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Original article

Geology-engineering integration to improve drilling speed and safety in ultra-deep clastic reservoirs of the Qiulitage structural belt

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Abstract:
The Qiulitage structural belt in Tarim Basin has a large reservoir burial depth and complex geological conditions. Challenges such as ultra-depth, high temperature, high pressure and high stress lead to significant problems related to well control safety and project efficiency. To solve these key technical issues that set barriers to the process of exploration and development, a drilling technology process via the integration of geology and engineering was established with geomechanics as the bridge. An integrated key drilling engineering technology was formed for improving the drilling speed and safety of ultra-deep wells, including well location optimization, well trajectory optimization, formation pressure prediction before drilling, stratum drillability evaluation, and bit and speed-up tool design and optimization. Combined with the seismic data, logging data, structural characteristics, and lithology distribution characteristics, a rock mechanics data volume related to the three-dimensional drilling resistance characteristics of the block was established for the first time. The longitudinal and lateral heterogeneities were quantitatively characterized, providing a basis for bit design, improvement and optimization. During the drilling process, the geomechanical model was corrected in time according to the actual drilling information, and the drilling "three pressures" data were updated in real time to support the dynamic adjustment of drilling parameters. Through field practice, the average drilling complexity rate was reduced from 18% to 4.6%, and the drilling cycle at 8,500 m depth was reduced from 326 days to 257 days, which comprised significant improvements compared to the vertical wells deployed in the early stage without considering geology-engineering integration.

1. Introduction

The Qiulitage structural belt is located in the northern margin of the Tarim Basin, with an exploration area of over 2.6×10^4 km^2 and proven natural gas reserves of over 1×10^{12} m^3. It is expected to become a large-scale continental ultra-deep clastic gas production base in China (Jiang and Sun, 2019). To date, the number of wells in this block has reached 36, with an average well depth of 7,026 m and the deepest well exceeding 8,200 m. The average drilling cycle is 326 days, and the proportion of complex accidents and aging accounts for 18%. Long drilling cycle, high accident complexity rate and low natural productivity of a single well are the key limiting factors of the effective development of ultra-deep natural gas in the Qiulitage structural belt (Hou et al., 2011).

The current drilling difficulties are mainly in two aspects. Firstly, the understanding of ultra-deep rock properties and mechanical behavior has been limited, the rock mechanics constitutive relationship is quite different from that of shallow layers, and the research on ultra-deep geomechanics is slightly lagging behind. The extreme conditions of "high temperature,

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high pressure and high stress" brought about by the great reservoir depth (maximum depth of more than 8,200 m) have aggravated the safety risk of well control and the difficulty of reservoir stimulation (Li et al., 2021), resulting in a major catastrophic safety risk in ultra-deep resource exploitation, i.e., a high risk of accidents. Secondly, the surface and underground geological structures of the Qiulitage structural belt are highly complex (Fig. 1). Under the action of strong compressive stress, a series of folds, fold-related faults and sudden structures are formed along the deep detachment layer (Shcherbakov et al., 2018). Besides, many drilling and completion engineering problems arise. The undulating ground surface brings difficulties to well site selection and surface engineering. Also, the shallow "roof-like" stratum is high and steep (the inclination of the stratum can be locally as high as 70°) and the fractures are developed, which can easily cause the instability of the wellbore and cause complicated drilling accidents (Savchenko, 2004). Poor drillability is one of the biggest problems restricting drilling efficiency. Mudstone, gypsum-salt, and salt-rock in plastic formations interact with each other, and their thickness varies greatly (several hundreds of meters to 4,000 m). The physical and chemical effects during drilling create complex wellbore environments, with coexisting problems of collapse, leakage and overflow, making drilling difficult amidst a high security risk.

The integration of geology and engineering mainly serves to predict the geological parameters related to drilling and completion quality through comprehensive studies such as reservoir characterization, geological modeling, geomechanics, and reservoir engineering evaluation. Geomechanics modeling plays an important role in the integration of geology and engineering. Its bridging role ensures a seamless connection between geological understanding and engineering technology and effectively solves engineering problems. Through the application of engineering, it can improve operational efficiency and development benefits, and achieve cost reduction and efficiency increase (Yu et al., 2011). In 2011, Cipolla first proposed the integrated workflow from seismic attributes to simulation for the challenge of unconventional reservoir development, which seamlessly integrated the whole process research method from seismic data interpretation to productivity simulation. From 2012 to 2016, during the development of deep shale gas in Haynesville, the integrated method of geology and engineering was widely used to carry out program design and parameter optimization. In addition, Baker Hughes, Schlumberger, Halliburton, and other companies have been actively cooperating with oil fields to provide integrated geological engineering services and software platforms, giving technical support for ultra-deep oil and gas development. In practice, a unique geological engineering integration technology has been gradually explored. However, the current geology-engineering integration technology focuses on the application of unconventional oil and gas production enhancement, especially in fracturing and reservoir stimulation, and ignores the positive aspects of safety, speed, efficiency, and the reduction of complex accidents in drilling engineering.

At present, geological research and engineering implementation in oil and gas exploration and development are technically separated, and the researches on well kick, well collapse, lost circulation, high drilling resistance and difficult fracturing caused by some special geological conditions are insufficient (Wilson, 2017). The control factors and geomechanical mechanism are unclear, resulting in a lack of scientific basis for engineering design and construction optimization. For the drilling of oil and gas wells in deep and complex geological conditions, geomechanical properties are key parameters affecting drilling well trajectory optimization, drillability assessment, wellbore stability, well completion, and reservoir stimulation (Liang et al., 2021). Therefore, geomechanics play a bridging role in drilling engineering and effectively solves engineering problems (Xie et al., 2018). Taking a typical gas reservoir in Qiulitage Zhongqiu block as an example, this paper builds a geo-engineering integrated collaborative platform and analyzes the key role of geomechanics in development science, such as well location deployment, well trajectory optimization, and drilling safety improvement. An integrated implementation process is established, key technical series are formed by tackling key problems, and the advantages of multi-disciplinary collaborative work are brought into full play. Using the drilling case of Zhongqiu 10 well, the practices of improving drilling speed and safety technology based on geology-engineering integration are explained in detail. Our research supports the efficient development of newly discovered deep gas reservoirs and facilitates the construction of large oil and gas fields.

2. Geomechanical model construction

2.1 Seismic fracture characterization

There are many commonly used seismic attributes for fracture prediction, including curvature, coherence volume, azimuth and dip, chaotic volume, variance volume, ant volume, amplitude variation with offset attributes, but their application effects in different regions are also different (Yang et al., 2013). Through the comparative analysis of various seismic attribute bodies that reflect the distribution law of fractures, it can be found that the fractures in the Qiulitage structural belt have better responses in terms of curvature and seismic attributes of the ant body. Before using the seismic attribute volume to predict the fracture distribution law, it is necessary to preprocess the original seismic data volume to remove random noise from the original seismic data, enhance the lateral continuity of the seismic event, and retain the boundary information like faults and fractures (Ernest and Zee, 2019). In this study, the structural smoothing method was used to preprocess the original seismic data volume. After processing, the stratigraphic continuity of the data became better, and the relationship between local fractures was clear, which effectively reduced the interference of noise and non-fracture factors (Fig. 2).

Curvature is one of the seismotectonic properties that is sensitive to fault and fracture response (Chopra and Marfurt, 2007). There are three main methods for calculating the seismic curvature attributes: (1) difference method; (2) Fourier transform method; (3) partial wave method. From the results of various curvature simulations (Fig. 3), the minimum curvature method has a better effect in the study area, followed by

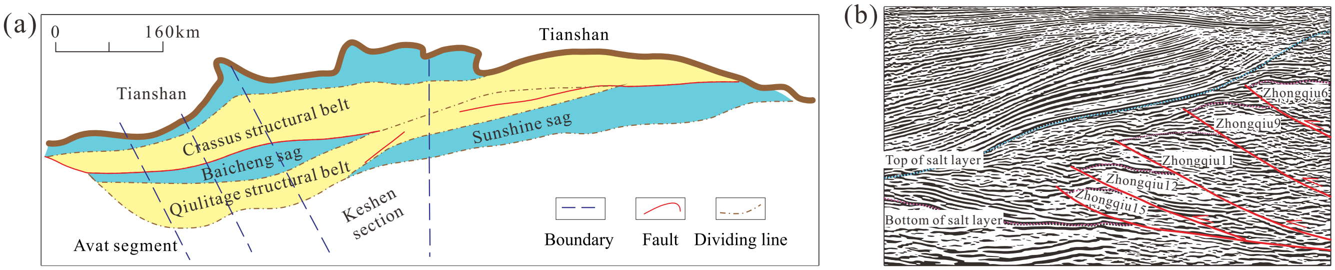

Fig. 1. (a) Location map and (b) structure map of the Qiulitage structural belt.

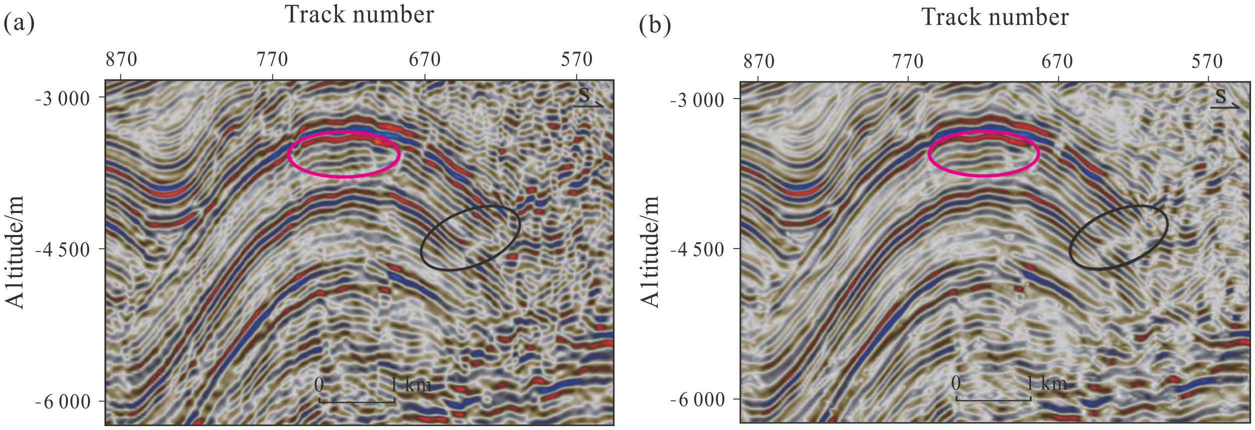

Fig. 2. Comparison of 3D seismic data preprocessing: (a) before data preprocessing, (b) after data preprocessing.

the maximum curvature (Di and Gao, 2016), and the average curvature noise is too high to be effective. The ant body is extremely sensitive to subtle changes in the seismic data and strata torsion, which provides an appropriate basis in terms of data for the fine interpretation of complex fault zone profiles and the three-dimensional characterization of fault shapes (Pedersen et al., 2002). In this paper, first, active ant tracking is performed on the high-definition variance volume. Since the dip angle in the study area is generally large, to reduce the interference of the stratum inclination on the ant tracking, the interference with the dip angle less than 50° is filtered when the ant body is extracted, and the preliminary results are obtained (Fig. 3(d)). A substantial level of noise occurs along the crossline. Therefore, while extracting the ant body, filtering is performed along the angular range of ± 2° (the minimum angle available) along the crossline direction, that is, the first noise reduction data of the ant body is obtained, which obviously suppresses the noise (Fig. 3(f)). Combined with the characteristics of profile faults and the strike of plane faults, adding azimuth filtering supplemented by light source enhancement and then performing passive ant tracking (Fig. 3(e)) makes the large faults clearer (Ding et al., 2012). The natural fractures in the Zhongqiu block are mainly near-north-slip faults. The fractures have good stability and are distributed in bands parallel to the NE-trending thrust faults on the south side. They are accompanied by a sudden change in the structural dip, therefore, are considered to be fold-related fractures. Fractures are very important for the production of ultra-deep wells. Therefore, in the design of drilling trajectory, this paper attempts to pass through as many fractures as possible to achieve the effect of stimulation.

2.2 Geomechanical model of Qiulitage structural belt

According to the characteristics of staggered superposition of subsalt reservoirs in the Qiulitage structural belt, in this study, the reverse finite element method is used to establish the three-dimensional crustal stress field model of the whole stratum of Zhongqiu structure (Fig. 4(a)) (Li and Sakhaee, 2019; Rojas et al., 2020). Firstly, by establishing the geological geometric model of the whole layer system, on the basis of the preprocessing of the point cloud data, such as thinning, local encryption and cutting, the reverse finite element engineering modeling is adopted with the aim of establishing a continuous and regular level that meets the in-situ stress simulation. This overcomes the technical difficulties of reverse fault and repeated stratigraphic modeling in contiguous in-situ stress modeling, and accurately establishes the complex intersecting relationship between faults and strata (Gale and Holder, 2008). Secondly, the X-Y bidirectional difference iteration method is applied to iteratively scan some long conjoined anticlines with large undulations and large spans, to further improve the accuracy of inverse finite element modeling and reduce the modeling error of local elements. Thirdly, by imagining the geometric layer in the finite element model, the mesh refinement and coarsening of the in-situ stress model are

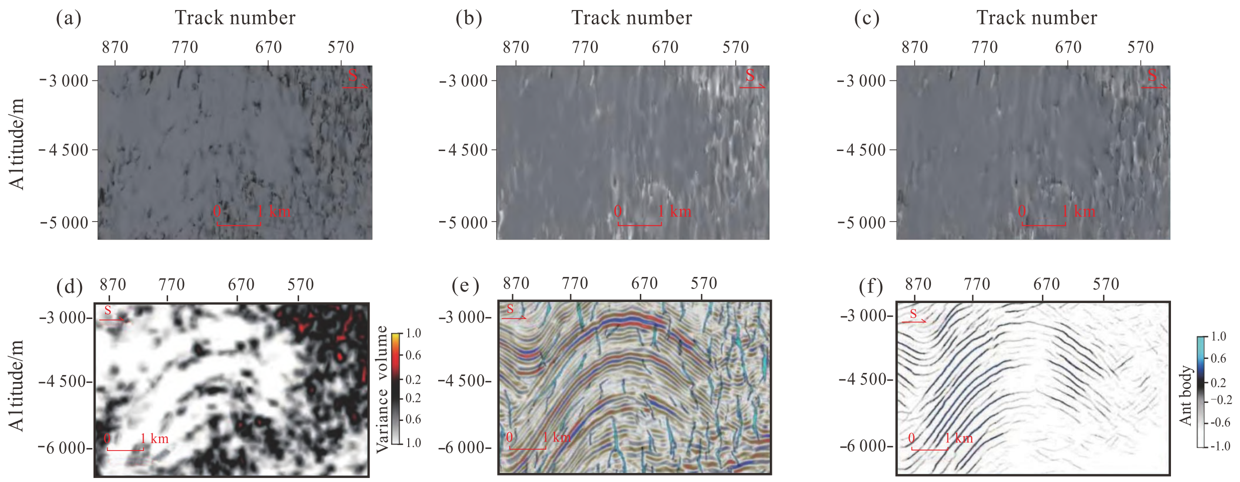

Fig. 3. Curvature and ant body identification crack results: (a) minimum curvature, (b) maximum curvature, (c) mean curvature, (d) variance volume, (e) 2 times ant body, (f) raw seismic data ant body.

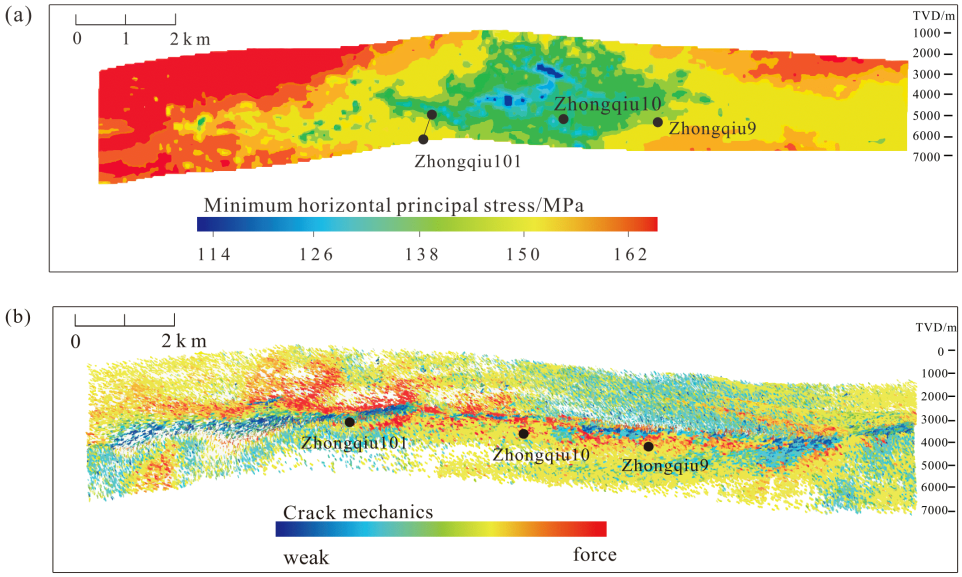

Fig. 4. Geomechanical model of Zhongqiu block: (a) minimum horizontal principal stress, (b) fracture mechanical activity.

flexibly realized, and the contiguous mesh model of the in-situ stress of the stacked nappe is established (Suarez et al., 2013). Finally, combined with the magnitude and direction of the in-situ stress at the well point, the boundary load constraints of the model are determined, and the modeling of the in-situ stress field of the whole layer system of the large-deformation geological body is realized. It can be seen that the in-situ stress field and fracture distribution within the structure are highly heterogeneous under the action of the gradient changing geological boundary, forming stress concentration areas and stress blank areas with significant differences. The color in Fig. 4(a) represents the minimum horizontal principal stress; blue indicates low values, red indicates high values, and the area with low stress value is selected as the advantageous area for well location deployment, which is easy to fracture and takes into account wellbore stability. Fig. 4(b) shows the predicted distribution of fracture mechanical activity. Fracture activity is an important index reflecting fracture permeability and fluid flow (Bai et al., 2019). This parameter is critical to the production of oil and gas wells. Therefore, the well location should be optimized for areas with strong fracture activity.

3. Geomechanical model construction

3.1 Optimization of well location and well trajectory

Based on the drilled well in the Qiulitage structural belt, great differences in per-well productivity, drilling borehole wall stability and stimulation effect of well completion reconstruction occur within the same tectonic belt or between different tectonic belts. Moreover, reservoir fractures develop that are highly heterogeneous, and the degree of fracture development and potential mechanical activity are the main factors affecting per-well productivity (Weng et al., 2014). Previous research has suggested that the distribution of stress field in the reservoir section controls the distribution of natural fractures. Natural fractures develop in low-stress areas and are easy to fracture in the later stage, resulting in the high productivity and good stability of drilling hole. Based on the above knowledge, it was proposed that the well location and well trajectory optimization technology should include four considerations, namely the shallow complex structure, avoiding the high-risk area for borehole wall stability, fracture development orientation with good activity, and preference for low-stress areas (Bouma and Lalehrohe, 2014). Taking the deployment of Zhongqiu 10 well in the Zhongqiu fault block as an example, the drilling in this fault block encounters a shallow nappe, so the risks of sticking and casing collapse are high. Therefore, to achieve the purpose of geological drilling, the Zhongqiu 10 well is planned to be drilled with a highly inclined well type to avoid the hanging wall nappe and the complex shallow surface, so as to prevent large-scale leakage, block falling, sticking and other complex events, or the failure to drill and uncover the target layer during drilling. Meanwhile, certain factors should be considered such as borehole wall stability, permeability fracture (Chenevert and Infante, 2013) encountered in drilling, and easy later reconstruction. This combined with the multi-source data such as seismic, logging, and core mechanical testing while drilling, the stress distribution model of the whole section of Zhongqiu 10 well was calculated (Fig. 5). The seismic data can be used to invert the velocity, density and shale content of the compressional and shear waves. Together with the regional geological structural model and reservoir model, and constrained by the seismic velocity, the regional in-situ stress model under the corresponding conditions can be obtained. In the well logging data, the formation stress, formation pressure and other data of the well can be acquired by using the longitudinal wave and shear wave logging data and the bulk density logging to obtain the dynamic elastic moduli of the formation. The modeling results show that the maximum and minimum horizontal principal stresses of the stratum are strongly unbalanced, and the distribution of the in-situ stress field is complex. Considering that directional wells have multiple advantages such as wide favorable area crossing, high fracture drilling rate, stable wellbore trajectory, and obstacle avoidance, it is considered that directional wells are an effective means to overcome heterogeneity under the given conditions, and they are suitable for complex geological environments. It is recommended to design the wellbore trajectory in the direction of low in-situ stress, well-developed fractures and stable wellbore. On the one hand, based on the previous drilling experience and borehole wall stability evaluation, multiple sets of pressure systems coexist, the longitudinal variations of leakage pressure and stratum collapse pressure are large, and there is no drilling fluid density window in local intervals. Under this strike slip stress state, a vertical well is the most unstable well type and its drilling cannot be realized. On the other hand, according to the actual drilling analysis of Zhongqiu 9 well, this area belongs to a fractured reservoir, and the angles of the majority of the fractures are high. Thus, a vertical well cannot guarantee the accurate vertical crossing of the fractures, which is not conducive to upscaling production. Taking this into account, the well type of highly inclined well was determined for the drilling process. First, we determined the target according to the stress field and fracture mechanical activity distribution, then evaluated the development orientation of natural fractures with good permeability after considering the actual drilling results of adjacent wells, and identified the drilling orientation conducive to borehole wall stability. On the basis of meeting the requirements of surface conditions and hole structure, the wellhead position and target orientation of the well were finally determined as 10° in the northeast direction with a hole inclination of 70°. The actual target orientation of the well was 15°, the hole inclination was 76°, and the closure distance was 1,221 m. Only 33 days were required to reach the target layer, and the average daily footage was 11.5 m. No complex drilling events were encountered, such as drilling fluid leakage. The well was completed and put into production using two-stage sand fracturing, with a 9 mm nozzle, a tubing pressure of 75.7 MPa, and a daily gas production of 74×10^4 m^3, three times that of other wells in the same block. The Zhongqiu 10 well was the first successful highly inclined well drilled in the Qiulitage complex tectonic belt to achieve high production, which laid a good foundation for the promotion of highly deviated wells in the block and explored a new well type for efficient development.

3.2 Pre-drilling pressure prediction

The accurate prediction of formation pressure is an important basis for well control safety and drilling fluid density design. However, due to the complex geological conditions of the Qiulitage structural belt, the coexistence of multiple sets of pressure systems, the development of an extremely thick gypsum salt rock stratum and the limited quality of seismic data, it is difficult to accurately predict the formation pressure. We established the formation pressure prediction technology of well-seismic joint inversion (Wu et al., 2006) to obtain the regional high-precision data volume through well-seismic joint inversion. Then, we adopted the pressure prediction method of man-machine interaction to describe the nonlinear compaction trend to attain the preliminary formation pressure profile, and then calibrate the preliminary profile by using the measured drilling pressure data. Finally, we acquired the three-dimensional data volume of formation pressure consistent with the geological background and engineering conditions, from which the data of newly deployed well points were extracted, so as to obtain the formation pressure profile and clarify the longitudinal distribution features for the purpose of designing the well structure and drilling fluid density. The pressure prediction method of well-seismic joint inversion can overcome the limitations caused by the monotonicity of the data. Fig. 6 shows the pre-drilling formation pressure prediction profile of Zhongqiu 10 well, in which the predicted stratum pore pressure coefficient rises from 3,185 m of Neogene Kangcun Formation to 2.02 at the top of the gypsum salt rock section of the Paleogene Kumgelimu Group, and then decreases to 1.60 in the Cretaceous Bashjiqik Formation of the target layer.

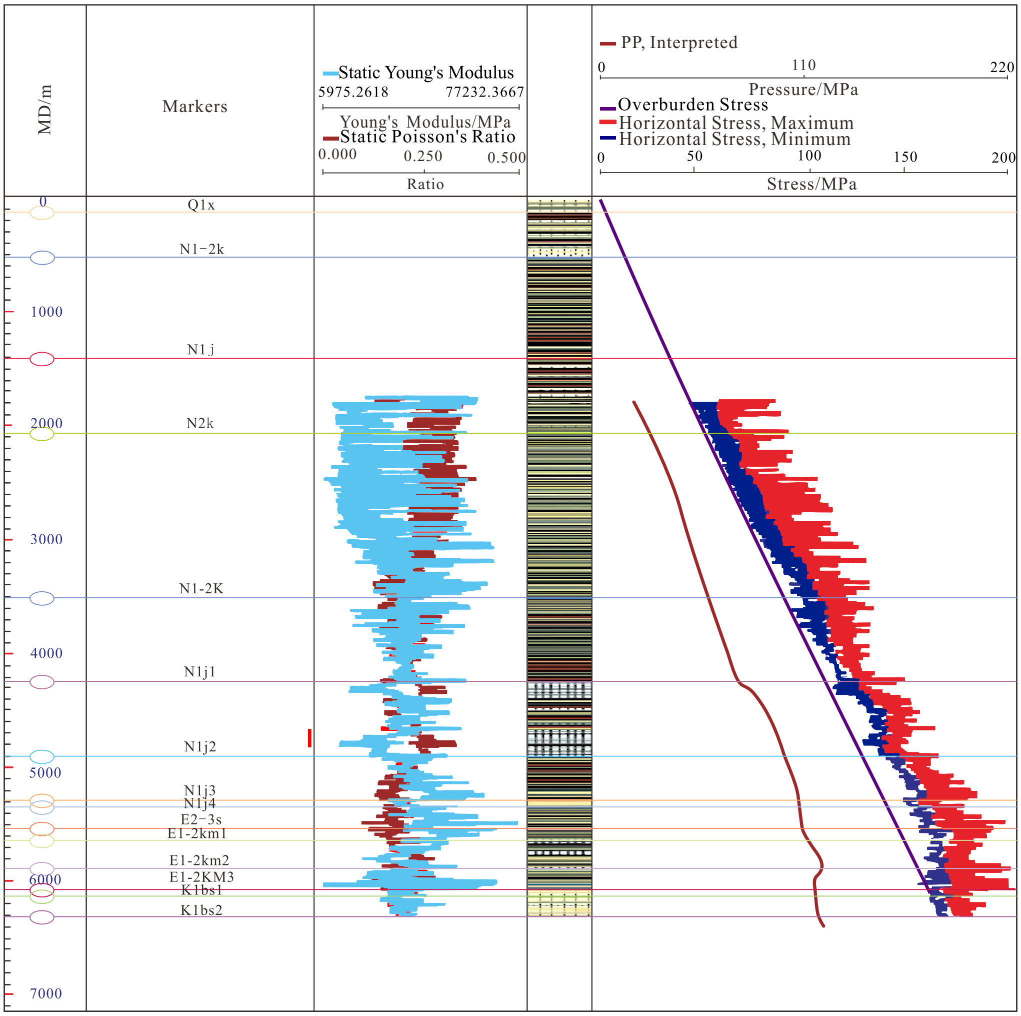

Fig. 5. Stress distribution in the whole section of Zhongqiu 10 well.

There is one fault and one set of salt layer developed in Zhongqiu 10 well, the identified collapse pressure of the fault is 1.86 g/cm^3, and the leakage pressure is 2.15 g/cm^3. Through the appropriate optimization of drilling fluid, the density of drilling fluid increased to 1.30 g/cm^3 at the middle layer of Kangcun Formation. At the top of gypsum salt rock section, with the increase of predicted pore pressure coefficient, the drilling fluid density increased to 2.30 g/cm^3, and then, at the Cretaceous System, the drilling fluid density decreased to 1.70 g/cm^3 according to the predicted pore pressure data. No serious drilling complications, such as overflow and leakage, happened in the whole well in the process, and the drilling was completed smoothly. The pre-drilling pressure was predicted by the human-computer interactive pressure prediction method of combined well-seismic inversion, the geomechanical model was reconstructed using multi-source data such as mechanical experimental data of cuttings while recording drilling and logging information, and the prediction model was corrected. The drilling section was re-predicted, and the coincidence rate between the prediction and the actual drilling reached 92%. Compared with the conventional single data source prediction method, the accuracy was increased by 22%. The non-productive time was effectively reduced and a foundation was laid for the improvement of well control safety and drilling efficiency.

3.3 Fine managed pressure drilling technology improves drilling safety

Using fine managed pressure drilling technology, according to the measured pore pressure and leakage pressure of the formation, the bottom hole pressure was adjusted in real time, and the downhole pressure was controlled smoothly. Due to the narrow window of safe density in super high-rise buildings, or even a lack of such window, the pressure control method of constant bottom hole pressure could not be adopted. It was necessary to adjust the size of the wellhead pressure, gradually explore the degree of overflow or leakage, and gradually achieve bottom hole pressure balance. The well was drilled to a depth of 6,449 m and the reservoir overflowed 0.5 m^3 for a period of time. The well was then shut in to obtain a reservoir pore pressure coefficient of 1.48 g/cm^3 to 1.49 g/cm^3, and the pressure was controlled at 1 to 3 MPa during the circulating exhaust process. Micro leakage occurred downhole, and the calculated formation leakage pressure coefficient was between

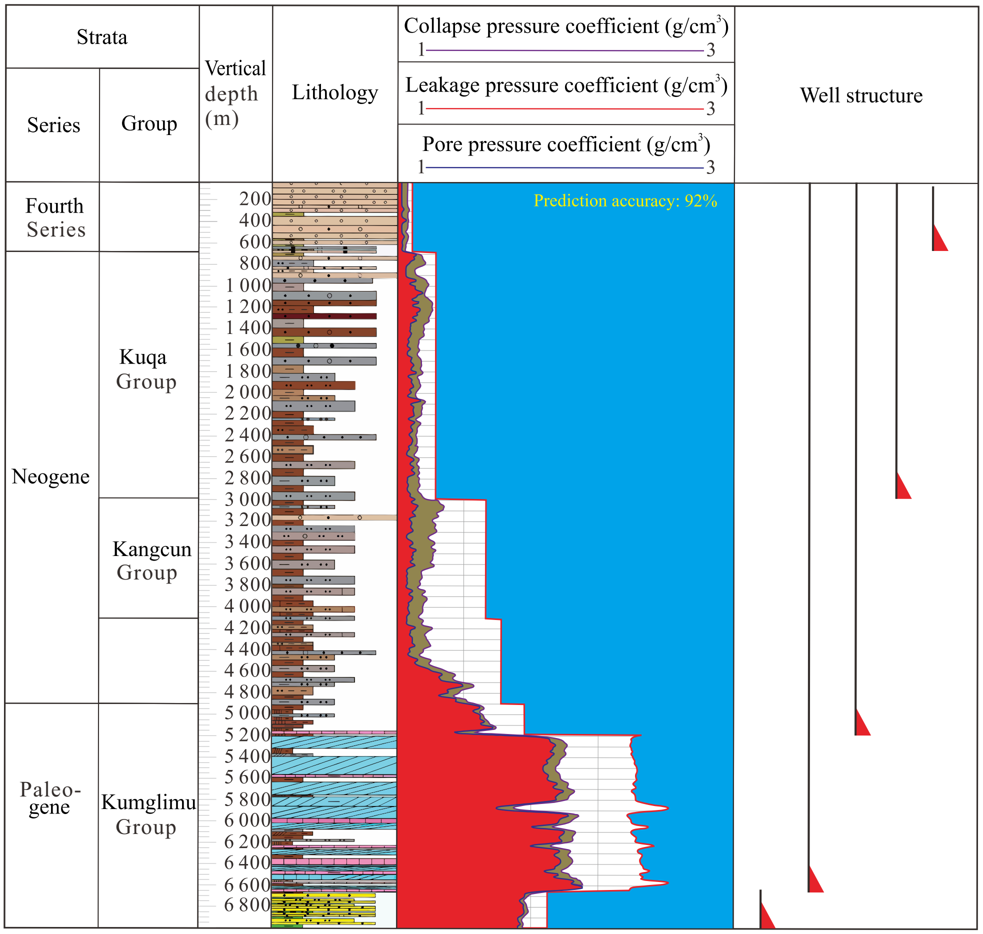

Fig. 6. Formation pressure prediction profile of Zhongqiu 10 well.

1.40-1.50 g/cm^3, with a safe density window of 1.48-1.50 g/cm^3. Then, according to the safe density window, the bottom hole pressure equivalent density was controlled to be 1.49-1.50 g/cm^3 for fine managed pressure drilling (MPD) drilling, and no loss of circulation occurred during the drilling process. Fig. 7 shows the bottom hole pressure during fine MPD drilling. At 6,686 m, the second showing reservoir was encountered, and the bottom hole pressure control test was carried out. According to the measured annulus liquid level, the leakage pressure coefficient of the reservoir was determined to be between 1.46-1.47 g/cm^3, which was slightly lower than the first reservoir pressure. coefficient. For two reservoirs with different pressure coefficients, to ensure the smooth implementation of drilling operations, the drilling strategy under the condition of lost circulation was finally adopted, and a reasonable control range of bottom hole pressure was selected according to the leakage situation of different equivalent densities. According to the leakage situation, a drilling fluid of 1.40-1.43 g/cm^3 was used, the casing pressure was controlled at 0-2 MPa, and the bottom-hole pressure equivalent density was maintained at 1.49-1.50 g/cm^3 for fine managed pressure drilling operations, and the leakage rate was 0.5-1 m^3/h. The drilling was completed safely and smoothly under the condition of micro-leakage.

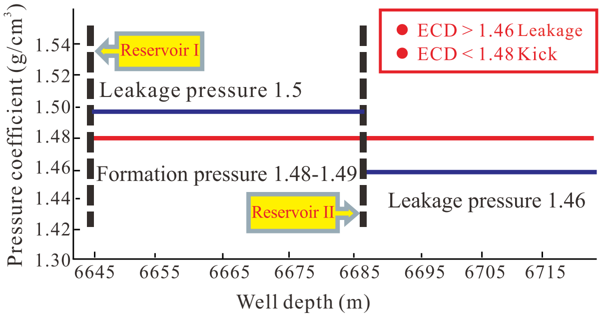

Fig. 7. Bottom hole pressure analysis curve of Zhongqiu 10 well.

3.4 Formation drillability analysis and drilling speed-up

Based on the formation core mineral composition, rock strength and drillability tests, combined with the logging data of the Zhongqiu block, the formation drillability profiles of 52 wells were established. The clustering algorithm was used to classify the rock strength of 52 wells vertically, and the seismic data was used as a constraint to identify faults and structures, and the PETREL software was employed to establish a three-dimensional rock drillability profile of the

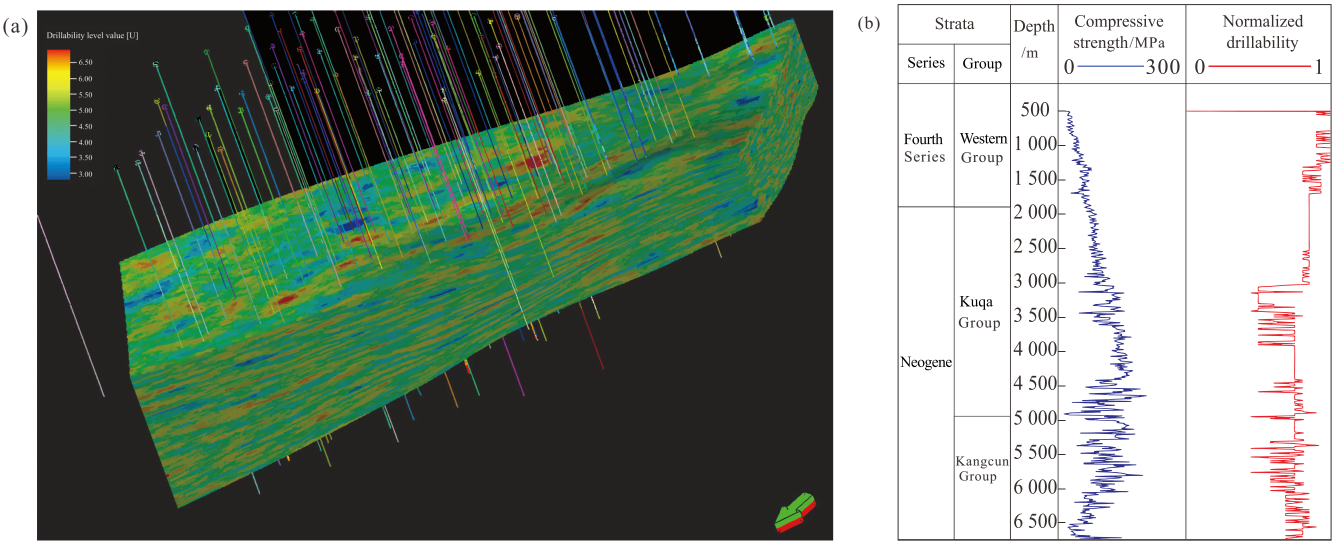

Fig. 8. Drillability prediction of the Zhongqiu block: (a) three-dimensional drillability distribution of the Zhongqiu block, (b) drillability distribution of the Zhongqiu 10 well.

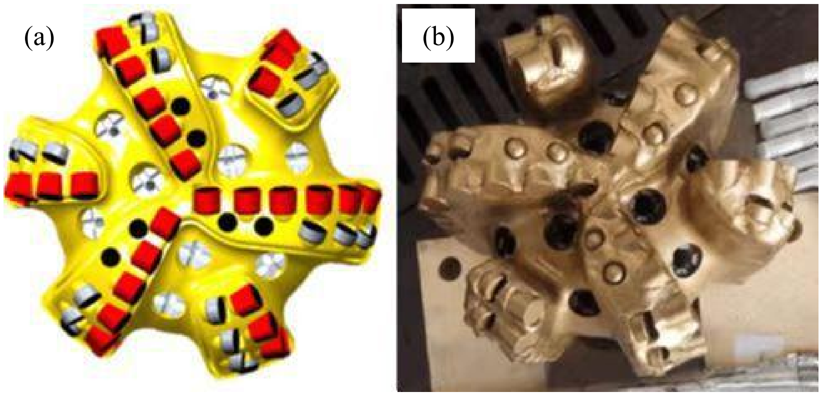

Fig. 9. SDR616 specified PDC bit: (a) bit design model, (b) real object of drill bit.

Zhongqiu block (Fig. 8), which is a heterogeneous glutenite (Andrews et al., 2007; Ma et al., 2011). Layer drill design, improvement and optimization provided the basis. The figure on the right shows the compressive strength and formation drillability distribution of the whole section of Zhongqiu 10 well. For the convenience of comparison, the formation drillability was normalized, and the drillability distribution was placed in the 0-1 interval. Judging from the formation drillability model, the distribution of formation compressive strength generally increases and then decreases from top to bottom. In terms of formation drillability, the drillability of the upper formation is significantly greater than that of the lower formation, because the upper formation in this area is a gravel layer, and the formation is very abrasive and heterogeneous, so the drillability is very poor and has a higher normalized drillability.

With the progress of research on the integration of geology and engineering, the understanding of formation compressive strength and drillability has been deepened. On the basis of optimizing the plane design of the cutting tooth core of the drill bit, the design of the drill bit teeth and the diameter gauge (Hareland et al., 2009; Akbari et al., 2014), the SDR616 personalized polycrystalline diamond compact (PDC) drill bit with high impact resistance and long life was developed and designed. For this bit, 16-mm cutting teeth were used to improve the tooth layout density of shoulder. A six-blade structure with three long blades and three short blades was adopted. The main cutting teeth are 6 more in number than that of the conventional five-blade bit, which enhances the stability and service life of the bit. Double rows of teeth are at the shoulder and stable torque teeth are at the core. To improve the bit stability, integrated structure and 4-inch diameter retaining were used, which make it applicable to a stably inclined well section. Moreover, when using the conventional “passive inclination prevention” drilling technology, it is difficult to deal with the salt formation with large dip angle (15°-87°). To solve the problem of deviation prevention and fast drilling in a high and steep formation, specified foreign vertical drilling tools were introduced, and a standard operation mode was established to form an inclination-prevention fast drilling technology for high and steep structure, of which the mechanical rate of penetration (ROP) was 3-6 times higher than that of conventional drilling, and the well inclination was controlled within 1°. To reduce vibration and improve the service life of drilling tools, shock absorbers and other speed-up tools were selected in the well section of gravel layer with lithology (non-diagenetic, quasi-diagenetic and diagenetic), and strengthening measures such as high weight on bit, high pump pressure, large displacement and large torque were adopted to further improve the mechanical ROP of the upper huge thick gravel layer.

4. Conclusions

1) This paper systematically combed the necessity and implementation scheme of geology-engineering integration under the background of Qiulitage complex structure in Tarim Basin, Northwest China. The integration of geology and engineering effectively coordinates the collaborative work between geological research and engineering practice, and organically integrates the aims of "geological research service engineering" and "engineering achieves geological purpose", so as to make the pre-drilling engineering scheme design more scientific and provide a better quantitative basis for the engineering parameter adjustment during drilling.
2) Taking the Zhongqiu block in the middle of the Qiulitage structural belt as an example, considering the whole life cycle of drilling, such as well location deployment, trajectory optimization, drilling design and drilling speed-up, we illustrated the main steps of the integrated practice of geology and engineering, and realized the drilling with zero complexity in the deployed Zhongqiu 10 well. The three-dimensional geological drillability distribution map of the Zhongqiu block was established, which effectively guided the design and selection of the drill bit. The drilling speed and production were significantly better than the vertical wells deployed in the early stage without considering the integration of geology and engineering. The feasibility and advantages of engineering integration was demonstrated. It was proved that the working concept and key technology of geology-engineering integration are not only applicable to the ultra-deep oil and gas drilling project in the Tarim Basin, but also provides a useful reference for the exploration and development of ultra-deep and complex oil and gas extraction in other petroliferous basins in western China.
3) The improvement of the use efficiency of multi-disciplinary data is still a basic need that cannot be ignored in the research of geology-engineering integration. At present, the Tarim Oilfield has a number of exploration and development database systems, which basically realizes the centralized management and data sharing of multidisciplinary data. However, the problem of information islands still exists, and the timeliness and data deep mining is still insufficient. To provide a more solid foundational guarantee for research regarding geology-engineering integration, it is necessary to realize the deep integration and effective mining of multi-disciplinary data through the remote decision support center for drilling and completion, as well as the integrated data platform of geology-engineering, so as to form a "remote, integrated, real-time, visual and diversified" integrated organization and management mode of geology-engineering.

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Conflict of interest

The authors declare no competing interest.

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