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INTRODUCTION

In the radioactive waste disposal program of Finland, the crystalline rock formations have been considered as potential host rocks for the disposal of reactor wastes from nuclear power plants. Underground storage seems to be the most feasible way to isolate the radioactive wastes from the biosphere, for the Precambrian rocks are recognized as stable formations of low permeability. Assessing the safety of underground disposal, however, the movement through the ground water system is regarded as the only probable means of escape or migration of the radioactive nuclides. Therefore, the essential problem in nuclear underground disposal is to recognize the factors that govern the water flow system both on a regional scale and at each prospective site.

The present report sets forth the results of investigations into the hydrogeological conditions in the coastal area of southwestern Finland (between Pori and Turku). The crystalline rocks of Olkiluoto island in Eurajoki have been considered as potential hosts for the disposal of reactor wastes. The bedrock of the island is composed of plutonic massifs and gneiss-migmatite formations which compose similar ground water environments. Our knowledge of the nature of the ground water in the study area is limited, for the information at hand is fragmentary. Hydrogeological research, in particular the investigations of the permeability of the rock and the chemistry of ground water, carried out on Olkiluoto island, enable an estimation of the distribution of hydraulic conductivity and the problems of water exchange in the bedrock aquifer. These details help determine the need for and targets of further investigations, chiefly offering estimates of hydraulic conditions and acquiring data for analytical models.

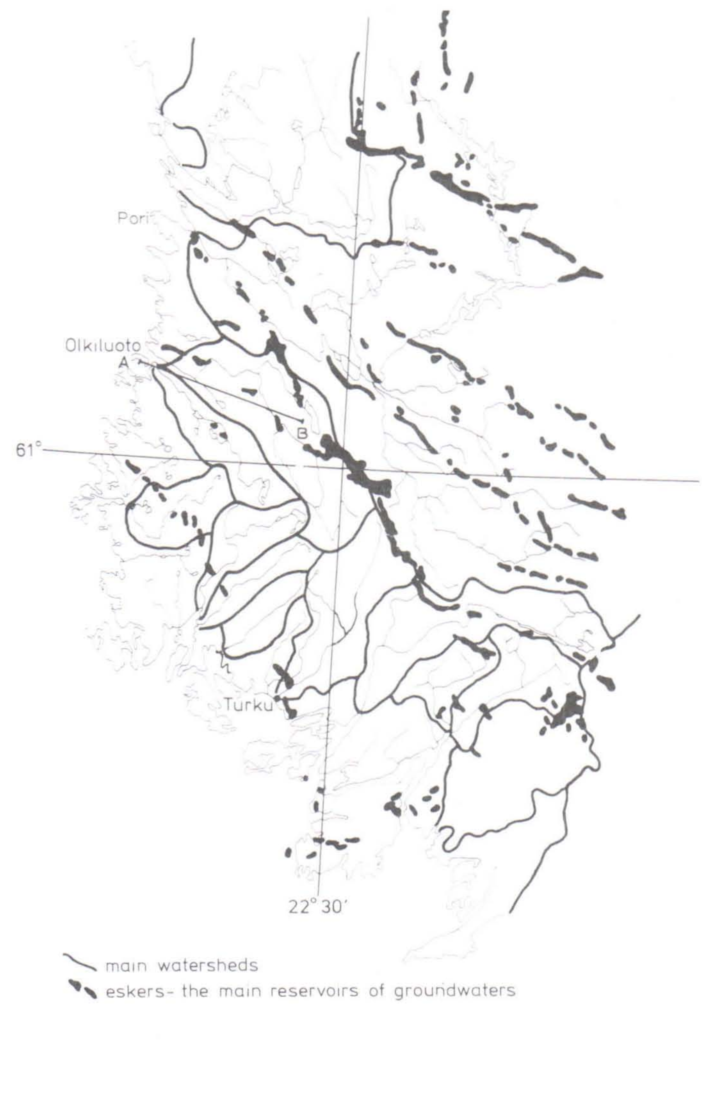

Fig. 1. The main catchment areas and groundwater reservoirs in the study area. The line running SE from Olkiluoto marks the location of the profile presented in Fig. 11.

GEOMORPHOLOGY AND SURFACE RUNOFF

The characteristic appearance of the variable relief of the coastal area of southwestern Finland is mainly created by the bedrock, and only in the northern part of the study area do the Quaternary deposits mask the bedrock topography. The rockmass structures generally trend NW—SE which is strongly reflected in the surface morphology. An abundance of valley and lake depressions has been eroded by the continental ice sheet along the faults and fractures, while the bedrock blocks compose the positive forms. On the coast, the rock blocks create numerous islands and peninsulas, while the negative morpho-structures on the mainland, i.e., valleys, have their continuation in sea-bottom depressions.

In general, the surface of the area studied is irregular, where outcrops of bedrock usually form hummocks and in other parts of the area the Quaternary deposits form moraine hills and eskers (Fig. 1). The morphological depressions of the bedrock are filled with till, clay, silt or peat, and certain parts of the valleys are filled with glaciofluvial sands. The mainland rises gradually from the shore (Fig. 2). For the most part, the region does not rise more than 100 m above sea level; only a few of the hummocks rise to levels of 140—180 m.

The runoff system of the region is depicted in Fig. 1. The coastal zone is drained by several dozens of rivers and streams. Their catchments are small. The northern and north-eastern parts of the region belong to the Kokemäenjoki basin, which comprises a large area of the lake district. Further, there are many lakes, which play an important role as reservoirs of surface water. Most of the lakes are shallow, i.e., just a few meters deep, and only a small number are considerable deep, namely: Kyrösjärvi 48.0 m, Kulovesi 37.0 m, Pyhäjärvi 25.0 m and Enäjärvi 19.9 m.

The main river valleys and lake basins do not divide the runoff system of the study area very deeply, because the ground water table is equally shallow everywhere.

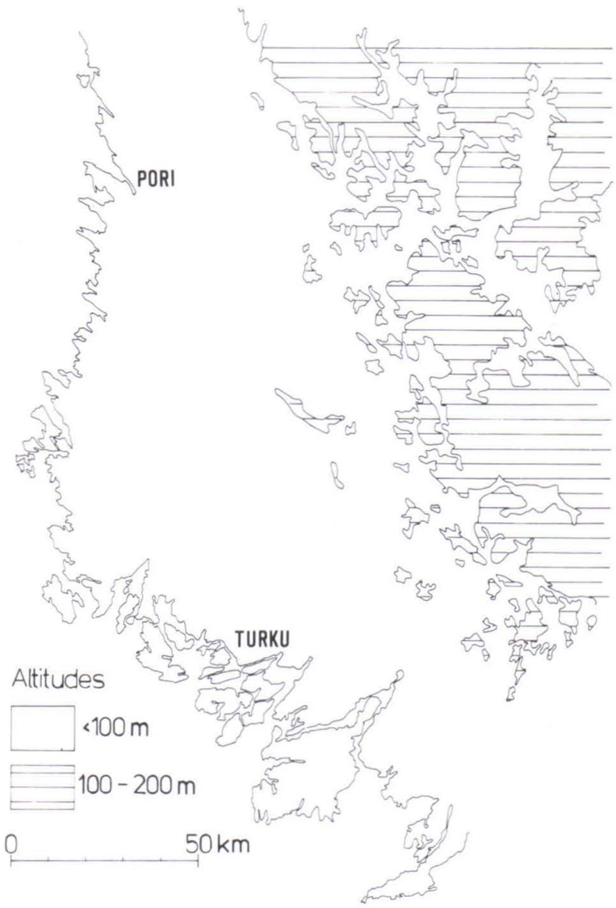

Fig. 2. The relief of southwest Finland.

GEOLOGY

Prequaternary rocks

The oldest rocks on the south-west coast of Finland are Svecokarelidic schists and gneisses as well as synorogenic igneous intrusions. They are penetrated by anorogenic rapakivi granites and olivine diabases and are covered in the NE corner of the study area by the sandstone of Satakunta (Hietanen 1943).

The gneisses and schists are mostly cordierite- and garnetbearing mica-schists, containing arkosic varieties and interbeds of amphibolite. The folding of the gneisses is either open or isoclinal, but the predominant trend of the schistosity is E—W. The synorogenic intrusive rocks of the so called trondhjemite series consist of gabbros, diorites and trondhjemites, which are folded and schistose. The contacts of the intrusions towards the supracrustal rocks are concordant and often laminated (tongue-shaped) (Hietanen 1943). The lateorogenic migmatization has affected the whole area.

The contacts of the wide rapakivi plutons with the surrounding rocks are sharp, intrusive and outward-sloping (Hietanen 1943, Simonen 1980). Gravimetric investigations have not proved that the rapakivi should continue under the Svecokarelidic rocks in the area of Olkiluoto (Elo 1981). The arkosic sandstone of Satakunta contains thin interbeds of clay schist. The layers are usually horizontal. The thickness of the sandstone may be some hundreds of meters (Sederholm 1913, Härme 1960).

The most common trend of the fracture zones of the west coast is NW—SE; and to some extent, there occurs a NE—SW trend (Härme 1960).

Quaternary deposits

The geological map of Quaternary deposits in Finland was used for the general description. The matter was discussed in detail by Sauramo (1924) and the National Board of Waters (Vesihallitus 1977, 1978). The Quaternary deposits of the study area consist of till, glaciofluvial sands and gravel, clay, silt and peat.

Till is predominant in the central and northern parts of the region and compose the main cover on the islands. The till forms a fairly thin, compact mantle over the rock surface. The internal structure and granulometric composition of the till is variable. In some places, it is mainly coarse-grained with some accumulations of stones and boulders; in other places, the till is more fine-grained.

The glaciofluvial deposits compose either the long, tortuous ridges of eskers (see Fig. 1) or the flat, sandy areas that accompany the eskers or occur in valleys.

The clay and silt occur mainly in depressions in the southern part of study area. They are connected with glacial varved sediments and postglacial basin sedimentation. Peat covers wide tracts, mainly as a thin cover over till deposits.

The thickness of the Quaternary deposits varies predominantly from 5 to 10 m. Only in a few places does the thickness exceed 50 m (Okko 1964, p. 242).

OCCURENCE OF GROUND WATER

In the study area, there are two different water-bearing environments; namely, the porous medium of Quaternary deposits and the fractured rock mass.

The Quaternary aquifers are mainly connected with the glaciofluvial facies and with till and peat. Owing to the character of the sedimentation of these deposits and of the bedrock morphology, the water-bearing structures are lacking in continuity. On a regional scale, they are divided into many separate, small ground water basins.

The glaciofluvial structures that are important as utilizable ground water resources have a limited extent. The distribution of the eskers is presented in Fig. 1. The composition of the eskers and other glaciofluvial structures varies greatly, but most commonly they consist of

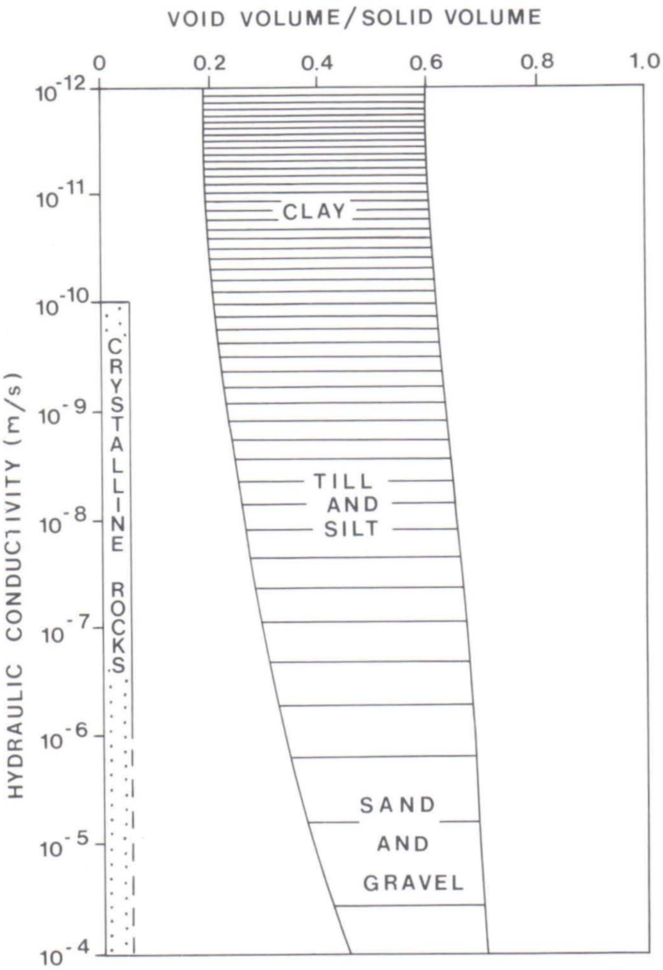

Fig. 3. Values of the hydraulic conductivity and porosity of Quaternary soil types and crystalline rock types measured in laboratory in Sweden (Olsson, 1979).

gravel and sand. The general occurrence of ground water in glaciofluvial structures of the coastal zone has been described by Lahermo (1971).

It has been observed that glaciofluvial formations may lie directly on the bedrock or, in other places, be surrounded by till or clay beds, which trap ground water in the eskers. The quantity of ground water available from the wells is comparatively abundant, due to the high permeability of the glaciofluvial material and, on the other hand, to its high infiltration and storage capacity. According to the data from investigations carried out by Sederholm, Ristola, Hyyppä and Brömssen (after Lahermo 1971, p. 12), the coefficient of infiltration is variable; but in general it is very high — from 0.3 to 0.8. Because of the high permeability of the esker material, the exchange of ground water is greater than in other hydrogeological structures.

The distribution of till deposits seems to have a mosaic character. They are mainly concentrated in the central part of the study area and on the islands. The hydraulic parameters of the till are quite variable and dependent on the internal structure of the soil, i.e., grain size distribution, grading and compaction of the material.

The hydraulic properties of the till in the region studied are not known, but the values of the hydraulic conductivity and porosity of certain Swedish tills arrived at in the laboratory have been presented by Fagerström and Wiesel; and the results are presented in Fig. 3, after Olsson (1979). The hydraulic conductivity of the till, as presented in Fig. 3, varies from 10^{-7} m/s down to 10^{-11} m/s, but the results of the in situ determinations obviously diverge from expectation with regard to granulometric composition. According to Olsson (1979): ''the in situ tests usually seem to give conductivity values which are more than one decade higher than those obtained in laboratory tests.''

The bedrock aquifer of the study area is composed of metamorphic and igneous rocks, which, from the point of view of ground water occurence and water conductivity- create similar environments. The water-bearing capacity derives mainly from interconnected fractures, which fundamentally determine the hydraulic properties of the rocks and constitute the principal pathways for water circulation in the rock mass. Hydrogeological investigations carried out in Finland show that the water-bearing capacity of crystalline rocks varies not only between different rock types but also within one and the same rock type. Analyses of well yields presented by Laakso (1966) and Lahermo (1971) show that considerably more ground water is obtained from rapakivi bedrock than from the wells sunk in bedrock in Finland taken as a whole (Fig. 4). It also happens that either the boreholes remain completely dry (Lahermo 1971, p. 17) or the rate of flow into wells is low (borehole YD-17 in Olkiluoto, Maa ja Vesi Oy 1981).

There are not many wells in the study area about which full data is available on the exploitation of ground water pumping tests. Enough information is available, however, to enable general recognition of the water capacity of the rock aquifer.

The yields of some of the drilled wells in the study area are shown in Table 1. Variations in the yields of wells within a given area are large, but there is a tendency for most yields to be small in comparison with the yields reported by Lahermo (Fig. 4). Moreover, there seems to be no significant correlation between depth and yield of drilled wells. The yield of wells depends on local conditions.

Comparisons made with the data contained in Table 1 and Fig. 4 reveal that the yields of drilled wells in the study area are in general lower than the average yield of boreholes in other parts of Finland, although their depths are similar. The low yield of the wells suggests, in spite of the local anomaly, that the water-bearing capacity and the permeability of environments described are very low.

Table 1. Yield and depth of some drilled wells in the study area.

Location	Depth of well (m)	Yield (l/h)
Kaarina	96	1,800
Kaarina, Littoinen	136	—
Olkiluoto YD-15	60	1,800
Olkiluoto YD-8	30	300
Olkiluoto YD-10	30	300
Olkiluoto YD-16	25	30
Olkiluoto YD-17	50	0.0
Piikkiö	67	500
Rusko	102	300
Pyhämaa, Sampaanala	58	500
Seinäjoki	307	4,200

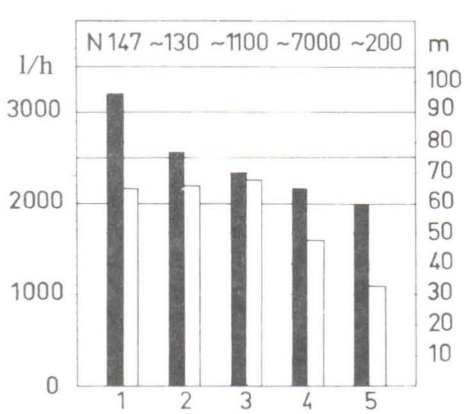

Fig. 4. Avarage yield of drilled wells (black column) as well as their depth (white column) in 1) rapakivi area of the coastal region of south-eastern Finland, 2) rapakivi area of Kymi as a whole (Laakso 1966), 3) Finland as a whole (Laakso 1966), 4) bedrock (also Paleozoic sedimentary rocks) area of southern Sweden (Wenner 1951, p. 1102), and 5) Lapland (Lahermo 1970, p. 28). N = number of observations. (After Lahermo, 1971, p. 17).

The water-bearing capacity of metamorphic and granitic rocks shows, however, a certain differentiation. Fractures associated with pronounced faults and contact zones of different rocks are characterized by a high water-bearing capacity and high permeability. The results of pumping tests in the Olkiluoto area reveal a somewhat different circumstance: the contact zones of the geological structures act as impermeable barriers and cause compartmentalization of the bedrock aquifer. Moreover, it is observed that the water-bearing capacity of the upper part of the rock mass is higher than in deeper parts. The upper part of the rock mass is weathered, the fissures are mostly open and ground water occasionally occurs in some abundance. This was confirmed during the pumping tests on Olkiluoto.

In many cases, however, the fissures in the upper part of the rock mass are filled with Quaternary deposits. The water-bearing capacity of the deeper part of the rock mass is unequal and depends on the distribution and frequency of the joints and fissures. Hydrogeological investigations carried out in the study area have confirmed the presence of open fissures to a depth of over 200 m.

Owing to the vertical zonality, which is mainly associated with conspicuous faults, and the horizontal zonality, which is associated with weathering, the permeability of the rock aquifer is quite variable. Investigations carried out on Olkiluoto island indicate that the hydraulic conductivity of the rock aquifer ranges, as arrived at by the methods applied, from 10^{-8} m/s to 10^{-5} m/s (pumping test) or from 10^{-10} m/s to 10^{-5} m/s (constant head injection test; Insinööritoimisto Saanio & Laine, 1981). Similar hydraulic conductivity values for the crystalline rock were obtained in Sweden. They range from about 10^{-8} m/s to 10^{-6} m/s, but according to Olsson (1979, p. 33), the variations may be great even between neighbouring holes or points within a hole.

With respect to the hydraulic conductivity values obtained from pumping tests, their relation to the local tectonic picture shows that the hydraulic conductivity of the fracture (fault) zone is fairly closely confined to the range 10^{-6} m/s — 10^{-5} m/s; the values of the hydraulic conductivity of the ''homogenous plutonic rock mass'' (tonalite) are lower and cover the range 10^{-8} m/s — 10^{-7} m/s.

Fig. 5 shows the hydraulic conductivity as a function of depth. The hydraulic conductivity values obtained by the double packer test (injection test) using 11 piezometers are of a rock aquifer 200 meters thick. The point distribution shows that the hydraulic conductivity varies widely, especially in the upper part of the aquifer; but the general conclusion is that the hydraulic conductivity decreases with increasing depth. This is clearly shown by the line that delimits the greatest values of hydraulic conductivity at each depth (see Fig. 5).

The hydraulic conductivity of rocks depends on their primary porosity, caused by the fractures through which the water flows. The secondary porosity, i.e., the residual porosity, represents the fractures in which no flow takes place. Generally, the total porosity of fresh metamorphic and igneous rock samples is less than 3 per cent and most commonly less than 1 per cent (Davies & De Wiest 1970). The porosity of the rocks of the study area is mainly below 1 per cent. Appreciable channels for water flow are, however, developed through fracturing and weathering of the rock. Field investigations show that the effective porosities determined by means of the tracer tests range from 10^{-6} m/s to 10^{-4} m/s (Maa ja Vesi Oy 1981). Similar values were obtained by using Olsson & Carlsson's method (Insinööritoimisto Saanio & Laine 1981), which shows the relation between hydraulic conductivity and effective porosity.

Table 2. Specific yields from Olkiluoto area calculated using Boulton's method (c.f. Kruseman and de Ridder 1976).

Pumped well	Data from piezometer	Specific yield ~ effective porosity (%)
YD-15	YD-11	3.8×10^{-4}
	YD-12	8.1×10^{-4}
	YD-13	1.2×10^{-2}
	YD-14	2.3×10^{-2}

However, the highest specific yield values (~ effective porosity) were calculated from the data of the long-term pumping test using Boulton's method (Table 2).

The values of specific yield set forth (Table 2) are scattered and varied over about two orders of magnitude. With respect to the results, the effective porosities obtained for the deeper part of the rock aquifer are in the range of 10^{-4} to 10^{-5} per cent, while in the upper part of the aquifer, which comprises the weathered and tectonic (fault) zones, they are in the range from 10^{-2} to 10^{-3} per cent.

The water-bearing Quaternary deposits and the water-bearing bedrock are in close hydraulic connection, creating an unconfined aquifer in the study area. However, in the same areas where there are clay deposits, the water-bearing series may be separated and a confined aquifer may occur. Observations of the water level indicate a similar phenomena in both deep boreholes and shallow piezometers. A comparison of the levels of the ground water table with distributions of precipitation indicates that the reaction of the water level is nearly simultaneous with precipitation, besides which the rhythmicity of the changes in all wells is similar. However, the amplitudes of water level variations in some boreholes are different, and extreme variations have been observed in rock aquifers (Insinööritoimisto Saanio & Laine 1981).

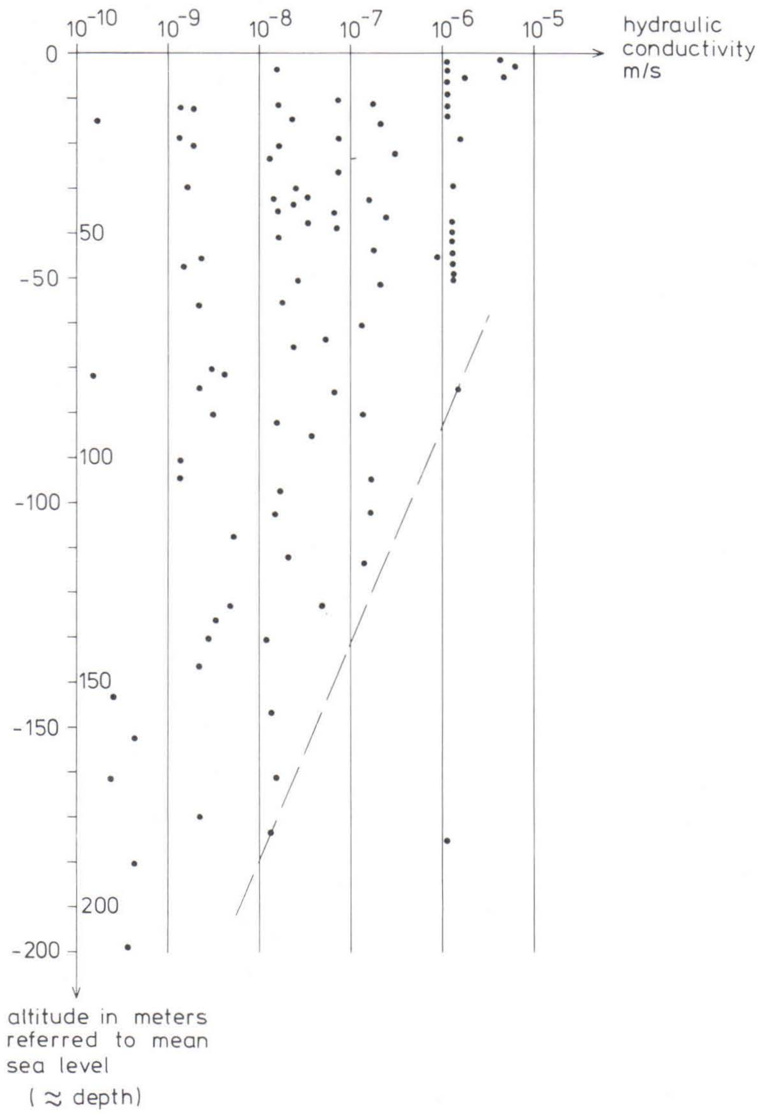

Fig. 5. Hydraulic conductivity as a function of depth in the Olkiluoto area, measured from 11 boreholes (Maa ja Vesi Oy 1981).

CHEMISTRY OF GROUND WATER OF THE BEDROCK AQUIFER

The chemical characterization of ground water is considered in two main aspects, namely:

— recognizing the regional background of water chemistry, which gives the basic indications of the paleohydrology, and of the possibility of the movement and exchange of water in the aquifer;

— understanding the local conditions of any given area against the background of regional relationships, and then control of their changes during constructions of disposal facilities for radioactive wastes.

The chemical composition of the ground water occurring in the rock aquifer of the coastal zone is known from the published papers and over 70 analyses from Olkiluoto carried out by Suunnittelukeskus Oy (1980). Samples of ground water of the Olkiluoto area were collected from boreholes at different depths as drilling operations progressed (boreholes: YD-1, YD-2, YD-6, August-October 1980); the water sampling was repeated in 1981 (April-July).

The total amount of dissolved solids in the ground water of a rock aquifer varies greatly, ranging from about 100 mg/l to more than 5500 mg/l in samples collected from Olkiluoto wells and over 6500 mg/l in Eura (Hyyppä 1963). For the determination of the nature of the ground water in the bedrock aquifer, the data yielded by the chemical analyses from the Olkiluoto area is presented graphically (Figs. 6—8). The graphs illustrate the concentrations of the main ions at different depths and, moreover, their variations over time. The latter information seems to be worthless for further discussion in this report because the variability in the content of the ions is too great considering the short time involved. This variation may be due to mixing of the water during sampling. The essence of the matter, however, seems to be the convergence of the shapes in the curves presented (Figs. 6—8).

Generally, the plots of the ions HCO_3^-, Ca^{2+} and Mg^{2+} (Figs. 7, 8) show that the concentration of those ions increase gradually with depth and the orientation of the plots is almost rectilinear.

In the case of ions Cl^-, SO_4^{2-} and Na^+ (Figs. 6, 7, 8), the plots are different. Considering the concentrations in a vertical direction, the profile of the aquifer may be divided into four zones:

— A the upper zone, with "fresh water", where the ion concentration increases very slowly with increasing depth. This zone occurs from the ground water table down to 60 to 80 meters (below sea level).

— B_1 the dispersion or contact zone between fresh and saline ground water

— B_2 the middle zone of the aquifer, with saline water, where the concentration of ions, mainly chloride and sodium, increases rapidly. Their maximum values are found to be at depths of between 110 to 130 meters; and

— B_3 the lower zone of the aquifer, likewise containing saline water, where the amount of chloride and sodium is less than in the middle.

Chemical profiles similar to those at Olkiluoto have been observed in other boreholes in western Finland. According to Ehlers and Lahermo (1981), the contact of fresh and saline water is well-defined in the wells near Turku and is found there at depths of between 60 and 80 m (see Fig. 9). At Eura, the border between fresh and saline water is not clear (Hyyppä 1963). The amount of dissolved salts increases with depth, down as much as 180 m (i.e. 120 m below sea level) and then, in deeper parts of the aquifer, the salinity of the water decreases slightly. There are several wells within the region surveyed and neighbouring areas with high chloride contents (Fig. 10). Chemical profiles, however, are not available.

With respect to the distribution of the concentration points on the graphs (Figs. 6, 8), the points of the upper and lower parts are in general situated rectilinearly, indicating an increasing amount of ions with increasing depth. The highly saline horizon (the "middle part of the aquifer" in the Olkiluoto area) composes a kind of "hydrochemical anomaly" in the vertical profile of the aquifer.

For the purpose of comparison, some results of the groundwater analyses from Olkiluoto and other places are presented in Table 3. It is evident that the chemical compositions of the water samples are different, although in relation to the amounts of chloride and sodium they are comparable.

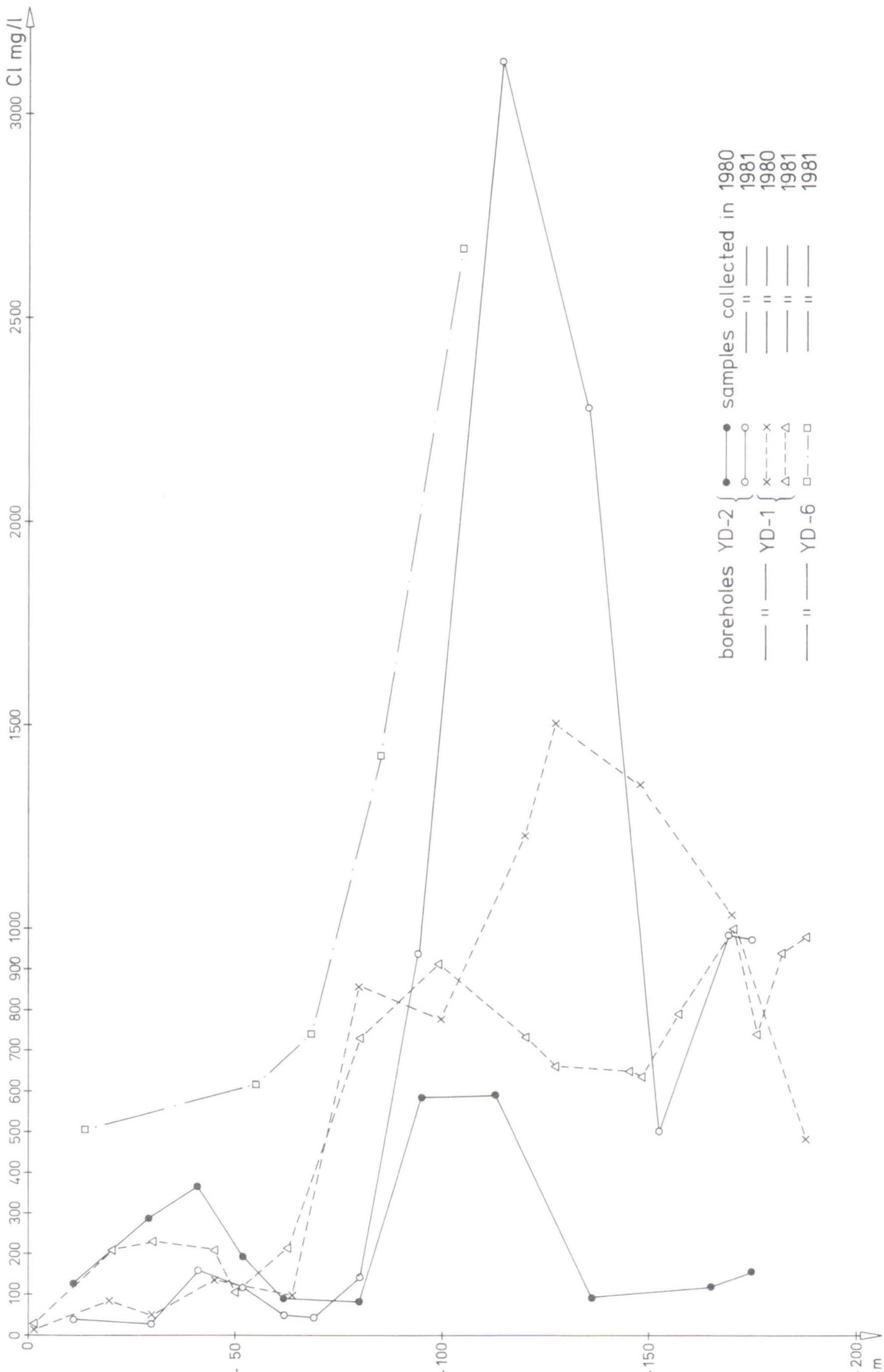

Fig. 6. Cl$^-$ -ion content in the ground water of Olkiluoto.

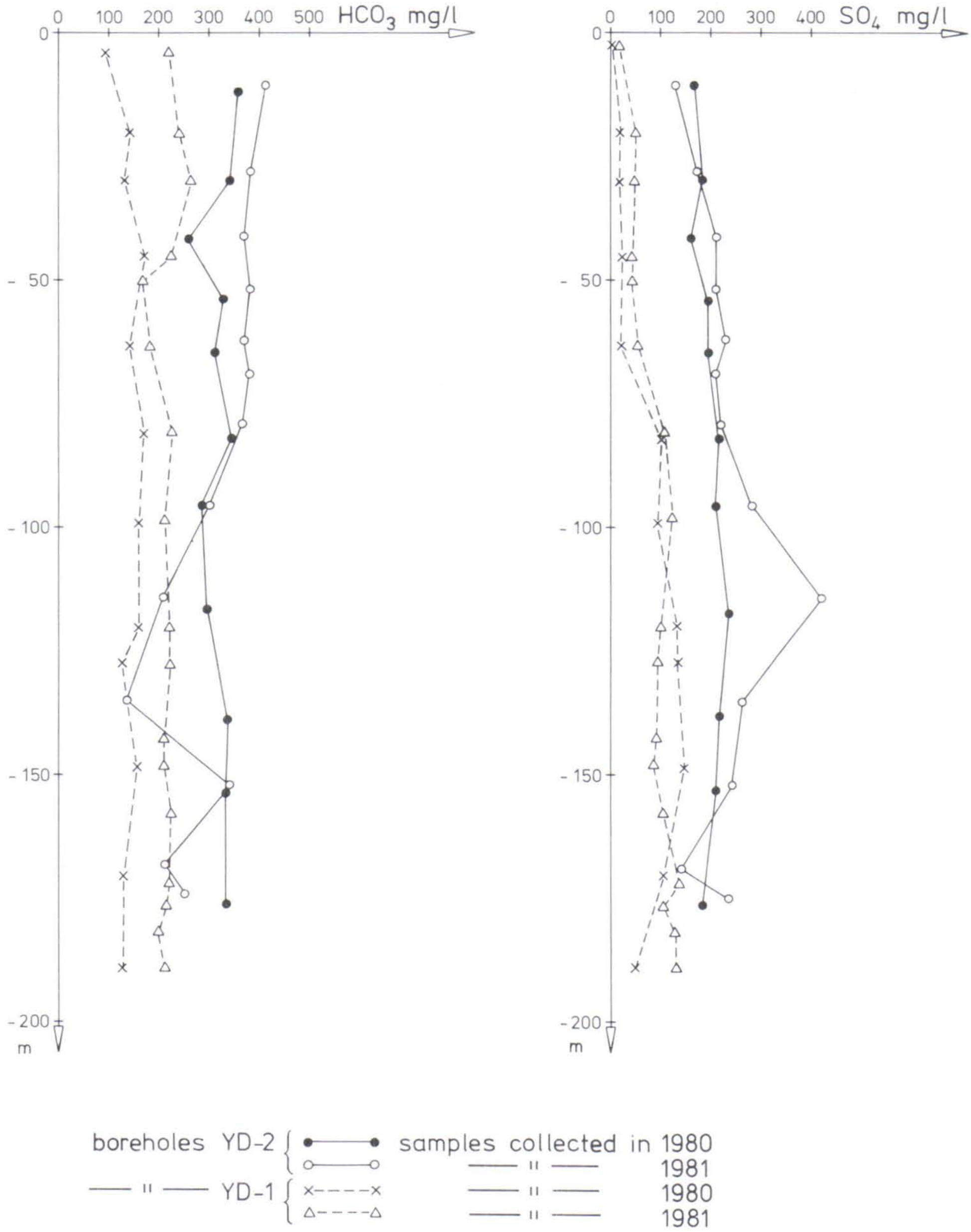

Fig. 7. HCO_3^- and SO_4^{2-} -ion content in the ground water of Olkiluoto.

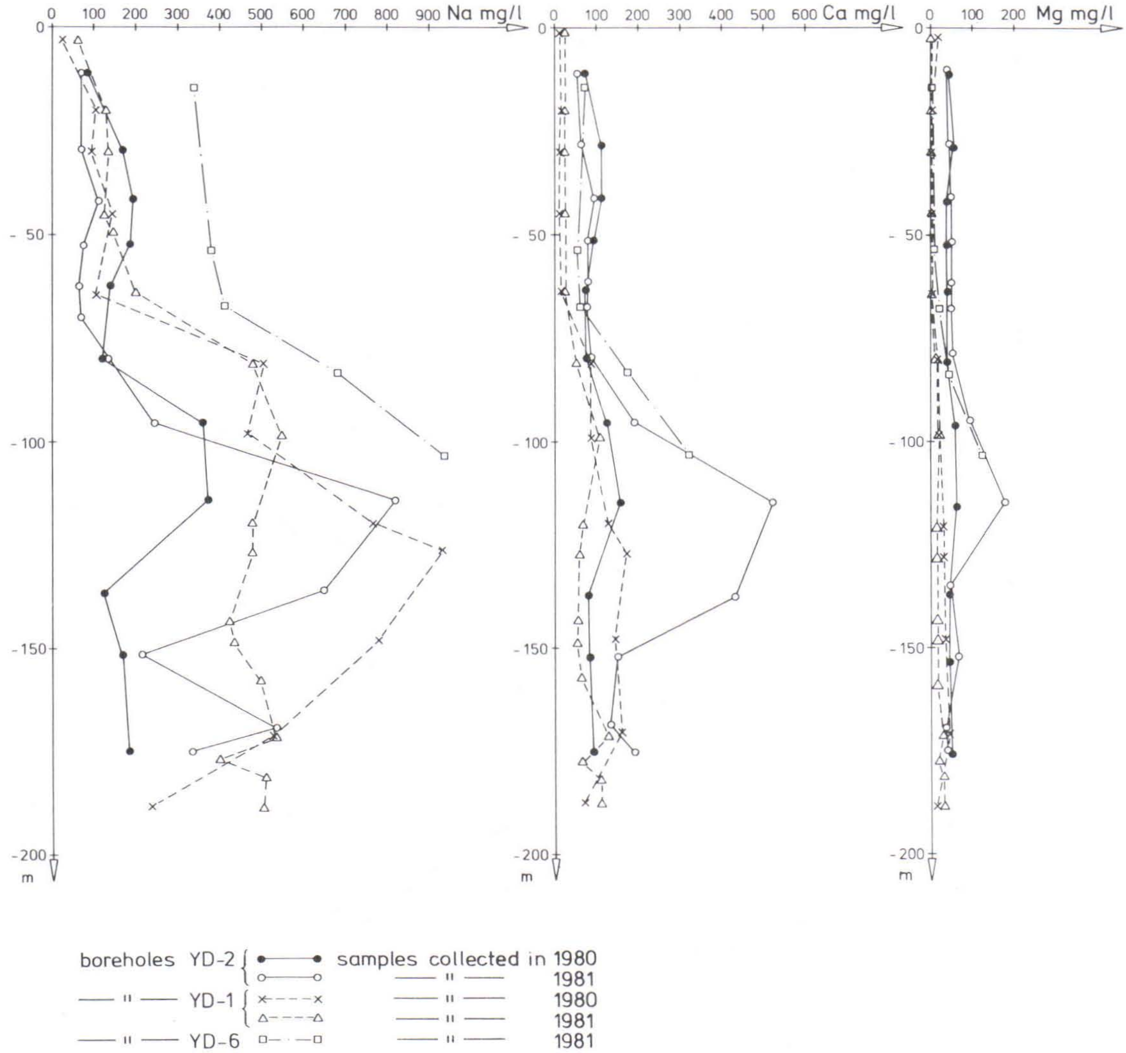

Fig. 8. Na^{+}, Ca^{2+} and Mg^{2+} -ion content in the ground water of Olkiluoto.

Table 3. Results of groundwater analyses.

Location	date of analysis	depth m	pH	Na^{+} mg/l	K^{+} mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^{-} mg/l	SO_4^{2-} mg/l	HCO_3^{-} mg/l
Seinäjoki*	July 1958	307	7.0			714	173	3700	59	104
Eura**	1963			1225	30	1032	107	4064	71	24
Olkiluoto/YD-2	July 1981	122	7.5	819	37	520	180	3110	420	201
Olkiluoto/YD-6	,,	122	7.7	930	27	320	120	2680	361	180
Olkiluoto/YD-1	Oct. 1980	136	8.1	937	19	161	30	1502	131	129

* after M. Salmi (1963)
** after J. Hyyppä (1963)

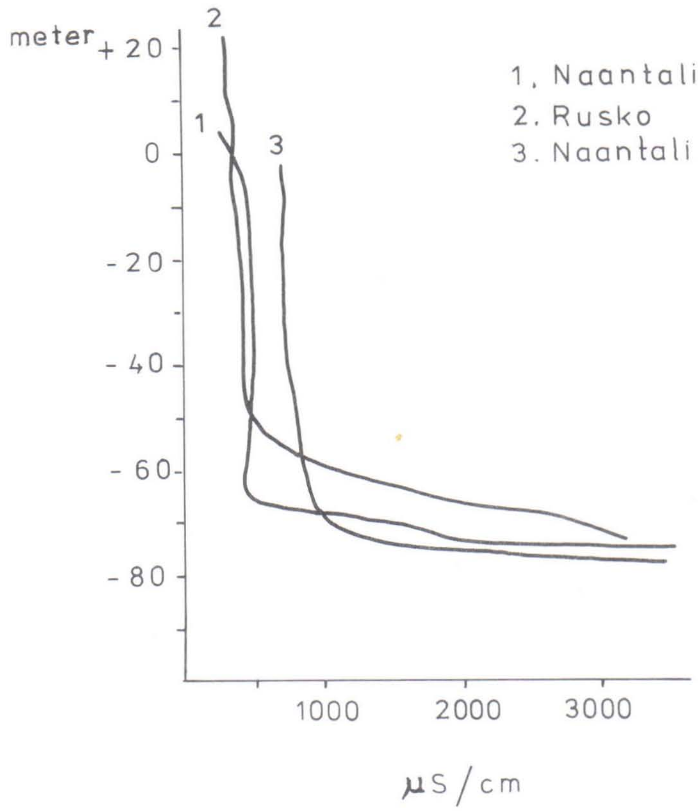

Fig. 9. Measurements of electrical conductivity in some drill holes near Turku. Variations in the electrical conductivity are caused by the salinity of the water. The content of elektrolytes increases highly every place at about the same depth. The border between the salt water and the fresh water is sharp (Ehlers & Lahermo 1981).

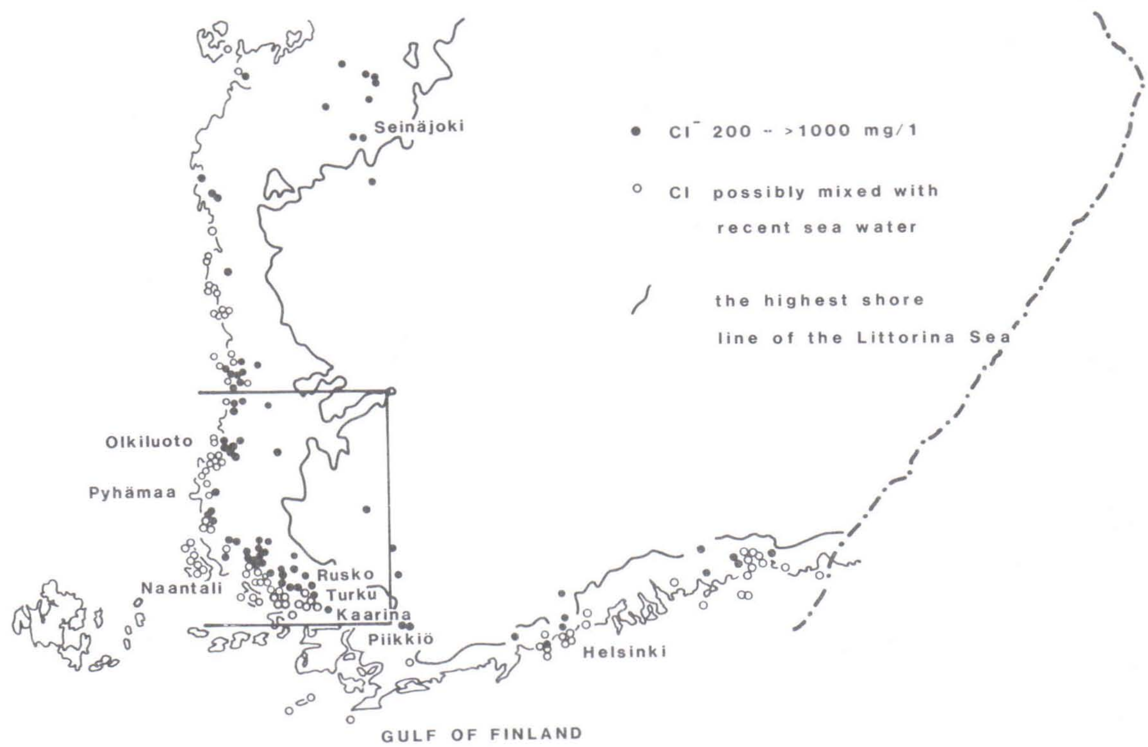

Fig. 10. Some wells with fresh and saline water in the coastal area and the highest shore line of the Littorina Sea. Some of the locations mentioned in Table 1, are presented along with the border of the study area (after Ehlers & Lahermo 1981).

For a full comparison of the relationships of ground waters — also with sea water —, the relations (ratio) of some ions are presented in Table 4.

As regards the sea water in both the Gulf of Bothnia and the Baltic Sea, the Na^+/Cl^-, K^+/Cl^-, Ca^{2+}/Cl^- and Mg^{2+}/Cl^- ratios are practically constant, and only the Ca^{2+}/Cl^- ratio recorded near the mouths of rivers may show a marked rise.

A comparison of the ratios presented in Table 4 shows that the values of the ground water from all the wells differ from that of sea water, although the Na^+/Cl^- ratios of some samples are equal. The most important circumstance in the genesis of ground water seems to be the contents of Ca^{2+} and Mg^{2+}, while in sea water the proportions are in reverse. The chemistry and genesis of the saline ground water in the coastal area of Finland have been considered by Salmi (1963), Hyyppä (1963) and Lahermo (1971). They suggest that the salinity of the ground water may be connected with the saltwater encroachment when the area was covered by the Littorina Sea (more than 1000 years BP), or it may have resulted from later infiltration of water, which dissolved the salts from the Littorina sediments.

The results of the radiocarbon datings from two boreholes on Olkiluoto (Kankainen 1981) show that the water is younger than the Littorina Sea (Table 5).

The occurence of a horizon of highly saline ground water (B_2) at Olkiluoto seems to confirm the genesis of saline water in Eura and Seinäjoki as connected with former sea water. Its extent may correspond to the maximum limit of the Littorina Sea (Fig. 10) as, according to E. Hyyppä (after Lahermo 1971, p. 21), "in the areas situated above the highest Littorina shore, the chloride concentration in the water generally does not increase when the well drilled in bedrock is deepened but actually tends to diminish".

Table 4. Range of ratios between cation concentrations (g/kg) and chloride (‰) in the Baltic Sea and the groundwater of the coastal zone.

Location	Date and/or sources of informations	Depth (m)	Ion (g/kg) / Cl^- ‰			
			Na^+	K^+	Ca^{2+}	Mg^{2+}
Baltic Sea	after K. Grasshoff and A. Voipio (1981)		0.5547 ± 0.0021	0.0203— 0.0209	—	0.0671— 0.0672
Gulf of Bothnia	Granqvist	0			0.0268	0.0698
Valassaaret	after M. Salmi (1963)	13			0.0259	0.0651
Seinäjoki	M. Salmi (1963)					
	29.03.1958	102			0.134	0.0743
	27.04.1958	200			0.167	0.0505
	16.05.1958	278			0.209	0.0615
	08.07.1958	307			0.192	0.0467
Eura	J. Hyyppä (1963)		0.3013	0.00738	0.2538	0.0263
Olkiluoto						
borehole YD-1	08.10.— 10.11.1980	29.8	1.25	0.0369	0.147	0.04
"	"	73.0	1.04	0.082	0.144	0.039
"	"	130.2	0.625	0.0149	0.0987	0.026
"	"	136.0	0.62	0.012	0.01	0.019
"	"	180	0.5072	0.0128	0.152	0.039
"	22.04.— 03.07.1981	73.0	0.925	0.0462	0.10	0.0287
"	"	130.2	0.657	0.0121	0.082	0.0246
"	"	180.2	0.53	0.010	0.124	0.033
borehole YD-2	"	122.0	0.26	0.012	0.167	0.057
borehole YD-6	"	122.0	0.34	0.010	0.119	0.04

Table 5. Results of groundwater age determinations at Olkiluoto (Kankainen 1981).

Borehole	Depth (m)	^{14}C — activity (%)	^{13}C	Average age (year)
YD-1	73.0—76.5	65.32 ± 0.69	—18.5	410—1030
YD-1	107.8—111.3	55.45 ± 0.60	—16.0	510—1180
YD-1	180.2—183.6	47.34 ± 0.67	—14.7	1150—1770
YD-2	56.7—60.2	57.38 ± 0.64	—15.1	24—440
YD-2	122.3—125.7	56.49 ± 0.62	—14.7	25—350

FLOW SYSTEM OF THE GROUND WATER IN THE BEDROCK

The results of the hydrogeologic study obtained from Olkiluoto and neighbouring areas show that the ground water movement on a regional scale is not well known and certain problems require further investigations, particularly in regard to the flow of water in the deeper part of the aquifer. However, the general model of the groundwater flow system in the study area may, according to the authors' opinion, be explained in the light of the distribution of the chemical composition of the ground water and taking into account the available hydrogeological data.

The hypothetical ground water flow system of the region is presented in Fig. 11 on the basis of previous considerations. From the point of view of the chemical composition of the ground water, the saturated zone in the bedrock may in general be devided into two sections:

— the upper part, with fresh water (zone A) and

— the deeper part, with saline water (zones B_1 — B_3)

This seems to be evident from both the paleohydrogeological history and the present processes at work in the study area.

The fresh ground water (zone A) composes a continuous horizon in the Quaternary deposits and the superficial part of the bedrock. The shape of the groundwater table conforms to the morphology of the area on a regional scale. From the point of view of the groundwater flow, it may be assumed that the horizontal extent of the main fresh ground water basins exceeds the main drainage basins of surface water (Fig. 1).

The thickness of the fresh water horizon varies in different basins and depends on the local features, such as the permeability of the rocks and the hydraulic connections within the aquifer structures as well as the local hydraulic gradient conditioned by the relations between the recharge and discharge zones. Generally, the thickness of the fresh water horizon varies from a few (in Eura about 22 m, Hyyppä 1963) to tens of meters (near Turku about 80 m, Ehlers & Lahermo 1981, and in Olkiluoto about 70—80 m).

The islands far out at sea seem to have their own local system. The precipitation on the islands forms a ''lenticle'' of fresh water, floating over salty water and flowing toward the shoreline. In the case of islands situated close to land, the replenishment of the aquifer may be more complicated because part of the fresh water originates through the infiltration of precipitation within the islands, while a part may come from the surrounding area to enter the deeper levels of the aquifer.

The fresh ground water part of the bedrock aquifer might be called the zone of intensive exchange connected with the present hydrologic cycle. The most rapid flow and, thereby, the main exchange of water takes place in the upper, weathered part of the aquifer and in the tectonic zones. With increasing depth, however, the intensity of the exchange of water diminishes gradually because of decreasing rock permeability (Fig. 5) and the hydraulic gradient of groundwater flow. This seems to indicate that the present horizon of fresh water developed as a result of the land uplift in southern Finland.

The saline ground water (zones B_1 — B_3) of the study area shows, in the authors' view, triplicity in a vertical direction:
B_1 zone of dispersion,
B_2 horizon of the highest concentration of Cl^- and Na^+ ions,
B_3 horizon of ''fossil saline ground water''.

This partition may be regarded as a conventional measure because some of problems have not been discussed in the literature before and further hydrogeological investigations may induce other considerations.

1) The upper part of the saline water (zone B_1) seems to compose the transitional zone — a zone of dispersion — between the fresh water and highly saline horizons (see Fig. 11). In theory, the thickness of the dispersion zone may be variable and even reduced to zero. It depends on the fluctuations of the water table and the velocities of ground water flows (De Wiest 1965).
In the region studied, the thickness of the dispersion zone varies from about ten meters at Olkiluoto to over 100 m in the inland area far from the coast (borehole at Eura).

2) The horizon of the highest concentrations of Cl^- and Na^+ ions (zone B_2) seems to be, as suggested by Salmi (1963) and Hyyppä (1963), the relict water of the Littorina Sea. Its extent might correspond with the maximum limit of the contemporaneous sea and create a regional horizon. However, it may happen that it will not be confirmed by new boreholes in some areas because the horizons are not restored once the highly saline water has been pumped out.

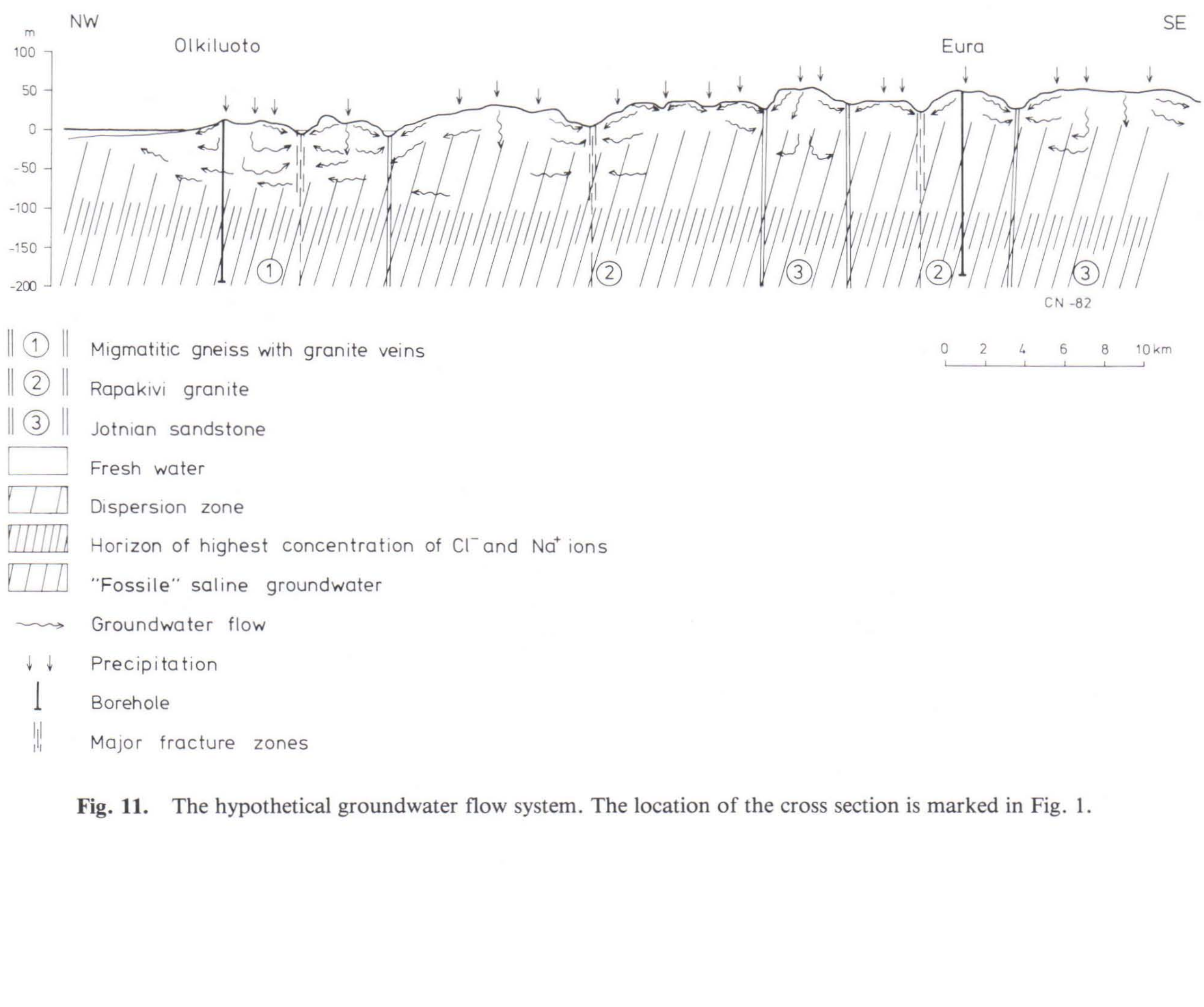

Fig. 11. The hypothetical groundwater flow system. The location of the cross section is marked in Fig. 1.

3) The deepest horizon (zone B_3) seems to contain the oldest water of the examined profile. The chemical composition of the water and the hydrodynamic conditions of that part of the aquifer are not known well because of the scattered nature of the observations on record.
However, taking occurrence of the middle horizon and other hydrogeological factors into account, it may be supposed that the water chemistry has been conditioned by a diffusive process. This horizon may be recognized as ''fossil saline ground water.''

As for the flow conditions of the saline water, the low permeability of the rock and the low hydraulic gradient cause a slow movement of water in the dispersion zone. The horizon of high salinity probably forms the border of water exchange. However, its position is neither static nor constant. The main reason for this seems to be the afore-mentioned land uplift of southern Finland.

CONCLUSION

The basic problem in the case of plans for the final underground disposal of nuclear wastes in stable crystalline formations involves proper estimation of the field conditions that govern the movement of ground water; for the only means by which radioactive nuclides could escape to the biosphere is the flow of ground water. The results presented concerning hydrogeological conditions refer to the 200 m zone, which comprises:

— the zone of intensive exchange of water — fresh water,
— the zone of leisurely exchange — the dispersion zone, i.e., the upper part, containing saline water, and
— the horizons of the highest concentrations of Cl^- and Na^+ ions and, at a lower level, the ''fossil'' saline ground water, where exchange of water takes place over time on a geological scale.

It would seem that full confirmation of the foregoing considerations demands further investigations, mainly with regard to the permeability of rocks and hydraulic gradients as well as the chemical composition of ground water. The results arrived at do not suffice to form yet any final conclusions about the suitability of the bedrock in the coastal area for the disposal of radioactive wastes.

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