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Wireline Geophysical Logging of the Nirex Deep Boreholes in the Sellafield Area: Comparisons between BVG Core and Wireline Derived Formation Factors

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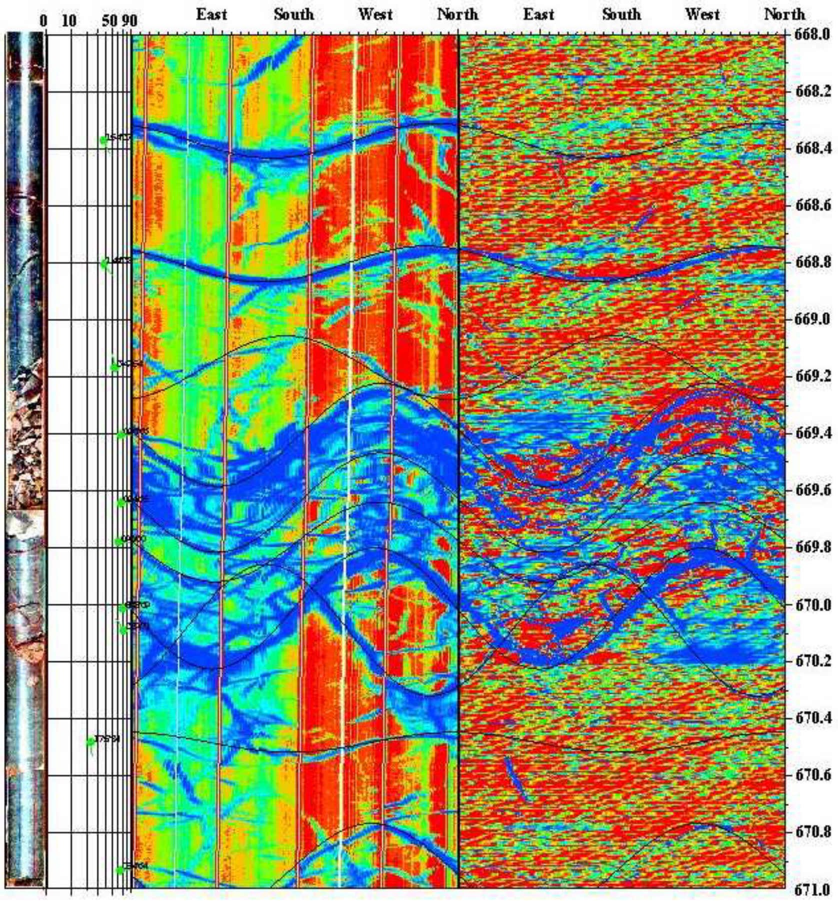

BRITISH GEOLOGICAL SURVEY

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N R Brereton and P D Jackson

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Front cover

FMS (left) and BHTV (right)
Images with scanned core
photograph of fractured
Borrowdale Volcanic Group
rocks, Sellafield Borehole RCF1

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1. INTRODUCTION

The formation (resistivity) factor of a rock unit is a parameter based on electrical measurements that can be related directly to the porosity and, to a lesser degree, to the permeability. A reasonable correlation had previously been found between core sample and wireline derived formation factors for the Borrowdale Volcanic Group (BVG) in Nirex Borehole RCF3 in the Sellafield area (Brereton et al., 1996). It was concluded that wireline logs are able to provide an effective means of estimating the broad characteristics of formation factor variability with depth in a borehole and furthermore that they may be suitable for use in estimating the rock matrix diffusion properties of the *in situ* rock.

The objective of the work reported here has been to further test this approach using core sample and wireline derived formation factors from other Nirex deep boreholes in the Sellafield area. For the purposes of calculating the wireline derived formation factors, the method used in Brereton et al., 1996 has been adopted in which the pore water resistivity in the BVG in the vicinity of any particular borehole has been taken to be constant. Values of pore water resistivity have been estimated from measurements on ground water produced from the Nirex boreholes and on pore water extracted from core samples. The wireline derived formation factors have then been compared with formation factor measurements made by the BGS on core samples during the Nirex Core Characterisation Programme.

2. THE EVALUATION OF FORMATION FACTORS

The electrical properties of fluid saturated rocks are determined by the conductivity of the mineral grains, the conductivity of the pore fluids, and the rock porosity, which determines the relative effect of the two previous factors. Rock forming minerals are mostly silicates having very high resistivities (in the range 10^6 to 10^{14} Ω m) while the resistivities of natural groundwaters can range from less than 0.1 Ω m to greater than 10 Ω m, depending upon the total dissolved solid concentrations.

The rock matrix rarely comprises an assemblage of grains of a single mineral species and most geologic minerals are a mixture of different materials, according to rock type. Diagenetic and mineralising processes will tend to redistribute the components of the existing rock matrix materials and produce new minerals that may locally be more concentrated. The direct influence of the rock matrix resistivity is generally relatively small and the wide range of measured bulk resistivities of water-saturated rocks primarily reflects the combined influence of the rock porosity and the associated pore fluid resistivity.

The formation factor, F, first introduced by Archie (1942), may be expressed as a ratio of the bulk resistivity of the saturated rock, R_0, to the resistivity of the pore fluid R_w:

$$F = \frac{R_0}{R_w} \qquad 2.1$$

Archie (1942) showed that the empirical relationship between F and the porosity ϕ is of the form

$$F = \frac{1}{\phi^m} \qquad 2.2$$

where m is the cementation factor whose value lies between 1.3 and 2.5.

Provided the mineral phase can be assumed to be an insulator and the pore water is sufficiently saline (to limit surface conduction) the formation factor can be regarded as an intrinsic parameter or the rock, related only to the geometry of the transport porosity (Brereton et al., 1996).

3. FORMATION FACTORS FROM CORE SAMPLES

Special precautions need to be taken to preserve the *in situ* fluids present in the core during drilling operations and to prevent the rock cores from subsequently drying out. Worthington *et al.* (1988) applied Archie's equation to both preserved and resaturated sedimentary core samples with porosities of about 20 %. They attributed differences in the results to induced changes in pore geometry, and thence to surface conduction, through the irreversible collapse of structurally delicate clay minerals related to the passage of a fluid interface through the sample during drying of the core plugs. Although this example may not be directly relevant to low porosity volcanic rocks such as the BVG, it serves to demonstrate the need for caution when preparing cores for laboratory evaluation. No such special precautions were taken with regard to the core samples used in this study.

In the absence of these special precautions, the core samples will generally be resaturated with a fluid of known properties. This procedure will render it unrealistic to make direct comparisons between wireline and core sample resistivity measurements, but formation factors, which represent the dimensionless ratio between the bulk resistivity of the saturated rock and the pore fluid resistivity, are more directly comparable.

As part of the Nirex Core Characterisation Programme on the drill core from the Nirex deep boreholes, the BGS carried out a total of 316 BVG resistivity measurements on core samples from Boreholes 2, 3, 4, 5 and 7A (Nirex, 1997a). Core plugs, having dimensions of 38 mm diameter by 76 mm long, were taken from the core sticks using standard cutting techniques. No special precautions were taken with regard to the fluids used during this cutting procedure and so some cross-contamination between the cutting fluids and the *in situ* pore fluids may have occurred. The core plugs were then vacuum dried and resaturated using fluids with compositions intended to simulate BVG groundwaters. Different fluid compositions were used at different depths in a given borehole using information provided from other Nirex programmes at the time. The resaturating fluid resistivities ranged from 0.16 to 0.30 Ω m. Resaturation was allowed to occur under vacuum for a period of several hours prior to resistivity measurements being made. The measurement temperatures ranged from 18 to 23 °C.

No attempt was made to flush out any residual pore fluids prior to resaturation; or salts that may have deposited while the core sticks were drying out; or any residual cross-contamination from fluid that may have entered during core plug cutting. Nor was any attempt made to establish whether the interstitial pore fluids had fully reached chemical equilibrium during the resaturation procedure. However, given the very low interstitial porosity of the BVG and the relatively large size of the core plug samples, it is unlikely that cutting fluid contamination would have been too significant. Also, because the resaturating fluids were intended to be similar in composition to the BVG groundwaters, the pore fluids experienced during the bulk resistivity measurements would be expected to exhibit similar electrical properties to the original *in situ* pore fluids. Nevertheless, uncertainties will remain in these expectations.

The measured saturated sample resistivities, water resistivities and formation factors (F_c) derived from core samples are listed in Table 3.1.

4. BVG FORMATION FACTORS FROM WIRELINE LOGS

4.1 Wireline measurements of formation resistivity

Boreholes are usually drilled with fluids other than the formation water and may either be fresh or saline water. Depending upon the local formation permeability and porosity distributions, and also upon relative difference between the *in situ* formation pore pressure and the borehole drilling fluid pressure, these drilling fluids will permeate into the rock formation. To accommodate these varying conditions near the borehole wall, a range of logging tools have been developed by the logging service companies, each with differing capabilities designed to penetrate greater or lesser distances into the formation (deep, medium or shallow) and also to provide greater or lesser focusing for improved vertical resolution. Induction tools (ILD© and ILM©) are usually used where the formation is more electrically conductive than the borehole fluid and focused laterolog tools (LLD© and LLS©) in other situations. The Nirex boreholes were predominantly logged using the LLD© and LLS© tools.

In low permeability, low porosity and relatively homogeneous rocks, where drilling fluid invasion is minimal, it may be expected that the deep and shallow resistivity measurements will be similar because they will both sample similar pore fluid characteristics. This is borne out by the borehole wireline log resistivity profiles, where the deep and shallow logs from the BVG tend to follow one another very closely. In Brereton et al., 1996 it was concluded that the deep resistivity LLD log is better able to represent the relationship between resistivity and porosity, as described by the Archie equation (2.2), than the shallow resistivity LLS log. Therefore the LLD resistivity log was previously used to evaluate an *in situ* formation factor log for Borehole RCF3 (Brereton et al., 1996). This practice has been adopted here.

4.2 Evaluation of *in situ* fluid resistivities

If quantitative formation factor assessments are to be made from the wireline logs, then estimates of the *in situ* pore fluid resistivity within the formations around each borehole are required. As part of the Nirex hydrogeological investigations, a series of borehole hydraulic tests were performed during which pumped water samples were collected from selected depth intervals. Chemical analyses were carried out on these water samples and, in many cases, electrical conductivity measurements were also made.

To characterise the chemistry of the interstitial pore fluids, experiments were conducted by both the BGS and AEA Technology using Boreholes 2 and 3, to extract pore waters from rock cores by leaching and by centrifugation (Nirex, 1992, Report No. 202 and Nirex, 1993, Report 213). Ranges of chemical constituents were analysed for, but neither fluid conductivities nor resistivities were included in those measurements. To overcome this, a correlation between chloride concentration and electrical conductivity was constructed from the water sample data collected during the hydraulic testing programme (Brereton et al., 1996). This took the following form:

$$\sigma_f = 0.1486 + 0.238\ 10^{-3}\ Cl - 0.486\ 10^{-9}\ Cl^2 \qquad 4.1$$

Where σ_f is the electrical conductivity of the fluid (S m^{-1}),
Cl is the chloride concentration (g m^{-3}).

All available hydraulic test interval and pore water sample data from the BVG sections of Boreholes 2, 3, 4, 5 and 7A were collated and Equation 4.1 was used to convert measured chloride concentrations into electrical conductivity and then into fluid resistivity. The results are listed in Table 4.1. [Note: conductivity is tabulated as ms/cm where y mS/cm is equivalent to 10/y Ω m

Table 4.1 also gives the mean fluid resistivity value for each borehole. Some individual values were excluded from these means for the reasons given below. Also, where hydraulic test interval fluid resistivity values have been derived both directly from conductivity measurements and indirectly from chloride measurements (via Equation 4.1), then only the conductivity-derived values have been used in the mean. This is because although the conductivity and chloride are independent measurements, the chloride-derived resistivity is based on a correlation between these two, and so, it might be argued, double counting may occur.

For Borehole 3, four of the interstitial pore water sample resistivity values (out of 22) were significantly greater than the rest (averaging about 0.61 Ω m) and so were considered anomalous and excluded from the mean. Similarly, for Borehole 7A two of the interstitial pore water sample resistivity values (out of 9) were much greater than the rest (averaging about 0.28 Ω m) and these were also excluded from the mean. All the pore water data from Borehole 4 are considered to be anomalous (Steve Swanton, AEAT; personal communication), and have also been excluded from the mean. It is unclear whether or not these anomalous interstitial pore water sample values from Boreholes 3, 4 and 7A can be attributed to sample preparation and handling or to genuine geological reasons.

Allowing for these exclusions, the resistivities of the interstitial pore water samples are, in general, very similar to those of the hydraulic test interval water samples. However, there is a tendency for the pore water sample resistivities to be slightly higher than the pumped water sample resistivities. This implies that the fluids flowing through the network of fractures are marginally more saline than the interstitial pore waters within the body of the rock.

The mean values of the pumped water samples for Boreholes 2, 3, 4, 5 and 7A are 0.27, 0.05, 0.30, 0.27 (one sample) and 0.11 Ω m. The mean values of the interstitial pore water samples for Boreholes 2, 3 and 7A are 0.39, 0.07 and 0.15 Ω m (Table 4.1). For comparison, the mean pumped water and pore water sample resistivities from below the Saline Transition Zone for all lithologies from all the Nirex boreholes (representing 122 hydraulic test intervals and 183 pore water samples) are 0.23 ± 0.18 and 0.22 ± 0.23 Ω m respectively (Brereton et al., 1996).

Water column fluid conductivity wireline logs were recorded in some boreholes during the water abstraction tests. These were primarily for the purpose of identifying fluid flow horizons under flowing conditions. Repeat water column logging runs were carried out over several days in Boreholes 4 (three runs) and 5 (four runs), while in Borehole 2 and 7A single profiles were recorded (Figure 4.1). All these profiles exhibit a gradational decrease in fluid resistivity with increasing depth. In Borehole 2 the profile decreases from 0.27 to 0.16 Ω m in a series of stepwise changes. The three logging runs in Borehole 4 decreased from about 0.70 to 0.28 Ω m and also decreased with time in the upper part of the profile. In Borehole 5, the first logging run showed a fairly linear gradient, decreasing from about 0.79 to 0.59 Ω m. Subsequent logging runs showed distinctive profiles, superimposed upon the linear gradient, which deviate away from the gradient line towards successively lower fluid resistivity values at specific borehole depths. These indicate distinct fluid flow horizons into or out of the borehole. The fluid resistivities at these depth horizons successively trend towards a value of about 0.45 Ω m or even lower. The single profile in Borehole 7A decreases from 0.80 to 0.47 Ω m and is similar in character to those in Boreholes 4 and 5.

Fluid resistivity is influenced by temperature. Quist and Marshall (1969) demonstrated significant increases in electrical conductivity (and hence decreases in fluid resistivity) of sodium chloride solutions up to temperatures of 400ºC. They also demonstrated that increases in pressure of up to 0.4 GPa over this temperature range had little influence.

Much of the gradational decreases in fluid column resistivity with depth in the Nirex boreholes can be attributed to temperature changes with depth. In Borehole 2 for example, the wireline logs show that from 475 to 1590 mbRT the temperature (T; ºC) increases with depth (*D*; m) from 19.3ºC to 47.2ºC according to the following relationship:

$$T = 0.025D + 7.4 \qquad 4.2$$

Over the same depth range a near linear relationship between fluid resistivity (R_w) and temperature approximates to:

$$R_w = -0.0038T + 0.33 \qquad 4.3$$

Therefore, at a temperature of say 20ºC, which is within the range at which most of the measurements on the pumped water samples were made, the fluid resistivity would be 0.25 Ω m, which is similar to the mean value of 0.27 Ω m directly measured on the pumped water samples from this borehole (Table 4.1).

These fluid resistivity profiles provide only limited quantitative information. Because of vertical fluid movements within the borehole water column, they will be more representative of fluids entering the borehole from higher permeability zones at different depths than of the interstitial pore fluids within the formation at the depth of measurement. Equally, fluid resistivities of pumped water samples, from relatively narrow intervals isolated by packers, will be more representative of fluids flowing through discrete fractures rather than of the interstitial waters, which may explain the tendency for the pore water sample resistivities to be slightly different to the pumped water sample resistivities.

Even so, it would be expected that there would be an overall agreement between the general ranges of values. Allowing for the various caveats outlined above, and for the effects of temperature on the fluid column wireline resistivities, there does appear to be a general agreement. Therefore, it appears to be reasonably justified to assume a constant R_w for each borehole, as was concluded by Brereton et al., 1996.

There is a further aspect that needs consideration, the effects of temperature. The wireline measurements of formation resistivity at any given depth in the borehole are made at the prevailing *in situ* temperature at that depth. These formation resistivity measurements are not subsequently adjusted to the ambient temperature at ground level. For each borehole, the derivation of wireline formation factors based upon Equation 2.1 should, in principle, incorporate a correction to R_w for temperature changes with depth similar to Equations 4.2 and 4.3. Wireline temperature logs were not run in all these boreholes and even where they were they would be subject to perturbations due to fluid movements within the water column similar to those that affect the fluid conductivity logs described above (Figure 4.1). Because of these difficulties temperature corrections to R_w have not been attempted.

Therefore, for the purposes of making comparisons between the core and wireline derived formation factors, a constant R_w has been assumed for the BVG around each borehole. It should be recognised that due to the effects of temperature changes with depth and the other factors discussed, the actual three-dimensional distribution of fluid resistivity within the BVG will be variable.

For simplicity, the mean R_w value derived from the pumped water samples and the interstitial pore water samples for each borehole (given the exclusions described previously), has been used as a basis for calculating formation factors from the wireline logs. No account has been taken of the borehole fluid column resistivity profile data for this purpose. For Boreholes 2, 3, 4, 5 and 7A these mean R_w values are 0.34, 0.06, 0.30, 0.27 and 0.14 Ω m respectively (see Table 4.1, means highlighted in bold).

5. DISCUSSION

5.1 Borehole / Core Comparison

Wireline derived formation factors (F_w) were calculated using Equation 2.1 where R_0 is the wireline deep resistivity (LLD) and R_w is the corresponding mean fluid resistivity. Cumulative frequency distributions for Boreholes 2, 3, 4, 5 and 7A are shown in Figures 5.1 to 5.5. Wireline derived formation factor profiles are shown in Figure 5.6 (black profiles), alongside the core sample formation factors (blue dots).

With the exception of Borehole 2 the core sample values are consistently less than the corresponding wireline derived values. It is clear from Figures 5.1 to 5.6 that in some cases the differences can be large and range to more than one order of magnitude. The largest differences occur in the upper section of Borehole 4 (above about 830 m; Figure 5.6) and the lower section of Borehole 5 (below about 1170 m). In the case of Borehole 4, this upper section coincides with the zone where significant departure from the general trend of the fluid resistivity profile is observed (Figure 4.1). This implies that it may be unreasonable to adopt the same mean R_w value of 0.30 Ω m over this depth zone as had been adopted for the whole borehole. Despite these offsets, the broad core sample value trends tend to follow the same broad trends followed by the wireline log profiles. This is particularly so for Boreholes 2, 3 and 7A.

For Borehole 2 the match is much closer. A correlation plot between core sample formation factors and wireline interpolated values for Borehole 2 is shown in Figure 5.7. The correlation is moderate, but this plot needs to be treated with caution owing to potential problems associated with the depth registration between the core and wireline data (Nirex Report SA/97/021). Although all core depths were corrected to the wireline log depths as part of the Core Characterisation Programme, errors will remain where core loss has occurred. These problems are exacerbated when dealing with logarithmic data in that small core to wireline depth misalignments could result in a large difference between formation factors. That is, the Figure 5.7 correlation might be better if absolute depth matching between the core and wireline data could be guaranteed.

Figure 5.8 demonstrates that a closer match between the core and wireline derived Formation Factors can be derived by using a fixed value of 035 ohm metres for all the boreholes.

Summary statistics for the core sample formation factors listed in Table 3.1 are given in Table 5.1a. It is noteworthy that the core sample formation factors for Borehole 2 are very much higher and more varied than those for the other boreholes, while those for Borehole 3 are relatively low. Summary statistics for the wireline derived formation factors are given in Table 5.1b. It is clear that not only are the ranges of wireline derived formation factors much greater than the core sample values but the mean values are also much greater.

5.2 General Review

It is clear from these comparisons that although the core sample formation factors broadly follow the variations in the wireline log derived profiles, there appear, with some exceptions, to be systematic differences, with the core sample values generally being less than the wireline derived values.

Formation factors are determined as a simple dimensionless ratio between the measured saturated bulk rock resistivity and the fluid resistivity. The wireline methods for measuring resistivity in boreholes are well established and well understood (Desbrandes, 1985) and there is little reason to question the wireline resistivity results. There is a broad agreement between the general ranges of formation fluid resistivity values, but some uncertainties remain because of the relatively small *in situ* fluid resistivity sample data sets and because of systematic differences between the pumped water and interstitial pore water resistivities. There will, therefore, be corresponding uncertainties in the wireline derived formation factors.

The core samples were saturated with fluids of known resistivity prior to the measurement of bulk resistivity. However, there are uncertainties as to whether, during this procedure, the interstitial pore fluids had fully reached chemical (thus electrical) equilibrium with the resaturating fluids. These uncertainties will carry through to the core sample formation factors.

The main uncertainties in making comparisons between core and wireline derived formation factors lie with those associated with the resaturation of the core samples and with the establishment of best estimates of fluid resistivity for the derivation of wireline formation factors.

It was stated in Section 3 that no deliberate attempt was made to flush out any residual pore fluids prior to resaturation of the core samples, or salts that may have deposited while the core sticks were drying out. On resaturation this may lead to the core samples containing water that is significantly more saline than the resaturating solution. For example, following resaturation of the Borehole 3 core samples, the actual pore fluid resistivity may have been closer to the value used to calculate the wireline derived formation factors (i.e. 0.06 Ω m), than the resistivity of the core sample resaturating solution (i.e. 0.23 Ω m). If this were true, then the mean core sample formation factor of 303 given in Table 5.1a would be about 1,200, which is much closer to the mean wireline derived formation factor of 1,398 given in Table 5.1b.

It is worth noting that, under the Nirex Safety Assessment Research programme, Borehole RCF3 core samples were passively resaturated for 3 to 5 months prior to resistivity measurements. Good agreement was found between formation factors measured after 3 and 5 months (Brereton et al., 1996) indicating that electrical equilibrium had been reached. For these RCF3 samples a better correlation between the core and wireline formation factor data was found than for the five boreholes considered here.

An additional possibility, that may partially explain the differences between the wireline and core derived formation factors, is that, during the coring and sub-coring operations, de-stressing of the core samples will have taken place which may result in slight increases in porosity. This, in turn, would result in a decrease in the measured core sample formation factors relative to what would have been measured had de-stressing not occurred. Since the core porosity is typically between 0 and 5 per cent in the BVG small per cent change in porosity could have dramatic effects on the Formation Factor.

Also, the effects of core sample bias during sampling can be significant. The core will for example only be sampled where it is relatively intact and also there will be a bias to sample a variety of rock types rather than sample at random intervals. The differences between core and wireline scales of measurement can also have a significant impact (Brereton et al., 1996) and are beyond the scope of this report.

6 CONCLUSIONS

This technical note describes the results of comparisons between BVG core sample and wireline derived formation factors for five of the Sellafield boreholes. The objective of these comparisons was to further test the reasonable correlation found previously in Borehole RCF3 (Brereton et al., 1996).

Although the resistivities of the interstitial pore water samples for the five boreholes are very similar to those of the hydraulic test interval water samples, there is a tendency for the pore water sample resistivities to be slightly higher than the pumped water sample resistivities. This implies that the fluids flowing through the network of fractures are marginally more saline than the interstitial pore waters within the body of the rock. Nevertheless, for the purposes of making comparisons between the core and wireline derived formation factors, it appears to be reasonably justified to assume a constant R_w for the BVG around each borehole, as was concluded by Brereton et al., 1996. However, no attempt has been made here to correct R_w for formation temperature changes with depth.

Two principal conclusions arise out of the comparisons between the core and wireline derived formation factors. Firstly, the core sample values broadly follow the variations in the wireline log derived profiles. Secondly, while for Borehole 2 there is a reasonable quantitative agreement, for Boreholes 3, 4, 5 and 7A there are systematic differences, with the core sample values being generally less than the wireline derived values.

It is very likely that these differences may largely be attributed to uncertainties associated with the question as to whether or not the core sample interstitial pore fluids had reached equilibrium during the resaturation process. Also, to a lesser degree, to de-stressing of the core samples during the coring and sub-coring operations; to core sample bias and scale of measurement effects; and with the establishment of best estimates of the *in situ* formation fluid resistivities.

In general, it may be concluded that, because of the additional uncertainties about the equilibration of the resaturated core samples, the resistivity measurements made as part of the Core Characterisation Programme were not as good a test of the correlation between core and wireline formation factors as had been expected. To reduce this uncertainty, it is recommended that, in future work, the primary objectives of the core measurement programmes are clearly defined and that sufficient care is taken during core sample preparation to ensure that those objectives can be met. In the particular case of formation factor measurements, it is important to ensure equilibration of the core samples prior to resistivity measurements being made. On the basis of the present data, it is probable that for these five boreholes the wireline derived formation factors are more indicative of the *in situ* formation factor values in the field than are the core sample measurements reported here.

Given these caveats, the findings of this report support the conclusions of Brereton et al., 1996 in that wireline logs are able to provide an effective means of estimating the broad characteristics of formation factor variability with depth in a borehole.

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Table 3.1: Resistivity measurements on BVG core samples and derived formation factors (data abstracted from Nirex Report SA/97/017).

Nirex Borehole Number	Sample	Depth mbRT	BVG unit	Measured Sample resistivity Ω m (Ro)	Assumed Water resistivity Ω m (Rw)	Temp. °C	Formation Factor (*Fc*)
BH2	324/P1-2	470.07	Longlands	796.08	0.29	19.0	2,726
BH2	330/P2-1	480.55	Longlands	1,394.02	0.29	19.0	4,774
BH2	350/P2-1	502.25	Longlands	1,646.50	0.29	19.0	5,639
BH2	357/P1-2	505.42	Longlands	621.99	0.29	19.0	2,130
BH2	1158/P2-1	512.21	Longlands	1,569.46	0.29	19.0	5,375
BH2	1159/P2-1	541.13	Longlands	2,107.91	0.29	19.0	7,219
BH2	376/P1-2	542.72	Longlands	1,342.70	0.29	19.0	4,598
BH2	1164/P2-1	544.70	Longlands	550.20	0.30	19.0	1,865
BH2	377/P2-1	544.70	Longlands	791.68	0.29	19.0	2,711
BH2	1160/P2-1	557.94	Longlands	1,385.05	0.29	19.0	4,743
BH2	387/P1-2	565.13	Longlands	2,042.50	0.29	19.0	6,995
BH2	1162/P2-1	623.07	Longlands	1,153.57	0.29	19.0	3,951
BH2	461/P2-1	674.47	Longlands	321.04	0.30	19.0	1,088
BH2	484/P1-2	699.36	Longlands	340.34	0.30	19.0	1,154
BH2	504/P1-2	719.11	Longlands	426.64	0.30	19.0	1,446
BH2	1167/P2-1	724.05	Longlands	570.20	0.30	19.0	1,933
BH2	507/P2-1	728.88	Longlands	582.78	0.30	19.0	1,976
BH2	516/P1-2	738.40	Longlands	433.97	0.30	19.0	1,471
BH2	1166/P2-1	746.41	Longlands	574.17	0.30	19.0	1,946
BH2	1079/P2-1	751.89	Longlands	438.65	0.30	19.0	1,487
BH2	1168/P2-1	757.82	Longlands	649.84	0.30	19.0	2,203
BH2	535/P1-2	761.91	Longlands	432.66	0.30	19.0	1,467
BH2	545/P2-1	782.14	Longlands	439.69	0.30	19.0	1,490
BH2	1170/P2-1	822.25	Longlands	72.21	0.30	19.0	245
BH2	577/P2-1	833.79	Town End	147.91	0.30	19.0	501
BH2	1171/P2-1	836.18	Town End	175.12	0.30	19.0	594
BH2	1173/P2-1	838.83	Town End	365.50	0.21	19.0	1,740
BH2	594/P2-1	855.04	Town End	525.78	0.30	19.0	1,782
BH2	1172/P2-1	871.60	Town End	409.41	0.30	19.0	1,388
BH2	1174/P2-1	896.99	Brown Bank	88.19	0.21	19.0	420
BH2	624/P1-2	909.24	Brown Bank	209.86	0.18	22.0	1,166
BH2	1175/P2-1	959.72	Brown Bank	167.86	0.21	19.0	799
BH2	665/P2-1	981.48	Brown Bank	134.86	0.18	22.0	749
BH2	1177/P2-1	991.88	Brown Bank	291.94	0.21	19.0	1,390
BH2	677/P1-2	1004.01	Brown Bank	93.38	0.18	22.0	519
BH2	681/P2-1	1012.12	Brown Bank	124.42	0.18	22.0	691
BH2	1180/P2-1	1019.93	Brown Bank	145.56	0.21	19.0	693
BH2	691/P1-2	1021.18	Brown Bank	80.60	0.18	22.0	448
BH2	701/P1-2	1043.27	Brown Bank	214.48	0.18	22.0	1,192
BH2	703/P2-1	1048.04	Brown Bank	326.26	0.18	22.0	1,813
BH2	717/P1-2	1057.96	Brown Bank	282.35	0.18	22.0	1,569
BH2	684/P3-1	1062.37	Brown Bank	702.56	0.18	20.0	3,903
BH2	720/P2-1	1064.61	Brown Bank	145.31	0.18	22.0	807
BH2	1182/P2-1	1071.28	Bleawath	84.75	0.21	19.0	404
BH2	729/P1-2	1079.31	Bleawath	80.83	0.18	22.0	449
BH2	1181/P2-1	1087.28	Bleawath	436.07	0.21	19.0	2,077

Nirex Borehole Number	**Sample**	**Depth mbRT**	**BVG unit**	**Measured Sample resistivity Ω m (Ro)**	**Assumed Water resistivity Ω m (Rw)**	**Temp. °C**	**Formation Factor (*Fc*)**
BH2	1184/P2-1	1091.79	Bleawath	572.90	0.21	19.0	2,728
BH2	1129/P1-2	1102.01	Bleawath	308.47	0.21	19.0	1,469
BH2	1183/P2-1	1112.07	Bleawath	411.03	0.21	19.0	1,957
BH2	751/P1-2	1120.08	Bleawath	603.37	0.21	19.0	2,873
BH2	756/P2-1	1130.97	Bleawath	58.28	0.21	19.0	278
BH2	1186/P2-1	1140.38	Bleawath	439.00	0.21	19.0	2,090
BH2	764/P1-2	1143.71	Bleawath	1,616.87	0.18	22.0	8,983
BH2	1185/P2-1	1152.21	Bleawath	1,689.28	0.21	19.0	8,044
BH2	771/P1-2	1159.80	Bleawath	580.29	0.18	22.0	3,224
BH2	772/P3-1	1163.74	Bleawath	222.52	0.18	22.0	1,236
BH2	773/P2-1	1166.67	Bleawath	511.80	0.18	22.0	2,843
BH2	1204/P2-1	1172.65	Bleawath	947.28	0.21	19.0	4,511
BH2	782/P1-2	1177.28	Bleawath	419.59	0.18	22.0	2,331
BH2	791/P1-2	1195.48	Bleawath	292.27	0.18	22.0	1,624
BH2	792/P2-1	1198.82	Bleawath	435.63	0.18	22.0	2,420
BH2	1203/P2-1	1205.62	Bleawath	912.41	0.21	19.0	4,345
BH2	802/P1-2	1214.86	Bleawath	2,232.65	0.18	22.0	12,404
BH2	808/P2-1	1227.36	Bleawath	435.32	0.18	22.0	2,418
BH2	816/P1-2	1236.20	Bleawath	335.76	0.18	22.0	1,865
BH2	1205/P2-1	1246.86	Bleawath	1,201.54	0.21	19.0	5,722
BH2	1140/P1-2	1258.03	Bleawath	948.64	0.21	19.0	4,517
BH2	1139/P2-1	1259.22	Bleawath	906.60	0.21	19.0	4,317
BH2	831/P3-1	1264.29	Bleawath	432.36	0.18	20.0	2,402
BH2	1206/P2-1	1272.62	Bleawath	566.96	0.21	19.0	2,700
BH2	836/P1-2	1276.28	Bleawath	235.37	0.18	22.0	1,308
BH2	844/P1-2	1294.50	Bleawath	427.46	0.18	22.0	2,375
BH2	848/P3-1	1294.87	Bleawath	1,402.62	0.18	22.0	7,792
BH2	1208/P2-1	1300.50	Bleawath	714.59	0.16	19.0	4,552
BH2	852/P1-2	1307.95	Bleawath	357.47	0.16	19.0	2,277
BH2	862/P1-2	1327.61	Bleawath	584.78	0.16	19.0	3,725
BH2	1207/P2-1	1334.86	Bleawath	661.11	0.16	18.0	4,211
BH2	872/P2-1	1344.83	Bleawath	435.35	0.16	18.0	2,773
BH2	877/P1-2	1347.60	Bleawath	555.56	0.16	19.0	3,539
BH2	1209/P2-1	1355.22	Bleawath	572.66	0.16	18.0	3,648
BH2	885/P2-1	1371.69	Bleawath	783.41	0.16	22.0	4,990
BH2	884/P1-2	1371.98	Bleawath	380.56	0.16	19.0	2,424
BH2	897/P1-2	1394.47	Bleawath	365.01	0.16	18.0	2,325
BH2	911/P1-2	1413.93	Bleawath	280.40	0.16	19.0	1,786
BH2	1146/P1-2	1429.01	Bleawath	287.66	0.16	18.0	1,832
BH2	927/P2-1	1447.39	Bleawath	160.40	0.16	19.0	1,022
BH2	930/P1-2	1451.37	Bleawath	255.48	0.16	19.0	1,627
BH2	941/P1-2	1470.78	Bleawath	320.67	0.16	19.0	2,042
BH2	956/P1-2	1483.22	Broom Farm	270.22	0.16	19.0	1,721
BH2	987/P1-2	1522.41	Moorside Farm	221.69	0.16	19.0	1,412
BH2	1216/P2-1	1525.43	Moorside Farm	218.84	0.16	19.0	1,394
BH2	990/P2-1	1528.58	Moorside Farm	128.68	0.16	22.0	820
BH2	1004/P2-1	1550.40	Moorside Farm	352.08	0.16	19.0	2,243
BH2	1218/P2-1	1577.58	Moorside Farm	188.83	0.16	18.0	1,203

Nirex Borehole Number	Sample	Depth mbRT	BVG unit	Measured Sample resistivity Ω m (Ro)	Assumed Water resistivity Ω m (Rw)	Temp. °C	Formation Factor (*Fc*)
BH2	1037/P1-2	1600.90	Moorside Farm	213.99	0.16	19.0	1,363
BH2	1041/P1-2	1605.21	Moorside Farm	263.33	0.16	19.0	1,677
BH2	1032/P2-1	1605.43	Moorside Farm	284.26	0.16	19.0	1,811
BH3	772/P1-2	1623.96	Ignimbrite	45.35	0.23	19.5	199
BH3	774/P1-2	1635.24	Ignimbrite	109.57	0.23	19.5	481
BH3	778/P1-2	1666.29	Ignimbrite	90.14	0.23	19.5	395
BH3	828/P2-1	1666.96	Ignimbrite	105.56	0.23	19.5	463
BH3	781/P1-2	1683.53	Ignimbrite	53.49	0.23	19.5	235
BH3	831/P2-1	1696.99	Ignimbrite	26.64	0.25	21.5	109
BH3	786/P1-2	1712.74	Ignimbrite	44.82	0.23	19.5	197
BH3	834/P2-1	1719.66	Ignimbrite	29.32	0.25	21.5	120
BH3	838/P2-1	1752.83	Ignimbrite	51.12	0.23	19.5	224
BH3	791/P1-2	1755.17	Ignimbrite	67.35	0.23	19.5	295
BH3	839/P2-1	1764.76	Ignimbrite	93.36	0.23	19.5	409
BH3	793/P1-2	1775.07	Ignimbrite	101.24	0.23	19.5	444
BH3	841/P2-1	1782.64	Ignimbrite	94.64	0.23	19.5	415
BH3	795/P1-2	1794.21	Volc.Unit B1	73.67	0.23	19.5	323
BH3	843/P2-1	1804.01	Volc.Unit B1	134.75	0.23	19.5	591
BH3	844/P2-1	1816.50	Volc.Unit B2	88.83	0.23	19.5	390
BH3	796/P1-2	1819.82	Volc.Unit B2	73.47	0.23	19.5	322
BH3	797/P1-2	1830.21	Volc.Unit B2	61.74	0.23	19.5	271
BH3	846/P2-1	1832.56	Volc.Unit B2	77.20	0.23	19.5	339
BH3	798/P1-2	1838.97	Ignimbrite	68.64	0.23	19.5	301
BH3	847/P2-1	1842.93	Ignimbrite	93.72	0.23	19.5	411
BH3	799/P1-2	1847.16	Ignimbrite	82.75	0.23	19.5	363
BH3	848/P2-1	1853.94	Ignimbrite	40.93	0.23	19.5	180
BH3	800/P1-2	1854.63	Ignimbrite	90.79	0.23	19.5	398
BH3	801/P1-2	1862.18	Ignimbrite	88.65	0.23	19.5	389
BH3	804/P1-2	1888.56	Ignimbrite	27.84	0.23	19.5	122
BH3	805/P1-2	1896.93	Ignimbrite	55.57	0.23	19.5	244
BH3	851/P2-1	1899.14	Ignimbrite	45.00	0.23	19.5	197
BH3	806/P1-2	1906.04	Volc.Unit C1	56.53	0.23	19.5	248
BH3	852/P2-1	1910.22	Ignimbrite	35.56	0.23	19.5	156
BH3	853/P2-1	1922.09	Volc.Unit C2	53.35	0.23	19.5	234
BH3	808/P1-2	1922.57	Volc.Unit C2	59.83	0.23	19.5	262
BH3	809/P1-2	1926.55	Volc.Unit C2	33.80	0.23	19.5	148
BH3	855/P2-1	1938.46	Volc.Unit C2	88.90	0.23	19.5	390
BH3	856/P2-1	1949.93	Volc.Unit C2	77.74	0.23	19.5	341
BH4	27/P2-1	421.91	Longlands Farm	168.51	0.26	21.0	661
BH4	1/P1-2	430.21	Longlands Farm	321.64	0.26	21.0	1,261
BH4	28/P2-1	433.94	Longlands Farm	280.13	0.26	20.0	1,099
BH4	29/P2-1	442.06	Longlands Farm	196.04	0.26	20.0	769
BH4	2/P1-2	453.04	Longlands Farm	263.33	0.26	21.0	1,033
BH4	30/P2-1	453.85	Longlands Farm	167.99	0.26	20.0	659
BH4	31/P2-1	466.09	Longlands Farm	323.31	0.26	21.0	1,268
BH4	32/P2-1	472.50	Longlands Farm	56.30	0.26	21.0	221
BH4	33/P2-1	482.33	Longlands Farm	182.06	0.26	20.0	714
BH4	34/P2-1	492.75	Longlands Farm	316.36	0.26	21.0	1,241

Nirex Borehole Number	**Sample**	**Depth mbRT**	**BVG unit**	**Measured Sample resistivity Ω m (Ro)**	**Assumed Water resistivity Ω m (Rw)**	**Temp. °C**	**Formation Factor (*Fc*)**
BH4	35/P2-1	501.82	Longlands Farm	239.86	0.26	21.0	941
BH4	36/P2-1	512.20	Longlands Farm	267.46	0.26	21.0	1,049
BH4	4/P1-2	517.63	Longlands Farm	219.82	0.26	21.0	862
BH4	38/P2-1	534.92	Longlands Farm	200.55	0.26	21.0	786
BH4	5/P1-2	543.57	Longlands Farm	205.14	0.30	21.0	693
BH4	39/P2-1	547.13	Longlands Farm	243.62	0.26	21.0	955
BH4	6/P1-2	580.40	Longlands Farm	281.33	0.26	21.0	1,103
BH4	40/P2-1	580.81	Longlands Farm	343.75	0.26	21.0	1,348
BH4	41/P2-1	593.03	Longlands Farm	250.55	0.26	21.0	983
BH4	42/P2-1	602.92	Longlands Farm	181.32	0.26	20.0	711
BH4	43/P2-1	612.00	Longlands Farm	182.66	0.26	20.0	716
BH4	7/P1-2	620.91	Longlands Farm	227.30	0.30	21.0	768
BH4	44/P2-1	621.10	Longlands Farm	196.37	0.26	20.0	770
BH4	46/P2-1	641.48	Longlands Farm	160.46	0.26	20.0	629
BH4	47/P2-1	649.83	Longlands Farm	210.24	0.26	21.0	824
BH4	8/P1-2	651.57	Longlands Farm	249.23	0.30	21.0	842
BH4	48/P2-1	662.99	Longlands Farm	195.27	0.26	20.0	766
BH4	49/P2-1	674.45	Longlands Farm	181.84	0.26	20.0	713
BH4	9/P1-2	677.71	Longlands Farm	220.84	0.30	21.0	746
BH4	50/P2-1	681.46	Longlands Farm	188.29	0.26	20.0	738
BH4	51/P2-1	685.73	Longlands Farm	182.35	0.26	20.0	715
BH4	52/P2-1	694.92	Longlands Farm	167.55	0.26	20.0	657
BH4	53/P2-1	707.59	Longlands Farm	168.08	0.26	20.0	659
BH4	54/P2-1	719.33	Longlands Farm	214.85	0.26	21.0	843
BH4	55/P2-1	730.51	Longlands Farm	214.64	0.26	20.0	842
BH4	56/P2-1	741.48	Longlands Farm	140.88	0.26	21.0	552
BH4	11/P1-2	746.89	Longlands Farm	411.09	0.30	21.0	1,389
BH4	57/P2-1	750.54	Longlands Farm	211.38	0.26	21.0	829
BH4	58/P2-1	761.16	Longlands Farm	160.92	0.26	20.0	631
BH4	59/P2-1	772.75	Longlands Farm	237.85	0.26	20.0	933
BH4	12/P1-2	775.27	Longlands Farm	219.83	0.30	21.0	743
BH4	60/P2-1	781.68	Longlands Farm	167.83	0.26	20.0	658
BH4	61/P2-1	792.50	Andesite	167.53	0.26	20.0	657
BH4	13/P1-2	801.68	Fleming Hall	199.86	0.30	21.0	675
BH4	62/P2-1	805.87	Fleming Hall	112.11	0.26	20.0	440
BH4	65/P2-1	834.23	Town End Farm	231.29	0.26	20.0	907
BH4	14/P1-2	835.47	Town End Farm	183.38	0.26	21.0	719
BH4	15/P1-2	865.33	Town End Farm	115.94	0.26	21.0	455
BH4	69/P2-1	886.38	Town End Farm	126.26	0.26	21.0	495
BH4	70/P2-1	902.04	Town End Farm	86.01	0.26	21.0	337
BH4	74/P2-1	934.62	Brown Bank	124.46	0.26	21.0	488
BH4	76/P2-1	950.48	Brown Bank	59.43	0.26	20.0	233
BH4	80/P2-1	1003.42	Brown Bank	52.60	0.26	21.0	206
BH4	81/P2-1	1008.13	Brown Bank	66.82	0.26	21.0	262
BH4	19/P1-2	1017.43	Brown Bank	58.93	0.30	21.0	199
BH4	83/P2-1	1041.03	Brown Bank	52.28	0.26	21.0	205
BH4	20/P1-2	1058.96	Bleawath	76.45	0.30	21.0	258
BH4	84/P2-1	1067.64	Bleawath	64.16	0.26	20.0	252

Nirex Borehole Number	**Sample**	**Depth mbRT**	**BVG unit**	**Measured Sample resistivity Ω m (Ro)**	**Assumed Water resistivity Ω m (Rw)**	**Temp. °C**	**Formation Factor (*Fc*)**
BH4	85/P2-1	1077.04	Bleawath	81.10	0.26	21.0	318
BH4	86/P2-1	1093.11	Bleawath	142.33	0.26	21.0	558
BH4	87/P2-1	1106.05	Bleawath	122.22	0.26	21.0	479
BH4	21/P1-2	1109.05	Bleawath	186.41	0.26	21.0	731
BH4	88/P2-1	1113.83	Bleawath	160.37	0.26	18.0	629
BH4	89/P2-1	1128.34	Bleawath	151.60	0.26	21.0	595
BH4	91/P2-1	1148.26	Bleawath	175.06	0.26	21.0	687
BH4	22/P1-2	1151.64	Bleawath	219.91	0.26	21.0	862
BH4	92/P2-1	1161.91	Bleawath	182.34	0.26	18.0	715
BH4	93/P2-1	1170.66	Bleawath	204.62	0.26	21.0	802
BH4	96/P2-1	1179.56	Bleawath	146.08	0.26	18.0	573
BH4	94/P2-1	1187.13	Bleawath	221.84	0.26	21.0	870
BH4	23/P1-2	1188.61	Bleawath	143.77	0.26	21.0	564
BH4	95/P2-1	1199.39	Bleawath	84.32	0.26	21.0	331
BH4	97/P2-1	1209.37	Bleawath	92.73	0.26	21.0	364
BH4	98/P2-1	1222.55	Bleawath	145.61	0.26	21.0	571
BH4	24/P1-2	1228.59	Bleawath	129.17	0.30	21.0	436
BH4	99/P2-1	1238.75	Bleawath	70.87	0.26	21.0	278
BH4	102/P2-1	1244.03	Bleawath	124.15	0.26	21.0	487
BH4	100/P2-1	1251.55	Bleawath	135.61	0.26	21.0	532
BH4	25/P1-2	1256.44	Bleawath	169.91	0.26	21.0	666
BH4	101/P2-1	1258.43	Bleawath	145.72	0.26	21.0	571
BH5	272/P2-1	511.35	Longlands Farm	275.82	0.30	20.5	929
BH5	252/P1-2	521.48	Longlands Farm	356.96	0.30	20.5	1,202
BH5	273/P2-1	543.23	Longlands Farm	162.63	0.23	19.0	713
BH5	274/P2-1	554.36	Longlands Farm	144.70	0.23	19.0	635
BH5	253/P1-2	554.66	Longlands Farm	209.14	0.30	20.5	704
BH5	254/P1-2	581.39	Longlands Farm	384.17	0.23	19.0	1,685
BH5	275/P2-1	583.02	Longlands Farm	226.84	0.30	20.5	764
BH5	276/P2-1	606.89	Longlands Farm	164.12	0.23	19.0	720
BH5	255/P1-2	616.94	Longlands Farm	442.98	0.30	20.5	1,492
BH5	277/P2-1	625.87	Longlands Farm	306.84	0.30	20.5	1,033
BH5	278/P2-1	636.44	Longlands Farm	90.38	0.23	19.0	396
BH5	256/P1-2	645.95	Longlands Farm	40.19	0.23	19.0	176
BH5	257/P1-2	677.86	Sides Farm	115.14	0.30	20.5	388
BH5	281/P2-1	708.51	Sides Farm	175.18	0.30	20.5	590
BH5	258/P1-2	727.68	Sides Farm	129.97	0.23	19.0	570
BH5	282/P2-1	731.64	Sides Farm	163.97	0.30	20.5	552
BH5	284/P2-1	766.28	Town End Farm	38.56	0.23	19.0	169
BH5	260/P1-2	840.33	Town End Farm	88.43	0.23	19.0	388
BH5	287/P2-1	841.94	Town End Farm	181.20	0.30	20.5	610
BH5	288/P2-1	851.20	Andesite	77.69	0.23	19.0	341
BH5	261/P1-2	861.68	Town End Farm	78.42	0.30	20.5	264
BH5	289/P2-1	881.86	Town End Farm	49.61	0.23	19.0	218
BH5	290/P2-1	891.78	Brown Bank	56.37	0.23	19.0	247
BH5	262/P1-2	905.09	Brown Bank	236.44	0.30	20.5	796
BH5	291/P2-1	911.95	Brown Bank	190.28	0.23	19.0	835
BH5	292/P2-1	921.36	Brown Bank	37.15	0.23	19.0	163

Nirex Borehole Number	**Sample**	**Depth mbRT**	**BVG unit**	**Measured Sample resistivity Ω m (Ro)**	**Assumed Water resistivity Ω m (Rw)**	**Temp. °C**	**Formation Factor (*Fc*)**
BH5	295/P2-1	986.74	Bleawath	117.17	0.23	19.0	514
BH5	264/P1-2	995.51	Bleawath	177.35	0.30	20.5	597
BH5	296/P2-1	1007.61	Bleawath	260.05	0.30	20.5	876
BH5	297/P2-1	1012.72	Bleawath	281.89	0.30	20.5	949
BH5	265/P1-2	1029.22	Bleawath	62.08	0.30	20.5	209
BH5	298/P2-1	1047.16	Bleawath	96.40	0.23	19.0	423
BH5	299/P2-1	1056.52	Bleawath	40.05	0.23	19.0	176
BH5	300/P2-1	1085.31	Bleawath	296.76	0.30	20.5	999
BH5	301/P2-1	1104.46	Bleawath	133.37	0.23	19.0	585
BH5	267/P1-2	1112.38	Bleawath	59.02	0.23	19.0	259
BH5	616/P1-2	1127.14	Bleawath	75.72	0.22	22.0	347
BH5	302/P2-1	1130.14	Bleawath	148.32	0.23	19.0	651
BH5	614/P1-2	1131.37	Bleawath	136.48	0.22	22.0	626
BH5	617/P1-2	1134.20	Bleawath	117.13	0.22	22.0	537
BH5	618/P1-2	1136.89	Bleawath	266.53	0.22	21.5	1,190
BH5	613/P1-2	1140.12	Bleawath	89.35	0.22	22.0	410
BH5	608/P1-2	1143.27	Bleawath	79.79	0.22	22.0	366
BH5	609/P1-2	1145.94	Bleawath	29.62	0.22	22.0	136
BH5	303/P2-1	1147.18	Bleawath	50.46	0.30	20.5	170
BH5	610/P1-2	1147.20	Bleawath	40.01	0.22	21.5	179
BH5	578/P1-2	1150.26	Bleawath	74.07	0.22	22.0	340
BH5	268/P1-2	1154.36	Bleawath	85.97	0.23	19.0	377
BH5	579/P1-2	1155.18	Bleawath	94.76	0.22	22.0	435
BH5	581/P1-2	1155.34	Bleawath	109.73	0.22	22.0	503
BH5	577/P1-2	1158.55	Bleawath	82.92	0.22	21.5	370
BH5	580/P1-2	1161.18	Bleawath	74.42	0.22	22.0	341
BH5	582/P1-2	1173.76	Bleawath	110.83	0.22	22.0	508
BH5	304/P2-1	1173.92	Bleawath	106.88	0.23	19.0	469
BH5	584/P1-2	1180.57	Bleawath	174.63	0.22	22.0	801
BH5	590/P1-2	1181.01	Bleawath	151.47	0.22	21.5	676
BH5	586/P1-2	1186.28	Bleawath	131.61	0.22	22.0	604
BH5	588/P1-2	1191.08	Bleawath	106.79	0.22	22.0	490
BH5	592/P1-2	1199.76	Bleawath	118.43	0.22	22.0	543
BH5	593/P1-2	1203.10	Bleawath	189.63	0.22	22.0	870
BH5	596/P1-2	1206.08	Bleawath	175.30	0.22	22.0	804
BH5	591/P1-2	1210.14	Bleawath	117.02	0.22	21.5	522
BH5	305/P2-1	1214.06	Bleawath	222.84	0.30	20.5	750
BH5	595/P1-2	1214.22	Bleawath	145.24	0.22	22.0	666
BH5	605/P1-2	1224.07	Bleawath	177.85	0.22	22.0	816
BH5	606/P1-2	1224.88	Bleawath	208.01	0.22	21.5	929
BH5	598/P1-2	1233.88	Bleawath	216.38	0.22	21.5	966
BH5	599/P1-2	1237.48	Bleawath	142.24	0.22	22.0	652
BH5	604/P1-2	1241.27	Bleawath	177.78	0.22	22.0	815
BH5	306/P2-1	1245.35	Bleawath	161.89	0.23	19.0	710
BH5	600/P1-2	1248.28	Bleawath	142.30	0.22	22.0	653
BH5	623/P1-2	1251.88	Bleawath	178.41	0.22	22.0	818
BH5	620/P1-2	1254.03	Bleawath	178.08	0.22	22.0	817
BH5	621/P1-2	1257.04	Bleawath	265.97	0.22	21.5	1,187

Nirex Borehole Number	**Sample**	**Depth mbRT**	**BVG unit**	**Measured Sample resistivity Ω m (Ro)**	**Assumed Water resistivity Ω m (Rw)**	**Temp. °C**	**Formation Factor (*Fc*)**
BH5	622/P1-2	1259.64	Bleawath	172.51	0.22	21.5	770
BH7A	195/P1-2	586.49	Yottenfews	44.20	0.21	22.0	208
BH7A	213/P2-1	620.94	Andesite	29.79	0.29	23.0	105
BH7A	221/P2-1	703.53	Yottenfews	299.73	0.29	23.0	1,052
BH7A	222/P2-1	712.44	Yottenfews	143.82	0.29	23.0	505
BH7A	223/P2-1	717.88	Yottenfews	178.06	0.29	23.0	625
BH7A	224/P2-1	729.41	Yottenfews	215.93	0.29	23.0	758
BH7A	225/P2-1	739.85	Yottenfews	130.85	0.29	23.0	459
BH7A	227/P2-1	756.29	Yottenfews	239.27	0.29	23.0	840
BH7A	228/P2-1	764.47	Yottenfews	191.99	0.29	23.0	674
BH7A	202/P1-2	769.40	Yottenfews	224.17	0.21	22.0	1,052
BH7A	233/P2-1	818.79	Newton 1	88.23	0.29	23.0	310
BH7A	234/P2-1	829.46	Newton 1	32.44	0.29	23.0	114
BH7A	235/P2-1	838.56	Newton 2	71.57	0.29	23.0	251
BH7A	236/P2-1	850.07	Newton 2	90.18	0.21	22.0	423
BH7A	204/P1-2	854.46	Newton 2	112.13	0.21	22.0	526
BH7A	237/P2-1	858.39	Newton 2	88.27	0.21	22.0	414
BH7A	238/P2-1	864.95	Newton 2	129.43	0.21	22.0	608
BH7A	205/P1-2	871.39	Newton 2	94.79	0.21	22.0	445
BH7A	239/P2-1	876.05	Newton 2	88.63	0.21	22.0	416
BH7A	241/P2-1	897.82	Dacite Sill	177.21	0.21	22.0	832
BH7A	206/P1-2	902.95	Dacite Sill	38.51	0.21	22.0	181
BH7A	242/P2-1	907.71	Dacite Sill	44.09	0.21	22.0	207
BH7A	243/P2-1	918.11	Dacite Sill	180.55	0.21	22.0	848
BH7A	207/P1-2	932.96	Dacite Sill	59.15	0.21	22.0	278
BH7A	240/P2-1	935.92	Dacite Sill	29.60	0.21	22.0	139
BH7A	246/P2-1	966.44	Dacite Sill	222.54	0.21	22.0	1,045
BH7A	208/P1-2	972.50	Dacite Sill	266.28	0.21	22.0	1,250
BH7A	247/P2-1	980.68	Dacite Sill	266.17	0.21	22.0	1,250
BH7A	248/P2-1	1004.61	Dacite Sill	91.71	0.21	22.0	431

Table 4.1: BVG fluid resistivity from hydraulic test water sample electrical conductivity and chloride measurements and from pore water sample chloride extraction measurements. NB: a) the overall means are for all the resistivity data for each borehole, but exclude those values in underlined italics. b) data sources are: (1) BGS (Nirex Report S/96/001; Nirex Report Nos. 202 and 203): leachate; (2) Nirex Report SA/95/008; (3) Nirex Report SA/97/089; (4)AEA: leachate (average of shape and density determinations).

Borehole	**Hydraulic test or Pore water sample**	**Depth range**	**Conductivity (σ_f)**	**Chloride (*Cl*)**		**Fluid Resistivity (*Rw*)**			**Data source**
		mbRT	**Hydro test** **mS/cm**	**Hydro test** mg/l	**Pore water** mg/l	**Hydro test (from σ_f) Ω m**	**Hydro test (from *Cl*) Ω m**	**Pore water (from *Cl*) Ω m**	
BH2	1093/P27	496.69 - 497.18			6,240			0.620	1
BH2	EPM9	511.10 - 559.85	28.9			0.346			2
BH2	DET 10	543.00 - 553.14	38.0	13,000		0.263	*0.317*		3
BH2	PDDET 4	547.29 - 558.13	33.5	14,600		0.299	*0.285*		3
BH2	1094/P27	554.41 - 554.91			9,933			0.407	1
BH2	EPM 10	558.00 - 613.42	32.0	11,106		0.313	*0.367*		1
BH2	1095/P27	605.21 - 605.71			7,912			0.501	1
BH2	1096/P27	654.23 - 654.66			9,119			0.440	1
BH2	1097/P27	705.70 - 706.21			12,589			0.327	1
BH2	DET 9	711.00 - 721.14	36.6	12,600		0.273	*0.326*		3
BH2	PDDET 3	710.65 - 721.49	33.7	15,700		0.297	*0.266*		3
BH2	EPM 13	710.00 - 760.39	35.2	13,703		0.284	*0.302*		3
BH2	1098/P27	748.19 - 748.69			12,113			0.339	1
BH2	1099/P27	794.79 - 795.29			6633			0.587	1
BH2	1100/P27	850.94 - 851.41			10,505			0.386	1
BH2	1101/P27	902.70 - 903.23			11,815			0.346	1
BH2	PDDET 7	913.09 - 969.08	43.9	15,800		0.228	*0.265*		3
BH2	1102/P27	952.75 - 953.25			26,306			0.165	1
BH2	1103/P27	992.51 - 993.01			12,403			0.331	1
BH2	EPM 18	968.00 - 1021.59		15,900			0.263		3
BH2	PDDET 2	1009.99 - 1025.46	41.4	16,700		0.242	*0.251*		3
BH2	DET 8	1011.00 - 1025.81	44.7	15700		0.224	*0.266*		3
BH2	EPM 19	1011.00 - 1069.02		17,300			0.243		3

Borehole	**Hydraulic test or Pore water sample**	**Depth range**	**Conductivity (σ_f)**	**Chloride (*Cl*)**		**Fluid Resistivity (*Rw*)**			**Data source**
			Hydro test	**Hydro test**	**Pore water**	**Hydro test (from σ_f)**	**Hydro test (from *Cl*)**	**Pore water (from *Cl*)**	
		mbRT	**mS/cm**	mg/l	mg/l	**Ω m**	**Ω m**	**Ω m**	
BH2	1104/P27	1049.01 - 1049.50			17,010			0.247	1
BH2	EPM 20	1066.50 - 1112.35		15,000			0.278		3
BH2	1105/P27	1105.95 - 1106.45			7,400			0.532	1
BH2	1106/P27	1154.71 - 1155.21			15,945			0.262	1
BH2	1107/P27	1200.91 - 1201.45			9,668			0.417	1
BH2	PDDET 6B	1191.35 - 1223.49	40.4	15,200		0.248	*0.274*		3
BH2	1108/P27	1248.98 - 1249.48			8,731			0.458	1
BH2	1109/P27	1303.93 - 1304.43			7,597			0.520	1
BH2	1110/P27	1349.76 - 1350.26			9,195			0.436	1
BH2	1111/P27	1399.50 - 1400.00			10,874			0.374	1
BH2	PDDET 5	1423.83 - 1474.31	33.3	15,100		0.300	*0.276*		3
BH2	1112/P27	1449.61 - 1450.11			14,603			0.285	1
BH2	1113/P27	1499.85 - 1500.35			9,229			0.435	1
BH2	1114/P27	1552.32 - 1552.88			14,202			0.292	1
BH2	PDDET 1	1586.07 - 1601.54	44.1	17,200		0.227	*0.245*		3
BH2	DET 7	1587.00 - 1601.81	47.1	17,400		0.212	*0.242*		3
BH2	1115/P27	1608.09 - 1608.59			17,674			0.238	1
		Mean				0.267 (17)		**0.389(23)**	
		Overall mean						**0.337 ± 0.108 (40)**	
BH3	1465/P27	1626.77 - 1627.27			92,795			0.056	1
BH3	1466/P27	1648.89 - 1649.43			73,145			0.067	1
BH3	1467/P27	1674.50 - 1674.80			78,003			0.064	1
BH3	FST2	1675.00	226.0			0.044			2
BH3	DET 7	1671.00 - 1681.99	203.0	104,000		0.049	*0.051*		3
BH3	1468/P27	1699.94 - 1700.24			80,212			0.062	1
BH3	1469/P27	1727.57 - 1728.07			68,193			0.071	1
BH3	207FE/19a/1	1738.19			290,000			0.036	4

Borehole	Hydraulic test or Pore water sample	Depth range mbRT	Conductivity (σ_f) Hydro test mS/cm	Chloride (Cl) Hydro test mg/l	Pore water mg/l	Fluid Resistivity (Rw) Hydro test (from σ_f) Ω m	Hydro test (from Cl) Ω m	Pore water (from Cl) Ω m	Data source
BH3	207FE/17/1	1738.29			503,000				4
BH3	207FE/15/1	1738.35			4,180			*0.883*	4
BH3	207FE/13/1	1738.43			100,250			0.052	4
BH3	207FE/11/1	1738.59			95,400			0.054	4
BH3	207FE/9/1	1738.73			7,335			*0.536*	4
BH3	207FE/7/1	1738.78			8,490			*0.469*	4
BH3	207FE/5/1	1738.86			99,550			0.053	4
BH3	207FE/3/1	1738.95							
BH3	207FE/1/1	1739.05			6,955			*0.563*	4
BH3	FST3	1740.00	157.0			0.064			2
BH3	1470/P27	1751.71 - 1752.21			87,739			0.058	1
BH3	1471/P27	1771.46 - 1771.96			57,930			0.081	1
BH3	1472/P27	1800.98 - 1801.48			53,043			0.088	1
BH3	1473/P27	1825.71 - 1826.21			58,874			0.080	1
BH3	1474/P27	1849.69 - 1850.19			68,050			0.071	1
BH3	1475/P27	1875.88 - 1876.38			69,927			0.070	1
BH3	1476/P27	1898.96 - 1899.46			78,231			0.063	1
BH3	1477/P27	1924.09 - 1924.59			70,494			0.069	1
BH3	1478/P27	1948.41 - 1948.92			64,298			0.075	1
		Mean				**0.052 (3)**		**0.065 (18)**	
		Overall mean						**0.063 ± 0.013 (21)**	
BH4	DET2	580.50 - 587.38	31.3	12,300		0.319	*0.334*		3
BH4	263/P10/3/7	718.72			103,100			*0.051*	4
BH4	263/P10/3/6	718.73			141,000			*0.042*	4
BH4	263/P10/3/5	718.74			66,900			*0.072*	4
BH4	263/P10/3/3	718.75			26,950			*0.161*	4
BH4	263/P10/3/4	718.75			89,700			*0.057*	4

Borehole	**Hydraulic test or Pore water sample**	**Depth range**	**Conductivity (σ_f)**	**Chloride (*Cl*)**		**Fluid Resistivity (*Rw*)**			**Data source**
		mbRT	**Hydro test mS/cm**	**Hydro test** mg/l	**Pore water** mg/l	**Hydro test (from σ_f) Ω m**	**Hydro test (from *Cl*) Ω m**	**Pore water (from *Cl*) Ω m**	
BH4	263/P10/3/2	718.76			74,650			*0.066*	4
BH4	263/P10/3/1	718.77			132,000			*0.043*	4
BH4	FST1	796.36 - 805.00	36.8			0.272			2
BH4	DET1	804.00 - 810.88	35.1	13,600		0.285	*0.304*		3
BH4	DET1A	870.60 - 877.42		13,400			0.308		3
		Overall mean						**0.296 ± 0.019 (4)**	
BH5	DET1	882.00 - 888.89	36.7	13,400		0.272	*0.308*		2
								0.272 (1)	
BH7A	516/P27	594.54 - 595.02			18,140			*0.233*	1
BH7A	517/P27	658.59 - 659.07			24,582			0.176	1
BH7A	EPM 13	666.00 - 711.07	82.3	35,788		0.122	*0.125*		3
BH7A	518/P27	695.08 - 695.64			33,539			0.132	1
BH7A	519/P27	744.00 - 744.62			27,159			0.160	1
BH7A	520/P27	790.91 - 791.44			33,360			0.133	1
BH7A	521/P27	846.23 - 846.73			27,719			0.157	1
BH7A	PCDET1	879.76 - 895.18	98.4	40,000		0.102	*0.113*		3
BH7A	522/P27	893.13 - 893.62			33,131			0.134	1
BH7A	523/P27	946.25 - 946.84			29270			0.150	1
BH7A	524/P27	995.68 - 996.14			12,381			*0.332*	1
		Mean				**0.112 (2)**		**0.149 (7)**	
		Overall mean						**0.140 ± 0.021 (9)**	

Table 5.1: Summary statistics for BVG formation factor values.

(a) Core sample formation factors (*Fc*); blue dots in Figure 5.6

Borehole	**BH2**	**BH3**	**BH4**	**BH5**	**BH7A**
Mean	2,587	303	684	613	560
Standard deviation	2,066	115	272	309	336
Maximum	12,404	591	1,389	1,685	1,250
Minimum	245	109	199	136	105
Number	97	35	80	75	29

(b) Wireline derived formation factors (*Fw*); black profile in Figure 5.6

Borehole	**BH2**	**BH3**	**BH4**	**BH5**	**BH7A**
Fluid resistivity, Ω m	0.34	0.06	0.30	0.27	0.14
Mean	6,918	1,398	11,411	7,079	2,490
Standard deviation	12,996	897	18,911	16,861	6,479
Maximum	101,544	6,387	114,467	104,736	69,080
Minimum	66	235	121	88	59

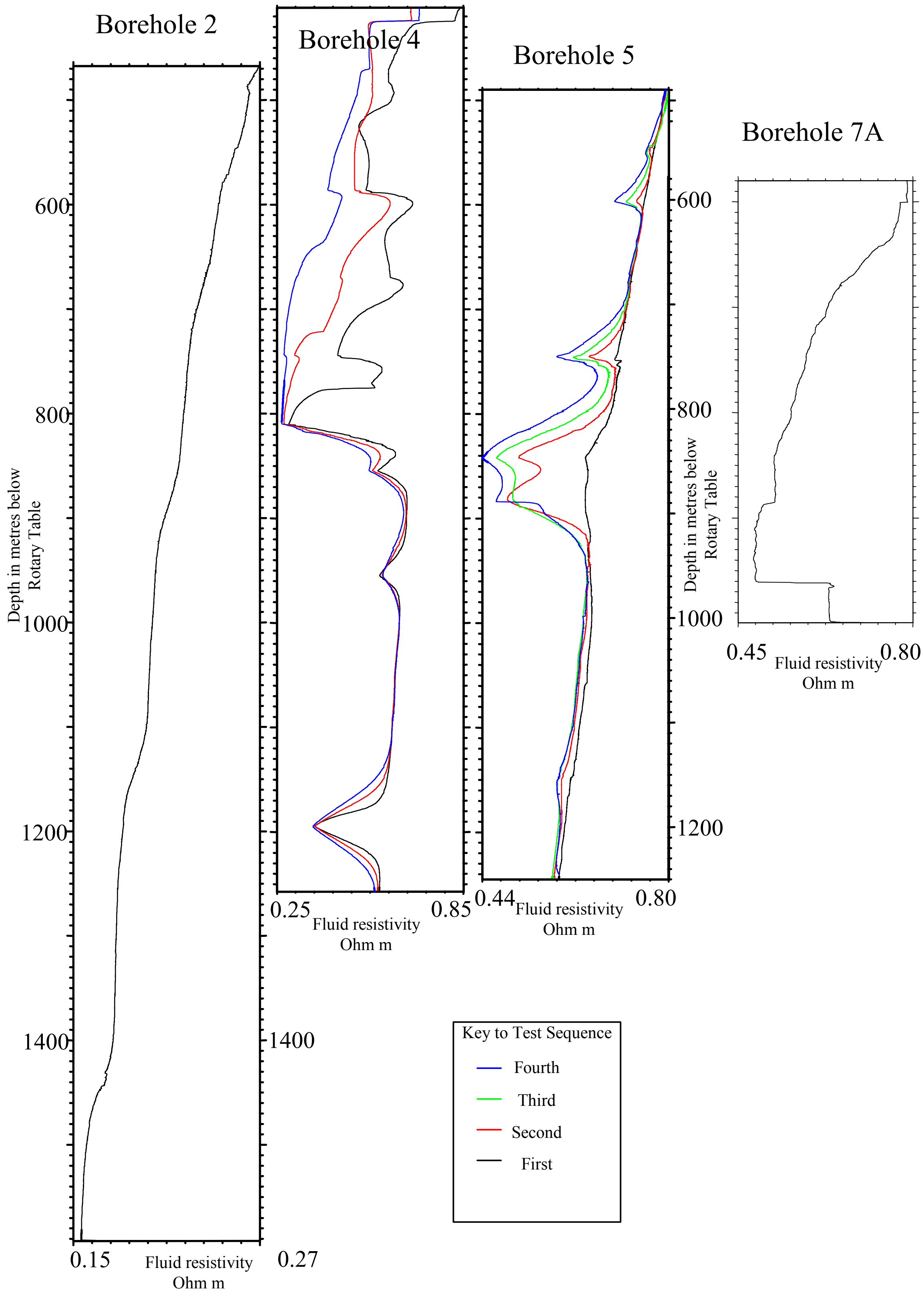

Figure 4.1: Fluid resistivity profiles derived from wireline conductivity logs through the water column of Boreholes 2, 4, and 5 over the BVG depth range (fluid resistivities in Ω m; depths in mbRT).

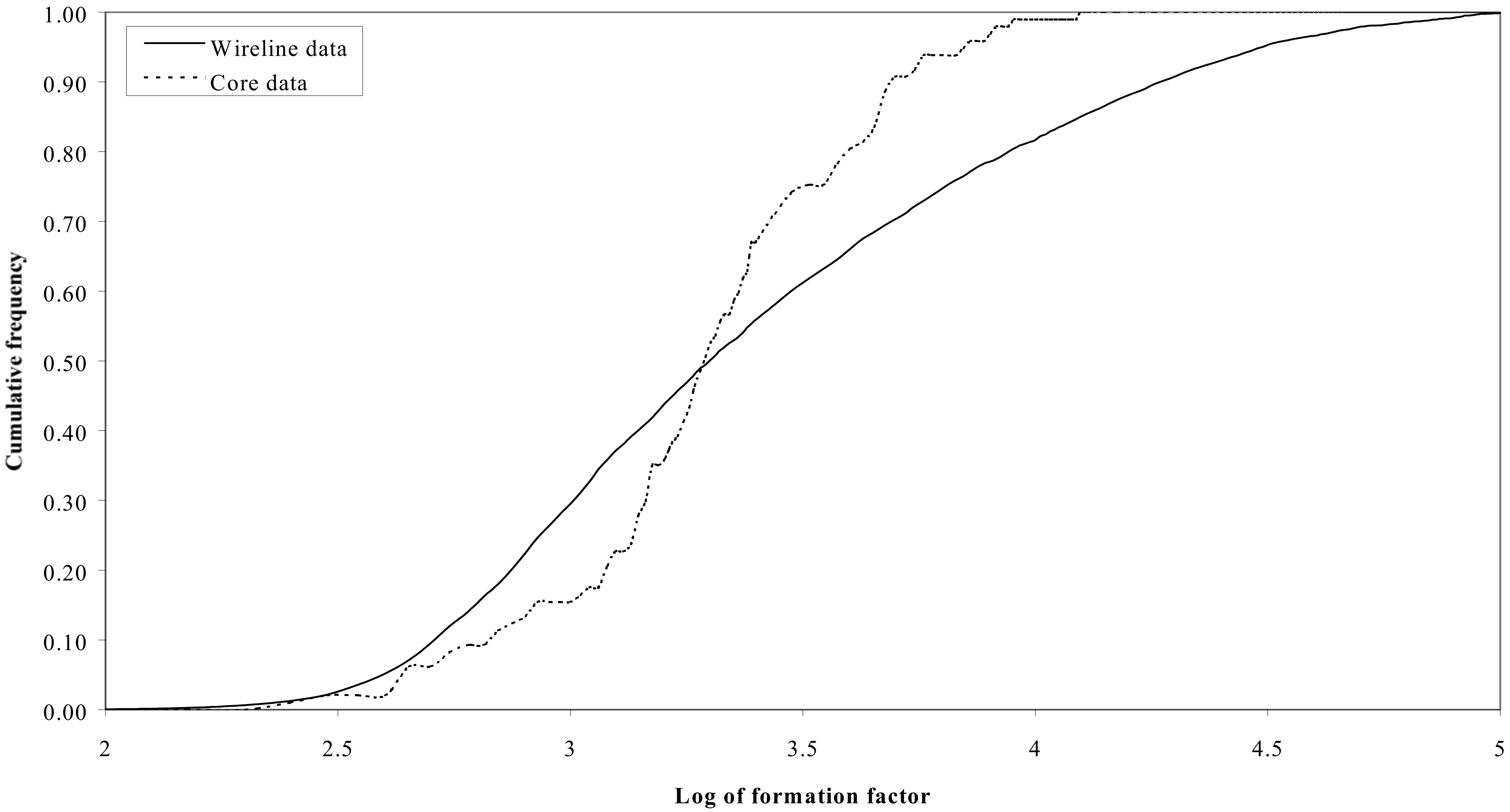

Figure 5.1: Cumulative frequency distributions for Borehole 2 of measured core sample formation factors compared with values derived from the wireline resistivity log (LLD) and a R_w value of 0.34 Ω m.

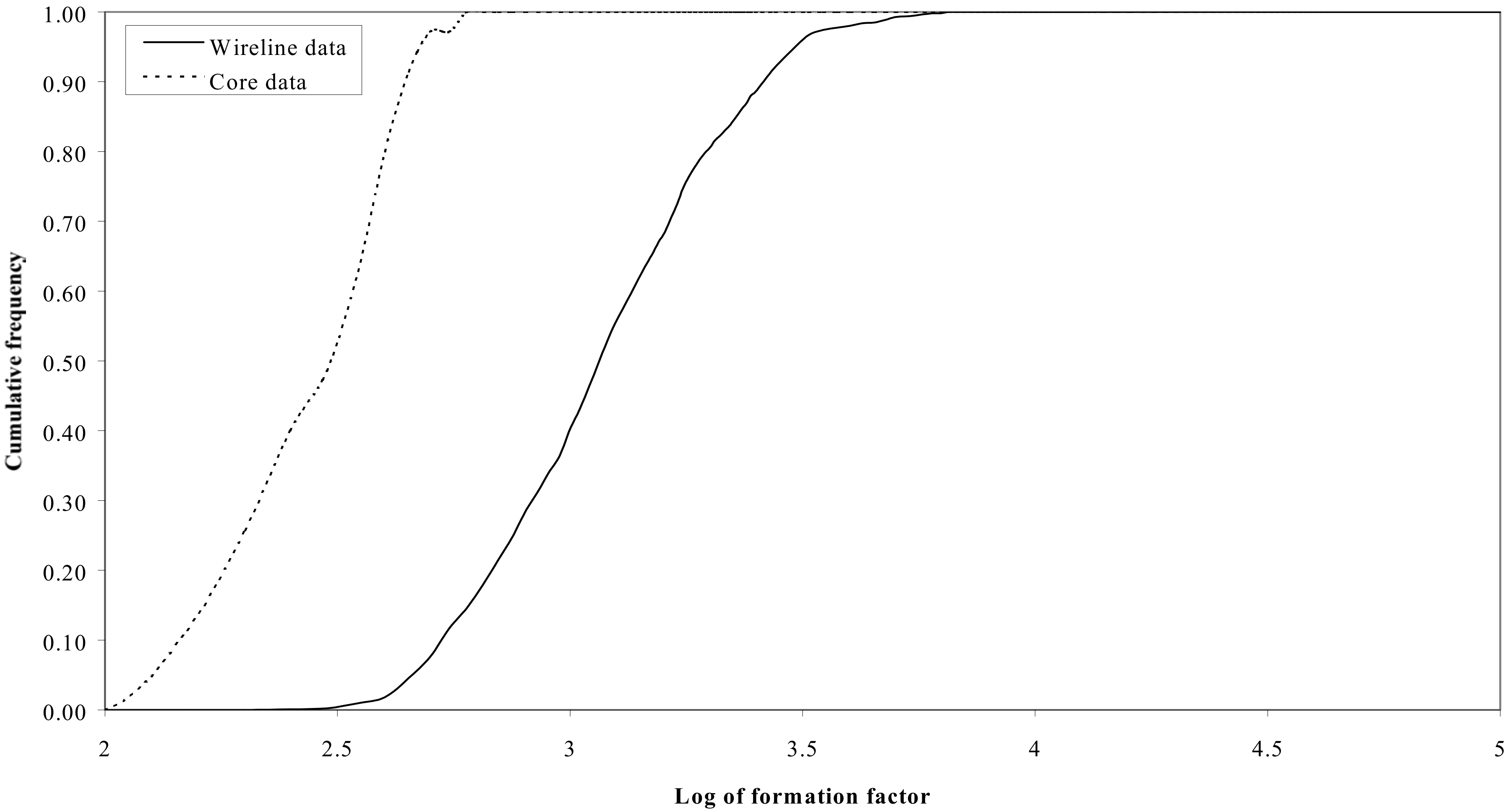

Figure 5.2: Cumulative frequency distributions for Borehole 3 of measured core sample formation factors compared with values derived from the wireline resistivity log (LLD) and a R_w value of 0.06 Ω m.

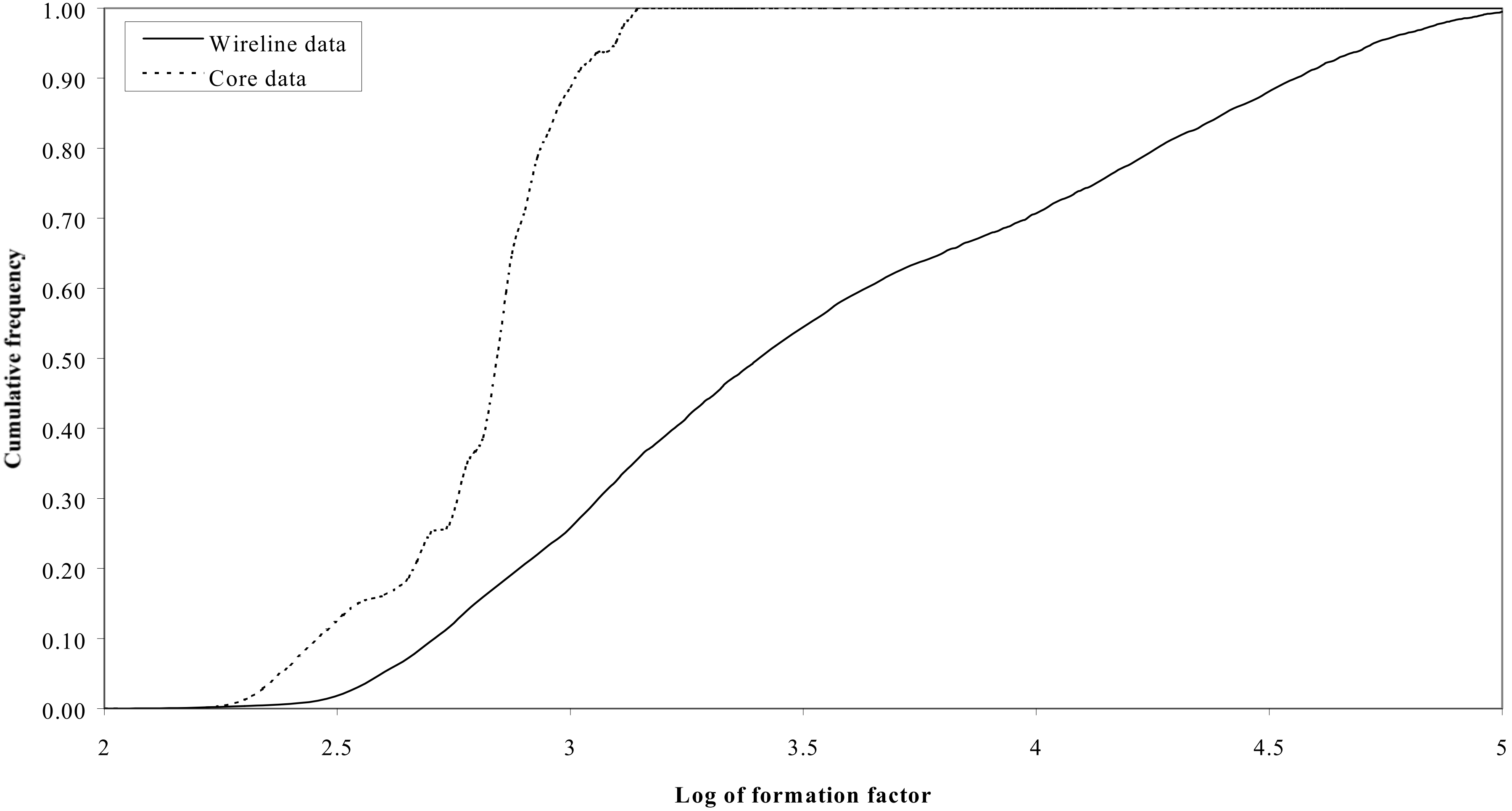

Figure 5.3: Cumulative frequency distributions for Borehole 4 of measured core sample formation factors compared with values derived from the wireline resistivity log (LLD) and a R_w value of 0.30 Ω m.

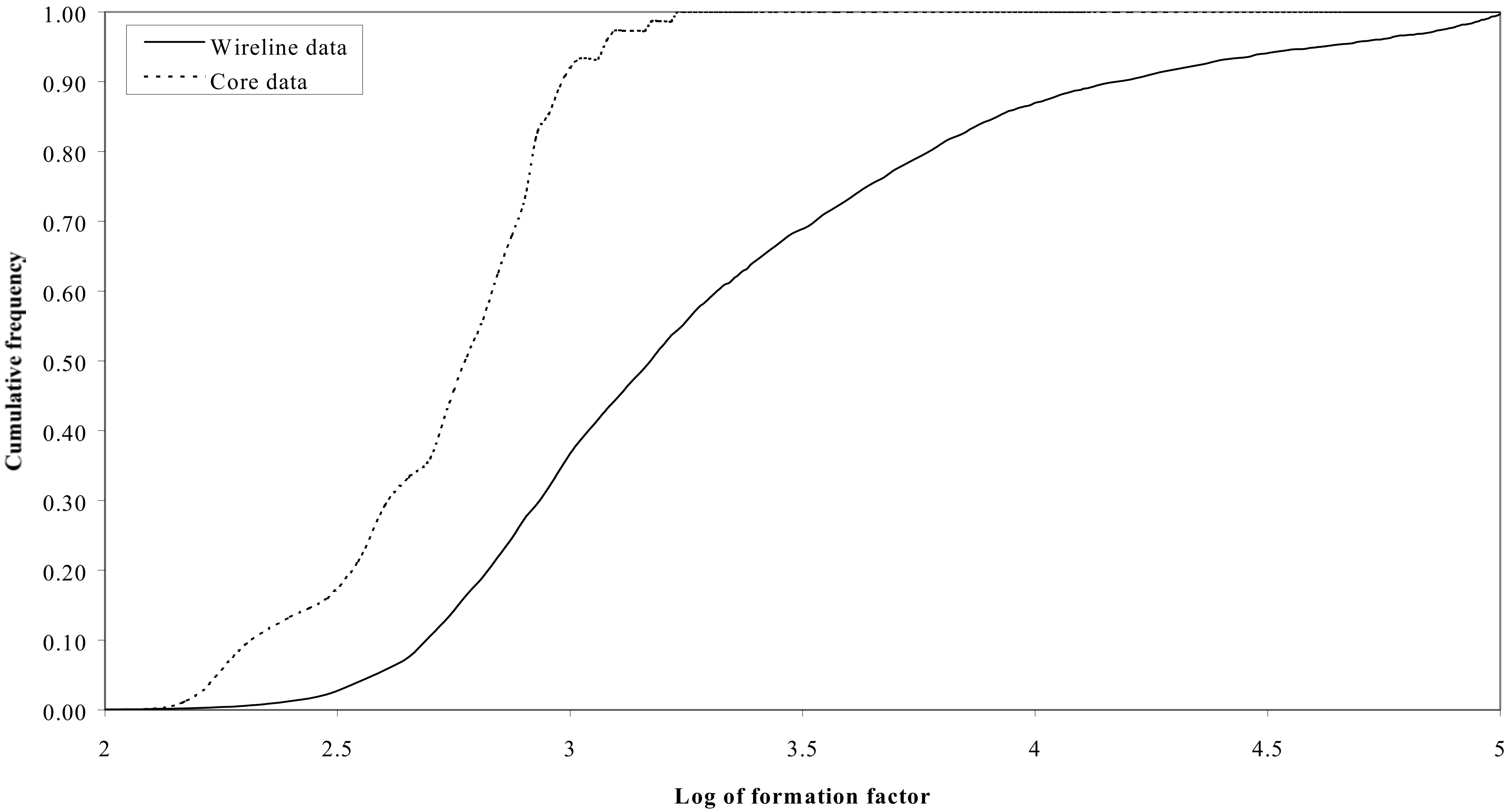

Figure 5.4: Cumulative frequency distributions for Borehole 5 of measured core sample formation factors compared with values derived from the wireline resistivity log (LLD) and a R_w value of 0.27 Ω m.

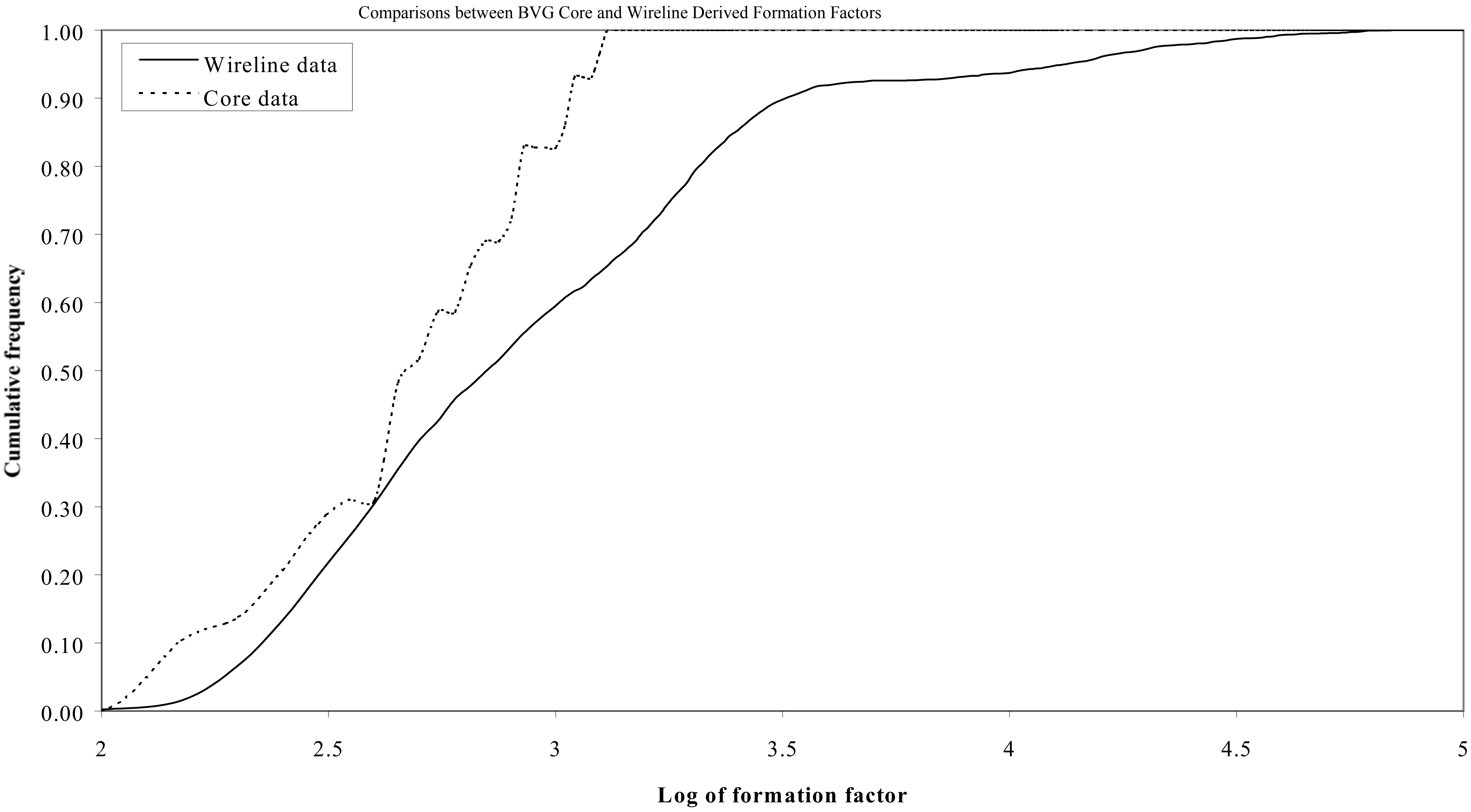

Figure 5.5: Cumulative frequency distributions for Borehole 7A of measured core sample formation factors compared with values derived from the wireline resistivity log (LLD) and a R_w value of 0.14 Ω m.

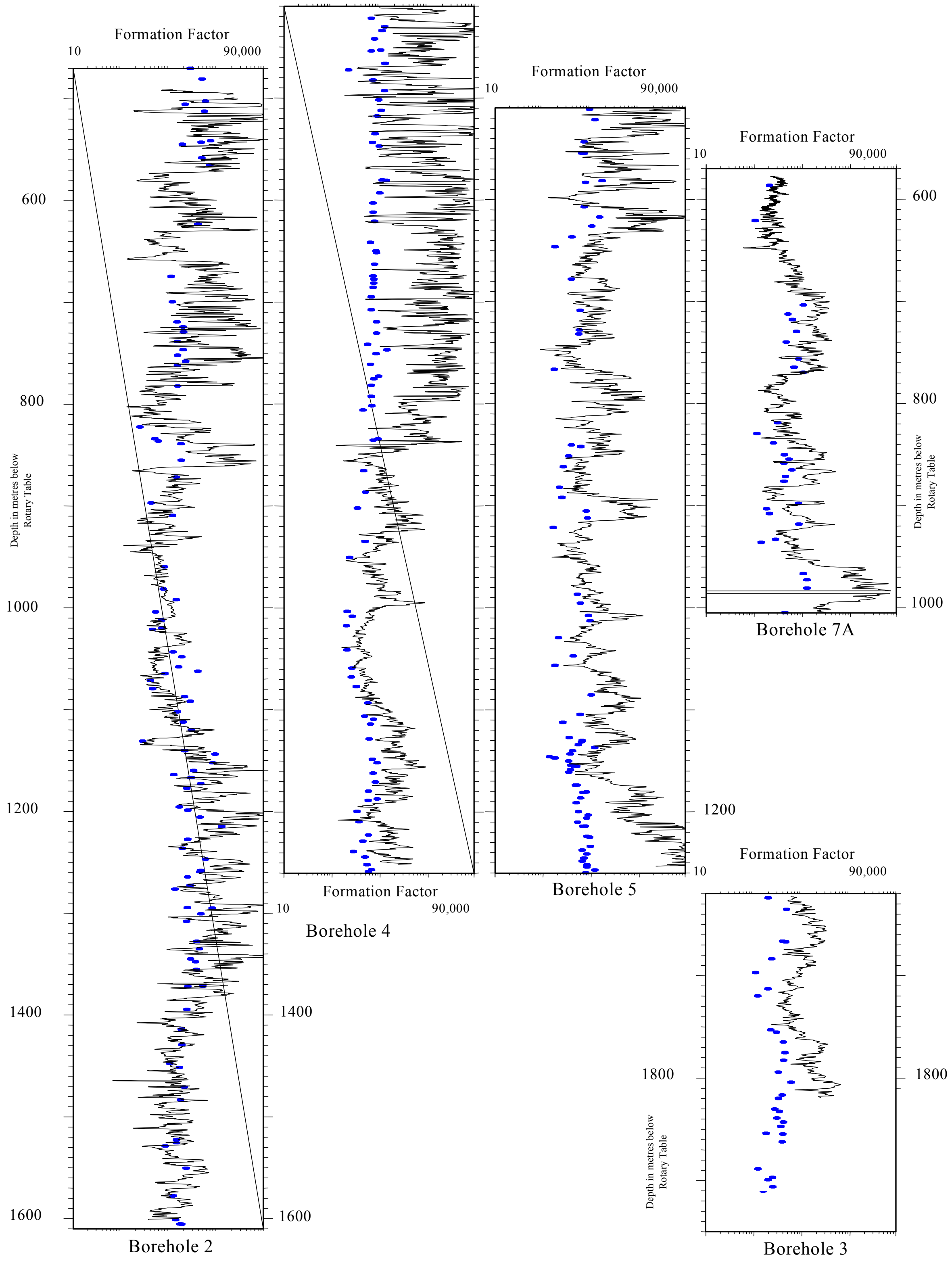

Figure 5.6: Formation factor profiles for Boreholes 2, 3, 4, 5 and 7A over the BVG depth range (formation factors are on a logarithmic scale from 10 to 90,000; depths in mbRT). The black profiles are wireline derived values using the fluid resistivities described in the text. The blue dots are core derived values.

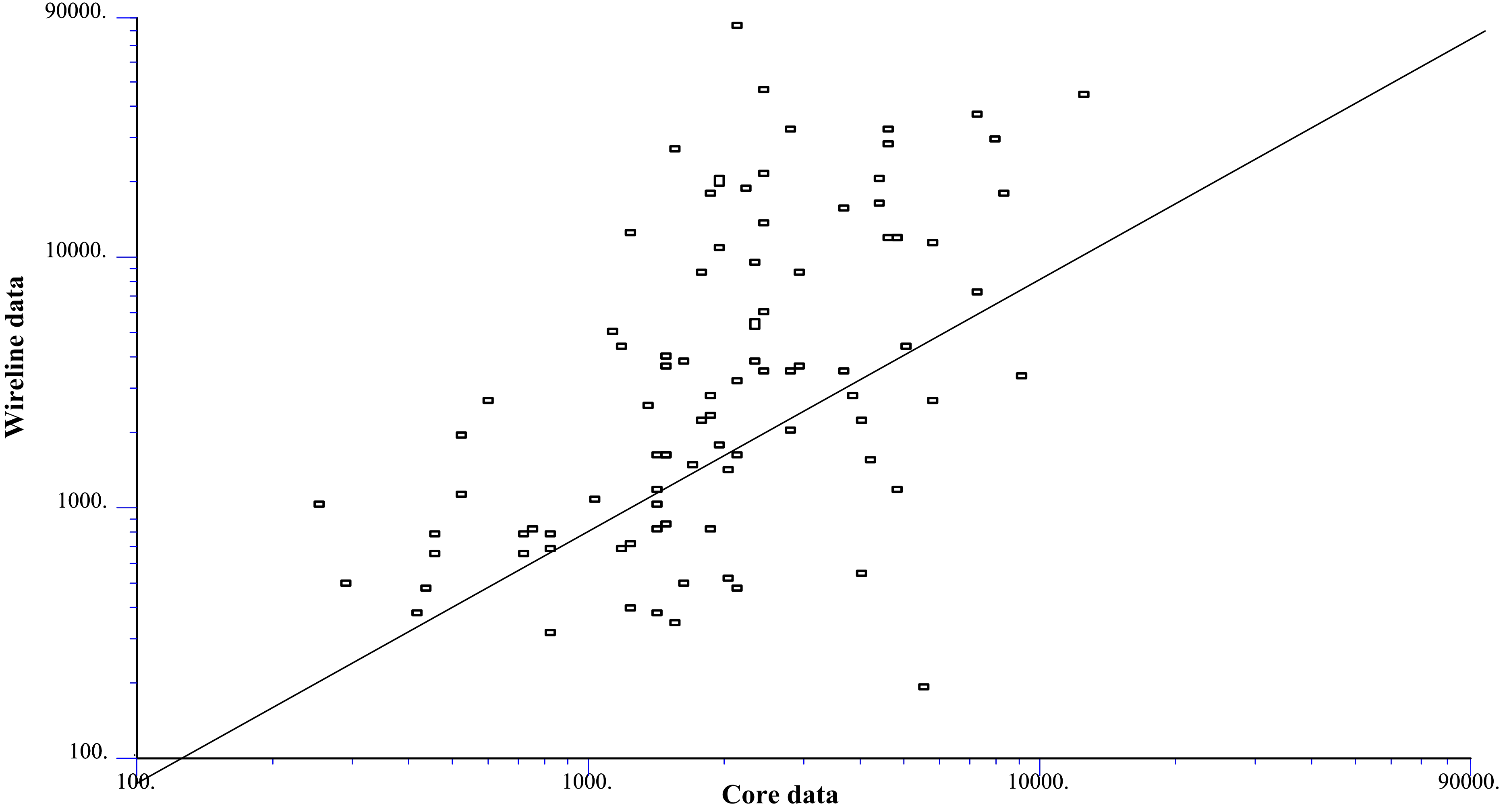

Figure 5.7: Correlation between formation factors derived from core samples and from wireline resistivity for Borehole 2

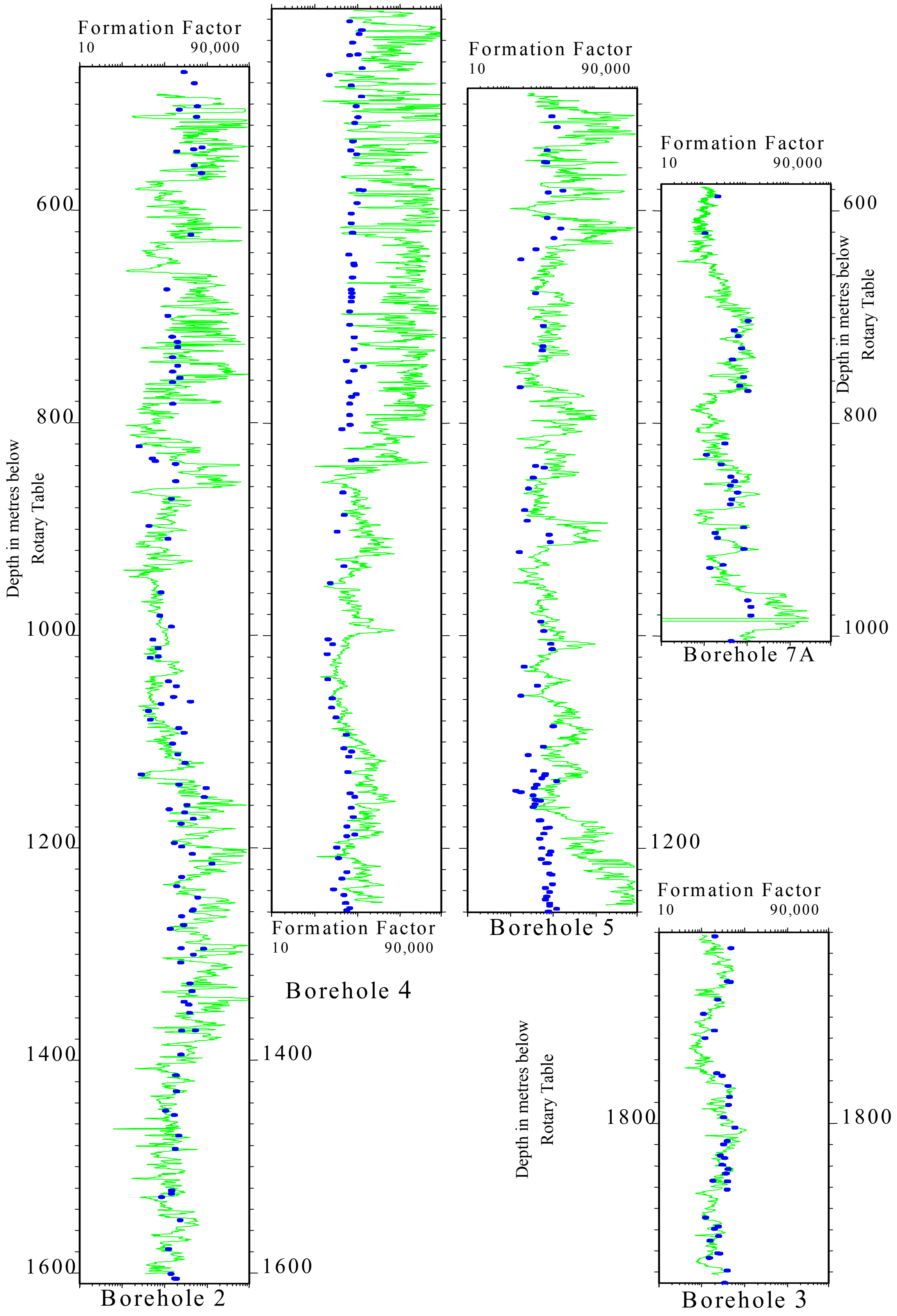

Figure 5.8: Formation factor profiles for Boreholes 2, 3, 4, 5 and 7A over the BVG depth range (formation factors are on a logarithmic scale from 10 to 90,000; depths in mbRT). The green profiles are wireline derived values using a single fluid resistivity of 0.35 Ω m for all boreholes. The blue dots are core derived values.