Preliminary Hydrocarbon Potential Evaluation of Hojedk Formation in Kerman Coaly Syncline (KCS), Iran: Geochemical Approach

- Ali Amiri* (Islamic Azad University, Zarand Branch, Kerman, Iran)
- Mansour Daftarian (Iranian Gas Institute, Tehran, Iran)

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Abstract

To evaluate the hydrocarbon potential of coal seams (D and E horizons) and their country rocks of Hojedk Formation (Middle to Upper Jurassic) at Kerman Coaly Syncline (KCS), 32 coal and 46 shale samples were collected. These samples were studied geochemically, and their quantity, quality and thermal maturity of organic matter were studied as well. According to Rock-Eval pyrolysis data, it was found that the total organic carbon (TOC) content of coal samples is in excellent condition. Such a situation is, more or less, the same for the shales. Genetic potential (GP) also indicated that the majority of the samples have acceptable potential for gas and oil generation. Therefore, the organic matter quality of Hojedk Formation was evaluated as good to excellent generally. The use of hydrogen Index (HI) as one of the most important factors determining the quality of source rocks showed that the coal and shale samples of Hojedk formation have fewer than 50 to over 600 mgHC/g rock, and majority of the samples fall in 50-200 and 200-300 mgHC/g rock category and therefore, it can be stated that the quality of organic matter varies from without potential to gas and oil potential. The existing kerogen types in these samples are mainly of the III and II-III and consequently, gas and oil generation in the region is likely. Relative high values of S2/S3 (3.70 to 402.36) confirmed the above-mentioned products. In order to evaluate the thermal maturity of organic matter, two different methods (Tmax and vitrinite reflectance) were used. Tmax values revealed that most samples of KCS are in the early to late oil generation window conditions. The highest Tmax (overmature condition) is related to the Tikdar stratigraphic section and this is probably due to its proximity to the Kuhbanan fault. Measurements of vitrinite reflectance also showed that Ro% ranges from 0.5 to 2% and the mean value of this factor is 1.18% and therefore, corresponds to the condition of oil generation window. Finally, based on the quantity, quality and thermal maturity of organic matter at KCS, it can be said that the region has adequate potential for gas and to a minor extent oil generation. Moreover, coal seams, because of enough liptinite contents (up to 22%), are in a better condition in general.

Keywords: Kerman Coaly Syncline (KCS), Hojedk, Hydrocarbon potential, Pyrolysis, Kerogen.

* Corresponding author. Email address: aliamiri731@gmail.com

Introduction

For many years, it has been well recognized that the source rocks of terrestrial origin have favorable potential for oil and gas generation worldwide (Hunt, 1996). For example, in the Gippsland Basin of southeastern Australia, such cases have been reported (Shanmugam, 1985; Burns et al., 1987; Bishop, 2000). Mahakam Delta of Indonesia (Huc et al., 1986; Peters et al., 2000) and Nigerian Delta (Tuttle et al., 1999) have a similar situation. Although such circumstances have been reported in many regions of the world and in spite of the wide spread of continental suitable sediments, this issue has still not been addressed in Iran seriously.

Between 4000 to 7000 meters of late Triassic to late Jurassic non-marine and marine deposits consisting of shale, coaly shale, siltstone, argillite, sandstone and limestone interlayer were exposed over 2200 square kilometers in the northern parts of Kerman Province. Outside the scope of this study, in Central Iran, especially in Yazd Province, outcrop of these strata covers several thousand square kilometers.

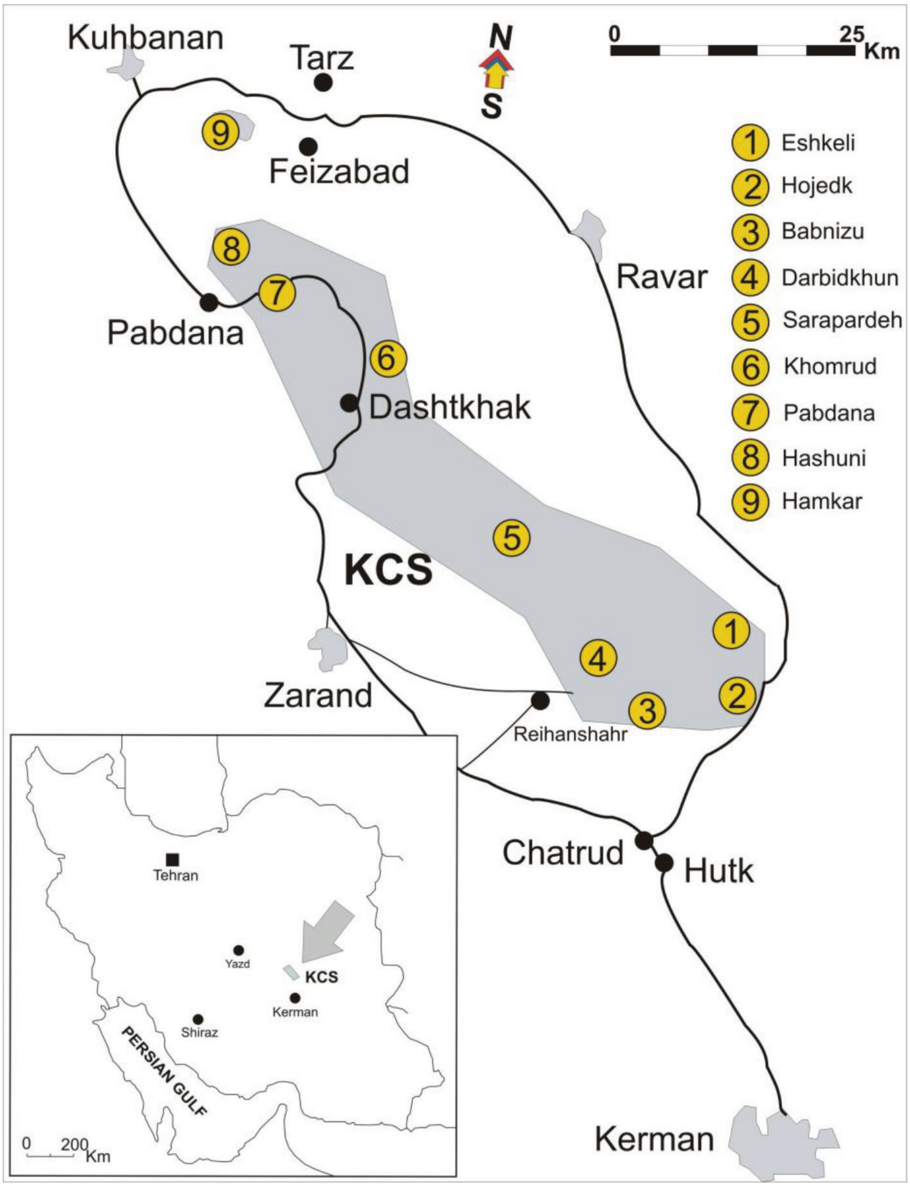

Fig. 1. Geographic and location map of north Kerman area. Main coal mines represented by numbers 1-9.

Additionally, extensive outcrops of Paleozoic deposits with suitable lithology as potential for hydrocarbon source rocks are reported in the central parts of Iran, such as Kerman Province (Abbasloo et al., 2013). Considering the fact that fourteen petroleum systems with Upper Jurassic source rocks contain one-fourth of the world's discovered petroleum (Klemme, 1994), study of Jurassic source rocks is important in Iran.

In the Kerman area, several coal mines (various types) are in operation (Fig. 1). Existence of gas (CH_4, H_2, CO_2, N_2…) in these coal mines is one of the undesirable factors for exploitation and unfortunately sometimes gas explosion occurs. Moreover, gas seepage and rarely oil seeps have been observed in the area. For example, it has been observed that after several years of Babnizu coal mine closure, gas outflow from mine wells continues.

Organic geochemical assessment for hydrocarbon potential of the Jurassic strata, as economic resources, is the main purpose of this research. These deposits have been subdivided into four stratigraphic formations (Nayband, Shemshak, Badamu and Hojedk), and we focus on the Hojedk formation (Bajocian-Bathonian) only. Therefore, defining the situation of stratigraphy, organic geochemistry and hydrocarbon potential of the succession was considered. Determination of TOC value, kerogen types and thermal maturity of organic matter in these deposits are the most important evaluations in this area.

Geological setting

According to Zarand 1:100,000 geological map (Vahdati Daneshmand, 1995) and 1:50,000 geological map of the Kerman coal deposits (Technoexport, 1969), in the northern Kerman area, a very thick sequence of different formations from Upper Proterozoic to Quaternary has been exposed. Due to the importance of Mesozoic deposits in the generation of hydrocarbon resources, these formations are studied in more detail.

General structure of the area is a large syncline with the northwest - southeast direction axis direction (Fig. 2) which is called Kerman coaly syncline (KCS). Geological studies of Triassic-Jurassic deposits in northern Kerman province were carried out for the first time by Huckriede et al (1962) and Poliansky and Safronov (1974). According to Poliansky and Safronov (1974), these formations are subdivided into 8 stratigraphic suites. These suites have been named as Dahrud, Darbidkhun and Toghrajeh of Triassic, and Neizar, Babnizu, Gumrud, Dashtkhak and Asadababd of Jurassic age. Based on nomenclature of the Mesozoic strata in Zarand area (Vahdati Daneshmand, 1995), the equivalent of these stratigraphic suites are Naiband, Shemshak, Badamu and Hojedk formations (Fig. 3).

A total of 6 coal horizons in the Mesozoic sequence in the KCS is known and named as A, B, C, D, E and F (Fig. 3). Each of these horizons consists of many coal seams; for example, the D horizon contains over 20 thin to thick coal layers. Relatively, the D horizon is more important than others and lies in the Hojedk Formation. This formation consists of shale, sandstone, argillite and carbonate interlayers. Carbonate interlayers of Hojedk Formation and ammonite (belemnite) bearing limestone of Babnizu suite (Badamu Formation) under the Hojedk Formation indicate the presence of marine environment.

Presence of gas bearing coal seams in the Hojedk Formation (D and E Horizon) and gas seeps accompanied with coal mines has led us to the hypothesis that the gas (and probably oil) reservoirs may be formed in this area. In order to investigate this hypothesis, a total of 13 sections of Hojedk Formation were evaluated geochemically. These sections are shown in Fig. 2 and consist of Eshkeli, Hojedk, Tikdar, Babnizu, Darbidkhun, north Darbidkhun, Sarapardeh, Khomrud, south and main Pabdana, Komsar, Hashuni and Hamkar.

Materials and Methods

For the purpose of organic geochemical evaluation of Hojedk Formation and considering principles of sampling (Hunt, 1996), 46 samples were collected from exposed black (and gray) shale in 6 sections. Furthermore, 30 samples were collected from D horizon coal seam. Moreover, 2 samples were collected from E horizon at Hamkar mine (Fig. 2). These samples (coal and carbonaceous shale), in the first step, were crushed, ground and dried at 105 °C oven. All samples were then analyzed by Rock-Eval II pyrolysis in the Research Institute of Petroleum Industry (RIPI) in Tehran. Geochemical parameters S1, S2, S3 and Tmax were obtained from pyrolysis and based on these parameters, the values of total organic carbon (TOC), hydrogen index (HI), oxygen index (OI), total production index (TPI), pyrolysed carbon (PC) and remnant (residual) carbon (RC) were calculated. The method of calculation of these parameters is presented in Table 1 briefly.

In the next step, 37 samples of coal and shale (with the best TOC contents) were analyzed for study of organic material. Petrography of organic matter and measurement of vitrinite reflectance were conducted by a Leitz-MPV-SP polarizing microscope equipped with photomultiplier in the same laboratory as pyrolysis (RIPI). A sapphire glass standard with 0.584% reflectance value was used for calibration. A combination of these two methods (pyrolysis and petrography) was used for achieving the aims of the research.

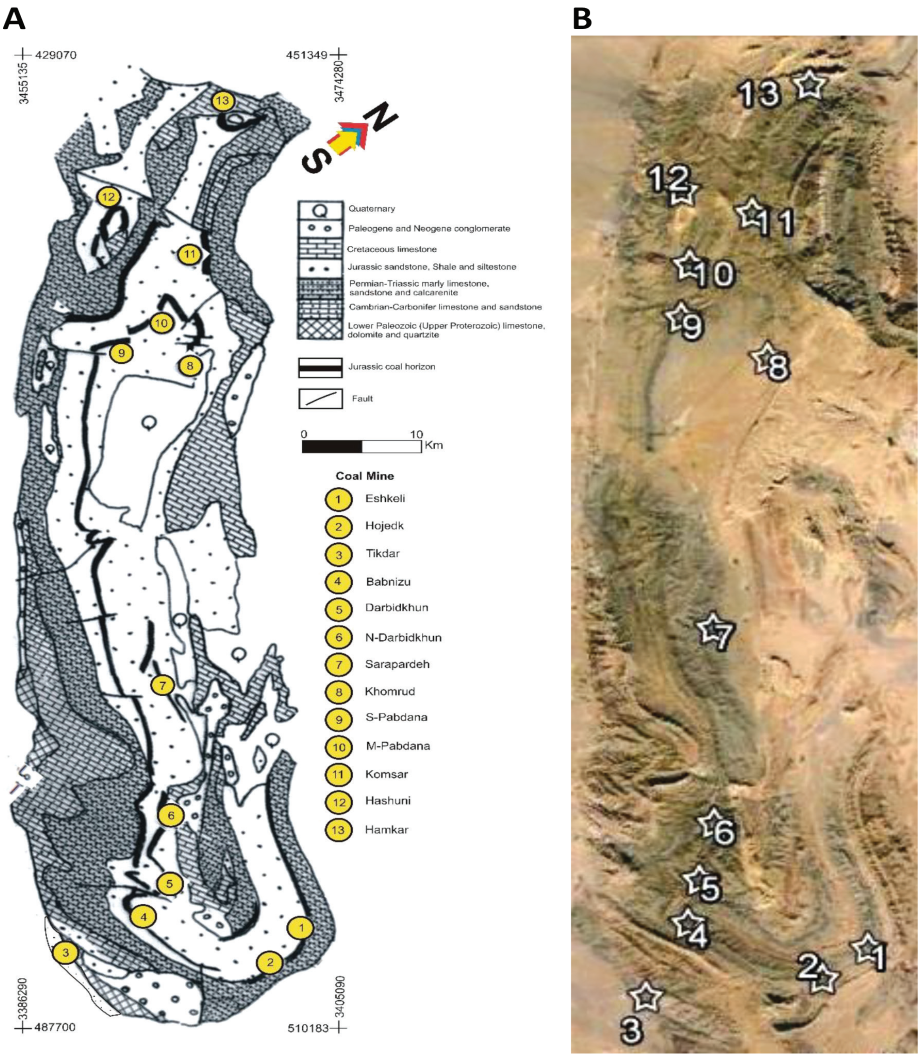

Fig. 2. A. General geological map (modified after Technoexport, 1969) and B. satellite image (after GoogleEarth) of Kerman coaly syncline (KCS). Location of sampling: 1. Eshkeli, 2. Hojedk, 3. Tikdar, 4. Babnizu, 5. S-Darbidkhun, 6. N-Darbidkhun, 7. Sarapardeh, 8. Khomrud, 9. S-Pabdana, 10. Main Pabdana, 11. Komsar, 12. Hashuni and 13. Hamkar.

Table 1. Rock-Eval parameters and calculations (Johannes et al., 2007).

Parameter	Formula	Description
S_1 (mgHC/g Rock)	--	Free hydrocarbon (HC)
S_2 (mgHC/g Rock)	--	Hydrocarbon generated through thermal cracking
S_3 ($mgCO_2$/g Rock)	--	Amount of CO_2 produced during pyrolysis
S_4 ($mgCO_2$/g Rock)	--	Amount of CO_2 produced during combustion
Tmax (°C)	--	The temperature of S_2 peak
PI	$S_1/(S_1+S_2)$	Production Index
PC (%)	$0.1[.83(S_1+S_2)+0.273S_3+$ $0.429(S_3CO+0.53S_3{}'CO)]$	Pyrolysable organic carbon
RC (%)	RC CO+ RC CO_2	Residual organic carbon
TOC (%)	PC+RC	Total organic carbon
BI (mgHC/g TOC)	$100S_1$/TOC	Bitumen Index
HI (mgHC/g TOC)	$100S_2$/TOC	Hydrogen Index
OI ($mgCO_2$/g TOC)	$100S_3$/TOC	Oxygen Index

Results and discussion

Theory

A petroleum source rock may be defined as fine-grained sediments that has generated and released enough hydrocarbons to form an accumulation of oil and gas while potential source rock is one that is not mature to generate petroleum in its natural setting but will form significant quantities of petroleum when required thermal maturity is attained (Hunt, 1996; Hunt et al., 2002).

Accurate characterization of the oil generation potential of source rocks is essential for hydrocarbon accumulation assessment in a petroleum system (Kwan-Hwa Su et al., 2006). The petroleum potential of any source rock is evaluated by determining the quantity, type and thermal maturity of organic matter contained in such rock. These parameters are discussed briefly in Table 2.

As presented in Table 2, the quantity of organic matter in source rocks is usually expressed as the total organic carbon (TOC). The minimum acceptable TOC values for various types of source rocks are 0.5% for shales, 0.3% for carbonates and 1.0% for clastic type rocks (Killops and Killops, 1993). A minimum of 1.5-2% TOC has generally been accepted for defining

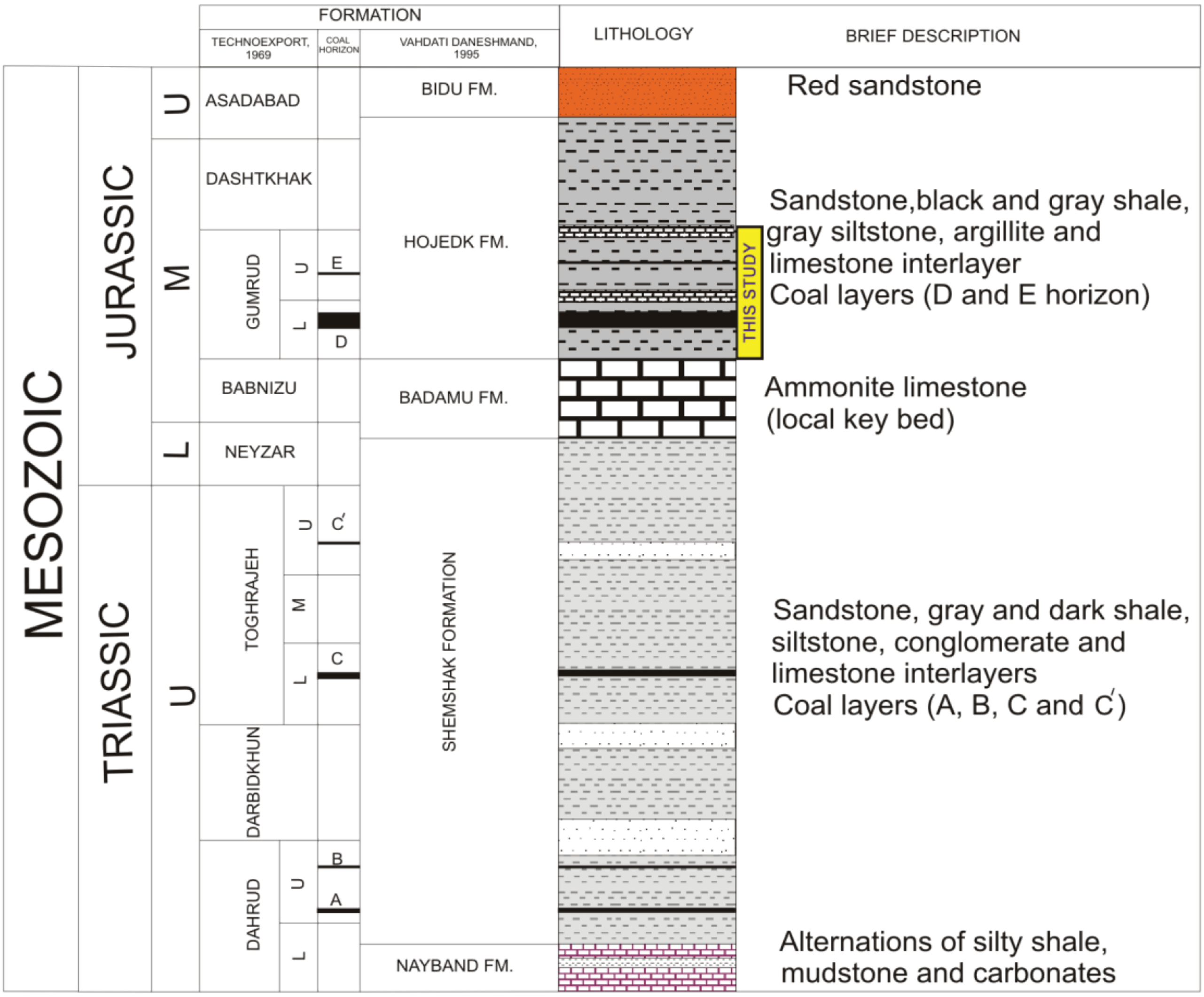

Fig. 3. Correlation of Mesozoic formations (not to scale), coal seams and situation of Hojedk Formation as subject of this study.

good source rocks (Hunt, 1996).

The amount of hydrocarbon isolated from the bitumen extracted from finely ground rock samples can also provide a useful indication of whether any oil potential exists. Oil source rocks are generally considered to require a minimum hydrocarbon content of 200-300 ppm (Killops and Killops, 1993). The genetic potential (GP) expressed in milligram hydrocarbon per gram of rock (mgHC/g rock) can also be used to evaluate the maximum quantity of hydrocarbon that a particular rock had already generated (S1) and would be generated (S2) if exposed to a sufficient prolonged thermal stress i.e. (S1+S2). Both the S1 and S2 values can be obtained from the Rock-Eval pyrolysis of rocks.

The quality of organic matter contained in rocks can be determined by optical and physiochemical methods. Maceral examination can be carried out using reflected light microscopy of thin sections of the whole rock or of isolated organic particles. Transmitted light microscopy can also be used for isolated maceral concentrates. Shape and degree of transmittance or reflectance and also fluorescence under UV-illumination can be used to identify broad maceral groups (liptinite, exinite, vitrinite and inertinite).

Elemental analysis of kerogen concentrate from rock is the most reliable method of characterizing the types or quality of organic matter. It is based on the major constituents (C, H, O), which have been used to define main types of kerogen based on the plot of H/C versus O/C in Van Krevelen diagram. The plot of hydrogen index (HI) vs. oxygen index (OI) provides an analogue to the van Krevelen diagram. Both the HI and OI can be obtained from Rock-Eval pyrolysis. Based on the plot of H/C vs. O/C and HI vs. OI, kerogen can be classified into types I to IV which are broadly equivalent to the maceral groups, liptinite, exinite, vitrinite and inertinite respectively for coals (Killops and Killops, 1993).

Information on the level of maturity of organic matter in the source rock is needed to determine if the source rock has reached the stage of hydrocarbon generation or not. The maturity status of source rock can be determined from Rock-Eval pyrolysis, petrographic and biomarker analyses. The major maturity parameters from the Rock-Eval pyrolysis are production index (PI) or transformation ratio (TR) and Tmax. These parameters increase with increasing maturation. The PI or TR expressed as the ratio of S1/S1+S2 measures the extent to which the genetic potential of the rock has been effectively utilized. It is expressed as the ratio of the hydrocarbon already generated to the total genetic potential. Generally, the threshold of the oil zone is fixed at about 0.1. The ratio reaches about 0.4 at the bottom of the oil window and increases to 1.0 when the hydrocarbon generative capacity of the kerogen has been exhausted. The Tmax

Table 2. Guidelines for pyrolysis parameters (and petrographic data) of quality, quantity and thermal maturity of organic matter (from Peters and Cassa, 1994).

Quantity	TOC(wt%)	S1(mgHC/gRock)	S2(mgHC/gRock)	S1+S2
Poor	0.5	0.5	0-2.5	0-3
Fair	0.5-1	0.5-1	2.5-5	3-6
Good	1-2	1-2	5-10	6-12
Very good	2+	2+	10+	12+
Quality	**H/C**	**S2/S3**	**HI(mgHC/gTOC)**	**Kerogen type**
Oil	>1.5	>15	>600	I
Oil	1.2-1.5	10-15	300-600	II
Gas and oil	1.0-1.2	5-10	200-300	II/III
Gas	0.7-1.0	1-5	50-200	III
None	< 0.7	< 1	< 50	IV
Maturation	**Tmax (°C)**		**Ro%**	**TAI**
Immature	< 435		0.2 - 0.6	1.5-2.6
Early	435-445		0.6 - 0.65	2.6-2.7
Peak	445-450		0.65 - 0.9	2.7-2.9
Late	450-470		0.9 -1.35	2.9-3.3
Postmature	> 470		> 1.35	> 3.3

Table 3. Rock-Eval pyrolysis data of coal samples at KCS (raw data of this study).

Sam. Loc.*	S1	S2	S3	OI	HI	Tmax	PI	RC	TOC	S1+S2	S2/S3	Coal Layer	Ref.**
Ham1	5.17	98.55	1.58	2	154	449	0.05	55.34	63.95	87.17	62.37	D2	1
Ham2	1.29	20.15	24.58	37	30	454	0.06	64.77	66.55	83.29	0.82	D4	
Ham3	0.44	3.91	40.22	73	7	436	0.1	54.46	54.82	82.44	0.1	E2	
Ham4	0.59	6.57	35	73	14	439	0.08	47.66	48.25	82.59	0.19	E3	
Has1	2.05	174.95	0	0	218	454	0.01	65.53	80.22	84.05		D2	2
Has2	2.78	158.11	0	0	240	449	0.02	52.65	66	84.78		D4	
Has3	1.97	147.76	0	0	209	443	0.01	58.28	70.71	83.97		D2	3
Has4	1.58	93.33	0	0	210	451	0.02	36.53	44.41	83.58		D6	
Pab1	2.67	74.21	1.35	2	100	463	0.03	66.25	73.52	84.67	54.97	D3	4
Pab2	4.98	141.02	2.5	3	179	457	0.03	70.22	78.7	86.98	56.41	D2	
Pab3	3.56	83.1	1.02	1	103	468	0.04	67.71	80.26	85.56	81.47	D6	
Pab4	4.33	152.33	2.07	3	193	458	0.02	71.02	78.8	86.33	73.59	D2	
Pab5	3.88	73.7	0.27	0	104	472	0.05	61.02	70.32	85.88	272.96	D1	
Pab6	5.03	177.01	1.9	3	238	469	0.02	67.23	74.42	87.03	93.16	D4	
Pab7	4.57	167.18	2.4	3	210	457	0.02	71.28	79.6	86.57	69.66	D2	
Pab8	2.16	107.27	1.07	1	143	473	0.02	62.02	75.15	84.16	100.25	D5	
Pab9	2.05	13.66	26.66	40	20	461	0.13	65.53	66.83	84.05	0.51	D2	5
Pab10	2.44	86.29	1.92	3	140	443	0.03	54.24	61.6	84.44	44.94	D3	
Pab11	3.76	145.65	0.47	1	229	445	0.03	51.22	63.62	85.76	309.89	D2	3
S-Pab	4.08	129.85	0.49	1	179	475	0.03	61.5	72.62	86.08	265	D2	
Kho	1.4	59.25	0	0	124	448	0.02	42.81	47.84	83.4		D2	
Sar1	8.54	151.25	2.45	3	202	443	0.05	61.7	74.96	90.54	61.73	D2	
Sar2	6.97	148.34	0	0	211	445	0.04	57.32	70.21	88.97		D3	
Sar3	6.5	171	0	0	217	442	0.04	64.23	78.96	88.5		D3	
Sar4	9.87	175.73	2.43	3	252	440	0.05	54.21	69.61	91.87	72.32	D3	
Sar5	10.73	154.38	2.47	4	229	444	0.06	53.83	67.53	92.73	62.5	D4	
Sar6	5.31	175.87	2.14	3	218	446	0.03	65.53	80.57	87.31	82.18	D5	
Sar7	4.41	174.1	2.4	3	217	445	0.02	65.53	80.35	86.41	72.54	D6	
Sar8	3.35	94.6	2.1	4	158	456	0.03	51.85	59.98	85.35	45.05	D8	
Bab	1.16	18.11	1.67	4	39	445	0.06	45.24	46.82	83.16	10.84	D2	6
Hoj	3.89	146.61	0.95	1	188	462	0.03	65.53	78.02	85.89	154.33	D2	
Esh	7.91	112.66	0.28	0	155	466	0.07	62.62	72.63	89.91	402.36	D2	

*- Sample location: Ham (Hamkar), Has (Hashuni), Pub (Pabdana), S-Pub (South Pabdana), Kho (Khomrud), Sar (Sarapardeh), Bab (Babnizu), Hoj (Hojedk) and Esh (Eshkeli).

**- Reference: 1. Ziaaldini (2012), 2. Safinejad (2013), 3. Dashtbozorgi et al. (2012), 4. Sohrabi (2013), 5. Mollaei (2013) and 6. Shakibi et al. (2013).

indicates the temperature of the maximum generation of S2 peak. Generally, the threshold of the oil zone is fixed at Tmax of 430-435 °C for type II and III kerogen while gas zone ranges from 450-455 °C and 465-470 °C for type II and type III respectively (Killops and Killops, 2005).

Organic petrography researchers also developed series of maturation indicators, the most reliable of which is vitrinite reflectance (Hunt et al., 2002). The use of vitrinite reflectance as a technique for determining the maturity of oil in sedimentary rocks was first described by Teichmuller (1958). Today, vitrinite reflectance is a widely used indicator of thermal stress because it extends over a longer maturity range than any other indicator (Hunt et al., 2002). Vitrinite reflectance can be used to assess thermal maturity in types II and III but cannot be used for type I kerogen due to absence of vitrinite. Vitrinite reflectance values for main phase of oil generation ranges from 0.65-1.3%Ro and values greater than 2.0%Ro indicate dry gas generation (Tissot and Welte, 1984).

Quantity of organic carbon

The first parameter in the process of evaluating a source rock is defining the quantity of organic carbon value. Values of TOC, S1 and S2 can provide good estimates of the quantity of organic carbon in a source rock (Peters and Cassa, 1994). In the studied samples, the amounts of total organic carbon from the

Table 4. Rock-Eval pyrolysis data of shale samples at KCS (raw data of this study).

Sam. No.*	S1	S2	S3	Tmax	OI	HI	PI	PC	RC	TOC	S1+S2	S2/S3	Ref.**
Ham1	0.07	0.2	0.2	478	20	20	0.28	0.02	0.97	0.99	0.27	1.00	1
Ham2	0.06	0.23	1.6	483	68	10	0.21	0.04	2.34	2.38	0.29	0.14	
Ham3	0.64	13.7	1.25	444	12	127	0.04	1.19	9.57	10.76	14.34	10.96	
Ham4	0.07	0.58	0.58	463	42	42	0.11	0.05	1.32	1.37	0.65	1.00	
Ham5	0.2	6.34	0.35	451	5	99	0.03	0.54	5.85	6.39	6.54	18.11	
Ham6	1.66	43.7	0.22	451	1	256	0.04	3.76	13.28	17.04	45.36	198.64	
Has1	0.09	0.23	1.36	443	425	73	0.28	0.03	0.29	0.32	0.32	0.17	2
Has2	0.6	23.52	0	456	0	133	0.02	2	15.69	17.69	24.12		
Has3	0.14	2.35	0	456	0	226	0.06	0.21	0.83	1.04	2.49		
Has4	0.19	2.42	0	470	0	109	0.07	0.22	2.01	2.23	2.61		
Has5	1.11	50.08	0	449	0	204	0.02	4.25	20.35	24.6	51.19		
Has6	0.27	5.75	0	455	0	179	0.04	0.5	2.71	3.21	6.02		
Pab1	0.21	5.22	0	447	0	74	0.03	1.74	5.28	7.02	5.43		
Pab2	0.06	0.59	0.31	580	129	246	0.09	0.05	0.19	0.24	0.65	1.90	
Pab3	0.16	1.8	0.18	450	9	93	0.08	0.16	1.78	1.94	1.96	10.00	
Pab4	0.12	1.33	0.13	448	11	113	0.08	0.12	1.06	1.18	1.45	10.23	

Pab5	0.09	0.61	0.69	490	66	59	0.13	0.06	0.98	1.04	0.7	0.88	
Pab6	0.06	0.39	0.17	529	212	488	0.13	0.04	0.04	0.08	0.45	2.29	
Pab7	0.06	0.46	0.78	472	67	40	0.12	0.04	1.12	1.16	0.52	0.59	
Pab8	0.07	0.5	1.44	505	78	27	0.12	0.05	1.8	1.85	0.57	0.35	
Sar	1.43	23.83	0	444	0	247	0.06	2.1	7.55	9.65	25.26		
Bab1	0.64	13.7	1.25	444	12	127	0.04	1.19	9.57	10.76	14.34	10.96	
Bab2	0.07	0.58	0.58	463	42	42	0.11	0.05	1.32	1.37	0.65	1.00	
Bab3	0.2	6.34	0.35	451	5	99	0.03	0.54	5.85	6.39	6.54	18.11	
Bab4	1.66	43.7	0.22	451	1	256	0.04	3.76	13.28	17.04	45.36	198.64	
Bab5	0.2	0.19	0.1	467	31	53	0.51	0.03	0.33	0.36	0.39	1.90	
Bab6	0.34	0.35	0.2	465	27	43	0.49	0.06	0.75	0.81	0.69	1.75	
Bab7	0.06	0.19	0.16	441	36	43	0.24	0.02	0.42	0.44	0.25	1.19	
Bab8	0.13	1.67	0.35	442	19	91	0.07	0.15	1.68	1.83	1.8	4.77	
Bab9	0.06	0.13	0.03	539	6	27	0.31	0.02	0.47	0.49	0.19	4.33	
Bab10	0.05	0.13	0.02	559	20	130	0.28	0.01	0.09	0.1	0.18	6.50	
Bab11	0.1	0.69	0.31	448	28	62	0.13	0.07	1.04	1.11	0.79	2.23	
Bab12	0.04	0.15	0.06		8	20	0.21	0.02	0.74	0.76	0.19	2.50	
Bab13	0.06	0.02	0.01		25	50	0.75	0.01	0.03	0.04	0.08	2.00	
Tik1	1.47	7.25	2.17	490	27	91	0.17	0.72	7.27	7.99	8.72	3.34	3
Tik2	0.11	0.44	0.26	466	36	61	0.2	0.05	0.67	0.72	0.55	1.69	
Tik3	0.53	3.35	7.31	476	54	25	0.14	0.16	13.46	13.62	3.88	0.46	
Tik4	0.27	2.35	6.17	501	49	19	0.1	0.22	12.41	12.63	2.62	0.38	
Tik5	0.12	0.77	0.12	490	38	241	0.13	0.08	0.24	0.32	0.89	6.42	
Tik6	0.16	1.26	0.18	540	33	233	0.11	0.12	0.42	0.54	1.42	7.00	
Tik7	0.15	1.01	0.05	525	21	421	0.13	0.1	0.14	0.24	1.16	20.20	
Tik8	0.14	1.06	0.14	460	70	530	0.12	0.1	0.1	0.2	1.2	7.57	
Tik9	0.6	4.54	0.21	430	29	631	0.12	0.43	0.29	0.72	5.14	21.62	
Tik10	0.18	0.66	0.09	541	53	388	0.21	0.07	0.1	0.17	0.84	7.33	
Tik11	0.15	0.88	0.31	496	56	160	0.15	0.09	0.46	0.55	1.03	2.84	
Tik12	0.11	1.17	0.07	588	25	418	0.09	0.11	0.17	0.28	1.28	16.71	

*- Sample location as same as Table 3.
**- References: 1. Ziaaldini (2012), 2. Safinejad (2013), 3. Hemmatafza (2014).

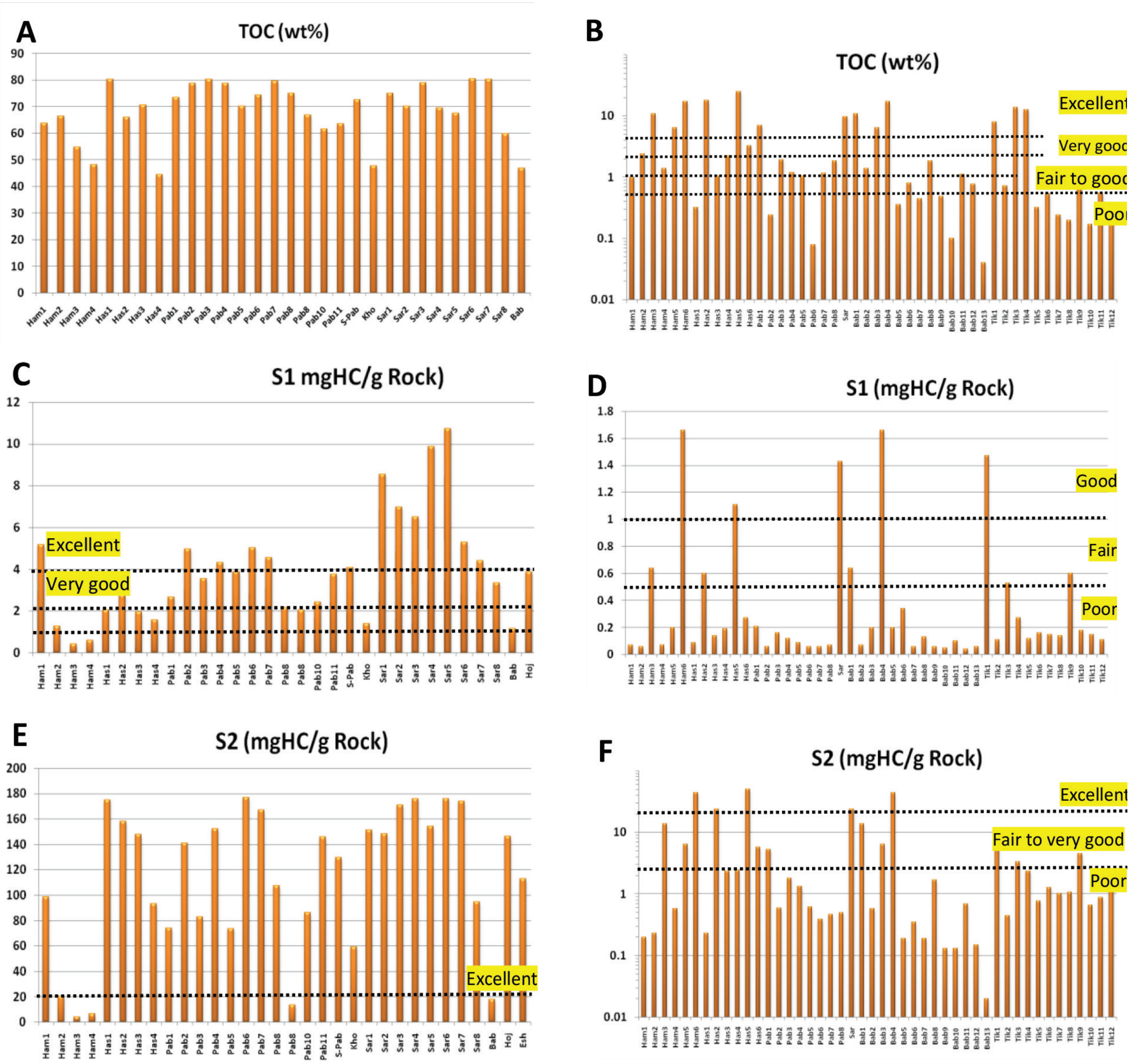

Fig. 4. Comparison of TOC, S1 and S2 of coal (A, C and E) and shale samples (B, D and F) from various parts of KCS.

pyrolysis were investigated. It is clear that the organic carbon content of coal samples should be high. In these samples, TOC content varies from 44.41 wt% to 80.57 wt% with a mean value of 68.68 wt% (Table 3). Obviously, the amount of TOC alone may not reflect the high quality of the rock and other quantitative parameters should be considered (Fig. 4A).

Total organic carbon content of the shale samples varies from 0.04 wt% to 24.6 wt% with a mean value of 4.16 wt% (Table 4). Comparison of TOC content in different samples indicates that all coal samples and most of the shale samples have sufficient organic carbon content as a source rock. However, TOC content of shale samples ranges from poor to excellent (Fig. 4B).

In addition to the TOC, the S1 parameter is used to evaluate the quantity of hydrocarbon source rocks (Peters and Cassa, 1994). In the present research, S1 contents of coal samples varies from 0.44 to 10.73 mgHC/g rock with a mean value of 4.04 mgHC/g rock. Accordingly, based on Peters and Cassa (1994), S1 content of the coal samples ranges from very good to excellent (Fig. 4C). Moreover, shale samples have S1 values from 0.04 to 1.66 (mean 0.32) mgHC/g rock and range from poor to good, but most of the samples are located at poor situation. In coal samples, the maximum value of S1 is related to Sarapardeh mine and in shale samples, Hashuni, Babnizu and Hamkar have higher values (Fig. 4D).

S2 is the other evaluating factor in determining quantity of hydrocarbon source rocks. Indeed, this parameter is the present potential of source rocks and consists of kerogen, bitumen and heavy hydrocarbons. Data obtained from pyrolysis of coal samples show that the S2 in these samples varies from 3.91 to 177.01 mgHC/g rock, and therefore the content of S2 represents very good to excellent condition (Fig. 4E). S2 values of shale samples of KCS range from 0.02 to 50.08 with a mean value of 6.00 mgHC/g rock and therefore, the values show poor to good conditions (Fig. 4F). The majority of these samples are plotted at poor to fair condition. One of the criteria for determining the quantity of source rocks is genetic potential (GP). As presented in Table 1, this parameter is the sum of S1 and S2 values. Based on Peters and Cassa (1994), the high values of GP can indicate the high quantity of source rocks. The mean value of GP for shale and coal samples of KCS is 6.33 and 86.04 mgHC/g rock respectively (Tables 3 and 4). These values also indicate that both shale and coals have sufficient potential for hydrocarbon generation, but the coal samples are in much better condition. Plotting S1 against S2 (log-plot) also shows that the coal samples, compared to the shale samples, have higher potential and fall in the very good to excellent field (Fig. 5).

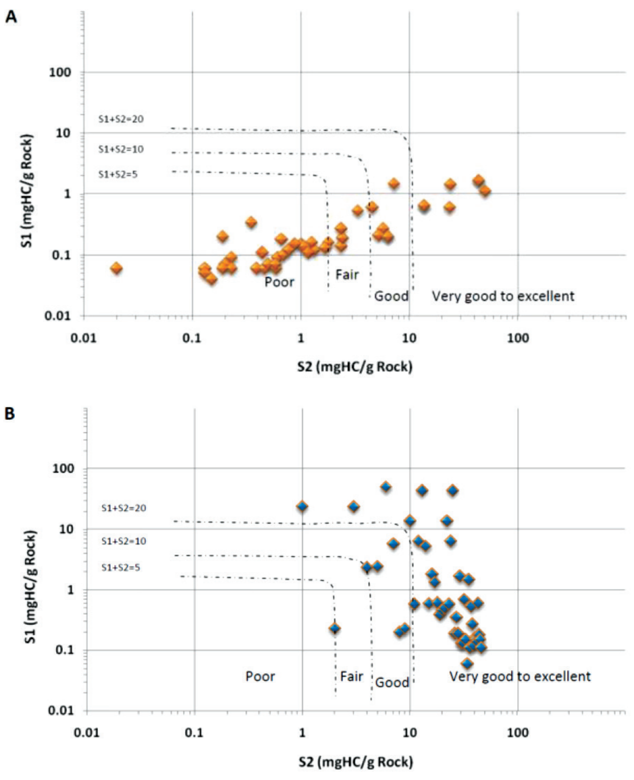

Fig. 5. Log-plot of S1 vs. S2 for determining the genetic potential (GP) of KCS, A. non-coal and B. coal samples.

Briefly, quality of organic material in the coal samples is obviously better than the shale samples, but, the shale samples are not so undesirable. In other words, shale strata at KCS can also be considered acceptable as a source rock.

Quality of organic material

Often when talking about the quality of source rocks, the amount of hydrogen and kerogen type is considered. The quality of the organic matter contained in the coal and shale samples was evaluated from pyrolysis data. Using HI vs. OI plot and HI vs. Tmax plot, the kerogen type and source of organic carbon in the source rocks can be determined.

In coal samples of KCS, the hydrogen index ranges from 7 to 252 with a mean value of 160 mgHC/g rock and indicates ability of gas generating as well (Table 3). The hydrogen index of shale samples has a greater extent and variability. In these samples, HI values range from 10 to 631 with a mean value of 154 mgHC/g rock. Based on this parameter and considering the guidelines provided by Peters and Cassa (1994), the shale samples represent potential for oil and gas. Plots of HI against OI, for the samples are shown in Figs. 6 and 7. As shown in Fig. 6A, most of the coal samples have a moderate hydrogen index and low oxygen index. In contrast, variation of these two parameters is much more for shale samples (Fig. 6B).

For a more general estimate of the position

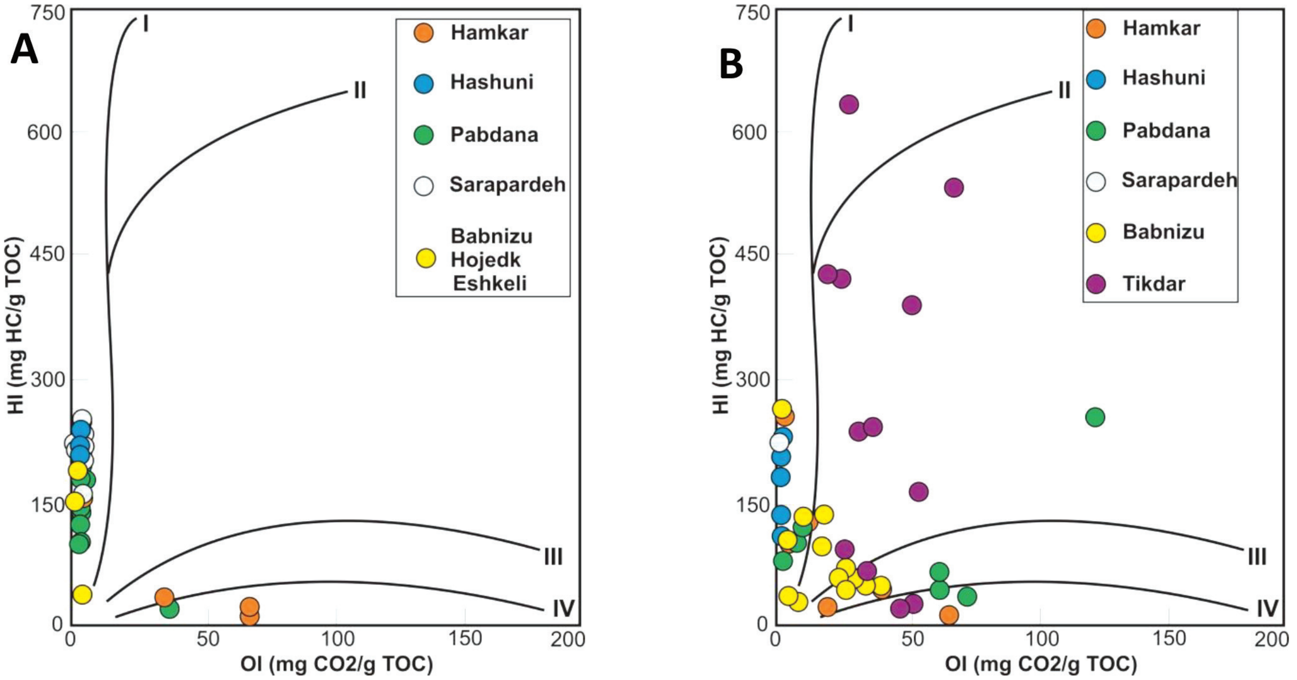

Fig. 6. Hydrogen index vs. oxygen index (Hunt, 1996) and position of A. coal samples and B. shale samples from KCS.

of kerogen types, all 78 samples of coal and shale are plotted in a single diagram (Fig. 7). As shown in Fig. 7, most of the samples fall in the III and II/III kerogen types (55 samples, 70.5% of the total samples). In a lesser amount, a few samples (18 samples, 23% of the total samples) were plotted in IV type. Finally, 4 samples (5% of the total samples) and only one sample fall in the field of II and I kerogen type respectively. Also, it can be seen that the majority of coal

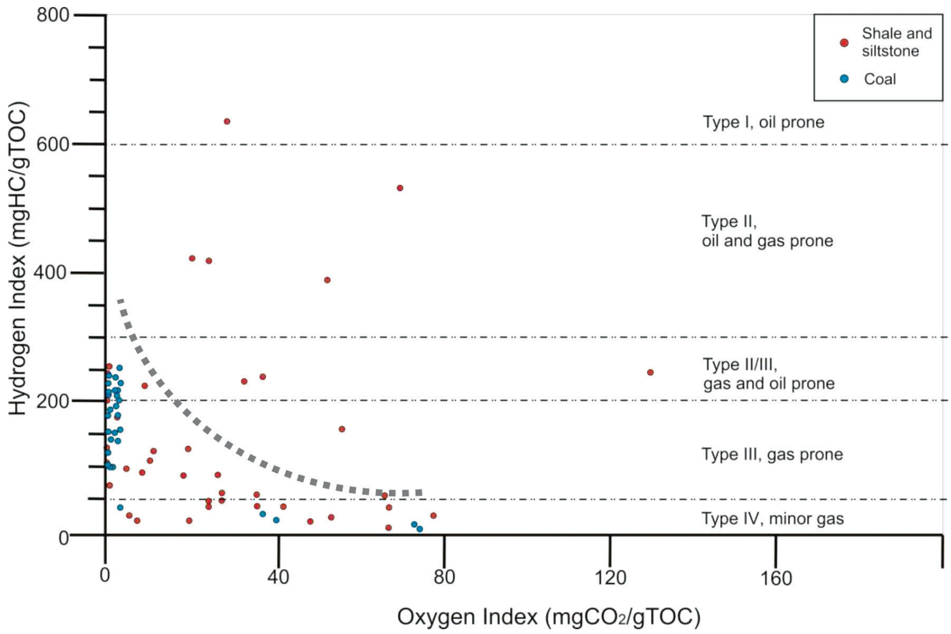

Fig. 7. Definition of kerogen types and hydrocarbon generating potential of KCS coal and non-coal samples in HI vs. OI cross plot.

samples are plotted near the axis of hydrogen index and this indicates that the samples are poor oxygenated compounds. Moreover, it is clear that most of these samples can produce gas and a lesser amount of oil.

In addition to the previous plots, for determining the kerogen types and generating hydrocarbon potential, we have used S2 vs. TOC diagram (Langford and Blanc-Valleron, 1990) (Fig. 8). In this diagram, two different clusters of samples can be seen. One of these clusters (arrow1) covers the non-coal samples and is plotted near the lower left corner of the diagram. In contrast, coal samples cluster with a more extensive area (arrow2) covers important parts of III and mixed II-III kerogen types fields. Based on this diagram, it is clear that most coal samples are located in the area of gas (and gas and oil) production. It should be noted that the results of this diagram are confirmed by the results of HI-OI plots (Figs. 6 and 7).

Thermal maturity of organic material

Pyrolysis data

The quantity and quality of organic matter alone is not sufficient to produce adequate hydrocarbon. In addition to these two factors, maturity of organic matter should be adequate enough to generate oil and gas. As mentioned above, thermal maturity can be reflected by pyrolysis data. Tmax alongside the production index (PI) are the two determining parameters. Moreover, using HI vs. Tmax plot is one of the multipurpose diagrams in organic geochemistry. This diagram can be used to determine the thermal maturity and kerogen types.

According to available pyrolysis data, the HI vs. Tmax plot (Hunt, 1996) was drawn for KCS samples (Fig. 9). As shown in Fig. 9A, all of the coal samples fall within the range of 430 to 470 °C tmax, and therefore thermal maturity of

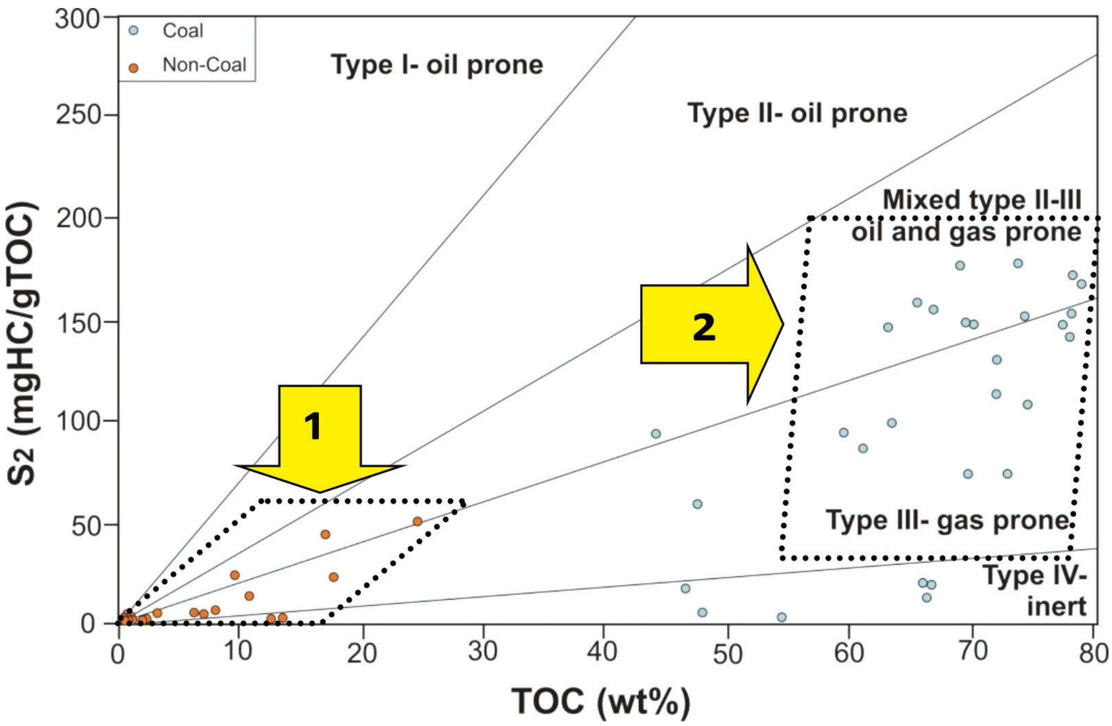

Fig. 8. S2-TOC cross-plot (Langford and Blanc-Valleron, 1990) and location of coal and non-coal samples.

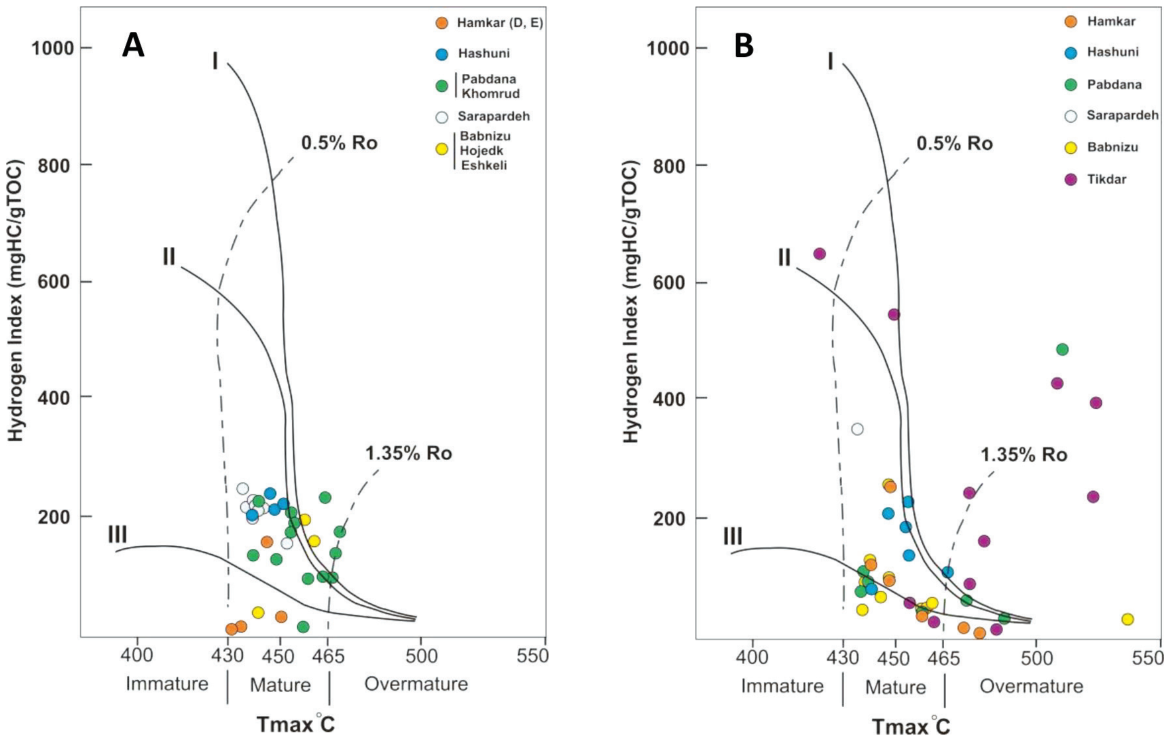

Fig. 9. HI vs. Tmax cross plot (Hunt, 1996) for determining thermal maturity and kerogen types of KCS. A. Coal samples and B. Non-coal samples.

the samples is presently within the oil window. Locating all data between lines of 0.5% and 1.35% vitrinite reflectance has confirmed the result too.

Despite the limited extension of coal samples in HI vs. Tmax, shale samples cover a wide range in this plot (Fig. 9B); therefore, maturity of these samples ranges from mature to overmature condition. Considering this plot and maturity conditions, coal samples are in the stage of oil and wet gas production and shale samples are in the stage of wet gas, condensate and dry gas. Also, the values of hydrogen index represent potential of gas and oil for majority of samples.

Petrography and vitrinite reflectance

In order to define thermal maturity and organic petrography, microscopic studies in reflected light were used. On this basis, the organic composition of 36 coal and shale samples was investigated. Although maceral identification in all samples was done, only 8 cases were examined to determine the percentage of macerals.

These investigations were carried out according to the definition and description of macerals given by Taylor et al. (1998).

In a general overview, all samples of KCS are vitrinite rich (Table 5). The percentage of vitrinite ranges from 49.3% to 75% with a mean value of 60.80%. In terms of frequency, total fusinite plus semifusinite macerals with an average of 23.8 % are in the second rank (Fig. 10).

The liptinite group contains cutinite, sporinite, exsudatinite, fluorinite, resinite, bituminite, suberinite and liptodetrinite. Liptinite, as a hydrogen rich maceral, can be found in all samples of KCS considerably (Table 5, Fig. 10).

This maceral as an accessory maceral ranges from 5% to 22.2% with an average of 15.46%. The highest value of liptinite (22.2%) is related

Table 5. Percentage of maceral groups in coal samples of KCS (data arter Shayestehfar et al. 2007).

Sample No.	Vitrinite %	Fusinite %	Semifusinite %	Liptinite %
Ham1	75	5	15	5
Ham2	63.5	9.78	10	17.6
Ham3	65	10	12	11
Has	54	18	12	16.8
Kom	53.3	18.6	13	16.7
M-Pab	49.3	19.7	9	22.2
Dar	66.81	9.1	8	16.38
Tik	60	14	8	18
Avg.	60.86	13	10.8	15.46

to Main Pabdana mine. Relative high amount of liptinite in Pabdana coal mine has been reported previously by Shayestehfar et al. (2007). However, this amount of liptinite in KCS coal samples indicates oil production capability by the rock. Moreover, Jones (1987) suggested that if the liptinite contents (exinite plus resinite) reach over 10-15% in coal, in addition to increasing the hydrogen index, it is possible to generate liquid hydrocarbon by such coal.

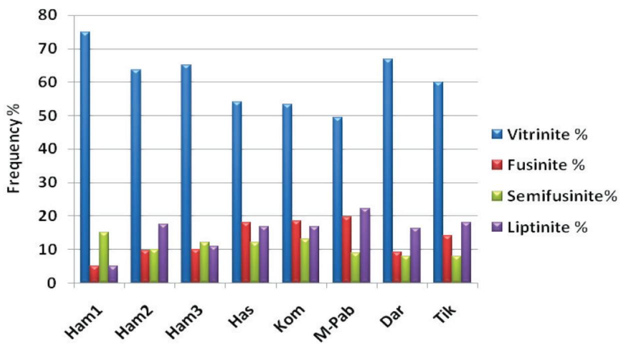

Fig. 10. Comparative frequency of maceral groups from KCS coals, (data after Shayestehfar et al. 2007).

Table 6. Petrography and vitrinite reflectance in emersion oil of coal and shale samples.

Location	Sample type	Maceral type(s)	Ro%	Variation	Tmax
Sarapardeh	Coal-D2	F	1.3	Min: 0.5 Max: 2 Mean: 1.25	--
	Shale	V+L	2		--
	Shale	F+V	0.6		--
	Coal-D3	F+L	0.85		--
	Shale	F	0.5		--
	Coal-D4	V+F	1.7		--
	Coal-D5	V+F	2		--
	Coal-D6	F+V	0.5		--
	Coal-D8	F+V	1.8		--

	shale	V+F+L	1.9		--
	Coal-D6	F+V	1.5		--
	shale	V+L	2		--
	shale	F	1		--
Hashuni	Coal-D4	V+F	1.8	Min: 0.73 Max: 2 Mean: 1.48	--
	shale	F	1		--
	shale	F	1.5		--
	Coal-D2	V+L+F	2		--
	shale	F	1.4		--
	Coal-D2		0.73		--
Hamkar	Coal-D2	V+S+F	0.8	Min: 0.8 Max: 0.89	--
	Coal-D4	V+S+F	0.89		--
	Shale	F	0.9		469
	Coal-D3	L	1.9		463
	shale	F	1.1		473
Pabdana	shale	F	1.1		472
	Coal-D2	F+V+L	1.2		457
	shale	F+L	1.1	Min: 0.59 Max: 1.9 Mean: 1.02	457
	shale	V	1.2		458
	Coal-D4	V+F	1		469
	shale	V+F+L	0.9		447
S-Pabbana	Coal-D2	V+L	0.59		461
	Coal-D2	V+L	0.69		443
	Coal-D2	--	0.71		--
	Coal-D2	--	0.96		--
Tikdar	shale	V+F+L	0.77	Min: 0.77 Max: 0.92 Mean: 0.84	--
	shale	V+F+L	0.92		--

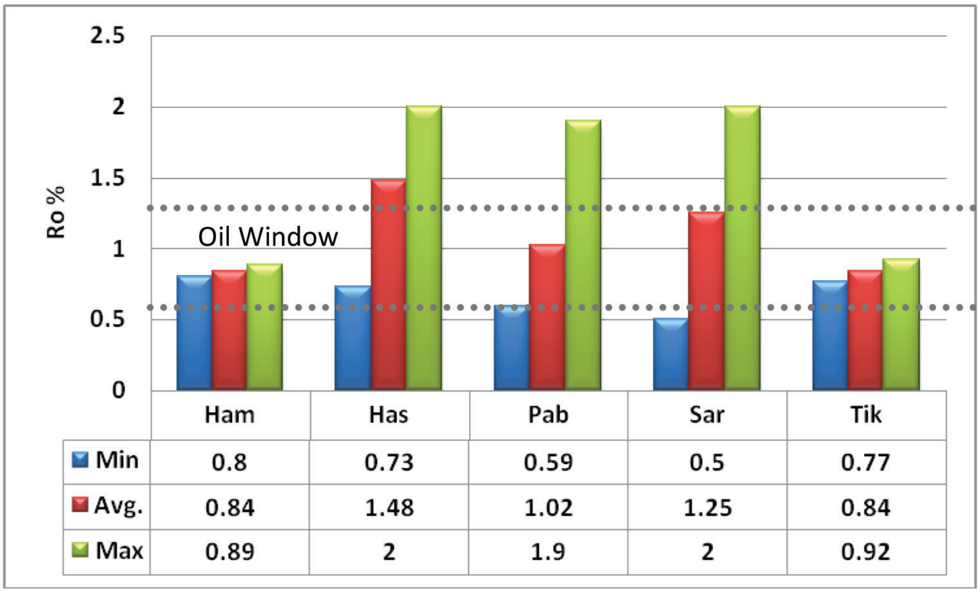

Fig. 11. Comparative assessment of vitrinite reflectance variations in different location of KCS.

In addition to petrography and definition of macerals, in 36 samples of coal and shale, measurement of vitrinite reflectance was done by polarizing microscope and photomultiplier. These measurements were carried out using a Leitz-MPV-SP microscope in organic petrography laboratory of Research Institute of Petroleum Industry. A sapphire glass standard with 0.584% reflectance value was used for calibration. The reflectance of vitrinite remains the most definitive measure of coal rank and maturity of source rocks, because, it is unaffected by oxidation, by changes of sample

Table 7. Summarized geochemical characteristics of KCS coal and shale samples.

Locality	Sample Type	Quantity			Quality			Thermal maturity			Hydrocarbon potential			Oil or Gas Seepage
		TOC %	S1 (Average)	S2 (Average)	HI Avg.	Krogen Type	S2/S3	Tmax °C	PI	Ro%	None	Gas	Gas and Oil	
Hamkar	Coal (D, E)	E	G	E	50-200	III	15.8	EM	0.07	0.84		■		
	Shale	E	P	E	50-200	III	38.3	EM	0.07			■		
Hashuni	Coal	E	VG	E	200-300	III, II-III	243	PM	0.01	1.56		■	■	■
	Shale	E	P	E	50-200	III	14.05	LM	0.08			■		
Pabdana	Coal	E	VG	E	50-200	III	118.57	LM	0.03	1.03		■	■	■
	Shale	G	P	P	50-200	III	3.7	OM	0.09			■		

Khomrud	Coal	E	G	E	50-200	III	-	PM	0.02			■		
Sarapardeh	Coal	E	E	E	200-300	III, II-III	66.05	PM	0.04	1.25			■	
	Shale	E	G	E	200-300	III, II-III	-	EM	0.06				■	
Babnizu	Coal	E	VG	E	0-50	IV	10.84	PM	0.06		■	■		■
	Shale	VG	P	VG	50-200	III, IV	19.68	PM	0.24					
Tikdar	Shale	P	P	P	200-300	III, II-III	7.96	OM	0.18	0.84		■	■	■
Hojedk	Coal	E	E	E	50-200	III	154.33	LM	0.03	1.05		■		
Eshkeli	Coal	E	E	E	50-200	III	402.36	LM	0.07	0.73		■		

type, or by carbonate mineral matrix.

As can be seen in Table 6, in the majority of the samples, vitrinite was found as main maceral. Also, the mean value of this maceral in 6 semi-quantitative measurements (Table 5) reaches 60.86%. Measurements of vitrinite reflectance in various location and sample types revealed that this parameter ranges from 0.5% to 2% with an average of 1.18%. These values clearly show that the majority of samples lie within the oil window.

A comparative estimate (Fig. 11) indicates that across regions, Hashuni, Sarapardeh and Pabdana have the highest Ro% and maturity (with average values of 1.48%, 1.25% and 1.02% respectively). However, because of scarcity of samples, this result should not be considered definitive. This estimate also shows that the average maturity of the samples correspond to the early to late oil window.

Conclusion

In the present research, the quantity, quality, thermal maturity and hydrocarbon potential of D (and E) coal horizon and its carbonaceous country rocks (Hojedk Formation), as a potential source rock were studied in KCS. To achieve these goals, the pyrolysis and petrographic techniques were used. Raw data were evaluated by standard procedures and hydrocarbon potential of the area studied. Based on this analysis, the following results were obtained (Table 7).

The quantity of carbonaceous rocks and coal seams in KCS using TOC content, S1 and S2 parameters were evaluated and it was found that in most cases, the amount of organic carbon is excellent. Due to the nature of the coal samples, the high organic carbon content is obvious (Fig. 4A). However, the shale samples (Fig. 4B) also have an acceptable condition. The value of S1 ranges from poor to excellent and coal samples have a better condition compared to shale samples (Figs. 4C and D). Finally, according to the S2 parameter as a quantity indicator, it was found that majority of samples fall in the excellent condition (Figs. 4E and F).

In order to evaluate the quality of shale and coal samples, hydrogen index (HI) was used. For the purpose of simplification, average of HI from each location was classified (Table 7) and compared to Peters and Cassa (1994) guidelines. Although the range of hydrogen index values of various samples of KCS is relatively high, the data can be categorized and placed in one of the five definitive classes (0-50, 50-200, 200-300, 300-600 and >600). Based on this classification, the average values of HI of 9 locations (from 14 locations), fall in the 50-200 class, four cases lie in the 200-300 class and only one case is classified in 0-50 class

Thus, it is clear that the majority of the samples are capable of generating gas and some are capable of generating oil and gas.

As can be inferred from Figs. 6, 7, 8 and 9 (and Table 7), type III kerogen is dominant in most cases, but in some cases (especially in coal samples), mixed II/III kerogen type also has been detected (Fig. 8). Considerable amounts of liptinite in some coal samples (up to 22% at Pabdana) support this finding. Therefore, kerogen types in Hojedk formation are suitable for gas and oil generation. Moreover, high S2/S3 ratio in most cases (Table 7) support oil generation hypothesis in the KCS.

After determining the amount and quality of organic matter, thermal maturity evaluation of the KCS was conducted.

According to Tmax values, it can be stated that the majority of the samples have passed adequate maturation to generate oil and gas. Table 7 also shows that in most cases, Tmax reflects early to late maturation corresponding to oil window and only in a few cases, overmaturation occurred. Vitrinite reflectance (Ro%) studies also confirmed that in most cases (Fig. 11), the maturity of the samples are in accordance to the oil generation window (top to bottom).

Finally, it can be stated that the quantity, quality (kerogen types) and thermal maturity of coal seams and its country rocks of Hojedk formation in KCS have sufficient potential for gas and to a lesser amount oil generation. Existence of gas and rarely oil seepage in the area confirm this claim.

References

1. Abbasloo, H., Amiri, A., Fariabi, A., 2013. A preliminary study of hydrocarbon potential of Sardar formation (Carboniferous) in eastern Zarand using rock-eval pyrolysis. Proceeding of Seventeenth Conference of Geological Society of Iran, Shahid Beheshti University, Tehran, 145-152 (in Farsi).
2. Bishop, M.G., 2000. Petroleum system of the Gippsland Basin. Australia. U.S. Geol. Survey E-Bulletin, Open-File Report 99-50-Q.
3. Burns, B.J., Bostwick, T.R., Emmett, J.K., 1987. Gippsland terrestrial oils- recognition of compositional variations due to maturity and biodegradation effects. The APEA Journal 27, 73-84.
4. Dashtbozorgi, R., Amiri, A., Shojaeibaghini, S.V., Abbaspour, M.H., 2012. The hydrocarbon potential of Kerman coal layers. Second Geological Congress of Iranian Plateau, Islamic Azad University, Zarand Branch, 863-872.
5. Dousta, H. and Nobleb, R.A., 2008. Petroleum systems of Indonesia. Marine and Petroleum Geology 25, 103-129.
6. Espitalié, J., Marquis, F., Barsony, I., 1984. Geochemical logging. In: Voorhees K. J. (Ed.), Analytical Pyrolysis, Techniques and Applications, Boston, Butterworth, 276-304.
7. Hemmatafza, M.R., 2014. A preliminary study of hydrocarbon potential of the Jurassic deposits in the East Tikdr Village using organic petrography and rock-eval pyrolysis. Unpublished M.Sc. Thesis, Geology Dept., Islamic Azad University, Zarand Branch (in Farsi).
8. Huc, A.Y., Durand, B., Roucachet, J., Vandenbroucke, M., Pittion, J.L., 1986. Comparison of three series of organic matter of continental origin. Organic Geochemistry 10, 65-72.
9. Huckriede, R., Kürsten, M., Venzlaff, H., 1962. Zur geologie des gebiets zwischen Kerman und Saghand (Iran): Beihefte zum Geologischen Jahrbuch, 51, Hannover.
10. Hunt, J.M., 1996. Petroleum Geochemistry and Geology (2nd ed.). Freeman and Company, New York.
11. Hunt, J.M., Philp, R.P. Kvenvolden, K.A., 2002. Early developments in petroleum geochemistry. Organic Geochemistry 33, 1025-1052.
12. Johannes, I., Kruusement, K., Veski, R., 2007. Evaluation of oil potential and pyrolysis kinetics of renewable fuel and shale samples by rock-

eval analyzer. Journal of Analytical and Applied Pyrolysis 79, 183-190.

13. Jones, R.W., 1987. Organic facies. In: Brooks, J. and Welte, D. (eds.) Advances in petroleum geochemistry. London, Academic Press 2, 1-90.

14. Killops, S.D., Killops, V.J., 1993. An Introduction to Organic Geochemistry. Longman Group Ltd., UK.

15. Killops, S.D., Killops, V.J., 2005. Introduction to Organic Geochemistry (2nd ed.). Blackwell Publishing Limited, UK.

16. Klemme, H.D., 1994. Petroleum systems of the world involving Upper Jurassic source rocks. In: Magoon, L.B. and Dow, W.J. (eds.), The petroleum system- from source to trap. AAPG Memoir 60, Tulsa, 51-72.

17. Kwan-Hwa, S., Jun-Chin, S., Ying-Ju, C., Wuu-Liang, H., 2006. Generation of hydrocarbon gases and CO_2 from a humic coal: experimental study on the effect of water, minerals and transition metals. Organic Geochemistry 37, 437-453.

18. Langford, F.F., Blanc-Valleron, M.M., 1990. Interpreting rock-eval pyrolysis data using graphs of pyrolizable hydrocarbons vs. total organic carbon. AAPG Bulletin 74(6), 799-804.

19. Mollaei, H., 2013. Organic geochemical characteristics evaluation of Hojedk formation at Pabdana coal mine, North West of Kerman coaly syncline. Unpublished M.Sc. Thesis, Geology Dept., Islamic Azad University, Zarand Branch (in Farsi).

20. Peters, K.E., Cassa, M.R., 1994. Applied source rock geochemistry In: Magoon, L.B. and Dow, W.J. (eds.), The petroleum system- from source to trap. AAPG Memoir 60, Tulsa, 93-120.

21. Peters, K.E., Snedden, J.W., Sulaeman, A., Sarg, J.F., Enrico, R.J., 2000. A new geochemical-sequence stratigraphic model for the Mahakam Delta and Makassar Slope, Kalimantan, Indonesia. AAPG Bulletin 84 (1), 12–44.

22. Poliansky, B. Safronov, D., 1974. Subdivision of Triassic and Jurassic coal bearing sediments in the Kerman region. National Iranian Steel Company (NISC), Rep. No. 8-9.

23. Safinejad, A., 2013. Petrography and thermal maturity of organic matter in Hashuni coal mine. Unpublished M.Sc. Thesis, Geology Dept., Islamic Azad University, Zarand Branch (in Farsi).

24. Shakibi, M., Shayestehfar, M.R., Ziaaldini, M., 2013. Hydrocarbon potential and depositional environment in the upper part of the Hojedk formation in the south east Zarand, Kerman area, central Iran. Journal of Geochemistry, Islamic Azad University, Zarand Branch, 1 (3), 205-214 (in Farsi).

25. Shanmugam, G., 1985. Significance of coniferous rain forests and related organic matter in generating commercial quantities of oil, Gippsland Basin, Australia. AAPG Bulletin 69, 1241-1254.

26. Shayestehfar, M.R., Banisi, S., Izadi, M., 2007. Microscopical study of coals from some Kerman mines. Journal of Geosciences, Geological Survey of Iran, 16 (62), 38-41 (in Farsi).

27. Sohrabi, H., 2013. Preliminary appraisal hydrocarbon potential of the D horizon coal seam on the main Pabdana mine based on rock-eval pyrolysis and organic petrography. Unpublished M.Sc. Thesis, Geology Dept., Islamic Azad University, Zarand Branch (in Farsi).

28. Taylor, G.H., Teichmüller, M., Davies, A., Diessel, C.F.K., Littke, R., Robert, P., 1998. Organic Petrology. Gebrueder Borntraeger, Berlin, Stuttgart.

29. Technoexport (Soviet Union), 1969, Geological map of the Kerman coal deposits. National Iranian Steel Company, Contract No. 1466.

30. Teichmuller, M. 1958. Metamorphism du carbon et propection du petrole. Review of Industrial Minerals, Special Issue, 1-15.

31. Tissot, B.T., Welte, D.H., 1984. Petroleum Formation and Occurrences (2nd ed.). Springer-Verlag, Berlin.

32. Tuttle, M.L.W., Charpentier, R.R., Brownfield, M.E., 1999. The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. Open-File Report 99-50-H.

33. Vahdati Daneshmand, F., 1995. Zarand 1:100,000 geological map. Geological Survey of Iran, sheet No. 7351.

34. Ziaaldini, M., 2012. Organic geochemical study of Hamkar coal mine. Unpublished M.Sc. Thesis, Geology Dept., Islamic Azad University, Zarand Branch (in Farsi).

ارزیابی مقدماتی توان هیدروکربن زایی سازند هجدک در ناودیس زغالی کرمان، ایران: رویکرد ژئوشیمیایی

- علی امیری (دانشگاه آزاد اسلامی، واحد زرند کرمان، ایران)
- منصور دفتریان (انجمن گاز ایران، تهران، ایران)

چکیـــــده

به منظور براورد توان هیدروکربن زایی لایه های زغالسنگ (افق های D و E) و سنگ دربردارنده آن ها در سازند هجدک (ژوراسیک میانی- پایانی) در ناودیس زغالی کرمان، ۳۲ نمونه زغالسنگ و ۴۶ نمونه شیل برداشت شد. این نمونه ها به طریقه ژئوشیمیایی مورد مطالعه قرار گرفت و کمیت، کیفیت و بلوغ حرارتی مواد آلی آنها تعیین شد. براساس داده های حاصل از پیرولیز راک- اِول مشخص شد که محتوای کل کربن آلی (TOC) در نمونه های زغالسنگ در وضعیت عالی قرار دارد. این شرایط برای نمونه های شیل نیز کم و بیش مشابه است. همچنین بررسی پتانسیل زایشی (GP) نیز نشان داد که اغلب نمونه ها پتانسیل قابل قبولی برای تولید گاز و نفت دارند. بنابراین، کمیت مواد آلی سازند هجدک در مجموع در شرایط خوب تا عالی ارزیابی شد. با بهره گیری از اندیس هیدروژن (HI) به عنوان یکی از مهمترین شاخص های تعیین کننده کیفیت سنگ های منشاء مشخص شد که نمونه های زغالسنگ و شیل سازند هجدک دارای اندیس هیدروژن از کمتر از ۵۰ تا بیش از ۶۰۰ میلی گرم هیدروکربن بر گرم سنگ بوده و عمده نمونه ها در بازه های ۵۰ تا ۲۰۰ و ۲۰۰ تا ۳۰۰ قرار می گیرند و بنابراین می توان کیفیت این مواد را از فاقد توان تولید هیدروکربن تا دارای توان تولید گاز و نفت در نظر گرفت. نوع کروژن موجود در این نمونه ها نیز در گروه های III و II-III قرار می گیرد و در نتیجه تولید گاز و نفت برای این ناحیه محتمل است. بالا بودن نسبت S3/S2 (۳.۷۰ تا ۴۰۲.۳۶) نمونه ها نیز تولید محصولات یادشده را تأیید می کند. به منظور براورد بلوغ حرارتی مواد آلی از دو روش Tmax و انعکاس ویترینایت استفاده شد. مقادیر Tmax اغلب نمونه های مورد بررسی نشانگر قرارگیری آن ها در ابتدا تا انتهای پنجره نفتی است. بالاترین مقدار Tmax مربوط به منطقه تیکدر است که این بلوغ بالا (شرایط فوق بالغ) احتمالاً به خاطر مجاورت با گسل کوهبنان است. اندازه گیری های قدرت انعکاس ویترینایت نیز از نشان داد که مقدار انعکاس از ۰.۵ تا ۲ درصد در تغییر بوده و میانگین آن ۱.۱۸ است و این مقدار با پنجره نفتی مطابقت دارد. در نهایت، براساس کمیت، کیفیت و بلوغ حرارتی مواد آلی در ناودیس زغالی کرمان می توان اظهار داشت که این ناحیه پتانسیل کافی برای تولید گاز و به مقدار کمتر نفت را دارد. بعلاوه، لایه های زغالی در مجموع به خاطر داشتن مقادیر بالاتر محتوای لیپتینایت (تا ۲۲ درصد) از شرایط بهتری برخوردارند.

واژگان کلیدی: ناودیس زغالی کرمان، هجدک، پتانسیل هیدروکربن زایی، پیرولیز، کروژن