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Estimation of oil in-place resources in the lower Oligocene Mezardere Shale, Thrace Basin, Turkey

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ABSTRACT

Tertiary Thrace Basin of northwestern Turkey contains Early/Middle Eocene through Pleistocene age sediments the thickness of which reaches up to 9000 m in its depocenter. In this time interval, the Mezardere Formation was deposited in the Early Oligocene (36 m.y.) through Middle Oligocene (30 m.y.). Mezardere Formation is characterized by thick marine-prodelta organic rich shales, marls and sandstones. Present and previous research results showed that the Mezardere Shale contains marine Type II+III kerogen (HI=3–744 mg HC/g TOC) and sufficient organic richness (TOC=0.08–3.39 wt%) and has favorable thermal maturity (%VRm=0.35–1.20) in order to generate oil, condensate as well as wet-gas. Furthermore, discoveries of conventional oil, condensate and wet-gas and correlation of these fluids with the Mezardere Shale gives us a confidence that Mezardere Shale may retain hydrocarbon fluids and could be a significant shale-oil play in the Thrace Basin. Hence, the aim of this study is to estimate oil in-place (OIP) resource volume in the Mezardere Shale. For this purpose, available Rock-Eval data acquired from 407 Mezardere Shale cuttings and core samples from 47 wells are studied and evaluated.

Five out of 47 wells show relatively continuous “Oil Saturation Index, (OSI=*S*1/TOC*100”) values. It is crucial to note that measured *S*1 and therefore OSI values are corrected against the evaporation loss. Corrections are made for 35, 40, and 45 API oils which are assumed to be present in the Mezardere Shale as retained oil. OIP resource estimations are conducted for the five wells as well as for the determined core area (e.g., 1000 km^2 in the northwestern Thrace Basin). An average Mean Swanson's value of OIP's of the five wells is estimated to be approximately 405 M bbl. The core area shows an average Mean Swanson's value of OIP as 325 MM bbl.

1. Introduction

Thrace Basin is located in northwestern Turkey and covers over 22,238 km^2 (Fig. 1a and b). Since the beginning of exploration in 1934, approximately 660 conventional oil and gas wells have been drilled in the basin resulting in the discovery of several gas fields and four oil fields. Consequently, the Thrace Basin is the second largest oil and gas producing province in Turkey where the discovered oil, condensate and wet-gas up to present are all conventional. In nature “such as oil and natural gas comes from both ‘conventional (easier to produce) and ‘unconventional’ (difficult to produce) formations. The key difference between the ‘conventional’ and ‘unconventional’ oil and natural gas is the manner, ease and cost associated with extracting the resource. Origin and composition of these hydrocarbons as well as the degree of contribution of the Mezardere Shale as a hydrocarbon generating source rock into these fields have been studied (Gürgey et al., 1993, 2001, 2005; Gürgey, 1999, 2009; Hoşgörmez and Yalçın, 2005; Hoşgörmez et al., 2005. It was realized that the Lower Oligocene Mezardere Shale is currently an active source rock and the second to Hamitabat shale in importance

Geochemical isotopic correlation study completed by Gürgey et al. (2005) revealed that the Mezardere Shale functions as a source of conventional Gelindere oil and Hayrabolu condensate in the Hayrabolu field, in addition to wet gas–condensates in the Umurca, Değirmenköy and Karaçalı fields (Fig. 2). These are all currently producing fields from the reservoirs placing on the top of Mezardere Shale (Fig. 1c). The isotopic study by Gürgey et al. (2005) brought out that the Mezardere Shale is capable of generating multiple phases of hydrocarbons; such as conventional oil, condensate and wet gas. Based on those findings, it is plausible that the Mezardere Shale could be a significant unconventional oil and gas resource.

Organic geochemistry (i.e., Rock-Eval *S*1 and TOC) has been

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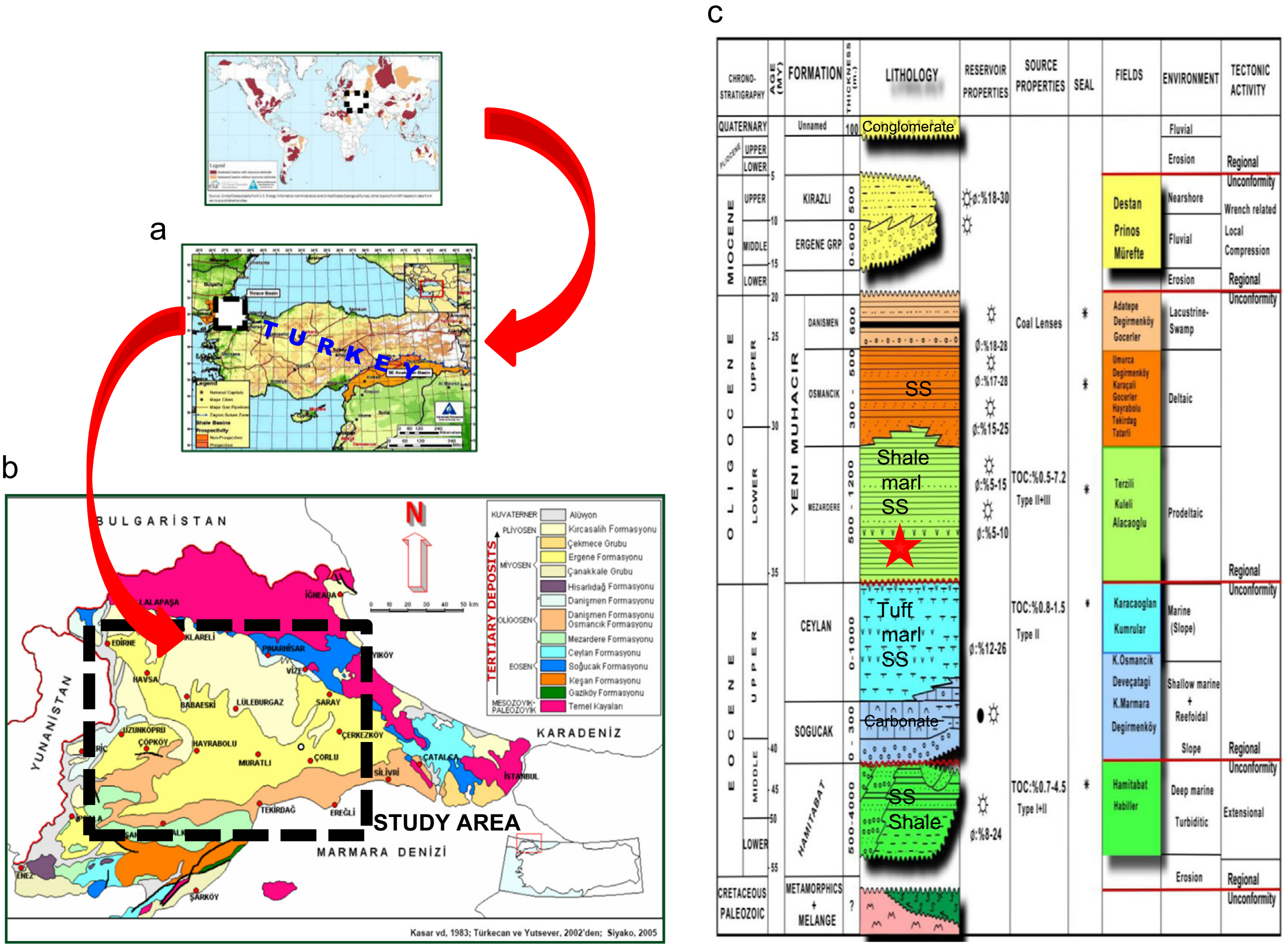

Fig. 1. Location (a) geological map (b) and generalized stratigraphic columnar section of the Thrace Basin (c).

successfully applied to potential unconventional shale-oil and shale gas formations around the world particularly in North America (BGS, 2014; Jarvie, 2012a,b,c; Jarvie et al., 2010; USEIA/ARI, 2011, 2013, USEIA/ARI=U.S. Energy Information Administration/Advanced Resource International; Jarvie et al. 2007). Among these, Jarvie (2012b) used Rock-Eval data and reported that Oil Saturation Index (OSI) is a useful parameter to indicate movable oil potential by a simple geochemical ratio that normalizes oil content to total organic carbon (TOC) referred to as the OSI. The OSI is simply an oil crossover effect described as when petroleum content exceeds more than 100 mg Oil/g TOC. Some examples of this kinds are the Late Cretaceous Eagle Ford shale, Texas (Technically Recoverable Resource=TRR =3.35 B bbl); Permian Avalon and Bone Springs, New Mexico (TRR=1.58 B bbl); Devonian Bakken Formation, Williston Basin (TRR=3.59 B bbl); Miocene Monterey Shale, Santa Maria Basin, California (TRR=15.42 B bbl). Total technically recoverable resource of these fields is about 23.94 B bbl (USEIA/ARI, 2011).

In comparison, the unconventional hydrocarbon resource potential of the Thrace Basin did not receive the warranted attention and analysis. There have been only two reports which have published by USEIA/ARI, in 2011 and 2013. The former report pointed out that the Mezardere Shale has 785 km^2 shale-gas prospective areas with average net organically rich thickness of 90 m, TOC of 2.5 wt% and thermal maturity of 1.10% Ro. This report claimed that Mezardere Shale contains 200 B m^3 (Billion m^3) of risked gas-in-place (GIP) and 56 B m^3 of technically recoverable gas (USEIA/ARI, 2011). The latter report (USEIA/ARI, 2013), contradicted the first report concluded that because of its low organic content ($<$2%), Mezardere Shale does not have either unconventional shale-oil or unconventional shale-gas potential. Therefore, they did not assess Mezardere Shale and its hydrocarbon resources quantitatively.

Given the importance of the parameters used in this study it is worth here defining Rock Eval $S1$, $S2$, TOC and $S1_{CF}$:

$S1$=Free movable retaine oil in the rock in mg HC/g Rock,
$S2$=Solid organic matter (kerogen) it may also contain absorbed hydrocarbons,
TOC=It consists of hydrocarbon generative, hydrocarbon non-generative organic matter and extractable hydrocarbons in wt%,
$S1_{CF}$ (CF=correction factor)=It is a corrected $S1$ against evaporative loss.

Most importantly, Turkey has a little domestic oil production and therefore relies heavily on imports. According to USEIA sources, Turkish daily oil production in April 2014 is 58.14 M bbl/day (thousand barrels/day), consumption is 676.39 M bbl and remaining proved reserves is 0.29 B bbl (billion barrels) (USEIA, 2014). Shortly, Turkey needs immediate hydrocarbon supply from its own sources. The aim of this study is three folds: (1) to review Mezardere Formation related geochemistry and combined it with the newly generated data of this study, (2) to examine the oil potential of Lower Oligocene Mezardere Shale in the wells and lastly, and (3) to estimate OIP resource volume of the Mezardere Shale in the core area.

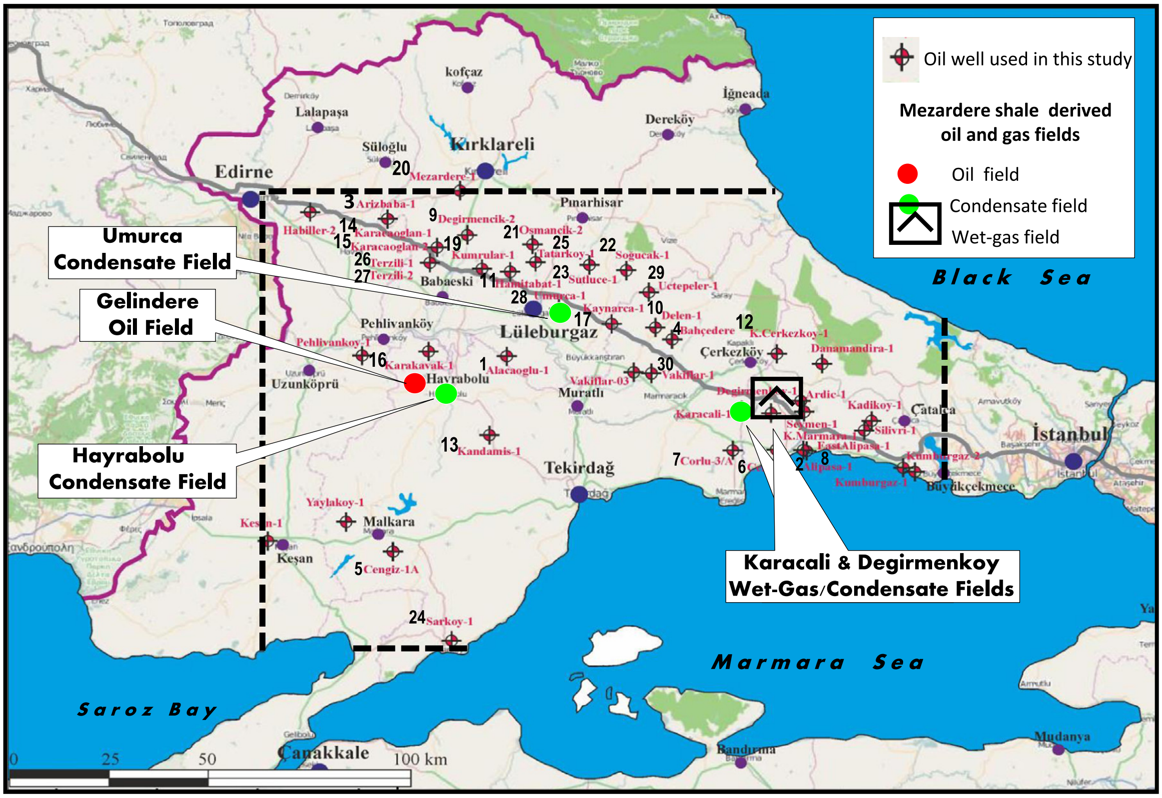

Fig. 2. Map showing locations of geochemically studied 47 wells and the Mezardere sourced oil, wet-gas and condensate fields. The numbers by the well names 1, 2, 3 through 30 indicate the well orders in the Tables 1 and 2 (see Tables 1 and 2 for the data).

2. Stratigraphy

Sedimentary sequence of Thrace Basin consists of Middle-Early Eocene to Pliocene aged deltaic clastic sediments with minor carbonates. Sediment thickness reaches up to 9000 m at the depocenter.

The geological framework and structural evaluation of the basin has been the subject of considerable research (Turgut et al. 1991; Perinçek, 1991; Turgut and Eseller, 2000; Siyako and Huvaz, 2007). Therefore, only a very brief stratigraphical summary will be given here. A simplified scheme of the stratigraphy of the basin is given in Fig. 1c. It shows that sedimentation in Thrace Basin began with Hamitabat Formation molasse and/or turbidite deposition, (i.e., primary source rock of the hydrocarbons within the conventional reservoirs) during Middle Eocene (Turgut et al., 1991). A widespread transgression along the basin took place between Middle and Late Eocene times during which neritic Middle-Late Eocene Soğucak Formation carbonates (i.e., significant conventional reservoir) were deposited in the shallow areas. In the deeper areas, Late Eocene Ceylan Formation pelagic shales, marls, turbiditic sandstones with tuffs were deposited. Towards the end of the Eocene, turbidite deposition stopped and deltaic deposition began continuing until the Late Oligocene. Characteristic sediment type of Lower Oligocene prodelta Mezardere Shale facies (i.e., secondary source rock of the hydrocarbons within the conventional reservoirs) is shales and marls and sands. Mezardere Shale outcrops in southern portion of the Thrace Basin (Fig. 3a) and show wide spread distribution in the underground (Fig. 3b). The Teslimköy Sand lense seen in Fig. 3a is characterized by offshore bar sediments and presents in cases 100 m thick outcrops and 400 m thick underground sand bodies. The Teslimköy member of porous sand lenses takes place between Mezardere Shale and marls and it is formed hybrid unconventional reservoir in the Mezardere Shale play which is followed by Middle Oligocene Osmancık deposition (i.e., significant conventional reservoir) characterized by coarsening upward sandy sediments. This sequence ended with Upper Oligocene Danişmen Formation which is composed of delta-plain deposits comprising of lake, swamp, marsh, and river sediments (i.e., a minor conventional reservoir). Following a significant erosional period, deposition of continental Mio-Pliocene Ergene Formation sediments with an angular unconformity covers all of the Thrace Basin (Fig. 1b and c).

3. Method and sampling

Available total Rock-Eval/TOC data for the 407 Mezardere Shale cuttings and core samples from 47 different wells in the Thrace Basin were studied and evaluated in terms of Rock-Eval $S1$, $S2$, TOC values. Jarvie (2012a,b) and Jarvie et al. (2007) suggested that absolute values of $S1$ over absolute values of TOC ($S1$/TOC > 100) points oil saturated zone and movable free oil and $S2 > 0.02$ mg HC/g Rock indicates sufficient organic richness. The depth of upper most layer of the sample must be greater than 1000 m. Therefore, the samples which do not meet these criteria are not considered for further evaluation. In addition, wells drilled using oil-based mud systems were also dismissed (i.e., Kepirtepe well). This approach allows us to reduce the number of samples from 407 to 277.

Winstat Statistic, PetroMod 11 1D Basin Modeling (Al-Hajeri et al., 2009) and Surfer 9.8 software programs are used for interpretation of data.

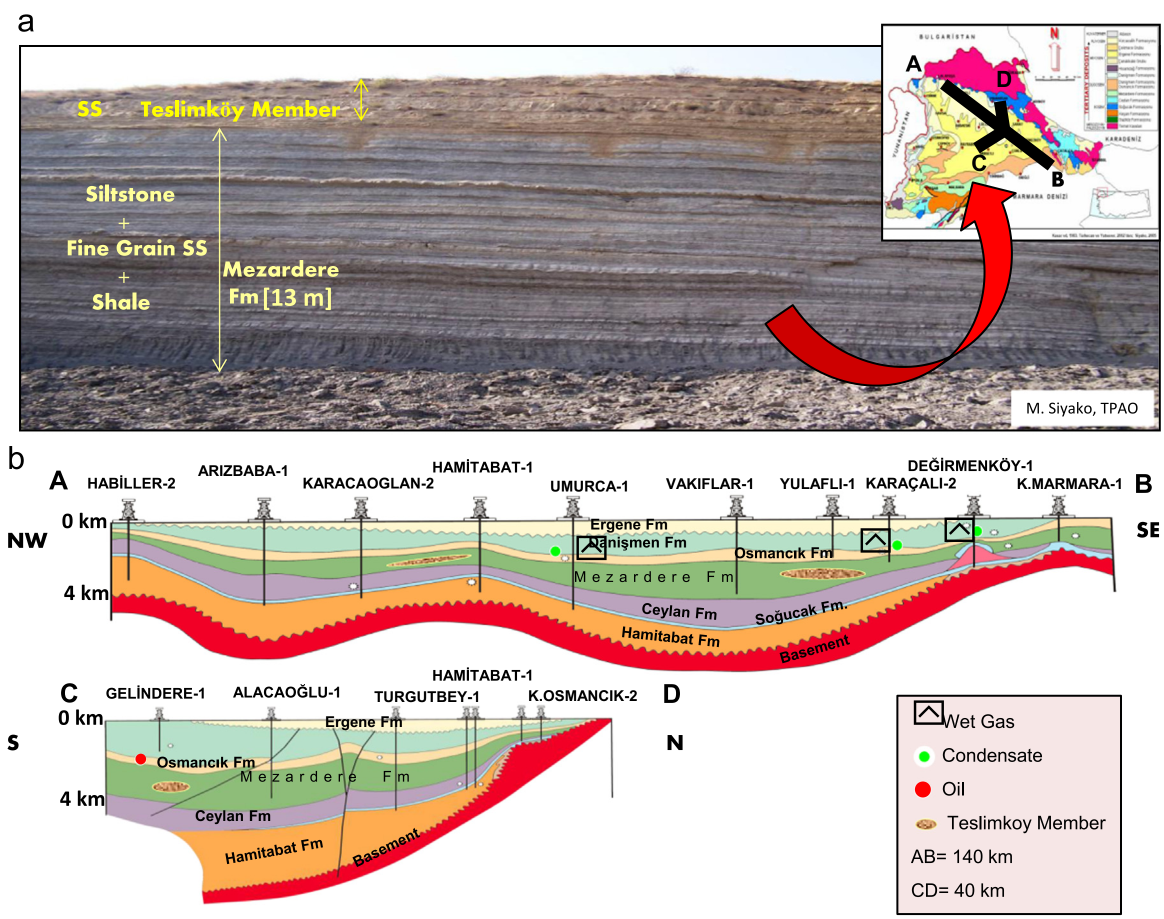

Fig. 3. Mezardere Shale outcrops from the clay quaary in Kumbag – Tekirdag including Teslimkoy Member sand lenses on top (a) and NW–SE and S–N geologic cross sections showing continuity and widesperead distribution of Mezardere Shales and (b) Mezardere Shale sourced wet gas, condensate and oils are also emphasized.

4. Result and discussion

Available data set from Rock-Eval pyrolysis analysis of 407 Mezardere Shale drill cutting and core samples are evaluated in this study. Table 1 shows Rock-Eval pyrolysis results of 277 samples from 30 wells since 130 samples and 17 wells are excluded on the basis of conditions described in Section 3. Additionally, TOC (wt%), HI (mg HC/g TOC), $S1$ (mg HC/g Rock), $S2$ (mg HC/g Rock), OSI (Absolute $S1$*100/TOC), %VRcal (calculated vitrinite reflectance) and PI (production index $= S1/S1+S2$) are also presented in Table 1. An average sampling depth of the 277 samples is 2375 m, and the depth range is between 1000 and 3689 m. TOC content ranges between 0.16 and 2.98 wt% with an average of 0.88 wt%. Tmax was converted to vitrinite reflectance using the formula given by Jarvie et al. (2001) (%VRcal = 0.018*Tmax − 7.16). Accordingly, the mean %VRcal is 0.67 in the range from 0.38 to 0.99. Moreover, a total of 82 measured vitrinite reflectance measurements which are independent of the Rock Eval data set are also available. In this data set, %VRm (measured vitrinite reflectance) ranges from 0.35 to 1.20%VRm and averages around 0.56%VRm. The $S1$ values are relatively high and change between 0 and 25.36 mg HC/g Rock with an average of 0.40 mg HC/g Rock.

$S2$ = generation of hydrocarbons at laboratory, mg hydrocarbons/g Rock; OSI = Oil Saturation Index = $S1$*100/TOC in mg Oil/g Rock; %VRcal = calculated vitrinite reflectance. Calculation is made by using the following formula: %VRcal = 0.018*Tmax − 7.16 (Jarvie et al. 2001); PI = Production Index = $S1/S1+S2$.

4.1. Geochemistry

4.1.1. Conventional source rock evaluation of the Mezardere Shale

Organic matter type of the Mezardere Shale samples is estimated based on the approach suggested by Longford and Blanc-Valleron (1990)'s S2 vs. TOC diagram that reveals that Mezardere Shale contains marine Type II + Type III kerogen although Type III and Type IV kerogens also exist (Fig. 4). This kind of kerogen may generate oil and gas if sufficient depth of burial and temperature is caused to the kerogen structure to crack. Hence, one of the ways of checking an occurrence of hydrocarbon generation in a basin is to examine vitrinite reflectance and present day temperature variations along the wells as seen in Fig. 5.

The hydrocarbon generation stage boundaries referenced from the Barnett shale which is one of the most important unconventional shale formations in not only North America but in the world (Jarvie et. al. 2007). Moreover, generation stage boundaries are also closely related to those of USEIA/ARI (2013):

Immature	< 0.55%VRm ………………… < 2300 m
Oil window	0.55–1.15%VRm ……………………2300–3600 m
Early oil	0.55–0.90%VRm ………………….. 2300–3200 m
Peak oil	0.90–1.15%VRm …………………… 3200–3275) – 3600 m
Condensate-wet gas	1.15–1.40%VRm ………………….. 3600–3800 m

Table 1
Measured Rock-Eval pyrolysis data for the Mezardere Shale samples in Thrace Basin. TOC = total organic matter in wt%; Tmax = temperature at peak point of *S*2 peak in °C; HI = Hydrogen Index = *S*2*100/TOC in mg HC/g TOC; *S*1 = already generated hydrocarbons in mg Oil/g Rock); *S*2 = generation of hydrocarbons at laboratory in mg hydrocarbons/g Rock); OSI = Oil Saturation Index = *S*1*100/TOC in mg Oil/g Rock; %VRcal = calculated vitrinite reflectance. Calculation is made by using the following formula: %VRcal = 0.018*Tmax − 7.16 (Jarvie et al., 2001); PI = Production Index = *S*1/*S*1 + *S*2.

	Well name	Depth (m)	TOC	Tmax	HI	*S*1	*S*2	OSI	%VRcal	PI
1	**Alacaoglu-1**	3010	0.26	435	103	0.15	0.27	58	0.67	0.36
		3020	0.30	442	116	0.25	0.35	83	0.80	0.42
		3030	0.41	438	131	0.36	0.54	88	0.72	0.40
		3040	0.39	434	138	0.34	0.54	87	0.65	0.39
		3050	0.28	437	117	0.35	0.33	125	0.71	0.51
		3060	0.46	437	100	0.33	0.46	72	0.71	0.42
		3070	0.40	440	102	0.33	0.41	83	0.76	0.45
		3080	0.41	434	121	0.33	0.50	80	0.65	0.40
		3090	0.35	438	114	0.28	0.40	80	0.72	0.41
		3100	0.23	437	113	0.23	0.26	100	0.71	0.47
		3110	0.32	433	118	0.32	0.38	100	0.63	0.46
		3130	0.41	440	109	0.27	0.45	66	0.76	0.38
		3140	0.36	442	94	0.23	0.34	64	0.80	0.40
		3110	0.30	433	70	0.10	0.21	33	0.63	0.32
		3140	0.24	442	120	0.16	0.29	67	0.80	0.36
		3160	0.47	437	217	0.19	1.02	40	0.71	0.16
		3162	0.40	434	82	0.25	0.33	63	0.65	0.43
		3180	0.35	453	105	0.20	0.37	57	0.99	0.35
		3200	0.33	447	160	0.28	0.53	85	0.89	0.35
		3240	0.19	452	105	0.09	0.20	47	0.98	0.31
		3280	0.19	449	121	0.16	0.23	84	0.92	0.41
		3300	0.26	439	111	0.16	0.29	62	0.74	0.36
		3320	0.16	440	156	0.08	0.25	50	0.76	0.24
		3340	0.31	450	103	0.12	0.22	39	0.94	0.35
		3380	0.52	436	51	0.13	0.27	25	0.69	0.33
		3400	0.96	432	31	0.17	0.30	18	0.62	0.36
		3420	0.67	433	53	0.18	0.36	27	0.63	0.33
		3480	0.47	435	68	0.22	0.32	47	0.67	0.41
		3520	0.46	441	52	0.11	0.24	24	0.78	0.31
		3580	0.56	444	42	0.15	0.24	27	0.83	0.38
		3600	0.62	443	41	0.13	0.26	21	0.81	0.33
		3620	0.48	452	43	0.09	0.21	19	0.98	0.30
		3660	0.77	439	38	0.18	0.30	23	0.74	0.38
2	**Alipasa-1**	1000	0.50	438	107	0.04	0.54	8	0.72	0.07
		1074	0.64	431	100	0.05	0.64	8	0.60	0.07
		1100	0.85	439	169	0.11	1.44	13	0.74	0.07
		1280	0.71	430	121	0.06	0.86	8	0.58	0.07
		1300	0.72	439	129	0.04	0.93	5	0.74	0.04
		1320	0.67	435	138	0.08	0.93	12	0.67	0.08
		1350	0.53	440	284	0.07	1.51	13	0.76	0.04
3	**Arizbaba-1**	2090	0.43	437	165	0.05	0.71	12	0.71	0.07
		2140	0.39	434	120	0.04	0.47	10	0.65	0.08
		2190	0.80	439	345	0.11	2.76	14	0.74	0.04
		2240	0.90	439	301	0.11	2.71	12	0.74	0.04
		2320	0.72	437	240	0.10	1.73	14	0.71	0.05
		2410	0.75	440	270	0.14	2.03	19	0.76	0.06
		2440	0.65	437	200	0.10	1.30	15	0.71	0.07
		2470	0.76	438	338	0.21	2.57	28	0.72	0.08
		2500	0.75	439	260	0.16	1.95	21	0.74	0.08
		2580	0.32	438	200	0.18	1.64	56	0.72	0.10
		2620	0.79	442	324	0.29	2.56	37	0.80	0.10
		2640	0.68	443	227	0.15	1.55	22	0.81	0.09
		2680	0.38	442	165	0.10	0.63	26	0.80	0.14
		2710	0.39	444	138	0.08	0.54	21	0.83	0.13
4	**Bahcedere-1**	1900	1.06	434	77	0.04	0.82	3	0.65	0.04
		2000	1.10	436	269	0.06	2.97	5	0.69	0.02
		2100	2.08	439	149	0.40	3.11	19	0.74	0.11
		2200	0.94	439	212	0.07	2.00	8	0.74	0.03
		2300	1.28	437	252	0.07	3.24	5	0.71	0.02
		2400	0.85	441	225	0.08	1.92	9	0.78	0.04
		2500	1.23	438	208	0.37	2.56	30	0.72	0.13
		2600	1.56	443	242	1.34	3.79	86	0.81	0.26
		2700	0.98	441	160	0.53	1.57	54	0.78	0.25
		2800	0.55	445	283	0.69	1.56	126	0.85	0.31
		2900	1.35	444	237	0.75	3.20	55	0.83	0.19
		3000	0.87	442	148	0.50	1.29	57	0.80	0.28
		3001	0.35	445	200	0.29	0.70	83	0.85	0.29

Table 1 (*continued*)

	Well name	Depth (m)	TOC	Tmax	HI	*S*1	*S*2	OSI	%VRcal	PI
5	**Cengiz/1A**	1170	0.40	440	65	0.08	0.26	20	0.76	0.24
6	**Celtik-1**	1100	1.61	437	330	0.43	5.32	26	0.71	0.07
		1300	0.82	442	124	0.06	1.02	8	0.80	0.06
		1500	0.62	440	67	0.08	0.42	12	0.76	0.15
		1700	0.81	442	72	0.12	0.59	15	0.80	0.17
		1900	0.55	444	134	0.12	0.74	22	0.83	0.14
7	**Corlu-3A**	1580	1.00	433	218	0.14	2.18	14	0.63	0.06
		1696	0.73	436	139	0.10	1.02	14	0.69	0.09
		1954	0.65	441	146	0.15	0.95	23	0.78	0.14
8	**D.Alipaşa**	1076	0.88	432	211	0.07	1.31	8	0.62	0.05
		1280	0.73	433	176	0.06	0.81	8	0.63	0.07
		1400	0.71	437	154	0.08	1.10	11	0.71	0.07
9	**Degirmencik-2**	1900	1.50	438	365	0.07	5.49	4	0.72	0.01
		2010	1.03	436	267	0.05	2.76	5	0.69	0.02
		2330	1.23	433	300	0.01	3.70	1	0.63	0.00
		2530	0.82	434	266	0.12	2.18	15	0.65	0.05
		2600	0.67	436	242	0.23	1.62	35	0.69	0.13
		2650	0.63	440	238	0.23	1.50	37	0.76	0.13
10	**Delen-1**	2718	2.17	438	423	0.23	9.20	11	0.72	0.02
		2480	1.10	440	166	0.14	1.83	13	0.76	0.07
11	**Hamitabat-8**	1938	1.05	440	205	0.14	2.16	13	0.76	0.06
		2064	0.79	435	170	0.08	1.35	10	0.67	0.06
		2202	0.65	441	132	0.08	0.86	12	0.78	0.09
		2324	0.44	435	125	0.06	0.55	14	0.67	0.10
		2412	0.44	439	113	0.06	0.50	14	0.74	0.11
		2510	0.57	441	145	0.08	0.83	14	0.78	0.09
		2636	0.72	442	165	0.09	1.19	13	0.80	0.07
12	**K.Cerkezkoy-1**	1044	1.07	427	246	0.12	2.64	11	0.53	0.04
		1250	1.47	430	414	0.16	6.09	11	0.58	0.03
13	**Kandamış-1**	1668	0.55	430	76	0.08	0.43	15	0.58	0.16
		1678	0.57	426	170	0.49	0.87	86	0.51	0.36
		1878	0.66	425	35	0.21	0.23	32	0.49	0.48
		2232	0.30	432	79	0.05	0.24	17	0.62	0.17
		2075	0.55	425	3	0.10	0.58	18	0.49	0.15
		2224	0.62	430	86	0.01	0.50	2	0.58	0.02
		2868	0.42	439	137	0.24	0.56	57	0.74	0.00
14	**Karacaoglan-1**	2096	0.60	439	90	0.03	0.58	5	0.74	0.05
		2122	0.94	437	195	0.10	1.84	11	0.71	0.05
		2130	1.21	433	414	0.23	5.01	19	0.63	0.04
		2346	0.61	438	121	0.04	0.73	7	0.72	0.05
		2570	0.84	441	244	0.68	2.05	81	0.78	0.25
		2596	0.46	441	106	0.04	0.65	9	0.78	0.06
		2669	1.50	443	261	0.38	3.92	25	0.81	0.09
		2750	0.62	438	162	0.11	1.01	18	0.72	0.10
		2786	0.36	442	20	0.06	0.47	17	0.80	0.11
		2792	0.44	445	72	0.02	0.26	5	0.85	0.07
15	**Karacaoglan-2**	1820	0.91	437	336	0.08	3.06	9	0.71	0.03
		1940	1.02	438	446	0.12	4.55	12	0.72	0.03
		2060	1.12	436	401	0.12	4.50	11	0.69	0.03
		2191	1.20	433	303	0.18	3.64	15	0.63	0.05
		2322	0.95	438	333	0.13	3.17	14	0.72	0.04
		2460	0.79	438	289	0.14	2.29	18	0.72	0.06
		2640	0.68	441	136	0.12	0.93	18	0.78	0.11
		2758	0.50	443	122	0.12	0.61	24	0.81	0.16
16	**Karakavak-1**	1706	0.85	434	196	0.09	1.67	11	0.65	0.05

Table 1 (*continued*)

	Well name	Depth (m)	TOC	Tmax	HI	*S1*	*S2*	OSI	%VRcal	PI
		1984	0.79	431	69	0.11	0.54	14	0.60	0.17
		2033	0.89	432	129	0.04	1.07	4	0.62	0.04
		2184	0.71	432	43	0.06	0.31	8	0.62	0.16
		2228	0.78	436	26	0.06	0.21	8	0.69	0.22
		2290	0.92	433	81	0.09	0.74	10	0.63	0.11
		2472	0.86	433	103	0.15	0.88	17	0.63	0.15
		2654	0.87	434	49	0.23	0.42	26	0.65	0.35
		2777	0.65	432	64	0.20	0.42	31	0.62	0.32
		2972	0.44	437	50	0.12	0.22	27	0.71	0.35
17	**Kaynarca-1**	2528	0.53	433	107	0.35	0.57	66	0.63	0.38
		2568	1.12	438	158	0.61	1.78	54	0.72	0.26
		2722	0.61	434	149	0.40	0.91	66	0.65	0.31
		2794	0.52	437	111	0.42	0.58	81	0.71	0.42
		2918	0.49	439	116	0.39	0.57	80	0.74	0.41
		3006	0.42	439	130	0.42	0.55	100	0.74	0.43
18	**Kepirtepe**	2130	0.89	425	125	1.72	1.12	193	0.49	0.61
		2350	1.15	424	195	0.30	2.25	26	0.47	0.12
		2440	1.32	427	159	3.86	2.11	292	0.53	0.65
		2480	0.97	425	218	0.14	2.12	14	0.49	0.06
		2540	1.58	433	289	1.26	4.57	80	0.63	0.22
		2600	1.20	428	288	0.45	3.46	38	0.54	0.12
		2706	2.96	419	171	3.50	5.07	118	0.38	0.41
19	**Kumrular-1**	1510	1.34	430	288	0.12	3.87	9	0.58	0.03
		1550	1.44	432	263	0.10	3.79	7	0.62	0.03
		1550	0.70	435	411	0.09	2.88	13	0.67	0.03
		1690	1.61	434	443	0.29	7.15	18	0.65	0.04
		1730	1.86	434	728	0.37	13.55	20	0.65	0.03
		1730	0.87	438	456	0.09	3.97	10	0.72	0.02
		1760	1.65	435	744	0.43	12.28	26	0.67	0.03
		1830	1.32	435	132	0.00	3.07	0	0.67	0.00
		1890	1.32	435	280	0.38	3.70	29	0.67	0.09
		1930	1.72	430	347	0.71	5.96	41	0.58	0.11
		1970	1.54	436	545	0.51	8.40	33	0.69	0.06
		2020	1.31	431	400	0.36	5.25	27	0.60	0.06
		2060	2.66	427	519	25.36	13.79	953	0.53	0.65
		2080	2.98	427	515	18.25	15.35	612	0.53	0.54
		2100	1.26	435	305	4.16	3.85	330	0.67	0.52
		2140	1.25	432	196	0.80	2.45	64	0.62	0.25
		2210	0.91	435	223	0.11	2.02	12	0.67	0.05
		2270	0.93	439	248	0.15	2.31	16	0.74	0.06
		2340	0.96	437	345	0.16	3.31	17	0.71	0.05
		2400	0.88	436	220	0.14	1.93	16	0.69	0.07
		2440	0.94	439	157	0.14	1.48	15	0.74	0.09
		2490	0.95	440	219	0.22	2.08	23	0.76	0.10
20	**Mezardere-1**	1000	0.91	438	212	0.03	1.94	4	0.72	0.02
		1050	0.63	442	119	0.05	0.75	8	0.80	0.07
		1100	0.57	432	79	0.02	0.45	4	0.62	0.05
		1150	0.98	433	206	0.02	2.03	2	0.63	0.01
		1200	0.69	434	95	0.05	0.66	7	0.65	0.07
21	**Osmancık-2**	1800	0.58	440	298	0.51	1.73	88	0.76	0.23
		1801	0.58	435	253	0.09	1.47	16	0.67	0.06
		1850	0.60	438	236	0.12	1.42	20	0.72	0.08
22	**Sogucak-1**	1000	1.92	421	444	0.07	8.53	4	0.42	0.01
		1050	2.33	428	377	0.12	8.80	5	0.54	0.01
23	**Sutluce-1**	1000	0.90	438	191	0.04	1.73	4	0.72	0.02
		1050	1.17	440	240	0.04	2.82	3	0.76	0.01
		1100	1.35	438	385	0.03	5.20	2	0.72	0.01
		1150	1.10	433	309	0.08	3.40	7	0.63	0.02
24	**Sarkoy-1**	1100	0.61	440	88	0.05	0.54	8	0.76	0.08
		1200	0.36	439	88	0.02	0.32	6	0.74	0.06
25	**Tatarkoy-1**	1410	0.81	435	324	0.07	2.63	9	%0.67	0.03

Table 1 (*continued*)

	Well name	Depth (m)	TOC	Tmax	HI	*S*1	*S*2	OSI	%VRcal	PI
		1450	0.66	436	215	0.07	1.42	11	0.69	0.05
		1510	0.80	436	320	0.10	2.56	13	0.69	0.04
		1550	1.24	431	421	0.30	5.23	24	0.60	0.05
		1610	1.10	425	391	0.31	4.31	28	0.49	0.07
		1640	0.70	434	274	0.14	1.92	20	0.65	0.07
		1690	0.68	434	319	0.17	2.17	25	0.65	0.07
		1910	0.83	438	331	0.21	2.75	25	0.72	0.07
		1960	0.98	433	243	0.14	2.39	14	0.63	0.06
		1990	0.73	435	252	0.11	1.84	15	0.67	0.06
		2060	0.58	438	272	0.08	1.58	14	0.72	0.05
		2080	0.52	435	178	0.09	0.93	17	0.67	0.09
		2130	0.64	440	328	0.12	2.10	19	0.76	0.05
		2200	0.45	435	217	0.09	0.98	20	0.67	0.08
		2240	0.50	437	178	0.09	0.89	18	0.71	0.09
		2300	0.50	439	262	0.15	1.34	30	0.74	0.10
		2360	0.30	437	220	0.09	0.66	30	0.71	0.12
26	**Terzili-1**	2560	0.84	436	503	0.60	4.23	71	0.69	0.12
27	**Terzili-2**	1840	0.86	439	311	0.18	2.68	21	0.74	0.06
		2150	0.92	439	298	0.34	2.75	37	0.74	0.11
		2200	1.05	433	163	0.39	1.72	37	0.63	0.18
		2570	0.81	440	162	0.57	1.32	70	0.76	0.30
		2600	0.91	443	212	1.51	1.93	166	0.81	0.44
		2874	0.71	444	142	0.49	1.01	69	0.83	0.33
28	**Umurca-1**	2190	1.43	429	224	0.09	3.21	6	0.56	0.03
		2200	0.96	435	67	0.02	0.64	2	0.67	0.03
		2240	1.23	432	118	0.08	1.45	7	0.62	0.05
		2270	1.04	434	289	0.05	3.00	5	0.65	0.02
		2290	1.43	436	327	0.10	4.67	7	0.69	0.02
		2368	0.86	429	149	0.06	1.28	7	0.56	0.04
		2430	0.92	430	121	0.08	1.12	9	0.58	0.07
		2500	1.17	429	140	0.08	1.64	7	0.56	0.05
		2630	0.92	431	236	0.11	2.17	12	0.60	0.05
		2640	1.12	431	208	0.10	2.33	9	0.60	0.04
		2690	0.84	434	184	0.14	1.55	17	0.65	0.08
		2720	0.77	439	190	0.01	1.95	1	0.74	0.01
		2750	1.23	434	76	0.10	0.94	8	0.65	0.10
		2860	0.99	434	221	0.10	2.19	10	0.65	0.04
		2878	0.82	435	95	0.07	0.78	9	0.67	0.08
		3110	0.97	433	103	0.17	1.00	18	0.63	0.15
		3250	1.03	435	109	0.28	1.12	27	0.67	0.20
		3280	0.80	435	116	0.21	0.92	26	0.67	0.19
29	**Uctepeler-1**	1850	1.01	434	318	0.96	3.22	95	0.65	0.23
		1850	0.77	430	275	0.22	2.12	29	0.58	0.09
		1900	0.65	438	207	0.14	1.35	22	0.72	0.09
		1950	0.39	441	176	0.05	0.69	13	0.78	0.07
30	**Vakıflar-1**	2013	0.79	429	69	0.02	0.54	3	0.56	0.04
		2059	1.12	430	229	0.15	2.56	13	0.58	0.06
		2104	1.47	426	289	0.12	4.26	8	0.51	0.03
		2151	1.28	436	237	0.09	3.04	7	0.69	0.03
		2181	0.81	431	89	0.04	0.72	5	0.60	0.05
		2210	1.12	432	310	0.04	3.47	4	0.62	0.01
		2226	1.14	421	257	0.02	2.93	2	0.42	0.01
		2241	1.07	427	216	0.06	2.31	6	0.53	0.03
		2271	1.07	427	579	0.24	6.20	22	0.53	0.04
		2287	1.02	428	257	0.09	2.75	9	0.54	0.03
		2302	0.93	428	363	0.07	3.37	8	0.54	0.02
		2357	1.14	427	504	0.10	5.75	9	0.53	0.02
		2390	1.34	434	530	0.09	7.10	7	0.65	0.01
		2439	0.95	430	293	0.04	2.78	4	0.58	0.01
		2454	1.17	428	457	0.13	5.35	11	0.54	0.02
		2470	1.23	423	603	0.20	7.41	16	0.45	0.03
		2485	1.20	426	529	1.38	6.35	115	0.51	0.18
		2531	1.20	426	404	0.22	4.85	18	0.51	0.04
		2576	1.10	429	368	0.16	4.05	15	0.56	0.04
		2598	1.20	430	356	0.15	4.27	13	0.58	0.03
		2616	1.10	431	165	0.14	1.81	13	0.60	0.07
		2683	1.11	431	184	0.31	2.05	28	0.60	0.13

Table 1 (*continued*)

Well name	Depth (m)	TOC	Tmax	HI	S1	S2	OSI	%VRcal	PI
	2698	1.10	429	209	0.16	2.30	15	0.56	0.07
	2713	1.48	430	280	0.21	4.14	14	0.58	0.05
	2729	1.05	427	187	0.16	2.30	15	0.53	0.07
	2851	1.01	431	117	0.14	1.18	14	0.60	0.11
	2872	1.16	428	428	0.29	1.83	25	0.54	0.14
	2876	1.02	431	137	0.19	1.40	19	0.60	0.12
	2918	1.01	429	170	0.29	1.72	29	0.56	0.14
	3049	1.01	435	140	0.28	1.41	28	0.67	0.17
	3122	1.22	435	80	0.33	0.98	27	0.67	0.25
	3137	1.08	431	293	0.31	3.17	29	0.60	0.09
	3156	1.07	434	72	0.34	0.77	32	0.65	0.31
	3186	1.00	433	133	0.21	1.34	21	0.63	0.14
	3217	1.10	432	188	0.19	2.06	17	0.62	0.08
	3247	0.99	431	230	0.18	2.27	18	0.60	0.07
	3262	0.94	437	124	0.16	1.90	17	0.71	0.08
	3323	0.91	427	72	0.17	0.65	19	0.53	0.21
	3338	0.91	429	106	0.19	0.96	21	0.56	0.17
	3384	0.80	430	75	0.21	0.60	26	0.58	0.26
	3430	0.95	433	127	0.22	1.31	23	0.63	0.14
	3445	0.84	428	130	0.24	1.24	29	0.54	0.16
	3506	0.86	431	119	0.32	1.02	37	0.60	0.24
	3537	0.87	432	148	0.20	1.29	23	0.62	0.13
	3582	0.81	430	109	0.25	0.88	31	0.58	0.22
	3628	0.91	429	154	0.17	1.40	19	0.56	0.11
	3643	0.91	431	57	0.22	0.52	24	0.60	0.30
	3674	0.88	431	90	0.14	0.74	16	0.60	0.16
	3689	0.83	435	35	0.22	0.29	27	0.67	0.43

Dry gas	> 1.40%VRm	> 3800 m

We apply these %VRm values to Mezardere Shale to show the hydrocarbon generation stages on the depth vs. %VRm graph in Fig. 5a. In addition, we plot the bottom hole temperatures of the 176 wells against depth in Fig. 5b to show the 50% kerogen conversion depth interval in the Thrace Basin.

Jarvie (2012a) suggested % kerogen conversion to hydrocarbons and their corresponding depth ranges and reported that 50% of kerogen is converted to hydrocarbons at temperatures between 130 and 145 °C. In Thrace Basin, this temperature range corresponds to 3200–3600 m depth interval (Fig. 5b). Compatibility between the peak oil generation depth range (i.e., 0.9–1.15%VRm) in Fig. 5a and 50% kerogen conversion depth range in Fig. 5b is a significant finding of this study because the maximum depth of

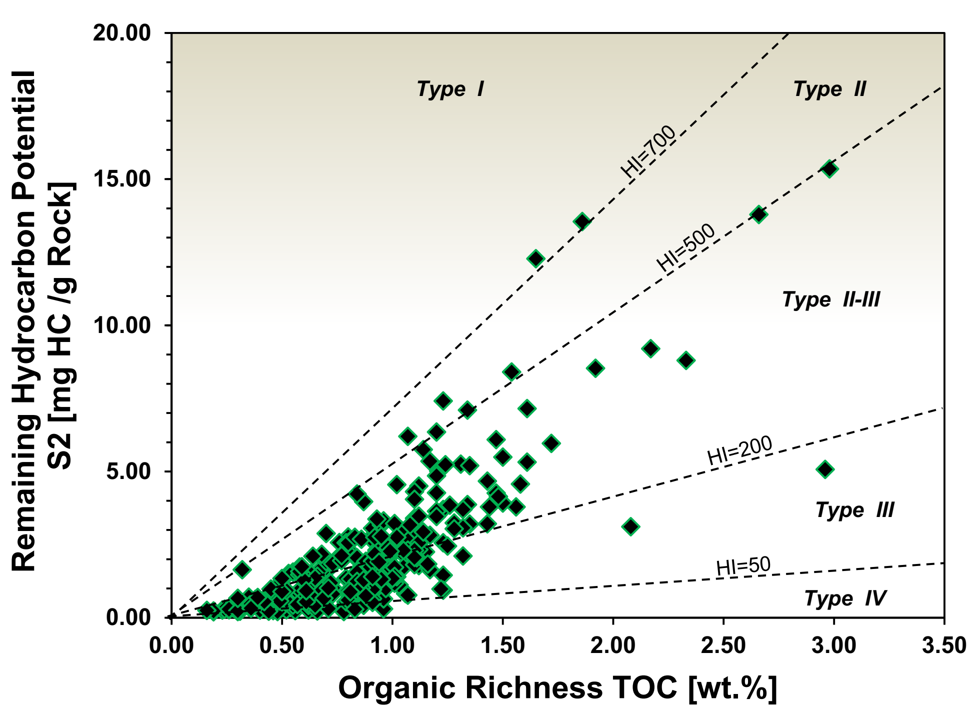

Fig. 4. Remaining hydrocarbon potential (S2) versus organic richness (TOC) graph of Mezardere Shale samples from Thrace Basin. Graph was originally designated by Longford and Blanc-Valleron (1990).

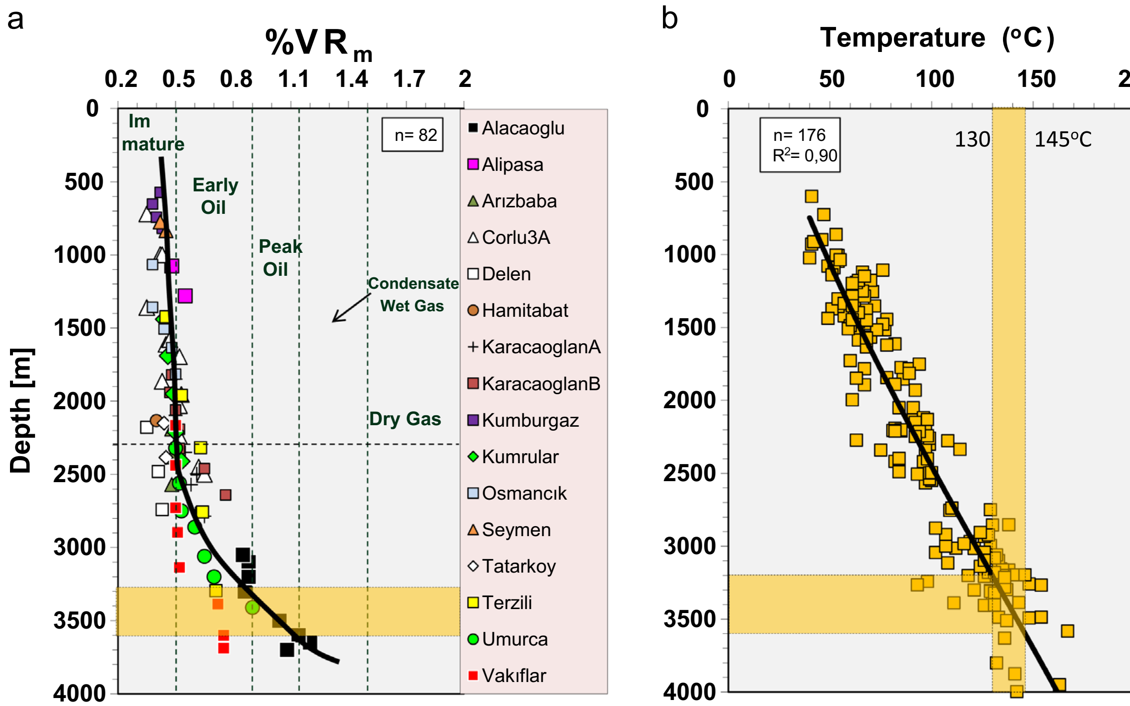

Fig. 5. Depth vs. %VRm graph illustrating hydrocarbon generation stages of the Mezardere Shale. The depth range of generation stages is given in the text. Available %VRm data cover 16 wells and 82 measurements (a). Depth vs. temperature graph (b). Note that 130–145 °C temperature range for 50% kerogen conversion at 3200–3600 m interval fits the peak oil generation interval in (a).

the Mezardere Shale is 3689 m indicating that Mezardere Shale is at oil generation stage in the Thrace Basin (Table 1). Furthermore, Fig. 5b lets us to draw the best regression line (R^2 = 0.90) to estimate an approximate geothermal gradient (GG) of 36 °C/1000.

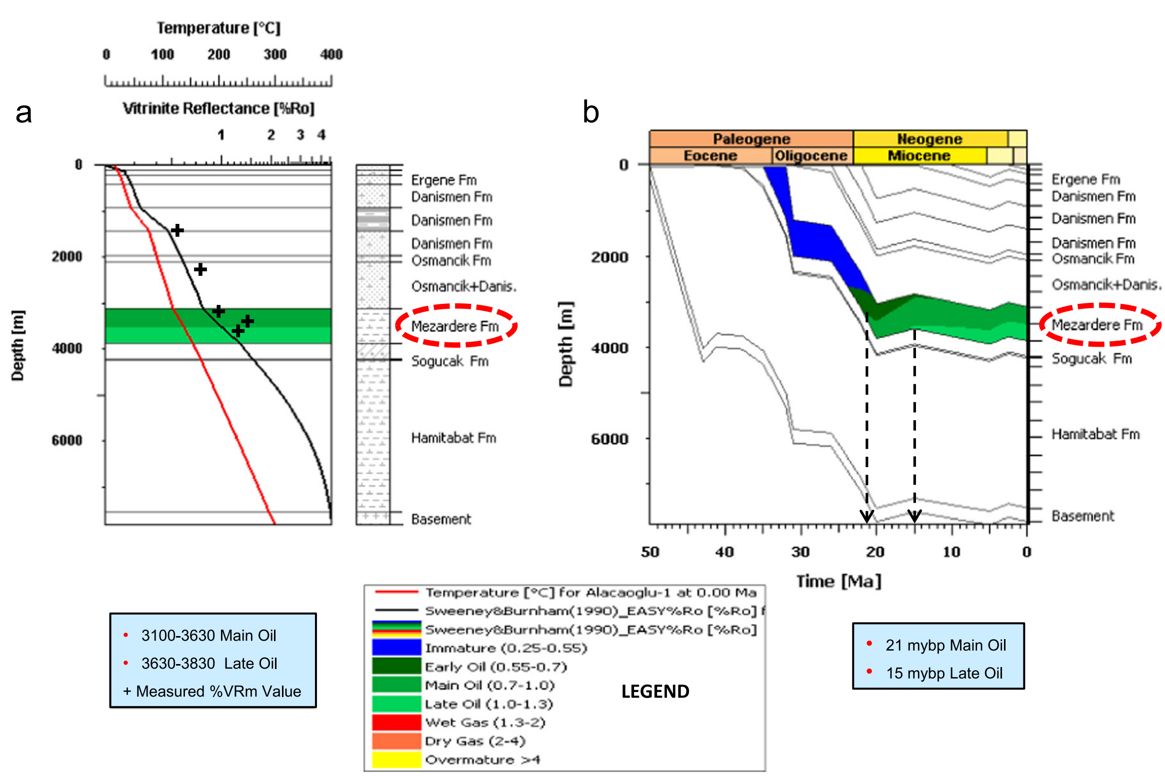

Fig. 6. Basin modeling application to Alacaoğlu-1 well showing both present day %VR and temperature variations with depth (a) and burial history and commences of hydrocarbon generation stages (b) where particular attention has been given to the Mezardere Formation. Basin modeling was performed using the *PetroMod one-dimentional basin modeling software (IES).*

This is a slightly higher GG than world average value of 25–30 °C/1000 m (Schlumberger, 2014).

4.1.2. *Correlation of discovered conventional hydrocarbons to Mezardere Shale*

It is plausible to think that in a given basin, presence of conventional hydrocarbon discoveries supports and encourages exploration of unconventional shale play resources. Particularly, correlation of discovered conventional hydrocarbons with an unconventional shale play candidate is substantially important. Gürgey et al. (2005) conducted a carbon isotopic correlation study covering all the conventional discovered hydrocarbon types in the Thrace Basin. They claimed that the Gelindere oil and Degirmenkoy, Karacali, Umurca and Hayrabolu wet gas and condensates (see Fig. 2 for locations) are genetically similar and derived from the Mezardere Shale source rock. In fact, carbon isotope and maturity related biomarkers show that all the Mezardere Shale related hydrocarbons are early mature (Gürgey et al., 2005, Gürgey, 2009). These results imply that unconventional oil resources in Mezardere Shale could be present not only at the peak oil depth range but also at the early generation depth range (i.e., range from 2300 to 3200 m). On the other hand, regardless of its early mature character of the conventional Gelindere oil, it has low asphaltene and low sulfur contents and show high API gravity of 35°. Wet gases are sweet and do not contain any sulfur or inorganic gases. Similarly, condensates contain no sulfur and asphaltene (Gürgey et al., 2005). These are the important criteria for the unconventional oil and condensate production from shale plays.

4.1.3. *Basin modeling*

The basin modeling application is conducted on the representative Alacaoglu-1 well where Mezardere Shale is in the deepest stratigraphic position. Present day temperature and vitrinite reflectance profiles of this well are shown in Fig. 6a and generation history and burial history is shown in Fig. 6b. Fig. 6a illustrates that Mezardere in the Alacaoglu-1 well is currently at the main oil (peak oil) to late oil (condensate) stages which could possibly produce several fluid types with a large API gravity range. The depth of main oil stage is from 3100 to 3630 m whereas that of late oil stage is from 3630 to 3830 m. Consistency is clearly seen if one compares the basin modeling results of Fig. 6a with that of the geochemical results of Fig. 5a. Both explicitly supports the idea that Mezardere Shale generated hydrocarbons with large range of API gravity, such as normal black oil with 25–30°, light oil with 30–40°, condensate with 40–60°, and wet gas with >60 API gravity. Fig. 6b shows the main oil and late oil generation stages begins as early as 21 m.a.b.p 15 m.a.b.p., respectively. Both stages have been ongoing today at Alacaoglu-1 well and possibly in the other wells which share the similar depth intervals and the similar burial depth history with the Alacaoğlu-1 well. These observations are supportive evidence of unconventional oil potential of the Mezardere Shale

Consequently, an integration of both basin modeling and geochemistry results allows us to reconstruct a map that shows iso-boundary contours of hydrocarbon generation stages beneath the Thrace area. It appears that peak oil and condensate–wetwet gas generating area covers approx. 4300 km^2 and epicenter of this area takes place at Muratlı Town (Fig. 7). Unfortunately, there are only a few wells around Muratlı Town for detail studies.

4.2. *Correction of S1 and determination of oil-saturated zones in the*

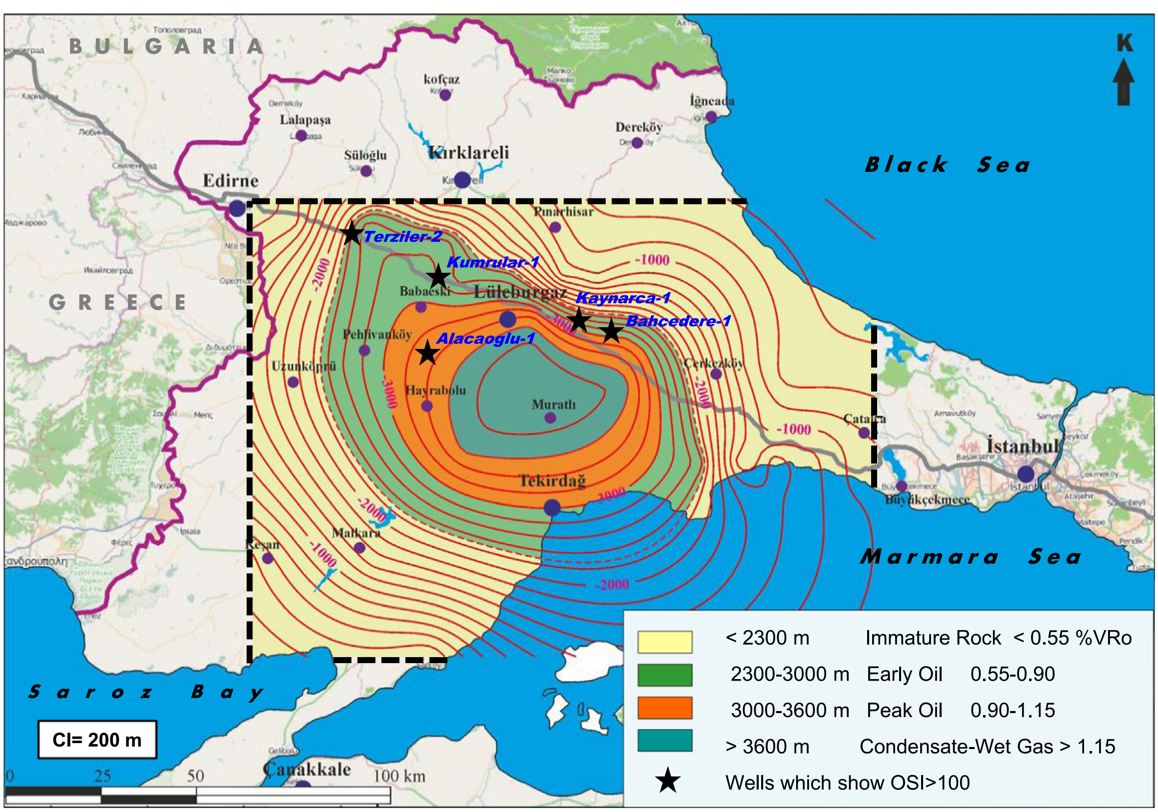

Fig. 7. A map showing the depth iso-countours of hydrocarbon generation stages of Mezardere Shale beneath the Thrace area. The five wells that show OSI > 100 are also shown in uppercase character (see Section 4.2).

Mezardere Shale

Aforementioned section, results attained from the Rock-Eval Pyrolysis data and basin modeling favor geochemical conditions which supports the Mezardere Shale for being a shale-oil play candidate. The question is that, is there any additional supportive evidence in the data set that could indicate the oil saturated zones in the Mezardere Shale? Indeed, to answer this question is the main interest in the shale oil exploration and production efforts. This kind of information is implicit in Rock-Eval $S1$ and TOC. Jarvie (2012b) proposed the absolute value of $S1$ exceeds that of TOC, called "oil crossover effect (OCE)" and expressed it as a term of "Oil Saturation Index"$=S1*100/\text{TOC}$ (OSI). The reservoir zones (i.e., both conventional and unconventional) having OSI > 100 are oil saturated and carry moveable free oil (Table 1). In addition, API gravity of oil in these kinds of zones is greater than 35° (Jarvie, 2012b).

The $S1$ value should in theory provide a quick estimate of the amount and carbon range of free oil which approximately extends from C7 to C30 (Wang et al. 2014). Nevertheless, evaporation of C15 minus hydrocarbons inevitably happens over the time, therefore we never measure the true $S1$ as it is in the sub-surface. Evaporative loss of C15 minus hydrocarbons from the shale sample causes a substantial decrease in the estimated oil-in place (OIP) values, especially if more volatile-high gravity oils could originally present in the sub-surface formation (Noble et al., 1997). Michael et al. (2013) and BGS (2014) (BGS=British Geological Survey) proposed that evaporative loss of % C15 minus loss of hydrocarbons from the high gravity light oils is much higher compare to heavy low-gravity oils. The following two equations are suggested to estimate %C15 minus loss from $S1$ and calculate $S1$ correction factor ($S1_{CF}$) assuming all the C15 minus hydrocarbons are lost (Michael et al., 2013; BGS, 2014):

$$\%\text{C15 minus loss} = (\text{Oil API gravity} - 20.799)/0.412$$

$$S1_{CF} = 1/[1 - \%\text{C15 minus loss}]$$

Accordingly, for 35, 40 and 45 API oils, %C15 minus loss and $S1_{CF}$ are 34.5% and 1,526, 46.6% and 1.873 and lastly 58.7%, 2.424, respectively as demonstrated in Fig. 8.

The Rock-Eval $S1$ carryover into Rock-Eval $S2$ and usage of oil-based mud during drilling are additional cases which affect Rock-Eval measured $S1$ values. Although we believe in significance and relevancy of $S1$ carryover into the $S2$, sampling as well as analytical limitations prevent us to consider it in the $S1$ assessments of the Mezardere Shale.

$S1$ carryover into the $S2$ occurs via absorption of $S1$ by the $S2$. $S2$ is an insoluble large organic molecule called kerogen. Hence, absorption depends on the amount of kerogen. Sandvik et al. (1992) suggest 10 g oil ($S1$) is absorbed per 100 g of total organic matter. Pepper (1992) suggests a slightly higher value of about

$$\text{OIP [bbl/acre-ft]} = S1 * \boxed{S1_{CF}} * \boxed{(\text{Shale Density/Oil Density}) * 7.758}$$

A

Oil API	$\%C_{15\text{-}}$ loss[1]	$S1_{CF}$[2]	Shale Density g/cm3	Oil Density g/cm3	A[3]
35	34.5	1.526	2.40	0.85	21.90
40	46,6	1.873	2.40	0.825	22.57
45	58,7	2,424	2.40	0.802	23.22

[1] $\%C_{15\text{-}}$ Lost= [Oil API - 20.799] /0.412 [2] $S1_{CF}$ = 1/1-[$\%C_{15}$ lost] [3] A= [Shale Density /Oil Density) * 7.758

Fig. 8. Oil in-place estimation formula and $S1$ correction procedure of Michael et al. (2013) and BGS (2014).

100 mg oil per gram of TOC. Jarvie (2012c) analyzed to the 12 Barnett shale samples before and after extraction and observed that $S2$ absorbed 2–3 × $S1$. When the averages of present day TOC and original TOC values of 4.48 wt% and 6.27 wt% are considered (Jarvie et al., 2007), absorption of 2–3 × $S1$ into the $S2$ of Barnett samples appears to be possible. Moreover, average present day TOC values of Mezardere Shale (0.88 wt%) is relatively lower compared to Barnett for a significant $S1$ carryover into the $S2$, so we think that this process is negligible for the Mezardere Shale samples in hand.

In order to make reliable correction against evaporative loss, we try to estimate the optimum API gravity of the retained oil in the Mezardere Shale. Firstly, as mentioned before, the Mezardere Shale derived Gelindere-1 oil (see its location in Fig. 2) shows 35 API gravity and contains very low sulfur and asphaltene (Gürgey et al., 2001). Secondly, Mezardere derived condensates in the Umurca, Karaçali, Hayrabolu and Değirmenköy fields have high API gravity by definition. Their API gravity is greater than 35°. Thirdly, Mezardere Shale shows three hydrocarbon generation stages as emphasized in Fig. 5a: Early oil stage, peak oil stage and condensate–wet stage late oil stage of the Mezardere Shale which we assume could generate 35 API, 40 API and 45 and higher API gravity fluids. API gravity assumptions are made considering Michael et al. (2013) and BGS (2014).

Table 2 shows measured TOC, $S1$ and OSI values as well as corrected OSI (OSI_{corr}) values for 35, 40 and 45 oil gravities. It shows that multiplication of $S1_{CF}$ of 1.526, 1.873 and 2.424 values with the measured $S1$ value resulted in %153, %187 and % 240 increase in free oil content indicating that in OIP estimation of shale oil resource studies, evaporative loss is significant and should be cautiously examined. Similar percentage increases are also observed in the corrected OSI values. Increasing S1 values (i.e. from measured $S1$ to $S1_{\text{corr}}$ values) are reflected in the 4 different graphs given in Fig. 9a–d: Fig. 9a is a measured $S1$ vs. TOC, Fig. 9b shows $S1_{\text{corr}}$ for 35 API oil vs. TOC, Fig. 9c is $S1_{\text{corr}}$ for 40 API oil vs. TOC and Fig. 9d illustrates $S1_{\text{corr}}$ for 45 API oil vs. TOC plots. Note the increasing number of samples above the OSI=100 line with increasing oil gravities (i.e., increasing $S1_{CF}$). The number of samples which has OSI greater than 100 is 10, 34, 45 and 50 for the measured $S1$, 35, 40, and 45 API oils, respectively (i.e., hachured samples in Table 2). It is interesting to note that OSI > 100 samples are concentrated in the five wells; Alacaoglu-1, Bahcedere-1, Kaynarca-1, Kumrular-1 and Terziler-2. Two of the three Kumrular-1 well samples are the exceptions among the all the samples and show overwhelmingly high OSIs.

Fig. 10 shows TOC, $S1_{\text{corr}}$ vs. Depth graph focuses only on the Alacaoglu-1 samples. As can be seen, there are three OCE zones. Zone-A shows 11 continuous OCE between 3020 and 3130 m (110 m in thickness). However, in this study, during OIP calculation, the 110 m itself is not taken as a net thickness of oil saturated zone instead the thickness of oil saturated zone is taken as of 16.5 m. In essence, we assume each of OCE showing sample presents 1.5 m oil saturated zone. Eleven OCE showing samples then form a 16.5 m continuous oil saturated zone. We also assume that an oil saturated zone must consist of at least two samples. Similar format of these assumptions is also applied to other wells. Zones B and C are oil saturated zones at 3200 and 3280 m and each zone consist of only one sample, therefore, these single zones are excluded from total thickness calculations (Fig. 10).

4.3. Estimation of oil in-place (OIP) resource volume in the Mezardere Shale

A spreadsheet showing OIP estimation algorithm for the five wells and for the core area is given in Table 3. For convenience, this section is divided into two subdivisions: OIP estimation for the five

Table 2
Corrected measured Rock-Eval *S*1 values for %C15 minus hydrocarbons when the retained oil API gravities in the Mezardere Shale are of 35°, 40° and 45°.

	Well name	Depth (m)	TOC	*S*1	35APIS1c	40APIS1c	45APIS1c	OSI	35APIOSIc	40APIOSIc	45APIS1c
1	**Alacao-1**	3010	0.26	0.15	0.23	0.28	0.36	58	88	108	140
		3020	0.30	0.25	0.38	0.47	0.61	83	128	156	202
		3030	0.41	0.36	0.55	0.67	0.87	88	134	164	212
		3040	0.39	0.34	0.52	0.64	0.82	87	133	163	211
		3050	0.28	0.35	0.54	0.65	0.85	125	191	234	303
		3060	0.46	0.33	0.50	0.62	0.80	72	110	134	174
		3070	0.40	0.33	0.50	0.62	0.80	83	126	154	200
		3080	0.41	0.33	0.50	0.62	0.80	80	123	151	195
		3090	0.35	0.28	0.43	0.52	0.68	80	122	150	194
		3100	0.23	0.23	0.35	0.43	0.56	100	153	187	242
		3110	0.32	0.32	0.49	0.60	0.77	100	153	187	242
		3130	0.41	0.27	0.41	0.50	0.65	66	101	123	159
		3140	0.36	0.23	0.35	0.43	0.56	64	98	119	155
		3110	0.30	0.10	0.15	0.19	0.24	33	51	62	81
		3140	0.24	0.16	0.25	0.30	0.39	67	103	125	161
		3160	0.47	0.19	0.29	0.36	0.46	40	62	76	98
		3162	0.40	0.25	0.38	0.47	0.61	63	96	117	151
		3180	0.35	0.20	0.31	0.37	0.48	57	88	107	138
		3200	0.33	0.28	0.43	0.52	0.68	85	131	159	205
		3240	0.19	0.09	0.14	0.17	0.22	47	73	89	115
		3280	0.19	0.16	0.25	0.30	0.39	84	130	157	204
		3300	0.26	0.16	0.25	0.30	0.39	62	95	115	149
		3320	0.16	0.08	0.12	0.15	0.19	50	77	94	121
		3340	0.31	0.12	0.18	0.22	0.29	39	60	72	94
		3380	0.52	0.13	0.20	0.24	0.31	25	38	47	61
		3400	0.96	0.17	0.26	0.32	0.41	18	27	33	43
		3420	0.67	0.18	0.28	0.34	0.44	27	41	50	65
		3480	0.47	0.22	0.34	0.41	0.53	47	72	88	113
		3520	0.46	0.11	0.17	0.21	0.27	24	37	45	58
		3580	0.56	0.15	0.23	0.28	0.36	27	41	50	65
		3600	0.62	0.13	0.20	0.24	0.31	21	32	39	51
		3620	0.48	0.09	0.14	0.17	0.22	19	29	35	45
		3660	0.77	0.18	0.28	0.34	0.44	23	36	44	57
2	**Alipasa-1**	1000	0.50	0.04	0.06	0.07	0.10	8	12	15	19
		1074	0.64	0.05	0.08	0.09	0.12	8	12	15	19
		1100	0.85	0.11	0.17	0.21	0.27	13	20	24	31
		1280	0.71	0.06	0.09	0.11	0.15	8	13	16	20
		1300	0.72	0.04	0.06	0.07	0.10	5	9	10	13
		1320	0.67	0.08	0.12	0.15	0.19	12	18	22	29
		1350	0.53	0.07	0.11	0.13	0.17	13	20	25	32
3	**Arizbaba-1**	2090	0.43	0.05	0.08	0.09	0.12	12	18	22	28
		2140	0.39	0.04	0.06	0.07	0.10	10	16	19	25
		2190	0.80	0.11	0.17	0.21	0.27	14	21	26	33
		2240	0.90	0.11	0.17	0.21	0.27	12	19	23	30
		2320	0.72	0.10	0.15	0.19	0.24	14	21	26	34
		2410	0.75	0.14	0.22	0.26	0.34	19	29	35	45
		2440	0.65	0.10	0.15	0.19	0.24	15	24	29	37
		2470	0.76	0.21	0.32	0.39	0.51	28	43	52	67
		2500	0.75	0.16	0.25	0.30	0.39	21	33	40	52
		2580	0.32	0.18	0.28	0.34	0.44	56	87	105	136
		2620	0.79	0.29	0.45	0.54	0.70	37	56	69	89
		2640	0.68	0.15	0.23	0.28	0.36	22	34	41	53
		2680	0.38	0.10	0.15	0.19	0.24	26	40	49	64
		2710	0.39	0.08	0.12	0.15	0.19	21	32	38	50
4	**Bahcedere-1**	1900	1.06	0.04	0.06	0.07	0.10	3	6	7	9
		2000	1.10	0.06	0.09	0.11	0.15	5	8	10	13
		2100	2.08	0.40	0.62	0.75	0.97	19	30	36	47
		2200	0.94	0.07	0.11	0.13	0.17	8	11	14	18
		2300	1.28	0.07	0.11	0.13	0.17	5	8	10	13
		2400	0.85	0.08	0.12	0.15	0.19	9	14	18	23
		2500	1.23	0.37	0.57	0.69	0.90	30	46	56	73
		2600	1.56	1.34	2.06	2.51	3.24	86	132	161	208
		2700	0.98	0.53	0.82	0.99	1.28	54	83	101	131
		2800	0.55	0.69	1.06	1.29	1.67	126	193	235	304
		2900	1.35	0.75	1.15	1.40	1.82	55	85	104	134
		3000	0.87	0.50	0.77	0.94	1.21	57	88	107	139
		3001	0.35	0.29	0.45	0.54	0.70	83	127	155	201
5	**Cengiz/1A**	1170	0.40	0.08	0.12	0.15	0.19	20	31	37	48

Table 2 (*continued*)

	Well name	Depth (m)	TOC	*S*1	35APIS1c	40APIS1c	45APIS1c	OSI	35APIOSIc	40APIOSIc	45APIS1c
6	**Celtik-1**	1100	1.61	0.43	0.66	0.80	1.04	26	41	50	65
		1300	0.82	0.06	0.09	0.11	0.15	8	11	14	18
		1500	0.62	0.08	0.12	0.15	0.19	12	20	24	31
		1700	0.81	0.12	0.18	0.22	0.29	15	23	28	36
		1900	0.55	0.12	0.18	0.22	0.29	22	34	41	53
7	**Corlu-3A**	1580	1.00	0.14	0.22	0.26	0.34	14	22	26	34
		1696	0.73	0.10	0.15	0.19	0.24	14	21	26	33
		1954	0.65	0.15	0.23	0.28	0.36	23	36	43	56
8	**D.Alipaşa**	1076	0.88	0.07	0.11	0.13	0.17	8	12	15	19
		1280	0.73	0.06	0.09	0.11	0.15	8	13	15	20
		1400	0.71	0.08	0.12	0.15	0.19	11	17	21	27
9	**Degirmencik-2**	1900	1.50	0.07	0.11	0.13	0.17	4	7	9	11
		2010	1.03	0.05	0.08	0.09	0.12	5	7	9	12
		2330	1.23	0.01	0.02	0.02	0.02	1	1	2	2
		2530	0.82	0.12	0.18	0.22	0.29	15	23	27	35
		2600	0.67	0.23	0.35	0.43	0.56	35	53	64	83
		2650	0.63	0.23	0.35	0.43	0.56	37	56	68	88
10	**Delen-1**	2718	2.17	0.23	0.35	0.43	0.56	11	16	20	26
		2480	1.10	0.14	0.22	0.26	0.34	13	20	24	31
11	**Hamitabat-8**	1938	1.05	0.14	0.22	0.26	0.34	13	21	25	32
		2064	0.79	0.08	0.12	0.15	0.19	10	16	19	25
		2202	0.65	0.08	0.12	0.15	0.19	12	19	23	30
		2324	0.44	0.06	0.09	0.11	0.15	14	21	26	33
		2412	0.44	0.06	0.09	0.11	0.15	14	21	26	33
		2510	0.57	0.08	0.12	0.15	0.19	14	22	26	34
		2636	0.72	0.09	0.14	0.17	0.22	13	19	23	30
12	**K.Cerkezkoy-1**	1044	1.07	0.12	0.18	0.22	0.29	11	17	21	27
		1250	1.47	0.16	0.25	0.30	0.39	11	17	20	26
13	**Kandamış-1**	1668	0.55	0.08	0.12	0.15	0.19	15	22	27	35
		1678	0.57	0.49	0.75	0.92	1.19	86	132	161	208
		1878	0.66	0.21	0.32	0.39	0.51	32	49	60	77
		2232	0.30	0.05	0.08	0.09	0.12	17	26	31	40
		2075	0.55	0.10	0.15	0.19	0.24	18	28	34	44
		2224	0.62	0.01	0.02	0.02	0.02	2	2	3	4
		2868	0.42	0.24	0.37	0.45	0.58	57	88	107	138
14	**Karacaoglan-1**	2096	0.60	0.03	0.05	0.06	0.07	5	8	9	12
		2122	0.94	0.10	0.15	0.19	0.24	11	16	20	26
		2130	1.21	0.23	0.35	0.43	0.56	19	29	36	46
		2346	0.61	0.04	0.06	0.07	0.10	7	10	12	16
		2570	0.84	0.68	1.05	1.27	1.65	81	125	151	196
		2596	0.46	0.04	0.06	0.07	0.10	9	13	16	21
		2669	1.50	0.38	0.58	0.71	0.92	25	39	47	61
		2750	0.62	0.11	0.17	0.21	0.27	18	27	33	43
		2786	0.36	0.06	0.09	0.11	0.15	17	26	31	40
		2792	0.44	0.02	0.03	0.04	0.05	5	7	9	11
15	**Karacaoglan-2**	1820	0.91	0.08	0.12	0.15	0.19	9	14	16	21
		1940	1.02	0.12	0.18	0.22	0.29	12	18	22	28
		2060	1.12	0.12	0.18	0.22	0.29	11	16	20	26
		2191	1.20	0.18	0.28	0.34	0.44	15	23	28	36
		2322	0.95	0.13	0.20	0.24	0.31	14	21	26	33
		2460	0.79	0.14	0.22	0.26	0.34	18	27	33	43
		2640	0.68	0.12	0.18	0.22	0.29	18	27	33	43
		2758	0.50	0.12	0.18	0.22	0.29	24	37	45	58
16	**Karakavak-1**	1706	0.85	0.09	0.14	0.17	0.22	11	16	20	26
		1984	0.79	0.11	0.17	0.21	0.27	14	21	26	34
		2033	0.89	0.04	0.06	0.07	0.10	4	7	8	11
		2184	0.71	0.06	0.09	0.11	0.15	8	13	16	20
		2228	0.78	0.06	0.09	0.11	0.15	8	12	14	19
		2290	0.92	0.09	0.14	0.17	0.22	10	15	18	24

Table 2 (*continued*)

	Well name	Depth (m)	TOC	*S*1	35APIS1c	40APIS1c	45APIS1c	OSI	35APIOSIc	40APIOSIc	45APIS1c
		2472	0.86	0.15	0.23	0.28	0.36	17	27	33	42
		2654	0.87	0.23	0.35	0.43	0.56	26	41	49	64
		2777	0.65	0.20	0.31	0.37	0.48	31	47	58	74
		2972	0.44	0.12	0.18	0.22	0.29	27	42	51	66
17	**Kaynarca-1**	2528	0.53	0.35	0.54	0.65	0.85	66	102	123	160
		2568	1.12	0.61	0.94	1.14	1.48	54	84	102	132
		2722	0.61	0.40	0.62	0.75	0.97	66	101	123	159
		2794	0.52	0.42	0.65	0.79	1.02	81	124	151	195
		2918	0.49	0.39	0.60	0.73	0.94	80	122	149	193
		3006	0.42	0.42	0.65	0.79	1.02	100	154	187	242
18	**Kepirtepe**	2130	0.89	1.72	2.65	3.22	4.16	193	297	361	468
		2350	1.15	0.30	0.46	0.56	0.73	26	40	49	63
		2440	1.32	3.86	5.94	7.22	9.34	292	450	547	708
		2480	0.97	0.14	0.22	0.26	0.34	14	22	27	35
		2540	1.58	1.26	1.94	2.36	3.05	80	123	149	193
		2600	1.20	0.45	0.69	0.84	1.09	38	58	70	91
		2706	2.96	3.50	5.38	6.55	8.47	118	182	221	286
19	**Kumrular-1**	1510	1.34	0.12	0.18	0.22	0.29	9	14	17	22
		1550	1.44	0.10	0.15	0.19	0.24	7	11	13	17
		1550	0.70	0.09	0.14	0.17	0.22	13	20	24	31
		1690	1.61	0.29	0.45	0.54	0.70	18	28	34	44
		1730	1.86	0.37	0.57	0.69	0.90	20	31	37	48
		1730	0.87	0.09	0.14	0.17	0.22	10	16	19	25
		1760	1.65	0.43	0.66	0.80	1.04	26	40	49	63
		1830	1.32	0.00	0.00	0.00	0.00	0	0	0	0
		1890	1.32	0.38	0.58	0.71	0.92	29	44	54	70
		1930	1.72	0.71	1.09	1.33	1.72	41	64	77	100
		1970	1.54	0.51	0.78	0.95	1.23	33	51	62	80
		2020	1.31	0.36	0.55	0.67	0.87	27	42	51	67
		2060	2.66	25.36	39.02	47.42	61.37	953	1467	1783	2307
		2080	2.98	18.25	28.08	34.13	44.17	612	942	1145	1482
		2100	1.26	4.16	6.40	7.78	10.07	330	508	617	799
		2140	1.25	0.80	1.23	1.50	1.94	64	98	120	155
		2210	0.91	0.11	0.17	0.21	0.27	12	19	23	29
		2270	0.93	0.15	0.23	0.28	0.36	16	25	30	39
		2340	0.96	0.16	0.25	0.30	0.39	17	26	31	40
		2400	0.88	0.14	0.22	0.26	0.34	16	24	30	39
		2440	0.94	0.14	0.22	0.26	0.34	15	23	28	36
		2490	0.95	0.22	0.34	0.41	0.53	23	36	43	56
20	**Mezardere-1**	1000	0.91	0.03	0.05	0.06	0.07	4	5	6	8
		1050	0.63	0.05	0.08	0.09	0.12	8	12	15	19
		1100	0.57	0.02	0.03	0.04	0.05	4	5	7	8
		1150	0.98	0.02	0.03	0.04	0.05	2	3	4	5
		1200	0.69	0.05	0.08	0.09	0.12	7	11	14	18
21	**Osmancık-2**	1800	0.58	0.51	0.78	0.95	1.23	88	135	164	213
		1801	0.58	0.09	0.14	0.17	0.22	16	24	29	38
		1850	0.60	0.12	0.18	0.22	0.29	20	31	37	48
22	**Sogucak-1**	1000	1.92	0.07	0.11	0.13	0.17	4	6	7	9
		1050	2.33	0.12	0.18	0.22	0.29	5	8	10	12
23	**Sutluce-1**	1000	0.90	0.04	0.06	0.07	0.10	4	7	8	11
		1050	1.17	0.04	0.06	0.07	0.10	3	5	6	8
		1100	1.35	0.03	0.05	0.06	0.07	2	3	4	5
		1150	1.10	0.08	0.12	0.15	0.19	7	11	14	18
24	**Sarkoy-1**	1100	0.61	0.05	0.08	0.09	0.12	8	13	15	20
		1200	0.36	0.02	0.03	0.04	0.05	6	9	10	13
25	**Tatarkoy-1**	1410	0.81	0.07	0.11	0.13	0.17	9	13	16	21
		1450	0.66	0.07	0.11	0.13	0.17	11	16	20	26
		1510	0.80	0.10	0.15	0.19	0.24	13	19	23	30
		1550	1.24	0.30	0.46	0.56	0.73	24	37	45	59
		1610	1.10	0.31	0.48	0.58	0.75	28	43	53	68
		1640	0.70	0.14	0.22	0.26	0.34	20	31	37	48

Table 2 (*continued*)

	Well name	Depth (m)	TOC	*S*1	35APIS1c	40APIS1c	45APIS1c	OSI	35APIOSIc	40APIOSIc	45APIS1c
		1690	0.68	0.17	0.26	0.32	0.41	25	38	47	61
		1910	0.83	0.21	0.32	0.39	0.51	25	39	47	61
		1960	0.98	0.14	0.22	0.26	0.34	14	22	27	35
		1990	0.73	0.11	0.17	0.21	0.27	15	23	28	36
		2060	0.58	0.08	0.12	0.15	0.19	14	21	26	33
		2080	0.52	0.09	0.14	0.17	0.22	17	27	32	42
		2130	0.64	0.12	0.18	0.22	0.29	19	29	35	45
		2200	0.45	0.09	0.14	0.17	0.22	20	31	37	48
		2240	0.50	0.09	0.14	0.17	0.22	18	28	34	44
		2300	0.50	0.15	0.23	0.28	0.36	30	46	56	73
		2360	0.30	0.09	0.14	0.17	0.22	30	46	56	73
26	**Terzili-1**	2560	0.84	0.60	0.92	1.12	1.45	71	110	134	173
27	**Terzili-2**	1840	0.86	0.18	0.28	0.34	0.44	21	32	39	51
		2150	0.92	0.34	0.52	0.64	0.82	37	57	69	89
		2200	1.05	0.39	0.60	0.73	0.94	37	57	69	90
		2570	0.81	0.57	0.88	1.07	1.38	70	108	132	170
		2600	0.91	1.51	2.32	2.82	3.65	166	255	310	402
		2874	0.71	0.49	0.75	0.92	1.19	69	106	129	167
28	**Umurca-1**	2190	1.43	0.09	0.14	0.17	0.22	6	10	12	15
		2200	0.96	0.02	0.03	0.04	0.05	2	3	4	5
		2240	1.23	0.08	0.12	0.15	0.19	7	10	12	16
		2270	1.04	0.05	0.08	0.09	0.12	5	7	9	12
		2290	1.43	0.10	0.15	0.19	0.24	7	11	13	17
		2368	0.86	0.06	0.09	0.11	0.15	7	11	13	17
		2430	0.92	0.08	0.12	0.15	0.19	9	13	16	21
		2500	1.17	0.08	0.12	0.15	0.19	7	11	13	17
		2630	0.92	0.11	0.17	0.21	0.27	12	18	22	29
		2640	1.12	0.10	0.15	0.19	0.24	9	14	17	22
		2690	0.84	0.14	0.22	0.26	0.34	17	26	31	40
		2720	0.77	0.01	0.02	0.02	0.02	1	2	2	3
		2750	1.23	0.10	0.15	0.19	0.24	8	13	15	20
		2860	0.99	0.10	0.15	0.19	0.24	10	16	19	24
		2878	0.82	0.07	0.11	0.13	0.17	9	13	16	21
		3110	0.97	0.17	0.26	0.32	0.41	18	27	33	42
		3250	1.03	0.28	0.43	0.52	0.68	27	42	51	66
		3280	0.80	0.21	0.32	0.39	0.51	26	40	49	64
29	**Uctepeler-1**	1850	1.01	0.96	1.48	1.80	2.32	95	146	178	230
		1850	0.77	0.22	0.34	0.41	0.53	29	44	53	69
		1900	0.65	0.14	0.22	0.26	0.34	22	33	40	52
		1950	0.39	0.05	0.08	0.09	0.12	13	20	24	31
30	**Vakıflar-1**	2013	0.79	0.02	0.03	0.04	0.05	3	4	5	6
		2059	1.12	0.15	0.23	0.28	0.36	13	21	25	32
		2104	1.47	0.12	0.18	0.22	0.29	8	13	15	20
		2151	1.28	0.09	0.14	0.17	0.22	7	11	13	17
		2181	0.81	0.04	0.06	0.07	0.10	5	8	9	12
		2210	1.12	0.04	0.06	0.07	0.10	4	5	7	9
		2226	1.14	0.02	0.03	0.04	0.05	2	3	3	4
		2241	1.07	0.06	0.09	0.11	0.15	6	9	10	14
		2271	1.07	0.24	0.37	0.45	0.58	22	35	42	54
		2287	1.02	0.09	0.14	0.17	0.22	9	14	17	21
		2302	0.93	0.07	0.11	0.13	0.17	8	12	14	18
		2357	1.14	0.10	0.15	0.19	0.24	9	13	16	21
		2390	1.34	0.09	0.14	0.17	0.22	7	10	13	16
		2439	0.95	0.04	0.06	0.07	0.10	4	6	8	10
		2454	1.17	0.13	0.20	0.24	0.31	11	17	21	27
		2470	1.23	0.20	0.31	0.37	0.48	16	25	30	39
		2485	1.20	1.38	2.12	2.58	3.34	115	177	215	278
		2531	1.20	0.22	0.34	0.41	0.53	18	28	34	44
		2576	1.10	0.16	0.25	0.30	0.39	15	22	27	35
		2598	1.20	0.15	0.23	0.28	0.36	13	19	23	30
		2616	1.10	0.14	0.22	0.26	0.34	13	20	24	31
		2683	1.11	0.31	0.48	0.58	0.75	28	43	52	68
		2698	1.10	0.16	0.25	0.30	0.39	15	22	27	35
		2713	1.48	0.21	0.32	0.39	0.51	14	22	27	34
		2729	1.05	0.16	0.25	0.30	0.39	15	23	28	37
		2851	1.01	0.14	0.22	0.26	0.34	14	21	26	34
		2872	1.16	0.29	0.45	0.54	0.70	25	38	47	61

Table 2 (*continued*)

Well name	Depth (m)	TOC	*S*1	35APIS1c	40APIS1c	45APIS1c	OSI	35APIOSIc	40APIOSIc	45APIS1c
	2876	1.02	0.19	0.29	0.36	0.46	19	29	35	45
	2918	1.01	0.29	0.45	0.54	0.70	29	44	54	69
	3049	1.01	0.28	0.43	0.52	0.68	28	43	52	67
	3122	1.22	0.33	0.51	0.62	0.80	27	42	51	65
	3137	1.08	0.31	0.48	0.58	0.75	29	44	54	69
	3156	1.07	0.34	0.52	0.64	0.82	32	49	59	77
	3186	1.00	0.21	0.32	0.39	0.51	21	32	39	51
	3217	1.10	0.19	0.29	0.36	0.46	17	27	32	42
	3247	0.99	0.18	0.28	0.34	0.44	18	28	34	44
	3262	0.94	0.16	0.25	0.30	0.39	17	26	32	41
	3323	0.91	0.17	0.26	0.32	0.41	19	29	35	45
	3338	0.91	0.19	0.29	0.36	0.46	21	32	39	51
	3384	0.80	0.21	0.32	0.39	0.51	26	40	49	64
	3430	0.95	0.22	0.34	0.41	0.53	23	36	43	56
	3445	0.84	0.24	0.37	0.45	0.58	29	44	53	69
	3506	0.86	0.32	0.49	0.60	0.77	37	57	70	90
	3537	0.87	0.20	0.31	0.37	0.48	23	35	43	56
	3582	0.81	0.25	0.38	0.47	0.61	31	47	58	75
	3628	0.91	0.17	0.26	0.32	0.41	19	29	35	45
	3643	0.91	0.22	0.34	0.41	0.53	24	37	45	59
	3674	0.88	0.14	0.22	0.26	0.34	16	24	30	39
	3689	0.83	0.22	0.34	0.41	0.53	27	41	50	64

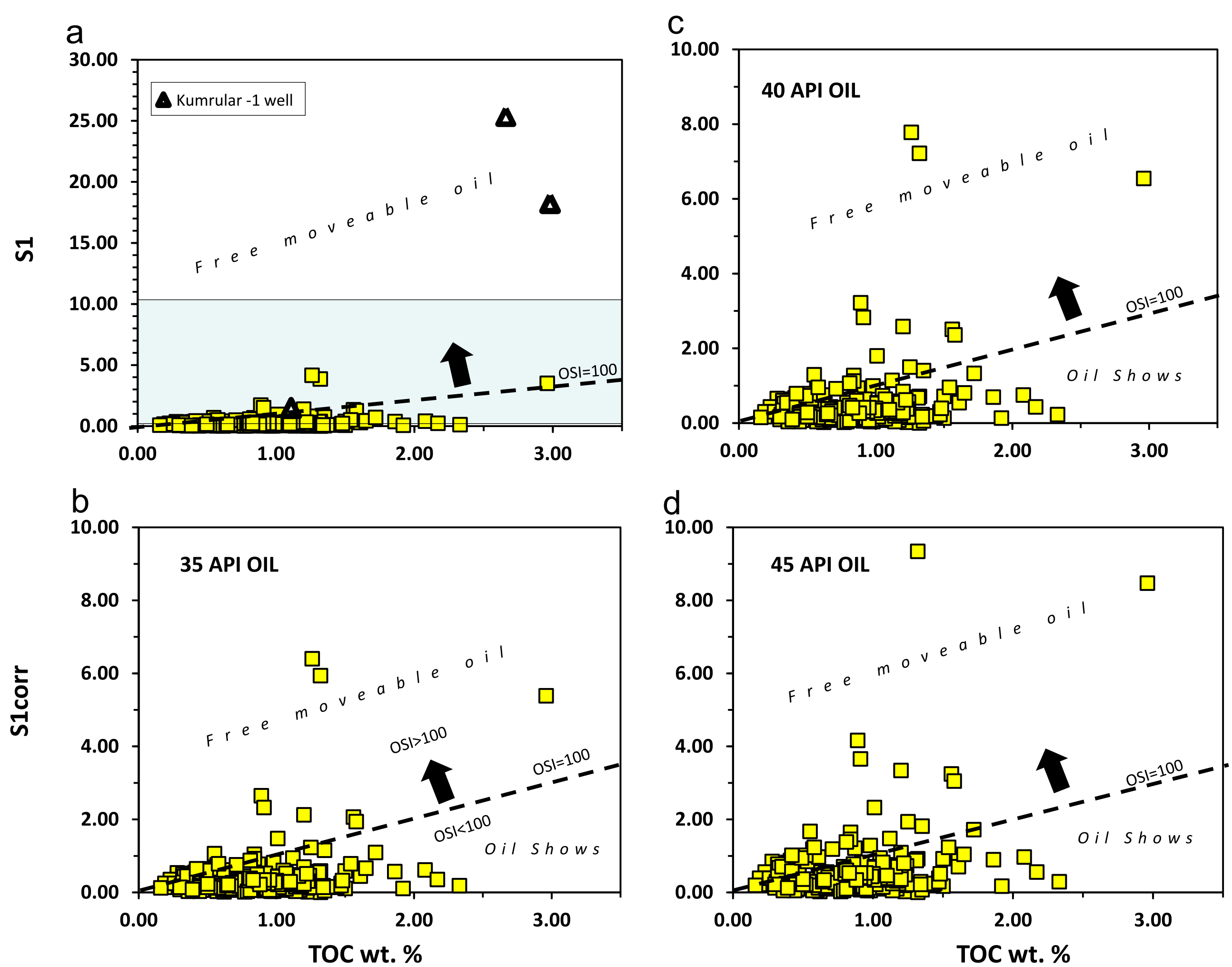

Fig. 9. Graphs showing increasing the retained oil crossover effect (*S*1 > TOC) in the Mezardere Shale samples with API gravity: Measured *S*1 vs. TOC (a), $S1_{corr}$ for 35 API oil (b), $S1_{corr}$ for 40 API oil (c) and $S1_{corr}$ for 45 API oil (d). Note the exceptionally high OSI values for two Kumrular-1 samples shown in (a) caused vertical axis changes from 0–30 to 0–10 in b–d.

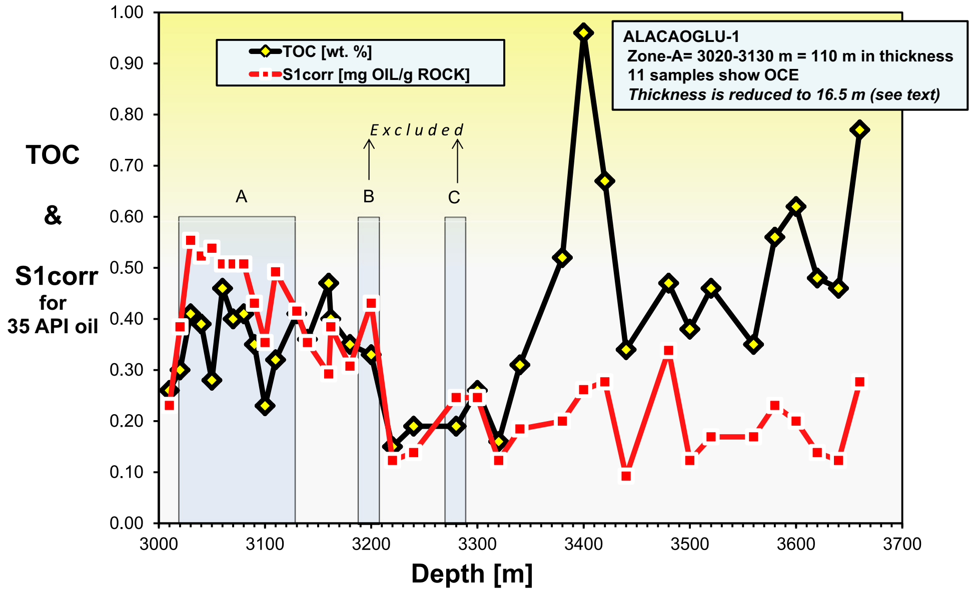

Fig. 10. TOC, $S1_{corr}$ for 35 API oil vs. TOC diagram showing oil cross over effect (OCE) zones in the Mezardere Shale along the Alacaoglu-1 well. Accordingly, oil saturated zones of A, B and C are 16.5 (11 OCE showing samples × 1.5 m), 1.5 and 1.5 m in thickness, respectively (see text for more detail).

wells and the total OIP estimation of the core area.

4.3.1. *OIP estimation at each of the five wells*

It should be emphasized that OSI is used in qualitative assessments such as selecting oil saturated zones whereas *S*1 is used as a multiplication parameter in the OIP formula. As previously mentioned, continuous oil saturated zones are encountered and concentrated in the Alacaoğlu-1, Bahçedere-1, Kaynarca-1, Kumrular-1 and Terzili-2 wells (see Fig. 7 for the well locations). OIP estimation is then carried out by placing the input data given in Columns 2–7 of Table 3 into the formula given by Michael et al. (2013):

$$\text{OIP (bbl/ac–ft)} = \text{S1corr}*(\text{Shale density/oil density})*7.$$

The first step is the calculation OIP in bbl/ac-ft (barrel/acre-foot) as in Column 13 of Table 3 and the second step is the scaling the first step OIP to well dimensions (Column 16 in Table 3).

Description of input parameters given in Columns 2–7 in Table 2 and their effect on the resulting oil volume are as follows:

Parameter 1 (%) (probabilistic distribution): Estimation is made at three levels: P10%, P90% and P50%. In conjunction with their long running AAPG School, Rose (2001), Capen (1996) and Megill (1984) developed a graphical procedure to carry out the analytical method by which several probabilistic distributions may be combined by multiplication. This procedure gives ideal results that occur through multi-trial Monte Carlo or Latin Hypercube simulation, In probabilistic estimations, we estimate high side P10% and low side P90% and we plot them on a cumulative log probability chart to find median P50% value (In detail see Rose (2001); Appendix B, p. 127).

Parameter 2 (API gravity): During OIP estimation of the five wells, we assume oil gravities of 45, 35 and 40 for the P10%, P90% and P50%, respectively. The character of Mezardere derived fluids, maturity levels of the wells and API gravity distribution in analogous basins (Barnett and Bakken shales in Jarvie, 2012b, Jarvie et al. 2011; Jurassic shales in Weald Basin in British Geological Survey – BGS, 2014) are considered in estimations. Selection of 45 API oil gravity would result in higher OIP values than selection of 35 API oil for the well or area.

Parameters 3 (oil density): Density of retained oil is calculated using the formula given by American Petroleum Institute. Higher values of oil density (i.e., low API gravity) would have a reducing effect on the OIP volume resources.

Parameter 4 (shale density): We use shale density of 2.6, 2.4 and 2.5 g/cm^3 for P10, P90 and P50 throughout this study. However, it is speculative subject since it is controlled by various features of the shale itself. While shale density increases the resulting OIP value increases.

Parameter 5 (measured *S*1): Measured Rock-Eval *S*1 (mg Oil/g Rock) indicates minimum free oil volume in the rock. In this study, measured *S*1 reading is corrected for evaporative loss from 35, 40 and 45 API oils. While measured *S*1 increases OIP value increases.

Parameter 6 (thickness, m): It is an effective parameter on OIP value. In this study, the thickness of the oil saturated zones is determined by using the method described in the Section 4.2.

Parameter 7 (Area, m^2): The average well spacing for Eagle Ford shale oil play, five wells per square mile (i.e., 1 well/518000 m^2) (USEIA, July 2011) is taken as an analogous with Thrace wells. That gives 407 m spacing between the two vertical wells. An area of 518,000 m^2 is applied to the five wells even for the high (P10) and Low (P90) sides of probabilistic estimations. In essence, while the area increases OIP value increases.

Parameter 8 (%C15 minus lost): it was calculated using the following formula: [(API gravity − 20.799)/0.412]/100 (Michael et al., 2013).

Parameter 9 (CF) (Correction Factor): Correction is *S*1 pyrolysis parameter using the following formula: CF = 1/[1 − (C15 minus lost)].

Parameter 10 ($S1_{corr}$): It is calculated as $S1_{corr}$ = measured *S*1 in Column 5 × CF in Column 9.

Parameter 11 (it is the *A* in Fig. 8): It is calculated using the following formula:

$$A = (\text{Shale density in Column 4/Oil density in Column 3}) \times 7.758$$

Parameter 12 (OIP, bbl/ac-ft): It is calculated as OIP (bbl/ac-

Table
3 A spread sheet showing OIP estimation algorithm for the five oil rich wells as well as for the core area in northwestern Thrace Basin. Location of the five wells and core area are given Figs. 7 and12.

Well name	1 **%**	2 **API gravity**	3 **Oil density**	4 **Shale density**	5 **Measured *S1***	6 **Thick. (m)**	7 **Area (m^2)**	8 **%C15 minus loss**	9 **CF**	10 $S1_{corr}$	11 **(2/3) *7758**	12 **OIP (bbl/ ac-ft)**	13 **OIP (bbl/ m^3)**	14 **GRV (m^3)**	15 **OIP (bbl)**	16 **OIP (M bbl^{-1})**	17 **OIP (MM bbl)**	18 **OIP (M bbl^{-2})**	19 **Msw**
Alacaoglu-	P10	45	0.802	2.6	0.31	30	518000	0.587	2.424	0.7513	25.15	18.8966	0.0153	15540000	238067	238	0.238	200	134
1	P90	35	0.85	2.4	0.28	16.5	518000	0.345	1.526	0.4273	21.90	9.3594	0.0076	8547000	64853	65	0.065	85	
	P50	40	0.825	2.5	0.29	27	518000	0.466	1.873	0.5431	23.51	12.7682	0.0104	13986000	144773	145	0.145	120	
Bahcedere-	P10	45	0.802	2.6	0.68	9	518000	0.587	2.424	1.6481	25.15	41.4507	0.0336	4662000	156664	157	0.157	115	84
1	P90	35	0.85	2.4	0.68	4.5	518000	0.345	1.526	1.0377	21.90	22.7301	0.0184	2331000	42954	43	0.043	51	
	P50	40	0.825	2.5	0.68	7	518000	0.466	1.873	1.2735	23.51	29.9391	0.0243	3626000	88010	88	0.088	86	
Kaynarca-	P10	45	0.802	2.6	0.43	9	518000	0.587	2.424	1.0422	25.15	26.2115	0.0212	4662000	99067	99	0.099	85	62
1	P90	35	0.85	2.4	0.41	6	518000	0.345	1.526	0.6257	21.90	13.7049	0.0111	3108000	34532	35	0.035	45	
	P50	40	0.825	2.5	0.42	8	518000	0.466	1.873	0.7866	23.51	18.4918	0.0150	4144000	62125	62	0.062	60	
Kumrular-	P10	45	0.802	2.6	15.92	6	518000	0.587	2.424	38.5849	25.15	970.4332	0.7867	3108000	2445183	2445	2.445	2100	1670
1	P90	35	0.85	2.4	15.92	4.5	518000	0.345	1.526	24.2936	21.90	532.1508	0.4314	2331000	1005638	1006	1.006	1200	
	P50	40	0.825	2.5	15.92	5	518000	0.466	1.873	29.8152	23.51	700.9276	0.5682	2590000	1471762	1472	1.472	1700	
Terziler-2	P10	45	0.802	2.6	0.86	4.5	518000	0.587	2.424	2.0844	25.15	52.4229	0.0425	2331000	99067	99	0.099	88	73
	P90	35	0.85	2.4	0.86	4.5	518000	0.345	1.526	1.3123	21.90	28.7468	0.0233	2331000	54325	54	0.054	60	
	P50	40	0.825	2.5	0.86	4.5	518000	0.466	1.873	1.6106	23.51	37.8642	0.0307	2331000	71554	72	0.072	71	
Core area																			
Scenario 1	P10	35	0.85	2.6	1	30	1E+09	0.345	1.526	1.5260	23.73	36.2121	0.0294	3E+10	880723751	880724	881	470	246
	P90	35	0.85	2.4	0.35	4.5	1E+09	0.345	1.526	0.5341	21.90	11.6993	0.0095	4.5E+09	42681228	42681	43	82	
	P50	35	0.85	2.5	0.52	11	1E+09	0.345	1.526	0.7935	22.82	18.1061	0.0147	1.1E+10	161466021	161466	161	200	
	P10	40	0.825	2.6	1	30	1E+09	0.466	1.873	1.8728	24.45	45.7892	0.0371	3E+10	1113651804	1113652	1114	620	
Scenario 2	P90	40	0.825	2.4	0.35	4.5	1E+09	0.466	1.873	0.6555	22.57	14.7934	0.0120	4.5E+09	53969280	53969	54	110	323
	P50	40	0.825	2.5	0.52	11	1E+09	0.466	1.873	0.9739	23.51	22.8946	0.0186	1.1E+10	204169497	204169	204	260	
	P10	45	0.802	2.6	1	30	1E+09	0.587	2.424	2.4237	25.15	60.9569	0.0494	3E+10	1482547343	1482547	1483	800	
Scenario 3	P90	45	0.802	2.4	0.35	4.5	1E+09	0.587	2.424	0.8483	23.22	19.6938	0.0160	4.5E+09	71846525	71847	72	130	407
	P50	45	0.802	2.5	0.52	11	1E+09	0.587	2.424	1.2603	24.18	30.4784	0.0247	1.1E+10	271800346	271800	272	320	

Calculations in Columns 8 through 19 were made using the following equations: **Column 8**=[(Column 2 − 20.799)/0.412]/100; **Column 9**=1/1 − (Column 8); **Column 10**=Column 5*Column 9; **Column 11**=(Column 4/Column 3) *7758; **Column 12**=Column 10*Column 11; **Column 13**=Column 12/1,233,489; **Column 14**=Column 6*Column 7; **Column 15**=Column 13*Column 14; **Column 16**=Column 15/1000; **Column 17**=Column 15/1,000,000; **Column 18** and **Column 19** are described in Rose (2006).

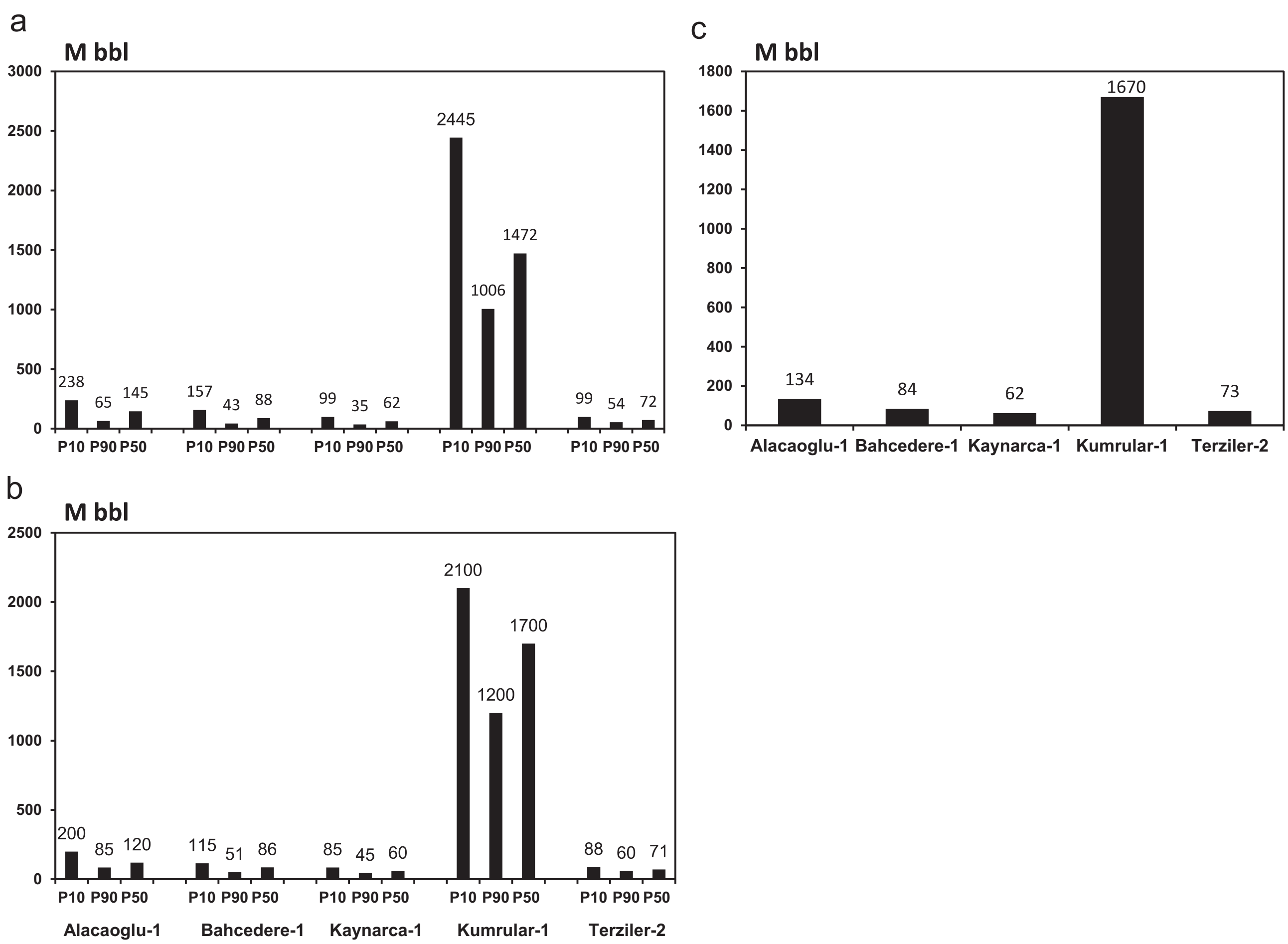

Fig. 11. A histogram prepared by using output data of the P10%, P90% and P50% OIP values belonging to the five wells given in the Column 17 of Table 3(a). Multiplication of the three P10 and P90 OIP values given in (a) result in P1.3% and P98.7%, respectively. In other words, P10% and P90% values given in (a) are plotted on a cumulative log probability plot as if they were P1.3% and P98.7%. A best line is then drawn between the two points and picked off new OIP P10%, P90%, P50% values of the each well. Finally, a new histogram is prepared (b). *Swanson's Rule* is applied to P10%, P90%, P50% values in (b) to find mean IOP values for each well. A histogram showing Msw values of each well is given in (c). Swanson's Mean (Msw)=0.3 (P90%)+0.4 (P50%)+0.3 (P10%). See Rose (2001) for more detail about estimations.

ft)=$S1_{corr}$ × Column 11
Parameter 13 (OIP, bbl/m^3): It is calculated as OIP (bbl/m^3)= OIP bbl/ac-ft/1,233,489
Parameter 14 (GRV): Gross Rock Volume (m^3)=Column 6 × Column 7
Parameter 15 (OIP bbl): Column 13 × Column 14
Parameter 16 (OIP M bbl^{-1}): Column 15/1000
Parameter 17 (OIP MM bbl): Column 16/1000
Parameter 18 (OIP Mbbl^{-2}): Calculation of P10, P50 and P90 of OIP Mbbl-2 is described in Fig. 12 of Rose (2001).
Parameter 19 (Msw): Swanson's Mean (Msw)=0.3 (P90%)+0.4 (P50%)+0.3 (P10%). See Rose (2001).

Output data for OIP well calculation are given in Table 3 and presented the three histograms shown in Fig. 11. P10%, P90% and P50% OIP values given in the Column 16 are direct calculation of the input data and presented in Fig. 11a. Fig. 11b and c demonstrates the histograms related to the Columns 18 and 19, respectively. Accordingly, Kumrular-1 well shows the highest OIP Mean Swanson (Msw) value of 1670 M bbl and Kaynarca-1 well shows the lowest Msw value of 62 M bbl (Fig. 11c) (see Fig. 11 caption for detail Msw). An average of the five wells is found to be 405 M bbl.

4.3.2. OIP estimation of the CORE area

OIP estimation of the core area, the input data (Columns 2–7) is given in Table 3. As seen, we establish the three scenarios based on the oil APIs of 35°, 40° and 45° as shown in the Column 2 of Table 3. Since the input parameters used in OIP estimation of the five wells are quite similar to the input parameters in OIP estimation for the core area, we give very brief information: For example, oil and shale densities are similar to those in Section 4.3.1. P10 and P90 values for the measured *S*1 are taken as one and 0.35. Plotting of both values on a cumulative log probability graph is resulted of P50 value of 0.52. In this case, the two measured *S*1 values from the Kumrular-1 well are not considered since we believe that measured *S*1 values of Kumrular-1 well are valid but exceptionally high. For the P10 and P90 selections of the effective thickness (Column 6), we select the highest value of P10 (30 m) and the lowest value of P90 (4.5 m) from the Column 6 of the well input data Table 3).

The core area which is the significant input parameter of the Column 7 (Table 3) is determined by plotting average OSI values of the 30 wells onto the Thrace Basin map. Then, iso-OSI contour lines are drawn using Surfer software program. Since the contour with OSI > 100 indicate oil saturated areas, we determine the area (km^2) within the OSI=100 contour line (i.e., core area) and calculate its area in km^2. Calculation shows that the area covers 1000 km^2 (Fig. 12). Locations of the five wells which contain continuous oil saturated zones are also located with respect to the core area. As noticed, the Kaynarca-1 and Bahcedere-1 wells stay

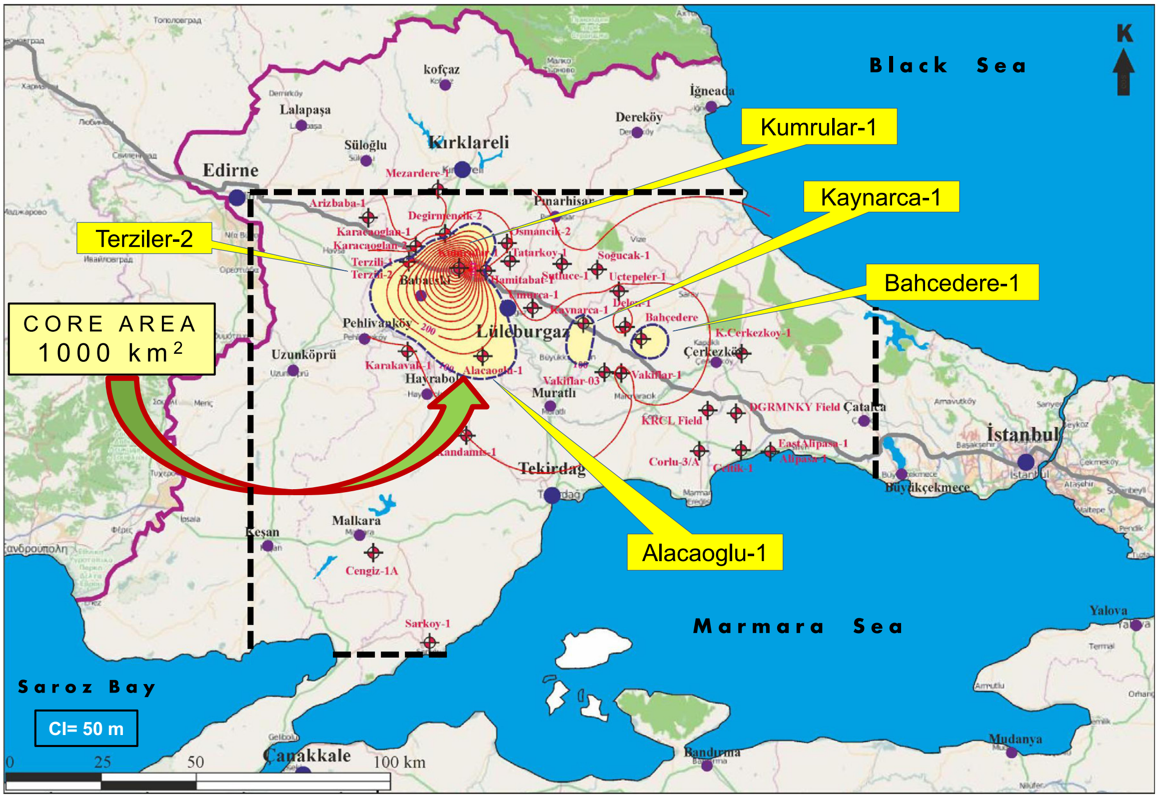

Fig. 12. A map showing iso-OSI lines of greater than 100. We selected the area within the OSI = 100 contour and call it "core area" implying that the area where we may encounter productive shale layers.

outside of the core area although both wells show oil saturated zones (Table 2). Therefore, these two wells are not considered in the resource calculation of the core area. Results of the OIP estimation of the core area is given in Table 3 and presented with three histograms shown in Fig. 13 which should be interpreted in a similar manner with Fig. 11. Accordingly, Scenario 1, Scenario 2 and Scenario 3 are organized in terms of 35, 40 and 45 API oil, respectively. Input parameters share the columns from 2 to 7 and output parameters share the columns from 8 to 19 (Table 3). Figs. 13a, b and c are prepared using the parameters in Columns 17, 18 and 19, respectively. As a result, scenario-1, -2 and -3 produce OIP Msw values of 246, 323 and 407 MM bbl (Fig. 13c). The average of the 3 scenarios is found to be 325 MM bbl.

5. Conclusions and summary

Previous work has documented the Lower Oligocene Mezardere Shale is organic-rich and thermally mature to generate hydrocarbons in the Thrace Basin. Furthermore, geochemical correlation techniques have documented that oils and condensates found in conventional reservoirs in the Thrace Basin were sourced by the Mezardere Shale. These properties of the Mezardere Shale suggest that it could be a viable target for unconventional oil and gas exploration and development provided there is a sufficient volume of hydrocarbons to economically pursue.

In this study, the total oil-in-place volume of the Lower Oligocene Mezardere Shale from Thrace Basin is estimated by using Rock-Eval pyrolysis analysis of 407 Mezardere drill cuttings and core samples belonging to 47 wells. Particular attention is paid to Rock-Eval *S*1 and TOC and maturity data. Only the samples and wells which do meet the following criteria are admitted; Sample depth > 1000 m, Rock-Eval *S*2 > 0.20 mg HC/g Rock, OSI = *S*1*100/TOC > 100 mg Oil/g TOC and oil-based mud should not be used while drilling. After exclusion of the some data, 30 wells and their 277 samples are left for further evaluation.

The following conclusions may be extracted from the current study:

1. Present and previous geochemical data suggest that API gravity of retained oil in the Mezardere Shale could range from 35° to 45° and averages at 40°. Therefore, measured *S*1 and OSI values are corrected separately for 35, 40 and 45 API gravities.
2. Based on the corrected OSI values, OIP values for the wells and the core area are estimated separately. Input data for the OIP estimations is API gravity, oil and shale densities, measured *S*1 (mg Oil/g Rock), thickness (m) of oil saturated zones with OSI > 100, and area (m^2) of the well (well spacing) and the core area (m^2).
3. OIP calculation is conducted by using Michael et al. (2013) formula for the wells as well as for the core area.
4. It was demonstrated that within the 47 wells investigated only the five wells show continuous oil saturated zones (OSI > 100). Accordingly, the Kumrular-1 well shows the highest OIP Mean Swanson (Msw) value of 1670 M bbl and the Kaynarca-1 well shows the lowest Msw value of 62 M bbl. The average Msw of the 5 well is of 405 M bbl.
5. OIP of the core area (1000 km^2) that is determined in the northwest Thrace Basin is estimated under three API gravity scenarios: 35°, 40° and 45°. Accordingly, Scenario 1, Scenario 2 and Scenario 3 produce OIP Msw values of 246, 323 and 407 MM bbl that result in an average OIP value of 325 MM bbl.

For the future study, oil-saturated zones determined in this

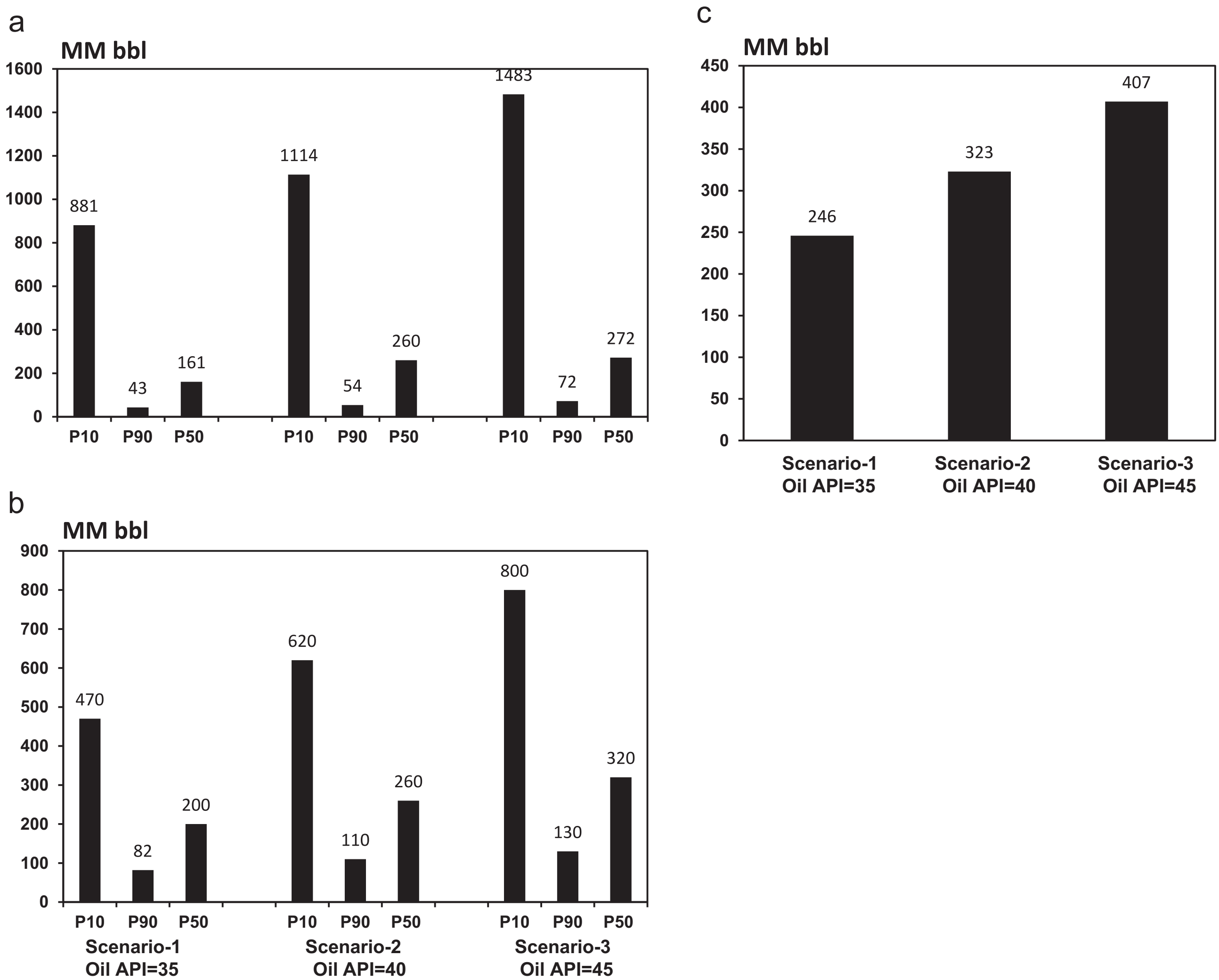

Fig. 13. Histograms showing OIP shale-oil resource estimation of the Mezardere Shale in the core area.Estimations are based on the three scenarios; 35, 40 and 45 API gravities. Resource histogram based on the input data given in Table 3(a), Resource histogram based on the new resource values obtained using the resource values given in (a), (b) and resource histograms showing Mean Swanson (Msw) values for each of the three scenarios (c). See Rose (2001) for more details about estimations.

study should be controlled by using well logs and seismic data. Density assumptions made should be validated by using core analysis and/or well logs.

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