PS The Characteristics and Formation Mechanism of Deep Tight-Gas Sandstone Reservoir in Kuqa Foreland Depression of Tarim Basin, NW China*

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Abstract

Deep, tight sandstones of the early Cretaceous Bashijiqike Formation (Kuqa foreland depression, Tarim Basin), are disconformably overlain by over 8,000 m of clastic red beds in a Cretaceous and Tertiary sequence. To study the reservoir potential of the tight sandstones, a variety of methods (including core, thin sections observation, logging, scanning electron microscope, core lab analysis, microprobe analysis, acoustic emission measure and Micro-CT scan, etc.) were applied to research the characteristics and formation mechanisms of deep tight sandstone reservoirs.

The results indicated the sandstones are feldspar lithic and arkosic rock debris, rich in sedimentary and volcanic rock fragments. Quartz overgrowths and pore-filling carbonate cements (calcite, dolomite, anhydrite and feldspars), assisted by late compaction that improved packing and fractured quartz grains, occluded most of the porosity during early to deep burial. Minor cements include pore-filling clays and authigenic feldspar. The store spaces included protogenesis intergranular pore, the intergranular dissolution pore, a little feldspar and lithic dissolution pore, the corrosion split, micropore, with some fractures. Porosity and permeability of 156 samples averaged 3.57% and 0.359 mD, indicating an extra-low porosity and permeability reservoir. However, the unusual growth of fractures provides considerable possibility that tight sandstones have high production.

The extra-low porosity and permeability mainly resulted from sedimentation, digenesis and tectonic compression. Sedimentary facies is the base of reservoir development. Compaction and cementation greatly reduced the original porosity, compaction narrowed the store spaces and cementation reduced the size of pores, which together resulted in the formation of tight sandstones. Tectonic fractures and dissolution improved the porosity. The maximum paleostructure stress that comes from tectogenesis is 80 Mp in the Kuqa foreland depression, which altered the porosity to as high as 6.2%. Based on the distribution characteristics and homogeneity temperature of fluid inclusion, and combined with the burial, thermal and hydrocarbon generation histories of source rock, the hydrocarbon charged reservoir formed after the tight sandstone.

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ABSTRACT

Tight sandstones, the early Cretaceous Bashijiqike Formation of the Kuqa foreland depression of Tarim basin, is disconformably overlain by over 8000m of clastic red beds in Cretaceous and Tertiary sequence, which is deep tight sandstone typical. To study the reservoir potential of the tight sandstones, a variety of methods (including core, thin sections observation, logging, scanning electron microscope, core lab analysis, microprobe analysis, acoustic emission measure and Micro-CT scan etc.) were applied to research the characteristics and formation mechanism of deep tight sandstone reservoir.

The results indicated the sandstones are feldspar lithic and rock debris arkosic, rich in sedimentary and volcanic rock fragments. Quartz overgrowths and pore-filling carbonate cements (calcite, dolomite, anhydrite and feldspars) occluded most of the porosity during early to deep burial, assisted by late compaction that improved packing and fractured quartz grains. Minor cements include pore-filling clays and authigenic feldspar. The store spaces include protogenesis intergranular pore, the intergranular dissolution pore, a little feldspar and lithic dissolution pore, the corrosion split, micropore, with some fracture. Porosity and permeability of 156 samples averages 3.57% and 0.359 mD, and it is extra-low porosity and permeability reservoir. However, the unusual growth of fracture provides considerable possibility that tight sandstones have high production.

The extra-low porosity and permeability mainly results from sedimentation, digenesis and tectonic compression. Sedimentary facies is the base of the reservoir development. Compaction and cementation greatly reduces the original porosity, compaction narrowed the store spaces and cementation reduced the size of pore, which together resulted in the forming of tight sandstone. Tectonic fracture and dissolution improved the porosity. The maximum paleostructure stress that comes from tectogenesis is 80Mp in Kuqa foreland depression, which reduced the porosity as high as 6.2%. Based on the distribution characteristics and homogeneity temperature of fluid inclusion, and combined the burial, thermal and hydrocarbon generation histories of source rock, the hydrocarbon charged reservoir after tight sandstone formed.

KEY WORDS: tight-gas, reservoir characteristics, deep bury, diagenesis, Tarim basin

1.INTRODUCTION

The development of porosity within deeply buried sandstones is a subject of considerable debate. Many authors have suggested that the removal of either framework grains or intergranular cements is the dominant process of porosity generation at depth in hydrocarbon reservoirs (Hayes, 1979; Schmidt and McDonald, 1979; Burley and Kantorowicz, 1986).A number of recent papers have demonstrated that abnormal high pressure alterations in sandstones, which are important for reservoir preservation during progressive burial (Jinghua Jia et al., 2002; Dakang Zhong et al., 2008).These authors have suggested that the main controlling factors of porosity and permeability of deeply buried strata, including depositional environment, geo temperature, time of deep burial, dissolution and cementation, hydrocarbon charge, abnormal pressure, and chlorite coats, are discussed systemically(Andrew C et al.,1994,Hao Fang et al.,1995, Chunfang C et al.,2001, Jansa L et al.,1990,Wilkinson M et al.,1990,Bloch S et al.,2002).

This study focuses on the static characteristics, diagenetic processes and porosity evolution in the deep Cretaceous Bashijiqike Formation tight-gas sandstones. The study makes use of previously published stratigraphy and depositional facies as well as detailed core descriptions (Lijuan Zhang et al., 2006; Jiayu Gu et al., 2001).

2.SETTING AND STRATIGRAPHY

The Kuqa Depression, bounded to the north by the South Tianshan Mountains, is a secondary structural unit within the northern Tarim Basin (Fig.1), and is typical continental sedimentation system (Fig.2). The basin is about 500km long and 20-70 km wide, area is about $2.85\times10^4 km^2$, and is commonly referred to as the Kuqa development area. This depression contains significant gas condensate resources, as well as small amounts of black oil (Digang Liang et al, 2003).The potential source rocks in this depression are the Upper Triassic lacustrine shales/ mudstones and thin coal beds formed in fluvio-deltaic and lacustrine systems, and the Lower-Middle Jurassic coal beds deposited in a swamp-lacustrine environment. The low cretaceous can be divided into Bashijiqike formation, Sushanhe formation, Baxigai formation and Shushanhe group. Gas production is derived primarily from the early Cretaceous Bashijiqike Formation, although parts of the area also produce gas from the overlying Paleogene Kumugeliemu Formation.

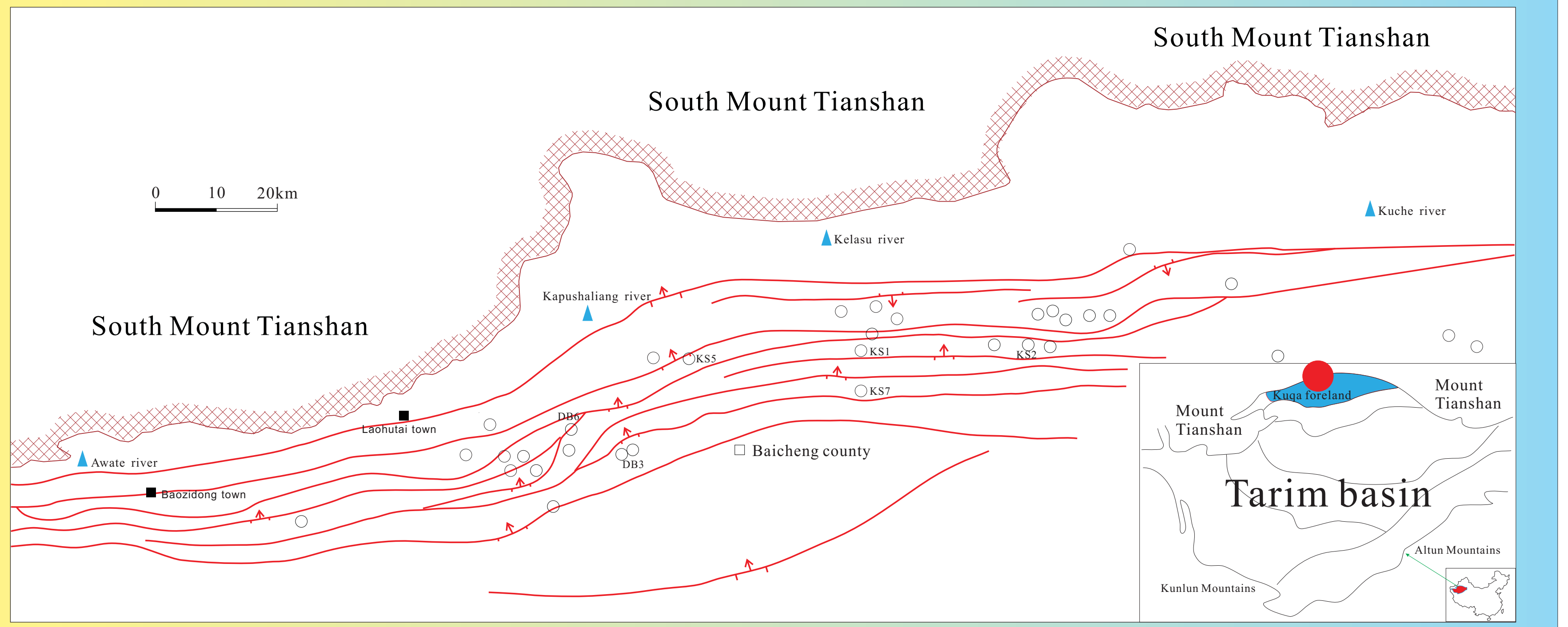

Fig.1. Location map of Kuqa deep area showing main structural units and the location of gas field (adapted from Liu et al, 2009;2010).

The early Cretaceous Bashijiqike Formation is a lithic-rich, tight gas sandstone reservoir in Kuqa sag, Tarim basin. The Bashijiqike has measured porosities of less than 5% and permeabilities that are generally less than 1md in deep field (depths of 6000-8000m). This is the result of significant mechanical and chemical compaction, precipitation of carbonate cements and authigenic clays, and deep burial cementation by carbonate (Chun Liu et al, 2009). Despite the advanced diagenesis and poor reservoir quality of this tight-gas sandstone, many core analysis techniques were used successfully to research it.

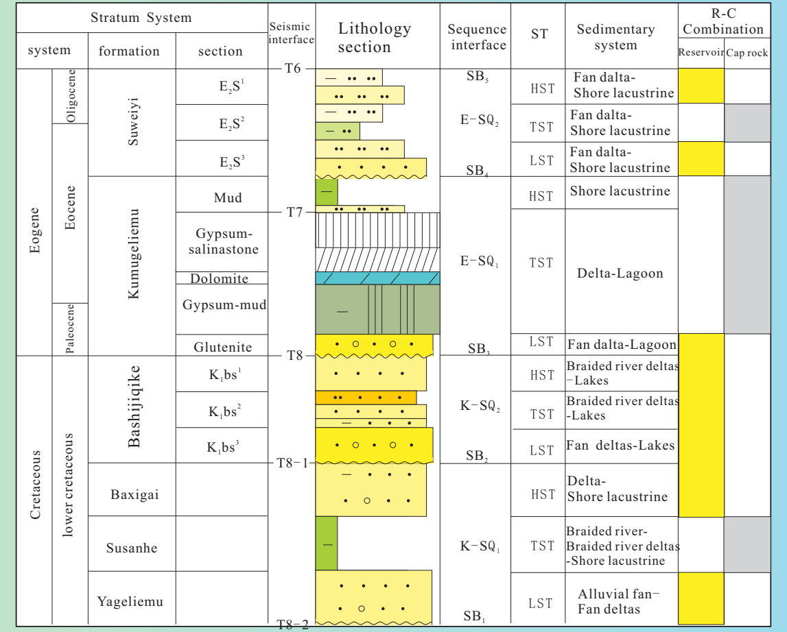

Fig.2. Simplified Lower Cretaceous to Eogene stratigraphy of Kuqa foreland Basin

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2.DEPOSITIONAL FACIES

The Bashijiqike formation can be subdivided into K_1bs^1, K_1bs^2 and K_1bs^3.The basal K_1bs^3 interval comprises fan delta plain conglomerate or pebbled medium-grain sandstone,fan delta fine-grain sandstone or siltstone and pro-delta mudstone(Jinghua Jia et al.,2000;Lijuan Zhang et al.,2006).

The K_1bs^2 is overlain directly by the K_1bs^3, which mainly consists of braided delta front and braided delta plain (Fig.3), which is made of conglomeratic sand, medium-fine grain sandstone and siltstone. The total sandstone proportion from 60%-80%,the maximum can be up to 95 %.Most of these sandstones are composed of feldspathic, lithic feldspathic and lithic sandstone with 30 %～50 % of quartz and rich in lithoclast. Sedimentary structures are mainly massive bedding, large t rough cross bedding and oblique bedding with few parallel bedding, wave bedding and horizontal bedding. main sedimentary period of the braided channel is flood stage, so the sedimentation is characterized by rapid migration of channels with different stages to form thick and continuous sandstone layers by lot s of super imposed sandbodies, which are separated by some thin intercalated pelitic beds(Jiayu Gu et al.,2001).The overlying K_1bs^1 consists of braided delta plain facies. The thickness is very thin, and the distribution range is very limitation due to erosion. So the K_1bs^2 is of vital importance for gas production.

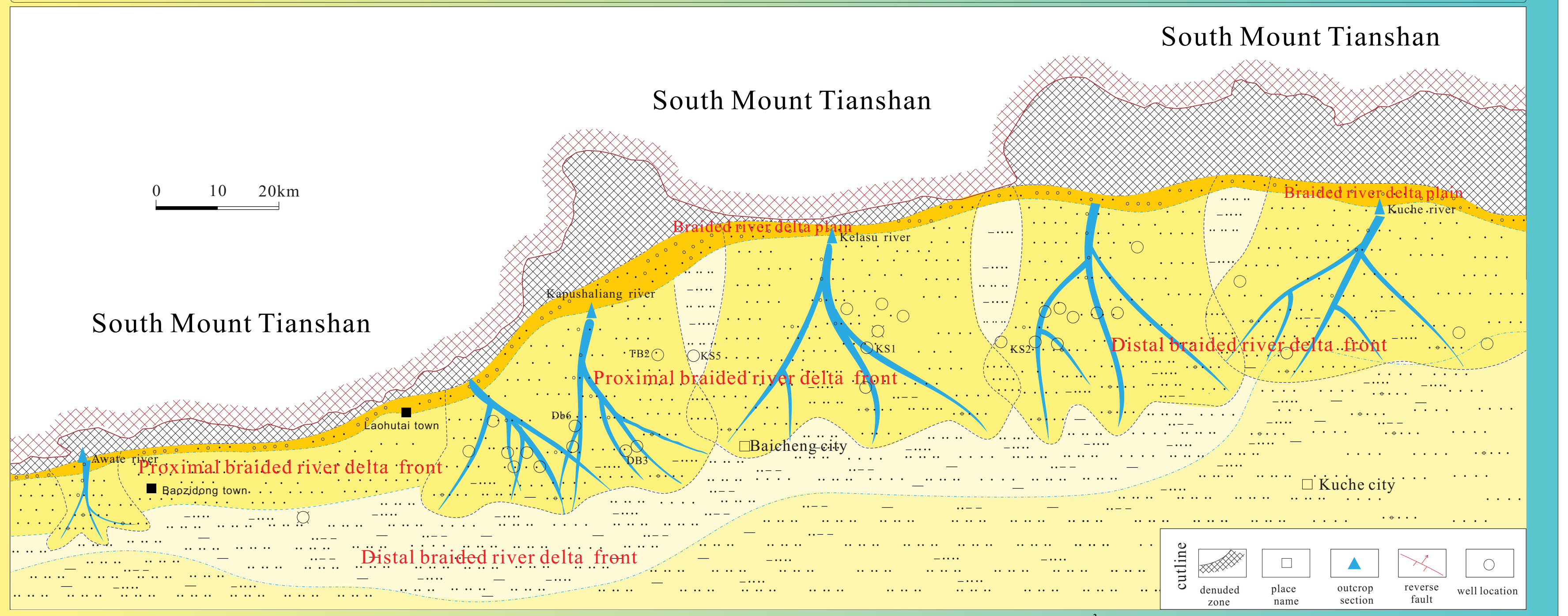


Fig. 3. Modified Lithofacies palaeogeography of medium-Bashijiqike formation(K_1bs^2)

3.RESERVOIR CHARACTERISTICS

3.1.Sandstone petrology

Seventy-six sandstone thin sections from the PetroChina KS1,KS2,KS5,KS7,DB3 and DB6 wells were petrographically evaluated. Each thin section was visually described, photographed, point counted, and evaluated for paragenetic relationships. To ensure hat quartz-cement estimates from transmitted light modal analysis were correct, scanning electron microscope cathodoluminescence (SEMCL) point-count analysis was performed on a small subset of the KS7, KS2, KS1, DB6 wells. Resulting quartz cement estimates from these well yielded minor differences between techniques, likely because of good dust rim preservation. A quantitative rock types for the B-F sandstone included in the study is given in Figure 4.

Representative photomicrographs are shown in Figure 5.The deep tight B-F sandstones are fine- to coarse-grained;grains are sub-angular to subrounded with moderately sorted. Minor clay matrix (pseudomatrix and epimatrix), Derived from mechanical deformation and alteration of the metamorphic rock fragments, and feldspars, occurs in all sandstone samples (< 1%). Quartz grains are monocrystalline with frequent corrosion cavities (pits). Few polycrystalline grains are present. Rock fragments are volcanic, metamorphic (quartzite) and sedimentary (< 2%). Minor heavy minerals are present.


A.KS7,8011m B.KS5,6780m C.KS2,6641m D.KS1,7003m E.DB3,7090.87m F.DB6,6860.4m

Fig. 5. Optical micrograph (plane-polarized light, PPL) showing micro-petrology of Bashijiqike formation tight sandstone.

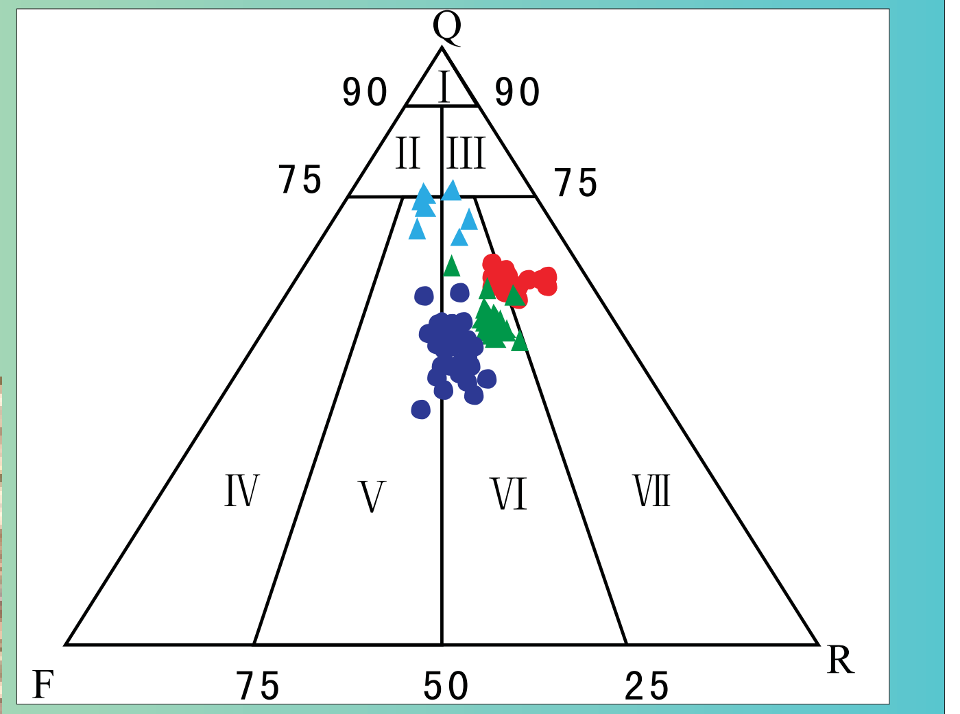
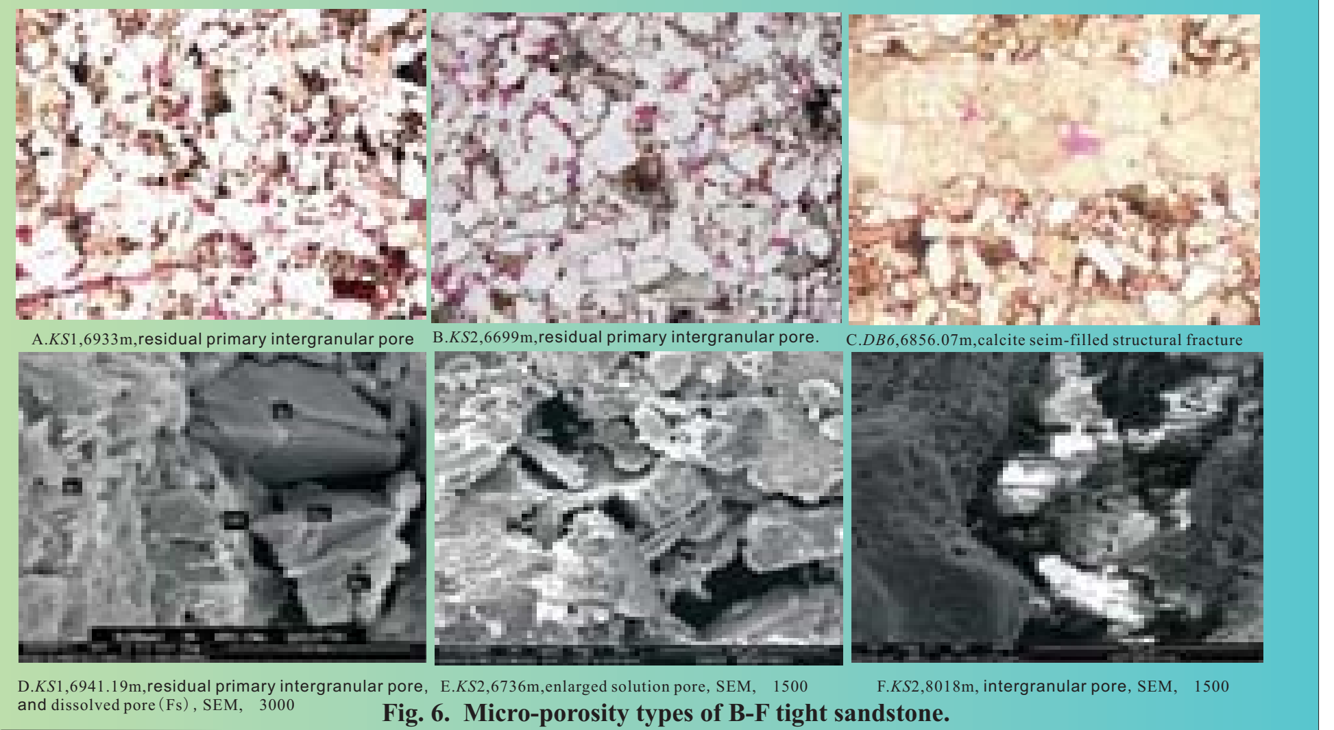


Fig. 4. Detrital composition of B-F sandstone samples plotted on Folk (1980) classification diagrams.

3.2.Diagenes and porosity types

The complex diagenesis (include compaction, cementation, dissolution) lead to all kinds of the porosity types, which mainly consists of primary intergranular pore, intergranular dissolution pore, the few feldspar and lithic dissolution pore, structural fracture and micro-pore(Fig.6). The residual primary intergranular pore and structural fracture are of vital importance for well high production among them in B-F sandstone.


A.KS1,6933m,residual primary intergranular pore B.KS2,6699m,residual primary intergranular pore. C.DB6,6856.07m,calcite seim-filled structural fracture

D.KS1,6941.19m,residual primary intergranular pore, and dissolved pore (Fs) , SEM, 3000 E.KS2,6736m,enlarged solution pore, SEM, 1500 F.KS2,8018m, intergranular pore, SEM, 1500

Fig. 6. Micro-porosity types of B-F tight sandstone.

3.3.Petrophysical data

The B-F sandstones are tough and compact, and average porosity of core plugs from 156 samples is 3.57%, with a range from 0.65 to 7.24 %(Fig.7A). These values match well with two-dimensional estimates from thin sections, which average 2.7%. A few porosity estimates from thin sections were as high as 11.6% and inspection shows that these more porous samples are either highly fractured or contain an unusual abundance of partially dissolved feldspar. Permeability of the 151 samples averages 0.359mD, with a maximum value of 33.7mD (Fig.7B). These porosity and permeability values are very low, which correlation is very poor (Fig.8).

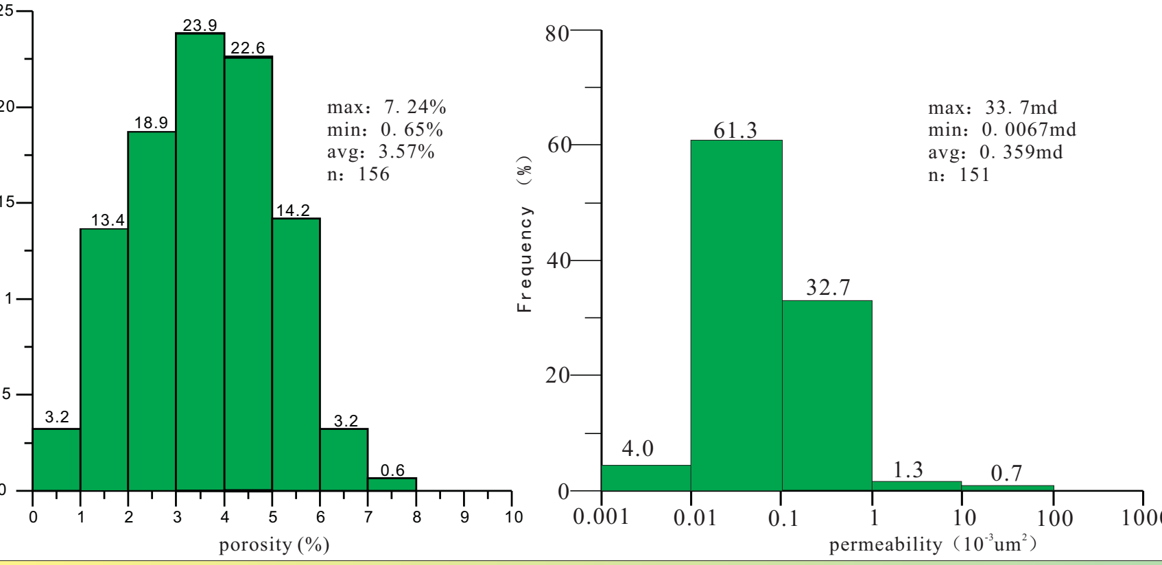


Fig. 7.Frequency plots of A) porosity and B) permeabilitydistributions

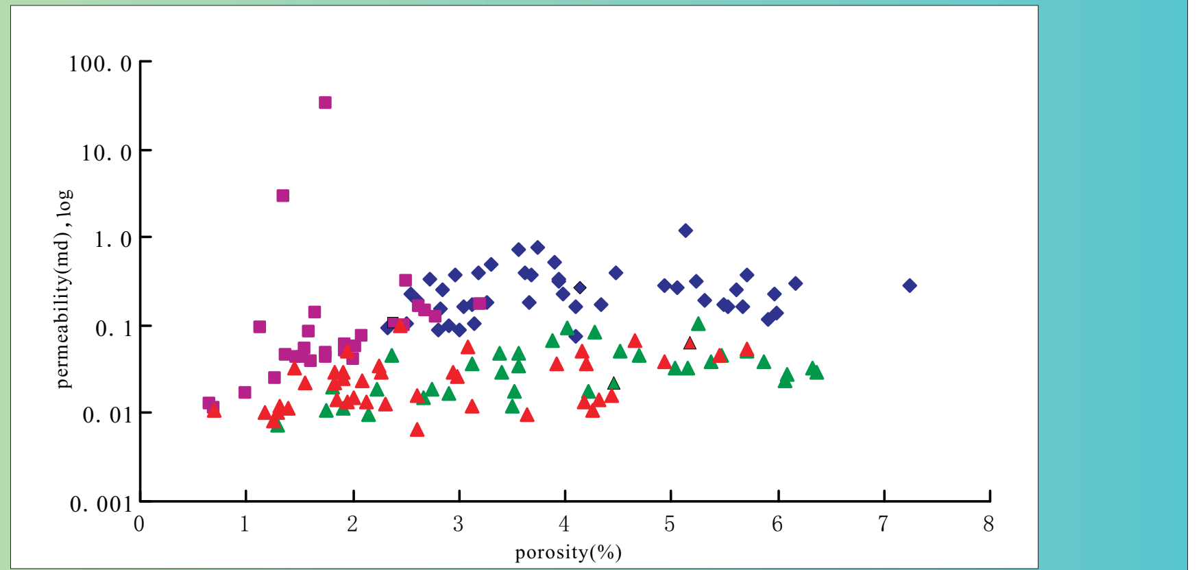


Fig. 8.Correlation plot of porosity versus gas permeability.

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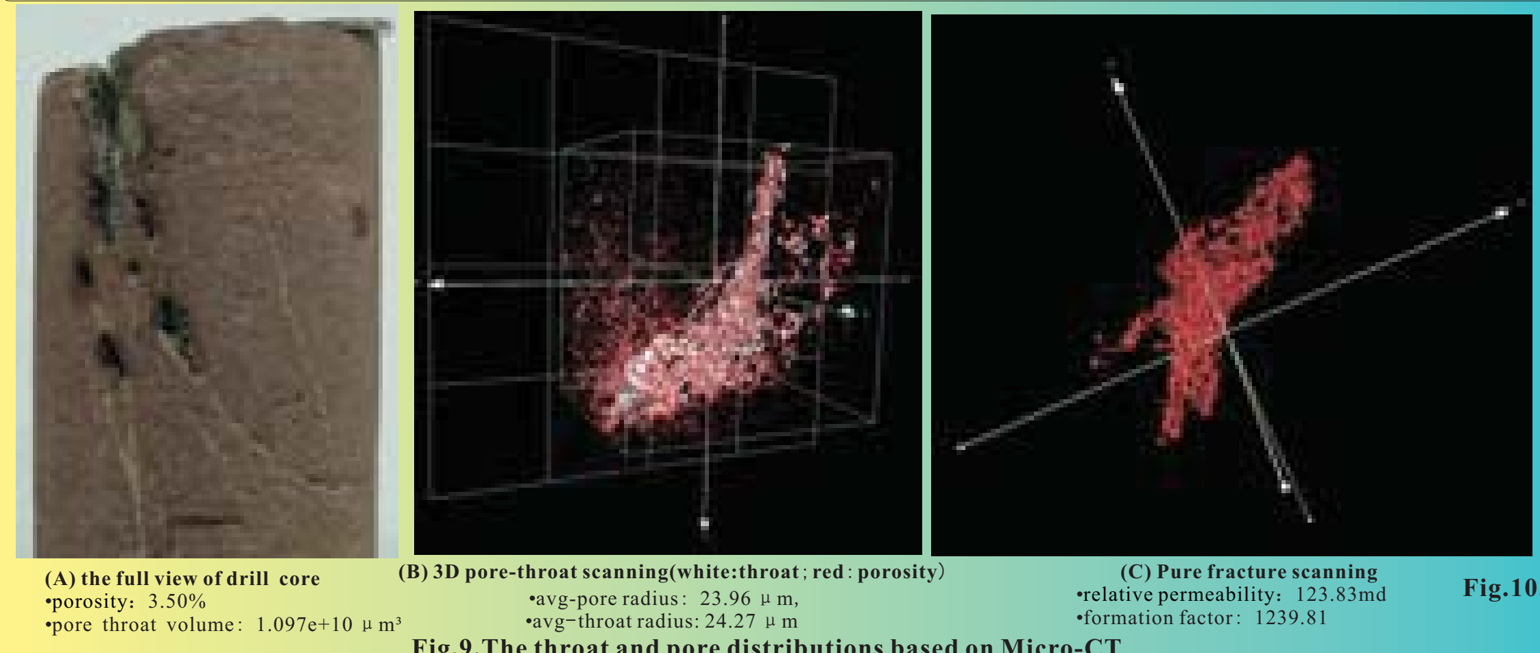
3.4.Micro-CT scan

Micro - CT (computed tomography) scans provide crucial data on the petrophysical properties of optimum reservoir lithologies and are proving to be an essential tool in identifying the optimum lithologies. Micro - CT images acquired from specimens of the B-F drill cores show that producing intervals are characterized by a homogeneous distribution of small pores (generally approximately 50 micron diameter). The interconnected pores are present as an isotropic network(Fig.9,Fig.10).


(A) the full view of drill core
•porosity: 3.50%
•pore throat volume: 1.097e+10 μ m³

(B) 3D pore-throat scanning(white:throat ; red : porosity)
•avg-pore radius: 23.96 μ m,
•avg−throat radius: 24.27 μ m

(C) Pure fracture scanning
•relative permeability: 123.83md
•formation factor: 1239.81

Fig.9.The throat and pore distributions based on Micro-CT

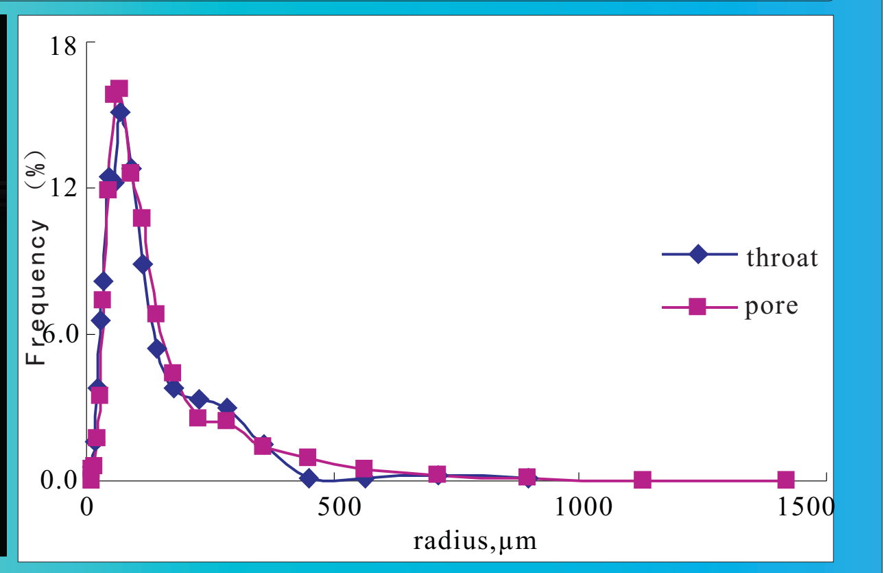


Fig.10.Frequency plots of throat and pore distributions based on Micro-CT

4.RESERVOIR FORMATION MECHANISM

4.1.Sedimentary facies is the base of the reservoir development

The major sandbody types are distributary channel sand and channel-mouth bar of the braided delta front, and sandy braided channel sandbody of the braided delta plain. The reservoir is characterized by a lot of braid channel arising one erosion after another, great thickness, extensive distribution, more continuous, high porosity and permeability, and only a few barrier beds(Fig.11,Fig.12).

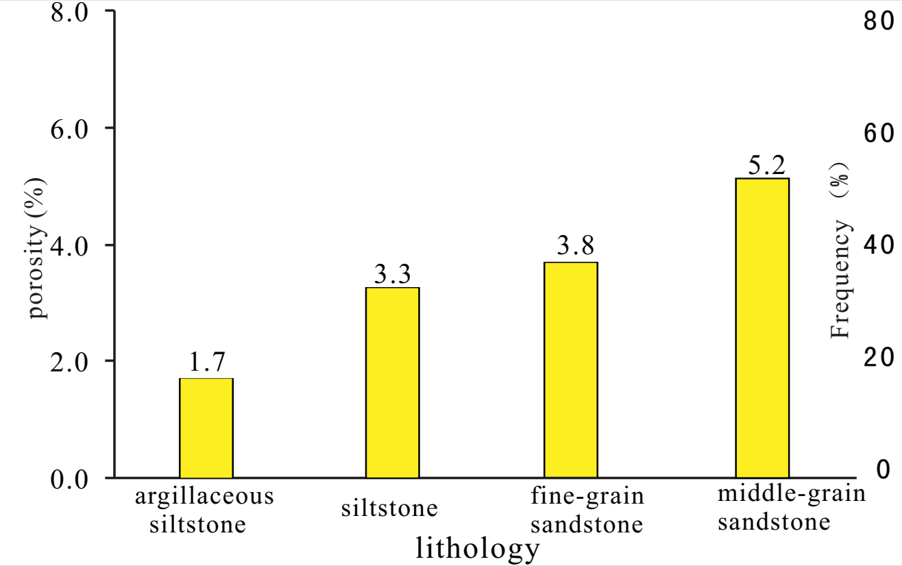


Fig.11.The contrast graphy of porosity in different grain-size sandstone

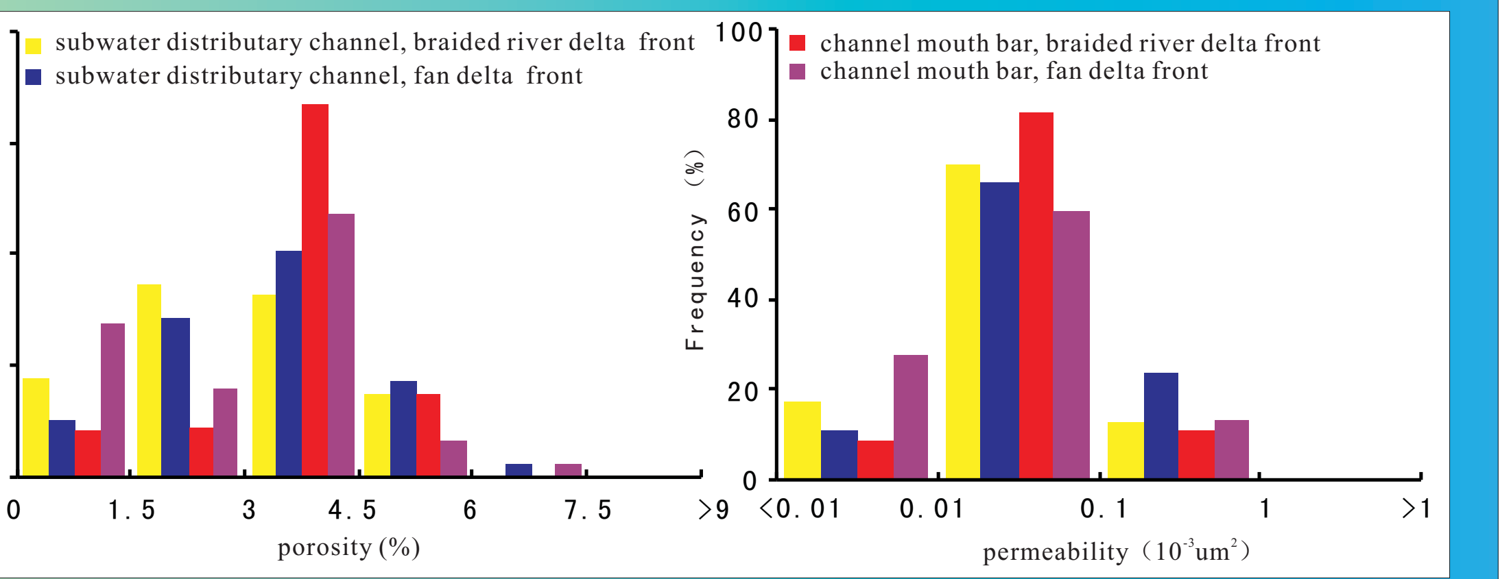


Fig.12.The histogram of porosity and pereambility of logging analysis of different facies sandstone

4.2.Compaction and cementation greatly reduction the original porosity

Buried compaction is the important reason that result in porosity loss. The vertical compaction immensely give rise to the loss of original porosity from theoretical model (Fig.13) .In addition, the porosity loss caused by lateral structure compression was 2.5%-23.6% of bulk porosity loss of sandstones(Fig.14).Furthermore, the carbonate cements are generally developed as intergranular, pore-filling crystals, which reduce the porosity and permeability. From a practical point of view, regardless of the mechanism of carbonate formation, its distribution can be used to estimate reservoir quality(Fig.15).

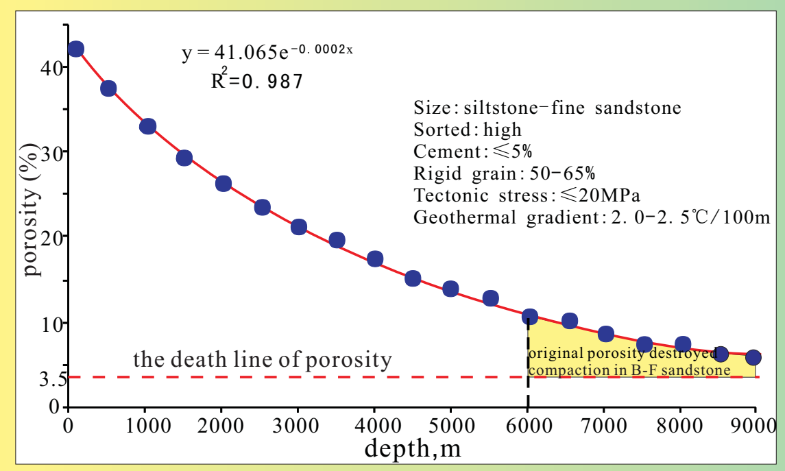


Fig.13.The theoretical residual porosity after burial and compaction

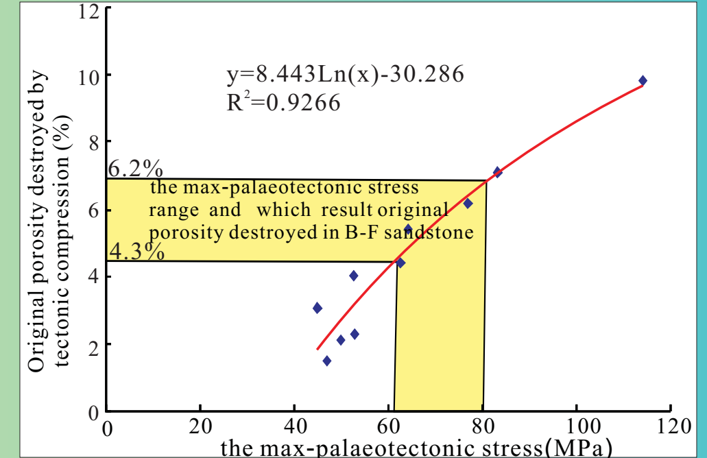


Fig.14.The theoretical porosity loss caused by lateral structure compression

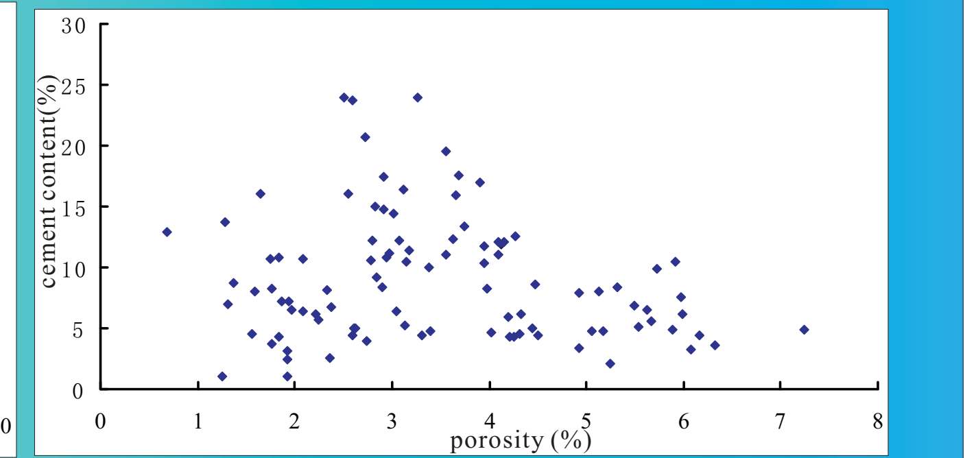


Fig.15.Correlation plot of porosity versus cement content.

4.3.Tectonic fracture and dissolution improved the porosity

The development extent of fractures is positively related to max-palaeotectonic stress, and the max value located the centre of anticline wing(Fig.16).Early formed fracture are semi−filled by calcite grain(Fig.17). The $\delta^{13}C$ values of calcite vary between -2.76 and -3.78‰, and $\delta^{18}O$ between -15.09 and -16.43‰ PDB. The later dissolution (acidic formation water) dissolve part calcite, which enlarge fracture so that improved the permeability.

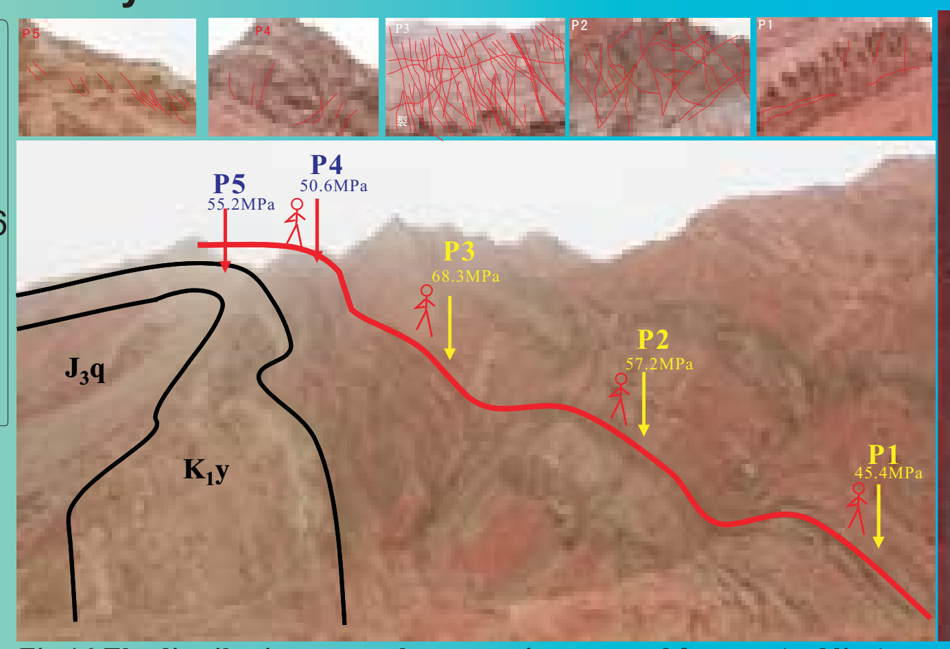


Fig.16.The distribution max-palaeotectonic stress and fracture(red line) in different location of anticline wing

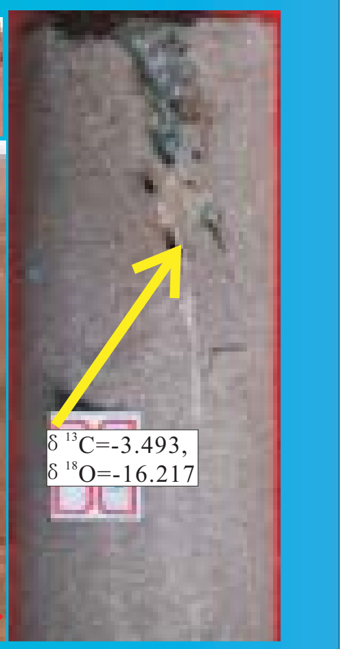


Fig.17.Fracture of drill core

4.4.Porosity evolution pattern

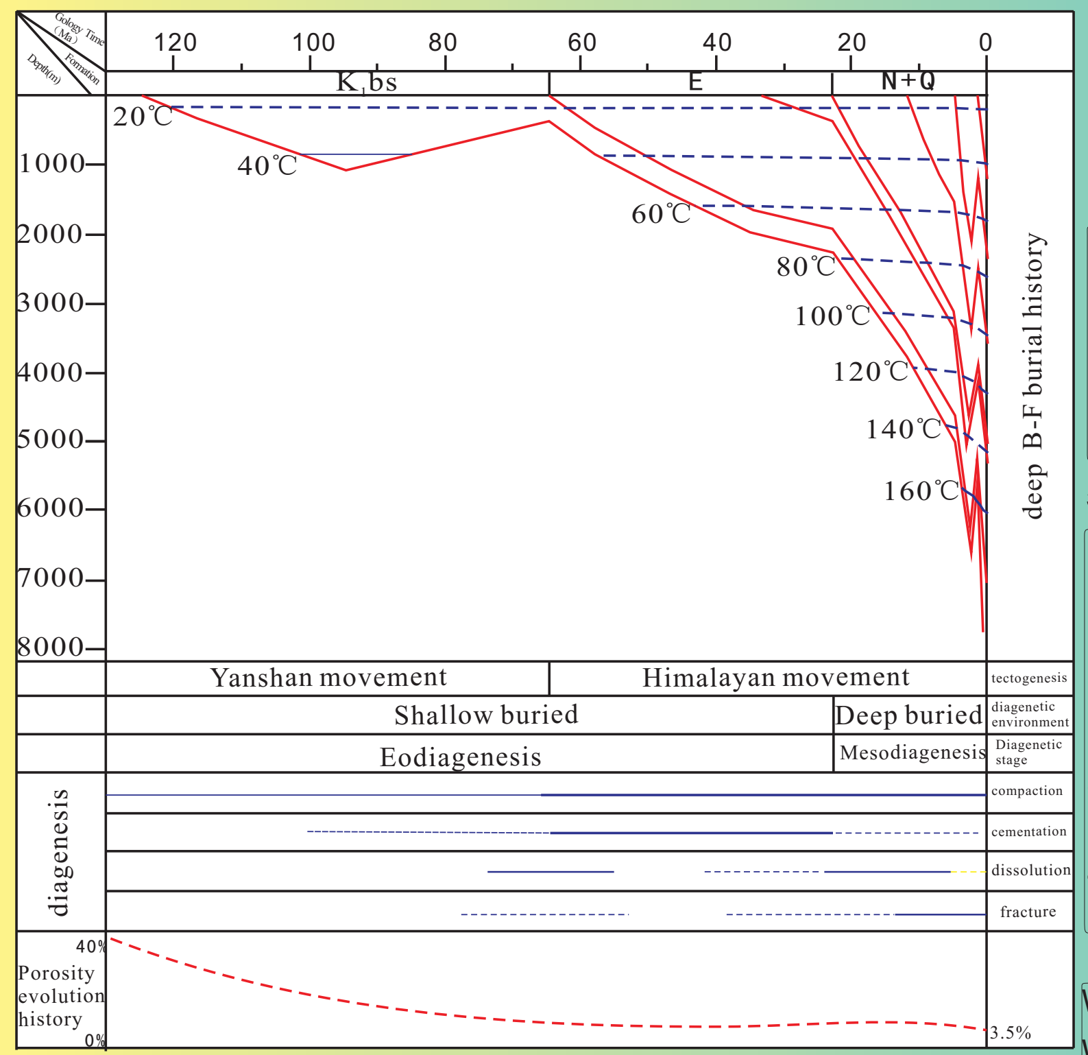


Fig.18.Simplified diagenetic processes and porosity evolution in reservoir sandstones of the B-F.

Detailed petrographic examination of the depositional, buried and diagenetic textural characteristics, in combination with estimations of the basic petrophysical parameters, reconstructed the porosity evolution paths of deep B−F tight sandstone(Fig.19).

5.CONCLUSIONS

1) The deep B-F tight sandstone has very poor porosityand permeability (averages 3.57% and 0.359mD). Primary intergranular pores are the main reservoir space, the unusual development of fracture provides considerable possibility that high production for such tight sandstones.

2)Sedimentary facies is the base of the reservoir development. Compaction and cementation greatly reduces the original porosity. Tectonic fracture and dissolution improved the porosity.

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