Pressure Regime and Hydrodynamic Study of Niger Delta Coastal Swamp: Implication for Hydrocarbon Recovery and Production*

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Abstract

The characteristics of pressure regimes observed in Nembe Creek, Akaso, Krakama and Adibawa oil fields in Coastal swamp of tertiary Niger Delta have been used to study hydrodynamic activities within the fields with a view of maximizing hydrocarbon production and improve reserves portfolio. We accomplished this by delineating the lithology and reservoir using appropriate well logs, constructing the pressure (Repeater Formation Test) - depth plots and Oil Water Contact (OWC) isopach structure maps, computing the dip/tilt of the OWC, and appraising of production history of the wells in each field.

The complex fault pattern in Nembe Creek has resulted in compartmentalized reservoir blocks with variable communication between blocks. Tilted oil water contact (OWC) due to aquifer heterogeneity was also observed while the pressure regime was hydrostatic. In Akaso and Adibawa fields, the measured pore pressure varied from hydrostatic, mild overpressure to hard over pressure regimes. Pressure regression phenomenon involving alternating bands of hydrostatic pressure sand and overpressured shale was also observed in one of the wells in each field and has resulted to hydraulic communication and lateral drainage. This has enabled the production and escape of hydrocarbons in wells where pressure regression was observed through one of the adjoining wells in Akaso and Adibawa field respectively. In Krakama field, high overpressure gradient has tilted the OWC.

Introduction

Hydrodynamics influences oil migration pathways (Brown, 2001), and may modify the geometry or location of pre-existing accumulations. Common effects include a tilted OWC, flushed or partially flushed traps, structurally offset oil and gas accumulations, hydrocarbon accumulations in non-closed geologic features, and gas accumulations down-dip from and underlying water (Cockroft et al., 2006). Tilted OWCs are a key indicator for identifying potentially thick Residual Oil Zones (ROZs) (Melzer, 2006). Early recognition of tilted OWCs is essential for correct evaluation of reserves and STOIIP (Dennis et al., 2005).

In general, reservoirs in the Niger Delta are known to have very good natural pressure support provided by large active aquifers and as such readily lend itself to hydrodynamic study. Most hydrodynamic systems have historically been associated with uplift, fluid recharge and tilting toward the basin centre. The pressure drive comes from either meteoric waters located in neighbouring highlands (Type-1 Hydrodynamic), or as a result of expulsion from over-pressured sediments met whenever over-pressured shales are connected to laterally-drained reservoirs (Type-2 hydrodynamics or compaction-driven hydrodynamic systems). These two forms of hydrodynamics system have been observed in upper Miocene sand Coastal Swamp depositional belts of tertiary Niger delta Nigeria (Figure 1) and have resulted into tilted OWC in Nembe Creek and Krakama field and pressure regression phenomenon in Akaso and Adibawa field. The effects of these hydrodynamic systems on hydrocarbon recovery in aforementioned fields are investigated.

Material and Method

Materials required include Repeat Formation Test (RFT) pressure data; well data (location and tops); reservoir structure maps (top and base); PSDM seismic structure map for fluids contacts mapping across all reservoir horizons; suites of well logs; and production history of the field. The workflow is illustrated by the flow chart in Figure 2.

Results and Discussion

Nembe Creek

Nembe Creek is a completely faulted rollover anticline system characterized by sub-parallel, mostly south dipping, east-west trending synthetic faults. The reservoirs are therefore intersected by several E-W synthetic and antithetic faults forming six distinct reservoir blocks X, H, E, J, K and L. The complex fault pattern has resulted in compartmentalized reservoir blocks with variable communication between blocks. The average fluid contacts (OWC) in different reservoirs therefore varied on block basis (Table 1).

The pressure-depth plots obtained across some wells in Nembe Creek is shown in Figure 3a. The pressure regime is hydrostatic except NEMC-022 that is mildly overpressure. This is in line with the hydrostatic pressure regime observed in majority of Niger Delta fields. However, the pressure-depth plots of OWC of wells in block-H, J and X for D-sands reservoir are the same yielding oil pressure gradient of 0.44 psi/ft indicating the oil pressure gradient constant (Figure 3b and 3c). Nonetheless, the oil is in communication across the fault while the aquifer flow is sustained by separate OWCs in each block with blocks on the down-throw having higher original OWCs than blocks on the up-throw. Thus, the faults separating the blocks, which appear like sealing faults or low-permeability baffles, are rather, hydrodynamic aquifers. The OWC structure maps obtained from Nembe Creek field across D-reservoir horizons are as depicted in Figure 4.

It indicates varying degrees of tilt within and inter-block because of aquifer heterogeneity. This is corroborated by constant oil pressure gradient in all blocks within D-reservoir; vindicating the varied OWC could not be attributed to compartmentalization but underlain hydrodynamic aquifer. Because of the tilted OWC, most productive wells are located down-dip of OWC surface and have the thickest oil column, e.g. NEMC-058 in block-H has been the most productive of the four hydrocarbon bearing reservoirs D2500H, D2500X, D2500E and

D2500J. It has produced 5.0MMstb of the 7.30MMstb ultimate recovery of D2500. It has also enabled the recommendation of NEMC-052 within the same block-H for recompletion with D2500H, D3000H and D5000H as candidate reservoir.

Krakama Field

Tilted OWC was observed within S2.0 and S9.1 reservoir sand involving wells Krak-04 (7,882 ftss), 08 (7,870 ftss), 11 (7,863 ftss), 14 (7,838 ftss) and Krak-09 (9,782 ftss), 13 (9,806 ftss), 15 (9,829 ftss) respectively. The greatest tilt was between Krak-04 and Krak-14 while the least tilted contact was between Krak-08 and Krak-04 indicating Krak-04 as most productive within S2.0 reservoir. However, Krak-15 appears the most productive within S9.1 reservoir with the greatest tilt between it and Krak-09.

Akaso Field

The pressure regime observed within Akaso field based on RFT pore pressure measurements varied from hydrostatic to overpressure (Figure 5a). However, the pressure gradient profile of Akaso-10 well within the field (Figure 5b) is characterized by varied course pressure profile with alternating progressive and regressive trend between overpressure shale and normally pressure sandstone. The pressure compartmentalizations are in four cascades and indicate pressure regression. This resulted to hydraulic communication between well Akaso-010 and offset well Akaso-02 forming lateral drainage through reservoir continuity. A detailed study of the PVT properties of the fluids (Table 2) at reservoir conditions also revealed similarities between fluids in Akaso-10 and Akaso-02 (in the same block as Akaso-10) specifically within E1000A, E2000A, E3000A, F2000A and G1100A reservoirs intervals thus corroborating the finding. This has enabled the investigation of undifferentiated hydrocarbon encountered in H1000A sands within Akaso-02, provided drainage on the F2000A sand and G1100A reservoir complex, as well as production of hydrocarbon in Akaso-10 through Akaso-02.

The evidence of pressure regression is also illustrated by the production history of Akaso-10 (Figure 5c). There was increase in water production within G1100A interval from 30%BSW to 56%BSW and corresponding decline in oil production from 3,700 BOPD to approximately 402 BOPD. Consequently, the interval E5000A sands produced dry and at a very low rate until August 1996 when traces of water were observed (Figure 5d). It continued producing at 474 BOPD with about 4% BSW until it finally stopped producing in March 1997. It was opened up again in March 1998 and produced for only a month before it stopped producing again. In August 2006, it was planned to work over the well as TSM with the E5000A sands behind sleeve. However, Schlumberger Reservoir Saturation Tool (RST) acquired during the work over in September 2006 indicated that the E5000A sands were flushed! This is in corroboration with the fact that pressure regressions are associated with de-watering from above and below the intervals of pressure regression (Connor and Swarbrick, 2008).

Adibawa Field

At M7000 level, the Adibawa field consists of two proven oil bearing blocks Y and Z. These blocks are both footwall closures against the main structure-building fault. In addition, a smaller NW-SE trending fault separates and downthrows block-Y relative to block-Z. The throw across blocks Y and Z is over 400 ft.

The M7000 reservoir is capped by shale that varies in thickness from 25 to 35 ft thick. The M7000 and M9000 sands are separated by less than 12 ft of shale (in well Adib-4, which reduces eastwards towards block-Z and is faulted out in well Adib-5). The reservoir thickness ranges from 132 to 154 ft (except in well Adib-5 where it is base faulted).

The reservoir comprises of a coarsening upwards-sand package that passes upwards into sharp-based, blocky GR profile (Figure 6a). The reservoir is thus a stack of prograding shoreface sands capped in places by distributary channels. The hydrocarbon bearing sand in the reservoir was penetrated by wells Adib-4 and Adib-1 in block-Y and Adib-5 in block-Z. The 45 ft of oil column with OGOC and OOWC at 11,537 ftss and 11,585 ftss respectively in block-Y was logged by wells Adib-1 and Adib-4. The OGOC at 10,508 ftss and OOWC at 11,570 ftss in block-Z were logged in Adib-5.

The pressure-depth plot obtained from Adib-5 is as shown in Figure 6b. The pressure envelopes indicate pressure regression. As in Akaso-10 in Akaso field, it indicates hydraulic communication and lateral drainage leading probably to the escape of fluids into the adjoining well, specifically Adib-4 in block-Y probably through the fault separating block-Y and block-Z. This is as corroborated by well history of Adib-5 within M7000 interval (11,532-11,538 ftss). The interval came on stream in 1972 immediately after the initial completion. Production test carried out in June 1975 confirmed high GOR between 10-15 Mscf/bbl and BSW of 1%. In June 1982 work over, gas shut off was carried out. Thereafter, it produced at about 100 BOPD at 0% BSW before it was closed-in in 1985 for low productivity. Total oil production from block-Z was 0.11 MMstb. In March 2007, Adib-5 was opened up and it came in and produced for few days before station shut down. It was decided to swab the well to flow but did not and in the process five bbl of crude oil with BSW of 10% recovered was taken to be oil in tubing column. Swabbing was therefore suspended due to drop in fluid level. Subsequently in April 2007, an integrated team review was carried out and re-perforation of the interval was recommended. However, Adib-4, the other well producing from the same M7000 reservoir was still producing without any other wells producing from the same block-Z. Thus, there is likelihood of escape of crude oil into Adib-4 thus undermining the seal integrity of NE-SW trending fault which separates and downthrows block-Y relative to block-Z.

Conclusions

The effect of hydrodynamics has been studied. Both pressure regression and tilted oil water contact observed had resulted to enhance oil recovery within the upper Miocene reservoir sand of coastal swamp depositional belt of tertiary Niger delta Nigeria.

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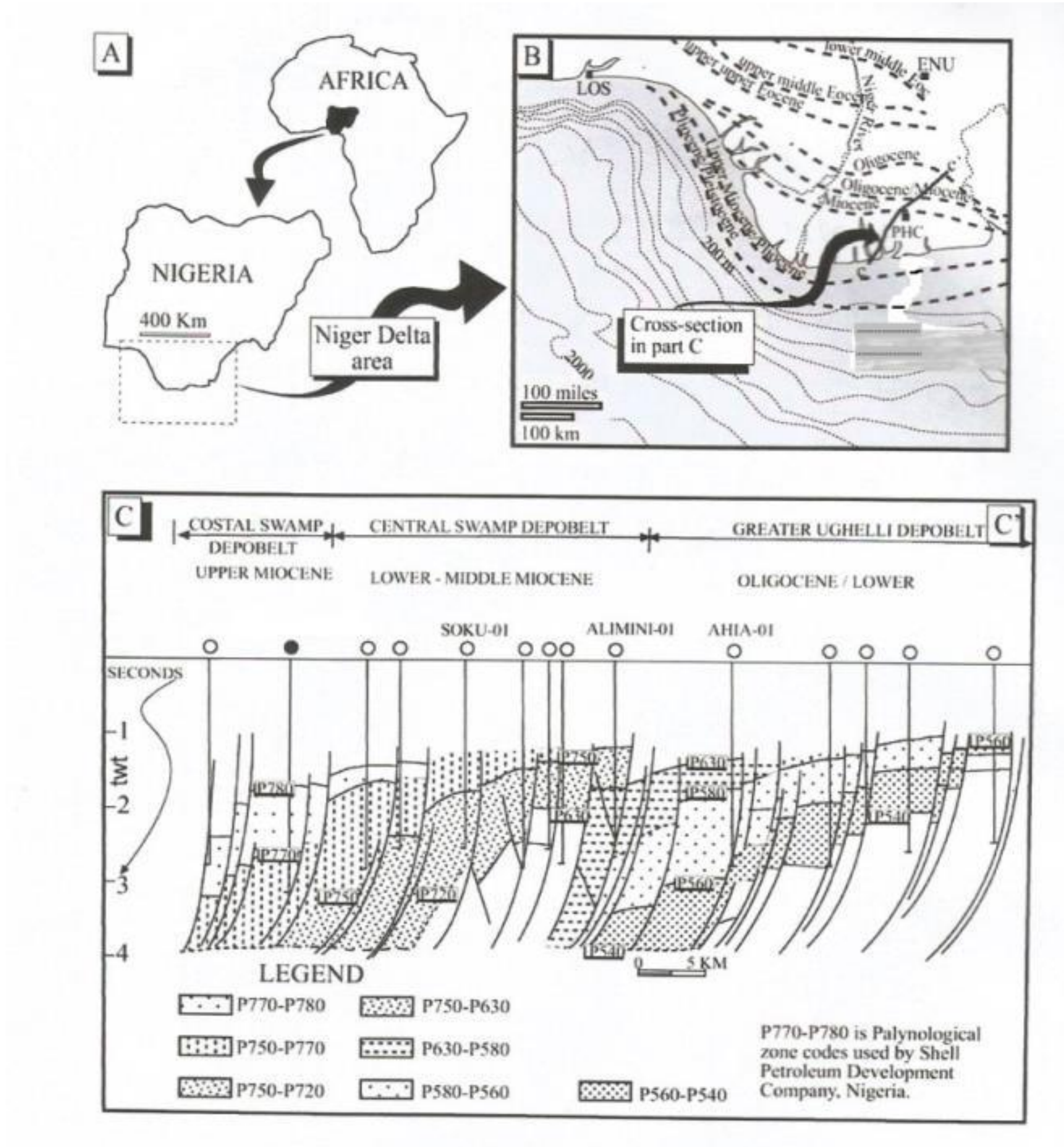


Figure 1. Location map of study area. (a) Location of Niger Delta along the west coast of Africa, (b) Coastal swamp depositional belt where Akaso, Nembe, Adibawa and Krakama fields are located, (c) Stratigraphic cross section from NNE to SSW showing the prograding geometry of the Niger Delta deposits (modified from Doust and Omatsola, 1990).

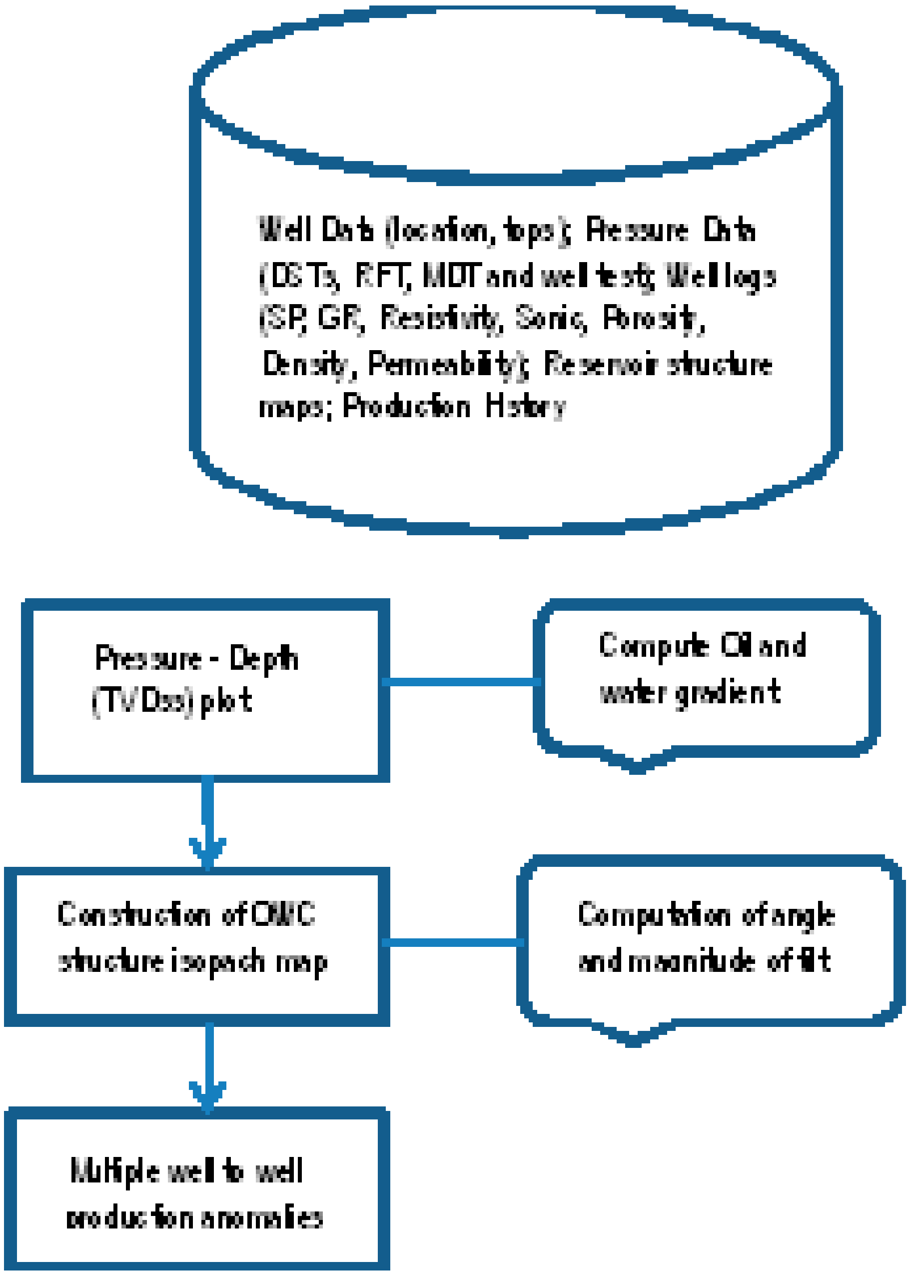


Figure 2. Work flow diagram.

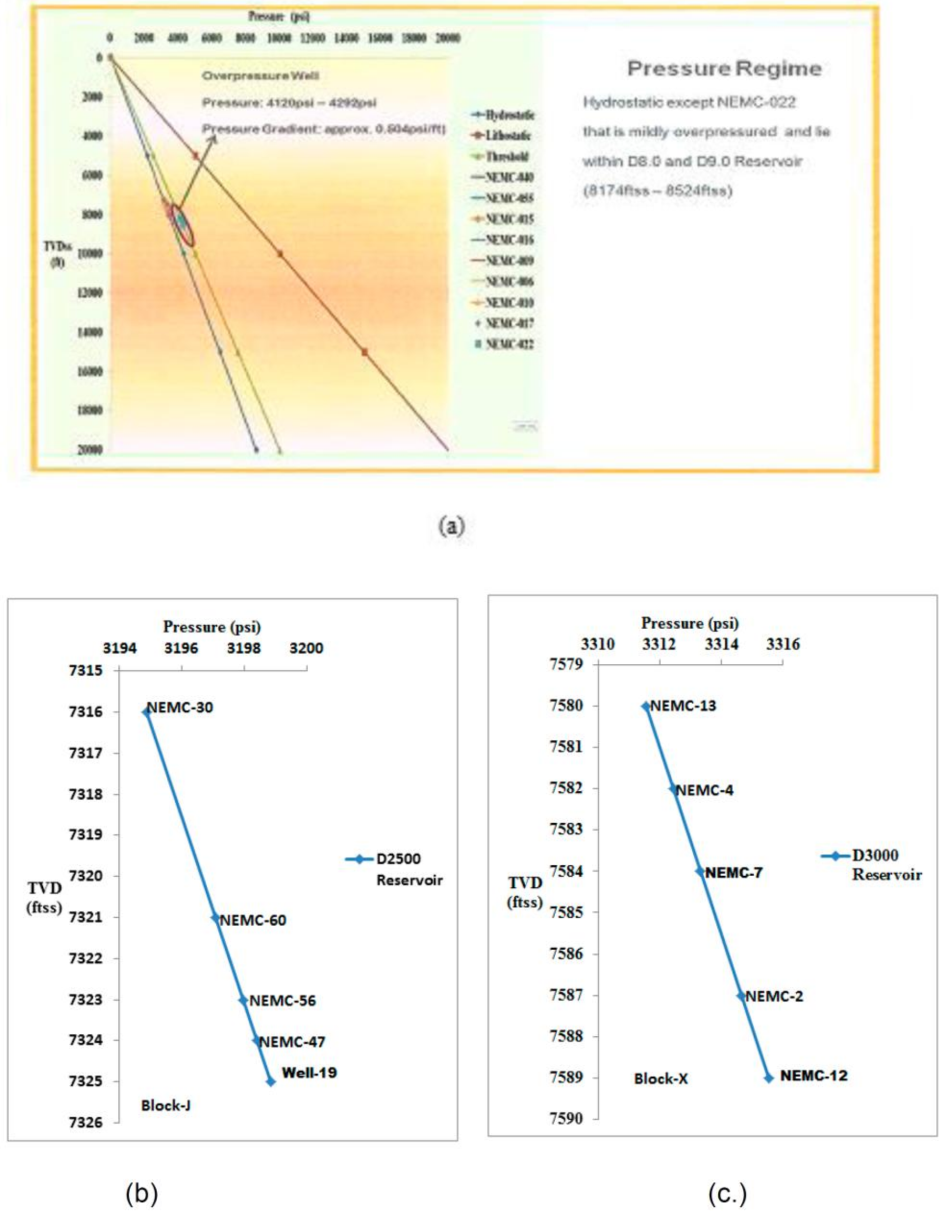


Figure 3. Pressure regime in Nembe Creek. (a) Pressure-depth plot of some wells in Nembe Creek, (b) Pressure-depth plot of OWC in wells in block-J for D2500-sands reservoir having oil pressure gradient of 0.44 psi/ft, (c) pressure-depth plot of OWC in wells in block-X for D3000-sands reservoir having oil pressure gradient of 0.44 psi/ft.

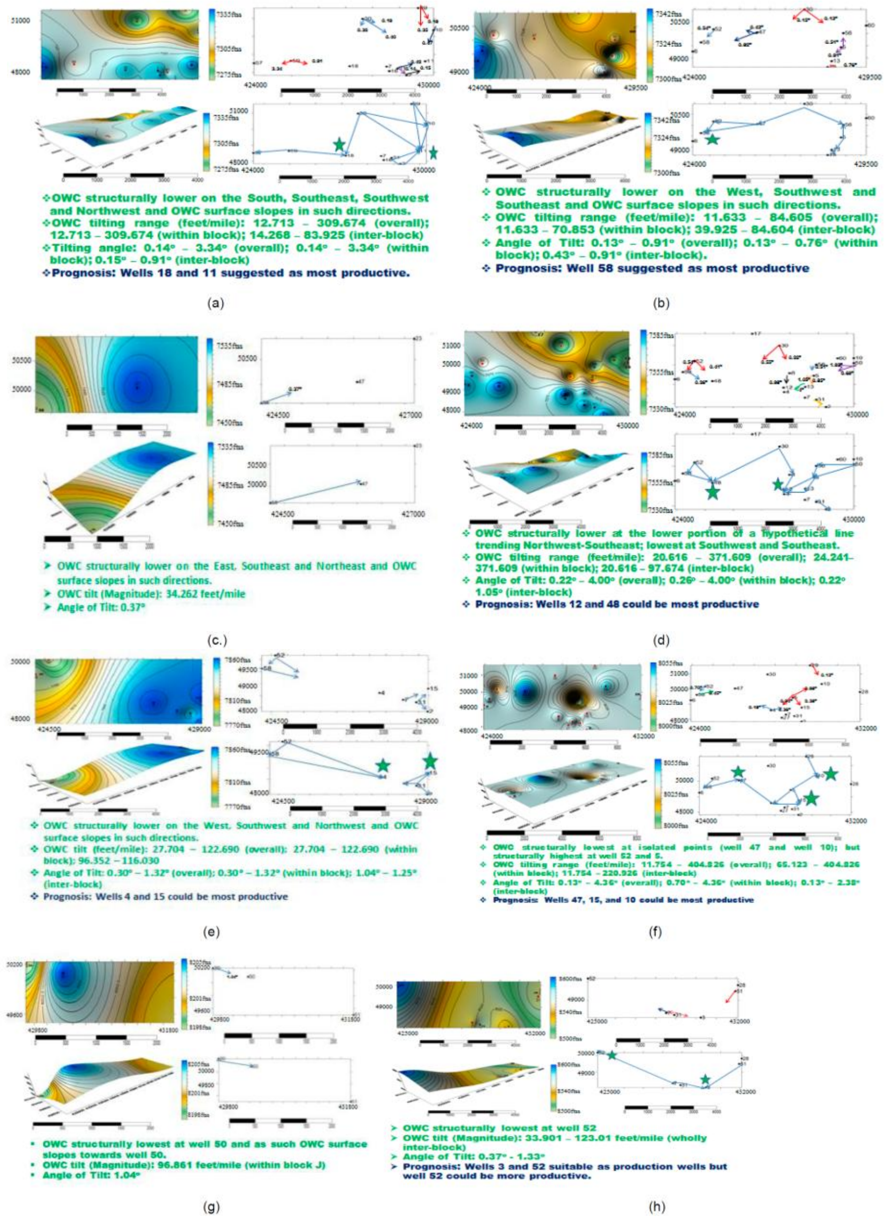


Figure 4. OWC structure map, D-reservoir, Nembe Creek, Niger Delta. (a) D2000, (b) D2500, (c) D2900, (d) D3000, (e) D5000, (f) D6000, (g) D8000, (h) D9000. (Counter-clockwise on each figure: 2-D OWC structure map, 3-D OWC structure map, direction of aquifer flow in the subsurface, and tilt direction.)

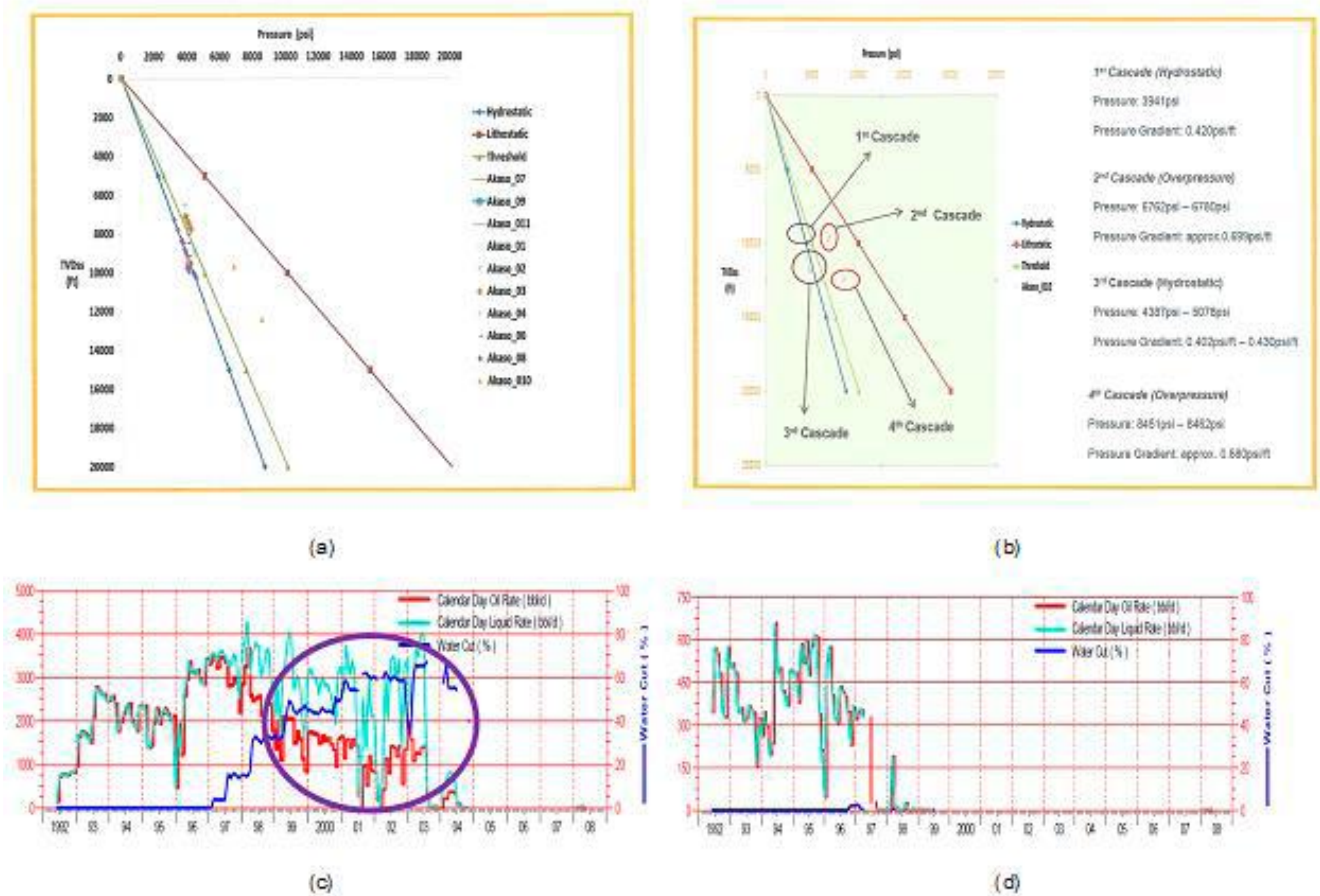
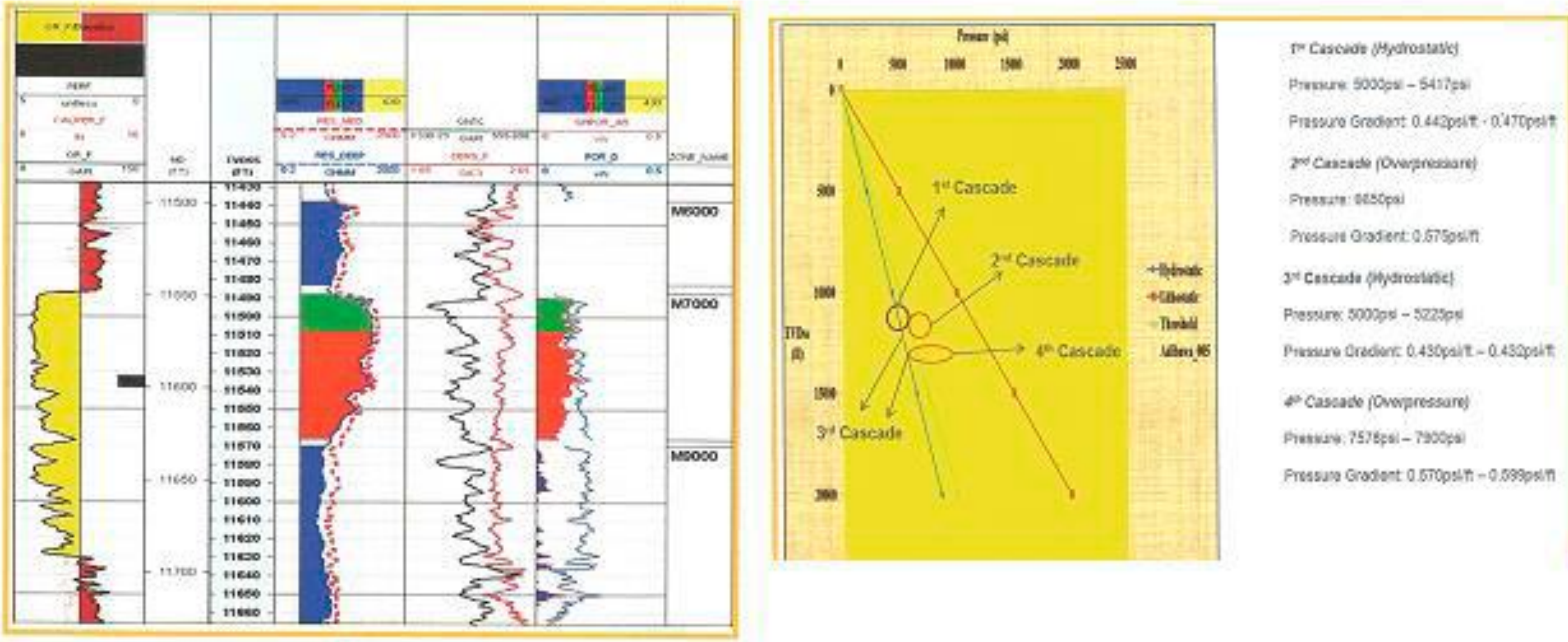


Figure 5. (a) Pressure-depth plot of wells in Akaso field, (b) pressure-depth plot of Akaso-10 showing pressure regression, (c) production history of Akaso-10 within G1100 reservoir, (d) production history Akaso-10 within E5000A reservoir, Akaso Field, Niger Delta Nigeria.



(a) (b)

Figure 6. (a) M7000 composite depth plot of Adibawa-5 well showing blocky GR profile, (b) pressure-depth plot of Adibawa-5 well showing pressure regression.

Sand	Block	OGOC	OOUT	OODT	OOWC
D2000	X & H	7273	-	-	7324
	J	-	7182	-	7284
	K	-	7196	-	7284
	E	7204	-	-	7306
D2500	X	-	-	-	7324
	J	-	-	-	7319
	H	-	-	-	7343
	E	-	-	-	7306
D2900	X	7516	-	-	-
	J	-	7401	-	7525
	L	-	7866	7881	7531
	K	-	7447	-	7531
	E	7494	-	-	7553
D3000	X & H	-	-	-	7585
	J	-	-	-	7531
	K	-	-	-	7543
	E	7494	-	-	7552
	L	-	-	-	7932
D6000	X1(N)	7983	-	-	8043
	X2(S)	7941	-	-	8043
	J	7878	-	-	8049
	H	7957	-	-	8044
	K	-	7917	-	8049
	E	7968	-	-	7998

N – North; S - South

Table 1. Average fluid contacts (in ftss) on block basis, ‘D’ Reservoir Nembe Creek.

Akaso-10								Akaso-02							
BLK	P_b (psia)	R_{si} (scf/b)	B_{oi} (v/v)	T_r (deg/f)	SG_{oil} (API)	η_{Oil} (cp)	η_{water} (cp)	BLK	P_b (psia)	R_{si} (scf/b)	B_{oi} (v/v)	T_r Deg/f	SG_{oil} (API)	η_{Oil} (cp)	η_{water} (cp)
C5000A	3614	772	1.316	160	0.733	0.6	0.39	E1000A	4120	1115.4	1.505	178	0.689	0.35	0.37
D6000A	3648	896	1.375	162	0.711	0.5	0.39	E2000A	4120	1118.66	1.505	178	0.689	0.35	0.36
D9500A	3986	1075	1.467	172	0.696	0.4	0.37	E3000A	4120	1116.88	1.505	178	0.689	0.35	0.36
E1000A	4120	1115.4	1.505	178	0.689	0.35	0.37	E4000A	4120	1118.27	1.505	178	0.689	0.35	0.36
E2000A	4120	1118.66	1.505	178	0.689	0.35	0.36	E4500A	4120	1113.07	1.505	178	0.689	0.35	0.36
E3000A	4120	1116.88	1.505	178	0.689	0.35	0.36	E5000A	4120	1138.21	1.505	178	0.689	0.35	0.36
E4000A	4120	1118.27	1.505	178	0.689	0.35	0.36	E8000A	4342	1200	1.614	183	0.651	0.35	0
E4500A	4120	1113.07	1.505	178	0.689	0.35	0.36	F2000A	4406	1270	1.601	185	0.666	0.35	0.34
E5000A	4120	1138.21	1.505	178	0.689	0.35	0.36	G1100A	4337	1250	1.689	191	0.633	0.4	0.33
E8000A	4342	1200	1.614	183	0.651	0.35	0	H1000A	4685	1400	1.843	216	0.595	0.3	0.29
F2000A	4406	1270	1.601	185	0.666	0.35	0.34								
G1100A	4337	1250	1.689	191	0.633	0.40	0.33								
H1000A	4685	1400	1.843	216	0.595	0.30	0.29								

Table 2. PVT Properties of Fluids in Akaso-10 and Akaso-02 at reservoir conditions, Akaso Field, Niger Delta Nigeria. P_b - Bubble Point Pressure; R_{si} - Initial Reservoir Pressure; B_{oi} - Oil Formation Volume Factor; T_r - Reservoir Temperature; SG_{oil} - Specific Gravity of oil; η_{Oil} - Oil viscosity; η_{water} - water viscosity.