ISSN: 2414-1895 DOI: 10.6919/ICJE.202603_12(3).0017

Characteristics and Controlling Factors of Tight Sandstone Reservoirs in the He 8 Member of Southeast Sulige Area

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Abstract

In order to clarify the development law and excellent reservoir formation mechanism of tight sandstone reservoirs in the southeast Sulige Area, systematic studies on the gas geological characteristics, reservoir space types, and pore structure of reservoirs in He 8 Member Sulige Gas Field were conducted, utilizing data from core cast thin sections, scanning electron microscope analysis, and mercury injection experiments. The paper gives a clear and systematic discussion of reservoir development, from which it naturally and logically concludes that the He 8 Member reservoirs in the studied area are mainly quartz sandstone and lithic quartz sandstone with interstitial materials including hydromica, kaolinite, and iliceous cements. Secondary pores constitute the dominant reservoir space, with intergranular dissolved pores accounting for 37.32% and intercrystalline pores for 28.60%. The rock is followed by residual primary intergranular pores, and its pore structure can be very naturally and accurately, with the throat type dominantly fine pore-micro throat. Sedimentation controls the macroscopic distribution of sand bodies, whereas diagenesis governs the evolution of microscopic physical properties of reservoirs. Mechanical compaction is the principal factor causing porosity reduction, dissolution is the key to the formation of high-quality reservoirs, and siliceous cementation further intensifies reservoir densification. Therefore, the results of this study provide a solid geological basis for the effective development of tight sandstone He 8 Member of Southeast Sulige Area, gas reservoirs.

Keywords

Sulige Gas Field; He 8; Tight Sandstone; Reservoir Characteristics.

1. Introduction

Tight sandstone gas reservoirs have become a central focus of global Unconventional oil and gas exploration and development, and foreign scholars have therefore developed a mature, well-established theoretical and technical system for tight sandstone gas reservoir creation and development, based on extensive studies of typical gas reservoirs such as the San Juan Basin and Powder River Basin in the United States [1]. In contrast, domestic research on tight sandstone gas reservoirs in the Ordos Basin has made significant progress in understanding reservoir formation. The paper presents a theory with Chinese characteristics concerning the controlling effects of sedimentation and diagenesis on reservoir development[2], and very naturally leads into the discussion of the Sulige Gas Field, which is the largest natural gas field in China in terms of production scale and reserves, located in the northern part of the Ordos Basin, with the main productive zones being the He 8 Member of the Permian Shihezi Formation and the Shan1 Member of the Shanxi Formation. Typical tight sandstone gas reservoirs have "three lows"(low porosity, low permeability and low

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abundance)[3], hence the Southeast Sulige Area, as an important production block of the gas field, has been exploited for more than ten years. However, it is worth noting that the upper and lower Paleozoic gas shales are superimposed in this block, and early development was focused on the lower Paleozoic reservoirs, so the reserves of the upper Paleozoic He 8 Member remain largely unexploited. The sand bodies of the He 8 Member reservoirs are characterized by multiple depositional phases with poor connectivity, hence gas reservoir development in this interval is particularly challenging[4]. The Sulige Gas field has therefore attracted considerable attention, and geologists from the field have systematically applied reservoir diagenesis, heterogeneity, and development technologies to investigate the problem, concluding that ion is the key factor in the formation of secondary pores[5]. However, it must be acknowledged that the rapid lateral variation of reservoir properties in the Southeast Sulige Area means that the comprehensive characteristics and main controlling factors of the He 8 Member reservoirs still require thorough discussion, which is of direct practical importance for improving reserve utilization rate and development economics.

2. Geological Setting

The study area is located in the central part of the Ordos Basin and lies on the Northern Shaanxi Slope from the tectonic point of view[6]. On the gently dipping monocline background, a series of soft nose uplift structures oriented northeast-southwest have developed, with an amplitude of 10-20 m, and neither faults nor other significant structural defects are well developed[7]. The Upper Paleozoic in the study area is well represented by the Carboniferous Benxi Formation and the overlying Shanxi Formation, Permian Taiyuan Formation, Shiqianfeng Formation, which together have a total thickness of approximately 700 m.

3. Reservoir Characteristics

3.1 Petrological Characteristics

From the statistical analysis of thin section data of coring wells in the study area, it is clearly and systematically established that the sandstone types of He 8 Member reservoirs are mainly quartz sandstone and lithic quartz sandstone, with clastic components dominated by quartz, which has the highest content, followed by lithic components, and feldspar occurs only locally. The lithic components themselves are dominated by metamorphic rocks, with eruptive rocks and sedimentary rocks coming next (Fig.1).

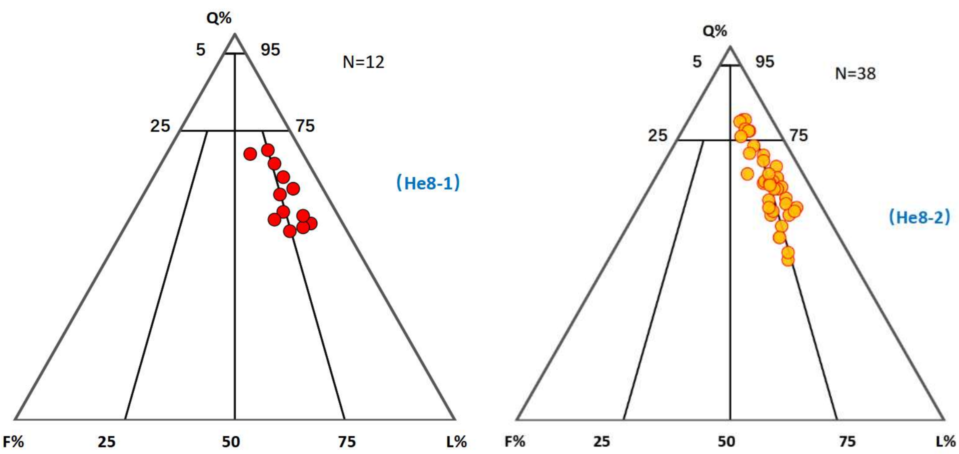


Fig.1 Characteristics of rock mineral composition in He 8 reservoir

The reservoir rocks of the He 8 Member in the study area are mainly gray, light gray and off-white medium sandstone, medium-fine sandstone, and fine sandstone (Fig.2), and there are clearly discernible differences in rock type between different sublayers: the He 8-2 Member is predominantly

Volume 12 Issue 3, 2026
DOI: 10.6919/ICJE.202603_12(3).0017

medium sandstone and medium-fine sandstone with relatively coarse grain size, whereas the He 8-1 Member has an increasing proportion of fine sandstone with overall finer grain size, which is a direct reflection of different sedimentary hydrodynamic conditions.

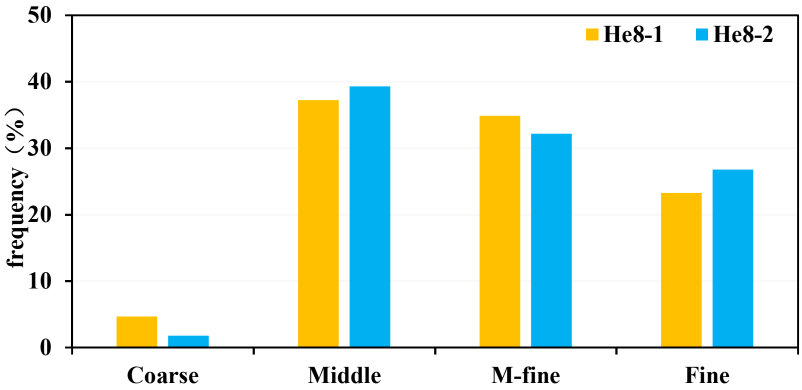


Fig.2 The reservoir rocks in He 8 Member's grain size distribution

Reservoir sandstone contains interstitial materials which can be unambiguously divided into cement and matrix: the cement is mainly siliceous and carbonate minerals with only minor amounts of tuffaceous interstitial material, whereas the matrix is predominantly clay minerals, namely kaolinite, hydromica, and chlorite, with the overwhelming majority being siliceous (Table 1). The Upper He 8 Member has an average interstitial material content of 19%, comprising 6% hydromica, 2.83% siliceous, and 2.33% kaolinite. In contrast, the Lower He 8 Member has an average interstitial material content of 18%, with 7.9% hydromica, 3.67% siliceous, and 3.64% siliceous.

Table 1. Interstitial material composition of sandstone reservoirs in He 8 (%)

Member	Kaolinite	Hydromica	Chlorite	Tuffaceous	Ankerite	Siderite	Siliceous	Total
He 8-1	2.33	6.00	0.83	2.83	3.83	0.33	2.83	19.00
He 8-2	3.64	7.90	0.00	5.13	2.31	0.17	3.67	18.00

3.2 Reservoir Space

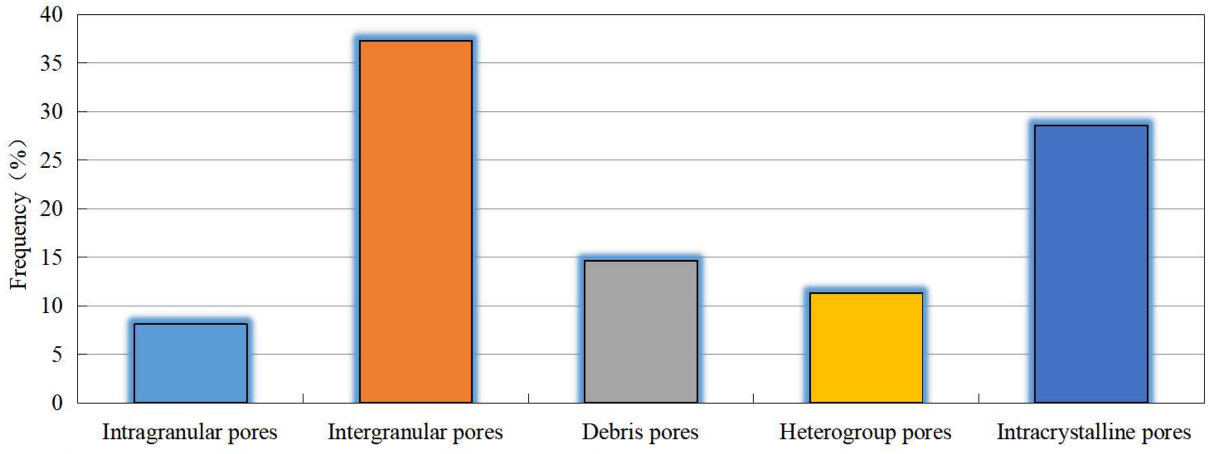
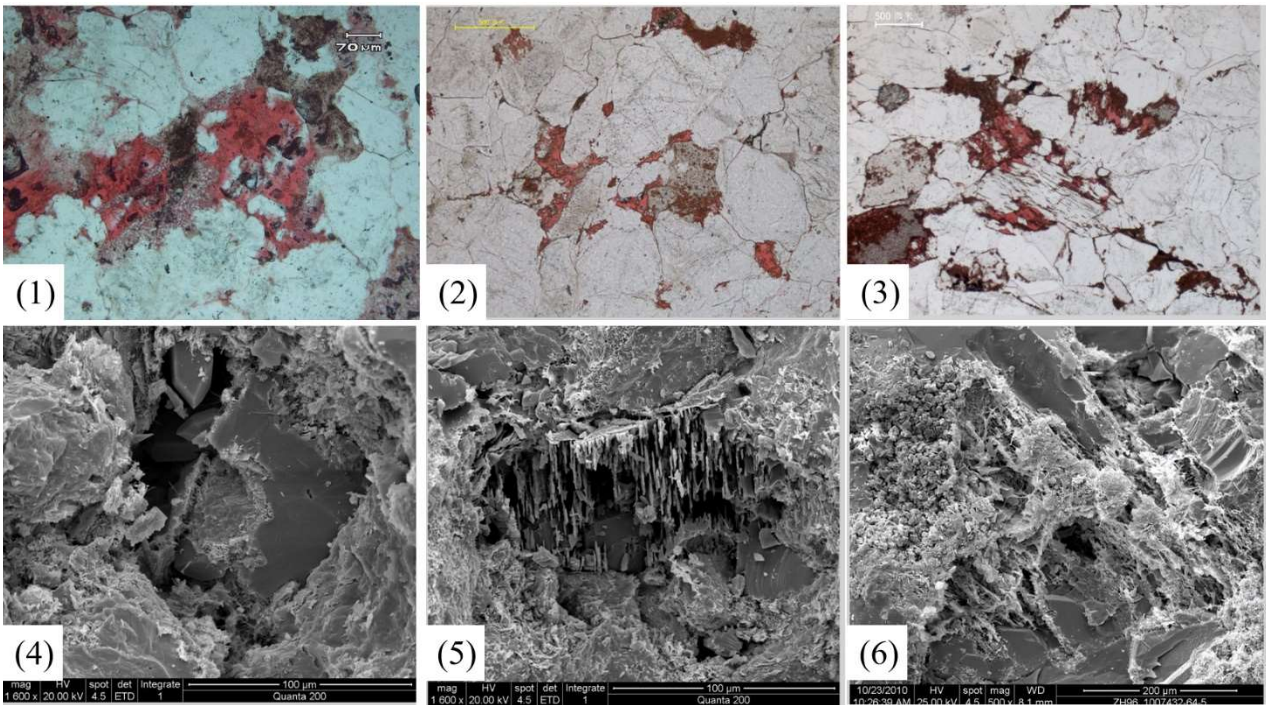


Fig.3 Distribution characteristics of main pore types in He 8 reservoirs



1.Intragranular dissolved pores(S253, 3354.93m);2-Intergranular dissolved pores(Y36, 2924.58m);3-Intergranular dissolved pores(S349, 3380.07m);4-Intergranular dissolved pores (T56, 3066.28m);5-Feldspar dissolved pores(T58, 3243.59m);6-Debris dissolved pores (Z96, 3204.87m)

Fig. 4 Microscopic characteristics of main pore types in He 8 reservoir

Thin section analysis confirms that the dominant reservoir pore type is secondary pores (Fig.3, Fig.4), with residual primary pores coming next. The intergranular dissolved pores are the dominant pore type in the reservoir, making up 37.28%, and are generally large in size with good connectivity, therefore the diagenetic types of He 8 Member reservoirs in the study area are quite complex, mainly comprising compaction-pressure solution, cementation, dissolution and metasomatism, all of which influence the evolution of reservoir physical properties in a coupled manner.

3.3 Pore Structure

Table 2. Classification standard of sandstone reservoirs in He 8

Type	Porosity(%)	Permeability (mD)	Lithology	Pore combination	Median throat radius(μm)
I	> 10	> 1	Quartz sandstone	Dissolved pores-intergranular pores	> 0.5
II	8~10	0.5~1	Quartz sandstone	Dissolved pores-intercrystalline pores	0.5~0.2
III	5~8	0.1~0.5	Lithic quartz sandstone	Dissolved pores-micropores	0.2~0.05
IV	< 5	< 0.1	Mainly lithic sandstone	Micropores	< 0.05

Since the development scale and the combination characteristics of pores and throats are the fundamental factors controlling the oil-water distribution law of oil and gas reservoirs, it is natural and reasonable to note that the throat types of He 8 Member reservoirs in the study area are mainly sheet or curved sheet throats, pore-constricted throats and bundle-shaped throats, with fine pore-micro

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throat(Type III) being dominant. On the basis of the features of capillary pressure curves such as displacement pressure, median pressure and mercury saturation, combined with physical property and cast thin section data, the He 8 Member reservoirs in the study area can reasonably and reliably be divided into four types (Table 2). Type reservoirs are characterized by porosity > 10%, permeability >1 mD, and consist mainly of quartz sandstone with dissolved pores-intergranular pores as the dominant pore type.

4. Main Controlling Factors of Reservoir

4.1 Control of Sedimentation

Sedimentation controls the rock type, pore structure, and lithologic component characteristics of reservoirs, determines the grain size, sorting, rhythm, and spatial distribution of reservoir sandstone, and therefore directly controls the changes in reservoir porosity and permeability. The He 8 Member in the study area is interpreted as a braided river-meandering river sedimentary system, so it follows that sedimentation controls the rock type, pore structure and lithologic component characteristics of reservoirs.

4.2 Influence of Diagenesis

Mechanical compaction is the principal factor causing porosity reduction in the study area because overlying pressure causes grains to compact and fluid pressure to decrease, thus leading directly to primary pore loss. The main cementation types are siliceous, calcareous and clay mineral cementation, with siliceous cementation having dual effects, calcite cementation having minimal impact, and clay cements (illite and kaolinite) each having distinct effects on permeability. Dissolution is a highly important constructive process that generates secondary pores (mainly lithic dissolution pores) which greatly enhance reservoir quality, whereas feldspar dissolution pores contribute little to this improvement.

5. Conclusion

(1)The lithology of the He 8 Member reservoirs in the Southeast Sulige Area of Sulige Gas Field is primarily quartz sandstone and lithic quartz sandstone, and the main interstitial minerals are hydromica, kaolinite and siliceous cements. It is well established that the content of interstitial elements in the Lower He 8 Member is slightly lower than in the Upper He 8 Member.

(2)Since the reservoir space is mainly composed of secondary pores with intergranular dissolved pores and intercrystalline pores as the principal reservoir types, it is reasonable to describe the pore structure as having a"micro-fine pore-throat combination" with poor pore-throat connection, and the dominant throat type is fine pore-micro throat.

(3)Sedimentation controls the macroscopic distribution of sand bodies, and therefore the central bar and point bar microfacies are the most favorable facies belts for the development of high-quality reservoirs. More importantly, diagenesis governs the evolution of microscopic physical properties of reservoirs, with mechanical compaction being the main cause of porosity reduction, dissolution the main mechanism for creating high-quality reservoirs, and siliceous cementation the main factor aggravating reservoir densification.

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