Petroleum Potential of Gombe Formation, Kolmani River-1 Well Gongola Basin, NE Nigeria

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Abstract

Gombe Formation is one of the promising potential source-rock of petroleum in the Gongola basin based on its appreciable amount of organic matter. The present study is therefore aimed at evaluating the hydrocarbon potential of Gombe Formation. Ditch-cutting samples were collected from the depth of 731.5 m to 1554.5 m from Gombe Formation that penetrated the Kolmani River-1 well. The source-rock potential was evaluated based on kerogen analysis and soluble organic matter content using Fourier Transform- Infra red spectroscopic (FT-IR) and Gas chromatography-Mass spectrometric (GC-MS) techniques respectively. There is presence of peak at 900-1000 cm⁻¹ which is due to CH₂ rocking vibration in long chain aliphatic substances, which is characteristic of liptinite macerals indicating good potential source-rock for oil and gas. The *n*-alkane ranges from C₁₁-C₃₃ maximizing at *n*C₁₆ which suggests that the organic matter are majorly derived from marine organic matter. The Pr/Ph (1.49-1.92) shows that the organic matter was deposited under sub-oxic condition. The distribution of hopanes, homohopanes (C₂₇-C₂₉) steranes, (C₀-C₄) alkylated naphthalenes and (C₀-C₃) alkylated phenanthrenes indicate the presence of angiosperm, gymnosperm, algae, marine and bacteria input to the organic matter contained in the samples. Also the plot of DBT/P vs. Pr/Ph classifies the samples into zone 3 (i.e. marine shale and other lacustrine). Various maturity parameters computed from saturate biomarker and polycyclic aromatic hydrocarbon distributions shows that the samples are low mature with the moderately mature zone at the bottom (>1408.2 m) of Gombe Formation. In conclusion, the kerogen was probably derived from type II/III organic matter capable of generating both oil and gas and the moderately mature zone lies at the bottom of the Formation.

Key words: Lacustrine, Gombe formation, Maturity, Hydrocarbon, Kerogen

1.0 Introduction

Gongola basin is the north-south trending of the Northern Benue Trough [1]. The structural history of this area commenced towards the beginning of the upper Cretaceous with the rifting of the Upper Benue Trough and the accumulation of considerable thickness of sediments in a number of depocentres within this NW-SE trending depression [2]. The Kolmani River-1 well (Fig. 1) is located at longitude 10 °E and latitude 10 °N in the Gongola Basin of the Upper Benue trough, Nigeria. The well penetrated four formations (Fig. 2) namely Gombe, Pindiga, Yolde and Bima Formations (Maastrichtian to Albian). The youngest Cretaceous sediment in the Gongola Basin is the coastal (deltaic) Gombe Sandstone, which unconformably

covers the pre-mid-Santonian sequences in several places [4].

In the past, search for petroleum source-rock in Gongola basin have been limited to Pindiga, Yolde and Bima formations [2, 5-8] probably based on the assumption that Gombe formation is relatively younger [4]. However, it was reported [8] that Gombe Formation has relatively high TOC (Table 1) which make it a good candidate to serve as potential source rock. The present study is to provide more information on the organic matter quality and thermal maturity of the shaly samples of Gombe Formation that were penetrated by Kolmani River -1 well in order to further assess its potential to serve as Petroleum source-rock in Gongola basin.

2.0 Sampling and experimental methods

Ditch-cuttings (14) were collected from Gombe Formation at various depths ranging

from 731.5 m – 1408.2 m. It was previously reported [8] that the samples from Gombe formation have high TOC and contain

mixed/marine organic matter (Table 1). The samples were crushed or pulverized using mortar and pestle. It was dried at a temperature of 80°C in an oven and later packed with aluminium foil and kept in a dessicator to avoid moisture prior to use. For isolation of kerogen, 20 mL of 6 M hydrochloric acid was added to 2 g of each sample in a digestion flask. This mixture was allowed to stand overnight (16 hours) at 60°C. Then the mixture was filtered wash with hot distilled water, after the residue was dried in an oven at 60 °C for 4 hours. The dried residue was put into the flask and 10 mL of 49% hydrofluoric acid was added in a fume cupboard. The mixture was allowed to stand at 50 °C for 24 hours. Then saturated boric acid solution was added followed by 10 mL of 6M hydrochloric acid and the mixture was heated at 60 °C for 2 hours. The mixture was filtered and hot washed with distilled water; the residue was dried at room temperature. 20 mL of 3M HNO₃ was added to dried residue and the mixture was heated at 45 °C for 1 hour. The mixture was filtered and hot washed with distilled water. The residue was dried at 60 °C for 2 hours. After, the samples were packed in aluminium foil and kept for infrared analysis.

10 g of ditch cutting samples were ultrasonically treated sequentially with 20 mL of methanol, 20 mL of dichloromethane: methanol (1:1) and 20 mL of dichloromethane respectively for 20 min to extract the soluble organic matter (SOM). The extracts were fractionated on a silica – alumina column using hexane, hexane: dichloromethane (3:2) and methanol to elute saturate, aromatic and NSO fractions respectively. The solvent in the three fractions were concentrated using rotator evaporator to remove excess solvent and then transferred into a weighed clean vial and kept at 4 °C for GC-MS analysis.

Infra-red analysis of the isolated kerogen was carried out using 1 mg of bulk powder sample (kerogen sample) added to 200 mg of potassium bromide (KBr) pellets and the mixture homogenized using a pestle in an agate mortar. Absorption spectra of the homogenized samples were collected using Fourier Transform infrared (FT – IR) Spectrometer (Nicolet Bench 505 p) with sample absorbance monitored using 256 scans with resolution of 4 cm⁻¹ from a wave number of 4000 – 600 cm⁻¹. Individual samples were

analyzed for functional groups. The spectra were interpreted according to the following method [9]. The height of the peaks at approximately 1705 and 1605 cm⁻¹ (corresponding to 1710 and 1630 cm⁻¹ in the spectra of kerogen concentrate) and at 2930 and 2860cm⁻¹ were measured. The A-factor and C-factor were calculated from the peak heights.

The saturate and aromatic hydrocarbon fractions were analyzed using a gas chromatography performed on a Hewlett-Packard 5973N mass spectrometer. The gas chromatography was equipped with a HP-5 fused silica capillary column (30 m x 0.25 mm, i.d., 0.25µm film thickness) and Helium was used as the carrier gas with flow rate of 1ml/min.

For saturate fractions, oven temperature was programmed from 80 °C for 2 minutes to 280 °C at the rate of 3 °C/min⁻¹, followed by an isothermal phase for 20 minutes at 280 °C. The samples were analyzed in the full scan and SIM modes respectively. The SIM modes; n-alkanes (m/z =85), sesquiterpanes (m/z = 123), triterpanes (m/z = 191), and disasteranes and regular steranes (m/z =218) were detected and individual compound were identified by the relative retention times and comparison of mass spectra with literature and library data. For aromatic fraction, the GC oven temperature was an isothermal of 2 minutes at temperature of 60 °C and then programmed for 60 °C to 290 °C at the rate of 3°C/min⁻¹ followed by isothermal phase of 20 minutes at 290 °C. The samples were also analysed in full scan and SIM modes respectively. The SIM modes; naphthalene, methylnaphthalene, dimethylnaphthalene, trimethylnaphthalene, tetramethylnaphthalene and benzothiophene (m/z =128, 142, 156, 170 and 184 respectively); phenanthrene, methylphenanthrene dimethyl phenanthrene and trimethyl phenanthrene (m/z =178, 192, 208 and 220 respectively) were detected and the identification of individual aromatic compounds was made by relative retention time and comparison of mass spectra with literature and library data. the mass spectrometer was operated with electron energy impact of 70 eV and an ion source temperature of 230 °C.

Fig. 1: This is a Geological map of Nigeria with an insert that shows the location of Kolmani River -1 well [4]

Fig. 2: Stratigraphic Section of Upper Benue Trough [10]

Table 1: Total Organic Carbon (TOC) and Elemental Composition Ratios

Samples	Depth (m)	Lithology	TOC (wt%)	%S	TOC/S	TOC/N	S/C	C/N
K1	731.5	CS	17.20	0.52	47.78	41.95	0.02	50.00
K2	749.8	CS	6.17	0.32	33.35	34.28	0.03	33.30
K3	823.0	CS	12.80	0.45	39.63	39.39	0.03	33.30
K4	896.1	CS	5.47	0.27	30.39	29.57	0.03	33.30
K5	969.30	CS	8.22	0.25	43.04	32.88	0.02	33.30
K6	1042.0	CS	5.58	0.37	18.12	31.00	0.05	33.30
K7	1115.6	CS	3.85	0.58	8.05	24.84	0.12	25.00
K8	1188.7	CS	2.82	0.21	4.90	20.14	0.21	20.00
K9	1261.8	S	0.86	1.22	1.11	9.05	0.89	9.10
K10	1335.0	S	0.98	1.41	1.24	6.32	0.64	7.70
K11	1344.2	S	0.80	0.98	1.32	8.42	0.66	10.00
K12	1408.2	S	0.89	1.45	1.19	5.93	0.80	6.30
K13	1481.3	S	0.71	1.35	1.05	4.73	0.94	4.8
K14	1554.5	S	1.02	1.98	1.10	9.27	0.95	9.10

Reference-[8]

3.0 Results and discussion

3.1 Kerogen characterization

The FT-IR spectra of the samples (Fig. 3) revealed strong aliphatic stretching bands in 2700-3000 cm^{-1} region, CH_2 bands between 1365 cm^{-1} and 1447 cm^{-1} were also prominent indicating the substantial content of aliphatic structures. There are strong aromatic carbon ($\text{C}=\text{C}$) absorption in the range 1609-1638 cm^{-1} . Also there is occurrence of CH bending of aromatic at 680 cm^{-1} - 800 cm^{-1} as well as $\text{C}=\text{O}$ stretching bands of carboxyl/ester at 1718 cm^{-1} - 1750 cm^{-1} . The peak intensities of the three major peaks used in calculating the A and C factors are given in (Table 2). Also the ratio B/F calculated from the two major peaks,

1609-1638 cm^{-1} ($\text{C}=\text{C}$) and 2923-2720 cm^{-1} ($\text{C}-\text{H}$) are presented in (Table 2). All the studied samples were plotted along the type II/III (Fig. 4) evolution pathway indicating the organic matter contained in the Gombe Formation are formed from mixed/terrestrial materials and suggest that the source rocks are capable of generating both oil and gas [9, 11-12]. The B/F (ratio of aliphaticity to aromaticity) ranges from 0.98-1.00 in all the samples. The B/F ratio values indicate that aliphatic content in all the samples are high. Therefore the samples have the potential to generate both oil and gas [13].

Fig. 3: IR spectra of the studied samples

Table 2: A & C-factors, B/F ratio obtained from the FT-IR spectra of the samples

Sample	Depth (m)	A-factor	C-factor	Kerogen type	B/F ratio
K1	731.5	0.6703	0.5044	Type II/III	0.9833
K3	823.0	0.6674	0.5032	Type II/III	0.9947
K5	969.3	0.6670	0.5018	Type II/III	0.9983
K6	1042.0	0.6668	0.4995	Type II/III	0.9989
K8	1188.7	0.6687	0.5023	Type II/III	1.0000
K10	1335.0	0.6703	0.5037	Type II/III	0.9832
K12	1408.2	0.6691	0.5035	Type II/III	0.9882

$$\text{A-Factor} = \frac{(2860+2930 \text{ cm}^{-1})}{(2860+2930+1630 \text{ cm}^{-1})}$$

$$\text{C-Factor} = \frac{(1705 \text{ cm}^{-1})}{(1705+1630 \text{ cm}^{-1})}$$

Fig. 4: Plot of A-factor and C-factor for kerogen typing

3.2 n-Alkanes and Isoprenoids

The n-alkane distribution in the samples ranges from C_{11} - C_{31} in most samples maximizing at C_{16} (Fig. 5; Table 3). This pattern of distribution indicates organic matter mainly derived from marine settings [14]. TAR and nC_{31}/nC_{19} ratio also ranges from 0.01 to 0.08 and 0.02 to 0.13 (Table 3) respectively supporting major contributions from phytoplankton to organic matter contained in the samples. The plots of $Pr/n-C_{17}$

and $Ph/n-C_{18}$ (Fig. 6) show that the samples have mixed terrestrial/marine source of organic matter [14]. The Carbon Preference Index (CPI) and Odd-Even Predominance (OEP) values (Table 3) range from 0.98-1.52 and 0.91-1.95 respectively. These values reflect low-marginal maturity status of the samples (Peters et al., 2005). The Pr/Ph ratio ranged from 1.49-1.92 (Table 3), indicating sub-oxic depositional environment [14].

Fig. 5: m/z 85 showing the distributions of n-alkanes, pristane and phytane in the samples

Table 3: N-Alkane and Isoprenoid Parameters

Sample	Depth (m)	Pr/Ph	Pr/nC17	Ph/nC18	nC31/nC19	TAR	CPI (1)	OEP (2)	Cmax	Crange
K1	731.5	1.49	0.62	0.46	0.03	0.09	1.52	1.95	C16	C11-C31
K3	823.0	1.88	0.62	0.39	0.02	0.03	1.00	1.18	C16	C11-C31
K5	969.3	1.88	0.62	0.39	0.08	0.12	1.07	1.07	C16	C11-C34
K6	1042.0	1.82	0.63	0.40	0.06	0.13	1.34	1.93	C16	C11-C32
K8	1188.7	1.79	0.63	0.40	0.01	0.05	0.98	1.12	C16	C11-C31
K10	1335.0	1.78	0.61	0.40	0.01	0.03	0.98	1.00	C16	C11-C31
K12	1408.2	1.92	0.63	0.39	0.01	0.02	1.14	0.97	C16	C11-C31

Figure 6: Kerogen typing and oxicity of depositional environment of the samples

3.3 Distribution of hopane and homohopanes

C₂₉ and C₃₀αβ-hopane are present in appreciable amount in all the samples (Table 5), indicating significant contributions of prokaryotic organisms (i.e. bacteria, cyanobacteria and blue algae) to the source organic matter. A Sterane/hopane ratio is often used as a measure of relative inputs of eukaryotic versus prokaryotic debris [15]. Generally the values of sterane/hopane ratio (0.55-0.63) for the samples suggest

incorporation of high level of bacteria inputs [15-17). C₃₁ and C₃₂ homohopane isomerisation ratio rises from 0 to approximately 0.6 during maturation with the value ranging from 0.5-0.54 indicates that a source rock is at the onset of oil generation [18]. The C₃₂ homohopane ratio in the samples ranges from 0.48-0.62 (Table 5). The results from the studied samples indicated that the mature zone lie at the bottom of the Formation (i.e. K12) at depth of 1408 m [14, 19-20].

Table 5: Source and Thermal Maturity Ratios based on Hopanes and Sterane

Sample	Depth (metre)	C ₂₉ H/C ₃ 0H	T _s /T _m	C ₃₁ H H (S/S+R)	C ₃₂ H H (S/S+R)	D/S	C ₂₇ /C ₂ 9 S	S/H	%C ₂ 9S	%C ₂ 8S	%C ₂ 7S	20S/ 20S+ 20R	ββ/β β+α α
K1	731.5	1.37	0.15	0.24	0.48	4.31	0.56	0.57	55.90	12.90	31.20	0.62	0.31
K3	823.0	1.22	0.12	0.32	0.58	3.81	0.53	0.57	56.10	14.00	29.90	0.61	0.32
K5	969.3	1.17	0.16	0.32	0.59	3.34	0.52	0.63	49.50	24.60	25.90	0.62	0.31
K6	1042.0	1.31	0.16	0.32	0.56	3.49	0.53	0.56	56.10	14.30	29.70	0.62	0.31
K8	1188.7	1.21	0.16	0.31	0.56	3.32	0.55	0.55	55.80	13.90	30.40	0.61	0.30
K10	1335.0	1.17	0.14	0.31	0.56	2.98	0.54	0.57	56.20	13.80	30.00	0.62	0.30
K12	1408.2	1.38	0.14	0.32	0.62	3.46	0.54	0.59	56.00	14.00	30.00	0.61	0.31

3.4 Distribution of steranes

The sterane distributions in the samples follows the order C₂₉ > C₂₇ > C₂₈ (Table 5). Predominance of C₂₉ over C₂₇ sterane reflects a greater input of terrestrial relative to marine organic matter [14, 21]. This is also reflected in the ratio of C₂₇/C₂₉ sterane which ranges from 0.52-0.56 (Table 5). An appreciable quantity of C₂₇ and C₂₈ in these samples also reflects contributions from phytoplankton, algae, diatoms, and dinoflagellates [14]. C₂₉ steranes are considered to be terrestrial plant marker, however can be found in algae species

while C₂₈ steranes are regarded as both algae and terrestrial higher plants indicators and attributed to higher plants indicators while C₂₇ steranes are indicator of zooplankton sources [14, 20]. The distribution of steranes and diasteranes in the samples reflect mixed terrestrial and marine organic input. The sterane ternary plot (Fig. 7) indicates organic matter deposited in terrestrial to estuarine bay depositional environment [21]. The 20S/20S + 20R and αββ/αββ + ααα C₂₉ ratios range from 0.61 to 0.62 and 0.30 to 0.31 respectively (Table 5). These values show that the samples are low mature to marginally mature.

Figure 7: This is a C27-C28-C29 sterane ternary diagram showing depositional environment of the samples

3.5 Polycyclic aromatic compounds

The distributions of naphthalene and its alkyl derivatives as well as phenanthrene and its alkyl derivatives are shown in Fig. 8 and 9 respectively. The notable presence of 1,6-, 1,7-, and 2,6-dimethylnaphthalenes in samples depicts terrestrial organic matter contribution [22-23]. The possible biological precursors of 1,2,5-trimethylnaphthalene and 1,2,5,6-tetramethylnaphthalene are β -amyrin and aromatic seco-hopanes, that are

constituents of angiosperms [24]. Also their source has been related to gymnosperms [25]. 1,2,7-TMN has been related to angiosperm markers [24, 26]. The notable presence of 1,2,5- and 1,2,7-trimethylnaphthalenes as well as 1,2,5,6-tetramethylnaphthalene in all the samples indicate contributions of both angiosperm and gymnosperm materials to the organic matter. Also, the occurrence of 1,2,6-trimethylnaphthalene, 1,2,5,7- and 1,3,6,7-tetramethylnaphthalenes in the samples indicate microbial input to the biomass [26].

Fig. 8: The m/z 128, 142, 156, 170 and 184 showing the distribution of naphthalene, methyl naphthalene, dimethyl naphthalene, trimethyl naphthalene, tetramethyl naphthalene and dibenzothiophene in sample K1

Table 6: Peak identities on m/z128, 142, 156, 170 and 184 mass chromatograms.

Peak	Abbreviation	Compound
A	Naph	Naphthalene
B	1-MN	1-Methylnaphthalene
C	2-MN	2-Methylnaphthalene
D	2-EN	2-Ethylnaphthalene
E	1-EN	1-Ethylnaphthalene
F	2,6 + 2,7-DMN	2,6 + 2,7-Dimethylnaphthalene
G	1,3 + 1,7-DMN	1,3 + 1,7-Dimethylnaphthalene
H	1,6-DMN	1,6-Dimethylnaphthalene
I	2,3 + 1,4-DMN	2,3 + 1,4-Dimethylnaphthalene
J	1,5-DMN	1,5-Dimethylnaphthalene
K	1,2-DMN	1,2-Dimethylnaphthalene
L	1,3,7-TMN	1,3,7-Trimethylnaphthalene
M	1,4,6 + 1,3,5-TMN	1,4,6 + 1,3,5-Trimethylnaphthalene
N	2,3,6-TMN	2,3,6-Trimethylnaphthalene
O	1,2,7 + 1,6,7 + 1,2,6-TMN	1,2,7 + 1,6,7 + 1,2,6-Trimethylnaphthalene
P	1,2,4-TMN	1,2,4-Trimethylnaphthalene
Q	1,2,5-TMN	1,2,5-Trimethylnaphthalene
R	1,3,5,7-TeMN	1,3,5,7-Tetramethylnaphthalene
S	1,3,6,7-TeMN	1,3,6,7-Tetramethylnaphthalene
T	1,2,4,6 + 1,2,4,7 + 1,4,6,7-TeMN	1,2,4,6 + 1,2,4,7 + 1,4,6,7-Tetramethylnaphthalene
U	1,2,5,7-TeMN	1,2,5,7-Tetramethylnaphthalene
W	2,3,6,7-TeMN	2,3,6,7-Tetramethylnaphthalene
X	1,2,6,7-TeMN	1,2,6,7-Tetramethylnaphthalene
Y	1,2,3,7-TeMN	1,2,3,7-Tetramethylnaphthalene
Z	1,2,3,6-TeMN	1,2,3,6-Tetramethylnaphthalene
Z*	1,2,5,6 + 1,2,3,5-TeMN	1,2,5,6 + 1,2,3,5-Tetramethylnaphthalene
	DBT	Dibenzothiophene

In all the samples, 9- methylphenanthrene (9-MP) predominates (Table 8) among the methylphenanthrenes indicating a presence of marine organic matter, though with a significant contribution from 1-MP, which is a terrestrial marker and also indicate low-medium thermal maturity [27], consistent with the observation based on tetramethylnaphthalene ratio (TeMNR). The dimethylphenanthrenes (DMPs) are dominated by 1,3-, 3,9-, 2,10-, 3, 10-, 2,5-, 2,9- and 1,6-DMP indicating presence of marine organic matter. On the other hand, notable presence of 1,7-DMP (pimanthrene) implies a significant contribution of terrestrial material [14]. Distribution of trimethylphenanthrenes (TMPs) also suggests mixed marine/terrestrial source due to substantial contribution of 1,3,7-, 1,3,6- and 1,6,9-TMPs, as well as 1,2,6-TMP [14]. The presence of 1,2,8-TMP isomer could

be related to bacterial, algal or terrestrial precursor material [14].

Low amount of dibenzothiophene to phenanthrene (DBT/P) ratio (0.11-0.19) (Table 8) indicates that organic matter is predominantly deposited in lacustrine or marine environment [28]. The cross plot of dibenzothiophene/phenanthrene (DBT/P) versus pristane/phytane in Fig.10 shows that organic matter of the studied samples plotted in zone 3, representing marine shale and other lacustrine depositional environment.

Various maturity parameters calculated from the distributions of naphthalene and their alky derivatives (ENR and TeMNR) in samples presented in Table 8 range from 2.03-2.58 and 0.44-0.47 respectively. The alkylphenanthrene maturity ratios, MPR-1, MPI-1, MPI-1* and %RcMPI-1 range from 1.28-1.33, 0.67-0.75, 0.75-0.82 and 0.80-0.85 respectively. The values obtained indicating that the samples are low mature to early stage of oil window.

Fig. 9: The m/z 178, 192, 208 and 220 showing the distribution of phenanthrene methylphenanthrene, dimethylphenanthrene and trimethylphenanthrene in sample K1

Table 7: Peak identities on m/z 178, 192, 208 and 220 mass chromatograms

Peak	Compound
1	Phenanthrene
2	3-Methylphenanthrene
3	2-Methylphenanthrene
4	9-Methylphenanthrene
5	1-Methylphenanthrene
6	3-Ethylphenanthrene
7	9-Ethylphenanthrene+ 1-Ethylphenanthrene+ 2-Ethylphenanthrene+3,6-Dimethylphenanthrene
8	3,5+2,6-Dimethylphenanthrene
9	2,7-Dimethylphenanthrene
10	1,3+3,9+2,10+3,10-Dimethylphenanthrene
11	2,5+2,9+1,6-Dimethylphenanthrene
12	1,7-Dimethylphenanthrene
13	2,3-Dimethylphenanthrene
14	1,9+4,9+4,10-Dimethylphenanthrene
15	1,8-Dimethylphenanthrene
16	1,2-Dimethylphenanthrene
17	1,3,6 + 1,3,10 + 2,6,10-Trimethylphenanthrene
18	1,3,7+2,6,9+2,7,9-Trimethylphenanthrene
19	1,3,9+2,3,6-Trimethylphenanthrene
20	1,6,9+1,7,9+2,3,7-Triimethylphenanthrene
21	1,3,8-Trimethylphenanthrene
22	2,3,10-Triimethylphenanthrene
23	UNKNOWN
24	1,6,7-Trimethylphenanthrene
25	1,2,6- Trimethylphenanthrene
26	1,2,7-Trimethylphenanthrene
27	1,2,8-Trimethylphenanthrene

Table 8: Source and Thermal Maturity Ratios based on Aromatic compounds

Sample	Depth(m)	1-MP/9-MP	DBT/P	MPR-1	MPI-1	MPI-1*	%RcMPI-1	ENR	TeMNR
K1	731.5	0.59	0.11	1.28	0.69	0.76	0.8	2.36	0.44
K6	1042.0	0.59	0.13	1.31	0.67	0.75	0.8	2.03	0.45
K12	1408.2	0.6	0.19	1.33	0.75	0.82	0.85	2.58	0.47

ENR= 2-EN/1-EN; MPR-1=2-MP/1-MP; MPI-1= 1.5[2-MP+3-MP]/ 0.69[P+1-MP+9-MP]; MPI-1*= 1.89 [2-MP+3-MP]/ P+1.26 [1-MP+9-MP] ; %R_c MPI= 0.6[MPI-1] + 0.4; TeMNR = 1,3,6,7-TeMN/ [1,3,6,7+1,2,5,6+1,2,3,5-]TeMN

Fig. 10: Cross plot of dibenzothiophene/phenanthrene (DBT/P) vs Pristane/Phytane (Pr/Ph) of the samples

Conclusion

All the samples were plotted along the type II/III evolution pathway indicated that the organic matter contained in the samples are formed from both terrestrial and marine settings and suggest that the source rocks are capable of generating both oil and gas. The B/F ratio values (0.98-1.00) indicated that aliphatic content in all the samples are high hence, suggests that samples have potential to generate oil and gas.

The n-alkane distributions in the samples range from C₁₁-C₃₂ maximizing at C₁₆, Pr/Ph ratio (1.49-1.92), there is abundant hopanes, homohopanes and predominant C₂₈, C₂₉ regular and rearranged steranes. These indicated a significant contribution of prokaryotic organisms to the source of organic matter and also showed that the organic matter contained in the samples has mixed marine/terrestrial input.

The notable presence of 1,2,5-, 1,2,6-, and 1,2,7-trimethylnaphthalenes, as well as 1,2,5,6-, 1,2,5,7-, 1,3,6,7-tetramethylnaphthalenes in the samples

indicate angiosperm, gymnosperms and microbial input. The predominance of 9-methylphenanthrene depicts presence of marine organic matter, while the occurrence of 1,2,8-trimethylphenanthrene reflects contribution from bacteria, algal or terrestrial materials.

The cross plot of dibenzothiophene/phenanthrene (DBT/P) versus pristane/phytane shown that organic matter of the studied samples was plotted in zone 3, representing marine shale and lacustrine depositional environment.

Various maturity parameters computed from biomarkers and polyaromatic hydrocarbon show that the lower part of Gombe formation is low-mature. However, moderately mature zone can be found at the bottom of the formation and therefore can serve as a potential source-rock in Kolmani River-1.

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