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Organic geochemical investigations of the Triassic Mianwali Formation in Surghar Range, Upper Indus Basin, Pakistan

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Abstract

The Shales of Mianwali Formation in Surghar Range, Pakistan has been analyzed and studied geochemically to assess its hydrocarbon potential, types of organic matter and thermal maturity. Organic geochemical analyses were carried out on fifteen outcrop samples of the studied formation. Various screening techniques including TOC measurement, Rock Eval pyrolysis were used to evaluate the hydrocarbon potential, types of organic matter and thermal maturity of the studied formation. The average total organic carbon values and genetic potential (GP) are < 0.5 wt. % & < 2 kg/ton respectively, indicated that the sediments has poor source rock potential. The different cross plots including hydrogen & oxygen indices HI vs OI, HI vs Tmax and S2 vs TOC indicated that the formation is dominated by type IV kerogen. The Tmax values of analyzed samples ranges from 418 °C to 429 °C showing insufficient temperature to produce hydrocarbon at present condition. The overall high values of oxygen index (OI) and low values of hydrogen index (HI) represents the organic matter of the studied samples are poorly preserved and oxidized consisting type IV kerogen in the studied section. The source rocks geochemistry is a best tool to identify a petroleum system in an area, as multiple source rocks are present in Surghar Range and most wells are abandoned in the study area. So, this study was aimed to geochemically analyzed and study the outcrop samples of this formation, and correlate with the subsurface.

Keywords: Geochemical analyses, Mianwali Formation, Surghar Range, Pakistan

1. Introduction

The studied Mianwali Formation of Early Triassic age is well exposed in Upper Indus Basin including Surghar and Khisor Ranges mainly composed of marl, limestone, sandstone, siltstone. The environment of deposition is shallow marine with high terrigenous influx (Kadri, 1995).

Fossil fuel is one of the main sources of energy which is provided by organic matters upon thermal maturation. The organic matter preserved in sediments will generate hydrocarbons upon thermal maturation (Tissot & Welte, 1984). Rocks preserved in sedimentary basin in anoxic environment and where organic productivity is high will generate hydrocarbons with time upon sufficient burial temperature. The marine organic matter is formed near the surface of the ocean mainly in photic zone due to abundance of phytoplanktons. Kerogen is produced at the end of diagenesis that has subsurface temperature > 60 ˚C and depth > 1km (Tissot & Welte, 1984). Kerogen is the precursor of hydrocarbon. The organic matter converted into different types of hydrocarbons in three phases, diagenesis, catagenesis, and metagenesis (Tissot & Welte, 1984). Diagenesis is the low temperature shallow depth stage, where physicochemical as well as biochemical change occurs in sediments after deposition and prior to the onset of liquid hydrocarbon. The continuous deposition of sediments results increase in depth which ultimately increase the temperature and pressure. Catagenesis is the main stage of hydrocarbon generation especially liquid hydrocarbons depending on nature of organic matters. The sediments containing Type I and type II kerogen will produce both oil and gas, while type III kerogen will generate gaseous hydrocarbons. With further increased sedimentation and subsurface temperature, kerogen will produce dry gas during this stage of metagenesis (Espitalié et al., 1977).

The content of organic matter in sedimentary rock units is one of the primary and basic criteria for the evaluation of a petroleum system of an area. The rock units containing < 0.5 w.t % TOC are considered as poor, 0.5 to 1 wt. % fair, 1-2 wt. % good, 2-4 wt. %, very good, and > 4 wt. % are excellent source rocks (Peters and Cassa, 1994). Another screening technique, Rock-Eval pyrolysis is widely used in oil industry to evaluate the quantity and quality organic matter contained in source sediments and its thermal maturity (Espitalié et al. 1985; Peters 1986; Peters and Cassa 1994; Langford and Blanc-Valleron 1990). The thermal maturity of organic matter is evaluated by using different parameters including vitrinite reflectance, Tmax, production index (PI), pollen and spore coloration index but dependent upon types of organic matter (Tissot & Welte 1984; Peters and Cassa 1994).

2. Geological Setting

Surghar Range is a part of lesser Himalayas of Pakistan (Yeats & Lawrence, 1984). It is actually an arc shape mountain belt forming the southeastern proximal end of Kohat plateau as shown in figure 1. The orientation of Surghar Range is towards east-west and represents the leading edge of Kohat Fold and Thrust Belt which is almost deformed due to its active nature and hence tectonically uplifted towards North. The Kohat Plateau separates Surghar Range from Kohat Ranges and towards west it is separated from northern Sulaiman Range by Kohat plateau. Being an active range front, the stress still accommodates and shortening of strata occurred. The studied area succession is from Permian to Eocene. Tectonically, the Surghar Range represents the leading front of an orogenic belt where deformations are still in progress provides an excellent opportunity for understanding the structural evolution of a mountain range which. At the southern margin of Surghar Range a north dipping thrust called Surghar Thrust is located, which is extended from Salt ranges and continuous along the southern/eastern margin of Trans Indus ranges.

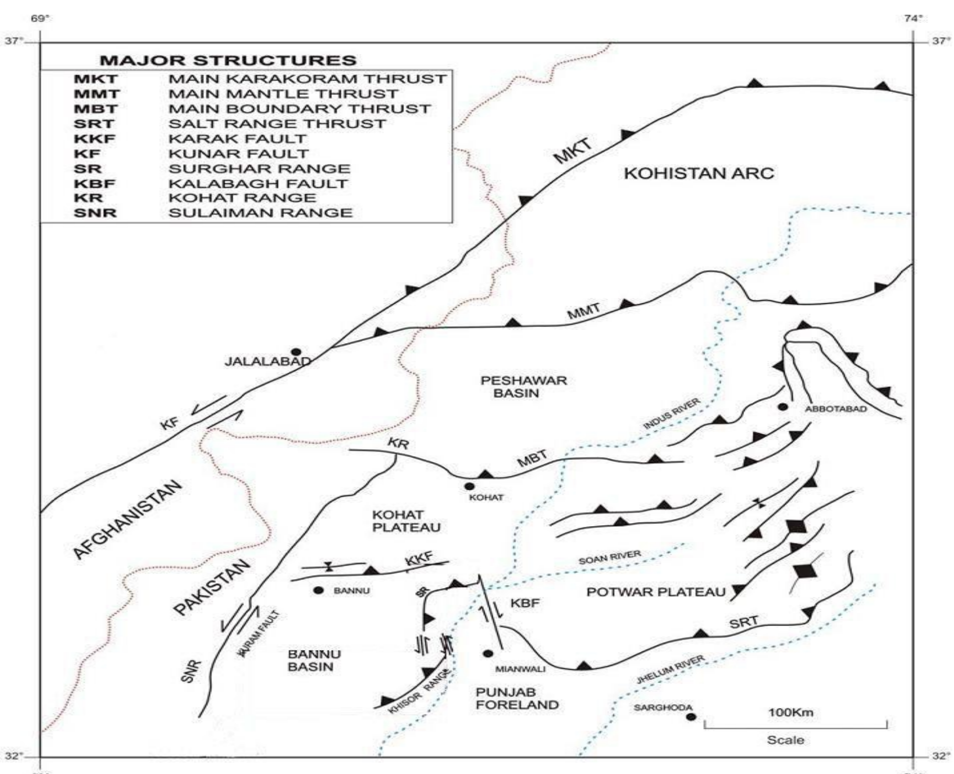

Fig. 1 Tectonic map of northern Pakistan showing major structural features (Kazmi & Rana 1982).

3. Materials and Methodology

The methodology for the entire research work is comprised of fieldwork and laboratory work/analysis. During the field observations, a thick section (50 m) of Mianwali Formation was sampled in the Surghar Range, Upper Indus Basin, and total of 15 samples were collected for source rock potential evaluation. In order to analyze these samples, detail laboratory analyses were performed on the studied samples such as TOC measurement and Rock Eval pyrolysis. The TOC was measured by using CS-580A & Rock Eval pyrolysis by Rock Eval-6 in the Geochemistry Branch of Geological & Reservoir Labs, OGDCL, Islamabad.

In the current research TOC and different Rock-Eval pyrolysis parameters including S1 (free hydrocarbon in a sample), S2 (hydrocarbon product of thermal cracking of kerogen), S3 (CO, CO2 by pyrolysis), oxygen index (OI: S3/TOC×100), hydrogen index (HI: S2/TOC×100), production index (PI: S1/S1+S2) and Tmax were used to determine the source rock potential, quality and thermal maturity of the studied Mianwali Formation sediments.

4. Results and Discussion

4.1 Total Organic Carbon

Total organic carbon (TOC) analysis was performed on fifteen (15) samples and the results obtained are given in table 1.1, showing most of the samples have TOC value less than < 0.5 wt.% which is the standard value for a potential source rock (Tissot & Welte, 1984) except one sample (M-5) having TOC value 1.68 wt.%. So, according to Peter & Cassa (1994) classification of source rock based on organic richness, it is assumed that the studied Mianwali Formation is a poor source rock for hydrocarbon generation in Surghar Range, Upper Indus Basin.

In order to further investigate about the source rock characteristics of the studied formation, these samples were subjected to another geochemical screening technique i.e. Rock-Eval pyrolysis and the result obtained is given in table 1.1.

Table 1.1 TOC and Rock Eval pyrolysis results of the studied samples of Mianwali Formation.

S. No.	Sample ID	Formation	Age	TOC (wt. %)	T_{max} (°C)	S_1 (mg/g)	S_2 (mg/g)	HI (mg/g)	OI (mg/g)
1	M-1	Mianwali	Triassic	0.14		0.02		0	86
2	M-2	Mianwali	Triassic	0.35	423	0.01	0.08	23	77
3	M-3	Mianwali	Triassic	0.29	422	0.01	0.06	21	86
4	M-4	Mianwali	Triassic	0.19	428	0.01	0.03	16	79
5	M-5	Mianwali	Triassic	1.68	429	0.03	4.26	254	30
6	M-6	Mianwali	Triassic	0.13	422	0	0.01	8	108
7	M-7	Mianwali	Triassic	0.26	425	0	0.09	35	77
8	M-8	Mianwali	Triassic	0.23	423	0.01	0.04	17	109
9	M-9	Mianwali	Triassic	0.13	418	0.01	0.01	8	154
10	M-10	Mianwali	Triassic	0.07		0.01	0	0	100
11	M-11A	Mianwali	Triassic	0.22	423	0	0.04	18	55
12	M-11B	Mianwali	Triassic	0.04		0.01	0	0	350
13	M-11C	Mianwali	Triassic	0.02		0.01	0	0	600
14	M-12	Mianwali	Triassic	0.24	425	0	0.07	29	71
15	M-13	Mianwali	Triassic	0.22	427	0	0.07	32	14

4.2 Rock-Eval Pyrolysis

Rock Eval pyrolysis is used to measure quality, and thermal maturity of organic matter in rock samples (Peters and Cassa, 1994). The pyrolysis analysis indicated by S1 yield (free hydrocarbon) values range from 0 mg HC/g in sample M-6 to 0.02 mg HC/g in sample M-1with an average value of 0.01 mg HC/g which shows that the analyzed sample values are much less than the standard values (< 0.5 mg HC/g rock) for source potential given by Peters and Cassa (1994), indicating poor source rock potential. Similarly, the values of S2 yield (cracked hydrocarbons on thermal maturation) ranges from 0 mg HC/g in sample M-10 to 4.26 mg HC/g in M-5 which suggest that majority of the samples have not hydrocarbon generation potential (Peters and Cassa, 1994). Finally, it is assumed that the Mianwali Formation in the Surghar Range is a poor source rock for hydrocarbon generation.

4.3 Kerogen Types & its Thermal Maturity

The Rock Eval pyrolysis data i.e. HI versus Tmax and OI vs HI is used to evaluate the kerogen type and thermal maturity level of the studied formation shown in figure 2. The hydrogen indices range from 0 mg HC/g (M-1) to 254 mg HC/g (M-5), while oxygen indices values for the studied formation are ranges from 14 mg CO2/g (M-13) to 600 mg CO2/g (M-11). As the HI values are very low and OI values are higher which can be source by terrestrial plants and oxygenated environment. The cross plot of modified van Krevelen's diagram (Espitalié, 1999) and plot between HI & Tmax were constructed for the evaluation of organic matter nature, this plot suggests Type IV kerogen for the studied samples of the Mianwali Formation shown in figure 4. The Tmax parameter of the Rock Eval pyrolysis which is the maximum temperature at which maximum S2 hydrocarbon is generated upon thermal stress of the organic contents has been used in the current research for thermal stress analysis of the studied samples. The Tmax values obtained during thermal heating of kerogen in the analyzed samples are ranged from 418 °C (M-9) to 429 °C (M-5). As 435 °C is the minimum value for the generation of free hydrocarbon and below this value the organic matter will be considered as thermally immature (Tissot & Welte, 1984). The Tmax values for the analyzed samples are below oil window (Tissot & Welte, 1984).

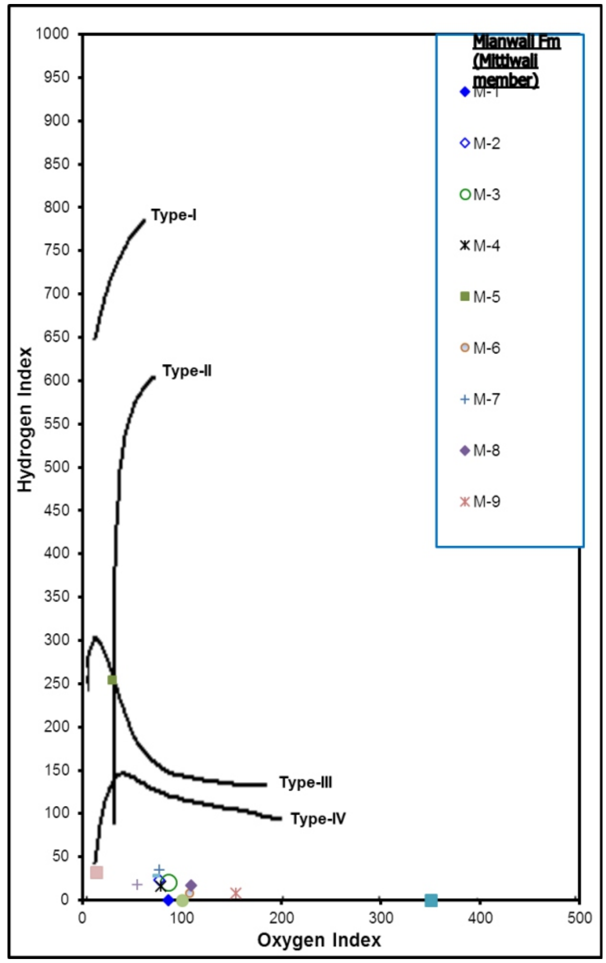

Fig. 2 Van Krevelen's diagram showing types of kerogen in the studied samples.

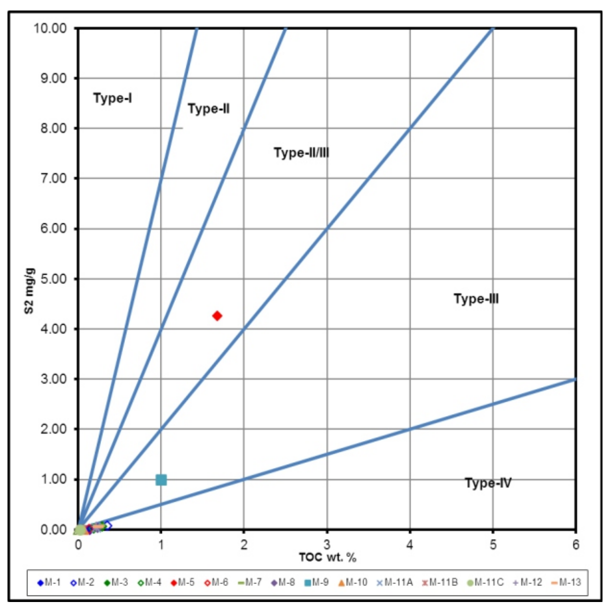

Fig. 3 S2 versus TOC showing kerogen types in the studied samples of Mianwali Formation.

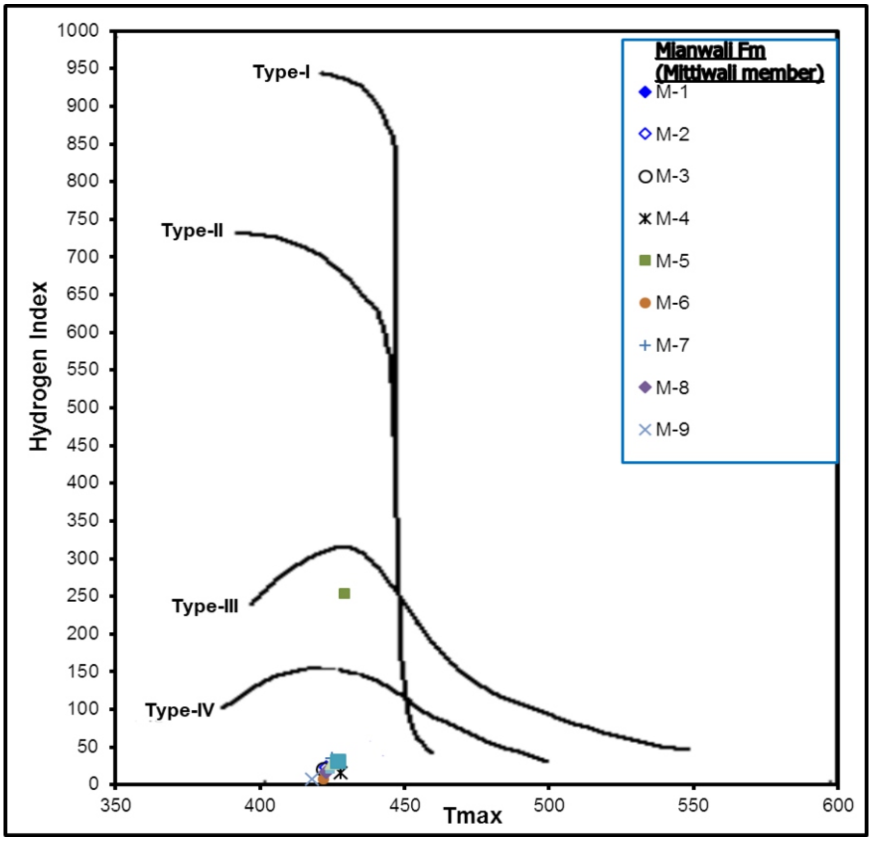

Fig. 4. HI versus Tmax showing kerogen types in the studied samples.

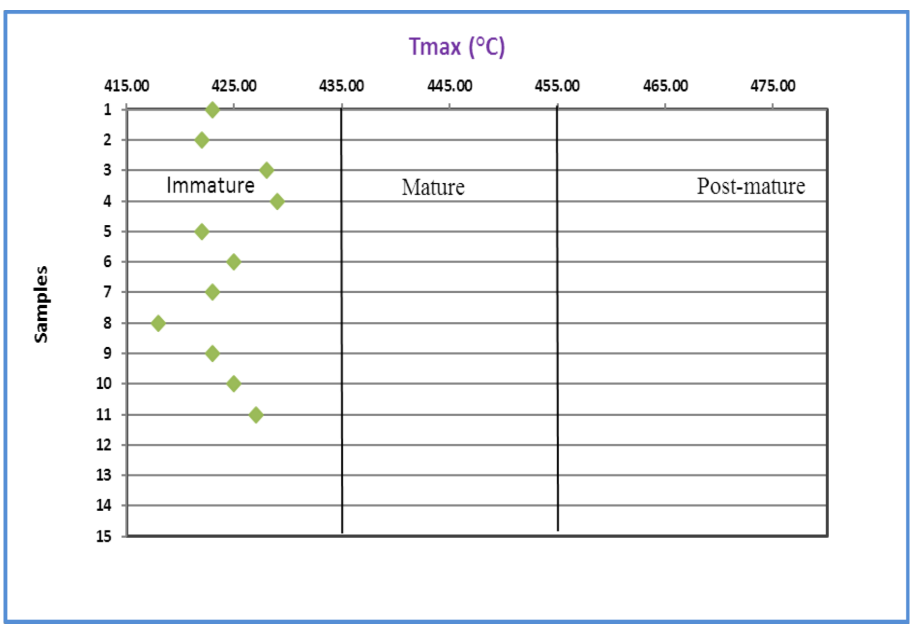

Fig. 5 Thermal maturity level of the studied samples.

5. Conclusions

The outcrop shale samples of the Triassic Mianwali Formation in Surghar Range were analyzed geochemically to evaluate its hydrocarbon potential in the studied section. The geochemical screening techniques including TOC and Rock Eval pyrolysis were performed on total fifteen shale samples. The TOC data is poor as majority of samples resulted in TOC < 0.5 % except one sample (1.68 %). As TOC decreases with thermal maturity too but in the current case Tmax values is not much higher, therefore, it is concluded that the studied samples of the formation are poor in organic matter and have no capability to generate hydrocarbon upon thermal maturation. The quality of organic matter was assessed by using different cross plots such as S2 vs TOC, HI vs OI and HI vs Tmax. All these plots indicate that the studied samples are hydrogen poor and oxidized containing type IV kerogen which can not generate neither liquid hydrocarbon nor gaseous hydrocarbon.

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Authors' Contribution

Syed Mamoon Siyar proposed the main concept & results interpretations, Abdullah, Sohail Hafeez and Nasir Khan and mehmood khan were involved in laboratory work & plots preparation. Imran Ahmad collected field samples, Adnan Khan khan provides relevant literature and was involved in manuscript formatting. Fayaz Ali reviews the article especially regional geological setting of the study area.

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