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Geophysical laboratory investigations on core samples from the Klipperås study site

Leif Stenberg
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Luleå, July 1986

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FISSURE FILLINGS FROM THE KLIPPERÅS STUDY SITE

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ABSTRACT

The Klipperås study site is located within the Småland-Värmland granitoid belt in southern Sweden. The area investigated can be subdivided into blocks with different hydraulic character and fracture frequency of the rocks. A fissure filling study has been carried out within the area. This includes identification of the minerals, mineral frequency, textures within the fissures and isotope analyses of calcites.

Four generations of fissure fillings, within the time space c. 1600 M.a. to present, has been distinguished. These are I) quartz; II) epidote + muscovite and adularia + hematite; III) calcite + chlorite +/hematite; IV) calcite, clay minerals and Fe-oxyhydroxide.

It is observed that the surface water affects the uppermost part of the bedrock resulting in calcite dissolution, break down of pyrite and precipitation of Fe-oxyhydroxide. It is also obvious from the fracture calcite frequency that calcite dissolution is more intensive close to and within the fracture zones. There, Fe-oxyhydroxide can be found down to at least 400 m depth. This gives valuable information about the physico-chemical character of the groundwater within the bedrock.

Several fracture zones have been reactivated. It is also suspected that relatively late movements have taken place causing crushing of the rock and only a slight cementation of the crushed material is visible.

Some of the fracture zones correspond to mafic dikes. These zones exhibit lower hydraulic conductivity than other zones due to fracture sealing by clay minerals but also by chlorite and calcite. In accordance with this the stable isotope analyses of calcites show that fractures within the basic dikes are less affected by low temperature-meteoric water than fracture calcites in the surrounding rocks in Klipperås.

CONTENTS

1. INTRODUCTION

The Klipperås study site is situated 45 km west of Kalmar in southern Sweden. (see Fig.1)

Cores have been taken from 14 drillholes within the site. Seven of the drillholes are more than 700 metres long and only 7 reach a core length of 200 to 250 metres. In addition 14 percussion drilled boreholes were made. Figure 2 shows the location of the drillholes and the dominating fracture zones.

Although outcrops in the area are scarse the soil cover is relatively thin. This has resulted in a geological description of the site mainly based on the drillcore mapping.

Geological investigations and tectonical studies within the study site have been reported by Olkiewicz and Stejskal (1986). Hydrogeological measurements have been carried out and was reported by Gentzschein (1986). Geophysical investigations including borehole logging was reported by Sehlstedt and Stenberg (1986). Groundwater chemistry from borehole Kl 1 was reported by Smellie et al. (1985).

This report presents a study of filling minerals in fissures and fracture zones, in order to reveal the tectonic history of the area, the effect of recharge water on the fracture minerals and the depth of recharge water influence in the bedrock and the fracture zones. Stable isotope analyses on calcite fillings have been carried out have been used as a tool to describe variations in the water circulation.

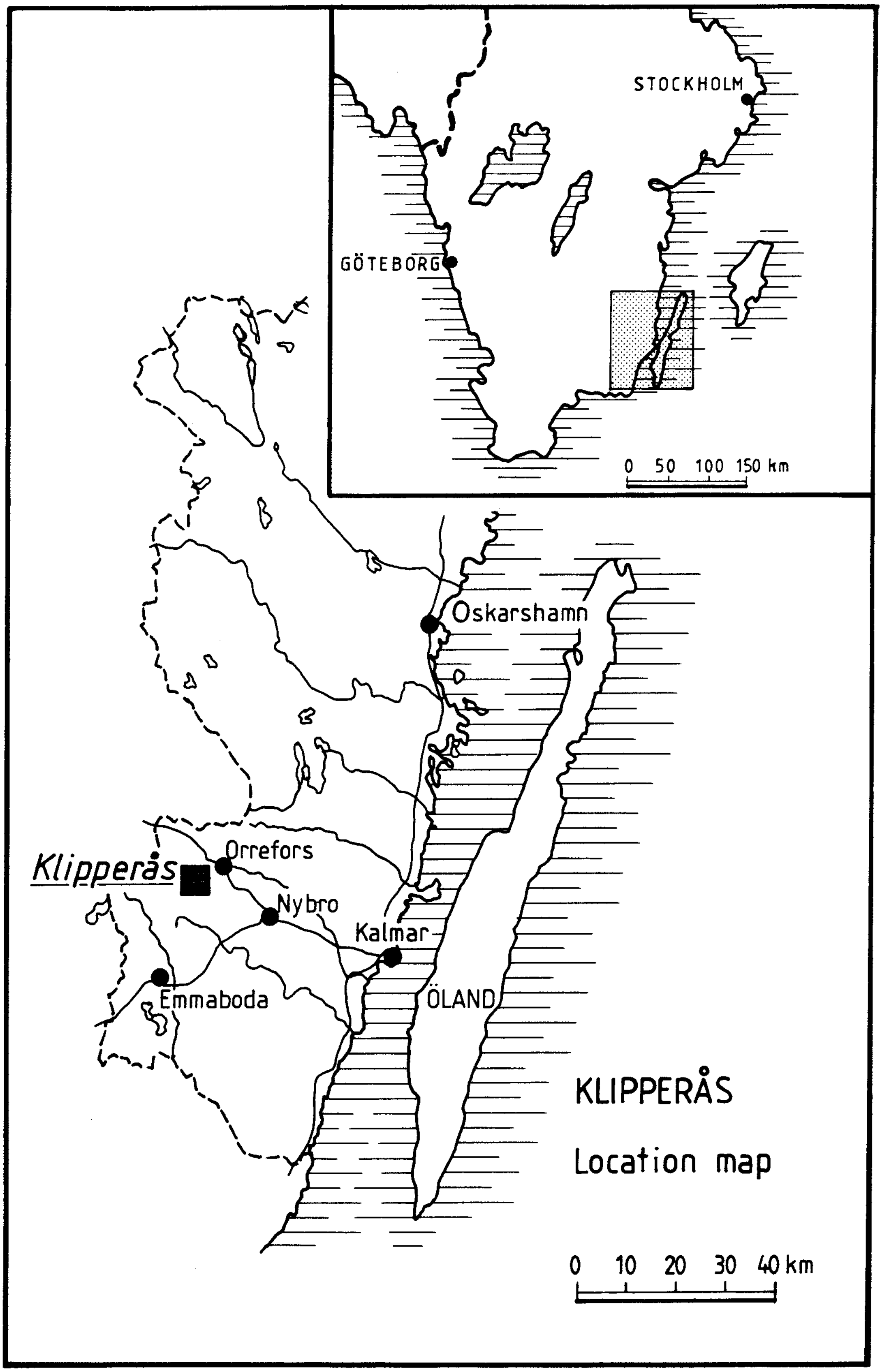


Figure 1. Location of the study site.

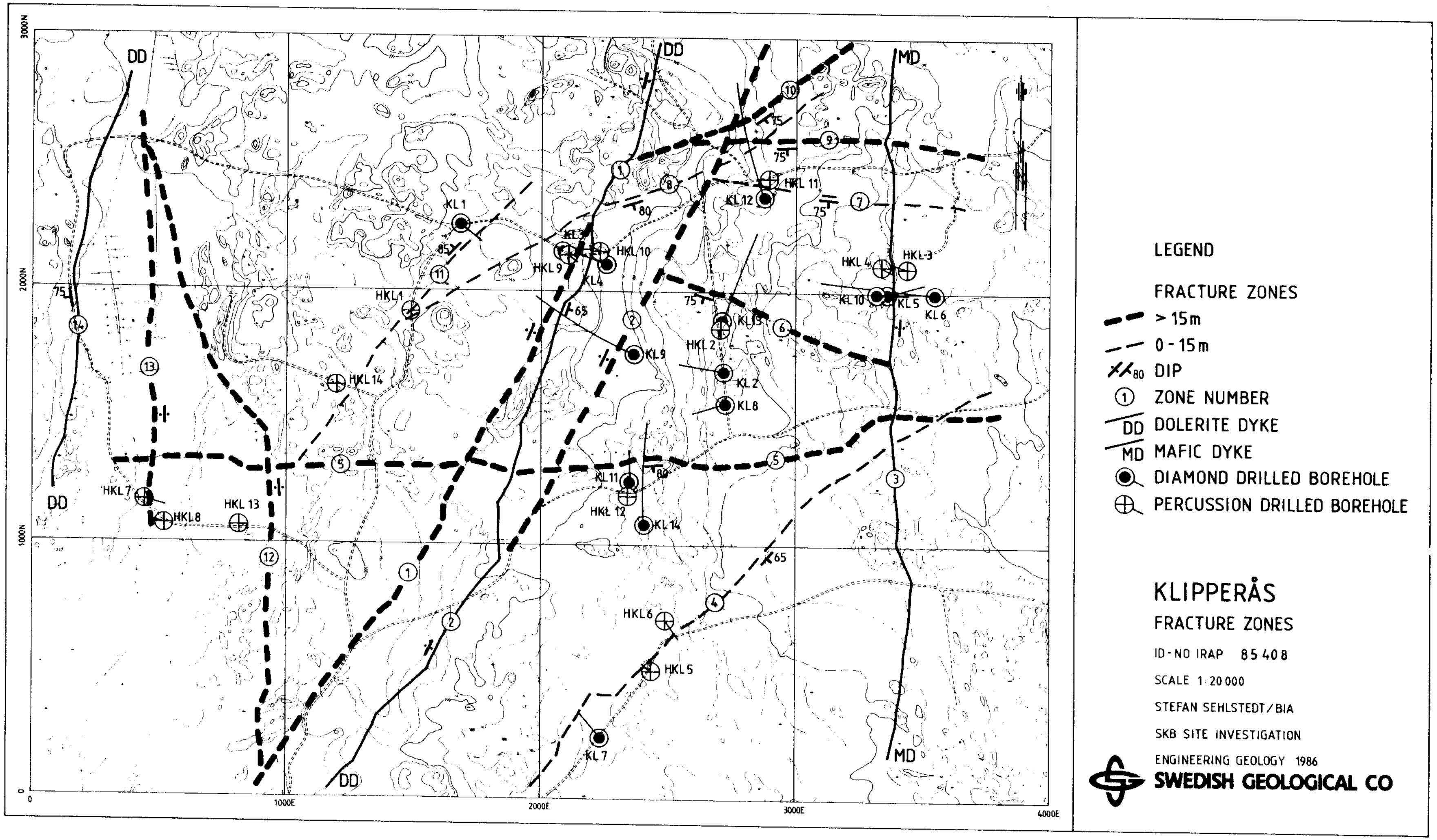


Figure 2. Location of fracture zones and basic dikes within the study site.

1.1 Geological setting

The study site is situated within serorogenic granites (Småland-Värmland granites) and acid volcanics (Småland porphyre) within the Svecokarelian belt, c.f. figure 3.

The area is dominated by a granite variety usually called Växjögranite. This is here greyish-red and homogenous. In parts a weak foliation-lineation is visible striking E-W to WNW-ESE.

Several radiometric datings have been carried out on Småland-Värmland granites. These datings yield intrusion ages between 1750 and 1650 M.a. (Åberg,1978; Aftalion, 1981). The Småland porphyries are suggested e.g. by Person (1985) to be closely related to the plutonism, i.e. they are of approximately the same ages as the granites.

Porphyry dikes have been found within the granite. These are often associated with uralitic basic dikes. Dating of Småland dike porphyries yielded Rb/Sr-ages of 1620 M.a.(Åberg,1978) which means that they are of similar ages as the Småland porphyries.

Also several generations of metabasite and basic volcanics occur. These are difficult to separate and they have been classified as "greenstones" in the coremapping (Olkiewicz & Stejskal, 1986).

The youngest rocks within the area are the dolerites which are suggested to be 900 to 1000 M.a. old (Patchett, 1978).

Within the mapsheets Vetlanda NW and NE, which cover a part of the same geological terrain as the study site, the dominating lineaments strikes NNW, NW and ENE-WSW (Persson, 1985). These coinside with the directions of the Jotnian dolerites within the mapsheets. Fissures sealed by quartz and epidote are randomly orientated with a dominance of fissures striking NW.

A tectonic study of southern Sweden shows that in the area east of the Protogine zone (Fig 3) lineaments striking N-S, NW

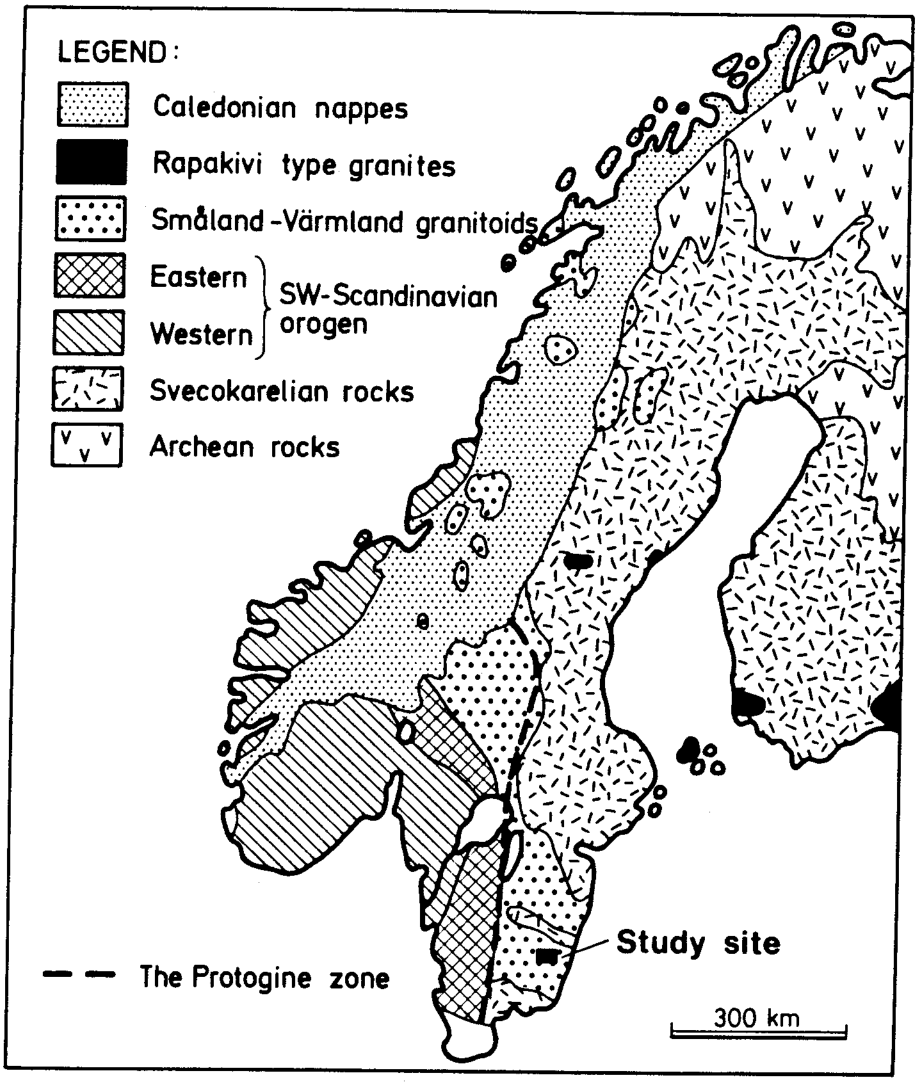


Figure 3. Simplified map showing the geological units in Scandinavia (Lindh and Gorbatschev, 1984).

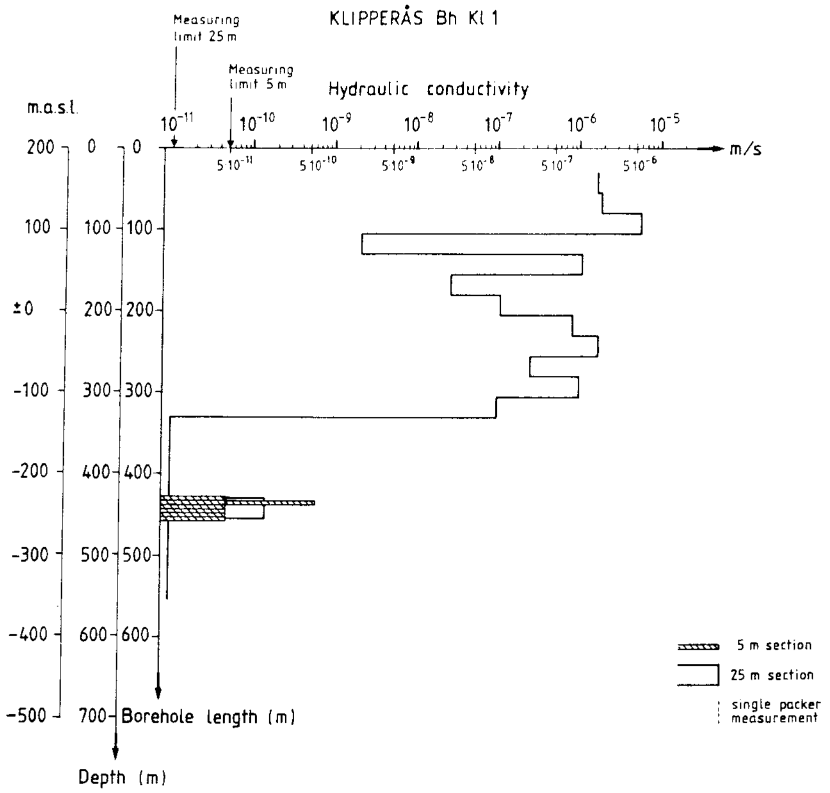
and WNW dominates (Röshoff & Lagerlund, 1977). It is also concluded that reactivation of old fracture zones are very common. Extensive neotectonism has not been found but late small-scale movements can not be ruled out.

From a tectonic point of view the study site at Klipperås is characterized by several distinct zones some of which coinsides with more or less vertical dikes of dolerite. The dominating lineaments in the area are shown in figure 2.

Most of the zones indicated by geophysical and hydrogeological measurements are vertical to subvertical. Although exceptions occur (e.g zone 4 which dips 65^{o} to SE). One horizontal zone at 780 m depth in boreole Kl 2 has also been found.

Results from investigations within the study site (Olkiewicz and Stejskal, 1986) show that distinct fracture zones strike in N-S, NE/NNE-SW/SSW and E-W. Dolerites have intruded in the N-S and NE/NNE-SW/SSW directions. Porphyre dikes strikes N70-80^{o}W.

The Klipperås area can therefore be characterized as an intensely fractured area. The faulting caused blocks with different hydraulic character and fractures of different orientation. This is clearly demonstrated by borehole Kl 1 which penetrates a fracture zone at 280-310 metres separating two blocks of different character (Fig.4). The upper part has a high hydraulic conductivity and is dominated by horizontal fractures while the lower part has only one section with hydraulic conductivity above the detection limit (10^{-11} m/s) and is dominated by vertical fractures. Water analyses from the conductive zone at 406 metres disclose water with long residence time (Smellie, 1985).



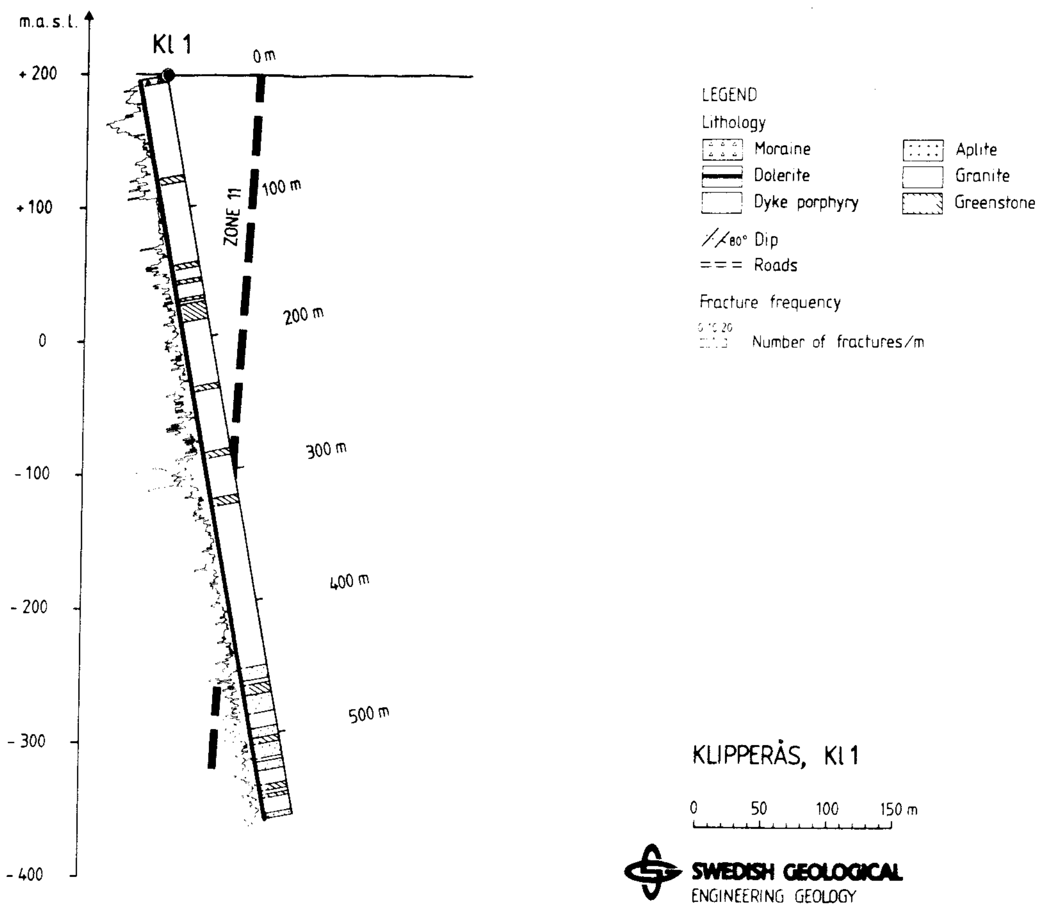


Figure 4. Hydraulic conductivity (Gentzschein, 1986) and core-log showing the litology of Kl 1 (Olkiewicz, 1986).

2. FRACTURE FILLING MINERALS

Fracture fillings have been mapped and are reported by Olkiewicz and Stejskal (1986). In order to do a more detailed study, fracture fillings have been investigated using microscopy, XRD and analyses of stable isotopes of oxygen and carbon, the results of which are reported within the present investigation. Frequency plots of mineral distribution versus depth have been used in order to explain the occurence of some of the minerals (calcite and some Fe-minerals).

The dominating fracture filling minerals in the area are chlorite, epidote, hematite, calcite, muscovite/illite, quartz, adularia and pyrite. In the metabasites and the dolerites has also, smectites been identified together with calcite.

This study concentrates on the carbonate-system and the Fe-minerals which yield information about the water circulation and the water chemistry at shallow to moderate depths within the rock. This is important as it is difficult to collect representative groundwater samples at these depths.

2.1 Mineral indentification by XRD

Several fracture fillings have been analysed by XRD during the investigation of the Klipperås study site. The XRD-analyses have been carried out by U. Hålenius (SGAB), L.Hanssen (VLF--GEO AB) och A.Sjödin (SGU).

It is obvious that muscovite/illite is a frequent mineral as well as chlorite and calcite. However, it is difficult to distinguish muscovite from illite and further attempts to separate illite and muscovite have not been carried out.

Traces of siderite ($FeCO_3$) and rodochrosite ($MnCO_3$) have also been recorded.

Some feldspar minerals identified from XRD as orthoclase/adularia are from microscopy classified as adularia, a low temperature K-feldspar which in Klipperås occur as hydrothermal mineralisations in fissures.

Epidote ($Ca_2Al_2FeSi_3O_{12}(OH)$) is a commom mineral in the cores. XRD-analyses show that in some cases the mineral mapped as epidote could be the Fe free varity called clinozoisite. Epidote is a hydrothermal mineral formed within the temperature range of 200 to 500 ^oC. Epidote is also suggested to be a stress related mineral (Deer et al., 1967).

Illite ($(KH_2O)Al_2((AlSi)Si_3O_{10})(OH)_2$) can be formed either by alteration of smectite at elevated temperatures or by breakdown of K-feldspar. The temperature needed to alter smectite to illite is depending on the water/rock ratio and the availble amount of K^+. A significant illite production can be recorded at 100 ^oC (Fritz et.al; 1984). However, the muscovite/ illite forming event at Klipperås seems to be related to the epidote forming period and it is reason to suggest temperature higher than 300 ^oC for the formation of all these minerals. This as well as the microscopy support that muscovite dominates over illite. Muscovite as well as epidote are suggested to have a stress associated origin.

Chlorite ($(Fe,Mg)_3(Si_4O_{10})(OH)_2(Mg,Fe)_3(OH)_6$) is a common mineral within the fissures. The microscopy indicates that both Mg-chlorite and Fe-chlorite occur. The reason for this is probably that chlorite have been formed during several periods and at different conditions. Chlorite can be formed within a wide temperature range but it is usually regarded as a hydrothermal mineral. However, theoretically it has been shown (Fritz et al., 1984) that chlorite can be formed in groundwater analysed from some of SKB´s study sites at 60 ^oC.

Some fracture filling samples from metabasites exhibit the presence of swelling clay minerals (e.g. smectites).

2.2 Textures and relative ages - result of microscopy

In order to find out relative ages of the fissure filling minerals, textures of different minerals have been studdied in thin sections. Most of the samples are from fissures in Småland-Värmland granite (40) but also fissures in porphyry (9), metabasite (7) and dolerites (3) have been sampled.

In the thin sections studied have the femic minerals, originally present in the granite, been altered to epidote and chlorite. The quartz grains have been stressed which have resulted in formation of subgrains. This stress also resulted in disslocations within the feldspars.

Accessory magnetite is present in the granite. Close to the fractures the magnetite has been oxidized to hematite. Accesory pyrite can also be seen in the granite as well as in fissure fillings. In some of the metabasites, pyrite is even more frequent (more than 1%) than within the granite.

Several generations of a mineral (for exampel chlorite or calcite) can be found within a single fracture . Concerning calcite the oldest generation shows more twinning than the younger and in some cases also exhibits prismatic textures. These observations have also been made for calcite in fissures from Finnsjön, central Sweden (Tullborg & Larson, 1982). The reason for the prismatic habit of calcite is suggested to be formation in a stress field (Kamb, 1959).

The first deformation visible (I) within the granite samples resulted in disslocation of feldspars and the formation of subgrains within the quartz crystals. These phenomena have also been observed by Olkiewicz and Stejskal (1986) in thin sections from "fresh granite" samples. Tullis and Yund (1977) found that the transition from mainly microfracturing to mainly disslocation in crystals occured at 300-400^{o} for quartz and 550-650^{o} for feldspars at crustal depths exceeding 18 km. This makes it reasonable to assume that the first visible deformation within the granite has taken place at great depths and early in the geological history of the granite. This was succeded by the intrusions of composite dikes of metabasite and porphyry and the first generation of quartz sealings.

A second event (II) represents a complex period with formation of hydrothermal minerals. This period is associated with extensive brecciation and mylonitisation. Two sequences of mineralizations can be distinguished within the period. The first mineralization (IIa) is dominated by epidote and muscovite mineralization and the latter (IIb) by adularia and hematite (IIb). Figure 5 shows a epidotized mylonite cut by a younger fracture sealed by calcite. It is difficult to discover the time spacing between the adularia-hematite generation and the older epidote-muscovite generation. However adularia has not been found in dolerite dikes suggested to be of jotnian age (Patchett,1978; Olkiewicz and Stejskal, 1986). K-Ar dating of biotites within south-eastern Sweden yielded metamorphic ages about 1400 M.a. (Magnusson, 1960). This can correspond to the metamorphic event responsible for the epidote--muscovite formation. The adularia-hematite formation probably occured between 1400 and 1100 M.a.

The absence of epidote and muscovite in the basic dikes sampled indicate that these dikes intruded the granite after the hydrothermal event (II) or that the formation of these minerals were not favoured by the composition of the basic dikes.

The third event (III), which includes mineralization of chlorite calcite and hematite, is possibly associated with or later than the intrusion of the dolerite dikes within the area as these minerals can be found also in most of the dikes. Similar dolerite dikes in the Karlshamn, Bräkne-Hoby and the Forserum region have been dated to 871+/-25 to 1048+/-35 M.a. The last period (IV) of fracture filling formation is still active resulting in formation of calcite, clay minerals and Fe-oxyhydroxides.

The history of events can be summarized as follows:

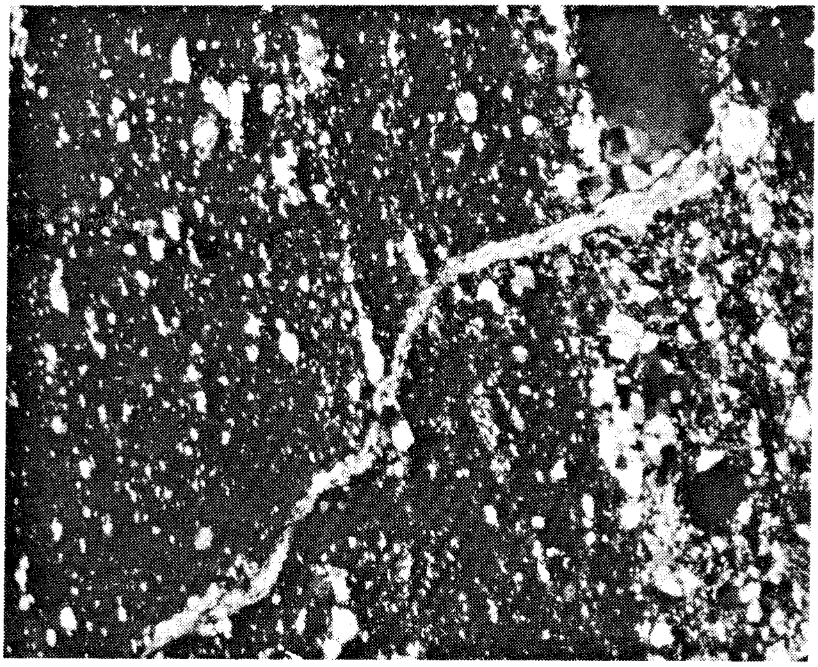


Figure 5. Epidotized mylonite crosscut by a calcite sealed fissure, Kl 1:424.4 m. Photo of thin section.

I) a) Dislocations in feldspars associated with formation of subgrains in quartz.

Intrusion of pophyry dykes.

b) Quartz

II) a) Epidote + Muscovite +/- Calcite +/-Quartz +/-Chlorite
b) Adularia + Hematite

Intrusion of dolerites.

III) Calcite + Chlorite +/- Hematite

IV) Calcite + Clay minerals + Fe-oxyhydroxides

In drillhole Kl 7 a section of crushed material was found at a level of 125 metres corelength. Grains with the size 0.1 to 2 mm are present with angular shape indicating an in situ formation. Some of the pieces were cemented together by Fe-oxides and in a few cases with calcite. The mineral composition shows that metabasites, granite as well as porphyry are present. There are also pieces of fissure fillings (Fig.6) within the crushed material

The most probable interpretation is that the "sand" was formed in situ during tectonic movements (faulting). The mineral composition of the grains makes it reasonable to assume that this is a reactivated fracture zone once initiated along dikes of metabasite and porphyry. The latest reactivation is probably young as the rim of clay alteration of the grains are very thin (Fig 7). The possibilty of neotectonism has to be considered. The seismic measurements carried out by FOA (Slunga, 1984) show that the area is aseismic. However seismic activity in Sweden has been recorded for a 90 years period and thus the results do not exclud neotectonic movements within the zone.

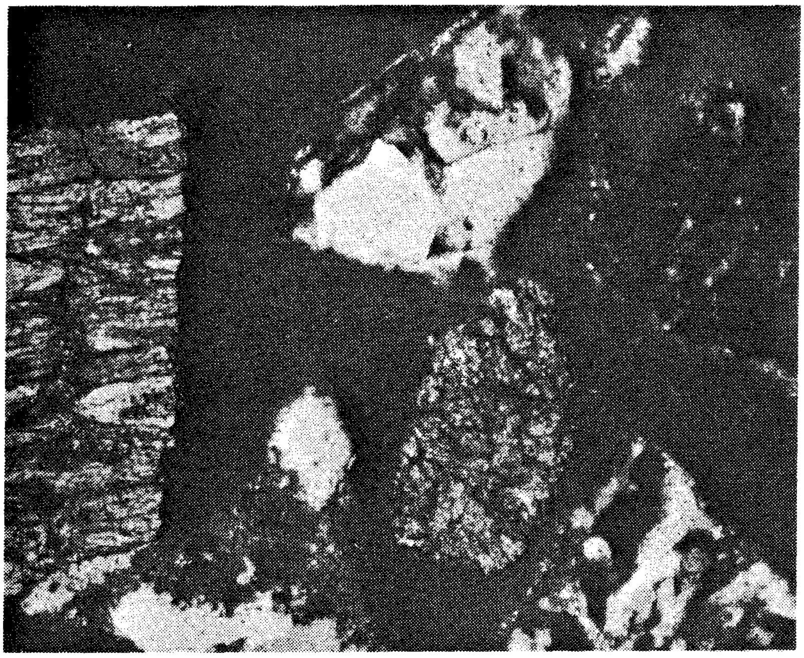


Figure 6. Crushed material from Kl 7:125.1 m. To the left a piece of fissure filling can be seen. Photo of thin section.

Figure 7. Single graines cemented together by Fe-oxyhydroxide. To the right a grain of basite shows a rim of clay minerals (Kl 7:125.1). Photo of thin section.

Table 1 Results from microscopy. Figures (1, 2, 3 and 4) give relative ages of the filling minerals.

	Ca	Chl	Qz	Ep	Mu	Ad	Hm
Kl 1							
22,5	1	1					
50,0	3			1	2		
60,9	2	1	1	1	1		
73,3	1,2			1		2	2
77,9 M	2,4	1	3			2	
105,0				1	1		
105,5	2	2		1			2
107,4	2						1
131,7	2			1			1
159,1	2					1	
180,9 M	1,2	2	1				
183,0 M	1,2	1					
183,7 M	1		1				
235,7 M	3	2		1			2
254,0	1,2	1		1			
285,7	1,2	1		1			1
293,5	2	1		1	1		
309,0 M	1,2		1				
309,2	4	4	2	1	1		3
359,2				1	1		
424,4	2	2			1		
428,5	3			2	1		1
453,5 V	2,3	1		1			
486,5	1		1	1	1		
511,0 V	2			1			
529,7	2	2				1	
561,8 V	2	1,2		1		2	
Kl 2							
328,7	2	2			1		
863,5	3			2	1		
867,1	3			1	1	2	2

	Ca	Chl	Qz	Ep	Mu	Ad	Hm	
Kl 6								
359,5 B		1						
424,7	3	3		1	1		2	
437.7				1			2	
454,2			1	1	1		2	
478,0 V		1		1			2	
500,2 V	2	1					1	
558,2	3		1,2	1				
680,8	3		1		2		3	
682,4	3		1	2	2		3	
682,9	3,4	2		1		3	3	
Kl 9								
698,9			1	2		3	3	
Kl 10								
75,0 V		1						
95.7 B	2	2					1	1 (microcline)
99,4 B	1,2	3						
Kl 14								
54,7		2		1,2	2	2	2	
118,9	2	2		1	1			
161,7	3,4	2	1	1				
210,3	2				1			
247,6a V	2		1					
247,6b V	2		1	1				
270,7 M	1,2	2						
298,1 V	2,3	2	1			1		
379,7 Qz	1,3	2	2					
379,9	3		1	1	1	2	2	

	Ca	Chl	Qz	Ep	Mu	Ad	Hm
381,2	1,3	3		1	2	2	2
413,7	2	1	1				1
447,0*	3,4		1	1			1,2
447,3	3		1			2	2
530,8	2	1	2			1	1
659,2	2		1			1	1
700,5	2,3		1	1	1		

Ca = Calcite
Chl = Chlorite
Qz = Quartz
Ep = Epidote
Mu = Muscovite
Ad = Adularia
Hm = Hematite
* = Breccia with calcite sealing and fragments of grteenstone and granite
V = Fissure in acid volcanics
M = Fissure in metabasite
B = Fissure in basic dyke
Qz = Fissure in quartz vein

2.3 Fe-minerals as indicators of redox conditions

Redox conditions of groundwater depends on the amount of dissolved O_2 and the oxidation state of iron, sulfur and uranium (Smellie et al., 1985). Measured Eh/pH values of deep groundwaters within SKB´s study sites plot within the pH intervall 6.5 to 9.0 and they mostly yield negativ Eh values (Allard et al.,1983; Smellie et al.,1986). As can be seen in figure 8 some of these deep groundwaters give siderite ($FeCO_3$) as a stable mineral phase. However, siderite is not a widespread fissure filling mineral at depths in the investigated areas. Presence of sulfide in the groundwater is an idicator of very reducing conditions. Most of the representative groundwater samples contain sulphide. The stability field of pyrite will therefore overprint the stability field of siderite. Pyrite is less soluble than siderite which means that the solubility of pyrite is the process controling S^{2-} and Fe^{2+} in most groundwaters at reducing conditions.

Most of the Fe-minerals present as fissure fillings are rust (oxyhydroxide, FeOOH), hematite (Fe_2O_3) and pyrite (FeS_2). These minerals represent different states of redox potential where rust and hematite contain ferric iron (Fe^{3+}) and pyrite ferrous iron (Fe^{2+}). Temperature, Eh, pH ,sulphide concentration and pCO_2 will control the Fe^{2+}/Fe^{3+} ratio and the stability fields of the Fe-minerals (Fig 8). Thus, the distribution pattern of these minerals will indicate the redox potential. However, one problem is to distinguish old oxidized fracture zones from zones still being oxidized. In Klipperås the host granite contain magnetite as a accessoric mineral. In the fracture zones most of the magnetite has been oxidized to hematite. If the hematite is coprecipitaded with hydrothermal minerals it is reason to suggest a Precambrian origin of the hematite (no later hydrothermal events is known in the area).

The dissolved iron in natural water commonly derives from oxidation of sulphide minerals, particularly pyrite as in the following reaction (Whittemore and Langmuir ,1975):

$FeS_2 + 7/2\ O_2 + H_2O = Fe^{2+} + 2SO_4^{2-} + 2H^+$

On the other hand downhole measurements from the SKB´s study sites indicate that the reaction: $2Fe_3O_4$ (magnetite) + $2H_2O = 3\ Fe_2O_3$ (hematite) + $2H^+ + 2e^-$ controls the Fe^{2+}/Fe^{3+} ratio (Wikberg, 1985). However, Nordström & Puigdomenech (1986) state that "all redox consideration (concerning groundwater in SKB´s study sites) must be prepared to include sulfide and dissolved organic carbon".

Hematite is a stable mineral at oxidizing conditions and can theoretically be formed during present conditions in the upper hundred of metres in Klipperås. However, the dominating Fe-mineral, containing ferric iron in these sections, is rust.
An oxidation of iron is suggested to produce ferric oxyhydroxide (rust) as a first step. Thus, most of the hematite present probably corresponds to earlier oxidizing events.

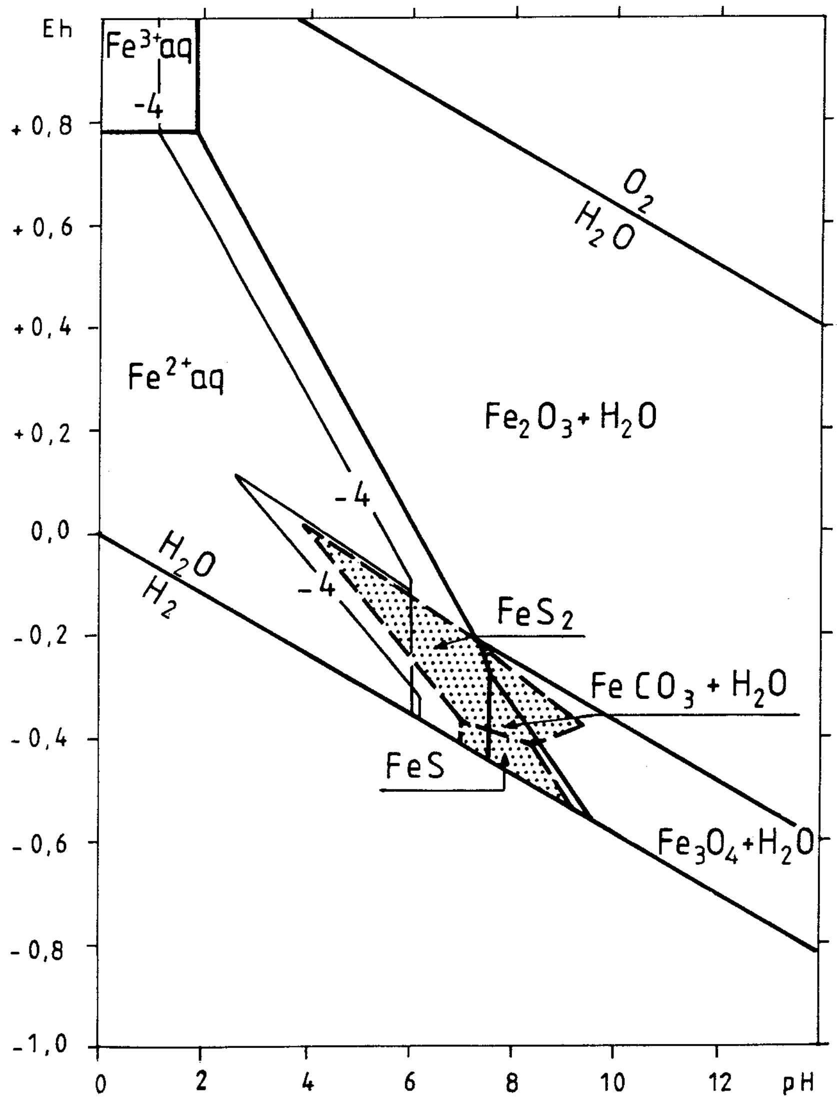


Figure 8. Fe-stability diagram according to Garrels and Christ, 1965.

2.4 Frequency of calcite and Fe- minerals in fissure fillings

The distribution of Fe-minerals and sulfides in fracture fillings has been shown to give information on the redox state within the bedrock (section 2.3). Other minerals, like calcite and clay minerals, will give information about the chemical character of the water and the changes in chemistry with depth.

The low pH and high content of dissolved O_2 in the precipitation will interact with the minerals in the overburden and in wall rock. Also the organic material will influence the groundwater as the breakdown of organic material will consume O_2. Figure 9 illustrates the processes occuring in an inflow area. The intervals A-C in the figure can be described as follows:

A) The water has a low pH resulting in calcite dissolution. The feldspars and the biotite are unstable. The O_2 content results in a high redox potential. Thus, sulfide will be oxidized to sulfate, Fe(II) minerals are unstable and Fe(III) minerals like rust will be produced. The stable clay mineral phase in this interval is kaolinite.
B) Constitutes the transition zone where a succesive change from calcite dissolution to calcite saturation will take place. The water is less aggressive to the wallrock minerals and the redox potential becomes more negative.
C) Due to the high content of dissolved ions, pH will be > 7 and calcite saturation/oversaturation will be reached. The stable clay minerals are kaolinite/smectite (in equilibrium). The content of dissolved O_2 in the waters are consumed.

The depth of each interval A-C depends on several factors: The thickness and composition of the soil cover. The water pathways of the bedrock (horizontal vs vertical fractures). The hydraulic conductivity and the gradient. Concerning the Klipperås area the soil cover is generally thin and the hydraulic conductivity is relatively high.

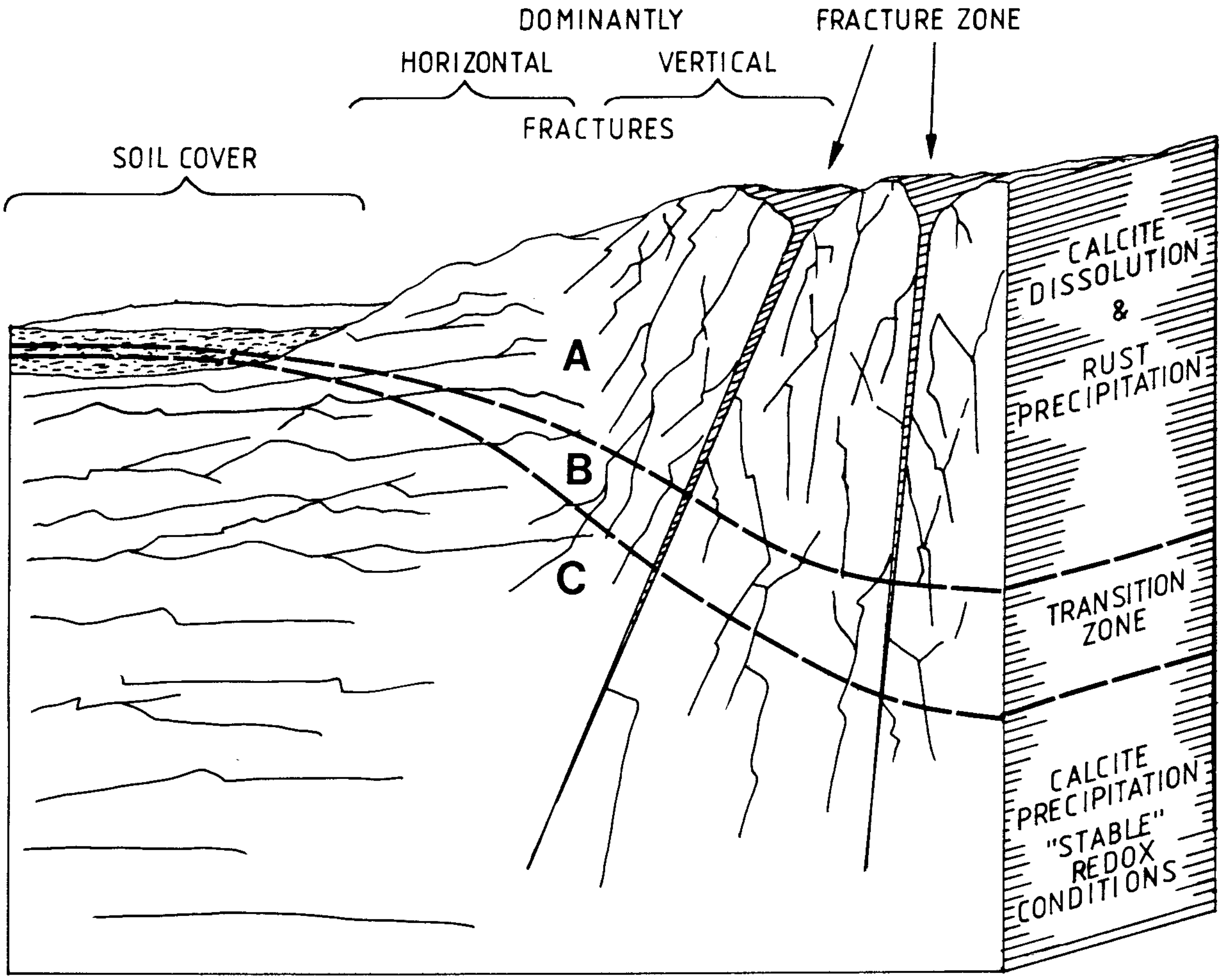


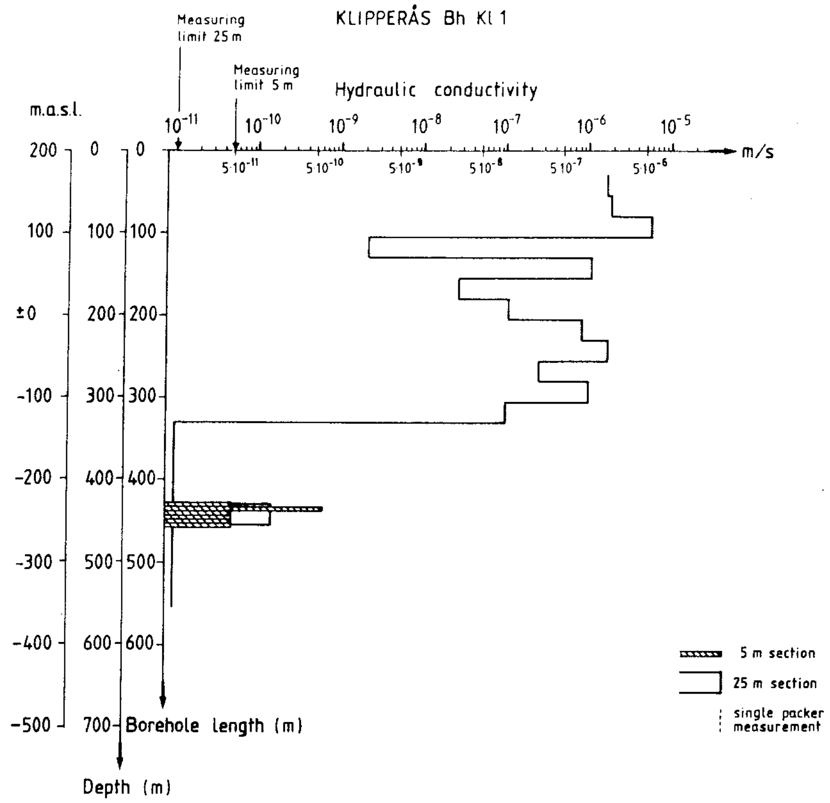
Figure 9. Simplified model of the occurance of calcite and Fe-oxyhydroxides within fissures in the recharge areas.

A thorough coremapping has been carried out of the drillcores from Klipperås. All data have been stored in a data base. The mapped fractures and fissures plotted have been classified as "open", which includes both open fractures and sealed fractures opened during the drilling operation. Some of the most "informative" fissure minerals have been choosen for the diagrams shown on the following pages.

The minerals selected are; calcite (Ca), Fe-oxyhydroxide (Fe), hematite (Hm), pyrite (Py) and epidote (Ep). Unfortunately "Fe" has not been distinguished from hematite in borehole 1,2, 3, 4, 5 and 7. In these coreloggs Fe + Hm includes both Fe-oxyhydroxides and hematite. Plots from these boreholes are thus less informative. Several plots of fracture filling frequency have been made. When comparing results from different drillcores it is important to notice the orientation of the boreholes; borehole 1 and 2 are subvertical (80^{o}) whereas the other boreholes dips 60^{o}. Hydraulic conductivity,shown in figure 10, has only been measured in the long drillholes (Kl 1, 2, 6, 9, 12, 13 and 14). The hydraulic properties of the fracture zones are shown in table 2.

Most of the boreholes within the study site are concentrated around the dominating fracture zones. These zones exhibit different characters. To compare two zones, boreholes situated in connection to fracture zone 1 (borehole 3,4 and 9) and 3 (drillhole 5,6 and 10) are of special interest. (In all diagrams the geophysically documented fracture zones are represented as shaded areas). For the other boreholes only Fe and Ca are plotted. The percentage of fissures coated by calcite in the upper 200 metres are shown for all boreholes. In the following, the diagrams are reffered to fracture zones but also discussed in connection to the surface effect of the fracture minerals.

Zone 1 transects the area from SSW to NNE and dips steeply. It is about 30 m wide. The northernmost part of the zone within the area, is roughly parallel to an c. 10 metres wide mafic dike (Olkiewicz and Stejskal, 1986). The fracture zone is typically brecciated and mylonitic. Three boreholes, Kl 3, Kl



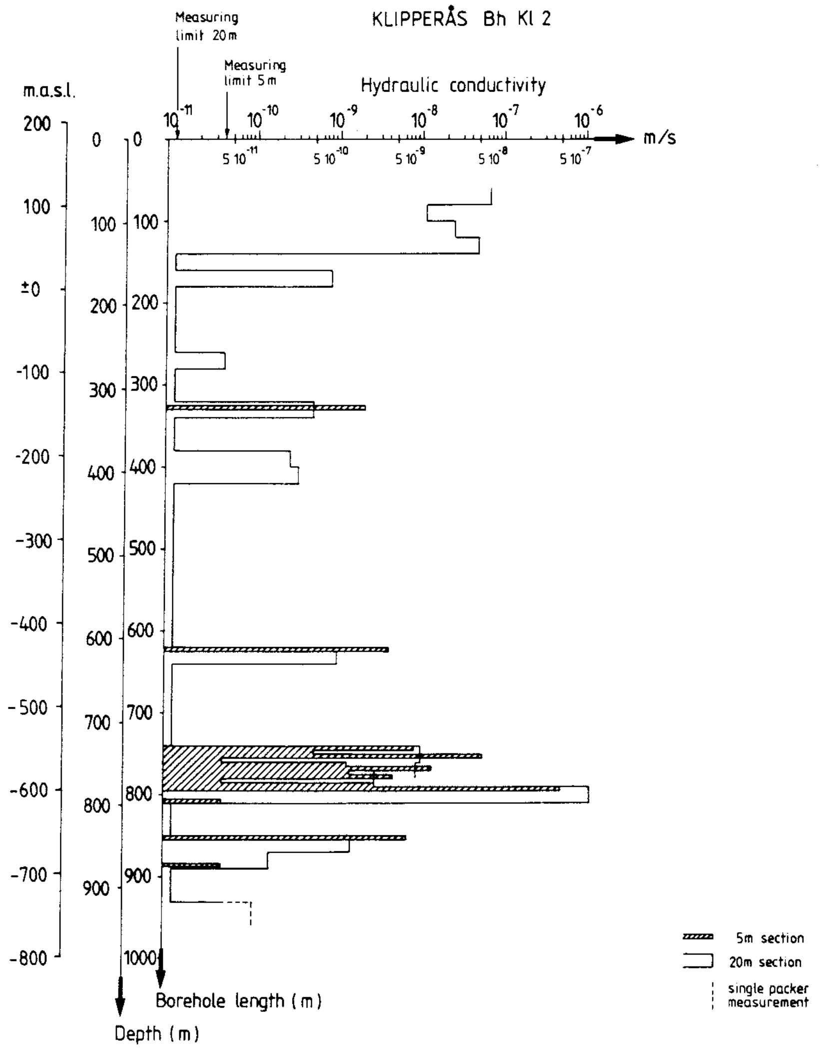
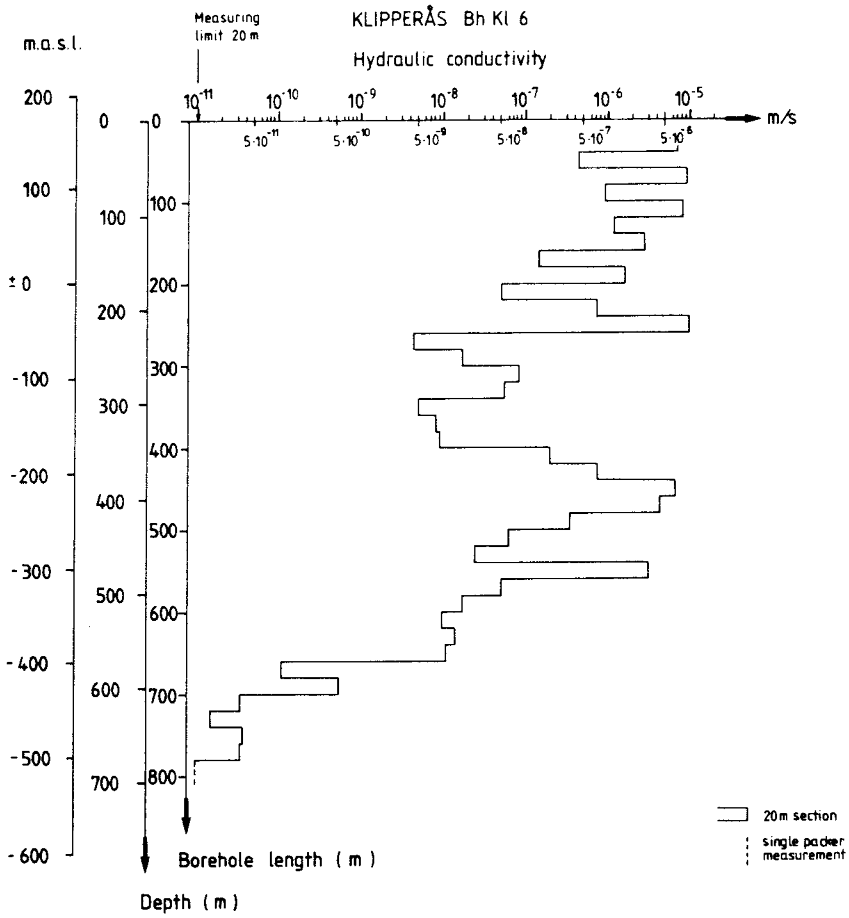


Figure 10. Hydraulic conductivity for drillholes Kl 1, Kl 2, Kl 6, Kl 9, Kl 12, Kl 13 and Kl 14 (Gentzschein, 1986).



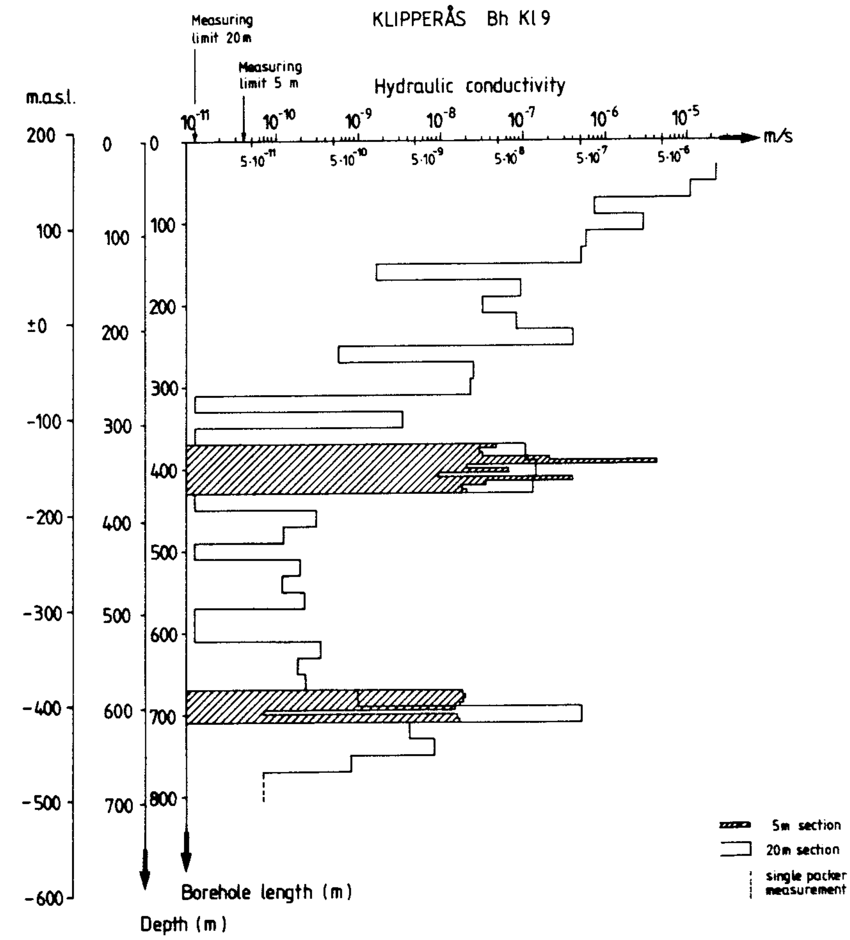
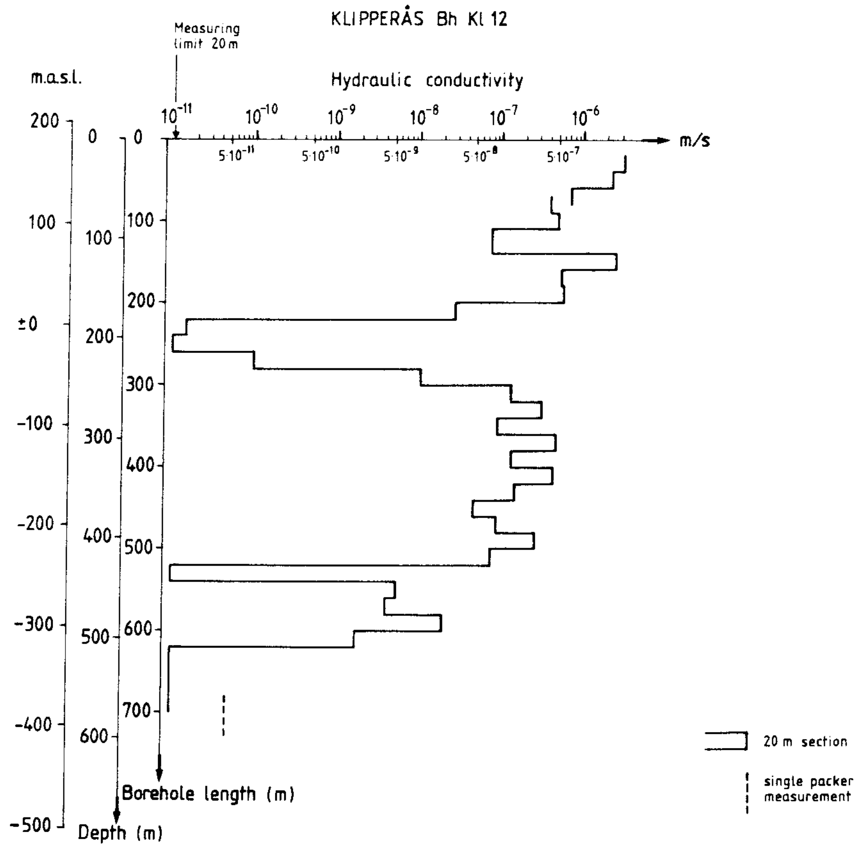


Figure 10 cont.



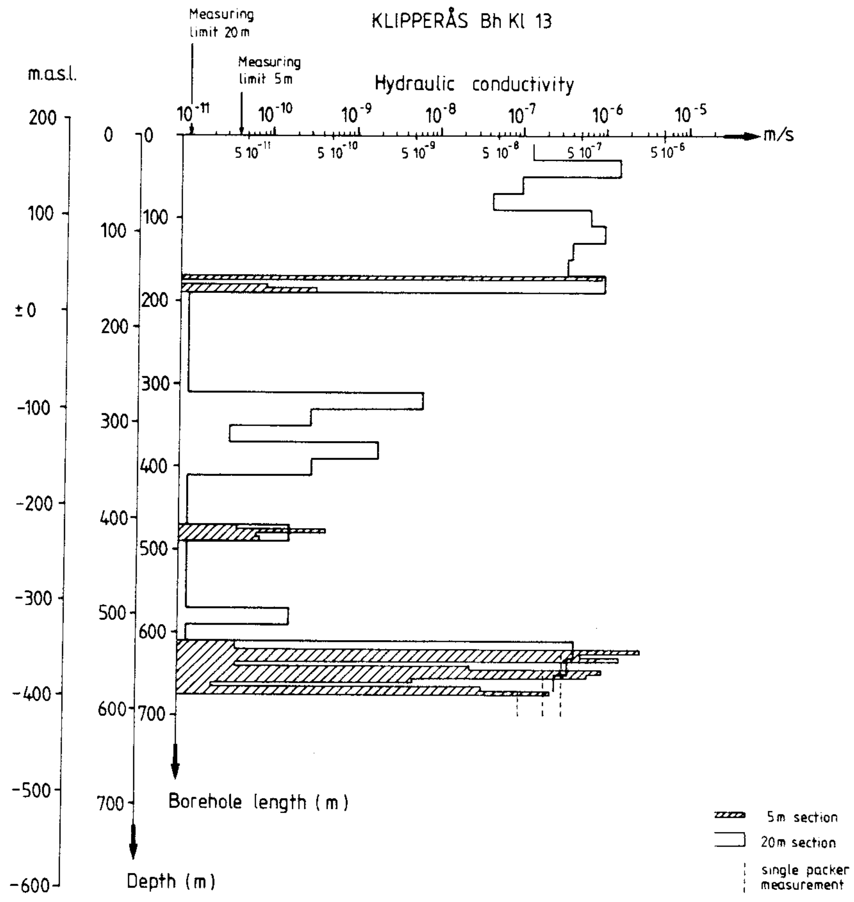


Figure 10 cont.

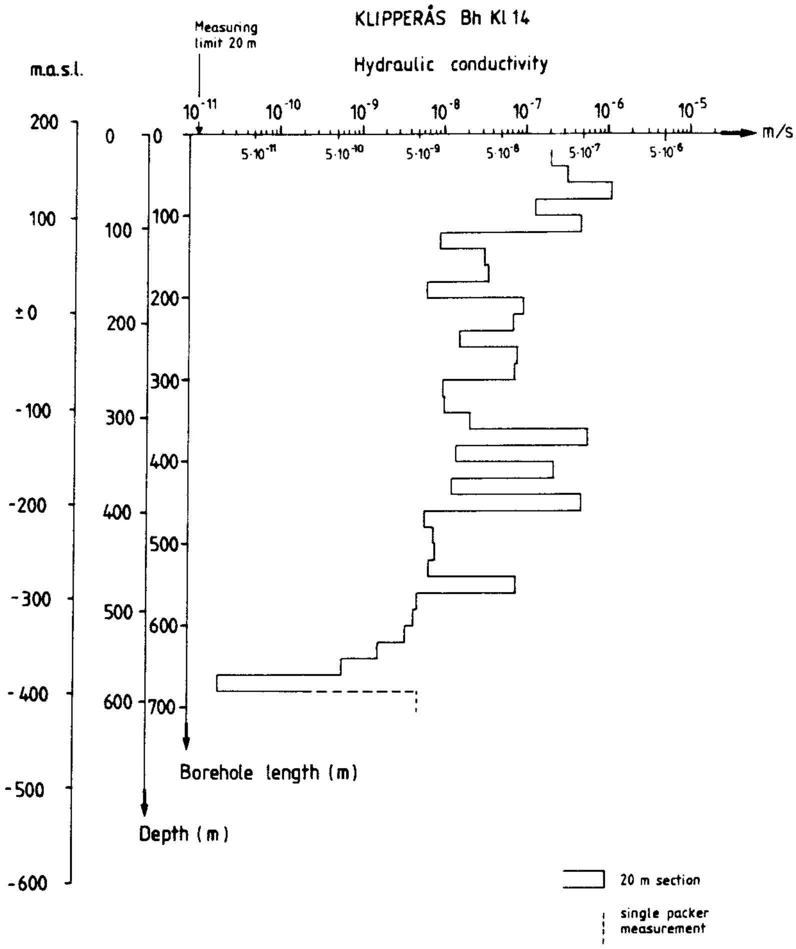


Figure 10 cont.

Table 2 The hydraulic conductivity (K) of the local fracture zones in the Klipperås area.

Zone	Position in borehole (m)	Vertical depth (m)	Strike/Dip (degrees)	True width (m)	K (m/s)
1	Kl 3 (140-195)	145.1	N-S /90	28	not tested
	Kl 4 (110-180)	125.6	N20E/90	36	"
	Kl 9 (615-665)	554.3	N30E/90	29	$3.1x10^{-10}$
2	Kl 9 (120-160)	121.2	N30E/90	22	$5.4x10^{-7}$
	Kl12 (595-630)	501.7	N15E/85E	13	$9.6x10^{-9}$
3	Kl 7 (115-130)	106.1	N35E/65S	12	not tested
4	Kl11 (108-148)	98.1	N75E/90	23	"
	Kl14 (368-410)	336.9	N85E/80	27	$3.9X10^{-7}$
5	Kl13 (152-188)	147.2	N80W/75S	23	$7.5x10^{-7}$
6	Kl12 (70- 88)	64.7	N75W/75S	12.5	$4.4X10^{-7}$
7	Kl12 (288-306)	257.2	N65E/80S	13.5	$2.5X10^{-7}$
8	Kl12 (312-347)	285.4	N85W/75S	28	$3.2x10^{-7}$
9	Kl12 (362-384)	323.0	N60E/75S	17.5	$5.5x10^{-7}$
10	Kl 1 (280-310)	290.5	N45E/85NW	10.5	$9.3X10^{-7}$
H1	Kl 2 (792-804)	785.9	subhorizontal	12	$2.0X10^{-6}$
11-13					not tested

4 and Kl 9 respectively were drilled in order to intersect the zone. Frequency of the fissure calcite, Fe-oxyhydroxide, hematite, pyrite and epidote is shown versus depth. The percentage of fissure fillings coated with calcite is also shown for the upper 200 metres of the boreholes in order to give a good picture of the dissolution of fissure calcite in the near-surface-region. Hydraulic conductivity has only been measured for borehole KL 9. The dolerite dike, visible at the surface, has also been found within borehole Kl 4. However, the dike does not correspond to any major fracture zone at depth. This is demonstrated with the hydraulic conductivity measurements in drillhole Kl 9 where the dolerite has been found within the 356-368.5 and 371.5-373.5 m intervals but were the hydraulic conductivity peaks are found at the 370-430 m interval (Fig.10). In the drillcore Fe-oxyhydroxides has been mapped around 400 metres (Fig. 11) which corresponds to the raised hydraulic conductivity. However this level has not been documented by the geophysical measurements as a fracture zone. The core mapping however indicates a higher fracture frequency at 400 metres.

Zone 1 is found within the interval 615-665 metres in borehole Kl 9. The zone is characterized by calcite, hematite and epidote. In borehole Kl 3 and Kl 4 (Figs 12 and 13) the zone appears at the 140-195 m interval and 110-180 m interval respectively. A fracture calcite frequency dip is evident within the zone in boreholes 3 and 4. It is suspected that this dip corresponds to the highest hydraulic conductivity within the zones (not measured in boreholes 3 and 4). The calcite frequency dip is not possible to trace within the zone in borehole Kl 9. The reason for this is probably saturation in respect to $CaCO_3$ at this great depth.

Zone (2) is subparallel to zone 1 and intersected by Kl 9 at 100-120 m borehole length. Also this zone containes fissure fillings of calcite, hematite and some epidote. However, at this shallow level a significant calcite depletion is visible which corresponds to a high hydraulic conductivity (Fig. 10). Borehole Kl 12 penetrates the zone at depth (595-630 m corelength). Also in this borehole Fe-oxyhydroxide is found (Fig.

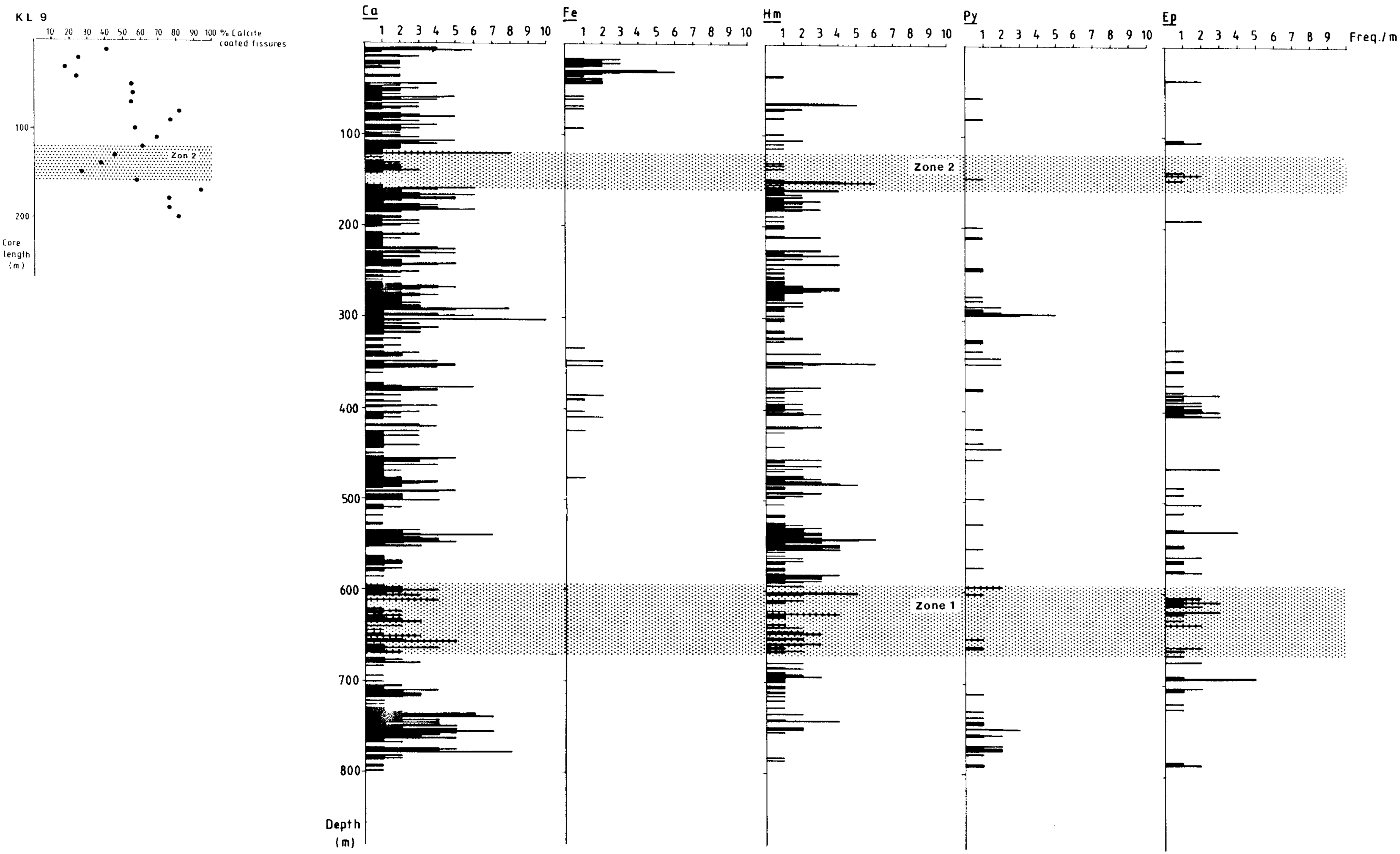


Figure 11. Frequency of fissure fillings versus depth, Kl 9.
To the left, percentage of calcite coated fissures.

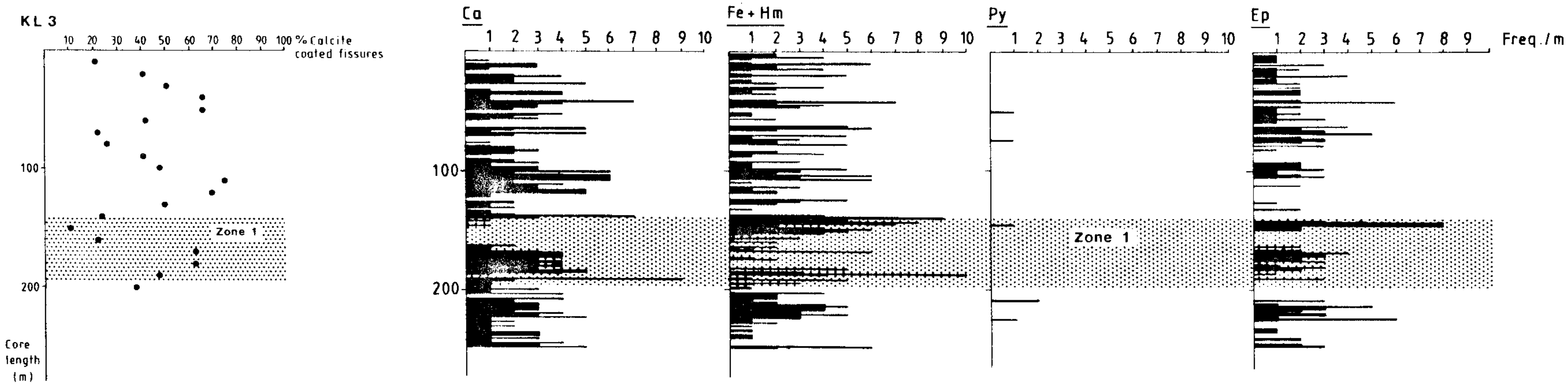


Figure 12. Frequency of fissure fillings versus depth, Kl 3.
To the left, percentage of calcite coated fissures.

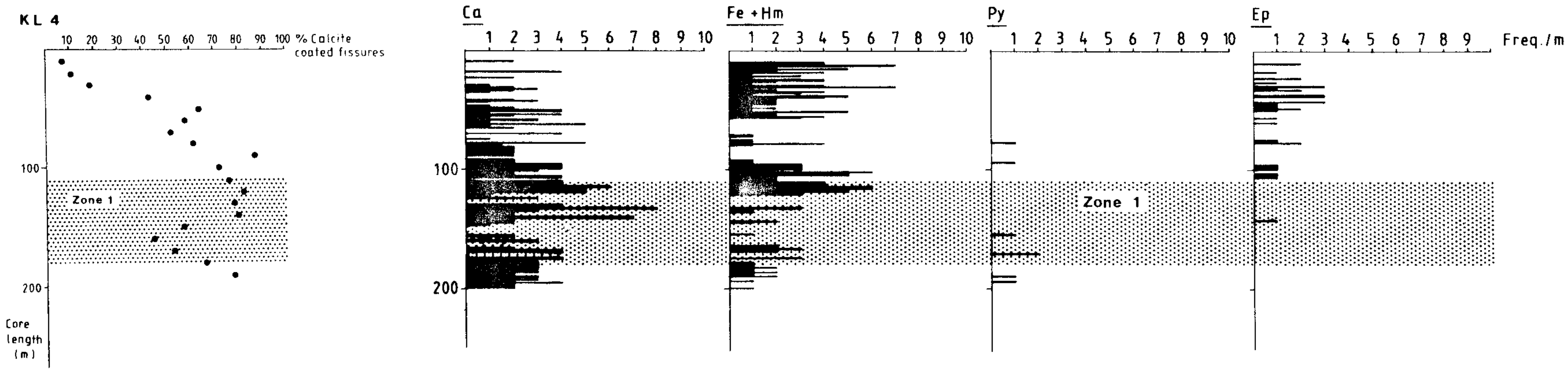


Figure 13. Frequency of fissure fillings versus depth, Kl 4.
To the left, percentage of calcite coated fissures.

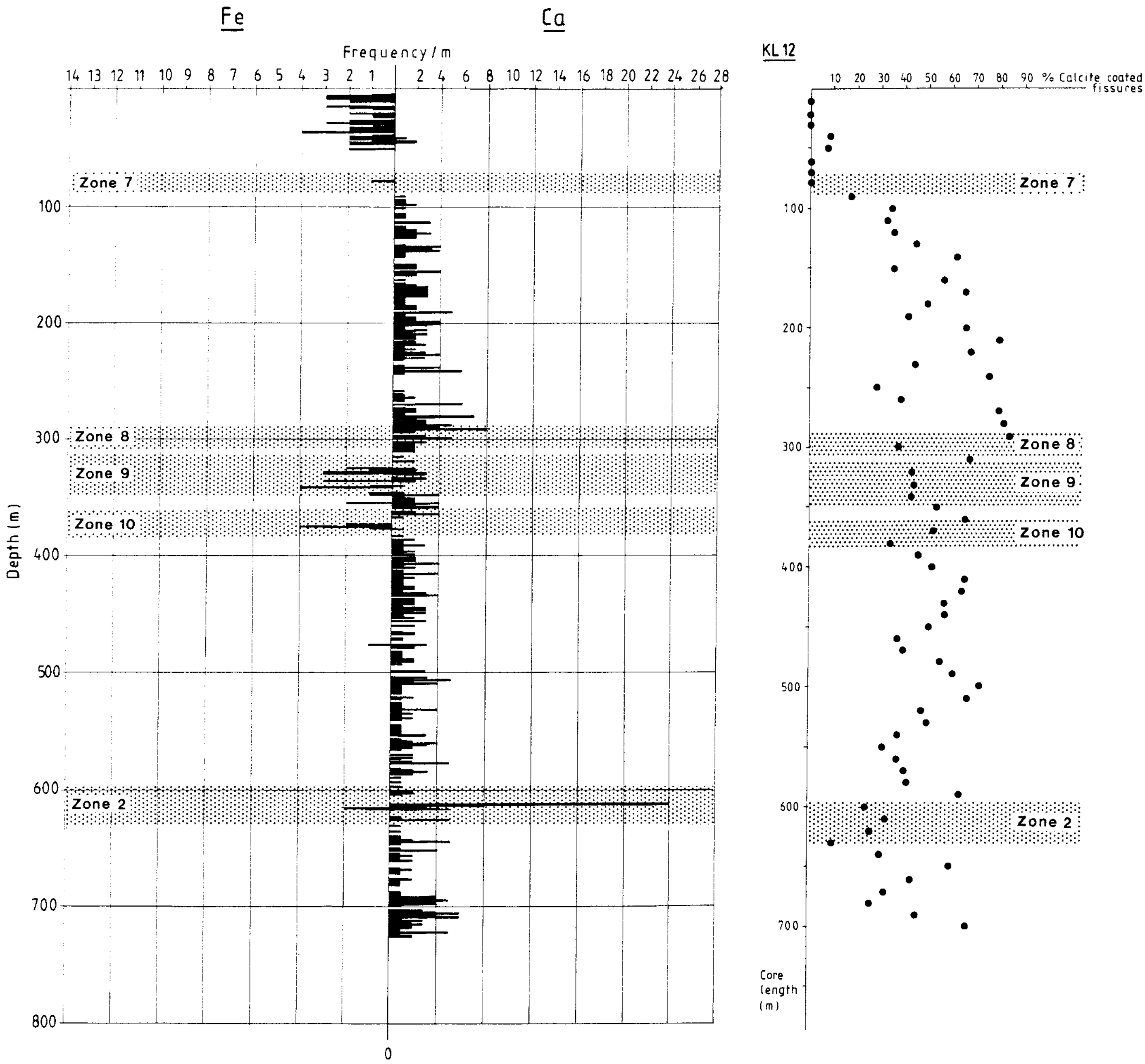


Figure 14. Frequency of Fe-oxyhydroxides and calcite versus depths, Kl 12. To the right, percentage of calcite coated fissures.

14) the apparent calcite depletion can also be seen. Probably this is not due to dissolution of calcite but a raised frequency of other fissure minerals within the zone giving a relative depletion of calcite.

Zone 3 runs approximately N-S and coinsides with a vertical mafic dike. Three boreholes penetrates the zone, Kl 5, Kl 6 and Kl 10. Diagrams are shown in figure 15 to 17. For borehole Kl 5 are only the percentage of calcite coated fissure shown. The hydraulic conductivity has only been measured in drillhole 6. Zone 3 differs significantly from zones 1 and 2. Thus Fe-oxyhydroxides are lacking, hematite is an unusual mineral and calcite is very common (Figs. 16 and 17). All this indicates a low hydraulic conductivity within the zone, an indication also shown by direct measure of the hydraulic conductivity (Fig 10). Another characteristic feature is the rare appearance of epidote within the zone. These characteristics are consistent to the fact that the fracture zone is common to the mafic dike section within the borehole. Results from microscopy strengthens that the fracturing of zone 3 probably is younger than the event which fractured zones 1 and 2. The "self sealing effect" of mafic dikes in comparision to surrounding granitoids has also been observed within other sites studied by SKB (Tullborg and Larson, 1983; Larson and Tullborg, 1984).

The highest hydraulic conductivity (more than 10^{-6} m/s) within borehole Kl 6 is found on both sides of the fracture zone (Fig.10). The appearance of Fe-oxyhydroxides c. 15 metres below the dike indicate a few fractures with a high hydraulic conductivity allowing rapid downward transport of surface water. A low calcite content at 230-240 m corelength is accompanied by a high Fe-oxyhydroxide and hematite content (Figs. 15) indicating a water conducting zone.

Zone 4 which strikes NE-SW and dips 65-75^{o} to the SE is penetrated by borehole Kl 7 (Fig. 18) (Olkiewicz and Stejskal,1986). An increase of calcite coated fractures is found below zone 4 (115-130 m corelength) but above and within this zone calcite fissures are rare or lacking. It is likely that

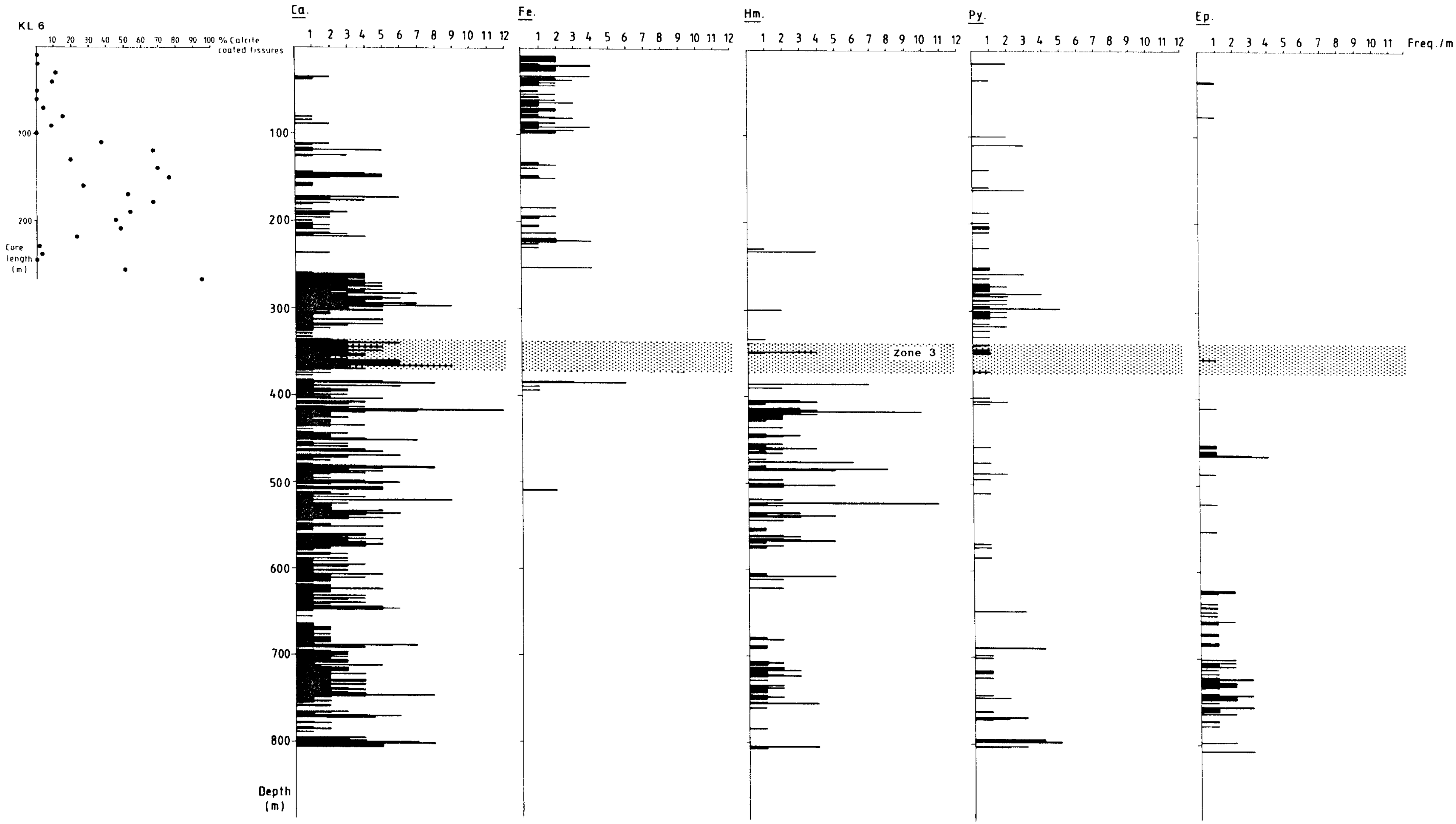


Figure 15. Frequency of fracture minerals versus depth, Kl 6.
To the left, percentage of calcite coated fractures in the upper 250 metres.

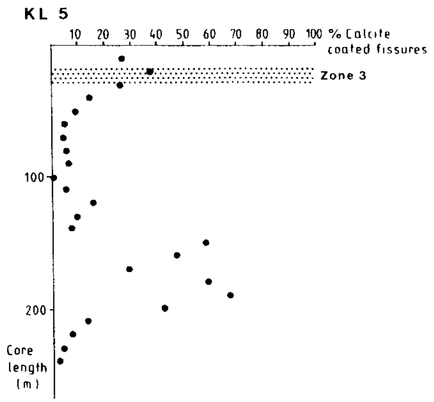


Figure 16. The percentage of calcite coated fissures versus depth, Kl 5.

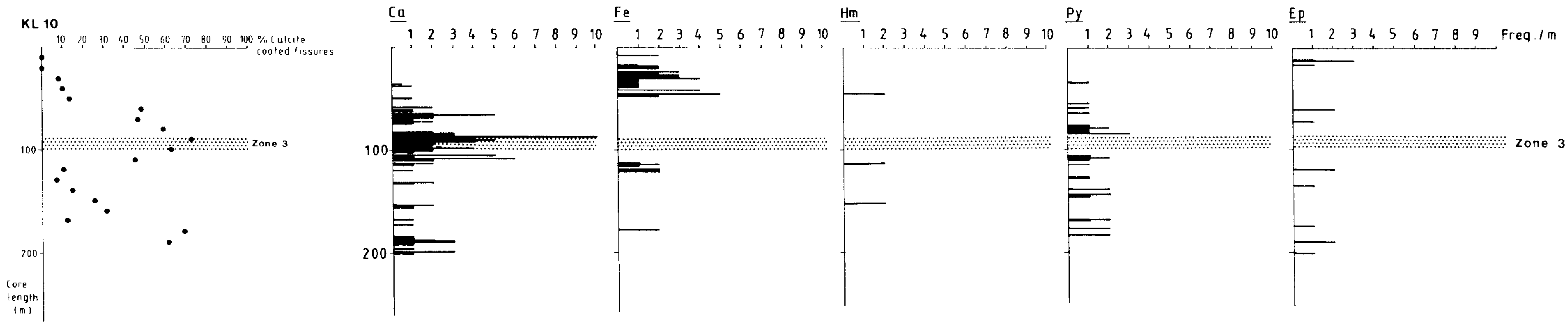


Figure 17. Frequency of fissure filling minerals versus depth, Kl 10. To the left, percentage of calcite coated fissures.

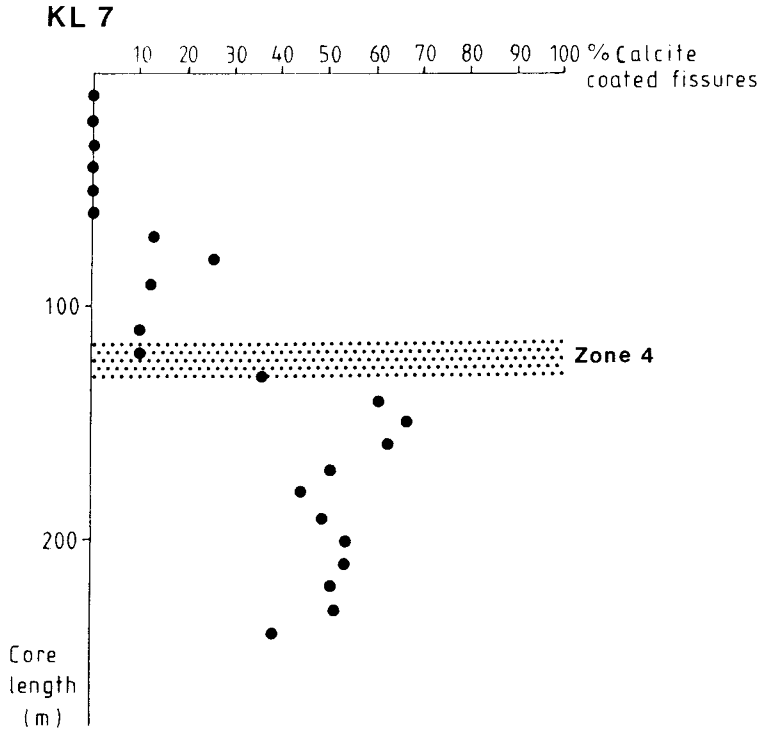


Figure 18. Percentage of calcite coated fissures versus depth, Kl 7.

the upper section, from the surface down to c. 130 m borehole length, of the borehole has a high permeability. The calcite frequency increases significantly below the zone. It is probable that the zone serves as a barrier for recharge water due to the high hydraulic conductivity. Similar observations have been made in the study site at Finnsjön where a subhorisontal zone separates two different water circulation systems (Ahlbom et. al, 1985).

Two boreholes, Kl 11 and Kl 14, were drilled in order to transect zone 5 (Figs 19 and 20). This zone has an E-W extension with a dip of c. 80 ^{o} to the south. It is about 25 m thick (Olkiewicz and Stejskal, 1986) In borehole Kl 11 the geophysically indicated zone (5) does not correspond to any significant $CaCO_3$ depletion. The only indications of high water circulation at this depth is a raised (Fe) frequency within a few sections (Fig. 19). A reason for the bad correlation is propably that tectonic movements has been traced also on both sides of the zone, i.e. the zone is not very well defined (Olkiewicz and Stejskal,1986). This is indicated in figure 10 which shows a relatively high hydraulic conductivity from the surface down to c. 450 m core length. Neither Fe-oxyhydroxide precipitation or calcite dissolution can be observed within zone 5 in Kl 14. This is however expected as saturation of calcite as well as low redox potential is a common feature at these depths (370-410 m corelength).

Zone 6 is transected by drillhole Kl 13 at a core length of 152-188 m (Fig. 21). This zone dips 75^{o} to the south and strikes N80^{o}W and is distinctly indicated geophysically. The zone has probably been reactivated several times (Olkiewicz and Stejskal, 1986). Fe-oxyhydroxide has not been found within the zone. However, a weak calcite depletion can be seen. The highest hydraulic conductivity within the zone is observed in the interval 170-190m (Fig.10). An increased frequency of Fe-oxyhydroxides is observed within the interval of high hydraulic conductivity 610-675 m. This section is not defined as a major fracture zone. However, it is likely that this interval represents a distinct hydraulically conductive zone. This is also supported by temperature logging and a loss a water at

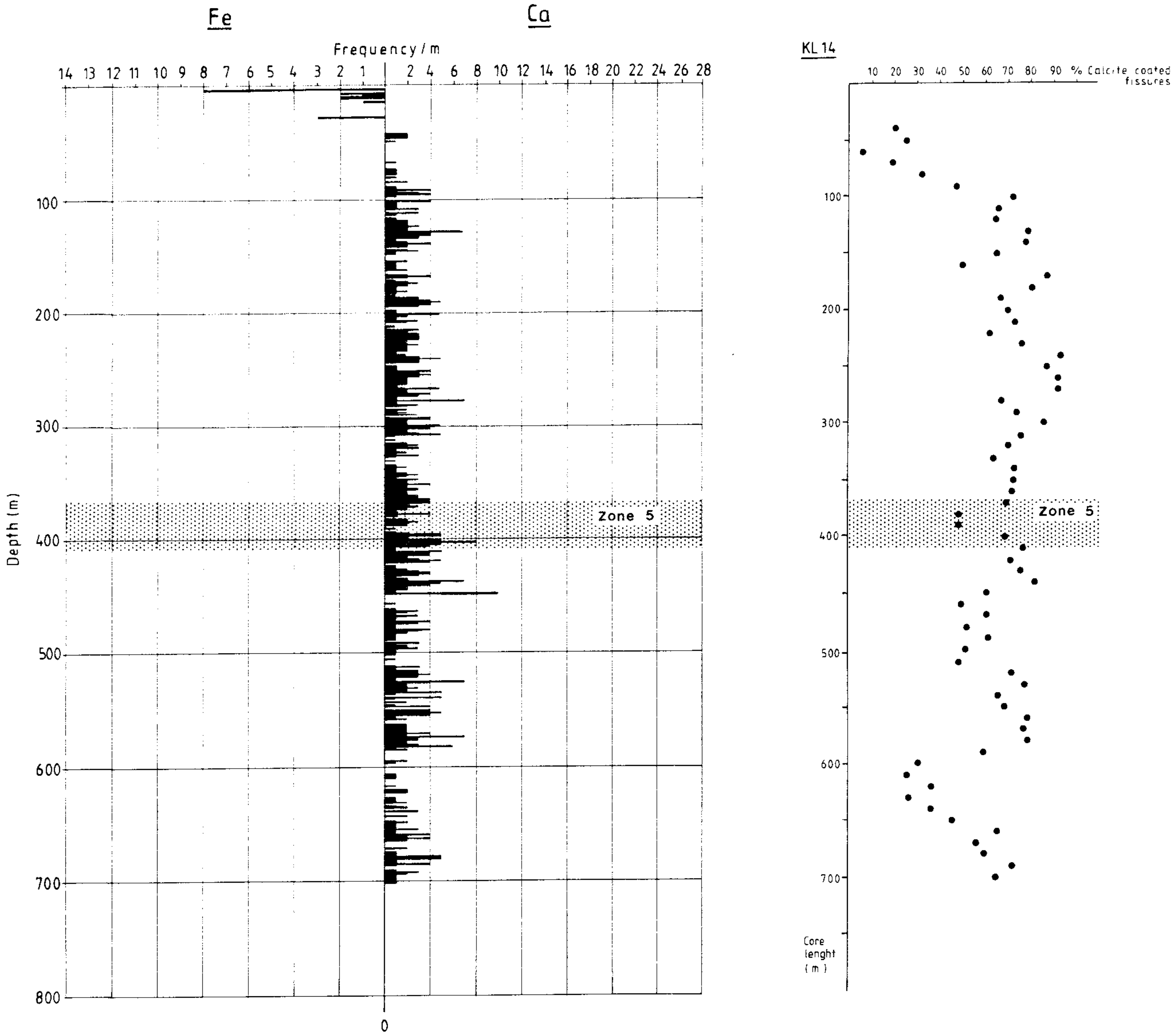


Figure 19. Frequency of Fe-oxyhydroxides and calcite versus depth, Kl 14. To the right, percentage of calcite coated fractures.

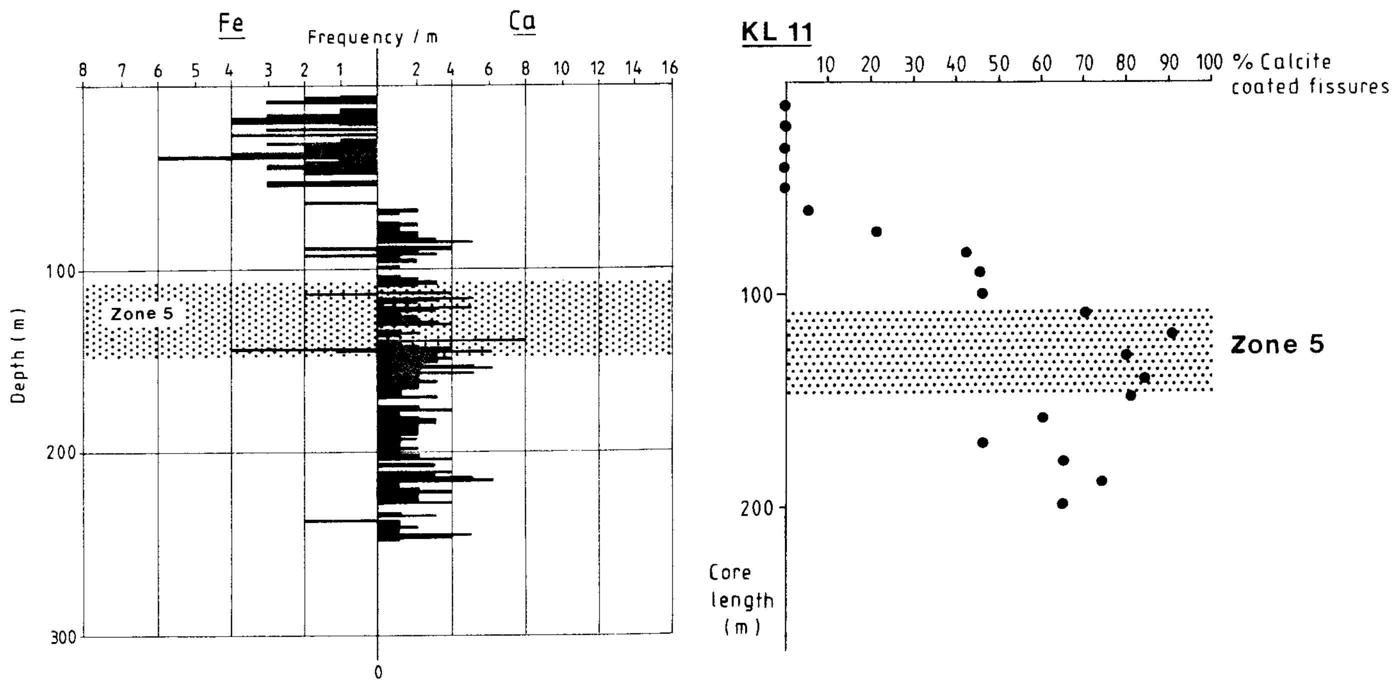


Figure 20. Frequency of Fe-oxyhydroxides and calcite, Kl 11. To the right, percentage of calcite coated fissures.

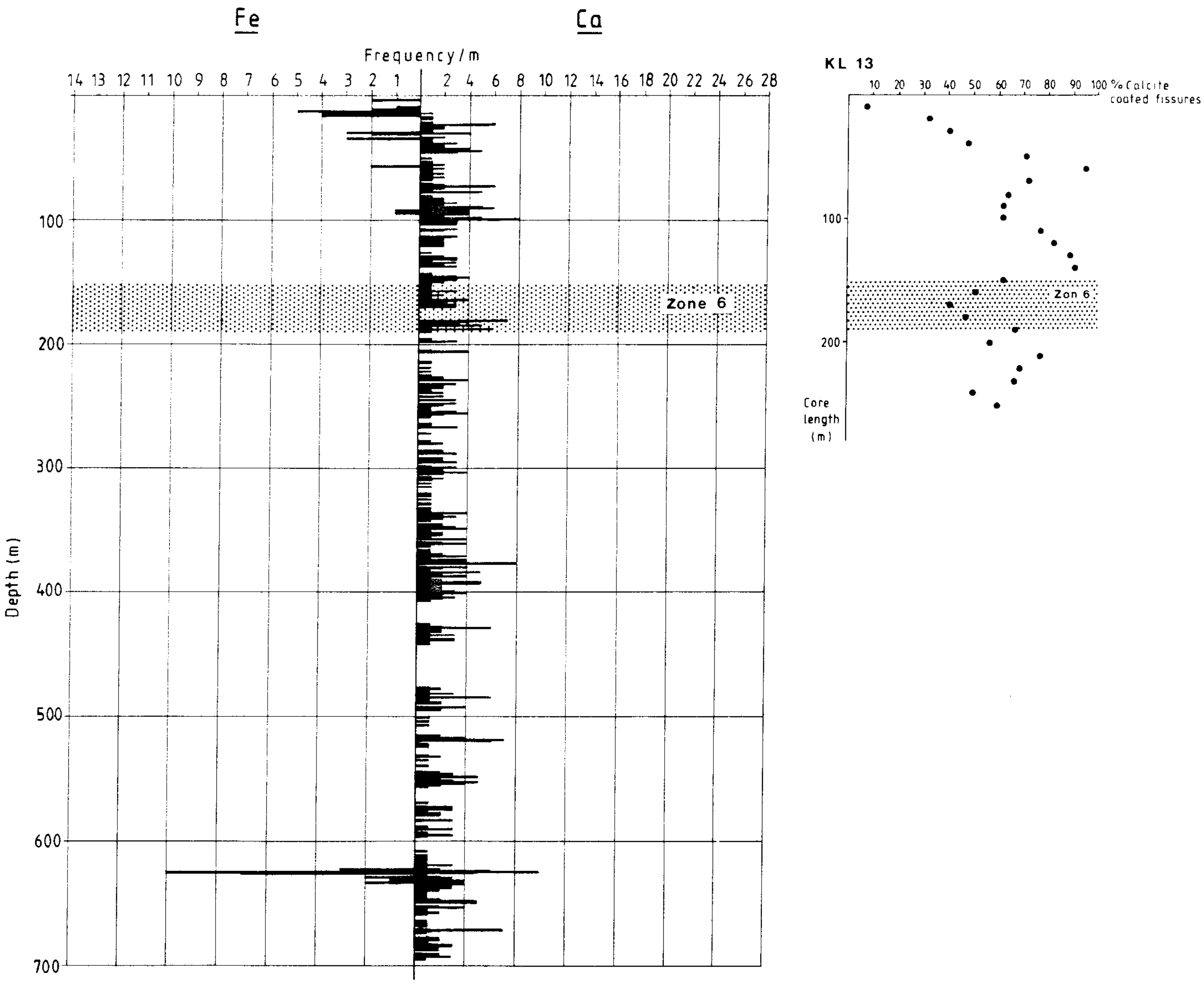


Figure 21. Frequency of Fe- oxyhydoxide and calcite versus depth, Kl 13. To the right, percentage of calcite coated fissures.

this depth during the drilling operation (Sehlstedt and Stenberg, 1986).

Borehole Kl 12 penetrates zones 7, 8, 9, 10 and 2 (Olkiewicz and Stejskal, 1986). Significant calcite dissolution is not found within any zone except for zone 7, which is penetrated by drillhole Kl 12 at a shallow level (Fig 13). Fe-oxyhydroxide is however detected in all zones penetrated except for zone 8.

Two boreholes Kl 1 and Kl 2 were drilled in order to penetrate relatively unfractured parts of the Klipperås area. They were drilled subvertically down to depths of more than 500 and 900 metres respectively (Olkiewicz and Stejskal, 1986). Only the upper part of these boreholes have been studied concerning frequency of calcite coated fissures (Fig. 22 and 23).

Borehole Kl 8 does not penetrate any fracture zone. Plots from Kl 1, Kl 2 and Kl 8 have been constructed in order to look at the near surface effect of water on the fissure fillings (Figs 22, 23 and 24).

A common feature shown in figure 9 is the nearsurface depletion of calcite. Most figures 11 to 24 show this effect but to varying depth. These depths ranges from c.20 to 120 m below the surface. Boreholes Kl 1 and Kl 2 show a calcite dissolution only down to 40 metres which reflects a low circulation of surface water in connection to these boreholes. This is in agreement with what was considered as more unfractured parts of the study site from the surface investigations. An anomalous pattern is shown in figure 16 where a mafic dike serves as a less permeable horizon preventing calcite to be dissolved within the dike. However, the dissolution of calcite is significant below the dike to a depth of c. 140 m corelength.

It can be seen in figures 11 to 24 that Fe-oxyhydroxide is correlated to the circulation of surface waters. It is also evident that hematite does not necessarely correspond to hydraulically conductive zones but is more likely to be remnants of earlier oxidation features. The lack of pyrite in the shal-

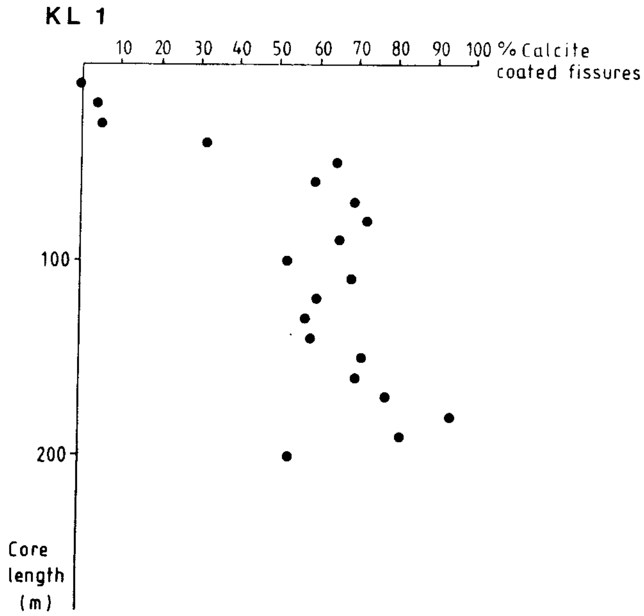


Figure 22. Percentage of calcite coated fissures versus depth, Kl 1.

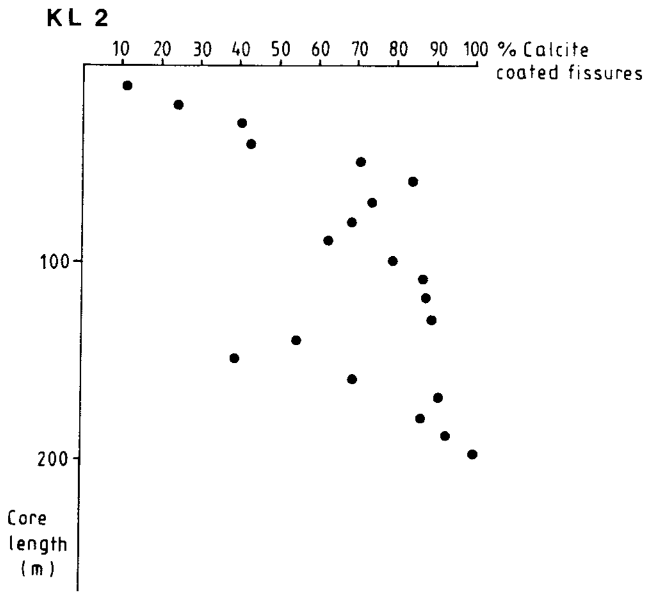
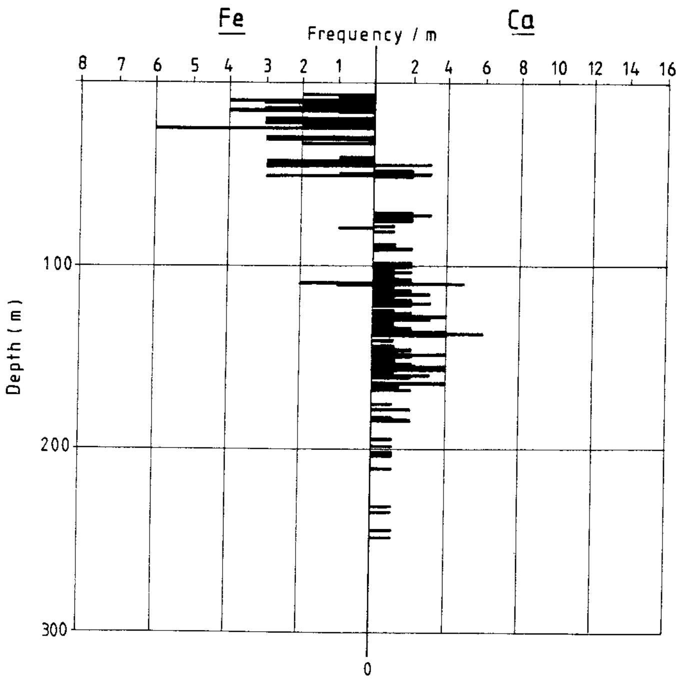


Figure 23. Percentge of calcite coated fissures versus depth, Kl 2.



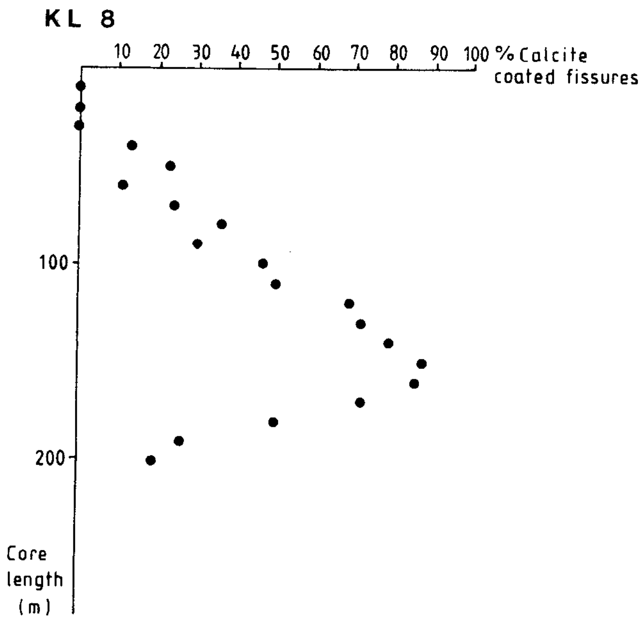


Figure 24. Frequency of Fe-oxyhydroxide and calcite in fissures versus depth, Kl 8. To the right, percentage of calcite coated fissures.

lower parts of the boreholes is also significiant. It is suggested that the pyrite has been oxidized within the near surface region to give Fe-oxyhydroxide.

It is evident that information about the changes in fissure filling mineralogy related to the surface can be of importanse for the interpretation of the groundwater chemistry within the area.

2.5 Isotope analyses

2.5.1 Isotope analyses on groundwater

Isotope analyses of water from Klipperås have been carried out on samples from Kl 1:406 m and Kl 9:696 m. Results from Kl 1 are reported by Smellie et al. (1985). Analyses from Kl 9:696 are reported by Laurent (in press). Results are shown in the table below.

Samples	$\delta^{18}O$ o/oo (SMOW)	$\delta^{2}H$ o/oo (SMOW)	$\delta^{13}C$ o/oo (PDB)	C-14 age years
Kl 1:406	-12.0	-86.3	-17.0	28 375
Kl 9:696	-11.9	-	-15.7	30 795

The analyses indicate a long residens time for the groundwater at the sampled levels. Tritium is lacking in both samples and the C-14 ages are high. The $\delta^{18}O$ values in the groundwater does not deviate significant from the calculated values of the precipitation in the area according to Tullborg and Winberg (1985).

The $\delta^{18}O$ and $\delta^{2}H$ plot of the water fits to the meteoric water line indicating that no serious redistribution of oxygen or hydrogen isotopes has taken place (Smellie et. al., 1985). The $\delta^{13}C$ values in the HCO_3 indicate a organic origin of the carbon but also repeated dissolution and precipitation of calcite can yield these low values $\delta^{13}C$ and give apparent high C-14 ages.

In conclusion the two waters sampled are probably representative of groundwater within less hydraulic conductive blocks at the study site.

2.5.2 Stable isotope analyses of calcite

Stable isotope analyses of $\delta^{18}O$ and $\delta^{13}C$ have been carried out on calcite samples from open as well as sealed fractures at different depths. It has not always been possible to distinguish originally sealed fissures from open fissures. However, samples from open fractures dominate. Fissure fillings from drillcores Kl 1, Kl 2, Kl 6, Kl 7, and Kl 14 have been analysed. Sampled depths range from 20 to 860 metres.

Institut for Energiteknikk in Oslo has carried out the analyses. Results are given in o/oo. The standard used is PDB (carbonate from a belemnite in the Pee Dee formation).

Results are shown in table 3. In figure 25 has $\delta^{13}C$ been plotted versus $\delta^{18}O$. Most of the samples plot within the range; $\delta^{18}O$ = -17 to -6 o/oo and $\delta^{13}C$ = -5 to -13 o/oo. No distinct groups can be separated within these intervalls. The variety in isotope ratios are probably caused by various degree of redistribution and also by influence of meteoric water with various composition i.e these fissures are open or have recently been open to meteoric water circulation. In figure 25 arrows connect calcites from older fissures with calcite from younger fissures within the same core sample. As can be seen most of the arrows point towards lower $\delta^{13}C$ and an $\delta^{18}O$ interval corresponding to a transition towards "meteoric water-low temperature" calcite. The groundwater sampled in Klipperås exhibit $\delta^{18}O$ values of about -12 o/oo (Smellie et al 1985) which yield, at 10^{o}, a calcite with $\delta^{18}O$ of -9 o/oo using the fractionation factor given by O´Neal (1969).

The three samples from drillcore Kl 1 (Fig. 25) which show extremely low $\delta^{18}O$; -24.0 to -25.9 o/oo, and relatively high $\delta^{13}C$; -3.0 to -4.2 o/oo, all belong to closed fissures in metabasites. In one sample (Kl 1:77.9) the calcite is cogenetic with adularia which is a hydrothermal mineral. All this suggests that these fissures have a hydrothermal origin. Water circulation in basites is often restricted due

Table 3 Stable isotopes in fissure filling calcites.

Drillhole	Core length	$\delta^{13}C$ ‰ (PDB)	$\delta^{18}O$ ‰ (PDB)
Kl 1	22,5	-13,8	-17,4
	22,7	-9,6	-10,9
	50,0	-8,5	-7,6
	60,9 (s)	-2,3	-16,4
	60,9 (o)	-10,4	-16,3
	73,3	-5,6	-15,6
	77,9 (s) M	-4,2	-24,3
	77,9 (o) M	-5,6	-14,7
	107,4	-12,3	-5,9
	131,7	-13,2	-18,8
	159,1	-9,5	-15,0
	180,9 M	-3,0	-24,0
	183,0 M	-6,0	-14,0
	183,7 M	-4,1	-25,9
	191,9	-9,2	-15,3
	235,7 M	-5,9	-8,3
	254,0	-5,0	-11,7
	285,7 M	-8,9	-6,0
	293,5	-10,2	-14,2
	295,2	-11,6	-15,8
	309,0 M	-4,6	-13,5
	309,2	-10,0	-15,6
	336,9	-10,7	-8,7
	424,4	-8,9	-12,5
	428,5	-9,1	-10,7
	453,5 (a) V	-8,5	-10,9
	453,5 (b) V	-7,7	-10,0
	486,5	-10,1	13,8
	511,0 V	-9,9	-9,7
	529,7 (o)	-7,9	-12,5
	529,7 (s)	-7,9	-19,8
	561,8 V	-9,7	-16,3
	563,5	-9,1	-13,9

Drillhole	Core length	$\delta^{13}C$ ‰ (PDB)	$\delta^{18}O$ ‰ (PDB)
Kl 2	328,7	-11,2	-13,7
Kl 6	558,2	-7,8	-14,2
	680,8	-9,6	-13,2
	682,9	-10,1	-8,1
Kl 7	125,1 *c	-17,7	-4,1
	125,1 *	-12,4	-9,0
Kl 14	161,7	-9,8	-6,5
	210,3	-7,8	-6,3
	247,6 (s) V	-5,6	-9,7
	247,6 (o) V	-10,0	-11,7
	298,1 V	-6,6	-7,6
	381,2	-10,9	-8,3
	413,7	-3,5	-8,1
	447,0 (a)	-7,8	-13,4
	447,0 (b)	-8,1	-12,9
	447,3	-9,5	-13,4
	659,2	-5,6	-10,1
	700,5	-9,0	-6,1

(o) = Calcite from open fissure
(s) = Calcite from sealed fissure
V = Fissure in acid volcanics
M = Fissure in metabasite
(a),(b) = Calcite from different fissures within the same section of the drillcore.
* = Crushed material from fracture zone 4; single grains
*c = - " - -"- ; cemented grains

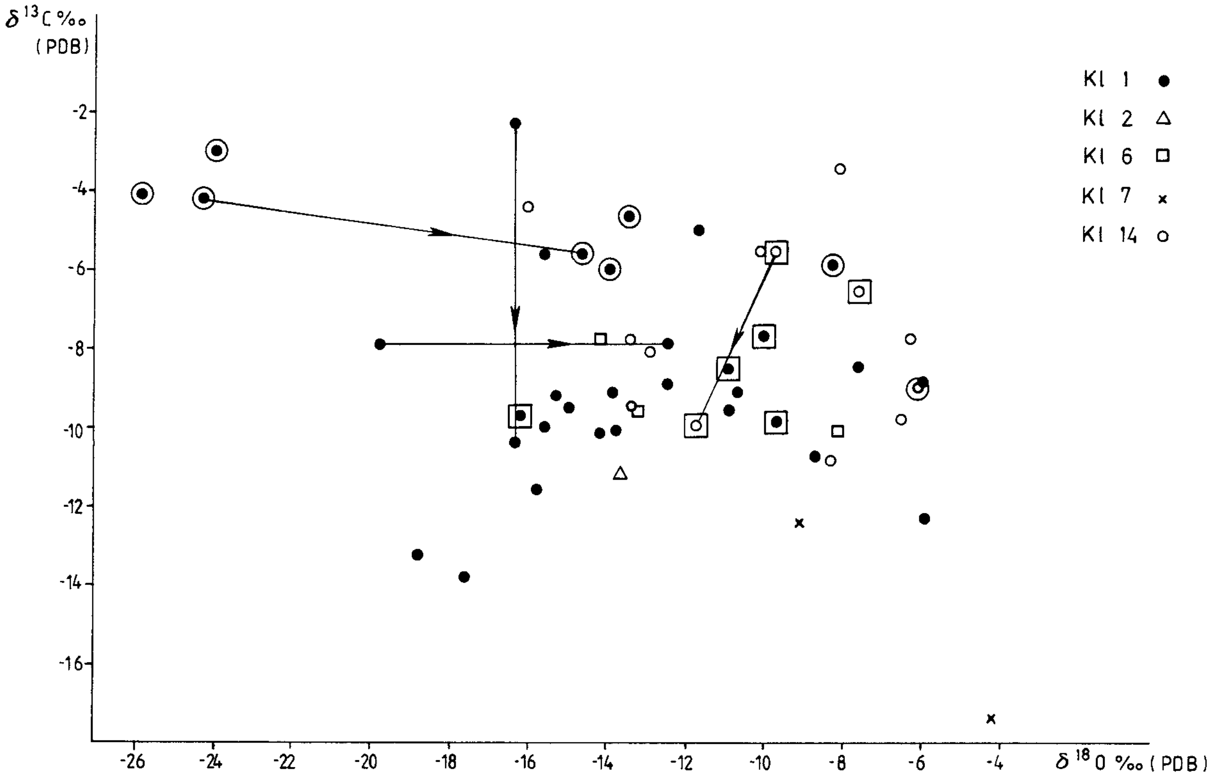


Figure 25. $\delta^{13}C$ versus $\delta^{18}O$ in fissure filling calcites.

O = Fissure in basite

□ = Fissure in porpyry

Arrows connect older and younger fissures within the same core sample, going from oldest to youngest.

to sealing of fissures e.g by formation of clay minerals. This is one explaination why only calcites from metabasites have preserved their anomalous isotope ratios. Also fissure fillings from porphyry dikes have been distinguished in figure 25. As can be seen there is no indications of a lower water circulation in these dikes.

$\delta^{13}C$ and $\delta^{18}O$ values for fissure filling calcite from fissures in granitic and gabbroic bedrocks are plotted in figure 26. The samples shown in this figure are from Gideå (Tullborg & Larson, 1983), Taavinunnanen (Larson & Tullborg, 1984) and Klipperås respectively. Calcites from these areas are from fissures within granitoids and metabasites as well as dolerite dykes (Gideå). As can be seen in the figure the fissures in the basic rocks have preserved the hydrothermal isotopic fingerprint to a larger extent than fissures within the granitic rocks. Most of the fissures in the granitic rocks indicate a later redistribution of the isotope ratios and the values have changed towards "present calcite formation" calculated from $\delta^{18}O$ fractionation given by O´Neal (1969) and a $\delta^{13}C$ fractionation factor given by Emrich (1970), at a groundwater temperature of $10^{o}C$ and suggesting groundwater of -17 to -12 o/oo $\delta^{18}O$ and -15 to -18 $\delta^{13}C$ (Fig 26). Stable isotope analyses evidently support the theory that basic rocks usually exhibit lower hydraulic conductivity than granitic rocks.

Figures 27 and 28 show $\delta^{18}O$ and $\delta^{13}C$ versus depths respectively. When looking at the $\delta^{18}O$ plot no trend can be seen. The lowest values recorded are fissure filling calcites from borehole KL 1. The values from borehole Kl 14 range from -13.4 to -6.1 o/oo (Fig 29). These values are in accordance with present day calcite deposited by the meteoric water circulating in the fissures. It is also notable that Kl 14 shows the highest hydraulic conductivity (Gentzschein,1986) i.e. suitable conditions for reequilibration of stable isotopes.

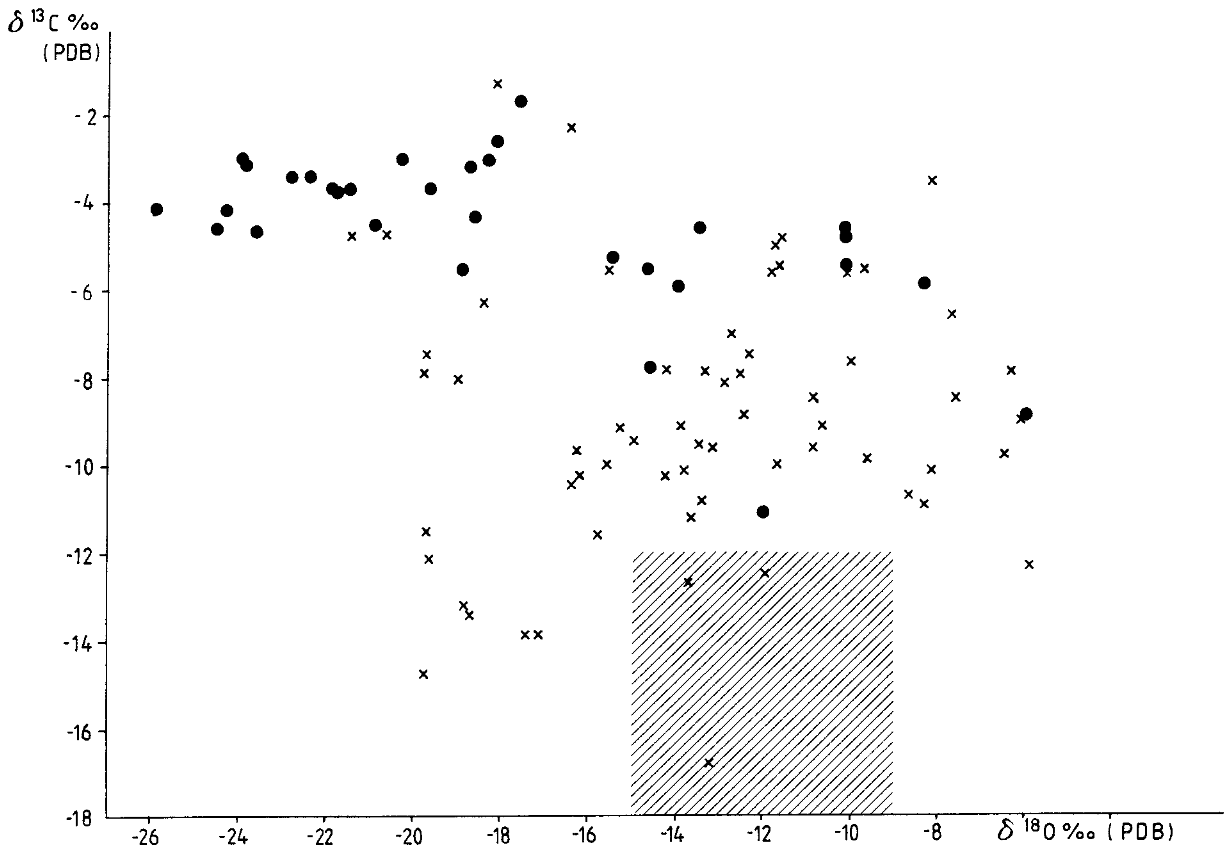


Figure 26. $\delta^{13}C$ versus $\delta^{18}O$ for calcite samples from basite (o) and granite (x). Striped area describes the isotope intervall of calcite precipitated at present temperatures from meteoric groundwaters.

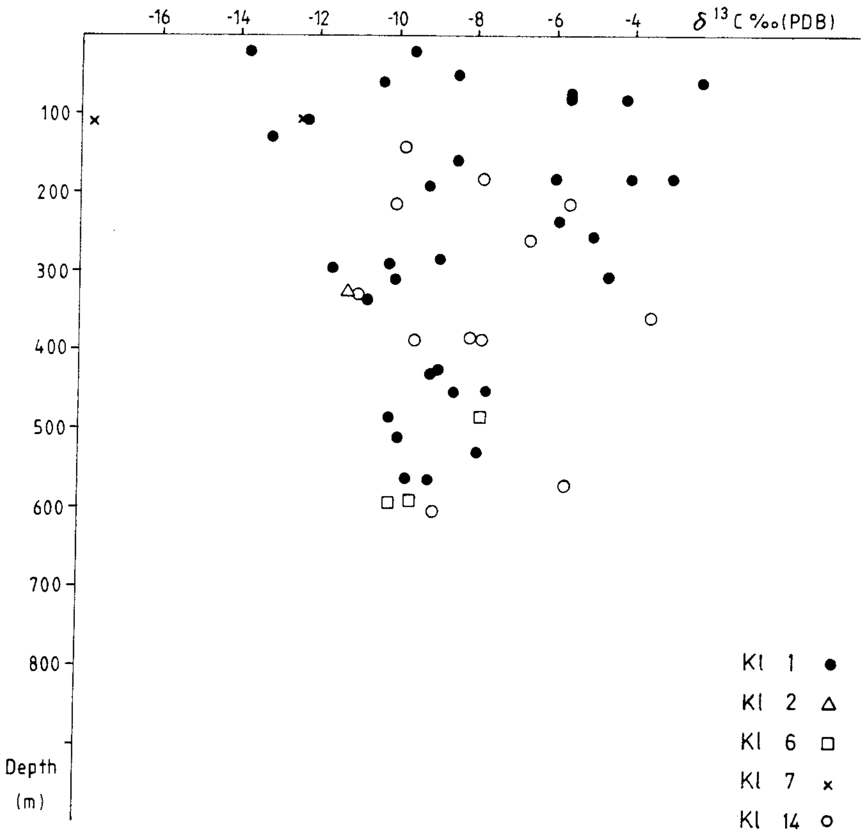


Figure 27. $\delta^{18}O$ versus depth for fissure filling calcite.

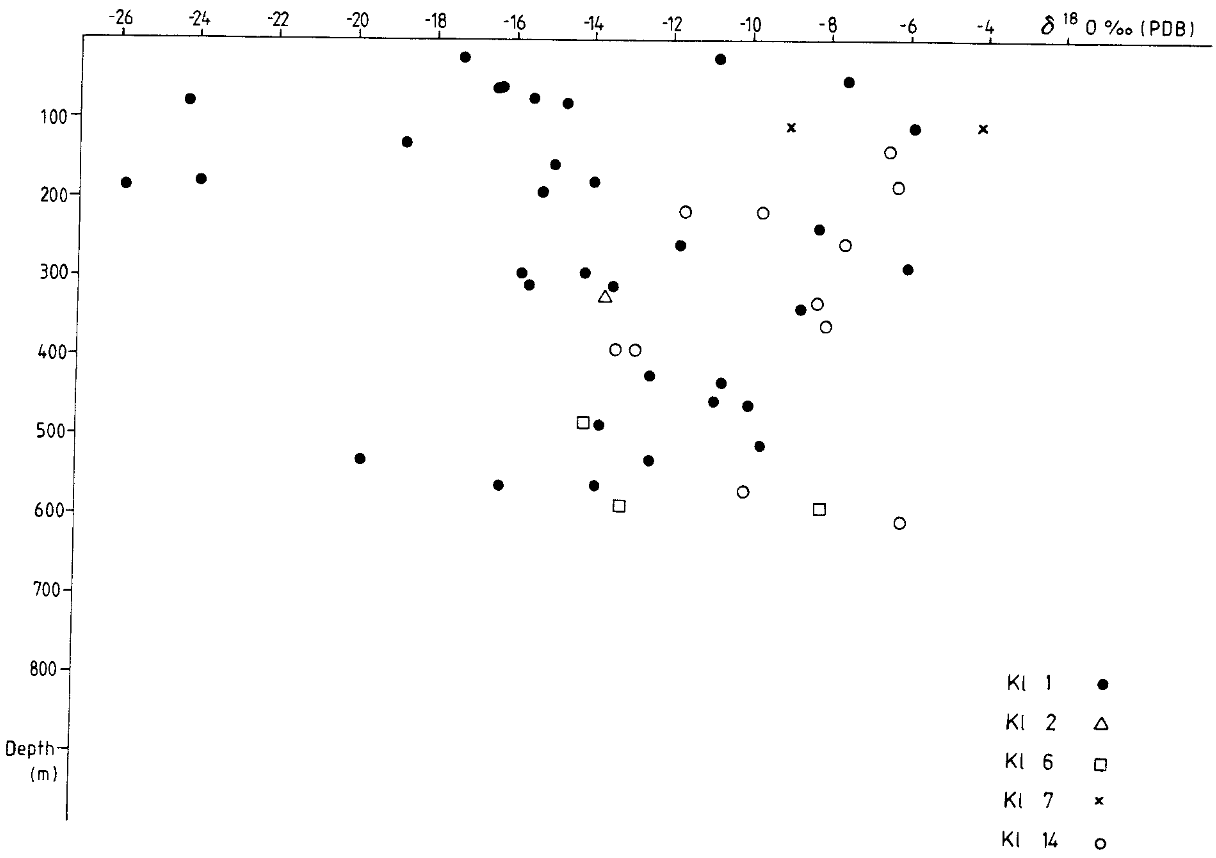


Figure 28. $\delta^{13}C$ versus depth for fissure filling.

$\delta^{13}C$ values versus depths show more uniform $\delta^{13}C$ values at depths below 350 metres. However, at shallow depths (0-200 metres) the $\delta^{13}C$ values range from -18 to -2 o/oo. The large spread observed is probably due to variation in hydraulic conductivity. The results described indicate a decreasing influence of organic carbon versus depths. However, modern meteoric water can get considerable contributions of inorganic carbon from dissolution of fissure filling calcites. Dissolution of calcite in the near surface is evident from the fracture frequency (c.f section 2.4). This means that modern precipitation of calcite can not be excluded even at great depths if the oxygen values are in accordance with present groundwater.

In drillcore Kl 7 a fracture zone with a content which is likely to be crushed material (c.f. section 2.2 and 2.4), was sampled. The two samples from this zone are anomalous; $\delta^{13}C$ -17.7 o/oo and $\delta^{18}O$ -4.1 o/oo in contrast to $\delta^{13}C$ -12.4 o/oo and $\delta^{18}O$ -9.0 o/oo in the other sample. In the former sample only grains cemented together by Fe-oxyhydroxides and small amounts of calcite were collected. The latter sample only contained uncemented single grains. It is difficult to interprete these results. However, it is quite clear that different generations of calcite occur within the cemented sample. One calcite generation is propably present as small peaces originating from calcite coated fissures. This is also supported from the microscopy (c.f. section 2.2), where broken fissure fillings have been identified. It can also be suspected that calcite occur in small amounts together with Fe-oxyhydroxid within the cement itself. It can be pointed out that the stable isotope analyses of the cemented grains do not coinside with calcite precipitated from present ground water at present temperature.

In drillhole Kl 14 a calcite sealed breccia (Fig. 30) have been analysed for stable isotopes. From microscopy it is known that the brecciation occured after the hydrothermal event responsible for the epidote and hematite formation. The isotope values indicate meteoric water and low temperature origin of the calcite. However, twinning is relatively extensive in the

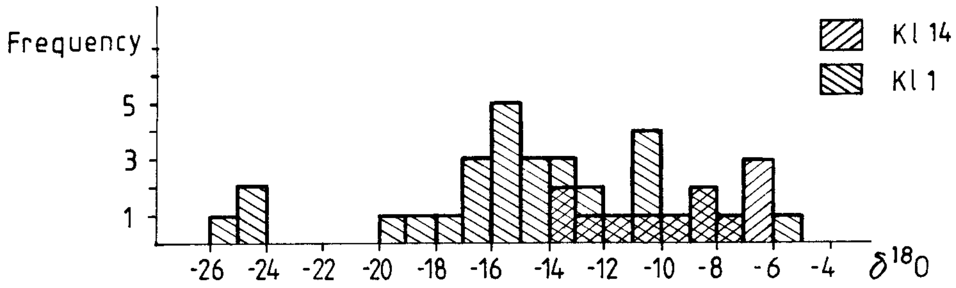


Figure 29. Frequency diagram for $\delta^{18}O$ in fissure filling calcites from Kl 1 and Kl 14.

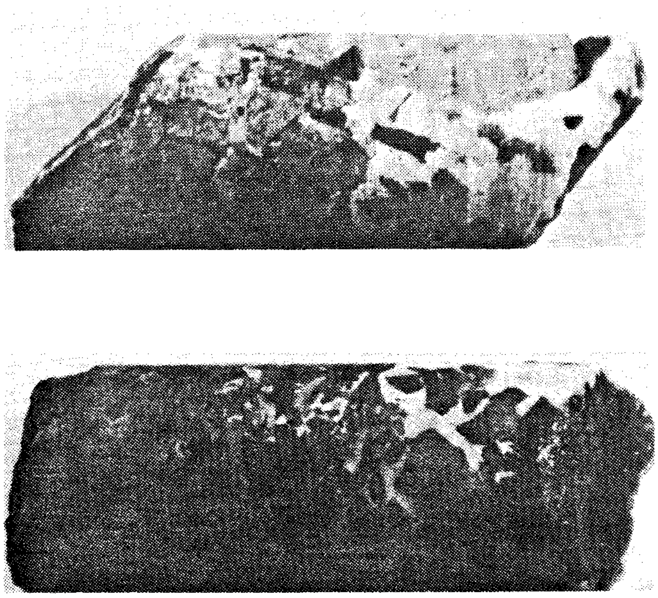


Figure 30. Photograph showing a calcite sealed breccia cut by an open calcite-chlorite coated fracture, Kl 14:447m

calcite sealing indicating a later stress deformation. the same breccia has also been found in borehole Kl 11 where the sealing in the breccia consists of quartz and calcite. these brecciation is suggested to be one reactivation in connection with fracture zone 5.

2.5.3 ^{14}C analyses of calcite sample

One relatively new method for ^{14}C analyses has been used on one sample from Klipperås (crushed material from fracture zone Kl 7:125.1 m). The new technique is based on accelerator mass spectrometry described by e.g. Possnert and Olsson (1984).

The sample has been leached in HCl. The obtained CO_2 gas was sublimated with liquid N_2. After evacuation of the polutions the CO_2 gas was converted to carbon ready for analyse. Results are shown in the table below.

Sample	Weight before HCl (mg)	Carbon (mg)	^{14}C-age BP
Kl 7:125.1 m	10 ml sand	0.16	2550+/-250

The obtained result is probaly a "mixed age" as the $\delta^{18}O$ and the $\delta^{13}C$ values of the two samples from the zone differed significantly. The apparent young age of the calcite in the zone indicates an intensed water circulation associated with calcite precipitation or recrystallisation which points to a change in conditions in recent time and is in agreement with a recent (possibly neotectonic) reactivation of the zone.

CONCLUSION

The Klipperås study site is located within the Småland-Värmland granitoid belt and exhibits a complicated tectonic pattern. The area is subdivided into blocks separated by faults with vertical components causing different character and with different fractures frequency. Indications of oxidation within fractures and fracture zones point to an intense water circulation within the area. But also blocks with very low water circulation is documented by e.g. very high ^{14}C ages (30 000 y).

Fracture zones with different orientations and ages transect the area. Vertical to subvertical zones dominate but also a horizontal zone has been found at great depth (780 m). Several fracture zones have been reactivated. It is also suspected that relatively late movements have taken place causing crushing of the rock (zone 4). Only a slight cementation of the crushed material is visible.

Some of the zones correspond to mafic dikes. These zones exhibit lower hydraulic conductivity due to fracture sealing by chlorite, clay minerals and calcite. In accordance with this the stable isotope analyses of calcites show that fractures within the basic dikes are less affected by low temperature-meteoric water than fracture calcites in the surrounding rocks in Klipperås.

Fracture minerals identified within the study site are chlorite, epidote, hematite, Fe-oxyhydroxide, calcite, muscovite, quartz, adularia, and pyrite. Smectite has only been identified within mafic dikes.

Hematite is a stable mineral during oxidizing conditions and can theoretically be formed during present conditions in the upper hundred of metres in Klipperås. However, the dominating Fe-mineral, containing ferric iron in these sections, is Fe-oxyhydroxide (rust). An oxidation of iron is suggested to produce Fe-oxyhydroxide as a first step and the absence of

Fe-oxyhydroxide indicates that stable or reducing conditions prevails.

It is observed that the surface water will affect the uppermost part of the bedrock resulting in calcite dissolution, break down of pyrite and precipitation of Fe-oxyhydroxide down to at least 120 metres below the surface. It is obvious from the plots of fracture calcite frequency that calcite dissolution is more intensive close to the fracture zones but is less intensive within the blocks. Within the fracture zones Fe-oxyhydroxides can be found down to at least 400 m.

Mineralogically the fracture zones in Klipperås exhibit different characters indicating a span of ages for their origin. Thus, NNE-SSW zones, 1 and 2, are brecciated and mylonitized and are characterized by fracture fillings like epidote, quartz and calcite. This in contrast to the N-S zone 3, which runs within a mafic dyke and is characterized by fracture fillings of calcite, chlorite and clay minerals. The mineralogy of this zone indicates a possible recent activation of the zone.

The NE-SW striking fracture zone 4 has been reactivated for several times and drillhole Kl 7 contains more than 10 metres of completely crushed rocks of which one metre consists of 0.1-1 mm fragments of rocks. It is suggested that this zone serves as a barrier for recharge water. Calcite has been dissolved all the way from the surface down to the zone at 115-130 metres corelength where the calcite frequency is distinctly increased. The possibility of neotectonism has to be considered. ^{14}C analyses of carbonates in the crushed material exhibit a low age (2500 y).

In the granite following results of deformation and fissure filling history can be estimated:

I a) Dislocations in feldspars associated with formation of subgrains in quartz

Intrusion of pophyry dykes (c.1620 M.a; Åberg, 1978)

b) Quartz

II) a) Epidote + Muscovite +/- Calcite +/-Quartz +/-Chlorite
b) Adularia + Hematite

Intrusion of dolerites (c.900-1000 M.a; Patchett, 1978)

III) Calcite + Chlorite +/-Hematite

IV) Calcite + Clay minerals + Fe-oxyhydroxide

In conclusion the granite has suffered extensive stress resulting in fracture zones and faults transecting the study site. The fractures have been path-ways for hydrothermal solutions which probably reached temperatures of at least $300^{o}C$. This hydrothermal period, which probably corresponds to a metamorphic age of about 1400 Ma (Åberg, 1978), was succeded by later periods of fracturing and mine ral formation, e.g. in connection with the intrusion of dolerite dikes. A later, probably still active, formation of low temperature fracture minerals like calcite (without twinning) clay minerals and Fe-oxyhydroxide is the last event traced in the samples studied.

Analyses of stable isotopes in fissure filling calcites shows that most of the samples plot within the range; $\delta^{18}O$ = -17 to -6 o/oo and $\delta^{13}C$ = -5 to -13 o/oo. Distinct groups can not be separated within these intervalls. The variety in isotope ratios are probably caused by various degree of redistribution and also by influence of meteoric water with various composition i.e these fissures are open or have recently been open to meteoric water circulation. However, samples from fissures in basites have preserved their original isotope ratios to a greater extent. This is in accordance with results from investigations in Taavinunnanen and Gideå (Larson and Tullborg, 1984; Tullborg and Larson, 1983) which indicate a lower water circulation in basites compared to granites.

REFERENCES

Ahlbom, K., Andersson, P., Ekman, L., Gustafsson, E., Smellie, J. and Tullborg, E-L. (1986). Preliminary investigation of fracture zones in the Brändan area, Finnsjön study site. SKB TR 86-??

Aftalion, M., Fallick, A.E. and Wilson, M.R. (1981) Age and isotope studies in Norrbotten and Småland: Preliminary results. Geol. Fören. Stockholm. Förh., vol 103, pp 519-520.

Allard, B., Larson, S.Å., Tullborg,E-L. and Wikberg, P. (1983). Chemistry of deep groundwaters from granitic bedrock. SKBF/KBS TR 83-59.

Deer, W.A. Howie, R.A. and Zussman, J. (1963). Rockforming minerals. Longmans, London.

Emrich, K., Ehhalt, D.H. and Vogel, J.C. (1970). Carbon fractionantion during the precipitation of calcium carbonate. Earth planet. Sci. Letters. 8, pp 363-371.

Fritz, B., Kam, M. and Tardy, Y. (1984). Geochemical simulation of the evolution of the granitic rocks and clay minerals submitted to a temperature increase in the vicinity of a respository for spent nuclear fuel. SKB/KBS TR 84-10.

Garrels,R.M. and Christ,C. L. (1965). Solutions, Minerals ans Equilibria. Freeman, Cooper & Company, California. 450 pp.

Gentzschein, B. (1986). Hydrological investigations at the Klipperås study site. SKB TR 86-08.

Kamb,W.B. (1959). teory of preferred orientation developed by crystallization under stress. Journal of Geology, vol. 67, No 2, pp 153-170.

Larson S.Å and Tullborg, E-L. (1984). Fracture fillings in the gabbro massif of Taavinunnanen, nothern Sweden. SKB, TR 84-08.

Lindh, A. and Gorbatschev, R. (1984). Chemical variation in a Proterozoic suite of granitoids extending across a mobile beltcraton boundary. Geol. Rundsch., vol 73, pp 881-893.

Magnusson,N.H. (1960). Age determinations of Swedish Precambrian rocks. Geol. Fören. Stockholm Förh., vol 59 pp 205-228.

Nordstrom, K. and Puigdomenech, I (1986): Redox chemistry of deep groundwaters in Sweden. SKB TR 86-03.

Olkiewicz, A. and Stejskal, V. (1986). Geological and tectonical description of the Klipperås study site. SKB TR 86-06.

O´Neal, J.R., Clayton, R.N. and Mayeda, T.K. (1969). Oxygen isotope fractionation in divalent metal carbonates. J. Chem. Phys., 51, No 12, p 5547.

Patchett, P.J. (1978). Rb/Sr ages of Precambrian dolerites and syenites in southern and central Sweden. Sver. Geol. Unders.C, 747, pp 1-63.

Persson,L. (1985). Description to the maps of solid rocks Vetlanda NV and NO. SGU Ser. Af No 150 and 151.

Possnert, G. and Olsson, I.U. 1984 : First Nordic Colloquium on accelerators and dating, March 11th-12th, 1983. Boreas, Vol. 13, pp 365-375.

Röshoff, K. and Lagerlund, E. (1977). Tektonisk analys av södra Sverige, Vättern-Norra Skåne. SKBF/KBS TR 20.

Sehlstedt, S. and Stenberg, L. (1986). Geophysical investigations at the Klipperås study site. SKB TR 86-07.

Slunga, R. (1985). The seismicity of southern Sweden, 1979-1984, Final report. FOA Rapport, C 20572-T1, ISSN 0347-3694.

Smellie, J.A.T, Larson, N.Å. and Wikberg, P. and Carlsson, L. (1985). Hydrochemical investigation in crystalline bedrock in relation to the existing hydraulic conditions: Experience from SKB test sites in Sweden. SKB,TR 85-11.

Tullborg, E-L. and Larson, S.Å. (1982). Fissure fillings from Finnsjön and Studsvik, Sweden. SKBF/KBS TR 82-20.

Tullborg, E-L. and Larson, S.Å. (1983). Fissure fillings from Gideå, central Sweden. SKB, TR 83-74.

Tullborg, E-L and Winberg, A. (1984). Comparison between ^{18}O in deep groundwaters and precipitation. IAHS/AIHS International symposium on hydrochemical balances of freshwater systems. Abstract 5:7.

Tullis, J. and Yund, Y.A. (1977). Experimental deformation of Westerly granite. Geophys. Res. vol 82, pp 5705-5718.

Whittemore, D.O. and Langmuir, D. (1975). The solubility of ferric oxyhydroxides in natural waters. Groundwater, vol 13, No 4.

Wikberg, P. (1985). The assessment of reducing conditions at depth in granitic rock. MRS, Scientific Basis for Nuclear Waste Management IX, Vol 50, pp 137-144.

Åberg, G. (1978). Precambrian geochronology of sout-eastern Sweden. Geol. Fören. Stockholm Förh., 100, pp 125-154.

Sehlstedt, S. and Stenberg, L. (1986). Geophysical investigations at the Klipperås study site. SKB TR 86-07.

Slunga, R. (1985). The seismicity of southern Sweden, 1979-1984, Final report. FOA Rapport, C 20572-T1, ISSN 0347-3694.

Smellie, J.A.T, Larson, N.Å. and Wikberg, P. and Carlsson, L. (1985). Hydrochemical investigation in crystalline bedrock in relation to the existing hydraulic conditions: Experience from SKB test sites in Sweden. SKB,TR 85-11.

Tullborg, E-L. and Larson, S.Å. (1982). Fissure fillings from Finnsjön and Studsvik, Sweden. SKBF/KBS TR 82-20.

Tullborg, E-L. and Larson, S.Å. (1983). Fissure fillings from Gideå, central Sweden. SKB, TR 83-74.

Tullborg, E-L and Winberg, A. (1984). Comparison between ^{18}O in deep groundwaters and precipitation. IAHS/AIHS International symposium on hydrochemical balances of freshwater systems. Abstract 5:7.

Tullis, J. and Yund, Y.A. (1977). Experimental deformation of Westerly granite. Geophys. Res. vol 82, pp 5705-5718.

Whittemore, D.O. and Langmuir, D. (1975). The solubility of ferric oxyhydroxides in natural waters. Groundwater, vol 13, No 4.

Wikberg, P. (1985). The assessment of reducing conditions at depth in granitic rock. MRS, Scientific Basis for Nuclear Waste Management IX, Vol 50, pp 137-144.

Åberg, G. (1978). Precambrian geochronology of sout-eastern Sweden. Geol. Fören. Stockholm Förh., 100, pp 125-154.

List of SKB reports

Annual Reports

1977–78
TR 121
KBS Technical Reports 1 – 120.
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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.

Technical Reports

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