Aspects of Source Rock Evaluation and Diagenetic History of the Akinbo Shale Eastern Dahomey Basin, Southwestern Nigeria

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Abstract

The Akinbo Formation comprises a sequence of mostly dark, pale-greenish grey, laminated shale, slightly glauconitic shale, sandy shale with subordinate claystone lenses. Selected subsurface samples of the shaly facies as penetrated by Akinside 1582 well in eastern Dahomey basin, were investigated by sedimentological, mineralogical and geochemical parameters to ascertain the hydrocarbon potential and deduce the influence of variations of clay mineral indicators on the prospect.

Values of total organic carbon (TOC) range from 0.46 to 1.98wt. % while the soluble organic matter (SOM) ranges from 71 to 1940 ppm and portrays that the organic matter is fair to good and adequate. Bitumen ratios have values of 15.25 to 98.98mg ext/gTOC which suggest that the sediments are immature to marginally mature. Average major elemental composition indicates 68.08% SiO_2 17.55% Al_2O_3, 4.07%K_2O, 1.82%CaO, 1.57%Na_2O, 1.29%MgO, 0.62%Fe_2O_3 and 0.50%MnO. A moderate increase in K_2O from 2.26 to 4.92wt. % with depth was observed and this corresponds with increase in illite content. Equally, an increase in $Al_2O_3/(Fe_2O_3 + MgO)$ ratio from 7.27 to 22.07 with depth points to increasing diagenetic conditions.

Illite and illite/smectite (mixed layer clays) dominate the clay mineral assemblage (>50%) while kaolinite and smectite (ca.35%) are comparatively low. Kaolinite and smectite were observed to disappear with depth as well as an increase in illite crystallinity. Smectite disappearance occurs at approximately vitrinite reflectance of 0.5 %(VR_o) and illite crystallinity values are from 0.16 to $1.6^{\circ}2\theta$, which are within values of normal burial diagenesis.

It can be deduced that the shale is a potential source rock varying from immature to marginally mature with prospects to generate gas rather than oil at appropriate thermal maturity. The clay mineral diagenetic indicators show that the hydrocarbon potential might have been affected by geothermal and tectonic history.

Introduction

The Dahomey Basin is an extensive sedimentary basin on the continental margin of the Gulf of Guinea. It extends from the Volta Delta in Ghana in the west to the Okitipupa Ridge in Nigeria in the east (Whiteman, 1982) (Fig.1). The basin is a marginal pull-apart (Klemme, 1975) or marginal sag basin (Kingston et al., 1983) which developed in the Mesozoic Era as the African and South American lithospheric plates separated and the continental margin foundered (Burke et al., 1971; Whiteman, 1982).

The basin contains extensive wedge of sediments, up to 3,000m, which thickens towards the offshore (Whiteman, 1982). Various aspects of the geology of the basin have 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).

For several years, attention has been focussed on the black shale in the Agbabu area, near Okitipupa, which is associated with the tar sands of the Afowo and Araromi Formations (Nwachukwu and Adedayo, 1987; Ekweozor and Nwachukwu, 1989). Recently, Nton (2001) and Elueze and Nton (2004), reported on a regional basis, the sedimentological and geochemical studies of different rock units in the eastern Dahomey Basin and deduced that the organic matter is immature with prospects to generate biogenic gas rather than oil in the basin at appropriate thermal maturity.

To date, very little attention has been paid to the influence of clay mineral diagenesis on organic matter transformation in this basin unlike other basins for example: Anambra basin (Akande and Erdtman, 1998; Akande and Viczian, 1996); Niger delta (Oboh, 1992) and the Gulf Coast (Weaver, 1960; Burst, 1969). It has been widely established that clay mineral diagenetic transformation can be correlated with organic matter maturation (Robert, 1988; Velde and Espitalie, 1989). This is strongly dependent on the chemical environment

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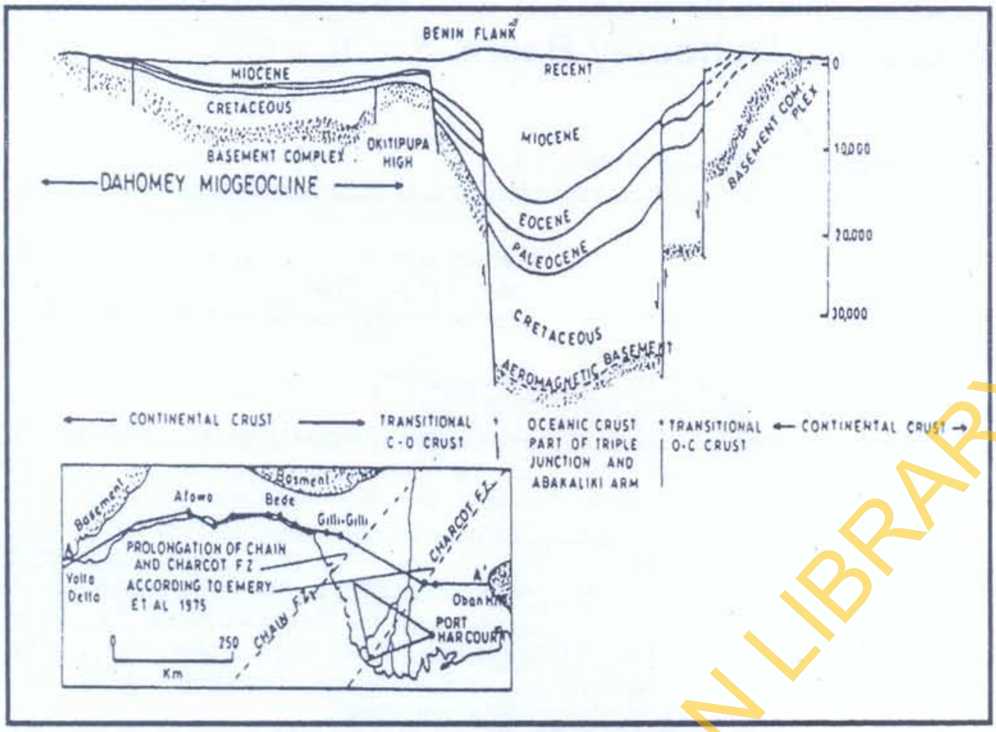

Fig. 1 East-West Geological section showing position, extent and sediment thickness variations in the onshore Dahomey Basin and the upper part of the Niger Delta (After Whiteman, 1982)

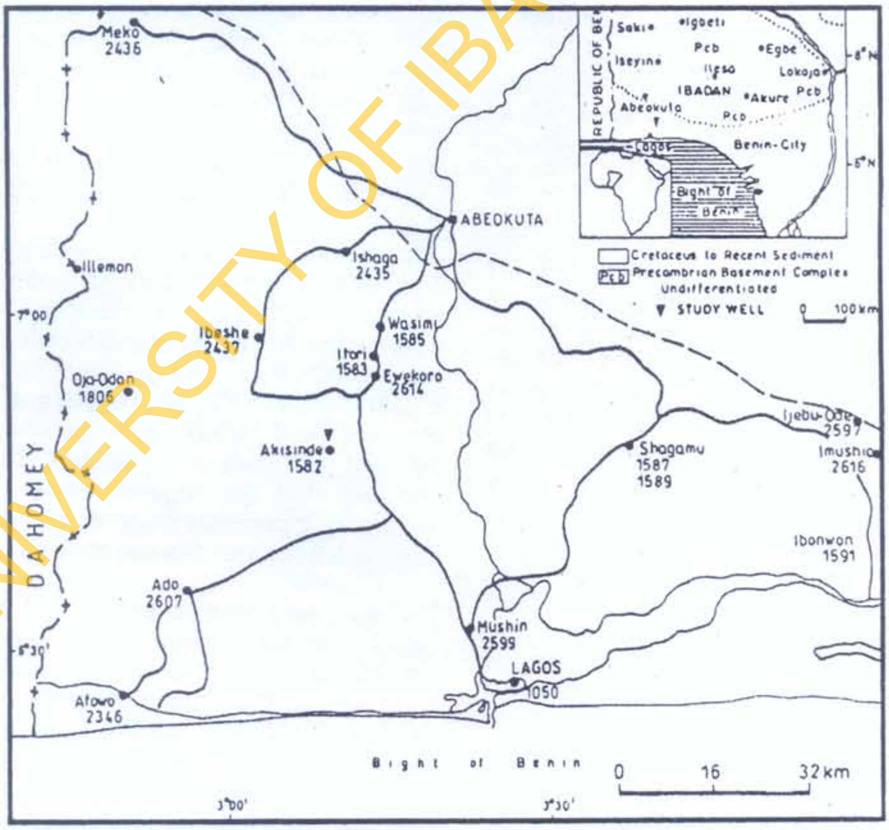

Fig. 2 Location of some boreholes in eastern Dahomey Basin (Modified after Jones and Honey, 1964)

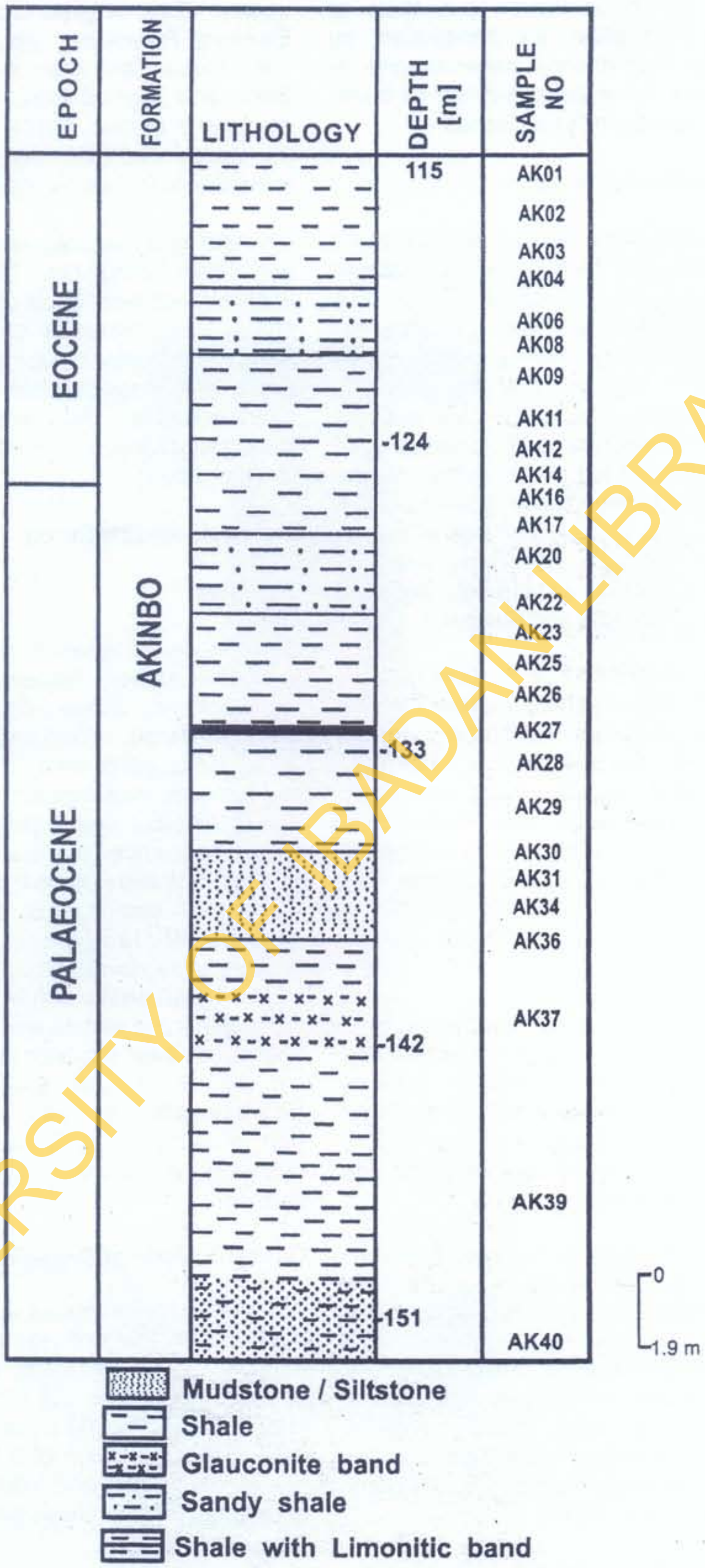

Fig. 3 Lithologic profile of part of Akinside 1582 well

of the deposited sediments and tectonics (Enu, 1987) as well as the geothermal gradient of the sediment infill of the basin (Avbovbo, 1978).

This study examines the hydrocarbon potentials of sediments of Akinbo Formation as penetrated by Akinside 1582 well. The clay mineral assemblages, in particular illite crystallinity have been applied to burial diagenesis in relation to source rock evaluation.

Outline of Geology and Stratigraphy

The study area lies between latitudes 6°45' to 7°00'N and longitudes 3°00' to 4°00'E and falls within the eastern Dahomey Basin (Jones and Hockey, 1964) (Fig. 2). The stratigraphy of the eastern Dahomey Basin indicates that the Ise Formation unconformably overlies the basement complex of southwestern Nigeria. The Formation is made up of grits and conglomerates at the base overlain by coarse-grained loose sands with intermediate kaolinite. Both the cross-bedding azimuths of the sandstones and the pebble alignments point to a NE palaeo-current system (Nton, 2001). The age of the Ise Formation is Neocomian to Albian. The Afowo, Araromi, Ewekoro and Akinbo Formations accordingly succeed this unit stratigraphically (Omatsola and Adegoke, 1981).

The Afowo Formation is composed of medium grained sandstones with inter-bedded shales, siltstones and claystones. The sandy facies are tar-bearing around Okitipupa, while the shales are organic-rich. The lower part of the formation is transitional with mixed brackish to marginal horizons that alternate with well-sorted, subrounded sands. These attributes point to a littoral or estuarine near-shore environment in which water level fluctuates (Enu, 1990). Billman (1992) assigned a Turonian age to this formation while the upper part ranges into the Maastrichtian.

The Araromi Formation is the youngest of the Cretaceous sediments in the eastern Dahomey Basin (Omatsola and Adegoke, 1981). It is composed of fine to medium grained sandstones at base, overlain by shales and siltstones with inter-bedded limestone, marl and lignite. The shales are light grey to black and organic - rich. The age is Maastrichtian to Palaeocene.

Overlying the Araromi Formation is the Ewekoro Formation made up predominantly of limestone. The limestone body is very extensive and is traceable for over a distance of about 320km continuously from Ghana eastward, towards the eastern margin of the Dahomey basin in Nigeria. The Ewekoro Formation is Palaeocene in age and is associated with shallow marine environment due to abundant coralline algae, gastropods, pelecypods, echinoid fragments and other skeletal debris (Elueze and Nton, 2004).

The Akinbo Formation (Ogbe, 1972) overlies the Ewekoro Formation and consists of shale/ clayey sequence. According to Ogbe (1972), the base of the formation is defined by the presence of a glauconitic band. The type locality of this formation is at the Ewekoro quarry. East of Ijebu Ode, the formation replaces the Ewekoro Formation, which thins-out here. Westward, the Akinbo Formation extends into the Republics of Benin and Togo (Slanky, 1962). In the field, the shales are grey in colour , fissile, clayey and concretionary and dip gently (<5°SW) (Nton, 2001). The age of the formation is Palaeocene to Eocene.

Younger and successive litho units are Oshosun, Ilaro and Benin Formations. The Oshosun Formation, which is phosphate bearing, is greenish grey or beige clay and shaley with interbeds of sandstones. The Ilaro and Benin Formations comprise mainly cross-bedded, poorly sorted sandstones with transitional to continental characteristics. For detailed and current studies on lithostratigraphic succession, reference should be made to Nton (2001)

Materials and Methods

Samples

Subsurface samples from Akinside 1582 well, drilled within the eastern Dahomey Basin were obtained from the Geological Survey Department, Federal Ministry of Solid Minerals, Kaduna, Nigeria. With an overall thickness of 207m for this well, the interval between 115 to 152m was investigated in this study. Within this range, the lithological sequences are made of lower sandy shale sequence overlain by glauconite band. The glauconitic band ranges in depth from 139 to 142m and is greenish in colour while the shale is dark to greenish grey, well laminated. Above this unit is a mudstone/siltstone sequence, which in turn is overlain by laminated shale with a limonitic band. The limonitic band within the middle shale sequence is at the depth of 132m. The overlying lithologies are sandy shale overlain by well-laminated shale unit in the top part. Representative samples and the lithological profile of part of Akinside 1582 well are shown in Fig.3. The following laboratory analyses were conducted on the samples:

Determination of Organic Richness

Twenty-six (26) samples were selected for total organic carbon (TOC) determination. Two grammes each of the selected samples were subjected to chromic acid titration method as put forward by Walkley and Black (1934). This afforded a preliminary screening based on TOC threshold value of 0.50 wt % reported for clastic sediments (Tissot and Welte, 1984). This analysis was conducted at the Geological Laboratory, University of Ibadan.

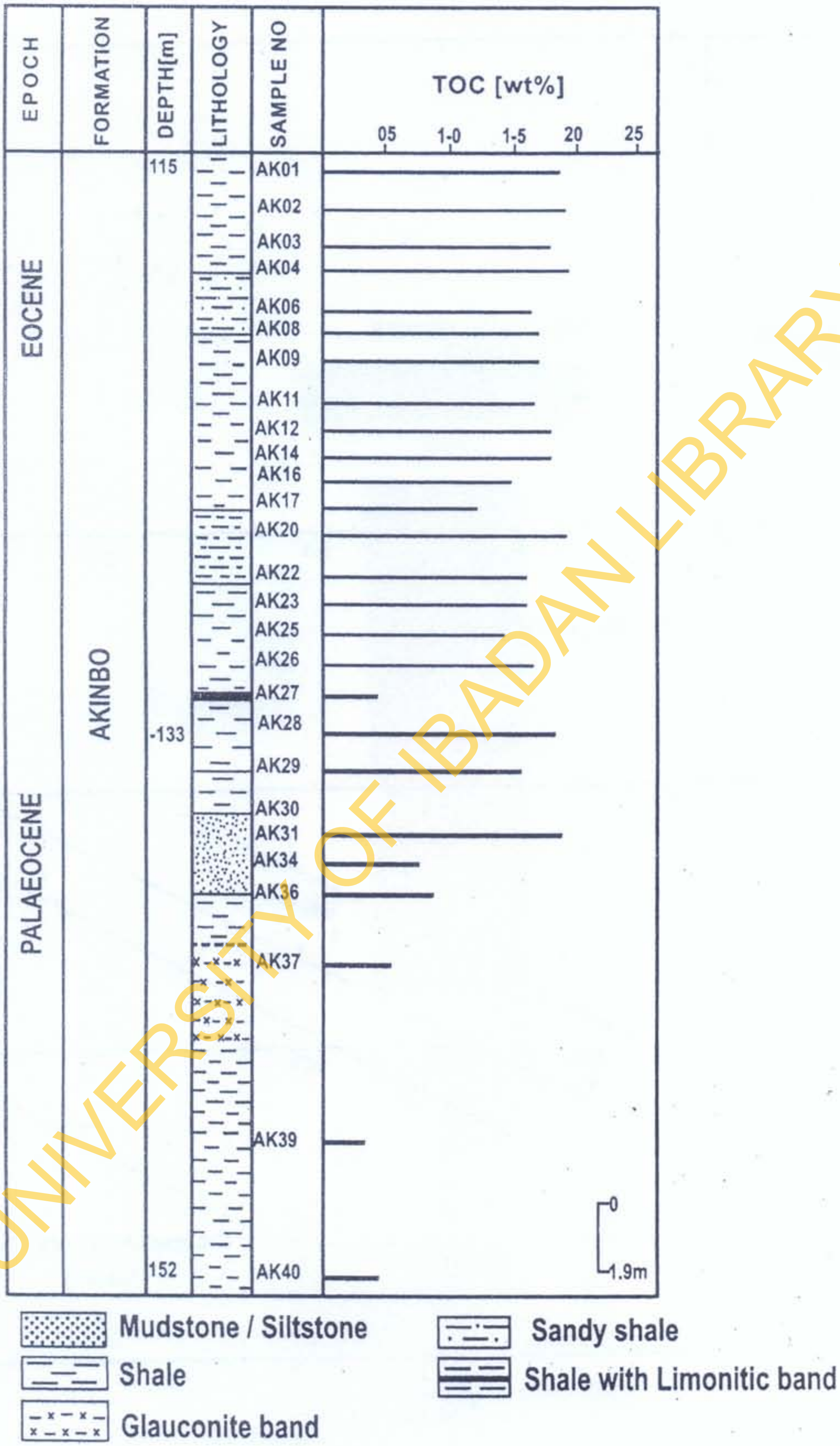

Fig. 4 Geochemical log for Total Organic Carbon (TOC, wt.%) with depth

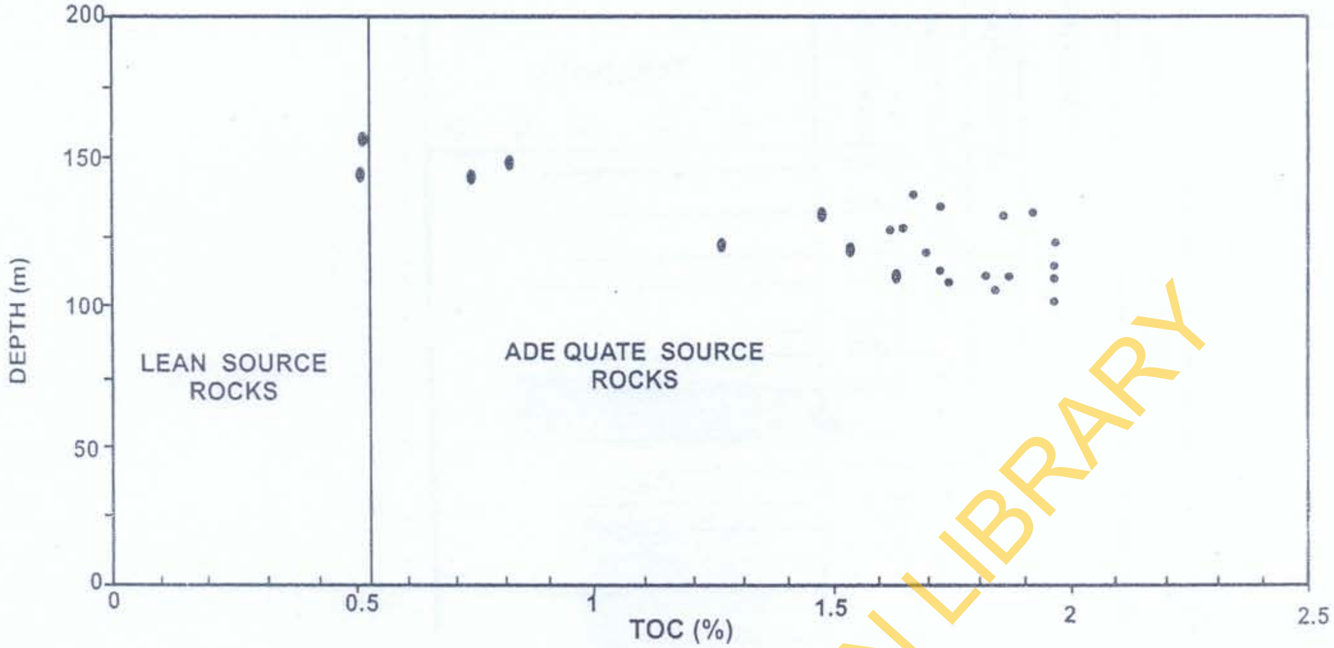

Fig. 5 Variation of TOC (wt.%) with depth (After Dow, 1977)

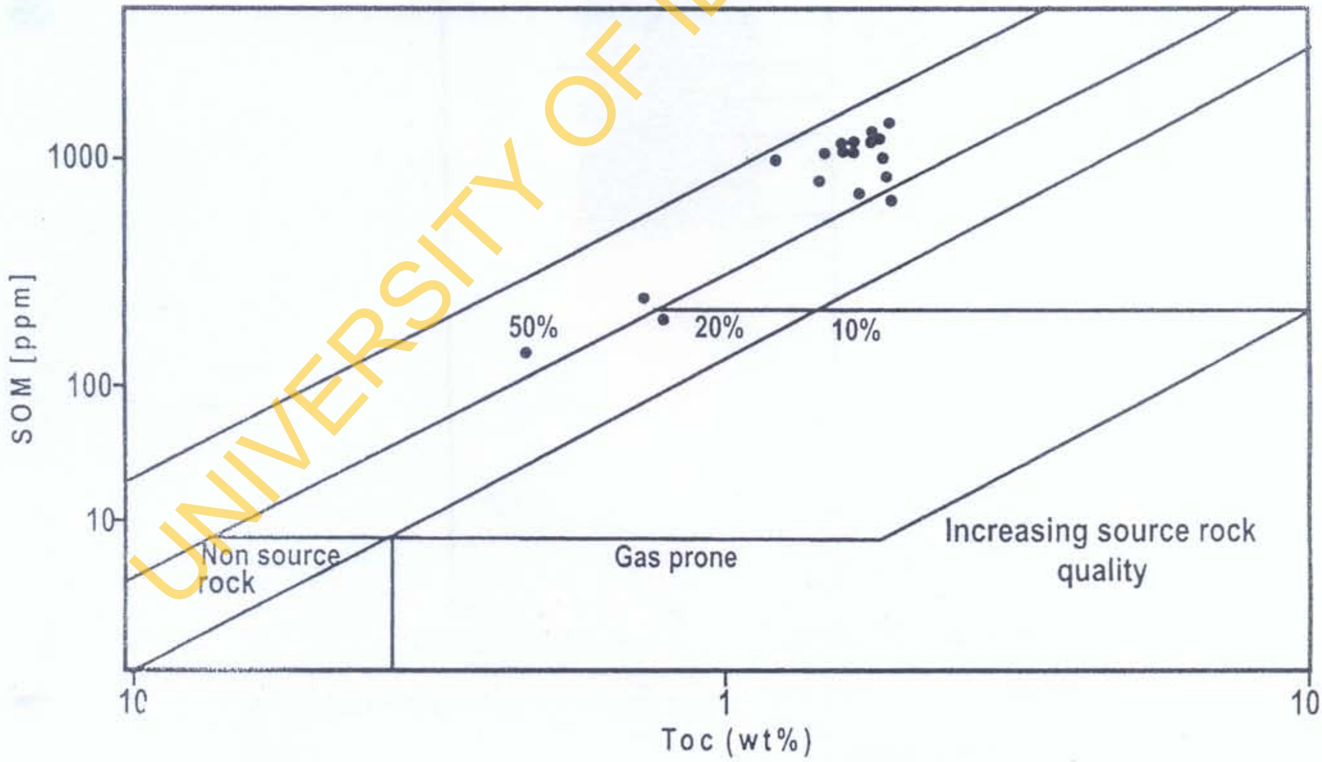

Fig. 6 Plot of SOM vs TOC for the studied well (Devised by Hunt, 1979)

Bitumen Extraction

About 10 to 30 grams each of screened pulverized samples (based on TOC adequacy) were taken into cellulose timbles and extracted in a standard Soxhlet apparatus using dichloromethane for 24 hours. The extract was evaporated at moderate temperature in an inert atmosphere. The SOM was weighed, stored in glass vials and concentrations were computed in parts per millions (ppm). This analysis was carried out at the Institute of Agricultural Research and Training (IAR&T), Moore Plantation, Ibadan.

X-Ray Diffraction

Twelve (12) selected samples made up of 11 shales and 1 glauconitic shale were used for this analysis. The <2micron fraction of each sample was pulverized for whole rock randomly oriented cavity smear mount with ethylene glycol and heated above 100°C. The smear mounts were obtained by dispersion method as described by Brindley and Brown (1980). The samples were analysed using a digital Phillips PW 1800 Diffractometer with a CuKa source. The equipment also coupled a Phillips PC workstation using PC-APD diffraction software. Their relative proportions were estimated as peak areas from the relative intensities (Brindley and Brown, 1980).

Illite crystallinity data was calculated from the diffractograms using the techniques of Kubler (1968). Kublers crystallinity index is defined as the width of the 10Å reflection peak at one half maximum height. This analysis was undertaken at the National Steel Raw Materials and Exploration Agency (NSRMEA), Kaduna, Nigeria.

Major Element Analysis

A total of 5 samples were pulverized and sieved for analysis. 0.2gm of each was taken in an airtight plastic container and digested with appropriate reagents. The major elements were determined by Perkin-Elmer 2380 atomic absorption spectrophotometer (AAS). The analysis was conducted at the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. Detailed analytical procedures for the different aspects of this study are documented in Ezeh (2002).

Results and Discussion

Organic matter quantity

The result of the total organic carbon (TOC) is presented in Table 1. It is known that adequate amount of organic matter (measured as %TOC) is a necessary pre-requisite for sediments to generate oil or gas (Conford, 1986). In this study, the TOC values range from 0.46 to 1.98 wt. %. These values indicate that the sediments have satisfied the required threshold value of 0.5wt. % for clastic rocks to generate petroleum (Tissot and Welte, 1984).

Geochemical log of TOC with depth (Fig.4) shows some consistency in TOC values for the different rock units. Lower values of TOC were recorded for the arenaceous mudstone/siltstone and sandy shale units of the lower section of the sampled sequence (AK34, AK36 and AK40). Again, sample AK27 shows a significantly low value (0.49wt. %; Fig. 4). This may be due to slight oxidation as noticed by the brownish to reddish colouration at this interval. The soluble organic matter (SOM) ranges from 71 to 1940ppm (Table 1). Based on the quality definition of Hunt and Meinert (1954) and Baker (1972), the organic matter is fair to good and adequate. Again, from the plots of TOC versus depth as put forward by Dow (1977), most of the shales also fall within the range of adequate source rocks (Fig. 5).

To further highlight the source rock potential of the sediments and ascertain possible level of contamination, the plot of SOM versus TOC (Fig. 6) (Hunt, 1979) shows that most of the samples fall within the field of gas proneness to increasing source rock quality. Within the same basin, Elueze and Nton (2004) utilised organic petrography to demonstrate that the sediments are mainly type III and IV kerogens with prospects to generate gas rather than oil at appropriate thermal maturity. This is consistent with the findings in this study.

Maturity of organic matter

The ratio of extractable bitumen to total organic carbon (Bitumen/TOC), sometimes called Transformation Ratio (TR), can be used in determining sediment maturity (Peters and Moldowan, 1993). It has been pointed out that such values range from near zero in shallow sediments to about 250 mg/gTOC at the peak of oil generation. It has been demonstrated that at greater depths, these values decrease as a result of conversion of bitumen to gas (Peters and Moldowan, 1993). In this study, the bitumen ratio is from 15.25 to 98.98mgext/gTOC (Table 1). These values imply that the sediments are immature to marginally mature (Miles, 1989) and may be associated with early diagenetic conditions.

Geochemical log of the variations of extract yield and bitumen ratio with depth (Fig. 7) show similar trends for both parameters in the studied well. This could indicate derivation from a single source and subsequent preservation in a relatively non-varying environment. The bitumen ratio shows a decrease with depth from 133m, which connotes immature strata down hole and could be associated with lithofacies changes. However, Elueze and Nton, (2004) proposed that more mature strata are likely to be encountered at greater depth in this basin, particularly within the Araromi Formation. This

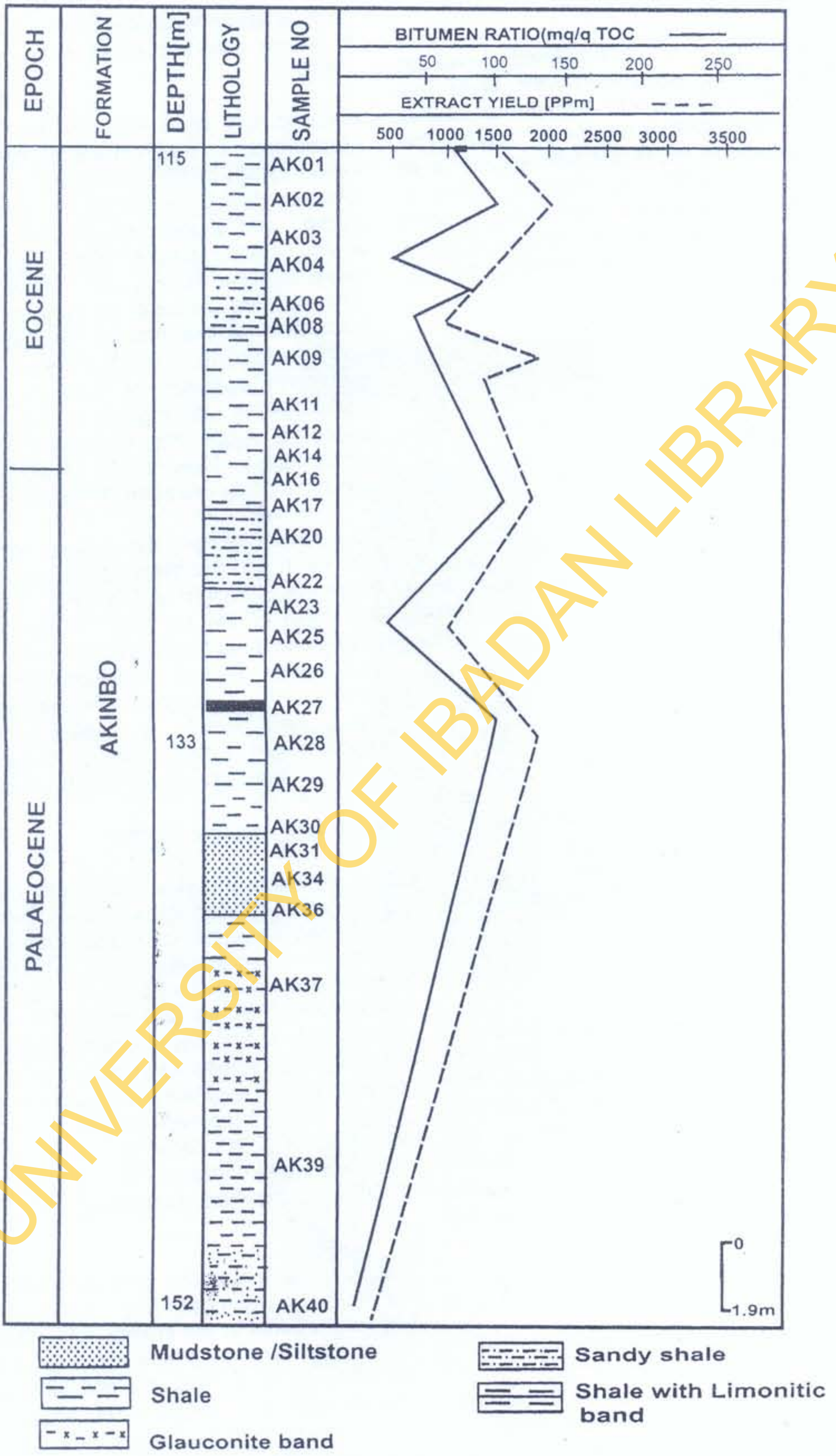

Fig. 7 Geochemical log for extract yield (ppm) and bitumen ratio (mg/g) TOC with depth

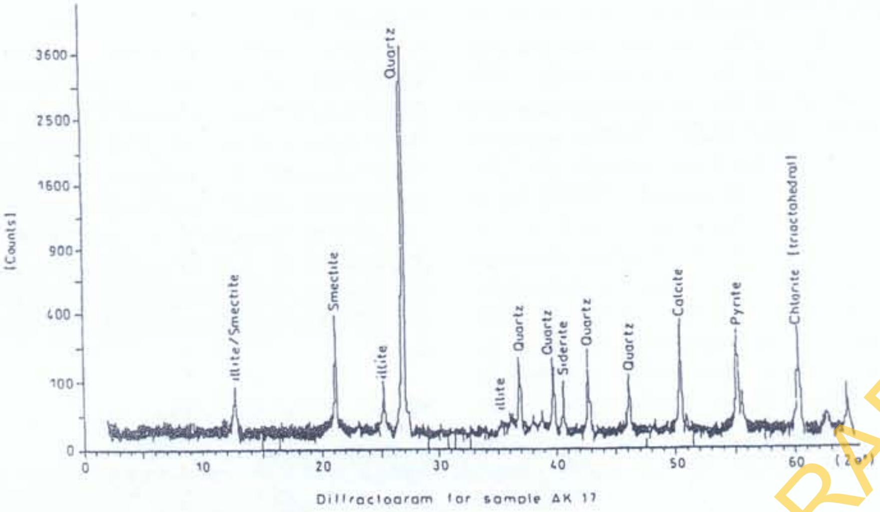

Fig. 8 Diffractogram for sample Ak17

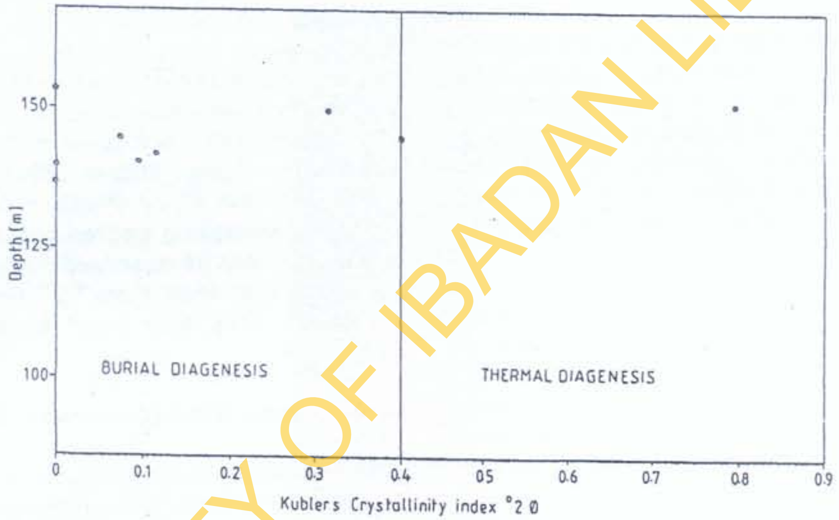

Fig. 9 Variation of Illite crystallinity with depth (After Kubler, 1968)

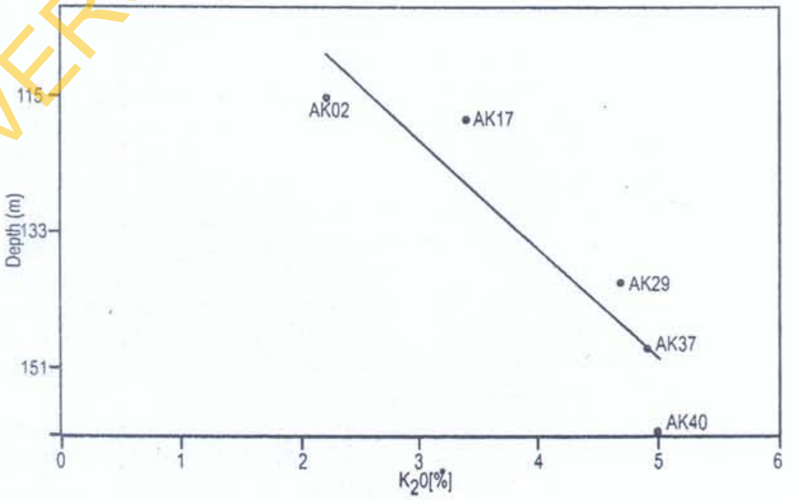

Fig. 10 Variation of potassium oxide content (%) with depth (m)

deduction however may not be ruled out in this study as the Akinbo Formation is stratigraphically above the Ewekoro Formation, which has low bitumen ratio, with sustained increase at depth, as the tar-bearing Araromi Formation is encountered (Nton,2001). Earlier workers in the eastern Dahomey basin such as; Mosunmolu Ltd, (1991) and Ekweozor and Nwachukwu, (1989) have proposed that more mature strata are likely to be encountered in the deep offshore. The shallow depth of sampling may affect deductions in this aspect. Based on the correlation of bitumen ratio obtained in this study with measured bulk maturation parameters according to Miles (1989), estimated vitrinite reflectance is between 0.50 0.69R_o (Table 2) (Miles, 1989). Waples (1985) has related these reflectance values with a Time $_{\text{Temperature}}$ Index (TTI) of 15, which corresponds to the onset of oil generation.

Clay mineralogy

The results of clay mineral assemblages are shown in Table 3. The non clay minerals include quartz, pyrite, feldspar, siderite and calcite. In this study, attention has been focused on the clay mineral suites, which include kaolinite (16.20%), smectite (18.48%), illite (29.17%), illite/smectite (30.45%) and others (5.71%). A typical diffractogram for one of the samples is shown in Fig.8.

Illite is predominant at the 10.00Å, 10.25 Å, 4.48? peaks. Kaolinite was identified mostly at 7.2 Å, while smectite occurred mostly at 9.7 ?, 12.4 ?, and 17.2 ?. This assemblage illustrates that smectite has been interstratified with illite at depth >120m. At depths greater than 130m, kaolinite and smectite are absent (Table 3). The persistence of the 7.12 Å and 3.56 ? basal reflections for kaolinite + chlorite upon heating, further establishes the presence of chlorite among the clay mineral assemblage (Akande and Erdtman, 1998). Further, the postures of the trioctahedral chlorite minerals at the 060°2è reflections near 1.53 and 1.54 ? indicate intense diagenetic conditions (Oboh, 1992., Bauer and Velde, 1995). Illite crystallinity values range from 0.16 to 1.60°2 Ø (Table 4, Fig. 9) and indicates normal burial to thermal diagenetic conditions. Akande and Viczian (1996) have attributed this range to anchimetamorphic conditions. However, the absence of pyrophyllite from the diffractograms precludes anchimetamorphic conditions.

As reported by Reynolds and Hower (1970), the presence of illite/smectite in the shale indicates that there has been diagenetic transformation of smectite. The shallow occurrence of this digenetic transformation within the studied section can be attributed to the geothermal history of the basin. Although heat flow values were probably higher during the Lower Cretaceous as a result of crustal thinning from rifting, such pulses are known to dissipate exponentially through time with active subsidence (Onuoha and Ofoegbu, 1988). Onuoha and Ofoegbu (1988) have explained this situation in the eastern Dahomey Basin, and also pointed out that the bulk of the decrement would have occurred earlier. The lack of dependable data for reconstruction of the burial history from this study limits further discussion on this. Nevertheless, Robert (1988) has shown that there is a range of time over which the maturation of clay minerals and organic matter can be compared to conditions of burial diagenesis. To some extent, this corresponds with the results obtained in this study.

Major elemental ratios

The results of major element oxides of selected samples are presented in Table 5. There is a moderate increase in K_2O with depth from 2.26 to 4.92% (Fig.10). The diagenetic implication of this moderate increase in K_2O between the intervals of 115 and 150m may be attributable to increase in illite content. Robert (1988) has reported that the transformation of smectite to illite is a diagenetic indicator, which can be monitored by the increase in potassium content. This is corroborated by this study. Again, Tucker (2001) has shown that the increase in the Al_2O_3/ (Fe_2O_3 + MgO) ratio with depth indicates increasing degree of diagenetic alteration. In this study, it can be observed that the values for this ratio increased with depth from 7.27(AK02) to (22.07 (AK 40) (Table 5). This also point to increasing diagenetic conditions.

Conclusions and Recommendations

Selected subsurface samples of the shaly facies of Akinbo Formation as penetrated by Akinside 1582 well in eastern Dahomey basin, were investigated to ascertain the hydrocarbon potential and deduce the influence of variations of clay mineral indicators on the prospect.

The values of the total organic content (TOC) show that the sediments have enough organic matter to generate petroleum. In addition, the values of soluble organic matter (SOM) indicate that the bitumen yield is adequate. The sediments are immature to marginally mature from values of bitumen ratio and may be associated with early diagenetic conditions. The cross plots of SOM versus TOC for the samples are within the field of gas proneness to increasing source rock quality. However, arising from the combination of bitumen ratio with bulk maturation parameters, it can be shown that the estimated vitrinite reflectance which is between 0.50-0.69Ro corresponds to the onset of oil generation.

Major element concentrations show moderate increases in K_2O and Al_2O_3/(Fe_2O_3 + MgO) ratio with depth, thus pointing to increasing diagenetic conditions. Clay mineral content of the investigated samples shows illite/smectite, chlorite, smectite, kaolinite while the non-

Table 1: Data of Total organic carbon, extract yield and bitumen ratios compared to maturity parameters of Miles (1989) for Akinside 1582 well

Sample No.	Depth	Lithology	TOC (Wt. %)	Sample Wt (g)	SOM (wt.%)	SOM (ppm)	Bitumen Ratio (mg/gTOC)	Maturity	Vitrinite Reflectance (VR$_0$) EST
AK01	115	shale	1.88	15.20	0.0241	1586	84.36	EM	0.5-0.69
AK02		shale	1.96	10.00	0.0194	1940	98.98	EM	0.5-0.69
AK03	117	shale	1.84	20.22	0.0301	1489	80.92	EM	0.5-0.69
AK04		shale	1.98	20.22	.0134	663	33.48	IM	<0.5
AK06	118	shale	1.63	28.47	0.0402	1412	86.63	EM	0.5-0.69
AK08		shale	1.74	24.20	.0172	712	40.92	IM	<0.5
AK09	120	shale	1.72	12.80	.0198	1547	89.94	EM	0.5-0.69
AK11		shale	1.70	12.80	.0172	1344	79.06	EM	0.5-0.69
AK12	122	shale	1.83	10.00	.0164	1640	89.62	EM	0.5-0.69
AK14		shale	1.83	10.00	.0142	1420	77.60	EM	0.5-0.69
AK15	126	shale	1.70	10.00					
AK16		shale	1.54	10.00	.0128	1280	83.12	EM	0.5-0.69
AK17		shale	1.26	10.00	.0114	1140	90.48	EM	0.5-0.69
AK 18	129	shale	1.64	15.20	0.0234	1539	93.84	EM	0.5-0.69
AK20		shale	1.94	12.08	.0112	927	47.78	IM	<0.5
AK22	134	shale	1.65	10.00					
AK23		shale	1.65	10.00					
AK25	135	shale	1.49	12.80	.0112	875	58.72	IM	<0.5
AK26		shale	1.71	12.80	.0184	1438	84.09	EM	0.5-0.69
AK27	138	shale	0.49	20.20					
AK28		shale	1.85	20.40	.0348	1706	92.22	EM	0.5-0.69
AK29		shale	1.64	10.00	.0125	1250	76.22	EM	0.5-0.69
AK31	141	shale	1.91	10.00	.0124	1240	64.92	IM	<0.5
AK34	145	sh/siltstone	0.74	20.20	.0033	163	22.03	IM	<0.5
AK36		sh/siltstone	0.80	20.20	.0025	122	15.25	IM	<0.5
AK40	152	sandy shale	0.46	20.20	.0015	71	15.43	IM	<0.5

EM-Early mature; MT-Mature; IM-Immature; EST-Estimated

Table 2: Major measured maturation parameters (After Miles, 1989).

	Spore Colour Index	TAI	VR^{0}%	Extract /TOC	Alkane / Extract %	CPI	LOM
Immature	1-3.5	<2.2	<0.5	<70	<25	>1.5	7.0
Early Mature	3.5-5.0	2.2-2.3	0.5-0.65	70-100	25-30	1.5-1.2	7.0-8.0
Peak Mature	5.0-7.0	2.3-2.6	0.65-0.9	>100	30-50	1.2-1.0	8.0-10.0
Late Mature	7- 8.5	2.6-3.5	0.9-1.3	100-50	50	1.0	10-11.5
Post Mature	8.5-10	>3.5	>1.3	<50	<50	1.0	>11.5

TAI=Thermal Alteration Index; VR=Vitrinite Reflectance; CPI=Carbon Preference Index; LOM=Level of Organic Metamorphism

Table 3: Semi-quantitative estimate of clay mineral abundance derived from relative peak intensities (%).

SAMPLE No.	Depth (m)	Lithology	K	I	ML	S	C	TOC %
AK01	115	Shale	10.30	82.4		4.6		1.88
AK02	115	Shale	7.75			0.4		1.96
AK03	117	Shale	13.6			5.0		1.84
AK09	120	Shale	7.1		64.4	5.2	3.5	1.72
AK14	122	Shale	5.8	17.9	0.1	2.4		1.83
AK17	126	Shale		2.4	4.0	12.0	3.8	1.26
AK22	134	Shale	11.2	21.0	62.4			1.65
AK27	138	Shale	3.3	3.3	1.4	16.0	4.9	0.49
AK29	138	Shale		80.6	0.3		7.5	1.64
AK36	145	Shale/siltstone		23.8	68.55		38.4	2.80
AK37	149	Glauconite		5.2			84.6	
AK40	152	sandy shale		5.3	24.7		82.8	0.46

K= kaolinite, I= Illite, ML= Mixed-layer clay (Illite- smectite), C = chlorite

Table 4: Data of variation of Illite Crystallinity with Depth

Epoch	Depth (m)	Sample No.	Lithology	Illite Crystallinity ''2Æ
PALEOCENE - EOCENE	115	AK01	Shale	0.96
	117	AK02	Shale	
	118	AK03	Shale	
	122	AK09	Shale	
	125	AK14	Shale	0.2
	127	AK17	Shale	0.24
	128	AK22	Shale	0.8
	132	AK27	Shale	0.16
	135	AK29	Shale	0.16
	138	AK36	Shale/siltstone	0.64
	141	AK37	Glauconite	1.6
	152	AK40	Sandy shale	

Table 5: Data of major element composition (Wt.%) for studied profile

Oxides	Sample Numbers				
	AK02	**AK17**	**AK29**	**AK37**	**AK40**
SiO_2	69.04	69.75	68.94	65.56	64.09
Al_2O_3	16.95	18.78	20.98	22.97	24.06
K_2O	2.26	3.43	4.72	4.92	5.01
Fe_2O_3	1.00	0.57	0.14	0.77	0.63
Na_2O	1.83	1.21	1.08	1.03	1.32
CaO	1.79	1.48	1,18	1.01	1.96
MgO	1.33	1.06	1.51	0.39	0.46
MnO	0.68	0.57	0.54	0.45	0.26
Others	5.12	3.15	1.36	2.90	2.21
Al_2O_3/ Fe_2O_3+MgO	7.27	11.52	12.70	19.80	22.07

clay minerals include quartz, feldspars, siderite and calcite. Illite crystallinity values range from of 0.16 to 1.60°2 Ø and portray normal to thermal diagenetic conditions. The presence of illite/smectite in the shale indicates that there has been a diagenetic transformation by smectite. These diagenetic transformations of clay minerals represent a progressive evolution, which can be quantified. According to Burst (1969), the transformation of smectite might promote petroleum migration through the release of its interlayer water molecules. In addition, Weiss (1969) has proved that such transformation might aid in organic matter preservation by transporting organic functional groups to adequate sites of physico-chemical alteration.

In this study however, no conclusions have been drawn as to whether the shale sequences of the Akinbo Formation have actually expelled hydrocarbon because the effect of timing has not been considered. Further studies of the migration pathways through mapping of the biomarkers using GC-MS (Gas chromatograph-Mass spectrometry) of the saturate and aromatic fractions of the extracted bitumen are hereby suggested.

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