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Significance of Fault Zones and API Gravities in Biodegradation of Crude Oils in Emeabiam-Apani-Okwukwe-Iloma-Iheoma-Jisike Parts of Eastern Niger Delta, Nigeria

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Abstract: ***The structural faults in this part of the Eastern Niger Delta has revealed four way dip closed anticline at both shallow and deeper levels, downthrown to the first major E-W trending structure, and showed that the fault zones in the near-subsurface were functional avenues for flushing freshwater sands of Benin Formation down to the underlying Oligocene reservoir sands. The freshwater oxidizes the occurring hydrocarbons in the presence of oil-eating bacteria in the fresh water habitat resulting in biodegradation of the crudes in the comparatively near-surface or shallow reservoirs. The consequent degraded crudes are highly viscous and of low API gravities. They comprise heavy crudes with emulsions, wax, and long-chain hydrocarbon crudes. These are indicators that the crudes have suffered biodegradation and characterized by their low API gravity values, occurrence of foamy patches, waxes, very viscous, thick crudes, sometimes condensates. The paleoenvironment of the host reservoir sands were traced to paralic, brackish to marine fluviatile, and fluvio-marine environments. Normal range of temperature values, normal to abnormal pressures, with invading Benin Formation freshwater occurrence enhanced the environment for biodegradation of hydrocarbons in the host reservoir rock. The occurrence of biodegraded crudes in reservoirs with invading fluids or freshwater flushing through the fault zones produced viscous and thick crudes of 8.3 °API gravity in some fields, while it is dryness and emulsions in others such as Owu, Omerelu, Emeabiam and Ilomba fields. The challenge is the case of "no sustained flow" to the surface due to the biodegradation and subsequent low API gravities ranging from 8.3 °API to 18.4 °API in the Alaoma and Iheomafields. Ohaji South reservoirs, mostly about 34 °API to 36 °API gravity also has a deviation from good quality crudes in Ohaji South-4 ST4 which suffered biodegradation, with 18.4 °API gravity of heavy crude.***

Keywords: Fault zones, near-subsurface structures, freshwater sands of Benin Formation, flushing, underlying reservoirs of Agbada Formation, oxidation, oil-eating bacteria, biodegraded crudes of low API gravities

1. Introduction

The Niger Delta basin has a step-wise progradation of sediments with structural zones which matured to depo-belts bounded by mega-structural growth faults. There is a common occurrence of faulting in the Niger Delta sediments whereby the heaves, the fault zones lend themselves into avenues of migration as well as for water flushing through the shallow reservoirs below the fresh water sands of the Benin Formation. The fault zones, the heaves provided medium for oxygen drain into the crude oil-bearing reservoirs for amixtureor pseudo-mixture with the accumulated crude oils and biodegrading-bacteria in the freshwater habitat. These crudes subsequently find their levels at comparatively shallow reservoirs occurring as heavy crudes, long-chain hydrocarbons, and particles of wax. The litho-stratigraphic subdivisions of Niger Delta subsurface consists of the sandy Benin Formation, a middle layer of alternating sand and shale sequences known as Agbada Formation, and the huge underlying shale deposit known as Akata Formation. These formations were laid down under continental, transitional and marine environments respectively. The Benin Formation was deposited in a continental – fluviatile environment and consists of sands, gravels, and black swamp deposits which vary in thickness from 0 to 7000ft.The Agbada Formation was laid down in paralic, brackish to marine fluviatile, coastal and fluvio-marine environments and consists of interbedded sands and shales. The Agbada Formation became much shalier with depth. The shale formation served as the source and cap rocks within the hydrocarbon bearing zones. The Akata Formation consists of marine silts, clays, and shales with occasional turbidite sands, and silts. Certain major faults identified in seismic sections apparently run from the shallow horizons to the deeper reservoirs, and invariably provide the paths or avenues for water flushing from the freshwater sands of the Benin Formation to the underlying reservoir sands resulting in heavy crudes and wax of Low API gravities (Ekweozor and Dakuoru, 1994). A similar picture was painted by Ejedawe and Okoh (1981) for occurrence of vertically draining hydrocarbon system as a secondary migration through the fault zones in the Niger Delta.

The study area was the part of the Eastern Niger Delta that depicted peculiar geologic characteristics revealing formations that were laid down in ancient continental, transitional, and marine environments. The fields include Omerelu (1well), Emeabiam (2 wells), Ilomba (1 well), Iheoma (5 wells), Ohaji South (6+2 wells), Alaoma (3 wells), Jisike (8 wells), and Owu (1well), Amara (1 well), Opani (1 well), and Okwukwe (1well). A total of 32 wells were studied to discern the characterization and attributes of the crudes in the reservoirs in this part of Eastern Niger Delta. Some wells of these oil fields have unique characterization of heavy crude oils sometimes described as "no flow" but swabbed to surface, following the path from the upper reservoir sands under the freshwater sands of

Miocene to Upper Oligocene age. The wells in this zone penetrate the massive sands of the Benin Formation, and the paralic sands and shales with sandstone and siltstone intercalations of the Agbada Formation. Generally, the wells comprise major reservoir sequences of Oligocene sands and shales lying below the base of the fresh water sands of the Benin Formation.

The crudes are of low API gravities (Tables 1 and 2), mostly ranging from 8.3° – 18.4 ° API gravities at Alaoma-1, Ilomba-1, Ohaji South-4DST3, with the crude-bearing reservoirs between the Benin Formation and alternating sand and shale sequences of middle Agbada Formation. However, the Akata Formation was not penetrated in these wells. These formations correlated with lithofacies sequences encountered at Owu-1were laid down in continental, transition, paralic, and marine/paralic environments. The Benin Formation was deposited in a continental– fluvia-tile environment consisting of sands, gravels.

The coordinates of the areas fall around
Latitude 05°25' 28.115" N and
Longitude 07 °04' 01.071" E;
05 °15' 11.342" N and Longitude 07 ° 02' 16.105" E.

The structures within and around the Ohaji South deep macro trend have recorded substantial hydrocarbon finds. The broad structure of the Ohaji South is cut by a minor fault which splits the prospect at 9920ft, with a fault throw of +/-100ft (from seismic section and wireline logs). OhajiSouth-2 structure is an elongate asymmetrical anticline developed and downthrown to an arcuate system of E-W trending, with very steep dips on its flanks (Courtesy: Seplat Petroleum Development Company Plc). This and other related structures such as simple rollovers and minor faults have developed within the OhajiSouth-2 structure, constituting traps for hydrocarbon accumulation.

By terminology in this paper, hydrocarbon can be interchanged with crude oil, while fault plane interchangeable with fault zone. Crude oil is a heterogeneous liquid consisting of hydrocarbons of almost entirely hydrogen and carbon elements in the ratio of 2 hydrogen atoms to 1 carbon atom (Hassanshahian and Cappello, 2013). It also contains elements such as nitrogen, sulfur and oxygen, all of which constitute less than 3% (v/v). The composition of crudes varies with location and age of the oil reservoir, and even depth dependent within an individual well.

The trace elements amount to less than1%, including phosphorus and heavy metals such as vanadium and nickel. Crude oils are also classified according to their distillation residues as paraffins, naphthenes or aromatics. Based on the relative proportions of the heavy molecular weight constituents as light, medium or heavy, or classified in the order of asphalt base, paraffin base or mixed base. Asphalt base contain little paraffin wax and an asphaltic residue. Sulfur, oxygen and nitrogen contents are often relatively higher in comparison with paraffin base crudes, which contain little or no asphaltic.

Significantly, biodegradation points to the ability of microorganisms, bacteria, fungi, algae to breakdown the accumulated hydrocarbons. Hassanshahian and Cappello 2013, arrived at results that hydrocarbon degrading bacteria and fungi were widely distributed in marine, freshwater and soil habitats. In addition, all marine and freshwater ecosystems contain some oil-degrading bacteria. However, no single species of microorganism or bacteria is capable of biodegrading all the components of the crude oil in the reservoir. Hence, many different bacteria are required for significant overall biodegradation of crude oils. This is the reason for differences in the degree or levels of biodegradation of crudes from one reservoir to another, and from one depth horizon to the deeper horizon and from one well to another well within an oil field.

There are 4 factors that must be in-place for crude oil biodegradation, viz,

1) Oxygen is essential and is sourced from the freshwater flushing. Microorganism or bacteria employ oxygen-incorporating enzymes to initiate attack on crudes.
2) (Nitrogen N, Phosphorus P, and Iron Fe), Trace elements nutrients are in availability at differential levels for biodegradation. But reservoirs are deficient of these mineral nutrients because they are in competitive demand with and being consumed by non-oil degradation bacteria. Iron Fe is more available in continental and paralic environment than in marine environment, as the provenance came from continental ferruginous deposits.
3) Temperature: Biodegradation thrives at low to normal temperatures, -2 to 35°C. At near-surface or shallow reservoirs, the temperatures are within this normal range, providing environment of survival to the crude-eating bacteria (Nwajide, 2013).
4) Other factors, such as Pressure, Salinity and pH count in biodegradation. Increase Pressure is correlated to decreasing rate of biodegradation. Salinity Imposes adverse effect to biodegradation, and pH: When Low, slowed down biodegradation activity.

2. Objectives

To find out factors affecting quality of crudes in the various reservoirs/wells, and fields (some cases of drilled and plugged-in, and abandonment cap installed). Identify any occurrence of biodegradation in place. Identify any repeatability of the biodegradation in more reservoirs/wells, and fields. To establish a pattern with respect to API gravities and environment of origin of sediments.

3. Methodology

Based on 32 wells studied, different aspects of their reports were reviewed and used, covering crudes analyses of various wells, and final Well reports. Records of crudes from various reservoir sands, shallow to deep reservoirs were checked to establish the trend and correlation with Low ° API's (for Heavy crudes) and High ° API's: 8.3 – 20 ° API.
Used Structural Features Associated with the Sands and crudes (in Seismic sections)
Deductions from attributes were made for depositional environments.

Geologic Setting

The Niger Delta has a stepwise progradation of sediments with structural zones which mature to depobelts bounded by mega-structural growth faults (Ajakaiye and Bally, 2002). The lithostratigraphic subdivisions of Niger Delta subsurface comprise the sandy Benin formation, a middle layer of alternating sand and shale sequences known as Agbada Formation, and the underlying shale deposit known as Akata Formation. These formations were laid down under continental, transitional and marine environments respectively. The Benin Formation was deposited in a continental - fluviatile environment and consists of sands, gravels. The Agbada Formation was laid down in paralic, brackish to marine fluviatile, coastal and fluvio-marine environments and consists of interbedded sands and shales. Many sub-environments have been recognized within these major units. The Agbada Formation becomes much shalier with depth. The shale formation served as the source and cap rocks within the hydrocarbon bearing zones. It varies in thickness from 0 to15,000ft (Short and Stauble, 1967).The Akata Formation consists of marine silts, clays, and shales with occasional turbidite sands, and silts.

4. Results and Discussion

Some wells of these oil fields have unique characterization of heavy oils, Table-2 and 3, sometimes described as “no flow” in the upper reservoir sands under the fresh water sands of Miocene to Oligocene age.

The crudes are of low API gravities mostly ranging from 8.3-18.4° API gravities at Alaoma.1, Ohaji South-4 DST3, between the Benin Formation and alternating sand and shale sequences of Mid Agbada Formation.

Evidence of hydrocarbon biodegradation was epitomized by occurrence of heavy crudes, or long-chain hydrocarbons and wax in crudes as displayed on Table-1. The structural features such asmega and minor faults in the sequences of thick sediments provided avenues via associated fault zones(see figure 1), for water washing or flushing into trapped hydrocarbons in the underlying anticlinal structures or traps. The freshwater flushing provides for the draining of oxygen though the freshwater sands of Benin Formation to the activation of biodegradation of the host hydrocarbon into heavy crudes, or long-chain hydrocarbons, wax and crudes of low API gravity. Ekweozor and Dakuoru (1994) reported occurrence of heavy crudes, wax and other particles in association with low API gravities, as a result of biodegradation. Nwajide (2013) reported that dewatering of clay during compaction is thought to be a major mechanism for primary migration. The inability of the Akata shales to dewater, which is the cause of overpressure, implied that it will also be unable to expel any hydrocarbons formed within it. It therefore follows that any drain of water to the reservoir would have followed the fault plane and/or possible fracture of shale- member of the Agbada Formation sequence.

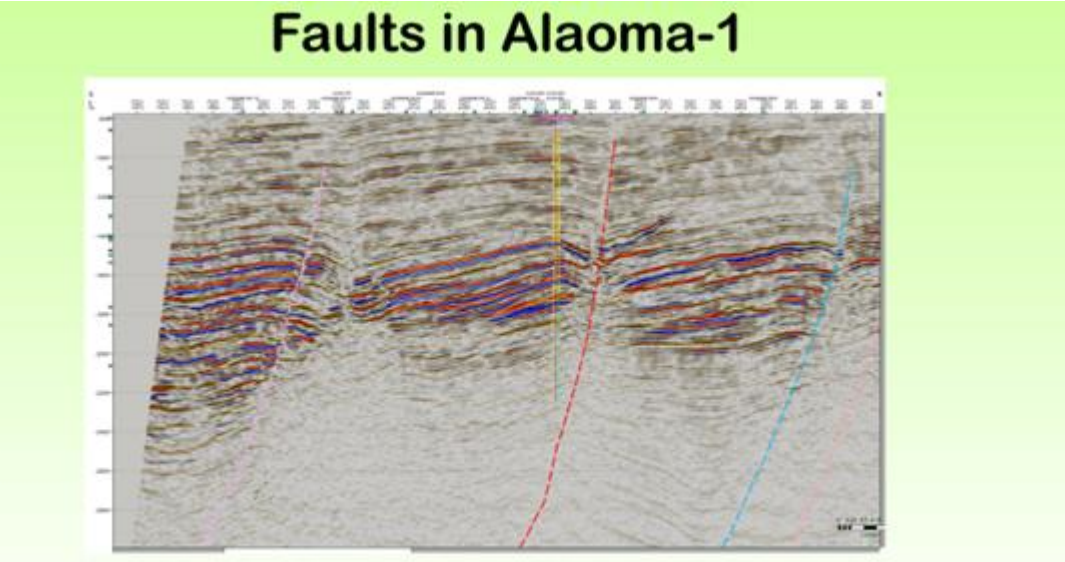

Figure 1: Structural section showing minor and major faults in Alaoma area, from near-surface or shallow subsurface to depths of below Benin Formation.

Basic Crude Quality:

Ohaji South field 4 DST3 has a sweet, biodegraded, naphthenic sweet crude.

Low in total sulphur, metals, asphaltenes and viscosity slightly acidic. Carbon residue, Nitrogen was rich in cyclic compounds12 – 13% yield from residuum inspite of the low gravity.

Draining of oxygen and flushing of water into the reservoir to result in weathering, oxidation, and selective solubilization of components gave rise to alteration or degradation of the hydrocarbon (Hassanshahian and Cappello, 2013).

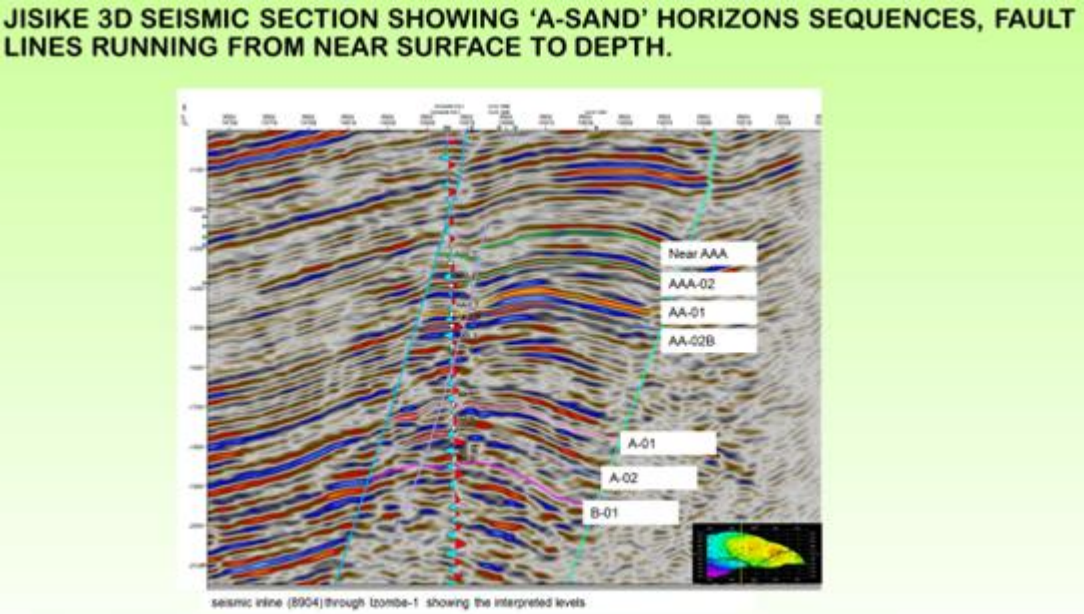

Figure 2: Jisike 3D Seismic Section showing some reservoir sands and shale sequences.

The growth faults penetrated only the upper part of the Akata Formation, and only the hydrocarbons generated here would migrate into the Agbada through the faults. Expulsion of oil from deeper parts of the Akata has not been proved in view of the likely absence of fractures in the shales. Similarly, the faults in overlying formations serve as medium of flushing water from the overlying sand into trapped hydrocarbons in lower reservoirs, which results in biodegradation of the crudes, provided there is availability of bacteria. (Nwajide, 2013)

The Alaoma prospect is associated with the sealing shale member of the main fault at deeper levels, and the flushing and biodegradation of hydrocarbons under the base of the freshwater sands of Miocene to Oligocene age, which may extend as deep as 6500ft (Courtesy: Seplat Petr. Dev. Plc). Through the fault systems, there occurs fresh water flushing, and penetration into the shallow crude oil bearing reservoirs thus, stimulating biodegradation of crudes in deeper reservoirs yielding poor or long chain hydrocarbons.

Table 1: Reservoir A-03, Ohaji South-4 DST 3, had a Biodegraded, Naphthenic, Sweet Crude.

Crude Oil Name	Ohaji South Field 4 DST 3, A-03 Reservoir
Pseudonym	
CAL-ID	Ohaji 184
Country of origin`	Nigeria
State	
Other Geographic Data	Niger Delta
Major Fields in Segregation	Not yet commercial
Production, Bbi/Day	
Reserves, bbl	120-200 million of recoverable heavy crude
Operator	Chevron
Chevron Equity Interest	
Basic Crude Quality	A biodegraded, naphthenic, sweet crude.

Whole Crude Information

As-received Gravity, "API	18.5	Viscosity, cSts@ 104^0F	90
Blended-back gravity, "API	18.4	Viscosity, cSts @ 122^0F	51.7
Total Sulfur, Wt%	0.29	Viscosity Slope	0.57
Mercaptan Sulfur, ppm	5	Characterization Factor	11.3-11.6
Free H_2S Observed, ppm	<1	RVP, psi/Slash Point, ^{0}F	<0.5/290
Total Nitrogen, Wt5	0.19	Acid, mg KOH/g	0.65
Hydrogen, Wt%	11.8	Carbon residue (MCR), Wt%	2.6
Pour Point, ^{0}F/^{0}C	-20/-28	Heptanesinsolubles, Wt%	0.17
Benzene, Vol.%	None	Ni/V, ppm	44/4

(Courtesy: Seplat Petroleum Development Company PLC).

The active source rock gushed from the lower Agbada and upper Akata formations and corresponds to 45-39 Ma (middle-late Eocene), while the overburden was made up of the Benin formation. The crude oils from this geologic deposit have waxy type of crudes (Courtesy: SEPLAT PETROLEUM DEVELOPMENT COMPANY PLC).

The comparatively near-surface or shallow structural faults-activated water flushing into trapped hydrocarbonsforming heavy crudes or poor hydrocarbons of long-carbon chains, and wax, and crudes of low API-gravity. See illustration on Table 2. Flushing of water into the reservoir and associated draining of oxygen resulted in weathering, oxidation, and selective solubilization of components to give rise to alteration or degradation of the hydrocarbon. Dewatering of clay during compaction is major mechanism for primary migration. The inability of the Akata Shales to dewater, which is the cause of overpressure, implied that it was unable

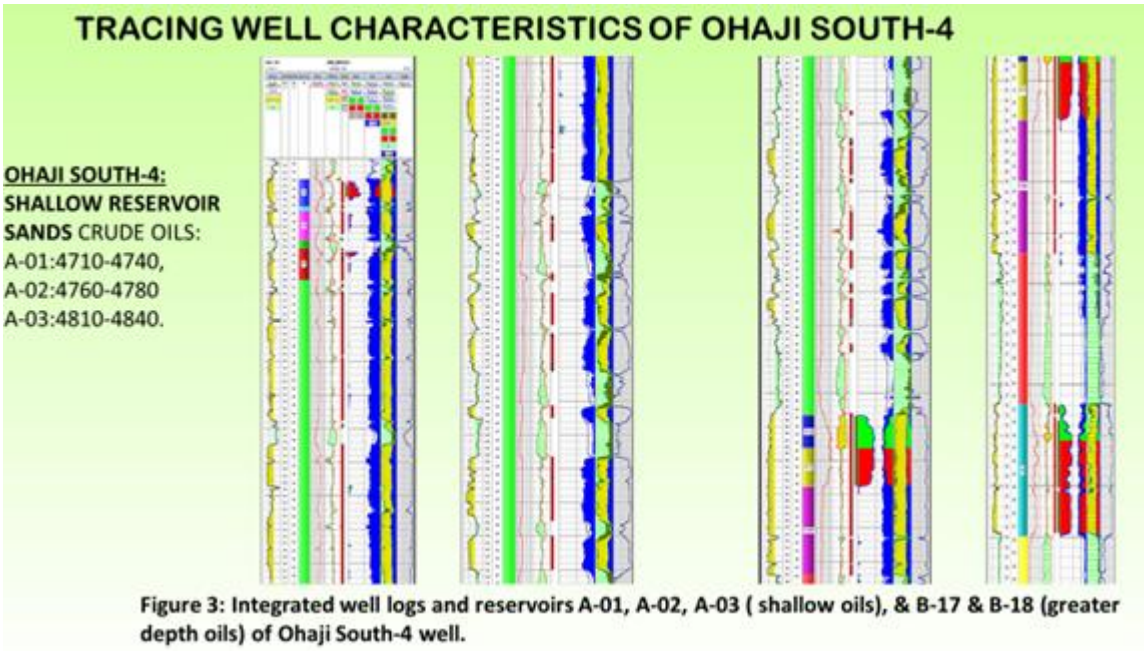

Figure 3: Integrated well logs and reservoirs A-01, A-02, A-03 (shallow oils), & B-17 & B-18 (greater depth oils) of Ohaji South-4 well.

to expel any hydrocarbons formed within it (Nwajide, 2013).Through the inability of Akata Shale to conform to dewatering mechanism, and concomitant expelling of any formed-hydrocarbon, it followed that any drain of water to the reservoir flushed through the fault plane into reservoirs resulting in biodegradation of crude oils in shallow reservoirs where oil eating bacteria had gained access through the freshwater.In addition, fractures in reservoirs are indicative of nearness to the surface. Heavy crudes in our predominantly light oil province in the Niger Delta Basin does suggest bacterial degradation upon hydrocarbon in the reservoir.

Alaoma-1Case Results

There was occurrence of high-pressure shales encountered in the Owu-1 offset well below depth of 8300ft.That appeared comparable and marching to Alaoma-1.The shallow target of Alaoma-1 comprised the coastal plain sequence of Miocene age, with the reservoirs originating from of point-bar, and distributary channel sand deposits.The uppermost portion of this section was stratigraphically equivalent to the freshwater hydrocarbon-bearing zones seen in Owu-1. There was a separator made up of **thick marine**

TABLE-2: CATEGORIZING RESERVOIR SANDS OF AREA USING OWU-1 FOR BENCH-MARKING

TABLE. 2: DRILL STEM. TEST RESULTS: OWU – 1

Pleased be advised that the following results were attained from Dillstem tests in our Owu-1 well.

PERFS: 1	5119 – 5125' -01A	No flow. Recovered water and sand with trace of 8.3° API oil.
: 2	5694 – 5700' A-06	No flow. Recovered formation water.
: 3	5875 – 5881' A-07	No flow. Recovered 3 gallons of **13.4° API** oil and formation water by swabbing.
: 4	6063 – 6069 – A08	No flow. Recovered 25bbls **20° API** Oil by swabbing. 25% (Emulsion)

shales likely to provide seals vertically and laterally. The sealing capacity of the main fault at deeper levels, with the characteristic flushing and biodegradation of hydrocarbons below the base of freshwater which extended as deep as +/- 6500ft. Faults from near-surface or shallow subsurface (figures 1 and 2), rooted down to deeper horizons below the Benin Formation enhanced the propensity of flushing to cause biodegradation of hydrocarbons at reservoirs of lower depths though about or below the base of the freshwater sands. Indicators that the crude has suffered biodegradation include, the low range of values of API gravities, occurrence of foamy patches, waxes, very viscous and thick crudes. Normal range of temperature values, normal to abnormal pressures, with invading Benin Formation freshwater enhanced the environment for biodegradation of hydrocarbons suffered in the host reservoir rock.

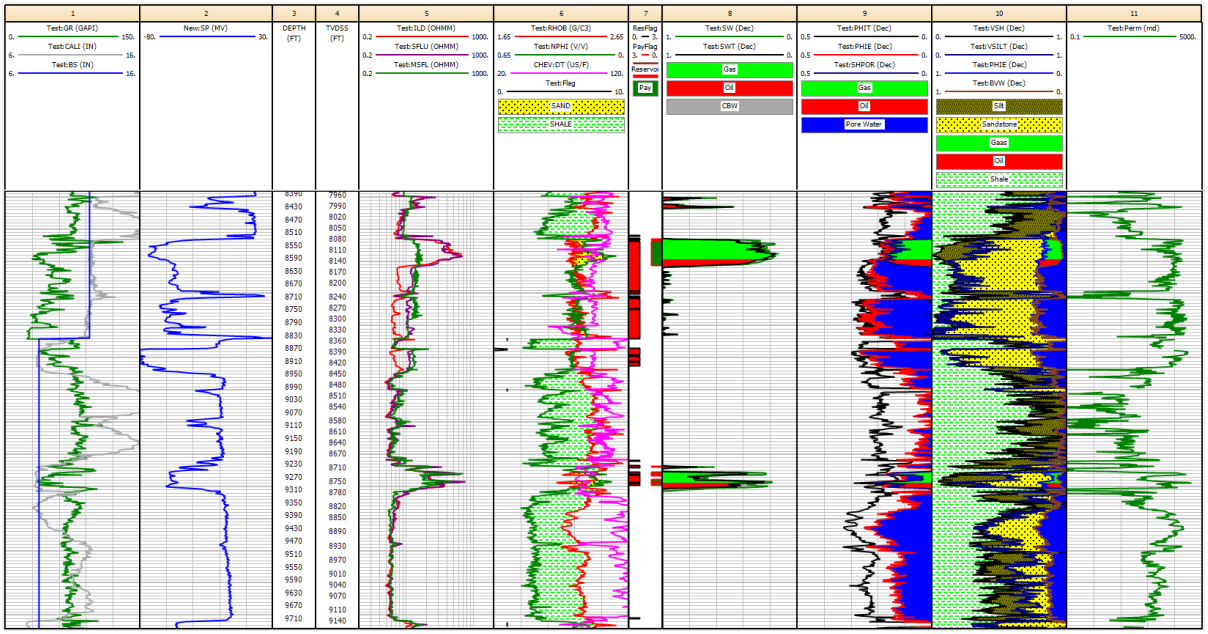

Figure 4: APANI-1 Well Computer Processed Interpretation (CPI) revealing large shale column development at depths near TD, and resulted in kick/tantamount to overpressure, and abandonment

Through the fault systems, there occurred fresh water flushing, penetrating to the shallow crude oil bearing reservoirs thus, stimulating biodegradation of crudes in relatively deeper reservoirs yielding poor or long chain hydrocarbons.

The Niger Delta has been shown as building up thick sedimentary pile with structural features and faults with occurrence of biodegraded hydrocarbons at shallow subsurface reservoirs. Subsurface water washing into reservoirs and are-suggestive of occurrence of crude oil in shallow reservoirs accessible to oil-eating bacteria.

Heavy crudes in our predominantly light oil province in the Niger Delta Basin suggest bacterial degradation of hydrocarbon in the reservoir. There was a separator made up of thick marine shales which would have provided seals vertically and laterally.

5. Conclusion

Indicators that crudes have suffered biodegradation include, the low API gravity values, occurrence of foamy patches, waxes, very viscous and thick crudes, sometimes condensates. Normal range of temperature values, normal to abnormal pressures, with Benin Formation freshwaters majorly flushing through the fault zones prepared the environment in the host reservoir rock for biodegradation of hydrocarbons.

The occurrence of biodegraded crudes in reservoirs with invading fluids or freshwater flushing through the fault zones produced viscous and thick crudes of 8.3 °API gravity in some fields, while in other fields such as Owu, Omerelu, Emeabiam and Ilomba, dryness and emulsions. The outstanding challenge was the case of "no sustained flow" to the surface due to the biodegradation and subsequent low API gravities ranging from 8.3 °API to 18.4 °API in the Alaoma and Iheomafields. This required extra-measures to flow the biodegraded crudes to the surface.

About 20km northwards was revealed a different and higher grade or quality of crude from the Ohaji South reservoirs, mostly about 34 °API to 36 °API gravity. However, amidst Ohaji South wells, there was a deviation from the trend identified in Ohaji South-4 ST4, which suffered biodegradation, with 18.4 °API gravity of heavy crude.

There is a potentially significant large amount of oil reserve in Alaoma in the shallow reservoirs. But the presence of waxy particles resulting from biodegradation, apparently impairs flow ability and production.

6. Acknowledgement

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