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REPORT

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Title:
Onshore - Offshore Resistivity studies. Basement resistivity at the Frøya High.

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Summary:

As a part of the prospecting activities of the oil company PERTRA at " The Frøya High", the Geological Survey of Norway (NGU) was asked to provide resistivity values of the underlying basement rocks. PL321 is considering to use Sea Bed EM Resistivity Logging to evaluate the hydrocarbon possibilities in the area. At the Frøya Høgda, Upper Jurassic reservoir sandstone is lying directly upon basement rocks, and it was important to know what kind of resistivity values which can be expected in basement. To get this information, two samples of the basement rock from well 6306/10-1 were measured in laboratory and in situ resistivity measurements from 16 groundwater wells in Aure, Halsa and Tustna municipalities were analysed.

Laboratory measurements on the two basement samples from the Frøya High showed that the resistivity can vary significantly from one sample to another. To get a representative value for small pieces like the ones in question, one needs a great number of samples. Porosity of the two samples was estimated to 2.3 and 1.5 %, while resistivity at room temperature was found be 26600 and 177000 ohm.m, respectively. We tried to calculate the in situ resistivity for these two samples, but since we do not know the parameters in Archie's law, results must be treated with caution.

However, in situ measurements in boreholes can give more representative values since the number of readings can be higher, and since the measured bulk volume is greater. In this study, resistivity was logged in 16 boreholes in Precambrian crystalline rocks within the Aure, Halsa and Tustna municipalities, Møre and Romsdal county. In what we define as unfractured bedrock (364 readings), the maximum and minimum resistivities are ca 24000 and 2500 ohm.m respectively while the mean value is 10100 ohm.m. With seawater salinity in the pores, and at a temperature of 90 ^{o}C, this will give in situ resistivity of ca 750 ohm.m. The corresponding value at 120 ^{o}C is ca 600 ohm.m. Bottom hole temperature of well 6306/10-1 is not listed in the well database published by The Oil Directorate (OD). From what we know from other wells, the temperature can be estimated to 102 ± 3 ^{o}C. This will give a resistivity of approximately 670 ± 20 ohm.m with seawater salinity in the pores. Higher salinity and fractured bedrock will show up even lower in situ resistivity values. On the other hand, reduced pore openings due to rock stress, will give higher resistivities.

Keywords: Geophysics (Geofysikk)	Pertophysics (Petrofysikk)	Resistivity (Resistivitet)
Labratory measurements (Laboratorieforsøk)	Well logging (Brønnlogging)	PL 321
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1. INTRODUCTION

As a part of the prospecting activities of the oil company PERTRA at " The Frøya High", the Geological Survey of Norway (NGU) was asked to provide resistivity values of the underlying basement rock. PERTRA is considering the use Sea Bed EM Resistivity Logging to evaluate the hydrocarbon possibilities in the area. At the Frøya Høgda, Upper Jurassic reservoir sandstone is laying directly upon basement rocks, and it is important to know what kind of resistivity values which can be expected in basement bedrock.

Since there is a lack of in situ resistivity logging in the underlying basement, these data have to be provided in other ways. In this study, two basement core samples from Well 6306/10-1 was measured in laboratory, and existing and partly new resistivity data from 16 onshore groundwater wells from the western gneiss complex were studied.

2. RESISTIVITY MEASUREMENTS AND PROCESSING.

Resistivity data from underlying basement rock at the Frøya Høgda were studied partly as laboratory measurements at two core samples, and partly by analysis for resistivity logs from onshore groundwater wells.

2.1 Laboratory measurements.

At two basement samples from well 6306/10-1 at the Frøya High (see figure 1) resistivity were measured in laboratory. The samples are from depth 3158.5 and 3159.2 metres, and consist of one quarter of the drill core. The bedrock is mapped as quartsmonzonitic gneiss, and might correlate with the outcropping Caledonien rock at the island Sula (Ø. Nordgulen, NGU, personal information). Physical parameters of the samples are listed in table 1.

Sample no (= depth, m)	Dry weight (g)	Wet weight (g)	Length, l (cm)	Area, A (cm^2)	Volume, V (cm^3)
3158.5	125.25	126.37	7.5	6.38	47.85
3159.2	137.0	137.72	7.5	6.61	49.58

Table 1: Physical parameters of basement samples from the Frøya High.

Resistivity was measured using four-electrode arrangement described in the literature (Telford et al 1978). The ABEM Terrameter SAS 4000 was used as energy source and measuring voltmeter. Current was distributed with a brass plate at both ends of the sample, and the electrical voltage was measured between two copper wires wrapped around the sample 3.8 cm apart central on the samples. The resistivity (ρ) was calculated using the formula

$$\rho = R\ A/l$$

where R is the measured resistance ($R = \Delta V/I$), A the area of the sample and l the length between the copper wires.

Before the measurements, the samples were kept separately in tap water for about 100 hours to achieve full water saturation. Conductivity of this water was 123.6 µS/cm. At the end of this saturation period, the conductivity of the water was measured equal to 244.1 µS/cm where sample 3158.5 was kept and 162.0 µS/cm in the other container where sample 3159.2 was kept. This can indicate that originally these samples were saturated with more saline water than the tap water, and that the salts were washed out of the sample.

Resistivity measurements were repeated about 20 times until the readings were stable. These variations are probably caused by water at the surface of the sample, which dried out. The measurements were taken in a period when the sample started to look dry. The average of the last 5 readings were used to calculate the resistivity.

2.2. Borehole measurements.

In the late eighties, NGU was involved in groundwater studies in the municipalities of Aure, Halsa and Tustna (Sand 1987a, 1987b and 1988). In total 40 wells were drilled in bedrock, and in 15 of these, resistivity logging were performed. The location of the investigated wells is presented in figure 2. Coordinates, depth of the wells and rock type is presented in table 2.

All wells except for the one called Kjørsvik are from the groundwater studies. Resistivity logging of these wells were performed with ABEM SAS-log 200 and ABEM SAS 300 Terrameter (ABEM 1979). Three different electrode configurations were measured Short Normal (SN, pole-pole a=16"), Long Normal (LN, pole-pole a= 64") and Long Lateral (LL, pole-dipole a= 18'). In addition the fluid resistivity was measured. Sampling interval was 2 metres, and all measurements represent an average of four subsequent readings. The data quality from these measurements is characterized as good.

The well called Kjørsvik was logged as a part of this project using Robertsson Geologging equipment (Robertsson 2002). The following parameters were measured: temperature, fluid conductivity, natural gamma radiation and resistivity with the two configurations, Short and Long Normal (see above). Sampling interval at these measurements was 1 cm. To avoid overrepresentation from this well, resistivity values were resampled to two metres station interval before statistical analysis. In addition the Optical Televiewer probe (OPTV) was used, but data from this is not presented in this report.

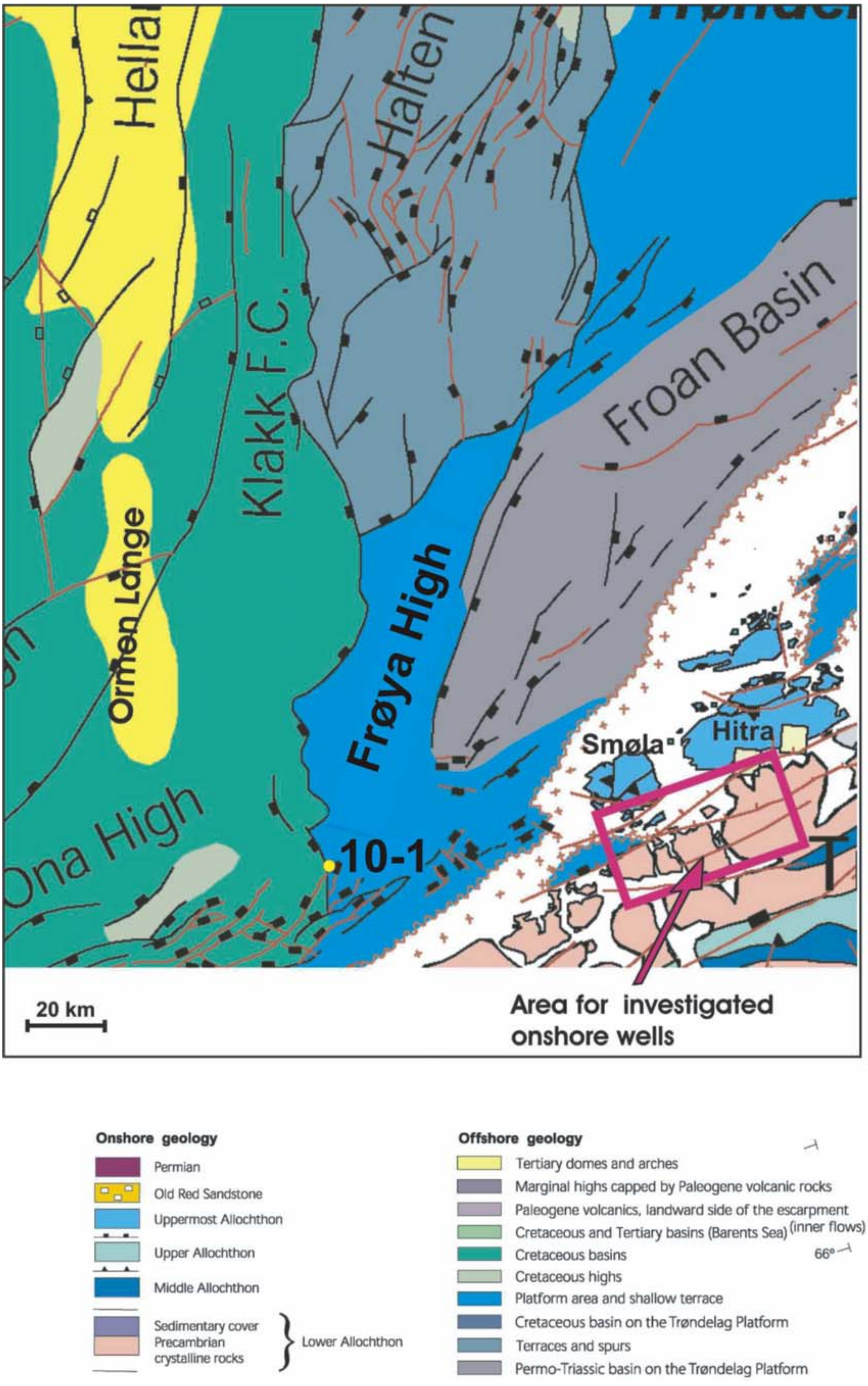

Figure 1: Location of the offshore well 6306/10-1 at the Frøya High and the onshore well area (map from Mosar et al 2002).

Figure 2: Detailed location of the investigated wells with bedrock geology as background (Askvik og Rokoengen 1985). For legend, see Appendix A.

Bore hole	**East coordinate WGS 84**	**North coordinate WGS 84**	**Depth (m)**	**No. of points**	**Geology, rock type**
Tustna 1	451500	7007640	64	30	Foliated granite
Tustna 2	451370	7007560	86	40	Foliated granite
Tustna 3	453121	7002590	80	37	Mica shist
Tustna 4	460740	7007830	92	43	Foliated granite
Tustna 5	457180	7008680	96	43	Mica shist
Gjerde	471620	7020190	62	26	Foliated granite
Lesund	474120	7023390	20	8	Foliated quartz diorite
Melan	483470	7020740	42	18	Granitic gneiss / migmatite
Otnes	474470	7000790	118	56	Granitic gneiss (eclogite ??)
Vihals	484320	7023990	100	34	Mica gneiss
Dromnes	485270	7028490	70	32	Foliated quartz diorite
Dromnes	485270	7028500	68	31	Foliated quartz diorite
Kjørsvik	486460	7031463	373	186	Foliated quartz diorite
Årvåg 1	493003	7024620	72	41	Migmatite gneiss /granite
Årvåg 2	492414	7024763	54	24	Migmatite gneiss / granite
Årvåg 3	492165	7024969	80	37	Migmatite gneiss / granite

Table 2: Name of investigated wells, coordinates, analysed depth, number of readings and lithology (from Askvik & Rokoengen 1985).

All the performed resistivity measurements show up as an apparent resistivity, being influenced by the diameter of the well, the thickness of the probe and the fluid resistivity in the borehole, as well as variations in the formation resistivity. In these measurements we have no information on variations in the diameter, but the fluid resistivity (conductivity) was measured. To correct for the fluid filled borehole and the variations in fluid resistivity, we used routines published by Thunehed & Olsson (2004). In this publication the authors use a modified version of Archie's law (Archie 1942) to calculate the porosity;

$$\sigma = a\,\sigma_w\,\Phi^m + \sigma_s$$

where σ is the electrical conductivity of the rock, σ_w represents the conductivity of the pore water while σ_s is a correction term for surface conduction. Φ corresponds to the rock porosity. The formation parameters a and m, and the surface conduction should be determined by measurements on rock samples for each case. This is out of the scope for this project, and we have chosen to use values for a, and σ_s fixed to 1.928 and 10^{-5} S/m (from Thunehed & Olsson 2004) while m was set to 2.2 for crystalline basement rock (O.B. Lile, NTNU, personal communication).

3. RESULTS.

In the following section the results from the investigations are presented.

3.1 Laboratory measurements.

Based on the dry and wet weight of the two samples, porosity estimation was performed. This calculation is based on water density of 1 g/cm^3. In table 3, calculated porosity, measured resistivity and calculated in situ resistivity for the two basement samples are listed. For the latter, we use Archie's low with parameters described in section 2.2 and the calculated porosity, to calculate the resistivity these samples will have in situ, saturated with seawater at 100 °C (see also section 3.2).

Sample no. (=depth, m)	Porosity (%)	Measured resistivity (ohm.m)	In situ resistivity (ohm.m)
3158.5	2.3	26 600	200
3159.2	1.5	177 000	510

Table 3: Calculated porosity, measured resistivity at room temperature and calculated in situ resistivity for basement samples from the Frøya High.

The calculated porosity is in the order of magnitude we can expect in crystalline basement rocks. Resistivity for sample 3158.5 is also reasonable, while the value for sample 3159.2 is higher than expected. The latter illustrates the problem with petrophysical measurements at small rock samples. The value can change a lot from one sample to another, and we have to do a lot of measurements to get a representative value for each bedrock type. The bulk resistivity of a very large volume of rock will be significantly lower than in small drillcore samples. This is due to the larger amount of fractures in a big rock volume.

3.2 Borehole measurements.

To get a uniform database, data from only one electrode configuration were compiled. We selected the Long Normal configuration, which we believe give the most representative data for the bulk bedrock resisivity. The Robertsson logging equipment do not support Long Lateral, and the Short Normal configuration is more sensitive to local resistivity anomalies (fractures, voids, etc.).

Corrected resistivity logs and calculated porosity from Archie's law for each individual borehole are presented in Appendix B. In figure 3, a Box-Whiskers plot for each borehole is presented in logarithmic scale. Lower and upper line represents minimum and maximum values of data. The box itself represents first and third quartile (25 to 75 %) of data, while the line in the box represent the median value.

When these wells were drilled, their location was selected where it was expected to give maximum groundwater yield. This means they were drilled in areas where we probably had fractured bedrock. Due to this, the data may be biased towards low resistivities. To account for this, resistivity values, which definitely represent fractured zones, were removed. Since the resistivity may change from one drillhole to another, this had to be done individually. Stable high resistivity values down the well were looked upon as unfractured bedrock, while depressed values were defined as fractured bedrock. In figure 4 and 5, corrected resistivity values for unfractured and fractured bedrock respectively are presented.

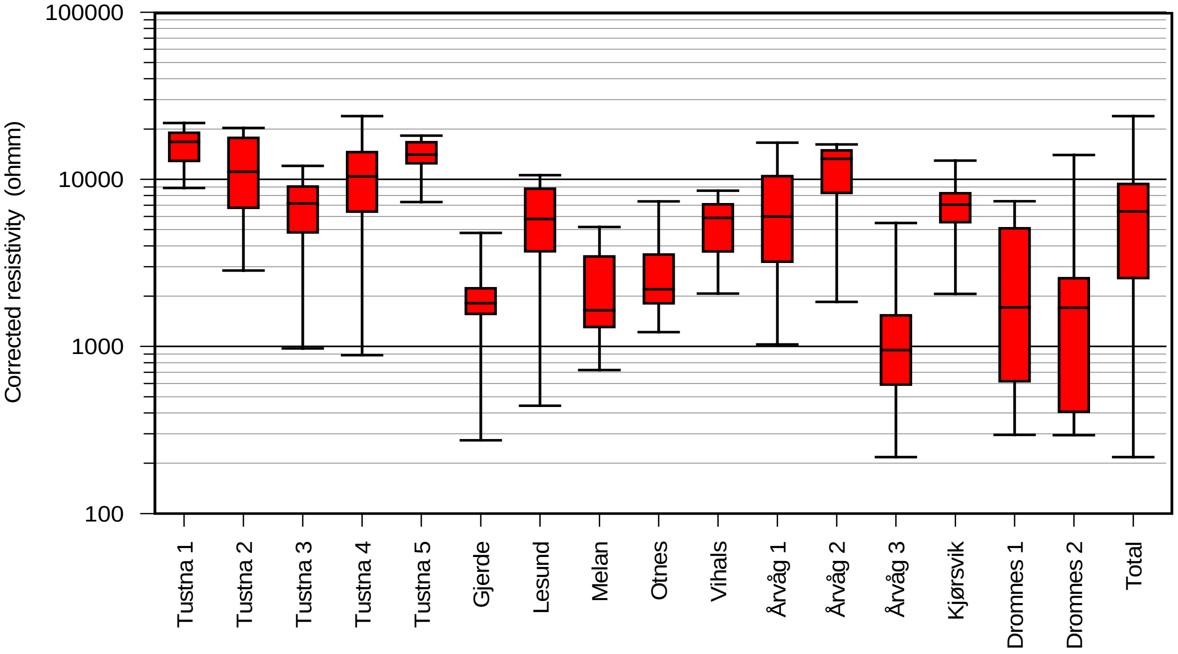

Figure 3: All corrected resisitivity values from the individual drillholes. The sum of all values is presented as total.

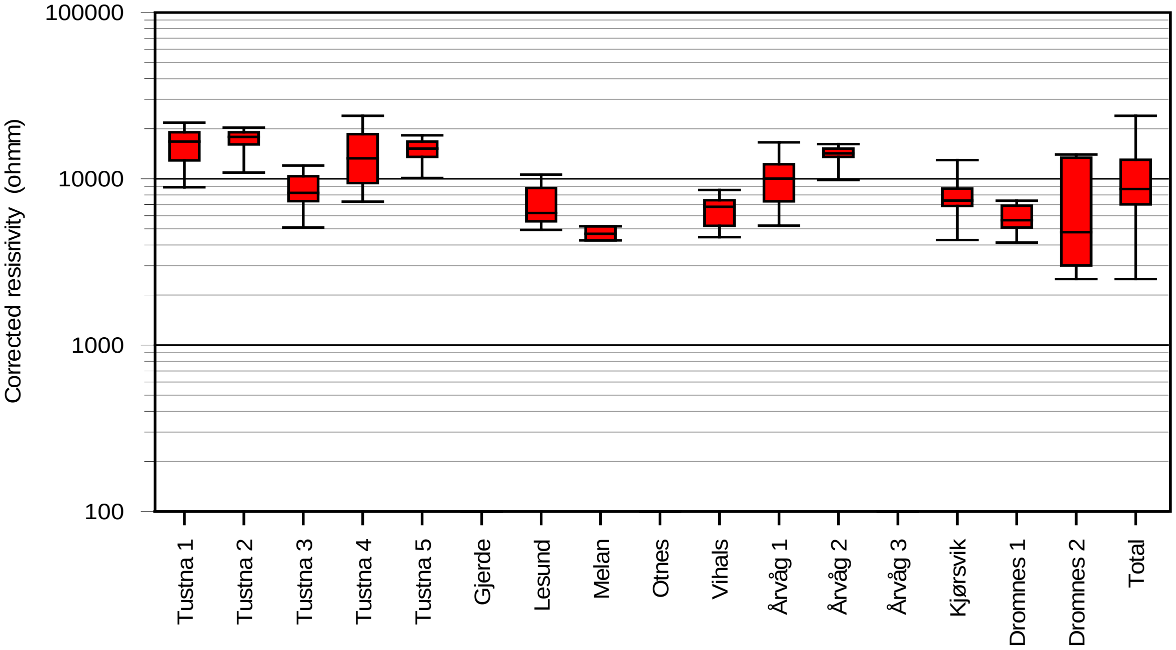

Figure 4: Corrected resisitivity values for unfractured bedrock from the individual drill holes. The sum of all values is presented as total.

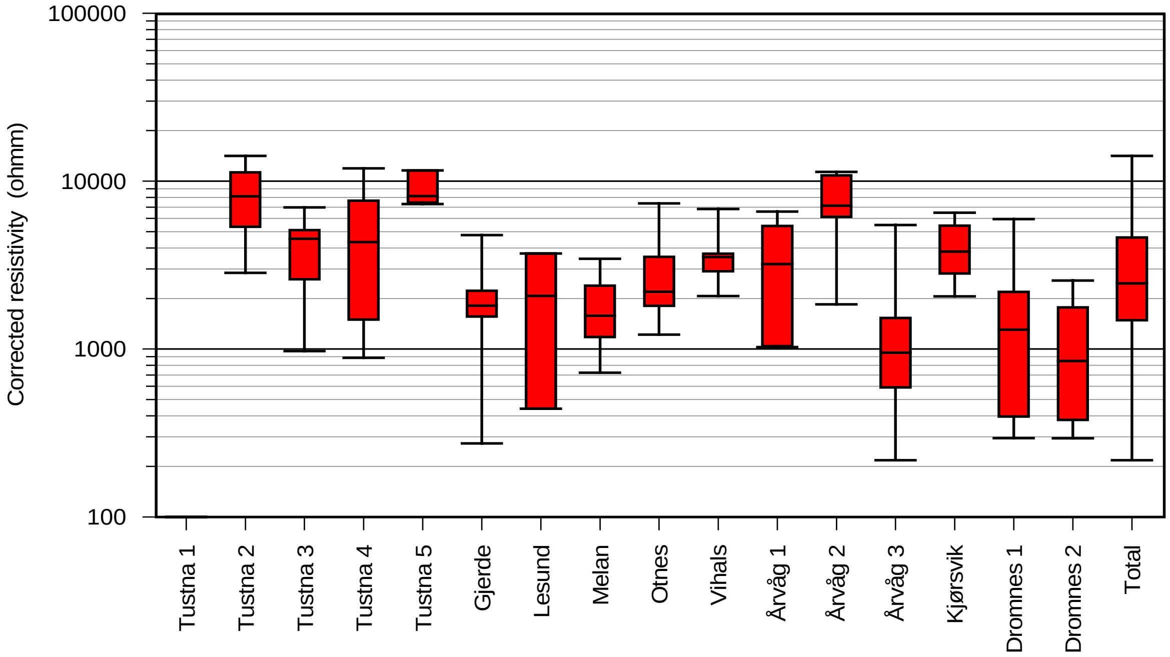

Figure 5: Corrected resisitivity values for fractured bedrock from the individual drillholes. The sum of all values is presented as total.

The resistivity data presented here, except for the well called Kjørsvik, are measured with the pore volume filled with natural groundwater of drinking water quality. The measured water resistivity varied from 20 ohm.m to 100 ohm.m. The corresponding conductivity data (inverse of resistivity) are 50 mS/m and 10 mS/m. The Kjørsvik well is located close to the ocean, and here there is saline water with resistivity 0.4 ohm.m at 250 metres depth. In the basement underneath the sediments at "Frøya Høgda", the pore volume will be filled with saline groundwater, and due to the thermal gradient the conductivity of this water will increase (resistivity decrease). The salinity of the pore water is not known to the authors. If we estimate this to be 3.5 % (normal sea water), the resistivity at 20 ^{o}C will be ca 0.2 ohm.m (Schlumberger 1984). At a temperature of 60 ^{o}C, this salinity will give a water resistivity of 0.1 ohm.m. Higher salinity and temperature will lead to lower pore water resistivity.

To study how different values of pore water resistivity influence on the formation resistivity, the well called Tustna 4 was studied. Using the modified version of Archie's law, we calculated formation resistivity based on previously calculated porosity and different values of pore water resistivity (see figure 6). Fluid resistivity equal to 0.2 ohm.m represents seawater at 20 ^{o}C whereas 0.1 ohm.m the same at approximately 60 ^{o}C. The corresponding values of fluid resisistivity will be 0.075 ohm.m at 90 ^{o}C, 0.06 ohm.m at 120 ^{o}C and 0.05 at 150 ^{o}C (Sclumberger 1984). Lower values represent more saline water.

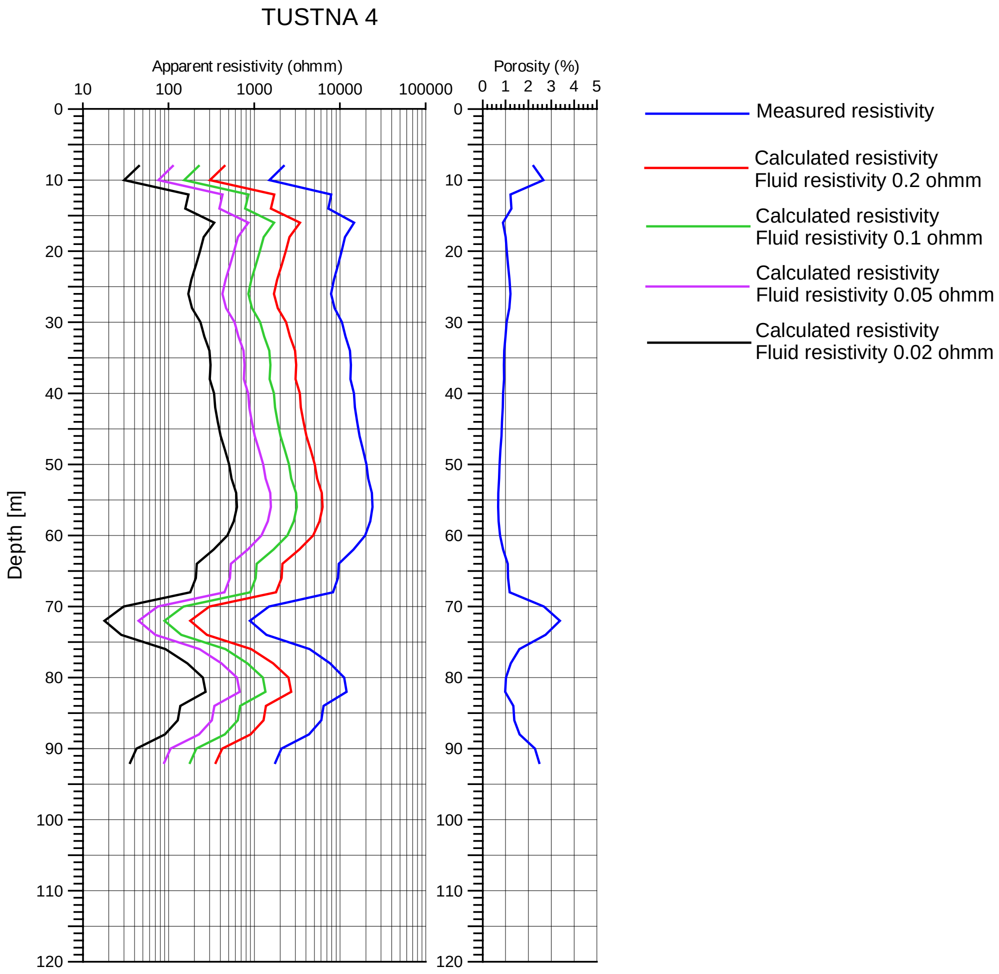

Figure 6: Expected basement resistivity values for well Tustna 4 with different pore water resistivities. Fluid resistivity equal to 0.2 ohm.m represents seawater (salinity 3.5 %) at 20 ^{o}C, 0.1 ohm.m seawater at approximately 60 ^{o}C whereas resistivity 0.05 ohm.m represent seawater at 150 ^{o}C (Sclumberger 1984). Lower values represent more saline water.

4. DISCUSSIONS.

Resistivity values measured on basement samples from the Frøya High varies quite a lot and one of the samples showed a higher value than expected. However, this value is within the range listed in the literature (Telford & al 1978). To confirm the measured values, the measurements were repeated the next day, and with the same and a slightly changed arrangement. The new measurements did confirm the first results. From this we conclude that the measurements were of good quality, the resistivity may change quite a lot from one sample to another and to get a representative value based on laboratory measurements, we need many samples.

It was observed that salt was washed out of the samples during the saturation process. This effect was higher for the sample with the largest porosity, and it can indicate that the original pore water salinity was higher than in the tap water, and that some salts still were in the sample. However, it is not possible for us to estimate this salinity, and hence, difficult to calculate the resistivity these samples had in situ. When we calculated in situ resistivity for these two samples, we used calculated porosity and Archie's law. We have not tried to find the formation parameters in Archie's law, but used values from the literature and recommendations. Due to this, the calculated in situ resistivity is highly uncertain.

Corrected resistivity values from onshore groundwater wells in basement rocks, also vary quite a lot. Lowest values are about 200 ohm.m whereas the maximum is in the order of 24.000 ohm.m (figure 4, Appendix C). If we split the data into a fractured and a non fractured group, the intervals will be more compressed. Unfractured basement rocks show up a minimum of 2500 ohm.m and a maximum in the order of 24.000 ohm.m. The majority of the data (50%) are in the range 7000 to 13000 ohm.m with a median of 8670 ohm.m. In the group we define as fractured bedrock, minimum and maximum values are approximately 200 and 14000 respectively. The majority of the data (50%) are in the range 1500 to 4600 ohm.m with a median of 2460 ohm.m. Mean resistivity values for not fractured and fractured basement rocks are 10100 and 3350 ohm.m respectively.

What we define as s fractured and not fractured bedrock can be a matter of discussion. In this study, we have defined the stable highest level in the drillholes as not fractured. The wells Årvåg 3, Gjerde and Otnes (see Appendix B) show special low resistivities, and these wells are defined as fractured all the way down.

When the porosity was calculated, we used a modified version of Archie's low. First of all we have to say that this law is not valid in case we have contribution to the conductivity (resistivity) from conductive minerals in the bedrock. When we did the fieldwork, we never saw sulfides or other electron conducting minerals in such amount that this should be any distortion. However, in fractures with special low resistivity (< 500 ohm.m, Lesund and Gjerde), clay minerals may contribute to the formation resistivity (Rønning & al. 2003).

Archie's law was originally developed based on studies on clean sandstone. How well the law describes the crystalline rocks as in our study, is not clear. We used the formation parameters Thunehed and Olsson (2004) found at Precambrian granites and greenstones in Sweden, and information from Prof. O.B. Lile, NTNU. Basically, we should have found the formation parameters which are specific for our bedrock type, but this was outside the scope of the project. The authors do think the applied values are reasonable, but the calculated porosities can be wrong. If we compare with the laboratory measurements, we should expect a much higher resistivity for a rock with only 1 % porosity. However, when we calculate the possible resistivity in bedrock underneath the Frøya High, we use the same formula and the same formation parameters again. Thus, the possibly wrong porosity values calculated from Archie's law will be corrected for. This means there are other factors that give higher uncertainty in the basement resistivity estimation underneath the Frøya High.

The most critical parameters for the basement resistivity are temperature and salinity of the pore water (see figure 6). If the pore volume is filled with seawater (3.5 % salinity) and the temperature is 60 ^{o}C, the onshore resistivity mean value of 10100 ohm.m will be reduced to approximately 1200 ohm.m (see figure 6). At a temperature of 90 ^{o}C , the formation resistivity will be reduced to ca 750 ohm.m and as low as 550 ohm.m at a temperature of 150 ^{o}C. Bottom hole temperature of well 6306/10-1 is not listed in the well database published by The Oil Directorate (OD). From what we know from other wells, the temperature can be estimated to 102 ± 3 ^{o}C. This will give a resistivity of approximately 670 ± 20 ohm.m with seawater salinity in the pores. In case the salinity is 7%, the resistivity in basement rocks underneath the Frøya High can be as low as 500 ohm.m in unfractured bedrock, and less than 200 ohm.m in fractured zones.

The diameter of the boreholes was not logged in this study. This means that calculated resistivity values may be slightly wrong in parts of the boreholes were fracturing have caused breakouts. For the unfractured bedrock, this will have minimal effect. In fractured bedrock breakouts are more common. Here we also have the problem with rapidly changing resistivity values, and the corrected resistivities have to be looked upon as apparent resistivity. From this we can conclude that corrected values in stable unfractured bedrock are close to the true resistivity while values in fractured parts of the boreholes may be slightly wrong.

The rock stress will not influence on the pore water conductivity, but will of cause influence on the pore space openings. In this analysis we have separated unfractured and fractured bedrock, and looked specific on the unfractured part. Due to reduced pore openings also in unfractured rock, we may expect some higher resistivities in the crystalline basement underneath the Frøya High than estimated here.

The largest uncertainty in this study is whether or not the rock types we have studied in the onshore wells are representative for the basement underneath the Frøya High. Unfortunately, we had to study the onshore wells that were available for this project, and not resistivity in the basement rock where these are exposed onshore. The authors do not think this is a significant error.

5. CONCLUSION

Laboratory measurements on two basement samples from the Frøya High showed that the resistivity can vary quite a lot from one sample to another. To get representative values for small pieces like the ones we had, one needs a great number of samples. Porosity of the two samples was estimated to 2.3 and 1.5 % while resistivity at room temperature was found be 26600 and 177000 ohm.m respectively. We tried to calculate the in situ resistivity for these two samples, but since we do not know the parameters in Archie's law, we do not trust these data.

In situ measurements in boreholes can give more representative values since the number of readings can be higher, and since the measured bulk volume is greater. In this study, resistivity is logged in 16 boreholes in Precambrian rocks within the Aure, Halsa and Tustna municipalities, Møre and Romsdal county. In what we define as unfractured bedrock (364 readings), the maximum and minimum resistivities are ca 24000 and 2500 ohm.m respectively while the mean value is 10100 ohm.m. With seawater salinity in the pores, and at a temperature of 90 ^{o}C, this will give in situ resistivity of ca 750 ohm.m. The corresponding value at 120 ^{o}C is ca 600 ohm.m. Bottom hole temperature of well 6306/10-1 is not listed in the well database published by The Oil Directorate (OD). From what we know from other wells, the temperature at 3160 meters depth can be estimated to 102 ± 3 ^{o}C. This will give a resistivity of approximately 670 ± 20 ohm.m with seawater salinity in the pores. Higher salinity and fractured bedrock will show up even lower in situ resistivity values. On the other hand, reduced pore openings due to rock stress, will give higher resistivities.

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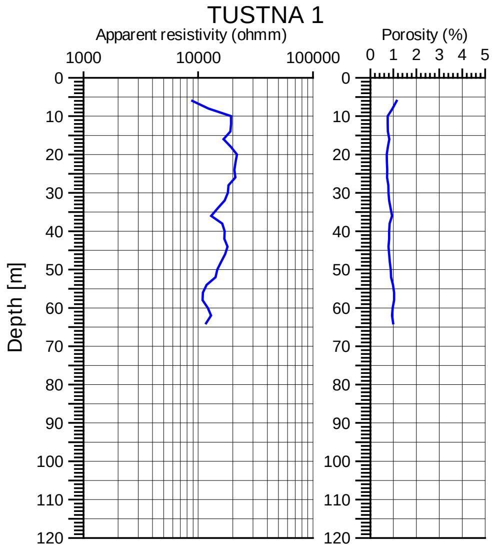
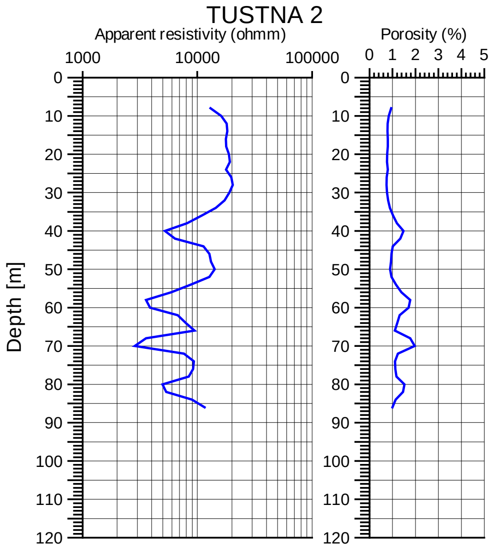
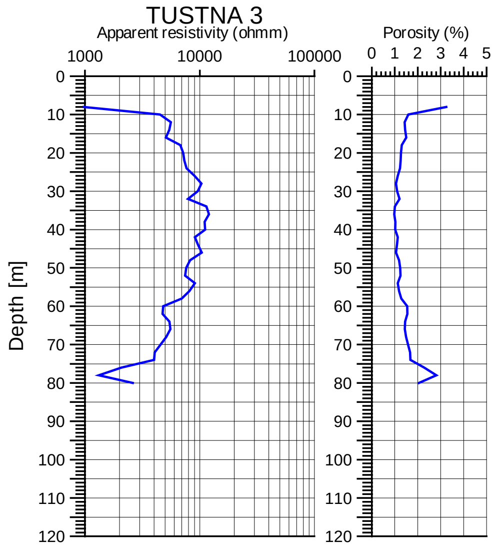
Appendix A: Legend to geological map Kristiansund (1:250 000) (Alsvik & Rokoengen 1985)

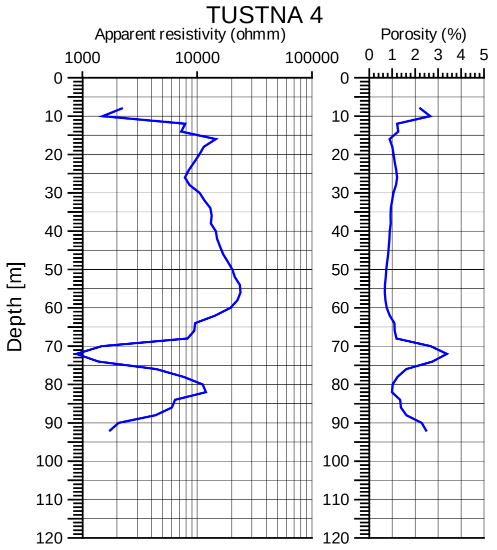
	Pa land
	Bergarter fra jordens oldtid (paleozoikum)
	Gangbergarter av permisk alder
• P	Syenittporfyr
	Sedimentære bergarter av oversilurisk til underdevonsk alder
	KYRHAUGGRUPPEN (underdevon - mellomdevon)
1	Grovblokket konglomerat
2	Konglomerat med lag av sandstein og leirstein
	HITRAFORMASJONEN (oversilur- underdevon)
3	Konglomerat
4 / 5	Grovblokket sedimentær bunnbreksje/Sandstein og leirstein, stedvis skifrig
	Sedimentære og vulkanske bergarter av ordovicisk alder
	FØLINGGRUPPEN
6	Metabasalt og basaltisk meta-andesitt med tynne lag av sure vulkanske bergarter (underordovicium - mellomordovicium)
	SKJØLBERGFORMASJONEN (øvre underordovicium - undre mellomordovicium)
7	Kalkstein, underordnet dolomitt; noe konglomerat og siltstein
	LEIRVIK KONGLOMERATFORMASJON (underordovicium eller eldre)
8	Konglomerat med boller vesentlig av sure vulkanske bergarter og andre størkningsbergarter.
	Dypbergarter av mellomordovicisk alder eller yngre
9	Alkaligranitt med inneslutninger av kvartsdioritt
10	Granitt, granodioritt
11	Granitt med inneslutninger av basiske bergarter
12	Migmatitt (grensefacies av granitt)
13	Tonalitt
14	Trondhjemitt (tonalitt)
15 / 15a	Kvartsdioritt/Forskifret kvartsdioritt
16	Dioritt, stedvis gabbroide bergarter
17	Monzogabbro
18 / 18a	Gabbro/Gabbronoritt
S ● 18b	Serpentinitt
	Bergarter fra jordens urtid og oldtid (prekambrium - paleozoikum)
	Størendekket. Sedimentære og vulkanske bergarter av antatt kambro-ordovicisk alder
19	Grønnskifer, amfibolitt (omdannet basalt)
20	Glimmerskifer
21	Kalkspatmarmor
	Blåhødekket. Bergarter av prekambrisk til ordovicisk alder
22	Glimmerskifer
23	Amfibolitt
	Sætradekket. Bergarter av antatt senprekambrisk alder
24	Helleskifer og amfibolitt, antatt omdannet sandstein og diabas
	Skardsøyformasjonen. Folierte dypbergarter av prekambrisk til ordovicisk alder
25	Foliert kvartsdioritt
26 / 26a	Foliert kvartsdioritt, rik på hornblende/Foliert kvartsdioritt, rik på hornblende og med øyne av feltspat
	Ertvågøykomplekset. Bergarter av prekambrisk til ordovicisk alder
27	Glimmerskifer, amfibolitt, kalksilikatskifer, metasandstein, kalkspatmarmor og gneis
28	Migmatittisk amfibolitt
29	Kalkspatmarmor
30	Grå, finkornet gneis (helleskifer), antatt omdannet sandstein
31	Granittisk gneis
	Bergarter fra jordens urtid (prekambrium)
	Frøykomplekset
32	Glimmergneis, biotittrik; antatt opprinnelig leirstein
33	Finkornede gneiser av varierende sammensetning med soner av amfibolitt
34	Migmatittisk gneis gjennomsatt av granitt/tonalitt. (Granitt/tonalitt av antatt kaledonsk alder)
35	Kalkspatmarmor
	Kristiansundformasjonen
36 / 36a	Foliert granitt/Foliert granitt, migmatittisk
	Valsøyfjordkomplekset
37	Migmatittgneis, granittisk gneis
38	Glimmerrik gneis og migmatitt
39	Amfibolitt
40	Foliert granitt
41	Øyegneis
42	Granodiorittisk gneis, antatt omdannet granodioritt
43	Kvartsitt
44	Øyegneis, glimmergneis, kvartsrik gneis (omdannet sandstein)
	Dypbergarter
45 / E 45a	Gabbro/Gabbro, stedvis eklogittisk
● 46	Eklogitt
47 / S 47a	Ultramafitt/Serpentinitt

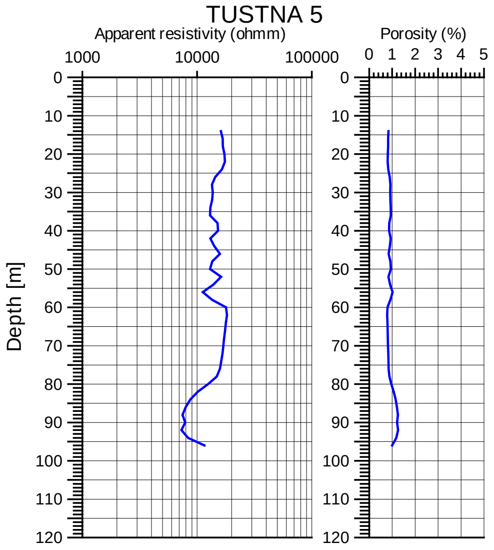
Appendix B1: Corrected resistivity logs (long normal) and calculated porosity.





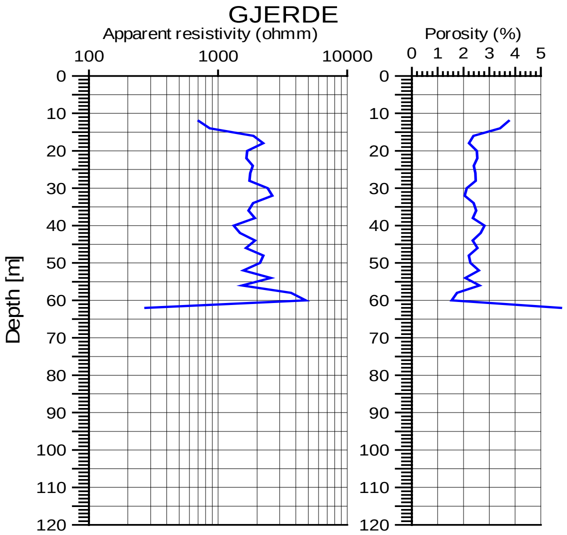


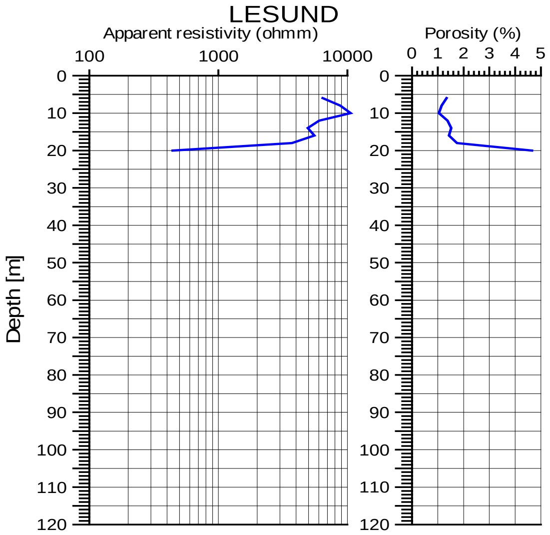


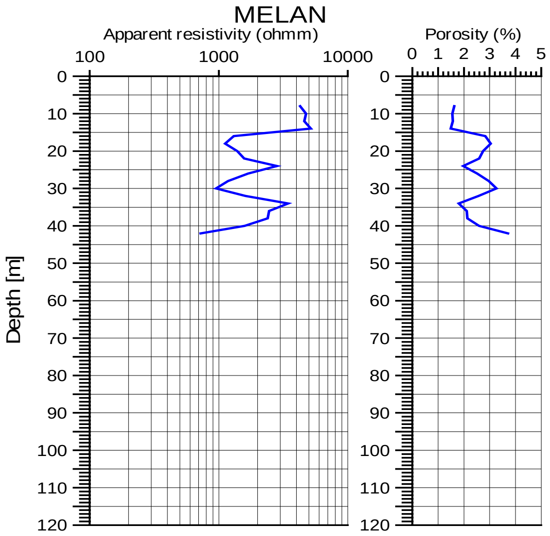


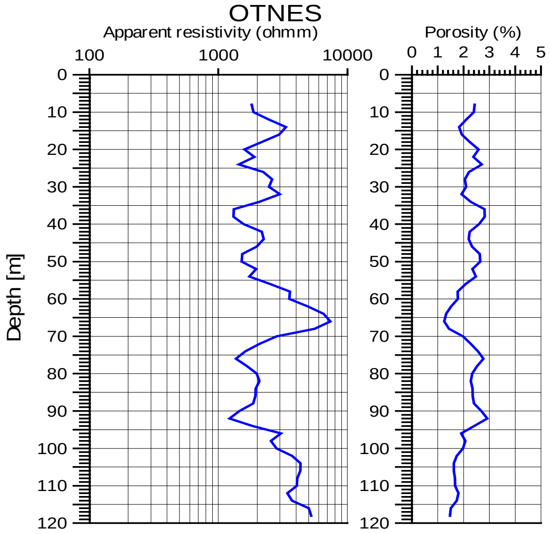
Resistivity in rock
Porosity
Long Normal

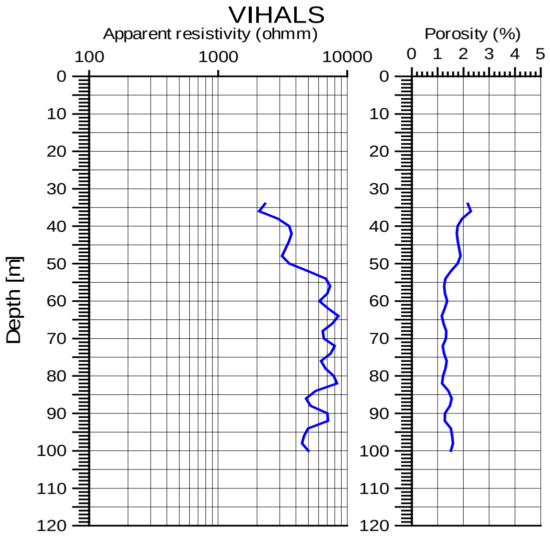
Appendix B2: Corrected resistivity logs (long normal) and calculated porosity.





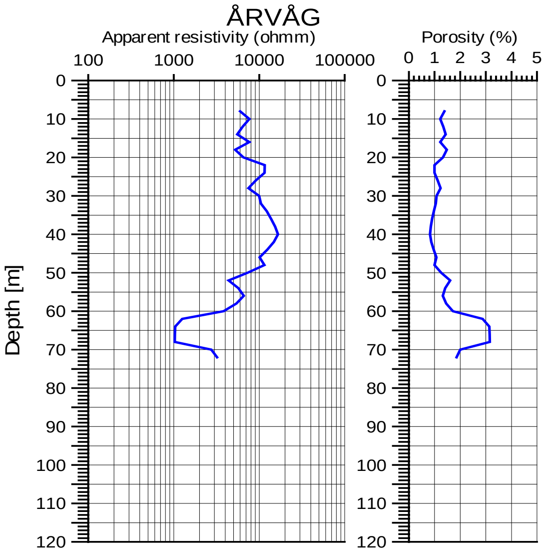


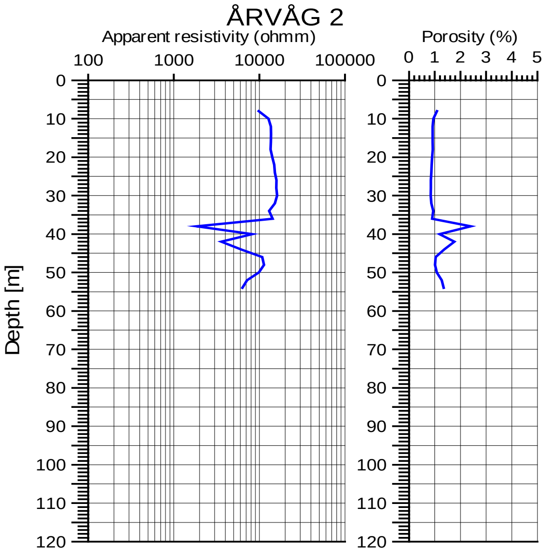


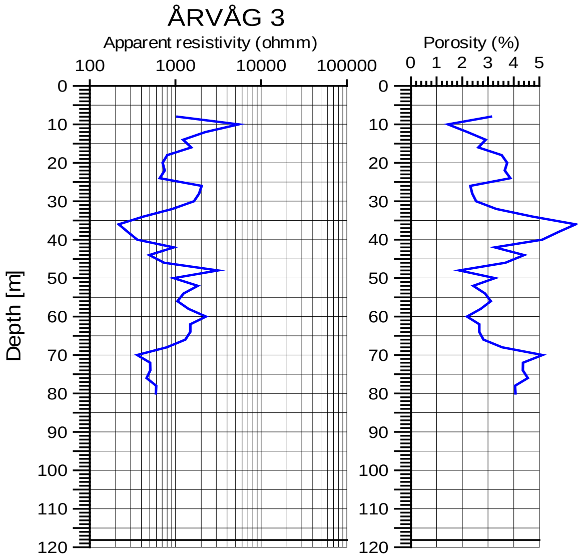


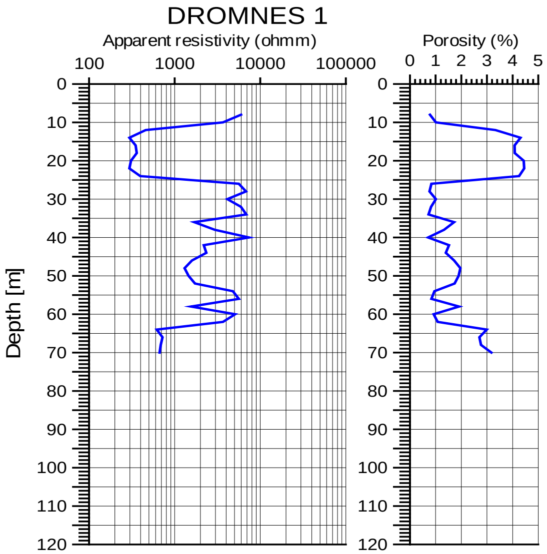
Resistivity in rock
Porosity
Long Normal

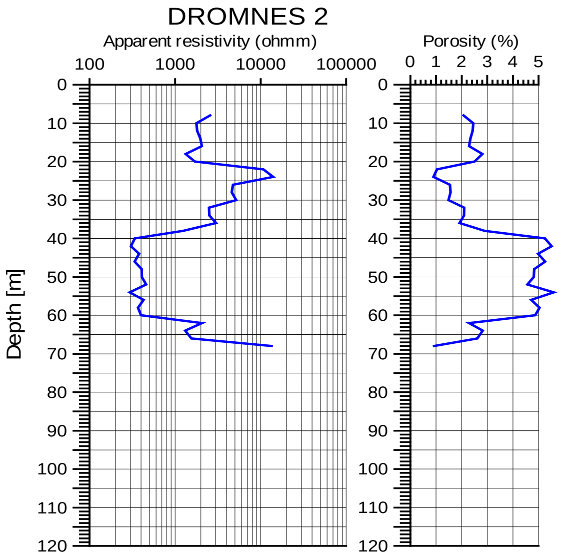
Appendix B3: Corrected resistivity logs (long normal) and calculated porosity.

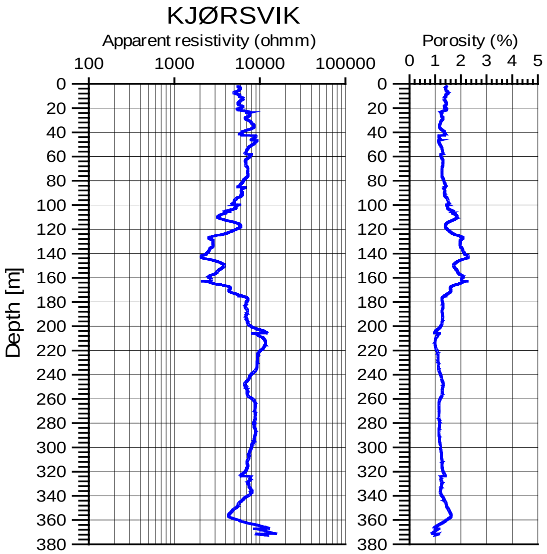












Appendix C: Statistics on resistivity data for all the investigated wells.

Bore hole	Tustna 1	Tustna 2	Tustna 3	Tustna 4	Tustna 5	Lesund	Melan	Vihals	Årvåg 1	Årvåg 2	Kjørsvik	Dromnes 1	Dromnes 2	Total
Number of values	30	15	23	28	35	6	4	23	22	15	138	9	9	364
Minimum	8878	10897	5086	7265	10120	4925	4265	4457	5222	9825	4278	4131	2494	2494
Maximum	21744	20292	12028	23886	18242	10576	5174	8552	16581	16164	12942	7386	13997	23886
Mean	16027	17223	8579	14012	15092	7047	4700	6538	9968	14120	7735	5812	6745	10131
Median	16741	17823	8224	13257	15192	6226	4679	6785	10022	14208	7410	5628	4773	8670
First quartile	12904	16387	7374	9525	13539	5548	4439	5329	7317	13554	6854	5019	2888	7012
Third quartile	19038	18980	10182	17683	16732	8781	4960	7427	12246	15181	8715	6842	11412	12995
Standard deviation	3522	2596	1951	5081	2048	2174	376	1238	3362	1590	1560	1069	4661	4422

Statistics of unfractured rock in all boreholes. Total is the sum of all data.

Statistics of fractured rock in all boreholes. Total is the sum of all data.

Bore hole	Tustna 2	Tustna 3	Tustna 4	Tustna 5	Gjerde	Lesund	Melan	Vihals	Otnes	Årvåg 1	Årvåg 2	Årvåg 3	Kjørsvik	Dromnes 1	Dromnes 2	Total
Number of values	25	14	15	8	26	2	14	11	56	11	9	37	48	23	22	321
Minimum	2849	973	887	7305	274	442	723	2073	1219	1027	1846	218	2062	295	294	218
Maximum	14145	6980	11909	11585	4779	3711	3452	6821	7368	6599	11354	5482	6493	5951	2564	14145
Mean	8072	4056	4759	8854	1925	2076	1734	3625	2741	3295	7267	1201	4134	1531	1068	3352
Median	8123	4541	4340	8152	1815	2076	1582	3542	2194	3209	7150	952	3809	1306	849	2460
First quartile	5325	2611	1561	7668	1566		1179	2960	1830	1094	5501	570	2826	412	379	1485
Third quartile	9902	5119	7341	10153	2228		2391	3668	3490	5148	10115	1499	5376	2079	1773	4585
Standard deviation	3254	1718	3663	1744	873	2311	774	1306	1370	2061	3208	980	1370	1422	761	2760