Coal forming environment and coal accumulation law of Upper Paleozoic in Huanghua Depression

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Abstract. The characteristics of sequence stratigraphy, geochemistry and coal petrology of Taiyuan and Shanxi formations of Upper Paleozoic in Huanghua depression are systematically analyzed in this paper. It is considered that the thick coal seams in the study area are formed near the transgressive surface, while the coal seams formed at the most flooding surface are not so thick. The thick coal seams are mostly formed in the transgressive system tract, and the coal seams in the highstand system tract are relatively thin, and the coal seams in the lowstand system tract are hardly developed. There are mainly three coal forming models in the study area: ① the land surface coastal coal forming model; ② the abandoned clastic system tract coal forming model; ③ the shallow water delta coal forming model. The main coal forming model is the epicontinental seashore coal forming mode, and the Taiyuan Formation thick coal seam is mainly formed in the epicontinental seashore coal forming mode, and the Shanxi Formation thick coal seam is mainly formed in the waste clastic coal forming mode.

Keywords: Huanghua Depression, Upper Paleozoic, Coal accumulation law, sequence stratigraphy.

1. Introduction

Bohai Bay basin is a large sedimentary basin rich in oil and gas resources in eastern China. Huanghua depression is an important negative structural unit in Bohai Bay Basin, with a total area of 1.7 × 10⁴ km². It is a complex superimposed rift basin within the Bohai Bay basin. It is located in the south of Yanshan fold belt, chengxian uplift in the East, Cangxian uplift in the West and Linqing depression in the south [1, 2](Fig.1-A). The width of Huanghua depression is 70 km, and it is distributed in NE-SW direction. It is a dustpan like fault depression with northwest fault and Southeast super fault (Fig.1-C). There are eight fourth order structural units in Huanghua depression, including Beitang sag, Nanpu Sag, Tangdong uplift, Banqiao sag, Qikou Sag, Dagang structural belt, Yangsanmu structural belt and zhaojiapu structural belt (Fig.1-A). The Carboniferous Permian coal measures are widely developed in the study area, with a thickness of about 700-1100m (Fig.1-B). The upper Paleozoic in
Huanghua depression is a set of coal bearing strata from marine facies to sea land transitional facies and then to continental facies. The strata are thick in the South and thin in the north \cite{3-4}.

2. Coal forming environment of Upper Paleozoic

According to previous studies \cite{5-7}, the development of hydrocarbon source rocks in North China is obviously affected by transgression. The coal seams in the study area are mainly developed in Taiyuan Formation and Shanxi formation. In the early stage of Taiyuan formation, seawater mainly intrudes from nee to SWW direction, while in the later stage of Taiyuan formation, seawater mainly intrudes from se to NW direction, and the sea water in Shanxi period mainly intrudes from se to NW direction, and the sea water basically exits from North China Basin in Shihezi period In this chapter, the coal forming environment of Taiyuan Formation and Shanxi formation is discussed by means of sequence stratigraphy, petrology, sedimentology and geochemistry.

According to the recognition of the sequence stratigraphic boundary of the upper Paleozoic in the study area and the previous understanding of the sequence stratigraphy in this area, the Taiyuan Formation and Shanxi Formation in the study area are divided into four third-order sequences. In sequence 2, calcareous sandstones, mudstones, carbonaceous mudstones, and thin coal seams are developed in the lowstand system tract of sequence 2, which is characterized by high frequency transgression. Therefore, there are also multi-layer argillaceous carbonate rocks and thick coal seams in the transgressive system tracts of sequence 2. Black mudstone and carbonaceous mudstone are developed in the highstand system tracts in the upper part of the sequence, and thin coal seams are occasionally seen, which are typical barrier coastal deposits. The thick calcareous sandstone developed in the lowstand system tract at the bottom of sequence 3 is distributary channel deposit. In the transgressive system tract of sequence 3, huge thick coal seam is developed, which is mud carbon swamp deposit. The top of coal seam is the most flooding surface, and the top highstand system tract deposit is denuded. The low stand system tract at the bottom of sequence 4 develops thick sandstone under delta plain subfacies. The natural gamma curve is box shaped, and the degree of toothing is not high, and the resistivity curve is also box shaped. Thin coal seams, dark mudstone and siltstone can be seen in the transgressive system tract of the sequence, and the deposition of the upper highstand system tract is eroded; Fine sandstone, thin coal bed and dark mudstone are developed in lowstand system tract at the bottom of sequence 5, with positive grain sequence structure. Fine sandstone and dark mudstone of delta front subfacies are developed in upper lacustrine spreading system tract, which...
are mainly fine sandstone with less argillaceous content, and cross bedding and small wavy bedding are developed.

We can judge the redox conditions by the relative enrichment of trace elements or the ratio of similar elements. In particular, V, Mo, Cr, u, Ni, etc. are very sensitive to the changes of sedimentary environment. In the oxidation environment, they exist in the form of free state. When they are in anoxic or reducing environment, they will combine with other elements and precipitate. Therefore, the enrichment degree of Mo, u, V and other elements can indicate the redox situation of water body, while V/(V + Ni), V, etc./The ratios of Cr, U/Th and other elements are often used to indicate the redox environment [8-11]. According to the change trend of trace elements, the water environment changes of Taiyuan Formation and Shanxi Formation in the study area were discussed respectively. In the vertical direction, the trace elements in the dark mudstone of Taiyuan formation have the peak values of MOEF (maximum 31.6 μg/g) and UEF (maximum value of 15.5 μg/g) (Fig. 2), indicating that the sedimentary water body is anoxic environment, U/Th value is 0.46~2.1 (average value is 1.03), V/Cr value is 0.71~4.9 (average value is 2.5), indicating that organic matter is developed in oxygen poor environment. In addition, the EU/EU* normalized by PAAS shows a significant positive anomaly, indicating that there is submarine hot water activity in this stage [12], which is easy to cause anoxic bottom water environment. The values of MOEF (maximum value is 1.7 μg/g) and UEF (maximum value is 5.24 μg/g) of dark mudstone in the upper member of Shanxi formation are low, U/Th value is 0.21 ~ 0.32 (average value is 0.25), V/Cr value is 1.55 ~ 2.33 (average value is 1.9). Abnormal sample points appear at the top, and MOEF, UEF, U/th are found at the top. The results show that there was a short period of anoxic period in the middle and top of this area. It can be considered
that the water environment of dark mudstone deposition period is mainly secondary oxidation, with short-term anoxic environment. According to the sedimentary sequence of the whole dark mudstone, the sedimentary environment of the dark mudstone in the study area has experienced multiple anoxic and oxidation cycles, which is related to the multiple transgressions in the whole North China area of the upper Paleozoic.

3. Analysis on coal accumulation law of Upper Paleozoic

The development of Upper Paleozoic source rocks in the study area is affected by the late Paleozoic sudden transgression events. The coal seams are mainly developed in Taiyuan Formation and Shanxi Formation (3 ~ 5m coal seams can be seen in Benxi Formation in some areas), and the overall thickness of coal seams is about 10 ~ 40m. Vertically, there are 4 coal accumulating systems (Fig. 3), which are thick in the South and thin in the north.

![Fig. 3 Spatial distribution characteristics of Upper Paleozoic coal measure in Huanghua Depression](image)

In SQ2 period (Fig. 4), the study area is dominated by tidal flat lagoon system. During this period, seawater intrudes from northeast to southwest, and coal accumulation is strong. Coal seams are developed in the whole area, with an overall thickness of 0~8m and a single layer thickness of less than 2m. The coal accumulating centers are located in Kongdian, Chenghai and Beidagang areas. The coal seam thickness and survival conditions in the north are better than those in the south.

During SQ3 period, seawater intruded from southeast to northwest in large scale, with the largest transgression scale. The whole study area is tidal flat lagoon sedimentary system. Coal seams were formed in the coal forming environment of epicontinental coastal system, and coal accumulation was still strong. Two coal accumulation centers, Wumaying and Kongdian, were formed. The thickness of coal seam was about 0 ~ 12M, and the thickness of single coal layer could reach 3 ~ 5m. There are coal seams in the whole area.

During SQ4 period, the sea water began to withdraw from the study area on a large scale, and only part of Qibei developed thin limestone. At this time, delta progradation occurred in the study area, the delta plain swamp was relatively developed, the coal seam was formed in the coal forming environment of waste clastic system, the coal seam thickness was about 0 ~ 8m, the coal accumulation in the North was relatively strong, the coal accumulation center was located in Chenghai area, and the coal seam thickness in other areas was relatively uniform. It is about 0 ~ 4m.

During SQ5 period, the sea water basically withdrew from the whole study area. The whole study area was dominated by delta sedimentary system, supplemented by river sedimentary system. The coal seam was formed in the coal forming environment of shallow water delta system. The coal
accumulation function was weakened, the single layer thickness was not large, and the overall thickness was about 0 ~ 8m. The coal accumulation center was located in Qikou area.

Fig. 4 Isoline map of SQ2 ~ SQ5 coal seam thickness in study area

Generally, the upper Paleozoic coal seams in the study area are mainly developed in Taiyuan Formation and Shanxi formation, and the coal seams are mainly formed in four major accumulation periods. The coal accumulating effect is the strongest in SQ3 and sq4 periods, and the thick coal seams are formed near the transgressive surface (Fig. 5), while the coal seams formed at the largest flooding surface are not thick, and the thick coal seams are mostly formed in transgressive system tract and high level system tract The thickness is relatively thin, and the coal seams in the lowstand system tract are hardly developed.

Fig. 5 Distribution pattern of thick coal seam in coastal shallow sea environment
4. Conclusions
In the upper Paleozoic strata of Huanghua depression, the active system formed a large number of medium thick thin coal seams. The thick coal seams in the study area are mainly formed in the coal forming environment of the epicontinental coastal system and the waste clastic system. The thick coal seams are more easily developed in the transgressive system tract of the upper Taiyuan formation, and the medium thick coal seams are mainly developed in the upper part of Taiyuan Formation and the lower part of Shanxi formation.

The coal bearing strata of Upper Paleozoic in Huanghua depression have the characteristics of diversity of coal forming modes in time and space. The coal seams of Taiyuan formation are formed in the coastal coal forming mode on the land surface, the coal seams in the lower part of Shanxi formation are formed in the waste clastic coal forming mode, and the coal seams in the upper part of Shanxi formation are formed in the shallow water delta coal forming mode.

In the study area, the thicker coal seams are formed near the transgressive surface, while the coal seams formed at the most marine flooding surface are not so thick. Most of the thick coal seams are formed in transgressive system tracts. The coal seams in the highstand system tracts are thinner than those in the lowstand systems tracts.

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