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Integrated organic geochemistry with palynofacies analysis of the Chia Gara Formation in the Kirkuk and Hamrin oilfields, North Iraq

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ABSTRACT

The idea of the present work was to combine Rock-Eval pyrolysis and palynofacies analysis in an integrated approach to study 51 source rock cores and cuttings samples collected from the middle Tithonian- Berriasian Chia Gara Formation, in well K-109, Kirkuk Oilfield and well Hr-1 drilled in the Hamrin Oilfield, north of Iraq to evaluate quantitatively and qualitatively the nature of sedimentary organic matter, generation potential and assess thermal maturity of the studied formation in both wells.

Rock-Eval pyrolysis and palynofacies data indicate that the Chia Gara Formation in well K-109, Kirkuk Oilfield has kerogen type III/II and II/I and the amorphous organic matter AOM is dense and amber brown to very dark brown in color assigned to type C and D which reflects mature to overmature stage (gas-oil prone). On the other hand, the source rock samples of the Chia Gara Formation encountered in well Hr-1, Hamrin Oilfield has kerogen type II/III and II/I and the AOM is dense rounded, yellow to yellowish brown typeD, mature and is oil-gas prone. The regional tectonic movements and thermal history may cause the diversity in kerogen type and the subtle color variation in the AOM from the Chia Gara Formation in the Kirkuk Field in the north to Hamrin Field in the south.

Keywords: *Rock-Eval pyrolysis, palynofacies analysis, Chia Ghara Formation, Hamrin and Kirkuk basins*

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تكامل الجيوكيمياء العضوية مع السحنات البالينولية الدقيقه لتكوين جياكارا في حقلي كركوك وحمرين، شمالي العراق.

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الملخص

تتمثل فكرة البحث في دمج طريقة الانحلال الحراري مع طريقة السحنات البالينولية الدقيقة لأحدى وخمسون عينه صخرية (لباب وفتات)، لتكوين جياكارا من حقلي كركوك وحمرين، شمال العراق وذلك لعمل دراسات كمية ونوعية لطبيعة المواد العضوية وتقييم جهدها الانتاجي وكذلك درجة نضجها الحراري.

دلت نتائج هذا البحث على ان تكوين جياكارا في حقل كركوك بئر(K-109)، يحتوي على كيروجين من النوع III/II، وكيروجين II/I، وان المواد العضوية العديمة الشكل تختلف في لونها وقوامها وانها وصلت الى درجة النضوج لإنتاج الغاز والنفط، وعلى الجانب الاخر نرى ان تكوين جياكارا في حقل حمرين بئر (Hr-1)، يختلف في طبيعة المواد العضوية الموجودة فيها والذي انعكس علي طبيعة الهيدروكاربونات المتولدة بها.

الكلمات الدالة: الانحلال الحراري، تحاليل السحنات البالينولية الدقيقة، تكوين جياكارا، حقلي كركوك وحمرين، العراق

1. INTRODUCTION

Iraq is a long-standing petroleum-producing country in the Middle East and a founding member of the cartel of the Organization of Petroleum Exporting Countries (OPEC). The current proven reserve of 133 billion barrels of oil and 110 trillion cubic feet of gas is recovered from stacked pay-zones along the stratigraphic column [1,2]. Major basins in the

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world have multiple source rock horizons. The northern part of Iraq is characterized by more than one source rock belonging to Sargelu, Najmah, Chia Gara and Balambo [3]. These source rocks feed the Cretaceous-Tertiary reservoirs [1,2]. Oil and gas reservoirs are dispersed through the Cretaceous and Tertiary rocks [4], sealed by the Middle Miocene Fatha Formation, that extends from the north to the middle of Iraq and includes mainly bedded anhydrite with shale intercalations [5]. [6] and [3] acknowledged that the principal source rocks were deposited during the Late Jurassic to Early-Middle Cretaceous, and the weight of evidence suggests that oil from these two sources are responsible for charging most of the Iraqi reservoirs.

2. GEOLOGIC BACKGROUND

The study area Fig. (1) is located in the northwestern part of the Zagros fold-thrust belt of the northeast Iraq. It was originated and developed between the Arabian and Eurasian plates as a result of multiple stages of convergence.

Tectonically, the Arabian Plate can be divided into the Arabian Shield and the Arabian Shelf. The Arabian Shelf in northern Iraq can be divided into Unfolded Area or Stable Shelf and a Folded Zone or Unstable Shelf [4,7,8,9]. [8] and [9] recognized five tectono-physiographic zones: three in the unstable shelf, and two in the stable shelf. These tectonic zones include 1) the Thrust Zone, 2) the Folded Zone, 3) the Mesopotamian Basin, 4) The Salman Zone, and 5) The Rutbah-Jezira Zone. The study area is related to low Folded/Foothill Zone of the Folded Zone in which mainly Cenozoic rocks are exposed [10,11].

The Kirkuk-Hamrin folded subzone, to the southeast of the Greater Zab River, contains long, unbroken anticlines [11]. The Kirkuk anticline contains three separate domes (Khurmala, Avanah and Baba), whereas the Hamrin anticline contains two separate domes (Nukhaila and Allass). Folds generally flatten towards the Mesopotamian Basin where relatively narrow anticlines are separated by wide synclines. These structures are open and simple with few thrusts [11]; its geometry suggests that it is a forced fold above the suspected Zagros Foredeep Fault Zone, which is thought to have been reactivated in the Pliocene to Recent [12].

Stratigraphically, the middle Tithonian–Berriasian Chia Gara Formation Fig. (2) is one of the formations in the sedimentary subcycle which extended from the Jurassic to the Early Cretaceous. It is underlain by the Barsarin Formation and overlain by the lower Sarmord

Formation Fig. (2). The type section of the Chia Gara Formation is located at the Chia Gara anticline, south of Amadiya town in the strongly Folded Zone of north Iraq [5]. Lithologically, the formation is uniform throughout Iraq, consisting of two basic lithofacies types: thinly bedded limestone and calcareous shale in the lower part of the section, followed upward by marly limestone and marl [6].

3. Samples and analytical procedures

Fifty-one core and cuttings samples recovered from the Chia Gara Formation in Kirkuk and Hamrin oilfields, northern Iraq, have been subjected to total organic carbon (TOC) and Rock-Eval pyrolysis analyses, which were conducted in StratoChem Laboratory, New Maadi, Cairo, Egypt. These analyses were carried out using a Rock-Eval 6 pyroanalyzer equipped with a TOC module. The samples were heated from 300°C (hold time 3 min) to 850°C (hold time 5 min) at 25°C/min for oxidation.

For palynofacies analysis, the samples were prepared palynologically using standard palynological maceration techniques [13] adopted at the Geology Department, Faculty of Science, Mansoura University, Egypt.

4. RESULTS AND DISCUSSION

Analytical data on rock samples using TOC/Rock-Eval are summarized in Table (1) and Figs. (3) and (4) , and palynofacies data in Table (2) , and Fig. (5) and Plate 1.

The cross plot of TOC and Rock-Eval S_2 are excellent approach for evaluating the organic richness of a source rock [14, 15, 16], whereas the cross plot of hydrogen index (HI) versus oxygen index (OI) is used for determining the kerogen type [17].

As displayed in Fig. (3) , the Chia Gara rock samples in the well K-109, Kirkuk Oilfield contain 0.68–3.95 % TOC (averaging 2.32 wt%), and yield Rock-Eval S_2 values ranging from 1.28 to 5.13 mg HC/g Rock (averaging 3.02 mg/g). On the other hand, the Chia Gara rock samples in the Hr-1 well, Hamrin Oilfield contain 1.01–1.37 % TOC (averaging 1.18 wt%), and yield Rock-Eval S_2 values ranging from 2.28 to 3.80 mg HC/g Rock (averaging 3.07 mg/g; Table (1). These data indicate that the petroleum potential of the Chia Gara Formation changes from fair–excellent in well K-109 (Kirkuk Oilfield) to good in well Hr-1 (Hamrin Oilfield; Fig. (3). Hydrogen index for the Chia Gara samples in well K-109, Kirkuk Oilfield and well Hr-1, Hamrin Oilfield ranges from 115 to 208 mg HC/g TOC, and 204 to 306 mg HC/g TOC, respectively. These results suggest that the organic matter in well K-109 is predominantly gas-prone, Type-III kerogen, while in Hr-1 well is mixed gas- and oil-prone, Type II/III kerogen Fig. (4) .

T_{max}, Production Index (PI) values from Rock-Eval Pyrolysis, vitrinite reflectance (R_o) from organic petrography and biomarkers are the most common parameters for assessing sedimentary organic matter thermal maturity [16,17, 18]. In this study, we use T_{max} in order to estimate the thermal maturity level of the Chia Gara rock samples Table (1).

The Chia Gara T_{max} values range from 428–451°C (Kirkuk Field), and 427–435°C (Hamrin Field; Table (1). These values indicate that source rocks in northern Iraq varied in their thermal maturity with regard to oil stage of generation. This maturity difference for the Chia Gara source rock may result from regional tectonic regimes and thermal history from one basin to another.

The palynofacies characteristics of the major potential source rocks in northern Iraq have been previously investigated for the Jurassic-Early Cretaceous Chia Gara Formation by [19, 20, 21, 22].

In the present work, the palynofacies analysis of the Tithonian-Berriasian Chia Gara Formation is based on the study of K-109 and Hr-1 rock samples. The samples retrieved from the Chia Gara Formation are recorded from 2835 m – 3045 m in well K-109 and from Hr-1 well spanning the interval 3075m – 3305 m Table (1). With one exception (Well Hr-1, all of the samples from which this palynofacies was identified were cuttings). Amorphous organic matter represents nearly 100% of the particulate organic matter. It is clear that the AOM recovered from the Chia Gara Formation varies in shape, size and color in the two studied wells. In well K-109, 2960-3045 m, the AOM is rounded, dense, very dark brown (Plate 1, a) and encompasses Type-C of [23] as opposed to its yellow color and its coarse-grained nature reported between 2920-2940 m, and is believed to match Type-D kerogen (Plate 1, b). In well Hr-1, 3115-3175m, the AOM is dense and rounded yellowish brown and amber reflecting Types-A and D (Plate 1, c and d).The regional tectonic movements and thermal history may cause the subtle color variation in the AOM from the Chia Gara Formation in Kirkuk Field in the north to Hamrin Field in the south. Caved material included the dinocyst *Selenopemphix nephroides* (Plate 1, e) probably from the Neogene hinterland. Only one dinocyst specimen assigned to *Gonyaulacysta* sp. is clearly seen at depth 3155 m (Plate 1, f), both are recorded from the Hamrin (Hr-1) well.

In this work, we use ternary diagrams for illustrating our data due to their good potential in showing a clear separation among various groups of samples or assemblages [24]. The AOM-phytoclast-palynomorph **APP** [25] is applied in this work. He uses it to characterize kerogen assemblages, pick out the differences in relative proximity to terrestrial organic matter sources, kerogen transport paths and the redox status of the depositional subenvironments that control AOM preservation.Data plotted on the **APP** ternary diagram indicated one main palynofacies type Fig. (5) , Table (2) . The palynofacies samples representing the Chia Gara Formation lie mainly within the field IX, which reflects distal-suboxic-anoxic basin, based on the high content of AOM that dilutes all other organic particles, and hence classified as type-II>>-I kerogen, highly oil-prone [24].

5. CONCLUSIONS

Fifty-one cores and cuttings samples retrieved from the Tithonian-Berriasian Chia Gara Formation succession in Kirkuk and Hamrin oilfields from northern Iraq, were studied by total organic carbon (TOC), Rock-Eval pyrolysis and palynofacies analyses. The following key points can be drawn:

1. Rock-Eval pyrolysis data indicated a wide variation of source richness and quality, but all contain varying quantities of Type-II (oil-prone) and Type-III (gas-prone).

2. The thermal maturity of the studied rock samples ranges from early to peak oil window based on the Rock-Eval T_{max} data.

3. Palynofacies analysis using the transmitted light microscopy enabled us to locate the Tithonian-Berriasian Chia Gara Formation palynofacies mainly within the field IX, which reflects distal-suboxic-anoxic basin, and hence classified as type-II-I, oil-prone [24].

4. In the present investigation, it seems that results gained from optically-predicted methods indicate that kerogen type is assumed to belong to type- II-I, oil-prone, and actual pyrolysis data confirm a mixed type- II-III and type-III, oil-prone to oil- and gas-prone.

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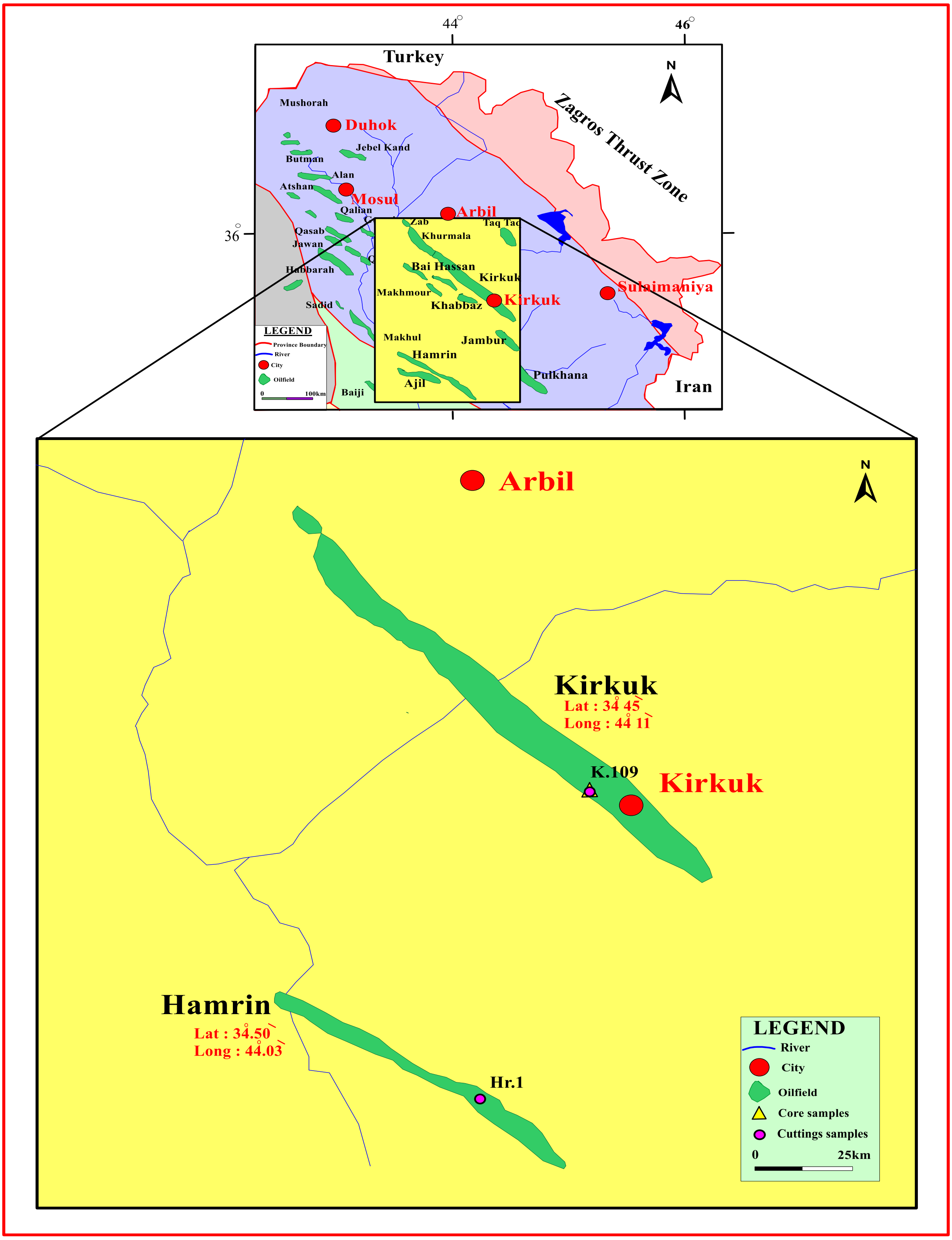

Fig. (1): Location map showing selected rock samples from wells (K-109, Kirkuk Oilfield and Hr-1, Hamrin Oilfield) in the study area, north of Iraq.

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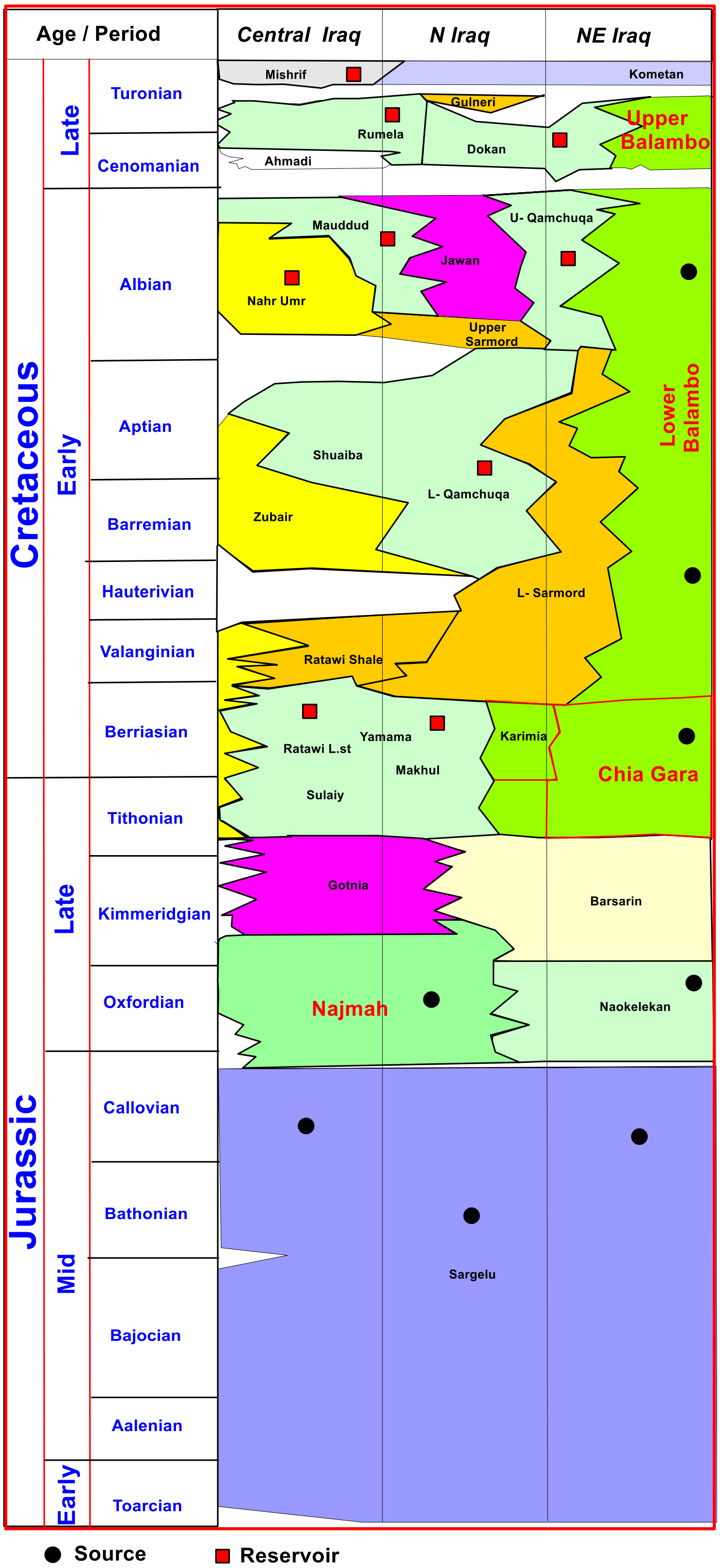

Fig. (٢): Lithostratigraphic column of the Jurassic – Cretaceous formations encountered in the present study [9]

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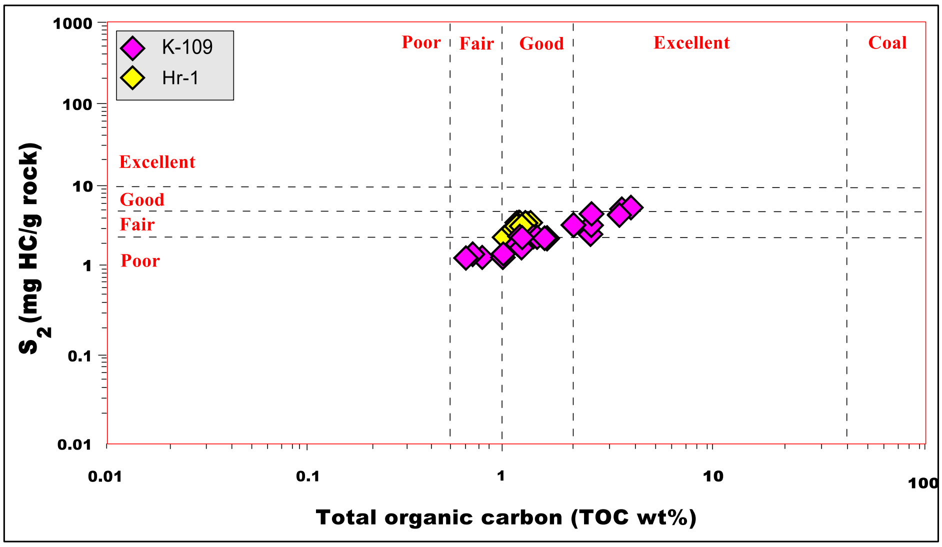

Fig. (3): Cross plot of TOC wt% versus S_2, shows the quantity of organic matter for the Chia Gara Formation from northern Iraq [16].

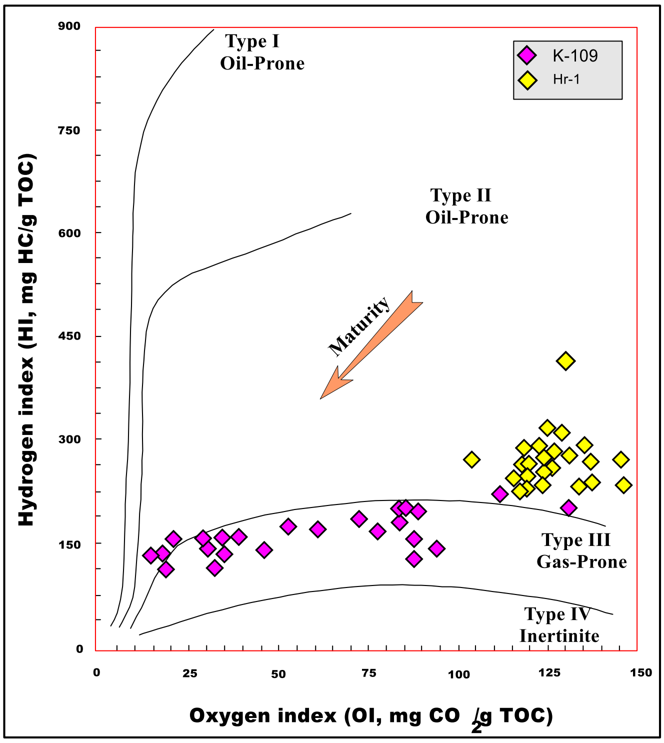

Fig. (4): Plot of OI versus HI for different kerogen types in the Chia Gara Formation [26].

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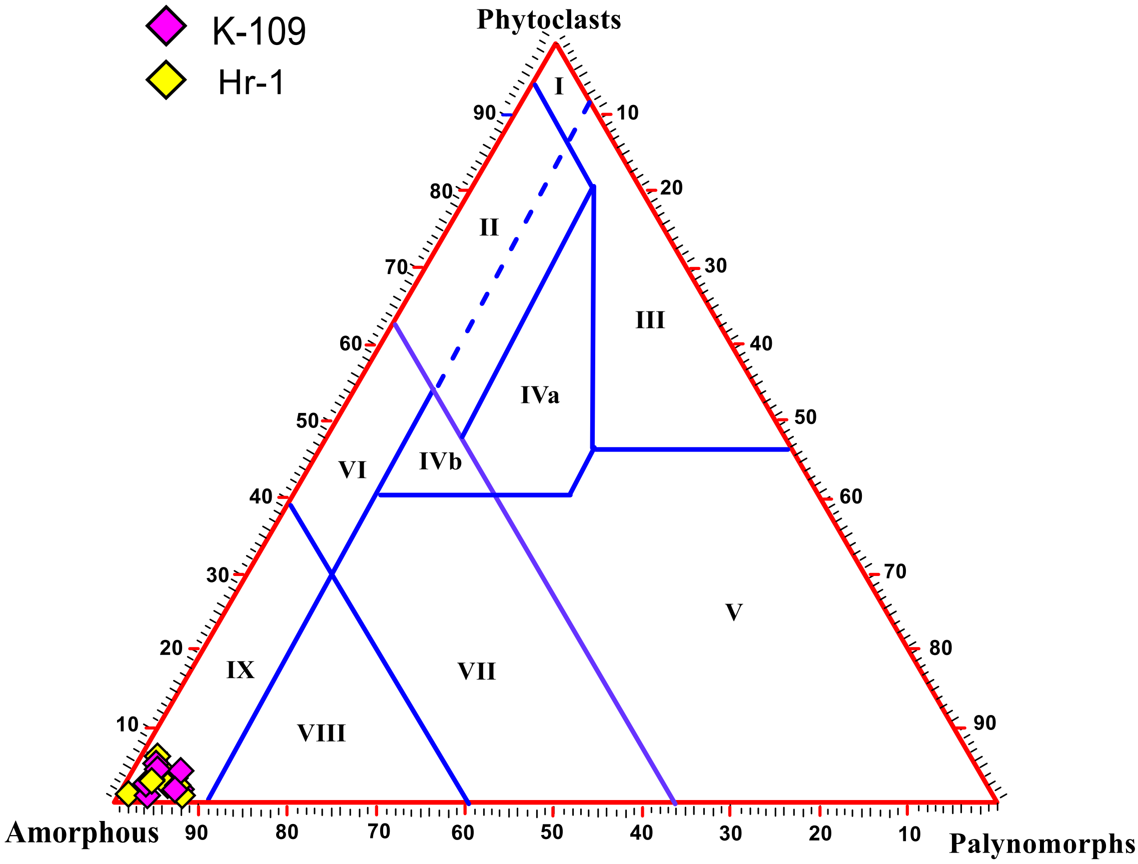

Palynofacies fields	Environment of deposition	Kerogen type
I	Highly proximal shelf or basin.	Type-III (Gas-prone)
II	Marginal dysoxic- anoxic basin.	Type-III (Gas-prone)
III	Heterolithic oxic shelf (.proximal shelf.).	Type-III or -IV (Gas-prone)
IV	Shelf to basin transition.	Type-III or -II (Gas-prone)
V	Mud- dominated oxic shelf (.distal shelf.).	Type-III > -IV (Gas-prone)
VI	Proximal suboxic-anoxic shelf.	Type-II (Oil-prone)
VII	Distal dysoxic- anoxic .shelf..	Type-II (Oil-prone)
VIII	Distal dysoxic- oxic shelf.	Type-II >> -I (Oil-prone)
IX	Distal suboxic- anoxic basin.	Type-II >-I (Highly oil-prone)

Fig. (5): Ternary AOM-Phytoclast-Palynomorph kerogen plot [25].

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Table (1): Results of TOC and Rock-Eval pyrolysis for the Chia Gara Formation.

Well Name	Field	Sample Type	Depth (m)	TOC wt%	S_1 mg/g	S_2 mg/g	S_3 mg/g	T_{max}	HI	OI
K-109	Kirkuk	Cutting	2835	1.21	0.42	2.05	0.72	444	169	60
K-109	Kirkuk	Cutting	2850	1.14	0.48	2.10	0.83	444	184	73
K-109	Kirkuk	Core	2860	2.39	0.83	2.76	0.75	445	115	31
K-109	Kirkuk	Cutting	2865	1.13	0.52	2.00	0.59	443	177	52
K-109	Kirkuk	Core	2880	0.82	0.45	1.28	0.72	439	156	88
K-109	Kirkuk	Cutting	2895	1.22	0.47	1.96	0.94	443	161	77
K-109	Kirkuk	Core	2900	1.63	0.48	2.28	0.51	443	140	31
K-109	Kirkuk	Cutting	2910	1.32	0.64	2.44	1.08	440	185	82
K-109	Kirkuk	Core	2920	1.50	0.39	2.26	0.43	447	151	29
K-109	Kirkuk	Cutting	2925	1.22	0.53	2.49	2.07	435	204	170
K-109	Kirkuk	Core	2940	0.77	0.66	1.60	0.65	433	208	84
K-109	Kirkuk	Cutting	2955	1.00	0.41	1.30	0.89	441	131	89
K-109	Kirkuk	Core	2960	0.68	0.67	1.29	0.56	428	191	83
K-109	Kirkuk	Cutting	2970	0.99	0.34	1.45	0.91	441	146	92
K-109	Kirkuk	Core	2980	2.50	1.20	3.23	0.44	446	129	18
K-109	Kirkuk	Cutting	2985	1.70	0.56	2.40	0.75	445	141	44
K-109	Kirkuk	Core	3000	2.39	1.54	4.75	2.15	445	199	90
K-109	Kirkuk	Core	3010	3.30	1.83	5.13	0.55	449	155	17
K-109	Kirkuk	Core	3020	2.01	0.95	3.13	0.75	445	156	37
K-109	Kirkuk	Core	3030	1.65	0.58	2.47	0.50	443	150	30
K-109	Kirkuk	Cutting	3035	3.95	1.40	5.04	0.54	451	128	14
K-109	Kirkuk	Core	3040	3.24	1.06	4.17	0.61	449	129	19
K-109	Kirkuk	Cutting	3045	3.19	1.59	4.71	1.06	448	148	33
Hr-1	Hamrin	Cutting	3075	1.27	0.07	3.38	1.32	431	266	104
Hr-1	Hamrin	Cutting	3085	1.20	0.08	3.18	1.52	431	265	127
Hr-1	Hamrin	Cutting	3095	1.09	0.07	2.74	1.36	431	251	125
Hr-1	Hamrin	Cutting	3105	1.23	0.09	2.86	1.67	431	233	136
Hr-1	Hamrin	Cutting	3115	1.23	0.09	3.36	1.64	430	273	133
Hr-1	Hamrin	Cutting	3125	1.37	0.11	3.80	1.61	431	277	118
Hr-1	Hamrin	Cutting	3135	1.20	0.08	3.11	1.46	431	259	122
Hr-1	Hamrin	Cutting	3145	1.18	0.07	2.72	1.42	433	231	120
Hr-1	Hamrin	Cutting	3155	1.12	0.07	2.28	1.47	432	204	131
Hr-1	Hamrin	Cutting	3165	1.18	0.07	2.90	1.40	431	246	119
Hr-1	Hamrin	Cutting	3175	1.25	0.10	3.39	1.56	431	271	125
Hr-1	Hamrin	Cutting	3185	1.20	0.09	3.03	1.40	432	253	117
Hr-1	Hamrin	Cutting	3195	1.15	0.08	2.78	1.43	434	242	124
Hr-1	Hamrin	Cutting	3205	1.17	0.07	2.69	1.33	435	230	114
Hr-1	Hamrin	Cutting	3215	1.15	0.08	2.89	1.38	432	251	120
Hr-1	Hamrin	Cutting	3225	1.25	0.06	2.95	1.43	434	236	114
Hr-1	Hamrin	Cutting	3235	1.01	0.09	2.39	1.35	432	237	134
Hr-1	Hamrin	Cutting	3245	1.16	0.08	3.03	1.37	431	261	118
Hr-1	Hamrin	Cutting	3255	1.21	0.12	3.67	1.55	430	303	128
Hr-1	Hamrin	Cutting	3265	1.16	0.09	3.35	1.41	432	289	122
Hr-1	Hamrin	Cutting	3275	1.09	0.10	3.02	1.73	428	277	159
Hr-1	Hamrin	Cutting	3285	1.25	0.11	3.64	1.69	428	291	135
Hr-1	Hamrin	Cutting	3295	1.09	0.11	3.05	1.50	427	280	138
Hr-1	Hamrin	Cutting	3305	1.12	0.13	3.43	1.41	429	306	126

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TOC = Total organic carbon, wt %; S1 = Free hydrocarbon content, mg HC/g rock; S2: Remaining hydrocarbon generative potential, mg HC/g rock; S3 = Carbon dioxide yield, mg CO_2/g rock; HI: Hydrogen index = S2×100/TOC, mg HC/g; OI = Oxygen index =S3×100/TOC, mg CO_2/g TOC; Tmax = Temperature

Table (2): Distribution of the retrieved palynodebris and percentages of the different types of organic matter in the Chia Gara (wells K-109 and Hr-1), Formation, northern Iraq.

Sample no.	Well name	Depth (m)	Sample type	Age	Formation	Lithology	Percentages of structured and structureless organic matter (%)		
							AOM	Phytoclasts	Palynomorphs
1	K-109	2835	Cutting	Tithonian-Berriasian	Chia Gara	Shale	100	0	0
2		3850	Cutting				100	0	0
3		2860	Core			Argillaceous limestone	100	0	0
4		2865	Cutting				100	0	0
5		2880	Core				100	0	0
6		2880	Cutting				100	0	0
7		2895	Cutting				100	0	0
8		2900	Core			Shale	100	0	0
9		2910	Cutting				100	0	0
10		2920	Core				100	0	0
11		2925	Cutting				100	0	0
12		2940	Core			Argillaceous limestone	98	0	2
13		2940	Cutting				100	0	0
14		2955	Cutting				100	0	0
15		2960	Core				100	0	0
16		2970	Cutting				100	0	0
17		2980	Core				100	0	0
18		2985	Cutting			Shale	100	0	0
19		3000	Core				99	0	1
20		3000	Cutting			Argillaceous limestone	100	0	0
21		3010	Core				100	0	0
22		3020	Core				100	0	0
23		3020	Cutting				100	0	0
24		2030	Core				100	0	0
25		3035	Cutting				100	0	0
26		3040	Core				100	0	0
27		3045	Cutting				100	0	0
28	Hr-1	3075	Cutting			Argillaceous limestone	100	0	0
29		3085	Cutting				100	0	0
30		3095	Cutting			Shale	100	0	0
31		3105	Cutting				100	0	0
32		3115	Cutting				97	0	3
33		3125	Cutting			Argillaceous limestone	100	0	0
34		3135	Cutting				100	0	0
35		3145	Cutting				100	0	0
36		3155	Cutting				96	1	3
37		3165	Cutting				100	0	0
38		3175	Cutting			Shale	98	0	2
39		3185	Cutting				100	0	0
40		3195	Cutting				100	0	0
41		3205	Cutting			Argillaceous limestone	100	0	0
42		3215	Cutting				100	0	3
43		3225	Cutting				100	0	0
44		3235	Cutting				100	0	0
45		3245	Cutting				100	0	0
46		3255	Cutting				100	0	0
47		3265	Cutting			Shale	100	0	0
48		3275	Cutting			Argillaceous limestone	100	0	0
49		3285	Cutting				100	0	0
50		3295	Cutting				100	0	0
51		3305	Cutting				100	0	0

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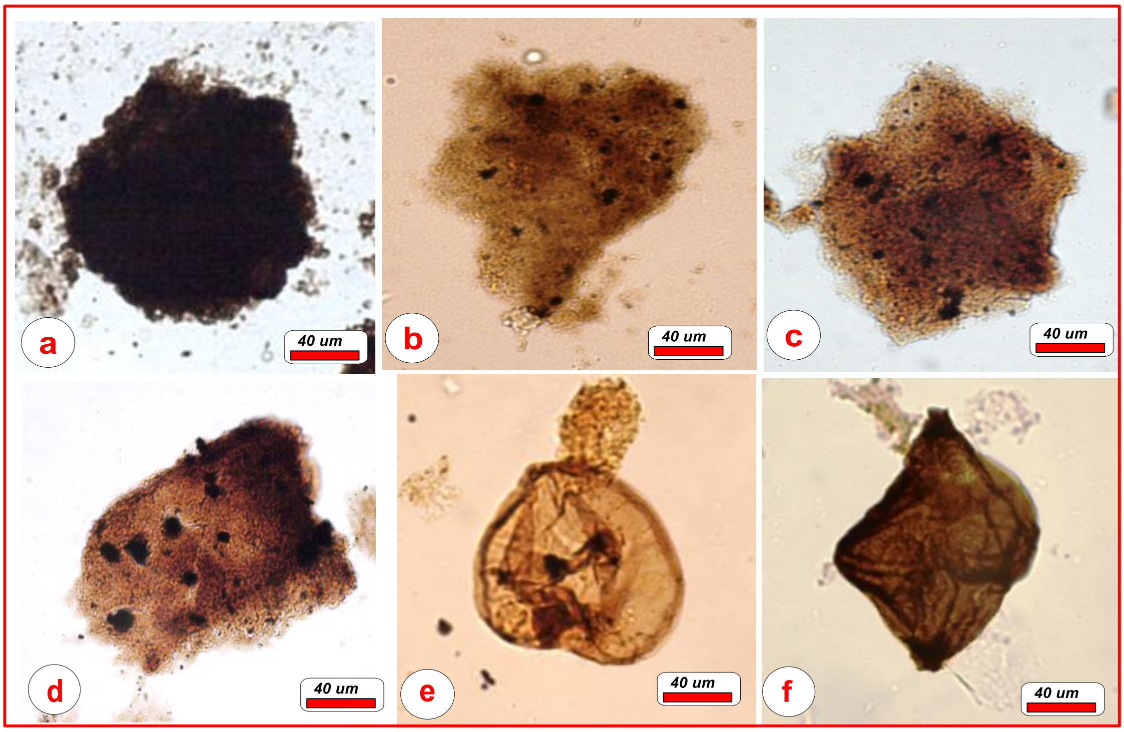

Plate 1. Bright field photomicrographs of amorphous organic matter (AOM), and palynomorphs assemblages from the Chia Gara (well K.109, Kirkuk Oilfield and well Hr.1, Hamrin Oilfield), Formation, northern Zagros Basin, NE Iraq. An England Finder reference follows the oilfield name, well name, sample type and corresponding depth for each illustrated specimen. Magnifications are in the form of a scale bar .**a**) Very dark brown, thick, type C (AOM), , Kirkuk Oilfield; well K-109, Core _2980 m_J31- 1: **b**) Light brown coarse-grained marine type D (AOM), , Kirkuk Oilfield; well K-109, Core _2920m_M37-2: **C**) Medium brown, marine type A (AOM), , Hamrin Oilfield; well Hr-1, Cuttings _3155 m_V41-3: **d**) Brown, dense rounded marine type D (AOM), Hamrin Oilfield; well Hr-1, Cuttings _3095 m_L35: **e**) *Selenopemphix nephroides* (caved dinocyst) , Hamrin Oilfield; well Hr-1, Cuttings 3115 m_L31: **f**)*Gonyaulacysta* sp. dinocyst specimen, , Hamrin Oilfield; well Hr-1,Cuttings _3155 m_O37.

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