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Analysis of groundwater from deep boreholes in Kråkemåla, Sternö and Finnsjön

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IVL
Stockholm, Sweden, 1982-12-22

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ANALYSIS OF GROUNDWATER FROM DEEP BOREHOLES IN KRÅKEMÅLA, STERNÖ AND FINNSJÖN

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This report concerns a study which was conducted for SKBF/KBS. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

A list of other reports published in this series during 1982, 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) and 1981 (TR 81-17) is available through SKBF/KBS.

ANALYSIS OF GROUNDWATER FROM DEEP BOREHOLES IN KRÅKEMÅLA, STERNÖ AND FINNSJÖN

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SUMMARY

Groundwater from deep boreholes in granitic rock at three different sites in Sweden - Finnsjön, Kråkemåla and Sternö - has been sampled and analysed. A total of ten different boreholes have been sampled; one at Kråkemåla, two at Sternö and seven at Finnsjön.

In general four levels per hole containing water-bearing fractures have been selected. Prior to sampling, a water-bearing level is isolated between packer sleeves. The deepest levels are down to about 500 m. The sampling was carried out by the Geological Survey of Sweden and a number of laboratories have participated in the water analyses.

The present report is a presentation of the results of the groundwater analyses. The reliability of the results is discussed but there is no evaluation in relation to geology and hydrogeology. This report will present the basic results from the groundwater analyses to be further evaluated by experts in different fields.

CONTENTS Page

APPENDICES

ANALYSIS OF GROUNDWATER FROM DEEP BOREHOLES in Kråkemåla, Sternö and Finnsjön

1 INTRODUCTION

Groundwater from Finnsjön, Kråkemåla and Sternö (Karlshamn) has been sampled and analysed. The sampling was carried out by the Geological Survey of Sweden. A number of laboratories have participated in the water analysis (see below).

A total of ten different boreholes have been sampled - one at Kråkemåla (K), two at Sternö (KA) and seven at Finnsjön (FI). Prior to sampling, the holes were pumped out with an airlift using nitrogen and, in most cases, allowed to stand undisturbed for over a year after that. The selected fracture zones were enclosed between packer sleeves, 2.7 m apart.

Sampling was carried out during the period from December 1977 to February 1982. In most cases, four levels were sampled per hole. Pumping was done without interruption for about one month at each level. Between 4 and 13 cubic metres of water were pumped from each fracture or fracture zone.

The present report consists primarily of a presentation of the results of the groundwater analyses. The reliability of the results is subjected to some scrutiny. There is, however, no evaluation in relation to geology or hydrology. The material in this report will be further processed by experts in different fields.

The geology and hydrology of the test areas has been described in KBS TR 61, 79-02, 79-05, 79-06, 79-09, 79-12, 80-01 and 80-10.

A general description of the chemistry of groundwater from great depths in granite and gneiss has previously been presented by G Jacks (KBS TR 88). The same author has also described the chemistry of groundwater in Blekinge (KBS TR 79-07), where Sternö is situated. A geochemical evaluation of fracture minerals and the relationship between fracture minerals and groundwater composition in Finnsjön has been published by E-L Tullborg and S Å Larson (KBS TR 82-20). The expected groundwater composition and its importance for the final storage of radioactive waste have been discussed in KBS TR 90 and the final report KBS-2 Volume 2 (Handling and Final Storage of Unreprocessed Spent Fuel, Technical Volume). Hydrology and groundwater age are also taken up in the latter report.

2 SAMPLING

2.1 Drilling water

Some of the drilling water that is used in the core drilling of the sampling holes can enter rock fractures and contaminate the groundwater there. In order to get rid of the groundwater that has been contaminated with drilling water so that the original, undisturbed groundwater can be sampled, long pumping times are used. Periodic sampling during a pumping period makes it possible to follow changes in the composition of the water that might derive from drilling water or some other source of contamination.

Water from percurssion-drilled boreholes was used as drilling water at Kråkemåla and Sternö, while lake water was used at Finnsjön. The drilling water from Sternö and from the FI4-FI8 boreholes at Finnsjön was filtered through mechanical filters of cellulose (18 CMC 3-2), which are supposed to retain particles with a diameter larger than 5 um. Previously, unfiltered water was used.

The filtered drilling water was then analysed. The results are presented in connection with the corresponding groundwater analyses from the different areas (see Table 1-9). Drilling water is designated KS (Kråkemåla), SS (Sternö) and FS (Finnsjön).

1.2 Sampling equipment

A schematic illustration of the equipment is shown in Fig. 1.

The boreholes are core-drilled with a diameter of 56 mm. The 2.7 m long sampling zone is sealed off by rubber packers that are expanded at 0.8-1 MPa above the groundwater pressure. The sampling pump is positioned immediately above the sealed-off zone. The intake is from the upper part of the zone. The pump, which is made of steel and provided with teflon seals, has a maximum capacity of 0.12 l/stroke, equivalent to 330 l/d. The water flow available for sampling decreases if the flow of water in the measured rock is lower than the capacity of the pump.

3 MAIN COMPONENTS OF WATER

Water samples were sent for analysis to AB Hydroconsult (Kråkemåla, Sternö and Finnsjön), the National Laboratory for Agricultural chemistry (Finnsjön) and the Geological Survey of Sweden's water laboratory (Finnsjön). pH was also measured in the field. The analysis results are presented in tables 1-9. In order to permit comparison with the water used as drilling fluid, the results of the analysis of this water are given at the end of each table.

The sample water was collected in 10-litre plastic containers, which were kept in a cool, dark place until the sample for analysis was prepared. The time during which the water was kept in the plastic containers varied from some hours to several months.

For determination of negative ions, pH, conductivity and organic carbon, samples were taken in bottles of borosilicate glass, and for metal ions in plastic bottles.

The metal samples were acidified before further storage. The pH determinations in the field were done immediately on water poured into a flask, except in FI8, where a closed system was used.

One level (FI1, 293m) shows increasing levels of sodium, chloride and phosphate and decreasing levels of calcium, magnesium and nitrate. Four other sampling levels (FI4, 247m; FI7, 301m; FI7, 322m and FI8, 215m) differ from the others in that they exhibit large and systematic differences between sampling occasions. These zones are dealt with separately in 3.1. In no case can the differences be explained by simple dilution with drilling water. The probable reason for the scatter is that water from different aquifers has been affected by the sampling. Three other zones (FI4, 368m; FI5, 141m and FI5, 205m) with greater scatter than average are dealt with in 3.1.5.

The precision in the other analyses is discussed in 3.2-3.5. Zones dealt with under 3.1 are not included in this assessment, and in order to facilitate study of the tables, these zones are marked with an asterisk. (Tables 3, 6 and 9).

3.1 Some deviant sampling zones

3.1.1 FI4, 247m exhibits the largest differences in concentrations during a sampling period and gives a much more fragmented picture than other levels. With the exception of HCO_3, the analysis parameters have their lowest concentrations in the last-sampled water and the highest concentrations in the middle sampling.

Chloride in particular has a very high concentration in the middle sample. Since chloride is one of the main components, an incorrect analysis should show clearly in the ratio between cations and anions.

We find, however, the ratio 12.1:12.4, 16.9:16.9 and 9.2:9.2 in the 1st, 2nd and 3rd samples, respectively. We find the largest error in the 1st sample, and it is only about 3%. We can therefore conclude that the determination of main components is probably accurate and that the scatter must have another reason.

3.1.2 FI7, 301m shows large differences in concentrations during the sampling procedure, but here as well, the concentrations match each other so well that it is out of the question that the large deviations between the sampling occasions could be due to analysis error.

In this case, the low concentrations at the start of the sampling period could be due to dilution of the groundwater with drilling water, which is also confirmed by the tritium analyses.

If, however, the ratio of groundwater to flushing water is calculated for the middle sample on the basis of the last sample and the drilling water analysis, the results are:

1:2 figured on Ca, Mg and Na

1:5 figured on Cl and SO_4

4.5:1 figured on TOC.

It can therefore not be a question of a mixture of these two waters. This is further confirmed by HCO_3, which reaches its highest value in the middle sample.

The conclusion must be that an intrusion of older, considerably saltier water has taken place in an aquifer of recent groundwater.

3.1.3 FI7, 322m gives the same picture as 3.1.2 but with much smaller deviations. Here, the first sample gives the highest concentrations of the main components Ca, Na, Cl and SO_4, which makes the admixture of drilling water less probable. Here as well, the change in HCO_3 concentration follows a deviant pattern.

3.1.4 FI8, 215m. The main components Ca, Na, Cl and SO_4 have lower concentrations at the start of the sampling period and follow each other with good agreement. All other components with measurable concentrations increase in concentration, however, and there is a large scatter between the concentrations of different components.

3.1.5 The deviations in FI4, 368m, FI5, 141m and FI5, 205m are relatively small and appear to be random. They can be explained by the fact that analysis error occasionally exceeds 8%.

3.2 pH and conductivity

The pH of the water was determined both directly in the field and in the laboratory. A precision better than ± 0.05 pH units can hardly be expected for pH measurements that were not performed at the same time. If the fact that the samples were shipped and stored for different lengths of time prior to measurement is also taken into account, an accuracy of ± 0.1 pH units can be considered good.

The discrepancy between field pH and laboratory pH is less than 5% for the Kråkemåla samples. The field values are generally higher than the laboratory values, which is not unusual for groundwater samples.

The field and laboratory values for pH from Sternö are in good agreement.

For Finnsjön, there is a considerable discrepancy between field and laboratory pH values. The large change in the field values during a pumping period, which is not in any way reflected in the corresponding laboratory values, indicates drift in the measuring equipment in the field. This must be taken into consideration in any attempt to evaluate these results.

An accuracy of ±5% is acceptable for conductivity. Only in two cases (FI1, 293m and FI5, 297m) are there greater deviations. In the first case, other analyses provide some support for a lower value.

3.3 Organic carbon (TOC)

The scatter in the analysis results within the levels is relatively high. Precision in carbon determination and low concentrations is, however, relatively poor for most types of analysis instruments.

3.4 Negative ions

The negative ions are presented in tables 4-6. In general, the results show good consistency within the zones. Only with regard to nitrate has reason been found to undertake a special examination (see 3.4.6).

3.4.1 As a rule, the scatter in analysis results for BICARBONATE within a zone is <<5%. Only in three cases with low concentrations were considerable deviations noted. Two of these samples have concentrations of <20 mg/l, which are the lowest concentrations noted in this study. The deviations may be due to special difficulties in analysing samples with such low concentrations and/or poorer stability of the samples.

3.4.2 CHLORIDE. In connection with the determination of the ratio between bromide and chloride (6) at 10 of the levels with high salt content, chloride determination was carried out by potentiometric titration and Gran evaluation. A comparison with previous results showed that the normal variation in the analysis results is probably ±5%. In one case, the difference was 10%.

3.4.3 The FLUORIDE concentration for Kråkemåla is around 3-7 mg/l. For other areas, the concentration is 1-2 mg/l. There is no great variation in the concentrations within the zones.

3.4.4 Not unexpectedly, the highest concentrations of SULPHATE are found in the salty waters. The ratio between chloride and sulphate varies considerably, however. At Sternö, the sulphate concentrations are HIGHER than the chloride concentrations.

3.4.5 The PHOSPHATE concentrations show good agreement within the zones. There is only one deviant value (FI5, 297m), but it is accompanied by an unexpectedly high content of total iron.

The highest concentrations were measured at Kråkemåla and the lowest at Sternö and Finnsjön, level 6 and 8.

3.4.6 NITRATE and NITRITE. Determination of these parameters was associated with some difficulties, which is why a number of values have not been included in this report. The Geological Survey of Sweden reported its values with low analysis sensitivity (<1 mg/l).

Of the analyses presented, the results from sampling at four levels (see the table below) show scatter in all nitrogen parameters. The first four columns in the table show the concentrations figured as NH_4, NO_2, NO_3 and the sum of these in mg/l. The last four columns give the equivalent content of nitrogen. As can be seen from the table, the nitrogen content is relatively constant, which strongly supports the correctness of the analyses. The redox shift is not reflected by the Fe^{2+} concentrations, however.

	NH4	NO2	NO3	Sum	NH4-N	NO2-N	NO3-N	Sum-N
K1, 491m	.05	.21	.11	.37	.039	.064	.025	.13
	.09	.07	.08	.24	.070	.021	.018	.11
	.14	.02	.07	.23	.109	.006	.016	.13
	.12	<.01	.07	.20	.093	<.003	.016	.11
KA3, 312m	.02	.02	.80	.84	.015	.006	.181	.20
	.02	.02	.64	.68	.015	.006	.145	.17
	.15	.03	.22	.40	.116	.009	.050	.17
	.02	.02	.63	.67	.015	.006	.142	.16
KA4, 397m	.02	.02	.57	.61	.015	.006	.129	.15
	.16	.03	.01	.20	.124	.009	.002	.14
	.15	.01	.05	.21	.116	.003	.011	.13
	.06	.21	.16	.43	.047	.064	.036	.15
FI5, 205m	.75	.04	<.01	.80	.582	.012	<.002	.60
	.85	.03	<.01	.89	.660	.012	<.002	.67
	.86	.02	<.01	.89	.668	.006	<.002	.68
	.87	.03	<.01	.91	.675	.009	<.002	.69
	.03	2.20	<.01	2.33	.023	.670	<.002	.69

3.5 Positive ions

The positive ions are presented in tables 7-9. As with the negative ions, consistency within the levels is generally good. Scatter in the magnesium value, however, appears to be more common than in other ions. The scatter in the results from the analysis of FI7 and FI8 is exceptionally high. Some zones with scatter in the ammonia results have been discussed in 3.4.6. Only iron is examined more closely below.

3.5.1 IRON exhibits some deviant values.

ST3, 232m: Consistently high values of both the iron parameters verify the correctness of the analysis. It is difficult to determine whether contamination is involved. Only magnesium and nitrate (both uncertain) show their lowest values here, while total N is slightly elevated, as are several other ions.

ST4, 397m: The first sample has a high concentration of iron(II), but surprisingly enough also a high nitrate concentration, while other samples are low. The entire Sternö area in general has a high proportion of iron(II).

The three low values could therefore be the incorrect ones, due to the samples having, for example, been in contact with air before they were acidified. The same explanation may apply in a couple of other cases with exceptionally low concentrations of iron(II).

FI5, 297m: The high total iron concentration is accompanied by a high phosphate concentration. The concentration of iron(II) is unaffected.

FI8, 442m: Total iron has its highest value in the first water and its lowest volume in the second. An examination of other analyses shows that a mixing of different groundwaters may be involved here.

4 TRACE ELEMENT ANALYSIS

The trace element analysis (table 15) was performed by the Geological Survey of Sweden's water laboratory in Uppsala with a computer-controlled emission spectrophotometer equipped with ICP. A total of 14 water samples from Finnsjön were analysed, all from different levels.

A pronounced correlation exists only between barium, strontium and calcium. The strontium concentrations (0.2-13 mg/l) are higher than the barium concentrations (0.02-0.11 mg/l).

Calcium and silicon are analysed both as trace element (T) and as main component (M). In the table below, the trace element analysis and the mean value (Mv) of all samples on the level according to tables 6 and 9 are given. If there is a sample that shows better agreement for BOTH calcium and silicon than the mean value does, this value (best value, Bv) is also given in the table.

	Calcium			Silicon dioxide		
	T	M		T	M	
		Mv	Bv		Mv	Bv
FI1, 206m	61.4	60		17.5	17.7	
293m	61.0	55.7		16.5	17	
FI4, 152m	23.1	23.8	23	16.1	14	15
247m	71.5	46.7		14.6	13.3	
368m	21.3	22.5		20.3	15.3	
534m	22.5	22		19.9	13	
FI5, 141m	603	641		14.1	10.7	
205m	863	896	875	11.5	8.7	10
297m	1384	1487		13.9	10.1	
384m	1614	1770	1730	13.5	11.7	12
FI7, 123m	37.6	30.3	36	17.5	15.3	16
301m	117	74	114	7.7	12.2	7.7
322m	113	108	107	14.1	12.7	14
511m	146	145		11.3	12	

The fact that the silicon concentration according to T is significantly higher than according to M can be explained by the fact that the total concentration of silicon was determined as trace element (emission). In the determination of main components only the dissolved portion of SiO_2 was determined (colorimetry).

If we disregard FI4, 247m and use the best value wherever one is available, the mean deviation between S and H for CALCIUM is 4.1% ± 2.8%. Deviations of this magnitude between analyses performed on two different occasions, by two different laboratories and/or with two different methods must be regarded as satisfactory.

5 ISOTOPE ANALYSIS AND DATING

The purpose of the isotope analyses was two fold: to date the groundwater and to characterize it.

The analyses whose results are presented in tables 11-13 were performed by the following laboratories:
Harwell, England: U-Th, deuterium
Department of Hydrology, Uppsala: ^{18}O (in water)
The Laboratory for Isotope Geology, Stockholm: ^{14}C, ^{13}C, ^{18}O (in carbonate), deuterium (in water) and S-34 (in sulphate)

5.1 Carbon isotopes and tritium

The carbon isotope analysis is performed for the purpose of direct dating of the water. The age obtained by ^{14}C analysis is presented in tables 11-13 as "Age BP" (BP = before present), and the age after correction based on ^{13}C as "Age BP, Corr ^{13}C".

The tritium determination (Table 11-13) was used to estimate the amount of surface water in the groundwater.

5.1.1 Sample preparation: Carbonate for determination of carbon isotopes and ^{18}C were precipitated in the field with the aid of an alkaline barium suspension. The precipitation was performed in a stainless steel cylindrical container with a conical bottom.

The container, which holds 67 l and was filled with nitrogen from the beginning, was filled with water (usually during the night). The alkaline barium solution was added, the solution was mixed and the precipitate allowed to settle until the next day. One litre of suspension was tapped off from the bottom of the container to a glass bottle and sent to the laboratory for analysis. In cases of small precipitate volumes, two precipitations were performed.

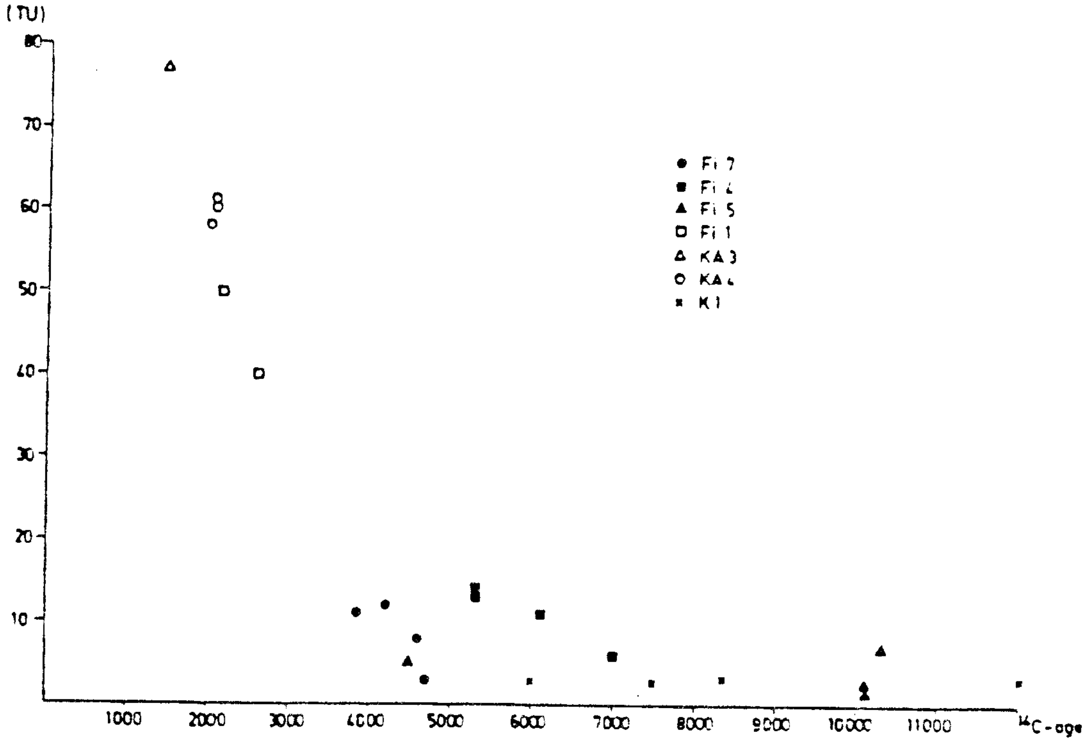
The precipitation was particularly difficult to perform in samples with a high salt content, since very voluminous precipitates were obtained.

5.1.2 Dating with the ^{14}C method is dealt with by Barbro Johansson in Appendix 1.

5.1.3 Owing to its short half-life (about 12 years), tritium is an important isotope for hydrological studies. The amount of tritium in the atmosphere has risen drastically due to nuclear fission experiments. The tritium concentration in rainwater has increased more than 10 times, which makes it possible to determine whether there is any recent water in a groundwater.

In the tables, the tritium concentration is given in the unit TU, which is the number of tritium atoms per 10^{18} hydrogen atoms.

5.1.4 The correlation between tritium concentration and ^{14}C age is good, as is shown by the figure below. The tritium concentrations are, however, unreasonably high for water of this age. The natural conclusion is therefore that the borehole waters are mixtures of very old groundwater and surface water.



5.2 Stable oxygen and hydrogen isotopes

The analysis results are presented in tables 11-13.

The ratio between the oxygen isotopes is determined both on precipitated carbonate (5.1) and water. The value for ^{18}C is given as deviation in o/oo from "Standard Mean Oceanic Water" (SMOW). See also appendix 2.

5.3 Uranium and thorium

Uranium and the ratio between different uranium and thorium isotopes was determined in three boreholes at Finnsjön. The results are presented in the table below.

BH Depth DATE
(Tabell)

BH	Depth	Date	U, ug/1	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$
ST4	397	800312	.56	1.50	.22	4.6
FI1	206	801021	.34	1.50	.121	3.2
FI1	293	801111	.34	2.41	.119	3.2
FI4	368	800429	.38	2.34	.55	5.9
FI4	534	800528	1.19	2.13	.13	5.5
FI5	297	800428	1.01	3.03	.026	4.0
FI5	384	800528	.38	3.02	.031	
FI7	123	800827	.40	2.35	.144	14.3
FI7	302	801007	.24	2.67	.047	5.2
FI7	322	801028	.24	2.68	.157	5.9
FI7	511	801119	.36	2.24	.054	11.0
RE			8.7%	9.7%	16%	39%
s-RE			5.3%	5.7%	11%	9.4%

Individual standard deviations are specified for the values given in the table. The "mean relative error" (RE) and its standard deviation (s-RE) were calculated.

The analyses were used for dating, among other things. Appendix 3 contains a calculation of the fraction of modern water in the borehole water on the basis of the ratio between ^{234}U and ^{238}U.

5.9 Sulphur isotope

The sample water was precipitated with an acid barium solution directly in the plastic container at sampling. ^{34}S was determined on the precipitate.

BH	Depth, m	^{34}S, %
FI7	302	35.6
FI7	322	31.7
FI7	511	28.3

6 BROMIDE/CHLORIDE RATIO

The analyses were performed by C. Haraldsson, Department of Analytical and Marine Chemistry, Chalmers University of Technology (Nov. 1982). The chloride was determined by means of potentiometric titration with Gran evaluation. The bromide was extracted and then determined colorimetrically. The standard deviation is 8.8% figured on three diluted standard sea waters, i.e. ± 0.31.

The analyses of FI5, 205m were performed on the water sampled on 80-01-29. Other analyses were performed on the most recently sampled water on the level.

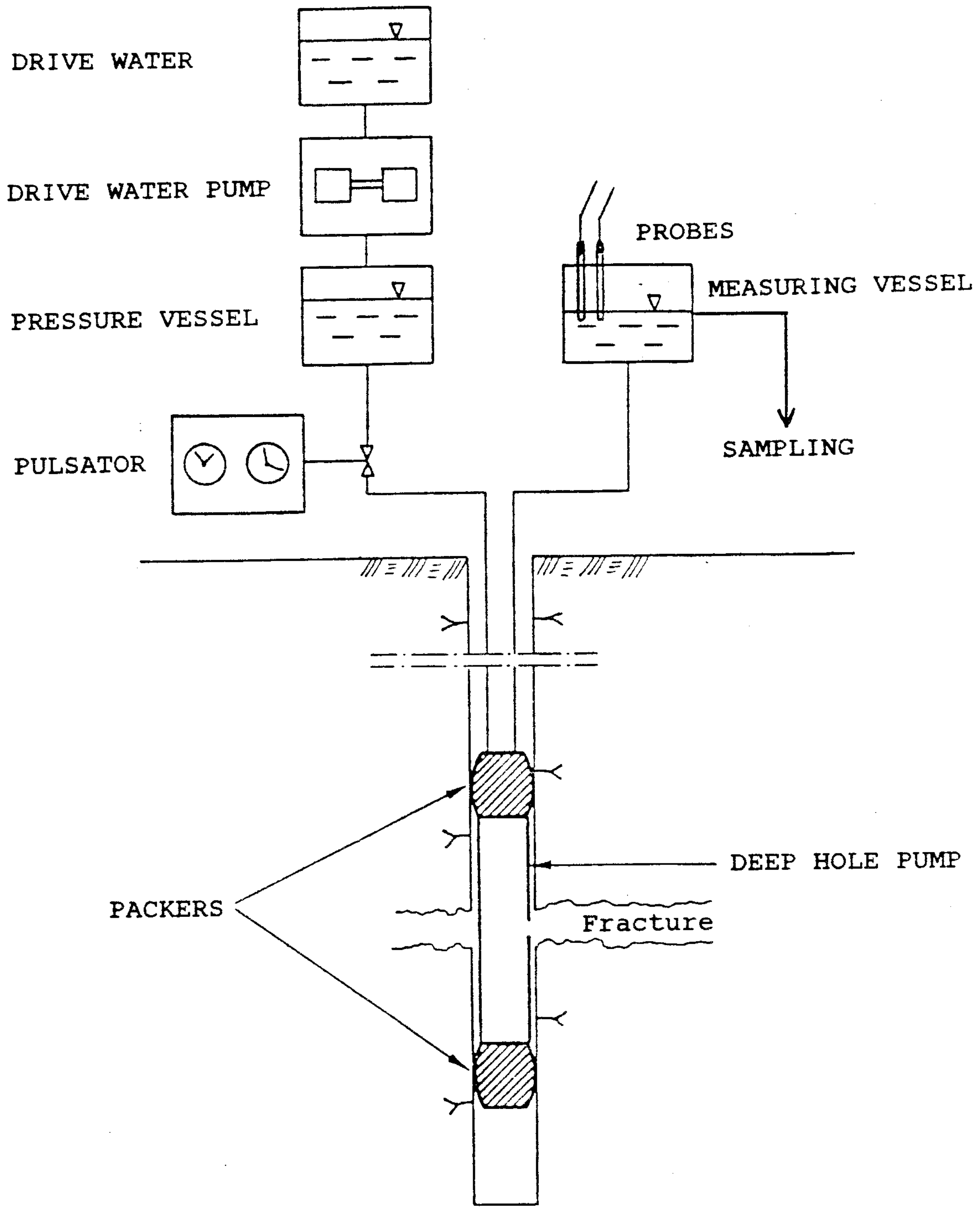
	Chloride g/l	Bromide mg/l	Br/Cl*1000
FI5, 205m	3.42	16	4.70
297m	4.61	27	5.88
384m	5.27	35	6.55
FI6, 250m	4.46	23	5.21
398m	5.36	37	6.91
688m	5.68	37	6.53
FI7, 511m	0.56	1.7	3.10
FI8, 215m	4.31	33	7.57
317m	4.29	33	7.61
442m	4.64	36	7.75
St. seawater	19.353	67.3	3.48

7 GAS ANALYSIS

Samples for gas analysis were taken in borehole 6 from the 685 and 698 m levels on the 14th and 20th of October, respectively.

The analyses were performed by AGA and the results are presented in the table below.

Depth:	685 m	698 m
Nitrogen, %	88.4	87.5
Helium, %	8.5	9.4
Argon, %	0.96	0.87
Oxygen, %	0.23	0.17
Methane, %	0.029	0.022
Carbon dioxide, %	0.0092	0.0081
Hydrogen, %	<.005	<.005
Carbon monoxide, %	<.001	<.001



SCHEMATIC ILLUSTRATION OF SAMPLING EQUIPMENT

KRAKEMALA - pH, conductivity and TOC

Bore-hole	Depth	Date	pH field	pH	Cond mS/m	TOC mg/l
K1	103					
		780828	7.7	7.3	34	5.1
		780908	7.6	7.3	34	5.0
		780919	7.7	7.3	34	5.4
		780925	7.7	7.3	34	5.2
K1	264					
		780730	8.1	7.9	37	4.2
		780809	8.1	7.9	37	3.8
		780815	8.1	7.9	37	2.7
		780824	8.1	7.9	40	4.0
K1	406					
		780530	8.4	8.2	105	2.6
		780601	8.4	8.2	110	2.4
		780606	8.4	8.1	112	2.8
		780613	8.4	8.1	112	2.6
		780622	8.3	8.2	110	2.5
K1	491					
		780703	8.1	7.8	43	4.1
		780712	8.1	7.8	43	4.1
		780716	8.2	7.8	44	4.0
		780725	8.1	7.8	45	3.9
KS						
		790820		6.9	36	5.2

Table 2

STERNÖ - pH, conductivity and TOC

Bore-hole	Depth	Date	pH field	pH	Cond mS/m	TOC mg/l
KA3	232					
		791031	6.4	6.3	67	22.0
		791128	6.3	6.3	64	22.0
		791206	6.3	6.3	65	21.0
		791214	6.3	6.3	64	23.0
KA4	226					
		800318	7.2	7.3	69	4.6
		800320	7.3	7.5	69	4.4
KA4	312					
		800123	7.3	7.3	67	4.6
		800130	7.1	7.6	66	5.0
		800206	7.3	7.3	66	5.0
		800213	7.2	7.3	66	4.6
KA4	397					
		800220	7.2	7.3	70	4.6
		800227	7.3	7.3	71	4.4
		800305	7.3	7.3	71	4.6
		800312	7.3	7.3	71	4.6
SS						
		781123		7.6	17	3.6
		781207		7.7	17	3.4

Table 3a

FINNSJÖN - pH, conductivity and TOC

Bore-hole	Depth	Date	pH field	pH	Cond mS/m	TOC mg/l
FI1	206					
		801009	7.3	7.4	43	10.1
		801014	7.3	7.6	44	11.0
		801021	7.1	7.5	46	11.0
FI1	293					
		801030		7.5	47	9.6
		801105	7.2	7.5	57	9.3
		801111	7.1	7.6	55	9.8
FI2	385					
		771203		7.8	51	9.8
		771207		7.7	52	9.8
FI4	152					
		791026	8.5	8.1	99	9.2
		791030	8.4	7.9	95	8.6
		791204	8.7	7.9	97	8.4
		791212	8.8	7.9	94	10.0
FI4	247					
		800117	9.1	8.0	120	8.6
		800123	9.1	7.8	160	8.4
		800229	8.0	7.8	78	10.0
FI4	368					
		800314	8.4	7.9	77	10.6
		800328	8.1	7.9	76	9.0
		800426	7.6	7.8	78	8.4
		800429	7.7	7.8	77	7.8
FI4	534					
		800507	7.7	7.8	78	7.8
		800514	7.8	7.8	78	7.8
		800521	7.6	7.7	77	7.8
		800528	7.7	7.8	77	8.0

Table 3b

FINNSJÖN - pH, conductivity and TOC

Bore-hole	Depth	Date	pH field	pH	Cond mS/m	TOC mg/l
FI5	141					
		790814		7.5	830	3.6
		790911	7.6	7.7	760	4.0
		791003	7.7	7.7	750	4.2
		791018	7.8	7.6	750	4.2
		791206	8.4	7.6	730	3.8
FI5	205					
		800118	8.6	7.6	960	4.3
		800125	8.8	7.7	950	3.7
		800129	8.7	7.6	940	3.9
		800208	7.9	7.6	910	3.8
		800215	7.9	7.3	900	3.6
FI5	297					
		800320	8.4	7.6	1250	3.0
		800328	8.3	7.6	1300	2.8
		800411	8.3	7.4	1200	1.9
		800417	7.8	7.4	1200	1.9
		800422	8.0	7.0	1200	1.9
		800428	7.8	7.6	1550	1.6
FI5	384					
		800514	7.8	7.4	1800	1.2
		800521	7.6	7.4	1850	1.0
		800528	7.7	7.5	1850	1.2
FI6	184					
		810716	7.9	7.6	790	
		810726	7.6	7.7	798	
		810730	7.7	7.8	790	
		810806	7.6	7.7	795	
FI6	250					
		810818	7.2	7.6	1320	
		810908	7.4	7.5	1310	
FI6	398					
		810916	8.4	7.1	1560	
		811007	8.3	7.3	1600	
FI6	688					
		811022	8.7	7.1	1670	
		811103	8.3	7.1	1670	

FINNSJÖN - pH, conductivity and TOC

Bore-hole	Depth	Date	pH field	pH	Cond mS/m	TOC mg/l
FI7	123					
		800902		7.8	50	6.2
		800919		8.1	53	5.5
		800927		7.9	52	6.2
FI7	301					
		800910		7.9	97	6.2
		800917	7.9	7.9	81	6.6
		801008	8.3	8.3	230	4.4
FI7	322					
		801015	7.9	8.3	160	6.0
		801022	7.8	8.4	137	6.2
		801028		8.2	152	6.0
FI7	511					
		801105	8.0	8.2	190	5.6
		801111	7.8	8.1	190	5.4
		801119	7.9	8.1	190	5.7
FI8	103					
		810716	7.8	8.2	160	
		810726	7.7	8.0	170	
		810731	7.9	7.9	155	
FI8	196					
		810818	7.8	7.8	860	
		810902	7.2	7.7	980	
		810908	7.2	7.4	1200	
FI8	283					
		810923	7.6	7.3	1320	
		811012	7.6	7.2	1290	
FI8	395					
		820113	8.0	8.4	1350	
		820121	8.0	8.4	1360	
		820128	8.6	8.3	1350	
		820203	8.8	7.9	1290	
FS						
		780502		7.0	9	16.0
		780502		6.9	8	16.6
		780502		7.1	9	16.8

KRAKEMALA - Negative ions

Bore-hole	Depth	Date	HCO3 mg/l	Cl mg/l	F mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	NO2 mg/l	SiO2 mg/l
K1	103									
		780828	223	15	2.6	4.2	.01	.07	<.01	18
		780908	224	15	2.7	4.2	.02	.09	<.01	18
		780919	224	15	2.7	3.6	<.01	.07	< 01	18
		780925	224	15	2.8	3.6	.01	.10	<.01	18
K1	264									
		780730	231	25	3.8	2.7	.01	.09	< 01	10
		780809	231	25	4.2	2.7	.02	.07	< 01	13
		780815	231	25	4.2	3.6	.03	.05	.01	14
		780824	227	23	4.5	1.5	.02	.09	< 01	11
K1	406									
		780530	210	260	6.4	36	<.01	.07	<.01	9.2
		780601	210	275	6.4	38	<.01	.07	.01	9.6
		780606	215	280	6.4	40	.05	.10	<.01	10
		780613	215	280	7.0	39	.05	.08	.01	10
		780622	215	280	7.0	38	.03	.07	< 01	11
K1	491									
		780703	222	44	4.5	9.6	.02	.11	.21	11
		780712	222	44	4.5	7.2	.04	.08	.07	11
		780716	223	45	5.2	8.1	.03	.07	.02	11
		780725	222	47	5.3	8.1	.03	.07	< 01	11
KS										
		790820	200	7	.13	10.0	.01	6.80	.01	9.6

STERNÖ - Negative ions

Bore-hole	Depth	Date	HCO3 mg/l	Cl mg/l	F mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	NO2 mg/l	SiO2 mg/l
KA3	232									
		791031	272	19	.52	170	.10	.05	.04	19
		791128	271	21	.52	160	.15	<.01	.07	18
		791206	265	19	.53	160	.14	.05	.06	20
		791214	265	20	.54	160	.13	.04	.08	21
KA4	226									
		800318	293	37	1.1	118	.23	.07	.23	13
		800320	293	36	1.1	118	.24	.07	.06	14
KA4	312									
		800123	295	38	1.0	110	.59	.80	.02	13
		800130	290	37	.90	110	.68	.64	.02	14
		800206	296	36	1.0	110	.71	.22	.03	15
		800213	293	36	1.0	110	.63	.63	.02	15
KA4	397									
		800220	295	37	.85	110	.64	.57	.02	13
		800227	295	41	.85	112	.55	.01	.03	13
		800305	295	41	1.0	112	.39	.05	.01	12
		800312	295	41	1.1	112	.35	.16	.21	13
SS										
		781123	38	13	.13	23	.01	1.9	.01	5.0
		781207	38	13	.10	23	.01	1.8	.01	5.0

Table 6a

FINNSJÖN - Negative ions

Bore-hole	Depth	Date	HCO3 mg/l	Cl mg/l	F mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	NO2 mg/l	SiO2 mg/l
FI1	206									
		801009	314	10	1.4	1	.10	4.3	.07	17
		801014	320	11	1.3	1	.11	.13	<.01	18
		801021	322	13	1.4	1	.11	.09	<.01	18
FI1	293									
		801030	325	9	1.3	1	.14	.06	<.01	17
		801105	325	18	1.5	1	.25	.07	<.01	18
		801111	350	37	1.5	1	.26	.03	<.01	16
FI2	385									
		771203	325	24	1.5	2.1	<.01	.18	<.01	6.2
		771207	320	32	1.5	2.4	<.01	.22	<.01	6.0
FI4	152									
		791026	383	136	3.3	47	.09	.04	.02	15
		791030	386	127	3.5	44	.07	.08	<.01	14
		791204	390	133	3.5	48	.06	.20	.01	13
		791212	389	124	3.5	46	.05	.10	.01	14
FI4*	247									
		800117	360	200	2.5	40	.06	.01	.01	14
		800123	335	360	2.5	51	.06	<.01	.02	10
		800229	390	74	2.1	30	.16	.09	<.01	16
FI4*	368									
		800314	388	72	2.1	30	.16	.09	<.01	16
		800328	387	70	2.1	28	.22	.09	<.01	17
		800426	397	72	2.6	25	.09	.04	<.01	13
		800429	395	72	2.0	29	.09	.04	<.01	15
FI4	534									
		800507	395	75	2.2	29	.09	.02	.03	12
		800514	393	75	2.2	29	.08	.03	.03	13
		800521	393	75	3.0	19	.09	.03	.03	13
		800528	393	75	3.0	19	.08	.03	.03	14

Table 6b

FINNSJÖN - Negative ions

Bore-hole	Depth	Date	HCO3 mg/l	Cl mg/l	F mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	NO2 mg/l	SiO2 mg/l
FI5*	141									
		790814	151	2650	.90	224	.05	.07	.02	8.6
		790911	166	2520	1.1	225	.06	.05	.03	11
		791003	161	2700	1.1	224	.05	.05	.02	12
		791018	161	2700	1.1	197	.07	.03	.02	12
		791206	161	2580	1.2	236	.10	.11	.02	10
FI5*	205									
		800118	70	3500	.74	300	.13	<.01	.04	5.0
		800125	84	3400	.90	325	.13	<.01	.03	10
		800129	85	3400	.86	325	.14	<.01	.02	9.0
		800208	85	3400	.82	320	.14	<01	.03	10
		800215	83	3450	.74	325	.13	.10	2.2	9.5
FI5	297									
		800320	39	4580	.74	325	.16	.10	.02	9.5
		800328	39	4700	.75	330	.18	.10	.03	11
		800411	38	4500	1.2	288	.16	.02	.01	11
		800417	39	4650	1.3	300	.15	.04	.01	11
		800422	33	4650	1.3	300	.39	.02	.01	7
		800428	39	4750	1.4	300	.15	<.01	.01	11
FI5	384									
		800514	39	5650	1.1	312	.16	.02	<.01	12
		800521	44	5650	1.1	324	.19	.02	<.01	11
		800528	41	5500	1.1	312	.17	<.01	<.01	12
FI6	184									
		810716	123	2500	.97	205	<.03		<.005	17
		810726	122	2480	.96	207	<.03		<.005	17
		810730	124	2480	.98	204	<03		<.005	17
		810806	124	2500	.89	204	<03		.012	17
FI6	250									
		810818	59	4650	1.2	340	<.02	<1	<.005	14
		810908	75	4650	1.2	330	<.02	<1	<.005	14
FI6	398									
		810916	9	5650	1.2	270	<.02	<1	<.005	7
		811007	16	5900	1.3	280	<.02	<1	.005	9
FI6	688									
		811022	36	5700	1.4	320	<.03	<1	<.005	10
		811103	38	5800	1.5	320	<.02	<1	<005	12

FINNSJÖN - Negative ions

Bore-hole	Depth	Date	HCO3 mg/l	Cl mg/l	F mg/l	SO4 mg/l	PO4 mg/l	NO3 mg/l	NO2 mg/l	SiO2 mg/l
FI7	123									
		800902	333	23	2.0	7.0	.03	.92	.12	16
		800919	332	29	2.0	10	.02	.12	<.01	14
		800927	334	27	2.3	8.0	.02	.12	<.01	16
FI7*	301									
		800910	314	173	1.6	18	.05	.93	.01	14
		800917	321	122	2.1	18	.06	.07	<.01	15
		801008	233	665	2.3	71	.03	1.78	.05	7.7
FI7*	322									
		801015	283	445	2.0	38	.05	.04	<.01	10
		801022	300	320	2.1	32	.05	.04	<.01	14
		801028	292	380	2.0	35	.05	.05	<.01	14
FI7	511									
		801105	278	545	1.5	51	.08	<.01	.01	12
		801111	277	555	1.5	47	.09	<.01	.02	12
		801119	278	555	1.5	49	.12	<.01	.04	12
FI8	103									
		810716	263	440	2.3	42	<.03		.37	12
		810726	264	450	2.4	44	.04		.005	13
		810731	257	400	2.3	41	.04		.005	13
FI8*	196									
		810818	68	3000	1.8	100	<.02	<1	.10	11
		810902	79	3400	1.8	110	<.02	<1	.043	10
		810908	30	4300	1.6	130	<.02	<1	<.005	10
FI8	283									
		810923	18	4550	1.4	140	<.02	<1	<.005	9
		811012	13	4500	1.4	130	<.02	<1	<.005	9
FI8	395									
		820113	21	4600	1.6	130	<.02	<1	<.005	7
		820121	25	4650	1.6	140	.02	<1	<.005	7
		820128	21	4400	1.6	140	.03	<1	<.005	8
		820203	11	4400	1.6	120	<.02	<1	<.005	8
FS										
		780502	37	5	.10	7.2	.01	.57	.01	4.8
		780502	37	5	.10	6.6	.01	.63	.01	5.2
		780502	38	5	.10	7.2	.01	.66	.01	5.2

Table 7

KRAKEMALA - Positive ions

Bore-hole	Depth	Date	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Mn mg/l	Fe,tot mg/l	NH4 mg/l
K1	103								
		780828	40	8.0	39	3.2	.42	4.8	.13
		780908	40	8.0	40	3.1	.42	5.0	.12
		780919	40	8.0	39	3.2	.42	4.9	.10
		780925	40	9.0	40	3.1	.42	4.8	.11
K1	264								
		780730	30	8.0	57	3.3	.20	3.5	.13
		780809	28	8.5	57	3.1	.18	3.1	.12
		780815	27	9.0	58	3.1	.15	2.8	.14
		780824	28	9.5	57	3.3	.10	2.5	.13
K1	406								
		780530	25	8.5	235	3.2	.04	5.2	.07
		780601	26	9.0	235	3.3	.04	4.6	.09
		780606	29	8.5	250	3.3	.06	3.8	.08
		780613	29	8.0	250	3.3	.06	3.5	.08
		780622	29	7.5	250	3.2	.04	3.0	.08
K1	491								
		780703	22	6.5	80	3.7	.26	6.1	.05
		780712	22	7.0	80	3.3	.22	5.9	.09
		780716	22	6.5	82	3.4	.20	6.6	.14
		780725	21	7.0	82	3.5	.22	5.3	.12
KS									
		790820	65	1.0	8	.8	.01	.06	.02

Table 8

STERNÖ - Positive ions

Bore-hole	Depth	Date	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Mn mg/l	Fe2+ mg/l	Fe,tot mg/l	NH4 mg/l
KA3	232									
		791031	130	12	17	2.9	1.05	28	29	.13
		791128	129	7.5	19	2.8	1.15	39	40	.11
		791206	127	9.5	19	2.7	1.05	27	28	.09
		791214	127	9.5	17	2.7	1.05	26	27	.08
KA4	226									
		800318	75	18	53	3.1	.54	2.3	10	.08
		800320	75	18	54	3.1	.53		10	.08
KA4	312									
		800123	86	17	55	3.3	.56	13	13	.02
		800130	85	15	55	3.2	.54	11	11	.02
		800206	85	15	54	3.2	.54	10	11	.15
		800213	85	16	53	3.2	.54	9.5	9.7	.02
KA4	397									
		800220	78	17	57	3.3	.54	14	15	.02
		800227	80	17	58	3.2	.56	1.3	13	.16
		800305	80	17	58	3.2	.53	1.0	13	.15
		800312	80	17	58	3.2	.56	1.1	14	.06
SS										
		781123	24	2.0	6	1.2	.01		.06	.01
		781207	24	2.0	6	1.2	.02		.36	.04

FINNSJÖN - Positive ions

Bore-hole	Depth	Date	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Mn mg/l	Fe2+ mg/l	Fe,tot mg/l	NH4 mg/l
FI1	206									
		801009	59	7.5	44	2.5	.36	24	24	.05
		801014	61	7.0	45	2.5	.33	18	19	.03
		801021	60	7.0	50	2.7	.31	17	17	.06
FI1	293									
		801030	58	8.0	50	2.8	.35	23	30	.09
		801105	59	7.5	56	2.9	.35	19	28	.04
		801111	50	6.5	88	2.8	.29	20	21	.06
FI2	385									
		771203	30	4.5	92	4.4	.14		6.6	.11
		771207	30	4.0	96	5.6	.10		7.8	.08
FI4	152									
		791026	23	6.0	180	2.9	.05		2.4	.18
		791030	25	4.0	225	3.0	.04	1.8	1.8	.17
		791204	24	5.5	225	3.1	.06	4.8	5.1	.20
		791212	23	9.5	210	3.1	.05	3.3	3.4	.17
FI4*	247									
		800117	40	7.0	215	3.0	.06	3.2	3.2	.26
		800123	76	10	275	4.0	.11	5.8	5.8	.29
		800229	24	4.0	170	2.8	.08	6.1	6.1	.20
FI4*	368									
		800314	23	4.0	165	2.7	.07	3.8	3.8	.21
		800328	23	4.0	165	2.8	.05	3.0	3.0	.20
		800426	22	4.0	165	2.8	.08	1.9	9.2	.24
		800429	22	4.0	165	2.7	.08	7.8	9.7	.23
FI4	534									
		800507	22	4.0	165	2.9	.08	7.3	8.0	.23
		800514	22	4.0	170	2.8	.07	6.8	6.8	.23
		800521	22	4.0	170	2.8	.05	2.4	7.9	.22
		800528	22	4.0	170	2.7	.06	5.9	5.9	.27

FINNSJÖN - Positive ions

Bore- hole	Depth	Date	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Mn mg/l	Fe2+ mg/l	Fe,tot mg/l	NH4 mg/l
FI5*	141									
		790814	650	89	900	10	.71		2.9	1.34
		790911	640	89	900	10	.75		2.8	1.38
		791003	641	62	875	9.1	.75		3.1	1.37
		791018	643	79	900	9.1	.75		2.7	1.32
		791206	630	70	1000	10	.74	7.4	9.2	1.40
FI5*	205									
		800118	955	110	1100	10	.59	3.2	3.7	.75
		800125	875	130	1100	10	.65	2.9	3.1	.85
		800129	875	110	1100	10	.66	3.0	3.0	.86
		800208	875	140	1100	10	.67	2.7	3.1	.87
		800215	900	110	1100	9.4	.67	3.4	6.2	.03
FI5	297									
		800320	1440	100	1250	7.6	.41	3.5	3.5	.21
		800328	1450	100	1300	7.5	.44	2.9	3.1	.21
		800411	1530	80	1380	7.3	.46	2.2	2.5	.20
		800417	1500	70	1380	7.2	.47	2.4	2.4	.21
		800422	1500	70	1320	7.2	.50	2.5	7.0	.20
		800428	1500	80	1320	6.9	.47	2.2	2.2	.21
FI5	384									
		800514	1730	125	1480	8.0	.70	2.5	3.0	.44
		800521	1790	100	1500	8.3	.70	2.4	3.4	.44
		800528	1790	90	1460	8.2	.83	2.8	3.4	.48
FI6	184									
		810716	554	69	922	16	.54		.91	.41
		810726	542	67	859	15	.55		.60	.43
		810730	555	67	866	15	.58		.39	.31
		810806	573	68	870	15	.57		.83	.40
FI6	250									
		810818	1219	120	1140	37	1.3		2.1	2.1
		810908	1183	112	1134	34	1.2		1.8	2.1
FI6	398									
		810916	1893	24	1138	19	.08		.22	.02
		811007	1936	31	1146	21	.17		.24	.09
FI6	688									
		811022	1900	74	1520	28	.59		3.2	.13
		811103	1900	75	1520	29	.60		2.3	.16

FINNSJÖN - Positive ions

Bore-hole	Depth	Date	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Mn mg/l	Fe2+ mg/l	Fe,tot mg/l	NH4 mg/l
FI7	123									
		800902	36	5.5	94	1.4	.13	2.9	2.9	.07
		800919	23	4.0	118	1.2	.06	2.4	2.4	.06
		800927	32	4.0	105	1.4	.09	2.5	2.5	.08
FI7 *	301									
		800910	57	7.5	164	1.6	.12	4.8	4.8	.09
		800917	51	7.0	140	1.6	.14	4.6	5.0	.07
		801008	114	18	390	2.9	.06	.53	.57	.03
FI7 *	322									
		801015	122	15	240	1.8	.12	.85	4.9	.04
		801022	96	13	195	1.7	.12	5.8	5.8	.05
		801028	107	16	224	1.8	.12	4.1	5.2	.04
FI7	511									
		801105	145	18	280	2.2	.14	3.0	7.4	.03
		801111	149	14	275	2.1	.13	3.2	6.8	.02
		801119	142	17	275	2.0	.13	1.8	7.0	.11
FI8	103									
		810716	37	12	286	12	.11		3.2	<.02
		810726	40	12	295	12	.10		.95	.12
		810731	35	12	283	12	.11		2.9	<.02
FI8 *	196									
		810818	1000	9.0	702	16	.19		2.2	<.02
		810902	1200	12	872	12	.21		3.1	<.02
		810908	1550	7.5	1042	9.7	.21		.95	<.02
FI8	283									
		810923	1630	7.2	922	13	.22		.38	<.02
		811012	1664	6.7	919	13	.23		.34	<.02
FI8	395									
		820113	1783	4.2	903	13	.14		.70	<.02
		820121	1807	4.4	943	13	.14		.10	<.02
		820128	1761	4.0	962	12	.14		.25	<.02
		820203	1625	3.5	1001	11	.13		.20	<.02
FS	993									
		780502	16	1.5	3	.7	.10		.78	.19
		780502	16	1.5	2	.6	.23		.78	.21
		780502	16	1.5	3	.7	.23		.78	.21

Borehole	Depth m	Pb ppm	Cr ppm	Co ppm	Hg ppm	V ppm	Mo ppm	Ni ppm	La ppm	Ca ppm	Sr ppm
KA 4	312	< 0.010	< 0.005	< 0.005	< 0.050	0.031	< 0.005	< 0.005	< 0.010	88.9	0.65
Fi 7	123	│	< 0.005	│	│	0.012	0.058	< 0.005	│	37.6	0.32
Fi 7	301	│	< 0.005	│	│	0.025	< 0.005	< 0.005	│	117	1.40
Fi 7	322	│	< 0.008	│	│	0.020	< 0.005	< 0.005	│	113	1.00
Fi 7	511	│	< 0.005	│	│	0.024	0.045	0.009	│	146	1.72
Fi 1	206	│	< 0.005	│	│	0.006	0.021	< 0.005	│	61.4	0.21
Fi 1	293	│	< 0.005	│	│	< 0.005	0.030	< 0.005	│	61.0	0.21
Fi 4	152	│	< 0.005	│	│	0.007	0.023	0.009	│	23.1	0.25
Fi 4	247	│	0.007	│	│	0.014	< 0.005	< 0.005	│	71.5	0.83
Fi 4	368	│	< 0.005	│	│	0.009	0.015	< 0.005	│	21.3	0.22
Fi 4	534	│	< 0.005	│	│	0.008	< 0.005	< 0.015	│	22.5	0.25
Fi 5	141	│	< 0.005	│	│	0.148	< 0.005	< 0.005	│	603	5.75
Fi 5	205	│	< 0.005	│	│	0.183	< 0.005	< 0.005	│	863	8.10
Fi 5	297	│	0.011	│	│	0.149	< 0.005	< 0.005	│	1384	13.30
Fi 5	384	│	< 0.005	│	│	0.161	< 0.005	0.009	│	1614	12.30

Table 10a Trace element analyses

Borehole	Depth m	Li ppm	B ppm	Al ppm	Si ppm	Cu ppm	Zn ppm	Rb ppm	Cd ppm	Ba ppm	Sm ppm
KA 4	312	0.023	0.416	0.017	7.9	0.040	0.155	<0.005	<0.005	0.075	<0.005
Fi 7	123	0.006	0.414	0.047	8.2	0.040	0.500	<0.005		0.030	
Fi 7	301	0.005	0.641	0.044	3.6	0.047	0.056	<0.005		0.065	
Fi 7	322	0.005	0.425	0.048	6.6	0.035	0.078	<0.005		0.078	
Fi 7	511	0.005	0.471	0.015	5.3	0.047	0.009	0.082		0.080	
Fi 1	206	0.007	0.344	0.016	8.2	0.048	0.076	<0.005		0.033	
Fi 1	293	0.004	0.284	0.076	7.7	0.039	0.138	<0.005		0.033	
Fi 4	152	0.008	0.611	0.086	7.5	0.050	0.056	<0.005		0.019	
Fi 4	247	0.012	0.627	0.071	6.8	0.051	0.024	<0.005		0.062	
Fi 4	368	0.008	0.519	0.104	9.5	0.039	0.101	<0.005		0.022	
Fi 4	534	0.015	0.576	0.032	9.3	0.040	0.049	<0.005		0.024	
Fi 5	141	0.045	0.671	<0.005	6.6	0.051	0.091	<0.005		0.074	
Fi 5	205	0.040	0.683	<0.005	5.4	0.048	0.054	<0.005		0.078	
Fi 5	297	0.045	0.910	<0.005	6.5	0.036	0.054	<0.005		0.105	
Fi 5	384	0.064	0.912	<0.005	6.3	0.030	0.139	<0.005		0.079	

Table 10b Trace element analyses.

Table 11

KRAKEMALA - Dating parameters

Bore-hole	Depth m	Date	Age BP year	Age BP korr C13 year	^{13}C o/oo	^{18}O carbonate o/oo	^{18}O water o/oo	Tritium TU	Deuterium o/oo
K1	103	780829		5985	-17.4	12.0	-10.3	<3	-78
K1	103	780908		5930	-16.4	3.6	-10.3	<3	-78
K1	103	780919		6090	-15.9	3.7	-10.3	<3	-78
K1	103	780925		6020	-16.2	3.0	-10.3	<3	-78
K1	264	780730		7570	-17.4	7.1	-10.4	<3	-77
K1	264	780809		7350	-17.9	6.9	-10.4	<3	-77
K1	264	780815		7420	-18.4	6.4	-10.4	<3	-77
K1	264	780824		7505	- 7.5	20.6	-10.4	<3	-77
K1	406	780531		12025	-15.2		-10.7	<3	-79
K1	406	780607		12895	- 7.3	6.3	-10.7	<3	-79
K1	406	780613		12950	-14.4	9.1	-10.7	<3	-79
K1	406	780621		12450	-14.4	3.2	-10.7	<3	-79
K1	491	780703		8030	-16.9	2.9	-10.4	<3	-83
K1	491	780712		7870	-16.9	4.7	-10.4	<3	-83
K1	491	780716		8160	-16.7	7.2	-10.4	<3	-83
K1	491	780725		8320	-16.9	7.6	-10.4	<3	-83

Table 12

STERNÖ - Dating parameters

Bore-hole	Depth m	Date	Age BP year	Age BP korr C13 year	^{13}C o/oo	^{18}O carbonate o/oo	^{18}O water o/oo	Tritium TU	Deuterium o/oo
KA3	232	791101	1155	1290	-16.6		- 8.7	103	
KA3	232	791107	1320	1470	-15.8		- 8.9	74	
KA3	232	791128	1270	1410	-16.4		- 8.7	99	
KA3	232	791207	1230	1370	-16.2			76	
KA3	232	791214	1295	1440	-16.2		- 8.8	77	-59
KA4	226	800318	1885	2025	-16.5	9.4	-10.0	58	-69
KA4	312	800124	1700	1840	-16.5	10.6	- 9.7	41	
KA4	312	800131	1705	1845	-16.1	9.8	- 9.5	48	-71
KA4	312	800207	1805	1945	-16.5	10.1	- 9.8	60	-71
KA4	312	800214	1900	2040	-16.4	10.6	-10.0	61	
KA4	397	800221	1860	2005	-16.2	6.8	- 9.9	60	-71
KA4	397	800228	1785	1935	-15.8	7.4	- 9.9	59	-71
KA4	397	800306	1945	2080	-16.5	9.9	- 9.9	58	-71
KA4	397	800312	1930	2065	-16.7	8.6	- 9.9	60	-71

Table 13a

FINNSJÖN - Dating parameters

Bore-hole	Depth m	Date	Age BP year	Age BP korr C13 year	^{13}C o/oo	^{18}O carbonate o/oo	^{18}O water o/oo	Tritium TU	Deuterium o/oo
FI1	206	801011	1760	2035	- 8.2		-11.6	38	-87
FI1	206	801014	1825	2065	-10.3	11.8	-11.6	40	-88
FI1	206	801022	1935	2185	- 9.7	13.4	-11.6	50	-90
FI1	293	801104	2275	2505	-10.8	4.2	-11.6	46	-88
FI1	293	801111	2305	2570	- 8.9	9.8	-11.6	40	-87
FI2	385	771203		3730	-12.9	9.8			
FI2	385	771207		3785	-11.9	13.5			
FI2	504	771203		3730	-13.0	9.8			
FI4	152	791029	6815	7035	-11.7		-11.3	6	
FI4	152	791203	6850	7055	-12.5		-11.3	7	
FI4	152	791214	6590	6805	-11.8		-11.3	6	-83
FI4	152	791221	6555	6775	-11.7	10.4	-11.4	6	-83
FI4	247	791221	6555	6775	-11.7	10.4			
FI4	247	800117	5835	6035	-12.6	7.8	-11.7	10	
FI4	247	800125	5920	6125	-12.3	9.2	-11.7	7	
FI4	247	800229	5340	5540	-12.8	8.4	-11.5	11	-81
FI4	368	800427	5205	5410	-12.3	10.8	-11.4	13	-85
FI4	368	800429	5185	5385	-12.6	10.4	-10.9	14	-85
FI4	534	800507	5295	5505	-12.2	11.1	-11.3	13	-85
FI4	534	800514	5182	5380	-12.7	8.1	-11.5	14	-85
FI4	534	800521	5050	5250	-12.8	9.2	-11.4	10	-85
FI4	534	800529	5100	5310	-12.2	9.8	-11.6	13	-85
FI5	141	790912	9350	9595	-10.1	5.2		<3	
FI5	141	791002	10490	10730	-10.3	3.8		<3	
FI5	141	791018	9700	9925	-11.3	4.8	-11.6	<3	
FI5	205	800129	10465	10715	- 9.7	4.6	-10.5	7	-86
FI5	205	800215	10240				-10.9	7	-86
FI5	297	800417	4345	4510	-14.6	1.6	-11.8	5	-88
FI5	384	800520	10380				-12.2	<3	-88

Table 13b

FINNSJÖN - Dating parameters

Bore-hole	Depth m	Date	Age BP year	Age BP korr C13 year	^{13}C o/oo	^{18}O carbonate o/oo	^{18}O water o/oo	Tritium TU	Deuterium o/oo
FI6	184	810716				17.6		4	
FI6	184	810718	8915	9145	-10.9	3.4			
FI6	184	810806	15150			17.6		<3	
FI6	250	810818				18.4		<3	
FI6	250	810908				18.7		<3	
FI6	398	810916				17.8		<3	
FI6	398	811007				17.8		<3	
FI6	688	811022				17.7		<3	
FI6	688	811104				17.7		<3	
FI7	123	800827	3765	3935	-14.3	12.0	-11.8	11	-86
FI7	123	800831	3760	3930	-14.4	11.3	-11.8	11	-87
FI7	123	800902	3735	3925	-13.3	13.3	-11.6	13	-87
FI7	301	800913	3910	4080	-14.5	8.0	-11.8	10	-87
FI7	301	801008	4515	4700	-13.6	10.2	-11.7	3	-90
FI7	301	801018	4225	4400	-14.0	9.8	-11.8	12	-87
FI7	322	801023	4590	4785	-13.1		-11.8	11	-88
FI7	322	801028	4005	4200	-13.1	12.0	-11.8	11	-88
FI7	511	801106	4085	4265	-13.9	6.3	-12.0	10	-89
FI7	511	801111	4275	4365	-14.0	1.8	-11.9	11	-89
FI7	511	801119	4440	4610	-14.6	3.0	-11.9	8	-89
FI8	103	810716	5770	5960	-13.4	18.2		17	
FI8	103	810731				18.3			
FI8	103	810806	5530	5715	-13.7	5.9			
FI8	103	810807						15	
FI8	196	810818	6360	6550	-13.2	3.5			
FI8	196	810818				17.8		6	
FI8	196	810909				17.2		<3	
FI8	283	810922				17.0		<3	
FI8	283	811013				17.1		<3	
FI8	395	820115				17.1		<3	
FI8	395	820203				17.3		<3	

Appendix 1

Dating with the ^{14}C method.

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There are different methods for dating groundwater with the aid of carbon-14. Whether the age determined by means of these models is the same as the actual age of the water is uncertain, since the values of many variables used in the calculations must be assumed for the time being. The water at a given depth can also consist of a mixture of younger and older waters, which cannot be determined solely with carbon-14. The calculations whose results are reported in the tables were done using a model that is described in KBS technical report 80-08. The report also explains how changes in the values of different variables affect the calculated age. The variables that have the greatest influence are the water's measured carbon-13 content and the assumed values of the carbon-13 content of the ground air and the weathering calcite. In order to get some idea of the size of the variations that are obtained, an age has been calculated for different values of the carbon-13 content of the ground air. Some values can give a negative calculated age.

The analysed water samples can be divided into two groups: those that are calcite-saturated with a high carbon-13 content and those that are unsaturated and usually have a lower carbon-13 content. The calculations are performed in slightly different ways in the two cases (see previously mentioned report). The samples from Finnsjön can be expected to belong to the former group, since there is a great deal of calcite (of marine origin) in the ground there. Most of the Finnsjön samples do, in fact, belong to the former group, but some are unsaturated with respect to calcite even though their carbon-13 content is high. This is probably due to admixture with modern water, since the tritium content of these samples is rather high. For two of the samples (FI1, 206 m and FI1, 293 m) it is not possible to obtain any results with the model. The tritium content of these samples is around 40 TU.

All samples from Kråkemåla and Karlshamn (Sternö) are unsaturated with respect to calcite. There as well, there is a sample with a high tritium content (KA3, 232 m) for which the model does not work. Many of the other samples also have a relatively high tritium content, which should be borne in mind when considering the calculated ages.

Analyses of the coolant used at Finnsjön revealed a concentration of 75-85 TU (Gidlund, private communication). This means that the admixture of coolant in FI1 may be 50%, which would mean that the ^{14}C age in FI1 should be increased by about 2,000 years.

Appendix 2

STABLE ISOTOPES OF OXYGEN AND HYDROGEN IN ANALYSED GROUNDWATERS FROM FINNSJÖN, KRÅKEMÅLA AND STERNÖ.

E-L Tullborg and Sven Åke Larsson, SGAB-SGU Gothenburg.

Stable isotopes of both oxygen and hydrogen were analysed in the sampled waters. The ratio $^{18}O/^{16}O$ in the water samples is given in relation to Standard Mean Ocean Water (SMOW) according to the equation:

$$\delta^{18}O = \frac{(^{18}O/^{16}O)_{prov} - (^{18}O/^{16}O)_{standard}}{(^{18}O/^{16}O)_{standard}} \times 10^3$$

δ^2H is determined in the same manner.

Figure 1 shows $\delta^{18}O$ in water samples from Finnsjön (FI), Kråkemåla (K) and Sternö (KA) as a function of depth. In cases of repeated sampling, the mean of the values for all samples from the same level was used. As is evident from the figure, the analysed waters from each area fall within a relatively narrow $\delta^{18}O$ interval.

The relationship between $\delta^{18}O$ and δ^2H in the precipitation is described by the equation $\delta^2H = 8\,\delta^{18}O + 10‰$, the so-called "meteoric water line" (MWL) (Craig 1961). The content of heavy isotopes in the precipitation decreases from the coast inland, from lower to higher latitude and from lower to higher altitude. Thus, Finnsjön exhibits the lowest values and Sternö the highest.

Dansgaard (1964) found a relationship between the annual mean temperature and $\delta^{18}O$ in the precipitation where $\delta^{18}O = 0.695\ T\ (^{\circ}C) - 13.6$. If the water's $\delta^{18}O$ is calculated for each area, and if the fact that precipitation during the winter half of the year constitutes about 70% of newly-formed groundwater, the analysed groundwaters appear to coincide relatively well with the waters expected under present-day circumstances. The position of the analysed waters in relation to the MWL is shown by figure 2. A deviation from the MWL can be caused by a number of secondary processes that affect a surface water or a groundwater (Fig. 3) (Fritz et al 1979). As is evident from Fig. 2, the analysed waters plot below the MWL but parallel to it. This indicates that secondary processes have not had any significant effect on the waters. However, more precise interpretations require knowledge of the local MWL. Such data is lacking at the present time.

In summary, the following can be said:

All analysed groundwaters have $\delta^{18}O$ and $\delta^{2}H$ values that are typical for a meteoric water. The $\delta^{18}O$ and $\delta^{2}H$ values for each area fall within a relatively narrow and characteristic interval. The difference in values between different areas can be explained by the geographical situation.

The analysed waters have not been affected by secondary processes to any great extent.

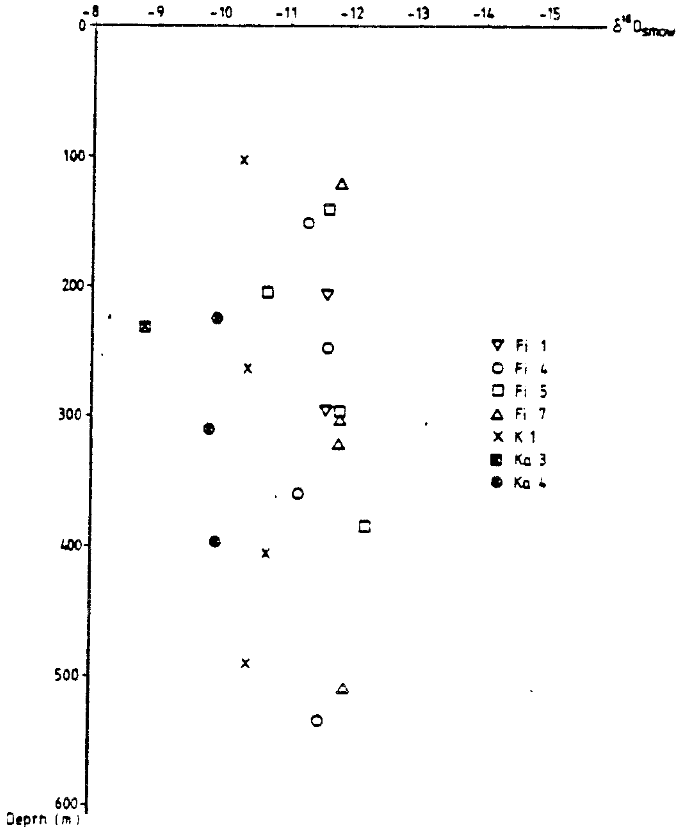

Figure 1 $\delta^{18}O_{water}$ versus depth

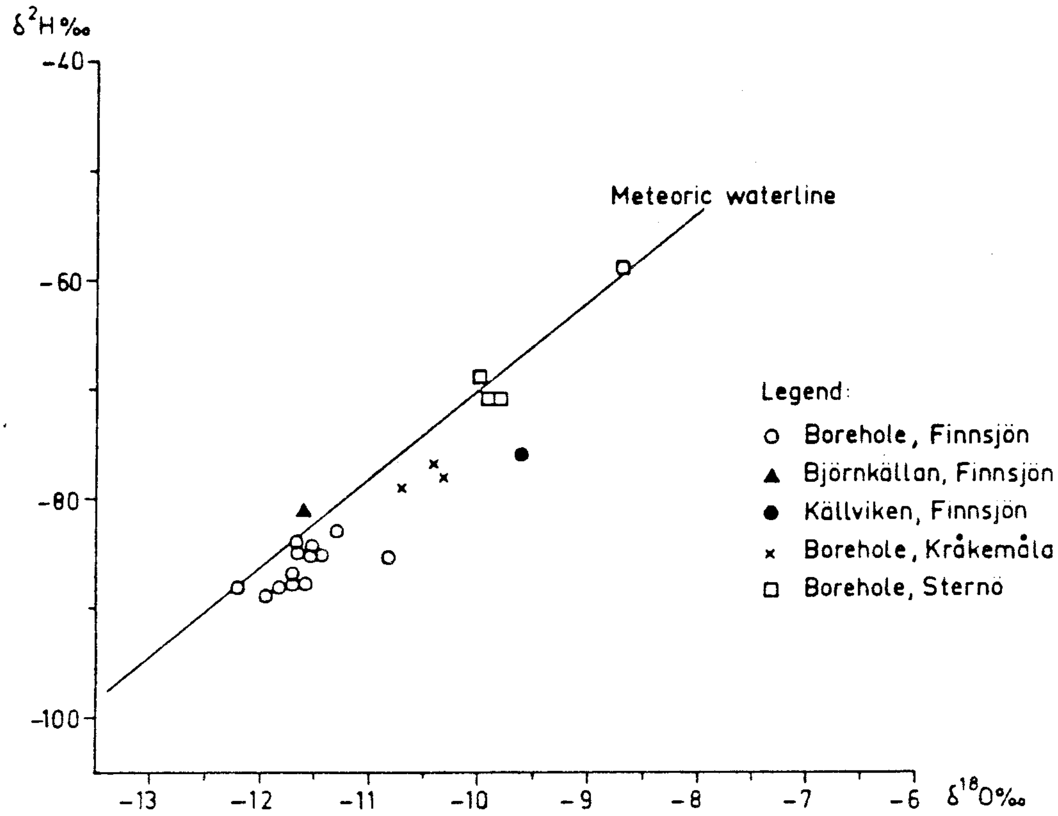

Figure 2 $\delta^{18}O$ versus $\delta^{2}H$ for analysed waters

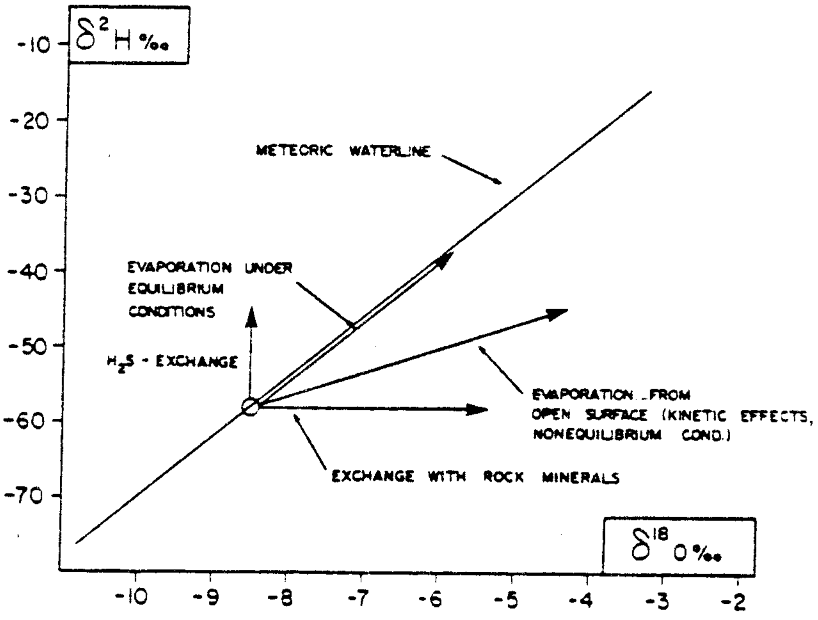

Figure 3 A generalized $\delta^{18}O$ versus $\delta^{2}H$ plot showing the Meteoric Water Line and processes commonly responsible for deviations from this line (Fritz et. al, 1979)

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Appendix 3

CALCULATION OF MODERN WATER FRACTION

John Andrews of the University of Bath has commented on the uranium and thorium analyses. He has also calculated the fraction of "modern" water in the samples on the basis of $^{234}U/^{238}U$, where the activity ratio for modern water has been set at 1 and 1.25 and for original water at 3.0 (see the table).

A comparison is also made with the ^{14}C age. Agreement is good between the modern water fraction calculated with the two methods. A good correlation is also obtained when mixing ratios and tritium content are compared.

	% modern^x from ^{14}C-age	% modern from $^{234}U/^{238}U$ (a)	(b)	TU
FI 1/206	66	75	85	50
FI 1/293	54	30	33	40
FI 4/387	31	32	37	14
FI 4/562	32	42	49	13
FI 5/382	40	0	0	5
FI 5/494	0	0	0	23
FI 7/123	45	32	37	13
FI 7/302	38	16	18	3
FI 7/323	44	16	18	12
FI 7/513	38	35	43	8

x based on mixing with a 10,000 year old end-member.

(a) based on mixing of recent water (assumed to have an activity ratio close to 1.0) and an end-member with an activity ratio of 3 (similar to FI 5).

(b) as (a) but for a modern end-member with an activity ratio of 1.25.

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Some calculated results obtained from a model based on the concept of stratified flow and matrix diffusion
Ivars Neretnieks
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Roland Pusch
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Klas Lundgren
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Trygve E Eriksen
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B Allard
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Sverker Evans
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