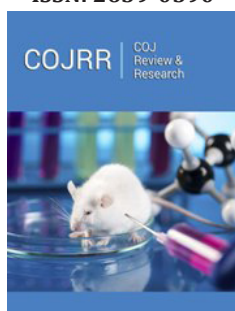


# Hydrocarbon Source Rock Potential Evaluation of the Paleozoic-Mesozoic of Punjab Platform, Pakistan: A Geochemical Approach

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## Abstract






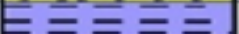











The hydrocarbon source rock potential of three formations encountered in Bijnot well, in Punjab platform was investigated using TOC and Rock-Eval pyrolysis measurements. Analysis was performed on sixteen well and core cutting samples of Shinwari, Datta and Khewra formations. Shinwari Formation consists of three distinct units, namely the upper (marl and limestone) middle (sandstone and clay) and lower (limestone and shale). Shinwari Formation have fair TOC 0.54-0.62 wt.%, as indicated by HI vs Tmax plot and lies in mature zone with kerogen Type III. The Datta Formation consists of sandstone and claystone lies in mature zone and having fair TOC 0.60-1.09 wt.%. Genetic potential is insignificant 0.67-1.05mg HC/g rock, low HI values falls in Type III kerogen. The Khewra Formation consists of sandstone with thin claystone beds and have a good TOC 0.80-1.38 wt% at 1630-1641m depth, and fair TOC 0.57wt% at 1710m depth. The HI vs OI and HI vs Tmax plots indicate Type III and mix Type II-III kerogen, having Tmax 441-448 °C and lies. Oil and gas prone mature zone. Based on analysis performed the Khewra Sandstone Formation sediments have poor generative potential.

**Keywords:** Punjab platform; Bijnot; Geochemical; Rock-Eval; Tmax

## Introduction

The Punjab platform located in the Middle Indus Basin (MIB) is westward dipping monocline covered by alluvium. MIB has been divided into three units Sulaiman Fold Belt, Sulaiman Depression and Punjab Platform [1]. In MIB is the least deformed part and is dipping gently towards Sulaiman Depression. The Punjab platform is bounded towards north by Sargodha High and south by Mari High, from west Punjab platform merges into Sulaiman depression and in east it extends into Bikaner-Nagaur of India [2]. In this region gas have been produced from these recognized source rock with kerogen Type III and mix Type II-III [3]. In the region three gas fields have been explored in the infra-Cambrian sediments in the region having TOC up to 30% and ranging from 0.80-4% wt.%, [4]. As not much data is available regarding the source rocks of Punjab Platform, and the formations present in southern part of the basin is comparable with Potwar Basin. In the Potwar basin, the major source rocks are Patala Shale, Datta, Shinwari, Hangu, Lockhart and Khewra formations. [4,5], these formations are also present in the study area which influenced this study (Table 1). Of late, there has been a discovery of a gas field in the Punjab Platform nearby the Panjpir Oilfield. The present study tries to interpret and investigate source rock maturity, kerogen type and organic richness for future hydrocarbon exploration and to investigate the source rock potential of proven source rocks formations in other parts of the basin. In this study sixteen well cutting samples of Shinwari, Datta and Khewra formations have been investigated.

**Table 1:** Stratigraphic column developed from Bijnot Well A (modified after Kadri, 1995; Shah and Shah, 2021; Shah, 2009).

AGE	Formation	Average Thickness (m)	Lithologies	Description
MIOCENE and PLOIOCENE	Siwaliks	430		Sandstone Shale Limestone
	Habib Rahi	49		Limestone
EOCENE	Ghazij	250		Sandstone Shale Limestone
	Ranikot	30		Sandstone/Shale
CRETACEOUS	Goru	900		Sandstone Shale Limestone Marl
	Sember	150		
JURASSIC	Chiltan/ SamanaSuk	300		Shale Limestone Marl
	Shinwari	200		Shale Limestone Marl
	Datta	80		Shale Sandstone
PERMIAN	Warcha/Dandot	110		Shale Conglomerates
	Tobra	60		Sandstone Shale
CAMBRIAN	Baghanwala	120		Sandstone Shale Silt
	Jutana	70		Dolomite Shale
	Kussak	150		Sandstone Shale Dolomite
	Khewra	150		Sandstone Shale Dolomite
INTRA CAMBRIAN	Salt Range	210		Sandstone Shale Dolomite Salt
	Basement			

### Geological background

The Indian Plate started to rift in Late Proterozoic from Supercontinent Gondwanaland [6] and resulted in sediment deposition of Infra-Cambrian over Precambrian. Because of dragging of Infra-Cambrian strata the second phase of rifting in Punjab Platform is not evidently observable, however the evidence of rifting can be seen on reflectors of seismic profile where in terms of petroleum exploration Punjab Platform has received much more attention due to discovery of various gas and a recent

oil field discovery in nearby field in neighboring country India on this Platform [1]. The studied samples are from Jurassic succession in Pakistan mainly represented by limestone, shale and sandstone (Table 2). The stratigraphic succession of the Punjab platform shows mainly marine Paleozoic-Cenozoic rocks of chemical precipitates (carbonates) and clastic origin. The Punjab Platform and Potwar Basin stratigraphy (most of the formations) of Early Triassic age are similar; in southern part stratigraphy of both Punjab platform and Potwar Basin is similar of ages Late Triassic and onwards [7].

**Table 2:** Paleocene Ranikot Formations was assessed for source rock potential at well A Bijnot, Fort Abbas, the measured values are shown in Table 2.

Formation (No. of samples)	Depth (m)	Hydrocarbon Potential			Maturity	OM Quality	Main Kerogen Type	Source Rock Potential
		TOC %	S1	S2	Tmax °C	HI		
Shinwari (04)	780-840	0.54-0.62	0.18-0.26	0.48-0.76	467-497	77-141	Type III	Poor
Datta (07)	850-940	0.60-1.09	0.19-0.26	0.48-0.79	445-475	44-127	Mix Type II-III	Poor
Khewra (05)	1610-1710	0.57-1.38	0.20-0.23	0.41-1.58	441-449	72-224	Type II-III	Poor-Fair

## Material and Methods

From well A in Bahawalpur, Punjab Platform a total of 16 samples have been used i.e., eleven drill cutting samples out of which 04, 07 and 05 are of Shinwari Formation, Datta formations, and Khewra Formation, respectively. Samples were obtained at 10-30 meters interval, the interval was already set by the drilling company and were used with the same interval, samples were of Jurassic and Early-Cambrian ages. Samples details are available in (Table 3). Samples were washed thoroughly with water and

then dried, crushed and were subjected to pass through 80m mesh sieve. The crushed samples were subjected to Total Organic Carbon (TOC) analysis, and after TOC analysis the samples were further subjected to Rock-Eval measurements, using Rock-Eval VI apparatus by following Peters [8]. In a helium atmosphere the samples of 100mg were pyrolyzed for 4mins at 300 °C, followed by programmed pyrolysis at 25 °C per min from 300-550 °C. For evolved hydrocarbons monitoring Flame Ionization Detector (FID) was used [9].

**Table 3:** TOC and Rock-Eval pyrolysis data of all three formations.

Depth (m)	FM	Lithology	TOC (%)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	Tmax	S2/S3	GP	HI	OI
780	Shinawari (Upper part)	Ml & Lst	0.56	0.2	0.49	0	484	0	0.7	88	0
790	Shinawari (Middle part)	Sst & clst	0.61	0.19	0.56	0	469	0	0.8	92	0
830	Shinawari (Lower part)	Lst	0.54	0.26	0.76	0.49	497	1.6	1	141	91
840	Shinawari (Lower part)	Lst	0.62	0.18	0.48	0	467	0	0.7	77	0
850	Datta	Sst, silt & sh.	0.6	0.22	0.55	0	445	0	0.8	92	0
860	Datta	Sst, silt & sh.	0.9	0.19	0.64	0	469	0	0.8	71	0
870	Datta	Sst, silt & sh.	0.66	0.22	0.58	0	475	0	0.8	88	0
880	Datta	Sst, silt & sh.	0.64	0.19	0.49	0	473	0	0.7	77	0
900	Datta	Sst, silt & sh.	0.62	0.26	0.79	0	465	0	1.1	127	0
920	Datta	Sst, silt & sh.	0.88	0.23	0.77	0	472	0	1	88	0
940	Datta	Sst, silt & sh.	1.09	0.19	0.48	0.47	452	1	0.7	44	43
1610	Khewara	Sst, silt & sh.	0.42	0.26	0.94	0.19	443	4.9	1.2	224	45
1630	Khewara	Sst & clst	0.8	0.23	1.58	2.04	441	0.8	1.8	198	255
1635	Khewara	Sst & clst	1.34	0.2	1.05	2.31	442	0.5	1.3	78	172
1640	Khewara	Sst & clst	1.38	0.2	1.12	2.76	449	0.4	1.3	81	200
1710	Khewara	Sst & clst	0.57	0.21	0.41	1	448	0.4	0.6	72	175

TOC: Total Organic Carbon, wt.%

HI: Hydrogen Index =  $S2 \times 100 / TOC$ , mg HC/g TOC

S1: Volatile Hydrocarbon (HC) content, mg HC/g rock

S2: remaining HC generative potential, mg HC/g rock

S3: Carbon dioxide yield, mg CO<sub>2</sub>/ g rock

Tmax: Temperature at maximum S2 peak

GP: Genetic potential

OI: Oxygen Index =  $S3 \times 100 / TOC$ , mg CO<sub>2</sub>/g TOC.

During isothermal pyrolysis at 300 °C from volatilization of free hydrocarbons the first peak S1 was obtained. S2 the second peak which represents hydrocarbons generated by thermal cracking of kerogen during pyrolysis at 300-500 °C. The third peak S3 which represents CO<sub>2</sub> generated from one gram of rock during pyrolysis were analysed by Thermal Conductivity Detector (TCD). Following Shah et al. [10], and Fazeelat et al. [11] maturity and type of organic matter were interpreted. The TOC measurements of rocks were determined by utilizing Leco CR-12 carbon determinator at Hydrocarbon Development Institute of Pakistan (HDIP). To remove carbonate the crushed samples of 100g were treated with 6N HCL and were combusted at 1200 °C in O<sub>2</sub> atmosphere. By Thermal Conductivity Detector (TCD) CO<sub>2</sub> amount were measured [12].

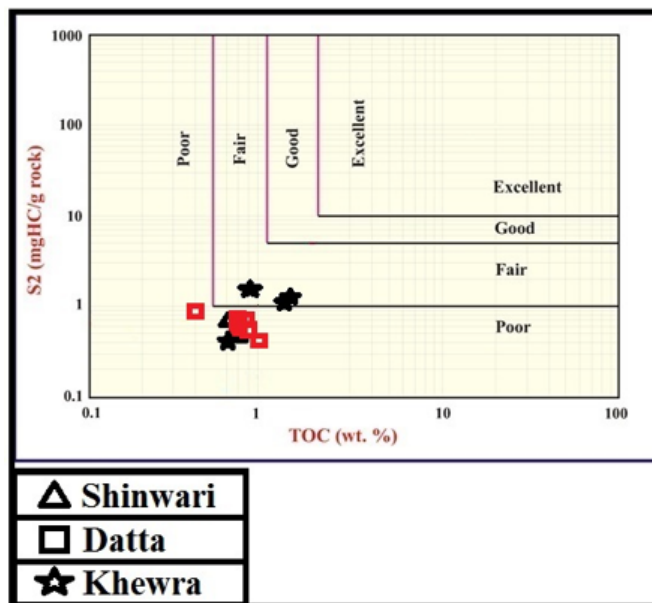
## Results and Discussion

### Total organic carbon content and Rock-Eval pyrolysis

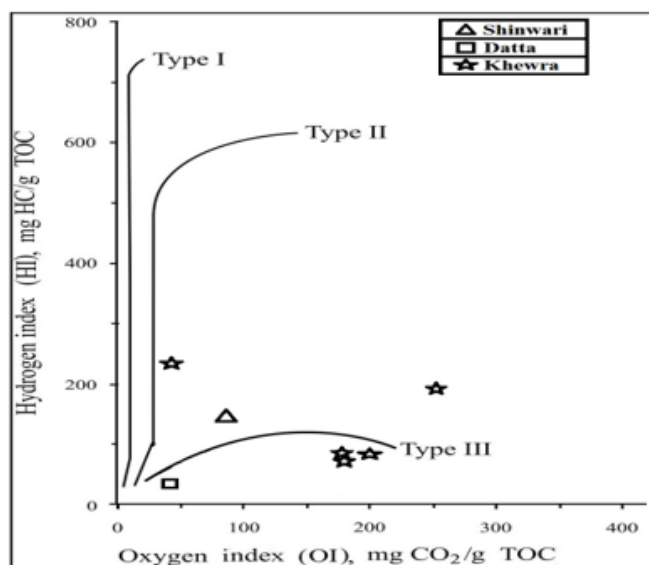
Shinwari Formation has three marginally different lithologic units, the upper unit (from 745-785m depth) consists of marl and limestone, the middle unit (from 790-830m depth) consists largely of sandstone and clay streaks, and the lower unit (from 830-840m depth) consists of limestone and shale [13]. The upper and lower unit have fair TOC ranging between TOC 0.54-0.62 wt.%. From pyrolysis measurements the values of S2 of analysed samples are in poor potential range, ranging from 0.48-0.76mg HC/g rock. These values lie below the standard acceptable values of a source rock hydrocarbon generative potential according to the classification by Peters [8] and indicated by S2 vs TOC plot (Figure 1). The sediments have poor genetic potential and lies in mature zone as indicated by HI vs Tmax plot, the kerogen is Type III. However, the Datta Formation has low is organic content. TOC ranging between 0.60-1.09wt.%. From pyrolysis measurements the values of S2 indicates poor potential, ranging from 0.48-0.79mg HC/g rock, these values also lie in the below standard acceptable values [14]. The formation has poor potential as indicated by S2 vs TOC plot (Figure 1). Low HI values and HI vs Tmax plot indicates Type III kerogen. Two of the samples of Datta Formation lies in mature zone and five samples lies in post-mature. The genetic potential of the formation is also insignificant 0.67-1.05mg HC/g rock.

The Khewra Formation is mainly composed of sandstone with thin beds of claystone, having fair to good TOC, ranging between 0.57-1.38wt.%. From pyrolysis measurements the S2 ranges from 0.41-1.58mg HC/g rock. And poor to fair potential as indicated by S2 vs TOC plot (Figure 1). HI vs OI (Figure 2) and HI vs Tmax plot (Figure 3) indicates predominantly Type III and mix Type II-III kerogen and having Tmax 441-448 °C, the sediments lie in mature zone as indicated by HI vs Tmax plot (Figure 3) i.e., oil and gas prone also supported by S2/S3 values. The genetic potential of the formation is at marginal 1.24mg HC/g rock. This indicates that gas is expected to have been produced by Khewra Formation as indicated by various plots of HI vs Tmax and is also supported by the Tmax temperature range which lies in gas producing zone. The investigation of Shinwari and Datta formations sediments shows poor generative potential for oil, which is indicated by S2 values

which are ranging from 0.48-0.79mg HC/g rock and low HI values ranging from 43-91mg CO<sub>2</sub>/g TOC (Table 2) and have OI values ranging from 43-91mg CO<sub>2</sub>/g TOC (Table 2), having predominantly kerogen Type III as indicated by HI vs OI plot and HI vs Tmax plot. Two of Datta Formation sediments lies in maturity zone however rest of the sample lies in post-mature zone. The analysis of Shinwari and Datta formations shows poor generative potential for oil and gas. However, Khewra Formation sediments lies in mature zone, having predominately Type III and mix Type II-III kerogen, the S2 vs TOC plot shows poor to fair generative potential for oil and gas which is also supported by S2/S3 values.

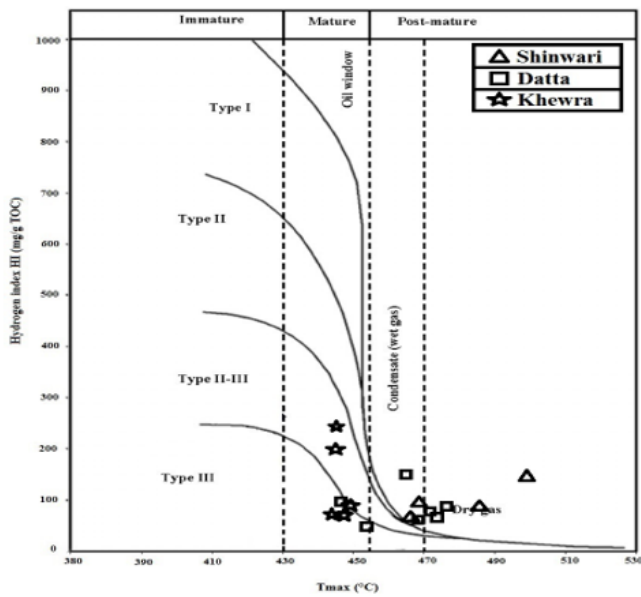


**Figure 1:** Pyrolysis S2 versus Total Organic Carbon (TOC) plot displaying source rock generative potential [8].



**Figure 2:** Plot of HI versus OI showing type of organic matter of analysed samples.





**Figure 3:** HI versus Tmax displaying thermal maturity and kerogen quality of the analysed samples.

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