International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Comparative Study of Rock Strength and Petrophysical Properties Derived from Core and Log Data

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Accepted 15 Feb 2015, Available online 01 April 2015, **Vol.5, No.2 (April 2015)**

Abstract

This study presents a uniaxial compressive strength property and petrophysical data obtained from log and core derived data of well R4 of a field in the Niger Delta region of Nigeria a continent in Africa. Petrophysical properties is referred to as the physical and chemical properties of rocks that are related to pore space and distributions of fluid especially as they apply to detection and evaluation of hydrocarbon bearing layers. This is one of the key properties in estimating the quantity of hydrocarbon original in place and without which no informed decision will be made on the field's development. As a result of the sensitivity of the petrophysical parameters, there is need to compare value of these properties from other sources of information for a quality control and assurance of the data used for analysis. Results showed that the formation is heterogeneous. This will help the management in decision making either to develop the field, where to place wells and in simulating full field study to predict future reservoir performance and optimum strategy to economically recover the subsurface hydrocarbon volume.

Keywords: *Petrophysical properties, uniaxial compressive strength, log, core, hydrocarbon in place, field development, rock strength.*

1. Introduction

One of the key properties in estimating the quantity of hydrocarbon original in place is the petrophysical properties which is refer to as the physical and chemical properties of rocks that are related to pore space and distributions of fluid especially as they apply to detection and evaluation of hydrocarbon bearing layers. Without these properties, there will be no informed decision on the development of a field since it is developed based on its commercial viability. And on the contrary; a wrong estimate of these properties can lead to a wrong value of the underground volume of the hydrocarbon in place which may result to a wrong decision made by management of the field. Thus, there is need to compare values of these properties from other sources of information for a quality control and assurance of the data used for analysis which is the focus of this study to validate the rock strength and petrophysical data obtained from log with core data of well R4 of a field in the Niger Delta region of Nigeria a continent in Africa. As stated by Amafule et al (1993) that one of the most important existing and emerging challenges of engineers and geoscientists is to improve the techniques of reservoir description which implies that an improvements in the description of a reservoir will greatly reduce the amount of hydrocarbon left behind pipe. Accurate determination of pore space and fluid distribution are central elements in improved reservoir description. Hence, they defined reservoir characterization as 'combined efforts aimed at discretizing the reservoir into subunits, such as layers and grid blocks and assigning values to all pertinent physical properties to these blocks' (Amafule et al, 1988).

Furthermore, Amafule et al (1993) also acclaimed that for enhanced reservoir characterization, macroscopic core data must be integrated with megascopic log data to account for the uncertainties that exist at both levels of measurement which must be recognized and incorporated in sensitivity studies. While Harris and Hewitt (1977) emphasized the importance of synergy in reservoir management and discussed the interplay of geological and engineering factors in reservoir characterization. Keelan (1982) showed how certain rock properties such as porosity, permeability, grain density, and capillary pressure varied with the geological factors such as the environment of deposition.

On the other hand, a better understanding of rock strength is important for designing recovery plans of a reservoir and for developing an appropriate reservoir simulation. Rock strength is of vital importance during

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the drilling and production of hydrocarbon wells when dealing with the stability problems encountered in the industry today. We should note here that only a discrete data points is provided by mechanical rock property test of core. This study presents a uniaxial compressive strength property from log and core derived data of well R4. Therefore, a comparative analysis of rock strength parameters from log and core derived data is used to investigate the potential stability of a well bore by calculating the differential stress conditions and comparing with failure criterion. It should be noted also that these properties obtain from log and core data help to determine the wellbore stress so as to check the formation strength. However, the mechanical strength behavior of porous media depend on elastic moduli value, variation in elastic moduli with stress conditions, overburden weight gradient, stress caused by geological conditions, strength of cementation between grains, fluid pressure and saturation, rate of flow and fracture pressure gradient etc.

There are several techniques which have been developed to determine rock strength from well log parameters. Coates and Denoo (1981) calculated stresses induced around a borehole and estimated failure from assumed linear envelopes with strength parameters derived from shear and compressional velocities.

$$\mathrm{UCS} = 0.008\mathrm{E}\mathrm{V_{cl}} + 0.0045\mathrm{E}(1-\mathrm{V_{cl}}) \quad (1)$$

$$\mathrm{V_{cl}} = \frac{\mathrm{GR}-\mathrm{GR_{sand}}}{\mathrm{GR_{shale}}-\mathrm{GR_{sand}}} \quad (2)$$

$$\text{Poisson's ratio (v)} = \frac{\frac{1}{2}\left(\frac{t_s}{t_c}\right)^2-1}{\left(\frac{t_s}{t_c}\right)^2-1} \quad (3)$$

$$\text{Shear Modulus (G)} = \frac{\rho_b}{t_s v} * \propto \quad (4)$$

Where $\propto$ is a unit conversion factor equal to 1.34×10^{10}

$$\text{Young's Modulus (E)} = 2G(1+v) \quad (5)$$

$$\text{bulk Modulus } (k_b) = (\rho_b)\left(\frac{1}{t_c^2}-\frac{4}{3t_s^2}\right) \propto \quad (6)$$

$$\text{Bulk Compressibility } (C_b) = \frac{1}{k_b} \quad (7)$$

$$\tau_i = \frac{0.025\mathrm{UCS}}{10^6 C_b} \quad (8)$$

They relied on the work of Deere and Miller (1966) to provide estimates of compressive strength from dynamic measurements. Simplified forms of these relationships are:

$$C_o = 1.839E^{1.058} \quad \text{for limestone} \quad (9)$$

$$C_o = 4.746E^{0.9665} \quad \text{for sandstone} \quad (10)$$

$$C_o = 9.015E^{0.901} \quad \text{for shale} \quad (11)$$

Where C_0 is uniaxial compressive strength and E is dynamic Young's modulus

2. Results and Interpretation

2.1 Core and Log Data Comparison

The core data obtained in the laboratory may be quite different from that of the in situ logging data due to pressure and temperature condition. The core may expand to the release of overburden stress, micro cracking, clay swelling, and associated changes in the elastic properties of sediments. As stated by Goldberg (1997) that one must remember that petrophysical properties measurements were performed on different scales when integrating log and core measurements: in the case of core, it is obtained on a small discrete sample while that of log is on the borehole wall. One must also consider different physical methods used to collect these data. Additionally, when core recovery is low there is a higher error in the estimation of the depths of core samples. These factors must be taken into account in data comparison, and they are, in addition to measurements errors, responsible for some scatter in the data sets. The uniaxial compressive strength and porosity values from log and core are given in Table 1 & 2 of the appendix section.

2.2 Description of Lithology

Study of well R4 reveals that the field's consists of four major hydrocarbon-bearing reservoirs designated as P9000, Q3000, Q4000 and Q8000 respectively. The sands encountered in the reservoirs are fairly correlatable indicating a relatively longer period of depositional cycle. A brief description of each reservoir is as follows:

Reservoir P9000 is hydrocarbon bearing and has a coarsening upward sequence. The reservoir is within depths of 8500ft to 9145ft with a gross thickness of 645ft, net sand thickness of 634ft. The reservoir is clean and well sorted and it contains oil and gas.

Reservoir Q3000 is not quite a thick sand but a very clean sand with net to gross ratio of unity. This reservoir is within depths of 9850ft to 9980ft with a gross thickness of 130ft, net sand thickness of 130ft.

Reservoir Q4000 is clean, thick sand that also suggests delta front shore face deposit. This unit represents the best reservoir unit and is associated with possible coarse grains that are well sorted. The reservoir is within depths of 10025ft to 10880ft of the well R4 with a gross thickness of 885ft, net sand thickness of 878ft. The shale separating this reservoir from the above reservoir thickens. The reservoir contains oil and gas.

Reservoir Q8000 is a clean sand. This reservoir is within depths of 11325ft to 11600ft in well R4 with a gross thickness of 275ft, net sand thickness of 271ft.

2.3. Log-Core density data comparison

The comparison of log-core density and uniaxial compressive strength results (Figure 1 & 2) shows that these two data sets are generally consistent with one another. The core data are more precisely measured than the log data, but lack the higher resolution provided by logging measurements. In the interval between 10100ft and 10600ft, the core data have slightly higher values than the log data. This discrepancy is most likely the result of a lithological factor.

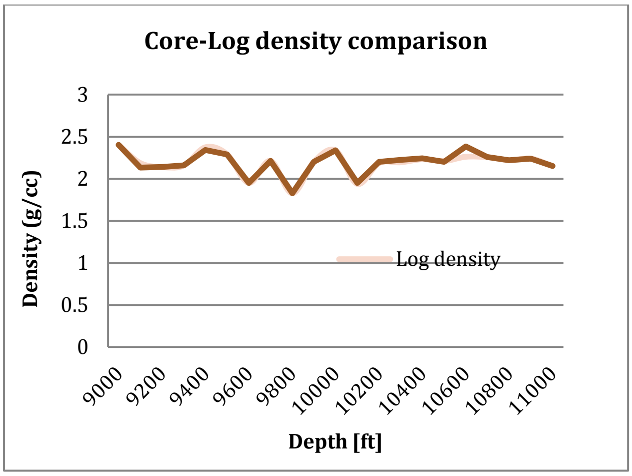

Figure 1: Core-log density data of well R4

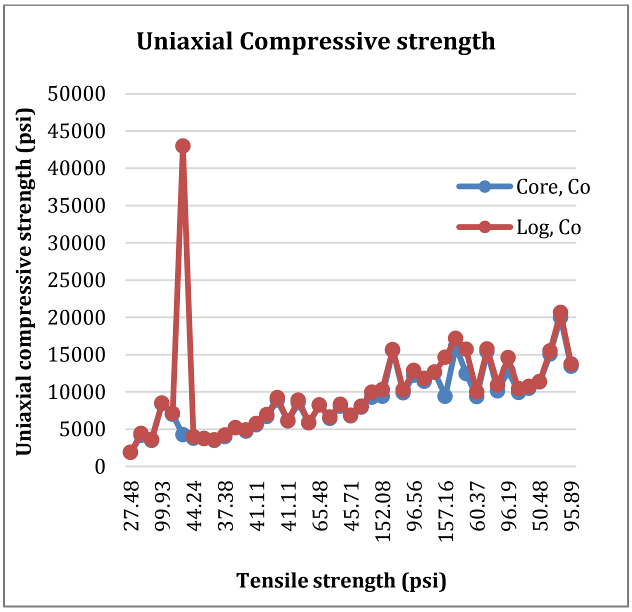

Figure 2: Uniaxial compressive strength of well R4

2.4 Comparison of porosity data

On the neutron-density curve, the gross well R4 sandstone ideally shows a variation in density porosity values, and neutron porosity values. This depicts gas bearing effect superimposed on the lithology effect as evidenced by the divergence of the two curves. Now, when comparing the values of porosity from log with that of core porosity values as shown in Figure 3 & 4, there is a closeness in the values with exception of some areas where there is a clear difference. Thus, the variation in value as the well R4 depth increases is an indication of the heterogeneous nature of the reservoir.

For the comparison with core porosity data, logging thermal neutron porosity was used. Some explanation for the discrepancy between core and log data may come from considering not only thermal neutron porosity, but epithermal neutron porosity as well. Because the measurement of standard log porosity is based on the detection of thermal neutrons, the presence of thermal neutron absorbing elements (e.g., boron, chlorine, and rare earth) in the formation can decrease thermal porosity values. Epithermal neutron detection, however, is insensitive to these thermal neutron absorbing elements, but has a reduced detector counting rate that can decrease the statistical precision. To improve the statistics, the epithermal neutron source and detector must be very closely spaced, which leads to measurements that are overly sensitive to bad hole conditions (Davis et al.,1981).

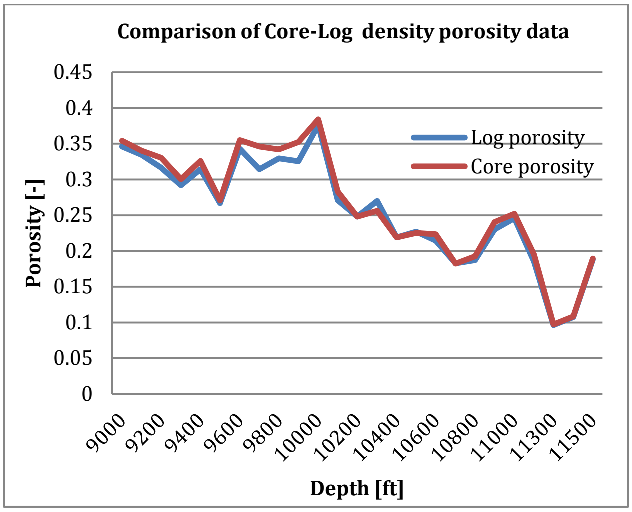

Figure 3: Core-log porosity density comparison

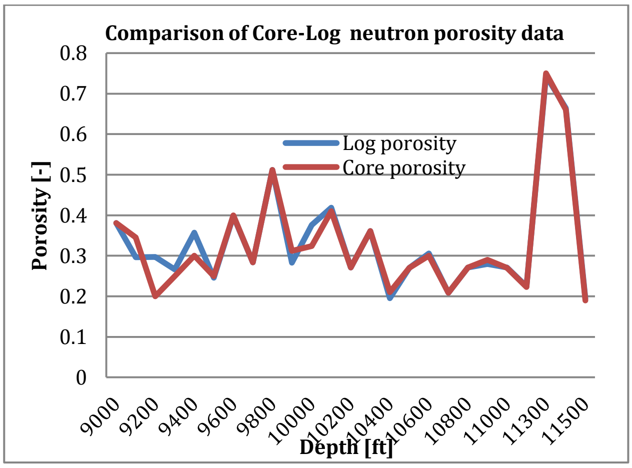

Figure 4: Core-log neutron porosity comparison

2.5 Petrophysical Result Summary

Reservoir qualities of the sands vary widely, with net pays ranging from 130ft to 878ft, porosity ranging from 0.168 to 0.332 for log derived data and 0.173 to 0.342 for core derived data, and the permeability is the same for all reservoir sand of well R4 in the hydrocarbon-bearing sections (Table 2). Also, the result of the net to gross ratio shows that the reservoir sands are clean with Q3000 completely a clean sand formation without any shale embedded in it.

It is noted as well; that the porosities values generally decreases with depth on thickness weighted average. The average petrophysical values for each reservoir are shown in Table 3. Details of the petrophysical summary are shown in appendix A.

3. Statistical Analysis on the Core and Log data of well R4

The results of the statistical analyses help us to understand the outcome of the claims of this study, for example, whether or not some variables have an effect, whether variables are related, whether differences among groups of observations are the same or different, etc. Hence, the statistical analysis was used to substantiate the findings of this study and help us to say objectively when we have significant results. Presented below are the t-test results for the various claims stated.

To determine if our results are significant, there is need to perform a statistical test. The comparisons of Core Values with Wire Line Values of the petrophysical result were done with t-test statistic, Correlation Coefficient and Regression Equation. It reveals a significant similarity in the porosity values determined by the two different methods.

3.1 T-test statistical analysis

The value read from the table of the student t-distribution table are actually interpolated because the value for the degree of freedom did not coincide with value given in mathematics or statistics textbooks.

Table 4: Critical value of t

Level of significance	10%	5%	1%
Critical value	1.6628	1.9882	2.6348

If the computed t-score equals or exceeds the value of t indicated in the Table 4, then we can conclude that there is a statistically significant probability that the relationship between the two variables exists and is not due to chance, and reject the null hypothesis. Hence, we put forth decision below.

3.2 Decision Rule

If $t_{calculated} > t_{table}$: we reject the null hypothesis H_o
If $t_{calculated} < t_{table}$: we accept the alternative hypothesis H_1

The sets of hypothesis used in this study are as follows:

- Now, if we are to justify that the values of porosity obtained from the log data with depth are the same with that obtained from core analysis. Thus, we put forth a hypothesis as:

H_o: There is no significant difference between the log porosity and core porosity values with depth and if there is any, it merely due to chance
H_1: There is significant difference between the log porosity and core porosity values with depth.

- If we are to test the variation in uniaxial compressive strength in the core-log data, we put forth a hypothesis as:

H_o: There is no significant difference between the uniaxial compressive strength in the core-log data and if there is any, it merely due to chance
H_1: The claim is not legitimated

The results of the statistical analyses help us to understand the outcome of the claims of this study, for example, whether or not some variables have an effect, whether variables are related, whether differences among groups of observations are the same or different, etc. Hence, the statistical analysis was used to substantiate the findings of this study and help us to say objectively when we have significant results. Presented below are the t-test results for the various claims stated above.

Following the result of the t-test on the stated hypothesis to justify the agreement of the core to log porosity value obtained at various depth of the formation used in this study, We observed that the value calculated is greater than the critical values at 10% and 5% level of significance for two-tail test (appendix A). Hence, we reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1) at 10% and 5%. This implies that there is significant difference in the porosity value gotten from core and log. Therefore, there is a need for a proper QC/QA on the data because a little discrepancy means a lot in the oil and gas business. Also, since the calculated value is less that the critical value based on the afore-stated decision, we accept this claim at 1% level of significant.

Comparing the calculated value for two-tail test with the critical value, since the calculated value is lesser than the critical value, we accept the null hypothesis (H_0) and reject the alternative hypothesis (H_1) at 5% level of significant (appendix A). which implies that there are no disparities between the core-log uniaxial compressive strength data for well R4. On the other hand, we reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1) at 10% and 1%. Thus, since there is no significant difference between the core permeability and log permeability data for well R4 means there is some level of accuracy in data obtained.

Conclusion

The evaluation of well A1 of the X-field was made possible by carefully analyzing the core-log data to ascertain the closeness of these data obtained. The result of the lithology description implies that the four reservoir sections are clean sand formation with little shale embedded in it. Also, the quality of the reservoirs as determined by the permeability; is excellent with permeability average value above 800md, and by porosity is very good with porosity values between 17.3 to 34.2 percent. Thus, the grain size of the reservoir could be inferred to as being coarse and uniformly arranged with low cementation. A petrophysical log porosity value of 17.2 to 34.2 percent or core analysis porosity value of 16.8 to 33.2 percent is necessary to generate any measurable permeability and permit hydrocarbon production from these reservoirs.

Furthermore, results from the statistical analysis indicated a discrepancy in the core-log porosity values and from our above stated hypothesis, we rejected the null hypothesis which stated that there is no significant difference in the core-log data at 5% and 10% level of significance. Also, the core-log data for permeability and uniaxial compressive strength were accepted based on our decision above. Hence, statistical analyses showed an agreement in the permeability and uniaxial compressive strength data and disagree with the porosity value. Therefore, there is a need for a proper QC/QA on the data because a little discrepancy means a lot in the oil and gas business. Also, since the calculated value is less that the critical value based on the afore-stated decision, we accept this claim at 1% level of significant.

Finally, the results obtained from this study will help the management in decision making either to develop the field, where to place wells and in simulating full field study to predict future reservoir performance and optimum strategy to economically recover the subsurface hydrocarbon volume.

Appendix

Table 1: Comparative analysis between log and core UCS data obtained from well R4

Uniaxial Compressive Strenght From LOG, C0(PSI)	Uniaxial Compressive Strenght From Core, C0(PSI)	Compressional Sonic Vc(us/ft)	Shear Sonic Vs(us/ft)	Young Modulus Y'(Psi)	Tensile Strength(Psi)
1887.99	1875.287181	146.137	497.839	308546.33	27.48
4414.82	4151.910949	134.299	374.411	587565.44	76.7
3605.95	3453.721775	129.18	336.662	678231.44	42.97
8505.03	8426.437886	124.443	245.651	1309905.91	99.93
7103.78	6994.307769	134.822	301.079	887971.97	86.59
42976.96	4230.849043	130.457	300.044	816674.34	31.56
3989.58	3774.826425	131.865	337.352	676610.25	44.24
3727.21	3718.392991	180.095	323.691	733570.62	45.22
3572	3475.150581	135.501	335.28	665337.41	33.1
4180.63	3986.01275	125.764	305.537	806298.62	37.38
5201.43	5171.752193	124.07	270.571	1035789.09	52.29
4875.52	4719.888006	129.978	334.262	693100.34	46.7
5725.83	5577.7622	121.958	301.812	835538.26	41.11
6928.77	6671.859203	120.618	272.202	1035789.09	71.42
9220.64	8899.632703	117.828	257.769	693100.34	97.3
6149.96	6073.187048	117.366	283.035	835538.26	41.11
8874.77	8528.308528	119.649	270.487	1065508.8	127.68
5875.69	5827.578746	121.491	243.039	1222113.2	52.81
8251.01	8231.731174	126.172	260.505	887631.14	65.48
6618.86	6414.289503	120.45	253.853	1155212.85	49.97
8328.4	8071.361819	109.6	284.895	1257263.93	127.68
6845.34	6780.204171	115.221	269.143	1142038.45	45.71
8047.8	7943.354779	119.646	216.38	1158374.43	76.7
9961.6	9250.077771	107.775	246.473	1041050.56	101.64
10316.67	9385.763074	116.893	257.121	1039637.56	152.08
15668.02	15586.2967	109.533	205.538	1637444.62	163.62
10239.37	9848.136675	110.152	259.134	1336321.55	152.63
12870.96	12217.91233	106.626	222.215	1289584.33	96.56

11796.26	11429.35966	106.424	238.789	1958502.76	132.9
12677.61	12632.3875	104.187	222.054	1279921.46	98.06
14646.82	9411.911027	102.774	214.15	1608872.1	157.16
17164.29	16103.60059	105.053	193.061	1474782.56	135.84
15694.2	12449.64324	106.226	215.006	1626935.35	295.19
9996.7	9348.149827	100.125	191.1	1830852.19	60.37
15768.46	15398.89948	105.029	210,285	2145536.39	232.6
10917.17	10134.95649	103.489	180.007	1961775.42	73.56
14572	12841.0096	100.381	207.957	1977951.2	96.19
10417.77	9920.562624	102.143	178.879	1971056.88	65.19
10718.07	10470.84167	107.314	177.647	2263782.96	76.38
11373.16	11311.40633	96.264	190.775	1821499.54	50.48
15477.21	15059.57759	106.772	210.809	2213640.61	208.95
20629.6	19973.20651	105.127	180.447	2314818.92	198.73
13738.17	13436.77903	104.432	193.612	1973434.65	95.89

Table 2: Comparative analysis between log and core data obtained from well R4

DEPT.F (Ft)	DEN.G/CC (Log)	DEN.G/CC (Core)	GR.API (Log)	GR.API (Core)	NEU.FRAC (Log)	NEU.FRAC (Core)	PERM.MD (Log)	PERM.MD (Core)	POR.FRAC(Log)	POR.FRAC (Core)
9000	2.4016	2.4021	-999.3	-999	0.381	0.381	38.058	38.1	0.3459	0.3543
9100	2.1862	2.1326	-999.3	-999	0.296	0.345	1298.04	1297.02	0.3346	0.3404
9200	2.1393	2.1393	-999.3	-999	0.297	0.2	3384.6	3384.23	0.3165	0.3303
9300	2.1578	2.1578	-999.3	-999	0.266	0.25	1359	1359	0.2917	0.3004
9400	2.3749	2.3435	-999.3	-999	0.357	0.3	39.466	39.466	0.3143	0.3261
9500	2.2903	2.2903	-999.3	-999	0.246	0.25	1044.71	1044.71	0.2669	0.2708
9600	1.952	1.952	-999.3	-999	0.398	0.4	1177.09	1177.09	0.3429	0.3548
9700	2.2128	2.2128	-999.3	-999	0.284	0.284	43.849	43.849	0.3143	0.3461
9800	1.8287	1.8287	-999.3	-999	0.512	0.512	2.783	2.783	0.3293	0.3422
9900	2.2013	2.2013	-999.3	-999	0.283	0.312	119.725	119.725	0.3256	0.3522
10000	2.3371	2.3371	-999.3	-999	0.376	0.324	6.928	6.928	0.3759	0.3843
10100	1.9391	1.9502	-999.3	-999	0.419	0.41	3.132	3.132	0.2707	0.283
10200	2.1867	2.2002	-999.3	-999	0.271	0.271	2757.38	2757.38	0.2481	0.2482
10300	2.1959	2.2242	-999.3	-999	0.361	0.361	858.513	858.513	0.2699	0.256
10400	2.2324	2.2431	-999.3	-999	0.195	0.21	2888.42	2888.42	0.2188	0.2188
10500	2.2115	2.2002	-999.3	-999	0.27	0.27	1401.56	1401.56	0.2271	0.2251
10600	2.2615	2.3842	-999.3	-999	0.306	0.3	253.836	253.836	0.2143	0.2234
10700	2.2568	2.2568	-999.3	-999	0.209	0.209	1316.58	1316.58	0.1827	0.1821
10800	2.2211	2.2211	-999.3	-999	0.271	0.271	761.256	761.256	0.1872	0.1924
10900	2.2398	2.2398	-999.3	-999	0.28	0.29	230.917	230.917	0.2301	0.2403
11000	2.1519	2.1519	-999.3	-999	0.271	0.27	1137.33	1137.33	0.2459	0.2522
11200	-999.25	-999.25	-999.3	-999	0.2246	0.223	7.929	7.929	0.1851	0.1951
11300	-999.25	-999.25	-999.3	-999	0.744	0.75	3.405	3.405	0.0963	0.0973
11400	-999.25	-999.25	-999.3	-999	0.6645	0.66	13.625	13.625	0.1074	0.1084
11500	-999.25	-999.25	-999.3	-999	0.1944	0.19	83.413	83.413	0.1882	0.1892

Table 3: Summary of the weighted averages petrophysical parameters

			Porosity		Permeability		Thickness (ft)		
Reservoir	**Top (ft)**	**Bottom (ft)**	**Log data**	**Core data**	**Log data**	**Core data**	**Gross**	**Net**	**N/G**
P9000	8500	9145	0.332	0.342	1573.522	1573.075	645	634	0.983
Q3000	9850	9980	0.312	0.328	540.941	540.941	130	130	1.000
Q4000	10025	10880	0.242	0.245	1047.859	1047.859	885	878	0.992
Q8000	11325	11600	0.168	0.173	208.942	208.942	275	271	0.985

t-Test: Two-Sample Assuming Equal Variances		
	POR.FRAC(Log)	***POR.FRAC(Core)***
Mean	0.257188	0.264536
Variance	0.005447466	0.006154818
Observations	25	25
Pooled Variance	0.005801142	
Hypothesized Mean Difference	0	
df	48	
t Stat	-0.341088753	
P(T<=t) one-tail	0.367262673	
t Critical one-tail	1.677224196	
P(T<=t) two-tail	0.734525346	
t Critical two-tail	2.010634758	

t-Test: Two-Sample Assuming Equal Variances		
	UNIAXIAL COMPRESSIVE STRENGHT FROM LOG,C0(PSI)	***UNIAXIAL COMPRESSIVE STRENGHT FROM CORE,C0(PSI)***
Mean	16159.85916	15126.43024
Variance	78832474.9	69020362.01
Observations	83	83
Pooled Variance	73926418.45	
Hypothesized Mean Difference	0	
df	164	
t Stat	0.774292096	
P(T<=t) one-tail	0.219936446	
t Critical one-tail	1.654197929	
P(T<=t) two-tail	0.439872891	
t Critical two-tail	1.974534576	

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