The assessment of potential source rocks of Maastrichtian Araromi formation in Araromi and Gbekebo wells Dahomey Basin, southwestern Nigeria

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A B S T R A C T

Drilled core samples of the Araromi Formation in the eastern Dahomey basin penetrated by Araromi and Gbekebo exploratory wells were investigated to establish the source rocks potentials in the onshore area of the basin. The sediments are of Maastrichtian age deposited in the shallow marine environment with varying thicknesses. Rock-Eval data of forty seven (40) shales give Total Organic Carbon (TOC) range of 0.50–4.78wt%, Hydrogen Index (HI) value range of 1 - 327mgHC/gTOC, T_max values from 398 °C-437 °C and Source Potential (SP) values range from 0.01 - 14.56kgHC/ton of rock. The maceral compositions of the shales are liptinite (av. 26.0%), abundance vitrinite (av. 38.1%) and inertinite (av. 35.9 %) with vitrinite reflectance (VRo) ranging from 0.51 - 0.68%Ro. Hydrocarbons and biomarkers results reveal a bimodal n-alkane envelope between (nC16 and nC18) and (nC27 and nC29) suggesting organic matter of mixed origin of algae and higher plant generally in the two well. The significant contribution of marine algae in the deeper part of Gbekebo well was observed by the presence of C30 24-n-propyl cholestane (%C30 sterane range from 0.45 to as high as 5.23%). Integration of the Rock-Eval, organic petrology and biomarkers data reveal that the kerogen constituents of the source rocks in Araromi well are mainly Type II/III, III and IV with a high amount of inertinite constituents suggesting they have been reworked. Type II and II/III kerogen derived from marine algae are better preserved in the deeper part of Gbekebo well located more southerly in the basin than in the Araromi well. The source rocks are generally immature to marginally mature and hydrocarbon exploration effort should be targeted towards Gbekebo well area where we have more promising potential source rocks capable of generating more hydrocarbons essentially at a deeper depth.

1. Introduction

The Dahomey Basin is an extensive sedimentary basin, in the Gulf of Guinea which extends from southeastern Ghana through Togo and Benin Republic on the west side to the Okitipupa ridge/Benin Hinge line on the east side in the southern, part of Nigeria Brownfield and Charpentier (2006) Fig. 1. The basin evolution involved basement fragmentation, block faulting and subsidence of the Jurassic basement complex couple with wrench movements of the basement blocks Omuoha and Ofogbe (1988), De Matos and Renoato (2000), Arthur et al. (2003). The basin consists of sedimentary formations (Cretaceous —Tertiary) that outcrop in an arcuate belt roughly parallel to the coastline Omatsoila and Adegoke (1981). This basin has attracted a lot of geoscientific interest, especially in the recent years in view of the availability of the new boreholes and recent road cuts which have improved the knowledge of its geology and hydrocarbon potential assessment.

The analysis of sedimentary basins is of great geoscientific interest, in the world today particularly in areas where there are potentials for hydrocarbon occurrence. The Dahomey basin is generally a combination of inland, coastal, offshore basin that is located in the Gulf of Guinea (Fig. 1). It is separated from the Niger Delta, Nigeria by a subsurface basement high referred to as the Okitipupa Ridge (Omatsoila and Adegoke, 1981) and its offshore extent is poorly defined. Sediment deposition in the basin follows an east-west trend with about Cretaceous strata thickness around 200 m thick in the onshore area where the studied wells are located (Okosun, 1990).
In the recent time, hydrocarbon exploration in Lagos, eastern Dahomey Basin in Nigeria and Tano Basin in Ghana which is presently producing oil is becoming more attractive to investors and thereby increasing motivation for intense study of the basin. This study aimed at examining the hydrocarbon potentials of the sediments in the post Santonian successions penetrated by the Araromi and Gbekebo wells in the northern onshore area of the basin (Fig. 2). The drill core samples used in this study were collected from the Geological Survey of Nigeria Agency (GSNA), Kaduna main office.

1. Geology and stratigraphy of Dahomey Basin

The Dahomey Basin evolved in the Late Jurassic - Early Cretaceous as a result of the separation of the Africa and South America plates which led to the opening of South Atlantic Ocean. The Romanche, Chain, and Charcot fractures zone which develops during the drifting stages of South America away from Africa enhances the development of numerous horst and graben features in the Dahomey basin.

The horst and graben structural features control deposition of Cretaceous to Tertiary sediments in the basin Adegoke (1969), Ako et al. (1980), Omatsola and Adegoke (1981), Adediran and Adegoke (1987), Brownfield and Charpentier (2006). The stratigraphic setting of the Dahomey Basin has been described in detail in the works of Adegoke (1969), Ogbe (1970), Kogbe (1974), Billman (1976), Omatsola and Adegoke (1981), Ako et al. (1980), Okosun (1990), Idowu et al. (1993), Adekeye (2004) and Adekeye et al. (2006). These authors reported five lithostratigraphic formations covering the Cretaceous to Tertiary ages. The formation from the oldest to the youngest include: Abeokuta Group comprises Ise, Afowo and Araromi formations (Cretaceous), Ewekoro Formation (Paleocene), Akinbo Formation (Late Paleocene-Early Eocene), Oshosun Formation (Eocene) and Ilaro Formation (Middle-Late Eocene) Fig. 3.

2. Materials and methods

2.1. Hydrocarbon source rock potential

The core samples from the Araromi Formation penetrated by the
Araromi and Gbekebo wells drilled on the eastern margin of the Dahomey Basin (Fig. 2) were analysed for their total organic carbon content (TOC) and hydrocarbon source quality by Rock-Eval Pyrolysis using standard experimental techniques. The Rock-Eval pyrolysis was carried out at the Organic Geochemistry Laboratory of the University of New Castle Upon Tyne following the standard procedure of Rock-Eval pyrolysis experimentation on Rock-Eval II machine. The Rock-Eval II analysis has the ability of measuring the total organic carbon (TOC) content on the pulverized samples at elevated temperatures of ca. 600 °C (Espitalie et al., 1977). Pyrolysis of 10–40mg of samples at 300 °C for 4 mins was followed by programmed pyrolysis at 25 °C/min to 550 °C in an atmosphere of helium. The parameters assessed from Rock-Eval Pyrolysis include Source Potential (SP), Genetic Potential (S1 + S2), Thermal Maturity of the organic matter (TMax), Total Organic Carbon content (TOC), Hydrogen Indices (HI) and Productive Index (PI).

Fig. 3. Generalised stratigraphic setting of the Dahomey Basin in the southwestern Nigeria.

Bitumen extracts from selected organic-rich source rock samples were analysed for their biomarker and stable carbon isotope composition of n-alkanes using the GC, GC-MS and GC-MS-MS techniques described below. Gas chromatography was performed on the saturated hydrocarbon fractions in order to obtain n-alkane and isoprenoid data as well as to determine sample concentration and complexity before GC-MS and gas chromatography-isotope ratio mass spectrometry (GC-IRMS) analyses. An HP 5890 series II gas chromatograph equipped with an HP-5 coated capillary column (60 m × 0.25 mm, 0.25μm film thickness) was used. The GC oven was initially set at 50 °C for 2 min and then the temperature was ramped from 50 °C at 4 °C/min to 300 °C and held at final temperature for 20 min with hydrogen as the carrier gas (flow rate approx 2 ml/min and initial pressure of 100 kPa).

The selected shale samples were crushed to less than 2mm and impregnated in epoxy for qualitative reflected light microscopy. Where organic constituents are sparse, kerogen concentrates were prepared, mounted and polished. Organic petrology studies were carried out on a Reichert Jung Polyvar Photomicroscope equipped with halogen and HBO lamps, a photomultiplier and computer unit at the Zentraleinrichtung für Elektronenmikroskopie (ZELMI), Technische Universität Berlin, Germany. Mean random reflectance of vitrinite in oil (Ro%, cf. Bustin et al., 1983) was calculated from the reflectance of at least 30 grains of vitrinite measured in random orientation using monochromatic (546 nm) non-polarised light in conjunction with a x40 oil immersion objective. Calibration of the microscope photometer was achieved using standards of known reflectance (1.23 and 3.16 %). Measured Ro% values of reflectance standards confirmed the photomultiplier to be consistently linear within the range of the measurements. Data collection and evaluation were done using the coal programme by Reichert Jung and macerals were identified through the use of white light and blue light excitation at 546 and 460 nm respectively. The mean reflectance as
compared to the median or modal reflectance appears to be an adequate measure of thermal maturity in this study (Tissot and Welte, 1984; Pol- lastro and Barker, 1986).

3. Results & discussions

3.1. Petroleum potential assessment of the source

The Rock-Eval pyrolysis result is presented in Tables 1 and 2. The various parameters for assessing the hydrocarbon, potential of a source bed are discussed here. The principal parameters discussed, below include: Source Potential (SP), Hydrogen Index (HI), Thermal maturity (Tmax), Kerogen Types and Total Organic Carbon (TOC).

3.2. Organic matter richness

High concentrations of organic matter tend to occur in sediments that accumulate in areas of high organic matter productivity. Environments of high productivity can include nutrient-rich coastal upwelling, swamps, shallow seas and lakes. The total organic matter (TOC) is a direct measurement of the organic matter richness of a given sedimentary rock. It is the measure of the quantity of organic matter (OM) present in a rock. According to North, 1985 the TOC values of any rock can be classified as poor, fair, good, very good and excellent. The analyzed Araromi shale samples from both Araromi and Gbekebo wells have a value range of 0.5–4.78 wt% (Tables 1 and 2), which indicates variable source rock organic carbon quality from poor to excellent. There is an overall trend of increasing TOC down the well (Fig. 4) suggesting better source rock quality from poor to excellent. The analyzed Araromi shale organic matter richness of a given sedimentary rock. It is the measure of the quantity of organic matter (OM) present in a rock. According to North, 1985 the TOC values of any rock can be classified as poor, fair, good, very good and excellent. The analyzed Araromi shale samples from both Araromi and Gbekebo wells have a value range of 0.5–4.78 wt% (Tables 1 and 2), which indicates variable source rock organic carbon quality from poor to excellent. There is an overall trend of increasing TOC down the well (Fig. 4) suggesting better source rock quality in deeply buried intervals. Most of the shales have TOC values >0.5 wt%, the minimum threshold value for hydrocarbon generation in siliciclastic source rock (Peters and Cassa, 1994) suggesting they are fair to good quality source rocks capable of generating hydrocarbon (Tissot and Welte, 1978; Hedberg et al., 1979).

3.3. Hydrogen index (HI)

Hydrogen Index (HI) is proportional to the amount of hydrogen contained in the kerogen and higher HI indicates a good quality of a source rock to generate hydrocarbon. Peters and Cassa (1994) gave geochemical parameters describing kerogen types and the quality in their work. The hydrogen index values of Araromi shales in the two wells vary from 1 - 327mgHC/gTOC (Tables 1 and 2) thus, suggesting source rock quality that spans from poor to good. The HI values ranging from 1 - 45mgHC/g TOC having kerogen Type IV in the upper part of the two wells indicate a highly reworked terrigenically derived OM perhaps in a highly oxic depositional environment. They form inert source which have no potential for hydrocarbon generation. The shales within the shallow upper to the middle part i.e. 200–400 m in Araromi well Fig. 4 and 800–885 m in Gbekebo well Fig. 5 are characterized with HI values of 45–132mgHC/g TOC with kerogen Type III suggest woody or herbaceous organic matter origin having gas prone characteristics. The deeper parts of Gbekebo well from the depth of 887 m have the best source rock quality with HI value ranging from 151 - 327mgHC/g TOC consisting of kerogen Type II and Type II/III oil and gas prone kerogen. The Type II and Type III kerogen apparently increases down-hole profile concomitant with TOC trend in the well logs (Figs. 4 and 5). The trend of increasing HI is also noticeable in Araromi well between 557 and 572 m to be 151 to 202 mgHC/gTOC respectively suggesting that the deeper section of the formation consists more organic-rich successions and thus presumably have greater potential to generate liquid hydrocarbon. Additionally, two organic-rich intervals (A and B) Fig. 5 contain HI values of 327mgHC/g TOC suggesting that more organic-rich strata in the deep offshore where we have the highest sediment thickness in the basin may have greater potential to generate liquid hydrocarbon.

3.4. Thermal maturation

A good match exists between the thermal maturation (Tmax) measured from the Rock-Eval pyrolysis which varies from 398 °C to 437 °C and the vitrinite reflectance values varying from 0.50 to 0.68 %Ro. These values suggest that the source rocks are thermally immature to marginally mature for hydrocarbon generation. The plots of Rock-Eval Tmax against hydrogen index also show thermally immature to early mature source rocks with respect to hydrocarbon generation and dominance of a mixture of oil prone Type II and gas prone Type III kerogens (Fig. 6).

Table 1

| Sample No | Depth (m) | Location | Fm | S1 (mgHC/grock) | S2 (mgHC/grock) | SP (kg/t) | Tmax (°C) | PI | VRo (%) | TOC (wt%) | HI (mgHC/grock) | Kerogen Type |
|-----------|-----------|----------|----|----------------|----------------|----------|-----------|----|---------|-----------|-----------------|--------------|
| Ar-91     | 405.38    | Araromi  | B1 | 0.02           | 0.01           | 0.03      | 403       | 1.00 | 0.51    | 0.65      | 1               | IV            |
| Ar-97     | 435.86    | Araromi  | B1 | 0.05           | 0.10           | 0.15      | 419       | 0.36 | -       | 0.61      | 16              | IV            |
| Ar-100    | 454.46    | Araromi  | B1 | 0.05           | 0.10           | 0.15      | 412       | 0.36 | -       | 0.75      | 13              | IV            |
| Ar-105    | 463.29    | Araromi  | B1 | 0.04           | 0.05           | 0.09      | 410       | 0.50 | -       | 0.66      | 7               | IV            |
| Ar-110    | 475.49    | Araromi  | B1 | 0.17           | 0.95           | 1.12      | 424       | 0.15 | -       | 1.69      | 56              | III           |
| Ar-114    | 487.68    | Araromi  | B1 | 0.11           | 0.57           | 0.68      | 428       | 0.16 | -       | 1.05      | 54              | III           |
| Ar-119    | 495.30    | Araromi  | B1 | 0.15           | 0.75           | 0.87      | 422       | 0.17 | -       | 1.77      | 40              | IV            |
| Ar-124    | 505.36    | Araromi  | B1 | 0.18           | 0.54           | 0.72      | 420       | 0.25 | -       | 1.19      | 45              | III           |
| Ar-132    | 518.16    | Araromi  | B1 | 0.08           | 0.26           | 0.34      | 409       | 0.24 | -       | 1.02      | 25              | IV            |
| Ar-139    | 539.49    | Araromi  | B1 | 0.08           | 0.18           | 0.26      | 411       | 0.31 | 0.51    | 1.01      | 17              | IV            |
| Ar-145    | 557.78    | Araromi  | B1 | 0.21           | 3.10           | 3.31      | 423       | 0.06 | 0.66    | 2.05      | 151             | II-III        |
| Ar-148    | 566.93    | Araromi  | B1 | 0.28           | 5.18           | 5.46      | 424       | 0.05 | -       | 2.75      | 188             | II-III        |
| Ar-151    | 572.72    | Araromi  | B1 | 0.52           | 3.70           | 4.22      | 426       | 0.12 | -       | 1.83      | 202             | II-III        |

Depth (m), Formation-Fm, S1-(mgHC/grock), S2-(mgHC/grock), SP-(kg/t), Tmax - °C, VRo-%, TOC - wt%, HI-(mgHC/grock).
A high S1 values commonly result from either potential or effective source rocks or rocks containing migrated oil or contaminated by drilling additives. Similarly, samples with migrated oil or drilling additives are readily distinguished from source rocks by anomalously high production indices (PI) for their level of thermal maturity (Espitalie et al., 1985; Huizinga et al., 1988). Source rocks having Tmax ranging 390–435 °C with PI ≤ 0.1, Tmax ranging 436–445 °C, with PI ≤ 0.3 and Tmax ranging 445–460 °C, with PI ≤ 0.4 are categorized as samples not contaminated by drilling additives or migrated oil (Espitalie et al., 1985; Huizinga et al., 1988). The production indices of the source rocks in Gbekebo indicate that the potential source rock intervals (A and B) are immature (Figs. 4 and 5). The shales in the entire shallow intervals of Gbekebo and Araromi wells which are immature but have high production indices that commonly suggest a significant hydrocarbon potential are interpreted as being stained or impregnated with migrated oil (Figs. 4 and 5).

### 3.5. Source potential (SP)

The source potential is calculated from the addition of S1 + S2 values and is a measure of the genetic potential of the rock. This is regarded as the total amount of petroleum that might be generated from a rock. This potential usually depends on the nature and abundance of kerogen, which in turn are related to the original organic input at the time of sediment deposition and to the conditions of microbial degradation and rearrangement of the organic matter in the young sediments. Dymann et al. (1996) gave a standard for SP qualities.
The Source Potential (SP) value ranges from 0.01 - 14.56 kgHC/ton of rock (Tables 1 and 2). The SP values are generally lower than the 2 kgHC/ton of rock expected for good source rock (Dymann et al., 1996), suggesting little or no oil source rock potential but some potential for gas. Samples with higher SP values; Ar 145 (3.31 kgHC/ton), Ar148 (5.46 kgHC/ton), Ar151 (4.22 kgHC/ton), GB455 (11.03 kgHC/ton) and GB456 (14.17 kgHC/ton) of rock suggest a moderate source rock with good oil potential. These source potentials in the Araromi and Gbekebo wells are consistent with the total organic contents and hydrogen index at that basal part indicating zones of the best and highest potential in the study area. Tissot and Welte (1984) also proposed a genetic potential (SP = S1 + S2) for the classification of source rocks. According to their classification scheme, rocks having SP of less than 2 mgHC/g rock correspond to gas-prone rocks or non-generative ones, rocks with SP between 2 mgHC/g and 6 mgHC/g rock are moderate source rocks, and those with SP greater than 6 mgHC/g rocks are good source rocks.

3.6. Maceral analysis

The organic petrological study of the disseminated organic matter in the shale samples was carried out using the techniques in studying optical characteristics of finely dispersed organic matter particles in coals, coaly shales, and carbonaceous shales. Terminologies of Stach et al. (1982) modified in Teichmuller (1987) were used here. Selected shale samples were polished and observed under organic petrological microscope. The different macerals of vitrinite, liptinite, and inertinite were observed. Photomicrographs of representative macerals are shown in Fig. 7. In general, the maceral composition includes liptinite (av. 26.0 %), vitrinite (av. 38.1 %) and inertinite (av. 35.9 %) in all the samples investigated. The dominance of vitrinite and inertinite macerals suggests terrestrially derived, reworked and oxidized organic matter in the shale sediments. There is no particular maceral variation pattern or zonation down deep in all the wells.
3.7. Biomarker compositions of the shales

Drilled core samples analysed by Gas Chromatography (GC) display a bimodal n-alkane GC fingerprint envelope with maxima between nC16 – nC18 and nC27 – nC29 (Fig. 8), suggesting variable inputs from both terrigenous and non-terrigeneous (probably marine algal) organic matter. However, some samples display a unimodal n-alkane GC fingerprint typical of dominantly normal marine algal contribution (maximizing between nC16 and nC18). There is a relatively high input from algal-bacterial precursors indicated by the abundance of the low molecular weight relative to high molecular weight n-alkane derived from terrigenous higher plants (Bray and Evans, 1961). Additionally, Pr/Ph ratios vary from 0.78 - 2.02 reflecting anoxic to sub-oxic source rock depositional environment (Didyk et al., 1978; Volkman and Maxwell, 1986).

Steranes in the saturated hydrocarbon fractions of the bitumen extracts of the Araromi shale samples analyse by GC-MS and GC-MS-MS show the C27 - C29 distributions to be nearing a ratio of 1.1:0.9:1.0, with higher C27 and C28 compounds on occasions relative to the C29 sterane homologues for the 5α(H),14α(H),17α(H) 20R configuration isomers. Figs. 9 and 10 show the sterane distributions of the bitumen extracts from the Araromi shales. The above observation suggests a
relatively higher input from the marine red algae and a low level of land plant contribution to the source organic matter (Goodwin, 1973). Additionally, the presence of the C30 24-n-propyl cholestane (detected by GC-MS-MS m/z 414-217 parent to daughter ion transition), confirms the relatively high marine algal contribution to the organic matter in the Araromi shales, as values of %C30 sterane range from 0.45 to as high as 5.23%, even in oleanane rich intervals in “Zone B” (Fig. 5).

4. Conclusion

The Late Cretaceous Araromi Formation in the Dahomey Basin, southwestern Nigeria has dominant of Type III and reworked organic matter in the shallow part of the studied wells probably as a result of the contribution of more of terrigenous components into the basin. The basal or deeper part of the wells indicate sterane distributions in the shale extracts dominated by C27 relative to C28 and C29 carbon homologues and significant C30 24-n-propyl cholestane concentrations diagnostic of marine algal inputs. The organic constituents suggest more contributions from marine settings at the base of the well than the terrigenous higher plant. They were probably deposited under anoxic to sub-oxic conditions as reflected by Pr/Ph ratios ranging from 0.78 - 2.02. The source rocks are predominantly immature to marginally mature at shallow levels particularly in this northern fringe of the basin where Gbekebo and Araromi are located but reaching proven maturity in the subsurface in the southerly coastal and offshore areas.

There are indications of migrated hydrocarbons in some parts of the Araromi Formation even though its potential source rocks are immature. The Araromi shales have predominantly gas resources and exploration efforts should be targeted toward where the more promising potential source rocks capable of generating hydrocarbons are deeply buried.

Declarations

Author contribution statement

Olabisi A. Adekeye: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Samuel O. Akande: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

James A. Adeoye: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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**Competing interest statement**

The authors declare no conflict of interest.

**Additional information**

No additional information is available for this paper.

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**References**

Adediran, S.A., Adegoke, O.S., 1987. Evolution of the sedimentary basins of the Gulf of Guinea. In: Current Research in Africa Earth Sciences, Mathis and Schandelmeier. Balkema, Rotterdam, pp. 283–286.

Adegoke, O.S., 1969. Eocene stratigraphy of southern Nigeria. Mem. Bur. Rech. Geol. Mins. 23–46.

Adekeye, O.A., 2004. Aspects of Sedimentology, Geochemistry and Hydrocarbon Potential of Cretaceous-Tertiary Sediments in the Dahomey Basin, South-Western Nigeria. Unpublished Ph.D thesis, University of Ilorin, 202p.

Adekeye, O.A., Akande, S.O., Erdtman, B.D., Samuel, O.J., Hetenyi, M., 2006. Hydrocarbon potential assessment of the upper Cretaceous-Lower Tertiary sequence in the Dahomey basin South-western Nigeria. NAPE Bulletin 19 (1), 50–60.

Ako, B.D., Adegoke, O.S., Petters, S.W., 1980. Stratigraphy of the Oshoun Formation in South-western Nigeria. J. Min. Geol. 17, 97–106.

Arthur, T.J., MacGregor, D.S., Cameron, N.R., 2003. Petroleum Geology of Africa—New Themes and Developing Technologies. Geological Society, London. Special Publication p. 207, 289.

Billman, H.G., 1976. Offshore stratigraphy and paleontology of the Dahomey embayment. Proc. 7th Afri. Micropal. Coll. Ile-Ife 27–42.

Brownfield, M.E., Charpentier, R.R., 2006. Geology and Total Petroleum Systems of the Gulf of Guinea Province of West Africa: U.S Geological Survey Bulletin 2207-C, 32p.

Bustin, R.M., Cameron, A.R., Greve, D.A., Kalkreuth, W.D., 1983. Coal petrology: its principles, methods and applications. Geol. Assoc. Canada Short Course Notes 3, 230p.

De Matos, D., Renato, M., 2000. Tectonic evolution of the equatorial South Atlantic. In: Atlantic Riffs and Continental Margins. American Geophysical Union. Geophys. Monogr. Ser., v. 115, p. 331 - 354.

Didyk, B.M., Simonetti, B.R.T., Brassell, S.C., Eglington, G., 1978. Organic geochemical indicator of paleoenvironmental conditions of sedimentation. Nature 272, 216–222.

Dymann, T.S., Palacios, J.G., Tysdal, R.G., Perry, W.J., Pawleswia, M.J., 1996. Source rock potential of middle Cretaceous rocks in southwestern Montana. AAPG (Am. Assoc. Pet. Geol.) Bull. 80, 1177–1184.

Espitalié, J., Deroo, G., Marquis, F., 1985. La pyrolyse Rock-Eval et ses applications (deuxième partie). Revue Institut Français du Pétrole 40, 755–784.

Espitalié, J., Madec, M., Tissot, B.P., Menning, J.J., Leplat, P., 1977. Source rocks characterization method for exploration. In: Offshore Technology Conf. Paper 2935, 11th Annual OTC, Houston, 3, pp. 439–444.

Goodwin, T.W., 1973. Comparative biochemistry of sterols in eukaryotic microorganisms. In: Erwin, J.A. (Ed.), Lipids and Biomembranes of Eukaryotic Microorganisms. Academic Press, New York, pp. 1–40.

Hedberg, H.D., Moody, J.O., Hedberg, R.M., 1979. Petroleum prospects of deep offshore. AAPG Bull. 63, 286–300.

Huizinga, B.J., Aizensthat, Z.A., Peters, K.E., 1988. Programmed pyrolysis-gas chromatography of artificially matured Green River kerogen. J. Energy Fuel. 74, 74–81.

Idowu, J.O., Ajiboye, S.A., Ilesanmi, M.A., Tanimola, A., 1993. Origin and significance of organic matter of Oshoun Formation south-western Dahomey basin Nigeria. J. Min. Geol. 29, 9–17.

Kogbe, C.A., 1974. Paleo-ecologic significance of vertebrate fossil in the Dukumaje and Dange formations (Maastrichtian and Paleocene) of northwestern Nigeria. J. Min. Geol. (Nigeria) 8, 49–55.

Ogbe, F.A.G., 1970. In: Dessauvage, T.F.J., Whiteman, A.J. (Eds.), Lipids and stratigraphy of strata exposed in the Ewekoro quarry western Nigeria. African Geology University of Ibadan Press, Nigeria, pp. 305–324.

Okozun, E.A., 1990. A review of the Cretaceous stratigraphy of the Dahomey embayment, West Africa. Cretac. Res. 11, 17–27.

Omatola, M.E., Adegoke, O.S., 1981. Tectonic evolution and Cretaceous stratigraphy of the Dahomey basin. J. Min. Geol. 8, 130–137.

Omotsola, M.E., Adegoke, O.S., 1980. Tectonic evolution and Cretaceous stratigraphy of the Dahomey basin. J. Min. Geol. (Nigeria) 8, 49–55.

Omosha, K.M., Onofegb, C.O., 1988. Subsidence and evolution of Nigeria’s continental margin: implications of data from Afowo-1 well. Mar. Petrol. Geol. 5, 175–181.

Peters, K.E., Cassa, M.R., 1994. Applied source rock geochemistry. In: Maugon, L.B., Dow, W.G. (Eds.), The Petroleum System From Source to Trap. AAPG Memoir, vol. 60, pp. 93–117.

Pollastro, R.M., Barker, C.E., 1986. Application of Clay Mineral, Vitritinite Reflectance and Fluid Inclusion Studies to the Thermal and Burial History of the Pinedale Anticline, Green River basin, Wyoming. 28. SEPM Special Publication, pp. 73–83.

Stach, E.M., Mackowsky, T.H., Teichmuller, M., Taylor, G., Chandra, D., Teichmuller, R., 1982. Stach’s Text Book of Coal Petrology. Gerbruder Bormtapge, Berlin, 535p.

Teichmuller, M., 1987. Organic material and very low grade metamorphism. In: Frey, M. (Ed.), Low Temperature Metamorphism. Blackie and Sons Pub, London, pp. 114–161.

Tissot, B.P., Welte, D.H., Hedberg, H.D., Moody, J.O., Hedberg, R.M., 1979. Petroleum prospects of deep offshore. AAPG Bull. 63, 286–300.

Tissot, B.P., Welte, D.H., 1978. Petroleum Formation and Occurrence. Springer-Verlag, New York, 538p.

Westphal, M.E., Barker, C.E., 1986. Application of Clay Mineral, Vitritinite Reflectance and Fluid Inclusion Studies to the Thermal and Burial History of the Pinedale Anticline, Green River basin, Wyoming. 28. SEPM Special Publication, pp. 73–83.

Onuoha, K.M., Ofoegbu, C.O., 1988. Subsidence and evolution of Nigeria’s continental margin: implications of data from Afowo-1 well. Mar. Petrol. Geol. 5, 175–181.

Peters, K.E., Cassa, M.R., 1994. Applied source rock geochemistry. In: Maugon, L.B., Dow, W.G. (Eds.), The Petroleum System From Source to Trap. AAPG Memoir, vol. 60, pp. 93–117.

Pollastro, R.M., Barker, C.E., 1986. Application of Clay Mineral, Vitritinite Reflectance and Fluid Inclusion Studies to the Thermal and Burial History of the Pinedale Anticline, Green River basin, Wyoming. 28. SEPM Special Publication, pp. 73–83.

Stach, E.M., Mackowsky, T.H., Teichmuller, M., Taylor, G., Chandra, D., Teichmuller, R., 1982. Stach’s Text Book of Coal Petrology. Gerbruder Bormtapge, Berlin, 535p.

Teichmuller, M., 1987. Organic material and very low grade metamorphism. In: Frey, M. (Ed.), Low Temperature Metamorphism. Blackie and Sons Pub, London, pp. 114–161.

Tissot, B.P., Welte, D.H., 1978. Petroleum Formation and Occurrence. Springer-Verlag, New York, 538p.

Tissot, B.P., Welte, D.H., 1984. Petroleum Formation and Occurrence, second ed. Spinger-Verlag, Berlin. 699p.

Volkman, J.K., Maxwell, J.R., 1986. Acyclic isoprenoids as biological markers. In: Johns, R.B. (Ed.), Biological Markers in Sedimentary Record. Elsevier, New York, pp. 1–42.