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Authors: Harald Elvebakk & Jan S. Rønning		Client: NGU	
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Summary:			
<p>NGU has carried out new test measurements using a borehole gamma-ray spectrometer from IFG Corporation at different sites in the North Calotte Region. Improved calibrations of the instrument were made doing long term measurements on calibration pads at NGU. In situ calculations of K, U and Th content gave promising results as long as only one radionuclide was present. Calculating the K content in a situation where higher energy radiating elements were present, proved difficult. This problem is caused by large stripping ratios and poor energy stabilisation in the instrument. The obtained data will be of great value when the new borehole gamma-ray probe developed by the Finnish company Astrock OY will be evaluated.</p> <p>To overcome the problem with temperature drift, a spectrum stabilisation source should have been placed permanently inside the probe. An other solution is to make electronic improvements which can reduce the temperature drift. To reduce the measuring time, a crystal which is able to absorb more of the gamma radiation should be considered when designing a new system.</p> <p>Deposit name and grid-reference: Biggejavre 34W 5958 76957 Bleikvassli 33W 4470 73105</p>			
Keywords: Geofysikk		Radiometri	Gammaspektrometri
Borhullslogging			
			Fagrapport

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1. INTRODUCTION

The project is a co-operation between the Finnish company Astrock OY and the Geological Survey of Norway. The project is sponsored from *North Calotte Interreg II* by 50 % of total cost. The aim of the project is to create base for a new geological and geophysical research method for further actions in the field of business development in the North Calotte Region. The new method may increase the efficiency of mineral prospecting by, for example, reducing the need for costly chemical analysis of rock samples. In mineral exploration and mining it means lower exploration and production costs. With the help of the new method it may be possible to find new mineralization zones of economic importance.

The borehole Gamma-ray spectrometry project started in 1997. The results from the first part of the project are described in NGU Report 98.091 (Elvebakk & Rønning 1998). The instrument was a borehole Gamma-ray spectrometer rented from IFG (Instrumentation For Geophysics), Canada. The main conclusion in this report is that the calibration of the instrument was not successful because of too short measuring time on the calibration pads. A geometric factor was estimated to correct for the difference between measurements on the flat pads and the borehole situation with rock surrounding the hole probe. The size of this factor (2.1) proved to be incorrect and will have great influence on calculating the K, U and Th content. Another problem was energy drift in the borehole spectra caused by temperature changes. Adjustment of the spectra requires clear peaks with known energy, and in some cases such peaks were difficult to observe.

In order to improve the results using the Gamma-ray spectrometry method the same Gamma-ray spectrometer, BSG-01, IFG Canada, was rented in 1999. New measurements on calibration pads were carried out with 40 – 90 minutes measuring time on each pad. Clear peaks in K, U and Th windows were observed which yielded a better calibration. A new geometric factor was found by comparing the pad measurements and measurements in a borehole with known K-content. 25 chemical analyses were used to calculate the geometric correction factor.

New borehole measurements were carried out in Bleikvassli (K-rich microcline gneiss), Biggejavre (Uranium) and in Apukka (Uranium and Thorium), Finland. The field work was carried out in August/September 1999 by Harald Elvebakk.

2. BACKGROUND OF THE PROJECT

Gamma-ray spectrum measurements are widely used in airborne geophysics to map out the Uranium, Thorium and Potassium content in the ground for the needs of environmental monitoring, mineral exploration etc. NGU has long experience in doing such measurements. In detailed research the gamma-ray spectrum measurements have mainly been used to classify rock types. Gamma-ray spectrometers are based on the photomultiplier tube system. However, instruments based on this system can be very sensitive to vibration and temperature changes which makes them troublesome and unreliable to use. Until now, the use of gamma-ray spectrometers in drillholes has been limited, mainly due to low response from a small crystal detector.

Astroek Oy is a Finnish geophysical service company located in Sodankylä. This company has recently developed a gamma-ray spectrometer based on new technology. This technology is expected to perform better during temperature changes, and get higher spectral resolution and counting efficiency using another crystal. The quality of data is expected to be better than the data measured with the old technique. Therefore, there would be many new applications possible for this method, but there is a lack of comprehensive reference data to test the method.

The geological background of the gamma-ray method is well-known. Therefore, with a reasonable probability, the possible applications of the borehole logging gamma-ray method can be evaluated. The new method is known to increase the knowledge of mineralogy of rocks. It can be utilised in mineral exploration and the mining industry for example in replacing some of the chemical analyses with borehole spectrum measurements. The chemical analyses are expensive and time consuming. Especially in production drilling the long waiting time for analyses makes the optimum drilling difficult and therefore creates extra costs. For these reasons chemical analyses should be avoided if possible. By gamma-ray spectrum measurements, when the method is fully developed, in situ measurements can be performed, and prospecting costs will be considerably reduced.

3. INSTRUMENT

The commercial instrument with the traditional photomultiplier tube system used in NGUs part of the project was rented from the Canadian company IFG Corporation. The name of this Gamma-ray spectrometer is BSG-01.

3.1 Description of the Gamma-ray spectrometer BSG-01

The BSG-01 is a fully digital borehole spectral gamma instrument which samples 256 channels of natural gamma radiation in the energy range of 0 keV to 3000 keV at a rate of one complete spectrum per second. The system is designed for use in slimline boreholes (diameter 46 mm). The standard detector used is a 25 mm by 76 mm Tl activated NaI crystal. The detector is optically coupled to a photo cathode and a photo multiplier tube (PMT). When a gamma ray strikes the detector, it emits a flash of light (or photon) which is detected by the PMT and converted into an electric voltage. The amplitude of this voltage is proportional to the energy of the photon which produced the light flash.

The probe is connected to the IFG logging cable (6 mm) which is stored on a winch equipped with a manual drive which also can be powered by an electric drill. The length of the cable used is 500 m. On the winch, there is a depth wheel controlling the logging positions in the borehole. The IFG surface electronics consist of a single interface console that supplies power to the probe and converts data received from the probe. From the interface console the data are transferred to the portable PC where they are stored.

3.2 Energy range and channel windows

Using gamma ray spectrometry, γ -rays from the following isotopes are used to map the natural radio element Potassium, Uranium, Thorium and the man made Cesium.

Element	Gamma Emitter	Peak Energy (keV)	Comment
Potassium	^{40}K	1460	Radiation from isotope itself
Uranium	^{214}Bi	1760	Daughter of ^{238}U
Thorium	^{208}Tl	2615	Daughter of ^{232}Th
Cesium	^{137}Cs	662	Radiation from isotope itself

For the system used, the energy range of 0 to 3000 keV is divided up into 256 channels numbered 0 to 255. Each channel is 11.719 keV wide. Gamma rays from each element are detected in ranged channels, called windows, centred on the element's peak energy. The windows used in the present investigation are described below:

Window name	Symbol	Peak energy (keV)	Energy window (keV)	Channel no.
Total count 1	TC1		0100 - 3000	008 - 255
Total count 2	TC2		0400 - 3000	034 - 255
K (^{40}K)	K	1460	1370 - 1570	116 - 133
U (^{214}Bi)	U	1760	1660 - 1860	141 - 158
Th (^{208}Tl)	Th	2615	2400 - 2800	204 - 238
Cs (^{137}Cs)	Cs	662	650 - 674	55 - 57

These energy windows are set as default by the acquisition software.

3.3 Data acquisition and processing

The data acquisition is controlled by a software, named G256 (IFG 1994 a), run on a portable PC. The data records transmitted by the IFG surface interface console are sent to the PC, which acts as the data acquisition unit. The data are received, displayed and permanently stored for later processing. Measurements can be carried out in continuous mode (logging with constant speed taking measurements every second) or in incremental mode (taking measurements at specific depths for a fixed time interval). During logging the total counts in each window are shown on the PC screen.

Due to temperature changes in the detector, the channel numbers of the spectra will not usually line up with the expected corresponding energy values. To adjust for this, a calibration file has to be made. This file is made by taking measurements near a calibration source of known spectral characteristics. For this purpose a ^{137}Cs source was used. The process is described in detail in the IFG reference manual (IFG 1994 a).

The data processing is done by a software called S256 (IFG Corporation 1994 b). S256 is designed for processing and display of binary data from the IFG spectral gamma probe. Further, the S256 converts the binary raw data files into ASCII files which means that any software may be used to display the data. Using the S256, spectra from any place in the borehole can be studied. There is an option for summing and plotting of spectra from specified positions in the borehole. Another option is creating window files which can be plotted in the same manner as other geophysical borehole logs. During the project some bugs in this sum up of spectra option, were discovered and it was not possible to get the summed values of total counts in each channel. NGU therefore had to make new software for these purposes. In this software, routines for stripping and calculations of concentration were included (Mauring 1998), see later.

4. NEW CALIBRATION OF BSG-01

In gamma-ray spectrometry, it is a drawback that high energy radiation is absorbed and registered in low energy windows. To find the right number of counts caused by one element in its window, the effect of other elements has to be stripped off. In order to use the method to calculate the concentration of the natural radio elements, the sensitivity of the crystal or calibration factor have to be known.

The 1997 calibration of the BSG-01 Gamma-ray spectrometer was not quite successful because of too short measuring time on the calibration pads (Elvebakk & Rønning 1998). Therefore, new measurements on the pads were carried out in 1999 before the field work started. The accumulated spectra from the pad measurements should come up with clear peaks of K, U and Th in the respective windows.

Figure 1 shows a typical gamma-ray spectrum showing the gamma-ray peaks of all three radioelements (IAEA 1991). Besides the main peaks in the K, U and Th windows two ^{214}Bi isotopes (daughter of ^{238}U) can be observed at 610 and 1120 keV. Two isotopes, ^{208}Tl and ^{228}Ac (daughters of Th), are observed at 580 and 910 keV.

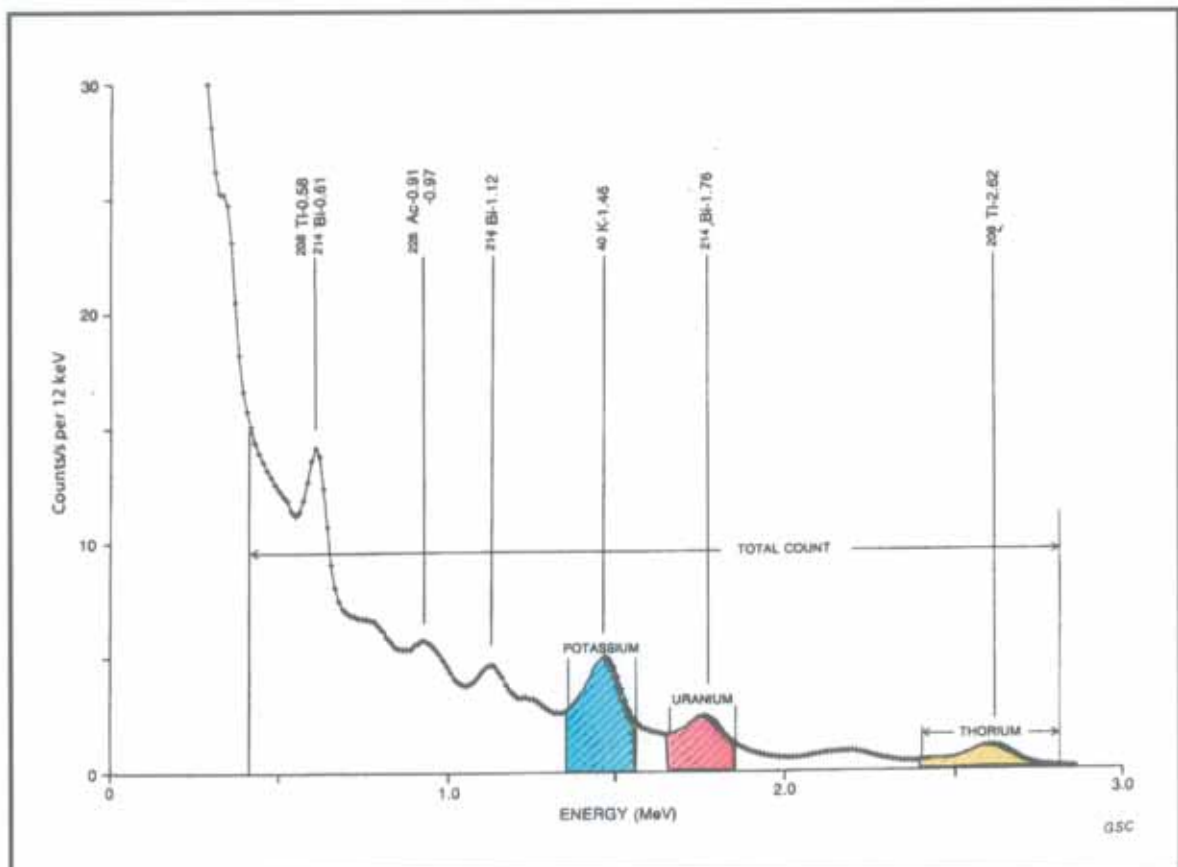


Figure 1. Typical gamma-ray spectrum showing the gamma-ray peaks of all three radioelements, along with the energy windows used to detect the three radioelements.

4.1 Pad measurements and adjustment of pad spectra

Table 1 shows the results from the pad measurements in total counts in each window. Table 2 shows the background corrected values transferred to counts per second (cps).

Table 1. Data from calibration pad measurements (total counts)

Pad	K (tot.counts)	U (tot.counts)	Th (tot.counts)	Time (sec.)
K	6503	205	232	2400
U	15211	8750	931	5460
Th	8429	5103	4833	3600
Background	1747	276	265	2400

Table 2. Background corrected pad values (cps)

Pad	K (cps)	U (cps)	Th (cps)
K	1.982	-	-
U	2.058	1.487	0.066
Th	1.613	1.302	1.232

The background corrected values for U and Th on the K-pad come up with small negative values. The reason for this could be natural statistical variations (cosmic radiation). The influence on the stripping ratios is minimal because the U and Th concentration in the K-pad are very small. (see later).

Figure 2 and 3 shows the summed spectra of the pad measurements. The background pad spectrum (figure 2) shows a clear peak in K-window but no other peaks. The K-pad spectrum is similar to the background spectrum. The K-peak is used to adjust the spectrum to the right energy level (1460 keV). The Uranium pad spectrum (figure 3) shows several peaks on summed spectrum, ^{214}Bi (1115 keV), ^{214}Bi (1760 keV) and ^{40}K (1460 keV) which all are used to adjust the spectrum to the right energy level. The Thorium pad spectrum shows two peaks, ^{228}Ac (910 keV) and ^{208}Tl (2620 keV), which both are used to adjust the spectrum.

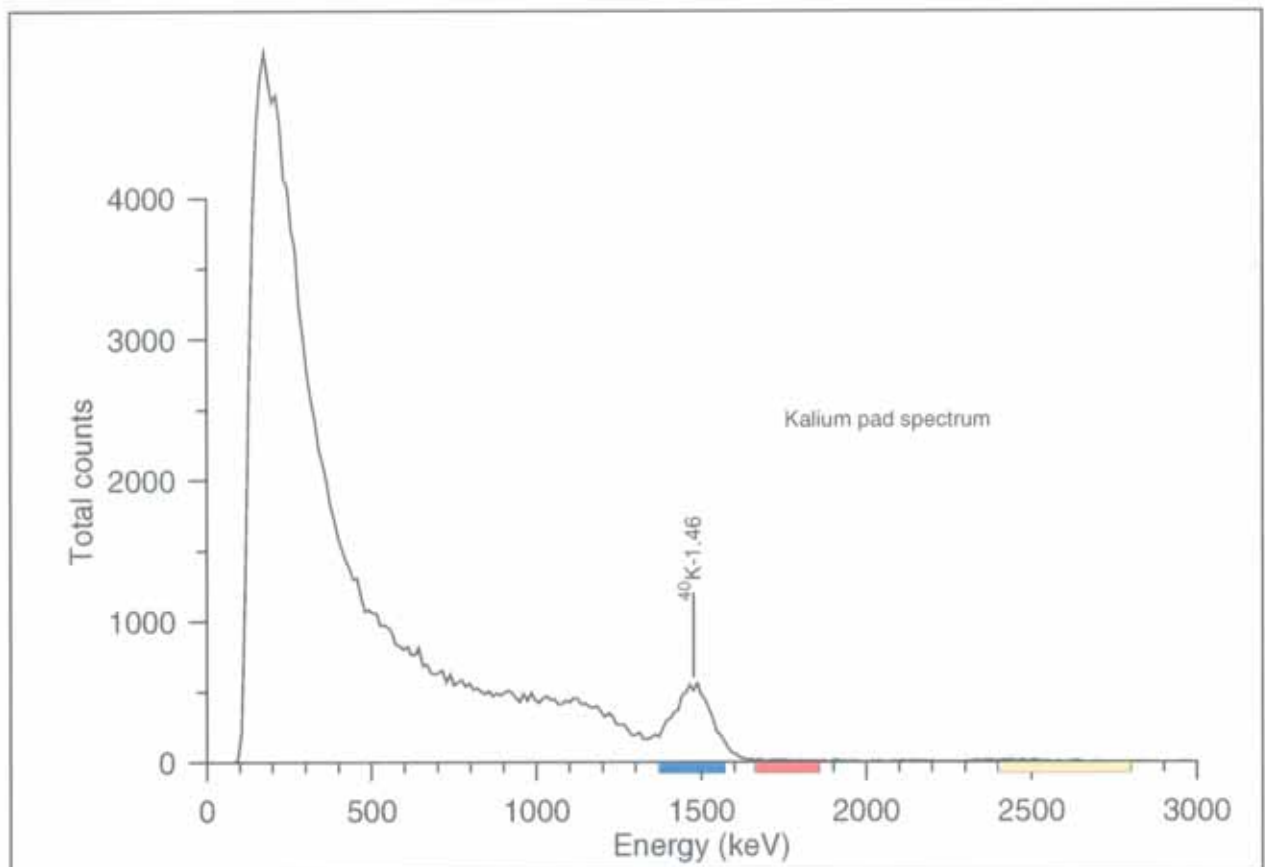
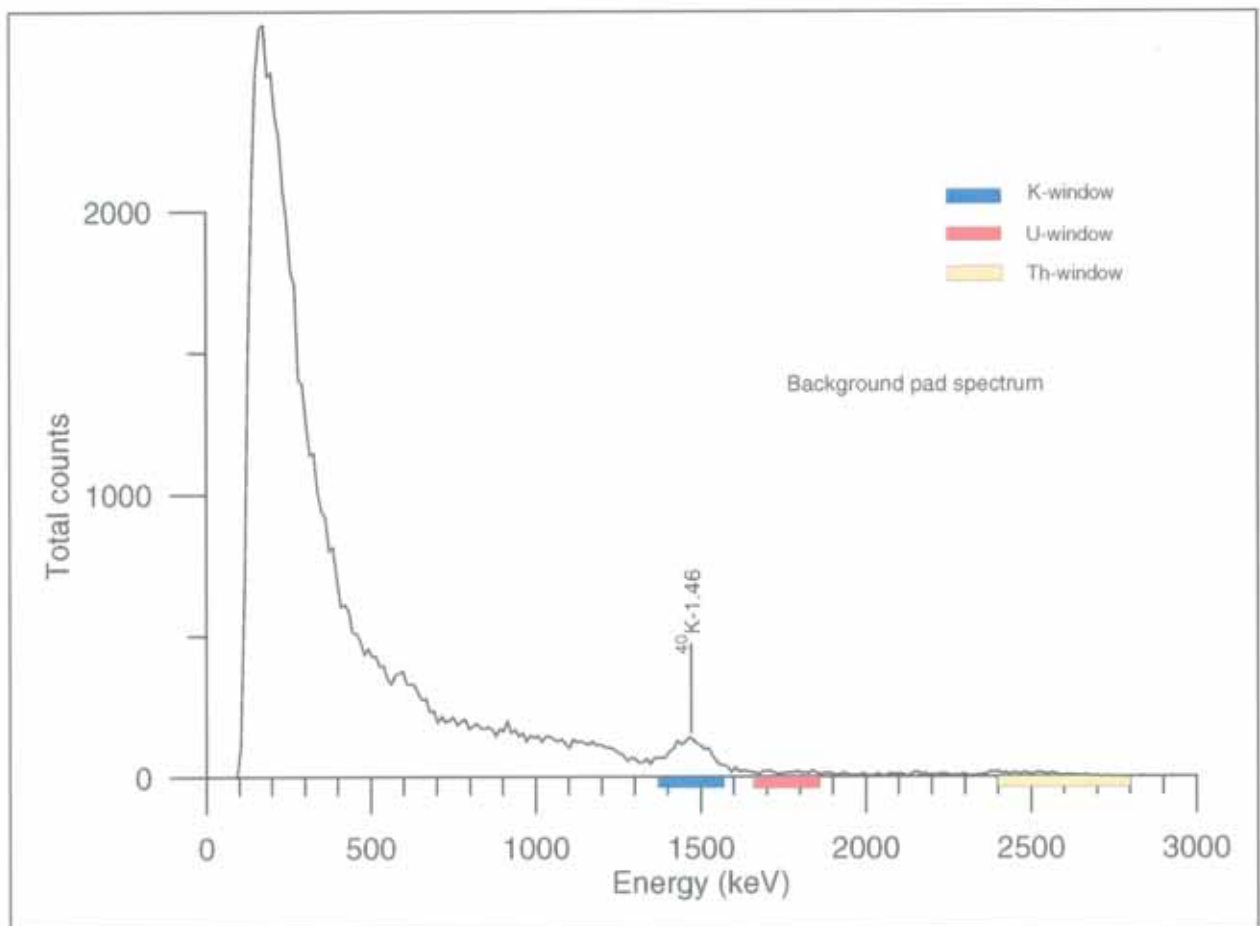


Figure 2. Spectrum of Background (above) and Kalium (below) calibration pad.

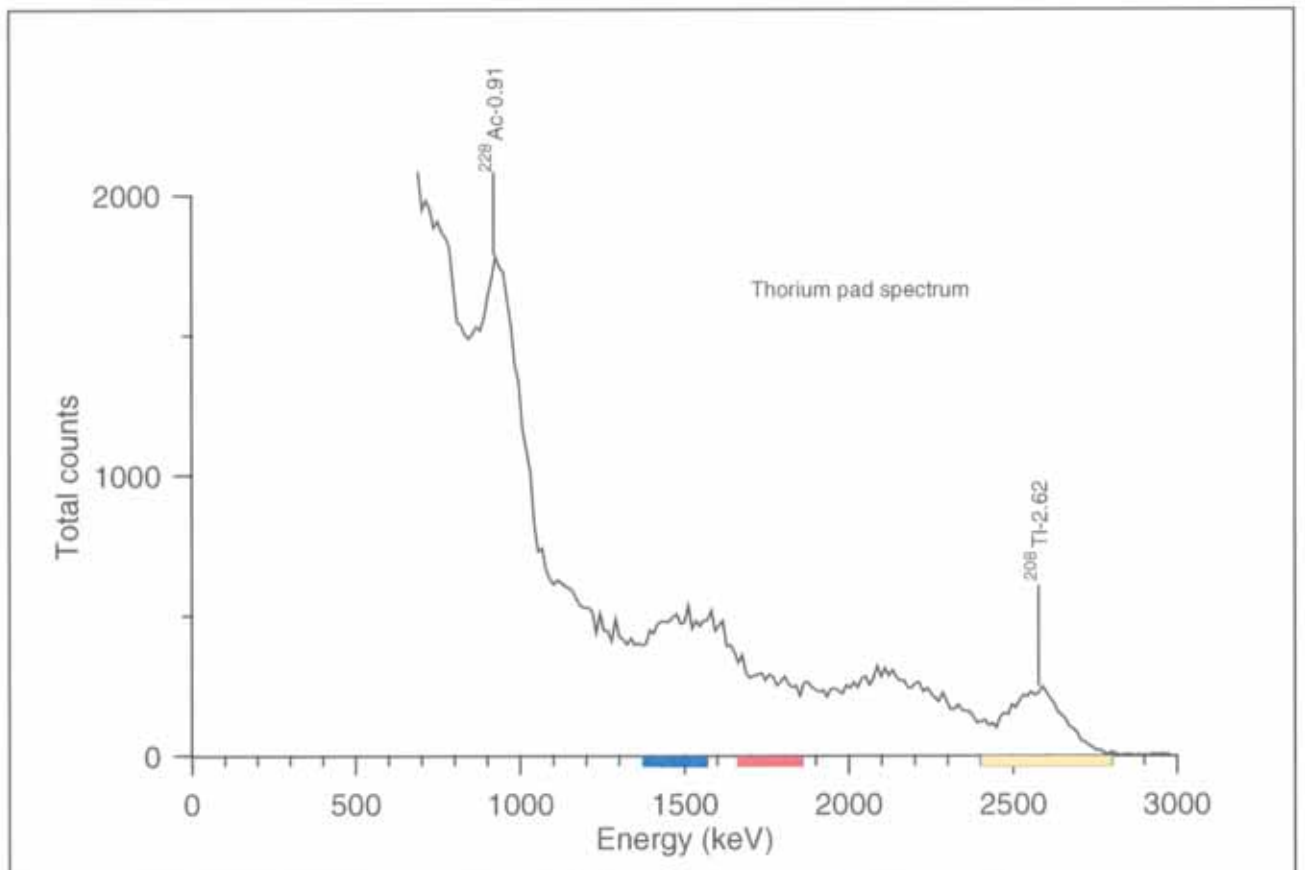
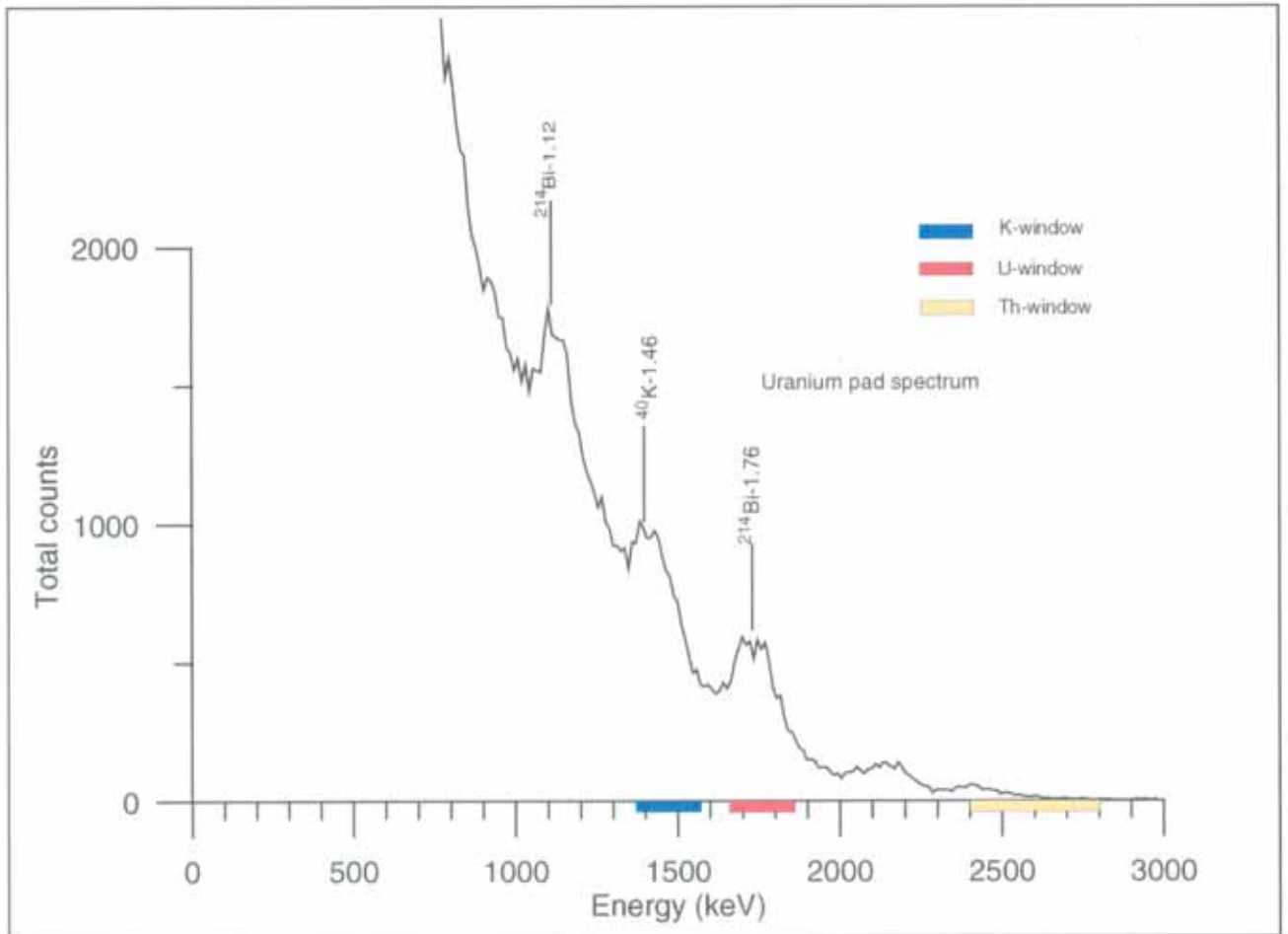


Figure 3. Spectrum of Uranium (above) and Thorium (below) calibration pad.

4.2 Calculation of stripping ratios

After adjusting the calibration pad spectra, the background corrected values, table 2, were used to calculate the stripping values for the instrument (Grasty 1977) :

$$\alpha = \text{count rate in U window} / \text{count rate in Th window} \quad - \quad \text{on Th pad}$$

$$\beta = \text{count rate in K window} / \text{count rate in Th window} \quad - \quad \text{on Th pad}$$

$$\gamma = \text{count rate in K window} / \text{count rate in U window} \quad - \quad \text{on U pad}$$

$$a = \text{count rate in Th window} / \text{count rate in U window} \quad - \quad \text{on U pad}$$

$$b = \text{count rate in Th window} / \text{count rate in K window} \quad - \quad \text{on K pad}$$

$$g = \text{count rate in U window} / \text{count rate in K window} \quad - \quad \text{on K pad}$$

The calculated stripping ratios for this instrument will then be :

$$\alpha = 1.302 / 1.232 = 1.057$$

$$\beta = 1.613 / 1.232 = 1.309$$

$$\gamma = 2.058 / 1.487 = 1.383$$

$$a = 0.066 / 1.487 = 0.044$$

$$b = 0$$

$$g = 0$$

4.3 Calculation of concentration factors

Before calculating the concentration factors, the stripped values (cps) in each window have to be found by using the stripping ratios. The stripped values are $n_{K,K}$, $n_{U,U}$ and $n_{Th,Th}$ ($n_{X,X}$ is the number of counts in window x caused by element x) are found by using the stripping equations:

$$n_{K,K} = (n_{Th}(\alpha\gamma - \beta) + n_U(a\beta - \gamma) + n_K(1 - a\alpha)) / A \quad (\text{on K-pad})$$

$$n_{U,U} = (n_{Th}(g\beta - \alpha) + n_U(1 - b\beta) + n_K(b\alpha - g)) / A \quad (\text{on U-pad})$$

$$n_{Th,Th} = (n_{Th}(1 - g\gamma) + n_U(b\gamma - a) + n_K(ag - b)) / A \quad (\text{on Th-pad})$$

where A is given by $A = 1 - g\gamma - a(\gamma - g\beta) - b(\beta - \alpha\gamma)$

n_K , n_U and n_{Th} are the background corrected values (cps) in the three windows from the pad measurements (table 2). By running the stripping program (Grasty 1977) the number of counts pr. second from element X in window X are found to be:

$$\begin{aligned} n_{K,K} &= 2.01 \text{ counts/sec} && \text{(on K-pad)} \\ n_{U,U} &= 1.51 \text{ counts/sec} && \text{(on U-pad)} \\ n_{Th,Th} &= 1.25 \text{ counts/sec} && \text{(on Th-pad)} \end{aligned}$$

Each calibration pad has a known content of K, U and Th as shown below:

	K (%)	U (ppm)	Th (ppm)	Background corrected
BLANK	1.34	0.98	2.28	
K-PAD	7.98	0.46	1.82	6.64 (% K)
U-PAD	1.25	53.33	3.20	52.35 (ppm U)
Th-PAD	1.34	2.31	110.0	107.72 (ppm Th)

If we take the background corrected contents of each element and divide by the stripped number of counts per second from element X in window X for each pad, we find the pad concentration factors $X_{FACTOR.PAD}$:

$$K_{FACTOR.PAD} = 6.64 / 2.01 = 3.303 \text{ (% K/cps)}$$

$$U_{FACTOR.PAD} = 52.35 / 1.51 = 34.669 \text{ (ppm U/cps)}$$

$$Th_{FACTOR.PAD} = 107.72 / 1.25 = 86.176 \text{ (ppm Th/cps)}$$

4.4 Calculation of geometric factor

A geometric factor, GF, have to be calculated to correct for the difference between the flat surface on the pad and the borehole situation with rock surrounding the entire probe. In general, the calibration factor for borehole situation, $X_{FACTOR.BH}$ can be found by

$$X_{FACTOR.BH} = X_{FACTOR.PAD} / GF$$

In 1998, GF was fixed to 2,1 as a qualified guess. This time we used 25 chemical analyses of K from two boreholes in Bleikvassli. The correlation was found between the chemical analyses and the corresponding calculated K-content using the K-pad concentration factor.

$$K_{FACTOR.BH} = 6.64 / 2.01 * GF = 3.303 / GF \text{ (% K/cps)}$$

Figure 4 shows the correlation between the calculated K-content using the K-pad concentration factor and the corresponding chemical analyses of K from two boreholes in Bleikvassli. The best fitting curve through origin is $Y = 0.4136 X$. The correlation factor is 0.9826. The gradient of the curve, 0.4136, means that calculated K-content using the K-pad concentration factor has to be multiplied by 0.4136 to get the borehole concentrations. The inverse of the gradient will be the geometric factor, GF.

$$GF = 1 / 0.4136 = 2.417$$

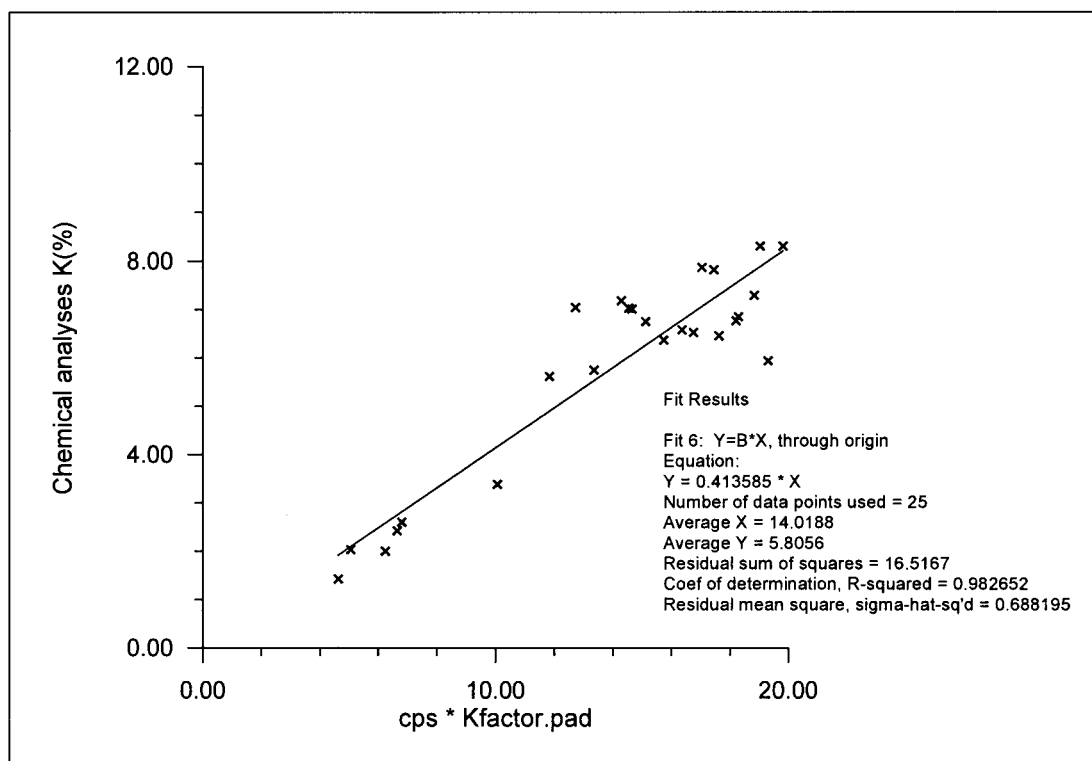


Figure 4: Correlation between chemical analyses of K and calculated K content using the K-pad concentration factor and 25 borehole samples from Bleikvassli.

Using the same geometric factor for all elements, we find the borehole calibration factors to be

$$K_{\text{FACTOR.BH}} = 3.303 / 2.417 = 1.367 \text{ (\% K/cps)}$$

$$U_{\text{FACTOR.BH}} = 34.669 / 2.417 = 14.344 \text{ (ppmU/cps)}$$

$$\text{Th}_{\text{FACTOR.BH}} = 86.176 / 2.417 = 35.654 \text{ (ppmTh/cps)}$$

Using a processing software made at NGU (Mauring 1998), the counts in each window are summed up at every position in the borehole. Further, this program calculates the stripped count rates using the above calculated stripping ratios and stripping equations. Finally the K, U and Th concentrations are calculated by multiplying the stripped values by the concentration factors.

5. INVESTIGATED SITES

Three sites in the North Calotte Region have been investigated: Bleikvassli and Bidjovagge in Norway, and Apukka close to Rovaniemi in Finland

5.1 Bleikvassli

The Bleikvassli Zn-Pb-Cu deposit is located about 50 km south of Mo i Rana in Nordland (map -01 and -02). The deposit occurs in the Uppermost Allochthon in the North Norwegian Caledonides (Ramberg 1967). The Bleikvassli mine was opened in the early 1950s and closed in 1998. The Mine sequence consists mainly of mica schists and kyanite schists, and in the mine area it contains the Bleikvassli Zn-Pb-Cu ore body and associated siliceous and feldspathic rocks. The average grades of the ore body are 8 % Zn, 3 % Pb and 0.4 % Cu. The ore zone is underlaid by a microcline gneiss in the footwall with a high K₂O content (up to 11.6 %) (Skauli 1992). The ore zone quartz-muscovite schist has a K₂O content of 4 - 5 %. The average content of U is 5 - 10 ppm (peaks of 20 - 30) and Th 30 - 50 ppm. The most interesting part of the investigations in Bleikvassli was to study the K content in the microcline gneiss. The gamma-ray spectrometry measurements were carried out in a borehole which cut through more than a 100 m thick layer of microcline gneiss. It was of great interest to map the variation in K content in this gneiss.

5.2 Biggejavre

Biggejavre is a scandium - Rare Earth Element (REE) deposit located some 40 km north of Kautokeino in Finnmark (Sandstad 1989). The area is shown on the location map no 99.112-03. The deposit was discovered using airborne gamma-ray spectrometry, AGRS (Håbrekke 1983). A Norwegian mining company has investigated the deposit by mapping and drilling. The deposit was never put into production. The Sc-bearing rock is an albitite consisting more

than 90 % albite. The main scandium mineral in the deposit is davidite which also consists Y, U, Cr, Ti, Fe, V and REE. The average analyses are 120 ppm Sc, 230 ppm Y, 830 ppm U, 4080 ppm Cr. The deposit is about 40,000 tons.

Two boreholes were investigated by gamma-ray spectrometry in 1999. Figure 5 shows a cross section of the central part of the deposit. Borehole 83-03 and 83-04 were investigated, and both these cut the main albitite zone.

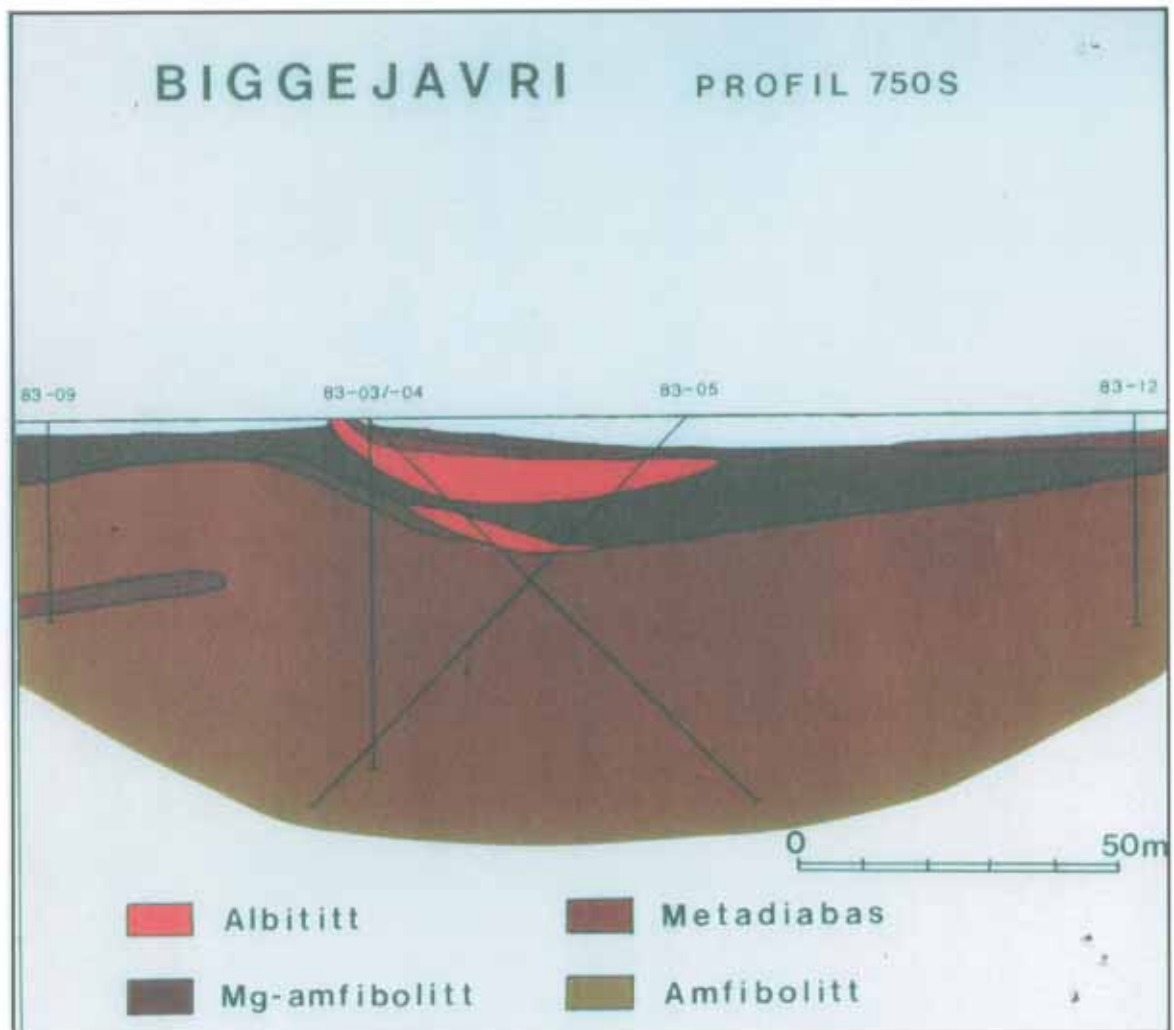


Figure 5. Biggejavre, crosssection of investigated Sc-deposit

5.3 Apukka, Rovaniemi

Borehole 306 is located in Apukka 17 km north of Rovaniemi in Finland. This borehole was investigated by the Finish company Astrock OY, and the results from the IFG gamma-ray spectrometer was of interest due to the development of the new spectrometer. No geological

information were available from this area except chemical analyses from selected parts of the borehole. In these parts there is an increased amount of U and Th.

6. RESULTS

The results from the borehole measurements are presented in borehole logs showing the calculated concentrations of K, U and Th. Chemical analyses exists from all boreholes and correlation calculations are performed for K in Bleikvassli, U in Biggejavre and K and Th in Apukka. Stripped data and calculated concentrations from all boreholes are listed in the appendix.

6.1 Energy adjustment of spectra from the borehole measurements

At each borehole a reference spectrum was obtained by taking measurements close to a calibration source, ^{137}Cs , with known spectral characteristics. It was intended that the relation between the ^{137}Cs peak in this reference spectrum and the spectrometer channels could be used to correct for temperature dependent instrument drift. However, when starting processing the data, these reference spectra could not be used to adjust the spectra from the borehole measurements. The reason was that the reference spectrum from the ^{137}Cs source on the ground only had a small energy drift while the borehole spectra indicated a drift of several channel numbers. The big energy drift in the borehole spectra was probably caused by the temperature difference between the ground and the borehole (up to 15°C). Instead of using the reference spectra, which gave no correction, known peaks of K and U observed in the borehole spectra were used for energy drift adjustment.

Figure 6 shows two spectra from Bh 17-98 in Bleikvassli at 20 and 25 m depth. The summed spectra indicates a clear K-peak. The peak is not in the centre of the K-window and before processing the data the K-peak was adjusted to the right energy level, 1460 keV.

Figure 7 shows the summed spectra from Bh 83-03 (6 m depth) and Bh 83-04 (16 m depth) at Biggejavre. Two clear peaks of ^{214}Bi are observed. The measured spectra are adjusted to the right level of these two isotopes, ^{214}Bi (1120 keV) and ^{214}Bi (1760 keV) (centre of U-window) before processing the data.

Figure 8 shows the summed spectra from Bh 306 in Apukka at 18 and 85 m depth. Two clear peaks ^{40}K (1460 keV) and ^{214}Bi (1760 keV) are observed at both spectra. The measured spectra are adjusted to the right level of these isotopes. At 18 m another peak is at a lower energy level, probably ^{214}Bi (1120 keV).

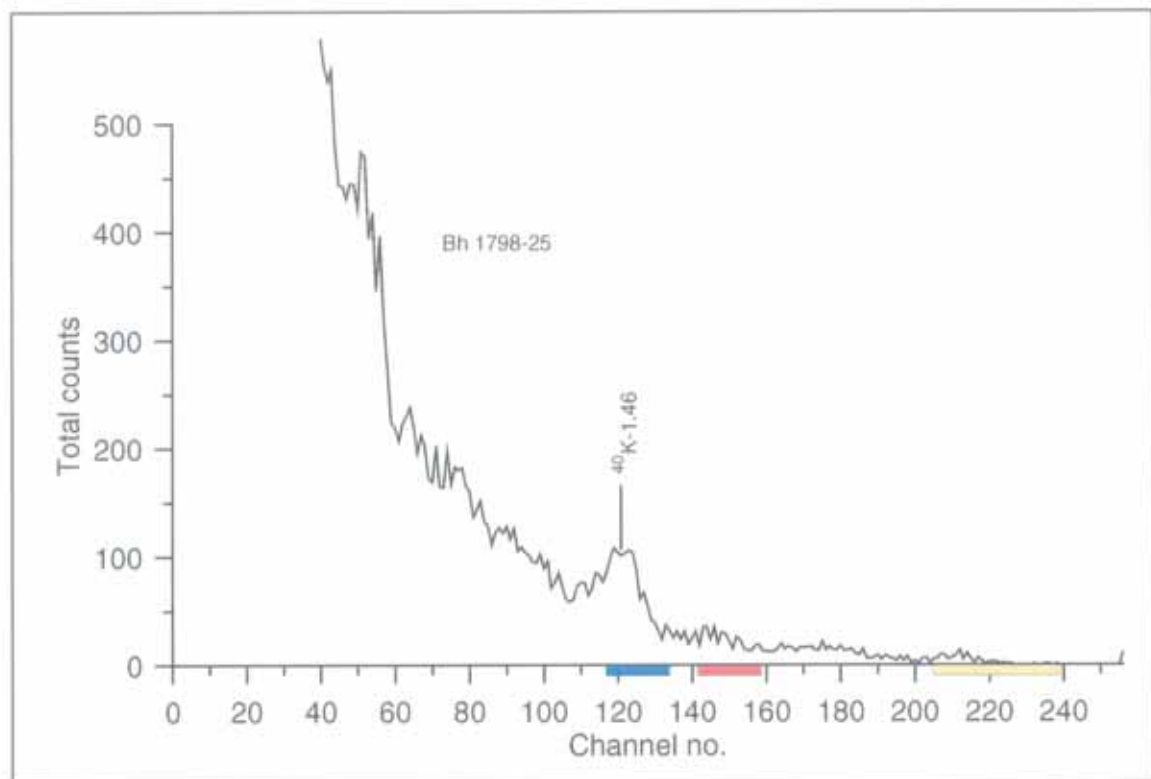
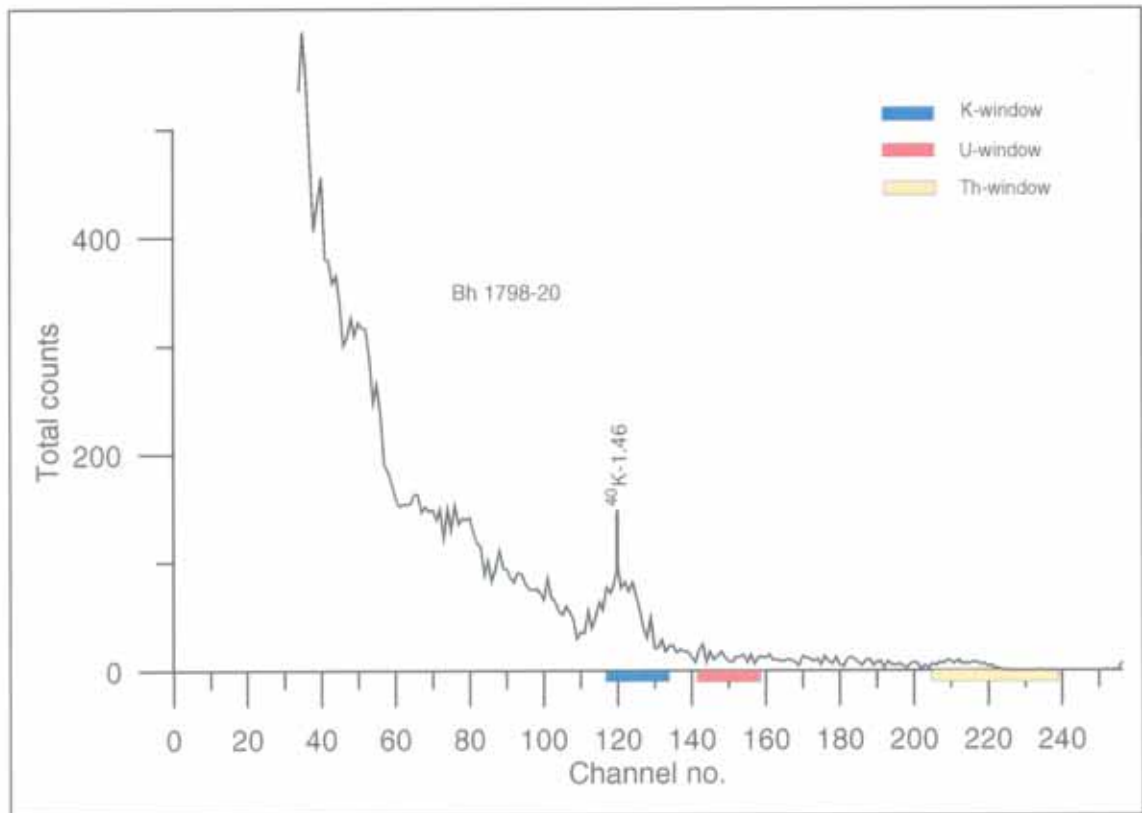


Figure 6. Spectrum Bh 17-98 Bleikvassli, 20 m depth (above), 25 m depth (below).

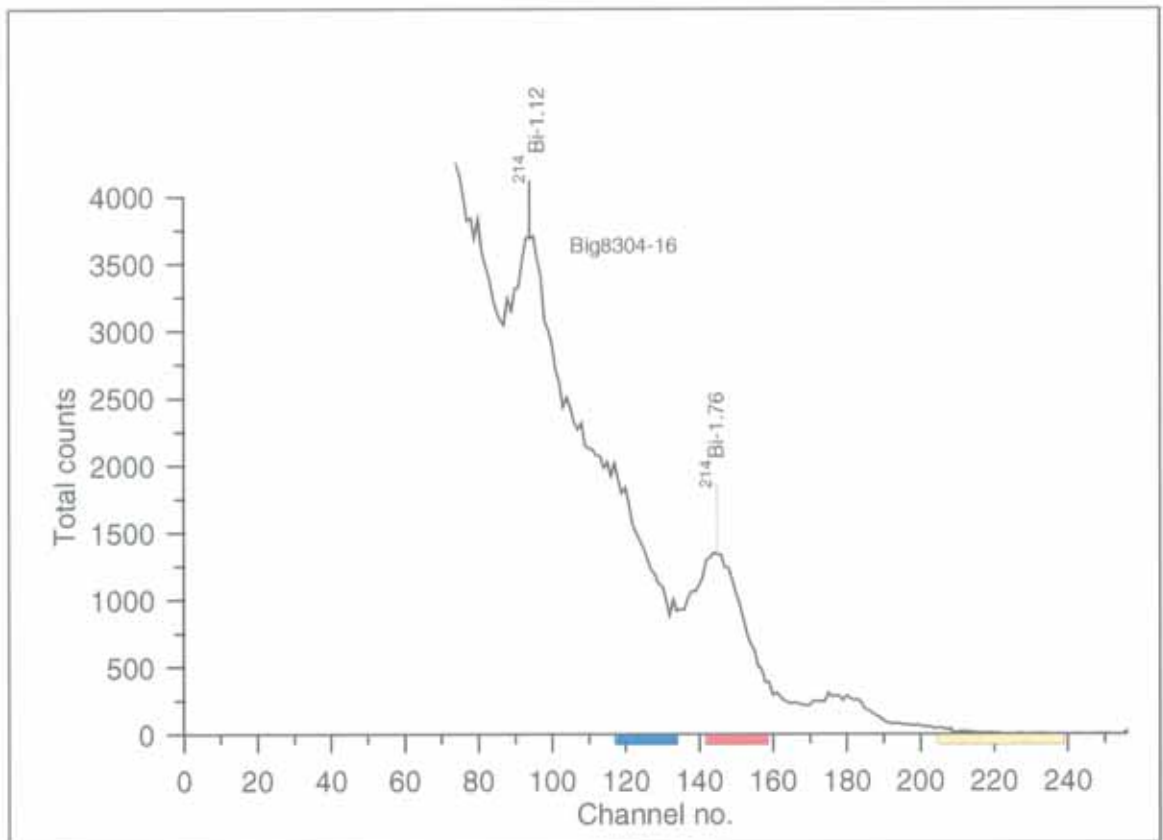
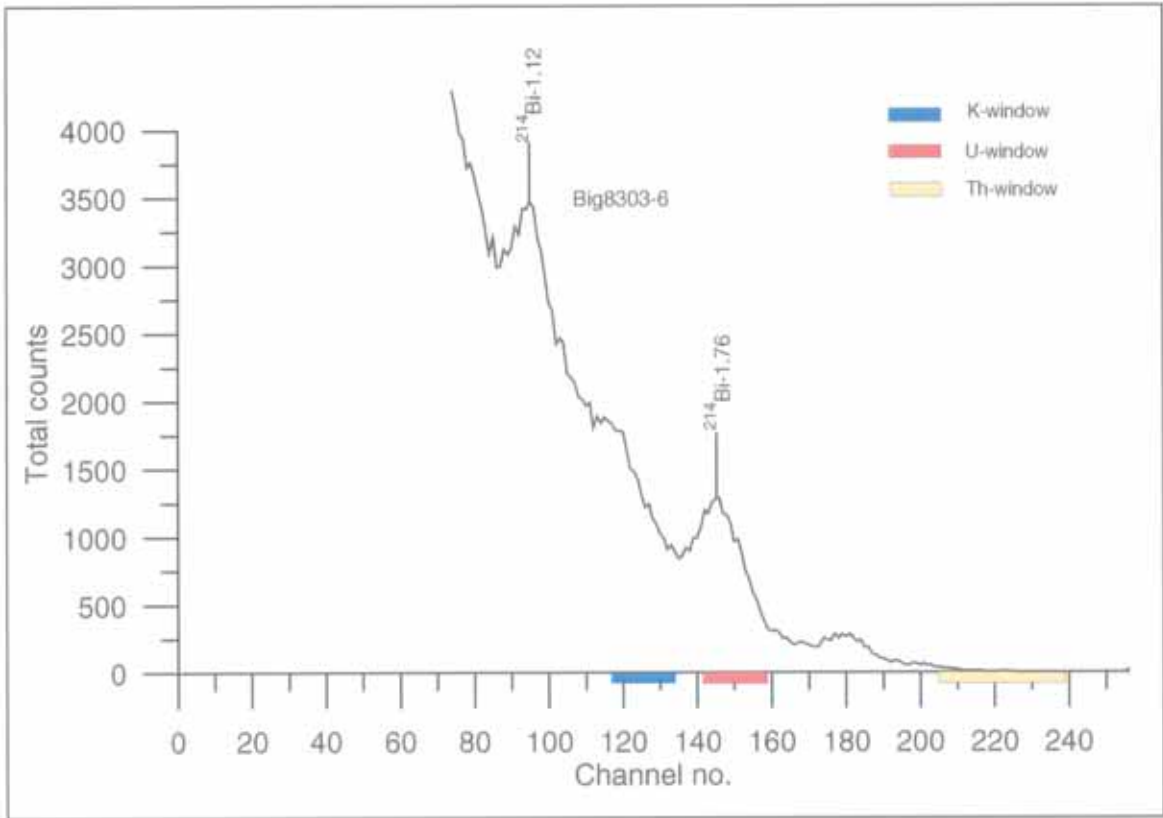


Figure 7. Spectra Bh 83-03 (6 m depth) and Bh 83-04 (16 m depth), Biggejavre

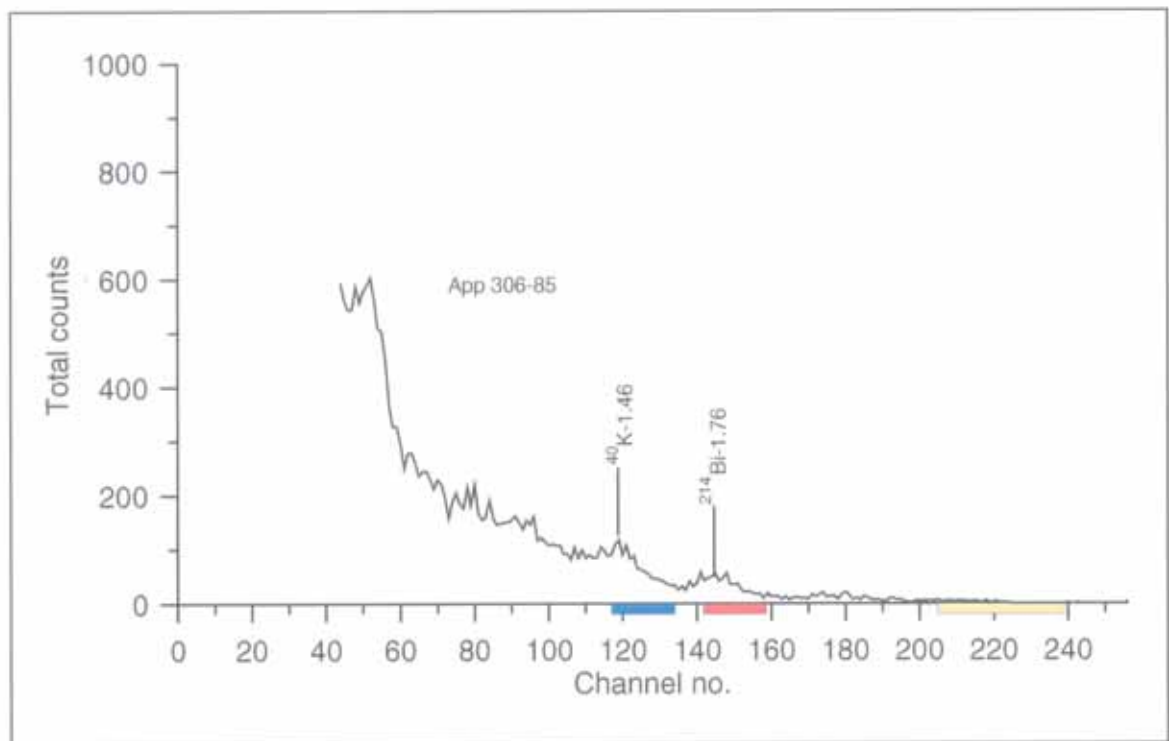
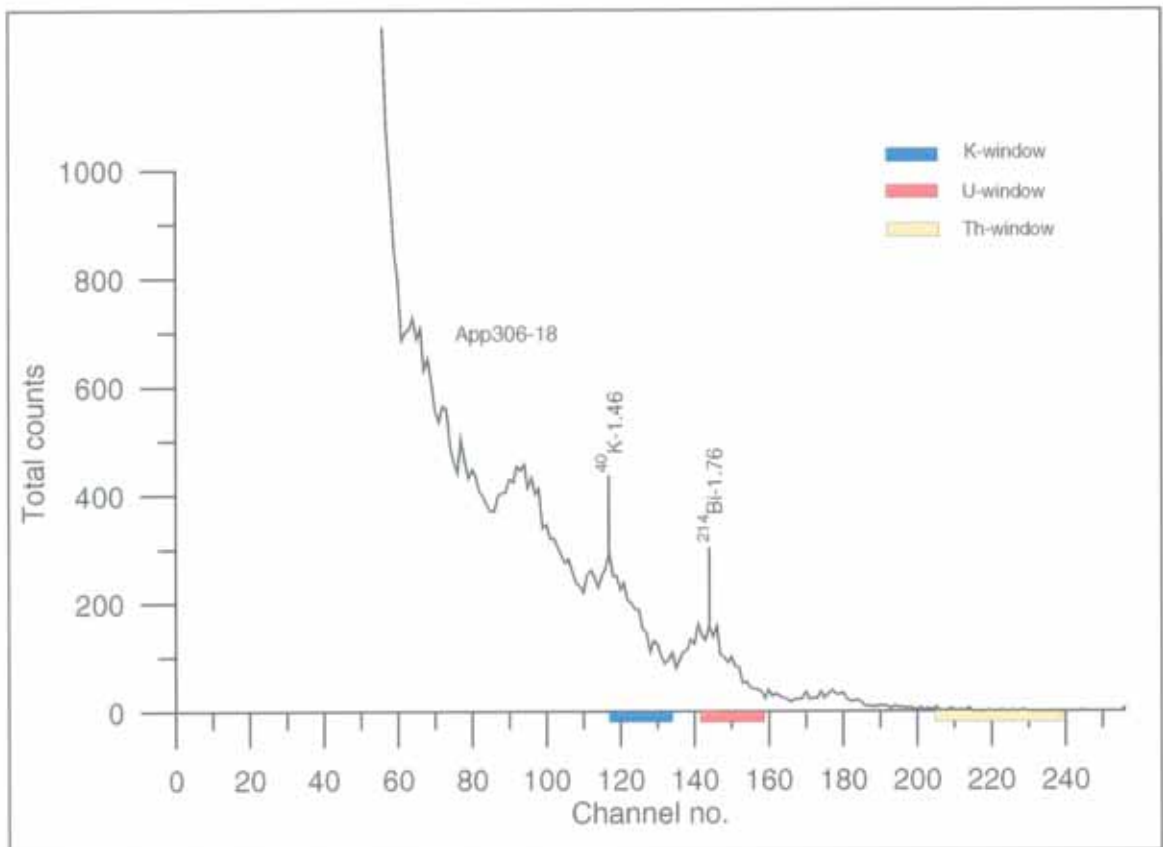


Figure 8. Spectra Bh 306, Apukka, 18 m (above) and 85 m (below).

6.2 Results from Bleikvassli

The results from Bleikvassli include results from new measurements in Bh 17-98 and reprocessing of data from Bh 1-97 at Brunsebekken close to the Bleikvassli Mine. Measuring interval in Bh 17-98 was 1 m, and measuring time in each point was 2.5 minutes. As described in section 4.4, data from these boreholes were used to find the geometric factor (GF).

Borehole Bh 17-89, close to the separation plant, was drilled to map the thickness of a microcline gneiss with high content of K. Gamma-ray spectrometry was carried out to map the variation of K in the more than 100 m thick layer of this gneiss. The results from the gamma-ray measurements are shown in figure 9.

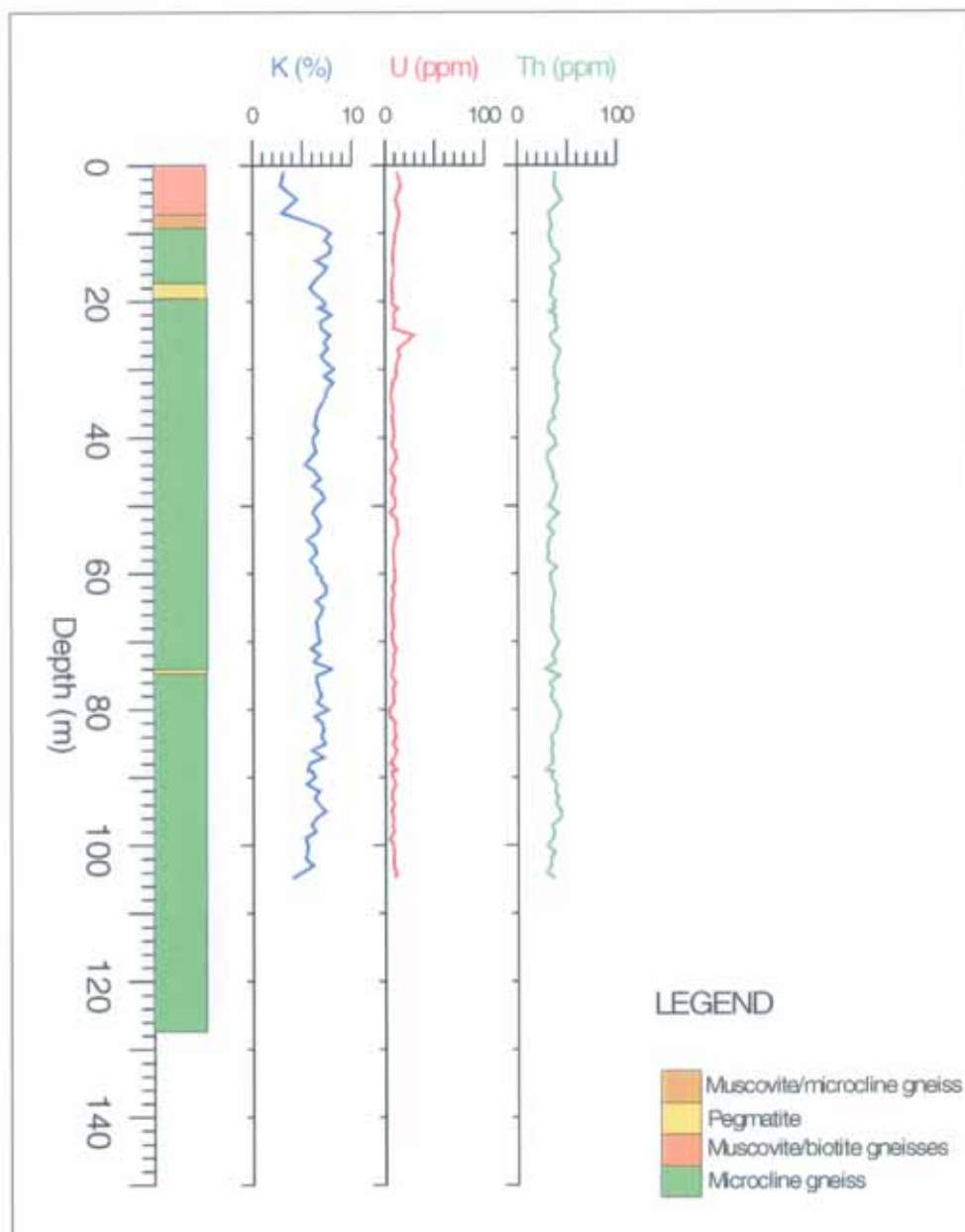


Figure 9. Bleikvassli, Bh 17-98. Calculated concentrations of K, U and Th.

Except for the upper 7 m of the borehole, the investigated rock is microcline gneiss. The calculated K content varies along the borehole with an average amount of 6.5% K. The highest K content is from 10 – 35 m with 7.25% K. The trend is decreasing K content to the depth. The deepest investigated part of the borehole, 95 – 105 m, has a K content of 5.6%. The U content is mostly below 10 ppm with the highest amount at 24 – 26 m with 25 ppm U. The Th content is 30 – 40 ppm along the entire borehole.

Figure 10 shows the correlation between chemical analyses of K and calculated K content from the gamma-ray spectrometry measurements in Bh 17-98 and Bh 1-97. Since these data were used to calculate the geometric factor, the slope of the best fitted line is close to 1. The correlation factor is 0.98 which is acceptable. This means that the gamma-ray spectrometry method can be used to map K content in the microcline gneiss and probably in other rocks containing potassium. Other statistic data are shown in figure 10.

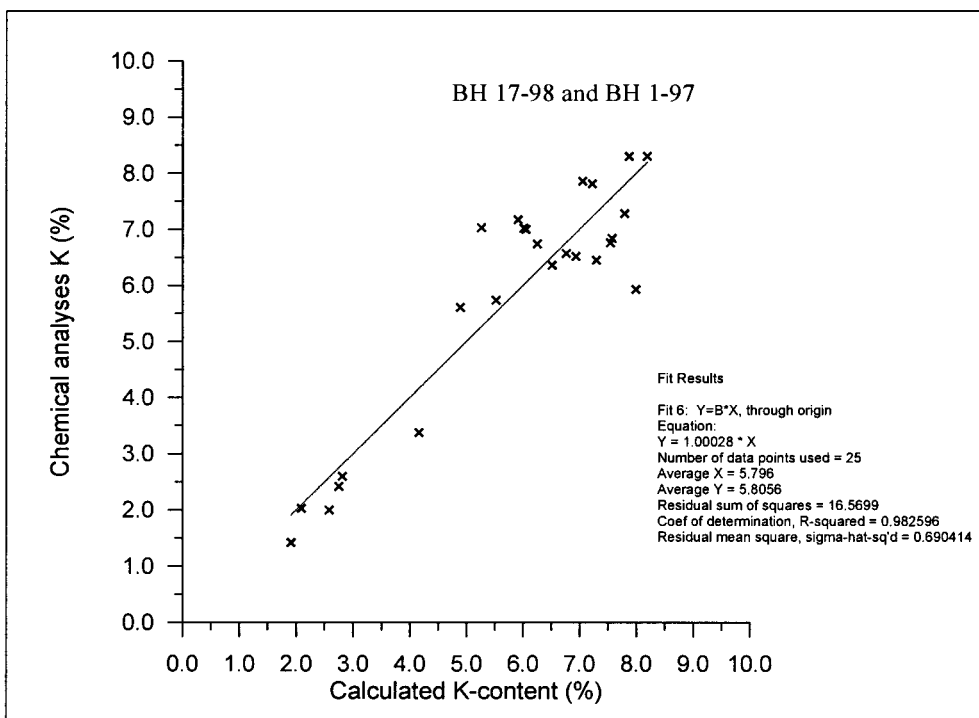


Figure 10. Correlation between chemical analyses of K and calculated K content. Bh 17-98, Bleikvassli and Bh 1-97, Brunesebeken.

Figure 11 shows the 1997 results and the reprocessed results from Bh 1-97, Brunesebeken. The black curves show the 1997 results. The reprocessed data show a bit lower K-content, The U content is similar in both data set and the Th content shows some small differences which may be caused by some change in the a stripping factor.

Chemical analyses of U and Th do not exist from these boreholes and calculation of correlation coefficients on these elements could not be done.

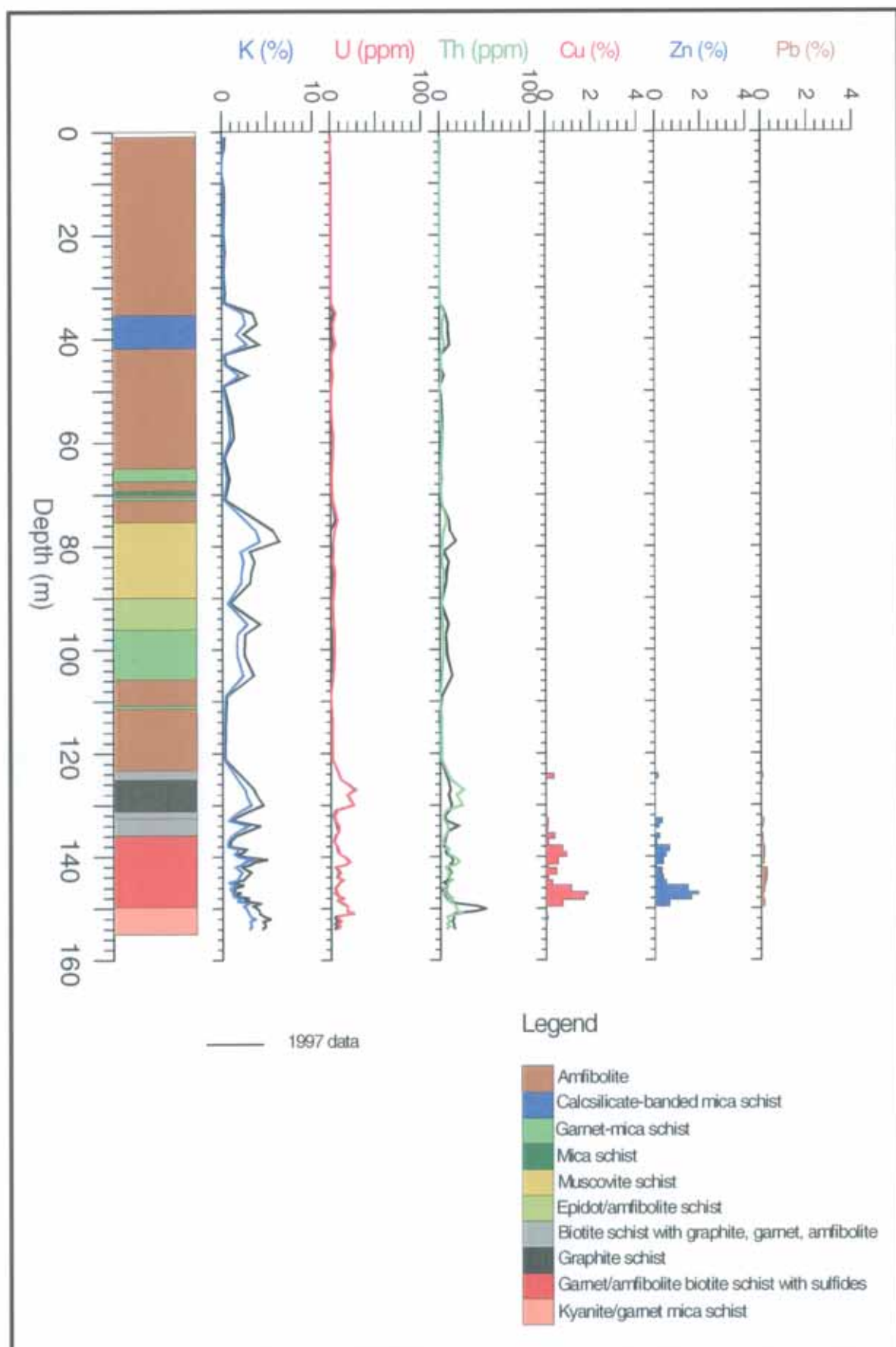


Figure 11. Brunesbekken Bh 1-97. Reprocessing of 1997 data. Calculated concentrations of K, U and Th. Borehole log and Cu, Zn and Pb content.

6.3 Results from Biggejavre

Figure 5 shows a cross section of the deposit and the positions of the investigated boreholes. The two boreholes 83-03 and 83-04 cut the albitite zone which contains the U/Sc mineral davidite. Measurements were taken every 0.25 m in the albitite and the measuring time was 2.5 minutes. Outside the albitite the measuring interval was increased to 0.5 and 1 m. Figure 12 and 13 show the results from Bh 83-03 and Bh 83-04 together with chemical analyses of U_3O_8 , Zn and Cu and a geological log. For a detailed study of the result see the appendix where a listing of stripped values (cps) and calculated concentrations at every position in the boreholes are shown.

Uranium correlations.

Figure 13 and 14 shows that there is a strong radiation in the albitite zone caused by the high U content, and it seems to be a good correlation with analyses on U_3O_8 . The radiation from the albitite is in some positions very strong. The chemical analyses indicate an average U_3O_8 content of 1700 ppm at 6 - 7 m depth in Bh 83-03 and a maximum value of 2200 ppm at 7 - 8 m in Bh 83-04. At the same position the Pb content is 260 ppm and the Zn content 10 ppm. Pb and Zn are mentioned to see if there is any correlation between the γ -radiation (radioactive minerals) and Pb, Zn content.

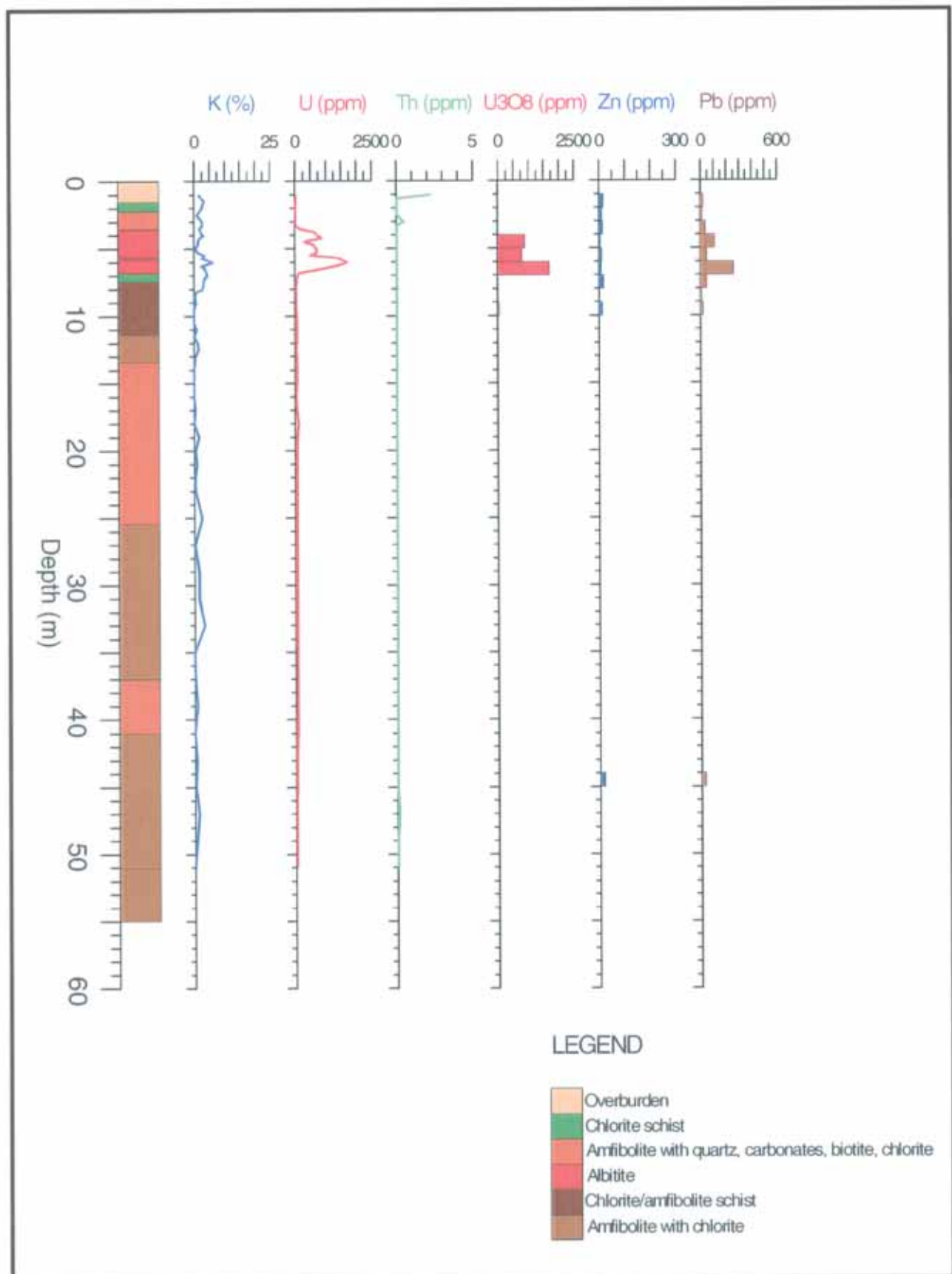


Figure 12. Biggejavre Bh 83-03. Calculated concentrations of K, U and Th, analyses of U3O8, Zn and Pb.

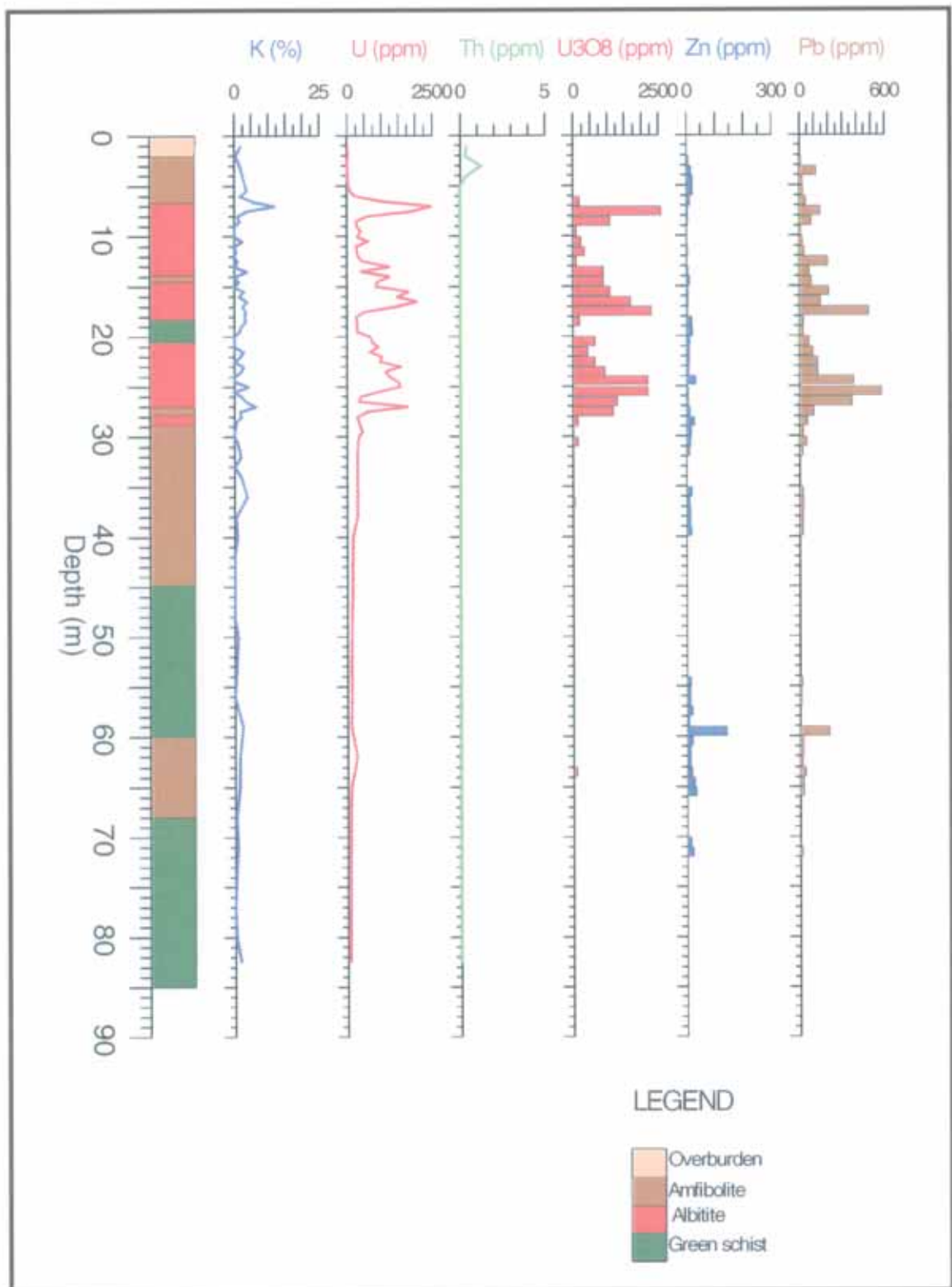


Figure 13. Biggejavre Bh 83-04. Calculated concentrations of K, U and Th, analyses of U3O8, Zn and Th.

Altogether 27 chemical analyses exists from the albitite in these boreholes and the correlation between chemical analyses of U and calculated U content are shown in figure 14. The slope of the best fitted straight line is 1,02, while the correlation coefficient is 0.944. The chemical analyses give the average U content at one meter intervals while the gamma-ray measurements were taken every 0.25, 0.5 or 1 m, which of cause will give some uncertainty. The calculated values will not refer exactly to the same volume of bedrock as the chemical analyses. Taking this into consideration, the correlation between calculated and analysed Uranium content is very good. The latter is an indication of well estimated geometric factor for the calibration.

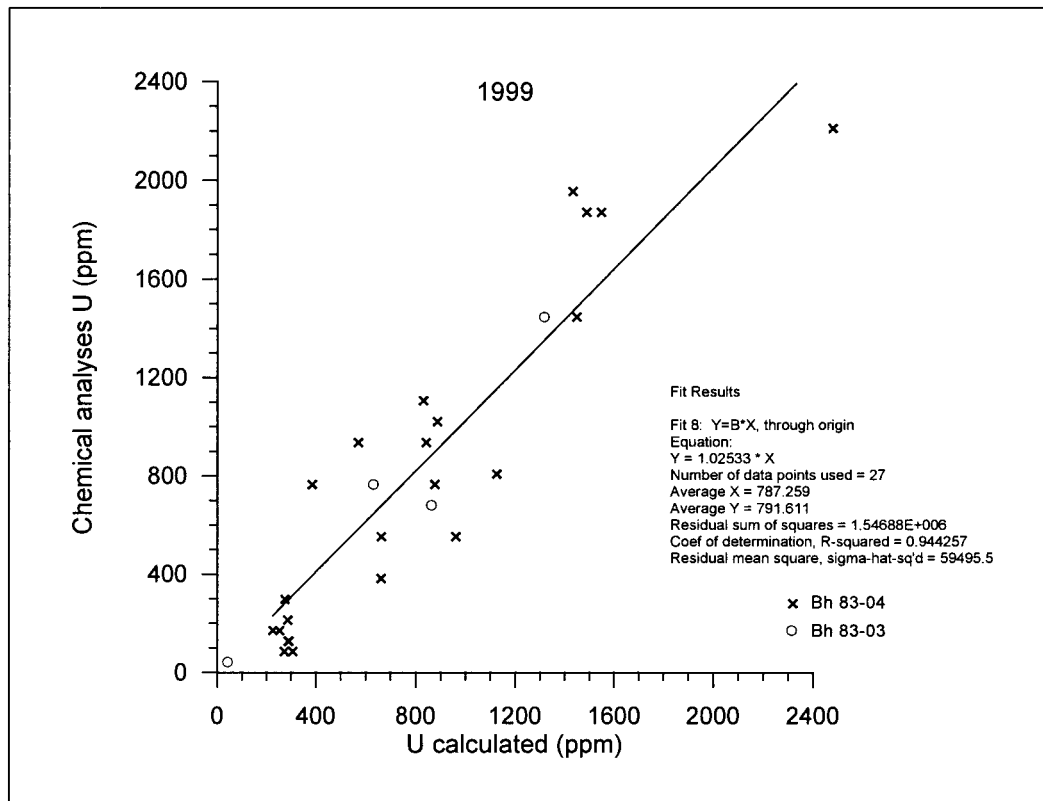


Figure 14 .Correlation between chemical analyses of U and calculated U content in Bh 83-04 and 83-03, Biggejavre, 1999 measurements.

Figure 15 shows the U correlation in the same boreholes in 1997. The slope of the best fitted line is 0,98 while the correlation coefficient is 0.94, nearly the same as with the new measurements with the new stripping constants, calibration and geometric factor. The new geometric factor has limited influence since the product of stripped values and GF is almost the same in 1998 and 1999. Since GF is higher in 1999, this can be caused by a reduction in the sensibility of the crystal. The geometric factor is constant and the same for all measurements in the borehole and will not effect much on the correlation coefficient. Some more (4) points were measured in 1999 in Bh 83-04. The better calibration in 1999 results in the same correlation coefficient.

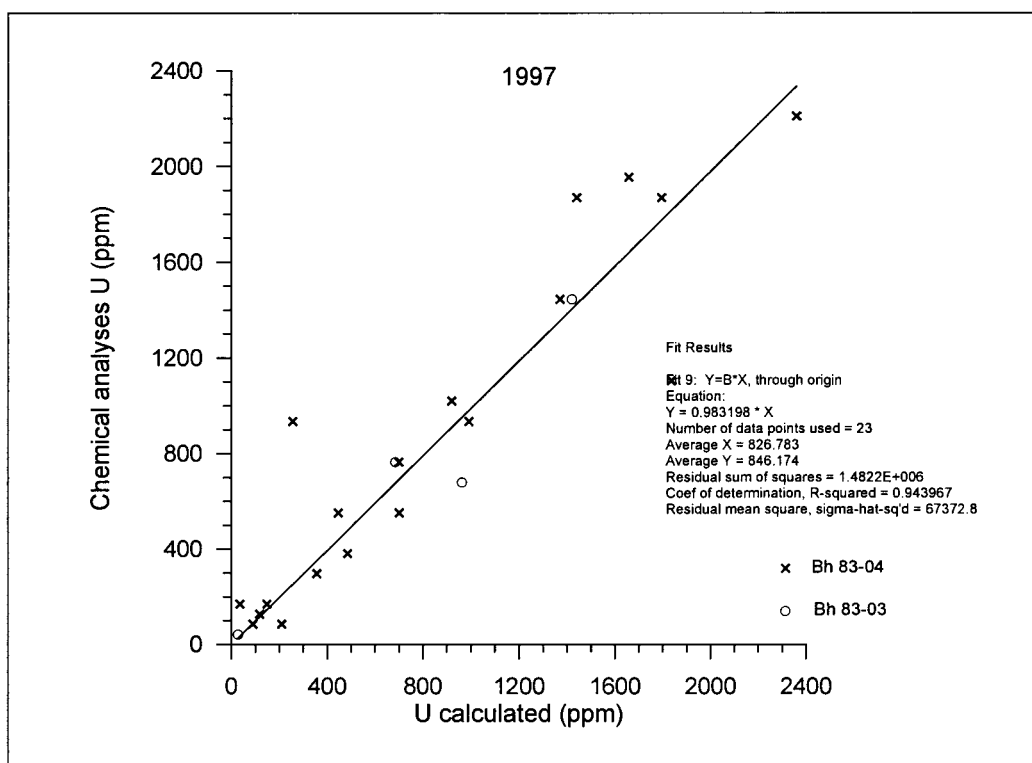


Figure 15. Correlation between chemical analyses of U and calculated U content in Bh 83-04 and Bh 83-03, Biggejavre, 1997 measurements.

Potassium correlations.

In the 1997 measurements, there was a good correlation between Uranium and Potassium in borehole 83-04 (Elvebakk & Rønning 1998). A maximum K content of 21 % for the albitite zone was calculated while the average analysed value for the whole zone was 0,22 %. This was obviously wrong, and it was concluded that the stripping of Uranium radiation from the Potassium window was not done properly. Figure 12 shows the new results from borehole 83-03, and figure 13 borehole 83.04.

Just outside the albitite zone, the analysed K content is quite high (4 – 5 %, see figure 16). The average K content within the zone is 0.22 %. The calculated K content just outside the albitite correlates well with the chemical analyses. The figure also shows that the calculated K content inside the albitite zone is much too high compared with the chemical analyses. The reason for this is probably that still not all the Uranium radiation in the K-window has been stripped off. The same problem occurred in 1997. The amount of indicated K in the albitite is less now, probably caused by better calibration of the instrument. The energy drift of the borehole spectra caused by temperature changes is probably the main reason for this stripping problem. When U is present, it seems impossible to get good calculation on K content.

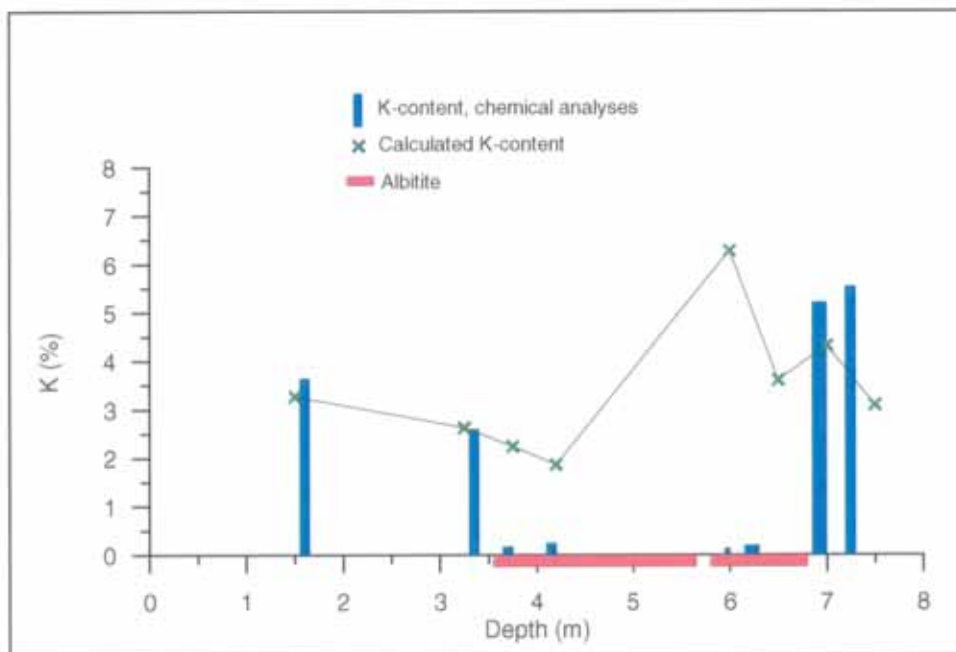


Figure 16. Bh 83-03, Biggejavre. Chemical analyses and calculated K content.

6.4 Results from Apukka

Measurements in Bh 306 in Apukka, north of Rovaniemi Finland, were taken at one meter intervals and the measuring time was 3 minutes. Astrock OY has earlier made total count measurements in this borehole, and their data are compared with our total count measurements in figure 17. The results seems to correlate well which is an indication of well functioning equipment. The small variations which can be seen, are caused by different sampling intervals.

The calculated content of K, U and Th based on our measurements are shown in figure 18. No geological log from the borehole was available so it is not possible to correlate the results to different rocks. It seems to be a layer from 25 to 60 m containing about 4 % potassium which could be related to one specific rock. From 70 to 95 m the K-content is 3 – 4 % K. In this layer there is an increase in the Th content at 70 to 84 m with up to 55 ppm Th. In the rest of the borehole the K content is mostly below 2 %. A sharp peak of U is indicated at 18 m (170 ppm U). Other peaks of U occurs at 51 m (63 ppm), 85 m (50 ppm) and 131 m (38 ppm).

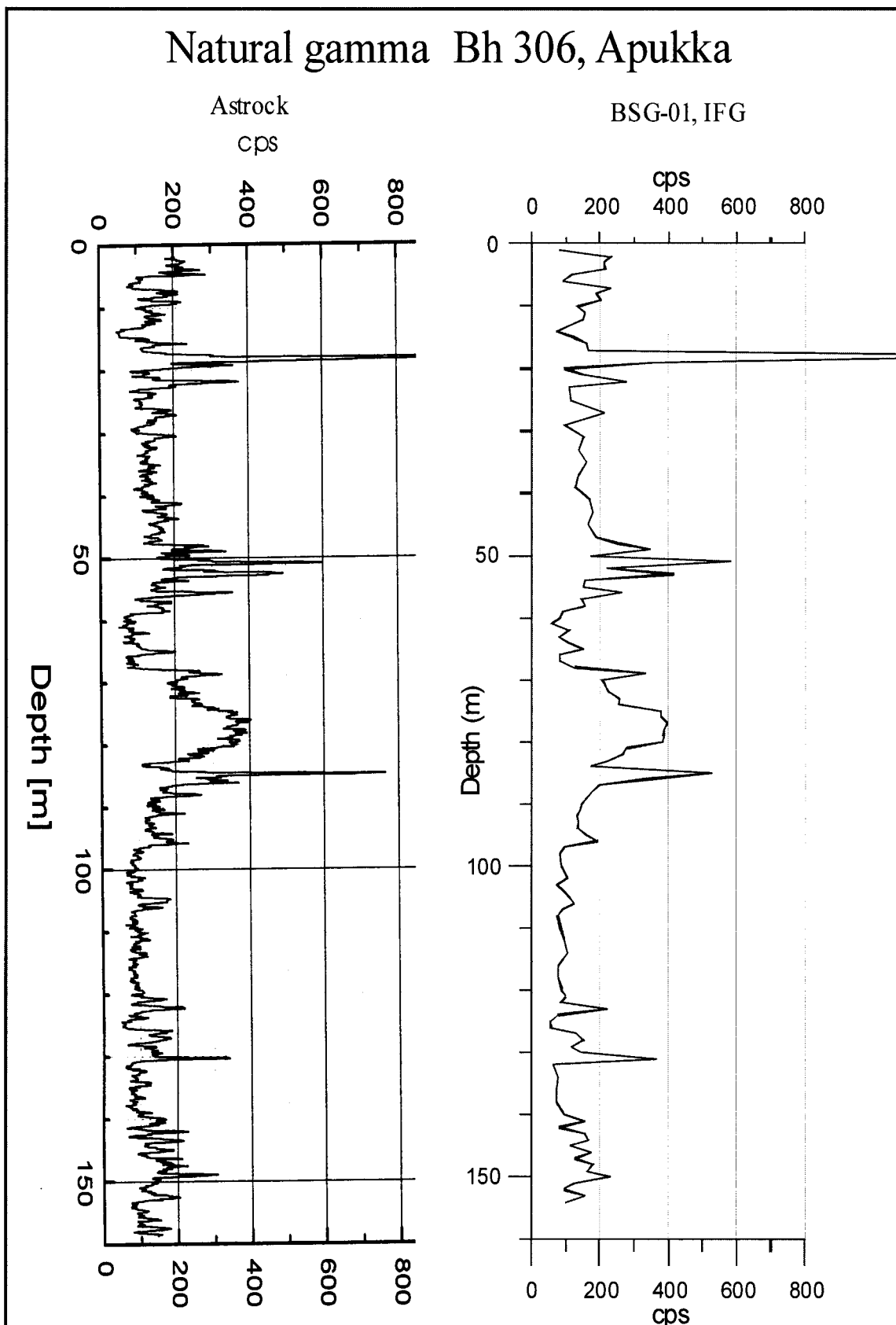


Figure 17. Total count measurements in Bh 306, Apukka. Astrock (left) and BSG-01, IFG (right).

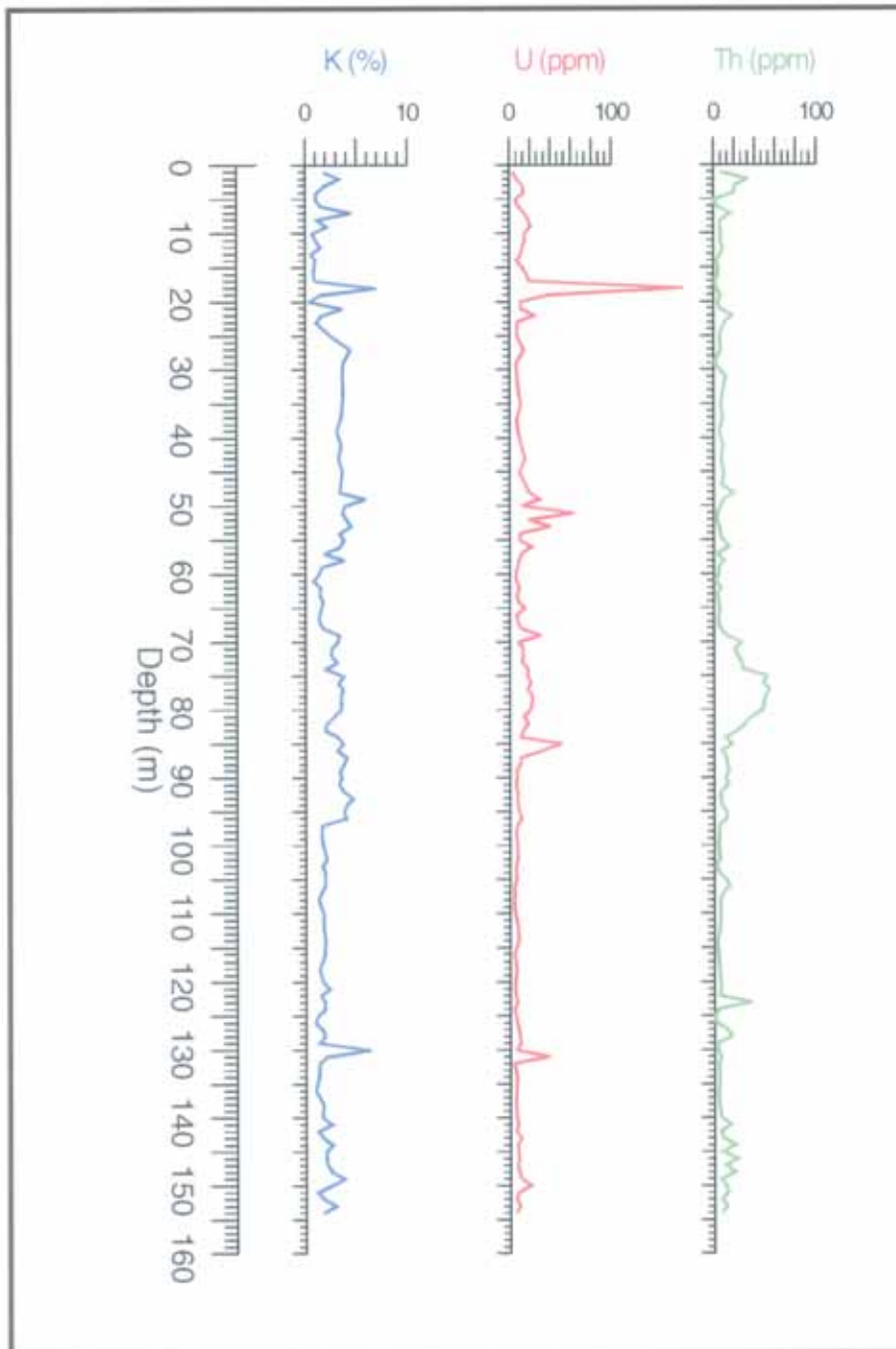


Figure 18. Apukka, Bh 306. Calculated concentrations of K, U and Th.

Potassium calculations.

Chemical analyses exist from the upper 25 m and from 50 to 85 m. The chemical analyses are an average of one m core and the measurements are taken at a specific point every meter. Figure 19 shows the calculated K content and the chemical analyses plotted as a function of depth. The calculated values are higher than the analysed values, and the correlation is partly contradictory.

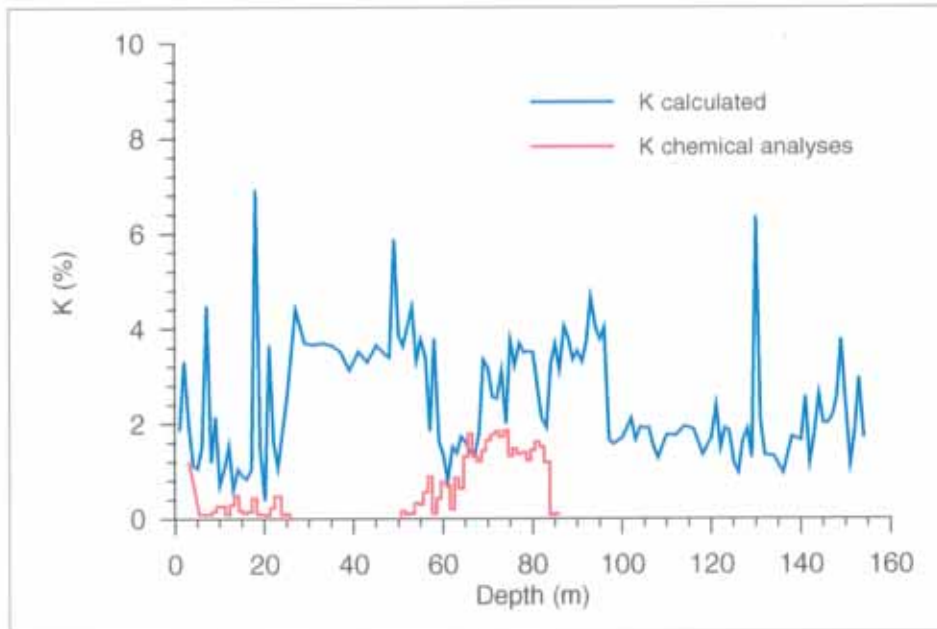


Figure 19. Chemical analyses and calculated content of K in Bh 306, Apukka

Figure 20 shows the correlation between chemical analyses and calculated content of K. In general, the calculated values are higher than the analysed, and the correlation is disappointing. The best fitted curve is $Y = 0.25 \cdot X$ and the correlation coefficient is 0.49. Based on the good results from Bleikvassli, these results are difficult to explain. The U content is not especially high, and there seems not to be a good correlation between U/Th and K. It could have been interesting to reanalyse these samples, but that is out of the scope for this project.

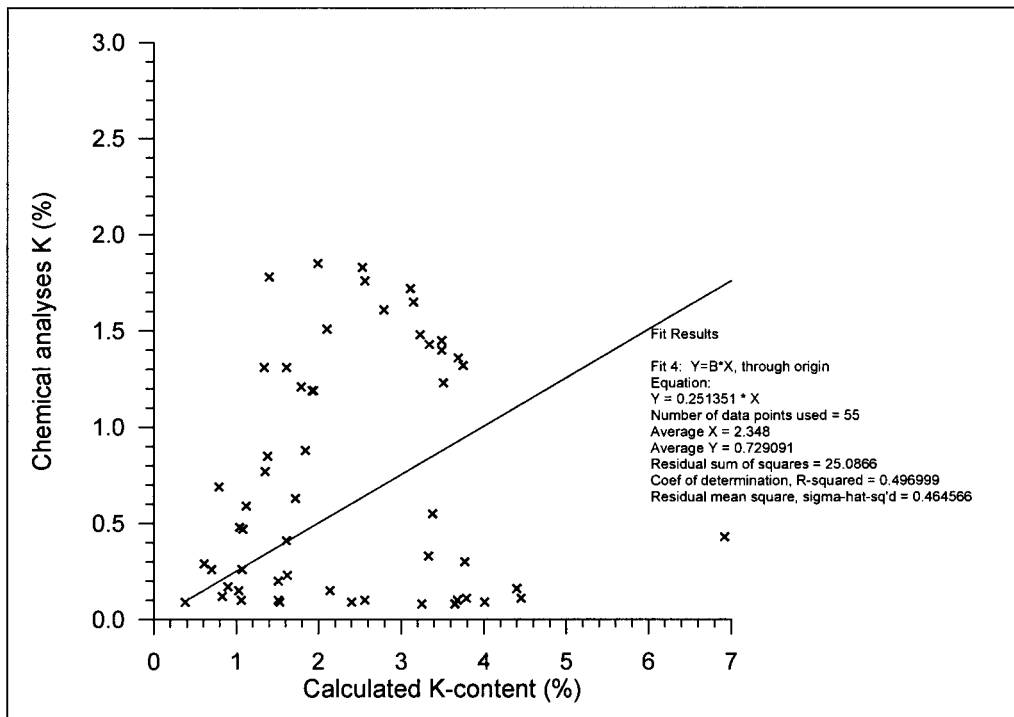


Figure 20. Correlation between chemical analyses and calculated content of K in Bh 306

Thorium calculations.

Figure 21 shows the correlation between analysed and calculated Th content in Bh 306, Apukka. The correlation is good (correlation coefficient is 0.97), but the level of the calculated Th content is somewhat low. The best fitting straight line is $Y = 1.42 * X$. Also these analyses come from 1 m core (the same as the K analyses), but in this case the correlation is very good. The wrong level can be explained with error in the calibration of the probe, error in the analyses, wrong geometric factor used or a combination of these three. The most important thing is that the correlation is good. The concentration factor can be adjusted to the actual investigated site.

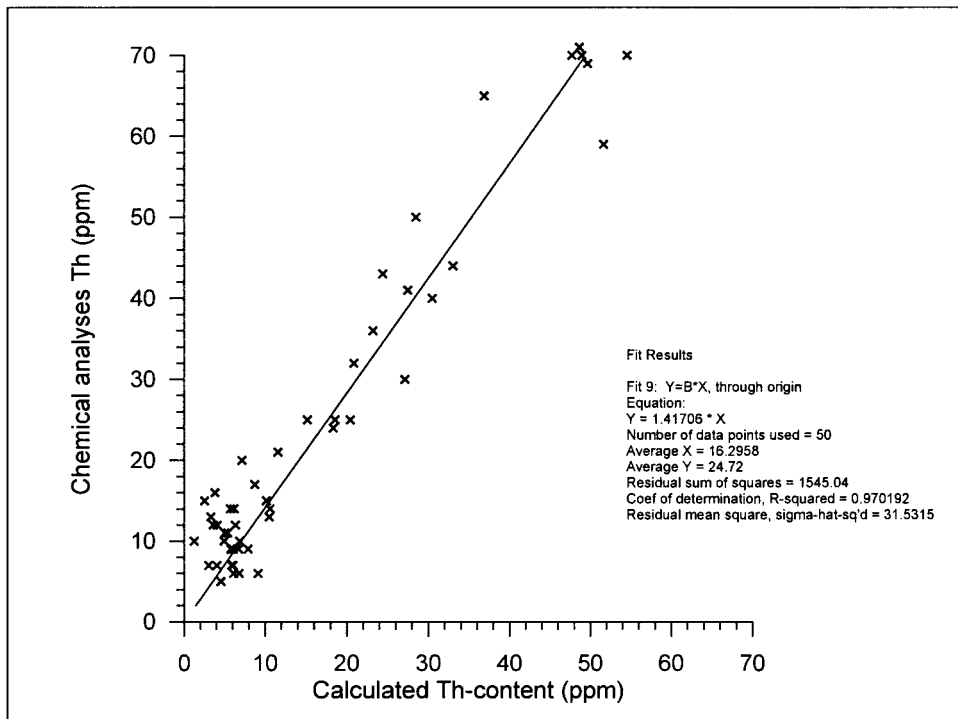


Figure 21. Correlation between chemical analyses of Th and calculated Th content, Bh 306.

To test the influence of the measuring time, two sites in borehole 306, 66 and 78 m, were measured at 3 and 10 minutes. The result are shown in table 3. Only small differences are observed, but only two points are not enough to make a statement regarding the influence of the measuring time.

Table 3. Data from 10 and 3 min. measuring time at 66 and 78 m depth, Bh 306

Depth	Time	K (cps)	U (cps)	Th (cps)	K (%)	U (ppm)	Th (ppm)
66.00	3 min.	1.03	0.50	0.15	1.40	7.11	5.38
66.00	10 min.	1.23	0.31	0.18	1.68	4.51	6.45
78.00	3 min.	2.55	1.56	1.40	3.49	22.36	49.65
78.00	10 min.	2.62	1.39	1.34	3.57	19.99	47.58

7. DISCUSSION

Testing of a borehole gamma-ray spectrometer, BSG-01, IFG Corporation Canada, has been carried out in Norway and Finland. The same instrument was tested and calibrated in 1997, but poor stripping constants caused by too short measuring time on the calibration pads required new calibration of the instrument. New calibration measurements were carried out in August 1999 using the calibration pads at NGU.

7.1 Stripping, calibration and geometric factor.

Calibration measurements were carried out at NGU using the flat K, U, Th and background pads. These pads are usually used for calibration of ground and airborne spectrometers and measurements on the flat surface will not be the same situation as measuring in a borehole with rock surrounding the whole probe. Measurements were taken until clear peaks in the K, U and Th window were obtained on the pad spectra. Measuring time was 40 – 90 minutes, and this gave a total number of counts in the order of 5000 to 9000 in the respective element windows (table 1). According to Grasty (1991), this should give an accuracy of about 2 –3 % in the calibration factors. This was much better than the 1997 measurements.

Table 4 shows the stripping constants calculated in 1997 and 1999. α and β have increased while the two others have decreased. Parts of this variation may be caused by natural variations in the crystal but the main part of the changes are an effect of longer registration time.

Table 4. Stripping constants in 1997 and 1999.

Year	α	β	γ	a
1997	1.022	1.238	1.470	0.055
1999	1.057	1.309	1.383	0.044
Deviation	+ 3,4 %	+ 5,7 %	- 6,3 %	- 25 %

The most important constant for the IFG instrument seems to be γ .

γ = count rate in K window/ count rate in U window on U pad, hence $K = \gamma * U$.

The γ -constant should be small to minimise the amount of registrations in K-window caused by U. The 1999 γ -constant (1.383) is better than the 1997 constant (1.470). The results from Biggejavre confirms the better γ -constant with a smaller calculated amount of K in the albitite zone. However, the K-content in the albitite is still too high, and it seems like not all the U radiation in the K window has been stripped off. Based on this, it seems difficult to get good calculation of K when U is present.

A geometric factor (GF) has been calculated to transform the pad measurement situation to a borehole situation. In 1997 this factor was estimated to 2.1. In this years investigations, 25 chemical analyses of K from Bh 17-98 and Bh 1-97 in Bleikvassli were used. This factor was found to be 2.41. Using this geometric factor when calculating the K content in Bleikvassli gave of cause impressing results. However, the same factor gave also a very good correlation in the U calculations in Biggejavre. The slope of the best fitted line was 1,02 while the correlation coefficient was 0,94. These good results indicates that the right geometric constant is calculated, and that the value calculated using K seems also to be valid for U. However, Th analyses in Apukka gave a good correlation, but the level of the calculated values were to low compared with chemical analyses (slope 1,42). The wrong level can be explained with error in the calibration of the probe, error in the analyses, wrong geometric factor used or a combination of these three. It is not possible to say more about this without doing further investigations.

As mentioned before, the volume of bedrock which were analysed do not correspond directly with the influence volume at the spectrometer measurements. Based on this, correlation coefficients close to 1.0 are impressing. We still have some questions to answer concerning the calculated levels, but the method seems promising. Unfortunately, it is not possible to do more investigations within this project.

7.2 Correlation with chemical analyses

Except for the K calculation in Bh 306, Apukka and in Biggejavre, the calculated K, U and Th content correlates well with the available chemical analyses. In Bleikvassli the correlation coefficient to K is 0.98 for the two boreholes, which is very good. In Biggejavre the correlation coefficient to U is 0.94 while the correlation coefficient for Th in Apukka was 0,97. Based on the fact that the analyses and the calculations do not refer to the same volume, this is a very good result. As long as only one radionucleide is present, it seems possible to get acceptable values of the K, U and Th content.

The calculated K content inside the albitite in Biggejavre is obviously wrong and insufficient stripping of radiation from U are probably the reason. The results from Apukka shows bad

correlation between analysed and calculated K content and the and the reason for this is not clear. Temperature drift in the measured spectra may be one of the reasons. Anyhow, calculating the K content in a situation where higher energy radiating elements is present, seems difficult.

Through borehole measurements it is possible to calculate the K, U or Th content at more than 100 points during one day. This is more economical than chemical analyses and it is possible to get the results immediately.

7.3 Technical improvements.

The most serious problem with the BSG-01 IFG spectrometer seems to be the temperature dependent instrument drift. The temperature change between the surface and the subsurface (up to 15° C) gave a nonlinear drift of the energy spectrum which had to be corrected. A calibration source, ¹³⁷Cs, was used to record a reference spectrum on the ground and this spectrum was supposed to be used to correct the borehole spectrums. However, the reference spectrum had no drift and could not be used to adjust the recorded borehole spectra. Instead, we had to use maximum response from each element and adjust the peak to the centre of the corresponding energy window. As long as there is sufficient response to give well defined peaks in the spectrum, this is possible to do. In case of low intensity of the radiation, this will be a problem especially since the drift is non-linear. To overcome the problem, a spectrum stabilisation source should have been placed permanently inside the probe. An other solution is to make electronic improvements which can reduce the temperature drift.

A small crystal, which is needed in a slimline borehole probe, have to be compensated with longer measuring time. With the BSG-1 probe we had to measure for 2,5 to 3 minutes to get a statistical good result. This is too time-consuming if the method should be introduced as a standard logging tool. Using a crystal which is able to absorb more of the gamma radiation should be considered when designing a new system.

8. CONCLUSION

NGU has carried out new test measurements using a borehole gamma-ray spectrometer from IFG Corporation at different sites in the North Calotte Region. Improved calibrations of the instrument were made doing long term measurements on calibration pads at NGU. In situ calculations of K, U and Th content gave promising results as long as only one radionuclide was present. Calculating the K content in an environment with higher energy radiating elements present, proved difficult. The obtained data will be of great value when the new borehole gamma-ray probe developed by the Finnish company Astrock OY will be evaluated.

To overcome the problem with temperature drift, a spectrum stabilisation source should have been placed permanently inside the probe. Another solution is to make electronic improvements which can reduce the temperature drift. To reduce the measuring time, a crystal which is able to absorb more of the gamma radiation should be considered when designing a new system.

ACKNOWLEDGEMENTS.

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APPENDIX

Listing of stripped K, U and Th window count rates and calculated K, U and Th content.

Bh 17-98, Bleikvassli

Depth	K(cps)	U(cps)	Th(cps)	K (%)	U (ppm)	Th (ppm)
1.00	2.29	0.86	1.10	3.13	12.27	38.94
3.00	2.06	1.11	1.03	2.81	15.86	36.64
5.00	3.28	0.73	1.27	4.48	10.42	44.86
7.00	2.15	1.03	0.88	2.94	14.78	31.27
9.00	5.11	0.85	0.98	6.97	12.17	34.90
10.00	5.77	0.69	0.90	7.87	9.92	31.81
11.00	5.34	0.67	0.94	7.28	9.59	33.27
12.00	5.82	0.60	1.00	7.94	8.63	35.29
13.00	5.65	0.56	1.19	7.71	8.06	42.02
14.00	4.67	0.57	1.19	6.37	8.16	42.25
15.00	5.52	0.59	0.92	7.54	8.39	32.69
16.00	5.13	0.62	1.06	7.00	8.87	37.64
17.00	4.59	0.43	1.00	6.26	6.11	35.32
18.00	4.24	0.48	0.98	5.78	6.83	34.77
19.00	4.64	0.53	0.91	6.34	7.59	32.30
20.00	5.29	0.50	1.09	7.22	7.13	38.79
20.50	5.38	0.54	1.01	7.34	7.71	35.62
21.00	4.87	0.89	1.08	6.65	12.79	38.40
21.50	5.46	0.64	0.89	7.45	9.12	31.66
22.00	5.81	0.58	1.08	7.93	8.35	38.41
23.00	5.02	0.65	1.08	6.85	9.36	38.30
24.00	5.05	0.56	1.14	6.90	8.00	40.36
25.00	5.71	2.00	0.92	7.79	28.67	32.61
26.00	5.27	1.48	1.00	7.20	21.24	35.33
27.00	5.55	0.87	1.21	7.57	12.48	42.73
28.00	5.04	1.04	1.16	6.88	14.84	41.28
29.00	5.38	0.82	1.09	7.35	11.78	38.52
30.00	6.00	0.75	1.04	8.19	10.71	36.73
31.00	5.26	0.78	1.05	7.18	11.21	37.15
32.00	5.93	0.52	1.14	8.09	7.50	40.42
33.00	5.49	0.45	1.08	7.49	6.44	38.39
34.00	5.35	0.39	1.15	7.30	5.57	40.87
35.00	5.08	0.51	1.07	6.93	7.25	38.06
36.00	4.82	0.59	1.00	6.57	8.43	35.31
37.00	4.66	0.46	1.06	6.36	6.56	37.42
38.00	4.58	0.57	0.88	6.24	8.23	31.04
39.00	4.83	0.60	0.87	6.59	8.64	30.76
40.00	4.44	0.60	1.04	6.05	8.59	36.96
41.00	4.50	0.39	1.11	6.14	5.61	39.19
42.00	4.67	0.71	0.87	6.37	10.15	30.83
43.00	4.22	0.79	0.83	5.76	11.39	29.50
44.00	3.85	0.54	0.90	5.26	7.80	32.04
45.00	4.61	0.37	1.00	6.29	5.30	35.41
46.00	4.98	0.69	1.01	6.80	9.83	35.63
47.00	4.41	0.56	1.12	6.02	8.02	39.64
48.00	5.07	0.41	1.05	6.91	5.86	37.26
49.00	5.29	0.66	1.02	7.22	9.52	36.14
50.00	4.68	0.66	0.87	6.39	9.44	30.91
51.00	4.41	0.33	1.16	6.01	4.66	40.97
52.00	4.74	0.79	0.99	6.47	11.36	34.99
53.00	4.96	0.82	0.84	6.77	11.69	29.71
54.00	4.71	0.89	1.02	6.42	12.74	36.26
55.00	3.97	0.66	0.88	5.42	9.44	31.14
56.00	4.58	0.59	0.85	6.25	8.45	30.06
57.00	4.69	0.54	0.88	6.40	7.72	31.09
58.00	4.20	0.59	0.82	5.73	8.48	29.10
59.00	4.65	0.61	1.10	6.35	8.74	39.09
60.00	4.77	0.63	0.91	6.51	9.01	32.15
60.50	5.07	0.65	0.94	6.91	9.38	33.30
61.00	5.03	0.63	0.92	6.87	9.10	32.61
62.00	5.41	0.44	1.01	7.38	6.30	35.78
63.00	5.36	0.62	1.05	7.32	8.89	37.16
64.00	4.62	0.45	1.01	6.31	6.40	35.77

65.00	5.17	0.39	0.97	7.05	5.62	34.42
66.00	4.97	0.43	0.98	6.79	6.22	34.83
67.00	4.65	0.56	1.00	6.35	8.02	35.35
68.00	4.73	0.55	0.94	6.46	7.87	33.22
69.00	4.80	0.40	1.04	6.55	5.77	36.79
70.00	4.96	0.50	1.16	6.76	7.18	41.17
71.00	4.25	0.71	1.06	5.81	10.18	37.74
72.00	4.92	0.57	0.98	6.72	8.14	34.62
73.00	4.45	0.60	1.08	6.08	8.55	38.39
74.00	5.85	0.49	0.77	7.99	7.00	27.36
75.00	4.66	0.39	1.18	6.37	5.55	41.82
76.00	4.70	0.70	0.90	6.41	10.02	32.03
77.00	4.87	0.48	1.01	6.64	6.90	35.95
78.00	5.06	0.56	0.92	6.91	8.09	32.72
79.00	4.69	0.58	1.04	6.40	8.29	36.99
80.00	5.54	0.25	1.16	7.57	3.55	41.09
81.00	4.54	0.30	1.20	6.20	4.31	42.67
82.00	5.10	0.66	1.12	6.97	9.53	39.72
83.00	5.18	0.61	1.10	7.07	8.74	38.85
84.00	5.04	0.72	0.93	6.88	10.30	32.96
85.00	5.32	0.49	1.00	7.26	7.01	35.46
86.00	4.33	0.77	0.94	5.91	11.10	33.35
87.00	5.21	0.60	0.98	7.11	8.64	34.81
88.00	4.16	0.31	0.97	5.68	4.49	34.36
88.10	4.18	0.46	0.94	5.70	6.64	33.22
89.00	4.02	0.76	0.80	5.49	10.90	28.21
89.10	4.33	0.41	1.00	5.91	5.92	35.34
90.00	4.58	0.51	0.94	6.25	7.27	33.29
91.00	3.94	0.70	1.11	5.37	10.05	39.18
92.00	4.89	0.47	1.06	6.67	6.76	37.64
93.00	4.53	0.44	1.14	6.18	6.28	40.55
94.00	4.87	0.62	1.09	6.64	8.85	38.60
95.00	5.34	0.36	1.23	7.29	5.20	43.53
96.00	4.66	0.59	1.20	6.36	8.45	42.69
97.00	4.33	0.46	0.97	5.90	6.64	34.31
98.00	4.62	0.61	1.03	6.31	8.80	36.46
99.00	3.81	0.26	1.00	5.21	3.78	35.58
100.00	4.04	0.54	0.82	5.52	7.77	28.94
101.00	3.97	0.59	1.04	5.42	8.49	36.97
102.00	3.87	0.58	0.92	5.28	8.29	32.70
103.00	4.43	0.56	0.94	6.05	7.97	33.21
104.00	3.58	0.75	0.81	4.89	10.70	28.86
104.80	2.92	0.69	1.04	3.99	9.90	36.81

Bh 83-03, Biggejavre

Depth	K (cps)	U (cps)	Th (cps)	K (%)	U (ppm)	Th (ppm)
1.00	1.11	1.45	0.06	1.52	20.72	2.26
1.30	1.90	1.73	0.00	2.59	24.83	0.00
1.50	2.40	1.16	0.00	3.27	16.66	0.00
2.00	1.85	0.16	0.00	2.52	2.23	0.00
2.50	0.72	0.15	0.00	0.98	2.12	0.01
3.00	1.94	0.45	0.01	2.65	6.44	0.48
3.30	1.93	2.68	0.00	2.63	38.44	0.00
3.50	1.26	8.32	0.00	1.72	119.23	0.03
3.80	1.64	45.56	0.00	2.24	653.10	0.00
4.00	2.20	50.50	0.00	3.00	723.86	0.00
4.20	1.37	61.07	0.00	1.87	875.38	0.00
4.50	0.92	19.46	0.00	1.26	278.91	0.00
4.70	0.91	40.46	0.00	1.25	579.97	0.00
5.00	0.22	48.76	0.00	0.29	698.94	0.00
5.30	0.91	48.85	0.00	1.25	700.17	0.00
5.50	2.44	33.10	0.00	3.33	474.45	0.00
5.70	1.94	98.79	0.00	2.65	1416.09	0.00
6.00	4.60	119.48	0.00	6.27	1712.72	0.00
6.30	1.87	94.00	0.00	2.55	1347.47	0.00
6.50	2.64	62.45	0.00	3.61	895.24	0.00
6.80	3.08	9.76	0.00	4.20	139.92	0.00
7.00	3.17	6.29	0.00	4.32	90.19	0.00
7.30	2.40	3.70	0.00	3.28	53.06	0.00
7.50	2.27	3.57	0.00	3.10	51.22	0.00
7.70	2.25	2.75	0.00	3.07	39.43	0.00
8.00	1.99	2.08	0.00	2.72	29.75	0.07
8.20	0.52	2.28	0.00	0.71	32.70	0.00
8.50	0.21	2.44	0.00	0.29	34.98	0.00
8.70	0.34	2.43	0.00	0.47	34.89	0.00
9.00	0.38	2.50	0.00	0.52	35.87	0.00
9.50	0.00	2.46	0.00	0.00	35.23	0.00
10.00	0.00	3.62	0.00	0.00	51.95	0.00
10.50	0.00	3.10	0.00	0.00	44.45	0.00
11.00	0.61	3.02	0.00	0.84	43.34	0.00
11.50	0.00	3.05	0.00	0.00	43.67	0.00
12.00	0.91	3.01	0.00	1.24	43.16	0.00
12.50	1.05	2.75	0.00	1.43	39.48	0.00
13.00	0.30	3.07	0.00	0.41	43.97	0.00
14.00	0.00	3.16	0.00	0.00	45.36	0.00
15.00	0.01	3.28	0.00	0.02	47.08	0.00
16.00	0.00	2.96	0.00	0.00	42.41	0.00
17.00	0.34	3.81	0.00	0.46	54.66	0.00
18.00	0.01	7.14	0.00	0.01	102.32	0.00
19.00	1.11	4.21	0.00	1.52	60.33	0.00
20.00	0.25	3.54	0.00	0.34	50.80	0.00
21.00	0.58	3.35	0.00	0.79	47.96	0.00
22.00	0.16	3.30	0.00	0.21	47.37	0.00
23.00	0.32	3.51	0.00	0.43	50.31	0.00
25.00	1.81	3.38	0.00	2.46	48.41	0.00
27.00	0.08	3.38	0.00	0.11	48.48	0.00
30.00	1.04	3.40	0.00	1.42	48.71	0.00
31.00	1.05	3.27	0.00	1.43	46.86	0.00
33.00	2.40	3.10	0.00	3.28	44.44	0.00
35.00	0.00	3.60	0.00	0.00	51.64	0.00
37.00	0.07	3.60	0.00	0.10	51.62	0.00
39.00	0.61	3.69	0.00	0.83	52.93	0.00
41.00	0.00	3.33	0.00	0.00	47.68	0.00
43.00	0.36	2.21	0.00	0.50	31.73	0.00
45.00	0.21	2.15	0.00	0.29	30.79	0.00
47.00	0.94	1.76	0.00	1.28	25.21	0.09
49.00	0.41	1.97	0.00	0.56	28.20	0.00
51.00	0.00	1.95	0.00	0.00	27.88	0.00

Bh 83-04, Biggejavre

Depth	K (cps)	U (cps)	Th (cps)	K (%)	U (ppm)	Th (ppm)
1.00	1.48	0.65	0.01	2.02	9.27	0.41
2.00	0.29	0.72	0.01	0.39	10.38	0.29
3.00	1.31	0.12	0.03	1.79	1.79	1.23
4.00	1.89	0.53	0.01	2.58	7.56	0.36
5.00	2.41	1.96	0.00	3.28	28.05	0.00
5.50	2.66	6.22	0.00	3.63	89.20	0.00
6.00	1.34	15.83	0.00	1.83	226.85	0.00
6.50	3.78	71.47	0.00	5.16	1024.41	0.00
7.00	8.78	173.19	0.00	11.98	2482.50	0.00
7.50	2.76	134.91	0.00	3.77	1933.79	0.00
8.00	0.64	39.83	0.00	0.88	570.97	0.00
8.50	1.17	17.84	0.00	1.59	255.66	0.00
9.00	0.13	18.99	0.00	0.18	272.26	0.00
9.50	0.00	27.13	0.00	0.00	388.90	0.00
10.00	0.05	19.99	0.00	0.07	286.56	0.00
10.50	1.66	41.26	0.00	2.27	591.37	0.00
28.40	4.87	16.99	0.00	6.64	243.57	0.00
11.00	0.00	17.11	0.00	0.00	245.33	0.00
11.50	0.38	19.19	0.00	0.52	275.04	0.00
12.00	0.00	21.37	0.00	0.00	306.25	0.00
12.50	0.75	32.24	0.00	1.02	462.07	0.00
13.00	0.00	87.76	0.00	0.00	1257.96	0.00
13.50	2.80	26.89	0.00	3.82	385.46	0.00
14.00	0.00	86.47	0.00	0.00	1239.44	0.00
14.50	0.91	61.21	0.00	1.25	877.38	0.00
15.00	0.00	58.76	0.00	0.00	842.33	0.00
15.50	2.02	125.90	0.00	2.76	1804.63	0.00
16.00	1.09	101.16	0.00	1.48	1450.06	0.00
16.50	2.73	143.12	0.00	3.72	2051.49	0.00
17.00	1.80	100.07	0.00	2.46	1434.43	0.00
17.50	2.49	35.95	0.00	3.39	515.26	0.00
18.00	2.32	17.70	0.00	3.16	253.75	0.00
18.50	2.48	19.55	0.00	3.38	280.17	0.00
19.00	1.47	19.00	0.00	2.00	272.34	0.00
19.50	1.11	19.87	0.00	1.51	284.80	0.00
20.00	0.00	46.20	0.00	0.00	662.26	0.00
20.50	0.01	49.85	0.00	0.01	714.59	0.00
21.00	0.00	62.78	0.00	0.00	899.85	0.00
21.50	1.99	46.17	0.00	2.72	661.84	0.00
26.10	9.42	71.91	0.00	12.86	1030.84	0.00
22.00	1.31	71.17	0.00	1.79	1020.13	0.00
22.50	0.00	67.10	0.00	0.00	961.77	0.00
23.00	1.92	109.96	0.00	2.62	1576.18	0.00
23.50	1.55	78.57	0.00	2.12	1126.19	0.00
24.00	0.00	86.09	0.00	0.00	1233.99	0.00
24.50	0.00	104.00	0.00	0.00	1490.78	0.00
25.00	3.18	108.18	0.00	4.34	1550.66	0.00
25.50	0.01	65.94	0.00	0.01	945.13	0.00
26.00	1.54	26.70	0.00	2.10	382.66	0.00
26.50	2.56	23.11	0.00	3.50	331.20	0.00
27.00	4.56	124.31	0.00	6.22	1781.93	0.00
27.50	1.28	41.49	0.00	1.74	594.67	0.00
28.00	1.56	20.08	0.00	2.13	287.79	0.00
28.50	0.46	22.27	0.00	0.63	319.17	0.00
29.00	0.23	26.14	0.00	0.32	374.76	0.00
29.50	0.00	30.19	0.00	0.00	432.82	0.00
30.00	0.00	22.54	0.00	0.00	323.02	0.00
30.50	0.57	21.01	0.00	0.78	301.14	0.00
31.00	0.92	20.33	0.00	1.25	291.35	0.00
32.00	1.43	19.73	0.00	1.95	282.83	0.00
33.00	0.00	19.71	0.00	0.00	282.53	0.00
34.00	1.49	19.42	0.00	2.03	278.44	0.00
36.00	2.80	19.89	0.00	3.83	285.04	0.00
38.00	0.37	19.12	0.00	0.50	274.04	0.00

40.00	0.55	10.11	0.00	0.75	144.91	0.00
42.00	0.00	10.32	0.00	0.00	147.95	0.00
44.00	0.00	9.12	0.00	0.00	130.69	0.00
46.00	0.00	9.02	0.00	0.00	129.29	0.00
48.00	0.00	8.22	0.00	0.00	117.80	0.00
50.00	0.74	7.37	0.00	1.01	105.66	0.00
53.00	0.40	7.09	0.00	0.55	101.64	0.00
56.00	0.00	7.16	0.00	0.00	102.69	0.00
59.00	1.75	6.63	0.00	2.39	94.98	0.00
62.00	1.04	18.32	0.00	1.42	262.60	0.00
65.00	0.98	5.76	0.00	1.34	82.50	0.00
68.00	0.31	4.80	0.00	0.42	68.82	0.00
71.00	0.61	4.67	0.00	0.84	66.90	0.00
74.00	0.28	4.40	0.00	0.38	63.05	0.00
77.00	0.04	4.15	0.00	0.05	59.53	0.00
80.00	0.19	3.74	0.00	0.26	53.63	0.00
82.50	1.24	4.06	0.00	1.69	58.19	0.00

Bh 306, Apukka

Depth	K(cps)	U(cps)	Th(cps)	K (%)	U (ppm)	Th (ppm)
1.00	1.38	0.22	0.21	1.88	3.19	7.41
2.00	2.43	0.52	0.93	3.31	7.45	32.99
3.00	1.42	0.95	0.58	1.94	13.56	20.39
4.00	0.82	1.01	0.57	1.12	14.41	20.09
5.00	0.78	0.42	0.02	1.06	5.96	0.74
6.00	1.12	0.61	0.07	1.52	8.77	2.62
7.00	3.29	1.05	0.48	4.49	14.99	17.05
8.00	0.87	1.29	0.20	1.19	18.42	7.13
9.00	1.57	1.45	0.17	2.14	20.81	6.07
10.00	0.51	1.04	0.22	0.70	14.96	7.90
11.00	0.79	1.08	0.17	1.07	15.51	6.05
12.00	1.12	0.89	0.26	1.53	12.82	9.13
13.00	0.45	0.82	0.19	0.61	11.70	6.87
14.00	0.76	0.48	0.09	1.04	6.91	3.02
15.00	0.66	0.91	0.13	0.90	13.02	4.54
16.00	0.61	1.22	0.11	0.83	17.49	4.05
17.00	0.75	1.37	0.03	1.03	19.67	1.02
18.00	5.07	11.90	0.07	6.92	170.51	2.37
19.00	1.10	2.64	0.19	1.51	37.87	6.78
20.00	0.28	0.78	0.11	0.38	11.18	3.94
21.00	2.67	0.79	0.17	3.65	11.30	6.12
22.00	1.19	1.74	0.52	1.62	24.88	18.55
23.00	0.79	0.53	0.30	1.08	7.66	10.50
25.00	1.87	0.51	0.16	2.56	7.27	5.77
27.00	3.23	0.97	0.21	4.40	13.96	7.42
29.00	2.71	0.47	0.02	3.70	6.80	0.65
31.00	2.68	0.51	0.33	3.66	7.37	11.72
33.00	2.70	0.62	0.26	3.69	8.95	9.16
35.00	2.67	0.76	0.18	3.65	10.95	6.55
37.00	2.57	0.50	0.25	3.51	7.10	8.96
39.00	2.29	0.58	0.16	3.12	8.28	5.65
41.00	2.58	0.80	0.27	3.52	11.47	9.48
43.00	2.41	1.08	0.22	3.29	15.47	7.65
45.00	2.68	0.68	0.28	3.65	9.69	9.87
47.00	2.53	1.13	0.22	3.46	16.22	7.96
48.00	2.48	1.34	0.56	3.39	19.21	19.77
49.00	4.31	2.06	0.28	5.88	29.55	9.88
50.00	2.82	0.83	0.21	3.85	11.85	7.45
51.00	2.67	4.40	0.11	3.64	63.10	3.81
52.00	2.94	1.31	0.07	4.01	18.79	2.51
53.00	3.26	2.83	0.17	4.45	40.50	5.90
54.00	2.44	0.76	0.17	3.33	10.87	6.16
55.00	2.76	0.65	0.25	3.77	9.38	8.71
56.00	2.48	1.49	0.43	3.38	21.43	15.15
57.00	1.35	0.81	0.09	1.84	11.62	3.30
58.00	2.78	0.65	0.29	3.79	9.26	10.12
59.00	1.18	0.56	0.13	1.61	8.05	4.49
60.00	0.99	0.44	0.14	1.35	6.28	4.88
61.00	0.58	0.48	0.03	0.79	6.87	1.23
62.00	1.10	0.67	0.19	1.51	9.60	6.70
63.00	1.01	0.49	0.10	1.38	7.07	3.60
64.00	1.26	0.59	0.14	1.72	8.46	5.04
65.00	1.18	1.04	0.16	1.61	14.92	5.72
66.00	1.03	0.50	0.15	1.40	7.11	5.38
67.00	0.98	0.56	0.12	1.34	7.98	4.10
68.00	1.31	0.78	0.18	1.79	11.12	6.34
69.00	2.45	2.13	0.33	3.34	30.52	11.57
70.00	2.31	0.60	0.76	3.15	8.60	27.10
71.00	1.87	0.90	0.59	2.56	12.96	20.85
72.00	1.85	0.94	0.65	2.53	13.41	23.19
73.00	2.28	0.88	0.77	3.11	12.63	27.45
74.00	1.46	1.26	0.80	1.99	17.99	28.45
75.00	2.75	1.20	1.46	3.75	17.27	51.60
76.00	2.36	1.46	1.37	3.23	20.96	48.61
77.00	2.70	1.23	1.54	3.69	17.62	54.54

78.00	2.55	1.56	1.40	3.49	22.36	49.65
79.00	2.57	1.51	1.38	3.51	21.62	48.93
80.00	2.56	1.41	1.35	3.49	20.22	47.70
81.00	2.05	0.99	1.04	2.79	14.17	36.83
82.00	1.54	1.25	0.86	2.10	17.95	30.45
83.00	1.41	0.93	0.69	1.92	13.38	24.38
84.00	2.38	0.73	0.30	3.25	10.52	10.58
85.00	2.70	3.53	0.52	3.68	50.55	18.32
86.00	2.29	2.24	0.21	3.13	32.05	7.42
87.00	2.96	0.77	0.34	4.04	10.99	11.92
88.00	2.77	0.75	0.37	3.78	10.71	13.14
89.00	2.46	0.48	0.41	3.35	6.89	14.56
90.00	2.59	0.52	0.31	3.53	7.39	10.92
91.00	2.42	0.40	0.40	3.30	5.72	14.09
92.00	2.74	0.57	0.19	3.73	8.17	6.66
93.00	3.40	0.50	0.18	4.65	7.17	6.37
94.00	2.94	0.55	0.21	4.02	7.82	7.30
95.00	2.77	0.66	0.35	3.78	9.46	12.29
96.00	2.94	0.82	0.36	4.02	11.72	12.83
97.00	1.21	0.51	0.14	1.65	7.29	4.97
98.00	1.15	0.41	0.14	1.57	5.94	5.12
100.00	1.25	0.52	0.13	1.70	7.46	4.55
102.00	1.54	0.52	0.17	2.10	7.51	5.94
103.00	1.22	0.44	0.05	1.66	6.27	1.90
104.00	1.41	0.43	0.15	1.92	6.10	5.30
105.00	1.39	0.48	0.33	1.90	6.87	11.58
106.00	1.40	0.29	0.42	1.91	4.18	15.05
107.00	1.12	0.34	0.25	1.53	4.92	8.81
108.00	0.93	0.31	0.17	1.28	4.40	5.88
110.00	1.29	0.36	0.17	1.76	5.16	6.00
112.00	1.28	0.55	0.17	1.75	7.85	6.10
114.00	1.42	0.59	0.09	1.94	8.43	3.05
116.00	1.37	0.29	0.11	1.88	4.20	3.91
118.00	0.99	0.48	0.15	1.35	6.85	5.41
120.00	1.24	0.37	0.17	1.70	5.24	5.99
121.00	1.75	0.34	0.19	2.39	4.80	6.63
122.00	1.09	0.41	0.15	1.49	5.93	5.32
123.00	1.39	0.50	1.04	1.90	7.18	37.00
124.00	1.35	0.30	0.12	1.84	4.36	4.29
125.00	0.85	0.43	0.01	1.16	6.13	0.52
126.00	0.71	0.48	0.04	0.97	6.95	1.42
127.00	1.20	0.59	0.37	1.64	8.52	13.18
128.00	1.38	0.69	0.49	1.89	9.93	17.40
129.00	0.94	0.73	0.11	1.28	10.43	3.83
130.00	4.65	0.45	0.10	6.35	6.40	3.47
131.00	1.51	2.67	0.20	2.07	38.20	6.94
132.00	0.98	0.27	0.12	1.34	3.85	4.35
134.00	0.96	0.47	0.15	1.31	6.68	5.43
136.00	0.70	0.43	0.12	0.95	6.21	4.29
138.00	1.26	0.37	0.13	1.72	5.35	4.78
140.00	1.21	0.46	0.19	1.65	6.57	6.84
141.00	1.88	0.54	0.45	2.57	7.77	16.05
142.00	0.88	0.41	0.17	1.19	5.91	6.11
143.00	1.28	0.75	0.26	1.75	10.80	9.16
144.00	1.92	0.51	0.58	2.62	7.24	20.68
145.00	1.47	0.55	0.23	2.01	7.88	8.08
146.00	1.47	0.60	0.65	2.00	8.53	22.93
147.00	1.58	0.52	0.30	2.16	7.40	10.72
148.00	1.88	0.63	0.57	2.57	9.02	20.09
149.00	2.77	0.77	0.19	3.78	11.03	6.74
150.00	1.82	1.40	0.32	2.48	20.09	11.32
151.00	0.85	0.56	0.38	1.15	8.01	13.44
152.00	1.32	0.41	0.19	1.80	5.90	6.71
153.00	2.17	0.67	0.35	2.97	9.54	12.48
154.00	1.26	0.40	0.21	1.72	5.71	7.33



NGU
 LOCATION MAP
SCANDINAVIA

GEOLOGICAL SURVEY OF NORWAY
 TRONDHEIM

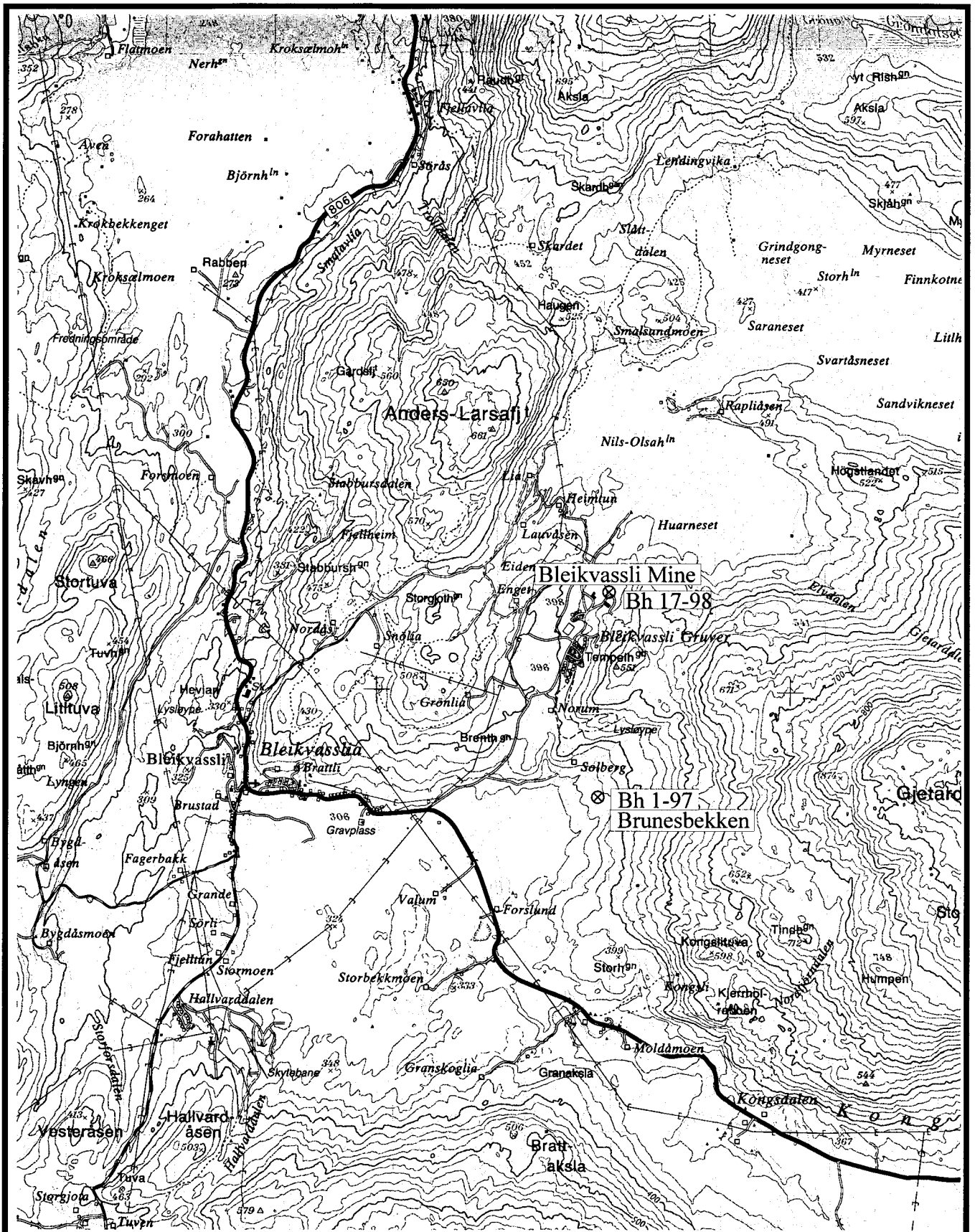
SCALE

OPER HE Sept. -99

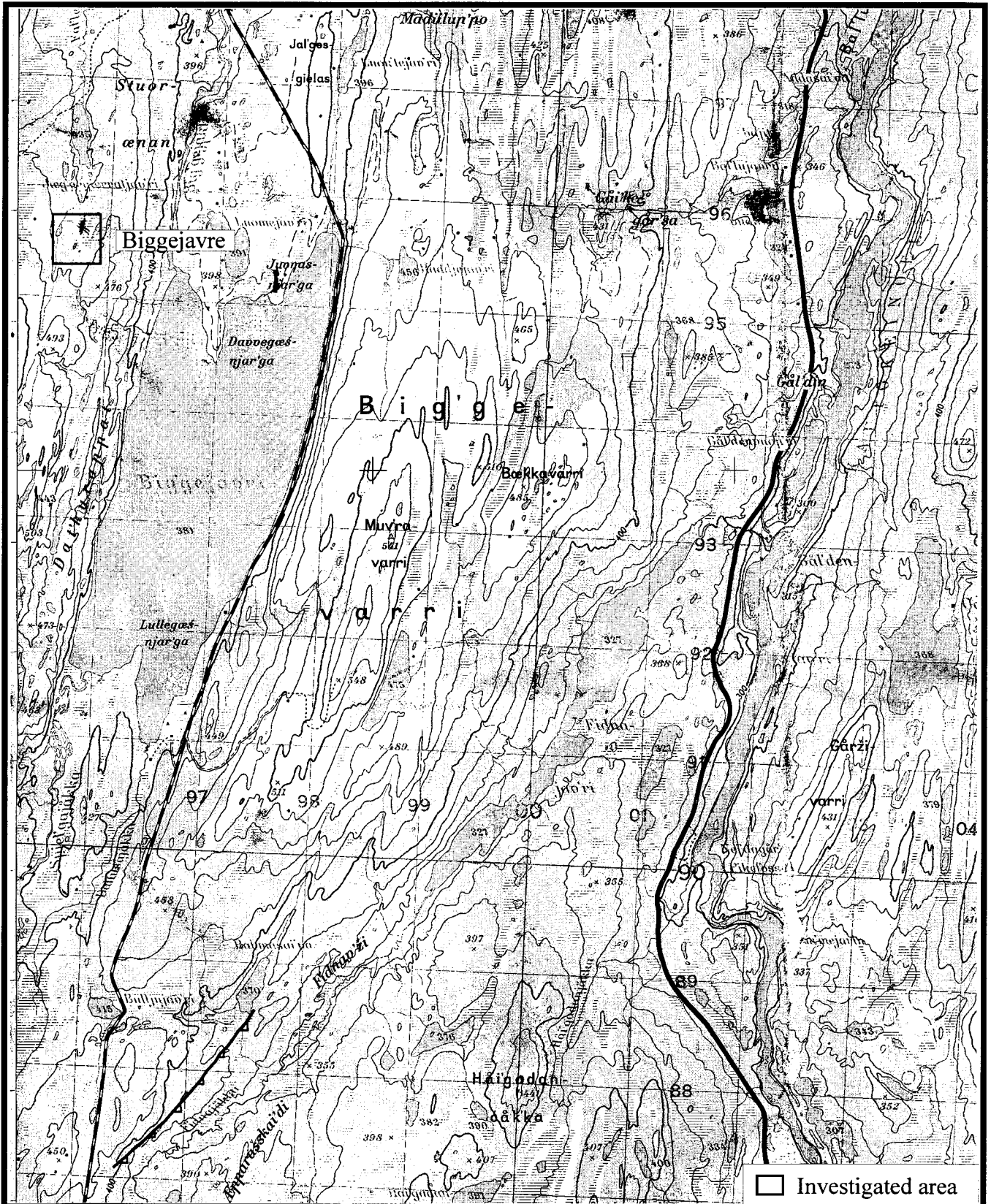
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MAP NO.
 99.112-01



NGU LOCATION MAP BLEIKVASSLI MINE HEMNES KOMMUNE, NORDLAND	SCALE	OPER HE	Sept. -99
	1:50 000	DRAW HE	Des.-99
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GEOLOGICAL SURVEY OF NORWAY TRONDHEIM	MAP NO. 99.112-02	KARTBLAD NR 1926 I	



NGU
 LOCATION MAP
BIGGEJAVRE
 FINNMARK, NORWAY
 GEOLOGICAL SURVEY OF NORWAY
 TRONDHEIM

SCALE	OPER HE	Sept. - 99
	DRAW HE	Des.-99
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MAP NO.	MAP 1:50 000	
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