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RESEARCH ARTICLE

PALEOENVIRONMENTAL STUDIES OF ODAGBO COAL MINE SEQUENCE, NORTHERN ANAMBRA BASIN, NIGERIA: INSIGHT FROM PALYNOMORPH AND GEOCHEMICAL ANALYSES

Adebayo, O. F., *Akinyemi, S. A. and Ojo, A. O.

Department of Geology, Ekiti State University, Ado Ekiti, Nigeria

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ABSTRACT

The palynological study of the northern section of the Anambra basin at Odagbo, southern part of the Benue River was carried out. The coal, silty shale and shaly siltstones were analyzed using standard palynological procedure to enrich the palynological data, date and determine the environment of deposition of the deposits. The heterolithic shales and siltstones yielded some well preserved palynomorphs consisting of 81 angiospermous pollen and 64 pteridophytic spores. Recovered angiosperms include among others *Monocolpites*, *Echitriporites*, *Psilatricolporites* and *Psilatricolpites* while *Laevigatosporites,* monolete and trilete spores constitute the spores. The coal seam underlying the sedimentary sequence is barren of sporomorphs. The monocolpates and tricolporates/tricolpates which dominate the taxa constitute 33% and 23% respectively. The association of *Zlivisporis blanensis, Longapertites marginatus, Mauritiidites lehmani, Proteacidites spp., Retidiporites magdalenensis and Periretisyncolpites spp.* enabled the assignment of Late Maastrichtian age to the deposits. The dominance of palmae flora suggests a tropical to subtropical climate and the recovered assemblage is interpreted as indicative of a warm and humid climate. The geochemical indices such as Th/Cr, Cr/Th, Th/Co and Cr/Ni ratios suggest that these shales were derived from felsic source rocks. The shale units exhibits different degrees of trace-element enrichment, with the approximate order of enrichment relative to an average shale being Y > Zr > Co> Mo > Pb > U>Ba > Cu > Ni > Zn > V > Sr. In addition, based on previously established thresholds, V/Cr, Ni/Co, Cu/Zn, U/Th and V/Sc ratios indicate that these shales were deposited under oxic environment. Besides, the ratio of V (Ni + V) in coal seam and associated shale sequence suggest suboxic to anoxic environment of deposition.

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INTRODUCTION

The first basin where intensive oil exploration was carried out in Nigeria is Anambra Basin. The basin contains about 12,000 m sedimentary fill in its thickest part. The detailed stratigraphic description of Anambra Basin and its environs is available in several publications which include Reyment (1965), Murat (1972), Adeleye (1975), Peters (1978), Ladipo (1988), Agagu and Adighije (1983), Hoque and Nwajide (1984), Agagu *et al*. (1985) and Reijers (1996). The biostratigraphy, paleoenvironments and petroleum geology of the basin have been studied by many authors. Obi *et al*. (2001) employed sedimentological evidences to suggest fluvio-deltaic sedimentation in some sections of the basin while Akinyemi *et al*. (2013) infer that the shale sequences at the western flank of the basin were deposited under oxidizing diagenetic environment based on the analyses of mineralogy and geochemical paleo-redox indicators. Other studies on paleoenvironment and biostratigraphy include Gebhardt (1998) who suggested that benthic foraminiferal assemblage from the lower Mamu Formation at Leru represents deposits of pro-delta to lagoonal environments. Mode (1991) dated the Nkporo Shale, south of Leru, Maastrichtian. There are other outcrop based studies of the Anambra Basin which suggest predominant influence of marginal marine in the Nkporo, Enugu and Mamu formations (Ladipo 1988; Nwajide and Reijers 1996). Agagu and Ekweozor (1982) report that the Awgu and Nkporo shales constitute the main source and seal rocks in the basin while Ekweozor and Gormly (1983) describe the Nkporo Shale as an example of a marine source rock composed of type II/III kerogens with low but consistent contribution from marine organic matter. The work of Unomah and Ekweozor (1993) reveals that the organo-facies of the Nkporo Shales are provincial with the Calabar Flank having the highest oil potential whereas those in the Anambra/Afikpo Basin are gas prone. According to Akande *et al*. (1992), the lower Maastrichtian Coals of the Mamu Formation are

****Corresponding author: Akinyemi, S. A.***
Department of Geology, Ekiti State University, Ado Ekiti, Nigeria

characterized by moderate to high concentrations of huminite and some minor amounts of inertinites and liptinites. Akaegbobi and Schmitt (1998) supported the earlier reports; that the Nkporo Shale is dominated by type III/II Kerogens with dominance of terrestrially derived organic matter. From the review of the literature on the basin, it is obvious that most of the previous investigations are concentrated on the area east and west of the lower Niger River to the exclusion of the parts of the basin north and south of the Benue River (Murat 1972; Dessauvagie, 1974, Avbovbo and Ayoola, 1981, Agagu *et al*., 1985, Ola-Buraimo and Akaegbobi, 2013, Adebayo *et al*., 2015). Much of the basin north and south of Benue River are known palynologically only from a limited number of sites (Umeji, 2005).

Trace elements typically show substantial enrichment in laminated, organic- rich facies, particularly those deposited under euxinic conditions and, equally, little if any enrichment in bioturbated, organic-poor facies (Wedepohl, 1971; Calvert and Pedersen, 1993; Algeo and Maynard, 2004). The geochemical behaviour of trace elements in modern organic rich fine grained sedimentary rocks (i.e. shales) and anoxic basins has often been documented (Brumsack, 1989; Calvert and Pedersen, 1993; Warning and Brumsack, 2000; Algeo and Maynard, 2004). Redox-sensitive trace element (TE) concentrations or ratios are among the mainly extensively used indicators of redox conditions in modern and ancient sedimentary deposits (e.g., Calvert and Pedersen, 1993; Jones and Manning, 1994; Crusius *et al*., 1996; Dean *et al*., 1997, 1999; Yarincik *et al*., 2000; Morford *et al*., 2001; Pailler *et al*., 2002; Algeo and Maynard, 2004). Enrichments of redox-sensitive elements replicate the depositional environment of ancient organic carbon-rich sediments and sedimentary rocks as well and can, consequently, be used to reveal the likely palaeoceanographic conditions leading to their formation (Brumsack, 1980, 1986; Hatch and Leventhal, 1992; Piper, 1994). The degree of enrichment/depletion is usually based on the element/Al ratio in a sample, and calculated relative to the respective element/Al ratio of a common standard material, e.g. average marine shale (Turekian and Wedepohl, 1961).

Although such comparisons have to be handled with care, as the composition of any common standard material is not necessarily representative for a certain erosional source area (Van der Weijden, 2002), they are unproblematic for elements with very high degrees of enrichment/depletion and/or low concentrations in the standard material. High enrichments of redox-sensitive elements in organic carbon rich sediments have been related to anoxic bottom waters. Under reducing conditions these metals may be precipitated as sulfides, co-precipitated with iron sulfides or bound to organic matter (Brumsack, 1980; Jacobs *et al*., 1985, 1987; Brumsack, 1989; Breit and Wanty, 1991; Hatch and Leventhal, 1992; Calvert and Pedersen, 1993; Piper, 1994; Nijenhuis *et al*., 1998). The objectives of the present study therefore include; (i) description of surface lithologic sections of Mamu Formation from Odagbo near Okaba, (ii) generate palynological data to reduce the problem of unavailability of literature on palynology in this section of the basin (iii) employ the recovered palynomorphs to determine the age and environment of deposition of the sediments and (iv) to appraise the use of well known geochemical proxies (i.e. Ni/Co, V/Cr, Cu/Zn and U/Th) for discerning paleogeographical conditions of the coal and associated shale sequence.

Geologic Setting of the Basin

Anambra Basin, a roughly triangular basin, is located in the south eastern part of Nigeria. It lies between longitudes 6.3^0E and 8.0^0E, and latitudes 5.0^0N and 8.0^0N. The basin is bounded in the west by the Okitipupa Ridge, in the south by the Niger Delta Basin, to the northwest it directly overlies the Basement Complex and interfingers with the Bida Basin. The basin is delimited in the north by the Basement Complex, the Middle Benue Trough and the Abakaliki Anticlinorium (Figure 1). Some authors (Akande and Erdtmann 1998, Obaje *et al*., 1999) considered the basin as the Lower Benue Trough, a NE-SW trending, folded, aborted rift basin that runs obliquely across Nigeria. Hence its origin was linked to the tectonic processes that accompanied the separation of the African and South American plates in the Early Cretaceous (Murat 1972; Burke *et al.,* 1972). The rift model had been supported by evidence garnered by structural, geomorphic, stratigraphic and paleontologic studies (Reyment 1969, Burke *et al*. 1972, Benkhelil 1989, Guiraud and Bellion 1995). The evolution of the basin represents the third cycle in the evolution of the trough and its associated basins when the Abakaliki Trough was uplifted to form the Abakaliki Anticlinorium whilst the Anambra Platform was downwarped to form the Anambra Basin (Murat 1972, Weber and Daukoru 1975) resulting in the westward displacement of the trough's depositional axis.

The basin is generally considered a sedimentary succession that directly overlies the facies of the Lower Benue Trough and consists of Campanian to Early Paleocene lithofacies. A great deal of work had been done to elucidate the age, paleoenvironment, paleogeography, sedimentary tectonics, origin of the deposits, the litho- and biostratigrapy and hydrocarbon (or fossil fuel) potentials of the basin (Reyment, 1965; Murat,1972; Salami, 1983; Agagu *et al*., 1985; Akande *et al*., 1992; Nwajide and Reijers, 1996; Akande *et al.,* 2007; Akinyemi *et al*., 2013, 2014). Deposition of sediments in Anambra Basin commenced during the Campanian, with Nkporo and Enugu shales and Owelli Sandstone which are regarded as the Nkporo Group, constituting the basal beds of the Campanian period. The Campanian was a period of short marine transgression and regression, the shallow-sea later became shallower due to subsidence, thereby resulting in a regressive phase during the Maastrichtian which deposited the flood plain sediments and deltaic foresets of Mamu Formation that was regarded as the Lower Coal Measures. Mamu Formation is overlain by the Ajali Sandstone, Nsukka and Imo formations and Ameki Group in that order (Table 1). The detailed stratigraphic description of these formations is available in several publications (Petters, 1978; Agagu *et al*., 1985; Reijers, 1996).

MATERIAL AND METHODS

Location and description of study area

The location of study lies between longitude 07^0 43' 40"E and latitude 07^0 28' 47" N (Fig. 2).

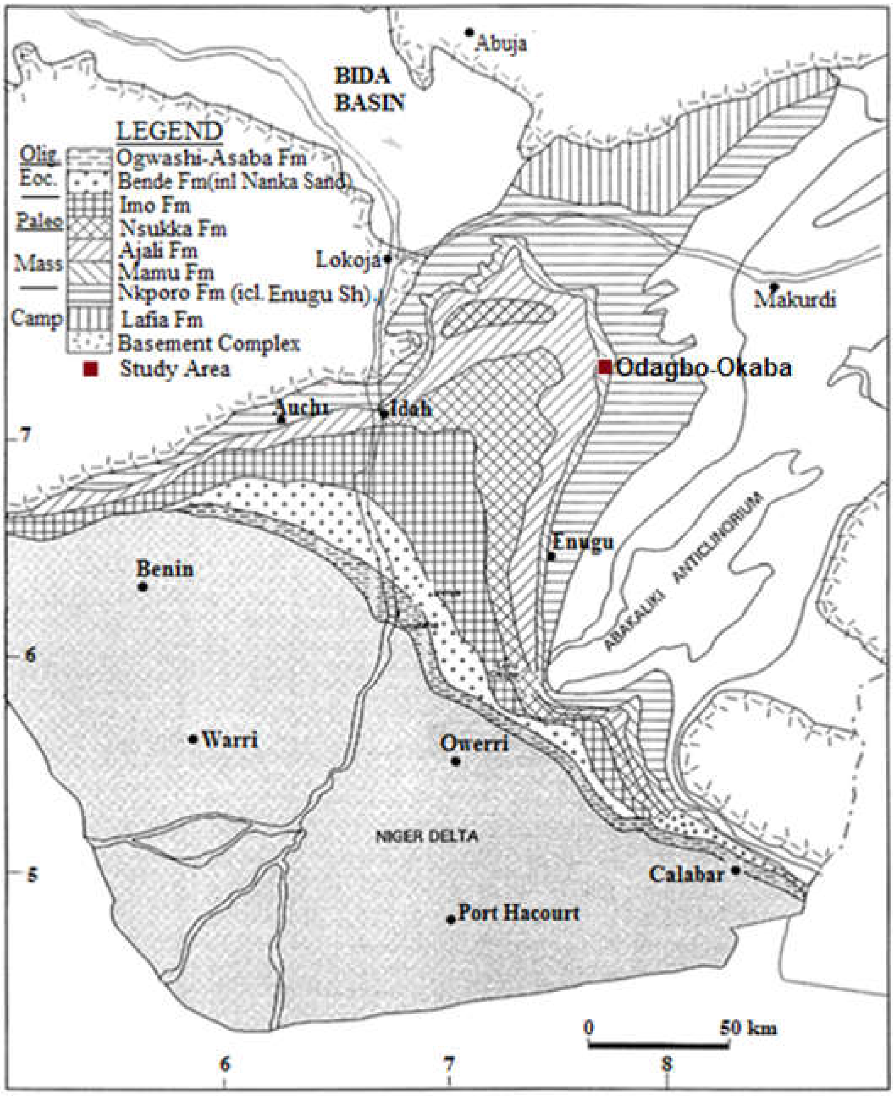


Fig. 1. Geological Map of Anambra Basin Showing the Area of Study (modified after Nwajide 1990)

Table 1. The formations in Abakaliki-Anambra Basin (modified after Nwajide, 1990)

AGE		ABAKALIKI – ANAMBRA BASIN
m.y 30	Oligocene	Ogwashi-Asaba Formation
54.9	Eocene	Ameki/Nanka Formation/ Nsugbe Sandstone (Ameki Group)
65	Palaeocene	Imo Formation
		Nsukka Formation
73	Maastrichtian	Ajali Formation Mamu Formation
	Campanian	Nkporo Shale /Oweli Formation/Enugu Shale **(Nkporo Group)**
83 87.5	Santonian	
88.5	Coniacian	Agbani Sandstone/Awgu Shale
	Turonian	Eze Aku Group
93 100	Cenomanian – Albian	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units
Precambrian		Basement Complex

It is an opencast coal mine at Odagbo which is about 4 km from Okaba, Kogi State. The mine consists of 0.8 m thick (exposed section) bituminous coal with over 3 - 6 m overburden (Fig. 3). The very dark coloured coal is overlain by light grey silty shale (heterolithic) that grades into light grey to brownish laminated and mottled siltstone at the top.

Fusion bead method for Major element analysis

- Weigh 1.0000 g ± 0.0009 g of milled sample
- Place in oven at 110^oC for 1 hour to determine H_2O+
- Place in oven at 1000^oC for 1 hour to determine LOI

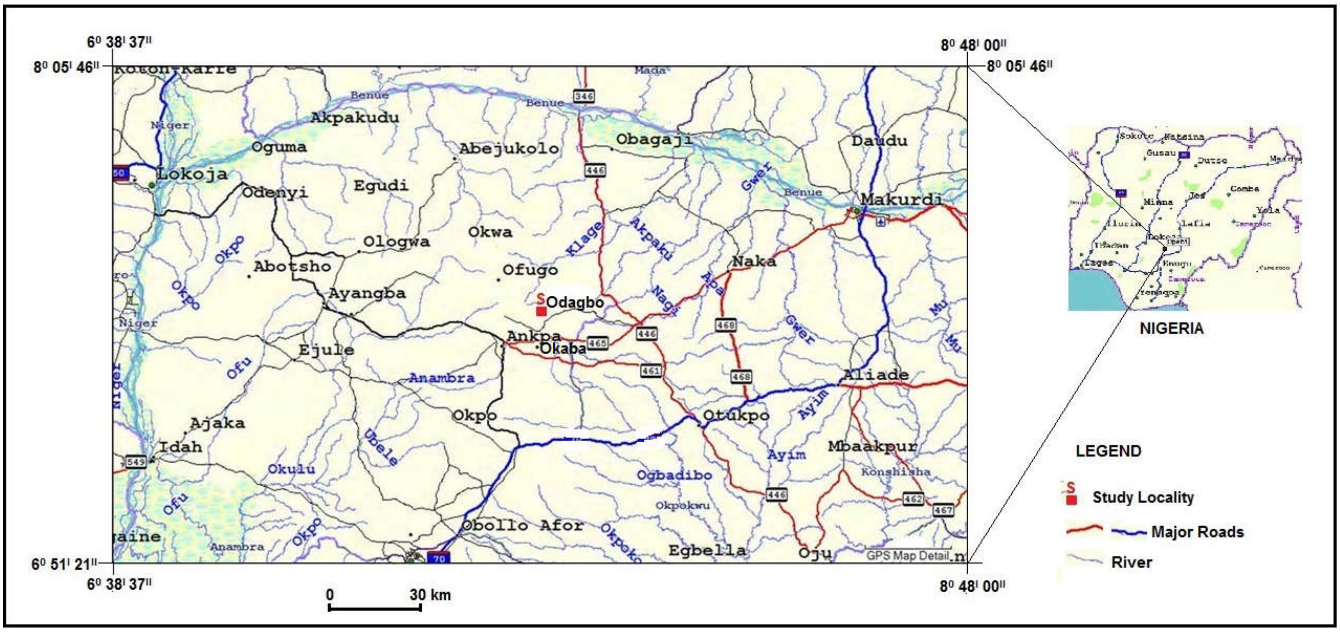


Fig. 2. Location map of Odagbo coal mine

Palynomorph analysis

Palynological sample preparation followed the standard procedures of using HF and HCl to remove the matrix (silicates and carbonates) and oxidized by adding concentrated nitric acid (Faegri and Iversen 1989, Wood *et al.* 1996). The residues were sieved through 5 µ size nylon sieve mesh. Photomicrographs were taken using a light microscope equipped camera.

XRF and LA-ICPMS analyses

The pulverized coal and shale samples were analysed with XRF and LA-ICPMS technique. The elemental data for this work have been acquired using X- ray fluorescence (XRF) and Laser Ablation inductively coupled plasma spectrometry (LA-ICPMS) analyses.

The analytical procedures are as follows;

Pulverised shale samples were analysed for major element using Axios instrument (PANalytical) with a 2.4 kWatt Rh X-ray Tube. Further, the same set of samples were analysed for trace element using LA-ICPMS instrumental analysis. LA-ICP-MS is a powerful and sensitive analytical technique for multi-elemental analysis. The laser was used to vaporize the surface of the solid sample, while the vapour, and any particles, were then transported by the carrier gas flow to the ICP-MS. The detailed procedures for sample preparation for both analytical techniques are reported below.

- Add 10.0000 g ± 0.0009 g Claisse flux and fuse in M4 Claisse fluxer for 23 minutes.
- 0.2 g of $NaCO_3$ was added to the mix and the sample+flux+$NaCO_3$ was pre-oxidized at
- 700°C before fusion.
- Flux type: Ultrapure Fused Anhydrous Li-Tetraborate-Li-Metaborate flux (66.67 % $Li_2B_4O_7$ + 32.83 % $LiBO_2$) and a releasing agent Li-Iodide (0.5 % LiI).

Pressed pellet method for Trace element analysis

- Weigh 8g ± 0.05 g of milled powder
- Mix thoroughly with 3 drops of Mowiol wax binder
- Press pellet with pill press to 15 ton pressure
- Dry in oven at 100^oC for half an hour before analysing.

These analytical methods yielded data for eleven major elements, reported as oxide percent by weight [SiO_2,TiO_2, Al_2O_3, Fe_2O_3, MgO, MnO, CaO, Na_2O, K_2O, Cr_2O_3 and P_2O_5] and 21 trace elements [Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Co, V, Pb, Th, U, Ti, Cr, Ba, La, Ce, Nd and P] reported as mg/kg (ppm).

RESULTS AND DISCUSSION

Sedimentology, palynomorph assemblage and paleoenviroment

The heterolith on top of the coal seam is sandier upward and is overlain by ripple, laminated and mottled siltstones (Fig 3).

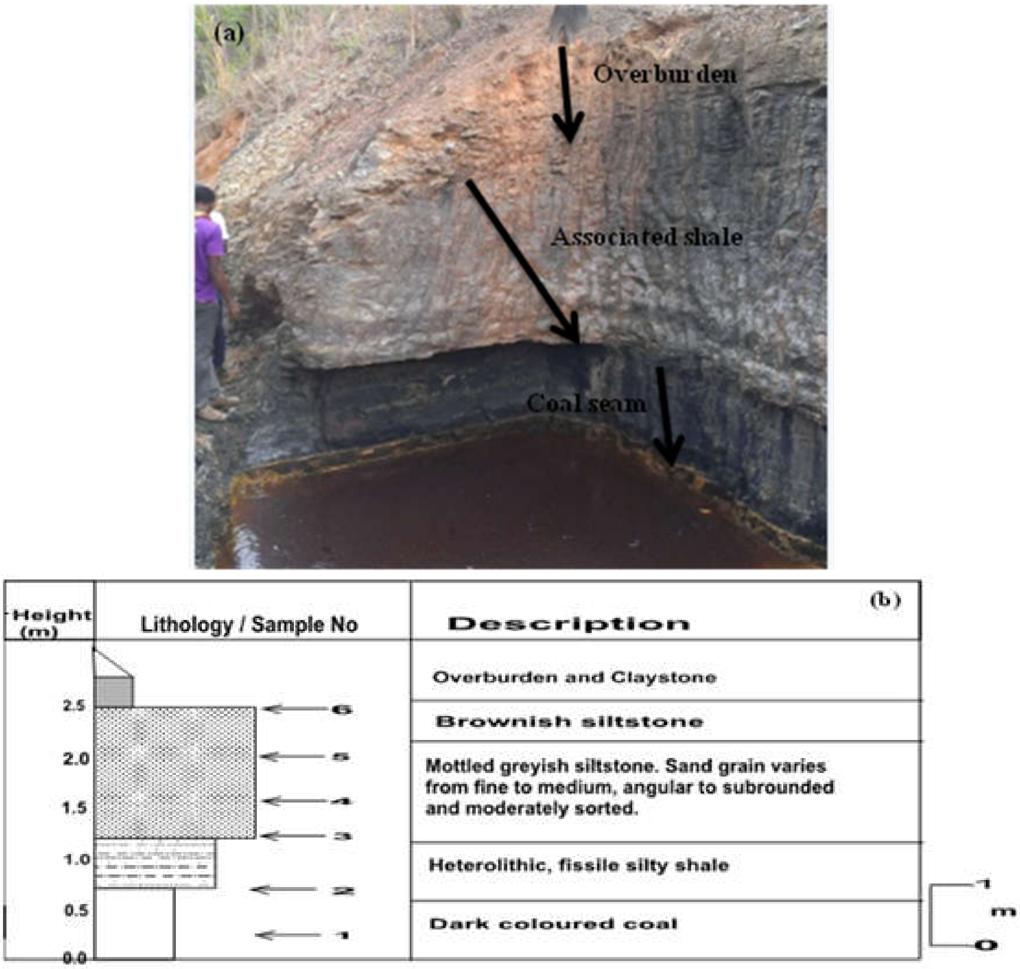


Fig. 3. (a) Odagbo coal seam and the overlying sedimentary sequence and (b) the litho-log of the section

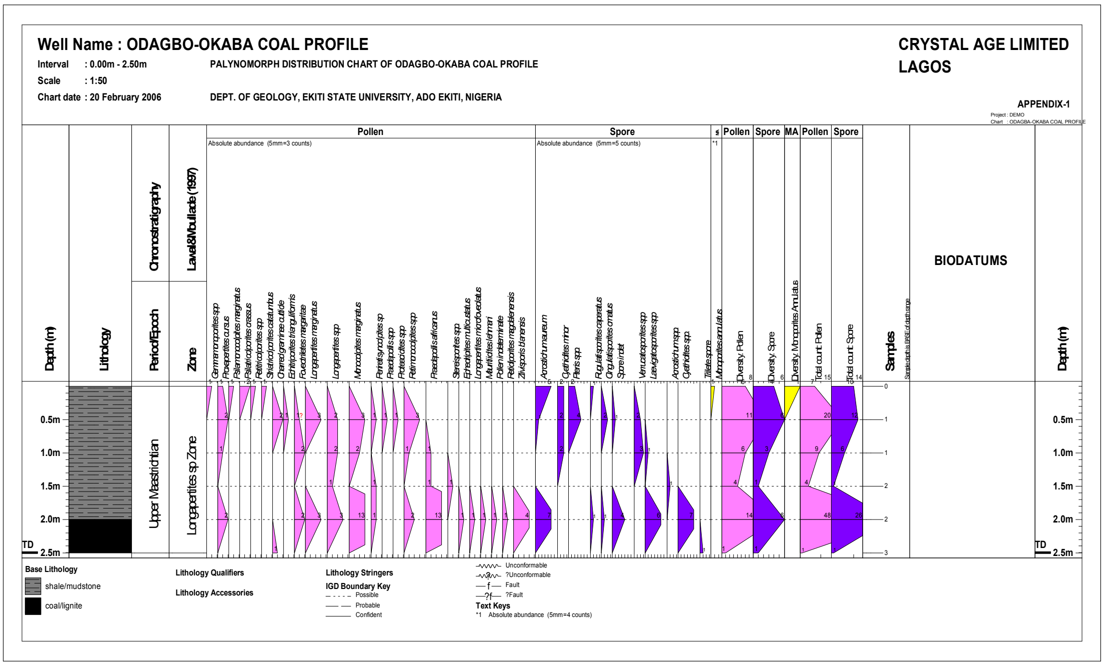
The heterolithic shales and siltstones yielded some well preserved palynomorphs consisting of 81 angiospermous pollen and 64 pteridophytic spores (Fig.4). Recovered angiosperms include among others *Monocolpites*, *Echitriporites*, *Psilatricolporites* and *Psilatricolpites* while *Laevigatosporites,* monolete and trilete spores constitute the spores. No marine palynomorph was recovered. The coal seam that underlies the sedimentary sequence is barren of sporomorphs with the exception of only one specimen of trilete spore. The most abundant taxa of angiosperm pollen recovered are monocolpates (e.g. *Monocolpites marginatus*, *Longapertites* spp.), tricolporates/tricolpates (e.g, *Psilatricolporites crassus, Praedapollis africanus*, *Periretisyncolpites* sp., *Retricolporites* sp.) which constitute 33% and 23% respectively. Other angiosperms occur in minor constituents. *Acrostichum aureum* (23.8%), *cyathidites minor/ cyathidites* spp. (23, 8%) dominate the pteridophytic spores.

The association of *Zlivisporis blanensis, Longapertites marginatus, Mauritiidites lehmani, Proteacidites* spp., *Retidiporites magdalenensis and Periretisyncolpites* spp. suggests a Maastrichtian age (Eisawi and Schrank 2008, Lawal and Moullade 1986, Schrank 1994). The monocolpate fossil pollen taxa listed above are essentially similar to the angiospermous elements recovered in Tani Basin in Ghana by Atta-Petters and Salami (2004). They have also been recorded from Palmae Province of Senegal and Ivory Coast (Jardiné and Magloire 1965), Brazil (Herngreen 1975), northern South America (Muller *et al*. 1987), Venezuela, Colombia, Nigeria, Carribean, Borneo (Germeraad *et al.* 1968), Nigeria (Edet and Nyong, 1994; Salami 1982, 1984, 1985, 1988, 1990), Northern Somalia (Schrank 1994), Egypt (Schrank 1987; El Beialy 1995), Sudan (Schrank 1987) and India (Thanikaimoni *et al.* 1984). These fossil palms fit into the Late Cretaceous Palmae Province of Africa, South America and India described by Herngreen and Chlonova (1981), Herngreen *et al.* (1996), and Atta-Petters and Salami (2004). The dominance of palmae flora suggests a tropical to subtropical climate and the recovered assemblage is interpreted as indicative of a warm and humid climate (Herngreen 1998). Paleoenvironments of deposition of the sediments are reconstructed by putting together evidence from the type of lithology, sedimentary structure, textural characteristic, fossil content and geochemical data.

The paleoenvironments of deposition of the sediments of Nkporo Formation have been the subject of discussion by various authors (Adebayo and Ojo, 2004, Ojo *et al*., 2009, Chiaghanam *et al*., 2012). Mottled siltstones suggest fluctuating climate while the wavy laminated heteroliths indicate deposition under a quite low energy condition. The presence of charred graminae cuticles denotes proximity to fluviodeltaic source and moderately distal oxic environment of deposition (Carvalho *et al.,* 2006). The trilete and monolete forms are structurally and sculpturally comparable to some of the extant forms of the families Cyatheaceae and Polypodiaceae, some of which are known to inhabit fresh water swamps and marshes (Atta-Peters and Salami, 2004). Al-Ameri *et al.* (2001) have also interpreted such as deposition in a swamp marsh and fluvial dominated environment. Palynologically, the sediments can be said to be deposited in lacustrine brackish-water swamps and marshes environments based on the preponderance of *Acrostichum aureum*, *Laevigatisporites* spp. and *Psilatricolporites crassus* (Tomlinson 1986, Velasquez, 1994).

Provenance and paleo-redox conditions

According to Armstrong-Altrin *et al.* (2004) a low concentration of Cr indicates a felsic provenance, and high contents of Cr and Ni are mainly found in sediments derived from ultramafic rocks. Chromium and nickel concentrations are low in the studied shale samples (Table 3). Consequently, the low Cr/Ni ratios (i.e. 3.76 – 27) indicate that felsic components were the main components among the basement complex source rocks. Ratios such as La/Sc, Th/Sc, Th/Co, and Th/Cr are significantly different in felsic and basic rocks and may allow constraints on the average provenance composition (Wronkiewicz and Condie, 1990; Cox *et al*., 1995; Cullers, 1995).



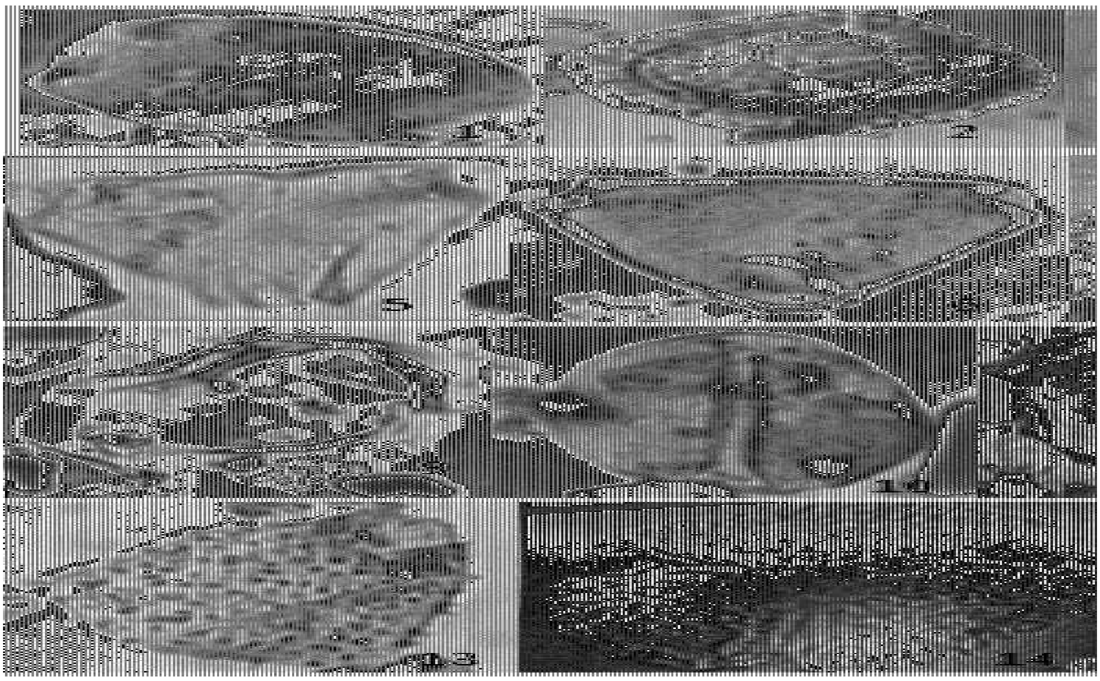


Plate (x1000)

Fig. 4: 1. *Retidiporites* spp.; 2. Cingulatisporites ornatus Germeraad, Hopping and Muller, 1968; 3. *Laevigatosporites* spp.; 4. *Foveotriletes margaritae* (Van der Hammen) *Germeraad*, Hopping and Muller, 1968; 5. *Proteacidites sigalli Boltenhagen*, 1978; 6. *Proteacidites* spp.; 7. *Pachydermites diederixi Germeraad*, Hopping and Muller, 1968; 8. *Gemmamonoporites* sp. 9. *Psilatricolporites* crassus van der Hammen and Wijmstra,1964; 10. *Monocolpites* marginatus van der Hammen, 1954; 11. *Verrucatosporites* spp.; 12, 13. *Echitriporites* trianguliformis van Hoeken-Klinkenberg 1964; 14. *Retitricolporites* irregularis van der Hammen and Wijmstra 1964; 15. *Cyathidites minor* Couper 1953; 16. *Longapertites* spp.

The ratios of Th/Cr (~0.24 – 0.43), Cr/Th (~2.6 – 4.18), Th/Co (~0.20 – 1.36) and Cr/Ni (~1.76 – 2.76) suggests that the shale sequence were derived from felsic source rocks (Cullers, 1994; 2000; Nagarajan, 2007). Trace element ratios such as Ni/Co, V/Cr, Cu/Zn and U/Th have been used to evaluate paleoredox conditions (Hallberg, 1976; Jones and Manning, 1994). The ratio of uranium to thorium may be used as a redox indicator with U/Th ratio being higher in organic rich mudstones (Jones and Manning, 1994). U/Th ratios below 1.25 suggest oxic conditions of deposition, whereas values above 1.25 indicate suboxic and anoxic conditions (Jones and Manning, 1994; Nath *et al*., 1997).

The present study shows low U/Th ratio (~0.27 – 0.31) (Tables 2 and3), which indicate that coal seam and associated shale sequence were deposited in an oxic environment. A few numbers of authors have used V/Cr ratio as an index of paleooxygenation (Dill, 1986; Dill *et al.,* 1988; Nagarajan, 2007). Bjorlykke (1974) reported the incorporation of Cr in the detrital fraction of sediments and its possible substitution for Al in the clay structure. Vanadium may be bound to organic matter by the incorporation of V^{4+} into porphyrins, and is generally found in sediments deposited in reducing environments (Shaw *et al.,* 1990). According to Jones and Manning (1994), the V/Cr ratios above 2 indicate anoxic conditions, whereas values below 2 suggest more oxidizing conditions. Accordingly, the V/Cr ratios of coal seam and associated shale sequence vary between 1.14 and 1.53, (Tables 2 and 3) which indicates that they were deposited in an oxic depositional environment. A number of authors have used the Ni/Co ratios as a redox indicator (Dypvik, 1984; Dill, 1986; Nagarajan, 2007). Jones and Manning (1994) showed that the Ni/Co ratios below 5 indicate oxic environments, whereas ratios above 5 suggest suboxic and anoxic environments. The Ni/Co ratios vary between 0.48-1.93 (Tables 2 and 3) suggesting that coal seam and associated shale sequence were deposited in a well oxygenated environment. The Cu/Zn ratio is also used as a redox parameter (Hallberg, 1976).

According to Hallberg (1976) high Cu/Zn ratios indicate reducing depositional conditions, while low Cu/Zn ratios suggest oxidizing conditions. Therefore, the low Cu/Zn ratios (~0.20 – 0.44) in the shale sequence (Table 3) indicate that they were deposited under oxidizing conditions. On the other hand, the high Cu/Zn ratio (~2.82) in the coal seam indicates reducing conditions. According to Hatch and Levantal (1992), V/(Ni + V) ratios below 0.46 indicate oxic environments, but ratios above 0.54 to 0.82 suggest suboxic and anoxic environments. The V/(Ni + V) ratios in the coal seam and associated shale sequence vary between 0.64 and 0.78 which indicate suboxic to anoxic environment of deposition. Kimura ve Watanabe (2001) showed that the V/Sc ratios below 9.1 indicate oxic environment of deposition. The V/Sc ratios in the coal seam and associated shale sequence (such as Sh_2, Sh_3, Sh_4 and Sh_5) indicate oxic environment of deposition. On the contrary, only shale sample code-named Sh_1 shows V/Sc ratio above 9.1. The closeness between Ni and Cr concentration levels as well as V/Ni ratio for the coal seam (Table 3) indicate that the organic matter is derived from terrestial/marine and are of low maturity. This agreed with earlier work done on this coal seam by other workers (Adedosu *et al*., 2007; Okorie and Egila, 2014).

Trace element enrichments

The enrichment factors (EF) were evaluated by normalizing each trace element to Al, which is understood to suggest the detrital influx, and comparing these ratios to those of normal shale. The enrichment factor (EF) is equal to (Element/Al) / (Element/Al) shale, where the ratio in the numerator is that for the shale in question, and the ratio in the denominator is that for a ‘‘typical’’ shale (using data from Wedepohl, 1971 and 1991). This approach has been used by various authors to evaluate trace-element enrichments in modern and ancient sediments (e.g., Calvert and Pedersen, 1993; Arnaboldi and Meyers, 2003; Rimmer, 2004). The trace elements data in the coal seam and associated shale sequence show different levels of enrichment (Table 4).

Trace element enrichments

The enrichment factors (EF) were evaluated by normalizing each trace element to Al, which is understood to suggest the detrital influx, and comparing these ratios to those of normal shale. The enrichment factor (EF) is equal to (Element/Al) / (Element/Al) shale, where the ratio in the numerator is that for the shale in question, and the ratio in the denominator is that for a‘‘typical’’ shale (using data from Wedepohl, 1971 and 1991). This approach has been used by various authors to evaluate trace-element enrichments in modern and ancient sediments (e.g., Calvert and Pedersen, 1993; Arnaboldi and Meyers, 2003; Rimmer, 2004). The trace elements data in the coal seam and associated shale sequence show different levels of enrichment (Table 4).

Summary and conclusion

The coal facies sequence at Odagba mine consists of a thick ~~of~~ coal seam, silty shales (heteroliths) and mottled siltstones. The typical vertical trend within this facies is one of coarsening-upwards, both within the heterolith and siltstone members. Miall (1996) was of the opinion that interbedded claystones/siltstones or laminated facies are common in overbank area, and represent deposition from suspension in a calm environment or weak traction currents. Therefore this sequence was probably deposited from suspension below storm-wave base where sediments are usually deposited in a quiet low energy environment.

According to Coleman and Prior (1981), lake bottoms deposits, where anoxic condition prevailed, consist of dark grey to black organic-rich clays containing scattered silt lenses. The presence of dark grey shales and some slumps suggest that deposition occurred at the apex of a distributary system, probably in a lacustrine environment. A swampy shallow lake is therefore suggested due to the lack of marine shells, presence of some faintly burrowed horizons, organic-rich shales (Ntamak-Nida *et al*. 2008, 2010) and some oxidised claystones.

Table 2. Some trace element ratios to evaluate paleoredox conditions

Element ratios	Oxic	Dysoxic	Suboxic to Anoxic	Euxinic
Ni/Co[1]	< 5	5 to 7	> 7	
V/Cr[1]	< 2	2 to 4.25	> 4.25	
U/Th[1]	< 0.75	0.75 - 1.25	> 1.25	
V/(Ni+V)[2]	< 0.46	0.46 - 0.60	0.54 - 0.82	> 0.84
V/Sc[3]	< 9.1			

[1]Jones and Manning (1994); [2]Hatch and Levantal (1992);[3]Kimura ve Watanabe (2001).

Table 3. Trace elements (mg/kg) and element ratios in coal seam and associated shale sequence

Element	Aver.shale	Sh_1	Sh_2	Sh_3	Sh_4	Sh_5	C_S	Element	Aver. shale	Sh_1	Sh_2	Sh_3	Sh_4	Sh_5	C_S
As	10	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	Mn	850	126.55	132.76	355.84	387.25	527.65	323.20
Ni	68	16.38	21.57	26.50	28.63	28.33	9.49	Ce	*nd*	67.73	98.53	98.96	111.81	138.25	12.90
Cu	45	15.40	18.38	22.95	12.76	31.70	9.52	Nd	*nd*	28.71	41.40	41.62	47.76	60.59	6.11
Zn	95	38.17	45.80	51.79	63.32	79.32	3.37	Sc	*nd*	12.83	13.28	14.32	14.58	17.25	4.24
Pb	22	20.77	21.77	34.57	13.23	49.18	2.88	Nb	*nd*	14.67	16.23	16.11	21.25	27.38	10.16
Rb	140	31.95	38.07	43.44	49.41	62.56	1.30	Cs	*nd*	1.45	1.63	1.33	1.79	4.00	0.11
Sr	300	65.43	62.72	77.04	82.19	82.49	24.17	Pr	*nd*	7.63	10.87	11.10	12.47	15.74	1.48
Y	41	23.48	31.69	29.85	42.98	45.44	16.59	Sm	*nd*	5.14	7.55	7.76	9.45	11.67	1.32
Zr	160	694.11	1082.84	867.83	860.26	659.67	106.89	Eu	*nd*	0.95	1.40	1.42	1.79	2.37	0.35
Nb	*nd*	14.67	16.23	16.11	21.25	27.38	10.16	Gd	*nd*	4.62	6.38	6.26	7.86	9.45	1.84
Pb	*nd*	20.77	21.77	34.57	13.23	49.18	2.88	Tb	*nd*	0.68	0.91	0.92	1.23	1.41	0.31
Th	*nd*	11.53	17.48	16.57	18.07	22.21	4.00	Dy	*nd*	3.77	5.68	5.59	7.38	8.39	2.10
U	3.7	3.28	5.15	4.45	5.63	6.62	1.07	Ho	*nd*	0.82	1.13	1.12	1.51	1.67	0.48
Mo	1	1.20	1.74	1.16	1.49	1.91	0.63	Er	*nd*	2.43	3.49	3.26	4.72	4.87	1.45
V	130	50.51	53.05	47.04	61.87	98.37	25.58	Tm	*nd*	0.34	0.49	0.45	0.71	0.68	0.20
Cr	90	40.05	46.56	38.85	51.89	78.22	16.70	Yb	*nd*	2.80	3.88	3.50	5.11	4.88	1.35
Co	19	8.48	20.06	24.15	25.22	35.31	19.65	Lu	*nd*	0.39	0.57	0.53	0.77	0.72	0.20
Ba	580	642.11	500.82	651.58	631.52	719.51	115.04	Hf	*nd*	18.40	29.24	22.84	23.19	17.88	2.74
La	*nd*	33.53	47.63	46.53	52.24	64.77	7.28	Ta	*nd*	1.07	1.25	1.50	1.62	2.14	0.99
Ni/Co	3.58	1.93	1.08	1.10	1.14	0.80	0.48	Cr/Th	28	3.47	2.66	2.34	2.87	3.52	4.18
V/Cr	1.50	1.26	1.14	1.21	1.19	1.26	1.53	Th/Co	0.006	1.36	0.87	0.69	0.72	0.63	0.20
U/Th	*nd*	0.28	0.29	0.27	0.31	0.30	0.27	Th/Cr	0.036	0.29	0.38	0.43	0.35	0.28	0.24
Cr/Ni	1.32	2.45	2.16	1.47	1.81	2.76	1.76	Cu/Zn	0.053	0.40	0.40	0.44	0.20	0.40	2.82
V/Sc	*nd*	10.14	3.99	3.29	4.24	5.70	6.04	V/(Ni+V)	0.66	0.76	0.71	0.64	0.68	0.78	0.73
V/Ni	1.91	3.08	2.46	1.78	2.16	3.47	2.69								

Palynological analysis of the heterolithic shales, siltstones and bituminous coal samples from the Mamu Formation at Odagbo mine in the upper Anambra Basin yielded a total of 145 species. Fifty six percent (56%) of the palynomorphs were pollen while 44% spores. The recovered palynomorphs such as *Retidiporites magdalenensis, Foveotriletes margaritae, Longapertites microfoveolatus, Proxapertites cursus, Periretisyncolpites* sp. enabled assignment of Late Maastrichtian to the studied sequence. The sediments are interpreted to be deposited in lacustrine brackish-water swamps and marshes environments based on the preponderance of *Acrostichum aureum*, *Laevigatisporites* spp. and *Psilatricolporites crassus*. The botanical affiliation of the recovered microflora shows close relationship to the palme taxa of the Senonian period and therefore belong to the Senonian Palme Province of tropical Africa and South America (ASA). The studied shales exhibit different degrees of trace-element enrichment, with the approximate order of enrichment relative to average shale being in the order: Y > Zr > Co> Mo > Pb > U>Ba > Cu > Ni > Zn > V > Sr. The trace element redox indices ratios such as V/Cr, Ni/Co, Cu/Zn, U/Th and V/Sc, infer that these shale sequence were deposited under oxic environment. Furthermore, the ratio of V (Ni + V) in coal seam and associated shale sequence suggest suboxic to anoxic environment of deposition. Therefore, the lithological, palynological and geochemical analyses of the studied coal – shale facies suggest environment ranging from suboxic to anoxic.

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