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Research Paper

Geochemical Evaluation of Source Rocks and Reservoir Oils of One of the Oil Fields in Abadan Plain

Kiani A.[1], Saberi M.H.[2*]

1- M.Sc, Dept. of Exploration, Faculty of Petroleum Engineering, Semnan University, Semnan, Iran
2- Assistant Professor, Dept. of Exploration, Faculty of Petroleum Engineering, Semnan University, Semnan, Iran

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Abstract: In this research, the hydrocarbon generation potential of probable source rocks was evaluated. Results of the Rock-Eval pyrolysis showed that, among the studied samples, the Pabdeh and Kazhdumi formations contained marine type-II/III kerogen and showed good to very good oil generation potential, making their organic matter (OM) immature and immature-in early oil production window, respectively. Containing mixed type-II/III kerogen, the Gadvan Formation was found to be within the oil production window, in terms of maturity, showing good hydrocarbon generation potential. The Sargelu and Garau formations were found to be dominated by type-II kerogen, exhibiting very good hydrocarbon generation potential. It was further figured out that the Garau and Sargelu formations were in the middle and late oil production window to early wet gas window, respectively. Outcomes of geochemical analyses on the studied crude samples showed that all of them were originated from the same source, with the potential source rock exhibiting a marl-carbonate lithology deposited in a reducing environment. The OM content of the probable source rock was primarily made from type-II kerogen formed in a marine environment, with evidence of intrusions by OMs dominated by terrestrial kerogen has been further observed. The studied crude samples were found to be sourced from Lower Cretaceous to Middle Jurassic source rocks with maturity levels corresponding to middle to late oil production window so that the crude samples from the Fahliyan Formation exhibited the highest levels of maturity. Sargelu and Garau formations were proposed as potential source rocks for the crudes accumulated in the Abadan Plain.

Keywords: Biomarker studies, Petroleum geochemistry, Hydrocarbon generation potential, Source rock, Stable isotopes.

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*Corresponding Author Email: *mh.saberi@semnan.ac.ir*

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INTRODUCTION

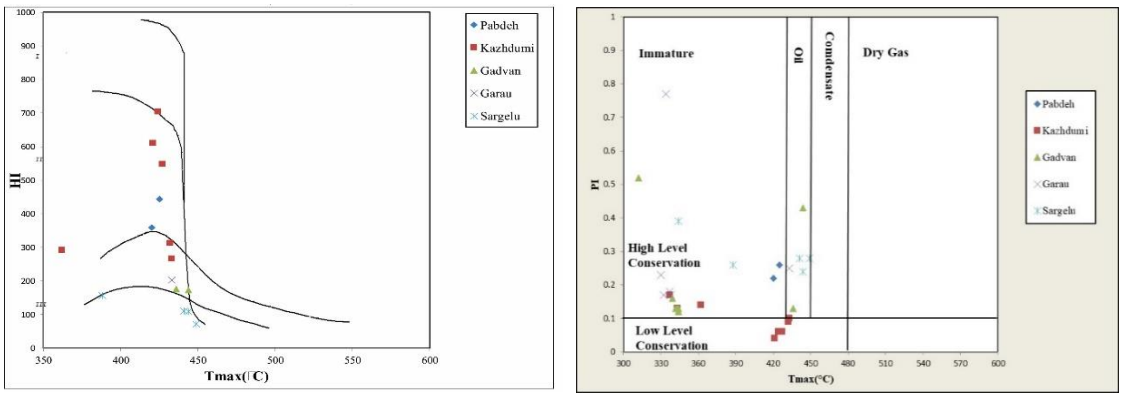
Presently, petroleum geochemistry serves as a principal tool for improving the exploration and development of hydrocarbon fields. It plays significant roles in source rock evaluation, oil family and hydrocarbon source identification, genetic investigation of reservoir fluid, the study of reservoir continuity and connection between multiple reservoirs, fluid injection for enhanced oil recovery (EOR), etc. [1,2]. Located in the southwest of Iran, Abadan Plain hosts proper source rocks and multitudes of reservoir rocks, making it one of the most hydrocarbon-rich regions in Iran. In the present study, given the importance of potential source rocks and reservoir units in the Abadan Plain, we begin with investigating the hydrocarbon generation potential of Pabdeh, Kazhdumi, Gadvan, Garau, and Sargelu formations as probable source rocks. This was done using the data obtained from Rock-Eval pyrolysis studies. Subsequently, geochemical studies (preliminary and complementary geochemical analyses) were performed on crude samples from Ilam, Sarvak, and Fahliyan formations as local reservoir units. At this point, geochemical parameters and composition of the crude samples from the mentioned reservoirs were investigated before proceeding to study and correlate biomarker and isotopic information of the corresponding crudes.

METHODS

In this work, a total of 31 samples of cuttings from Pabdeh, Kazhdumi, Garau, and Sargelu formations were retrieved from two exploratory wells penetrating an oilfield in the Abadan Plain were evaluated to assess their ability to serve as source rock. Using a Rock-Eval 6 instrument, the evaluation was conducted to identify kerogen type, maturity of organic matter (OM), and hydrocarbon generation potential. The thermal maturity of the OM was assessed based on T_{max} values obtained from the Rock-Eval pyrolysis. As a next step, for the sake of geochemical study of crudes accumulated in Ilam, Sarvak, and Fahliyan reservoirs, four crude samples were prepared. Finally, the OM of the samples was geologically dated based on C_{13} isotopic assessments on asphaltene cuts extracted from the bitumen and crude samples.

FINDINGS AND ARGUMENT

In this research, $S_1 + S_2$ or S_2 (outputs of Rock-Eval pyrolysis) was utilized to quantify the OM of the samples and hence estimate their hydrocarbon generation potential and classify the source rock [3-6]. Samples from Pabdeh and Kazhdumi formations in the Abadan Plain exhibited good to very good hydrocarbon generation potential, while most of the samples from Gadvan Formation in the Abadan Plain were found to possess only good hydrocarbon generation potential. Garau and Sargelu formations, on the other hand, were of very good hydrocarbon generation potential. Based on the diagram of total organic carbon (TOC) versus hydrogen index (HI), the majority of the samples from Pabdeh, Kazhdumi, Gadvan, and Garau formations could potentially generate oil. This was while the samples from Sargelu Formation were in the oil and mostly oil-gas production window. Combining the diagram of HI versus oxygen index (OI) and T_{max} in the Abadan Plain, the studied samples were found to contain type-II, type-III, or mixed type-II/II kerogens. In this respect, samples from Pabdeh Formation possessed relatively immature OM with mixed type-II/III kerogen. On the other hand, Kazhdumi and Gadvan formations contained type-II and mixed type-II/III kerogens, with their OM contents being immature-in early oil production window. Being matured enough to produce oil, Garau Formation exhibited T_{max} values in the range of 332 - 433°C, placing it in the middle oil production window. This formation was found to contain type-II kerogen. In the meantime, experimental results referred to relatively low T_{max} of the sample from the Garau Formation, which could be attributed to the effects of additives introduced into the drilling mud or impurities in the sample. On average, the corresponding HI was 204 mg/g of rock, indicating very good hydrocarbon generation potential for the Garau Formation. Based on the HI versus OI and T_{max} diagram, Sargelu Formation was dominated by type-III kerogen. However, the low value of HI and depositional environment of the Sargelu Formation suggest that the dominant kerogen type is type-II marine. Both diagrams show that the studied samples in the Abadan Plain contain type-II and type-III kerogens or a mixture of both (Figure 1-A). The plot of T_{max} versus productivity index (PI) proves that the Pabdeh Formation is immature while Kazhdumi and Gadvan formations are immature-in early oil production window. It further indicates that Garau and Sargelu formations are in the middle oil production window and late oil production window to early wet gas window, respectively (Figure 1-B).



(A) **(B)**

Figure 1. A: Hi versus T_{max} diagram for the studied samples [3], and **B:** PI versus T_{max} for evaluating thermal maturity of the studied samples [3]

On the Tissot-Welte ternary diagram [7], crude samples from Ilam and Sarvak reservoirs were close to one another and classified as paraffinic-naphthenic oils. Chemically speaking, the crude sample from Fahliyan Formation was somewhat different from the other crude samples, containing the highest content of saturated hydrocarbons and the lowest level of polar compounds (resin and asphaltene), classifying it as a paraffinic (light) oil. Distribution of C_{29} Sterane 20s/(20s+20R) versus C_{32} Hopane 22s/(22s+22R) showed that the source OMs of the crude samples from Ilam and Sarvak reservoirs were in the early-middle oil production window while the one for the crudes of Fahliyan Formation was more mature than the formers, being at the late of its oil production window. For the crude samples from Ilam, Sarvak, and Fahliyan reservoirs, the odd/even carbon preference index (CPI) obtained from gas chromatography (GC) was close to 1, indicating high thermal maturity of the corresponding OM and placing the corresponding source rocks within the middle- peak of the oil production window.

Variations of DBT/Phen versus Pr/Ph [8] showed that the crude samples from Ilam reservoir fall in the 1A zone, reflecting their marine carbonate nature. On the other hand, the crude samples from Sarvak and Fahliyan formations were found to be in the 1B zone, indicating their carbonate-marl source rock. Variations of C_{29}/C_{30} Hopane against C_{34}/C_{35} showed that the source rocks for Ilam, Sarvak, and Fahliyan formations in the Abadan Plain have been deposited in a reducing environment, with carbonates and marl lithologies. Moreover, changes in the Pr/Ph ratio showed that the corresponding source has been deposited on a carbonate platform to an open sea environment [8,9]. The abundance of C_{29} Sterane compared to C_{28} and C_{29} Steranes indicated that, within the Abadan Plain, the source rock has been formed in a marine environment where traces of OM containing terrestrial kerogen can be found. The plot of Pr/nC18 versus Ph/nC18 for the studied crude samples suggests a relatively reducing environment with type-II kerogen (algae and marine) at a relatively high level of maturity. As is shown in Figure 2, all of the crude samples studied in the Abadan Plain were properly correlated to one another, so that one could classify them under the same oil family.

The plot of Hopane 35/34 versus Gammacerane/Hopane C30 for the investigated samples in this work showed that those were originated from a source rock deposited in a transitional environment of shale and carbonates with normal salinity levels, with the source rock being dominated by marl at the time of deposition. In this work, we used the plot of Pr/Ph versus δ^{13} isotopic ratio to characterize the lithology of and date the source rocks producing the crude samples [10]. On this basis, the crude samples from Ilam, Sarvak, and Fahliyan reservoirs were found to be produced from carbonate source rocks formed back in the Mesozoic, with acceptable correlations to regional source rocks, including Garau and Sargelu formations, all of which have been dated back to the Mesozoic. For the crude samples studied in the Abadan Plain, the value of ETR ranged between 0.55 and 0.67. Being below 1.2, these levels of ETR show that the corresponding source rock has been formed during the Middle to Upper Jurassic or even younger age. For the studied samples, we observed Oleanane/ (Oleanane + Hopane) ratios below 0.09, indicating that the corresponding crudes were generated from source rocks formed during the Cretaceous or younger age. The

obtained value of C_{28}/C_{29} Sterane for the studied crude samples ranged from 0.5 to 0.7, indicating an age of Jurassic to Cretaceous for the corresponding source rock. According to the results of biomarker studies and isotopic assessments, the studied reservoir oils were from the same oil family. Sargelu (Middle Jurassic) and Garau (Lower Cretaceous) formations were therefore suggested as the main sources for the reservoir oils studied in this research.

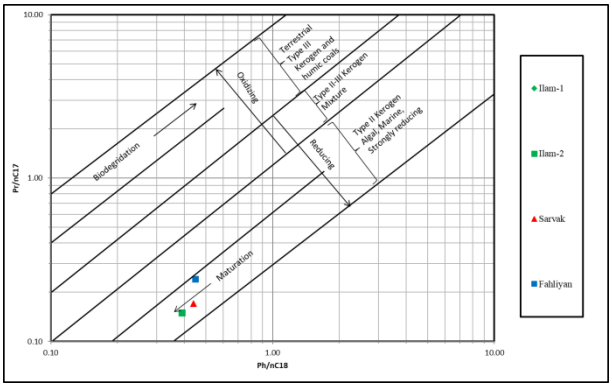


Figure 2. Plot of Pr/nC_{17} versus Ph/nC_{18} to detect the evolution of organic matter, identify reducing and oxidizing environments, and investigate biodegradation of the studied samples [8]

CONCLUSION

Results of the Rock-Eval analyses showed that the Pabdeh, Kazhdumi, and Gadvan formations were dominated by type-II and type-II kerogens, while Garau and Sargelu formations contained, for the most part, type-II kerogen. Focusing on the hydrocarbon generation potential, the Pabdeh and Kazhdumi formations were found to exhibit good to very good hydrocarbon generation potential while the Gadvan Formation was good in hydrocarbon generation potential, and the Garau and Sargelu formations exhibited very well hydrocarbon generation potential. Based on variations of productivity index (PI), hydrogen index (HI), and T_{max} in the studied samples, it was concluded that Pabdeh Formation is immature while Kazhdumi and Gadvan formations are immature-in early oil production window. Garau Formation showed evidence of reaching a suitable maturity level in its middle oil production window, and Sargelu Formation was found to be sufficiently matured in the late of its oil production window- early wet gas window. In general, compared to the Pabdeh, Kazhdumi, and Gadvan formations, the Garau and Sargelu formations were found to exhibit superior thermal maturity and quality for hydrocarbon generation.

According to the obtained hydrocarbon cuts and corresponding star diagram, the crude samples studied in this work exhibited relatively good overlaps, so that one can classify them under the same oil family – although minor differences are evident in particular parameters. Based on the maturity measures, like the plots of Pr/nC_{17} versus Ph/nC_{18}, C_{29} Sterane 20s/(20s+20R) versus C_{32} Hopane 22s/(22s+22R), and odd/even carbon preference index (CPI), the studied crude samples were sourced from highly matured source rocks, placing them somewhere between middle part and late of the corresponding oil production windows. To evaluate the lithology and depositional environment of the source rocks charging the studied reservoirs, biomarker studies were performed in terms of the plots of Pr/Ph versus DBT/Phen, C_{29}/C_{30} Hopane against C_{34}/C_{35}, Hopane 35/34 versus Gammacerane/Hopane C30, and Pr/Ph variations. The results showed that the potential source rock is Lithologically composed of carbonates and marl and is originally deposited in a reducing environment to produce type-II kerogen. The abundance of C_{29} Sterane compared to C_{28} and C_{29} Steranes indicated that the source rock has been formed in a reducing environment where traces of OM containing terrestrial kerogen can be found. The plot of C_{13} isotopes in aromatic and saturated compounds showed that the studied crude samples were originated in a marine depositional environment. Finally, based on age-assessment geochemical parameters like ETR, Oleanane/(Oleanane+Hopane), C_{28}/C_{29} Sterane, and Pr/Ph versus δ^{13} isotopic ratio, it was found that the crudes accumulated in Ilam, Sarvak, and Fahliyan formations were sourced from carbonate deposits formed during Cretaceous to Middle Jurassic. According to the results of biomarker analysis and isotopic studies, within the Abadan Plain, the crude accumulated in

the Fahliyan Formation was found to be sourced from a thermally more mature source rock than those of the crudes in Ilam and Sarvak reservoirs. As a final finding, Sargelu (dated back to Middle Jurassic) and Garau (dated back to Lower Cretaceous) formations were recognized as source rocks charging Ilam, Sarvak, and Fahliyan reservoirs.

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