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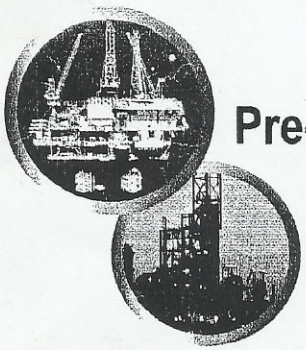

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THEME:

Nigeria Oil and Gas Exploration: The Next Frontier

The Cenomanian - Turonian Successions in The Benue Trough and Dahomey Basin, Nigerian: Petroleum Potential Evaluation from New Source Rock Data

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ABSTRACT

The Benue Trough and Dahomey Basin form part of the West Africa rift basins with potential source rocks for hydrocarbons. The Cenomanian to Turonian shales of Afowo, Eze-Aku and Yolde formations in the Dahomey, Abakaliki and Upper Benue Basins respectively were investigated and correlated. The Afowo and Eze-Aku shales consists of similar and high diversity of planktonic foraminifera including *Heterohelix globulosa, Heterohelix cenomana, Rotalipora greenhornensis, Hedbergella planispira, Whiteinella archaeocretacea* and very rare benthic forms. This assemblage is compared with those of Yolde shales with a predominance of benthic foraminifera including Ammobaculites sp, Bolivina sp and few planktonic forms. The foraminifera assemblage in the Afowo and Eze-Aku shales confirm that they were deposited within the neritic to upper bathyal (ca. 300m) with high productivity of organic matter of anoxic environment whereas the Yolde shales reflect a shallow marine environment.

Geochemical data shows that Afowo shales have an average value of 1.1wt% TOC, 525mgHC/gTOC HI, 0.82% VRom and 369oC Tmax, the Eze-Aku shales have 4.1wt% TOC, 333mgHC/gTOC HI, 0.5% VRom and 427oC Tmax while Yolde shales have 0.4wt% TOC, 108mgHC/gTOC HI, 0.5% VRom and 435°C Tmax. The Afowo and Eze-Aku shales consist essentially of Type II, II-III oil and gas prone kerogen while the Yolde shales consist of Type III gas prone kerogen. The Afowo and Eze-Aku shales are therefore classified as very good petroleum source rocks with high potential for oil and gas while Yolde shales are marginally mature with fair potential for gas generation.

This work reveals that the global tectonic Cenomanian – Coniacian eustatic sea level (Oceanic Anoxic Event-2) extended into the Dahomey and Abakaliki basins which conforms the potential of a Cretaceous Petroleum System in the Dahomey and Southern Benue Trough.

Keywords: Cenomanian, Turonian, Abakaliki and Dahomey Basin, Paleoenvironments, Source rock, OAE-2

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INTRODUCTION

The Dahomey and Abakaliki Basins were parts of the basins formed as a result of rifting in the Early Cretaceous in West Africa. These Cretaceous rift basins in offshore Ivory Coast, Ghana, Central African Niger, Chad and Sudan have hydrocarbon potential source rocks within the Albian to Coniacian time interval (Brownfield and Charpentier, 2006). Marine incursion into these basins deposited sediment rich in organic matter for hydrocarbon generation. The transgressions were in three stages which are the Albian-Cenomanian, Cenomanian to Coniacian and Campanian to Maastrichtian. The second transgression is the full marine incursion that cut across the Dahomey Basin and the whole Benue Trough in the Cenomanian to Turonian time. Despite earlier reports on the hydrocarbon potentials, the regional correlation of paleoenvironments and geochemical characteristics of the Cenomanian - Turonian source rock across these basins have not been carried out apart from those reported in the Abakaliki basin and the Calabar flank (Ehinola et al 2003, 2004). A regional correlation of these potential source rocks across the Dahomey and the Benue Basins is the focus of this study.

GEOLOGICAL SETTINGS

In the Late Jurassic to the Early Cretaceous, separation of South America and Africa plate was initiated as a result of crustal uplift, doming and subsidence. This led to the formation of the Dahomey Basin and Benue Trough (Benkhelil, 1989 and Omatsola and Adegoke, 1981). The tectonic evolution, paleothermometric, paleontology and geochemical investigations of parts of the Benue Trough and Dahomey Basin have been reported by several authors e.g. Adegoke, (1969), Omatsola and Adegoke, (1981), Petters and Ekweozor, (1982a,b), Ekweozor and Unomah, (1990), Unomah and Ekweozor, (1993) Gebhardt, (1997), Akande et al, (1998), Adekeye et al., (2006), Akande et al., (2012).

The development of horsts and grabens controlled deposition of immature thick clastic sediments of the Ise Formation in a fresh water intracratonic Dahomey Basin in the Neocomian before the opening of the Gulf of Guinea and incursion of the South Atlantic Ocean. This is overlain by evaporites and some paralic sequence which marked the top of the Ise Formation and as well the beginning of marine incursion into the basin. In the Abakaliki Basin, the Asu River Group represented the beginning of sedimentation by the first marine incursion of the Albian – Cenomanian and the flood stoped at the

middle Benue Trough. The second marine transgression flooded the whole Dahomey Basin and Benue Trough. Sedimentation of Afowo Formation which overlain the Ise Formation continued in the Dahomey Basin as well as deposition of the Eze-Aku Formation which are essentially shales and sandstones in the Abakaliki Basin. Overlying the Afowo Formation is the Araromi shale and limestone which is the third member of Abeokuta Group. The Awgu Formation conformably overly the Eze-Aku Formation and it consists of limestone bands within black shales. There is a wide spread interruption of sedimentation succeeding the deposition of the Awgu sediments and was succeeded by compressional deformation and magmatism in Benue Trough in the Santonian.

MATERIALS AND METHODS

Fifteen (15) ditch cuttings of the Afowo Formation from an exploratory well offshore Dahomey Basin, seven (7) samples of outcropping shales of the Eze-Aku Formation, six (6) outcrop and fifteen (15) ditch cutting samples of the Yolde shales were analyzed. Fresh samples were carefully collected to prevent them from being contaminated by the weathered one. Leco analyser was used to determine the TOC and Rock-Eval pyrolysis (Espitalie et al., 1984) at the Weatherford Commercial Laboratories, Shenandoah, Texas, USA. The shale samples were further subjected to maceral analysis. Their vitrinite reflectance was measured at the Zentraleinrichhtung fur Elektronenmihroskopie (ZELMI) Technical University of Berlin, Germany. A total of twelve (18) shale samples from the Afowo and Eze-Aku and Yolde Formations were sun dried, digested and washed for foraminifera study. The foraminifera species were identified, picked and described with the aid of binocular microscope in the Department of Geology, University of Ilorin. The different species identified and selected were photographed with the Scanning Electron Microscope at Johan Wolfgang Goethe, University, Frankfurt, Germany.

RESULTS

Rock-Eval Pyrolysis

TOC values of the Afowo shales range from 0.64 - 2.31 wt% averaging 1.07 wt%, HI values range from 331 – 667 mgHC/gTOC averaging 525 mgHC/gTOC, Tmax range from 350 – 424 °C averaging 369.1°C, vitrinite reflectance values range from 0.68 – 0.95% with mean value of 0.82% and the source potential ranges from 3.74-13.1 kgHC/t averaging 6.52kgHC/t of rock.

The Lokpanta Shale have TOC value ranging from 3.5 – 5.47 wt% averaging 4.07 wt% and this is similar to that of Ekweozor and Unomah, (1990) where they classified the Lokpanta shale as an oil shale. HI ranges from 237 – 387mgHC/gTOC averaging 332.9mgHC/gTOC, Tmax ranges from 424 – 430°C averages 427°C, vitrinite reflectance ranges from 0.43 to 0.58% averaging 0.5% and source potential ranges from 9.04 – 26.46kgHC/t rock with mean value of 16kgHC/t rock.

The Yolde Shale have TOC values ranging from 0.05 - 0.63wt% with mean value of 0.29wt% TOC. This TOC value is identical to the 0.13wt% TOC value of the outcropping Yolde shales reported by Abubakar et al., (2008). However, in the Nasara-1 well, the Yolde shales have an average TOC value of 0.6wt% slightly higher than the minimum threshold value for a potential source rock. The Hydrogen Index in the Yolde shales, ranges between 20-200mgHC/g TOC with average of 108mgHC/g TOC Akande et al., in preparation. The Yolde Shale is marginally mature with average Tmax of 435°C.

Maceral Data

The ratios of the average values of the Vitrinite (V), Liptinite (L) and Inertinite (I) maceral constituents (V:L:I) in the Lokpanta Shale, Afowo Shale and Yolde Shale are 55.1:37:7.9, 55.6: 18: 26.4 and 53.4:22.6:24. The dominant maceral is the vitrinite maceral in the entire samples with exceptional high percentage of liptinite in the Afowo and Lokpanta shales. Lamalginites are the dominant constituents of the liptinite maceral types in both the Afowo and Lokpanta shales. These data agree with the maceral composition earlier reported by Akande et al., 1998.

Thermal Maturity

Tmax is the temperature at which the maximum release of hydrocarbons from the cracking of kerogen occurs during pyrolysis (top of S2 peak) and an indication of the stage of maturation of the organic matter.

Reflectivity of maceral in organic matter generally increases with temperature and time. This is an empirical relationship which has also been noted between vitrinite reflectance and hydrocarbon generation. Crude oil generation occurs for VRom values between 0.6 and 1.5. Gas generation takes place between a VRom of 1.5 and 3.0 (Dow and O'Conor, 1979). The Afowo shale has Tmax value ranging from 350 – 424°C with mean value of 369.1°C and vitrinite reflectance range from 0.68 – 0.95% with mean value of 0.82%. The Lokpanta shale has Tmax value ranging from 424 - 430°C with mean value of 427°C and vitrinite reflectance value ranging from 0.43 to 0.58% with mean value of 0.5% while the Yolde shale has Tmax value ranges between 426 – 445°C with average value 434°C. The Afowo and Lokpanta shales are thermally immature to early mature while the Yolde shales are marginally mature. See Fig. 1 below.

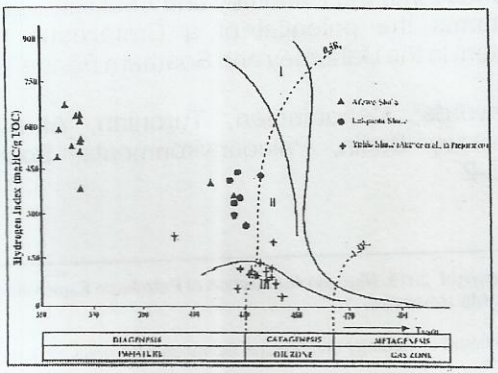

Fig. 1: HI against Tmax for the interpretation of kerogen types and maturity of the Afowo and Lokpanta Shales

Paleontological Data

In the X-well, the Afowo Formation is highly fossiliferous. There is abundance of planktonic foraminifera species representing almost 98% occurrence with rare benthic forms. The species identified are *Rotalipora greenhornensis, Hedbergella trocoidea, Hedbergella planispiral, Whiteinella inornata, Heterohelix globulosa, and Heterohelix moremani.* Likewise in the outcrop Eze-Aku shale, foraminifera present are essentially planktonic and of about 99% occurrence with rare benthic forms. The identified species are *Hedbergella planispira, Whiteinella archaeocretacea, Hedbergella delrioensis, Heterohelix moremani, and Heterohelix cenomana,* with an association of Algae and Coccolithes,. Benthic foraminifera constitute the foraminifera species found in the Yolde shale with only very few planktonic forms. The benthic represent about 95% in the samples. The benthic foraminifera identified are *Ammotium sp, Bolivina sp, Lenticulina sp, Gavelinella sp, and planktonic foraminifera Heterohelix reymenti. The Heterohelix Pulchra and whiteinella archaeocretacea Afowo* and Lokpanta shale in this study are good marker for Early Turonian (Enhiola et al., 2003) and on this basis classified the shales as Early Turonian in age.

DISCUSSIONS AND CONCLUSIONS

In the past, several authors have attempted interpretation of paleoenvironment based on the exclusive use of planktonic foraminifera (Eicher and Worstell, 1970, and Gebhardt, (1997, 2004)). The planktonic foraminifera have a floating habit and lives in the water column above the bottom waters and may be attached to other organisms such as algae as observed in the Lokpanta Shale. Planktonic population changes with latitude, water depth and change in salinity from one water to another. Bandy and Arnal, (1960) established that planktonic foraminifera are stenohaline and typically marine organism abundant in many ocean areas of the world where the surface salinity values generally fall within range of 34 and 37 (o/oo). The paleoecology of the Afowo and Eze-Aku

Formations were therefore interpreted on the basis of the occurrences of planktonic foraminifera. The Afowo and Lokpanta shales contain planktonic foraminifera species with about 99% abundance and diversity thereby signifying deep water marine environment (upper to middle bathyal environment of not deeper than 250m) associated with high organic matter productivity and a sustained anoxic environment.

The Afowo and Lokpanta shales are excellent source rocks with sufficiently good organic carbon contents above 1.0wt%. The 332.9 and 525mgHC/gTOC average Hydrogen Index value of the Afowo and Lokpanta shales respectively and high occurrence of liptinite maceral constituents indicates they consist essentially of Type II, II-III oil and gas prone kerogen. This is also significant because it shows that the organic matters are not only land derived but also have marine influence. These shales are at their late immature to early stage of maturity will expel oil at maturity. The low Tmax value of the Afowo Shale may be due to the confirmed oil stains believed to have been generated and expelled at deeper subsurface levels of the Cenomanian to Turonian stratigraphic levels in the X-Well. The source potential less than 2kg/t (2000ppm) suggest insignificant oil but some gas potential while rock having greater than 6 kg/t (6000ppm) are classified as good source rock with good potential to generate oil. The Afowo and Lokpanta shales have source potential averaging 6.5 kgHC/t and 16 kgHC/t rocks respectively thereby confirming them to be a potential source rock for oil generation at maturity.

The Yolde shale generally has very low TOC below 0.5wt and couple with dominance of Type II-III and III kerogen and will generate only gas at maturity.

The organic matter content in the Afowo and Lokpanta shales correlates with high organic matter productivity and preservation in deep water as inferred from their foraminifera study. These suggest that these shales probably represent a part of the sediments deposited during the worldwide Oceanic Anoxic Event - 2 (OAE-2) at the Cenomanian to Turonian time interval. Similar characteristics were observed in the shales of the Napo Formation, Oriente Basin, Ecuador where the most organic rich layers have approximate modal TOC value of 3wt% deposited in a middle neritic environment during a maximum sea level at the Cenomanian to Turonian interval (Mello et al., 1995). Furthermore, the neighbouring Tano Basin in Ghana has been reported by Michael and Charpentier, 2006 to have a Cretaceous Composite Total Petroleum System which consist essentially source rock of the Albian, Cenomanian and Turonian marine shales with Type II and II-III oil and gas prone kerogen. The Dahomey Basin and Abakaliki Basin sequences are proven from this study to have recorded the black shale source rocks formed during the worldwide anoxic ocean conditions of the Cenomanian to Turonian which is presently responsible for over 1billion barrel of crude oil in Jubilee field of the Tano Basin.

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