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Application of Thermal Modelling for Geochemical Characterization of Gadvan Formation, Persian Gulf, Iran

Ahmad Vaezian[1*], Mansur Ziaii[1], Mohammad Reza Kamali[2], Ali Kadkhodaie-Ilkhchi[3]

[1] *Faculty of Mining, Petroleum and Geophysics, Shahrood University, Shahrood, Iran*

[2] *Exploration and Production Research Division, Research Institute of Petroleum Industry, Tehran, Iran*

[3] *Geology Department, Faculty of Natural Science, University of Tabriz, Tabriz, NW Iran*

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**Corresponding author: a.vaezian@shahroodut.ac.ir*

Abstract

In the this research, the hydrocarbon generation potential of the Gadvan Formation as a probable source rock was investigated in the central part of the Persian Gulf at the borders of Iran. Type and maturity level of kerogen were investigated in six wells using the results of Rock-Eval pyrolysis and compared with results yielded by the modelling software program known as Pars Basin Modeler (PBM). The cross-plot of hydrogen index (HI) versus maximum temperature suggests that the Gadvan Formation reached early to mid-maturity stages in the studied area, which means that it could act as a gas prone source rock. Furthermore, the burial and thermal history of the Gadvan Formation was determined in one well. Two methods, Easy %Ro and time-temperature index (TTI) were used for the reconstruction of thermal modelling and studying the thermal maturity level in all of the drilled wells reaching the Gadvan Formation. The results of the TTI and Easy %Ro methods were in good agreement and both of confirmed the results of Rock Eval analysis. An integrated approach using different techniques showed that the Gadvan Formation can be classified as a poor gas bearing source rock in the studied area, while its maturity increases towards the southern parts of the Persian Gulf.

Keywords: *Gadvan Formation, Iran, pars basin modeller, source rock evaluation, thermal modelling.*

1. Introduction

Source rock is an important part of each petroleum system. Studying a petroleum system accomplishes obvious knowledge pertaining to the generation and migration of hydrocarbon from the source rock. A source rock generates hydrocarbon during geological time and several factors such as temperature, geological time, type and amount of organic matter, as well as lithology control hydrocarbon generation in source rock [7]. However, various quantitative and qualitative factors should be considered when studying hydrocarbon generation. The use of software modelling programs is necessary to ease the complexity and high loads of calculations in the modelling of hydrocarbon generation.

Source rock maturity is a function of temperature, time and the burial history of sediments. Thermal modelling is based on the Lopatin method [1], which has been proposed for studying the thermal maturity of organic matter. Waples [2] simulated petroleum generation using Lopatin's method, which stipulates that petroleum generation obeys a first order rule and its rate is doubled in a systematic manner. Today, the advancement of modelling software programs has made it possible to investigate the burial history and maturity of source rocks. In addition, the process of hydrocarbon generation, which has taken millions of years in nature, can be reconstructed using these programs. The capabilities of these programs are wide-ranging and they can be used to reconstruct the basin under study in 1, 2 and 3 dimensional models.

In 1D modelling, the process of hydrocarbon generation is simulated in one dimension. Mostly, one oil- or gas well is selected for 1D modelling. Geological and geophysical sections are used for 2D modelling and finally, the best method for regional investigations is 3D modelling, which is suitable for estimating the hydrocarbon reserve [3].

To date, several publications have discussed the importance and applications of thermal modelling and burial history reconstruction. Details of thermal modelling and burial history for oil and gas generation were explained by Laura et al. [4]. Additionally, the authors extended their research to a real case study in the Wind River Basin Province located in Wyoming. Kamali et al. [5] studied the petroleum geochemistry of the Pabdeh Formation in Dezful Embeyment using thermal modelling. Organic geochemistry and thermal modelling of the Aghajari oil field in SW Iran were investigated by Alizadeh et al. [6], which highlighted the Kazhdumi Formation as the richest source rock in this area.

Studying the existing literature uncovered thermal modelling as a potent technique for studying a formation from the perspective of oil and gas generation. In the present research, the capabilities of the Pars Basin Model (PBM) software program and Rock-Eval analysis of 30 samples taken from six wells in five hydrocarbon fields were employed to develop a thermal model for the Gadvan Formation. This formation deposits in some parts of Dezful Embayment, as well as in Fars Province. The presence of shaly intervals and clay limestone accompanying organic matter introduces this formation as a probable source rock. Palaeontology studies have shown that Gadvan exhibits Neocomian to Aptian stages/ ages [7]. The thickness of this formation is about 100 meters in the Dezful Embayment, and reaches to 2000 meters in Fars Province [8]. Brownish and greenish marl, shale and grey to black limestone make up the main lithology of the formation. The Lower Cretaceous Gadvan Formation, part of the upper Khami Group, conformably overlies the Fahliyan Formation and is conformably underlain by the Darian Formation in the study area [7].

2. Methods

Different types of data such as stratigraphy, paleontological data, formation top and lithology, geochemical data, as well as geothermal gradient are necessary for modelling the process of hydrocarbon generation [10]. This information can be obtained from laboratory measurements, seismic sections and outcrop investigations. The burial and maturity history of sediments can be reconstructed to study the temperature of a formation over a long period of time and consequently evaluate the potentiality of each formation for hydrocarbon generation. Lithological information is the most important inputs for the software. Additional information such as erosion, sedimentary gap, depth of water, surface temperature, amount of total organic carbon (TOC), vitrinite reflectance (Ro) and hydrogen index (HI) are also necessary for modelling.

2.1. Rock Eval analysis

Thirty cutting samples from the Gadvan Formation, taken from six wells in the Persian Gulf, were analysed by Rock Eval.

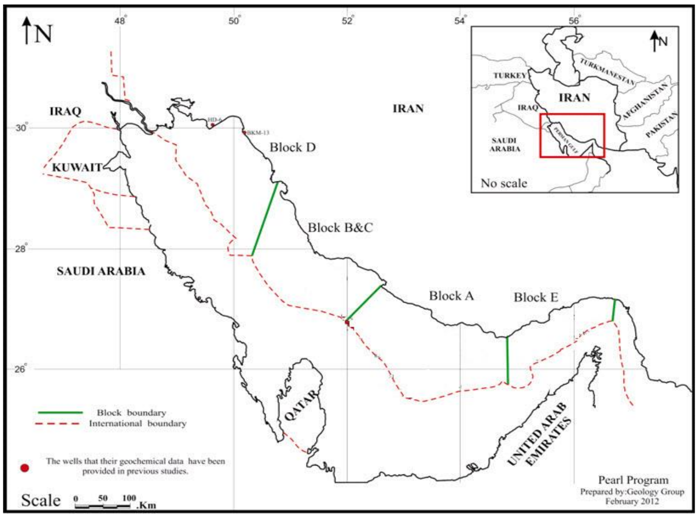

Fig. 1. Map shows the Persian Gulf and its main divisions. All samples used in the present research were selected from drilled wells in Block A.

All samples were washed and treated prior to Rock Eval pyrolysis to remove probable mud contaminations. The notion of the application and development of source rock pyrolysis via Rock Eval was first introduced by Espitalie in 1977 [9]. In this method, helium as a carrier gas passes over 100 milligrams of a powdered sample. The sample is heated up to 300°C in which the first peak, S_1, is detected using a flame ionization detector (FID). The bottom area of peak S_1 shows the amount of free hydrocarbon present in the sample. This hydrocarbon might be generated either during sedimentation or after from the in situ kerogen of the sample. Carboxyl groups of the rock's kerogen are broken at temperatures ranging from 300 to 390°C and converted to CO_2. This CO_2 is detected by thermal conductivity detector (TCD) as the third peak, named S_3. In the interval of 300 to 600°C, kerogen molecules are broken and converted into hydrocarbon. These hydrocarbons are detected by FID as peak S_2. The research shows that heavier hydrocarbons ($\geq C_{24}$) are not released below 350°C [9]. When the temperature of Rock Eval is increased up to 600°C at a rate of 25 degrees per minute, the heavier components are broken and their combined value is included in peak S_3. The remaining amount of carbon in kerogen is referred to as residual carbon. The oxidation system of Rock Eval detects the residual carbon as S_4 using a thermal conductivity detector. Total organic carbon (TOC) of the sample is determined based on S_1, S_2 and S_4. The ratios of S_2 versus TOC and S_3 versus TOC are known as hydrogen and oxygen indexes. A higher hydrogen index value is proportional to the higher potential of the source rock for hydrocarbon generation.

2.2. Maturity and kerogen evaluation

The results of Rock Eval pyrolysis, including S_1, S_2, S_3, HI, OI, T_{max} and TOC, were used for investigating the maturity of organic matters in the studied samples. Table 1 represents the results of Rock Eval analysis for 30 samples taken from the Gadvan Formation. Additionally, the kerogen type of the samples was identified using special cross-plots. The type of organic matter present not only affects the potential of the source rock for hydrocarbon generation, but also controls the type of hydrocarbon generated [10]. For example, kerogen type I and II are known as oil bearing, while type III is a gas bearing kerogen. A cross-plot of HI versus T_{max} was used to identify the type of kerogen. Figure 2 shows that type III was the dominant kerogen for the Gadvan Formation in all studied wells; a few samples were plotted at the border of type II and III, which are also known as type II/III. T_{max} was the best indicator for studying the maturity level of kerogen. Figure 2 shows that most samples from the Gadvan Formation were still immature; however, seven samples had reached their maturity stages.

Table 1. The results of Rock Eval analysis for 30 samples taken from the Gadvan Formation

Field Name	Well Name	Depth	TOC	Tmax	S1	S2	S3	PI	HI	OI
SIRRI	SIA-1	2409	0.21	431.0	0.2	0.2	0.4	0.41	110	200
		2431	0.20	434.0	0.2	0.2	0.5	0.55	75	270
		2446	0.18	425.0	0.1	0.1	0.5	0.71	28	256
Salman	2S-22	2295	1.41	402	2.18	2.45	4.92	0.47	174	349
		2325	0.59	423	0.75	0.91	3.36	0.45	154	569
		2353	0.52	420	0.75	0.78	2	0.49	150	385
		2379	0.94	417	0.73	1.28	5.32	0.36	136	566
		2433	0.43	419	0.29	0.69	2.59	0.3	160	602
		2464	1.59	421	0.63	2.01	2.35	0.24	126	148
		2495	0.41	419	0.31	0.8	1.34	0.28	195	327
		2524	0.49	421	0.27	0.81	1.39	0.25	165	284
		2550	0.58	424	0.46	0.98	1.8	0.32	169	310
		2578	0.2	450	0.14	0.45	1.16	0.24	225	580
		2603	0.64	426	0.82	0.94	3.28	0.47	147	512
	2S-K-1	1884	0.25	434	0.38	0.53	1.50	0.42	212	600
		1902	0.29	432	0.46	0.63	1.33	0.42	217	459
		1921	0.38	429	0.53	0.59	1.96	0.47	155	516
		1930	0.35	428	0.54	0.53	2.15	0.50	151	614
		1945	0.35	429	0.52	0.68	1.69	0.43	194	483
		1957	0.50	424	0.95	1.09	2.17	0.47	218	434
		1965	0.43	427	1.3	0.49	1.02	0.73	113	235
		2003	0.29	434	0.48	0.62	1.36	0.44	214	469
Tondar	T-2	2070	0.75	417	2.51	0.94	2.30	0.73	125	307
		2080	0.43	424	1.49	0.6	1.12	0.71	140	260
Kish	K-2	1740	0.3	430	0.06	0.3	0.6	0.17	100	200
		1780	0.45	422	0.07	0.21	0.7	0.25	47	156
Hamoon	3H-1	1349	0.85	432	0.47	2.16	1.62	0.18	254	191
		1356	0.91	424	0.99	3.57	1.07	0.22	392	118
		1370	1.25	421	1.43	4.28	0.83	0.25	342	66
		1385	1.13	420	1.30	3.81	0.51	0.25	337	45

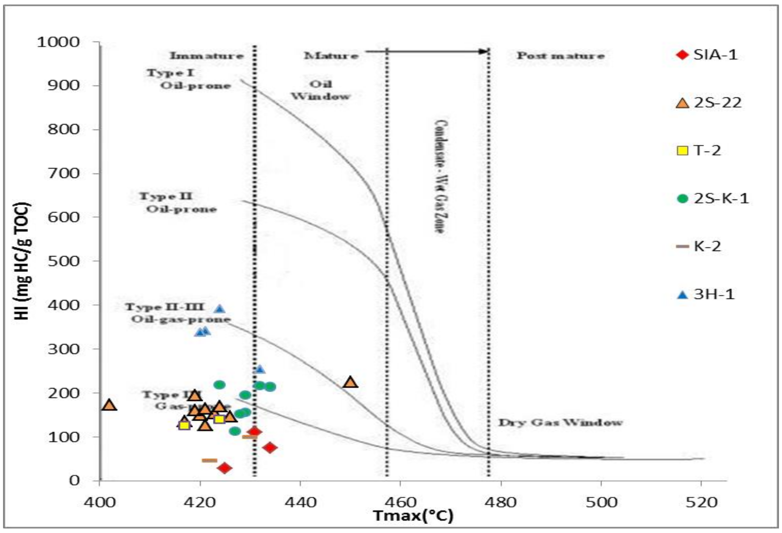

Fig. 2. Cross-plot of HI versus T_{max} used for the characterization and maturity evaluation of the Gadvan samples

A cross-plot of (S_1+S_2) vs. TOC is shown in Figure 3. This figure is used in organic geochemistry to study the quality of kerogen and its potential for hydrocarbon generation. As shown, the quality of Gadvan samples in the studied wells changed between lean and good; however, most of the samples exhibited moderate potential and only a few had either poor or good potential for hydrocarbon generation.

A cross-plot of (S_2/S_3) vs. TOC was used to investigate the type of hydrocarbon that could be generated by the Gadvan Formation in the studied wells. The results showed that the formation generated hydrocarbon in only one of the studied wells. Therefore, this indicates that the rock unit is not a good source rock in the studied area, due to its low TOC content; however, its current organic matter reached early maturity and it seems that it had produced gas in the past.

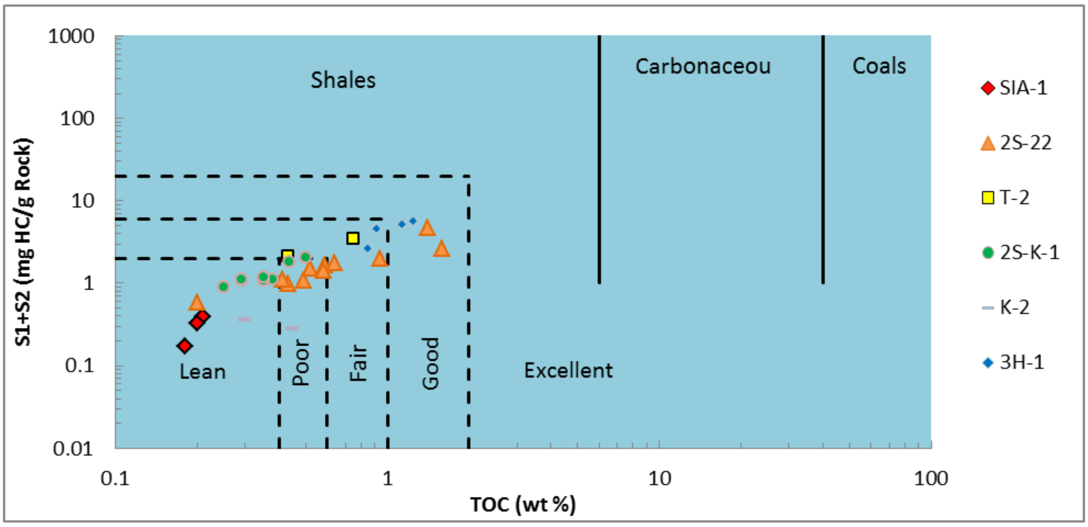

Fig. 3. A cross-plot of (S_1+S_2) vs. TOC for studying the hydrocarbon potential of the Gadvan samples

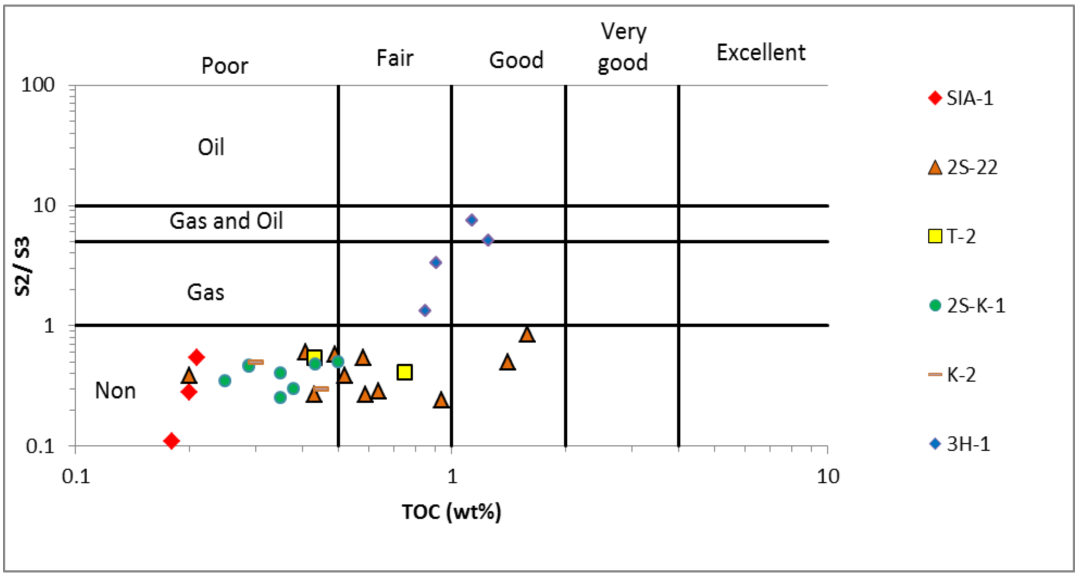

Fig. 4. A cross-plot of (S_2/S_3) vs. TOC for studying the type of generated hydrocarbon

3. Thermal modelling of the Gadvan Formation

Thermal modelling is an advanced method for indirect maturity identification. In addition, this method can be used to interpret the oil and gas generation window of formations. Oil generation from source rock is controlled by two parameters, i.e., time and temperature [2]. The most suitable range of temperature for hydrocarbon generation is between 50 to 130°C. At temperatures lower than 50°C, the source rock cannot reach the maturity limit and above 130°C it reaches past the mature stage in a short period of time.

Different methods have been introduced for thermal modelling; among them, time-temperature index (TTI) and easy %Ro are the most well-known. In the TTI method, studying the burial and thermal history is necessary for thermal maturity identification. Recently, vitrinite reflectance index as a maturity indicator have been widely used. Various models have been introduced for theprediction of %Ro based on time and temperature [10]. In the current research, both methods were applied for developing the thermal modelling of the Gadvan Formation in the studied area. Table 2 shows ranges of TTI and Easy %Ro for different maturity levels. To achieve this goal, the data of all wells were used for developing thermal models based on TTI and Easy %Ro methods. To date, various software programs have been developed in this regard. Among them, Pars Basin Modeler (PBM) is one of the most recent, developed by the Research Institute of Petroleum Industry (RIPI) of Iran.

Here, the developed thermal models for the Gadvan Formation in different wells of the studied area are interpreted and discussed. Figure 5 shows the burial history of the stratigraphic column of various formations in well SIA-1. As shown in this figure, deposition of the Gadvan Formation started about 130 million years ago. The thickness of the formation in this well is roughly 48 meters.

The thermal history of the stratigraphic column of well SIA-1 is shown in Figure 6. The surface temperature and geothermal gradient are 29°C and 26.3°C, respectively. The present temperature of the Gadvan Formation has reached 96°C, as shown in the thermal model.

Table 2. Range of Easy %Ro and TTI values for different stages of maturity [10]

Method	Early mature	Mid mature	Late mature	Main gas generation
Easy %Ro	0.5 – 0.7	0.7 - 1	1 – 1.3	1.3 – 2.6
TTI	3.5 - 15	15 - 65	65 - 200	200 - 3600

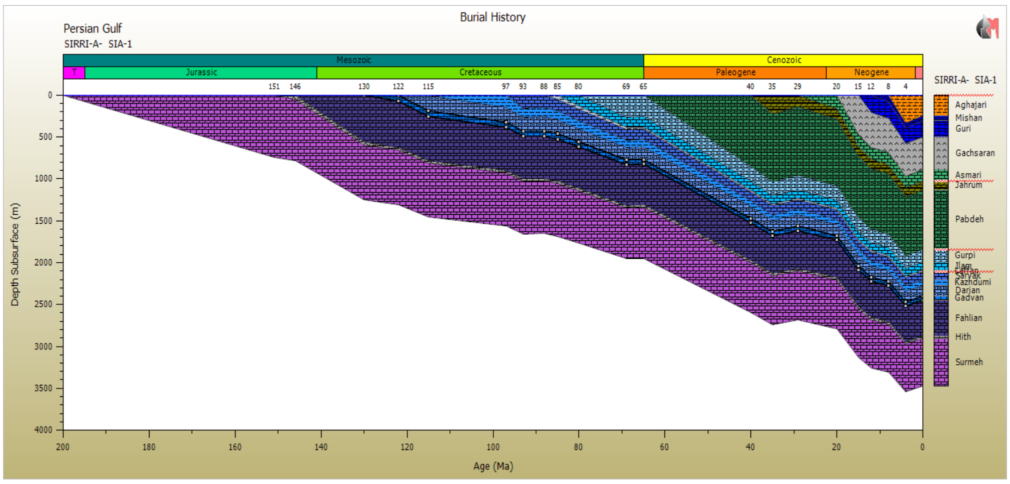

Fig. 5. Burial history of stratigraphic column of well SIA-1

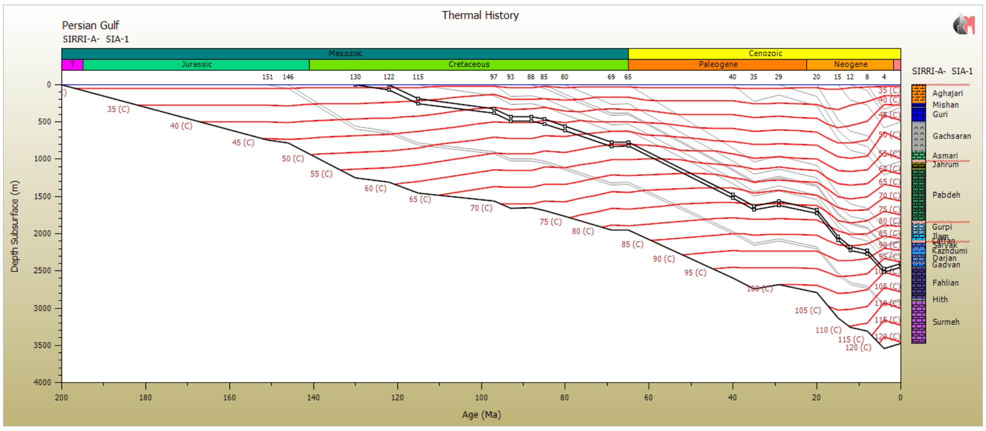

Fig. 6. Thermal history of the Gadvan Formation in well SIA-1

The maturity model of the stratigraphic column for well SIA-1 was reconstructed using the TTI and Easy %Ro methods (Fig. 7 & 8). In these figures, different stages of maturity are shown by different colours. Figure 7 shows the maturity model for the Gadvan Formation based on the TTI method. In this figure, the Gadvan Formation entered into an early mature stage around 35 million years ago at a depth of 1650 metres and since then, it has remained at this maturity stage. This stage is suitable for gas generation; therefore, the TTI model suggests that the Gadvan Formation in this well can generate gas. In the previous section, this view was confirmed by the cross-plot of HI versus T_{max}.

Figure 8 shows the maturity model of the Gadvan Formation based on the easy %Ro method. Vitrinite reflectance is a measure of the percentage of incident light reflected from the surface of vitrinite particles in a sedimentary rock, which is referred to as %Ro. Results are often presented as a mean Ro value based on all vitrinite particles measured in an individual sample [11]. To measure the vitrinite reflectance of samples, a thick polished section of taken samples from the Gadvan Formation should be prepared. An Axioplan-2 microscope (Zeiss) and a PMT III photometer were used. The optic lens of the microscope was set to x 100. These data were measured in the RIPI geochemistry laboratory. Figure 8 confirmed the results of TTI model; however, it also suggests that the formation entered into an early maturity stage 20 million years ago. As expected, there was a difference between the results of the TTI and easy %Ro models, which was most likely due to the differences in the fundamental aspects of these techniques. Meanwhile, the results of easy Ro are more reliable and most geochemists concur with it. However, the results obtained from these two methods should nevertheless be compared and checked with vitrinite measurement analysis represented by Ro versus depth plot.

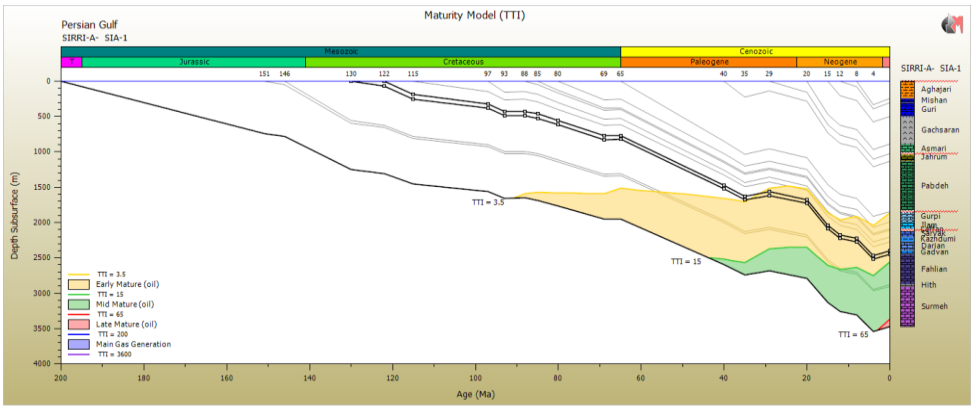

Fig. 7. Maturity model for the Gadvan Formation based on TTI methods in well SIA-1

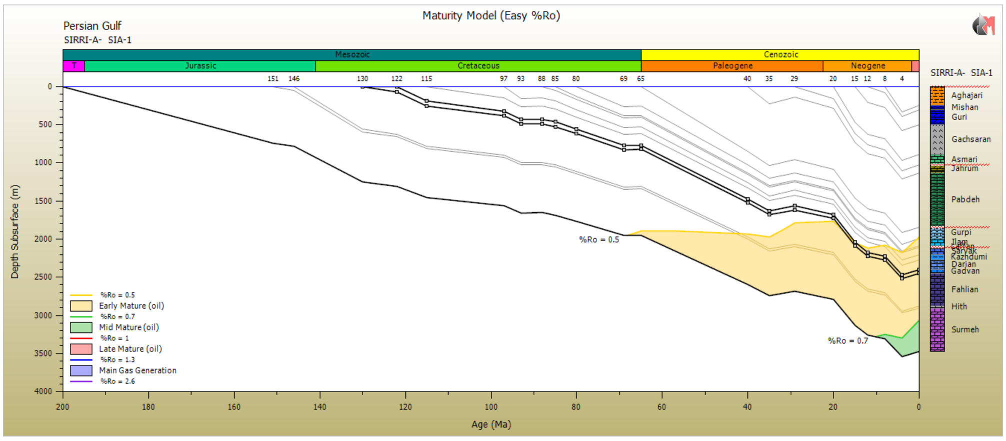

Fig. 8. Maturity model of the Gadvan Formation based on Easy %Ro methods in well SIA-1

Thermal modelling of the Gadvan Formation was developed for all of the studied wells. A schematic thermal modelling of Gadvan based on TTI and easy %Ro methods are shown in Figures 9 and 10. As can be seen, the Gadvan Formation reached peak maturity in well SIA-1, while its maturity was very low around well 3H-1. These results demonstrate that the maturity level of the formation increases towards the south of the Persian Gulf, whereas it did not reach high maturity in the central and northern parts of the Persian Gulf, which are located on the borders of Iran.

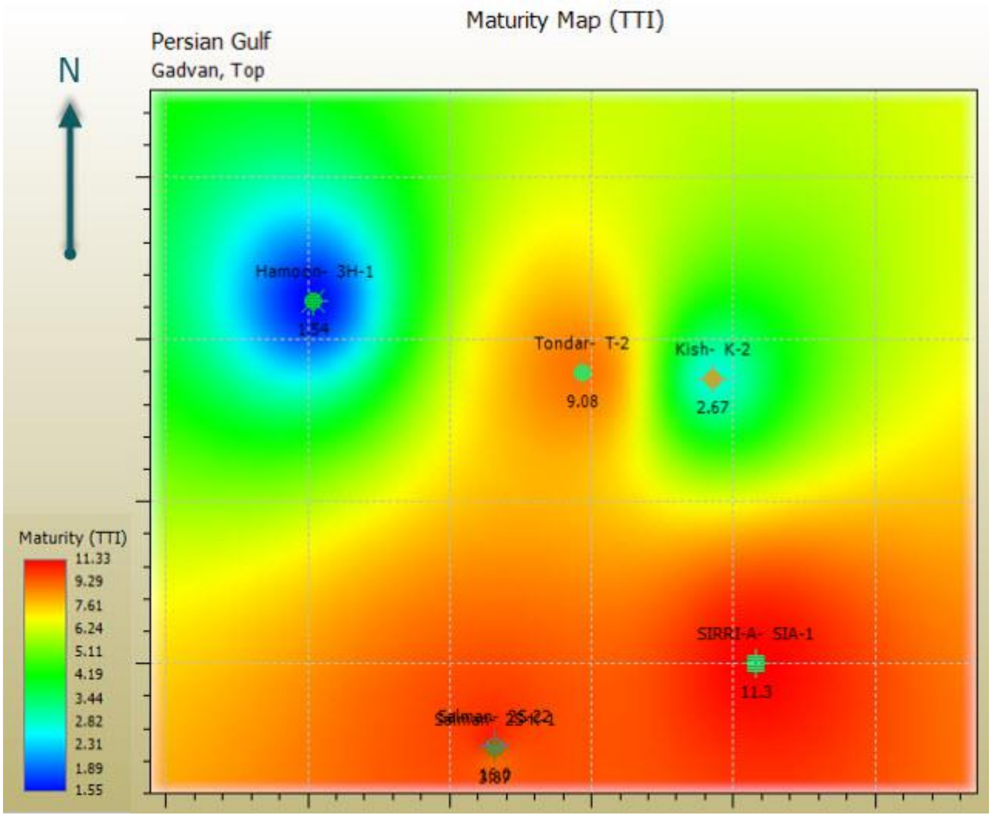

Fig. 9. A schematic illustration of the maturity levels around the studied wells based on the TTI method

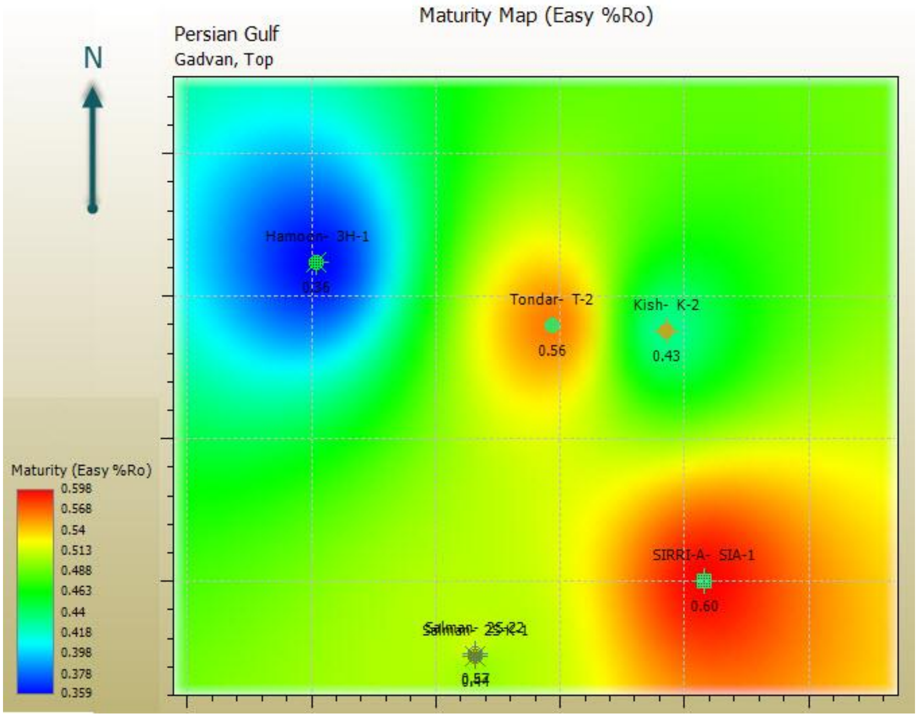

Fig. 10. A schematic illustration of the maturity levels around the studied wells based on the Easy %Ro method

4. Conclusion

In the present study, thirty samples from the Gadvan Formation from six wells, drilled in the Persian Gulf, were selected for studying by Rock-Eval pyrolysis. The results of the maturity evaluation showed that the studied samples had reached an early maturity level. Additionally, the dominant type of kerogen in these samples was kerogen type III. The mean value of TOC and HI in the studied samples was 0.58 and 174.16, respectively, which serves as evidence of poor source rock in the area. In addition, the mean value of Tmax was 425°C, which is smaller than the minimal threshold of Tmax for hydrocarbon generation. Therefore, it can be concluded that the Gadvan Formation is not an effective source rock in this area of the Persian Gulf.

The thermal maturity of the formation was modelled in all of the studied wells to recognize the maturity growth trends of organic matter. The results showed that the maturity of the formation increased toward the southern parts of the Persian Gulf. Among the studied wells, well SIA-1 had the highest maturity level. It is worth noting that this well is one of the most southern among the drilled wells on Iranian borders.

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