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Study on source rock potential and source rocks spatial distribution in the Manghan Faulted Sag, Kailu Basin*

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Abstract: Manghan Faulted Sag is an exploratory target area in Kailu Basin. In order to determine its exploration prospect, the effectiveness of its source rocks is evaluated by organic geochemical behavior analysis of the samples, and their distributions are predicted using trace integration seismic inversion technology. Studies on their organic matter abundance, type and maturity indicate that the source rocks in the Sag have great generating potentials. Furthermore, it is found that, based on the spatial distribution predication, the source rocks in the Sag are well developed. Therefore, the Sag has a promising prospect for exploration.

Key words: Source rocks, Hydrocarbon accumulation, Organic matter, Manghan Faulted Sag
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INTRODUCTION

Source rock is the foundation for petroliferous system and hydrocarbon accumulation (Magoon and Dow, 1994; Zhou, 2000; Johnson *et al*., 2003; Yang *et al*., 2004). The active source rock is a significant geologic factor in controlling hydrocarbon distribution (Hao *et al*., 2005; Isaksen and Ledje, 2001; Zhao *et al*., 2001; Bons and van Milligen, 2001). So the volume of the effective source rock in a basin determines its exploration prospect (Liu and Jin, 2004; Petersen *et al*., 2002). In order to evaluate the exploration prospect of the Manghan Faulted Sag in the Kailu Basin more effectively, this paper evaluates the generating potentials of source rocks by analyzing organic geochemical assay materials, predicts the effective source rock distribution patterns by identifying source rocks in the Sag using trace integration seismic inversion, and then defines the development of the effective source rock to provide a geological basis for quantitative evaluation of petroliferous prospect and selection of the favorable exploration targets in the Sag.

GEOLOGICAL BACKGROUND

In terms of regional structure, the Manghan Fault Sag lies in the middle of Zhelimu Meng Depression stretching from north to east. To the north, the Sag borders the Lujiapu Faulted Sag, while to the east, it borders the Longwantong Faulted Sag and to the west Baxiantong Faulted Sag, stretching 97 km from south to north in length, about 6 to 32 km in width, covering an area of about 2150 km^2. It is the biggest fault sag basin in the Kailu Basin in the Zhelimu Meng Depression (Fig.1).

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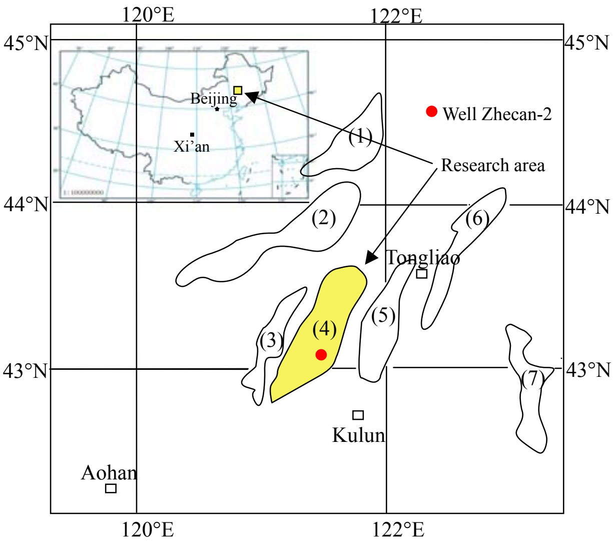


Fig.1 The structure location of Manghan Faulted Sag
(1) Baiyinhua Faulted Sag; (2) Lujiapu Faulted Sag; (3) Baxiantong Faulted Sag; (4) Manghan Faulted Sag; (5) Longwantong Faulted Sag; (6) Qianjiadian Faulted Sag; (7) Zhangqiang Faulted Sag

The main exploratory targets in the Sag include Cretaceous Jiufutang and Shahai Formations (Li *et al.*, 1988). According to the logging data obtained from Well Zhecan-2, which is the only parametric borehole in the Sag, the source rocks in Jiufutang and Shahai Formations mainly consist of the grey semi-abyss shale and abyss shale (Lin *et al.*, 2001; Carroll and Bohacs, 2001; Stein, 2007). The upper layer of shale in Jiufutang Formation is as thick as 451 m, among which the thickness of source rock (dark shale) is 202 m, occupying 44.8%. The thickness of shale in Shahai Formation is 303 m, with 208 m of source rock, occupying 68.6%. So the source rocks of Jiufutang and Shahai Formations in the Sag are well developed.

SAMPLE SET AND METHODOLOGY

A 50-m core is obtained from Well Zhecan-2, the only one parametric borehole in the Manghan Faulted Sag up to 2005. We make 75 core samples for organic geochemical behavior analysis, and collect a group of organic geochemical behavior data, including organic carbon (TOC), chloroform-bitumen "A", total hydrocarbon (HC), potential hydrocarbon generation (S_1+S_2), kerogen element component and so on, by which the generating potentials of the source rocks can be evaluated. Furthermore, 19 2D seismic lines acquired in 2004 are available, which cover most areas of south Manghan Faulted Sag. Then trace integration seismic inversion is used to identify the source rocks through these seismic lines, by which the source rock spatial distribution in the Sag can be predicted and the volume of source rocks in the sag can be determined.

RESULTS AND DISCUSSION

Organic matter characterization

The geochemical feature refers to the quantitative parameters for describing the quality of source rocks, including organic matter abundance, type and maturity, through which the generating potentials of the source rock and its effectiveness can be accurately determined (Banerjee *et al.*, 2002; Petersen *et al.*, 2002; Rabbani and Kamali, 2005; Younes, 2005).

1. Organic matter abundance

Organic matter abundance is a fundamental index for source rock evaluation, which directly influences the generating potentials of a basin or depression. Total organic carbon (TOC), chloroform-bitumen "A", total hydrocarbon (HC), and generating potentials (S_1+S_2) are all the indexes to describe the organic matter abundance of source rocks. Table 1 presents the organic matter abundance data obtained from the core samples of Well Zhecan-2 in the Manghan Faulted Sag.

We can see from Table 1 that source rocks of Jiufutang and Shahai Formations in Well Zhecan-2 contain an average of 1.4% TOC, 0.08% chloroform-bitumen "A", 406.31×10^{-6} HC, 4.65 mg/g S_1+S_2, and 2.76% HC/TOC. According to the organic matter abundance evaluation criteria for continental facies basins (Huang and Li, 1982), the source rock in Jiufutang and Shahai Formations of Well Zhecan-2 proves to be of moderate quality, while the total organic carbon (TOC) content index fits the high-quality standard of source rocks. So the source rocks of the two formations have great generating potentials.

2. Organic matter type

Different types of organic matter may be composed of different elements and chemical structures. Since the type reveals the evolution

Table 1 Some organic matter abundance data of Well Zhecan-2 in Manghan Faulted Sag

Sample No.	Formation	Depth (m)	TOC (%)	Chloroform-bitumen "A" (%)	HC ($\times10^{-6}$)	S_1+S_2 (mg/g)	HC/TOC (%)
1	K_{1sh}	1975.0	0.77	0.01	29.50	0.47	0.38
2		2003.0	2.15	0.10	454.40	6.51	2.11
3		2056.5	1.63	0.03	125.90	3.05	0.77
4		2068.0	1.21	0.03	191.00	1.18	1.58
5		2112.5	1.32	0.03	76.60	2.04	0.58
6		2176.0	1.26	0.19	1153.50	1.72	9.15
7		2238.0	1.64	0.06	305.60	2.47	1.86
8		2262.5	1.18	0.04	176.20	2.64	1.49
9		2272.0	1.61	0.06	505.00	10.73	3.14
10		2344.5	2.25	0.04	134.60	12.34	0.60
11		2372.0	2.08	0.18	1171.40	9.46	5.63
12	K_{1jf}	2480.5	0.43	0.01	42.20	0.29	0.98
13		2538.0	1.72	0.10	622.00	6.98	3.62
14		2594.5	1.97	0.19	1074.60	10.90	5.45
15		2667.0	1.86	0.14	967.50	9.85	5.20
16		2745.5	1.40	0.05	225.40	2.80	1.61
17		2872.0	0.68	0.03	154.40	0.48	2.27
18		2912.5	1.35	0.12	140.40	5.97	1.04
19		2955.0	0.90	0.04	257.40	2.57	2.86
20		3010.5	1.14	0.08	400.00	3.30	3.51
21		3055.0	0.78	0.06	325.00	1.82	4.17
Average			1.40	0.08	406.31	4.65	2.76

process of hydrocarbon generation of the source rock and its product features, it is a main index to evaluate the generating potential of organic matter. We adopt the kerogen element component index to study the organic matter type of Jiufutang and Shahai Formations. Fig.2 presents a kerogen element analysis of the source rocks, which shows that in Manghan Fault Sag, for most of samples H/C is over 1.0 while O/C is below 0.1. It is clear that most of them are II-type kerogen, except for only three of them being the III-type. It also shows that the kerogen in the Sag has strong generating potentials.

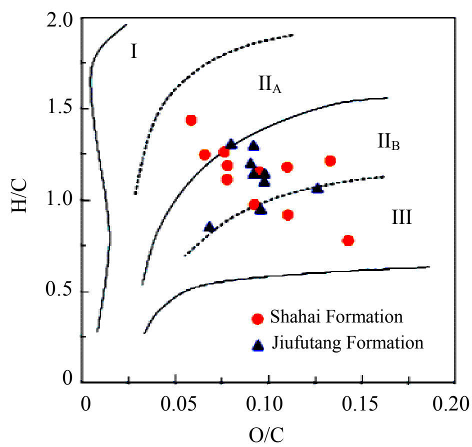


Fig.2 Modified Van-Krevelen diagram: the elemental analysis of source rock kerogen samples from the Well Zhecan-2

3. Organic matter maturity

The hydrocarbon generating potential depends on not only the organic matter type and abundance, but also the organic matter maturity (Jiang *et al.*, 2002; Zhu, 2002).

Thermal maturation is the main driving force for kerogen degradation and resulting hydrocarbon generation (Louis, 1964; Philippi, 1965; Albbecht and Ourission, 1969). The thermal maturity, a source rock experienced, is an important factor for basin evolution and crude oil predictions. Common maturity parameters are, for example, the vitrinite reflectance (Mukhopadhyay and Dow, 1994), color indices, such as for amorphous organic matter (Robison *et al.*, 2000), conodontes or sporinites, or parameters obtained from pyrolysis, like Rock-Eval (Behar *et al.*, 2001), and several molecular biomarker maturity parameters, mainly based on hopane and sterane distributions (Peters *et al.*, 2005).

For the present study, the vitrinite reflectance *Ro* varied with the depth, and other organic matter maturity index is used to study the mature of source rock in Manghan Faulted Sag comprehensively. Fig.3 is the comprehensive cross section of organic matter evolution phase of Well Zhecan-2, which shows that the thermal evolution can be divided into two phases, that is, the immature and the mature phase.

According to Fig.3, most of the source rocks in Jiufutang and Shahai Formations enter the oil generating window at the depth of 1900 m. Various maturity indexes show that the organic matter of the source rock has arrived at mature or post-mature phase. The *Ro* increases to above 0.7%, T_{max} to 450 °C, HC/CL to more than 5%, which proves that the source rock has been mature, entered into the hydrocarbon generation period and become the main effective source rock. And we can see from Fig.3 that the source rock is close to peak hydrocarbon generation at the depth of 2200 m.

To sum up, a geochemical feature analysis of organic matter indicates that the source rock of Jiufutang and Shahai Formations, of high abundance, containing good kerogen and high maturity, is the main hydrocarbon generating layers in the Manghan Faulted Sag, and has great generating potential.

SPATIAL DISTRIBUTION OF SOURCE ROCKS IN THE TARGET AREA

A comprehensive analysis of geochemical features of Well Zhecan-2 shows that the source rocks in Jiufutang and Shahai Formations have great generating potentials. So, the spatial distribution of the source rock and its volume determine the amount of hydrocarbon generated in the Sag. Since such distribution cannot be predicted by well data only, the seismic inversion, a core technology for predicting reservoirs in a sag and basin at the early exploratory period (Li, 1993) is introduced to study the spatial distribution of source rock in the Sag with the 19 seismic lines.

Acoustic impedance (AI) can be transformed from seismic reflection data by seismic inversion. Acoustic impedance is mutually related with the velocity and density of the rocks in formations. Because the velocity and density of source rocks and sandstone are different, we can identify different rocks by acoustic impedance derived from seismic inversion (Lu, 1993).

According to Well Zhecan-2, the lithology of source rocks in the Sag is dark shale formed in the semi-abyss and abyss sedimentary environment, and their acoustic impedance presents a value of high

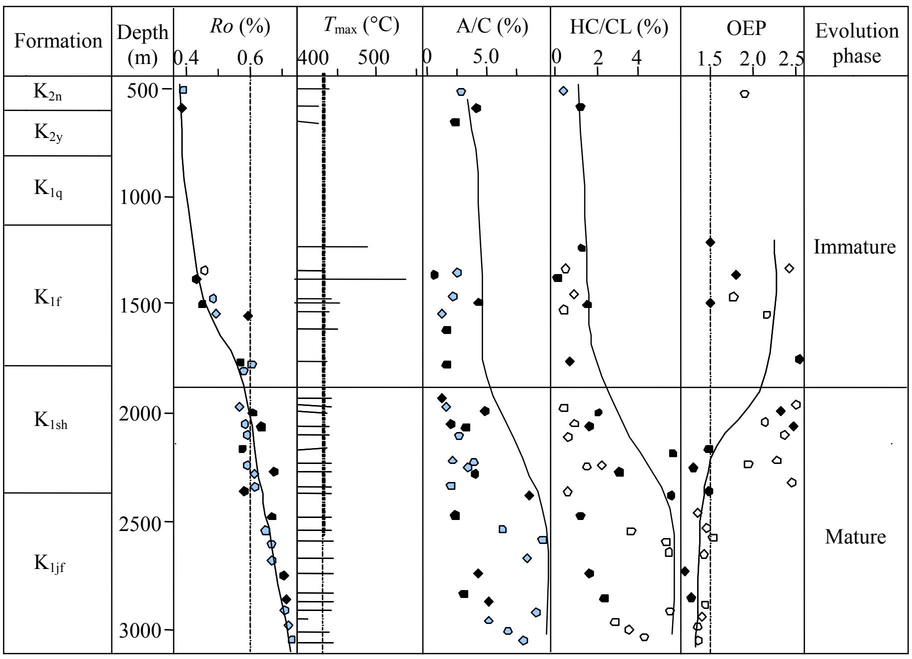


Fig.3 The comprehensive cross section of organic matter evolution phase of Well Zhecan-2 in Manghan Faulted Sag

abnormity, which is obviously different from that of sandstone in the same formation. Fig.4 shows the seismic-inverted KT04-109.7 acoustic impedence profile on which Well Zhecan-2 is located. At the seismic trace of Well Zhecan-2, acoustic impedence of source rocks is above 800~1000, i.e., the blue area in the profile, while that of sandstone is less than −1600~−1800. So we can define the discriminant critical values of acoustic impedance to identify source rocks (Table 2). Then, source rocks are identified from the 19 2D seismic inversion profiles, and as a result, we can predict the plane distribution of the source rocks in the Sag. Figs.5a and 5b show the planar isopachous maps of the source rock in Jiufutang and Shahai Formations.

Table 2 The acoustic impedance of different rocks in Manghan Faulted Sag

Formation	Sandstone	Transitional rock	Source rock
Shahai	$AI<-1600$	$-1600<AI<800$	$AI>800$
Jiufutang	$AI<-1800$	$-1800<AI<1000$	$AI>1000$

AI is acoustic impedance

From the figures, we can see that effective source rocks in Shahai Formation are widely distributed in the Sag (Fig.5a). At the center of the Sag where Well Zhecan-2 is located, the thickest source rock can be above 250 m, which becomes thinner and thinner to the edge.

The two figures show a wide distribution of effective source rocks in the Sag (Fig.5a). At the sag

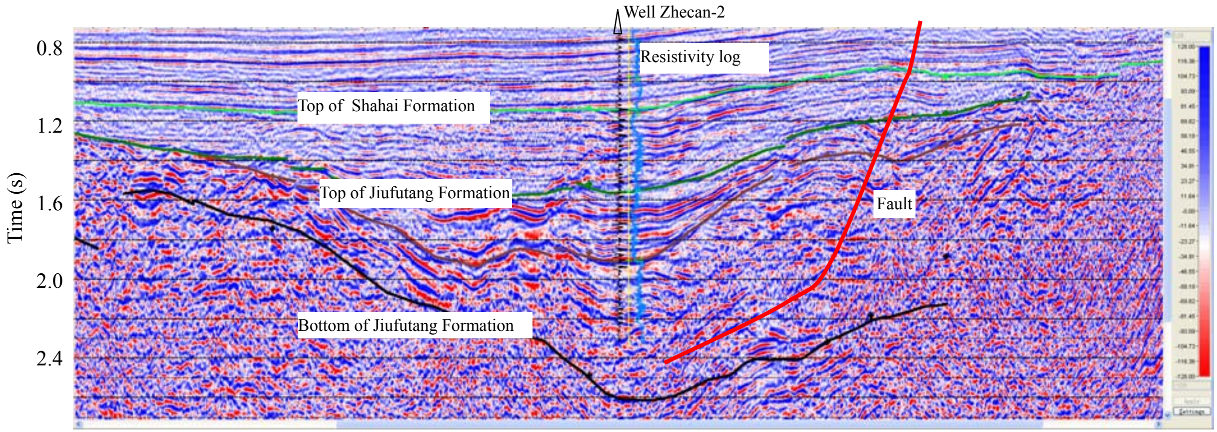
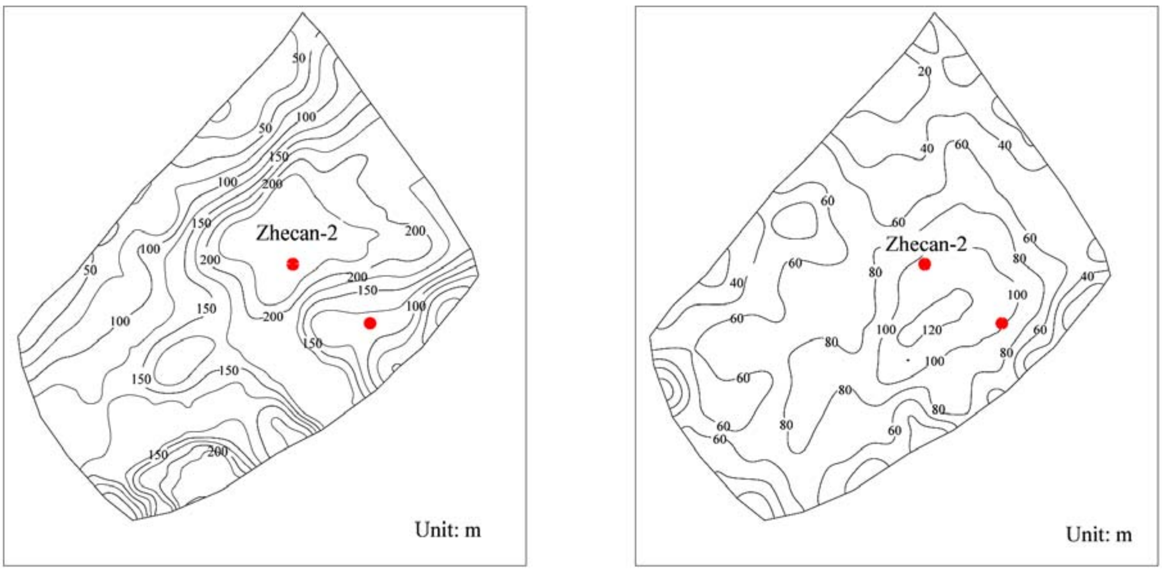


Fig.4 The acoustic impedance profile of LineKT04-109.7 in which the blue area is source rock



(a) (b)

Fig.5 The isopach map of source rock of Shahai (a) and Jiufutang (b) Formations in Manghan Faulted Sag

center where Well Zhecan-2 is located, the source rock can be up to above 250 m thick, and becomes thinner and thinner to the edge.

The main effective source rocks in Jiufutang Formation are distributed in the area where Well Zhecan-2 is located, whose southeastern part is thinner than that of Shahai Formation (with a thickness between 100 m and 150 m) (Fig.5b), covering a smaller area of distribution than Shahai Formation. Generally, the source rocks in Jiufutang and Shahai Formations are well developed, especially in the southeast, the total thickness of the two formations reaches up to 300 m, and turns out to be the hydrocarbon generating center of the Sag.

CONCLUSION

A comprehensive geochemical and geophysical analysis of the source rocks in Manghan Faulted Sag indicates that the organic matter in the Sag is of high abundance, preferable type and high maturity, which has a good potential for hydrocarbon generation. Seismic trace integration inversion reveals that the source rock is widely distributed with relatively high thickness, especially in the southeast of the Sag. Therefore, a good exploration prospect is expected of this Sag and the most favorite exploration target is the effective traps in the southeast of the Sag, where the source rock is most developed.

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