

# Hydrocarbon potential of the jurassic coal-bearing strata in the Liupanshan area, china

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**Abstract.** The Liupanshan area is situated to the southwest of the Ordos Basin. Because of larger stratigraphic thickness and thicker overlying sedimentary coverage, the coal-bearing Yan'an Formation in the Liupanshan area is supposed to have higher hydrocarbon potential than that in the Ordos Basin. 25 samples collected from 10 sedimentary sections in the Liupanshan area have been tested to evaluate the quality of the coals and dark mudstones of the Yan'an Formation. The Yan'an Formation in the Liupanshan area generally bears thick coals and dark mudstones, though the stratigraphic thickness and coal-bearing coefficient vary greatly. Most of the source rocks have high total organic carbon and chloroform bitumen "A", which can be classified to the category of "good to excellent source rocks". The main organic matter type of the source rocks is II<sub>2</sub> and III kerogen, having larger potential to generate gas. The maturity is the key factor because the coals in the Ordos Basin are mostly immature to low-mature. Results show that the maturity of the source rocks in the Liupanshan area is higher, most reaching mature to high-mature stage. Therefore, the hydrocarbon potential of the Yan'an Formation in the Liupanshan area is very high and this formation deserves further exploration.

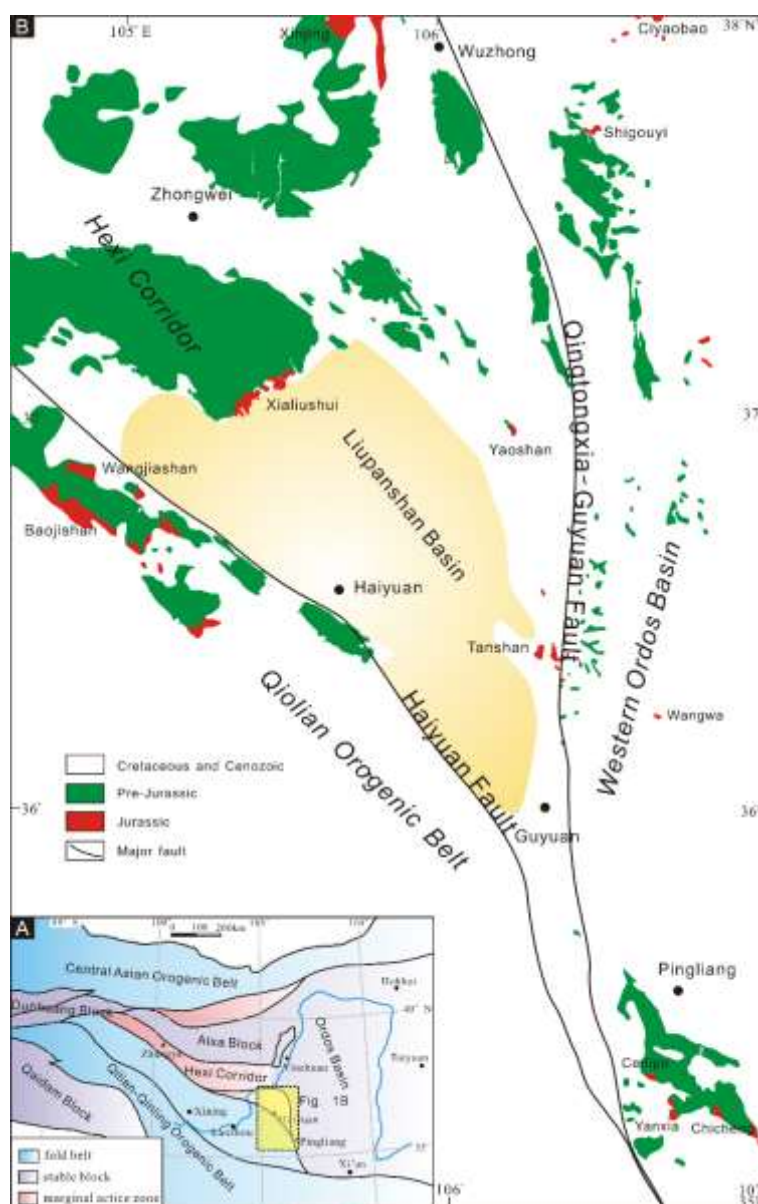
## 1. Introduction

The Early-Middle Jurassic Yan'an Formation is the most significant coal-bearing succession in the Northwest China <sup>[1]</sup>, especially in the Ordos Basin [2]. Numerous high-quality Jurassic coal seams have exposed or been uplifted in very shallow subsurface in the northern and western margin of the Ordos Basin [2], acting as the major economic source for local people. While in the interior of the basin, this coal-bearing succession was buried in relatively deep subsurface and has potential to generate coal-derived gas. However, previous study has shown that the maturity of these coals in the interior were not high enough to generate large-scale gas [3].

The Liupanshan area, situated to the west of the Ordos Basin (Fig. 1), was in the same sedimentary depression as the Ordos Basin during the Early-Middle Mesozoic [4]. It also contains the Jurassic coal-bearing succession <sup>[5]</sup>. Different from the Ordos Basin, the thickness of the Yan'an formation in the Liupanshan area is supposed to be larger and currently this formation is covered by thick Cretaceous and Cenozoic strata, indicative of possibly higher maturity for the Jurassic coals and mudstones. Therefore, the Yan'an Formation in the Liupanshan area may have great potential to generate



hydrocarbon. Previous work mostly focused on the Cretaceous source rocks in the Liupanshan area, most of which are only in immature to low-maturity stage [6, 7]. However, the hydrocarbon potential of the Jurassic coal-bearing strata has remained poorly studied.



**Figure 1.** (A) The tectonic setting of the Liupanshan area in China. (B) The sample locations of Jurassic source rocks, which can belong to three tectonic units: the Western Ordos Basin, Hexi Corridor and Qilian Orogenic Belt. Note that the Liupanshan area is mainly situated in the Hexi Corridor.

At present, there is only one well that has drilled the Early-Middle Mesozoic strata inside the Liupanshan area and the stratigraphic classification of this well has great controversy. In this paper, sampling of source rocks are mainly carried out in outcrops. Almost all the Jurassic outcrops in the Liupanshan area have been sampled to test the source-rock quality of the Jurassic coal-bearing strata.

## 2. The distribution of source rocks

As shown in Table 1, the thickness of the Yan'an Formation surrounding the Liupanshan area shows great variations, ranging from 100 m to 700 m, much distinct from that in the interior of the Ordos Basin and indicative of the subsidence instability during the Jurassic. In the Western Ordos Basin, from the north to south, the thickness of the Yan'an Formation and the number of coal seams decrease but the coal-bearing coefficient increases. In the Hexi Corridor, the thickness of the Yan'an Formation is mostly varied and the coal-bearing coefficient is smallest. Especially in the Xinjing area, the Yan'an Formation is only ca. 100 m and its coal-bearing coefficient varies from 0~38.5%. Three sections, the Tanshan, Yaoshan and Xialiushui, situated on the margins of the Liupanshan area, contain ca. 400~700 m coal-bearing strata. This means that the thickness of the Yan'an Formation inside the Liupanshan area may also reach 400 m. However, the coal-bearing coefficient is very small. In the Qilian Orogenic Belt, the Yan'an Formation is less than 200 m and the number of coal seams is 1~3. But the thickness of coal seam can reach to 37m, much higher than the other parts.

Another potential source rocks are the dark mudstones. According to the wells of coal fields, the thickness of dark mudstones in the Tanshan section can reach 327 m and that of the Yaoshan section can reach 50% of the whole thickness. This suggests that even the sections in the margins of the Liupanshan area is very low, its high proportion of dark mudstones can make up this defect. In summary, the Yan'an Formation surrounding the Liupanshan area generally bear coal and dark mudstones and their proportion of the strata can be very high.

**Table 1.** Thickness of the Yan'an Formation and its bearing coals. Location of the sections is referred to the Fig. 1B.

Region	Section		Strata thick(m)	Number of coal seam	Number of minable coal seam	Average thickness of coal(m)	Coal-bearing coefficient (%)
Western Ordos Basin	North	Ciyaobao	370	17-22	7	17	4.6
		Suishijing	300	17-26	13	21.2	7.1
		Yuanyanghu	294	16-23	2	4.47	1.5
		Majiatan	281	19-22	12	23.38	8.3
		Shigouyi	694		9	15.05	2.2
	Wangwa	North	160	4	1	19.25	12.0
		Middle	282	4	1	61.85	21.9
		South	114	4	1	17.85	15.7
	South	Cicheng	263	6~12	6	25.52	9.7
		Yanxia	146		6	22.77	15.6
		Cedipo	148.22		5	22.84	15.4
Hexi Corridor	Tanshan		395.62	10~25	5~10	26.68	6.7
	Yaoshan		>562.18	16	9	48.7	8.7
	Xialiushui		>729	11~17	1~5	25.92	3.6
	Xinjing		96	3	1	0-37	0~38.5
Qilian Orogenic Belt	Baojishan		110	5	3	26.64	24.2
	Wangjiawashan		175	6	3	37.73	21.6
	Honghui		70	2	1	15.68	22.4

## 3. Organic geochemical analysis

Generally, the quality evaluation of source rocks include three aspects: the organic matter abundance, type and maturity. In total, 25 samples of the Yan'an Formation have been tested, including 13 coal samples and 10 dark mudstones samples (Table 2).

### 3.1. Organic matter abundance

As shown in Table 2, the total organic carbon of the mudstone samples ranges from 1.06~26.7%, averaging at 9.347% and all higher than the lower limit value of source rocks [8]. Most of the dark mudstones are even in the category of “good or excellent source rocks”, except the samples in the Mahuanggou section. The chloroform bitumen “A” ranges from 0.77% to 5.19%, averaging at 1.66%. The hydrocarbon potential ( $S_1 + S_2$ ) ranges from 0.116 to 142.344‰, averaging at 33.705‰ and many falling in the category of “excellent source rocks” [9].

**Table 2.** The organic geochemistry characteristics of the source rocks of the Yan'an Formation in the Liupanshan area.  $S_1$ -soluble hydrocarbon,  $S_2$ -pyrolysed hydrocarbon,  $T_{max}$ - peak temperature of pyrolysis,  $P_g$ - hydrocarbon potential,  $PI$ - production index

Region	Sample	Location	Lithology	TOC (%)	SO <sub>2</sub> (%)	S <sub>1</sub> (‰)	S <sub>2</sub> (‰)	T <sub>max</sub> (°C)	P <sub>g</sub> =S <sub>1</sub> +S <sub>2</sub> (‰)	PI=S <sub>1</sub> /(S <sub>1</sub> +S <sub>2</sub> )	(S <sub>2</sub> ×100)/TOC	Ro (%)
Western Ordos Basin	NX-218	Shiganggou	mudstone	26.7	0.386	0.900	32.780	432	33.680	0.027	195	0.518
	NX-222		mudstone	11.9	0.167	0.090	15.550	437	15.640	0.006	225	0.622
	NX-133	Shigouyi	mudstone	21.3	0.14	0.130	0.190	449	0.320	0.406	1	0.463
	NX-207		coal	-	-	0.510	9.290	437	9.800	0.052	53	0.446
	NX-137		coal	-	-	0.550	62.760	399	63.310	0.009	213	0.546
	NX-10	Wangwa	coal	-	-	0.460	45.070	507	45.530	0.010	185	0.509
	NX-48		coal	-	-	0.870	64.570	435	65.440	0.013	164	0.591
Hexi Corridor	NX-54	Tanshan	coal	-	-	0.340	52.560	443	52.900	0.006	258	0.569
	NX-128		mudstone	1.9	0.0271	0.078	1.190	438	1.280	0.061	63	0.570
	NX-32		coal	-	-	1.408	140.364	422	142.344	0.010	-	0.560
	NX-87		coal	-	-	0.020	6.400	446	6.420	0.003	17	0.551
	NX-87		coal	-	-	0.100	7.040	449	7.140	0.014	38	0.551
	NX-92	Yaoshan	coal	-	-	0.190	37.740	347	37.930	0.005	137	0.453
	NX-92		coal	-	-	0.420	25.950	441	26.370	0.016	92	0.453
	NX-239		coal	-	-	0.340	42.440	444	42.780	0.008	122	0.626
	NX-04		coal	-	-	0.564	26.545	435	27.179	0.021	-	0.480
	NX-118	Xinjing	coal	-	-	0.500	81.280	459	81.780	0.006	154	0.859
	NX-280	Mahuanggou	mudstone	3.79	0.116	0.190	3.340	347	3.530	0.054	133	0.512
	NX-12		mudstone	1.06	0.00672	0.035	0.087	500	0.139	0.250	8	0.980
	NX-13		mudstone	6.18	0.0131	0.066	0.363	414	0.444	0.148	6	0.970
	NX-39	Xialiushui	mudstone	1.67	0.0148	0.027	0.072	505	0.116	0.234	4	1.690
	NX-49		mudstone	6.87	0.156	0.061	0.916	442	0.994	0.061	13	0.640
	NX-50		mudstone	12.1	0.343	0.113	4.261	434	4.394	0.026	35	1.140
Qilian Orogenic Belt	NX-150	Honghui	coal	-	-	0.882	78.010	437	78.920	0.011	-	1.110
	NX-25	Baojishan	coal	-	-	1.835	92.354	443	94.239	0.019	-	1.220

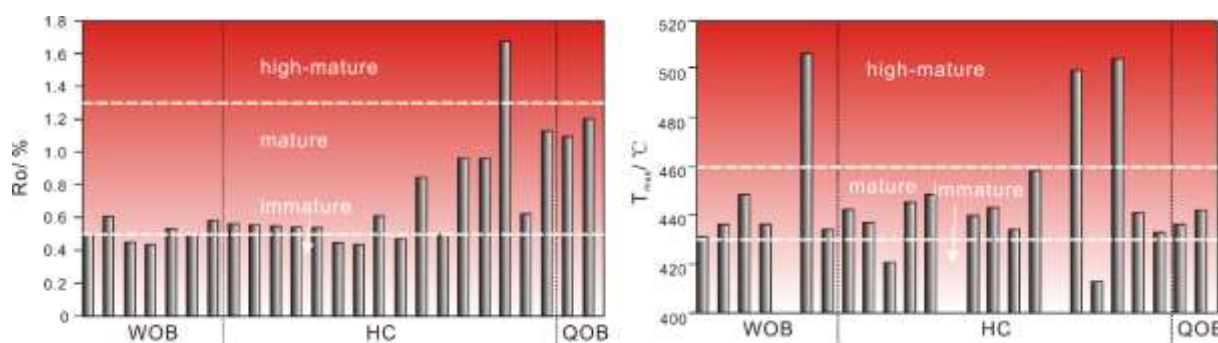
### 3.2. Organic matter type

According to the microscopic observation of kerogen maceral, rock pyrolysis, steroid terpene biomarkers and elementary composition of kerogen, the organic matter of the Jurassic mudstones is mainly type II<sub>2</sub> and III kerogen, accounting for 83.3%. Organic macerals are mainly vitrinite and inertinite, which can generally make up 60~90%, while the proportions of the sapropelinite and exinite are generally under 40%, indicative of low potential to generate oil. The hydrogen index ranges from 14~928 mg/g, averaging at 108 mg/g. All of these suggest that the organic matter sources of the Jurassic mudstones mainly come from terrigenous higher plants and minor plankton and have high potential to generate gas.

### 3.3. Organic matter maturity

According to the results of the Ro and rock pyrolysis (Table 2), the kerogens of Jurassic mudstone and coals are immature to high-mature, showing great variations (Fig. 2). In the western Ordos Basin, the Ro mostly falls in the range of 0.45~0.60%, suggestive of the immature property, just like the Jurassic source rocks in the interior of the Ordos Basin. The two sections (Tanshan and Yaoshan), on the boundary of the Ordos Basin and Hexi Corridor, also bear immature source rocks. As in the Xialiushui and Mahuanggou sections, on the northern margin of the Liupanshan area, most mudstones and coals reach the oil threshold with Ro ranging from 0.51 to 1.69%. The coals in the Xinjing section also reach the oil threshold, with Ro at 0.859%. While in the two sections in the northern margin of the Qilian Orogenic Belt, the Ro of the Jurassic coals exceeds 1.0%, showing higher maturity. The results of the peak temperature of pyrolysis ( $T_{max}$ ) also suggest most of the source rocks in the SW Ordos Basin are in low-mature stage, with several exceptions.

It is noteworthy that bounded by the Qingtongxia-Guyuan Fault (Fig. 1), source rocks in the east part are mostly immature or low-mature while those in the west part are mostly mature to high-mature.



**Figure 2.** The maturity of the Jurassic source rocks. WOB- Western Ordos Basin; HC- Hexi Corridor; QOB- Qilian Orogenic Belt. The classification is based on Wu, 1986<sup>[10]</sup>.

### 3.4. Hydrocarbon potential

As discussed above, the Yan'an Formation in the Liupanshan area generally bear coals in different degrees. Although the three sections on the margins of Liupanshan Basin have the lowest coal-bearing coefficient, the Yan'an Formation there have higher proportion of dark mudstones. Based on the thickness of the Yan'an Formation in above three sections, this formation in the Liupanshan Basin are supposed to reach 400~700 m. And the source rocks mainly contain type II<sub>2</sub> and III kerogen. It is suggestive that the coal-bearing strata in the Liupanshan have great potential to generate gas if the source rocks reach maturity. Although the maturity of the source rocks in the Tanshan and Yaoshan sections is not very high, just as that in the Western Ordos Basin, the other sections in the Hexi Corridor contain mature to high-mature source rocks. Moreover, the Cretaceous source rocks inside the Liupanshan area has partly reached the oil threshold ( $Ro=0.5\%$ ), implying that the maturity of the underlying Jurassic source rocks may be higher. Therefore, the Yan'an Formation in the Liupanshan area has great hydrocarbon potential.

## 4. Conclusion

25 samples collected from 10 sedimentary sections in the Liupanshan area have been tested to evaluate the quality of the coals and dark mudstones of the Yan'an Formation. The Yan'an Formation in the Liupanshan area generally bears thick coals and dark mudstones, though the stratigraphic thickness and coal-bearing coefficient vary greatly. Most of the source rocks have high total organic carbon and chloroform bitumen "A", which can be classified to the category of "good to excellent source rocks". The main organic matter type of the source rocks is II<sub>2</sub> and III kerogen, having larger potential to generate gas. The maturity is the key factor because the coals in the Ordos Basin are mostly immature to low-mature. Results show that the maturity of the source rocks in the Liupanshan area is higher, most

reaching mature to high-mature stage. Therefore, the hydrocarbon potential of the Yan'an Formation in the Liupanshan area is very high and this formation deserves further exploration.

## 5. Acknowledgments

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