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Palynofacies and predictions for hydrocarbon generation potential of the Upper Cretaceous lignite from Maiganga Coalfield, Northern Benue Trough, Nigeria.

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ABSTRACT

The Upper Cretaceous Coalfield of Northern Benue Trough, represent excellent hydrocarbon source rock potential within the Nigeria inland basins. The source rock potential of coal and shale whole rock samples from Maiganga and Yaya-Ngari areas in the Northern Benue Trough was investigated using palynofacies and organic geochemical methods for hydrocarbon generation predictions. Palynofacies is integrated in this study as a useful tool for kerogen typing, paleoenvironment indicator, thermal maturity determination and hydrocarbon generation potential of source rock which equally relies on the relative abundance of the three kerogen groups (AMO, Phytoclast and palynomorphs). Current result shows that identified palynomorphs (P), phytoclast (Ph) and amorphous organic matter (AOM) for the studied Yaya-Ngari shale show significant amount of dark-brown to orange colour phytoclast compared to brown heterogenous AOM and brown to orange palynomorphs. The palynomorphs are often <10 µm, although few ones are up to 80 µm sizes. In the case of Maiganga facies, they are characterized by mainly terrestrial kerogen group. This is evidently shown by the presence of highly oxidized black, opaque tissues of higher plants often associated with some brown degraded tissue of higher plants, light brown AOM (probably resin and algae material) and trilete spore and pollens of plants. Thus, it is an indication of a more gas-prone Type III kerogen than the associated liptinitic materials of oil-prone Type II kerogen as observed under the UV-light. The GC-MS result of saturated hydrocarbon as corroborated by the aromatic hydrocarbon fraction indicates low concentration of dibenzothiophenes compared to aromatic phenanthrenes (m/z 184 and 178) which resulted in DBT/P ratio of <1. This indicates a marginal marine environment mainly deltaic setting (Maiganga) associated marine shale at Yaya-Ngari for the analysed sediments. Similarly, It is further corroborated by high concentration of hopane compared to sterane resulting in hopane/(hopane+sterane) ratio > 0.7. Generally, biomarker studies suggest deposition of Type III/II kerogen within suboxic to oxic environment for the Maiganga, while Yaya-Ngari samples are characterized by mixed organic matter deposited in a suboxic conditions.

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1.0 Introduction

The Upper Cretaceous lignite (Maiganga Coalfield) that is interbedded with mudstones and shale from the Gongola sub-basin of Northern Benue Trough, Nigeria represents a good succession for hydrocarbon generation within the basin (Ayinla et al., 2017a). Integrating organic facies (Palynofacies) and geochemical analysis of the sedimentary rocks can provide useful information on organic matter quality determination (kerogen typing), paleoenvironment indicator, determination of thermal maturity and hydrocarbon generation potential of source rock (Mendonça Filho et al., 2012; Mustapha et al., 2017). Kerogens assemblages can be categorized into three palynofacies groups based on their shape and morphology as determined by degree of translucency and fluorescence properties under transmitted normal light and fluorescence UV light microscopy. These are phytoclast (fragment of tissue of higher plant), palynomorph (organic walled remains), and amorphous organic matter (structureless derived algae and plant resin) (Tyson, 1995; Mendonça Filho et al., 2012). The translucency and morphology of an organic particle represents the extent of their thermal alteration, botanical affinity, depositional environments and degree of terrigenous input. Thus, palynofacies analysis gives useful information about organic particles provenance, biological affinity, paleoenvironment, redox condition, preservation, hydrocarbon potential and thermal maturity (Tyson, 1995; Zulkefley et al., 2015; Mendonça Filho et al., 2012; Mustapha et al., 2017).

In recent years, in an effort to sustain the hydrocarbon production in Nigeria, attention is now focused on the search for oil and gas in the Nigeria's frontier inland basins. This includes Bida Basin, Sokoto Basin, Dahomey Basin, Anambra Basin, Bornu (Chad) Basin and Benue Trough (focus of this research) which shares the same evolutionary history with the prolific Muglad Basin (Sudan), Termit Basin (Niger republic) as well as Doba, Dosco and Bongor basin (Chad republic).

Despite the fact that some researchers have shone their search light on the Gongola Sub-basin of the Northern Benue Trough (Fig. 1) as one of the promising hydrocarbon exploration frontier inland basins in Nigeria; more data are still required for adequate evaluation of its organic and inorganic facies distributions. Although previous studies in the area have explore the quantity, quality, thermal maturity and paleoredox condition of the area (Onoduku and Okosun, 2014; Jimoh and Ojo, 2016; Ayinla et al., 2017a; Ayinla et al., 2017b). This study focuses on palynofacies and predictions for hydrocarbon generation of the Upper Cretaceous lignite from Maiganga and Yaya-Ngari Coalfields, Northern Benue Trough, Nigeria.

The central point of this study is to investigate the source rock potential of coal and shale whole rock samples from Maiganga and Yaya-Ngari areas in the Northern Benue Trough was using palynofacies and organic geochemical methods for hydrocarbon generation predictions in the area. Palynofacies is integrated in this study as a useful tool for kerogen typing, paleoenvironment indicator, determination of thermal maturity and hydrocarbon generation potential of source rock which relies on the relative abundance of the three kerogen groups (AMO, Phytoclast and palynomorphs. Additionally, other investigation carried out include the determination of the organic matter origin and paleodepositional environment/conditions (preservation) during sedimentation in the area.

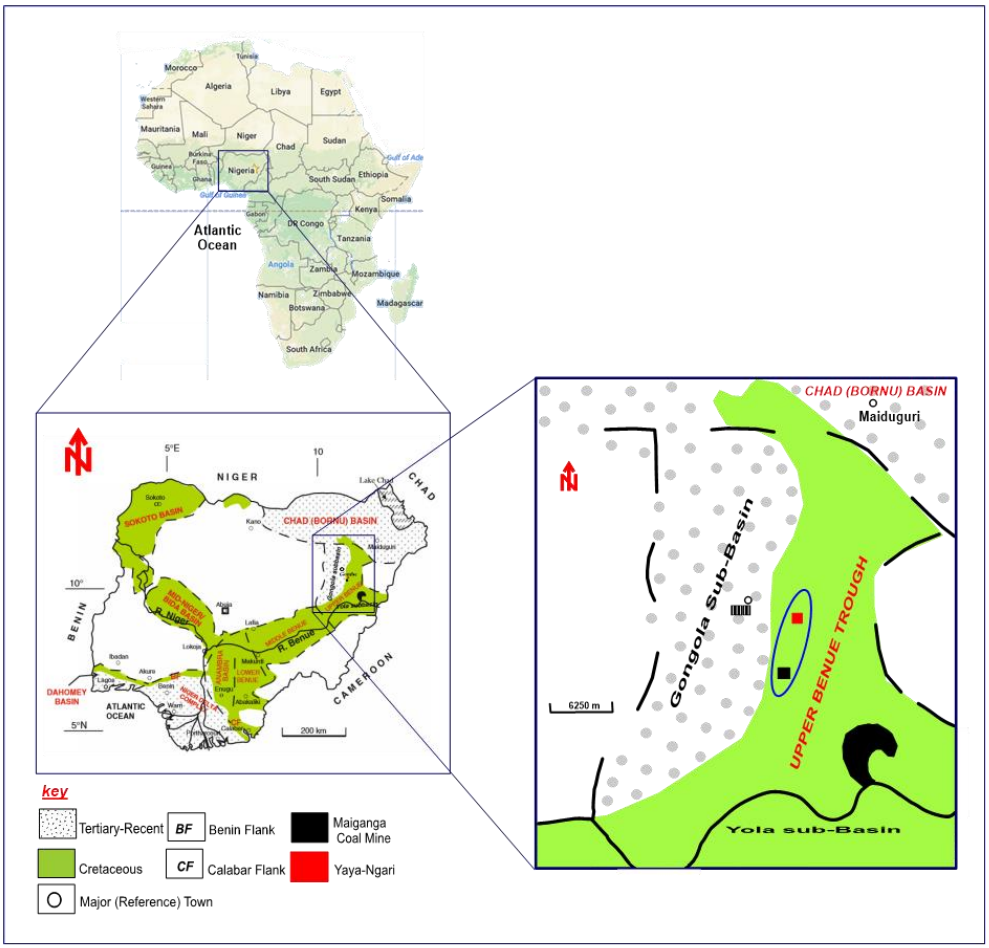

Figure 1: Map of Nigeria showing the sedimentary basins and study area, Maiganga coal mine (modified after Obaje, 2009 and Ayinla et al., 2017).

2.0 Stratigraphy of the Gongola Sub-Basin of the Northern Benue Trough

A number of authors have worked on the stratigraphy of the Gongola sub-basin (Fig. 2), most notably are: Carter et al. (1963), Popoff et al. (1986), and Zaborski et al. (1997) although fairly recently, Abubakar, et al. (2006); Hamidu et al. (2013); Ayok et al. (2014) and Ayinla et al. (2017b) proposed modifications for the Upper Cretaceous lithostratigraphic successions of the western and eastern regions of the Gongola sub-basin. According to Ayok et al. (2018), there are mark differences in the Upper Cretaceous lithostratigraphic successions between these two regions.

Zaborski (2003) provided a summarized Cretaceous history of the Northern Benue Trough as highlighted below:

i) An active rifting phase mainly characterized by the lower Bima Sandstone, this event being accompanied by uplift and subaerial exposure.

ii) A transitional period between the rifting and thermotectonic sag stages, typified the Middle and Upper Bima Sandstone.

iii) A shift from continental to marine environments during which the Cenomanian Yolde Formation was deposited.

iv) A first major packet of majorly eustatically controlled sediments deposited during a Late Cenomanian to Early Turonian marian transgression, comprises of the shales and limestones of the “Kanawa Member” of the “Pindiga Formation” and the Dukul Formation; followed by the Middle Turonian regressive deposits represented by the middle sandy units of Dumbulwa, Deba Fulani and Gulani “members” of the Pindiga Formation and Jessu Formation; and the lower part of the “Fika Member” of the “Pindiga Formation” and the Sekule/Numanha/Lamja formations depicting a Late Turonian to Early Santonian interval of mainly marine milieu.

v) End of Cretaceous compression that resulted to the uplift of the Cretaceous succession and deep dissection of the resultant land surface.

According to Ayok et al. (2018), these last sets of events (the Santonian and the terminal Cretaceous compressional events) have a marked impact on the present-day topography, and must have controlled the spatial erosivity and variation in thicknesses of the lithostratigraphic units across the Gongola sub-basin.

Succeeding a marked angular unconformity, the Kerri-Kerri Formation overlies the Gombe Formation (Carter et al., 1963; Ayinla et al., 2017a, 2017b). Paleocene-Eocene Kerri-Kerri Formation is composed of fluvial and lacustrine continental sandstones with shale and coaly shale intercalations. At western side, it ends sedimentation in the Gongola sub-basin, while the Biu plateau masked the Gongola stratigraphy to the extreme east.

Current study area (Maiganga and Yaya-Ngari) falls within the Gombe Formation (Fig. 1). Sedimentary succession (in Maiganga) is about 35 m thick covering about 48.16 km2 and is dated Late Senonian to Maastrichtian (Ayinla et al., 2017b). It consists of shale, sandstones, siltstones and coal beds in estuarine and deltaic setting (Okosun, 1995; Onoduku et al., 2013; Jimoh and Ojo, 2016; Ayinla et al., 2017b). The sediments from bottom to top consist of coal (seam B), carbonaceous mudstones (claystones and siltstones), coal (seam A3), mudstones, shale intercalated with lenticular coal pods, coal (seam A2), shale, mudstones, shale, coal (seam A1), shale, siltstones, mudstones, laminated siltstones, very fine sandstones, mudstones, fine sandstone and coarse sandstones (Fig. 2). Seam A1 and A2 gradually thin out towards the southern part of the Filed due to erosion, while seam B is relatively continuous.

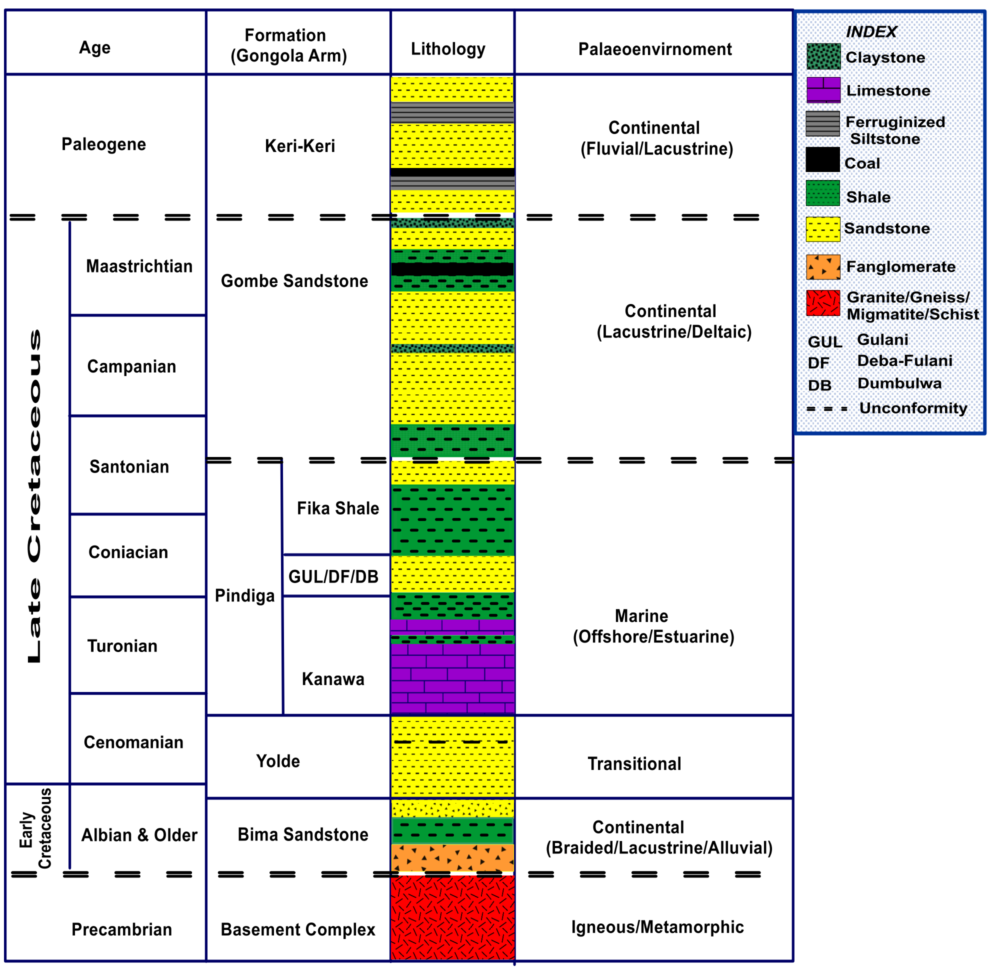

Figure 2: Stratigraphy of the Northern Benue Trough (modified after Abubakar, et al., 2006, Ayinla et al 2017b).

3.0 Methodology

A total of 81 outcrop samples (coal, mudstones and shales) collected from both Maiganga and Yaya-Ngari areas of the Gongola Sub-basin were used for this study. Organic petrographic method employed for characterization and interpretation of the analyzed organic facies was visual kerogen typing which involve isolated kerogens mounted on glass slide. Kerogen isolation was carried out in conformity with the standard methods for palynological analysis (Kaiser and Ashraf, 1974; Traverse, 1988; Wood et al., 1996) see Fig. 3. About 20 g of pulverized samples (~1 mm) placed in 250 ml polypropylene beakers was treated with 10 % hydrochloric acid (HCl) and left for at least 1-2 hours to remove any calcareous material. The content of the beaker was shaken gently for even distribution of the acid while avoiding splashing. After settling, the acid was decanted and the residue was washed with distilled water and centrifuged five times in order to remove the calcium ions that can form unwanted CaF_2 crystals when hydrofluoric acid (HF) is added. Taking necessary precaution, hydrofluoric acid (HF) with a concentration of 65 % was carefully added to the beaker and left for 24 hours in a fume cupboard to ensure a complete removal of silicate minerals. Afterward, distilled water was repeatedly, but periodically, used to wash the sample until a pH of 7 was attained. The sample was poured into a 25-ml test tube and centrifuged for five minutes at 2000 r.p.m. The heavy mineral particles were removed using a $ZnBr_2$ solution (specific gravity of 2.3). 20 ml of $ZnBr_2$ with five drops of concentrated HCl added to improve better heavy liquid separation that was added to the sample and agitated. The test tubes were placed in an ultrasonic bath for 10 seconds and subsequently centrifuged for 30 minutes at 1500 r.p.m. With the aid of pipette, suspended fraction (kerogen) was transferred into another test tube, while the remaining mineral fraction was discarded. The kerogen in the test tubes with distilled water was centrifuged for 5 minutes at 2000 r.p.m. A fraction of the isolated kerogen was for visual kerogen typing. All the steps were repeated for each sample to obtain the isolated kerogens. Wet isolated kerogens were carefully arranged on the glass slide and allowed to dry at 30 °C. Thereafter, permanent slides were prepared (mounted) using Sigma Aldrich Canada balsam (a mounting medium) covered with 24 x 32 mm cover slip. The slide was allowed to dry for about 20 minutes with excess glycerine removed after two days from the edge of the cover slip. One slide was prepared for each sample and used for visual kerogen study using a LEICA CTR 6000 Orthoplan microscope under transmitted light (Fig. 3).

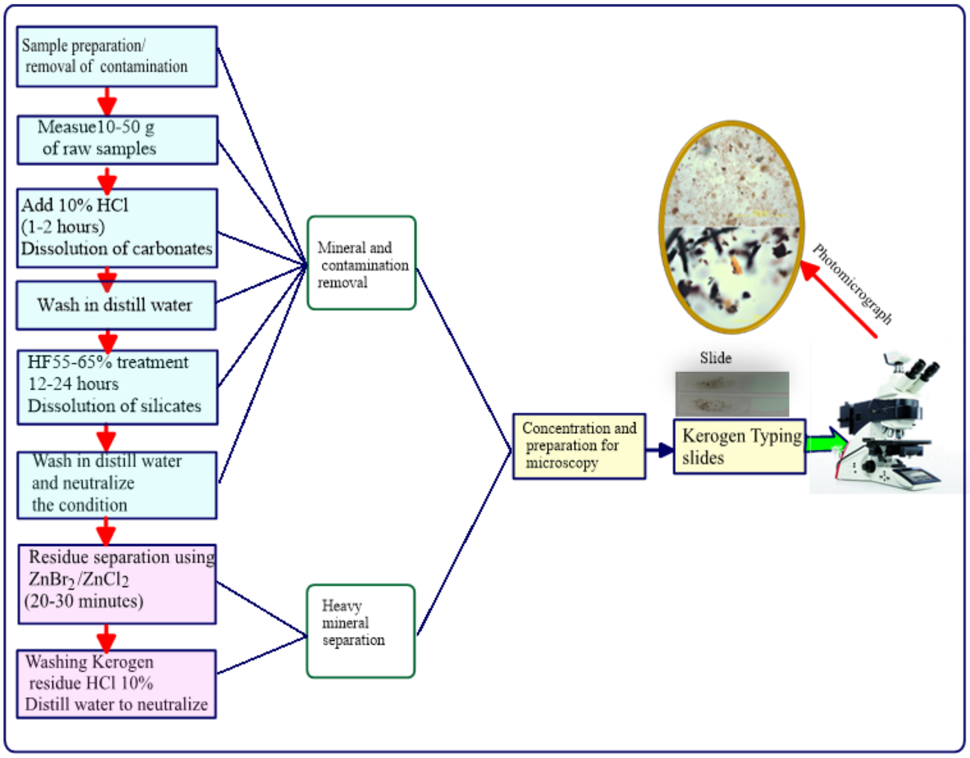

Figure 3: Flow chart of the kerogen isolation procedure for palynofacies studies.

Extraction and fractionation

All samples were crushed into fine powder (<75 microns) and about 8 g of each sample was extracted with an azeotropic mixture of dichloromethane (DCM) and methanol in a Soxhlet apparatus for a minimum of 72 hours. Liquid column chromatography was thereafter used to separate aliquots of the coal extracts into aliphatic, aromatic and polar fractions by using solvents of increasing polarity; petroleum ether (100 mL), DCM (100 mL) and methanol (50 mL), respectively. The fractions were evaporated under reduced pressure and with stream of nitrogen gas to remove excess solvent until constant weights were obtained. Fractions of aliphatic and aromatic hydrocarbons were thereafter concentrated with DCM for gas chromatography-mass spectrometry (GC-MS) analysis. The aliphatic and aromatic hydrocarbons were analyzed by gas chromatography-mass spectrometry (GC-MS) using an Agilent 5890 gas chromatograph coupled to an Agilent 5975B mass selective detector set at electron ionisation energy of 70 eV, 100 milliampere mA filament emission current and 230 °C interface source temperature. The gas chromatograph (GC) was equipped with flexible silica capillary columns (30 m x X0.32 mm I.D. x 0.25 µm) using helium as carrier gas. The GC temperature, which was programmed to start at 40 ℃, increased to 310 °C at the rate of 4 °C/min and was then held at

310 °C ℃ for 30 min. Aromatic biomarker data were acquired via mass chromatograms for phenanthrene and anthracene (m/z 178), methylphenanthrenes (m/z 192), dimethylphenanthrenes (m/z 206), fluorene (m/z 166), dibenzofuran (m/z 168), methyldibenzofuran (m/z 182), naphthalene (m/z 128), methylnaphthalenes (m/z 142), dimethylnaphthalenes (m/z 156), trimethylnaphthalenes (m/z 170), tetramethylnaphthalenes and dibenzothiophene (m/z 184), methyldibenzothiophenes (m/z 198), cadalene (m/z 183), 6-isopropyl-1-isohexyl-2-methylnaphthalene (m/z 197) and retene (m/z 219). Compounds in mass chromatograms were identified by comparing their relative retention times with standard samples and published mass spectra (Killops et al., 1995; van Aarssen et al., 1999, 2000; Radke et al., 2000; Weiss et al., 2000; Ahmed et al., 2009; Nakamura et al., 2010; Romero-Sarmiento et al., 2011; Marynowski et al., 2013; Stojanović and Životić, 2013; Escobar et al., 2016; Jiang and George, 2018; 2019; Cesar and Grice, 2019; Yan et al., 2019; Zakrzewski et al., 2020).

4.0 Result

4.1 Palynofacies

This is a useful tool for kerogen typing, paleoenvironment indicator, determination of thermal maturity and hydrocarbon generation potential of source rock (Tissot and Welte, 1984). It relies on the relative abundance of the three kerogen groups (AMO, Phytoclast and palynomorphs (Tyson, 1995; Mendonça Filho et al., 2012; Mustapha et al., 2017). Figure 4 shows the photomicrographs of identified palynomorphs (P), phytoclast (Ph) and amorphous organic matter (AOM) for the studied Yaya-Ngari shale (a and b) and Maiganga mudstones (c-h). Yaya-Ngari samples show significant amount of dark-brown to orange colour phytoclast compared to brown heterogenous AOM and brown to orange palynomorphs. The palynomorphs are often <10 µm, although few ones are up to 80 µm sizes (Figs. 4a and b). In the case of Maiganga facies, they are characterized by mainly terrestrial kerogen group. Figure 4c-h shows photomicrographs of highly oxidized black, opaque tissues of higher plants often associated with some brown degraded tissue of higher plants, light brown AOM (probably resin and algae material) and trilete spore and pollens of plants. Although, thermal maturity of the Formation suggests that Yaya-Ngari shale corresponds to an early oil generation window. In effect, the Gombe Formation thermal maturity ranges from pre-oil generation window to early oil generation window (Ayinla et al., 2017a).

This is an indication of a more gas-prone Type III kerogen than the associated liptinitic materials of oil-prone Type II kerogen as observed under the UV-light.

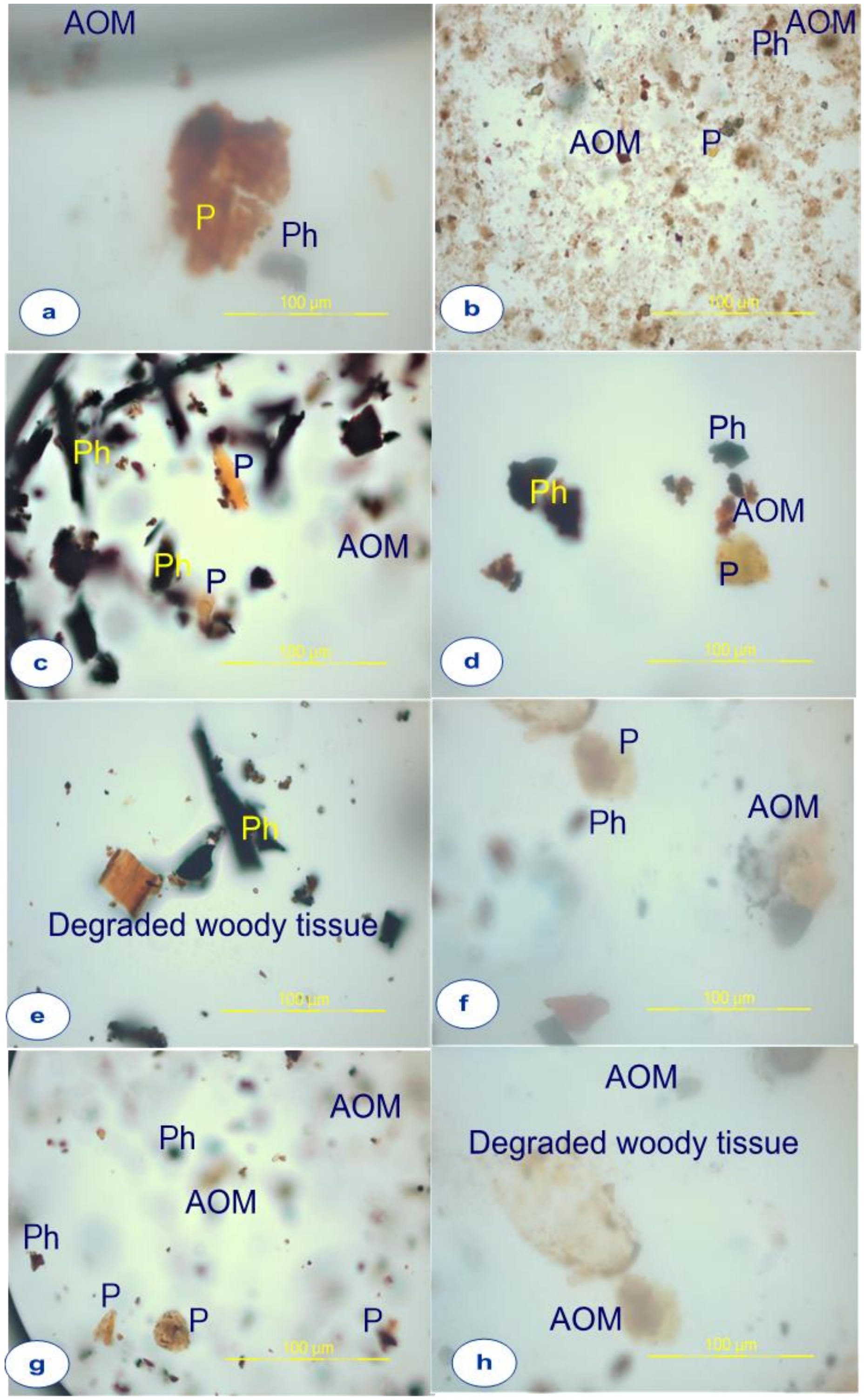

Figure 4: Photomicrographs of identified palynomorphs (P), phytoclast (Ph) and amorphous organic matter (AOM) in the studied Yaya-Ngari shale (a and b) and Maiganga mudstones (c-h).

4.2 Dibenzothiophenes/phenanthrenes (DBT/P) ratio

Figure 5 shows the mass fragmentograms of Phenanthrenes (m/z 178), Methylphenanthrenes isomers (m/z 192) and aromatic Dibenzothiophenes (m/z 184) for aromatic hydrocarbon fractions of the analyzed Maiganga and Yaya-Ngari samples. The result indicates that the aromatic Dibenzothiophenes/phenanthrenes (DBT/P) ratio (m/z 184 and 178) is significantly low (<1), following the high concentration of phenanthrenes compared to low dibenzothiophenes in all the analyzed samples (Fig. 5; Table 1). This is not surprising as deltaic settings are usually characterized by DBT/P ratio of <1 (Hughes et al., 1985; Peters et al., 2005).

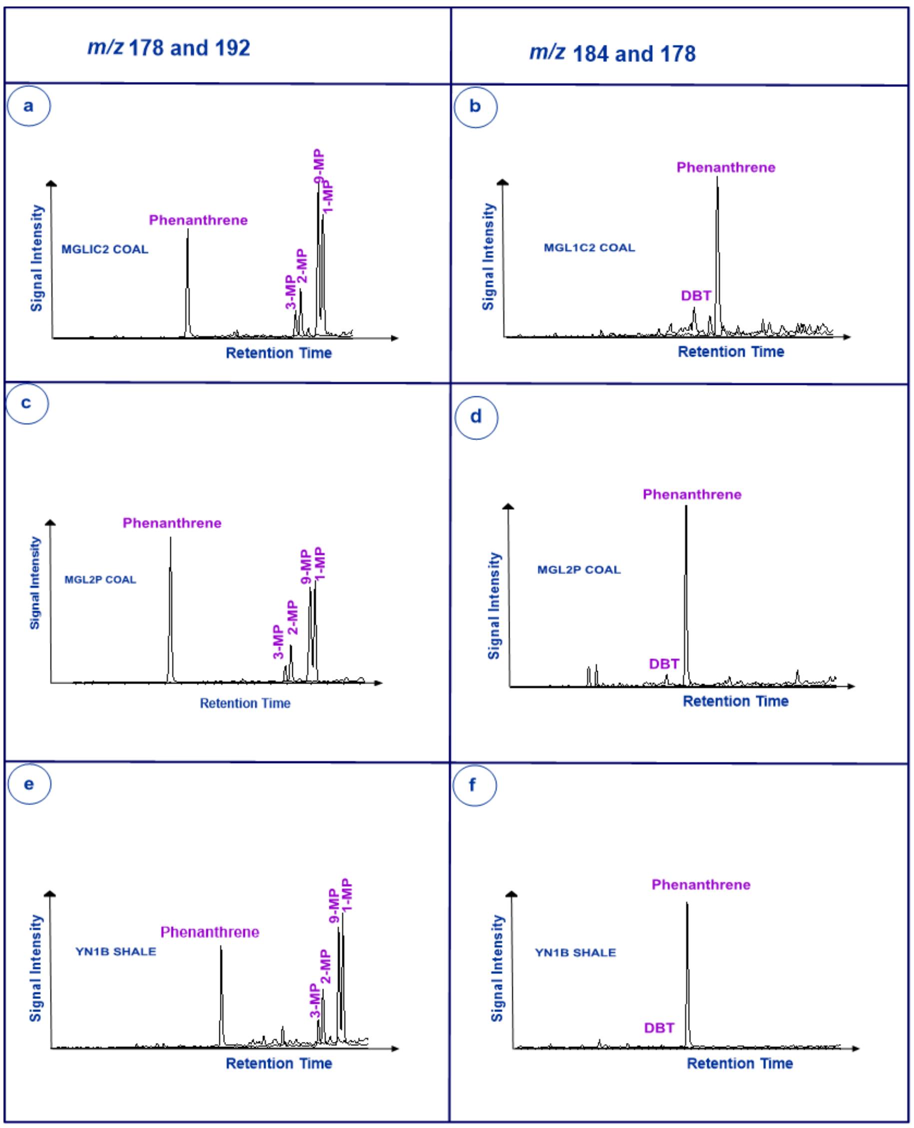

Figure 5: The mass fragmentograms of Phenanthrenes (m/z 178), Methylphenanthrenes isomers (m/z 192) and aromatic Dibenzothiophenes (m/z 184) for aromatic hydrocarbon fractions of the analysed Maiganga and Yaya-Ngari samples

Table 1: Biomarker ratios based on m/z 191, 217, 184 and 178 mass chromatograms for selected samples.

Sample ID	Lithology/ Seam	m/z 217 (Steranes)						steranes/ Hopanes ratio	DBT/P
		Regular steranes (%)			C_{27}/C_{29}	C_{29} 20S/(20S+20R)	C_{29} ββ/(ββ+αα)		
		C_{27}	C_{28}	C_{29}					
MGL1C2	Coal/seam B	14.71	38.24	47.06	0.31	0.26	0.34	0.03	0.17
MGL2A	Coal/seam B	32.38	33.33	34.29	0.94	0.30	0.33	0.05	0.20
MGL2B	Coal/seam B	23.33	20.00	56.67	0.41	0.26	0.35	0.12	0.10
MGL2C	Coal/seam B	15.38	41.03	43.59	0.35	0.23	0.22	0.03	0.12
MGL2D	Coal/seam B	22.06	32.35	45.59	0.48	0.31	0.33	0.07	0.13
MGL2E	Mudstone	23.19	33.33	43.48	0.53	0.33	0.32	0.03	0.02
MGL2F	Mudstone	37.76	24.49	37.76	1.00	0.21	0.32	0.04	===
MGL2G	Siltstone	34.44	26.67	38.89	0.89	0.32	0.39	0.78	===
MGL2H	Coal/seam A3	35.03	19.77	45.20	0.78	0.15	0.14	0.08	0.35
MGL2I	Coal/seam A3	20.48	28.92	50.60	0.40	0.14	0.25	0.01	0.20
MGL2L	Shale	20.72	26.13	53.15	0.39	0.33	0.39	0.03	0.12
MGL2N	Shale	25.64	21.79	52.56	0.49	0.20	0.26	0.02	0.30
MGL2P	Coal/seam A2	10.60	21.19	68.21	0.16	0.24	0.33	0.01	0.07
MGL2Q	Shale	14.05	34.71	51.24	0.27	0.17	0.32	0.02	0.09
MGL2R	Mudstone	20.18	22.81	57.02	0.35	0.36	0.38	0.04	===
MGL2S	Shale	14.10	21.79	64.10	0.22	0.18	0.29	0.02	0.09
MGL2S2	Shale	15.07	21.92	63.01	0.24	0.36	0.38	0.03	0.09
MGL2T	Coal/seam A1	15.44	22.82	61.74	0.25	0.18	0.36	0.02	0.10
MGL2U	Shale	15.04	25.56	59.40	0.25	0.27	0.30	0.03	0.10
YN1A	Shale	37.42	17.79	44.79	0.84	0.43	0.55	0.17	0.30
YN1A2	Shale	37.31	16.42	46.27	0.81	0.44	0.54	0.17	===
YN1B	Shale	36.82	22.39	40.80	0.90	0.35	0.54	0.19	0.08
YN1B2	Shale	36.84	21.05	42.11	0.88	0.43	0.53	0.18	0.20
YN1C	Shale	32.06	21.53	46.41	0.69	0.40	0.55	0.24	0.40
YN1C2	Shale	31.96	21.65	46.39	0.69	0.50	0.55	0.25	===
YN1D	Shale	35.07	20.38	44.55	0.79	0.50	0.51	0.19	===
YN1D2	Shale	34.95	20.39	44.66	0.78	0.49	0.52	0.20	===

5.0 Discussion

5.1 Kerogen Type and hydrocarbon generation potential

According to Tissot and Welte (1984) palynofacies is a useful tool for kerogen typing and hydrocarbon generation potential of source rock. Based on the relative abundance of the three kerogen groups (AMO, Phytoclast and palynomorphs) as shown in Figure 4, the study area has a gradual transition from mixed organic matter source input at Yaya-Ngari to more gas-prone Type III kerogen than the associated liptinitic materials of oil-prone Type II kerogen at Maiganga area. This is evident from more dark-brown to orange colour phytoclast associated with brown heterogenous AOM and brown to orange palynomorphs at the Yaya-Ngari area. In support of this is the observed relatively large palynomorphs of up to 80 µm sizes (Figs. 4a and b) within the area. Maiganga facies are basically composed of terrestrial kerogen group (Figs. 4c-h) as shown by the clear evidence of brown tissues of higher plants often associated with some light brown AOM (probably resin and algae material) and trilete spore and pollens of plants. Thus, palynofacies results suggest more gas-prone Type III kerogen than the associated liptinitic materials of oil-prone Type II kerogen as observed under the UV-light. This is in line with Py-GC finger print and the cross plot of Pr/n-C17 versus Ph/n-C18 (Fig. 6) showing the organic matter source input for the analysed Maiganga and Yaya-Ngari samples (modified after Ayinla et al., 2017a). Meaning that, there is potential for hydrocarbon generation within the Upper Cretaceous Benue Trough.

Figure 6: The cross plot of Pr/n-C17 versus Ph/n-C18 showing the organic matter source input for the analysed Maiganga and Yaya-Ngari samples (modified after Ayinla et al., 2017a).

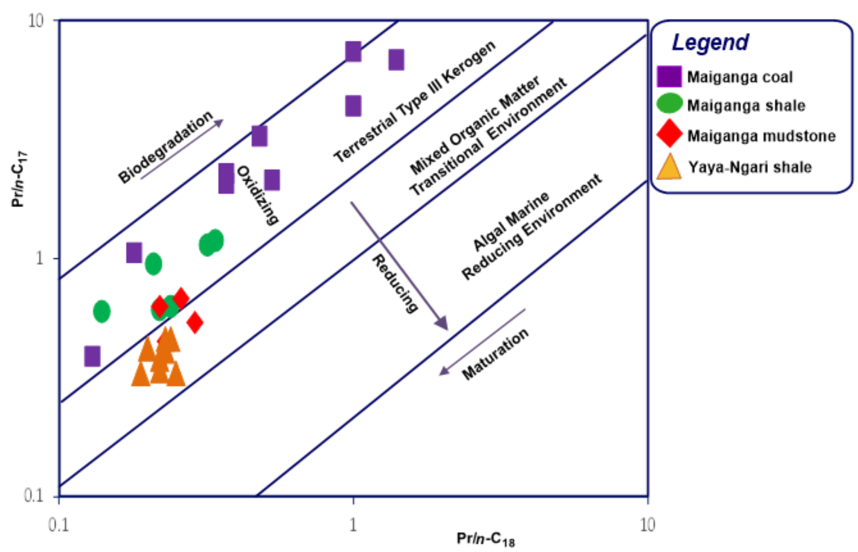

Figure 6: The cross plot of Pr/n-C_{17} versus Ph/n-C_{18} showing the organic matter source input for the analysed Maiganga and Yaya-Ngari samples (modified after Ayinla et al., 2017a).

5.1 Organic matter origin

Evidence from palynofacies analysis reveals presence of pollen, trilete spore, resin and algae material and higher plants tissues of different shades of colours which were also observe on the field. The relative abundance of these kerogen groups (Fig. 4) clearly suggests more terrigenous origin for the study area. This is consistence with Ayinla et al., (2017a) who reported that terpane and sterane biomarkers distribution on the m/z 191 and 217 chromatogram respectively were indicative of more terrigenous origin for Gombe Formation samples. As a common feature of the m/z 191 chromatograms of saturated hydrocarbon fraction of all the analysed samples (Ayinla et al., 2017a) is high concentration of the hopanes relative to tricyclic and tetracyclic terpanes as well as steranes on m/z 217 (Ayinla et al., 2017a). Thus, a low sterane/hopane ratio generally <1 suggests more terrigenous and/or microbially reworked organic matter source for the Gombe Formation samples (Tissot and welte, 1984; El-Diasty and Moldowan., 2012). Similarly, reported presence of oleanane suggests source input of angiosperms (Ayinla et al., 2017a), as well as the cross plot of C23/C24 tricyclic terpane versus C24 tetracyclic/C26 tricyclic (Fig. 7) indicate a significant terrigenous source with more marine contribution in Yaya-Ngari compared to Maiganga facies.

Murray et al. (1994) suggested that oleanane is best preserved in deltaic rocks influenced by marine waters during early diagenesis, which supports the depositional setting of the studied samples. The high C29 norhopane also supports terrestrial organic matter source whereby the bacterial influence is apparent from the cross plot of Pr/n-C17 vs. Ph /n-C18 (Fig. 6).

Steranes derived from sterol in higher plant and algae are the second most important group of biomarkers and their concentrations have proved useful in discrimating source input of organic facies (El Diasty and Moldowan, 2012, 2013; Makeen et al., 2015c; Han et al., 2017). The dominating percentages of C27, C28 and C29 steranes on m/z 217 would suggest marine, lacustrine and terrestrial sources respectively (Waple and Machilhara, 1991; Peters et al., 2005). Higher amount of C29ααα(20R) steranes, in the studied samples compared to other steranes, in the range of 34.29% to 68.21% (Table 1) also supports dominance of terrestrial source with varying marine and lacustrine influences.

Result based on the relative percentages of C27, C28 and C29 ααα(20R) steranes of the analysed samples (Table 1) indicate dominance of terrestrial high plant with planktonic and bacterial influence. This is consistent with cadalene/m(+p) xylenes (cd/xy) concentration ratio in Section 5.4 above and Pr/n-C17 vs. Ph/n-C18 plot (Fig. 6) which indicates terrestrial Type III kerogen for Maiganga, trending to transitional mixed organic matter source input in Yaya-Ngari. The interpretation of organic matter source based on the clustered plot of C27/C29 regular sterane versus pristane/phytane ratio (Ayinla et al., 2017a) shows a gradual transition from mainly terrigenous source input for Maiganga in the southern area to mixed organic matter for Yaya-Ngari in the northern part of the study location (see Fig. 1). This is a clear indication of predominace of terrigenous source input in the studied Gombe Formation samples.

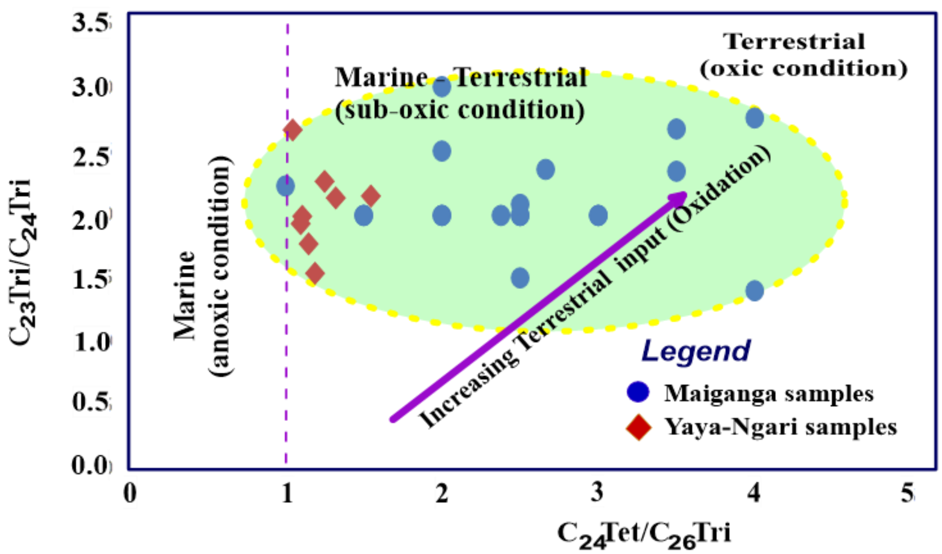

Figure 7: The cross plot of C23/C24 tricyclic terpane versus C24 tetracyclic/C26 tricyclic indicating significant terrigenous source input with more marine contribution in Yaya-Ngari compared to Maiganga facies.

5.2 Deposition Condition

The GC-MS result of saturated hydrocarbon is corroborated by the aromatic hydrocarbon fraction. Observed low concentration of dibenzothiophenes compared to aromatic phenanthrenes (m/z 184 and 178) resulted in DBT/P ratio of <1 (Fig. 5 and Table 1). Thus, Hughes et al., (1995) suggest that the cross plot of DBT/P versus Pr/Ph ratio is a powerful way of discriminating source rock depositional environment. This plot indicates a marginal marine environment mainly deltaic setting (Maiganga) associated marine shale at Yaya-Ngari (Fig. 8) for the analysed sediments. Similarly, Holba, et al. (2003) observed that deltaic settings are usually characterised by high concentration of hopane compared to streane resulting in hopane/(hopane+sterane) ratio > 0.7. Such a relationship exists between hopane and steranes in the studied sample and is consistent with deltaic depositional environment.

The relationship between the Pr, Ph, n-C17 and n-C18 as illustrated on the cross plot of Pr/n-C17 vs. Ph/n-C18 (Fig. 6) indicates a deposition of

Type III kerogen within an oxidizing environment in Maiganga and mixed organic matter source input in Yaya-Ngari area within a suboxic conditions. The high ratios of C23/C24 tricyclic terpane (1.4-3) and C24 tetracyclic/C26 tricyclic terpane (1-4) observed in this study favours gradual transition from mainly terrestrial sourced organic matter deposited under oxic to suboxic conditions in Maiganga to basically suboxic depositional conditions in Yaya-Ngari (Fig. 7). This is illustrated based on the plot C23/C24 tricyclic terpane versus C24 tetracyclic/C26 tricyclic (Fig. 7) as described by El-Diasty and Moldowan (2012) showing predominatly terrestrial organic facies with varying bacterial and algal contributions.

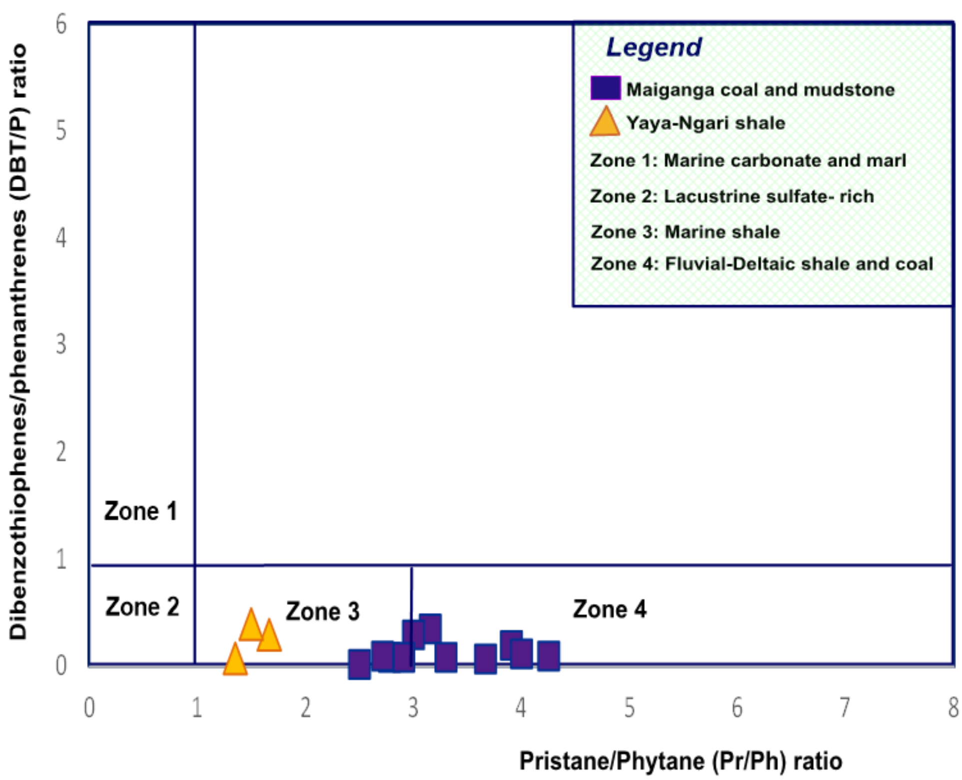

Figure 8: Cross plot of aromatic Dibenzothiophenes/phenanthrenes (DBT/P) ratio (m/z 184 and 178) versus Pr/Ph ratio for discriminating the source rock depositional environment (after Hughes et al., 1995).

Furthermore, Ayinla et al. (2017a), suggest that the C31R/C30 hopane ratio is a good molecular tool to differentiate marine from lacustrine environmental influence in the source input of shales and mudstones (since low rank coals are known to show high values). Marine depositional setting is characterised by C31R/C30 hopane ratio above 0.25 while lacustrine environment is known to have value below 0.25 (Peters et al., 2005). According to Ayinla et al. (2017a), a range between 0.36 and 2.11 obtained for this area further confirm presence of a marginal marine (delta) environment. It can thus be inferred that the area under study has marine influence. This observation is consistent with the depositional setting of the lateral equivalence of Gombe Formation in the Chad (Bornu) basin as reported by Ayinla et al., 2013.

Additionally, the depositional environment of sediments dictates the quality and quantity of organic matter preservation. The studied sediments were deposited in a deltaic environment, (Fig. 8), under suboxic-oxic conditions. The high terrestrial source input of forest material with some marine and lacustrine influence occurs at a high rate, thus promoting higher input of land plants with reasonable marine and lacustrine inputs. This is supported by maceral analysis indicating predominance of huminite (average 58%) and significant contributions from liptinites (21%) and inertinites (20%) maceral during deposition of the Gombe Formation sedimentary facies (Ayinla et al., 2017b).

Conclusion

The source rock potential of coal and shale whole rock samples from Maiganga and Yaya-Ngari in the Northern Benue Trough was investigated using palynofacies and organic geochemical methods for hydrocarbon generation predictions in the area. The following are the conclusion drawn from the results of the analyses:

1. Palynofacies studies shows that identified facies from the Yaya-Ngari shale show significant amount of dark-brown to orange colour phytoclast compared to brown heterogenous AOM and brown to orange palynomorphs ranging from <10 µm to 80 µm sizes. In the case of Maiganga facies, they are characterized by mainly terrestrial kerogen group. This is evidently shown by the presence of highly oxidized black, opaque tissues of higher plants often associated with some brown degraded tissue of higher plants, light brown AOM (probably resin and algae material) and trilate spore and pollens of plants.

2. This study further confirms that the organic matter quantity and quality are favourable for hydrocarbon generation within the study area. Thus, it is an indication of a more gas-prone Type III kerogen than the associated liptinitic materials of oil-prone Type II kerogen as observed under the UV-light.

3. The GC-MS result of saturated hydrocarbon as corroborated by the aromatic hydrocarbon fraction indicates low concentration of dibenzothiophenes compared to aromatic phenanthrenes (m/z 184 and 178) which resulted in DBT/P ratio of <1. This indicates a marginal marine environment mainly deltaic setting

(Maiganga) associated marine shale at Yaya-Ngari for the analysed sediments.

4. Generally, the paleoredox conditions based on biomarker studies suggest deposition of Type III/II kerogen within suboxic to oxic environment for the Maiganga, while the Yaya-Ngari samples are characterized by mixed organic matter deposited in a suboxic conditions.

5. Although, thermal maturity of the Formation suggests that Yaya-Ngari shale corresponds to an early oil generation window. In effect, the Gombe Formation thermal maturity ranges from pre-oil generation window to early oil generation window.

6. This study therefore, suggests that the Upper Cretaceous petroleum system of the Gongola Sub-basin has good source rocks potential (mainly "gas-prone" and to a less extent "oil-prone").

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