New advances in oil and gas survey of the Qianjin depression in Sanjiang basin, north china

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Abstract. With more difficult of the development of oil and gas exploration in the large oil and gas bearing basins in Northeast China, the development level of old oil field has entered the late stage, and new oil and gas area is an urgent need to find. As one of the seven primary prospective basins in the periphery of the Songliao Basin, Sanjiang Basin has a great potential for oil and gas exploration. Through a series of oil and gas geological survey work carried out in Sanjiang Basin recently, we made some new progress in biogas resources, Late Paleozoic strata dark mudstone and the hydrocarbon potential of silica rock. These advances are significant to evaluate oil and gas potential resource in Northeast China.

1. Introduction

Sanjiang Basin is located in the Sanjiang plain in northeast of Heilongjiang Province, west from Jiamusi, east to the Wusuli River and Wanda Mountain, north of Heilong River and south of Shuangyashan watershed. It is the same basin with Middle Amur Basin in Russia, extends in the north-east direction with an area of 33730 km^2 in China (Fig. 1).

Figure 1 Geographic location of the Sanjiang Basin, Northeast China

The oil and gas exploration work in the Sanjiang Basin began in 1959, after years of unremitting exploration (Table 1), several oil and gas shows have been found in the basin and its surroundings,

indicating the oil and gas generation and migration occurred in Sanjiang Basin(Hu et al., 2006; Liu et al., 2006; Wu et al., 2004, 2009).

Under the urgent need of strategy replace area for Chinese exploration area of gas and oil today, small and medium sized sedimentary basins in the periphery of Songliao Basin have become the important fields of oil and gas exploration. In recent years, a series of basic research and exploration work in the small and medium-sized basins being carried out, made some important oil and gas discoveries, such as new breakthroughs in oil and gas exploration in Zhangwu Basin, oil and gas discoveries of Tucan1 well in Tuquan Basin, Fang 4 and Fang 6 well in Fangzheng Rift, Yan 4 well and Yan 10 well in Yanji Basin, and these show that the small and medium-sized basins around the Songliao Basin have good prospect for exploration. Based on the application of the basic geological framework, basin simulation and oil and gas geological conditions in the basin, we sorted the oil and gas prospect of the outer basin of Songliao area, and Sanjiang Basin is one of the seven first-class prospect basins with the characteristics of large area, deep burial, well developed hydrocarbon source rocks and large amount of resources. The oil resources of Sanjiang Basin is 2.81×108t, showing the great oil and gas exploration potential.

Table 1 Statistical table of oil and gas exploration in Sanjiang Basin

Structural belt	Seismicexploration		Well drilling		Aeromagnetic survey (km)	MT (point)	Gravity prospecting (point)	Magnetic prospecting (point)
	Simulate (km)	Digitization (km)	Well	Total footage (m)				
Suibin depression		4202	4	7902.15		233	7566	
Fujin uplift							4111	3149
Qianjin depression	320.8	1529.3	7	15044.08	14359	89	27110	11418
Total	320.8	5731	8	21428.07	14359	322	34676	

2. Geological background

The Sanjiang Basin is located in the east of Heilongjiang Province in Northeast China. The boundary faults are the Yitong-Shulan and the Dunhua-Mishan fault zones (Fig. 2). The present structures belong to the Pacific Ocean tectonic domain. The multi-stage tectonic evolution determines the particularity and complexity of the evolution of the basic tectonic framework in Sanjiang Basin.

Figure 2 Division of tectonic units of Sanjiang Basin, Northeast China

Sanjiang Basin is a Meso-Cenozoic superimposed residual basin. The structural unit from west to east is Suibin depression, Fujin uplift, and Qianjin depression (Zhang and Ma, 2010; Liu et al., 2006; Fig. 2). The uplift and depressions are arranged in sequence with the characteristics of east-west zoning and the north-south blocking. Suibin depression in the west of the basin, with the area of 6440km^2, and mainly composed of Lower Proterozoic metamorphic rocks (Mashan Group) and intrusive granites, with

the development of late Jurassic and early Cretaceous strata. The basement of Fujin uplift is the Paleozoic variscan folded rock series that are dominated by the Upper Paleozoic shallow metamorphic rocks and the Variscan granitic intrusion. The Qianjin depression (ca.22000km^2), between the Fujin uplift and the Dahezhen fault, is mainly composed of the Cenozoic sediments and Mesozoic strata.

3. Progress of Petroleum geology survey

3.1. Progress in the study ofMeso-Cenozoic mud shale

Strata developed in Qianjin depression of Sanjiang Basin from bottom to top is Lower Cretaceous Dongshan Formation, Upper Cretaceous Hailang Formation, Qixinghe Formation, Yanwo Formation, Tertiary Baoquanling Formation, Fujin Formation and Quaternary(Bi, 2011). The depth of "Well Fudi 1" in the Qianjin depression is 1518.16m, and its ending formation is Qixinghe Formation, to reveal the thick dark mudstone formed in Baoquanling Formation, Yanwo Formation and Qixinghe Formation(Fig. 2, Fig. 3).The mudstone thickness of Yanwo Formation is 115.34m, accounted for 34% of the formation. Qixinghe Formation developed carbonaceous mudstone, whose thickness up to 45m.

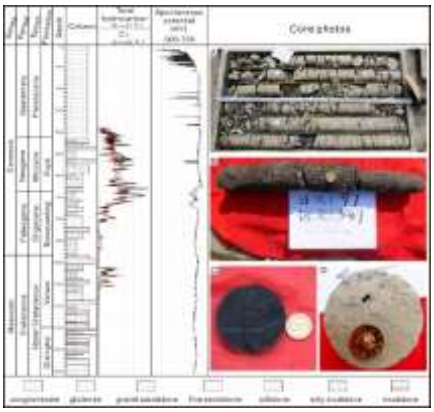

Figure 3 Integrated histogram of Fudi 1 well

During Fudi1 well drilling, we found continuousgas logging abnormal in Neogene Fujin Formation and Paleogene Baoquanling Formation, with characteristics that total hydrocarbon content more than 1%, dry gas, $C_1/(C_1{\sim}C_5)>0.9$, and small content of heavy hydrocarbon and non-hydrocarbon. Statistics can be seen, gas logging abnormal in total 220 m/15 layers, the highest total hydrocarbon content anomalies is 2.78% measured at 658m(Fig. 3). Through observing the corresponding cores of Fujin Formation and Baoquanling Formation, they are mainly composed of grayish black mudstone and carbonaceous mudstone which display gas logging abnormal, some of the core visible carbon chip particles(Fig. 3A-C). The organic geochemical test results show that gas source rock is the dark mudstone, carbonaceous mudstone and coal seam mainly(Table. 2). The TOC content of the dark mudstone ranging from 0.36% to 2.64%, good organic matter type(Ⅱ1-Ⅱ2), Ro value between 0.32%-0.33%, these reflect the source rock in the immature stage (Table. 2).

According to the specific characteristics of the gas logging, we know it has obvious biological characteristics, and biogas is an important unconventional gas reservoir now, generation and accumulation on a large scale(Lin et al., 1997, 2007). Research and exploration results indicate that the formation of biogas is mainly affected or controlled by temperature, reduction-strong reduction environment, salinity, pH value of water medium, type and abundance of organic matter, rapid deposition and burial, good cap rock, favorable traps and many other chemical and geological conditions, and the favorable combination of these factors can contribute to the formation of rich biogas resources (Shurr and Ridgley, 2002).

Table 2 Fudi 1 well core geochemical indicators

Sample Number	Stratum	Lithology	TOC/%	S_1+S_2/ mg·g-1	Tmax/℃	Ro/%	Abundance of organic matter	kerogen type
FD1-449	Fujin Formation	mudstone	0.47	0.43	428	0.32	poor	Ⅱ$_1$
FD1-457	Fujin Formation	mudstone	2.64	3.03	437	0.34	high	Ⅱ$_1$
FD1-547	Fujin Formation	coal	49.21	146.80	371	0.33	high	Ⅱ$_2$
FD1-915	Baoquanling Formation	carbonaceous mudstone	31.59	144.88	419	0.33	high	Ⅱ$_1$
FD1-1187	Yanwo Formation	mudstone	1.11	0.84	434	0.35	high	Ⅱ$_1$
FD1-1309	Qixinghe Formation	mudstone	2.07	4.63	426	0.35	high	Ⅱ$_2$
FD1-1317	Qixinghe Formation	carbonaceous mudstone	19.02	48.17	416	0.37	high	Ⅱ$_2$
FD1-1326	Qixinghe Formation	coal	49.73	173.65	418	0.35	high	Ⅱ$_2$
FD1-1345	QixingheFormatin	coal	50.59	169.04	417	0.36	high	Ⅱ$_2$
FD1-1368	Qixinghe Formation	carbonaceous mudstone	34.61	114.52	419	0.37	high	Ⅱ$_2$
FD1-1387	Qixinghe Formation	carbonaceous mudstone	38.47	115.08	418	0.37	high	Ⅱ$_2$
FD1-1429	Qixinghe Formation	coal	43.81	207.84	411	0.39	high	Ⅱ$_2$
FD1-1475	Qixinghe Formation	mudstone	0.36	0.59	449	0.36	not	Ⅱ$_2$

The Sanjiang Basin has favorable conditions for the formation of biogenic gas reservoirs, such as cold weather in favour of the preservation of organic matter, if the surface temperature is high, large number of organic matter may be oxidized by bacteria degradation in oxidation zone to no formation of biogas; Quaternary lacustrine clay layer as cap rock is widely distributed, continuous and thick, conducive to the preservation of biological gas; black, dark gray mudstone layer and coal in Neogene Fujin Formation and Paleogene Baoquanling Formation, which can be used as good gas producing strata; well-developed reservoir stratum in Quaternary and Tertiary are favorable for biogas accumulation.

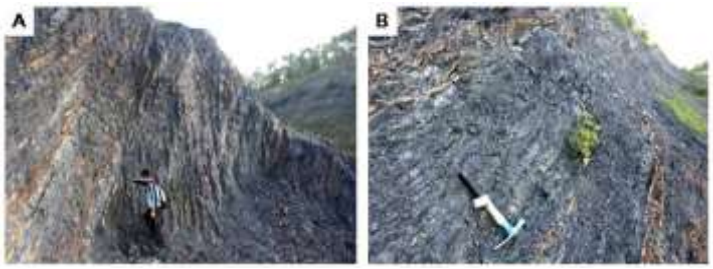

Figure 4 Black shale with sandstone of Zhenzishan Formation

A, Carbonaceous mudstone and coal seam of Zhenzishan Formation, Baolong coal mine; B, Black mudstone with thin siltstone of Zhenzishan Formation on the east side of highway 308, Baoqing country

3.2. Progress in the study of Paleozoic mud shale

With the continuous discovery of large and medium-sized oil and gas fields in the Paleozoic strata, Paleozoic oil and gas resources have become one of the important successor areas of oil and gas exploration in China (Kang, 2006). The Late Paleozoic stratum in northeast China has long been regarded as the Hercynian fold belt or the collisional orogenic belt, a metamorphic base of the Mesozoic and Cenozoic basins, so it was a restricted area for oil and gas exploration before. But recent studies have indicate that Late Paleozoic stratumin the northeastern region is the first caprock with regional distribution on the composite block basement, to a new stratigraphy for oil and gas exploration in northeast China (Zhou et al., 2009). Through oil-gas exploration and evaluation of Paleozoic strata in Sanjiang Basin recently, we know Sanjiang basin develops Paleozoic, Mesozoic, Cenozoic and other hydrocarbon source layers. Paleozoic hydrocarbon source beds are mainly developed in the Devonian and Carboniferous-Permian. Mesozoic hydrocarbon source beds are developed in the Middle-Upper Jurassic system, the upper and lower Cretaceous system. Cenozoic source rocks are mainly developed in the Paleogene.

The upper Paleozoic stratum in Sanjiang Basin are exposed in Yanshan town east of Fujin city, Baoqing country in southern margin of the basin and other places in Heilongjiang province in different degrees, or was revealed by a few shallow wells. Among them, Heitai Formation (D1-2h) is a set of coastal-shallow sea terrestrial clastic-carbonate rock construction, and the source rocks are marine limestone, bio-limestone and mudstone. Zhenzishan Formation (C2P1z) which is mainly distributed in Fujin, Mishan and Baoqing areas in Heilongjiang province, is a set of normal continental clastic sedimentary rock with coal seams and a small amount of tuffaceous slate assemblage (Fig. 4). The cumulative thickness of dark mudstone of Zhenzishan Formation in Baoqing area is 56.34m, with 21.5m thick coal seam, and the TOC of dark mudstone is 2.88-3.87%; vitrinitere flectance (Ro) is 2.19-4.15%; its organic matter type is Ⅲ, small amounts of Ⅱ 2. The TOC of dark mudstone of Zhenzishan Formation in Mishan is 0.57-1.83%, vitrinitere flectance (Ro) is 1.12-1.28%.

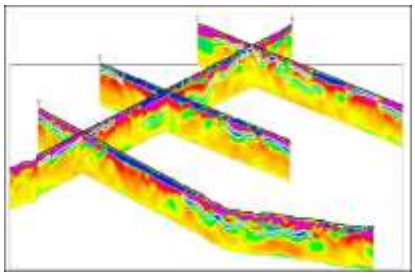

Figure 5 Three-dimensional view of electricity residual section

In order to initially determine the depth and fluctuation characteristics of Paleozoic strata in Sanjiang Basin, to further explore the distribution of Paleozoic mudstone, Oil & Gas Survey of China Geological Survey deployed gravity-magnetic-electric prospectings engineering which total 415km in 2015 (Fig. 2). Through the systematic research of petrophysical properties, include the stratum and different kinds of rock mass, we analyse the difference of physicalproperties among the responses of gravity, magnetic and the electrical, then, to establish the internal contact between these anomaly and physical properties. In order to separation of gravity and magnetic source, we use various methods include the upward continuation, tendency analysis and wavelet transform to extract the exception information of deep-seated geological mass, tectonic framework and distribution, speculated that strata and rock mass distribution; Meanwhile using the residual to extract the electrical abnormal of mudstone; Based on electrical layers, build the geological and geophysical model, then carries on the forward and inverse modeling fitting calculation and integrated geological explanation. At last, we determine the distribution and buried depth of the Paleozoic pluton and mudstone in section line.

We are taking four gravity-magnetic-electric profiles for the skeleton (Fig. 2), while using the results of the previous electrical profile and combining with gravity anomaly, can initially determine that the Paleozoic mudstone in this area is mainly developed in the middle-upper part of the Zhenzishan

Formation of Carboniferous-Permian system. Figure 5 is the three-dimensional perspective of residual method sections of this area, and the low value electrical anomaly in the middle-lower part of the picture can roughly reflect the distribution of mudstone in the Carboniferous-Permian strata in this area. From the plane point of view, Paleozoic mudstone mainly distributed in the northwest, northeast and eastern regions of the study area (Fig. 6). The distribution of Paleozoic mudstone has a tendency to further expand in the northwest, northeast and east direction. Due to the multi-period magmatic intrusion in the middle and south of the study area, the distribution of mudstone in the Paleozoic is relatively limited. The distribution area of Paleozoic mudstone in the study area is about 4900km2. The thickness of Paleozoic mudstone is generally 200-800m, the maximum of which can reach about 1100m in the northern part of the Qianjin farm, the thickness in the southwestern part of the area is about 1000m. Therefore, according to the results of gravity-magnetic-electric prospectings engineering, the strata of Zhenzishan Formation is widely distributed in the middle and eastern part of Sanjiang Basin, and the dark mudstone is developed well, which is the new stratum of deep oil and gas exploration in this area.

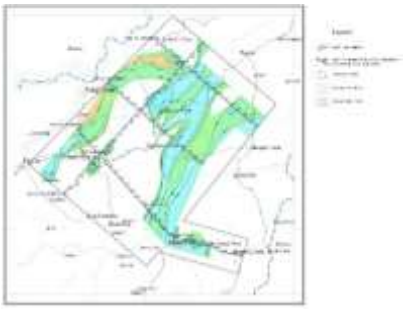

Figure 6 Distribution and thickness of Paleozoic mudstone in the Qianjin depression

3.3. Progress in the study of siliceous rocks

The distribution of oil and gas in siliceous rocks is very extensive in the world, but the hydrocarbon generating potential of siliceous rocks needs to be further studied. First, this stratigraphy rich in micro-fossil fossils with siliceous shells (such as Radiolaria, diatoms and sponges) is often excellent hydrocarbon source rocks in petroliferous basins; Secondly, because the siliceous rocks are dense, hard and fragile, it is often in the development of cracks, which can be used as a good oil and gas reservoir. Therefore, there is a significant relationship between some siliceous rocks and oil/gas fields in spatial and temporal distribution (Lu et al., 2011). At present, oil and gas field from siliceous mudstone have been found in the world, such as the Caspian Sea Basin, the Volga-Ural Basin and the Timan–PechoraBasin in Russia, which are top oil fields in the world currently under development. However, there is no report on this kind of oil and gas fields in China, so it is necessary to explore the hydrocarbonpotential of siliceous rocks in Sanjiang Basin.

Figure 7 Intercalation of siliceous rocks and mudstone in Wandashan complex

The siliceous rocks of late Triassic-early Jurassic are extensively developed in the Fuyuan and Wandashan area (Fig.7). In order to further evaluate the hydrocarbon generation potential of siliceous rocks in Sanjiang area, we collected samples from Fuyuan, Raohe, Hongqiling three regions in Sanjiang

Basin and did some geochemical tests(Fig.2). The results of the identification of the whole rock XRD (X-raydiffraction) show that in the Fuyuan area of Sanjiang basin the siliceousrock(quartz content> 50%) and siliceous shale(clay content> 50%) are developed in the Dajiashan Formation (T3-J1d). The brittle mineral content in siliceous rocks is mainly distributed in 59-95%, with an average value of 75%; siliceous shale has a brittle mineral content of 42%, both satisfying the conditions as a shale gas reservoir. In Raohe and Hongqiling areas, the siliceous rocks (quartz content> 50%) are developed in the Dajiashan Formation (T_3-J_{1d}), and the brittle mineral content ranged from 75.6% to 82.5%, with an average value of 79.4%.

Test results of organic geochemical indicat, the organic carbon content of siliceous rocks is between 0.09-1.89% with the average value of 0.45%, and the organic carbon content of siliceous rocks in Fuyuan area is high with the average value is 0.64%, which belongs to medium source rock; the hydrocarbon generation potential (S_1+S_2) is between 0.01mg/g and 1.55 mg/g with the average content of 0.16 mg/g; organic type of silicalite is mainly type Ⅲ, a small part of type Ⅱ1. The maturity of organic matter (Ro) is 2.06%-6.26%withthe average content of 4.67％; the Tmax value ranges from 451℃ to 566 ℃ with an average value of 480 ℃, and the average crystallinity of illite is 0.39, so siliceous rocks are clearly at high and overmature stages(Table 3). Research Institute of Exploration and Development of Daqing Oilfield Company Ltd. has also carried out the organic carbon content test of the radiolariansilicalite from Wandashan area, the organic carbon content is generally between 0.5%-0.6%.

Table 3 Organic geochemical characteristics of siliceous source rock inRaohe, Fuyuan, Hongqiling area

Region	Stratum	Lithology	TOC/%	S1+S2 /mg·g-1	Chloroform asphalt "A"	Tmax/℃	Ro/％	Abundance of organic matter
Raohe	T3-J1d	Siliceous rock	0.09~0.81 0.43(14)	0.01~0.07 0.04(14)	0.0036-0.0127 0.0083(4)	450~556 484(14)	4.74-6.3 5.7(3)	poor
Fuyuan	J1d	Siliceous rock	0.07~1.89 0.64(5)	0.04~1.55 0.38(5)	0.0051~0.0067 0.0059(2)	446~492 463(5)	6.26	medium
Hongqiling	T3-J1d	Siliceous mudstone	0.06~0.55 0.28(5)	0.02~0.09 0.05(5)	0.0070(1)	460~525 493(5)	2.06	not

On the whole, the organic geochemical indicators of siliceous rocks in Sanjiang area are somewhat low, and of course, long-term weathering may lead to a decrease in some organic geochemical indicators. At present, it can't be used as an effective exploration layer in this area. But in view of the discovery of siliceous oil and gas fields in the world, the hydrocarbon generating potential of marine siliceous rocks in Sanjiang area is worth further exploration and research.

4. Prognosis Prospective Province

According to the gravity-magnetic-electric prospecting results, Zhenzishan Formation in the Paleozoic are widely distributed in the central and eastern Sanjiang Basin, especially in the north and east of the Qianjin depression, where the dark mudstone is developed and with good conditions for source rocks; the local tectonic form is faulted anticline, which is favorable for oil and gas reservoir; the upper Middle Cenozoic mudstone can be used as a good caprock, therefore, the Upper Paleozoic strata can be used as a new stratum for deep oil and gas exploration in this area. The northern and eastern parts of Qianjin despression in Sanjiang Basin are prospective area for deep Paleozoic oil and gas exploration. There are some cases of large oil and gas fields that have been discovered and mined in the siliceous rocks so far. The research and exploration of siliceous rocks in late Triassic-Early Jurassic, which extensively developed in Fuyuan and Wandashan area, can better evaluate its hydrocarbon generation potential.

5. Conclusions

(1) Thick dark mudstone is developed in Fujin and Baoquanling Formation in Qianjin depression of Sanjiang Basin, which has high organic matter content, good organic matter type and abundant gas

logging abnormal(220 meters/15 layers), and these are similar to the characteristics of biogas. As an important unconventional gas reservoir, biogas reservoir has the characteristics of wide distribution and shallow burial, and has been paid more and more attention. Sanjiang Basin has favorable conditions for the formation of biogenic gas reservoirs, which is worthy of further exploration and exploration.

(2) Late Paleozoic strata as a new layer of oil and gas exploration in Northeast China, is developed extensively in the eastern part of Sanjiang Basin. Dark mudstone of Paleozoic Zhenzishan Formation in Qianjin depression of Sanjiang Basin has a large thickness, high organic content, with the value of TOC is 2.88%-3.87%, the value of Ro is 2.19%-4.15%, and the organic matter is mainly of Ⅲtype. The results of latest high-precision gravity-magnetic-electric prospectings exploration show that the mudstone in Paleozoic Zhenzishan Formation in Qianjin depression of Sanjiang Basin has a wide distribution area, up to about 4900km2, thickness of 200-800m.

(3) As a special set of source rocks, a large suite of siliceous rocks of Late Triassic-early Jurassic in Fuyuan area of Sanjiang Basin and Wandashan area, which need to be systematically and comprehensively studied and explored to evaluate its hydrocarbon generation potential. Organic geochemical indicators show that the organic carbon content of siliceous rocks is between 0.09%, and 1.89%, with an average value of 0.45%; the hydrocarbon generation potential (S_1+S_2) is between 0.01mg/g -1.55 mg/g with an average value of 0.16 mg/g; the type of organic matter in is mainly Ⅲ type, and a small part is Ⅱ1 type; the maturity of organic matter Ro is 2.06mg/g -6.26%,with an average value of 4.67%. In a word, although the organic geochemical indicators of siliceous rocks are low, in view of a number of large oil and gas fields have been found in this type of strata in world and the research is still very limited in China, it is necessary to intensify the research and exploration on siliceous rocks, and further determine its hydrocarbon potential.

Acknowledgements
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