https://jssr.ui.ac.ir/?lang=en
Journal of Stratigraphy and Sedimentology Researches
E-ISSN: 2423-8007
Vol. 40, Issue 4, No. 97, Winter 2024, pp 63-74
Received: 14.12.2024 Accepted: 26.01.2025

Research Paper

Organofacies heterogeneity of the Aptian–Albian source rock (Kazhdumi Formation) in selected oilfields from the Zagros Basin

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Abstract
Organic geochemical data for the Aptian–Albian Kazhdumi Formation of SW Iran were reviewed to better understand its organic geochemical characteristics. Rock-Eval pyrolysis data from 382 samples, sourced from both published literature and proprietary data, were used in this study. Prior to interpreting the geochemical data, a robust screening procedure was applied to eliminate anomalous values. The refined dataset, consisting of 135 samples from 22 different oilfields, was subsequently used to evaluate the variation of Kazhdumi source rock organofacies in a regional context. Our results indicate that different stratigraphic horizons within the Kazhdumi Formation are represented by different organofacies characteristics. This organofacies heterogeneity was most likely controlled by the palaeo-depositional environments in which strongly anoxic conditions (e.g., during times of relative sea-level high) were intervened by suboxic conditions (e.g., at times of sea-level fall) during Kazhdumi deposition. This organofacies heterogeneity is an important risk factor for containing the Kazhdumi-Ilam/Sarvak petroleum system of the Zagros Basin, as it controls the ultimate generative capacity and expulsion characteristics of the Kazhdumi source rock. In addition, the results of this study further emphasize the importance of considering source rock effective thickness in future basin and petroleum system modeling studies.
Keywords: Kazhdumi Formation, Source rock evaluation, Organofacies variation, Palaeo-environments, Dezful Embayment

Introduction

The Aptian–Albian Kazhdumi Formation of southwestern Iran is a significant hydrocarbon source rock that contributes substantially to the discovered oil and gas reserves in the Dezful Embayment (Van Buchem et al. 2010; Bordenave 2014; Alipour 2022, 2024). Previous studies have extensively explored its organic geochemistry (Bordenave and Burwood 1995; Bordenave and Huc 1995; Bordenave and Hegre 2010; Alizadeh et al. 2012) and sequence stratigraphy (Van Buchem et al. 2010; Vincent et al. 2010; Shabani et al. 2022). Recently, Alipour (2022) conducted a detailed study of the palaeo-depositional environments of this critical source rock in the Zagros Basin of Iran.

An overwhelming body of research exists on the organic geochemistry of the Kazhdumi Formation in the Zagros Basin (Table 1). These studies provide an extensive Rock-Eval pyrolysis data set that can be applied to the regional characterization of the Kazhdumi source rock (Table 2). However, caution is necessary when interpreting these analytical data, as many measurements are influenced by notably high concentrations of free hydrocarbons from oil-based mud (i.e., S_1 values exceeding S_2 parameters in pyrolysis) (Hunt 1996).

In particular, most previously published studies have overlooked that proper screening of the Rock-Eval pyrolysis datasets lies at the core of reliable geochemical interpretations. This is evidenced by the reports of the Rock-Eval pyrolysis S_1 being greater than the S_2 parameter in most of the previously reported datasets (Tables 1 and 2). Therefore, our main concern in the present study was to apply strict database screening methods to filter out unreliable values from geochemical interpretations. With this approach,

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Gholami Z. Alipour M. and Ammari A. (2024). Organofacies heterogeneity of the Aptian–Albian source rock (Kazhdumi Formation) in selected oilfields from the Zagros Basin. Journal of Stratigraphy and Sedimentology Researches, 40(4):63-74. https://doi.org/10.22108/jssr.2025.143672.1303

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https://doi.org/10.22108/jssr.2025.143672.1303

it was possible to identify significant trends of variation in the geochemical data of the Kazhdumi source rock. The new findings about organofacies heterogeneity of the Kazhdumi source rock can have practical implications for basin and petroleum system modeling studies in the Zagros Basin. In addition, they may be useful in fine-tuning the mass balance estimates in the Kazhdumi-Ilam/Sarvak petroleum system, which in turn may help to identify low-risk zones of interest for future exploration/production activities.

Table 1- A summary of previously published studies reporting geochemical information of the Kazhdumi Formation in the Zagros Basin.

Field(s)	Area	Analytical methods	Number of samples	Key findings	Reference
Filed A	Dezful Embayment	Rock-Eval pyrolysis, Stable carbon isotope analysis	10	About 300 meters of bituminous marls (TOC≈ 3-11 wt%) were deposited under anoxic conditions in the Rag-e-Sefid Area, the organic matter in mainly of type II algal origin, the onset of oil generation was about 4 Ma in the Rag-e-Sefid Area.	(Bordenave and Burwood 1990)
Kuh-e-Mond, Kaki, Zirreh, Namak, North Pars	Fars Province	Rock-Eval pyrolysis, Burial history modeling	9	Light brown marls deposited under oxic shallow-marine settings, very low organic content, thermally immature	(Kamali and Rezaee 2003)
South Pars	Persian Gulf	Rock-Eval pyrolysis, Palynofacies	22	Thickness ≈50 m, Predominantly gas-prone type III organic matter, thermally mature, grey to greenish shales with abundant terrestrial organic input, near-shore marine palaeo-environment with strong fluvial-deltaic influence	(Ghasemi-Nejad et al. 2009)
South Pars	Persian Gulf	Rock-Eval pyrolysis	22	Average TOC ≈ 0.49 (wt%), thermally immature (VRo<0.5%), high oxygen index values suggesting oxic depositional conditions	(Rahmani et al. 2010)
Ahvaz	Dezful Embayment	Rock-Eval pyrolysis, Burial history modeling	27	Thermally mature (peak oil window), Oil generation started at ≈15 Ma,	(Rabbani and Bagheri Tirtashi 2010)
Rag-e-Sefid, Kilur Karim, Siah Makan	Dezful Embayment	Rock-Eval pyrolysis, Organic petrography	40	Organic matter is composed of mixed type II/III origin, early to peak stages of maturity, and oil generation started at ≈6 Ma.	(Alizadeh et al. 2012)
Kuh-e-Bangestan (Tang-e-Maghar)	Dezful Embayment	Rock-Eval pyrolysis, Palynofacies	8	Dark shales (≈270 m) with marl intercalations, Palaeo-depositional settings were relatively anoxic with a restricted connection to open-marine, high concentration of amorphous (Type II) organic matter with minor terrestrial input.	(Mirzaloo and Ghasemi-Nejad 2012)
Rag-e-Sefid	Dezful Embayment	Rock-Eval pyrolysis, Organic petrography, Burial history modeling	12	Amorphous (liptinitic) organic matter, open marine depositional settings	(Opera et al. 2013)
Azadegan	Abadan Plain	Rock-Eval pyrolysis, Organic petrography, Burial history modeling	45	Marginal maturity (VRo≈ 0.5-0.7 %), the predominant type of organic matter is of type II and mixed type II/III.	(Bolandi et al. 2015)
Salman, Balal, Sirri, South Pars	Persian Gulf	Rock-Eval pyrolysis, Organic petrography, Burial history modeling	68	Average TOC values are ≈1.2 (wt%), the type of organic matter is of mixed type II/III origin, and hydrocarbon generation started in the Early Eocene and Oligocene times respectively in eastern and western Persian Gulf areas.	(Mashhadi et al. 2015)
Marun	Dezful Embayment	Rock-Eval pyrolysis, GC-MS	16	Excellent source rock potential with average TOC of ≈3.9 (wt%), Type II organic matter, thermally mature (average Tmax values ≈ 442 ˚C)	(Asadi Mehmandosti et al. 2015)
Darquain	Abadan Plain	Rock-Eval pyrolysis, Organic petrography, Burial history modeling	10	Lower quality source rock, the main phase of hydrocarbon generation at ≈40 Ma, present-day transformation ratio ≈80%	(Zeinalzadeh et al. 2015)
Ahvaz	Dezful Embayment	Rock-Eval pyrolysis, Kinetic analysis, Modeling	13	Narrow range of activation energy distribution, Fair to good potential for hydrocarbon generation, highly mature with a transformation ratio of 85%	(Karimi et al. 2016)
Different oilfields	Dezful Embayment, Fars Province, Abadan Plain	Rock-Eval pyrolysis, Organic petrography, Burial history modeling	30	TOC values range from 0-11 (wt%) with the lowest values on the Qatar-Fars-Arch, amorphous algal organic matter is dominant in the Dezful Embayment, terrigenous organic input increases towards Fars Platform	(Sfidari et al. 2016)
Darquain	Abadan Plain	Rock-Eval pyrolysis, GC, GC-MS	20	Type II/III organic matter with average TOC of 2.4 (wt%), early stages of oil generation window	(Zeinalzadeh et al. 2018)
Khaviz Oilfield	Dezful Embayment	Rock-Eval pyrolysis	28	Type II organic matter with average TOC of 2.8 (wt%), early stages of oil generation window (Tmax≈435 ◌̊C)	(Khalatbari et al. 2020)

Geological background

The Cretaceous period was a time of worldwide sea-level high associated with a warm and humid climate. The sedimentary record of the Zagros Basin during the Cretaceous period is composed predominantly of carbonates due to its positioning near the palaeo-equator (Sharland et al.

2001). However, strong siliciclastic influxes entered into the carbonate depositional environments due to warm and humid palaeo-climatic conditions. This resulted in the development of mixed clastic-carbonate successions in which the lithofacies distribution was controlled by sea-level fluctuations (Davies et al. 2019). Periods of relative sea-level fall corresponded to "strong clastic influxes" in the proximal areas and "exposure/karstification of platform tops" in the distal settings (Davies et al. 2002). On the other hand, the clastic wedge was pushed back landward during times of relative sea-level rise, which corresponded to the deposition of highly organic-rich sediments in the basinal areas (Alipour 2022). The Kazhdumi organic-rich marls were deposited under a period of sea-level high at the center of an intrashelf basin which is known as the Kazhdumi Intrashelf Basin (KISB) (Fig 1).

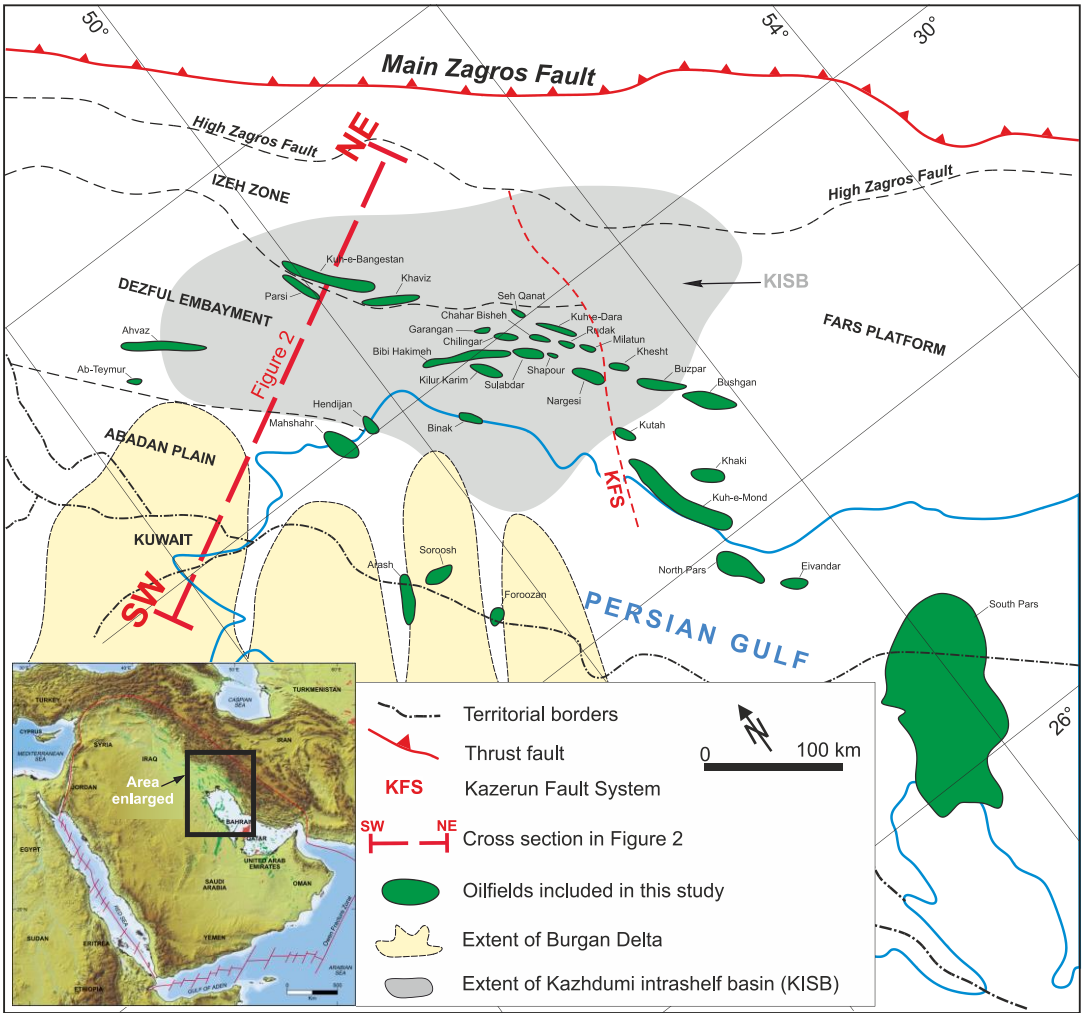

Fig 1- Generalized location of oilfields from which geochemical information on the Kazhdumi Formation is available.

The KISB was separated from the open Neo-Tethyan oceanic waters by shallow-water carbonates of the Dariyan Formation (Fig 2). This rimmed intra-shelf setting also received considerable clastic influxes from the southwest through the Burgan deltaic system (Van Buchem et al. 2010; Davies et al. 2019; Shabani et al. 2022) (Fig 2). Anoxic bottom conditions favoring organic matter preservation prevailed at the center of the KISB and led to the deposition of highly organic-rich marls of the Kazhdumi Formation (Davies et al. 2002; Van Buchem et al. 2010; Vincent et al. 2010; Alipour 2022). Oxygenation of these settings during times of relative sea-level fall resulted in the periodic development of suboxic conditions and deposition of organic-poor carbonate-rich horizons within the Kazhdumi Formation.

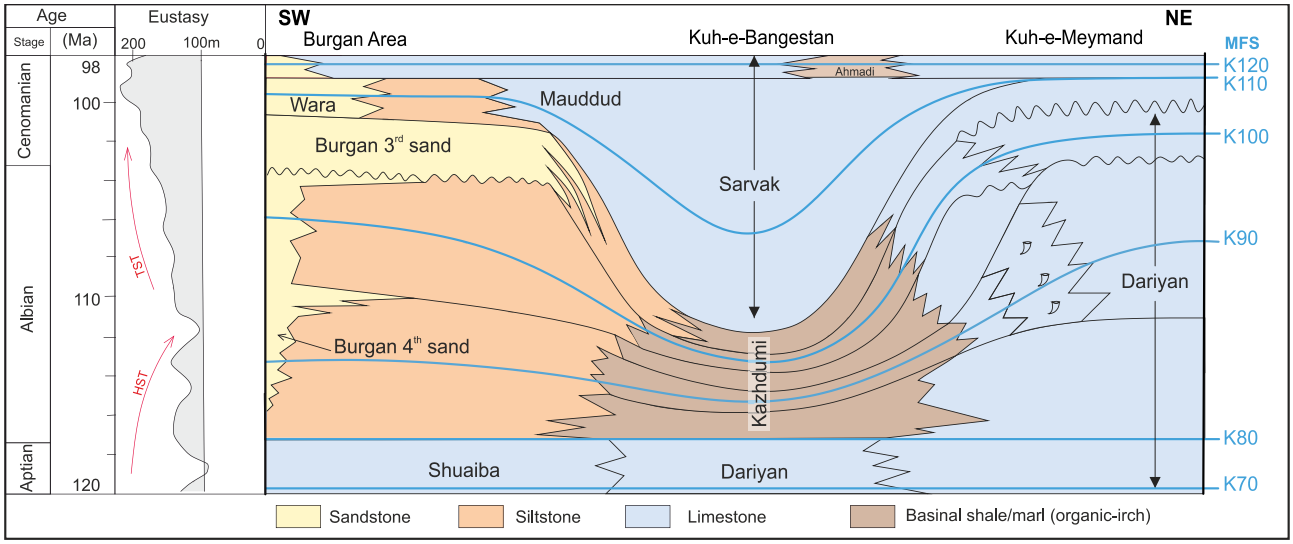

Fig 2- Generalized chrono-stratigraphic section through the Kazhdumi intra-shelf basin (see Figure 1 for section location) based on previously published information (Davies et al. 2002; Van Buchem et al. 2010; Davies et al. 2019)**. Maximum flooding surfaces and the relative sea-level curve are adapted from Sharland et al. (2001).**

Material and methods

Rock-Eval pyrolysis

Our database of Rock-Eval pyrolysis parameters included analytical data from 382 samples, including those reported in previous publications and those from our proprietary database (Table 2). Rock-Eval pyrolysis is a cost-effective analytical technique for acquiring information on the bulk geochemical characteristics of source rock samples (Lafargue et al. 1998). This instrument uses ~70 mg of powdered rock samples for programmed heating in a pyrolysis oven. The first 3 minutes include iso-thermal heating at ~300 ℃, which releases the free hydrocarbons in the sample (Fig 3). These vaporized hydrocarbons are recorded as peak S_1 (mg HC/g rock). In the next step, the temperature of the pyrolysis oven is increased at a rate of 25 ℃/min, and this causes the generation of hydrocarbons from thermal cracking of the associated kerogen (Fig 3). The released hydrocarbons are recorded as the S_2 peak (mg HC/g rock), which can generally be considered as an indicator of source rock generative potential (Hunt 1996). The temperature corresponding to the peak hydrocarbon generation at the pyrolysis step is called the Tmax which is used toevaluate the thermal maturity of the source rock samples (Behar et al. 2001). Other useful parameters calculated from the Rock-Eval pyrolysis data, which include the Hydrogen Index (HI), Oxygen Index (OI), and Production Index (PI) (Peters 1986) (Fig 3).

Table 2- A list of Rock-Eval pyrolysis data (from previously published papers and our proprietary data) are used in this study highlighting the average values for several important parameters and indicating the number of samples before and after the screening procedure.

Previous studies										
	Before screening					After screening				
Field name(s)	Number of samples	Average TOC (wt%)	Average HI (mg HC/g TOC)	Average Tmax (℃)	Average PI	Number of samples	Average TOC (wt%)	Average HI (mg HC/g TOC)	Average Tmax (℃)	Average PI
Ab-Teymoor	7	2.85	345	439	0.27	6	2.55	342	438	0.24
Ahvaz	43	2.64	268	436	0.46	13	2.21	336	471	0.26
BiBi Hakimeh	4	1.3	237	440	0.15	4	1.3	237	440	0.15
Buushgan	5	0.37	134	433	0.31	-	-	-	-	-
Buzpar	3	0.87	153	440	0.36	1	0.75	237	438	0.36
Chahar Bishe	2	1.03	191	434	0.45	1	1.12	197	434	0.31
Chilingar	6	0.98	172	434	0.32	5	1.01	172	435	0.31
Dorood	9	1.57	206	428	0.68	-	-	-	-	-
Garangan	2	1.32	181	432	0.17	-	-	-	-	-
Kaki	1	0.9	335	435	-	1	0.9	335	435	-
Khaviz	27	2.92	397	451	0.14	27	2.92	397	451	0.14
Khesht	3	0.93	74	437	0.21	-	-	-	-	-
Kilur karim	17	2.33	265	436	0.47	5	1.11	192	440	0.17
Kuh-e- dara	5	0.86	251	432	0.22	4	1.03	301	435	0.16
Kuh-e- Kaki	1	1.42	227	438	0.04	-	-	-	-	-
Kutah	2	0.63	301	432	0.25	2	0.63	301	432	0.25
Kuh-e-Mond	5	0.38	207	429	0.3	-	-	-	-	-
Kuh-e-namak	1	0.44	100	370	-	-	-	-	-	-
Nargesi	2	1.21	120	436	0.24	2	1.21	120	436	0.24
Parsi	1	3.07	110	445	-	-	-	-	-	-

Previous studies										
	Before screening					After screening				
Field name(s)	Number of samples	Average TOC (wt%)	Average HI (mg HC/g TOC)	Average Tmax (°C)	Average PI	Number of samples	Average TOC (wt%)	Average HI (mg HC/g TOC)	Average Tmax (°C)	Average PI
Rudak	6	0.36	99	425	0.55	-	-	-	-	-
Seh Ganat	11	0.63	167	431	0.15	3	1.36	293	438	0.17
sarvestan	3	0.16	110	432	0.23	-	-	-	-	-
Shapour	3	0.7	174	432	0.26	2	0.95	153	430	0.26
Sulabdar	6	0.54	165	422	0.34	-	-	-	-	-
Tange-e-Maghar	8	3.08	338	430	0.04	8	3.08	338	430	0.04
Milatun	4	0.27	200	425	0.37	-	-	-	-	-
TOTAL	181					84				
Arash	6	1.61	175	428	-	6	1.61	175	428	-
Balal	5	0.38	464	327	0.22	-	-	-	-	-
Binak	25	1.22	205	435	0.27	7	2.3	280	438	0.22
Eivandar	5	0.27	123	423	0.28	-	-	-	-	-
Farur	2	1.32	58	424	0.91	-	-	-	-	-
Farzam	3	0.2	90	435	1.32	-	-	-	-	-
Foroozan	18	1.58	197	427	0.31	9	2	192	428	0.27
Golshan	4	2.67	129	423	0.67	-	-	-	-	-
Hendijan	36	5.98	306	440	0.67	7	1.98	386	435	0.11
Hormuz	8	0.66	325	441	0.63	-	-	-	-	-
IRIS	4	2.58	69	361	0.92	-	-	-	-	-
Javdan	2	0.19	137	415	0.55	-	-	-	-	-
Kish	2	0.16	170	424	0.5	-	-	-	-	-
Mahshahr	10	2.85	408	434	0.38	1	5.51	501	431	0.23
North Pars	4	0.27	191	429	0.61	-	-	-	-	-
Reshadat	6	1.65	333	382	0.11	3	2.04	412	414	0.06
SIRRI D	5	0.82	105	428	0.51	-	-	-	-	-
Soroush	21	1.1	174	456	0.15	18	1.16	189	458	0.15
South Pars	26	0.5	143	412	0.6	-	-	-	-	-
Suru	5	0.54	226	448	0.56	-	-	-	-	-
Tousan	4	0.52	434	448	0.11	-	-	-	-	-
TOTAL	201					51				

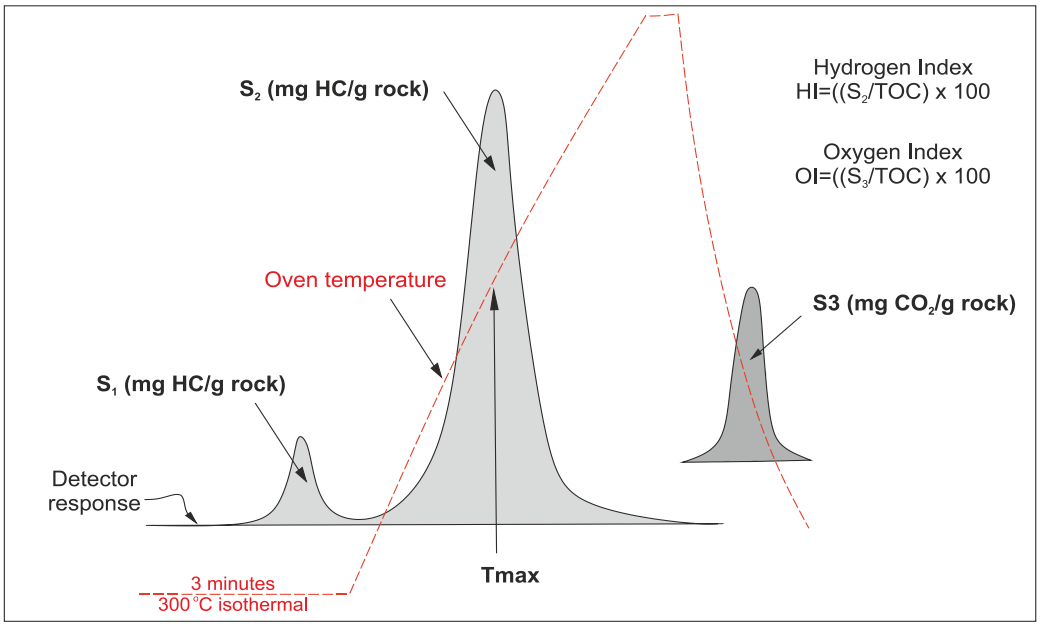

Fig 3- Schematic representation of the Rock-Eval pyrolysis analytical procedure (Hunt 1996).

Database screening

In this study, preliminary steps were taken to eliminate anomalous samples from the database, following the standard guidelines established in earlier studies (e.g., Katz 1983; Peters 1986; Peters and Cassa 1994; Dembicki 2009). Chemometric methods can be used to enhance the screening of bulk geochemical information, especially for datasets containing large numbers of values (Alipour et al. 2019). However, in the present study, a simpler screening procedure was applied for the preparatory screening of the Kazhdumi database by using plots of the PI versus Tmax (Fig 4a and b). It is generally known that PI values increase with increasing thermal

maturity (Peters 1986; Peters and Cassa 1994). According to these authors, immature samples (i.e., Tmax < 435˚C) exhibit very low PI values (i.e., PI ≤ 0.1), while PI values as high as 0.4 are expected at peak maturity (Fig 4a). Therefore, low-maturity samples exhibiting anomalously high PI values should be excluded from further consideration (Fig 4b).

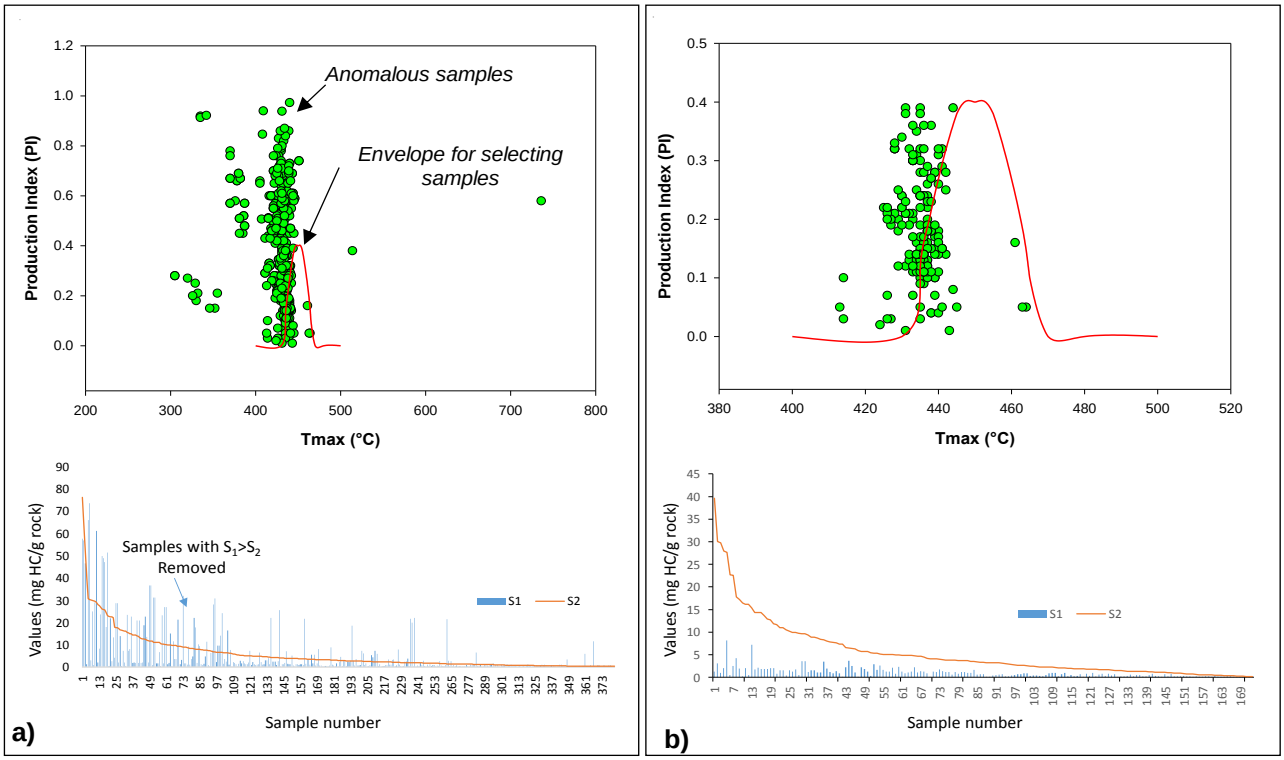

Fig 4- Data set structure captured by the Production Index (PI) versus Tmax (˚C) diagrams and bar diagrams of S_1 and S_2 parameters showing the raw database of 382 samples before screening (a) and removal of anomalous values after the screening which leaves a total of 135 samples for further processing (b).

A significant number of samples were excluded due to anomalously high concentrations of free hydrocarbons in their matrices. Nevertheless, the resulting dataset provided adequate sample coverage from 22 different oilfields (Figure 1 and Table 2) and was suitable for understanding the regional geochemical characteristics of the Kazhdumi source rock in the study area.

The screening step applied in this study ensured the omission of samples contaminated with non-indigenous hydrocarbons (Figure 5). Following these preparatory procedures, 135 samples remained out of 382 samples in our database, which were subsequently used for the geochemical evaluation of the Kazhdumi source rock (Table 2).

It is worth mentioning that samples with S_2 values less than 1 mg HC/g rock should also be excluded from the database because these samples represent unreliable Tmax values (Peters 1986; Peters and Cassa 1994; Lafargue et al. 1998; Dembicki 2009). However, this step was not necessary in the present study because the main aim was to highlight the organic geochemical heterogeneity within the Kazhdumi Formation.

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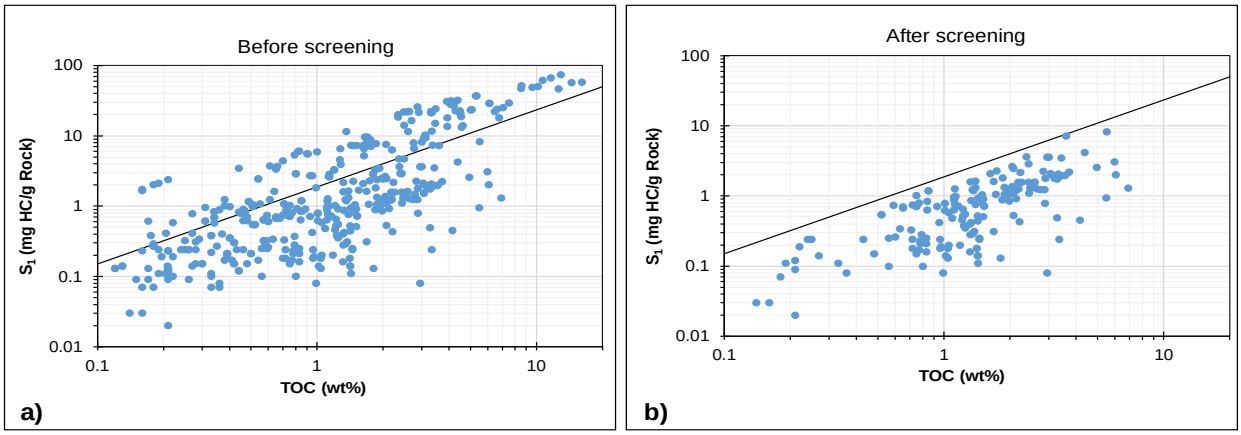

Fig 5- Diagrams of S_1 versus TOC for studied Kazhdumi samples before (a) and after (b) screening steps.

Organic petrographic examinations

Organic petrography is a powerful technique for the visual examination of organic matter contained in source rock samples (Gonçalves et al. 2024). This approach provides useful insights into the type and maturity of the organic matter contained in the source rock samples, especially when combined with bulk rock pyrolysis data (Amiri and Alipour 2023, Ammari and Alipour 2024). In this study, we used a Zeiss Axioplan-II microscope to study the organic matter contained in the Kazhdumi samples under oil immersion and reflected white light with 100x objective magnification.

Results and discussion

Source rock evaluation by Rock-Eval pyrolysis data

The geochemical evaluation of petroleum source rocks includes three main steps that are necessary to define the quantity, quality, and thermal maturity of the contained organic matter (Hunt 1996; Dembicki 2017). The amount of organic matter in the source rock is a critical factor, typically reported as Total Organic Carbon (TOC) in weight percent. Nevertheless, it must be emphasized that TOC alone cannot be a reliable indicator of source rock potential (Hunt 1996). Therefore, other parameters such as HI and S_2 must be considered in combination with TOC to better understand the petroleum generative potential of source rock samples. A comparison of TOC histograms of the Kazhdumi samples indicates that the screening procedure has satisfactorily removed anomalous values (Fig 6a). Most of the remaining samples are characterized by TOC values in the range of 1–1.5 (wt%).

Additionally, plots of HI versus TOC indicate that a more linear correlation can be obtained after screening the anomalous pyrolysis values (Figure 6b). This indicates that the higher TOC samples in the Kazhdumi samples are also characterized with greater generative potential, which in turn suggests that the S_1 cross-over effect is mostly cured by the screening procedure (Figure 6b).

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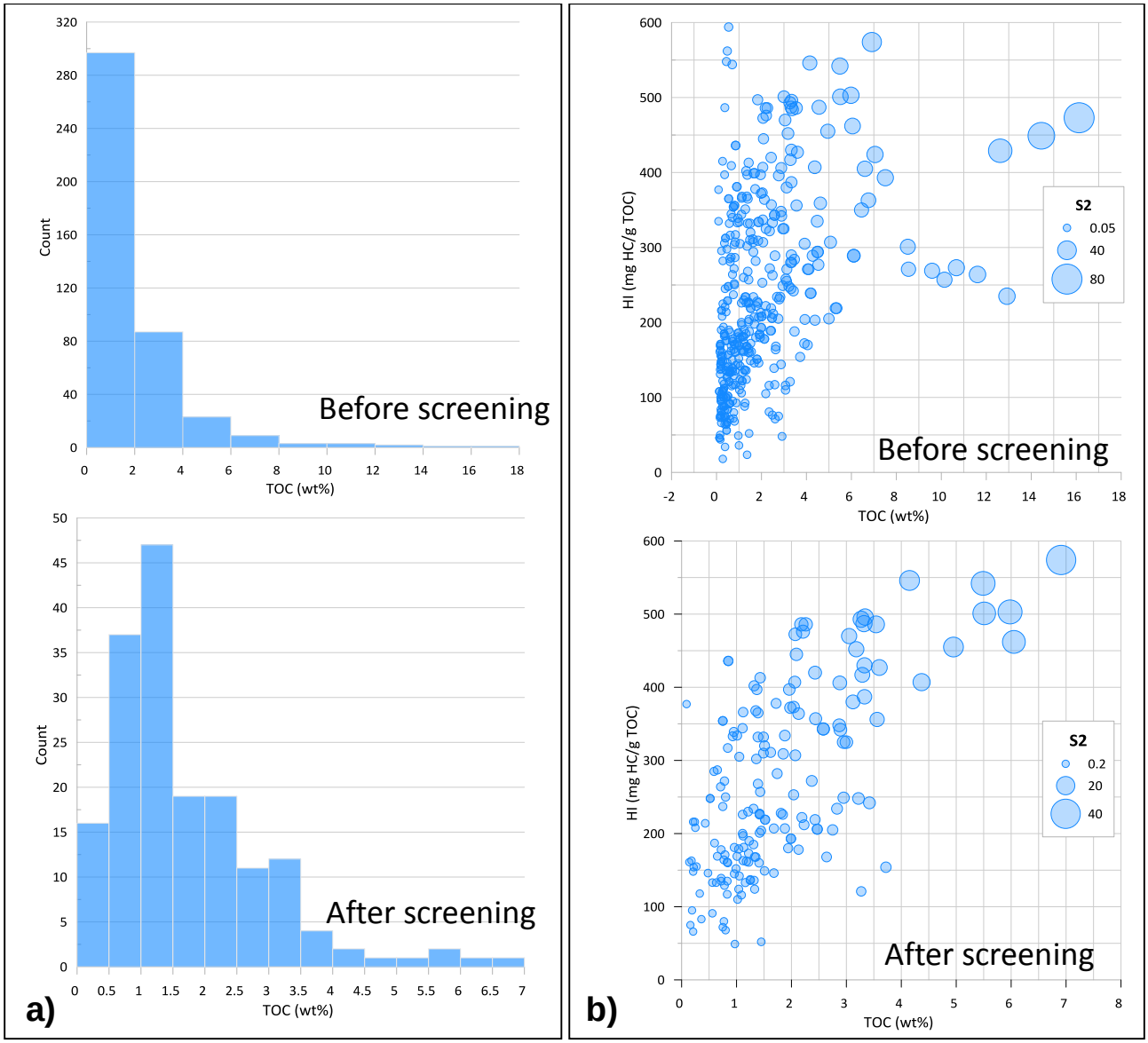

Fig 6- TOC histograms of the Kazhdumi samples before and after screening (a) and a comparison of the HI versus TOC plots for Kazhdumi samples before and after screening (b).

The type of organic matter in source rock samples can be assessed using HI versus OI diagrams (Hunt 1996). A 3D plot of HI, OI, and S_1+S_2 parameters for the Kazhdumi samples after screening reveals that the organofacies vary within each of the studied oilfields (Fig 7). A trend of variation from hydrogen-rich (i.e., highly oil-prone) to hydrogen-poor (i.e., less oil-prone) organic matter is observed for most of the studied oilfields (Fig 7). This conclusion agrees well with previously published results on the geochemical characteristics of the Kazhdumi source rock in the Zagros Basin (Alipour 2022).

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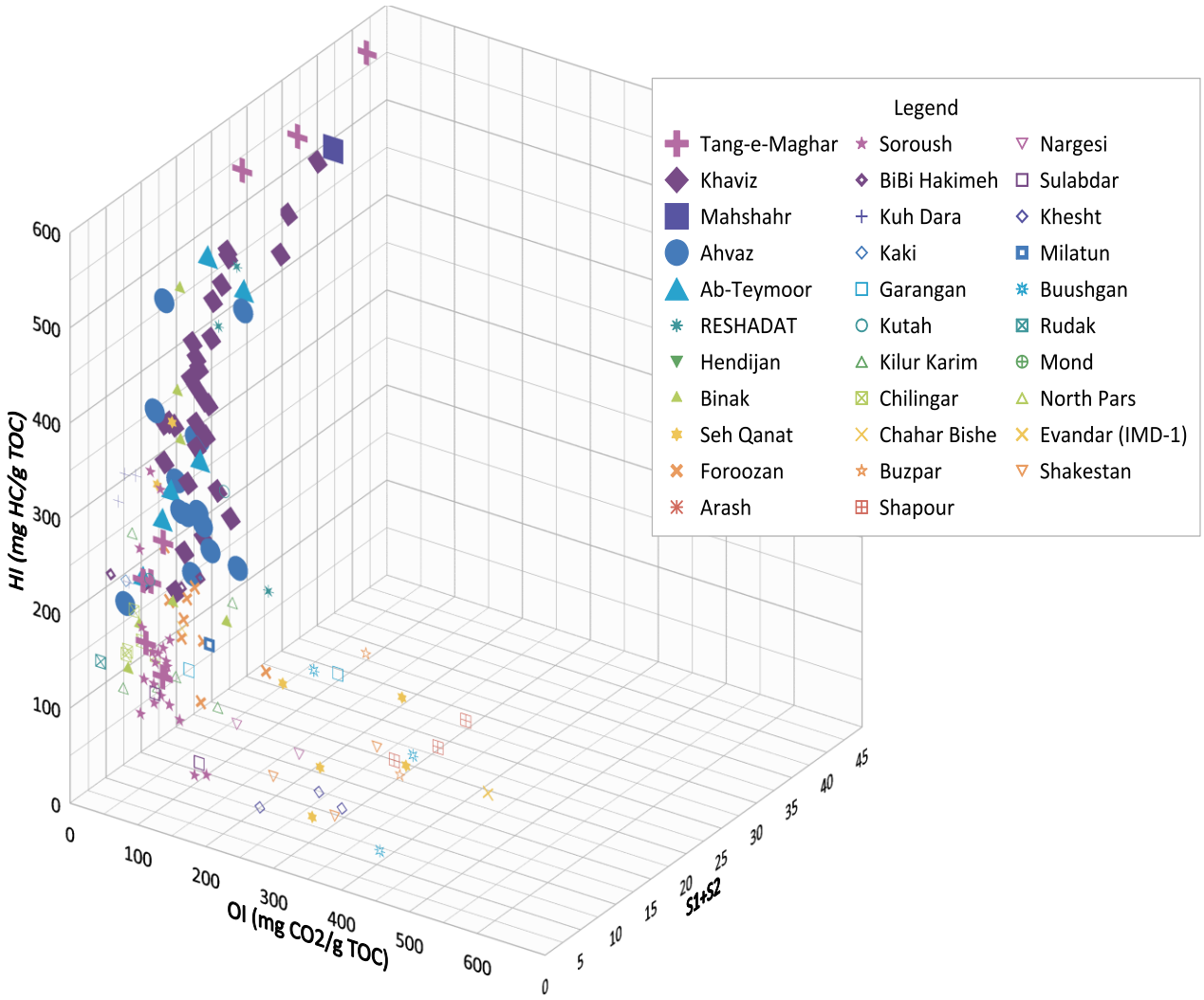

Fig 7- 3D plot of HI, OI, and S_1+S_2 parameters for Kazhdumi samples after preparatory screening steps.

Organic petrographic observations

Additional support for the organofacies heterogeneity of the Kazhdumi source rock is provided by independent lines of evidence coming from the organic petrographic observations (Fig 8). The hydrogen-rich organofacies are characterized by the widespread occurrence of amorphous organic matter and framboidal pyrite (Fig 8a and b). These petrographic signs are consistent with favorable conditions for organic matter preservation in the palaeo-depositional environments of the Kazhdumi Formation (Alipour 2022). On the other hand, the hydrogen-poor organofacies are mostly characterized by the lack of amorphous organic matter, minor occurrences of inertinites, and abundant fossil remains (Fig 8c,d). These petrographic signs suggest that periods of dysoxic conditions prevailed in the palaeo-depositional environments of the Kazhdumi Formation.

The level of thermal maturity can be assessed using HI versus Tmax diagrams (Hunt 1996). This is based on the assumption that due to the generation of hydrocarbons from the sedimentary organic matter, HI values progressively decrease with increasing Tmax (Tissot and Welte 1984). However, under a certain geothermal regime, different types of organic matter follow specific pathways on these plots due to their differing reactivity (Behar et al. 1997). In the present study, the hydrogen-rich oil-prone organofacies of the Kazhdumi Formation exhibit a thermal evolutionary pathway distinct from the hydrogen-poor organofacies (Fig 9). This supports the conclusion that the Kazhdumi Formation is composed of different organo-facies with different reactivity (i.e., kinetic properties) in the study area.

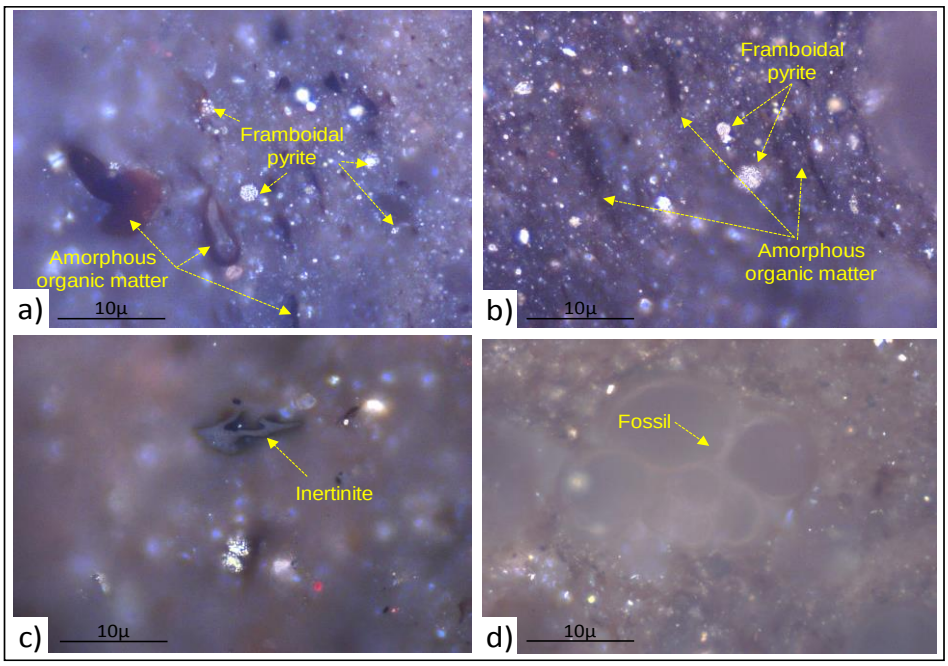

Fig 8- Photomicrographs of the Kazhdumi hydrogen-rich organofacies (a,b) and hydrogen-poor organofacies (c,d) in the Rag-e-Sefid Oilfield under oil immersion and reflected white light with x100 magnification.

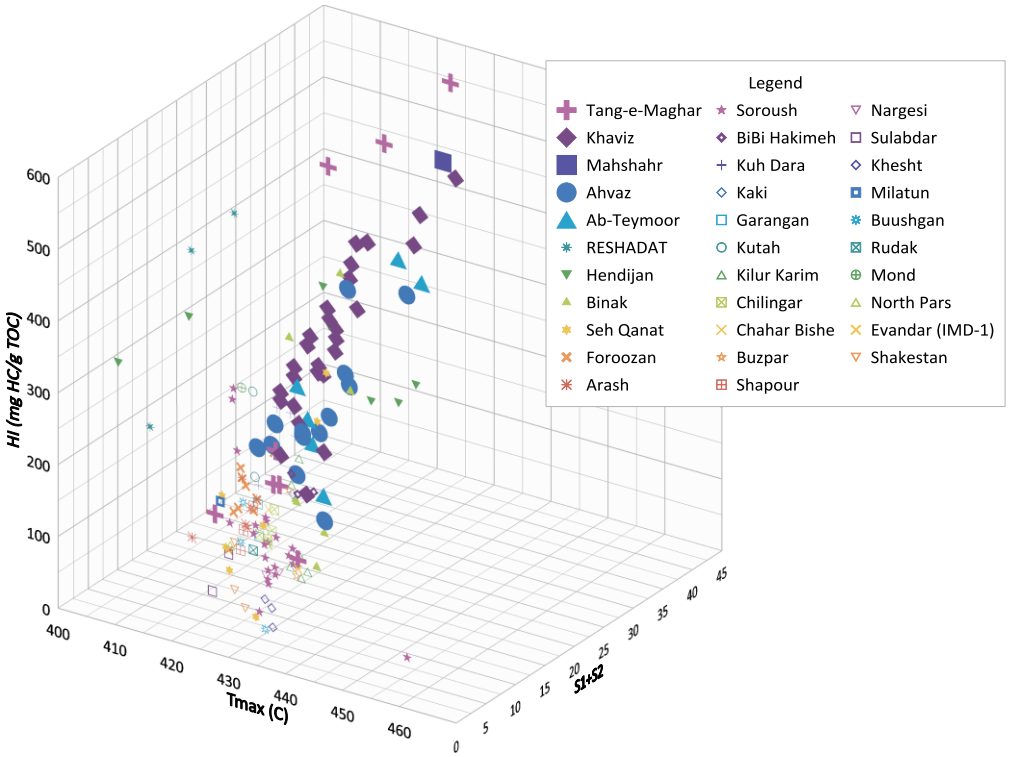

Fig 9- 3D plot of the HI, Tmax, and S_1+S_2 parameters for the Kazhdumi samples after preparatory screening steps.

Based on the above discussion, it appears that the Kazhdumi Formation has greater source potential in certain intervals than in others, reflecting the inherent organic-facies heterogeneity of this important source rock. These conclusions have practical implications for future basin and petroleum system modeling studies in the Zagros Basin. For

https://doi.org/10.22108/jssr.2025.143672.1303

example, the whole thickness of the Kazhdumi Formation cannot be considered a source horizon in these models because this will exaggerate the volume of in-place oil in identified prospects. In addition, the source rock heterogeneity reported in this study can potentially affect petroleum expulsion/migration processes from the Kazhdumi source rock. Therefore, additional research is required to carefully constrain the spatial distribution (i.e., geographic and stratigraphic) of the Kazhdumi oil-prone organofacies in the Zagros Basin.

Conclusions

A synthesis of the available geochemical information for the Kazhdumi Formation of SW Iran was performed with careful preliminaryscreening steps. The results indicate that the organofacies properties of the Kazhdumi Formation vary throughout the whole thickness of this formation. This organofacies heterogeneity is evidenced by the occurrenceof hydrogen-rich highly oil-prone organofacies and hydrogen-poor less oil-prone organofacies in different stratigraphic horizons within the Kazhdumi Formation. Different organofaceis of the Kazhdumi Formation also exhibit different thermal evolutionpaths on HI versus Tmax diagrams, reflecting different reactivity of the associated organic matter. The results of this study suggest that additional research is required to map the hydrogen-rich organofacies and determine the effective thickness of the Kazhdumi source rock in the Zagros Basin.

Acknowledgments The authors are grateful for the valuable and constructive comments from anonymous reviewers which greatly enhanced the quality of this manuscript.

References

Alipour M. 2022. Organic facies and paleo-depositional environments of the Aptian–Albian Kazhdumi source rock in the Zagros basin of Iran. Marine and Petroleum Geology, 145: 105887. https://doi.org/10.1016/j.marpetgeo.2022.105887

Alipour M. 2024. Petroleum systems of the Iranian Zagros Fold and Thrust Belt. Results in Earth Sciences, 2: 100027. https://doi.org/10.1016/j.rines.2024.100027.

Alipour M. Alizadeh B. Ramos L. S. Mirzaie S. and Chehrazi A. 2019. Chemometrics-enhanced classification of source rock samples using their bulk geochemical data, Southern Persian Gulf Basin. Iranian Journal of Oil and Gas Science and Technology, 8(4):1-17. https://doi.org/10.22050/ijogst.2019.142950.1469.

Alizadeh B. Sarafdokht H. Rajabi M. Opera A. and Janbaz M. 2012. Organic geochemistry and petrography of Kazhdumi (Albian–Cenomanian) and Pabdeh (Paleogene) potential source rocks in southern part of the Dezful Embayment, Iran. Organic Geochemistry, 49: 36-46. https://doi.org/10.1016/j.orggeochem.2012.05.004.

Amiri S. and Alipour M. 2023. Organic facies and organic petrographic characteristics of the Pabdeh Formation in the Kilur-Karim Oilfield, SW Iran. Journal of Stratigraphy and Sedimentology Researches, 39(3):1-14. https://doi.org/10.22108/jssr.2023.139363.1270

Ammari A. and Alipour M. 2024. Organic geochemistry and petrography of the early Cretaceous Garau Formation in the Kabir-Kuh Anticline, Ilam. Journal of Stratigraphy and Sedimentology Researches, 40(3):29-46. https://doi.org/10.22108/jssr.2024.142350.1294

Asadi Mehmandosti E. Adabi M. H. Bowden S. A. and Alizadeh B. 2015. Geochemical investigation, oil–oil and oil–source rock correlation in the Dezful Embayment, Marun Oilfield, Zagros, Iran. Marine and Petroleum Geology, 68: 648-663. https://doi.org/10.1016/j.marpetgeo.2015.01.018.

Behar F. Beaumont V. and Penteado H. D. B. 2001. Rock-Eval 6 technology: performances and developments. Oil & Gas Science and Technology, 56(2): 111-134. https://doi.org/10.2516/ogst:2001013.

Behar F. Vandenbroucke M. Tang Y. Marquis F. and Espitalie J. 1997. Thermal cracking of kerogen in open and closed systems: determination of kinetic parameters and stoichiometric coefficients for oil and gas generation. Organic Geochemistry, 26(5): 321-339. https://doi.org/10.1016/S0146-6380(97)00014-4.

Bolandi V. Kadkhodaie-Ilkhchi A. Alizadeh B. Tahmorasi J. and Farzi R. 2015. Source rock characterization of the Albian Kazhdumi Formation by integrating well logs and geochemical data in the Azadegan Oilfield, Abadan Plain, SW Iran. Journal of Petroleum Science and Engineering, 133: 167-176. https://doi.org/10.1016/j.petrol.2015.05.022.

Bordenave M. and Burwood R. 1990. Source rock distribution and maturation in the Zagros orogenic belt: provenance of the Asmari and Bangestan reservoir oil accumulations. Organic Geochemistry, 16(1): 369-387. https://doi.org/10.1016/0146-6380(90)90055-5

Bordenave M. L. 2014. Petroleum systems and distribution of the oil and gas fields in the Iranian part of the Tethyan region, *in* Marlow, L., Kendall, C., and Yose, L., eds., Petroleum systems of the Tethyan region, American Association of Petroleum Geologists Memoir 106, p. 505-540. https://doi.org/10.1036/13431865M1063614

Bordenave M. L. and Burwood R. 1995. The Albian Kazhdumi Formation of the Dezful Embayment, Iran: one of the most efficient petroleum generating systems, *in* Katz, B. J., ed., Petroleum source rocks: Heidelberg, Springer Verlag, p. 183-207. https://doi.org/10.1007/978-3-642-78911-3_11.

Bordenave M. L. and Hegre,J. A. 2010. Current distribution of oil and gas fields in the Zagros Fold Belt of Iran and contiguous offshore as the result of the petroleum systems. Geological Society, London, Special Publications, 330: 291-353. https://doi.org/10.1144/SP330.14

Bordenave M. L. and Huc A. Y. 1995. The Cretaceous source rocks in the Zagros foothills of Iran. Revue Institut Français du Pétrole, 50: 727–753. https://doi.org/10.2516/ogst:1995044.

Davies R. B. Casey D. M. Horbury A. D. Sharland P. R. and Simmons M. 2002. Early to mid-Cretaceous mixed carbonate-clastic shelfal systems. Examples, issues, and models from the Arabian Plate. GeoArabia, 7: 541-598. https://doi.org/10.2113/geoarabia0703541.

Davies R. B. Simmons M. D. Jewell T. O. and Collins J. 2019. Regional controls on siliciclastic input into Mesozoic depositional systems of the Arabian plate and their petroleum significance, *in* Al-Anzi, H. R., Rahmani, R. A., Steel, R. J., and Soliman, O. M., eds., Siliciclastic reservoirs of the Arabian plate. AAPG Memoir 116: 103-140. https://doi.org/10.1306/13642165M1183798.

Dembicki H. J. 2009. Three common source rock evaluation errors made by geologists during prospect or play appraisals. American Association of Petroleum Geologists Bulletin, 93(3): 341-356.

https://doi.org/10.1306/10230808076
Dembicki H. J. 2017. Practical petroleum geochemistry for exploration and production, Elsevier, 330 p.
Ghasemi-Nejad E. Head M. J. and Naderi M. 2009. Palynology and petroleum potential of the Kazhdumi Formation (Cretaceous: Albian–Cenomanian) in the South Pars field, northern Persian Gulf. Marine and Petroleum Geology, 26(6): 805-816. https://doi.org/10.1016/j.marpetgeo.2008.05.005.
Gonçalves P. Kus J. Hackley P. C. Borrego A. Hámor-Vidó M. Kalkreuth W. Mendonça Filho J. Petersen H. Pickel W. and Reinhardt M. 2024. The petrology of dispersed organic matter in sedimentary rocks: Review and update. International Journal of Coal Geology, 294: 104604. https://doi.org/10.1016/j.coal.2024.104604.
Hunt J. M. 1996. Petroleum geochemistry and geology, WH Freeman and Company, 743p.
Kamali M. R. and Rezaee M. R. 2003. Burial history reconstruction and thermal modelling at Kuh-e Mond, SW Iran. Journal of Petroleum Geology, 26(4): 451-464.
Karimi A. R. Rabbani A. R. and Kamali M. R. 2016. A bulk kinetic, burial history and thermal modeling study of the Albian Kazhdumi and the Eocene-Oligocene Pabdeh formations in the Ahvaz anticline, Dezful Embayment, Iran. Journal of Petroleum Science and Engineering, 146: 61-70. https://doi.org/10.1016/j.petrol.2016.04.015.
Katz B. J. 1983. Limitations of 'Rock-Eval'pyrolysis for typing organic matter. Organic Geochemistry, 4(3):195-199. https://doi.org/10.1016/0146-6380(83)90041-4.
Khalatbari M. Kamali M. Arian M. and Ghorbani B. 2020. Geochemical characterization of Kazhdumi source rock in the Khaviz Oilfield, Southwest of Iran, using Rock-Eval pyrolysis. Iranian Journal of Oil and Gas Science and Technology, 9(1): 85-93. https://doi.org/10.22050/ijogst.2019.187983.1508.
Lafargue E. Marquis F. and Pillot D. 1998. Rock-Eval 6 applications in hydrocarbon exploration, production, and soil contamination studies. Oil & Gas Science and Technology, 53(4): 421-437.
Mashhadi Z. S. Rabbani A. R. and Kamali M. R. 2015. Geochemical characteristics and hydrocarbon generation modeling of the Kazhdumi (Early Cretaceous), Gurpi (Late Cretaceous) and Pabdeh (Paleogene) Formations, Iranian sector of the Persian Gulf. Marine and Petroleum Geology, 66: 978-998. https://doi.org/10.1016/j.marpetgeo.2015.08.008.
Mirzaloo M. and Ghasemi-Nejad E. 2012. Combined use of palynology and organic geochemistry in petroleum potential evaluation and paleoenvironmental interpretation of the Kazhdumi Formation (Aptian-Cenomanian) in the southwestern Zagros Basin, Iran. Journal of Geopersia, 2(1):27-40. 10.22059/JGEOPE.2012.24799.
Opera A. Alizadeh B. Sarafdokht H. Janbaz M. Fouladvand R. and Heidarifard M. H. 2013. Burial history reconstruction and thermal maturity modeling for the Middle Cretaceous-Early Miocene petroleum system, southern Dezful Embayment, SW Iran. International Journal of Coal Geology, 120: 1-14. https://doi.org/10.1016/j.coal.2013.08.008.
Peters K. 1986. Guidelines for evaluating petroleum source rock using programmed pyrolysis. American Association of Petroleum Geologists Bulletin, 70(3): 318-329. https://doi.org/10.1306/94885688-1704-11D7-8645000102C1865D
Peters K. E. and Cassa M. R. 1994. Applied source rock geochemistry, *in* Magoon, L., and Dow, W. G., eds., Petroleum system-From source to trap, American Association of Petroleum Geologists Memoir, 96: 93-120.
Rabbani A. R. and Bagheri Tirtashi R. 2010. Hydrocarbon source rock evaluation of the super giant Ahvaz Oilfield, SW Iran. Australian Journal of Basic and Applied Sciences, 4(5): 673-686.
Rahmani O. Aali J. Rahimpour_Bonab H. and Zalaghaie S. 2010. Organic geochemistry of Gadvan and Kazhdumi formations (Cretaceous) in South Pars field, Persian Gulf, Iran. Journal of Petroleum Science and Engineering, 70: 57-66. https://doi.org/10.1016/j.petrol.2009.09.009.
Sfidari E. Zamanzadeh S. M. Dashti A. Opera A. and Tavakkol M. H. 2016. Comprehensive source rock evaluation of the Kazhdumi Formation, in the Iranian Zagros Foldbelt and adjacent offshore. Marine and Petroleum Geology, 71: 26-40. https://doi.org/10.1016/j.marpetgeo.2015.12.011
Shabani F. Amini A. Tavakoli V. Honarmand J. and Gong C. 2022. 3D forward stratigraphic modeling of the Albian succession in a part of the northeastern margin of the Arabian Plate and its implications for exploration of subtle traps. Marine and Petroleum Geology, 145: 105880. https://doi.org/10.1016/j.marpetgeo.2022.105880
Sharland P. R. Archer R. Casey D. M. Davies R. Hall S. H. Heward A. P. Horbury A. D. and Simmons M. 2001. Arabian plate sequence stratigraphy, Manama Bahrain, Gulf PetroLink, v. 4, 370 p.
Tissot B. P. and Welte D. H. 1984. Petroleum formation and occurrence, Berlin, Springer-Verlag, 720 p.
Van Buchem F. S. Baghbani D. Bulot L. G. Caron M. Gaumet F. Hosseini A. Keyvani F. Schroeder R. Swennen R. and Vedrenne V. 2010. Barremian-Lower Albian sequence-stratigraphy of southwest Iran (Gadvan, Dariyan and Kazhdumi formations) and its comparison with Oman, Qatar and the United Arab Emirates, *in* van Buchem, F. S., Al-Husseini, M., Maurer, F., and Droste, H., eds., GeoArabia Special Publication 4, Volume 2: Bahrain, Gulf PetroLink, p. 503-548.
Vincent B. van Buchem F. S. Bulot L. G. Immenhauser A. Caron M. Baghbani D. and Huc A. Y. 2010. Carbon-isotope stratigraphy, biostratigraphy and organic matter distribution in the Aptian–Lower Albian successions of southwest Iran (Dariyan and Kazhdumi formations), *in* van Buchem, F. S., Al-Husseini, M., Maurer, F., and Droste, H., eds., GeoArabia Special Publication 4, Volume 1: Bahrain, Gulf PetroLink, p. 139-197.
Zeinalzadeh A. Moussavi-Harami R. Mahboubi A. and Sajjadian V. A. 2015. Basin and petroleum system modeling of the Cretaceous and Jurassic source rocks of the gas and oil reservoirs in Darquain Field, southwest Iran. Journal of Natural Gas Science and Engineering, 26: 419-426. https://doi.org/10.1016/j.jngse.2015.05.041.
Zeinalzadeh A. Moussavi-Harami R. Mahboubi A. and Sajjadian V. A. 2018. Source rock potential of the Early Cretaceous intervals in the Darquain field, Abadan Plain, Zagros Basin, SW Iran. Geosciences Journal, 22(4): 569-580. http://dx.doi.org/10.1007/s12303-017-0075-8.