Research and application of fracturing process for low permeability reservoir of Triassic in Junggar Basin

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Abstract. Baikouquan formation of Triassic in the northwest margin of Junggar Basin has long been regarded as the synonym of “alluvial fan, ultra-low permeability and no benefit”. Moreover, the effect of Triassic conglomerate reservoir reconstruction in Mabei oilfield is not obvious, which leads to ineffective production and benefit development. In this paper, based on the research results and practical production application of Triassic conglomerate reservoir fracturing reconstruction technology in Junggar Basin in recent years, four kinds of adaptive reservoir reconstruction technology for low permeability conglomerate reservoir are explored, which effectively improves the single well production and realizes the increase of reserves and productivity in conglomerate reservoir exploration. (a) In view of the three reservoir conditions of multiple sets of sand layers, large vertical oil and gas display span and large difference of stress between each set of sand layer and surrounding rock, in order to ensure that multiple sets of sand layers are effectively reconstructed, the separate layer fracturing technology is implemented. Before fracturing, the process can realize circulation fluid replacement, and after fracturing, it can realize combined production; (b) For the reservoir with poor physical properties and high formation pressure, which cannot realize the stratified fracturing of tubing packer, the casing bridge plug layered fracturing technology is adopted; (c) In view of the fact that the oil and gas reservoirs are mostly located in the upper part of the thick sand layer and the fractures extend downward to easily connect the water layer, the reservoir reconstruction technology of secondary sand addition is implemented; (d) In view of the poor physical properties of the reservoir, the oil and gas production after the vertical well fracturing is not high, or the initial oil and gas production is high, but the production decline is fast, unable to stabilize the production for a long time, the horizontal well multi-stage fracturing technology is implemented. The successful field application of the open hole packer ball sliding sleeve fracturing technology and the bridge plug perforation combined fracturing technology in horizontal wells is realized. The research and practical application of adaptive reservoir reconstruction technology further promote the reconstruction of Triassic low permeability conglomerate reservoir and single well production increase in Junggar Basin. It can be used for reference in other basins for low permeable conglomerate reservoir fracturing, and it presents good application value.

1. Introduction
The area of Junggar basin is about 130,000 square kilometers. The northwest margin and Mahu depression are located in the northwest of Junggar basin. Mahu depression is the most important hydrocarbon rich depression in the basin, and the northwest margin is the most favorable hydrocarbon
accumulation area in the basin (figure. 1). Karamay oilfield, Baikouquan oilfield, Hongshanzui oilfield, Urho oilfield and Xiazijie oilfield have been discovered successively, among which the Karamay oilfield is the first large oilfield in China found in Triassic conglomerate. In recent years, aiming at the continuous development of oil and gas exploration of Triassic sandy conglomerate, a large number of stratigraphic-lithologic oil and gas reservoirs have been found in Baikouquan formation of Triassic in the slope area of Mahu depression, represented by Mabei oilfield. Previous studies on hydrocarbon source rocks, structures and other reservoir forming conditions in the northwest margin of Junggar basin are relatively clear [1-4], and researches on the basic characteristics [5-6], diagenesis and its impact on physical properties of Triassic reservoirs have also been carried out [7-8]. The research results of low porosity and low permeability reservoirs are relatively rich, which has important guiding significance for the selection of favorable zones and the determination of drilling targets of Triassic in the northwest margin. However, in the later stage of evaluation and development, the reconstruction effect of the Triassic low porosity and permeability reservoir in Mabei oilfield is not ideal, resulting in the failure of effective production and benefit development. Although there are some attempts to develop low porosity and low permeability oil and gas resources at home and abroad, and the effect is good [9-10], most of them are for fine-grained clastic rock reservoir, the special fracturing and reconstruction technology of low porosity and low permeability sand and gravel reservoir in Baikouquan formation of Triassic in the northwest margin of Junggar basin is rarely mentioned, especially for various special reservoir conditions such as multiple sets of sand gravel layers superimposed, long vertical oil and gas display span, and large differences in stress of each set of sand gravel layer and surrounding rock, and so on, targeted reservoir fracturing and reconstruction technologies are under exploration. Based on the exploration and development practice of low porosity and low permeability glutenite reservoir reconstruction technology in Baikouquan formation of Triassic in Junggar basin, this paper systematically summarizes the fracturing reconstruction technology and countermeasures of low porosity and low permeability glutenite reservoir, with good effect and worthy of reference.

![Location map of study area](image)

**Figure 1. Location map of study area**

### 2. Geological Overview

A unified water body has been formed in the Triassic in Junggar basin, but the dry and hot paleoclimate in the Late Permian inherited and developed in the Early Triassic, which resulted in the distribution of coarse clastic sediments on the edge of the lake basin. The lower Baikouquan formation of the lower Triassic in Junggar basin is dominated by brown sandy conglomerate and pebbly sandstone, and the upper part is interbedded by pebbly argillaceous sandstone and brown and brown silty mudstone. The middle series in Karamay formation is composed of gray siltstone, argillaceous siltstone, silty mudstone and brown mudstone with unequal thickness. The Baijiantan formation of the upper series is generally gray mudstone, with a small amount of sandstone deposition at the bottom (figure. 2). The lower series
has only sedimentary distribution in the footwall of the front fracture, while the middle and upper series are widely distributed in this area.

Baikouquan formation of Triassic system was deposited on the unconformity surface after uplift and denudation at the end of Late Permian. Under the dry and hot paleoclimate background of subtropics, a section of massive reddish brown, variegated, grayish green and grayish white sandy conglomerate was deposited, with variegated, reddish brown, grayish green silty mudstone and medium fine sandstone locally. From the bottom to the top, the scale of conglomerate deposition decreases gradually, the grain size of conglomerate becomes finer, the color of conglomerate also changes from reddish brown to greyish green, and the sedimentary facies belt changes from fan delta plain to fan delta front, which shows a cycle of water progradation and retrogradation as a whole.

The Baikouquan formation of Triassic in the northwest ring of Mahu depression in Junggar basin develops fan delta sedimentary system, which can be divided into fan delta plain subfacies, fan delta front subfacies and channel microfacies in front subfacies. According to the results of drilled reservoir physical property analysis, the fan delta front subfacies are better than the fan delta plain subfacies, and the channel microfacies in the front subfacies are better than other microfacies. The reservoir lithology of Baikouquan formation in Triassic is mainly composed of glutenite and lithic sandstone, followed by conglomerate. The maturity of rock composition and structure is low. The whole reservoir is a typical low porosity and low permeability sand conglomerate reservoir with an average porosity of 7.69% and a permeability of 0.33mD. There are some "dessert" reservoirs with good porosity and permeability.

3. Reserve Characteristics
The Baikouquan formation of Triassic is mainly composed of sandstone conglomerate and lithic sandstone, mainly grayish green. The size of gravel varies, the maximum gravel diameter is 45mm, generally 2-40mm, mostly in sub circle shape, with poor sorting performance. The gravel is mainly composed of tuff and granite. The sandstone particles are sub-circular and sorted medium, and the sandy components are mainly tuff and debris. The braided channel in the fan delta plain is composed of conglomerate and sandy conglomerate, which are characterized by poor sorting, medium - poor rounding and high content of complex base.
The main pore types are intragranular solution pore, intergranular solution pore, microcrack, matrix solution pore and residual intergranular pore.

Rock composition is the basic factor to control the development of reservoir. In the area with developed rigid particles, the compaction is weak, the content of soluble minerals is high, the dissolution is strong, and the physical properties of the reservoir are good. Compared with the front subfacies, the fan delta plain subfacies have a higher degree of compaction, a higher content of complex base, a weaker dissolution, and a relatively poor reservoir physical properties; the compaction, cementation and dissolution in diagenesis also have a controlling effect on the reservoir physical properties. The first two are mainly diagenesis, which can reduce the reservoir performance. Dissolution can form intergranular and intragranular dissolution pores, which can improve the reservoir physical properties.

The definition of reservoir physical properties and its control factors has a strong guiding significance for the subsequent implementation of reservoir reconstruction technology.

4. Production Increase and Reconstruction Technology

The main factors affecting the production increase and reconstruction technology are the thickness of sand conglomerate reservoir, the superposition relationship, the configuration of sand mudstone and the stress difference of surrounding rock in Baikouquan formation of Triassic. In development practice, different reservoir conditions, location of oil and gas display, surrounding rock stress and low oil and gas production after vertical well fracturing should have corresponding stimulation measures and precautions. Now combined with the exploration practice of Triassic low-permeability conglomerate reservoir fracturing reconstruction technology in Junggar basin, different reservoir conditions correspond to different reconstruction technologies, which are described as follows for reference of peers.

4.1. Production Increase and Reconstruction Technology of Separate-layer Fracturing

In Baikouquan formation of Triassic system, there are many sets of sand layers with large span; the vertical oil and gas display and physical property are different greatly, and the stress of each set of sand layer and surrounding rock is different greatly. If most of them are compressed together, some of the sand layers may be completely reconstructed, and some of the sand layers cannot be effectively reconstructed. The principle of separate layer fracturing and layer selection: organic combination of oil and gas display, physical properties and longitudinal stress, fracturing and reconstruction of single set of sand body with good oil and gas display, good physical properties and small stress, so as to fully reconstruct each set of sand layer and improve the production rate of reservoir. At the same time, the plane stress and sand body distribution are combined to create effective long cracks.

4.1.1. Separate-layer Fracturing Technology of Atmospheric Pressure Layer. The sand layer span of Baikouquan formation of Triassic in the north slope area of Mahu depression is 60~80m, there are 2~6m mudstone intercalations between the upper and lower sand layers, and there are 1~4m thin mudstone Intercalations in the upper and lower sand layers, at the same time, it is more difficult to open multiple sets of sand layers. In order to ensure that many sets of sand layers can be effectively reconstructed, the separate-layer fracturing technology is selected in the development practice with good effect.

The separate-layer fracturing packer string is composed of the adapting pipe + Y441 fracturing packer (with setting ball seat) + level-1 fracturing sliding sleeve + Y441 fracturing packer + level-2 fracturing sliding sleeve + Y441 fracturing packer + level-3 fracturing sliding sleeve + Y441 fracturing packer + level-4 fracturing sliding sleeve + Y441 fracturing packer + hydraulic anchor + safety joint + kill valve (Figure. 3).
Figure 3 Schematic diagram of layered fracturing string

Y441-114 packer adopts the way of hydraulic seat sealing, two-way anchoring, lifting and lowering the pipe string to work step by step. When the packer goes down to the design well depth, hydraulic pressure is added from the oil pipe, and the hydraulic pressure is transmitted to the hydraulic cylinder through the pressure transmitting hole of the central pipe, which pushes the lower piston down, spreads out the slip and anchors it on the pipe sleeve, and at the same time, the piston goes up to compress the sealing oil sleeve annulus of the packer. When it is necessary to unseal, lift up the string, and the central pipe goes up with the string. Cut and unseal the shear pin, release the packer, and then go up. The slip is separated from the casing, and the packer is unsealed. The specific construction process is as follows:

(1) Tool entry: connect the tool to the designed position according to the design requirements, calibrate the tool entry position, sit on the wellhead, and replace the kill fluid in the tubing.

(2) Packer seat sealing: throw 25 mm steel ball from the wellhead, wait for the steel ball to be in place, pressurize the tubing for 10, 15, 20, 25 and 30 MPa respectively for 3 min, and when the pressure continues to reach 32~35 MPa, knock the ball seat out to the receiving pipe.

(3) Fracturing: the method of throwing ball to open the fracturing sliding sleeve is adopted to conduct fracturing step by step from bottom to top.

(4) Unsealing: lift the string 80~110kN, unseal the highest level fracturing packer firstly, then salvage by stages and unseal the packer.

The technology has the following characteristics: (a) it can achieve 5 layers of fixed string fracturing, which can realize combined production after fracturing; (b) the packer adopts hydraulic setting mode, which can realize circulating fluid replacement before fracturing and effectively prevent reservoir pollution; (c) the string can realize disconnection and staged salvaging, which improves the safety of the string.

In the development practice, 15 well tests were carried out on site, with 4 layers at most. The maximum sand inflow of single layer is 70m³, the maximum construction pressure is 68MPa, the maximum depth is 3304m, and the success rate is 100%.
4.1.2. Separate-layer Fracturing Technology of Casing Bridge Plug. The reservoir physical properties of Baikouquan formation of Triassic in the west slope area of Mahu depression are poor, and the oil and gas production is not high. However, the formation pressure is relatively high, with a pressure coefficient of 1.6~1.74, and oil and gas will be produced after perforation; since the formation continuously produces oil and gas, it is necessary to lift the perforating gun and lower the fracturing string to kill the well with mud, which will not only pollute the oil layer, but also cause no way to replace the mud in the wellbore after running the separate-layer fracturing packer in the tubing, and the separate-layer packer will not be raised after mud sedimentation, which will lead to engineering accidents. Therefore, this kind of reservoir cannot achieve the purpose of separate-layer fracturing reconstruction of tubing packer. In the development practice, the high-pressure reservoir in the west slope area of Mahu depression can achieve the purpose of separate-layer fracturing by selecting perforation and bridge plug tools.

Principle of casing bridge plug separate-layer fracturing technology: the wellhead blowout prevention equipment can achieve cable perforation with pressure, and the perforating gun can be put forward if the pressure in the wellbore rises after the first section of perforating. After perforating, the first section will be fractured. After fracturing, the bridge plug with pressure and penetration rate will be put in. The second section will be perforated and then the second section will be fractured. By analogy, numerous stages of perforation and fracturing can be realized in theory. Bridge plug with single flow valve can realize combined production after fracturing. If sand is produced in the wellbore, the coiled tubing can be run to drill out the bridge plug of the wellbore, so as to ensure the smoothness of the wellbore.

In the development practice, 4 wells in the west slope area of Mahu depression selected this separate-layer fracturing tool, and the fracturing operation was carried out efficiently and safely. After fracturing, high-yield industrial oil and gas flow were obtained, and the daily oil production was much higher than that of the adjacent wells with large-scale fracturing measures.

4.2. Secondary Sand Reconstruction Technology
In addition to the above-mentioned separate-layer fracturing technology, the Triassic reservoir reconstruction in the west slope area of Mahu depression also faces the following two difficulties in order to fully reconstruct the reservoir and improve the productivity: first, the reservoir thickness is large, the main oil and gas reservoir is located in the upper part of the reservoir, and the fracture has the trend of downward extension. In addition, the long formation closure time and the proppant settlement affect the reconstruction effect of the main oil and gas reservoir in the upper part; second, there is no high stress barrier layer in the longitudinal direction, the fracture height is easy to lose control, and there is a risk of connecting the water layer.

For the above difficulties in the reconstruction of Triassic glutenite reservoir, the reservoir reconstruction technology of secondary sand is proposed. The secondary sand fracturing is to add the designed total sand amount into the oil layer through a reasonable secondary pump. After the first fracturing, stop the pump, wait for the proppant to settle and the fracture to close, and then carry out the next fracturing, and lay it step by step to achieve the purpose of fully reconstructing the oil layer. Figure 4 is the schematic diagram of multistage sand fracturing effect. The proppant sand dike formed in the first fracturing can provide a certain stress shelter for the next fracturing.
The secondary sand has the following two characteristics:

(1) Filling fracture and improving fracture conductivity

Conventional sand fracturing, due to proppant settlement and other reasons, often leads to the upper part of the fracture proppant filling is not solid and become invalid fracture. The secondary sand fracturing can further fill the fracture, make the effective fracture height larger, and increase the fracture width, increase the conductivity of the fracture, and extend the validity of the fracture.

(2) Controlling crack to extend downward

After the first sand addition, the proppant will move to the bottom of the fracture and form a stable shelter layer at the bottom. This has the same effect as the former sinking agent used to control the seam height. Moreover, since the amount of sand added for the first time is much larger than that of the conventional sinking agent, if the net pressure of sand added for the first time is properly controlled, the effect of controlling the height of the joint can be better achieved, so as to ensure that the fracture will not extend downward when secondary sand. The main function of secondary sand is to force the proppant to be placed upward to improve the fracture conductivity of the upper part of the oil layer, and to change the in-situ stress state, control the fracture height expansion and increase the fracture length. For the Triassic sand conglomerate reservoir in the north slope area of Mahu depression, it is necessary to increase the placement of proppant in the longitudinal direction of the fracture and ensure the fracture length. The technical advantage of secondary sand is particularly obvious.

The reservoir reconstruction technology of secondary sand effectively solves the two problems, one is that the oil and gas reservoir is located in the upper part of the reservoir and the fracture extends downward, the other is that the fracture height is easily out of control to connect the water layer, so as to fully reconstruct the reservoir and improve the productivity. The daily oil production of secondary sand is significantly higher than that of adjacent wells with primary sand, and the fracturing effect of production increase is obvious (figure 5).
4.3. Staged Fracturing Technology of Horizontal Well

In the development practice, due to the poor physical properties of Baikouquan formation reservoir in Triassic, the oil and gas production after vertical well fracturing is not high, or the initial oil and gas production is high, but the production decline is fast, so the long-term stable production cannot be achieved. According to the characteristics of reservoir and completion mode of horizontal wells, it is urgent to explore the multi-stage fracturing technology of horizontal wells. The horizontal well reconstruction technology of the Triassic ultra-low permeability reservoir in Mahu depression is mainly the horizontal well open hole packer ball sliding sleeve fracturing technology and the multi-cluster perforation combined fracturing technology of the casing bridge plug.

4.3.1. Horizontal Well Open Hole Packer Ball Sliding Sleeve Fracturing Technology. (1) The technology of transferring fiber to primary multi fracture in open hole well

Horizontal well multi-stage fracturing is to form multiple fractures perpendicular to the wellbore, so as to increase the drainage area of the reservoir and increase the oil and gas production of a single well. Theoretically, the larger the number of fractures, the larger the drainage area, the higher the single well production. However, due to the limitation of fracturing stages of open hole packer and the small difference of stress in horizontal section, the technology of fiber transfer to one stage and multiple fractures is explored in the horizontal well completed by open hole packer.

The experiment of fiber transferring fracturing was carried out in the laboratory. The first fracturing formed two fractures near the north-south direction on the artificial core. At the end of the first fracturing, high concentration fiber was added, and the fracturing was carried out again after stopping the pump for 10 minutes. The second fracturing formed a fracture near the south-west direction. The laboratory experiment proved that the temporary plugging in the fiber fracture can improve the net pressure in the fracture and form the steering fracture.

In the development practice, the technology of transferring fiber to primary multi fracture is to carry out secondary sand in the same open hole section, to temporarily block the fracture port by adding high concentration fiber carrying sand at the end of sand in the first stage of fracturing, to carry out the second fracturing in the same open hole section after stopping the pump for 60 minutes, and the fracturing fluid will start from the relatively weak internal stress in the open hole section after entering the formation.

The minimum horizontal stress in the horizontal section of X92_H well is less than 0.3MPa. The technology of transferring fiber to primary multi fracture is adopted. At the end of sand addition, high concentration fiber is added for temporary plugging, and the fiber concentration is increased from 2-4kg/m³ to 10-12kg/m³. In order to reduce the risk of sand plugging, the sand concentration is reduced from 600kg/m³ to 240kg/m³. According to the electrical monitoring data, 23 fractures have been formed in the 12 stage fracturing (figure. 6), basically achieving the purpose of forming 2 fractures in the same open hole section.
(2) The technology of crack height control by artificial barrier

The second section of Baikouquan formation in Triassic system, the target interval of fracturing reconstruction, has a sand layer thickness of more than 30m. The oil and gas display is mainly in the sand layer about 10m on the top. The whole set of sand layer has no high stress shelter layer, and the horizontal section passes through the top of the sand layer. In order to control the fracture height, the fracturing sand should be added to the oil reservoir at the top of the reservoir as much as possible. In the fracturing operation, the technological measures such as low mucus and reduced displacement should be selected. At the same time, the artificial barrier should be used to develop fracture height technology. The technology of crack height control by artificial barrier is to use low mucus to carry composite small particle size (100~200 meshes) sinker into the formation before injecting sand carrying fluid. The sinking agent sinks at the bottom of the fracture to form a low permeability or non-permeability artificial barrier, which increases the stress difference between it and the reservoir and controls the increase of the fracture height.

4.3.2. Multi-cluster Perforation Combined Fracturing Technology of the Casing Bridge Plug

With the promotion of horizontal wells in tight oil, the staged fracturing technology of horizontal wells is mainly based on multi-stage crosscutting fractures, which can improve the overall seepage capacity of the horizontal section and improve the reconstruction volume. The fracturing technology of horizontal well hydraulic pump in fast drilling bridge plug is characterized by reliable sealing, unlimited staged fracturing stages and accurate fracture distribution.

Fracturing reconstruction should be carried out after perforation of horizontal well with casing completion. In order to maintain the reasonable spacing of the artificial fractures in the horizontal section, it is necessary to control the starting point of the artificial fractures. The perforated section is relatively short, mostly 0.5-1m. Therefore, the friction of the perforated hole is very large, and the construction pump pressure can be increased by 30-40MPa. For this reason, the soil acid (formula composition: 15% HCL+2% HF +2% corrosion inhibitor +0.3% drag reducer +1% drainage aid +1% demulsifier +3% clay stabilizer) is selected for acidizing pretreatment, and the construction pump pressure is greatly reduced. The construction displacement of X92_H well is 3m³/min, the construction pump pressure is 63.5-61.5MPa, the construction pump pressure drop to 25.9MPa after the acid enters the formation, and the fracturing construction is carried out smoothly.

Casing bridge plug perforating fracturing technology can use coiled tubing to drill off the bridge plug in the well after fracturing, which can not only ensure the smooth flow of oil and gas in the well bore, but also implement production logging and other technologies to evaluate the fracturing effect.
A total of 3 times of horizontal well fracturing reconstruction were carried out on the site, including 2 times of open hole packer ball sliding sleeve fracturing and 1 time of bridge plug perforation combined fracturing. After fracturing, the trial production can be basically stable for a long time, and a relatively ideal production has been achieved (Table 1).

### Table 1. Fracturing construction statistics of horizontal wells in Baikouquan formation of Triassic in slope area of Mahu depression

| Well number | Fracturing method | Process technology | Fracturing stage | Intake fluid volume (m³) | Intake sand volume (m³) | Daily oil production (m³) | Cumulative oil production (m³) | Stable production time (d) |
|-------------|------------------|--------------------|------------------|--------------------------|--------------------------|---------------------------|-----------------------------|--------------------------|
| X91_H       | Open hole packer | Fiber steering     | 12               | 5310                     | 657.7                    | 27-17                     | 2600                        | 150                      |
| X92_H       | Perforation bridge plug | Multi cluster perforation and fracturing | 13               | 6696                     | 658.8                    | 27-15                     | 1000                        | 60                       |
| M132_H      | Open hole packer | Secondary sand addition | 12               | 5659                     | 672.9                    | 40-25                     | 6000                        | 230                      |

### 5. Conclusion

On the basis of geological knowledge, the reservoir characteristics and control factors of Baikouquan formation in Triassic are further clarified, the mechanism of artificial fracture propagation is studied, and 4 kinds of adaptive reservoir reconstruction technologies for low permeability conglomerate reservoir are explored, which effectively improves the single well production and realizes the increase of storage and production in conglomerate reservoir exploration.

1. For the reservoir conditions of multiple sets of sand layers, large vertical oil-gas display span and large difference of stress between each set of sand layer and surrounding rock, in order to ensure effective transformation of multiple sets of sand layers, the separate-layer fracturing technology is implemented, which can realize circulation fluid replacement before fracturing and combined production after fracturing;

2. For the reservoir with poor physical properties and high formation pressure, which cannot realize the stratified fracturing of tubing packer, the casing bridge plug separate-layer fracturing technology is adopted;

3. For the fact that the oil and gas reservoirs are mostly located in the upper part of the thick sand layer and the fractures extend downward to easily connecting water layer, the reservoir reconstruction technology of secondary sand is implemented;

4. For the poor physical properties of the reservoir, the oil and gas production after the vertical well fracturing is not high, or the initial oil and gas production is high, but the production decline is fast, unable to stabilize the production for a long time, the horizontal well multi-stage fracturing technology is implemented. The successful field application of the horizontal well open hole packer ball sliding sleeve fracturing technology and bridge plug perforation combined fracturing technology are realized.

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