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Organic-geochemical characteristics of the Miocene Lycian Basin, western Taurides, Turkey

O. Özçelik[a], M. Altunsoy[a]*, F. Acar[a] and N. Y. Erik[b]

[a]*Department of Geological Engineering, Faculty of Engineering, Akdeniz University, Antalya;* [b]*Department of Geological Engineering, Faculty of Engineering, Cumhuriyet University, Sivas, Turkey*

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In the Lycian Basin (SW Turkey), the Miocene Karabayır and Karakuştepe formations consist of algal limestone, conglomerate, sandstone, shale and limestone. Total organic carbon (TOC) analysis of the Miocene units show that these formations are poor in organic matter. TOC values are generally between 0.02 and 0.51%, but reach 3.47% in the Karabayır Formation. Hydrogen indices (HI) are mostly below 600 mgHC/gTOC, increasing to 1200 mgHC/gTOC in the Karabayır Formation. S_2 vs. TOC diagrams are used to evaluate the sedimentary environments and hydrocarbon potential of the Lower–Middle Miocene sediments (the Isparta, Bucak and Korkuteli-Elmalı areas). The organic material contains about 63 (type I), 35 (type II) and 29 (type II/III) pyrolysable hydrocarbons, respectively. The dominant organic matter is type II kerogens, and hydrocarbon generating potential is quite low. A positive x-intercept has been calculated in analysed samples according to S_2 vs. TOC diagrams; this value shows a rock-matrix effect. Clay is the main agent of adsorption. Biomarker characteristics also verify these results. Isoprenoid rates are Pr/Ph: 2, Pr/n-C17: 1.9, and Pr/n-C18: 0.5, and a high Pr/Ph ratio (pristane/phytane) indicates an oxic environment; the terpane C29 NH/C30 H ratio is >1 for the Karabayır Formation, and this value indicates a carbonate lithology. On the other hand, the C25 NH/C30 H ratio is <1 for the Karakuştepe Formation; this indicates that the hydrocarbons were derived from terrestrial organic matter. According to m/z 191 mass fragmentograms, the Miocene units contain oleanane, indicating a Tertiary age. The abundance of sterane C29>C28>C27 shows that the kerogens formed from algal organic matter.

Keywords: western Taurides; Lycian Basin; organic geochemical

Introduction

The western Taurides of SW Turkey comprise a central, relatively autochthonous carbonate platform unit. The Beydağları autochthon is bordered by two allochthonous units; the Lycian nappes to the west and the Antalya nappes to the east. The Miocene Lycian Basin is located on the Beydağları autochthon. As shown by the map in Figure 1, Miocene deposits of the Lycian Basin unconformably overlie a Mesozoic carbonate platform overthrust by both the Lycian and the Antalya nappes. The Lycian nappes comprise a composite unit of ophiolites, accretionary

*Corresponding author. Email: altunsoy@akdeniz.edu.tr

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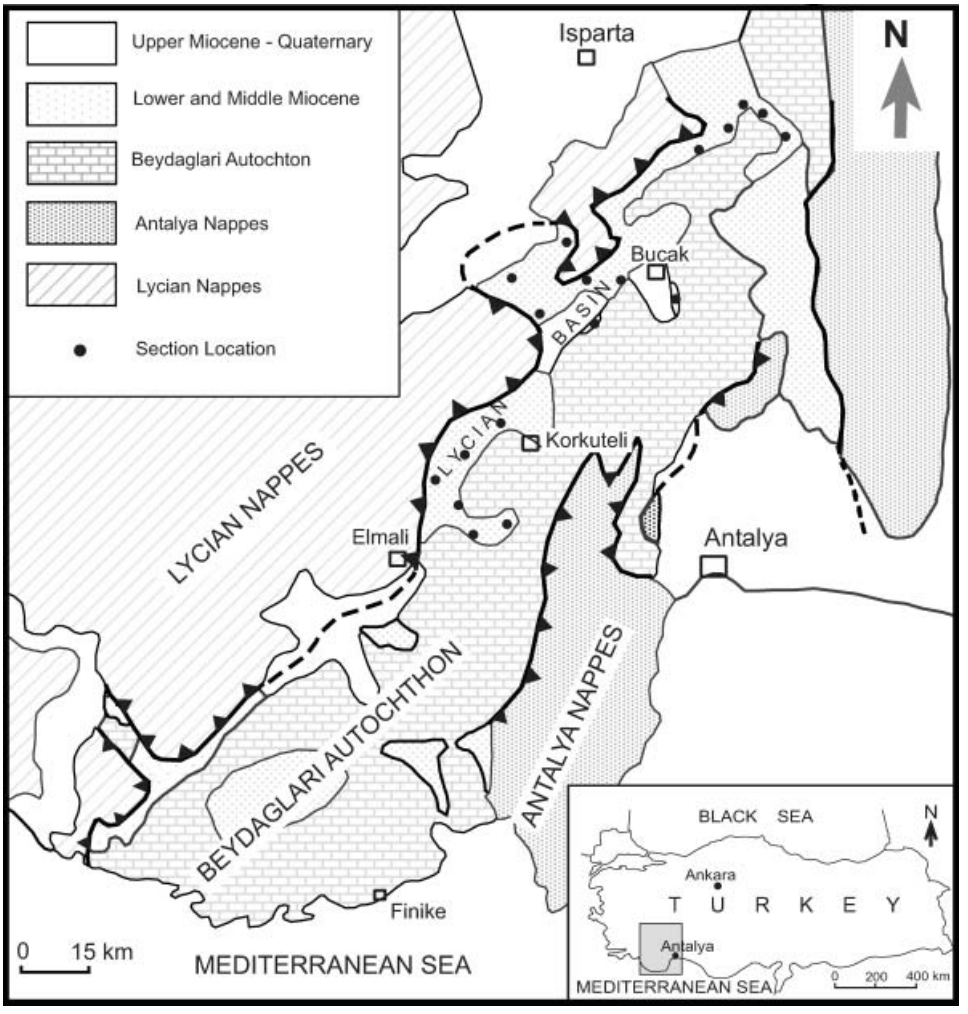

Figure 1. Map showing the main tectonic belts of the Western Taurides and location of the study area (modified from Poisson *et al.*, 1983).

prism-type volcano-sedimentary units and sedimentary thrust sheets of Carboniferous-Permian to Late Cretaceous age (Poisson 1977; Poisson *et al.* 1983; Collins and Robertson 1998). The Antalya nappes represent an allochthonous unit of mainly Mesozoic rocks exposed within the study area. This unit differs markedly in structure, lithology and timing of emplacement from the Lycian nappes (Robertson 2000). The central units of the western Taurides comprise the Taurus autochthon, a regionally extensive unit of shallow-water limestones belonging to a carbonate platform ranging in age from Liassic to Early Miocene, with several Early Tertiary non-sequences (Poisson 1977; Dumont *et al.* 1972; Hayward 1984). Miocene sediments were derived from both the allochthonous units timing and direction of their emplacement onto the carbonate platform (Hayward 1984). During the Neogene, the Lycian Basin formed in the southwestern part of the present-day Antalya province. The sedimentary fill of this basin spans the Aquitanian (Karabayır Formation) to Burdigalian-Langhian (Karakuştepe

Formation) ages, and consists of algal limestone, conglomerate, sandstone, shale and limestone deposited under shallow-marine conditions, overlain by a thick succession of marls and turbidites derived from the Lycian nappes.

Previous studies of this basin have defined and described the rock units, sedimentary associations, stratigraphy, tectonics and petroleum geology. General geological investigations and reports have been presented by Özgül (1976), Poisson (1977), Gutnic *et al.* (1979), Hayward (1984), Akay *et al.* (1985), Görmüş and Hançer (1997), Flecker *et al.* (1998, 2005), Robertson (2000), Sarı and Özer (2002) and Poisson *et al.* (2003), who studied the sedimentological character and tectonics of the study area and environs. Petroleum-geological studies have also been carried out; important ones include the works of Altunsoy (1999), Demirel *et al.* (2001, 2002) and Özçelik *et al.* (2005).

In this study, we describe organic-geochemical characteristics of the Lower Miocene (Karabayır Formation) and the Middle Miocene (Karakuştepe Formation) sediments of the Lycian Basin in the western Taurides. In order to determine the amounts, types and maturation of organic matter in these strata, outcrop samples of carbonates, sandstone and shale were collected.

Experimental

The Lower–Middle Miocene Karabayır and Karakuştepe formations (Lycian Basin) have been investigated with respect to their organic-geochemical characteristics. About 350 outcrop samples were collected from surface stations. Selected samples, representing the Lower–Middle Miocene sequence, were obtained from limestone, sandstone and shale units in 18 stratigraphic sections. For analysis, the selection of samples was based primarily upon changes in colour, type of lithology and other sedimentary characteristics. In order to determine the nature of the organic matter, a number of organic-petrographic and geochemical analyses were made upon kerogen isolated from the outcrop samples.

Total organic carbon (TOC), Rock – Eval pyrolysis, vitrinite reflectance (Ro), gas chromatography and gas chromatography mass spectrometry analyses were undertaken in the Turkish Petroleum Research Centre (Ankara, Turkey). Other microscopic studies were carried out in the laboratories of Akdeniz University (Antalya, Turkey) and Cumhuriyet University (Sivas, Turkey).

Rock-Eval pyrolysis provides information on the quantity and type of organic matter in a sedimentary rock, in addition to the level of organic maturation (Espitalié *et al.* 1985). Samples from each interval were pulverized, and about 100 mg from each sample was analysed using a Rock-Eval/TOC analyser (RE-2, Institut Français du Pétrole Standard) following techniques outlined by Espitalié *et al.* (1985). Thus, S1, S2, S3 and T_{max} values were obtained. Parameter S1 is a measure of the amount of hydrocarbon liberated at 300°C. Peak S2 is the amount of hydrocarbon released during temperature-programmed pyrolysis (300–600°C). TOC is determined by oxidizing the pyrolysis residue in a second oven (600°C in air). The hydrogen index (HI) is the normalized S2 value (S2/TOC), expressed as mg HC/gTOC. The oxygen index (OI) is the normalized S3 value (S3/TOC), expressed in mg CO2/gTOC. The production index (PI) shows the level of thermal maturation. The S2/S3 values indicate the type of organic matter for low to moderately mature samples (Leckie *et al.* 1988).

The screening results were followed by analyses of three samples by gas chromatograpy (performed using a Varian 3400 instrument) and gas chromatography-mass

spectrometry (performed using a Finnigan-Mat instrument) of rock extracts. Kerogen was isolated from the rock matrix using standard palynological preparation procedures. All samples were first decontaminated and crushed to about 2.0 mm. Carbonates were removed with 40% cold HF. After decantation, organic residue was sieved at 10 μm and a portion of the retained material was strew-mounted on glass slides. Organic-petrographic analyses were undertaken using transmitted-light microscopes at Cumhuriyet University (Sivas, Turkey) and in the Research Group Laboratories of the Turkish Petroleum Corporation.

Vitrinite-reflectance measurements followed established procedures (Stach *et al.* 1982). The results are represented as mean random reflectance values (R0). Maceral analysis was performed under incident and blue light excitation and by point counting transects (100 points/sample).

Results and discussion

Table 1 illustrates the values of total organic carbon, Rock-Eval pyrolysis and vitrinite reflectance for the Karabayır and Karakuştepe samples. Total organic carbon values were measured on 61 samples (Table 1). The obtained data show that the total organic carbon values are between 0.01 and 3.47%, with an average around 0.10%. For the Karakuştepe Formation, the total organic carbon values range from 0.02 to 1.00%, with an average of 0.12%. The organic-matter contents are higher in detrital sediments, such as sandstone and shale. The total organic carbon contents of the outcrop samples indicate that the Karabayır and Karakuştepe formations have insufficient organic matter to be petroleum source rocks.

In the Karabayır sediments, hydrogen index ranges from 155 to 1200 mgHC/gTOC, with an average of around 529 mgHC/gTOC. PI ranges from 0.08 to 0.68, with an average of 0.27, and T_{max} ranges from 300 to 459°C, with an average of 421°C. Organic-geochemical measurements of the samples were plotted on a hydrogen index – T_{max} diagram (Figure 2); the results indicate that the samples contain dominantly type II kerogen. In the Karakuştepe sediments, hydrogen index ranges from 187 to 1150 mg HC/gTOC, with an average around 422 mg HC/gTOC. PI ranges from 0.24 to 0.66, with an average of 0.32, and T_{max} ranges from 337 to 445°C, with an average of 418°C. T_{max} and production index show that the organic matter in the samples is immature to marginally mature.

The graph of S2 vs. TOC is an informative way of displaying Rock-Eval data. The use of a linear regression curve on the S2 vs. TOC diagram is the best way of calculating HI. S2 vs. TOC diagrams yield boundaries between kerogen types (Langford and Blanc-Valleron 1990). Also, the diagrams indicate the petroleum potential and the type of kerogen present. Peters (1986) and Espitalié *et al.* (1985) recommended that rocks with S2 greater than 5 and 10 mg HC/g rock be considered as having good and very good source-rock potential, respectively. The sedimentary suites may be compared with respect to their petroleum potential using the S2 vs. TOC diagram. Katz (1983, 1984) and Espitalié *et al.* (1985) have shown that the rock matrix adsorbs some of the hydrocarbons liberated by pyrolysis, with clay minerals as the main agents of adsorption (Espitalié *et al.* 1985); moreover, more hydrocarbon should be released from carbonate than from argillaceous matrices given similar organic contents. The matrix effect is indicated by a positive x-intercept on the S2 vs. TOC diagram, and the position of that intercept is a measure of the amount of adsorption. The regression lines in the S2 vs. TOC diagram should pass through the origin because even very small amounts of organic material may

Table 1. Total organic carbon and Rock-Eval pyrolysis values.

	Sample No.	TOC	S1	S2	S3	T_{max}	HI	PI
1	A7	–	0.01	0.03	–	446	–	0.25
2	A13	–	0.01	0.02	–	423	–	0.50
3	D1	–	0.02	0.11	–	451	–	0.17
4	D6	0.01	0.15	0.07	–	459	700	0.68
5	D11	0.01	0.07	0.10	–	445	1000	0.44
6	I2	–	0.01	0.12	–	435	–	0.08
7	I5	–	0.01	0.04	–	425	–	0.25
8	I8	0.02	0.11	0.15	–	419	750	0.42
9	I11	3.47	1.20	1.17	0.34	436	407	0.51
10	B2	1.70	2.79	9.24	–	424	543	0.23
11	KB-34	0.04	0.10	0.27	0.25	434	675	0.28
12	KB-40	0.07	0.10	0.36	0.36	434	514	0.22
13	KB-41	0.02	0.08	0.23	0.12	378	1150	0.27
14	KB-42	0.02	0.08	0.21	0.36	300	1050	0.29
15	BR-1	0.02	0.09	0.26	0.18	425	0	0.26
16	BR-4	0.02	0.08	0.22	0.13	373	1100	0.27
17	BO-3	0.10	0.13	0.45	0.62	431	450	0.22
18	BO-7	0.06	0.10	0.36	0.30	438	600	0.22
19	BO-9	0.10	0.11	0.37	0.50	415	370	0.23
20	BO-14	0.07	0.10	0.37	0.39	431	528	0.22
21	BO-17	0.09	0.10	0.33	0.52	413	366	0.24
22	KT-2	0.02	0.09	0.26	0.35	375	0	0.26
23	KT-5	0.02	0.08	0.24	0.23	369	1200	0.25
24	KT-6	0.31	0.50	0.89	1.20	430	287	0.36
25	KT-11	0.02	0.09	0.25	0.19	330	0	0.26
26	KT-12	0.02	0.08	0.24	0.13	374	1200	0.25
27	KK-18	0.21	0.44	0.88	1.02	440	419	0.33
28	KK-26	0.02	0.08	0.23	0.31	443	1150	0.27
29	KK-29	0.05	0.10	0.33	0.37	446	660	0.24
30	KK-42	0.05	0.09	0.29	0.33	440	580	0.24
31	KK-45	0.03	0.12	0.31	0.23	435	1033	0.29
32	KBy-1	0.03	0.09	0.26	0.30	454	866	0.26
33	KBy-3	0.45	1.46	1.46	1.48	439	324	0.50
34	KBy-5	0.02	0.09	0.24	0.26	391	1200	0.28
35	KBy-10	0.07	0.12	0.37	0.40	432	528	0.25
36	BBÜ-5	0.03	0.08	0.26	0.33	389	866	0.24
37	BBÜ-12	0.09	0.12	0.44	0.55	429	488	0.21
38	BSf-1	0.27	0.37	0.86	0.94	432	318	0.30
39	BSf-6	0.11	0.08	0.26	0.27	440	236	0.24
40	BSf-36	0.16	0.25	0.54	0.82	426	337	0.32
41	BSf-37	0.35	0.15	0.82	0.17	443	234	0.16
42	BDf-23	0.26	0.09	0.41	0.24	425	157	0.18
43	BPmf-6	0.11	0.10	0.37	0.30	433	336	0.22
44	BPmf-11	0.18	0.08	0.28	0.18	459	155	0.22
45	BPmf-17	0.10	0.08	0.27	0.24	440	270	0.24
46	BYf-27	0.15	0.09	0.34	0.31	432	226	0.21
47	BYf-37	0.15	0.08	0.34	0.40	440	226	0.19
48	BHf-4	0.25	0.40	1.02	0.91	424	408	0.28
49	BKef-18	0.14	0.32	0.65	0.70	427	464	0.33
50	BKAf-8	0.15	0.32	0.67	0.71	429	446	0.33
51	BKAf-20	0.12	0.11	0.34	0.51	410	283	0.25
52	BR-18	0.02	0.09	0.26	0.42	417	0	0.26
53	BO-29	0.03	0.09	0.26	0.31	387	866	0.26
54	BO-30	0.02	0.09	0.23	0.21	337	1150	0.28
55	BSf-49	0.51	2.24	1.17	1.75	441	229	0.66

Table 1. (*Continued.*)

	Sample No.	TOC	S1	S2	S3	T_{max}	HI	PI
56	BSf-70	0.11	0.10	0.33	0.39	427	300	0.24
57	BDf-6	1.00	3.52	2.85	2.44	442	285	0.55
58	BDf-9	0.11	0.10	0.28	0.62	416	254	0.26
59	BDf-21	0.17	0.08	0.33	0.26	432	194	0.20
60	BAf-56	0.10	0.10	0.34	0.48	431	340	0.23
61	BPf-19	0.16	0.09	0.30	0.19	445	187	0.24

yield hydrocarbons during pyrolysis. However, S2 vs. TOC regression lines typically have positive intercepts on the x-axis; this means that a threshold amount of organic material must be present before enough hydrocarbons can be detected during pyrolysis (Langford and Blanc-Valleron 1990).

The Miocene sediments of the Lycian Basin serve as an example of the use of the S2 vs. TOC diagram in this study. On the northern margin of the basin (Isparta area), for Miocene sediments, the amounts of pyrolysable hydrocarbons are only about 63% of the TOC, which are close to type I kerogen. The amount of organic material is much less and the slope of regression line is higher, apparently due to the

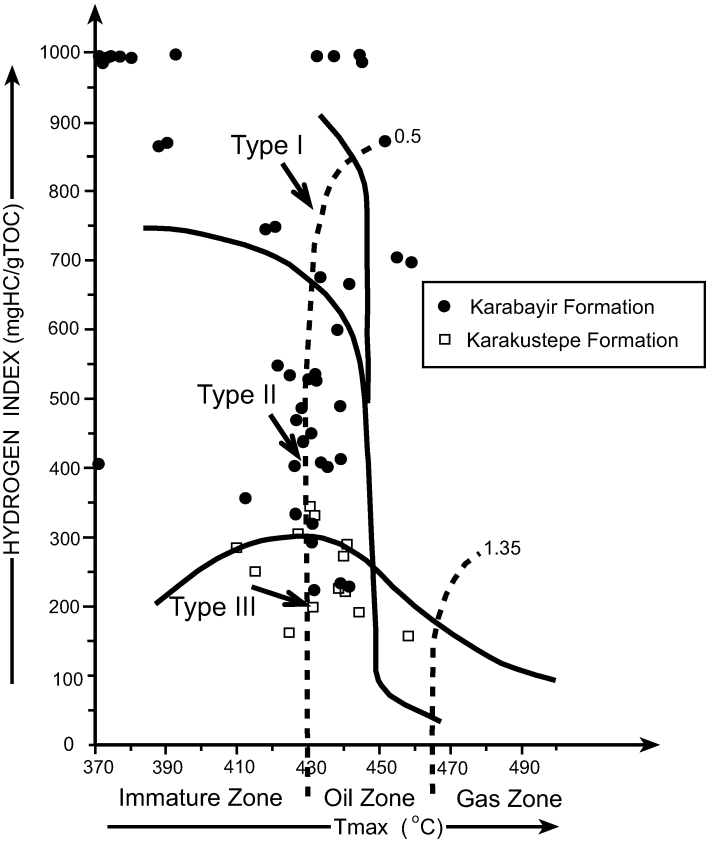

Figure 2. Kerogen typing using hydrogen index (HI) vs. T_{max}.

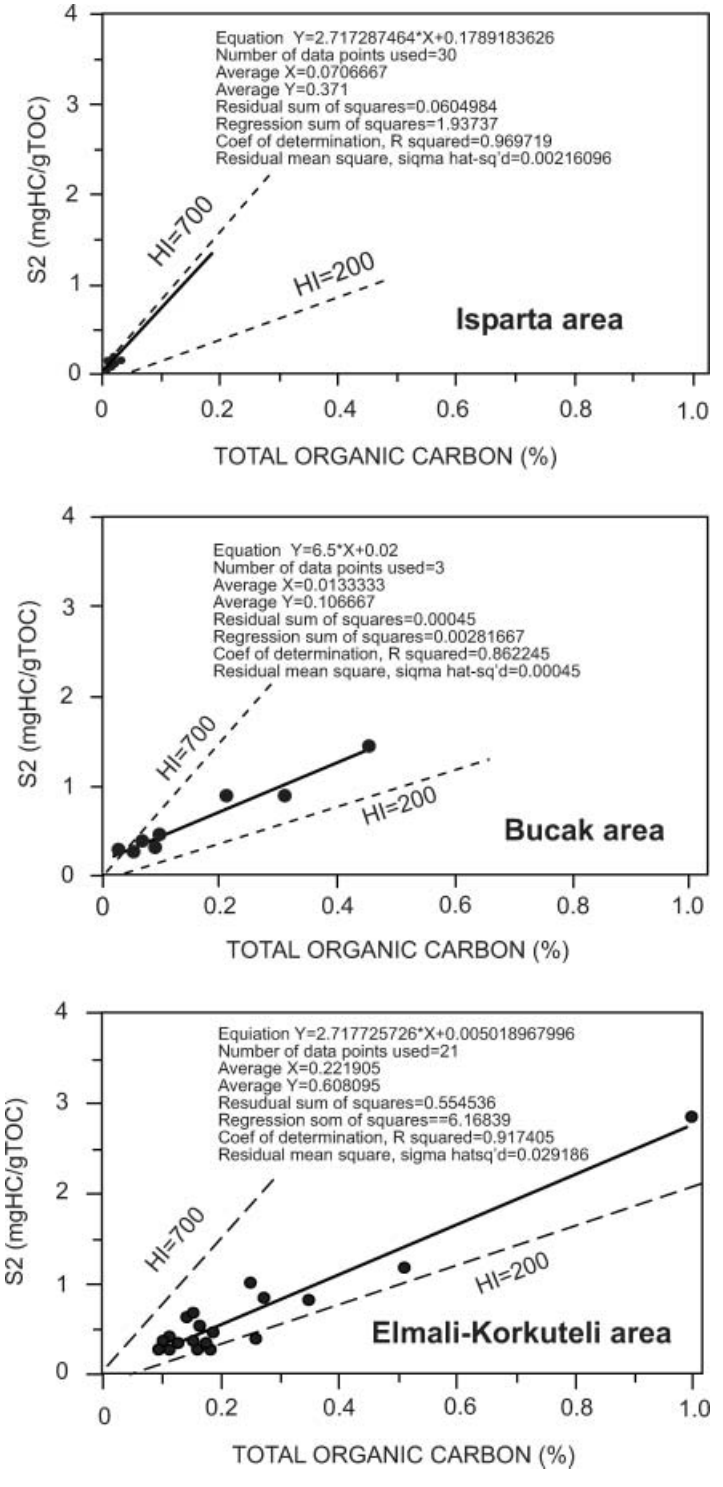

Figure 3. S2 vs. TOC diagram for the Karabayır and Karakuştepe formations.

presence of type I material; this cannot be considered a petroleum source rock because all samples have less than 5 mg HC/g sample. In the central (Bucak) area, the organic material contains about 35% pyrolysable hydrocarbons (type II) (Figure 3); thus, in this area, the Miocene units are a poor potential source rock for oil. In the southern part of the study area (Elmalı – Korkuteli area), the Karabayır and Karakuştepe formations have low TOC, and the low slopes of the regression curves indicate the presence of type III kerogen (pyrolysable hydrocarbons are about 29% of the TOC) (Figure 3); thus, the units are a poor potential source rock for oil. The slightly high positive x-intercept is consistent with the presence of clay. In summary, there is a small variability between individual Rock-Eval measurements and the calculated HI on the S2 vs. TOC diagram for Early-Middle Miocene units in the Lycian Basin. This means that a certain amount of organic material must be present before enough hydrocarbons may be detected during pyrolysis. The rock matrix adsorbs some of the hydrocarbons released by pyrolysis, with clay as the main agent of adsorption.

Vitrinite reflectance was measured in 34 Miocene samples (Table 2). Thirty samples belong to the Karabayır Formation, and four belong to the Karakuştepe Formation. In the southern part of the study area (Elmalı – Korkuteli area), no vitrinite was found and no reflectance was measured inasmuch as the Karabayır Formation generally consists of carbonate units. Vitrinite reflectance values in the central part of the area were measured between 0.54 and 0.67%. The values in the northern part of the area are generally low, varying between 0.14 and 0.41% (mean value 23%). On the basis of microscope observations, we have determined that the kerogens are dominated by marine (amorphous) organic matter (ranging from 60 to 90%) and a little terrestrial organic matter (ranging from 5 to 35%; Table 3).

In the Karakuştepe Formation, the four samples containing determinable vitrinite yielded reflectance values of 0.52–0.67%, with an average mean value of 0.61%. Kerogens are dominated by amorphous organic matter (60–90%) with lesser terrestrial (herbaceous, woody and coaly) organic matter (5–30%; Table 3).

Table 2. Vitrinite reflectance values.

Sample No.	Ro	Sample No.	Ro
A1	0.15	Y9	0.18
A2	0.20	Y10	0.21
A3	0.31	I5	0.24
A6	0.44	Is6	0.17
A7	0.43	I6	0.24
A10	0.22	B4	0.14
A11	0.19	BSf-6	0.56–0.67
A14	0.35	BSf-37	0.54
D1	0.35	BDf-23	0.56
D2	0.21	BPmf-11	0.61
D4	0.15	BYf-27	0.55
D5	0.15	BYf-37	0.52
Y3	0.13	BSf-70	0.52–0.67
Y4	0.15	BDf-21	0.59
Y5	0.12	BPf-19	0.63

Table 3. Organic-matter types within the investigated units.

Sample No.	Organic matter types			
	Amorp.	Herba.	Woody	Coaly
Karabayır Formation				
KB-l	80	10	5	5
KB-6	70	15	10	5
KB-16	75	15	5	5
KB-19	90	5	5	–
KB-42	60	5	25	10
KK-21	75	10	10	5
KK-34	80	5	10	5
KK-43	75	10	5	10
KK -44	80	10	5	5
KK-46	80	10	5	5
KU-3	70	10	5	15
KU-7	60	5	10	25
BR-1	60	35	5	–
BR-3	80	15	5	–
BR-5	90	5	5	–
BO-3	80	15	5	–
BO-7	80	15	5	
BO-14	65	20	10	5
BBü-9	70	10	15	5
BBü-11	70	20	5	5
KT-2	75	15	5	5
KT-3	80	10	5	5
KT-5	90	5	5	–
KT-6	85	10	5	–
KT-11	85	10	5	–
KBY-l	95	5	–	–
KBY-3	90	5	5	–
KZ-1	70	15	10	5
BSf-1	70	20	8	2
BSf-6	90	5	5	–
BSf-20	80	10	5	5
BSf-33	70	25	5	–
BSf-36	85	10	5	–
BSf-37	80	10	5	–
BDf-36	90	5	5	–
BHf-1	80	7	10	3
BHf-10	90	5	5	–
BKef-14	90	5	5	–
BKef-18	90	5	3	2
BKAf-8	90	5	5	–
A.1	80	5	10	5
A.3	90	–	7	3
A.5	90	–	5	5
A.6	90	–	7	3
A.7	90	–	7	3
A.9	85	3	10	2
A.10	90	–	7	3
A.11	90	–	5	5
D.1	90	–	7	3
D.2	80	2	10	8
D.4	85	–	10	5
D.5	85	–	10	5
D.6	80	2	15	3
D.8	90	–	7	3
D.11	90	–	5	5

Table 3. (*Continued.*)

Sample No.	Organic matter types			
	Amorp.	Herba.	Woody	Coaly
Y.1	95	–	3	2
Y.3	90	–	5	5
Y.4	80	3	12	5
Y.5	90	–	5	5
Y.6	80	–	15	5
Y.7	90	–	5	5
Y.8	90	–	5	5
Y.9	85	–	10	5
I.2	75	–	15	10
I.5	65	5	20	10
I.6	70	3	20	7
I.8	95	–	3	2
Karakuştepe Formation				
BBÜ-45	80	10	5	5
BBü-47	65	30	5	–
BO-24	75	10	10	5
BO-27	75	10	10	5
BO-29	80	10	5	5
BO-30	65	15	10	10
BR-18	85	10	5	–
BSf-49	80	10	5	5
BSf-53	80	10	5	5
BSf-70	80	10	5	5
BDf-2	80	10	5	5
BDf-6	85	5	5	5
BDf-9	80	10	5	5
BDf-11	50	25	20	5
BDf-21	50	25	20	5
BAf-1	80	10	5	5
BAf-9	80	10	5	5
Baf-20	85	10	5	–
Baf-42	75	15	5	5
Baf-56	80	10	7	3
BPf-13	80	5	10	5
BPf-15	80	10	5	5
BPf-19	80	10	7	3
BPf-21	75	15	5	5
BPf-22	80	10	5	5
BPf-24	75	15	5	5
BPf-27	90	7	3	–
BPf-29	80	10	5	5
BPf-30	80	10	5	5
BPf-31	80	10	5	5
BPf-32	75	15	5	5
BPf-33	75	10	5	10
BYf-30	65	20	10	5
BYf-61	70	15	10	5
BYf-75	75	15	5	5
BKef-19	75	10	5	10
BKef-27	80	10	5	5
BKef-34	60	30	5	5
BKAf-15	80	10	5	5
BKAf-20	70	15	5	10
BOf-6	75	10	10	5
BOf-13	70	15	10	5
BOf-20	60	20	15	5

Table 3. (*Continued.*)

Sample No.	Organic matter types			
	Amorp.	Herba.	Woody	Coaly
BHf-25	80	10	5	5
BFf-6	75	10	10	5
BFf-13	70	15	10	5
BFf-20	60	20	15	5

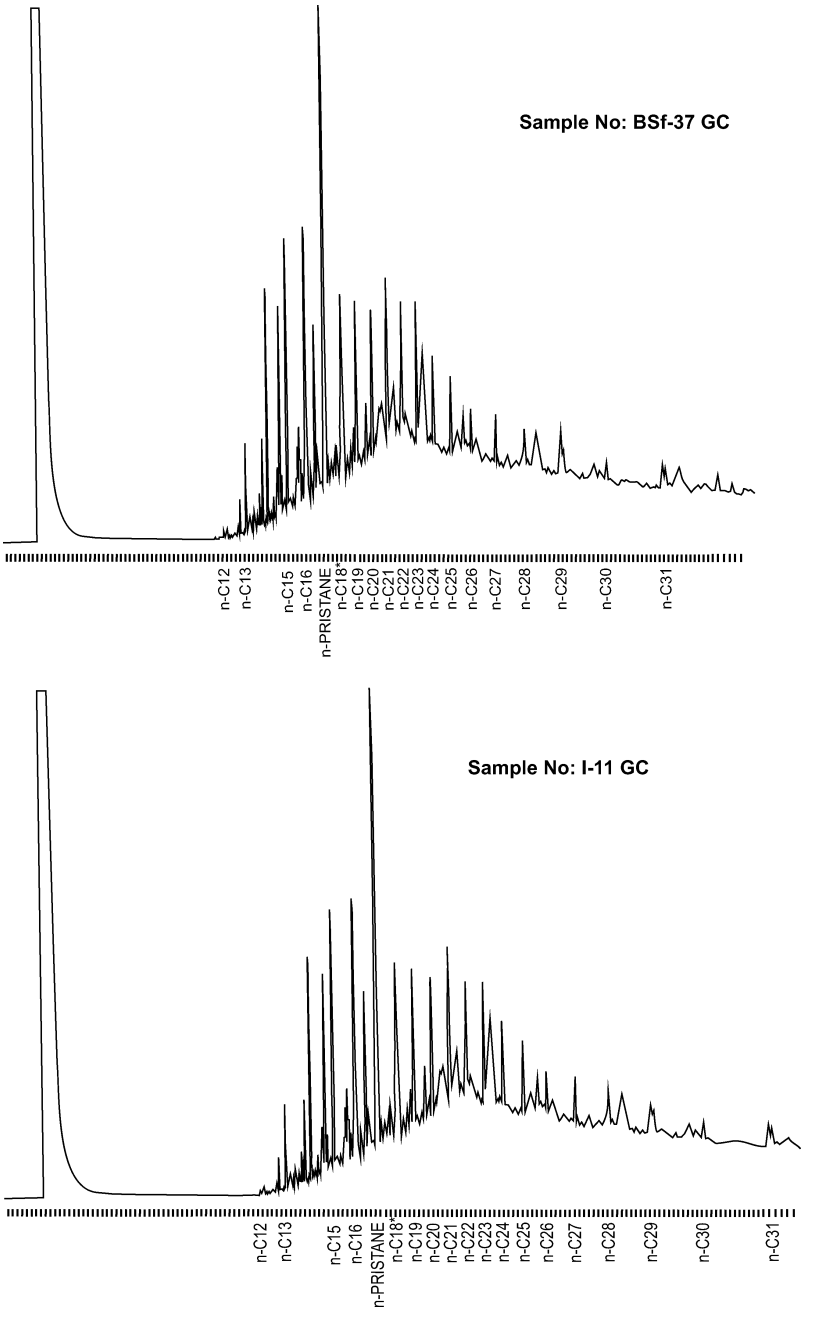

Figure 4. Gas chromatogram for rock samples from the Miocene units.

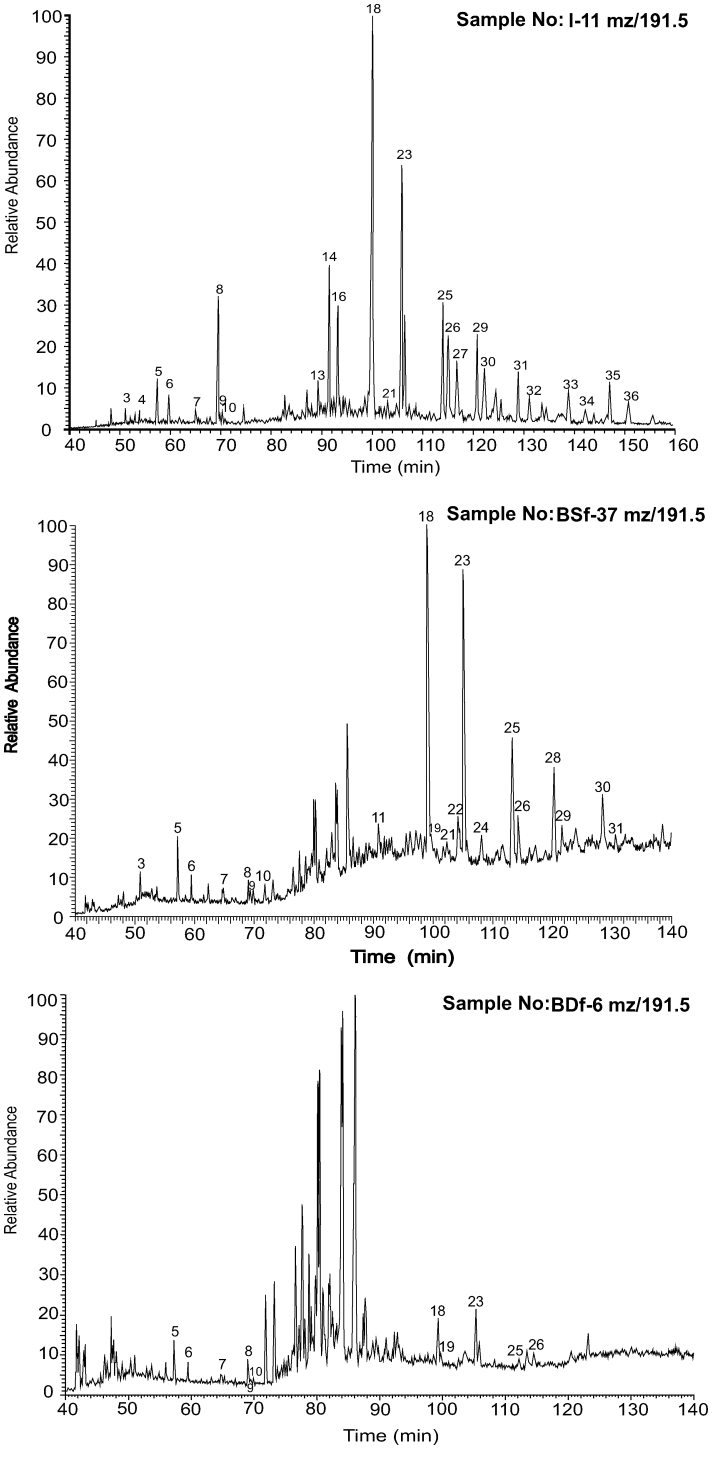

Figure 5. Terpane mass chromatogram (m/z 191) of the rock samples from Miocene units.

In general terms, the thermal-maturity window for fully mature organic matter can be designated by a vitrinite reflectance value that ranges from about 0.7 to 1.0%, and for early mature organic matter from about 0.5 to 0.7% (Taylor *et al.* 1998). The window varies with maceral composition because of the different kinetics involved in oil generation from various organic-matter types (Tissot and Welte 1984).

According to the above findings, the northern units of the Karabayır Formation contain immature organic matter whereas the central units contain early mature organic matter. The Karakuştepe Formation units also contain early mature organic matter. Thus, organic-matter maturation increases from north to south in the study area.

The gas chromatograms of the saturated hydrocarbon fractions obtained from samples from the Lower–Middle Miocene units are shown in Figure 4. The pristane (Pr)/phytane (Ph) ratios of the samples are significantly higher than 1.0 (2.0), and the n-alkane isoprenoids are more abundant than the n-alkanes (Pr/n-C17>1). In general, higher Pr/Ph ratios (>1) are associated with oxidizing depositional

Table 4. List of identified biomarkers for the terpanes.

Peak	Terpane idendification
1	C_{19} Tricyclic Terpane
2	C20 Tricyclic Terpane
3	C_{21} Tricyclic Terpane
4	C_{22} Tricyclic Terpane
5	C_{23} Tricyclic Terpane(18, 19-Bisnor-13β(H), 14α(H) Cheilanhane
6	C_{24} Tricyclic Terpane
7	C_{25} (22S + 22R) Tricyclic Terpane
8	Tricyclic Hopane (Secohopane)
9	C_{26} 22(S) Teicyclic Terpane
10	C_{26} 22(R) Tricyclic Terpane
11	C_{28} Tricyclic Terpane
12	C_{29} Tricyclic Terpane
13	C27 18α(H)-22,29,30-Trisnorneohopane (T_s)
14	C27 17α(H)-22,29,30-Trisnorneohopane (T_m)
15	17α(H)-29,30-Bisnorhopane
16	C30 Tricyclic Terpane
17	17α(H)-28,30-Bisnorhopane
18	C29 17α(H), 21β(H)-30-Norhopane
19	C29 Ts(18α(H)-30-Norneohopane
20	C30 (17α(H)-Diahopane
21	C29 17β(H), 21α(H)-30 Normoretane
22	Oleanane
23	C30 17α (H), 21β(H)-Hopane
24	C30 17β(H),21α(H)-Moretane
25	C3117α(H), 21β(H)-30-Homohopane (22S)
26	C3117α(H), 21β(H)-30-Homohopane (22)
27	Gammacerane
28	Homomoretane
29	C32 17α(H), 21β(H)-30,31-Bishomohopane (22S)
30	C32 17α(H), 21β(H)-30,31-Bishomohopane (22R)
31	C33 17α(H), 21β(H)-30,31,32-Trishomohopane (22S)
32	C33 17α(H), 21β(H)-30,31,32-Trishomohopane (22R)
33	C34 17α(H), 21β(H)-30,31,32,33-Tetrakishomohopane (22S)
34	C34 17α(H), 21β(H)-30,31,32,33-Tetrakishomohopane (22R)
35	C34 17α(H), 21β(H)-30,31,32,33,34-Pentakishomohopane (22S)
36	C34 17α(H), 21β(H)-30,31,32,33,34-Pentakishomohopane (22R)

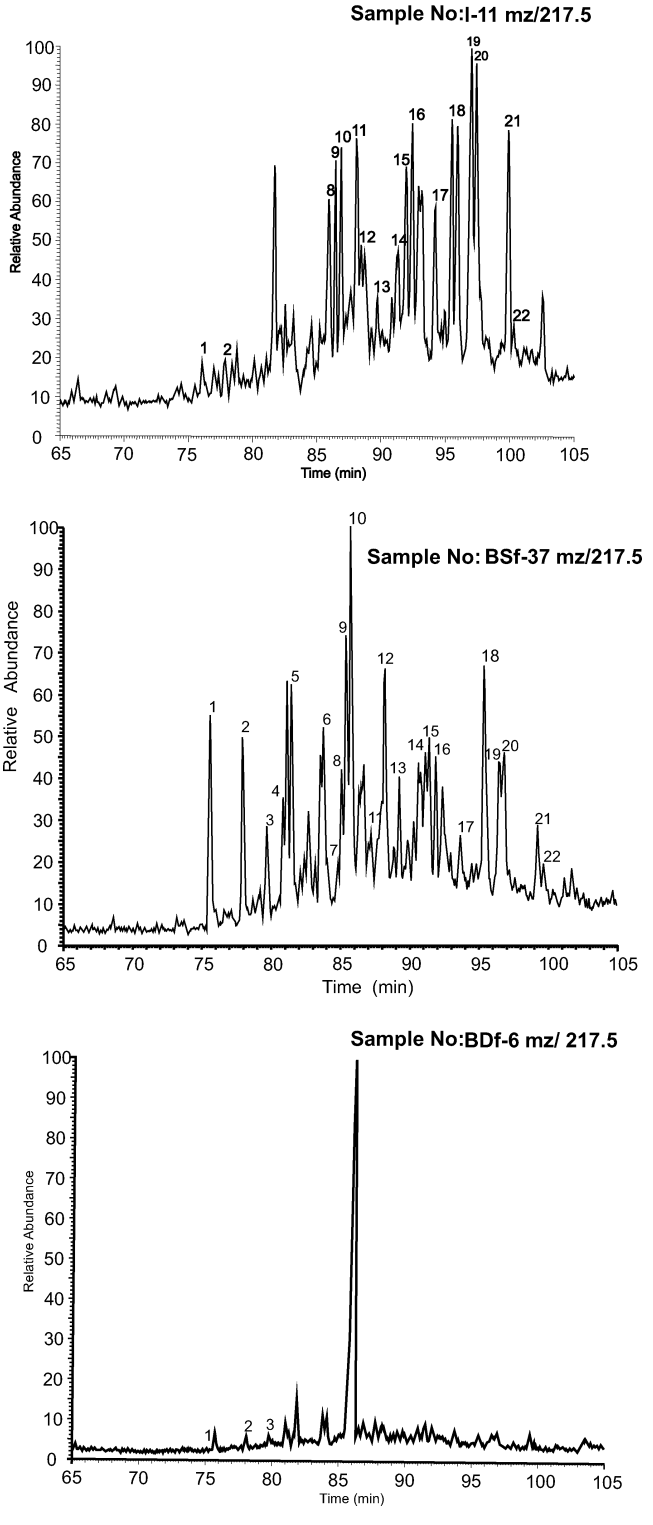

Figure 6. Sterane mass chromatogram (m/z 217) of the rock samples from Miocene units.

environments, assuming a common source for the Pr and Ph (Tissot and Welte 1984; ten Haven *et al.* 1987). The Pr/Ph ratio indicates the immaturity of organic matter. The T_s/T_m (C2718 α (H)-22,29,30 Trinorneohopane/C27 17α (H)-22,29,30 Trisnorhopane) ratio of the investigated units is 0.7 and indicates the immaturity of the organic matter (Figure 5 and Table 4). The terpane C29 NH / C30 H ratio is >1 for the Karabayır Formation; this value indicates a carbonate lithology. On the other hand, the C29NH/C30H ratio is <1 for the Karakuştepe Formation; this indicates that the hydrocarbons were derived from terrestrial organic matter. The abundance of sterane C29>C28>C27 shows that the kerogens were formed from algal/terrestrial organic matter. According to m/z 191 mass fragmentograms, the Miocene units contain oleanane, indicating that they were derived from terrestrial organic matter (Figure 6 and Table 5). Oleanane is a marker for angiosperm input (flowering higher plants), and the flowering plants only appeared toward the end of the Cretaceous and/or in the Early Tertiary.

Conclusions

Based on biomarker characteristics of the Karabayır Formation samples, the carbonate rocks were deposited in an oxidizing environment and their organic-matter types were mainly amorphous organic matter. The Karakuştepe Formation is of terrestrial origin. This information should help to constrain the exploration for hydrocarbon resources in the western Taurides of SW Turkey.

Table 5. List of identified biomarkers for the steranes.

Peak	Sterane idendification
1	C27 13β(H), 17α(H)-Diasterane (20S)
2	C27 13β(H), 17α(H)-Diasterane (20R)
3	C27 13α(H), 17β(H)-Diasterane (20S)
4	C27 13α(H), 17β(H)-Diasterane (20R)
5	C28 13β(H), 17α(H)-Diasterane (20S)
6	C28 13β(H), 17α(H)-Diasterane (20R)
7	C28 13α(H), 17β(H)-Diasterane (20S)
8	C27 5α(H), 14α(H), 17α(H)-Sterane (20S) + C28 13α(H), 17β(H)- Diasterane (20S)
9	C27 5α(H), 14β(H), 17β(H)-Sterane (20R) + C29 13β(H), 17α(H)- Diasterane (20S)
10	C27 5α(H), 14β(H), 17β(H)-Sterane (20S) + C28 13α(H), 17β(H)-Diasterane (20S)
11	C27 5α(H), 14α(H), 17α(H)-Sterane (20R)
12	C29 13β(H), 17α(H)-Diasterane (20R)
13	C29 13α(H), 17β(H)-Diasterane (20S)
14	C28 5α(H), 14α(H), 17α(H)-Sterane (20S)
15	C28 5α(H), 14β(H), 17β(H)-Sterane (20R) + C29 13α(H), 17β(H)-Diasterane (20R)
16	C28 5α(H), 14β(H), 17β(H)-Sterane (20S)
17	C28 5α(H), 14α(H), 17α(H)-Sterane (20R)
18	C29 5α(H), 14α(H), 17α(H)-Sterane (20S)
19	C29 5α(H), 14β(H), 17β(H)-Sterane (20R)
20	C29 5α(H), 14β(H), 17β(H)-Sterane (20S)
21	C29 5α(H), 14α(H), 17α(H)-Sterane (20R)
22	C30 5α(H), 14α(H), 17α(H)-Sterane (20S)
23	C30 5α(H), 14β(H), 17β(H)-Sterane (20R)
24	C30 5α(H), 14β(H), 17β(H)-Sterane (20S)
25	C30 5α(H), 14α(H), 17α(H)-Sterane (20R)

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