Paleodepositional environment and hydrocarbon potential of Ora Formation, North and West Iraq

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Abstract

Ora Formation (Lower Carboniferous) in Akkas gas field, and in outcrop in the north Iraq, was examined by using the total organic carbon (TOC), total inorganic carbon (TIC), sulfur content (S), Rock-Eval pyrolysis, Gas Chromatography (GC), and incident light microscopy to evaluate their hydrocarbon potentiality and paleodepositional environment. These measurements are indicated that these successions can be considered potential source rocks. The organic matters are mixed of marine and terrestrial; and they are immature. These successions were deposited in more oxic environment.

Key words: Ora Formation, Palaeodepositional enivironment, source rocks, Akkas gas field

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كفاءة توليد الهيدروكاربونات والبيئة الرسوبية القديمة لتكوين اورا في شمال وغرب العراق

محمد وكاع الخفاجي

قسم علوم الارض التطبيقية، كلية العلوم، جامعة تكريت، تكريت، العراق

الخلاصة

تمت دراسة تتابعات تكوين اورا في حقل عكاز الغازي، غرب العراق، وفي المكشف الصخري في شمال العراق باستخدام تحاليل جيوكيميائية عضوية تتمثل بقياس محتوى الكاربون العضوي واللاعضوي ومحتوى الكبريت والتكسر الحراري (Rock-Eval pyrolysis) والغاز كروماتوغراقي والدراسة المجهر ية بهدف تقييم كفاءة توليد الهيدروكاربونات وظروف البيئة الرسوبية لتكوين اورا. كل هذه التحاليل دللت على ان صخور تكوين اورا في حقل عكاز يمكن اعتبارها صخورا مصدرية محتملة لتوبيد الهيدروكاربونات، كما ان المواد العضوية في هذه الصخور هي مزيج من المواد العضوية البحرية والقارية وهي غير ناضجة حراريا، وقد ترسبت في بيئة غير مختزلة.

الكلمات المفتاحية: تكوين اورا، البيئة الرسوبية القديمة، الصخور المصدرية، حقل عكاز الغازي

Introduction

Akkas field was discovered by the Iraqi Oil Exploration Company in 1992. It is located in the western desert of Iraq, close to the border with Syria (Fig. 1). This field contains sweet gas, condensate, and small amounts of light oil (42 API) in Khabour, Akkas, and Ora/Kaista Formations. These formations consist predominantly of sandstone and shale (Al-Juboury and Al-Hadidy, 2009). Source rocks of the Paleozoic petroleum system consist of several potential organic-rich shales in Khabour, Akkas, and Ora Formations (Al-Juboury and Al-Hadidy, 2009). The gas of this field is free of H_2S (sweet gas) and composed of up to 85% methane and ethane (Al-Habba *et al*., 1994). Organic matter of the Khabour and Akkas Formations is marine type II composed predominantly of algal matter; and it is late mature in the lower part of Khabour Formation and early-mid mature in Akkas Formation (Alkhafaj *et al*., 2015).

Lower Carboniferous (Tournaisian) Ora Formation consists of fissile black shale with subordinate amounts of sandstone. It represents a transgressive facies of siliciclastic ramp upon

open marine platform (Al-Hadidy, 2007). It crops out in North Iraq close to the borders with Turkey; and penetrated in many wells in west Iraq (e. g. Akkas 1-5, Khleisia 1, Key Hole KH 5/1, and Qaim-1), with thickness range between 100-300 m (Al-Hadidy, 2007). The average values of TOC of the formation in Akkas-1 well is about 1.5; and 3.5% in Khleisia-1 well (Al-Habba *et al*., 1994). Organic petrology study suggested that the organic matter is composed of mixed marine (represented by alginite and bituminite) and terrestrial (sporinite with minor amount of vitrinite) (Alkhafaji, 2017). This study aimed to evaluate the hydrocarbon potentiality of this formation and the depositional environment conditions by using the organic geochemical analysis.

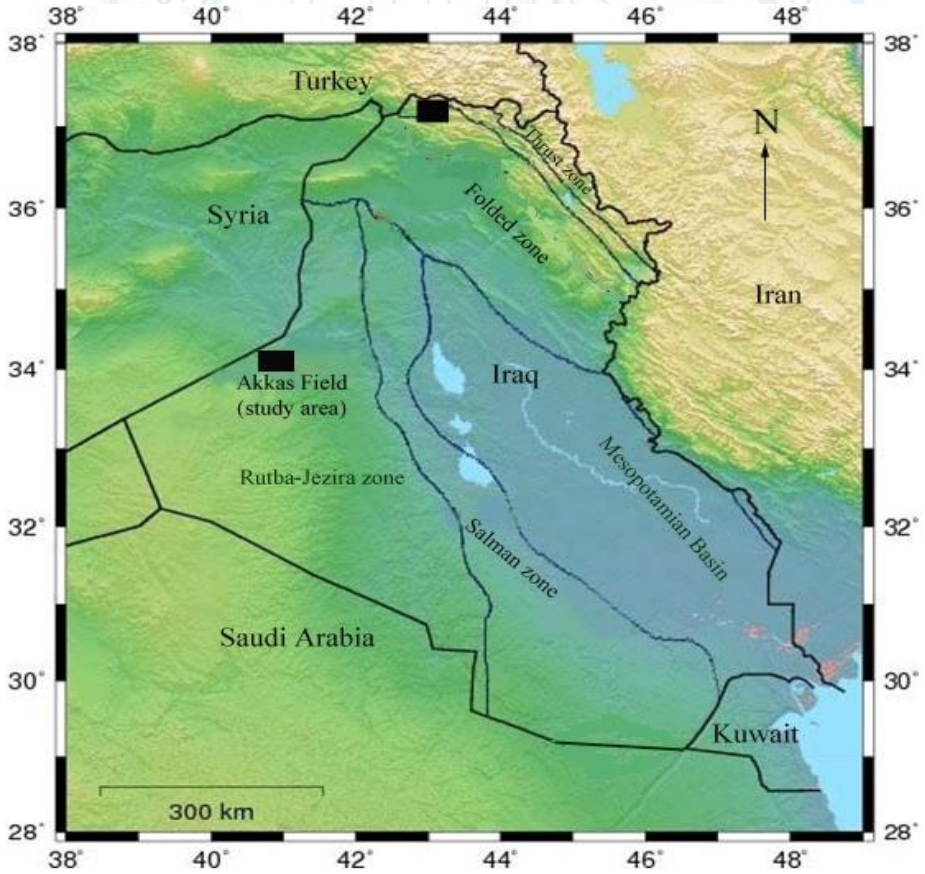

Figure 1: Map of Iraq showing the study areas (black boxes) and the main tectonic zones (according to Jassim and Goff, 2006).

Material and Methods

Cuttings and cores rock samples of Ora Formation from two wells drilled in the Akkas field are collected from North Oil Company (NOC), Kirkuk Governate. According to the North Oil Company (NOC); Ora/Kaista Formation in Akkas-1 well are at depth interval of 1082-1464m; and in Akkas-3 well at depth interval 941-1377 m. (Al-Hadidy, 2007) noted that Ora Formation is at interval 1297-1402 m in Akkas-1 well. Outcrop samples from type section at Ora village, Zakho district; in Northern Iraq close to Iraqi-Turkish borders (Fig. 1). All samples from wells and outcrops were washed with water then dried, and selected the dark colored samples for geochemical analysis.

TOC and Sulfur measurements:

This analysis is the first step to determine the potential source rocks, and the rocks that have TOC value exceeding 0.5-1.0 wt% are considered potential source rocks (Tissot and Welte, 1984; Hunt, 1996). Sulfur concentration was measured for some samples using Leco S0200 sulfur analyzer.

Rock-Eval pyrolysis:

In this method, the sample was heated for 5 minutes at 300 ^{0}C using helium carrier gas; this will vaporize the bitumen already present allowing it to be quantified by flame-ionization detector (FID) as S_1 parameter. The temperature was then raised progressively at a rate of 25 C^0/min. to 600 ^{0}C converting all the remaining petroleum potential of the kerogen into bitumen and gas, and the S_2 parameter was then measured. The temperature of peak hydrocarbon generation due to thermal cracking of kerogen occurs during the S_2 measurement is T_{max} parameter.

Reflected light microscopy:

To prepare the polished sections, samples were embedded in a mixture of epoxy resin and hardener at the rate of 10:3 and hardened in an oven at 37 ^{0}C for about 12 hours. Samples are grounded and polished using automated Struers Tegra Pol 21 polishing machine.

Zeiss Axio Imager M2m microscope was used for the examination of the samples. This microscope uses incident light and fluorescence mode exited by ultraviolet.

Gas Chromatography (GC):

Extraction of bitumen from powdered samples are done by using Dichloromethane (DCM)(CH_2Cl_2) as a solvent. The mixture (sample and solvent) remained 24 hours on magnetic stirrer. The extracted solution was filtered, then concentrated. Sulfur was removed from the solution by adding an activated copper. Concentrated solution is fractionated into saturated hydrocarbons, aromatic hydrocarbon, and resin (NSO compounds) by column chromatography. Fisons Instruments GC 8000 series ECD 850 using hydrogen as carries gas, is used for Gas Chromatography (GC) of saturated hydrocarbons. The program of the oven temperature was 80 ^{0}C for 5 min. to 300 ^{0}C for 20 minutes at 5 ^{0}C / min.

Results and Discussion

Organic richness:

From table 1, It is clear that the examined outcrop samples are organic-lean; TOC values for most of them are low, they have an average of 0.2%; and most of values are lower than 0.4%, only one sample higher than 0.4%. According to these values, the outcrop samples have no potentiality for hydrocarbon generation, and not considered as potential source rocks.

The average TOC of Ora Formation in Akkas-1 well is about 1.5% (Al-Habba *et al.*, 1994). The TOC values of well samples of the present study are generally higher than those of the outcrop samples, they are with an average of 2.16%, and range between 0.76- 4.0%. The higher value (4.0) are recorded at the depth 1233-1243m in Akkas-3 well. therefore, according to these values, Ora Formation in Akkas field considered as potential source rocks.

Table 1: TOC, sulfur, carbonate contents, and Rock-Eval pyrolysis of the Ora samples

Location	Depth (m)	TOC	CaCO3	S	S1	S2	Tmax	HI	S/C
Outcrop	-	0.28	11.02	0.22	0.13	0.08	552	29	0.79
Outcrop	-	0.37	17.11	0.38	0.20	0.05	340	14	1.03
Outcrop	-	0.27	22.73	0.09	0.36	0.14	341	52	0.33
Outcrop	-	0.1	6.33						
Outcrop	-	0.51	2.01	0.21					0.41
Outcrop	-	0.11	3.73						
Outcrop	-	0.12	3.27	0.11					0.92
Outcrop	-	0.13	0.45	0.08					0.62
Outcrop	-	0.19	3.60						
Outcrop	-	0.09	1.80						
Outcrop	-	0.15	7.20	0.10					0.67
Outcrop	-	0.1	7.46						
Ak-1	1300	1.05	7.25		6.1	1.7	423	162	
Ak-1	1330	1.86	15.62	1.06	7.8	5.1	343	274	0.57
Ak-1	1365	3.94	9.84	0.98	4.8	6.29	428	160	0.25
Ak-1	1400	0.76	5.41		1.33	1.3	424	171	
Ak-3	1205	0.96	35.33	0.35	2.19	2.8	420	292	0.36
Ak-3	1225	1.43	6.95		2.52	2.4	421	168	
Ak-3	1233	3.31	4.36	0.67	15.35	7.59	422	229	0.20
Ak-3	1243	4.00	3.30	0.89	16.1	6.55	416	164	0.22

Type of organic matter:

Few of the outcrop samples were subjected for Rock-Eval pyrolysis because most of them with low TOC values. The average S2 (mg HC/g rock) and hydrogen index (mg HC/g TOC) values of the examined well samples is 4.22 and 202 respectively. These values and the cross plot of hydrogen index (HI) versus Tmax and S2 versus TOC (Fig. 2 and 3) indicate that the kerogen contained in these rocks is mixed II-III. This result is supported by organic petrological study, which indicated that the organic matter is mixture of marine and terrestrial origin; marine

organic matter is dominated by alginite and bituminite, whereas the terrestrial organic matter is dominated by sporinite with minor amounts of vitrinite (Alkhafaji, 2017).

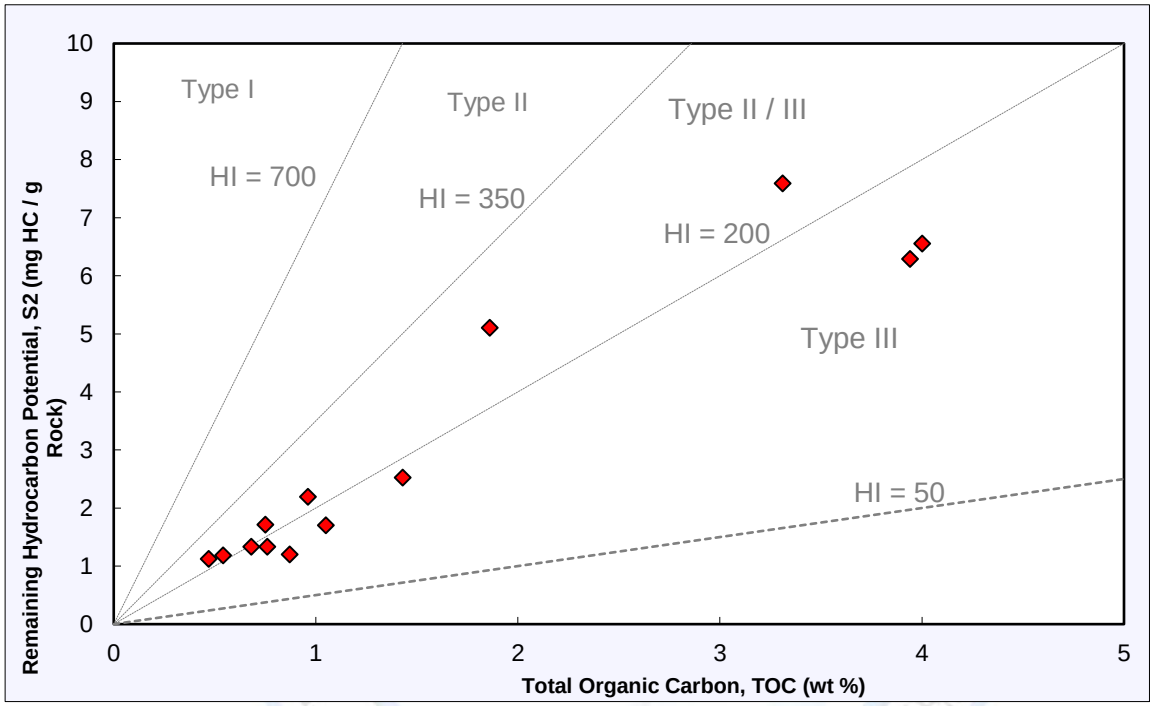

Figure 2: TOC versus S2 diagram. It is evident that the organic matter is type II/III kerogen and it is mixed of marine and terrestrial.

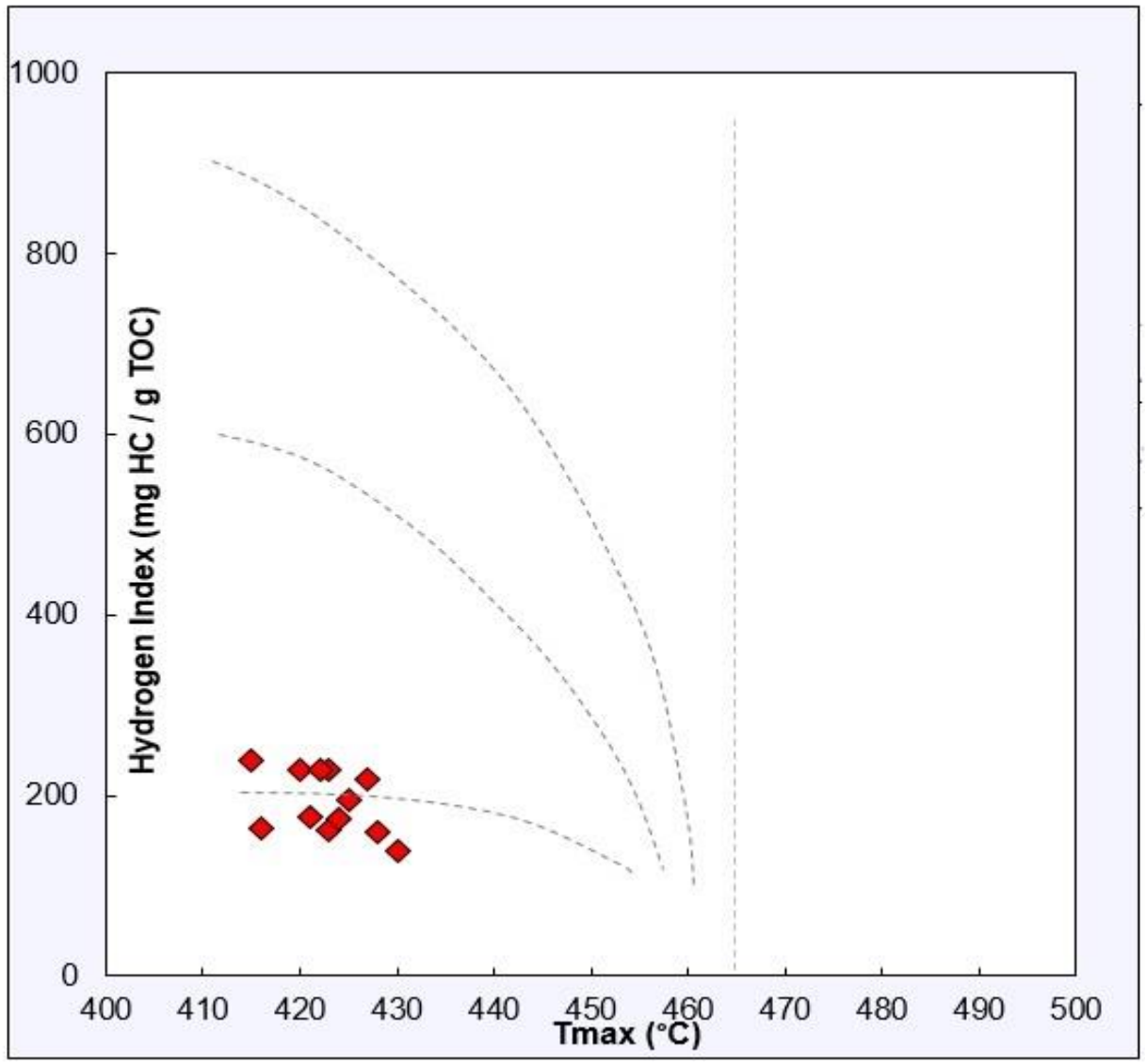

Figure 3: HI versus Tmax diagram. The samples are lies between type II and type III

Molecular geochemistry study and gas chromatography fingerprint also indicate high planktonic algal component in the source of the organic material. Normal alkanes distribution is smooth and unimodal in the range of (nC13-nC24) with short- chain normal alkanes predominance, maximum at C16-C18 with harmonic decrease in the normal alkanes abundance with increasing carbon number (Fig.4). These characteristics of normal alkanes distribution is

typical for algal matter input (Tissot and Welte, 1984; Peters and Moldowan, 1993). These results also indicate that these potential source rocks would expect to produce mainly gas because the high content of the terrestrial organic matter represented by sporinite, and they would also generate some amount of oil because the high content of the marine –origin organic matter dominated by alginite and bituminite.

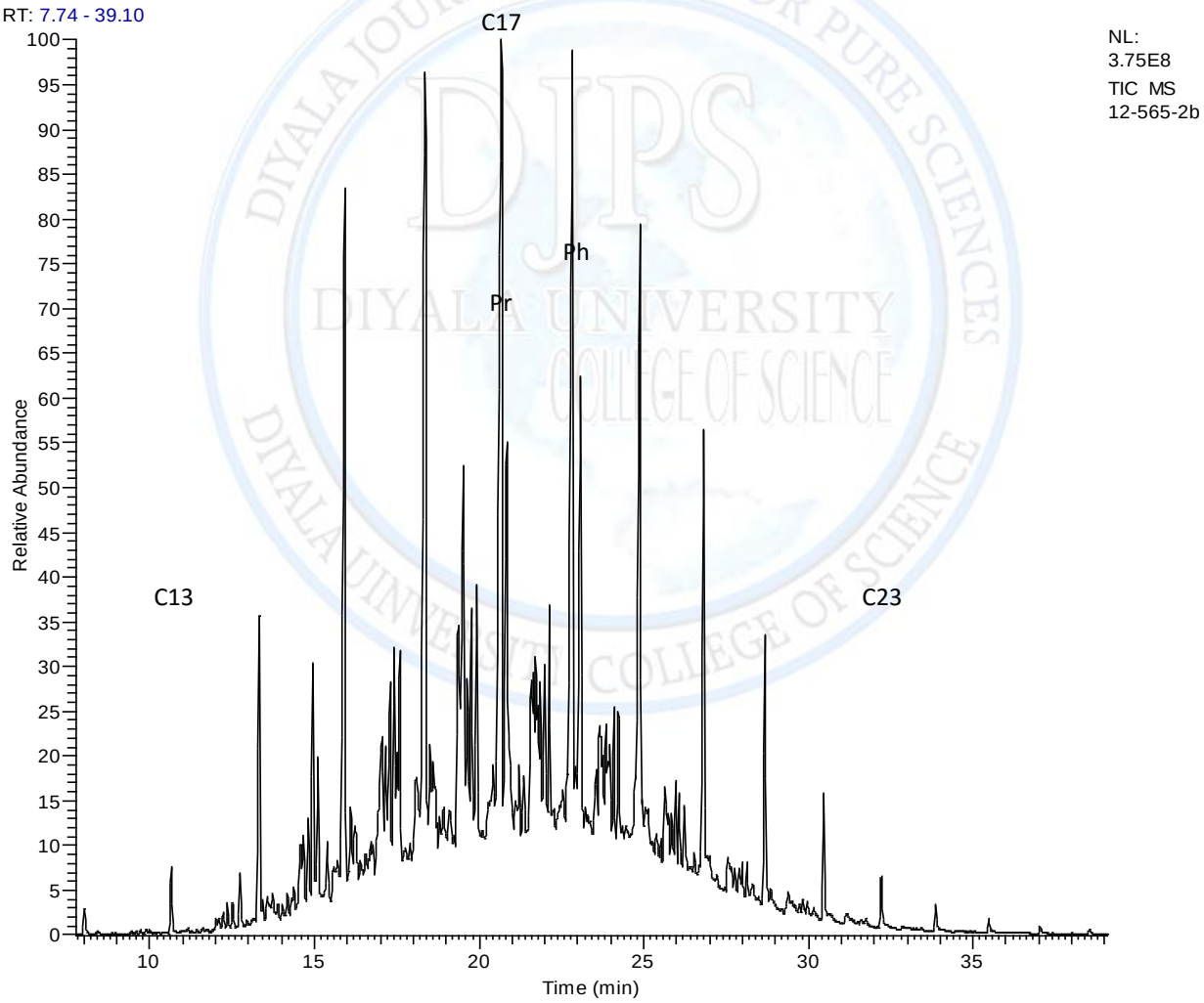

Figure 4: Normal alkanes distribution (Ak-3; 1233m depth). Pr=Pristane; Ph=Phytane

Thermal maturity of organic matter:

Tmax values of the present study are between 343-428 C^0, indicating immature organic matter. This immaturity of the organic matter is supported by the microscopic investigation represented by vitrinite reflectance (VR%) and the fluorescence intensity of the organic matter. VR% values, which were measured from a few particles found in few well samples, were between 0.35-0.49%. These VR% values are in agreement with Tmax data which indicates that the organic matter is immature. The organic matters of the present study are highly yellow fluorescent and some of them are shiny under the blue light excitation, indicating low thermal maturity level. This low level of maturity of these shales is also supported by molecular geochemistry study represented by the medium Pr/nC17 and Ph/nC18 ratios, which got an average of (0.27) and (0.46) respectively (Table 2). Thermal gradient of the interval 1050-1450 m is 2.37 C^0/100m in Akkas-1 well; and the present-day temperature between 45 and 55 C^0 in this interval (Majedee, 1999). This temperature indicates that the contained organic matter within these shales of this interval is immature (Peters and Cassa, 1994).

Table 2: Some of normal alkanes parameters

Sample	Depth (m)	Pr/Ph	Pr/C17	Ph/C18
outcrop	-	1.02	0.27	0.44
Outcrop	-	1.60	0.27	0.51
Outcrop	-	1.32	0.22	0.38
Outcrop	-	1.16	0.24	0.47
Outcrop	-	1.45	0.23	0.42
Ak-1	1330	1.31	0.30	0.51
Ak-1	1365	1.09	0.30	0.50
Ak-1	1400	1.81	0.25	0.46
Ak-3	1233	0.96	0.33	0.47
Ak-3	1243	0.83	0.32	0.47

Depositional environment:

The total sulfur content (TS) was measured for some outcrop and well samples. The TS values, which represents pyritic sulfur, are generally low in the outcrop samples (0.09- 0.38%); and medium in well samples (0.35- 1.06%). As the outcrop samples are exposed and subjected to the oxidation of the present pyrite and the organic matter through the reaction with surface water. The pyrite crystals of the outcrop samples show oxidation to iron oxides minerals which appear in red colors on the rims of the pyrite crystals. This pyrite oxidation process led to reduce the original sulfur content. Therefore; it is thought that the original sulfur content is higher than the present-day content and could be similar to the well samples content, where Ora Formation with an overall lateral homogeneity in deposition from the type section in the northmost Iraq to the westernmost Iraq (Al-Juboury and Al-Hadidy, 2008).

Total inorganic carbon content (TIC), thus, carbonates content, was also measured for all samples in which TOC was measured. Carbonates content was generally low to medium, it has an average of 7.23% (ranges between 0.45-22.73%) in the outcrop samples; and 11.01 % (ranges between 3.3-35.33%) in well samples. In some samples carbonates content is relatively high (more than 30%), this high carbonates content may suggest a strong marine influence during deposition. Low to medium carbonates content in the other samples may indicate marine depositional environment influenced by high terrestrial input. The generally low organic carbon content, low carbonates content, relatively high S/C ratios, relatively high pristine/phytane ratio, absence of well lamination; and low to medium proportions of bituminite (in comparison with alginite) indicate the establishment of more oxic bottom waters during deposition. A high proportion of terrigenous origin particles was also observed. The high amount of terrestrial-derived organic matter indicates high inputs of eroded material in the basin during deposition; and the low carbonates content suggest terrestrial oxic depositional environment (Taylor *et al*., 1998). Ora Formation which was deposited in shallow marine conditions and represent a progradation of a silisiclastic ramp upon shallow to open marine platform (Al-Hadidy, 2007).

The presence of contrasted organic matter composition (mixed of marine and terrestrial origin) suggests the existence of a mixed organic matter input.

Conclusions

The present study concluded that the Ora Formation is a potential source rock for hydrocarbons, especially the lower part of the Formation in Akkas field. Rock-Eval pyrolysis, visual examination, and molecular geochemistry criteria indicates that the organic matter is mixed of marine and terrestrial; and it is immature. Pristane/Phytane ratio, lower organic carbon and carbonates content, relatively high S/TOC ratios indicate that these successions were deposited under more oxic conditions.

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