Geologica Acta, Vol.5, N° 3, 2007, 245-254
Available online at www.geologica-acta.com

New potential hydrocarbon source-rocks in the Lower Eocene Metlaoui Formation (Central-Northern Tunisia, Northern Africa)

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ABSTRACT

Significant quantities of organic matter accumulated and were preserved in central-northern Tunisia during the Ypresian (Early Eocene). The organic geochemical characterization of the organic-rich facies of the Ypresian Metlaoui Formation (Ousselat and Es-Sfeïa sections) shows their significant potential as source rocks and increases interest in the Central-Northern Tunisia oil play. The TOC content in these rocks ranges from 0.09 to 3.71% suggesting their petroleum potential, whereas their T_{max} fluctuates from 429 to 439°C. These values and the predominance of the hetero compounds (NSO; 2-95%) point to low organic matter maturation. The diverse maturity levels reported for these organic-rich rocks never reached the conventional oil window peak stage and resulted from their different locations within the basin. The HI values and the high saturate concentrations (1-91%) compared to aromatics (1-33%), as well as the predominance of short-chain *n*-alkanes centered at n-C_{18} and n-C_{20} are indicative of unequivocal type-II kerogen. The fluctuation of the pristane/phytane ratio (0.97-2.53) records changes of the basin redox conditions, which mainly evolved around the sub-oxic range.

KEYWORDS **Ypresian. Source rocks. TOC. T_{max}. n-Alkanes. Sub-oxic conditions. Tunisia.**

INTRODUCTION

This paper focus on the Ypresian (Early Eocene) Ousselat and Es-Sfeïa organic-rich facies of the Metlaoui Formation (Fm) (Central-Northern Tunisia) and deals with assessing their geochemical signatures by means of Rock-Eval pyrolysis, Liquid Chromatography analyses and a study of *n*-alkanes distribution. This study also aims at providing information about the organic matter types and their thermal maturity level. The organic geochemical characterization of these rocks constitutes a preliminary step in establishing their petroleum potential and the characteristics of their depositional environments in Central-Northern Tunisia.

GEOLOGICAL SETTING

The studied early Eocene rocks are included in the Tunisian intermediate Atlas (Boukadi et al., 2000), and in the so-called "North-South Axis" (NOSA), which was a tectonically active area from the beginning of the Mesozoic (Burollet, 1956). The Atlas structure is dominated by the so-called Atlasic folding, which is characterized by NE-SW trending folds that were generated during later Tertiary compressive phases.

The Ypresian Metlaoui Fm successions crop out 40 km to the West of Kairouan (Central-Northern Tunisia; Fig. 1), in the central and eastern parts of so-called Ypresian basin (Burollet, 1956). These successions show a wide facies variation from their northern to southern outcrops and are coeval with the main phosphatic facies (Chouabine Formation) that crop out extensively in western Tunisia (Ben Ferjani et al., 1990).

The studied Ypresian outcrops are located at the Ousselat and Es-Sfeïa Jebels in the western and the eastern parts of the so-called Ypresian basin, where the Metlaoui Carbonate Group was deposited (Fig. 1).

The Ypresian outcrops in Jebel Ousselat, to the West of Kairouan, are exceptional exposures of mid-ramp to basin transition along continuous, three-dimensional outcrops in an area of 10 by 20 km (Vennin et al., 2003). The Jebel Ousselat anticline is a ten kilometer wide box anticline that evolves into a reverse fold-fault anticline and a backthrust (Rigane, 1991). The studied Ypresian carbonates crop out extensively in this fold (Fig. 2). The field data show that in this zone the Campanian to Ypresian successions are exceptionally thick (Fig. 2), and that the outcropping sequences thin and show rapid lateral facies changes across a fault (Fig. 2). As in other similar areas (i.e. the Bou Dabbous area described by Turki, 1985), the Jebel Ousselat sedimentary record shows the development of thick syntectonic extensional graben successions until the Ypresian, before tectonic inversion affected the area (Rigane, 1991).

The Es-Sfeïa Limestone overlies the so-called "Kairouan Island" Cretaceous paleo-high (Ben Jemia-Fakhfakh et al., 2002). This limestone unit crops out extensively both in Jebel Es-Sfeïa and the southern side of Jebel El Afaïr (Fig. 3), and makes up a fringe outlining the paleo-high related to the reactivation of the Mrhila - Cherichira E-W fault system. This limestone consists of red algae and bryozoan-bearing grainstones, some 20 meters thick, and is interpreted as high-energy shoal deposits reflecting a shore-face setting

METHODOLOGY

Sampling

This study is based on 52 outcrop samples collected from Ousselat Jebel (AS-0 to AS-51) and 11 samples from Es-Sfeïa Jebel (JE-01 to JE-11), with an average

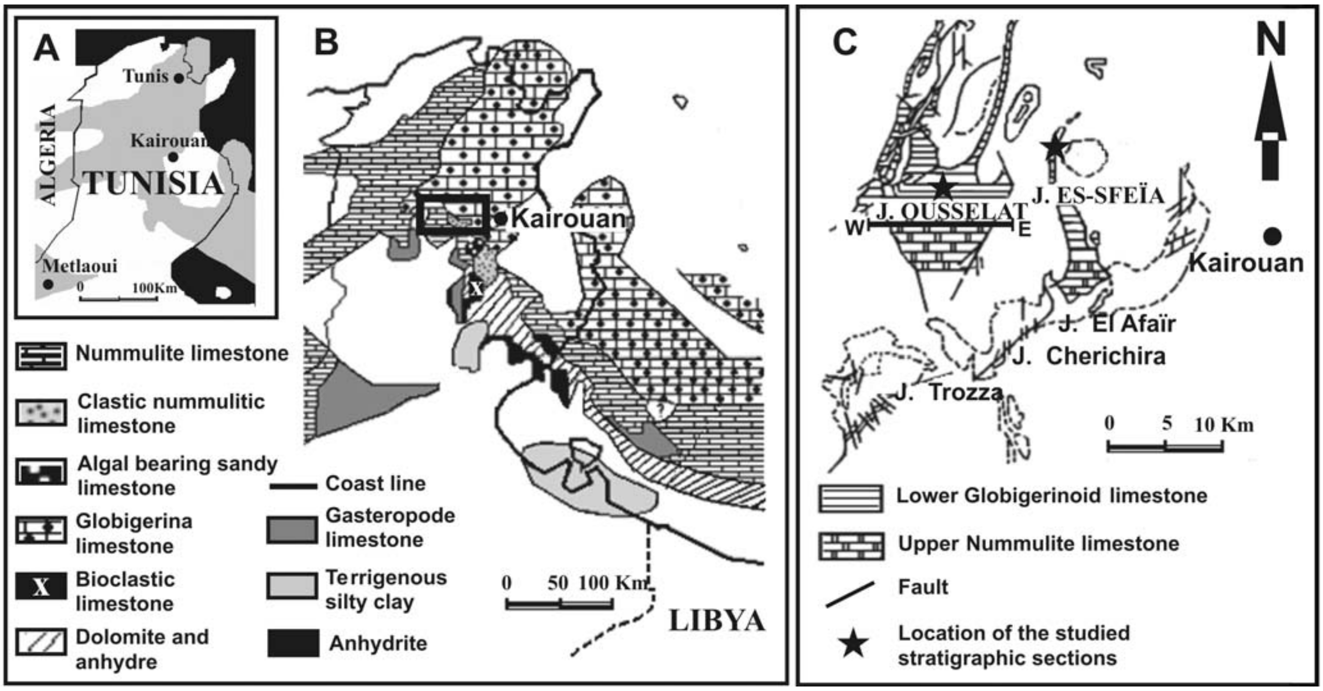

FIGURE 1 **A) Recorded depositional zones (gray pattern) during the Ypresian (Early Eocene) in the onshore and offshore of Tunisia (Northern Africa). B) Major onshore and offshore lithofacies distribution in the Ypresian basin (modified from Bishop, 1988). C) General lithological and structural characteristics of Jebel Ousselat and Jebel Es-Sfeïa. Stars show the location of the studied sections (adapted from Boukadi et al., 2000). See cross section in Fig. 3.**

amount of 500-1000 g per sample. All these samples were selected on account of their organic matter richness (dark grey limestones). Immediately after collection all samples were dried at 40°C and then finely ground prior to analysis.

Analytical procedures

Rock-Eval II analyses

To obtain Total Organic Carbon (TOC) content, Hydrogen Index (HI, mg HC/g TOC), Oxygen Index (OI, mg CO2/g TOC), and Tmax (°C), Rock-Eval (RE) analyses were performed on 21 selected samples. These analyses were undertaken by the Entreprise Tunisienne d'Activités Pétrolière" (E.T.A.P.) using the Rock-Eval II instrument, according to the procedure of Espitalié et al. (1977).

Bitumen extraction and liquid-column chromatography

Bitumen, from powdered sample (30-40 g), was extracted with dichloromethane as solvent (300-400 cm^3) for 1 hour at 40°C. After filtration the solvent was evaporated (rotary evaporator with water aspirator, evaporation temperature 40°C). Then the extracts ("free oils" or bitumen) were concentrated by allowing the oil-solvent solution to stand at room temperature until the CH_2 Cl_2 was removed.

The "free oils" were fractionated by column chromatography on alumina over silica gel. A variety of fractions, including aliphatics (F1), aromatics (F2) and polar compounds (F3), were obtained. Hexane and hexane: dichloromethane (65:35 Vol/Vol) were used as eluants for FI and F2, respectively.

Gas chromatography/mass spectrometry

Aliphatic fraction F1 was analysed by gas chromatography/mass spectrometry using HP 6890-HP 5973 MSD combination (Agilent Technologies, Wilmington DE, USA). The GC was used with a 30 m fused-silica column (0.25 mm i.d.) coated with 5% phenyl methyl siloxane. Helium was used as the carrier gas at a flow rate of 1.4 ml min^{-1}. A 100-290°C temperature programme with ramping at 4°C min^{-1} was employed. The samples were injected in the splitless mode with an injector temperature of 280°C. Samples were run in the electron impact mode at 70 eV with a 2.9 s scan time over a 50-550 Dalton range resolution. *n*-Alkanes distribution analysis was based on m/z 99 fragmentogram. The relative contents of particular compounds were calculated from peak areas.

RESULTS AND DISCUSSION

Rock-Eval parameters

The RE data are presented in Table 1. This table shows RE parameters of selected outcrop samples from Ousselat and E-Sfeïa Jebels. These facies were selected on account of their organic matter richness, as potential hydrocarbon source rocks. Type and maturity of the organic matter are shown in the HI versus T_{max} and HI versus OI diagrams, respectively.

Total Organic Carbon (TOC)

The measurements of TOC were performed using Rock-Eval II module. Table 1 shows TOC distribution of the studied outcrop sample and reveals that the sediments in Ousselat and Es-Sfeïa Jebels display a clear fluctuation of TOC values. Some samples are lean in organic matter

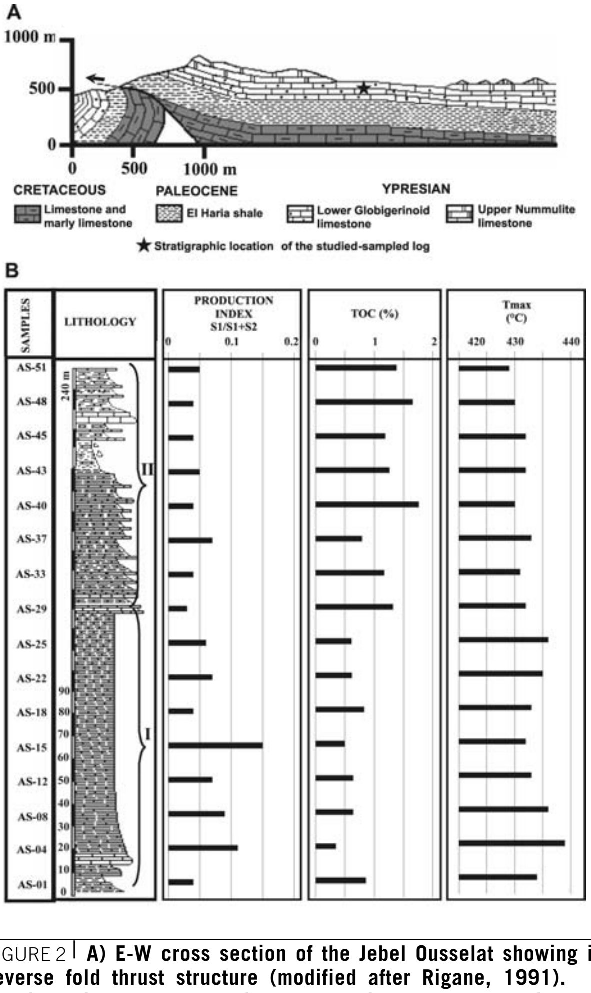

FIGURE 2 | **A) E-W cross section of the Jebel Ousselat showing its reverse fold thrust structure (modified after Rigane, 1991). B) Stratigraphic log of the Ypresian sequence in Jebel Ousselat with location of the samples of organic matter rich rocks. Lower part I: Gray to dark, organic matter rich limestones. Upper part II: interbedded yellowish limestone and organic rich clayey limestone.**

(< 1%), whereas others are dark colored and organic matter rich with high TOC values (up to 3.71%; Table 1). Compared to Es-Sfeïa samples (Fig. 3), the relative low TOC content measured on some outcrop samples from Ousselat area (Fig. 2), are probably due to the dilution effect caused by the high sedimentation rate and the poorer organic matter preservation. On the other hand, most of the samples from Es-Sfeïa area display relatively higher TOC contents (1.54-3.71%). This difference may have resulted from diverse depositional conditions, which could be more prone for preservation/ accumulation of relatively higher amount of organic matter in Es-Sfeïa.

"Free" (S1), and potential (S2) hydrocarbons

In this study S1 and S2 values do not show major differences between all the studied samples. The "free hydrocarbons" (S1) are extremely low ranging from 0.07 to 0.95 mg hydrocarbon per gram of rock. These low values may reflect the low thermal maturity of organic matter in Ousselat and Es-Sfeïa areas. This assumption is supported by the relatively low concentration of potential hydrocarbons (S2), which range from 0.02 to 19.75 mg hydrocarbon per gram of rock (Table 1).

Maximum pyrolysis temperature (T_{max})

The temperature for which the S2 peak is maximum (T_{max}) is a useful indicator of the thermal evolution of a source rock. In this study, T_{max} values range from 429°C (AS-51) to 439°C (AS-04; Table 1). A general assessment of thermal maturity using T_{max} values shows a small difference between the studied samples from each area (Figs. 2 and 3). The lowest T_{max} values are detected in Es-Sfeïa samples which range from 430 to 431°C (Table 1). Generally all the T_{max} values suggest that the organic matter has only reached a relatively low thermal maturity in both Ousselat and Es-Sfeïa areas, corresponding to the end of diagenesis and beginning of catagenesis (Bordenave et al., 1993).

Hydrogen Index (HI) and Oxygen Index (OI)

The marine source of Ypresian organic matter is supported by the dominance of algal-derived organic matter with HI-values ranging from 138 (AS-15) to 607 (JE-05) mg HC/g TOC (Table 1). Generally, theses values indicate an uniform source of organic matter for all study samples from Es-Sfeïa and Ousselat areas. Classifying the OM and specifying its main biological precursors is

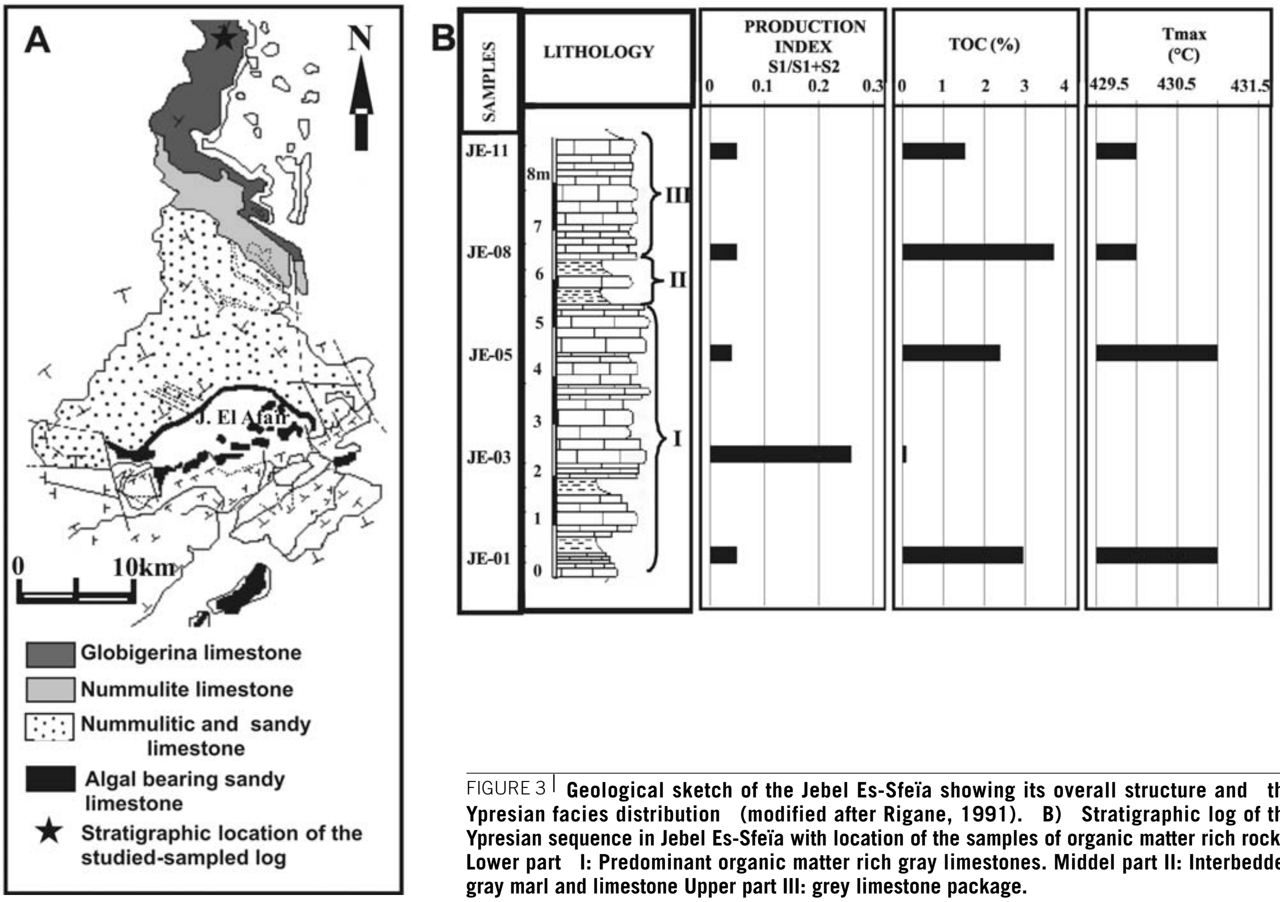

FIGURE 3 **Geological sketch of the Jebel Es-Sfeïa showing its overall structure and the Ypresian facies distribution (modified after Rigane, 1991). B) Stratigraphic log of the Ypresian sequence in Jebel Es-Sfeïa with location of the samples of organic matter rich rocks. Lower part I: Predominant organic matter rich gray limestones. Middel part II: Interbedded gray marl and limestone Upper part III: grey limestone package.**

TABLE 1 | **Result of Rock-Eval analyses of representative samples from Ousselat and Es-Sfeïa areas.**

Sample	TOC	mg hydrocarbon per g of rock		HI[b]	OI[c]	T_{max}
	(%)[a]	S1	S1			(°C)
OUSSELAT JEBEL						
AS-01	0.86	0.11	3.03	352	34	434
AS-04	0.35	0.08	0.62	177	134	439
AS-08	0.64	0.13	1.38	216	91	436
AS-12	0.64	0.12	1.69	264	67	433
AS-15	0.5	0.12	1.69	138	128	432
AS-18	0.83	0.11	2.51	302	46	433
AS-22	0.62	0.09	1.25	202	127	435
AS-25	0.61	0.08	1.33	218	103	436
AS-29	1.32	0.16	2.35	405	38	432
AS-33	1.17	0.2	4.66	398	62	431
AS-37	0.79	0.16	2.08	263	105	433
AS-40	1.76	0.3	7.16	407	52	430
AS-43	1.26	0.29	5.11	406	48	432
AS-45	1.19	0.22	5.11	429	61	432
AS-48	1.66	0.27	7.05	425	44	430
AS-51	1.38	0.32	5.86	425	58	429
Average	0.97	0.17	3.43	292.4	74.9	433
ES-SFEIA JEBEL						
JE-01	2.97	0.78	16.15	544	16	431
JE-03	0.09	0.07	0.2	222	356	—
JE-05	2.4	0.62	14.56	607	15	431
JE-08	3.71	0.95	19.75	632	15	430
JE-11	1.54	0.44	9.21	598	23	430
Average	2.14	0.57	11.97	500.6	85	430

[a] TOC: Total organic carbon (weight percent)
[b] HI: Hydrogen index (H I= S2/TOC x 100)
[c] OI: Oxygen index (O I= mg CO2 sample/TOC x 100)

obtained on the basis of a diagram of HI versus T_{max}. Figure 4 shows the relationship between hydrogen index, T_{max}, and kerogen types. According to this Figure, the marine source predominance is clear for the Ypresian organic matter. In addition a relative contribution from higher plants, concerning Ousselat samples, is deduced from this diagram. The comparison of T_{max}-temperatures with HI-indices allows defining three organic matter evolution pathways (Espitalié et al., 1985). Therefore, the localization of samples within HI vs T_{max} diagram suggests that the Ypresian organic matter ranges between the end of diagenesis and the beginning of catagenesis.

Rock Eval analysis of bulk samples provided OI values of 16 (JE-01) to 356 (JE-03) (mg CO_2 /g TOC) (Table 1). This large fluctuation of OI values may reflect the variations in redox conditions during deposition of the Ypresian organic matter. Oxidation may also be linked to outcropping conditions.

When plotted in a standard HI vs OI diagram (Espitalié et al., 1977, 1985; Tissot and Welte, 1984), half of the data points are located close to the Type-II kerogen field (Fig. 5). For Ypresian sediments, this is characteristic for predominately autochthonous algal organic matter. A trend of decreasing HI and complementary increasing OI values (Fig. 5) is noted for the Ousselat samples. Such distribution is commonly interpreted as a result of either mixing of variable proportions of Type-II and -III organic matter or increasing degradation/oxidation of Type-II organic material.

Bitumen extraction and liquid chromatography

The results of the hydrocarbon extractions and their chromatographic separations are listed in Table 2. The quantities of the dichloromethane extracts are low, ranging from 0.01 (JE-03) to 6.00 (JE-08) mg/g dry weight for the analysed samples. The low concentrations probably result from the low thermal maturity of organic matter (Tissot and Welte, 1984; Durand 1993; Vandenbroucke et al., 1993).

The normalized percentage compositions of the aliphatic, aromatic and NSO fractions of each sample are plotted in a ternary diagram (Fig. 6). The hachured area in the figure represents typical conventional petroleum com-

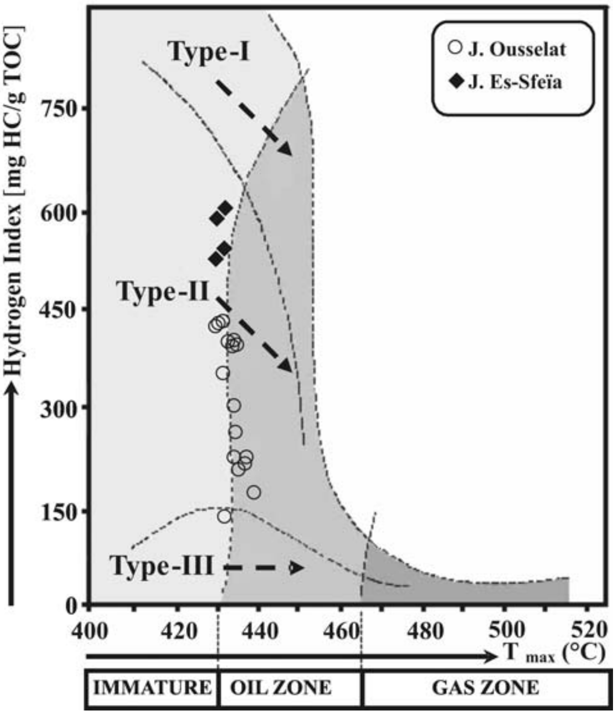

FIGURE 4 | **Organic matter type discrimination diagram of the studied samples from Ousselat and Es-Sfeïa areas based on crossplot of T_{max} and hydrogen index.**

TABLE 2 **Extract yields and relative percentages of saturated hydrocarbons, aromatic hydrocarbons and asphaltic (NSO) compounds of the representative samples from Ousselat and Es-Sfeïa areas.**

Sample	Total bitumen extract Total yield (mg/g dry weight)	Aliphatic hydrocarbons F1 (% of three fractions)	Aromatic hydrocarbons F2 (% of three fractions)	Asphaltic (NSO) compounds F3 (% of three fractions)	F1/F2
OUSSELAT JEBEL					
AS-00	0.35	10	12	78	0.8
AS-01	0.38	17	7	76	2.4
AS-02	1.63	82	9	9	9.1
AS-03	0.28	30	17	53	1.7
AS-04	0.1	33	17	50	1.9
AS-05	0.47	1	4	95	0.2
AS-06	0.29	18	9	73	2
AS-07	1.47	83	4	13	21
AS-08	0.27	25	18	57	1.4
AS-09	0.32	22	5	73	4.4
AS-10	0.23	16	27	58	0.6
AS-11	0.25	26	14	60	1.9
AS-12	0.3	23	21	56	1.1
AS-13	0.31	7	20	73	0.3
AS-14	0.23	8	8	84	1
AS-15	0.19	17	17	66	1
AS-16	0.24	6	6	88	1
AS-17	0.34	4	14	82	0.3
AS-18	0.29	38	9	53	4.2
AS-19	0.48	28	13	59	2.1
AS-20	3.29	76	3	21	25
AS-21	0.11	8	17	75	0.5
AS-22	0.19	11	11	78	1
AS-23	2.06	92	6	2	1.5
AS-24	0.33	22	10	68	2.2
AS-25	0.13	39	17	44	2.3
AS-26	1.92	19	4	77	4.8
AS-27	0.52	14	9	77	1.6
AS-28	2.17	13	4	83	3.2
AS-29	0.46	33	17	50	1.9
AS-30	0.42	32	2	66	16
AS-31	0.6	14	11	75	1.3
AS-32	2.9	47	5	48	9.4
AS-33	0.5	32	11	57	2.9
AS-34	1.22	12	6	82	2
AS-35	0.71	19	16	65	1.1
AS-36	0.38	26	11	63	2.3
AS-37	0.21	30	7	63	4.2
AS-38	0.12	27	9	64	3
AS-39	0.67	9	8	83	1.1
AS-40	0.89	1.5	8	77	1.8
AS-41	1.23	22	14	64	1.5
AS-42	0.2	24	19	57	1.2
AS-43	0.45	32	17	51	1.9
AS-44	2.8	25	12	63	2
AS-45	0.36	14	14	72	1
AS-46	2.24	37	11	52	3.3
AS-47	0.78	19	9	72	2.1
AS-48	0.79	18	17	65	1
AS-49	0.59	16	9	75	1.8
AS-50	2.10	63	5	32	12
AS-51	0.46	9	2	89	4.5
Average	0.8	26	11	63	4
ES-SFEIA JEBEL					
JE-01	3.62	33	11	56	3
JE-02	0.66	91	6	3	15
JE-03	0.01	33	33	34	1
JE-04	0.27	21	19	60	1.1
JE-05	2.9	36	7	57	5.1
JE-06	0.07	17	17	66	1
JE-07	2.02	35	9	56	4
JE-08	6	26	1	73	26
JE-09	3.41	57	6	37	9.5
JE-10	0.61	37	16	47	2.3
JE-11	2	44	2	54	22
Average	2	39	12	49	8

positions (Tissot and Welte, 1984). Most of the samples are located in the asphaltic pole (NSO) of the diagram. This distribution may be attributed to the low thermal maturity of organic matter (Tissot and Welte, 1984; Waples, 1985) and eventually to a possible removal of aliphatic compounds by post-generation processes such as weathering and biodegradation (Yamanaka et al., 1999).

Gas chromatography of saturated fraction

The m/z 99 fragmentogram indicates that hydrocarbons present in the sediments from Ousselat and Es-Sfeïa Jebels have a n-alkanes distribution ranging from 13 to 28 (Fig. 7). As shown in Fig. 7, three *n*-alkane series, i.e., n-C_{13} ~ n-C_{20}, n-C_{20} ~ n-C_{25}, and n-C_{25} ~ n-C_{28} alkane series are present in the sediments. The n-C_{13} ~ n-C_{21} alkane series is often attributed to sourcing by microorganisms and/or algae (Peters and Moldowan, 1993). The algal-marine Type-II organic matter signatures clearly occur with predominance of short-chain *n*-alkanes (n-C_{13} ~ n-C_{21}): On the contrary, continental higher plant signatures with predominance of long-chain odd carbon numbered are undetectable. This is made evident by the uni-

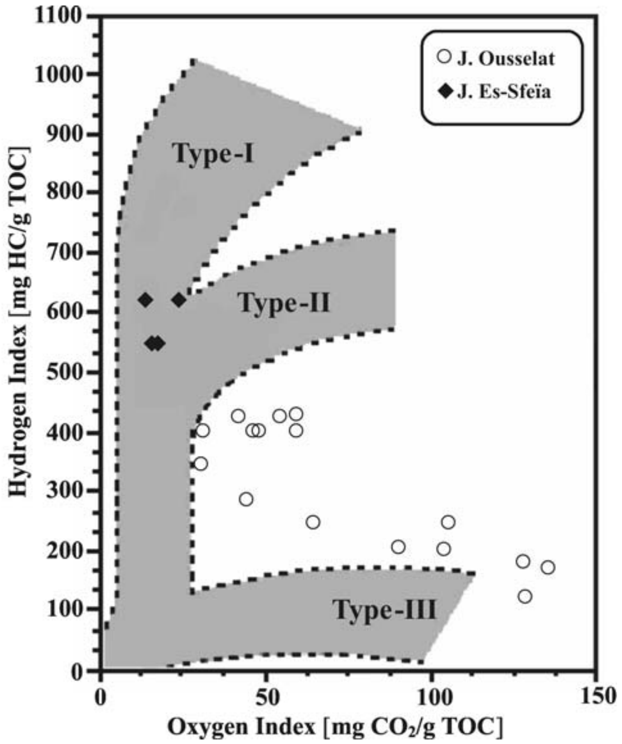

FIGURE 5 **HI vs. OI crossplot referred to as pseudo-van Krevelen diagram with indications for diagenetic evolutionary pathways for Type-I, -II and -III organic matter.**

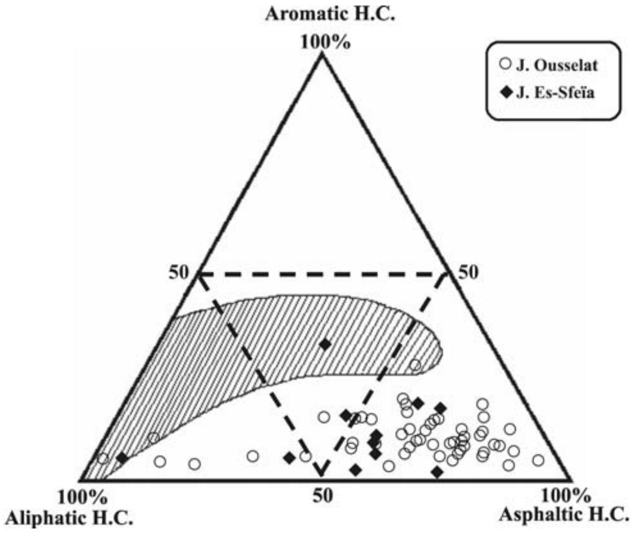

FIGURE 6 **Ternary diagram of saturated and aromatic hydrocarbons, and NSO compounds. Typical crude oils fall within the hachured area (Tissot and Welte, 1984).**

modal hydrocarbon distribution with a major mode centered at *n*-C_{18} or *n*-C_{21}.

Pristane and phytane occur in very high concentration in all the sample extracts (Fig. 7 and Table 3). The Pr/Ph ratios of the outcrop samples vary from 0.97 (AS-48) to 2.53 (JE-11) (Table 3). These relatively high Pr/Ph ratios may imply that the Ypresian organic matter was deposited in suboxic depositional environments in Ousselat and Es-Sfeïa areas.

Pristane to normal C_{17}-alkane (Pr/*n*-C_{17}) and Phytane to normal C_{18}-alkane (Ph/*n*-C_{18}) ratios are variable ranging from 1.40 (AS-37) to 4.61 (AS-18) and 0.72 (JE-05) to 2.18 (AS-43), respectively (Table 3). Didyk et al. (1978) suggested that high Pr/*n*-C17 ratio (>1) in petroleum may evidence that terrigenous higher plant contribution played a major role in its origin. The Pr/*n*-C17 vs. Ph/*n*-C18 diagram originally proposed by Lijmbach (1975) also provides information about the source material type, environment of deposition, and maturity (Connan and Cassou, 1980; Peters et al., 1999). From this diagram the Ypresian organic matter, from Ousselat and Es-Sfeïa areas, appears to have been deposited under oxic to suboxic conditions (Fig. 8).

The Ousselat organic matter samples occur in two diagram zones: the reducing transitional environments and in the oxic peat coal environments. Such result possibly indicates major changes in depositional setting (particularly in the concentration of dissolved oxygen). This suggestion is also supported by the fluctuation of Pr/Ph ratios (Table 3).

Biodegradation-weathering effects

In this study, the humps of UCM are not detected in m/z 99 mass chromatograms (Fig. 7). In contrast, the biodegradation fingerprint is clearly seen by the much higher concentration of acylic isoprenoids (e.g. Pr and Ph) relative to their *n*-alkane homologous (Fig. 7; Table 3). Pristane/*n*-C_{17} (Pr/*n*-C_{17}) and phytane/*n*-C_{18} (Ph/*n*-C_{18}) indices have been widely used as indicators of oil biodegradation (Overton et al., 1981; Kennicutt, 1988; Didyk and Simoneit, 1989). As the easily degraded normal hydrocarbons (*n*-C_{17} and *n*-C_{18}) are lost, the more degradation resistant isoprenoids (pristane and phytane) are conserved, resulting in a relative increase of the ratios of Pr/*n*-C_{17} and Ph/*n*-C_{18} in outcrop samples. The results presented in Table 3 and Fig. 8 indicate that these samples displayed relative change in the ratios of Pr/n-C_{17} and Ph/n-C_{18} with values in the range of 1.40-4.61 and 0.72-2.18, respectively (Table 3). In general, these characteristics correspond to moderate degrees of biodegradation (Peters and Moldowan, 1993). Samples from Ousselat area, such as AS-18 and AS-43 were degraded to a much greater extent. Commonly all samples were biodegraded (and/or weathered) to such a degree that alkanes (*n*-C_{17} and *n*-C_{18}) have much lower concentrations. However, the absolute concentrations of pristane and phytane are relatively constant for most of the samples, which may suggest a selective removal of *n*-alkanes over isoprenoids in biodegraded samples. The preferential degradation of short-chain *n*-alkanes over isoprenoids is illustrated in Fig. 8.

TABLE 3 **Analytical results of *n*-alkanes for the representative samples from Ousselat and Es-Sfeïa areas.**

Sample	n-Alkanes		Isoprenoids		
	Range	Predominance	Pr/Ph	Pr/n-C_{17}	Ph/n-C_{18}
OUSSELAT JEBEL					
AS-04	C14-C27	C18	1.88	2.42	1.17
AS-08	C15-C27	C18	1.48	1.96	1.27
AS-12	C15-C26	C18	2.03	2.46	1.11
AS-18	C15-C27	C21	2.23	4.61	1.67
AS-25	C15-C27	C21	1.84	2.7	1.35
AS-29	C15-C26	C21	0.99	4.37	2.12
AS-33	C15-C27	C21	1.80	3.68	1.8
AS-37	C15-C28	C21	1.28	1.40	0.84
AS-43	C15-C27	C21	1.74	4.45	2.18
AS-48	C15-C26	C21	0.97	3.13	1.86
AS-49	C15-C27	C21	1.97	3	1.34
	Average		1.65	3.10	1.52
ES-SFEIA JEBEL					
JE-01	C13-C27	C18	2.21	2.90	1.27
JE-05	C13-C27	C18	1.55	2.43	0.72
JE-11	C13-C26	C18	2.53	2.34	0.95
	Average		2.09	2.55	0.98

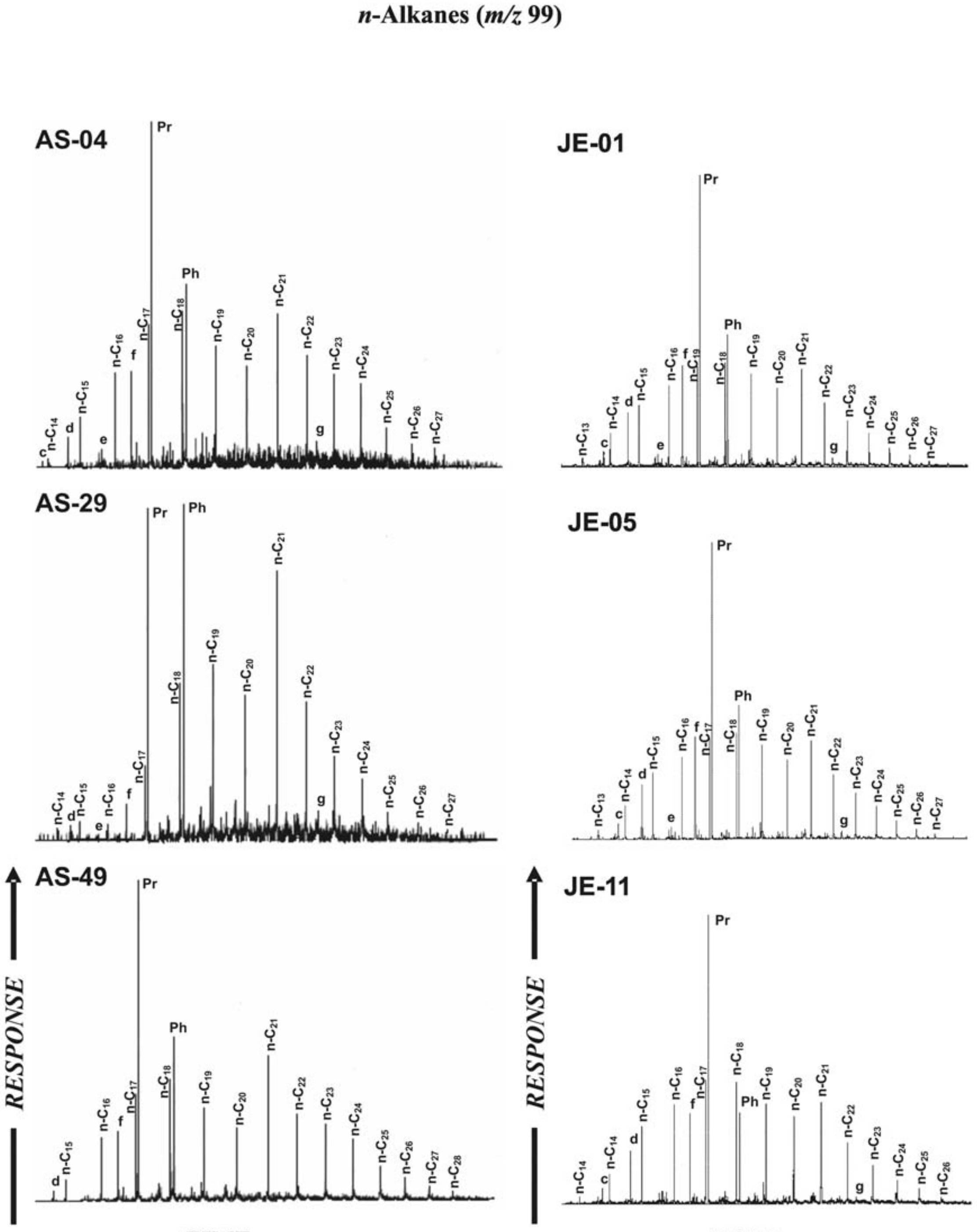

FIGURE 7 **Mass chromatograms (m/z 99) of the aliphatic hydrocarbon fractions for representative samples from Ousselat (AS-04; AS-29 and AS-49) and Es-Sfeïa (JE-01; JE-05 and JE-11) areas. (*n*-C_{14}) Tetradecane; (*n*-C_{15}) Pentadecane; (*n*-C_{16}) Hexadecane; (*n*-C_{17}) Heptadecane; (*n*-C_{18}) Octadecane; (*n*-C_{19}) Nonadecane; (*n*-C_{20}) Eicosane ; (*n*-C_{21}) Heneicosane; (*n*-C_{22}) Docosane; (*n*-C_{23}) Tricosane; (*n*-C_{24}) Tetracosane; (*n*-C_{25}) Pentacosane; (*n*-C_{26}) Hexacosane; (*n*-C_{27}) Hepatacosane; (*n*-C_{28}) Octacosane ; (c) 2,6,10-trimethyldodecane; (d) 2,6,10-trimethyltridecane; (e) 2,6,10-trimethyltetradecane; (f) nor-pristane; (Pr) pristane; (Ph) phytane; (g) 2,6,10,14,18-pentamethyleicosane.**

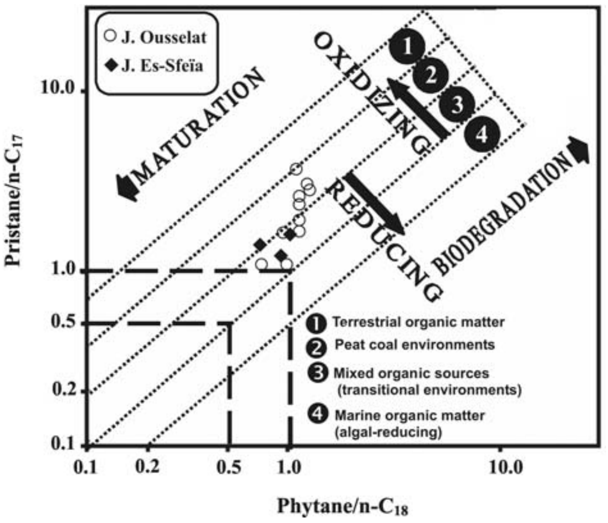

FIGURE 8 | **Relation between isoprenoids and *n*-alkanes showing source and depositional environments (Lijmbach, 1975).**

CONCLUSIONS

According to Rock-Eval pyrolysis, Liquid Chromatography analyses and n-alkane distribution study, the organic matter in the Ypresian source rocks from Ousselat and Es-Sfeïa Jebels is clearly related to type-II kerogen, and has evolved to the end of diagenesis and to early catagenesis. These results record the occurrence of sub-oxic depositional conditions during the Ypresian, which led to deposition of organic rich-carbonates in Ousselat and Es-Sfeïa areas. Despite of the slightly changing redox conditions, this depositional episode was prone to preservation of significant organic matter amounts (TOC >1). Moreover, these geochemical results suggest that the slight differences between both source rocks may have resulted from different organic matter primary production or preservation or from diverse thermal evolution. The geochemical features of the organic rich facies in the Ypresian successions of Ousselat and Es-Sfeïa Jebels make the Central-northern Tunisia a promising region for renewed hydrocarbon exploration.

ACKNOWLEDGEMENTS

Financial support for this study was provided by GEOGLOB (code: 03/UR/10-02, Tunisia). The authors are deeply indebted to Drs. Neila Chine and Moncef Saïdi from E.T.A.P. for their help and assistance with Rock-Eval pyrolysis and to Professor Moonam Kallel from L.A.R.S.E.N. for his assistance with GC/MS analysis. Our special thanks go to Professor Adel Rigane for his help during the sediment sampling and supplementary information. We would like to thank anonymous reviewers for helpful reviews.

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Manuscript received June 2006;
revision accepted December 2006.