SKB TECHNICAL 84-08
KBS REPORT

Fracture fillings in the gabbro massif of Taavinnanen, northern Sweden

Sven Åke Larson
Geological Survey of Sweden
Eva-Lena Tullborg
Swedish Geological Company

Göteborg August 1984

SVENSK KÄRNBRÄNSLEHANTERING AB
Swedish Nuclear Fuel and Waste Management Co
MAILING ADDRESS: SKB, Box 5864 S-102 48 Stockholm, Sweden
Telephone: 08-67 95 40

FRACTURE FILLINGS IN THE GABBRO MASSIF OF TAAVINUNNANEN, NORTHERN SWEDEN

Sven Åke Larson
Geological Survey of Sweden

Eva-Lena Tullborg
Swedish Geological Company

Göteborg August 1984

A list of other reports published in this series during 1984 is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28) and 1983 (TR 83-77) is available through SKBF/KBS.

IRAP-no: 84060

Fracture fillings in the gabbro massif of Taavinunnanen, northern Sweden

Sven Åke Larson
Geological Survey of Sweden

Eva-Lena Tullborg
Swedish Geological Company

Göteborg, August 1984

CONTENTS Page

SUMMARY

SUMMARY

A characterization of fracture filling minerals as well as an account of the distribution of fractures and fracture fillings within the Taavinunnanen gabbro massif, northern Sweden is reported. Sampling of a 700 metres long (vertical) drill core, of fracture filling minerals has been carried out from the gabbro but also from granite dikes intersecting the gabbro. Dominating fracture fillings in the gabbro are chlorite, smectite, calcite, prehnite and zeolite minerals. In the granite dikes calcite, chlorite and quartz are the dominating fracture fillings.

Generally fractures have steep or vertical dips all along the borehole. More or less horizontal fractures correspond to zones with more intense igneous layering in the gabbro. Commonly fractures have been reactivated showing complex fracture fillings. The dominating strike of fractures, as measured on the surface, is NNE-NE.

The granite dikes have got more fractures than the gabbro and show higher hydraulic conductivities. Steep fractures are more common in the granite than within the gabbro.

The upper part of the borehole corresponds to high fracture frequency, high hydraulic conductvity and low frequency of calcite fracture fillings.

Several generations of both calcite and chlorite are present. One of the calcite generations is coprecipitated with prehnite. Zeolites have always been found to be younger than the calcite-prehnite generation. The oldest fracture fillings found are chlorite and smectite. Most fractures in the gabbro show alteration zones in contrast to what is found in the granite. However the granite dikes contain simple fillings of low-temperature minerals and show no reactivation or brecciation.

Analyses of $\delta^{18}O$ and $\delta^{13}C$ show a distinct group of calcites, some of which have been coprecipitated with prehnite. This group of calcites have got low $\delta^{18}O$ (-20 o/oo

to -25 o/oo) and relatively high $\delta^{13}C$ (-3 o/oo to -5 o/oo). It is suggested that these calcites have been precipitated from hydrothermal solutions. The $\delta^{18}O$ and $\delta^{13}C$ of calcites sampled from open fissures with high hydraulic conductivity show influence of a recharge water.

It is known that Taavinunnanen is a typical recharge area where downward transport of surface water mainly through fractures within the granite dikes has occured. Most of the fractures within the gabbro originated very early and have been reactivated. However some granite fractures are potentially young.

1. Introduction

The study of fracture filling minerals has been included as a part of the KBS Standard Program for the search of suitable areas for radioactive waste disposal within rocks in Sweden. Previous test sites have been situated within granitoids. In contrast to these, the test site at Taavinunnanen is situated within basic to ultrabasic rocks in a layered gabbro massif.

This report contains a characterization of fracture filling minerals as well as an account of the distribution of fractures and fracture filling minerals within the Taavinunnanen gabbro massif. The chemistry of some minerals found are also reported.

2. Geological setting

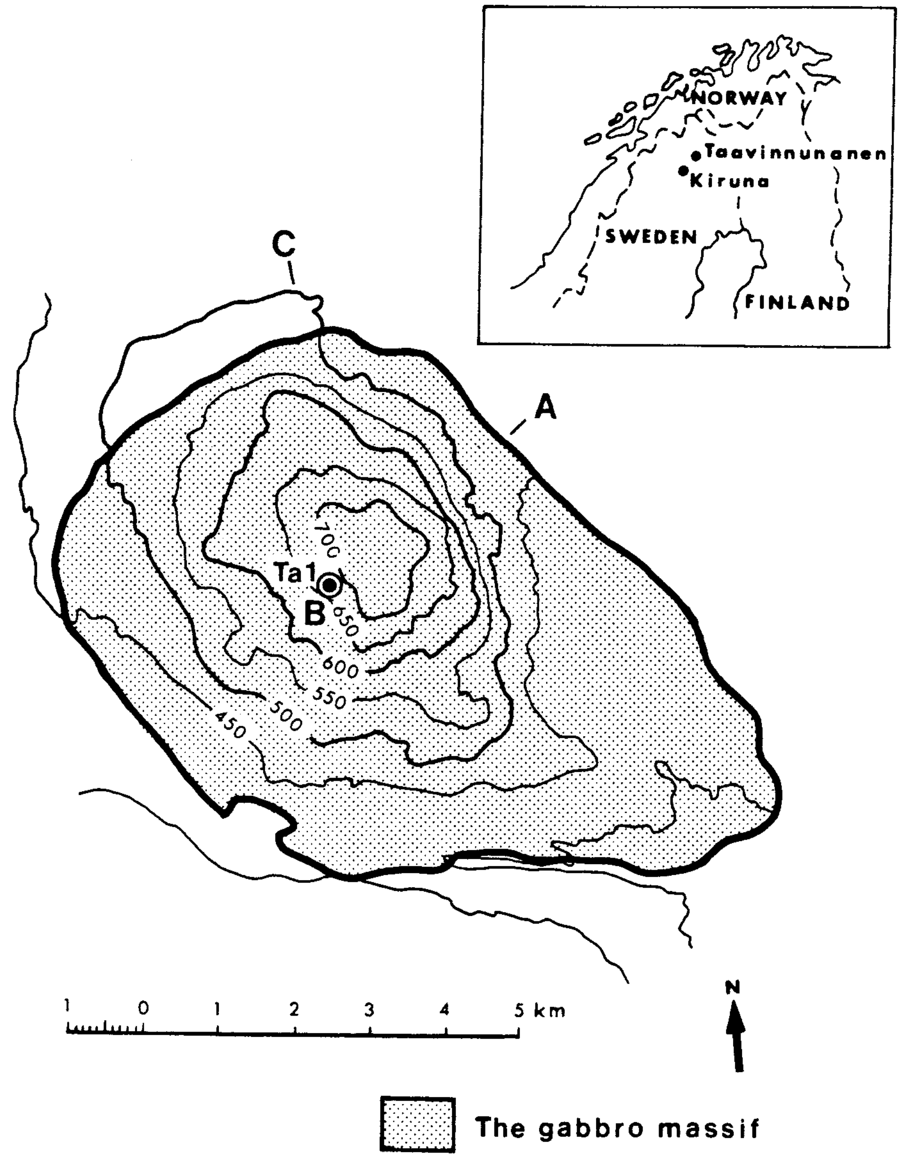
The Proterozoic Taavinunnanen gabbro (topographical map-sheet 30K Soppero SW) is situated approximately 35 km ENE of Kiruna. The gabbro area constitutes a hill with a top level of 780 m.a.s.l., rising 250 to 400 metres above the surroundings (Fig 1).

The gabbro massif has been included in "the younger series of deep-seated rocks" according to Hallgren (1979). This series consists of pegmatite, aplite, granite, perthite-monzonite, syenite, gabbro and anorthosite (Ambros, 1980), and is regarded as the last major plutonic event within the map area. Components of the series are considered to be approximately 1.5 Ga (Welin, 1970; Gulson, 1972).

Mapping within the map-sheet 30K Soppero (Hallgren, 1979) as well as within the adjacent areas (Ambros, 1980; Eriksson & Hallgren, 1975) has shown that several circular gabbro massifs, considered to have intruded during the same plutonic event as the Taavinunnanen gabbro, appears. These are mostly traced from geophysical indications (cf. H. Henkel in Ambros, 1980) as outcrops are scarce. From the aeromagnetic maps compiled by the Geological Survey of Sweden a complex composition is indicated for several of the gabbro bodies (Henkel, 1981).

A detailed mineralogical study has so far only been carried out on the Taavinunnanen gabbro body (Larson et al., 1984). It is likely that these data will show characteristic features common to several circular gabbro bodies in nothern Sweden. A cross section through the Taavinunnanen gabbro is shown in figure 2.

The gabbro massif is intersected by dikes of granite, aplite and (more rare) dolerite. Also xenoliths of quartzite have been found (Andrzej Olkiewicz, SGAB, pers. com.). Some of the granite dikes are likely to be late differentiates of "the younger series of deep-seated rocks". The dolerite dikes belong to the group of "youngest dolerites" mapped elsewhere on the map sheet (Hallgren, 1979).



FIGURES

Fig. 1 Location of the test site at Taavinunnanen. A, B and C refer to the profile in figure 2.

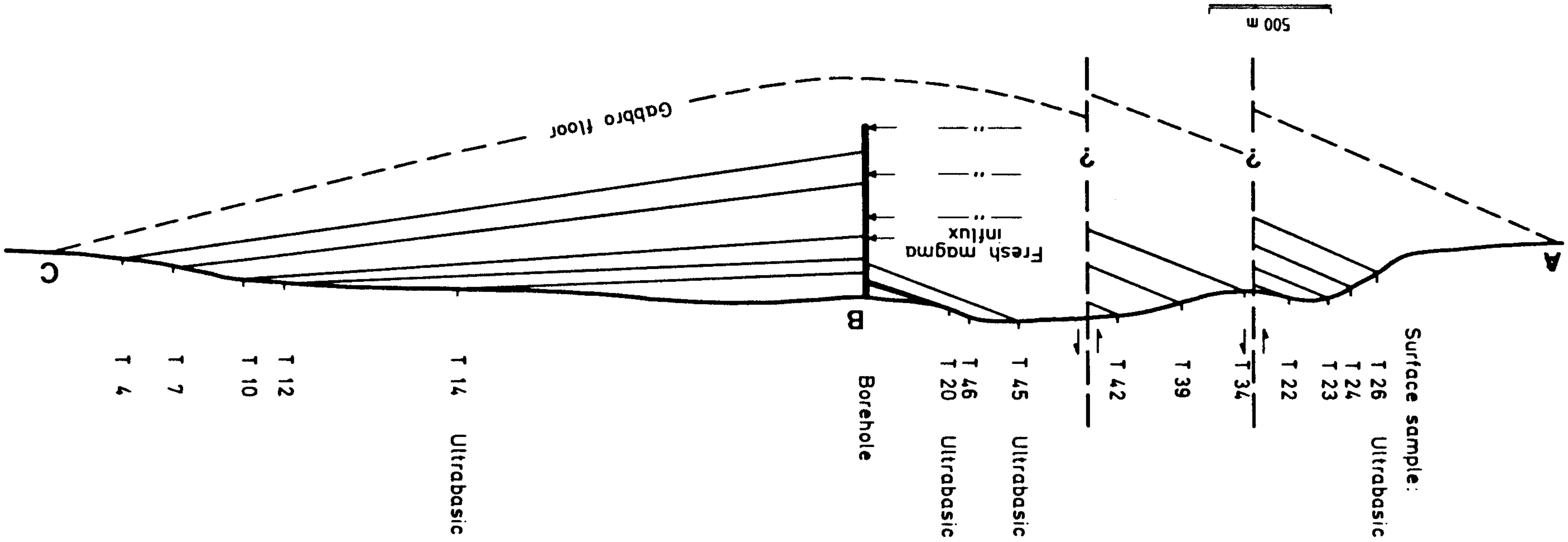


Fig. 2 Tentative cross-section of the layered Taavinunnanen gabbro massif.

3. Fractures and fracture fillings

Only one borehole (Ta 1) was drilled within the Taavinunnanen massif (Fig 1). The borehole is approximately vertical and drilled down to a depth of 700 meters below the surface. A detailed core mapping is reported by Ahlbom et al., 1982. This includes lithology, fractures and fracture filling minerals. From the simplified core map, in figure 3, it is evident that the granite dikes have got a higher fracture frequency than the surrounding gabbro. Dominating fracture filling minerals in the gabbro are chlorite, smectite, calcite, prehnite and zeolite minerals. However, in the granite dikes calcite, chlorite and quartz are the dominating fracture fillings (figures 4 to 7).

3.1 Fracture statistics

To get a general view of the relations between fracture directions, hydraulic conductivity and the history of deformation, some diagrams on fractures and their relation to depth, hydraulic conductivity, calcite fillings etc., are discussed. The significance of fracture statistics is limited due to the fact that only one hole has been drilled and that the core sampled was not orientated.

Dips of all fractures, for every 100 metres section, are shown in figure 8. The dips of fractures are related to the borehole axis (more or less vertical) and have been corrected by a factor 1/sin x, where x is the dip, to get a more accurate representation of the dip distribution. As can be seen steep fractures dominates all along the borehole. An increased frequency of more or less horizontal fractures can be seen especially within the 100-200 m section but also less obvious within the lower sections of the borehole. These sections correspond to zones with more intense layering in the gabbro, manifested through great variations in density of the rock.

In a mine at Kiruna approximately 35 km away from Taavinunnanen, principal horizontal stresses are greater than the vertical stress from the surface down to a depth of 1000 metres (A.Holmstedt, LKAB pers. com.; Leijon, 1981). If this is con-

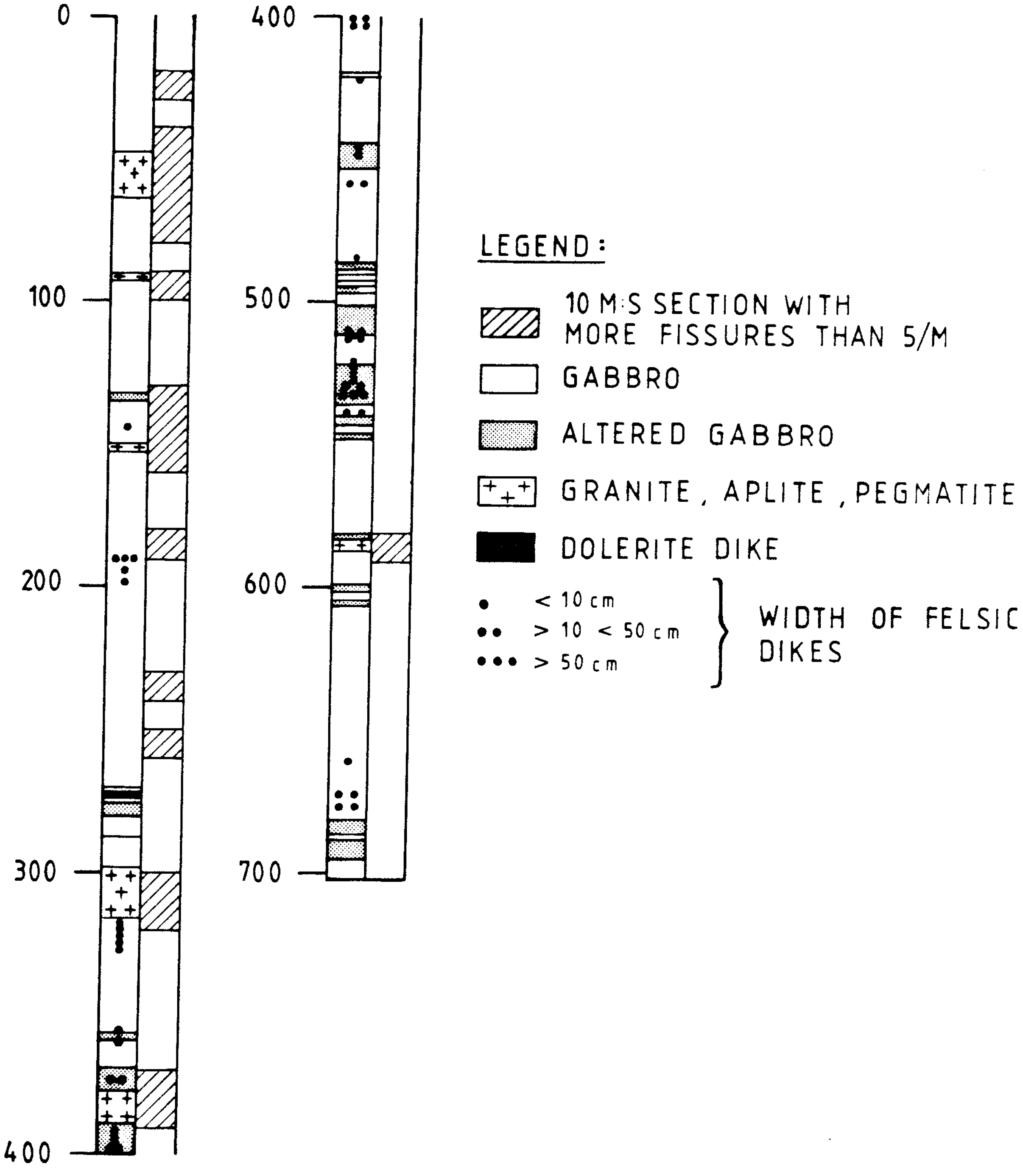


Fig. 3 Simplified core map of borehole Ta 1 at Taavinunnanen (Ahlbom et al., 1982).

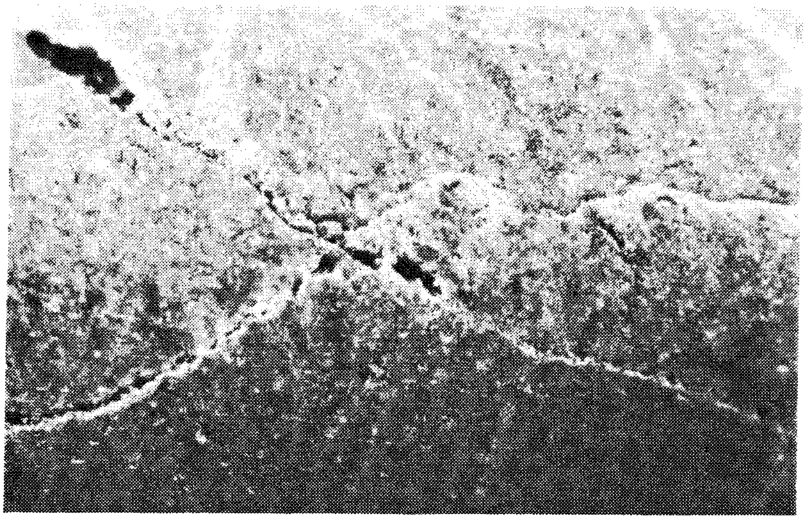


Fig. 4 Partly sealed fissures in a granite dike. Fissure fillings are calcite and chlorite. Level 583.5 m.

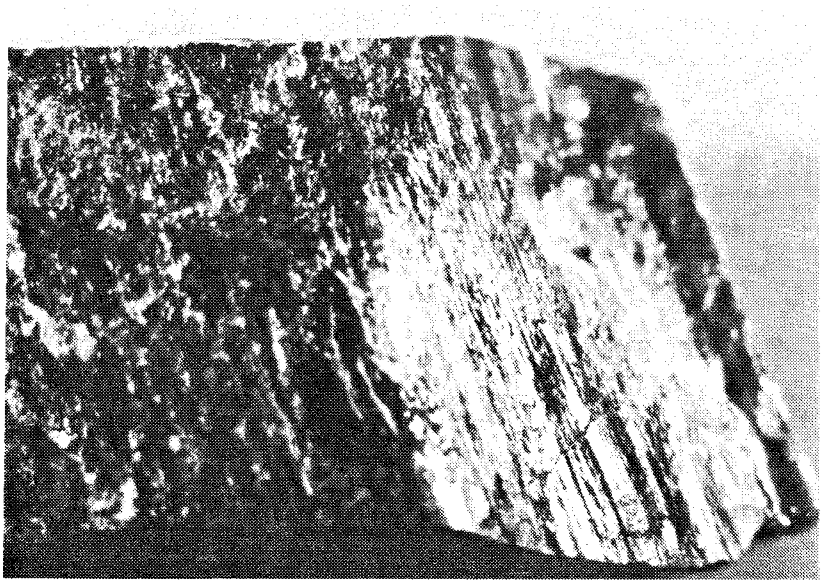


Fig. 5 Fissure surface, showing slicken side texture, coated with chlorite and clay minerals. Level 233.6 m.

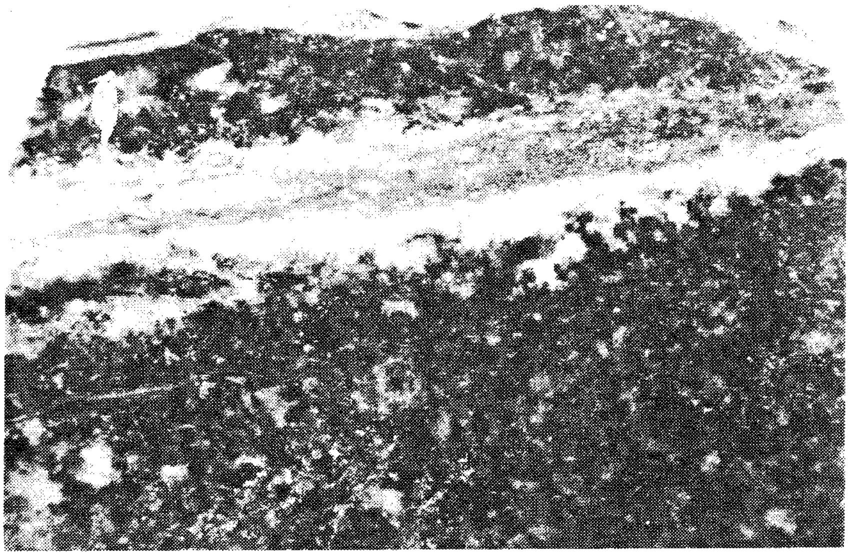


Fig. 6 Composite fissure filling in gabbro containing calcite, prehnite, quartz and chlorite. Level 416.9 m.

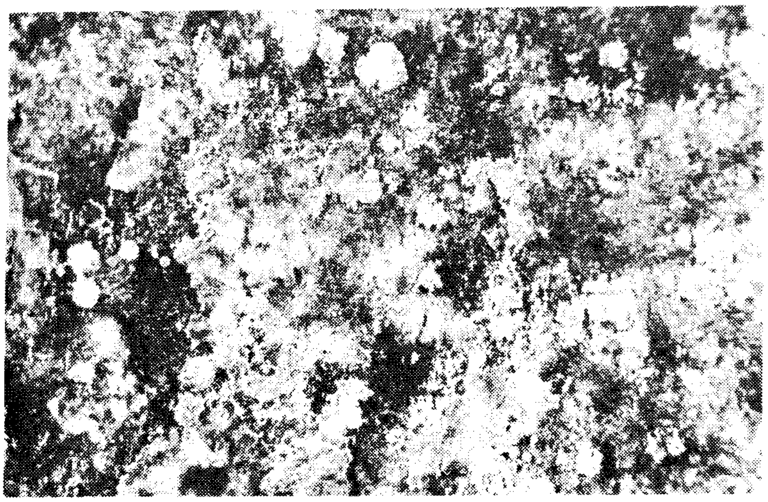


Fig. 7 Fissure surface partly coated with calcite and chlorite. Sample from open fissure in gabbro (576.9 m).

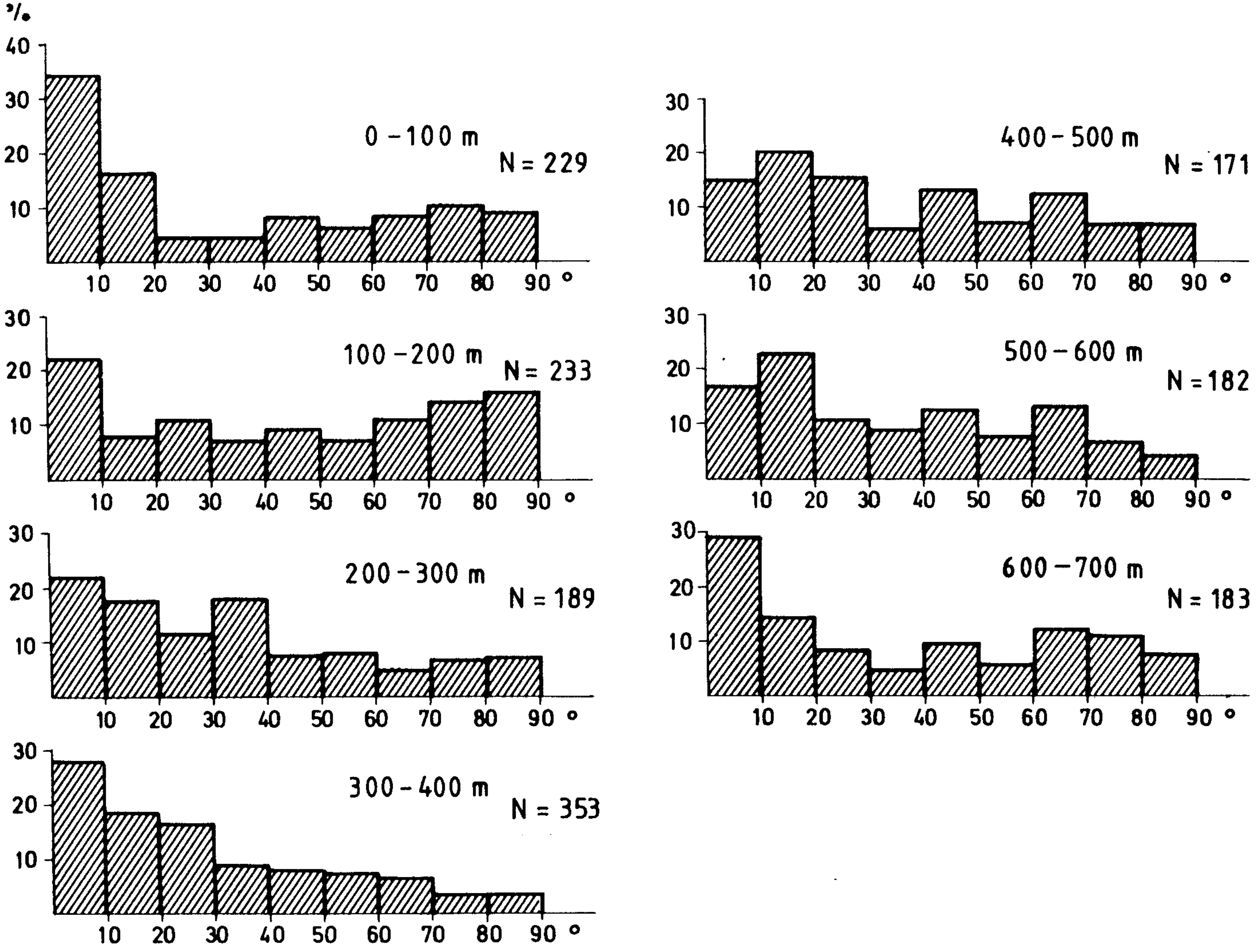


Fig. 8 Dip of all fractures seen in borehole Ta 1 for every 100 m section.

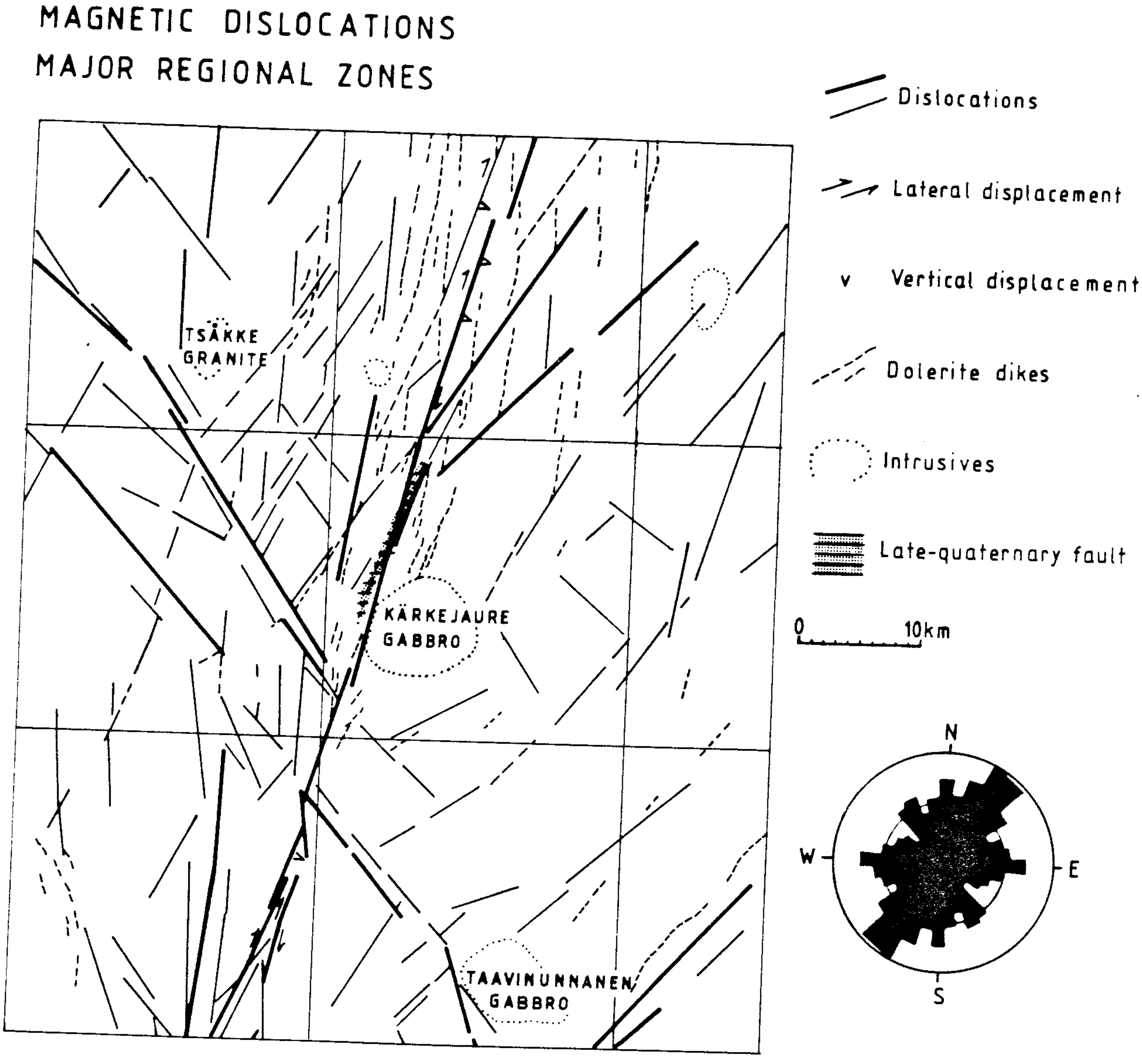


Fig. 9 Magnetic dislocations and major regional zones in the surroundings of Taavinunnanen (Henkel et al., 1983). To the right is also seen a diagram showing strikes of fractures measured from outcrops at Taavinunnanen (Ahlbom & Olkiewicz, 1981).

sistent with the regional stress pattern it is concluded that most fractures induced at Taavinunnanen were initiated during a period with a rock stress field different from what can be registrated at present. However fractures have been reactivated during several periods. This has i.a. been shown by Henkel et al. (1983) at Kärkejaure approximately 20 km away from Taavinunnanen, where late quarternary faults have reactivated an older tectonic zone (fig.9) The fault zone at Kärkejaure also constitutes part of the seismic belt shown by Bååth (1983).

Strikes of fractures from outcrops (Ahlbom & Olkiewicz, 1981) are shown in figure 9. One set of gently dipping fractures were shown to be paralell to the layering of the gabbro. As can be seen is the dominating direction approximately NNE-NE. This is also the dominating direction of regional displacements and magnetic dislocations according to Henkel et al., 1983 (see figure 9).

The dip of fractures from gabbro and granite dikes respectively have been plotted in figure 10a. The granite exhibits more fractures than the gabbro with dips of 10-20 deg. and 40-60 deg. The gabbro has got more subhorizontal fractures than the granite which probably is due to the ability of the bedrock to be fractured along the planes of layering. From hydrogeological investigations (Gentzschein,1983) it is evident that the granite has got a higher hydraulic conductivity than the gabbro. A comparision of dips of fractures, including fractures in granite as well as in gabbro, with high hydraulic conductivity (> 1.9x10 exp -11 m/s) and low hydraulic conductivity (< 1.9x10 exp -11 m/s) respectively, is shown in figure 10b. As can be seen is the highest frequency of dips for fractures of high conductivity, within the intervals 10-30 deg. and 40-60 deg. These intervals are common to those predominating in the granite (fig 10a).

When comparing dips of all fissures to dips of fissures coated with calcite (fig 10c) no significant differences can be seen. However the small differences observed are approximately within the same intervals as those mentioned above.

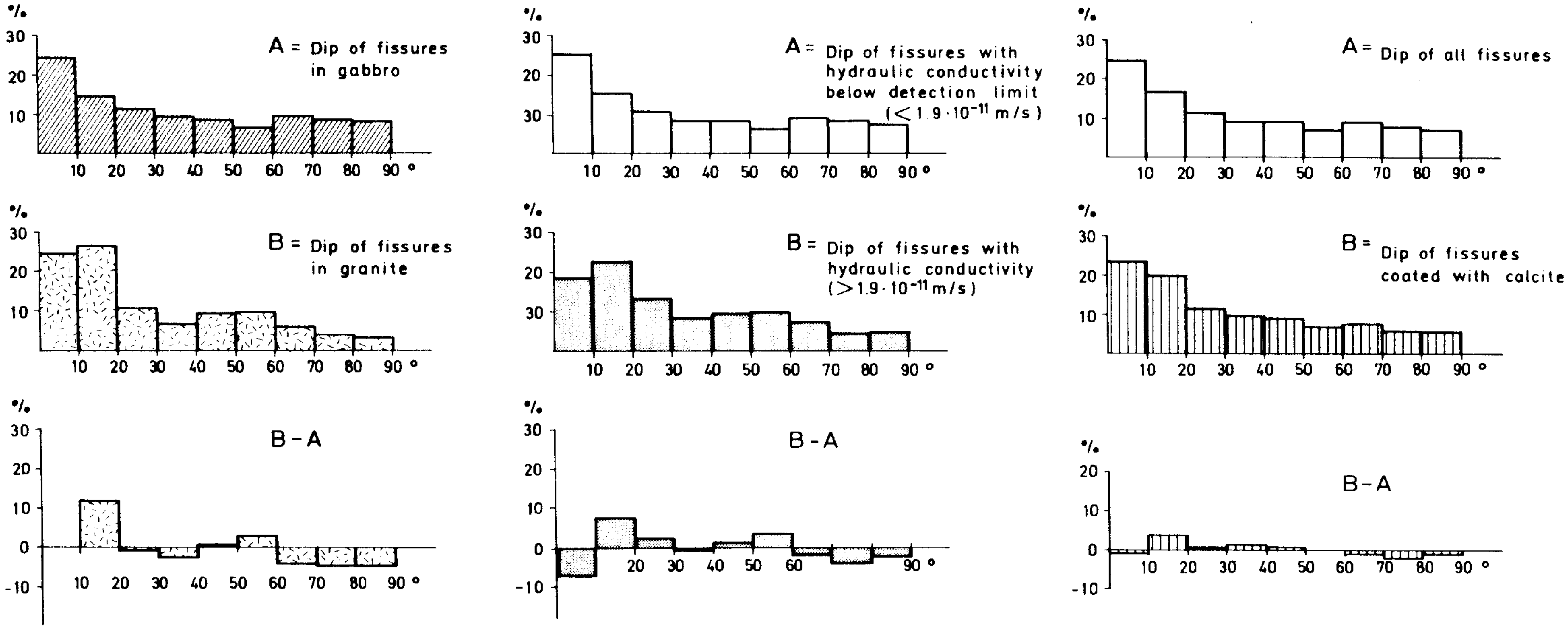


Fig. 10.

a/ Dips of fractures from gabbro and granite dikes respectively.

b/ Dips of all fractures with high and low hydraulic conductivity respectively.

c/ Dips of all fractures and fractures coated with calcite respectively.

It has been very difficult to distinguish between different clay and zeolite minerals during the core mapping. This means that it is impossible to construct relevant frequency diagrams of fracture fillings from the data reported (Ahlbom et.al 1982). However, calcite is a mineral easily distinguished. Thus calcite/depth (fig 11) as well as calcite/dip-plots (fig 10c) have been constructed. In figure 11 fracture frequency, hydraulic conductivity as well as frequency of calcite fillings are shown. As can be seen are calcite fillings common at depth below 100 metres. It is also concluded that calcite is almost lacking down to a depth of 75 metres. Thus, no new calcite has been precipated on the fracture walls at shallow depth within the rock. Taavinunnanen is a pronounced recharge area, and apparently aggressive water has passed down and dissolved old calcite fillings at shallow depth within the rocks. This is also consistent with the observations made during the core mapping, that coating of rust was present down to a depth of approximately 100 metres but was lacking at greater depths.

In conclusion the upper part of the borehole corresponds to high fracture frequency, high hydraulic conductivity and low frequency of calcite fracture fillings.

3.2 Identification

The drillcore was sampled in order to prepare thin sections and powder of fracture fillings for microscopy and X-ray diffraction analyses respectively. More than 40 thin sections were examined and approximately 20 XRD´s were run. To avoid interferences between calcite peaks and other mineral phases in the XRD diagrams, calcite was (if possible) removed from the samples before the XRD-runs. Results from the XRD are shown in table 1.

Dominating fracture fillings in the gabbro are chlorite, calcite and clay minerals (mostly of smectite type). Other fracture fillings are principally Ca/Al-silicates of hydrothermal origin. These minerals are prehnite and zeolites like thomso-

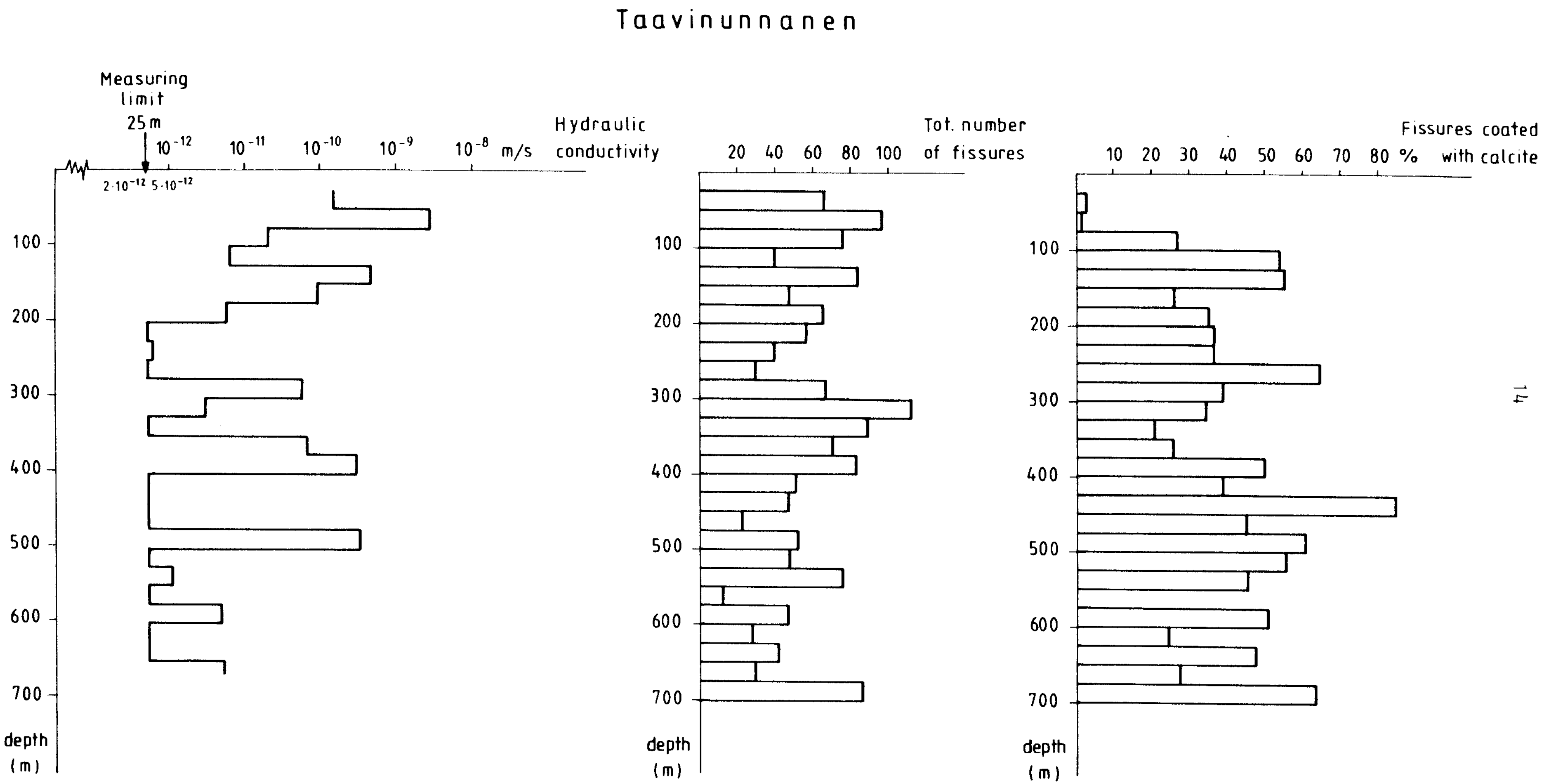


Fig. 11 Hydraulic conductivity, total number of fissures and fissures coated with calcite respectively versus depth.

nite, chabazite and stilbite. The paragenesis is different from what is found within fractures in the granite dikes. These are dominated by chlorite, calcite and quartz. In one sample also stilbite and synchysite was identified. (Synchysite is a calcium carbonate containing Ce and F). The conditions for formation of clay minerals of smectite type are more favorable in the gabbro than in the granite as reflected above.
In contrast to the composition of simple minerals like quartz and calcite, are chlorite and smectite very complex. These complex minerals are both Mg-Fe-Al-silicates. Chlorite types, in respect of Mg and Fe, as interpreted from XRD are shown in table 2. It is seen that chlorite from fissures in granite dikes are all of the Fe-type. However in the gabbro both Mg- and Fe-types are represented. This is in accordance with observations made during the thin section studies where several generations/types of chlorite were seen in gabbro fissures but only one type in granite fissures.

Zeolites identified are Ca-Na-Al-silicates with varying contents of H_2O. As shown in figure 12 stilbite and chabazite has got the highest water content, i.e. formed at relatively low temperatures. A recent study carried out in a geothermal field in Iceland (Kristmannsdottir & Thomason, 1978) shows that chabazite can be formed at temeratures below 70 deg C. The study also shows that thomsonite and stilbite will appear in the temperature ranges 70 to 110 deg C.

As already has been pointed out the Taavinunnanen massif is intersected by granite dikes having fractures with high hydraulic conductivities. Thus, it is interesting to show the differences in physical properties of filling minerals,in the granite and the gabbro respectively. Figure 13 shows the cation exchange capacities (Allard et al., 1983) for rock forming minerals within the granite and the gabbro respectively but also for some fracture filling minerals identified in both rock types. As can be seen in the figure, common fissure fillings in the gabbro like chlorite, smectite and zeolites (e.g. stilbite) show high cation exchange capacities. Calcite and quartz on the other hand show very low CEC. Rock forming minerals in the granite and gabbro show similar cation exchange capacities.

Table 1 Fissure filling minerals identified by XRD

Core length (m)	Fissure fillings in Gabbro	Fissure fillings in Granite
36.8	SC, Th	
56.4		St, Chl, Mu
60.5		Synchysite
64.6	Ch, St, Chl	
78.1	Pr, Chl, Ca	
95.7	Chl, SC	
123.5	Ch, SC	
140.9	Chl, SC	
156.1	Ch, Chl, SC, Ca	
181.1	Th, SC, Pr	
222.3	SC, Ch, Chl, Ca	
233.6	Chl, Pr, SC	
248.4	Chl, SC, Qz	
263.5	Chl, SC, Pr	
284.7	Chl, SC	
303.9		Ca, Qz
313.0		Ca, Chl, Qz
316.0	St, Chl, Qz	
336.6	Chl, Ca	
369.7	Chl, St, Ch	
383.7		Chl, Qz
387.1	St, Ch, Chl	
449.3	SC, Chl, Ca	
579.1	Chl, Pr, Ca	
604.8	Chl, SC, Ca	
654.0	SC, Chl, Pr	
680.9	Chl, SC	

Ca = Calcite

Chl = Chlorite

Pr = Prehnite

Ch = Chabazite

Th = Thomsonite

St = Stilbite

SC = Swelling clay minerals (mostly of smectite type).

Qz = Quartz

Mu = Muskovite-Illite

Table 2 "Chlorite type" as interpreted from XRD.

Sample	Chlorite type
Ta 56.4*	Fe
Ta 78.1	Fe
Ta 233.6	intermediate to Mg
Ta 248.4	Mg
Ta 263.5	intermediate
Ta 313.0*	Fe
Ta 316.5	intermediate
Ta 369.7	Fe
Ta 387.1*	Fe
Ta 519.1	Fe
Ta 604.8	intermediate

*) = fissure in granite dike

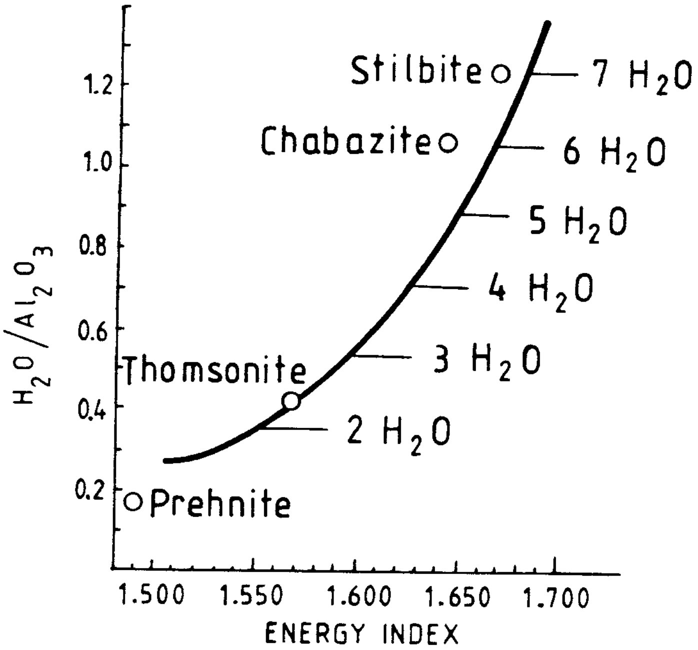
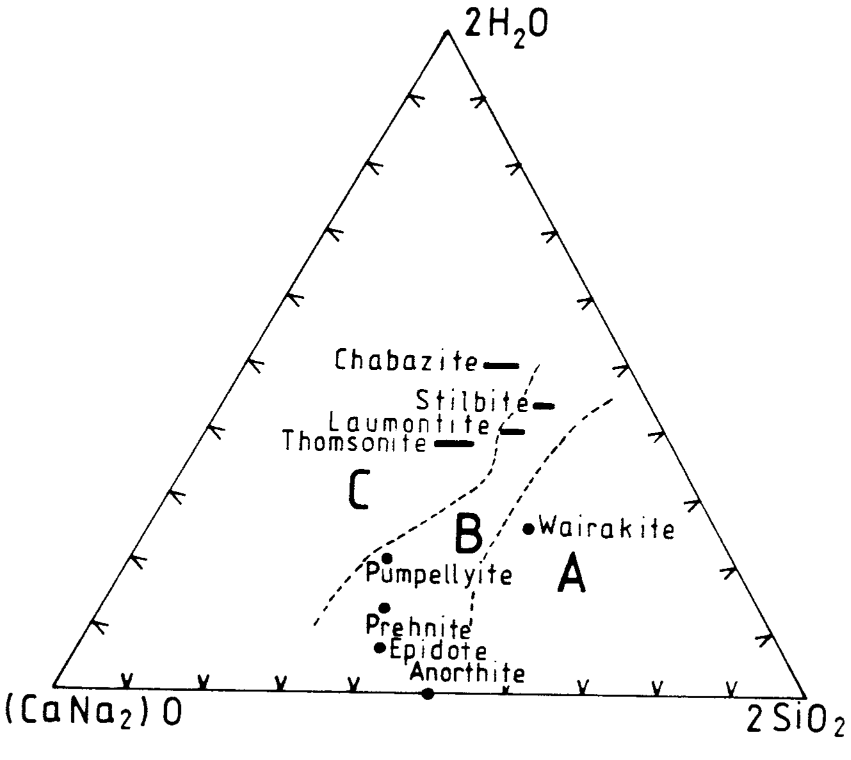


Fig. 12 a/ Energy index versus H_2O / Al_2O_3 for zeolites. The site for prehnite is also shown (Kostov, 1968).



b/ Composition in molecular proportions of calcium zeolites and other Ca-Al silicates. A = field of phases favoured by supersaturation with respect to silica. B = field of phases commonly coexisting with silica minerals. C = field of phases favoured by a silica-poor enviroment (Coombs et al., 1959)

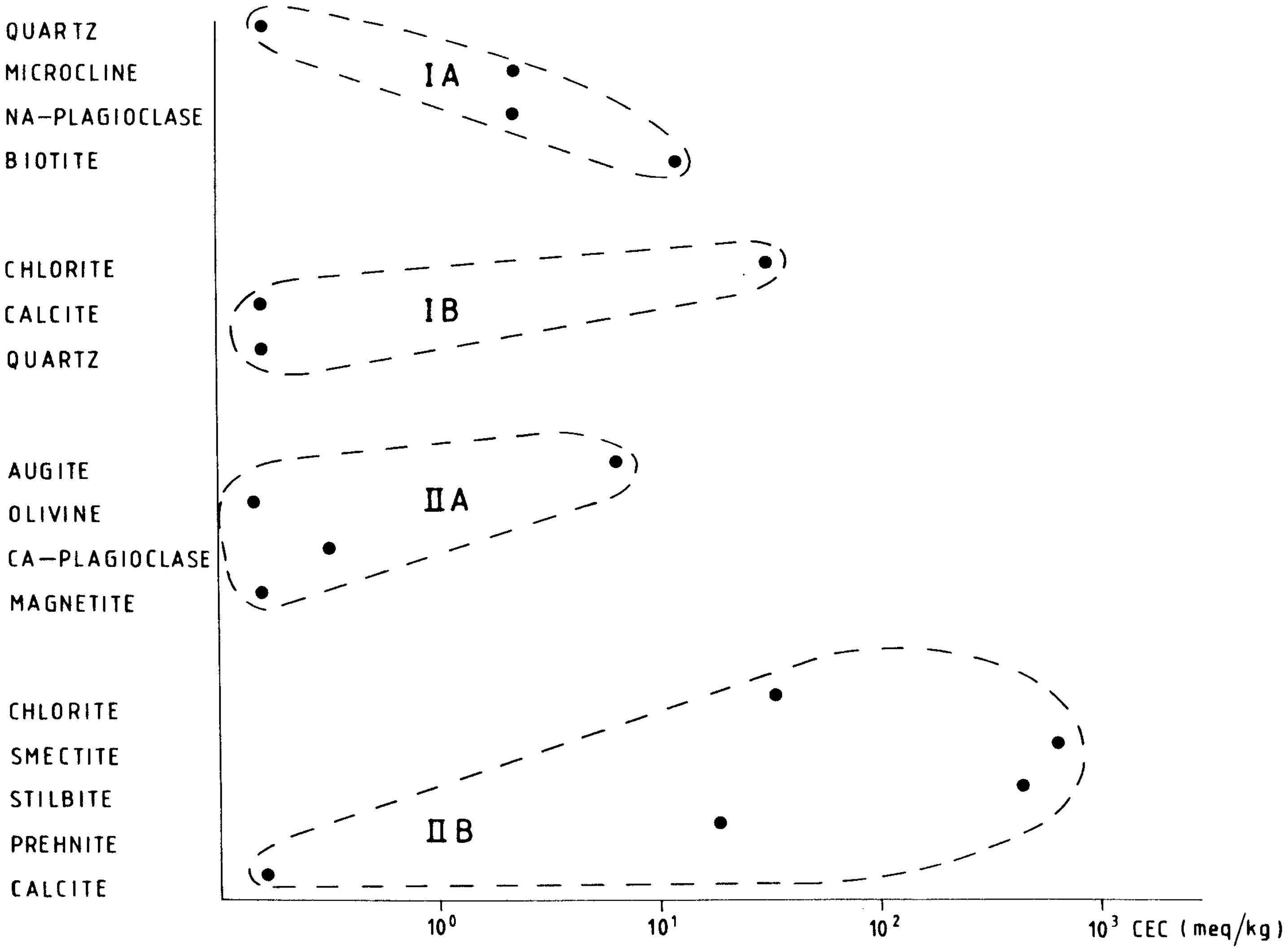


Fig. 13 Cation exchange capacities (CEC) for IA: rockforming minerals in granite, IB: common fissure fillings in granite, IIA: rockforming minerals in gabbro, IIB: common fissure fillings in gabbro.

3.3 Relative ages

The relative ages for fracture filling minerals have been interpreted from microscopy (table 3). It is shown that several generations of both calcite and chlorite are present. Some thin sections contain three generations of calcite within one single fracture. (Also two generations of prehnite have been observed in one of the thin sections). One of the calcite generations is cogenetic with prehnite and thus is precipitated from hydrothermal solutions. This generation of calcite is probably preceded by formation of chlorite and smectite. The zeolites have always been found to be younger than the cogenetic calcite-prehnite precipitate.

Some thin sections show microbreccias. These are only found in samples from the gabbro and are mostly sealed by calcite. The fracture fillings are much simpler and thinner in the granite than in the gabbro. It is assumed that fractures within the gabbro were filled with fracture minerals during several events before the intrusion of granite dikes (fig 14). The hydrothermal minerals (formed within the gabbro) are probably precipitated from deuteric solutions of the gabbro.

Very few fractures within the gabbro can be classified as unambiguous young fractures. In contrast, most fractures show considerable alteration zones. This does not exclude late reactivation of the fractures (cf. Henkel, 1983). However within the granite, potentially young fractures are present containing simple fillings of low temperature minerals and with no alteration of the wall rock. Reactivation and brecciation of fractures have not been observed in the granite.

Table 3 Fracture filling minerals and their relative ages as interpreted from microscopy.

Core length (m)	Ca	Chl	Ze	Pr	Qz	Ep	Clay minerals
31.0	1			1			
36.8			2^{Th}				1
*56.4		2			2		1,3
64.6		1	$2^{St,Ch}$				
78.1	1			1			2
87.5				1			
105.7	2	1					
123.5	2	1	2^{Ch}			1	2
140.9	2						1
*150.6	1						
156.1	2	1	2^{Ch}				1
181.1	2	1	3^{Th}	2			
191.8	1						
202.8	2			1			
222.3	1	1					1
233.6	2,3	1,2,3		2			
248.4	1	1			1		1
263.5	1	1		1			1
278.7	1	1					
*313.0	1	1					
316.5	1,4	2,3			1		
369.7	2	1	$2^{Ch,St}$				
*385.6	1						
387.1	1	1	$2^{Ch,St}$				
416.9	2	1		2	1		
480.5	1,2						
496.0	1,2,3						
519.1	2	1		2			
532.5	1		1^{Ch}		1		
*542.5	1						

Table 3 (continued)

Core length (m)	Ca	Chl	Ze	Pr	Qz	Ep	Clay minerals
*583.3	1	1					1
*583.5	1,2	2			1		2
604.6	1,2,3	3			3		
604.8	1,3	3			2		3
615.7	2			1			
634.7	2	1					
653.6	1,3			1,2			
654.0	1	1					
663.3	1,2,3		4^{St}	1,3 ev.			
683.6	1						

*) = fissure in granite dike
Ca = Calcite
Chl = Chlorite
Ze = Zeolite minerals
Pr = Prehnite
Qz = Quartz
Ep = Epidote
Ch = Chabazite
St = Stilbite
Th = Thomsonite

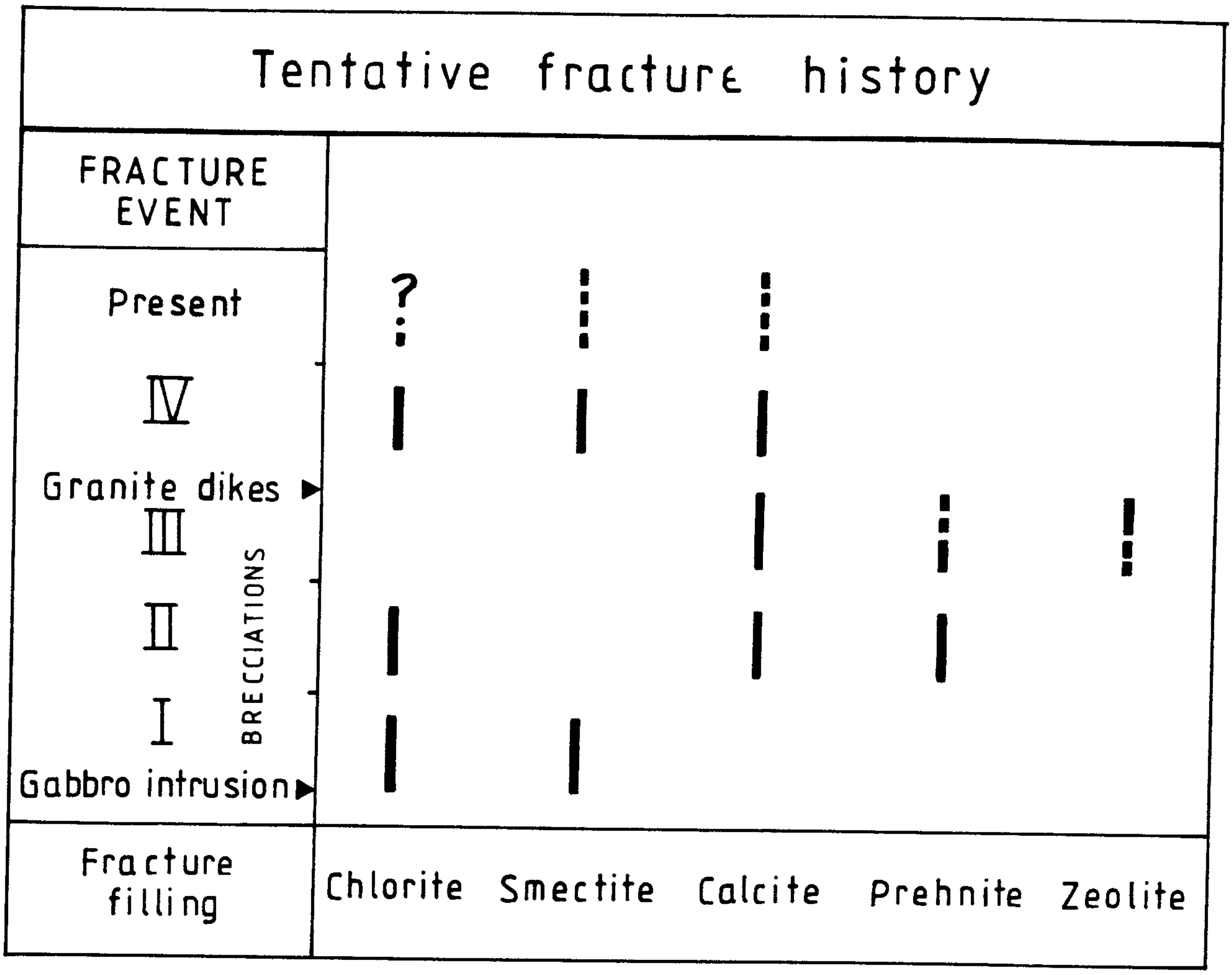


Fig. 14 Tentative fracture history at Taavinunnanen.

3.4 Chemistry

3.4.1 Stable isotopes

Twentyeight samples were analysed in respect of $\delta^{18}O$ and $\delta^{13}C$. The samples analysed were selected according to results obtained from the microscopy of thin sections. When several generations of calcite were found within one single fissure, attempts were made to separate these into different samples. Results from the analyses are shown in table 4.

It has been difficult to get sample volumes big enough for the stable isotope analyses, as most fissure fillings are thin and as the diameter of the core is only 42 mm. As has been shown in section 3.1, calcite as fissure filling is almost lacking in the upper part of the borehole. Thus, it has not been possible to get a sample volume of calcite sufficient enough in the upper 140 meters of the borehole. Open a well as originally sealed fractures have been sampled.

Figure 15 show analysed calcite fillings from sealed and open fissures in the gabbro as well as in the granite dikes. As can be seen fillings from sealed fissures have got lower $\delta^{18}O$ and less spread in $\delta^{13}C$ than coatings from open fissures. Several calcite fillings from sealed fissures are coprecipitated with hydrothermal minerals like prehnite, chlorite and to a lesser degree with zeolites. Thus at least one generation of calcite is considered as precipitated from hydrothermal solutions. This is in accordance with the results from other testsites (Tullborg & Larson 1982, 1983) investigated by KBS. Calcite from open fissures normally shows lower $\delta^{13}C$ than calcite from sealed fissures. When plotting $\delta^{13}C$ for calcite coatings from open fractures versus depth, there is a distinct minimum (-16.8 o/oo) at the 385 m level (fig.16). This minimum is also shown when plotting the same parameters for calcites from sealed fissures but it is much less evident (-10.2 o/oo). These calcite coatings exhibiting minima are common to those which are close to equilibrium with the estimated ground water compostion (cf. fig. 15). It is suggested that the 385 m level corresponds to a depth level where calcite saturation has been reached in the recharge water.

Table 4 Stable isotope analyses of calcites

Core length (m)	$\delta^{13}C$ o/oo (PDB)	$\delta^{18}O$ o/oo (PDB)	Open/Sealed
78.1	-4.6	-23.6	S
105.7	-3.14	-23.9	S
140.9	-5.3	-15.5	O?
150.6	-1.3	-18.1	S
156.1	-1.7	-17.6	S
191.8	-11.1	-12.0	O
202.8	-3.2	-18.7	O
248.4	-4.3	-18.6	S
278.7	-5.6	-18.9	S
303.9	-4.8	-21.5	O
313.0	-6.3	-18.4	S
316.5	-4.6	-24.5	S
369.7	-10.2	-16.2	S
385.6	-16.8	-13.2	O
480.5 I	-4.5	-20.9	S
480.5 II	-4.2	-19.0	S
496.2 I	-3.7	-19.7	S
496.2 II	-7.8	-14.6	O
532.5	-3.4	-22.8	S
542.5	-4.7	-20.7	O?
583.3	-7.5	-19.7	O
583.5 II	-8.0	-19.0	O
604.6 II	-3.4	-22.4	S
604.6 III	-3.7	-21.9	O
634.7	-3.7	-21.8	S
653.6 III	-3.1	-18.3	O
654.0	-2.7	-18.1	O
663.3	-3.0	-20.3	S
683.6	-3.7	-21.5	S

(I, II and III correspond to different generations of calcite following table 3).

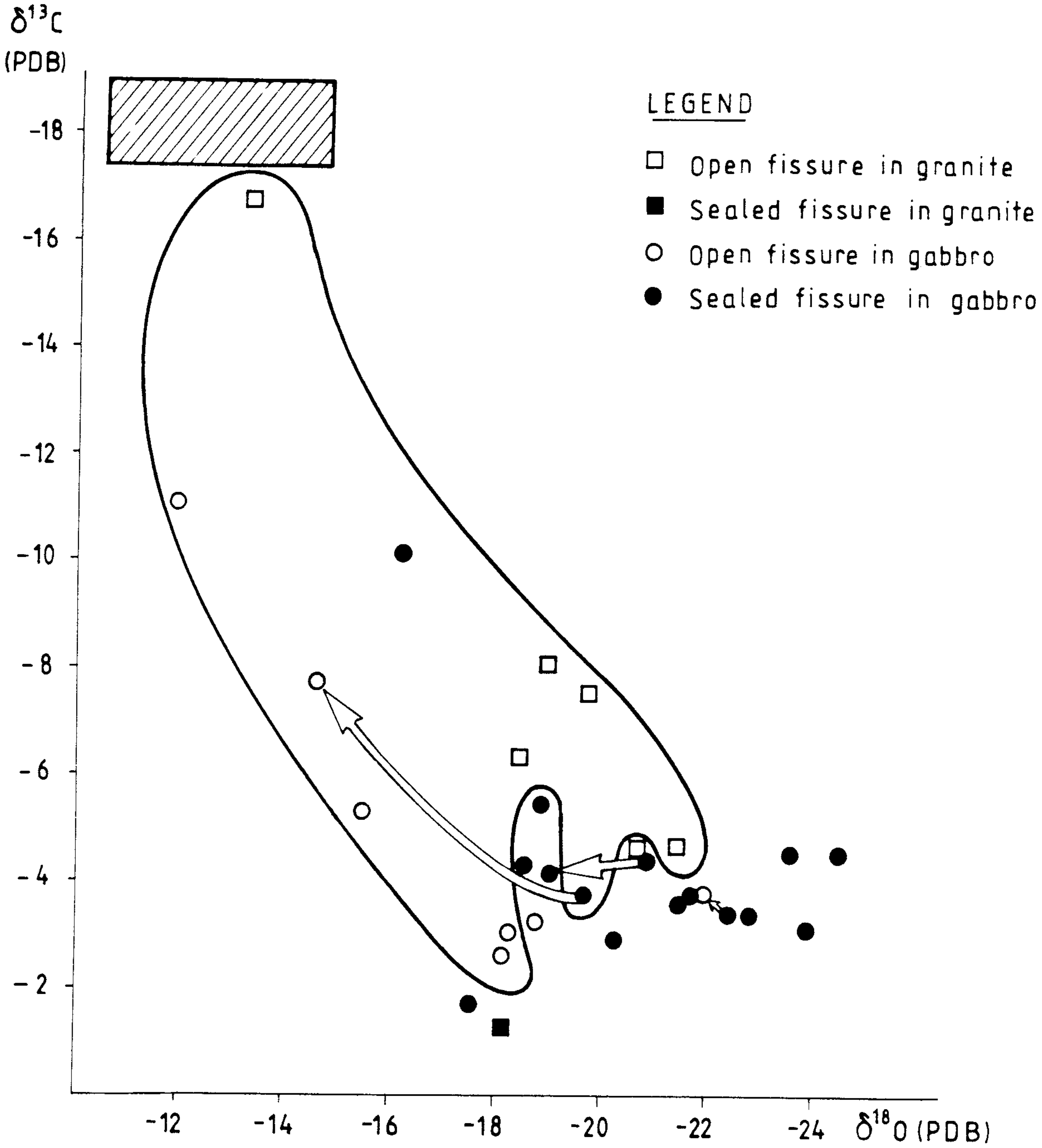


Fig. 15 $\delta^{13}C$ versus $\delta^{18}O$ (PDB). Ruled area represents composition of calcites precipitated from an estimated ground water composition (Tullborg & Winberg in prep). Encircled are calcites from borehole sections showing hydraulic conductivity > 1.9 x 10 exp -11 m/s. Arrows connect different calcite generations from single fissures.

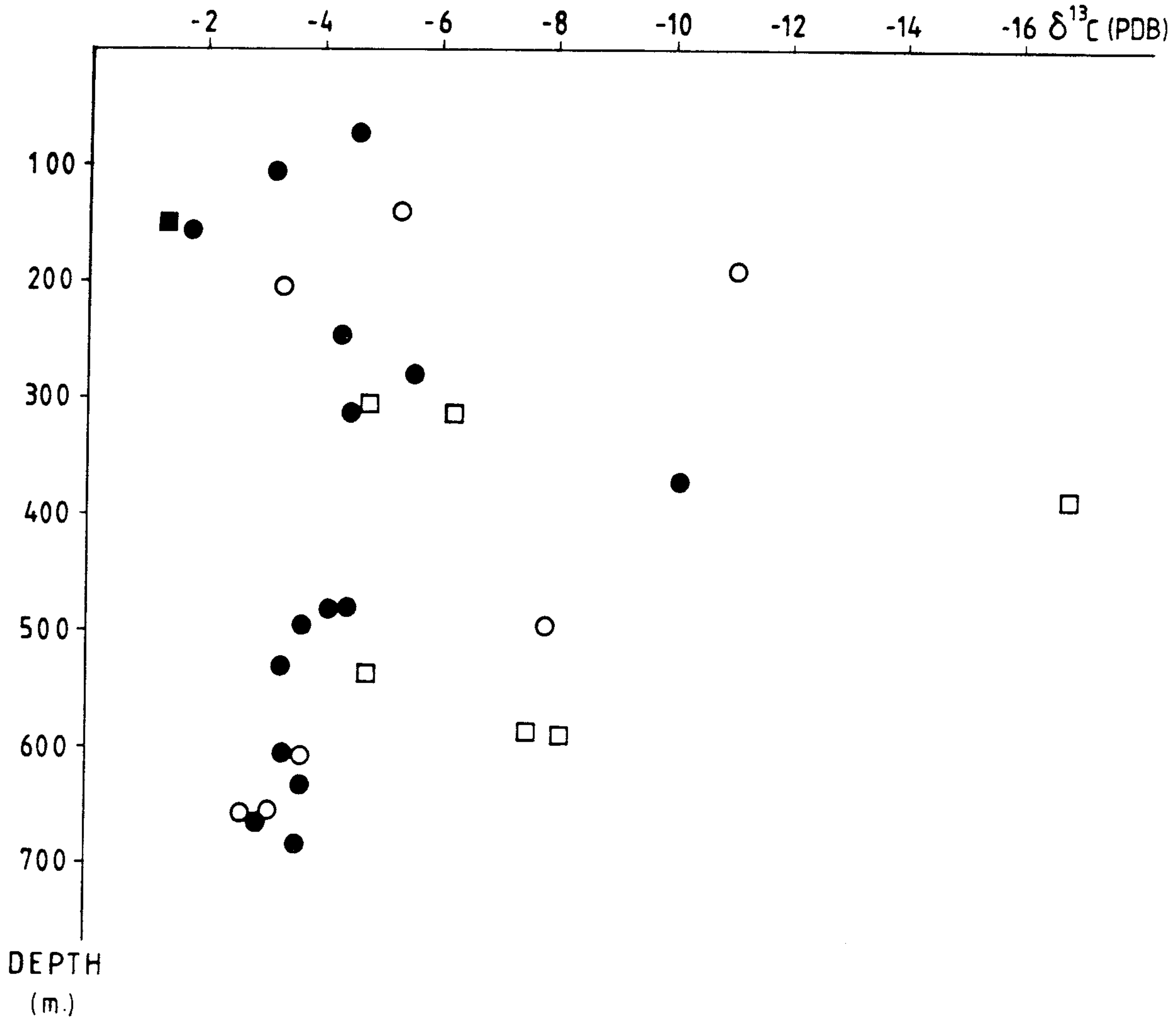


Fig. 16 $\delta^{13}C$ for calcite fissure fillings versus depth (symbols as in figure 15).

Corresponding minima for $\delta^{13}C$ in calcite have also been seen at other test sites.

Also water from the borehole has been analysed in respect of $\delta^{18}O$ and $\delta^{13}C$. This was made in order to see if the water present could has precipitated some of the calcite fillings analysed. Water from only two and one section respectively was analysed in respect of $\delta^{13}C$ and $\delta^{18}O$. The analyses yielded values of -18.7 o/oo and -21.2 o/oo $\delta^{13}C$ and -14.0 o/oo $\delta^{18}O$. If these vales are considered as representative for the rest of the borehole and if temperatures measured along the borehole (Albino, 1984) are used, calcite with a $\delta^{18}O$ of -10 to -11 o/oo should result. However most calcites from open fissures show a much lower $\delta^{18}O$. This is probably due to the fact that analysed water is not representative for the water precipitating calcite at Taavinunnanen. This conclusion is also strengthened by the chemical composition of analysed water (cf. Smellie, 1983).

The annual mean $\delta^{18}O$ for precipitation at Kiruna (35 km away from Taavinunnanen) is -15 o/oo. No measurements have been done at Taavinunannen. Two models have been used to calculate the annual mean $\delta^{18}O$ for precipitation at Taavinunnanen (Tullborg & Winberg, in progress). The results are different depending on what model is used. If the modified Dansgaard equation is applied (Burgman et al., 1983), i.e. an equation based on annual mean temperature, the result is -14.22 o/oo $\delta^{18}O$ SMOW. However, if the correction for longitude, latitude and altitude is used, a value of -17 o/oo is recorded. $\delta^{18}O$ for precipition and ground water is usually similar (Förstel & Hützen, 1983; Saxena 1984) therefore these values are used here to represent the ground water.

In figure 15 is shown a square representing the estimated composition of calcites precipitated from a ground water as calculated above using corrections for measured temperatures (Albino, 1984) in the borehole, and the fractionation factor given by Craig (1965) respectively. The $\delta^{13}C$ interval is constructed from waters analysed at two levels sampled, using the fractionation factor given by Emrich et al., (1970). These values seems reasonable to use as they are similar to what has been found for groundwaters at other places (e.g. Tullborg & Larson, 1983).

It is known that small amounts of the ground water will affect the $\delta^{18}O$ of calcite much easier than the $\delta^{13}C$ (Sverjensky, 1981). This is indicated in figure 15.

Most calcite from fractures in granite dikes have got lower $\delta^{13}C$ than calcite from fractures in the gabbro implying different influences from circulating waters. The area encircled in figure 15, includes calcites from sections showing measurable hydraulic conductivity. As can be seen the area is elongated towards the area representing calcites precipitated from present waters. The hydraulic tests normally show a higher permeability for the granite dikes than for the gabbro (Gentzschein, 1983). Thus, it is suspected that it is easier to find precipitations from present water within fissures in the granite dikes than in the gabbro.

Arrows in the figure connect two generations of calcite from one single fracture. The trend is always that the younger filling exhibits the highest $\delta^{18}O$, i.e. is more influenced by a modern water.

Figure 17 shows the $\delta^{18}O$ of calcite fillings versus depth. Calcites from sealed and open fissures in granite and gabbro have been plotted. The figure also shows calcites coprecipitated with prehnite and zeolites. It is evident that calcite coatings from open fissures generally have got high $\delta^{18}O$ values at shallow depths whereas calcite from sealed fissures show no such trend. This also implys a greater influence of present water at shallow depth. Coprecipitated prehnite is only found within sealed fissures. These calcites have got low $\delta^{18}O$ values. Calcites coprecipitated with zeolite mostly have got higher $\delta^{18}O$ values. This is in accordance with a cooling hydrothermal system. A similar trend is established at Finnsjön (Tullborg & Larson, 1982) where a great number of calcite fillings were analysed.

To sum up, it is concluded that several generations of calcite exists in fissures at Taavinunnanen. Calcites coprecipitated

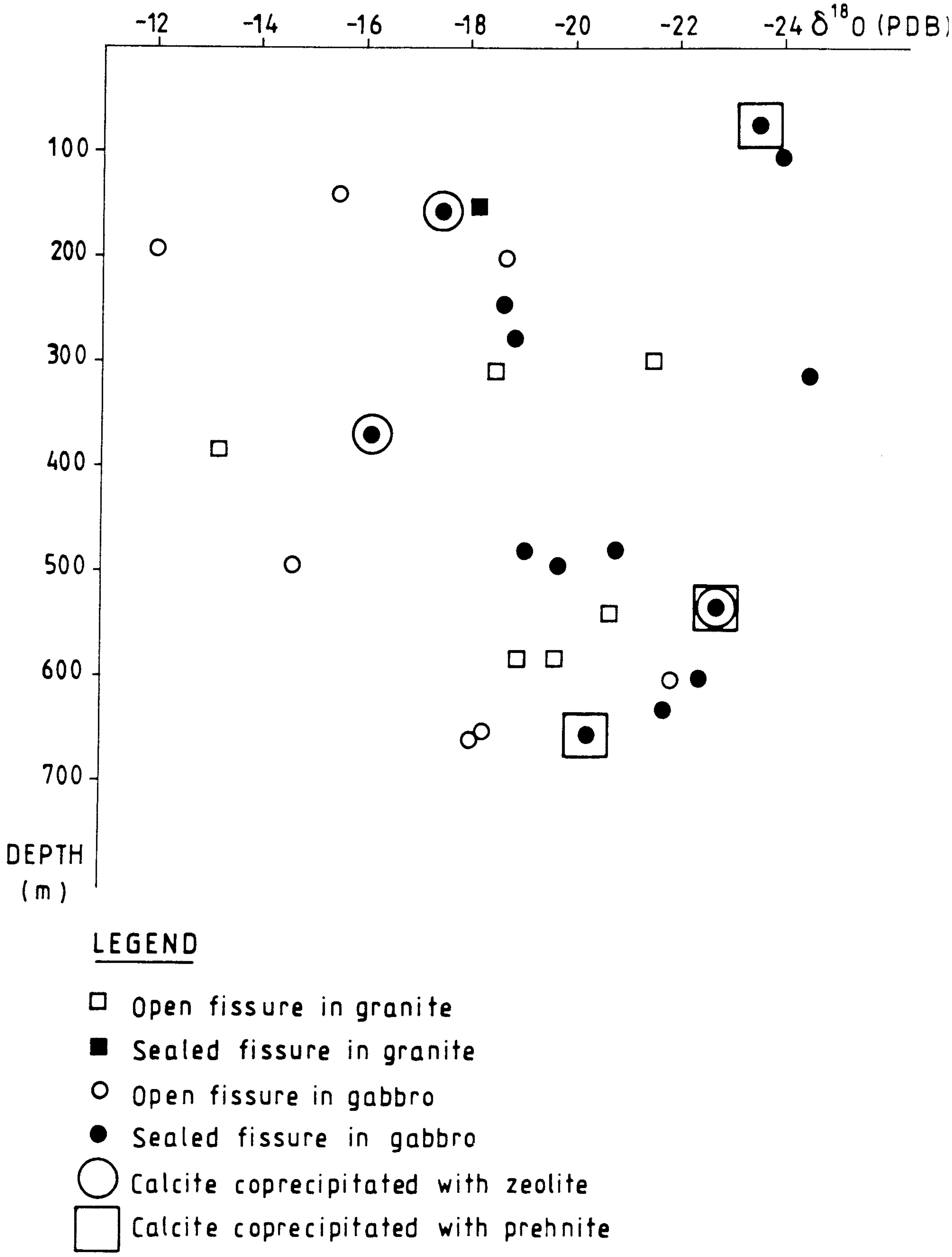


Fig. 17 $\delta^{18}O$ for calcite fissure fillings versus depth.

with prehnite and zeolites show the same imprint of stable isotopes as in Finnsjön. A distinct group of calcites with low $\delta^{18}O$ and relatively high delta $\delta^{13}C$ (ca -20 o/oo to -25 o/oo and -3 o/oo to -5 o/oo respectively) can be distinguished. Some of these calcites are coprecipitated with prehnite and have been sampled from sealed fissures. They have not been seriously influenced by later waters. This group of calcite was also distinguished at Finnsjön as precipitated from hydrothermal solutions (Tullborg & Larson, 1982). Most calcites from open fissures, especially those from sections with high hydraulic conductivity, show influence of a recharge water.

3.4.2 Microprobe analyses

Microprobe analyses have been carried out on three zeolite crystals and eight calcite crystals. The three zeolite minerals identified at the test site, stilbite, chabazite and thomsonite, are represented. All of them belong to the Ca-zeolite family. Results of the analyses are shown in table 5.

The stilbite and chabazite crystals analysed have been sampled from a single fissure (level 64.6 m). As can be seen, both of them show high contents of potassium. Concerning chabazite, this is in accordance with data presented by Breck (1974). He advocated that chabazite has a preference for large cations like K^+. A comparision between stilbite analyses from Gideå and Taavinunnanen show good similarities except for the potassium content. This is much higher in stilbite from Taavinunnanen (1.1 and <0.1 weight % respectively). The thomsonite sample contain more sodium than potassium and has got a CaO/Na_2O ratio of approx. 0.5. TiO_2, MgO, MnO and FeO contents are less than 0.05% in all of the zeolites analysed.

Calcite samples have been chosen to represent fillings from the granite dikes and the gabbro respectively. As it has also been shown that calcite samples from Taavinunnanen show a great spread in $\delta^{18}O$ and $\delta^{13}C$ it was interesting to find out if these could be distinguished chemically. As can be seen from table 6, no major differences where obtained. It is also seen that all calcites are relatively pure except for sample 532.5 which show higher contents of Fe, Mg and Mn than other calcites. Generally Taavinunnanen calcites show lower MgO and FeO contents than calcites from Gideå and Finnsjön (Tullborg & Larson 1982, 1983). This seems somewhat confusing as Mg and Fe should be more easily available within a gabbro than within a granitic terraine. As small cations will easily participate in ion exchange processes most Mg and Fe will be found in the clay minerals. Thus the apparent contradiction could be explained by a greater content of clay minerals as fissure fillings in Taavinunnanen in comparision to the other areas investigated.

Table 5 Microprobe analyses of zeolites. Contents are given in weight-%.

ample	SiO_2	Al_2O_3	CaO	Na_2O	K_2O
Stilbite (64.4)	61.3	17.7	8.6	0.5	1.1
Chabazite (64.4)	54.1	18.9	8.7	0.2	3.9
Thomsonite (181.1)	40.5	28.8	10.8	5.0	<0.1

Table 6 Microprobe analyses of calcite. Contents are given in weight-%.

Sample	CaO	MgO	MnO	FeO	SrO	BaO
78.1 (h)	56.38	0.13	<0.05	-	<0.05	<0.05
191.8	55.80	0.14	<0.05	-	<0.05	0.11
*385.6	55.46	0.14	<0.05	-	0.06	0.08
496.2 I (h)	56.32	0.15	0.06	<0.05	0.05	<0.05
496.2 II	56.15	0.15	0.06	<0.05	-	<0.05
532.5 (h)	54.81	0.51	0.22	0.51	<0.05	-
*583.5 II	56.08	0.15	0.16	<0.05	<0.05	0.07
653.6 III(h)	56.39	0.16	-	-	-	<0.05

(I, II and III correspond to different generations of calcite following table 3).

* = Fissure filling in granite dike

(h) = Calcite of hydrothermal origin verified isotopically.

4. Conclusion

The Taavinunnanen gabbro massif is a differentiated and composite gabbro intrusion (Larson et al., 1984). This means that the rock mass investigated is very inhomogeneous in respect of chemistry as well as physical properties. Thus, to describe the bedrock at the test site as a gabbro only, is not satisfactory as ultrabasic as well as gabbroic zones are present. It is more convenient to characterize the rock mass a layered gabbro intrusion intersected by granite dikes.

The fracture frequency varies mostly between 30 to 110 fissures / 25 metres section, with a raised frequency for the granite dikes. Most fissures are steep. However, an increased frequency of gently dipping fractures are recorded within sections showing more intense layering of the gabbro.

The upper part of the borehole shows the highest hydraulic conductivity as well as the lowest frequency of fissures coated with calcite. Fractures within granite dikes generally show a higher hydraulic conductivity than within the gabbro (Gentzschein, 1983). It is concluded that water will pass down to a depth of more than 200 metres before saturation in respect of calcite is reached. This is also reflected in the decreased $\delta^{13}C$ in calcites from open fractures at this level.

Dominating fracture fillings in the gabbro are chlorite, calcite and clay minerals. Less frequent are prehnite, thomsonite, chabazite and stilbite. In the granite chlorite, calcite and quartz are most frequent.

Several generations of fracture minerals can be seen. A tentative history of fracture fillings has been suggested. This is: gabbro intrusion followed by 1/ chlorite and smectite; 2/ chlorite, calcite and prehnite; 3/ calcite, prehnite and zeolites; during events 1-3 brecciation has taken place; Intrusion of granite dikes followed by 4/ chlorite, smectite and calcite; 5/ smectite, calcite (and chlorite ?) precipitation in progress.

A distinct group of calcite has been distinguished as precipitated during hydrothermal conditions. They are characterized by a high $\delta^{13}C$ (> -6 o/oo PDB) and low $\delta^{18}O$ (< -18 o/oo PDB). Some of these fillings showing very low $\delta^{18}O$ (< -20 o/oo PDB) and are coprecipitated with prehnite. Other calcite fillings have been influenced or precipitated by meteoric water of low temperature. These calcites are situated within sections corresponding to a high hydraulic conductivity. Equilibrium is not established between calcite fillings and water analysed. This probably means that the water analysed is not representativ for the ground water at sampled levels.

To sum up, the results here reported show that Taavinunnanen is a typical recharge area with an indicated rapid downward transport of surface water mainly through fractures within granite dikes. Most fractures in the gabbro originated very early during the geological history. However, some of the fractures in the granite dikes are potentially young. Repeated reactivations of fractures have occured.

REFERENCES

Ahlbom, K., Henkel, H., Scherman, S., and Tirén, S. 1980: Rekognoserande studier för typområden i mellersta och norra Norrland under 1979 - 1980. Rapport PRAV 4.22

Ahlbom, K., Larson, S.Å. and Olkiewicz, A. 1982: Borrkärne- och ytkarteringsresultat från Taavinunnanen gabbron. SKBF/KBS AR 82-55.

Ahlbom, K. and Olkiewicz, A. 1981: Rekognoserande studier för typområden i Västernorrlands och Norrbottens län, 1980 - 1981. Rapport PRAV 4.31.

Albino, B. 1984: Borrhålsgeofysiska undersökningar och parametermätningar från borrhålet i Taavinunnanen. Swedish Geological, internal report.

Allard, B., Karlsson, M., Tullborg, E-L. and Larson, S.Å. 1983: Ion exchange capacities and surface areas of some major components and common fissure filling minerals of igneous rocks. SKBF/KBS, Technical Report 83-64.

Ambros, M. 1980: Beskrivning till berggrundskartorna NV, NO, SV, SO och Karesuando SV och SO. Sveriges Geologiska Undersökning. Af 25-30.

Breck, D. W. 1974: Zeolite Molecular Sieves. Wiley Interscience, New York.

Burgman,J. O., Eriksson, E. and Westman, F. 1983: A study of oxygen-18 variations in river waters and monthly precipitation in Sweden and determination of mean residence times. Laboratory of massspectrometry, Division of Hydrology, Department of Physical Geography, University of Uppsala, Sweden, 1983.

Bååth, M. 1983: Earthquake Data Analyses. An example from Sweden. Earth Science Reviews 19, 181-303. Elsevier Science Publishers.

Craig, H. 1965: The measurments of oxygen isotope paleotemperatures, in Tongiorgi, E., ed., Stable isotopes in Oceanographic studies and paleotemperatures: Pisa, Consiglio Nazionale delle Ricerche Laboratorio di Geologia Nucleare, 161-182.

Deer, W.A., Howie, R.A., and Zussman, J. 1963: Rockforming minerals. Vol 4. Framework silicates. W. Clowes & sons, Limited, London and Beccles.

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

Eriksson, B. and Hallgren, U. 1975: Beskrivning till berggrundskartbladet Vittangi NV, NO, SV, SO. Sveriges Geologiska Undersökning. Af 13-16, 1-203.

Förstel, H. and Hützen, H. 1983: Paleoclimates and paleowaters: A collection of enviromental isotope studies. International Atomic Energi Agency, Vienna.

Gentzschein, B. 1983: Hydrogeologiska undersökningar i Taavinunnanen gabbron. Swedish geological, internal report.

Gulson, B.L. 1972: The precambrian Geochronology of granitic rocks from northern Sweden. Geologiska föreningen i Stockholms förhandlingar, 94, 229-244.

Hallgren, U. 1979: Berggrundskartorna Soppero NV, NO, SV, SO. Sveriges Geologiska Undersökning. Af 31-34.

Henkel, H. 1981: Stora gabbro intrusioner i norra Sverige. Kompletterad version. Sveriges Geologiska Undersökning, Sektionen för regionalgeofysik. Rapport 8110. 44-51.

Henkel, H., Hult, K. and Eriksson, L. 1983: Neotectonics in northern Sweden - geophysical investigations. SKBF/KBS Technical Report 83-57.

Kostov, I. 1968: Mineralogy. Oliver & Boyd, Edinburgh and London.

Kristmannsdottir, H. and Tomasson, J. 1978: in Natural zeolites. Ocurrence, properties, use. Eds.: Sand, L. B. and Mumton, F.A. Pergamon Press, Oxford.

Larson, S.Å., Olkiewicz, A., Ahlbom, K. and Ålinder, C. 1984: Geologiska föreningen i Stockholms förhandlingar 106 (2).

Leijon, B. 1981: Bergspänningsmätningar i LKAB:s gruvor 1979 - 1980. Avdelningen för Bergmekanik. Högskolan i Luleå. Tr 1981: 67 T

Saxena, R.K. 1984: Surface and groundwater mixing and identification of local recharge - discharge zones from seasonal fluctuations of 18 O in groundwater in fissured rock. Division of Hydrology, University of Uppsala.

Smellie, J. A.T. 1983: Groundwater pump flow-rate and it´s effect on some physico-chemical parameters - A controlled experiment carried out at Taavinunnanen. SKBF/KBS. AR. 83-45.

Sverjensky, D.A. 1981: Isotopic alteration of carbonate host rock ratio - an example from the upper Mississippi Valley zinc - lead district. Econ. Geol. 76. 154-172.

Tullborg, E-L and Larson, S.Å. 1982: Fissure fillings from Finnsjön and Studsvik, Sweden. Identification, chemistry and dating. SKBF/KBS, Technical Report 82-20.

Tullborg, E-L and Larson, S.Å. 1983: Fissure fillings from Gideå, central Sweden. SKBF/KBS Technical Report 83-74.

Welin, E. 1970: Den Svekofenniska orogena zonen i norra Sverige - En preliminär diskussion. Geologiska föreningen i Stockholms förhandligar 92, 433 - 451.

List of KBS's Technical 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.

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

1984
TR 84–01
Radionuclide transport in a single fissure
A laboratory study of Am, Np and Tc
Trygve E Eriksen
Royal Institute of Technology
Stockholm, Sweden 1984-01-20

TR 84-02
Radiolysis of concrete
Hilbert Christensen
Studsvik Energiteknik AB,
Nyköping, Sweden
Erling Bjergbakke
Risö National Laboratory,
Roskilde, Denmark 1984-03-16

TR 84-03
Effect of β-radiolysis on the products from α-radiolysis of ground water
Hilbert Christensen
Studsvik Energiteknik AB,
Nyköping, Sweden
Erling Bjergbakke
Risö National Laboratory
Roskilde, Denmark
1984-07-10

TR 84—04
Analysis of some laboratory tracer runs in natural fissures
Luis Moreno
Ivars Neretnieks
The Royal Institute of Technology
Department of Chemical Engineering
Trygve Eriksen
The Royal Institute of Technology
Department of Nuclear Chemistry
Stockholm, Sweden 1984-03-15

TR 84—05
Diffusion in clay—Experimental techniques and theoretical models
Trygve Eriksen
Royal Institute of Technology, Stockholm
Arvid Jacobsson
University of Luleå, Luleå
Sweden 1984-06-28

TR 84—06
Uranium series disequilibrium studies of drillcore Km3 from the Kamlunge test-site, northern Sweden
John AT Smellie
Swedish Geological
Luleå, Sweden 1984-03-30

TR 84—07
Study of strontium and cesium migration in fractured crystalline rock
Erik Gustafsson
Carl-Erik Klockars
Swedish Geological Co
Uppsala, Sweden 1984-09-28