

# **PS Reservoir Characteristics, Formation and Gas Accumulation of Ordovician Ultra-Tight Paleokarst Carbonates in Eastern Ordos Basin, China\***

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Search and Discovery Article #10942 (2017)\*\*

Posted May 15, 2017

\*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017

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## **Abstract**

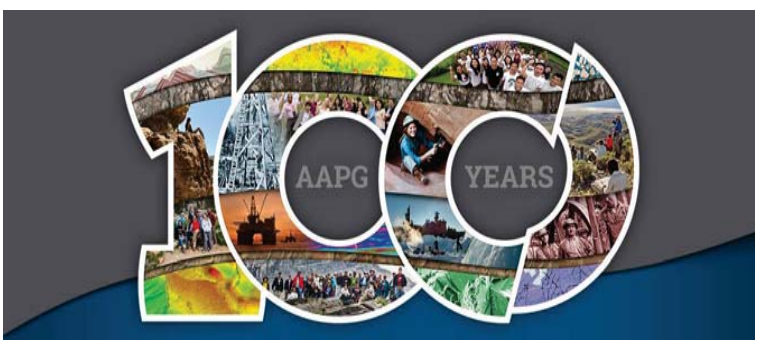
Ordos Basin is one of the most important hydrocarbon producing basins in China. The Ordovician Palaeokarst carbonates, which are tight reservoirs, are important hydrocarbon-bearing reservoirs and have been believed to develop in the central part of the basin only. However, recent discovery of commercial gas flow from a few wells in eastern basin have attracted much attention to reevaluate the carbonate reservoir potential. In this study, we use cores, scanning electron microscope (SEM), and pore-throat image analysis of casting sections to study pore structure, karst caves and fracture systems of Ordovician Palaeokarst carbonates reservoirs. Two kinds of pores are identified, including solution and dolomite intercrystal pores. Solution pores, which were initially formed during epigenic karstification and partly filled during burial diagenesis, are the most important storage spaces. The pore sizes are usually micrometer to millimeter scale, with pore diameter from 1µm to 2mm and throat diameter less than 15µm. The carbonates with pores size less than 30 µm and throats radius less than 5µm are not considered as effective reservoirs. Because karst cave and fracture systems are mostly filled during burial diagenesis process, Paleokarst reservoirs are featured by low to ultra-low porosity and low permeability to tight. Porosity of 3% and permeability of 0.05 mD are regarded as lower limit of reservoir physical property. Depositional environment, karstification, and burial diagenesis are major factors controlling the formation of high-quality carbonate paleokarst reservoirs. The dolomite with anhydrite concretions, which were dissolved during epigenic karstification and incompletely filled during burial diagenesis, can form high-quality reservoirs. Palaeokarst landform, especially upland and slope, have important effect on gas accumulation. Palaeokarst upland and slope mainly distribute in higher karst intensity area where high-quality reservoirs develop well, and palaeokarst unconformity as migration pathway can easily connect overlying coal-bearing source rock and underlying reservoirs in this area. This study explores the reservoir characteristics of Ordovician Paleokarst carbonates in eastern Ordos Basin, which could be beneficial to understand hydrocarbon accumulation mechanism for both ultra-tight carbonate reservoir in China and other basins in the world.



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## INTRODUCTION

Ordos basin is one of the most important hydrocarbon producing basins in China. The Ordovician Paleokarst carbonates are important hydrocarbon-bearing reservoirs and have been believed to develop only in the central part of the basin. Jingbian gas field is located in this area, which was estimated to contain 17.9 tcf of proven in-place gas (Fig. 1). However, recent discovery of commercial gas flow from a few wells in eastern basin have attracted much attention to reevaluate the carbonate reservoir characteristics, formation and gas accumulation (Fig. 2).

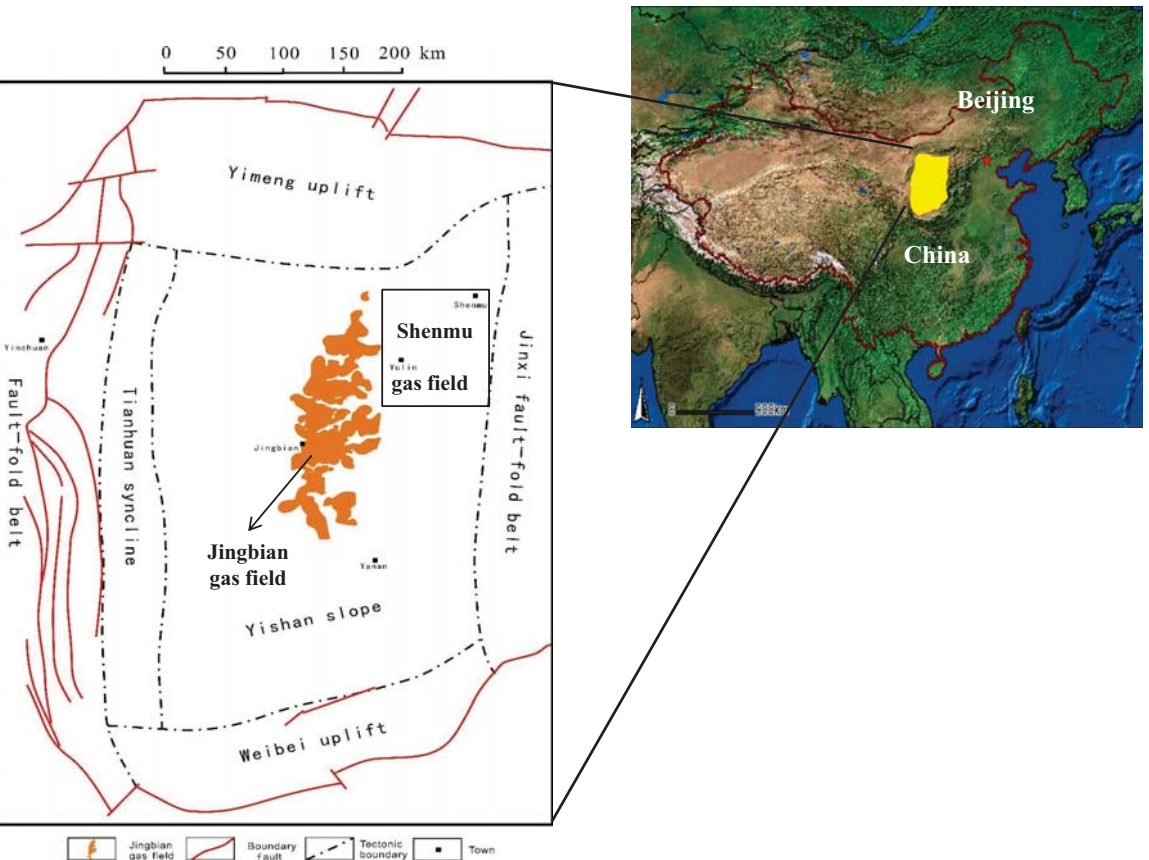


Figure 1. The Shenmu gas field location map

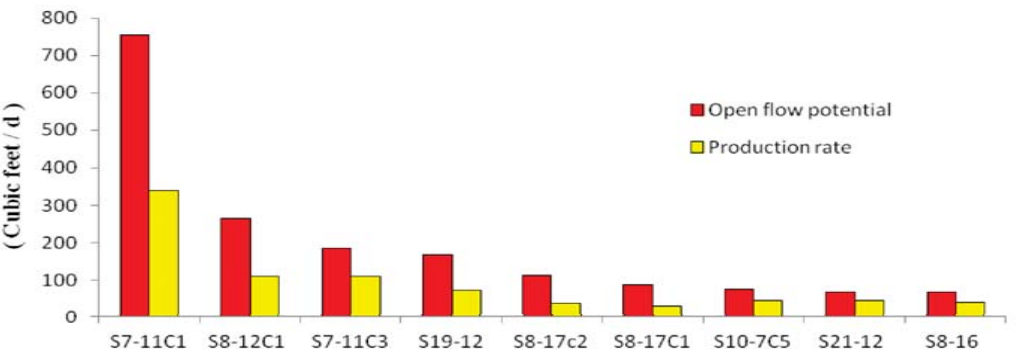


Figure 2. Gas well production from Ordovician Paleokarst carbonates in Shenmu gas field

## STRATIGRAPHY

The target zones are upper Majiagou formation  $Ma_5^1$  to  $Ma_5^4$  in Ordovician (Fig. 3), with an average burial depth of 2,850-3,040m, which were deposited in epicontinental marine environment (Fig. 4). Subsequent Karstification occurred in 150-130 Ma induced the dissolution of the upper Majiagou dolomite (Fig. 5). The Silurian, Devonian, and middle to lower Carboniferous are missed in the study area, and therefore the top of Majiagou formation was overlain by the upper Carboniferous Benxi Formation.

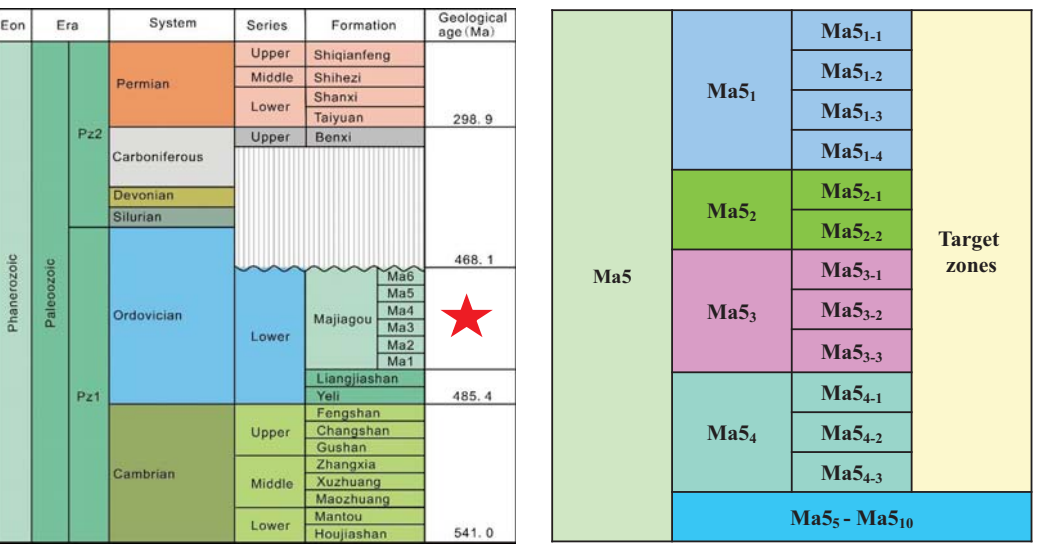


Figure 3. Stratigraphic chart of eastern Ordos and target zones

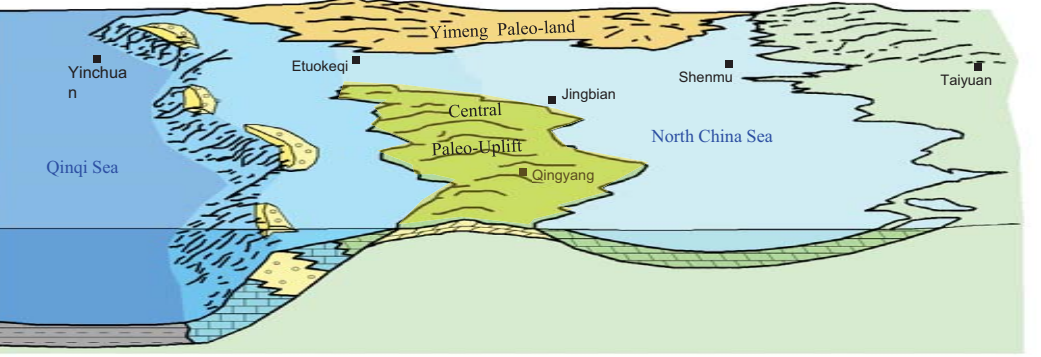


Figure 4. The lithofacies- paleogeographical environment of Majiagou Formation

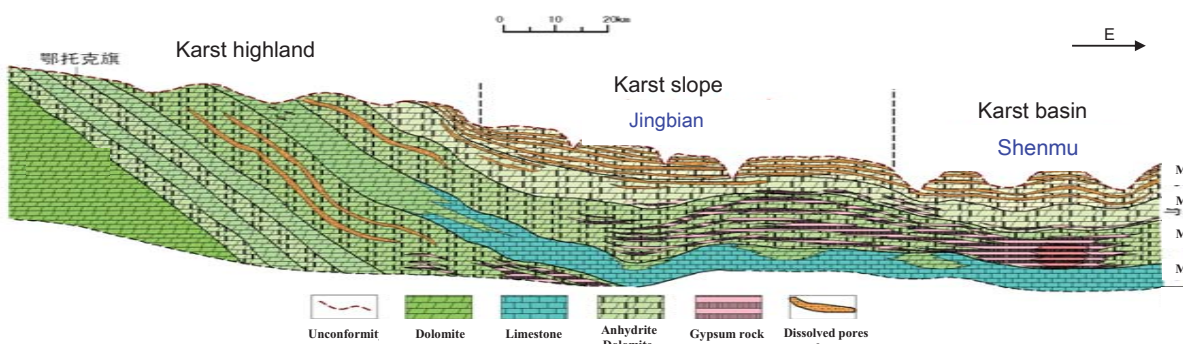


Figure 5. The ancient karst landform landscape of Majiagou Formation

There are no preservation of Ma6 in the study area. The karstification is strong in northwestern part of study area, and  $Ma_{5-3}$  was partly missed locally (Fig. 6).

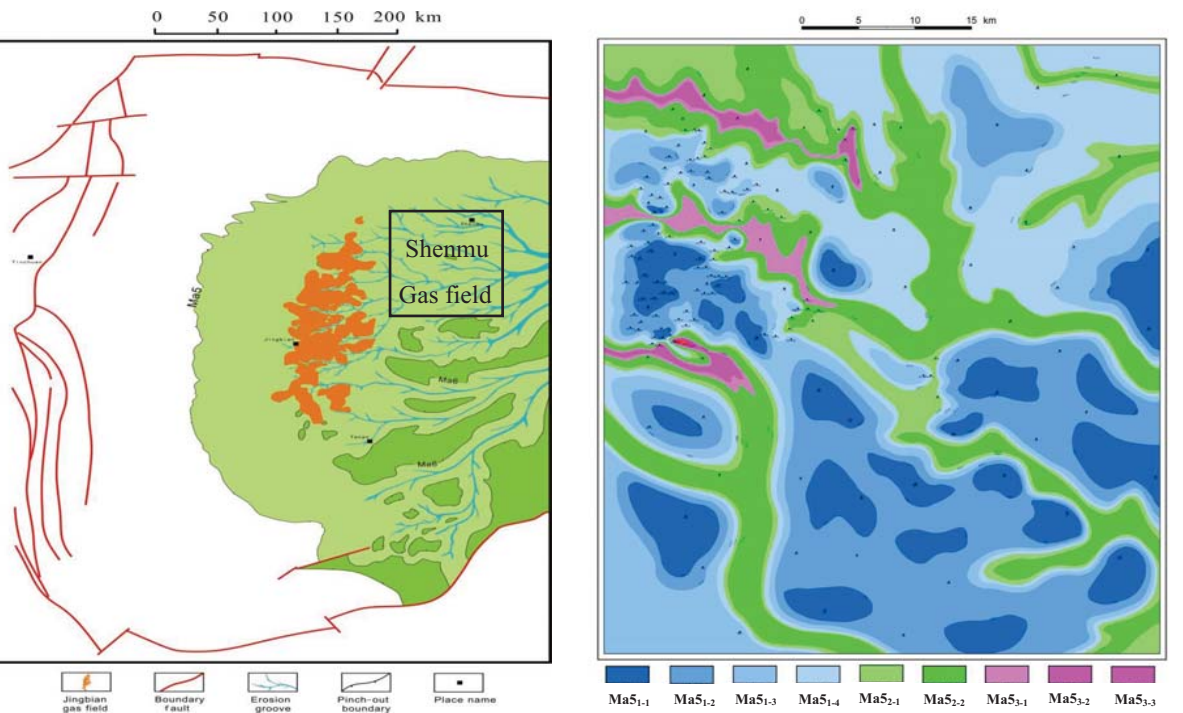


Figure 6. Residual map of Ma5 in Shenmu gas field

## PETROPHYSICS

Paleokarst carbonate reservoirs in the eastern Ordos basin are characterized by low porosity and low permeability (Fig.7). The porosity and permeability cutoff for net pays is 3% and 0.05 mD, respectively (Fig. 8). The dolomite with anhydrite concretion solution pores, which have higher porosity and permeability, are high- quality reservoir (Fig. 9), and other types of lithofacies can not form productive reservoirs.

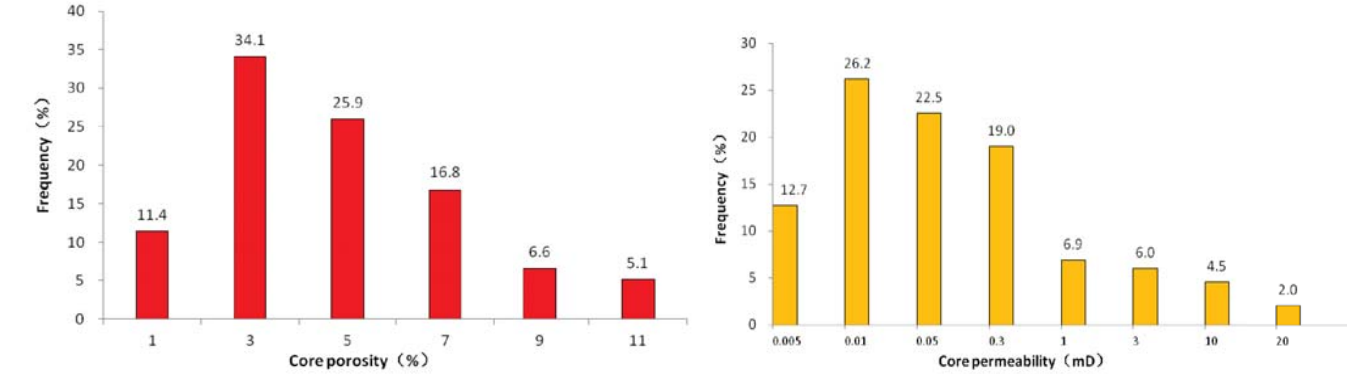


Figure 7. Porosity and permeability of paleokarst carbonate reservoirs in the eastern Ordos



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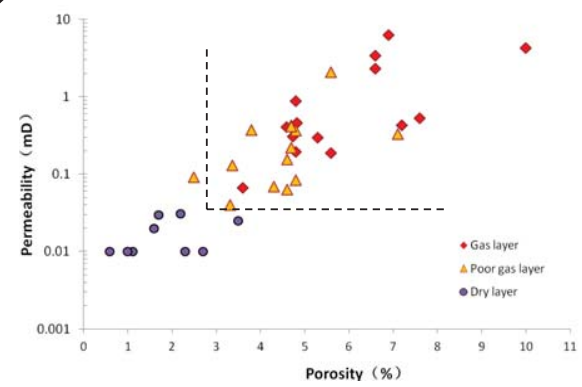
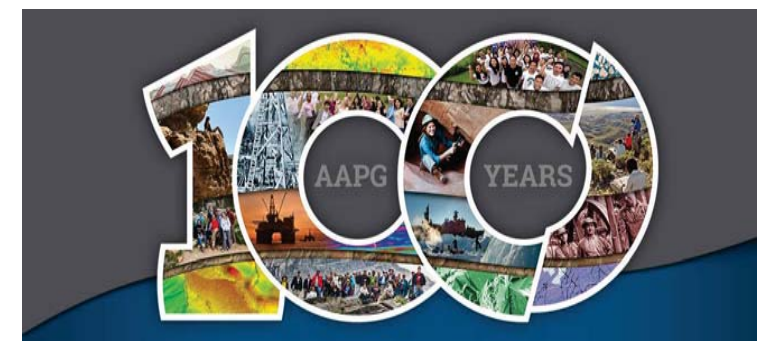


Figure 8. The porosity and permeability cutoff for net pays



Figure 9. The dolomite with anhydrite concretion solution pores

## PORE AND THROAT

Three types of reservoir space including pores, caves, and fractures can be observed, and most caves and fractures are completely filled (Fig. 10). Two kinds of pores are identified, including anhydrite concretion solution pores and dolomite intercrystal pores. The anhydrite concretion solution pores are about 100 $\mu$ m to 2.0mm, partly or completely filled by dolomite, calcite, quartz, anhydrite, or other diagenetic mineral during diagenesis (Fig. 11, Fig. 12). The dolomite intercrystal pores is about 1 $\mu$ m to 100 $\mu$ m (Fig. 13). The pore sizes of Ordovician paleokarst carbonates reservoir are micrometer to millimeter scale.

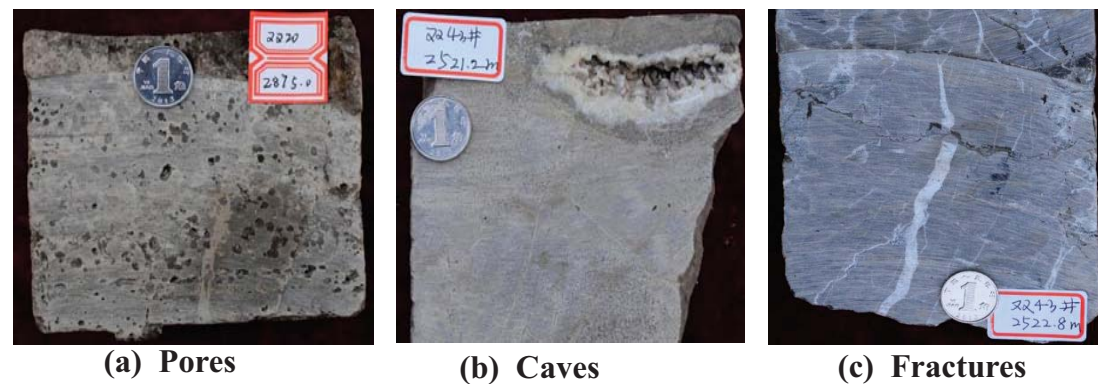


Figure 10. Three types of reservoir space in eastern part of Ordos basin (cores)

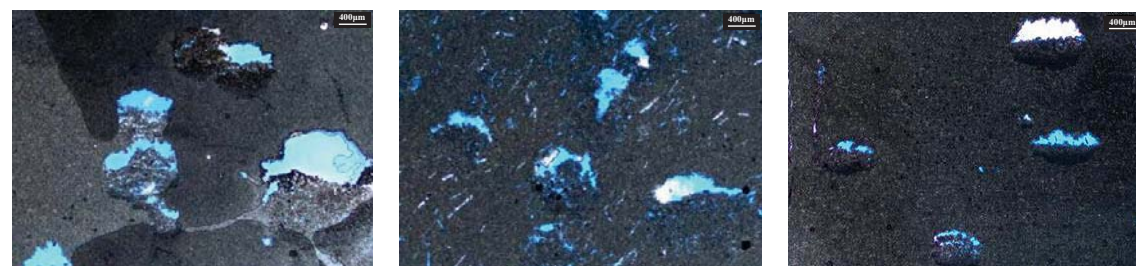


Figure 11. Partly filled anhydrite concretion solution pores (Casting thin sections)

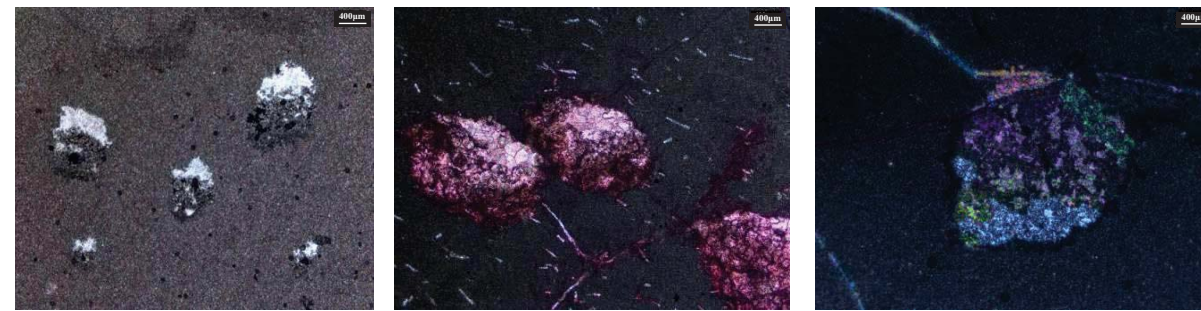


Figure 12. Completely filled anhydrite concretion solution pores (Casting thin sections)

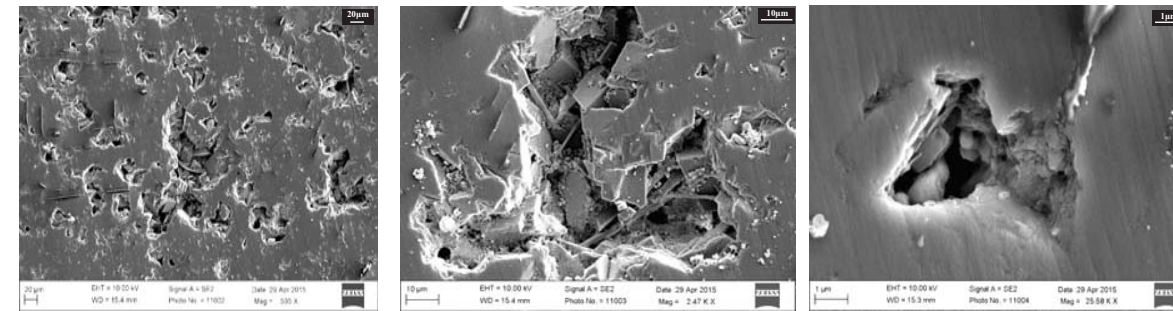
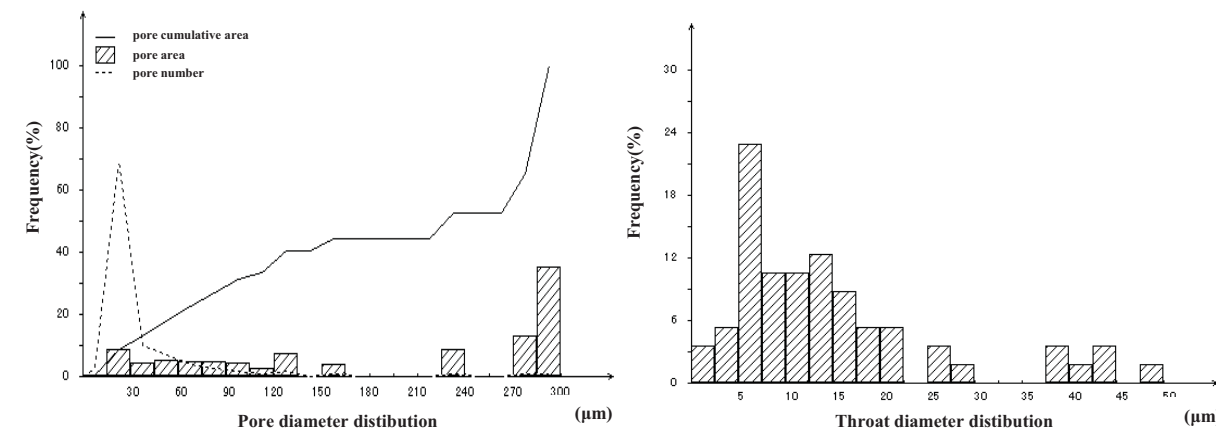
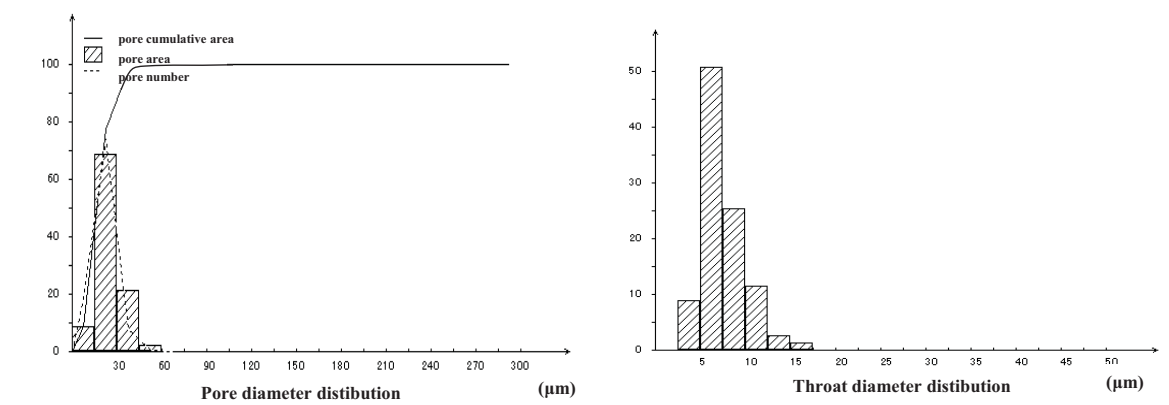


Figure 13. Dolomite intercrystal pores (Scanning electron microscopy)

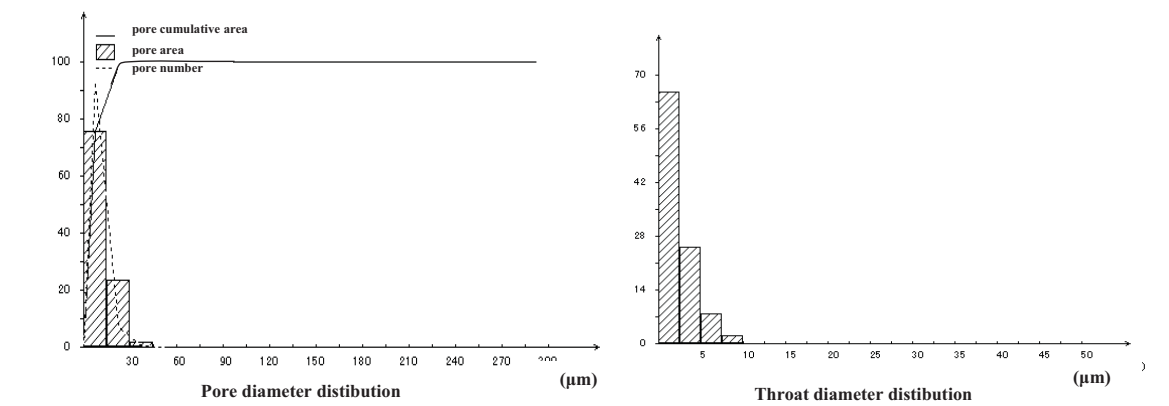
Four kinds of lithofacies mainly develop in the study area: dolomite with partly filled anhydrite concretion solution pores, dolomite with completely filled anhydrite concretion solution pores, dolomite and argillaceous dolomite. Different lithofacies have different pore and throat structures. As anhydrite concretion solution pores reduce, pores and throat size become smaller. The carbonates with pores size less than 30  $\mu$ m and throats radius less than 5  $\mu$ m are not considered as effective reservoirs.



(a) Dolomite with anhydrite concretion solution pores, partly filled por:10%, perm:2.55mD, high-quality reservoir



(b) Dolomite with completely filled concretion solution pores and dolomite por:3.6%, perm:0.19mD, poor reservoir



(c) Argillaceous dolomite, por:0.3%, perm:0.001mD, non-reservoir

Figure 14. Pore-throat distribution of different lithofacies ( Pore-throat image analysis of casting sections)

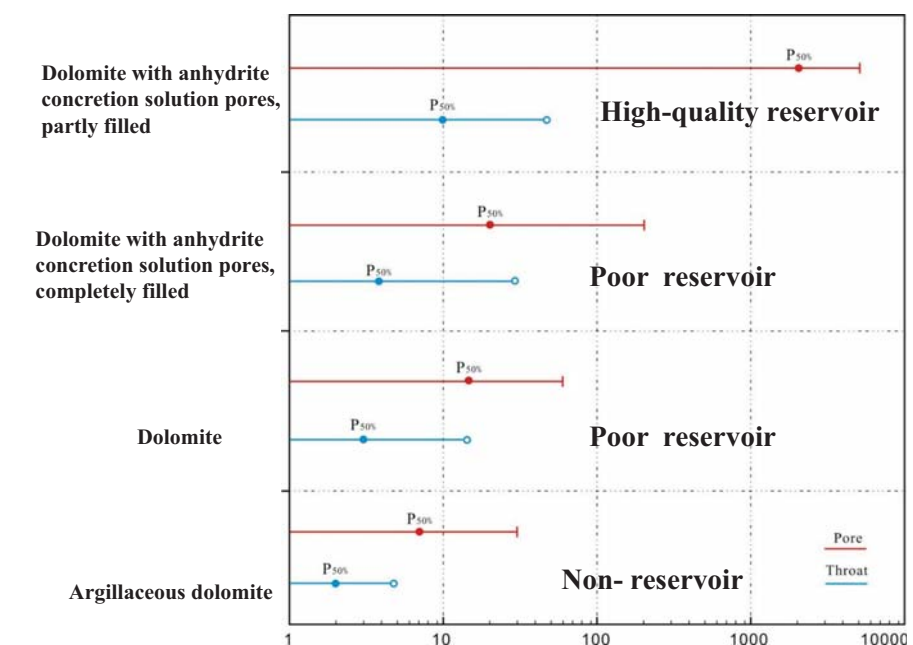


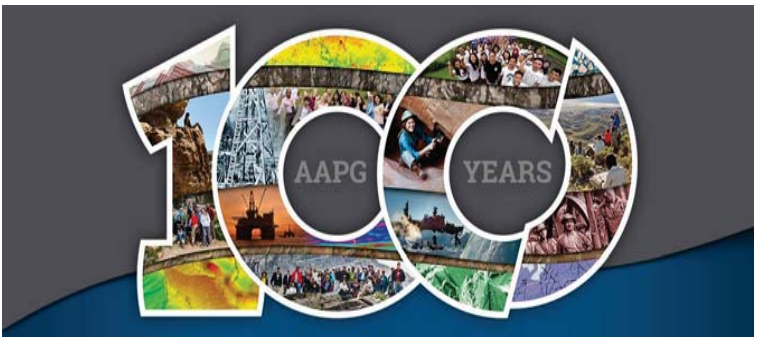
Figure 15. Pore -throat diameter contrast of different lithofacies



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## RESERVOIR FORMATION

Depositional environment, karstification, and burial diagenesis are major controlling factors for the formation of paleokarst reservoirs. The dolomite with anhydrite concretions, which were deposited in epicontinental marine environment, were dissolved during epigenic karstification and incompletely filled during burial diagenesis, and formed reservoirs finally. Palaeokarst landform, especially upland and slope, have important effect on distribution of high-quality reservoirs(Fig. 16).

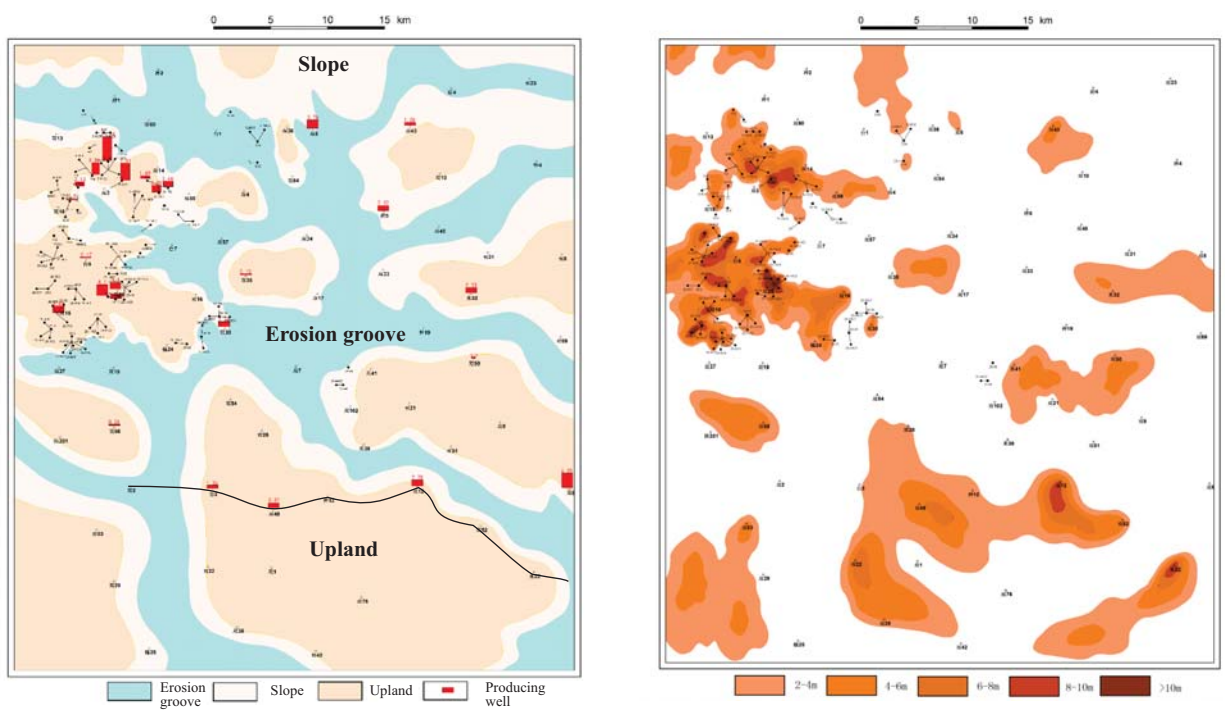


Figure 16. Sub-palaeogeomorphology division and reservoir thickness of Shenmu gas field in eastern part of Ordos Bain

## GAS ACCUMULATION

The good space-matching relationship among source rock, migration pathway and high-quality reservoirs is the key for gas accumulation. High-quality reservoirs which are distributed on upland and slope can easily capture the natural gas which was generated from overlying coal-bearing formaion of Permian and Carboniferous and migrated along paleokarst unconformity(Fig. 17, Fig. 18).

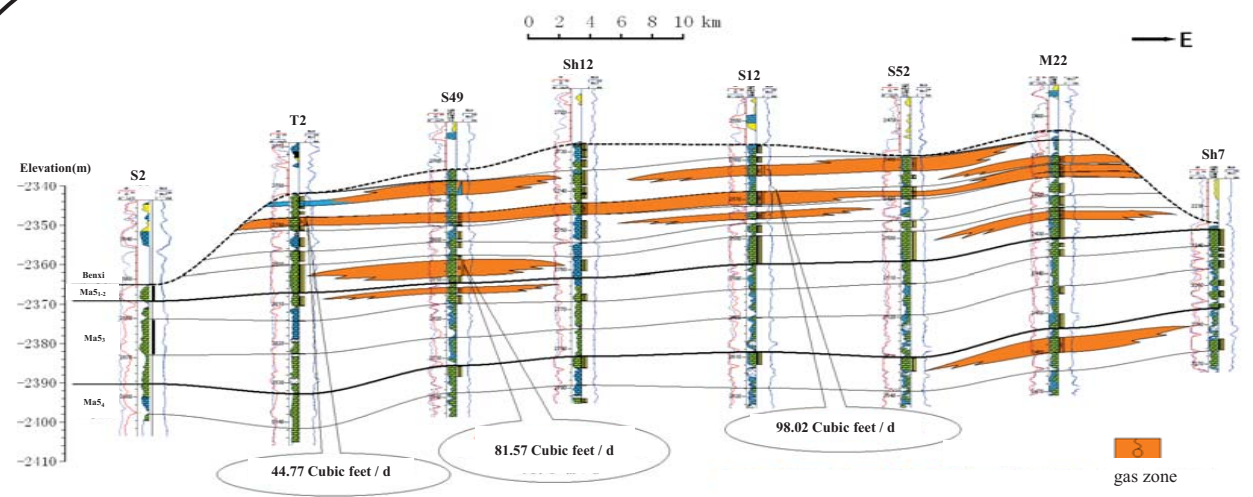


Figure 17. Gas-bearing profile showing the characteristics of gas accumulation

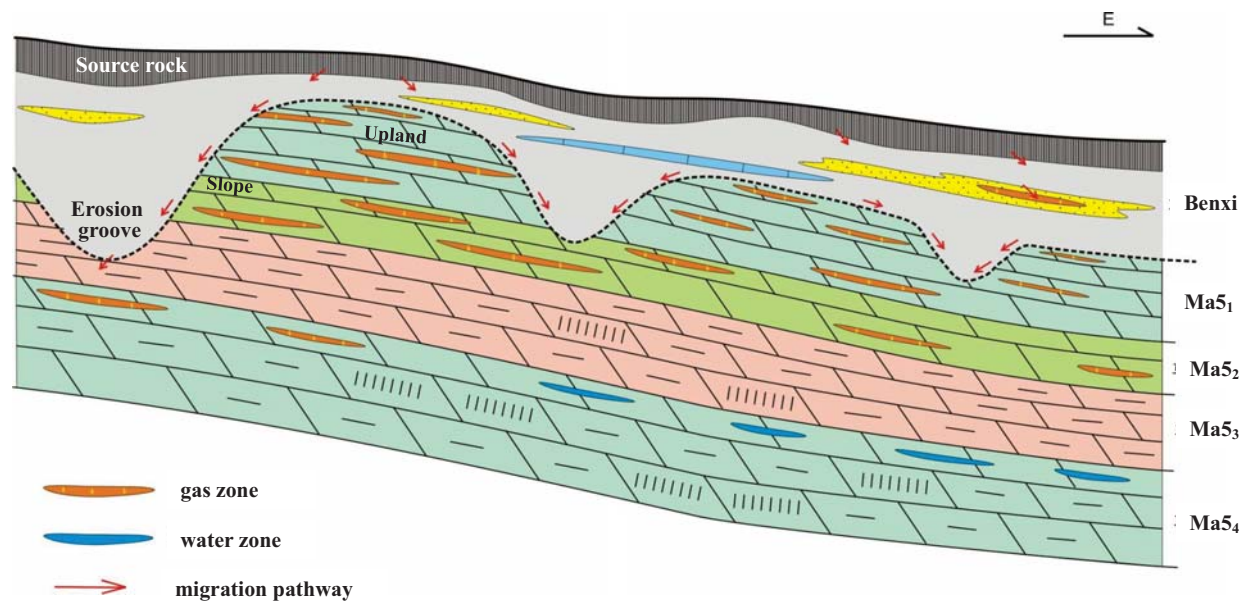


Figure 18. Gas enrichment pattern of lower Paleozoic paleokarst in eastern part of Ordos

## CONTRAST WITH JINGBIAN GAS FIELD

Ordovician Paleokarst carbonate reservoirs in eastern Ordos Basin are characterized by weaker karstification, poorer reservoir quality, lower gas richness, and poorer reservoir connectivity compared to central part of the basin. However, favorite conditions for gas enrichment still exist in local area, and the exploration and development prospect should be bright.

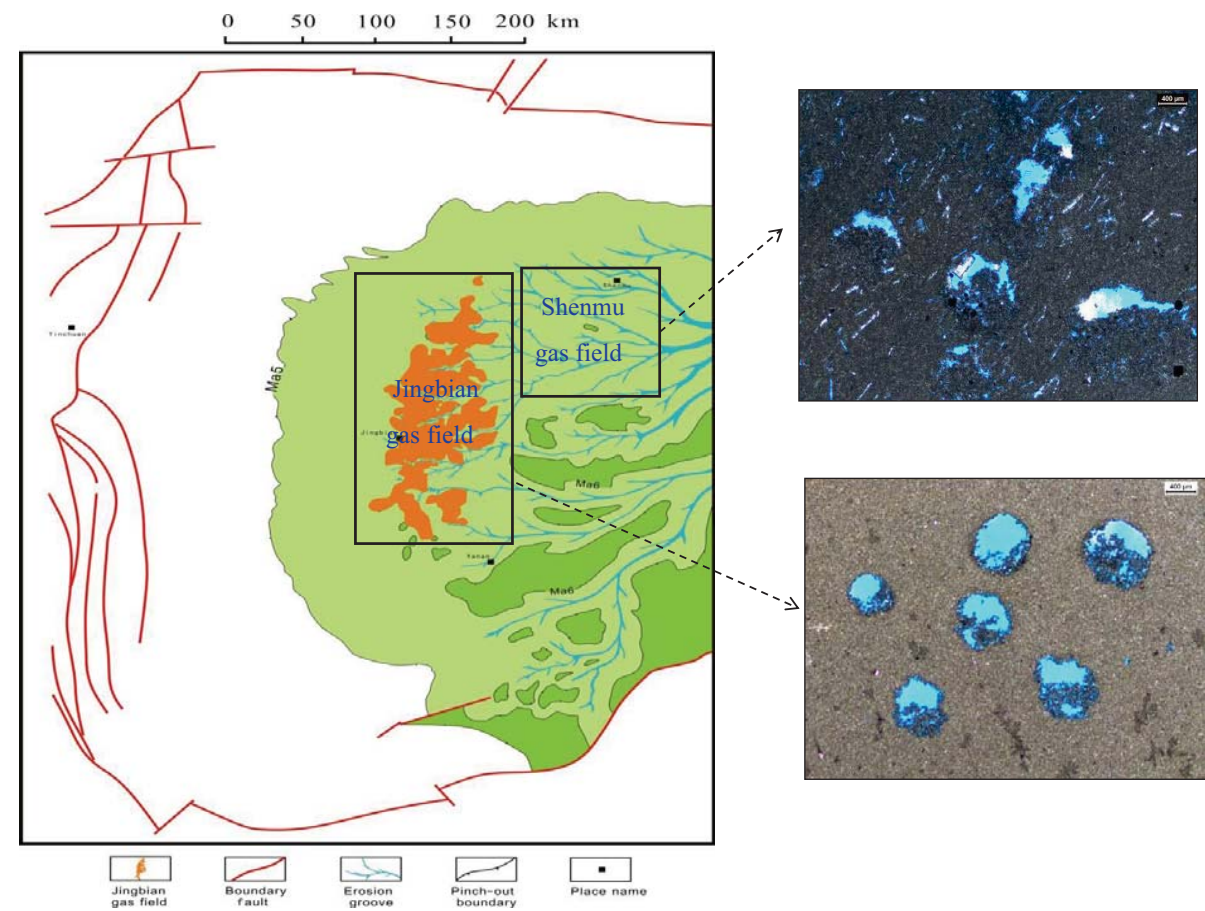


Figure 19. Comparison with Jingbian gas field in central part of Ordos basin

This study explores the reservoir characteristics of Ordovician Paleokarst carbonates in eastern Ordos Basin, which could be helpful to understand the formation and gas accumulation mechanism for tight carbonate reservoirs in China and other basins in the world.