



## EFFICIENCY OF OIL AND GAS GENERATION OF PALAEOZOIC FORMATION OUTCROPS IN NAZDUR AREA, KURDISTAN REGION, NORTHERN IRAQ: INSIGHTS FROM PALYNOLOGICAL STUDY

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Received: 19 June 2019; accepted: 9 October 2019

### ABSTRACT

*The studied samples were collected from the Palaeozoic outcrops, Khabour, Pirispiki, Kaista, Ora, Harur, and Chia Zairi formations in Nazdur Anticline, Amadia about 457 km due north of Baghdad, Iraq's capital city. Qualitative assessments of 29 samples were conducted by using textural microscopy in determining the percentage of amorphous organic matter for palynofacies type belonging to different types of kerogen. This organic matter contains acritarchs, spores, and algae deposited in the dysoxic-anoxic environment. The organic matters are from mature to post mature and have a thermal alteration index of -3 to +3 by Pearson's and Staplin's scales, respectively, with palynomorphs of orange to dark brown colors on the palynomorphs. These ranges of colors indicate mature organic matters.*

Keywords: Palaeozoic; Khabour; Pirispiki; Kaista; Ora; Harur; Chia Zairi; Palynofacies; Nazdur

### INTRODUCTION

The Palaeozoic of Arabian Plate covers massive areas of eastern Jordan, northwest Saudi Arabia, eastern Syria, and Iraq, but it is considered to have important exploration potential in Iraq (Aqrabi *et al.*, 2012). Paleozoic rocks are intended to be within the thermal petroleum generative zone in some parts of southern Iraq (Ibrahim, 1984). The dark color of the palynomorphs and other organic matter components within outcrops near Chalki Nasara Village indicates that the lower part of Khabour Formation in the studied area is thermally within the postmature state (Baban and Lawa, 2016). The

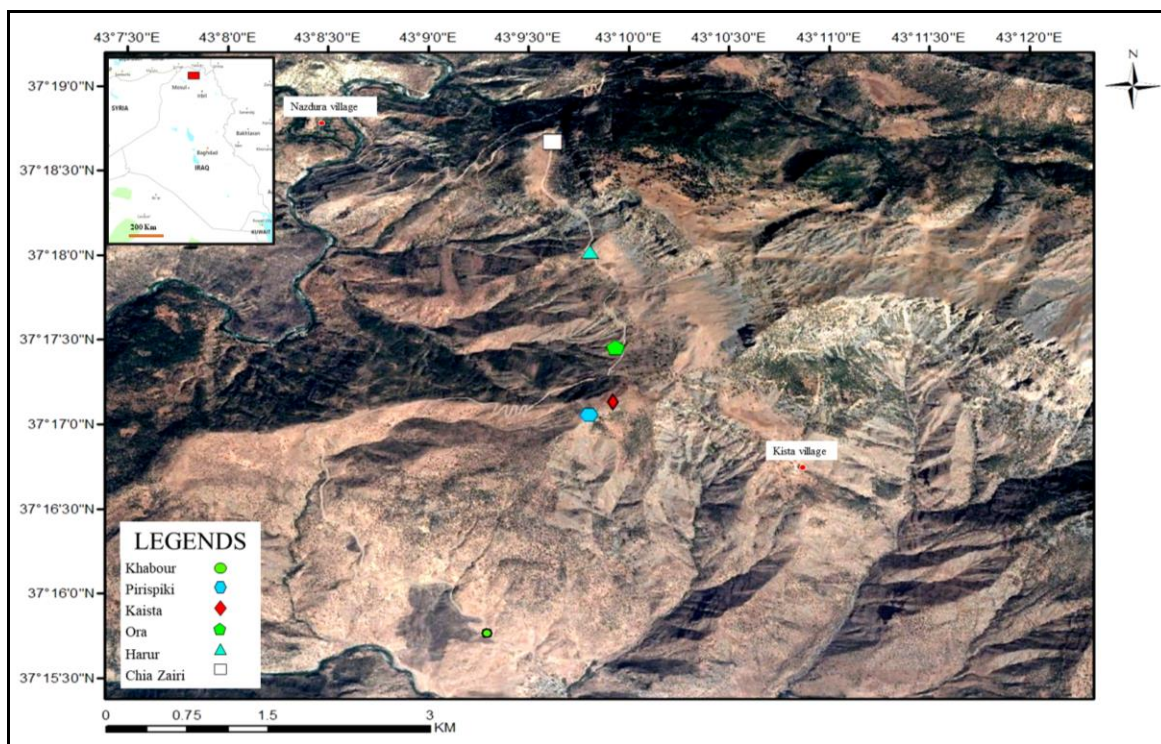
detection of Paleozoic oil in the Akkaz Field in the western part of Iraq makes the Western Desert a Palaeozoic hydrocarbon area whose potential and reserves were assessed (Shafiq, 2009). The acritarch species, *Neoveryhachium carminae*, within Suffi Formation in well K.H. 5/6 indicates cold climate during the Silurian Period (Al-Naqshabandy, 1988). The Lower Silurian (hot) shale, in the Akkas-1 Well in the Western Desert, is supposed to be the main Palaeozoic source rock in the western and southeastern deserts (Aqrawi, 1998). In the well Kand-1, the Palaeozoic rocks are either within the late gas zone or postmature source rocks (Al-Habba, 1988). The potential Palaeozoic source rocks for the gas in the region are Ordovician, Silurian, and Upper Devonian-Lower Carboniferous shales (Grunau, 1981; Al-Habba *et al.*, 1994; Aqrawi *et al.*, 2012). The investigation that recovered palynomorphs and palynofacies from the Akkas-1 and Khleisya-1 boreholes confirm potentiality for gas in the Ordovician Khabour Formation (Baban, 1996; Al-Ameri and Baban, 2002; Al-Ameri and Wicander, 2008). The Lower Palaeozoic total petroleum system of generation, migration, and accumulations could be assessed for a basin includes Widyan Basin-Inner Platform Region in northern Saudi Arabia and western Iraq and their extensions in Jordan and Syria (Al-Ameri, 2010; Fox and Ahlbrandt, 2002). This study aims to detect the type of organic matter that occurs within the Palaeozoic formations and their potentiality as source rock.

## STUDY AREA

This study focuses on Palaeozoic outcrops in North Iraq. There are 26 samples from six surface outcrops of Palaeozoic formations in Nazdur Anticline were collected (Fig. 1 and Table 1). All the outcrop sections are located in the Northern Thrust Zone in the uppermost northwestern Iraq approximately five km from the Iraq-Turkey border. The area is located north of Zakho city, it is of about 457 km north of Baghdad, the country's capital city.

**Table 1: Formation names, tectonic zones, coordinates, and number of samples that were collected from each formation for palynological analysis**

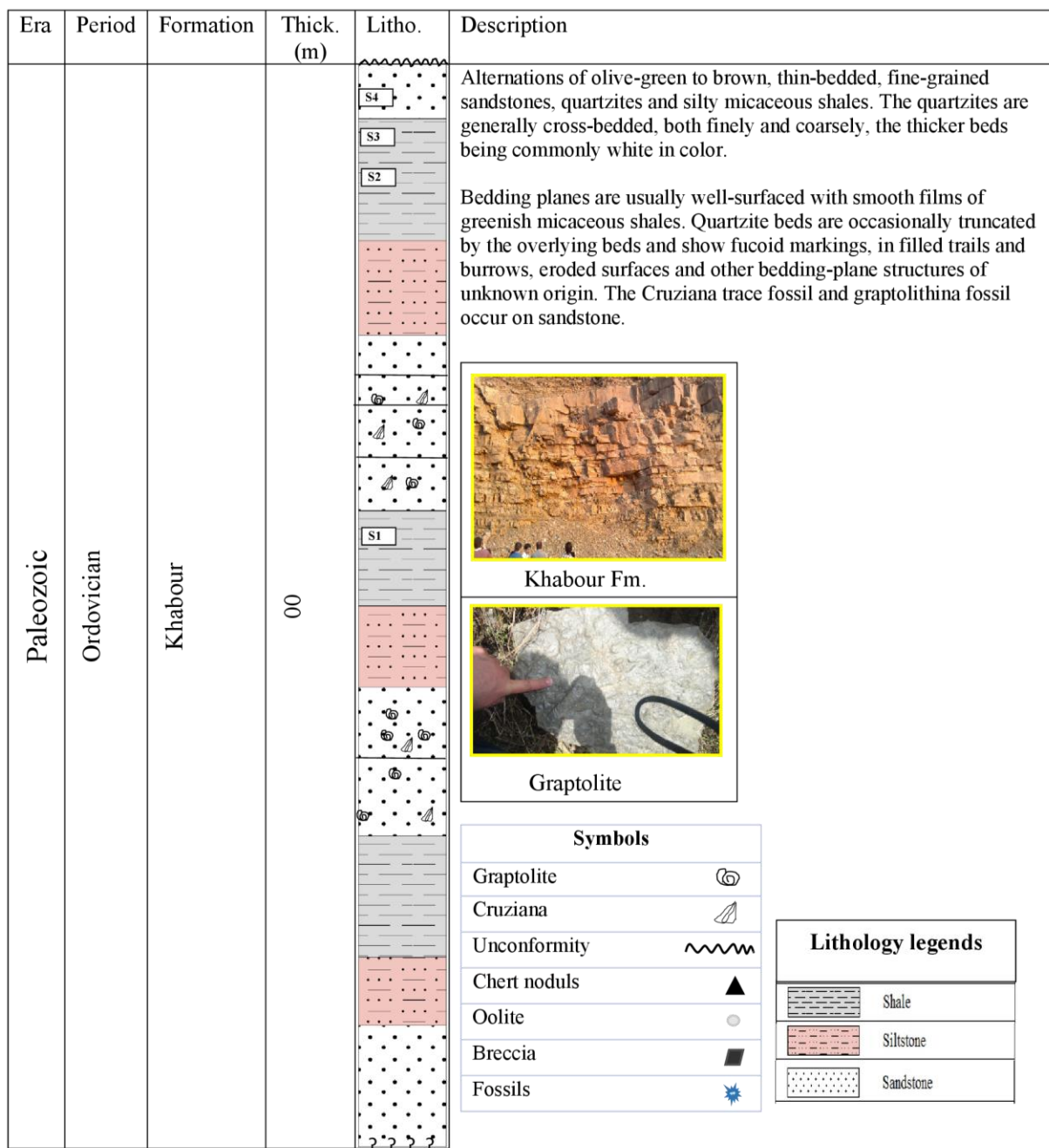
Se.	Formation Name	Tectonic Zones	Latitude	Longitude	No. of Samples
1	Khabour	Northern Thrust	37°15'45.9"	43°09'17.7"	4
2	Pirispiki	Northern Thrust	37°17'03.3"	43°09'48.4"	9
3	Kaista	Northern Thrust	37°17'07.8"	43°09'55.5"	3
4	Ora	Northern Thrust	37°17'27.0"	43°09'56.2"	5
5	Harur	Northern Thrust	37°18'01.1"	43°09'48.5"	5
6	Chia Zairi	Northern Thrust	37°18'40.2"	43°09'37.4"	3
Total					29



**Fig. 1: Location map showing studied area, North Thrust Zone of Iraqi Kurdistan (Coutesy of Earth Google)**

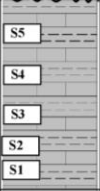



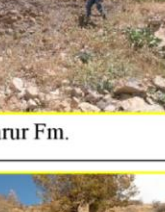






## METHODS AND MATERIALS

The designated samples are from six Palaeozoic formations (Figs. 2–4). To obtain rock samples, a detailed field-work was carried out in autumn 2014. The samples were obtained from organically rich horizons and they do not represent whole formations. The samples were collected after removing weathered parts. Palynomorphs were accomplished from the rocks by normal palynological methods of dissolving the carbonate and silicates of the rock with Hydrochloric (HCl) and Hydrofluoric (HF) acids and staining the organic matters on disseminating slides for further microscopic studies. All 26 samples were studied under reflected light microscopy. The entire attained data were reviewed and used to show detailed regional situations of the source rocks and their constraints.



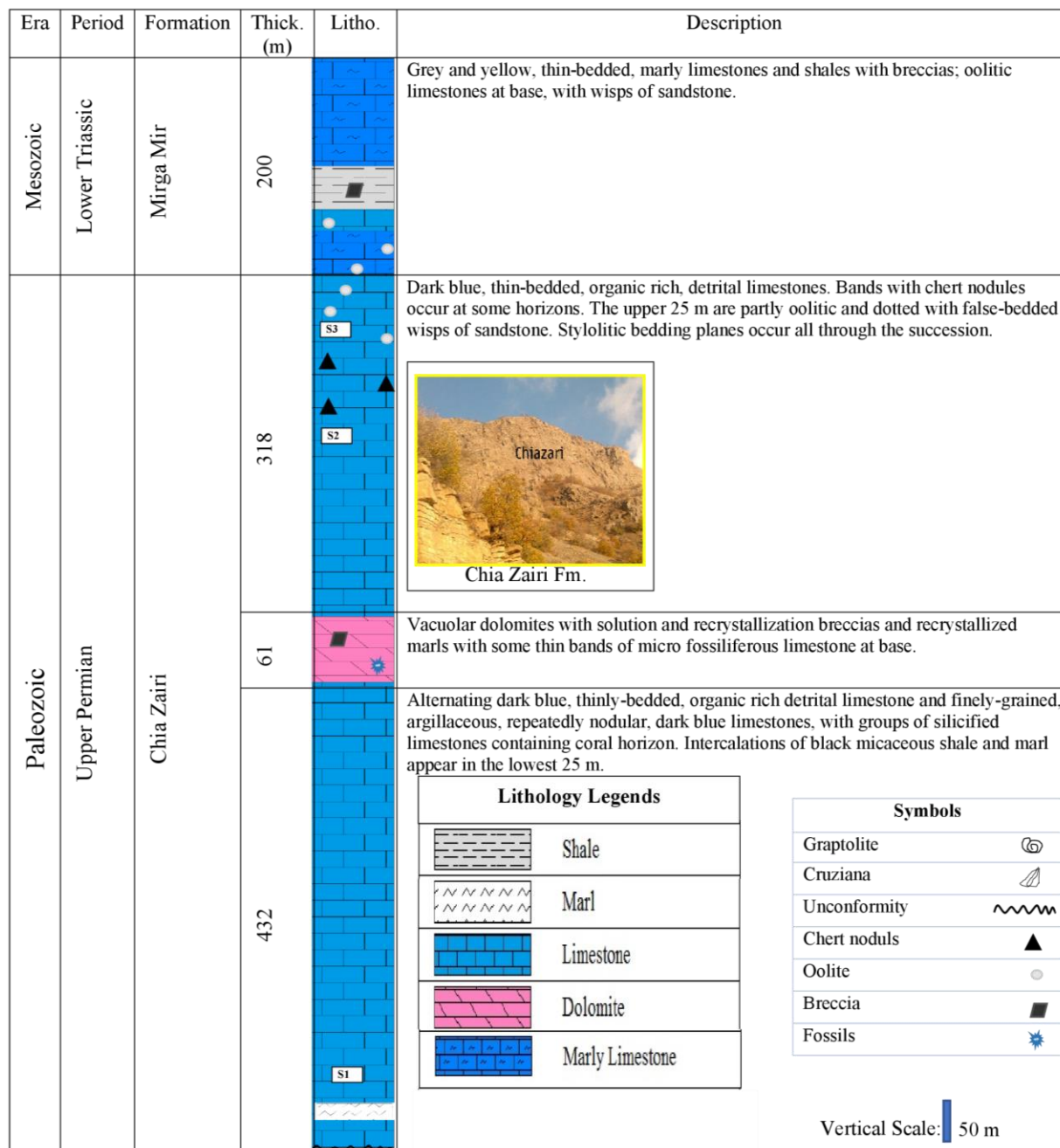
Not to scale

**Fig. 2: Lithological column (not to scale), showing image, age, and lithology of the succession of Palaeozoic strata in the region. Thicknesses are approximate regional averages. Khabour Formation was deposited during the late Early Cambrian-Early Ashgill Megasequence AP2 (Cambrian-Ordovician Megasequence)**

Era	Period	Formation	Thick. (m)	Litho.	Description																							
Paleozoic	Lower Carboniferous	Harur	62		Black, thinly-bedded, organic rich, detrital limestone, with intercalations of black calcareous micaceous shales.																							
					<p>Black, finely micaceous, calcareous shales, with olive-green, blocky, silty marls; beams and thin lentils of organic, detrital limestones and of fine-grained sandstones occur occasionally over the succession.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  Harur Fm.                 </div> <div style="text-align: center;">  Pirsipiki Fm.                 </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div style="text-align: center;">  Kaista Fm.                 </div> <div style="border: 1px solid black; padding: 5px;"> <p><b>Lithology legends</b></p> <table border="1" style="font-size: small;"> <tr><td></td><td>Shale</td></tr> <tr><td></td><td>Siltstone</td></tr> <tr><td></td><td>Sandstone</td></tr> <tr><td></td><td>Shaly Limestone</td></tr> <tr><td></td><td>Marl</td></tr> <tr><td></td><td>Limestone</td></tr> </table> </div> <div style="border: 1px solid black; padding: 5px;"> <p><b>Symbols</b></p> <table border="1" style="font-size: small;"> <tr><td></td><td>Graptolite</td></tr> <tr><td></td><td>Cruziana</td></tr> <tr><td></td><td>Unconformity</td></tr> <tr><td></td><td>Chert nodules</td></tr> <tr><td></td><td>Oolite</td></tr> <tr><td></td><td>Breccia</td></tr> <tr><td></td><td>Fossils</td></tr> </table> </div> </div>		Shale		Siltstone		Sandstone		Shaly Limestone		Marl		Limestone		Graptolite		Cruziana		Unconformity		Chert nodules		Oolite	
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Upper Devonian	Kaista	30		Dark blue thin-bedded, argillaceous limestones weathering to a distinctive yellow to orange color and sandy bands occur regularly in the limestone. This grade downwards by alternations to a series of silty shales and sandstones.																								
		35		Streaks of fine grade breccia, with small angular pieces of quartzite and limestones origin in a clastic matrix. Green, irregularly purplish siltstone and silty shale with patchy bands of quartzite, commonly cross-bedded.																								
Early- Middle Devonian	Pirsipiki	33		White, massive, cross-bedded quartzites, with thick aggregates of reddish marls and sandstones. Some dolomitic, with patchy conglomerates, comprising pebbles of red sandstone, quartzite and debris of green igneous rocks.																								
		24		White, cross bedded quartzite, with eroded upper surface, alternating downwards with red and purple, soft sandstones and shales.																								
		16		Yellowish brown, well-bedded sandstone, with bands of dull red shales.																								
		10		Blocky siltstones, conchoidal, soft, brownish, weathering pale grey-greenish; grading locally to green, fine-grained, soft sandstone with onion-weathering pattern. Irregular beams of hard, ferruginous, quartzite sandstones.																								

Vertical Scale: 10m

**Fig. 3: Stratigraphic column, showing image, age, and lithology of the succession of Palaeozoic strata in the same region. Thicknesses are approximate regional averages**



**Fig. 4: Stratigraphic column, showing image, age, and lithology of the succession of Palaeozoic strata in the same region. Thicknesses are approximate regional averages**

## GEOLOGICAL EVOLUTION DURING PALAEOZOIC ERA

Late Precambrian suturing combined several basic and dense volcanic and plutonic terranes and made the Arabian Plate. The Arabian Plate remained a part of the long and wide northern passive margin of Gondwana throughout most of the Palaeozoic and Mesozoic eras (Haq and Al-Qahtani, 2005) bordering the Paleo-Tethys Ocean (Beydoun, 1991 and Loosveld *et al.*, 1996). Iraq rests in the outer northeastern part of an intracratonic basin (Konert *et al.*, 2001 & Jassim, 2006). During Late Ordovician times, a glacial episode affected the western part of the Arabian Plate and the superior effect of ice was at highest in the Ashgillian (McGillivray and Hussein, 1992; Vaslet, 1990). At that time, the Arabian Plate lied in the southern hemisphere which occupied a high southern latitudinal location (Hussein, 1992 and Beydoun, 1997; Haq and Al-Qahtani, 2005). The eustatic sea-level fell due to glaciations and caused major erosion along the basin flanks. Furthermore, the majority of the Palaeozoic basins were formed as a result of faulting and slow sedimentation (Ibrahim, 1979 and Al-Shara'a, 2008). In the Early Silurian Period, the sea level rose due to deglaciation (Haq and Al-Qahtani, 2005). Until the end of the Silurian, the clastic was the main type of sedimentation (Beydoun, 1991; Hussein, 1992; Beydoun, 1997). The first tectonic episode that affected the Arabian Plate was the Hercynian Orogeny (Haq & Al-Qahtani, 2005 and Konyuhov & Maleki, 2006). This orogeny broadly affected the Arabian Plate which uplifted the region in the Carboniferous time that caused a break and erosion of most Palaeozoic sequences (Ahlbrandt *et al.*, 2000 and Konyuhov & Maleki, 2006). The middle Palaeozoic hiatus includes the Late Silurian to Middle/Late Devonian. It is a plate-tectonic origin and may be associated with local tectonism, such as the detachment of the Hun Superterrane (Von Raumer, 1998 and Stampfli *et al.*, 2001). In the Zagros Foothills, Devonian and Carboniferous rocks are entirely eroded and Silurian sediments are absent due to the Caledonian Orogeny (Konyuhov & Maleki, 2006). Due to the same break and erosion, the lower Silurian 65m thick shale in the Akkas-1 Well (Aqrabi, 1998 and Loydell *et al.*, 2013) which is believed to be the main Palaeozoic source rock in the western and southwestern Iraq (Aqrabi, 1998 and Majidee, 1999) and is obscured in the studied area. Additionally, the high amount of Ordovician and Silurian sediments was eroded because they outcropped in the western part in Early Jurassic (Al-Ahmed, 2007). The Late Palaeozoic-Early Mesozoic includes two sedimentary megacycles that follow the end of the Tappan Zee Cycle in the Early Devonian (Arabian Plate 3): (1) the Kaskaskia Cycle (Arabian Plate 4), which starts from the late Early Devonian to latest Mississippian; and (2) the early part of the Absaroka Cycle, which starts from

the post-late Mississippian to Early Jurassic (Arabian Plate 5 and Arabian Plate 6) (Sloss & Speed, 1974 and Sadek, 1977). The Late Devonian-Early Carboniferous formations are composed of siliciclastic-carbonate facies and lately combined in the Khleisia Group (Al-Hadidy, 2007; Al-Juboury and Al-Hadidy, 2009). The break between the Kaskaskia (Arabian Plate 4) and Absaroka (Arabian Plate 5) cycles are reasonably discrete. The platform subsidence that had continued since the Early Phanerozoic consolidation of Gondwana was ended by the above break as an outcome of uplift and erosion. Thus, the first Absaroka deposits (Chia Zairi Formation) overlie an unconformity since Gaara Formation is absent due to Hercynian Orogeny in the studied area in north Iraq (Alsharhan and Nairn, 2003). This Hercynian (Variscan) break is of regional extent in north Iraq and southeast Turkey and north Iraq; there is no continuous «Permo-Carboniferous» (Schmidt, 1964). In the Early Permian Period, the Neo-Tethys Ocean started to open (Muttoni *et al.*, 2009). Later in the Late Permian Period, the Arabian-Gondwana/Iranian-Laurasia supercontinent was fragmented due to crustal extension and rifted along the Zagros line to form the Neo-Tethys Sea by the Early Triassic time (Beydoun, 1991; Zeigler, 2001). During this time frame, the region experienced a moderate climate in general, but (sub) humid periods with carbonate deposition occurred (Beydoun, 1991). The area experienced comparatively tectonic stability, extensive carbonates, and evaporates sediments accumulated (Alsharhan & Kendall, 1986).

### GENERAL OUTLINE OF STRATIGRAPHY

In Iraq, the Proterozoic Basement does not crop out; nevertheless, its depth is inferred from seismic and geophysical data to be about 12-15 and 6-10 km in the eastern and western Iraq, respectively (Al-Hadidy, 2007). Comparatively little is known about the Palaeozoic sequence because of limited outcrop and unavailable subsurface data (Aqrawi *et al.*, 2010). Neither of the nine exploration wells nor shallow boreholes that drilled in the west of Iraq by the Geological Survey of Iraq for stratigraphic purposes has penetrated Cambrian formation and/or Precambrian Basement (Aqrawi *et al.*, 2012). The Palaeozoic units are known at surface only from exposures of very limited areal extent in the up-faulted cores of anticlines at Ora and Nazdur (Kaista and Harur areas near Chalki Khabour Valley, Geli Sinat, and Derashish areas, northwest of Shiranish of extreme north and northwest of-Amadia areas (Bellen *et al.*, 1959). The entire thickness of the Palaeozoic layers ranges from 1.5 to 6.0 km (Jassim, 2006). The Palaeozoic formations and their image, age, thickness, and lithology are shown in Figures (2–4). The Palaeozoic formations in Iraqi Kurdistan can be assembled to three different sedimentary cycles. The



effect of the Caledonian and Hercynian orogeneses may be inferred from the main breaks between formations (Sadek, 1977 and Buday, 1980). The cycles from older to younger are:

- 1) The Cambro-Ordovician (? Silurian) Cycle (Arabian Plate 3) characterized by the Khabour Formation;
- 2) The Late Devonian-Lower Carboniferous Cycle (Arabian Plate 4), characterized by the Pirispiki, Chalki, Kaista, Ora, and Harur formations; and
- 3) The Upper Carboniferous (?)-Upper Permian Cycle (Arabian Plate 5), characterized by the Chia Zairi Formation (Buday, 1980).

The Palaeozoic formations are following ordinary superposition in a straightforward sequence (Bellen *et al.*, 1959) which is complicated in the field by a rather extensive faulting and thrusting. These formations have the same lithologic characteristics both in the subsurface and outcrop sections (Al-Juboury and Al-Hadidy, 2008). The oldest recognized rock-unit in Iraq is the Khabour Quartzite-Shale Formation, which is of Ordovician age. These Ordovician lithologic units represent shallow-water settings in which several marine transgressions are documented by graptolite-bearing shales, trilobites from Jordan, and *Orthoceras* sp. in Saudi Arabia and Iraq (Powers *et al.*, 1966–1985; Al-Hadithi, 1972; Isa'ac, 1975; Sharland *et al.*, 2001). During this time frame, two main facies were deposited. The clastics were accumulated on the western side, Arabian Plate and the mixture of clastics and carbonates in the eastern side, Iranian Plate (Sadek, 1977). The Ordovician sediments are represented by thick layers of sandstones and shales of Khabour Formation (Fig. 2). This thick succession of Khabour Formation is deposited in a low stand system which created lowstand wedge (Gaddo and Parker, 1959; Karim, 2006). There are two sources for clastics: recycled granitic plutonic rock and more proximal low-grade (phyllitic) metamorphic rocks (Al-Bassam, 2010). The lithofacies and ichnofacies analysis of the Khabour Formation leads to the identification of eight facies associations at the type locality (Al-Hadidy, 2009 and Omer, 2012). The Khabour's upper black shales are expected to be source rocks within the region. In Iraqi Kurdistan, during the Late Devonian-Early Carboniferous times the Pirispiki, Kaista, Ora, and Harur formations were deposited. Depositional regimes are categorized by a diverse facies of carbonate-siliciclastic rocks and are considered as a continuation of deposition in a homoclinal ramp (Fig. 3) (Al-Juboury and Al-Hadidy, 2001a; Al-Juboury and Al-Hadidy, 2001b; Al-Juboury and Al-Hadidy, 2008; Al-Juboury, 2012). All formations including the Pirispiki and Chalki formations were deposited after the Caledonian uplift (Seilacher,

1958). The Chalki Volcanic occurs within and near the top of Pirispiki Formation. The Late Palaeozoic Era (Devonian-Permian) sequence in Iraq, generally composed of siliciclastic and mixed (carbonate-siliciclastic) corresponding to the 1<sup>st</sup> order cycle of worldwide sea-level change (Al-Hadidy *et al.*, 2002). The Devonian-Carboniferous Ora Shale Formation was deposited in a mixed shelf environment (Grunau, 1981) generally was shallow near the shore (Naqishbandi *et al.*, 2010). In the same way, the Harur Formation was deposited in a shallow marine (Naqishbandi, 2006). The Chia Zairi Formation (Fig. 4) spreads from Ora outcrops northern Iraq to southern Iraq. Accordingly covering the central and eastern parts of the country and it is absent in the far Western Deserts (Al-Hadidy and Aqrawi, 2011).

## RESULTS AND DISCUSSION

The palynomorph assemblages isolated from the samples examined from Palaeozoic formations contain numerous palynomorphs (average 5.1–36.3%), with an association of phytoclasts ((average 31.1–54.3%) and amorphous organic matter (AOM) (average 9.4–62.8%) (Table 2). The low abundance of palynomorphs is due to masking. In some samples, AOM comprise up to 76.9% of the palynological content. Microscopic studies of Palaeozoic palynological slides showed the presence of all types of kerogen. Amorphous kerogen was distinguished by a mottled, interconnected network or a weakly polygonal texture. It usually occurs in large, compact masses that show an orange brown to dark brown color under reflected light. Maturation assessments for palynofacies in the Palaeozoic formations were based on the palynomorphs color. Maturation based on TAI (following Pearson's (1984) and Staplin's (1969) scales) indicates the presence of mature organic matter of dark orange and light brown with TAI 2 to +3.

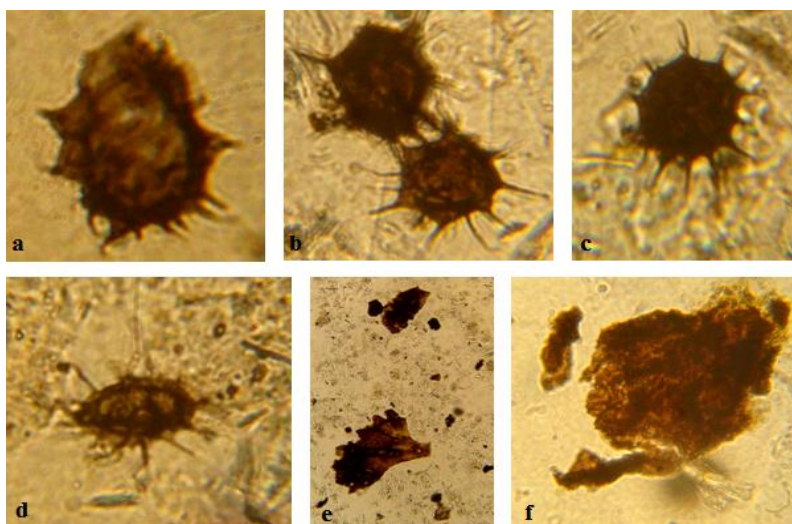
### **Khabour Formation**

The Khabour Quartzite Shale Formation in Iraq is almost certainly correlative with the oldest formation on Turkish territory, the Giri Quartzite Formation in adjacent to the Nazdur section, in the Ser Ashuti Mountain area (Bellen *et al.*, 1959). The total of four samples was collected from this formation (Table 1). The samples contain *Timofeevia lancarae* (Cramer and Díez, 1972) (Fig. 5a), which has a broad stratigraphic range with TAI = +3. This palynomorph occurs also within Late Cambrian Mila Formation in Alborz Mountains, Iran (Ghavidel-Syooki, 1993). The *Acanthodiacrodium spinum*, (Fig. 5b) with TAI = 3 to +3, *Acanthodiacrodium complanatum* with TAI = +3 (Fig. 5c), *Arbusculidium mamillosum* with TAI = 3 to +3 (Fig. 5d). Additionally, the samples contain phytoclast (Fig. 5e) and amorphous organic matter <20% (Fig. 5f). The distribution of different Kerogen components throughout the

studied formation shows a clear organic facies shift from low to high freshwater influx, mud-dominated oxic shelf at the lower part to heterolithic (proximal) shelf at the upper part (Fig. 6). Following the kerogen classification scheme of Tyson (1995), kerogen type III (gas prone material) is interpreted for palynofacies within this formation (Table 2). Based on the presence of these species, this lower assemblage zone is considered to be uppermost Cambrian to lowermost Tremadocian. Based on the occurrence of, *acritarch taxa*, *Acanthodiacrodium complanatum*, this lower zone is considered to be the uppermost part of the Tremadocian.

### Pirispiki Formation

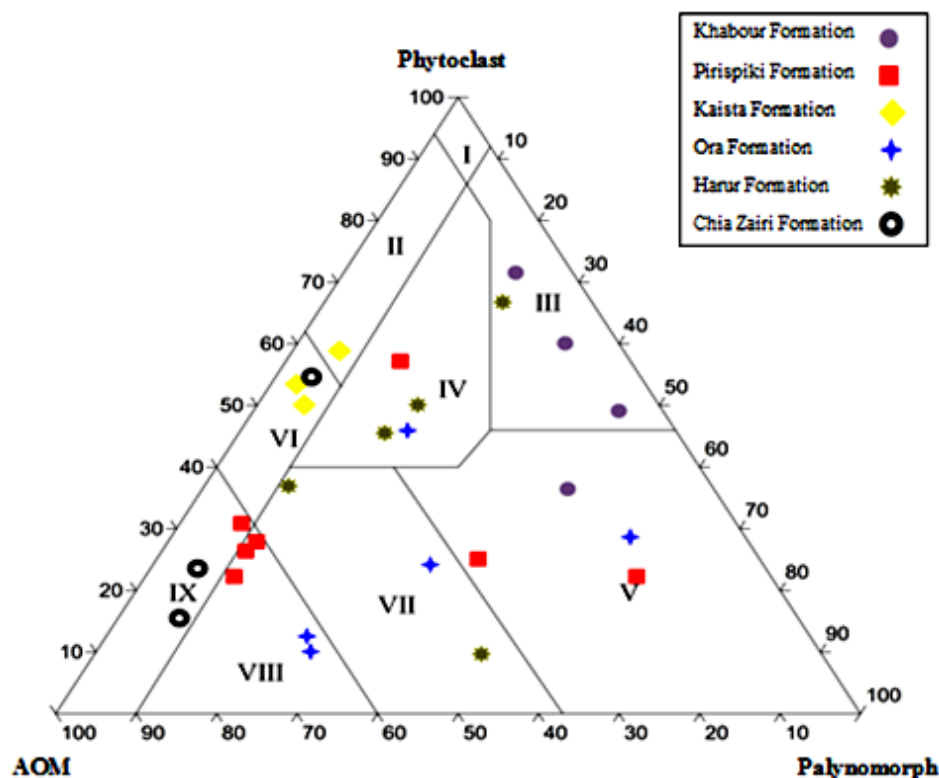
The boundary of the formation is occasionally transected by igneous intrusions. The lower unconformable contact of Pirispiki emphasized by the disappearance of the Silurian deposits related to Akkas Formation. The total of nine samples was collected from this formation (Table 1). The occurrence of organic matter throughout the formation reflects different depositional environments (Fig. 6). The samples contain *Priscogalea distincta* (Fig. 7a) with TAI = +2. *Horriditriletes remosus* (Fig. 7b) with TAI = -3, *Priscogalea distincta* (Fig. 7c) with TAI = -3. Furthermore, the samples contain 22.2-57.1% phytoclast (Figs. 7d, 7e, and 7f) and 16.7-66.7% amorphous organic matter (Fig. 7g). In general, the formation was deposited from bottom to top in a mud dominated oxic shelf, distal dysoxic-oxic, distal suboxic-anoxic basin, and shelf to basin transition (Fig. 6).



**Fig. 5: Images from Khabour Formation of a) *Timofeevia lancarae* with TAI = +3 (100x); b) *Acanthodiacrodium spinum* with TAI = 3 to +3 (100x); c) *Acanthodiacrodium complanatum* with TAI = +3 (100x); d) *Arbusculidium mamillosum* with TAI = 3 to +3 (100x); e) phytoclast (10x); and f) amorphous organic matter (100x)**

**Table 2: Formation names, sample numbers, palynomorph%, phytoclast%, amorphous organic matter (AOM) %, and kerogen type for samples from Palaeozoic formations in Nazdur, Iraq**

Formation	Sample No.	Palynomorph%	Phytoclast%	AOM%	Kerogen type
Khabour	KH-1	45.4	36.4	18.2	III>IV (gas prone)
	KH-2	45.5	49.1	5.4	III (gas prone)
	KH-3	33.3	60.0	6.7	III (gas prone)
	KH-4	21.4	71.5	7.1	III (gas prone)
Pirispiki	P-1	61.1	22.2	16.7	III>IV (gas prone)
	P-2	10.5	26.3	63.2	II>>I (oil prone)
	P-3	11.1	27.8	61.1	II>>I (oil prone)
	P-4	7.7	30.8	61.5	II>I (highly oil prone)
	P-5	40.0	25.0	35.0	III>IV (gas prone)
	P-6	14.3	57.1	28.6	III or II (mainly gas prone)
	P-7	11.1	22.2	66.7	II>>I (oil prone)
	P-8	14.3	57.1	28.6	III or II (mainly gas prone)
	P-9	14.3	57.1	28.6	III or II (mainly gas prone)
Kaista	K-1	5.9	58.8	35.3	III (gas prone)
	K-2	5.9	50.0	44.1	II (oil prone)
	K-3	3.4	53.3	43.3	II (oil prone)
Ora	O-1	26.7	10.0	63.3	II>>I (oil prone)
	O-2	25.0	12.5	62.5	II>>I (oil prone)
	O-3	20.8	45.8	33.4	III or II (mainly gas prone)
	O-4	34.5	24.1	41.4	II (oil prone)
	O-5	57.1	28.6	14.3	III>IV (gas prone)
Harur	H-1	48.1	9.6	42.3	II (oil prone)
	H-2	22.2	66.7	11.1	III (gas prone)
	H-3	18.2	45.4	36.4	III or II (mainly gas prone)
	H-4	20.0	50.0	30.0	III or II (mainly gas prone)
	H-5	10.6	36.8	52.6	II (oil prone)
Chia Zairi	CH-1	7.7	15.4	76.9	II>I (highly oil prone)
	CH-2	4.6	54.5	40.9	II (oil prone)
	CH-3	5.9	23.5	70.6	II>I (highly oil prone)



Environments					
I	Highly proximal shelf/basin	IV	Shelf to basin transition	VII	Distal dysoxic-anoxic shelf
II	Marginal dysoxic-anoxic basin	V	Mud-dominated oxic shelf	VIII	Distal dysoxic-oxic shelf
III	Heterolithic (proximal) shelf	VI	Proximal suboxic-anoxic shelf	IX	Distal suboxic-anoxic basin

**Fig. 6: Ternary Phytoclast-AOM-Palynomorphs plot (modified after Tyson, 1995) for the samples from the Palaeozoic formations in Nazdur Anticline, Zakho City, northern Iraq**

The lower part was deposited in low to high freshwater influx, the middle part was deposited in an anoxic environment, and the upper part was deposited in storm-dominated shelf. Following the kerogen classification scheme of Tyson (1995), kerogen types IV, III, II, and I (oil and gas prone materials) are interpreted for palynofacies within this formation, but predominant types were II and III (Table 2).

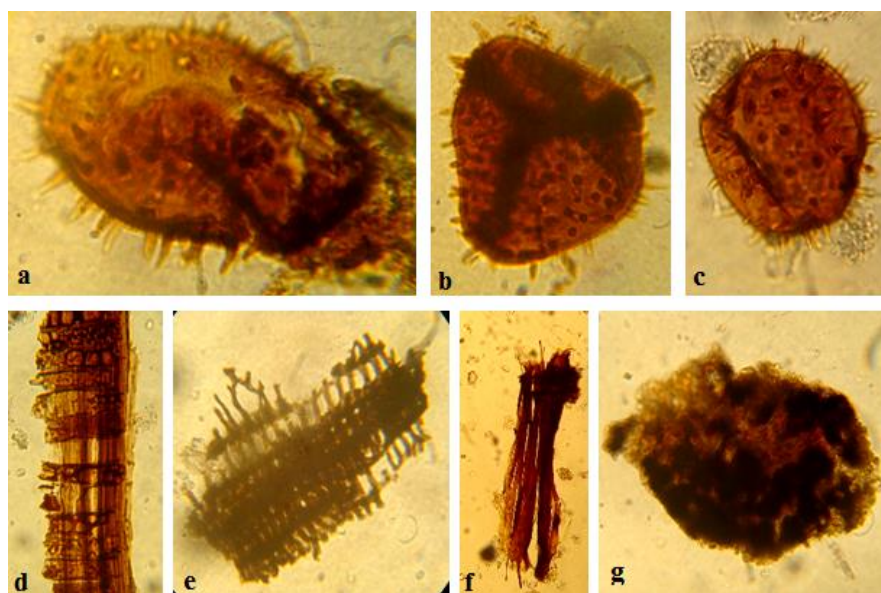
**Kaista Formation**

The total of three samples was collected from this formation (Table 1). The distribution of different kerogen components throughout the studied formation shows a clear organic facies shift from marginal dysoxic-anoxic basin in the lower part to proximal suboxic-anoxic shelf at the upper part (Fig. 6). The formation contains <6% palynomorphs. Among the palynomorphs, the *Retusotriletes septalis* was

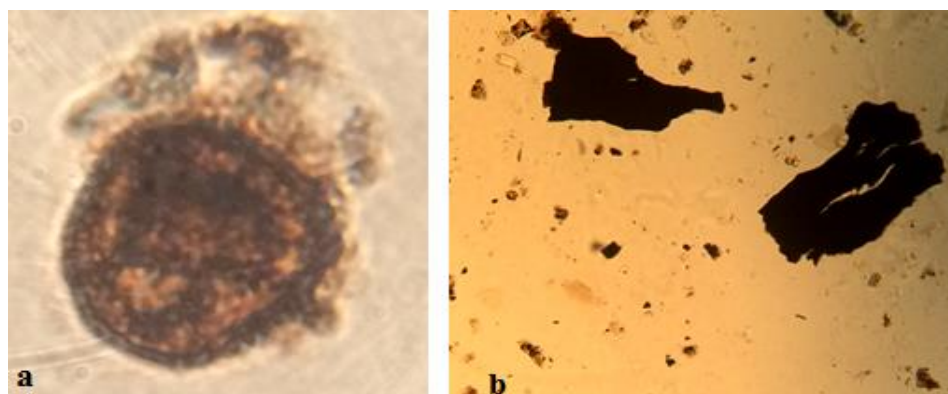
recognized (Fig. 8a) with TAI = -3 to +3. The phytoclast comprises >50% of total organic components (Fig. 8b) and AOM ranges 35.3-44.1%. The organic matter represents type III kerogen (gas prone) in the lower part and type II kerogen (oil prone) in the upper part.

### Ora Formation

The total of five samples was collected from this formation (Table 1). The distribution of different kerogen components throughout the studied formation shows clear organic facies shift from distal dysoxic-anoxic in the lower part to mud dominated oxic shelf in upper part (Fig. 6).



**Fig. 7:** Pirispiki Formation of a) *Priscogalea distincta* with TAI = 3 (100x); b) *Horriditriletes remosus* with TAI = -3 (40x); c) *Priscogalea distincta* with TAI = -3 (40x); d) phytoclast (40x); e) phytoclast (100x); f) phytoclast (10x); g) amorphous organic matter (40x)

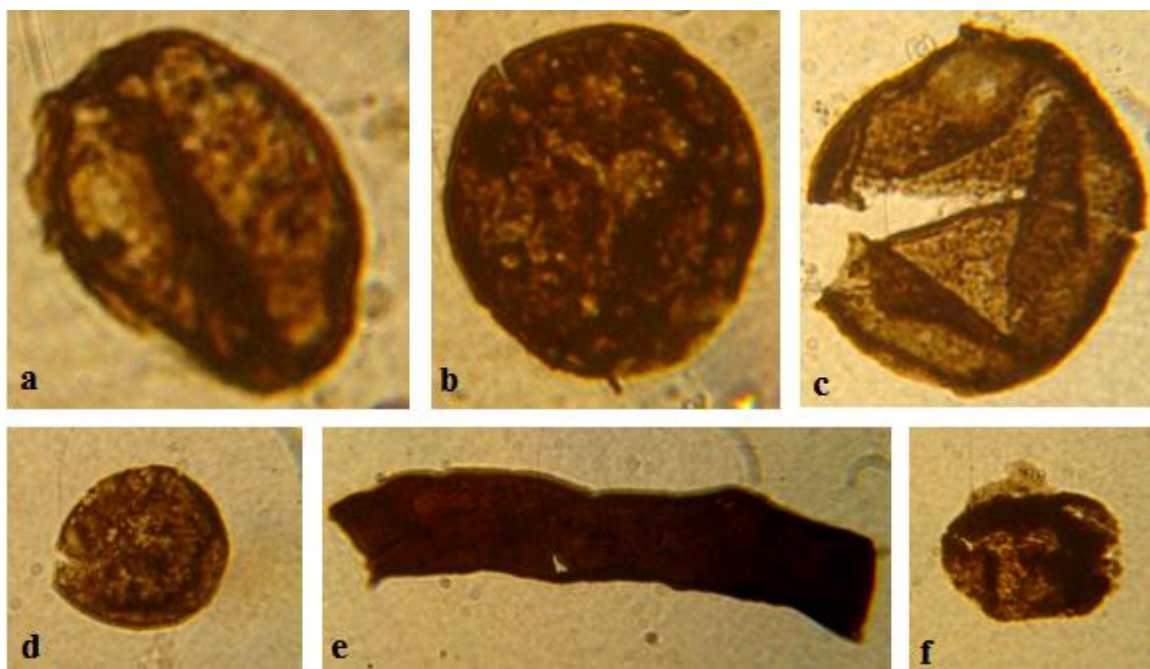


**Fig. 8:** Images from Kaista Formation of a) *Retusotriletes septalis* with TAI = -3 to +3 (100x) and b) phytoclast (10x)

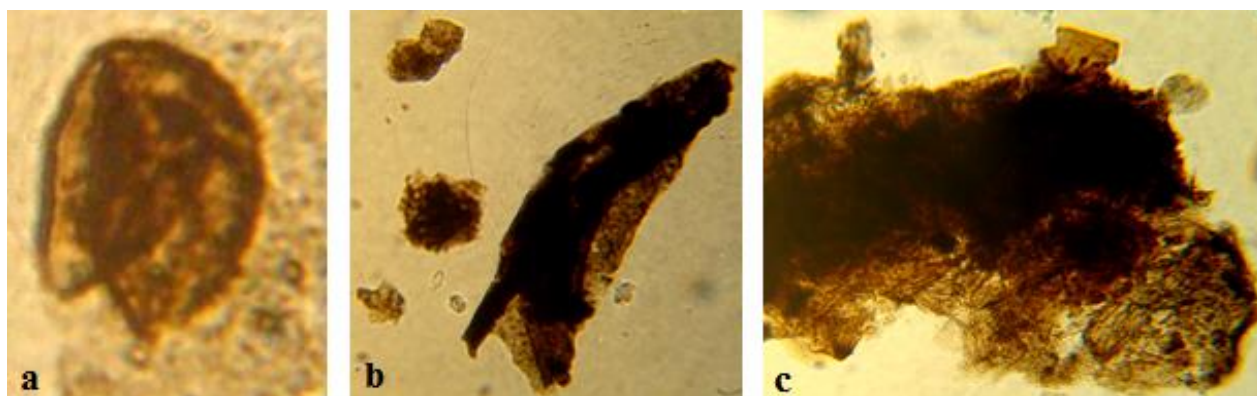
The formation contains >20% palynomorphs. Among the palynomorphs, the *vulgaris* with TAI = -3 (Fig. 9a) with TAI = -3 to +3, *Densoisporites velatus* with TAI = -3 (Fig. 9b), spore named *insculptospora maxima* sp.nov (Fig. 9c) and amorphoused spore (Fig. 9d). The phytoclasts are comprised of 10.0-45.8% of total organic components (Fig. 9e) and AOM reaches up to >60 % in lower part of the formation. The organic matter mainly comprises of types I and II (mainly oil prone) with type III kerogen (gas prone) in the middle part.

### Harur Formation

The total of five samples was analyzed (Table 1). The samples contain 23.8% in average palynomorphs such as spore named *insculptospora maxima* sp. nov with TAI +3 (Fig. 10a), phytoclast (Fig. 10b) 41.7% in average, and the mean of AOM (Fig. 10c) content is 34.5%. The distribution of kerogen types indicates three different environments, they are distal dysoxic-anoxic in the lowermost and uppermost horizons and heterolithic and shelf to basin transition in the middle horizons (Fig. 6). The organic matter mainly is type II kerogen (oil prone) in lower and upper parts and III kerogen (gas prone) in the middle part (Table 2).



**Fig. 9:** Ora Formation of a) *Laevigatosporites vulgaris* with TAI = -3 (100x); b) *Densoisporites velatus* with TAI = -3 (100x); c) spore named *insculptospora maxima* sp. Nov (100x); d) amorphoused spore (100x); e) phytoclast (100x); f) amorphous organic matter (100x)



**Fig. 10: Images from Harur Formation of a) spore named *insculptospora maxima* sp. nov with TAI +3 (100x); b) phytoclast (40x); c) amorphous (40x)**

### Chia Zairi Formation

The ChiaZairi Limestone in Iraq is closely comparable to Harbol Formation in southeast Turkey (Schmidt, 1964). The total of three samples was collected from this formation. This formation contains <8% of palynomorphs, an average of 62.8% of AOM, and phytoclasts 31.1%-in average. The samples from the upper part and lower part were deposited in a distal suboxic-anoxic basin, while the sample from the middle part indicates the proximal suboxic-anoxic shelf. The organic matter belongs to the mixture of types I and II kerogen (highly oil prone) in lower and upper parts and type II (oil prone) in the middle part.

### CONCLUSIONS

The following findings can be concluded from this study:

1. Microscopic studies of Palaeozoic palynological slides showed the presence of all types of kerogen, but mainly type II kerogen.
2. The palynofacies analysis for Palaeozoic formations indicates that these formations were deposited in variety of environments ranging from marginal dysoxic-anoxic basin to distal suboxic-anoxic basin. Thus, they have more tendencies to be oil prone.
3. Khabour Formation was deposited in heterolithic oxic shelf. The type of kerogen can be assemblage in type III. Thus, it is mainly gas prone.
4. Distal dysoxic – anoxic shelf assumed for Pirispiki Formation, hence this formation is mostly oil prone due to the presence of a high percent of AOM (43.3%).



5. Kaista Formation can be oil-bearing formation, the palynological study pointed out the proximal suboxic-anoxic shelf as a depositional environment.
6. Ora Formation contains high amount of AOM (43%); thus, it has the ability to generate oil, hence it is deposited in distal dysoxic- anoxic-oxic shelf.
7. Shelf to basin transition proposed for Harur Formation. This formation is mainly prone to gas, due to high abundance of phytoclast particles.
8. Chia Zairi Formation contains the highest amount of AOM, which represents types I and II kerogen; thus it is considered highly oil prone.
9. Maturation based on thermal alteration index (TAI) indicates the presence of mature organic matter of orange brown to dark brown with TAI -3 to + 3.

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