Sequence Stratigraphy and Coal Accumulation of the Lower Permian in Xinji Mining Area of Huainan Coalfield

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Keywords: Huainan coal field, Lower permian, Sequence stratigraphy, Coal accumulation.

Abstract. The coal-bearing formation of Lower Permian in Huainan coalfield is well developed with lagoon-tidal flat deposition and delta system deposition. According to the identification of the sequence boundaries represented by regional unconformity and incised valley filling sandstone base, combined with the characteristics of sedimentary cycles, the high resolution sequence stratigraphy of the Early Permian coal seams (the Shanxi formation and Lower Shihezi formation) have been analyzed. The coal seams are divided into 3 third-order sequences from bottom to top and the sequence stratigraphic framework has been established. The thickness variation of the coal seams shows that the major minable seams were developed in the transgressive systems tract of lagoon-tidal and the delta plain environments, in which the total coal seams are thicker in SQ3 and thinner in sequence SQ2, with the thinnest in SQ1. Within the sequence, the thickest coals were developed in the transgressive systems tract, the thicker coals in the high-stand systems tract and the thinnest coals were preserved in the low-stand systems tract.

Introduction

The theory of sequence stratigraphy has been widely applied in the coal-bearing formation exploration and development of offshore Basins [1-3]. As one of five main coal field in China, Huainan Coal field is located in the northern part of Anhui province, the Early Permian coal seams consist mainly of clastic rocks of marine-continental transitional environment with the apparent markers and sedimentary cycles. On the basis of sedimentology, sequence stratigraphy, coalfield geology, this paper has taken regional unconformity and incised valley filling sandstone base as the sequence boundaries to divide Lower Permian coal seams into 3 third-order sequences and establish the sequence stratigraphic framework furthermore to discuss the controlling function of the coal seams thickness variation.

The Regional Geological Conditions

Coal-Bearing Formation

Shanxi Formation. The total strata thickness of Shanxi formation is 42~83m with the average thickness of 57m and the coal seams include 1~3 levels with the total thickness of 7.4m. The Shanxi formation are mainly composed of sandstone, mudstone, siltstone, sandy mudstone with the high mudstone content. The Shanxi formation and the underlying Taiyuan formation were developed continuously and conformably, and the boundary between each other is the limestone marker (L1) on top of Taiyuan formation.

Lower Shihezi Formation. The total strata thickness of Lower Shihezi formation is 141~176m with the average thickness of 157m and the coal seams include 8~12 levels with the total thickness of 18.9m. The Lower Shihezi formation is mainly composed of mudstone, sandstone, siltstone, oolitic mudstone. The Lower Shihezi formation and the underlying Shanxi formation were developed continuously and conformably, and the boundary between each other was the medium-coarse sandstone marker (S1) on the bottom of Lower Shihezi formation.
Sedimentary Evolution

In the Permian period, the formation and evolution of North China craton were controlled by the development of Paleo-Tethys ocean\textsuperscript{5,6}. The large-scale tectonic activity of "uplifting in north and descending in south" changed the paleotopography of the study area and determined the sedimentary evolution of Shanxi formation and Lower Shihezi formation in the study area.

In Shanxi stage, the paleotopography of higher in north and lower in south were further intensified by the continuous uplift of the northern part of North China craton. The overall marine regression from north to south occurred in study area and the bottom of Shanxi formation developed the lagoon-tidal flat deposits including lagoon facies, tidal tract facies and peat swamp facies, but the top of Shanxi Formation transited into delta front deposits. The coal seams formed above lagoon deposition were the main minable coal seam with thick seam and wide distribution in study area, such as 1 # coal and1-1 # coal.

In Lower Shihezi stage, with the overall marine regression from north to south, the bottom of Lower Shihezi formation developed coastal delta front deposits including underwater distributary channel facies, interdistributary bay facies and peat swamp facies. The upper parts of Lower Shihezi were transformed into delta plain deposits, including channel facies, interdistributary bay facies. The Lower Shihezi formation contained massive minable coal seams of which the two major seams were 8# coal and6-1 # coal and others were with thinner seam, such as 9# coal, 7# coal, 5# coal, 4# coal.

The Characteristics of Sequence Stratigraphy

The sequence definition and division of system tract from Vail's school points are introduced in this paper, and the key boundaries are identified by the recognition of sequence boundary, initial marine flooding surface, the maximum flooding surface\textsuperscript{7}.

Recognition of Sequence Boundary

1) Regional unconformity. The regional unconformity caused by paleotectonic movement is typical and easily recognized sequence boundary.

2) Incised valley filling sandstone base. Incised valley filling sandstone are found usually on the bottom of the third-order sequence with the characteristics of large thickness and double overlapping structure, which can be considered as a sequence boundary, such as the medium-coarse sandstone marker (S1) of underwater distributary channel deposits between SQ1 and SQ2.

Recognition of the Initial Marine Flooding Surface

The initial marine flooding surface is the first flooding surface overlaying incised valley filling sandstone and develop grey mudstone or thin coal seam generally. In the study area, it is identified as the bottom of grey mudstone or thin coal seam overlaying the medium-coarse sandstone of channel deposits and underwater distributary channel deposit.

Recognition of the Maximum Flooding Surface

As a symbol of the maximum transgression during the sequence, the maximum flooding surface is considered as the bottom of rock unit reflecting the maximum increasing speed of accommodation space and deepest water\textsuperscript{8}. In the study area, the bottom of first charcoal mud stone above thick coal seam with large thickness and continuous distribution in the horizontal direction is identified as the maximum flooding surface.

Division of Sequence Stratigraphy

According to the identification of the sequence boundaries and the characteristics of sedimentary cycles, 4 sequence boundaries were identified in the Early Permian coal seams, which could be divided from bottom to top into 3 third-order sequences and 8 system tracts (Fig 1). Fig 1 shows the sedimentary environments and sequence stratigraphy of the Lower Permian coal seams of Huainan Coalfield.
1) SQ1 (Shanxi formation): it is consisted of low-stand system tract (LST), transgressive system tract (TST), high-stand system tract (HST). LST: it is consisted of charcoal mudstone and grey sandstone, representing the sediments of lagoon facies and tidal tract facies correspondently. There is no main minable coal seam in this system tract. TST: the bottom of thin coal seam (1 #coal) is identified as the initial marine flooding surface, the bottom of first charcoal mudstone above thick coal seam (1-1 # coal) with large thickness and wide distribution is identified as the maximum flooding surface. There are two major minable coal seam (1#coal and 1-1#coal) in this system tract. HST: it is consisted of quartz sandstone, sandstone, mudstone, siltstone of coastal delta front deposits.

2) SQ2 (Lower Shihezi formation from S1 to 5#coal): The medium-coarse sandstone marker (S1) of underwater distributary channel deposits is considered as a sequence boundary, between SQ1 and SQ2, it is consisted of low-stand system tract (LST), transgressive system tract (TST) with HST deletion. LST: it is an upward thinning sequence with the medium-coarse sandstone on the bottom and purplish red-brownish yellow variegation mudstone and al mudstones on the top, which represents floodplain deposit in the hot and dry circumstances. TST: it is consisted of thick silty mudstone and mudstone, and the coal seams (4-1#, 4-2#, 5-1# and 5-2# coal) were thin stems with unstable distribution.

3) SQ3 (Lower Shihezi formation from S2 to S3): it is consisted of low-stand system tract (LST), transgressive system tract (TST), high-stand system tract (HST) of delta plain deposits. LST: it is an upward thinning sequence and mainly consisted of sandstone of channel deposits and mudstone of interdistributary bay deposits. TST: it is consisted of thick silty mudstone and mudstone and the bottom of first charcoal mudstone above 8 # coal seam with large thickness and wide distribution is identified as the maximum flooding surface. HST: it is consisted of grained sandstone, mudstone, siltstone with an upward coarsening tendency. Suffering from channel scouring and over-bank deposits[^9], the thin coal seams (7# and 9# coal) were formed on the bottom of this system tract.

Regularities of Coal Accumulation

The total coal seams thickness in SQ1 is 7.42m, 5.59m in SQ2, 15.77m in SQ3. In study area, the lagoon-tidal flat deposits developed in SQ1, the rate of peat accumulation was slow and the rate of peat accumulation and the rate of accommodation creation reached balance near the initial marine flooding surface, where major minable coal seams with large thickness and wide distribution formed. 1 # coal and 1-1 # coal are the examples in SQ1. The delta front deposits and delta plain deposits developed in SQ2 and SQ3. In SQ2, purplish red-brownish yellow variegation mudstone represents the ancient hot and dry circumstances, which led to harsh growth environment and the insufficient supply of plant debris, finally thin and discontinuous coal seams were formed. In SQ3, delta plain deposits provided plenty of plant debris, the rate of peat accumulation was high and the rate of peat accumulation and the rate of accommodation creation reached balance near the maximum flooding surface, where major minable coal seams with large thickness and wide distribution formed, such as 8# coal. It could be inferred comprehensively that the mechanism of the coal accumulation in SQ3 is the best one, better in SQ2, the worst in SQ1.
Conclusion

1) According to the recognition of the sequence boundaries represented by regional unconformity and incised valley filling sandstone base, 4 sequence boundaries have been identified and 3 third-order sequences and 8 system tracts have been divided in the Early Permian coal seams (the Shanxi formation and Lower Shihezi formation) with the HST deletion in SQ2.

2) The thickness variation of the coal seams is under the control of sedimentary environment and the sequence stratigraphic framework. In SQ1, the lagoon-tidal flat deposits developed with thicker...
coal stem and wider distribution. In SQ2-SQ3, the sedimentary environment in study area experienced the transformation from lagoon-tidal deposits to delta plain deposits with most levels and largest total coal seams thickness in SQ3.

3) In all three third-order sequences, the total coal seams are thicker in SQ3 and thinner in sequence SQ2, with the thinnest in SQ1. Within the sequence, the thickest coals were developed in the transgressive systems tract, the thicker coals in the high-stand systems tract and the thinnest coals were preserved in the low-stand systems tract.

Acknowledgement
This research was financially supported by Provincial Training Programs of Innovation and Entrepreneurship for Undergraduates (Item number: 201510379075), Natural Science Research Project of Suzhou College (Item number: 2014yyb08), Teaching Research Project of Suzhou College (Item number: szxyjyxm201421).

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