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Tight Sandstone Reservoir Characteristics and Sand Body Distribution of the Eighth Member of Permian Shihezi Formation in the Longdong Area, Ordos Basin

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Abstract: The eighth member of the Permian Shihezi Formation is one of the main tight sandstone gas layers in the Longdong Area of Ordos Basin, and the source rocks are dark mudstones and shales located in the Shanxi Formation and Taiyuan Formation of the Permian. The tight muddy sandstone at the top provides shielding conditions and constitutes traps. The lithology is mainly lithic quartz sandstone, followed by lithic sandstone. The reservoir space is mainly dissolved pores, inter crystalline pores, intergranular pores and so on. Clay minerals are the main interstitial materials, and chlorite has the highest content in it, a product of alkaline, moderate- to high-temperature, reducing conditions, effectively inhibited quartz cementation and enhanced secondary porosity development during mesodiagenesis. The average porosity of the reservoir is about 4.01%, and the average permeability is about 0.5×10^{-3} μm^3, which is a typical low porosity and ultra-low permeability tight reservoir. The thickness of the sandstone reservoir in the study area is from 5 m to more than 25 m, mainly in the NE direction. The sand bodies are distributed in lenses on the plane.

Keywords: the Ordos Basin; the Longdong Area; Shihezi Formation; reservoir characteristics; sand body distribution

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1. Introduction

Current research in the international petroleum industry focuses on the petrological characterization of unconventional reservoirs, innovative evaluation of petrophysical parameters, and breakthroughs in efficient exploitation technologies. The "Five-High" characteristics of coal-measure gas (high pressure, high temperature, high gas content, high saturation and high free gas ratio) and nanopore-scale analysis of shale gas reservoirs exemplify advancements in petrological studies. Meanwhile, reservoir stimulation technologies (e.g., energized fracturing) and AI-driven dynamic simulations highlight cutting-edge interdisciplinary integration. Future efforts must address critical challenges such as predicting heterogeneity in deep reservoirs and developing low-cost environmentally friendly fracturing technologies to achieve efficient exploitation of unconventional resources [1–5].

The Ordos Basin is an important oil and gas basin in China, which has the advantages of rich oil and gas resources and great potential for exploration and development. The Upper Paleozoic tight sandstone reservoirs in the Longdong Area are widely distributed

and have great exploration potential. The gas reservoir group of the lower eighth member of the Permian Lower Shihezi Formation (hereinafter called He 8, which is likely an informal layer, numbered for practical purposes without formal stratigraphic status) is the main gas-producing layer, which can be used as a strategic replacement area for sustained and stable production and production increase. At present, the research scholars mainly focus on the source, sedimentary facies and sedimentary system, pore structure and accumulation characteristics of the target horizon in this area, while the research on reservoir characteristics and sand body distribution is relatively weak, and there is still room for improvement [6–11].

The Longdong Area is located in the northwest of the Ordos Basin. It spans the two major structural areas of the Tianhuan Depression and the northern Shaanxi slope in the structural unit. It is adjacent to the Weibei Uplift in the south and the western margin thrust belt in the west. The study area is controlled by the wide and gentle tectonic background of the Ordos Basin.

The Upper Paleozoic in the study area is relatively complete. From the bottom to the top, the Upper Carboniferous Benxi Formation, Lowermost Permian Taiyuan Formation, Shanxi Formation, Permian Shihezi Formation and Shiqianfeng Formation are successively deposited, and the main gas-producing layer is He 8. Continental deposits are widely developed in the area. Previous studies, through the sediment color and lithology, field outcrop facies marks, fossils, and logging facies marks means to divide the sedimentary facies types and sedimentary environment in the study area indicating that the sedimentary facies of the Permian Shihezi Formation are dominated by braided river delta front. According to the different sedimentary environments, it can be further divided into two microfacies (Figure 1) [12–14]. The underwater inter-distributary bay microfacies are developed in the seventh member and the upper eighth member of the Shihezi Formation. This is a sedimentary microfacies with gray-white pebbly sandstone and coarse sandstone as the main lithology, low maturity and strong hydrodynamic environment [15–17]. The lower section of He 8 develops underwater distributary channel microfacies and estuary dam microfacies from bottom to top [18]. The lithology is from silty mudstone to pebbly sandstone. The grain sequence shows a positive grain sequence that becomes finer upward, indicating that the hydrodynamic conditions become stronger.

In this study, authors comprehensively used the methods of petrology, petroleum geology, geophysics and geochemistry to carry out the research. The petrological characteristics, physical properties and pore structure characteristics of He 8 were cleared, and the spatial differences and main control factors of the reservoir reservoir performance were discussed. This will provide an effective geological scientific basis for further exploration and development of the low porosity and permeability tight gas of the Lower Shihezi Formation in this area.

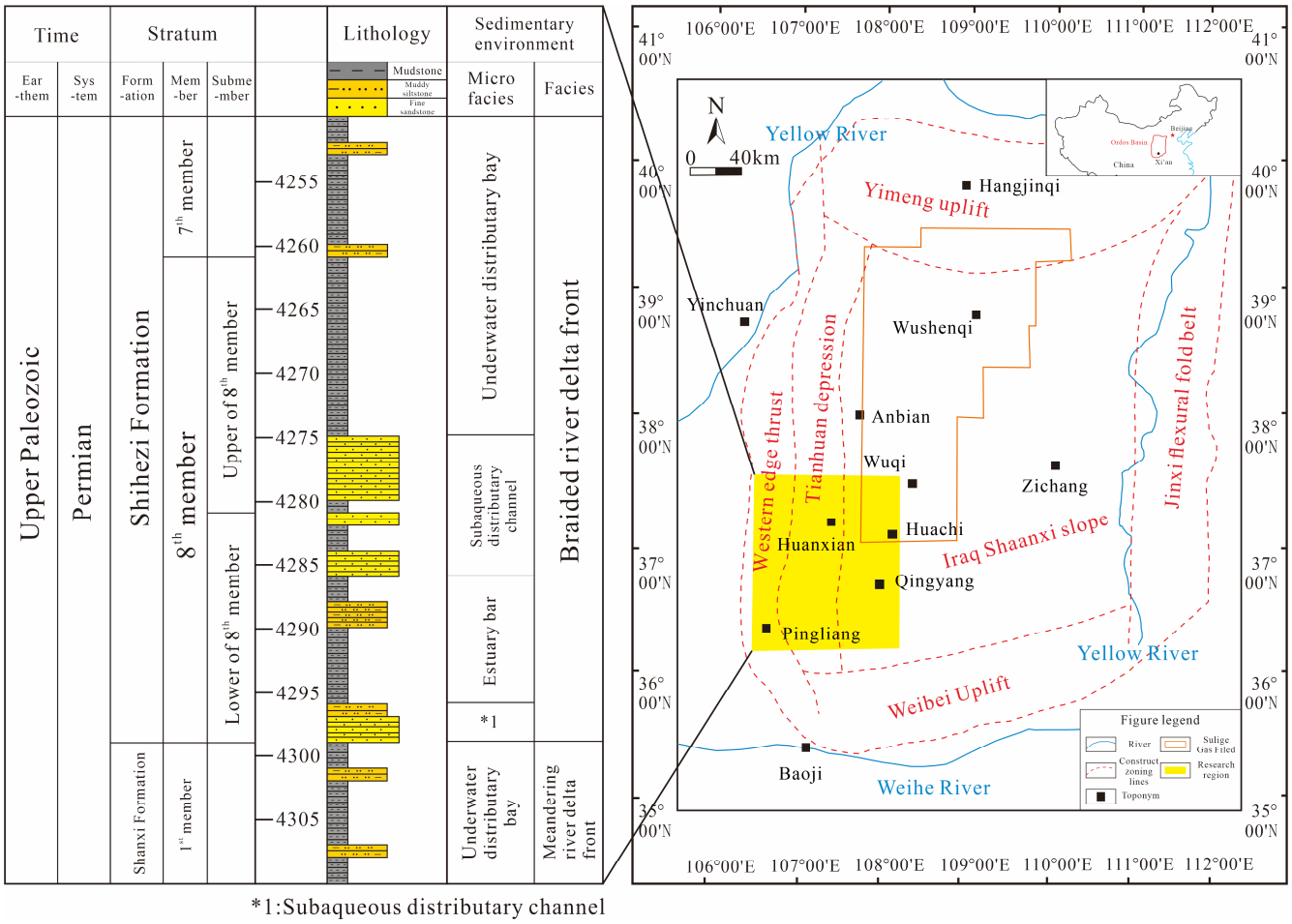


Figure 1. Structural location of the Longdong Area in Ordos Basin and sedimentary characteristics of main gas-producing intervals in Upper Paleozoic.

2. Materials and Methods

This paper is based on a large number of research on previous literature, comprehensively using drilling, logging, core observation, physical properties, analysis and testing data, and uses clay mineral X-ray diffraction, pressure pump experiments and other means to study the Permian Lower Shihezi Formation in Longdong Area of Ordos Basin, and the sand body distribution of the target horizon in the study area was characterized by the well profile.

Core observation is a common method in the study of reservoir petrological characteristics. By sampling and observing the coring data of drilling in the Longdong Area, the lithology of He 8 in the study area is mainly sandstone (Figure 2). Rock color from gray to gray, hard texture. The particles are mostly sub-circular, with good sorting, often accompanied by argillaceous cementation, and the overall structure is dense. No reaction occurred after dropping 5% diluted hydrochloric acid into the sample. If it contains silty sand, it is characterized by hard, poor water absorption and poor plasticity. The samples are usually dry, have massive structures, and bubbles appear intermittently in the immersion test. In addition, this paper also carried out lithology statistics based on the sample size of the core column, and named the sandstone with the largest proportion based on the ternary phase classification method of Folk (1968) [19].

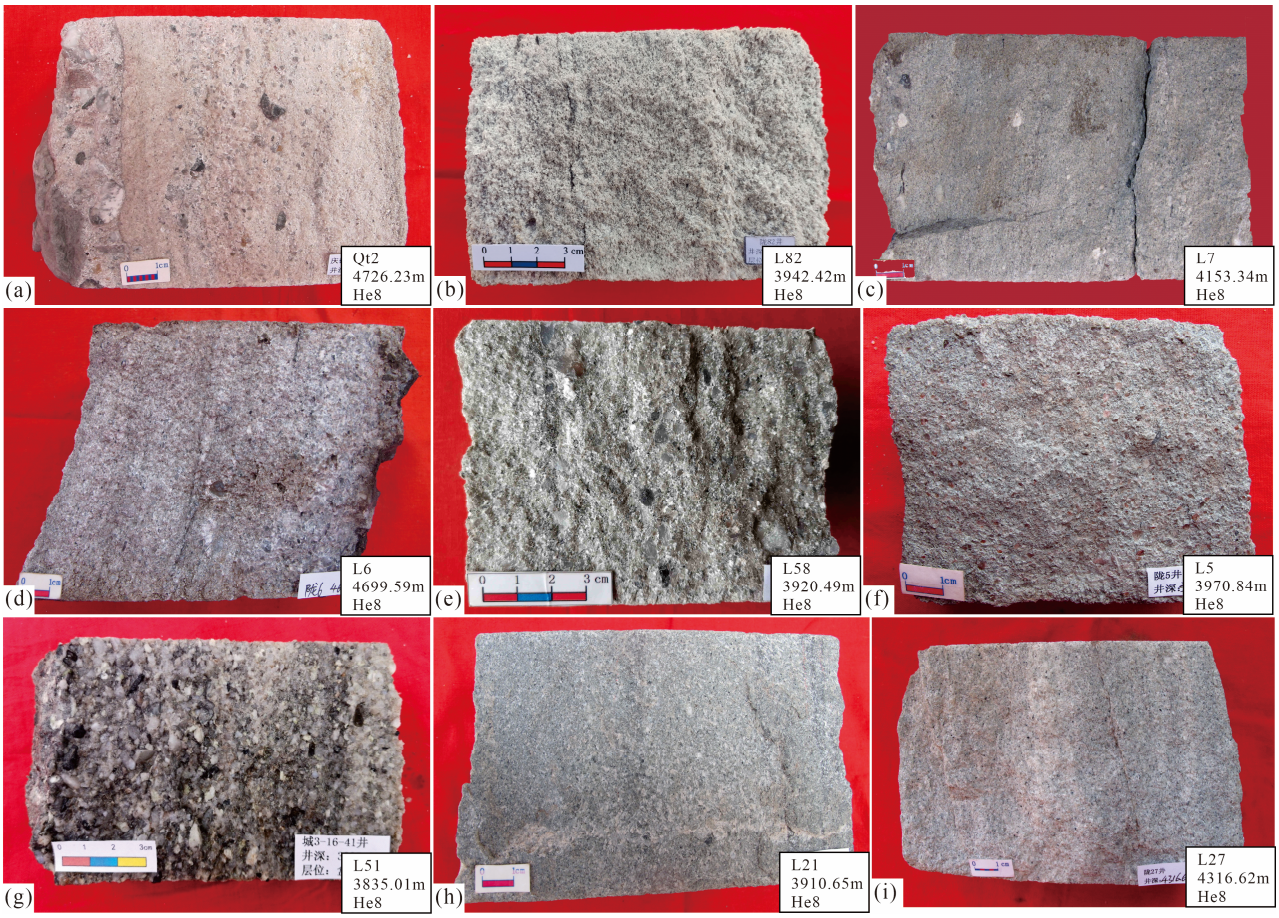


Figure 2. Drilling coring of Upper Paleozoic Permian Shihezi Formation in the Longdong Area, Ordos Basin. (**a**) Lithic quartz sandstone, Qt2 well, 4726.23 m, He 8; (**b**) Gray-white fine sandstone, L82 well, 3942.42 m, He 8; (**c**) Light gray pebbly coarse sandstone, L7 well, 4153.34 m, He 8; (**d**) Light gray coarse sandstone, L6 well, 4699.59 m, He 8; (**e**) Gray-white pebbly coarse sandstone, L58 well, 3970.84 m, He 8; (**f**) Light gray fine sandstone, 3970.83 m, L5 well, He 8; (**g**) Light gray pebbly coarse sandstone, L51 well, 3835.01 m, He 8; (**h**) Light gray medium-coarse sandstone, L21 well, 3910.65 m, He 8; (**i**) Light gray fine sandstone, L27 well, 4316.62 m, He 8.

The X-ray diffraction experiment of clay minerals was carried out according to the China Petroleum Industry Standard SY/T 5163-2010 [20]. The XRD equipment used was the German Bruker AXS D8-Focus X-ray diffractometer (Bruker, Karlsruhe, Germany). The sample state is solid powder, the environmental conditions are temperature 20 degrees Celsius, air humidity 32%, and the detection category is a semi-quantitative analysis of the phase. The software used is XROCK XRD® (Ver 1.0). By identifying the characteristic peaks in the diffraction patterns, the author estimated the mineral content and clay mineral content in the samples.

3. Results and Discussion

3.1. Reservoir Petrological Characteristics

According to the lithology statistics of 22 core samples from nine wells, the grain size of the Upper Paleozoic He 8 in the Longdong Area varies from fine sandstone to gravelly coarse sandstone, mostly coarse sand. Based on the ternary element classification method of sandstone proposed by Folk (1970), the rock composition mapping (Figure 3) was carried out [19]. The results show that the main component of the target layer in the study area is lithic quartz sandstone, accounting for about 71%, and the content in the lower section

of He 8 is slightly higher than that in the upper section. The second is lithic sandstone, accounting for about 15%, and the feldspar content is less than 14%, which may be due to the fact that it is not easy to preserve due to the influence of weathering in the long-distance transportation of the source. The type of debris is mainly hard terrigenous debris, mainly metamorphic rock debris, followed by sedimentary rock and magmatic rock debris. The combination of rigid quartz and debris makes the reservoir have strong compressive capacity, which is conducive to the formation and preservation of pore structure, provides reservoir space for oil and gas molecules, and is an important condition for the formation of high-quality reservoirs.

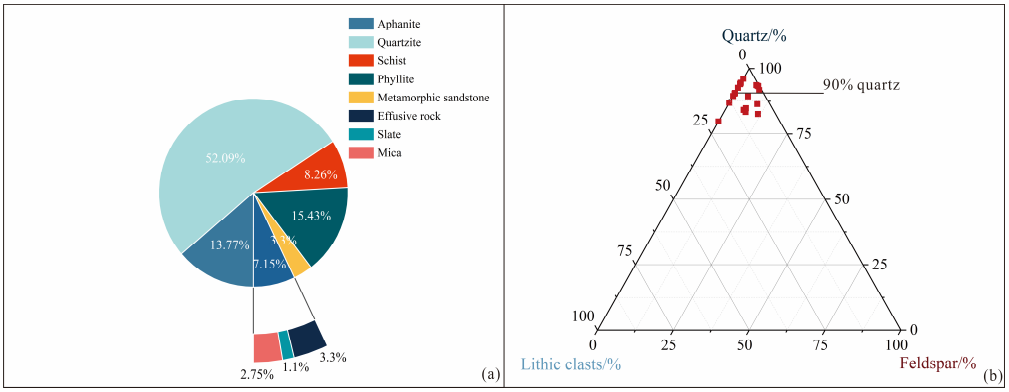


Figure 3. Reservoir petrological characteristics of Upper Paleozoic Permian Shihezi Formation in the Longdong Area, Ordos Basin. (**a**) Lithologic component statistics; (**b**) Classification of sandstone by ternary element method.

3.2. Reservoir Microstructure Characteristics

During the burial process, sediments are often affected by changes in temperature and pressure conditions, fluid pH, potential changes, etc., and various diagenesis occurs, such as compaction, cementation, metasomatism and dissolution. These effects are often associated with various primary and secondary microscopic pore throat structures, so that the clastic particles and cuttings in the sandstone reservoir are inlaid with each other, accompanied by crystal growth such as quartz, which has a great influence on the physical properties of the reservoir and indirectly participates in the formation of oil and gas reservoirs [15,16,18]. In this study, the thin sections of the Upper Paleozoic He 8 in the Longdong Area were selected to observe the microstructure by optical microscope, and the composition of the interstitial material was analyzed and tested (Figure 4). At the same time, this study carries out auxiliary analysis and research by means of porosity and permeability measurement, fitting and pressure pump experiment, so as to carry out a comprehensive and systematic evaluation of reservoir microscopic pore throat characteristics.

Secondary pore structures, such as dissolved pores, inter crystalline pores, intergranular pores, microfractures and dense structures, are mainly developed in the thin sections of the Upper Paleozoic He 8 in the Longdong Area. Their formation is related to the differential dissolution of clastic grains, quartz overgrowth and the secondary alteration of feldspar. Rock interstitials include matrix and cement. The matrix is a general term for clay minerals and terrigenous debris, and the cements are usually carbonate minerals and siliceous cements.

The observation results of sample thin sections show that the content of rock interstitials in He 8 of the Longdong Area is about 20%. The content of clay minerals in the interstitial material is high, accounting for more than 60%. The content of carbonate mineral cements and terrigenous debris is roughly equal, and the siliceous cements only account for a small amount. Through X-ray diffraction analysis of rock samples, the proportion

of various clay minerals was determined. Kaolinite, illite, chlorite and montmorillonite are the main clay minerals. The abundance of mixed layer illite-smectite is less than 10%, which is helpful in improving the physical properties of the reservoir (Figure 5) [19].

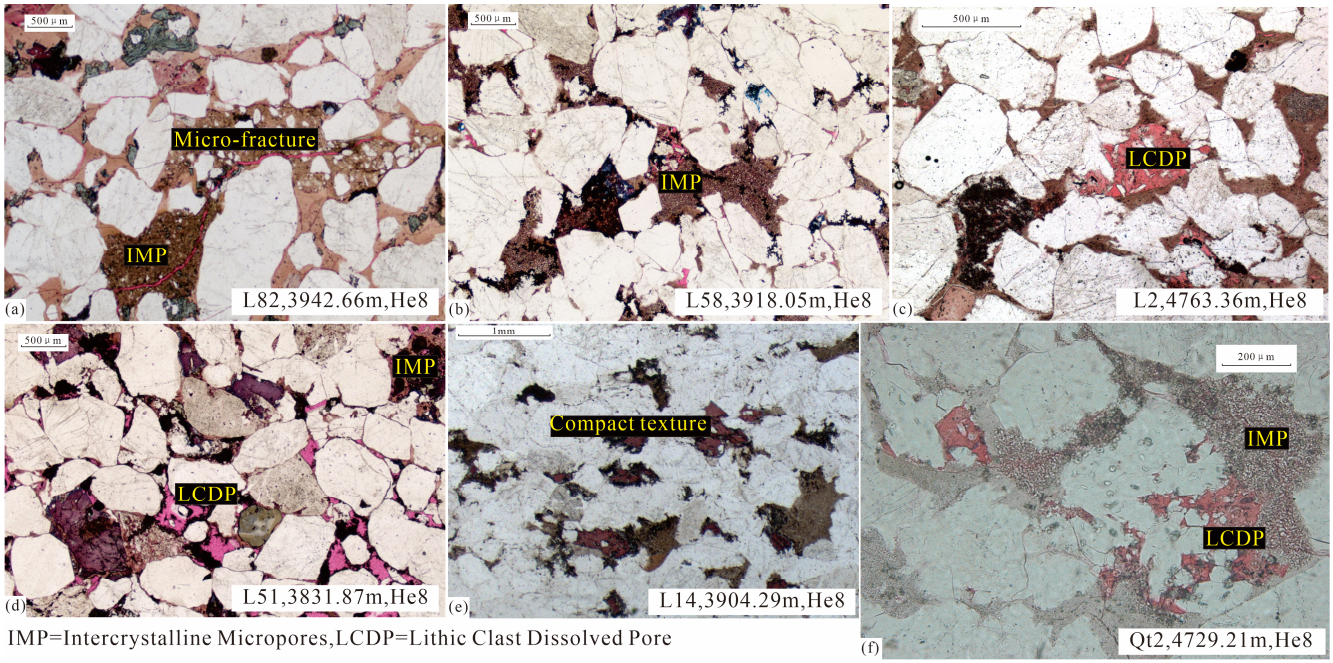


Figure 4. Microstructure of Upper Paleozoic Permian Shihezi Formation in the Longdong Area of Ordos Basin under thin section microscope. (**a**) Micro-fractures, inter crystalline pores, L82 well, 3942.66 m, He 8; (**b**) Inter crystalline pore, L58 well, 3918.05 m, He 8; (**c**) Lithic clast dissolved pore, L2 well, 4763.36 m, He 8; (**d**) Inter crystalline pore, lithic clast dissolved pore, L51 well, 3831.78 m, He 8; (**e**) Compact structure, L2 well, 4763.36 m, He 8; (**f**) Inter crystalline pore, lithic clast dissolved pore, Qt 2 well, 4729.21m, He 8.

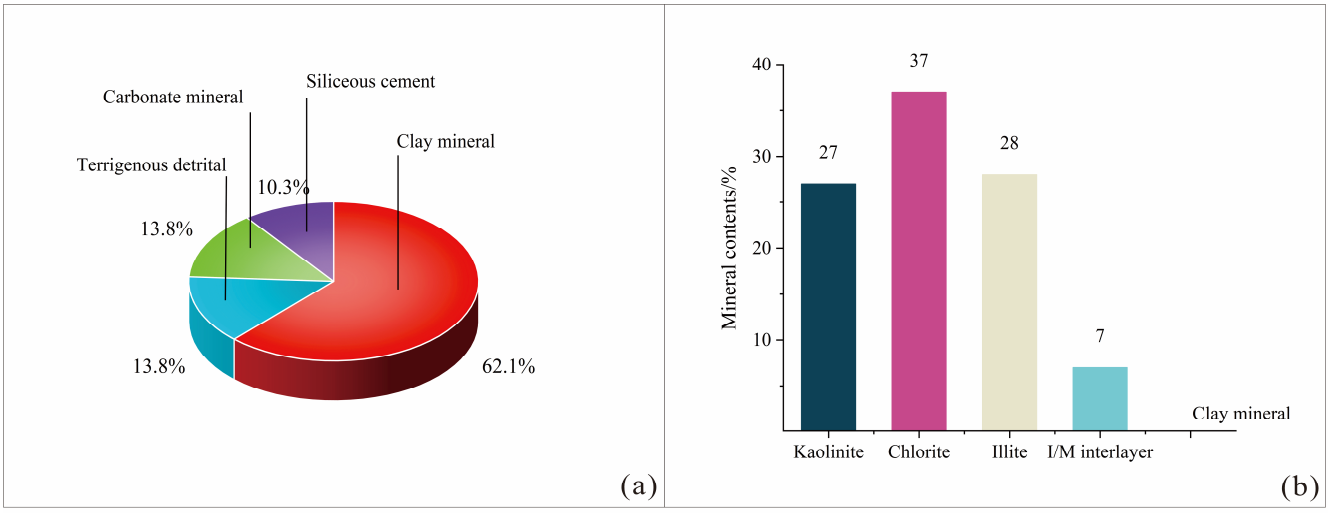


Figure 5. Reservoir microstructure characteristics of Upper Paleozoic Permian Shihezi Formation in the Longdong Area, Ordos Basin. (**a**) Type of interstitial material; (**b**) Clay mineral composition.

3.3. Reservoir Physical Characteristics

According to the results of porosity and permeability measurement, the minimum porosity of the He 8 reservoir in the study area is 0.10%, the maximum porosity is more than 10%, the average porosity is about 4.01%, and the main distribution interval is 4–6%. The minimum permeability is 0.01 × 10^{-3} μm^3, the maximum permeability is

2.12 × 10^{-3} μm^3, the average permeability is about 0.5 × 10^{-3} μm^3, the main distribution interval is 0.1–1 × 10^{-3} μm^3, and the lower section of He 8 is better than the upper section. In general, the physical properties of the He 8 reservoir in the Longdong Area are relatively low, the structure is relatively dense, and the heterogeneity is strong. It is a typical low porosity, low permeability and ultra-low permeability tight reservoir. The scatter diagram shows that there is a good correlation between porosity and permeability, water saturation and porosity and permeability, respectively (Figure 6).

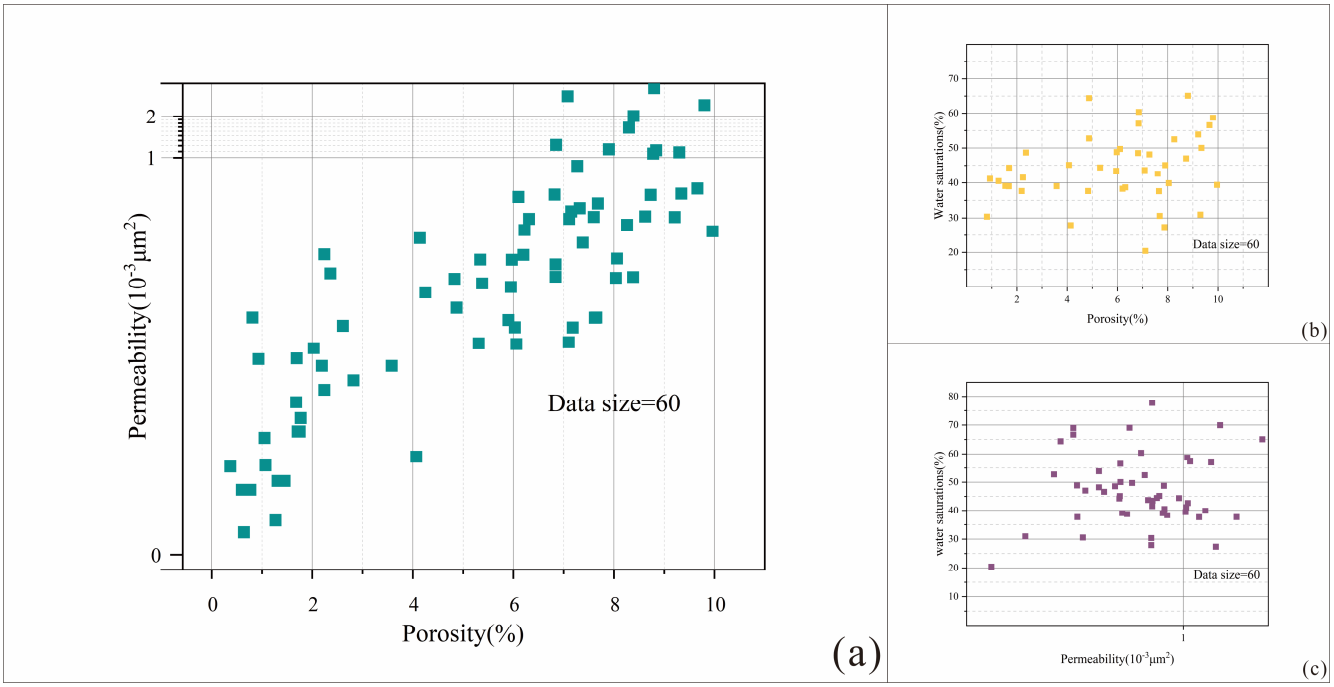


Figure 6. Reservoir physical characteristics of Upper Paleozoic Permian Shihezi Formation in the Longdong Area, Ordos Basin. (**a**) Porosity–permeability relationship; (**b**) Porosity–water saturation relationship; (**c**) Permeability–water saturation relationship.

3.4. Characteristics of Reservoir Capillary Pressure Parameters

Sandstone reservoirs are widely distributed in the study area. Affected by strong compaction, these reservoirs mostly form curved, tubular and sheet throats. For low permeability reservoirs, capillary pressure has a significant effect on oil-water two-phase flow. With the aid of the capillary pressure method, previous scholars studied the characteristics and distribution of pore throats [21]. There are three common methods for determining the capillary pressure curve of rock: semi-permeable diaphragm method, mercury intrusion method and centrifugal method. Based on their research, the author makes the pressure pump curve and the sorting parameter curve characteristic diagram (Figure 7). The results show that the throat size generated by the displacement pressure generated by the compaction of sandstone reservoirs is medium, with high pump saturation and good sorting. On the whole, it shows strong pore heterogeneity. The densification caused by this compaction eventually causes the reservoir to break and produce cracks, which changes the porosity and permeability.

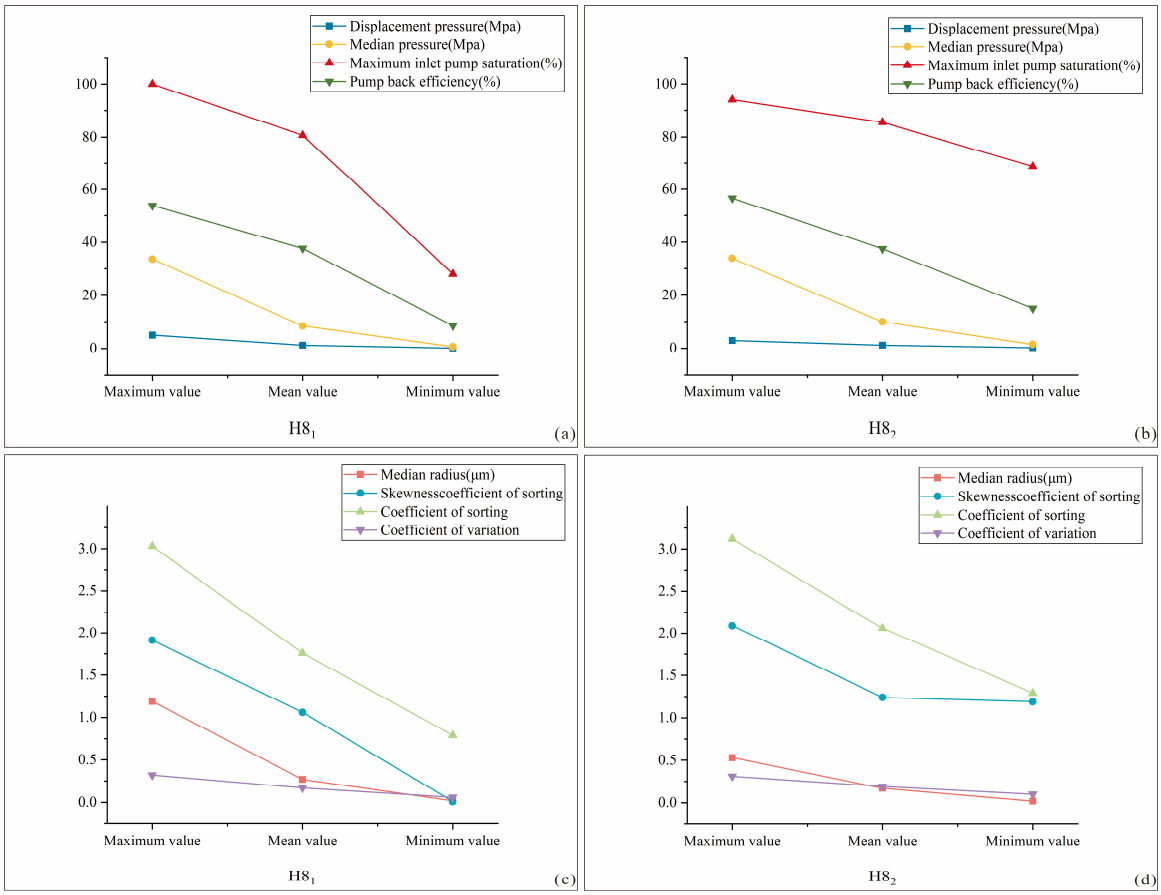


Figure 7. Point-line diagram of capillary pressure parameters of sandstone in the upper and lower sections of He 8 in the Longdong Area, Ordos Basin. (**a**) The pressure pump curve of the upper section of He 8; (**b**) The sorting parameter curve of the lower section of He 8; (**c**) The sorting parameter curve of the upper section of He 8; (**d**) The sorting parameter curve of the lower section of He 8.

3.5. Distribution Characteristics of Sandstone Reservoir

Influenced by the short-term uplift of the terrigenous clastic source area in the northern Ordos Basin, the Longdong Area obtained sufficient sandy debris transport supply in the Lower Shihezi period of the late Early Permian (typical in the He 8 sub-period). In this paper, based on a large number of previous literature and the collection of relevant logging data, the sedimentary environment and sand body thickness of the Upper Paleozoic Shihezi period in the study area were studied, and the sedimentary facies zoning and sand sandstone reservoir thickness contour map were drawn [15–18].

The distribution of sedimentary relative dominant reservoirs has an important influence [16,22,23]. In the late Early Permian, the surface water system was widely distributed in the Lower Shihezi period, and fluvial facies sedimentation was generally developed. The core color of He 8 was mainly gray and variegated, with more sandy components, indicating that it was in a shallow water sedimentary environment with alternating oxidation-reduction [24,25]. The delta plain deposits are mainly developed in the periphery of the study area, and gradually transition to delta front and shallow lake deposits inward (Figure 8).

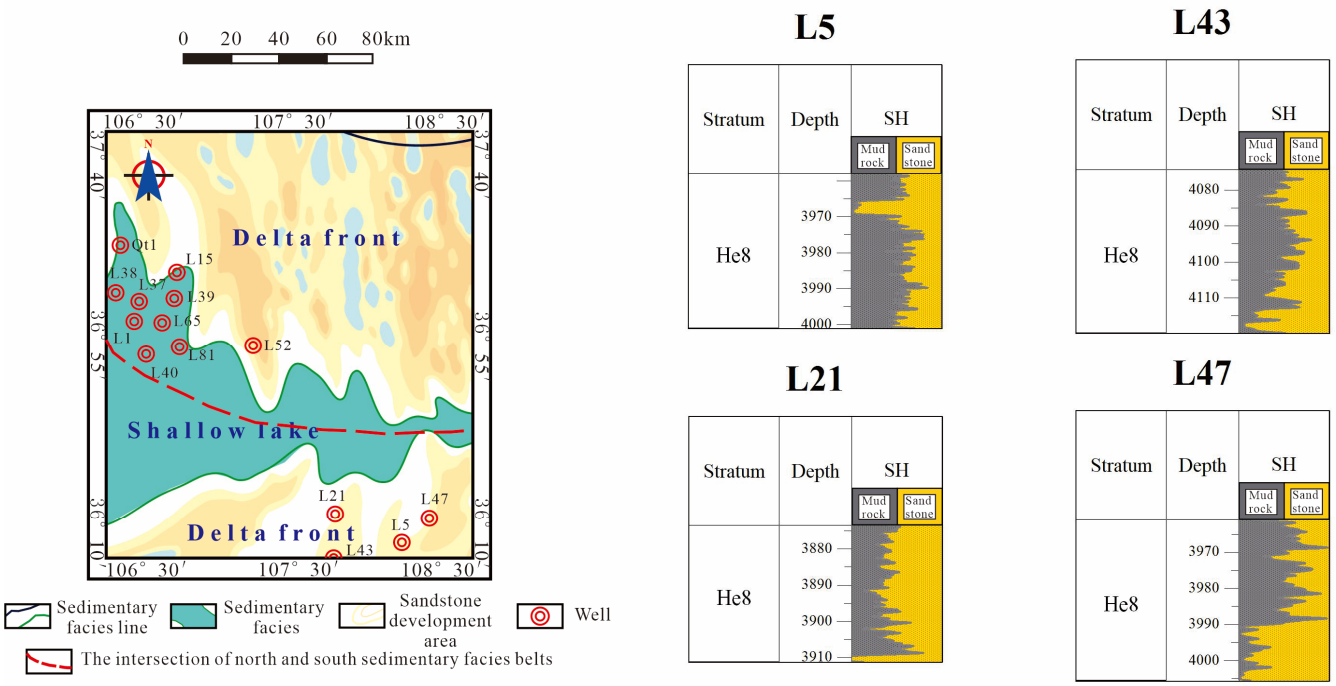


Figure 8. Sedimentary facies zoning and sandstone reservoir development of He 8 in the Longdong Area, Ordos Basin.

The thickness of the sandstone reservoir in He 8 of the Longdong Area varies from 5 m to more than 25 m, 10–15 m is the most common thickness, and only some areas are more than 25 m thick. In the plane, the NE direction is the dominant distribution direction (Figure 9). The faults are developed in the southwest of the study area and cut through the sandstone reservoir. Parts of the southern and northern margins were eroded.

3.6. Discussions of Reservoir Sand Body Distribution

The sand body connecting well profile is a common method to study the distribution characteristics of the sand body. The author selected five high-yield drilling wells of the study area in the NNW direction, which is vertical to the dominant distribution direction of the sandstone reservoir, and drew the well-connected profile of the Upper Paleozoic sand body to explore the dominant distribution and spatial zoning (Figure 10).

The different hydrodynamic conditions affect the distribution of sand bodies [25]. The sand bodies are cut or spliced in the vertical direction and distributed in lenses on the plane. The western sand belt of the Upper Paleozoic in the Ordos Basin has a short extension distance, and it is bifurcated and thinned in the Longdong Area. The lithology is dominated by argillaceous sandstone and sandy mudstone. The grain size becomes finer, the development degree is low, and the reservoir is dense. From the vertical point of view, the delta plain distributary channel sand bodies are developed in the upper section of He 7 and He 8, and the water depth is large. The sand body is unloaded in the contact zone between the delta plain and the front edge, which makes it extend in the plane. The distance is shorter. Due to the change in hydrodynamic strength, the single-layer development mode of the sand body changed from isolated type to cutting type, and the scale and lateral ductility of the sand body decreased from the upper section to the lower section of He 8. The logging gamma curve of the lower section of He 8 is a Coarsening-upward & Fining-upward Cyclic Succession which has the sedimentary characteristics of a braided river delta front [26,27].

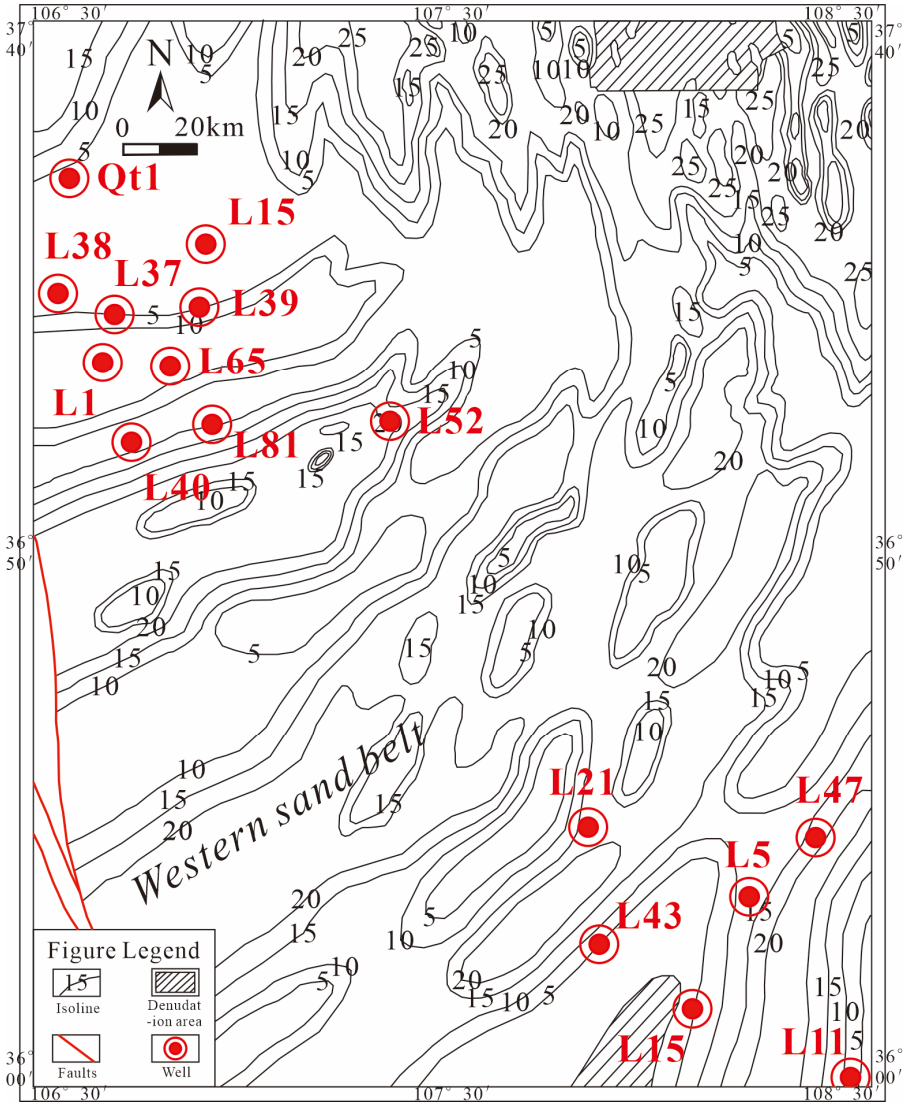


Figure 9. Sandstone reservoir thickness contour map of He 8 in the Longdong Area, Ordos Basin.

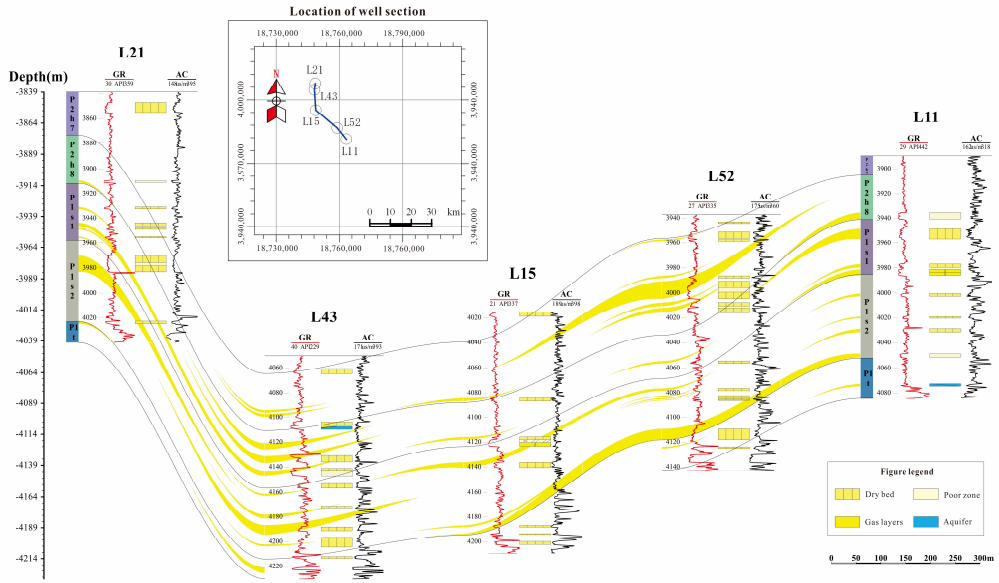


Figure 10. Well–tie section of L21–L43–L15–L52–L11 Upper Paleozoic sand body in the Longdong Area, Ordos Basin.

From the plane point of view, the structural characteristics of the 8th member of the sand body of well L21 are similar to those of well L11. Well L21 is controlled by the multi-stage distributary channel of the delta plain facies belt, the multi-stage superimposed sand body is developed, and the cumulative thickness of the sand layer is large. To the northwest of the study area, the L11 well is dominated by argillaceous sandstone and sandy mudstone deposition, and the argillaceous content is increased, reflecting that the formation environment has changed significantly, the surface water system power is weakened, the ability to carry sand body migration is reduced, and the degree of sand body development is significantly reduced [24]. According to the characteristics of lithology combination, it is speculated that the sedimentary period is the delta front facies belt with relatively weak hydrodynamic conditions.

In general, the sand body of He 8 of the Upper Paleozoic in the Longdong Area has a certain thickness, but the distance of lateral continuity is short. The control of sedimentation leads to a large difference in the thickness of local sand bodies, and the sand bodies change rapidly at the intersection of north and south sedimentary facies belts. Therefore, it is necessary to comprehensively select drilling targets around the existing gas production wells, combined with the gas-bearing range and scale, in areas with large sand body distribution and a relatively high degree of implementation, so as to improve the accuracy of prediction and help the exploration and development of natural gas in the basin [28].

4. Conclusions

The Longdong Area, situated in the southwestern Ordos Basin, has recently emerged as a key target for tight gas exploration, with the Upper Paleozoic He 8 serving as the primary gas-producing interval. Petrological analysis based on core observations indicates that the reservoir lithology is dominated by fine- to coarse-grained sandstone, containing approximately 20% lithic fragments, which classifies it as lithic quartz sandstone according to Folk's ternary classification scheme.

Microscopic examination of thin sections reveals that the He 8 predominantly develops secondary pore systems, including dissolution pores, inter crystalline pores, intergranular pores and microfractures. Clay minerals constitute the primary interstitial material (>60%), with chlorite (37%) and illite (28%) being the dominant species. Physical property measurements demonstrate a porosity range of 0.10–10% (average: 4.01%, concentrated between 4% and 6%) and permeability values spanning 0.01–2.12 $\times$ 10^{-3} μm^2 (average: 0.5 $\times$ 10^{-3} μm^2, predominantly 0.1–1 $\times$ 10^{-3} μm^2), characteristic of a low-porosity and low-permeability reservoir.

Sedimentologically, He 8 of the Longdong Area was deposited in shallow-water delta-front facies, with sandstone reservoirs exhibiting NE-trending orientations and thicknesses varying from 5 m to 25 m. These sand bodies display lenticular geometries in plan view with limited lateral continuity, while vertical stacking of multi-phase sand units shows significant heterogeneity, thinning northwestward—a pattern attributed to differential sedimentary processes during deposition.

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