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Vertical and Lateral Reservoir Compartmentalization in Ohaji Oil Field, Nigeria

Botwe Takyi[1*], Selegha Abrakassa[2], Frederick K. Bempong[3], 1John Tanee[4], Bennet Yeboah Opoku[5] & Gabriel A. Fordjour[6]

[1,3,5,6]*Department of Petroleum Geosciences and Engineering, School of Petroleum Studies, University of Mines and Technology, Tarkwa, Ghana*
[2,4]*Department of Geology, Faculty of Science, University of Port Harcourt, Port Harcourt, Nigeria*

***Corresponding author:** Botwe Takyi, Department of Petroleum Geosciences and Engineering, School of Petroleum Studies, University of Mines and Technology, Tarkwa, Ghana.

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Abstract

The Ohaji oil field was evaluated for reservoir compartmentalization, oil samples were obtained from well heads of four (4) producing wells from both the short-string and long-string reservoirs. Whole oil analysis was performed on samples for m/z 71. The interparaffins were used for evaluation. The profile of the envelopes of m/z 71 chromatograms for all the oils for both short string and long string reservoirs indicate that there is no connectivity of the long and short strings reservoirs for the same well among the suite of wells studied, there is vertical compartmentalization. The use of interparaffins indicates lateral/horizonal compartmentalization for the short-string reservoirs, while the long strings reservoir shows lateral/horizontal connectivity between Well 1LS and Well 3LS. Vertical connectivity was also observed between the short string reservoir of Well 1SS and the long string reservoir of Well 2LS. This implies that several source kitchens within the volume of source rock could have charged the reservoirs via different migratory pathways, or the same source kitchen could have charged the reservoir via different migratory pathways. The compartmentalized configuration of the reservoirs could have provided for different degrees of homogenization of reservoir fluids hence the differences in their compositional distributions.

Keywords: Reservoir Compartmentalization, GC-MS, Inter Paraffins, Ohaji Oil Field.

List of Abbreviations

- **GC-MS:** Gas chromatography-mass spectrometry
- **GC:** Gas chromatography
- **LS:** Long String
- **m/z:** Mass to charge ratio
- **MSD:** Mass Selective Detector
- **OML:** Oil Mining Lease
- **SS:** Short String

Introduction

Reservoirs are basically sand bodies that are deposited mostly between shales and other combinations, these sand bodies are where oils are accumulated due to their porosities and permeabilities [1]. However, these reservoirs' plumbing and structural orientation result in their continuous or compartmentalized nature [2]. Continuous reservoirs connect and ensure fluid communication due to extensive sandstone deposits, a network of fractures, and faults [3]. The connecting nature of reservoirs provides for the mixing of reservoir fluids. Nonetheless, compartmentalized reservoirs are those that do not have any link with other reservoirs but exist independently of others. Their reservoir fluids are always significantly different from those of other adjacent or nearby reservoirs, even if they are of the same Oil field [3]. Compartmentalized reservoirs are synonymous with seals that completely prevent fluid flow, hence their diagenetic processes and evolving changes in the compositional distributions of the accumulated oils are independent of other nearby reservoirs. These observations could be due to specific structural configurations defined by perfect seals that constitute the fault and fractures that define the reservoir orientation. The depositional architecture which defines the depositional environment and characteristic facies determines the quality of sand packages and their potential effectiveness as flow units, where this package exhibits a lower permeability interface, then they may serve as seals that probably prevent fluid flow. Fault juxtapositions consisting of sand body and shale units may also result in compartmentalized reservoir units. The objective of the study is to delineate compartmentalization [1].

The Ohaji Oil field

The Ohaji oil field is in concession/block OML (Oil mining Lease) 53 (Ohaji South) (figure 1), this falls within latitude 5º30'N–5º39'N and longitude 6º40'E–6º52'E. The operators are Seplat. The field is within the Northern Depobelt and is a large rollover structure, with a major growth fault and boundary fault. The Ohaji oil field has a collection of smaller dissecting synthetic and antithetic faults. The smaller faults are suggested to have small throws and are expected to serve as baffles that may restrict fluid flow but will not prevent fluid flow completely [4].

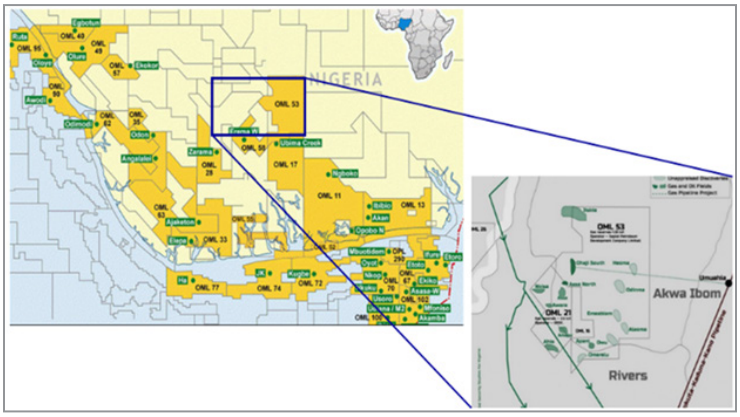

Figure 1: Map showing the location of Ohaji Oil field

Materials and Methods

The material entails the samples and tools used in sampling, the crude oil samples were obtained from the well heads [5]. Eight samples were obtained from four (4) oil Wells, and two (2) samples were obtained from each well, from the short string (SS) producing reservoirs and the long string (LS) producing reservoirs. The samples were stored in glass vials with Teflon caps. The samples were stored in a refrigerator till analysis was performed to preserve their compositional integrity. The samples were analyzed using GC–MS (Gas chromatography–Mass Spectrometry). Whole oil analysis was performed such that mass chromatograms for m/z 57, 71, and 85 were obtained also m/z 191 and 218 were extracted. The ratios of corresponding inter-paraffins in each of the samples were used for evaluation [6]. Samples were prepared for analysis by diluting 0.2mg of oil with 0.2mL of hexane to achieve 1µg/µL which is the recommended concentration for injection into the GC–MS. The GC model HP5890 with a split/splitless injector was linked to an HP 5972 MSD (Mass Selective Detector). The GC was temperature programmed for 40ºC–300ºC at 4oC per minute and held at the final temperature for 20 minutes. Helium was used as the carrier gas (flow rate of 1mL/min.), at a pressure of 50Kpa. The ionization and identification were performed in the HP 5792MSD. The electron voltage was 1600eV at a temperature of 300oC. The acquisition was by HP Vectra 48PC chemstation computer in full scan mode. Peak integration was performed with the RTE integrator. Data was obtained as a percentage report Peters [6].

Results and Discussion

The results derived from the analysis are presented in Tables 1, 2, and Figures 2 to 3.

Table 1: Ratios for pairs of the inter paraffin peaks for the Short String reservoirs

Samples	A	B	C	D	E	F	G	H
W4 SS	0.63	0.13	0.56	1.24	0.84	0.77	0.75	2.05
W3 SS	0.64	0.21	0.52	4.57	1.14	0.71	0.63	0.99
W2 SS	-	0.48	0.78	0.98	0.17	4.08	0.55	0.32
W1 SS	0.60	0.14	0.61	4.05	2.66	0.75	0.87	1.00

Table 2: Ratios for pairs of the inter paraffin peaks for the long string reservoirs

Samples	A	B	C	D	E	F	G	H
W4 LS	0.98	0.93	0.65	2.26	1.29	0.75	1.39	0.72
W3 LS	1.05	0.97	0.80	3.26	0.86	0.92	0.82	0.76

W2 LS	0.97	0.17	0.44	4.12	3.31	0.71	1.12	1.76
W1 LS	1.17	1.10	0.75	3.16	0.87	0.92	0.82	0.76

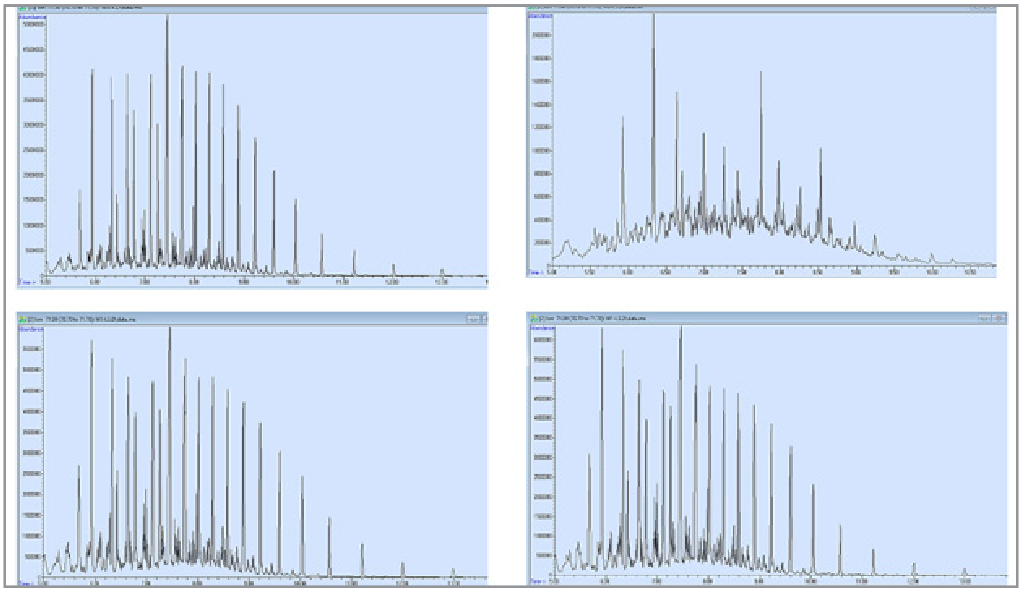

Figure 2: EICs for m/z 71 for the Long String Oils

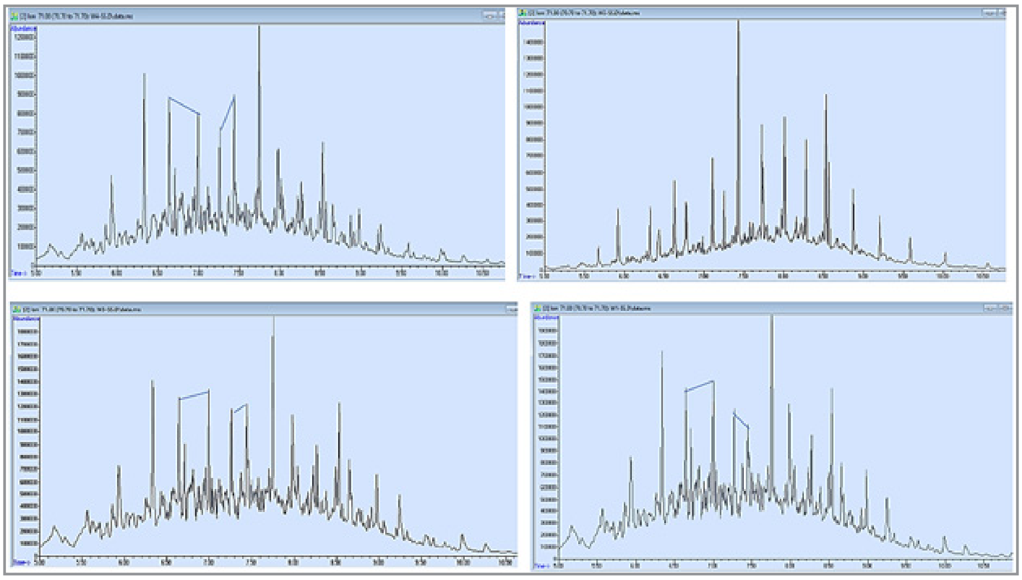

Figure 3: EICs for m/z 71 for the Short String Oils, showing differences in interparaffin composition

The Chromatographic Profile for the Reservoirs

The chromatographic profiles for the m/z 71 chromatograms (figure 2) show that the profile for oil of Well 2LS (Well 2 long string) reservoir is significantly different from that of other long string producing reservoirs, this implies that the long string reservoir of Well 2LS is horizontally or laterally compartmentalized from other long string reservoirs. The profiles for oils of Well 4LS, Well 3LS and Well 1LS look similar but with minor differences in peak areas, this observation suggests the presence of baffles with a high permeability sealing interface that permits restricted fluid flow. Baffles at different points may allow different degrees of mixing, which result in different degrees of chemical and mechanical equilibration. This infers that Well 4LS, Well 3LS, and Well 1LS reservoirs are connecting laterally via baffles while Well 2LS is compartmentalized from them.

The profiles of the m/z 71 chromatograms for the short string reservoir oils (figure 3) show that Well 2SS has a significantly different profile from the other short string reservoirs. The profiles for the oils of Well 1SS, Well 3SS, and Well 4SS look very similar, but close examination shows the differences in the pairs of isoprenoids, this observation shows that the reservoirs are not perfectly connecting, the slight differences could be attributed to the presence of baffles which are high permeability sealing interface, which limits fluid flow but does not completely prevent flow. This structural configuration provides for incomplete mechanical and chemical equilibration of reservoir fluids over time [7]. Thus, horizontally, or laterally, the reservoir of Well 2SS is compartmentalized from reservoirs of Wells 1SS, 3SS, and 4SS which are partially connected.

Comparative study of the m/z 71 chromatograms for each set of oils from the short string and long string reservoirs in each well, show significant differences, thus implying the absence of vertically connecting reservoirs but the presence of vertically compartmentalized reservoirs for each set in the same well, meaning that all the short string reservoirs are compartmentalized from all the long string reservoir for each set in the wells [8].

Interpretation from Radar/Star plots

Radar/star plots have been used for evaluating continuity, the concept is that sensitive parameter of the reservoir fluid is expressed in graphical format as star/radar plot, and reservoir fluids with matching profiles imply continuity of the reservoirs, while fluid with non-matching profiles implies compartmentalized reservoirs [9, 10]. The star/radar (figure 4a) for oils from all the short string reservoirs shows that the profiles of all the oils are out of phase with each other, this observation implies that all the reservoirs are compartmentalized from each other. This further suggests there is no horizontal or lateral continuity but compartmentalization (Smalley and Hale 1996) [10].

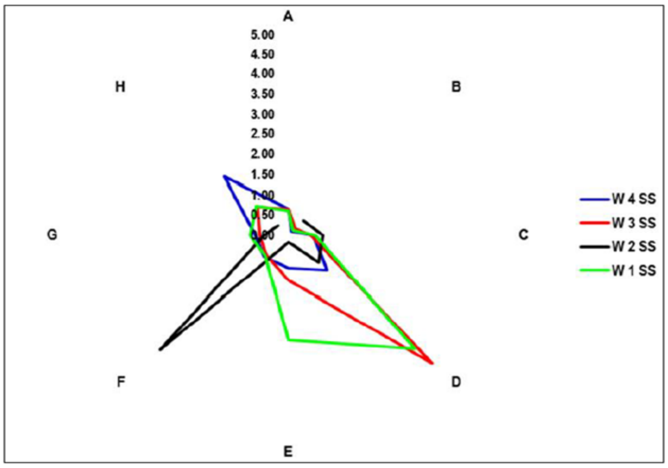

Figure 4a: Star Plots for Oils from All Short-String Reservoirs

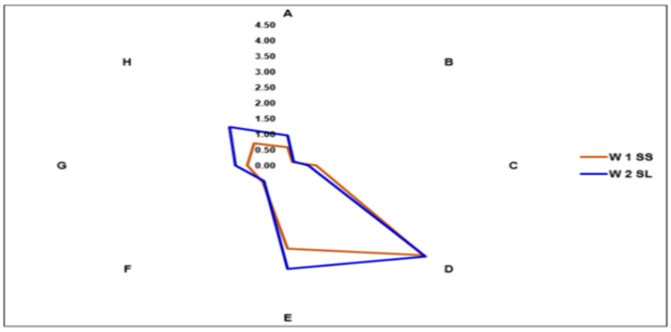

Figure 4b: Star Plot for Oil from Well 1 SS Reservoir and Well 2 SL Reservoir

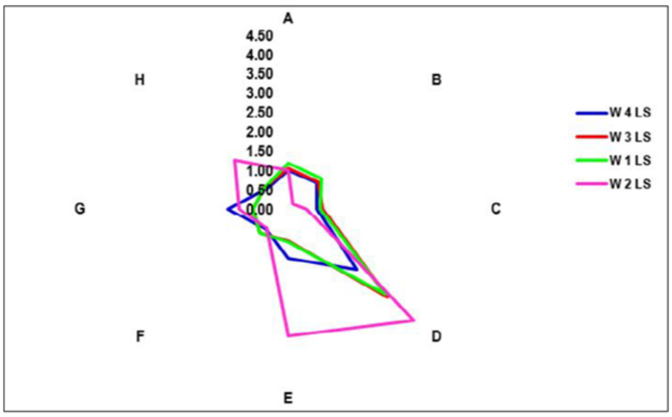

Figure 5a: Profile of Oils of All Long String Reservoirs

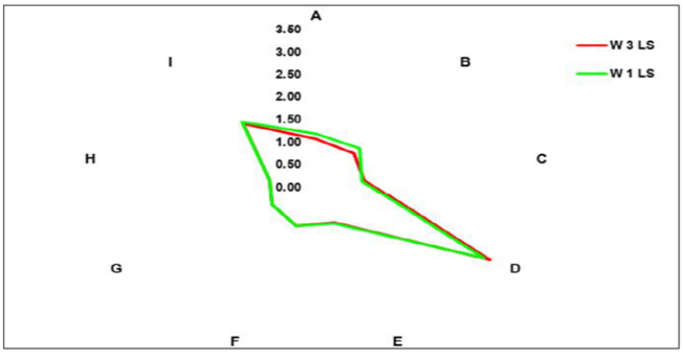

Figure 5b: Profile of Oils of Well 3LS and Well 1LS

Nonetheless, figure 4b shows a close similarity of the profiles of oils of Well 1SS and Well 2LS, the observation implies that there is a connectivity between Well 1 short reservoir and Well 2 Long string reservoir, this sort of connectivity could be fostered by the presence of a fault and most probably a juxtaposition where the two reservoirs are interfaced each other, thereby providing the avenue for mixing of reservoir fluid which over time will result in the homogenization of heterogeneous reservoir fluids. This is a case of vertical continuity [11].

Figure 5a shows the profiles for the oils of all the long string reservoirs, the profiles portray limited similarities, however, close examination shows close similarity for oils of Wells 3LS and 1LS as in Figure 5b. The similarities of the profiles for oils of Wells 1LS and 3LS imply horizontal or lateral connectivity between Wells [10].

The suite of oils studied did not indicate any vertical connectivity between the short-string reservoir and the long-string reservoir for each of the wells. Thus, vertically compartmentalized reservoirs for each well.

Conclusion

The study indicates that for the suite of oils evaluated, there is vertical compartmentalization between the short-string and long-string reservoirs of each well. There is horizontal or lateral connectivity between two long string reservoirs which are Wells 1LS and 3LS and vertical connectivity between the short reservoir and long reservoir of different wells which are Wells 1SS and 2LS. This further implies that a single string cannot be used for production in these wells. It also implies that different source kitchens within the source rock might have charged the reservoirs differently or the same source kitchen might have charged the reservoir differently via different migratory pathways, the compartmentalized configuration of the reservoirs provided for different evolutionary changes of the oils which is reflected in the differences in their compositional distribution.

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