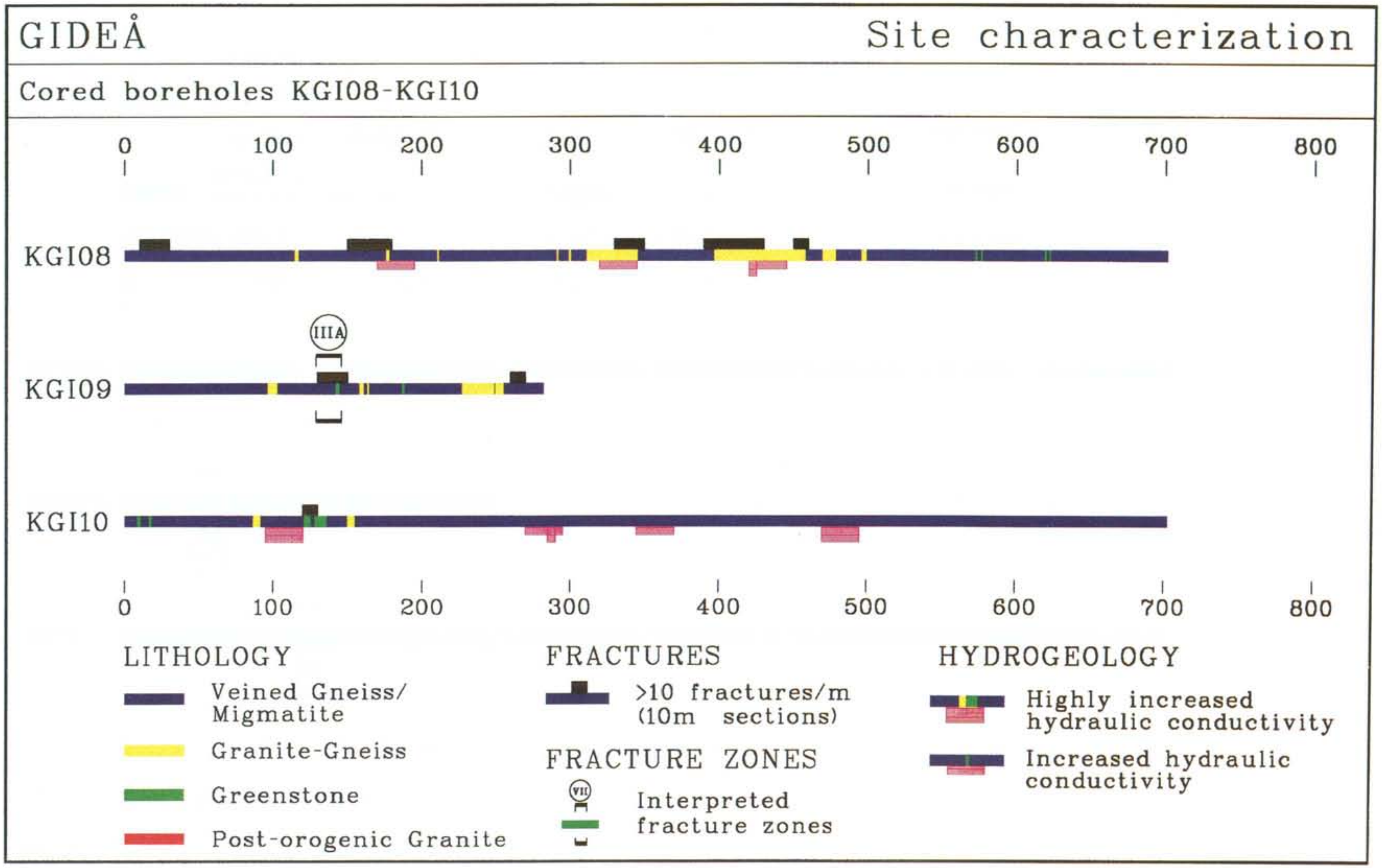


Figure B3. Results from borehole surveys in KGI08–KGI10. The horizontal axis represent borehole length.

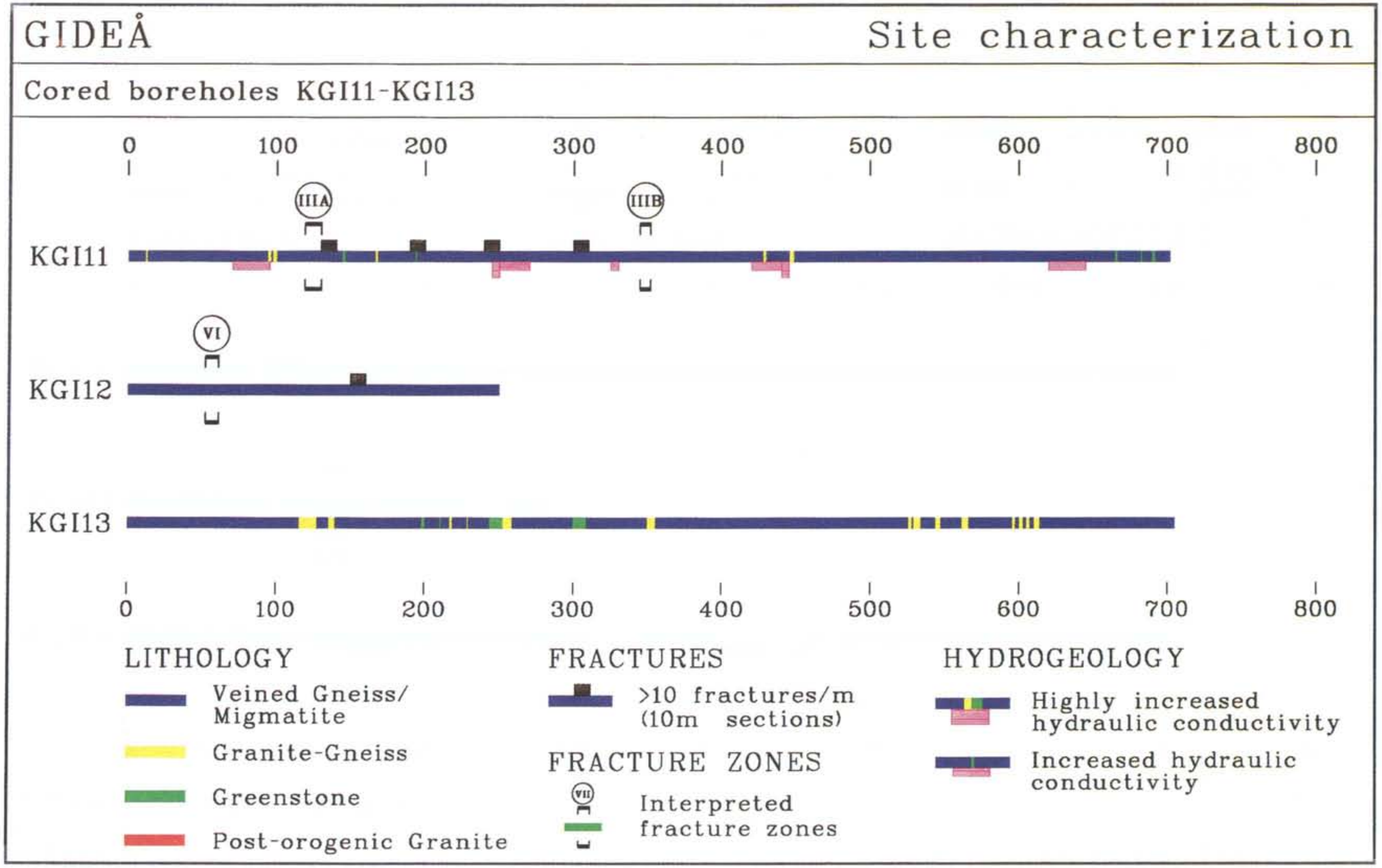


Figure B4. Results from borehole surveys in KGI11-KGI13. The horizontal axis represent borehole length.

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 at Gideå are summarized in Section 5.3.

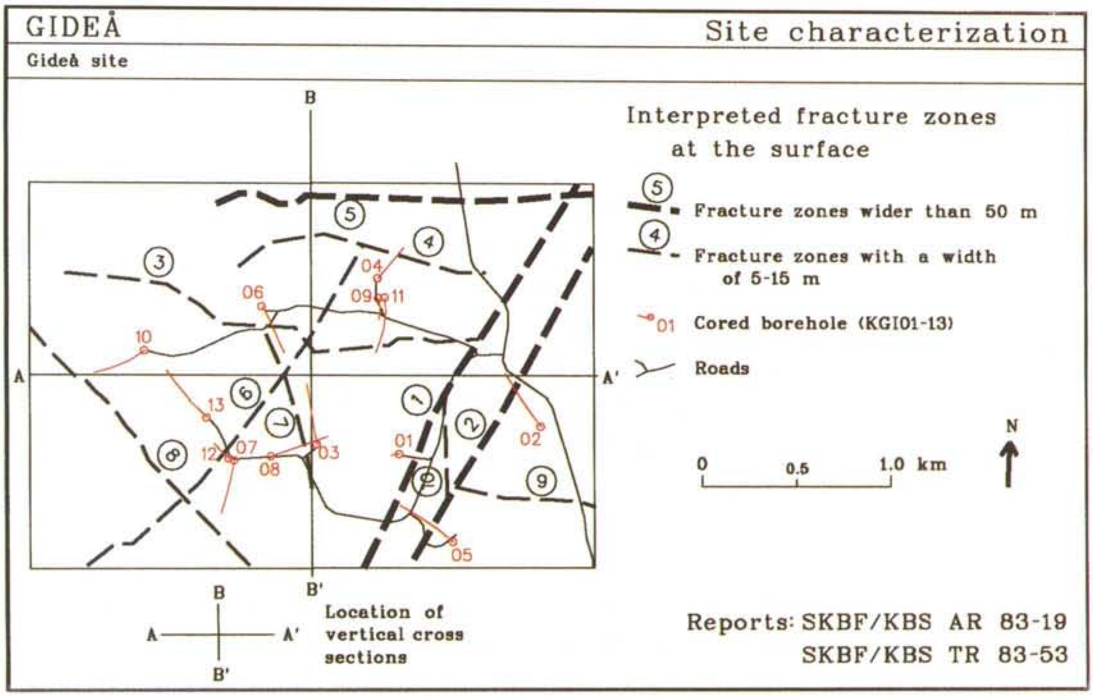


Figure C1. Map of interpreted fracture zones at the Gideå site.

ZONE 1

Zone 1 is oriented NNE. The zone is clearly expressed on geophysical maps (resistivity and slingram) and on refraction seismic profiles, were it is indicated as a narrow, 10 m wide, low velocity section. The geophysical anomaly follows a c. 200 m wide gully.

Four percussion boreholes (HGI01, 05, 23 and 24) are interpreted to penetrate the Zone 1. Three of these boreholes show strong inflows of groundwater (3000–4000 l/h, Table 1), while the fourth borehole is dry. Interpolating between the boreholes and the ground surface suggests a dip of 40° to SE for the fracture zone.

Using the above mentioned location and dip, Zone 1 are interpreted to intersect the cored boreholes KGI02 and KGI05 at 309–335 and 210–232 m, respectively. The cores at both locations display weathered and partly crushed rock indicating a width of Zone 1 of 22–24 m.

An alternative and steeper dip (70–80 SE) for Zone 1 is indicated from mise á la masse measurements (Magnusson, 1985), see below under Zone 2. These measurements were performed after the KBS–3 studies were finalized.

Reliability; although there are many boreholes intersecting the zone there still exist some doubt of the proposed dip. According to the Bäckblom nomenclature the reliability level is "probable".

ZONE 2

Zone 2 is oriented NNE and located c. 250 m SE and parallel to Zone 1. The zone is clearly indicated on the slingram and resistivity measurements and and on refraction seismic profiles, were it is indicated as a narrow, 10 m, low velocity section.

Two percussion boreholes (HGI15 and 16) are interpreted to partly penetrate Zone 2. The boreholes, located on each side of the zone, are drilled towards each other and show strong inflows (6000 and 900 l/h, respectively) at both ends of the boreholes. Interpolating between inflow sections in the boreholes and the anomaly in the ground geophysical surface suggests a steep dip of Zone 2.

Zone 2 are interpreted to intersect the cored borehole KGI05 at 520–567 m borehole length, suggesting a dip of Zone 2 of 70° NW. The cores at this section are partly crushed with clay alteration and weathered wall rock.

In the above mentioned mise á la masse measurements a current electrode was positioned at 547 m in borehole KGI05 (at the assumed location of Zone 2) and the resulting potential field was measured at the ground surface. The measurements indicated that the fractured section in borehole KGI05 at 520–567 m was not connected to the geophysical anomaly at the ground surface representing Zone 2. Instead a connection to the anomaly representing Zone 1 was observed. If this interpretation is correct the proposed dip of Zone 2 has to be changed.

Reliability; although there are two percussion and one cored borehole intersecting the zone there still exist some doubt of the proposed dip. According to the Bäckblom nomenclature the reliability level is "probable".

ZONE 3

Zone 3 is located in a E–W gully in the central–northern part of the site. Geophysical measurements clearly indicate a fractured zone both on the resistivity and slingram maps, as well as in the seismic refraction profiles, where there is a 50 m low velocity section in the gully.

The dip of the zone has been investigated along two drilling profiles, comprising 2 and 3 boreholes, respectively. The results from the percussion borehole investigations are somewhat ambiguous, but the results suggests a gently dipping zone, 30–45° towards the north. However, in this case both dry boreholes and boreholes with high groundwater inflows will intersect the zone.

Later, cored boreholes KGI04, 06, 09 and 11 strengthen the interpretation of a gently dipping (30°) fracture zone towards north, but the cored boreholes also indicated a steep fracture zone dipping 80°, towards the north. Both fracture zones are interpreted to outcrop at the same location. The notation of the zones are 3A for the gently dipping and 3B for the steeply dipping zone.

The rock in Zone 3A consists of partly crushed, partly brecciated rock and contains also a 0.2 m dolerite dyke. Estimates regarding the width of the zone varies between 10–20 m. Zone 3B is penetrated by the boreholes KGI 06 and 11. The rock are partly crushed. Kaolinite is reported as a fracture mineral. Estimated width of Zone 3B varies between 4–9 m.

The existence of Zone 3A was strengthen by a seismic tomography survey (Pihl, 1987), performed in some boreholes in the Gideå area. This survey indicated a low–velocity zone at the interpreted location of the gently dipping Zone 3A.

Reliability; the gently dipping Zone 3A is apparent as a geophysical anomaly at the ground surface and is penetrated by 4 cored and 4 percussion boreholes. In addition, the results from the borehole tomography survey strengthen the interpreted location of the zone. According to the Bäckblom nomenclature the reliability level for Zone 3A should therefore be "certain".

The steeply dipping Zone 3B is penetrated by 2 cored boreholes and 3–4 percussion boreholes. Reliability level: "probable".

ZONE 4

Zone 4 is oriented E–W and is located in the northern part of the site. It is clearly indicated as a topographical feature and as a anomaly on the resistivity and slingram maps. However, the zone is not reflected as a low velocity section in the seismic survey.

A percussion borehole (HGI13) was drilled to obtain hydraulic data of Zone 4. The borehole was dry. However, it is possible that the borehole never reached the zone. Zone 4 is interpreted to be penetrated by the cored borehole KGI04 at 606–655 m borehole length. At this location the cores display a high fracture frequency with some small crushed and altered sections. Estimated width for Zone 4 is 10 m.

Reliability; the zone is indicated as a lineament and as a geophysical anomaly at the ground surface. The zone is also interpreted to be intersected by one cored, and possible one percussion, borehole. The large distance between the surface expressions and the interpreted location in the cored borehole suggest a reliability level of "possible".

ZONE 5

Zone 5 is oriented E–W and is located in the northernmost part of the site. Its outcroping is covered by a peat–bog. It is parallel to Zones 3 and 4. The zone it apparent on the slingram and resistivity measurements, as well as by the refraction seismic survey as a low velocity section of at least 30 m width. The seismic survey indicate a depression infilled with 16 m of soil at the location of Zone 5. This is by far the greatest overburden depth at the site. No boreholes have been drilled to investigate Zone 5. From the geophysical data a vertical dip and a width of 50 m is assumed.

Reliability; the zone is indicated by a lineament and a geophysical anomaly. No borehole information exist, thus reliability – "possible".

ZONE 6

This zone intersect the central part of the site, subparallel to Zones 1 and 2. It is oriented NE and dips 70° SE. Only minor small geophysical anomalies and a weak topographical expression is apparent along the interpreted extension of Zone 6. The existence of the zone was tested and confirmed by the cored borehole KGI12, which intersect a zone between 52–73 m. Zone 6 is also interpreted to occur in borehole KGI03 and KGI04 at 622–629 m and 670–690 m, respectively. The cores from boreholes KGI12 and KGI03 are at these localities strongly weathered, brecciated and partly crushed. The tectonized character is less pronounced in borehole KGI04. The width is estimated to 5 m.

Reliability; the zone is only weakly indicated as a lineament and as a geophysical anomaly. The zone is therefore mainly interpreted from interpolations between cored boreholes. Although the interpolation involve 4 boreholes, frequent occurrence of fractured sections in these boreholes make several interpretations possible. Reliability level – "possible".

ZONE 7

This zone is oriented NNW and dips 75^0 E. It is located in the central part of the site. This zone is weakly indicated both on the geophysical maps and on the topographical map. The existence of the zone was tested by borehole KGI08, but because of subparallel dips, the borehole did not intersect the zone (although several brecciated sections occur in the cores). Instead, the zone is interpreted to occur in boreholes KGI03 and KGI6 at 329–342 and 443–452 m, respectively. The core from Zone 7 in borehole KGI06 is strongly crushed for c. 2 m, while the degree of fracturing is less pronounced in borehole KGI03. Estimated width of Zone 7 varies between 1–7 m.

Reliability; the same as for Zone 6, thus "possible".

ZONE 8

This zone is oriented NW and is located in the southwestern part of the site where there is no outcrops. The zone is indicated by a topographical feature and by slingram and resistivity anomalies (the geophysical anomalies only occurs westward of Zone 6). Since Zone 8 is not identified in boreholes KGI07 and KGI10, the zone could either be vertical or dip towards the south. The geophysical measurements indicate an dip of 70^0 SW and a width of 10 m.

Reliability; the zone is interpreted from topographical and geophysical indications only. Reliability level: "possible".

ZONE 9

Zone 9 is oriented E–W and is located in the eastern part of the site. The zone is indicated by the slingram and resistivity measurements. No boreholes have been drilled to investigate Zone 9. From the geophysical measurements a dip of 70° N and a width of 5 m is assumed.

Reliability; the zone is interpreted from an weak geophysical indication only. The Zone 9 should therefore be considered "possible".

ZONE 10

This zone is oriented N–S and is located in the eastern part of the site. The zone is primarily indicated by the seismic refraction survey as two 5 m low-velocity sections located in a 5 m deep depression. There are also some indications from the slingram and resistivity measurements, as well as a topographical expression. No boreholes have been drilled to investigate Zone 10. A vertical dip and a width of 5 m is assumed for Zone 10.

Reliability; the zone is interpreted from topographical and geophysical indications only, thus "possible".

List of SKB reports

Annual Reports

1977-78
TR 121
KBS Technical Reports 1 – 120
Summaries
Stockholm, May 1979

1979
TR 79-28
The KBS Annual Report 1979
KBS Technical Reports 79-01 – 79-27
Summaries
Stockholm, March 1980

1980
TR 80-26
The KBS Annual Report 1980
KBS Technical Reports 80-01 – 80-25
Summaries
Stockholm, March 1981

1981
TR 81-17
The KBS Annual Report 1981
KBS Technical Reports 81-01 – 81-16
Summaries
Stockholm, April 1982

1982
TR 82-28
The KBS Annual Report 1982
KBS Technical Reports 82-01 – 82-27
Summaries
Stockholm, July 1983

1983
TR 83-77
The KBS Annual Report 1983
KBS Technical Reports 83-01 – 83-76
Summaries
Stockholm, June 1984

1984
TR 85-01
Annual Research and Development Report 1984
Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01 – 84-19)
Stockholm, June 1985

1985
TR 85-20
Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01 – 85-19)
Stockholm, May 1986

1986
TR 86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

1987
TR 87-33
SKB Annual Report 1987
Including Summaries of Technical Reports Issued during 1987
Stockholm, May 1988

1988
TR 88-32
SKB Annual Report 1988
Including Summaries of Technical Reports Issued during 1988
Stockholm, May 1989

1989
TR 89-40
SKB Annual Report 1989
Including Summaries of Technical Reports Issued during 1989
Stockholm, May 1990

1990
TR 90-46
SKB Annual Report 1990
Including Summaries of Technical Reports Issued during 1990
Stockholm, May 1991

Technical Reports

List of SKB Technical Reports 1991

TR 91-01
Description of geological data in SKB's database GEOTAB
Version 2
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