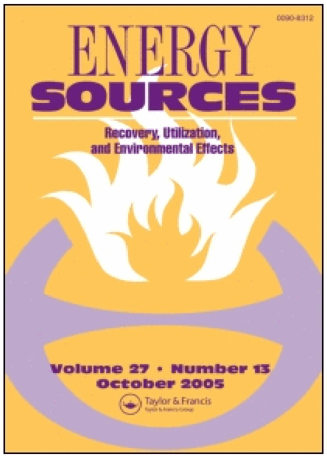

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Source Rock Characteristics and Hydrocarbon Potential of the Late Cretaceous Deposits in the Eastern Black Sea Region, NE Turkey

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Abstract *In this article, source rock characteristics and hydrocarbon potential of the late Cretaceous turbidite sequences in the eastern Black Sea region were investigated. The total average organic carbon (TOC) contents of sequences in Trabzon, Gümüshane, Giresun, and Erzurum are 0.06, 0.18, 0.12, and 0.30 wt%, respectively. In addition, low potential yield (PY), low hydrogen index (HI), and very high oxygen index (OI) values were calculated for these sequences. On the basis of T_{max} values, most of sequences are thermally immature, and only some parts are mature and overmature. Sequences generally contain residual organic matter and lesser amounts of type III kerogen. CPI values higher than 1, n-alkane distributions with high carbon numbers, and type III kerogen content indicate that organic matter has a terrestrial origin. The Pr/Ph ratios calculated as 1.10 and 2.15 for the Mescitli section of the Gümüshane region and the Tortum section of the Erzurum region reveal that the Mescitli section was deposited in a suboxic environment, while the Tortum section was in an oxic environment. According to these data, late Cretaceous sequences show weak source rock characteristics.*

Keywords GC, late Cretaceous, maturity, oil generation, source rock, TOC

Introduction

Late Cretaceous clastic deposits are widely exposed in Gümüshane, Alucra (Giresun), Tortum (Erzurum), and Trabzon in the eastern Black Sea region. They are composed of mainly sandstone, claystone, and marl alternations and have a thickness of 96–750 m. In this study, 14 different stratigraphic sections of the sequences were measured and systematic samples were collected. Stratigraphic sections were studied in Dagbasi and Hacimehmet (Trabzon), Mescitli, Yaglidere, Musalla, Pirahmet, Balkaya, Kale, Kelkit, Telme, Inözü (Gümüshane), Evliyatepesi and Camliyayla (Giresun-Alucra), and Caglayan (Erzurum-Tortum) areas (Figure 1). Total organic carbon (TOC) content, pyrolysis (Rock-Eval), and gas chromatography (GC) analyses were conducted on the selected marl samples. The analyses were carried out at the Canada Geological Survey Organic Geochemistry Laboratories. TOC and pyrolysis analyses were conducted with Rock-Eval

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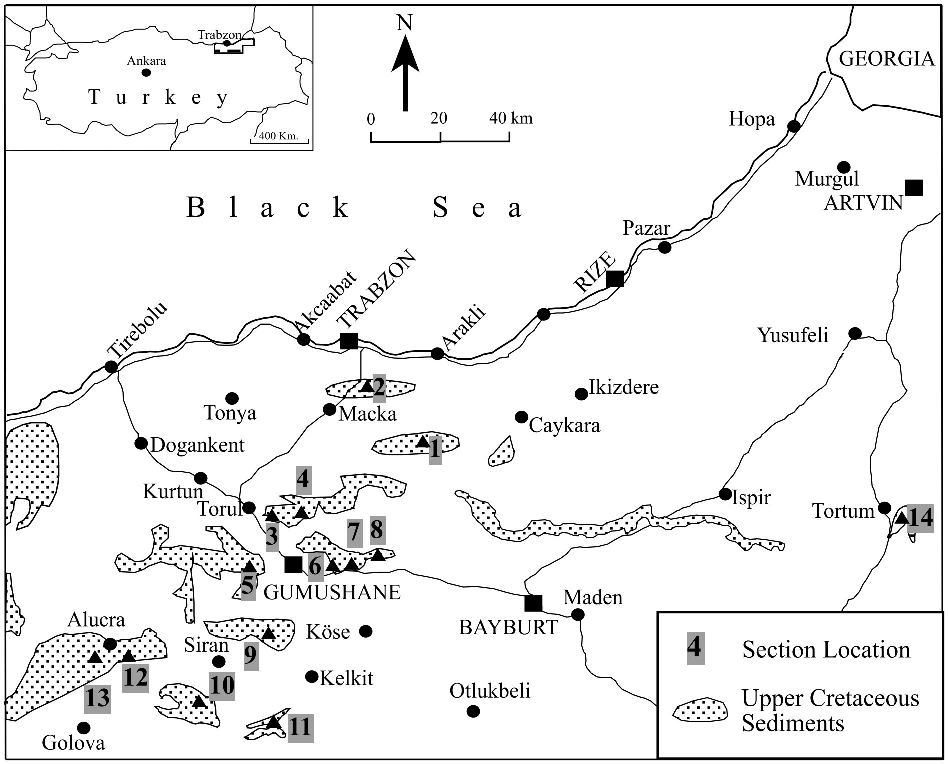

Figure 1. Location map of sections and distribution of Late Cretaceous sediments.

6/TOC Turbo model device and GC analyses were made with Varian 3800 FID and HP 5980.

Geological Setting

The northern part of Turkey was described as a Pontide tectonic unit by Ketin (1966), which was subsequently divided as western and eastern Pontide by Şengör and Yilmaz (1981). Many geological studies for various reasons have been conducted in the eastern Pontide. In addition, Korkmaz et al. (1995), Gedik et al. (1996), Okay and Sahintürk (1997), and Güven (1998) studied the general stratigraphic features of the Pontides. The main geological properties of eastern Pontide are briefly described below.

The basement rocks of the eastern Pontide consist of metamorphic rocks and granitoids intruding the metamorphic rocks. Liassic volcanics, volcaniclastic, and clastic deposits rest disconformably on this basement rocks. This unit is overlain by pelagic and neritic carbonates of Malm-Lower Cretaceous age. The very thick units of Upper Cretaceous age lie disconformably over the carbonates. The Upper Cretaceous, largely represented by volcanics in the north, has developed into a turbiditic facies in the south. Miocene and Pliocene deposits occur in restricted areas and are characterized by clastic material. The thickness of the Late Cretaceous clastic sequence in the region was measured as 170 m at Dagbasi, 96 m at Hacimehmet, 304 m at Mescitli, 342 m at Yaglidere, 210 m at Musalla, 288 m at Pirahmet, 266 m at Balkaya, 180 m at Kale, 135 m at Telme, 233 m at Inözü, 150 m at Kelkit, 315 m at Camliyayla, 400 m at

Evliyatepesi, and 750 m at Tortum. These sequences are composed mainly of sandstone, marl, and shale alternation and partly contain limestone, conglomerate, and tuffaceous levels. Moreover, some sedimentation structures are also observed such as exfoliation, parallel and convolute lamination, grading, load and flute casts.

Organic Geochemistry

Amount of Organic Matter

Total organic carbon analysis is conducted to determine the organic matter content in a rock, and it gives information on the abundance of organic matter. The organic carbon content in a rock is the sum of organic carbon in association with free hydrocarbons and kerogen in that rock (Tissot and Welte, 1984; Barker, 1986; Jarvie, 1991; Hunt, 1995). In source rock classifications, rocks with less than 0.50 wt% organic matter are described as the weak source rock (Welte, 1965; Momper, 1978; Kraus and Parker, 1979).

Marl and shale samples selected from the Late Cretaceous clastic sequence were analyzed for their total organic carbon (TOC) contents and results are shown in Table 1. In this respect, the average total organic carbon content of the units is 0.05 wt% at the Dagbasi section and 0.1 wt% at the Hacimehmet section in the Trabzon region. The average TOC values of the Mescitli, Yaglidere, Musalla, Pirahmet, Baklaya, Kale, Telme, Inözü, and Kekit sections in the Gümüshane region are found as 0.30, 0.16, 0.20, 0.21, 0.18, 0.25, 0.22, 0.33, and 0.04 wt%, respectively. The average total organic carbon contents at the Camliyayla and Evliyatepesi sections in the Giresun region are 0.14 and 0.11 wt%; TOC value of the Tortum section in the Erzurum region is 0.30 wt%.

Rock-Eval Pyrolysis

Results of pyrolysis analyses provide information on the type, maturity, and hydrocarbon potential of the organic matter in the rock (Tissot and Welte, 1984; Espitalie et al., 1985; Peters et al., 1986; Bordenave et al., 1993; Hunt, 1995).

In the pyrolysis analysis, the temperature (T_{max}) is measured at which free hydrocarbons (S_1) and hydrocarbons (S_2, CO_2, S_3) released as a result of thermal disintegration of kerogen in a rock are attained maximum values. Using these values, HI, OI, PY, PI parameters are calculated (Espitalie et al., 1977; Tissot and Welte, 1984).

In this study, pyrolysis analyses of a total of 98 marl and shale samples were carried out (6 from the Dagbasi section and 5 from the Hacimehmet section in the Trabzon region; 10 from the Mescitli section, 11 from the Yaglidere section, 10 from the Musalla section, 6 from the Pirahmet section, 9 from the Balkaya section, 10 from the Kale section, 2 from the Telme section, 4 from the Inözü section, and 7 from the Kelkit section in the Gümüshane region; 3 from the Camliyayla section, and 7 from the Evliyatepesi section in the Giresun region; and 8 from the Tortum section in the Erzurum region) (Table 1).

S_1 values of the Dagbasi and Hacimehmet section in the Trabzon region are very low, and, except for one sample from the Dagbasi sequence, S_2 values of all other samples are zero. Potential yield values are very low for all the samples. In general, HI values are zero and OI values are very high. T_{max} value for a sample from the Dagbasi sequence was measured as 379°C, but no measurement was made for other samples.

S_1 and S_2 values of sections in the Gümüshane region are generally low. Potential yield (PY) values and HI values of these sequences are very low, while OI values are found as very high. T_{max} values of the Yaglidere, Musalla, Telme, and Inözü sequences

Table 1
Results of Rock—Eval/TOC analysis and calculated parameters

Field name	Sample no.	TOC, % wt	S_1 mgHC/g rock	S_2 mgHC/g rock	S_3 mgCO$_2$/g rock	PY ($S_1 + S_2$) mgHC/g rock	T_{max}, °C	HI (S_2/TOC)*100 mgHC/g TOC	OI (S_3/TOC)*100 mgCO$_2$/g TOC
Dagbasi (Trabzon)	D–2	0.05	0.01	0.00	0.30	0.01	—	0	600
	D–6	0.06	0.03	0.04	0.17	0.07	379	67	283
	D–24	0.08	0.01	0.00	0.60	0.01	—	0	750
	D–25	0.05	0.01	0.00	0.48	0.01	—	0	960
	D–30	0.03	0.01	0.00	0.28	0.01	—	0	933
	D–31	0.01	0.01	0.00	0.19	0.01	—	0	1,900
	Mean	**0.05**	**0.02**	**—**	**0.34**	**0.02**	**—**	**—**	**904**
Hacimehmet (Trabzon)	H–5	0.02	0.00	0.00	0.29	0.00	—	0	1,450
	H–11	0.00	0.00	0.00	0.33	0.00	—	0	0
	H–14	0.18	0.01	0.00	0.27	0.01	—	0	150
	H–15	0.13	0.01	0.00	0.17	0.01	—	0	131
	H–17	0.03	0.02	0.00	0.37	0.02	—	0	1,233
	Mean	**0.10**	**0.02**	**—**	**0.29**	**0.02**	**—**	**—**	**741**
Mescitli (Gumushane)	M–2	0.24	0.00	0.00	0.59	0.00	—	0	246
	M–4	0.20	0.00	0.00	0.48	0.00	—	0	240
	M–6	0.21	0.00	0.00	0.49	0.00	—	0	233
	M–8	0.42	0.02	0.03	0.27	0.05	492	7	64
	M–11	0.20	0.00	0.00	0.38	0.00	—	0	190
	M–19	0.32	0.00	0.00	0.22	0.00	—	0	69
	M–20	0.36	0.02	0.02	0.16	0.04	471	6	44
	M–23	0.29	0.02	0.00	0.14	0.02	—	0	48
	M–28	0.32	0.05	0.09	0.18	0.14	498	28	56
	M–40	0.37	0.02	0.00	0.39	0.02	—	0	105
	Ort.	**0.30**	**0.03**	**0.03**	**0.36**	**0.05**	**487**	**14**	**130**
Yaglıdere (Gumushane)	Y–2	0.13	0.02	0.00	0.34	0.02	—	0	262
	Y–3	0.09	0.01	0.00	0.33	0.01	—	0	367
	Y–4	0.10	0.00	0.00	0.31	0.00	—	0	310
	Y–20	0.03	0.00	0.00	0.32	0.00	—	0	1,067
	Y–30	0.16	0.01	0.00	0.34	0.01	—	0	213
	Y–32	0.19	0.01	0.00	0.33	0.01	—	0	174
	Y–35	0.20	0.02	0.00	0.33	0.02	—	0	165
	Y–44	0.20	0.01	0.00	0.40	0.01	—	0	200
	Y–46	0.18	0.00	0.00	0.16	0.00	—	0	89
	Y–50	0.24	0.00	0.00	0.35	0.00	—	0	146
	Y–54	0.27	0.00	0.00	0.56	0.00	—	0	207
	Mean	**0.16**	**0.01**	**0.00**	**0.34**	**0.01**	**—**	**0**	**291**
Musalla (Gumushane)	N–3	0.03	0.01	0.00	0.58	0.01	—	0	1,933
	N–7	0.02	0.01	0.00	0.70	0.01	—	0	3,500
	N–10	0.02	0.01	0.00	0.34	0.01	—	0	1,700
	N–15	0.16	0.01	0.00	0.33	0.01	—	0	206
	N–18	0.20	0.02	0.00	0.31	0.02	—	0	155
	N–20	0.14	0.00	0.00	0.68	0.00	—	0	486
	N–21	0.08	0.00	0.00	0.39	0.00	—	0	161
	N–28	0.18	0.01	0.00	0.29	0.01	—	0	126
	N–35	0.23	0.01	0.00	0.29	0.01	—	0	116
	N–42	0.25	0.01	0.00	0.29	0.01	—	0	116
	Mean	**0.20**	**0.01**	**0.00**	**0.42**	**0.01**	**—**	**0**	**850**
Pirahmet (Gumushane)	P–11	0.20	0.01	0.00	0.68	0.01	—	0	340
	P–13	0.22	0.00	0.00	0.72	0.00	—	0	327
	P–18	0.18	0.00	0.00	0.73	0.00	—	0	406
	P–20	0.20	0.03	0.05	0.89	0.08	333	25	445
	P–23	0.23	0.03	0.03	0.40	0.06	340	13	174
	P–24	0.25	0.01	0.01	0.62	0.02	435	0	248
	Mean	**0.21**	**0.02**	**0.03**	**0.6**	**0.04**	**369**	**19**	**282**
Balkaya (Gumushane)	B–1	0.14	0.05	0.15	0.77	0.20	360	107	550
	B–3	0.08	0.01	0.00	0.45	0.01	—	0	563
	B–6	0.32	0.03	0.24	1.01	0.27	350	75	316
	B–12	0.26	0.04	0.17	0.74	0.21	401	65	285
	B–15	0.18	0.01	0.00	0.50	0.10	—	0	278
	B–17	0.11	0.03	0.00	0.41	0.03	—	0	373
	B–21	0.16	0.01	0.00	0.69	0.01	—	0	431
	B–22	0.16	0.01	0.00	0.72	0.01	—	0	450
	B–23	0.23	0.01	0.00	0.73	0.01	—	0	317
	Mean	**0.18**	**0.02**	**0.19**	**0.66**	**0.10**	**370**	**82**	**396**

(*continued*)

Table 1
(*Continued*)

Field name	Sample no.	TOC, % wt	S_1 mgHC/g rock	S_2 mgHC/g rock	S_3 mgCO$_2$/g rock	PY ($S_1 + S_2$) mgHC/g rock	T_{max}, °C	HI (S_2/TOC)*100 mgHC/g TOC	OI (S_3/TOC)*100 mgCO$_2$/g TOC
Kale	K–1	0.14	0.02	0.00	0.38	0.02	—	0	271
(Gumushane)	K–3	0.19	0.01	0.00	0.40	0.01	—	0	211
	K–15	0.12	0.01	0.00	0.54	0.01	—	0	450
	K–20	0.19	0.00	0.00	0.54	0.00	—	0	284
	K–22	0.17	0.00	0.00	0.56	0.00	—	0	329
	K–29	0.29	0.00	0.00	0.81	0.00	—	0	279
	K–30	0.41	0.00	0.04	0.50	0.04	—	10	122
	K–31	0.43	0.00	0.04	0.52	0.04	452	9	121
	K–34	0.42	0.00	0.02	0.61	0.02	456	5	145
	K–43	0.18	0.01	0.00	0.63	0.01	—	0	350
	Mean	**0.25**	**0.01**	**0.03**	**0.55**	**0.02**	**454**	**8**	**256**
Telme	T–12	0.18	0.00	0.00	0.66	0.00	—	0	367
(Gumushane)	T–15	0.25	0.00	0.00	0.95	0.00	—	0	380
	Mean	**0.22**	**0.00**	**0.00**	**0.36**	**0.00**	**—**	**0**	**374**
Inozu	İ–8	0.26	0.02	0.00	0.30	0.02	—	0	115
(Gumushane)	İ–12	0.11	0.01	0.00	0.41	0.01	—	0	373
	İ–14	0.09	0.02	0.00	0.29	0.02	—	0	322
	İ–23	0.05	0.05	0.00	0.26	0.05	—	0	520
	Mean	**0.33**	**0.03**	**0.00**	**0.32**	**0.03**	**—**	**0**	**333**
Kelkit	E–10	0.09	0.05	0.04	0.75	0.09	357	44	833
(Gumushane)	E–12	0.03	0.01	0.00	0.35	0.01	—	0	1,167
	E–14	0.03	0.07	0.02	0.25	0.09	345	67	833
	E–16	0.01	0.02	0.06	0.73	0.08	388	0	730
	E–23	0.01	0.01	0.00	0.17	0.01	—	0	1,700
	E–25	0.01	0.01	0.00	0.19	0.01	—	0	1,900
	E–30	0.05	0.04	0.00	0.46	0.04	—	0	920
	Mean	**0.04**	**0.03**	**0.04**	**0.35**	**0.05**	**367**	**56**	**1,155**
Camliyayla	Ç–20	0.10	0.01	0.00	0.58	0.01	—	0	580
(Giresun)	Ç–21	0.18	0.02	0.00	0.71	0.02	—	0	394
	Ç–22	0.14	0.01	0.02	0.75	0.03	327	14	536
	Mean	**0.14**	**0.01**	**—**	**0.68**	**0.02**	**—**	**—**	**503**
Evliyatepesi	A–6	0.07	0.01	0.01	0.66	0.02	351	14	945
(Giresun)	A–7	0.07	0.03	0.02	0.50	0.05	380	29	714
	A–8	0.07	0.02	0.00	0.33	0.02	—	0	471
	A–9	0.08	0.01	0.00	0.50	0.01	—	0	625
	A–15	0.06	0.01	0.00	0.41	0.01	—	0	683
	A–23	0.26	0.01	0.05	0.50	0.06	438	19	192
	A–39	0.12	0.01	0.00	0.57	0.01	—	0	475
	Mean	**0.11**	**0.02**	**0.03**	**0.50**	**0.03**	**390**	**21**	**586**
Tortum	TO–3	0.49	0.01	0.09	0.61	0.10	451	18	124
(Erzurum)	TO–5	0.27	0.01	0.01	0.47	0.02	459	4	174
	TO–6	0.24	0.01	0.10	0.36	0.11	459	42	150
	TO–7	0.41	0.00	0.07	0.71	0.07	449	17	173
	TO–8	0.53	0.02	0.26	0.79	0.28	454	49	149
	TO–11	0.22	0.02	0.08	0.72	0.10	438	36	327
	TO–27	0.20	0.01	0.00	0.56	0.01	—	0	280
	TO–34	0.03	0.01	0.00	0.33	0.01	—	0	1,100
	Mean	**0.30**	**0.01**	**0.09**	**0.66**	**0.09**	**452**	**28**	**310**

were not measured. The average T_{max} values for the Pirahmet, Balkaya, Kale, and Kelkit sequences were measured as 487°C, 369°C, 370°C, and 367°C, respectively.

S_1 and S_2 values of the Camliyayla and Evliyatepesi sections in the Giresun region are very low, and S_2 values are mostly zero. These sections are represented by very low potential yield (PY) and hydrogen index (HI) values and very high oxygen index (OI) values. The average T_{max} values for the Camliyayla and Evliyatepesi sections were measured as 327°C and 390°C. Samples from the Tortum section in the Erzurum region are characteristic with low S_1 and S_2 potential yield and hydrogen index values and high oxygen index values. The average T_{max} value was found as 452°C.

Molecular Composition

GC analyses were conducted on selected 4 samples (2 samples from the Tortum Section and 2 samples from the Mescitli Section) and n-alkane distribution, and isoprenoids were evaluated on the basis of gas chromatograms (Figure 2).

n-Alkane, Isoalkane and Isoprenoids

In the gas chromatogram of sample M-8 from the Gümüshane-Mescitli section, n-alkanes were recorded in C_{13}–C_{33} range. n-Alkanes in C_{25}–C_{31} range are more dominant with respect to others, and the maximum peak belongs to n-alkane of C_{27} number. Isoprenoid values detected in the gas chromatogram are very low in comparison to n-alkanes. In gas chromatogram of sample M-28 from the same section, n-alkane and only C18 number isoalkane were recorded in the C_{15}–C_{32} range. Values of n-alkanes in the C_{16}, C_{18}, and C_{25}–C_{30} range are more dominant with respect to others, and the maximum peaks belong to C_{25}, C_{26} n-alkanes. In general, gas chromatograms of both samples show a bimodal n-alkane distribution in which high carbon numbers are dominated. In addition, in these gas chromatograms, n-alkanes are dominant over the isoprenoids and comprise the main peaks. The Pr/Ph ratio of the sample M-8 was calculated as 1.10 (Table 2).

CPI (carbon preference index) was calculated from the gas chromatography data using the n-alkanes in the C_{23}–C_{29} (Bray and Evans, 1961) and C_{25}–C_{30} range (Tissot and Welte, 1984; Barker, 1986; Peters and Moldowan, 1993; Marzi et al., 1993). In this respect, CPI values of sample M-8 are 1.08 and 0.998, and those of sample M-28 are found as 1.190 and 1.100, respectively. These CPI values indicate that single carbon number n-alkanes are slightly more abundant than n-alkanes with even carbon numbers.

In the gas chromatogram of sample TO-3 from the Erzurum-Tortum section, n-alkanes and C_{18} isoalkane were recorded in the C_{14}–C_{29} range. The values of C_{24}–C_{25}

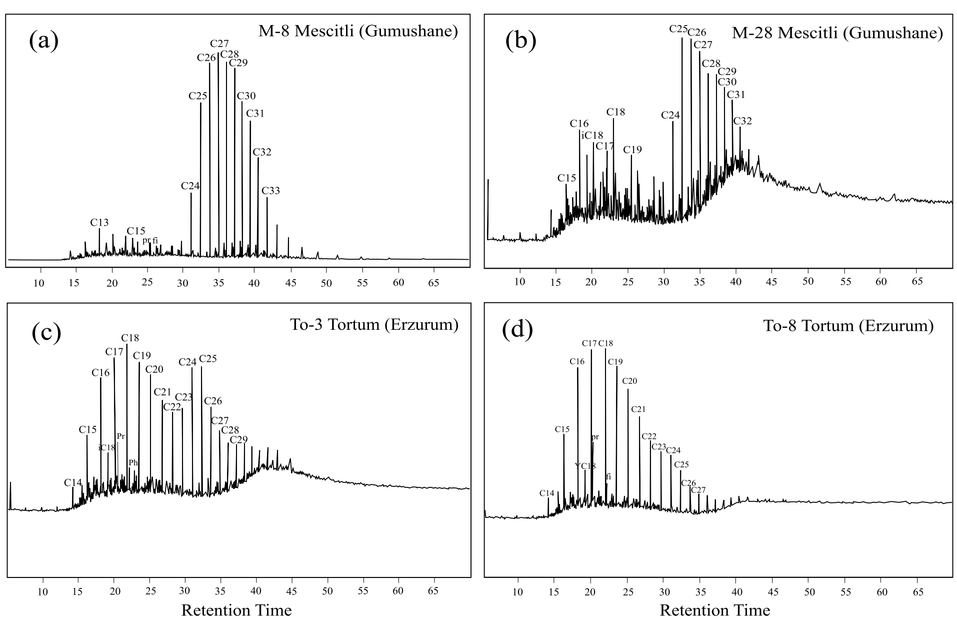

Figure 2. Gas chromatograms of selected samples.

Table 2
CPI, Pr/Ph, isoprenoid/n-alkanes ratios and fractions (%) of selected samples

Sample No.	CPI 1	CPI 2	Pr/Ph	Pr/nC_{17}	Ph/nC_{18}	Saturate, %	Aromatic, %	Asphaltane, %	Resine, %
M-8	1.080	0.998	1.10	0.73	0.62	30.5	15.12	12.0	37.3
M-28	1.190	1.100	—	—	—	17.5	17.50	10.0	47.5
To-3	1.174	1.043	1.78	0.50	0.24	8.0	2.00	19.3	33.5
To-8	1.143	1.024	2.51	0.51	0.20	9.0	9.00	7.7	38.4

numbered n-alkanes in the C_{16}–C_{20} range are more dominant with respect to other n-alkanes, and the maximum peak belongs to nC_{18}. Isoalkane (iC_{18}) and pristane (Pr) values are very close, but the phytane (Ph) value is lower. In the gas chromatogram of sample TO-8, n-alkanes and C_{18} isoalkane were recorded in the C_{14}–C_{27} range. n-Alkanes in the C_{16}–C_{19} range are more dominant with respect to others, and the maximum value belongs to C_{17}, C_{18} n-alkanes. C_{18} isoalkane and phytane values are almost equal but the pristane value is higher. The gas chromatogram of sample TO-3 shows the presence of a bimodal n-alkane distribution in which low carbon numbers are dominated over the high carbon numbers. However, the gas chromatogram of sample TO-8 reveals a unimodal n-alkane distribution, where low carbon numbered n-alkanes are dominant. In both chromatograms, dominant peaks are comprised by n-alkanes.

The Pr/Ph ratio of the samples TO-3 and TO-8 were calculated as 1.78 and 2.51 (Table 2). CPI values of sample TO-3 are found as 1.174 and 1.043, and those of sample TO-8 were determined as 1.143 and 1.024. On the basis of these values, n-alkanes with single carbon number are slightly dominated over the n-alkanes of dual-carbon number.

Type of Organic Matter

Using the pyrolysis results, the type of organic matter in a rock could be determined. Kerogen classification diagrams were constructed using the TOC and Rock-Eval results. In this study, in order to determine kerogen types, diagrams of HI-OI (Espitalie et al., 1977) and HI-T_{max} (Mukhopadhyay et al., 1995) were used. Tmax value changes with the type of organic matter, as well as with maturity of kerogen, and therefore the HI-Tmax diagram can be used for discriminating the kerogen type (Hunt, 1995).

In these diagrams, marl-shale samples from all the sections are plotted in the type III kerogen field (Figure 3). In addition, S_1 and S_2 values were also measured in the samples. In this respect, samples mainly contain residual organic matter with no hydrocarbon generation capacity.

The bimodal distributions with high n-alkanes in the samples from the Mescitli (Gümüshane) sequence are originated from terrestrial organic material input. Dominancy of low carbon numbered n-alkanes in samples from the Tortum (Erzurum) section may indicate the presence of algal (marine) organic material input. In addition, CPI $>$ 1 in samples from both sections may also show terrestrial material input to the depositional environment (Tissot et al., 1987).

In general, samples from all the fields mostly contain type III kerogen and predominantly residual organic carbon. Little amount of algal organic material was only found in the Tortum section.

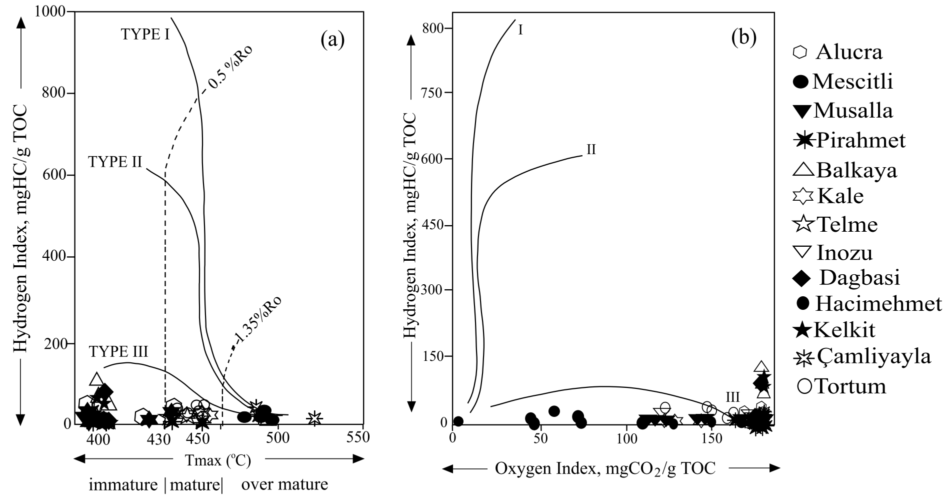

Figure 3. Distribution of samples into (a) HI vs. T_{max} and (b) HI vs OI plots.

Maturity of Organic Matter

Maturity of organic matter is described as a process starting from its deposition in a sedimentary basin and then its physicochemical transformation under various agents such as temperature, pressure, burial, and time, ending with production of hydrocarbons. Thermal development of an organic matter changes various physical and chemical properties, and using these characteristics, maturity of organic matter can be measured (Tissot and Welte, 1984; Hunt, 1995).

T_{max} measured in pyrolysis analyses is closely related to thermal development of an organic matter (Tissot and Welte, 1984; Waples, 1985). The T_{max} value of only one sample from the Trabzon region was measured (379°C). On the basis of this value, sequence is in immature character. The T_{max} values of the Pirahmet, Balkaya and Kelkit sequences in the Gümüshane region are calculated as 369°C, 370°C, and 367°C, and these values are indicative of an immature source rock. T_{max} values of the Mescitli and Kale sequences are found as 487°C and 454°C. According to these values, the Mescitli sequence is over-mature and the Kale sequence is in mature character. In the Mescitli samples, CPI values are very close to one and they support over-mature character. Since S_2 was not recorded, T_{max} values could not be measured for the Yaglidere, Musalla, Telme, and Inözü sections in the Gümüshane region. The average T_{max} values of the Camliyayla and Evliyatepesi sections in the Giresun region are 327°C and 390°C, and these values indicate that sequence is immature.

The average T_{max} value of the Tortum sequence in the Erzurum region was computed as 452°C which indicates a mature character. In addition, CPI values of this section are very close to one, also supporting the mature character.

The Pr/nC_{18} and Ph/nC_{17} ratios of sample M-8 from the Mescitli section 0.73 and 0.62 and those of samples TO-3 and TO-8 from the Tortum section are computed as 0.50–0.24 and 0.51–0.20, respectively. Low isoprenoid/n-alkane values may indicate that Tortum and Mescitli sections are thermally mature (Peters et al., 2000).

Hydrocarbon Potential

The potential yield parameter is the sum of free hydrocarbons in the rock (S_1) and the amount of organic material that can be transformed to the hydrocarbons (S_2) by pyrolysis. Therefore, it can give information on the total amount of hydrocarbons that could be derived from a mature rock and can be used for the evaluation of hydrocarbon potential of a source rock (Tissot and Welte, 1984; Demaison and Huizinga, 1994; Ritts et al., 1999).

The average potential yield values of the Dagbasi and Hacimehmet sequences in the Trabzon region are 0.02 and 0.02 mg HC/g rock. Those of the Mescitli, Yaglidere, Musalla, Pirahmet, Balkaya, Kale, Telme, Inözü, and Kelkit sequences in the Gümüshane region are 0.05, 0.01, 0.01, 0.04, 0.10, 0.02, 0.03, and 0.05 mg HC/g rock. Those of the Camliyayla and Evliyatepesi sequences in the Giresun region are 0.02 and 0.03 mg HC/g rock, and the Tortum sequence in the Erzurum region is calculated as 0.09 mg HC/g rock. The potential yield values of sequences in different regions are very low, and this may indicate that these sequences have no hydrocarbon generation potential. This is also supported with abundant residual organic material, lesser amount of Type III kerogen content, and very low hydrocarbon index values determined in these sequences. Therefore, it is concluded that these sequences have no hydrocarbon potential.

Conclusions

The average total organic carbon (TOC) contents for the Trabzon, Gümüshane, Giresun, and Erzurum regions are calculated as 0.06, 0.18, 0.12, and 0.30 wt%, respectively. In addition, low potential yield, low hydrogen index, and very high oxygen index values were obtained. On the basis of these values, the late Cretaceous sequences are in weak source rock character. All the sequences contain abundant residual organic matter and lesser amount of Type III kerogen. Type III kerogen is indicative of terrestrial organic matter input, which is also supported by the n-alkane distribution for the Mescitli sequence. n-Alkane distribution for the Tortum sequence indicates that this sequence is composed of residual organic matter, Type III kerogen, and a lesser amount of algal (marine) organic matter. In addition, CPI values higher than 1 for the Mescitli and Tortum sequences also support the terrestrial organic matter input. The Trabzon-Dagbasi sequence, the Pirahmet, Balkaya, and Kelkit sequences in the Gümüşhane region, and Camliyayla and Evliyatepesi sequences in the Giresun region have low T_{max} values and they are immature. The Kale (Gümüshane) and Tortum (Erzurum) sequences are mature, and Mescitli (Gümüshane) sequence is over-mature. Since T_{max} values were not measured for the Trabzon-Hacimehmet and the Yaglidere, Musalla, Telme, and Inözü sequences in the Gümüshane region, their maturity could not be determined.

The Pr/Ph ratio of the Mescitli section from the Gümüshane region is 1.10, and the average of Pr/Ph ratios of the Tortum section from the Erzurum region is computed as 2.15. According to these values, the late Cretaceous basin of the eastern Black Sea region indicates a suboxic-oxic depositional environment.

According to results of organic geochemical analyses, the late Cretaceous sequences in the eastern Black Sea region are generally in similar character and have no hydrocarbon generation potential.

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