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Borehole logging in Smøla and Bømlo

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NORGES GEOLOGISKE UNDERSØKELSE
- NGU -

REPORT

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Borehole logging in Smøla and Bømlo

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Summary:

AS a part of the Base 2 project NGU has performed geophysical borehole logging in four boreholes at Smøla, Møre and Romsdal county and three at Bømlo, Vestland county. The purpose of the drilling and logging was to study onshore deep weathered basement rocks. Such rocks can be a potential oil reservoir offshore, on the continental shelf.

The logged parameters were resistivity, porosity, seismic velocity, water conductivity, total gamma radiation, spectral gamma, magnetic susceptibility, Induced Polarisation, and Self Potential. All boreholes were logged using acoustic and optical televiewer. Flow measurements and pumping were performed. Lugeon test were done by the drilling company.

The results show heavily fractured rock in all boreholes. Especially in Bh4 at Smøla the resistivity was very low. Combined with low p-wave velocity and fracturing it can be interpreted as weathered and altered rock. IP anomalies may indicate clay.

The Lugeon tests showed quite low values and correlates well with the fracture frequency. From the Lugeon numbers the hydraulic conductivity and permeability are calculated. Calculated apparent porosity from the resistivity log, using Archi's law, is in the same range as laboratory porosity measurements on cores performed by NTNU. Most of the porosity values are in the range of 1 – 4 %.

Flow measurements showed no vertical flow in the boreholes and no in/out flow from fractures. Pumping indicated very low water capacity in all wells except Bh3, Bømlo. Near surface water just below the casing flowed into the borehole.

Bh2 at Bømlo was stuck at 27 m depth. Reopening of the borehole failed, and masses (sand, clay) flowed into the borehole and blocked it.

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

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1. INTRODUCTION

As part of the Base 2 project, NGU has performed geophysical borehole logging in four boreholes at Smøla, Møre and Romsdal county and three at Bømlo, Vestland county. The purpose of the drilling and logging was to study onshore deep weathered basement rocks. Such rocks can be a potential oil reservoir offshore, on the continental shelf.

The drilling was performed by Geodrilling AS, a Norwegian company, in October-December 2019 (Smøla) and January/February 2020 (Bømlo). Figure 1 shows one of the drilling locations at the Smøla wind farm. Most of the boreholes cut through heavily fractured or weathered rock, and the drilling company had to use cement to stabilise the borehole wall. Several geophysical parameters were measured (see table 1). Both optical and acoustic televiewers were run, and the well was pumped to map the water capacity. Before cementing the borehole wall, the drilling company performed Lugeon tests several times during the drilling operation.

The logging was done by Harald Elvebakk and Jomar Gellein, NGU a few weeks after drilling: November 2019 (Smøla), January 2020 (Smøla), Mars 2020 (Bømlo) and October 2020 (Bømlo).

Figure 1. Drilling in the windfarm area at Smøla. (Photo: NGU).

2. BOREHOLE LOGGING PARAMETERS

NGU has been doing borehole logging onshore since 1999. Since then, the number of probes has increased, 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/).

2.1 Probes and logging parameters.

Table 2 gives an overview of all measured parameters in the Smøla and Bømlo boreholes (See also NGU's website).

https://www.ngu.no/emne/borehullslogging

Table 1. 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
Optical Televiewer	1 m/min	1 mm
Borehole deviation (HIRAT)	1 – 3 m/min	1 cm
Flow measurements	5 m/min	1 cm

Temperature

Measuring exact temperature should be performed some days after the drilling ends since the energy from the drilling process (hot drilling fluid, rock crushing, and friction) increases the temperature in the borehole. From the temperature log, the temperature gradient ($^{o}C/km$) can be calculated. Local changes in the gradient may indicate fractures related to the inflow (or the outflow) of water. A change in the thermal conductivity of the rock also influences the gradient.

Fluid conductivity

The fluid conductivity (µS/cm) depends on the fluid salinity. The conductivity measurements can identify zones of water inflow/outflow and locate zones of different water quality. The measured values are temperature compensated to a reference temperature of 25ºC.

Natural Gamma

The natural gamma log (API standard) is useful for geological mapping along the walls of a borehole. All rocks contain small quantities of radioactive material, given that certain minerals contain trace amounts of Uranium and Thorium. Potassium-bearing minerals (usually the most common) 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 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 relatively easy to pick, while the arrival of the S-wave is less distinct. 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 to identify lithological boundaries and 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 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 impact 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 the resistivity, the calculated porosity using Archie's law will be incorrect.

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 minor SP anomalies.

Induced Polarisation, IP

IP is an electrical method that is primarily 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 when minerals 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 called the BHTV probe (Bore Hole Tele Viewer), 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, strike and fracture 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. Digitalising 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 the 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.

Optical televiewer

The DOPTV (Digital Optical Televiewer) films the inside borehole wall continuously every mm down the borehole. The probe of the optical televiewer comprises a conventional light source, a camera, and an orientation device. The high-technology optical system of the camera, i.e., including a 360° circle view lens, allows a 360° simultaneous imaging of the wall of the drill hole every mm downward. The pixel resolution of the images is of 1 by 1 mm. In real-time, the images of the walls are taken orientated relative to the magnetic N and unwrapped. The orientation device also provides the drill hole deviation from its vertical axis. The borehole deviation is measured every 5 cm during the logging, and the velocity of the logging is 1 m/min.

Specific geological features, such as fractures, crushed zones observed in the image, are digitised. Their characteristics (thickness, opening, infill, etc.) and orientation (dip direction and angle) are gathered relative to the magnetic N and corrected from the drill hole deviation. Digitalising the observed features on the borehole image generates the strike and dip of the identified structures that can be presented in fracture stereograms, rose diagrams, fracture frequency histograms, and thickness calculations of beds, bands, and fractures.

Borehole deviation

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

Flow measurements

By using a flowmeter, vertical waterflow (up and down) in a borehole can be detected. Also, the inflow and outflow of water (in fractures) are mapped. If data quality is good, the amount of the water flow can be calculated (l/h). Flow measurements are often combined with pumping. The data quality is often poor in deviated boreholes.

3. INVESTIGATED AREAS

As mentioned in chapter 1, the investigated areas should be in fractured, deep weathered basement rock. Such areas are found at Smøla, Møre and Romsdal and at Bømlo, Vestland. Locations are seen in Figure 2.

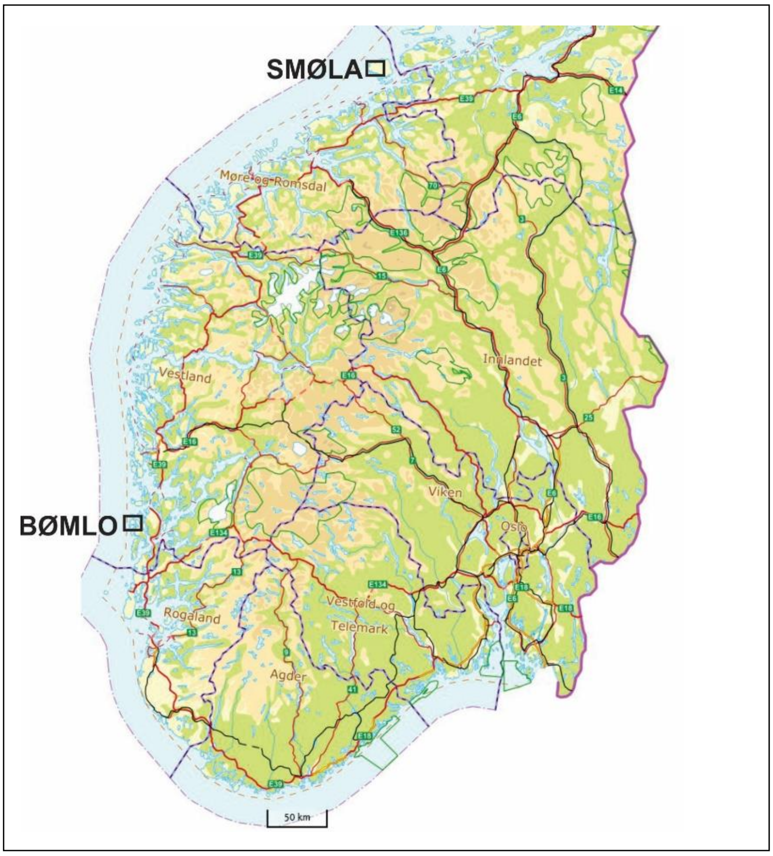


Figure 2. Borehole locations, Smøla and Bømlo.

3.1 Smøla

Four boreholes were drilled at Smøla. Table 2 shows coordinates and technical data for the Smøla boreholes. Bh1 and Bh2 were drilled at Jøstølen, not far from the sea. Bh3 and Bh4 were drilled inside the Smøla Windfarm. Figure 3 shows the geological map of Smøla with the boreholes.

Table 2. Smøla borehole data.

Bh	E	N	Sone	Dip	Azimuth	Length	Diameter	M.a.s.l
Bh1	447080	7025814	32 wgs84	55 º	N331	99.1 m	96 mm	6.4 m
Bh2	447008	7025835	32 wgs84	60 º	N303	102.3 m	96 mm	7.2 m
Bh3	445820	7031251	32 wgs84	60 º	N032	68.5 m	96 mm	27.1 m
Bh4	446841	7030851	32 wgs84	60 º	N282	100.0 m	96 mm	26.9 m

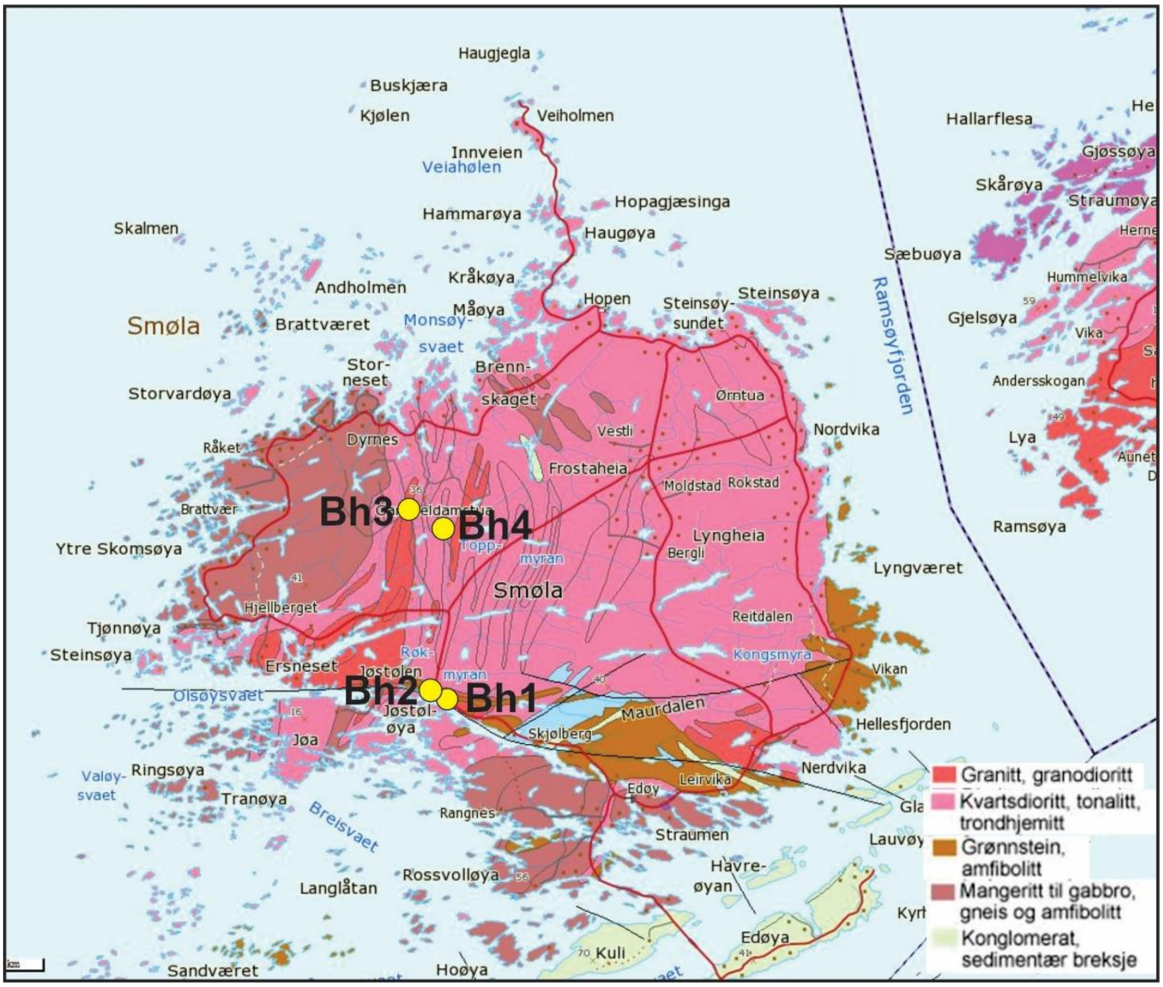


Figure 3. Geological map of Smøla including borehole locations.

Bh1 and Bh2 were drilled in reddish granite with cutting veins of amphibolite/gabbro. Both boreholes were heavily fractured. A picture from the borehole location rock is shown in Figure 4. Bh3 and Bh4 were drilled in Quartz diorite inside the Smøla windfarm. There were few fractures in Bh3 with no cementing during drilling, while Bh4 was heavily fractured/weathered.


Figure 4. Granite rock close to Bh1 and Bh2 location.

3.2 **Bømlo**

Three boreholes were drilled at Bømlo. Table 3 shows the coordinates and technical data of the boreholes. All boreholes were drilled in granite. Figure 6 shows logging in Bh2.

All boreholes were fractured/weathered. Bh2 was stuck at 27 m depth, probably caused by a fracture zone. Masses from this zone probably blocked the borehole.

Table 3. Bømlo borehole data.

Bh	E	N	Sone	Dip	Azimuth	Length	Dimeter	M.a.s.l
Bh1	284487	6640186	32 wgs84	60 °	N330	80 m	96 mm	1 m
Bh2	284547	6640353	32 wgs84	60 °	N167	80 m	96 mm	19 m
Bh3	284905	6636551	32 wgs84	80 °	N011	41.6 m	96 mm	15 m

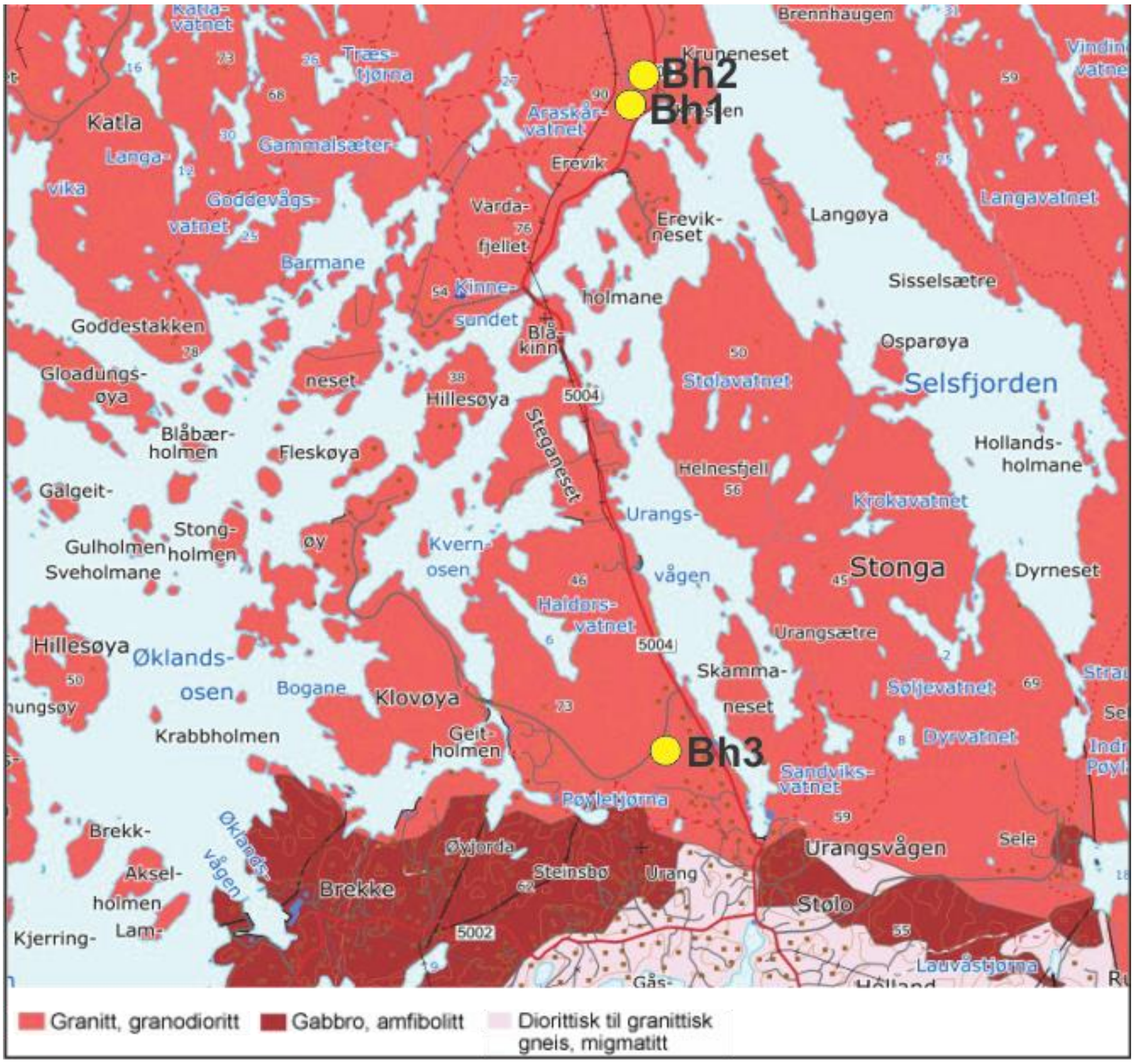


Figure 5. Geological map of Bømlo including borehole locations.

Figure 6. Logging in Bh2 at Bømlo in mars 2020.

4. RESULTS

All boreholes are presented as combined logs (resistivity, seismic velocity, magnetic susceptibility, IP, SP, total gamma radiation and apparent porosity). Logs showing the gamma spectrometry (U, Th, K) and temperature, thermal gradient, water conductivity, total gamma are also presented. Data from acoustic televiewer are used to present fracture frequency histograms, fracture stereograms, ovalisation and caliper logs. The optical televiewer data was some bad due to muddy water.

Flow measurements and pumping were performed in all boreholes. However, these measurements were done after cementation and re-drilling of the boreholes. It is not possible to do flow measurements before cementing. Therefore, these measurements seem to be useless.

Special attention is paid to the Lugeon test. This test is described in Figure 7. It was performed by the drilling company at several sections in the boreholes before cementing while all the factures were open. NGU researchers use the Lugeon test and consider it to be the best way to evaluate rock permeability. From the Lugeon number (l/m/min), the hydraulic conductivity can be calculated, see Figure 7 (Camilo Quiñones-Rozo, P.E. 2013).

Lugeon tests

Lugeon test: A section of the borehole is locked by packers while water is pressed into the fractures with an over pressure of 10 bars.

Time used was 5 min and the water quantity was measured.

The Lugeon number is l/min/m.

From the Lugeon number the hydraulic conductivity can be calculated

These tests were performed before the fractures were cemented

Under ideal conditions (i.e., homogeneous and isotropic) one Lugeon is equivalent to 1.3×10^{-5} cm/sec (Fell et al., 2005). Table 2 describes the conditions typically associated with different Lugeon values, as well as the typical precision used to report these values.

Table 2. Condition of rock mass discontinuities associated with different Lugeon values

Lugeon Range	Classification	Hydraulic Conductivity Range (cm/sec)	Condition of Rock Mass Discontinuities	Reporting Precision (Lugeons)
<1	Very Low	$< 1 \times 10^{-5}$	Very tight	<1
1-5	Low	$1 \times 10^{-5} - 6 \times 10^{-5}$	Tight	± 0
5-15	Moderate	$6 \times 10^{-5} - 2 \times 10^{-4}$	Few partly open	± 1
15-50	Medium	$2 \times 10^{-4} - 6 \times 10^{-4}$	Some open	± 5
50-100	High	$6 \times 10^{-4} - 1 \times 10^{-3}$	Many open	± 10
>100	Very High	$> 1 \times 10^{-3}$	Open closely spaced or voids	>100

Figure 7. Description of the Lugeon test and classification of hydraulic conductivity.

4.1 **Smøla results**

Logging at Smøla was performed in November 2019 and January 2020. The logging was fulfilled without any problems: figures 8 and 9 show logging at the four locations at Smøla.

Figure 8. Logging in Bh1 (left) and Bh2 (right). Jøstølen, Smøla, Nov. 2019.

Figure 9. Logging in Bh3 (left) and Bh4 (right). The Smøla Wind farm, Feb. 2020.

4.1.1 <u>Temperature, water conductivity and total gamma, Bh1, Bh2, Bh3 and Bh4</u>

Figures 10 – 13 display logs of temperature, water electric conductivity, the total gamma and the calculated thermal gradient of the four Smøla boreholes. There are no significant variations in the temperature. The thermal gradient is low, 8 -10 ^{o}C/km. The seawater influences water conductivity at 30 m depth in Bh1, 95 m depth in Bh2 and about 90 m in Bh4. In Bh1 and Bh2 the gamma radiation clearly differs between the granite and amphibolite. The total gamma in the granite is 300 - 400 cps (API) and 20 – 100 cps in the amphibolite, which are typical values for these rocks (Elvebakk 2011).

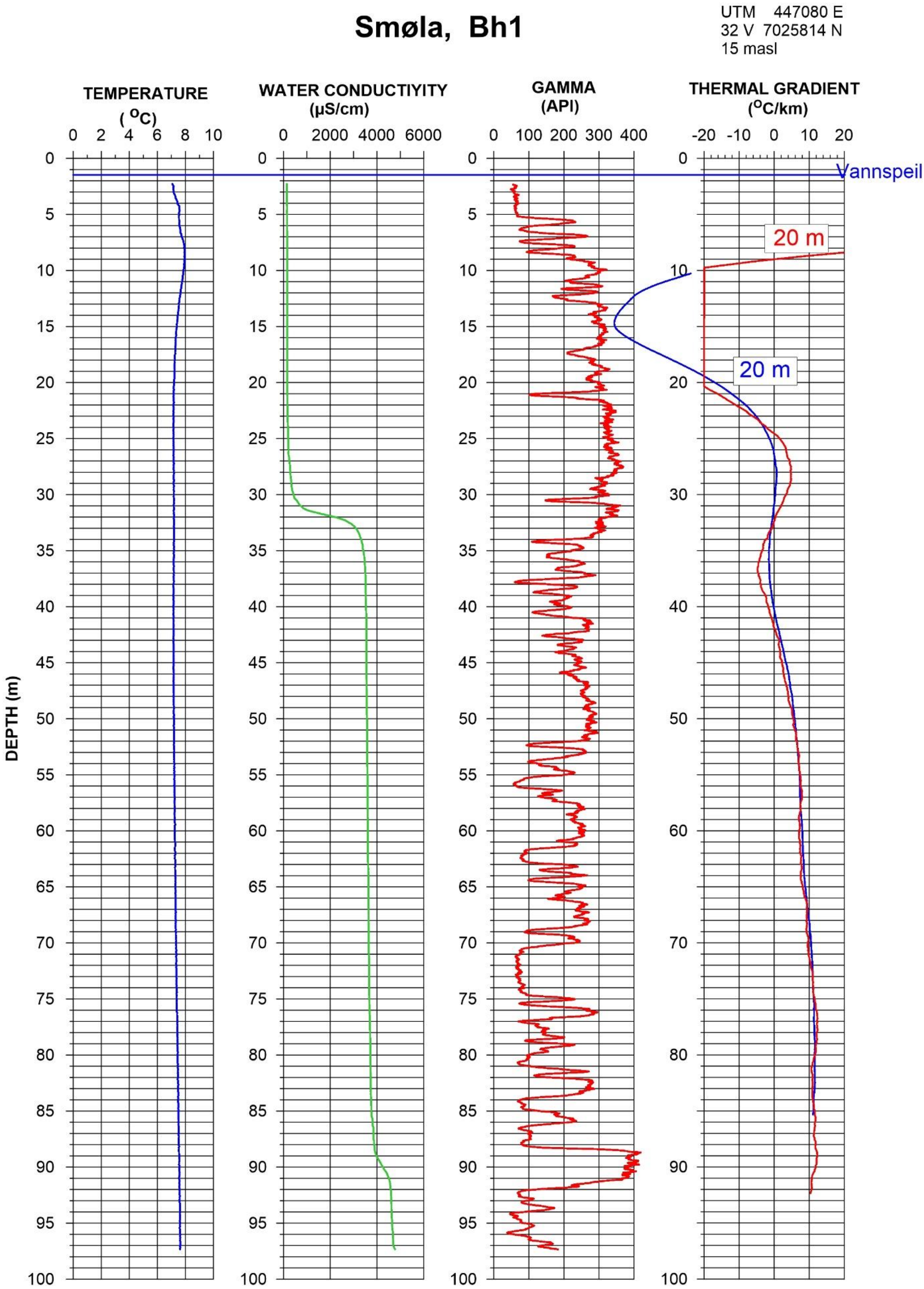


Figure 10. Smøla Bh1. Temperature, water conductivity, total gamma and thermal gradient.

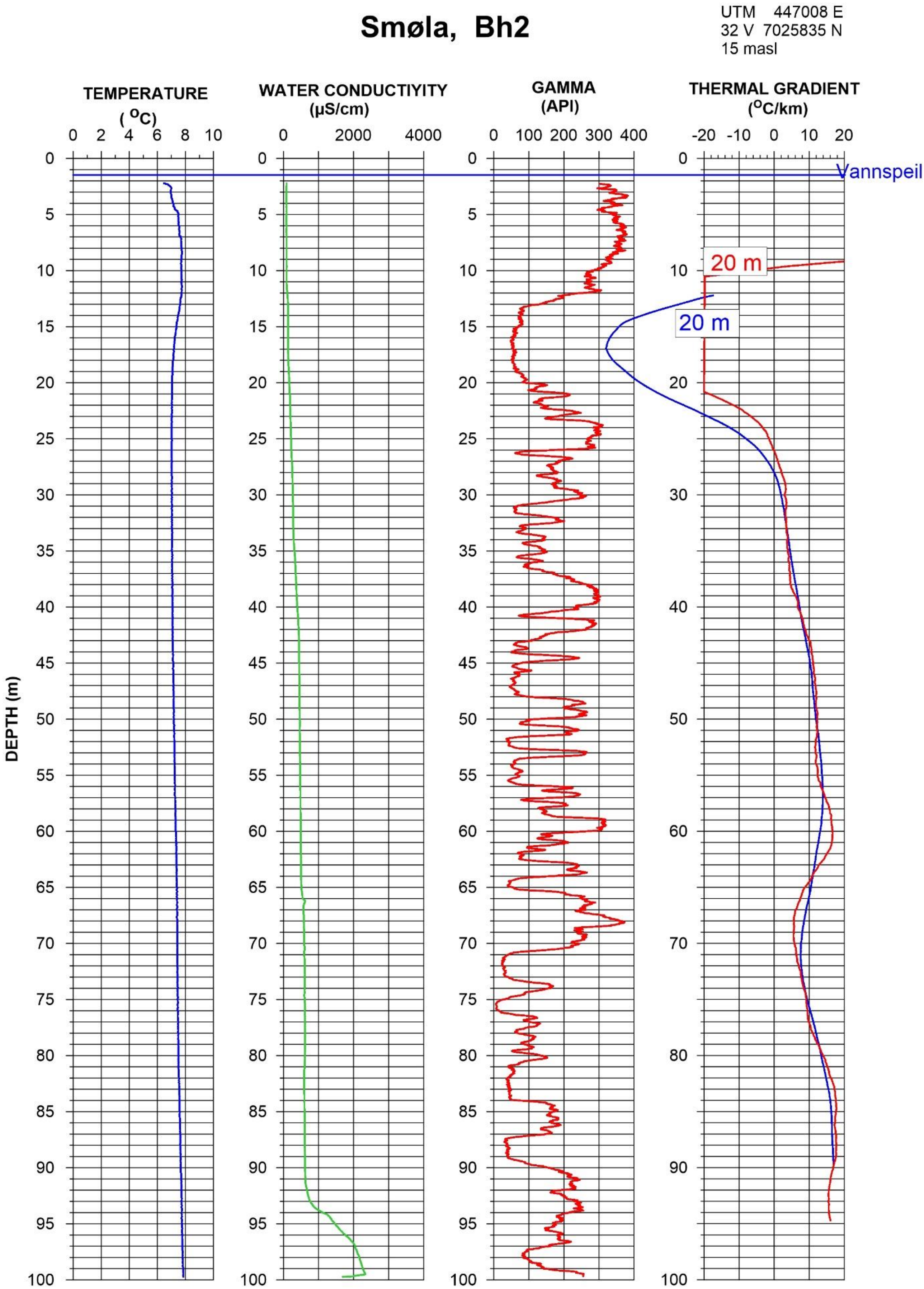


Figure 11. Smøla Bh2. Temperature, water conductivity, total gamma and thermal gradient.

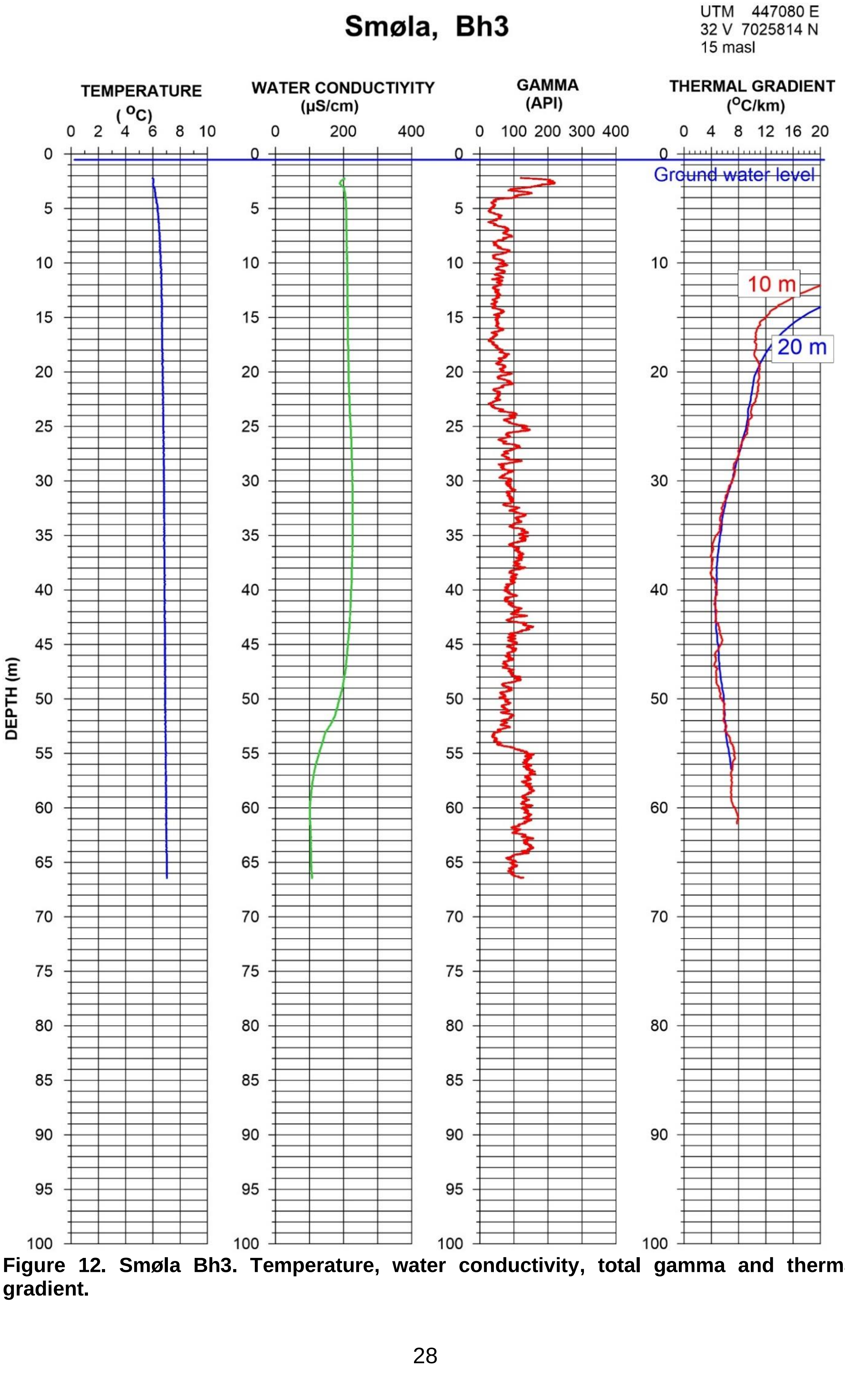


Figure 12. Smøla Bh3. Temperature, water conductivity, total gamma and thermal gradient.

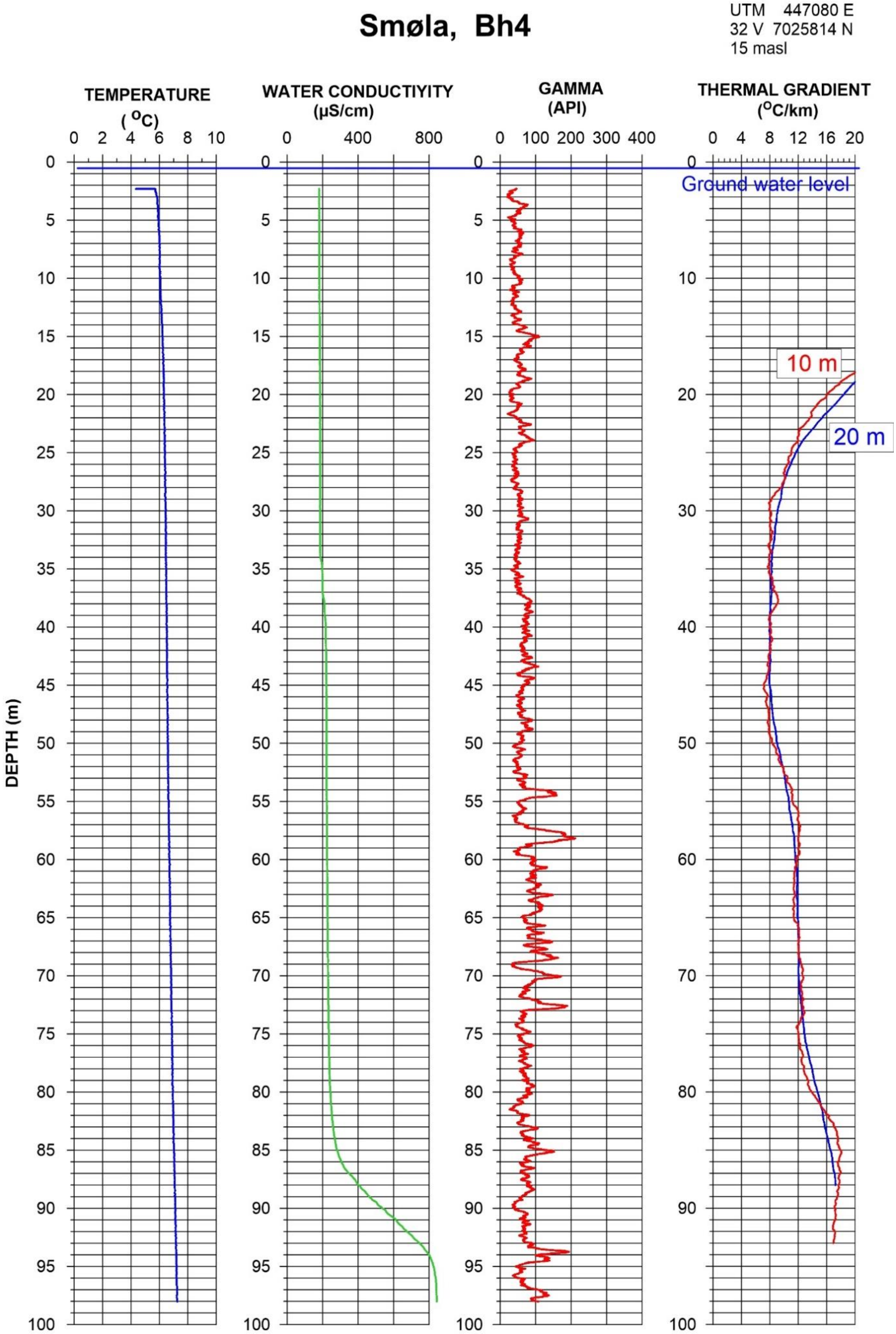


Figure 13. Smøla Bh4. Temperature, water conductivity, total gamma and thermal gradient.

4.1.2 Gamma spectrometry Smøla, Bh1, Bh2, Bh3 and Bh4.

Gamma spectral logs are shown in Figure 14 – 17. The total gamma logs clearly show the difference between the granite (high gamma) and the amphibolite (low gamma) in Bh1 and Bh2. The granite has 300 – 400 cps (API), while the amphibolite has about 50 - 100 cps (API). Most of the highest gamma radiation comes from the U element, up to 26 ppm in Bh1. The Th content is about 3 ppm except at 25.5 m depth in Bh1 where 15 ppm is measured. About 10 ppm is observed at 60 m and 98 m depth. K is low, less than 1 %. The same pattern is observed in Bh2, figure 15 with a very clear correlation between U and the granite.

In Bh3, Figure 16, quartz diorite, the gamma radiation is 50 -150 cps. At 55 m depth the gamma radiation increases clearly, and so the U content. Figure 18 shows the cores from 53.6 -57.4 m. There is a change in the grain size at about 55 m, and the U content increases. U content is 5 -14 ppm, Th.

In Bh4, Figure 17, also quartz diorite, the gamma radiation is quite constant, 50 – 100 cps, except some peaks at 54, 58 and 73 m depth where both U and Th are increasing.

Table 4 show the mean, minimum and maximum content of U, Th and K for all the Smøla boreholes. U content in Bh1 and Bh2 is almost twice the content in Bh3 and Bh4 due to the granitic rock. The Th content is slightly higher in Bh1 and Bh2, while K is almost the same.

Table 4. U, Th and K content in the Smøla boreholes.

Bh	Umean	Umin	Umax	Thmean	Thmin	Thmax	Kmean	Kmin	Kmax
Bh1	12.9	2.3	26.8	2.9	0	14.2	0.3	0	2.4
Bh2	10.2	0	28.6	1.9	0	13.9	0.3	0	2.9
Bh3	6.9	0.6	14.0	2.3	0	10.2	0.3	0	1.5
Bh4	5.3	0.4	14.9	0.9	0	8.8	0.2	0	1.4

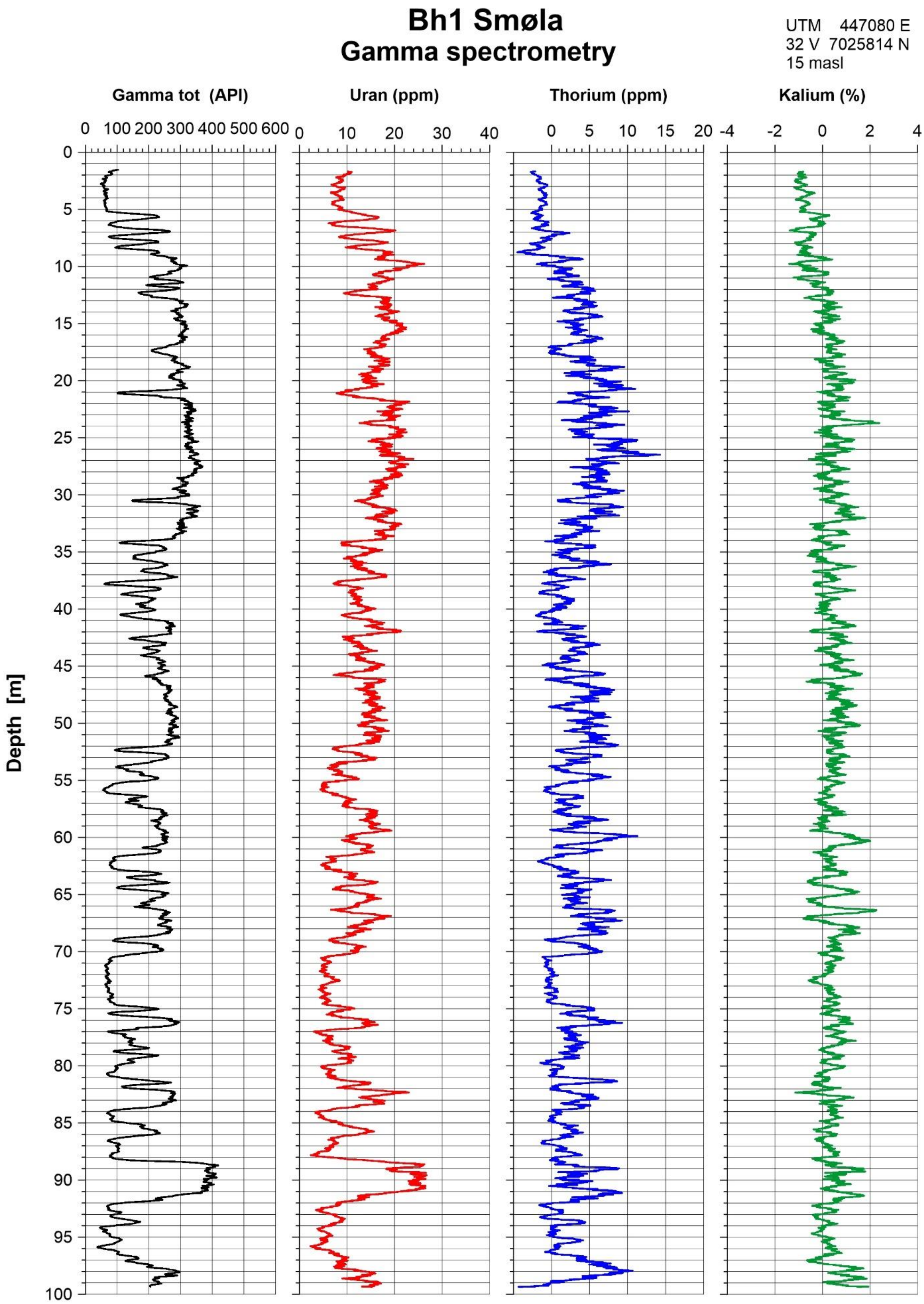


Figure 14. Bh1, Smøla. Total gamma, U (ppm), Th (ppm) and K (%)

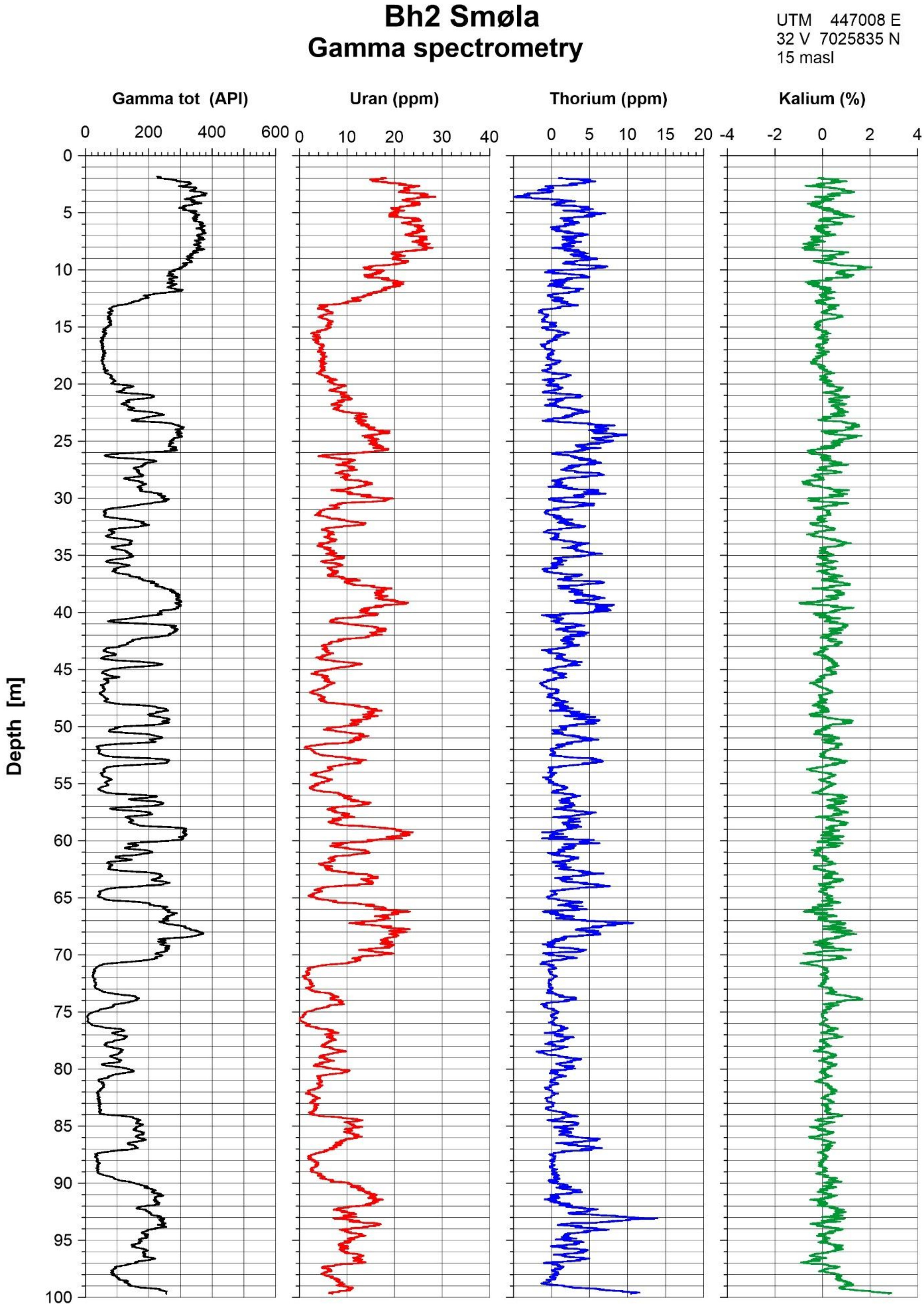


Figure 15. Bh2, Smøla. Total gamma, U (ppm), Th (ppm) and K (%).

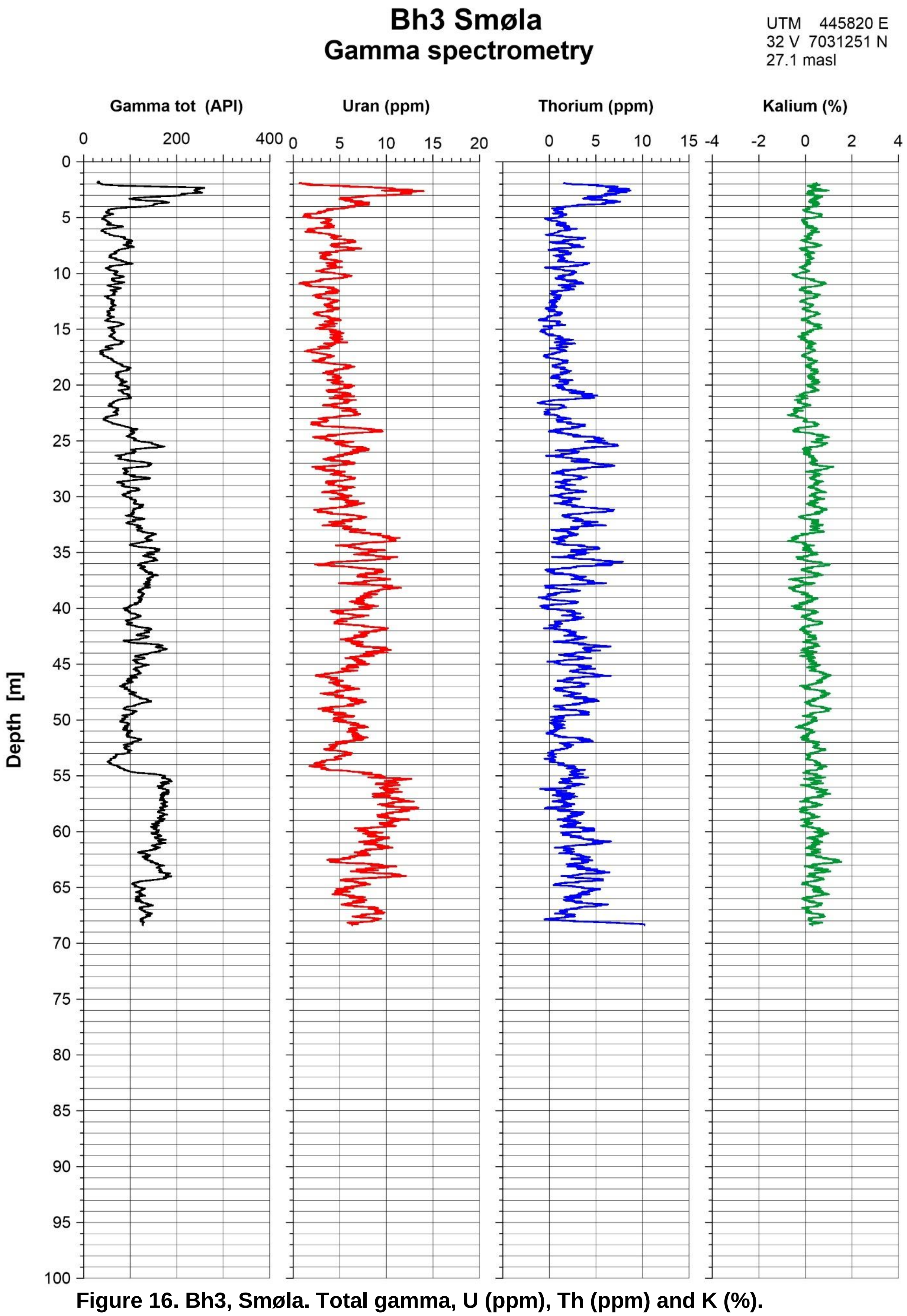


Figure 16. Bh3, Smøla. Total gamma, U (ppm), Th (ppm) and K (%).

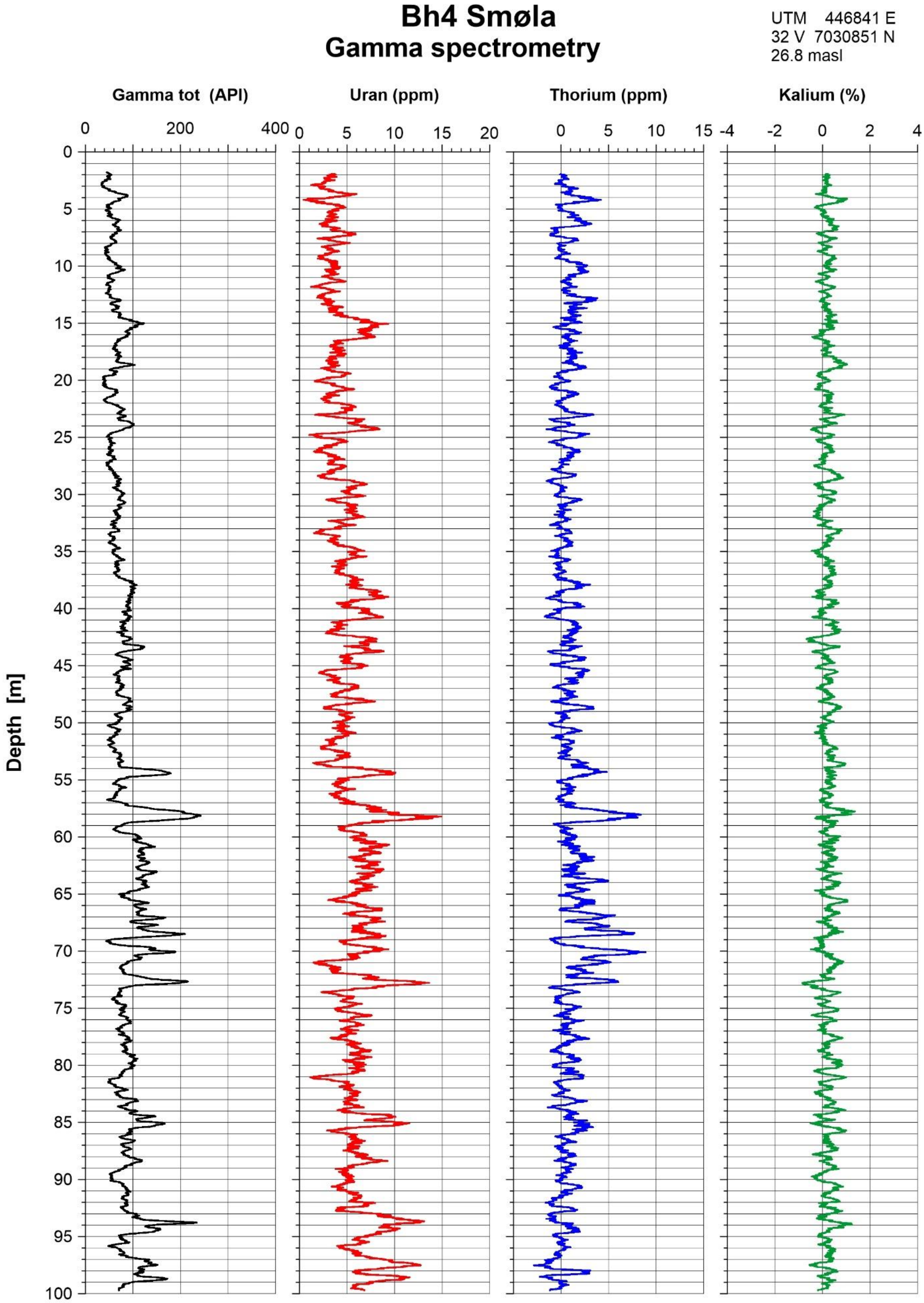


Figure 17. Bh4, Smøla. Total gamma, U (ppm), Th (ppm) and K (%).

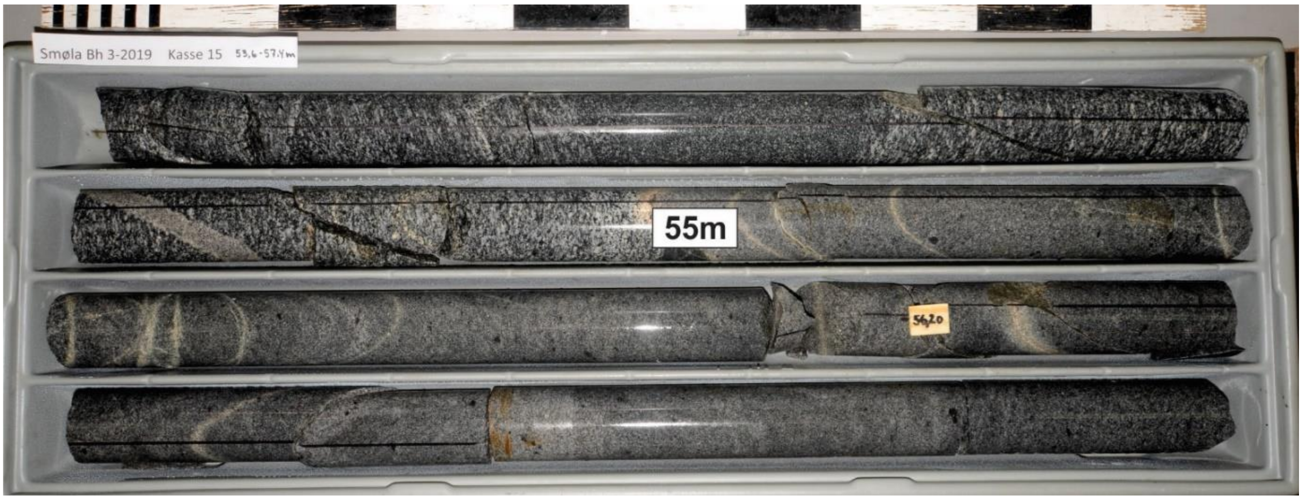


Figure 18. Bh3, Smøla. Cores 53.6 – 57.4 m.

4.1.3 Seismic P-velocity, total gamma, magnetic susceptibility, Resistivity, SP, IP and apparent porosity in Smøla Bh1, Bh2, Bh3, and Bh4.

Figures 19 – 25 show the combined logs in all Smøla boreholes. The data quality is overall quite good except for the P-wave data. Picking the first arrival of the seismic signal was somewhat tricky, which may be due to deviation of the borehole and/or an off-centred tool. The P-velocity is somewhat varying due to the alternating granite and amphibolite layers. P-velocity is 4000 – 5000 m/s in all four boreholes. This is slightly lower than in known granite and amphibolite rock in Norway (5000 - 6000 m/s). The reason for this could be fractured rock.

The total gamma results are described in Chapter 4.1.1. Total gamma radiation clearly differs between the granite (high) and amphibolite (low) in Bh1 and Bh2. In Bh3 and Bh4 the total gamma radiation is almost constant (only quartz diorite).

Bh1 resistivity.
The resistivity measurements are clearly influenced by the salt pore water below 30 m in Bh1. Local variations are caused by fractures. In the upper part, the resistivity is 6000 – 8000 ohm m which is a typical value for granite. Minor SP anomalies at 18.5 m and 29 m depth coincide both with IP anomalies and low resistivity. This is most likely caused by conductive minerals (sulphides or graphite). The resistivity in Bh1 decreases down to the bottom of the borehole, below 1000 ohmm. Usually, this means fractured rock with water. However, the more conductive porewater to the bottom will make the interpretation difficult. Alternatively, the results from the acoustic televiewer could confirm heavily fractured rocks in Bh1 (see Figure 20 and Chapter 4.2.1 later in this report). The fracture frequency increases from ca. 25 m depth. The cemented parts of the borehole also contribute to uncertainty, and the influence on the resistivity is unknown.

Bh2 resistivity.
The resistivity decreases from ca 3000 ohmm m in the upper part to 200 – 600 ohmm in the lower part. The water conductivity increases to the bottom but is still relatively low, close to fresh water. The borehole is heavily fractured, which can be seen on the fracture frequency histograms in Figure 22. Resistivity below 1000 ohmm usually means fractured rock with water-bearing fractures. The variation in resistivity is, in some way, also caused by the alternating layers of granite and amphibolite.

Bh3 resistivity.
In Bh3, Figure 23, the resistivity is almost constant and high (5000 – 6000 ohmm), and the water conductivity is low. There was no need for cementation, and no Lugeon tests were performed. An acoustic televiewer mapped only minor fractures (hairline fractures) in the quartz diorite.

Bh4 resistivity.
The resistivity in Bh4 is very unusual in that it shows very low values below 100 ohmm (Figure 24). The resistivity log was run two times to be sure of correct data and no instrument failure. Both logs showed the same result. There are no SP anomalies to indicate conductive minerals. A few weak IP anomalies correlate in some cases with low resistivity. These anomalies might be caused by clay. Several magnetic susceptibility high values occur in the lower part of the borehole but will probably not influence resistivity. It seems that the low resistivity is caused by the highly fractured rock. The fracture frequency (acoustic televiewer) correlates well with the resistivity log. This is shown in Figure 25. There are few fractures above 30 m depth and below 85 m depth. Between these depths, the resistivity is very low. Cores from 79.4 – 86.7 m depth are shown in Figure 26 and 27. The rock is highly fractured, almost like gravel. Increased IP values might indicate clay, and the metamorphic grade seem to be high.

In Bh1 and Bh2 some magnetic susceptibility high values can be observed, which correlate with low gamma in the amphibolite. Possibly, there are small amounts of magnetite or sulphides in the amphibolite. Such minerals were not observed when checking the cores. In large portions of the Bh3 and Bh4, the magnetic susceptibility is very low or zero. The low values are unusual and cannot be explained. Also, in the Veiholmen Bh (Olesen et al. 2019), the magnetic susceptibility was measured to be zero in parts of the borehole. All these boreholes are in quartz diorite.

The apparent porosity is calculated using Archie's law, SN resistivity, LN resistivity and borehole water conductivity. If conductive minerals and high conductive water are present, the porosity values are incorrect; however, this is not the situation in Bh4. The calculated porosity is relatively high, 4 – 6 %, with a top value of 10 % at 84.5 m depth. The conclusion is that the low resistivity in Bh4 is caused by fractures, weathered, or altered rock.

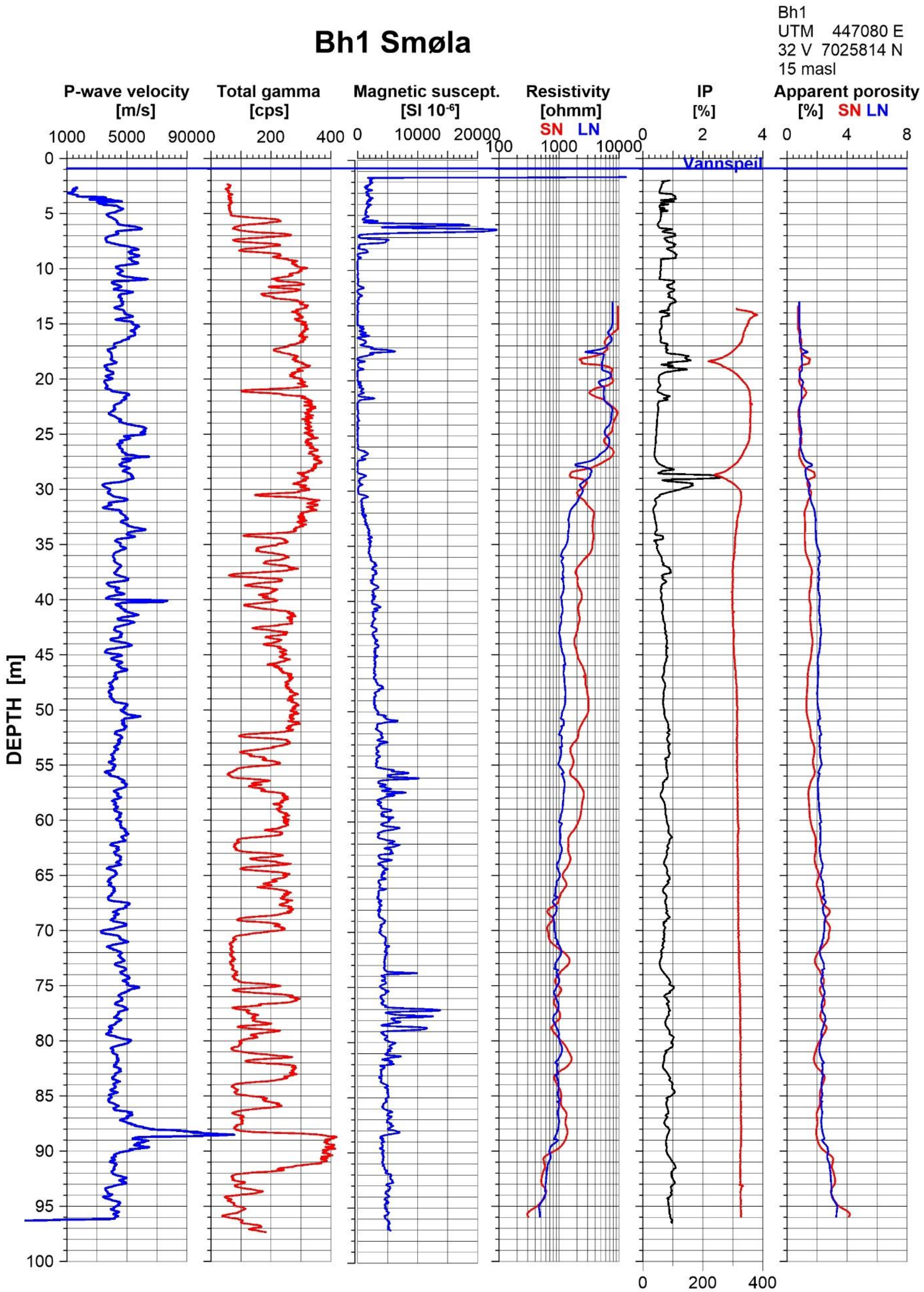


Figure 19. Smøla Bh1. P-wave velocity, total gamma, magnetic susceptibility, resistivity, IP, SP, and apparent porosity.

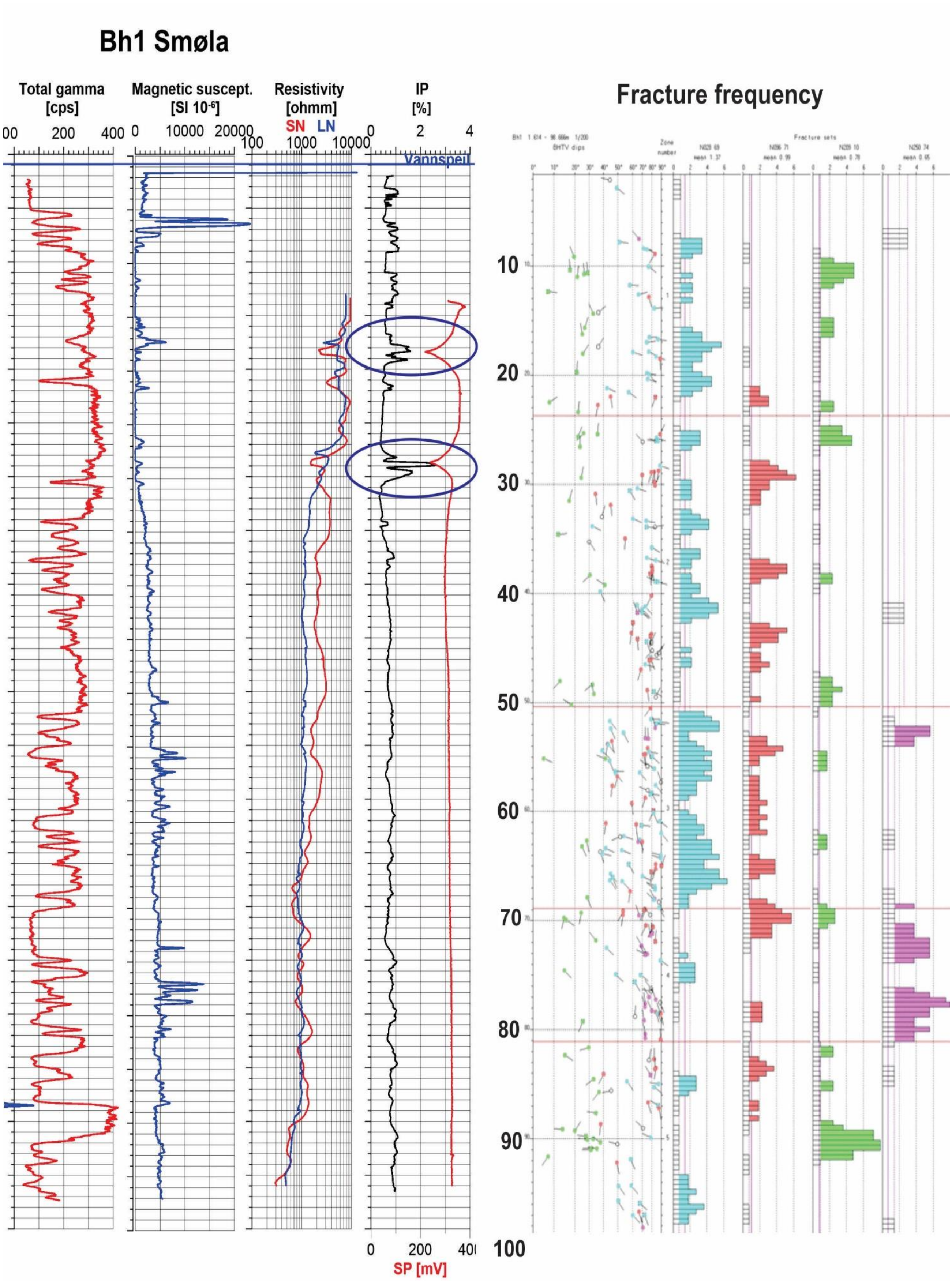


Figure 20. Smøla Bh1., Total gamma, magnetic susceptibility, resistivity, SP, IP and fracture frequency

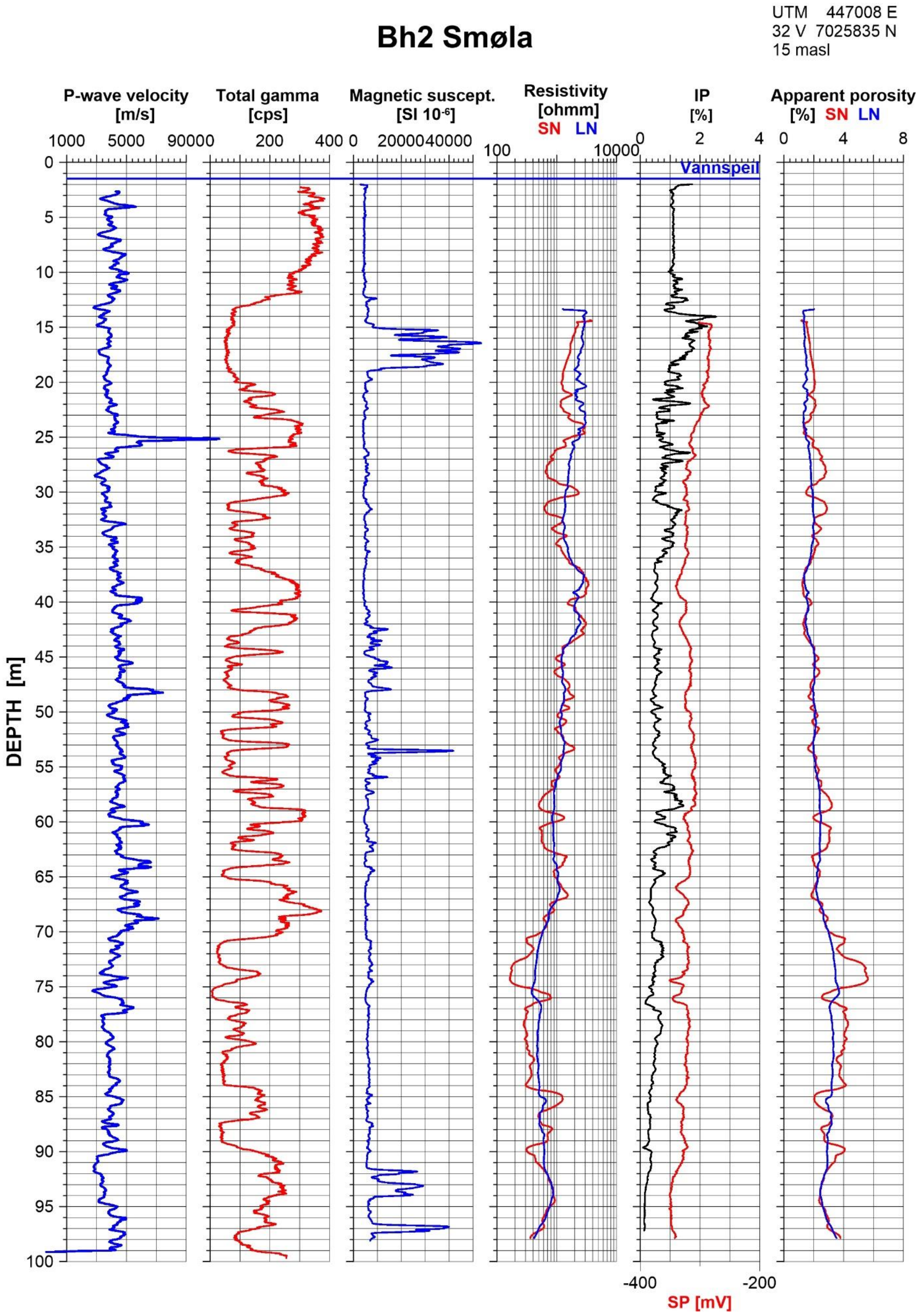


Figure 21. Smøla Bh2. P-wave velocity, total gamma, magnetic susceptibility, resistivity, IP, SP, and apparent porosity.

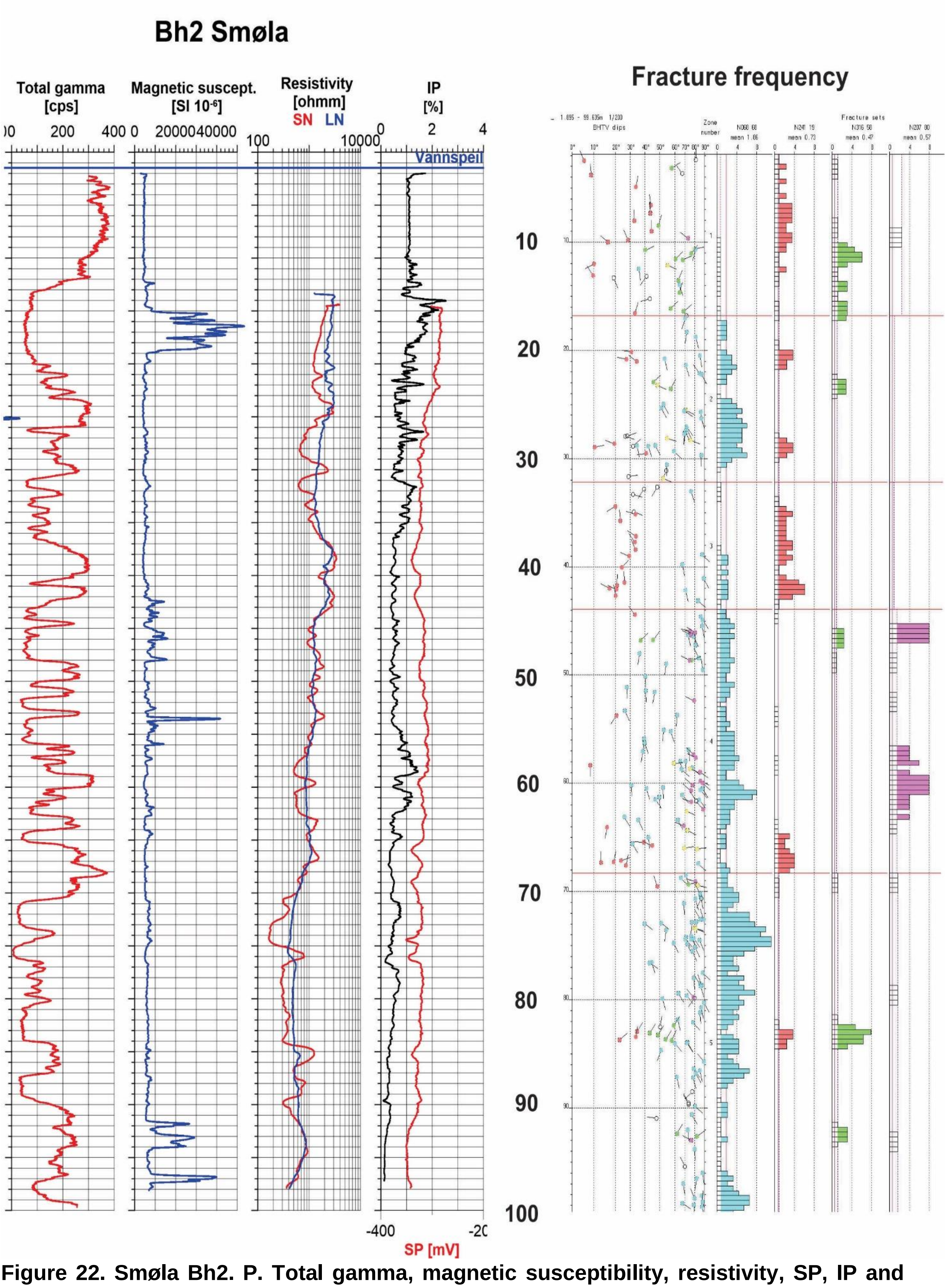


Figure 22. Smøla Bh2. P. Total gamma, magnetic susceptibility, resistivity, SP, IP and fracture frequency.

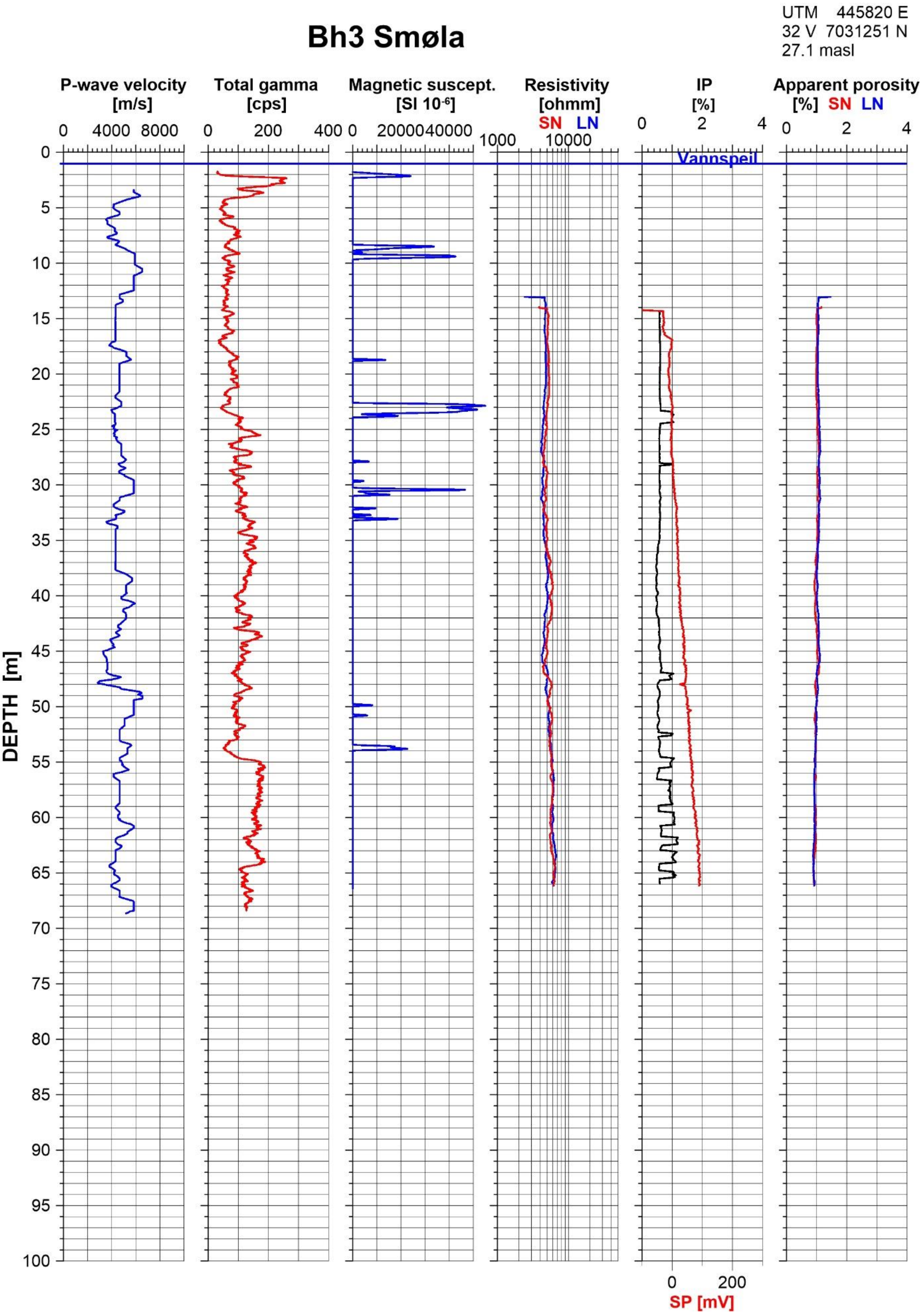


Figure 23. Smøla Bh3. P-wave velocity, total gamma, magnetic susceptibility, resistivity, IP, SP, and apparent porosity.

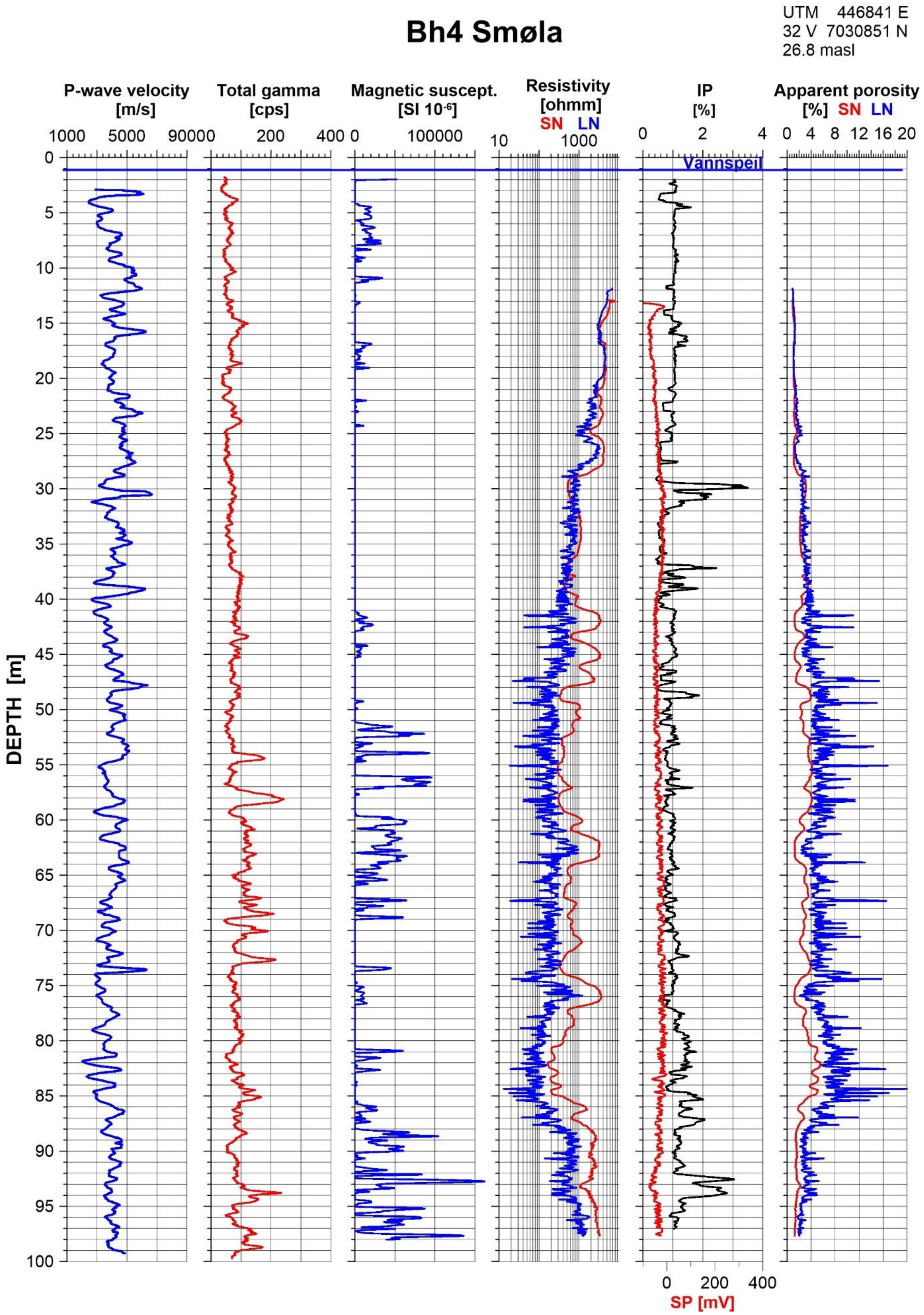


Figure 24. Smøla Bh4. P-wave velocity, total gamma, magnetic susceptibility, resistivity, IP, SP, and apparent porosity.

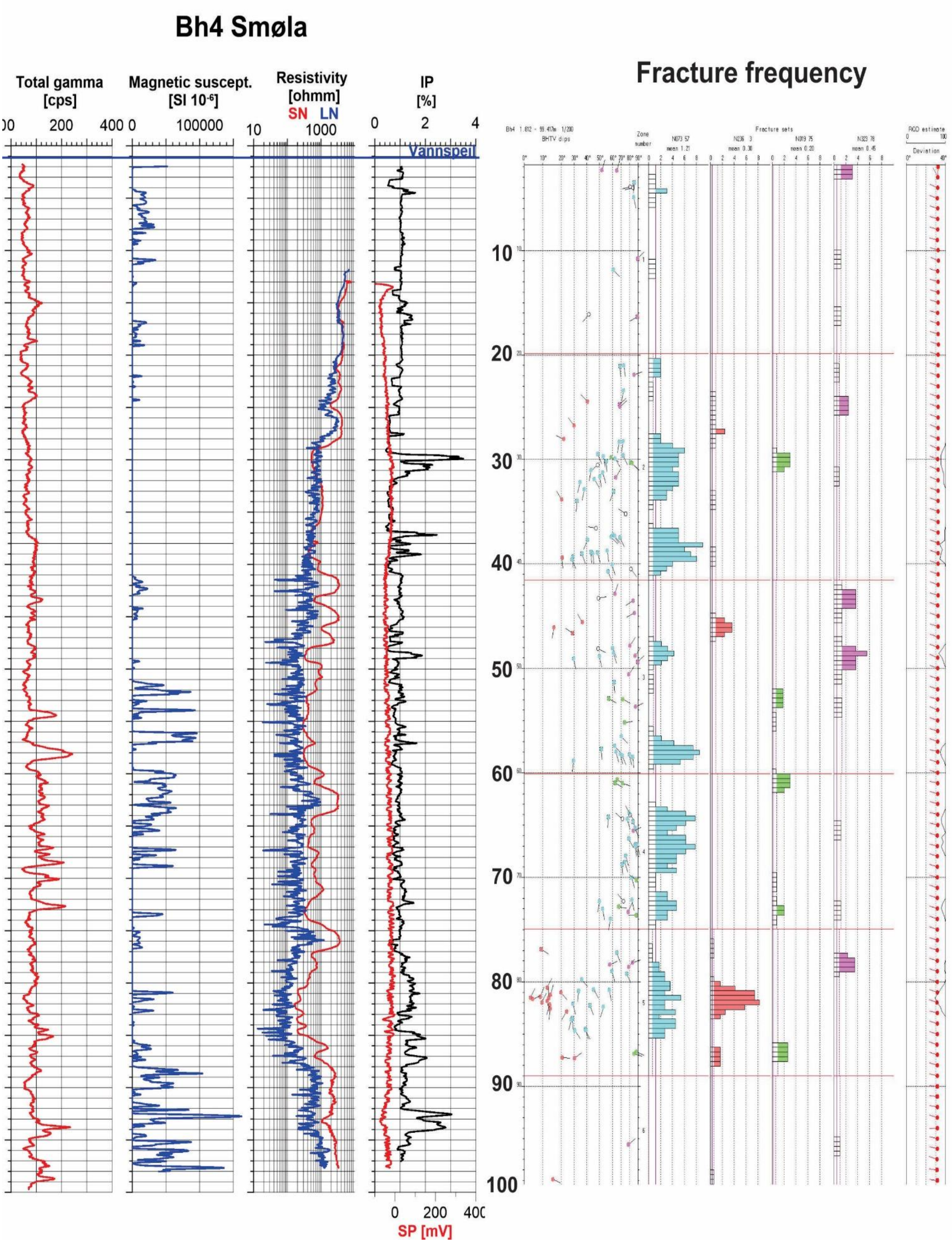


Figure 25. Bh4, Smøla., Total gamma, magnetic susceptibility, resistivity, SP, IP and fracture frequency.

Figure 26. Bh4, Smøla. Cores 79.4 – 83.0 m depth.

Figure 27. Bh4, Smøla. Cores 83.0 – 86.7 m depth.

4.2 **Acoustic Televiewer**

The acoustic televiewer allows us to digitise observed fractures on the acoustic images by calculating fracture strikes, azimuth, dip, and fracture frequency. Data are presented in stereograms, rose diagrams and fracture frequency histograms.

From the acoustic televiewer data, a caliper log can be evaluated by calculating the borehole radius using the 2-way travel time of the sonic pulse. The travel time will increase when the pulse hits an open fracture.

An ovalisation log is presented by calculating the ratio between the maximum and minimum diameter of the borehole. From this ratio, the direction of the maximum horizontal stress can be estimated.

The ovalisation and caliper log might hide some of the fractures because of the cementing. Cement fills the fracture's space volume after redrilling the borehole when the cement was hardened.

Acoustic data images can also be presented as oriented cores, breakout logs and caliper-image logs. This is not done for the entire boreholes, but examples are shown from heavy fractured areas with open fractures.

All fracture data, deviation data, caliper and breakout can be found at ftp2.ngu.no.

OVALISATION AND BREAKOUT LOGS

Borehole breakouts are stress-induced enlargements of a wellbore cross-section. When a borehole is drilled the material removed from the subsurface is no longer supporting the surrounding rock. As a result, the stresses become concentrated in the borehole wall. Borehole breakouts occur when stresses around the borehole exceed the strength of the rock. This might cause compressive failure of the borehole wall (Zobak et al. 1985). Development of intersecting conjugate shear planes leads to enlargements of the wellbore. This can be measured by measuring the borehole diameter using caliper log or acoustic televiewer. The ovalisation of the borehole will indicate breakouts.

Around a vertical borehole stress concentration is greatest in the direction of the minimum horizontal stress S_h. Hence, breakouts are oriented approximately perpendicular to the maximum horizontal stress orientation, S_H, see figure 28, (Plumb and Hickman 1985).

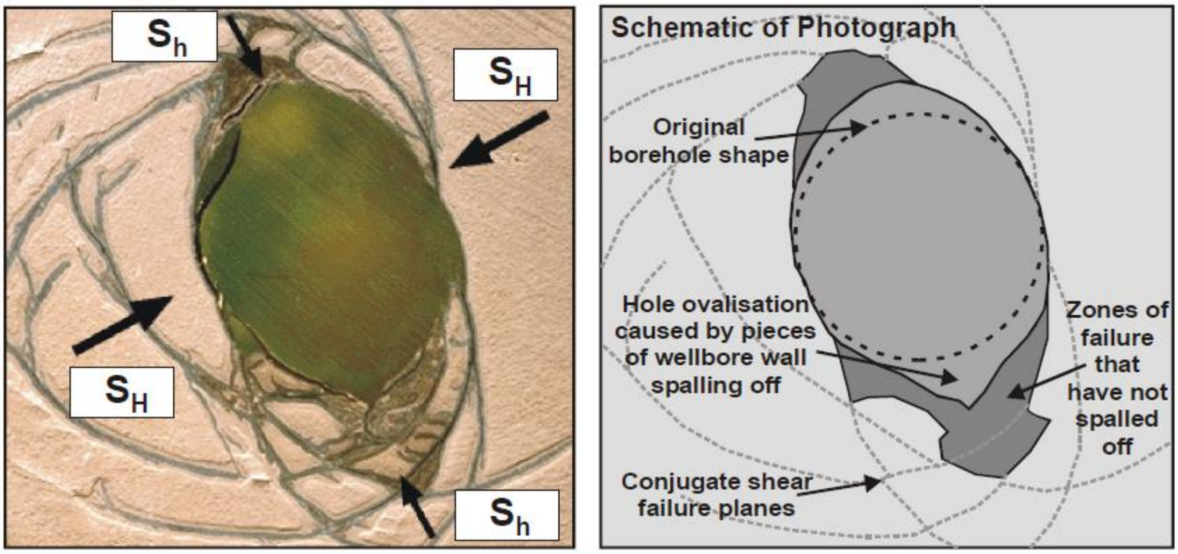


Figure 28. Result of a lab test simulating borehole breakout showing maximum horizontal stress S_H is perpendicular to the wellbore enlargement caused by intersecting conjugate shear planes. Lab test is performed by CSIRO, Division of Geomechanics (Plumb and Hickman 1985).

With the acoustic televiewer, the normalised maximum (alpha) and minimum (beta) diameter are measured. The ratio alpha/beta will be the ovalisation of the borehole cross-section. Values higher than 1 indicates an oval cross-section (breakouts?). However, all kinds of fractures influence the measured diameter and, thereby, the ovalisation ratio. The azimuth of Alpha is the azimuth of maximum diameter (breakout), and from this, the direction of maximum horizontal stress S_H can be calculated.

If breakouts caused by horizontal stress are present in a borehole this will be seen on the borehole image log as vertical dark stripes ca 180º apart.

4.2.1 <u>Fracture analysis in Smøla Bh1</u>

Figure 29 and 30 show the fracture stereogram and fracture rose diagrams of indicated fractures in Bh1. Most of the fractures are dipping in a direction between E and S (see rose azimuth). The main dip angle is steep, 70 – 90 °. The colours in the stereogram represent fractures groups. The same group colours are used in the fracture frequency histograms in Figure 31. In the histograms, every fracture is represented by the arrow plots to the left. The dip angle axis is shown on the top, and the arrows represent the dip direction, N is up, and S is down. Fracture frequency is up to 6 – 7 fractures pr. meter.

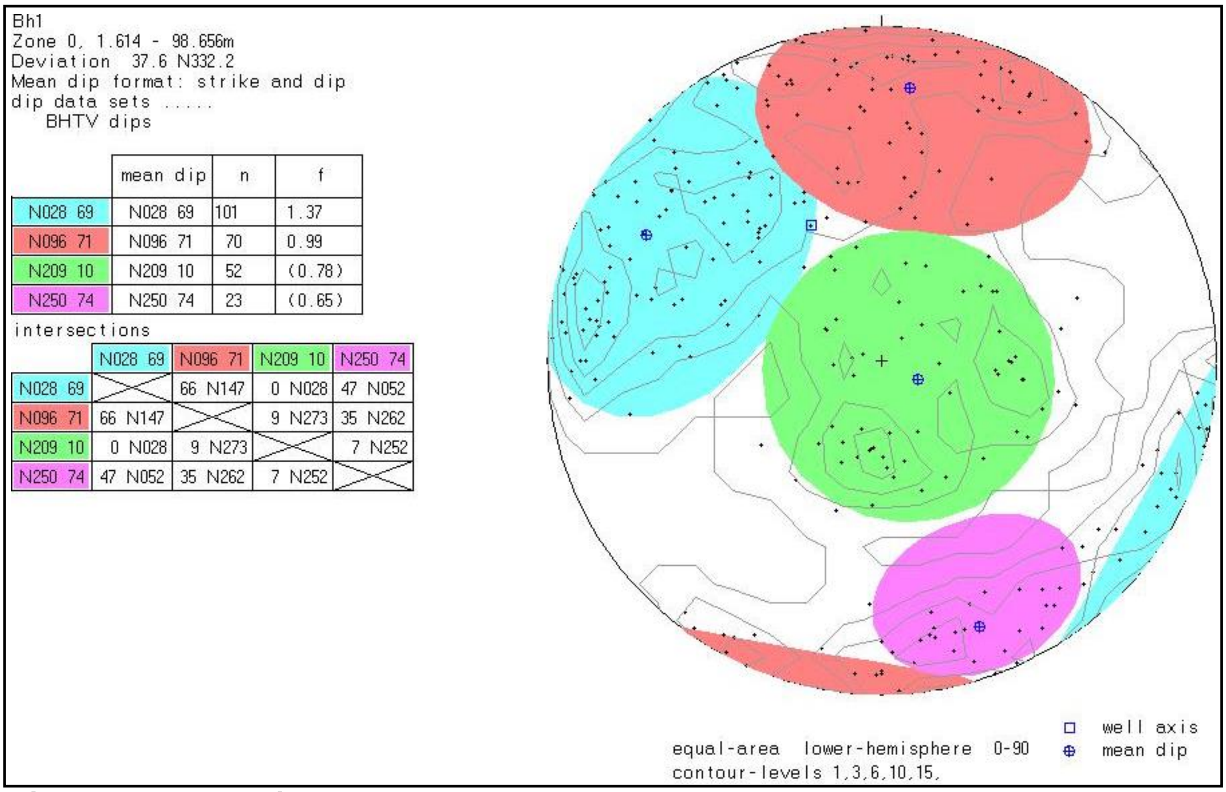


Figure 29. Smøla Bh1. Fracture stereogram.

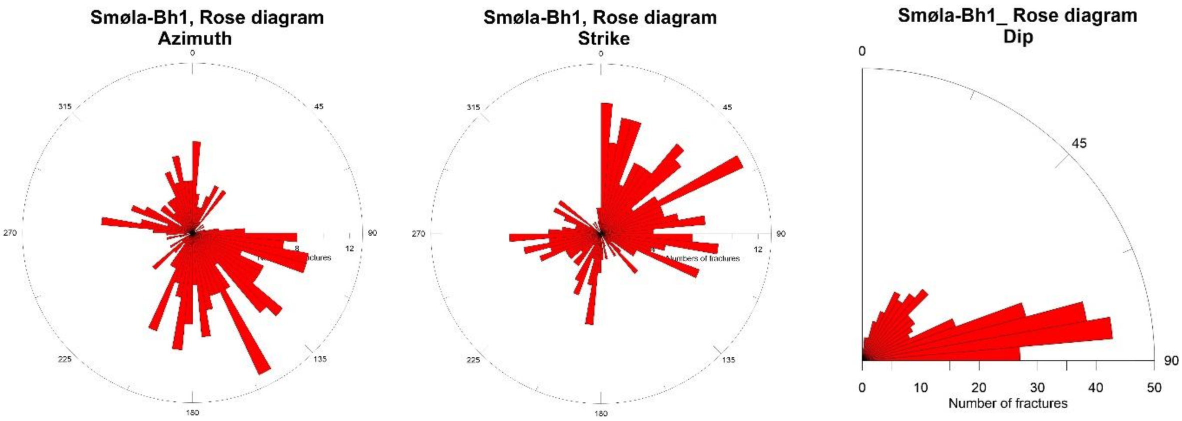


Figure 30. Smøla Bh1. Rose diagram of fracture azimuth, strike and dip.

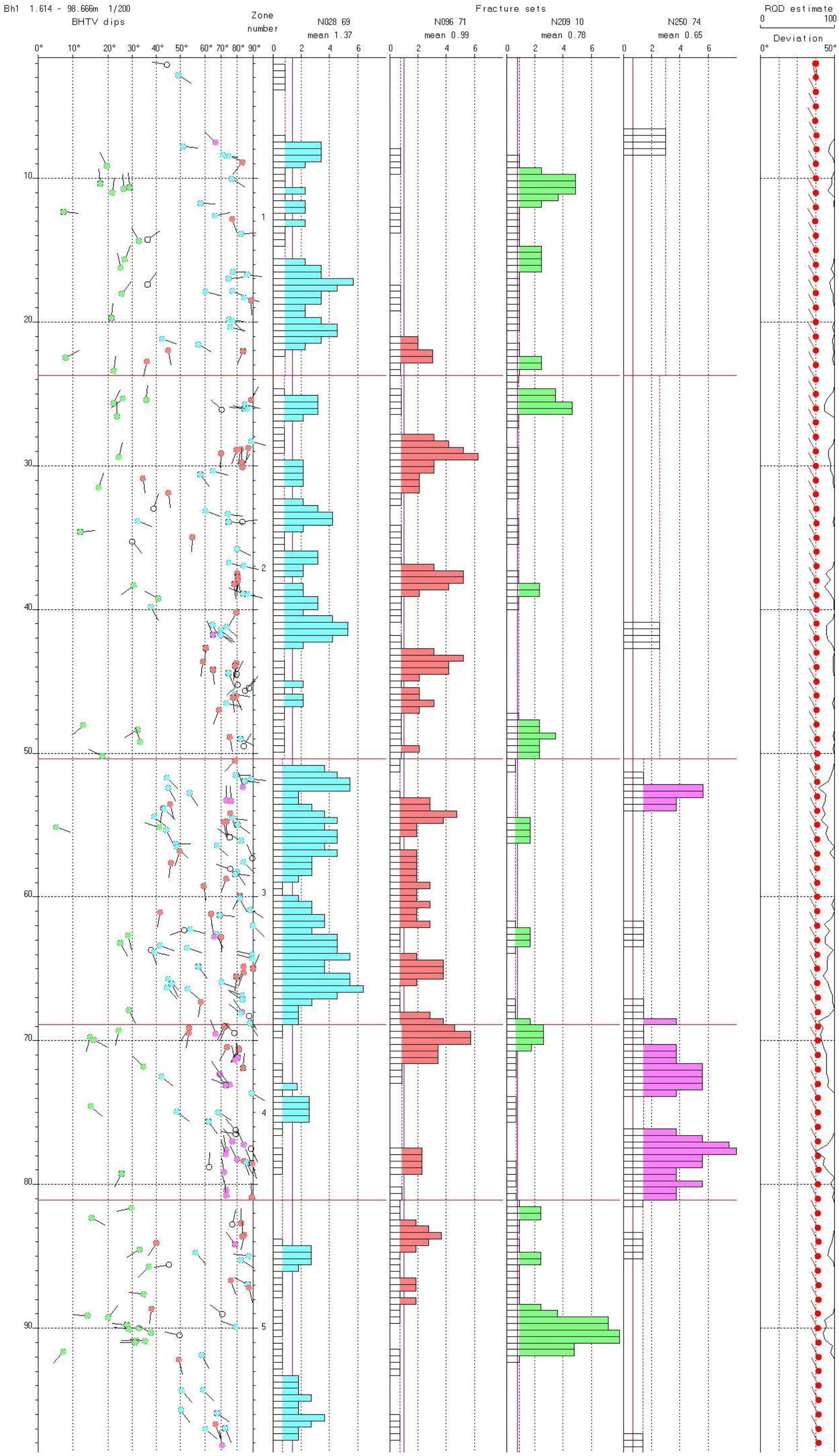


Figure 31. Smøla Bh1. Fracture frequency histograms.

4.2.2 Ovalization and caliper log Bh1

Ovalization and caliper logs are shown in Figure 32 and Figure 33. An open facture can be seen at 6 – 8 m on both logs. Several fractures are indicated by increased diameter. On the acoustic image, there is no indication of breakouts caused by horizontal stress. The azimuth of Alpha is about 45^{o}, and the direction of maximum horizontal stress should be perpendicular to 45^{o}.

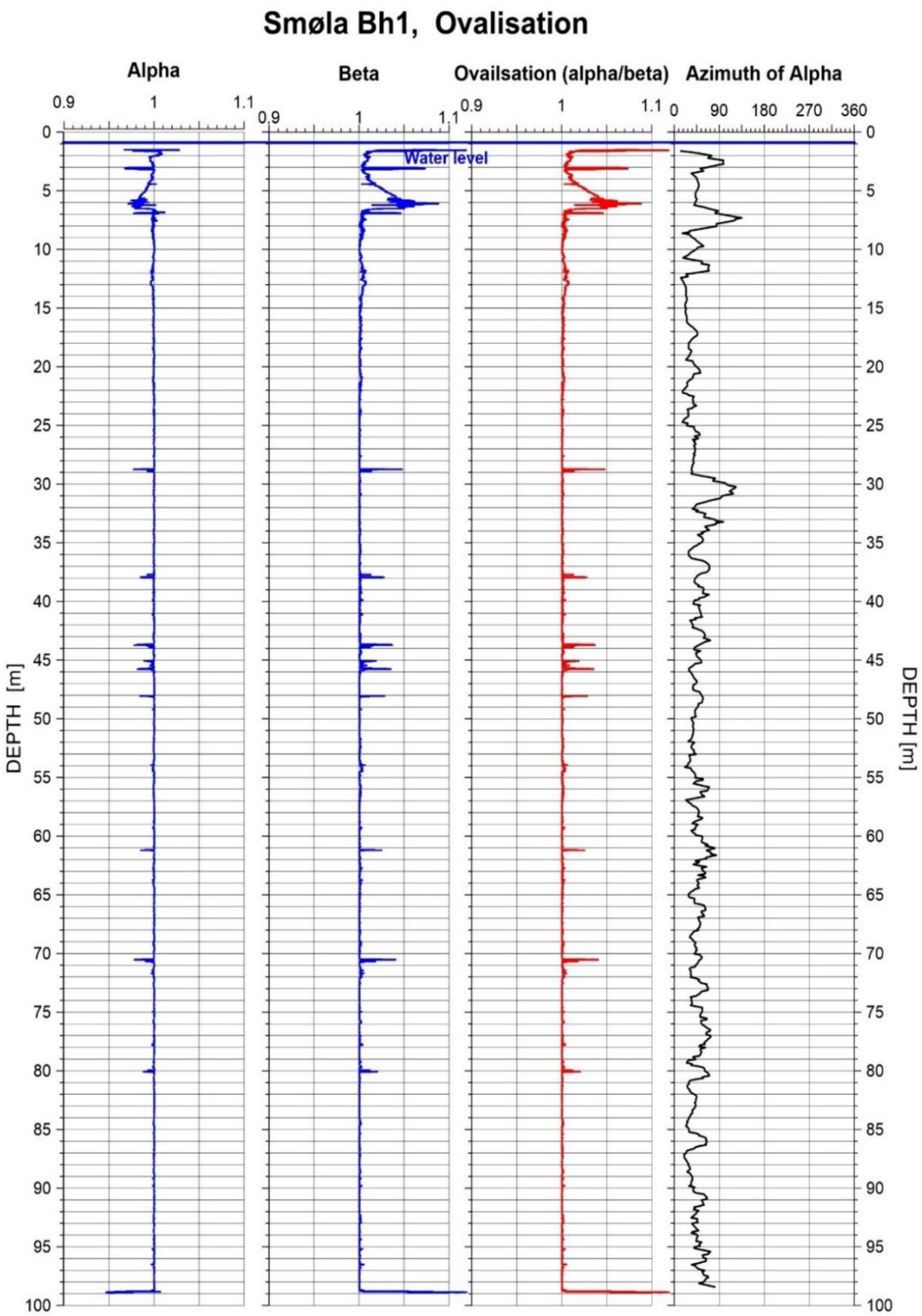


Figure 32. Smøla Bh1. Ovalization log

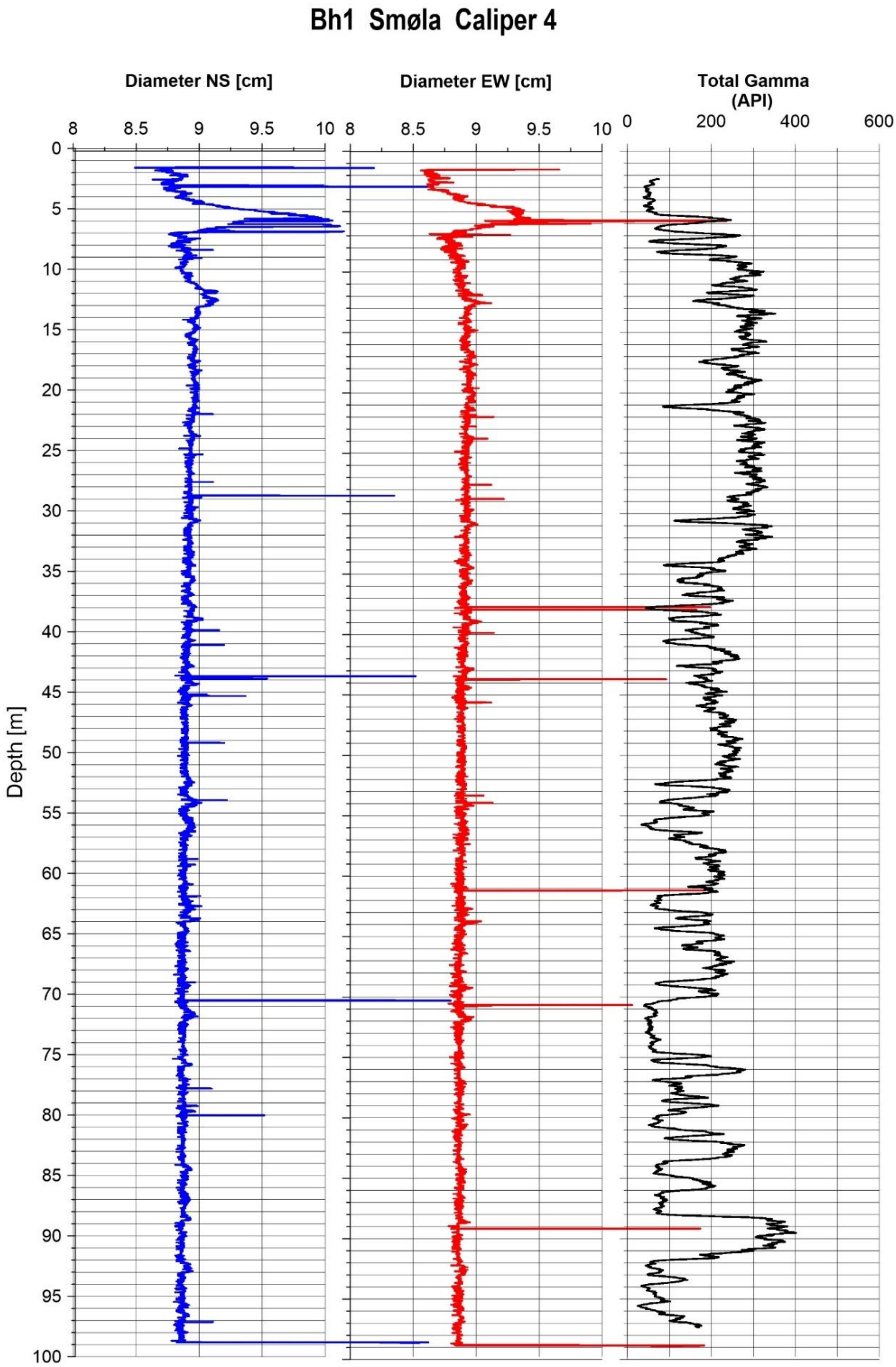
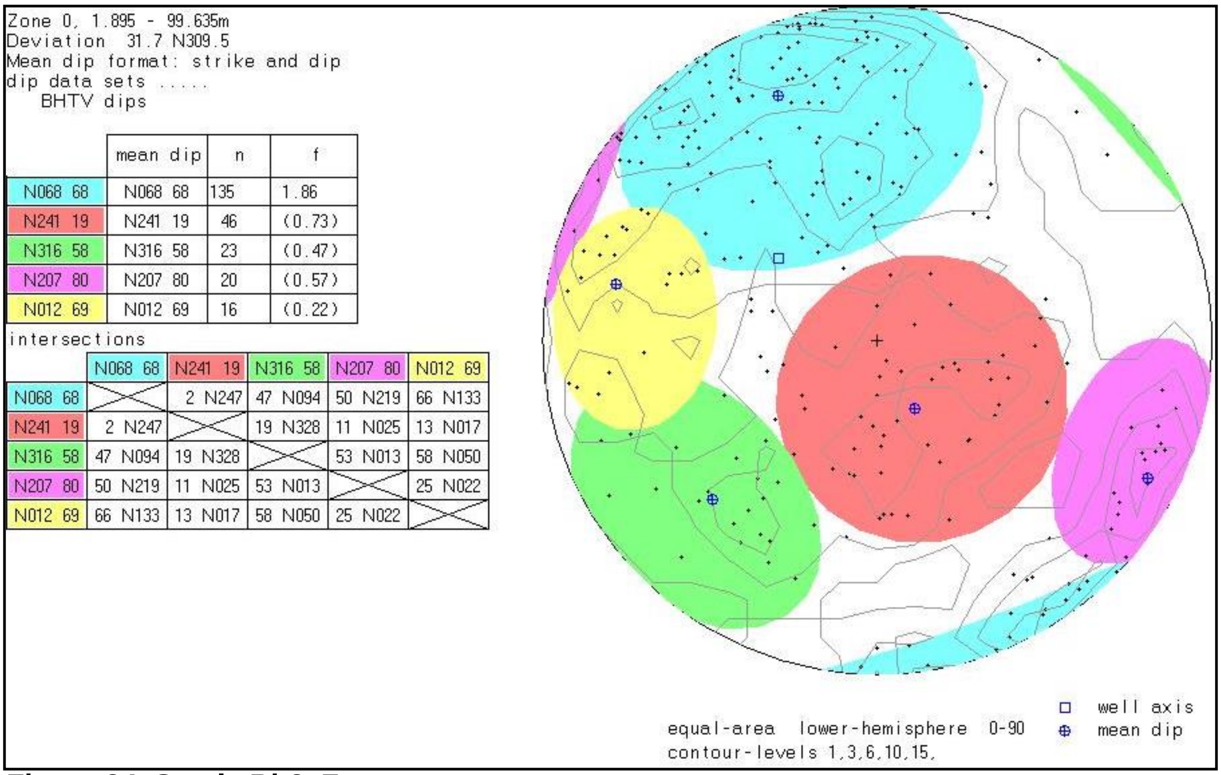


Figure 33. Smøla Bh1. Caliper log.

4.2.3 Fracture analysis in Smøla Bh2

Figures 34 and 35 show the fracture stereogram and fracture rose diagrams of indicated fractures in Bh2. Most of the fractures are dipping to SSW (see rose azimuth). The main dip angle is steep, 70 – 90º. The colours in the stereogram represent fractures groups. The same group colours are used in the fracture frequency histograms in Figure 34. In the histograms, every fracture is represented by the arrow plots to the left. Dip angle axis is shown on the top, and the arrows represent the dip direction, N is up, and S is down. Fracture frequency is highest below 70 m depth, up to 7-8 fractures/m.



	mean dip	n	f
N068 68	N068 68	135	1.86
N241 19	N241 19	46	(0.73)
N316 58	N316 58	23	(0.47)
N207 80	N207 80	20	(0.57)
N012 69	N012 69	16	(0.22)

intersections

	N068 68	N241 19	N316 58	N207 80	N012 69
N068 68		2 N247	47 N094	50 N219	66 N133
N241 19	2 N247		19 N328	11 N025	13 N017
N316 58	47 N094	19 N328		53 N013	58 N050
N207 80	50 N219	11 N025	53 N013		25 N022
N012 69	66 N133	13 N017	58 N050	25 N022	

Figure 34. Smøla Bh2. Fracture stereogram.

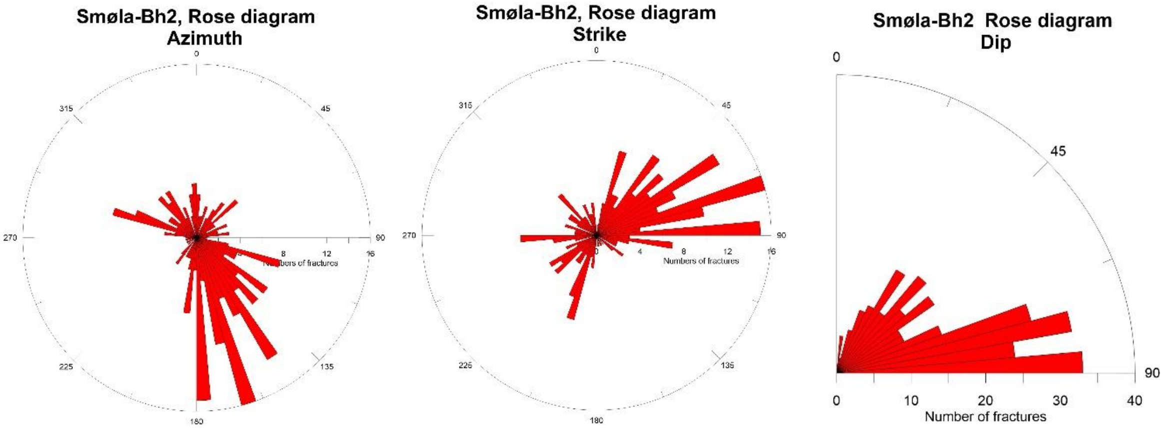


Figure 35. Smøla Bh2. Rose diagram of fracture azimuth, strike and dip.

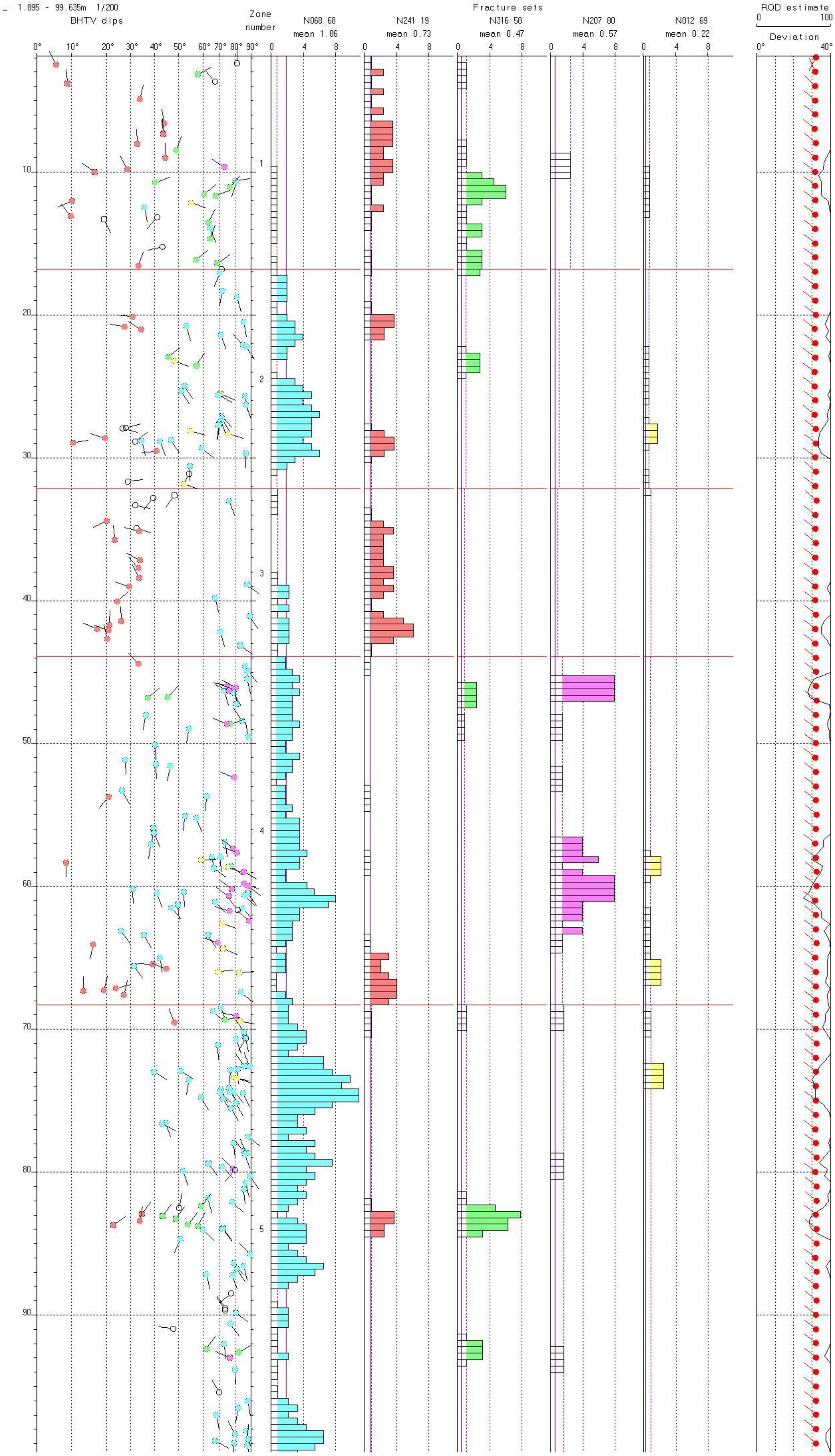


Figure 36. Smøla Bh2. Fracture frequency histograms.

4.2.4 Ovalization and caliper log Bh2

Ovalization and caliper logs are shown in Figure 37 and Figure 38. An open facture can be seen at 6 – 8 m on both logs. Several fractures are indicated by increased diameter. In the acoustic image, there is no indication of breakouts caused by horizontal stress. The azimuth of Alpha is about 45°, and the direction of maximum horizontal stress should be perpendicular to 45°.

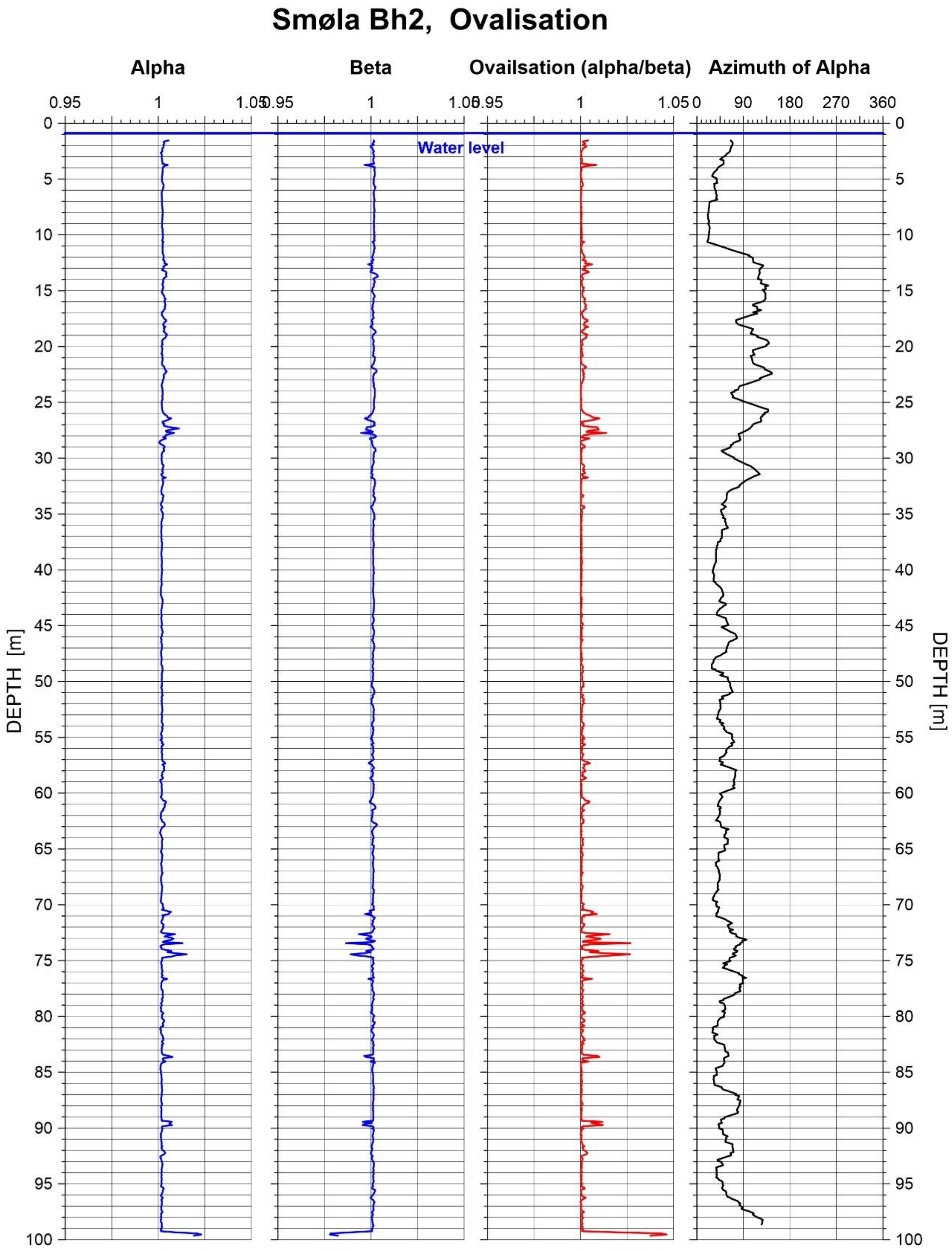


Figure 37. Smøla Bh2. Ovalization log

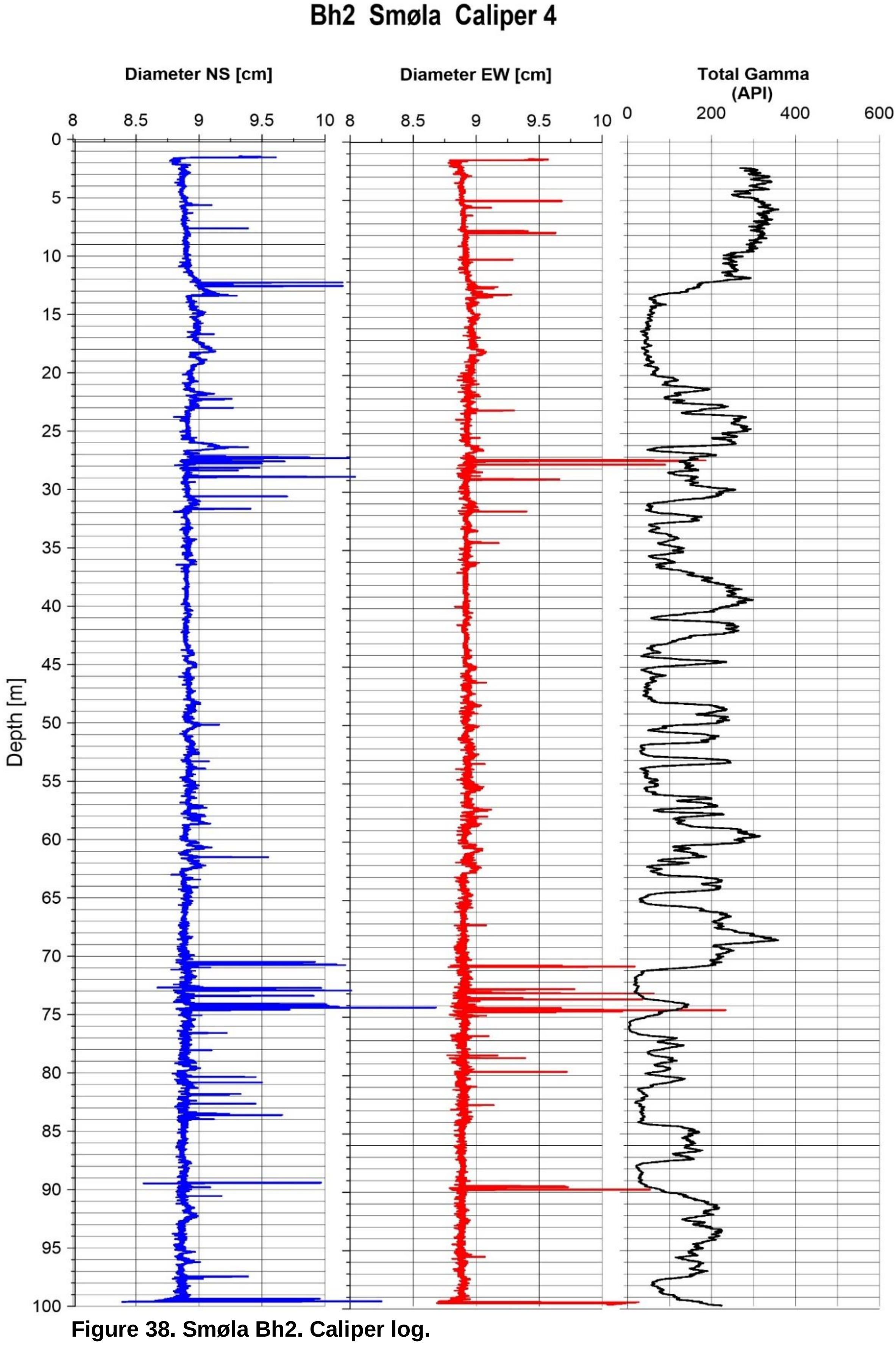


Figure 38. Smøla Bh2. Caliper log.

Figure 39 shows oriented cores and breakout log from section 72.5 – 75 m in Bh2. The breakout log indicates fractures in the borehole that leads to an increased borehole diameter. Figure 40 shows cross-sections of the borehole, 73.7 and 74.4 m depth, and an increased and irregular diameter at 74.4 m.

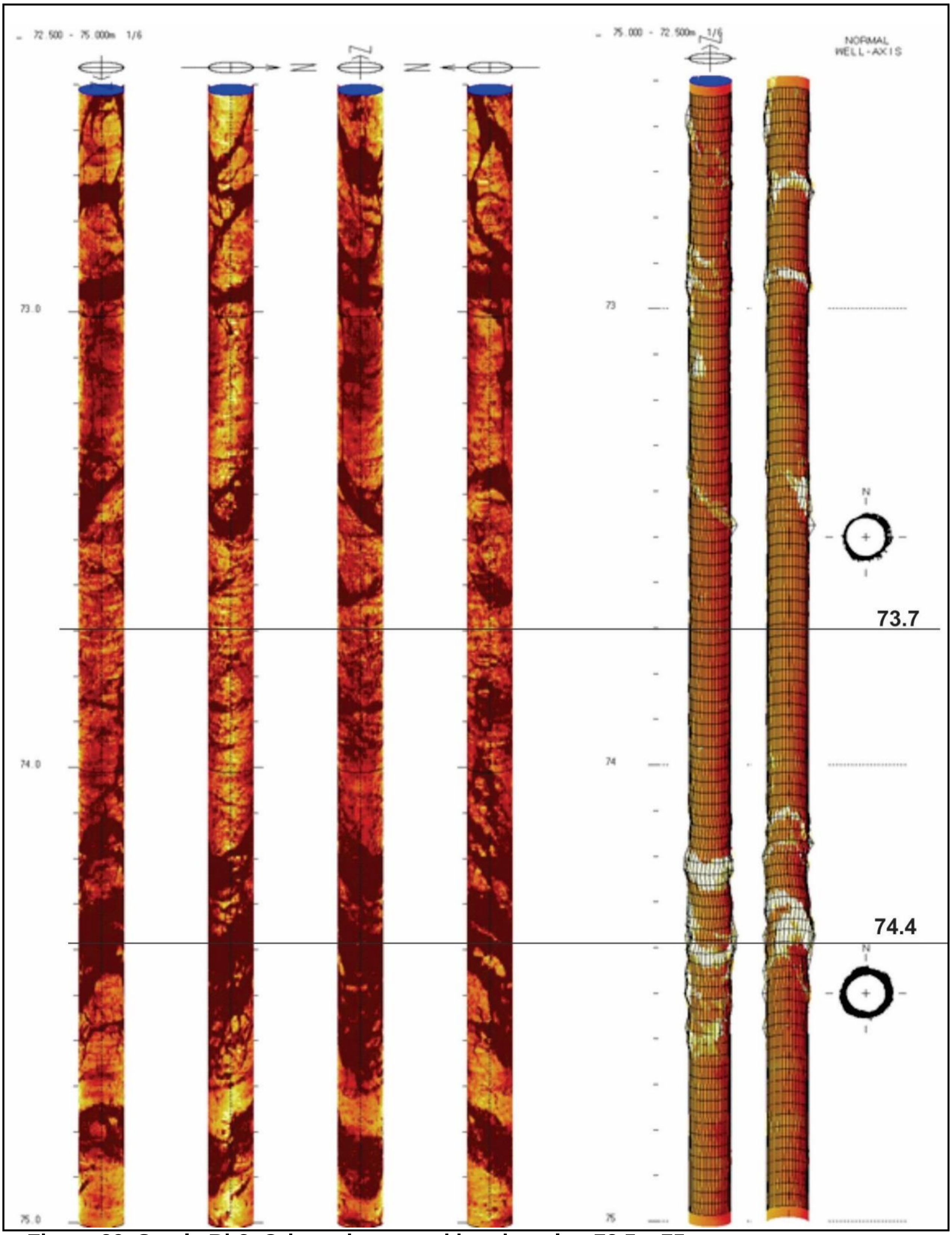


Figure 39. Smøla Bh2. Oriented core and breakout log 72.5 – 75 m.

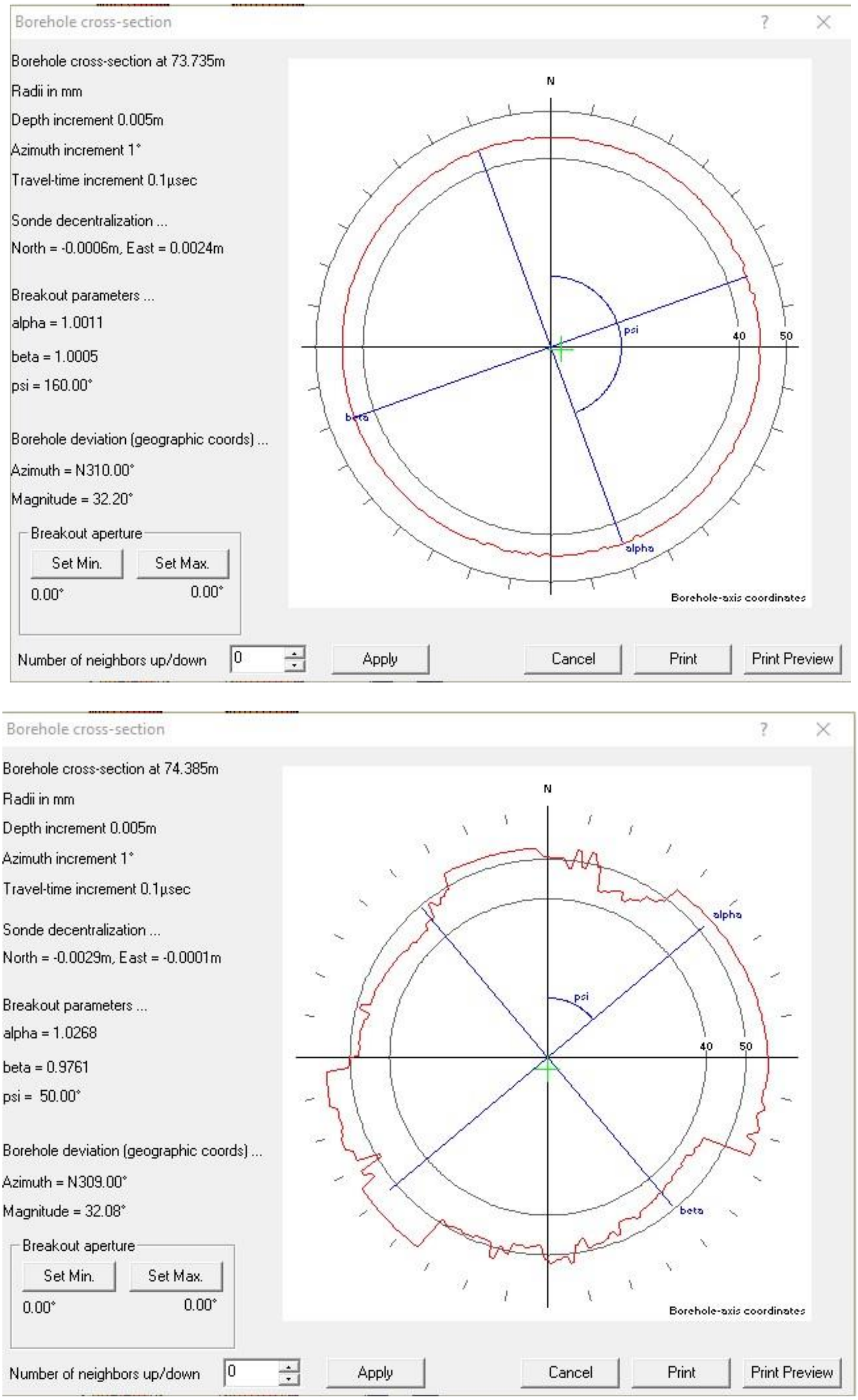
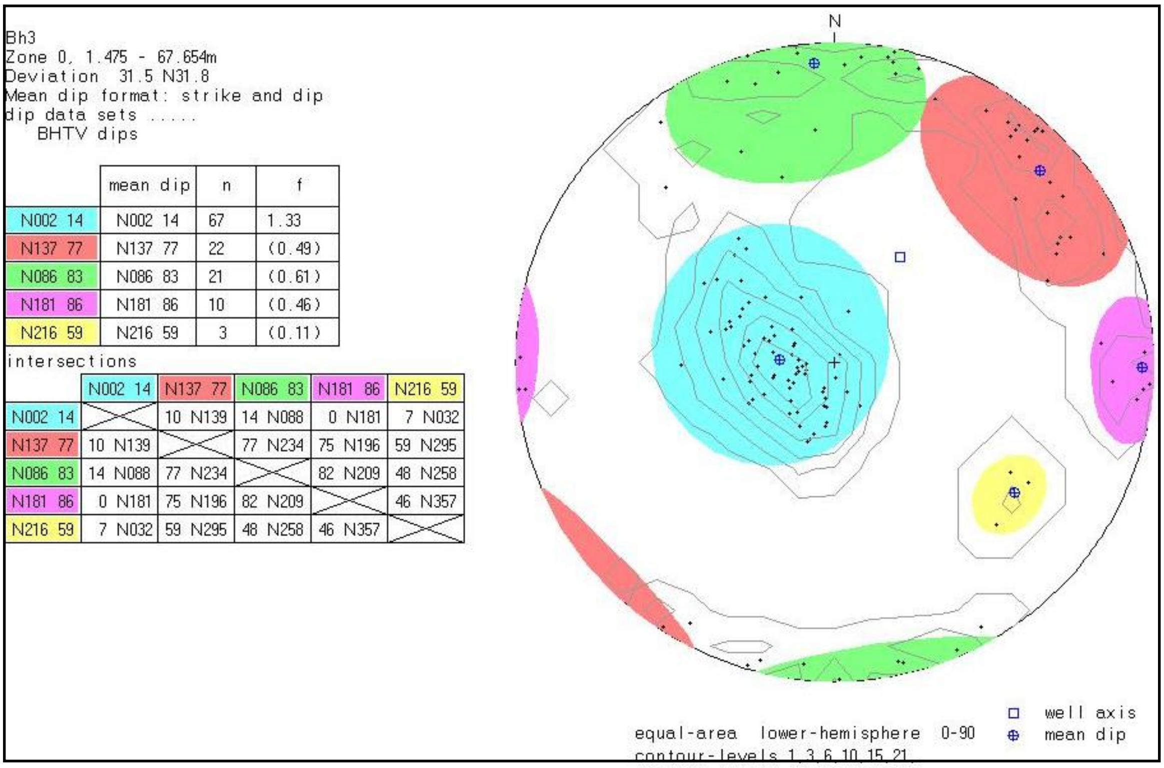


Figure 40. Smøla Bh2. Cross-section of Bh2 showing borehole diameter at 73.7 and 74.4 m.

4.2.5 Fracture analysis in Smøla Bh3

Figure 41 and 42 show the fracture stereogram and fracture rose diagrams of indicated fractures in Bh2. Fractures in the main fracture group (blue) are dipping close to E (see rose azimuth). The main dip angle is slight (average 14º). The colours in the stereogram represent fractures groups. The same group colours are used in the fracture frequency histograms in Figure 43. In the histograms, every fracture is represented by the arrow plots to the left. The dip angle axis is shown on the top, and the arrows represent the dip direction, where N is up, and S is down. Fracture frequency is up to 6 – 7 fractures pr. meter.



	mean dip	n	f
N002 14	N002 14	67	1.33
N137 77	N137 77	22	(0.49)
N086 83	N086 83	21	(0.61)
N181 86	N181 86	10	(0.46)
N216 59	N216 59	3	(0.11)

	N002 14	N137 77	N086 83	N181 86	N216 59
N002 14		10 N139	14 N088	0 N181	7 N032
N137 77	10 N139		77 N234	75 N196	59 N295
N086 83	14 N088	77 N234		82 N209	48 N258
N181 86	0 N181	75 N196	82 N209		46 N357
N216 59	7 N032	59 N295	48 N258	46 N357	

Figure 41. Smøla Bh3. Fracture stereogram.

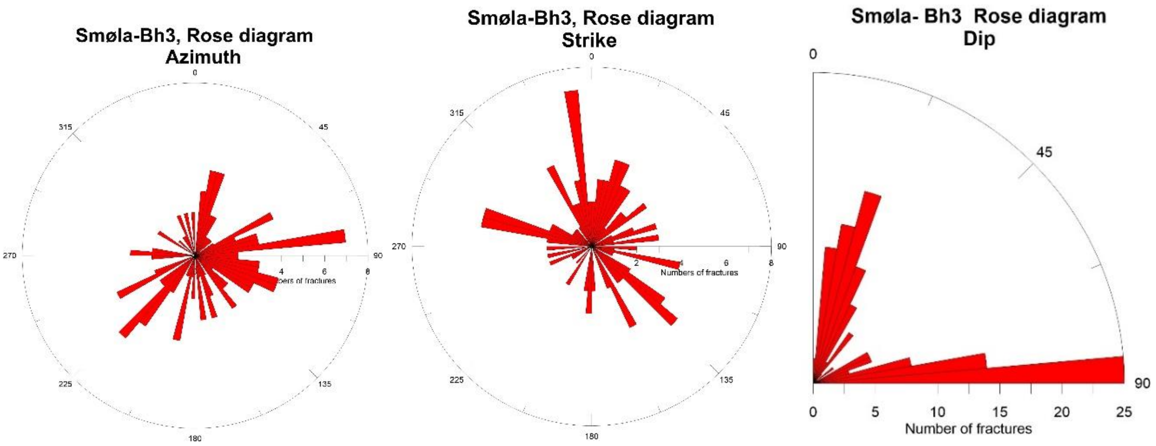


Figure 42. Smøla Bh3. Rose diagram of fracture azimuth, strike and dip.

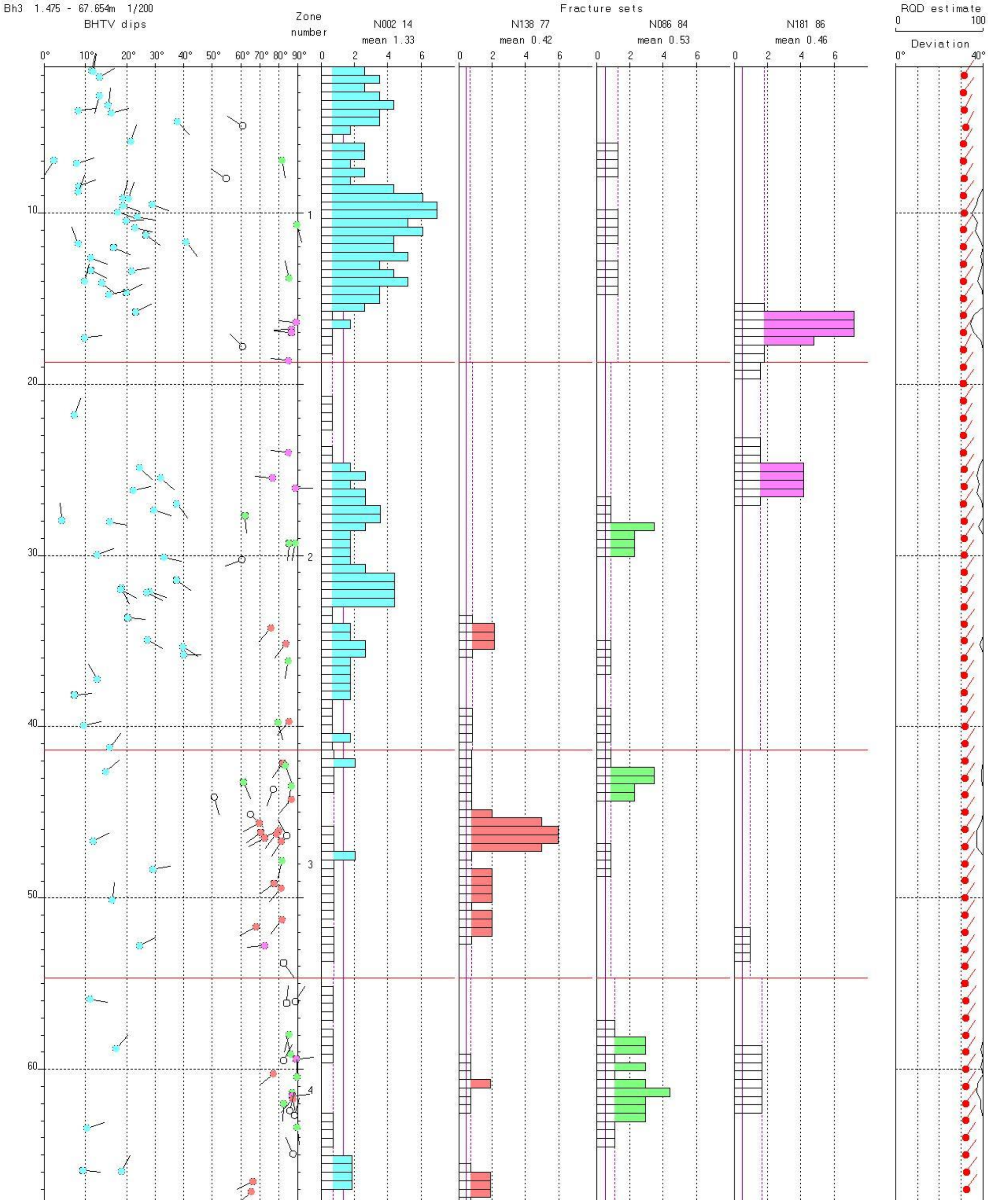


Figure 43. Smøla Bh3. Fracture frequency histograms.

4.2.6 Ovalization and caliper log Bh3

Ovalization and caliper logs are shown in Figure 44 and Figure 45. An open facture can be seen at 2 m depth on both logs. On the acoustic image, there is no indication of breakouts caused by horizontal stress. The azimuth of Alpha is about 45°, and the direction of maximum horizontal stress should be perpendicular to 45°.

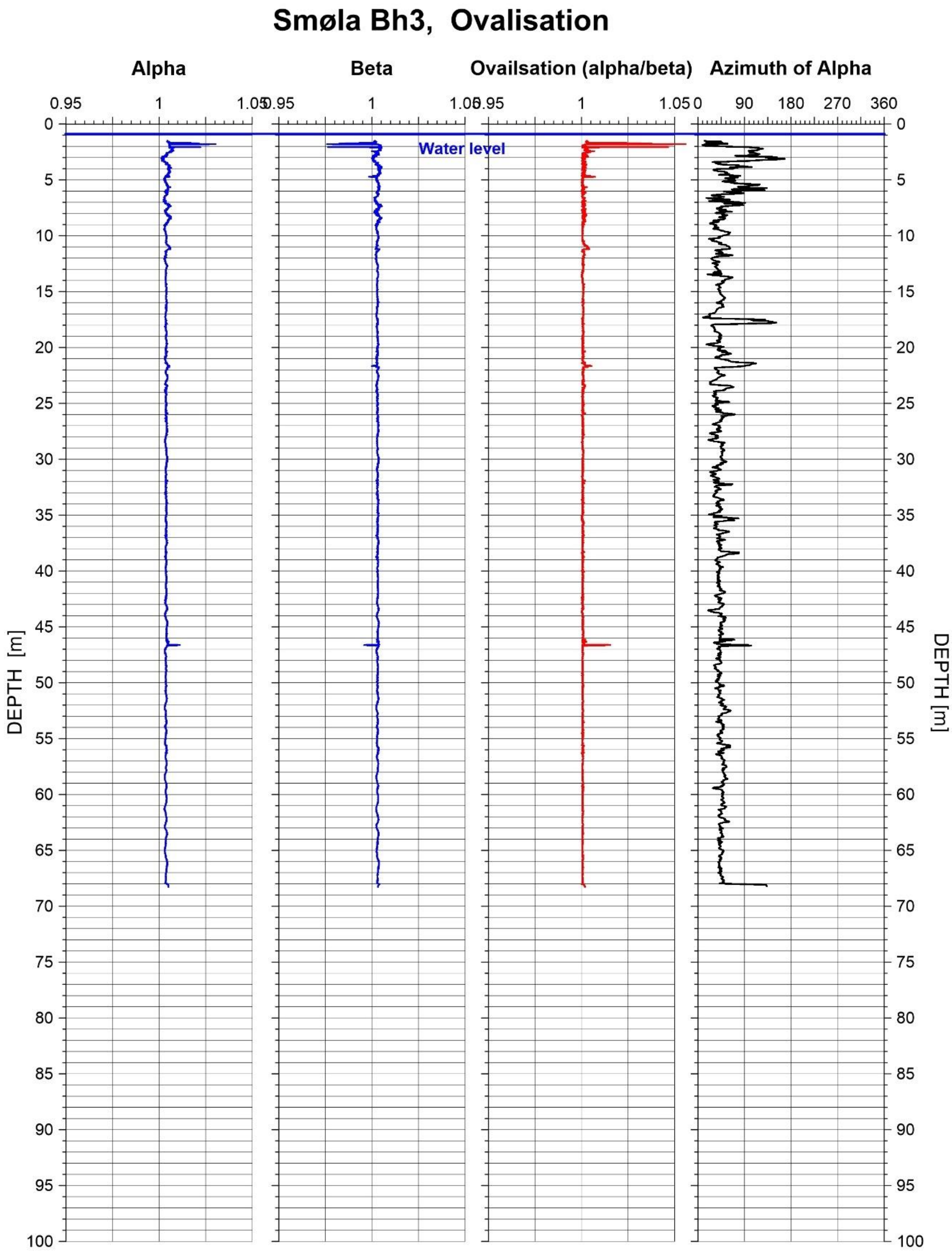


Figure 44. Smøla Bh3. Ovalization log.

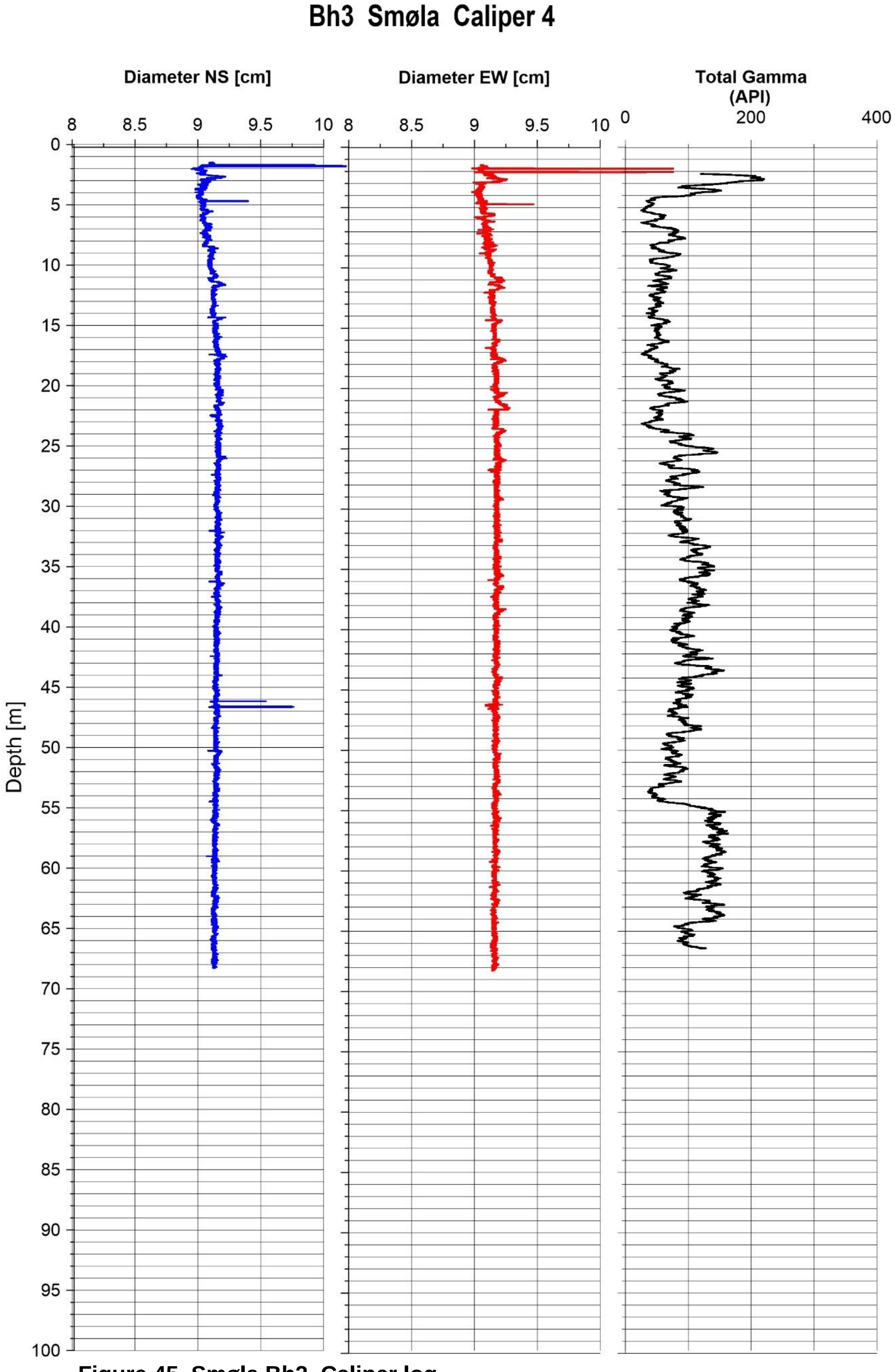


Figure 45. Smøla Bh2. Caliper log.

4.2.7 Fracture analysis in Smøla Bh4

Figure 46 and 47 show the fracture stereogram and fracture rose diagrams of indicated fractures in Bh4. Fractures in the main fracture group (blue) are dipping to SSE (see rose azimuth) with an average dip angle of 57. The colours in the stereogram represent fractures groups. The same group colours are used in the fracture frequency histograms in Figure 48. In the histograms, every fracture is represented by the arrow plots to the left. The dip angle axis is shown on the top, and the arrows represent the dip direction, N is up, and S is down. Fracture frequency is up to 8 - 9 fractures pr. meter. See also Figure 18, Chapter 4.1.2, which shows the low resistivity and high fracture frequency coincidence.

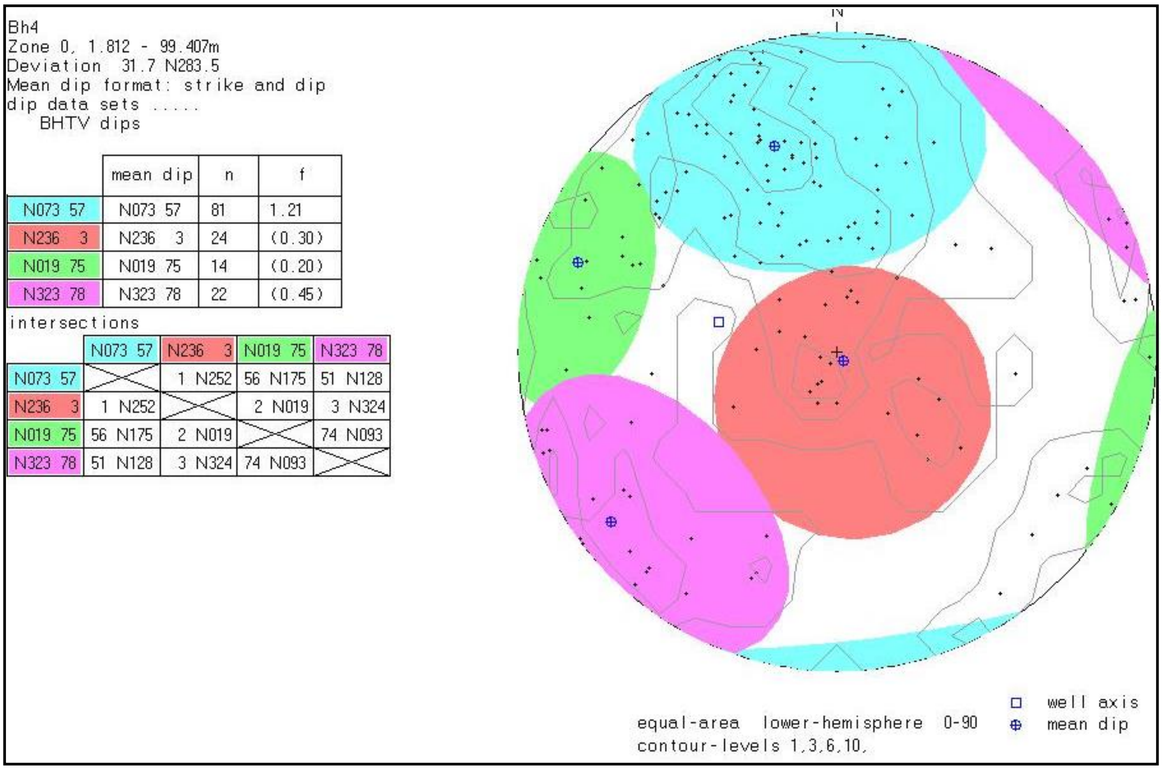


Figure 46. Smøla Bh4. Fracture stereogram.

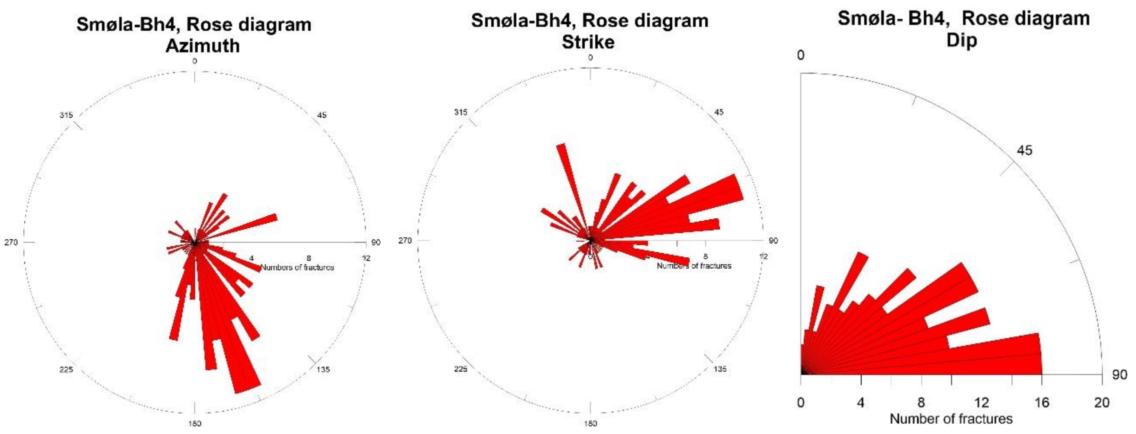


Figure 47. Smøla Bh4. Rose diagram of fracture azimuth, strike and dip.

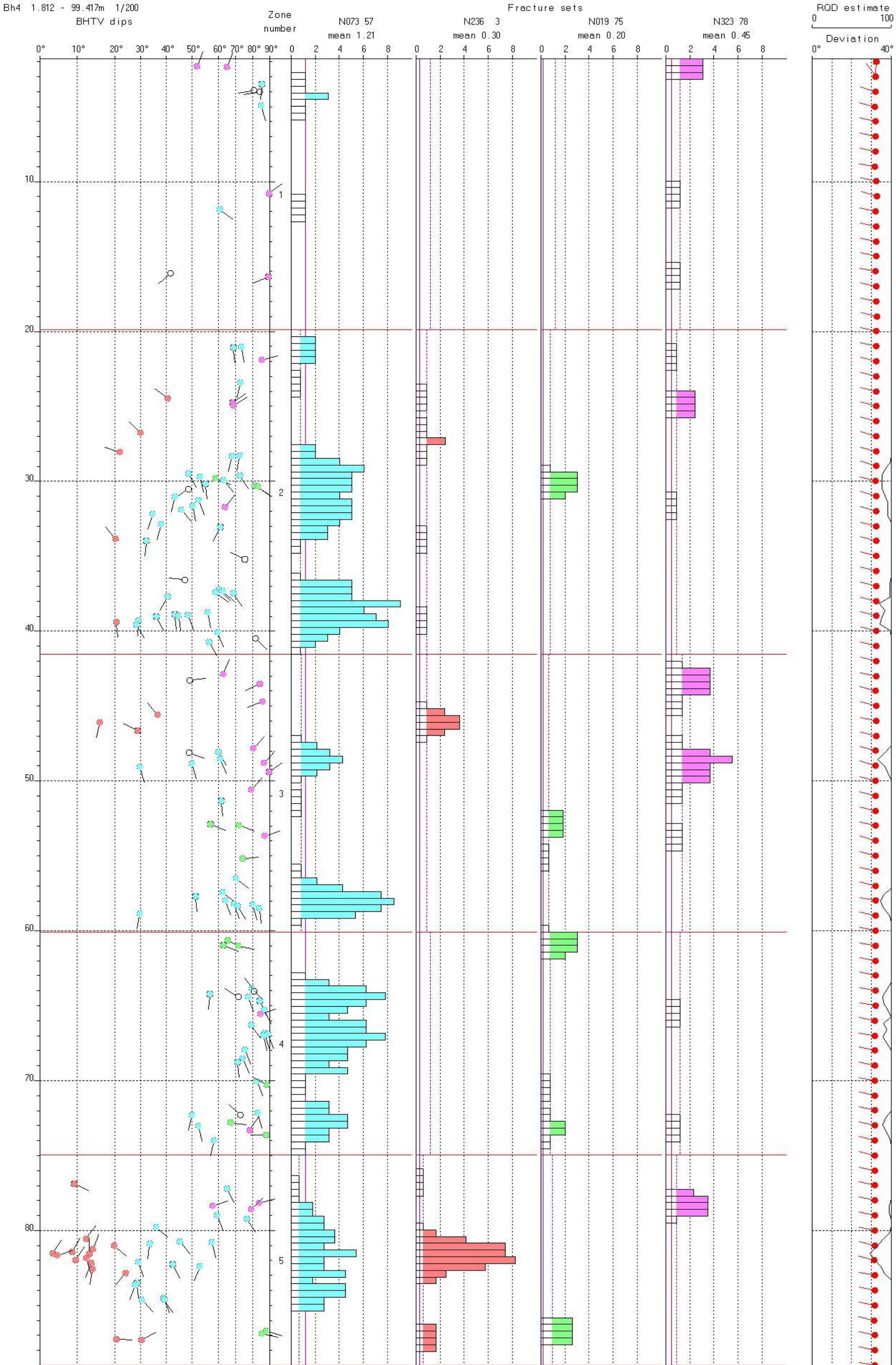


Figure 48. Smøla Bh4. Fracture frequency histograms.

4.2.8 Ovalisation and caliper log Bh4

Ovalisation and caliper logs are shown in Figure 49 and Figure 50. Several clear increases in both ovalisation and caliper are observed on the logs. These increases are related to open fractures, as seen in Figure 51, showing open fractures at 29.5 and 29.9 m depth together with increased diameter. The azimuth of Alpha shows significant variations due to fractures. The average azimuth is about 135º and the direction of maximum horizontal stress should be perpendicular to 135º. This is a displacement of 90º from Bh1, Bh2 and Bh3.

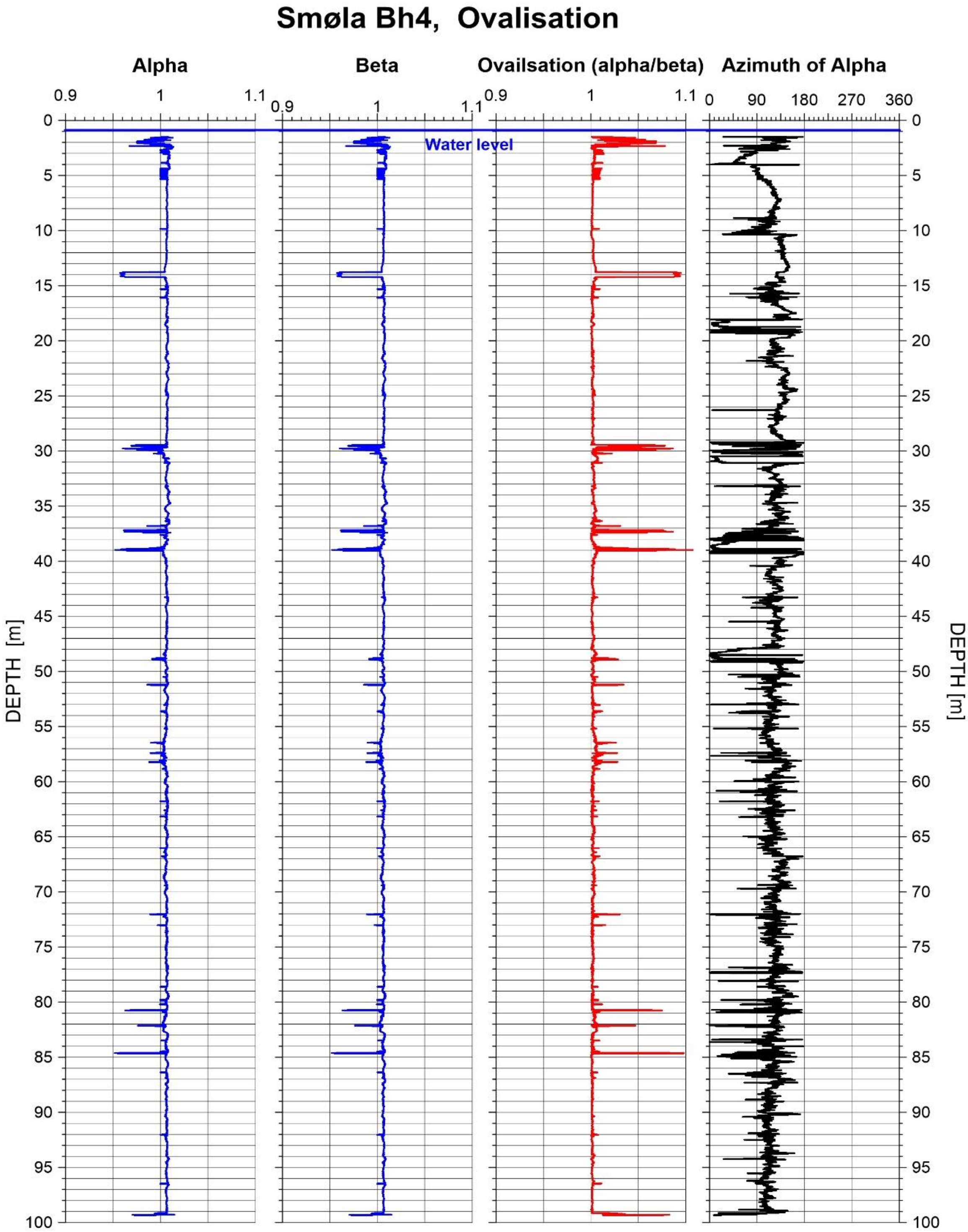


Figure 49. Smøla Bh4. Ovalization log.

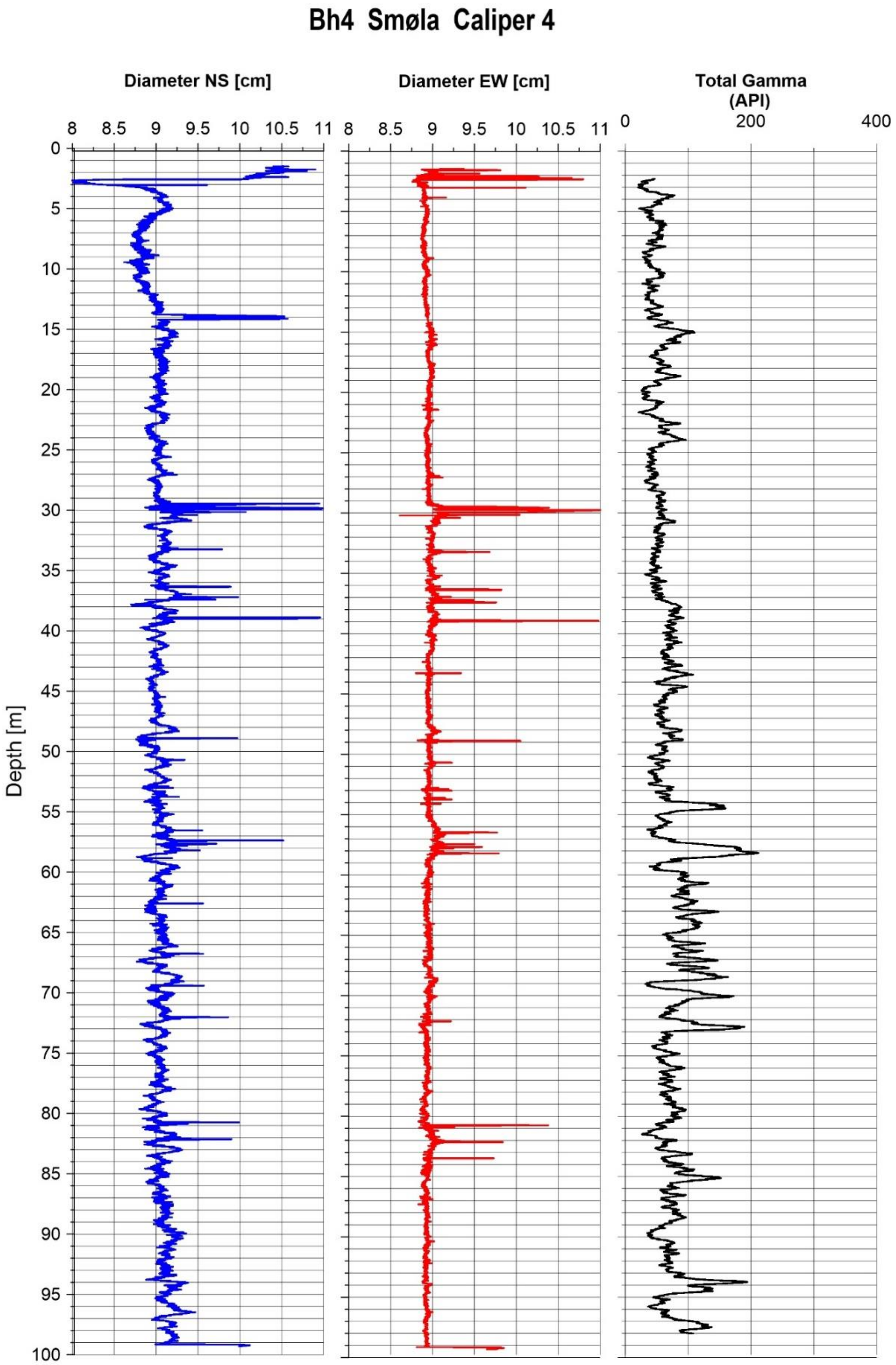


Figure 50. Smøla Bh4. Caliper log.

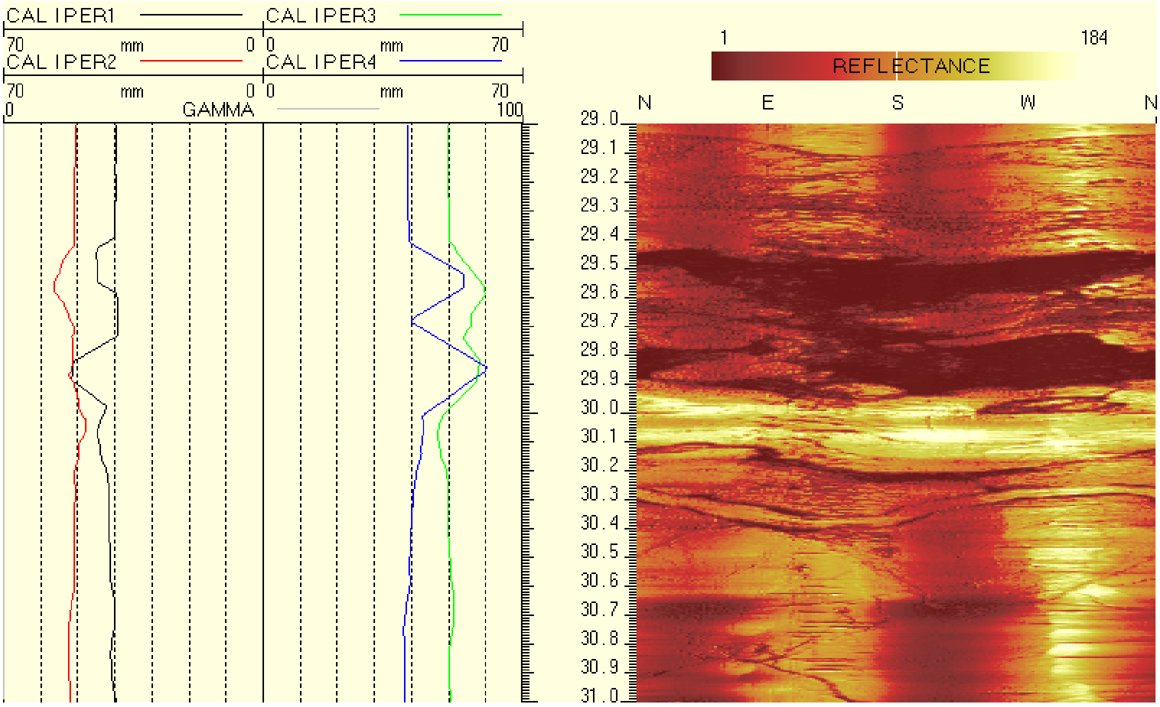


Figure 51. Smøla Bh4. Caliper 4 and acoustic image showing open fractures at 29.5 and 29.9 m depth.

4.2.9 Borehole deviation Smøla

Borehole deviation is calculated as an integrated part of the televiewer logging. The values for the dip and direction of the borehole are needed to calculate the dip and strike of indicated fractures in a borehole. Both optical and acoustic televiewer can be used. In this case, the acoustic data are used.

Figure 52 and 53 show the borehole deviation components for the Smøla boreholes, NE-component and horizontal component.

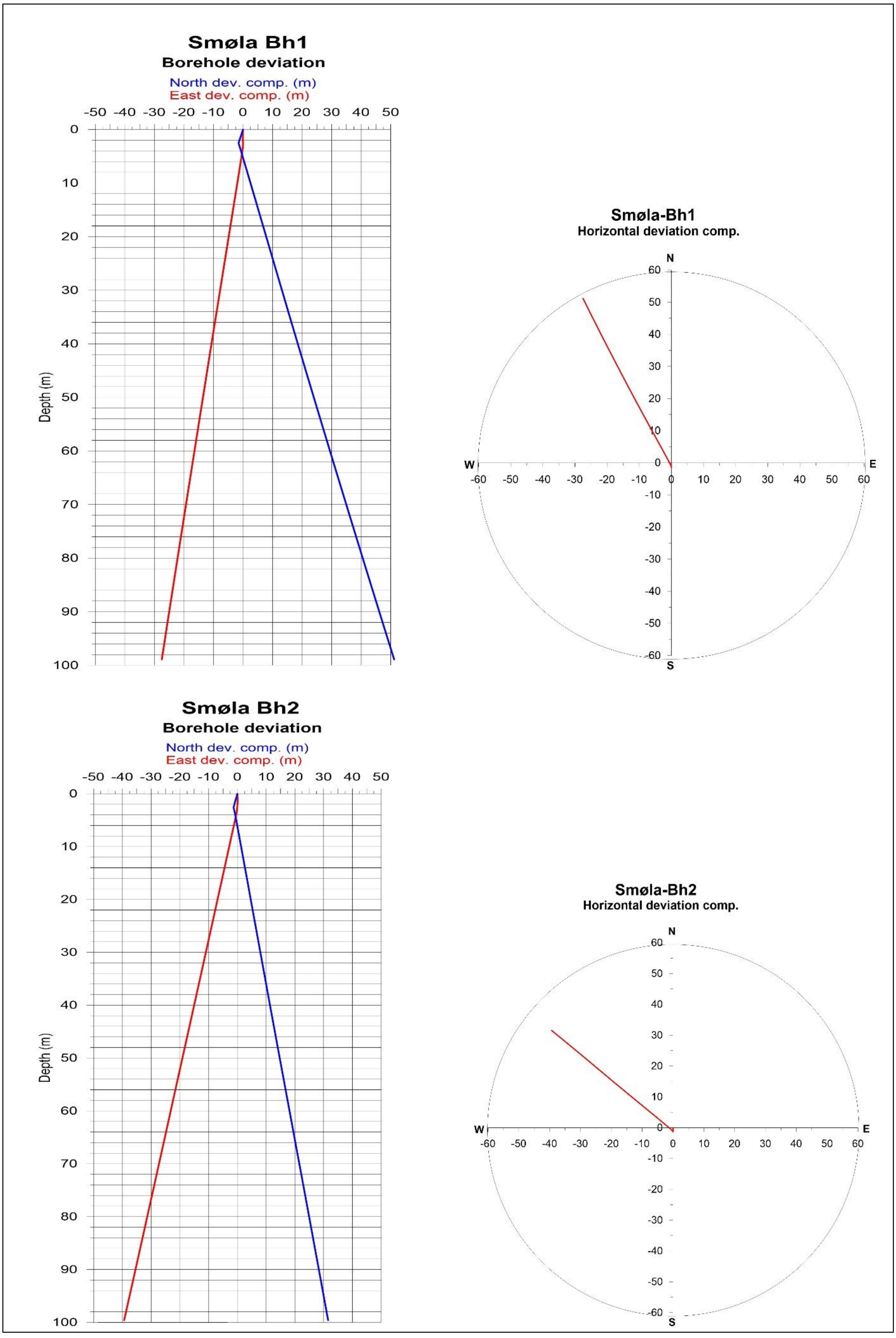


Figure 52. Deviation component Smøla Bh1 and Bh2.

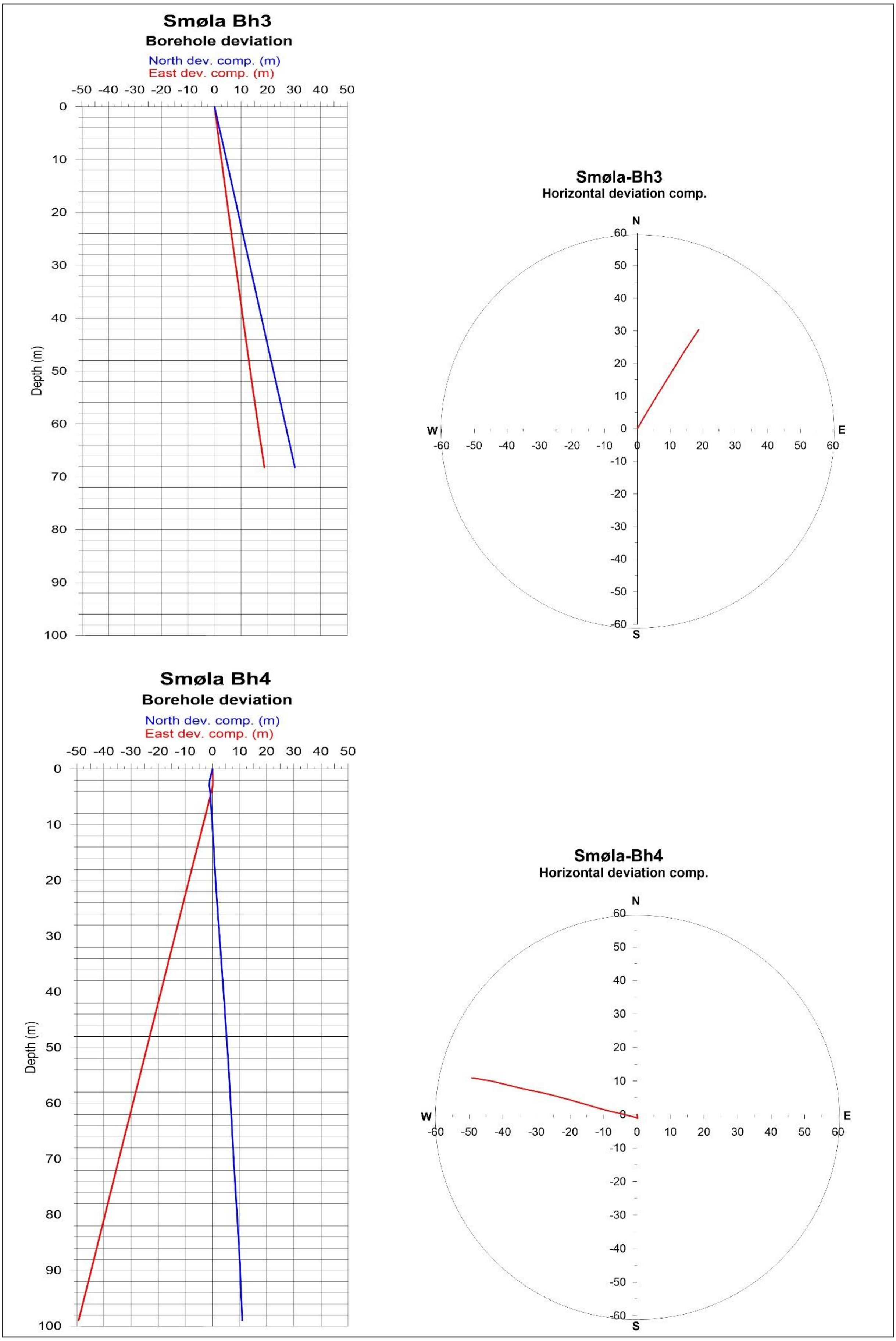


Figure 53. Deviation component Smøla Bh3 and Bh4

4.3 Flow measurements in Smøla Bh1, Bh2, Bh3 and Bh4

Flow measurements were performed in all boreholes, both with pumping and without pumping. This is done by running a flowmeter probe (a propeller) down and up the borehole at a constant speed. The propeller rpm is measured. The difference between the rpm down and up may suggest a vertical flow in the borehole. Changes in rpm can indicate water in- or outflow. Such measurements can also be taken during pumping. A pump is placed in the upper part of the borehole (at 10 m depth), and flow measurements are done below the pump while the pump runs. In this way, water can be sucked from water-bearing fractures. The pumping process will also give the water capacity of the well.

Figure 54 shows the flow measurements results from Bh1 and Bh2. The upward measurements are noisier than downhole measurements. This noise is probably caused by a borehole dip and a little turbulence in front of the propeller. There is no vertical flow indicated either with or without pumping; net flow is close to zero. The pumping showed that the capacity in both Bh1 and Bh2 was minimal (Table 5).

The pump was run for one hour in each borehole to calculate the capacity in litres/hour. The typical capacity in Norwegian crystal rock is about 500 l/h. Unfortunately, the boreholes (fractures) were cemented when the pumping was performed, which reduces the capacity. In Bh3, there was no cement. The water volume pumped from Bh1 and Bh2 is shown in Figure 55. The capacity of Bh1 and Bh2 are shown in Table 5.

Bh1 and Bh2 were quite close to each other, about 75 m. The ground water level in Bh2 was measured when pumping in Bh1 and vice versa. There was no change in the water level in the wells during the pumping period. This observation may indicate that there is no hydraulic connection between the wells, an assumption that is supported by the low water capacity in both wells.

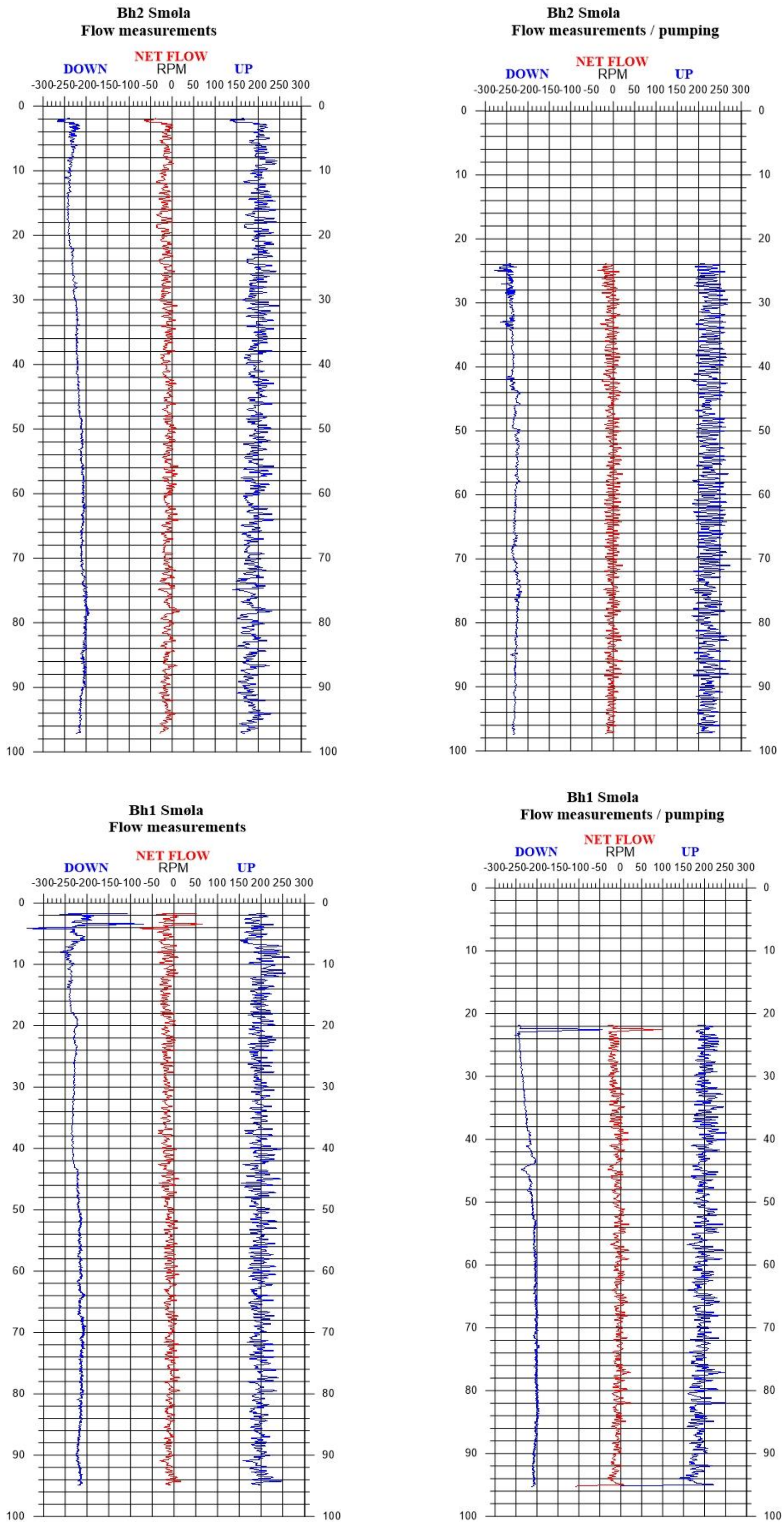


Figure 54. Flow measurements in Bh1 (upper) and Bh2 (lower)

Figure 55. Water volume from pumping in Bh1 (upper) and Bh2 (lower)

Table 5. Water capacity of Smøla boreholes

Bh	Capacity
Smøla Bh1	32 l/h
Smøla Bh2	15 l/h
Smøla Bh3	200-300 l/h
Smøla Bh4	10-12 l/h

Figure 56 shows the pumping results from Bh3 and Bh4. The net flow in both boreholes is ca.25 rpm, which usually means a small upward flow from the bottom to the top. There is no indication of inflow/outflow anywhere in the borehole, and pumping/not pumping gives the same result. The capacity in Bh3 was a bit higher than in Bh1 and Bh2 caused by an open near-surface fracture. We heard the sound of flowing water into the borehole. Close to the borehole, there was a pond, which could explain the open fracture. The capacity in Bh4 was even smaller than in Bh1 and Bh2, see table 5.

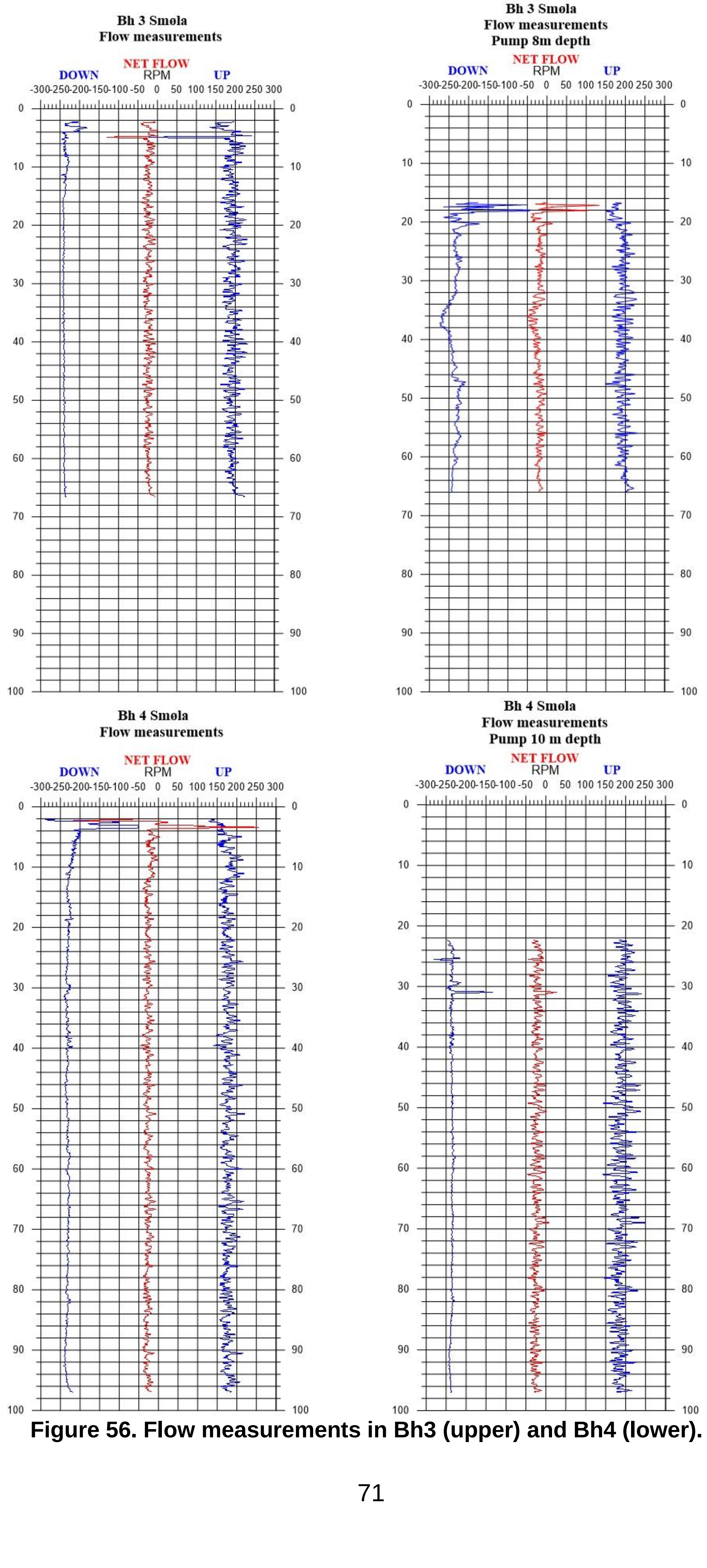


Figure 56. Flow measurements in Bh3 (upper) and Bh4 (lower).

4.4 Lugeon test, Smøla

The Lugeon test is described in Chapter 4, Figure 7. Appendix 1 shows the test intervals in each Smøla borehole. Intervals that contained fractures were locked by packers, and water was pressed into the rock for 10 minutes using 10 bars overpressure. Figure 57 shows the intervals and the results from the Lugeon tests in the Smøla boreholes. The intervals with the highest Lugeon number are 42 - 48 m in Bh1 and 60 – 66 m in Bh4, where L>5 (l/min/m). L = 5 -15 is classified as moderate due to the bedrock condition (few partly open fractures). Using the Lugeon number, the hydraulic conductivity can be determined (Figure 7). Hydraulic conductivity measures how easily water can pass through soil or rock. High hydraulic conductivity values indicate highly permeable material, while low values indicate low permeability materials (See Chapter 4.10).

In Bh1, the highest hydraulic conductivity is observed in the upper part of the borehole (25 - 48 m). In Bh2, the hydraulic conductivity is low, and in Bh4 the conductivity is moderate or somewhat low along most of the borehole. It decreases to the bottom of the borehole. This borehole with the highest Lugeon numbers correlates well with its resistivity and fracture frequency (See Figure 58).

The cemented intervals in each Smøla borehole are shown in Appendix 3. Drilling reports are shown in Appendix 5.

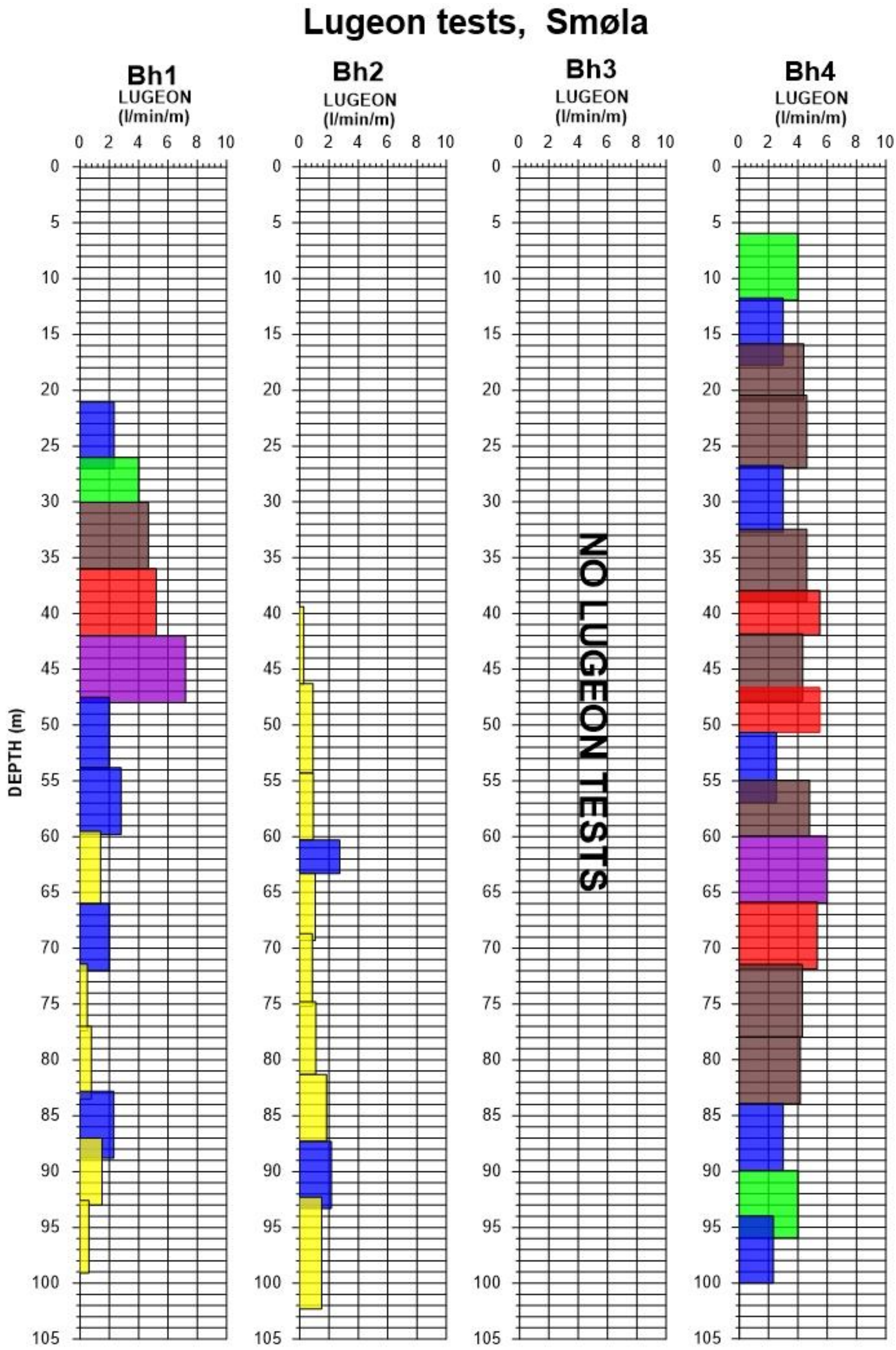


Figure 57. Lugeon test results in the Smøla boreholes.

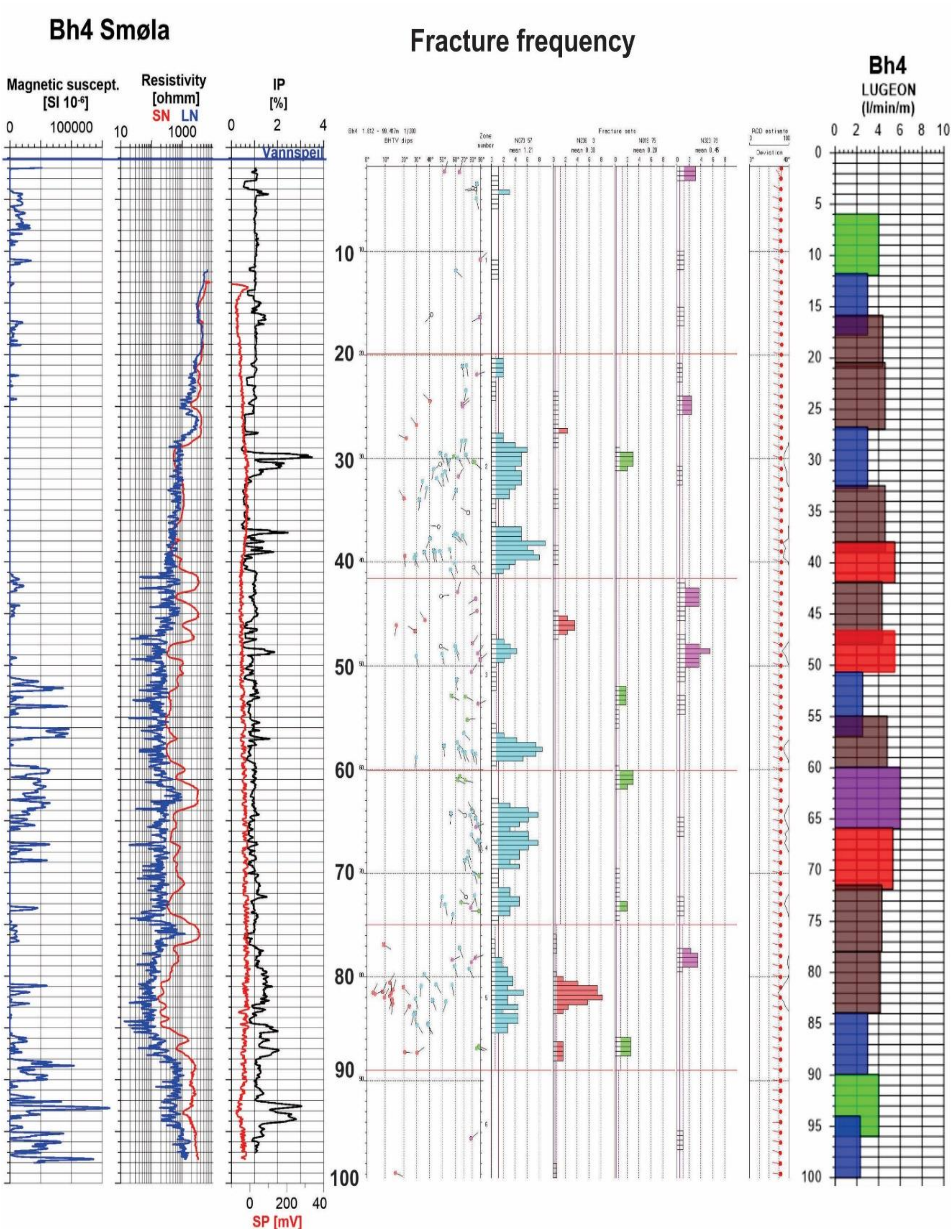


Figure 58. Bh4 Smøla, resistivity, magnetic susceptibility, IP, SP and Lugeon test numbers.

4.5 **Optical televiewer**

The optical televiewer was run in all boreholes. The data quality was in general bad due to muddy water. Optical televiewer can only be used in clear water (or without water). The borehole water in dipping boreholes (60^o) needs a longer time to clear up than vertical holes. Because of that, the acoustic televiewer is used for fracture mapping. However, lithological limits are difficult to see on the acoustic images.

In Smøla Bh2, the optical data was quite good. In this borehole, there are alternating layers (veins) of red granite and amphibolite. An example is shown in Figure 59 (left), 25 - 30 m depth. Close to the bottom, at 75 – 80 m, some veins of white carbonite rock occur. All this, and other geological information, can be seen on cores and core photos.

Figure 60 shows an interpretation of optical televiewer data in Bh2, 25 – 30 m depth. The red granite veins are digitised. The dip and azimuth are calculated for each vein. The red dots with tale indicate the dip and dip direction, a dip of 90 ^{o} is to the right on the logarithmic x-axes. Azimuth N is up and S down. Also, the thickness of the veins is calculated.

Figure 61 shows the full interpretation of dip and azimuth for the granite veins in Bh2. The average azimuth for the upper 66 m is about N160, SE. The average dip angle is 35 – 40^o. In the lower part, the veins are much steeper, 66^o, dipping to SE (N130 – N155), a bit more to the E than in the upper part. To the right of the figure, the borehole deviation is shown, dip and azimuth.

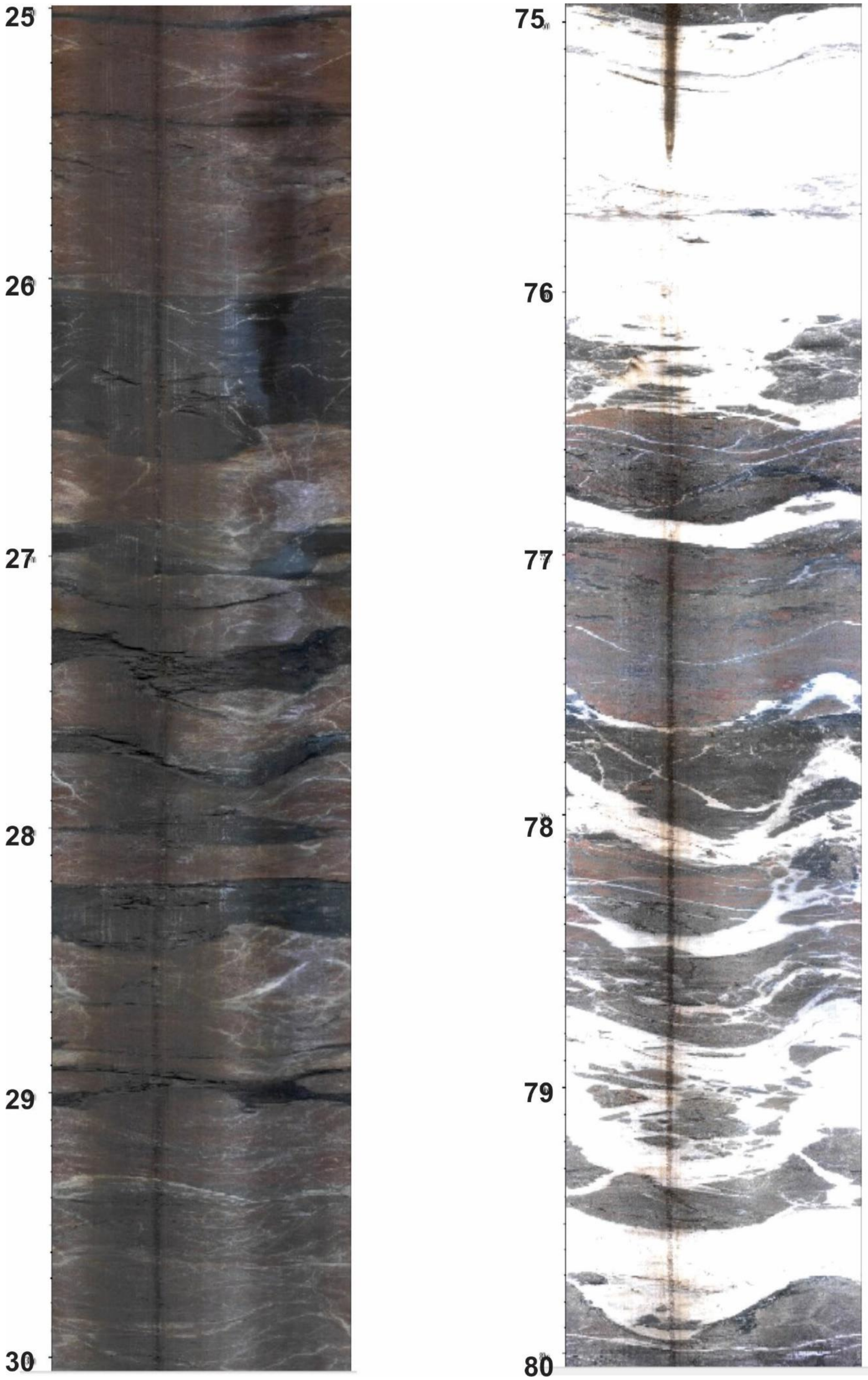


Figure 59. Smøla Bh2, images from optical televiewer, 25 – 30 m (l), 75 – 80 m (r)

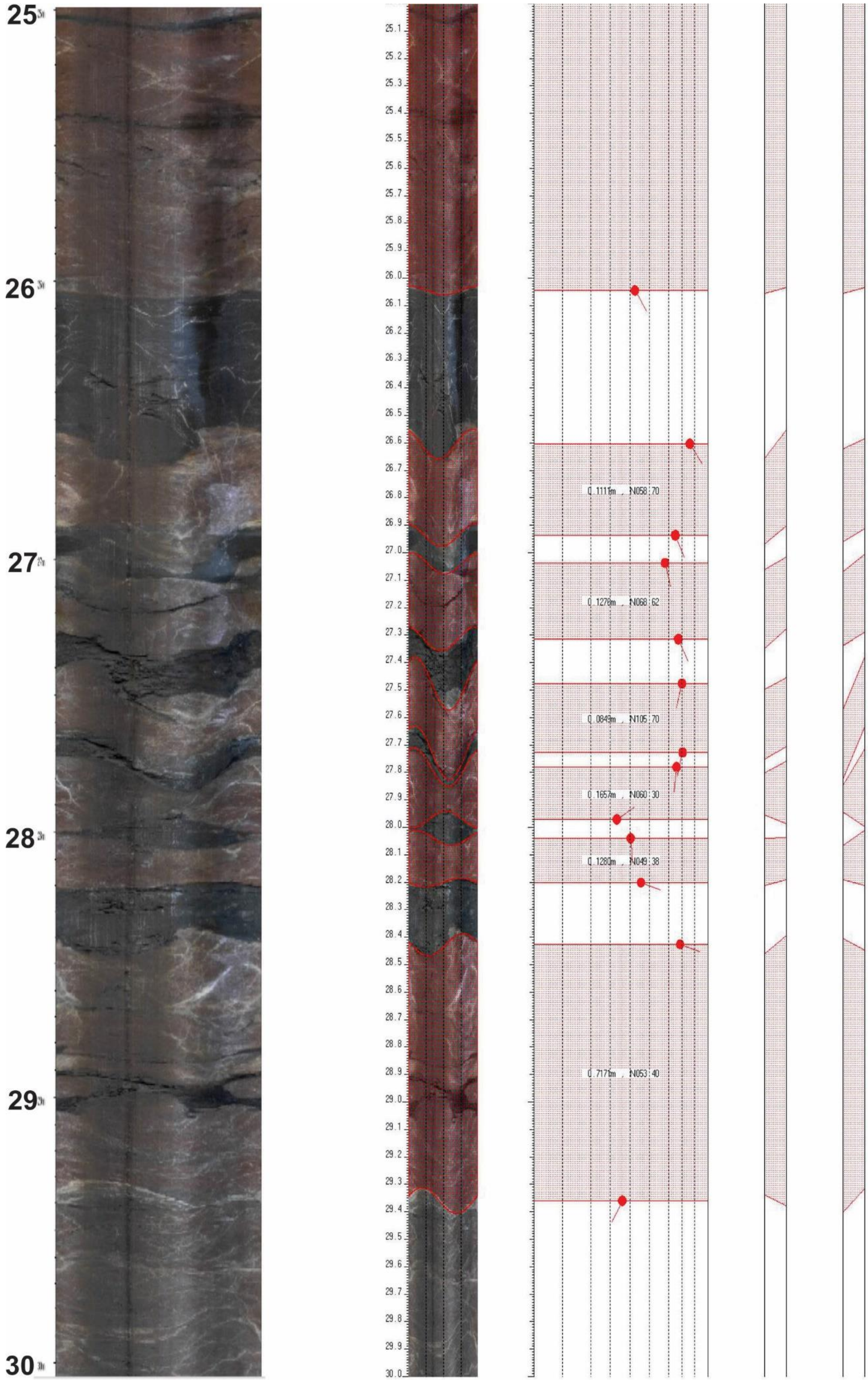


Figure 60. Smøla Bh2, interpreted section of OPTV image, 25 – 30 m depth.

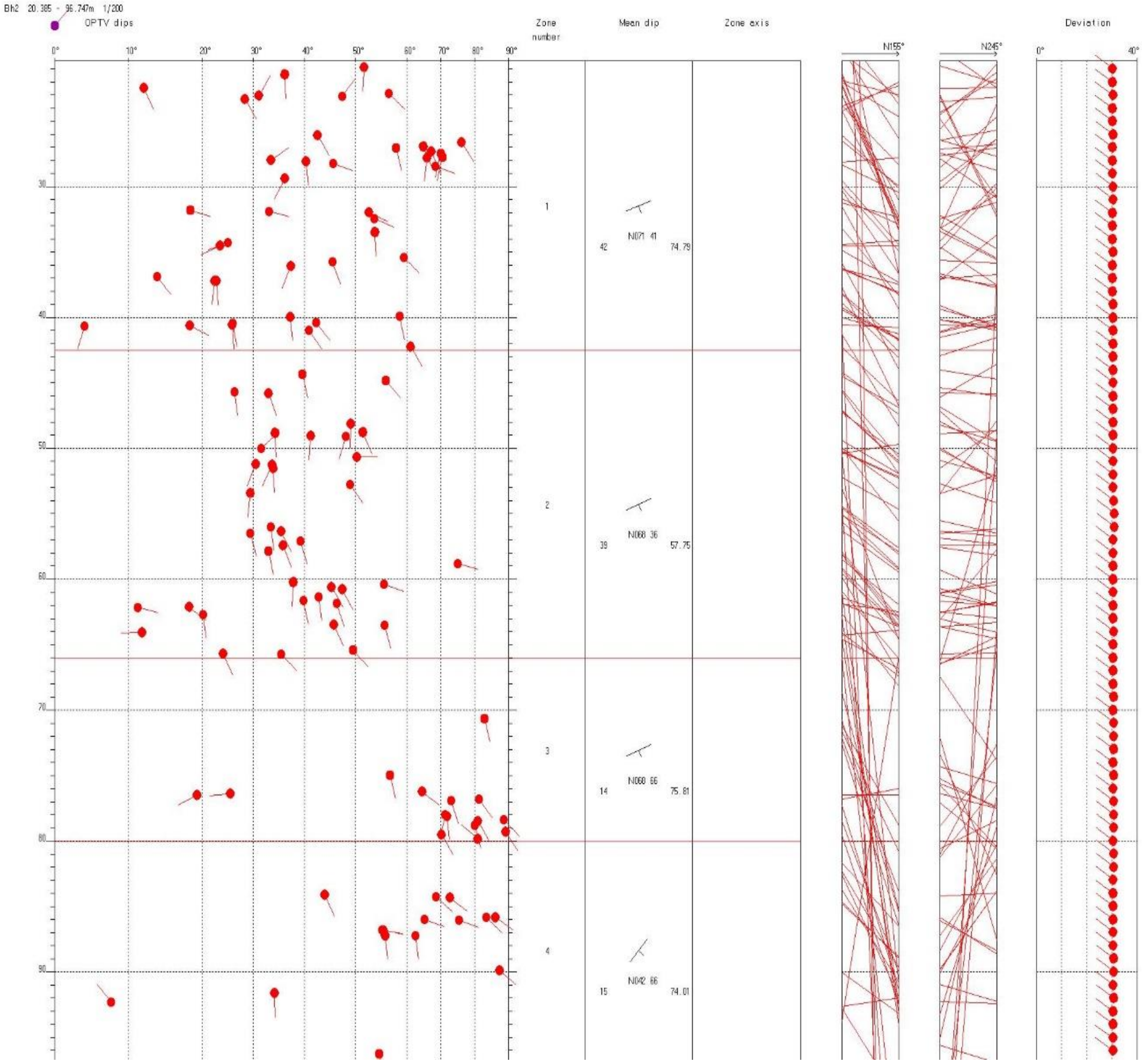


Figure 61. Smøla Bh2. Interpreted dip and azimuth of granite veins from OPTV data.

4.6 Bømlo results

Logging at Bømlo was performed in March and October 2020. The logging was fulfilled without any problems except in Bh2, which became jammed at 26 m. Figure 62 shows the logging locations at Bømlo.

Figure 62. Borehole locations at Bømlo, Bh1, Bh2 and Bh3.

While logging in March 2020, Bh2 jammed at about 27 m depth, and all logs stopped at that depth. In October 2020, a drilling company tried to reopen the borehole. Cutting through the blocked part of the borehole was unproblematic. Flushing with water and compressed air released significant amounts of muddy clay (?) and sand from the borehole (Figure 63). But, when the bore string was removed from the borehole, clay and sand plugged the borehole at the same depth. Flushing was repeated twice. Extra water had to be transported to the borehole from the Fire station because there was no inflow of water into the borehole after flushing. The MagSus-gamma probe was the only probe to pass through. The fracture zone (fault) at 24 -26 m depth appeared to contain large volumes of muddy clay and sand, which flew into the borehole once the bore string was removed.

Figure 63. Reopening of Bh2. Clay (?) and sand were flushed out of the borehole.

4.6.1 Temperature, water conductivity and total gamma, Bh1, Bh2, and Bh3

Figures 64 – 66 show logs of temperature, water electric conductivity, total gamma and the calculated thermal gradient of the Bømlo boreholes.

In Bh1, Figure 64, there is a slight change in the temperature and water conductivity at 20 m depth. This can indicate water inflow, but no open fracture is indicated at that depth on other logs. The thermal gradient is low, 5 -10^{o}C/km and the water conductivity is influenced by the seawater (1500 – 1800 µS/cm). The total gamma radiation varies from ca 75 cps to ca 200 cps, with the highest values in the lower part of the borehole, which is most likely caused by an increased U content. This value is slightly lower than usual for granite.

In Bh2, Figure 65, the water conductivity is much higher, 15000 µS/cm. Seawater has a conductivity of ca 40000 µS/cm. The gamma log is from the MagSus probe (Oct. 2020). The average cps value is 100, with some high values in the lower part. This could be thin pegmatites veins (more reddish cores).

In Bh3, Figure 66, the water conductivity indicates fresh water. The gamma radiation is about 100 cps (API), which is measured in Bh1 and Bh2. The rock is described as granite/granodiorite.

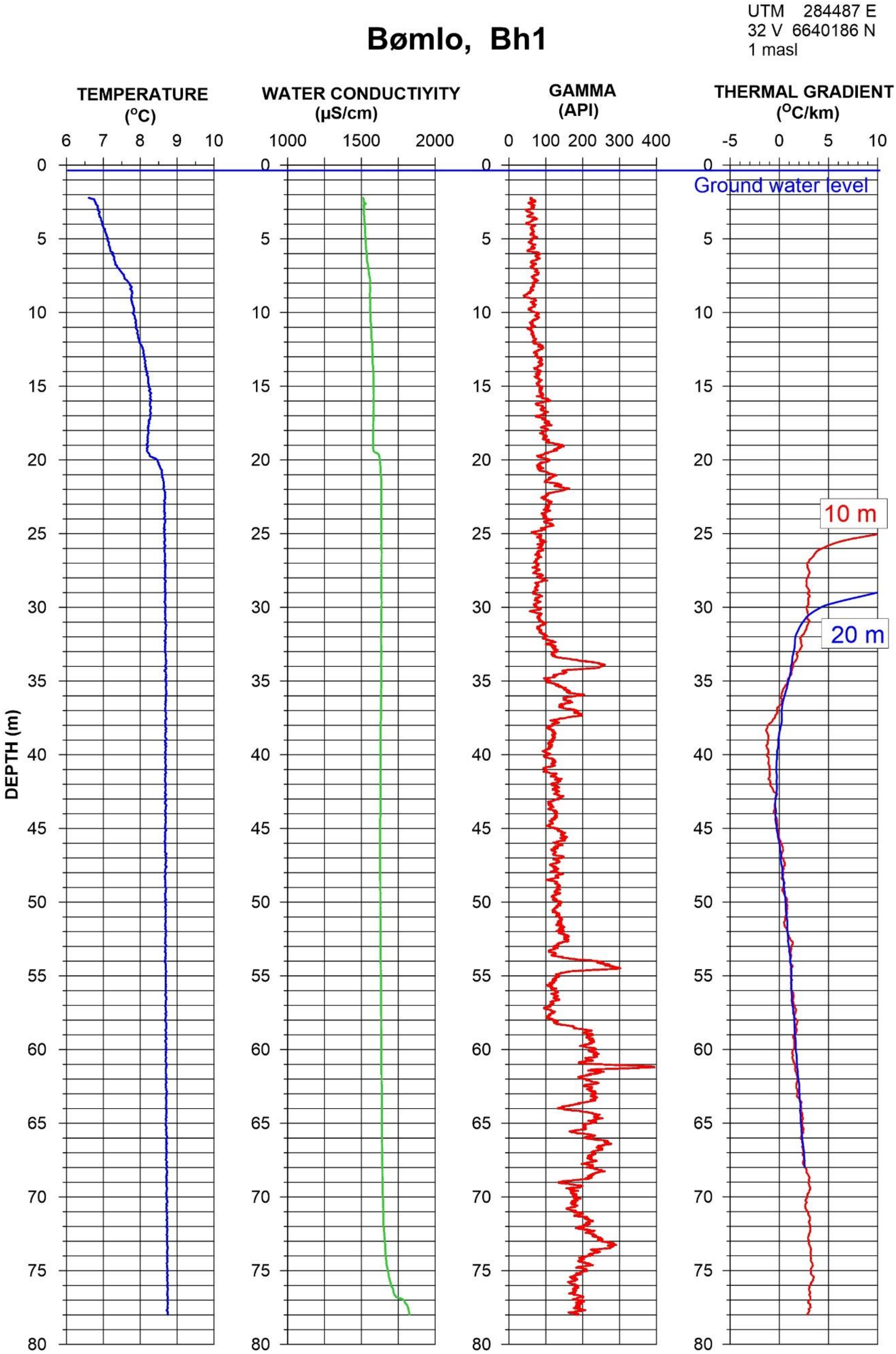


Figure 64. Bømlo Bh1. Temperature, water conductivity, total gamma, and thermal gradient.

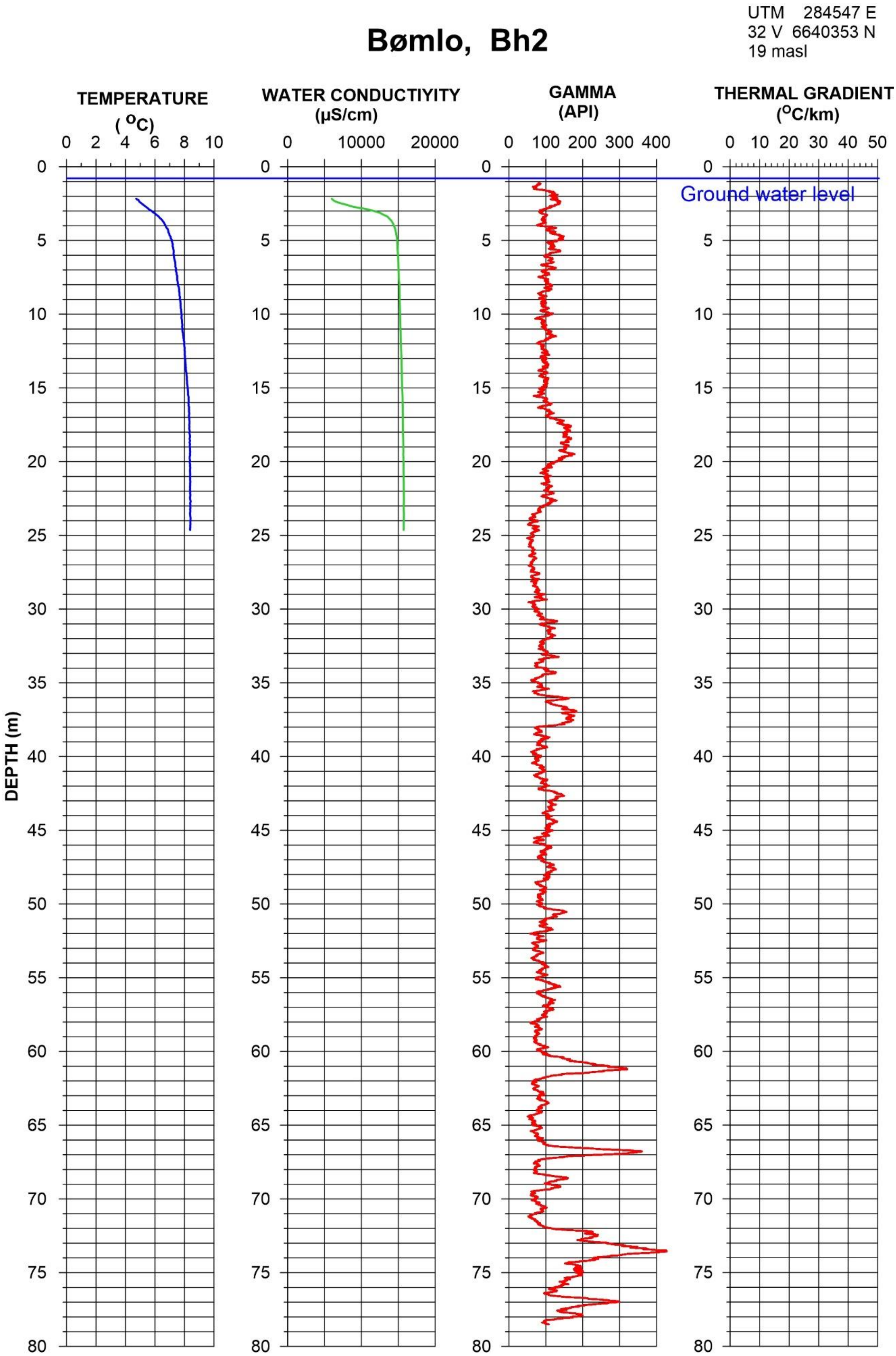


Figure 65. Bømlo Bh2. Temperature, water conductivity and total gamma.

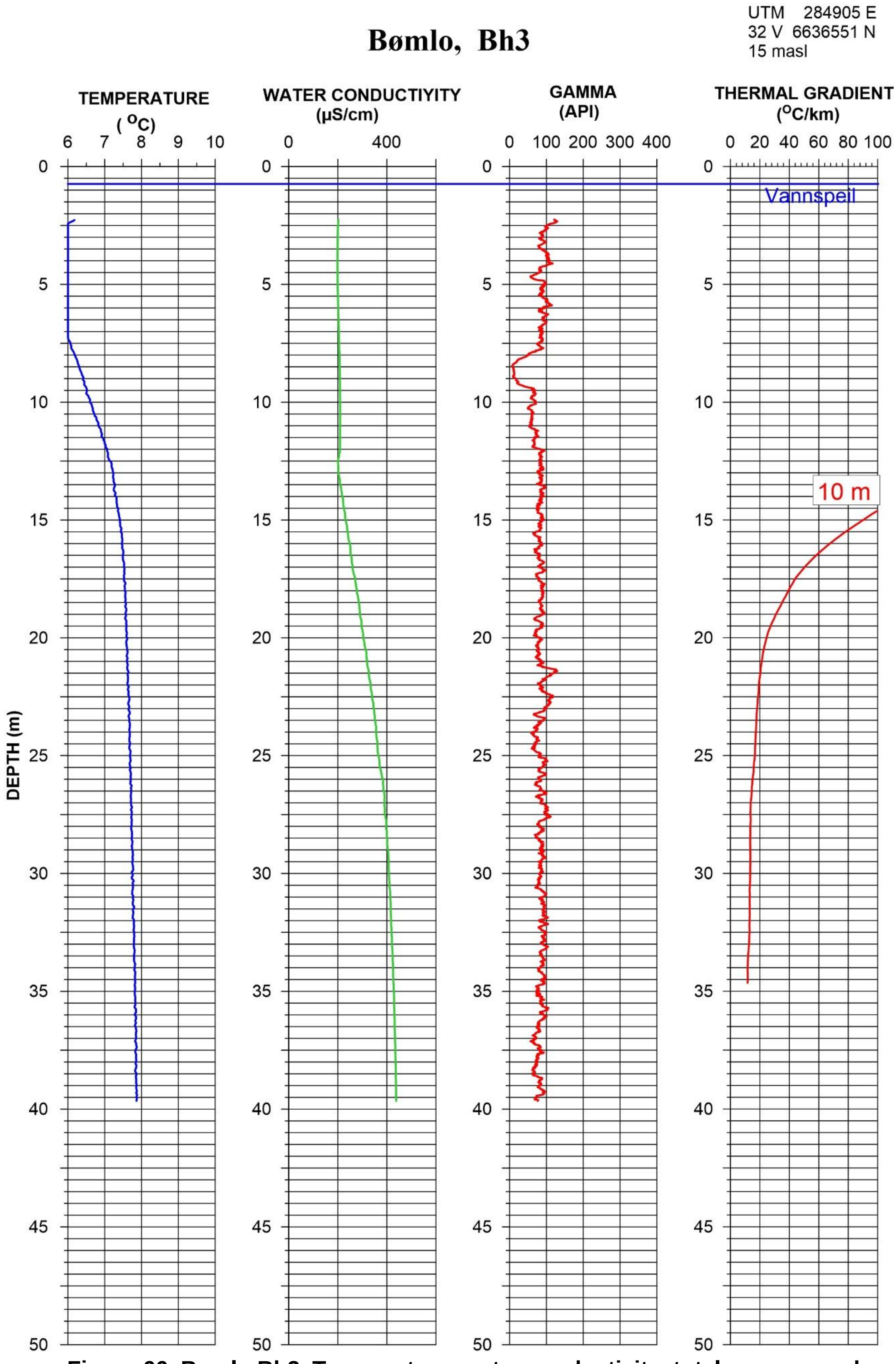


Figure 66. Bømlo Bh3. Temperature, water conductivity, total gamma, and thermal gradient.

4.6.2 Gamma spectrometry Bømlo, Bh1, Bh2 and Bh3

Gamma spectral logs are shown in Figure 67 – 69. The total gamma radiation in the Bømlo granite is relatively low, about 100 cps. In Bh1, the total gamma radiation increases to the depth, up to 250 cps. The U content correlates well with the total gamma. Some Th high values in Bh1 correlates with U peaks (34 and 55 m depth)

Table 6 shows the mean, minimum and maximum content of U, Th and K in all the Bømlo boreholes. Bh1 has the highest U and Th content. K is low in all boreholes.

Table 6. U, Th and K content in the Bømlo boreholes.

Bh	Umean	Umin	Umax	Thmean	Thmin	Thmax	Kmean	Kmin	Kmax
Bh1	10.2	2.3	23.7	0.9	0	16.1	0.4	0	3.9
Bh2	8.1	3.5	16.3	0.5	0	5.0	0.2	0	1.6
Bh3	6.6	0.2	11.7	0.9	0	7.8	0.2	0	1.1

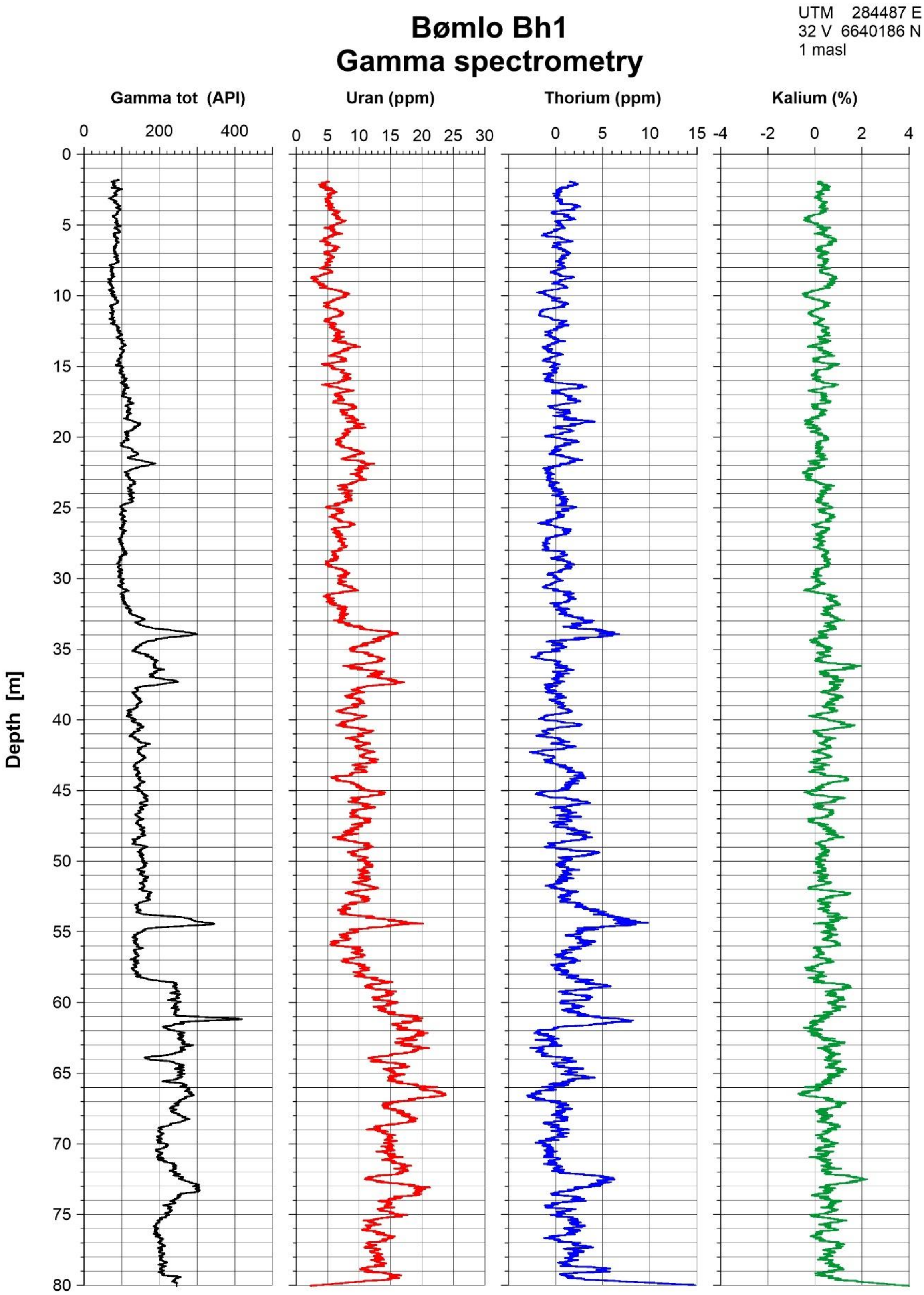


Figure 67. Bh1, Bømlo. Total gamma, U (ppm), Th (ppm) and K (%).

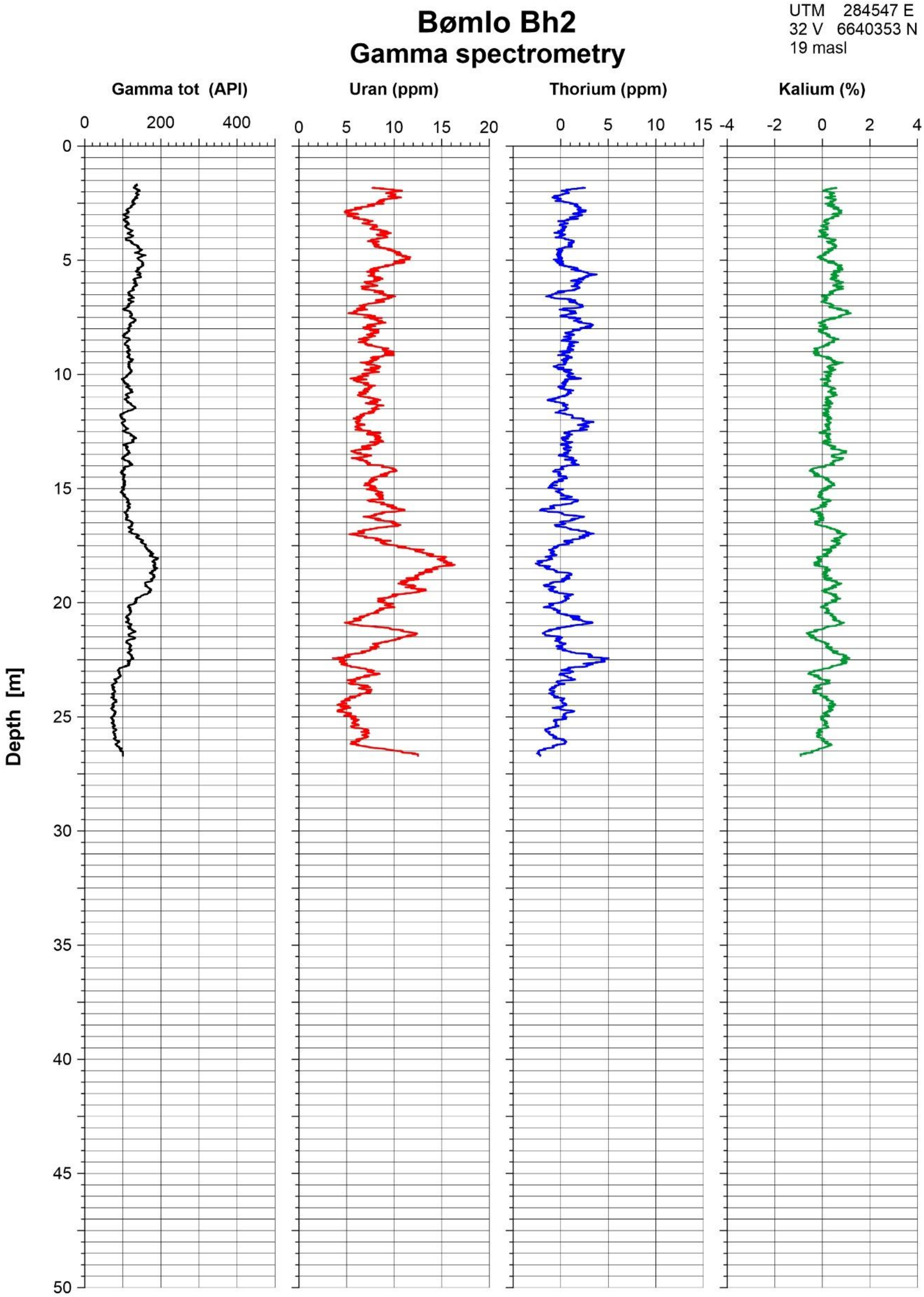


Figure 68. Bh2, Bømlo. Total gamma, U (ppm), Th (ppm) and K (%).

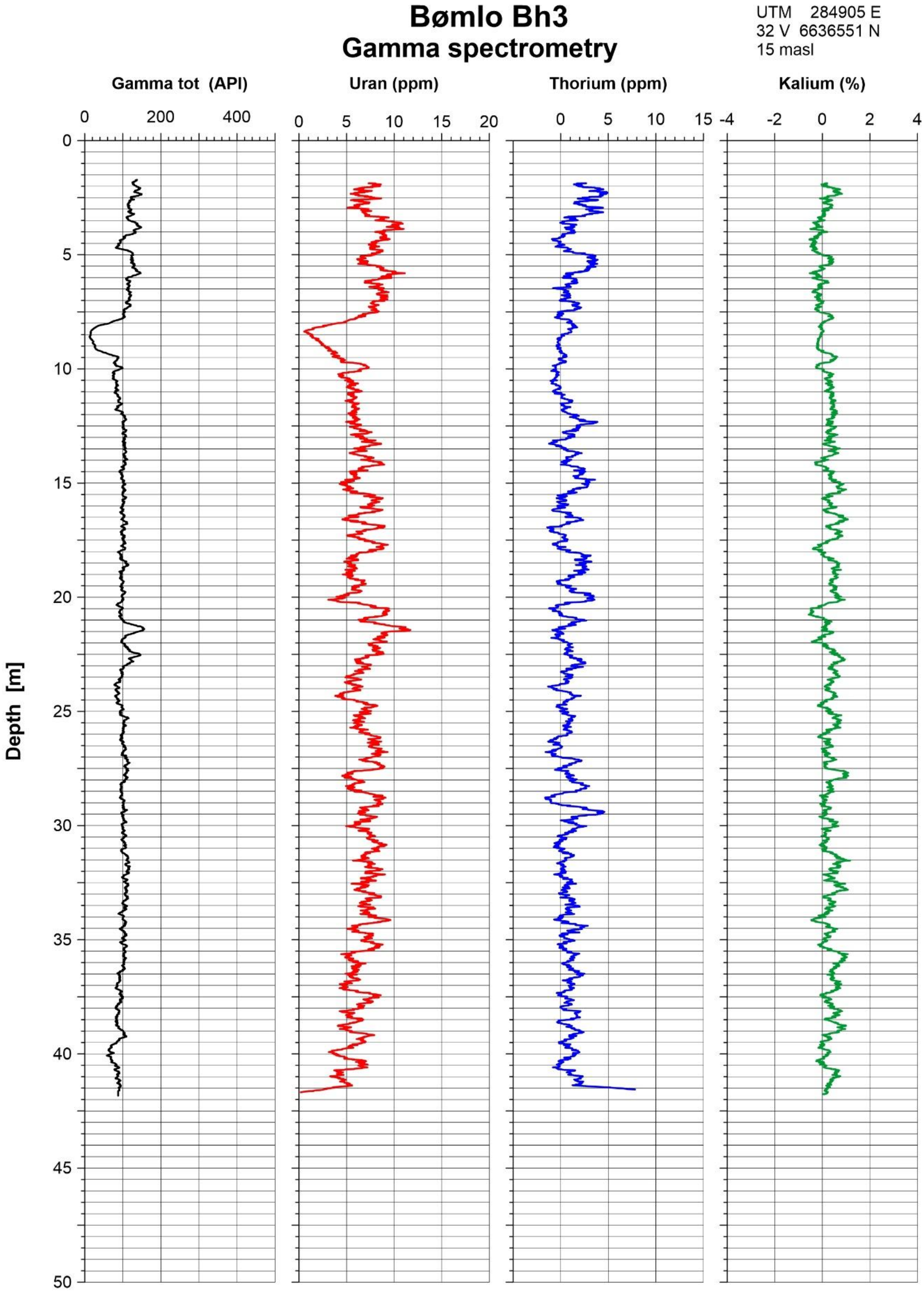


Figure 69. Bh3, Bømlo. Total gamma, U (ppm), Th (ppm) and K (%).

4.6.3 Seismic P-velocity, total gamma, magnetic susceptibility, Resistivity, SP, IP and apparent porosity in Bømlo Bh1, Bh2 and Bh3

Figure 70 - 76 show the combined logs in all Bømlo boreholes. Data quality is quite good.

The P-velocity in Bh1 is just below 4000 m/s in the upper 30 m. Below 30 m, it is about 4500 m/s. There are no significant variations. The P-velocity is a bit lower than average values for granite (Elvebakk 2011). This could be caused by high fracture frequency and somewhat increased porosity, 4 % in Figure 70.

In Bh2, the P-velocity is at the same level, with somewhat more variation, likely caused by fractures. This borehole was stuck at ca 27 m depth due to large fracture zone.

In Bh3, the P-velocity drops clearly from 27 m depth to 2000 – 3000 m/s. This is rather usual, but the resistivity also drops at the same level. The porosity increases to 4 – 6 %. This will be discussed later.

Resistivity Bh1
The resistivity is very low in the upper 35 m. 200 – 400 ohmm means fractured rock and high porosity. The fracture frequency is relatively high in the upper 45 m, see Figure 71. The water conductivity is 1500 -1800 µS/cm, a bit higher than fresh water. The fracture frequency is less in the lower part, and the resistivity increases up to 4000 ohmm. There are no conductive minerals indicated due to the IP and SP logs.

Resistivity Bh2
The resistivity decreases down to 25 m depth showing 10 - 100 ohmm in the fracture zone, see Figure 72 and 73. The water conductivity is close to sea water 15000, µS/cm. The cores from this part of the borehole were very soft. A wooden stick could easily be pushed into the core, see Figure 74 (upper). Below 32.5 m, the rock is hard and massive; see Figure 74 (lower). No logs were produced except total gamma and MagSus exits below 25 m.

Resistivity Bh3
In Bh3, the water conductivity is low and will not influence the rock resistivity. The borehole was drilled through a 12 m overburden (rock fill). Above ca 27 m depth, the resistivity is about 1000 ohmm, see Figure 75 and 76. This is relatively low and indicates fractured rock. Below 27 m, the resistivity drops to 150 – 300 ohm, which means highly fractured rock (or high porosity). Figure 77 shows the resistivity, caliper and acoustic televiewer image. An extensive fracture is indicated on the caliper log at ca 27 m depth. The resistivity starts to drop from this depth, and the acoustic image change colour (getting darker). A darker colour means that the amplitude of the acoustic pulse is more attenuated. The reason for this is unknown, but the rock is obviously softer. The rock is less fractured below 27 m, but deeply weathered rock could be the reason.

The total gamma results are described in Chapter 4.6.1. Total gamma radiation is mostly the same in all boreholes. It should be remarked that the gamma radiation in Bh3 is constant and does not change below 27 m depth.

The magnetic susceptibility is almost the same (0.001 SI) in all boreholes except in Bh2. In the upper 45 m, the susceptibility is close to zero. In the fractured area at ca 25 m depth in Bh3, the susceptibility is also zero. The reason could be deep weathering and low magnetic properties, which is also seen in Bh3 and Bh4 at Smøla.

The apparent porosity is calculated using Archie's law where SN resistivity, LN resistivity and borehole water conductivity. If there are conductive minerals, and high conductive water present, the porosity value is incorrect.

In Bh1, the porosity is ca 1-2 % below 45 m (less fractured) and ca 4 % in the upper fractured part. In Bh2, the very low resistivity and the high water conductivity led to a calculated porosity 4-10 %. In Bh3, the porosity is highest below 27 m depth, 4-6 %.

SP shows no anomalies, which means that no conductive minerals are present. Minor IP anomalies may indicate clay.

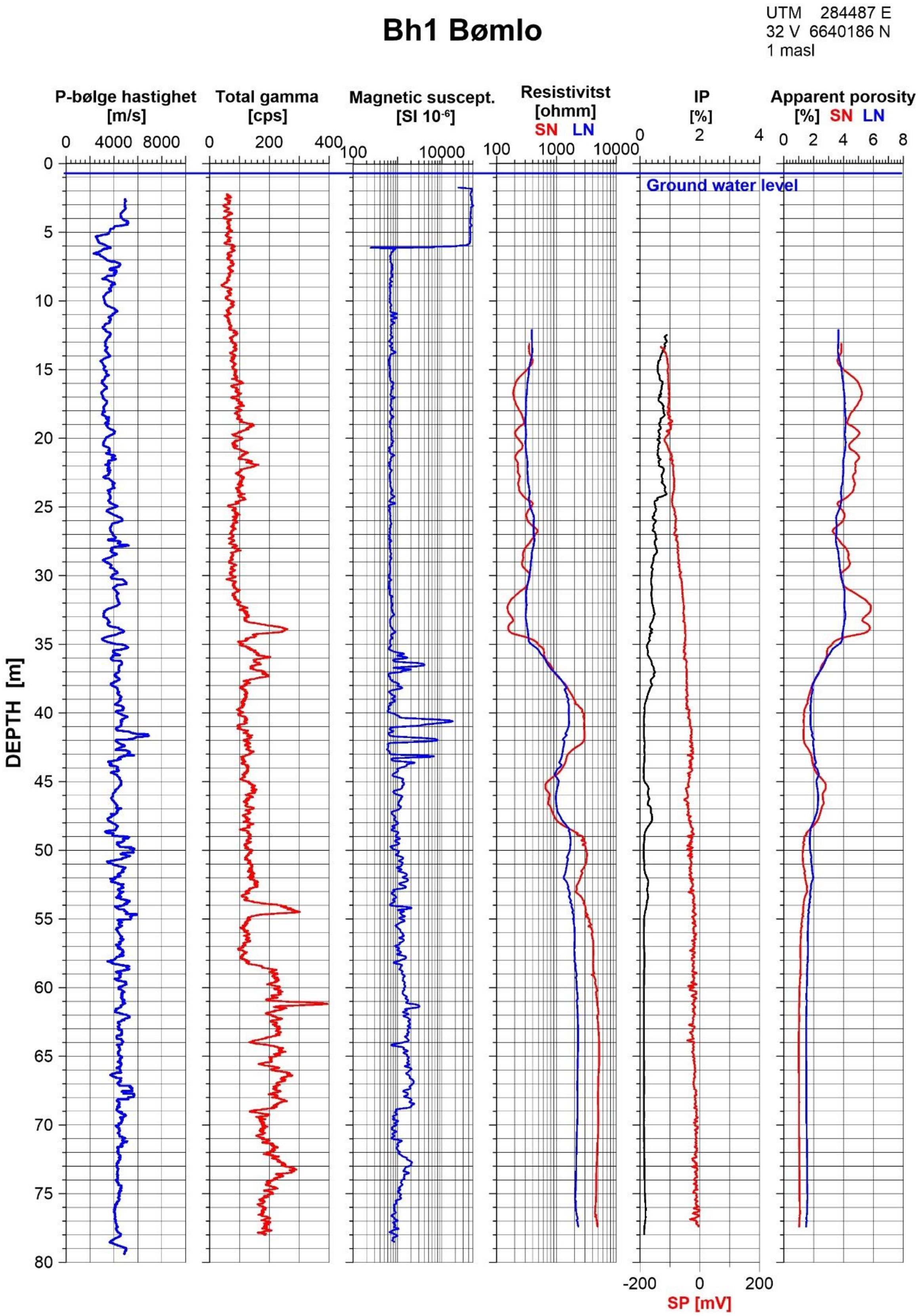


Figure 70. Bømlo Bh1. P-wave velocity, total gamma, magnetic susceptibility, resistivity, IP, SP, and apparent porosity.

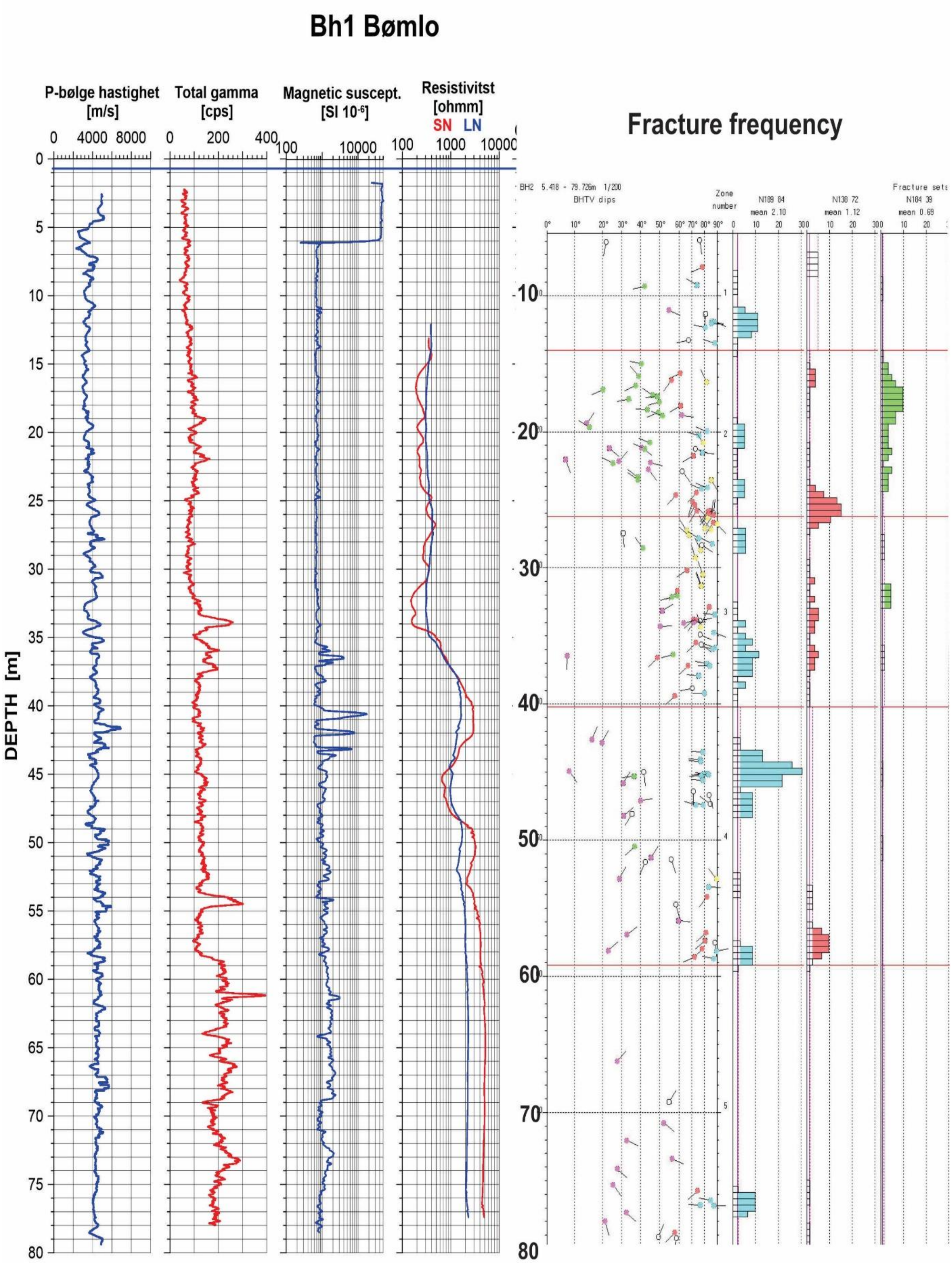


Figure 71. Smøla Bh1. P-wave velocity, total gamma, magnetic susceptibility, resistivity and fracture frequency.

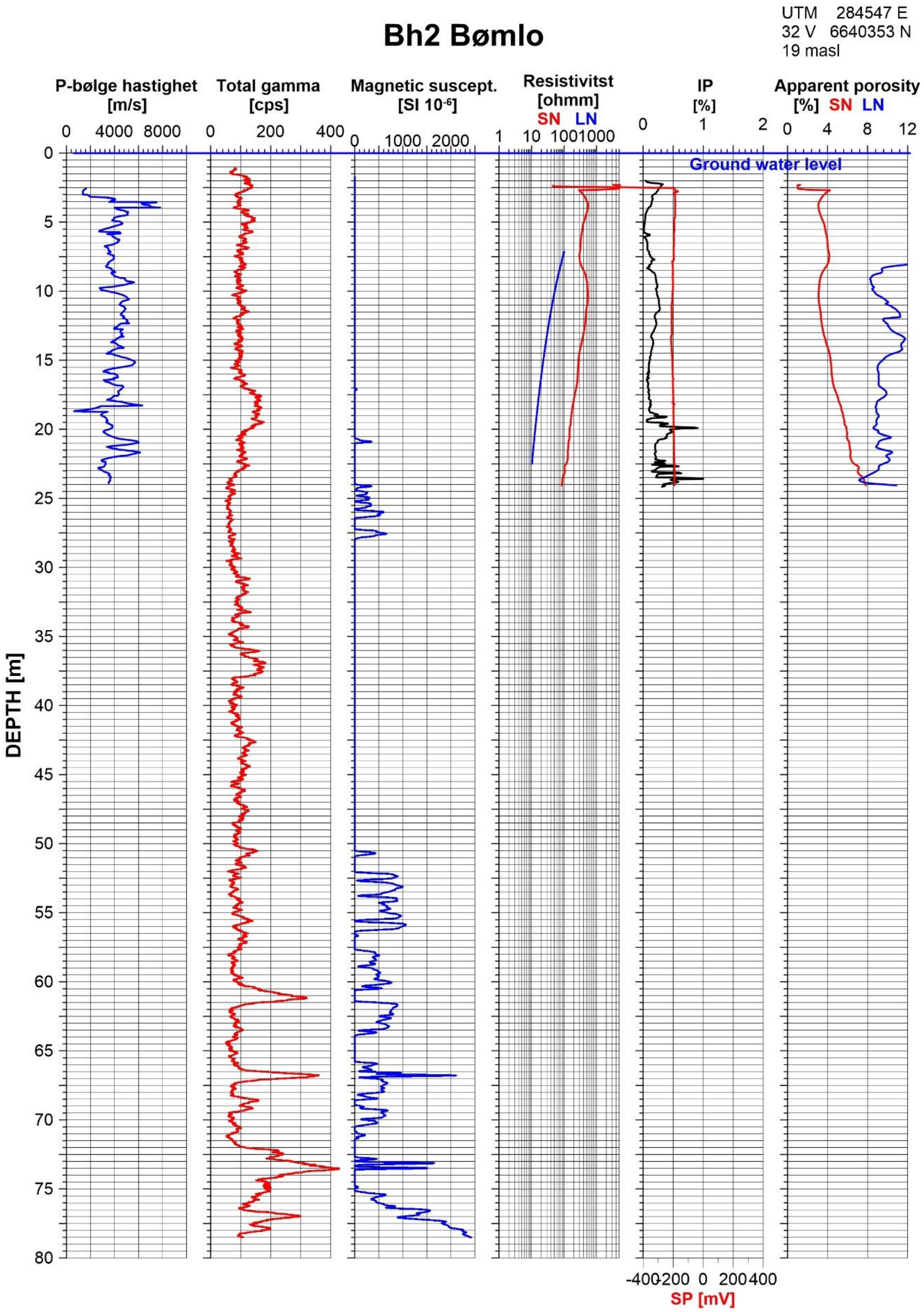


Figure 72. Bømlo Bh2. P-wave velocity, total gamma, magnetic susceptibility, resistivity, IP, SP, and apparent porosity.

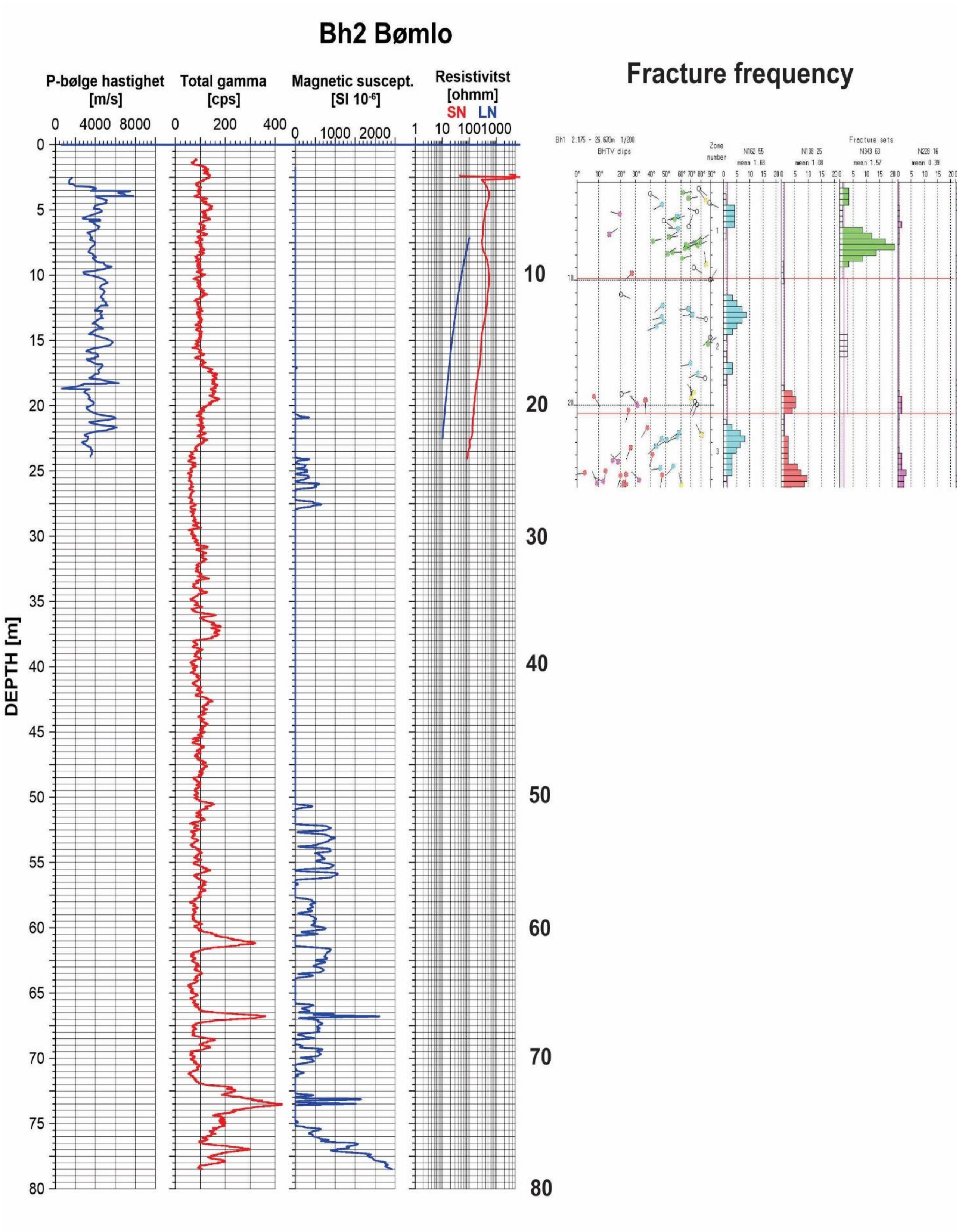


Figure 73. Smøla Bh2. P-wave velocity, total gamma, magnetic susceptibility, resistivity, and fracture frequency

Figure 74. Bømlo Bh2. Soft rock at 25 m (upper) and hard rock from 32.5 m (lower).

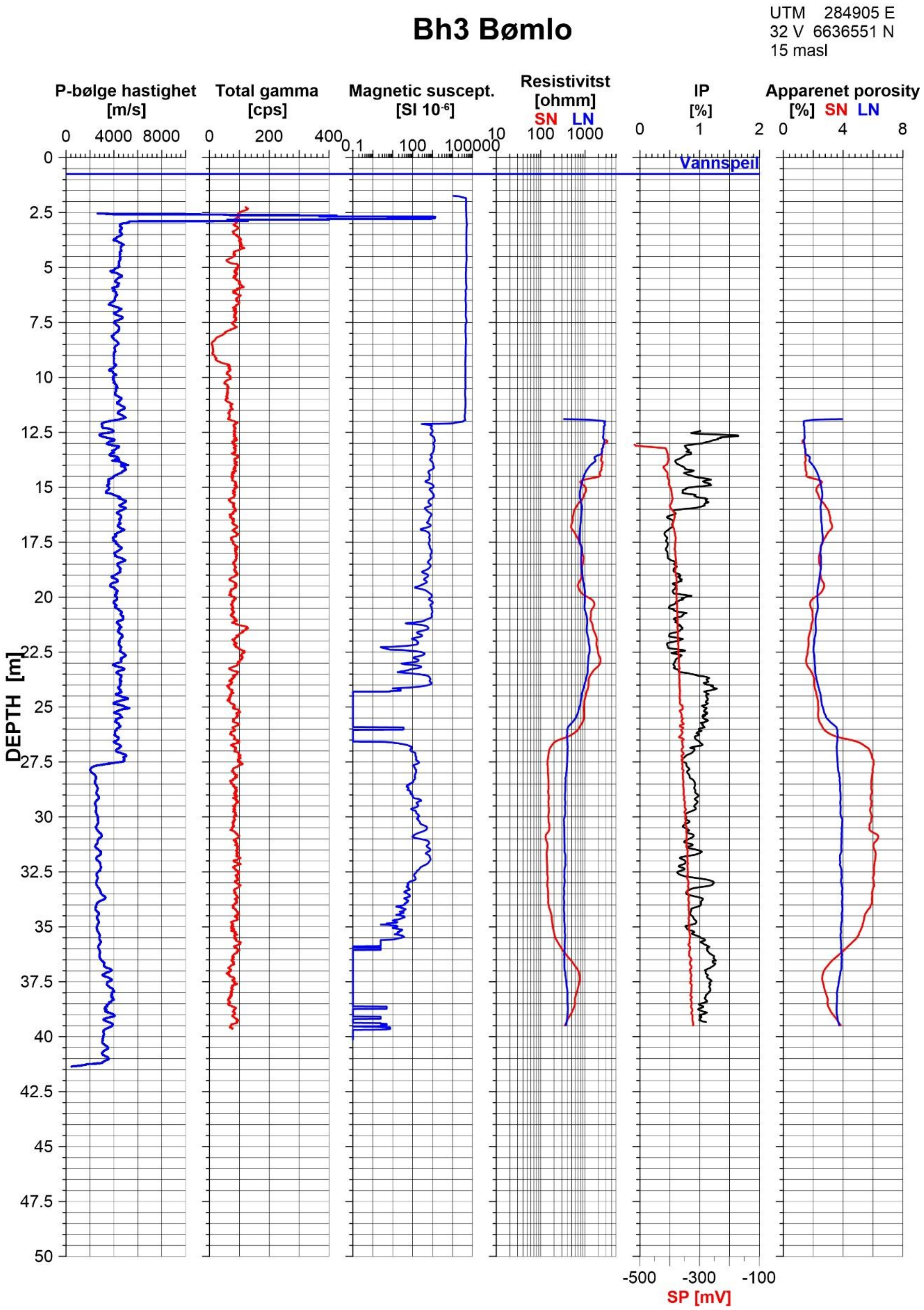


Figure 75. Bømlo Bh3. P-wave velocity, total gamma, magnetic susceptibility, resistivity, IP, SP, and apparent porosity.

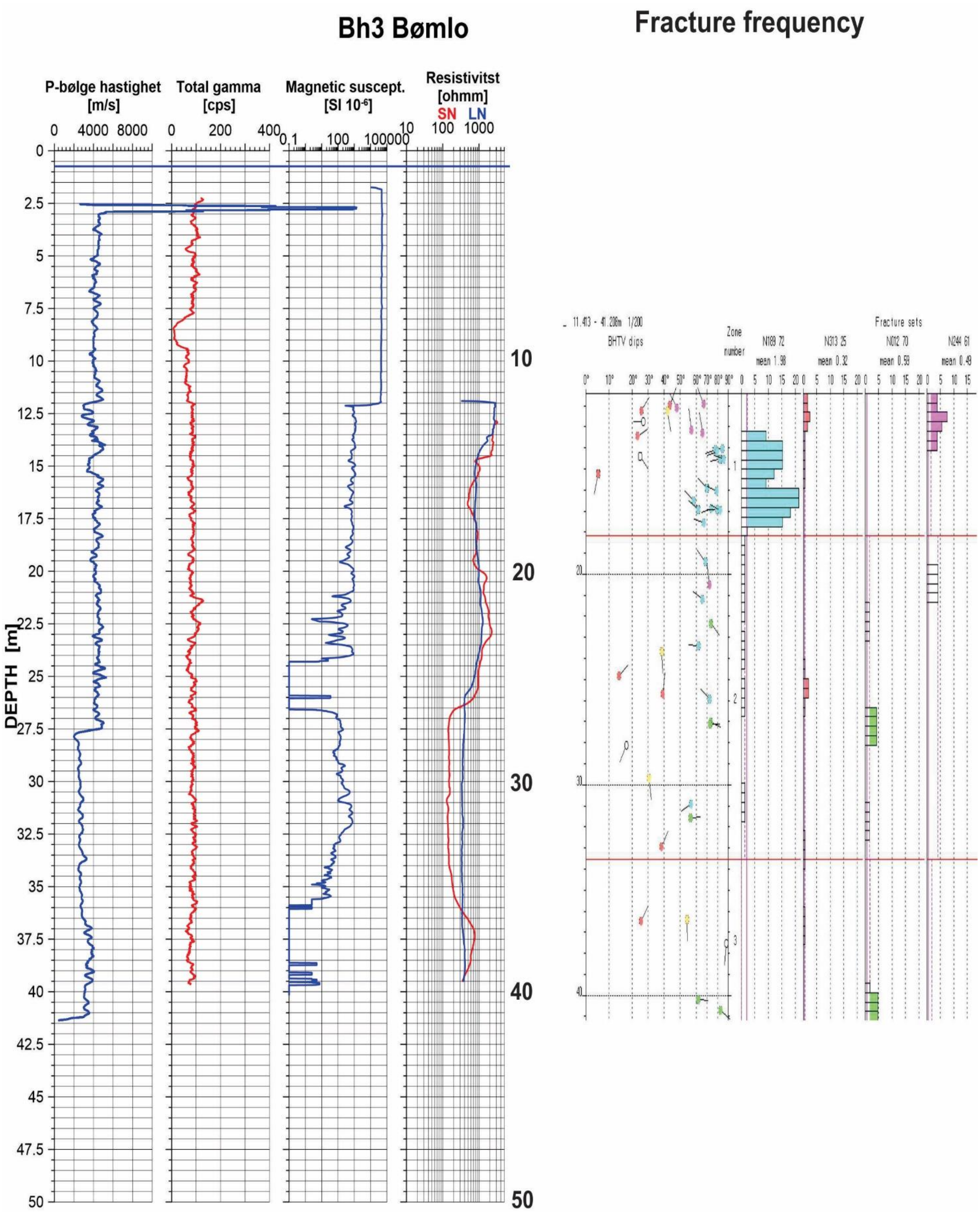


Figure 76. Smøla Bh3. P-wave velocity, total gamma, magnetic susceptibility, resistivity, and fracture frequency.

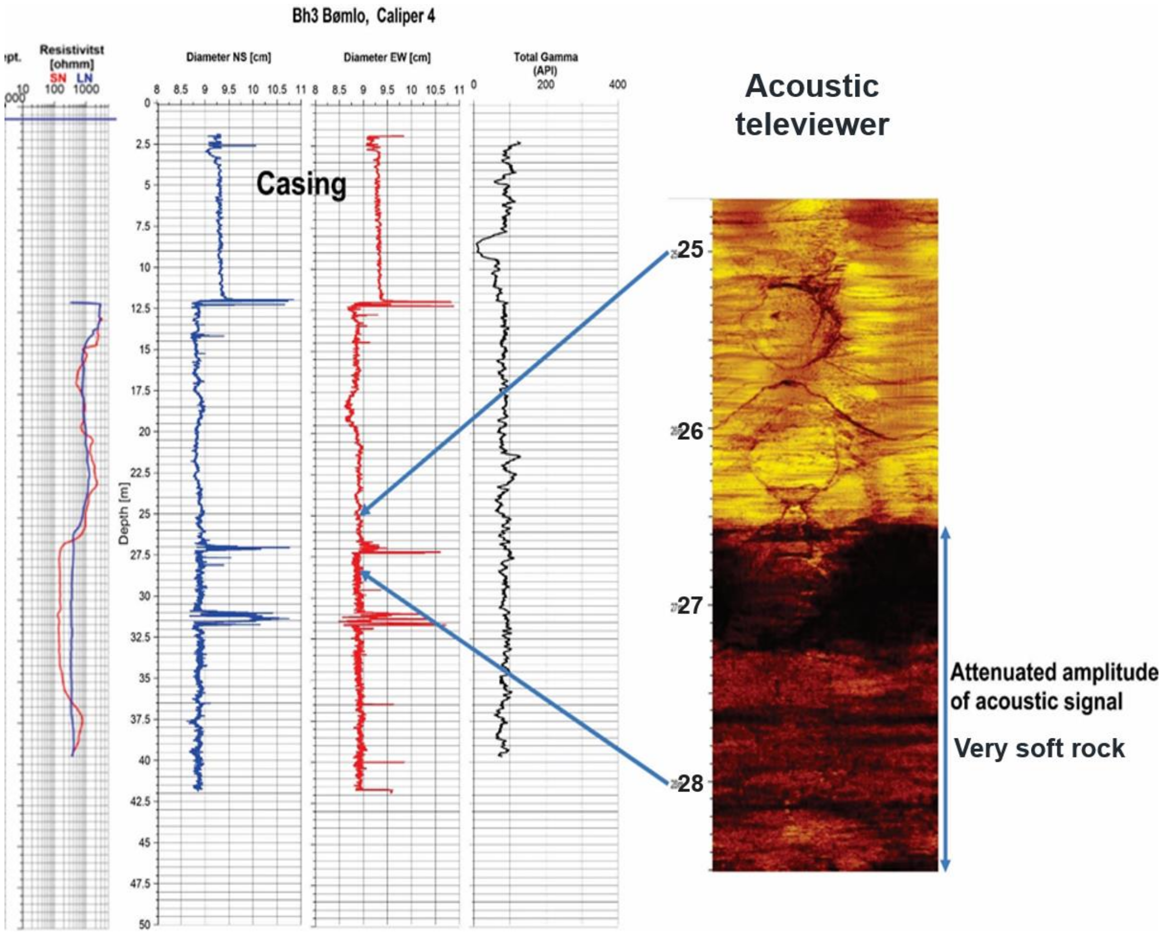


Figure 77. Bømlo Bh3. Resistivity, caliper, and acoustic televiewer.

4.7 **Acoustic Televiewer, Bømlo**

Using the acoustic televiewer, observed fractures in the borehole are digitised by calculating fracture strike, azimuth, dip, and fracture frequency. Data are presented in stereograms, rose diagrams and fracture frequency histograms.

From the acoustic televiewer data, a caliper log can be evaluated by calculating the borehole radius using the 2-way travel time of the sonic pulse. The travel time will increase when it hit an open fracture.

An ovalisation log is presented by calculating the ratio between the maximum and minimum diameter of the borehole. From this ratio, the direction of the maximum horizontal stress can be estimated; see Chapter 4.2 and Figure 28.

The ovalisation and caliper log might hide some of the fractures because of the cementing. Cement is filling the fracture's space volume after redrilling the borehole when the cement was hardened.

Acoustic data images can also be presented as oriented cores, breakout logs and caliper-image logs. This is not done for the entire boreholes, but examples are shown from heavy fractured areas with open fractures.

All fracture data, deviation data, caliper and breakout can be found at ftp2.ngu.no.

4.7.1 Fracture analysis in Bømlo Bh1

Figure 78 and 79 show the fracture stereogram and fracture rose diagrams of indicated fractures in Bh1. Most of the fractures are dipping in a direction between W and SW (see rose azimuth). The main dip angle is steep, 60 – 90 ^{o}. The colours in the stereogram represent fractures groups. The same group colours are used in the fracture frequency histograms in Figure 80. In the histograms, every fracture is represented by the arrow plots to the left. The dip angle axis is shown on the top, and the arrows represent the dip direction, N is up, and S is down. Fracture frequency is up to 6 – 7 fractures pr. meter. To the right, borehole deviation and RQD index are shown.

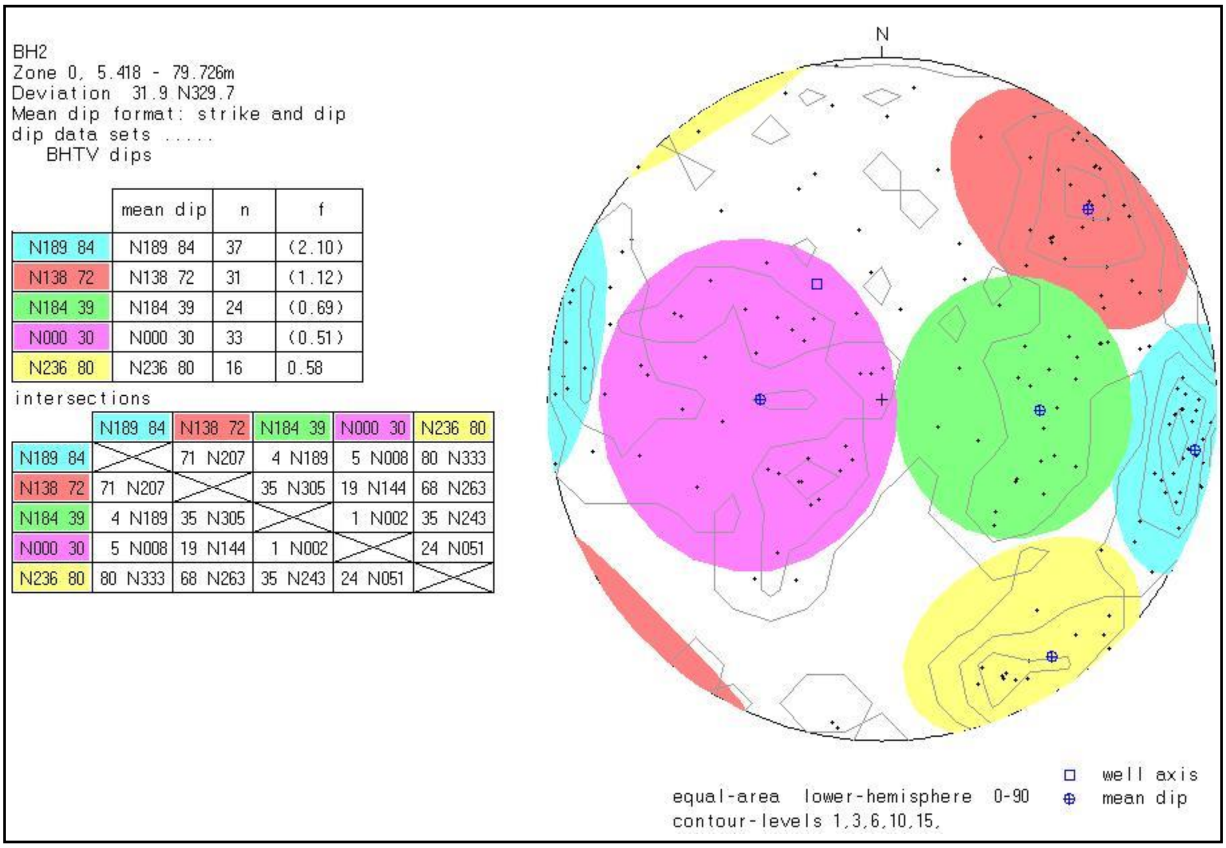


Figure 78. Bømlo Bh1. Fracture stereogram.

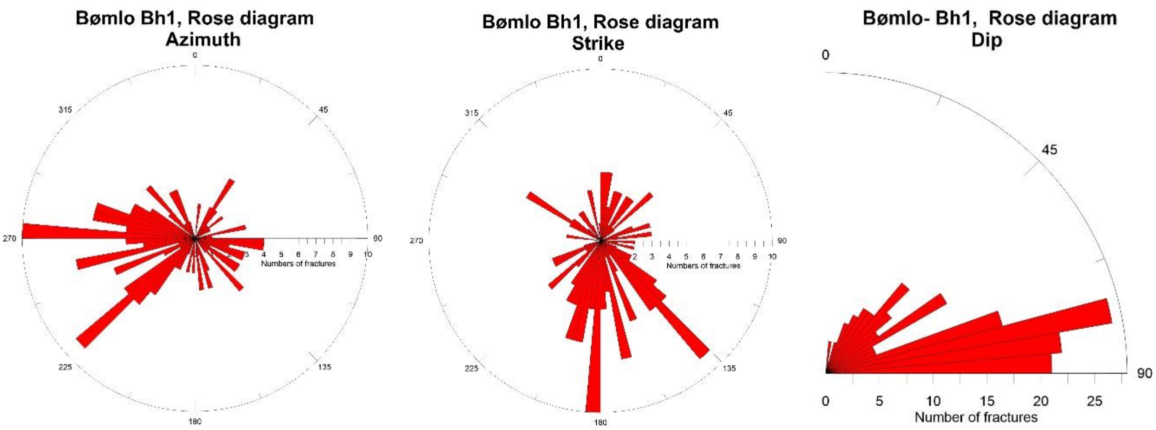


Figure 79. Bømlo, Bh1. Rose diagram of fracture azimuth, strike, and dip.

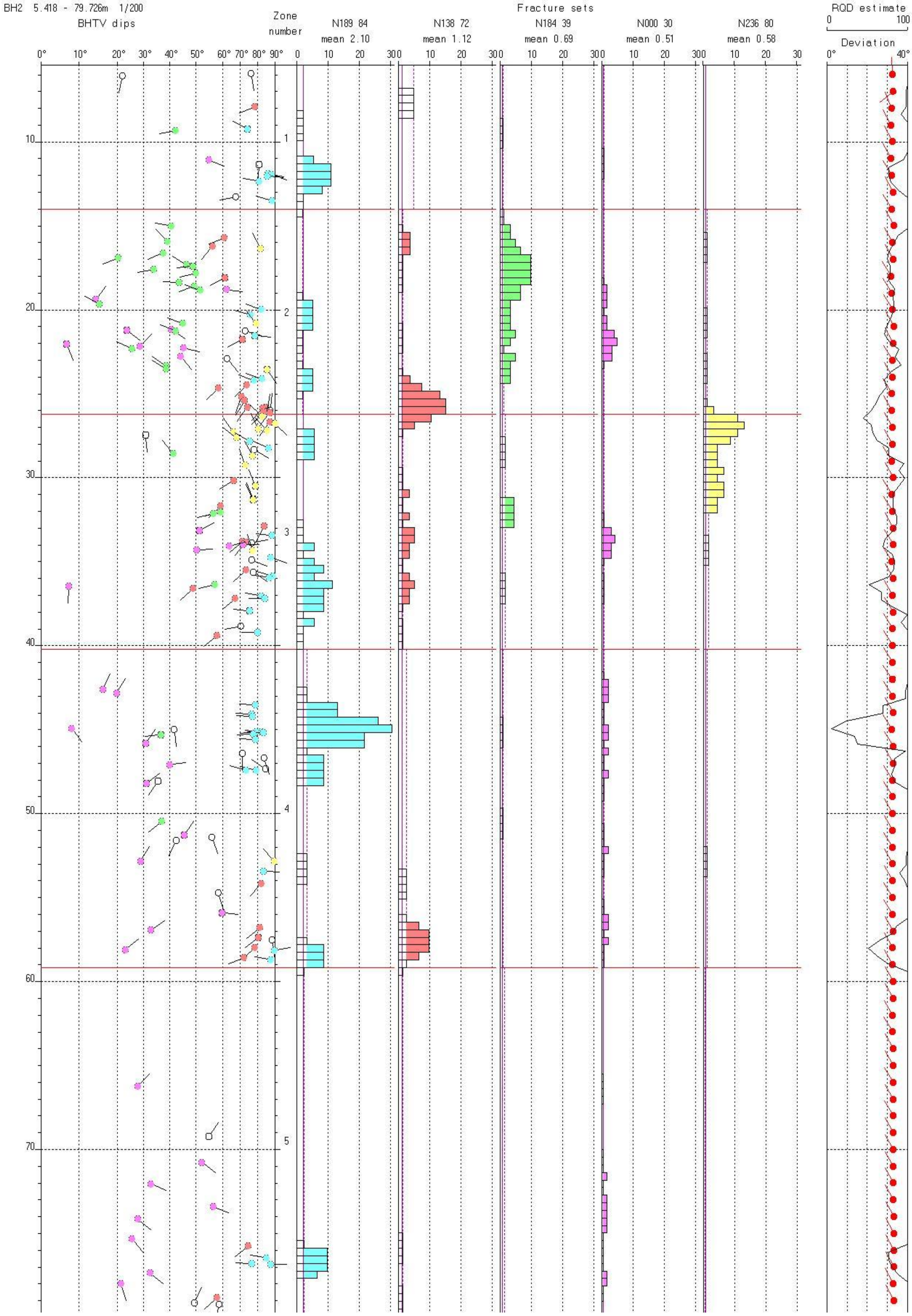


Figure 80. Bømlo Bh1. Fracture frequency histograms.

4.7.2 Ovalization and caliper log Bh1

Ovalization and caliper logs are shown in Figure 81 and Figure 82. Several fractures are indicated by increased diameter in the upper half of the borehole. This fits well with the indicated fracture frequency in Figure 80. On the acoustic image, there is no indication of breakouts caused by horizontal stress. The azimuth of Alpha is 45º-90º, and the direction of maximum horizontal stress should be perpendicular to this direction.

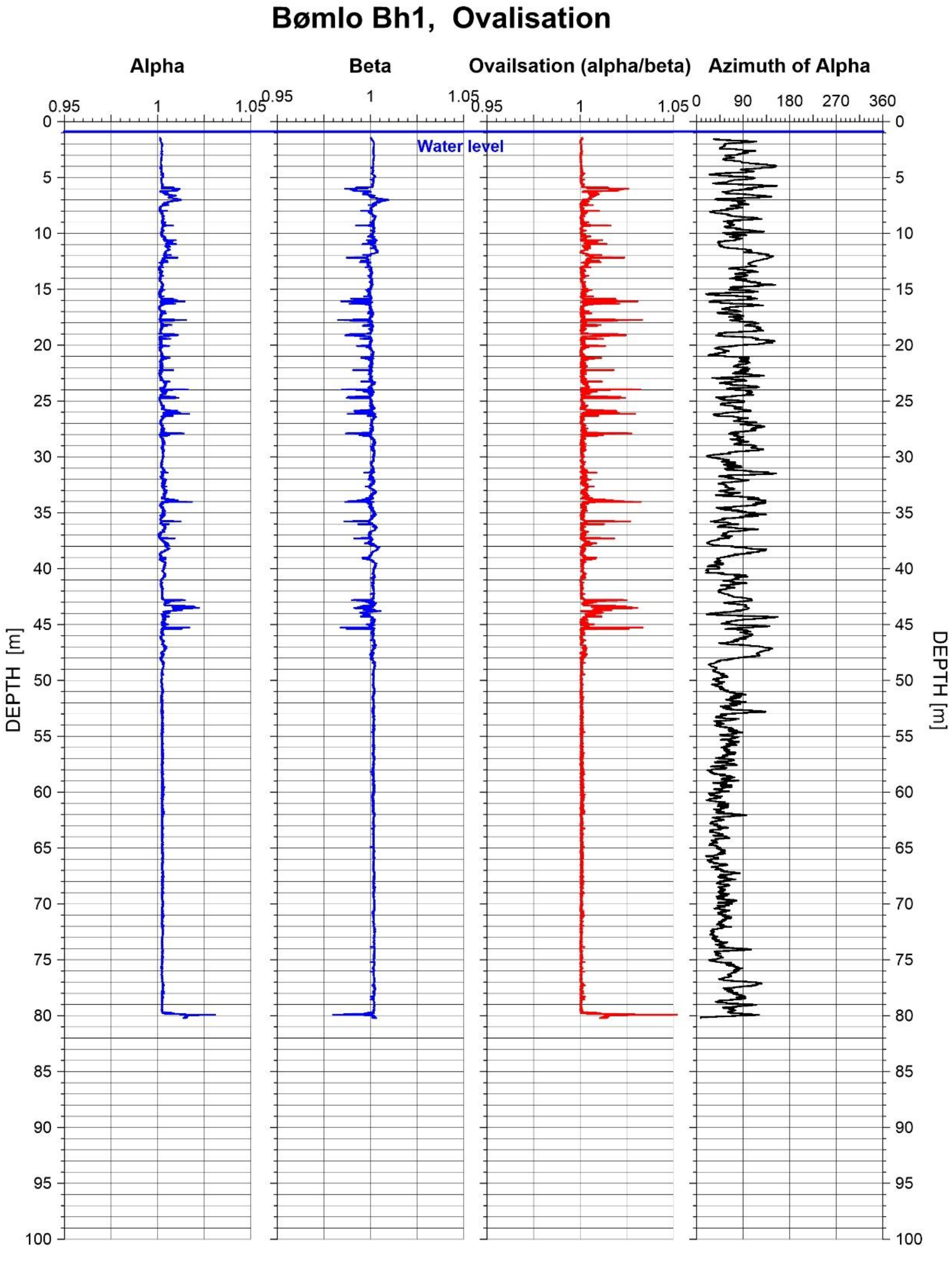


Figure 81. Bømlo Bh1. Ovalization log.

The Caliper 4 log in Figure 82 shows the same pattern with several fractures above 45 m depth.

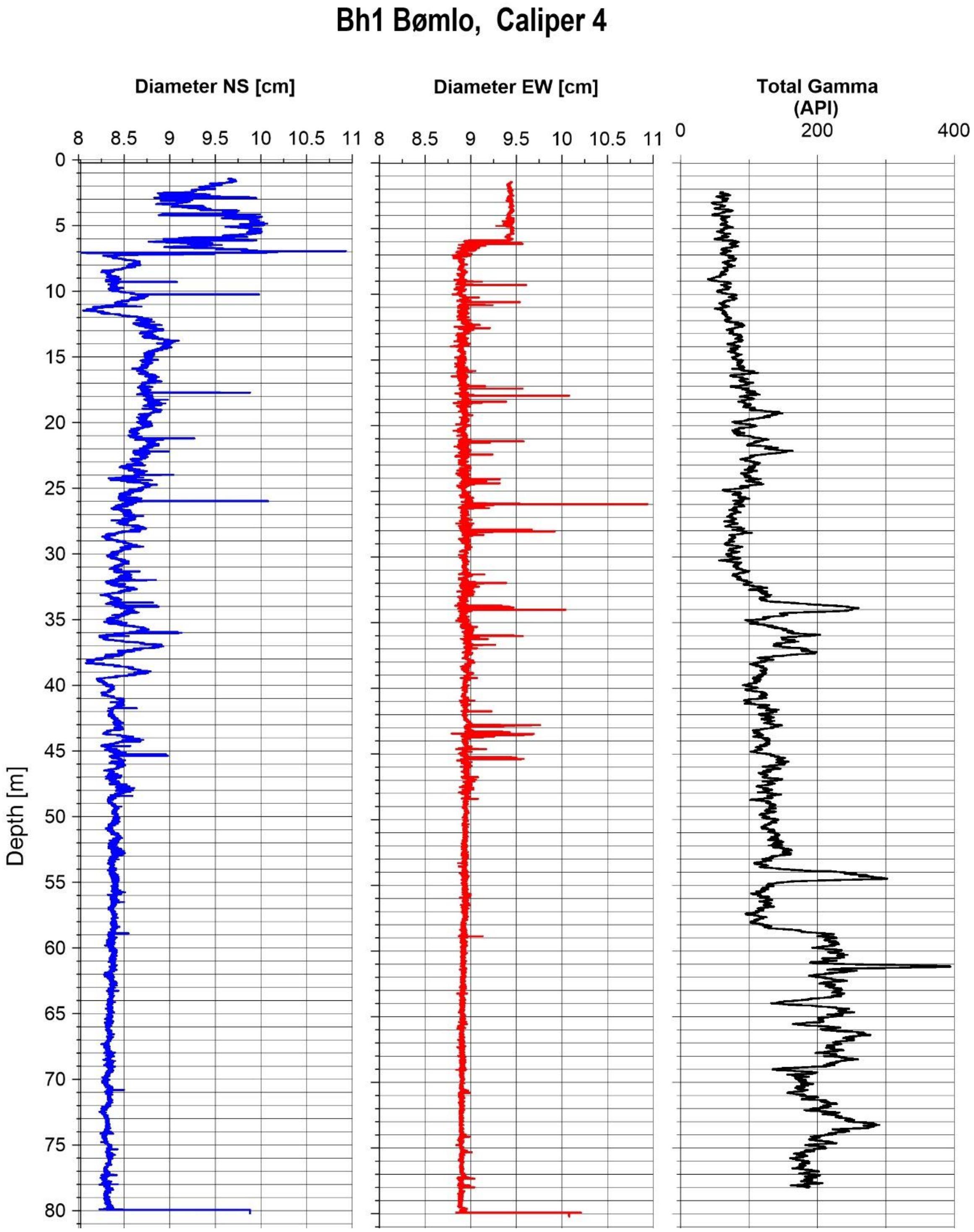


Figure 82. Bømlo Bh1. Caliper log.

4.7.3 Fracture analysis in Bømlo Bh2

Figure 83 and 84 show the fracture stereogram and fracture rose diagrams of indicated fractures in Bh2. Most of the fractures are dipping close to W or close to E (see rose azimuth). The dipping angle is 30 – 90 ^{o}. The colours in the stereogram represent fractures groups. The same group colours are used in the fracture frequency histograms in Figure 85. In the histograms, every fracture is represented by the arrow plots to the left. The dip angle axis is shown on the top, and the arrows represent the dip direction, where N is up and S is down. To the right, borehole deviation and RQD index are shown.

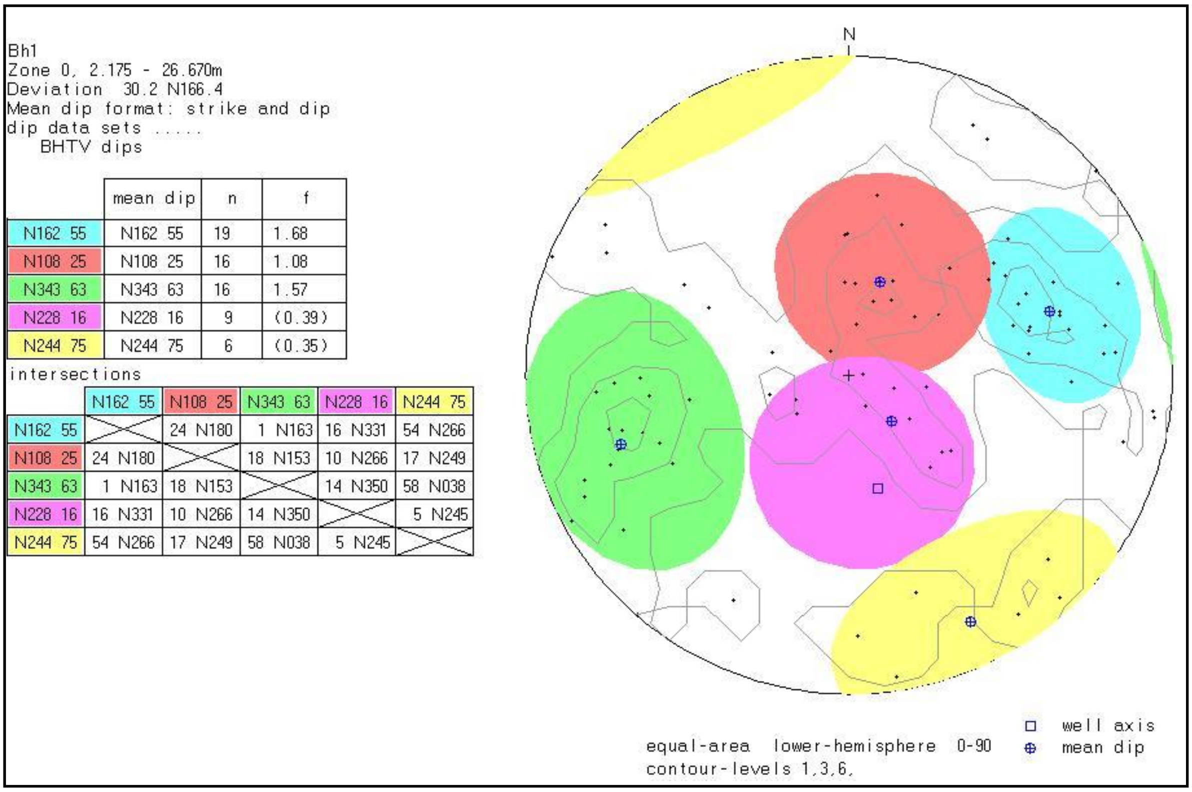


Figure 83. Bømlo Bh2. Fracture stereogram.

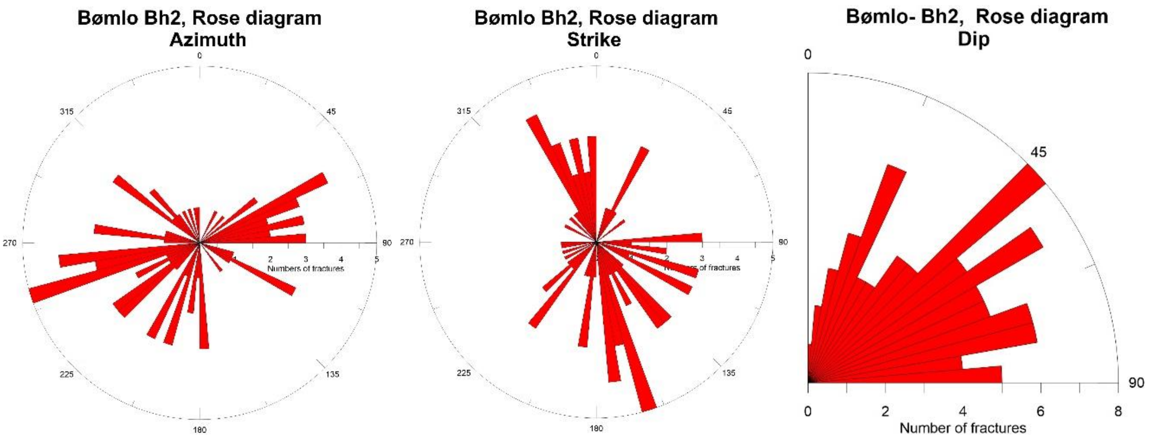


Figure 84. Bømlo, Bh2. Rose diagram of fracture azimuth, strike, and dip.

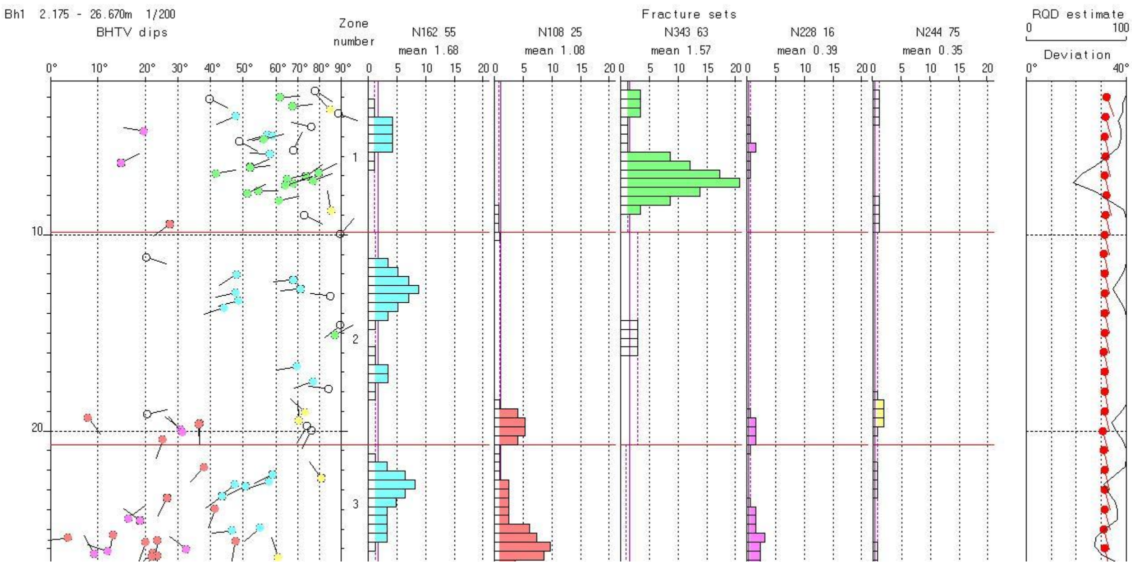


Figure 85. Bømlo Bh2. Fracture frequency histograms.

The big fracture zone at about 23 – 25 m depth is shown in Figure 86. The figure shows the acoustic image and interpretated strike-dip. The strike and dip of this zone is N163 49. This means that the zone's strike is almost parallel to the road and to the borehole dip direction. The dip direction (azimuth) is to the SW. The calculated thickness of the zone is about 1.5 m. This is close to true thickness because the dip and azimuth of the borehole have been taken care of in the calculation.

This fracture zone seems to belong to the main fracture group in the borehole, the blue one in Figure 85. In the upper part of the borehole the green group shows opposite direction with azimuth close to the E.

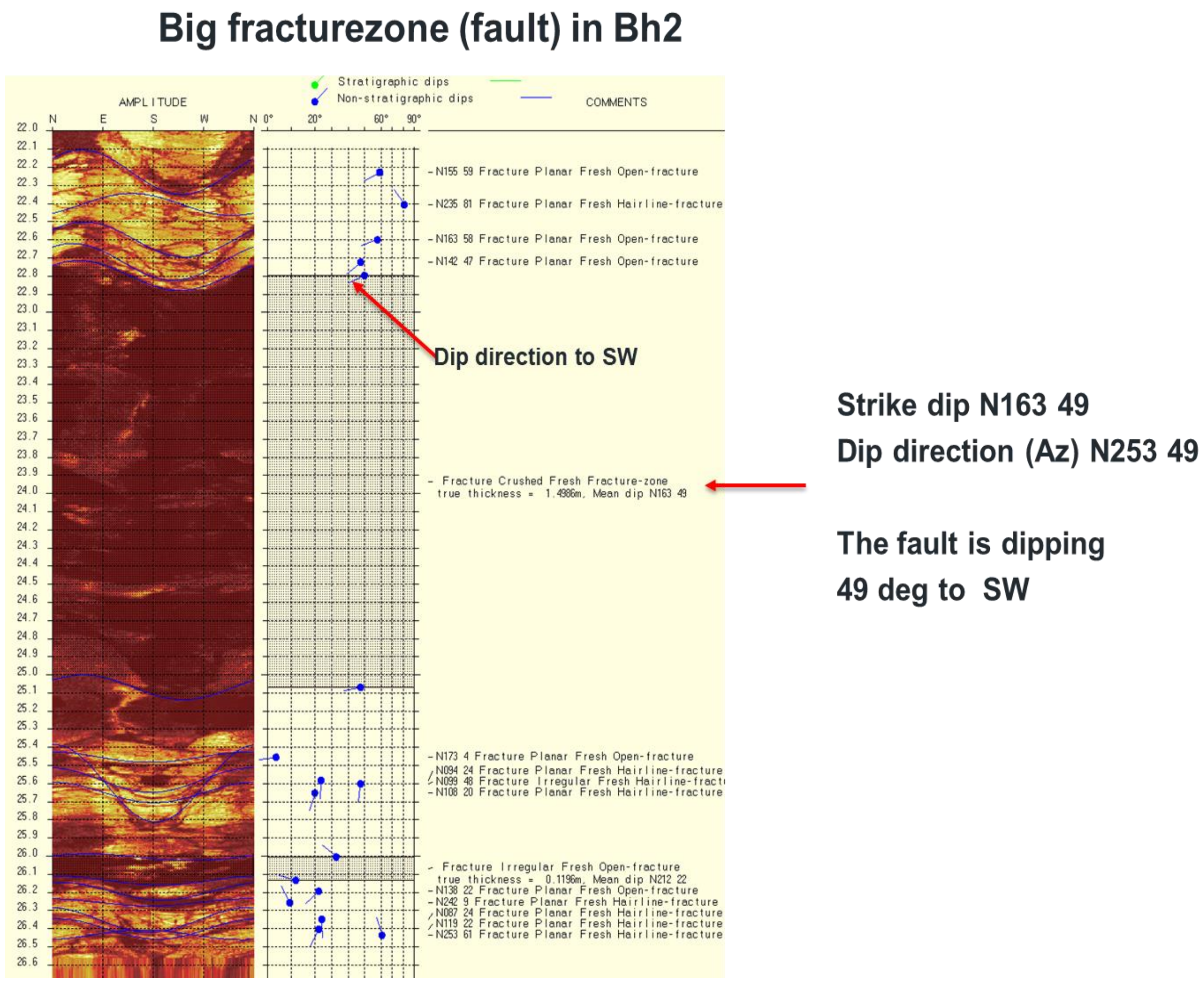


Figure 86. Interpretation of the big fracture zone in Bømlo Bh2.

4.7.4 Ovalization and caliper log Bh2

Ovalization and caliper logs are shown in Figure 87 and Figure 88. Several fractures are indicated by increased diameter from 17.5 m. This fits well with the indicated fracture frequency in Figure 85. On the acoustic image, there is no indication of breakouts caused by horizontal stress. The azimuth of Alpha varies a lot in this borehole, and it is impossible to say anything about stress directions.

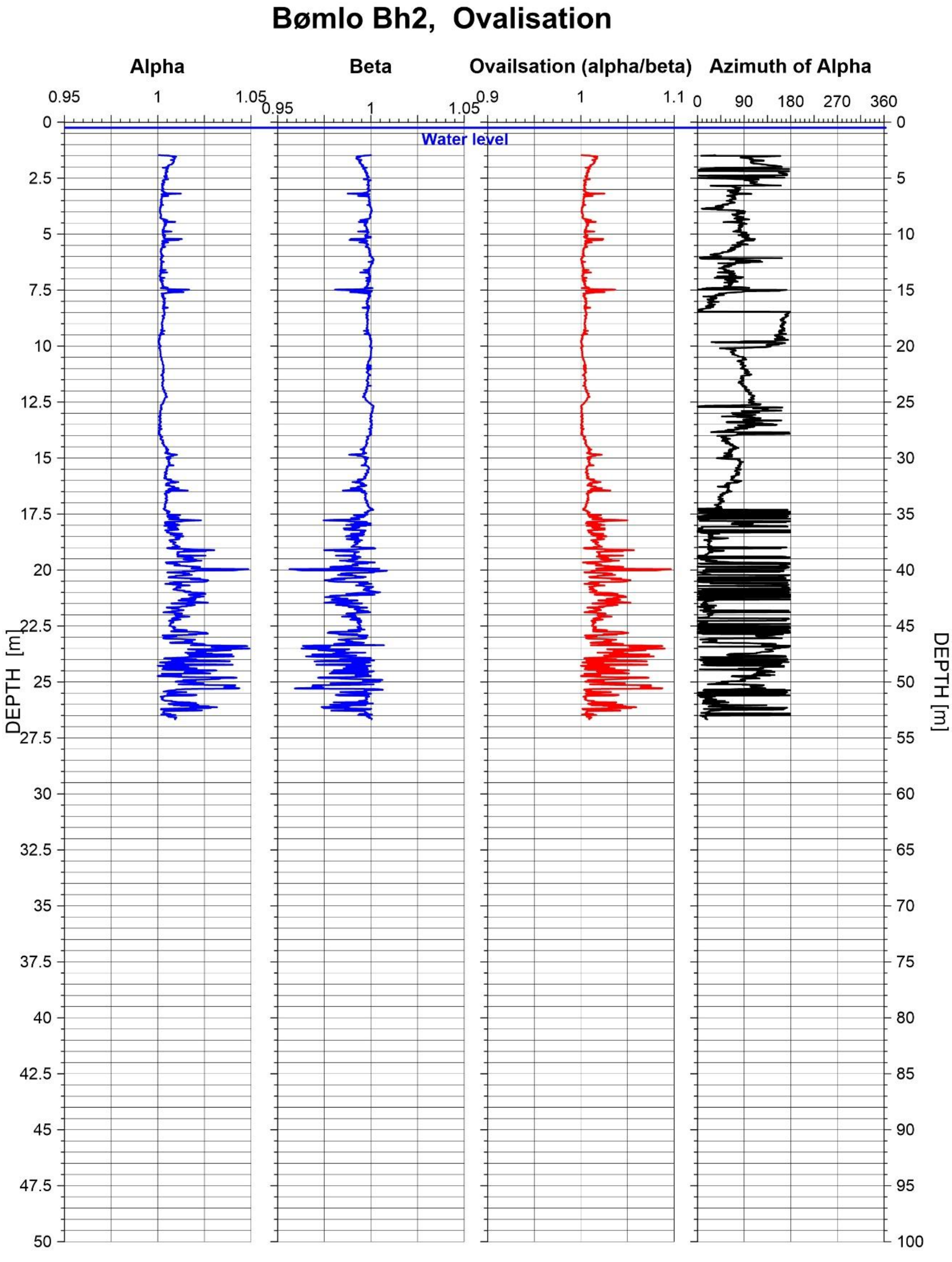


Figure 87. Bømlo Bh2. Ovalization log.

The caliper log in Figure 88 clearly shows the increased borehole diameter from 17.5 m to 26.5 m. The same is shown in Figure 89, which also shows the acoustic image of the fracture zone. The mean dip is N163 49.

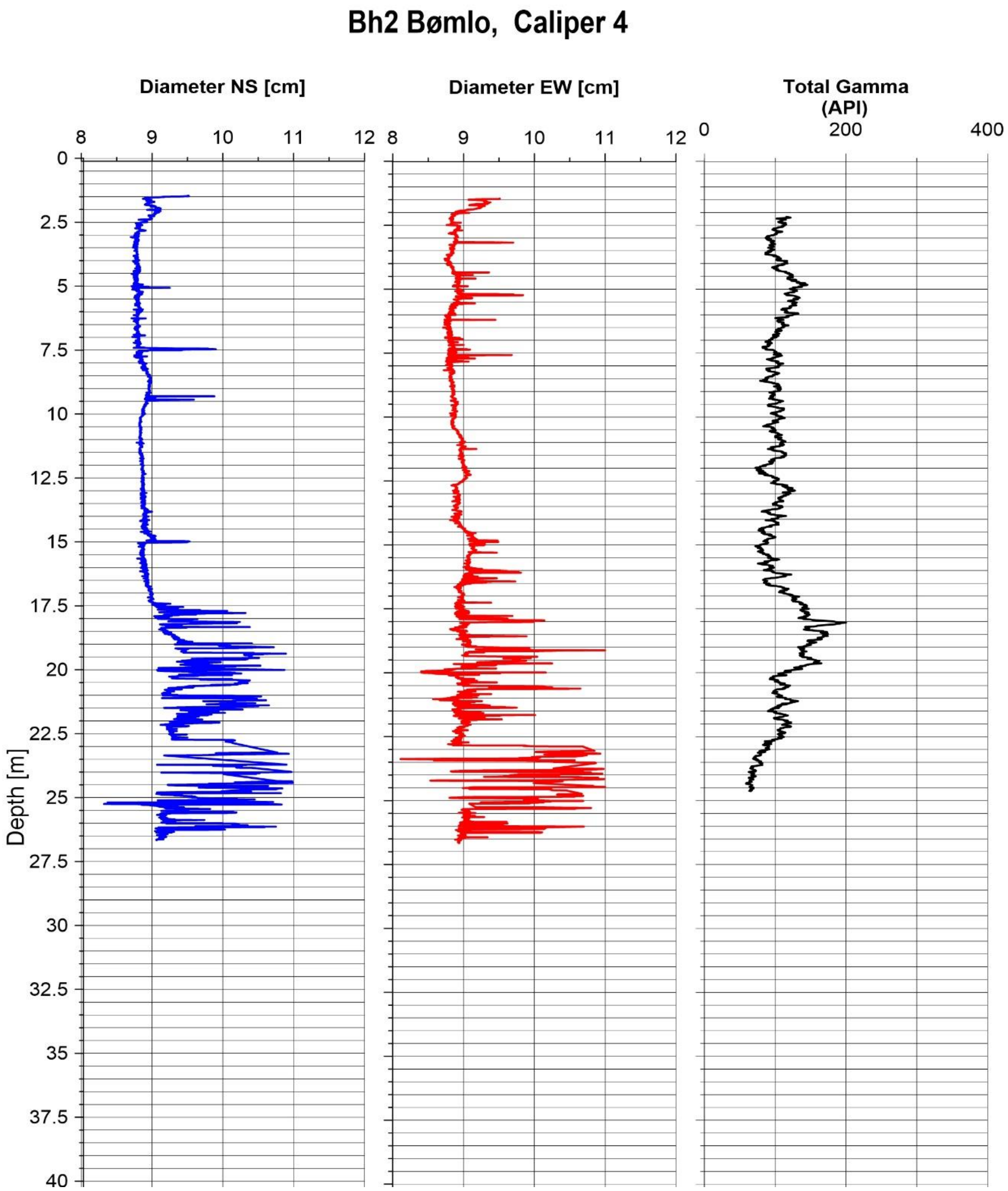


Figure 88. Bømlo Bh2. Caliper log.

Bh2, Caliper and acoustic televiewer

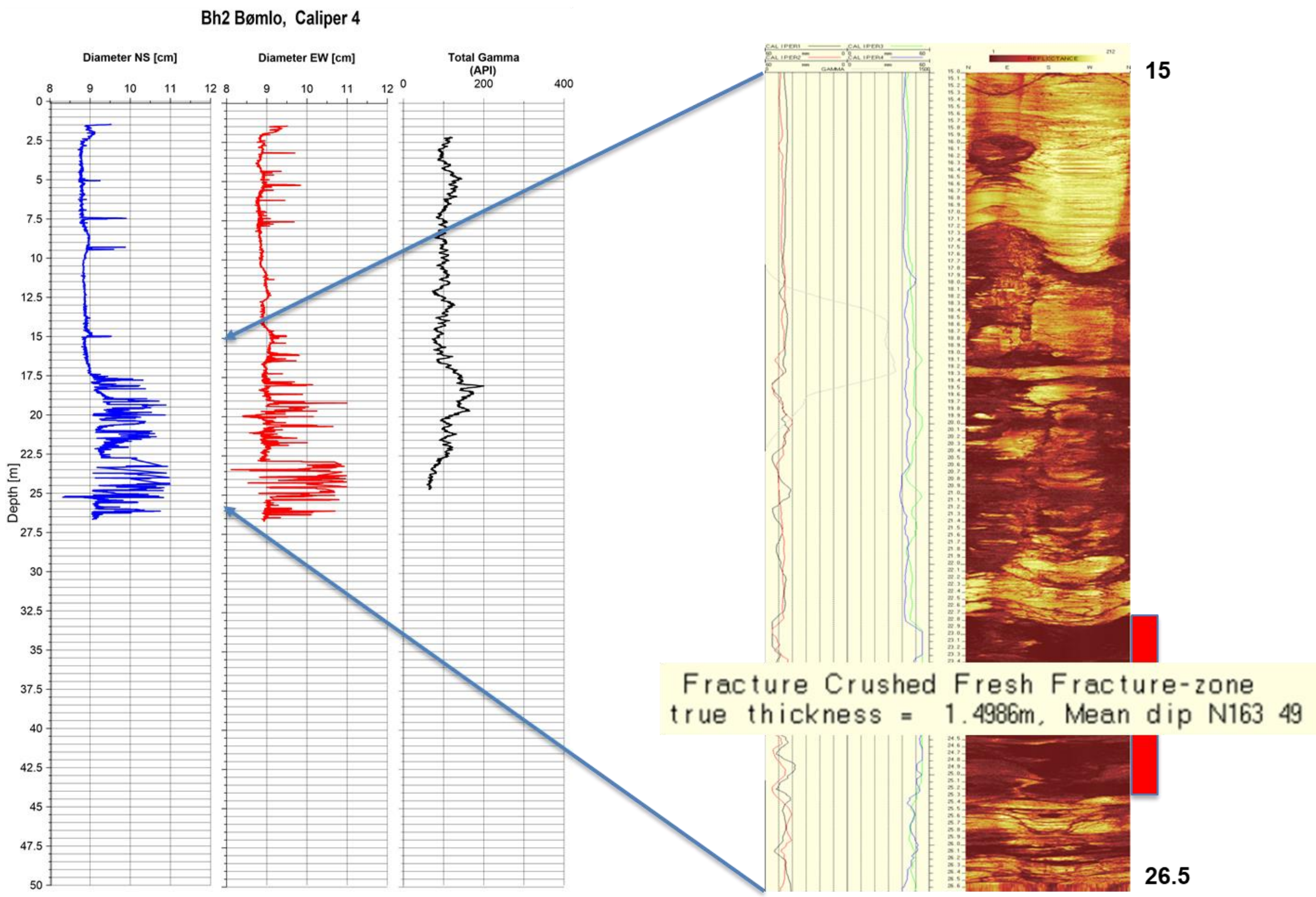


Figure 89. Caliper of Bømlo Bh2 and acoustic image of fracture zone at 23 – 25 m depth.

4.7.5 Fracture analysis in Bømlo Bh3

Figure 90 and 91 show the fracture stereogram and fracture rose diagrams of indicated fractures in Bh3. Most of the fractures are dipping close to W. Main dipping angle is 50°-85°. The colours in the stereogram represent fractures groups. The same group colours are used in the fracture frequency histograms in Figure 88. In the histograms, every fracture is represented by the arrow plots to the left. The dip angle axis is shown on the top, and the arrows represent the dip direction, N is up, and S is down.

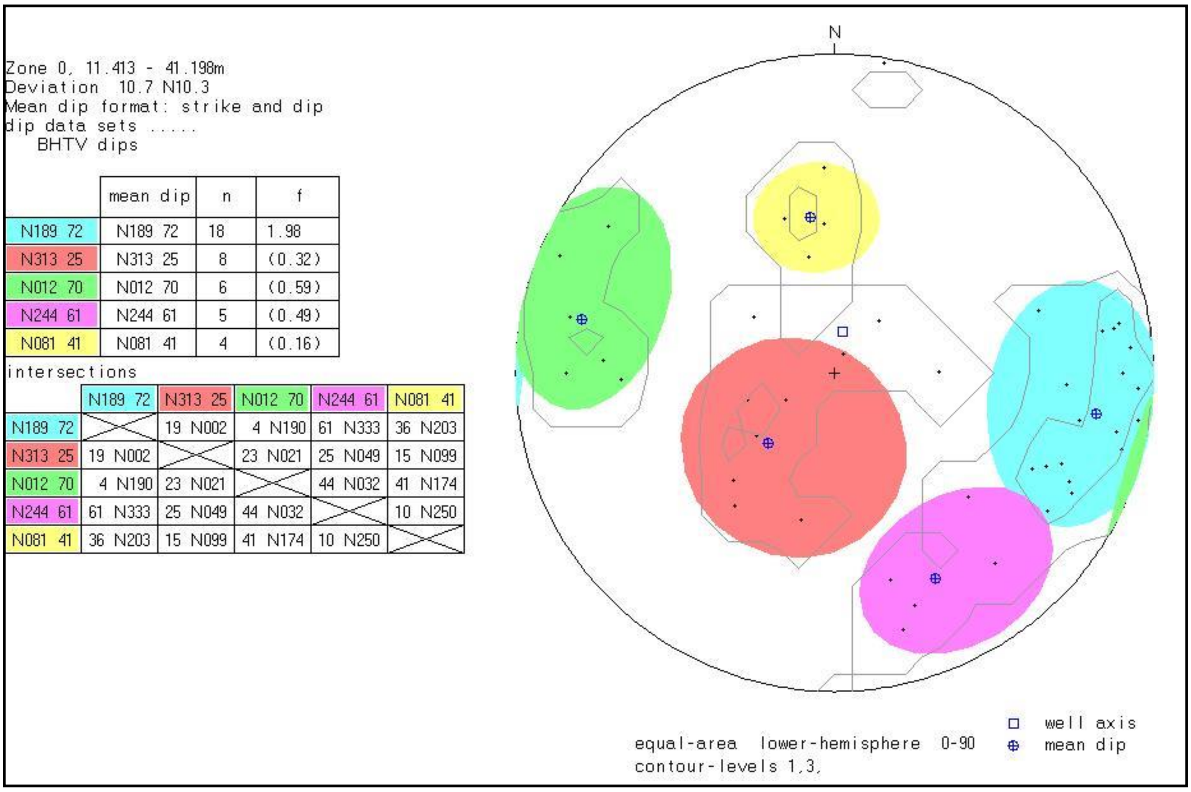


Figure 90. Bømlo Bh3. Fracture stereogram.

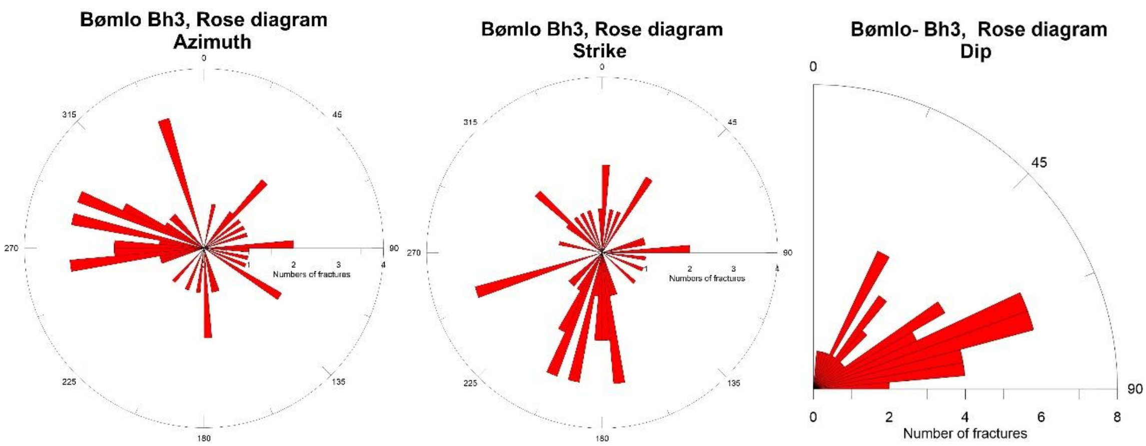


Figure 91. Bømlo, Bh3. Rose diagram of fracture azimuth, strike, and dip.

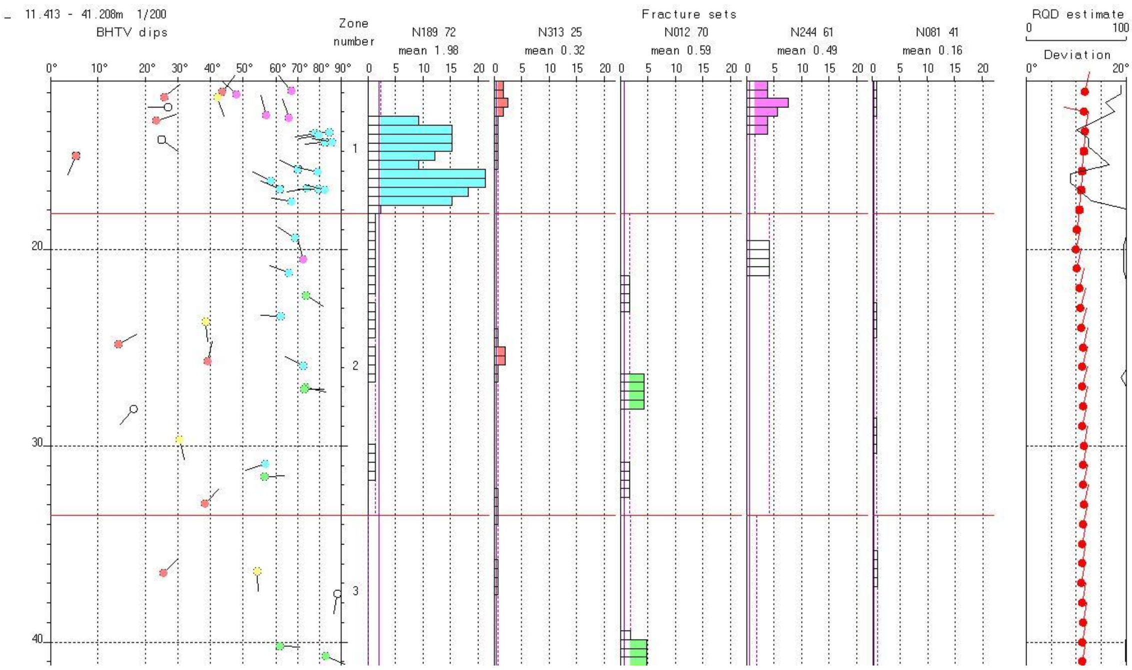


Figure 92. Bømlo Bh3. Fracture frequency histograms.

4.7.6 Ovalization and caliper log Bh3

Ovalization and caliper logs are shown in Figure 89 and Figure 90. Increased diameter is measured just below the casing at 12.5 m depth, at 27.5 m (open fracture) and 31.5 m. Below 27.5 m, the rock is very soft, probably caused by altering weathering (see Figure 72, Chapter 4.6.2.).

On the acoustic image, there is no indication of breakouts caused by horizontal stress. The average azimuth of Alpha is 90 º and should indicate a main stress direction perpendicular to this.

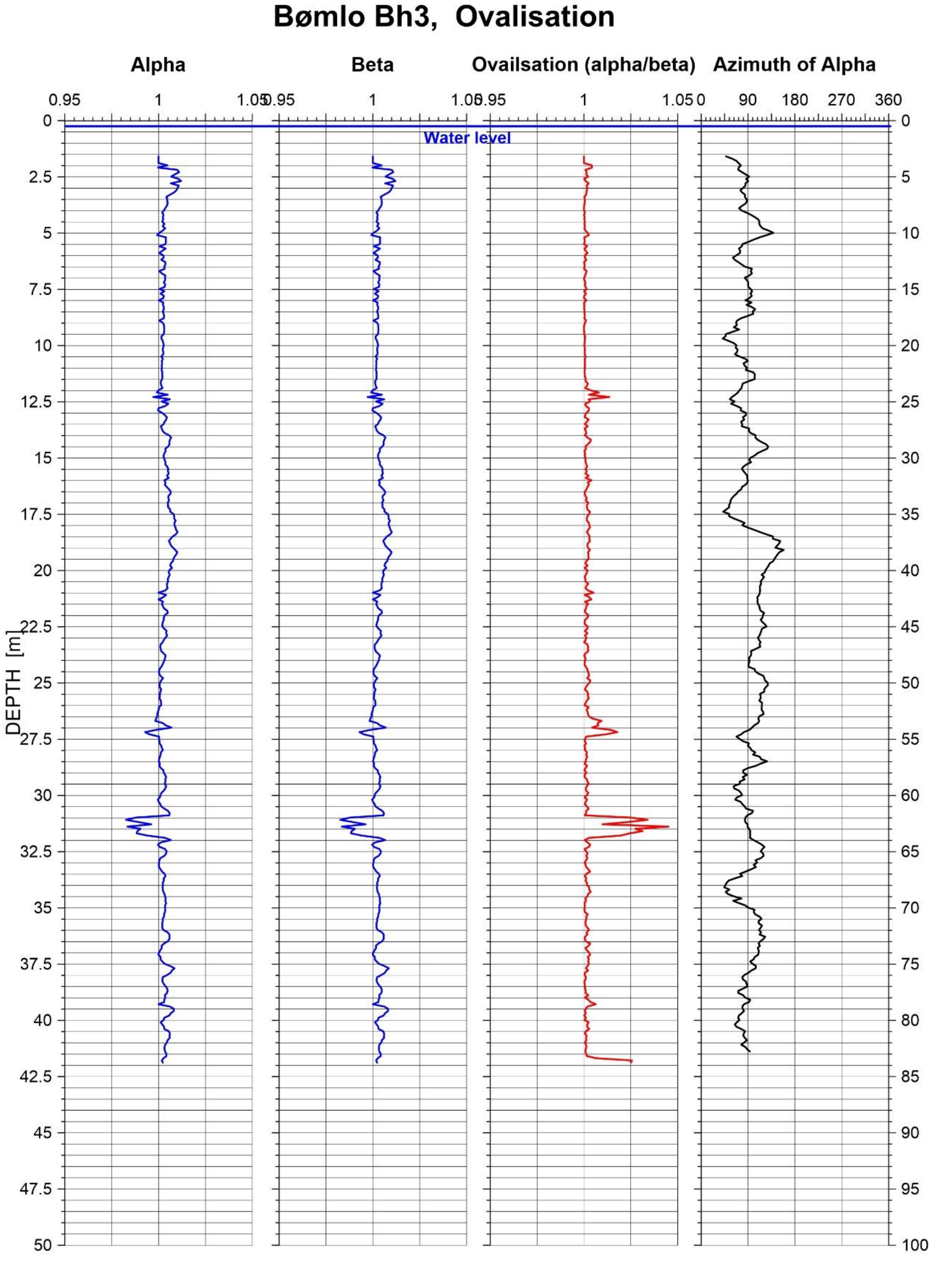


Figure 93. Bømlo Bh2. Ovalization log.

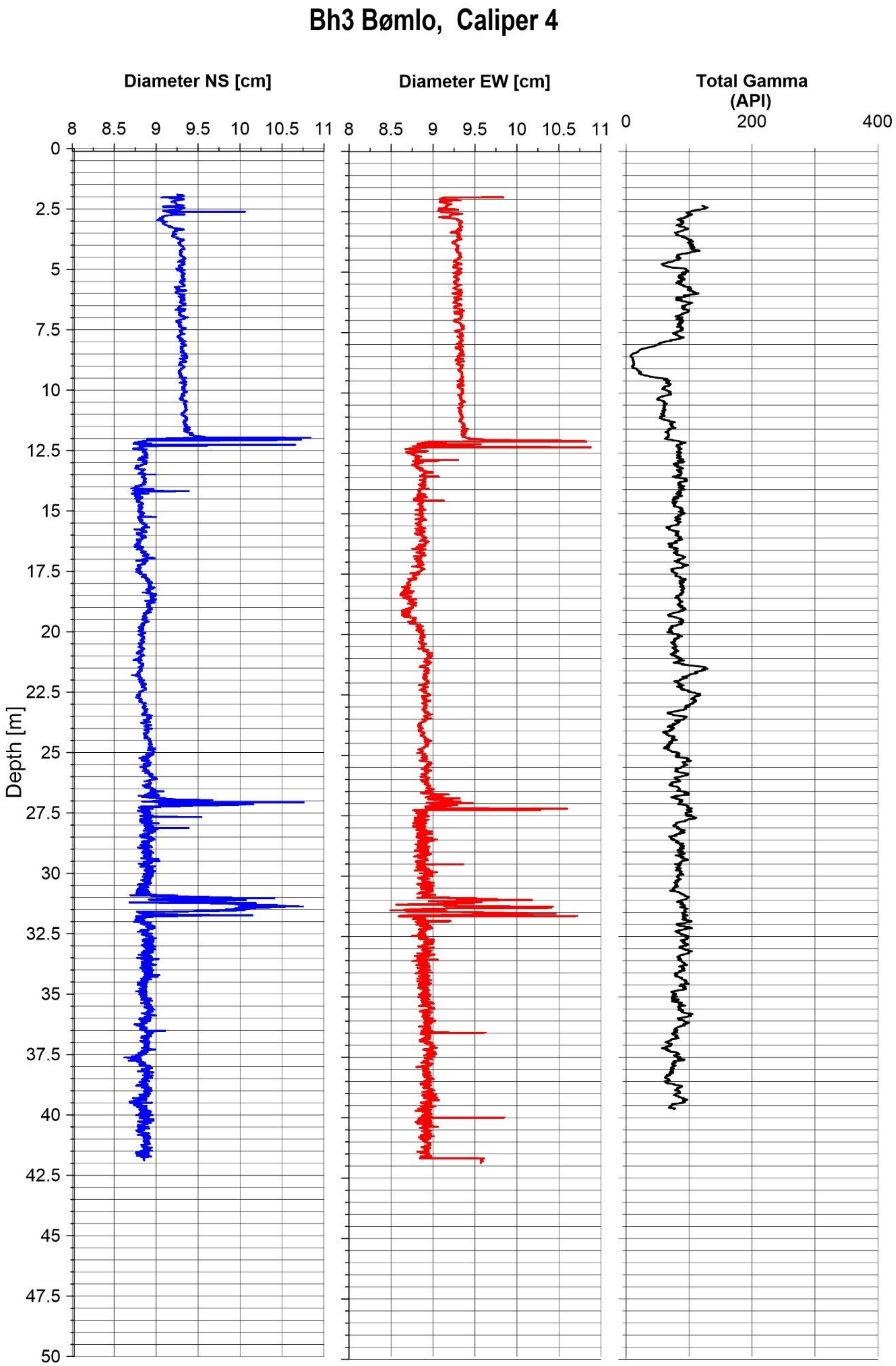


Figure 94. Bømlo Bh2. Caliper log.

As described in Chapter 4.6.3., the resistivity drops to a low level from about 27 m depth. The fracture frequency also drops. At about 27 m depth, there is an open fracture, as shown in Figure 95 on the caliper log with increased borehole diameter. Below this depth, the amplitude of the seismic signal is attenuated, resulting in a darker image. The drilled cores were quite soft, and the calculated porosity was higher than above 26 m, 4 - 6%. The total gamma radiation is constant, which indicates that a single rock type in the entire borehole.

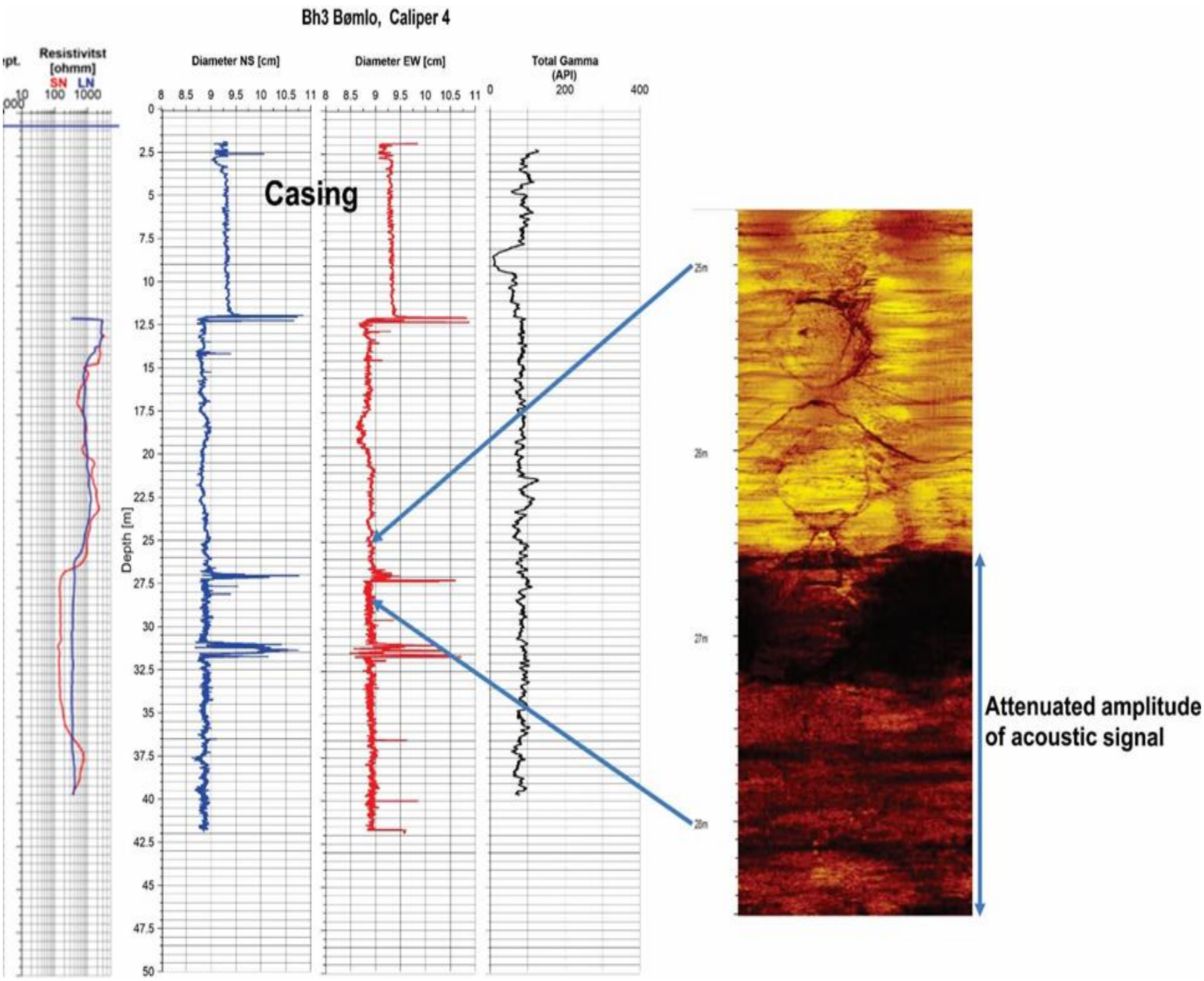


Figure 95. Bømlo Bh3, resistivity, caliper, total gamma and acoustic televiewer image.

4.7.7 Borehole deviation Bømlo

Borehole deviation is calculated as an integrated part of the televiewer logging. The borehole's direction and direction are needed to calculate the dip and strike of indicated fractures in a borehole. Both optical and acoustic televiewer can be used. In this case, the acoustic data are used.

Figure 96 and 97 show the borehole deviation components for the Smøla boreholes, NE-component and horizontal component.

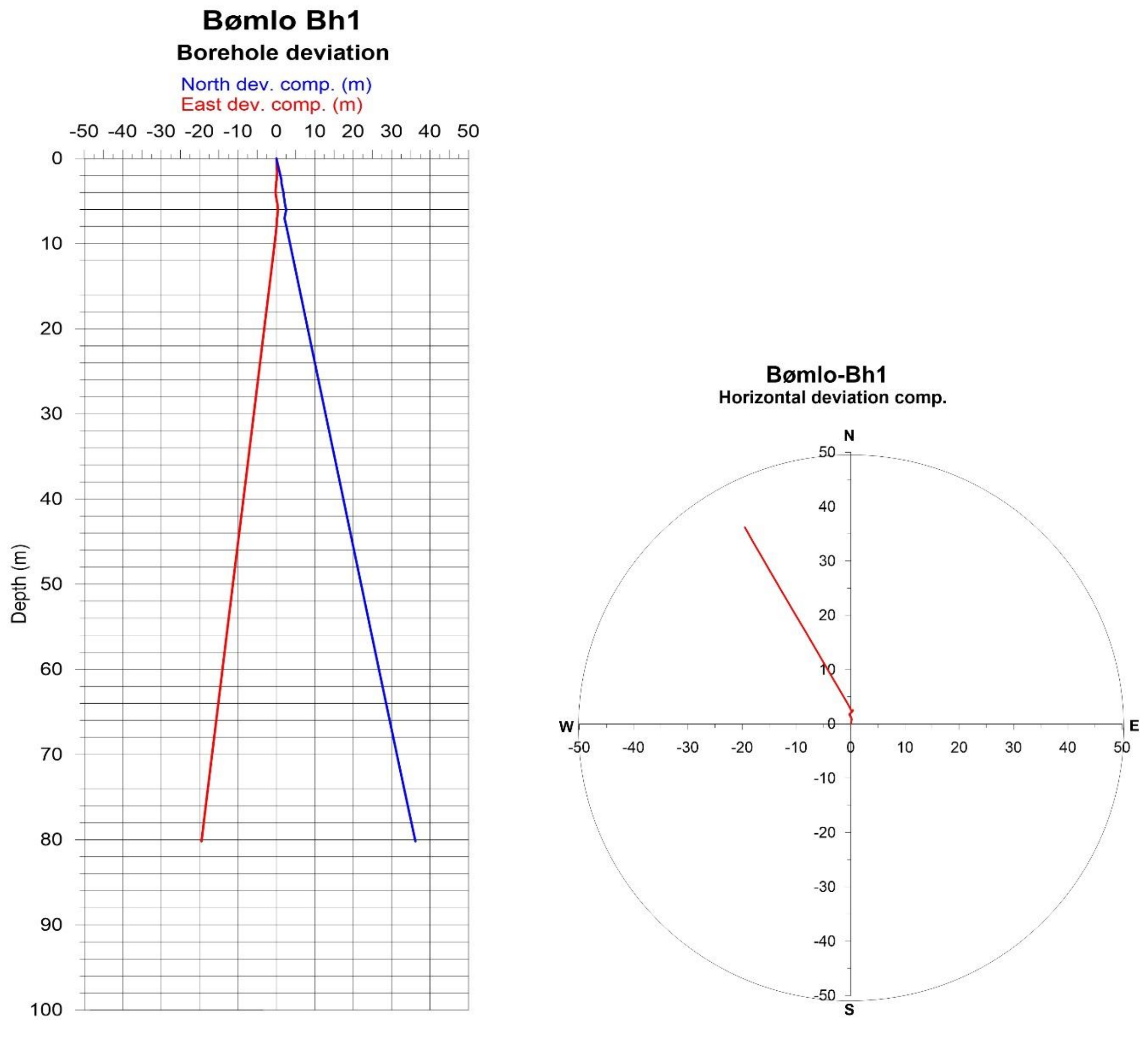
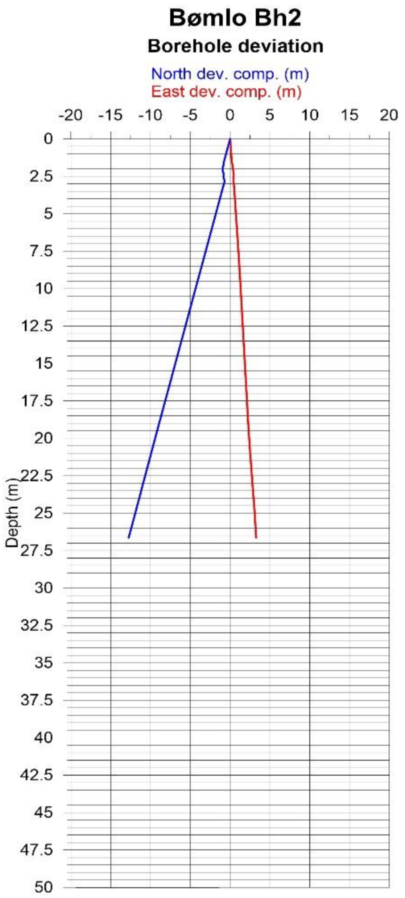
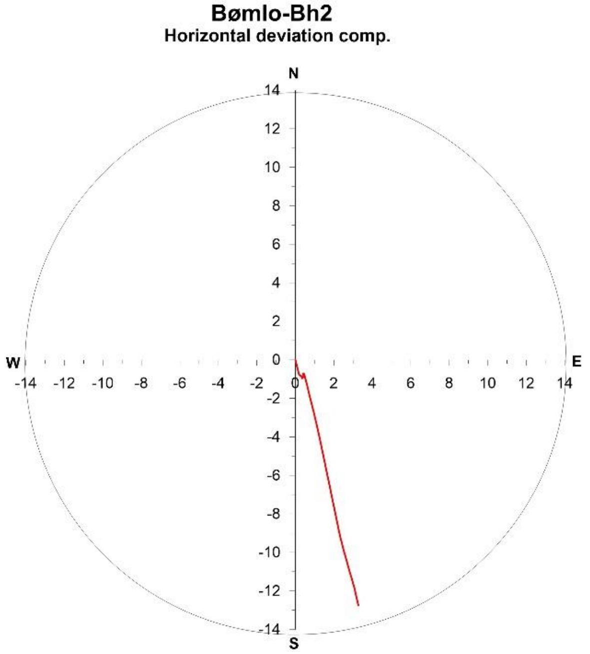
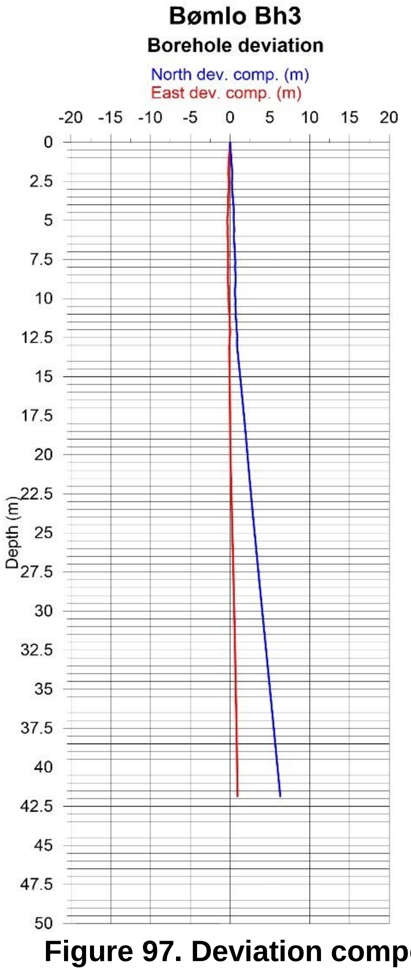


Figure 96. Deviation component Bømlo Bh1.







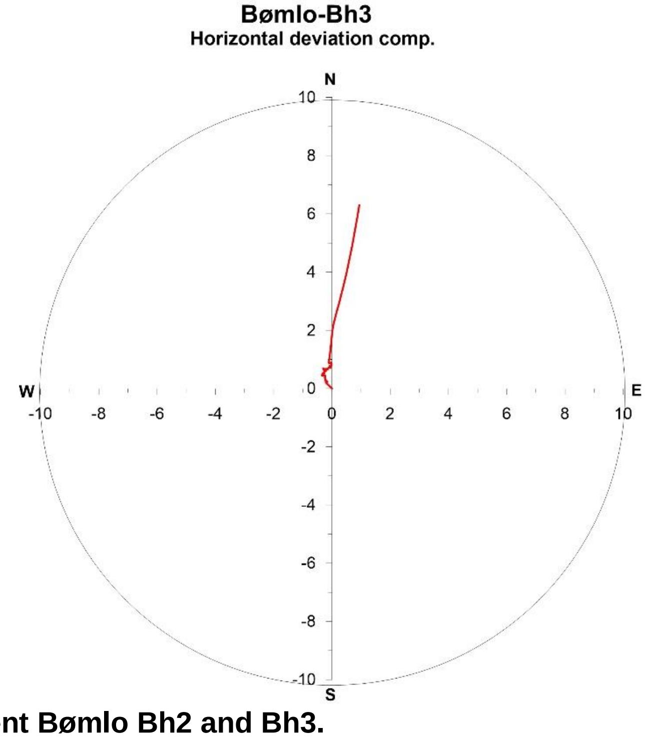


Figure 97. Deviation component Bømlo Bh2 and Bh3.

4.8 Flow measurements in Bømlo Bh1, Bh2, and Bh3.

Flow measurements were performed in all boreholes, both with pumping and without pumping, which was achieved by running a flowmeter probe (a propeller) down and up the borehole at a constant speed. The propeller rpm is measured. The difference between the rpm down and up can indicate a vertical flow in the borehole. Changes in rpm can indicate water in- or outflow. Such measurements can also be performed combined with pumping. A pump is placed in the upper part of the borehole (at 10 m depth), and flow measurements are done below the pump while the pump is running. In this way, water can be sucked from water-bearing fractures. The pumping process will also give the water capacity of the well.

Figure 98 shows the pumping results from Bh1 and Bh2. The upward measurements are noisier than downhole measurements, which is probably due to the dipping borehole and some turbulence in front of the propeller. There is no vertical flow indicated either with or without pumping, and net flow is close to zero. Some peaks on the curves are supposed to be noise, probably caused by small grains of sand in the water.

Figure 99 shows the result in Bh3. There is a prominent peak at 29 m depth on the upward measurements. If this should be caused by water inflow, it should also be indicated on the downward measurements.

The pump was run for one hour in each borehole to calculate the capacity in litre/hour. A normal capacity in Norwegian crystal rock is about 500 l/h. The pumping showed that the capacity in both Bh1 and Bh2 was minimal; see Table 7. In Bh3, the capacity was high, 1570 l/h, most likely due to surface water from a fracture just below the casing. The borehole location was close to a wet boggy area.

Unfortunately, the boreholes (fractures) were cemented when the pumping was performed. This will reduce the capacity.

Table 7. Water capacity in the Bømlo boreholes

Bh	Capacity
Bømlo Bh1	**65 l/h**
Bømlo Bh2	**4 l/h**
Bømlo Bh3	**1570 l/h**

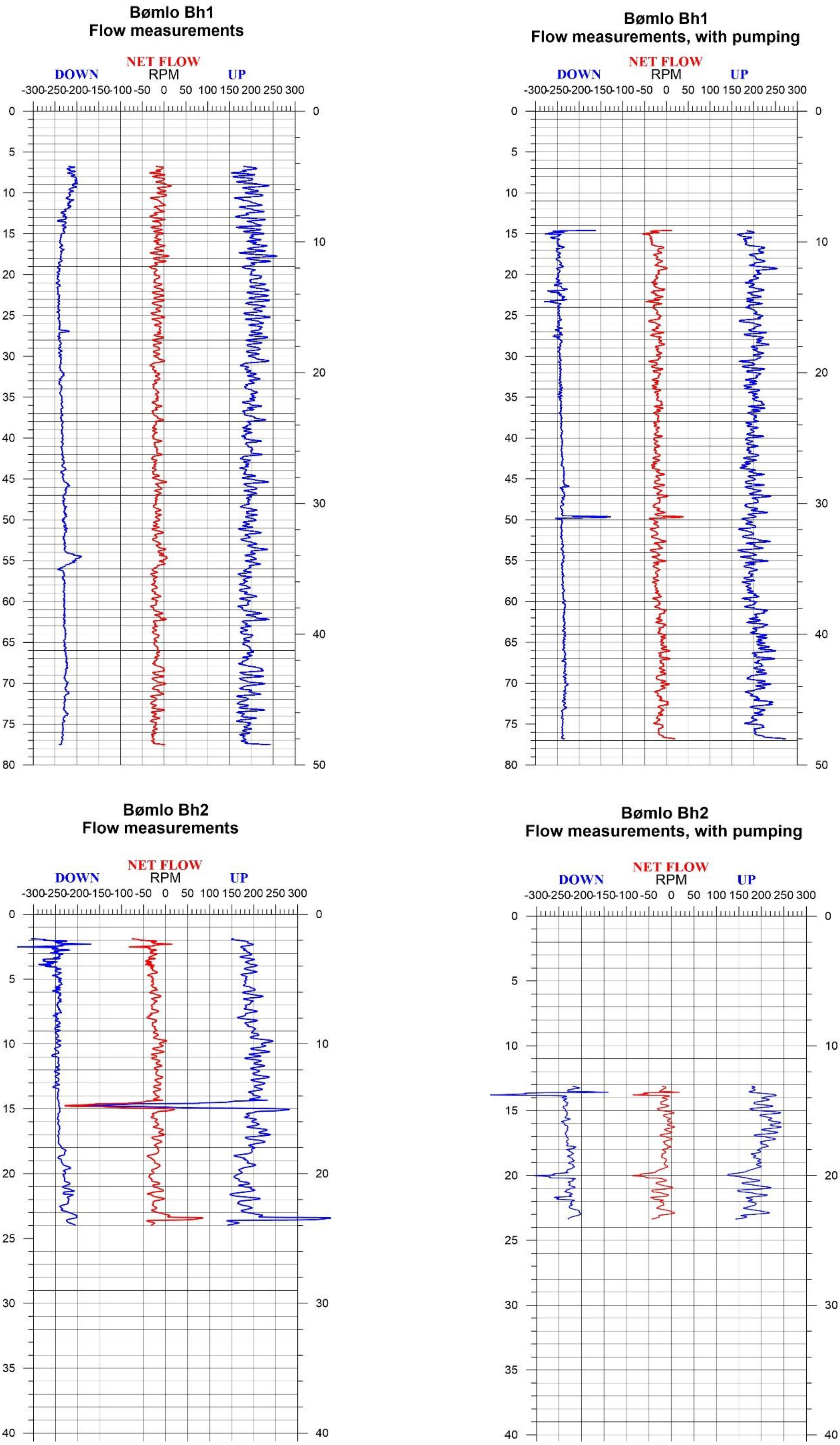


Figure 98. Flow measurements in Bh1 (upper) and Bh2 (lower).

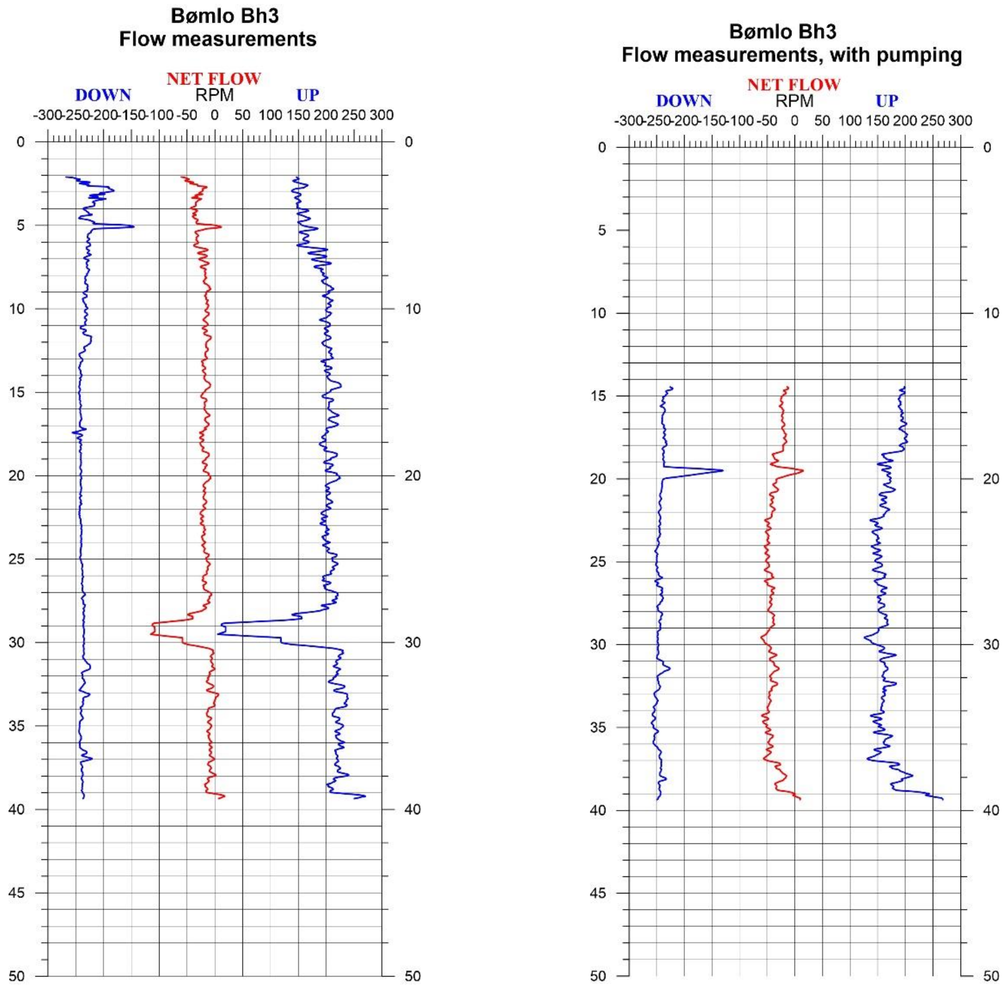


Figure 99. Flow measurements in Bh3.

4.9 **Lugeon test, Bømlo**

The Lugeon test is described in Chapter 4, Figure 7. Appendix 2 shows the test intervals in each Bømlo borehole. Intervals containing fractures were locked by packers and water pressed into the rock for 10 minutes using 10 bars overpressure. Figure 100 shows the intervals and the results from the Lugeon tests in the Bømlo boreholes. The intervals with the highest Lugeon number are 33 - 39 m in Bh1 and 15- 21 m in Bh3 where L>5 (l/min/m). L = 5-15 is classified as moderate due to the condition of rock mass (few partly open fractures). From the Lugeon number, the hydraulic conductivity can be determined; see Figure 7. Hydraulic conductivity is a measure of how easily water can pass through soil or rock. High values indicate a permeable material where water can easily pass through; low values indicate that the material is less permeable.

In Bh1, the highest hydraulic conductivity is observed in the upper part of the borehole (20-50 m). In Bh2, the hydraulic conductivity is low, and in Bh3, the conductivity is moderate at 15- 21 m depth.

The Lugeon numbers fit quite well with the fracture frequency in Bh1 and Bh3, as shown in Figure 101.

Cemented intervals in each Bømlo borehole are shown in Appendix 4. Drilling reports are shown in Appendix 6.

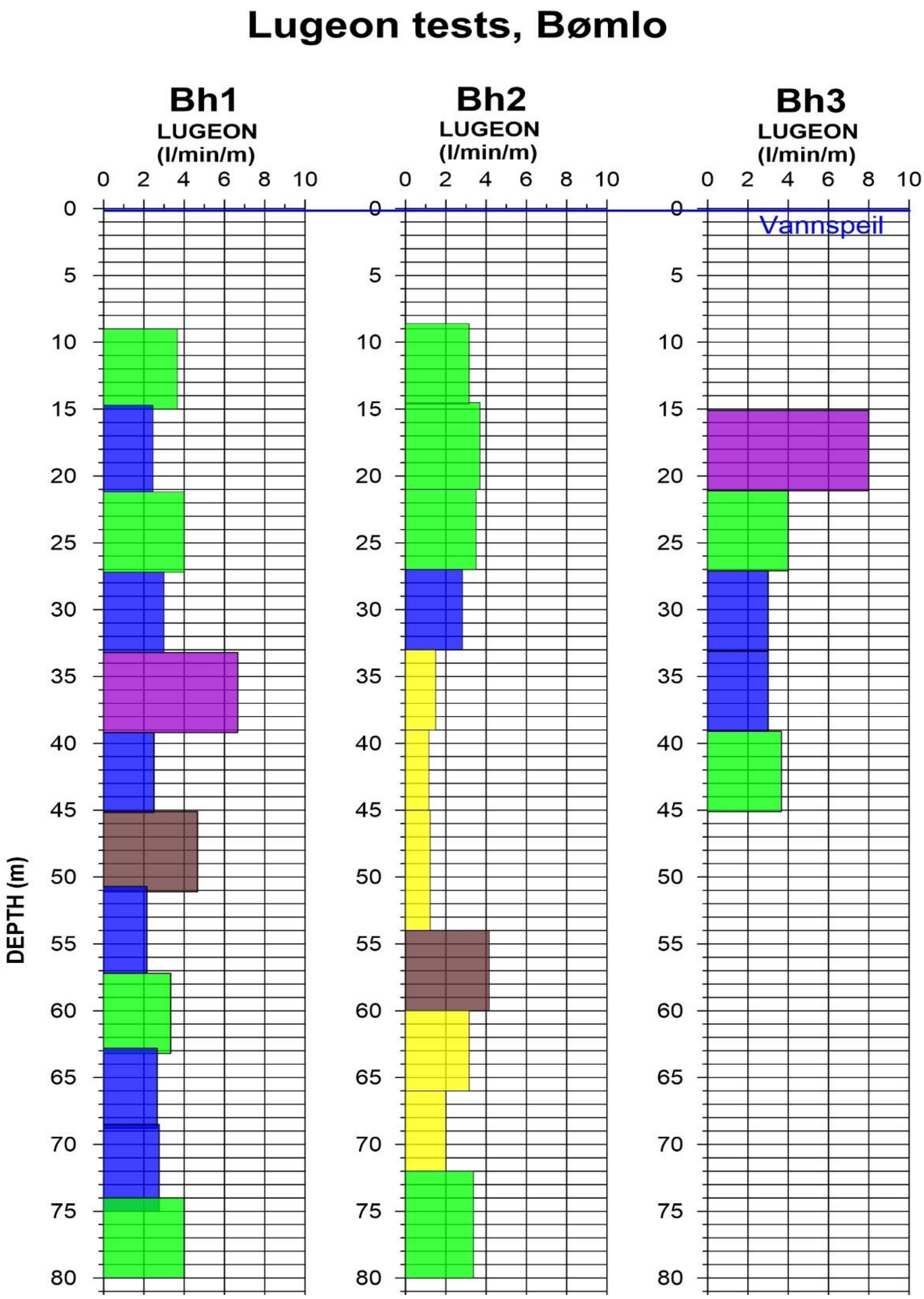


Figure 100. Lugeon test results in the Bømlo boreholes.

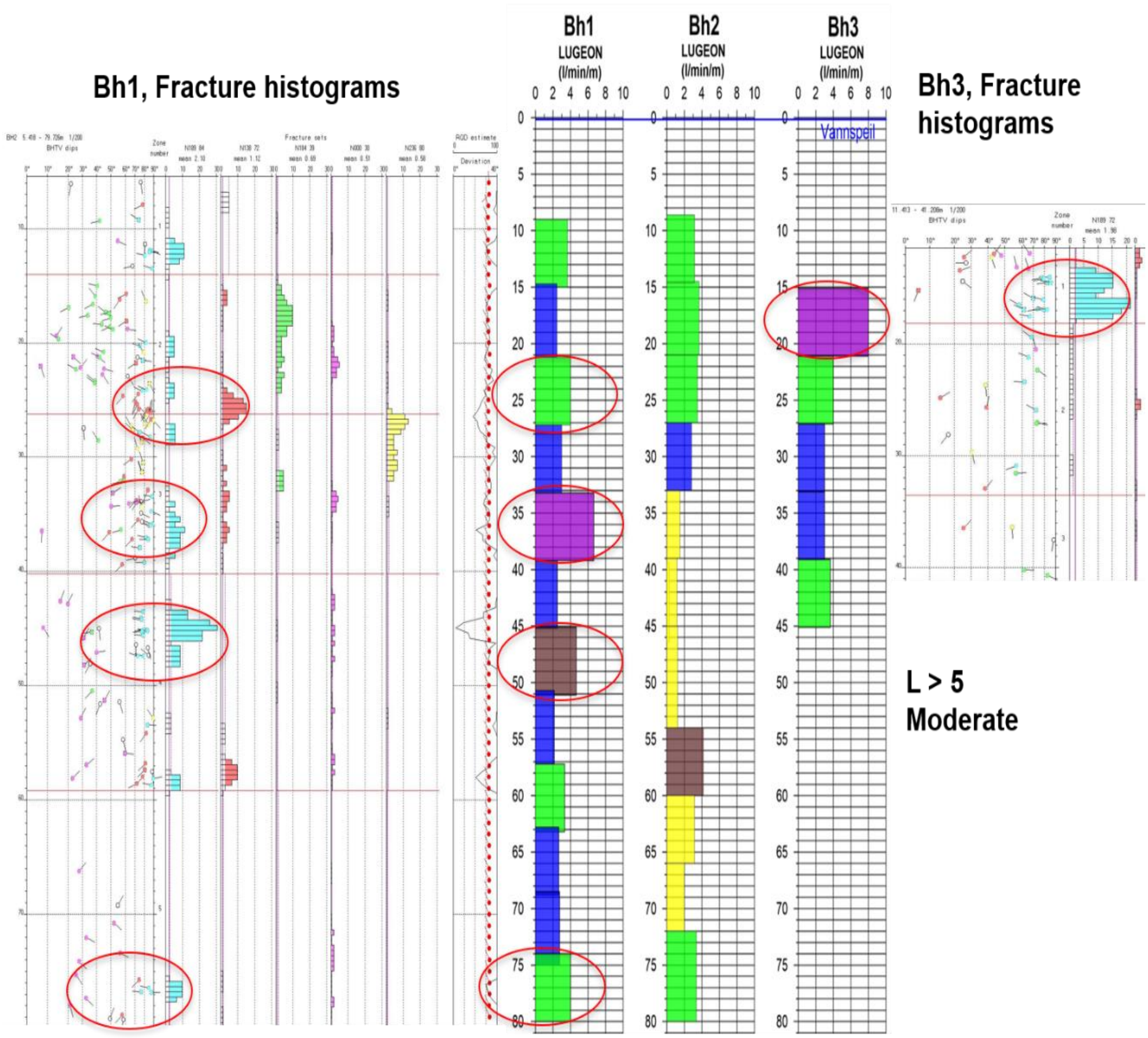


Figure 101. Fracture frequency and Lugeon test in Bh1 and Bh3.

4.10 **Permeability from Lugeon tests**

Using the average values of water pressure and flow rate measured in each stage (section), the average hydraulic conductivity of the rock mass is expressed in terms of the Lugeon unit. The Lugeon value could also represent the rock jointing conditions (Figure 7), considering a significant influence of rock discontinuities condition on the value of hydraulic conductivity.
(Geotech : https://www.geotech.hr/en/permeability-test-lugeon-test/)

1 LU = 1.3 x 10^{-7} [m/s] ≈ Hydraulic conductivity, K

$$LU = \frac{q}{L} \times \frac{P_0}{P} \left[1 \frac{l}{\min(m')}\right]$$

$$\left(1LU \approx 1{,}3 \times \frac{10^{-7} m}{s}\right)$$

$q - flow\ rate \left[\frac{l}{min}\right]$

$L - \ lenght\ of\ the\ borehole\ [m]$

$P_0 - reference\ pressure\ of\ 1\ MPa\ [MPa]$

$P - test\ pressure\ [MPa]$

From the hydraulic conductivity the permeability can be found:

$$\text{perm} = \frac{K\ \mu}{\delta\ g}\ [m^2]$$

K = hydraulic conductivity (m/s)
μ = fluid viscosity (1.002 mPa s)
δ = fluid density (1000 kg/m^3)
g= gravitational acceleration (9.82 m/s^2)

1 Darcy is equivalent to: 9.869233 x 10^{-13} [m^2]

https://www.calculator.org/properties/permeability.html
https://engineering.stackexchange.com/questions/15473/darcy-to-si-permeation-units

Table 8 and 9 show the calculated permeabilities from the Lugeon test sections in Bømlo Bh1 and Smøla Bh4. The above equations are used. The porosity is the average values calculated from the resistivity measurements using Archie's law.

Using this method, the permeability will be linear to the Lugeon number, but the permeability is a more convenient way to describe the fluid flow in rock.
This is not the actual rock permeability but a permeability measured in the blocked borehole sections during the Lugeon tests. These sections are 5 – 6 m long and the permeability is most probably controlled by the fractures. This permeability must be used with some caution. First, the pressure measurements are made on the borehole wall that has suffered possible drilling damage and pore throat plugging from mud solids. The permeability determined is an effective permeability, not an absolute permeability. Depending on rock type and fluid saturations, the effective permeability may be an order of magnitude too small.
https://petrowiki.spe.org/Permeability_determination

Table 8. Calculated permeability from LU number, Bømlo Bh1

Bh1 section	LU	K [m/s] x 10^{-7}	Perm [m^2] x 10^{-13}	Perm [mD]	Porosity Φ [%]
9-15	3.66	4.758	0.4845	49.09	
14,7-21.2	2.46	3.198	0.3263	33.06	4.70
21.2-27.2	4	5.200	0.5305	53.05	4.25
27.2-33.2	3	3.900	0.3979	40.32	4.55
33.2-39.2	6.66	8.600	0.8834	89.51	3.08
39.2-45.2	2.5	3.250	0.3316	33.36	1.69
45.1-51.1	4.66	6.058	0.6181	62.63	1.98
50.7-57.2	2.15	2.795	0.2851	28.89	1.30
57.2-63.2	3.33	4.329	0.4417	44.75	1.06
62.8-68.8	2.66	3.458	0.3528	35.75	1.01
68.5-75	2.76	3.588	0.3661	37.09	1.03
74-80	4	5.200	0.5305	53.76	1.06

Table 9. Calculated permeability from LU number, Smøla Bh4

Bh4 section	LU	K [m/s] x 10^{-7}	Perm [m^2] x 10^{-13}	Perm [mD]	Porosity Φ [%]
5.95-11.95	4	5.20	0.5252	53.22	0.87
11.75-17.75	3	3.90	0.3979	40.32	1.15
15.85-20.85	4.4	5.72	0.5836	59.14	1.18
20.45-26.95	4.61	5.99	0.6111	61.93	1.60
26.75-32.75	3	3.90	0.3979	40.32	2.43
32.45-38.95	4.61	5.99	0.6111	61.93	3.03
37.95-41-95	5.5	7.15	0.7295	73.92	3.70
41.85-47.85	4.33	5.63	0.5744	58.20	4.32
46.65-50.65	5.5	7.15	0.7295	73.92	5.92
50.65-56.95	2.33	3.02	0.3081	31.22	5.92
54.95-59.95	4.8	6.24	0.6367	64.51	5.42
59.95-65.95	6	7.80	0.7958	80.64	4.61
65.85-71.85	5.33	6.93	0.7071	71.65	5.56
71.45-77.95	4.3	5.59	0.5704	57.79	5.36
77.95-83.95	4.16	5.41	0.5520	55.93	7.69
83.95-89.95	3	3.90	0.3979	40.32	5.69
89.95-95.95	4	5.20	0.5252	53.22	3,03
94.00-100.0	2.33	3.02	0.2377	24.09	2.32

Figure 102 shows the relationship between permeability and porosity for the Lugeon sections in the Smøla and Bømlo boreholes. It does not seem to be any linearity, which is not surprising. The calculated porosity is an average porosity in the Lugeon sections. If there are no fractures, the resistivity will be higher and thereby lower porosity (Archie's law). In Figure 103, the same relationship in different types of sandstones is shown. The Bømlo and Smøla permeabilities are in the upper range of consolidated sandstones, 20 – 100 mD, (https://petrowiki.spe.org/Rock_type_influence_on_permeability).

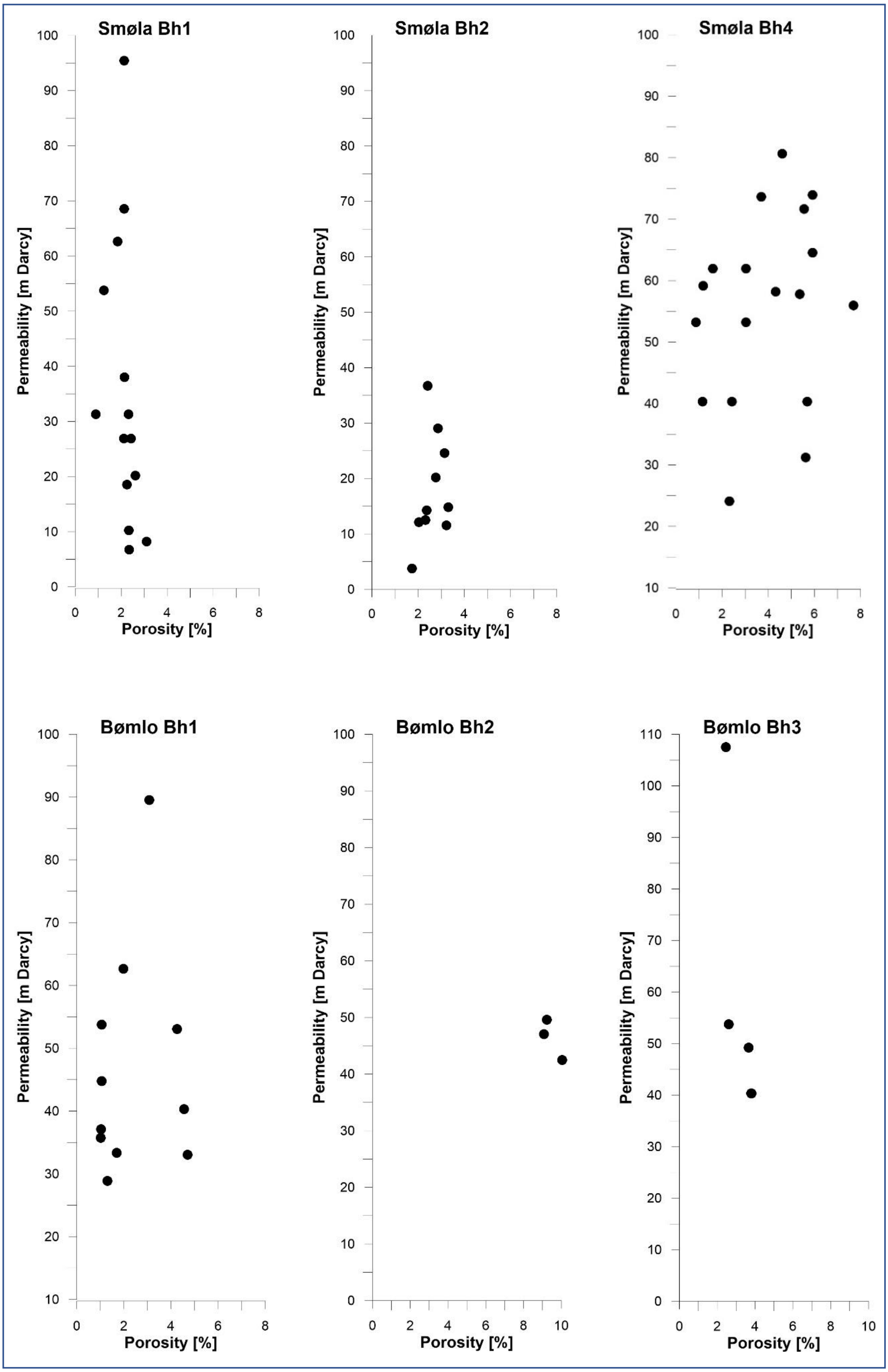


Figure 102. Calculated permeability and porosity in Lugeon test sec

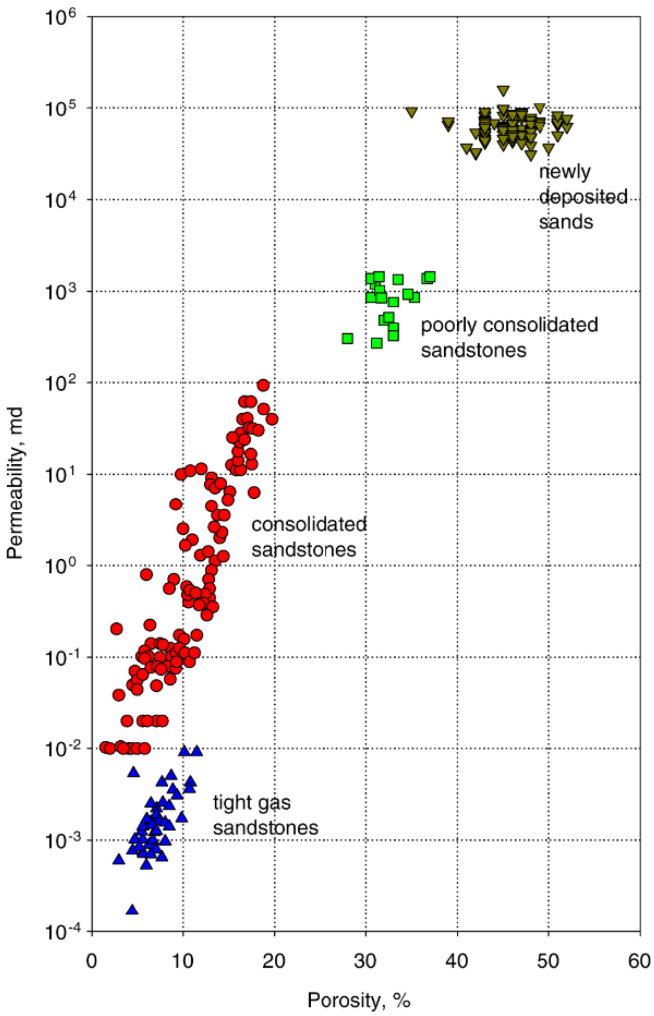


Figure 103. Permeability and porosity in in different sandstones

4.11 NTNU porosity and permeability measurements

Porosity and permeability have been measured on 19 core samples from the Smøla Bh1, Bømlo Bh1 and Bømlo Bh2 by .the Department of Geoscience and Petroleum at NTNU.

The results are shown in Table 10, below. The porosity is in the same range as the porosity calculated from the NGU resistivity logs using Archie's law.

The permeability values differ a lot because NTNU uses air instead of water as a fluid medium. The permeability depends on the fluid viscosity, which is less in the air:

Water: viscosity = 1.002 mPas (milli Pascal second)

Air: viscosity = 18×10^{-3} mPas

Viscosity in water is 1002/18 ≈ 54 x viscosity in air.

Table 10. Porosity and permeability measured on Bømlo and Smøla cores by NTNU.

Depth	Porosity [%]	Permeability [md]	Comments
Bømlo Bh1			
16.5	4.8	2400	Hard rock, FF= 7 - 10 (16 -17 m)
19.7	6.4	2793	Fracture along core, FF = 5 (19 – 20 m)
33.5	8.2		Heavily fractured, crushed (33 – 34 m)
34.5	5.1	2467	Some fractures
36.1	2.4	7.6	Hard rock, FF= 5 – 6 (36 – 37 m)
Bømlo Bh2			
14.5	6.7	2323	Crushed rock 14.55 – 14.9 m)
15.5	4	3661	Hard rock,
17.4	1		Hard rock, heavily fractured from 17.5m
27.2	2.1	2197	Big open fracture 23 – 25 m, fault zone
29.5	8.7	2700	Soft rock, altered, no logs, soft cores.
30.4	0		
38.5	5.7	1000	Hard rock (no logs)
Smøla Bh1			
44.9	4.1	2642	Massive granite, crushed 44.5 – 44.7 m.
55.7	3.2		, FF= 5 – 8 (55 – 56 m)
56.4	1.2	2482	Massive amphibolite FF= 4 – 6 (56 – 57 m)
70.7	2.6		Massive granite/amphibolite, some fractures
88.4	1.9	2254	Massive amphibolite
88.9	1	3093	Massive granite,

In Smøla Bh1, the NTNU permeabilities values are in the range of 2000 – 3000 mD. By using the air viscosity in calculating the permeability from the Lugeon number in the same borehole, the permeability values are in the same range. Table 11 shows the permeability values (water and air) in Smøla Bh1. The values cannot be compared directly because the Lugeon permeabilities are from 5 – 6 m sections in the borehole.

It is debatable whether it is correct to replace the water viscosity with the air viscosity when calculating the permeability from the Lugeon number. The same flow rate is used in both cases, and this may be incorrect.

Table 11. Calculated permeabilities in Smøla Bh1 using air viscosity.

Depth [m]	LU	K [m/s] x 10^{-7}	Perm [m^2] x 10^{-13}	Perm [mD]	Porosity Φ [%]	Permeability (air) [mD]
21 – 27	2.33	3.029	0.3090	31.31	0.9	1691
26 – 30	4	5.2	0.5305	53.76	1.25	2903
30 – 36	4.66	6.058	0.6181	62.63	1.84	3382
36 – 42	5.1	6.63	0.6765	68.54	2.13	3701
42 – 48	7.1	9.23	0.9417	95.42	2.13	5153
47.5 – 54	2	2.6	0.2652	26.88	2.11	1451
53.8 – 59.8	2.83	3.679	0.3753	38.03	2.14	2054
59.5 – 65	1.38	1.794	0.1830	18.54	2.25	1001
66 – 72	2	2.6	0.2652	26.88	2.42	1451
71.4 – 77.4	0.5	0.65	0.0663	6.720	2.34	362
77 – 83.5	0.76	0.988	0.1008	10.21	2.33	551
82.8 – 88.8	2.33	3.029	0.3090	31.31	2.32	1691
87 – 93	1.5	1.95	0.1989	20.16	2.62	1088
92.6 – 99.1	0.61	0.793	0.0809	8.198	3.1	442

The diagrams below, Figure 104, show the porosity - permeability for both NTNU and NGU independent of the depth. It does not seem to be any linearity between the permeability and porosity.

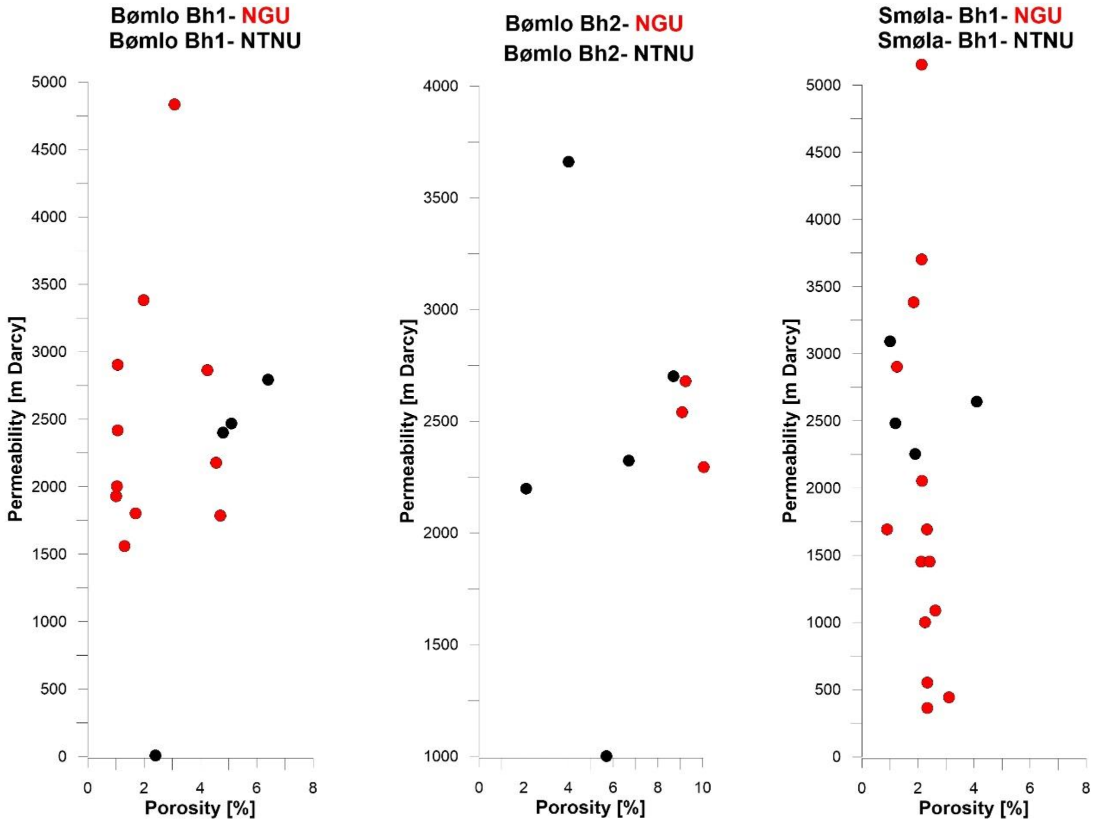


Figure 104. Permeability and porosity in Bømlo Bh1, Bh2 and Smøla Bh1.

Figure 105 shows the porosity logs from the resistivity measurements and the porosity core measurements done by NTNU. Some of the values fit well, and all are in the same range. No log exists below 25 m in Bømlo Bh2. The NGU logs use a 40 cm (electrode distance) section of the borehole to calculate the resistivity and thereby its porosity. Measurements are taken every cm by moving the electrodes downwards. This will be an apparent porosity. The NTNU measurements are measurements at a certain point (depth).

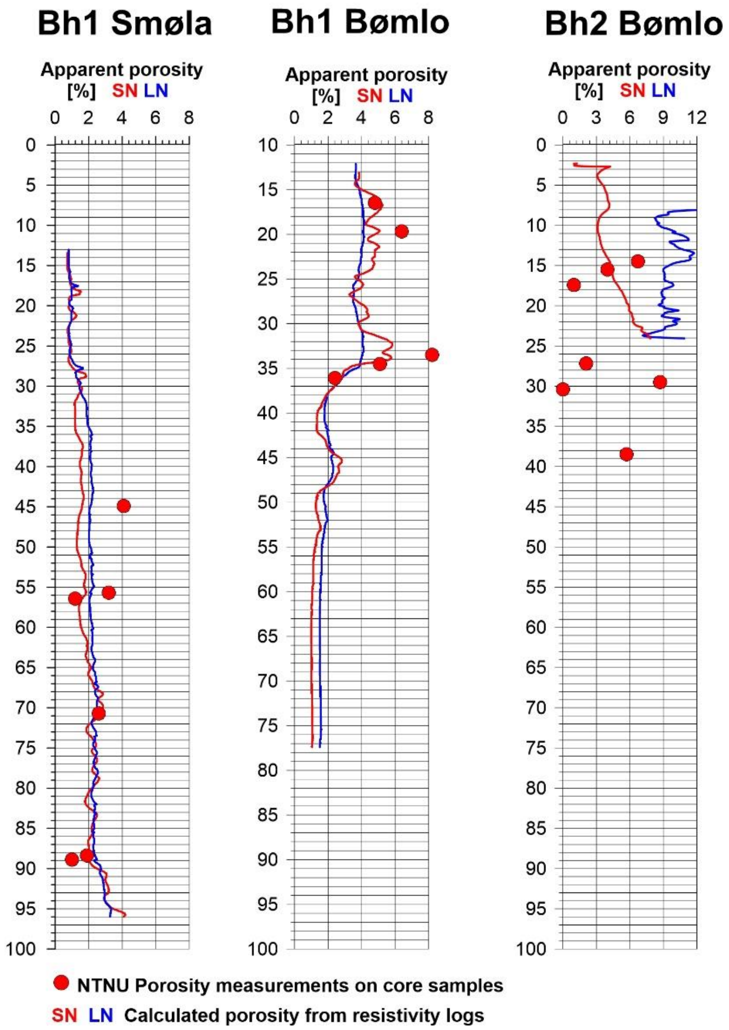


Figure 105. Porosity logs (NGU) and porosity core measurements (NTNU).

These examples show that the porosity logs are in the same range as laboratory measurements if conductive minerals are not present. However, no correlation is seen between porosity and permeability, either in the NGU or the NTNU measurements.

4.12 **Open fractures and clay**

Clay minerals in a certain amount will produce weak IP voltages, which can be measured. Electrically conductive minerals like sulphides, iron oxides and graphite, which have very low resistivity, will give IP effect and SP effect. Usually, clay cannot be detected by SP. So, a criterion to detect clay could be low resistivity, weak IP effect and no SP.

In table 12, all weak IP, SP, and resistivity anomalies in the Smøla and Bømlo boreholes are listed. The anomalies occur on fractures at different depths in the boreholes. Just two of the fractures are indicated by SP, which means that it could be conductive minerals, while the remainder might be caused by clay.

Table 12. Probably clay containing fractures indicated by IP.

Borehole, location	**IP** (%)	**SP** (mV)	**Resistivity** (ohmm)	**Strike** (fracture opening)
Bh1, Smøla, Depth				
18.2 – 18.6 m	1.4	-104	2360	N136
19.05 -19.2	1.39	-	7690	
21.5 -22.0	0.78	-	3380	N074
28.7 – 29.05	2.38	-99	1707	N102
29.45 – 29.71	1.68	-	2773	N277
Bh2, Smøla, Depth				
13.9 – 14.3	2.18	-	2814	N070
21.8 - 22.0	1.60	-	1182	-
26.3 – 26.5	1.47	-	915	N069
58.4 – 58.6	1.41	-	503	N032
60.5 - 60.97	1.17	-	543	N086
Bh4, Smøla, Depth				
29.8 – 30.0	3.20	-	532	N054 (6 cm)
30.4 – 31.0	2.06	-	584	N054 (6 cm)
37.0 – 37.25	2.09	-	477	N059 (5 cm)
38.98 – 39.08	1.74	-	464	N068 (3.8 cm)
48.67 – 48.78	1.82	-	333	N065 (2.5 cm)
Bh2, Bømlo, Depth				
19.81 – 20.05	0.68	-	150	N171
23.50 – 23.63	0.81	-	90	N138
Bh3, Bømlo, Depth				
14.5 – 15.0	1.07	-	1083	N159
15.5 – 15.9	1.09	-	774	N170
23.15 – 26.5	1.08	-	930	-
31.5	1.00	-	140	N358 (60 cm)
32.85 – 33.15	1.20	-	141	N313
35.5 – 38.0	1.15	-	531	-

The most exciting borehole due to detecting clay and open fractures is Smøla Bh4. The borehole is heavily fractured showing five open fractures (red text). The resistivity is very low below ca 30 m depth, 20 – 200 ohmm (LN configuration), see Figure 106. The pore water is not saline and does not influence on the resistivity. The low resistivity is not caused by conductive minerals. The strike direction is almost the same for all five fractures, NE – SW, dipping SE.

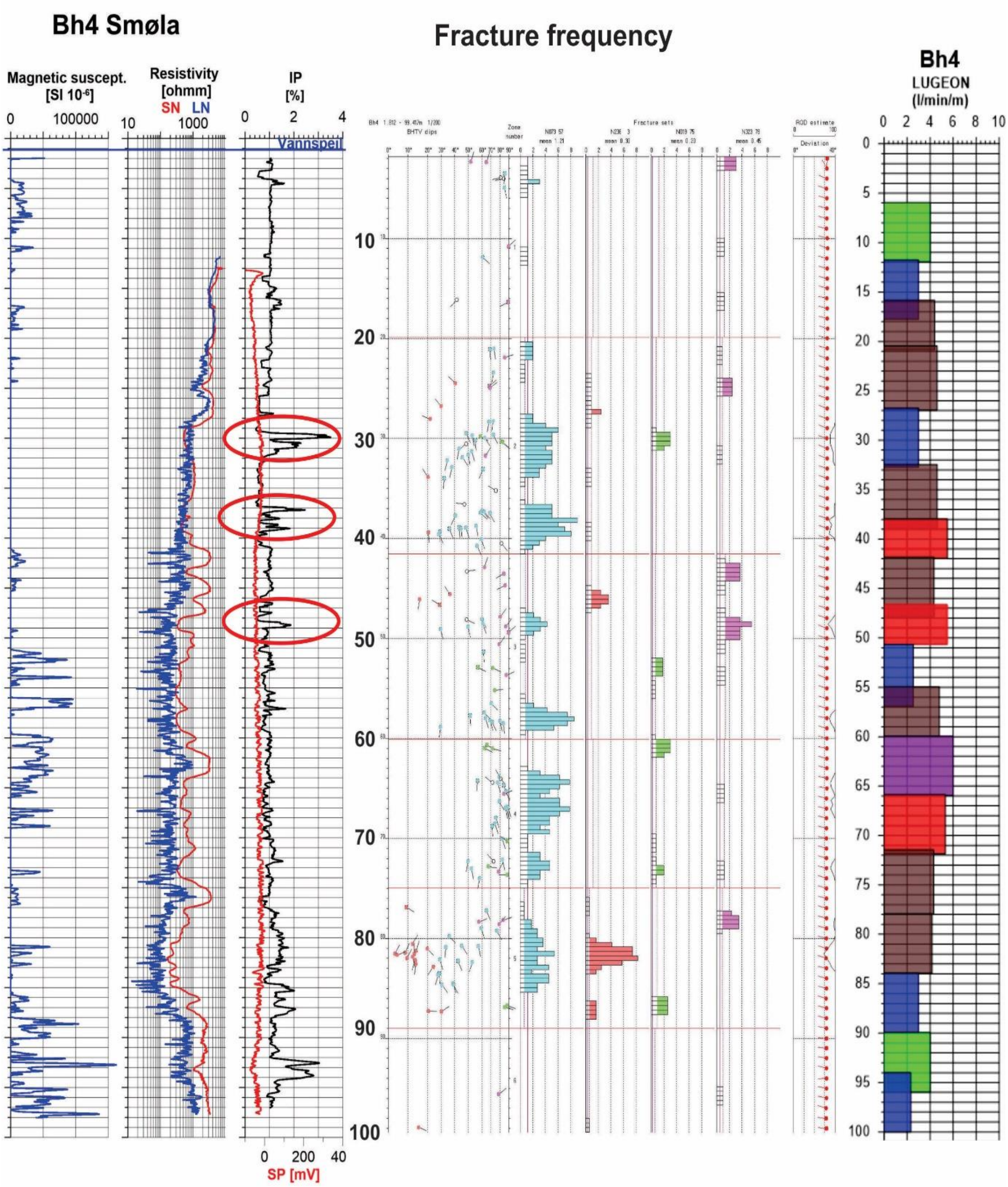


Figure 106. Possible clay zones indicated by IP measurements in Smøla Bh4.

Figure 107 shows IP, SP, and resistivity logs in Smøla Bh1 indicating conductive minerals at 18 m and 29 m depth.

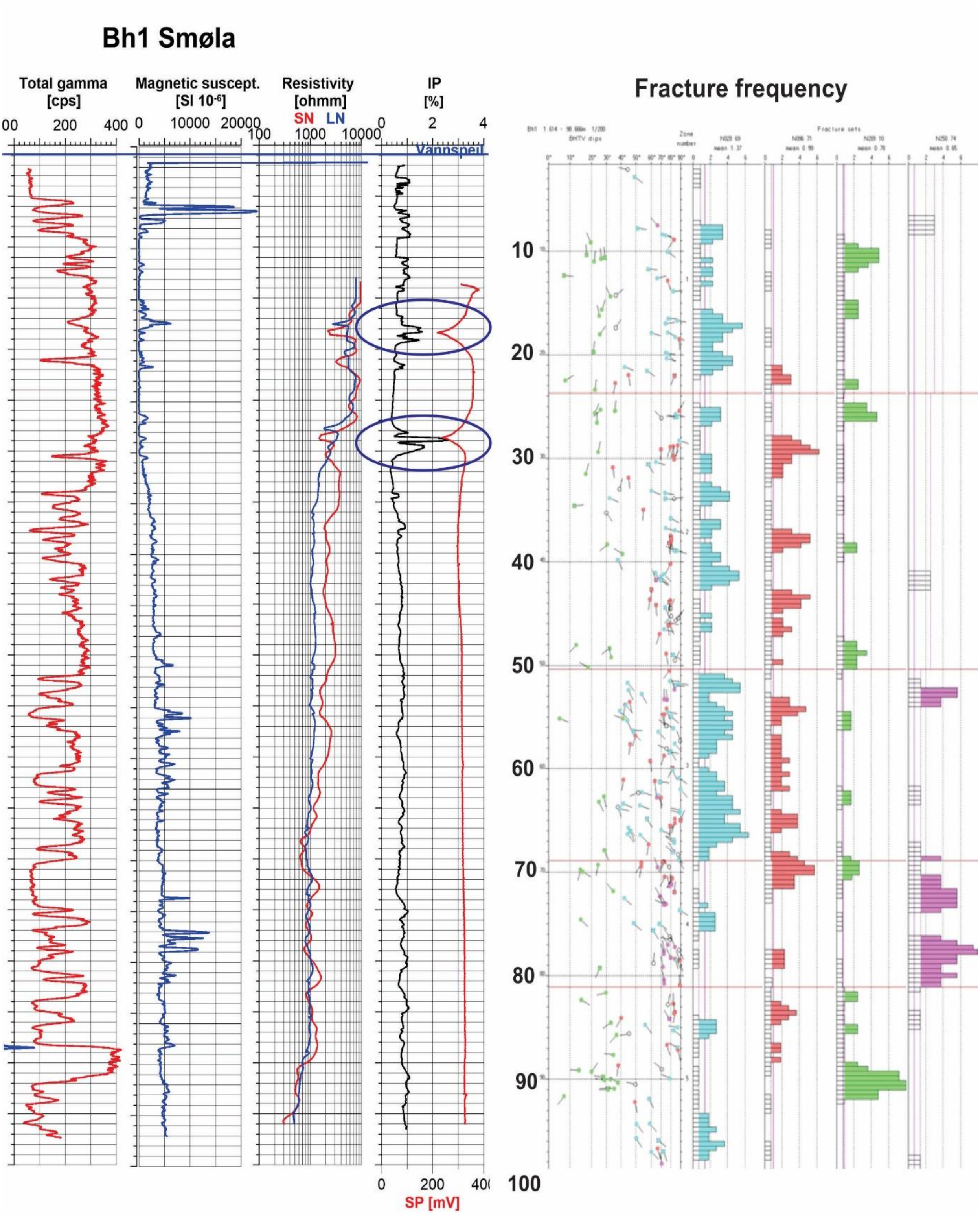


Figure 107. Smøla Bh1, IP, SP, and resistivity anomalies indicating conductive minerals.

4.13 **Reopening of Bømlo Bh2**

As mentioned in Chapter 4.6 Bh2 was stuck at about 26 m depth. All logs stopped at that depth when logging in Mars 2020. A drilling company from Bergen, Brønn og Spesialboring AS, was engaged to reopen the borehole in October 2020, see Figure 108.

Figure 108. Reopening Bh2 by *AS Brønn og Spesialboring.*

The borehole was flushed with water and compressed air using the bore string. A big amount of mud (clay) and sand from the fracture zone came to the surface during this process, see Figure 109.

Figure 109. Clay and sand from the fracture zone at 24 – 26 m in Bh2

The reopening (with flushing) was not successful. When removing the bore string from the borehole, new material of mud and sand flowed into the borehole and blocked it. The flushing was repeated two times with the same result. Extra water had to be supported (from the local Fire Station) because there was no inflow of water into the borehole. If logging below 26 m should be performed the borehole must be cased to this depth. This will be a quite expensive operation.

5. DISCUSSION AND CONCLUSION

A lot of borehole data has been collected during logging in seven boreholes at Smøla and Bømlo. How can these data be used for studying fractured, altered, and weathered basement rocks? Can any of the measured geophysical parameters tell us something about the fracturing and weathering processes? Two issues are important to study, fracture sets (fracture frequency and fracture directions) and the presence of clay minerals. To map fracture directions the acoustic or optical televiewer can be used. To map the presence of fractures besides the televiewers, seismic velocity and resistivity can be used. Low seismic P-velocity and low resistivity will indicate fractures. Waterfilled fractures is quite easy to detect. One should be aware of electrically conductive minerals like sulphides, iron oxides and graphite which have very low resistivity. To differ between conductive minerals and fractures Self Potential (SP) and Induced Potential (IP) should be measured. It is also known that clay minerals can be detected by IP (weak effect) but not by SP. So, a criterion to detect clay could be low resistivity, weak IP effect and no SP. It should be mentioned that a certain amount of clay should be present.

Besides the geophysical logs the rock permeability is a very important parameter to characterise an oil reservoir. In this project permeability is measured on core plugs in the laboratory at NTNU. However, from the Lugeon tests performed by the drilling company, the hydraulic conductivity and thereby the permeability can be calculated. This is not the real rock permeability, but a permeability measured in the locked borehole sections during the Lugeon tests. These sections are 5 – 6 m long and the permeability is most probably controlled by the fractures.

5.1 Porosity and permeability

As mentioned earlier the apparent porosity is calculated using the resistivity log and Archie's law. In the Smøla boreholes the apparent porosity is 1 – 5 %, except a top value of 20 % in Bh4. In the Bømlo boreholes the apparent porosity is 1 – 10 %. The variation is caused by different grade of fracturing. The logged porosities are in the same range as laboratory measurements performed by NTNU.

The calculated permeabilities from the Lugeon tests are in the range of 4 – 108 mD.This is an average permeability in the locked Lugeon sections (5 – 6 m) using water as fluid medium. The air-based measurements at NTNU came up with 2000 – 3000 mD. If the viscosity of air is used for the Lugeon permeabilities, the values are in the same range as NTNU. It is not clear if this is right to do, and it is difficult to compare measurements on cores (NTNU) and 5 – 6 m sections in a borehole.

5.2 **Main fracture directions**

All boreholes at Smøla and Bømlo are heavily fractured. Fracture interpretation is done by processing the acoustic televiewer data.

In the Smøla boreholes the average strike direction of the main fracture group varies from N002 – N073.This mean that the fractures are dipping to the east direction. For details, see chapter 4.2.1. – 4.2.7.

In the Bømlo boreholes the average strike direction of the main fracture group varies from N162 – N189 dipping W – SW. For details see chapter 4.7.1 – 4.7.5.

5.3 **Stuck Bømlo Bh2**

As described earlier the Bømlo Bh2 was stuck at 27 m. The detailed image from acoustic televiewer shows that the probe stopped at 27.4 m depth. The reopening failed and masses from the fracture zone blocked the borehole at the same depth. The borehole was filled with grouting from 21 – 24.3 m depth as shown in Appendix 3 page 1. The images below, Figure 110, is from 21.9 - 24.3 m taken after redrilling of the grouting. However, the big open fracture at ca 23 m seems still to be open and not filled with grouting as it should. The grouting process seems to have failed and may be the reason for the stuck Bømlo Bh3 borehole. There was no grouting from 24.3 – 27.4 and the blocking masses could come from this section as well.

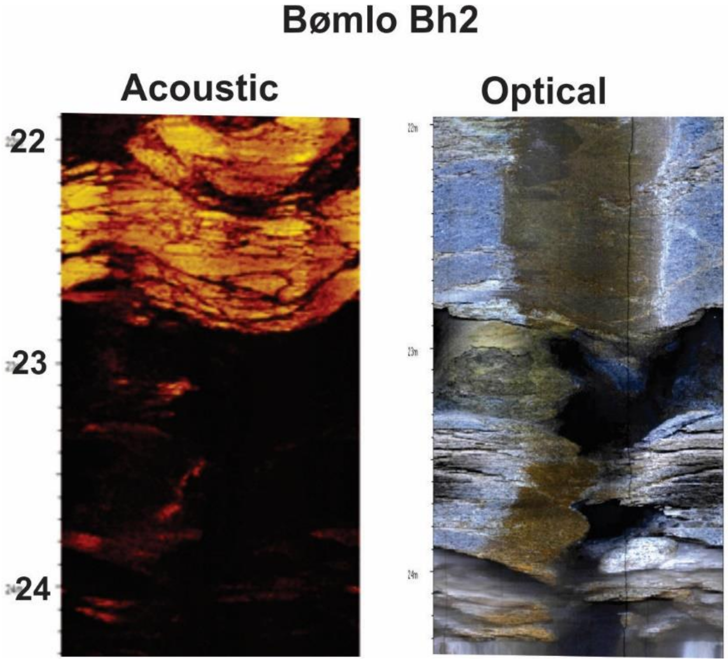


Figure 110. Bømlo Bh2, acoustic and optical image of section 21 – 24.3 m.

6. REFERENSES

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GEO DRILLING

RAPPORT - VANNTAPSMÅLING - Lugeon

Side 1 av sider 1

Lokalitet: Smøla		Dato: Oktober	Forsøkstype: X enkelt pakker under boring
Borehull nr: KBH-01-19	Helning: 55gr	Retning:	enkelt pakker etter boring
Grunnvannstand under terreng: m			doble pakkere

DATO	MÅLESEKSJON			TRYKK	VANNMENGDE		TID	VANNTAP PR MIN	VANNTAP Mpa	VED 0,98 (10kp/cm2)	KOMMENTARER
	Fra	Til	Lengde		MÅLT	KORR. FOR 0,98 MPa (10 kp/cm2)			Pr. Seksjon	Pr. "lugeon"	
	m	m	m	98 KpA (KP/CM2)	l	l	min	l/min	l/min	l/min/m	
1	2	3	4 = 3-2	5	6	7 = 6/5 x 10	8	9 = 6/8	10 = 7/8	11 = 10/4	
	21,04	27,04	6,00	10	70	70	5	14	14	2,33333333	
	26,04	30,04	4,00	10	80	80	5	16	16	4	
	30,04	36,04	6,00	10	140	140	5	28	28	4,66666667	
	36,00	42,00	6,00	10	155	155	5	31	31	5,16666667	
	42,00	48,00	6,00	10	215	215	5	43	43	7,16666667	
	47,50	54,00	6,50	10	65	65	5	13	13	2	
	53,80	59,80	6,00	10	85	85	5	17	17	2,83333333	
	59,50	66,00	6,50	10	45	45	5	9	9	1,38461538	
	66,00	72,00	6,00	10	60	60	5	12	12	2	
	71,40	77,40	6,00	10	15	15	5	3	3	0,5	
	77,00	83,50	6,50	10	25	25	5	5	5	0,76923077	
	82,80	88,80	6,00	10	70	70	5	14	14	2,33333333	
	87,00	93,00	6,00	10	45	45	5	9	9	1,5	
	92,60	99,10	6,50	10	20	20	5	4	4	0,61538462	

GEO DRILLING

RAPPORT - VANNTAPSMÅLING - Lugeon

Side 1 av 1 sider

Lokalitet: Smøla
Borehull nr: KBH - 02 - 19 Helning: 60gr
Grunnvannstand under terreng: m
Dato: Okt. Nov.
Retning:
Forsøkstype: X enkelt pakker under boring
enkelt pakker etter boring
doble pakkere

DATO	MÅLESEKSJON			TRYKK	VANNMENGDE		TID	VANNTAP PR MIN	VANNTAP Mpa	VED 0,98 (10kp/cm2)	KOMMENTARER
	Fra	Til	Lengde		MÅLT	KORR. FOR 0,98 MPa (10 kp/cm2)			Pr. Seksjon	Pr. "lugeon"	
	m	m	m	98 KpA (KP/CM2)	l	l	min	l/min	l/min	l/min/m	
1	2	3	4 = 3-2	5	6	7 = 6/5 x 10	8	9 = 6/8	10 = 7/8	11 = 10/4	
	39,40	46,40	7,00	10	10	10	5	2	2	0,28571429	
	46,30	54,30	8,00	10	36	36	5	7,2	7,2	0,9	
	54,30	60,30	6,00	10	28	28	5	5,6	5,6	0,93333333	
	60,30	63,30	3,00	10	41	41	5	8,2	8,2	2,73333333	
	63,30	69,30	6,00	10	32	32	5	6,4	6,4	1,06666667	
	68,70	75,20	6,50	10	28	28	5	5,6	5,6	0,86153846	
	74,80	81,30	6,50	10	36	36	5	7,2	7,2	1,10769231	
	81,30	87,30	6,00	10	55	55	5	11	11	1,83333333	
	87,30	93,30	6,00	10	65	65	5	13	13	2,16666667	
	92,30	102,30	10,00	10	75	75	5	15	15	1,5	

GEO DRILLING

RAPPORT - VANNTAPSMÅLING - Lugeon

Side 1 av sider

Lokalitet:	Smøla, Vindparken		Dato:	Nov-Des	Forsøkstype:	X	enkelt pakker under boring
Borehull nr:	KBH - 04	Helning: 60gr	Retning:	Øst			enkelt pakker etter boring
Grunnvannstand under terreng:		m					doble pakkere

DATO	MÅLESEKSJON			TRYKK	VANNMENGDE		TID	VANNTAP PR MIN	VANNTAP Mpa	VED 0,98 (10kp/cm2)	KOMMENTARER
	Fra	Til	Lengde		MÅLT	KORR. FOR 0,98 MPa (10 kp/cm2)			Pr. Seksjon	Pr. "lugeon"	
	m	m	m	98 KpA (KP/CM2)	l	l	min	l/min	l/min	l/min/m	
1	2	3	4 = 3-2	5	6	7 = 6/5 x 10	8	9 = 6/8	10 = 7/8	11 = 10/4	
	5,95	11,95	6,00	10	120	120	5	24	24	4	
	11,75	17,75	6,00	10	90	90	5	18	18	3	Alle vanntapsmålinger er gjort før støping
	15,85	20,85	5,00	10	110	110	5	22	22	4,4	
	20,45	26,95	6,50	10	150	150	5	30	30	4,61538462	
	26,75	32,75	6,00	10	90	90	5	18	18	3	
	32,45	38,95	6,50	10	150	150	5	30	30	4,61538462	
	37,95	41,95	4,00	10	110	110	5	22	22	5,5	
	41,85	47,85	6,00	10	130	130	5	26	26	4,33333333	
	46,65	50,65	4,00	10	110	110	5	22	22	5,5	
	50,65	56,95	6,30	10	80	80	5	16	16	2,53968254	
	54,95	59,95	5,00	10	120	120	5	24	24	4,8	
	59,95	65,95	6,00	10	180	180	5	36	36	6	
	65,85	71,85	6,00	10	160	160	5	32	32	5,33333333	
	71,45	77,95	6,50	10	140	140	5	28	28	4,30769231	
	77,95	83,95	6,00	10	125	125	5	25	25	4,16666667	
	83,95	89,95	6,00	10	90	90	5	18	18	3	
	89,95	95,95	6,00	10	120	120	5	24	24	4	
	94,00	100,00	6,00	10	70	70	5	14	14	2,33333333	

GEO DRILLING

RAPPORT - VANNTAPSMÅLING - Lugeon

Side 1 av 1 sider

Lokalitet: Goddeveien, Bømlo
Borehull nr: KBH - 01 - 20 Helning: 60gr
Grunnvannstand under terreng: m
Dato: Januar
Retning:
Forsøkstype: X enkelt pakker under boring
enkelt pakker etter boring
doble pakkere

DATO	MÅLESEKSJON			TRYKK	VANNMENGDE		TID	VANNTAP PR MIN	VANNTAP Mpa	VED 0,98 (10kp/cm2)	KOMMENTARER
	Fra	Til	Lengde		MÅLT	KORR. FOR 0,98 MPa (10 kp/cm2)			Pr. Seksjon	Pr. "lugeon"	
	m	m	m	98 KpA (KP/CM2)	l	l	min	l/min	l/min	l/min/m	
1	2	3	4 = 3-2	5	6	7 = 6/5 x 10	8	9 = 6/8	10 = 7/8	11 = 10/4	
24.01.2020	9,00	15,00	6,00	10	110	110	5	22	22	3,66666667	
26.01.2020	14,70	21,20	6,50	10	80	80	5	16	16	2,46153846	
27.01.2020	21,20	27,20	6,00	10	120	120	5	24	24	4	
28.01.2020	27,20	33,20	6,00	10	90	90	5	18	18	3	
29.01.2020	33,20	39,20	6,00	10	200	200	5	40	40	6,66666667	
30.01.2020	39,20	45,20	6,00	10	75	75	5	15	15	2,5	
30.01.2020	45,10	51,10	6,00	10	140	140	5	28	28	4,66666667	
31.01.2020	50,70	57,20	6,50	10	70	70	5	14	14	2,15384615	
02.02.2020	57,20	63,20	6,00	10	100	100	5	20	20	3,33333333	
02.02.2020	62,80	68,80	6,00	10	80	80	5	16	16	2,66666667	
03.02.2020	68,50	75,00	6,50	10	90	90	5	18	18	2,76923077	
03.02.2020	74,00	80,00	6,00	10	120	120	5	24	24	4	

GEO DRILLING

RAPPORT - VANNTAPSMÅLING - Lugeon

Side 1 av 1 sider

Lokalitet:	Bømlo		Dato:	Februar	Forsøkstype: X enkelt pakker under boring
Borehull nr:	KBH-02-Bømlo	Helning: 60gr	Retning:		enkelt pakker etter boring
Grunnvannstand under terreng:		m			doble pakkere

DATO	MÅLESEKSJON			TRYKK	VANNMENGDE		TID	VANNTAP PR MIN	VANNTAP Mpa	VED 0,98 (10kp/cm2)	KOMMENTARER
	Fra	Til	Lengde		MÅLT	KORR. FOR 0,98 MPa (10 kp/cm2)			Pr. Seksjon	Pr. "lugeon"	
	m	m	m	98 KpA (KP/CM2)	l	l	min	l/min	l/min	l/min/m	
1	2	3	4 = 3-2	5	6	7 = 6/5 x 10	8	9 = 6/8	10 = 7/8	11 = 10/4	
08.02.2020	8,60	14,60	6,00	10	95	95	5	19	19	3,16666667	
09.02.2020	14,50	21,00	6,50	10	120	120	5	24	24	3,69230769	
10.02.2020	21,00	27,00	6,00	10	105	105	5	21	21	3,5	
11.02.2020	27,00	33,00	6,00	10	85	85	5	17	17	2,83333333	
12.02.2020	33,00	39,00	6,00	10	45	45	5	9	9	1,5	
12.02.2020	39,00	45,00	6,00	10	35	35	5	7	7	1,16666667	
13.02.2020	45,00	54,00	9,00	10	55	55	5	11	11	1,22222222	
15.02.2020	54,00	60,00	6,00	10	125	125	5	25	25	4,16666667	
15.02.2020	60,00	66,00	6,00	10	95	95	5	19	19	3,16666667	
16.02.2020	66,00	72,00	6,00	10	60	60	5	12	12	2	
17.02.2020	72,00	80,00	8,00	10	135	135	5	27	27	3,375	

GEO DRILLING

RAPPORT - VANNTAPSMÅLING - Lugeon

Side 1 av 1 sider

Lokalitet:	Djupedalen, Bømlo	Dato:	Februar
Borehull nr:	KBH-03-20	Helning: 80gr	Retning:
Grunnvannstand under terreng:	m		

Forsøkstype:
- X enkelt pakker under boring
- enkelt pakker etter boring
- doble pakkere

DATO	MÅLESEKSJON			TRYKK	VANNMENGDE		TID	VANNTAP PR MIN	VANNTAP Mpa	VED 0,98 (10kp/cm2)	KOMMENTARER
	Fra	Til	Lengde		MÅLT	KORR. FOR 0,98 MPa (10 kp/cm2)			Pr. Seksjon	Pr. "lugeon"	
	m	m	m	98 KpA (KP/CM2)	l	l	min	l/min	l/min	l/min/m	
1	2	3	4 = 3-2	5	6	7 = 6/5 x 10	8	9 = 6/8	10 = 7/8	11 = 10/4	
23.02.2020	15,10	21,10	6	10	240	240	5	48	48	8	
23.02.2020	21,10	27,10	6	10	120	120	5	24	24	4	
24.02.2020	27,10	33,10	6	10	90	90	5	18	18	3	
24.02.2020	33,10	39,10	6	10	90	90	5	18	18	3	
24.02.2020	39,10	45,10	6	10	110	110	5	22	22	3,66666667	

Geo Drilling as

NGU, SMØLA

P - 180619

Støpinger av dårlige soner, KBH-01, Smøla

Dato :	Støpt fra :	Vent på herding :	Utboring sement :
04.10.19	4,59 meter	1 time	2,10 meter
05.10.19	7,04 meter	2 timer	0,00 meter
06.10.19	7,04 meter	7 timer	3,80 meter
07.10.19	15,04 meter	4 timer	2,90 meter
08.10.19	21,04 meter	1 time	4,30 meter
09.10.19	30,04 meter	2 timer	4,10 meter
14.10.19	36,04 meter	2 timer	4,50 meter
Totalt :	7 stk. støpinger	19 timer	21,70 meter utboring

Geo Drilling as

NGU, SMØLA

P - 180619

Støpinger av dårlige soner, KBH-02, Smøla

Dato :	Støpt fra :	Vent på herding :	Utboring sement :
23.10.19	13,50 meter	4 time	4,00 meter
24.10.19	27,00 meter	3 timer	3,10 meter
30.10.19	48,30 meter	5 timer	3,40 meter
31.10.19	54,30 meter	5 timer	3,60 meter
01.11.19	60,30 meter	6 time	4,10 meter
02.11.19	63,30 meter	6 timer	1,20 meter
03.11.19	63,30 meter	5 timer	3,20 meter
04.11.19	69,30 Meter	4 timer	4,40 meter
05.11.19	75,20 meter	3 timer	4,10 meter
06.11.19	87,30 meter	4 timer	4,00 meter
07.11.19	93,30 meter	3 timer	4,30 meter
08.11.19	99,65 meter	3 timer	1,80 meter
Totalt :	12 stk. støpinger	51 timer	41,20 meter utboring

Geo Drilling as

NGU, SMØLA

P - 180619

Støpinger av dårlige soner, KBH-03, Smøla

Dato :	Støpt fra :	Vent på herding :	Utboring sement :
13.11.19	2,90 meter	1 time	1,50 meter
Totalt :	1 stk. støpinger	1 timer	1,50 meter utboring

Geo Drilling as

NGU, SMØLA

P - 180619

Støpinger av dårlige soner, KBH-04, Smøla

Dato :	Støpt fra :	Vent på herding :	Utboring sement :
27.11.19	02,95 meter	3 time	1,30 meter
28.11.19	11,95 meter	5 timer	4,20 meter
29.11.19	20,85 meter	5 timer	4,30 meter
30.11.19	32,75 meter	4 timer	4,10 meter
02.12.19	41,95 meter	4 time	4,80 meter
03.12.19	50,65 meter	4 timer	3,70 meter
04.12.19	59,95 meter	5 timer	3,40 meter
05.12.19	65,95 Meter	4 timer	3,20 meter
06.12.19	71,85 meter	6 timer	4,70 meter
07.12.19	77,95 meter	6 timer	3,10 meter
08.12.19	83,95 meter	5 timer	4,30 meter
09.12.19	89,95 meter	4 timer	5,60 meter
10.12.19	95,95 meter	4 timer	3,10 meter
Totalt :	13 stk. støpinger	59 timer	49,80 meter utboring

Geo Drilling as

NGU, BØMLO

P - 180619

Støping av dårlige soner, KBH-01, Bømlo

Dato :	Støpt fra :	Vent på herding :	Utboring sement :
22.01.20	9,20 meter	5 timer	0 meter
23.01.20	9,20 meter	7 timer	4,40 meter
24.01.20	15,00 meter	4 timer	0 meter
25.01.20	15,00 meter	6 timer	4,20 meter
26.01.20	21,20 meter	5 timer	4,00 meter
27.01.20	27,20 meter	4 timer	4,30 meter
28.01.20	33,20 meter	5 timer	4,50 meter
29.01.20	39,20 meter	6 timer	5,10 meter
30.01.20	51,10 meter	4 timer	3,40 meter
31.01.20	57,20 meter	4 timer	0 meter
01.02.20	57,20 meter	7 timer	5,80 meter

Totalt : 11 stk. støpinger 57 timer 35,70 meter utboring

Geo Drilling as

NGU, Bømlo

P - 180619

Støpinger av dårlige soner, KBH-02, Bømlo

Dato :	Støpt fra :	Vent på herding :	Utboring sement :
06.02.20	3,70 meter	2 time	2,80 meter
07.02.20	9,00 meter	3 timer	2,70 meter
08.02.20	14,60 meter	3 timer	3,10 meter
09.02.20	21,00 meter	2 time	3,30 meter
10.02.20	27,40 meter	3 timer	6,60 meter
11.02.20	36,00 meter	2 time	3,60 meter
12.02.20	45,00 meter	2 timer	2,90 meter
13.02.20	54,00 meter	3 timer	3,10 meter
14.02.20	57,00 meter	4 time	3,40 meter
16.02.20	73,60 meter	2 timer	2,70 meter

Totalt : 10 stk. støpinger 26 timer venting 34,20 meter utboring

Geo Drilling as

NGU, BØMLO

P - 180619

Støpinger av dårlige soner, KBH-03, Bømlo

Dato :	Støpt fra :	Vent på herding :	Utboring sement :
22.02.20	15,10 meter	2 timer	3,30 meter
23.02.20	21,10 meter	3 timer	4,60 meter
Totalt :	2 stk. støpinger	5 timer	7,90 meter utboring

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 1		
PROSJEKT: P-180619		STED: Smøla			HULL-NR: KBH - 01		KRONE: HQ	DATO: Oktober	MASKIN: U-6 APC	FALL/RETNING: 55gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
1,25	2,64	1,39	800	2000-2500	7-9	5-6	Grått	Casing til 1,50 meter, fjell fra 1,25 meter		
2,64	4,59	1,95	800	2500-2800	10-12	5	Grått	Knust, kiler, Støpt		
4,59	5,69	1,10	800	2500-2800	10-12	6	Grått	Knust, kiler		
5,69	6,04	0,35	800	2800-3200	10-12	5	Grått	Rød granitt, knust		
6,04	7,04	1,00	800	2800-3200	10-12	4	Grått	Sprukket og knust, Støpt		
7,04	8,22	1,18	800	2900-3500	10-12	4	Grått	Sprukket og knust, hardt		
8,22	8,34	0,12	800	2900-3200	9-10	5	Grått	Kiler, stopp, hardt		
8,34	9,04	0,70	800	3200-3500	8-11	5	Grått	Knust		
9,04	10,04	1,00	800	3500-3800	5-8	3	Grått	Sprukket og knust, hardt		
10,04	10,64	0,60	800	3800-4100	5-8	3	Grått	Hardt, sprukket		
10,64	11,79	1,15	800	4000-4400	5-11	4	Grått	Sprukket, knust		
11,79	13,69	1,90	800	3800-4600	7-12	5	Grått			
13,69	15,04	1,35	800	3900-4500	7-10	4	Grått	Delvis helt, noen sprekker, Støpt		
15,04	15,14	0,10	800	4000-4500	5-7	3	Grått			
15,14	16,24	1,10	800	3800-4300	5-7	3	Grått	Litt sprukket, hardt		
16,24	16,89	0,65	800	4000-4500	5-8	3	Grått			
16,89	18,04	1,15	800	4000-4500	5-9	3	Grått	Sprukket, litt knust, hardt		
18,04	18,54	0,50	800	4000-4500	5-8	3	Grått	Veldig oppsprukket, hardt		
18,54	19,59	1,05	800	4000-4500	5-8	3	Grått			
19,59	20,14	0,55	800	4200-4500	5-7	3	Grått	Helt fjell		
20,14	20,29	0,15	800	4500	5-6	2	Grått			
20,29	20,74	0,45	800	4500-4700	5-6	2	Grått	Kiler, stopp, hardt		
20,74	21,04	0,30	800	4100-4200	6-8	2	Grått	Kommer ikke ned uten å rotere, Støpt		
21,04	22,04	1,00	800	4000-4500	6-8	3	Grått	Litt sprukket, hardt		
22,04	23,89	1,85	800	4000-4500	6-8	2	Grått			
23,89	25,64	1,75	800	4000-4500	6-9	2	Grått	Litt sprukket, hardt		
25,64	27,04	1,40	800	4000-4500	6-9	2	Grått			
27,04	29,69	2,65	800	3900-4500	6-9	2	Grått	Sprukket, leire 28,95 meter		
29,69	30,04	0,35	800	3900-4200	6-8	3	Grått	Fastboring, må støpe sonen, Støpt		
30,04	31,54	1,50	800	3500-3800	8-10	5	Grått	Litt sprukket, knust, hardt		
31,54	33,04	1,50	800	3900-4200	8-10	4	Grått			
SUM	33,04	31,79								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	2	GEO DRILLING
PROSJEKT: P-180619		STED: Smøla			HULL-NR: KBH - 01		KRONE: HQ	DATO: Oktober	MASKIN: U-6 APC	FALL/RETNING: 55gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
33,04	33,84	0,80	800	4000-4500	5-7	3	Grått	Sprukket, kiler, hardt		
33,84	35,24	1,40	800	3900-4600	5-9	3	Grått	Sprukket, kiler,knust, hardt		
35,24	36,04	0,80	800	3900-4400	7-10	3	Grått	Helere fjell, støper sonen over, Støpt		
36,04	39,00	2,96	800	2600-3800	14-18	5	Grått	Delvis helt		
39,00	42,00	3,00	800	2500-3500	10-18	7	Grått	Hardt og mykt, mye leire		
42,00	44,80	2,80	800	3000-5000	8-18	10	Grått	Hardt og mykt, mye leire		
44,80	46,00	1,20	800	3700-5000	3-10	4	Grått	Hardt, lange kiler, stopp		
46,00	48,00	2,00	800	4200-5200	8-13	5	Grått	Hardt, kiler		
48,00	49,90	1,90	800	3500-5000	8-14	11	Grått	Hardt, kiler, sprukket		
49,90	50,40	0,50	800	4000-5200	5-12	10	Grått	Hardt		
50,40	52,50	2,10	800	2900-3500	10-14	6	Grått	Hardt helt fjell		
52,50	54,00	1,50	800	2800-3200	10-13	5	Grått	Delvis helt, kiler		
54,00	56,30	2,30	800	2600-3000	11-15	6	Grått	Sprøtt, mye kiling		
56,30	58,50	2,20	800	2500-4200	8-13	5	Grått			
58,50	58,70	0,20	800	2500-4300	8-11	8	Grått			
58,70	59,80	1,10	800	2500-4000	8-10	8	Grått			
59,80	61,00	1,20	800	2500-4500	8-10	6	Grått	Noe kjerne står igjen		
61,00	63,00	2,00	800	2500-3000	10-12	8	Grått	Sprukket, knust, kiler		
63,00	63,80	0,80	800	2500-3000	8-12	11	Grått	Sprukket, kiler, bergartsoverganger, fastboring, havari		
63,80	66,00	2,20	800	2500-3500	9-15	6	Grått	Blandede bergarter, sprukket		
66,00	68,20	2,20	800	2800-4500	8-13	5	Grått			
68,20	69,00	0,80	800	2200-3600	8-15	9	Grått	Sprukket, overganger, sprøtt og hardt		
69,00	72,00	3,00	800	1800-3400	8-15	12	Grått			
72,00	75,00	3,00	800	600-1800	10-13	8	Grått	Sprukket, overganger, sprøtt og hardt		
75,00	77,40	2,40	800	1600-4300	9-12	10	Grått			
77,40	78,50	1,10	800	1500-2900	8-11	7	Grått	Kilstopp, helt fjell med lange kiler		
78,50	79,80	1,30	800	2000-2700	10-15	8	Grått			
79,80	81,00	1,20	800	1800-2300	10-13	10	Grått	Mye sprukket, svakt, kiler		
81,00	83,50	2,50	800	2200-2800	10-14	9	Grått			
83,50	86,70	3,20	800	2000-2300	12-15	10	Grått	Noe sprukket, bergartsoverganger		
86,70	88,80	2,10	800	2000-2400	12-15	10	Grått			
SUM	88,80	55,76								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	3	GEO DRILLING
PROSJEKT: P-180619		STED: Smøla			HULL-NR: KBH - 01		KRONE: HQ	DATO: Oktober	MASKIN: U-6 APC	FALL/RETNING: 55gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
88,80	90,30	1,50	800	2300-3100	8-15	7-18	Grått	Sprukket, kiler, stopp		
90,30	91,20	0,90	800	2500-4700	4-8	4-6	Grått	Sprukket, kiler, stopp		
91,20	93,00	1,80	800	2500-3000	10-14	8-12	Grått			
93,00	96,00	3,00	800	1200-2500	9-15	6-12	Grått	Dårlige soner, mykt og svakt		
96,00	99,10	3,10	800	800-3000	8-16	6-15	Grått			
								HULL AVSLUTTET		
SUM	99,10	10,30								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	1	GEO DRILLING
PROSJEKT: P - 180619		STED: Smøla			HULL-NR: KBH - 02-19		KRONE: HQ	DATO: Okt. / Nov.	MASKIN: Diamec U6 APC	FALL/RETNING: -60gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
0,00	1,50	0,30	800	1800-2200	10-12	0-3	Gråvitt	Dårlig dagfjell, Casing til 1,50 meter fjell fra 1,20 meter		
1,50	3,30	1,80	800	1800-2200	10-12	2	Gråvitt	Hardt, variabelt		
3,30	5,90	2,60	800	1900-4000	6-10	0-3	Gråvitt	Hardt, mye kiler, stopp		
5,90	7,00	1,10	800	2000-3800	6-11	0-7	Gråvitt	Hardt, sprukket, kilstopp		
7,00	8,50	1,50	800	2900-3300	8-13	3-5	Gråvitt	Sprukket, kilstopp		
8,50	9,70	1,20	800	2300-3000	10-15	0-3	Gråvitt	Mye kiler, sprukket		
9,70	10,60	0,90	800	2400-3000	10-15	0-5	Gråvitt	Mye kiler, sprukket		
10,60	12,20	1,60	800	2600-4100	10-12	0-3	Gråvitt	Kilstopp		
12,20	12,80	0,60	800	2600-3200	8-11	0-6	Gråvitt	Dårlig fjell, mykt, knust, kilstopp		
12,80	13,50	0,70	800	1200-1400	8-12	0-5	Gråvitt	Dårlig fjell, mykt, knust, kilstopp, Støpt		
13,50	15,30	1,80	800	2000-2500	8-11	10-12	Gråvitt	Mykt, sprukket, leireaktig		
15,30	16,00	0,70	800	2000-2400	9-14	5-6	Gråvitt	Mykt, sprukket, leireaktig		
16,00	18,30	2,30	800	2000-3400	9-14	4-6	Gråvitt	Mykt, sprukket, leireaktig		
18,30	21,30	3,00	800	1500-4300	8-13	6-14	Gråvitt	Hardere, svakt med sprekker		
21,30	22,80	1,50	800	1800-4400	9-12	6-17	Gråvitt	Varierende hardhet, noe mykt og svakt		
22,80	24,00	1,20	800	2100-4500	4-10	3-5	Gråvitt	Hardt og kilende, noen knusninger		
24,00	25,70	1,70	800	2900-4600	4-12	3-6	Gråvitt	Kiler, sprukket, hardt		
25,70	27,00	1,30	800	2700-3400	8-13	4-7	Gråvitt	Kraftig leirsone, 25,80 meter, mye dårlig, Støpt		
27,00	29,20	2,20	800	2600-3200	9-14	4-25	Gråvitt	Kilestopp, store leirsoner, kjernetap		
29,20	30,30	1,10	800	3000-4500	5-8	0-3	Gråvitt	Hardt, dårlige soner		
30,30	33,40	3,10	800	1400-2900	9-15	4-10	Gråvitt	Bergartsoverganger, mykt og hardt		
33,40	35,00	1,60	800	800-2500	8-14	3-5	Gråvitt	Litt knust, bergartsoverganger		
35,00	36,10	1,10	800	1200-2000	9-15	6-9	Gråvitt	Løse og myke soner, overganger		
36,10	38,50	2,40	800	1200-4500	10-13	4-5	Gråvitt	Hardt		
38,50	39,30	0,80	800	2800-4500	4-8	2-4	Gråvitt	Hardt		
39,30	41,60	2,30	800	2800-4500	8-10	4-8	Gråvitt	Striper med løsere fjell, overganger		
41,60	43,90	2,30	800	2400-2800	10-14	4-6	Gråvitt	Løsere, sprukket		
43,90	45,40	1,50	800	2400-2800	10-14	4-7	Gråvitt	Løsere, sprukket		
45,40	46,40	1,00	800	1500-2000	10-14	5-7	Gråvitt			
46,40	47,75	1,35	800	1000-1200	9-14	7	Gråvitt	Sprukket og knust		
47,75	48,30	0,55	800	1000-1100	10-12	7	Gråvitt	Sprukket og knust, Støpt		
SUM	48,30	47,10								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	2	GEO DRILLING
PROSJEKT: P - 180619		STED: Smøla			HULL-NR: KBH - 02-19		KRONE: HQ	DATO: Okt. / Nov.	MASKIN: Diamec U6 APC	FALL/RETNING: -60gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
48,30	48,85	0,55	800	2000-2500	8-12	7	Gråvitt	Knust, sprukket, leire		
48,85	51,00	2,15	800	1900-2200	9-13	7	Gråvitt	Sprukket, knust		
51,00	52,65	1,65	800	1900-2400	10-15	8	Gråvitt			
52,65	54,30	1,65	800	1900-2200	10-15	8	Gråvitt	Mye knusning, leire, Støpt		
54,30	55,50	1,20	800	1500-1900	12-16	7	Gråvitt	Knust, sprukket, leire		
55,50	57,10	1,60	800	2000-2600	10-14	7	Gråvitt	Sprukket, knust		
57,10	58,10	1,00	800	1800-2400	10-16	6	Gråvitt	Sprukket, knust		
58,10	59,05	0,95	800	1800-2600	10-12	7	Gråvitt	Sprukket, knust		
59,05	60,30	1,25	800	2000-2500	8-10	7	Gråvitt	Sprukket, knust, Støpt		
60,30	60,70	0,40	800	2600-2900	8-10	6	Gråvitt	Knust, kjernetap, leire og sand		
60,70	61,30	0,60	800	2400-2800	8-11	6	Gråvitt	Leire, sprukket		
61,30	61,80	0,50	800	2500-2800	8-10	6	Gråvitt	Sprukket		
61,80	62,65	0,85	800	2000-2400	10-14	6	Gråvitt	Knust, sprukket		
62,65	63,30	0,65	800	2200-2500	10-12	6	Gråvitt	Litt sprukket, Støpt, Støpt		
63,30	65,75	2,45	800	2200-2600	10-14	7	Gråvitt	Sprukket, leire, knust		
65,75	66,70	0,95	800	2200-2500	9-12	7	Gråvitt	Sprukket, knust		
66,70	69,30	2,60	800	2400-2800	9-14	6	Gråvitt	Sprukket og knust, Støpt		
69,30	72,30	3,00	800	1800-2800	8-16	5	Gråvitt	Sprukket, knust, leire		
72,30	75,20	2,90	800	1200-2500	10-15	5	Gråvitt	Sprukket, knust, leire, Støpt		
75,20	78,30	3,10	800	1200-1500	10-15	6	Gråvitt	Delvis helt, litt kiler		
78,30	81,30	3,00	800	1400-1700	10-15	6	Gråvitt	Helt fjell		
81,30	84,30	3,00	800	1400-1800	10-15	6	Gråvitt	Helt fjell		
84,30	87,30	3,00	800	1500-2500	10-18	6	Gråvitt	Litt sprukket, Støpt		
87,30	88,65	1,35	800	2000-2200	10-12	6	Gråvitt	Litt sprukket		
88,65	90,30	1,65	800	2200-2400	10-14	6	Gråvitt	Knusningssoner		
90,30	92,10	1,80	800	2200-2400	10-12	6	Gråvitt	Sprukket, leire, ras		
92,10	93,30	1,20	800	2200-2400	10-14	6	Gråvitt	Sprukket, knust, ras, Støpt		
93,30	95,70	2,40	800	2200-2500	10-12	6	Gråvitt	Sprukket, knust		
95,70	98,70	3,00	800	2200-2600	10-14	7	Gråvitt	Sprukket, knust		
98,70	99,65	0,95	800	1800-2200	12-16	7	Gråvitt	Sprukket, knust, ras, Støpt		
99,65	102,30	2,65	800	1800-2500	10-15	7	Gråvitt	Delvis helt, leire		
SUM	102,30	54,00								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	1	
PROSJEKT: P-180619		STED: SMØLA			HULL-NR: KBH - 03		KRONE: HQ	DATO: November	MASKIN: Diamec U6 APC	FALL/RETNING: 60gr / Øst
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
0,00	2,90	2,90	800	2200-3200	8-11	0-4	Grått	Ansett HQ rett på fjell, mistet returvann, Støping		
2,90	5,90	3,00	800	2400-2800	10-17	0-4	Grått	Løse partier, noen sprekker		
5,90	8,90	3,00	800	2700-3400	9-13	0-3	Grått	Hardt, noe sprukket, godt fjell		
8,90	10,90	2,00	800	2800-3500	8-10	3-16	Grått	Hardt, kilestopp		
10,90	11,20	0,30	800	2800-3500	8-10	3-25	Grått	Kilestopp		
11,20	11,90	0,70	800	1400-2200	9-12	3-5	Grått	Litt sprukket		
11,90	14,90	3,00	800	1800-2200	9-12	3-6	Grått	Bra fjell		
14,90	16,40	1,50	800	2500-3700	5-10	2-4	Grått	Hardt og godt fjell		
16,40	17,90	1,50	800	2600-3200	10-14	4-6	Grått	Hardt og godt fjell		
17,90	20,90	3,00	800	2600-3500	10-13	4-5	Grått	Hardt og godt fjell		
20,90	21,90	1,00	800	2900-3800	4-8	2-3	Grått	HARDT...		
21,90	23,90	2,00	800	2700-2900	10-12	3-4	Grått	Godt fjell, noen sprekker		
23,90	26,50	2,60	800	1800-4000	10-14	3-4	Grått	Hardt bra fjell		
26,50	29,50	3,00	800	1800-3500	10-15	3-4	Grått	Mykere partier, bra fjell		
29,50	32,60	3,10	800	2600-3500	10-15	3-6	Grått	Hardt bra fjell		
32,60	33,00	0,40	800	3200-3800	4-8	3-4	Grått	Hardt bra fjell		
33,00	35,90	2,90	800	2700-3200	10-14	3-5	Grått	Hardt bra fjell		
35,90	37,00	1,10	800	3200-3900	4-7	2-4	Grått	Hardt bra fjell		
37,00	38,90	1,90	800	2000-2400	10-14	3-4	Grått	Løsere		
38,90	41,50	2,60	800	2300-4000	6-11	4-6	Grått	Hardt bra fjell		
41,50	44,40	2,90	800	1600-4000	14-15	4-6	Grått	Løst og hardt, kilstopp		
44,40	46,00	1,60	800	2900-4000	6-10	4-6	Grått	Hardt		
46,00	47,80	1,80	800	3600-4500	6-8	5-10	Grått	Hardt, noen svake soner		
47,80	50,90	3,10	800	2200-3200	12-15	5-7	Grått	Løst, helt fjell		
50,90	52,30	1,40	800	2700-4000	5-11	6-9	Grått	Hardere, helt		
52,30	53,00	0,70	800	3500-4400	5-7	5-7	Grått	Hardt, helt, kiler		
53,00	53,90	0,90	800	2600-2700	10-14	4-5	Grått	Hardt, helt, kiler		
53,90	56,20	2,30	800	1900-4200	12-14	4-6	Grått	Hardt, helt, kiler		
56,20	56,80	0,60	800	3900-4500	4-6	3-4	Grått	Hardt		
56,80	59,80	3,00	800	2900-3700	9-13	3-4	Grått	Hardt		
59,80	62,10	2,30	800	3900-4400	6-10	3-5	Grått	Hardt		
SUM	62,10	62,10								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 2		GEO DRILLING
PROSJEKT: P-180619		STED: SMØLA			HULL-NR: KBH - 03		KRONE: HQ	DATO: November	MASKIN: Diamec U6 APC	FALL/RETNING: 60gr / Øst
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
62,10	62,90	0,80	800	2900-3100	10-14	4-5	Grått	Hardt godt fjell		
62,90	65,90	3,00	800	3200-4000	4-9	4-5	Grått	Hardt godt fjell		
65,90	68,40	2,50	800	3600-4400	4-11	4-5	Grått	Hardt godt fjell		
68,40	68,50	0,10	800	4000-4500	4-6	4-5	Grått	Hardt godt fjell		
								Hull brutt av geolog, finner ikke dårlig fjell.		
SUM	68,50	6,40								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE	1	GEO DRILLING
PROSJEKT: P-180619		STED: Smøla, Vindparken			HULL-NR: KBH - 04		KRONE: NQ2"	DATO: Nov - Des	MASKIN: Diamec U6 APC	FALL/RETNING: -60gr / Øst
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
0,00	1,80	1,50	800	2500-2800	9-12	4	Grått	Oppsprukket. Casing 1,50 meter, Fjell fra 0,30 meter		
1,80	2,95	1,15	800	2300-2600	10-14	4	Grått	Litt sprukket, Støpt		
2,95	4,90	1,95	800	2300-2600	10-12	5	Grått	Helt fjell		
4,90	5,95	1,05	800	2500-2900	8-12	5	Grått	Helt fjell		
5,95	7,90	1,95	800	2800-3300	8-12	5	Grått	Sprukket, kiler		
7,90	8,95	1,05	800	2800-3300	8-10	5	Grått	Sprukket, knust		
8,95	10,85	1,90	800	2400-2700	10-12	5	Grått	Sprukket, sleppe 9,55 - 9,60 meter		
10,85	11,95	1,10	800	2500-3200	8-12	5	Grått	Sprukket, Støpt		
11,95	13,85	1,90	800	2800-3500	8-10	3	Grått	Sprukket, kiler		
13,85	14,95	1,10	800	2400-3500	10-14	4	Grått	Sprukket, kiler		
14,95	17,30	2,35	800	2800-3600	8-12	3	Grått	Sprukket, kiler		
17,30	17,75	0,45	800	3000-3500	8-10	2	Grått	Kiler, ras		
17,75	20,85	3,10	800	2800-3800	9-14	2	Grått	Oppsprukket, Støpt		
20,85	20,95	0,10	800	2800-3200	9-10	3	Grått	Utrensking		
20,95	23,95	3,00	800	2900-3600	10-12	3	Grått	Sprukket, kiler		
23,95	25,75	1,80	800	3200-3700	8-10	2	Grått	Sprukket, kiler		
25,75	26,95	1,20	800	3400-3800	7-11	2	Grått	Helt fjell, hardt		
26,95	27,75	0,80	800	3500-3800	7-10	2	Grått	Helt fjell, hardt		
27,75	29,65	1,90	800	2900-3500	10-14	3	Grått	Kiler, leire, knust, 29,45 - 29,50 meter		
29,65	32,75	3,10	800	2000-3200	10-15	4	Grått	Sprukket, Støpt		
32,75	32,95	0,20	800	2000-2200	10-12	3	Grått			
32,95	35,95	3,00	800	2000-3000	10-15	3	Grått	Sprukket, kiler		
35,95	36,55	0,60	800	2200-2500	10-12	3	Grått	Knusning, 36,40 - 36,55 meter		
36,55	38,95	2,40	800	2500-2800	10-14	3	Grått	Sprukket, ras		
38,95	41,05	2,10	800	2800-3000	10-12	3	Grått	Oppsprukket, knust		
41,05	41,95	0,90	800	2400-2800	10-12	4	Grått	Helt fjell, Støpt		
41,95	44,75	2,80	800	2800-3000	10-14	5	Grått	Litt sprukket		
44,75	47,85	3,10	800	2800-3400	10-12	5	Grått	Sprukket, knust		
47,85	50,65	2,80	800	2800-3400	10-14	5	Grått	Sprukket, knust, Støpt		
50,65	50,95	0,30	800	3000-3500	8-10	5	Grått	Helt fjell		
50,95	53,95	3,00	800	3000-3500	8-10	5	Grått	Sprukket, noe knust		
SUM	53,95	53,65								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 2		
PROSJEKT: P-180619		STED: Smøla, Vindparken			HULL-NR: KBH - 04		KRONE: NQ2"	DATO:	MASKIN: Diamec U6 APC	FALL/RETNING: -60gr / Øst
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
53,95	56,95	3,00	800	2800-3200	10-14	4	Grått	Sprukket, leire, litt knust		
56,95	59,95	3,00	800	3000-3400	9-12	4	Grått	Helt oppsprukket, ras, leire, Støpt		
59,95	62,95	3,00	800	2500-2800	10-14	5	Grått	Sprukket,litt knust		
62,95	65,05	2,10	800	2800-3600	9-14	5	Grått	Helt oppsprukket, knust		
65,05	65,95	0,90	800	2800-3200	10-12	5	Grått	Sprukket, Støpt		
65,95	67,25	1,30	800	2200-2800	10-14	6	Grått	Sprukket, knust		
67,25	68,95	1,70	800	2400-2900	10-14	6	Grått	Sprukket, ras		
68,95	71,85	2,90	800	2400-3200	10-14	5	Grått	Sprukket, knust, ras, Støpt		
71,85	71,95	0,10	800	2400	12	5	Grått			
71,95	74,40	2,45	800	2400-2900	10-13	6	Grått	Oppsprukket, knust		
74,40	76,15	1,75	800	2500-3200	10-12	6	Grått	Noe sprukket		
76,15	77,95	1,80	800	2200-2800	10-14	6	Grått	Sprukket, knust, ras, Støpt		
77,95	79,70	1,75	800	2200-2800	10-14	7	Grått	Sprukket		
79,70	80,70	1,00	800	2200-2600	10-15	6	Grått	Sprukket, leire, litt knust		
80,70	82,00	1,30	800	2000-2500	12-16	6	Grått	Oppsprukket, knust, ras		
82,00	83,95	1,95	800	2000-2400	12-15	7	Grått	Sprukket, knust, ras, Støpt		
83,95	85,90	1,95	800	2200-2800	12-14	6	Grått	Sprukket, knust, leire		
85,90	86,85	0,95	800	2200-3200	10-14	5	Grått	Sprukket		
86,85	87,80	0,95	800	2500-3900	10-15	6	Grått	Sprukket, sleppe 87,25 - 87,30 meter		
87,80	89,45	1,65	800	2500-3300	10-15	6	Grått	Sprukket		
89,45	89,95	0,50	800	2800-3200	8-12	6	Grått	Litt ras, Støpt		
89,95	92,95	3,00	800	1800-2500	10-15	5	Grått	Sprukket, ras		
92,95	95,95	3,00	800	1800-2200	12-14	5	Grått	Sprukket, ras, Støpt		
95,95	98,95	3,00	800	1900-2500	10-15	6	Grått	Sprukket		
98,95	100,00	1,05	800	2000-2200	12-14	6	Grått	Sprukket, knust		
SUM	100,00	46,05								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 1		GEO DRILLING
PROSJEKT: P - 180619		STED: Bømlo			HULL-NR: KBH - 01		KRONE: HQ	DATO: Januar	MASKIN: Diamec U6 APC	FALL/RETNING: 60gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
0,00	8,10	2,10	350-800	1400-1800	2-8	0-12	Gråhvit	Casing til 6,00 meter, elendig dagfjell, spylevann ut i bekk, fjell fra 5,0 m		
8,10	9,20	1,10	800	1500-1800	11-12	2-3	Gråhvit	Oppsprukket, støpt		
9,20	10,00	0,80	800	1800-2000	10-12	2-4	Gråhvit	Kiler, delvis helt		
10,00	12,20	2,20	800	1800-2500	10-12	2-4	Gråhvit	Knust, sprukket, dårlige soner		
12,20	15,00	2,80	800	1700-2800	10-15	3-4	Gråhvit	Sprukket, knust, støpt		
15,00	17,90	2,90	800	1800-2200	10-15	3-4	Gråhvit	Leirsoner, knust		
17,90	20,30	2,40	800	2000-2400	10-12	3-4	Gråhvit	Knust, oppsprukket		
20,30	21,20	0,90	800	2000-2200	10-12	3-4	Gråhvit	Knust, sprukket, støpt		
21,20	24,20	3,00	800	2200-2600	12-15	4-5	Gråhvit	Knust, sprukket		
24,20	25,35	1,15	800	2200-2600	10-14	3-4	Gråhvit	Knust, sprukket		
25,35	27,20	1,85	800	2500-3000	10-14	3-4	Gråhvit	Knust, sprukket, støpt		
27,20	29,60	2,40	800	2400-3000	10-14	3-4	Gråhvit	Knust, sprukket		
29,60	32,60	3,00	800	2400-3200	10-15	3-4	Gråhvit	Leirsoner,sprukket, knust		
32,60	33,20	0,60	800	2500-2800	10-12	3-4	Gråhvit	Delvis helt, porøst, støpt		
33,20	35,30	2,10	800	2500-2800	10-15	3-4	Gråhvit	Leirsoner, sprukket, litt knusning		
35,30	37,30	2,00	800	2500-2800	10-14	3-4	Gråhvit	Sprukket, knust		
37,30	39,20	1,90	800	2400-3200	8-12	3-4	Gråhvit	Sprukket, ras, støpt		
39,20	42,20	3,00	800	2500-3800	8-15	4-5	Gråhvit	Delvis helt fjell		
42,20	45,20	3,00	800	2800-3500	9-15	4-5	Gråhvit	Sprukket, delvis helt fjell		
45,20	48,20	3,00	800	2800-3700	9-14	3-5	Gråhvit	Sprukket, delvis helt fjell, leire		
48,20	51,10	2,90	800	2500-3500	8-14	3-6	Gråhvit	Sprukket, ras, støpt		
51,10	54,20	3,10	800	3000-3800	8-12	2-4	Gråhvit	Sprukket, knust		
54,20	57,20	3,00	800	3000-3800	8-12	2-4	Gråhvit	Delvis helt fjell, støpt		
57,20	60,20	3,00	800	3000-3800	8-12	2-5	Gråhvit	Delvis helt, noe sprukket		
60,20	63,20	3,00	800	2800-3800	8-12	2-5	Gråhvit	Helt fjell		
63,20	65,70	2,50	800	2500-3800	8-14	2-6	Gråhvit	Helt fjell		
SUM	65,70	59,70								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 2		
PROSJEKT: P - 180619		STED: Bømlo			HULL-NR: KBH - 01		KRONE: HQ	DATO:	MASKIN: Diamec U6 APC	FALL/RETNING: 60gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
65,70	68,80	3,10	800	2900-3800	8-14	2-5	Gråhvit	Helt fjell		
68,80	70,10	1,30	800	3000-3800	8-10	2-4	Gråhvit	Helt fjell, hardt		
70,10	70,70	0,60	800	2800-3800	8-10	2-3	Gråhvit	Helt og hardt		
70,70	72,10	1,40	800	3200-3800	8-10	2-3	Gråhvit	Helt fjell		
72,10	74,10	2,00	800	3500-3800	8-10	2-3	Gråhvit	Helt, hardt		
74,10	75,00	0,90	800	3500-3800	8-10	2-3	Gråhvit	Helt, hardt		
75,00	78,00	3,00	800	3500-3800	8-10	2-3	Gråhvit	Helt, litt sprukket		
78,00	80,00	2,00	800	3500-3800	8-10	2-3	Gråhvit	Helt, litt sprukket		
								BOREHULL AVSLUTTET, 80,00 METER		
SUM	80,00	14,30								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 1	GEO DRILLING
PROSJEKT: P-180619		STED: Bømlo			HULL-NR: KBH - 02		KRONE: HQ	DATO: Februar / MASKIN: Diamec U-6 APC	FALL/RETNING: 60gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR	
0,00	6,00	5,00	800	1500-2000	8-10	3	Rød-grått	Casing til 1,50 meter Fjell fra 1,00 meter, dårlig dagfjell, Støpt	
6,00	7,00	1,00	800	1500-2000	8-10	3	Rød-grått	Knust og sprukket	
7,00	8,10	1,10	800	1500-2000	8-10	4	Rød-grått	Knust og sprukket	
8,10	8,40	0,30	800	1500-2000	8-10	4	Rød-grått	Knust og sprukket	
8,40	9,00	0,60	800	1500-2000	8-10	4	Rød-grått	Knust og sprukket, Støpt	
9,00	10,60	1,60	800	2000-2500	5-8	4	Rød-grått	Knust og sprukket	
10,60	12,00	1,40	800	2000-2500	4-6	4	Rød-grått	Knust og sprukket	
12,00	13,30	1,30	800	2000-2500	4-6	4	Rød-grått	Knust og sprukket	
13,30	14,60	1,30	800	1500-2000	5-8	4	Rød-grått	Knust og sprukket, Støpt	
14,60	15,00	0,40	800	1500-2000	5-8	3	Rød-grått	Ras, knust	
15,00	16,50	1,50	800	1500-2000	5-8	3	Rød-grått	Leire 15,10 - 15,30	
16,50	17,50	1,00	800	2000-2500	5-8	4	Rød-grått	Knust, kiling	
17,50	18,00	0,50	800	2000-2500	5-8	4	Rød-grått	Knust, kiling	
18,00	19,70	1,70	800	1500-1700	10-15	3	Rød-grått	Sprukket, leire, fastboring	
19,70	21,00	1,30	800	1500-1700	10-15	3	Rød-grått	Leire, fastboring, Støpt	
21,00	22,30	1,30	800	1000-1500	8-10	8-26	Rød-grått	Fast i leire, mye rensking	
22,30	24,00	1,70	800	1000-1500	8-10	10-25	Rød-grått	Sprukket fjell	
24,00	25,90	1,90	800	1500-2000	8-10	7	Rød-grått	Sprukket fjell	
25,90	27,00	1,10	800	1500-2000	8-10	7	Rød-grått	Sprukket fjell, leire	
27,00	27,40	0,40	800	1500-2000	8-10	8	Rød-grått	Sprukket fjell, leire, Støpt	
27,40	28,00	0,60	800	1000-1500	8-11	3	Rød-grått	Sprukket, knust	
28,00	29,80	1,80	800	1000-1500	10-12	4	Rød-grått	Sprukket, knust	
29,80	32,20	2,40	800	1000-1500	10-12	4	Rød-grått	Sprukket, knust	
32,20	33,00	0,80	800	1500-2000	10-12	5	Rød-grått	Sprukket, knust	
33,00	34,20	1,20	800	1500-2000	8-11	5	Rød-grått	Sprukket, knust	
34,20	36,00	1,80	800	1500-2000	7-9	4	Rød-grått	Noe helt, sprukket, Støpt	
36,00	37,10	1,10	800	2500-3000	3-7	4	Rød-grått	Noe helt, sprukket	
37,10	38,00	0,90	800	2500-3000	3-7	4	Rød-grått	Noe helt, sprukket	
38,00	39,00	1,00	800	2800-3000	4-8	3	Rød-grått	Noe helt, sprukket	
39,00	40,40	1,40	800	1500-2000	9-11	4	Rød-grått	Noe helt, sprukket	
40,40	42,00	1,60	800	1500-2000	9-11	4	Rød-grått	Noe helt, sprukket	
SUM	42,00	41,00							

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 2		GEO DRILLING
PROSJEKT: P-180619		STED: Bømlo			HULL-NR: KBH - 02		KRONE: HQ	DATO:	MASKIN: Diamec U-6 APC	FALL/RETNING: 60gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
42,00	42,90	0,90	800	1500-2000	9-11	5	Grått	Noe helt, sprukket, rasbiter, huker fast		
42,90	44,30	1,40	800	1500-2000	9-11	5	Grått	Noe helt, sprukket, rasbiter, huker fast		
44,30	45,00	0,70	800	1500-2000	9-11	5	Grått	Noe helt, sprukket, rasbiter, huker fast, Støpt		
45,00	45,80	0,80	800	1500-2000	9-11	5	Grått	Noe helt, sprukket, rasbiter, huker fast		
45,80	48,00	2,20	800	1500-2000	9-11	4	Grått	Noe helt, sprukket, rasbiter, huker fast		
48,00	49,40	1,40	800	1500-2000	7-10	4	Grått	Noe helt, sprukket, rasbiter, huker fast		
49,40	51,00	1,60	800	1500-2000	7-10	5	Grått	Noe helt, sprukket, rasbiter, huker fast		
51,00	53,10	2,10	800	1500-2000	7-10	5	Grått	Noe helt, sprukket, rasbiter, huker fast		
53,10	54,00	0,90	800	1500-2000	7-10	4	Grått	Noe helt, sprukket, rasbiter, huker fast, Støpt		
54,00	54,80	0,80	800	2000-2500	5-7	3	Grått	Noe helt, sprukket, rasbiter, huker fast		
54,80	55,10	0,30	800	2500-3000	3-6	3	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
55,10	56,10	1,00	800	2500-3000	3-6	2	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
56,10	57,00	0,90	800	2500-3000	3-6	2	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell, Støpt		
57,00	58,80	1,80	800	2000-2500	5-7	6	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
58,80	60,00	1,20	800	3000-3500	5-7	6	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
60,00	61,60	1,60	800	3000-3500	5-7	6	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
61,60	63,00	1,40	800	2000-2500	7-10	4	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
63,00	66,00	3,00	800	2500-3000	7-10	4	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
66,00	69,00	3,00	800	2500-3000	7-10	5	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
69,00	69,90	0,90	800	2500-3000	5-7	5	Grått	Noe helt, sprukket, rasbiter, huker fast, hardt og sprøtt fjell		
69,90	72,00	2,10	800	2500-3000	5-7	5	Grått	Noe helt, sprukket, rasbiter, huker fast, meget hardt fjell		
72,00	73,20	1,20	800	2500-3000	5-7	6	Grått	Noe helt, sprukket, rasbiter, huker fast, meget hardt fjell		
73,20	73,60	0,40	800	2500-3000	3-6	4	Grått	Noe helt, sprukket, rasbiter, huker fast, meget hardt fjell, Støpt		
73,60	75,00	1,40	800	3000-4000	3-6	3	Grått	Noe helt, sprukket, rasbiter, huker fast, meget hardt fjell		
75,00	78,00	3,00	800	3000-4000	3-6	3	Grått	Noe helt, sprukket, rasbiter, huker fast, meget hardt fjell		
78,00	80,00	2,00	800	3000-4000	3-6	3	Grått	Noe helt, sprukket, rasbiter, huker fast, meget hardt fjell		
								HULL AVSLUTTET ETTER AVTALE.		
SUM	80,00	38,00								

GEO DRILLING AS		REGISTRERING BOREDATA						SIDE 1		
PROSJEKT: P-180619		STED: Bømlo			HULL-NR: KBH-03-20		KRONE: HQ	DATO: Februar	MASKIN: Diamec U-6 APC	FALL/RETNING: 80gr
FRA BOREDYP	TIL BOREDYP	KJERNE LENGDE	ROTASJON RPM	MATEKRAFT KILO	PENETRERING ca CM/MIN	Mottrykk Spyl.vann Bar	FARVE SPYLEVANN	KOMMENTAR		
0,00	12,00	0,70	300-500	950-2750	0-5	0-16	Grått	Casing til 12,00 meter, fjell fra 11,30 meter, Mye stein og blokk, sand		
11,30	13,30	2,00	800	2000-2500	8-10	2-3	Grått	Knusningssoner, rensking, 11,80-11,95 og 12,80-12,90 meter		
13,30	13,90	0,60	800	2500-3000	9-12	3	Grått	Kilstopp, leire i sprikkesoner		
13,90	15,10	1,20	800	2500-3500	9-11	4	Grått	Delvis helt, litt leire, ras, Støpt		
15,10	17,00	1,90	800	2800-3500	8-12	4	Grått	Knusning, leire, slepper		
17,00	18,10	1,10	800	2500-3500	8-12	4	Grått	Litt knust, rassoner, noe helt		
18,10	21,10	3,00	800	2500-3300	8-12	4	Grått	Litt knust, rassoner, Støpt		
21,10	23,30	2,20	800	2500-3000	10-10	4	Grått	Delvis helt, litt knust		
23,30	26,10	2,80	800	2500-3000	10-12	4	Grått	Delvis helt, litt knust		
26,10	27,10	1,00	800	1800-2200	10-14	4	Grått	Veldig porøs kjerne		
27,10	30,10	3,00	800	1800-2200	12-16	5	Grått	Knusningssoner, porøst fjell, leire		
30,10	33,10	3,00	800	1800-2000	12-16	5	Grått	Helt, men porøst		
33,10	36,10	3,00	800	2000-2500	14-18	6	Grått	Helt, men porøst		
36,10	38,60	2,50	800	1800-2200	12-16	6	Grått	Oppsprukket porøst fjell		
38,60	39,10	0,50	800	2000-2400	14-16	7	Grått	Helt fjell		
39,10	42,10	3,00	800	2000-2400	12-15	6	Grått	Sprukket, delvis helt fjell		
42,10	45,10	3,00	800	2000-2400	12-15	6	Grått	Helt fjell		
								HULLET AVSLUTTET AV OPPDRAGSGIVER.		
SUM	45,10	34,50								

GEOLOGICAL
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