Why the resistivity log should not be used to calculate or predict pore pressure in the North Sea

Carl Fredrik Gyllenhammar[1]* compares 98 wells from the North Sea with wells from several basins around the world using sonic, density, neutron, gamma ray and resistivity as well as Principal Component Analysis.

Abstract

Models to calculate pore pressure from the resistivity log have been developed in the Gulf of Mexico since the 1960s. The same approach has been difficult in the North Sea. Eight hundred released Norwegian exploration wells have been studied in detail. The statistical relationship between the following five logs; the sonic, density, neutron, gamma ray and resistivity log evaluated on 98 selected exploration wells. The statistical method chosen is the Principal Component Analysis. It suggests that the resistivity response is more or less random compared to the typical porosity logs; density, neutron and sonic. Which suggests that no porosity or compaction information can be extracted from the resistivity log in the North Sea, Norwegian Sea or the Barents Sea. The resistivity log should therefore not be used to calculate porosity or predict or calculate pore pressure offshore Norway, UK, Denmark or Holland.

It has been suggested that the main case for the random resitivity (salinity) could be fresh water input form the glacial ice cover during Quaternary. But there are also studies that suggest there must be a meteoric water influx that is much older than Quaternary. Influx, not from the surface and down, but either laterally or from deeper down in the strata.

This suggests that detailed resistivity analysis must be done prior to interpreting CSEM data. So, fare CSEM acquired in the North Sea have given questionable results.

Introduction

Models to calculate pore pressure from the resistivity log have been developed in the Gulf of Mexico (GoM) since the famous publication by Hottman and Johnson in 1965. In 1986, I was confronted by the idea of using the resistivity log to calculate pore pressure in the North Sea (NS). Before, I had only used the sonic log that clearly represent compaction. The advantage of the resistivity log was the availability and coverage. Then the gamma ray and resistivity measurement were included in the Teleco's MWD tool in the early 1980s and it became normal practice to do these measurements from just a few hundred metres below seabed. It became quickly evident to me that no compaction curve could be established from the resistivity curve in the NS, although it led to less than favourable comments from colleges in the US. It culminated in 1998, when I resigned and went to Durham University and joined the GeoPoP team to do a PhD with the aim of solving this issue.

At that time, I had only access to log data from five Norwegian exploration wells, but the results from running Principal Component Analysis (PCA) were clear; the resistivity log was random with respect to the sonic, density and neutron log in the NS (Gyllenhammar, 2003). All five wells showed the same results: that the resistivity log was random with respect to the compaction trend derived from the sonic, density and neutron curve.

In the GoM the resistivity log has been successfully used to measure pore-pressure as well as being used in equations to calculate pseudo density curves (Hottman and Johnson, 1965). In this study 98 wells from the Norwegian sector have been analysed and compared with wells from several basins around the world. The five logs used in this study are sonic, density, neutron, gamma ray and resistivity. In the same statistical analysis, PCA was applied and proves that the resistivity curve in the NS do not represent compaction.

Background

As a Conoco wellsite geologist, I was expected to do pore-pressure prediction while drilling. Following the development of MWD/LWD resistivity and gamma ray, normal compaction correlations with the resistivity measurements were developed in the GoM with success. Applying the same methodology on the on the other side of the Atlantic Ocean in the North Sea, Norwegian Sea and Barents Sea was not so successful. In some cases, it appeared to work, but only by adjusting the normal trend many times on one single well. Seldom has Eaton's famous statement from 1975 been truer; 'the methods used to establish normal trends vary as much as the number of people who do it' (Eaton, 1975).

A data set was created by loading all the logs normally used to interpret a well from all 1500 released exploration wells in the Norwegian sector into a standard interpretation software. The criteria for selecting wells for this analysis was that the well must be relatively vertical, and drilled relatively deep. The sonic (HDT), density (HRHOB), Neutron (HNPHI), gamma ray (HGR) and resitivity (HRD) log must be run from 1000 m or shallower

[1] Independent consultant, CaMa GeoScience

* Corresponding author, E-mail: cfg@camageo.no

DOI: xxx

	PC1	PC2	PC3	PC4	PC5
Eigenvalue	3.1846	1.0001	0.4831	0.1861	0.1462
Proportion	0.637	0.200	0.097	0.037	0.029
Cumulative	0.637	0.837	0.934	0.971	1.000

Table 1 Eigen-analysis of the Correlation Matrix for well 34/10-20. This shows the Eigenvalues for the five principal components, with their proportions and cumulative proportions.

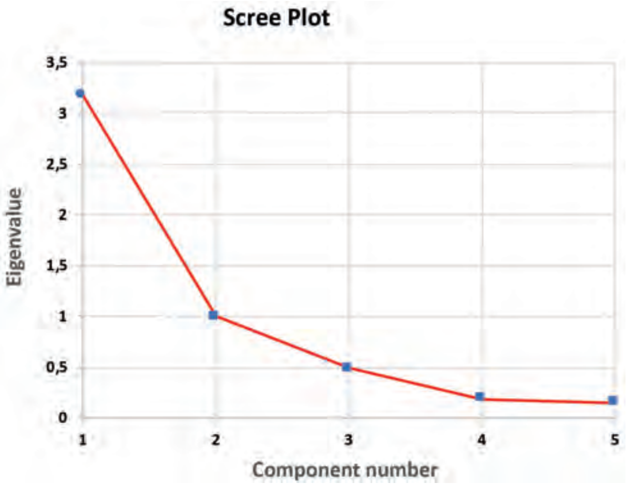


Figure 1 The scree plot (Eigenvalues) for well 34/10-20.

Variable	PC1	PC2	PC3
HDT	0.514	0.001	0.366
HRHOB	-0.515	-0.011	-0.367
HNPHI	0.521	-0.003	0.009
HGR	0.446	-0.004	-0.855
HRD	-0.003	1	-0.008

Table 2 Scores (loadings) for the first three principal components, well 34/10-20.

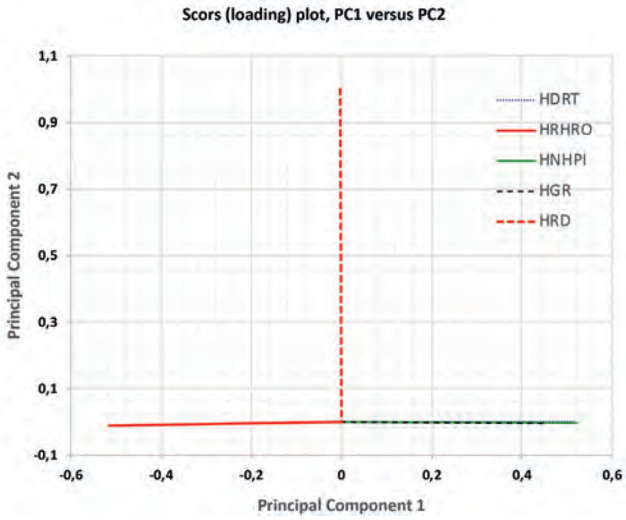


Figure 2 Scores (loading) plot for 34/10-20. PC1 on the x-axis and PC2 on the y-axis.

down to TD, and the well should be relatively dry. Relatively dry in this context mean no substantial hydrocarbon (HC) column.

Based on these criteria, 98 wells were selected: 61 from the NS, 16 from the Norwegian Sea and 21 from the Barents Sea. These wells were compared with some wells from the GoM, Vietnam, Nile Delta, Morocco offshore and the Caspian Sea.

Principal Component Analysis

Many petrophysical software packages have PCA included. PCA is very sensitive to bad or wrong data. This tends to occur at the top and bottom of each log run as well at each casing shoe level. In this case all five logs were exported to Excel and all bad data deleted. Then they were loaded into Minitab.

For PCA analysis there are two options: Correlations or Covariance. With Correlation selected in our case; the software will standardize all variables prior to running PCA. Standardizing means centring the variables at zero and standardizing the variance at 1. The average value will then be 0 and the standard deviation 1 for all five curves.

Multivariate statistical methods, such as PCA, are a useful tool to test the importance of each variable with respect to any common trend as well as showing the potential relationship between logs. In an exploration well several different physical properties (data) are measured using the same sample depth interval. The standardization converts the variance-covariance matrix to a matrix of correlation coefficients. The correlation matrix can be illustrated geometrically as an ellipse (Doveton, 1986). The major and the minor axis of the ellipse is the principal components of the correlation matrix, or the eigenvectors (Table 1). There will be the same number of axes as variables/dimensions (Jolliffe, 1986). The first principal component (PC1) will represent the most important and common variability trend in the data set. In our study with five wireline logs, the data points projected on to the PC1 are scaled in terms of the major source of common variation between the different logs. The sum of the eigenvalues from each log should be the same as the number of variables, in our case; 5, seen in Table 1 and Figure 1. Their relative location on this axis are calculated as scores (often called loadings) (Table 2 and Figure 2).

The scree plot is a graphical presentation of the eigenvalues listed in Table 1, first proposed by Cattell (1966). Cattell suggested using the scree plot to find the place where the smooth decrease of eigenvalues appears to level off as a method of determining the importance of individual Principal Components. The initial screening of the data is often done using this plot.

The Kaiser criterion suggests that we should only retain factors with eigenvalues greater than 1 (Kaiser, 1960). PCA indicate which variables in a data set that are important and which ones may be of little importance. Some of the low-importance variables might therefore be 'weeded out' and removed from consideration in order to simplify the overall analyses. That would, for example, be the case in pollution studies searching for the most important source.

Well 34/10-20 (Norway), was selected quite randomly from the list of 98 wells, to show what analysis was done on each of the 98 Norwegian wells, including the international wells.

If one followed Kaiser's criterion in the case of 34/10-20 one would only retain PC1 and PC2. In log evaluation the importance is the eigenvalues of each wireline log with respect to each principal component and its corresponding loading. For 34/10-20, 63% of the variability is represented by PC1, 20% for PC2 and 10% for PC3, and thus 93% of the variability is captured in the first three principal components axis. The three first principal components are therefore included in the following evaluation. The graph of the loading values of PC1 shows that the sonic, density and neutron log in many ways represent PC1 (Figure 2), while the resistivity has limited to no influence on PC1. In this particular well, the gamma ray is also an important part of PC1 (score at 0.446), which is not the case in other wells.

Example using well 34/10-20

Table 2 and Figure 2 shows the scores of PC1 versus PC2 to reflect their relative influence on those two principal components. The scores for PC1 show that the sonic, density and neutron measurements all have an absolute score of about 0.52. The same logs have scores close to zero for PC2. The resistivity in this well has the largest score on PC2 (1.0). In fact, 1.0 is the maximum possible score, but close to zero on PC1. The gamma ray has some influence on PC1 (0.446), but controls PC3 (-0.855).

Table 3 lists only wells from Norway. First; the eigenvalues of the three first principal components followed by the corresponding scores of the resistivity log for each of these first principal components. The last three columns show the eigenvalue proportions. The yellow is just to highlight the scores of the resistivity log on PC1. The red highlighted where the resistivity log has the highest score, or most influence.

What does PC1 represent?

Summing up the proportions in table 3 shows that the sum of the three first principal components is on average 92% for these 98 Norwegian wells. The bulk of the data cloud is constrained to a three-dimensional ellipsoid crossing through an imaginary five-dimensional space. The question is what do they represent? Doveton (1986) did the same test on onshore wells in Oklahoma, using in addition to the same five logs, the spontaneous potential log. In that case the first two principal components accounted for 98% of the variability. He concluded that the variability was a function of changing porosity and volume of clay.

Figure 3 shows that the PC1 are tracking all three porosity curves; sonic, density and the neutron curve. Which suggest that PC1 is closely connected to reduction of porosity with depth or rather general compaction. But what about PC2 and PC3?

For the Norwegian wells PC1 represents on average 58% of the variability, compared to 21% for PC2 and 14% for PC3. When the resistivity log controls PC2, the gamma ray log controls PC3, or opposite. Table 3 show that the resitivity curve control PC2 in 37 of the 98 wells listed and PC3 for the remaining 61 wells. Figure 4 show how well the gamma ray curve track PC2 and the resistivity PC3 in well 34/10-20.

While the PC2 in Doveton's study was interpreted to be a function of volume of clay, the situation in offshore Norway is somewhat more complex. With the gamma ray track PC2 or PC3, it is likely that the answer is the same as in Doveton's case; it is a function of the volume of clay.

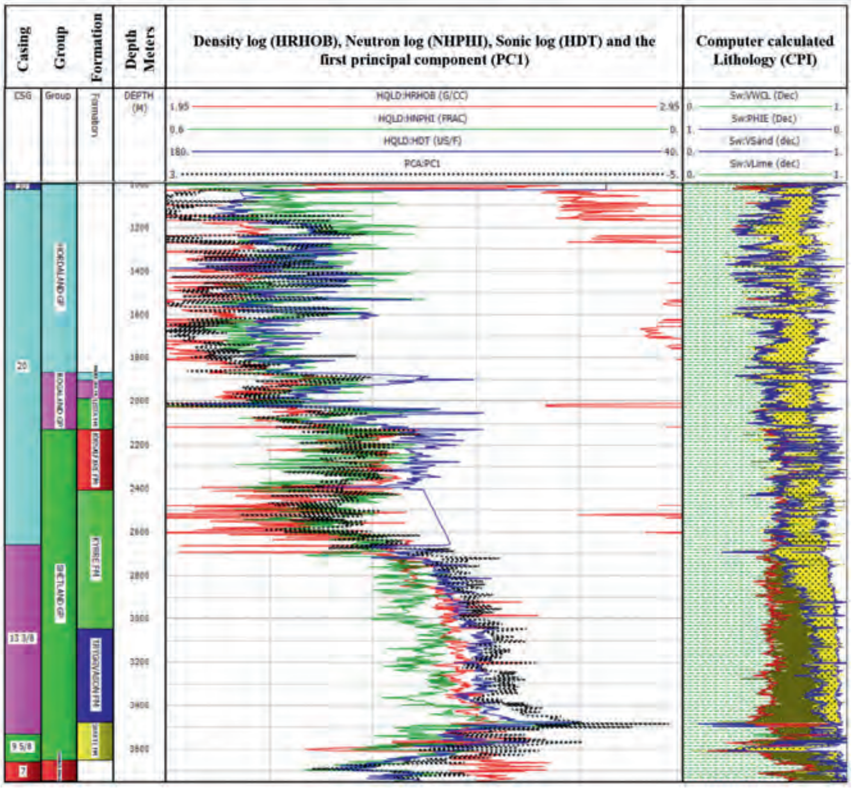


Figure 3 Well 34/10-20. Track 4 shows the PC1 (black dots) compared with the density, neutron and the sonic log.

Well	Eigenvalue			Deep resistivity score			Eigenvalue Proportion		
Norway	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
1/2-1	3.76	0.62	0.44	-0.35	-0.93	0.01	0.75	0.12	0.09
1/2-2	3.58	0.74	0.45	-0.39	0.63	0.53	0.72	0.15	0.09
1/3-3	3.59	0.77	0.48	-0.29	0.94	0.18	0.72	0.15	0.10
1/3-4	4.12	0.56	0.22	-0.36	0.92	0.15	0.83	0.11	0.04
1/6-6	3.64	0.75	0.51	-0.39	-0.03	0.92	0.73	0.15	0.10
1/6-7	4.09	0.47	0.35	-0.39	0.88	-0.27	0.82	0.09	0.07
2/2-1	2.42	1.01	0.89	0.02	0.98	0.15	0.48	0.20	0.18
2/2-4	2.39	1.01	0.95	0.06	-0.95	-0.27	0.48	0.20	0.19
2/5-7	3.11	0.97	0.76	-0.13	0.99	0.10	0.62	0.19	0.15
2/11-9	2.48	1.09	0.85	-0.36	0.55	-0.57	0.50	0.22	0.17
3/7-2	2.74	1.01	0.68	0.00	0.99	0.11	0.55	0.20	0.14
3/8-1	3.32	1.03	0.47	-0.10	0.96	0.18	0.66	0.21	0.09
6/3-1	3.22	0.96	0.65	-0.36	0.25	-0.90	0.64	0.19	0.13
7/7-3	3.10	0.93	0.57	-0.34	0.62	0.71	0.62	0.19	0.12
7/8-3	3.68	0.71	0.46	-0.32	0.92	0.21	0.74	0.14	0.09
7/8-4	3.77	0.59	0.53	-0.38	0.58	0.71	0.75	0.12	0.11
7/11-8	2.60	0.98	0.37	-0.10	1.00	0.02	0.65	0.25	0.09
9/1-1S	2.59	1.44	0.71	-0.36	0.25	0.90	0.52	0.29	0.14
9/2-1	2.00	1.02	0.99	-0.07	-0.43	0.90	0.40	0.20	0.20
9/2-7S	2.37	1.25	1.02	-0.11	0.16	-0.86	0.40	0.21	0.17
9/3-1	2.15	1.17	0.89	-0.29	-0.66	0.14	0.43	0.23	0.18
10/7-1	3.34	0.89	0.38	-0.27	0.90	-0.30	0.67	0.18	0.08
9/2-11	2.39	1.25	1.03	0.03	0.40	-0.87	0.48	0.25	0.21
15/6-7	3.36	0.77	0.68	-0.30	0.92	-0.24	0.67	0.15	0.14
15/12-23	3.11	0.97	0.69	-0.19	0.90	-0.36	0.62	0.20	0.14
16/1-3	2.64	1.05	0.91	-0.17	0.54	0.82	0.53	0.21	0.18
16/1-16	2.72	1.00	0.87	0.26	-0.20	0.94	0.54	0.20	0.17
16/1-21S	2.84	1.15	0.53	-0.20	-0.80	-0.51	0.57	0.23	0.11
16/2-4	3.04	1.10	0.69	-0.31	-0.47	-0.82	0.61	0.22	0.14
16/3-8S	3.21	0.94	0.66	-0.17	0.97	-0.15	0.64	0.19	0.13
16/4-1	3.09	0.93	0.74	-0.22	0.90	-0.37	0.62	0.19	0.15
16/4-6S	3.26	1.10	0.39	-0.46	0.02	0.88	0.65	0.22	0.08
16/5-4	3.00	1.01	0.83	-0.14	0.86	-0.49	0.60	0.20	0.17
16/5-5	3.32	1.16	0.32	0.49	0.13	-0.67	0.67	0.23	0.06
16/10-1	3.26	1.00	0.59	-0.01	1.00	-0.03	0.65	0.20	0.12
17/6-1	2.30	1.55	0.78	-0.36	-0.24	-0.88	0.46	0.31	0.16
17/9-1	2.53	1.12	0.73	-0.39	-0.37	0.76	0.51	0.22	0.15
17/10-1	2.70	1.81	0.28	-0.17	0.68	0.43	0.54	0.36	0.06
18/10-1	2.74	1.18	0.82	0.29	0.33	-0.88	0.55	0.24	0.16
24/12-2	2.05	1.20	0.94	0.10	-0.45	0.88	0.41	0.24	0.19
25/8-6	2.46	1.12	0.93	-0.06	0.58	-0.81	0.49	0.22	0.19
25/8-8S	2.74	0.99	0.84	0.31	0.26	0.89	0.55	0.20	0.17
25/8-9A	2.54	1.00	0.88	0.02	0.99	0.16	0.51	0.20	0.18
25/8-14S	2.82	1.03	0.95	0.00	0.83	0.56	0.56	0.21	0.19
25/10-7S	2.48	1.16	0.77	-0.33	0.42	0.81	0.50	0.23	0.15
25/10-9	3.36	1.04	0.36	0.46	0.17	0.85	0.67	0.21	0.07
25/10-10	2.88	0.98	0.79	0.27	0.58	-0.75	0.58	0.20	0.16
30/11-14	2.54	1.13	1.00	0.02	0.07	-1.00	0.51	0.23	0.20
31/2-8	2.95	1.23	0.57	-0.36	-0.44	-0.81	0.59	0.25	0.11
31/2-10	2.57	1.06	0.97	-0.09	-0.40	0.91	0.51	0.21	0.20
31/4-2	3.21	1.03	0.40	0.48	0.09	-0.63	0.64	0.21	0.08
31/6-1	2.60	1.18	0.80	-0.24	-0.59	0.73	0.52	0.24	0.16
33/9-17	3.54	0.67	0.54	0.40	0.19	-0.88	0.71	0.13	0.11
33/12-6	2.72	1.12	0.71	0.38	0.14	-0.91	0.54	0.23	0.14
34/4-3	3.76	0.53	0.47	0.40	0.83	-0.21	0.75	0.11	0.09
34/8-5	3.30	0.99	0.51	0.42	0.00	0.90	0.66	0.20	0.10
34/10-20	3.18	1.00	0.48	0.00	1.00	-0.01	0.64	0.20	0.10
35/1-1	3.32	1.16	0.23	-0.23	0.82	-0.11	0.66	0.23	0.05
35/3-4	2.65	1.11	0.94	0.11	0.51	0.85	0.53	0.22	0.19
35/4-1	3.44	0.75	0.52	-0.42	0.32	-0.74	0.69	0.15	0.10
35/11-11	2.73	1.14	0.83	-0.29	-0.16	0.94	0.55	0.23	0.17
6201/11-1	3.55	1.04	0.28	0.47	-0.14	0.85	0.71	0.21	0.06

Well	Eigenvalue			Deep resistivity score			Eigenvalue Proportion		
6204/10-1	2.76	1.24	0.72	0.13	0.70	0.71	0.55	0.25	0.14
6204/11-1	2.41	0.91	0.57	-0.29	0.90	0.32	0.60	0.23	0.14
6406/2-7	2.68	1.15	0.96	-0.04	0.45	-0.89	0.54	0.23	0.19
6406/3-1	2.89	0.89	0.72	0.37	0.18	0.89	0.58	0.18	0.14
6406/9-2	3.11	1.03	0.68	-0.38	0.23	0.84	0.62	0.21	0.14
6407/2-1	2.63	1.09	0.84	0.04	0.79	0.61	0.53	0.22	0.17
6407/6-1	2.88	0.95	0.76	0.25	0.88	-0.32	0.58	0.19	0.15
6407/8-3	2.37	1.05	0.99	0.03	0.37	-0.93	0.47	0.21	0.20
6407/8-7	2.65	1.07	0.98	-0.04	0.41	0.91	0.53	0.22	0.20
6407/9-5	2.47	0.96	0.80	-0.26	0.75	-0.61	0.49	0.19	0.16
6407/9-8	2.36	1.00	0.91	0.29	0.57	0.70	0.47	0.20	0.18
6408/4-1	2.88	1.20	0.65	-0.30	-0.62	0.65	0.58	0.24	0.13
6507/2-1	2.93	1.01	0.66	-0.42	0.16	0.80	0.59	0.20	0.13
6607/11-1	2.74	1.06	0.74	0.33	0.48	-0.77	0.55	0.21	0.15
6610/3-1R	3.14	0.85	0.48	0.38	-0.71	-0.19	0.63	0.17	0.10
7119/7-1	3.66	0.76	0.36	0.33	0.85	0.42	0.73	0.15	0.07
7119/9-1	2.16	1.55	0.74	-0.31	0.40	0.86	0.43	0.31	0.15
7119/12-2	2.40	1.54	0.66	0.30	0.50	-0.74	0.48	0.31	0.13
7120/1-2	2.67	1.33	0.63	0.32	0.49	0.80	0.54	0.27	0.13
7120/2-1	2.94	0.98	0.69	0.17	0.92	-0.34	0.59	0.20	0.14
7120/6-3S	3.16	0.89	0.82	0.28	0.33	0.89	0.63	0.18	0.16
7120/9-2	2.74	1.16	0.73	0.16	-0.73	0.67	0.55	0.23	0.15
7120/12-4	3.01	1.31	0.41	0.40	-0.45	0.77	0.60	0.26	0.08
7120/12-5	2.89	1.05	0.51	-0.38	0.53	0.75	0.58	0.21	0.10
7122/2-1	2.26	1.75	0.65	0.22	0.66	0.33	0.45	0.35	0.13
7124/3-1	2.94	1.03	0.79	-0.25	0.59	-0.77	0.59	0.21	0.16
7125/1-1	2.49	1.64	0.42	0.17	-0.69	-0.11	0.50	0.33	0.09
7128/6-1	2.69	1.07	0.85	-0.26	0.47	-0.83	0.54	0.21	0.17
7219/9-1	2.46	1.04	0.98	0.06	-0.43	-0.90	0.49	0.21	0.20
7223/5-1	2.44	1.43	0.64	-0.42	-0.27	-0.85	0.49	0.29	0.13
7224/6-1	2.64	1.32	0.51	-0.43	-0.36	-0.59	0.53	0.26	0.10
7224/7-1	2.78	1.06	0.70	-0.46	-0.29	0.48	0.56	0.21	0.14
7227/10-1	2.84	1.00	0.71	-0.01	1.00	0.01	0.57	0.20	0.14
7316/5-1	2.72	1.09	0.97	-0.06	0.43	0.90	0.54	0.22	0.19
7321/7-1	2.83	1.12	0.64	-0.36	0.43	-0.83	0.57	0.22	0.13
7324/10-1	2.59	0.92	0.76	0.41	-0.09	-0.78	0.52	0.19	0.15

Table 3.The 98 Norwegian exploration wells included in this study. Following the well column are the eigenvalues as shown as the first row in Table 1. The next three columns are the deep resistivity loadings (scores) taken from the last row (HRD) in Table 2. The last three columns are the proportions of the eigenvalues taken from the second row in Table 1. Highlighted in yellow is the loading of the resistivity log on PC1, and highlighted in red is the principal component with the highest loading of the resistivity log.

The resistivity log response is more complicated to understand. At the moment one can say that it is not a function of porosity, compaction or the volume of clay.

How does this compare with other basins?

Table 4 show that it is only the well offshore UK in the North Sea that has the same character as the Norwegian wells. In all the other basins, the resistivity curve has a bigger influence on PC1. But it is important to note that the resistivity is also an important contributor to PC3, although PC3 seldom represents more than 10% of the variability.

The gamma ray response

The gamma ray is not only a function of the volume of clay (Vcl) (Gyllenhammar, 2020). Different clay minerals have a different level of radioactive energy (MeV) (Serra, 2008). In the North Sea the clay composition is very complex (Thyberg et al., 2000). In addition, clays with high organic content (source rocks) have a high uranium response. The gamma ray is a function of the sedimentary source, including clay mineralogy and organic content in addition to some compaction as well.

What changes the resistivity log offshore Norway?

Is the resistivity log random with respect the sonic, density and neutron log? The PCA results suggest that. In this particular well, 34/10-20, the resistivity is clearly more random compared to the other logs. Or expressed in another way, it measures something completely different.

The resistivity curve has a relatively big impact on PC1 in the Gulf of Mexico, Nile Delta and offshore Morocco. These basins have, like the North Sea, large salt deposits. So something else must be making the resistivity curve independent of compaction in the North Sea.

The North Sea, Norwegian Sea and the Barents Sea are all quite shallow basins with respect to the sedimentary cover over the basement rock. Fresh water influx from the glacial ice cover during the Quaternary has been suggested as a possible

Country	Eigenvalue			Deep resistivity			Eigenvalue Proportion		
	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
UK-9/26-1	2.47	1.43	0.76	0.06	0.61	0.78	0.50	0.29	0.15
Gulf of Mexico	2.21	1.09	0.88	-0.52	-0.14	-0.06	0.44	0.22	0.18
Caspian Sea_1	2.35	1.79	0.47	-0.48	0.30	-0.79	0.47	0.36	0.09
Caspian Sea_2	2.13	1.58	0.57	-0.52	0.08	0.83	0.43	0.32	0.11
Nile Delta	3.05	1.40	0.28	-0.50	0.17	-0.80	0.61	0.28	0.06
Morocco	3.82	0.62	0.26	-0.46	0.19	-0.83	0.77	0.12	0.05
Vietnam	2.97	1.43	0.38	0.41	-0.44	0.78	0.60	0.29	0.08

Table 4 This is the same table as Table 3, but showing wells from different basins to compare with offshore Norway. Highlighted in yellow is the loading of the resistivity log on PC1, and highlighted in red is the highest loading of the resistivity log.

difference between the basins (Gyllenhammar, 2003). Further studies of 800 Norwegian exploration wells in the North Sea suggest that there must also be a fresh water source from below as well (Gyllenhammar, 2018).

Chemical analysis of brines in the North Sea suggest a mixture of connate ancient seawater mixed with ancient meteoric water (McCartney and Rein, 2005). So far there has been no real explanation for the source of this ancient meteoric water. It is possible that the basement was initially saturated with meteoric water prior to later subsidence, transgressions followed by sedimentary input. And the meteoric water is slowly getting mixed with saline brine in contact with the salt deposits.

Conclusion

The salinity varies more in the North Sea, Norwegian sea and the Barents Sea than many other basins in the world. Offshore Norway, the Gulf of Mexico, Mediterranean, and offshore West Africa have salt deposits including salt diapirs. So, there must be another fundamental difference in the history of these basins. Among this group of basins, only the North Sea, Norwegian Sea and Barents Sea were under the Quaternary ice cover. But that

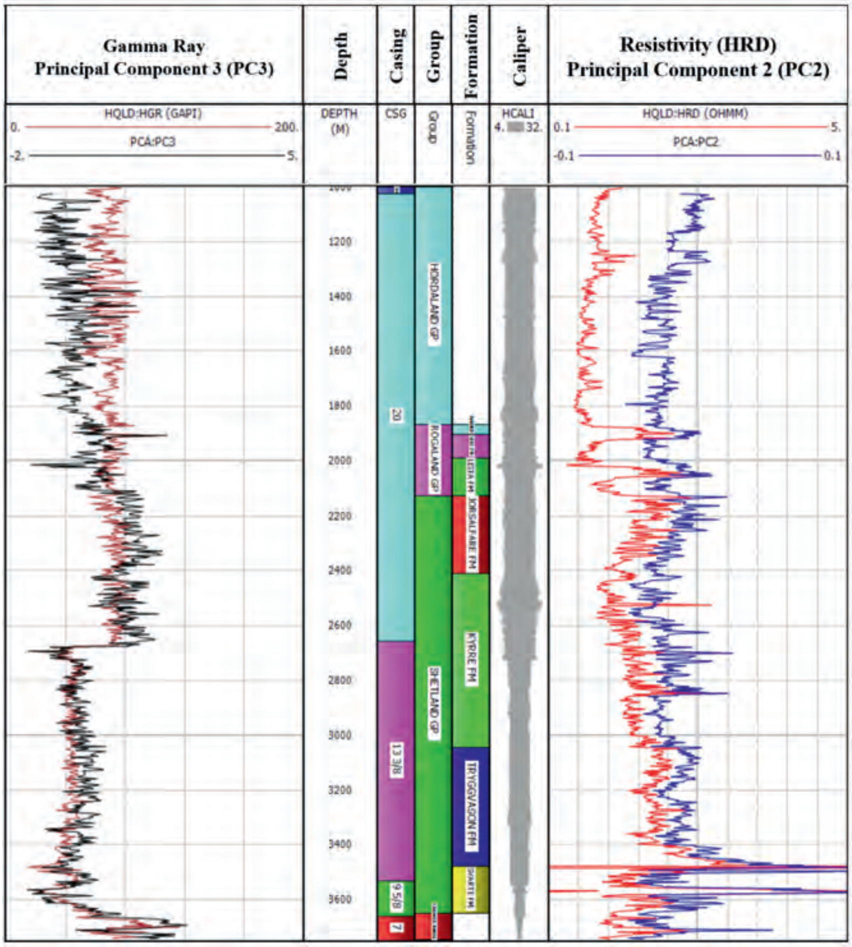


Figure 4 Well 34/10-20, the GR column shows the PC3 (black). The resistivity (HRD) curve is in red and the principal component 2 (PC2) in blue.

would only cause an influx of fresh water into the surface sediments. The publication by McCartney and Rein, 2005, suggests an influx of ancient meteoric water. This is supported by the later study by Gyllenhammar, 2018, demonstrating that there must be a fresh water source to explain low salinity brine in reservoirs close to basement rocks. The large variations of the salinity could be one of the reasons why it has been so many false positive responses from CSEM surveys in the North Sea (Fanavoll et al., 2010). False positive EM signals could be from low salinity brine rather than hydrocarbons.

Even without being able to definitely determine the source of fresh water, the consequence is quite clear. The resistivity log in the North Sea, Norwegian Sea and Barents Sea should not be used to calculate porosity, compaction, pore pressure or calculating other pseudo logs. In the GoM it is common to predict and calculate pore pressure while drilling from the MWD/LWD logs. That should not be done in the North Sea, Norwegian Sea or the Barents Sea.

Generally, this study is based on very few non Norwegian wells compared to the Norwegian wells. And I urge the readers with access to more data to run similar tests prior to deciding on logs to be used to calculate porosity, compaction, pore pressure or calculating other pseudo logs.

Acknowledgements

I want acknowledge Professor Brian Smart for constructive discussions and review during generation off this research paper.

References

Cattell, R.B. [1966]. The Scree test for the number of factors. *Multivariate Behavioural Research*, **1**, 245-276.

Doveton, J.H. [1986]. *Log Analysis of Subsurface Geology. Concepts and Computer Methods.* R Willey-Interscience Publication. John Wiley & Sons.

Eaton, B.A. [1975]. The Equation for Geopressure Prediction from well logs. *50th Ann. Fall Mtg. Preprint Soc. Petroleum Eng.*, **5544**, 11.

Fanavoll, S., Hesthammer, J., Danielsen, J. and Stefatos, A. [2010]. Controlled Source electromagnetic technology and hydrocarbon exploration efficiency. *First Break*, **27** (5), 61-69.

GeoPOP: Geosciences Project on OverPressure, is a multi-disciplinary research group investigating overpressure in sedimentary basins. It is led by Durham University in conjunction with University of Newcastle, and funded by the hydrocarbon industry. www.geopop.org.uk

Gyllenhammar, C.F. [2003]. *A critical review of currently available pore pressure methods and their input parameters. Glaciations and compaction of North Sea sediments.* PhD dissertation, Durham University, UK.

Gyllenhammar, C.F. [2016]. Is there space for petrophysics in Rock Physics? *New Advances in Geophysics (NAG) meeting*, Conference Abstract.

Gyllenhammar, C.F. [2018]. Where is the fresh water coming from. *Fractured Reservoirs*, Geological Society of London, Abstract.

Gyllenhammar, C.F. [2020]. Calculating a synthetic density curve using volume of clay and velocity. *First Break*, **37** (6), 45-49.

Hottmann, C.E. and Johnson, R.K. [1965]. Estimation of formation pressures from log-derived shale properties: *Journal of Petroleum Technology*, **17** (6), 717-722.

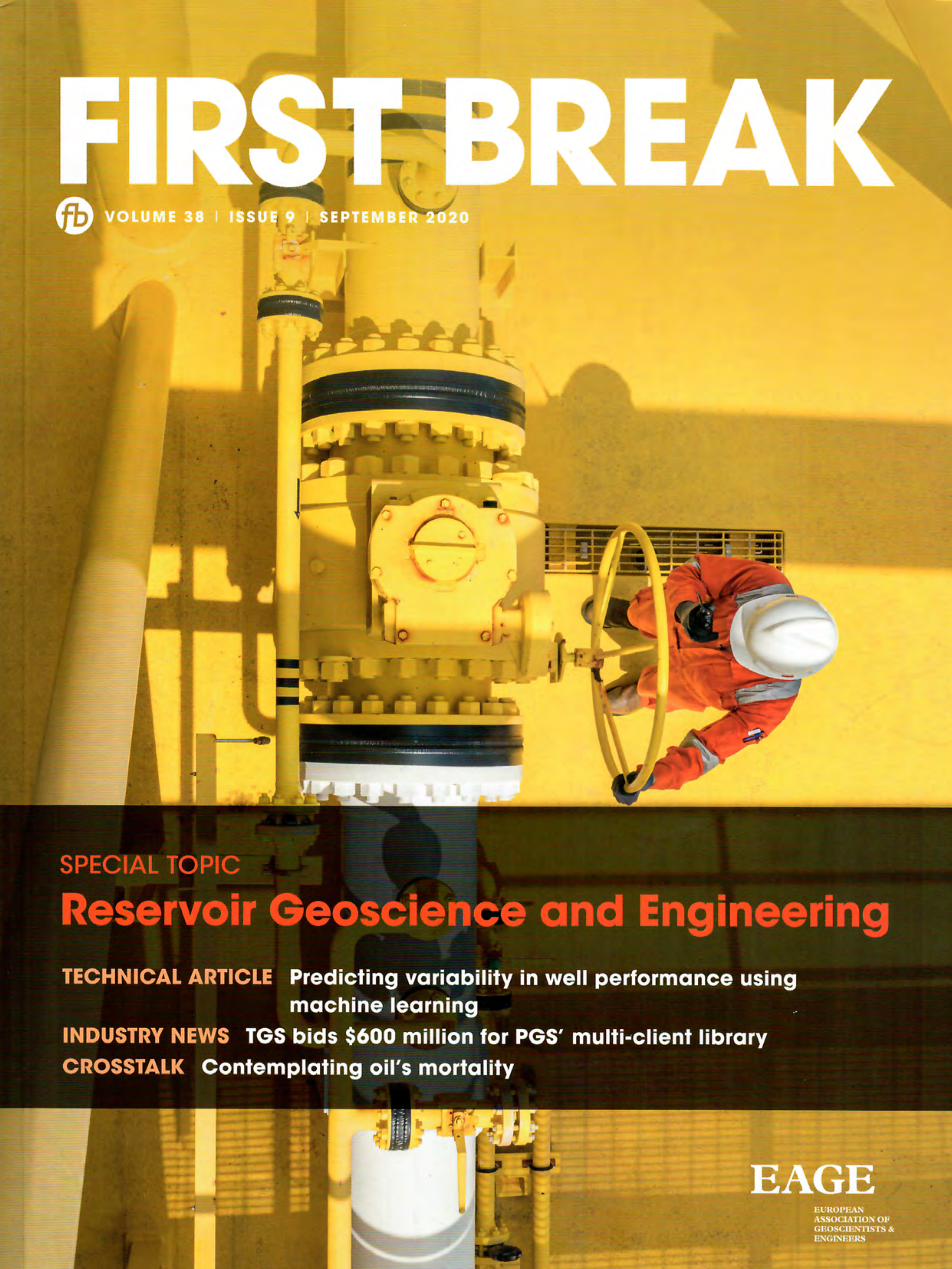
Kaiser, H.F. [1960]. The application of electronic computers to factor analysis. *Educational and Psychological Measurement*, **20**, 141-151.

McCartney, R.A. and Rein, E. [2005]. Formation waters of the Norwegian Continental Shelf. *16th International Symposium on Oilfield Chemistry*, Abstracts.

Jolliffe, I.T. [1986]. *Principal Component Analysis*. Springer-Verlag.

Serra, O. [2008]. *The well logging handbook*. Editions Technip, Paris.

Thyberg, B.I., Jordt, H., Bjørlykke, K. and Faleide, J.I. [2000]. Relationships between sequence stratigraphy, mineralogy and geochemistry in the Cenozoic sediments of the northern North Sea. *Dynamics of the Norwegian Margin, Geol.Soc.Spes.Pub*. **167**, 245-272.



FIRST BREAK

VOLUME 38 | ISSUE 9 | SEPTEMBER 2020

SPECIAL TOPIC

Reservoir Geoscience and Engineering

TECHNICAL ARTICLE Predicting variability in well performance using machine learning

INDUSTRY NEWS TGS bids $600 million for PGS' multi-client library

CROSSTALK Contemplating oil's mortality

EAGE
EUROPEAN
ASSOCIATION OF
GEOSCIENTISTS &
ENGINEERS