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OVERPRESSURE PREDICTION THROUGH POROSITY ESTIMATION IN SEDIMENTARY FORMATIONS USING GEOPHYSICAL WELL LOGS IN THE SOUTH-WESTERN PART OF THE NIGER DELTA BASIN OF NIGERIA

O. I. HORSFALL[1] & J. E. COOKEY[2]

[1]Department of Physics, Rivers State University of Science and Technology, Diobu, Port Harcourt, Nigeria

[2]Department of Physics, Alvan Ikoku Federal College of Education, Owerri, Nigeria

ABSTRACT

Gamma-ray and Sonic-log data from nine petroleum wells in South-Western Niger Delta were used to determine porosity values for sandstone and shale beds in an attempt to predict over pressured zones, establish surface porosities and compaction trends so as to deduce compaction factors for the lithology, investigate the relationship between transit time/velocity, and hydrocarbon prospects in the basin. Gamma ray log was used to delineate the lithologies while Sonic log was used to predict overpressure and to compute acoustic transit times, velocities and porosities of the formation. The results showed that porosity decreases linearly with depth in normal compacted formations, but increases with depth in an over pressured zone for both sandstone and shale beds. In well XA-1 at depths (3671m; 13% and 3695m; 15%) and (3639m; 14% and 3680m; 16%) for sandstone and shale beds respectively. Velocity increases with depth in normal compacted formations while it decreases with an increasing depth in over pressured zones. In normal compaction sandstone porosity (13%) is less than shale porosity (15%) at the same depth (3700m) while in over pressured zones sandstone porosity (28%) is higher than shale porosity (26%) at the same depth (4000m) in well XA-1. Sandstone porosity (42.02%) is greater than shale porosity (38.73%) at the earth's surface. The average compaction factors for both sandstone and shale beds are 0.0071 and 0.0050 respectively. The result of this study can be useful in the evaluation of oil reservoir, overpressure prediction and sedimentary basin analysis.

KEYWORDS: Gamma Ray, Lithology, Overpressure, Porosity, Sandstone, Shale and Sonic Log, Transit Time, Velocity

INTRODUCTION

Abnormal pressure is defined as any departure from normal hydrostatic pressure at a given depth (Bruce and Bowers, 2002). Abnormal subsurface pressures, either overpressure (geopressure) or underpressure, are encountered in hydrocarbon basins throughout the world in all lithologies, from all geologic ages, and at all depths (Fertl et al, 1994). Abnormal pressure (overpressure) conditions in the subsurface can pose significant drilling hazards if not detected (Bowers G.L, 2002). Early and reliable detection of geopressure is vital to avoid or mitigate potential drilling and safety hazards, such as blowout of oil well/rigs, shallow water flow, shale instability and loss of human life (Chilingar et al, 2002). Geopressuring in hydrocarbon reservoirs may result from a variety of geologic and tectonic processes. Undercompaction is the primary mechanism for creating overpressure, particularly in deltaic basins in which high rates of deposition commonly prevent the escape of pore water trapped in shales. Under compacted shales have higher acoustic transit times (i. e, higher apparent porosity) than normally pressured shales at the same depth (Evans, B.J, 1999; Draou, A and Osisanya, S.O, 2000).

Porosity is one of the fundamental petrophysical properties of reservoir rocks and it is a measure of the void space in a rock. (Dewan, 1983; Schlumberger, 2000; Tittman, Wahl 1965). The potential and performance of a reservoir rock depends on Porosity ($\emptyset$), Permeability (k), Water saturation (%), grain size, grain shape, degree of compaction, cementation and amount of matrix. (Etu-Efeotor, 1997; Murray et al, 1975; Prem 1997; Sheriff, 1991) The two essential attributes of any reservoir are porosity and permeability (Keary, Brooks and Hill 2002; Wyllie 1965). Porosity is normally obtained either with wireline logs or by direct measurements on core samples. Coring is one of the oldest and still practiced technique. However, coring every well in a large field is a time consuming practice and can be very expensive. Geophysical logs are available for most of the wells, while cores and well tests are available from few wells in the reservoir. Therefore, the evaluation of porosity from well log data is an important step to minimize cost. However, are many occasions when core analysis porosity is not available for calibration of log results. The next best set of data is petrographic thin section visual porosity analysis. This thin section can often be made from sample chip when no core exists. Thin section samples is tiny and it is sometimes difficult to scale up these results to a whole reservoir (Etu-Efeotor, 1997).

METHODOLOGY

To actualize the goal of this study, data from nine exploratory well logs obtained from Nigerian Agip Oil Company were used to evaluate the parameters of interest. Using the gamma ray log runs for the different wells, the lithologies of the formation were delineated into sandstone and shale beds. Clean sandstones normally exhibits low level of natural radioactivity, while shale show higher levels of radioactivity due to adsorption of heavy radioactive elements. However, the amount of each lithofacies is estimated by counting the interval of each lithofacies and then assigning a fraction of this to the total interval within the sand-shale baselines which is then expressed as a percentage. Determination of porosity values was achieved by digitizing the sonic logs at intervals of within the sandstone and shale beds.

DETERMINATION OF LITHOLOGY

The sedimentary sequence in the Niger Delta Complex is a simple series of sandstones and shales. The sandstone and shale matrix were detected by using the Gamma ray logs with reference to shale baseline, operating by appropriately choosing an average fit of the log

The % (shale/sand) is computed from the gamma ray log as:

$$\%\ \text{Shale} = \left(\frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}\right) \times 100 \quad (1)$$

(Schlumberger, 2000).

Where;

%shale = volume of shale in the formation by percentage

GR_{log} = Gamma Ray Log Reading

GR_{max} = Gamma Ray Log Reading in Shale Zone

GR_{min} = Gamma Ray Log Reading in clean Sand Zone

From the above equation,

% sand = 100% - %shale (2)

Lithological presumptions are made based on which percentages is greater than or equal to 50%

DETERMINATION OF SONIC POROSITY

The interval transit time at various depths were digitized and then used to compute sonic porosity using Wyllie's time average equations (**cite author**);

$$\Delta t = (1-\emptyset)\Delta t_{ma} + \Delta t_f \quad (3)$$

$$\emptyset_{sonic} = \frac{\Delta t_{log}-\Delta t_{ma}}{\Delta t_f-\Delta t_{ma}} \quad (4)$$

Where,

Δt_{log} = Acoustic travel time from the Sonic log in $\mu Sec/ft$

Δt_{ma} = Acoustic travel time of the rock matrix $(55\ \mu Sec/ft)$.

Δt_f = Acoustic travel time of interstitial fluid in $(189\ \mu Sec/ft)$.

The above equations can be used to determine porosity in clean, consolidated sandstone and carbonate with inter granular porosity containing fluids. Where a sonic log is used to determine porosity in unconsolidated and compacted formations, an empirical relationship is used as follows;

$$\phi = C[t - t_{ma}/t] \quad (5)$$

Where, C = 0.67. This relation was used to compute the porosity values in the nine wells.

RESULTS AND DISCUSSIONS

Numerical data obtained from two out of the nine digitized well logs are presented in Tables 1 - 4, showing the depths, interval travel times, velocities and porosities. Table 5 shows lithologies, surface porosities and compaction factors for the study area. Figures 1 - 12 showed the plots of the parameters (porosity, velocity and transit times) of interest with depth. Porosity decreases with depth in both sandstone and shale beds. The trend line showed Transit time decreases with increasing depth, while velocity increases with an increasing depth in normal compaction and shows a decreasing trend in an over pressured zones. This is shown with an arrow in figures 1 and 2 below.

Table 1: Depth, Interval Transit Times, Velocity and Porosity Values for Sandstone Beds of Well XA-1

Sandstone Beds			
Depth(m)	**Δt(μs/ft)**	**Velocity(ft/μs)**	**Porosity**
1408	120	8.33	34
1415	125	8.00	35
1454	126	7.94	35
1484	105	9.52	29
1524	120	8.33	34
1609	120	8.33	34
1655	110	9.09	31
1695	105	9.52	29
1771	100	10.00	28

Table 1: Contd.,

1865	105	9.52	29
1871	100	10.00	28
1978	110	9.09	31
2063	100	10.00	28
2100	100	10.00	28
2106	100	10.00	28

Table 2: Depth, Interval Transit Times, Velocity and Porosity Values for Shale Beds of Well XA-1

Shale Beds			
DEPTH(m)	**Δt(μs/ft)**	**Velocity(ft/μs)**	**Porosity**
1431	136	7.35	37
1463	125	8.00	35
1544	118	8.47	33
1725	110	9.09	31
1876	100	10.00	28
2001	105	9.52	29
2150	103	9.71	29
2237	95	10.53	26
2323	95	10.53	26
2434	95	10.53	26
2548	92	10.87	25
2704	90	11.11	24
2835	85	11.76	22
2996	90	11.11	24
3048	87	11.49	23
3171	82	12.20	20
3200	85	11.76	22

Table 3: Depth, Interval Transit Times, Velocity and Porosity Values for Sandstone Beds of Well XA-2

Sandstone Beds			
Depth(m)	**Δt(μs/ft)**	**Velocity(ft/μs)**	**Porosity**
461	145	6.90	39
466	150	6.67	39
496	150	6.67	39
655	135	7.41	37
750	140	7.14	38
833	135	7.41	37
941	130	7.69	36
988	125	8.00	35
1067	120	8.33	34
1103	125	8.00	35
1175	120	8.33	34
1237	120	8.33	34
1271	120	8.33	34
1387	112	8.93	32
1463	110	9.09	31
1551	110	9.09	31
1603	110	9.09	31
1698	105	9.52	29
1825	98	10.20	27
1966	95	10.53	26
2017	95	10.53	26
2067	90	11.11	24
2195	95	10.53	26

Table 4: Depth, Interval Transit Times, Velocity and Porosity Values for Shale Beds of Well XA-2

Shale Beds			
Depth(m)	Δt(μs/ft)	Velocity(ft/μs)	Porosity
1139	125	8.00	35
1292	115	8.70	32
1341	130	7.69	36
1426	120	8.33	34
1496	105	9.52	29
1524	120	8.33	34
1617	110	9.09	31
1662	100	10.00	28
1770	120	8.33	34
1795	115	8.70	32
1865	110	9.09	31
1990	95	10.53	26
2030	100	10.00	28
2154	87	11.49	23
2251	85	11.76	22
2295	90	11.11	24
2376	85	11.76	22
2410	90	11.11	24
2890	85	11.76	22
2924	85	11.76	22
2991	85	11.76	22
3093	80	12.50	19

Table 5: Lithology, Surface Porosity, and Compaction Factor for the Study Area

	Surface Porosity($Ø_0$)		Compaction Factor (C)	
Wells	Sandstones	Shale	Sandstones	Shale
XA-1	35.252	35.443	0.0038	0.0037
XA-2	42.144	41.219	0.0074	0.0066

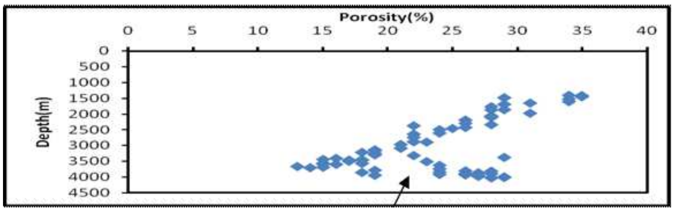

Figure 1: Porosity vs Depth for Sandstone Beds of Well Xa-1

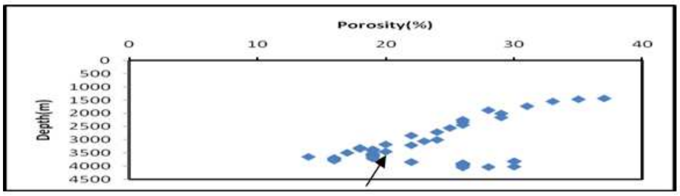

Figure 2: Porosity vs Depth for Shale Beds of Well Xa-1

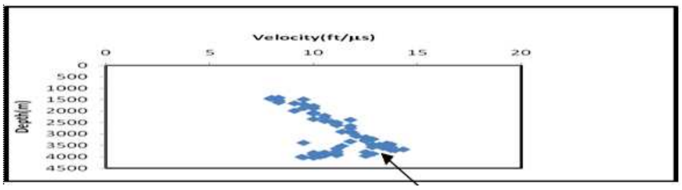

Figure 3: Depth vs Velocity for Sandstone Beds of Well Xa-1

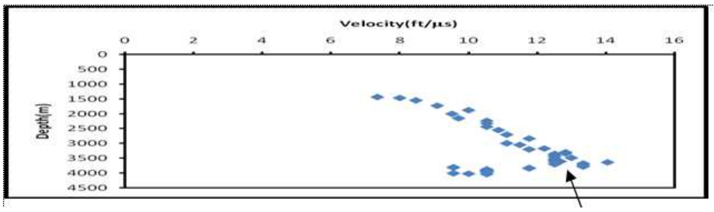

Figure 4: Depth vs Velocity for Shale Beds of Well Xa-1

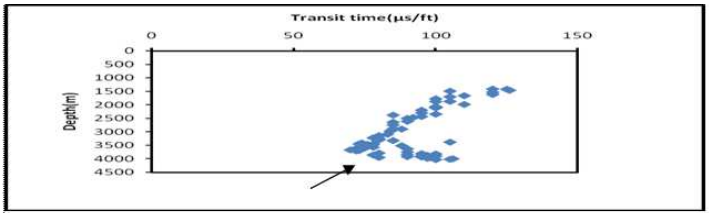

Figure 5: Depth vs Transit Time for Sandstone Beds of Well Xa-1

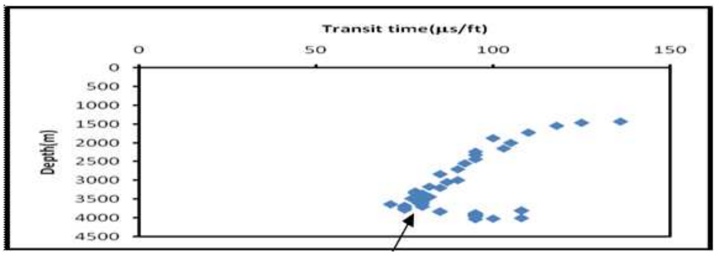

Figure 6: Depth vs Transit Time for Shale Beds of Well Xa-1

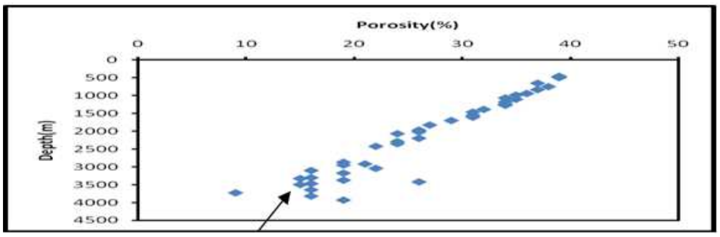

Figure 7: Porosity vs Depth for Sandstone Beds of Well Xa-2

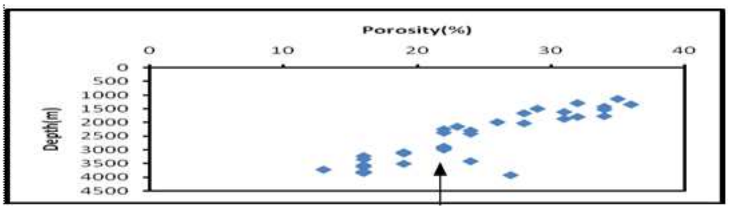

Figure 8: Porosity vs Depth for Shale Beds of Well Xa-2

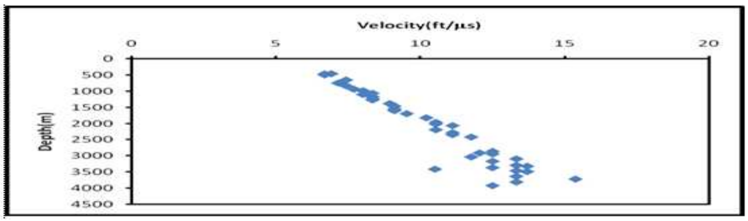

Figure 9: Depth vs Velocity for Sandstone Beds of Well Xa-2

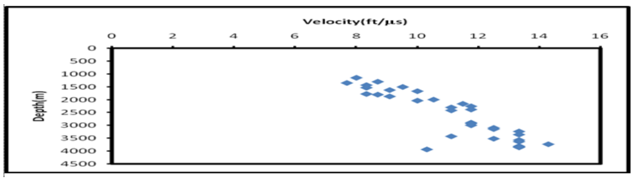

Figure 10: Depth vs Velocity for Shale Beds of Well Xa-2

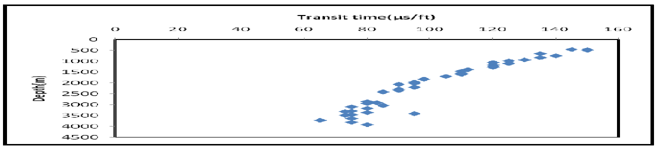

Figure 11: Depth vs Transit Time for Sandstone Beds of Well Xa-2

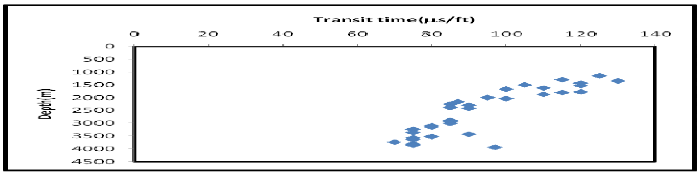

Figure 12: Depth vs Transit Time for Shale Beds of Well Xa-2

CONCLUSIONS

From the results of this study, the following observations and conclusions were reached:

- Porosity decreases with an increasing depth in normal compacted formations for both sandstone and shale beds, and increases in over pressured formations.
- Transit time decreases with depth but varies at some depth due to changes in lithology, vuggy pores and abnormal pressure zone.
- In normal compaction, sandstone has lower porosity than shale, while in over pressured formation shale is more porous than sandstone.
- Velocity increases with an increasing depth in normal compacted formation, while it decreases with an increasing depth in over pressured formations.
- Surface porosity for sandstone (42.02%) is higher than that of shale (38.73%).
- The sandstone and shale compaction factors for the study area are 0.0071 and 0.0050 respectively.

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