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A STUDY OF GEOHYDROLOGICAL AND ROCK ENGINEERING ENVIRONMENT AT LAPPVATTNET EXPERIMENTAL MINE

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ABSTRACT

The paper describes a hydrogeological and geotechnical study of rock mass at an experimental nickel mine at Lappvattnet, Sweden. The mine is situated 30 km south-west of the township of Skelleftea and was mainly developed for the exploration purposes. The mine consists of 1000 m of underground roadways from where a number of diamond cored boreholes were drilled for geotechnical studies and mine valuation. The main problem encountered during the development stage of the mine was very high quantities of ground water inflows at relatively high hydraulic pressures. The geological and hydrogeological conditions along the length of the drifts are described together with the methods used for ground-water inflow control. The study shows that there is a strong need for modifying the grouting methods to suit the rock conditions in order to control the groundwater inflows. A discussion regarding the need for a detailed geotechnical investigation prior to the planning and design stage of the project is also included.

INTRODUCTION

The nickel deposit in Vasterbotten in the north-western part of Sweden is found in a zone about 120 km long which extends from the town Skelleftea on the east coast towards the south-west (see figure 1). In the early nineteen-seventies the Geological Survey of Sweden started block sampling in the nickel zone. Diamond core drilling within the deposit at Lapvattnet was started in 1974 and continued during 1975 and 1976. The borehole cores indicated nickel-copper mineralisations down to the depth of 120 m below the surface. The percentage nickel-copper was estimated to be in excess of 0,4% in the richest part of the ore body. The test mine was started at Lappvattnet in 1978 when the orebody was explored along the 120 m level and also along 10 cored boreholes drilled from the drifts. The results of the investigations indicated that the full scale mining operations will not be profitable on account of relatively small ore reserves, poor ore content and high rates of ground-water seepage through bed-rock.

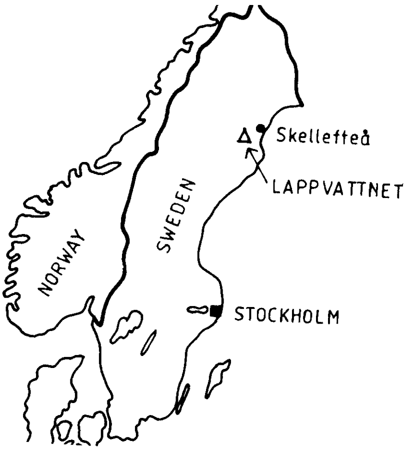

Figure 1 Location of the test mine at Lappvattnet

INVESTIGATION APPROACH AND OBJECTIVES

The main purpose of this geohydrologic and rock engineering study was to:

- document the geohydrologic conditions in the test mine
- evaluate and describe the geohydrologic and rock engineering conditions along the ore mineralisation
- analyse "Project Lappvattnet" with a view of applying experiences to similar projects

The study has, amongst other things, included the following approaches:

- mapping of the drifts
- study of the drill cores
- study of the experiences from the driving of the drifts, for example the performance of grouting.

STRUCTURAL MAPPING OF DRIFTS

The geological mapping has been done for the purpose of recording the position of fissures, tectonic zones, schistosity and ground-water inflow. The results have been presented according to BERGAB's system of classification. This system gives a classified description of the rock conditions with reference to the degree of crushing, clay alteration and the presence of ground-water. A complete description of the BERGAB's classification system is given in Table 1. The system has been used for

Table 1

Bergab System of Rock Mass Classification

ROCK-TYPES

Marked with different kinds of screen or described in text

TECTONIC

20°	Strike and dip of schistosity
45°	Fissure; vertical and inclined resp.
BL	Area where the bedrock is broken along intersecting fissures, demarcating blocks with edges of 60 – 200 cm

Tectonic zones: Tectonic zone – zone in the bedrock mecanically chrushed of widht <10 cm

K1	Zone of "slaty cleavage" – zone where the bedrock is broken mainly along plane-parallel fissures at the interval ≥ 10 cm
K2	Zone of "thin slaty cleavage" – zone where the bedrock is broken mainly along plane-parallel fissures at the interval <10 cm
K3	Zone of "blocky rock" – zone where the bedrock is broken mainly along intersecting fissure groups, demarcating blocks with edges of ≥ 20 cm
K4	Zone of "partly crushed rock" – zone where the bedrock is broken mainly along intersecting fissure groups, demarcating blocks with edges of <20 cm
K5	Zone of "completely crushed rock" – zone where the bedrock is entirely chrushed to fragments by fissures of intersecting directions

CLAY-ALTERATION

Clay-alteration – alterations of the bedrock which have entailed the formation of clay-minerals. These can be of both swelling and non-swelling type

L1	"Clay filled fissure" – single fissure (width ≤ 10 cm) with clay minerals between the fissure planes
L2	"Clay filled vein" – single fissure (width <10 cm) with clay minerals between the fissure planes
L3	"Zone with clay-alteration in all fissures" – zone where the bedrock is entirely traversed by clay fissures
L4	"General clay-alteration" – zone where the whole bedrock mass is dissintergrated to gravel / clay

GROUND WATER FLOW

Ground water flow – the leaking in of ground water which arises, when water-bearing fissures or zones intersect a rock tunnel, rock cavern etc.

V	Small water flow
V V	Moderate water flow
V V V	Strong water flow
V V V V	Extremely strong water flow

REMARKS

The symbols are combined to give a differen[t] description of each tectonic zone. For exampl[e]

K3
L1
V V

Zone with "blocky rock", single "cl[ay] filled fissures" and "moderate wat[er] flow"

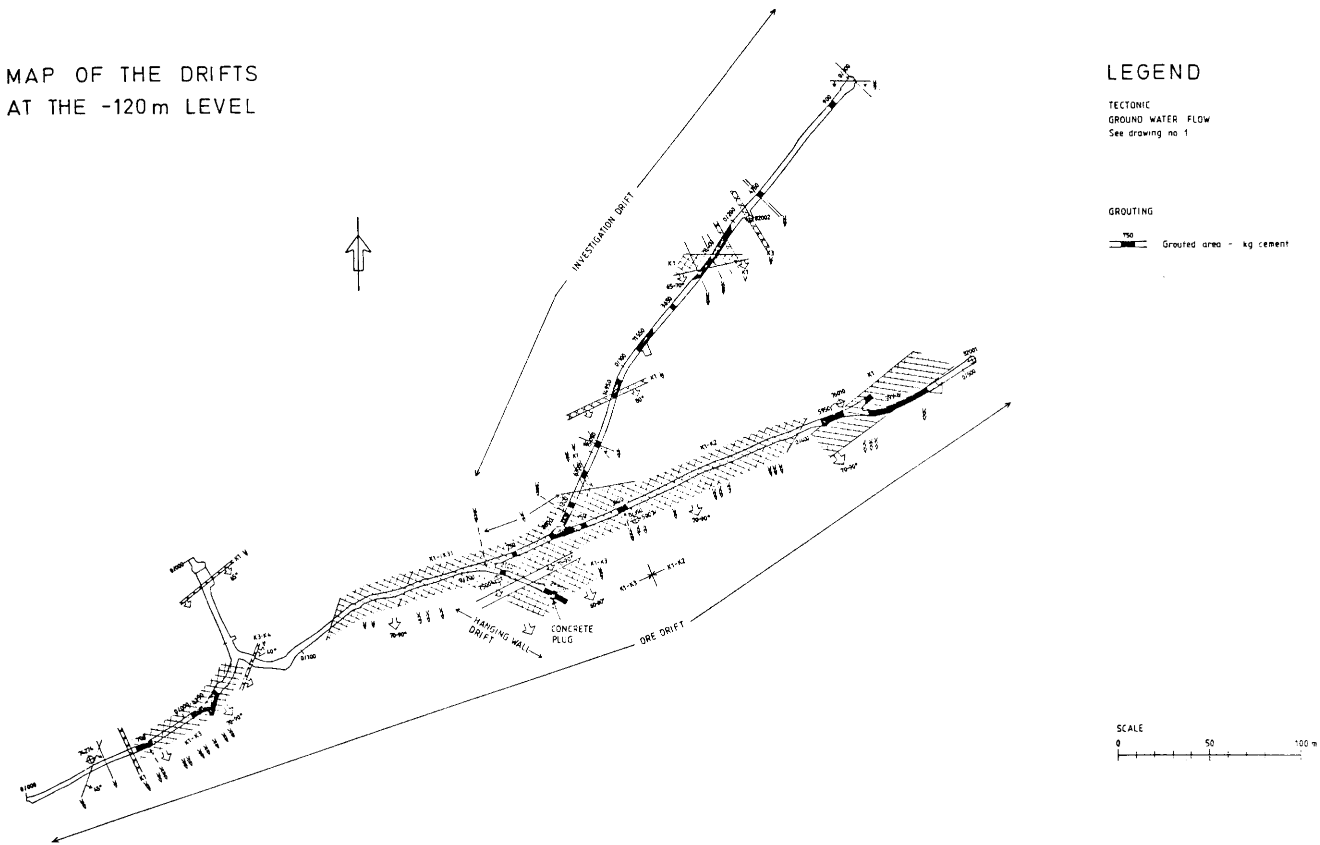

Figure 2 Layout of site of investigation

about 15 years in a large number of projects, both at the planning and development stages. The structure plan of the drifts is given in Fig. 2 which show the fissures and water bearing zones at the time of the geological mapping.

The ore drifts were driven parallel to and in the zone of ore mineralisation. From a hanging wall drift (Fig. 2) it was planned to carry out core drilling to obtain samples from the ore mineralisation on deeper levels. The driving of the hanging wall drift however, had to be discontinued because of low quality ore together with high rates of ground-water inflows presenting a risk of the tunnel face collapse. At this stage it was decided to plug up the inbye end of the drift with a concrete dam. An investigation drift was then developed, where the planned exploratory drilling was carried out (Fig. 2).

Rock Structures

The dominating rock type was gneiss. The strike direction of the schistosity was about N50-70°E with the dip of 50-80°S. Fissures and tectonic zones appeared mainly along the schistosity and along more or less vertical planes with the direction N25-40°E. Along the schistosity planes there were thin veins of graphite. In some parts the percentage of graphite was high. The graphite forms conspicuous planes of weakness in the bedrock. Where the percentage of graphite was high the bedrock had a distinct slaty-thin slaty cleavage along the schistosity. The ore mineralisation had occurred in the "weakest" parts of the bedrock, in addition to the parts, rich in graphite. Consequently, the ore body forms a slab orientated along the schistosity. The percentage of graphite was normally high in the ore drifts and hanging wall drift but considerable lower in the investigation drift.

The ground-water flow was in general very strong. Both fissures along the schistosity and vertical fissures orientated about N25-40°W carried water. The ground-water reservoir was large. The bedrock was covered with a 12-15 m thick layer of glacifluvial sand, in which the ground-water level was just below the surface. Depending upon the presence of graphite, the bedrock conditions were markedly different in the ore drifts/hanging wall drift and investigation drift. This is indicated by the differing degrees of deformations.

Because the bedrock had been subjected to tectonic deformation the built up tensions caused movements thus, creating fissures. These movements had mainly taken place along existing planes of weaknesses. In principle, the bedrock had been subjected to deformation during two separate epochs.

In the plastic deformation mode the bedrock had partly recrystallized simultaneously with the development of the schistosity planes. Movements in the bedrock had taken place along existing planes of schistosity and parallel graphite veins. Secondary tension cracks had been formed along a strike direction about perpendicular to the schistosity. In reality these correspond to the vertical fissures striking N25-40°W. These types of fissures are most distinctly formed in the parts poor in graphite where tensions have not been relieved due to movements along the schistosity/graphite veins.

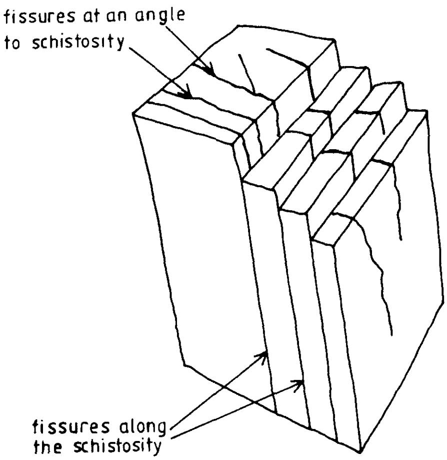

Figure 3 Principle type of fissure formation

In the ruptural deformation after consolidation of the bedrock to a rigid mass, it had been exposed again to deformation. Older schistose veins and planes formed during the plastic deformation have then controlled the new movements along the schistosity/graphite veins. Further movements had also occurred along the earlier tension cracks. The experience from areas of similar geological structure shows that fissures/schistosity zones often limit the extent of other types of fissures. Fissures at an angle to the schistosity terminate in many cases, just to fissures along the schistosity zones or continue to diffuse (see Fig. 3).

The ore drift is situated in the bedrock containing a high percentage of graphite and is characterized by the presence of slaty cleavages and minor types of fissures. The investigation drift is located in the rock mass containing a low percentage of graphite and predominantly characterized by structural features such as fissures intersecting the schistosity at an angle and to a lesser extent by the slaty cleavages. (Fig. 2 and 4).

The ground-water flow was strong in both the graphite poor and graphite rich parts. In the graphite rich part the water flow is almost completely linked to the fissures flow along the schistosity and sometimes to "channels" along the graphite veins (see Fig. 5). The tension cracks formed perpendicularly to the schistosity are open and water bearing. This has been possible to verify within some grouted parts of the investigation drift where the grout was seen to have filled open fissures of this type.

A STUDY OF CORES OBTAINED BY DIAMOND CORE DRILLING

The site and the direction of the boreholes were selected so as to obtain the following information.

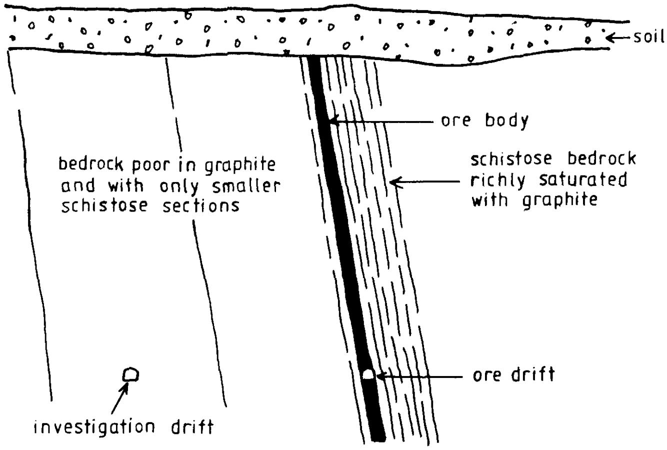

Figure 4 Diagrammatic presentation of the bedrock around the ore drift and investigation drift

1. Cores drilled in advance of the drifts in different geological environments. The purpose of these cores was to make a comparison between the cores and the corresponding structural mapping of the actual drift.

2. Cores from corresponding geological environments taken from higher levels. The purpose of these cores was to compare them to the cores obtained from the drift level.

3. Cores obtained from holes intersecting fissure zones not far from the rock surface. The purpose of these cores was to investigate "the quality of the surface rock" especially considering the conditions for water infiltration from the soil layer.

4. The bore hole cores were obtained from the drift's walls which have been repeatedly grouted. The purpose of these cores was to compare grouted parts of the bedrock to geological conditions.

The study of the core drilling can be summarized as follows:

- In the parts of the drifts where the bedrock had a markedly slaty cleavage along the schistosity, the cores were "cut into small pieces". These pieces are in most cases defined by fissures along the schistosity.

- The slaty cleavage in the drifts was in most cases connected to parts of the bedrock rich in graphite. The corresponding cores show distinct veins of graphite along the schistosity.

- In the zone where the hanging wall drift had to be abandoned the corresponding cores were of a very low rock quality. Several losses of cores had been noted. Of the relatively few core holes which have been examined, the conditions in the zone appeared to alter slightly along the drift.

- In the foot wall of the ore mineralisation the fissure frequency is considerably lower than in the hanging wall.

- Distinct fissures at an angle to the schistosity had been observed in the cores from the foot wall. Mostly these fissures were regarded as vertical with the strike about N25-40°W.

In the structure mapping by borehole cores, the water bearing open fissures are normally identified by the presence of a layer of rust on the fissure surfaces. However, in the present study these direct indications of the presence of water were very rare. The absence of rust in itself is natural in the parts where the graphite veins in contact with the water bearing fissures along the whole surface or in open channels. No natural rust occurs in such an environment. (Fig. 5).

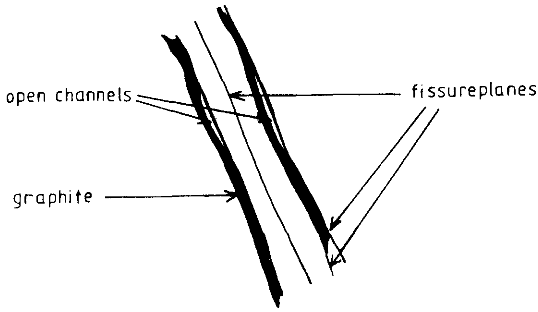

Figure 5 Diagrammatic presentation of open "channels" along graphite veins

Further, no rust could be traced in the vertical fissues striking about N25-40°W which were partially water bearing. This fissure direction was however under-represented in the cores, because of the general direction of the core holes which were more or less perpendicular to the ore mineralisation.

The records from the drill cores drilled from the drifts indicate several incidence of groutings to stop the water inflow. However, it was not possible to say if the groutings were done because of a single fissure/zone or if the holes had been accumulating water from longer sections.

Core drilling both from the surface and from the underground drifts, clearly demonstrate the need for water loss measurements using a packer test. With these measurements interesting sections can be tested and compared to geological conditions observed in the cores. A great deal of important information concerning engineering geology could be added to the project in this way.

EXPERIENCES FROM DRIVING THE DRIFTS

Water inflow

The difficulty with water inflow to the drifts under strong hydraulic pressure has been the dominating problem when driving the drifts. When driving the drifts, water inflow caused considerable disturbances, of which some are listed below:

- difficulties to drill for blasting
- difficulties to pump the drifts free from water
- poor environmental conditions
- continual interruptions in the driving cycle caused by the drillings for grouting and groutings.

About 1500 l/min have been pumped out from the completed system of drifts.

Blasting

The project was based on the use of hand-held drilling. Many problems arise when drilling in the presence of strong water flows. The drillers had to work with water flowing in from the ceiling of the drift, from the drilled holes and from the holes being drilled. If the water in the drilled holes was stopped by packers, the pressure would rise in the holes impeding the drilling operations. It was almost impossible to charge the holes due to strong water flow. To make the driving of the drifts possible, pregrouting was extensively used. Also during the project the hand-held drilling was changed to a drill rig.

Support

The fissures in the bedrock were more or less vertical which was favourable for the driving of the drifts. There was no need for shotcreting and only a few rock bolts were used. No ordinary stability problems occurred.

Grouting

The work to seal off the water was a dominating problem right from an early stage. No records had been kept to show how the sealing work was executed in detail. All information about the grouting is to be found in a diary, which contains only information entered about when the grouting was done, how many hours had been worked and how much cement was used. A technical analysis of how the work was carried out was not possible because of the lack of information.

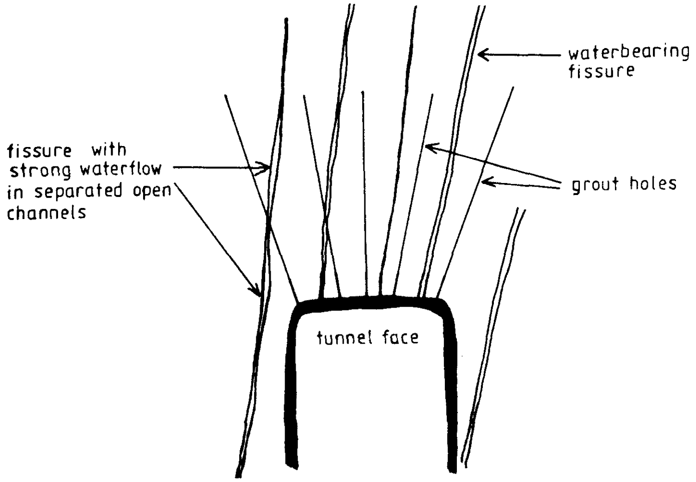

Figure 6a Conventional grouting with fissures parallel to the drift. When the grout holes are conventionally placed and directed the chances to obtain a good sealing of the fissures are small

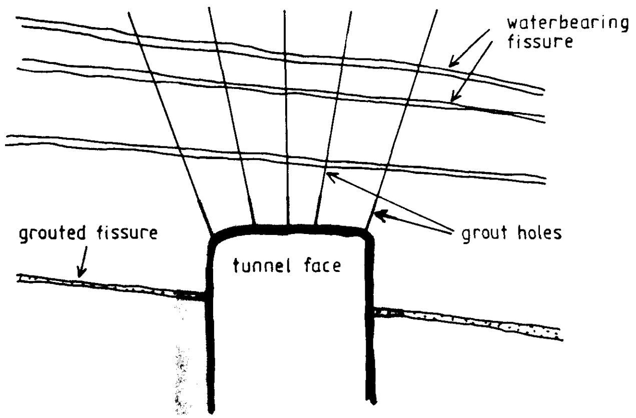

Figure 6b Conventional grouting with fissures perpendicular to the drift. Good conditions to attain a good sealing result. Each grout hole intersects several fissures and the same fissures are intersected in several places

When the drifts were mapped some substantial leakages were also observed in sections where extensive groutings had been done. An explanation could be, that the drifts, especially the ore drifts, where driven parallel to a large number of fissures which had a bad communication with each other, due to lack of transverse fissures. The forward drilling, which is almost parallel to the drift in this type of pre-grouting, could not intersect all the fissures. Many of these are therefore left ungrouted because of the lack of transverse fissures. An aggravating circumstance for the grouting can also be the water bearing channels along the fissure planes which were observed during the survey (see Fig. 6). It is difficult to achieve good grouting results under the circumstances where bad communication prevailed between the fissures together with a relatively high ground-water pressure (about 1,2 MPa). Good sealing calls for good knowledge, technical imagination and good equipment.

Figure 2 shows the area of drifts grouted by cement together with the information about used quantity of cement, as marked for every grouted section. The majority of the grouted sections are to be found in the parts of the drifts, where the fissure frequency is high and the ground-water flow strong. Despite occasional high quantities of cement the still leaking parts often have strong water inflows. However, there are some grouted sections in the investigation drift which do not correspond to water bearing fissures or zones (Fig. 2). Only the fissures and zones which were leaking at the time of the survey are represented in Fig. 2. If on the other hand the grouted sections were compared to a detailed drawing of the investigation drift, where all information is available, the following would appear:

- in the grouted sections there were especially vertical fissures stricking about N30-35^{o}W
- in the grouted section around 0/190 there is a zone about 2 m wide, striking N35^{o}W. In this zone the grouting cement can be seen along the previous open fissures
- the fissures still leaking within the grouted sections had small leakage (v).

The results from the grouting in these sections are very good and show how the varying geological conditions are important to the grouting. To sum up, the following typical cases can be distinguished:

- when the fissures are parallel to the drift the grouting results are often poor (Fig. 6a)
- when the fissures are perpendicular to the drift the grouting results are often good (Fig. 6b).

This clearly stresses the need for a grouting method which is adjusted to the rock condition, if the ground-water inflow is to be reduced.

SUMMARY OF THE GEOHYDROLOGICAL AND ROCK ENGINEERING CONDITIONS AROUND THE MINERALISATION ZONE

An examination of the cores intersecting the ore mineralisation on different levels, shows that the rock conditions are directly comparable to the conditions in the ore drifts. Thus the rock conditions along the ore mineralisation can be summarized as follows:

- the ore mineralisation occurs mainly in gneiss

- the ore mineralisation occurs as a slab along the schistosity, dipping steeply towards the south

- the ore mineralisation has taken place in a part of the bedrock with a high frequency of graphite veins. Thse veins are orientated along the schistosity

- the bedrock has a distinctly slaty-thin slaty cleavage along the schistosity

- the frequency of fissures at an angle to the schistosity is negligible.

Considering the high frequency of water bearing fissures, the ground-water conditions along the ore mineralisation are very important. It is estimated that the ore drifts are representative of other parts of the ore mineralisation, at least when it comes to the width opening of fissures. The change of ground-water pressure on different levels from the ore drifts are however, very essential.

This study indicated that the strong ground-water flow combined with the high ground water pressure has been the main problem when driving the drifts. Since the water pressure is lower on higher levels the problems with the water inflow will be reduced higher up in the ore mineralisation. The ground-water conditions in the ore mineralisation can be summed up as follows:

- high frequency of water bearing fissures

- in connection with the ore mineralisation the water flow is linked to fissures along the schistosity

- in the parts outside the ore mineralisation there are open water bearing fissures perpendicular to the schistosity

- on top of the bedrock surface there is a thick glacifluvial sand deposit

- this soil forms a large ground-water reservoir

- the conditions are good for a rapid infiltration from the soil into the bedrock

- the natural ground-water level in the soil is level with the surface.

The bedrock and ground-water situation around the ore mineralisation is shown in Fig. 7.

DISCUSSIONS AND CONCLUSIONS

An appraisal of the present project indicates that no meaningful information with reference to Rock Engineering and hydrogeology have

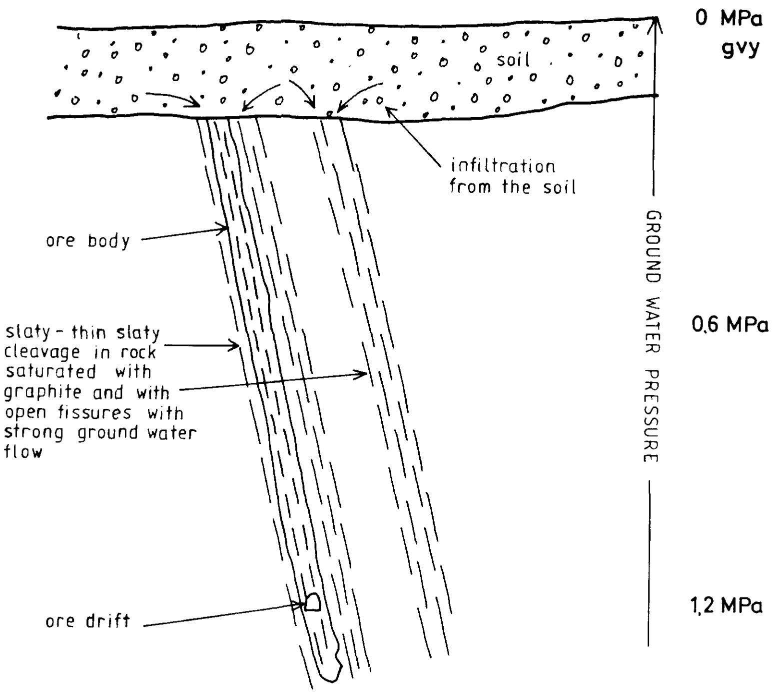

Figure 7 Bedrock and ground water condition around the ore mineralisation

been obtained prior to opening an exploratory mine. The existing technique of rock mass characterization and the study of glasifluvial deposit was inadequate. It is suggested that for a successful site investigation and evaluation the following approach should have been adopted:

a large number of exploratory boreholes should have been drilled from the surface prior to the time of invitation of tenders

better borehole logging and analyses techniques should have been used in relation to soil penetration tests, core examinations and hydrogeological studies.

This approach would have assisted in identifying the major geotechnical problems at an early stage of the project.

In order to assess the ground-water problems a series of hydrogeological tests should have been carried out in the exploratory boreholes to evaluate aquifer characteristics and to identify a range of water problems.

The exploratory mine should have been developed only after the preliminary feasibility study proved encouraging.