

Palynofacies Analysis and Hydrocarbon Generation Potential of the Tithonian-Berriassian Chia Gara Formation from Selected Wells in Ajil, Hamrin, and Tikrit Oilfields, Northern Iraq

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Abstract

The recovered sedimentary organic matter from the Tithonian-Berriassian Chia Gara Formation was studied from three selected wells of Ajil-12 (Aj-12), Hamrin-1 (Hr-1), and Tikrit-3 (Tk-3) in Northern Iraq. Amorphous organic matters appeared to be the dominant components of the organic matters within the formation with more than 93%, whereas phytoclasts and palynomorphs comprised only few percentages. As no intensive variations observed in the percentages of the determined organic matters along the studied Chia Gara Formation except a slight increase in phytoclasts and palynomorphs in its uppermost part, therefore the formation considered to be representing only one main palynofacies type that subdivided into two secondary palynofacies. Using Tyson's APP ternary, the formation appeared to be deposited in a distal suboxic-anoxic basin. As source rock, the formation in the studied locations contains moderate to very good quantity of organic matters which compose mainly of type II and Type III kerogen (separately or mixed). The whole formation has the ability to generate oil or gas except the upper part of the formation in the location of the well Aj-12 in which less than the lower limit of the required S₂ values for considering as source rock is recorded.

Keywords: Chia Gara Formation, Palynofacies, Organic matter, Phytoclasts, Palynomorphs, Source rock.

تحليل السحنات الباليولوجية و تقييم الصخور المصدرية لتكوين جيا كارا التيثوني - البرياسي في ابار مختارة من حقول العجيل, حميرين, و تكريت في شمال العراق

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المخلص

تمت دراسة المواد العضوية الرسوبية المستخلصة من نماذج صخرية عائدة لتكوين جيا كارا ذو العمر التيثوني- البرياسي و ذلك من الابار النفطية الثلاثة عجيل -12, حميرين-1, و تكريت-3 في شمال العراق. تبين من خلال الدراسة بأن المواد العضوية عديمة الأشكال هي السائدة ضمن التكوين بنسبة أكثر من 93% بينما المواد الأخرى و المتمثلة بالبقايا النباتية و الأشكال الحياتية العضوية شكلت و بصورة متساوية تقريبا النسب الضئيلة المتبقية. بما أن التغيرات في نسب مكونات المواد العضوية الرسوبية في التكوين لم تكن كبيرة على طول المقاطع المدروسة الا قليلا و ذلك في الجزء الأعلى من التكوين فقط , لذا فأن سحنة الباليولوجية رئيسية واحدة فقط تم تسجيلها و التي قسمت الى سحنتين بالباليولوجية ثانوية. اعتمادا على مثلث تايسون لتحليل السحنات الباليولوجية و المعتمد اساسا على التغيرات في نسب المواد العضوية عديمة الأشكال , البقايا النباتية , و الأشكال الحياتية العضوية فقد أستنتج بأن تكوين جيا كارا في منطقة الدراسة قد ترسب في بيئة حوضية شبه أوكسجينية الى لا أوكسجينية بعيدة عن الساحل من حيث مواصفات التكوين كصخرة مصدرية فقد أظهرت الدراسة بأن التكوين يحتوي على نسبة معتدلة الى جيدة جدا من المواد العضوية المتكونة بصورة رئيسية من النوع الثاني و الثالث للكروجين (منفصلة أو ممتزجة). كما أستنتج من الدراسة بأن تكوين جيا كارا في منطقة الدراسة له القدرة على توليد النفط و الغاز في كل أجزاءه عدا الجزء الأعلى منه في بئر عجيل -12.

الكلمات الدالة: تكوين جيا كارا , السحنات الباليولوجية , المواد العضوية , البقايا النباتية , الأشكال الحياتية, الصخور المصدرية.

1. Introduction

Sedimentary Organic Matter (SOM) can be defined as biogenic material that is preserved in sedimentary rocks. The organic matter is composed of both insoluble materials known as kerogen, and soluble bitumen and oil [1]. Both the composition and distribution of the organic matter are controlled by ecological conditions and sedimentological processes in the depositional environment, while microbial, physical and biogeochemical processes in sediments influence its abundance [2].

Among the importance of studying origin and character of SOM in sediments is to determine the amount and type of hydrocarbons that may be generated from sediment during burial and thermal maturation [2]. Palynofacies as concept first introduced by [3]. His definition for the term as paraphrased by [2] is the palynological study of the total assemblage of particulate organic matter contained in a sediment following removal of the sediment matrix by HCl and HF [2] extended the definition of the palynofacies to be "a body of sediment containing a distinctive assemblage of palynological organic matter thought to reflect a specific set of environmental conditions, or to be associated with a characteristic range of hydrocarbon - generating potential".

On the other hand, palynofacies analysis refers to the process that involves identification of organic matter constituents, calculating their relative and absolute abundances, and determining their size and degree of preservation [4].

In this study, an attempt done to characterize one of the effective source rocks within the Iraqi geological column known as Chia Gara Formation and that through analyzing the percentages of its sedimentary organic matter's components. Chia Gara Formation generally consists of a succession of thin beds of organic matter rich limestone, argillaceous limestone, and shales with rich ammonite faunas and diverse species of foraminifera, radiolarian, and ostracodes [5, 6, 7]. Determining the nature of the depositional environment, dominant types of the organic matters, and ability of the formation to generate hydrocarbons were among the main aims of this study.

2. Sampling and Methodology

The total of 49 rock samples of Chia Gara Formation from the wells of Aj-12 (Ajil Oilfield), Hr-1 (Hamrin Oilfield), and Tk-3 (Tikrit Oilfield) in Northern Iraq **Fig. 1** are selected and used in this study. The studied Chia Gara Formation is of 218m thickness in Aj-

12, 229 m thickness in Hr-1, and 120m thickness in Tk-3. The formation in the three wells is overlain by the Berriasian-Aptian Lower Sarmord Formation and underlain by the Kimmeridgian-Lower TithonianGotnia Formation as documented in the final reports of the studied wells.

The routine conventional palynological procedure was followed in preparing the slides from the studied samples. The recovered organic matters from the rock samples (after removing the silicates and carbonate materials using HF and HCl acids) were studied under transmitted light microscopy to characterize their components. Pyrolysis analysis done for 26 samples from the two wells of Aj-12 and Tk-3 in the laboratories of StratoChem, Cairo in Egypt. The pyrolysis analysis data of additional 23 samples of ChiaGara Formation from the wellHr-1of [8] also were acquired in this study after getting the author's personal permission 2.2.

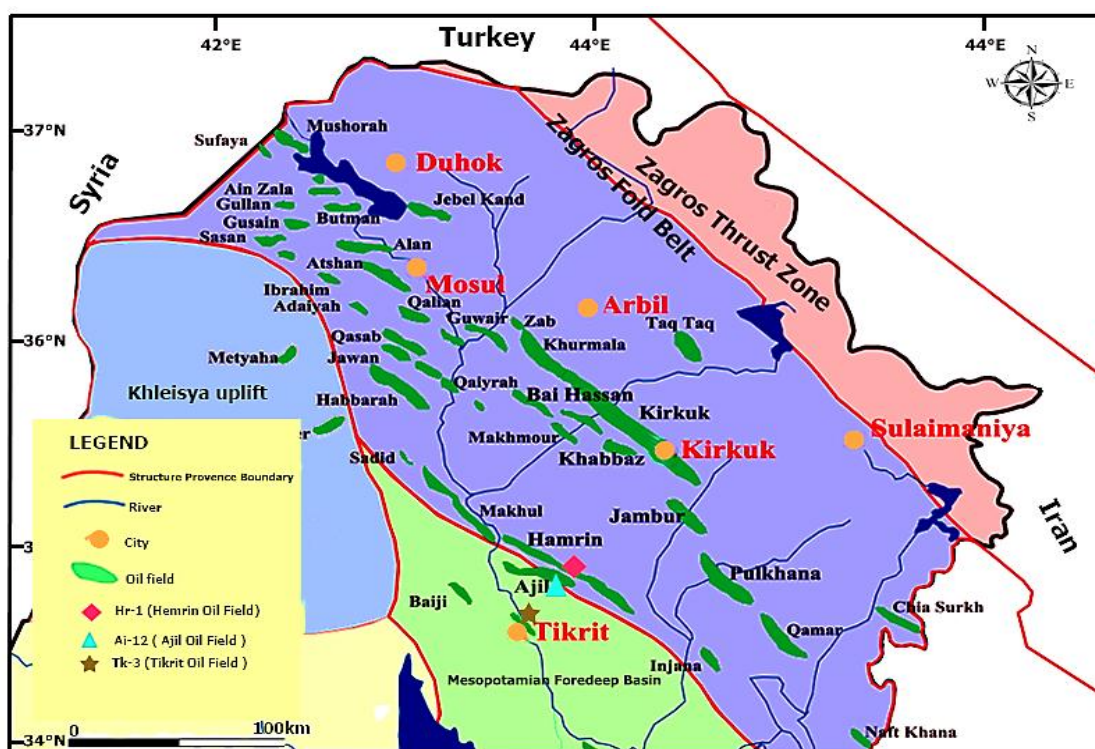


Fig. 1: Location map of the studied wells the map modified from (9)

2. Classifications of Sedimentary Organic Matters

The palynological organic matter classified according to [2] and [10] into two major categories: Structureless or Structured palynological organic matter:

Structureless organic matter is defined as an organic matter that lacks a definite internal structure when observed using light microscopy, lacks a distinct and recognizable outline, and which does not infer its biological affinity. Accordingly, structureless organic matter includes materials such as Amorphous Organic Matter (AOM), resin, and humic gel. Structured organic matter is made of discrete and recognizable individuals or colonial entities (i.e. palynomorphs) and plant or animal fragments (i.e. phytoclasts and zooclasts) that demonstrate their biological affinities.

AOM is a heterogeneous, yellow to grey colored material that is made of amorphous materials and is mainly produced by biodegradation of algal phytoplankton blooms, derived from zooplankton faecal pellets, or derived from biodegradation of cyanobacteria and thiobacteria [2]. AOM is considered the major contributing component to structureless organic matter in ancient marine and lacustrine sediments [2]. The high relative or absolute abundances of AOM – usually associated with sediments beneath upwelling water masses – was taken to indicate bottom water of low (dysoxic) oxygen concentrations [11, 12]. Palynomorphs are either of botanical or zoological affinities, whereas phytoclast particles with coherent, angular to irregular outlines that may show some internal structures can be attributed at least to a type of larger plant (phytoclasts) or animal (zooclasts) debris [2]. In this study, the identified and examined organic matter components subdivided into three main classes namely Amorphous Organic Matter (AOM), Phytoclasts, and Palynomorphs. AOM included all the structureless organic matters (without determining their sources). The phytoclasts included opaque organic materials, wood debris, and cuticles, whereas the palynomorphs represented all kinds of fossilized organic walled organisms including foraminiferal test linings. Accordingly, the categories used in this study are very similar to those used by [2] as shown in [Table 1](#)

Table 1: Categories used in this study to identify the organic matter components with their representative sources and constituents (after [2]).

Category	Source	Constituent
Palynomorphs	Zoomorphs	Scolecodonts Foraminiferal linings
	Organic-walled Phytoplankton	Dinocysts
Phytoclasts	Macrophyte plant debris	Cuticle
		Cortex tissues
		Wood
		Charcoal
AOM	Phytoplankton	Organic aggregates and Faecal pellets

Table 2 shows the percentages of the identified organic matter components in the studied samples of Chia Gara Formation from the wells Aj-12, Hr-1, and Tk-3. The percentages are carried out of at least 250 counts of organic matter particles using transmitted light microscopy with 40X magnification lens. The dominant AOM is so easy to be observed in all of the examined samples with percentages exceeding 90%. No significant variations in the low percentages of both phytoclasts and palynomorphs is noticed except a slight increasing in the total percentages of the both components at the uppermost part of the formation.

Table 2: Percentages of the identified sedimentary organic matter's components from the cutting samples of Chia Gara Formation in the studied wells of Aj-12, Hr-1, and Tk-3.

Well name	Sample no.	Depth (m)	Common Lithology	POM (%)		
				Structur less	Structure	
				AOM	Phytoc lasts	Palynomorphs
Aj-12	Aj 1	3222	Limestone	93	3	4
	Aj 2	3240		94	4	2
	Aj 3	3260		96	3	1
	Aj 4	3280		97	1	2
	Aj 5	3300		95	2	3
	Aj 6	3322		96	2	2
	Aj 7	3350		97	1	2
	Aj 8	3360		97	2	1
	Aj 9	3370		98	1	1
	Aj 10	3380		96	4	0
	Aj 11	3390	Shale	98	2	0
	Aj 12	3400		97	2	1

Well name	Sample no.	Depth (m)	Common Lithology	POM (%)		
				Structur less	Structure	
				AOM	Phytoc lasts	Palynomorphs
	Aj 13	3410	Argillaceous Limestone	96	3	1
	Aj 14	3420		97	2	1
	Aj 15	3430		95	3	1
	Aj 16	3440		96	2	1
Hr -1	Hr 1	3090	Limestone	94	4	2
	Hr 2	3100		96	2	2
	Hr 3	3110	Shale	97	3	0
	Hr 4	3125	Argillaceous Limestone	97	2	1
	Hr 5	3135		96	4	2
	Hr 6	3145		95	3	2
	Hr 7	3155	Limestone	95	3	2
	Hr 8	3165		98	2	0
	Hr 9	3175		95	3	2
	Hr 10	3185	Shale	96	4	0
	Hr 11	3195	Argillaceous Limestone	98	2	0
	Hr 12	3205		95	3	2
	Hr 13	3215		97	2	1
	Hr 14	3220		95	4	1
	Hr 15	3230	Limestone	95	3	2
	Hr 16	3240		96	2	2
	Hr 17	3250		98	2	0
	Hr 18	3260		98	2	0
	Hr 19	3270	Shale	98	2	0
	Hr 20	3280		95	3	2
	Hr 21	3290		96	3	2
	Hr 22	3300	Limestone	96	3	1
	Hr 23	3305		97	2	1
Tk -3	Tk 1	2770	Limestone	96	3	1
	Tk 2	2790		98	2	0
	Tk 3	2805		98	2	0
	Tk 4	2820	Argillaceous Limestone	99	1	0
	Tk 5	2830		98	2	0
	Tk 6	2840	Shale	98	2	0
	Tk 7	2850		98	2	0
	Tk 8	2860	Argillaceous Limestone	98	2	0
	Tk 9	2870	Shale	99	1	0
	Tk 10	2880		97	3	0

3. Palynofacies analysis

[2] defined palynofacies analysis as a palynological study of depositional environment and hydrocarbon source rock potential based upon the total assemblage of particulate organic matter. Palynofacies analysis evaluates the total microscopic particulate organic matter assemblage within a sedimentary rock following the chemical breakdown and removal of any

carbonate and siliciclastic mineral constituents. The remaining HF and HCl insoluble organic matter provides valuable information about the sedimentary facies, paleoenvironment, and source rock potential, including the relative importance and distance from terrestrial source areas, depositional energy, and basin redox conditions[13].

4. Palynofacies types in the studied Chia Gara Formation

As appeared in the [Table 2](#), AOM dominates the organic materials within the studied samples of Chia Gara Formation in the three studied wells with no noticeable variations in the palynomorphs and phytoclasts percentages. Accordingly, only one main type of palynofacies recognized in this study which easily can be noticed in the [Figs. 2-4](#). The mentioned palynofacies (PF.1) characterizes by more than 90% of AOM with generally less than 5% of the remained palynomorphs and phytoclasts. No great variations in the percentages of the sedimentary organic matters within Chia Gara Formation in the studied area are observed and that is mostly due to stability in the paleodepositional environment of the formation.

It's important to mention that the uppermost part of Chia Gara Formation showed a slight increase in the percentages of both phytoclasts and palynomorphs reflecting a slight change in the paleodepositional environment [Figs.2-4](#). As the variation was not so intense, therefore the main palynofacies PF.1 subdivided to two secondary palynofacies namely PF.1A and PF.1B [Figs. 2-4](#). Such increase in the percentages of palynomorphs and phytoclasts in the uppermost part of Chia Gara Formation (near the contact with Balambo or Sarmord formations) can be interpreted as:

- Changes in the ecological factors of the depositional basin which lead to higher productivity of organic matters (more suitable conditions for living organisms), or
- Occurring of better preservation conditions for the deposited organic matters (more euxinic condition and suitable dilution with intermediate deposition rate of fine sediments).

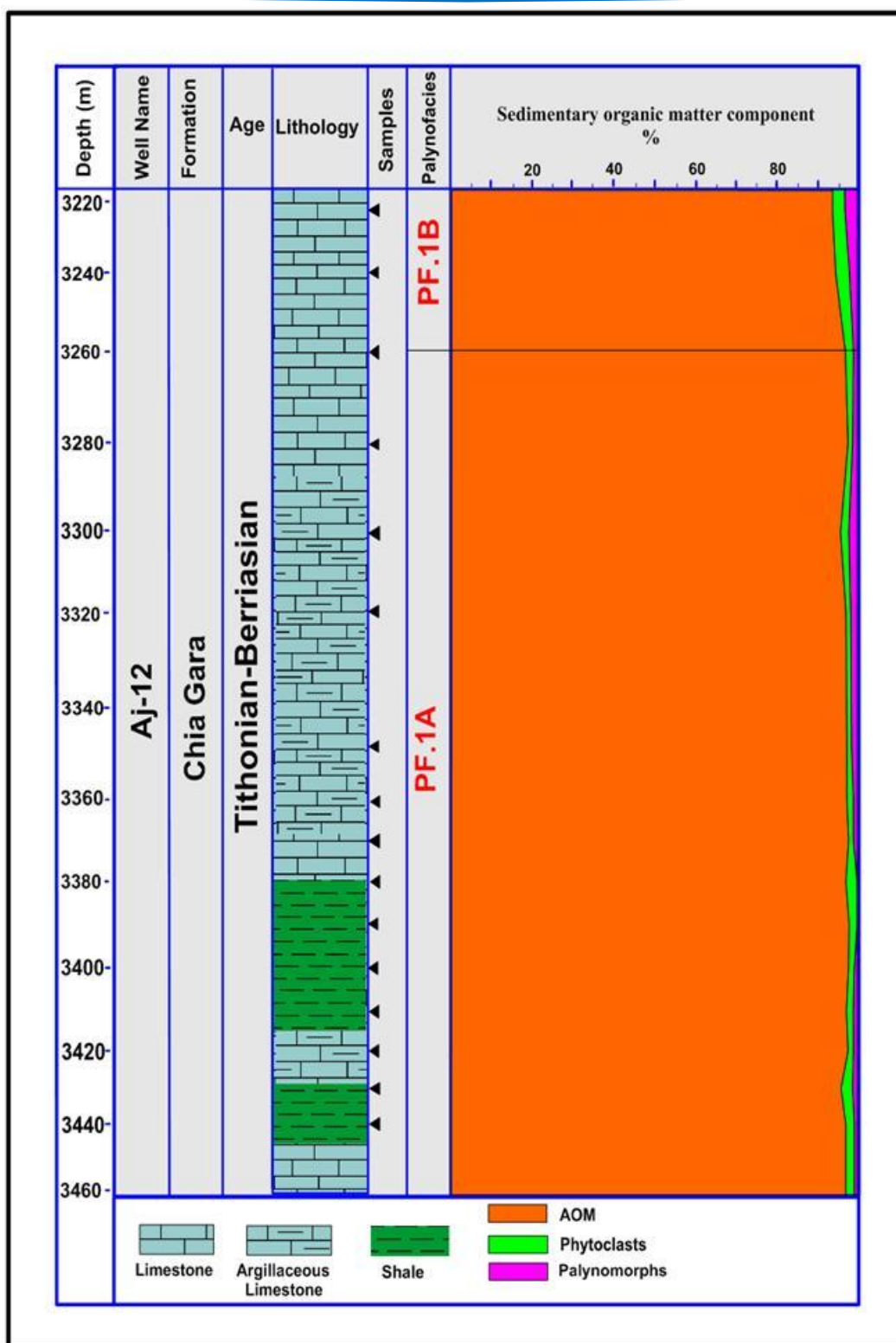


Fig. 2: Percentages of the sedimentary organic matter's components for the studied Chia Gara Formation in the well Aj-12.

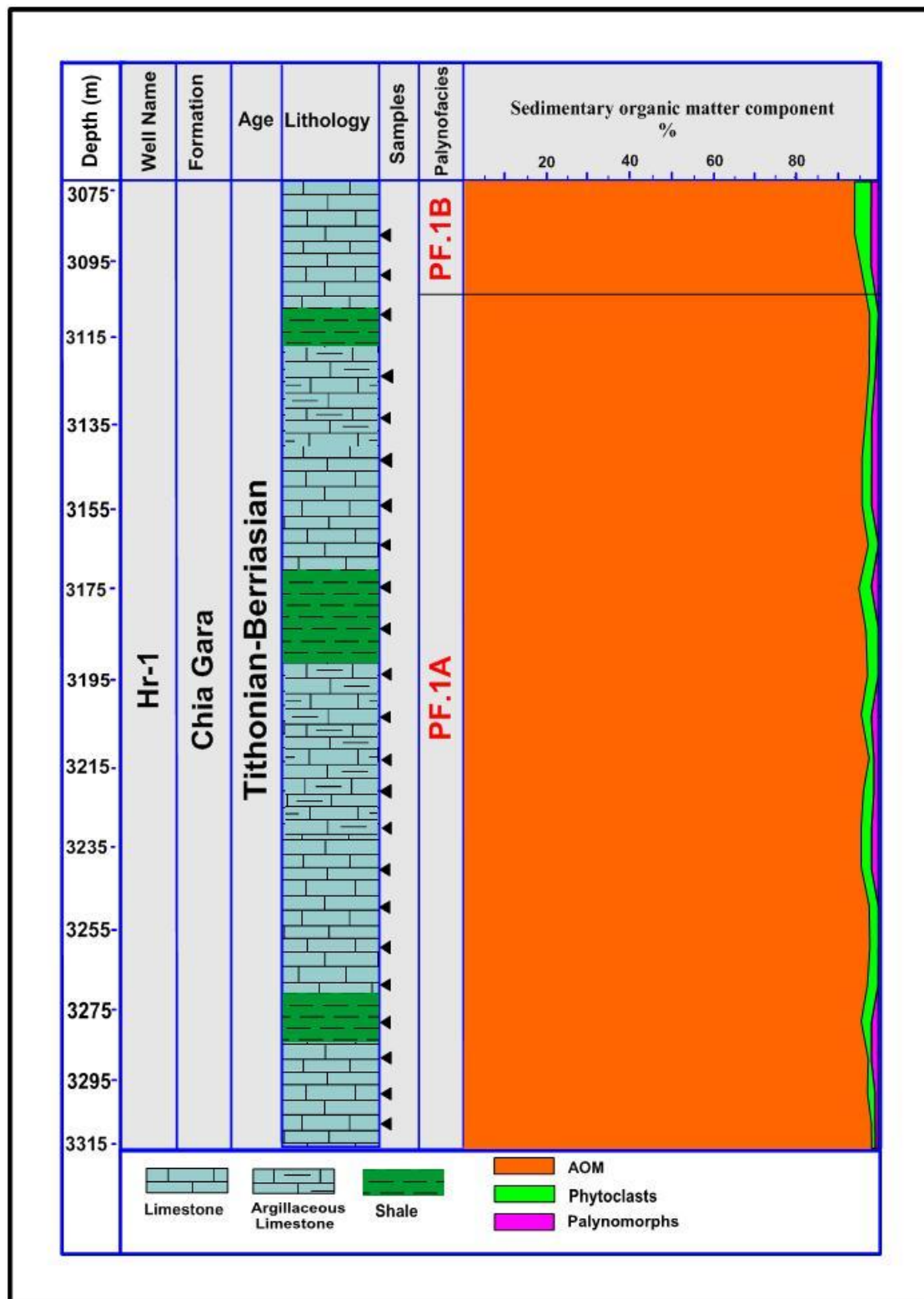


Fig. 3: Percentages of the sedimentary organic matter's components for the studied Chia Gara Formation in the well Hr-1.

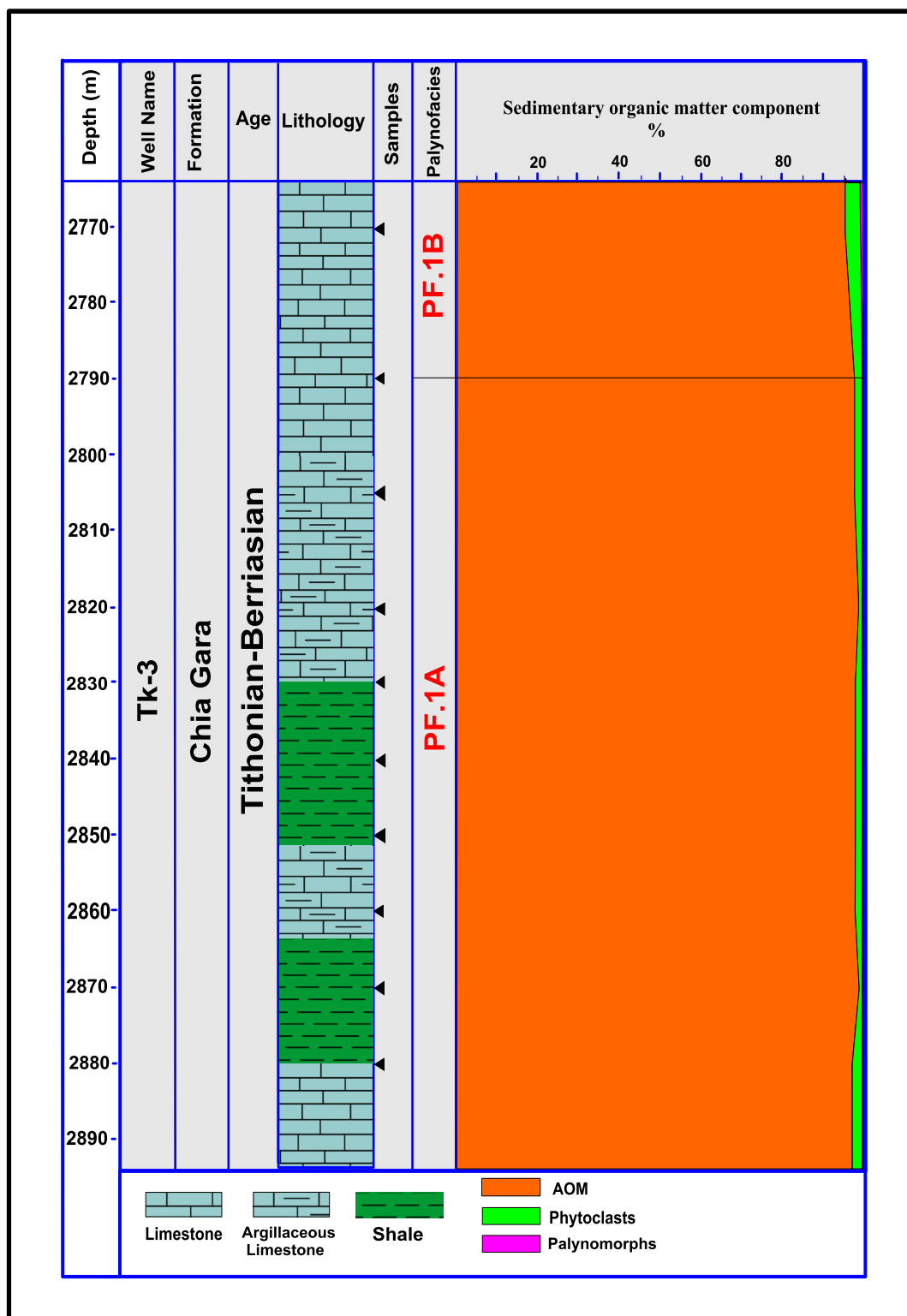


Fig. 4: Percentages of the sedimentary organic matter's components for the studied Chia Gara Formation in the well Tk-3.

interpreted as:

- Changes in the ecological factors of the depositional basin which lead to higher productivity of organic matters (more suitable conditions for living organisms), or
- Occurring of better preservation conditions for the deposited organic matters (more euxinic condition and suitable dilution with intermediate deposition rate of fine sediments).

Plates 1 and 2 contain representative images for few species of spores and dinoflagellates (palynomorphs) (Pl.1, images 1-8), different kinds of phytoclasts (Pl. 1, images 9-13), in addition to particles of AOM of different thicknesses (Pl.2, images 1-3). Representative figures for PF.1A and PF.1B exist in Plate 2 (images 4&5).

Plate - 1

Image (1): *Cribroperidinium* sp., Depth 3185m, PF.1A, Hr-1 well, 400X.

Image (2): *Kyrtomisoris* sp., Depth 3135m, PF.1A, Hr-1 well, 400X.

Image (3): *Gagiella* sp., Depth 3240m, PF.1B, Aj-12 well, 400X.

Image (4): *Cicatricosporite* sp., PF.1B, Depth 3075m, Hr-1 well, 400X.

Image (5): *Lycopodiumsporites* sp., Depth 3185m, Hr-1 well, 400X.

Image (6): Cluster (bunch) of dinoflagellates, PF.1B, Depth 3222m, Aj-12 well, 200X.

Image (7): Cluster (bunch) of dinoflagellates, PF.1A Depth 3285m, Hr-1 well, 200X.

Image (8): *Botryococcus* algae, PF.1B, Depth 3240m, Hr-1 well, 200X.

Image (9): Wood debris (Phytoclast), PF.1B, Depth 2770m, Tk-3 well, 200X.

Image (10): Foraminifera test lining, PF.1A, Depth 3300m, Aj-12 well, 200X.

Image (11): Cuticle (Phytoclast), PF.1A, Depth 3145m, Hr-1 well, 200X.

Image (12): Unknown Phytoclast, PF.1A, Depth 3145m, Hr-1 well, 200X.

Image (13): Opaque organic matters (Phytoclasts), PF.1A, Depth 2880m, Tk-3 well, 200X.

Plate - 2

Image (1): Thin particle of AOM, PF.1A, Depth 3225m, Hr-1 well, 200X.

Image (2): AOM of moderate thickness, Depth 3085m, Hr-1 well, 200X.

Image (3): Thick particle of AOM, PF.1A, Depth 2880m, Tk-3 well, 200X.

Image (4): PF.1A, Depth 3400m, Aj-12, 100X.

Image (5): PF.1B, Depth 2790m, Tk-3 well, 100X.

Plate - 1

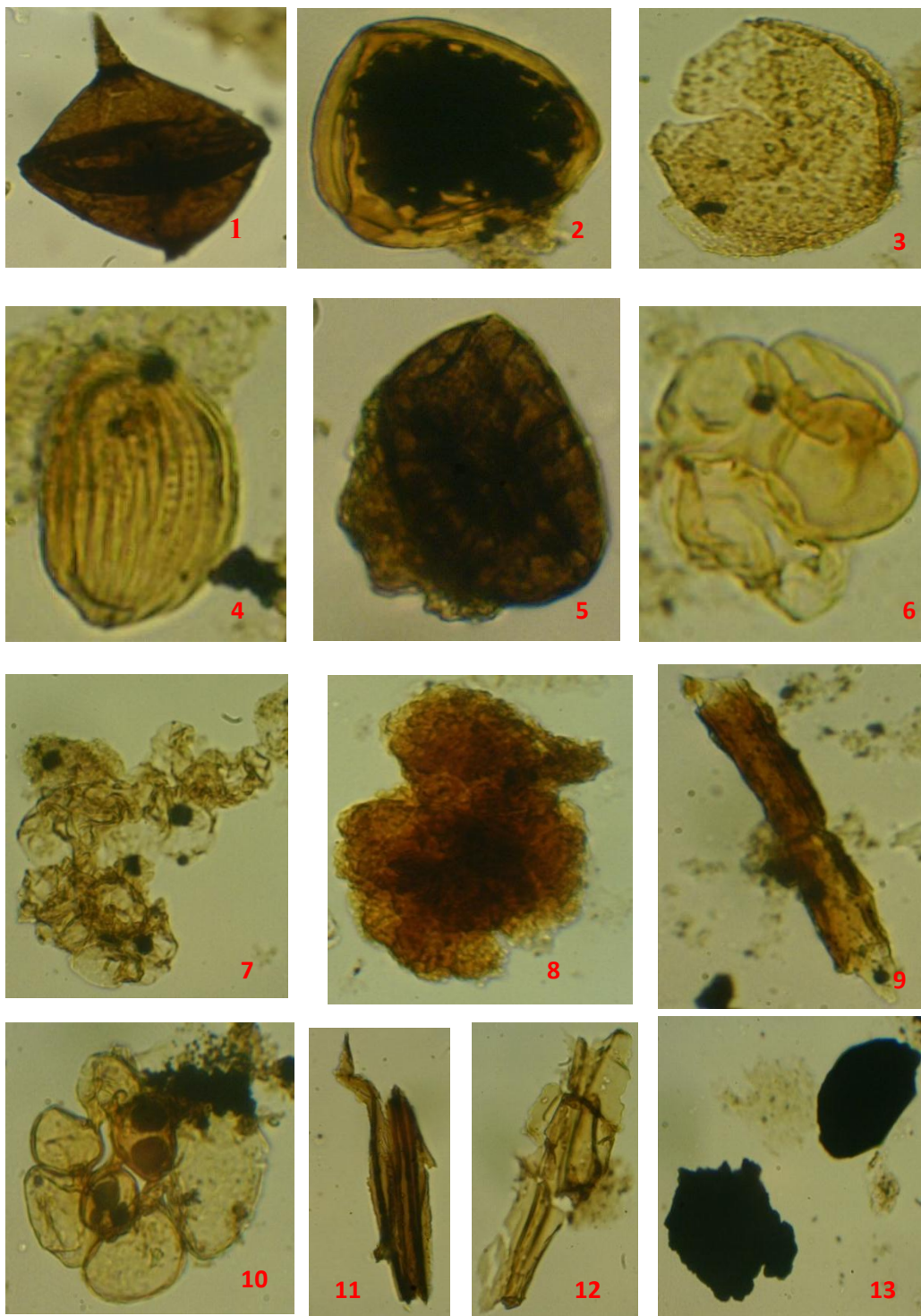
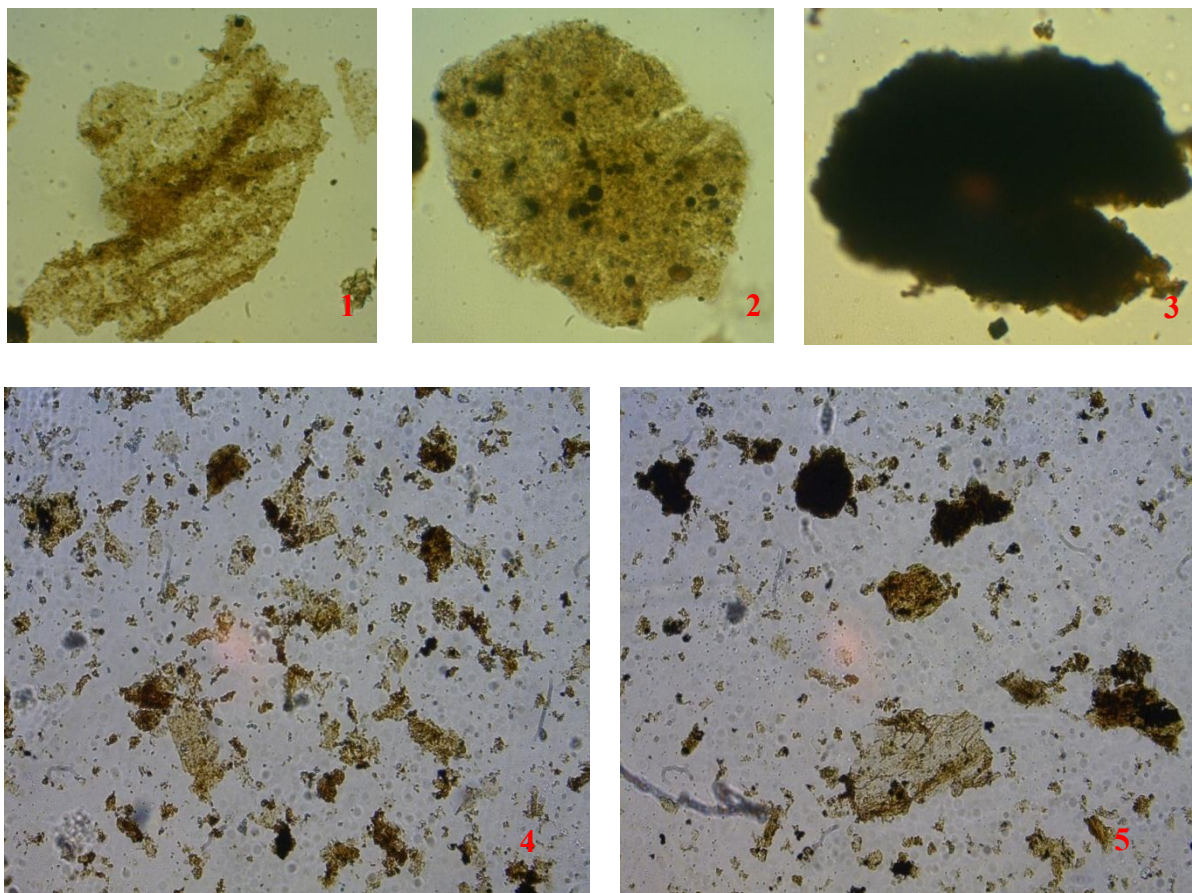


Plate - 2



5. Interpretation of palynofacies data

In this study, the AOM-Phytoclast-Palynomorph (APP) ternary of [2] which originally based on Relative Numeric Frequency (%RNF) data of [14, 15, and 16] has been chosen to determine the paleodepositional environment of the identified palynofacies. The determination based on the quantitative and qualitative variations in the kerogen content and the distribution of AOM versus phytoclasts and palynomorphs.

Sample points plotted on the APP ternary diagram for Chia Gara Formation in the studied three sections indicated (as expected) only one main palynofacies type which represents the deposition in a distal suboxic-anoxic basin (Field IX) Fig. 5. According to [2], the field IX of this ternary has the following properties:

- The dominance of amorphous organic matter assemblages.
- Low abundance of palynomorphs partly due to masking.
- Frequently rich of alginate.
- Deep basin or stratified shelf sea deposits, especially sediment starved basins.

- Bisaccate spores and Prasinophyte microplanktons are generally low.
- The organic matters are expected to be oil prone and the type II kerogen is more dominant than type I.

6. Hydrocarbon Generation Potential of Chia Gara Formation

To understand the hydrocarbon generation potentiality of the identified palynofacies of Chia Gara Formation; pyrolysis analysis done for the selected 26 rock samples from wells Aj-12 and Tk-3 wells. In addition, pyrolysis data from [8] also used for the well Hr-1. For source rock evaluation, three parameters focused on for characterizing Chia Gara Formation in this study which are Total Organic Carbon (TOC), Hydrogen Index (HI), and S₂. These parameters have a direct relationship with the initial inputs of organic matters during deposition of the formation (as quantity and quality) and also may give information about their thermal maturity state. According to [17], the correlation of palynofacies data along with TOC and HI information provide highlight on the processes occurred and lead to generate and accumulate hydrocarbons in a sediment. Figs. 6-8 show the distribution of the organic matter components within the identified palynofacies along with the variations in values of TOC, HI, and S₂ for Chia Gara Formation in the studied wells.

The quantity of organic matters represented by TOC% showed observable variations between PF.1A and PF.1B in the two wells of Aj-12 and Tk-3, whereas no such variations were recorded in the well Hr-1 which showed almost equal percentages of TOC ranged between 1.0 and 1.4%. Highest values of TOC appeared to be at the lowermost part of the formation in the two wells of Aj-12 (depth 3440m) and Tk-3 (depth 2880m at the TOC reached to 7.48%). In these two wells, PF.1A showed more richness in organic matters than PF.1B (especially in the shaley horizons). Lowest recorded percentages of TOC was in the upper part of the formation in the well Aj-12 (depth from 3222 -3280m) and ranged between 0.56 and 0.84%. Based on the qualitative classification of [18] for ranges of TOC in source rocks, Chia Gara Formation in the studied wells can be considered as moderate to very good source rock.

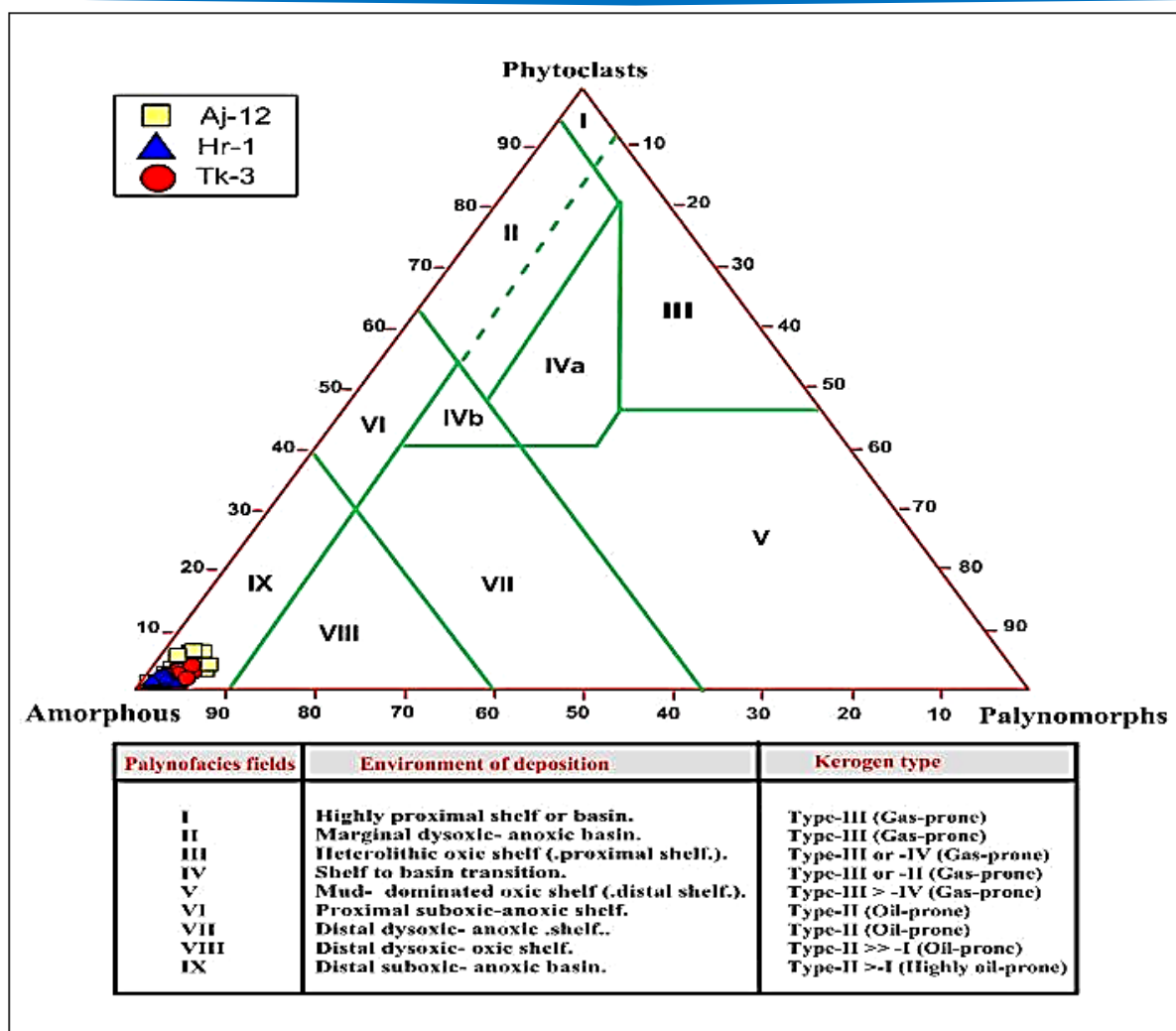


Fig. 5: Distribution of the sample points representing percentages of AOM, Phytoclast, and Palynomorphs for the studied Chia Gara Formation on the ternary proposed by [16]

The value of S2 in the process of pyrolysis represents the amount of hydrocarbons generated from the kerogene by thermal cracking at temperatures between 400 and 460°C. Generally, samples showing less than 2.0mg hydrocarbons/g rock consider as poor source rocks. The recorded S2 values for Chia Gara Formation showed high similarity with the mentioned case of TOC. No noticeable variations in the S2 values seen in the well Hr-1. The analyzed samples of this well were of S2 values ranged between 2.4 and 3.7 mg hydrocarbons/g rock (no poor samples recorded). PF.1A in the other two wells showed high S2 values especially at the lowermost part of the formation (excellent S2 values of higher than 36 mg hydrocarbons/g rock recorded in the well Tk-3). On the other hand, PF.1B appeared to

be of lowest S2 values especially in the well Aj-12 in which poor samples of less 1.0mg hydrocarbons/g rock were recorded.

The HI parameter which represents the quantity of hydrocarbons in mg that can be generated by a gm of TOC is helpful in determining the quality of the organic matters (type of Kerogen) and their ability to generating oil or gas. According to [19], HI values higher than 600 represents source rocks of type I oil prone kerogen, whereas HI values between 300 and 600 indicate source rocks of type II oilprone kerogen, HI values between 200 and 300 represent source rocks of mixed type II and III oil and gas prone kerogen. Rock samples showing less than 200 HI value indicate the ability to generate gas rather than oil (type III kerogen). **Fig. 6** shows that PF.1A of Chia Gara Formation in the well Aj-12 has the ability to generate oil and PF.1B able to generate only gas. The whole formation in the well Hr-1 has ability to generate oil and gas with almost same efficiency along the section **Fig. 7** . Good ability for Chia Gara Formation to generate oil and gas recorded for both PF.1A and PF.1B in the well Tk-3 **Fig. 8**.

7. Conclusions

The following are summarization for the main conclusions of the study:

- The organic matters within Chia Gara Formation in the studied sections of the wells Aj-12, Hr-1, and Tk-3 compose of high percentages of AOM with only few percentages of phytoclasts and palynomorphs. Therefore, only one primary palynofacies type can be distinguished in the formation which can be subdivided into two secondary palynofacies due to a slight increase in the percentages of the phytoclasts and palynomorphs at the upper part of the formation.

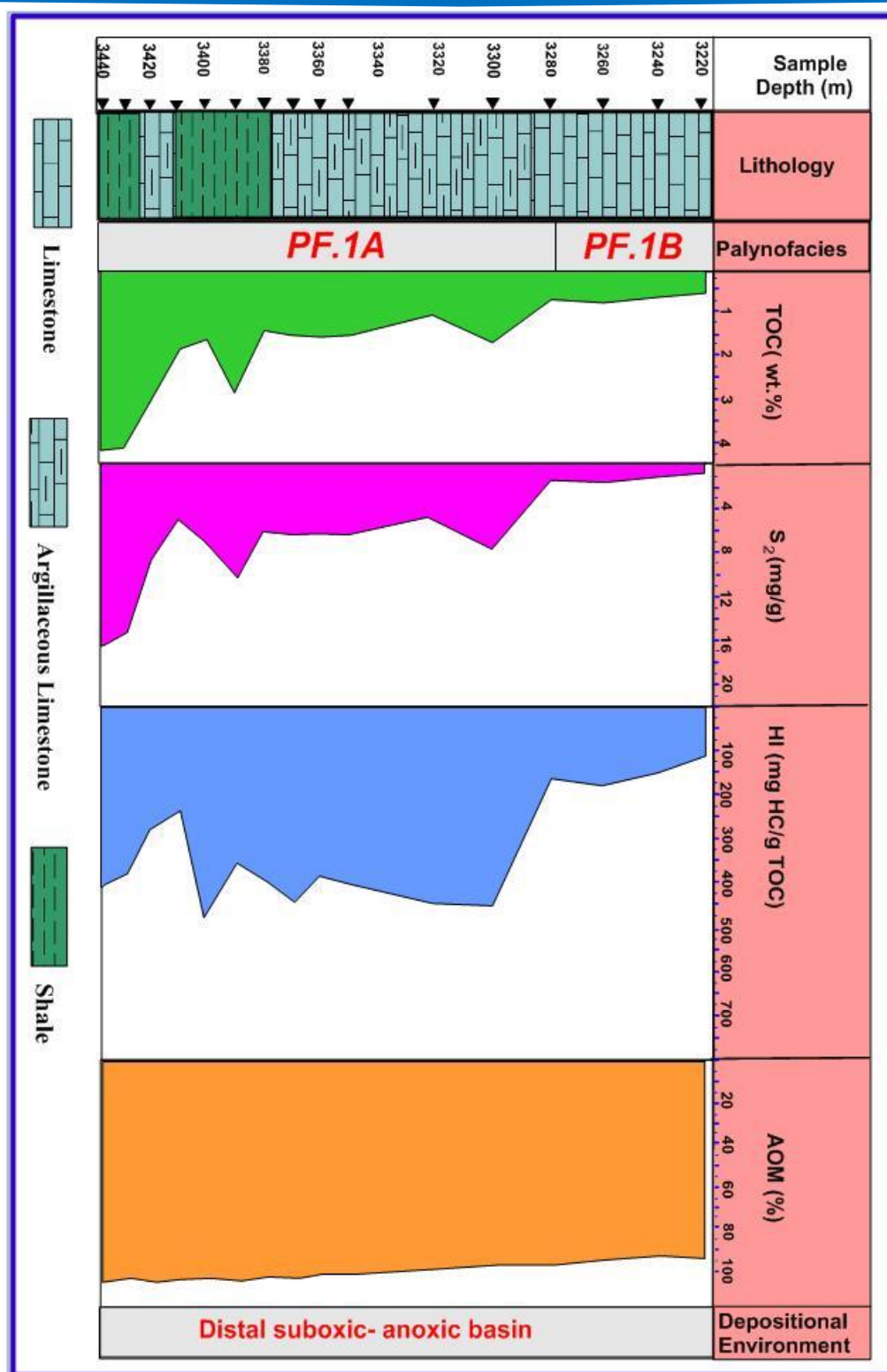


Fig. 6: Variations in the values of TOC, S₂, and HI along the identified PF.1A&B of Chia Gara Formation in the well Aj-12.

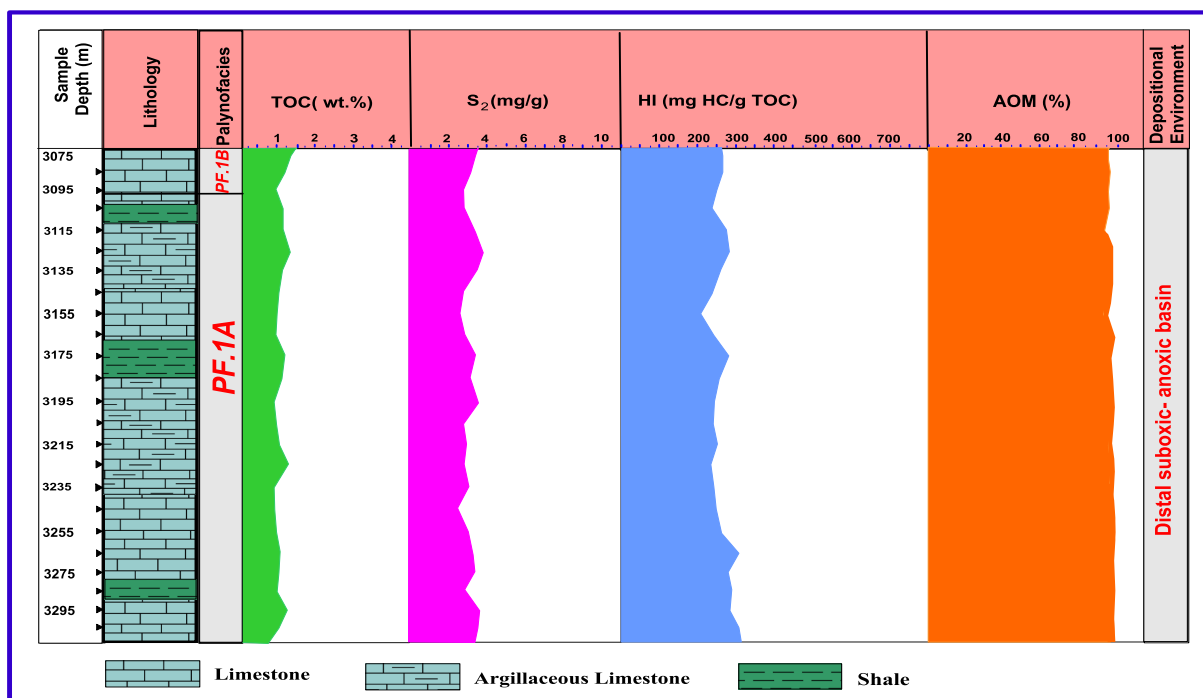


Fig. 7: Variations in the values of TOC, S₂, and HI along the identified PF.1A&B of Chia Gara Formation in the well Hr-1.

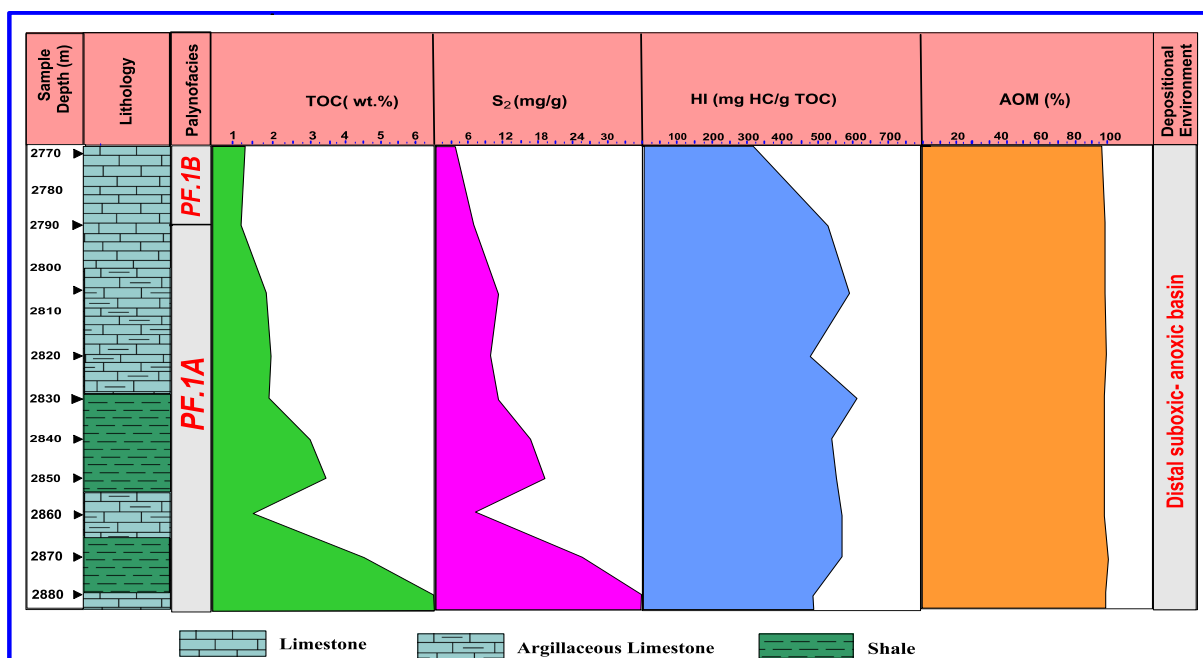


Fig. 8: Variations in the values of TOC, S₂, and HI along the identified PF.1A&B of Chia Gara Formation in the well Tk-3.

- No intense variations occurred to the environmental factors during deposition of Chia Gara Formation in the studied locations (especially in the location of Hr-1 well).
- AOM of different shapes and thicknesses can be found in Chia Gara Formation which believed to be of mixed sources (marine and terrestrial). This true also with the palynomorphs in Chia Gara Formation which compose mainly of marine dinoflagellates and terrestrial spores and pollen grains.
- The formation contains moderate to very good quantity of organic matters. As noticed in the wells Aj-12 and Tk-3, the lowermost part of the formation appears to be the richest of organic matters and the upper part the lowest.
- According to the palynofacies analysis results, the organic matters within the formation consists mainly of type II kerogen with contribution from type I kerogen also. This is not totally coincides with the results of the pyrolysis analysis which indicated clearly to contribution of type III kerogen also especially in the well Hr-1.
- The hydrocarbon potentiality of the formation as source rock can be considered as moderate to very good except the upper part of the formation in the studied section of Aj-12.

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