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Application of Brine Concentrations as a Reconnaissance Geochemical Tool for Hydrocarbon Exploration: Case Study of Field "X", OML63, Coastal Swamp 1 Depobelt, Niger Delta Basin, Nigeria.

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ABSTRACT

Analysis of benzene concentrations in brine samples obtained from two test wells in "Field X'' in the Oil Mining Lease (OML) 63,Coastal Swamp I, Depobelt, Niger Delta, Nigeria was carried out with the objective of determining the possibility of using benzene concentrations in brine to confirm the approximate distance from a dry hole to a reservoir in the same hydro-geologic system by mapping the plume of dissolved petroleum constituents emanating from the nearby accumulations The concentrations of benzene in eight brine samples obtained from the study area were analyzed using photo-ionization detector gas chromatograph. The results revealed that the concentrations of benzene in the brine samples vary from 5.0 to 6.5 ppm (corresponding to a drill depth range of 700 to 1,000m) in test well 1, to 4.50-6.55ppm (corresponding to a drill depth of 600 to 1,020m) in test well 2. This amount of concentration of benzene revealed the presence of oil prospects below the test wells. The estimated distance from 1,000m (where the 5ppm of benzene was obtained) to the top of the oil prospect below is about 1.93km which implies a drill depth of approximately 2.93km from the surface to the top of the oil prospects. This estimated depth values are consistent with the depths to the top of oil kitchen in the Niger Delta Basin. These findings are indications that the analysis of benzene concentration can serve as a cost effective and reliable geochemical exploratory tool in the study area.

Keywords: *Benzene Concentration, Brine, Geochemical Exploration, Niger Delta, Petroleum Accumulation.*

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1. INTRODUCTION

The study area (Fig. 1) is located in Oil Mining Lease (OML) 63 within the Coastal swamp I of the Eastern Niger Delta, Nigeria. Although some studies [1-13] have been carried out on the petroleum potential, stratigraphy, paleontology and structural styles of the Niger Delta basin, there is a paucity of information on the use of geochemical methods such as benzene concentrations in brine samples as an exploratory tool for hydrocarbon exploration in the basin. Over the years geochemists have explored the application of benzene analysis as a proximity indicator of petroleum deposits [14] .Such studies have been shown to be highly effective in confirming the approximate distance from a dry hole to a reservoir in the same hydrogeologic system by mapping the plume of dissolved petroleum constituents emanating from the nearby accumulations [15]. Extensive reservoir fluid compositional studies have shown that soluble hydrocarbons such as benzene, toluene, ethyl benzene and xylene (BTEX) make up a large portion of dissolved hydrocarbons associated with crude oil reservoirs [15-16].BTEX aromatic hydrocarbons are the primary volatile liquid hydrocarbons dissolved in brines due to their high solubility. Benzene and related aromatic constituents can emanate from the vicinity of crude oil reservoirs forming a plume of decreasing magnitude with increasing distance from the crude oil reservoir edge. The concentration of the benzene plume is therefore a useful crude oil geochemical exploratory tool. Furthermore, the concentrations of benzene in brines can be used to predict the presence of oil prospect as well as the distance to the top of the oil edge.

The use of the concentrations of benzene in brine samples as a proximity indicator of the presence of petroleum accumulation is not new in the oil and gas industry [14-19]. However, the concept is yet to be fully embraced by most developing oil producing economies of the world such as Nigeria. Jones [16] outlined documented petroleum discoveries near benzene anomalies in some oil fields in the world (Table 1). Zarella et. al [15] analyzed benzene content of brines co-produced with crude oil which was produced by several wells worldwide, thus confirming the reliability of benzene concentration in the prediction of the presence of petroleum accumulation (Table 2). As summarized in Table 2, empirical studies by [15], indicated that the benzene content of brines from typical oil reservoirs range from about 5 to 20 ppm depending on oil composition and source. This study was therefore carried out with the objective of determining the possibility of using benzene concentrations in brine as a proximity indicator of petroleum accumulation in the study area.

1.1 Physiography, Geomorphology and Geology of the Study Area

The study area lies within the rain forest belt of Nigeria. This belt is characterized by thick vegetation which includes shrubs, trees, Indian bamboo and raffia palms. Available rainfall records show that the average annual rainfall is about 3,000mm, most of which falls between the months of May and October. This period is characterized by moderate temperatures and high relative humidities. The months of November to April have scanty rains, high temperatures and low relative humidities.

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The Niger delta is the largest delta in Africa with a sub-aerial exposure of about 75,000km^2 and a clastic fill of about 9,000 to 12,000m (30,000 to 40,000ft) and terminates at different intervals by transgressive sequences [2]. The geology of the Niger delta basin has been studied extensively by several authors authors and the geology is therefore sufficiently understood[1-3,6-7,20-21] .The Onshore Niger delta is situated on the Gulf of Guinea on the West Coast of Africa and lies between latitudes 4^0 and 6^0 N and longitudes 4^{0}30^1 and 8^{0}00^{1}E(Fig.1).

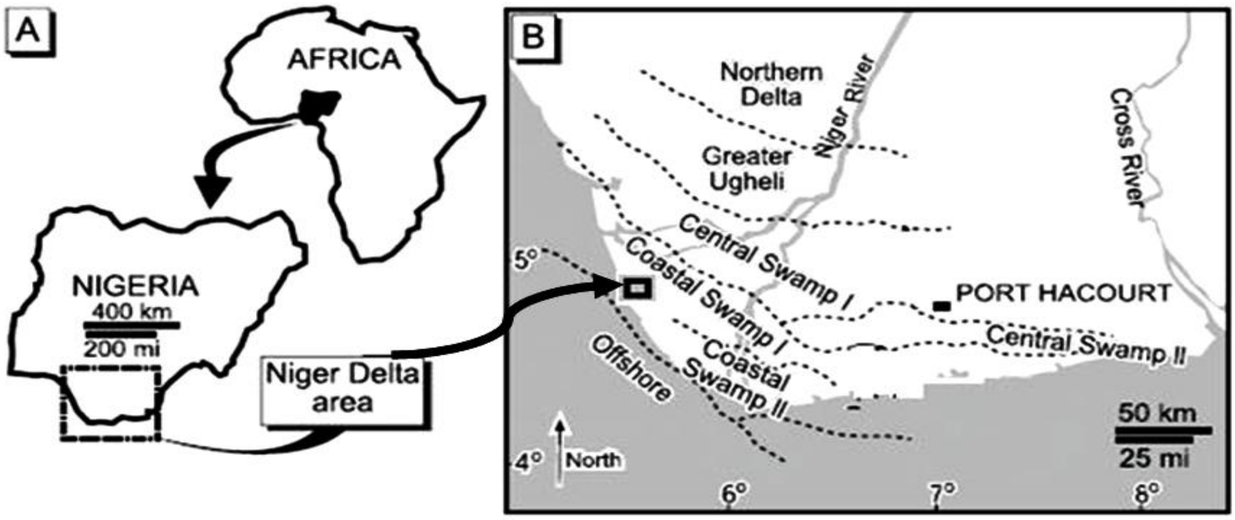

Fig.1: Location Map of the Niger Delta Basin Showing the Different Depositional Belts

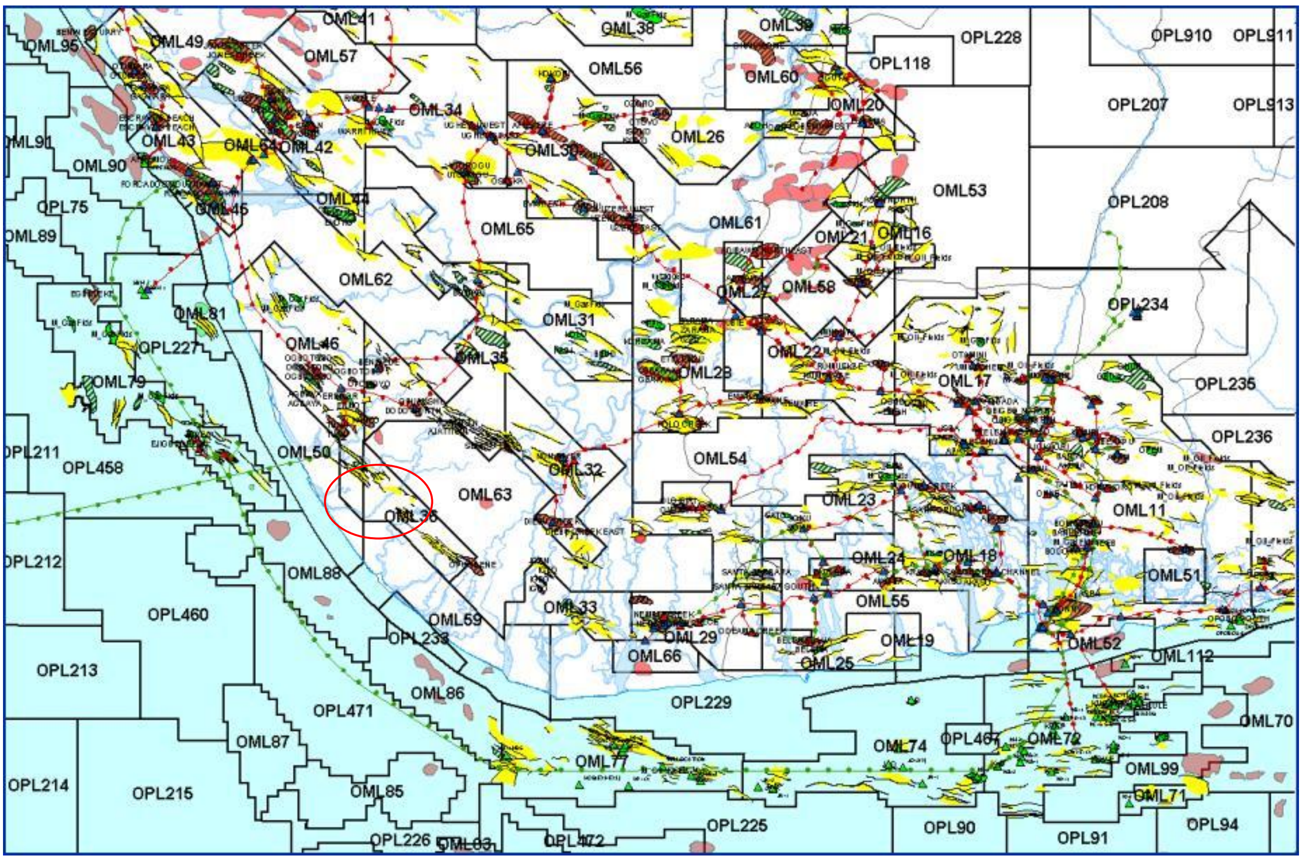

Fig.2: Prospective Map of the Niger Delta showing OML 63

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Table 1: Some Documented Petroleum Discoveries near Benzene Anomalies[16]

Test well	Formation	Distance to production pool (km)	Estimated distance to new pool (km)	Distance to discovery, (km)
West Texas	Holt	21	5.6	4.8
W.N. Waddel 542C	Cleafork	>40	7.7	8.9
McElroy J.1	Pennsylvanian	>40	3.9	1.6
McElroy Ranch G-2	Wolfcamp	29	6.5	4.8
U.S. Smelting 1	Wolfcamp	32	3.9	8.0
W.N. Waddell 589	Silurian	27	3.9	1.6
W.N. Waddell 522	Devonian	80	3.7	3.2

Table 2: Showing Benzene Content of Brines in ppm from Various Oilfields in the USA [15]

Field	Area	Formation	Type of production	Benzene content of brine, ppm
Gwinvile	Mississippl	Eagle Ford	Condensate	18.6
Bough	Lea Co., N.M	Pennsylvania	Crude oil	10.7
Golden Spike	Alberta	Basal Quartz	Crude oil	7.1
Lampman	Saskatchewan	Frobisher-Alida	Crude oil	7.0
Keystone	Crane Co., Tex	Holt	Crude oil	5.6-4.7
Stettler	Alberta	Leduc	Crude oil	6.0-4.8
Stettler	Alberta	NISKU	Crude oil	6.0-4.9
Darst Creek	Texas	Edwards Island	Crude oil	0.21
Breabum	Alberta	Permo Penn	Gas	0.0
Herford	Alberta	Viking	Gas	0.0

Similarly, the location of the Oil Mining Lease (OML 63) and the Coastal Swamp Depobelt is shown in fig.1&2. The northern boundary of the Niger Delta is the Benin flank; an east - northeast trending hinge line south of the West African Basement Massif. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank - a hinge line bordering the adjacent Precambrian. The tectonic framework of the Niger delta is related to the stresses that accompanied the separation of African and South American plates, which led to the opening of the South Atlantic.

Short and Stauble [2] recognized three litho-stratigraphic units within the basin, namely (from top to bottom): Benin, Agbada and Akata Formations. The Benin Formation consists of friable sands, clay lenses, very coarse sandstone, conglomerated and isolated units of gravel [4] , while the Agbada Formation consists of sands and shale inter-beds. The Akata Formation consists essentially of pro-deltaic shale and serves as the main source rock for petroleum generation in the basin. The incidence of reservoir rocks, structural and stratigraphic traps in the Agbada Formation makes it to function as the reservoir for both genetic and epigenetic hydrocarbons. Test wells 1&2 penetrated both the Benin and Agbada Formations. The detailed geology map of the study area is presented in fig.3.

However, the stratigraphy of Niger Delta is complicated by the syn-depositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation deposits . Three major depositional cycles have been identified within Niger Delta [2,7]. The first two, involving mainly marine deposition, began with a middle Cretaceous marine incursion and ended in a major Paleocene marine transgression. The second of these two cycles, starting in late Paleocene to Eocene time, reflects the progradation of a "true" delta, with an arcuate, wave- and tide-dominated coastline.

These sediments range in age from Eocene in the north to Quaternary in the south[7].Deposits of the last depositional cycle have been divided into a series of six depobelts[7] also called depocentres or mega-sequences, separated by major syn-sedimentary fault zones (Fig.1).These cycles (depobelts) are 30 - 60 kilometers wide, prograde southwestward 250 kilometers over oceanic crust into the Gulf of Guinea[22], and are defined by syn-sedimentary faulting that occurred in response to variable rates of subsidence and sediment supply[7]. A depobelt therefore, forms the structurally and depositionally most active portion of the delta at each stage of its development. In comparison with other Tertiary deltas, depobelts may be likened to the pro-gradational wedges, or depocentres of the United States Gulf Coast[23].

The Niger delta basin evolved in a protracted style where subsidence and sedimentation within a depobelt may have been facilitated by large scale withdrawal and seaward movement of undercompacted and geopressured marine shales under the weight of advancing paralic clastic wedge [7] .At a certain stage however, further subsidence and sedimentation could no longer be accommodated and the focus of deposition shifted basinward to form a new depobelt. Similarly, syn-

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sedimentary and mostly post-sedimentary faulting ceased with the abandoned depobelt. Normal faults triggered by the movement of deep-seated, overpressured, ductile, marine shale have deformed much of the Niger Delta clastic wedge. Growth faults affecting the sequence within depobelts form the boundaries of macro-structures (or individual delta units), each with its own sand-shale distribution pattern and style. Depobelts or mega-structures comprise in fact families of genetically and temporally related growth fault trends, or macrostructures [7].

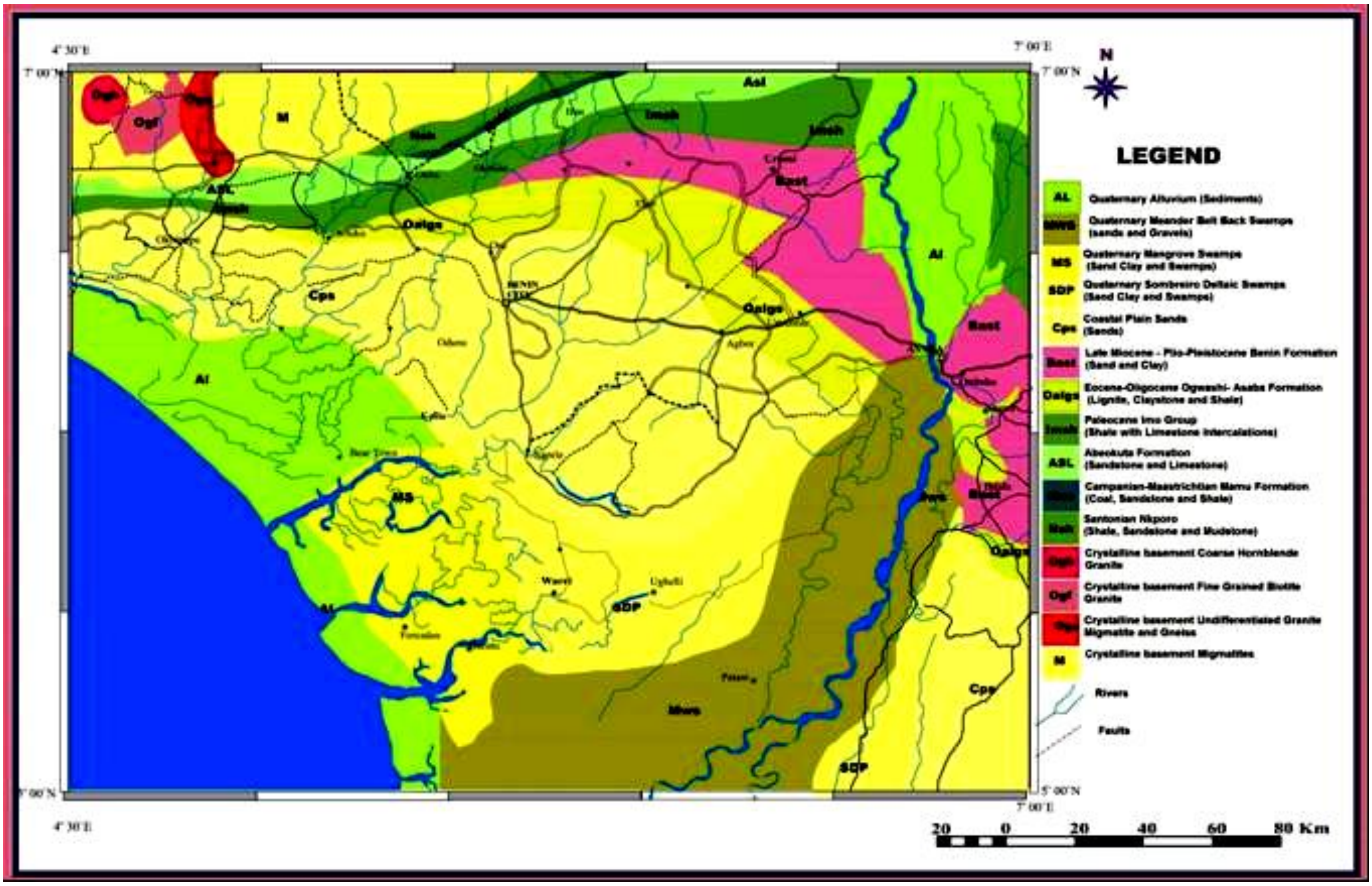

Fig.3: Regional Geology Map of the Niger Delta Basin, Nigeria [24]

2. THEORY AND METHODS

Benzene and related aromatic constituents, which are in chemical equilibrium with adjacent oil accumulations, emanate from the vicinity of the reservoirs, forming a plume of decreasing magnitude with increased distance from the reservoir edge. Studies by [15] revealed that the distance to an oil reservoir is directly proportional to the log of the benzene concentration of the adjacent brines. This relationship, as plotted on Fig.4, is due to solubility and diffusion factors associated with aromatic compounds like benzene.

$$D_{op} = k \log (B_c) \quad \text{……………………………(1)}$$

where D_{op}= distance to pool, B_c = Benzene concentrations in adjacent wells and k is a constant determined from regional studies of the area as 2.76.

Analysis of benzene concentrations in brine samples from non-productive exploration wells can therefore be used to predict the distance to a nearby petroleum accumulation with a reasonable level of confidence. With tests from the same formation, in two or more nearby wells, results can often be used to provide a much more accurate prediction of the distance and direction to potential undiscovered reservoirs within the stratigraphic horizon tested. As a data base of local wells is developed, the benzene magnitude to distance relationship can further be refined for a specific basin or formation of interest, improving the quality of the distance predictions [15].Brine analysis for dissolved aromatic hydrocarbons can be applied in new field exploration programs, development drilling, and

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predicting extensions of existing fields. It can also be used to confirm if, despite an apparent dry hole, the formation has an oil accumulation within a radius of up to about 12 miles (20 km). This information is extremely valuable when assessing the results of rank wildcat areas and international concessions, when decisions must be made with respect to the general prospectiveness of a lease position, in addition to its obvious use in selecting step-out locations and for evaluation of similar structures in the basin. Results provide a lease evaluation tool by predicting the presence or absence of petroleum within a known radius of an exploration well location. During development drilling and step-outs, brine analyses can be used to help confirm the location of a well with respect to the edge of the reservoir zone. Extensions to existing fields may be predicted by comparing brine samples from groups of producing wells. As fluids are extracted, formation waters from adjacent areas are drawn to the producing wells. If the brine is drawn from barren areas, the benzene content will continue to decrease over the life of the well. Wells which draw brine from beneath adjacent, undrained accumulations, or untested extension areas in the field often show consistently higher benzene content, since produced brines from these wells were in contact with fresh, unproduced petroleum deposits. This technique is also useful for confirming whether individual wells are influenced by water injection or other secondary and tertiary recovery operations which would alter the magnitude and composition of indigenous formation brines.

In acquiring brine samples however, care should be taken to obtain samples with minimal drilling fluid dilution or contamination from petroleum products used during the drilling operation. As a control measure total dissolved solids (TDS) may also be measured on brine samples to help determine solubility factors of organics in the formation fluids.

Eight brine samples from various depths (Table 3&4) were obtained from the flow line close to the mud pumps of the two test wells. The samples were collected with the aid of a clean separation funnel and allowed to phase separate for about five minutes. The brine samples were then drawn from the bottom of the funnel and placed into sample jars. The benzene extracts from the brine samples were obtained with the aid of carbon-tetrachloride (CCL4) and sodium sulphate (NaSO4). The benzene extracts were injected into photo-ionization detector (PID) gas chromatograph through its gas column: the PID which is equipped with an 11.7ev lamp was used to monitor the extracts. The benzene was ionized in the PID and the resultant concentrations in parts per million (ppm) were obtained. Conversions were done with a software plot from GIS series. The model developed by [15], was employed to determine the depth to the top of the oil accumulation/prospect from the points where the benzene anomalies were observed (equation1, and fig.4).

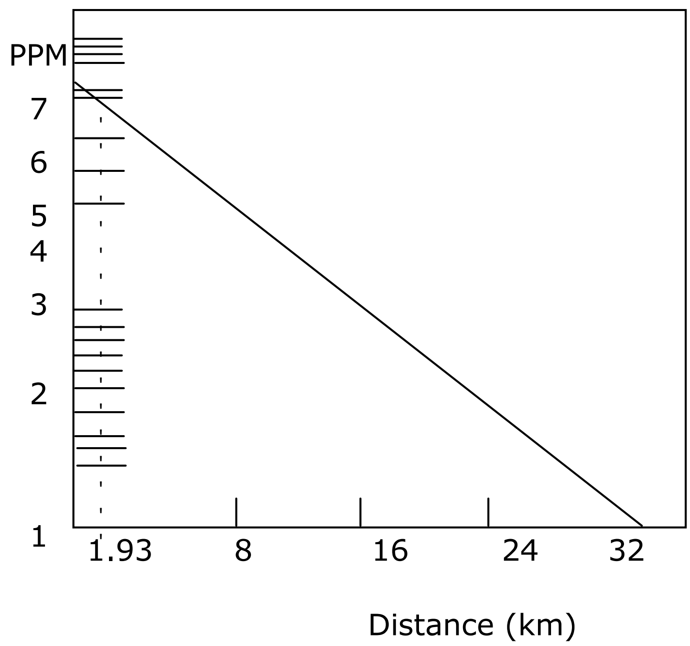

Fig.4: Log Plot of Benzene Concentration Versus Distance from Oil Pool (after Zarrella et al., 1967)

Table 3: Benzene Concentrations in Brine Samples from Test Well '1'

Sample depth/km	Benzene concentrations (ppm)	Distance to oil pool(km)

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0.70	5.00	1.930
0.80	5.50	2.043
0.90	6.03	2.154
1.00	6.50	2.244

Table 4: Benzene Concentrations in Brine Samples from Test Well '2'

Sample depth/km	Benzene concentrations (ppm)	Distance to oil pool/km
0.60	4.50	1.8029
0.70	5.30	1.9990
0.85	6.10	2.1675
1.02	6.55	2.2528

3. RESULTS AND DISCUSSION

The result of the concentrations of benzene in the brine samples obtained at various depths is shown in Table 3 and 4. The result shows that the concentrations of the benzene vary from 5.0 to 6.5ppm corresponding to drill depths of 0.7 to 1.0km. It is important to note that benzene concentrations in brines of typical oil reservoirs vary from 5 to 20ppm depending on composition and source [15] . The benzene concentrations of 5 to 6.50ppm is therefore indicative of presence oil accumulation below the test wells. A plot of the test drill depth values versus benzene concentrations indicate that the basin concentration increased with increased depth (Fig. 5): the plot follows Zarella et. al.,[15] model (Fig. 2). It is evident from the model that benzene concentrations increase towards the edge of the oil accumulation or prospect below the test well. The model is therefore a reliable and cost effective tool in predicting the presence of oil pool as well as the distance to the top of it. Based on Zarella et. al.[15] model, the distance to the top of oil accumulation below the test wells from the depth where the 5ppm concentration of benzene was obtained is about 1.93km. Since the drill depth to this point from the surface is about 0.7km, it implies that the total distance to the top of the oil accumulation from the surface is about 2. 63km (Fig.6&7). This depth is within the depth range to top of oil accumulation in OML 63[25]. Furthermore, the distance of the test wells from oil discoveries in the lease varies from 4 to 8km. There is therefore, no doubt that if test wells 1and 2 are drilled down to 2.63km, it would definitely hit the top of the accumulation suspected to occur below.

Petroleum occurs throughout the Agbada Formation of the Niger Delta; however, several directional trends form an "oil-rich belt" having the largest field and lowest gas: oil ratio [3,7,26]. The belt extends from the northwest offshore area to the southeast offshore and along a number of north-south trends in the area of Port Harcourt. It roughly corresponds to the transition between continental and oceanic crust, and is within the axis of maximum sedimentary thickness. Similarly, the temperatures of 2400F(1150c) and 3000F(1500C) are considered to represent respectively the top of the oil and gas kitchens for the Tertiary provinces which lies between the depth ranges of 10,000ft to 14,000ft (fig.8).This hydrocarbon distribution was originally attributed to timing of trap formation relative to petroleum migration (earlier landward structures trapped earlier migrating oil).

Similarly, analysis of samples from a wide variety of depositional environments in the Niger delta from previous studies revealed that not only was the organic content low , but it was of the humic and mixed types which are purported to be the precursors for gas and light oil respectively. The source rocks of the Niger delta yield a light waxy paraffinic oil, which is transformed bacterially to heavier non waxy crude at temperatures below 150- 1800F(65 to 800C) .The oil within the delta has a gravity range of 16-50° API, with the lighter oils having a greenish-brown color[27]. Fifty-six percent of Niger Delta oils have an API gravity between 30° and 40°. Most oils fall within one of two groups. The first group are light paraffin based, waxy oils from deeper reservoirs (wax content up to 20%, but commonly around 5%[28-29] ; high paraffin/ naphthene of 0.86). The second group of oils are biodegraded and from shallow reservoirs. They have lower API gravity (average API of 26°;) and are naphthenic non-waxy oils (n–paraffin/naphthene =0.37). Biodegradation and washing is extreme in some Pleistocene sands of the Agbada Formation, forming extra heavy oils (API 8-20°). Oils with less than 25° API account for only 15% of the Niger Delta reserves.

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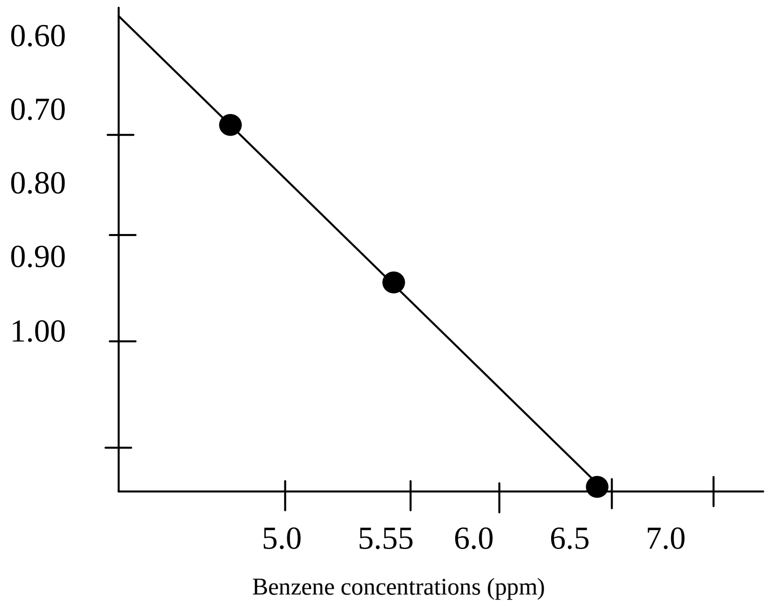

Fig. 5: Cross Plot of Drill Depth versus Benzene Concentrations in the Study Area

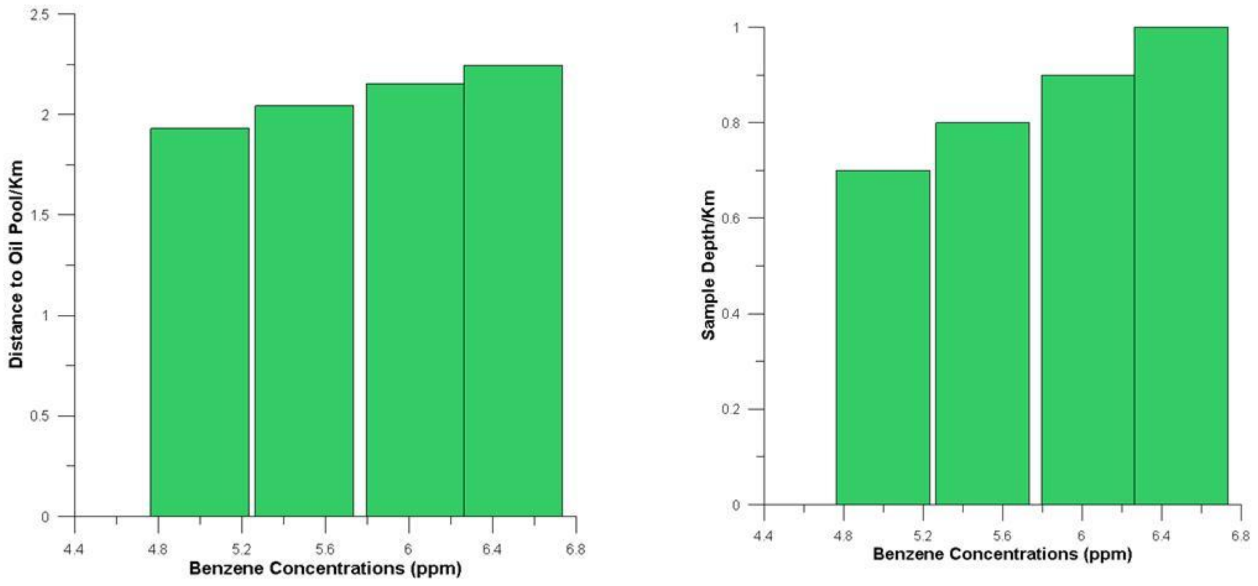

Fig. 6: Benzene Concentrations in Brine Samples from Test Well '1'

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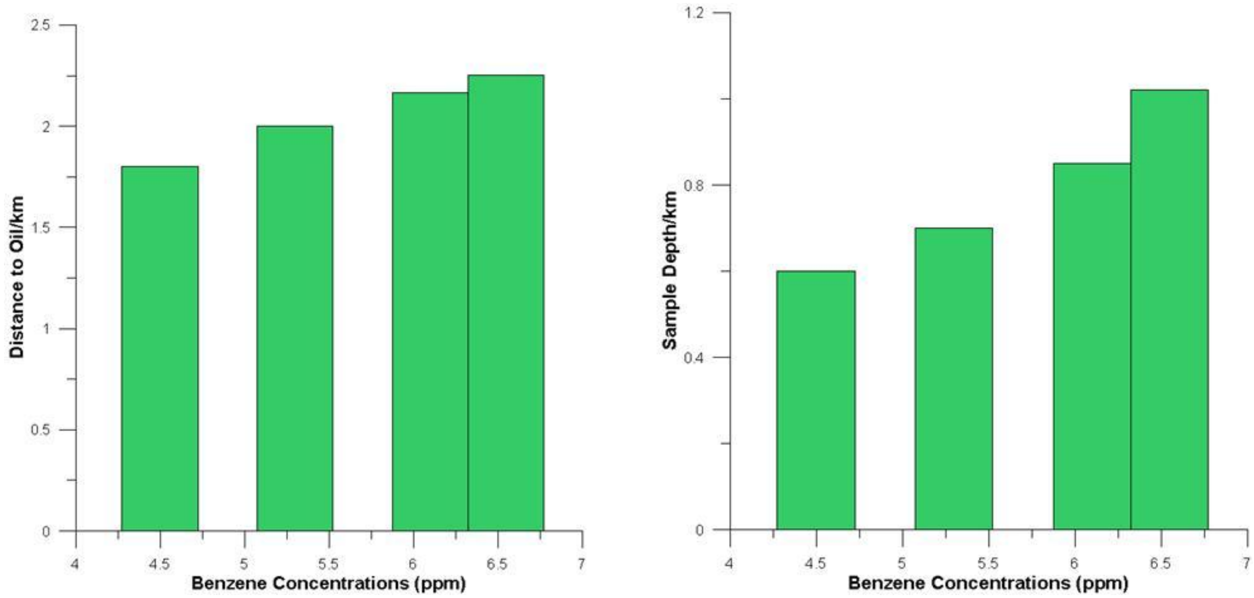

Fig. 7: Benzene Concentrations in Brine Samples from Test Well '1'

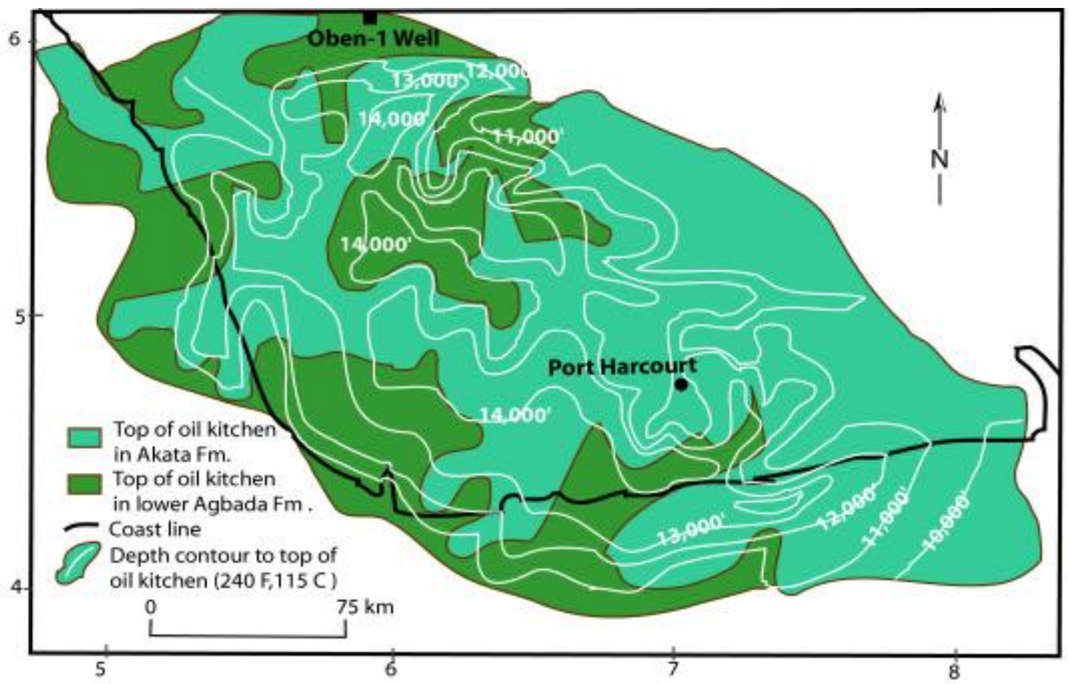

Fig 8: Subsurface Depth to Top of the Niger Delta Oil Kitchen showing where only the Akata Formation is in the Oil Window and where a Portion of the Lower Agbada is in the Oil Window. Contours are in Feet (from Evamy, et al , 1978);Depths are in Feet.

4. CONCLUSION

Benzene content of brines is a reliable and cost-effective geochemical exploration tool for prediction of oil accumulation. The method is also useful in predicting with high degree of accuracy the depth to an oil prospect. Benzene contents of 5 to 20ppm, in brines are regarded as anomalies indicative of presence of crude oil. The concentration of benzene in the brine samples from the two wells studied falls within this range and thus indicates the presence of oil prospect below the well; the depth to the top of the oil prospect from the surface is about 2.63km and this is within the depth range values to top of oil accumulation in the study area. The use of benzene anomalies in brines in predicting oil accumulation has been widely used by most developed nations of the world (Table 1).All the documented cases show a high degree of success in the prediction of oil accumulation using benzene content of brines. The use of this method in oil exploration in developing nations such as Nigeria would definitely reduce drastically the colossal sum of money spent on exploration of crude oil.

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