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The Resource Estimation and Geologic Risk Assessment for the Southern Structure Belt in Block 69, Yemen

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Abstract

Block 69 in Yemen is characterized by several poor oil forming conditions, such as being low in trap confirmation and poor reservoir quality etc.. Though three wells have been drilled, no commercial hydrocarbon discovery has been made, showing the great difficulties for oil and gas exploration in the block. The author, on the basis of analyzing the oil and gas accumulation conditions, has performed trap conformation in the block and carried out trap resources estimation and geologic risk assessment, thus suggested that the Prospect-1 trap is the most favorable drilling target in the future.

Key words: Yemen; Block 69; Resource estimation; Risk assessment

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INTRODUCTION

Block 69 in Yemen is located in the middle of the Marib-Shabwah basin in central Yemen (Figure 1). On January 12, 2005, the Sinopec Group International Petroleum Exploration and Development co., LTD. (SIPC) signed block 69 in Yemen PSA with Yemen Petroleum Department of mineral resources, the agreement came into effect in July 12, 2005, Sinopec accounted for 90% of the shares. In November 2007, the cooperation agreement with Dodar came into force, Sinopec investment ratio and equity were changed to 55.56% and 50% respectively. Before SIPC entered, predecessors had completed two-dimensional seismic acquisition of about 2157 kilometers in this block, the net density reached 2×4~4×10km. There were 2 wells drilled in the Mashaf structure in the northwestern part of the block, and one of the exploration wells (Mashaf-1 well) was tested for low oil flow in the salt sandstones of the Jurassic sabine group. The process of hydrocarbon migration and accumulation in the block had been confirmed. However, the further analysis suggested that the sandstone in sabine group in the block was located in the front of the delta belt and the former delta belt. The sandstone transverse changes are larger, the shale content was large and the salt cement was common, which greatly influences the oil and gas content.

Since the SIPC entered the exploration of the block, it had collected more than 1,000 kilometers of seismic data of two dimensions and carried out a probe in the southern part of the block (abelat-1 well). The purpose of the drilling of the well was the lyem group, which was designed to be the base of the basin, and since the cementing accident it was a pre-drilled drill in the hukula group, and the drilling depth was 3310.21 m, and there was a good oil and gas show in lyem's log and cores, but the logging and core data showed that the rock was dense, it had less gas. Therefore, no test work had been carried out.

According to the comprehensive view, the block 69 had the disadvantage of low degree of trap implementation, poor reservoir property, and poor drilling effect, which was in a difficult period. Therefore, on the basis of further implementation of the trap, the calculation of trap resources and the evaluation of trap geological risk would help to make decision on the next exploration trend of the block.

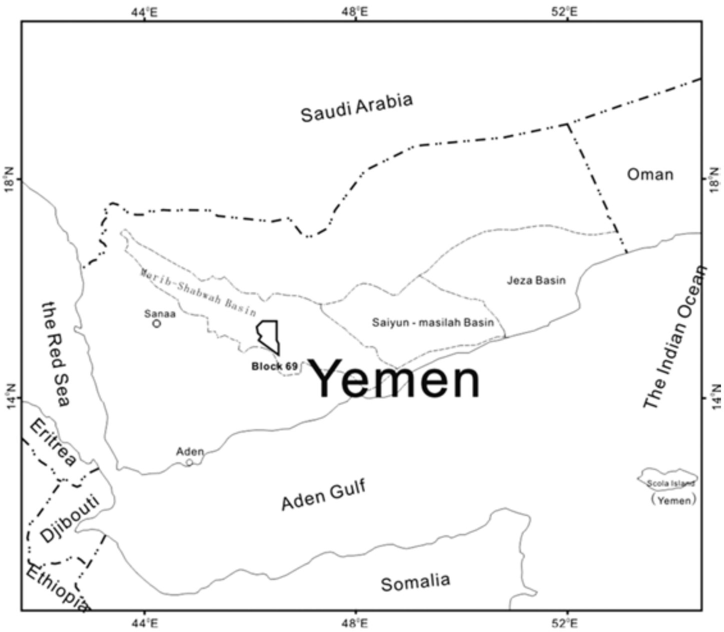

Figure 1
Location Map of Marib-Shabwah Basin and the Block 69 in Yemen

1. PETROLEUM GEOLOGY CHARACTERISTICS

Yemen is located in the southwest corner of the Arabian plate, located in the high position of the Arab shield, since the late Precambrian gondwana plate formed to Mesozoic Jurassic period, accepted only sporadic palaeozoic era continental strata. During the late Jurassic period, affected by the split of the Indian Ocean, the three rift basins were developed along the ancient NW-SE to the Najd fault system in the territory of Yemen, namely the marib-chabbasa basin, the sany- masila basin and the jeza basin.

The Marib- Chabbasa basin was surrounded by faults around the ground, and the evolution of the basin had undergone three stages, pre rift stage, rift stage and late rift stage. The first stage was in the early stage of the rift valley: on the Paleozoic metamorphic rock and granite basement,there were the Middle Jurassic Kurland group's transgressive clastic sedimentary rocks and Xiukula group's carbonate deposition sedimentated. The second stage was the rift stage: starting from the late Jurassic, the rifting begined under the tensile stress near SN direction, fracture developed, to the end of the Jurassic, sedimentated Mimu group marine shale, Lam group clastic rock intercalated with limestone and Sabat Don group thick bedded salt rock intercalated clastic rock. The third stage was late rift stage: from early cretaceous to the early tertiary period, some faults were further activated, and the lower cretaceous was dominated by Marine limestone and clastic rocks. The upper cretaceous was mainly dominated by continental clastic rocks. The plastic flow of the first period of salt rock occurred at the same time. Since the late tertiary period, the Arabian plate had gradually separated from the African plate, formed the narrow ocean of the gulf of Aden, the new ocean of the red sea, the gulf of suez and the rift valley of East Africa. As the Arabian plate continued to collide with the Eurasian plate, on the basis of the plastic flow of the first stage of salt rock, the plastic flow of second periods of salt rock occurred, and the salt diapir structure developed strongly, resulting in the phenomenon of salt rock penetrating to the earth surface in some areas.

There were abundant types of structure in the block 69, such as salt arch, salt diapir structure, salt block, fault block and fault nose. But there were differences in the structure of salt and salt. The subsalt tectonics was divided into the northern depression zone, the central slope belt and the southern tectonic belt.

1.1 Hydrocarbon Source Rocks

The block 69 was located in the depression of the Marib-Shabwah basin, and the source rock was developed. The drilling in the block revealed Madbi under sait, the Sabatayn in salt, Nayfa on salt, Saar several sets of source rock strata, and the source rock lithology of the hydrocarbon was mainly mudstone, shale, clay limestone, etc.

Among them, Madbi formation was the main source rock block. According to the analysis data of the source rocks of the two Wells (Mashaf-1, Abelat-1) in the block, the source rock thickness of the hydrocarbon source rocks in the block 69 was 1200-1500m, and the TOC value was 0.3-6.8%, with an average of 2.61%, which was of medium-good grade. S1+S2 was 0.65-33.06 mg/g, averaging 22.87 mg/g. Kerogen type was II - III model. The average HI value was 245.1, the Tmax range was 431-475 ℃, and the average temperature was 447℃. The formation depth of the formation was 1850m ~ 4090m, which was below the threshold of oil production (1730m), indicating that the source rock was in the mature high mature stage.

1.2 Reservoir Rock

According to the drilling and adjacent area data in the block, the block 69 might mainly develop five sets of reservoir, which could be divided into:

(a) Basement crack+kuran river facies sandstone (Basement+Kohlan) reservoir

At present, the drilling depth of this reservoir was not enough, and there was no well to reveal.

Basement: mainly refers to the metamorphic rocks (gneisses, schist), granite, diabase, lamprophyre, etc., while the matrix porosity was very low, permeability was very poor, but due to stress concentration zones for the development of cracks or fault fracture zone, permeability could greatly improve its performance, and better reservoir formation. At present, in the block S2 of Marib-Chabbasa basin, the basement was mainly production layer. In addition, a weathering crust was often formed at the top of the basement, which was also a good reservoir. Kurlan: the main reservoir was sandstone group. Thickness change might be sporadic distribution.

There was generally no effective non-permeable layer between the basement and the kuran sandstone reservoirs, so they were often considered as a set of reservoirs.

(b) Pore-fractured carbonate reservoir of Shuqra group

It was a shallow sea facies fractured- pore type carbonate reservoir, and the part of it was locally developed with granular limestone. According to the analysis of drilling data in S1 and S2, the thickness of the mainland of block 69 was 200-500m. The Nisr-1 well of S2 was produced in the Shuqra limestone reservoir with low yield. Block 4 and block 1 also found oil flow in the Shuqra reservoir.

(c) The mixed accumulation reservoir of the slope of Lam group under salt

In block 69, the Lam formation was dark mudstone and argillaceous (or sandy), argillaceous limestone intercalated with sandstone, in which the sandstone was an effective reservoir. The An Nagyah oilfield in the S1 of southwest block 69 drilling core, confirmed that its lime formation was the alluvial fan and fan delta deposit near the Piedmont (covering the fault block on the base), and the provenance was the basin margin uplift in the southwest of the block. Comprehensive analysis, Lam group of block 69's detrital origin group might mainly come from the southwest, mainly developed mixed continental shelf facies, but in the southern local tectonic belt might develop distal turbidite fan sandstone, fromed sandstone siltstone reservoir, but generally speaking, the sand layer was thin and the physical property was poor.

(d) Deltaic sandstone reservoir of Sabatayn group in the salt

Delta sandstone in the salt of Sabatayn group could be divided into upper and lower two segments, the upper sait clastic rock segment (UISC) and lower salt clastic rock segment (LISC), the provenance came from the northwest direction of the work area. The northwest of the block 69 was in the transition zone of delta and front and front delta, in the southeast, it becomes a former delta facies. Lithology was delta front end facies, thin interbed of sand and mudstone and gypsum dolomite or cloud gypsum rock, the sandstone was extremely undeveloped. On the whole, the lithology was fine and the content of cement (salt rock) was high, which led to the poor physical property of reservoir. For example, in Mashaf-2 well, clear sandstone's thickness was 60 meters, which was in the sandstone section in salt. While the salt cementation sandstone reached 42 meters, the effective reservoir thickness only had 18 meters, the sandstone section under salt's clear sandstone thickness was20 meters, however the salt cementation sandstone reached 15 meters, the effective reservoir thicknesswas 5 meters.

(e) The pore-fissure carbonate reservoir of Nayfa group on salt

It was the hole - shallow shelf environment of fractured carbonate reservoir, the porosity was 6-15%. The reservoir was mainly high energy shallow water granular limestone, usually distributed along the margin of the basin and in the basin, and the quality of the reservoir depended on the degree of fracture development. At present, it is difficult to predict reservoir distribution and physical property. This reservoir was located in the Sabat Don salt layer, which was not conducive to connect with Madebi source rocks, the conditions of hydrocarbon accumulation were poor.

1.3 Capping Layer

Sabatayn salt layer could be used as high quality cover of Madebi petroleum system. There were other could be used as cover: mudstone of Lam formation, tight carbonate rocks and the thick mudstone at the bottom of Mimu group, tight carbonate carbonate rock of Shuqra group.

Most of the oil and gas migration and accumulation was carried out under salt rock. Oil and gas charging began late in the early Cretaceous and ended at the end of the early third century. The old faults in Jurassic rift period, faults and permeable layers of the Tertiary system provided the channel for vertical and lateral migration of oil and gas, and oil and gas were mainly accumulated in salt and salt trap.

According to the comprehensive evaluation, the currently more promising exploration strata of the block 69 were the Shuqra group, the base + Kohlan group and the Lam group. Mainly located in the southern tectonic zone of the block. In the northwest, there was also the potential for small-scale reservoir exploration in the Sabatayn group.

2. CALCULATION OF TRAP RESOURCES AND GEOLOGICAL RISK EVALUATION

2.1 Trap Identification and Implementation

Comprehensive study showed that the Amal-Alm-Magraf structure in the eastern block 4 and south tectonic belt of block belonged to the same tectonic belt, was an inherited uplift of the fault block tectonic belt. The northern part was the middle slope belt and the northern sag belt, and the south as the Atak sag. It was the favorable direction of oil and gas migration and accumulation, and the favorable conditions for oil and gas accumulation.Using PSDM (prestack depth migration) data for fine seismic data interpretation of the southern block, made three layer structure map which were the top of Lam, the top of Shuqra and the top of Basement. A number of traps had been found. Among them, there were 3 traps with high level of implementation and (Prospect), respectively, Prospect-1, Prospect-2 and Prospect-3 (Figure 2).

Figure 2
Basement Trap Distribution Map of the Block 69

Among them, the Prospect-1 trap consisted of two plates, the ascending disk and the falling disk, which was a trap for nose breaking, having anticlinal features in the Northwest. Prospect-3 trap was a faulted anticline traps, 4 blocks were shown on the Basement top tectonic map. Prospect-2 trap was a fault nose trap.

2.2 Calculation of Trap Resources

The calculation of the amount or reserves of a basin or a block was of great significance for the planning and management of exploration and development, as well as the improvement of the ultimate economic efficiency. In the past, we used the concept of resources and geological reserves to describe the amount of oil underground in a basin or block. But in fact, the physical, economic, and political factors such as reservoir physical properties, ultimate recovery, sales prospects and required mining conditions were often not given due consideration. Therefore, although huge amount of resources could be put forward, it had not been effectively rewarded after a great deal of exploration effort, resulting in the failure of oil and gas exploration projects. At present, we has adopted the current international reserves and resources evaluation methods, whether the reserves have been found or the amount of resources to be found, we both should be based on economic recoverable reserves. Moreover, in line with the international classification requirements of calculation and estimation, the amount of resources should reflect the investment choice of exploration targets. In this way, although it will be much smaller in number, but it has higher credibility, and will be more conducive to effective exploration and development of various levels of planning and implementation.

According to the international resources or reserves calculation standard, the three traps in the south of the block 69 should calculate the prospective resources.

The volume of traps was calculated according to volume method. Formulas and related parameters were as follows:

$$G\ oil=6.11\times Area\times H\times Phi\times So/Bo\times R,\ mmbl \quad (1)$$

$$G\ assoc\ gas= G\ oil\times GOR\times 5.7795715/1000,\ bcf \quad (2)$$

Among them, G oil, mmbl, oil recoverable resources, millions of barrels

G assoc gas, bcf, recoverable gas resources, one billion cubic feet

Area, trap area

H, the thickness of oil reservoir depends on the combination of drilling and adjacent area

Phi, porosity

So, oil saturation

Bo, volume factor

GOR, gas oil ratio

R, recovery ratio

The probability method was used to calculate the potential resource of the trap. Each calculation parameter was given an underestimate value (Min), an intermediate value (Mod) and an overvalued value (Max). The resulting amount of resources was also divided into undervalued, intermediate and overvalued values, in which intermediate values were considered to represent the amount of resources of the trap.

We carried out the resource calculation of three exploration strata (Lam, Shuqra, Basement).

The main parameters: The trap area was determined by the structural map of each exploration target. Oil saturation: Base valued 83%, Shuqra valued 62.8%/64.9%/69.2%, Lam group valued 55%/60%/65%. Volume coefficient: based on adjacent oil fields, Shuqra and Basement valued 1.377 and Lam valued 1.09. As for gas oil ratio, taking into account 1 and 2 traps near Amal oil field of block 4, and the content of dissolved gas in this oilfield was very high, the comprehensive value was 380. Trap 3 valued 250. Recovery rate: three layers were same, valued 20%/30%/40%.

The calculated results of recoverable resources of petroleum and dissolved gas are shown in table 2.

2.3 Evaluation of Trap Geological Risk

For each layer trap, we carried out geological risk evaluation. Risk evaluation mainly considered five factors. The specific evaluation indicators were as follows:

Source: source rock distribution, type, evolution degree, oil and gas injection, peripheral display

Reservoir: distribution, type, quality, tectonic activity, buried depth

Timing: generation, migration, aggregation matching

Trap: size, type, integrity, seismic control network density, seismic data quality, sealing of faults

Seal: distribution, quality (including regional and local cap), and later preservation conditions.

Each index of each trap was scored according to the above criteria, and its likelihood value (Possibility, referred to as POS) was obtained. The value was 1. Such as POSsource indicated oil source possibility value, and POSreservoir indicated reservoir possibility value and so on.

The geological success ratio of each layer trap (Geologic Chance of Success, abbreviated as GCOS) is:

$$GCOS=POSsource \times POSreservoir \times POStrap \times POSseal \times POStiming$$

A trap might contain 1 or more layers of traps. The success rate of a trap could be defined as the success of the trap as long as one of the layers is successfully drilled. Assuming that the success rate of each layer trap was defined as GCOS1, GCOS2, GCOS3 and so on, the total success rate of a trap is GCOStotal. Then,

$$GCOStoatal=1-(1-GCOS1)(1-GCOS2)(1-GCOS3)$$

Often, a trap often contained two or more fault blocks, which were generally separated by faults, but they belonged to the same local structure and had the same tectonic setting and hydrocarbon filling conditions. Therefore, it was appropriate to evaluate the geological risk of these blocks as a whole. For example, Prospect-3 traps contained 4 fault blocks, although they might be individually formed reservoirs, but in risk assessment, taked them as a whole. The same was true for Prospect-1 traps.

Geological risk assessment results of the major traps in the south of block 69 were shown in table 1. Among them, the success rate of geological discovery with Prospect-1 trap was the highest.

Table 1
Geological Risk Assessment Results of Traps in the South of Block 69

Trap name	Stratum	Source	Timing	Reservoir	Trap	Seal	Success rate,%
Prospect 3	Lam	100%	100%	70%	40%	80%	22%
	Shuqra	60%	100%	60%	20%	70%	5%
	Basement	40%	100%	50%	20%	60%	2.5%
Prospect 2	Shuqra	100%	100%	40%	70%	90%	25%
	Basement	50%	100%	30%	60%	80%	7%
Prospect 1	Shuqra	100%	100%	50%	80%	90%	32%
	Basement	50%	100%	40%	60%	80%	10%

CONCLUSION

The calculation results of the amount of resources (Table 1) showed that the Prospect-1 traps had the largest trap resources in the three traps, and their recoverable petroleum resources and dissolved gas resources were 51.64mmbbl and 113.41bcf respectively. The trap geological risk evaluation indicates that the Prospect-1 trap had high geological exploration success rate. Therefore, the favorable target for drilling in the lower part of the 69 block was the Prospect-1 trap.

Table 2
The Calculation Table of the Lam/ Shuqra / Basement Group Trap Resource in Block 69, Yemen

Trap name		Stratum	The trap resource calculation																					
			Area, km2			H(m)			Phi, %			So %			Bo			GOR, m^3/m^3	Recoverable oil resources. mmbbl			Dissolved gas resources. bcf		
			Min	Mod	Max	Min	Mod	Max	Min	Mod	Max	Min	Mod	Max	Min	Mod	Max		Min	Mod	Max	Min	Mod	Max
Prospect1	1-1	Basement	14.8	28.0	50.0	8.0	15.0	22.0	1.4	3.6	6.0	83.0	83.0	83.0	1.257	1.377	1.440	380	1.17	16.71	106.51	2.56	36.70	233.92
	1-2		1.4	5.0	11.2	8.0	15.0	22.0	1.4	3.6	6.0	83.0	83.0	83.0	1.257	1.377	1.440	380	0.11	2.98	23.86	0.25	6.55	52.40
	1-1	Shuqra	9.6	20.0	38.2	10.0	15.0	20.0	6.9	7.6	8.8	62.8	64.9	69.2	1.257	1.377	1.440	380	3.50	19.66	90.46	7.70	43.17	198.67
	1-2		2.8	12.5	17.0	10.0	15.0	20.0	6.9	7.6	8.8	62.8	64.9	69.2	1.257	1.377	1.440	380	1.02	12.29	40.26	2.24	26.98	88.41
	Subtotal																		5.81	51.64	261.08	12.75	113.41	573.40
Prospect 2		Basement	1.9	6.4	13.0	8.0	15.0	22.0	1.4	3.6	6.0	83.0	83.0	83.0	1.257	1.377	1.440	380	0.15	3.82	27.69	0.33	8.39	60.82
		Shuqra	6.5	9.7	15.1	10.0	15.0	20.0	6.9	7.6	8.8	62.8	64.9	69.2	1.257	1.377	1.440	380	2.37	9.53	35.76	5.21	20.94	78.53
	Subtotal																		2.52	13.35	63.45	5.54	29.33	139.35
Prospect 3	No.1	Basement	0.7	2.4	9.3	8.0	15.0	22.0	1.4	3.6	6.0	83.0	83.0	83.0	1.257	1.257	1.257	250	0.06	1.57	19.81	0.09	2.27	28.62
	No.2		0.5	2.7	4.7	8.0	15.0	22.0	1.4	3.6	6.0	83.0	83.0	83.0	1.257	1.257	1.257	250	0.05	1.76	10.01	0.07	2.55	14.47
	No.3		1.0	1.6	2.0	8.0	15.0	22.0	1.4	3.6	6.0	83.0	83.0	83.0	1.257	1.257	1.257	250	0.09	1.05	4.26	0.12	1.51	6.16
	No.4		0.5	1.7	6.0	8.0	15.0	22.0	1.4	3.6	6.0	83.0	83.0	83.0	1.257	1.257	1.257	250	0.05	1.11	12.78	0.07	1.61	18.47
	No.1	Shuqra	0.4	1.5	2.8	10.0	15.0	20.0	6.9	7.6	8.8	62.8	64.9	69.2	1.257	1.257	1.257	250	0.17	1.61	6.63	0.24	2.33	9.58
	No.2		0.5	0.9	2.0	10.0	15.0	20.0	6.9	7.6	8.8	62.8	64.9	69.2	1.257	1.257	1.257	250	0.23	0.99	4.74	0.33	1.43	6.84
	No.3		1.1	1.8	2.3	10.0	15.0	20.0	6.9	7.6	8.8	62.8	64.9	69.2	1.257	1.257	1.257	250	0.46	1.94	5.45	0.66	2.80	7.87
	No.4		0.5	1.9	7.5	10.0	15.0	20.0	6.9	7.6	8.8	62.8	64.9	69.2	1.257	1.257	1.257	250	0.19	2.05	17.76	0.27	2.96	25.66
	No.1	Lam	1.0	1.7	2.7	5.0	16.0	27.0	7.0	12.0	17.0	55.0	60.0	65.0	1.090	1.090	1.090		0.22	3.29	18.06			
	No.2		0.9	0.9	1.2	5.0	16.0	27.0	7.0	12.0	17.0	55.0	60.0	65.0	1.090	1.090	1.090		0.19	1.74	8.03			
	No.3		2.0	3.7	5.1	5.0	16.0	27.0	7.0	12.0	17.0	55.0	60.0	65.0	1.090	1.090	1.090		0.43	7.17	34.12			
	Subtotal																		2.12	24.28	141.64	1.85	17.45	117.67
	total																		10.45	89.27	466.18	20.14	160.19	830.42

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