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The Taavinunnanen gabbro massif. A compilation of results from geological, geophysical and hydrogeological investigations.

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Swedish Geological Company

Uppsala, January 1985

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THE TAAVINUNNANEN GABBRO MASSIF

A compilation of results from geological, geophysical and hydrogeological investigations

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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 SKB.

ABSTRACT

The gabbro massif at Taavinunnanen, northern Sweden, is one of the study sites which has been investigated by the Swedish Nuclear Fuel and Waste Management Co (SKB) in order to study different geological environments within the scope of the long-range program for final disposal of spent nuclear fuel.

A 700 metres long borehole was drilled within the gabbro. Regional geophysics, geological mapping, petrographical studies, mineralogical studies of rock-forming minerals and of fracture fillings as well as hydrogeological tests were carried out.

The gabbro shows primary differentiation. Thus, the composition varies from gabbroic to ultrabasic.

The gabbro body is intersected by several granite dikes. These dikes exhibit a higher hydraulic conductivity and a higher fracture frequency than the gabbro.

Comparison of hydraulic conductivity and fracture frequency in the gabbro itself indicates a high degree of sealing of the fractures mainly caused by smectites.

Calcite is almost lacking down to a depth of 75 metres, indicating a relatively rapid transport of surface waters down to this depth.

CONTENT

SUMMARY

The gabbro massif at Taavinunnanen, northern Sweden, is one of the study sites which has been investigated by the Swedish Nuclear Fuel and Waste Management Co (SKB) in order to study different geological environments within the scope of the long-range program for final disposal of spent nuclear fuel.

One 700 metres long borehole (inclination 85^{0}) was drilled. Regional geophysics, geological mapping, petrophysical studies, mineralogical studies of rockforming minerals and of fracture fillings as well as hydrogeological tests were carried out.

The major part of the drill core represents a differentiated gabbro which exhibits rhythmic layering. The composition varies from ultrabasic to gabbroic. Clinopyroxene is the dominating mafic mineral. Other major minerals are plagioclase, olivine, magnetite and sporadically also orthopyroxene. Approximately 8% of the drill core consists of aplite and granite dikes. A lopolitic shape is suggested for the Taavinunnanen gabbro massif.

A higher fracture frequency has been observed in the granite than in the gabbro. A complete orientation of the fractures intersecting the borehole has not been obtained as the core is unorientated but a dominance of steep fractures is evident all along the borehole. Generally, no regional tectonic zones have been observed intersecting the gabbro massif.

Dominating fracture fillings in the gabbro are chlorite, calcite and smectites. Prehnite and zeolites are also present. In the granite dikes chlorite, calcite and quartz are dominating fillings. A higher degree of sealing of the fractures in the gabbro gives lower hydraulic conductivities than within the granite dikes. Calcite is almost lacking down to a depth of 75 metres, and rust has been mapped down to an approximate depth of 100 metres, indicating a relatively rapid transport of surface water down to this depth.

1. INTRODUCTION

1.1 Background

The gabbro massif at Taavinunnanen (Fig. 1) is one of the study sites which has been investigated by SKB within the scope of the long-range research program for final disposal of spent nuclear fuel. One 700 metres deep borehole was drilled in order to obtain better knowledge of mafic rocks regarding geological, geophysical and hydrogeological conditions at great depths. The investigations were initiated during the summer 1981 and were ended during the summer 1983.

1.2 Reporting of results

The present report constitutes a summary and evaluation of data from the Taavinunnanen test site. The results obtained are accounted for in detail in the following reports and papers:

- Ahlbom, K., Henkel, H., Scherman, S. and Tirén, S., 1980: Rekognoserande studier for typområden i mellersta och norra Norrland under 1979-1980. Rapport PRAV 4.22. Available in Swedish only.
  The report comprises a short presentation of the geography of the site, an aeromagnetic map, a gravity map and results of petrographical studies performed on the Taavinunnanen gabbro body.

- Ahlbom, K. and Olkiewicz, A., 1981: Rekognoserande studier för typområden i Västernorrlands och Norrbottens län under 1980-1981. Rapport PRAV 4.31. Available in Swedish only.
  The report gives a short review of the geology of the area, the fracture frequency and the strike of fractures and fracture zones.

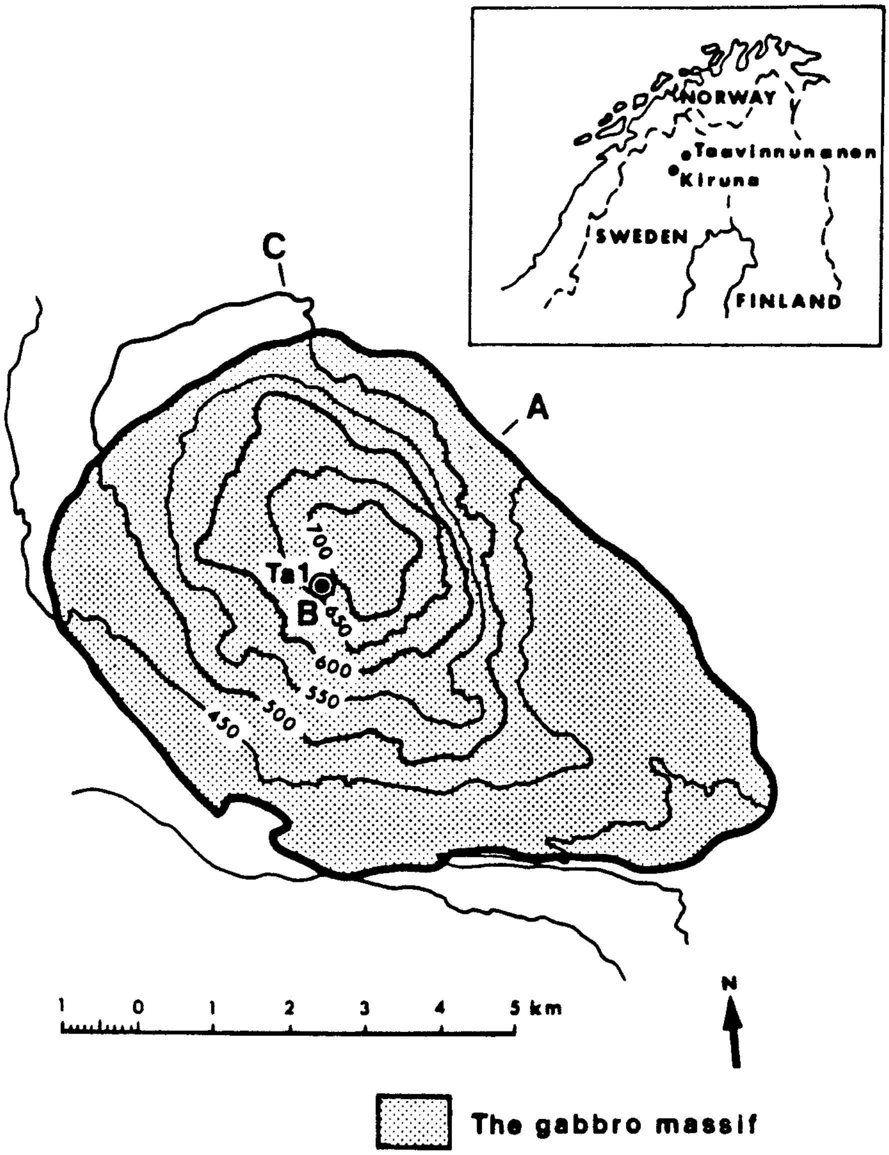


Fig. 1 Location of the study site.
A, B and C correspond to figure 5.

- Henkel, H.,1981: Stora gabbro-intrusioner i norra Sverige. Kompletterad version. Internal report, SGU. ID-nr 8110. Available in Swedish only.
  The report accounts for the geophysical as well as the petrophysical properties of i.a. the Taavinunnanen gabbro.

- Ahlbom, K., Larson, S. Å. and Olkiewicz, A., 1982: Borrkärne- och ytkarterings-resultat från Taavinunnanengabbron. Arbets-rapport, SGAB. Available in Swedish only.
  The report accounts for the geological information obtained from surface- as well as core-mapping. Whole rock as well as mineral analyses are presented.

- Gentzschein, B., 1983: Hydrogeologiska undersökningar i Taavinunnanen gabbron. SKBF/KBS AR. 84-25. Available in Swedish only.
  The report presents results from the hydrogeological investi-gations carried out in the 700 metres deep borehole at Taavi-nunnanen.

- Smellie, J. A. T., 1983: Ground water pump flow-rate and its effect on some physico-chemical parameters - a controlled experiment carried out at Taavinunnanen, Norrbotten. SKBF/KBS. AR. 83-45

- Albino, B., 1984: Borrhålsgeofysiska undersökningar och para-metermätningar från borrhålet i Taavinunnanen. Internal report, SGAB. ID-nr 84014. Available in Swedish only.
  The report presents results from geophysical measurements carried out in the borehole at Taavinunnanen.

- Larson, S. Å., Olkiewicz, A., Ahlbom, K. and Ålinder, C., 1984: A tentative model of the Taavinunnanen gabbro - results from a core-drilling. Geologiska föreningen i Stockholm för-handlingar, Vol. 106. Pt 2.
  The paper presents mineral analyses from the Taavinunnanen drillcore. A model of the gabbro body is suggested.

- Larson, S. Å. and Tullborg, E-L., 1984: Fracture fillings in the gabbro massif of Taavinunnanen, northern Sweden. SKBF/KBS TR 84-08.
  The report presents identification, chemistry and frequency of fillings from fractures within the drill-core at Taavinunnanen.

- Ruth, T., 1984: Equilibrium calculations for water-mineral interactions at the Taavinunnanen test site. SGAB, Internal report 84001.

1.3 Selection of the study site

During the period up to 1980 only granitoids were investigated as potential repository sites. The reason for studying a gabbro intrusive was some properties of this rocktype considered favourable for a final disposal of radioactive waste, like e.g. competency and rock chemistry.

For selection of a suitable study site the following criteria have to be fullfilled:

- the gabbro area have to be at least 4 square km
- the gabbro intrusion must be at least 1 km thick
- a high frequency of outcrops
- as few fracture zones as possible should penetrate the gabbro body

Of the gabbro massifs studied, the Taavinunnanen gabbro was considered the most favourable in respect of these criteria.

2. LOCATION OF THE STUDY SITE

The Taavinunnanen study site is situated approximately 170 kilometres north of the arctic circle, 35 kilometres ENE of Kiruna, (topographical map sheet 30 K Soppero). The massif can not be reached by car as there is 10 kilometres to the closest road. The gabbro massif constitutes a hill reaching above the timber line with the top at 780 m.a.s.l. The topography of the gabbro area which covers approximately 50 km^2 is shown in figure 1.

The last landice moved to the northeast in the area and the erosion resulted in a gentle slope on the SW side of the hill and a steep and rough slope on the NE side of the hill. Outcropping rock is mainly encountered on the NE side and on the top of the hill. However, most of the gabbro is covered by till. The overburden reaches a depth of 17.5 metres at the drill site.

The estimated water balance for the area, based on long-term data from three meteorological stations in the vicinity of Taavinunnanen, is: precipitation (760-875 mm/year), snow (430-520 mm/year), evaporation (200 mm/year), run off (560-675 mm/year).

3. GEOLOGY

3.1 Regional geology

The Proterozoic Taavinunnanen gabbro is included in "the younger series of deep seated rocks" according to Hallgren (1979). This series consists of the pegmatite, aplite, granite, perthite-monzonite, syenite, gabbro and anorthosite (Ambros,1980), and is regarded as the last major plutonic event within the mapped area (Fig. 2). Components of the series are considered to be approximatly 1.5 Ga (Welin, 1970; Gulson, 1972). Older rocks on the map sheet are i.a. quartzites, the Haparanda series (quartz, diorite, granodiorite, monzonite and gabbro-diorite) and metadiabase. Oldest rocks are quartzite, limestone, basalt, tuffite and tuff. A granitic basement has been found.

Mapping within the map sheet 30 K 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 gravity and aeromagnetic maps compiled by the Geological Survey of Sweden (Fig 3a, b) a complex composition is indicated for several 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 however likely that these data show characteristic features common to several circular gabbro bodies in northern Sweden.

3.2 The Taavinunnanen massif

The major part of the drill core represents a differentiated gabbro. The composition varies from pyroxenitic to gabbroic types due to a rhythmic layering as well as multiple magma intrusions. The thickness of the layers varies from some millimetres to several tens of metres.

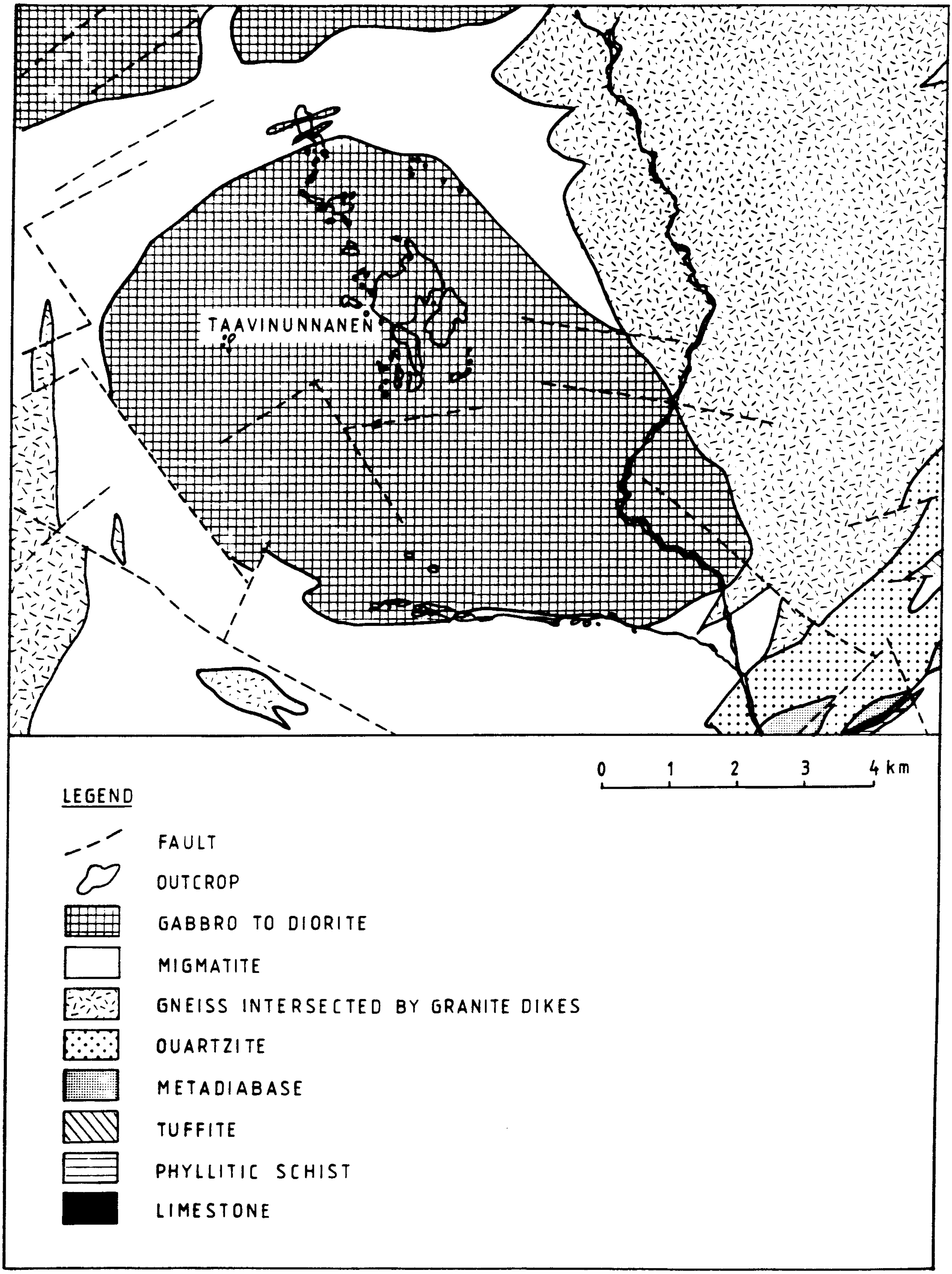


Fig. 2 Petrographical map according to Hallgren (1979).

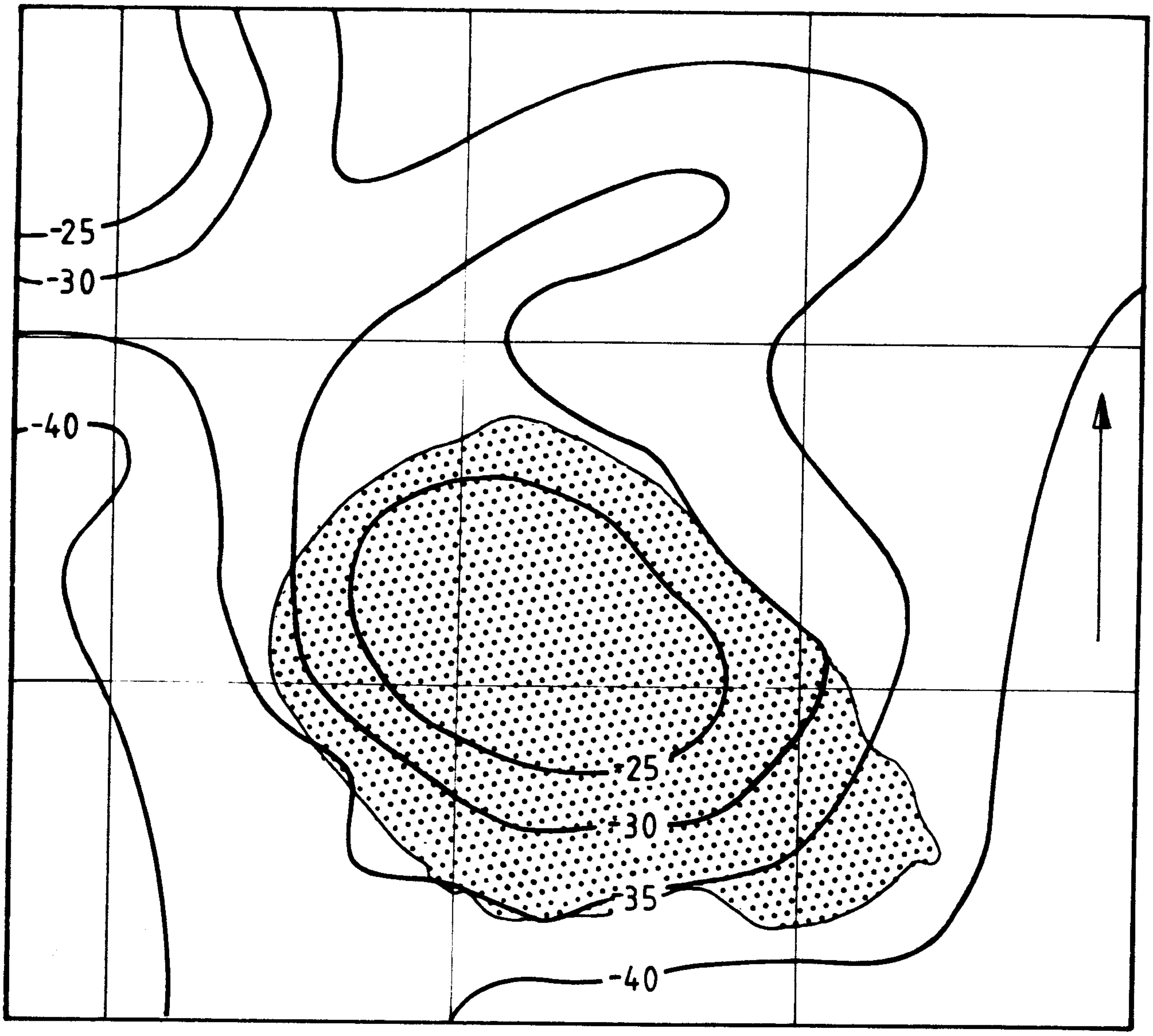


Fig. 3a) Gravity map of the Taavinunnanen area. Pointed area corresponding to the extension of the gabbro. Contour lines in mgal.

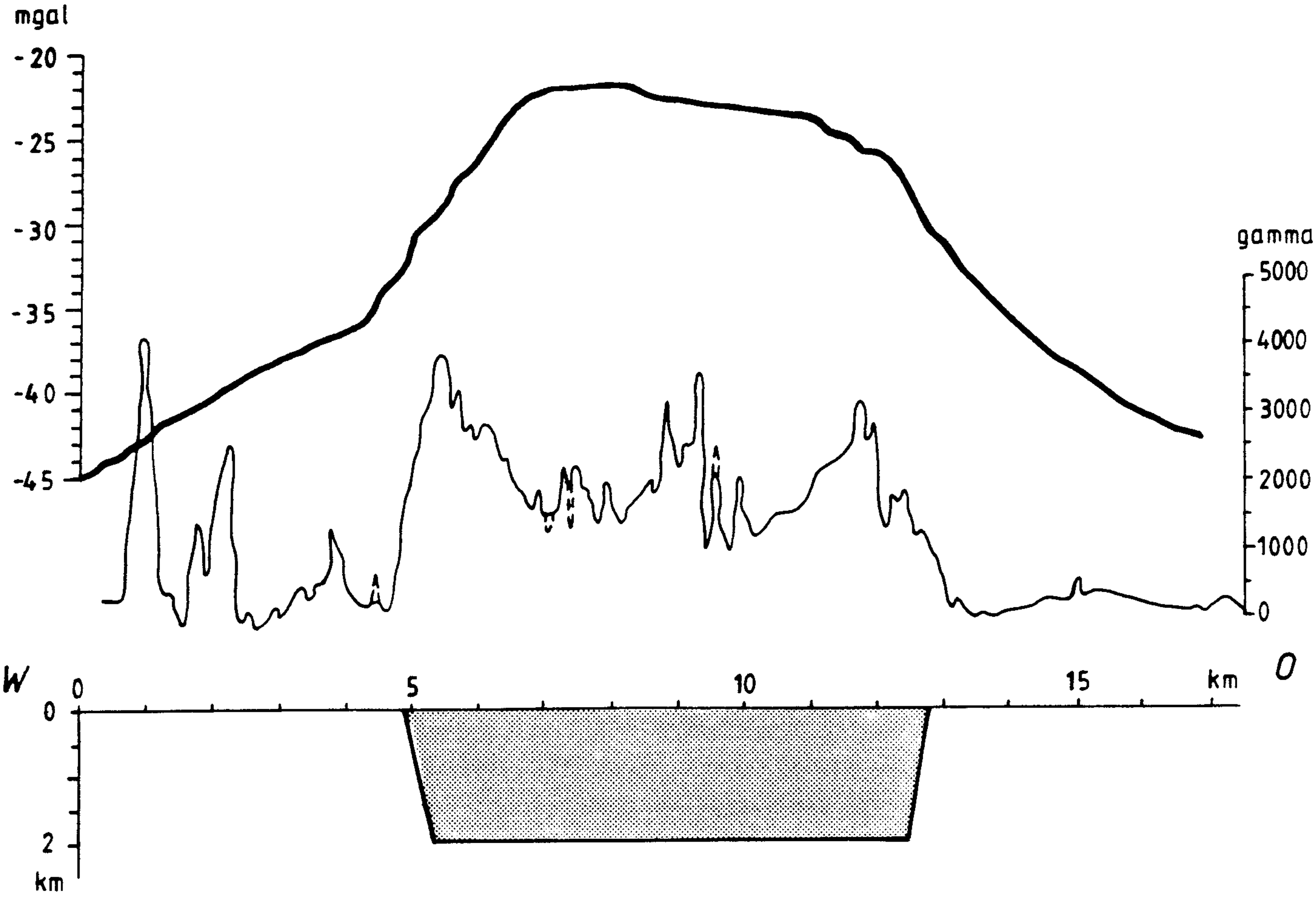


Fig. 3b) W-E profile over the Taavinunnannen massif showing the gravity field (upper graph) and the magnetic field (lower graph) as well as a rough model of the depth extension of the massif.

Approximately 8 % of the drillcore consists of aplite and granite dikes. Some solitary thin basic dikes are also present (Fig. 4).

A lopolitic shape is suggested for the Taavinunnanen gabbro (Fig. 5). Thus the layers dip 10-40 deg. towards the central part of the massif. The major components are plagioclase (0-75%), clinopyroxene (0-90%), olivine (0-30%) and magnetite (0-20%). Sporadically orthopyroxene is encountered. However, mostly it is formed as a secondary mineral and with a low frequency. Secondary mineral alteration is found in connection with fractured sections. Clinopyroxene is the dominating mafic mineral in the gabbro. High density samples mostly correspond to a high content of magnetite (Fig. 6a). Most cumulus minerals show adcumulus growth. A plagioclase lamination is mostly distinct within the lower part of the core.

Analyses of samples from the core indicate a tholeiitic character of the magma. Mineral analyses gives a great variation in the forsterite content of olivine, in the enstatite content of augite and in the anorthite content of plagioclase (Fig.6).

In conclusion the data presented suggest that the Taavinunnanen is a lopolithic gabbro intrusion showing primary mineral contents and textures. It has suffered secondary alteration commonly restricted to fractures and fracture zones. Contents of element considered to be of economic interest have not been found.

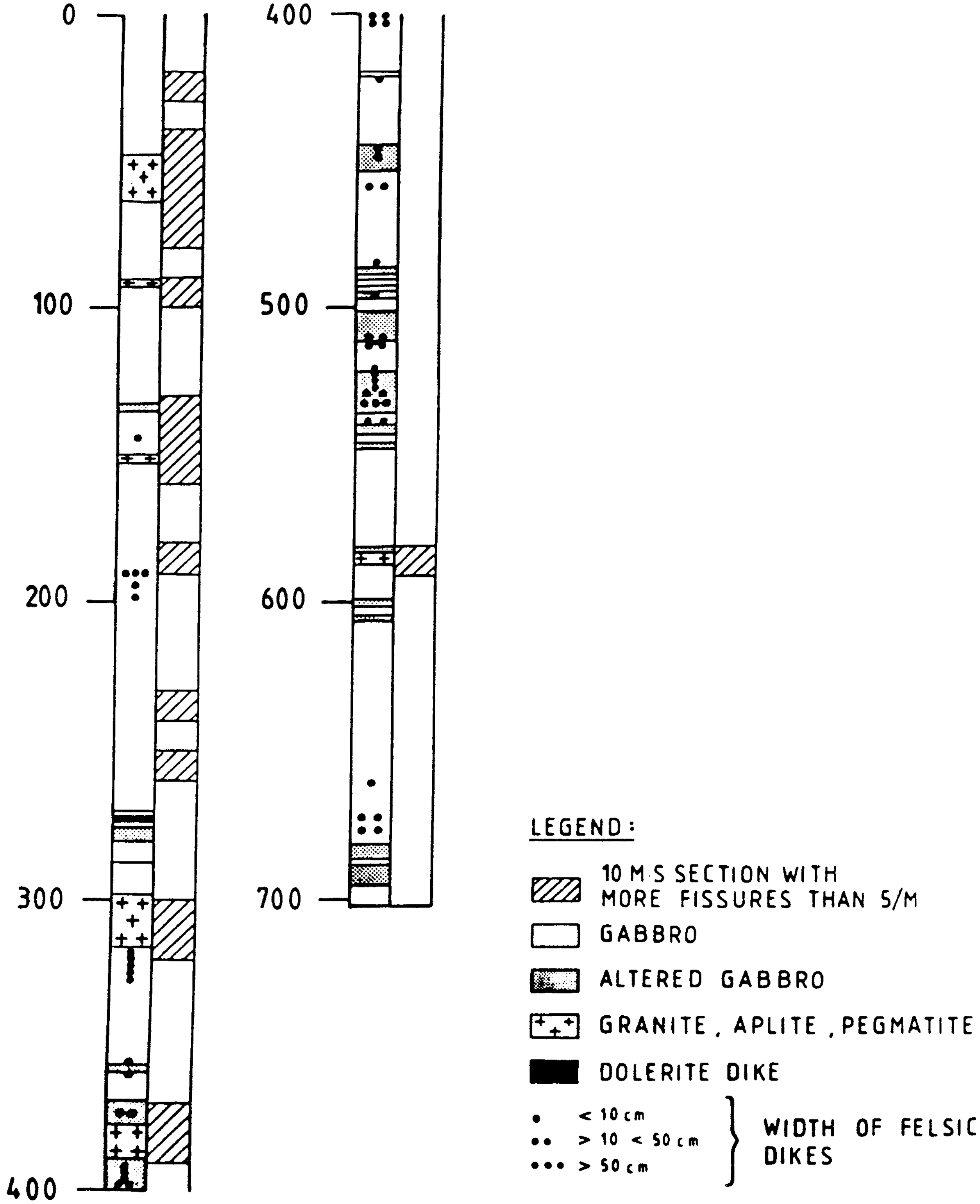


Fig. 4 Simplified core log of the borehole Ta 1 at Taavinunnanen.

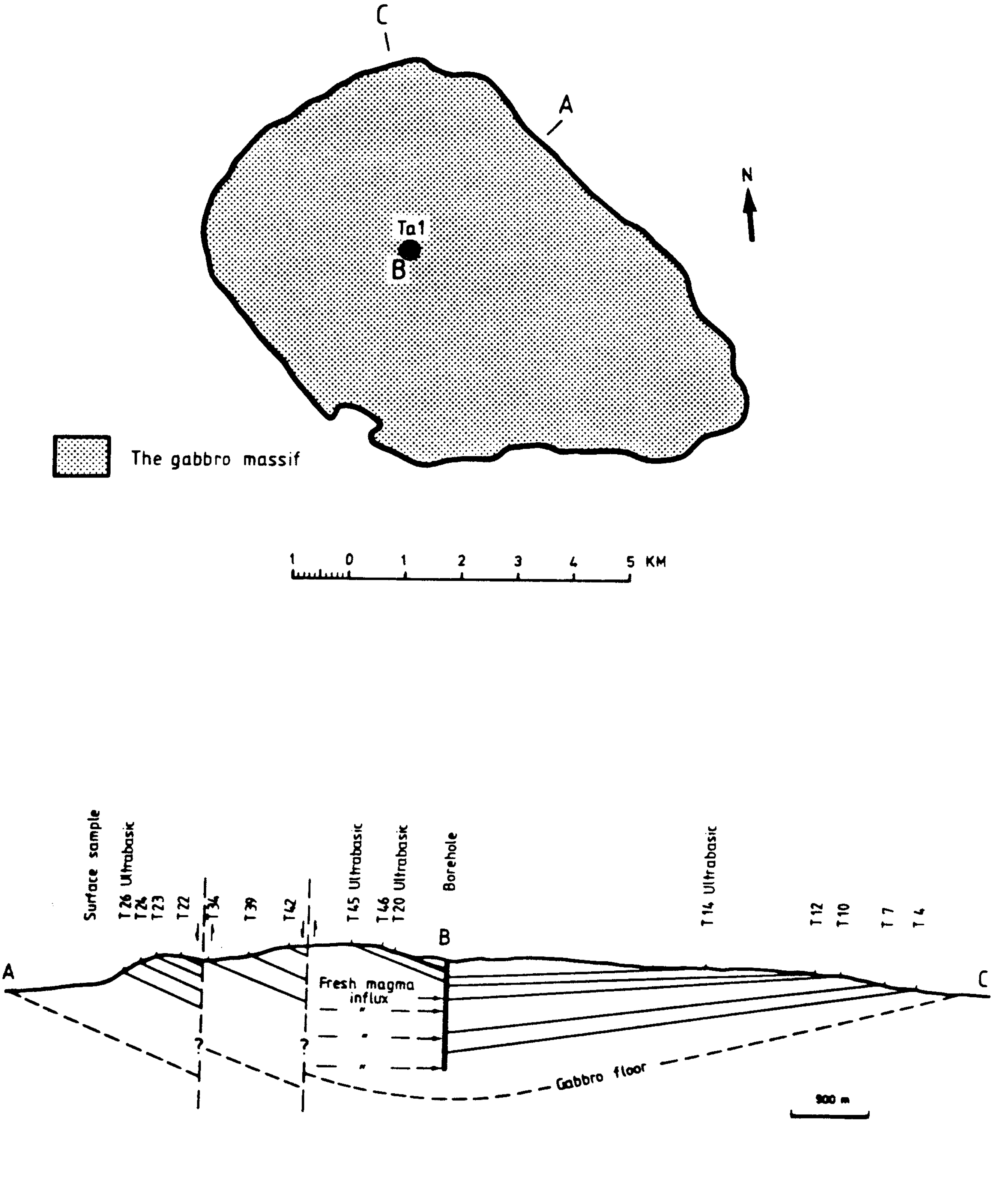


Fig. 5 Tentative cross section of the Taavinunnanen massif.

4. FRACTURE TECTONICS

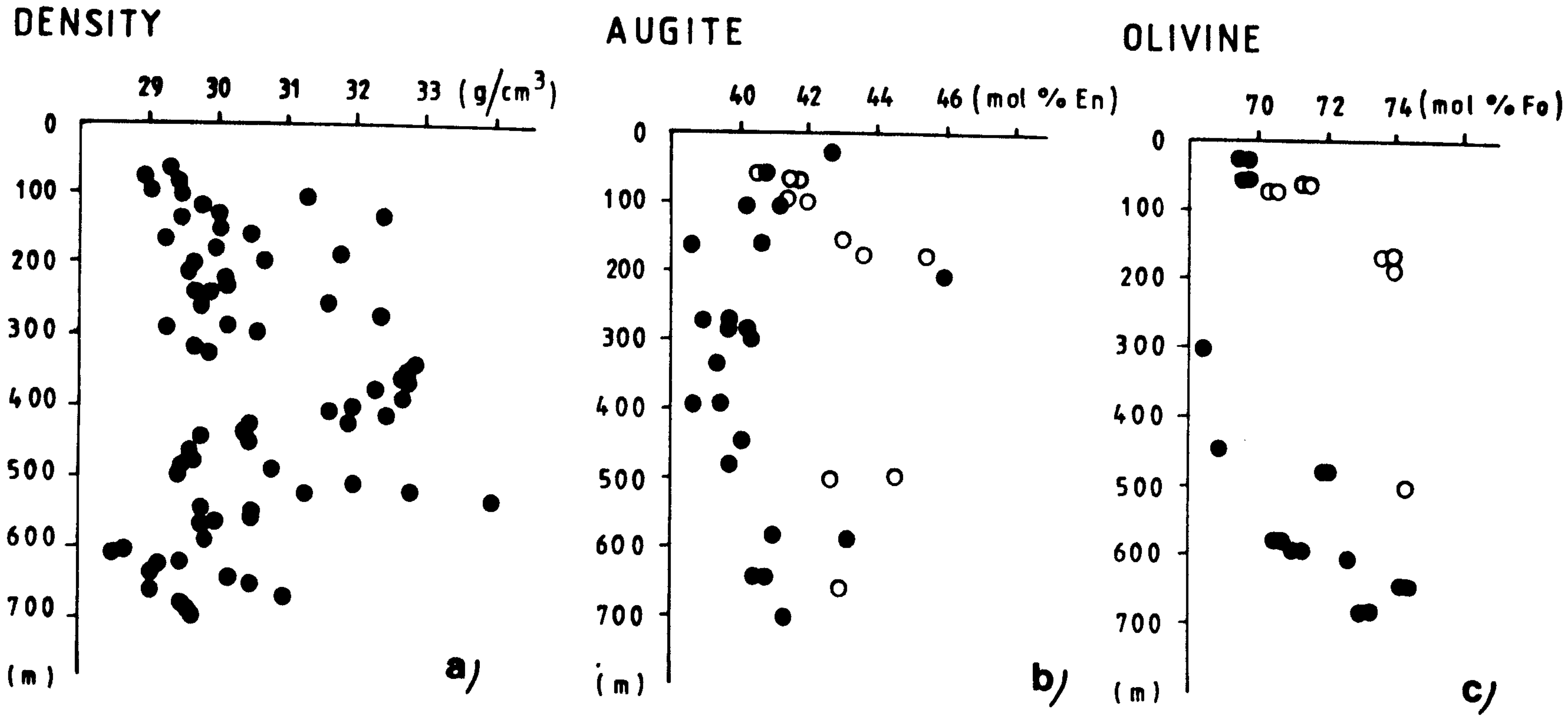
Analyses of data from airborne magnetic measurements, aerial photographs as well as from measurements of fractures within outcrops are shown in figure 7. Regionally a concentration of NE to NNE strikes of fractures is observed. Old as well as young reactivated fractures can be recognised. Late quarternary faults have reactivated an older tectonic zone at Kärkejaure, approximately 20 km away from Taavinunnanen (Henkel et al., 1983). This zone constitutes a part of the seismic belt shown by Bååth (1983).

Within the Taavinunnanen massif disturbances of the magnetic pattern which might indicate faulting can be seen (Fig. 7). Interpretation of aerial photographs only reveals one fracture zone within the gabbro massif which can be related to faulting. Surface studies show mylonitization and brecciation along this zone.

Another evidence of tectonic activity within the gabbro is shown by a geochemical study in which breaks in chemical trends have been interpreted as due to faulting. All these zones are restricted to the gabbro massif. Thus, it has not been possible to trace any major fracture zone from the surrounding granites crossing the gabbro. However, especially along the southern boundary of the gabbro massif, fracturing of the surrounding granite has resulted in eroded vallies.

Measurements of fractures in the outcrops show that short, steep, NE to NNE striking fractures dominate within the gabbro. Some fractures, with gentle dips, are parallel to the igneous layering present.

Measurements of fractures in the core show a dominance of steep fractures all along the borehole (Larson & Tullborg, 1984). However, zones with intense layering show an increased frequency of more or less horizontal fractures. The variation of fracture frequency with depth is shown in figure 8.



● Drillcore sample

○ Surface sample (corresponding to an estimated borehole depth)

Fig. 6 a) *Density-depth plot of samples from the drill-core*
b) *Variation of augite composition with depth*
c) *Variation of olivine composition with depth*

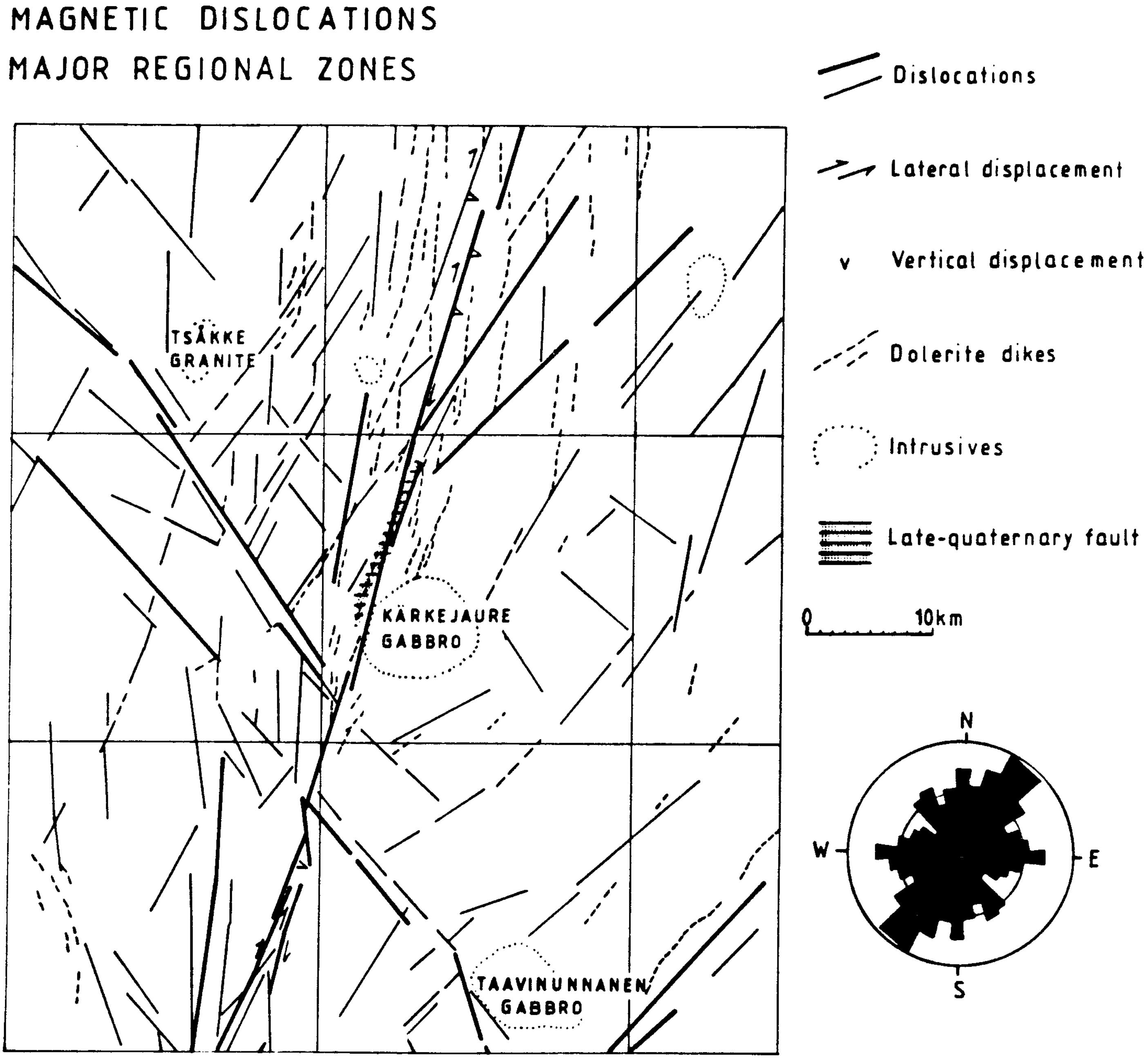


Fig. 7 Magnetic dislocations and major regional zones in the surroundings of Taavinunnanen (Henkel et al., 1983). To the right is also seen a diagram showing strikes of fractures measured from outcrops at Taavinunnanen (Ahlbom & Olkiewicz, 1981).

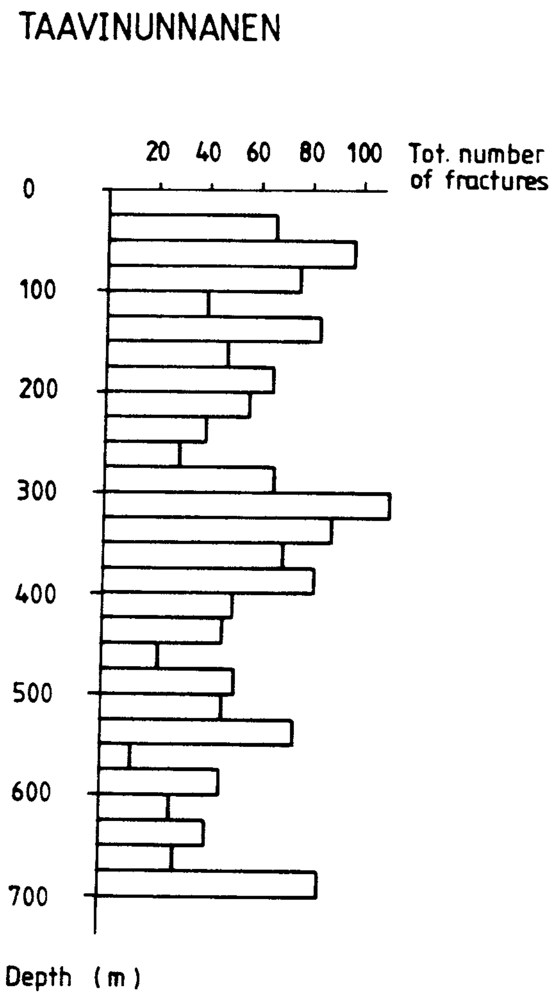


Fig. 8 Total number of fractures versus depth in the Ta 1 drill hole.

5. FRACTURE FILLING MINERALS

Dominating fracture fillings in the gabbro are chlorite, calcite and smectite. Prehnite and zeolites are also present. Within the granite dikes chlorite, calcite and quartz are dominating fracture fillings. The consequence of this difference is a higher degree of sealing of the fractures within the gabbro in comparison to those within the granite, resulting in lower hydraulic conductivities in the gabbro.

Several generations of calcite have been found. From stable isotope analyses it is evident that low-temperature calcite precipitated by meteoric water preferentially can be found within sections corresponding to high hydraulic conductivity (Fig.9). Another group of calcite has been deposited by hydrothermal solutions and has sometimes been precipitated together with prehnite.

Rust is present but calcite is almost lacking down to a depth of 75 metres due to dissolution by an aggressive water. It is concluded that water will pass down to a depth of more than 200 metres before supersaturation in respect of calcite is reached.

A tentative history of fracture fillings is suggested (Fig. 10). Thus the gabbro intrusion was followed by precipitation of chlorite and smectite into fractures. This event was succeded by precipitation into fractures of a second chlorite generation, calcite and prehnite. Next generation of fillings was calcite, prehnite and zeolites. All these events were accompanied by brecciation (only observed within the gabbro). The intrusion of granite dikes which followed was succeded by precipitation of chlorite, smectite and calcite into fractures. Fracturing of the granite dikes mostly resulted in reactivation of old fractures within the gabbro. Recent precipitation are smectite, calcite and rust.

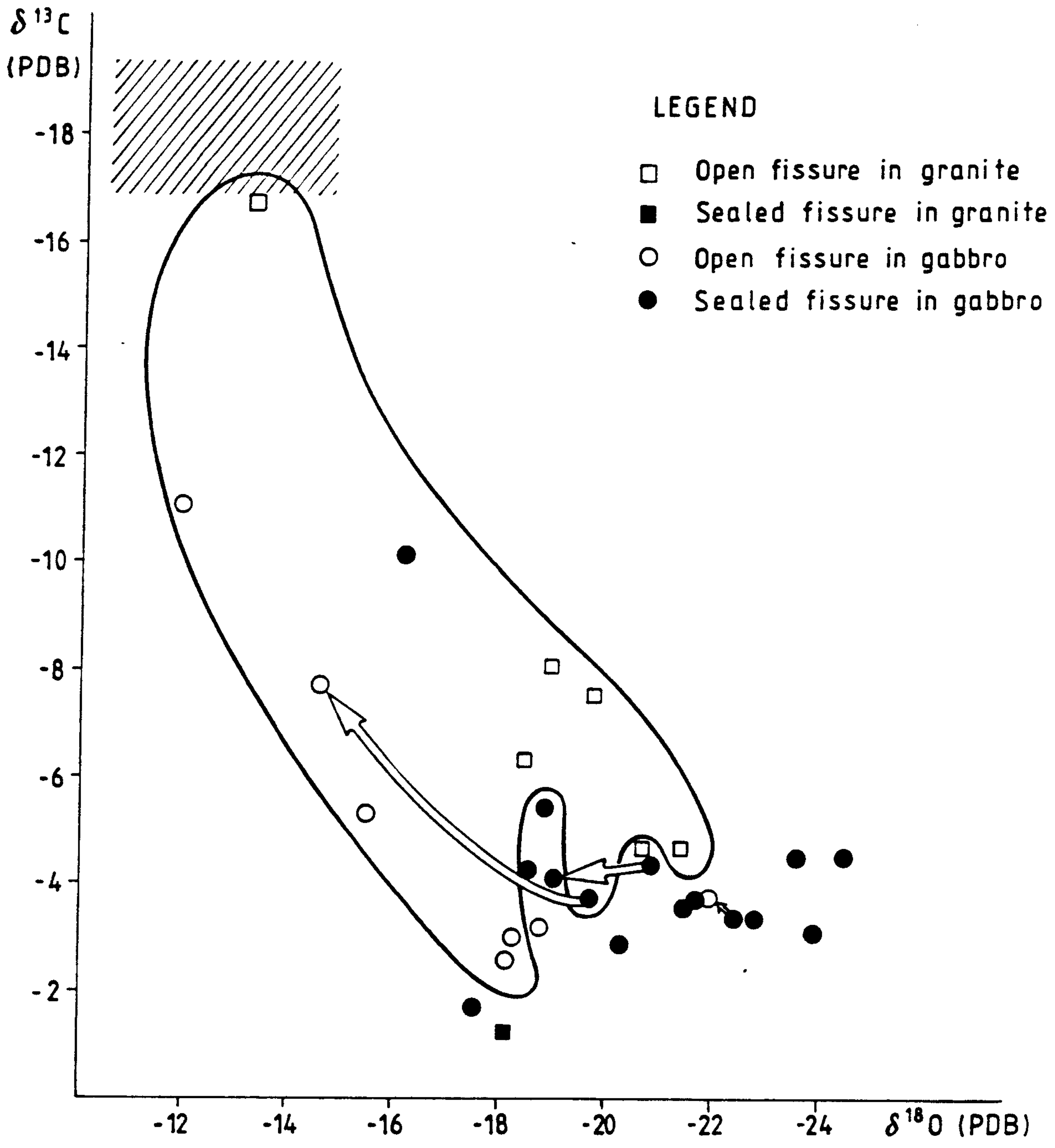


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Fig. 9 $\delta^{13}C$ versus $\delta^{18}O$ (PDB). Ruled area represents composition of calcites preciptated from an estimated ground water composition (Tullborg & Winberg in prep). Encircled are calcites from borehole sections showing hydraulic conductivity >2.0 x 10exp -11 m/s. Arrows connect different calcite generations from single fractures.

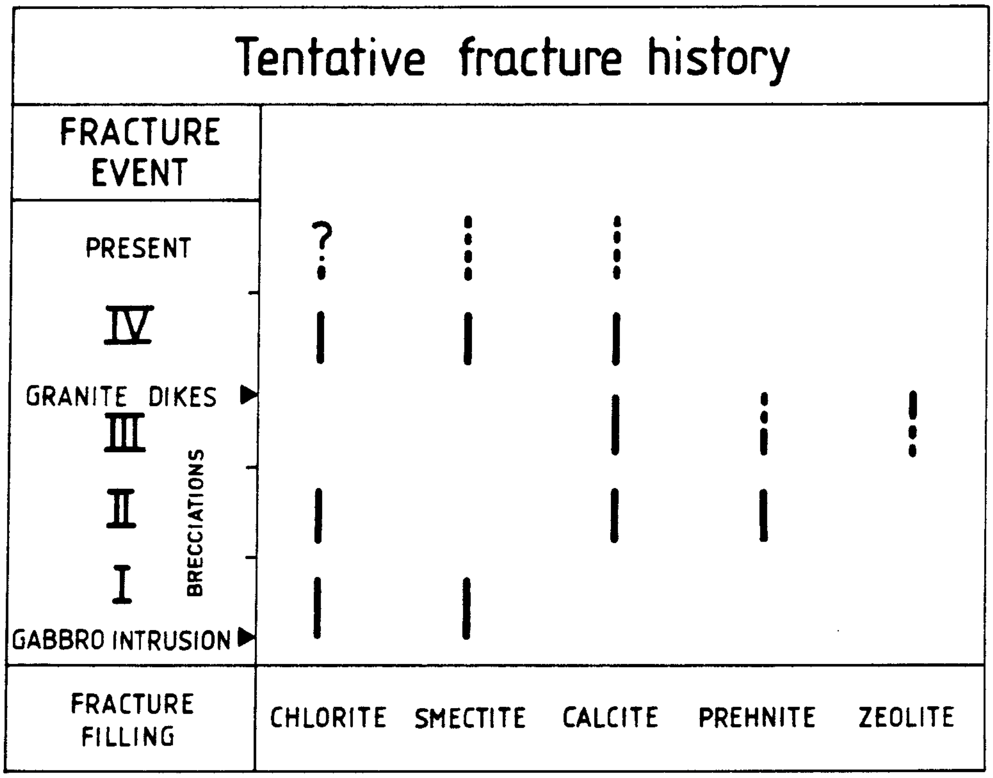

Fig. 10 Tentative fracture history at Taavinunnanen.

6. WATER CHEMISTRY

Water have been pumped up from selected water conductive zones and analysed. Two sections have been successively isolated with packer sleeves and sampled; one section at a depth of 493 m and the other at 651 m. However, the water composition found is far from expected. The concentration of total dissolved inorganic solids is extremely low (60 - 70 mg/l), the tritum concentration is high (99 - 178 TU) and there is an abnormal simultaneous presence of iron(II) and oxygen (Laurent, 1984).

A plausible explanation have been given by Smellie (1983) who performed a separate experiment during the sampling in Taavinunnanen. The pumping rate was lowered to about a third of the normal and water samples were taken before, during and after the low-flow conditions. The concentration of tha main water components did not change but the concentration of oxygen and iron(II) tended to drop. This could be explained as a failure to isolate effectively the sampled section from the water in the open borehole above the packer sleeves. Young oxygenated water might have infiltrated that way in contact with the unprotected outside of the iron covered sampling line. Low-flow conditions would imply further reactions in the dynamic oxygen-iron system, changing pH, iron(II) and oxygen concentrations.

These indications and similar findings reported from water sampling in Kamlunge (Laurent, 1983) have initiated the development of an improved sampling system with longer packer sleeves and all essential parts in plastic or stainless material. The results of the testing of this equipment in Fjällveden, in fact give further credit to the interpretation above.

So in conclusion the water sampled in Taavinunnanen is probably not relevant for the water composition at depth in a gabbro massif and renewed sampling should of course be of prime importance if this site is seriously considered.

7. HYDRAULIC CHARACTERISTICS

7.1 Hydraulic tests

The hydraulic conductivity (K) of the bedrock has been determined by means of water injection tests in the drill hole (Gentzschein, 1983). The tests were carried out under constant pressure (Almén et al, 1982) and were performed in delimited 25 m and 100 m sections down to 680 m borehole length. Two single packer tests from 630 m and 680 m respectively down to the bottom of the drill hole have also been performed. The hydraulic conductivity in the drillhole Ta 1 is shown in figure 11.

Supplementary detailed measurements, with the section length 2 m, were executed in permeable sections below 186 m borehole length for the purpose of delimiting the conductive parts of the individual 25 m sections. Hydraulic conductivity values calculated from 2 m (and 25 m) sections are shown in figure 12 together with a lithological log.

7.2. Depth-dependence

The results of the water injection tests indicate that dikes of granite have higher K-values than the surrounding gabbro. As a consequence the bedrock has been divided into two hydraulic units, one representing granite and one representing the gabbro. The depth-dependence of the hydraulic conductivity in the two hydraulic units has been calculated by means of regression analysis. A power regression ($K(z) = a \times z^{-b}$, a,b = constants, z = depth) has been utilized.

The hydraulic conductivity values of the gabbro, used in the regression analysis, have been based on K-values from the 25 m sections and the hydraulic conductivity has been calculated according to the equation:

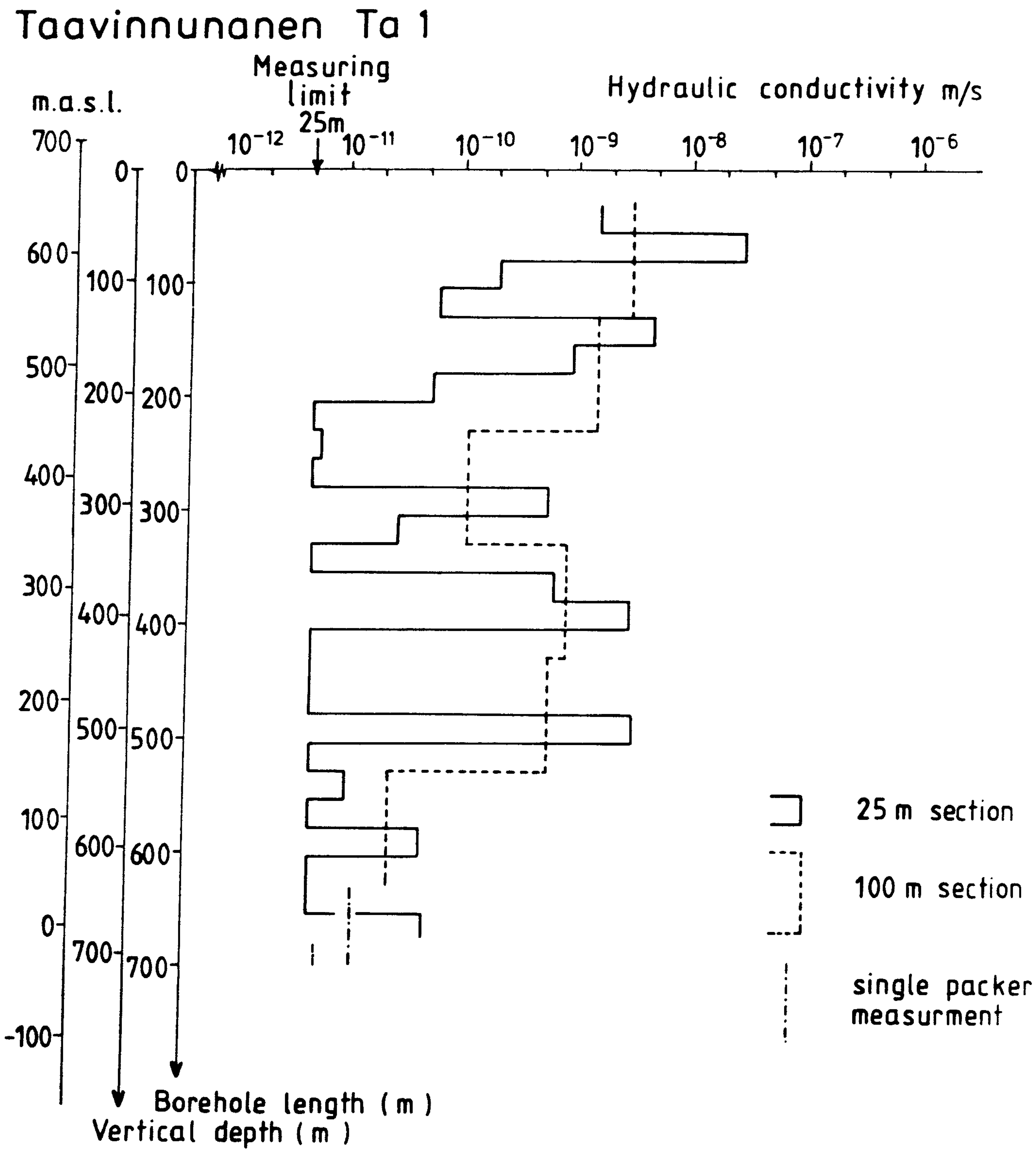

Fig. 11 Hydraulic conductivity, drillhole Ta 1.

TAAVINNUNANEN Borehole Ta 1

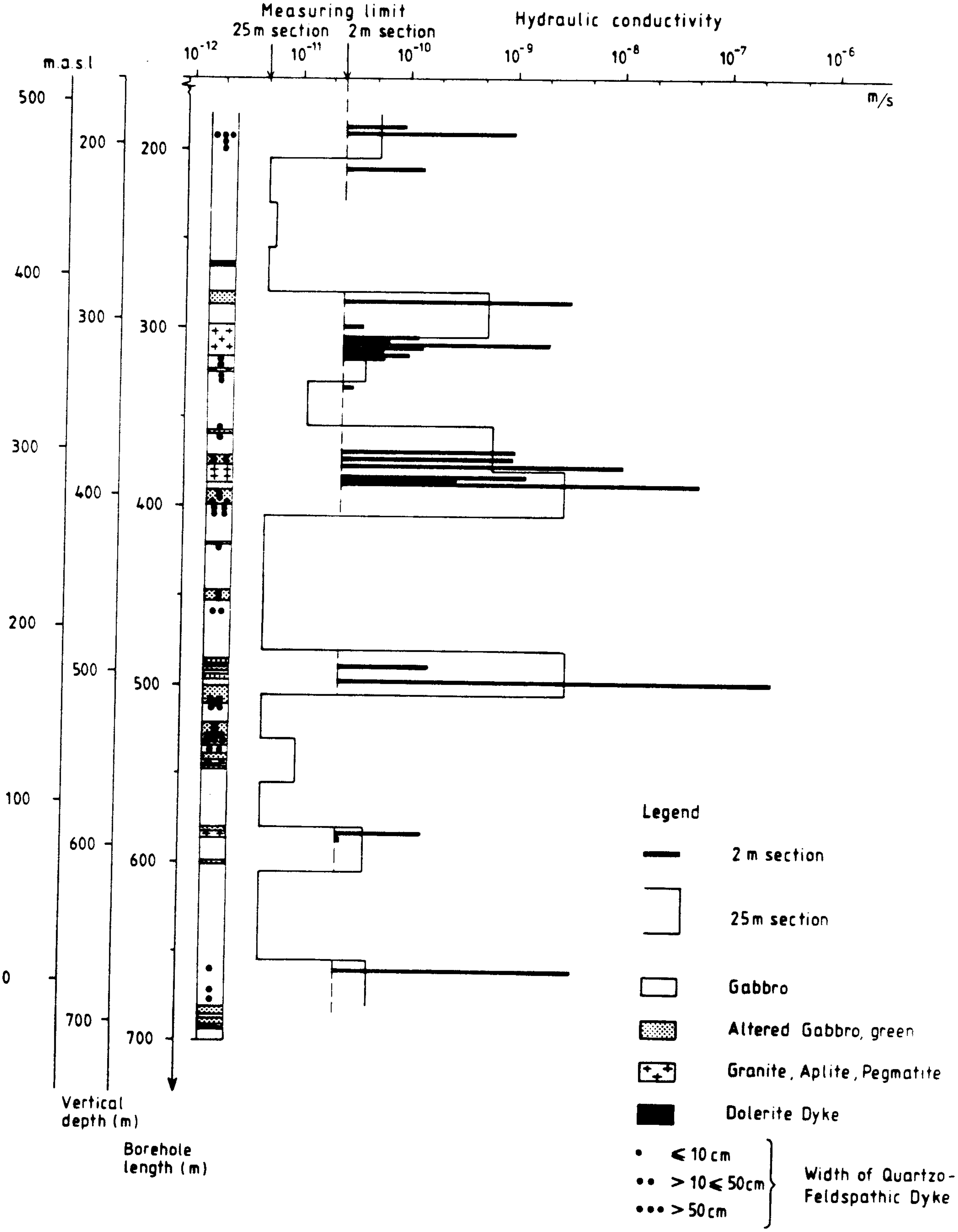

Fig. 12 Hydraulic conductivity and lithological log, drillhole Ta 1.

$$K(GO) = (KL \times L - K(GT) \times L(GT)) / L(GO) \tag{7.1}$$

where

K(GO) = the gabbro K-value

KL = K-value of the 25 m section concerned

K(GT) = K-value of the granite obtained from the 2 m tests

L(GT) = length of the granite in the 25 m section

L = total length of section, 25 m

L(GO) = length of the gabbro in the 25 m section

In the three uppermost 25 m sections (containing both gabbro and granite) where no 2 m sections have been tested, the K-values of the gabbro have been given the measured value of the 25 m section respectively.

The hydraulic conductivity values of the granite have been obtained by calculating the arithmetic mean value of the K-values in the 2 m sections, which are intersected by granite dikes. Granite above 105 m borehole length has been given the K-value of the corresponding 25 m section in the same way as for gabbro.

The results of the power curve regression is shown in table 1 and figure 13. In granite, aplite and pegmatite are included. The values obtained indicate that the hydraulic conductivity of the granite is higher than that of the gabbro. At the depth of 500 m the difference is approximately one order of magnitude.

Table 1 Depth dependence of the hydraulic conductivity in gabbro and granite

Rock type	Power curve	r^2	n
Gabbro	$K = 4.79 \times 10^{-6} \times Z^{-2.11}$	0.38	27
Granite	$K = 1.86 \times 10^{-6} \times Z^{-1.52}$	0.30	11

Z = depth

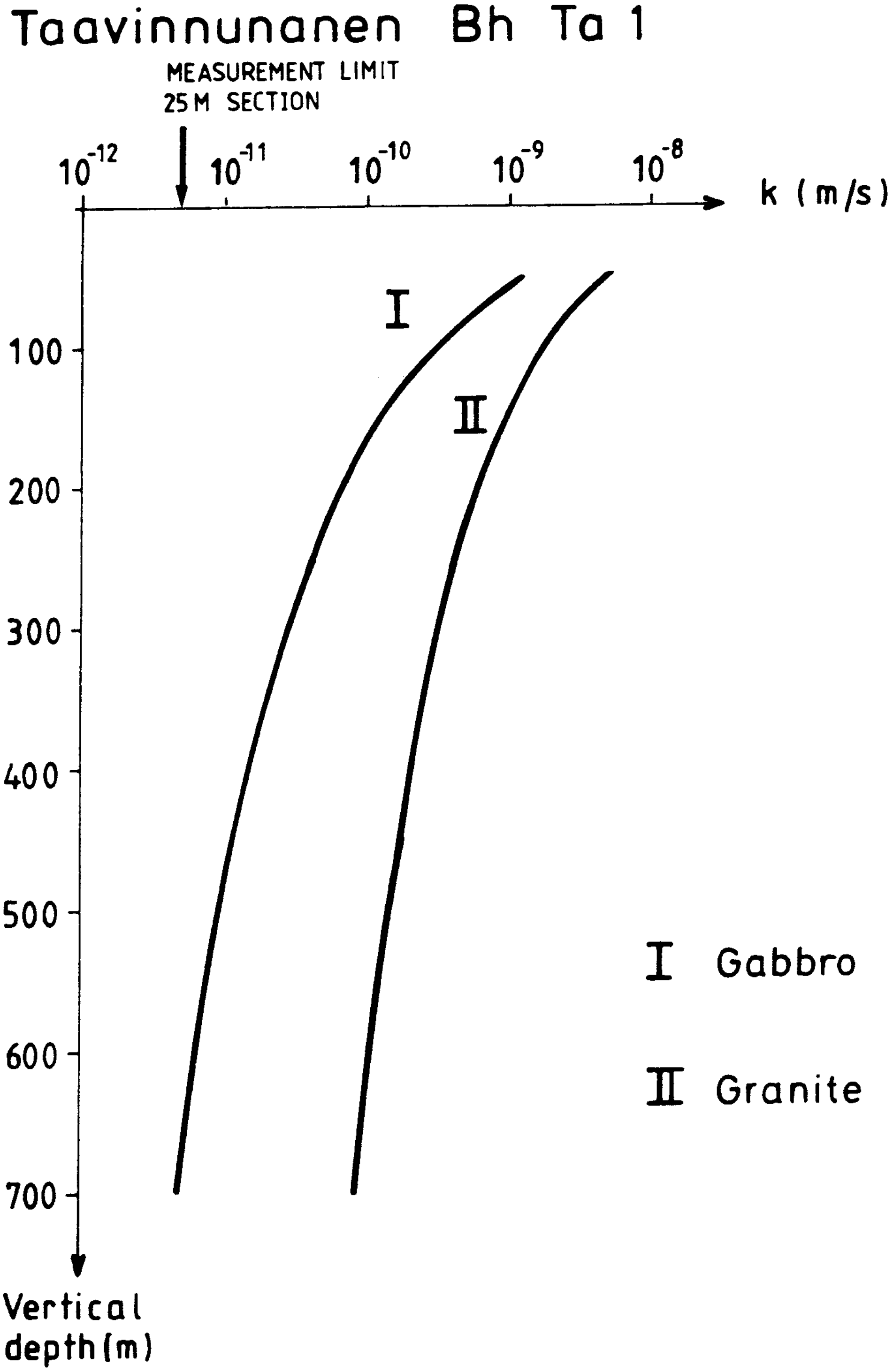

Fig. 13 Relations between hydraulic conductivity and depth in gabbro and granite. The K-values represent length intervals of between 2.7 and 25.0 m in drillhole Ta 1.

In the power curve regression of table 1 and figure 13 each K-value represents a borehole interval of between 2.7 and 25.0 m. A regression analysis based on 2 m intervals has also been carried out. The rock type of every 2 m section in drill hole Ta 1 was determined in accordance with the lithological log and the K-value was taken from the 2 m tests. In the parts of the drill hole where no detailed measurement were performed the 2 m sections were given the K-value of the corresponding 25 m section. The hydraulic units used in the 2 m section regression analysis are granite and gabbro. The results of the regression analysis are shown in table 2 and in figure 14.

Table 2 Depth dependence of the hydraulic conductivity in different rock types. Each K-value represents 2 m section in drill hole Ta 1.

Rock type	Power curve	r^2	n
Granite	$K = 3.63 x 10^{-7} x Z^{-1.34}$	0.26	39
Gabbro	$K = 8.9 x 10^{-7} x Z^{-1.64}$	0.46	279

This regression analysis also indicates that the gabbro is less permeable than the granite. However the conductivity values of the gabbro are higher at great depth, which is primarly due to the fact that the 2 m tests lead to a higher measuring limit (2.0×10^{-11} m/s). The granite gets somewhat lower K-values with this regression analysis as compared to the values presented in table 1.

Table 3 shows the hydraulic conductivity at the depth of 500 m of the two rock types calculated from the regression equations of tables 1 and 2.

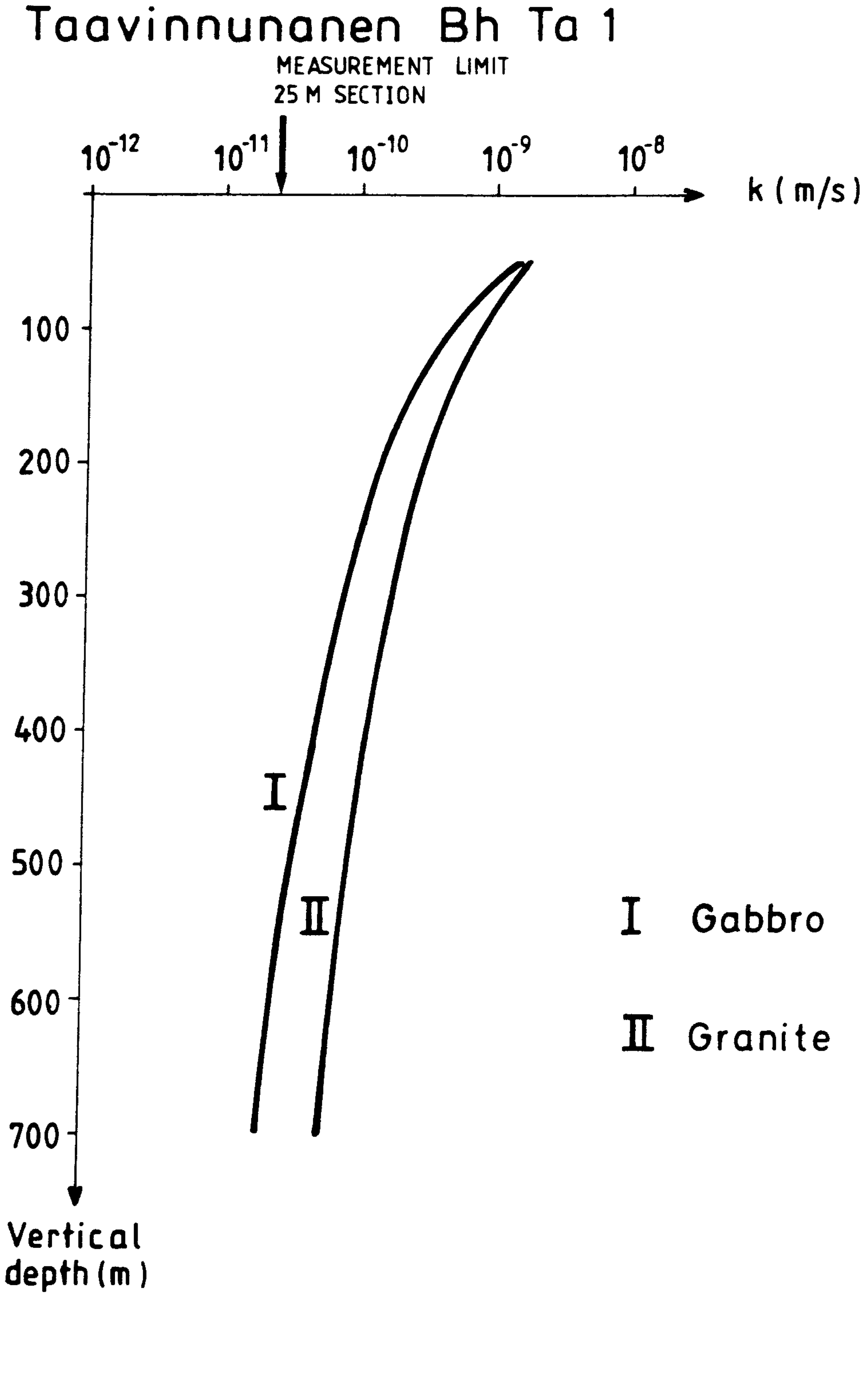

Fig. 14 Relations between hydraulic conductivity and depth in gabbro and granite. The K-values represent 2 m intervals in drillhole Ta 1.

Table 3 Hydraulic conductivity at the depth of 500 m (K_{500}) in different rock types. K_{500} is calculated from different power curves.

Rock type	Power curve	From table	K_{500} (m/s)
Gabbro (all)	$K = 4.79 \times 10^{-6} \times Z^{-2.11}$	1	9.7xE-12
"	$K = 8.9 \times 10^{-7} \times Z^{-1.64}$	2	3.3xE-11
Granite	$K = 1.86 \times 10^{-6} \times Z^{-1.52}$	1	1.5xE-10
"	$K = 3.63 \times 10^{-7} \times Z^{-1.34}$	2	8.8xE-11

8. DISCUSSION

The hydraulic conductivity measured in the borehole Ta 1 is equivalent to the conductivity values measured in the previously investigated study sites located in areas with granitic rock.

The Taavinunnanen massif was however less favourable in respect of some other basic properties such as homogenity and accessibility. The inhomogenity is manifested by the layered character of the massif itself but also, more seriously, by intrusions of granitic dikes. These dikes, with different strength and deformation properties as compared to the rest of the massif have been more fractured when the area was exposed to tectonic activity and have a higher hydraulic conductivity than the gabbro.

A factor favouring a homogenous gabbro body as a potential site for radioactive waste is the mechanical properties. It is known from several field studies that basites and metabasites may react as resistant bodies with respect to tectonic deformations with intense foliation and brittle deformation usually restricted to the marginal parts of a massif. This has also been observed at Taavinunnanen where regional dislocations have influenced the massif very little (Ahlbom et al.,1980; cf also Stigh, 1982).

The mafic character of a basite facilitates self-sealing of fractures by clay-mineral formation which is well demonstrated at Taavinunnanen where quite different fracture fillings are found in the gabbro and the granite respectively. Thus a high fracture frequency in the gabbro does not necessary significantly correspond to an increased hydraulic conductivity.

The chemical composition of basites further favours formation of zeolites, which also has been verified at Taavinunnanen. These minerals, like the clay minerals, commonly show high cation exchange capacities (Allard et al., 1983), acting as natural barriers for distribution of radioactive species (Fig. 15).

The values determined in heat conductivity measurements on 5 samples from the Taavinunnanen gabbro give an average of 2.2 W/m ^{o}C (Ahlbom pers. comm.). This is significantly lower than the average heat conductivity of granitic rocks (approx. 3.5 W/m ^{o}C). Due to the lack of heat producing minerals in gabbro, great gabbro massifs tend to have low temperature gradients. This is shown in Taavinunnanen where the temperature gradient is only 9.4^{o}C/km (Albino, 1984). The low heat conductivity and the low temperature gradient are counteracting factors, considering temperature build up in a repository and have to be taken in account in the design and when delimiting the required rock volume.

Experiences from the Taavinunnanen study indicate that homogenous bodies of basic rock might be of interest for siting of a repository and further studies are recommended.

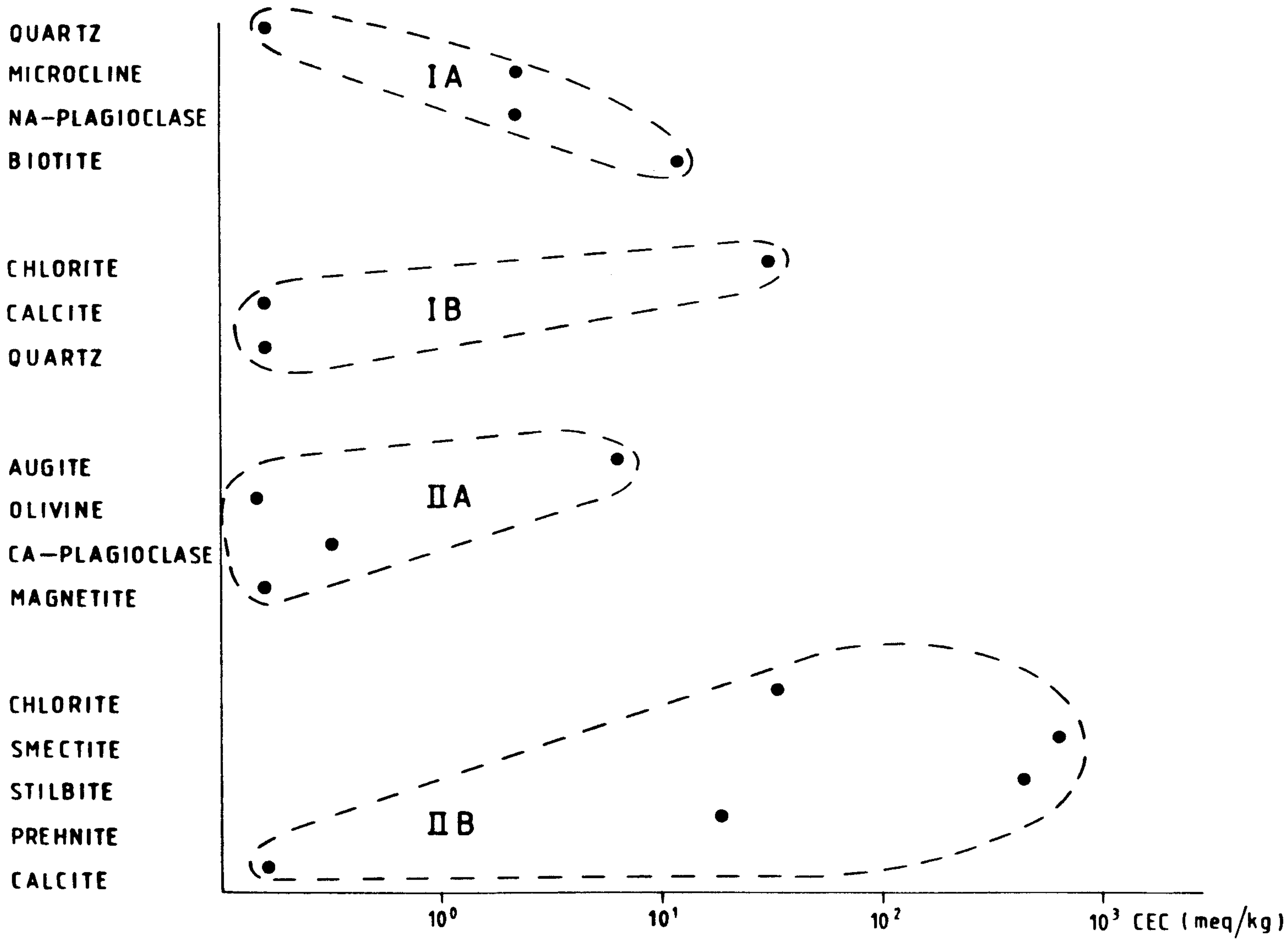

Fig. 15 Cation exchange capacities (CEC) (Allard et al., 1983) for IA: rockforming minerals in granite, IB: common fissure fillings in granite, IIA: rockforming minerals in gabbro, IIB: common fissure fillings in gabbro.

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