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The net primary productivity of Mid-Jurassic peatland and its control factors: Evidenced by the Ordos Basin

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ABSTRACT

Using the large-scale thick 4# coal seam from the Mid-Jurassic in the southern Ordos Basin as an example, this paper studied the net primary productivity (NPP) level of the Mid-Jurassic peatland, and discussed its control factors. Geophysical logging signals were used for a spectrum analysis to obtain the Milankovitch cycle parameters in coal seam. These were then used to calculate the accumulation rate of the residual carbon in 4# coal seam. The carbon loss can be calculated according to the density and residual carbon content of 4# coal seam. Then, the total carbon accumulation rate of the peatland was further derived, and the NPP of peatland was determined. The results show that the NPP of Mid-Jurassic peatland is higher than that of Holocene at the same latitude. Comprehensive analysis indicates that the temperature, carbon dioxide and oxygen levels in atmosphere are the main control factors of the NPP of Mid-Jurassic peatland.

1. Introduction

The peatland areas, which are important environments for the massive growth, death, and remains accumulations of plants, first appeared in the Late Devonian period, and have played an important role in the global carbon cycle [1]. The previous research data have shown that approximately 455 Gt of carbon are contained in the current major peatland areas of the northern hemisphere, including the USSR, Canada, the USA, Fennoscandia, etc. [2]. Simultaneously, 88–97% of the peatland areas are made up of water [3], and this very large amount of water plays an important role in the global water cycle. As the carbon and water cycles affect climate changes, the peatland areas play an important role in global climate change [4]. Coal is the main product and an important sedimentary carrier of the peatland areas, and has recorded the related climate characteristic information of the peatlands' developmental stages [5]. The previous research results regarding the carbon accumulation rates in coal, as well as the total carbon accumulation rate and net primary productivity (NPP) in peatland, have been beneficial to the understanding of the carbon cycle characteristics in geologically historic periods, and thereby have provided assistance in the study of paleoclimates [6].

The accurate dating limit of coal accumulation has been recognized to be a current difficulty in the research studies which are specific to the process of carbon accumulation rates in coal. At the present time, radioactive isotope dating technology is widely applied. However, there has been a large range of error observed in the test results [7]. It has been found that, as a result of the generally shorter time limit of coal seam formations, radioactive dating technology has been unable to receive wide application in the study of coal seam records. Therefore, the search for a more accurate dating method has become the premise of coal research, as an information carrier for the further examination of paleoclimate characteristics.

The Milankovitch cycle theory is an astronomical theory by which to study the relationship between sun exposure and the Earth's climate on a global scale. This theory has been applied to the cycle research of stratigraphic sequences by a number of researchers [8–12]. Large et al. determined that the information of the Milankovitch cycle was contained in Neogene coal seams. This cycle signal was taken as a tool of time measurement, in order to more accurately obtain the accumulation time of the coal seam, and also to study the peatland ecosystem, successfully calculate the productivity level of the Pre-Quaternary peatland area, and make a reasonable explanation regarding the results [4,13,14]. The Milankovitch cycle theory is an effective method by which to more precisely "measure" the stratigraphic accumulation time limit, in particular, the Pre-Quaternary "deep time" stratigraphic

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accumulation age [8,15,16]. By applying orbital period cycle dating, the ecological characteristics of the Holocene peatland area with a high research degree, were used for an analogy. Thereby, an estimate of the ecology parameters of the peatland in the geological history was obtained [4]. Unfortunately, this method has been found to have certain defects. However, it is still able to more reasonably determine the productivity of peatland areas, and this method is likely to be the only means to study the relevant information of Cenozoic coal seams for the time being.

This study attempted to use geophysical logging signals to extract the Milankovitch cycle contained in the coal seam by using the huge thick 4# coal seam of the Mid-Jurassic Yan'an Formation in the Dafosi Coalmine of the Binchang Coalfield as an example, which is located in the southern Ordos Basin. Also, this study determined the accumulation time of the coal seam, and calculated the residual carbon accumulation rate in the coal seam, as well as the total carbon accumulation rate and NPP of the peatland. Furthermore, this study discussed the control factors of NPP.

2. Geological setting of the study area

The Ordos Basin, which is a large Meso-Cenozoic depression basin in north-central China, is an important integrated energy basin containing abundant mineral resources, such as coal, oil, natural gas, and uranium. Among these, its coal production accounts for approximately a quarter of the national total, especially the rich coal resources from the Mid-Jurassic coal-bearing rock series.

The Ordos Basin is surrounded by the Qinling, Liupan, Helan, Daqing, and Lvliang Mountains. It neighbors the Fenwei Basin in the south, with its southern boundary roughly located in Wei River Valley. The Yinchuan Basin and Liupan Mountain Basin neighbor the Ordos Basin in the west, with the western boundary located in the west piedmont of the Helan Mountain-Qingtongxia-Guyuan area. The Hetao Basin also neighbors the Ordos Basin, with a northern boundary roughly located in the Ural Mountain-Daqing Mountain area. A serious denudation has occurred in the eastern boundary, presumably to the east of the Datong-Yima area, as shown in Fig. 1 [17,18]. The Dafosi Coalmine of the Binchang Coalfield is located in the southwestern area of the Ordos Basin. During the coal forming period, several ancient uplifts with no strata deposition occurred in the coalfield, which provided the source to a certain extent. The Dafosi Coalmine is located in the southern area of the Binchang Coalfield, as shown in Fig. 1c.

The coal-bearing strata in the Binchang Coalfield have been determined to be a Mid-Jurassic Yan'an Formation, where sandstone, mudstone, coal, etc. have been mainly developed. In these study, this strata were divided into five members: Members 1 to 5, from the bottom to the top. A coal group was developed in the upper part of each member, while the lower part of each member was dominated by sandstone sediments. Within the scope of the basin, the preservation degree of the Yan'an Formation was determined to be gradually improved from the southeast to northwest. A serious denudation had been found to have occurred in the southeastern and southern strata of the Ordos Basin, while only Member 1 remained. In the Dafosi Coalmine of the Binchang Coalfield, serious denudation existed in the upper part of the Yan'an Formation. Also, the mid-upper strata of the Yan'an Formation had undergone various degrees of denudation in different areas (Fig. 2). In the Dafosi Coalmine, the coal seams in the Yan'an Formation were found to be generally very thick. The 4# coal seam of ZK1 in this study had a single-layer thickness of 11.3 m, where the main coal forming environments were determined to be river flood plain, lakeshore plain, and so on (Fig. 2).

In the Binchang Coalfield, the 4# coal seam of the Yan'an Formation had a body color of blackish-brown black; a streak color of dark brown with a pitchy luster; jagged-conchoidal shaped fracture; thin strip-line structure; and block-layer structure. The 4# coal seam was found to be dominated by dark coal, followed by bright coal, and then less commonly by vitrain. In the 4# coal seam, the organic maceral had an average content of 89.19%, and the total mineral content averaged 10.81%. Among the organic maceral, the average contents of inertinite, vitrinite, and exinite in 20 coal samples were found to be 50.74%, 30.73%, and 7.72%, respectively, and it belonged to vitrinertite (Table 1).

In the 4# coal seam of Yan'an Formation in the Binchang Coalfield, the sporo-pollen was found to be dominated by a Classopollos-Cyathidites minor sporo-pollen assemblage. The gymnosperms pollen content was higher than that of the fern spores, and characterized by a high Classopollis pollen content. Cyathidits minor spores also accounted for an important proportion, which reflected that the coal-forming plants mainly consisted of ferns and gymnosperms [19,20]. It is generally considered that Classopollis maternal plants mainly include Cheirolepidiaceae, and generally appear in hot-dry climate conditions [21–23]. However, they can also adapt to humid climates [24]. The maternal plants of Cyathidits minor spores which consist of Cyatheaceae and Dicksoniaceae (part), mainly grow in humid tropical and subtropical environments [25]. In this study, the paleo-plant pollen-spore characteristics reflected the complexity of the paleoclimate environment in the coal forming period of the 4# coal seam in the Yan'an Formation. It was determined that the coal-forming swamp was mainly a forest swamp, and a swamp environment with a relative enrichment of herbaceous plants existed locally. The development situation of the plant community during this period reflected that the coal forming period was mainly as a warm temperate to subtropical climate environment [19,20].

3. Data sources and research methods

3.1. Data sources

When the Milankovitch cycle is used for "deep time" stratigraphic dating research, the required prerequisites include the following: (1) the vertical strata are continuous to ensure the continuity of the Milankovitch cycle; (2) the strata thickness is large enough to ensure the deposition time covers at least one complete eccentricity cycle [8,26]; and (3) the strata sediments are driven more by the orbital climate than other impact factors. Therefore, the 4# coal seam of Yan'an Formation in the ZK1 borehole of the Dafosi Coalmine, Binchang Coalfield, in southern of the Ordos Basin was selected as the research object due to its larger 11.3 m thickness (489.00–477.70 m), with no obvious dirt band (Fig. 2).

As viewed from the industrial analysis results, the 4# coal seam had a higher ash content (average of 18.35%) as shown in Table 2, which confirmed that the coal-forming peatland had been affected by the surface terrigenous clastic material supply to a certain extent. This type of peatland is found in lowland bog, which had access to surface water supplies during a certain development stage [27]. It was assumed that other conditions (such as tectonic conditions) were more stable, so that the hydrological conditions were mainly influenced by climate. Meanwhile, the Milankovitch cycle played a driving role in the climate change during a geological period, which inevitably had an impact on the sediment (such as the ash and salt contents) which had been affected by the hydrology and climate during the entire development process of the peatland [6].

The logging data record the geological evolution history from different angles [28]. The natural gamma rays (GR) in the coal seam, as well as the density logging signals (DEN), reflected the