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Geophysical logging of two deep boreholes at Fen, Nome municipality, Vestfold and Telemark county

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Geological Survey of Norway
P.O.Box 6315 Torgarden
NO-7491 TRONDHEIM
Tel.: 47 73 90 40 00

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Title:
Geophysical logging of two deep boreholes at Fen, Nome municipality, Vestfold and Telemark county.

Authors: Harald Elvebakk and Jan S. Rønning	**Client:** NGU, Vestfold and Telemark County (Geological Advisor)
County: Vestfold and Telemark	**Commune:** Nome
Map-sheet name (M=1:250.000) Skien	**Map-sheet no. and -name (M=1:50.000)** 1713-4 Nordagutu
Deposit name and grid-reference: Fen Complex LHKB-1: E517182 N6570372 32 V LHKB-2: E516554 N6571021	**Number of pages:** 105 **Price (NOK):** 300,- **Map enclosures:**

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Summary:
NGU has performed geophysical logging in two deep boreholes at the Fen complex at Ulefoss, Vestfold and Telemark county. The boreholes were 1000 and 716 m, deep drilled in the carbonate volcano. The purpose was to get petrophysical data for this very unusual carbonatite volcanic rock and to see if there are any correlation between REE content and petrophysical data. Temperature data was also of interest.

Logging parameters were temperature, electric conductivity of water, gamma radiation, spectral gamma (U and Th) seismic velocities (P and S), resistivity, IP, SP and magnetic susceptibility. Acoustic televiewer was used to map fractures and borehole deviation. The REE content was found by chemical analyses (Coint & Dahlgren 2019).

The logging data show that there is no correlation between REE and geophysical logging parameters. In some cases, REE correlates to U and Th, and in some cases to the electrical parameters. There is no correlation in the content of REE and the content of U and Th found by the geophysical logging.
The P-wave velocity is high (≈ 6000 m/s in rauhaugite) and shows small variations. Some fracture zones were found, the most interesting is a 1.5 m wide open facture at 512 m depth in LHKB-1. Rock fall from this fracture blocked the borehole and stopped the logging. The borehole was reopened by the drilling company.

The resistivity is in general quite high, 3000 - 5000 in the carbonatite rocks (some higher in the lower part of LHKB-1). IP and SP indicate several zones of electric conductive minerals such as sulphides or magnetite. Magnetite gives high magnetic susceptibility in some of these zones.

Acoustic televiewer logging shows that there is no specific main fracture group (main strike/dip) in LHKB-1. In LHKB-2 the trend is a SE – SW azimuth of the fractures. Most of the fractures are dipping steeply, > 50 °. Deviation log shows a ca. 12 m horizontal deviation in north-west direction for borehole LHKB1 and ca. 20 m in south-southeast direction in LHKB-2.

Measured petrophysical properties at selected samples (one sample each 10 m) and detailed core drilling registrations from the drilling company are also presented.

Keywords: Geophysics	Borehole logging	Resistivity, IP, SP
Seismic velocity	Magnetic susceptibility	Gamma spectrometry
Temperature	Acoustic televiewer	Scientific report

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1. INTRODUCTION

NGU has performed geophysical logging in two deep boreholes in the Fen Complex, Ulefoss in Telemark and Vestfold county. The area of the Fen Complex is about 5 km^2. The boreholes were 1001 m and 716 m deep and drilled in late 2017 and winter/spring 2018. The rocks in the Fen Complex are parts of an old carbonatite volcano. The eastern part is enriched in REE (Rear Earth Elements) and the radioactive element Thorium. The REE bearing rock can be interesting for mining in the future due to an increased demand from the electronic industry.

The purpose of the deep drilling was to map the extension of the REE bearing rock to the depth. The project was initiated by the county geological advisor Sven Dahlgren and funded by the Norwegian government. NGU was responsible for the drilling and the logging. The drilling was performed by the Norwegian company Geodrilling AS. The plan was to drill two boreholes, each 1000 m, but the second borehole had to be stopped at 716 m because of heavily fractured rock.

The logging took place in February and May 2018 and was done by Harald Elvebakk, NGU. Figure 1 shows the location of borehole 1 (LHKB-1) close to the old school at Fen.

Figure 1. Drilling of LHKB-1 next to the old Fen school (Photo: NGU).

2. BOREHOLES

Borehole LHKB-1 is located close to the old school at Fen and LHKB-2 east of Søve agricultural school. The map in figure 2 shows the location of the two boreholes. Table 1 shows technical data of the boreholes. Logging in LHKB-2 stopped at 695 m depth due to heavily fractured rock and the risk for loosing logging tools. Detailed information from the drilling are presented in Appendix 2. Two pictures of very bad rock quality are presented in Appendix 3.

Table 1. Borehole data.

Borehole	East 32V	North 32V	Elevation m.a.s.l. (m)	Depth (m)	Dip (deg)	Azimuth	Diam. NQ-2 (mm)	Logged depth (m)
LHKB-1	517182	6570372	104	1001	90	-	76	1000
LHKB-2	516554	6571021	55	716	90	-	76	695

Both boreholes were drilled using the NQ-2 drilling gear giving a drillcore with diameter 56 mm and borehole diameter 76 mm.

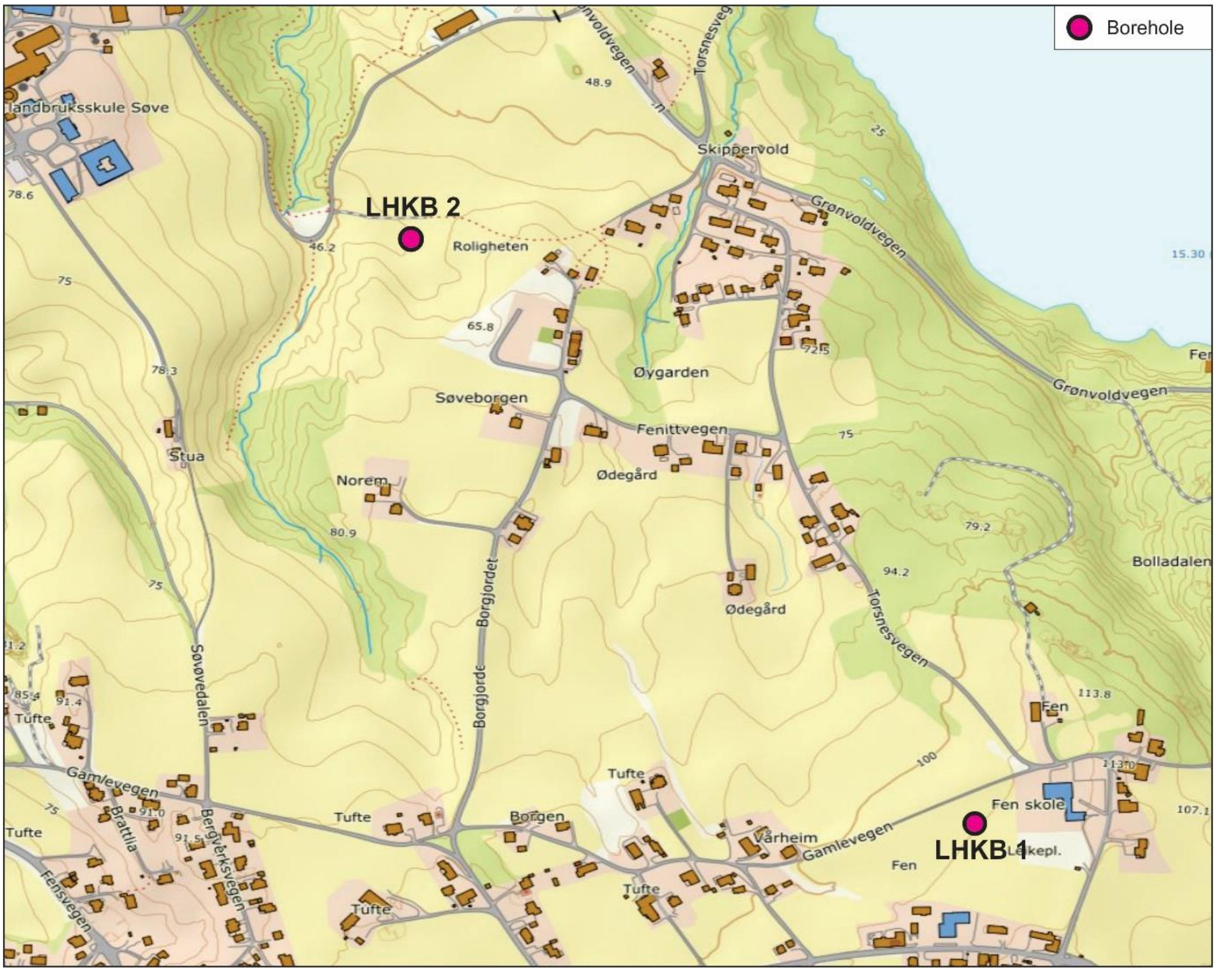


Figure 2. Overview map showing the borehole locations.

3. BOREHOLE LOGGING

NGU has been doing borehole logging onshore since 1999. The number of probes has increased since then and NGU can now measure the most important geophysical parameters in slim boreholes. All logging equipment, including two winches, is produced by Robertson Geologging ltd, Wales (https://www.robertson-geo.com/).

3.1 **Probes and logging parameters.**

Borehole LHKB-1 was logged from February 12th to 17th and May 10th to 11th while LHKB-2 was logged in the period May 3rd to 9th, both ca. two weeks or more after finished drilling. Table 2 gives an overview of all measured parameters in the Fen boreholes.

Table 2. Logging parameters, logging speed and sampling interval.

Measured parameter	Logging speed	Sampling interval
Temperature	3 m/min	1 cm
Water conductivity	3 m/min	1 cm
Natural total gamma radiation	3 m/min	1 cm
Gamma spectrometry, U and Th	1 m/min	1 cm
Rock resistivity	5 m/min	1 cm
Induced Polarisation, IP	5 m/min	1 cm
Self Potential, SP	5 m/min	1 cm
Seismic velocity (P- and S-wave)	2.5 m/min	1 cm
Magnetic susceptibility	5 m/min	1 cm
Acoustic Televiewer (HIRAT)	3 m/min	1 mm
Borehole deviation (HIRAT)	1 – 3 m/min	1 cm

Temperature

To measure exact temperature the measurements should be performed some days after the drilling stops, since the energy from the drilling process (hot drilling fluid, rock crushing, and friction) will increase the temperature in the borehole. At Fen, temperature was logged two weeks after finished drilling. From the temperature log the temperature gradient (^{o}C/km) can be calculated. Local changes in the gradient may indicate fractures and related inflow (or outflow) of water. A change in thermal conductivity will also influence the gradient.

Fluid conductivity

The fluid conductivity (µS/cm) depends on the fluid salinity. The conductivity measurements can identify zones of water in-flow/out-flow and locate zones of different water quality. The measured values are temperature compensated to a reference temperature of 25^{o}C.

Natural Gamma

The natural gamma log (API standard) is useful for geological mapping along walls of a borehole. All rocks contain small quantities of radioactive material, in that certain minerals contain trace amounts of Uranium and Thorium. Potassium-bearing minerals (normally most common) will include traces of a radioactive isotope of Potassium (K^{40}). Natural gamma measurements are useful because the radioactive elements are concentrated in certain rock types, e.g. alum shale and granite, and depleted in others, e.g. sandstone. The unit is in API standard units which mean that data can be compared to other measurements performed in the same standard.

Gamma spectroscopy

The natural gamma spectroscopy probe analyses the energy spectrum of gamma radiation from naturally occurring or man-made isotopes in the formation surrounding a borehole. By doing gamma spectroscopy measurements the content of U (ppm), Th (ppm) and K (%) can be determined in situ. Log applications are shale/clay typing, lithology determination, correlations in complex mineral situations, radioactive waste pollution measurements. Continuous logs or single energy spectra for higher precision can be made.

Seismic velocity

The sonic probe has one transmitter and three receivers separated by 20.0 cm that records the full sonic wave-train at all receivers simultaneously and also the velocity of the first arrival. Both P-velocity (compression) and S-velocity (shear wave) are calculated every cm. Data can be filtered using a running average filter over e.g. 0.4 m. The first arrival of the P-wave is quite easy to pick while the arrival of the S-wave is more indistinct. P-velocity (formation velocity) is used for lithological identification and fracture mapping. Data processing is done by software from ALT (ALT 2006).

Resistivity

Resistivity logging in boreholes is extensively used in hydrocarbon exploration of sedimentary rocks both to identify lithological boundaries and to estimate the rock porosity. The resistivity depends on porosity, pore filling and pore water conductivity. In addition, the content of electronic conductive minerals such as sulphides, oxides, graphite and clay influence on the bulk resistivity. The resistivity is measured using two configurations, Short Normal (SN) and Long Normal (LN). The resistivity data are processed using a program that corrects borehole resistivity logging data for the influence of the borehole liquid salinity, borehole diameter and probe size (Thunhead & Olsson 2004).

The apparent porosity is calculated using the measured resistivity and Archie's law (Archie 1942). Archie's law was found to be correct for porous sandstones with uniform grain size, and is not necessarily valid for any rock type, therefore apparent porosity. If other parameters than the porosity (e.g. electronic conductive minerals) influence on the resistivity, the calculated porosity using Archie's law will be wrong.

Self Potential, SP

SP is measured as an integrated part of the resistivity measurements. SP is a natural potential in the ground which can be measured when crossing electric conducting minerals (sulphides, graphite). Clay and water flow in the ground can also create small SP anomalies.

Induced Polarization, IP

IP is an electrical method which is primary used for detecting disseminated sulphide mineralisation. Current pulses (e.g. 110 ms) are applied to the ground by two electrodes. When the current is turned off, an induced voltage can be measured if there are minerals that give an IP effect in the ground. The size of the voltage increases with the amount of conducting minerals.

Acoustic televiewer

The HIRAT (High Resolution Acoustic Televiewer), also named BHTV (Bore Hole Tele Viewer) probe uses a fixed acoustic transducer and rotating mirror system to acquire 2-way travel-time and amplitude of the acoustic signal reflected to the transducer from a spiral trajectory on the borehole wall. From this an image of the borehole wall is constructed using both the travel-time and amplitude signal. The pixel size at the borehole wall depends on the borehole diameter but is approximately 1 mm x 1 mm, or better, using the highest resolution (360 shots per revolution).

Fracture study through processing aims to identify geometric sets of fractures/veins, and then estimate variations in mean dip and frequency within the sets and lines of intersection among the sets, with depth. In crystalline rocks the foliation can be mapped. In sedimentary rocks, the structural interpretation aims to extract formation dip and to identify geological structures such as unconformities, folds and faults, from the distribution and orientation of dips assigned to bedding. Digitalizing the observed features on the well bore image creates strike and dip of identified structures which can be presented in fracture stereograms, rose diagrams, fracture frequency histograms, and thickness calculations of beds, bands and fractures. The deviation of the borehole can also be calculated.

From the recorded acoustic televiewer data it is possible to make a breakout/ovalisation log. The ratio between maximum and minimum diameter (alpha/beta) in the borehole is calculated continuously (ovalisation log). The azimuth to alpha (max diameter) is also calculated. Using the breakout log it is possible to look at borehole cross-sections at selected depths showing breakout sections in the borehole. Such breakouts can be related to rock stress, and the main horizontal stress orientation can sometimes be estimated.

Borehole deviation

The borehole deviation is measured by a deviation probe or as an integrated part of the acoustic televiewer. Borehole azimuth and dip angle are measured by three component magnetometers and accelerometers.

4. GEOLOGY

An overview geological map (NGU) of the Fen Complex is shown in Figure 3. The volcanic rocks are carbonatites from an old volcano. The Fen Complex is surrounded by Precambrian gneisses on the western side of lake Norsjø.

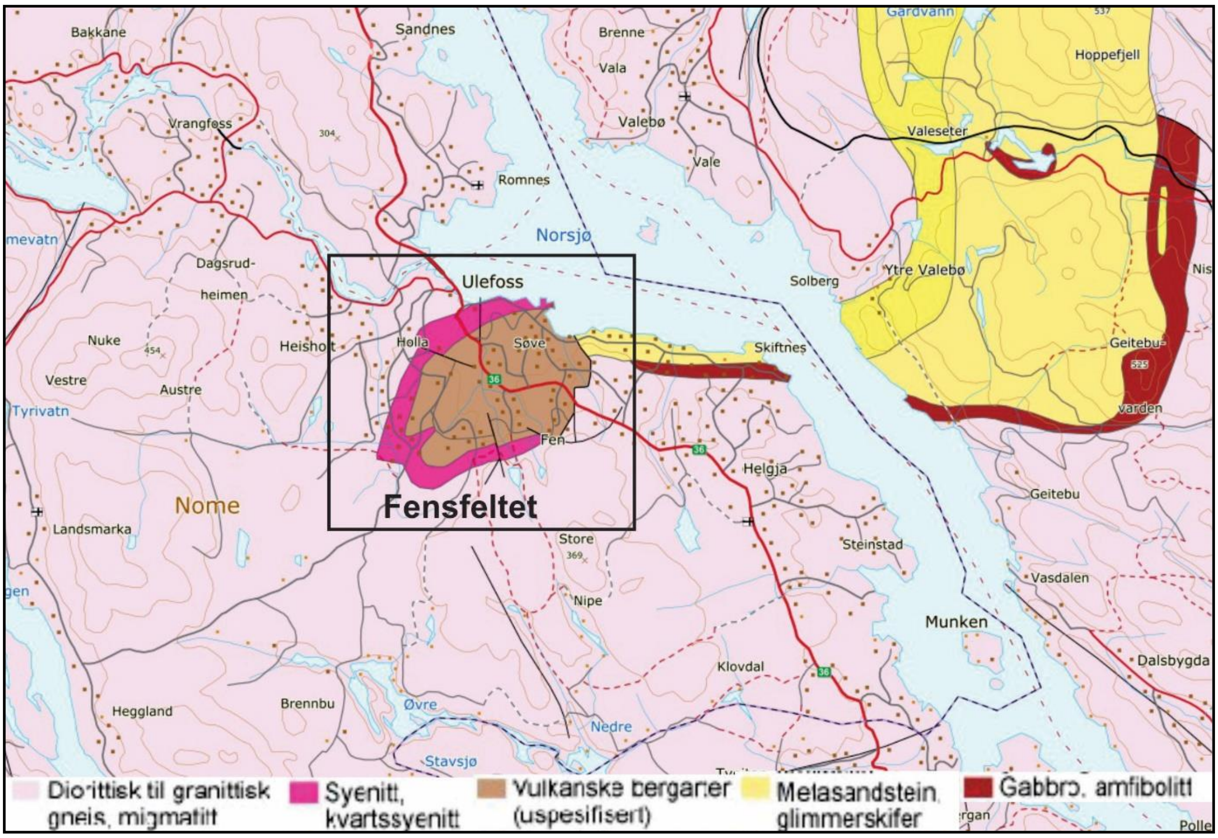


Figure 3. Overview geological map of Fen Complex and the surrounding areas (www.ngu.no)

A more detailed geological map (from Sven Dahlgren) is shown in Figure 4. The two main carbonate rocks are rauhaugite and rødbergite. Rauhaugite is the most interesting REE bearing rock and the two boreholes are drilled in this rock. A more detailed description of the geological settings is done by Coint and Dahlgren (2019).

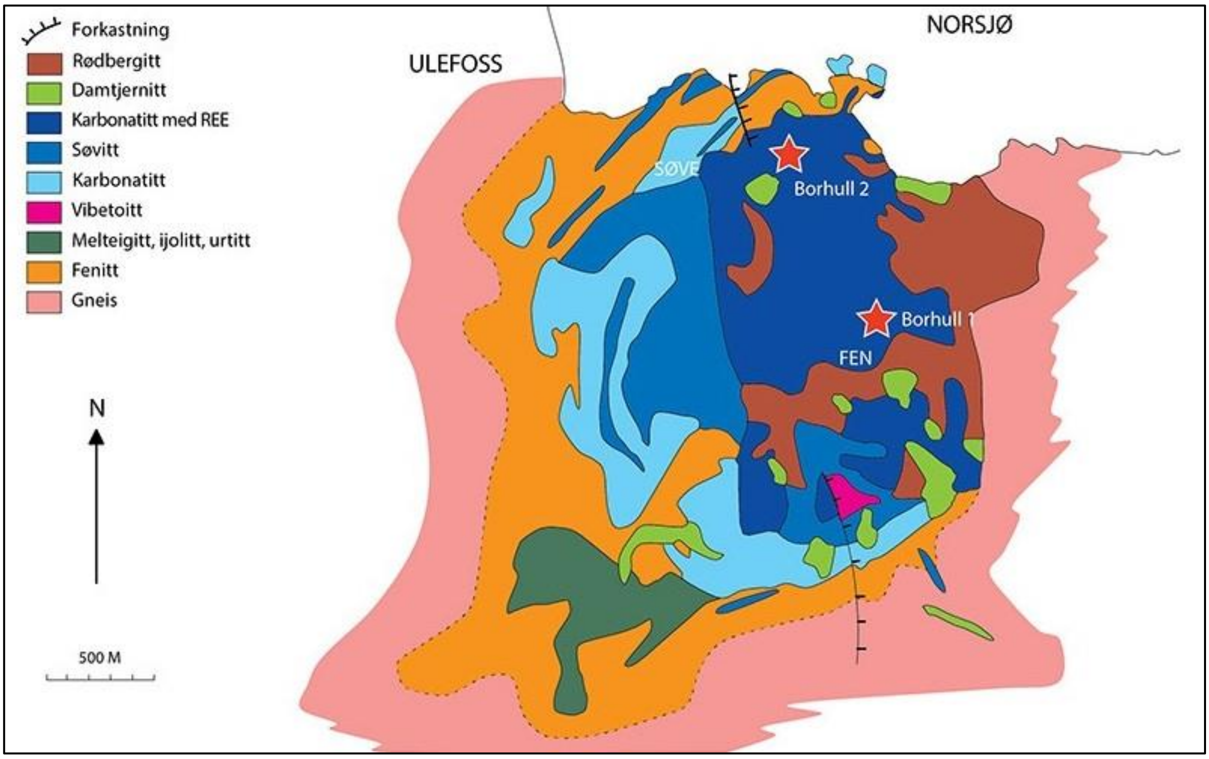


Figure 4. Geological map of the Fen Complex (from Sven Dahlgren). Boreholes are drilled in the rauhaugite (carbonite rock containing REE).

5. RESULTS

The purpose of the logging was to map several geophysical parameters of the REE bearing rauhaugite. Could there be any correlations to magnetic susceptibility, resistivity, Induced Polarisation, Self Potential and Gamma ray radiation including U, Th and K content (gamma spectrometry)? By measuring seismic velocities (P-and S-wave) and using acoustic televiewer, the fracturing of the rock could be mapped.

The logging of LHKB-1 started in February 2018, ca. two weeks after finished drilling. The borehole was stuck at 515 m depth. Probably a small rock fall from the borehole wall blocked the borehole. All logs were run to this depth and it was decided to reopen the borehole after finishing the drilling of LHKB-2. On the acoustic televiewer data, a big fracture zone was observed just above 515 m as an open cavity. Images from this cavity will be shown later in this report. The reopening of LHKB-1 was done in May 2018, and the lower 500 m was logged immediately after.

The logging in LHKB-2 was fulfilled in May 2018 without any problems. It was decided to stop the logging at 695 m depth because of the heavy fractured rock below this depth. The drilling had to stop at 716 m for the same reason.

The results from each borehole will be presented as logs of the different geophysical parameters. Each log will be described and discussed. Afterwards, the observed anomalies will be correlated to each other and to the chemical analyses of total REE.

5.1 LHKB-1, temperature, water conductivity, natural total gamma and temperature gradient.

Figure 5 shows the logging in LHKB-1. The winch in the van can be used for up to1850 m logging depth.

Figure 5. Logging in LHKB-1 in February 2018 (Photo: NGU).

Figure 6 shows temperature, water conductivity, total gamma and temperature gradient in LHKB-1. Bottom temperature at 999 m depth is 23.7 ^{o}C. Average temperature gradient below 100 m is 17.95 ^{o}C/km. A higher gradient was expected in this rock which contains big amounts of the heat producing elements U and Th. The temperature gradient is calculated both in a 20 m interval and a 100 m interval.

In general, the water conductivity is low. The water conductivity increases down to ca. 600 m (260 µS/cm). From this depth it decreases to ca. 100 µS/cm. This change may be caused by water inflow. Small changes in the temperature gradient at the same depth may indicate the same.

The gamma radiation is generally quite high. In the upper 600 m the average radiation is 1300 cps (API). In the lower 400 m it is approximately 1600 cps (API). There are peak values up to 12000 cps (API). Both the average values and the peak values are very high and are mainly caused by the Th-content (see later, gamma spectrometry). In some parts of the borehole the U-content is the dominating contribution to the high gamma radiation. The gamma radiation in rauhaugite at Fen is much higher than e.g. granites in Norway (Elvebakk 2011).

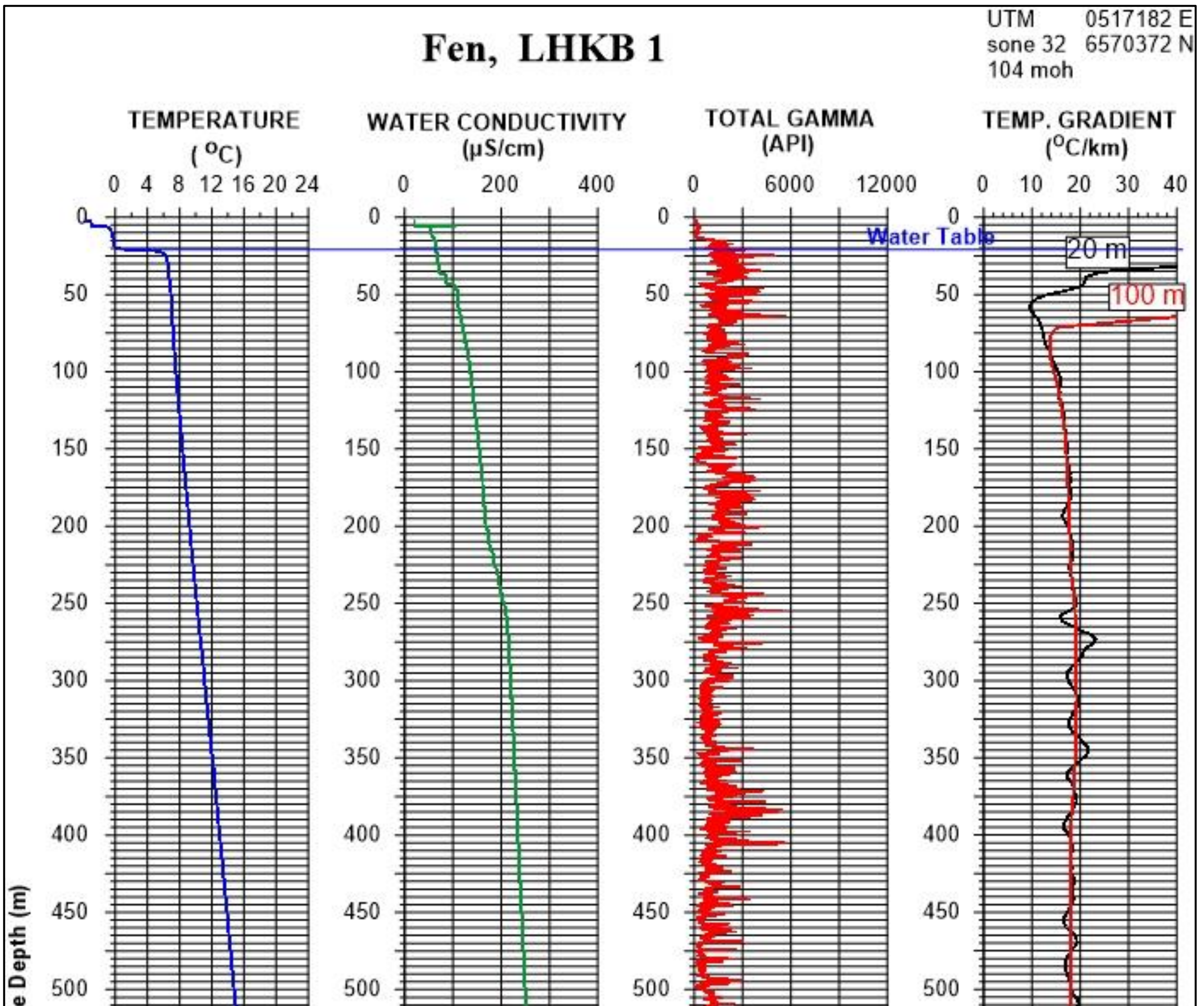


Figure 6. LHKB-1. Temperature, water conductivity, natural gamma and temperature gradient (20m and 100m).

5.2 LHKB-1, seismic velocity, resistivity, natural gamma, magnetic susceptibility, Induced Polarisation, Self Potential and apparent porosity.

Figure 7 shows logging in LHKB-1 after reopening in May 2018. The drilling rig was still at the location in case of new rock falls and blocking of the borehole.

Figure 7. Logging in LHKB-1 after reopening in May 2018 (Photo: NGU).

As mentioned earlier the LHKB-1 was blocked at 515 m depth. All probes stopped at this depth. A fracture zone was indicated on the seismic log. In figure 8 the first arrival travel times from three receivers are shown when passing the open fracture at 512 – 514 m depth. Increased travel time means lower velocity.

Figure 9 shows the result and the complete logs of seismic velocity, resistivity, natural gamma, magnetic susceptibility, Induced Polarisation, Self Potential and apparent porosity in LHKB-1.

<u>Seismic velocity</u>. Both P- and S-wave velocities were measured. The P-wave velocitiy is quite high in the rauhaugite, 6200 m/s. It is almost constant in the entire borehole. Fractures at 512 m, 570 m, 584 m and 607 m indicates lower velocity. The fracture at 512 m caused a rock fall that blocked the borehole. The P-velocity is ca. 2000 m/s in this zone. The S-velocity is constant at approximately 3400 m/s.

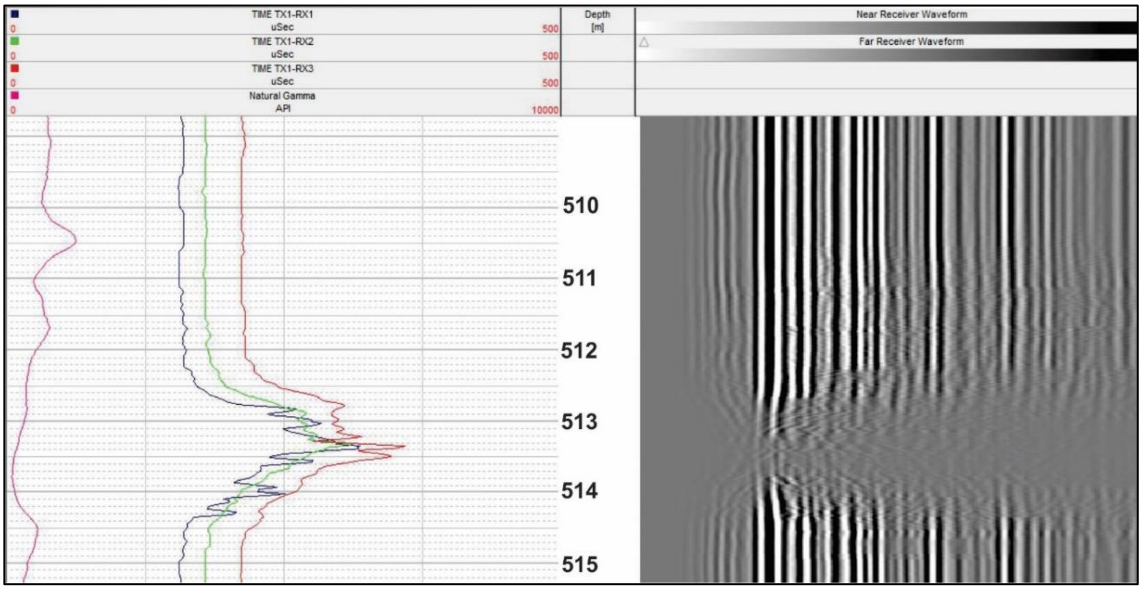


Figure 8. Natural gamma and first arrival travel times for three receivers (left) measured when passing a fracture at 512-514 m depth and full waveform train at Near receiver (right).

The total natural gamma radiation is described in Chapter 5.1.

In Figure 9 the magnetic susceptibility shows large variations. In the upper part, 75 - 200 m depth, the average susceptibility is quite low (0.004 SI). From 225 m to 500 m depth the average susceptibility is quite high (0.05 SI) including peaks up to 0.85 SI which is most likely caused by magnetite enrichments. In lower part of the borehole the background level is about 0.06 SI. Several high values indicate magnetite and the highest value is 1.01 SI indicate a high magnetite concentration locally.

The resistivity is in general high. In the upper 600 m the background resistivity is 3000 – 5000 ohmm. In the lower part the background value is 8000 – 9000 ohmm. There are a lot of zones in the borehole indicating low resistivity, down to 50 – 60 ohmm. Most of these zones correlates with the high magnetic susceptibility zones. It is obvious that these are thin magnetite zones. Magnetite ore from Rana Gruber has a resistivity in the range of 10 – 150 ohmm (Elvebakk 2015).

The low resistivity zones also correlate with SP anomalies below 625 m depth. In some of the zones SP anomalies of -400 mV are measured. It is well known that magnetite gives SP anomaly. However, the SP and resistivity anomalies can also be caused by sulphides (pyrite or pyrrhotite).

The IP measurements show a background IP value of 2 – 3 %, which is natural for non-mineralised bedrock. High IP values, up to 25 %, correlate with most of the low resistivity zones. In many cases all the measured parameters resistivity, magnetics susceptibility, SP and IP correlates quite well. In some cases, this correlation is supported by high total gamma radiation. Later, the correlation to REE will be described.

The apparent porosity is only reliable in the borehole where no electronic conductive minerals are indicated. In zones with IP and SP anomalies, resistivity low can be caused by sulphides and iron oxides. The apparent porosity in the rauhaugite is in general about 1 %.

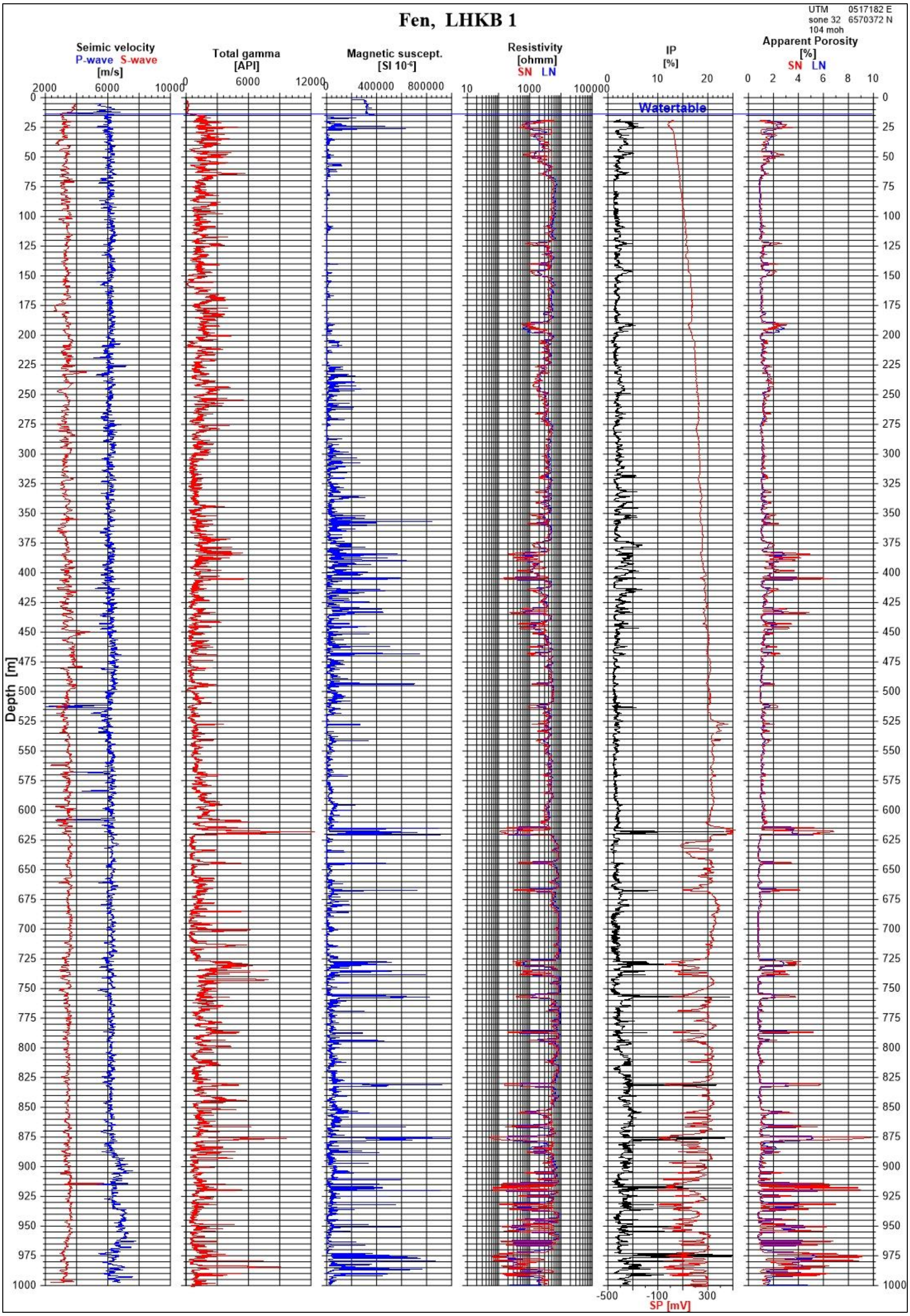


Figure 9. LHKB-1. Seismic velocities, total gamma radiation, magnetic susceptibility, resistivity, IP, SP and apparent porosity.

5.3 LHKB-1, Gamma Spectrometry

When processing the spectral data, we discovered that the stripping process was obvious wrong. The K chemical analyses from cores did not fit at all to the logged K data. The logged K data was much too high. There was a bad match for the U data as well while Th was better. It looks as if the processing is not correcting for the Th radiation falling into the U and K windows correctly, known as the Compton effect. This might be caused by the very high Th content at Fen. NGU has discussed the problem with Robertson Geo without getting a clear understanding how the processing (stripping) is done. However, Robertson Geo came up with an improved user function taking care of a better stripping process. By using this function, the Th content was quite good compared to the chemical analyses. The U correlation was improved but not good. The K content was almost stripped away showing bad correlation to the chemical analyses.

The gamma spectral data from both boreholes were reprocessed. The concentrations of K were still incorrect and is not presented in the report. The uranium concentration is reliable only in areas where the thorium content is low.

Figure 10 shows the total gamma radiation and the gamma spectrometry logs (U and Th) for LHKB-1. Data has been filtered using a running average filter (21 point average). As described in Chapter 5.1 the total gamma radiation is quite high with average values of 1300 – 1600 cps (API). The radiation seems to increase below 600 m depth. There are peak values up to 12000 cps (API) at approximate depth 620 m.

Statistical U and Th values are shown in Table 3. Both average and maximum values are shown for the U and Th elements at two intervals. As discussed earlier, the K content from borehole logging is not reliable.

Table 3. Total gamma, U and Th content in LHKB-1 from gamma spectrometry logging (Log) and chemical analyses (Lab).

LHKB-1	Gamma total aver.	Uranium average	Uranium maximum	Thorium average	Thorium maximum
Log 0 - 600	1300 cps	6.7 ppm	60 ppm	185 ppm	993 ppm
Log 600 - 1000	1600 cps	9.2 ppm	87 ppm	206 ppm	1950 ppm
Log 0 - 1000	1400 cps	7.2 ppm	87 ppm	194 ppm	1950 ppm
Lab 0 - 1000	-	9.5 ppm	249 ppm	230 ppm	1780 ppm

In most cases the Th content is controlling the total gamma radiation. But the high Th content is not always correlated to the high U content. This can be seen at 100 m, 715 m, 895 m and 950 m depth. The average chemical U content is 31.9 % higher than the logged data. For Th, the chemical analyses show 18.5 % higher values than the logged data.

Correlation between REE minerals and U and Th content will be described later.

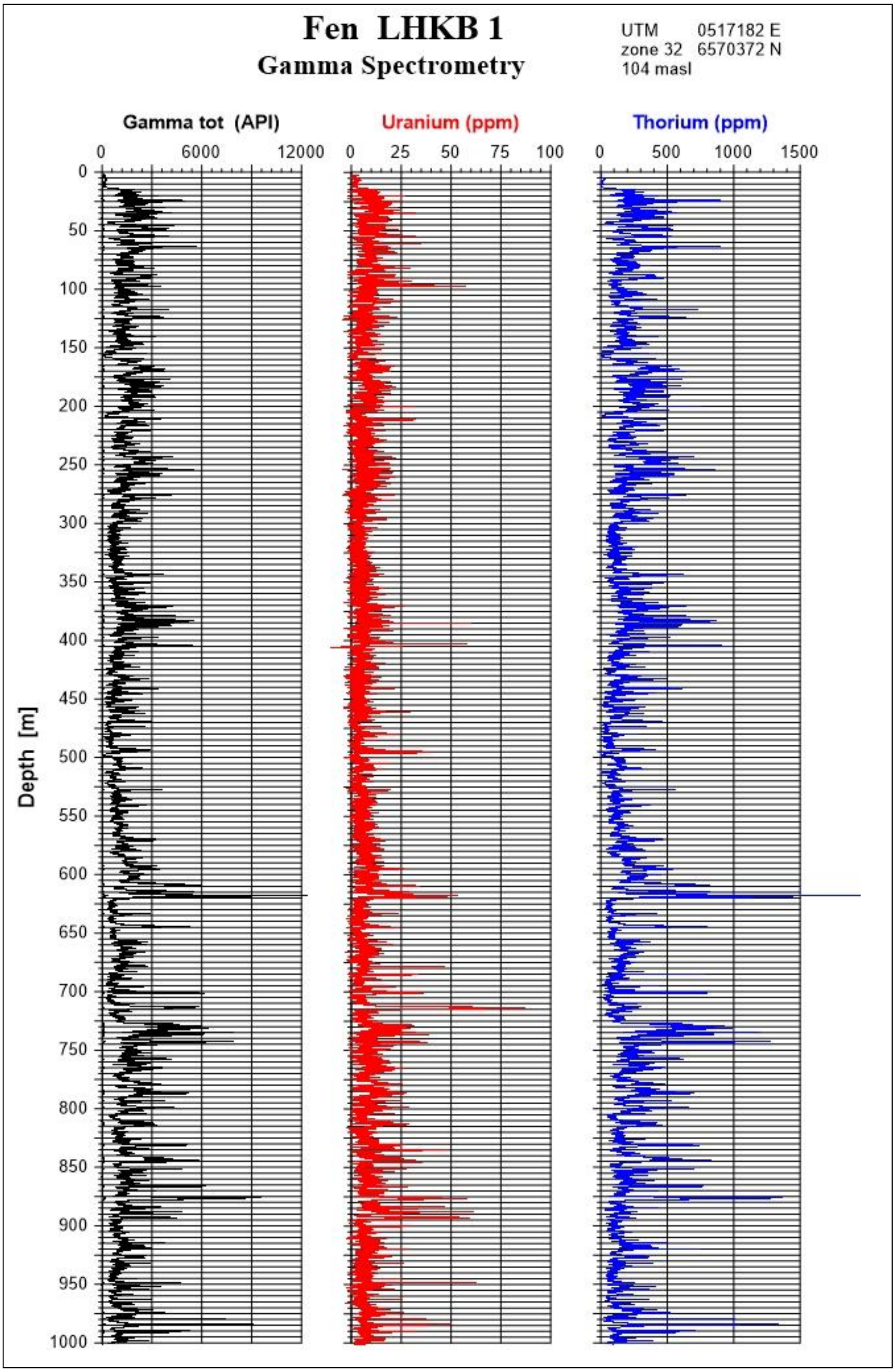


Figure 10. LHKB-1. Gamma spectrometry logs. Total counts in cps API standard, U and Th concentrations in ppm.

5.4 LHKB-2, temperature, water conductivity, natural total gamma and temperature gradient.

Figure 11 shows the logging in LHKB-2. The winch in the van can be used for up to 1850 m logging depth.

Figure 11. Logging in LHKB-2 in May 2018.

Figure 12 shows temperature, water conductivity, total gamma and temperature gradient in LHKB-2. Bottom temperature at 692 m depth is 18.2 ^{o}C. Average temperature gradient (100 m interval) below 100 m is 18.06 ^{o}C/km. A higher gradient was expected in this rock which contains large amounts of the heat producing elements U and Th.

In general, the water conductivity is low (ca. 250 µS/cm). A small increase at 175 m depth may indicate a small inflow of water. At ca 630 m depth the conductivity decreases to approximately 100 µS/cm probably caused by in/out flow of water. Small changes in the temperature gradient at the same depth and at 400 m depth, may indicate the same.

The gamma radiation is generally quite high. The average background gamma radiation is about 940 cps (API). Several peak values in the lower part of the borehole have values up to 6200 cps (API). See Chapter 5.6 for more details on the gamma log.

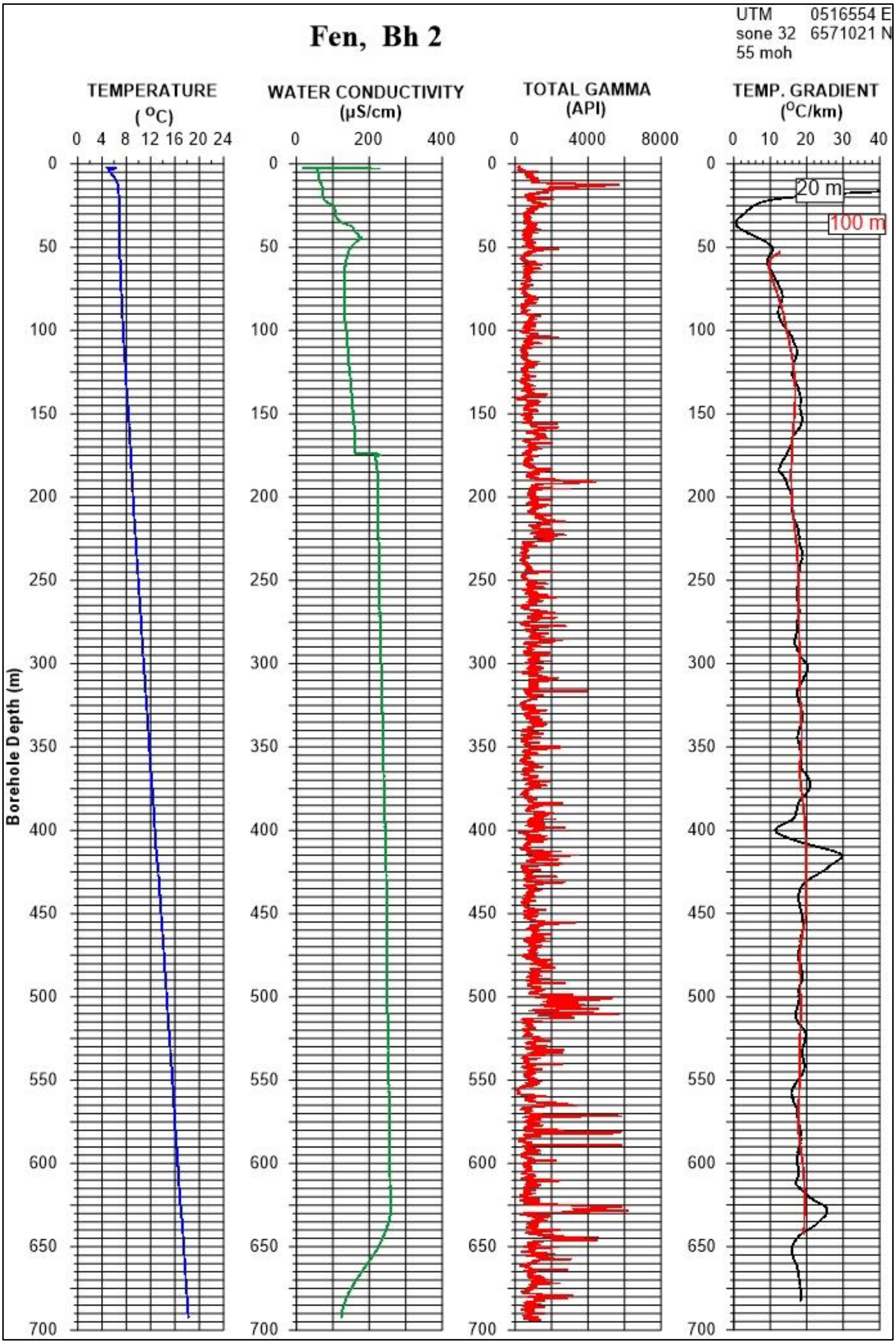


Figure 12. LHKB-2. Temperature, water conductivity, natural gamma and temp. gradient.

5.5 LHKB-2, seismic velocity, resistivity, natural gamma, magnetic susceptibility, Induced Polarisation, Self Potential and apparent porosity.

The plan was to drill LHKB-2 to a depth of 1000 m. Due to heavily fractured rock from about 700 m (see Appendix 3), the drilling stopped at 716 m. All logs were stopped at 695 m depth because of the risk to lose logging tools. The lithology is a bit different in LHKB-2. Large intervals of damtjernite was drilled through at several levels (Coint & Dahlgren 2019). A simplified lithological log is added to the logs in Figure 13, the green colour represents the damtjernite.

Figure 13 shows the result and the logs of seismic velocity, resistivity, natural gamma, magnetic susceptibility, Induced Polarisation (IP), Self Potential (SP) and apparent porosity.

Seismic velocity. Both P- and S-wave velocities were measured. The P-wave velocity in the rauhaugite is ca. 6000 m/s. In the damtjernite the P-velocity is a little bit lower, 5700 – 5900 m/s. No big fracture zones with low velocity were indicated in the logged part of the borehole.

The total natural gamma radiation has an average background value of 940 cps (API). This is high compared to other rocks in Norway like granites and gneisses (Elvebakk 2011). The reason is the high U and Th content. The gamma radiation is close to similar in damtjernite and rauhaugite except in the interval of damtjernite at 498 – 514 m depth. In this part the radiation is 4000 – 5000 cps (API) because of the high Th content, see later. Several peaks of high gamma values (up to 6000 cps) are indicated in the rauhaugite below this zone.

In Figure 13 the magnetic susceptibility shows large variations. The background susceptibility is 0.02 – 0.03 SI both in the rauhaugite and damtjernite. Several zones with high susceptibility are indicated in both rocks. Values up to 0.5 – 0.95 SI indicate magnetite enrichments.

The resistivity is in general high, 3000 – 5000 ohmm, in unfractured rock. A low resistivity zone is indicated at 191 m depth, 130 ohmm. This zone has also high susceptibility and high IP. Most likely this is a magnetite or pyrrhotite rich zone. Three low resistivity zones are indicated at 625, 645 and 670 m depth (200 – 400 ohmm). These zones are indicated at all the other logs too. It can be sulphides or magnetite combined with U and Th bearing minerals.

The low resistivity zones also correlate with SP and IP. The three zones below 600 m is clearly indicated by SP, most likely caused by sulphides.

The apparent porosity is only reliable in the borehole where no conductive minerals are indicated. Based on this the apparent porosity in the rauhaugite and the damtjernite is 1 – 1.2 %.

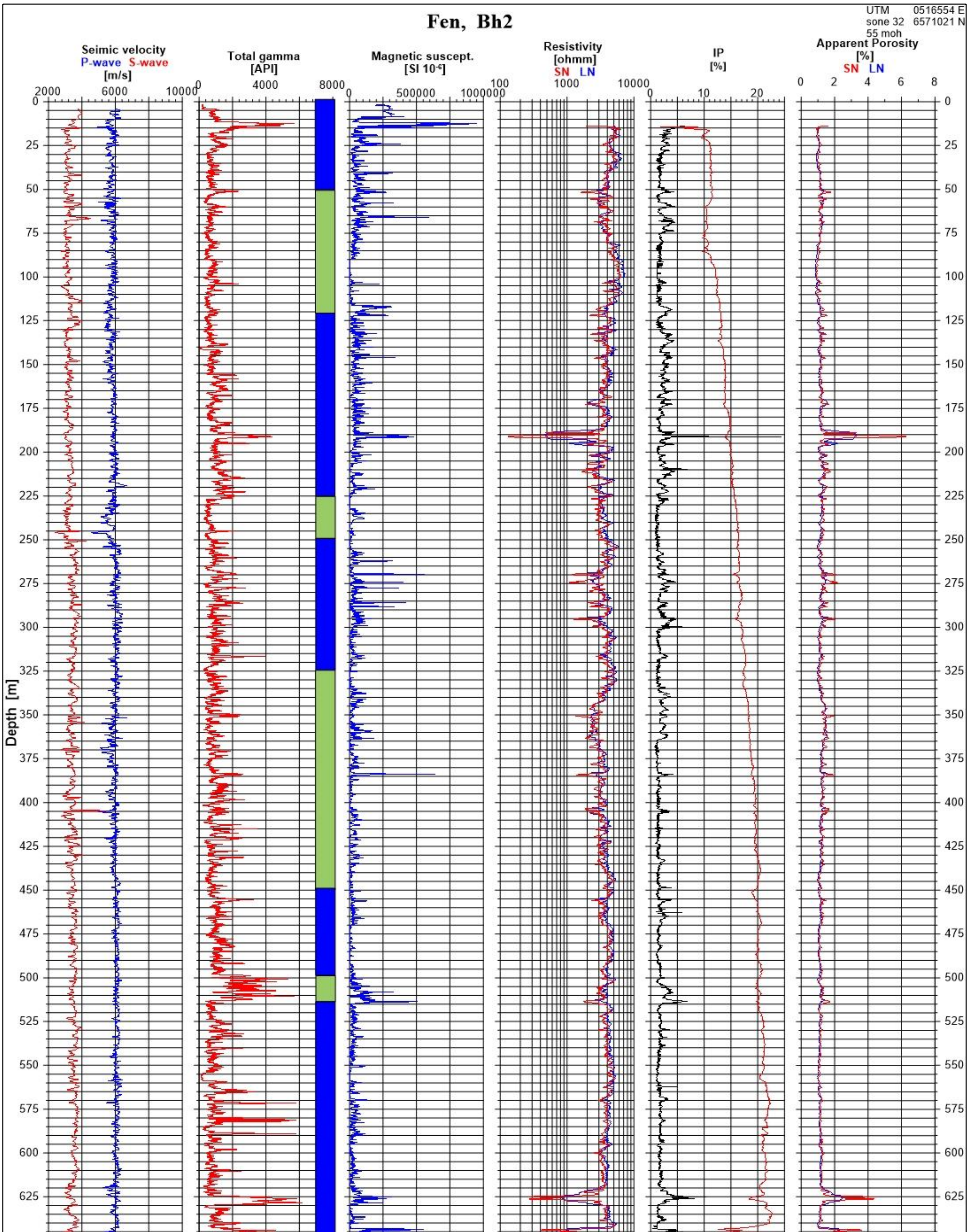


Figure 13. LHKB-2. Seismic velocities, total gamma, magnetic susceptibility, resistivity, IP, SP and apparent porosity. Geological data from Coint and Dahlgren (2019).

5.6 LHKB-2, Gamma Spectrometry

As discussed in Chapter 6.3, the original processing of the spectral radiation data, was not reliable. Reprocessing proposed by the instrument manufacturer Robertson Geo improved the Th concentration, but the U concentration is still influenced by Th radiation where this is high. Processed K data are not reliable at all and skipped in the presentation.

Figure 14 shows the total gamma radiation and the gamma spectrometry logs for LHKB-2. As described in Chapter 5.5 the total gamma radiation is quite high with average values of 940 - 1200 cps (API). The radiation seems to increase below 450 m depth. There are peak values up to 6000 cps (API).

U and Th values are shown in Table 4. Both average and maximum values are shown for the U and Th elements.

Table 4. Total gamma, U and Th content in LHKB-2 from gamma spectrometry logging (Log) and chemical analyses (Lab).

LHKB-2	Gamma total aver.	Uranium average	Uranium maximum	Thorium average	Thorium maximum
Log 0 - 450	940 cps	7.1 ppm	67 ppm	109 ppm	911 ppm
Log 450 - 695	1200 cps	9.5 ppm	109 ppm	134 ppm	908 ppm
Log 0 - 695	1030 cps	7.9 ppm	109 ppm	118 ppm	911 ppm
Lab 0 - 695	-	11.5 ppm	174 ppm	158 ppm	1150 ppm

In most cases the Th content is controlling the total gamma radiation. But the high Th content is not always correlated to the high U content. This can be seen at 571 m, 581 m and 589 m depth with a U content of approximately 400 ppm.

High Th content is found at 10 – 15 m, 498 – 514 (damtjernite), 625 – 630 m and 645 m depth.

Correlation of REE minerals and the U and Th contents will be described later.

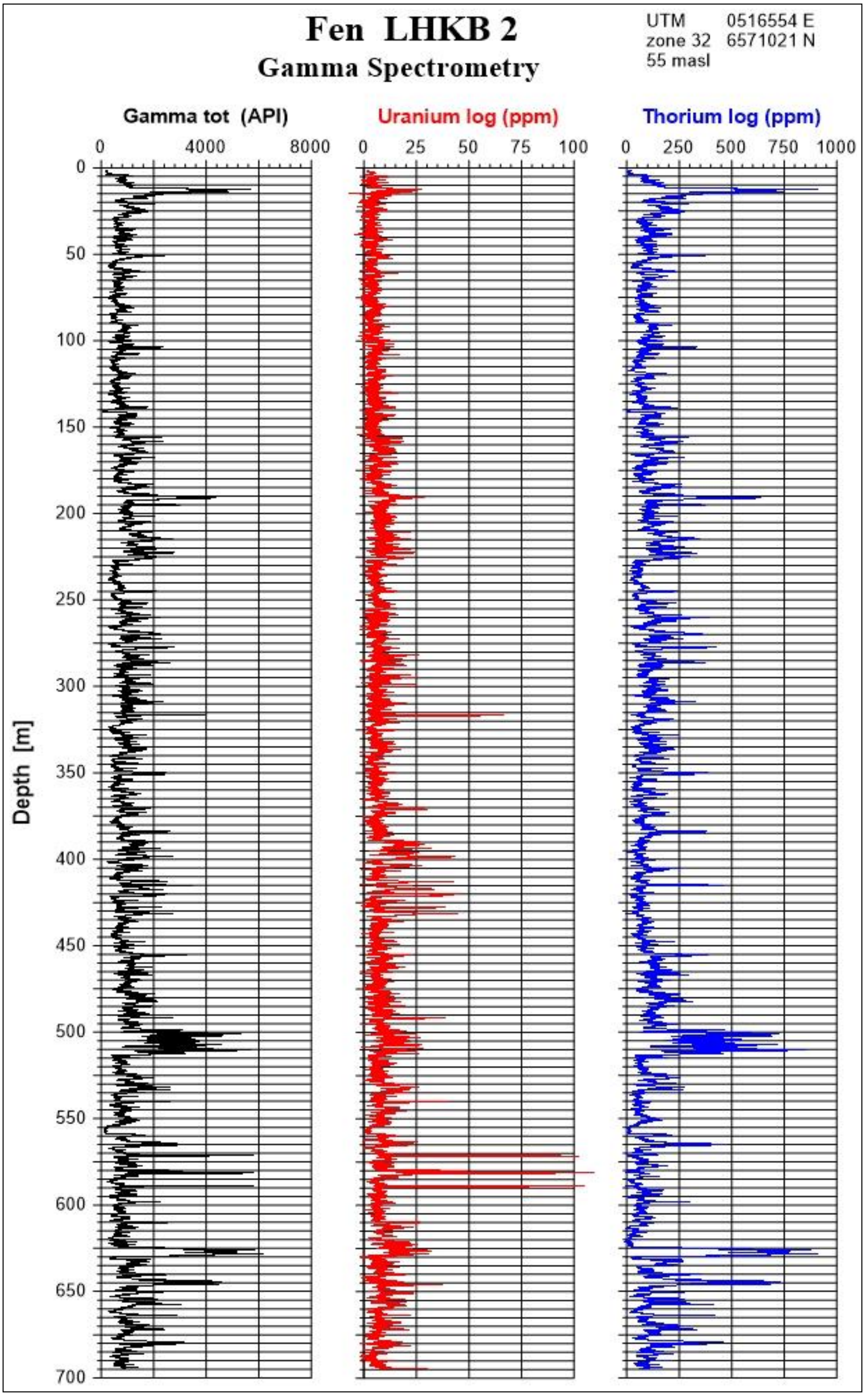


Figure 14. LHKB-2. Gamma spectrometry logs, total counts in cps API standard, U and Th concentrations in ppm.

5.7 Acoustic televiewer results

Acoustic televiewer was run in both boreholes to map the fracturing (azimuth and dip). It was useful to find the reason for the rock fall in LHKB-1 at 512 m depth. The acoustic images clearly showed an open space from where parts of the borehole wall had slipped and blocked the borehole. All the probes stopped just below this depth. Figure 15 shows an acoustic image and calculated borehole diameter from the rock fall zone in LHKB-1. The diameter is calculated using the travel time for the acoustic pulse. The maximum measured diameter is ca. 30 cm. The drilling diameter is 7.6 cm. The fracture zone is 1.6 m wide which means that quite a big volume of rock had fell into the borehole. The top of this fracture zone indicates a dip to the west - southwest. The reopening of the borehole was successful.

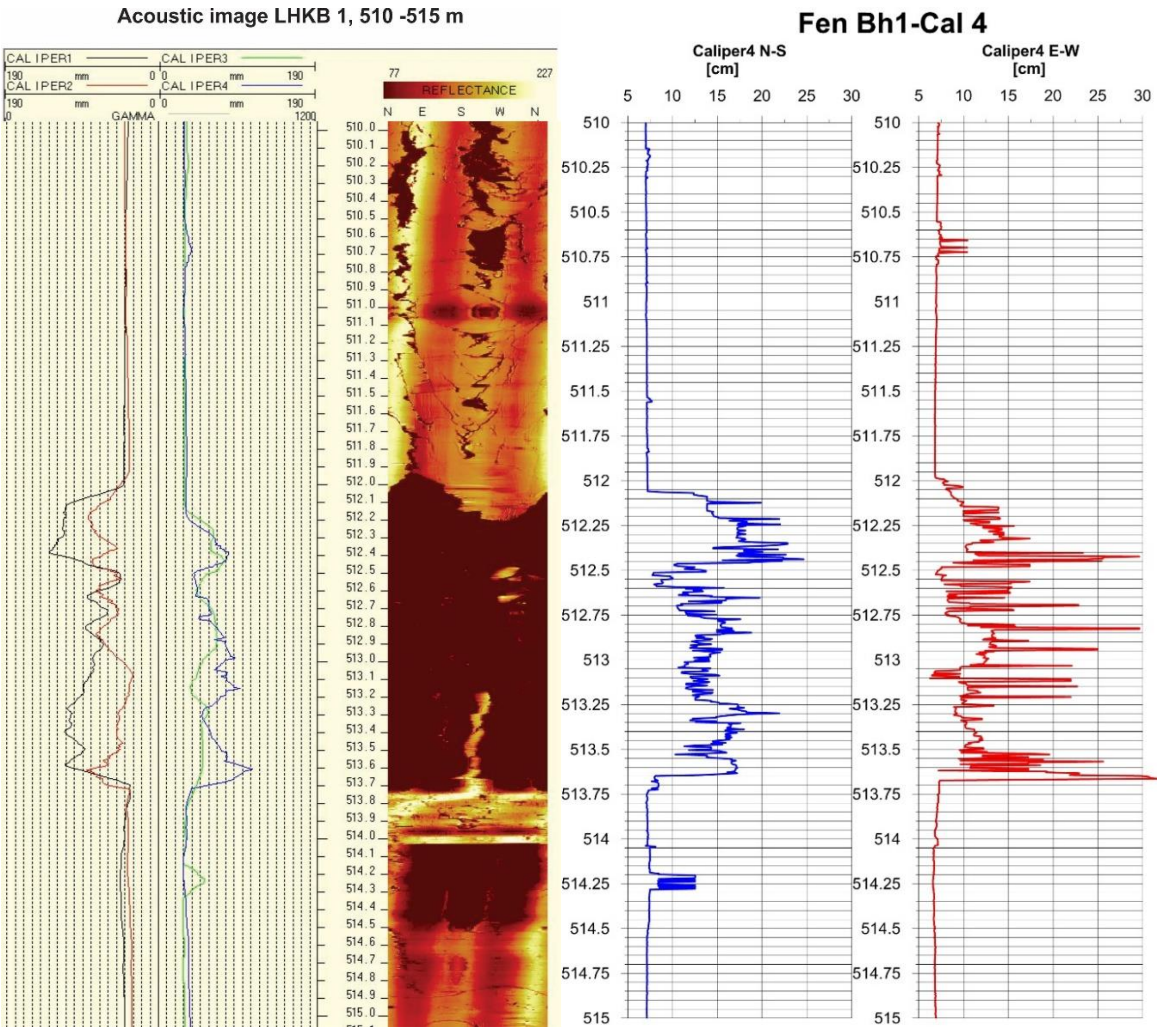


Figure 15. Calculated caliper radius in four directions (left), Acoustic reflectance image (middle) and calculated borehole diameter (right) at the rock fall zone in LHKB-1.

5.7.1 <u>Fracture mapping in LHKB-1</u>

Figure 16 shows a stereogram of all indicated fractures in LHKB-1. The coloured circles represent fracture groups with different dip and strike. As can be seen on the stereogram, there is no specific main fracture group (main strike/dip). In Figure 17 the fracture rose diagrams for azimuth and dip angle confirm the widespread in azimuth while most of the fractures have a dip angle larger than 45^o.

Zone 0, 14.000 - 1000.000m
Deviation 0.7 N314.1
Mean dip format: strike and dip
dip data sets .....
BHTV dips

	mean dip	n	f
N072 11	N072 11	111	0.11
N346 70	N346 70	57	(0.17)
N288 61	N288 61	74	(0.16)
N095 69	N095 69	53	(0.15)
N224 66	N224 66	43	(0.11)
N154 63	N154 63	46	0.10

intersections

	N072 11	N346 70	N288 61	N095 69	N224 66	N154 63
N072 11		11 N162	6 N105	5 N097	5 N226	11 N160
N346 70	11 N162		61 N026	57 N132	50 N012	13 N161
N288 61	6 N105	61 N026		14 N100	59 N356	36 N312
N095 69	5 N097	57 N132	14 N100		46 N252	62 N228
N224 66	5 N226	50 N012	59 N356	46 N252		60 N274
N154 63	11 N160	13 N161	36 N312	62 N228	60 N274	

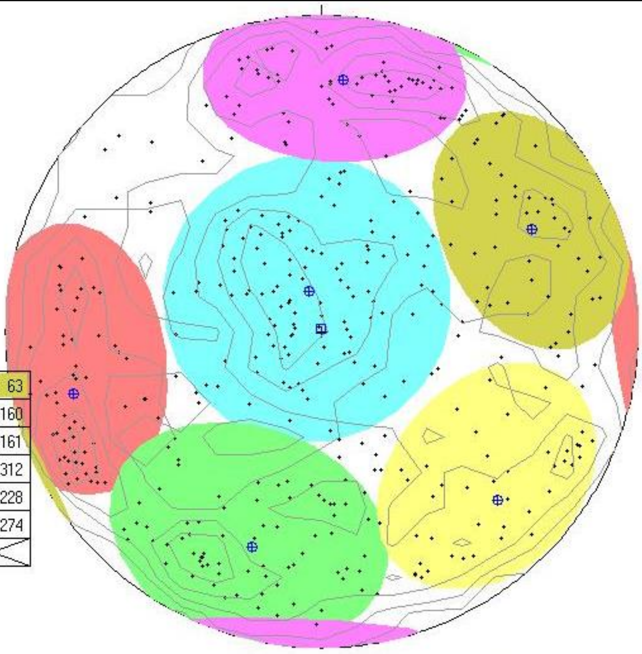


Figure 16. Stereogram of indicated fractures in LHKB-1. The upper table shows average strike - dip and number fractures in each fracture group. The lower table shows the crossing lines between each average fracture groups.

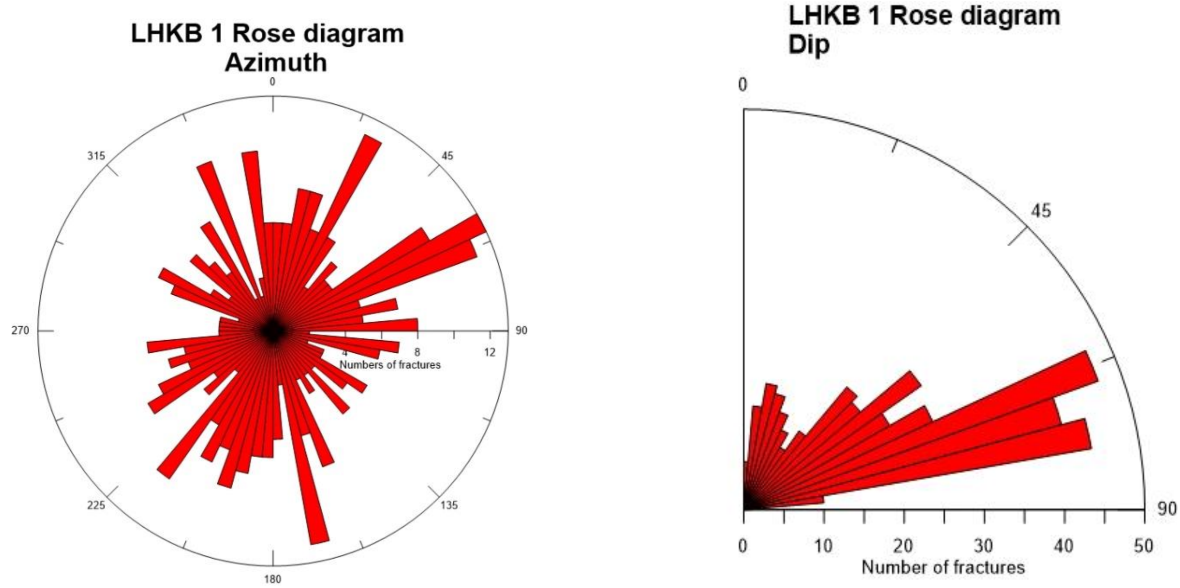


Figure 17. Fracture rose diagrams for indicated fractures in LHKB-1.

Figure 18 – 22 show fracture frequency histograms of indicated fractures in LHKB-1. The coloured histograms and the needles in the left side of the figure are representing the same colours as the fracture groups in the stereogram (Figure 16). The needles to the left indicate the dip angle (head) and dip direction of each fracture (north is up, east to the right, south is down and west to the left). Most fractures are indicated in the intervals 0 – 270 m and 470 – 620 m depth. Locally the fracture frequency comes up to 6 fractures/meter.

To the right on the diagram the borehole deviation is plotted (angle from vertical and azimuth).
The borehole is close to vertical. If the borehole is vertical there is no direction (azimuth). Small changes in deviation from vertical can change azimuth by 180^o as can be seen on the small “needles” on the plot.

In the same graph the RQD index indicates the highest fractured areas in the borehole.

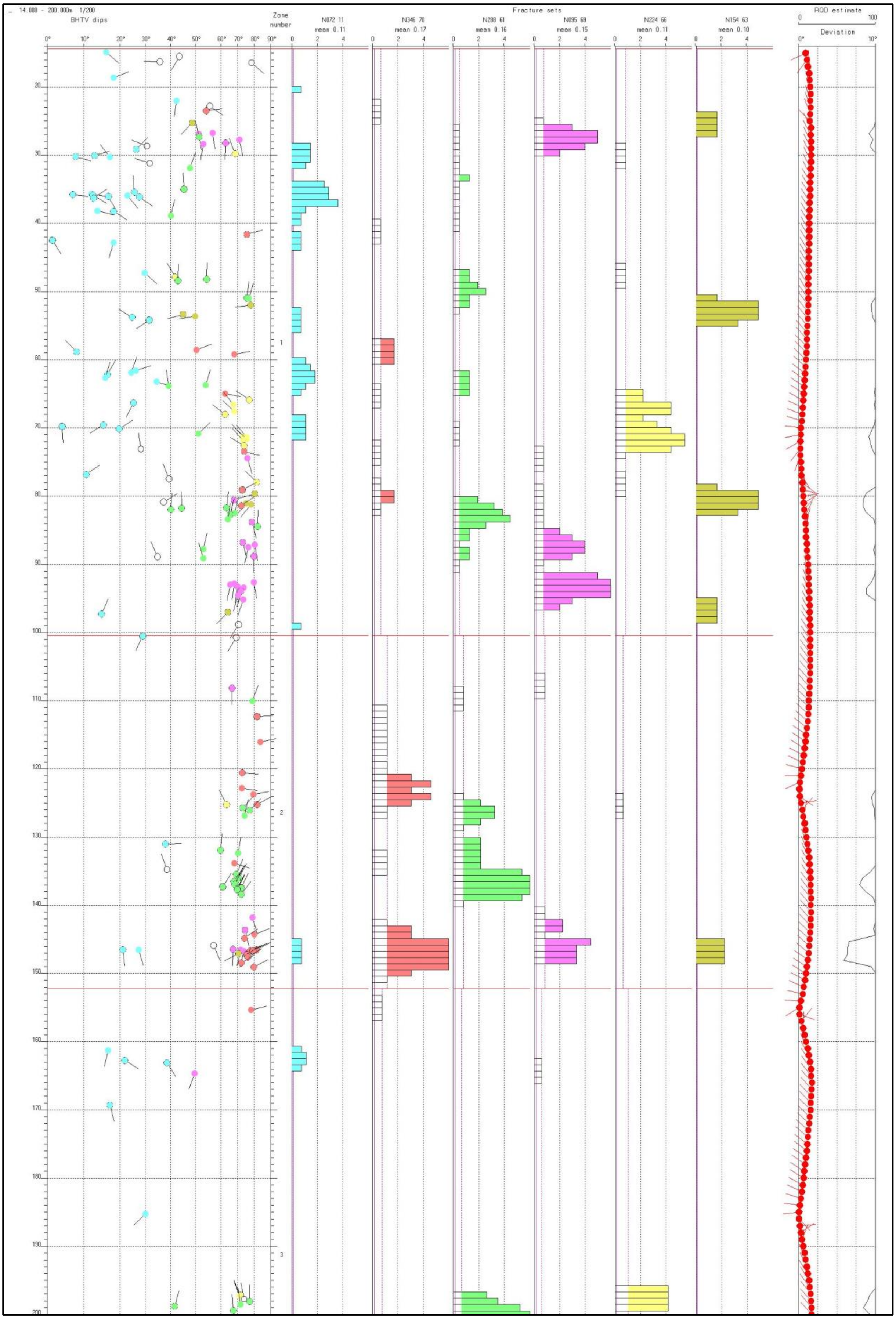


Figure 18. LHKB-1. Individual fractures and fracture frequency histogram of indicated fractures, 8 - 200 m (mean strike and dip can be seen in Figure 16). Borehole deviation and RQD value to the right.

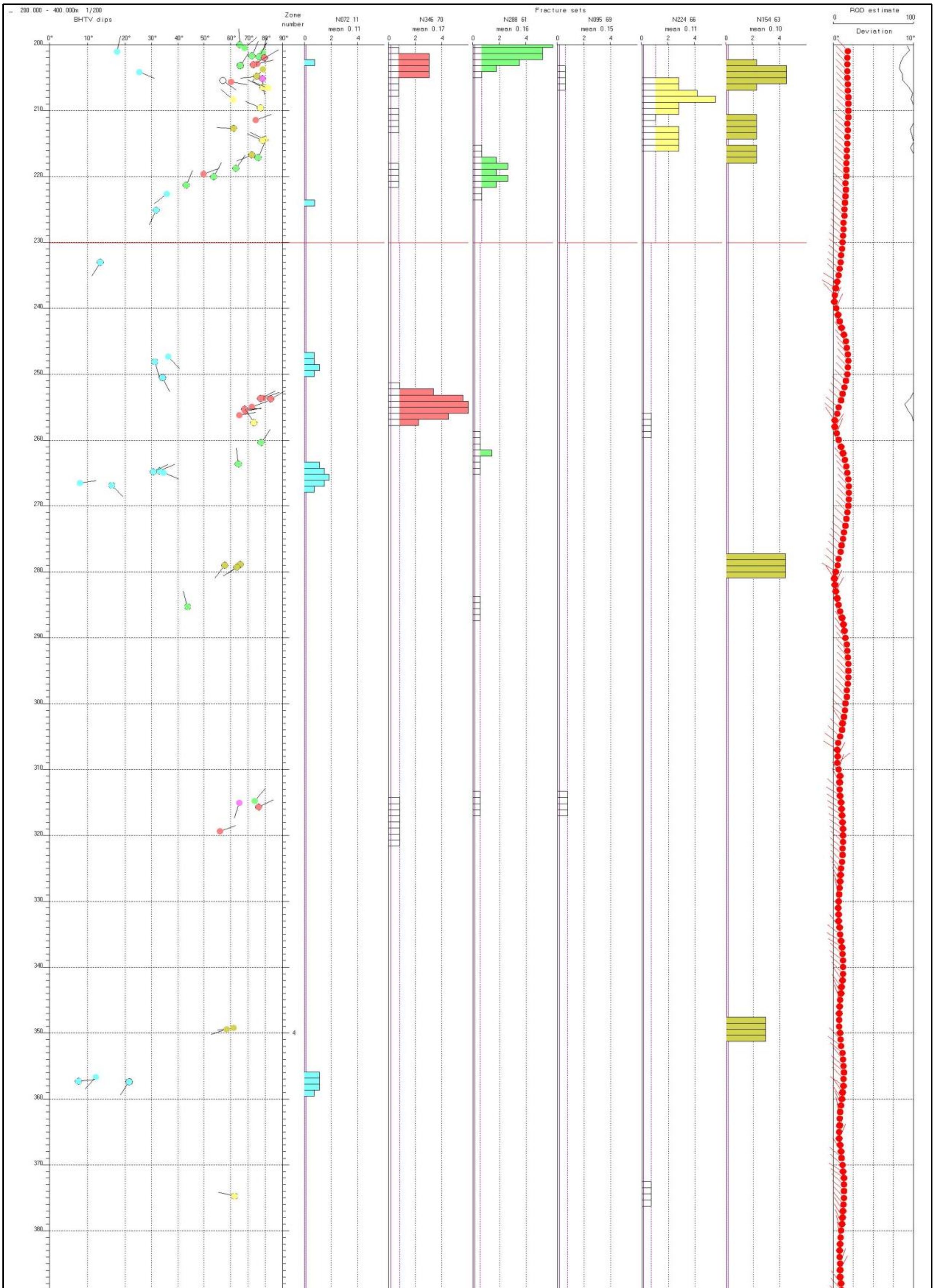


Figure 19. LHKB-1. Individual fractures and fracture frequency histogram of indicated fractures, 200 - 400 m. (mean strike and dip can be seen in Figure 16). Borehole deviation and RQD value to the right.

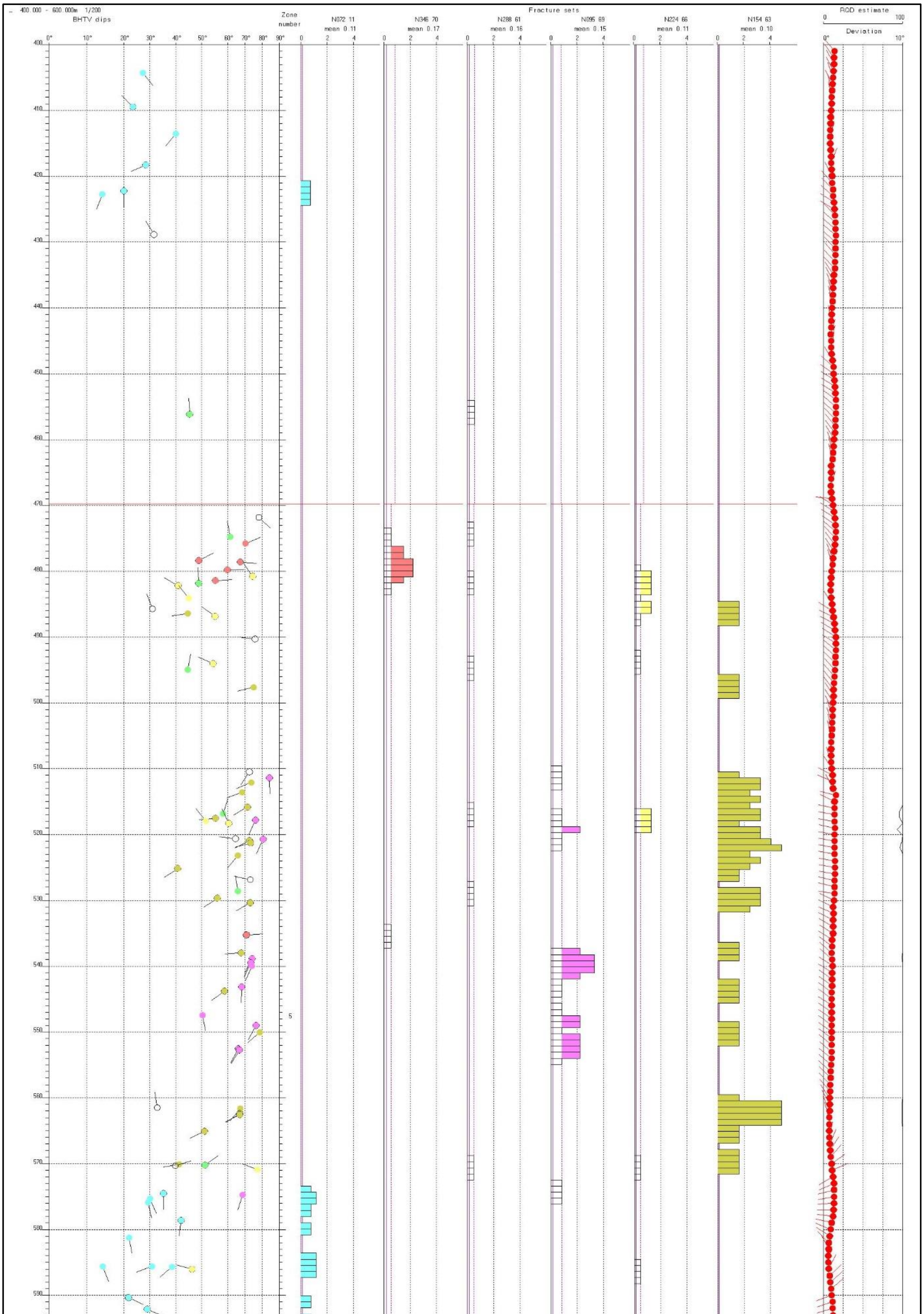


Figure 20. LHKB-1. Individual fractures and fracture frequency histogram of indicated fractures, 400 - 600 m (mean strike and dip can be seen in Figure 16). Borehole deviation and RQD value to the right.

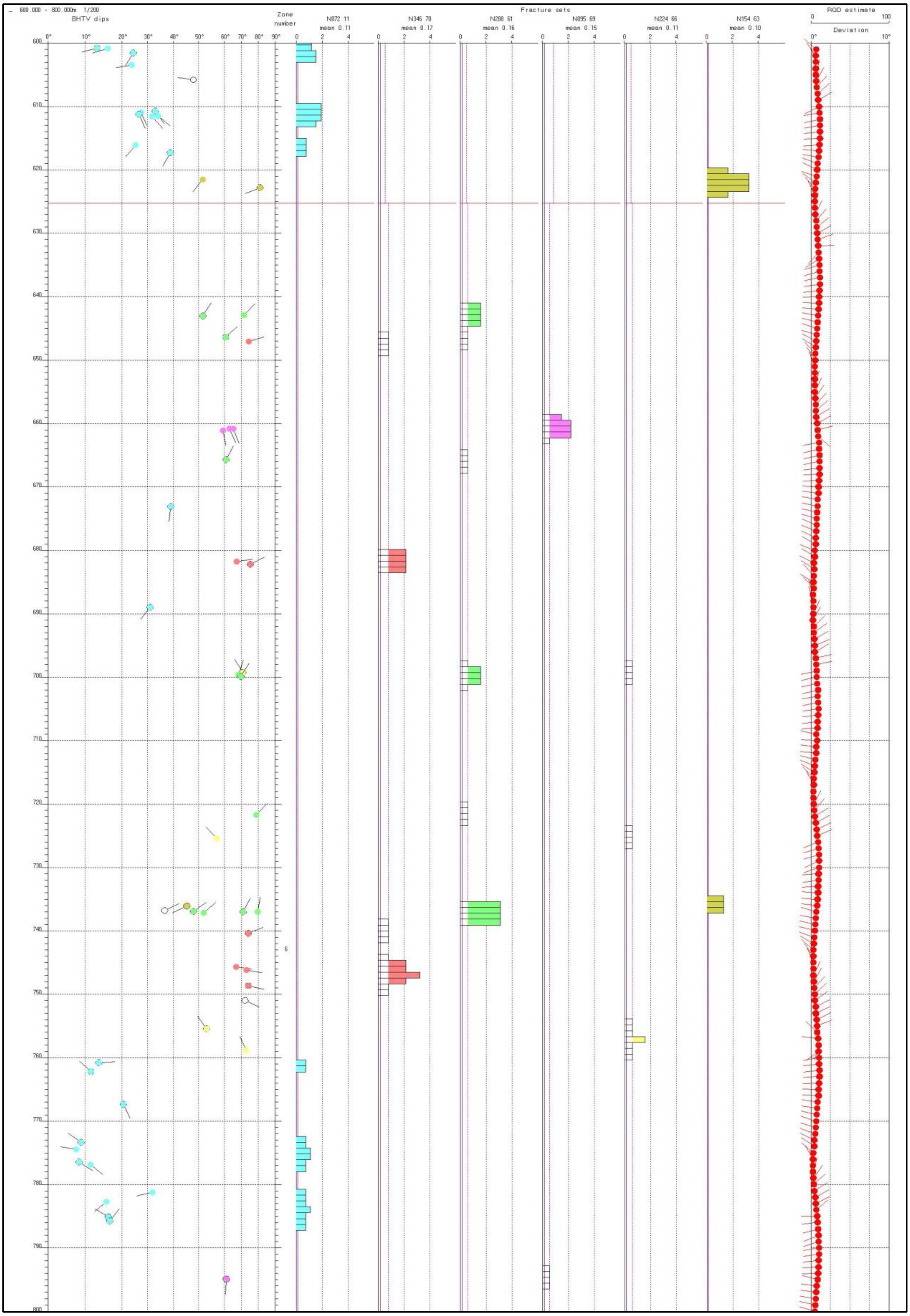


Figure 21. LHKB-1. Individual fractures and fracture frequency histogram of indicated fractures, 600 - 800 m (mean strike and dip can be seen in Figure 16). Borehole deviation and RQD value to the right.

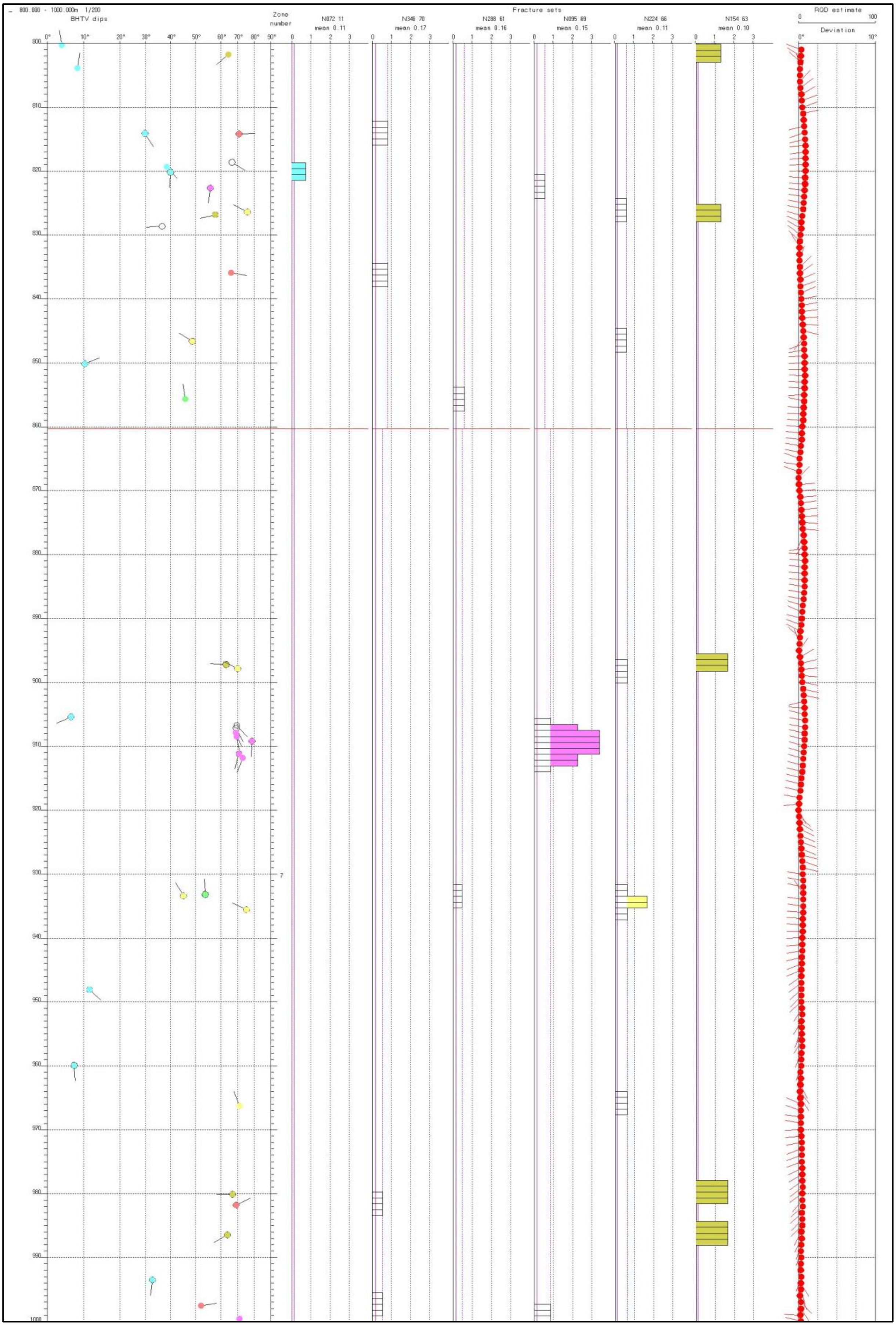


Figure 22. LHKB-1. Fracture frequency histogram of indicated fractures, 800 - 1000 m (mean strike and dip can be seen in Figure 16). Borehole deviation and RQD value to the right.

5.7.2 Fracture mapping in LHKB-2

Figure 23 shows a stereogram of all indicated fractures in LHKB-2. The coloured circles represent fracture groups with different dip and strike. Figure 24 shows the rose diagrams for azimuth and dip angle. The trend is a SE – SW azimuth of the fractures. Most of the fractures are dipping steeply, > 50 º.

Fen Bh2
Zone 0, 8.395 - 695.236m
Deviation 1.6 N148.8
Mean dip format: strike and dip
dip data sets .....
BHTV dips

	mean dip	n	f
N142 11	N142 11	74	0.11
N040 58	N040 58	66	(0.19)
N315 63	N315 63	69	(0.22)
N103 64	N103 64	48	(0.16)
N254 61	N254 61	19	(0.05)
N163 64	N163 64	51	0.17

intersections

	N142 11	N040 58	N315 63	N103 64	N254 61	N163 64
N142 11		10 N213	1 N316	8 N279	10 N259	4 N165
N040 58	10 N213		52 N094	56 N150	26 N058	41 N188
N315 63	1 N316	52 N094		29 N119	58 N010	26 N329
N103 64	8 N279	56 N150	29 N119		26 N269	61 N223
N254 61	10 N259	26 N058	58 N010	26 N269		53 N302
N163 64	4 N165	41 N188	26 N329	61 N223	53 N302	

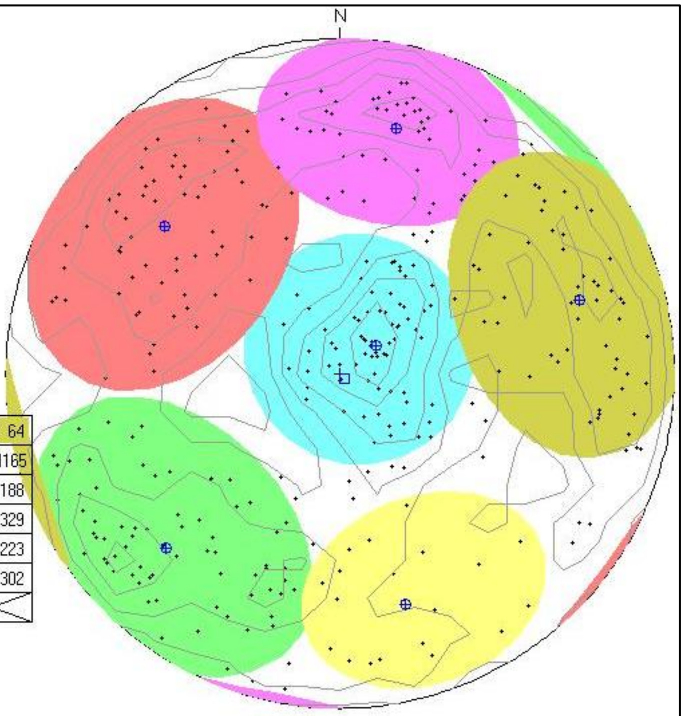
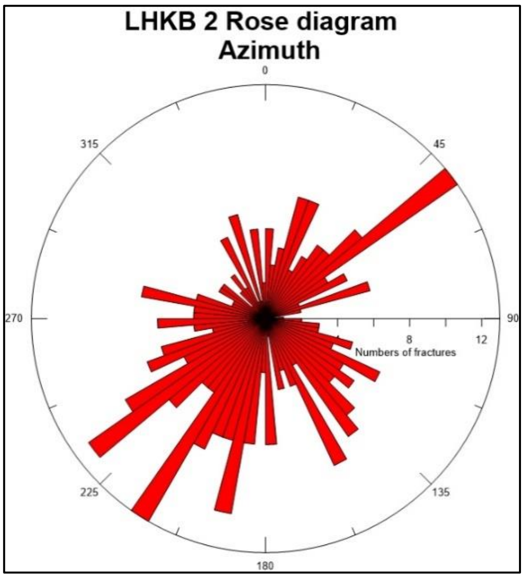


Figure 23. Stereogram of indicated fractures in LHKB-2. The upper table shows average strike - dip and number fractures in each fracture group. The lower table shows the crossing lines between each average fracture groups.



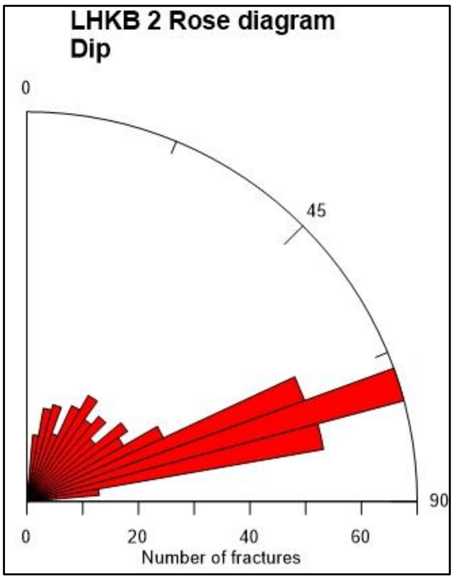


Figure 24. Fracture rose diagrams for indicated fractures in LHKB-2.

Figure 25 – 28 show fracture frequency histograms of indicated fractures in LHKB-2. The coloured histograms and the needles in the left side of the figure are representing the same colours as the fracture groups in the stereogram (Figure 23). The needles to the left indicate the dip angle and dip direction of each fracture (north is up, east to the right, south is down and west to the left). Most fractures are indicated above 400 m depth. In fractured areas the fracture frequency is 2 – 6 fractures /meter.

To the right of the diagram the borehole deviation is plotted (angle from vertical and azimuth).
In the same graph the RQD index indicates the highest fractured areas in the borehole.

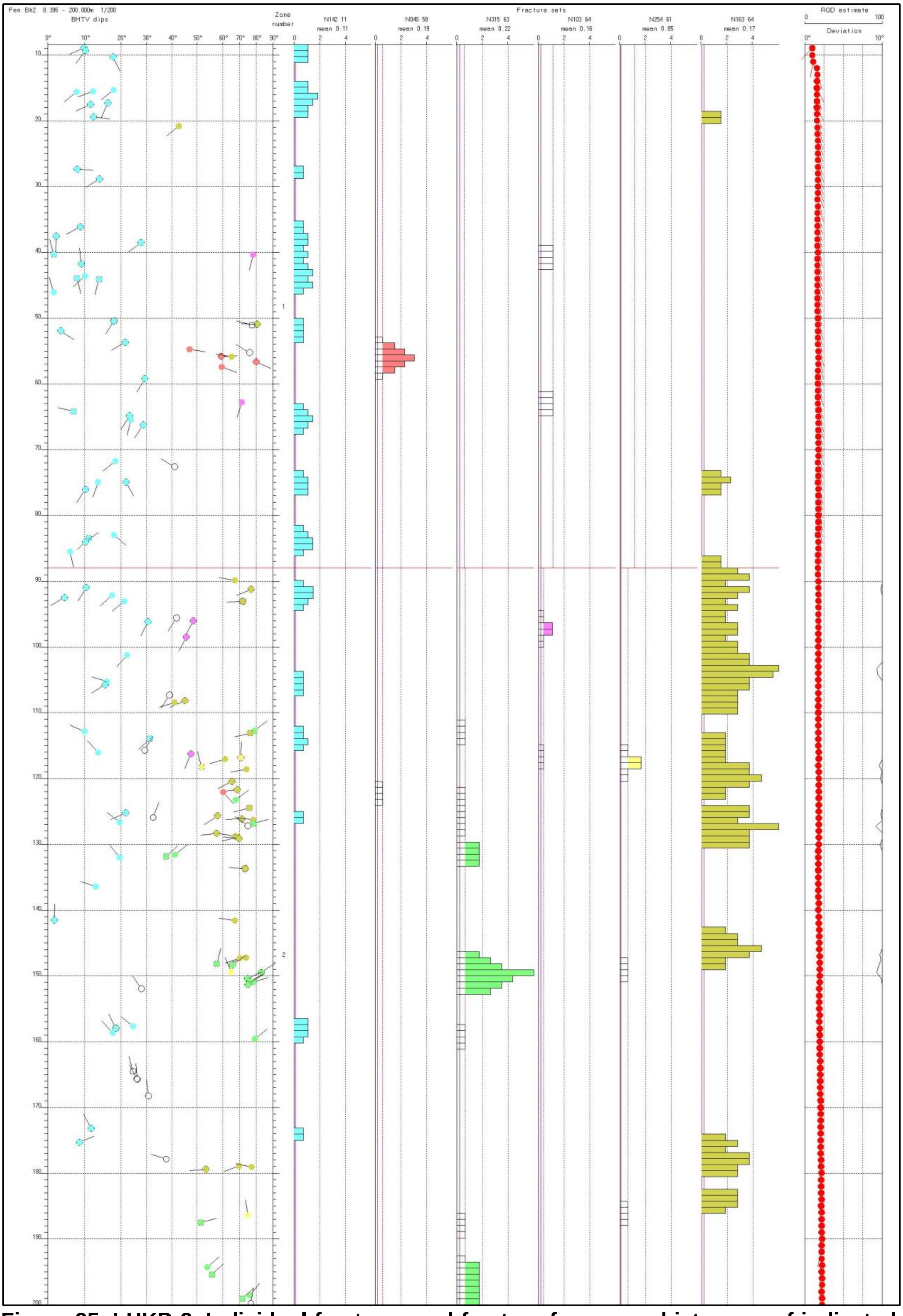


Figure 25. LHKB-2. Individual fractures and fracture frequency histogram of indicated fractures, 0 - 200 m (mean strike and dip can be seen in Figure 23). Borehole deviation and RQD value to the right.

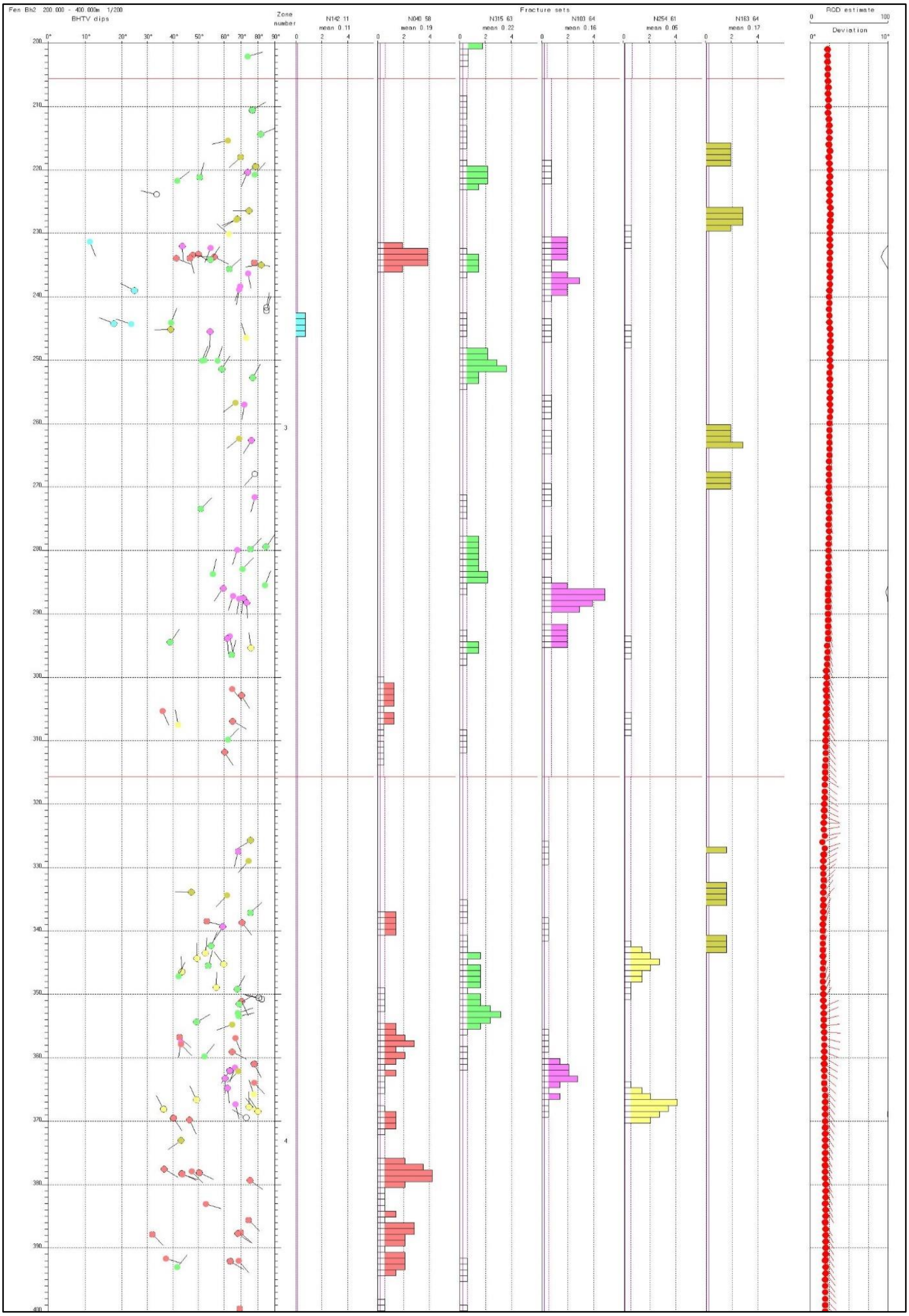


Figure 26. LHKB-2. Individual fractures and fracture frequency histogram of indicated fractures, 200 - 400 m (mean strike and dip can be seen in Figure 23). Borehole deviation and RQD value to the right.

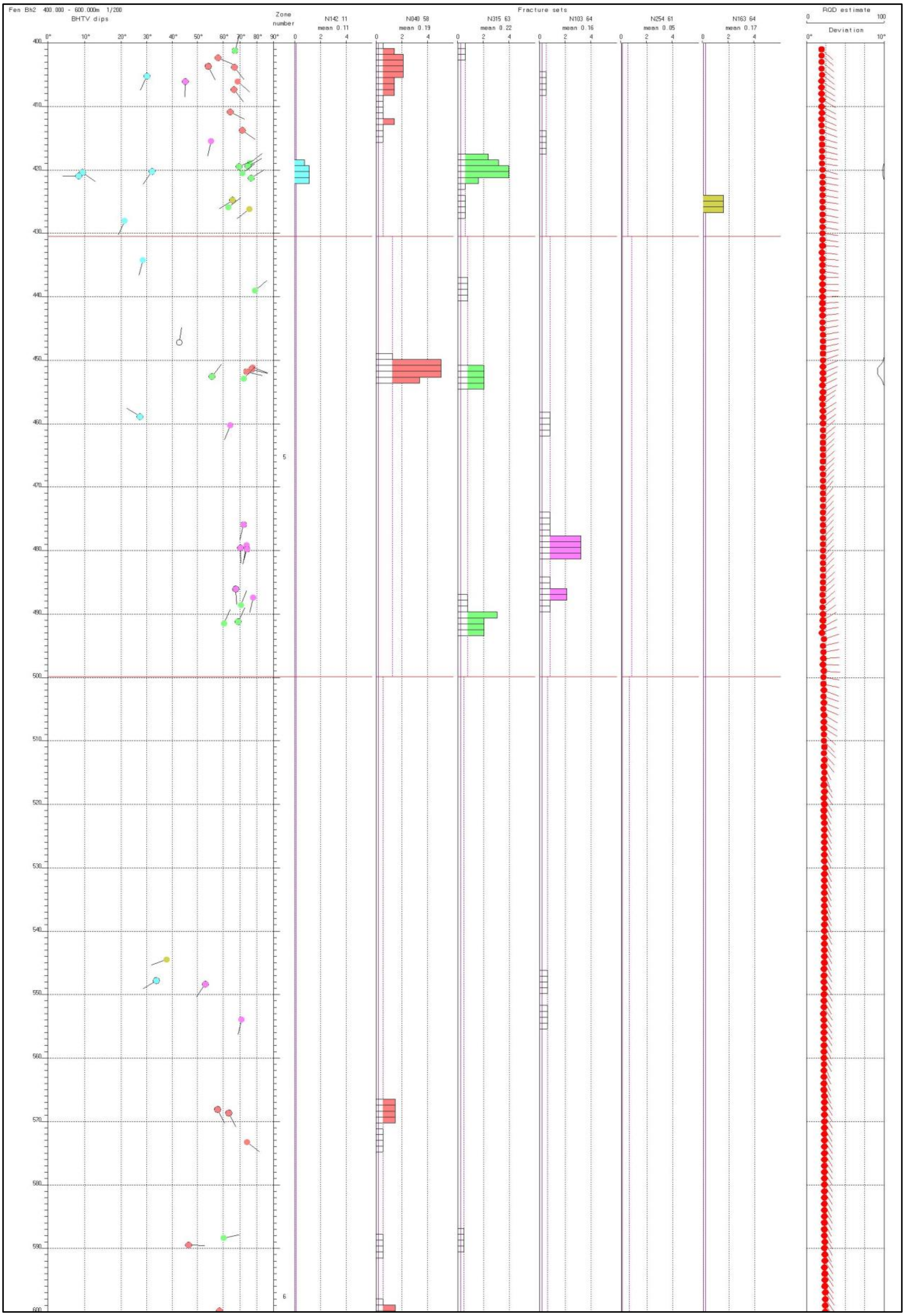


Figure 27. LHKB-2. Individual fractures and fracture frequency histogram of indicated fractures, 400 - 600 m (mean strike and dip can be seen in Figure 23). Borehole deviation and RQD value to the right.

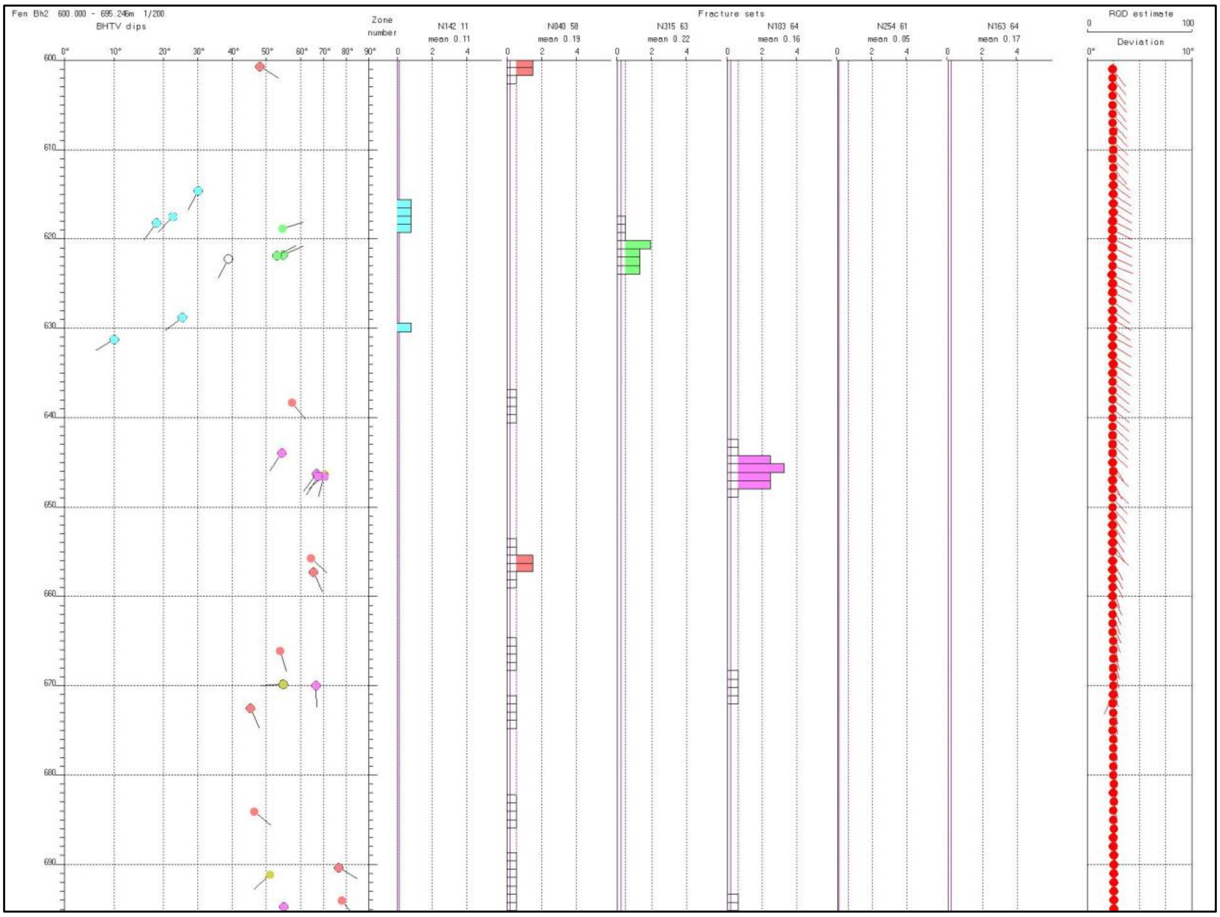


Figure 28. LHKB-2. Individual fractures and fracture frequency histogram of indicated fractures, 600 - 695 m (mean strike and dip can be seen in Figure 23). Borehole deviation and RQD value to the right.

5.7.3 <u>Caliper calculations in LHKB-1 and LHKB-2</u>

By using the travel time from the Acoustic televiewer, the borehole radius can be calculated in four directions. If the acoustic pulse hits an open fracture the travel time will increase, and the calculated radius will also increase.

The calculated diameters along the boreholes are shown in Figure 29. It is calculated in N-S and E-W direction. The drill bit was 7.6 cm and the caliper value is about 7.5 cm. The travel time depends on the water temperature and no corrections are done because of that.

Figure 29 shows the calculated diameters in LHKB-1 (left) and LHKB-2 (right). The fracture zone at 512 m is clearly indicated in LHKB-1 showing a diameter of maximum 30 cm. Some other open fractures indicated by increased diameter are also shown, especially in the upper half of the boreholes. Note that this caliper logs are generated after concrete injection in some areas.

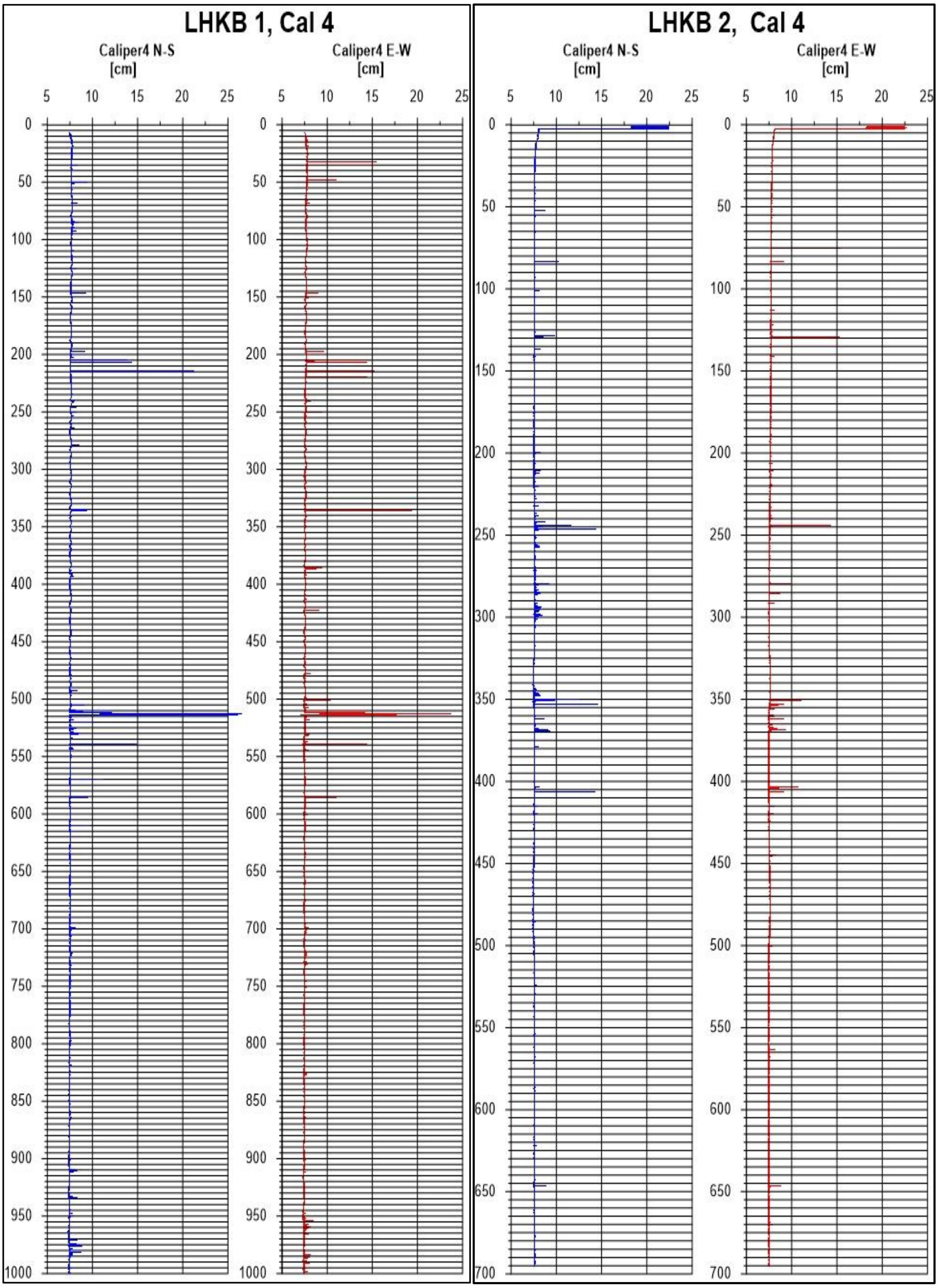


Figure 29. Calculated borehole diameters in LHKB-1 (left) and LHKB-2 (right) from acoustic televiewer measurements.

5.7.4 Borehole deviation in LHKB-1 and LHKB-2

Figure 30 shows deviation plots of LHKB-1. NS deviation (left) is about 8 m to the north in the bottom of the borehole and 9 m to the west in EW direction. Borehole direction is towards north-west, figure 28 (right).

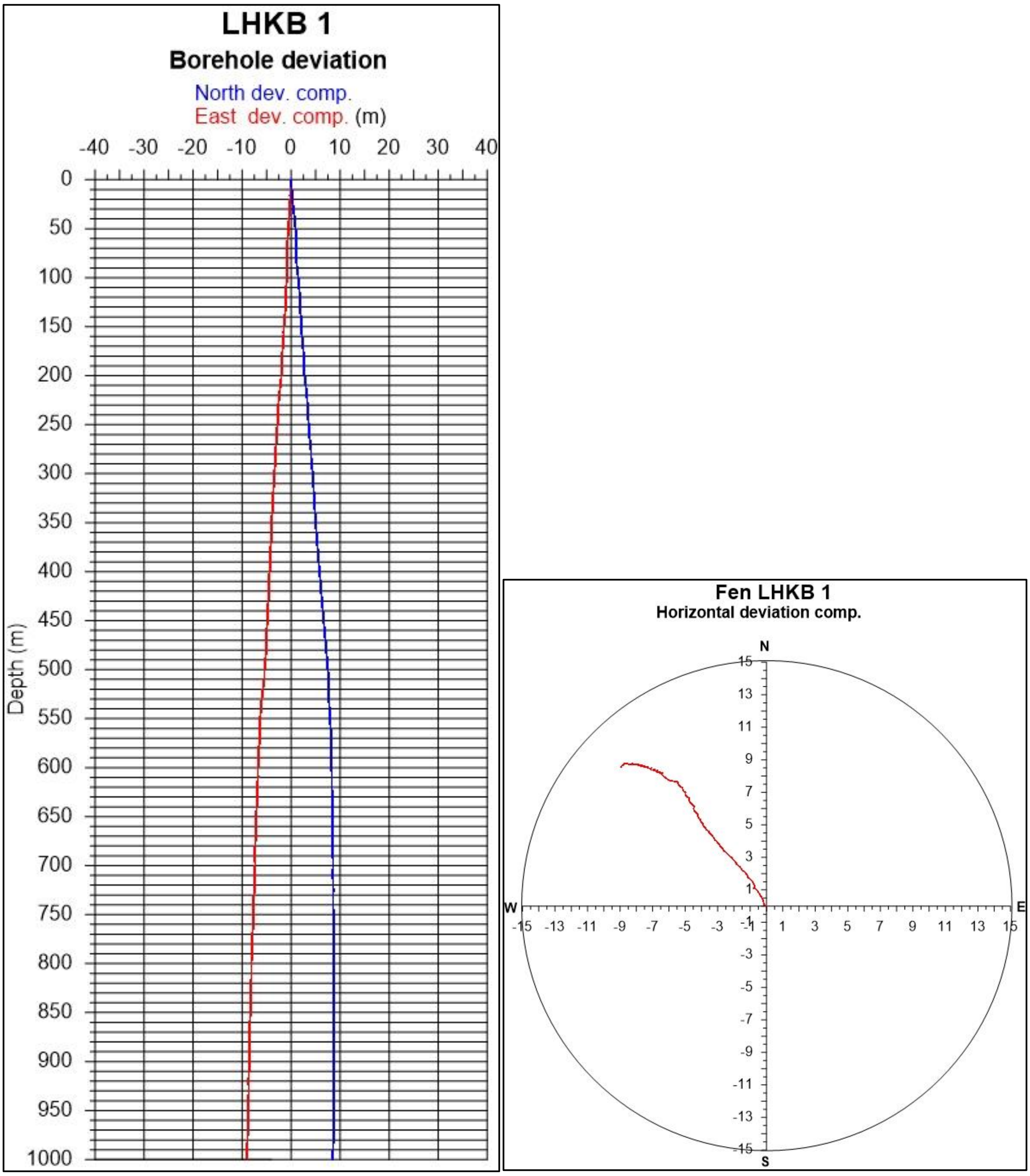


Figure 30. Borehole deviation of LHKB-1.

Figure 31 shows the deviation for LHKB-2. NS deviation is about 17 m to the south and 10 m to the east in EW direction in the bottom of the borehole. Borehole direction is to the south in the upper 300 m, then it turns to SE.

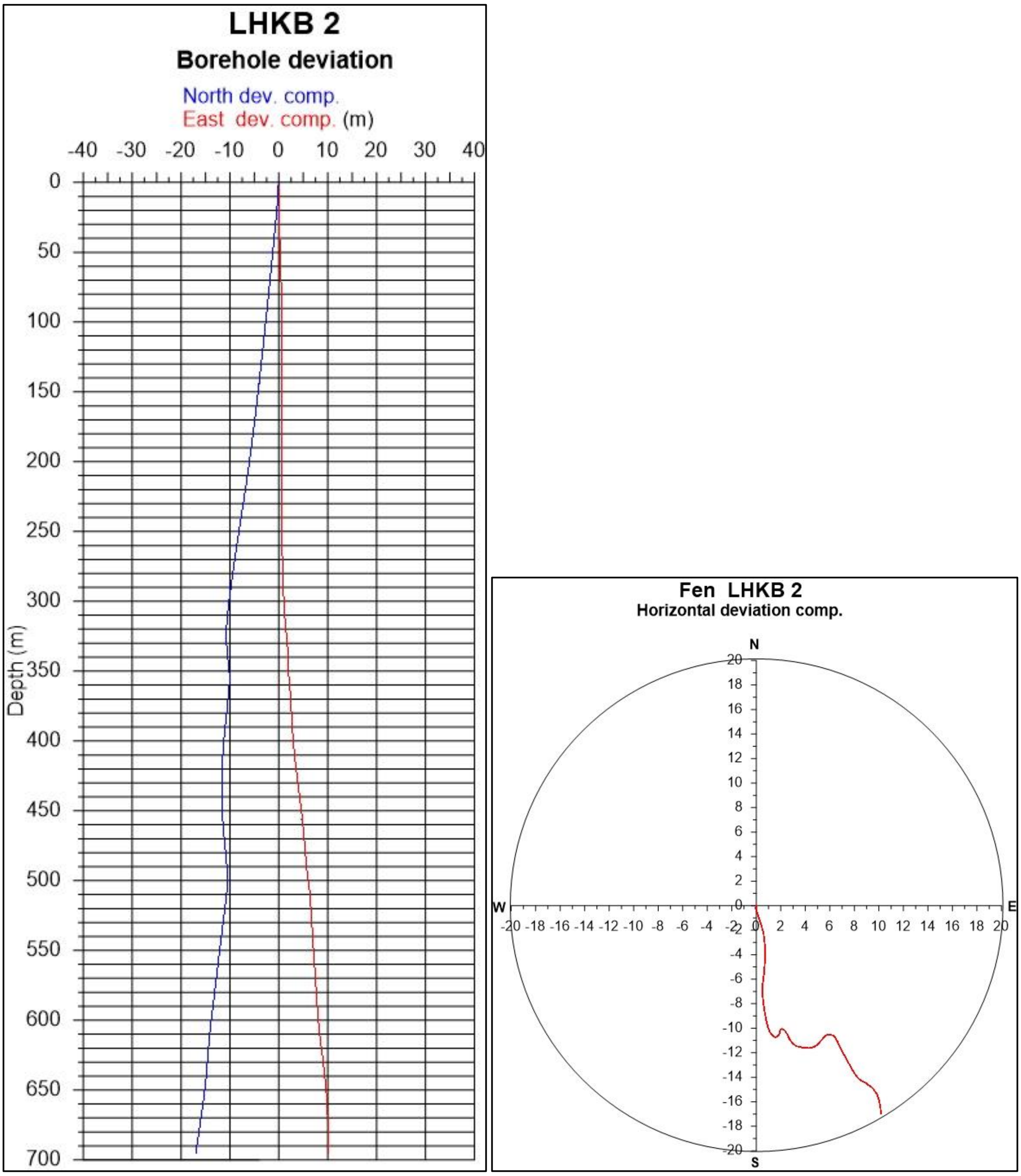


Figure 31. Borehole deviation of LHKB-2.

6. CORRELATION OF GEOPHYSICAL LOGS TO PETROFYSICAL AND CHEMICAL ANALYSES

Both petrophysical and chemical analyses have been done on the Fen cores. Samples for petrophysical analyses were taken every 10 m (Appendix 1) while chemical analyses were taken each meter (mixed sample of one meter core), (Coint & Dahlgren 2019). The geophysical logging sampled every cm. This will make some uncertainty in the correlation process. Therefore, the log data from both boreholes were resampled to an average value for each meter (average of 100 readings). Core samples were not taken continuously in LHKB-2.

The mineralogy of the Fen cores is well described by Coint & Dahlgren (2019). This report also describes the content and distribution of the Total Rare Earth Oxide (TR_2O_3) and some interesting elements like P, Ba, Th, Nd and Dy.

In this Chapter the geophysical logs are plotted together with analysis of magnetic susceptibility and the REE total (ppm) trying to find some correlations.

6.1 Magnetic susceptibility, correlation of logged data and laboratory data.

Magnetic susceptibility is the only parameter measured both in the boreholes and on core samples (Appendix 1). Appendix 1 shows the result of the petrophysical measurements at the NGU petrophysical laboratory. In Figures 32 and 33 the LHKB-1 and LHKB-2 logs are shown including the magnetic susceptibility laboratory measurements (red dots). The main level of the susceptibility is the same for both data sets, even variations in the level correlates well. In some areas the logged susceptibility is measured almost to zero ($< 10^{-4}$ SI) which is not picked up by the laboratory measurements. Because the core samples are taken every tenth meter this is not surprising. The same description can be used for the LHKB-2 logs and laboratory data in Figure 33.

It is difficult to estimate correlation between logged and analysed data because of different sampling intervals.

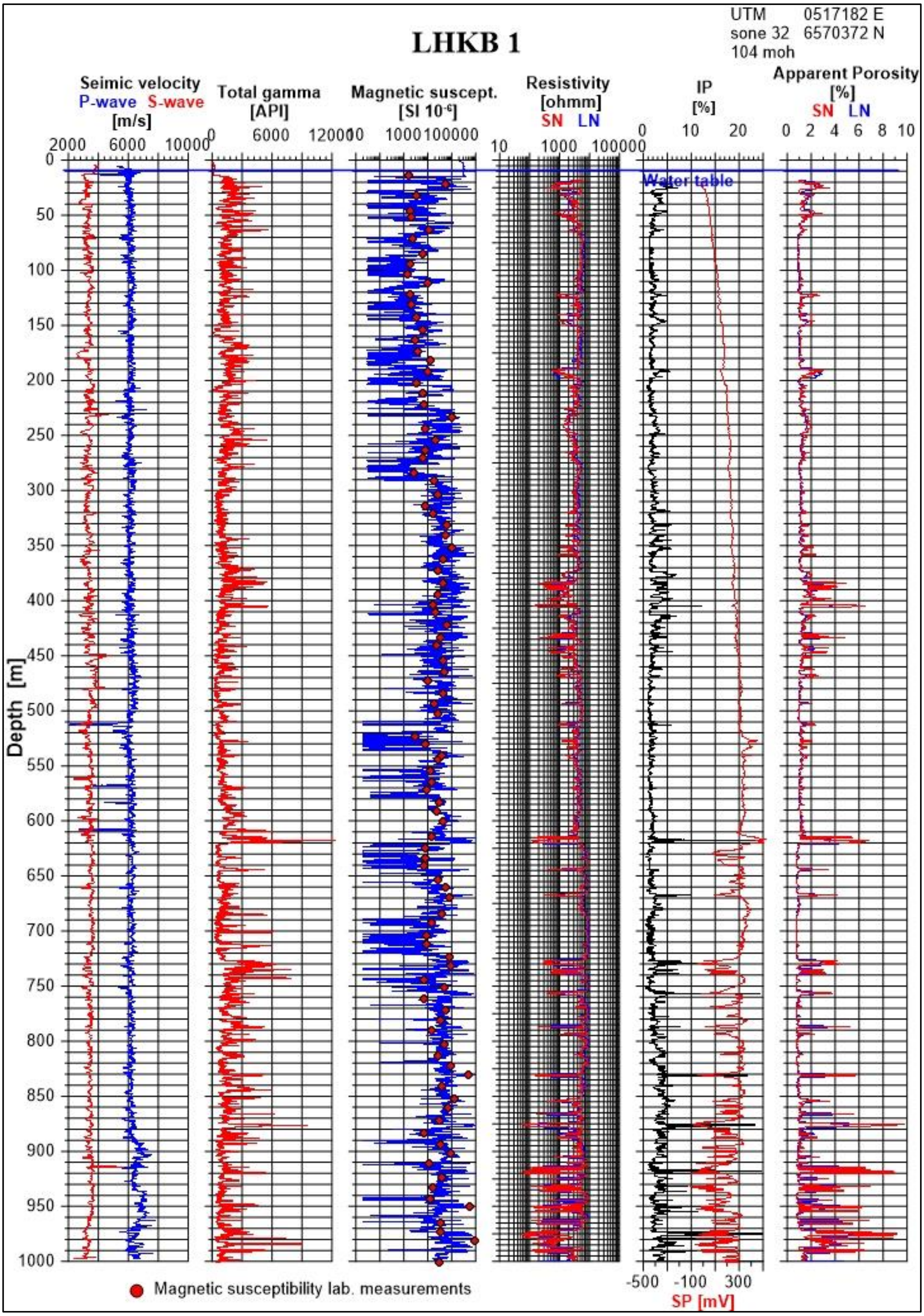


Figure 32. LHKB-1, geophysical logs including magnetic susceptibility from laboratory measurements (red dots).

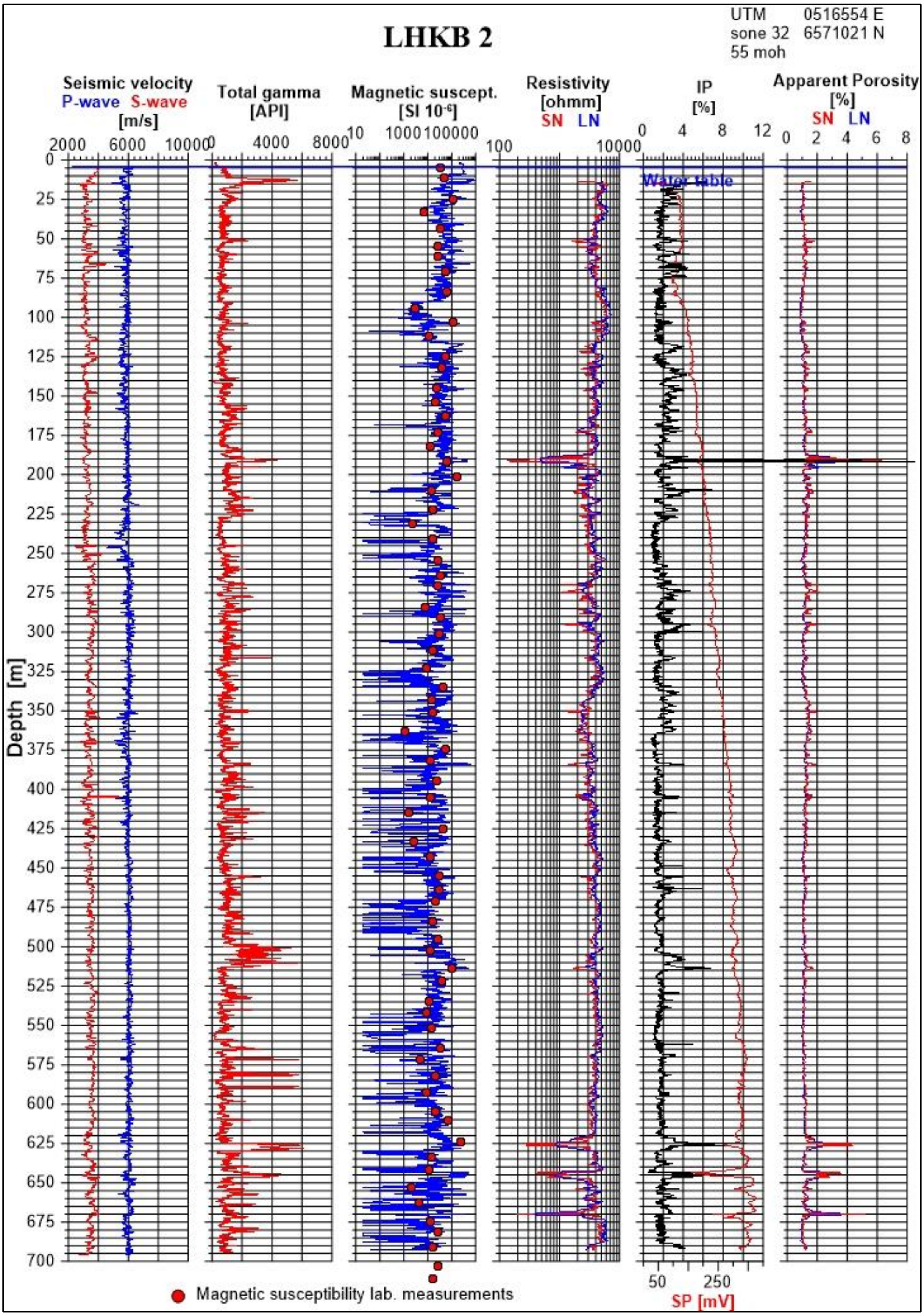


Figure 33. LHKB-2, geophysical logs including magnetic susceptibility from laboratory measurements (red dots).

6.2 Gamma spectral logs and total REE content

In this Chapter we look for any correlation between gamma spectral logs (U and Th) and total REE content.

6.2.1 LHKB-1, spectral logs and REE

In Figure 34 the spectral data of LHKB-1 are resampled to 1 m average value and presented together with the REE analysis. As can be seen the REE total shows high values at several depth: 200, 230, 250, 343, 682, and below 850 m.

It does not seem to be any correlation between U, Th and REE total. The poor correlation is confirmed in Figures 35 and 36 which show correlation calculations between logged and analysed values of U, Th and REE. The “best” correlation is between REE total and chemical analyses of Th, $R^2 = 0.17$. In these calculations values from the entire borehole are used. Selected intervals at specific depth might give other results.

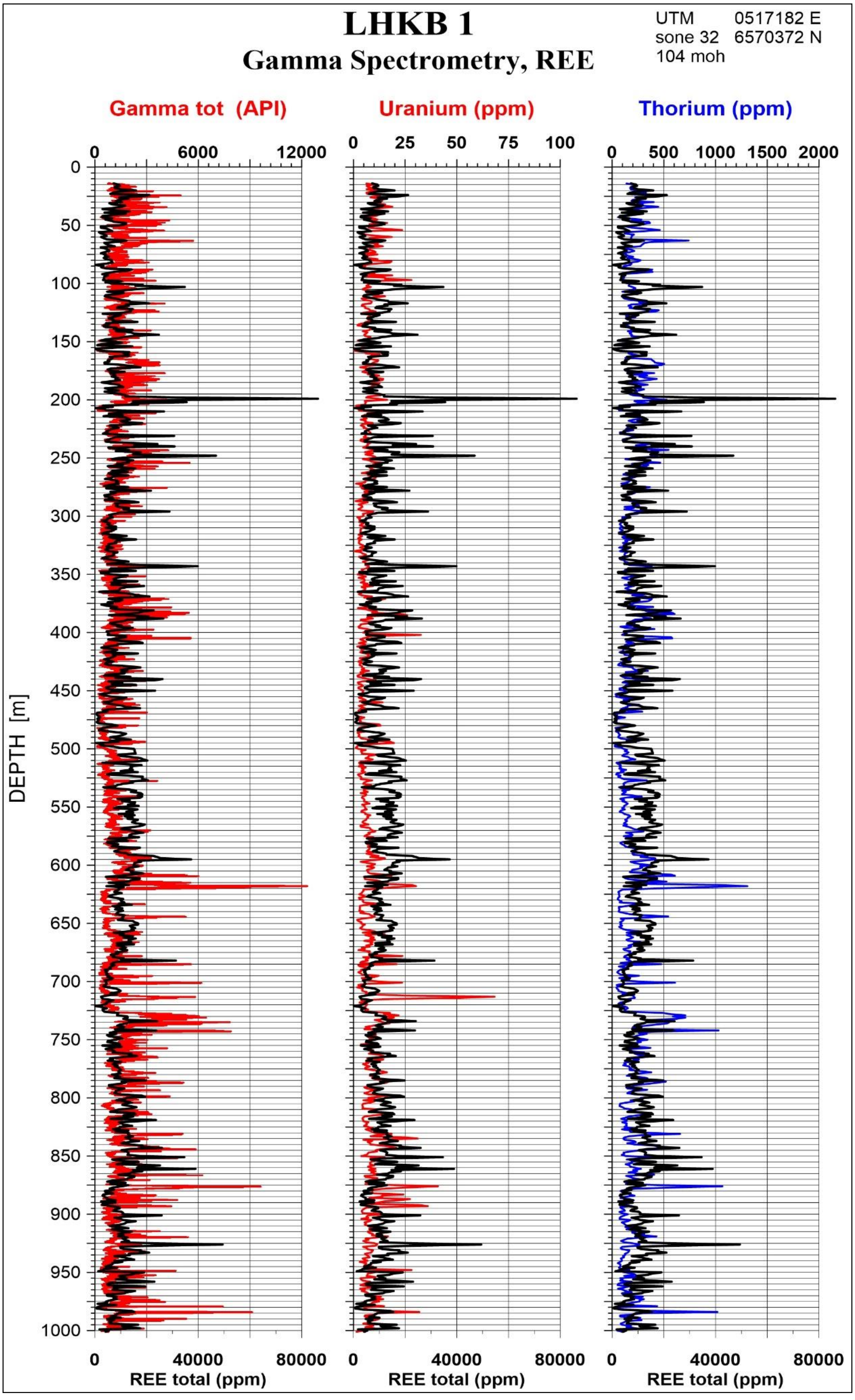


Figure 34. LHKB-1, Gamma spectral logs (U and Th) and total REE analysis (black line). Logging radiometric data are resampled to an average value for each meter.

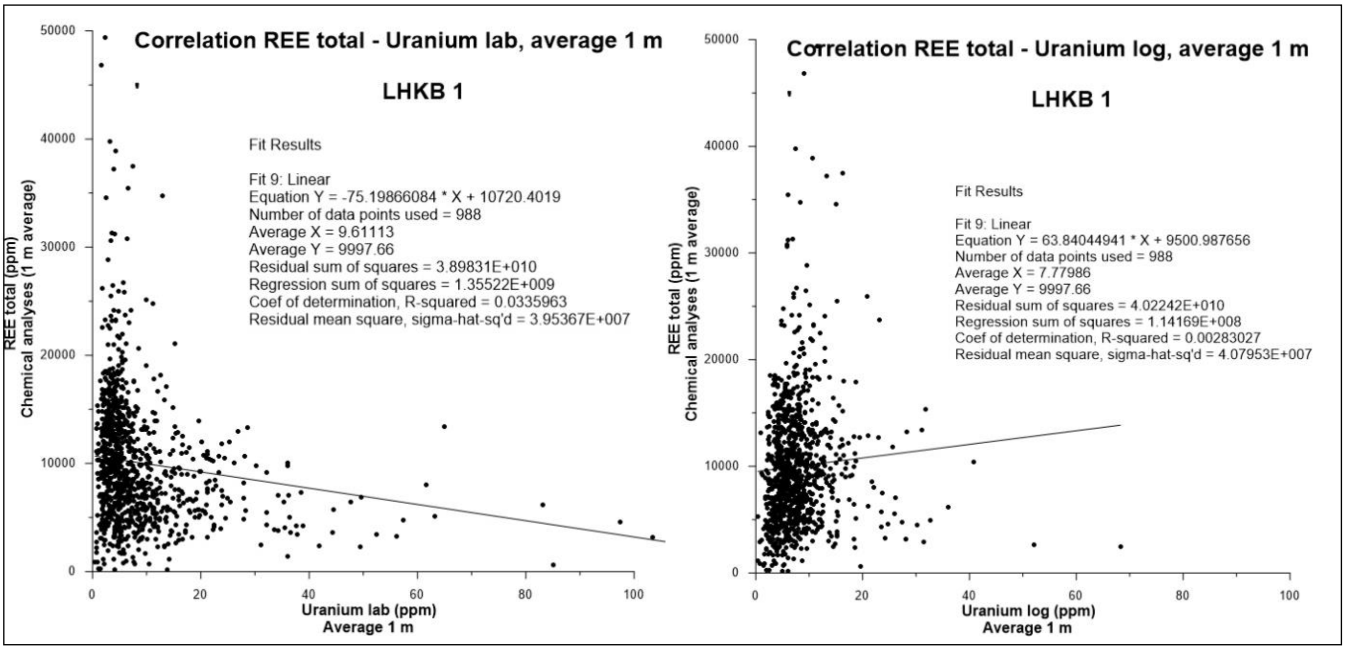


Figure 35. LHKB-1. Correlation between REE and U chemical (left), and U log (right).

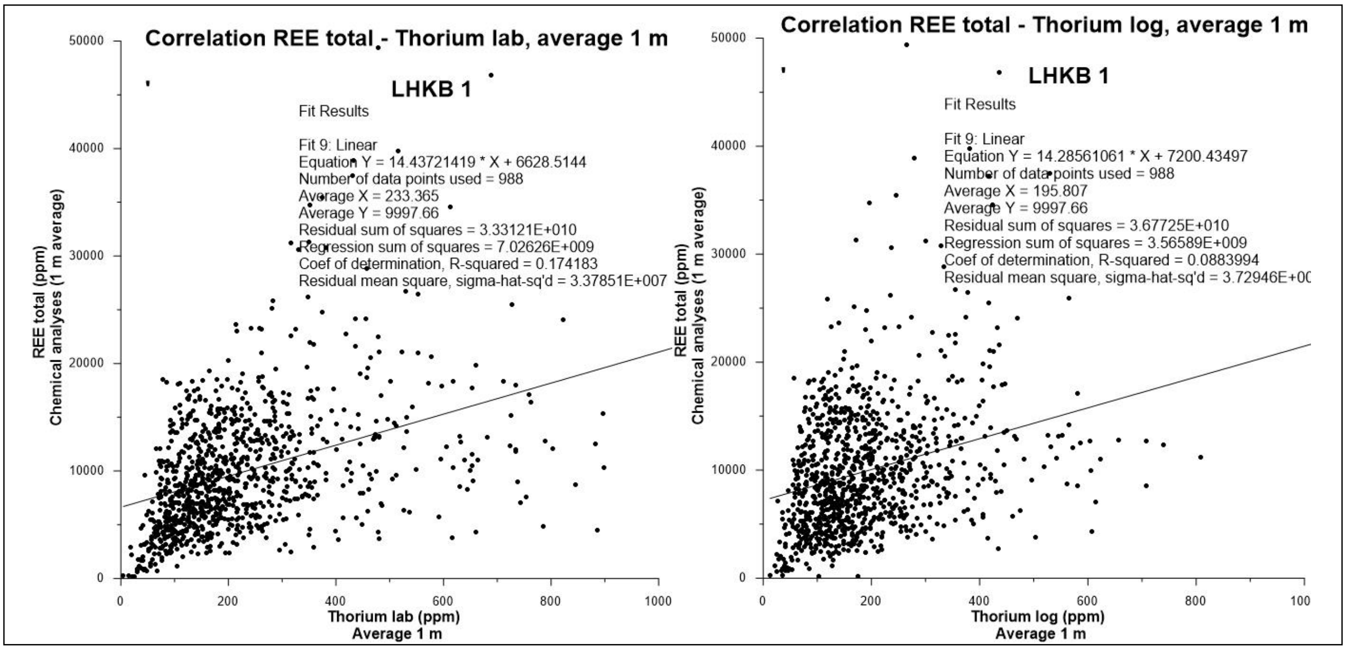


Figure 36. LHKB-1. Correlation between REE and Th chemical (left), and Th log (right).

6.2.2 LHKB-2, spectral logs and REE

In Figure 37 the spectral data of LHKB-2 are resampled to 1 m average value and presented together with the REE analysis. Chemical analyses are missing in the interval 227 m – 250 m and 330 m – 450 m depth.

The upper part at 5 – 225 m depth shows a high level of REE total. Also, in the lower part, 625 – 700 m depth, the REE level is high and the highest level in LHKB-2 is found at 673 m depth.

There is no visible correlation between total REE and high U and Th values. For instance, three zones at 570 – 590 m depth with high U content do not lead to an increase in REE. The bad correlation is confirmed in Figures 38 and 39 which show correlation calculations between logged and analysed values of U, Th and REE. As can be seen, the correlation is poor.

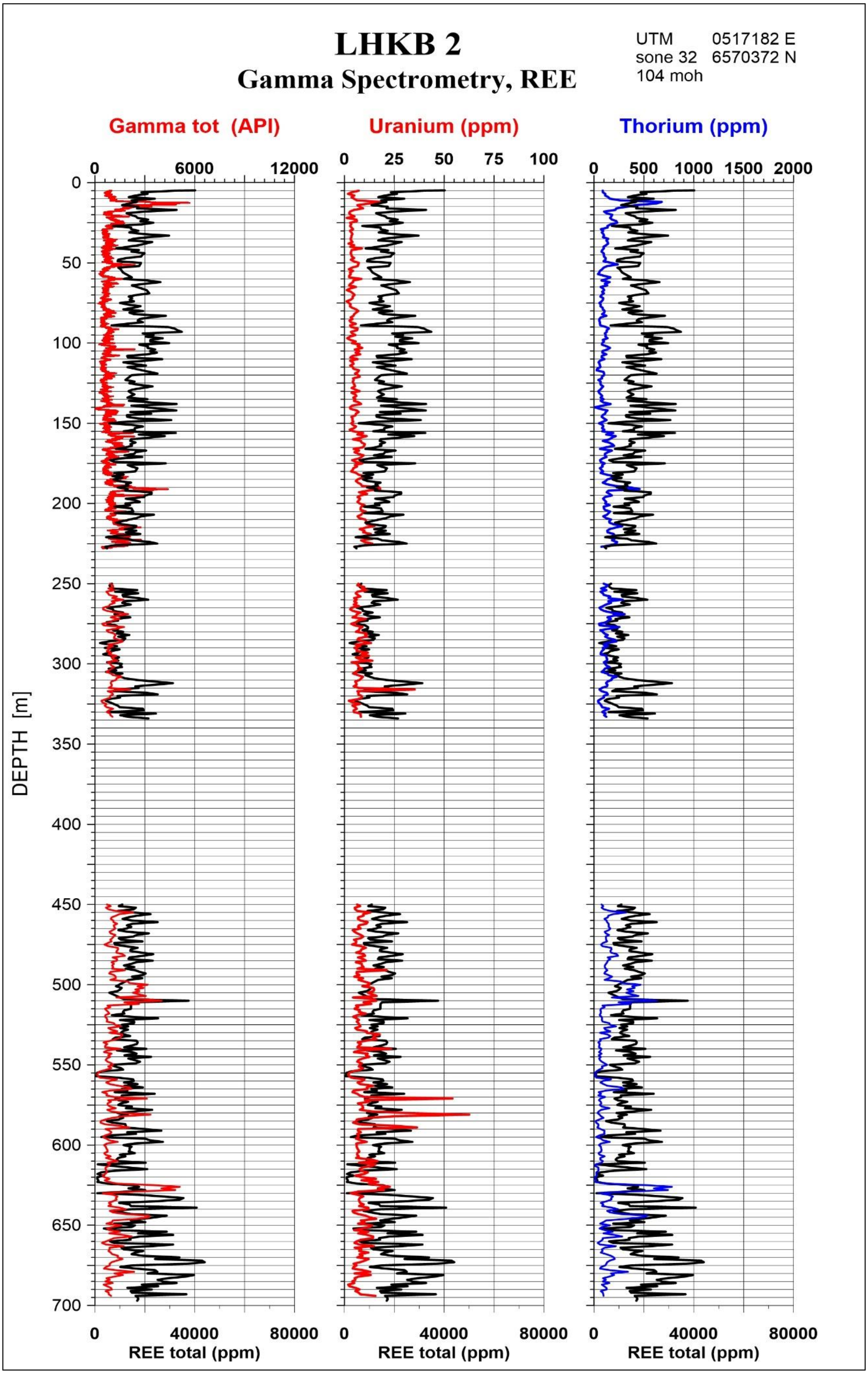


Figure 37. LHKB-2, Gamma spectral logs (U and Th) and total REE analysis (black line). Logging radiometric data are resampled to an average of 100 values for each meter.

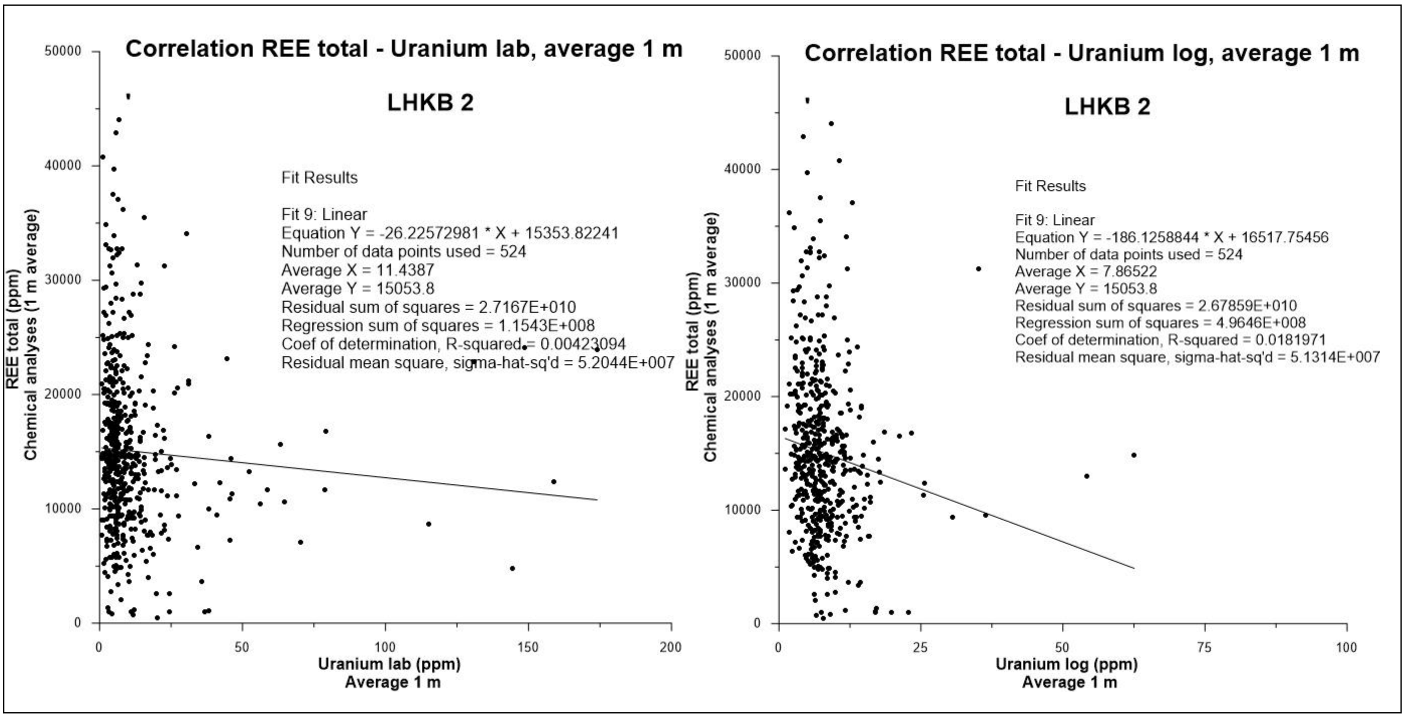


Figure 38. LHKB-2. Correlation between REE and U chemical (left), and U log (right).

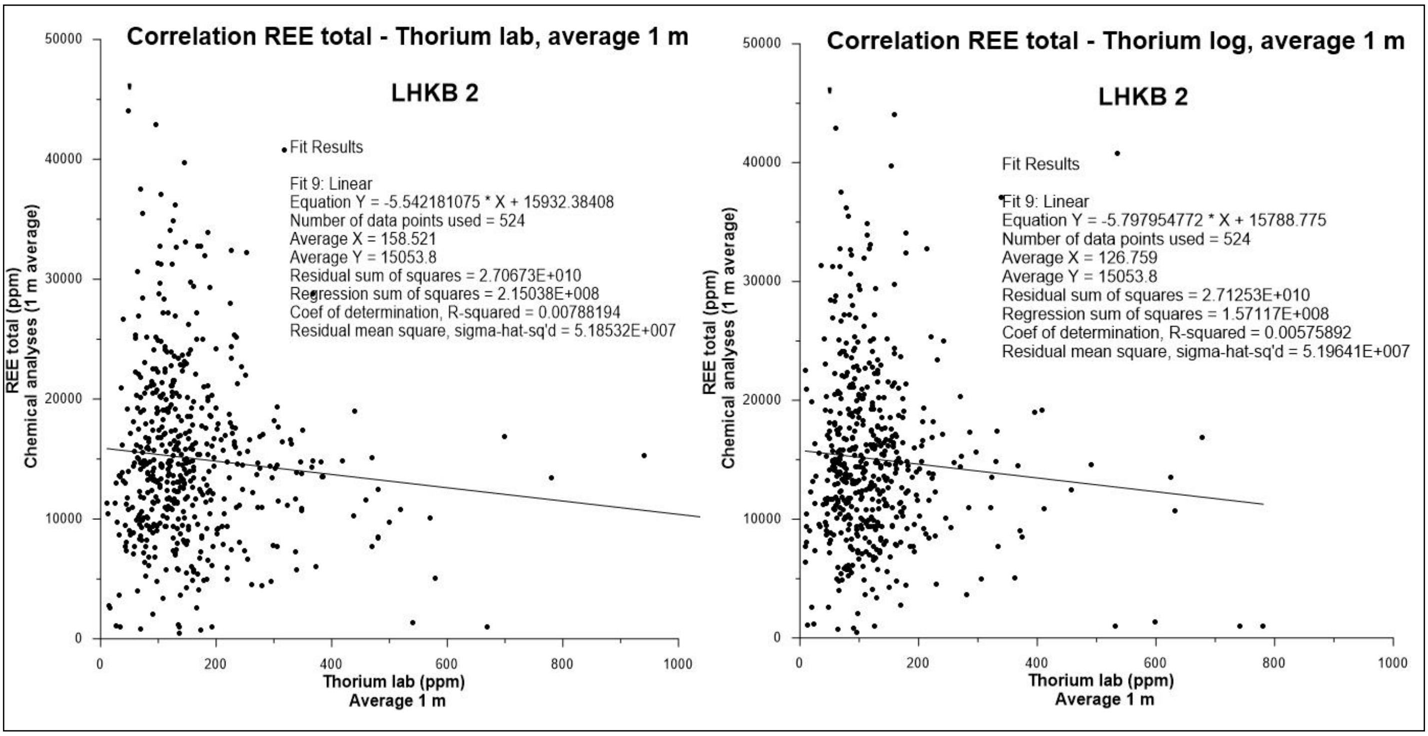


Figure 39. LHKB-2. Correlation between REE and Th chemical (left), and Th log (right).

6.3 **Gamma spectral logs vs. chemical analyses of U and Th**

In this Chapter the gamma spectral logs are compared to chemical analyses of U and Th. As mentioned earlier, the K logs are removed from the logs due to the problems with the Compton effect and counts from the Th-radiation are detected in the K-window.

Figure 40 shows the spectral logs and chemical analyses of U and Th in LHKB-1. The logged data is the average of one meter logging. The chemical analyses are also the average U and Th content of one meter core. The Th logs correlates quite well with the Th-lab (chemical analysis). Observed peaks fit well and the average level is also in the same range. The U-log level is in the same range as U-lab, but the U-lab shows several peaks of high U which are not seen on the logged data.

Figure 41 shows the spectral logs and chemical analyses of U and Th in LHKB-2. The logged data is the average of one meter logging. The chemical analyses are also the average U and Th content of one meter core. There is some correlation between Th-lab and Th-log and the average level is in the same range. The U level is also in the same range. U-lab peaks do not fit with the U-log except between 570 – 590 m depth. At this level three U-log peaks occur at the same location as the U-lab peaks. The U concentrations are, however, much lower in the logged data. There are no Th peaks correlating to these U peaks.

Figures 42 and 43 show the calculated correlations between chemical analyses and logged content of uranium and thorium. The best correlation is between Th-lab and Th-log in LHKB-1. The fitting result shows R^2= 0.69 and the slope is 1.15.
For the U-fitting result the factors are 0.39 and the slope 1.82, see Figure 46.

In LHKB-2 the correlation is less for Thorium, R^2=0.25 and the slope is 0.61. For uranium the correlation is bad except in the three zones at 570 – 590 m depth.

The lack of correlation in uranium data can be explained by the processing problems described earlier (Chapters 6.3 and 6.6). Partly reliable uranium data appears only as high values in depths where the thorium content is low.

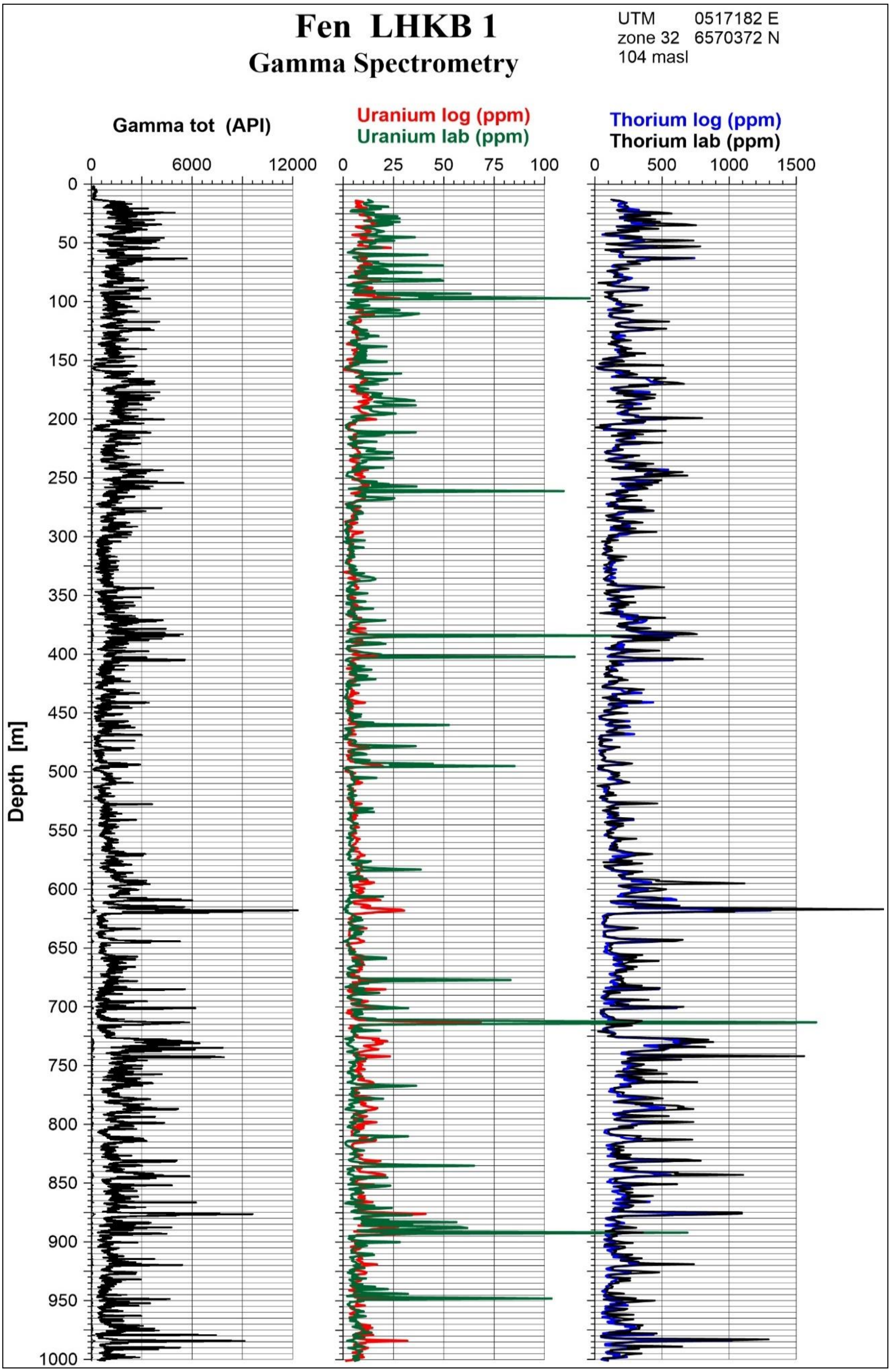


Figure 40. LHKB-1, Gamma spectral logs U and Th and chemical analyses of U and Th.

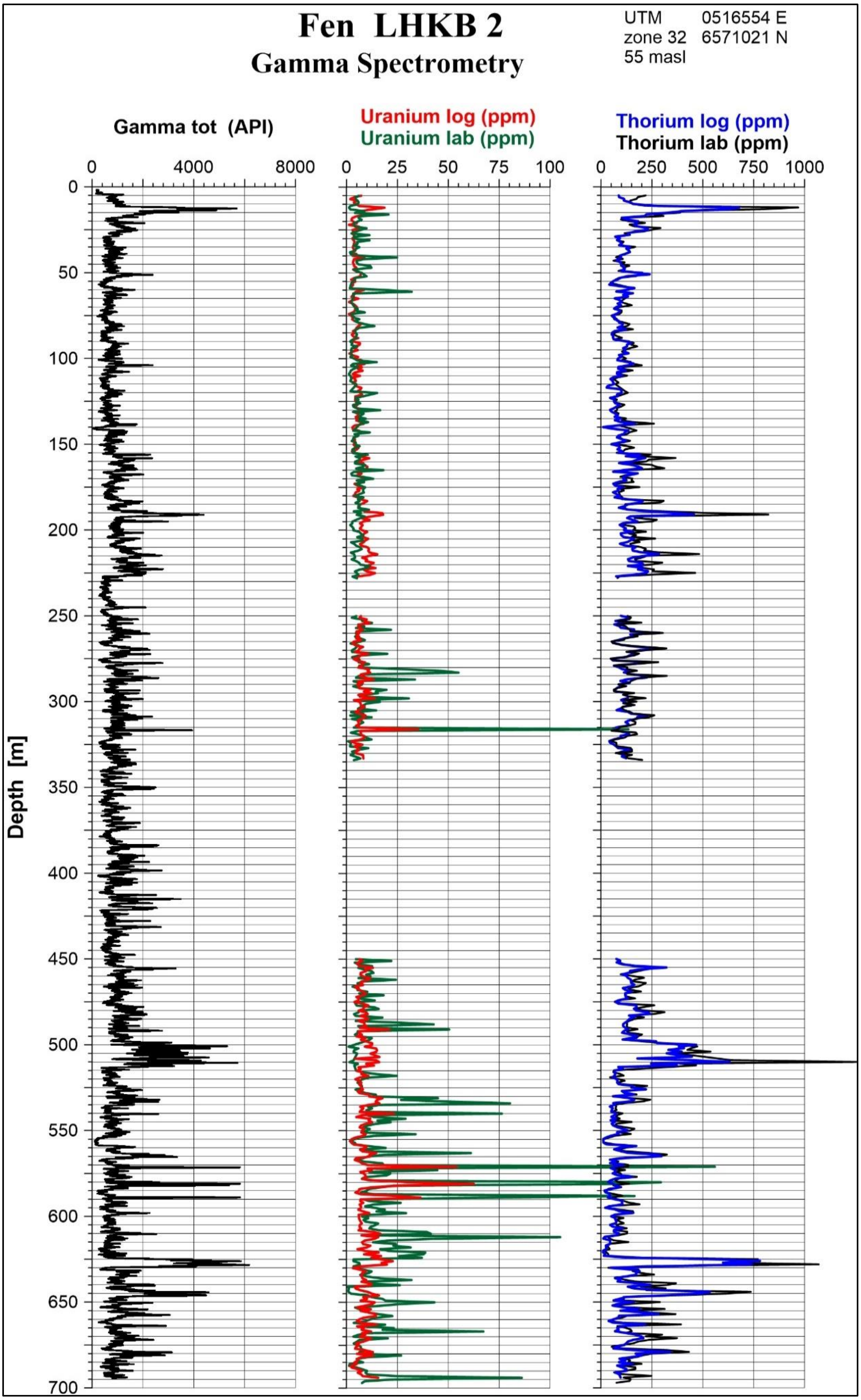


Figure 41. LHKB-2, Total gamma, gamma spectral logs U and Th and chemical analyses of U and Th.

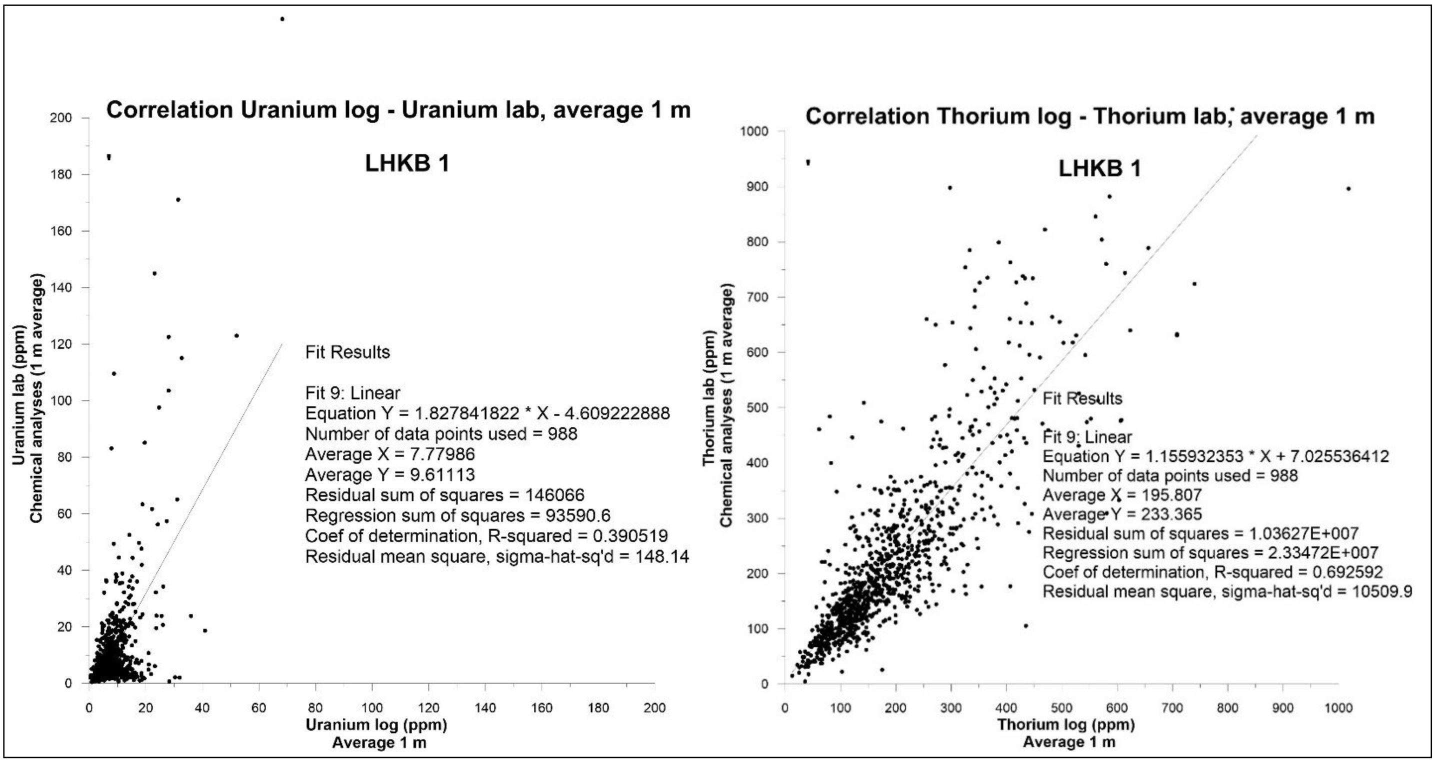


Figure 42. LHKB-1. Correlation between U-lab and U-log (left), and Th-lab-Th-log lab (right).

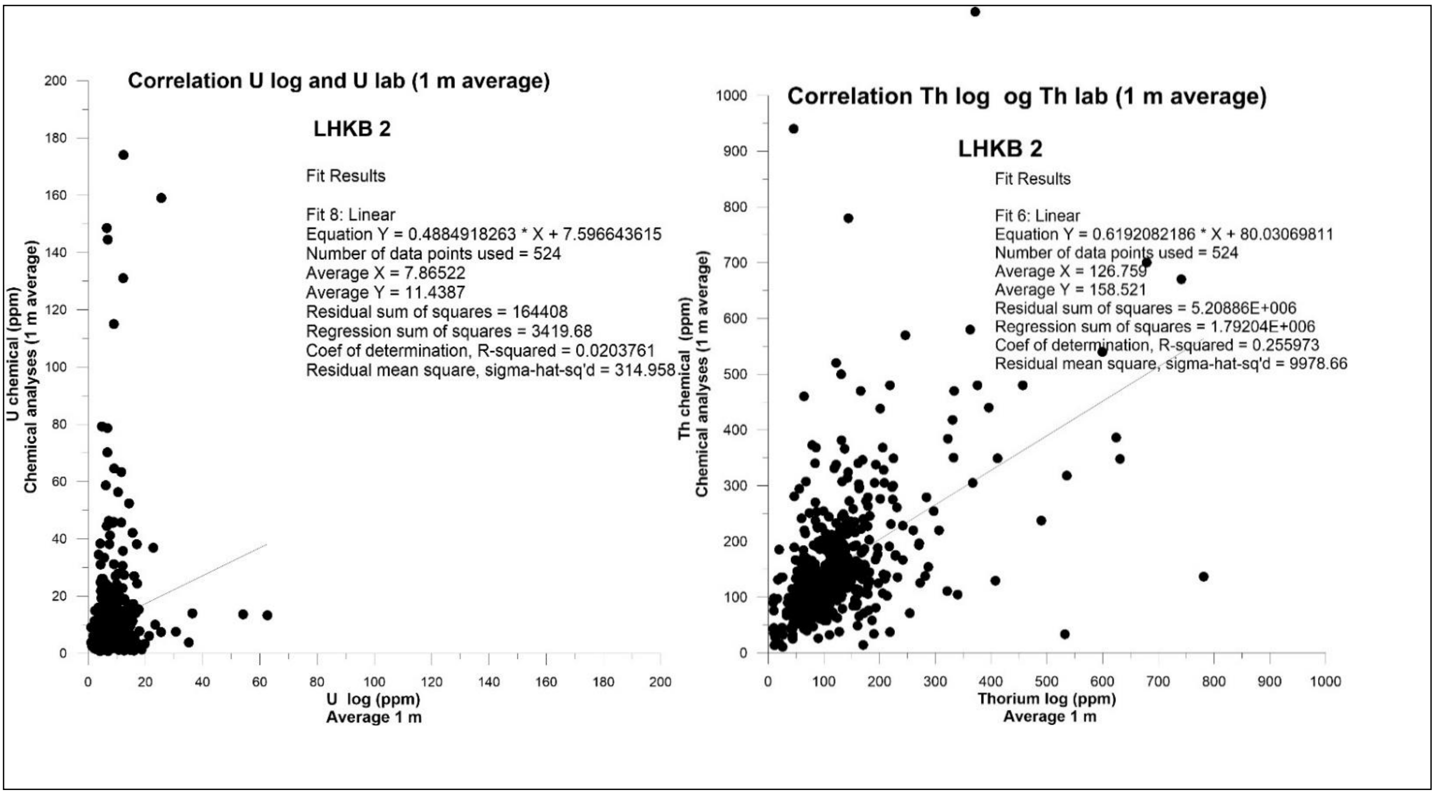


Figure 43. LHKB-2. Correlation between U-lab and U-log (left), and Th-lab and Th-log (right).

6.4 Magnetic susceptibility, IP, SP, resistivity and Fe, S

The geophysical logs indicate several zones with coincident anomalies of resistivity, magnetic susceptibility, IP and SP. Most likely these zones consist of magnetite or sulphides.

In Figure 44 the geophysical logs in LHKB-1 are presented together with the analysed content of Fe and S. Several anomalies occur below 600 and most of them correlate with Fe, marked with grey in Figure 44. Just a couple of zones have coincident geophysical anomalies with both Fe and S, at 920 m and 980 m depth. A zone at 619 m depth has clear low resistivity, magnetic susceptibility, and IP anomalies but no SP. The magnetic susceptibility coincides in all zones with the Fe content, which is not surprising. High S content at 250 m depth does not coincide with any of the geophysical parameters.

Figure 45 shows geophysical logs and content of Fe, S in LHKB-2. Two low resistivity zones between 620 and 670 m depth are indicated by susceptibility, IP and SP. Two of them have enriched content of Fe and S. High S content at 460 m depth is not indicated at geophysical logs and Fe content log. At 11 m depth the magnetic susceptibility is about 0.95 SI which is close to pure magnetite. Fe content is 25% and S content is low. Resistivity, IP and SP measurements start below 10 m depth and will not cover this shallow zone.

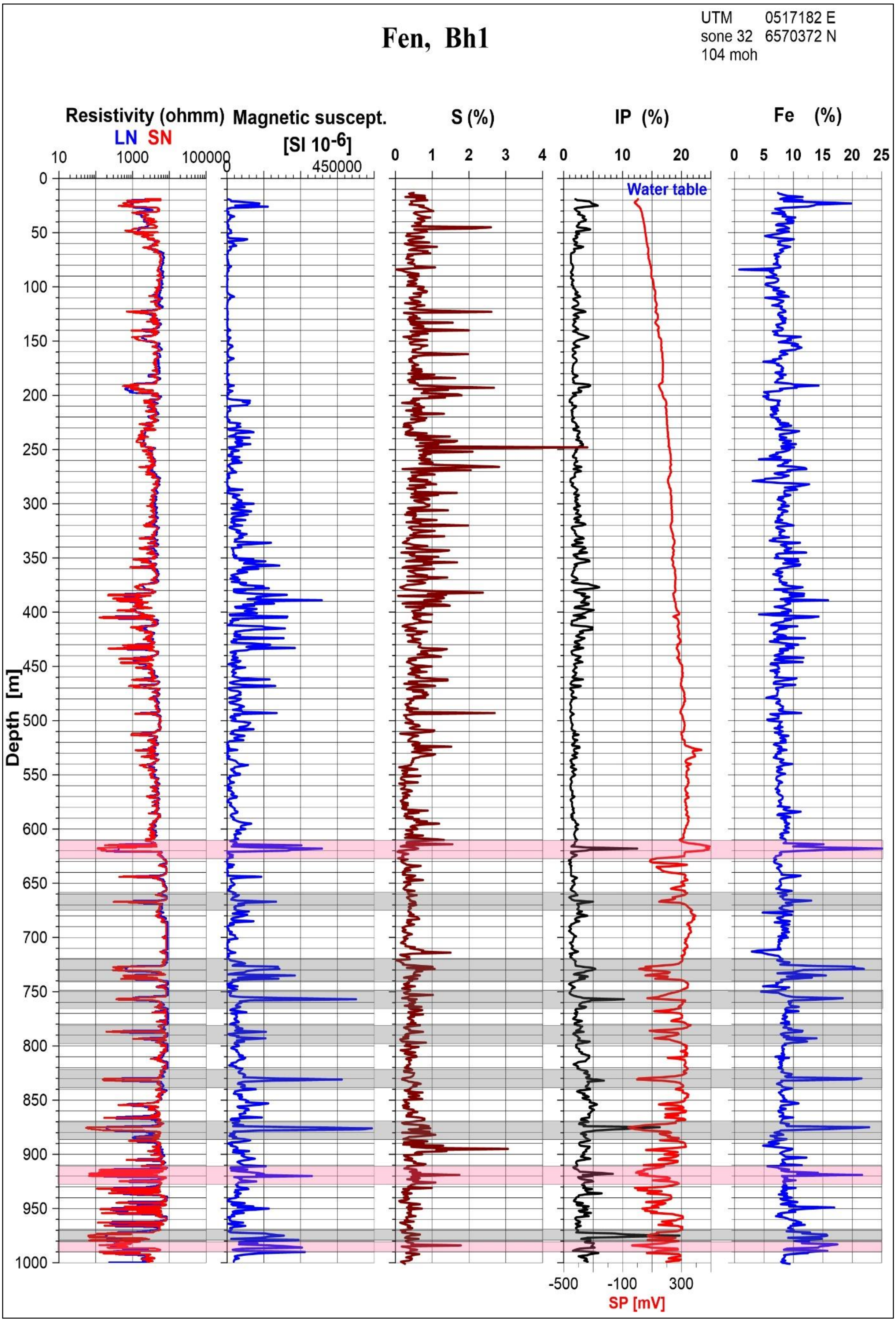


Figure 44. LHKB-1. Geophysical logs, resistivity, magnetic susceptibility, IP, SP and the Fe and S concentrations.

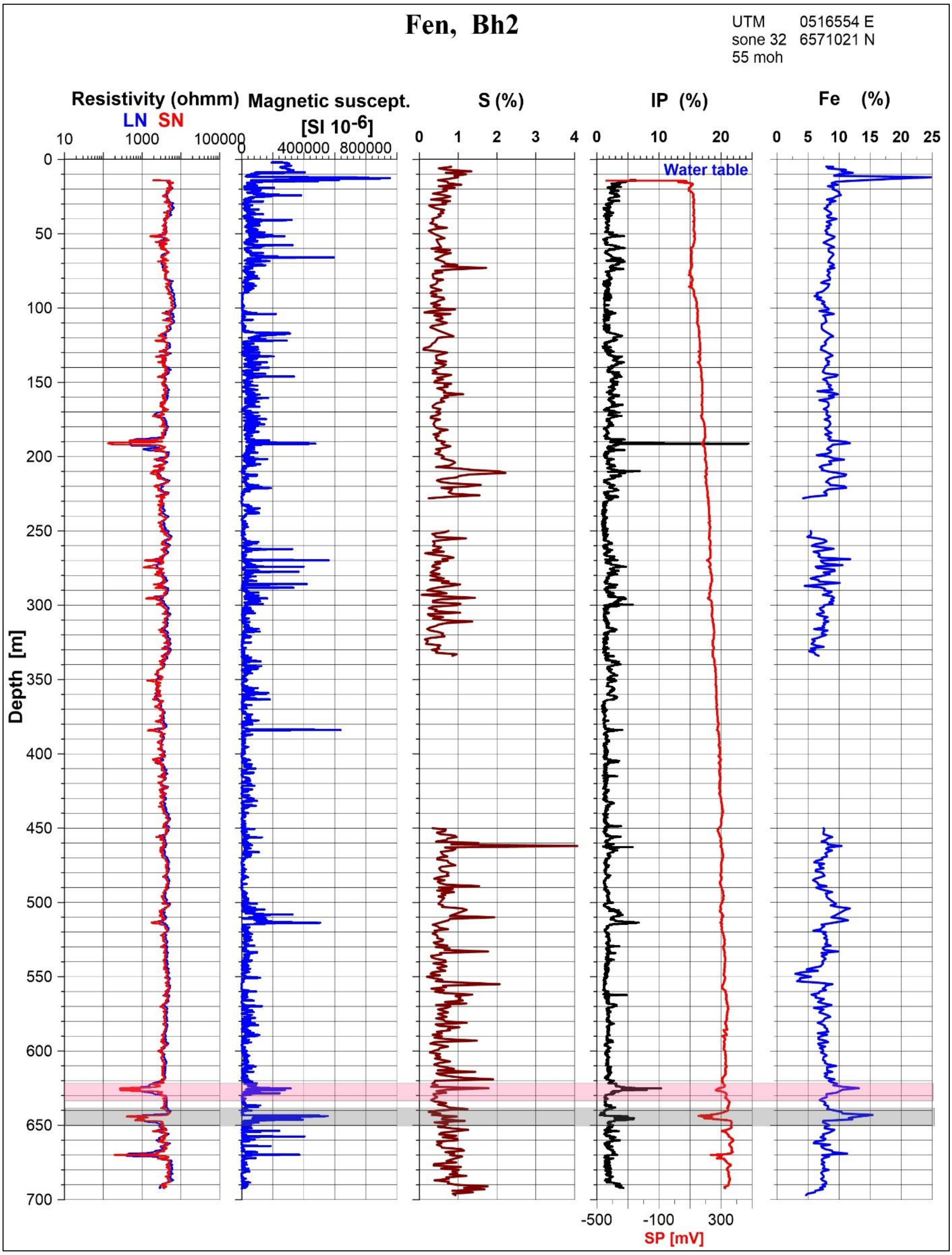


Figure 45. LHKB-2. Geophysical logs, resistivity, magnetic susceptibility, IP, SP and the Fe and S concentrations.

6.5 **Geophysical logs and total REE content**

This Chapter describes if there are any correlations between the different geophysical logs. It also describes possible correlation between the geophysical logs and the total REE content, often described as REE (data).

6.5.1 Geophysical logs and total REE in LHKB-1.

In Figure 46 the total REE analyses from LHKB-1 are presented together with seismic velocities, total gamma, magnetic susceptibility, SP and IP. Plotting the REE data in the resistivity graph was problematic due to logarithmic axes. Most of the anomalies occur below 600 m depth and there are good correlations between the magnetic zones and the electric related anomalies (resistivity, IP, SP). Figure 47 shows the geophysical logs in LHKB-1 below 600 m depth. The yellow marked intervals indicate geophysical anomalies which correlate to each other. At the susceptibility graph the REE curve is marked in black for values above 10,000 ppm. If the black indications are inside the yellow intervals there might be a correlation between the geophysical logs and REE total. Figure 48 shows a more detailed plot of the lower 100 m. High REE values that correlates with geophysical anomalies can be seen at 925, 933, 950 and 984 m depth.

6.5.2 Geophysical logs and total REE in LHKB-2.

In Figure 48, the total REE analysis from LHKB-2 are presented together with seismic velocities, total gamma, magnetic susceptibility, SP and IP. There are few clear anomalies related to resistivity, IP and magnetic susceptibility in LHKB-2. Correlations between these parameters can be seen at 625, 645 and 670 m depth as shown in yellow intervals in Figure 49. A weak double SP anomaly can be seen at 645 m. In these four zones, REE content correlates with the zone at 645 m and partly at 625 and 670 m depth. The highest REE zones do not correlate with magnetic susceptibility, IP, SP and resistivity.

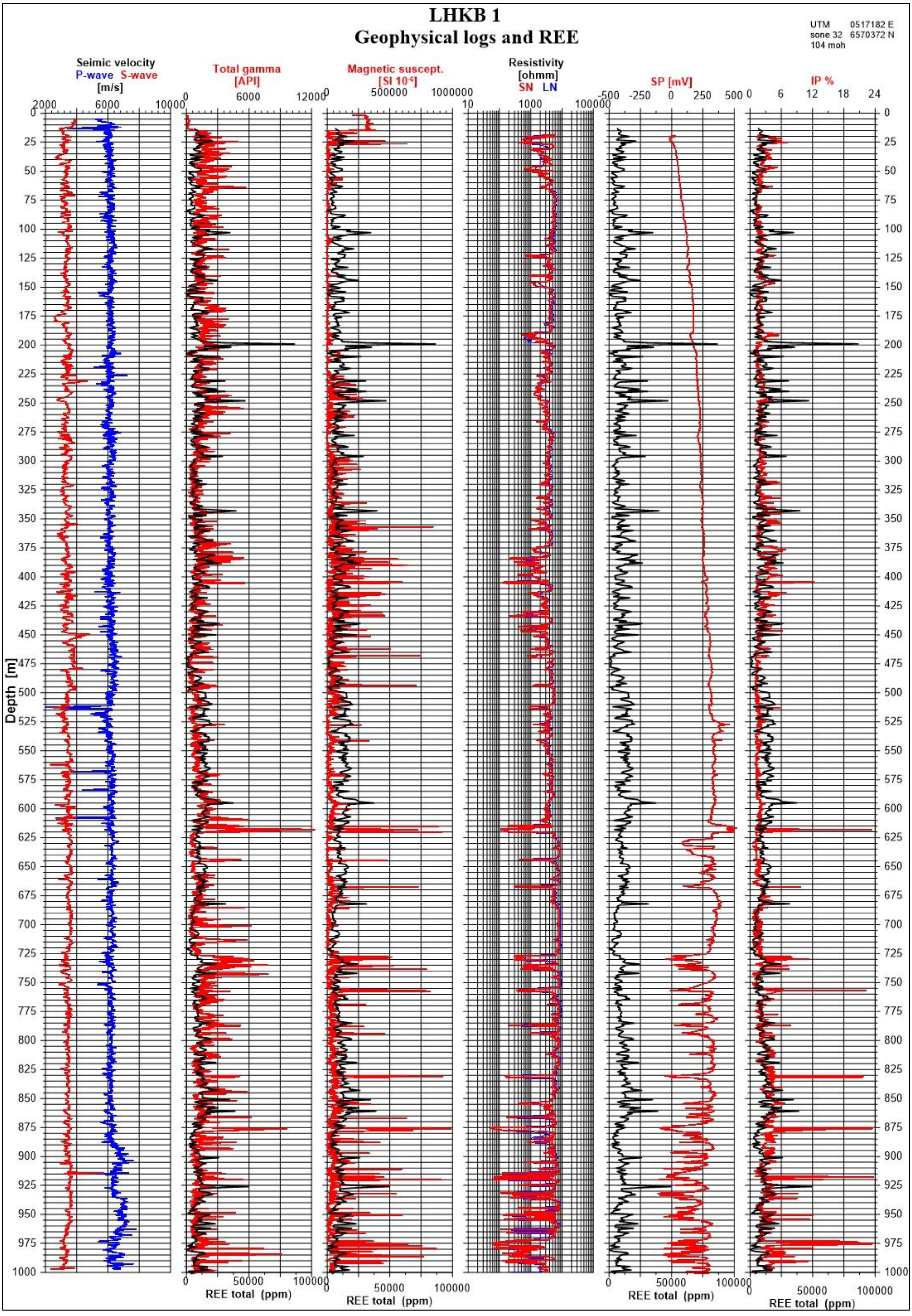


Figure 46. LHKB-1. Geophysical logs and total REE content (black curve).

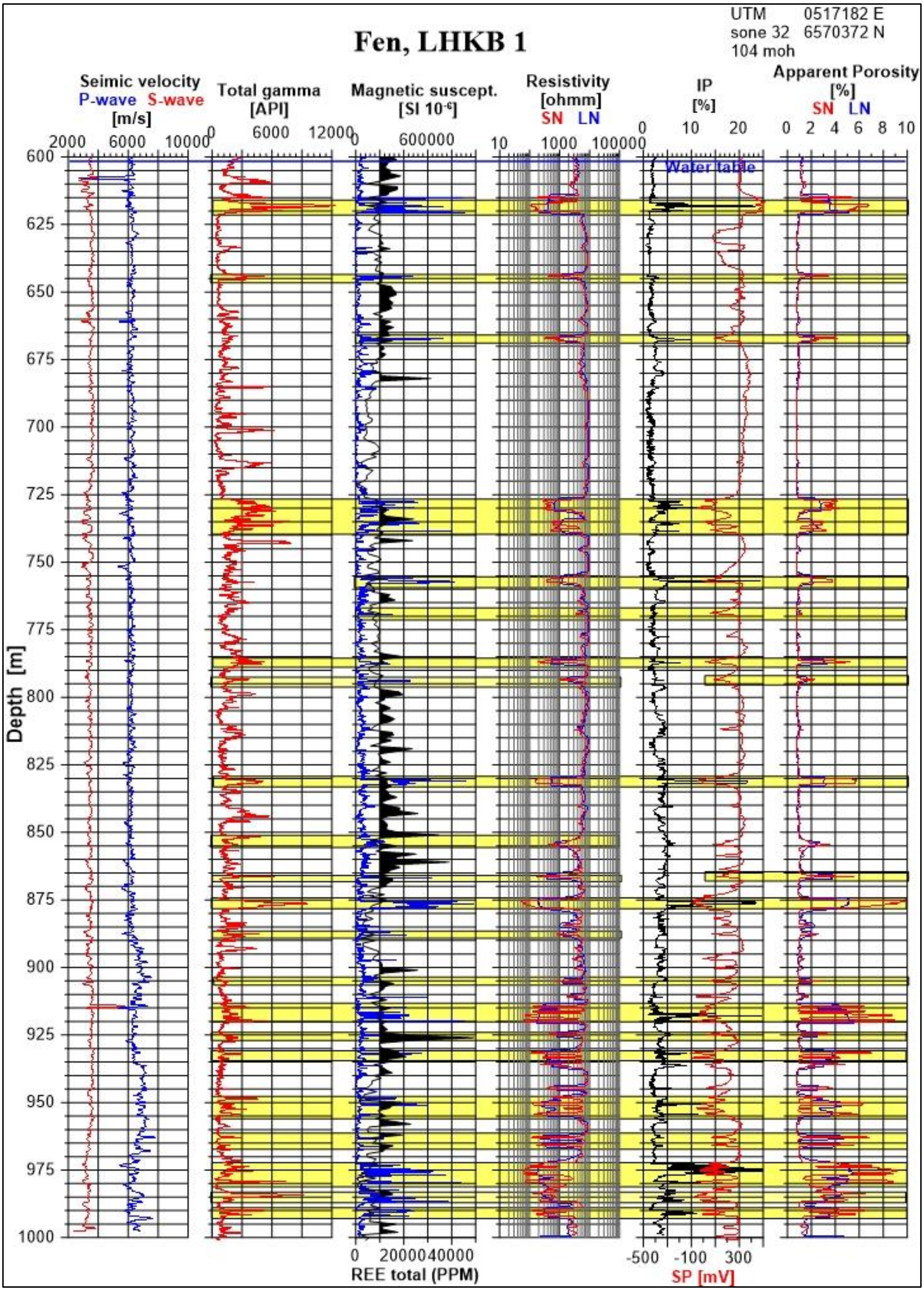


Figure 47. LHKB-1, 600 -1000 m, Correlation between geophysical logs and total REE content.

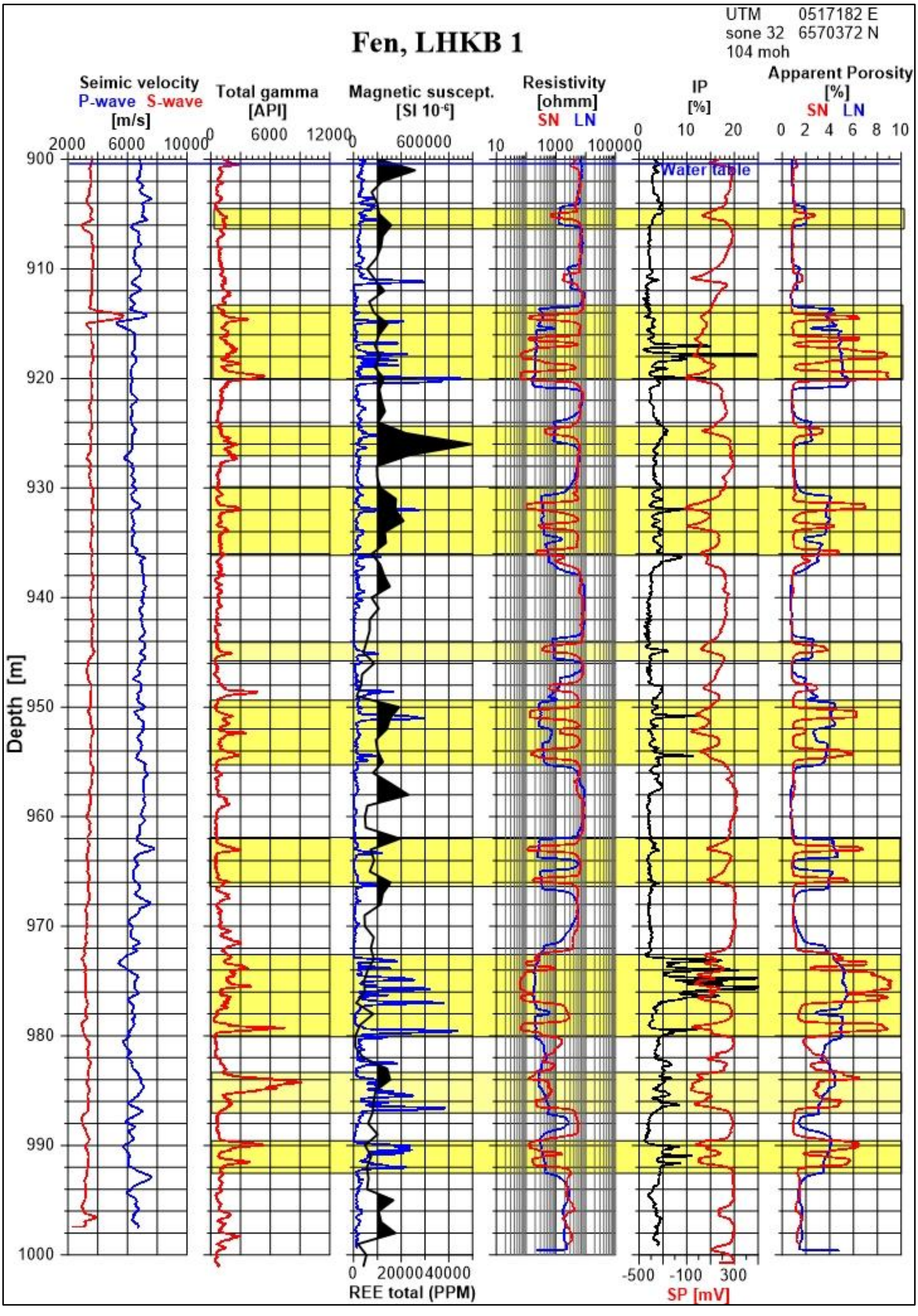


Figure 48. LHKB-1, 900 -1000 m, Correlation between geophysical logs and total REE content.

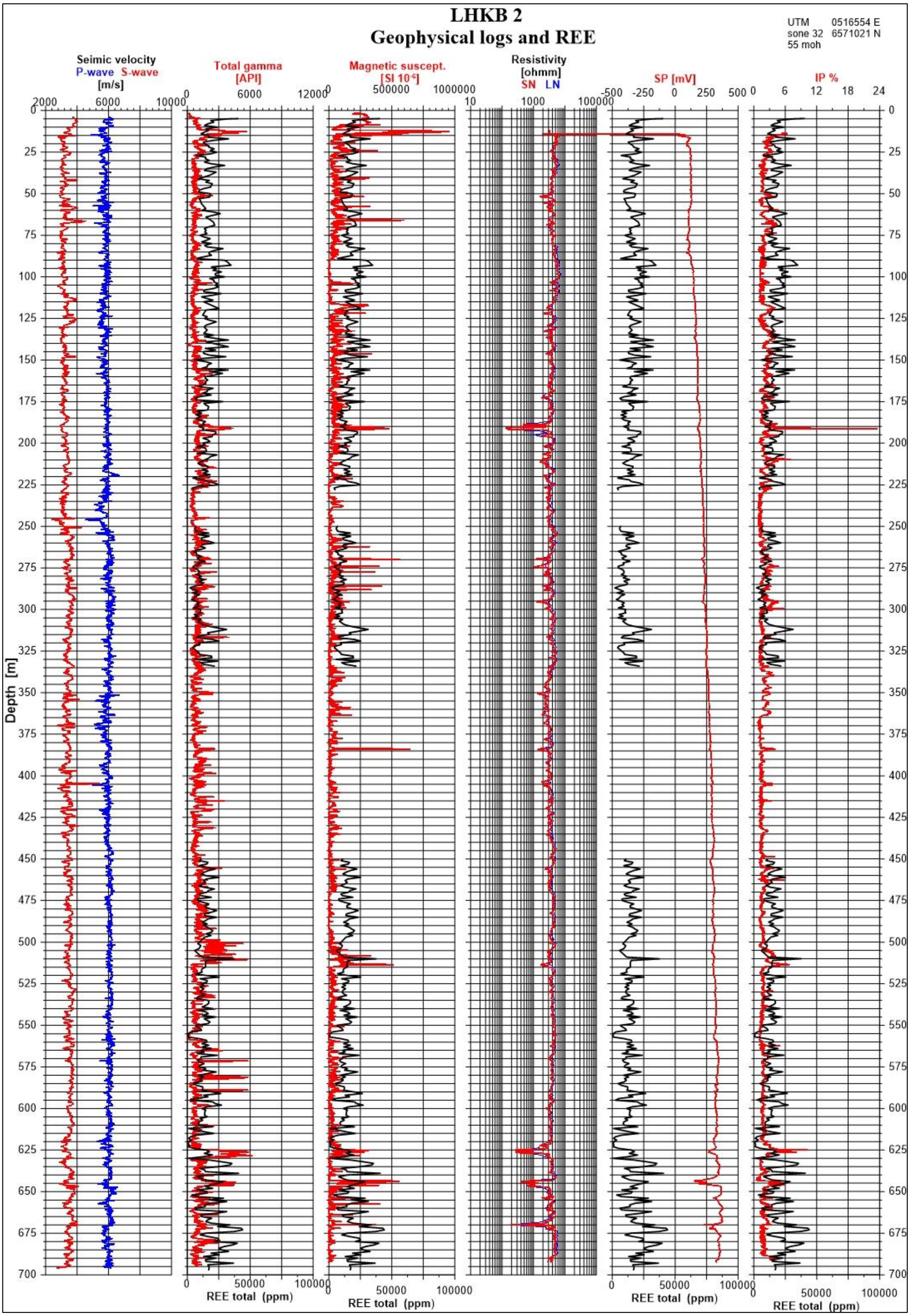


Figure 49. LHKB-2. Geophysical logs and total REE content (black curve).

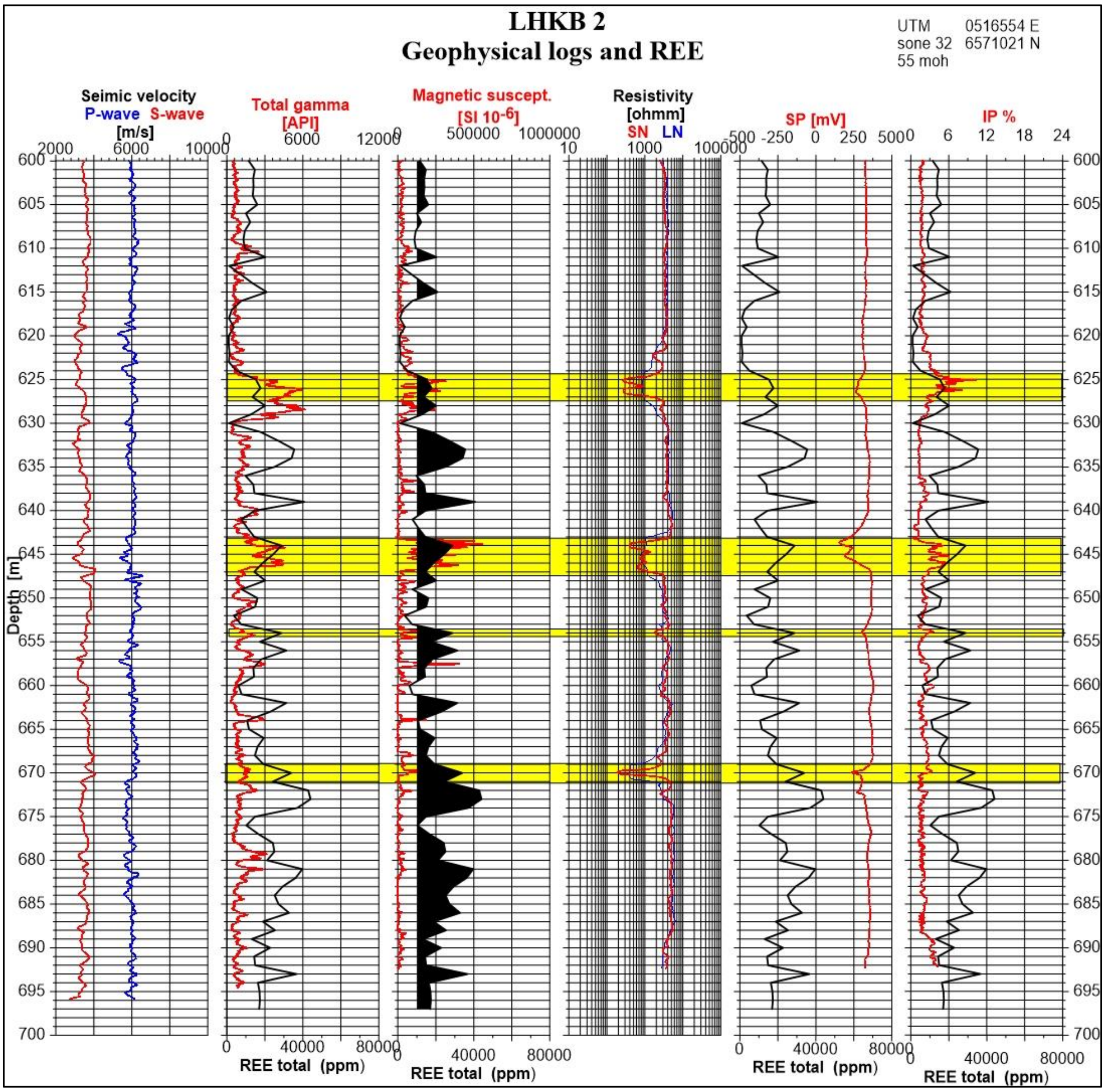


Figure 50. LHKB-2, 600 -700 m, Correlation between geophysical logs and total REE content.

7. DISCUSSION

The goal for the geophysical logging at Fen was to map the content of radioactive elements in two deep boreholes continuous from the surface to the depth of 1000 m. In addition, all geophysical parameters like resistivity, seismic velocity, magnetic susceptibility, Induced Polarization and Self Potential should be measured to support the drill core analysis.

Correlation of REE /Uranium(log) and REE/Thorium(log) seem to be negative. In this calculation the average total REE content in one-meter core length is used. The logging data are resampled to the average value for each meter. This is shown in figures 35, 36, 38 and 39.

In Table 5 the average and maximum logged content of U and Th are shown. Chemical average analyses of U and Th are also shown. The logged U content in LHKB-1 at 600 – 1000 m depth is similar to the chemical analyses. In general, the lab data are a bit higher. This is also true for the Th element. Also, in LHKB-2 the lab data are a bit higher than the logged data both for the average and maximum values.

Table 5. Average and maximum content of logged and laboratory analyses of U and Th in LHKB-1 and LHKB-2.

LHKB-1	Gamma total aver.	Uranium average	Uranium maximum	Thorium average	Thorium maximum
Log 0 - 600	1300 cps	6.7 ppm	60 ppm	185 ppm	993 ppm
Log 600 - 1000	1600 cps	9.2 ppm	87 ppm	206 ppm	1950 ppm
Log 0 - 1000	1400 cps	7.2 ppm	87 ppm	194 ppm	1950 ppm
Lab 0 -1000	-	9.5 ppm	249 ppm	230 ppm	1780 ppm

LHKB-2	Gamma total aver.	Uranium average	Uranium maximum	Thorium average	Thorium maximum
Log 0 - 450	940 cps	7.1 ppm	67 ppm	109 ppm	911 ppm
Log 450 - 695	1200 cps	9.5 ppm	109 ppm	134 ppm	908 ppm
Log 0 - 695	1030 cps	7.9 ppm	109 ppm	118 ppm	911 ppm
Lab 0 - 695	-	11.5 ppm	174 ppm	158 ppm	1150 ppm

The average Th content is highest in LHKB-1, see Table 6. From the logs, the deepest part of LHKB-1 has the highest Th content (206 ppm).

The highest average REE content is in the upper and lower part of LHKB-2. The Th content is lower in LHKB-2 even if the REE content is higher. The average U content is about the same in both boreholes.

Table 6. Average content of total REE and logged U, Th in LHKB-1 and LHKB-2.

LHKB-1	**REE total (ppm)**	**Uranium (ppm)**	**Thorium (ppm)**
0 – 600 m	9815	6.7	185
600 – 1000 m	10215	9.2	206
0 – 1000 m	9994	7.2	194
LHKB-2			
0 – 228 m	16900	5.9	122
250 – 334 m	10818	7.3	120
450 – 697 m	15182	9.5	134
0 – 697 m	15168	7.9	118

The correlation between Th log and Th chemical analyses in LHKB-1 is quite good, see Figure 42. The fitting result shows R^2= 0.69 and the slope is 1.15. The logged data is a bit lower than the lab data. The problem with the Compton effect and bad stripping might be the reason. This is discussed earlier. The distribution of U and Th (Nugget-effect) might be another reason. Attenuation of the radiation in water due to the borehole diameter may also influence.

The fitting result for uranium logs LHKB-1 is R^2= 0.39 and the slope is 1.82, see Figure 42. The bad stripping coefficients make a bigger influence on this element. For the same reason the K data set was skipped in this report.

The logs of magnetic susceptibility, resistivity, IP and SP often correlate in both boreholes. This is because of the presence of conductive minerals, magnetite and sulphides. In some cases, the REE minerals occur in conductive zones as shown in Figures 47, 48 and 50. The same figures also show that high total gamma radiation in some cases occurs in the conductive zones. This means that U and Th occur in some of these zones.

It is difficult to calculate the correlation of magnetic susceptibility between logged and analysed data because of different sampling intervals.

8. CONCLUSION

NGU has performed geophysical logging in two deep boreholes at the Fen complex in Ulefoss, Vestfold and Telemark county. The boreholes were 1000 and 716 m deep drilled in the carbonate volcano. The purpose was to get petrophysical data for this very unusual carbonatite volcanic rock and to see if there are any correlation between REE content and petrophysical data. Temperature data was also of interest.

Logging parameters were temperature, electric conductivity of water, gamma radiation, spectral gamma (U and Th) seismic velocities (P- and S-wave), resistivity, IP, SP and magnetic susceptibility. Acoustic televiewer was used to map fractures and borehole deviation.

The REE content was found by chemical analyses (Coint & Dahlgren 2019).

The logging data shows that there is no correlation between REE and geophysical logging parameters. In some cases, REE correlates to U and Th, and in some cases to the electrical parameters. But there is no linearity in the content of REE and the content of U and Th found by the geophysical logging.

The seismic P-wave velocity is high (≈ 6000 m/s in rauhaugite) and shows only small variations. Some fracture zones were found, the one to mention is a 1.5 m wide facture zone (open cavity) at 512 m depth in LHKB-1. Rock fall from this fracture blocked the borehole and stopped the logging. The borehole was reopened by the drilling company.

The resistivity is in general quite high, 3,000 – 5,000 ohmm in the carbonatite rocks (some higher in the lower part of LHKB-1). IP and SP indicate several zones of electric conductive minerals such as sulphides and/or magnetite. Magnetite gives high magnetic susceptibility in some of these zones.

Acoustic televiewer logging shows that there is no specific main fracture group (main strike/dip) in LHKB-1. In LHKB-2 the trend is a SE – SW azimuth of the fractures. Most of the fractures are dipping steeply, > 50 ^{o}.

9. REFERENCES

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Appendix 1: Petrophysical properties on samples from LHKB-1 and LHKB-2.

Volume (cm^3), Density (g/cm^3), Porosity (cm^3), Porosity (%), Magnetic susceptibility (10^{-6} SI), Remanent magnetisation (mA/M), Heat conductivity, k (W/mK) and heat capacity, Cp (J/kgK).

Sample no. (NGU nr.) 191301 to 191397 and 77251 to 77253 are from LHKB-1.
Sample no. (NGU nr.) 77255 to 773000 and 191401 – 191425 are from LHKB-2.

Sample ID (Prøve ID) represent core depth (from – to) in LHKB-1 and LHKB-2.

NORGES GEOLOGISKE UNDERSØKELSE
- NGU -
7491 TRONDHEIM
Tlf.: 73 90 40 00
E-post: lab@ngu.no

Bestemmelse av petrofysiske parametre
GEOLOGISK MATERIALE
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NGU nr.	Prøve ID	Kartblad	UTM Zone	UTM X	UTM Y	LitoKode	METKode	StratKode	Prøvebeskrivelse
191301	14,00-14,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191302	22,42-22,67		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191303	32,69-32,90		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191304	43,16-43,35		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191305	52,00-52,19		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191306	63,00-63,15		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191307	71,00-71,15		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191308	84,80-85,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191309	94,80-95,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191310	103,85-104,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191311	111,62-111,78		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191312	122,00-122,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191313	131,07-131,24		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191314	143,08-143,24		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191315	154,00-154,16		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191316	163,00-163,17		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191317	173,87-174,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191318	181,46-181,61		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191319	192,08-192,21		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191320	202,58-202,75		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191321	212,00-212,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191322	222,88-223,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191323	233,00-233,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191324	243,87-244,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191325	254,17-254,35		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191326	264,00-264,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191327	270,00-270,16		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191328	283,84-284,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191329	291,44-291,63		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191330	303,86-304,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191331	313,80-313,95		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191332	321,00-321,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191333	331,65-331,82		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt

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- NGU -
7491 TRONDHEIM
Tlf.: 73 90 40 00
E-post: lab@ngu.no

Bestemmelse av petrofysiske parametre
GEOLOGISK MATERIALE
Analysekontraktnr. 2018.0154

NGU nr.	Prøve ID	Volum (cm^3)	Tetthet (g/cm^3)	Porevolum (cm^3)	Porøsitet (%)	Susceptibilitet (10^{-6} SI)	Remanens (mA/M)	Varmeledningsevne, k (W/mK)	Spesifikk varmekapasitet, c_p (J/kgK)
191301	14,00-14,20	269.25	2.98	1.05	<0.01	1621	9	4.02	749
191302	22,42-22,67	307.22	3.18	7.31	0.02	54155	337	4.94	735
191303	32,69-32,90	286.32	3.01	1.00	<0.01	3324	26	4.15	747
191304	43,16-43,35	285.81	2.97	0.58	<0.01	1771	4	3.95	749
191305	52,00-52,19	273.69	3.03	1.00	<0.01	2150	10	3.44	713
191306	63,00-63,15	264.01	3.09	0.69	<0.01	11121	48	3.51	702
191307	71,00-71,15	261.43	3.03	0.89	<0.01	2217	6	2.66	680
191308	84,80-85,00	274.59	2.98	0.65	<0.01	6053	17	3.92	746
191309	94,80-95,00	311.01	2.99	0.39	<0.01	1829	8	4.18	753
191310	103,85-104,00	260.17	3.19	0.52	<0.01	1507	11	2.84	653
191311	111,62-111,78	247.87	2.93	1.19	<0.01	9736	30	3.68	748
191312	122,00-122,20	299.44	3.00	1.14	<0.01	1735	4	3.78	735
191313	131,07-131,24	275.54	3.00	0.57	<0.01	1997	8	3.87	739
191314	143,08-143,24	244.72	2.99	0.84	<0.01	3255	23	3.78	737
191315	154,00-154,16	249.94	2.97	0.69	<0.01	5971	39	4.10	755
191316	163,00-163,17	259.43	3.00	0.71	<0.01	3093	11	3.97	742
191317	173,87-174,00	245.51	3.03	0.34	<0.01	3929	25	3.99	736
191318	181,46-181,61	240.10	2.99	0.51	<0.01	12495	102	3.45	723
191319	192,08-192,21	235.88	3.19	0.78	<0.01	10637	104	3.72	689
191320	202,58-202,75	259.76	3.16	1.43	<0.01	3325	8	3.60	690
191321	212,00-212,20	296.93	3.01	0.52	<0.01	6075	21	3.42	718
191322	222,88-223,00	233.88	3.00	0.39	<0.01	7206	20	4.00	744
191323	233,00-233,20	245.95	3.06	0.59	<0.01	104882	1071	4.11	733
191324	243,87-244,00	248.84	3.12	0.53	<0.01	7816	49	3.66	702
191325	254,17-254,35	236.66	3.01	2.05	<0.01	21477	158	3.78	732
191326	264,00-264,20	268.83	2.99	0.87	<0.01	8208	40	4.15	752
191327	270,00-270,16	172.29	3.01	0.85	<0.01	5925	38	3.05	701
191328	283,84-284,00	250.57	3.01	0.41	<0.01	2783	16	3.88	737
191329	291,44-291,63	252.12	3.03	0.82	<0.01	19540	338	3.77	727
191330	303,86-304,00	255.96	3.05	0.70	<0.01	28240	302	3.63	717
191331	313,80-313,95	270.14	2.97	0.96	<0.01	7788	167	3.41	727
191332	321,00-321,20	266.82	2.98	1.19	<0.01	16956	221	4.03	750
191333	331,65-331,82	255.82	3.16	0.86	<0.01	65750	2582	4.27	716

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Tlf.: 73 90 40 00
E-post: lab@ngu.no

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NGU nr.	Prøve ID	Kartblad	UTM Zone	UTM X	UTM Y	LitoKode	METKode	StratKode	Prøvebeskrivelse
191334	340,05-340,25		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191335	352,80-352,95		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191336	362,80-363,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191337	372,78-372,95		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191338	384,77-384,93		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191339	394,88-395,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191340	403,83-404,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191341	411,15-411,35		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191342	422,62-422,78		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191343	433,80-434,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191344	441,15-441,33		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191345	454,12-454,29		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191346	464,34-464,49		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191347	472,88-473,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191348	483,88-484,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191349	494,03-494,23		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191350	503,14-503,35		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191351	511,46-511,60		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191352	523,83-524,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191353	530,27-530,44		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191354	541,03-541,19		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191355	554,85-555,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191356	564,55-564,68		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191357	572,00-572,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191358	582,83-583,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191359	591,00-591,17		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191360	601,00-601,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191361	613,85-614,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191362	624,85-625,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191363	634,06-634,25		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191364	640,68-640,84		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191365	653,83-654,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191366	660,80-661,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191367	670,00-670,14		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt

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7491 TRONDHEIM
Tlf.: 73 90 40 00
E-post: lab@ngu.no

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191334	340,05-340,25	257.64	3.07	1.18	<0.01	56711	1692	3.81	719
191335	352,80-352,95	252.96	3.01	0.97	<0.01	100653	2380	3.68	728
191336	362,80-363,00	280.77	3.06	2.45	<0.01	45972	379	3.82	722
191337	372,78-372,95	239.25	3.01	1.08	<0.01	26211	296	3.82	734
191338	384,77-384,93	240.12	3.04	0.79	<0.01	44531	2183	4.10	738
191339	394,88-395,00	247.20	2.98	0.73	<0.01	25951	397	3.97	747
191340	403,83-404,00	264.68	3.04	1.07	<0.01	15685	207	3.99	734
191341	411,15-411,35	252.91	3.07	1.34	<0.01	19839	247	4.05	729
191342	422,62-422,78	239.31	3.05	1.32	<0.01	61936	469	3.52	712
191343	433,80-434,00	272.74	3.05	0.97	<0.01	32895	566	3.93	729
191344	441,15-441,33	273.35	3.29	1.35	<0.01	24024	491	4.07	681
191345	454,12-454,29	258.57	2.99	1.14	<0.01	42939	273	3.76	736
191346	464,34-464,49	250.14	3.04	1.18	<0.01	46498	530	3.68	721
191347	472,88-473,00	219.87	2.97	0.85	<0.01	9611	25	4.03	753
191348	483,88-484,00	214.94	2.97	0.84	<0.01	44165	420	4.04	753
191349	494,03-494,23	262.44	3.16	2.22	<0.01	19102	438	2.66	652
191350	503,14-503,35	279.06	3.05	0.72	<0.01	26794	171	3.96	730
191351	511,46-511,60	228.22	2.99	0.53	<0.01	25219	169	4.25	756
191352	523,83-524,00	267.72	2.96	2.62	<0.01	3052	8	3.95	752
191353	530,27-530,44	258.02	2.95	2.84	0.01	7826	303	3.89	752
191354	541,03-541,19	264.74	3.01	0.79	<0.01	38782	439	3.90	737
191355	554,85-555,00	274.07	2.99	0.91	<0.01	12367	147	3.93	743
191356	564,55-564,68	245.87	2.99	1.31	<0.01	13890	73	3.93	743
191357	572,00-572,20	279.89	3.01	1.06	<0.01	8559	25	3.72	730
191358	582,83-583,00	272.79	2.98	1.10	<0.01	28679	331	3.81	741
191359	591,00-591,17	260.01	3.00	0.69	<0.01	24501	245	3.90	740
191360	601,00-601,20	219.17	3.02	0.98	<0.01	43299	283	3.80	731
191361	613,85-614,00	217.26	3.01	0.98	<0.01	15189	119	3.94	739
191362	624,85-625,00	229.51	2.99	1.26	<0.01	7954	66	3.90	742
191363	634,06-634,25	226.37	2.99	1.01	<0.01	7615	9	3.91	742
191364	640,68-640,84	211.70	3.00	0.86	<0.01	6810	49	4.02	744
191365	653,83-654,00	207.50	3.02	1.31	<0.01	27183	324	4.00	739
191366	660,80-661,00	207.25	2.98	0.68	<0.01	57382	487	4.07	752
191367	670,00-670,14	214.17	3.05	1.20	<0.01	80824	2796	3.98	731

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Bestemmelse av petrofysiske parametre
GEOLOGISK MATERIALE
Analysekontraktnr. 2018.0154

NGU nr.	Prøve ID	Kartblad	UTM Zone	UTM X	UTM Y	LitoKode	METKode	StratKode	Prøvebeskrivelse
191368	684,00-684,13		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191369	692,85-692,96		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191370	704,22-704,33		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191371	711,89-712-00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191372	724,00-724,15		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191373	731,86-732,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191374	744,00-744,15		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191375	750,85-751,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191376	761,88-762,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191377	771,80-771,92		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191378	780,82-780,96		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191379	790,00-790,14		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191380	803,00-803,11		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191381	813,67-813,80		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191382	822,86-823,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191383	830,90-831,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191384	841,00-841,12		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191385	852,00-852,10		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191386	861,00-861,12		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191387	871,90-872,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191388	883,15-883,25		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191389	893,90-894,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191390	902,06-902,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191391	911,00-911,10		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191392	924,00-924,11		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191393	933,04-933,20		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191394	942,90-943,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191395	950,00-950,15		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191396	964,65-964,81		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
191397	973,78-973,90		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
77251	981,88-982,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
77252	991,87-991,92		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt
77253	1000,89-1001,00		32V	517182	6570372				Borkjerner fra Fen, hovedsakelig rauhaugitt

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Tlf.: 73 90 40 00
E-post: lab@ngu.no

Bestemmelse av petrofysiske parametre
GEOLOGISK MATERIALE
Analysekontraktnr. 2018.0154

NGU nr.	Prøve ID	Volum (cm^3)	Tetthet (g/cm^3)	Porevolum (cm^3)	Porøsitet (%)	Susceptibilitet (10^{-6} SI)	Remanens (mA/M)	Varmeledningsevne, k (W/mK)	Spesifikk varmekapasitet, c_p (J/kgK)
191368	684,00-684,13	228.77	3.01	0.94	<0.01	40253	565	4.04	743
191369	692,85-692,96	168.34	2.98	1.00	<0.01	15118	306	3.91	745
191370	704,22-704,33	181.63	2.97	0.99	<0.01	8643	87	4.12	756
191371	711,89-712-00	197.12	3.03	0.98	<0.01	8526	347	3.71	725
191372	724,00-724,15	209.31	3.01	0.71	<0.01	75850	256	3.74	731
191373	731,86-732,00	196.13	3.19	1.41	<0.01	95628	2424	3.52	681
191374	744,00-744,15	250.05	2.95	0.75	<0.01	7271	420	4.03	758
191375	750,85-751,00	195.82	2.86	0.64	<0.01	52081	3576	3.41	754
191376	761,88-762,00	200.66	2.99	0.79	<0.01	7294	34	3.90	742
191377	771,80-771,92	158.95	3.02	0.82	<0.01	52910	1233	4.16	745
191378	780,82-780,96	193.10	3.00	0.86	<0.01	33992	306	3.65	729
191379	790,00-790,14	192.21	3.00	0.93	<0.01	14596	262	3.82	736
191380	803,00-803,11	189.94	3.01	1.44	<0.01	49710	737	3.92	738
191381	813,67-813,80	190.75	3.01	1.40	<0.01	27148	213	3.75	731
191382	822,86-823,00	187.72	3.02	1.02	<0.01	89027	3135	3.96	737
191383	830,90-831,00	172.93	3.28	2.08	0.01	502500	45552	3.87	676
191384	841,00-841,12	197.91	3.04	1.18	<0.01	36277	608	3.87	729
191385	852,00-852,10	170.41	3.13	0.67	<0.01	122702	3426	4.06	715
191386	861,00-861,12	196.77	3.06	1.18	<0.01	67835	1187	3.70	717
191387	871,90-872,00	156.02	3.01	0.85	<0.01	30124	469	3.77	732
191388	883,15-883,25	147.07	2.94	0.72	<0.01	7258	85	4.23	768
191389	893,90-894,00	181.66	3.00	0.79	<0.01	35097	730	4.13	749
191390	902,06-902,20	193.29	3.03	1.19	<0.01	93118	2028	4.12	741
191391	911,00-911,10	194.59	2.83	1.16	<0.01	11005	34	3.41	762
191392	924,00-924,11	201.56	3.01	1.13	<0.01	39345	988	3.90	737
191393	933,04-933,20	182.68	3.00	1.10	<0.01	17235	515	3.94	741
191394	942,90-943,00	187.43	3.00	0.78	<0.01	12949	178	4.15	750
191395	950,00-950,15	195.78	3.26	0.86	<0.01	568697	81161	4.05	686
191396	964,65-964,81	230.21	3.01	0.96	<0.01	34319	852	4.23	750
191397	973,78-973,90	211.17	3.00	1.07	<0.01	32234	322	3.92	741
77251	981,88-982,00	189.55	3.35	1.24	<0.01	869414	35546	3.65	653
77252	991,87-991,92	182.54	3.00	0.69	<0.01	29894	759	3.77	734
77253	1000,89-1001,00	199.28	2.96	0.69	<0.01	30068	979	3.69	741

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GEOLOGISK MATERIALE
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NGU nr.	Prøve ID	Kartblad	UTM Zone	UTM X	UTM Y	LitoKode	METKode	StratKode	Prøvebeskrivelse
77255	11,00-11,18		32V	516554	6571021				Borkjerner fra Fen
77256	24,90-25,00		32V	516554	6571021				Borkjerner fra Fen
77257	32,89-33,00		32V	516554	6571021				Borkjerner fra Fen
77258	43,80-44,00		32V	516554	6571021				Borkjerner fra Fen
77259	54,38-54,50		32V	516554	6571021				Borkjerner fra Fen
77260	60,85-60,98		32V	516554	6571021				Borkjerner fra Fen
77261	70,70-70,83		32V	516554	6571021				Borkjerner fra Fen
77262	83,58-83,71		32V	516554	6571021				Borkjerner fra Fen
77263	94,54-94,70		32V	516554	6571021				Borkjerner fra Fen
77264	103,23-103,35		32V	516554	6571021				Borkjerner fra Fen
77265	112,02-112,15		32V	516554	6571021				Borkjerner fra Fen
77266	124,88-125,00		32V	516554	6571021				Borkjerner fra Fen
77267	131,88-132,00		32V	516554	6571021				Borkjerner fra Fen
77268	144,90-145,00		32V	516554	6571021				Borkjerner fra Fen
77269	153,89-154,00		32V	516554	6571021				Borkjerner fra Fen
77270	162,90-163,00		32V	516554	6571021				Borkjerner fra Fen
77271	173,31-173,45		32V	516554	6571021				Borkjerner fra Fen
77272	181,90-182,00		32V	516554	6571021				Borkjerner fra Fen
77273	191,90-192,00		32V	516554	6571021				Borkjerner fra Fen
77274	201,67-201,80		32V	516554	6571021				Borkjerner fra Fen
77275	210,00-210,18		32V	516554	6571021				Borkjerner fra Fen
77276	222,00-222,14		32V	516554	6571021				Borkjerner fra Fen
77277	231,00-231,13		32V	516554	6571021				Borkjerner fra Fen
77278	240,84-241,00		32V	516554	6571021				Borkjerner fra Fen
77279	254,83-255,00		32V	516554	6571021				Borkjerner fra Fen
77280	263,85-264,00		32V	516554	6571021				Borkjerner fra Fen
77281	270,56-270,67		32V	516554	6571021				Borkjerner fra Fen
77282	283,90-284,00		32V	516554	6571021				Borkjerner fra Fen
77283	290,87-291,00		32V	516554	6571021				Borkjerner fra Fen
77284	301,00-301,15		32V	516554	6571021				Borkjerner fra Fen
77285	311,37-311,50		32V	516554	6571021				Borkjerner fra Fen
77286	323,00-323,16		32V	516554	6571021				Borkjerner fra Fen
77287	334,87-335,00		32V	516554	6571021				Borkjerner fra Fen
77288	343,00-343,16		32V	516554	6571021				Borkjerner fra Fen

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Analysekontraktnr. 2018.0154

NGU nr.	Prøve ID	Volum (cm^3)	Tetthet (g/cm^3)	Porevolum (cm^3)	Porøsitet (%)	Susceptibilitet (10^{-6} SI)	Remanens (mA/M)	Varmeledningsevne, k (W/mK)	Spesifikk varmekapasitet, c_p (J/kgK)
191301	14,00-14,20	269.25	2.98	1.05	<0.01	1621	9	4.02	749
191302	22,42-22,67	307.22	3.18	7.31	0.02	54155	337	4.94	735
191303	32,69-32,90	286.32	3.01	1.00	<0.01	3324	26	4.15	747
191304	43,16-43,35	285.81	2.97	0.58	<0.01	1771	4	3.95	749
191305	52,00-52,19	273.69	3.03	1.00	<0.01	2150	10	3.44	713
191306	63,00-63,15	264.01	3.09	0.69	<0.01	11121	48	3.51	702
191307	71,00-71,15	261.43	3.03	0.89	<0.01	2217	6	2.66	680
191308	84,80-85,00	274.59	2.98	0.65	<0.01	6053	17	3.92	746
191309	94,80-95,00	311.01	2.99	0.39	<0.01	1829	8	4.18	753
191310	103,85-104,00	260.17	3.19	0.52	<0.01	1507	11	2.84	653
191311	111,62-111,78	247.87	2.93	1.19	<0.01	9736	30	3.68	748
191312	122,00-122,20	299.44	3.00	1.14	<0.01	1735	4	3.78	735
191313	131,07-131,24	275.54	3.00	0.57	<0.01	1997	8	3.87	739
191314	143,08-143,24	244.72	2.99	0.84	<0.01	3255	23	3.78	737
191315	154,00-154,16	249.94	2.97	0.69	<0.01	5971	39	4.10	755
191316	163,00-163,17	259.43	3.00	0.71	<0.01	3093	11	3.97	742
191317	173,87-174,00	245.51	3.03	0.34	<0.01	3929	25	3.99	736
191318	181,46-181,61	240.10	2.99	0.51	<0.01	12495	102	3.45	723
191319	192,08-192,21	235.88	3.19	0.78	<0.01	10637	104	3.72	689
191320	202,58-202,75	259.76	3.16	1.43	<0.01	3325	8	3.60	690
191321	212,00-212,20	296.93	3.01	0.52	<0.01	6075	21	3.42	718
191322	222,88-223,00	233.88	3.00	0.39	<0.01	7206	20	4.00	744
191323	233,00-233,20	245.95	3.06	0.59	<0.01	104882	1071	4.11	733
191324	243,87-244,00	248.84	3.12	0.53	<0.01	7816	49	3.66	702
191325	254,17-254,35	236.66	3.01	2.05	<0.01	21477	158	3.78	732
191326	264,00-264,20	268.83	2.99	0.87	<0.01	8208	40	4.15	752
191327	270,00-270,16	172.29	3.01	0.85	<0.01	5925	38	3.05	701
191328	283,84-284,00	250.57	3.01	0.41	<0.01	2783	16	3.88	737
191329	291,44-291,63	252.12	3.03	0.82	<0.01	19540	338	3.77	727
191330	303,86-304,00	255.96	3.05	0.70	<0.01	28240	302	3.63	717
191331	313,80-313,95	270.14	2.97	0.96	<0.01	7788	167	3.41	727
191332	321,00-321,20	266.82	2.98	1.19	<0.01	16956	221	4.03	750
191333	331,65-331,82	255.82	3.16	0.86	<0.01	65750	2582	4.27	716

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Bestemmelse av petrofysiske parametre
GEOLOGISK MATERIALE
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NGU nr.	Prøve ID	Kartblad	UTM Zone	UTM X	UTM Y	LitoKode	METKode	StratKode	Prøvebeskrivelse
77289	350,86-351,00		32V	516554	6571021				Borkjerner fra Fen
77290	363,23-363,37		32V	516554	6571021				Borkjerner fra Fen
77291	374,10-374,20		32V	516554	6571021				Borkjerner fra Fen
77292	381,86-381,98		32V	516554	6571021				Borkjerner fra Fen
77293	394,74-394,85		32V	516554	6571021				Borkjerner fra Fen
77294	404,90-405,00		32V	516554	6571021				Borkjerner fra Fen
77295	414,33-414,48		32V	516554	6571021				Borkjerner fra Fen
77296	424,85-425,00		32V	516554	6571021				Borkjerner fra Fen
77297	433,06-433,20		32V	516554	6571021				Borkjerner fra Fen
77298	442,66-442,80		32V	516554	6571021				Borkjerner fra Fen
77299	454,80-454,94		32V	516554	6571021				Borkjerner fra Fen
77300	464,00-464,13		32V	516554	6571021				Borkjerner fra Fen
191401	470,87-471,00		32V	516554	6571021				Borkjerner fra Fen
191402	484,00-484,13		32V	516554	6571021				Borkjerner fra Fen
191403	494,90-495,00		32V	516554	6571021				Borkjerner fra Fen
191404	502,90-503,00		32V	516554	6571021				Borkjerner fra Fen
191405	513,86-514,00		32V	516554	6571021				Borkjerner fra Fen
191406	521,90-522,00		32V	516554	6571021				Borkjerner fra Fen
191407	534,90-535,00		32V	516554	6571021				Borkjerner fra Fen
191408	542,02-542,18		32V	516554	6571021				Borkjerner fra Fen
191409	551,90-552,00		32V	516554	6571021				Borkjerner fra Fen
191410	564,88-565,00		32V	516554	6571021				Borkjerner fra Fen
191411	572,00-572,16		32V	516554	6571021				Borkjerner fra Fen
191412	581,88-582,00		32V	516554	6571021				Borkjerner fra Fen
191413	592,90-593,00		32V	516554	6571021				Borkjerner fra Fen
191414	604,88-605,00		32V	516554	6571021				Borkjerner fra Fen
191415	610,16-610,30		32V	516554	6571021				Borkjerner fra Fen
191416	624,52-624,64		32V	516554	6571021				Borkjerner fra Fen
191417	633,70-633,84		32V	516554	6571021				Borkjerner fra Fen
191418	642,05-642,16		32V	516554	6571021				Borkjerner fra Fen
191419	652,87-653,00		32V	516554	6571021				Borkjerner fra Fen
191420	662,78-662,92		32V	516554	6571021				Borkjerner fra Fen
191421	674,82-674,95		32V	516554	6571021				Borkjerner fra Fen
191422	681,00-681,14		32V	516554	6571021				Borkjerner fra Fen
191423	691,05-691,17		32V	516554	6571021				Borkjerner fra Fen
191424	703,10-703,27		32V	516554	6571021				Borkjerner fra Fen
191425	711,16-711,30		32V	516554	6571021				Borkjerner fra Fen

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NORGES GEOLOGISKE UNDERSØKELSE · NGU ·
7491 TRONDHEIM
Tlf.: 73 90 40 00
E-post: lab@ngu.no

Bestemmelse av petrofysiske parametre
GEOLOGISK MATERIALE
Analysekontraktnr. 2018.0154

NGU nr.	Prøve ID	Volum (cm^3)	Tetthet (g/cm^3)	Porevolum (cm^3)	Porøsitet (%)	Susceptibilitet (10^{-6} SI)	Remanens (mA/M)	Varmeledningsevne, k (W/mK)	Spesifikk varmekapasitet, c_p (J/kgK)
77289	350,86-351,00	200.01	3.03	1.58	<0.01	17088	125	3.50	716
77290	363,23-363,37	194.90	2.88	1.40	<0.01	1140	5	3.37	748
77291	374,10-374,20	212.15	2.88	4.26	0.02	54115	423	3.17	738
77292	381,86-381,98	207.05	2.97	1.11	<0.01	13413	139	4.01	752
77293	394,74-394,85	197.00	2.94	1.64	<0.01	23355	288	3.85	753
77294	404,90-405,00	196.41	2.99	1.14	<0.01	12156	383	3.14	710
77295	414,33-414,48	211.72	2.99	1.29	<0.01	1582	16	4.40	762
77296	424,85-425,00	190.49	3.01	1.49	<0.01	45626	266	3.47	719
77297	433,06-433,20	208.73	2.96	0.77	<0.01	2757	14	4.19	761
77298	442,66-442,80	205.87	2.79	0.97	<0.01	13355	244	3.44	775
77299	454,80-454,94	210.70	3.01	1.01	<0.01	31864	285	4.04	743
77300	464,00-464,13	204.95	3.04	1.48	<0.01	29404	353	3.80	726
191401	470,87-471,00	208.46	2.99	1.54	<0.01	21221	796	3.93	743
191402	484,00-484,13	197.05	3.00	0.93	<0.01	15603	2045	3.87	738
191403	494,90-495,00	178.26	3.05	1.05	<0.01	25525	183	3.79	723
191404	502,90-503,00	193.13	3.02	0.92	<0.01	12174	60	3.84	732
191405	513,86-514,00	206.61	3.10	0.54	<0.01	102113	863	3.24	689
191406	521,90-522,00	184.70	3.00	1.62	<0.01	38100	5428	3.69	731
191407	534,90-535,00	184.76	3.01	1.02	<0.01	12046	51	3.84	735
191408	542,02-542,18	205.91	2.96	1.14	<0.01	8640	142	4.05	756
191409	551,90-552,00	189.16	2.86	0.77	<0.01	14443	154	3.65	765
191410	564,88-565,00	210.59	3.04	1.12	<0.01	32645	210	3.72	723
191411	572,00-572,16	214.41	2.99	1.39	<0.01	5062	168	4.03	747
191412	581,88-582,00	207.03	3.02	1.51	<0.01	19818	921	2.60	680
191413	592,90-593,00	183.57	2.96	0.75	<0.01	8814	65	3.72	742
191414	604,88-605,00	195.93	3.04	0.99	<0.01	20143	76	4.18	741
191415	610,16-610,30	202.55	3.03	1.24	<0.01	69235	1383	2.32	666
191416	624,52-624,64	201.28	3.11	0.56	<0.01	235294	101741	3.58	701
191417	633,70-633,84	194.21	3.16	0.94	<0.01	15336	118	3.49	686
191418	642,05-642,16	201.10	3.07	0.85	<0.01	11757	171	3.49	706
191419	652,87-653,00	198.31	2.97	1.08	<0.01	2148	35	3.50	730
191420	662,78-662,92	200.21	3.07	1.19	<0.01	4321	8	3.53	708
191421	674,82-674,95	181.26	3.04	1.67	<0.01	12451	201	3.49	713
191422	681,00-681,14	193.68	3.10	0.92	<0.01	27266	875	3.82	713
191423	691,05-691,17	209.26	3.00	1.12	<0.01	17407	378	4.05	746
191424	703,10-703,27	207.09	3.01	1.39	<0.01	27750	686	2.87	693
191425	711,16-711,30	198.00	2.98	0.97	<0.01	16670	1147	3.29	719

Appendix 2. Detailed core drilling registrations from drilling company (Geodrilling AS).

Translation of important terms from Norwegian to English:

Bedre fjell	Better rock quality
Boredyp	Drilling depth
Bra fjell	Good rock quality
Casingboring	Casing drilling
Dårlig fjell	Bad rock quality
Dårlige soner	Zones with bad rock quality
Godt fjell	Good rock quality
Farge spylevann	Colour of return water
Hardt godt fjell	Hard and good rock quality
Helt og fint fjell	Continuous and nice rock
Kjerne lengde	Core length
Kjernetap	Core loss
Kommentar	Comment
Matekraft	Drilling power
Meget dårlig fjell	Very bad rock quality
Mottrykk Spyl.vann	Drilling water pressure
Mistet spylevann	Lost water pressure
Noe oppsprukket	Somewhat fractured
Noe bedre	Somewhat better
Noen dårlige soner	Some bad rock quality zones
NQ2	Drill-bit (drillhole diameter 76 mm)
Oppsprukket	Fractured
Penetrering	Penetration
Returvann tilbake	Water pressure OK
Ras	Rack-fall in drillhole
Rotasjon rpm	Rotation (round per minute)
Sandsleppe	Sandy lose rock
Sprukket	Fractured
Støyping	Grouting (Concrete injection)
Åpen sone	Open cavity

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GEO DRILLING AS — REGISTRERING BOREDATA — SIDE 1

GEO DRILLING

PROSJEKT:	STED:	HULL-NR:	KRONE:	DATO:	MASKIN:	FALL/RETNING:
P - 160417	Fen feltet, Ulefoss	LHKB - 01	NQ2"	November	Diamec U 8 APC	Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
0,00	15,00		550	500 - 900	5 - 10	5 - 8	Grått	Casingboring, fjell fra 13,20 meter
13,20	15,10	1,90	900	500	10	4	Grått	
15,10	16,20	1,10	900	700	10	4	Grått	
16,20	17,50	1,30	900	800	10	4	Grått	
17,50	20,50	3,00	900	600	10	4	Grått	
20,50	23,50	3,00	900	500	10	4	Grått	
23,50	26,50	3,00	900	500	10	5	Grått	
26,50	29,50	3,00	900	500	10	5	Grått	
29,50	32,50	3,00	900	500	10	5	Grått	
32,50	35,10	2,60	900	500	10	5	Grått	
35,10	38,15	3,05	900	500	10	5	Grått	
38,15	41,25	3,10	900	500	10	4	Grått	
41,25	44,30	3,05	900	500	10	6	Grått	
44,30	47,30	3,00	900	500	10	5	Grått	
47,30	50,35	3,05	900	600	10	5	Grått	
50,35	53,40	3,05	900	500	10	5	Grått	
53,40	56,40	3,00	900	600	10	5	Grått	
56,40	59,40	3,00	900	550	10	5	Grått	
59,40	62,50	3,10	900	550	10	6	Grått	
62,50	65,30	2,80	900	550	10	6	Grått	
65,30	68,40	3,10	900	550	10	6	Grått	Dårlig fjell, oppsprukket
68,40	70,90	2,50	900	500	10	5	Grått	
70,90	74,00	3,10	900	500	10	5	Grått	Oppsprukket
74,00	77,00	3,00	900	600	10	5	Grått	
77,00	80,10	3,10	900	600	10	6	Grått	Oppsprukket
80,10	83,10	3,00	900	600	10	6	Grått	
83,10	86,20	3,10	900	500	10	6	Grått	
86,20	86,50	0,30	900	600	10	6	Grått	
86,50	89,50	3,00	900	600	10	6	Grått	
89,50	92,50	3,00	900	600	10	6	Grått	
92,50	95,00	2,50	900	550	10	6	Grått	
SUM	95,00	81,80						

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Appendix 2 side 3
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GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 2	
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO:	MASKIN: Diamec U 8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR	
95,00	98,00	3,00	900	550	10	6	Grått		
98,00	101,00	3,00	900	600	10	6	Grått		
101,00	104,15	3,15	900	600	10	6	Grått		
104,15	107,20	3,05	900	550	10	6	Grått		
107,20	110,30	3,10	900	500	10	6	Grått		
110,30	113,35	3,05	900	550	10	6	Grått		
113,35	116,35	3,00	900	550	10	6	Grått		
116,35	119,45	3,10	900	550	10	6	Grått		
119,45	122,20	2,75	900	550	10	6	Grått		
122,20	125,25	3,05	900	550	10	6	Grått		
125,25	128,35	3,10	900	550	10	6	Grått		
128,35	131,45	3,10	900	550	10	6	Grått		
131,45	134,50	3,05	900	550	10	6	Grått		
134,50	137,25	2,75	900	550	10	6	Grått		
137,25	140,30	3,05	900	550	10	6	Grått		
140,30	143,20	2,90	900	550	10	6	Grått		
143,20	146,30	3,10	900	550	10	6	Grått		
146,30	148,95	2,65	900	550	10	6	Rødt	Noe sprukket	
148,95	152,05	3,10	900	550	10	6	Grått	Sprukket	
152,05	155,10	3,05	900	550	10	6	Grått		
155,10	158,15	3,05	900	550	10	6	Grått		
158,15	161,10	2,95	900	550	10	6	Grått		
161,10	164,20	3,10	900	550	10	6	Grått		
164,20	167,20	3,00	900	550	10	6	Grått		
167,20	170,25	3,05	900	550	10	6	Grått		
170,25	173,30	3,05	900	550	10	6	Grått		
173,30	176,15	2,85	900	550	10	6	Grått		
176,15	179,20	3,05	900	550	10	6	Grått		
179,20	182,25	3,05	900	550	10	6	Grått		
182,25	185,30	3,05	900	550	10	6	Grått		
185,30	187,95	2,65	900	550	10	6	Grått		
SUM	187,95	92,95							

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GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	3
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO:	MASKIN: Diamec U 8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR	
187,95	191,00	3,05	900	600	10	6	Grått		
191,00	194,05	3,05	900	600	10	6	Grått		
194,05	197,15	3,10	900	600	10	6	Grått		
197,15	198,05	0,90	900	600	10	6	Grått	Oppsprukket, dårlig fjell	
198,05	199,55	1,50	900	1000	10	8	Grått		
199,55	200,50	0,95	900	1100	10	8	Grått	Oppsprukket, dårlig fjell	
200,50	203,15	2,65	900	1200	10	9	Grått		
203,15	206,20	3,05	900	900	12	12	Grått		
206,20	209,15	2,95	900	1200	13	15	Grått	Oppsprukket, dårlig fjell	
209,15	210,50	1,35	900	1200	13	15	Grått		
210,50	212,50	2,00	900	1300	13	17	Grått	Dårlig fjell	
212,50	215,50	3,00	900	1100	10	17	Grått		
215,50	217,20	1,70	900	1200	11	17	Grått	Dårlig fjell	
217,20	218,50	1,30	900	900	11	18	Grått		
218,50	220,20	1,70	900	900	12	18	Grått	Dårlig fjell	
220,20	221,50	1,30	900	800	13	15	Grått		
221,50	224,50	3,00	900	900	13	15	Grått		
224,50	226,80	2,30	900	1100	12	15	Grått		
226,80	227,50	0,70	900	1200	13	16	Grått		
227,50	230,50	3,00	900	1000	14	17	Grått		
230,50	233,50	3,00	900	1000	14	17	Grått		
233,50	236,50	3,00	900	1100	14	17	Grått		
236,50	239,50	3,00	900	1100	14	17	Grått		
239,50	242,50	3,00	900	1000	15	17	Grått		
242,50	245,50	3,00	900	900	15	16	Grått		
245,50	248,50	3,00	900	950	15	17	Grått		
248,50	251,50	3,00	900	950	15	17	Grått		
251,50	254,50	3,00	900	1000	15	17	Grått		
254,50	257,50	3,00	900	1100	15	17	Grått		
257,50	260,50	3,00	900	1100	15	17	Grått		
260,50	263,50	3,00	900	1050	16	17	Grått		
SUM	263,50	75,55							

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GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	4
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO:	MASKIN: Diamec U 8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR	
263,50	266,50	3,00	900	1100	16	17	Grått		
266,50	269,50	3,00	900	1200	16	15	Grått		
269,50	272,50	3,00	900	1000	16	15	Grått		
272,50	275,50	3,00	900	900	16	14	Grått		
275,50	278,50	3,00	900	1000	16	15	Grått		
278,50	281,50	3,00	900	1000	16	14	Grått	Noe sprukket	
281,50	284,50	3,00	900	1100	16	15	Grått		
284,50	287,50	3,00	900	1100	16	15	Grått		
287,50	290,50	3,00	900	1000	16	15	Grått		
290,50	293,50	3,00	900	1100	16	15	Grått		
293,50	296,50	3,00	900	1000	16	14	Grått		
296,50	299,50	3,00	900	1100	16	13	Grått		
299,50	302,50	3,00	900	1000	16	13	Grått		
302,50	305,50	3,00	900	900	16	12	Grått		
305,50	308,50	3,00	900	1000	16	12	Grått		
308,50	311,50	3,00	900	1000	16	13	Grått		
311,50	314,50	3,00	900	900	16	13	Grått		
314,50	317,50	3,00	900	1000	16	14	Grått		
317,50	320,50	3,00	900	1100	16	14	Grått		
320,50	323,50	3,00	900	1000	16	14	Grått		
323,50	326,50	3,00	900	1100	16	12	Grått		
326,50	329,50	3,00	900	1200	16	12	Grått		
329,50	332,50	3,00	900	1200	16	13	Grått		
332,50	335,50	3,00	900	1200	16	13	Grått		
335,50	338,50	3,00	900	1200	16	13	Grått		
338,50	341,50	3,00	900	1300	16	14	Grått		
341,50	344,50	3,00	900	1300	16	14	Grått		
344,50	347,50	3,00	900	1300	16	14	Grått		
347,50	350,50	3,00	900	1400	16	14	Grått		
350,50	353,50	3,00	900	1300	16	13	Grått		
353,50	356,50	3,00	900	1300	16	14	Grått		
SUM	356,50	93,00							

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GEO DRILLING AS — REGISTRERING BOREDATA — SIDE 5

PROSJEKT:	STED:	HULL-NR:	KRONE:	DATO:	MASKIN:	FALL/RETNING:
P - 160417	Fen feltet, Ulefoss	LHKB - 01	NQ2"		Diamec U 8 APC	Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
356,50	359,50	3,00	900	1300	16	13	Grått	
359,50	362,50	3,00	900	1300	16	13	Grått	
362,50	365,50	3,00	900	1300	16	13	Grått	
365,50	368,50	3,00	900	1200	16	13	Grått	
368,50	371,50	3,00	900	1200	16	14	Grått	
371,50	374,50	3,00	900	1300	16	13	Grått	
374,50	377,50	3,00	900	1300	17	14	Grått	
377,50	380,50	3,00	900	1300	17	15	Grått	
380,50	383,50	3,00	900	1400	17	15	Grått	
383,50	386,50	3,00	900	1400	17	15	Grått	
386,50	389,50	3,00	900	1300	17	15	Grått	
389,50	392,50	3,00	900	1400	18	13	Grått	
392,50	395,50	3,00	900	1400	18	14	Grått	
395,50	398,50	3,00	900	1300	18	14	Grått	
398,50	401,50	3,00	900	1400	18	14	Grått	
401,50	404,50	3,00	900	1500	18	14	Grått	
404,50	407,50	3,00	900	1500	18	15	Grått	
407,50	410,50	3,00	900	1200	18	14	Grått	
410,50	413,50	3,00	900	1300	18	15	Grått	
413,50	416,50	3,00	900	1400	18	14	Grått	
416,50	419,50	3,00	900	1400	18	15	Grått	
419,50	422,50	3,00	900	1400	18	15	Grått	
422,50	425,50	3,00	900	1500	18	15	Grått	
425,50	428,50	3,00	900	1400	18	14	Grått	
428,50	431,50	3,00	900	1500	18	15	Grått	
431,50	434,50	3,00	900	1300	18	13	Grått	
434,50	437,50	3,00	900	1300	18	13	Grått	
437,50	440,50	3,00	900	1300	18	14	Rødt	
440,50	443,50	3,00	900	1300	18	14	Rødt	
443,50	446,50	3,00	900	1200	18	14	Grått	
SUM	446,50	90,00						

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GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 6
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO: Desember / MASKIN: Diamec U 8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
446,50	449,50	3,00	900	1250	18	15	Rødt	
449,50	452,50	3,00	900	1250	18	15	Grått	
452,50	455,50	3,00	900	1300	18	15	Grått	
455,50	458,50	3,00	900	1300	18	14	Grått	
458,50	461,50	3,00	900	1400	18	15	Grått	
461,50	464,50	3,00	900	1300	18	14	Grått	
464,50	467,50	3,00	900	1400	18	16	Grått	
467,50	470,50	3,00	900	1400	18	16	Grått	
470,50	473,50	3,00	900	1500	18	17	Grått	
473,50	476,50	3,00	900	1500	18	17	Grått	
476,50	479,00	2,50	900	1700	17	15	Grått	Sprukket, dårlig fjell
479,00	479,50	0,50	900	1600	15	13	Grått	
479,50	482,30	2,80	900	1700	15	13	Grått	Sprukket, dårlig fjell
482,30	484,80	2,50	900	1700	14	12	Grått	
484,80	485,50	0,70	900	1600	15	12	Grått	
485,50	488,50	3,00	900	1600	15	13	Grått	Bedre fjell
488,50	491,50	3,00	900	1600	15	13	Grått	
491,50	494,50	3,00	900	1500	15	13	Grått	
494,50	497,50	3,00	900	1500	15	14	Grått	
497,50	497,90	0,40	900	1600	15	14	Grått	
497,90	500,50	2,60	900	1600	15	14	Grått	
500,50	503,50	3,00	900	1600	15	14	Grått	
503,50	506,50	3,00	900	1500	16	15	Grått	
506,50	509,50	3,00	900	1600	16	16	Grått	
509,50	512,50	3,00	900	1600	16	16	Grått	
512,50	515,50	3,00	900	1700	15	13	Grått	
515,50	516,60	1,10	900	1800	13	13	Grått	Sprukket, dårlig fjell
516,60	517,90	1,30	900	1700	14	14	Grått	
517,90	518,50	0,60	800	1500	13	14	Grått	Sprukket, dårlig fjell
518,50	521,50	3,00	900	1400	13	15	Grått	
521,50	523,30	1,80	900	1400	13	14	Grått	Sprukket, dårlig fjell
SUM	523,30	76,80						

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 7		
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO: Desember	MASKIN: Diamec U 8 APC	FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
523,30	524,50	1,20	900	1400	13	15	Grått	Dårlig fjell		
524,50	527,50	3,00	900	1500	14	15	Grått	Noe bedre		
527,50	530,50	3,00	900	1400	15	14	Grått	Godt fjell		
530,50	533,50	3,00	900	1500	15	15	Grått			
533,50	536,50	3,00	900	1500	15	15	Grått			
536,50	538,60	2,10	900	1500	15	15	Grått	Dårlig fjell		
538,60	539,50	0,90	900	1300	10	13	Grått			
539,50	542,50	3,00	900	1200	12	15	Grått	Dårlig fjell		
542,50	545,50	3,00	900	1300	15	13	Grått			
545,50	548,50	3,00	900	1300	13	15	Grått			
548,50	551,50	3,00	900	1300	13	17	Grått			
551,50	554,50	3,00	900	1400	13	17	Grått			
554,50	557,50	3,00	900	1300	13	17	Grått	Helt og fint fjell		
557,50	560,50	3,00	900	1300	13	17	Grått	Helt og fint fjell		
560,50	563,50	3,00	900	1300	13	17	Grått			
563,50	566,50	3,00	900	1200	12	17	Grått			
566,50	569,50	3,00	900	1300	13	17	Grått			
569,50	572,50	3,00	900	1200	13	17	Grått			
572,50	575,50	3,00	900	1200	13	17	Grått			
575,50	578,50	3,00	900	1300	13	17	Grått			
578,50	581,50	3,00	900	1300	13	17	Grått			
581,50	584,50	3,00	900	1300	13	17	Grått			
584,50	587,50	3,00	900	1200	13	17	Grått			
587,50	590,50	3,00	900	1200	13	17	Grått			
590,50	593,50	3,00	900	1300	13	17	Grått			
593,50	596,50	3,00	900	1300	13	17	Grått			
596,50	599,50	3,00	900	1200	13	17	Grått			
599,50	602,50	3,00	900	1200	13	17	Grått			
602,50	605,50	3,00	900	1300	13	17	Grått			
605,50	608,50	3,00	900	1300	13	17	Grått			
608,50	611,50	3,00	900	1300	13	17	Grått			
SUM	611,50	88,20								

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Appendix 2 side 9
LHKB-1

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 8
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO: Desember; MASKIN: Diamec U 8 APC; FALL/RETNING: Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
611,50	614,50	3,00	900	1700	13	17	Grått	
614,50	617,50	3,00	900	1700	13	18	Grått	
617,50	620,60	3,10	900	1800	14	18	Grått	
620,60	623,50	2,90	900	1700	14	18	Grått	
623,50	626,50	3,00	900	1700	13	18	Grått	
626,50	629,50	3,00	900	1800	14	17	Grått	
629,50	632,50	3,00	900	1800	13	17	Grått	
632,50	635,50	3,00	900	1800	13	18	Grått	
635,50	638,50	3,00	900	1800	13	18	Grått	
638,50	641,50	3,00	900	1700	13	18	Grått	
641,50	644,50	3,00	900	1800	13	18	Grått	
644,50	647,50	3,00	900	1800	13	18	Grått	
647,50	650,50	3,00	900	1800	13	18	Grått	
650,50	653,50	3,00	900	1800	13	18	Grått	
653,50	656,50	3,00	900	1700	13	18	Grått	
656,50	659,50	3,00	900	1500	12	10	Grått	
659,50	662,50	3,00	900	1400	13	13	Grått	Mistet spylevannet i retur.
662,50	665,50	3,00	900	1300	14	12	Grått	Returvann tilbake
665,50	668,50	3,00	900	1300	14	13	Grått	
668,50	671,50	3,00	900	1300	12	13	Grått	
671,50	674,50	3,00	900	1300	12	14	Grått	
674,50	677,50	3,00	900	1300	13	14	Grått	
677,50	680,50	3,00	900	1300	13	14	Grått	
680,50	683,50	3,00	900	1300	12	13	Grått	
683,50	686,50	3,00	900	1300	12	13	Grått	
686,50	689,50	3,00	900	1400	14	14	Grått	
689,50	692,50	3,00	900	1300	14	14	Grått	
692,50	695,50	3,00	900	1300	13	14	Grått	
695,50	698,50	3,00	900	1400	13	14	Grått	
698,50	701,50	3,00	900	1400	14	14	Grått	
SUM	701,50	90,00						

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Appendix 2 side 10
LHKB-1

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 9
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO: / MASKIN: Diamec U 8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
701,50	704,50	3,00	900	1700	13	13	Grått	
704,50	707,40	2,90	900	1800	14	14	Grått	
707,40	710,50	3,10	900	1700	13	14	Grått	
710,50	713,50	3,00	900	1700	12	12	Grått	
713,50	716,50	3,00	900	1600	13	13	Grått	
716,50	719,50	3,00	900	1700	13	13	Grått	
719,50	722,50	3,00	900	1800	10	14	Grått	Kjernetap,
722,50	725,50	3,00	900	1700	14	14	Grått	
725,50	728,50	3,00	900	1700	13	13	Grått	
728,50	731,50	3,00	900	1700	14	14	Grått	
731,50	734,50	3,00	900	1100	15	16	Grått	
734,50	736,00	1,50	900	1000	12	17	Grått	Kjernetap, 734,10-734,40 meter
736,00	737,50	1,50	900	900	12	17	Grått	
737,50	740,50	3,00	900	1200	13	17	Grått	
740,50	743,50	3,00	900	1300	14	18	Grått	
743,50	744,40	0,90	900	1400	15	17	Grått	
744,40	746,50	2,10	900	1600	15	17	Grått	
746,50	749,50	3,00	900	1200	15	17	Grått	
749,50	752,50	3,00	900	1100	16	17	Grått	
752,50	755,50	3,00	900	1000	16	17	Grått	
755,50	758,50	3,00	900	1200	18	17	Grått	
SUM	758,50	57,00						

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Appendix 2 side 11
LHKB-1

GEO DRILLING AS	REGISTRERING BOREDATA		SIDE	10	GEO DRILLING
PROSJEKT: P - 160417	STED: Fen feltet, Ulefoss	HULL-NR: LHKB - 01	KRONE: NQ2"	DATO: Januar	MASKIN: Diamec U 8 APC

FALL/RETNING: Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
758,50	761,50	3,00	900	1400	18	17	Grått	
761,50	764,50	3,00	900	1500	18	16	Grått	
764,50	767,50	3,00	900	1000	18	16	Grått	
767,50	770,50	3,00	900	1100	18	17	Grått	
770,50	773,50	3,00	900	1000	18	17	Grått	
773,50	776,50	3,00	900	1100	18	17	Grått	
776,50	779,50	3,00	900	1200	18	17	Grått	
779,50	782,50	3,00	900	1200	18	18	Grått	
782,50	785,50	3,00	900	1300	18	18	Grått	
785,50	788,50	3,00	900	1200	18	18	Grått	
788,50	791,50	3,00	900	1300	18	18	Grått	
791,50	794,50	3,00	900	1300	18	18	Grått	
794,50	797,20	2,70	900	1300	18	18	Grått	
797,20	799,10	1,90	900	1300	16	17	Grått	
799,10	800,50	1,40	900	1300	18	17	Grått	
800,50	803,50	3,00	900	1300	18	16	Grått	
803,50	806,50	3,00	900	1300	18	16	Grått	
806,50	809,50	3,00	900	1400	18	15	Grått	
809,50	812,50	3,00	900	1400	18	15	Grått	
812,50	815,50	3,00	900	1300	18	18	Grått	
815,50	818,50	3,00	900	1300	18	16	Grått	
818,50	821,50	3,00	900	1300	18	16	Grått	
821,50	824,50	3,00	900	1300	18	15	Grått	
824,50	827,50	3,00	900	1400	18	16	Grått	
827,50	830,50	3,00	900	1300	18	16	Grått	
SUM	830,50	72,00						

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	11
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO: Januar	MASKIN: Diamec U 8 APC	FALL/RETNING: Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
830,50	833,50	3,00	900	1200	18	17	Grått	
833,50	836,50	3,00	900	1200	18	17	Grått	
836,50	839,50	3,00	900	1300	18	17	Grått	
839,50	842,50	3,00	900	1300	18	15	Grått	
842,50	845,50	3,00	900	1400	18	15	Grått	
845,50	848,50	3,00	900	1200	18	16	Grått	
848,50	851,50	3,00	900	1300	18	16	Grått	
851,50	854,50	3,00	900	1300	18	16	Grått	
854,50	857,50	3,00	900	1300	18	17	Grått	
857,50	860,50	3,00	900	1300	18	16	Grått	
860,50	863,50	3,00	900	1300	18	16	Grått	
863,50	866,50	3,00	900	1600	18	16	Grått	
866,50	869,50	3,00	900	1400	18	16	Grått	
869,50	872,50	3,00	900	1300	18	16	Grått	
872,50	875,50	3,00	900	1300	18	16	Grått	
875,50	878,50	3,00	900	1000	18	16	Grått	
878,50	881,50	3,00	900	1000	18	16	Grått	
881,50	884,50	3,00	900	900	18	17	Grått	
884,50	887,50	3,00	900	900	18	16	Grått	
887,50	890,50	3,00	900	1000	18	17	Grått	
890,50	893,50	3,00	900	1100	18	17	Grått	
893,50	896,50	3,00	900	1000	18	17	Grått	
896,50	899,50	3,00	900	1200	18	17	Grått	
899,50	902,50	3,00	900	1200	18	17	Grått	
902,50	905,50	3,00	900	1200	18	15	Grått	
905,50	908,50	3,00	900	1100	18	16	Grått	
908,50	911,50	3,00	900	1200	18	16	Grått	
911,50	914,50	3,00	900	1000	18	16	Grått	
914,50	917,50	3,00	900	1000	18	16	Grått	
917,50	920,50	3,00	900	1100	18	17	Grått	
920,50	923,50	3,00	900	1100	18	17	Grått	
SUM	923,50	93,00						

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Appendix 2 side 13
LHKB-1

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 12
PROSJEKT: P - 160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 01		KRONE: NQ2"	DATO: Januar / MASKIN: Diamec U 8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
923,50	926,50	3,00	900	900	18	17	Grått	
926,50	929,50	3,00	900	1200	18	17	Grått	
929,50	932,50	3,00	900	1200	18	17	Grått	
932,50	935,50	3,00	900	1200	15	18	Grått	
935,50	938,50	3,00	900	1300	15	18	Grått	
938,50	941,50	3,00	900	1200	15	18	Grått	
941,50	944,50	3,00	900	1300	15	18	Grått	
944,50	947,50	3,00	900	1300	15	18	Grått	
947,50	950,50	3,00	900	1400	13	18	Grått	
950,50	953,50	3,00	900	1400	15	18	Grått	
953,50	956,50	3,00	900	1300	16	18	Grått	
956,50	959,50	3,00	900	1400	16	18	Grått	
959,50	962,50	3,00	900	1400	16	18	Grått	Kilefjell
962,50	962,75	0,25	900	1400	15	18	Grått	
962,75	965,50	2,75	900	1400	15	18	Grått	Kilefjell
965,50	968,50	3,00	900	1300	14	17	Grått	
968,50	971,60	3,10	900	1200	14	17	Grått	Sprukket
971,60	974,00	2,40	900	1300	14	17	Grått	
974,00	977,10	3,10	900	1200	15	18	Grått	
977,10	980,20	3,10	900	1200	13	18	Grått	Dårlig fjell
980,20	983,25	3,05	900	1300	13	18	Grått	
983,25	984,30	1,05	900	1300	13	18	Grått	
984,30	985,10	0,80	900	1200	13	18	Grått	
985,10	986,50	1,40	900	1200	13	17	Grått	
986,50	989,50	3,00	900	1300	12	17	Grått	
989,50	992,45	2,95	900	1300	12	17	Grått	
992,45	995,50	3,05	900	1500	10	18	Grått	
995,50	998,50	3,00	900	1500	10	18	Grått	
998,50	1001,50	3,00	900	1500	10	18	Grått	
								Hull avsluttet.
SUM	1 001,50	78,00						

GEO DRILLING AS	REGISTRERING BOREDATA	SIDE	1

PROSJEKT:	STED:	HULL-NR:	KRONE:	DATO:	MASKIN:	FALL/RETNING:
P-160417	Fen feltet, Ulefoss	LHKB - 2	NQ2"	Februar	Diamec U-8 APC	Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
0,00	7,50		550	1250	6	12	Grått	Casing til 7,50 Fjell fra 4,90 meter
4,90	8,40	3,50	900	800	12	4	Grått	
8,40	11,40	3,00	900	800	12	4	Grått	
11,40	14,40	3,00	900	800	14	4	Grått	
14,40	17,40	3,00	900	750	15	5	Grått	
17,40	20,40	3,00	900	800	15	5	Grått	
20,40	23,40	3,00	900	800	16	6	Grått	
23,40	26,40	3,00	900	800	15	6	Grått	
26,40	29,40	3,00	900	800	18	6	Grått	
29,40	32,40	3,00	900	800	18	7	Grått	
32,40	35,40	3,00	900	750	18	7	Grått	
35,40	38,40	3,00	900	800	18	7	Grått	
38,40	41,40	3,00	900	1000	18	7	Grått	
41,40	44,40	3,00	900	1100	17	7	Grått	
44,40	47,40	3,00	900	1100	19	7	Grått	Sandsleppe ved 46,20 meter
47,40	50,40	3,00	900	1000	15	5	Grått	Åpen sone
50,40	53,40	3,00	900	900	18	7	Grått	
53,40	56,40	3,00	900	1100	18	7	Grått	
56,40	59,40	3,00	900	1050	19	7	Grått	
59,40	62,40	3,00	900	1150	20	7	Grått	
62,40	63,40	1,00	900	1100	18	8	Grått	
63,40	65,40	2,00	900	1050	20	8	Grått	
65,40	68,40	3,00	900	1050	20	8	Grått	
68,40	71,40	3,00	900	1000	20	8	Grått	
71,40	74,40	3,00	900	950	20	8	Grått	
74,40	77,40	3,00	900	1050	17	8	Grått	Dårlige soner ved 75,10 og 76,20 meter
77,40	80,40	3,00	900	1100	18	3	Grått	
80,40	83,40	3,00	900	1100	20	6	Grått	Dårlig sone ved 83,60 meter
83,40	86,40	3,00	900	700	18	8	Grått	
86,40	89,40	3,00	900	950	20	9	Grått	
89,40	92,40	3,00	900	1000	20	9	Grått	
SUM	92,40	87,50						

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Appendix 2 side 15
LHKB-2

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 2	GEO DRILLING
PROSJEKT: P-160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 2		KRONE: NQ2"	DATO: / MASKIN: Diamec U-8 APC	FALL/RETNING: Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
92,40	95,40	3,00	900	900	20	9	Grått	
95,40	98,40	3,00	900	1000	20	9	Grått	
98,40	101,40	3,00	900	850	20	9	Grått	
101,40	104,40	3,00	900	700	20	9	Grått	
104,40	107,40	3,00	900	700	20	9	Grått	Dårlig fjell, mistet spylevannet
107,40	110,40	3,00	900	700	16	9	Grått	Støpt
110,40	113,40	3,00	900	700	20	9	Grått	Dårlig fjell, vann delvis borte
113,40	116,40	3,00	900	700	20	9	Grått	Dårlig, støpt
116,40	119,40	3,00	900	700	20	9	Grått	
119,40	122,35	2,95	900	700	18	9	Grått	Dårlig formasjon
122,35	124,90	2,55	900	700	18	9	Grått	
124,90	127,20	2,30	900	700	18	9	Grått	Dårlig fjell
127,20	128,40	1,20	900	700	18	9	Grått	
128,40	130,20	1,80	900	700	19	8	Grått	Dårlig
130,20	131,40	1,20	900	700	18	8	Grått	
131,40	134,40	3,00	900	700	18	8	Grått	
134,40	137,40	3,00	900	700	20	8	Grått	
137,40	140,40	3,00	900	700	20	8	Grått	
140,40	143,40	3,00	900	700	20	8	Grått	
143,40	146,40	3,00	900	700	19	8	Grått	
146,40	149,40	3,00	900	800	20	8	Grått	
149,40	152,40	3,00	900	800	20	8	Grått	
152,40	155,40	3,00	900	800	20	8	Grått	
155,40	158,40	3,00	900	800	20	8	Grått	
158,40	161,40	3,00	900	800	20	8	Grått	
161,40	164,40	3,00	900	800	20	8	Grått	
164,40	167,40	3,00	900	800	20	8	Grått	
167,40	170,40	3,00	900	800	20	8	Grått	
170,40	173,40	3,00	900	800	20	8	Grått	
173,40	176,40	3,00	900	800	20	9	Grått	
176,40	179,40	3,00	900	800	20	8	Grått	
SUM	179,40	87,00						

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LHKB-2

GEO DRILLING AS	REGISTRERING BOREDATA	SIDE	3

PROSJEKT:	STED:	HULL-NR:	KRONE:	DATO:	MASKIN:	FALL/RETNING:
P-160417	Fen feltet, Ulefoss	LHKB - 2	NQ2"		Diamec U-8 APC	Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
179,40	182,40	3,00	900	800	20	8	Grått	
182,40	185,40	3,00	900	800	20	8	Grått	
185,40	188,40	3,00	900	800	20	8	Grått	
188,40	191,40	3,00	900	800	20	8	Grått	
191,40	194,40	3,00	900	800	20	8	Grått	
194,40	197,40	3,00	900	800	20	8	Grått	
197,40	200,40	3,00	900	800	20	8	Grått	
200,40	203,40	3,00	900	800	20	8	Grått	
203,40	206,40	3,00	900	900	20	8	Grått	
206,40	209,40	3,00	900	850	20	8	Grått	
209,40	212,40	3,00	900	850	20	8	Grått	Dårlig fjell
212,40	215,40	3,00	900	900	20	8	Grått	
215,40	218,40	3,00	900	950	20	8	Grått	
218,40	221,40	3,00	900	1000	20	9	Grått	
221,40	224,40	3,00	900	1000	20	9	Grått	
224,40	227,40	3,00	900	1000	20	9	Grått	
227,40	230,40	3,00	900	1000	20	9	Grått	
230,40	233,40	3,00	900	1200	20	9	Grått	Dårlig fjell
233,40	236,40	3,00	900	1200	19	9	Grått	
236,40	239,40	3,00	900	1200	17	9	Grått	
239,40	242,40	3,00	900	1200	17	9	Grått	
242,40	245,40	3,00	900	1200	17	9	Grått	Dårlig fjell
245,40	248,40	3,00	900	1200	17	9	Grått	
248,40	251,40	3,00	900	1200	17	9	Grått	Dårlig fjell, mistet spylevannet
251,40	254,40	3,00	900	1150	17	9	Grått	Dårlig fjell, støping
254,40	257,40	3,00	900	1200	17	9	Grått	
257,40	260,40	3,00	900	1200	20	9	Grått	
260,40	263,40	3,00	900	1200	20	9	Grått	
263,40	266,40	3,00	900	1200	20	9	Grått	
266,40	269,40	3,00	900	120	20	9	Grått	
269,40	272,40	3,00	900	1200	20	9	Grått	
SUM	272,40	93,00						

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Appendix 2 side 17
LHKB-2

GEO DRILLING AS	REGISTRERING BOREDATA			SIDE	4
PROSJEKT: P-160417	STED: Fen feltet, Ulefoss	HULL-NR: LHKB - 2	KRONE: NQ2"	DATO:	MASKIN: Diamec U-8 APC

FALL/RETNING: Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
272,40	275,40	3,00	900	1200	20	10	Grått	
275,40	278,40	3,00	900	1200	20	11	Grått	
278,40	281,40	3,00	900	1200	20	11	Grått	
281,40	283,30	1,90	900	1200	20	11	Grått	
283,30	284,40	1,10	900	1200	20	11	Grått	Dårlig formasjon
284,40	287,40	3,00	900	1200	20	11	Grått	
287,40	290,40	3,00	900	1200	20	11	Grått	
290,40	293,40	3,00	900	1200	20	11	Grått	
293,40	296,40	3,00	900	1200	20	11	Grått	
296,40	299,40	3,00	900	1200	20	11	Grått	
299,40	302,40	3,00	900	1200	20	11	Grått	
302,40	305,40	3,00	900	1200	20	11	Grått	
305,40	308,40	3,00	900	1200	20	11	Grått	
308,40	311,40	3,00	900	1200	20	11	Grått	
311,40	314,40	3,00	900	1200	20	11	Grått	
314,40	317,40	3,00	900	1200	20	11	Grått	
317,40	320,40	3,00	900	1200	20	13	Grått	
320,40	323,40	3,00	900	1200	20	13	Grått	
323,40	326,40	3,00	900	1200	20	14	Grått	
326,40	329,40	3,00	900	1200	20	14	Grått	
329,40	332,40	3,00	900	1200	20	12	Grått	
332,40	335,40	3,00	900	1200	20	12	Grått	
335,40	338,40	3,00	900	1200	20	13	Grått	
338,40	341,40	3,00	900	1200	20	13	Grått	
341,40	344,40	3,00	900	1200	20	13	Grått	
344,40	347,40	3,00	900	1200	20	13	Grått	
347,40	350,40	3,00	900	1200	20	12	Grått	
350,40	353,40	3,00	900	1200	20	13	Grått	
353,40	356,40	3,00	900	1200	20	13	Grått	
356,40	359,40	3,00	900	850	15	15	Grått	
359,40	362,20	2,80	900	900	20	15	Grått	
SUM	362,20	89,80						

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Appendix 2 side 18
LHKB-2

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 5
PROSJEKT: P-160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 2		KRONE: NQ2"	DATO: / MASKIN: Diamec U-8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
362,20	365,20	3,00	900	1050	20	15	Grått	
365,20	368,30	3,10	900	1300	18	15	Grått	Dårlig sone fra 367,50 - 368,00 meter
368,30	371,20	2,90	900	1350	18	16	Grått	
371,20	374,30	3,10	900	1400	17	16	Grått	
374,30	377,40	3,10	900	1400	18	16	Grått	
377,40	380,40	3,00	900	1450	19	16	Grått	
380,40	383,40	3,00	900	1500	19	16	Grått	
383,40	386,40	3,00	900	1400	19	16	Grått	
386,40	389,40	3,00	900	1450	19	16	Grått	
389,40	392,40	3,00	900	1500	17	16	Grått	
392,40	395,40	3,00	900	1500	16	15	Grått	
395,40	398,40	3,00	900	1500	18	14	Grått	
398,40	401,40	3,00	900	1550	18	16	Grått	
401,40	403,80	2,40	900	1500	17	17	Grått	
403,80	405,80	2,00	900	1500	18	16	Grått	
405,80	407,40	1,60	900	1650	16	8	Grått	Dårlig sone mellom 406,00 - 406,10 meter, rassone
407,40	410,40	3,00	900	1150	15	8	Grått	
410,40	413,40	3,00	900	900	17	9	Grått	
413,40	416,40	3,00	900	1250	16	9	Grått	
416,40	419,40	3,00	900	1450	15	10	Grått	
419,40	422,40	3,00	900	1500	18	10	Grått	
422,40	425,40	3,00	900	1500	18	10	Grått	
425,40	428,40	3,00	900	1500	18	11	Grått	
428,40	431,40	3,00	900	1500	15	11	Grått	
431,40	434,40	3,00	900	1500	18	11	Grått	
434,40	437,40	3,00	900	1500	15	11	Grått	
437,40	440,40	3,00	900	1500	17	11	Grått	Helt og godt fjell
440,40	443,40	3,00	900	1700	16	11	Grått	
443,40	446,40	3,00	900	1750	15	11	Grått	Helt og godt fjell
446,40	449,40	3,00	900	1650	15	11	Grått	
449,40	452,40	3,00	900	1500	17	11	Grått	Helt og godt fjell
SUM	452,40	90,20						

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Appendix 2 side 19
LHKB-2

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 6
PROSJEKT: P-160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 2		KRONE: NQ2"	DATO: / MASKIN: Diamec U-8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
452,40	455,40	3,00	900	1500	16	12	Grått	Bra fjell
455,40	458,40	3,00	900	1500	16	12	Grått	
458,40	461,40	3,00	900	1450	16	10	Grått	Bra fjell
461,40	464,40	3,00	900	1450	16	10	Grått	
464,40	467,40	3,00	900	1450	16	10	Grått	Bra fjell
467,40	470,40	3,00	900	1450	16	11	Grått	
470,40	473,40	3,00	900	1500	16	11	Grått	
473,40	476,40	3,00	900	1500	16	11	Grått	
476,40	479,40	3,00	900	1500	16	11	Grått	
479,40	482,40	3,00	900	1500	16	11	Grått	Hardt godt fjell
482,40	485,35	2,95	900	1600	16	12	Grått	
485,35	487,45	2,10	900	1600	16	12	Grått	Hardt, men dårligere
487,45	490,45	3,00	900	1600	16	12	Grått	
490,45	493,55	3,10	900	1600	16	11	Grått	Hardt, men dårligere
493,55	496,65	3,10	900	1600	16	11	Grått	
496,65	499,55	2,90	900	1600	16	11	Grått	
499,55	502,65	3,10	900	1600	16	11	Grått	
502,65	505,70	3,05	900	1600	16	11	Grått	
505,70	508,80	3,10	900	1600	16	11	Grått	
508,80	511,90	3,10	900	1600	16	12	Grått	
511,90	514,95	3,05	900	1600	16	12	Grått	
514,95	518,05	3,10	900	1600	16	13	Grått	
518,05	521,10	3,05	900	1600	16	13	Grått	
521,10	524,20	3,10	900	1600	16	14	Grått	
524,20	527,30	3,10	900	1600	16	14	Grått	
527,30	530,40	3,10	900	1600	16	14	Grått	
530,40	533,40	3,00	900	1600	16	14	Grått	
533,40	536,40	3,00	900	1600	16	14	Grått	
536,40	539,40	3,00	900	1600	16	14	Grått	
539,40	542,40	3,00	900	1600	16	14	Grått	
542,40	545,40	3,00	900	1600	16	14	Grått	
SUM	545,40	93,00						

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Appendix 2 side 20
LHKB-2

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 7		
PROSJEKT: P-160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 2		KRONE: NQ2"	DATO:	MASKIN: Diamec U-8 APC	FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
545,40	551,40	6,00	900	1650	15	15	Grått			
551,40	554,40	3,00	900	1600	15	15	Grått			
554,40	557,40	3,00	900	1200	15	15	Grått	Dårlig fjell		
557,40	560,40	3,00	900	1100	15	15	Grått			
560,40	563,30	2,90	900	1150	15	15	Grått	Dårlig fjell		
563,30	566,40	3,10	900	1200	17	15	Grått			
566,40	567,70	1,30	900	1200	17	15	Grått	Dårlig fjell		
567,70	569,40	1,70	900	1200	17	15	Grått			
569,40	572,40	3,00	900	1200	17	15	Grått			
572,40	575,40	3,00	900	1200	17	15	Grått			
575,40	578,40	3,00	900	1200	17	15	Grått			
578,40	581,40	3,00	900	1200	17	15	Grått			
581,40	584,40	3,00	900	1200	17	15	Grått			
584,40	587,40	3,00	900	1200	17	15	Grått			
587,40	590,40	3,00	900	1200	17	15	Grått			
590,40	593,40	3,00	900	1200	17	15	Grått			
593,40	596,40	3,00	900	1200	17	15	Grått			
596,40	599,40	3,00	900	1200	17	15	Grått			
599,40	602,40	3,00	900	1200	17	15	Grått			
602,40	605,40	3,00	900	1200	17	15	Grått			
605,40	608,40	3,00	900	1200	17	15	Grått			
608,40	611,40	3,00	900	1200	17	15	Grått			
611,40	614,40	3,00	900	1200	17	15	Grått			
614,40	617,40	3,00	900	1200	17	15	Grått	Dårlig fjell		
617,40	620,10	2,70	900	1200	17	15	Grått	Dårlig fjell		
620,10	623,20	3,10	900	1200	17	15	Grått			
623,20	626,25	3,05	900	1200	17	15	Grått			
626,25	629,35	3,10	900	1200	17	15	Grått			
629,35	632,40	3,05	900	1200	17	15	Grått			
632,40	635,40	3,00	900	1150	16	16	Grått			
635,40	638,40	3,00	900	1200	17	15	Grått			
SUM	638,40	93,00								

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Appendix 2 side 21
LHKB-2

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	8
PROSJEKT: P-160417		STED: Fen feltet, Ulefoss			HULL-NR: LHKB - 2		KRONE: NQ2"	DATO:	MASKIN: Diamec U-8 APC / FALL/RETNING: Lodd
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR	
638,40	641,40	3,00	900	1100	18	15	Grått		
641,40	644,40	3,00	900	1150	17	15	Grått		
644,40	647,00	2,60	900	1150	16	16	Grått		
647,00	650,10	3,10	900	1200	16	16	Grått		
650,10	653,15	3,05	900	1200	16	15	Grått		
653,15	656,25	3,10	900	1200	16	15	Grått		
656,25	659,35	3,10	900	1200	16	15	Grått		
659,35	662,40	3,05	900	1200	16	15	Grått		
662,40	665,40	3,00	900	1200	16	15	Grått		
665,40	668,40	3,00	900	1200	16	15	Grått		
668,40	671,40	3,00	900	1200	16	15	Grått		
671,40	674,40	3,00	900	1200	16	15	Grått	Noen dårlige soner	
674,40	677,40	3,00	900	1200	16	15	Grått		
677,40	680,40	3,00	900	1200	16	15	Grått	Noen dårlige soner	
680,40	683,40	3,00	900	1200	16	15	Grått		
683,40	686,40	3,00	900	1200	16	15	Grått	Noen dårlige soner	
686,40	689,40	3,00	900	1200	16	15	Grått		
689,40	692,40	3,00	900	1200	16	15	Grått		
692,40	694,90	2,50	900	1150	16	14	Grått	Dårlig berg	
694,90	697,85	2,95	900	1100	15	14	Grått		
697,85	700,70	2,85	900	1200	15	15	Grått	Dårlig berg	
700,70	702,30	1,60	900	1200	16	15	Grått		
702,30	704,40	2,10	900	900	14	14	Grått	Meget dårlig fjell, ras	
704,40	705,00	0,60	900	1100	13	16	Grått	Meget dårlig fjell, ras	
705,00	706,30	1,30	900	1400	12	16	Grått	Meget dårlig fjell, ras	
706,30	707,40	1,10	900	1250	12	15	Grått		
707,40	708,90	1,50	900	1300	15	16	Grått	Noe bedre fjell	
SUM	708,90	70,50							

GEO DRILLING AS	REGISTRERING BOREDATA	SIDE	9

PROSJEKT:	STED:	HULL-NR:	KRONE:	DATO:	MASKIN:	FALL/RETNING:
P-160417	Fen feltet, Ulefoss	LHKB - 2	NQ2"		Diamec U-8 APC	Lodd

FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR
708,90	710,60	1,70	900	1200	10	18	Grått	Dårlig fjell
710,60	712,10	1,50	900	1500	10	20	Grått	Dårlig fjell, ras 711,90 - 712,10 meter
712,10	713,40	1,30	900	1150	10	19	Grått	Dårlig fjell, litt kjernetap
713,40	713,90	0,50	900	1200	10	21	Grått	Dårlig fjell
713,90	715,00	1,10	900	1350	12	22	Grått	Dårlig fjell, ras
715,00	716,40	1,40	900	1300	13	19	Grått	Dårlig fjell, ras
								HULL AVSLUTTES ETTER MANGE STØPINGER.
SUM	716,40	7,50						

Appendix 3. Selected drill-core pictures.

NGU Report 2019.022
Appendix 3 side 1
LHKB-2, 700 – 705 m

NGU Report 2019.022
Appendix 3 side 2
LHKB-2, 710 – 715 m

GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

Geological Survey of Norway
PO Box 6315, Sluppen
N-7491 Trondheim, Norway

Visitor address
Leiv Eirikssons vei 39
7040 Trondheim

Tel (+ 47) 73 90 40 00
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/