JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 7, Issue No. 2 (December-2021)

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Palynofacies Analysis of Selected Organic-rich Shales from Libyan Sahara: Implication to Palaeoenvironment and Hydrocarbon Source Rock Potential

Ismail Elforjani Shushan

Department of Geology & Environmental Science, Faculty of Sciences, Elmergib University, Khoms, Libya.

E-mail: elforjismail@yahoo.com

التحليل السحني للحفريات النباتية والحيوانية الدقيقة (بالينوفاشيز) لعينات مختارة من الطفل الغنية بالمواد العضوية بالصحراء الليبية: دراسة للاستدلال على بيئة الترسيب القديمة وطاقة التوليد للهيدروكربونات للصخور المصدرية

اسماعيل الفرجاني الشوشان

قسم علوم الأرض والبيئة، كلية العلوم، جامعة المرقب، الخمس، ليبيا.

Received: 04 September 2021; Revised: 18 November 2021; Accepted: 29 November 2021.

Abstract

Palynofacies analysis was carried out on three (3) packages of shale-cutting samples derived from a well drilled within Gadames Basin. These included: the upper package (Carboniferous at 5,530 ft), the middle package (Carboniferous/Devonian at 5,600 ft and 5,780 ft), and the lower package (Devonian at 6,700 ft). Two palynofacies were identified: "P-1", involving the upper and middle packages (Carboniferous/Devonian), and "P-2", involving the lower package (Devonian). P-1 and P-2 were considered to form one "palynofacies association" located at a mud-dominated oxic shelf (distal shelf) and are analogous to other palynofacies from other countries that are characterized by the dominance of terrestrial upon marine palynomorphs and moderate to low phytoclasts and AOM respectively that typically deposited within a shoreline zone (probably fluvial-deltaic source or marginal marine environment). Spore color index "SCI" evaluation for source rock and thermal maturation, in turn, indicates early mature oil/gas prone (kerogen type II>III) to post mature kerogen type III>IV "gas prone" for the studied cutting sample packages.

Keywords: *Palynofacies Analysis, Organic-rich Shale, Libyan Sahara, Palaeo-environment, Hydrocarbon Source Rock Potential.*

الملخص

لقد تم اجراء التحاليل البالينولوجية لعدد ثلاث (3) حزم من عينات بئرية لصخور الطفل (shale) والتابعة للعصر الديفوني والكربوني لاحد الابار النفطية التي تم حفرها بحوض غدامس. هذه الحزم قسمت كالآتي: الحزمة العليا والمترسبة خلال العصر الكربوني على عمق 5,530 قدم, الحزمة الوسطى وتشتمل على عصري الكربوني والديفوني على أعماق 5,600 قدم و 5,780 قدم, أما الحزمة السفلى فتتبع عصر الديفوني على عمق 6,700 قدم. من خلال الدراسة الميكروسكوبية تم تحديد سحنتين بالينولوجيتين هما: P1 (وقد اشتملت على الحزمة العليا والوسطى) و P2 (وشملت الحزمة السفلى). واستنادا على المكونات العضوية التي احتوتها تلك السحنتين, تم اعتبار كلتا السحنتين (P1 و P2) كسحنة واحدة متقارنة ترسبت

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

بداخل منطقة الرف المؤكسد المشرفة على الشاطئ (وبالتحديد الرف الاقصى) المتميزة بسواد الطين بها. لقد وجد أن السحنتين المذكورتين بمنطقة الدراسة تماثل العديد من السحنات البالينولوجية بمناطق أخرى من العالم والتي تتميز بسواد المحتويات العضوية (بالينومورفس) ذات الأصل القاري على البحري بالإضافة إلى المحتويات العضوية المعتدلة والمقلة للفيتوكلاست والمواد العضوية الهلامية "AOM" على التوالي والتي تعكس بيئات ترسيب نموذجية بالمناطق الساحلية والحواف البحرية المتأثرة بالنشاط النهري الدلتاوي. بالاستناد على مؤشر اللون لحبيبات الأبواغ وفيما يخص طاقة التوليد للهيدروكربونات للصخور المصدرية ودرجة النضوج الحراري لتلك المواد يمكن القول بأن الحزم الصخرية التي خضعت للدراسة الحالية تتخصص بإنتاج نفط/غاز خلال المراحل المبكرة للنضوج الحراري (نوع الكيروجين III/II) بالإضافة إلى انتاج غاز فقط خلال المراحل ما بعد المتأخرة من النضج الحراري (نوع الكيروجين IV/III).

الكلمات الدالة: التحليل السحني للحفريات النباتية والحيوانية الدقيقة، الطفل الغني بالمواد العضوية، الصحراء الليبية، البيئة القديمة، طاقة توليد الهيدروكربونات للصخور المصدرية.

1. Introduction

The term "Palynology" is that branch of science concerned with the study of pollen, spores, and similar palynomorphs, living or fossils which was suggested by (Hyde & Williams, 1944). The term "Palynology" can be used in many fields of study such as: (Geology, Archaeology, Palaeontology, and Medicine). Palaeopalynology has dealt before with the study of spores and pollen grains only, but recently it comprised the study of fossilized pollen and spore grains and microorganisms which have cutin origin organic membrane (Oskay, 2009). "Palynofacies" is a term introduced by Combaz (1964) to describe the total organic content of a palynolgical assemblage (ex: tracheids, woody tissue, microplankton, microforaminiferal linings). In 1969, Staplin related these organic types to hydrocarbon generation where later expressed geochemically by Tissot & Welte (1984). In 1995, Tyson defined the term "Palynofacies" as: "a body of sediment containing a distinctive assemblage of palynological organic matter which reflect specific environmental conditions or to be associated with a characteristic range of hydrocarbon-generation potential". He also proposed classification for palynofacies. works of many other researchers were considered as basics in palynofacies studies may inclue: (Burgess, 1974; Habib, 1979; Parry *et al*., 1981; Boulter & Riddick, 1986; Boulter, 1994; Dabros & Mudie, 1986; Hart, 1986, 1994; Kovach, 1988; Lorente, 1986, 1990; Van Bregen *et al.*, 1990; Tyson, 1989a, 1990, 1993; Kovach & Batten, 1994; Sebag *et al*., 2006; and Weller *et al*., 2005). In a paleological sense, kerogen refers to the dispersed particulate organic matter (POM) contained in sedimentary rocks that are resistant to the palynological extraction techniques (including treatment with the inorganic acids HCl and HF) (Pearson, 1984; and Traverse, 1988).

1.1. Location of Study Area

The area of study is located within Ghadamis Basin, North West Libya. The Ghadamis basin is a large paleozoic intracratonic sag basin (Echikh , 1998) which covers an area of about 340,000 km², and extends over three countries*:* NW Libya, also called (Al Hamada El Hamra), Southern Tunisia (Berkine basin) and West-central Algeria (Figure 1).

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

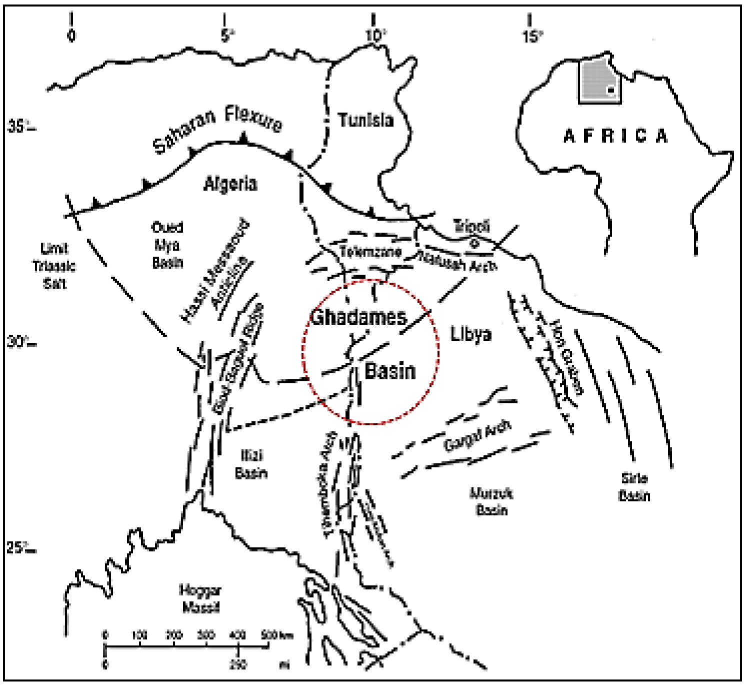


Figure 1. Location of study area (Modified from: Hedi *et.al*., 2001)

1.2. Purpose and Scope of Study

The purpose and scope of this paper is to describe the palynofacies characteristics observed in the selected cutting samples from Libyan Sahara and to determine their conditions and environment of deposition. The study is also trying to determine the hydrocarbon source rock potential for the studied samples.

2. Materials and Methods of Study

This study is carried out using four (4) cutting samples from boreholes drilled in the region. This included three packages from Palaeozoic organic-rich sediments. The lower package consists of flaky silty-shale, brownish-grey in color (Devonian). The middle package consists of sandy-shale, grey and grayish-brown in color (Carboniferous/Devonian). The upper package consists of silty-shale to sandy-shale, grey to brownish-grey in color (Carboniferous). The analyzed cutting samples are shown in Figure (2). The palynofacies samples were processed in the Libyan Petroleum Institute Labs, Tripoli following procedures according to Batten and Morrison (1983). Slides were then microscopically studied in normal transmitted light at the Geology Department laboratory, Faculty Sciences, University Elmergib.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

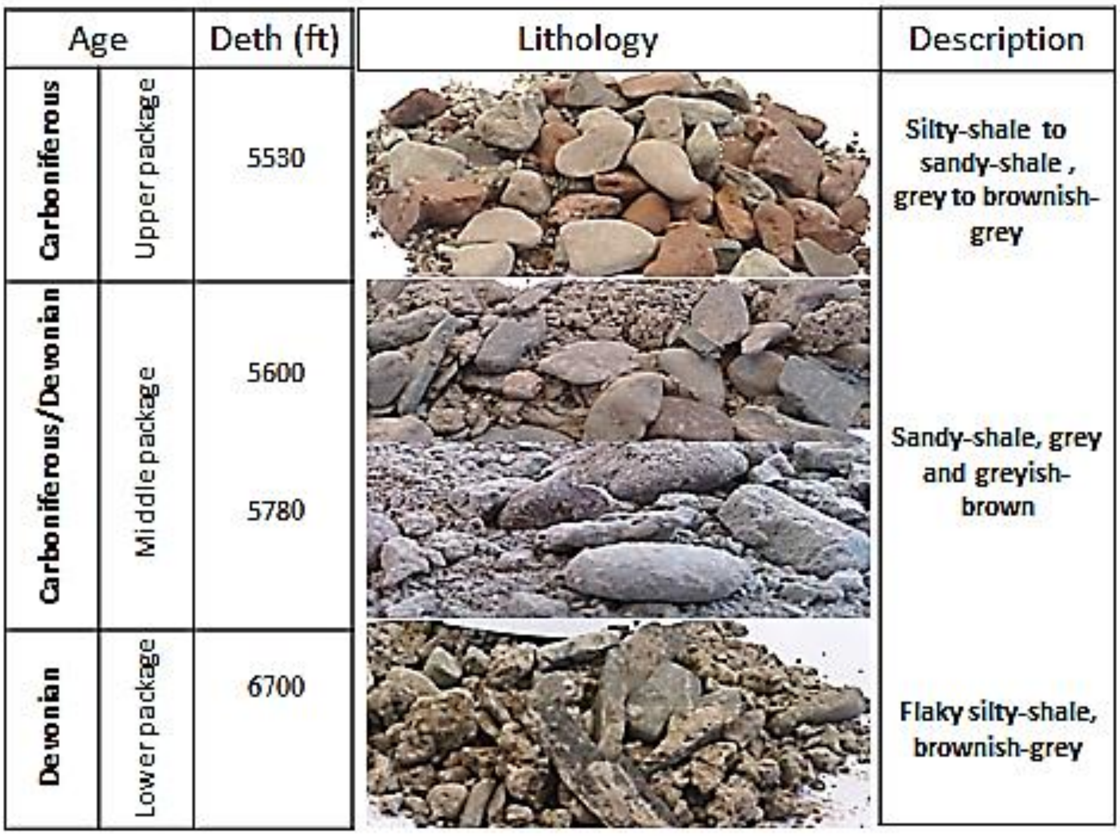


Figure 2. The three analyzed packages of cutting samples

3. Geologic Setting and Stratigraphic Section of the Study Area

Echikh (1998) considered one of the geologists who studied the sedimentary basins from North Africa that represent provinces of hydrocarbon accumulation in Libya, Tunisia, and Algeria. Palaeozoic rocks in Ghadamis Basin play an important role in generating and trapping the petroleum oils and become a petroleum province in Libya. Ghadamis basin is bounded on the north by Talemzane, Tatahouine and Nafusah arches. To the east, the boundary is not as well defined due to the complicating NW-SE trending faults system of Sirt basin, which is separated from Ghadamis basin by Hun graben. On the south, the Al Qarqaf arch and Ahara dome (in Algeria) separate Ghadamis from Murzuq and Illize basin respectively and on the west by Amguid El Biod high (Figure 1). The stratigraphic section has a maximum thickness 15,000 – 17,000 ft at the depocentrc of the basin. It is composed of two sedimentary mega-cycles. Paleozoic and Mesozoic-Tertiary divided by a major angular unconformity of Hercynian movement (Figure 3).

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

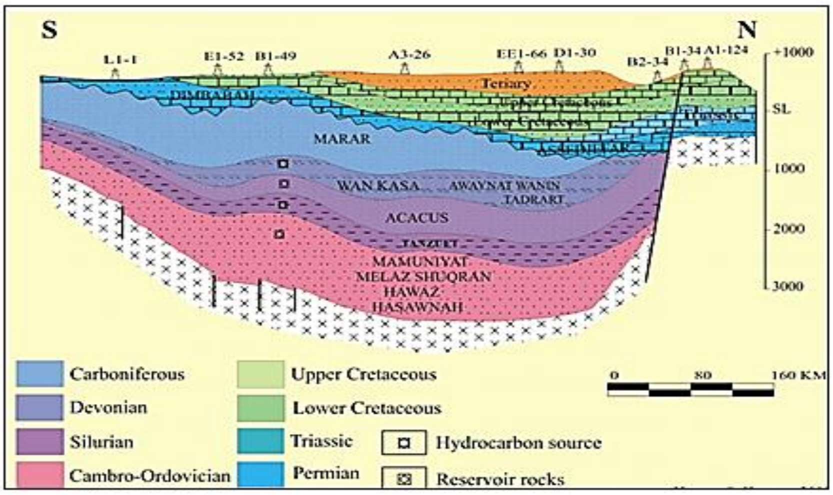


Figure 3. The stratigraphic section of Ghadamis Basin (Echikh, 1998).

4. Palynofacies Analysis Studies

Before discussing the results of palynofacies analysis of the selected cutting samples in the study area, it is better to define the classification of the different palynofacies terms introduced by (Tyson, 1993, 1995; Carvalho, 2001; van der Zwan, 1990; Ergovac & Kostic, 2006; Batten, 1996; and Tschudy, 1969). The following tables will refer to planyofacies terms and classification (Tables 1-4).

Table 1. Classification of amorphous organic matter (AOM) (Tyson, 1995; and Carvalho, 2001)

AOM Group	Origin	Description
AOM	Derived from phytoplankton Or degradation of bacteria.	Structureless material. Colour: yellow-orange-red; orange-brown; grey. Heterogeneity: homogeneous; with "speckles"; clotted; with inclusions (palynomorphs, phytoclasts, and pyrite). Form: flat; irregular; angular; pelletal (rounded elongate/oval shape).
Humic Gel	Derived from biodegradation of plants	Structureless particle, homogenous, rounded, sharp to diffuse outline, non-fluorescent

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Table 2. Classification of the phytoclast group (phyt) (van der Zwan, 1990 and Carvalho, 2001)

Phytoclast Group		Origin	Description	Palynomaceral Group	Coal Maceral Equivalent
Opaque	Equidimensional (O-Eq)	Derived from the lignocellulosic tissues of terrestrial higher plants or fungi.	Black particle from woodmaterial.Long axis less than twice the short axis. Without internal biostructures	Palynomaceral 4	Inertinite
	Lath (O-La)		Black particle from woodmaterial.Long axis more than twice the short		
Trans-lucent	Wood trachieds with pits (Tw)		Brown particle from woody tissue with visible internal structures.	Palynomaceral 2	Vitrinite
	Wood trachieds without pits (Tp)		Brown particle from woody tissue without internal structures.	Palynomaceral 1	
	Cuticle (Cu)		Thin cellular sheets, epidermal tissue, in some case with visible stomata	Palynomaceral 3	Cutinite
	Fungal hyphae (Fh)	Derived from fungi	Individual filaments of mycelium of vegetative phase of eumycote fungi.		

Table 3. Classification of the Palynomorph Group (pal),(Carvalho, 2001)

Palynomorph Group		Origin
Sporomorph	Spores	Terrestrial palynomorph produced by pteridophyte plants and fungi.
	Pollen	Terrestrial palynomorph produced by Gymnosperm and Angiosperm plants.
Zoomorph	Foraminiferal test linings	Organic linings of benthic Foraminifera.
	Scolecodonts	Mouth parts of some oolychaete worms (mostly marine).
Phytoplankton	Acritarchs	Small microfossils of unknown and probably varied biological affinities.
	Dinoflagellate Cysts	Resting cysts produced during the sexual part of the life cycle of Class Dinophyceae survives.
	Prasinophytes	Fossilising structures produced by small quadriflagellate algae
	Chlorococcale Algae	Exclusively colonial freshwater algae (*Botryococcus* and *Pediastrum*

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Table 4. Classification of sedimentary organic matter (based on Tyson, 1995 and Ergovac & Kostic, 2006)

<table>
<tr><th colspan="4">Category</th><th>Constituent/Source</th></tr>
<tr><td rowspan="3">Structurless Organic Matter</td><td colspan="3">AOM</td><td>Derived from high degradation of phytoplankton or bacteria of organic matter</td></tr>
<tr><td colspan="3">Humic gel</td><td>Degraded higher plant debris, humic cell-filling material</td></tr>
<tr><td colspan="3">Resin</td><td>Derived from higher plants of tropical and subtropical forest</td></tr>
<tr><td rowspan="6">Structured Organic Matter</td><td rowspan="3">Fragmentary Particle/Clast</td><td rowspan="2">Phytoclast</td><td>Opaque</td><td>Charcoal, Biochemically oxidized wood</td></tr>
<tr><td>Translucent</td><td>Cuticle, cortex tissue of root/stem, woody tissues (Gymnosperm/Angiosperm tracheids)</td></tr>
<tr><td colspan="2">Zooclast</td><td>Animal-derived fragments (esp. Arthpod exo-skeletal, organic linings of bivalve shells and ostracode carapaces)</td></tr>
<tr><td rowspan="3">Discrete individual or colonial entity</td><td rowspan="3">Palynomorph</td><td>Sporomorph</td><td>Spores and pollen</td></tr>
<tr><td>Zoomorph</td><td>Foraminiferal test linings, scoledonts, chinitnozoa</td></tr>
<tr><td>Phytoplankton</td><td>Dynocysts, acritarchs, botryococcales</td></tr>
</table>

5. Presentation of Palynofacies Results

Studies on the organic matter comprised within the three selected packages of rock sample cuttings in the area of study has been done on (10) thin-sections. The upper package is represented by thin-sections (1 to 3, see appendix), tables (5 to 7), the middle package is represented by thin-sections (4 to 6, see appendix), tables (8 to 10) while the lower package represented by thin-sections (7 to 10, see appendix), tables (11 to 14). The results are presented briefly as follows:

A) Palynofacies results of the upper package: (thin-section; 1, 2, & 3):

Table 5. Summary of percentages of organic matter groups & sub-groups (thin-section-1)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	5	AOM	30
		Humic Gel	25
		Resin	45
Phytoclast (Phyt)	5	Opaque	25
		Wood Tracheid	5
		Cuticle	70
Palynomorph (Pal)	90	Spores & Pollens	75
		Algal Remains	10
		Microforaminiferea	15

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Table 6. Summary of percentages of organic matter groups & sub-groups (thin-section-2)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	5	AOM	30
		Humic Gel	30
		Resin	40
Phytoclast (Phyt)	15	Opaque	30
		Wood Tracheid	10
		Cuticle	60
Palynomorph (Pal)	80	Spores & Pollens	100

Table 7. Summary of percentages of organic matter groups & sub-groups (thin-section-3)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	20	AOM	80
		Humic Gel	-
		Resin	20
Phytoclast (Phyt)	30	Opaque	40
		Wood Tracheid	10
		Cuticle	50
Palynomorph (Pal)	50	Spores & Pollens	80
		Palynodebris	20

B) Palynofacies results of the middle package: (thin-section; 4, 5 & 6)

Table 8. Summary of percentages of organic matter groups & sub-groups (thin-section-4)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	5	AOM	100
		Humic Gel	-
		Resin	-
Phytoclast (Phyt)	15	Opaque	60
		Wood Tracheid	20
		Fungal Hyphae	20
Palynomorph (Pal)	80	Spores & Pollens	75
		Algal Remains	15
		Microforaminiferea	10

Table 9. Summary of percentages of organic matter groups & sub-groups (thin-section-5)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	5	AOM	100
		Humic Gel	-
		Resin	-
Phytoclast (Phyt)	15	Opaque	25
		Wood Tracheid	75
		Fungal Hyphae	-
Palynomorph (Pal)	80	Spores & Pollens	80
		Algal Remains	10
		Dinoflagelates	10

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Table 10. Summary of percentages of organic matter groups & sub-groups (thin-section-6)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	20	AOM	30
		Humic Gel	70
		Resin	-
Phytoclast (Phyt)	30	Opaque	90
		Wood Tracheid	10
Palynomorph (Pal)	50	Spores & Pollens	30
		Algal Remains	50
		Microforaminiferea	20

C) Palynofacies results of the lower package: (thin-section; 7, 8, 9, & 10)

Table 11. Summary of percentages of organic matter groups & sub-groups (thin-section-7)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	5	AOM	90
		Humic Gel	-
		Resin	10
Phytoclast (Phyt)	-	-	-
Palynomorph (Pal)	95	Spores & Pollens	60
		Algal Remains	20
		Dinoflaglagellates	20

Table 12. Summary of percentages of organic matter groups & sub-groups (thin-section-8)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	4	AOM	50
		Humic Gel	50
		Resin	-
Phytoclast (Phyt)	1	Opaque	100
Palynomorph (Pal)	95	Spores	80
		Dinoflagellates	10
		Acritarchs	5
		Algal Remains	5

Table13. Summary of percentages of organic matter groups & sub-groups (thin-section-9)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	5	AOM	95
		Humic Gel	5
		Resin	-
Phytoclast (Phyt)	5	Wood Tracheid	100
Palynomorph (Pal)	90	Spores & Pollens	85
		Algal Remains	15

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Table14. Summary of percentages of organic matter groups & sub-groups (thin-section-10)

Organic Matter Group	%	Organic Matter Sub-group	%
Amorphous Organic Matter (AOM)	**25**	**AOM**	**40**
		Humic Gel	**40**
		Resin	**10**
Phytoclast (Phyt)	**15**	**Opaque**	**95**
		Cuticles	**5**
Palynomorph (Pal)	**60**	**Spores & Pollens**	**90**
		Algal Remains	**10**

Table15. Characteristics of the organic matter particles that constitute Carboniferous cutting samples (upper package), {slides: 1, 2, 3}

	Organic Matter Group	Organic Matter Sub-group	Description
CARBONIFEROUS	**AOM**	**AOM**	Yellowish-brown. reddish-brown, brown.
		Humic Gel	Reddish-brown, yellowish-brown, dark-brown.
		Resin	Reddish-brown, dark-brown.
	Phtoclasts (Phyt)	**Opaques**	Lath & equdimensional, black, angular, sub-angular, sub-rounded.
		Tracheids	Dark-brown, reddish-brown, brownish-black.
		Cuticles	Yellowish-green, brownish-green, yellow, brownish-Yellow, yellowish-brown.
	Palynomorphs (Pal)	**Spores & Pollens**	Reddish-brown, yellowish-brown, brown.
		Algal Remains	Dark-brown to brownish-green.
		Foraminiferea	Yellowish-brown

6. Discussion of Palynofacies Results (Note: check "Appendix" for figures & tables)

Referring to Figure (14) which summarizing the average percentages of organic material constituents (Av.OMC %) and Figure (15) which representing the Ternary AOM-phytoclast-palynomorph plot for the three studied rock packages that inferred from palynofacies analysis results of Carboniferous, Carboniferous-Devonian and Devonian cutting sample packages in the area of study mentioned before, the following notes could be extracted:

The upper and middle rock cutting sample packages (Carboniferous and Carboniferous-Devonian) showed similarity in (Av.OMC%). These are characterized by palynomorphs dominant (up to 70%) of total particulate organic matter (POM), with low to moderate AOM (up to 10-12%) and phytoclasts (up to 18-20. This represents the "Palynofacies-1", "P-1". In "P-1", Palynomorphs of terrestrial origin are the dominant forms (up to 75%) with marine palynomorphs of (about 25%**).** The color of palynomorphs varied from yellow, yellowish-brown, reddish-brown to brown (thermal maturity depending on "SCI" varied as "immature, mature and over mature, see text and Table-18). AOM showed semi-rounded and diffused-edges shapes with color varied from yellowish-brown, reddish-brown to dark-brown and sometimes black (thermal maturity depending on "SCI" varied as mature and over mature). Opaque particles were rectangular to equant and corroded and with, brownish-black to black

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

colors (thermal maturity depending on "SCI" fall within over-mature zone). The other phytoclasts showed yellowish-green, brownish-green and brownish-yellow colors (thermal maturity depending on "SCI" varied from immature to mature). Palynofacies -1 may suggest a type III>II kerogen "gas/oil prone (Zobaa *et al*., 2013 and Atta-Peters & Achaegakwo, 2015) as well as a type III>IV kerogen "gas prone" (Joao Graciano *et al*., 2011). The color of palynomorphs varied from yellow, yellowish-brown, reddish-brown to brown (thermal maturity depending on "SCI" varied as "immature, mature and over mature, see text and Table 18). AOM showed semi-rounded and diffused-edges shapes with color varied from yellowish-brown, reddish-brown to dark-brown and sometimes black (thermal maturity depending on "SCI" varied as mature and over mature). Opaque particles were rectangular to equant and corroded and with, brownish-black to black colors (thermal maturity depending on "SCI" fall within over-mature zone). The other phytoclasts showed yellowish-green, brownish-green and brownish-yellow colors (thermal maturity depending on "SCI" varied from immature to mature). Palynofacies -1 may suggest a type III>II kerogen "gas/oil prone (Zobaa *et al*., 2013 and Atta-Peters & Achaegakwo, 2015) as well as a type III>IV kerogen "gas prone" (Joao Graciano *et al*., 2011).

The lower rock cutting sample package (Devonian) showed quite different (Av.OMC%). It is characterized by palynomorphs dominant too of total (POM), (but the amount is increased up to 85% as compared to the upper and middle packages which was about 70%). AOM was low to moderate (up to about 10%). Dramatic decrease in the amount of phytoclasts was distinct here (up to about 6%) as compared with upper and lower packages (18 to 20%). This represents the "Palynofacies-2", "P-2". In P-2, Palynomorphs of terrestrial origin are also the dominant forms (up to about 80%) with marine palynomorphs of (about 20%**)**. The color of palynomorphs varied from yellow, yellowish-brown, yellowish-green to dark-brown (thermal maturity depending on "SCI" varied as " immature, early-mature and over- mature, see text and Table-18). AOM showed also semi-rounded and diffused-edges shapes with color varied from yellowish-brown, reddish-brown to dark-brown (thermal maturity depending on "SCI" varied as early-mature to over-mature). Opaque particles were rectangular to corroded and were black, (thermal maturity depending on "SCI" placed within over-mature zone). The other phytoclasts showed yellow, yellowish-brown and dark-brown colors (thermal maturity depending on "SCI" varied from immature, early-mature to post-mature). Palynofacies-2 may also suggests a type III>II kerogen "gas/oil prone (Zobaa *et al*., 2013 and Atta-Peters & Achaegakwo, 2015) as well as a type III>IV kerogen "gas prone" (Joao et *al*., 2011).

Paleoenvironmental interpretation of the studied cutting samples packages in the area of study could be inferred from the palynofacies investigations using AOM-Phytoclast-Palynomorph (APP) ternary diagram or plot proposed by (Tyson, 1995), Figure (15). Cutting sample packages which reflect Palynofacies Assemblages 1 and 2 (PA-1 & PA-2) are located in field (V) (Figure 15) which is interpreted as being indicative of mud-dominated oxic shelf (distal shelf). Both are dominated by palynomorphs with predominately miospores and few dinoflagellate (dinocysts) and algal remains (see results). This may suggest deposition in the vicinity of fluvio-deltaic source (marginal marine environment as well) (Joao Graciano *et al*., 2011). This is comparable with palynofacies-1 from Albian-Cenomanian succession of the Epunsa-1 well, onshore Tano Basin,western Ghana which was reported by (Atta-Peters & Achaegakwo, 2015). Palynofacies Assemblages 1 and 2 (PA-1 & PA-2) from the study area are also comparable with palynofacies type3 from sediments found in northern Tierra del Fuego, Argentina reported by (Quattrocchio *et al*., 2006) who suggested a nearshore marine environment for them. According to (Martinez *et al*., 2008), the high percentages of continental palynomorphs may indicate varied and abundant vegetation associated with shoreline. A delta top setting may propose by (Zavattieri *et al*., 2008) for sediments with high percentage of sporomorphs in relation to other palynomorphs. Zobaa *et al*. (2013), stated that, the high abundance of spores and pollens may reflect a distal deposition within the nearshore zone (probably outer shelf). According to (Ibrahim, 2002), dominant palynomorphs associated with common phytoclasts and opaques, with few marine palynomorphs and AOM suggested a shallow, nearshore marine environment**.**

7. Conclusion

Based on palynofacies analysis, the three packages of cutting samples inspected in this paper were classified into tow palynofacies. Palynofacies-1 "P-1", comprises the upper and middle packages that belong to Carboniferous (collected at depth of 5,530 ft, silty to sandy-shales, greyish to brownish-grey) and Devonian (collected at depths of 5,600 ft and 5,780 ft, sandy-shales, grey and greyish-brown). This was dominated by palynomorphs (up to 70% from the existed "POM") associated with phytoclasts and AOM (up to 18-20% and 10-12% respectively). Palynofacies-2, "P-2", involves the lower package of the cutting sample belonging to Devonian (collected at depth of 6,700 ft, flacky, silty-shales, brownish-grey). It was dominated by palynomorphs too (up to 85% from the existed "POM") associated with diminished amount of phytoclasts (up to about 6%) and moderate amount of AOM (up to about 10%). In general, "P-2" has been subjected to a lit bit lower terrestrial/freshwater influx than "P2".

The tow palynofacies (P-1 & P-2) discussed here was considered to form a one "palynofacies association" located at mud-dominated oxic shelf (distal shelf). Concerning palynofacies implications for paleoenviroment, "P-1" and "P-2" from the area of study were very comparable with many palynofacies from the world which suggesting deposition within a variety of very close paleoenvironments which may include: vicinity of fluvio-deltaic source (marginal marine environment as well), a nearshore marine environment, shoreline setting , a delta top setting**,** a distal deposition within the nearshore zone (probably outer shelf) and shallow, nearshore marine environment**.**

According to spore colour index (SCI) which determines source rock potential for hydrcarbons and levels of thermal maturation of the "POM" within rock samples, in general, "P1" and "P2" probably comprises early mature kerogen type II>III " oil/gas prone" to post mature kerogen type III>IV "gas prone". This was also due to the dominance of terrestrial palynomorphs, moderate phytoclasts and low AOM within the palynofacies studied here.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

8. Recommendations

More intensive palynofacies studies were recommended to run including sufficient number of cutting samples at varied depths involving additional wells. Vitrinite reflectance is also recommended to insure the source rock potential for hydrocarbons.

Acknowledgments

Acknowledgements were directed to the National Oil Corporation "NOC" for offering the cutting samples as well as to the Libyan Petroleum Institute for lab facilities concerning kerogen analysis processing and thin-section preparations. Greetings were also directed to the Geology Department, Faculty of Science, Elmergib University for optical studies facilities.

References

Atta-Peters D. and Achaegakwo C.A., (2015). Palynofacies and palaeoenvironmental significance of the Albian-Cenomanian succession of the Epunsa-1 well, onshore Tano Basin, western Ghana. *Journal of African Earth Sciences*, 114.

Batten D.J. & Morrison J. (1983). Methods of palynological preparation for paleoenvironmental source potential and organic maturation studies. In: Costa, L. (ed.) *Palynology-Micropaleontology: Laboratories, Equipment and Methods*. Bulletin of the Norwegian Petroleum Directorate, 2: 35–53.

Batten D.J. (1996). Palynofacies and paleoenvironmental interpretation, In: Jansonius, J., McGregor, D. C. (Eds.), *Palynology: Principles and Applications*. American Association of Stratigraphic Palynologists Foundation, 3: 1011-1064.

Boulter M.C. (1994). An approach to standard terminology for palynodebris. In: Traverse, A. (Ed.). *Sedimentation of organic particles*. Cambridge University Press, Cambridge, 199-216.

Boulter M.C., & Riddick A. (1986). Classification and analysis of palynodebris from the Paleocene sediments of the Forties Field. *Sedimentology*, 33(6): 871–886.

Burgess J.D. (1974). Microscopic examination of kerogen (dispersed organic matter) in petroleum exploration. *GSA Special Paper* 153: 19–30.

Carvalho M.A. (2001). *Paleoenvironmental reconstruction based on palynological and palynofacies analyses of the Aptian-Albian succession in the Sergipe Basin, northeastern Brazil*. Ruprecht-Karls-Universitt Heidelberg, PhD. Thesis, Heidelberg, pp.: 192.

Combaz A. (1964). *Les palynofaciès*. Revue de Micropaléontologie, 7: 205–218.

Dabros M.J. & Mudie P.J. (1986). An automated microscope system for image analysis in palynology and micropaleontology. *Geological Soceity of Canada*, 86(1a): 107-112.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Echikh K. (1998) Geology and hydrocarbon occurrences in the Ghadames Basin, Algeria, Tunisia, Libya. In: *Petroleum Geology of North Africa* (Ed. by D.S. MacGregor, R.T.J. Moody & D.D. Clark-Lowes), Geol.Soc.Lond.Spec.Publ., 132: 109-129.

Ergovac M. and Kostic A. (2006). Organic facies and palynofacies: Nomenclature, classification and applicability for petroleum source rock evaluation. *International Journal of Coal Geology*, 68: 70-78.

Habib D. (1979)**.** Sedimantology of palynomorphs and palynodebris in Cretaceous carbonaceous facies south of Vigo Seamount. In: Sibuet, J-C., Ryan, W.B.F. (Eds.), I*nitial Reports of the Deep Sea Drilling Project*, 47(2): 451-467.

Hart G. F. (1986). Origin and classification of organic matter in clastic systems. *Palynology*, 10: 1–23.

Hart G.F. (1994). Maceral palynofacies of the Louisiana deltaic plan in terms of organic constituents and hydrocarbon potential. In: Traverse A. (Ed.). *Sedimentation of organic particles* (141-176). Cambridge University Press, Cambridge.

Hedi A.M., M’Rabet A., Ghariani H., Ouahchi A., & Montgomery S.L. (2001). Ghadames basin, southern Tunisia: A reappraisal of Triassic reservoirs and future prospectively. *AAPG Bulletin*, 85(5): 765–780.

Hyde H.A. & Willams D. A. (1944). The right world. *Pollen Analysis Circular*, 8(6).

Ibrahim M.I.A. (2002). Late Albian-Middle Cenomanian palynofacies and palynostratigraphy, Abu Gharadig-5 well, Western Desert, Egypt. *Cretac. Res*., 23: 775-788.

Joao G.M. Filho, Taissa R. Menezes, Joalice de Oliveira Mendonça, (2011). Organic Composition (Palynofacies Analysis)"Chapter-5". *ICCP Training Course on Dispersed Organic Matter*.

Kovach W.L. & Batten D.J. (1994). Association of palynomorphs and palynodebris with depositional environments: quantitative approaches. In: Traverse, A. (Ed.). *Sedimentation of organic particles* (391-407). Cambridge University Press, Cambridge

Kovach W.L. (1988). Quantitative palaeoecology of megaspores and other dispersed plant remains from the Cenomanian of Kansas, USA. *Createaceous Research*, 9: 265-283.

Lorente M.A**.** (1990). Digital image analysis: an approach for quantitative characterization of organic facies and palynofacies. In: Fermont, W. J. J., & Weegink J.W. (eds.). *International Symposium in Organic Petrology*, Mededlingen Rijks Geologie Dienst, vol. 45, p. 103–109.

Lorente M.R. (1986). Palynology and palynofacies of the Tertiary in Venezuela. *Dissertations Botanica*, 99: 1-225.

Lucas F.A & Omodolor Hope E. (2018). Palynofacies Analysis, Organic Thermal Maturation and Source Rock Evaluation of Sedimentary Succession from Oligocene to Early Miocene Age in X2 Well, Greater Ughelli DepoBelt, Niger Delta Basin, Nigeria. *Journal of Geosciences and Geomatics*, 6,(2): 85-93.

Martinez M.A., Pramparo M.B., Quattrocchio M.E., & Zavala C.A., (2008). Depositional environment and hydrocarbon potential of the Middle Jurassic Los Molles Formation, Neuqquen Basin, Argentina: Palynofacies and Organic Geochemical Data, *Rev. Geol. Chile,* 35(2): 279-305.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Oskay R.G. (2009). *Palynofacies Analysis of Coal Bearing Sediments in the Canakkale-Can Basin (NW-TURKEY)*. Graduate School of Natural and Applied Sciences of Dokuz Eylül University, İzmir.

Parry C.C., Whitley P.K.J., & Simpson R.D.H. (1981). Integration of palynological and sedimentological methods in facies analysis of the Brent Formations. In: Illing, I. V. and Hobson, G.D. (Eds.). *Petroleum geology of the continental shelf of North-West Europe*. Institute of Petroleum, London, pp. 205-215.

Pearson D.L. (1984). *Pollen/Spore Colour 'Standard'*, Version 2. Phillips Petroleum Company, geology branch, privately distributed.

Quattrocchio M.E., Martinez M.A., Pavisich A.C., & Volkheimer W., (2006). Cretaceous palynostratigaphy, palynofacies and paleoenvironments of well sections in northeastern Tierra del Fuego, Argentina. *Cretac. Res*., 27: 584-602.

Sebag D., Di Giovanni C., Ogier S., Mesnage V., Laggoun-Défarge F. & Durand A. (2006). Inventory of sedimentary organic matter in modern wetland (Marais Vernier, Normandy, France) as source-indicative tools to study Holocene alluvial deposits (Lower Seine Valley, France). *International Journal of Coal Geology* , 67: 1-16.

Staplin F.L., (1969). Sedimentary organic matter, organic metamorphism, and oil and gas occurrence: *Bulletin of Canadian Petroleum Geology*, 17(1): 47–66.

Tissot B.P., & Welte, O.N., (1984). *Petroleum Formation and Occurrence*. Berlin, Springer-Verlag, 233 p.

Traverse A., (1988). *Palaeopalynology*: Unwin Hyman, London, 600 p.

Tschudy R.H., (1969). *The plant kingdom and its palynological representation*. Aspects of Palynology Wiley-interscience, chapter 2, pp. 5-34.

Tyson R.V. (1989). Late Jurassic palynofacies trends, Piper and Kimmeridge Clay Formation, UK onshore and offshore. In: Batten, D.J., Keen, M.C. (Eds.), *North-west European Micropaleontology and Paleontology*. British Micro-paleontological Society Series, pp. 135-172.

Tyson R.V. (1990). Automated transmitted light kerogens typing by imagine analysis. In: Fermont, W.J. and Weegink, J.W. (Eds.), *Proceedings of the International Symposium on Organic Petrology*, Zeist, Mededelingen Rijks Geologische Dienst, 45, 139-150.

Tyson R.V. (1993). Palynofacies analysis, In: Jenkins, D.J. (Eds.), *Applied Micro-paleontology*. Kluwer Academic Publishers, Dordrecht, pp. 153-191.

Tyson, R.V., (1995). *Sedimentary Organic Matter, Organic fancies and palynofacies*. Chapman and Hall, London, 615 p.

Van Bregen P.F., Janssen N.M.M., Alferink M., & Kerp J.H.F. (1990). Recognition of organic matter types in standard palynological slides. In: Fermont, W.J. and Weegink, J.W. (eds.), *Proceedings of the International Symposium on Organic Petrology*, Zeist, Mededelingen Rijks Geologische Dienst, 45, 921.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

van der Zwan C.J. (1990). Palynostratigraphical and palynofacies reconstruction of the Upper Jurassic to lowermost Createaceous of the Draugen Field, offshore midNorway. *Review of Palaeobotany and Palynology*, 62: 157-186.

Weller A.F., Corcoran J., Harris A.J., & Ware J.A. (2005). The semi-automated classification of sedimentary organic matter in palynological preparations.*Computers & Geosciences*, 31(10): 1213–1223.

Zavattieri A,N., Rosenfield U., & Volkheimer W. (2008). Palcies analysis and sedimentary environment of Early Jurassic coastal sediments at the southern border of the Neuquen Basin, Argentina. *J. S. Am. Earth Sci*., 25: 277-245.

Zobba M., El Beialy S.Y., El-Sheikh H.A., & Beshtawy M.K. (2013). Jurassic-Cretaceous palynomorphs, palynofacies and petroleum potential of the Sharib-1X and Ghoroud-1X wells, North Western Desert, Egypt. *J. Afr. Earth Sci.*, 78: 51-65.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Appendix

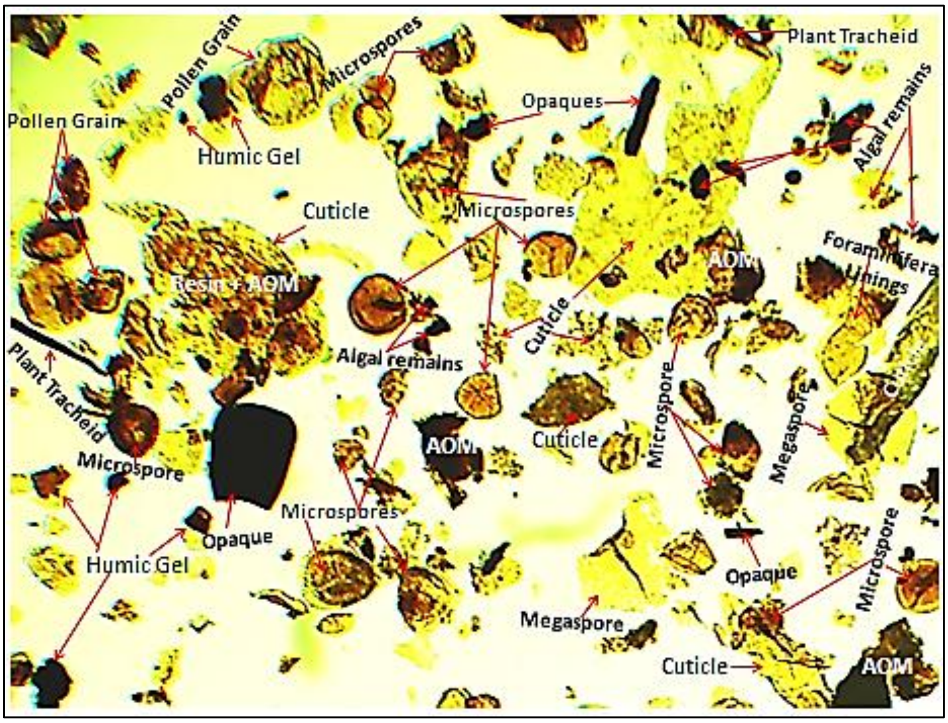
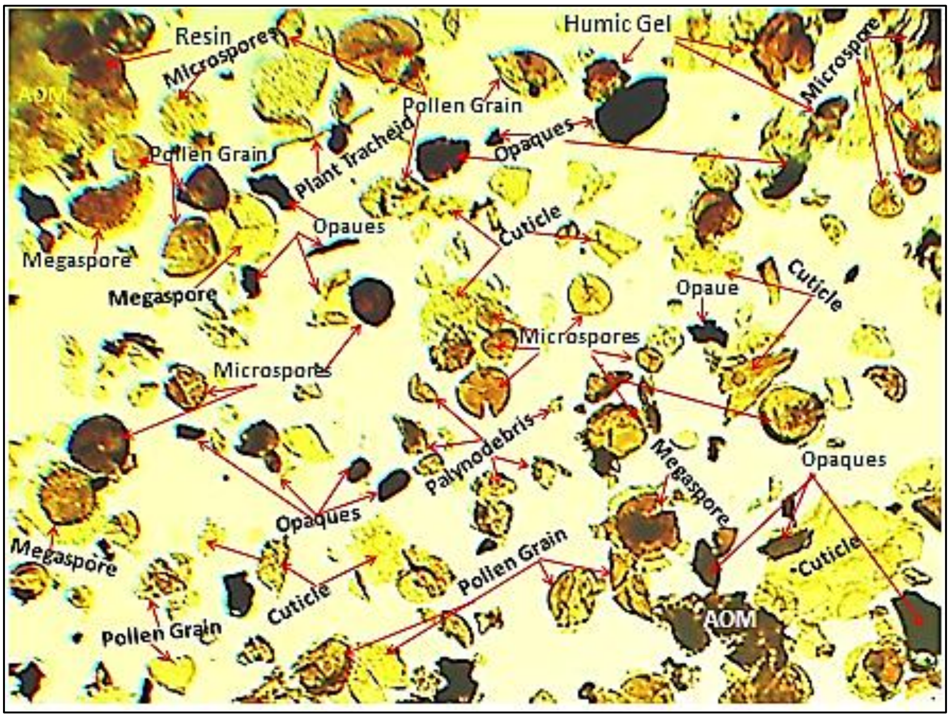


Figure 4. The organic matter that constitute the upper package rock sample (thin-section-1) (Mag. X40)



ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Figure 5. The organic matter that constitute the upper package rock sample (thin-section-2) (Mag. X40)

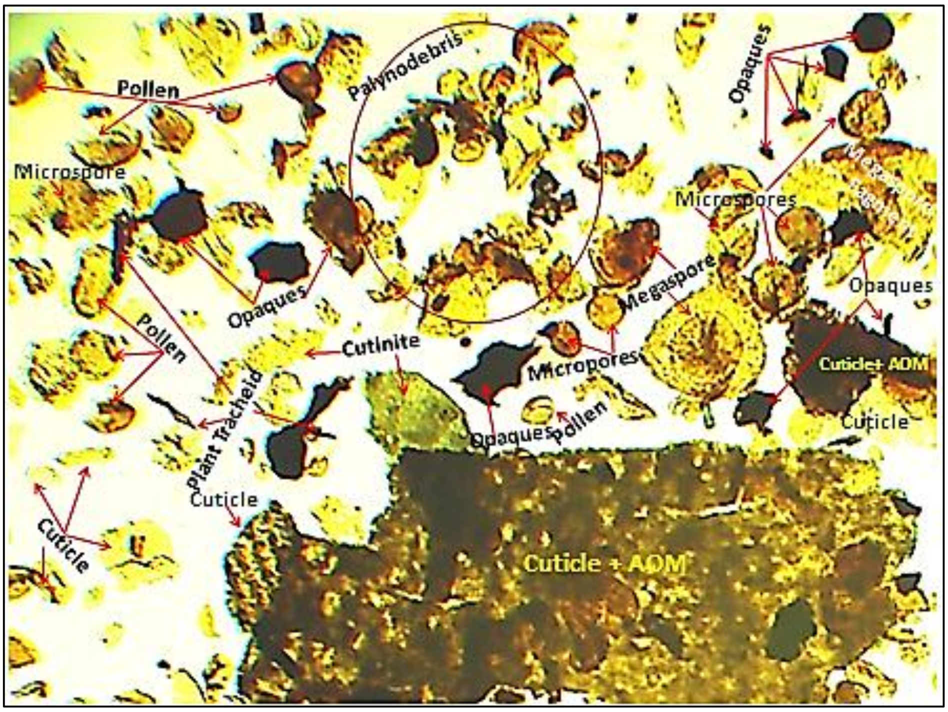


Figure 6. The organic matter constituents in the upper package rock sample (thin-section-3) (Mag. X40)

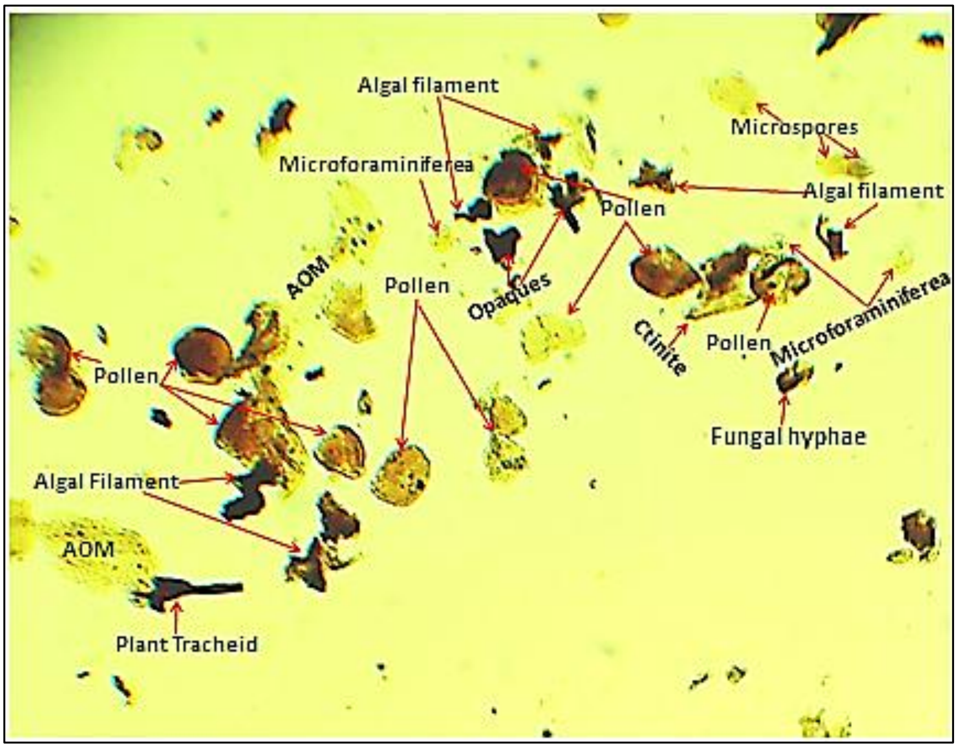


Figure 7. The organic matter constituents in the Middle package rock sample (thin-section-4) (Mag. X40)

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

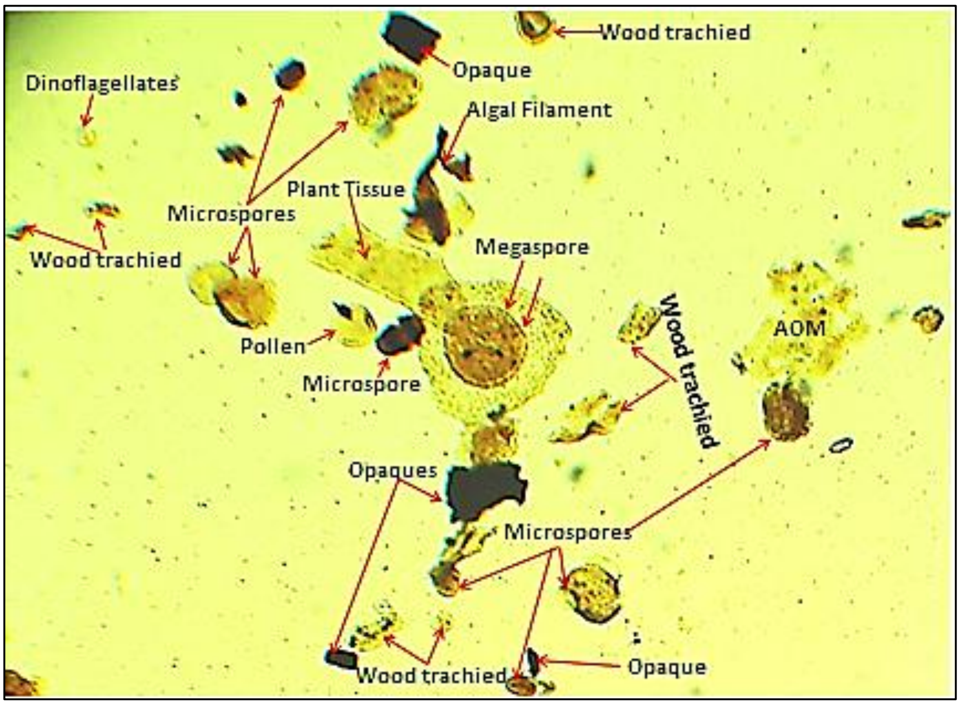


Figure 8. The organic matter constituents in the Middle package rock sample (thin-section-5) (Mag. X40)

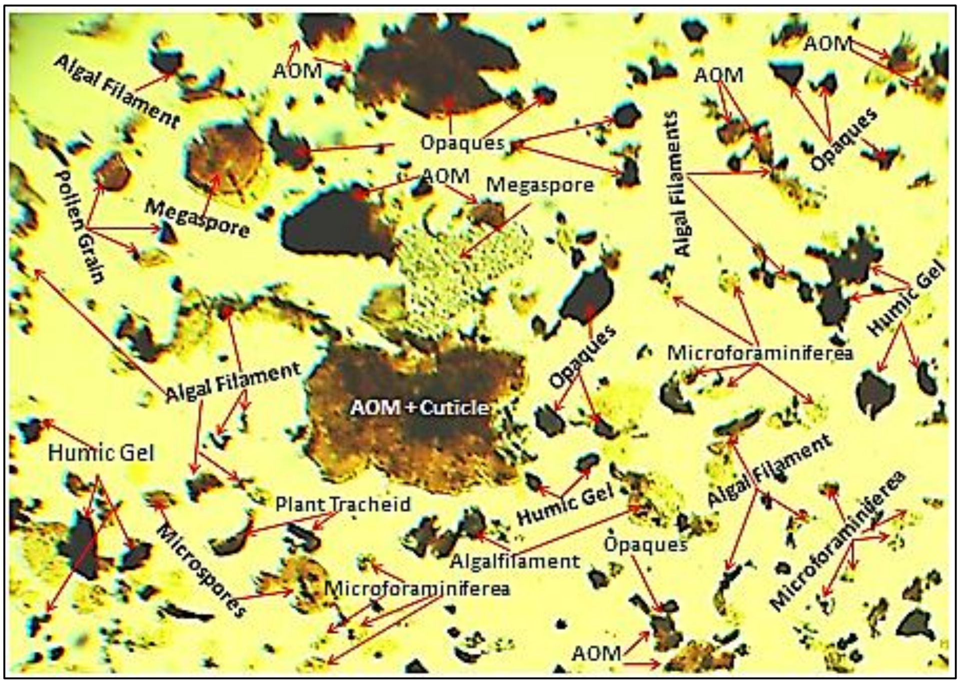


Figure 9. The organic matter constituents in the Middle package rock sample (thin-section-6) (Mag. X20)

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

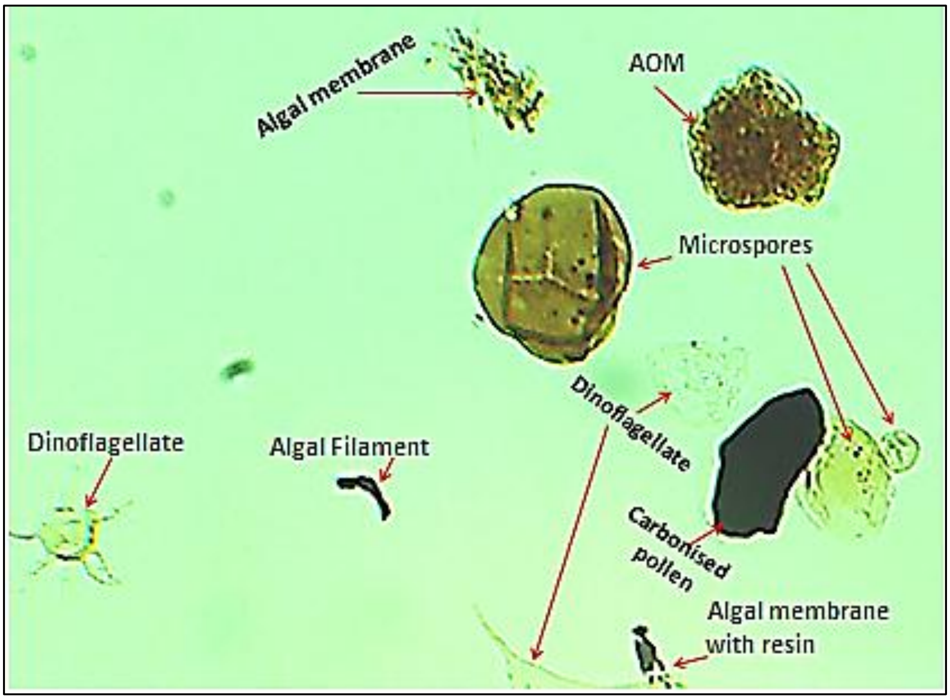


Figure 10. The organic matter constituents in the Middle package rock sample (thin-section-7) (Mag. X50)

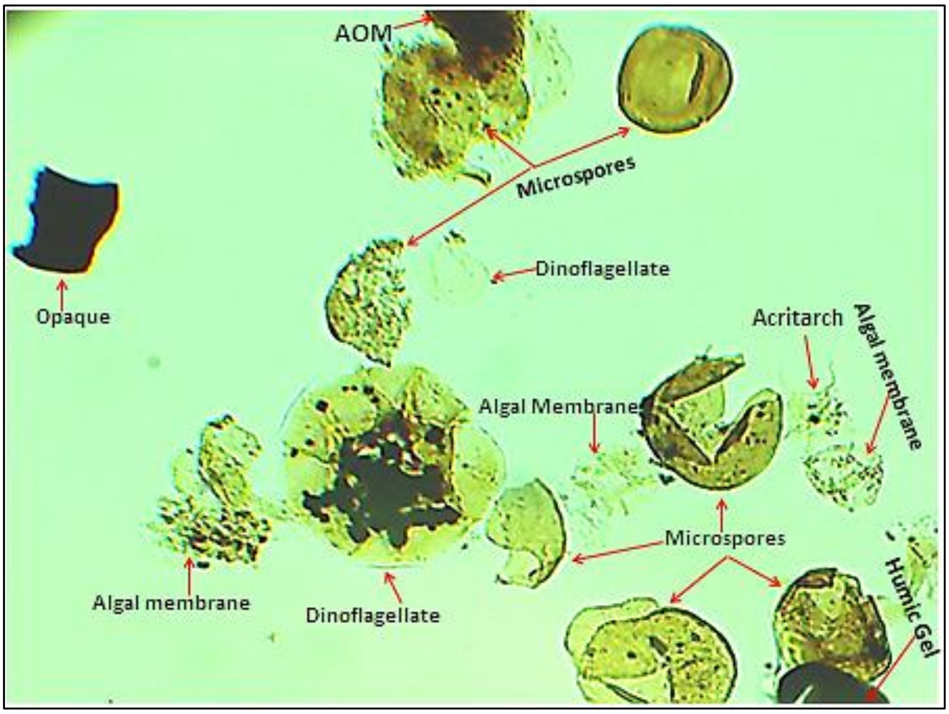


Figure 11. The organic matter constituents in the Middle package rock sample (thin-section-8) (Mag. X50)

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

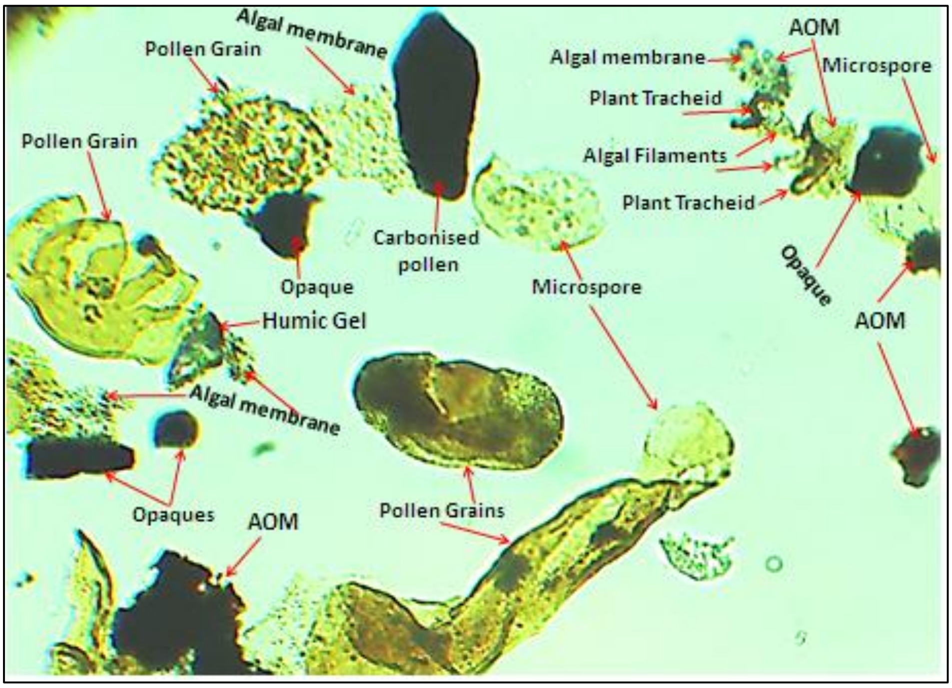


Figure 12. The organic matter constituents in the Middle package rock sample (thin-section-9) (Mag. X50)

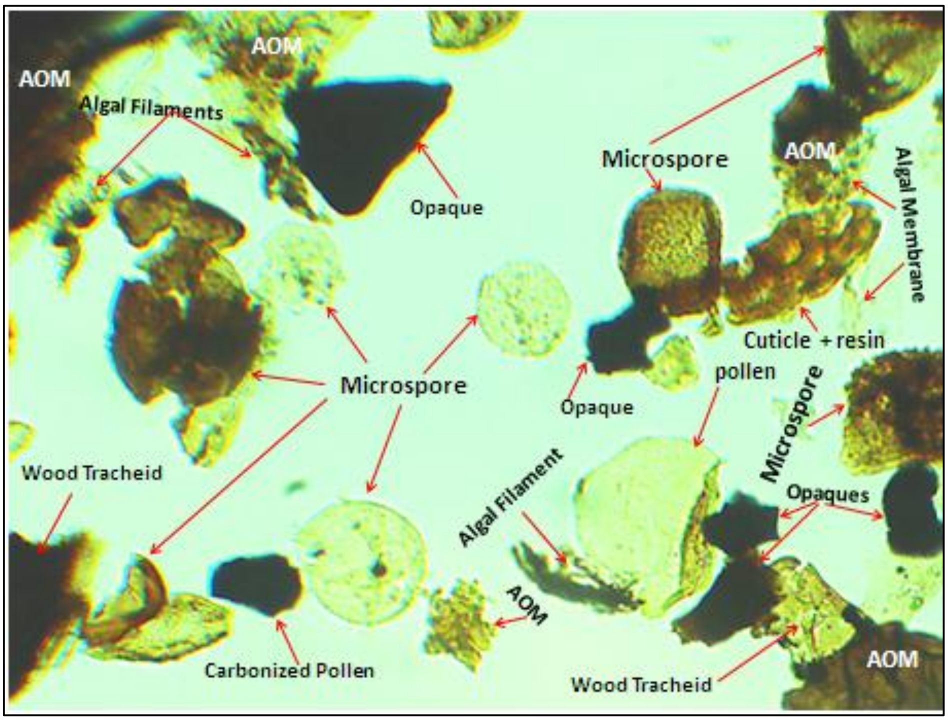


Figure 13. The organic matter constituents in the Middle package rock sample (thin-section-10) (Mag. X50)

Table 18. Shows spore color index (SCI) used to describe organic thermal maturation (OTM) for the analyzed cutting samples within the study area, (after Lucas and Omodolor, 2018)

Organic thermal maturity	Spores/pollen Color	Spore color index (SCI)
IMMATURE		1
		2
MATURE MAIN PHASE OF LIQIUD PETROLEUM GENERATION		3
		4
		5
DRY GAS OR BARREN		6
		7
		8
		9
		10

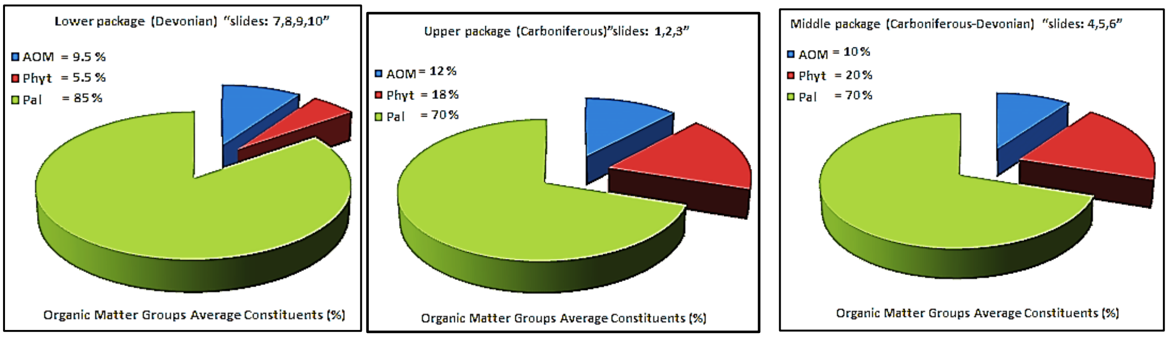


Figure 14. The average organic material constituents (%) of the three groups (AOM, Phytoclast, Palynomorph) in the area of study (**A:** upper package "Carboniferous", **B:** middle package "Carboniferous-Devonian", **C:** lower package "Devonian").

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

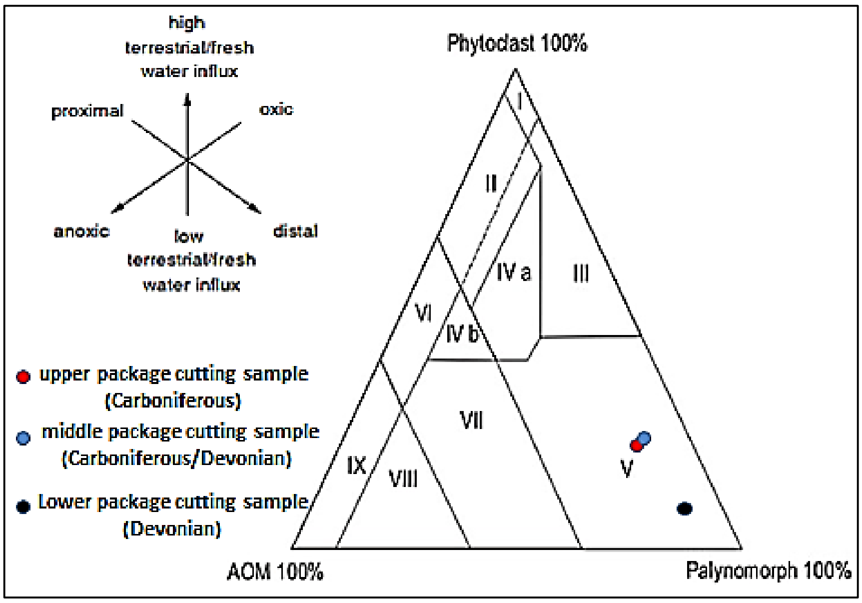


Figure 15. Shows the ternary AOM-phytoclast-palynomorph plot (APP) for the organic material groups constituted in the upper, middle and lower package cutting samples in the area of study (modified from Tyson, 1995); [**I**: Highly proximal shelf or basin, **II:** Marginal dysoxic-anoxic basin, **III:** Heterolithic oxic shelf (proximal shelf), **IV**: Shelf to basin transition, **V:** Mud-dominated oxic shelf (Distal shelf), **VI**: Proximal suboxic-anoxic shelf, **VII**: Distal dysoxic-anoxic shelf, **VIII**: Distal anoxic shelf, **IX**: Distal suboxic-anoxic basin].