

Principal Component and Cluster Analyses of Palynodebris from Aj-X Well, Offshore Dahomey Basin and their Environmental Significance

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Abstract

The palynofacies study carried out on offshore ditch cuttings from AJ-X well in Dahomey basin revealed different types of palynodebris. To assess the pattern of distribution of the palynofacies types, their abundances were submitted to Cluster analysis and Principal component analysis. The PCA diagram consists of four curves, PC1, PC2, PC3 and PC4 with a cumulative variance of 45.8% showing fluctuations in PC curves supporting the response of the palynodebris to changing environments. The cluster for the well revealed two super clusters based on the abundance and composition of the kerogen groups. These are informally designated as: super cluster X, which is subdivided into X1, X2 and X3, and super cluster Y, subdivided into Y1 and Y2. X1 is composed mostly of phytoclasts and a moderate abundance of the AOM group (Phy/AOM); X2 of high abundances of phytoclasts combined with moderate to high abundances of palynomorphs (Phy/Pal); and X3 is composed of very high abundances of phytoclasts (Phy). The high abundances of the AOM group occur in super cluster Y. Y1 is characterized by very high abundances of the AOM group. In Y2 this group occurs with phytoclasts and, in particular with the palynomorph group (AOM/Pal). The major break that occurred between clusters X and Y is strongly related to the abundance of the phytoclasts group. The size, shape and texture of all the components were integrated with sedimentological features and palynomorphs to recognize distal suboxic-anoxic shallow neritic shelf environment.

Keywords: Palynodebris; Cluster analysis; Principal component analysis; Nearshore estuarine; Middle/outer neritic; Dahomey basin

Introduction

Combaz [1] introduced the concept of palynofacies which refers to suites of palynodebris. Subsequently, Batten [2,3] applied the concept towards understanding provenance of sediments and the association of palynodebris with hydrocarbon. Its usefulness for environmental interpretations had been demonstrated by several workers, e.g., Fisher [4], van der Zwan [5] and Davies et al. [6]. A wide range of terminologies for classifying palynodebris have resulted from these studies, some of which can be found in Bujak et al. [7], Habib [8], Venkatachala [9], Masran and Pocock [10], Parry et al. [11], Whitaker [12], Boulter and Riddick [13] and Lorente [14]. The eastern Dahomey basin or the Nigeria sector contains extensive wedge of Cretaceous to Recent sediments, up to 3000 m which thicken towards the offshore.

Various workers have studied the various sediments of the eastern Dahomey basin and came forward with documentations concerning its age, lithology, structure, mineralogy etc. In coastal and offshore areas of the basin, sediments in excess of 3000 m thick ranging from Albian to late Miocene have been recorded from exploration drilling [15-17]. Biostratigraphic zonations of the sediments from these wells have been studied based on palynological studies [15,16] and on micropaleontological work [16,17]. Sediments age range generally from upper cretaceous to Miocene. However, Neocomian age sediments have been identified in Ise-1 and Ise-2 wells [16] and Pre-Albian folded sediments in offshore Benin Republic [18]. Upper Albian sediments have been recognized based on palynological studies [15].

Billman [18] showed from wells drilled a few kilometers off the coast of Benin Republic that late Cretaceous rocks (Afowo formation) unconformably overlie essentially non marine sandstones of early cretaceous (Albian) which in turn conformably overlie unknown thickness of non fossiliferous folded pre-Albian sediments. Jan du Chene et al. [15]; De Klasz [19] and Billman [18] have all shown the presence of stratigraphic gaps in some of the coastal and offshore wells. However, Billman [20] was the only published work on the offshore part. Billman [20] worked on offshore samples from the Republic of

Benin end of the basin. The study area lies within latitude 0070381 N–0070401 N and longitude 0030341 E- 0030371 E, within the offshore eastern Dahomey basin about 40 miles southwest of Lagos on the border with Benin Republic (Figure 1).

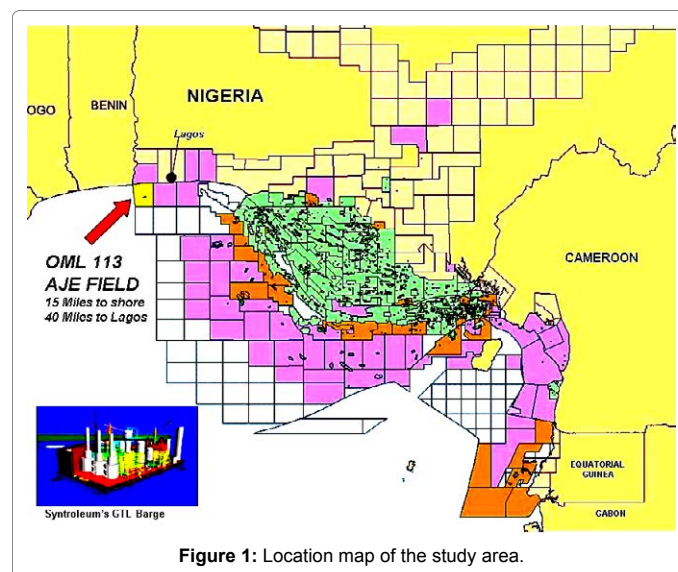


Figure 1: Location map of the study area.

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This work presented here is on the multivariate statistical analysis of palynodebris as seen by transmitted light microscope from 30 samples from the AJ-X well to enhance further understanding of the evolution of the basin, offshore. They were subjected to Principal component analysis and Average linkage analysis and the emergent palynofacies showed good correlations with the lithofacies identified from grain size and textures.

Methods

The six lithofacies units identified in the well formed the samples used for the analysis (Table 1). These lithofacies units varied from light to medium grey homogenous shales to very fine grained, poorly sorted sandy siltstones. However, most samples for palynodebris analysis were taken from the shaly fractions because of more abundance of sedimentary organic matter in such lithologies.

The maceration residues were obtained from the digestion of sediments in 50% HCL acid for 24 hrs followed by two weeks in cold 60% HF acid. Boiling the samples in 50% HCL acid for about 10 mins allowed the removal of excess fluorosilicates and fluorides which might have formed during the HF acid treatment. For the purposes of good color preservation of the palynodebris to aid in interpretation, oxidation stage was omitted. The residues were then sieved to remove the acid insoluble materials below 10 µm in size after heavy liquid separation with Zinc bromide (Specific gravity =2.1). The samples were also centrifuged after each step outlined above. Two hundred counts per slide were made and care was taken to macerate about 25 g of sediments and standardize the concentrations of residues mounted on the slide in order to minimize slide-making bias.

Multivariate statistical analysis was performed with PAST (Paleontological statistics software package for education and data analysis) software for principal component analysis and the average linkage cluster analysis. The principal component analysis was used to analyze the log transformed percentage values of the palynodebris using a covariance matrix because of the reduction in skewness of the data resulting from the log transformation. The unweighed paired average clustering method was carried out on a matrix generated by the Spearman rank-order which is a non parametric version of the Pearson product-moment correlation coefficient for the palynodebris and samples. It is a quantitative, similarity measure in which correlations are based on the rank-order rather than on the actual abundance [21].

Discussion of Results

Descriptions of palynodebris types identified

Amorphous organic matter group: This group is made up of AOM and RESIN which are structureless particles (Figure 2A and 2B).

AOM is a structureless material, yellow-orange-red; orange-brown;

grey, homogeneous; with “speckles”; and clotted; with inclusions (pyrite). It is flat; irregular; angular; pelletal (rounded elongate/oval shape). It is present in very large amounts in most of the samples.

Resin is a structureless particle, hyaline, homogeneous, non-fluorescent, rounded, sharp to diffuse outline. It is derived from higher plants of tropical and subtropical forest. They appear to be more common in sandstones fractions than the shales and this can be attributed to the predominance of angiosperms in the vegetation.

Phytoclasts group: The phytoclasts group consists of structured particles which includes Opaque equidimensional (O-Eq), opaque-lath (O-La), fungal hyphae (Fh), wood tracheid with visible pits (Wp), wood tracheid without visible pits (Ww), cuticles (Cu) and membranes (Mb) (Figure 2C-2I).

Equidimensional (O-Eq): Are black particles from wood material

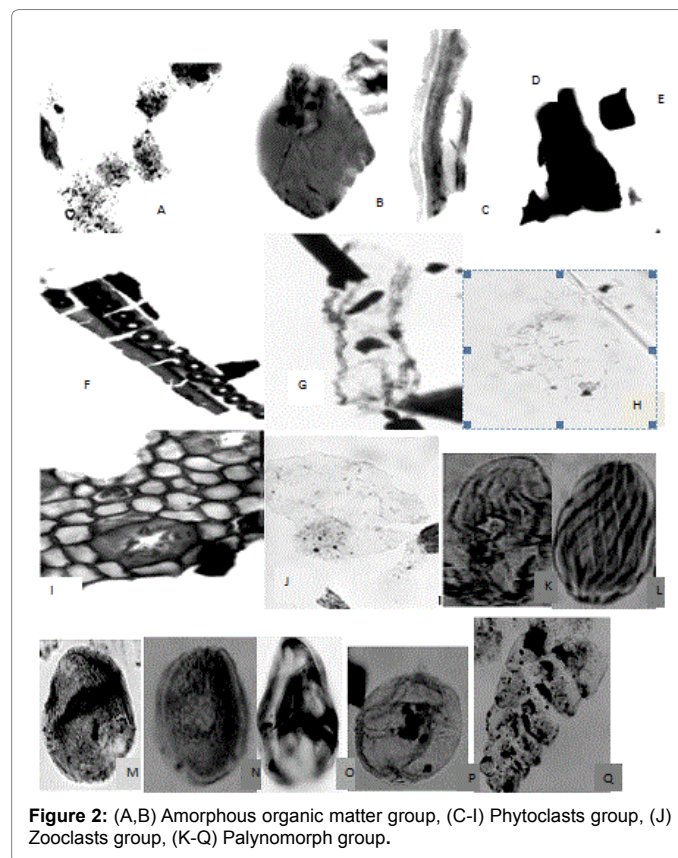


Figure 2: (A,B) Amorphous organic matter group, (C-I) Phytoclasts group, (J) Zooclasts group, (K-Q) Palynomorph group.

Facies	Thickness	Characteristics
100% shale	289 m	Light grey to medium grey, firm to moderately hard, earthy to waxy texture, in part very soft and sticky. In parts moderately hard, blocky to sub fissile, very slightly calcareous (shows effervescence with dilute HCL), with very rare pyritised microfossils. Contains glauconitic materials
100% Glauconitic sequence of shales	406 m	medium grey, pale blue grey, soft to moderately firm, moderately hard, sub blocky to blocky, rarely sub fissile, earthy to waxy texture, very slightly calcareous in part, very rare pyritised micro fossils with trace Limestone which is white, off white, very hard to hard, and microcrystalline.
80% Sandstone +20% Siltstone		grey brown, very fine to fine grained, sub angular to sub rounded, micromicaceous, moderately well sorted
70% Siltstone +30% sandstones		Light grey, medium grey, very soft to soft, sticky, slightly calcareous.
		Poorly sorted interbeds
60% Siltstone +30% Shale	299 m	Light grey, medium grey, very soft to soft, sticky, firm to amorphous, slightly calcareous, micromicaceous
		Light grey, medium grey, sub blocky to blocky, soft to firm, very sticky, slightly calcareous, traces of pyrite.

Table 1: Summarized lithofacies units identified in the well and their characteristics.

with long axis less than twice the short axis. They have no internal biostructures.

Lath (O-La): Are black particles from wood material with long axis more than twice the short axis. They have no internal biostructures.

Fungal hyphae (Fh): Which are Individual filaments of mycelium of vegetative phase of eumycote fungi.

Cuticle (Cu): Thin cellular sheets, epidermal tissue, in some case with visible stomates.

Wood tracheid with pits (Wp): Brown particle from wood tracheid with visible pits.

Wood tracheid without pits (Ww): Brown particle from wood tracheid without visible pits.

Zooclasts group

The zooclast group consists of animal-derived fragments. According to Tyson [22] most zooclast fragments include arthropod exoskeletal debris, organic linings from bivalve shells and ostracode carapaces. They were found in very trace amounts over the succession studied (Figure 2J).

Palynomorph group

The palynomorph group is subdivided into the spores and pollen grains; the dinoflagellates and the foraminiferal test linings (Figure 2K-2Q).

Spores: These are terrestrial palynomorphs produced by pteridophyte plants and fungi. They appear as triangular or circular palynomorph; Trilete spore with 3 laesurae (Y-mark); Monolete spore single laesura; varied ornamentation.

Pollen grains: Terrestrial palynomorph produced by Gymnosperm

and Angiosperm plants. Palynomorphs with complex to simple morphology; usually spherical to subspherical shapes; with several ornamentation types; apertures may be present.

Dinoflagellate cysts: Resting cysts produced during the sexual part of the life cycle of Class Dinophyceae survives. Main feature is the paratabulation which divides the theca and cyst in rectangular or polygonal plates separated by sutures; 3 main morphologies: proximate, cavate and chorate; often with an opening (arceopyle) through which excystment occurs.

Foraminiferal test linings: Organic linings of benthic foraminifera with Chitinous linings; brown colored; inner smaller chambers often darker.

For analysis, the Kerogen (palynodebris) categories were counted and their distribution trends and parameters were applied, based on percentages and subject to multivariate statistical analysis. Six broad palynofacies association defined along the sample depths are given in Table 2.

Principal Component Analysis

For the Principal Component Analysis (PCA), the covariance matrix approach was employed to find the components (from their respective eigenvectors). These give different results (PC loadings and scores), because the eigenvectors between both matrices are not equal. The palynofacies data was log transformed to generate four main principal components that accounted for over 80% of the total variance of a centered covariance matrix (Table 3). The PCA values are based on an analysis of the combined palynofacies data across the sample depths and palynodebris with high component loadings (absolute values >0.20) defined four palynofacies association.

The PCA diagram (Figure 3) consists of four curves, PC1, PC2,

Palynofacies 6		Kerogen groups				Phytoclasts group							Palynomorphs group			
		AOM %	Ph %	Pa %	Zoo %	Opaque				Translucent			Marine		Terrestrial	
						O-Eq	O-La	Fh	Wp	Cu	Ww	FTL	DF	FWL	PL	SP
2441 m – 2313 m	Max	45.2	82.2	30.1	0.3	5.1	91.5	0.9	3.5	4.9	64.8	11.5	10.2	-	16.9	9.7
	Min	13.5	20.2	11.1	0.8	2.2	42.5	0.1	0.8	-	13.3	-	0.1	-	85.2	0.2
	Mean	31.8	22.5	13.2	0.6	2.5	71.5	0.6	0.4	1.1	26.3	2.4	1.9	-	97.5	3.1
General Mean	.....	46.1	79.4	15.1	0.2	11.7	65.4	0.2	0.5	2.9	25.9	2.8	5.6	-	93.8	7.5

Palynofacies 5		Kerogen groups				Phytoclasts group							Palynomorphs group			
		AOM %	Ph %	Pa %	Zoo %	Opaque				Translucent			Marine		Terrestrial	
						O-Eq	O-La	Fh	Wp	Cu	Ww	FTL	DF	FWL	PL	SP
2313 m – 227 7m	Max	65.5	71	32	1.5	8.2	88.0	1.3	4.8	5.3	62.7	13.4	9.9	-	12.0	9.1
	Min	15.0	18.0	13.0	0.9	2.9	39.2	-	1.0	-	11.2	-	-	-	80	-
	Mean	38.0	19.0	16.1	0.7	4.1	66.2	0.7	0.9	1.8	25.3	2.9	1.7	-	96.2	2.9
General Mean	.....	52.2	75.1	18.6	0.6	15.5	61.3	0.4	0.8	3.2	22.8	3.0	5.1	-	89.8	7.2

Palynofacies 4		Kerogen groups				Phytoclasts group							Palynomorphs group			
		AOM %	Ph %	Pa %	Zoo %	Opaque				Translucent			Marine		Terrestrial	
						O-Eq	O-La	Fh	Wp	Cu	Ww	FTL	DF	FWL	PL	SP
2277 m-2112 m	Max	70.5	74.2	30.8	0.4	5.6	52.3	0.4	2.5	3.1	49.2	9.5	15.6	3.2	6.7	4.1
	Min	11.2	20.9	11.5	0.3	1.4	31.5	0.1	0.4	0.1	0.6	-	6.8	1.4	57.5	0.2
	Mean	45.1	14.3	10.5	0.2	3.1	59.2	0.2	0.2	0.7	19.4	1.9	4.5	0.9	65.1	1.4
General Mean	.....	56.7	78.2	16.4	0.1	10.4	53.9	0.1	0.1	2.1	17.9	1.5	5.5	0.3	54.2	5.9

AOM (Amorphous organic matter); Ph (Phytoclasts); Zoo (Zooclasts); Wood tracheid without pits (Ww); opaque lath (O-La); opaque equidimensional (O-Eq); Wood tracheid with pits (Wp); Fungal hyphae (Fh); Cuticle; FWL (foraminiferal wall linings); DF (Dinoflagellates); PL (Pollen); SP (Spores)

Table 2: Broad palynofacies association, AOM (Amorphous organic matter); Ph (Phytoclasts); Zoo (Zooclasts); Wood tracheid without pits (Ww); opaque lath (O-La); opaque equidimensional (O-Eq); Wood tracheid with pits (Wp); Fungal hyphae (Fh); Cuticle; FWL (foraminiferal wall linings); DF (Dinoflagellates); PL (Pollen); SP (Spores).

Palynodebris	Eigen vectors (Component loadings)			
	PC-1	PC-2	PC-3	PC-4
AOM	-0.46*	-0.42*	-0.06	0.45*
Ph	-0.38	-0.21*	0.50*	0.35*
ZOOCLASTS	-0.07	0.01	0.13	0.06
O-Eq	0.36	-0.12	0.19	0.05
O-La	-0.19	-0.15	-0.42*	0.01
Fh	0.24	-0.20	0.24*	0.04
Wp	-0.02	0.38*	0.35*	0.37*
Cu	-0.32	-0.04	-0.14	0.17
Ww	-0.06	-0.51*	-0.13	0.06
FTL	-0.01	-0.49*	0.35*	-0.58
DF	-0.09	-0.02	0.52*	-0.17
PL	0.02	-0.01	0.05	0.50
SP	-0.15	-0.15	-0.01	0.01

*indicates principal component loadings with absolute values >0.20. Eigen value 1=0.092 (15.12% of total variance); Eigen value 2=0.015 (5.26% of total variance); Eigen value 3=0.196 (49.08%); Eigen value 4=0.061 (10.54%)

Table 3: Principal components loading values for the palynodebris.

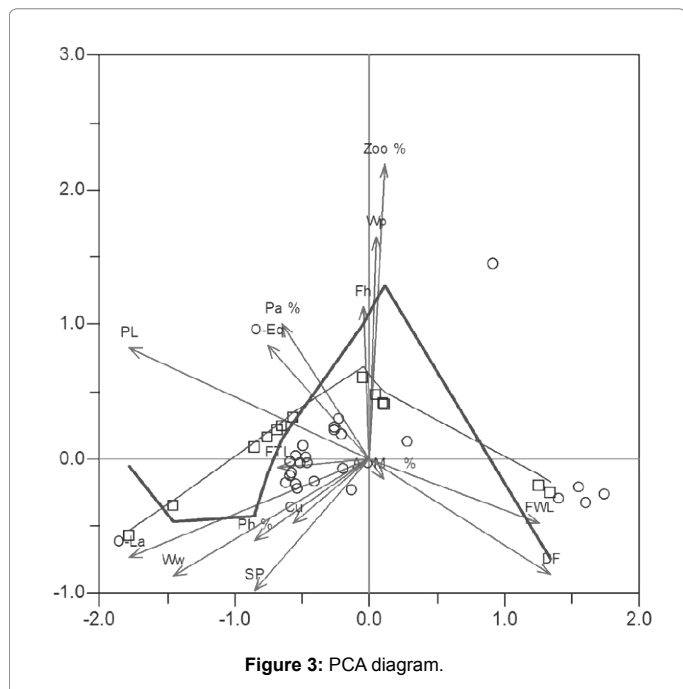


Figure 3: PCA diagram.

PC3 and PC4 with a cumulative variance of 45.8% with fluctuations in PC curves supporting the response of the palynodebris to changing environments. The PC-3 curve is characterized by a high negative loading for the opaque lath particles, cuticles, wood fragments without pits, amorphous organic matter and spores. The PC-4 curve shows negative loadings for foraminiferal test linings and the dinoflagellate cysts. In principal component curve PC-2, wood fragments with pits and the Zooclasts shows positive loading while the PC-1 curve shows a very high positive loadings for the pollen, opaque equidimensional and the fungal hyphae particles. PC-3 curve represent the most prominent palynofacies association present while PC-2 curve represents the least.

The PCA screen plot (Figure 4) shows the fraction of the total variance in the data represented by each principal component. Although, the ordination of Principal Components Analysis is most affected by palynodebris occurring in high abundances and those with

low abundances are not distinguished. Since some of the low abundance types might be environmentally significant, it is pertinent to say that this method might not be give satisfactory results.

Cluster Analysis (R- and Q-mode Combined)

The palynodebris abundances was subjected to cluster analysis (r- and q-mode combined) to assess their pattern of distribution. These revealed two super clusters based on the abundance and composition of the kerogen groups (Figure 5). These are: super cluster X, which is

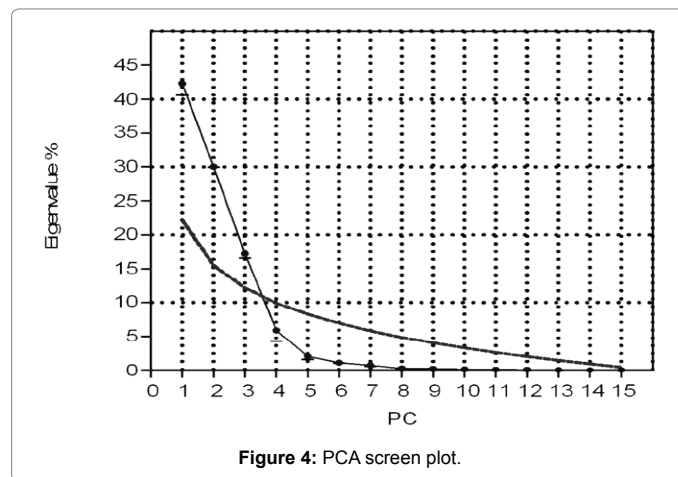


Figure 4: PCA screen plot.

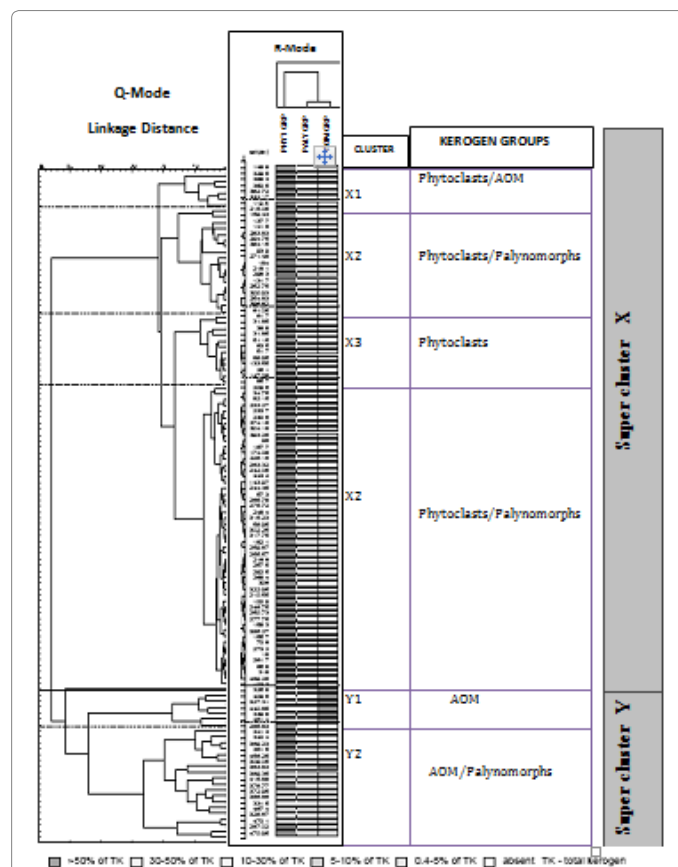


Figure 5: Dendrograms by r and q-mode of palynodebris data showing the grouping of samples (q-mode) and kerogen groups (r-mode).

subdivided into X1, X2 and X3, and super cluster Y, subdivided into Y1 and Y2.

The phytoclasts (opaque equidimensional fragments, opaque lath fragments, fungal hyphae, wood tracheid with pits, wood tracheid without pits and cuticles) constituted above 50% of all the samples in super cluster X. X1 is composed mostly of phytoclasts and a moderate abundance of the AOM group; X2 is composed of high abundances of phytoclasts combined with moderate to high abundances of palynomorphs (Pollen, spores and dinoflagellate cysts); and X3 composed of very high abundances of phytoclasts. Super cluster Y showed very high abundances of the AOM group which is mostly evident in Y1 whereas the phytoclasts and in particular with the palynomorph group formed the major abundances in Y2.

The abundance of the phytoclasts group defined the major break that occurred between these two super clusters. The cluster analysis by r-mode (Figure 5) clearly shows that the phytoclasts group is separated from the palynomorph and AOM groups. The lower part of the sequence is characterized by moderate to high abundances of 'AOM' and an upper part with very high contents of phytoclasts group showing a progressive increase upwards, in particular the opaque particles. The variations in the pattern of stratigraphic distributions of the palynofacies associations reflects mainly from environmental changes consequent upon shoreline shifts that influenced a proximal-distal trend. Although the palynofacies units differ in their occurrence in the well, they are related to lithofacies types which are a reflection of the prevalent hydrodynamic conditions during deposition. Consequently, these units have been grouped into three basic palynofacies associations.

Palynofacies association AOM/Pal-s

This unit is characterized by relatively large amounts of the AOM group with an average abundance (44.3%) which is higher than its general mean (15.7%), which are combined with a moderate abundance of terrestrial palynomorphs (sporomorph subgroup). Its abundances decrease towards the top, where they make up only 1.4% of the kerogen.

Palynofacies association Phy-o/Pal-s

This unit is strongly dominated by phytoclasts group in particular the opaque-lath particles and the woody tracheid without pits (Ww), associated with moderate to high contents of terrestrial palynomorphs (pollen grains). The marine palynomorphs are represented by only two forms (FTL and dinocysts).

Palynofacies association Phy-o

This unit is strongly dominated by opaque phytoclasts composed mainly of O-La particles. Translucent particles are present in moderate to high abundances, in which the Ww particles are the most abundant. The abundance of the AOM group in this unit is very low to moderate.

The environment as reflected by the composition of the palynodebris in the PCA diagram indicates an alternating cycle of warm and dry conditions for most of its history, and this is reflected in the plant material and cuticle particles. A low but constant quantity of plant and cuticle material in general reflects stable dry conditions terrestrially [2]. Cuticle fragments suggests near shore deposition [2]. The presence of Amorphous Organic Material (AOM) in all the facies suggests a terrigenous source associated with shallow fresh to brackish water of lagoons and swamps [2]. Resins indicate a stable, flourishing community of angiosperms and gymnosperms. These were the most prolific producers of resin at the time. The presence of marine palynomorphs supports deposition in a marginal marine

or saline estuarine marsh environment [23]. The sporomorph and fungi component remained low in value in all facies; however it does reflect a great diversity of hinterland vegetation. In the entire area the sequence starts with fine siliciclastic sediments dominated by relatively dark shales. The siliciclastic influx also brought a high concentration of phytoclasts; therefore, the sequence is interpreted as representing as shallow-neritic.

A number of Ternaries which are of much use in determining the paleoenvironment of deposition, depending on the palynodebris data was summarized by Tyson [22]. He used an AOM-Phytoclasts-Palynomorph plot to characterize kerogen assemblages to pick out the differences in relative proximity to terrestrial organic matter sources, kerogen transport paths and the redox status of the depositional sub environments that control AOM preservation. Some shallow shelf settings are characterized by relatively high palynomorph percentages (>10%) and high phytoclasts percentages (>50%).

From the estimated ratios (Figure 6) of the sedimentary organic matter components in the studied sections plotted on the mentioned ternary of Tyson, [22]. It is clearly evident from the result of the ternary that the paleodepositional environments of the palynodebris are mainly represented by distal suboxic-anoxic basin (IX field). According to Tyson, this field is of AOM dominated assemblages, low abundance of palynomorphs partly due to masking. The field is also of low spore and prasinophyte content and of type I&II kerogen (II>I), and is highly oil prone. Absolute phytoclasts content may be moderate to high due to turbiditic input and /or general proximity to source, variable, low to moderate spore content, low to common dynosist dominant, with a type II kerogen (oil prone).

Conclusions

- The Principal component and cluster analysis based on the abundance and composition of all palynodebris in AJ-X well revealed four super clusters.
- Based on the distribution of palynofacies associations that defined five palynofacies units in well, a continuous terrestrial

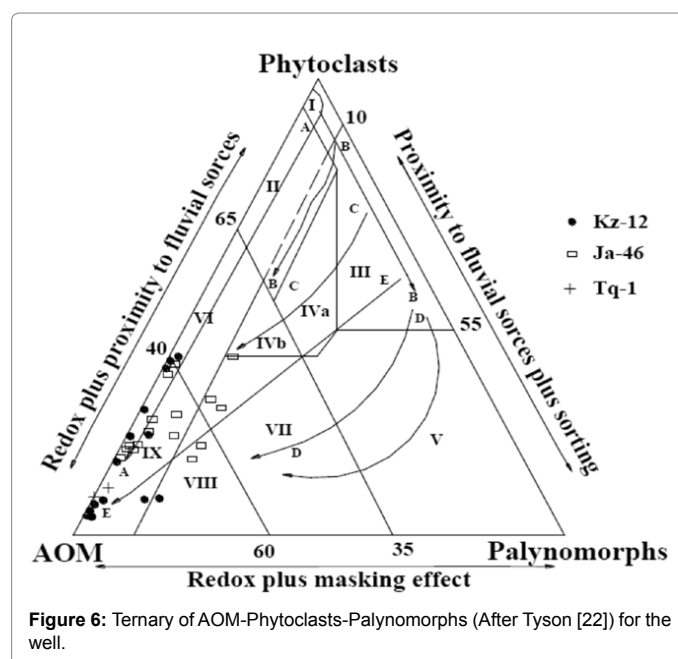


Figure 6: Ternary of AOM-Phytoclasts-Palynomorphs (After Tyson [22]) for the well.

influx is indicated throughout the succession by moderate to very high abundances of phytoclasts. The AOM and palynomorph groups show moderate to high abundances. The increase in abundance of these groups indicates a transgression or a decrease in terrestrial influx in the area.

- Generally, the well is rich from organic matter content point of view and the phytoclasts and amorphous organic matter comprises the greatest part among their components. It generally poor in their palynomorph content, which consist mainly of Dinoflagellates, Fungi Spores, and Pollens in addition to Foraminiferal test linings. The components of the sedimentary organic matter in the well vary in their ratio along the studied sections representing different Palynofacies.
- The paleodepositional environment of the well seems to be distal suboxic-anoxic shelf as appeared from the results of the plotting the ratio of the main organic components (Palynomorphs, Phytoclasts, and AOM) on APP triangle of Tyson [22].

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