Petroleum Geochemistry and Thermal Modeling of Pabdeh Formation in Dezful Embayment

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Abstract

Dezful Embayment located in Southwest of Iran is one of the most potential areas for exploration and development of hydrocarbon reservoirs in the world. There are several source rock units with different geological ages. Burial and thermal history modeling was performed to determine timing of hydrocarbon generation in the Pabdeh source rock in Dezful Embayment. Geology and sequence stratigraphic analysis of borehole data including drill-cuttings provided fundamental constraints for burial history reconstruction. In addition, estimates of exhumation from log-derived compaction data provide key insight into depositional patterns. One-dimensional and two-dimensional models of thermal evolution were derived from the burial history and calibrated with vitrinite reflectance, thermal conductivity, surface and bottom-hole temperature measurements, as well as with paleoclimate data. The resulting thermal history models were combined with the measured geochemical parameters in order to determine the timing of hydrocarbon generation for the candidate source rock (Pabdeh Formation). Results were compiled in maps and cross-sections representing multiple stages of basin evolution. Most hydrocarbon generation in the Dezful Embayment generally took place in Kazhdumi Formation and partly in Pabdeh Formation. The Pabdeh Formation is the most youngest source rock in Dezful Embayment with type II and a mixture of type II and III Kerogens and has reached oil generation at most parts of the Dezful Embayment. Higher amounts of hydrocarbon were generated at deep and central part related to higher maturity levels. Based on thermal maturity modeling, Pabdeh Formation is early mature to mid mature.

Keywords: Zagros, Dezful Embayment, Organic geochemistry, Thermal modeling, Pabdeh.

1. Introduction

Dezful Embayment is located in southwest Iran and bounded to Balarud flexure towards northwest, Izeh fault zone towards southeast, and Mountain front fault towards north and Zagros front flexure towards south and consists of thick sedimentary sequences from Mesozoic to Cenozoic. This zone is characterized by intense structural depression (Fig. 1).

Several potential source rock units and reservoir rocks with different geological ages were deposited in this tectonically developed depression making this area as the most prolific region in the Middle East (Alsharhan 1989). So far, Petroleum potential and thermal modeling of Pabdeh has not been investigated adequately. Therefore, this study is focused on evaluation of petroleum generation potential and thermal history of the Pabdeh Formation in the Dezful Embayment. The emphasis is placed on thermal modeling and timing of hydrocarbon generation. The previous studies including preliminary source rock evaluation and geochemical modeling were carried out by Burwood & Bordenave (1990), Kamali & Rezaee (2003) and Ghazban *et al.* (2000).

Geology and Stratigraphy

The sediments composing the Zagros Fold Belt are up to 12000 m thick and, except for the Devonian and Carboniferrous systems missing throughout the belt, the section is a nearly continuous, conformable sequence from the Infra-Cambrian to the Pliocene. Sedimentation began with important Infra-Cambrian (Vendian) evaporites, followed by the shallow marine carbonate and clastic deposits of the Lower Paleozoic from the Permian and throughout most of the Mesozoic and up to Lower Miocene, the area was part of a broad, shallow carbonate platform**.**

Subsequently, thick evaporates followed by continental red beds characterize the Mio-Pliocene. Folding accompanied by syntectonic and post-tectonic molasses took place in Plio-Pleistocene time. The statigraphic column is summarized in Fig. 2.

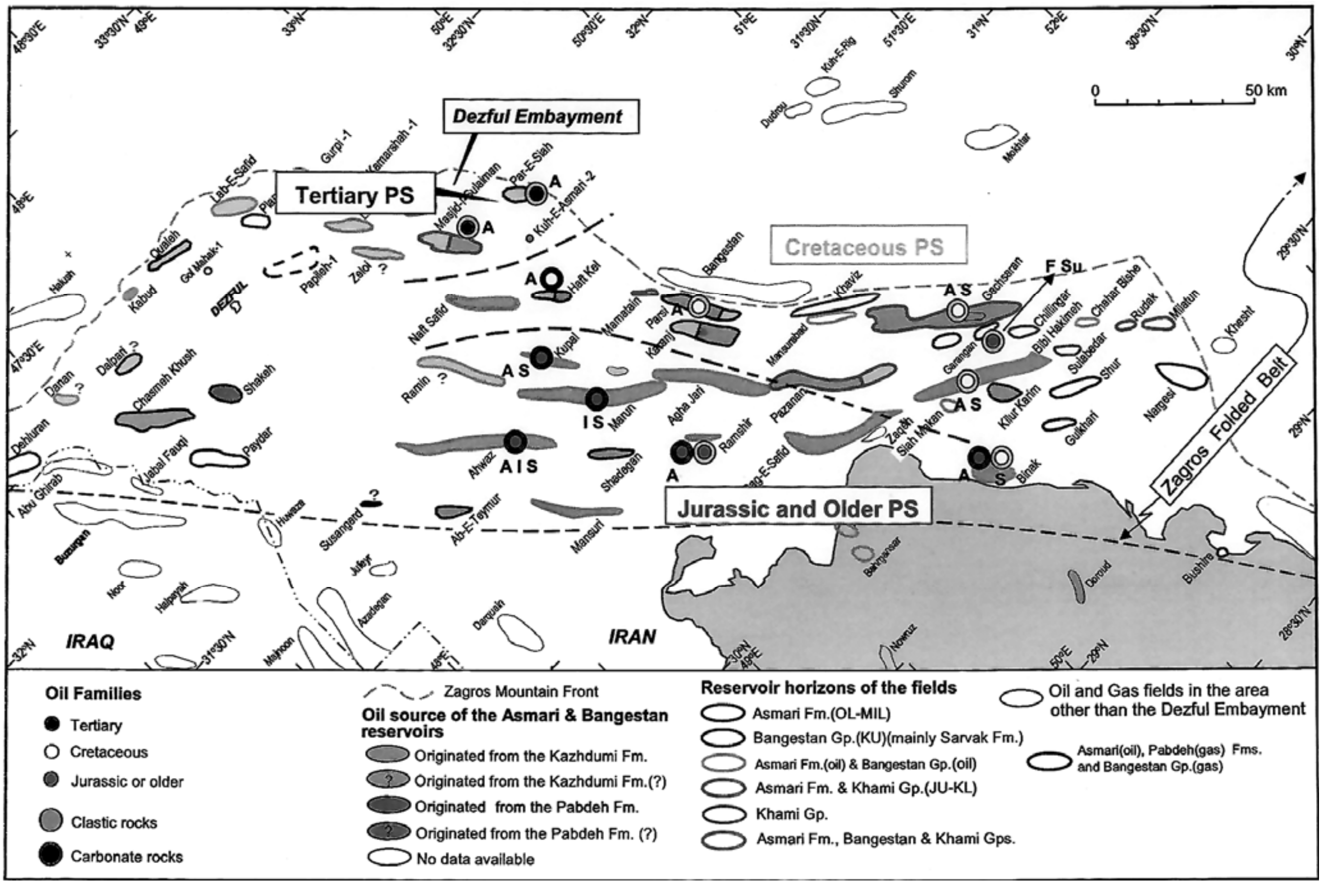


Fig. 1- Dezful Embayment parentage between source rock and oil accumulation in Asmari and Bangestan reservoirs.

Pabdeh Formation

The formation is named after Kuh-e-Pabdeh in the Khuzestan Province, where James & Wynd (1965) and Setudhenia (1972) described the type section at Tang-e-Pabdeh, 32° 25′ N, 49° 16′ 22″ E. This formation is known in outcrop and in subsurface in the provinces of Khuzestan, Fars and Lurestan of Iran. Anoxic conditions during the Middle to Late Eocene occurred in a SE-NW trending trough from the northern edge of the Fars province, through the Dezful Embayment and Lurestan into Iraq. Argillaceous sedimentation continued through Paleocene and Eocene time in the Dezful Embayment and Fars, and until the end of the Oligocene in Lurestan. In the northern Fars, several field sections show 150-250 m of fine grained dark grey marls of a mainly algal Kerogen type with limited terrestrial organic matter, as demonstrated by the presence of angiosperm pollen and herbaceous debris (Darvishzadeh 1992). These marls include pelagic fauna such as Globigerina and Rotalids. Benthic fossils were absent, probably due to the anoxic conditions at the sea bottom. In the Rag-e-Safid and Bibi Hakimeh area, about 200 m of marls are considered to be excellent potential source rocks. In southwest Lurestan, several field sections of middle-upper Eocene strata include 80-120 m of organic marls. In a few sections anoxic conditions persisted into the Oligocene and were responsible for the deposition of another 100 m of organic marls, albeit less rich in organic matter.

The Rock-Eval pyrolysis is one of the simplest and fastest methods used for assessing the hydrocarbon generation potential of petroleum source rocks that meet the needs of petroleum prospects (Espitalie *et al.* 1985). It provides data on organic content of rocks type and maturity of organic matter. This method enables us to predict oil and gas windows and estimates the quantity of hydrocarbon generated from a specific source rock. Pyrolysis is a laboratory simulation of hydrocarbon generation that occurred in a sedimentary basin.

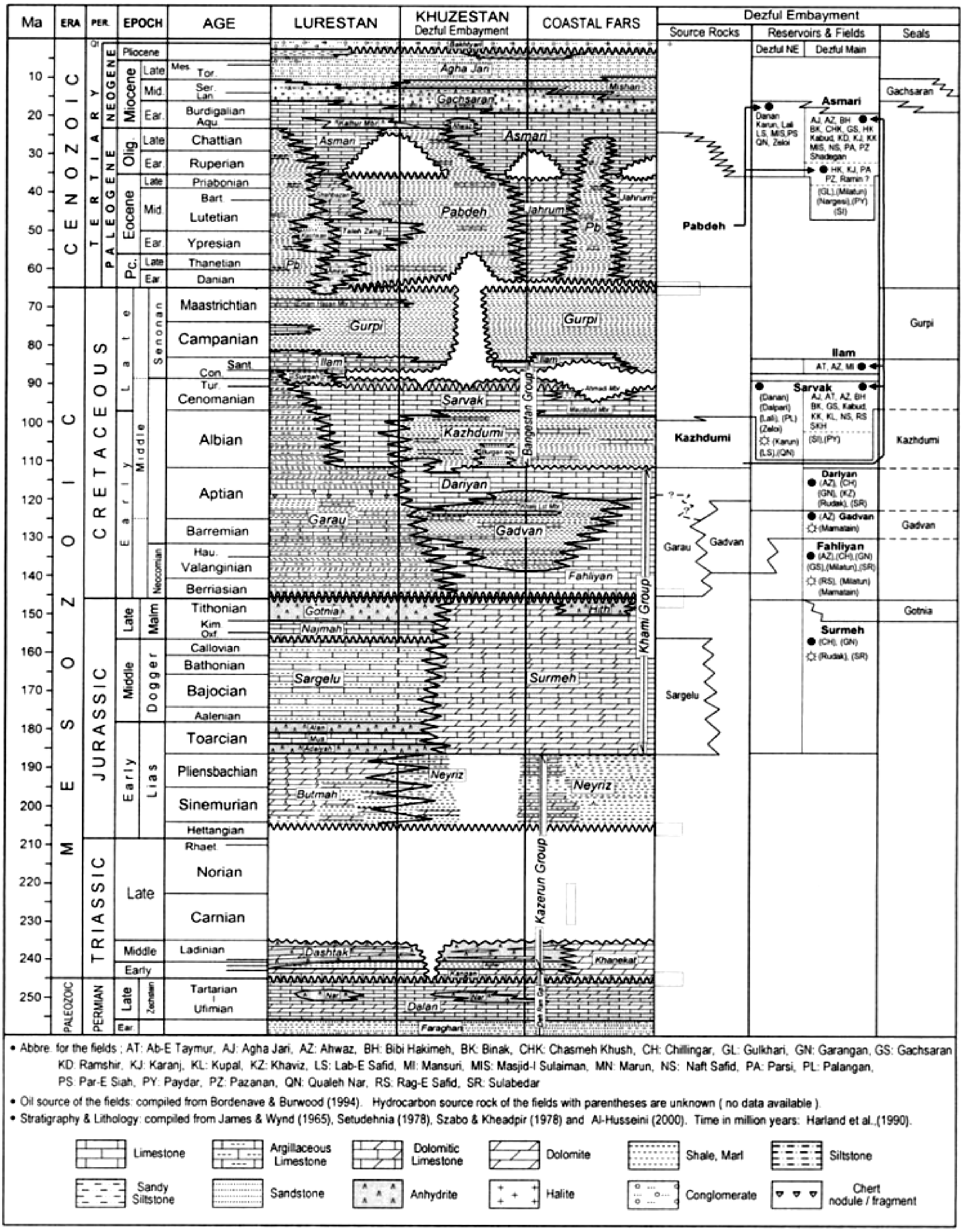


Figure 2- Schematic stratigraphy for the Dezful Embayment and neighboring areas (Bordenave 2002).

Source rock evaluation using Rock-Eval Pyrolysis method

Rock-Eval parameters include S_1 (volatile hydrocarbons), S_2 (remaining hydrocarbon potential), S_3 (amounts of CO_2), Hydrogen Index (HI), maximum maturity experienced by source rock (T_{max}) and Total Organic Carbon (TOC) used to characterize petroleum potential, types of organic matter, degree of evolution, weathering, migration phenomena etc. Data obtained from Rock-Eval pyrolysis are represented in Tab. 1. Kerogen type and maturity level can be determined using HI vs. T_{max} diagram (Fig. 3). As shown in the Fig. 3, most samples fall in regions of early and mid-oil generation window suggesting that Pabdeh Formation is early mature to mature but never entered gas generation window. HI and T_{max} values range between 25 to 1080 and 416 to 445 respectively. The sample from depth 3319m (Ramshir field) shows exceptionally high HI value (1080). This is due to hydrocarbon migration and is reflected by high S_1 (0.85), S_2 (6.48) and low T_{max} (426) values (Tab. 1). If unrecognized, such rock unit might be interpreted as prolific source rock based on its high HI value (Peters 1986).

The other problem associated with Pabdeh source rock particularly in samples analyzed from depth intervals 3173 and 3206 meters, is linked to mineral matrix effect. Such effect is generally noticed in rocks containing less than 0.5 wt%TOC. Clay minerals tend to adsorb the organic compounds on to the mineral matrix. As a result, HI values are likely to be low and T_{max} too high.

Most samples have kerogen type II and III and sometimes a mixture of type II/III is also noticed. A few samples that fall in kerogen type I and VI are considered to be due to experimental error or weathering. A plot of Genetic Potential (GP) vs. TOC was established to determine hydrocarbon potential qualitatively and quantitatively where, GP is the sum of S_1 and S_2 (Fig. 4). As seen in Fig. 4, there is a good agreement between TOC and GP values with each other. However, most measured data points are concentrated in regions named as fair and good suggesting that Pabdeh Formation is a moderate to good hydrocarbon source rock.

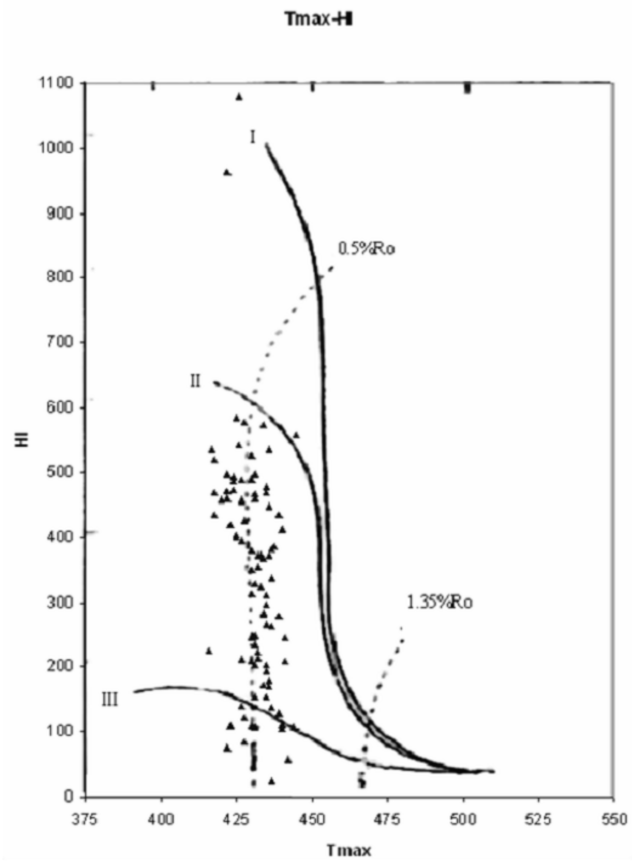


Fig. 3- HI vs. T_{max} Diagram for Pabdeh Formation.

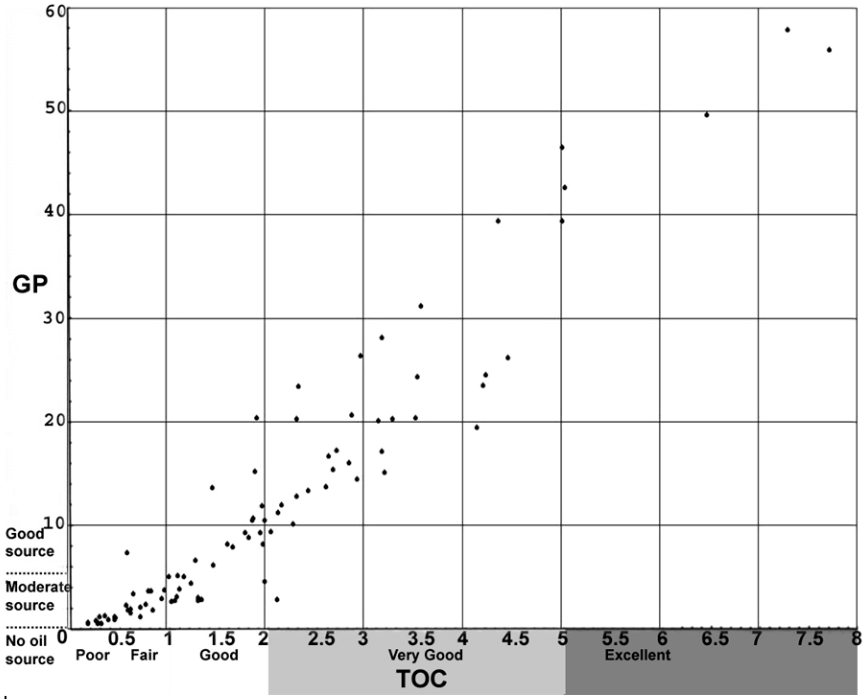


Fig. 4- TOC vs GP diagram for Pabdeh Formation in Dezful Embayment.

Organic Petrography

In this study three essential groups of maceral constituents including liptinites, vitrinites and inertinites were studied quantitatively.

Microscopic examination of the liptinite (exinite) distribution in samples selected from different wells can be categorized into three groups as dominant (29%), common (21%) and minor (31%). Therefore, the relative dominance of liptinite group as inferred from petrographic study suggests a potential hydrocarbon source rock with mainly type II kerogen for Pabdeh Formation. Fig. 5 shows abundance and changes of liptinite in different well locations.

Vitrinite group of macerals are rare in Pabdeh Fomation. Vitrinite is absent in more than 60% of the samples but was noticed in 32% of samples in minor amounts. This suggests that the Pabdeh Formation was deposited in marine environment with some terrestrial inputs. Fig. 6 on the left shows abundance and distribution of vitrinite maceral in the studied well locations. The lowest and highest measured vitrinite reflectance (Ro) are 0.22 and 1.22 with an average value of 0.5 respectively. Vitrinite reflectance contour map (Fig. 6, on the right) reflects the trend of maturity for Pabdeh Formation. According to this iso-reflectance map maturity increases from south to northwest indicating that Pabdeh Formation is early mature to the south (Ro=0.5) and reaches peak oil generation window (Ro=1.2) in NW Dezful Embayment. The inertinite group of macerals is not seen and if present their quantity would be negligible.

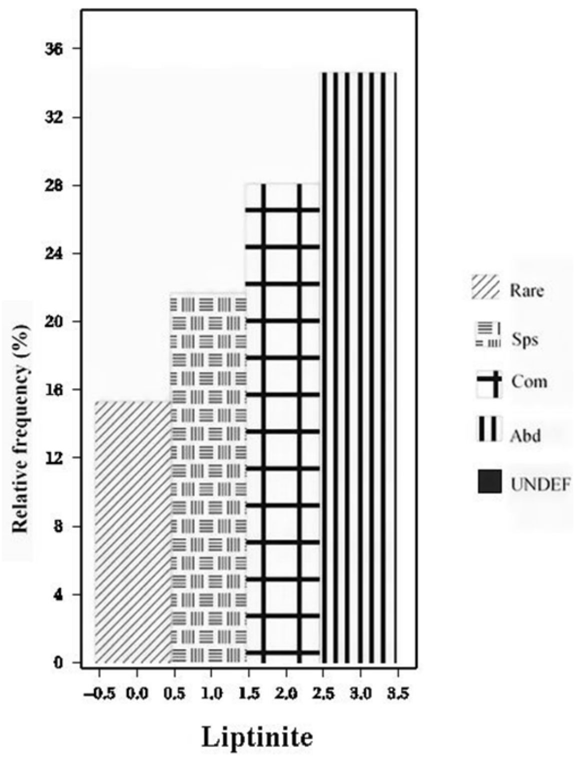


Fig. 5- Abundance and distribution of Liptinite macerals.

Tab. 1- Rock-Eval pyrolysis data.

Well	Depth(M)	S_1	S_2	S_3	T_{max}	TOC	HI
Paydar	3356	1.65	12.02	2.13	422	2.62	459
	3367	0.21	0.49	1.7	436	0.29	169
	3374	1.6	15.49	1.75	424	3.19	486
	3415	1.09	8.22	1.98	425	2.06	399
	3432	0.3	1.47	1.17	434	0.86	171
Shakheh	4050	18.49	24.09	0.52	435	5.04	478
	4056	15.64	15.53	0.38	439	3.58	434
	4120	7.32	12.93	3.47	445	2.32	557
	4144	15	11.31	9.18	437	2.97	381
Sulabdar	882.4	1	3.33		435	1.25	266
	945	1.19	2.1		430	0.67	313
Ghachsaran	1642	1.2	1.05		436	0.59	178
	1692	1.57	8.55		436	2.29	373
Garangan	1247	1.26	13.12		436	2.93	448
	1267	1.81	13.22		440	3.21	412
	1320	1.31	10.55		436	1.97	536
Bibihakime	1710	1.26	6.92		428	1.62	427
	1743	2.23	0.54		437	2.12	25
	1801	1.8	8.79		435	1.88	468
Siamakan	3772	1.38	3.65		432	1.03	354
	3810	1.75	6.4		433	1.98	323
	3862	2.71	6.03		431	1.84	328
Binak	2598	0.55	1.5		431	0.74	203
	2560						
	2632	0.51	1.37		432	0.64	214
	2660	0.41	0.16		422	0.21	76
Parsi	2070	1.78	18.25		428	3.15	579
	2080						
	2090	1.71	18.59		430	3.53	527
	2120	1.35	11.93		430	2.44	489
	2150	0.57	5.98		431	1.3	460
Karanj	2320	0.28	1.24		435	0.64	194
	2350	1.37	18.88		434	3.29	574
	2380	1.2	11.53		431	2.32	497
	2398	1.15	9.33		431	2	467
Ramshir	3235	1.77	18.53		422	1.92	965
	3265	2	17.44		423	4.15	420
	3292	0.23	2.35		432	1.05	224
	3319	0.85	6.48		426	0.6	1080
	3347	0.42	1.86		431	0.79	235
Golkhari	2842	0.51	3.06		432	0.82	373
	2872	0.68	5.44		434	1.48	368
	2902	0.64	4.39		433	1.18	372
Agha-jari	2195	3.62	20.88		424	4.24	492
	2222	2.27	14.4		426	2.65	543
	2258	1.5	6.33		430	1.67	379

Tab. 1 (continued)- Rock-Eval pyrolysis data.

Well	*Depth(M)*	S_1	S_2	S_3	T_{max}	*TOC*	*HI*
Parsiah	2579	0.35	0.81	1.48	427	0.38	213
	2789	0.75	4.32	1	438	1.12	386
	2855	0.65	3.18	1.55	434	1.13	281
	3062	0.43	0.67	3.29	441	0.32	209
Asmari	1104	0.8	2.25	1.38	435	1.11	203
	1310	0.14	0.38	0.26	428	0.31	123
	1880	1.29	15.94	0.68	425	2.73	584
	2248	0.58	2.33	0.34	441	0.95	245
	2425x	0.21	0.26	0.26	428	0.31	84
	2425	0.22	0.23	0.28	423	0.21	110
Kupal	3699	1.09	1.85	2.73	427	1.32	140
	3720	0.36	0.79	1.32	431	0.74	107
	3842	0.3	0.76	1.31	435	0.49	155
	3903	1.36	7.85	1.98	425	1.95	403
Maron	2840	19.13	30.49	1.38	422	6.48	471
	2900	28.95	17.58	1.31	430	5.01	351
	2944	17.21	6.17	0.91	437	2.34	264
	2987	9	4.56	0.87	435	1.47	310
Ahwaz	2877	0.95	2.73	1.55	439	0.98	279
	2902	1.72	1.92	1.96	416	0.85	226
	2943	1.27	10.61	1.8	427	2.17	489
	2948	1.17	9.32	1.78	422	1.87	498
	2958	2.25	23.9	1.75	417	4.46	536
	2987	1.43	9.74	2.21	427	2.13	457
	880	0.44	1.28	2.16	430	0.61	210
	887	1.67	21.84	1.89	418	4.21	519
	924	0.35	0.74	1.88	431	0.48	154
	926	0.27	0.53	1.63	430	0.48	110
Mansouri	2704	2.1	7.11	1.81	427	1.8	395
	2732	2.74	12.6	1.92	418	2.69	468
	2772	2.5	13.46	1.87	424	2.85	472
Lab-sefied	2755	1.89	2.6	0.82	439	2	130
	2800	1.2	1.52	0.6	437	1.09	139
	2861	1.27	1.4	0.75	444	1.32	106
	2890	1.25	1.53	0.68	440	1.36	112
	3173	0.28	0.2	0.38	442	0.34	59
	3206	0.38	0.43	0.26	440	0.41	105
Ab-tymor	2680x	24.5	33.4	2.04	420	7.3	458
	2689x	22.33	33.58	2.01	418	7.72	435
	2720x	16.51	22.84	1.75	427	5.01	456
	2750x	8.75	6.42	1.31	437	1.9	338
Palangan	3836	18.63	9.47	1.29	435	3.19	297
	3936	28.58	10.83	1.32	431	4.36	248
	3982	12.47	8.17	1.24	434	2.88	284
	4008	16.08	8.27	1.07	430	3.55	246

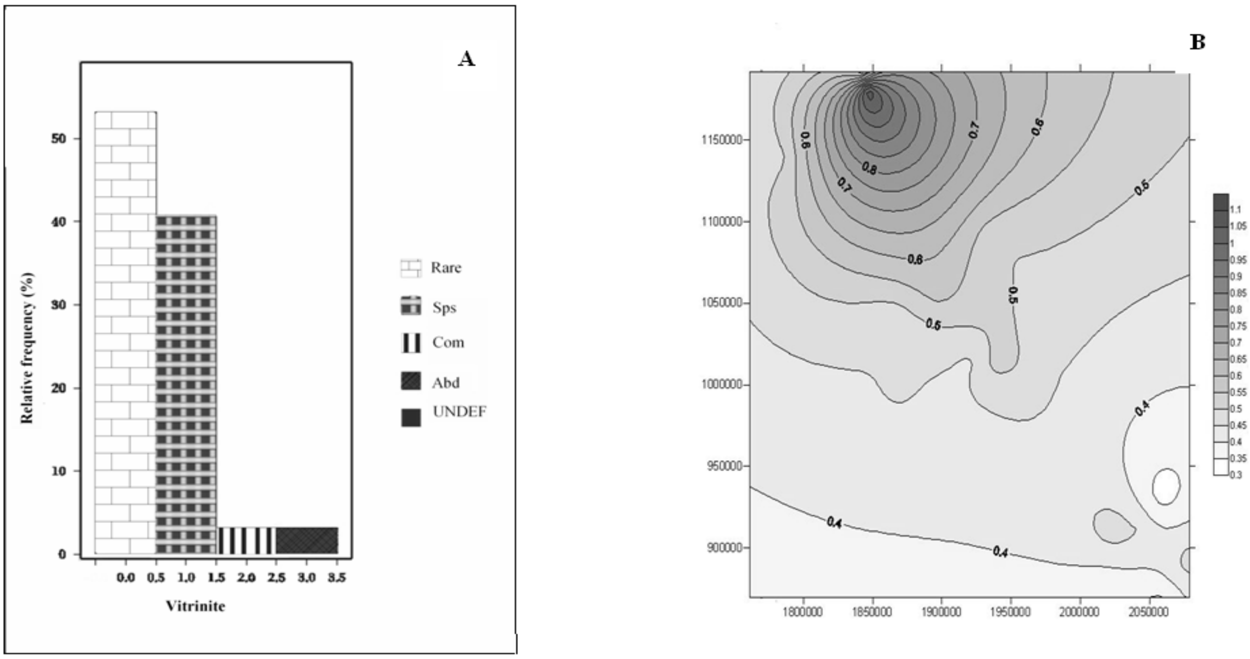


Fig. 6. Abundance and distribution of Vitrinite group of macerals in Dezful Embayment (A) and distributions in the study area (B).

Burial history reconstruction and thermal modeling

Analysis of source rock samples provides information on their present maturation status and reflects the integrated past time/ temperature exposure. For mature or post-mature rocks, present day maturity gives no information about actual time when they became mature. This is a gap that can be filled by thermal modeling. In many cases the timing of events is critically important in exploration, and this is especially true for the time of trap formation relative to the time of maturation and migration. Maturity is commonly displayed on burial history diagrams by showing the position of the oil window through time (Lopatin 1971, Waples 1985, 1980). Burial history is based on the best information available to the geologist. In case where biostratigraphic data are available and deposition has been reasonably continues, it is easy to construct burial history curves with a high level of confidence.

These curves represent our best understanding of the geological history of an area (Fig. 7).

The first model is Lopatin's method, a simple model that is widely applied in the petroleum industry. The method is based on the assumption that the maturation rate doubles with 10°C increase in temperature. Maturity is expressed non-dimensionally as a time-temperature index, or TTI, which can be interpreted as described below. According to the model, for example, sediment generates oil when the TTI is in the range of 15 to 160, with peak generation occurring at a value of 75. In this method the data required to contract burial history include well data, the formation tops, base or thickness and age of rock units (Waples 1985, Waples *et al.* 1990).

In the second maturity modeling method we can calculate source layer maturation using the Arrhenius model of Lewan (1985). According to this model, oil generation is governed by the Arrhenius equation, which employs an activation energy and pre-exponential factor to calculate, the oil generated form a layer as a fraction of its capacity. Subsequently the conceptual model is generally calibrated with true experimental data such as vitrinite reflectance (Ro) which is shown in Fig. 8.

In this study well data from seven oil producing fields were used to reconstruct burial history followed by determining timing of oil generation and maturity status for the Pabdeh Formation. The above-mentioned fields include Aghajari, Mansuri, Siahmakan, Bibihkimeh, Garangan, Binak and Gachsaran.

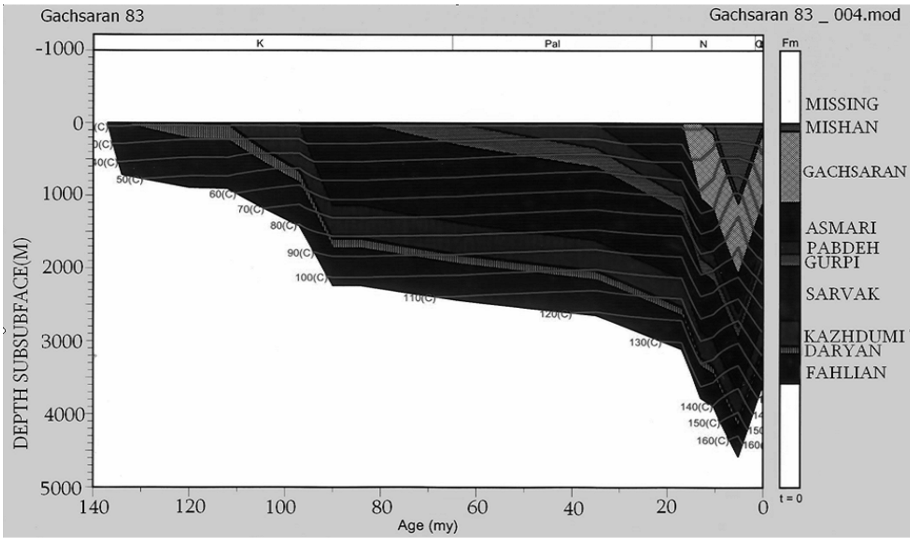


Fig. 7- Thermal history modeling with isothermal lines.

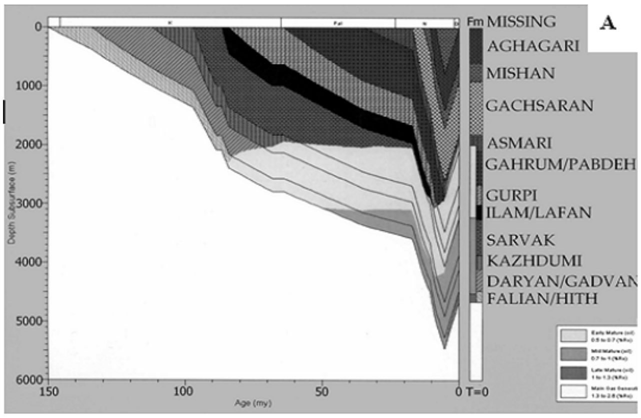
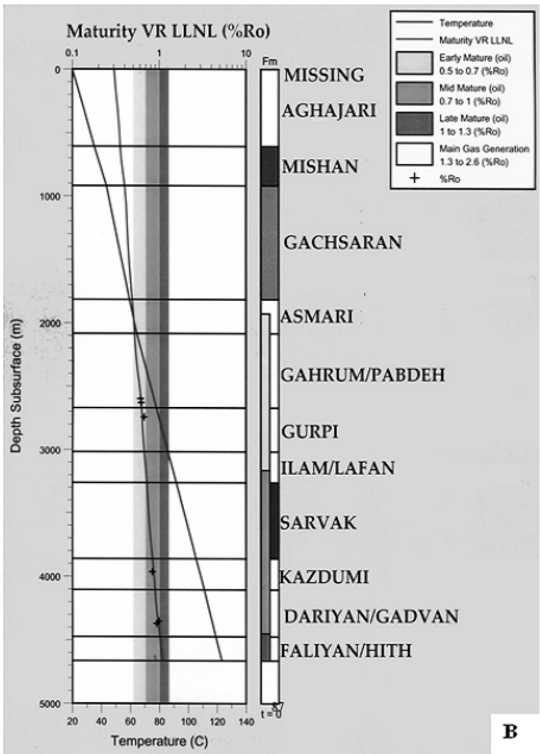


Fig. 8(A)- Binak4 one dimensional burial history curve with (TTI) maturity windows showing onset of oil generation for each formation and degree of maturity .Pabdeh and Gurpi are early mature and Kazhdumi is mid mature to near late mature.

Fig. 8(B)- A comparison between maturity obtained from modeling (straight line) and maturity derived from Ro measurements (shown as +).



Thermal maturity modeling indicates that there is no any significant difference between maturity calculated with TTI and LLNL. In selected wells from Mansuri, Bibihakimeh, Binak and Aghajari Field, Pabdeh is in early mature state. Pabdeh Formation is mid mature in selected wells from Siahmakan and Gachsaran fields and early-mid mature in Garangan field (Fig. 9).

Events Chart

The event chart shows the temporal relationship of the rock units, essential elements, processes, preservation time, and critical moment for each total petroleum system in bar graph form (Ulmishek and Klemme 1990). It includes the ages of source rock intervals and their volume percentage contribution to the known oil and gas reservoir and trap formation (Fig. 10). The event chart on Fig. 10 reflects formation of source rock, reservoir, seal and trap during geological past.

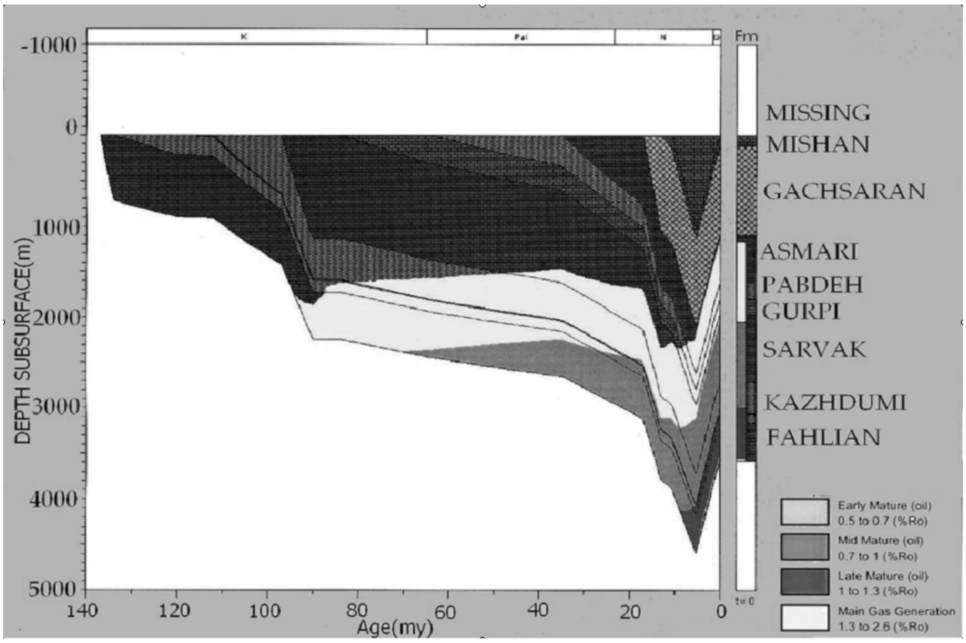


Fig. 9- Burial history modeling with maturation windows (Gachsaran).

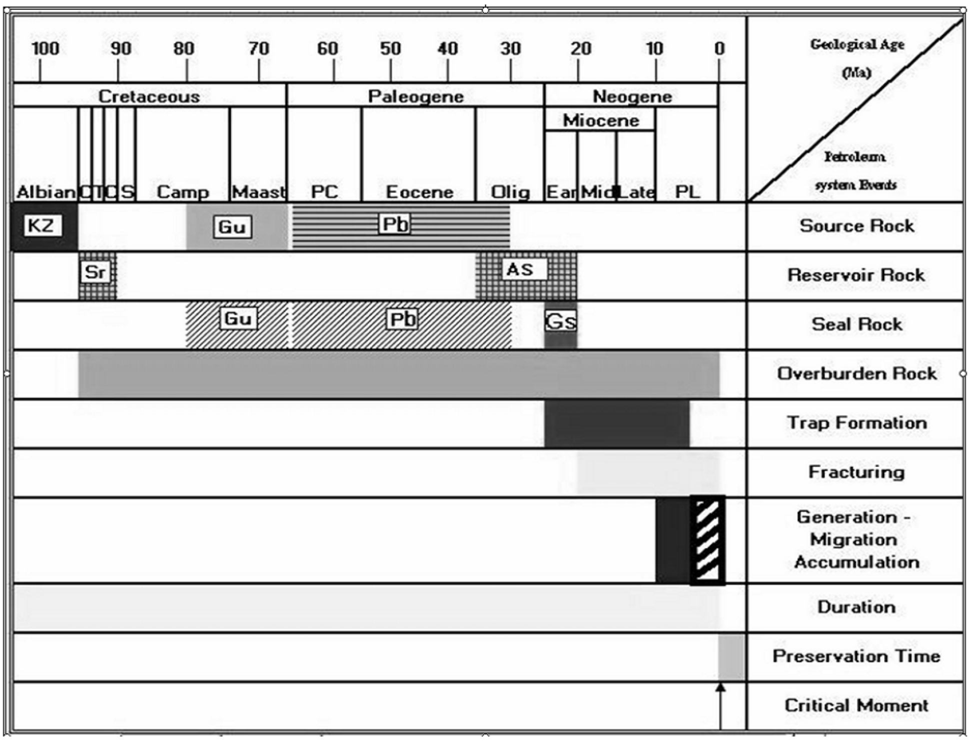


Fig. 10- Events chart for Dezful Embayment petroleum system. As: Asmari Fm; Gs: Gachsaran Fm; Gu: Gurpi Fm; Kz: Kazhdumi Fm ;Sr: Sarvak Fm; Pb: Pabdeh Formation. The area shown as hatched is indicative of hydrocarbon generated from Pabdeh Formation.

Conclusions

In Dezful Embayment the main reservoir rocks are Bangestan and Asmari and the main seal rock is Gachsaran for the Asmari Formation and Gurpi and Pabdeh act not only as a good seal for Bangestan but also are considered to contribute significant amounts of hydrocarbon to the Asmari Formation.

Results of Rock-Eval pyrolysis suggested that the average S_2 for Pabdeh is 7.80 indicating good hydrocarbon source rock. The T_{max} values for the studied samples range from 416 to 433 for Gurpi and 435 indicative of the oil generation stage. The average HI for Pabdeh Formation is 398, which is regarded as indicative of oil-generative kerogen (type II and a mixture of type II and III)

In Dezful Embayment the candidate source rock was deposited during Paleocene and Eocene followed by deposition of overlying strata and successive compaction due to deep burial and increasing time and temperature helped hydrocarbon generation in Pabdeh concurrent with Zagros orogeny. Parallel to this time trap formation helped migration of early expelled oil to the anticlines of Asmari Formation. Fractures developed during Zagros folding facilitated the migration of hydrocarbons to structurally developed traps. Hydrocarbon generation seems to continue in at places outside the deepocenter presently.

TTI and LLNL methods used in this study show no any significant difference with the measured geochemical data such as Ro and T_{max} in the studied wells. Thermal modeling suggests that Pabdeh Formation is early mature to the south and reaches peak oil generation window in NW Dezful Embayment

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