

## LIGHT HYDROCARBONS FRACTION LOSS CORROBORATES INFILLING DIRECTION OF A NIGER DELTA OILFIELD

S. Abrakasa<sup>1,2</sup>, and M. C. Onojake<sup>\*3,4</sup>

<sup>1</sup> Department of Geology, University of Port Harcourt, P.M.B 5323, Choba, Port Harcourt, Nigeria

<sup>2</sup> Centre for Petroleum Geosciences, University of Port Harcourt, Choba, Port Harcourt, Nigeria

<sup>3</sup> Department of Pure and Industrial Chemistry, University of Port Harcourt, Port Harcourt, Nigeria

<sup>4</sup> Centre for Marine Pollution Monitoring and Seafood Safety, University of Port Harcourt, Port Harcourt, Nigeria

Received September 17, 2019; Accepted December 6, 2019

---

### Abstract

Infill direction has always been delineated using the concept of lateral maturity gradient; however, in Niger Delta, most of the reservoirs have meteoric water; hence, biodegradation, water flushing and possible gas flushing are in reservoir processes that accompany meteoric water charge. Parameters that express the loss of hydrocarbon light ends relative to heavy molecular weight fractions were used to delineate the direction of charge, and this direction, which is in the Southwest to Northeast, corroborates with the infill direction earlier determined using maturity gradient of biomarkers.

**Keywords:** Biodegradation, Infill direction, Gas flushing, Meteoric water, Reservoir, Water flushing.

---

### 1. Introduction

The infilling direction of reservoirs is of primary concern, and it's a design consideration taken into account during the production of the field, field development, and during enhanced oil recovery (EOR) processes. Several empirical data have been used to delineate the infilling direction of a field and are mostly related to the maturity of the oil charging the reservoir. However, reservoir dynamics and in-reservoir processes may assist in unraveling another concept that could corroborate the lateral maturity concept in delineating infilling direction of reservoirs.

The known in-reservoir processes are water washing or flushing and gas flushing, biodegradation, evaporative fractionation. Water washing or removal of hydrocarbon by solution in water can play a role in the generation of compositional heterogeneity (variation) across reservoirs [1]. Evaporative fraction is the process of separating the gas fraction from the oil in the subsurface. Successive evaporative fractionation of migrating oils will result in lower concentrations of the lighter end of hydrocarbons [2-4]. Biodegradation is the process whereby micro-organisms make use of lighter fractions of hydrocarbon for the generation of energy for their existence [5]. Biodegradation in a reservoir exists for reservoirs that are below 70°C. Biodegradation may also occur for reservoirs that had experience influx of marine waters carrying along microorganisms, minerals which will serve as a source of nutrients to sustain the micro-organisms [6]. The infill direction during EOR processes could serve as thief zones through which loss of displaced and displacing fluids could be sustained as well as the direction of invading influx from marine waters. The lateral maturity gradient shows that infill direction bears the highest maturity values due to continuous subsidence over geologic periods, due to that fact that subsequent hydrocarbon charges into the reservoir bear higher maturity oils [7]. The continuous influx/incursion of a reservoir with nutrient bearing waters will continue to foster the thriving of micro-organism, which will result in the depletion of lighter hydrocarbon fractions [8]. This effect will be less pronounced in oils distant relative to the oils close to the infill direction.

---

The subtle changes in various ratios of isoprenoids to n-alkanes and n-alkanes to n-alkanes can be used to express the cumulative effects of the possible in-reservoir processes, by deductive reasoning based on empirical data, this may invariably provide an insight into using the lateral profiles of these ratios to infer the direction of invasion of meteoric water and gaseous hydrocarbon charges that signifies maturity and hence infill direction of the reservoir [9-10].

Changes in these ratios in increasing order across the reservoir relative to the infill direction indicates the variable contact of recent charges of nutrient bearing water with older oils. Hence there is the relative change in the profiles of the GC-FID fingerprints of the oils, showing increasing depletion of lighter hydrocarbon fractions for oils closer to the infill direction in a reservoir that experiences water influx which is characteristic of reservoirs of most oil fields in the Niger Delta Basin [9]. Reservoirs that are faulted may have various degree of connectivity, depending on the tortuosity of the faults and fractures within the reservoir, hence varying levels of fluid communication within oil wells that constitutes the reservoir. This will also impact on the extent to which nutrients that come with fresh charges of meteoric water into the reservoir will migrate to colonies of micro-organism at other sample points (wells) within the reservoir. The profiles of the GC-FID fingerprints of the oils sampled at various points (wells) will also vary according to the degree of biodegradation.

## 2. Reservoirs in Niger Delta

The reservoirs in the Niger delta basin are mostly found in the Agbada formation; they consist mostly of sandstones and unconsolidated sands, most of the reservoirs are Eocene to Pliocene in age, mostly stacked ranging from 15metres to 45metres in thickness [11]. According to Edwards and Santogrossi [12], most of the reservoirs have 40% porosity and 2darcys permeability. Dickely *et al.* [9] emphasis that the upper part of the Agbada Formation is extremely sandy in nature; this property permits the meteoric water to penetrate very deeply in the formation. Biodegradation has been used to explain variations in oil quality in many exploration provinces, including Marañon Basin in Peru and the Powder River Basin [9]. Recently biodegradation has been used to date infilling in the Eromanga/Cooper basin in Australia [5].

Evamy *et al.* [11] had stated that in some fields with shallow and deep reservoirs, shallow reservoirs were characterized with heavy, asphaltic oils, while the deeper reservoirs had light, waxy oils. This implies the possible presence of a vertical barrier between the shallow and deeper reservoirs. The Agbada Formation is characterized by shale intercalations providing potential vertical barriers and baffles. Where there are connectivity and fluid communication, deeper reservoirs will be feed with the nutrients bearing influxed waters. Intake of meteoric waters or marine waters could be from the outcrop of extensive sand stringers, which in most cases grades into less sandy Agbada Formation. In a study presented by Dickely *et al.* [9], Shell petrophysicists observed that interstitial water in the oil leg was saltier than the edge and bottom water, and they inferred that oil accumulated in the trap contained connate water, but the structure was later invaded by meteoric water. Dickely *et al.* [9] observed most degraded oils were with meteoric water, and where the degraded oils were found with connate waters, could imply migrated oils.

## 3. Materials and methods

### 3.1. Sampling

A suite of oil samples was obtained from the Kolo Creek Oil field. Samples were obtained from the wellhead, hence serves as a true representative of the bulk in the reservoir. Samples that were stored in Teflon capped glass vials were preserved in a refrigerator till the sample was analyzed.

### 3.2. Fractionation of oil samples

Oil samples were fractionated using a chromatographic column, which is about 50cm in length and 0.5cm internal diameter (supplied by BDH England). The column was packed with

stationary phase silica gel 60size, 0.063–0.2mm (70–230) mesh, ( $\text{SiO}_2$ ) (AnalaR grade supplied by BDH, England) Light Petroleum spirit (30°–40°), (Pet Ether) (AnalaR grade supplied by BDH, England). The oils were blended with activated alumina and introduced into the column. The saturates and aromatics were eluted using 70mLs each of the petroleum ether and dichloromethane (AnalaR grade supplied by BDH, England).

### 3.3. GC–MS analysis

GC–MS analysis of the saturates was performed for monitoring some fragment ions of some biomarker compounds on a Hewlett–Packard 5890 II GC with a split/splitless injector (280°C linked to a Hewlett–Packer 5972MSD with electron voltage of 70eV, filament current of 220 $\mu$ A, source temperature of 160°C a multiplier voltage 1600V and interface temperature 300°C. the acquisition was controlled by HP Vectra 48 PC Chemstation computer both in full scan mode and selected ion mode (30ions, 0.7cps 35ms dwell) for greater sensitivity. The separation was performed on a fused silica capillary column (30m X 0.25 mm i.d.) coated with 0.25 $\mu$ m, 5% phenyl methyl silicone (HP–5), which is supplied by HP which is currently known is Agilent, UK.

## 4. Results and discussion

The results in table 1.0 show the variable extent of biodegradation. The various parameter that has been used for expressing biodegradation was used.

Table 1. Biodegradation parameters

WELLS	WI	$C_{17}/Pr$	$(C_{17}+C_{18})/(Pr+Ph)$	$((C_{10} + C_{12})+C_{22}+C_{24})$
SA16	0.54	2.50	2.87	0.12
SA19	1.87	1.55	2.20	1.33
SA20	0.99	1.60	2.24	0.20
SA21	0.77	1.72	2.31	0.23
SA22	0.39	1.33	1.93	0.08
SA23	1.88	1.57	2.23	1.22
SA25	2.07	1.55	2.15	1.51
SA29	0.50	1.64	2.21	0.14
SA2	1.85	1.86	2.44	1.37
SA3	0.49	1.58	2.16	0.10

Various parameters are  $C_{17}/Pr$ ,  $(C_{17}+C_{18})/(Pr+Ph)$ ,  $((C_{10}+C_{12})+C_{22}+C_{24})$ , WI (weathering index) expressed as  $(C_8+C_{10}+C_{12}+C_{14})/(C_{22}+C_{24}+C_{26}+C_{28})$  [10]

### 4.1. Impact of biodegradation in reservoirs

Biodegradation in reservoirs is as aspect of reservoir alteration processes. This process can be monitored with changes in the oil profiles as portrayed by the GC–MS fingerprint of the oils in the reservoir. The degree of biodegradation is variable depending on the size/dimension of the water leg, the supply of nutrients, the mixing of fresh water, and the oils. Reservoir characteristics also contribute to the degree of biodegradation, connectivity of reservoirs, porosity and tortuosity of the reservoir, including reservoirs temperature all affect the extent of biodegradation. The mixing time scale of the reservoir for the homogenization of the reservoir also affects the extent of biodegradation.

The GC–FID profile of the oils in different parts of the reservoir of an oil field can give information on the degree of biodegradation imprinted on the GC fingerprints. Biodegradation is noted by loss of the lighter fractions of hydrocarbons specially the alkanes, there after the isoprenoids. In this study, the m/z value 85 chromatograms, which is termed reconstructed GC, and highlights mainly the alkanes, and the Isoprenoids were used.

The hypothesis on which this study rest is that fresh oil charging reservoir fluids enter into a wet reservoir and will migrate into other areas of the reservoir depending on the reservoir dynamics, the reservoir process plays significant roles in biodegradation at the oil–water contact. The subsequent charges into the reservoir may be accompanied by fresh water, which

will supply nutrients and oxygen there by subjecting the oils at the entry point to more degradation process relative to oils in other areas of the reservoir.

During generation, expulsion, and migration burial and subsidence concurrently takes place, thereby resulting in maturation which may provide for more gaseous content with subsequent charges, gases with subsequent charges will enter the reservoir, and the gases will abstract the lighter components leaving behind more viscous and denser intermediate molecular weight fractions. The oils at the direction of the infill will be more affected relative to the rest of the reservoir.

The influx of meteoric water could also result in biodegradation in the reservoir; the migration pathway is always extensive sandstone stringers, fractures, or faults. These are possible carrier pathways through which meteoric water could assess the reservoir. These pathways also correspond to pathways in potential infill directions, thus invading meteoric water is most likely to assess the reservoir via infill pathways, and the oils at and around the entry point will under a higher degree of biodegradation and water washing.

There are cases where the meteoric water could have been initially invaded the reservoir and later followed by a charge of oil; this could portray a situation where the oils at the infill point may be fairly replenished relative to oil in other areas within the reservoir [9].

#### 4.2. Lateral biodegradation gradients

The gradual percolation of meteoric water through the reservoir will result in biodegradation that will decrease in intensity from the infill direction across the reservoir. This observation is due to the availability of nutrients; however, contact will be determined by carrier/migrational pathways such as sandstone stringers, fractures and faults. A faulted system will provide a better contact surface area of petroleum with meteoric water.

Figure 1 shows the lateral distribution of the biodegradation parameter ( $C_{17}/Pr$ ) across the reservoir. Well 22 (SA22) has the lowest ratio, though the ratio gradually averages increases across the reservoirs in conformity with the distribution of faults within the reservoir. The ratio increases from the Southwest to Northeast direction. The lowest value is 1.33 for well SA22, while the highest value is 2.50 for well SA16. This invariably means that charging hydrocarbon and the invading meteoric water migrates in the Southwest to Northeast direction. This also corroborates with an earlier study on the infilling direction of the same reservoir using a lateral maturity gradient [7]. Biodegradation will be higher for wells closer to Well SA22 and will gradually decrease away across the reservoir in the Northeast direction.

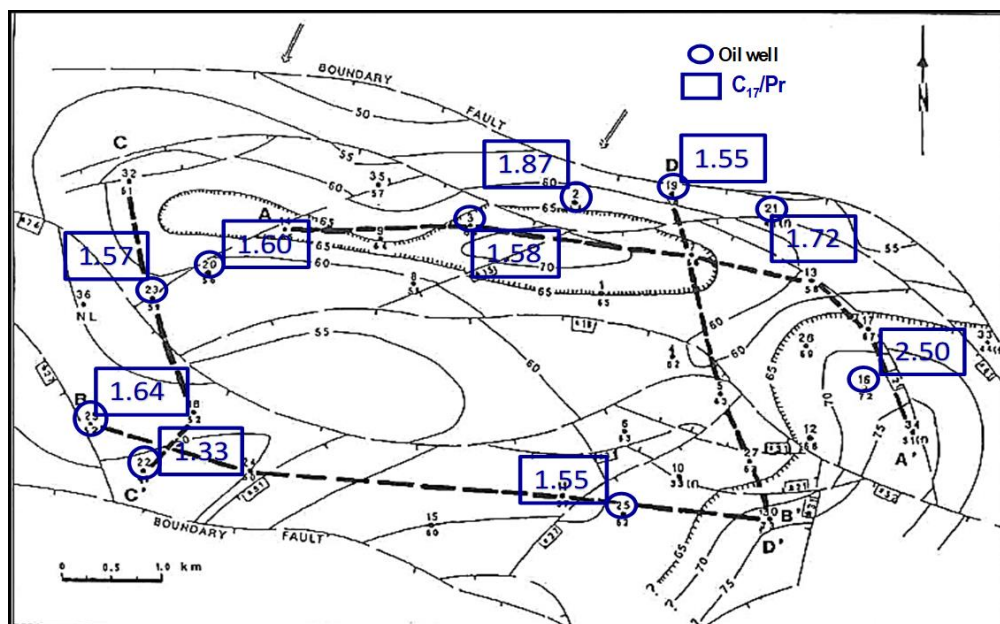


Figure 1. Lateral distribution of biodegradation parameter ( $C_{17}/Pr$ ) across the Kolo Creek reservoir



Figure 2. shows the distribution of the biodegradation parameter  $(C_{17}+C_{18})/(Pr+Ph)$  across the Kolo creek reservoir. This is a well-known and popularly used biodegradation parameter [13-14]. The ratio is used based on the fact that the n-alkanes are more prone to biodegradation relative to the isoprenoids. The  $nC_{17}$  and  $nC_{18}$  alkanes degrade relatively at the same rate and faster than the isoprenoids.

The parameter, as used in Figure 2, decreases from the Southwest to the Northeast, corresponding from Well 22 (SA 22), which bears the lowest value (1.93) to Wells 16 and 25, which bears the highest values 2.87 and 2.95. This observation infers that meteoric water invading the reservoir will impart Well 22 result in the contact of oils in well 22 with fresh water enriched in nutrients which fosters biodegradation of the n-alkanes relative to the isoprenoids in decreasing intensity across the reservoir, because the nutrients are increasingly removed/abstracted from the meteoric water as the water percolates across the reservoir with the require buoyant capillary pressure.

The resultant effect will be in decreasing intensity across the reservoir bearing subtle lateral gradient, as shown in Figure 2. The fact that the profile of the parameter bears a lateral gradient in increasing trend from the Southwest to the Northeast indicates that the meteoric waters charge the reservoir from the Southwest this also corroborates with the infilling direction of the Kolo Creek reservoir as determined in Abrakasa and Muhammad [7]. With this corroboration, it invariably means that the biodegradation parameter  $(nC_{17}+nC_{18})/(Pr+Ph)$  could be used to infer the infilling direction of the Kolo Creek reservoir given the suite of oils studied.

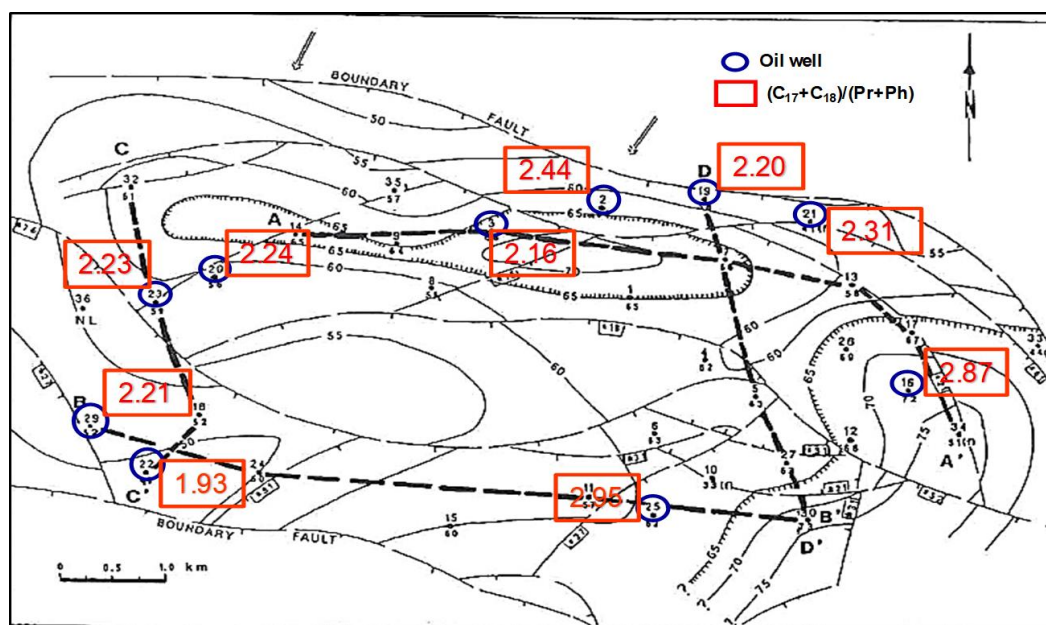


Figure 2. Lateral distribution of biodegradation parameter  $(C_{17}+C_{18})/(Pr+Ph)$  across the Kolo Creek reservoir

Figures 3 and 4 also show the trend of the profiles for the parameters  $(C_{10}+C_{12})/(C_{22}+C_{24})$  and  $(C_8+C_{10}+C_{12}+C_{14})/(C_{22}+C_{24}+C_{26}+C_{28})$ . These parameters were used by Wang and Fingas [10] to evaluate the degree of biodegradation, which was termed as weathering index. The parameter is adopted based on the fact the  $C_8$  to  $C_{14}$  hydrocarbons are more prone to biodegradation, water flushing, and also gas flushing relative to the  $C_{22}$  to  $C_{28}$ . This will present the profile of the parameter as a subtle trend with a gradient across the field in increasing order from the Southwest to the Northeast of the field. Meteoric water, charging gas due to increasing maturation accesses the reservoir via thief zones, which are fractures and faults through which charging fluid and meteoric water enter the reservoir [15]. Figure 3 shows the profile of the parameter  $(C_{10}+C_{12})/(C_{22}+C_{24})$  across the reservoir, Well 22 (SA22) bears the lowest ratio, while Well 2 (SA 2) and Well 25 (SA25) bears the highest ratios. The gradual variation of the  $(C_{10}+C_{12})/(C_{22}+C_{24})$  ratio across the reservoir indicates gradual percolation of meteoric

through the reservoir with decreasing nutrients that foster biodegradation and reducing the effect of gas flushing that results in removal of light hydrocarbon ends.

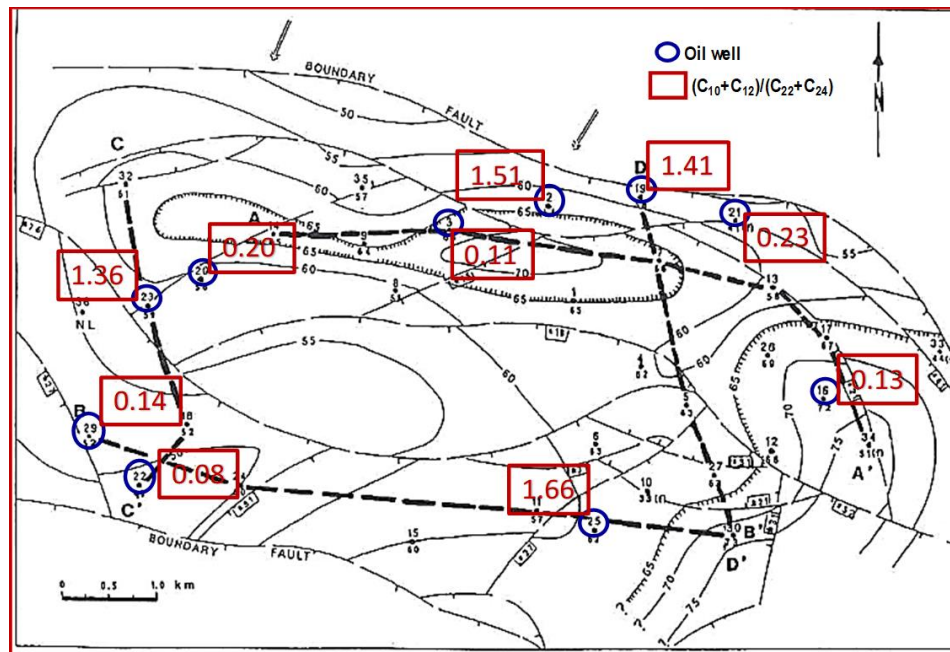


Figure 3. Lateral distribution of the parameter  $(C_{10}+C_{12})/(C_{22}+C_{24})$  across the Kolo Creek reservoir

Figure 4 shows that the profile of  $(C_8+C_{10}+C_{12}+C_{14})/(C_{22}+C_{24}+C_{26}+C_{28})$  ratio across the reservoir, and this ratio is also used as the weathering index for evaluating spilled hydrocarbons [10].

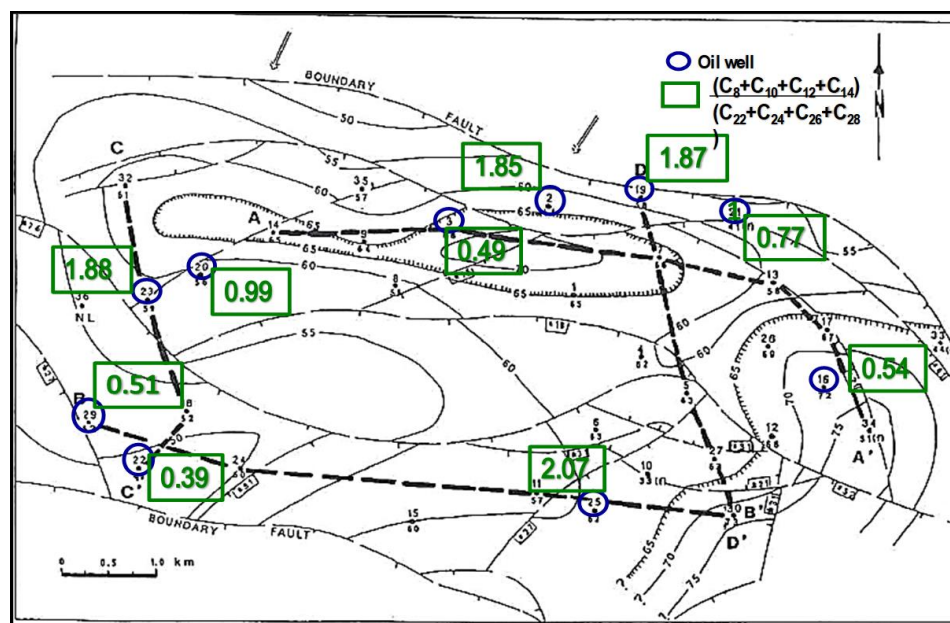


Figure 4. Lateral distribution of the parameter  $(C_8+C_{10}+C_{12}+C_{14})/(C_{22}+C_{24}+C_{26}+C_{28})$  across the Kolo Creek reservoir

In most petroleum hydrocarbon, the  $C_8$  to  $C_{14}$  are more abundant than  $C_{22}$  to  $C_{28}$ , however, during biodegradation and water flushing/washing,  $C_8$  to  $C_{14}$  hydrocarbons are preferentially removed; hence the ratio approaches zero indicating significant loss of  $C_8$  to  $C_{14}$  hydrocarbons relative to  $C_{22}$  to  $C_{28}$  hydrocarbons. The tendency for loss of the  $C_8$  to  $C_{14}$  hydrocarbons reduces

away from the thief zone, which are the fractures and faults through which the reservoirs are charged. This process gives rise to a subtle lateral gradient across the reservoir with the infill point bearing the lowest ratio because the loss of the  $C_8$  to  $C_{14}$  hydrocarbons is more prominent being the first contact point with charging meteoric water. Hence the thief zone area [15] within which is the charge point of the reservoirs can be referred to be the infilling direction of the reservoir.

## 5. Conclusion

The Niger Delta is fault prone, hence meteoric invades most of the reservoir enriched with nutrients to foster biodegradation, accompanied by water flushing, which results in the removal of the light molecular weight hydrocarbons. Parameters that expresses the loss of light molecular weight hydrocarbons were used to delineate the direction of the charge of meteoric water. The profile of all the parameters indicated the trend of increasing values across the reservoir in the Southwest to Northeast direction. The direction corroborates with the infill direction of the reservoir, which was earlier determined using biomarker maturity ratios.

## Acknowledgements

*The Department of Petroleum Resources of Nigeria is acknowledged for the permission to access crude oil samples used for this research. The authors are thankful to Giolee Resources Limited, Port Harcourt for providing workstation with Chemstation software.*

## References

- [1] Lafargue E, and Le Thiez P. Effect of waterwashing on light ends compositional heterogeneity. *Org. Geochem.*, 1996; 24 (12): 1141–1150.
- [2] Thompson KFM. Fractionated Aromatic Petroleum and the Generation of Gas-condensates. *Org. Geochem.*, 1987; 11:573-590.
- [3] Thompson KFM. Gas-condensate Migration and Oil Fractionation in Deltaic Systems: *Mar. and Petrol Geol.*, 1988; 5:237-246.
- [4] Masterson WD, Dzou LIP, Holba AG, Fincannon AL and Ellis L. Evidence for biodegradation and evaporative fractionation in West Sak, Kuparuk and Prudhoe Bay field areas, North Slope, Alaska. *Org. geochem*, 2001; 32: 411–441.
- [5] Elliott L. Using Biodegradation to Date Hydrocarbon Entry into Reservoirs: Examples from the Cooper/Eromanga Basin, Australia. *AAPG ICE Melbourne*.
- [6] Wenger LM, Davis CL and Isaksen GH. Multiple Controls on Petroleum Biodegradation and Impact on Oil Quality. *Reservoir Evaluation & Engineering*. (SPE 80168), 2015; 375–383.
- [7] Abrakasa S and Muhammad AB. Infilling direction and fluid communication in the E2.0 reservoir of Kolo Creek oil field, Niger Delta. *Nig. J. Bas. and Appl Sci*, 2008; 16: 115–121.
- [8] Peters KE, Walters CC and Moldowan JM. *The Biomarker Guide*, second ed., Cambridge, 2005.
- [9] Dickey P, George G, and Barker C. Relationships among oils and water compositions in Niger Delta. *AAPG Bulletin*, 1982; 71(10): 1319–1328.
- [10] Wang Z and Fingas M. Study of the effects of weathering on chemical composition of a light crude oil using GC–MS, GC–FID. *J. Microcolumn Separations*, 1995; 7(6): 617–639.
- [11] Evamy RD, Haremboure J, Kamerling P, Knaap WA, Molloy FA and Rowlands PH. Hydrocarbon habitat of tertiary Niger Delta, *AAPG Bulletin*, 1978; 62: 1.
- [12] Edwards JD and Santogrossi PA. Summary and conclusions, *in*, Edwards, J.D., and Santogrossi, P.A., eds., *Divergent/passive Margin Basins*, AAPG Memoir 48: Tulsa, 1990; 239–248.
- [13] Huang H. Effects of Biodegradation on crude oil compositions and reservoir profiles in the Liaohé basin, NE China. Unpublished PhD Thesis. Newcastle University, UK (2004).
- [14] Larter S, Wilhelms A, Head I, Koopmans M, Aplin A, Di Primio R, Zwach C, Erdmann M and Telnaes N. The controls on the composition of biodegraded oils in the deep subsurface—part 1: biodegradation rates in petroleum reservoirs. *Org. Geochem.*, 2003; 34:601–613.
- [15] Huang B, Xu R, Fu C, Wang Y and Wang L. Thief Zone Assessment in Sandstone Reservoirs Based on Multi-Layer Weighted Principal Component Analysis. *Energies*, 2018; 11:1274.

*To whom correspondence should be addressed: Dr. M. C. Onojake, Department of Pure and Industrial Chemistry, University of Port Harcourt, P.M.B 5323, Choba, Port Harcourt, Nigeria, E-mail [mudiaga.onojake@uniport.edu.ng](mailto:mudiaga.onojake@uniport.edu.ng)*