Wellbore stability mechanism of igneous rock in Shunbei block

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Abstract. Shunbei area is located in the belt structural of the northern margin of the shuntuogole low uplift. The proven oil reserves of the adjacent blocks are 142.93 million tons, which has the potential of exploration and development. In the igneous strata of Shunbei block, there are many complicated conditions, such as wellbore collapse, sticking pipe and so on, which seriously restrict the exploration and development speed and benefit of the block. In order to solve this problem, firstly, the composition, microstructure, mechanical properties and other parameters of igneous rock intrusion in Shunbei block are determined through laboratory experiments. The experimental results show that the igneous rock intrusion in Shunbei block does not contain expansive clay minerals, has weak hydration ability, and has developed micro fractures. Thirdly, the wellbore stability model considering fractures is established, and the influencing factors of wellbore instability are analyzed by combining the mechanical properties of igneous rocks, porosity and permeability characteristics, and in-situ stress state. The results show that the micro fractures and weak surfaces have a controlling effect on wellbore stability. The longer the immersion time is, the deeper the drilling fluid invasion depth is, and the higher the wellbore collapse pressure is. Finally, according to the microstructure and physicochemical properties of igneous intrusions, the main points of drilling fluid technology are determined, that is, the anti-sloughing drilling fluid technology is mainly strong plugging. In this paper, through the analysis of the rock characteristics of igneous rocks and the main controlling factors of wellbore instability mechanism in Shunbei block by using the method of mechano-chemical synthesis, the clear main controlling factors of wellbore stability are of positive significance for ensuring the safe well construction, shortening the drilling cycle, reducing the drilling cost and improving the development efficiency in Shunbei block.

1. Introduction
Shunbei well area is located in the northern margin of shuntuogole low uplift in Tarim Basin, covering an area of 3126.22km². The area is adjacent to the oil and gas enrichment area of Akekule uplift in Shaya uplift in the north, the oil and gas migration direction belt of Manjiaer depression in the East, the shuntuogole low uplift in the middle of Tarim Basin in the south, and the Yingmaili buried hill structural belt in Tabei Uplift in the West. The oil and gas exploration results in the adjacent area are remarkable, but the accidents in diabase formation are complex and frequent, which seriously affect the normal drilling

(1) The physical and chemical properties of igneous intrusions are not clear[1-3], and many accidents such as sticking pipe occur during drilling, resulting in a lot of time loss.
(2) The rock properties and mechanical properties of igneous intrusions are not clear[4], the wellbore instability mechanism can not be accurately determined, and the influencing factors and degree of wellbore instability need to be analyzed.
(3) There are micro fractures in igneous rock intrusions[5,6], and the safety density window of drilling fluid is narrow. Too small drilling fluid density will lead to downhole overflow, and too large drilling
fluid density will cause downhole leakage, and the supporting effect on wellbore will fail, which will aggravate wellbore collapse, and the drilling fluid density and Countermeasures are limited. In order to ensure the safe and efficient drilling operation in Sangtamu igneous intrusive formation, it is necessary to study the rock characteristics of igneous intrusive formation, analyze the wellbore instability mechanism, optimize the drilling fluid performance, and develop a stable wellbore drilling technology suitable for the formation.

2. Physical and chemical properties of igneous intrusions analysis

The main diagenetic minerals of basalt and diabase are relatively stable pyroxene and unstable basic plagioclase. The pyroclastic rock, crystal and glass are widely sourced and the mineral composition is complex. According to the petrology of metasomatic altered rocks, intermediate and basic igneous rocks, especially pyroclastic rocks, are prone to argillization (clayization) under the action of hydrothermal solution (contact with formation fluid at high or high temperature), and plagioclase is often transformed into kaolinite and montmorillonite minerals. Therefore, firstly, the physical and chemical properties of diabase are tested to analyze whether there are easily hydrated and dispersed substances in diabase from the perspective of rock mineralogy, so as to provide support for wellbore stability countermeasures and drilling fluid formulation optimization.

![Figure. 1. Pictures of igneous rock blocks and cuttings](image)

2.1 Mineral composition analysis
The composition and relative content of igneous intrusive and mudstone of Ordovician Sangtamu formation in Shunbei 11 well were measured and analyzed by X-ray diffraction instrument. Mineral composition and content distribution of Ordovician Sangtamu formation igneous rock and mudstone in Shunbei 11 well.

| NO. | Test results (%) |
|-----|------------------|
| Clay | Quartz | Plagioclase | Calcite | Gypsum | Pyrite | Anatase | Pyroxene |
| 1 | 2 | 23 | 20 | 30 | 4 | 3 | 18 |
| 2 | 3 | 7 | 58 | 15 | 8 | 4 | 5 |

It can be seen from table 1 that the clay content of Sangtamu igneous rock intrusion is 2% - 3%, quartz content is 23% and 7%, calcite content is 30% and 15%, quartz content is high. Generally, this kind of igneous rock has high rock strength, hard and brittle rock mass, and weak hydration effect.

| NO. | Test results (%) |
|-----|------------------|
| Kaolinite | Chlorite | Illite-montmorillonite mixed-layer | Layer ratio |
| 1 | 0 | 8 | 81 | 11 |
| 2 | 2 | 9 | 80 | 9 |

It can be seen from table 2 that the clay mineral of Ordovician santamu formation mudstone in Shunbei 11 well is mainly composed of illite-montmorillonite mixed-layer, with the content of 81%
and 80% respectively, but the mixed layer ratio is very low, which indicates that the content of montmorillonite is very low and contains a small amount of chlorite and kaolinite. It is judged that the Ordovician santamu formation mudstone is mainly composed of non expansive clay, with weak hydration expansion ability.

2.2 Microstructure of igneous intrusions
Because of the particularity of igneous rock diagenesis and the influence of tectonic movement in the process of igneous rock diagenesis, igneous rock contains microcracks. According to the genesis of igneous rocks, microfractures can be divided into primary fractures, secondary fractures and artificially induced fractures. The primary fractures are mainly formed in the magmatic stage. Due to different mineral condensation velocity and condensation contraction, joint fractures and intergranular fractures often occur in the solidification process of magma; The secondary fractures are mainly formed in the later stage of igneous rock formation, which are caused by tectonic movement; The artificial fracture is the mechanical fracture caused by the vibration of downhole drilling tools in the later drilling process.

![Figure. 2 FEM analysis of diabase core](image-url)

According to the FEM results of diabase core, it can be seen that there are microcracks developed in diabase. The direction of microcracks is not uniform, and they are interwoven vertically and horizontally. The microcracks include filling closed joint, no filling open joint, and the filling materials between the joints are feldspar, calcite and other calcareous filling. Calcareous filling has high rock mechanical strength, but there is no filling crack, no joint between cracks, and the strength between cracks is low.

2.3 Test and analysis of hydration expansion performance
The experimental device mainly includes core holder, stress displacement sensor, data converter and data acquisition system. The hydration expansion strain of two groups of core samples under the condition of steam frying water was tested by using the hydration expansion strain test device, as shown in Figure. 3.

![Figure 3](image-url)

It can be seen from Figure 3 that the hydration expansion strain of the two groups of diabolos in distilled water environment is very small, and there is almost no expansion property. It is concluded that the influence of hydration effect on diabase is negligible, and hydration effect is not the controlling factor of diabase wellbore collapse.
3. Establishment of diabase wellbore instability model

In the process of drilling, wellbore instability can be summarized into two categories: collapse and cracking. The manifestations of wellbore instability include wellbore collapse, wellbore shrinkage, wellbore erosion or mud filtration. The consequences of wellbore instability include: difficult tripping, sticking and sidetrack. Such problems are time-dependent. These problems will not occur at the moment when the bit opens the formation, but after the bit has passed through the problem section.

The basic methods to study this kind of wellbore instability include: applying the porous media mechanics equation to calculate the time-dependent stress / pressure redistribution in the core and accessories of the wellbore, and then calculating the mud density window. These time-dependent processes affecting drilling stability, such as fluid flow, chemical permeability and thermal effect, should be analyzed as time-dependent phenomena, so as to accurately understand wellbore instability when drilling fractured formations.

The dual porosity constitutive equation is transformed from the deformation of linear elastic isotropic rock following Hooke's law

\[ \sigma_{ij} = \frac{E}{1+\nu} \left( \varepsilon_{ij} + \nu \frac{E}{1-2\nu} \varepsilon_{ii} \delta_{ij} \right) + \alpha p l \delta_{ij} + \alpha p f l f \delta_{ij} \]  

Where \( \sigma_{ij} \) is the total stress tensor,
\( \varepsilon_{ij} \) is the total strain tensor,
\( E \) is the young's modulus,
\( \nu \) is Poisson's ratio,
\( \delta_{ij} \) is a Kronecker function.
\( \alpha \) is the weighted pore pressure coefficient,
\( p \) is pressure,
\( I \) is matrix pore,
\( f \) represents fracture porosity.

Two fluid composition strain pressure equation:

\[ \frac{\Delta \varepsilon}{\nu} = - \alpha \varepsilon_{kk} + \frac{p_f}{M_f} + \frac{p_f}{M_f} \]  

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The pressure equation of elastic model of porous medium is as follows:

Matrix i
\[ P_I = p_o + L^{-1} \left\{ -\frac{p_o - p_m}{s(m^t-m^l)} \left[ (1-m^l) \frac{K_0[U^l_r]}{K_0[U^l_R]} - (1-m^l) \frac{K_0[U^l_r]}{K_0[U^l_R]} \right] \right\} \]

Crack II

\[ P^{II} = p_o + L^{-1} \left\{ \frac{1}{2s} K_v \left( C_1 K_2[U^l_r] - C_2 K_2[U^l_r] + \frac{\mu^l}{2} C_3 R^2 \right) \cos (\theta - \theta_r) \right\} \]

In formulas (4) and (5), \( L^{-1} \) denotes inverse Laplace transform; \( K_0 \) and \( K_1 \) are zero order and first order corrections of Bessel functions; \( C_1, C_2, \xi^l, \xi^l, m^l, \) and \( m^{II} \) are polymerization constants; \( K_v \) is the strength coefficient.

Formula (6) is the general radial stress equation of the elastic model of double porosity medium. Where \( H(t) \) is time-dependent and \( L^{-1} \) is inverse Laplace transform. \( C_1, C_2, C_3, \xi^l, \xi^l, m^l, \) and \( m^{II} \) are polymerization constants.

\[ \sigma_{\theta\theta} = -\sigma_m + \sigma_d \cos 2(\theta - \theta_r) - \sigma_m \frac{R^2}{R^2} H(t) \]

Formula (7) is the total tangential stress equation of the elastic model of double porosity medium. Where \( H(t) \) is time-dependent and \( L^{-1} \) is inverse Laplace transform. \( C_1, C_2, C_3, \xi^l, \xi^l, m^l, \) and \( m^{II} \) are polymerization constants\(^9\).

Due to the development of weak plane, after comparison the Mogi-Coulomb failure criterion\(^{10}\) is representative of wellbore failure. Equations 8-10 are the strength constant related to both cohesion and internal friction (a), and the strength constant related to internal friction (b), the mean normal stress, and the octahedron shear stress (\( \tau_{\text{oct}} \)).

\[ a = 2 \times C_0 \times \frac{\sigma^2}{3} \cos(\phi) \]

\[ b = 2 \times \frac{\sigma^2}{3} \sin(\phi) \]

\[ \tau_{\text{oct}} = \frac{1}{3} \sqrt{(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_1 - S_3)^2} \]

4. Wellbore stability analysis
Based on the geo-mechanical analysis of fractured formations in the Permian and Ordovician, it is found that the collapse pressure of the Permian is highly sensitive to the pore pressure of the formation, while the collapse pressure of the Ordovician is sensitive to the pore pressure, horizontal stress and weak plane property of the formation, and the pore pressure is the most sensitive.

![Figure 4: Sensitivity analysis of collapse pressure in Permian strata](image)

![Figure 5: Collapse pressure sensitivity analysis of Ordovician strata](image)

Considering the characteristics of dual media porosity and permeability, combined with the change of pore pressure around the wellbore under the condition of chemical coupling, the pore pressure changes greatly around the wellbore, which leads to the dramatic change of collapse pressure around the wellbore. The weak surface has a decisive influence on the collapse pressure of the Silurian diabase formation, and is the main controlling factor of the collapse pressure and whether the formation collapses or not.

![Wellbore Stability: Weak plane inclination 0°](image)  ![Wellbore Stability: Weak plane inclination 10°](image)
5. Conclusion

1) In Shunbei block, micro fractures and weak planes are developed in diabase formation, the content of expansive clay minerals is less, the chemical aspect has little influence on wellbore stability, and the main control factor of wellbore is mechanical aspect.

2) The calculation results of double porosity and double permeability model show that the change of pore pressure has obvious influence on the collapse pressure of formation.

3) In view of the leading role of micro fractures in wellbore stability, it is suggested to strengthen the plugging effect of various sizes of drilling fluid and optimize the formulation of drilling fluid.

6. References

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