A Discussion on the transgression model of Upper Paleozoic in Huanghua Depression

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Abstract. In this paper, the sedimentary, geochemical and coal petrographic characteristics of the Upper Paleozoic Taiyuan and Shanxi Formations in Huanghua Depression are systematically analyzed. It is found that the formation process of Taiyuan Formation coal seam is greatly influenced by sea water. The overlapping relationship between limestone and its floor rock is a typical progressive transgressive sedimentary type. Geochemical data show that the limestone roof and floor strata are also formed in high salinity sedimentary environment, similar to the limestone development environment, which also shows that the transgression process in the study area is gradual, not sudden transgression.

1. Introduction

The northwest part of Huanghua Depression is Cangxian Uplift and Cangdong Fault, and the eastern part is Chengning Uplift, which is located in North China. Influenced by the uplift of Caledonian movement at the end of Middle Ordovician, the Paleozoic generally lacked the Early Carboniferous strata and formed a sedimentary discontinuity of 138 Ma\textsuperscript{[1]}. In the Late Carboniferous, the study area was deposited again. From lower to upper, Benxi Formation, Taiyuan Formation, Shanxi Formation, Lower Shihezi Formation, Upper Shihezi Formation and Shiqianfeng Formation were developed\textsuperscript{[2]}. Benxi Formation-Taiyuan Formation was transitional facies, Shanxi Formation was delta facies and Shihezi Formation was fluvial facies. The transgression mainly occurred in Benxi Formation and Shiqianfeng Formation. The transitional facies strata of the Taiyuan Formation underwent multiple transgressions, and the scale of transgression reached its maximum in the Taiyuan Formation period, and then generally in the regression period \textsuperscript{[3]}. For the study of transgression types in North China, some scholars have found that marine limestone and continental sediments are often found in coal-bearing strata of Late Paleozoic in North China, and they are multicyclic. They believe that there is a typical sudden transgression in North China\textsuperscript{[4]}, while some scholars believe that the Carboniferous-Permian transgression in North China is gradual type transgression\textsuperscript{[5]}. Previous studies on the types of transgression of the Upper Paleozoic in the study area are still controversial \textsuperscript{[6]}, and need to be refined and demonstrated. Therefore, this paper focuses on the types of transgression of the strata of the Taiyuan Formation.
2. Sequence Stratigraphy and Sedimentary Characteristics of Taiyuan Formation

According to previous studies [7], the North China region experienced large-scale transgression in the Late Paleozoic, reaching the largest scale in the mid-Taiyuan Formation, and then experienced large-scale transgression with small-scale transgression. Coal seams in the study area are mainly developed in the strata of Taiyuan Formation and Shanxi Formation. Taiyuan Formation is marine-continental transitional facies deposit and Shanxi Formation is delta facies deposit. This paper mainly discusses the transgression types of Taiyuan Formation.

2.1 Sequence stratigraphic characteristics of Taiyuan Formation

The Taiyuan Formation can be divided into two lithologic segments, the upper and lower Taiyuan Formation. According to the method of single well sequence stratigraphy, the author divides the Taiyuan Formation into three third-order sequences. Each sequence consists of lowstand systems tract, transgressive system tract and highstand systems tract, which corresponds to three large-scale transgressions respectively (Fig. 1).

![Figure 1. Sequence Stratigraphic Column of Taiyuan Formation in Well GG16102, Huanghua Depression](image)

In Sequence 1, the thick sandstone deposits at the bottom are diversion channel deposits, and tend to thin upward. They are typical low-level system tract downcut valley filling deposits, and the upper part is coal seam and its interbeds, representing the mud-carbon marsh environment developed under
transgression conditions at that time. In Sequence 2, a set of fine lime sandstone, mudstone and carbonaceous mudstone assemblages are developed at the bottom, and the ratio of sand to mudstone decreases from bottom to top, which is a tidal channel deposit developed under low-level system tract. The transgressive system tract of sequence 2 develops mudstone, carbonaceous mudstone and coal seam interbedding in the mudstone marsh environment. The transgression of this period is high frequency transgression. Therefore, there are also multi-layered mudstone carbonate rocks in the transgressive system tract of sequence 2. Black mudstone, carbonaceous mudstone and sandy limestone are developed in the high-level system tract of the upper part of the sequence. In sequence 3, the thick sandstones developed in the low-level system tract at the bottom are distributary channel deposits, the upper coal seams are peat swamp deposits under the transgressive system tract, the top of the coal seam is the largest flooding surface, and the top of the high-level system tract deposits are denuded.

2.2 Sedimentary characteristics of Taiyuan Formation

There are essential differences in sedimentary characteristics between progressive transgression and sudden transgression. Generally speaking, the surface sea slope is very gentle. If the sea water intruded during transgression is dispersed and the sea level does not rise rapidly, a gradual transgression will take place. With the expansion of transgression scope and the deepening of sea water, marine limestone will develop. Marine limestone generally covers coal seam or mudstone, and is continuous in phase sequence. If the transgression process is fast and the water level increases rapidly, the mud carbon accumulation rate is less than the accommodation space increase rate, the upper marine limestone will directly cover the terrestrial root soil and rock.

![Figure 2. Lithology and sedimentary structure](image)

The Taiyuan Formation in the study area develops sedimentary environments such as distributary channels, peat marshes, tidal flat channels and carbonate platforms (Fig. 2). Under marine limestone is dark mudstone, which belongs to progressive transgressive lithologic assemblage. At the bottom, distributary channel sandstone develops. With the deepening of water body, mudstone, carbonaceous mudstone and coal seam develop. When mudstone accumulates rapidly, mudstone accumulates rapidly. When the ratio is less than the increasing rate of accommodation space, the mud carbon ceases to develop and the marine limestone covers the mud carbon. The sedimentary water medium conditions
in the study area are diverse, and the strata of Taiyuan Formation are mostly saline-reducing deposits, which is beneficial to the preservation of organic matter and sapropelation.

3. Stratigraphic Geochemistry of Taiyuan Formation

The sedimentary environment formed by progressive transgression is different from that formed by event transgression. The limestone formed by progressive transgression does not change abruptly with the development environment of its roof and floor, while the floor of event transgressive limestone is rooted soil rock, which is in a partial oxidation environment. It is quite different from the development environment of marine limestone, so their geochemistry is very different. The academic characteristics are quite different. The authors mainly discuss the types of transgression from the geochemical characteristics of limestone, coal seam and their roof and floor strata.

3.1 Paleosalinity environment

In geochemistry, the ratio of trace elements is often used to determine paleosalinity [8]. Therefore, the ratio of trace elements is one of the criteria for determining sedimentary facies (Table 1).

Table 1. Paleosalinity criteria.

| Index | Ratio | Paleosalinity          |
|-------|-------|------------------------|
| (MgO/Al₂O₃) *100 | <1    | Low salinity           |
| According to References[9] | 1-10  | Medium salinity        |
|       | >10   | High salinity          |
| B/Ga  | <3.3  | Freshwater facies      |
| According to References[10] | 3.4-5 | Inshore marine facies  |
| Sr/Ba | <0.5  | Freshwater-brackish water |
| According to References[11] | 0.5-1 | Brackish water         |
| Rb/K  | >0.006| Marine facies          |
| According to References[12] | 0.004-0.006 | Brackish water         |
|       | 0.0028| Fluvial facies         |

References The experimental results show that (Table 2,3), the values of (MgO/Al₂O₃)*100 in Taiyuan Formation are all greater than 10, even 20 in the bottom of Taiyuan Formation, Sr/Ba in limestone floor are greater than 10, and the values of (MgO/Al₂O₃)*100 in limestone floor are also greater than 10 or slightly less than 10, indicating that the sedimentary environment of limestone is similar to that of its roof and floor strata. Both of them are in high salinity environment. Coal seams are also developed in saltwater-reduction environment. The transgression process is gradual rather than event transgression.

Table 2. Data Table of Trace Elements in Well GG16102.

| Depth | Lithology | B (ppm) | Ga (ppm) | Sr (ppm) | Ba (ppm) |
|------|-----------|---------|----------|----------|---------|
| 1977 | mudstone  | 103     | 22.262   | 745.394  | 417.837 |
| 2184.3 | coal  | 24.7    | 13.064   | 589.316  | 499.920 |
| 2196 | mudstone  | 41.1    | 7.145    | 674.494  | 508.818 |
| 2197.2 | mudstone | 32.6    | 15.877   | 550.052  | 494.435 |
| 2210.98 | mudstone | 141     | 25.5     | 625      | 287     |
| 2219.73 | mudstone | 140     | 29.1     | 293      | 283     |
| 2215.87 | mudstone | 125     | 14.153   | 579.442  | 490.274 |

3.2 Ash component index
Ash composition index K= \( w (\text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO}) / w (\text{SiO}_2 + \text{Al}_2\text{O}_3) \) in coal seams can indicate the origin of coal seams. The influence degree of seawater is positively correlated with the value of K. Generally, the K value of marine strata is much larger than that of continental strata.

The experimental results show that (Table 3), the ash composition index K in sequence 2 and sequence 3 is greater than 0.1, which is 0.187, 0.157, 0.133, 0.156 and 0.183, respectively. It shows that the coal-forming environment is affected by seawater, and the water area is relatively open and stable in the saline cement carbon marshes of delta or restricted lagoon. Because of its stability, coal seams and black mudstones are widely developed in the Taiyuan Formation. The author also calculated the ash composition index of the roof and floor strata of the Taiyuan Formation, and found that the value of the ash composition index is also greater than 1, and the difference between the value and that of the ash composition index of the coal seam is not significant. It shows that the development environment of the coal seam and its roof and floor strata is similar, they are all in saline water environment, their sedimentary environment is transitional, and the transgression occurs progressively. Transgression is not an event-type transgression.

### Table 3. Constant Element Data of Well GG16102

| Depth   | Lithology    | Fe\(_2\)O\(_3\) (%) | CaO (%) | SiO\(_2\) (%) | Al\(_2\)O\(_3\) (%) | MgO (%) | K     |
|---------|--------------|----------------------|---------|--------------|----------------------|---------|-------|
| 2197.09 | Carbonaceous | 5.31                 | 3.83    | 51.01        | 15.72                | 2.83    | 0.179 |
| 2200    | coal         | 4.914                | 6.945   | 55.016       | 14.568               | 2.738   | 0.187 |
| 2203.86 | mudstone     | 4.43                 | 4.34    | 55.59        | 15.03                | 3.28    | 0.171 |
| 2201    | mudstone     | 7.321                | 3.898   | 56.064       | 18.771               | 1.991   | 0.157 |
| 2210.98 | mudstone     | 5.93                 | 1.84    | 52.64        | 19.23                | 2.37    | 0.141 |
| 2212    | coal         | 6.093                | 3.672   | 58.145       | 17.277               | 2.449   | 0.133 |
| 2222.23 | mudstone     | 6.52                 | 1.18    | 56.58        | 16.93                | 1.36    | 0.12  |
| 2224.5  | coal         | 6.074                | 4.761   | 55.272       | 16.729               | 2.552   | 0.156 |
| 2225    | coal         | 5.174                | 6.785   | 55.891       | 14.522               | 3.021   | 0.183 |

4. Conclusion

Based on the analysis and research of logging data, lithological profile and geochemical data of the Upper Paleozoic Carboniferous Permian coal measures strata in Huanghua Depression, the theory and method of sequence stratigraphy, sedimentology, coal petrology and geochemistry are comprehensively applied. It is found that the formation process of Taiyuan Formation is greatly influenced by seawater and has gone through the process. Three large-scale transgressions, the overlapping relationship between coal seams and roof and floor strata is a typical progressive transgressive sedimentary type. Geochemical data show that the limestone roof and floor strata are also formed in high salinity sedimentary environment, similar to the limestone development environment, which also shows that the transgression process in the study area is gradual, not sudden transgression. In the early stage of the Taiyuan Formation, transgression was dominant, and the scale of transgression reached its maximum in the middle stage, then it was in the period of regression. The transgression during this period provided a variety of water media for the study area, which made the strata of the Taiyuan Formation in the study area in a saline-reducing environment, and conserved and sapropelled the previously deposited marshes. Therefore, coal seams, mudstones and carbonaceous mudstones developed in large quantities.

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