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Analysis of groundwater from Taavinunannen

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SKB Rapport R-08-21

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Förord

Under åren 1977–1985 utförde SKB och Prav (Programrådet för radioaktivt avfall) omfattande kartläggningar och undersökningar av förutsättningarna att anlägga ett slutförvar för använt kärnbränsle i landet. Mer omfattande undersökningar, s k typområdesundersökningar, utfördes på åtta platser. Begränsade insatser utfördes på ytterligare nio platser.

Ett av de områden som undersöktes var Tavinnunanen i Kiruna kommun, Norrbottens län.

Undersökningsområdet ligger inom raketuppskjutningsfältet Esrange, cirka 35 kilometer nordost om Kiruna. Valet av Tavinnunanen baserades på att berggrunden till största delen består av bergarten gabbro. Våren 1981 borrades ett 700 meter djupt kärnborrhål. Borrkärnan undersöktes med avseende på bergarter, sprickfördelning, sprickmineral samt hållfasthetsegenskaper. Dessutom utfördes geofysisk borrhålsloggning, vatteninjektionstester för bestämning av hydrauliska egenskaper samt grundvattenkemisk provtagning i borrhålet. Undersökningarna finns redovisade i /Gentzschein och Tullborg 1985/, i Appendix till /Ahlbom et al. 1992/ samt i /Laurent 1984/.

Den sistnämnda rapporten ingår inte i SKB:s officiella rapportserie. En granskning av rapporten, utförd av Peter Wikberg, SKB, visar att den uppfyller de krav SKB ställer på rapporter i rapportserien för R-rapporter. Rapporten har därför tagits med i denna rapportserie och fått nummer R-08-21. Hänvisningar har gjorts till appendix och avsnitt i rapporten för förtydligande. En referenslista har tillfogats. Företagsförkortningar och hänvisningar till tabeller har förtydligats.

Stockholm, januari 2008

Svensk Kärnbränslehantering AB

Summary

Groundwater from a borehole in the gabbro massif at Taavinunnen has been sampled and analysed. Some samples have also been taken from two lakes and a creek in the vicinity. This is part of a larger program of geological, geophysical and hydrogeological investigations aimed at finding a suitable site for a high level radioactive waste repository.

Two water-bearing levels in the borehole at a depth of 493 and 651 m were selected. Prior to sampling, the water-bearing level is isolated between packer sleeves. The water is then pumped to the surface where sensitive parameters such as redox potential, pH, sulphide and oxygen content are measured electrochemically on the flowing water in a system isolated from the air. Water, filter and gas samples are sent to several laboratories for further analysis.

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. The main conclusion of this report is that a failure to isolate the selected sampling zones cannot be excluded. So the reported results are probably not at all relevant for the composition of undisturbed groundwater at depth in the gabbro massif at Taavinunnen. Further sampling is recommended in case this place is seriously considered for future investigations.

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1 Introduction

Groundwater from a borehole in the gabbro massif at Taavinunnen has been sampled and analyzed. The borehole TA1 is core drilled and two sampling levels were chosen on the basis of hydrological measurements in the borehole. Sampling, field measurements and sampling was carried out by personnel from Industrins Processkonsult AB (IPK). Several laboratories participated in the water analysis (see below).

The borehole was pumped out with a gas lift prior to the hydrological investigation and immediately before the equipment for water sampling was lowered to the first sampling level. On the latter occasion, three such gas lift pumpings – called mammoth pumpings – were performed in a row. Sodium iodide (NaI, 0.01 mmol/l) was added to the drilling water during drilling to enable any residual drilling water to be traced in the groundwater. The selected fractured zones were sealed off by packers spaced at a distance of 2.7 m.

Sampling was carried out in TA1 (2 levels) during August and September 1983. The borehole is almost vertical. Depth is given both as vertical depth (depth) and/or borehole length (length). It is always vertical depth that is given, unless otherwise specified in the table heading.

The work was carried out in periods of 14 days–4 days off while the sampling pump works and 9 days field measurement and water sampling. The 493 m level was sampled during two consecutive work periods and the 651 m level during one period. Lowering to the new level is done on the last day of a work on the 493 m level.

For control reasons, two lakes and a creek in the vicinity have also been sampled. One of the lakes was used as drilling water source.

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 further evaluation in relation to geology or hydrogeology. The material in this report may be further analyzed by experts in different fields.

The geological, geophysical and hydrogeological investigations of the study area are described in /Gentzschein and Tullborg 1985/. A characterization of fracture minerals, sampled from the 700 m long drill core, has been published by /Larson and Tullborg 1984/.

2 Sampling

2.1 Drilling water

Some of the drilling water that is used in the core drilling of the sampling holes can penetrate into fractures and contaminate the groundwater there. In order to get rid of the drilling water to as great an extent as possible prior to sampling, three mammoth pumpings (using nitrogen gas) are performed immediately prior to installation of the sampling equipment.

The sampling equipment (Section 2.2) is lowered to the chosen level and allowed to work for 3–4 days before sampling begins. Periodic sampling during a period of 8–9 days makes it possible to follow changes in the composition of the water that might derive from drilling water or some other source of contamination. The changes may also be due to the incursion of water from different aquifers.

Water from a small lake near the borehole TA1 has been used as drilling water. The drilling water was filtered through mechanical filters of cellulose (18 CMC 3-2), which are supposed to retain particles with diameters larger than 5 μm . The filtered drilling water was then analyzed (see Tables 2 to 5 in Appendix).

Before the drilling water was used, it was “marked” by the addition of 0.01 mmol/l (1.3 mg/l) sodium iodide in order to make it possible to trace any drilling water that may have contaminated the sampled water.

2.2 Sampling equipment

The core borehole TA1 was drilled with a diameter of 56 mm. At the 493 m level a 2.7 m long sampling zone is sealed off by rubber packers that are expanded to a pressure that is 0.8–1 MPa above the groundwater pressure. The 651 m level is sealed off by one packer, and sampling has taken place between this packer and the bottom at about 690 m. 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 furnished with teflon seals, has a capacity of 0.12 l/stroke and pumps 300–390 l/d. The water flow at some levels is lower due to the fact that the flow of water in the rock is lower than the capacity of the pump. A schematic illustration of the sampling pump and packers is shown in Figure 1, see Appendix.

The water is pumped up through polyethylene-lined pipes to a test chamber of stainless steel on the ground surface. The test chamber is equipped with electrodes and measuring cells for recording pH, Eh (glassy carbon), Eh (platinum), pS, oxygen content and conductivity. The test chamber is also equipped with valves for the extraction of water samples.

The equipment has been augmented with an extra measuring chamber of glass, which is positioned between the borehole and the test chamber as described above. It is equipped with 2 Eh electrodes of the same kind as those in the test chamber (glassy carbon and platinum). In order to give these electrodes plenty of time to stabilize, they are not calibrated and they are only cleaned when the level is changed. The measurement results are given under Eh–C, g and Eh–Pt, g in Table 2.

2.3 Water flow during sampling

The normal pumping rates for sampling in the two sections at 493 and 651 m depth were 220–260 l/day. A separate experiment was carried out in the section at 493 m where the pumping rate was varied during sampling between 90 and 380 l/day /Smellie 1983ab).

3 Field measurements

The field measurements are recorded in Tables 1 and 2, the E° values obtained from the field calculations in Table 1 and the field values obtained during water sampling in Table 2, see Appendix.

It should be noted that the Eh electrodes marked with g (see section 2.2) have not functioned properly this time. The same is true for the O_2 -probe, the values of which can only be used for qualitative interpretations.

3.1 Calibrations

Each calibration has been assigned a calibration number. Measurements made after the calibration have the same number. All calibration solutions are freshly prepared from concentrate and deaerated distilled water, except the one used for calibration of the conductivity cell. During calibration, the solutions are circulated through the test chamber.

Three buffer solutions with pH 4, 7 and 10 are used for calibration of the pH electrode. Quinhydrone is added to the buffer solutions with pH 4 and 7 for simultaneous calibration of the Eh electrodes. Concentrate diluted to solutions that are 0.01 and 0.05 molar with respect to sulphide ion is used for calibration of the sulphide electrode. The E° values obtained are presented in Table 1, see Appendix.

If a calibration shows that the electrodes have to be cleaned, the reading before the cleaning is normally also noted in order to document the condition of the electrodes immediately prior to the calibration.

The oxygen probe is calibrated against air-saturated distilled water and the conductivity cell against 0.01 and 0.1 mol/l KCl (see also Section 3.5).

3.2 Measurement results

Each measuring occasion is identified with a calibration number, borehole designation, depth of borehole as well as day and time.

3.3 Temperature measurement

The temperature is measured in the test chamber to permit calibration and calculation of the electrode potentials.

Owing to the relatively slow rate of water turnover in the test chamber, the temperature measured is not representative of the groundwater. It is therefore not reported.

3.4 Measurement of pH, Eh and pS

The system in general need to remain undisturbed for at least a week before the Eh and pS values are more or less stable. The pH value normally stabilizes much faster.

3.5 Oxygen measurement with probe

It would appear that the oxygen probe has to be calibrated more frequently than is possible with a view towards the other electrodes. In fact the performance of the O₂-probe was so poor this time that the values should only be used for qualitative interpretations.

3.6 Measurement of conductivity

The conductivity measurements were consistently stable. Calibration was done at the beginning of each level.

4 Main components of the water

Each sampling occasion has been assigned a unique sampling number which is the same for all samples taken on the same occasion (“No.” in the tables).

The main components were analyzed by IMAB, Linköping. The analysis results are reported in Tables 3 to 5. Some of the filters were also analyzed by Scandlab in Sollentuna (see Table 6 in Appendix).

The following analysis methods were used in the water analysis for dissolved components.

- pH, conductivity and turbidity, conventionally according to Swedish Standard (SS).
- Sulphide, colorimetrically on Zn-preserved specimen (SS).
- Iron (II), colorimetrically with ferrozine.
- Other metals in water with atomic absorption.
- Nutrient salts, colorimetrically according to SS.
- Bicarbonate, chloride and fluoride, titrimetrically according to SS.
- Sulphate, titrimetrically or by ion chromatography.
- TOC, carbon analyzer (Astro at Institutet för vatten och luftvårdsforskning (IVL), Carlo Erba at Industrins Miljöanalys AB (IMAB)).
- Iodide, photometric method according to Standard Methods.

All determinations of metals are presented in Table 3, see Appendix. Parameters that contain nitrogen are compiled in Table 4 and other anions as well as TOC, turbidity and silicic acid are presented in Table 5.

4.1 Sampling

The water samples were taken through a valve immediately after the test chamber. On each sampling occasion, a new tube, kept well protected from dust, was attached to the valve. The free and untouched end of the tube was inserted down to the bottom of the sample bottle. At least two bottle volumes of sample water were allowed to run over before the bottle was sealed, without any air having been trapped inside. The samples were kept in a refrigerator awaiting transport. Sampling bottles were supplied by IMAB.

The samples for metal analyses were preserved with 0.5 ml of concentrated hydrochloric acid (super-pure) per 100 ml of sample. The acid was added through a dispenser below the sample surface immediately before the sample bottle was sealed. Hydrochloric acid was chosen as a preservative because iron (II) was to be determined.

Filtration through a membrane filter with a pore diameter of 0.45 μm was done on each sampling occasion. The filter was thereby attached immediately after the test chamber.

The first water that passed the filter was discarded, after which a polyethylene bottle containing concentrated hydrochloric acid for preservation was filled with filtrate. Iron (II and total) was determined in the filtrate. The total quantity of aluminium, iron, sulphur, calcium, manganese and silicon was determined on the filter. The concentration in the water was calculated (Table 6 in Appendix).

4.2 pH

pH was determined directly in the field (Table 2) and at laboratory (Table 5), see Appendix. The values varies between 7.5 and 10. In general lower values are found in the laboratory analyses which is common and has been attributed to changes during the transport of samples. The drop in pH by approximately one unit due to lower pumping rate should also be noted (see Table 2).

4.3 Conductivity

Conductivity was determined both in the field (Table 2) and in the laboratory (Table 5), see Appendix. The values are low in general and particularly low considering the sampling depth.

4.4 Organic carbon (TOC)

The concentration of organic matter in TA1, 496 m is quite acceptable, at least in the later part of the sampling period. However, unusually high values are recorded for TA1, 654 m and the strong fall in this organic content concentration with sampling time would indicate a contamination of the borehole rather than a natural organic content of the deep groundwaters (see Table 5).

Further analyses of organic matter from both levels give support to this explanation. Because they are not humic substances (Allard B, pers. comm.). It could be an accidental spill of diesel oil – it could be something else.

4.5 Main inorganic components

In accordance with the low conductivity, the concentrations of main inorganic components such as sodium, calcium, potassium, magnesium, bicarbonate, chloride and sulphate ions are of course also low (Tables 3 and 5), see Appendix.

5 Particulate matter

5.1 Chemical composition of particles

The water was filtered through a membrane filter (Section 4.1). Iron (II and total) was determined in the filtrate and iron, aluminium, sulphur, calcium, manganese and silicon on the membrane. The results are presented in Table 6, see Appendix. The concentrations are reported as mg/l of filtered sample.

6 Isotope analysis

Isotope analysis is done mainly to permit calculations of the age and origin of the water. The heavy radioactive isotopes are determined primarily because the natural background concentrations are of great interest for the KBS project.

The analyses were carried out at the following laboratories:

- Laboratory for Isotope Geology, Stockholm (Section 6.1 and 6.3).
- Mass Spectrometry Laboratory, Uppsala University (Section 6.2).
- Studsvik Energiteknik, Nyköping (Section 6.4).
- Tekniska Högskolan i Helsingfors, 02150 Esbo 15.

6.1 Carbon isotopes

The determination was used for dating by means of the carbon 14 method. The water's contents of carbon dioxide and carbonate have to be concentrated before the determination. It is thereby of the utmost importance that the concentrate not be contaminated by carbon-containing chemicals or contact with air.

Sample preparation is done in the field. A polyethylene barrel holding 130 l and filled from the beginning with nitrogen is filled with water. Hydrochloric acid is added to disintegrate carbonates present in the water. A nitrogen gas stream is then used to drive the carbon dioxide over to a wash bottle containing carbonate-free sodium hydroxide.

Groundwater age is presented in Table 6-1 below as "Age BP" and after correction for C-13 content as "Age BP, corr".

Table 6-1. Taavinunnenen – Age dating.

Borehole	Depth (m)	No.	Age BP	Age BP corr	C-13 (‰)
TA1	651	555	2,305	2,405	-18.7
		561	3,065	3,125	-21.2

6.2 Tritium

Owing to its short half-life (about 12 years) tritium is an important isotope in hydrologic studies. The amount of tritium in the atmosphere increased drastically during the experiments with nuclear fission in the atmosphere. The tritium content of rainwater has increased by more than 10 times, which makes it possible to determine whether “young” water is present in a groundwater sample.

The tritium content is given in Table 7, see Appendix, in the unit TU, which is the number of tritium atoms per 10^{18} hydrogen atoms.

The tritium content at depth in Taavinunnen is unusually high even for surface conditions and of course much higher than would be expected according to the tritium content in the drilling water (samples no. 574 and 594, see Table 2 and 7, Appendix).

6.3 Oxygen-18

The analyses can furnish information on the climatic conditions prevailing at the time of infiltration.

The concentrations in Table 7, see Appendix, refer to deviations in per mill from SMOW (Standard Mean Oceanic Water).

6.4 Sulphur-34

The sulphur is precipitated as barium sulphate and SO_2 is produced by Dr. Smejkalas “direct conversion method” and the sulphur-34 is measured. The results are given in Table 7, see Appendix.

6.5 Uranium, thorium, radium and radon

Only two samples from the deepest level have been analyzed and is presented in Table 6-2:

Table 6-2. Taavinunnen – Uranium, thorium, radium and radon.

Borehole	Depth (m)	No.	Th ($\mu\text{g/l}$)	U (Bq/l)	Ra-226 (Bq/l)	Rn-222 (Bq/l)
TA1	651	555	<1.4 E-2	(3.9 \pm 0.8) E-2	<1.0 E-3	26.1 \pm 1.7
		561	<1.7 E-2	(4.2 \pm 0.8) E-2	<2.5 E-3	42.4 \pm 1.9

The concentrations for U, Ra and Rn are given in Bq/l. The following relationships apply:

39.4 μg U per Bq.

2.74 $\times 10^{-5}$ μg Ra-226 per Bq.

1.76 $\times 10^{-10}$ μg Rn-222 per Bq.

7 Gas analysis

Helium, carbon dioxide and nitrogen were determined in the gas that spontaneously leaves the water on its passage through a Horst bottle. The analyses were carried out by AGA SpecialGas, Lidingö.

In Table 8, see Appendix, besides the gas phase's percentage content of the analyzed gases, the amount of water that has passed through the Horst bottle and the gas volume obtained are also given. This enables the reader to form his own rough idea of the quantity of dissolved gases in the water. The gas content of the water has not been calculated, since degassing is dependent on a number of uncontrolled parameters. We know, for example, that temperature variations of $>20^{\circ}\text{C}$ occur in the tent where the borehole opens out and the sampling equipment is located.

8 Conclusions

There are good reasons to suspect that the analysed water samples are not relevant for the deep groundwaters in Taavinunnanen. So in case this area should remain interesting for other reasons, further groundwater sampling is recommended preceding any extensive attempt to interpret the groundwater chemistry.

References

Ahlbom K, Leijon B, Liedholm M, Smellie J, 1992. Gabbro as a host rock for a nuclear waste repository. SKB TR 92-25, Svensk Kärnbränslehantering AB.

Gentzschein B, Tullborg E-L, 1985. The Taavinunnanen Gabbro massif. A compilation of results from geological, geophysical and hydrogeological investigations. SKB TR 85-02, Svensk Kärnbränslehantering AB.

Larson S-Å, Tullborg E-L, 1984. Fracture fillings in the Gabbro massif of Taavinunnanen, northern Sweden. SKB/KBS TR 84-08, Svensk Kärnbränslehantering AB.

Laurent S, 1984. Analysis of groundwater from Taavinunnanen. SKBF/KBS, Arbetsrapport, AR 84-36, Svensk Kärnbränslehantering AB.

Smellie J, 1983a. Uranium series disequilibrium studies of some ground waters from the Gideå, Fjällveden and Svartboberget areas. SKBF/KBS, Arbetsrapport, AR 83-39, Svensk Kärnbränslehantering AB.

Smellie J, 1983b. Groundwater pump flow-rate and its effect on some physicochemical parameters – A controlled experiment carried out at Taavinunnanen, Norrbotten. SKBF/KBS, Arbetsrapport, AR 83-45, Svensk Kärnbränslehantering AB.

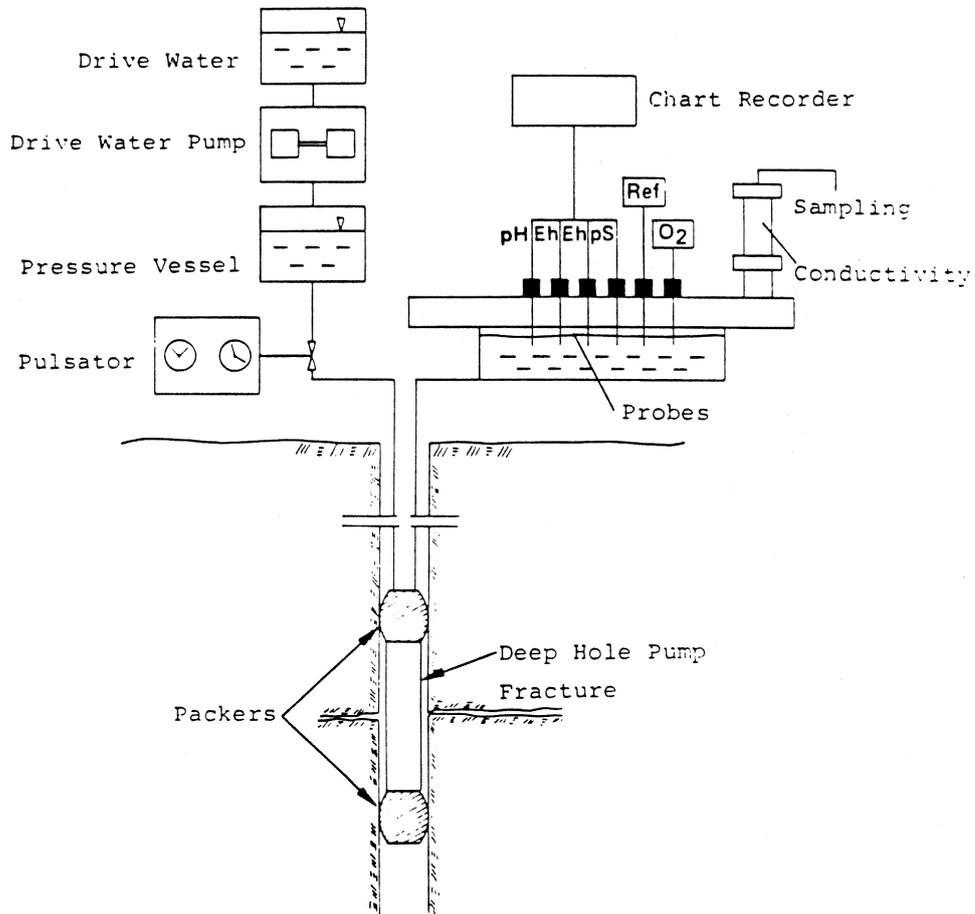


Figure 1. Schematic illustration of sampling equipment.

Table 1. Taavinunnen - E^o-values (field).

Core-hole	Depth m	Length m	Cal. no.	E ^o ,pH4 mV	E ^o ,pH7 mV	E ^o ,pH10 mV	E ^o ,C4 mV	E ^o ,C7 mV	E ^o ,Pt4 mV	E ^o ,Pt7 mV	E ^o ,S1 mV	E ^o ,S5 mV
TAI	493	496	4	380.2	381.8	386.1	258.2	256.2	250.2	253.4	-836.5	-834.0
			5	399.1	430.6	487.3	255.5	258.8	254.4	258.6	-558.6	-579.8
			6	382.5	384.5	388.3	257.0	254.4	256.7	256.3	-842.2	-823.3
			7	384.8	386.7	390.7	257.8	256.2	256.8	256.0	-843.4	-837.3
			8	373.8	374.9	382.5	262.2	262.5	261.2	262.3	-810.6	-783.3
TAI	651	654	1	392.3	392.7	395.1	255.9	257.3	252.9	255.8	-847.3	-817.9
			2	385.1	384.5	388.9	255.4	256.3	254.4	256.2	-836.2	-833.7
			3				267.0		247.6			

Table 2. Taavinunnen - Field measurements.

Core-hole	Length m	Depth m	No.	Sampling Date	Water flow l/day	pH,s	Eh-C,s mV	Eh-C,g mV	Eh-Pt,s mV	Eh-Pt,g mV	pO ₂ ,s mS/m	Cond,s mg/l	O ₂ ,s			
TAI	496	493	562	83-35-3	274	9.1	165	232	59	212	19.4	8.3	.20			
			563	83-35-4	266	10.1	199	216	40	207	17.8	7.9	.10			
			564	83-35-6	259	9.2	447	202	249	249	24.9	7.7	.45			
			565	83-35-7		9.1	467		301		25.5	7.7	1.00			
			566	83-36-1	256	9.0	468		318		26.0	7.7	1.15			
			567	83-36-2	245	9.1	470		328	280	26.3	7.6	1.21			
			568	83-37-2	259	9.1	367	194	179	290	27.1	8.6	.37			
			569	83-37-3	245	9.1	320	153	122	70	24.3	8.2	.19			
			570	83-37-4	232	9.0	93	106	35	-210	19.1	7.9	.06			
			571	83-37-6	261	9.1	181	112	156	-156	19.0	7.6	.05			
			572	83-37-7	252	9.1	187	200	170	-61	19.1	7.4	.01			
			573	83-38-1		9.0	187	238	174	-40	19.2	7.4	.02			
			575	83-39-1	370	9.1	231	248	318	397	28.8	7.0	1.25			
			576	83-39-2	98	7.9	249	95	265	136	27.5	7.4	.05			
			577	83-39-2	88	7.5	254	85	260	-15	28.1	7.3	.00			
			578	83-39-3	86	7.6	241	75	212	-163	27.7	7.2	.01			
			580	83-39-3	91	7.8	230		195		27.3	7.2	.00			
			581	83-39-4	94	8.1	211	69	175	-295	26.6	7.3	.01			
			582	83-39-4	94	8.0	208		178		26.6	7.4	.00			
			583	83-39-5	86	8.3	192		158		26.1	7.6	.00			
			584	83-39-5	88	8.3	186		161		25.9	7.6	.00			
			585	83-39-6	222	9.0	103	-4	59	-372	23.4	7.7	.00			
			588	83-39-6	222	9.0	89	-17	42	-377	21.8	7.8	.00			
			589	83-39-7	216	8.7	81	-43	14	-374	18.4	7.6	.01			
			590	83-39-7	216	8.8	78	-53	10	-375	17.8	7.6	.00			
			591	83-40-1	384	9.0	60	-82	-4	-380	15.9	7.6	.00			
			592	83-40-1	384	8.9	72	-76	29	-370	15.7	7.4	.00			
			593	83-40-2	360	8.9	102	-57	63	-374	16.7	7.2	.01			
			TAI	654	651	551	83-31-3	281	9.8	184		77		22.8	8.1	.35
						552	83-31-4	262	9.9	194	-30	70	25	22.7	8.1	.28
						553	83-31-6	262	9.8	185	195	116	98	23.9	8.0	.47
						554	83-31-7		9.8	191	327	165	195	25.1	7.9	.40
						555	83-32-1	259	9.7	194	337	219	225	25.6	7.8	.50
556	83-33-2	223				9.5	424		384		27.5	7.8	1.05			
557	83-33-3	216				9.6	427	198	373	290	27.4	7.9	.63			
558	83-33-4	216				9.6	445	105	366	82	27.1	7.9	.60			
559	83-33-6	235				9.5	411		351	43	26.1	8.1	.55			
560	83-33-7					9.5	430		356		26.2	8.0	.60			
561	83-34-1	213				9.5	434		360		26.3	8.0	.62			
TAKK			374	83-38-2	Small lake close to TAI, used as drilling water source											
			379	83-39-3	Creek SE TAI											
			386	83-39-6	Creek SE, summit Taavi											
			387	83-39-6	Lake NNW, summit Taavi											
			394	83-40-2	Small lake close to TAI, used as drilling water source											

Table 3. Taavinunnen - Metal ions.

Bore-hole	Length m	No.	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Sr mg/l	Mn mg/l	Al mg/l	Fe2+ mg/l	Fe-tot mg/l	Fe(II) <4 µm mg/l	Fe ₂ tot <4 µm mg/l
TAI	496	562	4.8	1.1	7.5	1.3	.027	.011	.082	.40	1.5	.04	.04
		563	4.2	1.0	7.0	1.4	.016	.012	.063	.22	1.3	.03	.03
		564	3.9	1.0	6.4	1.4	.021	.013	.076	.13	1.4	.02	.03
		565	3.9	.9	7.2	1.4	.028	.011	.079	.14	1.5	.02	.04
		566	3.9	1.0	6.2	1.4	.023	.013	.072	.14	1.6	.02	.03
		567	3.9	1.0	6.2	1.4	.018	.014	.072	.14	1.7	.02	.03
		568	3.7	1.0	7.5	1.3	.018	.014	.044	.33	1.7	.08	.12
		569	4.9	.9	6.9	1.3	.018	.010	.040	.16	1.6	.06	.20
		570	4.5	.9	6.7	1.4	.018	.014	.028	.17	1.3	.04	.09
		571	4.5	.9	6.1	1.4	.018	.013	.068	.09	1.3	.04	.11
		572	4.2	.9	5.8	1.4	.019	.021	.036	.09	1.6	.05	.23
		573	3.9	.9	6.7	1.4	.018	.017	.048	.09	1.8	.04	.16
		575	3.7	.9	5.4	1.4	.017	.017	.052	<.01	1.2	<.01	.23
		576	3.7	.9	5.5	1.5	.020	.041	.047	.03	1.7	<.01	.23
		577	3.7	1.0	5.3	1.4	.023	.075	.046	<.01	1.4	<.01	.25
		578	4.3	1.0	5.3	1.4	.017	.043	.044	<.01	1.4	<.01	.31
		580	4.1	1.0	5.4	1.4	.016	.016	.058	<.01	1.4	<.01	.32
		581	4.6	.9	5.5	1.4	.023	.017	.030	<.01	1.3	<.01	.28
		582	4.5	1.0	5.6	1.4	.016	.016	.048	.01	1.3	<.01	.20
		583	3.9	1.0	6.0	1.3	.016	.016	.047	.01	1.3	<.01	.27
		584	4.0	1.0	6.2	1.4	.023	.016	.047	.02	1.2	<.01	.31
		585	4.3	1.0	6.4	1.3	.021	.013	.047	.02	1.2	<.01	.34
		588	4.4	.9	6.6	1.3	.017	.014	.047	.02	1.1	<.01	.21
		589	4.1	.9	6.5	1.4	.016	.016	.043	.01	.95	<.01	.37
		590	4.1	.9	6.5	1.4	.016	.018	.041	.01	.94	<.01	.13
		591	4.2	.9	6.4	1.4	.016	.017	.044	.02	.92	<.01	.09
		592	4.1	.9	6.4	1.4	.020	.018	.042	.01	.91	<.01	.12
593	4.0	.9	5.9	1.3	.017	.018	.043	<.01	.97	<.01	.13		
TAI	654	551	5.7	1.5	7.1	.9	.022	.020	.290	1.7	3.4	.05	.05
		552	5.4	1.4	7.4	.8	.026	.017	.180	.94	2.5	.04	.07
		553	5.0	1.3	9.5	1.2	.022	.014	.130	.30	1.7	.06	.22
		554	4.4	1.2	8.6	1.2	.026	.012	.110	.20	1.7	.03	.07
		555	4.8	1.3	7.9	1.1	.028	.010	.100	.19	1.6	.02	.06
		556	4.0	1.3	7.3	1.3	.019	.011	.061	.19	1.7	.03	.10
		557	4.3	1.3	7.4	1.2	.020	.010	.061	.23	1.7	.03	.07
		558	4.7	1.3	7.4	1.2	.019	.011	.048	.22	1.5	.03	.06
		559	4.3	1.3	7.4	1.2	.020	.011	.047	.23	1.6	.06	.07
		560	4.3	1.1	8.1	1.2	.020	.010	.060	.19	1.6	.05	.11
		561	4.5	1.3	6.9	1.2	.020	.010	.083	.26	1.4	.04	.05
TARE*		574	.8	.1	.3	.5	<.010	.006	.580	.19	.20		
		579	3.6	.3	1.3	1.2	.010	<.001	.013	<.01	.08		
		586	.9	.2	1.4	1.0	<.010	.001	.012	<.01	.06		
		587	.8	.1	1.3	.7	.012	.001	.024	<.01	.04		
		594	.1	.1	.4	.5	.010	.008	.520	.02	.10		

*See explanation in Table 2.

Table 4. Taavinunnen - Nitrogen containing ions.

Core-hole	Length m	Date lab	No.	NO2 mg/l	NO3 mg/l	NH4 mg/l	NO2-N mg/l	NO3-N mg/l	NH4-N mg/l	Sum-N mg/l		
TAI	496	36-4	562	.003	<.04	<.01	.001	<.01	<.01	<.02		
		36-4	563	.003	<.04	<.01	.001	<.01	<.01	<.02		
		36-4	564	.003	<.04	<.01	.001	<.01	<.01	<.02		
		36-4	565	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		36-4	566	.003	<.04	.01	.001	<.01	.01	<.02		
		36-4	567	.003	<.04	<.01	.001	<.01	<.01	<.02		
		38-4	568	<.003	<.04	.01	<.001	<.01	.01	<.02		
		38-4	569	<.003	<.04	.01	<.001	<.01	.01	<.02		
		38-4	570	<.003	<.04	.03	<.001	<.01	.02	<.03		
		38-4	571	<.003	<.04	.01	<.001	<.01	.01	<.02		
		38-4	572	<.003	<.04	.01	<.001	<.01	.01	<.02		
		38-4	573	<.003	<.04	.02	<.001	<.01	.01	<.02		
		40-5	575	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	576	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	577	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	578	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	580	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	581	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	582	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	583	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	584	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	585	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	588	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	589	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	590	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	591	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	592	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		40-5	593	<.003	<.04	<.01	<.001	<.01	<.01	<.02		
		TAI	654	32-4	551	.007	<.04	.05	.002	<.01	.04	<.05
				32-4	552	.003	<.04	.03	.001	<.01	.02	<.03
32-4	553			.003	<.04	.03	.001	<.01	.02	<.03		
32-4	554			.003	.04	.05	.001	.01	.04	.05		
32-4	555			.003	<.04	.01	.001	<.01	.01	<.02		
34-4	556			.007	.04	.01	.002	.01	.01	.02		
34-4	557			.003	.04	.01	.001	.01	.01	.02		
34-4	558			.003	<.04	.01	.001	<.01	.01	<.02		
34-4	559			.003	.04	.01	.001	.01	.01	.02		
34-4	560			.003	<.04	.03	.001	<.01	.02	<.03		
34-4	561			.003	<.04	.01	.001	<.01	.01	<.02		
TARE*	920			38-4	574	.003	<.04	.04	.001	<.01	.03	<.04
		40-5	579	<.003	.44	<.01	<.001	.10	<.01	<.11		
		40-5	586	<.003	.13	<.01	<.001	.03	<.01	<.04		
		40-5	587	<.003	.04	<.01	<.001	.01	<.01	<.02		
		40-5	594	<.003	<.04	.08	<.001	<.01	.06	<.07		

*See explanation in Table 2.

Table 5. Taavinunnen - Remaining parameters.

Bore-hole	Length m	No.	pH	Cond mS/m	HCO3 mg/l	Cl mg/l	F mg/l	PO4 mg/l	SO4 mg/l	Si2- mg/l	TOC mg/l	Si.tot mg/l	Turb PTU	I mg/l
TAI	496	562	9.0	7.9	31	2	.16	.03	7.8	<.01	19	7.6	3.9	.01
		563	9.1	7.6	32	2	.13	.03	7.2	<.01	19	7.9	2.9	<.01
		564	9.0	7.4	32	2	.12	.03	7.1	<.01	15	7.7	3.2	<.01
		565	9.0	8.1	31	1	.13	.03	6.7	<.01	14	6.6	4.0	<.01
		566	9.1	7.4	32	2	.12	.03	6.9	<.01	12	7.3	2.5	<.01
		567	9.0	7.2	31	<1	.12	.03	6.9	<.01	12	7.8	3.4	<.01
		568	8.6	8.3	31	<1	.21	.03	8.0	<.01	12	5.7	2.6	<.01
		569	8.6	8.1	33	<1	.17	.03	7.7	<.01	10	6.0	14.0	<.01
		570	8.6	7.9	33	<1	.14	.06	7.6	<.01	11	6.0	6.7	<.01
		571	8.5	7.8	32	<1	.12	.06	7.6	<.01	5.4	9.8	6.9	<.01
		572	8.6	7.5	32	<1	.12	.06	6.4	<.01	4.3	6.8	8.7	<.01
		573	8.5	7.8	32	<1	.11	.06	6.2	<.01	4.4	6.5	6.1	<.01
		575	9.0	7.5	26	<1	.11	.03	4.8	<.01	2.6	6.2	1.8	<.01
		576	8.8	7.0	32	<1	.12	.03	5.7	<.01	5.4	5.9	1.4	<.01
		577	8.4	7.2	30	<1	.10	.03	5.2	<.01	4.2	5.8	1.7	<.01
		578	8.2	7.0	28	<1	.10	.03	5.3	<.01	2.8	6.6	1.2	<.01
		580	7.9	6.7	30	<1	.10	.03	5.2	<.01	1.8	5.7	2.0	<.01
		581	8.1	6.8	30	<1	.10	.03	5.2	<.01	.8	5.6	2.2	<.01
		582	8.4	7.1	31	1	.12	.03	5.3	<.01	1.8	6.1	1.8	<.01
		583	8.3	7.2	32	<1	.12	.03	9.1	<.01	2.0	8.1	2.2	<.01
		584	8.3	7.2	32	<1	.12	.03	6.3	<.01	2.0	5.5	1.6	<.01
		585	8.5	7.4	32	<1	.12	.06	6.4	<.01	5.4	5.5	2.1	<.01
		588	8.3	7.2	31	<1	.12	.03	6.9	.03	5.0	5.4	2.6	<.01
		589	8.4	7.1	32	<1	.11	.03	6.5	.03	5.1	5.7	2.0	<.01
		590	8.6	7.2	32	1	.11	.03	7.1	.04	4.0	5.8	1.9	<.01
		591	8.3	7.3	32	<1	.11	.03	5.5	.02	4.0	5.4	1.6	<.01
		592	8.7	7.2	31	<1	.11	.03	7.0	<.01	3.9	5.5	1.4	<.01
593	8.4	6.8	31	<1	.10	.03	6.7	<.01	4.7	5.6	2.0	<.01		
TAI	454	551	7.3	7.9	25	1	.17	<.03	7.2	.01	85	3.5	4.5	.03
		552	9.0	8.0	24	1	.15	<.03	6.3	<.01	67	3.6	2.2	.02
		553	9.0	7.6	25	1	.13	<.03	6.2	<.01	51	4.1	1.8	.01
		554	9.1	8.3	26	<1	.12	.03	6.5	<.01	40	4.4	1.7	.04
		555	9.1	7.9	25	<1	.12	.03	5.8	<.01	32	4.2	1.5	.01
		556	9.2	7.1	28	<1	.12	.06	5.6	<.01	22	3.2	2.0	<.01
		557	9.2	7.4	28	<1	.11	.06	5.7	<.01	18	3.6	2.6	<.01
		558	9.2	7.6	30	<1	.12	.06	5.8	<.01	23	3.6	2.0	<.01
		559	9.2	7.5	30	<1	.13	.06	5.8	<.01	19	4.1	1.8	<.01
		560	9.2	7.2	30	1	.13	.06	6.2	<.01	13	4.5	2.3	<.01
		561	9.2	7.6	30	<1	.12	.09	5.8	<.01	12	4.6	1.8	<.01
TARE ^a	920	574	5.8	1.7	<1	<1	<.10	.03	4.3	<.01	12.0	2.3	.6	<.01
		579	8.0	3.1	15	<1	<.10	.06	1.9	<.01	.6	6.5	.3	<.01
		586	7.8	2.7	10	<1	<.10	.06	3.2	<.01	.9	4.1	.5	<.01
		587	7.8	2.1	7	<1	<.10	.03	2.8	<.01	.8	4.9	.5	<.01
594	5.4	1.8	<1	<1	<.10	<.03	3.3	<.01	9.1	2.4	1.4	<.01		

^aSee explanation in Table 2.

Table 6. Analyses of particulate material (>0.4 µm).
Concentrations given as mg/l of filtered sample.

No.	Length m	Fe	Al	S	Ca	Mn	Si
562	496	1.6	0.002	0.0001	0.030	0.014	0.004
563		1.4	0.002	0.0002	0.034	0.012	0.004
564		1.2	0.002	0.0001	0.024	0.011	0.001
565		1.2	0.005	0.0002	0.035	0.010	0.006
566		1.1	0.003	0.0001	0.026	0.011	0.001
567		1.5	0.006	0.0003	0.040	0.013	0.003
568		1.4	0.004	0.003	0.033	0.011	0.003
569		0.3	0.002	0.0001	0.008	0.003	0.002
570		1.1	0.003	0.0002	0.028	0.010	0.001
571		1.2	0.006	0.0005	0.048	0.011	0.006
572		2.0	0.007	0.003	0.052	0.018	0.009
573		1.9	0.003	0.001	0.047	0.018	0.007
551	654	1.9	0.008	0.0002	0.040	0.017	0.007
552		1.6	0.006	0.0001	0.033	0.016	0.005
553		1.4	0.004	0.0002	0.045	0.015	0.002
554		1.2	0.003	0.0003	0.037	0.014	0.005
555		1.6	0.003	0.0002	0.037	0.017	0.003
556		1.4	0.008	0.0001	0.032	0.016	0.010
557		1.4	0.005	0.0002	0.026	0.016	0.006
558		1.2	0.003	0.0002	0.034	0.013	0.002
559		0.9	0.002	0.0001	0.028	0.011	0.002
560		1.7	0.002	0.0001	0.030	0.018	0.003
561		1.5	0.002	0.0001	0.031	0.016	0.002

Table 7. Taavinunnen - Isotope analysis.

Bore- hole	Depth m	No.	Tr TU	0-18 ‰	S-34 ‰		
TAI	493	562	137				
		564	145				
		566		-14.0	3.8		
		567	149				
		568	123				
		570		-13.9			
		571	120				
		573	123	-13.9	4.0		
		575	123	-13.9	4.5		
		576	157	-13.9	4.0		
		577	160	-13.9	4.2		
		578	162	-13.9	4.4		
		580	178	-13.9	4.0		
		581	129	-13.9			
		582	121	-13.8	4.1		
		583	131	-13.9	4.0		
		584	155	-13.8	3.0		
		585	99	-13.9	3.2		
		588	146	-13.9	3.8		
		589	121	-13.9	4.1		
		590	116	-13.8	4.5		
		591	148	-13.9	4.2		
		592	158	-13.8	4.3		
		593	153	-13.9			
			651	551	142		
				555	129	-13.8	
				556	176		
	558	156					
	560				3.6		
	561	115		-13.8			
TARE ^a		574	23				
		579	83				
		586	31				
		587	50				
		594	39				

^aSee explanation in Table 2.

Table 8. Teavinunnenen - Gas analysis.

Bore-hole	Depth m	Length m	No.	Watervol. l	Gasvol. ml	He %	CO2 %	N2 %
TAI	493	496	573	82	160	<.001	.0084	97.2
		496	590	101	150	~.001	.9600	97.2
	651	654	555	5	175	<.001	.0550	96.8
		654	561	18	190	<.001	.1300	97.3