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Geomechanical Properties Estimation for Marginal Oil Field Development at Onshore Niger Delta, Nigeria

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ABSTRACT: Rock geomechanical properties were estimated for an onshore marginal field in Niger Delta with the aim of boosting hydrocarbon production in the field. Rock elastic properties and rock strength properties revealed bulk modulus ranged from 1.45 to 1.73 Mpsi, young's modulus from 1.01 to 1.58 Mpsi, shear modulus from 0.37 to 0.59 Mpsi and Poisson's ratio from 0.35 to 0.39. These results indicate that the shales are very stiff and harder to fracture, making them very good caprocks. Unconfined Compressive Strength ranged from 785.80 to 1357.65 psi, angle of internal friction ranged from 28.92 to 29.87 deg and cohesion ranged from 232.09 to 393.67 psi respectively. Results of shale geomechanics revealed overburden pressure (vertical stress) ranged from 1648.99 to 5652.36 psi, formation pore pressure from 2083.75 to 3277.22 psi, fracture pressure from 1648.99 to 4821.53 psi, hydrostatic pressure from 2025.10 to 3159.94 psi, maximum horizontal stress from 1648.99 to 11205.70 psi and minimum horizontal stress from 1648.99 to 4507.96 psi. Two under-pressure zones were identified across the entire field at depths ranging from 7000 to 8500 ft in UPX-01 well and 7000 to 9000 ft in UPX-05. Safe drilling mud pressures for maintaining a stable borehole in UPX field should not exceed fracture pressures of 1648.99 psi at shallow depths and 4821.53 psi at deeper depths to prevent loss in circulation. Similarly, drilling mud pressures should not be less than formation's pore pressure of 2083.75 psi at shallow depths and 3277.22 psi at deeper depths to prevent a kick and blow-out from occurring in the field. This study recommends well break-outs be acquired in order to determine the directions of horizontal principal stresses for geosteering.

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Geomechanical methods are very useful for planning and development of oil and gas fields. With the help of geomechanics, it is possible to assess the behaviour and changes in the environment during drilling and field development, to predict the pore pressure and aid in the design of adequate mud window, to assess the properties of reservoir formation, to determine the values of stress in formations, to assess the stability of the walls of the well, to calculate the optimal trajectory of the wellbore, and to optimize the process of drilling the well. Wellbore instability problems bring huge cost implications on drilling operations. These problems may occur in various forms including stuck pipe, unintentionally induced tensile fractures, hole enlargement, difficult directional control incidents or loss circulation (Zoback, 2007). Li and Purdy (2012) revealed that wellbore instability problems have been estimated to cost about 10% of the total drilling time. Even in the Niger Delta region, Exxon-Mobil pegged the minimum cost of well instability at 10% of the total drilling cost per annum. SPDC reports a cost estimate ranging between \$500 – \$700M per annum. Hence, the objective of this study is to conduct geomechanical evaluation on a marginal oil field in the onshore Niger Delta Region, Nigeria for wellbore trajectory optimization and field wide development.

MATERIALS AND METHODS

The study area (UPX Field) is located in the onshore part of the Niger Delta, Nigeria. The Niger Delta is bounded geographically by Latitudes 5˚00ˈN to 8˚00ˈ N and Longitudes 4˚00ˈE to 6˚00ˈE of the Greenwich meridian. The Rock Mechanical Properties of the field were determined for this study using the following materials; well deviation survey data for all five wells which were used to show the trajectory of the well. The well deviation survey file contains information on the well trajectory path, the drill depth (in metres), the

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azimuth and the well inclination (dip). This is needed to calculate the true vertical depth of the well. After the well deviation data were loaded, the wells were no longer vertical, but were all dipping at different angles. Another material used are wireline well logs which includes compressional sonic, gamma ray (GR in gAPI unit), resistivity (RES in Ohm.m), neutron (NEU in m^3/m^3) and density logs (DEN in g/cm^3) which was also available for all five wells (UPX 01, UPX 02, UPX 03, UPX 04, UPX 05). Gamma ray log was used for lithology identification. Gamma ray was also used for estimating shale volume. Resistivity log was used for fluid discrimination and estimating water and hydrocarbon saturation. Density log was used for total porosity estimation. Total porosity and shale volume were used for estimating effective porosity. The Rock mechanical Properties includes; Elastic properties which consist of Poisson ration (ν) which is derived and computed from acoustic measurements such as sonic log usually displayed in terms of slowness, the reciprocal of velocity called interval transit times, (ΔT) in units of microseconds per foot.

The Slowness of the compressional wave (ΔTc) and slowness of the shear wave (ΔTs) ratio is used to determine the Poisson ratio (Jones et al 1992, Moos 2006), Elastic modulus (E) (Young's modulus or modulus of elasticity) which is determined from the relationship between Young's modulus, shear modulus and Poisson ratio, Shear/rigidity modulus (G) which is the ratio of the shear stress to the shear strain, Bulk and matrix/grain moduli (Kb and Km) which is a static modulus but an equivalent dynamic modulus can be computed from the sonic and density logs, and Biot's coefficient. Inelastic properties are Fracture Gradient and Rock strength: Fracture Gradient uses the method of mapping Gamma Ray to Friction Angle with a linear correlation and a cutoff is applied to Friction Angle. In-situ rock tensile strength was evaluated following the equation of Coates and Denoo (1981) equation. This model provides the simple correlation to compute tensile strength directly from UCS (Uniaxial Compressive Strength). Rock strength parameters are made up of Uniaxial compressive strength, Friction angle, Tensile strength and Cohesive strength. Several empirical relationships proposed for application in sandstones, shales and Carbonate rocks, the Coates-Denoo algorithm was introduced in the late 1960's and is based on the Deere and Miller's sandstone and shale data (1963).. It suggests that you can predict the strength of shaly sands by combining the sandstone and shale correlations of Deere and Miller (1963, 1966).Initial shear strength. The software utilized for visualization and interpretation is Schlumberger Techlog. The choice of Techlog was based on its widespread acceptance and utilization in the exploration and production sector of the petroleum industry. The method adopted for this study began with loading the datasets into the Techlog platform for quality assessment prior to interpretation. The data set were all provided in digital format. The projection coordinates and unit systems for the Field were set in Petrel prior to the loading of any dataset. Each log used in this study was carefully assessed in terms of quality. The well logs were provided in ASCII digital format. There were no hard copies (printed logs) provided for validation. The well logs were loaded into Techlog in ASCII format and attached to their respective templates. Afterwards, the scale of each of the log was set as follows; GR (0 to 150 gAPI), resistivity (0.2 to 2000 Ohm.m), neutron (-0.15 to 0.45 m^3/m^3), density (1.65 to 2.65 g/cm^3) and sonic (40 to 240 µs/ft). The neutron and density were placed in the same tract and with neutron log reversed for identification of gas bearing zones

Rock Mechanical Properties Rock mechanical properties of the field were determined using wireline logs and includes; Poisson ration, young's modulus, Shear modulus, Bulk modulus, Unconfined Compressive Strength, Angle of Internal Friction and Cohesion. Various equations applicable to the Niger Delta formations were utilized for their computation and are presented as follows;

$$K_{dyn} = 13474.45 \times \frac{\rho_b}{(\Delta t_c)^2} - \frac{4}{3} G_{dyn} \quad (1)$$

$$G_{dyn} = 13474.45 \times \frac{\rho_b}{(\Delta t_s)^2} \quad (2)$$

$$E_{dyn} = \frac{9 G_{dyn} K_{dyn}}{G_{dyn} + 3K_{dyn}} \quad (3)$$

$$v_{dyn} = \frac{3K_{dyn} - 2G_{dyn}}{6K_{dyn} + 2G_{dyn}} \quad (4)$$

$$C_o = 0.0866 \times \frac{E_{dyn}}{C_{dyn}} \left(0.008 V_{sh} + 0.0045(1 - V_{sh})\right) \quad (5)$$

$$C_o = \frac{UCS}{2\left[\sqrt{(1 + (tanFANG)^2)} + tanFANG\right]} \quad (6)$$

$$TSTR = K_{dyn} \times UCS \quad (7)$$

Rock Stresses: The following equations were used to determine stress states across the field;

$$FG = P_p + \left(OBG - P_p\right)\left(\frac{v}{1-v}\right) \quad (8)$$

$$\sigma v = \int \rho b(z)\, g dz \quad (9)$$

$$\sigma_H = tan^2\left(\frac{\pi}{4} + FANG/2\right) \times \left(\sigma_v + \alpha P_p\right) + \alpha P_p \quad (10)$$

$$\sigma_h = \left(\sigma_v + \alpha P_p\right) / tan^2\left(\frac{\pi}{4} + FANG/2\right) + \alpha P_p \quad (11)$$

Where; Δt_s = Shear sonic transit time in µS/ft; Δt_c = Compressional sonic transit time in µS/ft; ρb= bulk density in g/cm^3; G = shear modulus; ν = Poisson ratio; E = young modulus; C_{dyn} = Unconfined Compressive Strength (Mpsi); E_{dyn} = Dynamic Young's Modulus (Mpsi); K_{dyn} = Dynamic Bulk

Modulus (Mpsi); C_o = Cohesion; FANG = Angle of internal friction; UCS = Unconfined conpressive strength; FG = fracture gradient; OBG = overburden gradient; Pp = pore pressure gradient; α = Biot′sconstant; σ_v = Vertial Stress; σ_H = Maximum Horizontal Stress; σ_h = Minimum Horizontal Stress

RESULTS AND DISCUSSION

The results of geomechanical properties performed on six (6) shale beds in UPX field are summarized in Table 1. The elastic properties determined includes; Vp/Vs ratio, bulk modulus, shear modulus, young modulus and poisson ratio. Rock geomechanical properties determined for the Shale beds included; unconfined compressive strength, angle of internal friction and cohesion.

Shale Geomechanical properties: The results of shale strength assessment are presented in Table 2-6. Compressional-shear velocity ratios for the shaley intervals are 2.31, 2.36, 2.28, 2.24, 2.26 and 2.08 for Shale A, B, C, D, E and F respectively. According to Castagna et al. (1985), clay or shales have Vp-Vs ratio > 2.0. The results obtained in this study for the shaley intervals all have Vp-Vs ratios exceeding 2.0. This result shows that Vp-Vs ratio can be used as a complimentary tool for lithology identification in UPX field. Bulk modulus ranged from 1.45 to 1.73 Mpsi, young's modulus ranged from 1.01 to 1.58 Mpsi, shear modulus ranged from 0.37 to 0.59 Mpsi and Poisson's ration ranged from 0.35 to 0.39. Generally, young modulus, bulk modulus and shear modulus all increases with depth in UPX field.

Only Poisson ratio decreases with depth. According to Zhang (2019), low Poisson's ratio (0.1–0.25) means rocks fracture easier whereas high Poisson's ratio (0.35–0.45) indicates the rocks are harder to fracture. Poisson ratio recorded in this study all fall in the range of 0.35 to 0.45, suggesting that the shales are harder to fracture. Unconfined Compressive Strength ranged from 785.80 to 1357.65 psi.

The UCS is the maximum axial compressive stress that the shales can withstand under unconfined conditions. These results shows that any applied uniaxial stress during drilling that exceeds 1357.65 psi will fracture the shale formations.

The angle of internal friction for the shaley rocks ranges from 28.92 to 29.87 deg while cohesion ranges from 232.09 to 393.67 psi in UPX field. The high cohesion obtained in this study suggests that the shales are hard and competent. Both UCS and cohesion increases with depth in UPX field.

Table 1: Average geomechanical and geochemical properties for shaly rocks in UPX field

Shale Zone	Top (ft)	Base (ft)	Gross (ft)	Vp/Vs ratio	BM	SM	PR	YM	UCS	Ø	Cohesion
Shale A	4924.82	5022.85	98.03	2.31	1.49	0.39	0.38	1.07	827.40	29.15	243.09
Shale B	5093.31	5157.03	63.72	2.36	1.45	0.37	0.39	1.01	785.80	29.21	232.03
Shale C	5245.87	5293.05	47.18	2.28	1.51	0.41	0.38	1.12	861.30	29.87	250.88
Shale D	5533.23	6126.31	593.09	2.24	1.55	0.45	0.37	1.21	1004.76	28.92	297.74
Shale E	6218.83	6564.39	345.56	2.26	1.59	0.47	0.37	1.29	1116.38	29.09	330.64
Shale F	6811.30	6883.60	72.30	2.08	1.73	0.59	0.35	1.58	1357.65	29.87	393.67

Table 2: Results of wellbore stability analysis conducted on well UPX-01

Well	Zones	Top	Bottom	Hydrostatic Pressure	Vertical Stress	Pore Pressure	Fracture Pressure	Shmax	Shmin
		ft	Ft	Psi	Psi	Psi	psi	Psi	psi
UPX-01	Sand A	4801.67	4890.51	2083.71	3509.07	2145.31	3191.88	5452.15	2946.67
UPX-01	Shale A	4890.51	4997.73	2125.87	3601.29	2189.43	3350.01	4924.07	3145.94
UPX-01	Sand B	4997.73	5071.26	2164.73	3686.42	2230.09	3288.50	5748.47	3050.55
UPX-01	Shale B	5071.26	5135.59	2194.36	3751.42	2261.11	3424.61	5314.63	3209.88
UPX-01	Sand C	5135.59	5215.24	2225.32	3819.70	2293.51	3433.57	6244.23	3159.39
UPX-01	Shale C	5215.24	5267.32	2253.64	3882.09	2323.15	3584.83	5419.24	3355.12
UPX-01	Sand D	5267.32	5515.46	2318.19	4025.64	2390.70	3580.70	6891.60	3258.80
UPX-01	Shale D	5515.46	6063.82	2489.44	4412.06	2569.91	3964.70	6151.73	3740.29
UPX-01	Sand E	6063.82	6143.47	2624.46	4717.18	2711.21	4247.52	7268.76	3932.83
UPX-01	Shale E	6143.47	6434.50	2704.16	4897.72	2794.61	4317.75	7069.37	4063.45
UPX-01	Sand F	6434.50	6679.58	2819.42	5152.15	2915.24	4385.16	9721.88	3940.81
UPX-01	Shale F	6679.58	6762.29	2889.89	5305.89	2988.99	4428.92	8192.94	4188.59
UPX-01	Sand G	6762.29	7126.84	2986.05	5518.33	3089.63	4530.48	10234.80	4126.17
Minimum				2083.71	3509.07	2145.31	3191.88	4924.07	2946.67
Maximum				2986.05	5518.33	3089.63	4530.48	10234.80	4188.59
Mean				2452.25	4329.15	2530.99	3825.28	6817.99	3547.58

Table 3: Results of wellbore stability analysis conducted on well UPX-02

Well	Zones	Top	Bottom	Hydrostatic Pressure	Vertical Stress	Pore Pressure	Fracture Pressure	Shmax	Shmin
		ft	Ft	Psi	Psi	Psi	psi	psi	psi
UPX-02	Sand A	5290.22	5387.46	2083.06	1912.55	2150.25	1912.55	1912.55	1912.55
UPX-02	Shale A	5387.46	5505.03	2123.88	2001.28	2192.97	2001.28	2001.28	2001.28
UPX-02	Sand B	5505.03	5587.53	2162.09	2085.47	2232.96	2085.47	2085.47	2085.47
UPX-02	Shale B	5587.53	5662.77	2192.39	2151.26	2264.67	2151.26	2151.26	2151.26
UPX-02	Sand C	5662.77	5764.87	2226.63	2225.98	2300.51	2225.98	2225.98	2225.98
UPX-02	Shale C	5764.87	5812.41	2255.63	2288.93	2330.85	2288.93	2288.93	2288.93
UPX-02	Sand D	5812.41	6059.92	2312.90	2413.27	2390.78	2407.11	2451.21	2402.34
UPX-02	Shale D	6059.92	6739.67	2494.78	2824.73	2581.12	2763.82	3057.54	2734.37
UPX-02	Sand E	6739.67	6841.53	2650.14	3183.30	2743.71	3081.40	3802.46	3006.88
UPX-02	Shale E	6841.53	7212.08	2745.00	3402.76	2842.99	3261.68	3980.18	3187.97
UPX-02	Sand F	7212.08	7464.62	2870.16	3689.71	2973.97	3449.15	5045.13	3314.97
UPX-02	Shale F	7464.62	7546.90	2937.33	3839.56	3044.26	3552.24	4793.63	3468.08
UPX-02	Sand G	7546.90	7771.32	2998.59	3978.02	3108.37	3632.49	5743.03	3477.67
Minimum				2083.06	1912.55	2150.25	1912.55	1912.55	1912.55
Maximum				2998.59	3978.02	3108.37	3632.49	5743.03	3477.67
Mean				2465.58	2768.99	2550.57	2677.95	3195.28	2635.21

.

Table 4: Results of wellbore stability analysis conducted on well UPX-03

Well	Zones	Top	Bottom	Hydrostatic Pressure	Vertical Stress	Pore Pressure	Fracture Pressure	Shmax	Shmin
		ft	Ft	Psi	Psi	Psi	psi	psi	psi
UPX-03	Sand A	5509.08	5632.58	2106.78	1648.99	2169.23	1648.99	1648.99	1648.99
UPX-03	Shale A	5632.58	5732.17	2149.59	1743.43	2214.03	1743.43	1743.43	1743.43
UPX-03	Sand B	5732.17	5797.39	2181.20	1814.78	2247.11	1817.55	1817.55	1817.55
UPX-03	Shale B	5797.39	5879.72	2209.52	1876.23	2276.75	1876.23	1876.23	1876.23
UPX-03	Sand C	5879.72	5985.90	2245.74	1957.49	2314.65	1957.49	1957.49	1957.49
UPX-03	Shale C	5985.90	6043.69	2277.35	2027.03	2347.73	2027.03	2027.03	2027.03
UPX-03	Sand D	6043.69	6310.13	2341.42	2167.94	2414.78	2167.94	2167.94	2167.94
UPX-03	Shale D	6310.13	6958.56	2529.99	2594.99	2612.12	2585.17	2630.58	2581.13
UPX-03	Sand E	6958.56	7065.72	2687.69	2959.92	2777.16	2916.12	3233.18	2883.53
UPX-03	Shale E	7065.72	7396.52	2779.24	3172.57	2872.97	3084.75	3482.60	3050.72
UPX-03	Sand F	7396.52	7582.35	2887.26	3423.73	2986.01	3257.21	4344.49	3173.45
UPX-03	Shale F	7582.35	7632.74	2936.66	3536.60	3037.71	3329.24	4139.30	3291.31
UPX-03	Sand G	7632.74	7843.73	2991.33	3658.37	3094.92	3462.64	4717.72	3360.23
Minimum				2106.78	1648.99	2169.23	1648.99	1648.99	1648.99
Maximum				2991.33	3658.37	3094.92	3462.64	4717.72	3360.23
Mean				2486.44	2506.31	2566.55	2451.83	2752.81	2429.16

Table 5: Results of wellbore stability analysis conducted on well UPX-04

Well	Zones	Top	Bottom	Hydrostatic Pressure	Vertical Stress	Pore Pressure	Fracture Pressure	Shmax	Shmin
		ft	Ft	Psi	psi	Psi	psi	psi	psi
UPX-04	Sand A	5210.10	5308.54	2025.10	2147.11	2083.75	2134.19	2226.95	2123.32
UPX-04	Shale A	5308.54	5417.45	2061.30	2227.36	2121.63	2203.50	2327.22	2189.76
UPX-04	Sand B	5417.45	5498.85	2094.89	2303.71	2156.79	2267.76	2487.34	2244.37
UPX-04	Shale B	5498.85	5571.77	2122.56	2365.00	2185.74	2319.35	2551.25	2295.91
UPX-04	Sand C	5571.77	5654.52	2150.88	2427.99	2215.38	2384.34	2707.01	2347.53
UPX-04	Shale C	5654.52	5700.90	2174.61	2479.83	2240.22	2417.94	2718.63	2388.54
UPX-04	Sand D	5700.90	5962.39	2231.83	2604.01	2300.10	2519.85	3133.82	2460.92
UPX-04	Shale D	5962.39	6614.08	2401.58	2990.39	2477.74	2840.83	3530.47	2781.14
UPX-04	Sand E	6614.08	6713.94	2540.16	3317.70	2622.77	3123.28	4184.99	3025.87
UPX-04	Shale E	6713.94	7177.75	2644.72	3565.66	2732.19	3358.25	4374.24	3256.59
UPX-04	Sand F	7177.75	7480.44	2787.75	3898.18	2881.87	3511.88	5751.27	3348.17
UPX-04	Shale F	7480.44	7571.79	2861.59	4062.51	2959.15	3617.62	5464.29	3515.85
UPX-04	Sand G	7571.79	7866.48	2933.97	4228.21	3034.89	3624.49	7466.04	3399.23
Minimum				2025.10	2147.11	2083.75	2134.19	2226.95	2123.32
Maximum				2933.97	4228.21	3034.89	3624.49	7466.04	3515.85
Mean				2387.00	2970.59	2462.48	2794.10	3763.35	2721.32

Wellbore Stability Analysis: Well bore stability assessment was conducted on UPX field to determine the pressures and stress field required for a stable well bore trajectory during drilling infill wells in the field. Vertical stress (overburden pressure) ranged from 3509.07 to 5518.33 psi, 1912.55 to 3978.02 psi, 1648.99 to 3658.37 psi, 2147.11 to 4228.21 psi and 3520.21 to 5652.36 psi for UPX-01, UPX-02, UPX-03, UPX-04 and UPX-05.

Table 6: Results of wellbore stability analysis conducted on well UPX-05

Well	Zones	Top	Bottom	Hydrostatic Pressure	Vertical Stress	Pore Pressure	Fracture Pressure	Shmax	Shmin
		ft	Ft	Psi	psi	Psi	psi	psi	psi
UPX-05	Sand A	5037.56	5141.72	2188.44	3520.21	2260.53	3216.75	5277.71	2997.16
UPX-05	Shale A	5141.72	5242.81	2232.57	3616.37	2306.71	3386.11	4777.88	3203.07
UPX-05	Sand B	5242.81	5322.46	2271.43	3700.17	2347.38	3301.80	5671.47	3079.73
UPX-05	Shale B	5322.46	5374.54	2299.75	3762.95	2377.02	3500.48	5054.76	3304.78
UPX-05	Sand C	5374.54	5481.76	2334.00	3835.74	2412.86	3469.31	6096.61	3204.61
UPX-05	Shale C	5481.76	5530.78	2367.59	3907.35	2448.02	3588.16	5422.42	3378.47
UPX-05	Sand D	5530.78	5785.04	2432.79	4045.42	2516.26	3604.55	6650.95	3317.18
UPX-05	Shale D	5785.04	6388.55	2617.21	4445.33	2709.26	4083.50	6088.49	3847.91
UPX-05	Sand E	6388.55	6486.58	2768.04	4781.03	2867.10	4465.51	7005.73	4140.28
UPX-05	Shale E	6486.58	6854.19	2868.16	5003.86	2971.87	4618.16	6808.77	4347.05
UPX-05	Sand F	6854.19	7163.60	3013.72	5325.44	3124.20	4272.38	11019.20	3839.49
UPX-05	Shale F	7163.60	7237.13	3096.05	5509.04	3210.36	4821.53	8304.63	4507.96
UPX-05	Sand G	7237.13	7460.76	3159.94	5652.36	3277.22	4529.34	11205.70	4105.37
Minimum				2188.44	3520.21	2260.53	3216.75	4777.88	2997.16
Maximum				3159.94	5652.36	3277.22	4821.53	11205.70	4507.96
Mean				2588.44	4392.71	2679.14	3912.12	6875.72	3636.39

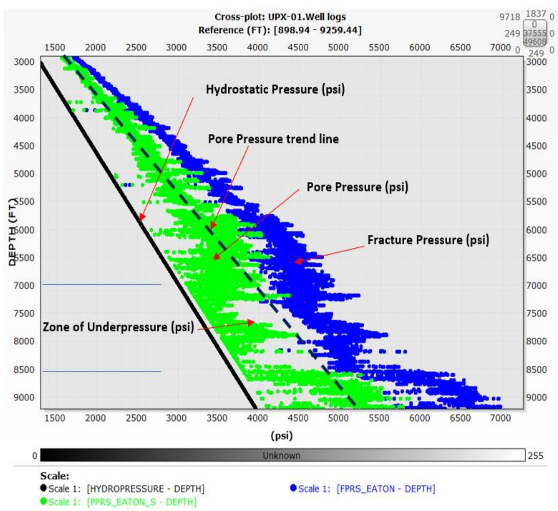

Fig 1. A depth plot of pore pressure, fracture pressure and hydrostatic pressure for UPX-01

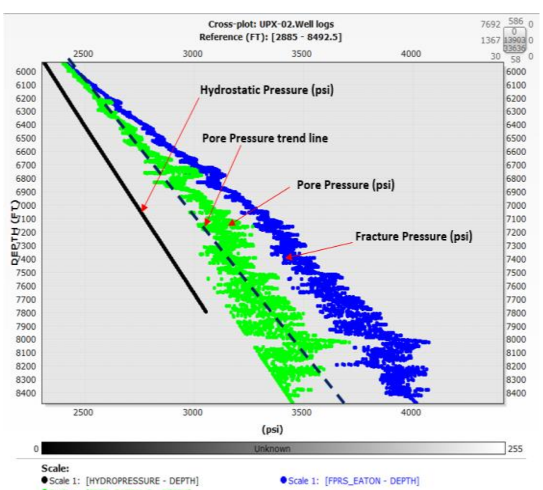

Fig 2. A depth plot of pore pressure, fracture pressure and hydrostatic pressure for UPX-02

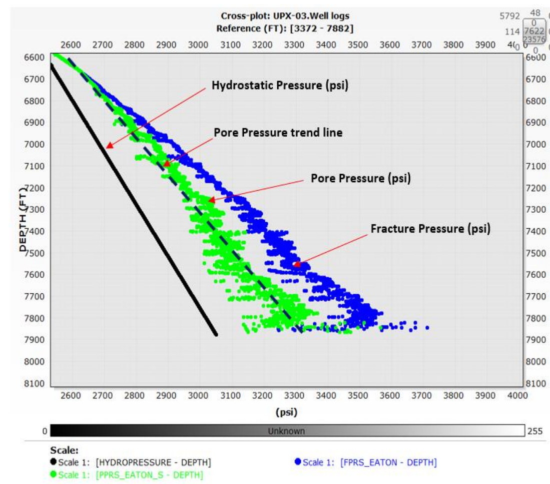

Fig 3. A depth plot of pore pressure, fracture pressure and hydrostatic pressure for UPX-03

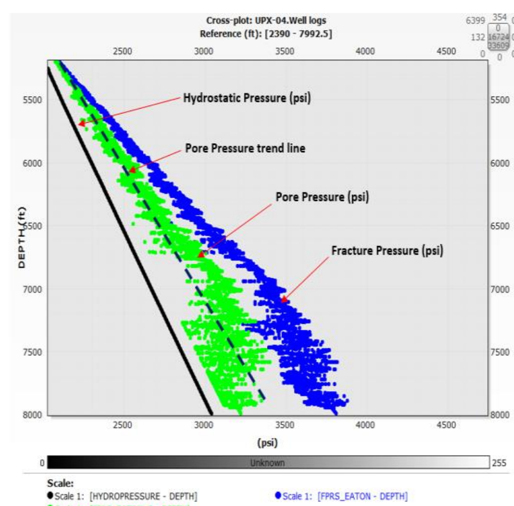

Fig 4: A depth plot of pore pressure, fracture pressure and hydrostatic pressure for UPX-04

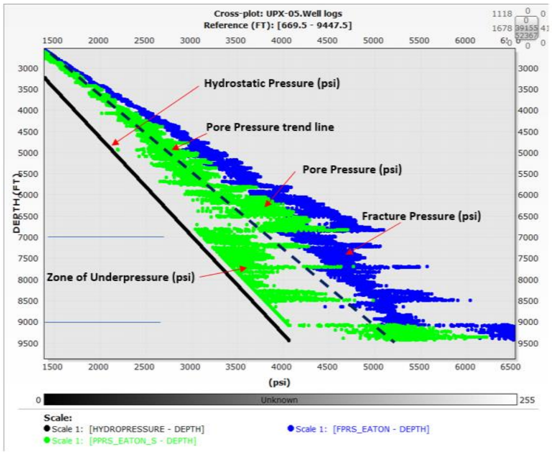

Fig 5: A depth plot of pore pressure, fracture pressure and hydrostatic pressure for UPX-05

The maximum overburden pressure recorded in UPX field was 5652.36 psi. Generally, overburden pressure increases with depth with the maximum overburden pressure recorded in UPX-05 field (5652.36 psi) at 7300 ft. Formation pore pressures recorded ranged from 2145.31 to 3089.63 psi, 2150.25 to 3108.37 psi, 2169.23 to 3094.92 psi, 2083.75 to 3034.89 psi and 2260.53 to 3277.22 psi. Generally, pore pressure increases with depth across the UPX field. No abnormal overpressure zones were identified across the field. Meanwhile, two zones of under-pressure were identified in UPX-01 at depths ranging from 7000 to 8500 ft (1500 ft under-pressure zone) and in UPX-05 at depths ranging from 7000 to 9000 ft (2000 ft under-pressure zone). The pore pressure of the formation defines the lower limit for pressures of the drilling mud. On no account should the mud used for drilling be less than the formation pore pressures so as to prevent formation fluids from seeping into the bore well and causing a blow-out over time. Hydrostatic pressures ranged from 2083.71 to 2986.05 psi, 2083.06 to 2998.59 psi, 2106.78 to 2991.33 psi, 2025.10 to 2933.97 psi and 2188.44 to 3159.94 psi in UPX-01, UPX-02, UPX-03, UPX-04 and UPX-05 wells respectively. The hydrostatic pressure is always lower than the formation pore pressures. Formation fracture pressures ranged from 3191.88 to 4530.48 psi, 1912.55 to 3632.49 psi, 1648.99 to 3462.64 psi, 2134.19 to 3624.49 psi and 3216.75 to 4821.53 psi in UPX-01, UPX-02, UPX-03, UPX-04 and UPX-05 respectively. The formation fracture pressure defines the upper limit of drilling pressures (drilling mud pressure) above which the formation will fracture causing loss of formation fluids into the formation during drilling. The pressure of the drilling mud utilized for drilling in the UPX field should be higher than the pore pressure of the formation to prevent a kick which could result to a blow-out and less than the fracture gradient of the formation to prevent lost circulation and stuck pipe. The maximum horizontal principal stress and minimum horizontal principal stresses in UPX field ranges from 4924.07 to 10234.80 psi and 2946.67 to 4188.59 psi in UPX-01, 1912.55 to 5743.03 psi and 1912.55 to 3477.67 psi in UPX-02, 1648.99 to 4717.72 psi and 1648.99 to 3360.23 psi in UPX-03, 2226.95 to 7466.04 psi and 2123.32 to 3515.85 psi in UPX-04 and 4777.88 to 11205.70 psi and 2997.16 to 4507.96 psi in UPX-05. Wellbore trajectories are always in the direction of minimum horizontal stress in order to prevent unstable boreholes.

Conclusion: Rock elastic properties (young modulus, shear modulus, bulk modulus and poisson ratio), unconfined compressive strength, angle of internal friction and cohesion have all revealed that shales in UPX field are stiff, compact and harder to fracture. Based on these properties, the shales are good cap rocks as they are hard to fracture. Well bore stability assessment revealed that the overburden pressure, pore pressure, fracture pressure, hydrostatic pressure, maximum horizontal stress and minimum horizontal stress are within a very good range. These properties are relevant in planning a stable path for an infill well in UPX field. Safe drilling mud pressures for maintaining a stable borehole should not exceed 4821.53 psi (maximum fracture pressure) to prevent loss in circulation and should not be less than 3277.22 psi (maximum pore pressure) to prevent a kick and blow-out in the field.

REFERENCES

Castagna, J; Batzle, M; Eastwood, R (1985). Relationship between compressional and shear-wave velocities in classic silicate rocks. *Geophysics. 50. 571-581.*

Coates, GR; Denoo, SA (1981). Mechanical properties programme using borehole analysis and Mohr circle. *SPWLA, 22nd Annual Logging Symposium*.

Eaton, BA (1969). Fracture gradient prediction and its application in oilfield operations. *Journal of Petroleum Technology, 246, 1353 - 1360.*

Eaton, BA (1972). Graphical method predicts geopressure worldwide. *World Oil, 182, 51 – 56.*

Li, S; George, J; Purdy, C (2012). Pore pressure and wellbore stability prediction increases drilling efficiency. *J. Pet. Tech. 64, 98 –101.*

Zhang, JJ (2019). Applied Petroleum Geomechanics. Elsevier Inc. Gulf Professional Publishing, United Kingdom.

Zoback, MD (2007). Reservoir geomechanics: earth stress and rock mechanics applied to exploration, production and wellbore stability. Cambridge: Cambridge Press; Pp. 449.