Genesis of the low-permeability reservoir bed of upper Triassic Xujiahe Formation in Xinchang gas field, western Sichuan Depression

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Abstract: The genesis of a reservoir is a result of the combined action of deposition, diagenesis, tectonic reworking, and interaction of rock and fluid and the evolutionary environment. We discuss the genetic and evolution mechanism of a low-permeability reservoir bed of the Xujiahe Formation in the western Sichuan Depression on the basis of the study of diagenesis, diagenetic reservoir facies and the diagenetic evolution sequence. The research indicated that this reservoir bed can be divided into five types of diagenetic reservoir facies, namely strong dissolution, chlorite-lined intergranular pores, compaction and pressure solution, carbonate cementation and secondary quartz increase. There are, however, just two diagenetic reservoir facies which provide low-permeability reservoir beds, namely strong dissolution and chlorite-lined intergranular pores. We also analyzed their diagenetic evolution sequences and the origin of the low-permeability reservoir bed. Besides, it was also indicated that the composition and structure of sandstones, types of sedimentary microfacies, diagenesis history as well as the tectonic reworking in later periods are the main factors controlling the formation of the low-permeability reservoir bed. The above-mentioned factors establish the foundation for the forecasting the distribution of high quality reservoir beds.

Key words: Low-permeability reservoir, diagenetic reservoir facies, Xujiahe Formation, upper Triassic, Xinchang gas field, western Sichuan Depression

1 Introduction

In the western Sichuan Depression, in the upper Triassic Xujiahe Formation thick bedded sandstone were deposited in blocks and medium-to-thick bedded siltstone in layers as well as finely laminated mudstone. There was a river delta depositional system in the Xujiahe Formation. In the Xinchang gas field of the western Sichuan Depression, the Xujiahe Formation is mainly braided river delta front subfacies. It is further divided into five sedimentary microfacies: underwater distributary channel, mouth bar, underwater interdistributary bay, distal bar and sand sheet. The reservoir beds of the Xujiahe Formation are mainly developed in the Xujiahe second member (T_3x^2) and the Xujiahe fourth member (T_3x^4). The varieties of sandstones primarily include litharenite, lithic quartzarenite, feldspathic lithic quartzarenite, lithic feldspathic quartzarenite, calcarenaceous sandstone. The sandstones in which gas might accumulate are litharenite, lithic quartzarenite, feldspathic lithic quartzarenite and calcarenaceous sandstone. The reservoir bed quality is characterized by low porosity and low

permeability. The porosity is 1%-10% and the permeability is $0.5 \times 10^{-3} \mu m^2$, so the reservoir bed is a super low-porosity and low-permeability one. Lü (2005), Zhu (1999), Zhu et al (2001) and Zeng et al (2005) think that sandstone is developed in the Xujiahe Formation, but relatively high quality reservoir beds are few. The distribution of sandstone is extremely non-uniform both areally and in the vertical direction. The advantageous reservoir beds are distributed throughout the thick sandstone in the vertical direction, and are controlled by sedimentary microfacies, diagenesis and fracture development caused by tectogenesis. As to the primary pores preservation, further analysis is needed as follows: 1) origin of chlorite growth; 2) the reason why the primary pores preservation of part of the Xujiahe second member is better than that of the Xujiahe fourth member, which is 1000m shallower than the Xujiahe second member; 3) origin of primary pores growth in calcarenaceous sandstone; 4) the relationship between hydrocarbon infill and pores preservation. As to the formation of secondary porosity, further analysis is needed as follows: 1) the determination of the key dissolution phase amongst many dissolution phases; 2) the main controlling factor of denudation intensity; 3) the effective preservation of dissolution porosity. In this paper, we take the upper Triassic Xujiahe Formation in the Xinchang gas field, western Sichuan Depression as an example, then consider diagenetic reservoir

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facies as the key clue and discuss the genetic mechanism and controlling factors of the low-permeability reservoir beds in the Xujiahe Formation through an integrated study of sedimentary microfacies, lithogenesis and their diagenetic evolution sequences.

2 Types and characteristics of diagenesis

We examined 1219 cuttings samples, undertook 200 scanning electron microscope examinations of samples from 3 wells, and performed cathodoluminescence analysis on 54 samples of 3 wells of 8 coring key wells in the Xujiahe Formation. From this work we know that there are mainly three kinds of diagenesis, namely compaction and pressure solution, authigenic mineral cementation and dissolution in the formation process of the reservoir beds in T_3x^4 and T_3x^2 .

2.1 Compaction and pressure solution

2.1.1 Mechanical compaction

Mechanical compaction in the Xujiahe fourth and second members mainly occurred in the early diagenetic phase, and the main manifestation is as follows: 1) The plastic deformation of plastic grains such as phyllite and mudstone etc.; 2) The flexural deformation, rupture and undulatory extinction of micaceous lamellar minerals; 3) The local breaking and dislocation of stiff grains, such as quartz and feldspar; 4) The contact intensity between the grains increases along with the enhancement of compaction, and the contact relationship is from point contact to line contact and from line contact to concave-convex contact.

2.1.2 Pressure solution

Pressure solution mainly occurred in the middle diagenetic phase. Dissolution occurred at the contact point or the contact interface of quartz particles and the dissolved silica was reprecipitated, which formed secondary enlargement of quartz or intergranular authigenic quartz. The grains assumed a mosaic-like structure to contact closely, which resulted in increasing compactness of the reservoir bed.

2.2 Cementation

The common cementing material in the reservoirs of the Xujiahe fourth and second members include carbonate, siliceous and clay minerals. The content of carbonate mineral is high, the siliceous mineral content is relatively high and clay mineral content is comparatively low.

2.2.1 Carbonate mineral cementation

Carbonate minerals are the most common and universal authigenic minerals in the Xujiahe Formation. The types of carbonate minerals include calcite, ferroan calcite, dolomite and ankerite, and their forms of occurrence are pores fillers or selective replacement of fragments.

1) Calcite: Early stage, calcite is non-ferroan. It fills intergranular pores with macrocrystalline, megacrysts or intergrowths, or replacement of the fragments. The precipitation temperature of calcite cement ranges approximately from 53°C to 66°C in the top of the Xujiahe fourth member, which was formed in the early diagenetic A phase. Late stage calcite fills intergranular pores and secondary dissolved pores with medium-crystalline and finely

crystalline ferroan calcite. The formation temperatures of calcite from the isotopic temperature equation are 127.8°C and 104.9°C, which was formed in the early stage of the late Jurassic and the last stage of the middle Jurassic, respectively. It is up to middle diagenetic B phase. The compound staining calcite is red, and ferroan calcite is mauve, while they cathodoluminescence crocus and yellowish-orange respectively.

2) Dolomite: Dolomite and ankerite fill pores with euhedral crystal to subhedral crystal, or replacement fragments. The compound staining ankerite is blue. The replacing ankerite surrounds the ferroan calcite, and does not cathodoluminescence. The precipitation temperature of dolomite cement ranges approximately from 117°C to 164°C in the sandstone of the Xujiahe second member, which was formed in the middle diagenetic A and B phases.

2.2.2 Siliceous cementation

Four kinds of siliceous cement occur: 1) The edge of secondary enlargement, which shows no cathodoluminescence. The formation temperature of quartz at the secondary edge generally is 70°C to 88°C, which was formed in the early diagenetic phase B and middle diagenetic phase A; 2) Filling residual intergranular pores, associated with chlorite or euhedral crystals of chlorite. It sometimes fills together with bitumen. The inclusion temperature of the filling quartz which was formed in the early diagenetic phase B in residual intergranular pores of the Xujiahe second member is 76°C; 3) Filling intragranular dissolved pores; 4) Filling intergranular dissolved pores. The kaolinite from the Xujiahe second member is mainly distributed below the 4000m level. The kaolinite mainly exists in the reservoir beds of the Xujiahe fourth member, and is not found in thin section and scanning electron microscope examination of samples from the Xujiahe second member. The relative content of kaolinite is 11%-31% with hexagonal crystals, vermicular and book aggregation. It fills the intragranular dissolved pores and intergranular dissolved pores or adheres to particle surfaces in flake shaped. The kaolinite cathodoluminescences indigo under the microscope.

2.2.3 Hydrosialite cementation

X-diffraction analysis of samples from three wells X853, CX560 and CX565 shows the clay minerals of the Xujiahe fourth and Xujiahe second members mainly include illite with lesser chlorite. Kaolinite is mainly distributed in the Xujiahe fourth member, and there are slight illite/montmorillonite mixed-layers in other areas, with a mixed ratio less than 10%.

1) Illite: It is widely distributed accounting for 26%-100% of clay minerals. Illite fills pore spaces or grows around particle edges with shapes of platy, needle, or cluster and replaces the fragments. Illite often grows in association with authigenic kaolinite and authigenic quartz, and it often grows on the surface of kaolinite in flake or needle shaped. The stability of illite is high, but the feldspar grains could dissolve to produce Si^{4+} , Al^{3+} and K^+ which form illite, authigenic quartz and authigenic kaolinite in an acidic aqueous environment. The dissolution of K-feldspar in later periods may cause the environment to favor illite precipitation.

2) Chlorite: The absolute content of chlorite is low, generally less than 2% in this area, while its relative content is

high, which is only less than illite. It accounts for 11%-74% of clay minerals (possibly including some land-derived chlorite). Authigenic chlorite includes two kinds of occurrences, namely pore lining and pore filler. The characteristics of pore lining chlorite are that crystals with acicular shape grows to the center of pore space in the direction vertical to the pore surface and then forms drusy texture. The crystal grows with micro-laminated shape and its pellicle is thin, whose thickness generally ranges from 2 to 10 μm , and a few are up to 15 μm . The characteristics of pore-filling chlorite are that a compound of chlorite and hydromica fills intergranular pores, and it often intergrows with authigenic quartz.

2.3 Dissolution

Any detrital grain, mixed matrix, cement and metasomatic mineral including most stable quartz and siliceous cement may dissolve under certain diagenetic environments. Dissolution is another key element which decides reservoir bed quality in the Xujiahe Formation. It can form secondary pores and improve the quality of the reservoir bed. The intragranular dissolved pores, intergranular dissolved pores and molding pores in this area are the results of dissolution. The most common phenomenon is the dissolution of feldspar, next is the dissolution of lithic fragments, quartz and interstitial matter. Secondary porosity caused by dissolution is the most important constructional diagenesis in the reservoir beds of the Xujiahe Formation.

The observation of cast sections shows that feldspar is dissolved in fenestra shapes. This forms intragranular dissolved pores. Some feldspar dissolves intensively, even dissolve completely to form molding pores. The dissolution of lithic fragments is rare and weak, and many lithic fragments dissolve partly, thus forming intragranular dissolved pores. In sandstones of the Xujiahe Formation, we can sometimes see some weak intragranular dissolution in quartz grains. Corroded authigenic quartz which fills intergranular pores is common as well as the corroded quartz fringe or solution quartz. After the analysis of thin sections and scanning electron microscopy, we know that the dissolution of the Xujiahe second member is weak, and is obviously weaker than that of the Xujiahe fourth member.

3 Diagenetic reservoir facies

The concept of diagenetic reservoir facies of reservoir beds has experienced more than ten years of development since it was proposed (Xiong et al, 1991; 1994; Xiong, 1993). Different scholars have done fruitful research from different perspectives in different areas. These include Xu et al, 1994a; 1994b; Liu et al, 2002; Huang and Dou, 2002; Song et al, 2004; Li et al, 2004; Li and Peng, 2007a; 2007b; Song et al, 2006; 2007; Zhou et al, 2006; Xue et al, 2006; Xue and Cheng, 2007 and Zou et al, 2007. Research on diagenetic reservoir facies has developed quickly in recent years, and has become an important domain in the reservoir bed research. According to petrologic characteristics, sedimentary microfacies, diagenesis types, apparent compaction rate, apparent cementation rate, diagenesis coefficient, combination of reservoir space, porosity, permeability and so on, the

reservoir beds of the Xujiahe Formation can be divided into five categories of diagenetic reservoir facies. As shown in Table 1, they are named as follows: strong dissolution, chlorite-lined intergranular pores, compaction and pressure solution, carbonate cementation and secondary quartz increase. In these facies, only strong dissolution and chlorite-lined intergranular pores are conducive to the formation of relatively high quality reservoir beds.

4 Characteristics of diagenetic evolution sequences

Diagenetic evolution is the dynamic modality in a diagenetic process (Zhang et al, 1997; Alaa M et al, 2000; Liu and Dou, 2003; Zhu et al, 2004; Liu et al, 2005; Jiang et al, 2007). It is the manifestation of burial depth, geothermal gradient, tectonic setting, types of sedimentary facies, diagenetic media condition and other factors. Through the diagenetic evolution sequence, we can sum up the evolutionary trend, evolutionary method and evolutionary result of diagenetic reservoir facies in the process of diagenesis. Different diagenetic reservoir facies have different diagenetic evolution sequences. In this article, we only elaborate the diagenetic evolution sequences of two kinds of diagenetic reservoir facies which are the typical representatives of the Xujiahe second member and the Xujiahe fourth member.

4.1 Diagenetic evolution sequence of strong dissolution

According to the observation of the characteristics under the optical microscope and a scanning electron microscope, cathodoluminescence observation and inclusion homogenization temperature, we think that the relative order of the main diagenetic events in strong dissolution diagenetic reservoir facies can be identified as follows (Fig. 1): chlorite liner $\rightarrow$ early corrosion by atmospheric freshwater $\rightarrow$ authigenic kaolinite $\rightarrow$ secondary enlargement $\rightarrow$ acidic dissolution of coal measure strata $\rightarrow$ authigenic quartz (intergranular vugular-solution pores, intragranular vugular-solution pores) $\rightarrow$ calcite and dolomite $\rightarrow$ organic matter maturation acidic water solution $\rightarrow$ authigenic quartz $\rightarrow$ ferroan calcite and dolomite. Rock types mainly are feldspathic lithic arenite and lithic arkose. Original rocks with a high content of feldspar and lithic fragments have better sorted, low-level matrix content, point to line particle contact, and moderate-strong compaction. Intergranular cements are mainly quartz, a small amount of chlorite and kaolinite. With strong dissolution, soluble components commonly dissolved to form all kinds of secondary dissolution pores, feldspar partly dissolved to form intragranular dissolution pores, and completely dissolved to form molding pores, and intergranular matrix, cement and particulate margin dissolved to form intergranular dissolution pores or super large dissolution pores. Reservoir spaces are mainly secondary dissolution pores, as well as the combination of intragranular dissolution pores, intergranular dissolution pores, molding pores, super large dissolution pores and caulking intergranular micropores.

Strong dissolution diagenetic reservoir facies forms the best reservoir beds in the region, in which porosity is more than 7%, and permeability ranges from 0.05 to $0.5 \times 10^{-3} \mu\text{m}^2$. Microfacies are mainly mouth bar, secondly underwater distributary channel, all of which are mainly distributed in the Xujiache fourth member.

4.2 Diagenetic evolution sequence of chlorite-lined intergranular pores

Different from strong dissolution diagenetic reservoir facies, the relative order of the main diagenetic events of chlorite-lined intergranular pores diagenetic reservoir facies can be identified as follows (Fig. 2): chlorite pore lining → quartz secondary enlargement → acidic dissolution of coal measure strata → authigenic quartz (quartz is filled in residual intergranular pores) → late carbonate cementation (mainly dolomite, calcite next) → organic matter mature acidic water solution → authigenic quartz (cave type, oversized pore type) → late alkaline water erosion and so on. Rock types

are mainly lithic quartzitic sandstones. Original rocks with a high content of quartz, feldspar and other rigid particles have better sorted, low-level matrix content, point to line particle contact and moderate-strong compaction. On the margin of the original intergranular pores, there was chlorite-lining, and the pores became narrow after compaction, then authigenic quartz filled the pores, and late quartz dissolved into intergranular cement dissolution pores. With moderate dissolution, soluble components commonly dissolved to form secondary dissolution pores, feldspar and lithic fragments dissolved to form intragranular dissolution pores, and intergranular matrix, cement and particulate margin dissolved to form intergranular dissolution pores. Reservoir spaces are mainly intergranular dissolution pores and micro-cracks, as well as a small amount of residual intergranular pores and intragranular dissolution pores. Chlorite-lined intergranular pores diagenetic reservoir facies is the better reservoir bed in the region, and its porosity is more than 4% and permeability ranges from 0.05 to $0.5 \times 10^{-3} \mu\text{m}^2$. Microfacies are mainly

Table 1 Types and characteristics of diagenetic reservoir facies of Xujiache Formation in the Xinchang gas field

Diagenetic reservoir facies	Strong dissolved diagenetic reservoir facies	Chlorite-lined intergranular pores diagenetic reservoir facies	Compaction and pressure solution diagenetic reservoir facies	Carbonate cementation diagenetic reservoir facies	Secondary quartz increase diagenetic reservoir facies
Rock types	Feldspathic litharenite Lithic arkose	Lithic quartzarenite	Litharenite	Feldspathic litharenite Lithic arkose	Feldspathic lithic quartzarenite Feldspathic quartzarenite
Contact relationship between particles	Point-line contact	Point-line contact	Pressure-inlay	Point contact Pore-cementation	Pressure-inlay
Main microfacies	Mouth bar Distributary channel	Mouth bar Distributary channel	Distal bar Sand sheet Interdistributary bay	Distributary channel Interdistributary bay Distal bar Sand sheet	Distributary channel Distal bar Sand sheet
Main diagenesis	Dissolution	Chlorite-lined cementation Quartz dissolution in intergranular pore	Compaction Pressure solution	Carbonate cementation metasomatism	Quartz secondary enlargement Autogenic quartz filling
Secondary diagenesis	Compaction Cementation	Compaction Cementation	Cementation	Compaction	Compaction Cementation
Apparent compaction rate %	60-70	70-90	>90	<40	70-90
Apparent cementation rate %	10-30	30-50	<20	>50	<20
Diagenesis coefficient %	>2	1-4	<1	<1	<1
Reservoir space composition	Intergranular pores Intragranular pores Molding pores Super dissolved pores Interstitial material between the microporous crystalline	Intergranular cement dissolved pores Residual intergranular pores Intragranular dissolved pores Microfracture	A very small amount of intragranular dissolved pores	A very small amount of intragranular dissolved pores	A very small amount of intragranular dissolved pores
Porosity, %	>7	>4	<2.0	<2.0	<2.0
Permeability, $\times 10^{-3} \mu\text{m}^2$	0.05-0.5	0.05-0.5	<0.008	<0.008	<0.008
Reservoir performance	Reservoir	Reservoir	Dense layer	Dense layer	Dense layer

Fig. 1 Diagenetic evolution sequence of strong dissolved diagenetic reservoir facies

mouth bar, secondly underwater distributary channel, all of which are mainly distributed in the Xujiache second member.

5 Discussions

Through the investigation of cuttings from key wells in the Xujiache Formation with optical microscopy, scanning electron microscopy and cathodoluminescence analysis, we think that there are mainly three kinds of diagenesis, namely compaction and pressure solution, authigenic mineral cementation, and dissolution in the Xinchang gas field during the formation process of the reservoir bed.

During the early diagenetic stage, grain contact in the reservoir bed is point contact first, then line contact, last concavo-convex contact with stronger and stronger mechanical compaction. Therefore, the intergranular porosity decreases and the reservoir bed becomes tight. In the middle diagenetic stage, pressure solution is the main diagenesis, dissolved matter is carried from the grain contact point by diffusion, and the arrangement mode of grains ranges from point/line contact to concavo-convex/suture contact with

increasing burial depth. After compaction, there are many types of diagenesis, such as carbonate cementation, siliceous cementation and clay mineral cementation in the intergranular pores space of clastic grains. Owing to the cementation, sediments in the reservoir bed further transformed to sedimentary rocks, resulting in decreasing intergranular space, which caused poor reservoir quality. After compaction and pressure solution as well as autogenic mineral cementation, clastic grain, miscellaneous matrix, cement material and replacement minerals dissolved in different degrees and formed intragranular pores, intergranular pores, molding pores and so on, which resulted in the growth of secondary porosity, and thus improved the quality of the reservoir bed to a certain extent.

From the diagenetic features mentioned above, we conclude that mechanical compaction, pressure solution and cementation could decrease porosity and permeability with increasing burial depth. The inhomogeneous corrosion and dissolution could generate some secondary pores, even generate induced pores development belts at different depths,

Fig. 2 Diagenetic evolution sequence of chlorite-lined intergranular pores diagenetic reservoir

and thus improved the quality of the reservoir bed. In general, diagenesis mainly influenced the reservoir quality in two ways: first, compaction decreased reservoir bed porosity and worsened reservoir bed quality; second, dissolution generated secondary pores, which increased reservoir bed porosity and improved reservoir bed quality.

According to the genesis and evolutionary mechanisms of low-permeability reservoirs described above, we conclude that the controlling factors of low-permeability reservoirs mainly comprise the structure and composition of sandstone, sedimentary microfacies, diagenesis and tectonization.

5.1 Structure and composition of sandstone are the basis of forming low-permeability reservoir beds

From the influence of the composition and structure of sandstones, the main factors which affect the quality of a reservoir bed are composition, size grade and sorting (Shou et al, 2006). When the content of a stable component that is to say quartz increases and the sandstone's component maturity increases and matrix and cement is eliminated greatly

after long-distance transportation. Because of relatively concentrated quartz, preferable gradation and psepchicity of grains and higher textural maturity, this environment is favorable for forming a high quality reservoir bed. But when the content of an unstable component, i.e. feldspar or lithic fragments, is high, which means sandstone's component maturity is low, matrix and cement is still present in large amount after transportation. Owing to the complexity of the arenite's mineral component, disaggregation of quartz, poorly rounded and poorly sorted, and lower textural maturity, it is easy to form low-permeability reservoir beds.

Through analysis, we know that the main rock types of the Xujiahe Formation are quartz sandstone and lithic quartz sandstone. The quartz content is between 60% and 90%, the feldspar content is 2%-6%, the lithic fragments content is 10%-40%, and the interstitial material content is 2%-12%. In this area, the mineral composition is complex, and the compositional maturity of sandstone is low. The sandstone granularity of the reservoir bed is mainly from medium-grained sand to fine sand, the particle sorting is

ordinary, psephicity is mainly subangular shape and the textural maturity of sandstones is low. From the structure and composition, we can see that the reservoir bed of the Xujiache Formation does not have the material condition of high porosity and high permeability. But the presence of lithic fragments at a relatively high concentration provides the material base of lyotrope for the late occurrence of advantageous diagenesis and provides the effective accommodation space for the formation of secondary pores. Thus it is advantageous for the formation of a low-permeability reservoir bed.

5.2 Types of sedimentary microfacies are the conditions of forming low-permeability reservoir beds

Sedimentary microfacies play an important role on the development and distribution of reservoir rocks. It not only constrains the thickness and scale of reservoir and spatial distribution characteristics macroscopically, but also determines the particle size of sedimentary rocks, the amount of interstitial content and the quality of the rock structure from a microscopic aspect. Thus it controls the quality of the rock's original porosity and original permeability.

5.3 Diagenesis is the internal cause of forming low-permeability reservoir beds

Diagenesis plays a key role in the formation, destruction and reconstruction of porosity and permeability during the formation and evolution process of the low-permeability reservoir bed. Cementation, compaction and pressure solution resulted in stronger surface durability of clastic particles, and destroyed the original porosity of the reservoir bed. Thus it made the reservoir bed tight and poor. But dissolution formed secondary pores in certain diagenetic environments, which increased the intergranular porosity and its communication. Then the quality of the reservoir bed could be improved.

Through the analysis of diagenetic reservoir facies, we think that the distribution of effective diagenetic reservoir facies (strong dissolution and chlorite-lined intergranular pores) is tightly controlled by sedimentary microfacies in the Xujiache Formation. Also, strong dissolution diagenetic reservoir facies is only confined to the river mouth bar and distributary channel microfacies. Chlorite-lined intergranular pores diagenetic reservoir facies belongs to river mouth bar, in which the middle basic magmatic rocks and the dark color ferromagnesian minerals are abundant. Owing to the transportation of the dissolved iron deposits in the delta front river mouth bar, chlorite sedimentation occurred.

Strong dissolution diagenetic reservoir facies is developed in T_3x^4 whose dissolution is stronger than that in T_3x^2 . But the burial depth of T_3x^2 is deeper than that of T_3x^4 whose last diagenetic stage is the diagenetic period of middle A. At the same time, some layers of T_3x^2 have entered the diagenetic period of middle B.

5.4 Tectonism is the favorable factor of reforming low-permeability reservoir bed

Fractures are developed in the reservoir beds of the

Xujiache Formation due to multi-phase tectonic action. But fracture distribution is extremely non-uniform. The crack growth is different in different structures and locations due to structure deformation intensity and fault growth. In the anticlinal belt and break growth belt of structural high, massive high-angle cracks in calcarenaceous sandstone favored reservoir bed growth. It both increased reservoir space and improved permeability, and also opened the oil and gas migration path. Thus it improved the accumulation performance of the low permeability reservoir bed.

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