

A RESEARCH PROPOSAL

On

**SEDIMENTOLOGICAL, GEOCHEMICAL AND
PETROPHYSICAL-STUDIES OF WELLS IN THE EASTERN
DAHOMY BASIN, SOUTHWESTERN NIGERIA**

BY

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Sedimentological, Geochemical and Petrophysical Evaluation will be carried out on subsurface samples from wells within the eastern Dahomey basin to determine the lithofacies association, provenance, tectonic setting, depositional environment, organic matter quality; source, quantity, type, maturity, biomarkers present in the study area and possible reservoir.

The samples that will be used for this study will be subjected to; sedimentological description, thin section petrography, geochemical analyses entailing major elemental oxides, trace elements and rare earths element analysis using X-ray fluorescence method (XRF) and inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) respectively. Total organic carbon content ((TOC) of the samples will also be determined using Leco analyzer, Rock-Eval analysis using HAWK Pyrolysis instrument, Vitrinite Reflectance using microscope with oil immersion objectives, thermal alteration index (TAI) using microscopic examination of spore colour, Palynological slides will be prepared and evaluated using transmitted light microscope and Gas chromatography-Mass spectrometry (GC-MS) equipment will be used for the biomarker analysis. Furthermore, Seismic and wireline data would be analyzed and interpreted using Petrel software. Analysis from seismic profiles will include identification of faults, unconformities and erosional surfaces, while from logs, lithology, depositional patterns and environments of deposition would be interpreted.

Conclusively, results obtained from the Sedimentological, petrography, inorganic and organic geochemical analyses, wireline logs and seismic data will be modeled and/or interpreted with standards and appropriate plots. The findings from the study will provide information necessary to enhance exploration activities in the eastern Dahomey basin with a view of improving on past investigations in the study area.

Introduction

The search for hydrocarbons in the Nigerian sedimentary basin has been a major task for many decades now. For many years, Geoscience research in the aspects of hydrocarbon search in the Nigerian sector of the Dahomey basin has been so few. In the last decade, due to oil discovery and production in the neighboring Benin Republic sector west of the basin coupled with the social unrest in the prolific Niger Delta east of the basin, there has been a considerable interest and geoscience research in the aspects of hydrocarbon search in the basin.

The Dahomey Basin located on latitude $7^{\circ} 6' 0''$ N and longitude $3^{\circ} 25' 60''$ is an extensive sedimentary basin on the continental margin of the Gulf of Guinea which extends from the Volta Delta in Ghana in the west to the Okitipupa Ridge in Nigeria in the east (Whiteman, 1982) (Fig.1). The area of the onshore part of the Dahomey Basin in all four countries involved (Ghana, Togo, Benin and Nigeria) up to the shelf break, probably does not exceed 30,400sq.km (Whiteman, 1982). The basin contains extensive wedge of Cretaceous to Recent sediments up to 3000m, which thickens from the onshore margin.

The eastern part of the Dahomey Basin in Nigeria hosts the second-largest bitumen resources in the world, with an estimated proven reserve of about 42.47 billion tonnes of bitumen and oil sand that is yet to be explored for economic purposes (Famakinwa et al. 2010; Olabemiwo et al. 2016). Oil seeps in the eastern Dahomey (Benin) Basin were a source of attraction to early explorationists, between 1907 and 1960. The results of these early exploration campaigns confirmed the presence of heavy biodegraded oils in shallow wells and boreholes in the basin (Coker et al. 2002). Bitumen and oil sands have been found in Cretaceous outcrops, and flows/shows in drilled and cored wells (Nwachukwu and Ekweozor, 1989; Macgregor et al. 2003; MSMD, 2006). Oil indications from outcrop sections and boreholes in the eastern Dahomey (Benin) Basin are suggestive of potential economic discoveries, but the overall petroleum geology of the region has not been fully understood

An Upper Cretaceous petroleum system, characterized by Type II-III kerogens with an average total organic carbon (TOC) content of 2.9 wt. %, has been established in the Basin. (e.g., Kaki et al. Oil is currently being produced in the Aje Field from Upper Cretaceous sandstone facies of the Abeokuta Group. With recent exploration data and geochemical evaluations of bituminous sand outcrops from onshore areas of the basin in southwest Nigeria

suggesting the existence of a Lower Cretaceous petroleum system (e.g. Kaki et al., the Benin Basin is proving to be a basin with significant hydrocarbon potential.

Stratigraphy of Dahomey

The stratigraphy of the eastern Dahomey Basin has been discussed by various workers; (Jones and Hockey, 1964; Reyment, 1965; Fayose, 1970; Ogbe, 1972; Omatsola and Adegoke, 1981; Agagu, 1985; Billman, 1992; Nton, 2001; Elueze and Nton, 2004; Nton *et al.*, 2006) amongst others, and several classification schemes have been proposed (Omatsola and Adegoke, 1981; Billman, 1992; Ogbe, 1972). Omatsola and Adegoke (1981), proposed the Cretaceous sequence in the eastern Dahomey Basin as beginning with the Abeokuta Group; **The Abeokuta Group** is the oldest sedimentary unit resting unconformably on the basement complex (Table 1) and made up of the Ise, Afowo and Araromi Formations successively. The Ise Formation is made up of grits and conglomerate at the base overlain by coarse-grained loose sands with intermediate kaolinite (Nton, 2001). Overlying the Ise Formation is the Afowo Formation, which is composed mainly of coarse to medium-grained sandstone, with variable, thick interbedded shales, siltstones and clays; with the shale component increasing towards the top. Its maximum known thickness is 2,300m (Omatsola and Adegoke, 1981). The Afowo Formation is overlaid by the Araromi Formation, which comprised fine to medium – grained sands at base, and overlain by shale and siltstone with thin interbedded limestones and marls. This formation is the youngest of the Cretaceous sequences in the eastern Dahomey basin (Omatsola and Adegoke, 1981). The shales grade from light grey to black, and are mostly marine with a high organic content (Nton, 2001; Elueze and Nton, 2004). The Ewekoro Formation overlies the Araromi Formation and it is predominately limestone; the top is highly scoured and consists of red, dense, glauconitic, phosphatic and fossiliferous limestone. It is Palaeocene in age and associated with shallow marine environment due to abundance of coralline algae, gastropods, pelecypods, echinoid fragment and other skeletal debris (Nton, 2001).

The Ewekoro Formation (where encountered) is overlain by predominantly shaley unit of the Akinbo Formation (Ogbe, 1972). The Akinbo Formation consists of dark micro micaceous, fine-textured shale that is locally silty with glauconitic marl and conglomerate at the base (Dessauvage, 1975). It consists of laminated and glauconitic shale and kaolinitic clay sequence (Nton and Elueze, 2005). The shales are grey, fissile, clayey and concretionary and dip gently (<5°SW) (Nton, 2001). The Oshosun Formation overlies the Akinbo Formation and consist of greenish- grey or beige clay and shale with interbeds of sandstone. The shale is thickly laminated and glauconitic. This formation is phosphate-bearing and is compositionally phosphorite (Nton, 2001). The Ilaro

Formation overlies the Oshosun Formation in the eastern Dahomey basin, and consist of massive, yellow, poorly consolidated, cross bedded sandstone (Nton, 2001). The Benin Formation, is the youngest sedimentary unit in the eastern Dahomey basin and consist of a series of poorly sorted sands with lenses of clays and are in parts cross bedded (Agagu, 1985).

A lot of interest has recently been shown in the eastern Dahomey Basin (Nigeria sector) fig. 1, as new road cut exposures and borehole availability have enhanced our understanding of the region's geology. In this area of the basin near Okitipupa, east of Lagos, where bituminous sands outcrop, exploration work started in 1908. After oil was discovered in the Niger Delta in 1956, attention was diverted from the eastern Dahomey basin to the Niger Delta, and this exploratory work was later abandoned and termed dry well. Also, it is relevant to note that conventional hydrocarbons in commercial quantity, have been found offshore in the Republic of Benin (Billman, 1992). However, in comparison with the adjacent Niger Delta, few studies have been conducted in the eastern Dahomey basin in terms of hydrocarbon potential. For several years, attention has been focused on the black shales in the Agbabu area, associated with the tarsands of the Afowo and Araromi Formations (Enu, 1987). Recently, there has been a resurgence of interest in exploration activities in the basin due to increased government incentives to prospectors and re-evaluation of data gathered from previous unsuccessful attempts (Elueze and Nton, 2004). Hence, the need for this research which tends to focus on subsurface samples (ditch cuttings, well logs and seismic data) to further appraise the Dahomey basin. This research will provide further insight into the geology of the basin and complement the existing database for both current and future petroleum exploration program and resource assessment in the basin.

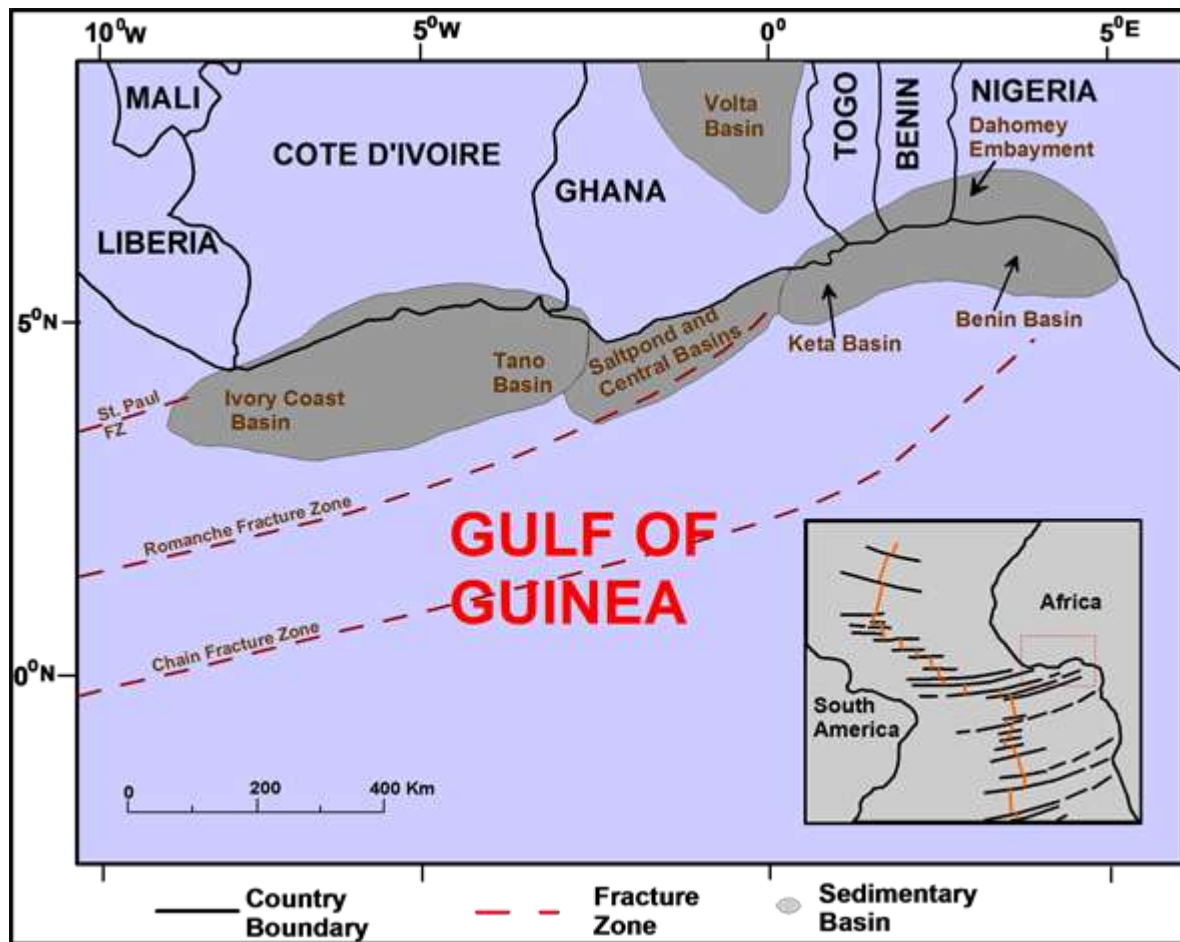


Fig 1. Regional map of the Gulf of Guinea showing the location of Benin (Dahomey) Basin in relation to other basins (modified after Brownfield, M.E. and Charpentier, R.R. (2006).

Table 1: Generalized stratigraphic column showing age, lithology, and sequence of the formations and tectonic stage of basin development in the Nigerian sector of the Benin Basin.

Chronozones		Lithology	Formations										Tectonic stage/ Basin Development			
Period	Epoch/Age		Jones and Hockey (1964)	Reyment (1965)	Ogbe (1972)	Billman (1980)	Omatsola and Adegoke (1981)	Ajakaiye and Bally (2002)	Brownfield and Charpentier (2005)	Ajakaiye and Bally (2002)	Brownfield and Charpentier (2005)					
Tertiary	Quaternary	Holocene to Pleistocene										Drifting phase				
	Neogene	Pliocene	Coastal Plain Sands	Benin				Benin/Ijebu								
		Miocene		Ijebu				Afowo	Afowo							
	Paleogene	Oligocene		?				A								
		Eocene	Ilaro	Ameki	Ososun			Ososun	Ososun							
				Ilaro	Akinbo											
		Paleocene	Ewekoro	Ewekoro	Ewekoro			Imo/Ewekoro	Imo							
	Cretaceous	Late	Senonian	Maastrichtian	Abeokuta	Abeokuta	Nkporo Shale									
				Campanian												
				Santonian												
				Coniacian												
				Turonian												
				Cenomanian												
Cretaceous	Early	Neocomian	Albian				Albian Sands	?	Albian Sandstone	Albian Sandstone						
			Aptian													
			Barremian													
			Hauterivian													
			Valanginian													
			Berriasian													
	Late															
	Jurassic		?										Pre-transform			

Siltstone
Shale
Limestone
Sandstone
Sandstone/Clay Conglomerate
Sandstone/Clay
Conglomerate

Unconformity

A

B

C

Oligocene Unconformity
Senonian Unconformity
Albian Unconformity

- Siltstone
- Shale
- Limestone
- Sandstone
- Sandstone/Clay
- Conglomerate
- Unconformity
- A Oligocene Unconformity
- B Senonian Unconformity
- C Albian Unconformity

Problem Statement

According to the report from The Guardian newspaper on "Nigeria and the future without oil" by Seun Awogbenle, february 06, 2024, it was stated that the 2024 budget estimates that the oil sector will contribute 42 per cent to government revenue. Crude oil, without any doubt, remains the centerpiece of the Nigerian economy. Nigeria depends on fossil fuels as the major source of energy, although there is awareness that the global dependence on the use of fossil fuels as energy sources has to be reduced due to climate change and renewable energy alternatives should be provided in other to protect the environment and also to meet our ever increasing energy needs. Yet, there is an understanding that for now and the future, to be able to meet the exponential increase in our energy needs, more oil and gas deposits must be discovered. Currently, crude oil accounts for 80 per cent of Nigeria's export, a significant proportion of our foreign exchange earnings and government revenue. This has created a surge in exploration all around the possible/probable sedimentary regions in Nigeria. The basic problems to be solved in petroleum exploration are those of hydrocarbon potential, source rock evaluation, reservoir evaluation. Some geochemical, Sedimentological and petrophysical models will be designed by this research to provide a quantitative approach to solving of these problems. Sedimentology, organic geochemistry and petrophysics has proved to be relevant in evaluating environment of deposition, source rock characterization and in predicting reservoir plays. This study therefore seeks to provide sufficient information concerning the depositional model, geological features, fossil assemblage, organic matter types, thermal maturation, correlation and reservoir characteristics of the wells in the Dahomey Basin. A detailed understanding of these parameters will be of vital benefits to exploration, production and also researchers.

Aim and Objectives

The aim of this PhD thesis is to evaluate subsurface data for sedimentological characteristics, hydrocarbon potential, reservoir property and trapping mechanism, which is significant to exploration. The specific objectives of this study includes.

1. Detailed Sedimentological description of cores and to determine environment of deposition, depositional setting and conditions under which sediments were deposited
2. To determine major oxides, trace and minor elements from subsurface data
3. To investigate the organic matter quality, source, quantity, identify the type, maturity of the organic matter and to detect petroleum potentials in the sediments and also to investigate the biomarkers present in the study area

4. Petrophysical analysis to determine possible reservoirs and provision of necessary information such as fault analysis to optimize development in the study area

Scope

The current study will focus on ditch samples, Well logs and seismic survey of the respective wells from Eastern Dahomey basin southwestern Nigeria. Comprehensive logging of the sections and description of the samples would be carried out. Representative rock samples comprising of sandstones, mudstones, claystones, limestone and shales would be subjected to grain size analysis, thin section petrography, inorganic geochemical analysis using X- ray refraction method (XRF) for major element analysis and inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) for minor and trace element analysis. Finally, organic geochemical studies will be carried out on the samples using Rock-Eval pyrolysis, Total organic carbon (TOC), Vitrinite reflectance, Thermal alteration index, Palynofacies, Biomarker analyses and also petrophysical evaluation.

Preliminary literature review.

Sedimentology is the study of sediments such as clay, mud, silt, and sand and the processes that result in their formation, transportation, deposition and diagenesis. Sedimentology is applied in the interpretation of ancient environmental conditions in the geologic record and this is done by studying grain sizes, textures, structures and fossil content of the sediments laid down in different environments. Chemical composition of sedimentary rocks are commonly used as sensitive indicators of lithofacies association, provenance, paleo-depositional environment, palaeoclimatic as well as paleowathering and geochemical maturity of sediment, and in some cases, as tools for unraveling tectonic history (Cullers, 2000).

Organic geochemistry is the study of the origin and fate of sedimentary organic matter as it relates to petroleum formation, migration, accumulation and alteration (Eglinton and Murphy, 1969). It is a highly diversified applied science with a variety of concepts and techniques which now play an important role in exploration decisions. Geochemistry today provides an increasingly significant input to many basin evaluations (Idowu, 1990). Petrophysics is the study of the physical and chemical rock properties which are related to pore and fluid distributions particularly as they pertain to detection and evaluation of hydrocarbon bearing layers (Archie, 1950). Petrophysics is a relevant tool used in studying reservoirs in the hydrocarbon industry.

The earliest study of the Dahomey basin commenced in 1960 in Togo, where the outcrop of the formations were recognized in the Mono Valley (Antohni. 1968). Water wells were seen in the vicinity of the Adabion and they penetrated limestone at varying depths of between 18 and 30m.

In Nigeria, the reported occurrence of tar sands within the eastern Dahomey basin, led to the establishment of the Nigeria-British Corporation, which carried out an appraisal on suitability of the tar sands for roads surfacing between 1907 and 1914. As a follow-up to this initial investigation, a number of boreholes were drilled in the outcrop zone with a view to determining the possibility of obtaining heavy oil.

Several published works exist on the geology of Dahomey basin. Some of these works basically discuss the geological setting of Ewekoro Formation and assigned age to the important strata in the area, though the Cretaceous and Tertiary strata of western Nigeria have been studied by a number of workers since pioneer work of Russ, (1924) and Reyment, (1965), the identity of the Ewekoro Formation was not recognized until 1977, when Adegoke and others initiated some series of studies. The first detailed study in Nigeria was by the Associated Portland Cement Manufacturers Limited, in the search for raw materials for a cement factory (Adegoke, 1977). The stratigraphic relationships and palaeontology of the strata exposed at the Ewekoro quarry have variously been described by Adegoke, (1977); Adegoke *et al.*, (1972); Ogbe, (1976); Jan Du Chene *et al.*, (1978). Reyment, (1965) first suggested the Paleocene age for the Ewekoro Formation, based on the typical Paleocene planktonic foraminifera recorded from the quarry section. Ogbe, (1976) examined the algae preserved in the Ewekoro Formation and concluded that they are mostly Paleocene forms.

Various aspects of the geology of the eastern Dahomey basin have also been discussed, viz: stratigraphy (Fayose, 1970; Ogbe, 1972; Omatsola and Adegoke, 1981; Nwachukwu *et al.*, 1992); sedimentology (Nton, 2001; Elueze and Nton, 2004; Nton and Elueze, 2005) and hydrocarbon source potential (Nwachukwu and Adedayo, 1987; Ekweozor and Nwachukwu, 1989; Ekweozor, 1990; Elueze and Nton, 2004; Nton *et al.*, 2009) among others. Nton *et al.* (2009), also conducted some Rock-eval studies of Maastrichtian-Paleocene shales and limestones within the offshore Dahomey Basin and reported that the organic matter is low to adequate arising from the total organic matter (TOC) values and that the sediments are terrestrial organic matter, immature to slightly mature, with prospect to generate gas rather than oil at appropriate maturity.

Ikhane *et al.*, (2011), examined the mineralogy of the some sandstone from part of the eastern Dahomey Basin in order to infer the provenance and paleodepositional environment. Nton and Adeyemi (2014), studied the isotope geochemistry and petrography of the limestone facies of the Ibese well. Values of the U/TH ratios (~0.25 to 2.3; av 1.2) and Ce anomaly (~0.7-0.94, av 0.85) indicated oxygenated environment with little fluctuation in bottom water oxygen. Also, Popola *et al.*, (2014), carried out an inorganic geochemical study of clay and shale sediments of the eastern

Dahomey basin, aimed at determining the depositional conditions, provenance and tectonics setting of the basin. Their findings revealed prominent kaolinite, montmorillonite and illite peaks; accessory minerals included quartz and microcline. Major element abundance showed that the shale samples consist average of SiO₂ (44.77%), Al₂O₃ (15.01%) and Fe₂O₃ (5.75%), constituting more than 65% of bulk chemical composition. Value of U, U/Th, Ni/Co and Cu/Zn ratios, indicated deposition in oxic conditions while the Al₂O₃/TiO₂ ratio revealed intermediate igneous rocks provenance for the shale as well as mixed provenance for the sediments.

Akaegbobi *et al.*, (2016), investigated the depositional settings and provenance of the Paleocene Ewekoro Formation from exploratory drill cores within Ibese cement quarry, southwestern Nigeria. The major oxides concentration showed significant variations among the limestone facies. The geochemical parameters such as Ce anomaly, authigenic U, Mn*, V/(V+Ni), V/Ni, Th/U ratios indicated that the limestones were deposited in restricted to open shallow marine environments under fluctuating oxidizing to anoxic conditions.

Methodology

Data Procurement.

The data set to be used for this study will be provided by the Nigerian Geological Survey Agency, Nigeria. They would include ditch cuttings, wireline logs, and seismic data. The following methods will be employed in this research work.

- **Granulometric Analysis:** Grain size analysis would be carried out on the sandstone samples and appropriate interpretations will be done.
- **Thin section petrography:** Thin sectioning of the ditch samples would be done and photomicrographs of features of interest will be taken with petrological microscope
- **Inorganic Geochemical Analysis:** XRF and ICPMS measurements will be carried out to determine major oxides and trace element composition of the samples.
- **Organic Geochemistry Analysis:** Total organic carbon(TOC) would be carried out on the potential source rock samples using Leco analyzer , Rock-Eval analysis would be done using the HAWK Pyrolysis instrument, Vitrinite Reflectance will be done using microscope with oil immersion objectives, the thermal alteration index (TAI) would be determined through microscopic examination of spore colour, Palynological slides will be prepared and evaluated using transmitted light microscope , Gas chromatography-Mass spectrometry (GC-MS) equipment will be used for the biomarker analysis.
- **Petrophysical Evaluation:** The Seismic and wireline data would be analyzed and interpreted using Petrel software. Analysis from seismic profiles will include identification of faults, unconformities and erosional surfaces, while from logs, lithology, depositional patterns and environments of deposition would be interpreted.

Conclusively, results obtained from the Sedimentological, petrography, inorganic and organic geochemical analyses, wireline logs and seismic data will be modeled and/or interpreted with standards and appropriate plots. The findings from the study will provide information necessary to enhance exploration activities in the eastern Dahomey basin with a view of improving on past investigations in the study area.

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