

Exploration and Practice of Improving Formation Pressure Prediction Accuracy

--Taking Dagang Complex Fault Block Oilfield as an Example

Fenyi Nie¹, Bo Luo¹, Wenhua Ma¹, Zhipan Zhang¹, Zilong Hu², Gang Wang²

¹Exploration and Development Research Institute of Dagang Oilfield Company, Tianjin, China;

²The fourth oil production plant of Dagang Oilfield (Tanhai development company), Tianjin, China.

Abstract

Formation pressure prediction is an important work in petroleum exploration and development. Accurate pressure prediction is an important guarantee for high-yielding and oil and gas sources. Formation pressure includes formation pore pressure, fracture pressure and collapse pressure. In order to ensure the safety of drilling and effectively release the potential of oil and gas reservoir, this paper combined with pre-drilling pressure prediction, drilling pressure monitoring and post-drilling pressure estimation, this paper explores how to improve the prediction accuracy of formation three pressure, and has achieved a series of innovative results. (1) A four step method of formation pore pressure prediction based on "regional law logging prediction actual measurement calibration comprehensive verification" is proposed to control the prediction error of formation pore pressure within 10%; (2) By combining the predicted and measured data, the critical value of formation fracture pressure in Dagang Oilfield is obtained, and the linear law of formation fracture pressure coefficient and vertical depth is determined (3) Based on the collapse theory research, borehole quality evaluation and formation three pressure relationship model, the rapid and accurate prediction of formation collapse pressure is realized. Finally, a set of formation pressure prediction and Optimization Countermeasures with reliable technology and strong operability are formed. In Dagang Oilfield, the incidence of drilling complications caused by formation pressure is zero in 2020.

Keywords

Formation Pressure; Drilling Well Control; Reservoir Protection.

1. Introduction

Formation pressure includes pore pressure, fracture pressure and collapse pressure. For the prediction of formation pore pressure, there are seismic interval velocity method, DC index method, measured pressure method, material balance method, log curve method [1][2][3], etc. However, the application of these methods alone has certain limitations [4]. The prediction of formation collapse pressure is mainly realized by the Mohr Coulomb criterion [5] [6] [7] [8]. This formula has its application conditions, and the rock mechanics parameters of different blocks vary greatly. In the process of drilling and production, the available data are limited, so it is difficult to realize the prediction of formation collapse pressure. There are two main ways to obtain formation fracture pressure: indoor rock mechanics experiment and logging curve data extraction [6]. However, the number of wells tested is limited, and the fracture pressures of different sand bodies are different; The prediction accuracy of logging curve method is relatively high, but it requires high logging data and is difficult to be widely used. In view of the

double goals of "well control safety" and "reservoir protection", it is urgent to accurately and quickly predict the formation three pressures and efficiently guide the drilling of new wells in Dagang Oilfield. This paper studies the prediction methods of formation pore pressure, formation collapse pressure and formation fracture pressure respectively, further improves the prediction accuracy of the three pressures, and forms the pressure prediction and optimization countermeasures. These technologies are applied to the new well drilling in Dagang Oilfield, and the effect is remarkable.

2. Study on improving the accuracy of formation pressure prediction

Formation pressure is the key of drilling geological design, including pore pressure, fracture pressure and collapse pressure. The formation pressure coefficient is the ratio of the formation pressure and the water column pressure at a certain point, dimensionless and equal to the equivalent drilling fluid density at that point. Both formation pressure and formation pressure coefficient can be used to express formation pressure. However, if the predicted value of formation pressure is too high, the oil and gas reservoir will be crushed and the formation will fracture. If the predicted value is too low, the risk of lost circulation, overflow and even blowout may occur. Both of these situations will damage the oil and gas reservoir, reduce the oil and gas development benefit and increase the oil and gas production cost [9]. Therefore, the accurate prediction of formation pressure and the research on improving the prediction accuracy of formation pressure are of great significance for improving the quality of drilling geological design and efficiently guiding the drilling of new wells.

2.1. Formation pore pressure

At present, the prediction methods of formation pore pressure mainly include seismic interval velocity method, DC index method, measured pressure method, material balance method, log curve method, etc [1][2][3], but the application of these methods alone has certain limitations [4]. Seismic interval velocity method can only macroscopically judge the vertical pressure distribution and whether there is abnormal pressure layer, and the seismic data are obtained in the early stage of exploration, so the timeliness is limited; DC index method is only suitable for shale formation; Logging curve method is greatly influenced by logging curve acquisition and drilling fluid configuration of adjacent wells; The measured pressure method is limited by the pressure measurement location and test conditions of adjacent wells; The material balance method can only qualitatively analyze the pressure change and is limited by the reservoir sealing.

Through the research, a four step method of pore pressure prediction based on "regional law logging prediction actual measurement calibration comprehensive verification" is formed. A variety of pressure prediction methods are used to complement and verify each other, and the prediction accuracy of formation pore pressure is improved.

The specific method steps are as follows (as shown in Figure 1)

1. Using seismic velocity data of the block, the distribution law of pore pressure and abnormal pressure distribution area are determined;
2. Select the nearest adjacent well which is in the same reservoir as the target layer of the designed well, and calculate the pressure value of the whole well section by using logging acoustic wave and density curves;
3. The pressure test data of adjacent wells are screened out;
4. Other auxiliary data are used to check the measured pressure data, including Dynamic Analysis of Material Balance method, drilling fluid density of adjacent wells and complex conditions during drilling, and finally determine the pore pressure value of the whole well section.

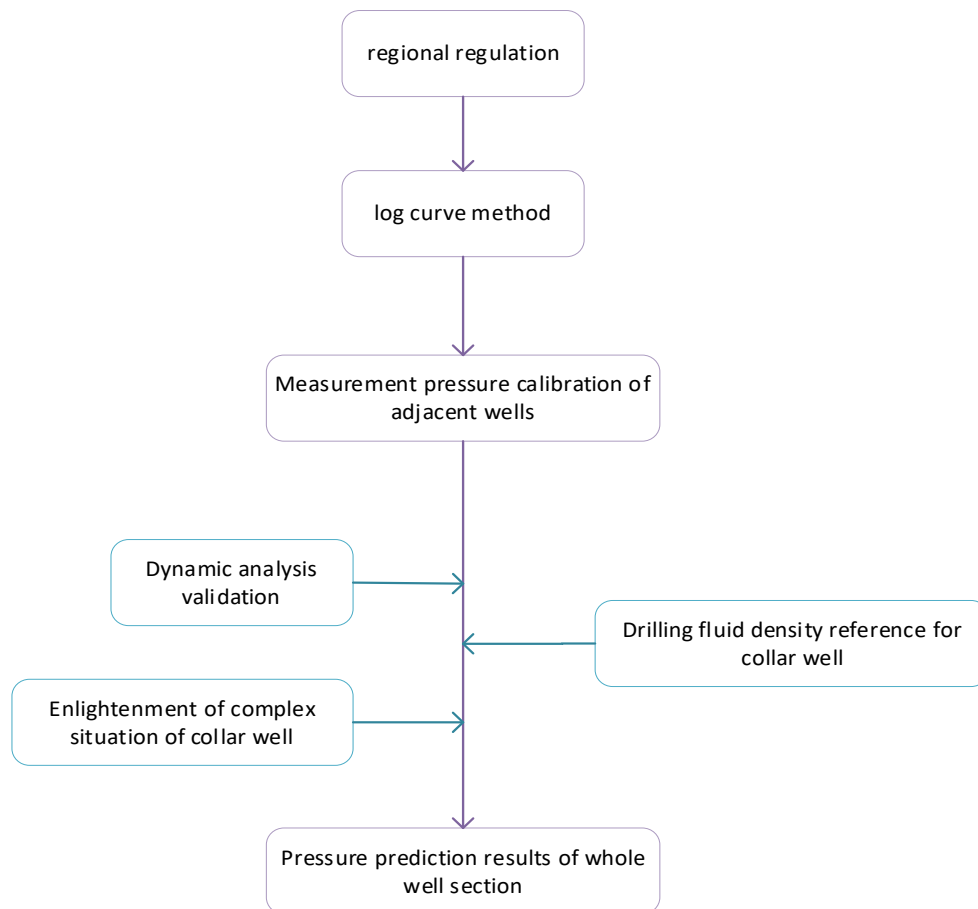


Figure 1. Formation pore pressure prediction process

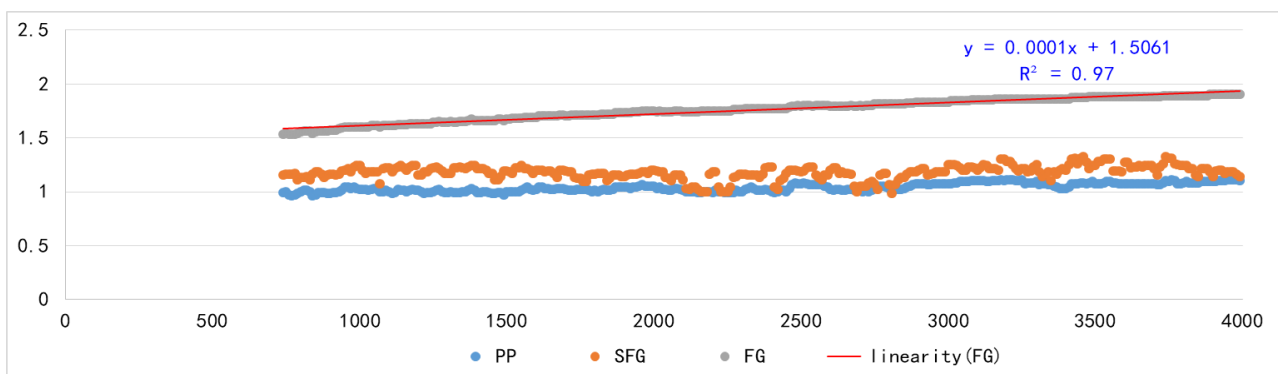


Figure 2. Linear relationship between fracture pressure coefficient and vertical depth of XX well

2.2. Formation fracture pressure

At present, there are two main ways to obtain formation fracture pressure: indoor rock mechanics experiment and logging curve data extraction [6]. The fracture pressure obtained by experiment has high accuracy, but it is the fracture pressure of the first sand body below the casing shoe, which has individuality, high cost and few wells have done experiments. Logging curve prediction method requires high logging curve data, which is mainly used in exploration wells at present.

Based on the analysis of the formation three pressure coefficients predicted by exploration and evaluation wells in the central and northern part of Dagang Oilfield in recent five years, a similar law is obtained: the fracture pressure coefficient has a linear relationship with the vertical

depth, and the fracture pressure coefficient increases by 0.1 for every 1000 meters of vertical depth, and the confidence is close to 1 (Fig. 2).

Based on the analysis of the measured ground breaking test data of 1200 wells in Dagang Oilfield, it is concluded that the formation fracture pressure value has a certain correlation with the vertical depth. The formation fracture pressure value is between the values corresponding to the linear $y = 0.0014x$ and the linear $y = 0.0021x$, that is, the critical values of the formation fracture pressure coefficient in Dagang Oilfield are 1.4 and 2.1 (Fig. 3).

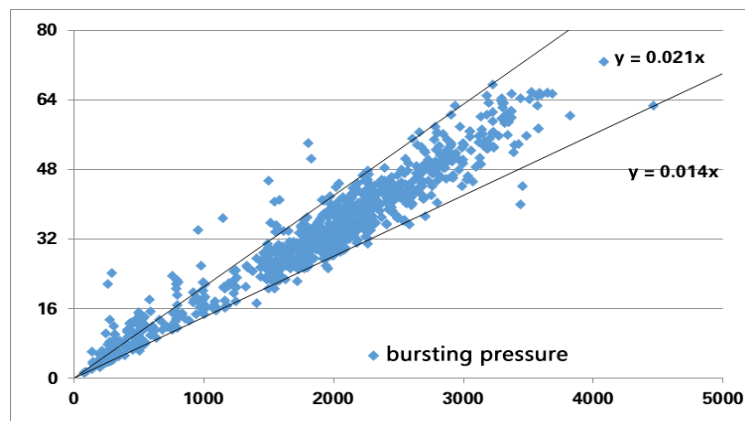


Figure 3. Distribution of measured rupture pressure versus vertical depth

Through fast qualitative analysis of formation fracture pressure with big data, the distribution law of formation fracture pressure in Dagang Oilfield is determined, and a new method for prediction of formation fracture pressure is proposed, which greatly improves the prediction accuracy of fracture pressure in development wells. At the same time, this method has certain reference value for the study of formation fracture pressure in other areas.

2.3. Formation collapse pressure

The formation collapse pressure refers to the stress concentration of the rock around the wellbore after the formation of the wellbore. When the difference between the tangential stress and the radial pressure of the rock around the wellbore reaches a certain value, the shear failure will be formed, resulting in the borehole collapse. At this time, the drilling fluid column pressure is the formation collapse pressure. The calculation formula is as follows:

$$Bp = \frac{\eta(3\sigma_H - \sigma_p) - 2\tau K + \alpha p_p(K^2 - 1)}{(K^2 + \eta)} \quad (1)$$

In formula(1):

BP is formation collapse pressure, MPa;

σ_H, σ_p is horizontal maximum and minimum principal stress, MPa;

$K = \tan^{-1}(\pi/4 - \phi/2)$, ϕ is angle of internal friction;

τ is Rock cohesion, Mpa;

α is Biot elastic coefficient, dimensionless;

p_p is formation pore pressure, Mpa;

η is Nonlinear correction coefficient of stress, dimensionless.

From the mechanical point of view, in-situ stress is the fundamental force source affecting the direction and degree of borehole collapse[7]. However, in the actual drilling process, it can be seen from formula (1) that the collapse pressure is also affected by borehole trajectory and lithology [10], and it is difficult to obtain the cohesion and principal stress of rock, which makes it difficult to directly predict the collapse pressure.

Although the collapse pressure can not be measured directly, it is related to the stability of the well after drilling. Therefore, the collapse pressure can be deduced by the stability of the well after drilling. The well diameter change rate is an index to evaluate the well stability. It is generally considered that when the well diameter change rate (well diameter change rate = (well diameter - bit size) / bit size * 100%) is 5% ~ 15%, the well is relatively stable, then the collapse pressure in this section is less than or equal to the drilling fluid density used. Based on the evaluation of borehole quality, the critical value of collapse pressure is predicted (Fig.4).

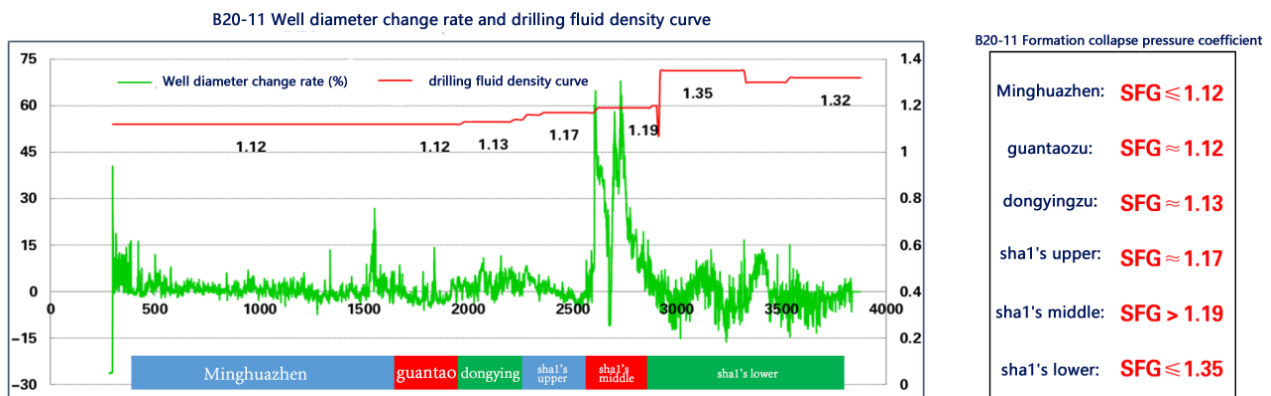


Figure 4. Prediction of critical value of formation collapse pressure

The formation three pressures exist independently, but they are also related to each other. Based on log curve method and geostatistics, through large data analysis, three pressure relationship chart is established to form the understanding of the distribution law of the difference between formation collapse pressure and formation pore pressure, formation fracture pressure and formation collapse pressure (Fig. 5 and Fig. 7), as well as the relationship between formation collapse pressure and formation pore pressure. The cumulative distribution of the difference probability between the formation fracture pressure and the formation collapse pressure (Fig. 6 and Fig. 8) is quite obvious. The difference between the formation collapse pressure and the formation pore pressure is normally distributed, and the difference is concentrated between - 0.1 and 0.2, of which 0.1 is the most common, and the cumulative probability of the difference in 0.2 is more than 99%; The difference between the formation fracture pressure and the formation collapse pressure is normally distributed, and the difference is concentrated in the range of 0.3 to 0.7, of which 0.5 is the most common, and the cumulative probability of the difference in 0.7 is more than 97%.

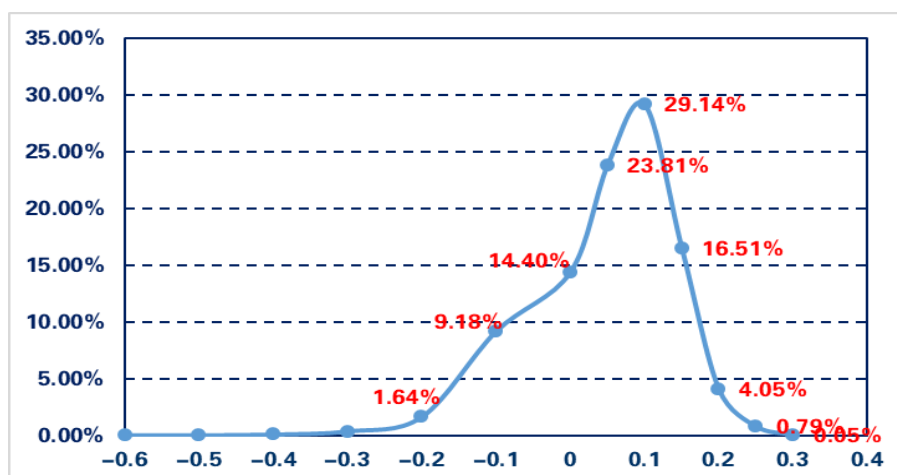


Figure 5. Probability distribution of formation collapse pressure formation pore pressure

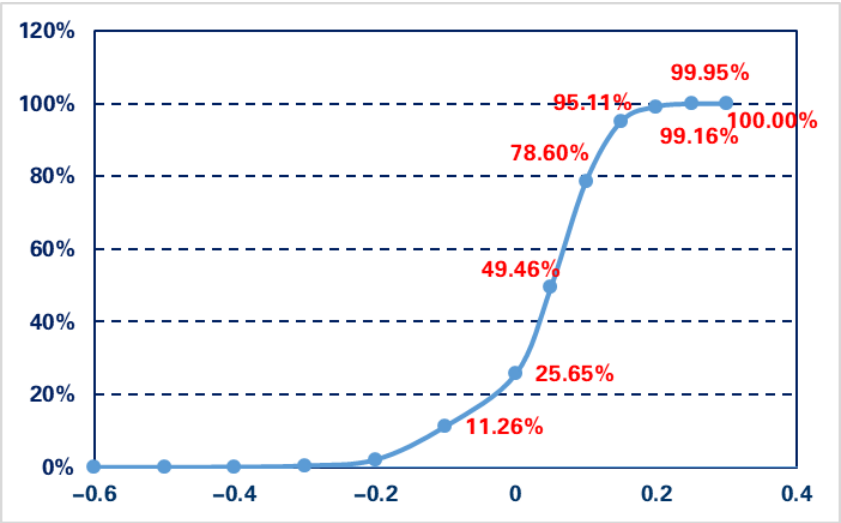


Figure 6. Probability cumulative distribution of formation collapse pressure and formation pore pressure

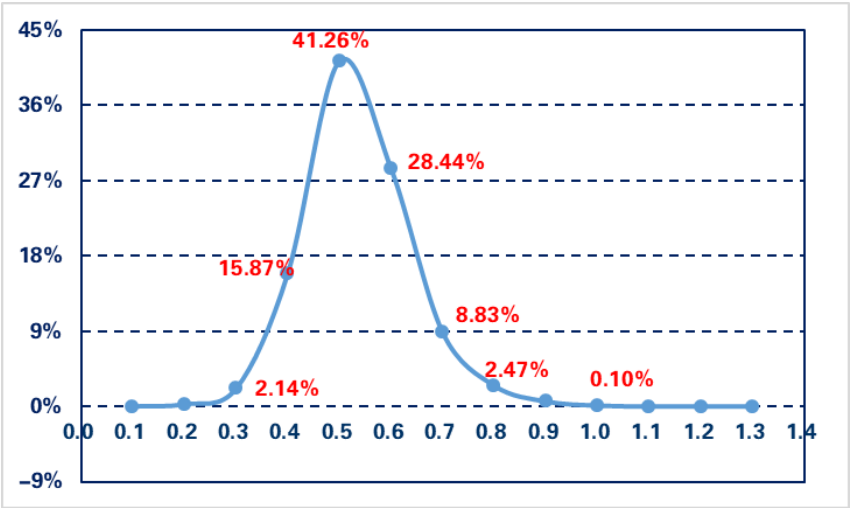


Figure 7. Probability distribution of formation fracture pressure and formation collapse pressure

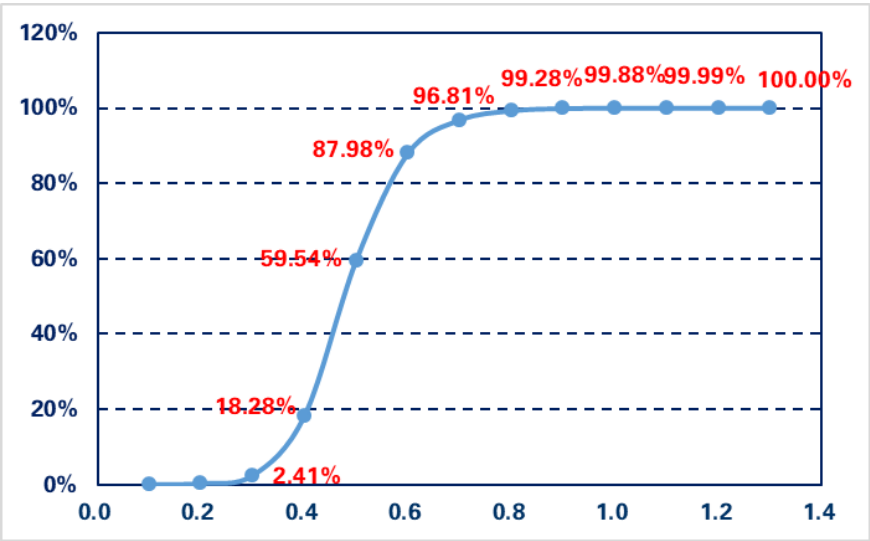


Figure 8. Cumulative probability distribution of formation fracture pressure and formation collapse pressure

Through the relationship between collapse pressure and pore pressure and the difference between fracture pressure and collapse pressure, the formation collapse pressure is predicted by using formation pore pressure and formation fracture pressure, and the rapid and accurate prediction of formation collapse pressure is realized.

2.4. Enlightenment of formation pressure prediction optimization

The formation pressure is continuous, and the configuration of drilling fluid density is designed in sections. In order to predict the formation pressure more reasonably and guide the configuration of drilling fluid in later stage efficiently, two understandings are formed

(1) The "high and low" optimization principle of formation pore pressure and formation fracture pressure: for a large set of formations, the high drilling fluid density is beneficial to improve ROP and ensure safety; The formation fracture pressure and the drilling fluid density of a large set of formations are lower, which can effectively reduce the risk of well control caused by lost circulation (Figure 9)

(2) For the key oil and gas intervals, it is necessary to have a fine understanding of the formation pore pressure, and design the formation pore pressure by sections. (Figure 10)

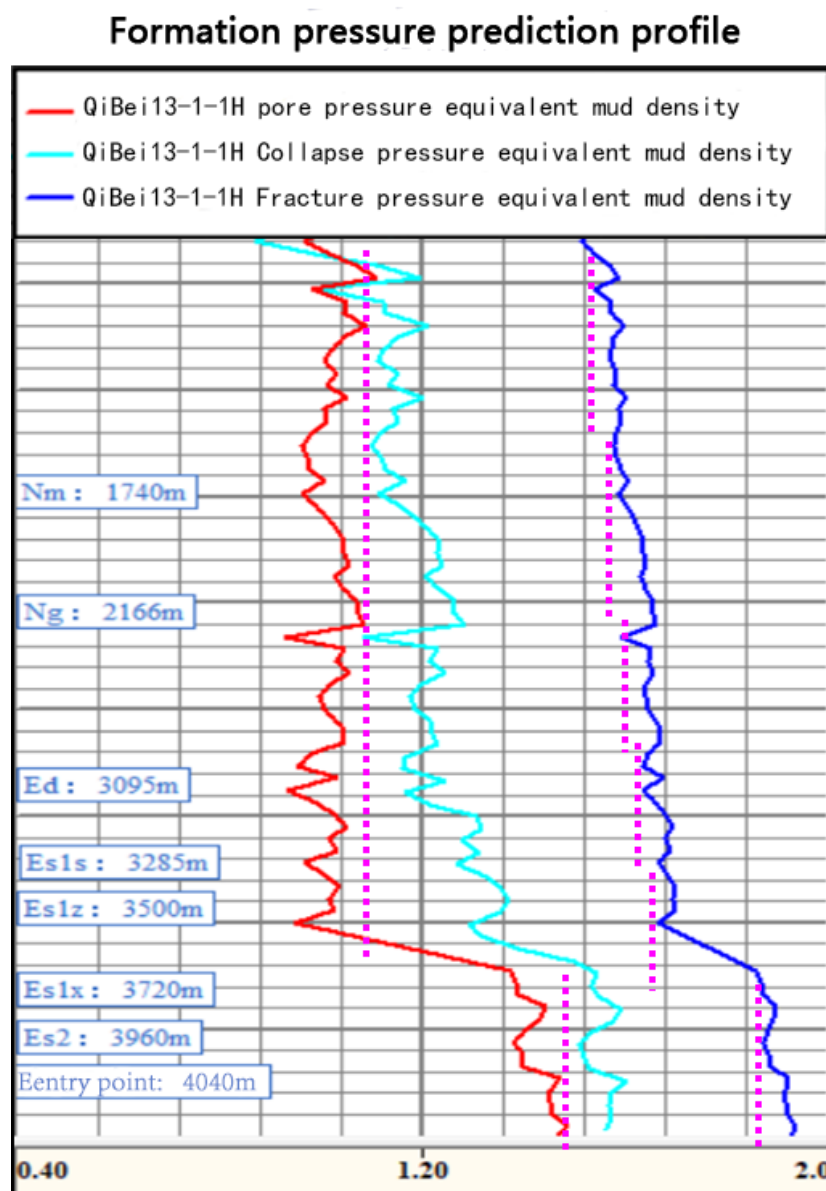


Figure 9. Formation pressure prediction optimization model

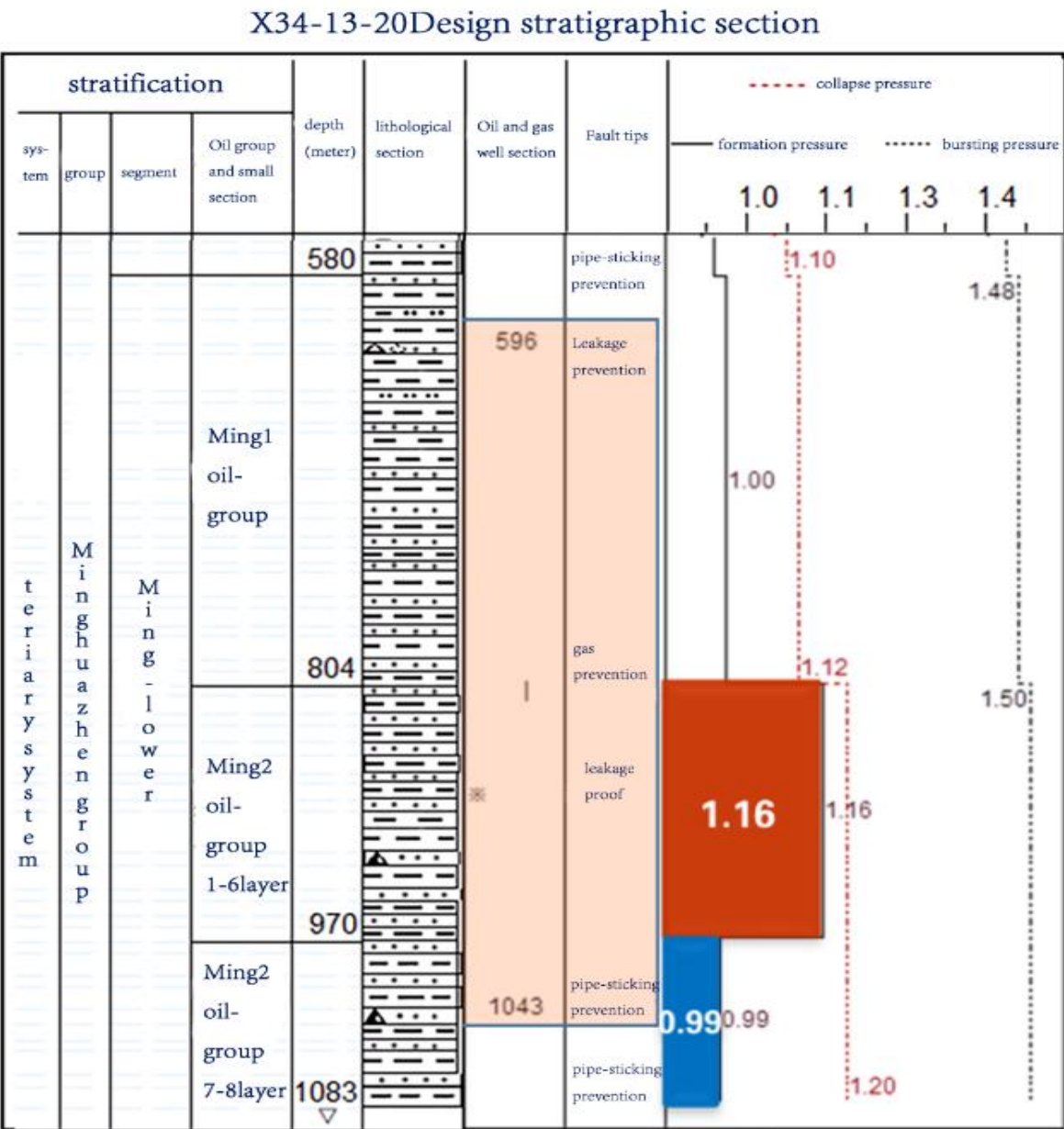


Figure 10. Pore pressure prediction of fine key strata

3. Application of achievements

(1) In order to ensure the safety of drilling well control and ensure no accident drilling in Dagang Oilfield in 2020, the incidence of drilling complications caused by formation pressure is zero in 2020.

(2) The Banqiao area with relatively complex pressure system is selected for post evaluation of pressure prediction.

In terms of pore pressure in the past two years, the error between the design pressure coefficient and the actual pressure coefficient is small, with an average error of 8.2% (Table 1). Because the pressure predicted by the design is optimized by comprehensive factors, and the measured pressure also has certain error, in this case, the error of formation pore pressure is still within 10%, and the accuracy is relatively high.

In terms of formation collapse pressure, the qualified rate of wellbore quality in Banqiao area in 2020 is 100%.

Table 1. Comparison of design formation pressure and measured pressure in Banqiao area

well number	Medium depth of oil layer	manometric measurement	Design pressure coefficient	Measured pressure coefficient	Pressure coefficient error(%)
B22-18	3683.55(MD)/3496.36(TVD)	34.393	1.08	1	8
B20-21	3632.10(MD)/3464.60(TVD)	30.96	1.04	0.91	14
B18-15	3554.35(MD)/3500.91(TVD)	34.34	1	1	0
B106X1	3905.90(MD)/3804.90(TVD)	40.58	1.2	1.09	10
B22-13	3849.25(MD)/3457.20(TVD)	40.09	1.07	1.18	9
average					8.2

4. Understanding and conclusion

(1) Using the four step method of "regional law logging prediction actual measurement calibration comprehensive verification" to determine the formation pore pressure coefficient of the whole well section by multi-means comprehensive analysis, the prediction error of formation pore pressure is controlled within 10%, and the pressure prediction accuracy is improved.

(2) Based on big data analysis and research, the critical values of formation fracture pressure coefficient in Dagang Oilfield are 1.4 and 2.1, and they have a linear relationship with vertical depth, that is, the fracture pressure coefficient increases by 0.1 with every 1000 meters of vertical depth.

(3) Through collapse theory analysis, wellbore quality evaluation and formation three pressure relationship research, the collapse pressure can be predicted quickly and efficiently.

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