Chapter 50
Reserves Evaluation Based on Reservoir Geological Knowledge Database

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50.1 Introduction

Oil and gas reserves are not only the substance basis for the exploitation of oil and gas fields, but also the reference to guiding exploitation and investment scale [1]. Reserves calculation and evaluation are a long-term task through the whole process of oil and gas exploration and exploitation [2]. Recalculation and further evaluation of reserves are important with the increase of data and our knowledge to the oil and gas reservoir. There are a few reserves calculation methods, including volumetric method, dynamics method, analogy method, stochastic method, and so on [3–7]. Volumetric method is the most popular method and is applicable to every exploration and exploitation phases, and also applicable to oil and gas reserves with different trap types, reservoir types, or

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different driving mechanisms. The reliability of the calculation result depends on the quality and quantity of data and the way to acquire or calculate the parameters [8–10]. Gas-bearing area and effective thickness are the two main geological factors which affect the result of reserves calculation [11].

For the tight inhomogeneous sandstone gas reservoir, the key point of reserves recalculation is to reconfirm the calculation parameters on the basis of our understanding of reservoir spatial distribution. During the exploration stage in Sulige gas field, the data of drilling, wire logging, cores, and pressure testing are limited. Besides, reservoirs here have the characteristics of strong inhomogeneity, small-scale effective sand body, abundant multilayer vertically, frequent conversions between vertical and horizontal layers. So, it is difficult to accurately calibrate the horizontal variation of effective sand bodies in each layer due to the lower resolution of seismic data. In addition, when submitting proven reserves during the exploration phase, He8 member reservoir was equated with a calculation unit vertically in order to describe gas boundary and calculate proven reserves with volumetric method, which decrease impact of reservoir inhomogeneity on the reserves. Therefore, in the stable production stage, we choose the block with high well-spacing density, better well control, abundant sample data, and better understanding as the research object in this paper. We established the database of geological knowledge about reservoir by dissecting reservoir configuration at high well-spacing density area. Guided by this database, the description and prediction of inter-well reservoir will be more accurate. Reserves calculating parameters and evaluation criteria are confirmed on the basis of reservoir-detailed description and inter-well prediction; thus, reserves recalculation and evaluation are conducted. Results of reserves recalculation and evaluation are of great importance to confirming reserves scale, adjusting and optimizing well deployment, and improving quality of gas field exploitation.

50.2 Overview

Su15 block is located in the middle of Sulige gas field and also is structurally located in the middle of Yi-Shan slope of Ordos Basin (Fig. 50.1). Main gas layers are accumulated at He8 member in Paleozoic Shihezi group and S1 member in Paleozoic Shanxi group with 3200–3400 m deep, and upper He8 sub-member and S1 member belong to meandering fluvial sedimentary facies, while lower He8 sub-member belongs to braided fluvial facies. Point bar and channel bar sediments are the main reservoir. Structure is gentle in this area. A series of NE-SW direction nose-shaped uplifts, which are low and mild, growth partly on the background of the incline, inclining to the west. Meanwhile, nose uplifts and depressions exist occasionally. This gas field is a driving mechanism gas reservoir with the characteristics of universal gas bearing, and no obvious bottom boundary water, and its reservoir distribution is controlled by extension and physical property of sand body [12–14].

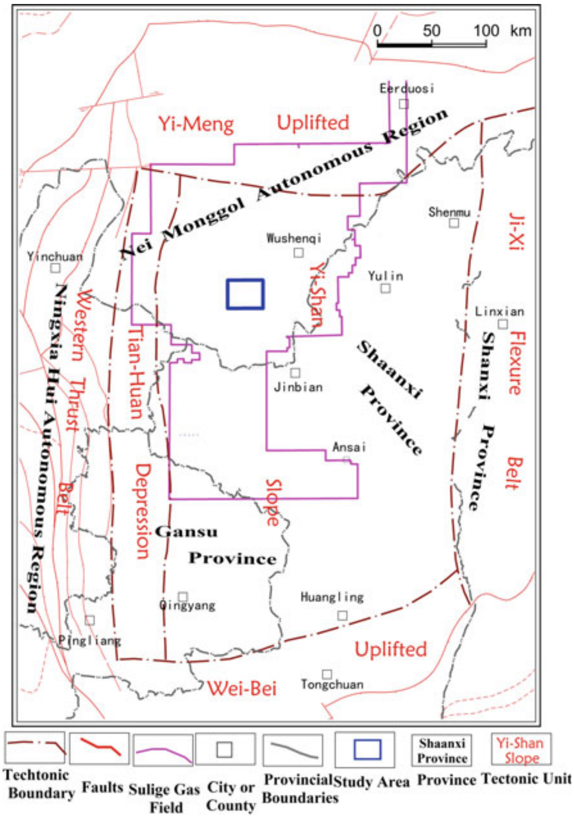

Fig. 50.1. Location of study area

In order to enhance gas recovery by optimizing well network and type, we have established dense well network area, integrated horizontal exploiting area, and three-dimensional seismic experimental area according to main reservoirs distribution characteristics. Basic well networks distance is 600–800 m × 800–1200 m. The infilling well block has the biggest well spacing density, the gas-bearing area is 6.35 km^2, the well patterns and spacing is 350–500 m × 400–650 m, and the well spacing density is 2.8 wells per square kilometer. Abundant drilling, wireline logging, well testing, and dynamic production data are the basis of reservoir fine description and reserves recalculation.

50.3 Reserve Recalculation

50.3.1 Idea and Method of Reserve Recalculation

Both quantities of samples and gas reservoir type satisfy the requirements of calculating reserves with volumetric method in the study area. For the convenience of comparing with proven reserves, we adopted volumetric method to evaluate reserves. The cut-off value of physical property for available reservoir is equivalent to the cut-off value used on submitted proven reserves. The lower limit of porosity and permeability is 5% and 0.1×10^{-3} μm^2, respectively [15]. The volumetric method calculating formula as follows:

$$G = 0.01 \cdot A \cdot h \cdot \phi \cdot S_{gi} \cdot \frac{P_i \cdot T_{sc}}{P_{sc} \cdot T \cdot Z_i} \tag{50.1}$$

Symbols in formula

G	Original gas geologic reserves, 10^8 m^3.
A	Gas-bearing area, km^2.
h	Average effective thickness, m.
Φ	Average effective porosity, decimals.
S_{gi}	Average original gas saturation, decimals.
T_i	Average formation temperature, K.
T_{sc}	Standard temperature at the ground level, K.
P_i	Average original formation pressure, MPa.
P_{sc}	Ground standard pressure, MPa.
Z_i	Original gas deviation coefficient.

Concrete process of reserves recalculation and evaluation is as follows.

(1) Referred to drilling and well logging date of the gas well reservoirs, sum up the characteristics of sedimentary cycle of fluvial channel sand bodies, thus divide the reserves into several calculating units vertically.
(2) Based on the well data and geological database at the infilling wells area, draw isopach maps of single fluvial channel sandy bodies and effective sand bodies, and isocline maps of gas saturation and porosity.
(3) Determining reserves recalculation parameters and recalculating reserves.
(4) The reserves are classified and evaluated according to comprehensive evaluation standard of reservoir, accumulative production per well, reserves abundance, and interior return rate (IRR).

50.3.2 Reservoir Geologic Knowledge Database

The database of geological knowledge about reservoir can summarize the geological characteristics of the reservoirs that are formed by different geological origins. In addition, the database can also guide the reservoir description in the area with less dense well network and it is also important to guide the determination of quantitative parameters in the process of establishing geological model, respectively [16]. Our predecessors established corresponding geologic knowledge databases according to observation of outcrops and modern sediments, dissection of infilling well configuration, simulation of sedimentary process, and other data [17–21]. Reservoir geologic knowledge database established according to dissection of configuration of infilling well network in the study area is more targeted and applicable. The gradation and accuracy of reservoir configuration dissection is affected by the distance of well network and production demand. Su15 infilling well network sector reservoir configurations was dissected to the level of single fluvial channel, equivalent to the fourth-level configuration boundary of Mail standard.

With the static data of coring, wireline logging curves, etc., and based on the recognition of single well configuration interface and configuration elements analysis, we conducted two-dimensional and three-dimensional inter-well reservoir correlation with the idea of sedimentary cycle correlation, thickness control, and model adaptation. Furthermore, we established the reservoir geological model. Besides, in order to make the model more similar to the objective geological body in the infilling well network area, we conducted verification and positive match of the model referred to the productive and dynamic monitoring data. By dissection of reservoir configuration, we concluded three sand body correlation models such as lateral sedimentary facies change correlation, sandbody superimposition correlation, and fluvial channel incision. In addition, we established database of geological knowledge about reservoir (Table 50.1; Figs. 50.2 and 50.3).

Table 50.1. Reservoir geological knowledge database established based on infilling well zone

Characteristic parameters		$He8_U$	$He8_D$	S1
Sand body of single fluvial channel	Sedimentary facies types	Meandering	Braided	Meandering
	Width to thickness	60:1–80:1	35:1–60:1	40:1–80:1
	Width	800–1500	100–2000	700–1200
	Thickness	2–4	3–5	3–4
Single effective sand body	Length	500–700	600–800	500–800
	Width	450–500	500–600	600–750
	Length to width	2:1–15:1	2:1–15:1	2:1–15:1
	Thickness	2–4	3–5	3–4
	Width to thickness	40:1–55:1	30:1–40:1	35:1–65:1

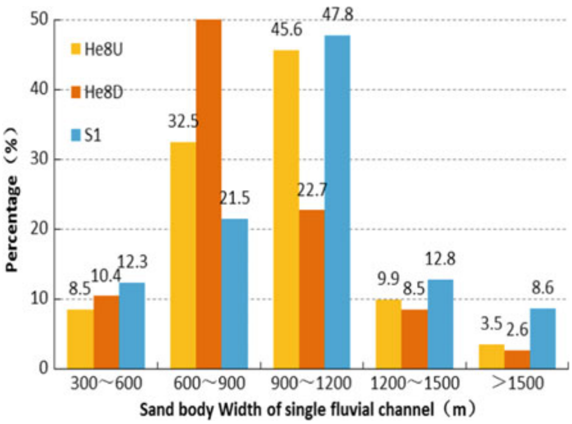

Fig. 50.2. Scale of reservoir sand body

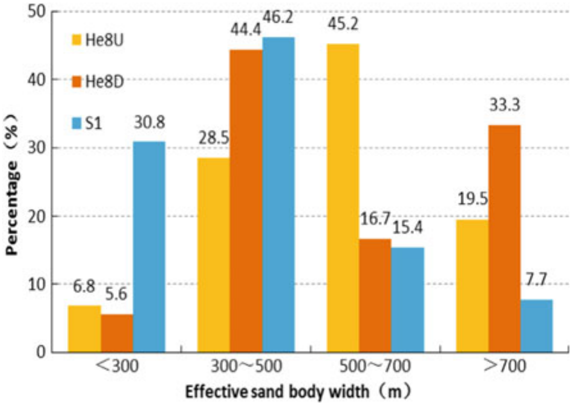

Fig. 50.3. Scale of effective sand body

50.3.3 Calculation Units Division

50.3.3.1 Vertical Calculation Units Subdivision

Vertical calculation units should be divided into different parts according to the lithology, physical property, fluids distribution characteristics, and the needs for the division of exploitation layers [22, 23]. The reserves calculation results vary from one type of reservoir to another, if the gas layers are subdivided or incorporated. For the lithological hydrocarbon reservoir, our predecessors, respectively, calculated the reserves by merging and subdividing calculation units, and the error was close to 17% [23]. The main reason is due to the detailed rules of the lithological reservoir reserves calculation in China. The rules required that “when the sandbody of adjacent well is transformed into mudstone or when the permeability gets worse to make the reservoir a nonreservoir (dry reservoir) although the sandbody still exists, draw the lithological gas-bearing boundary at the place where it is 1/2–1/3 distance from the gas well to the adjacent well and take this boundary as the zero line of effective thickness [24]. If two gas layers A and B were drilled in well W1, while only one gas layer A was drilled in well W2, the zero line of the effective thickness of gas layer B should be drawn at the point of the well W2 if the two gas layers were merged into one unit, but when A and B were considered as two separated calculation units, line should be drawn at the middle of the two wells (Fig. 50.4). The effective thickness zero lines are differently drawn by these two different methods, thus leads to the different results of gas-bearing area and reserves.

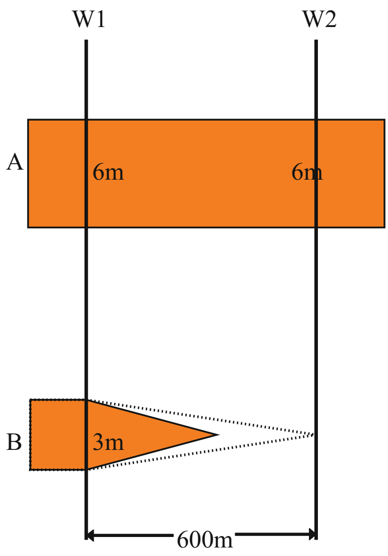

Fig. 50.4. Gas-bearing boundaries drawn with the method of merging layers and subdividing of layers

Sulige gas field is a fluvial sandstone reservoir with low permeability. Multiple superimposition channels are abundant, the reservoirs are strongly inhomogeneous and rich in multilayers [25]. It cannot show the reservoir inhomogeneity vertically when merging gas reservoirs into one unit to calculate reserves, thus weaken the influence of inhomogeneity on the accuracy of reserve volume calculation. Based on the characteristics of gas reservoirs, we divided the He8 member into ten vertical calculation units (single channel), by identifying configuration boundary of single well and correlations of wells in the infilling well network area referring to Mail's configuration boundary dividing scheme [26]. The upper and lower of He8 member are divided into four and six vertical units, respectively, and the Shan1 member is divided into six vertical units (Figs. 50.5 and 50.6).

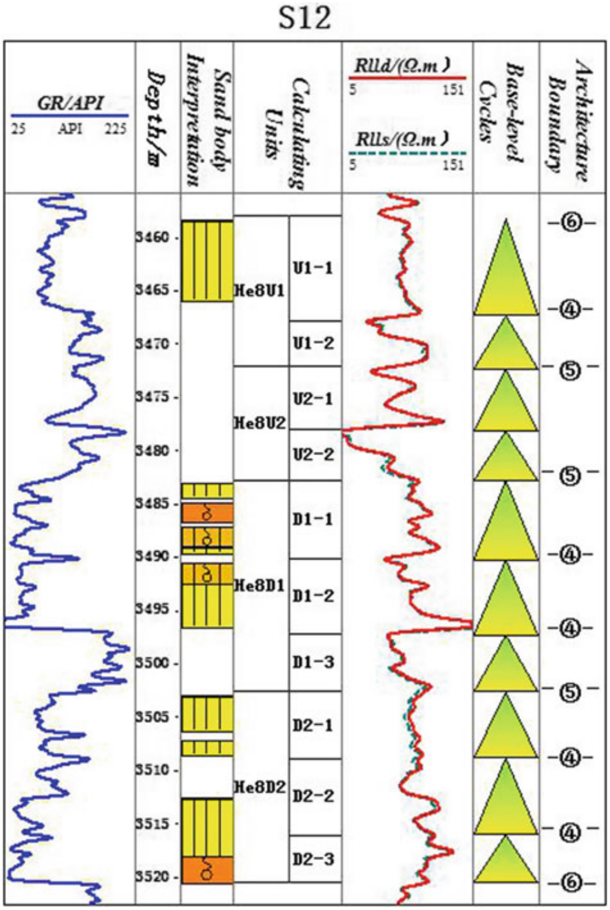

Fig. 50.5. Calculation units division of He8 member

50.3.3.2 Plane Gas-Bearing Boundary Depiction

The rules of the gas-bearing boundary depiction in the reserves calculation are only suitable for the depiction of the gas-bearing boundary between the effective reservoir and nonreservoir in the small spacing well network area. Database of geological knowledge about reservoir in this area is needed in order to predict the boundary of effective reservoir of sandbody which lies in the large wells spacing area or stretches across different fluvial channels. With the help of the database, the predicted gas boundary is more reliable. After reservoir configuration analysis in the infilling well network area, conclusions were made as follows: (1) The thickness of single fluvial channels is between 2 and 6 m; (2) the width of fluvial channel sandbody is from 600 to 1200 m; (3) the extrapolated width of single sandbody is from 100 to 500 m; (4) there is a good linear function between the width and thickness of thickness is between 2 and

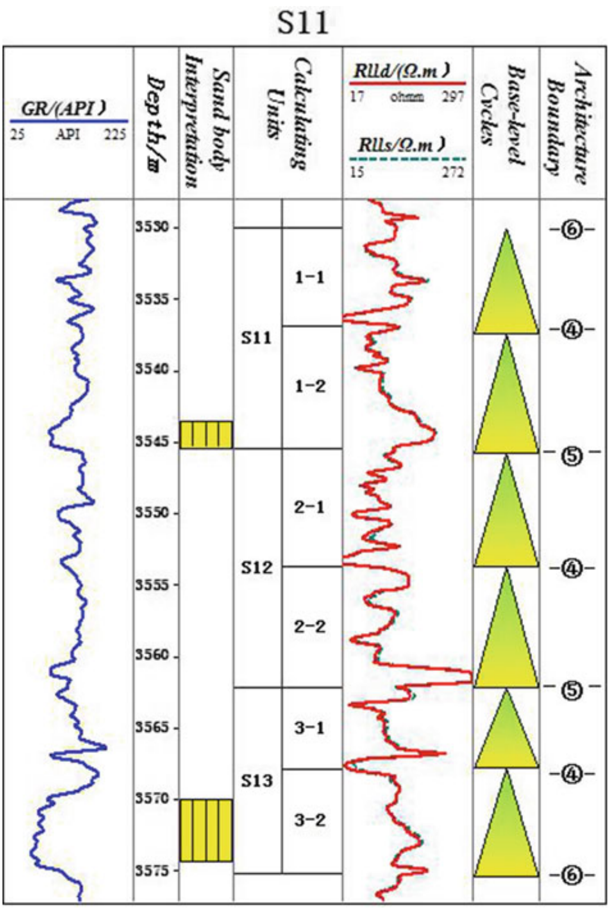

Fig. 50.6. Calculation units division of S1 member

4 m, the width is from 450 to 550 m, and the width to thickness ratio is 40–80:1. The drilling information and dynamic monitoring data of horizontal wells verified the rationality of the database of geological knowledge.

As shown in Fig. 50.7, both well S15-2 and well S15-4 drilled a gas layer in lower part of He8 member. Before well S15-3 was drilled, it was speculated that the two completed wells may drill the same gas layer A (Fig. 50.7a). But by the comparison of geological knowledge database based on the reservoir configuration analysis, we found that gas layers drilled in well S15-2 and well S15-4 belong to two different fluvial channels sandbodies deposited at the same conditions (Fig. 50.7b). The later infilling well S15-3 drilling information proves the accuracy of effective reservoir boundary constrained by geological knowledge database (Fig. 50.7c).

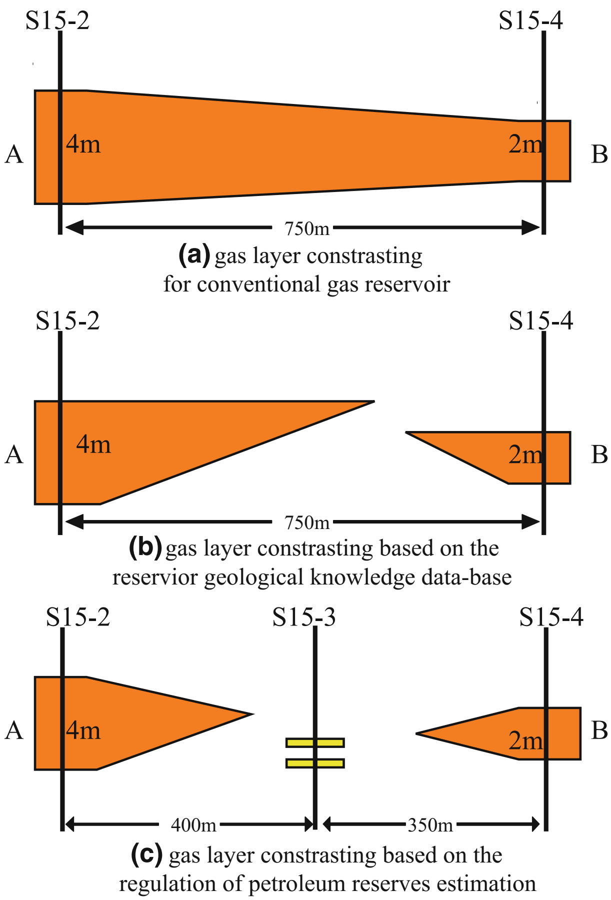

Fig. 50.7. Gas reservoir contour dividing based on different methods and rules

50.3.4 Other Parameters and Reserve Recalculating

In order to indicate the strong heterogeneity of reservoir and improve the accuracy of reserves recalculation, the effective reservoir minimum standard calculation thickness of each sublayer (vertical calculation unit) is 1 m. Every-one meter on the plane, we divided the effective reservoir gas-bearing area of each sublayer into some plane calculation units. In each plane calculation unit, we confirmed reserves calculation parameters including effective thickness (h), porosity (φ), saturation (Sg), and so on. A stands for gas-bearing area in the calculation unit, and the other parameters are average value. The effective thickness is arithmetic average value. We obtain the porosity according to the average weight of each sublayer effective thickness of each well. Gas saturation is calculated according to the weighted volume ($h.\varphi$). Other parameters like temperature and pressure are shown in Table 50.2.

Table 50.2. Temperature and pressure parameters

Parameters	He8	S1
P_i (MPa)	29.91	32.64
T_{sc} (K)	293	293
P_i (MPa)	0.1	0.1
T_i (K)	381	384
Z_i	0.966	1.054

The results show that the recalculation reserves of He8 and S1 member were 54.6×10^8 m^3 and 86.7×10^8 m^3 less than the proven reserves, respectively. The decrease of reserves is mainly caused by the decrease of gas-bearing area and reserve abundance. The gas-bearing area decrease is the main cause of geological reserves decrease, which is about 108.3×108 m^3 with 76.3% of the total reserves change. The decrease caused by reserve volume abundance is 33.0×10^8 m^3, taking 23.3%. In He8 member, decrease of geological reserves caused by gas-bearing area takes 42% of the total change, while that percentage in Shan1 member is 83.15. Decrease of reserves caused by reserve abundance in Shan1 member takes 16.9% of the total change.

50.4 Reserve Classification Evaluation

Gas field is usually exploited according to the principle "Exploiting gas field stage by stage and firstly rich gas areas then poor gas areas" [23]. For the large-scale strong inhomogeneous gas reservoir, in order to exploit the reserves to the largest extent under the present economic and technical conditions, and improve the exploitation effect, it is better to evaluate the geological reserves with the thoughts of reserves classified evaluation, then to optimize the construction of the most favorable exploitation area according to different types of reserves distribution and economic benefits. Reserves classified evaluation should incorporate all related factors. We put forward the comprehensive classified evaluation standards of inhomogeneous tight sandstone reservoir reserves in Sulige gas field, referring to the comprehensive classified evaluation standards of Sulige gas field's reservoirs, and based on the analysis and evaluation of static drilling data, static classification of reservoirs, dynamic exploitation index, and economic benefits (Table 50.3).

Table 50.3. Comprehensive classified evaluation standards for reserves in Sulige gas field

Classification	h (m)	ϕ (%)	K (mD)	Saturation (%)	Absolute open flow ($10^4 m^3/d$)	Cumulative production ($\times 10^4$ m^3)	Reserves abundance ($\times 10^8$/ k m^2)	IRR (%)
I	>8	>10	>0.7	>60	>10	>2000	>1.2	>12
II	6–8	8–10	0.5–0.7	55–60	4–10	1500–2000	0.9–1.2	8–12
III	3–6	5–8	0.1–0.5	45–55	<4	<1500	<0.9	<8

The evaluation criteria are mainly revealed by parameters such as the inner return rate, the predicted final cumulative gas production of each well and reserves abundance. The inner return rate reveals the ratio of return considering the gas production cost during the project cycle, and it is positively correlated to the final cumulative gas production of the gas well. The final cumulative gas production is controlled dynamic geological reserve volume considering conditions of abandoning a well, and it can reflect the geological reserves indirectly. Reserves abundance is the most direct and important parameter of regional geological reserves, and its value can reflect the geological condition. According to the classifying standards, in the study area, the I + II geological reserves in the abundant gas-bearing area is XX $\times$ 10^8 m^3, accounting for 64.5% of total reserve, while the geological reserve volume in poor gas-bearing area is XX $\times$ 10^8 m^3, accounting for 35.5% of the total reserves.

50.5 Conclusions

(1) For the tight sandstone gas reservoir with strong inhomogeneity, it is difficult to calibrate the gas-bearing boundary, especially for the well networks with large spacing. In this paper, the method of reserves calculation unit boundary calibration constrained by database of geological knowledge in the infilling well network areas is more feasible, and it can improve the accuracy of reserves calculation.

(2) After reserves recalculation, we found that the recalculated geological reserves of He8 member and Shan1 member in the study area are 54.6 $\times$ 10^8 m^3 and 86.7 $\times$ 108 m^3 less, respectively, than the proven reserves. The reserves gap is mainly caused by gas-bearing area and reserves abundance. The reserves in the study area are substantially reliable, and it can support a long-term stable production.

(3) Considering the comprehensive classification evaluation standards of the reservoir in Sulige gas field, we put forward a comprehensive classified evaluation standard of reserves combining with the inner return ratio, cumulative gas production, and reserves abundance. This standard is helpful to verify the abundant reserves area, thus guide the optimizing of well location during productivity construction period.

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