

Formation Environment of Main Brown Coal Seam in Xi-2 Minefield of Shengli Coalfield Based on Coal Ash Phase Analysis

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ABSTRACT

The formation environment of the main coal seam in Shengli coal mine is analyzed, and the effect of coal ash parameters on the coal-forming environment is mainly discussed according to gray component parameters combined with other coal quality test analysis data. Results show that the hydrodynamic conditions of the main coal during coal accumulation have a general pattern of strong northeast and weak southwest, and lakeside swamp is generally in the retrograde process from south to north. The No.5 coal seam is a water entry cycle, and the No.5_{lower} coal is a water withdrawal cycle. The No.6 thick coal seam is formed in the peat swamp environment where the water is shallow and the groundwater activity is weak. The input of terrestrial debris material was most abundant in the formation period of No.5_{lower} coal, followed by No.5 coal, and that in No.6 coal is the least. Vertically, the peat swamp environment changed from weak reduction to weak oxidation to strong reducing environment. The ash yield was low to high to low from bottom to top. The organic sulfur is the main type of sulfur in the main coal seam. The weaker the hydrodynamic condition, the higher the organic sulfur content in the reduction environment, while lower organic sulfur content in the oxidation environment. The peat swamp water of No.5_{lower} coal is medium alkaline, and the peat swamp water of No.5 and No. 6 coals is weakly alkaline or acidic.

INTRODUCTION

Several scholars have analyzed the formation environment of coal seam through coal petrology, coal chemistry, coal geochemistry, mineralogy, theory, and method of coal forming (Gürdal and Bozcu, 2011; Singh et al., 2012; Farhaduzzaman et al., 2012; Barbacka et al., 2015; Lv et al., 2017; Lamourou et al., 2017; Song et al., 2017). They have mainly focused on comprehensive analysis of rock phase, mineral phase, geochemical phase, and coal-forming biological phase. The majority of researchers pay attention to the genetic information of coal lithofacies and geochemistry. However, the genetic information implied by the mineral phase has been ignored. General mineral phases include content and type of mineral and chemical composition of ash. Ash content is mainly affected by changes in theseimentary environment. Unfortunately, the mineral species, source, and relative content in coal cannot be reflected by ash content. Few researchers have focused on the geochemical significance of the deposition of ash component (Turner and Richardson, 2004; Sun et al., 2010; Kalaitzidis et al., 2010; Yang et al., 2011). Meanwhile, previous studies have focused on the formation of bituminous coal and anthracite by the interaction of land and sea (Dai et al., 2002; Alias et al., 2012; Hakimi et al., 2014), but the sedimentary environment of the lignite with a thick layer is seldom analyzed. Therefore, this paper takes the main mineable coal seam of Xi-2 minefield in Shengli coalfield as an

example. It then analyzes the plane distribution characteristics of coal ash geochemistry by using an analysis method based on ash composition combined with coal petrology, coal chemical parameters, and results of coal-bearing stratum sedimentary environment. Finally the formation environment of main mineable coal seam to provide a basis for a thorough understanding of coal seam genesis is discussed.

GEOLOGICAL BACKGROUND

The X-2 minefield of Shengli coalfield is located in Bayinheshuo sag, which is in the southeast of the Erlian basin, the eastern part of Inner Mongolia (Fig.1). The Erlian basin is Mesozoic continental rift basin that developed on the Inner Mongolia-Daxinganling hercynian fold basement. Five deep faults developed in the basin, forming a tectonic framework with five depressions and one uplift and composed of a series of secondary fault depressions (Huang et al., 2003; Ding et al., 2016). Shengli coalfield is located in the southwest of Bayinheshuo sag and is considered a rift basin with an area of 342 km² (Qi and Zhang, 2007; Huang et al., 2008).

The Xi-2 minefield is located in the west part of Shengli coalfield. The minefield is a gentle monocline structure. The general formation strikes northwest with dip northeast. Wide secondary folds and faults are developed (Fig. 1). During the coal forming period, the syn-depositional fault (Ft14) on the footwall, developed at the boundary of Bayinheshuo sag, has undergone increasing denudation for a long time, there by providing terrigenous clastic material to form the coal bearing strata in the region. The activity of the fault determines the thickness, lithology, lithofacies, and the development characteristics of the coal bearing strata (Qi and Zhang, 2007).

The coal bearing strata in this area are the Shengli Formation and the Xilin Formation of the early Cretaceous Bayanhuaqun Group. At present, the mining has exploited only the Shengli coal seam with a lower buried depth (Fig.1). The Shengli Formation coal seam has multiple layers and large thickness. No.5, No.5_{lower}, and No.6 coals are the main coal seams in this area, the thickness of which is 0.3m–12m (average: 2.14m), 0.1–2.3m (average: 1.1m), and 1.9–30.3m (average: 18.8m), respectively. The Xilin Formation coal seam is dispersed, and is thin.

SAMPLES, METHODS, AND PRINCIPLES

Sample Collection and Experimental Testing

Numerous bore holes are present in the study area and coal samples No.5, No.5_{lower}, and No.6 coal seams are collected (Figs. 3, 4, and 5). Fresh coal samples are stored in plastic wrap and packed and sealed in water to prevent oxidation. Representative coal samples are selected to measure the maximum reflectivity ($R_{o,max}$) of the vitrinite and the coal maceral contents by optical microscopy under oil-immersed reflected light condition according to the national standard GB/T6948-

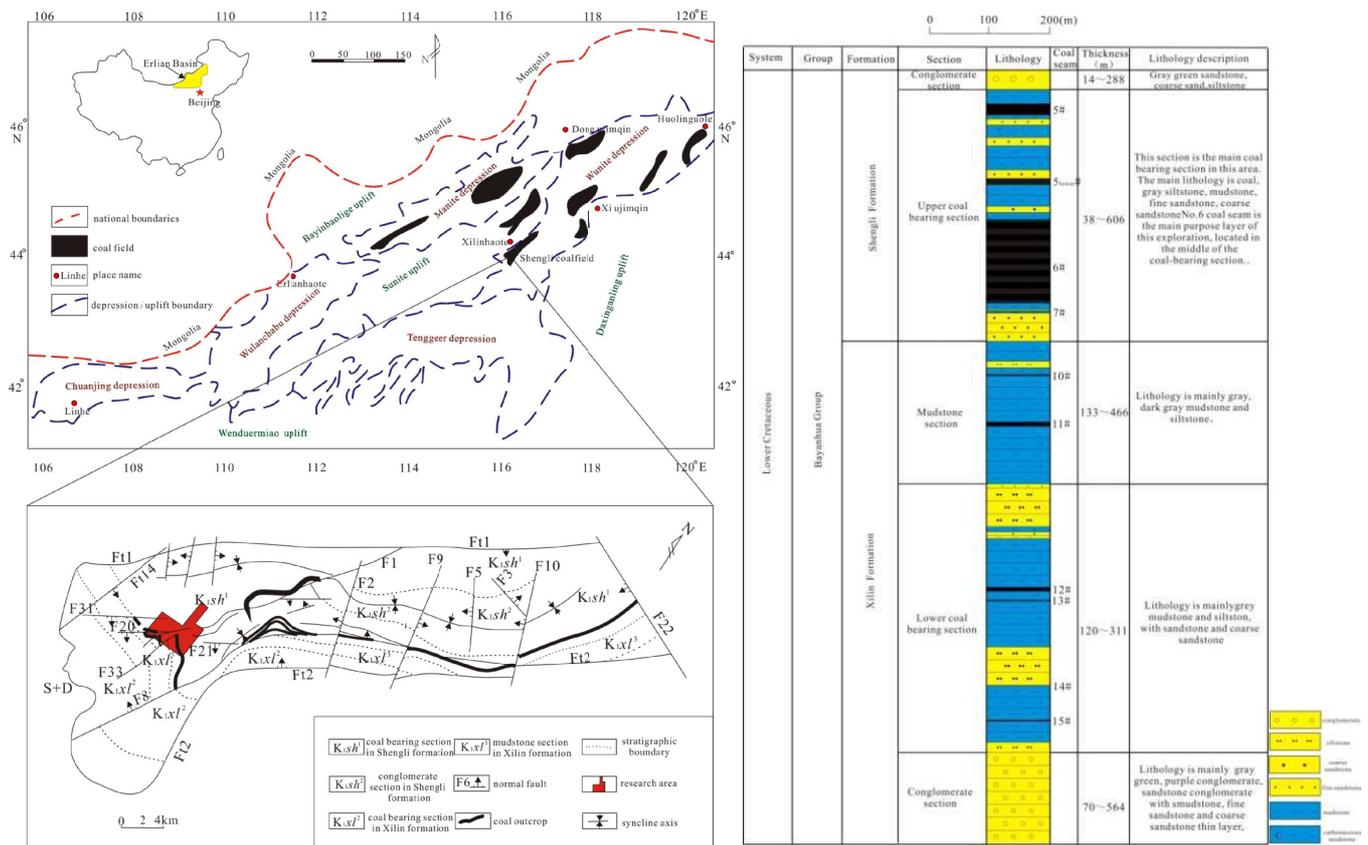


Fig.1. Location of study area and coal bearing strata histogram.

2008. Elemental analyses of samples were conducted following GB/T 212-2008 and GB/T 31391-2015. The total sulfur and various pattern sulfur in coal were analyzed following GB/T 215-2003 and GB/T 214-2007. High-temperature ash sample is prepared in muffle furnace with the highest temperature of 815 ± 10 °C for the determination of coal ash composition according to GB/T1574-2007. Low-temperature ash is prepared by using a low-temperature plasma ashing apparatus (EMITECH K1050X); the temperature is always less than 200 °C, and the ashing time is more than 72 h. The low-temperature ash is analyzed by using X-ray diffraction (XRD) with a high voltage of around 40KV, an electric current of around 40MA, and a scanning angle that ranges from 3° to 45°. The relative content of clay is determined by using suspension method. Clay minerals with a diameter less than 2µm were extracted for orientation slicing, including natural air drying slice, glycol saturated slice, and 550 °C slice, and then the corresponding mineral content is obtained by using the diffraction peak intensity contrast method and adiabatic equation (Jozanikohan et al., 2016).

Anthracology analysis shows that organic macerals of the main coal seam in the study area are dominated by huminite, and inertinite and liptinite contents are low. The mineral content of main coal seam is between 0.36%–35.1%, with an average of 15.08% (Table 1). The inertinite and mineral contents in No.5_{lower} coal were higher than those in the other two coals. XRD analysis of low-temperature ash shows similar mineral composition between the No.5 and No.6 coals, with a quartz content of more than 69%, clay mineral content of approximately 25%, with low pyrite and calcite. The mineral composition of No.5_{lower} coal is mainly clay with an average content of up to approximately 60%, quartz content of approximately 36%, and a small amount of siderite (Table 2). XRD analysis of clay minerals indicates that the clay mineral composition in No.5 coal is mainly illite and I/S. No.6 coal is mainly composed of kaolinite, and No.5_{lower} coal clay mineral composition is in between (Table 2).

Method of Analysis Based on Ash Composition

The method of analysis based on ash composition is used to analyze coal accumulating environment using $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-CaO-MgO}$, and $\text{Fe}_2\text{O}_3\text{-SO}_3$ as a triangle diagram (Fig.2) (Hao et al., 2000).

SiO_2 and Al_2O_3 represent quartz and clay minerals with high compositional maturity, respectively. The low-value of $\text{SiO}_2+\text{Al}_2\text{O}_3$ represents the hydrodynamic condition of the deep overlying water-semi deep water-covered peat swamp environment. The isoline of $\text{SiO}_2+\text{Al}_2\text{O}_3$ can reflect the overall direction of the medium. The transition from the high-value to the low-value region reflects the migration process of the hydrodynamic condition from strong to weak. The high-to-low $\text{MgO}+\text{CaO}$ content reflects the change from the water environment of the closed basin with occlusion-semi occlusion changes to the near-surface shallow water peat swamp environment (Yi et al., 2007). The CaO content was higher than that of MgO, thereby indicating that the main minerals in coal are calcite or humate calcium salt; otherwise, calcium and magnesium minerals such as dolomite and gypsum are present, which mainly form in semi-arid climates. $\text{SO}_3/\text{Fe}_2\text{O}_3$ reflects the redox of sedimentary water medium. A low ratio indicates that the freshwater medium is weakly oxidized to weakly reduced, and a high ratio indicates a strong reducing environment (Hao et al., 2000).

RESULTS AND DISCUSSION

Ash Composition and its Plane Distribution

The ash composition indicates that the relative contents of CaO and $\text{MgO}+\text{CaO}$ in No.5 coal has good coincidence. XRD analysis indicates that the absence of calcite in No.5, thereby indicating that the calcium mineral in coal is mainly humate calcium salt, and the whole region is dominated by the wet overlying water environment. The relative contents of $\text{SiO}_2+\text{Al}_2\text{O}_3$ has a decreasing trend from northwest to southeast, thereby indicating that the hydro-

Table 1. Statistical results of quantitative analysis of coal components

Coal	Number	Huminite /%			Inertinite /%			Liptinite /%			Mineral composition /%		
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
No.5	6	60.62	90.30	79.94	0.87	12.82	7.09	0	10.66	2.07	0.93	35.10	10.89
No.5 _{lower}	5	41.20	83.30	56.80	13.92	18.91	16.45	0	9.45	2.14	2.00	34.80	24.60
No.6	14	42.69	96.10	69.44	2.00	35.57	14.40	0	16.81	2.64	0.36	50.80	13.47

Table 2. LTA+XRD results

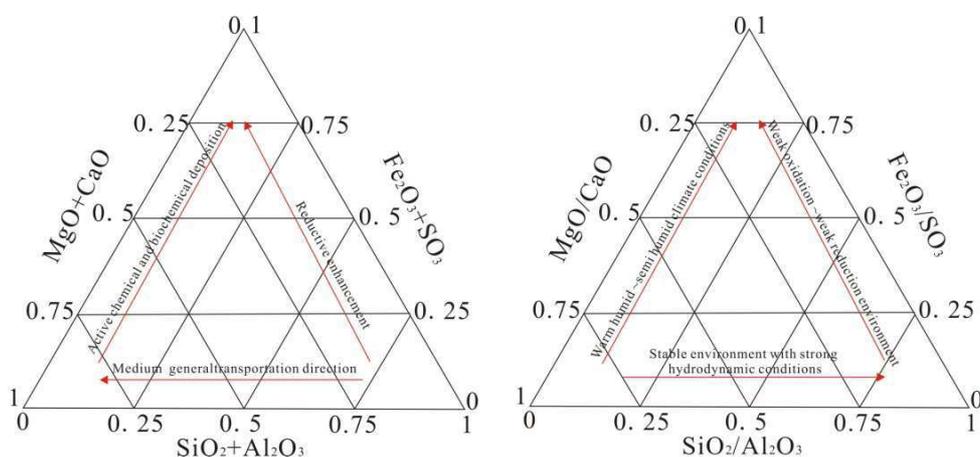
Coal	Number	Mineral content %					Clay minerals relative content %			
		Quartz	Calcite	Siderite	Pyrite	Clay minerals	I/S	Illite	Kaolinite	Chlorite
No.5	4	69			2	29	51	43	5	1
No.5 _{lower}	4	36		4		60	22	47	31	
No.6	4	74	1			25	6	2	92	

dynamic conditions of the peat swamp weakened gradually from the northwestern or northeastern near the continental crust to the southern overlying water basin. The relative content of $Fe_2O_3+SO_3$ shows a trend of high to low to high from southwest to northeast. The relative contents of SO_3 and $Fe_2O_3+SO_3$ has good coincidence, and a certain amount of pyrite being present in No.5 coal, thereby indicating that the peat swamp of No.5 coal is a strong reducing sedimentary environment with deep overlying water (Fig.3).

The relative contents of $SiO_2+Al_2O_3$ in No.5_{lower} coal has a trend of high to low to high from east to west, which shows that the overall transport direction of the medium is from east-west to the interior. The high-value in the east is near the 1307 and 526 holes, and the high-value in the west is located west of the 902 hole. The high-value in the east has a high content of clay minerals in the coal, representing peat swamp environment with fresh water as medium near the continental crust. While in the west, the proportion of detrital minerals such as quartz increases gradually, which reflects the stable environment of enhanced hydrodynamic conditions. This finding indicates that the transitional peat swamp environment is influenced by fresh water. The holes 1005 and 1205 is a low-value area, which shows weak mechanical deposition and differentiation, and it is a peat swamp environment with deep overlying water or semi-deep overlying water (Fig.4). These features indicate that the depositional environment of peat swamp of No.5_{lower} coal is developed from the east-west edge near the continental crust to the overlying water in the inner part of the basin and the direction of water flow of No.5_{lower} and No.5 coals is the same during coal deposition. However, compared with the value of $SiO_2+Al_2O_3$ of the same hole between No.5_{lower} and No.5 coals, the value and the gradient of No.5_{lower} coal is higher, and the low-value

area ($SiO_2+Al_2O_3<50\%$) is narrower than No.5 coal, thereby indicating that the study area rises relatively during the deposition of No.5_{lower} coal. The trend of the relative contents of $MgO+CaO$ in No.5_{lower} coal show the value to the south is higher than the surrounding area. A retention area with overlying water near the lake (the high-value area of $MgO+CaO$) of No.5_{lower} coal is more concentrated than that of No.5 coal. This finding further suggests the enhanced effect of water from east-west direction during the deposition of No.5_{lower} coal. The value of $Fe_2O_3+SO_3$ in the central part of the basin is higher than that of the surrounding area. The value of SO_3/Fe_2O_3 of No.5_{lower} coal is lower than that of No. 5 coal, and the main content of iron minerals is siderite. These findings reflect that the depositional environment of No.5 coal is peat swamp environment with weak oxidization in the shallow inland water basin, which is mainly affected by fresh water (Fig. 4).

The high-value area of $SiO_2+Al_2O_3$ in No.6 coal, the relative content of which is more than 50%, is widely distributed in the whole area; only the southwest area has a low value. The coal-forming environment is sedimentary environment of peat swamp with shallow water in the northeast near the continental crust, shifting to the southwest with deep overlying water. The trend of the relative contents of $MgO+CaO$ in No.6 coal shows that the value of the center is higher than that of the surrounding area. The trend of the relative contents of CaO , MgO , and $MgO + CaO$ shows similar distribution characteristics, and the dominant mineral is either calcite or calcium humate, thereby indicating that the climatic conditions are semi humid-warm humid during the deposition of No.6 coal. The $Fe_2O_3+SO_3$ contents are uniformly distributed, divided by 1001 holes as the center presents a high-value area outside. The ratio of SO_3 and Fe_2O_3 in

**Fig.2** Triangle graph of ash composition analysis.

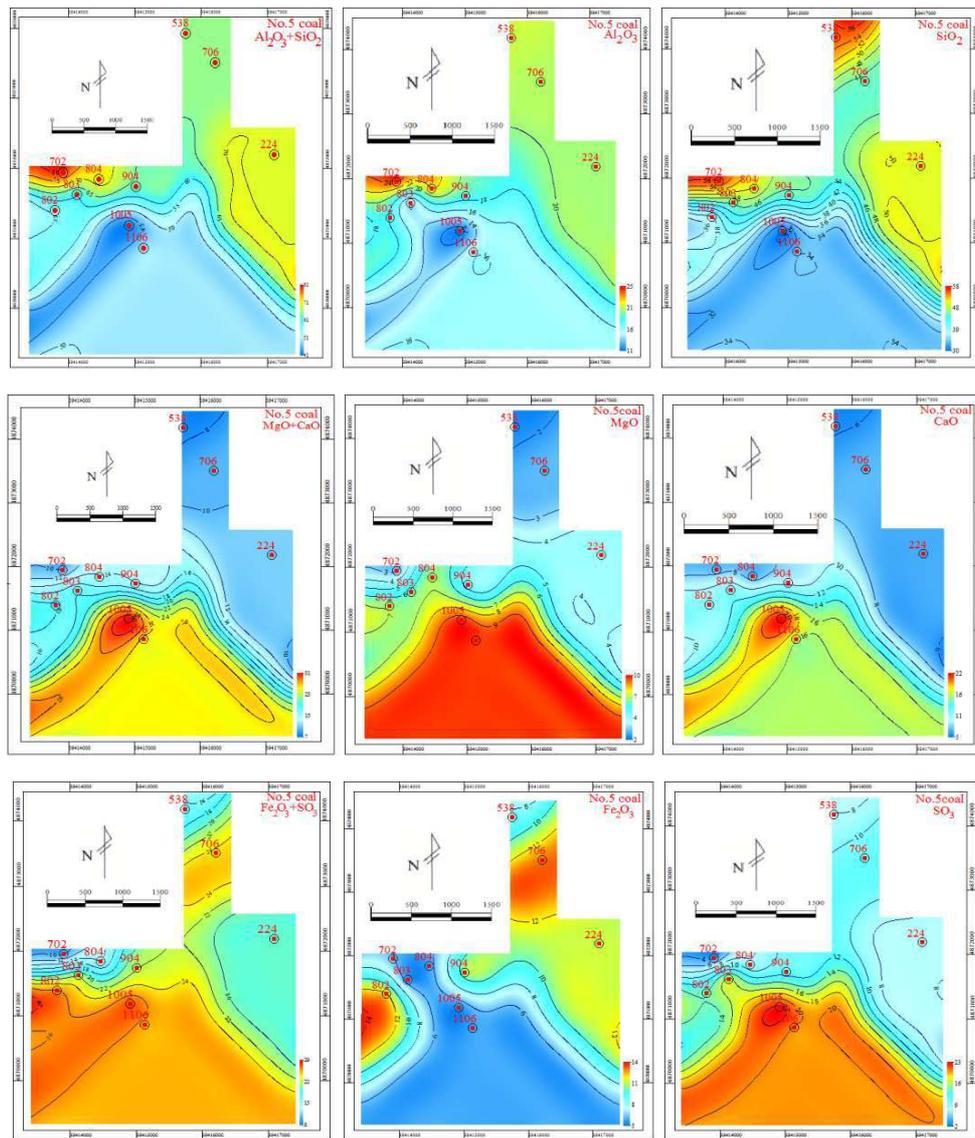


Fig.3. Plane isoline graph of ash composition relative content of No.5 coal.

No.6 coal is situated between No.5 and No.5_{lower} coals, thereby indicating that the coal-forming environment of No.6 coal is a weak reductive sedimentary environment with shallow water.

Vertical Distribution and Variation of Ash Composition

Previous research shows that the solubility of SiO₂ is proportional to the pH value. The solubility of SiO₂ is very low in a solution with a pH value of less than 8, and it increases rapidly with the alkaline enhancement of the medium, especially in alkaline peat swamp with high calcium and magnesium contents (Zhao, 1991). The input of terrestrial debris material is most abundant during the deposition of No.5_{lower} coal, but the SiO₂ content in No.5_{under} coal is lowest, thereby proving that the medium of peat swamp is weakly alkaline (Saikia, 2016). The common perception is that in the change trend of SiO₂ and Al₂O₃ in ashes should not be great as silicon and aluminum mainly associated with peat swamp and exists in forms of clay minerals such as kaolinite. Nevertheless, they are opposite in the study area, and the average ratios of SiO₂ and Al₂O₃ in No.5, No.5_{under} and No.6 coals are 2.42, 2.32, and 2.37, respectively. Overall, these ratios are greater than that of Chinese coal, whose average value is 1.42% (Kang, 2015). This finding indicates that SiO₂ exists in free state, but no free Al₂O₃ is present in coal. Moreover, a higher ratio of SiO₂ and Al₂O₃ corresponds to more silicon-rich minerals (such as

quartz). The aluminum in coal mainly originates from the accumulation of terrigenous clastics during peat accumulation, and it is usually carried by clay mineral such as kaolinite and chlorite. Thus, Al₂O₃ can be used for dividing the contents of clay mineral in the study area. The clay mineral content in No.5_{under} coal is higher than that in the other coals, and the results are consistent with XRD data (Kang, 2015).

The average CaO content in the main coal from top to bottom is 9.68%, 15.63%, and 12.28%, and is greater than that in Chinese coal, whose average value is 1.23% (Kang, 2015). XRD analysis indicates that no calcium mineral is present in the main coal seams, and only a small amount of calcite was found in No.6 coal. The CaO and Al₂O₃ contents have the same high-to-low trend, with the greatest amount found in No.5_{under} coal followed by No.6 and No.5 coals. Zhang et al. (2004) found that calcium ions could be adsorbed on the surface of clay minerals in the form of Ca(OH)₂ sediment, and the adsorption capacity increases with the enhancement of pH. Therefore, the peat swamp environment exhibited partial alkalinity during the deposition of No.5_{lower} coal, which had the highest pH. The peat swamp environment of No.5 and No.6 coals were weakly alkaline or acidic, and the No.5 coal peat swamp environment has the lowest pH. The No.5_{lower} coal has the highest CaO content and the lowest MgO content, thereby indicating that the magnesium-bearing mineral in No.5_{lower}

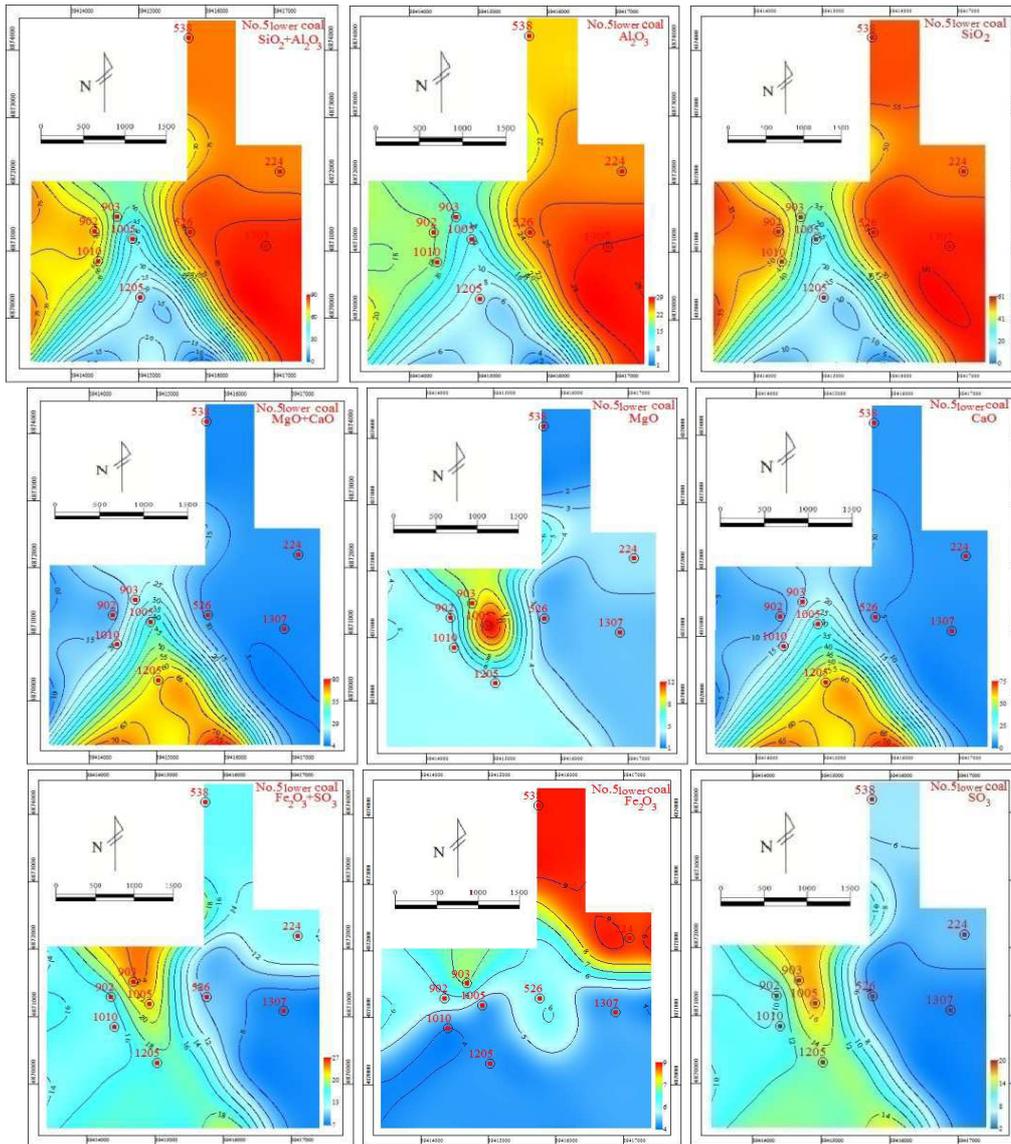


Fig.4. Plane isoline graph of ash composition relative content of No.5_{lower} coal.

coal is dolomite. However, the majority of calcium ions in No.5_{lower} coal existed in the form of $\text{Ca}(\text{OH})_2$, thereby resulting in the formation of less dolomite. Given that the Ca-bearing minerals of No. 5 and No. 6 coals are mainly calcite and calcium humate, the peat swamp environment of No. 5 and No. 6 coals was weakly alkaline or acidic.

The average Fe_2O_3 contents in the main coal from top to bottom are 7.74%, 5.52%, and 4.96%, and is greater than Chinese coal, whose average value is 4.85% (Kang, 2015). The correlation coefficient between Fe_2O_3 and total sulfur in No.5 coal is 0.76, thereby indicating that iron is due to pyrite. In No.5_{lower} coal, Fe_2O_3 has the weakest correlation with total sulfur because the iron is mainly carried by siderite. The trend of Fe_2O_3 and total sulfur is decreasing in No.6 coal, thereby showing that the sulfur is organic sulfur, the content of

which reaches up to 72% (Table 3) and has the lowest iron content (Fig.7) (Sinninghe Damsté et al., 1989).

Calibration of Coal Ash Phase Parameters and Environmental Indication

The sulfur in the main coal seam dominated by organic sulfur in the study area. The ratio of $S_{o,d}$ and $S_{t,d}$ is 76.34%, 59.67%, and 65.79% from bottom to top (Table 3). This phenomenon can be explained in two ways. First, the hydrodynamic conditions were gradually enhanced, thereby resulting in the evolution of the water medium from relative hypoxia to relative oxygen enrichment, and a large number of cations increased the alkalinity of the swamp water medium. The alkaline swamp water medium is beneficial in the formation of plant gelation, and a large number of humic acids are produced, thereby increasing

Table 3. Ash composition analysis

Coal	Number	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	TiO_2	SO_3
No.5	10	26.75-51.06	4.42-12.18	10.09-22.21	5.34-19.22	1.63-8.67	0.36-1.02	3.59-19.95
No.5 _{lower}	9	23.04-56.08	3.92-8.31	6.58-26.59	2.93-55.24	1.34-11.77	0.46-1.06	3.56-15.22
No.6	49	23.36-58.06	1.58-12.12	10.09-24.69	6.05-20.31	2.5-8.64	0.02-1.09	3.34-17.57

Note: minimum ~ maximum

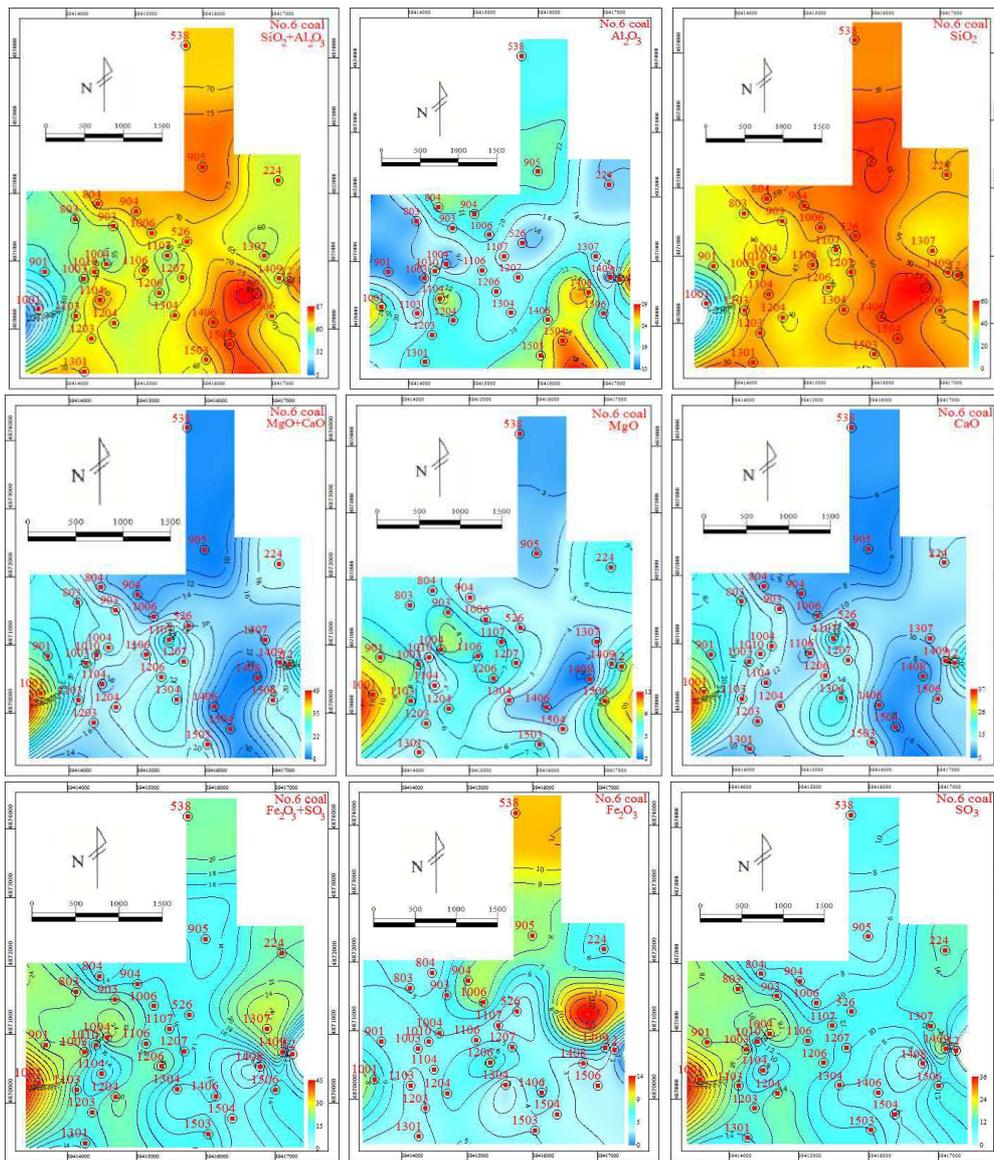


Fig.5. Plane isopleth graph of ash composition relative content of No.6 coal.

the sulfur ions in an aqueous medium with sedimentary organic matter (Singh et al., 2012). Second, the water stagnation of peat swamp, with weak hydrodynamic conditions increase the salinity of the water, thereby enhancing the reduction of the water medium and the activity of anaerobic microbials. This in turn intensified the gelation of plant remains and increased the sulfur ions in an aqueous medium with sedimentary organic matter (Qin et al., 2005). Combined with the previous analysis, the sedimentary environment change from weak reduction-weak oxidation-strong reduction from bottom to top, thereby indicating that the high organic sulfur content of the No.5 and No.6 coals is mainly affected by the second mechanism, whereas the No.5_{lower} coal is affected by the first mechanism. The ratio of huminite and inertinite and the ratio of $S_{p.d}$ and $S_{i.d}$ in the No.5 coal are higher than in the others, and pyrite is the main iron mineral, further indicating that the coal-forming environment of the No.5 coal is strongly reductive.

The characteristics of the sedimentary environment during the coal accumulation period are reflected by different maceral compositions (Baruah et al., 2013). The ratio of huminite and inertinite of the main coal seam in the study area showed a low to high trend in No.5_{lower} coal (3.45), No.6 coal (4.82), and No.5 coal (11.2). An analysis of lithotype indicated a relatively high water level with the strong medium reduction and the high degree of gelation during the deposition of

No.5 coal. Thus, the huminite content in No.5 coal is highest, whereas the inertinite content is the lowest (Singh et al., 2017). The coal seam gloss brightened, and macroscopic lithotypes are dominated by semi-bright coal. The water level is relatively low, and the surface of the peat layer is periodically exposed to air during the deposition of No.5_{under} coal; thus, the inertinite content is highest, and macroscopic lithotypes are dominated by dark coal (Sarate, 2010a; Sarate, 2010b; Li and Zhou, 2012). The ash content in coal mainly reflects the content of inorganic components (mainly minerals) in coal. It also reflect to some extent the relative height of the underground water level and the groundwater activity. The ash content of the main coal seam in the study area showed a low to high trend; No.6 coal had the lowest ash content, the ash content of No.5 coal was higher, and No.5_{lower} coal had the highest ash content. Combined with the previous analysis, it indicates that the coal-forming environment of No.5 coal is a strong reducing sedimentary environment with deep overlying water. Given the rising phreatic surface and the intensified water coverage during the peat growth, the influence of groundwater and provenance detritus is relatively enhanced, thereby increasing ash production in coal. The growth rate of the peat swamp surface is equal to the peat growth rate during the deposition of No.6 coal. As a result of the stable-weak turbulent water with less debris, the minerals in coal are few and the ash content is the lowest. The coal-forming environment of No.5_{under}

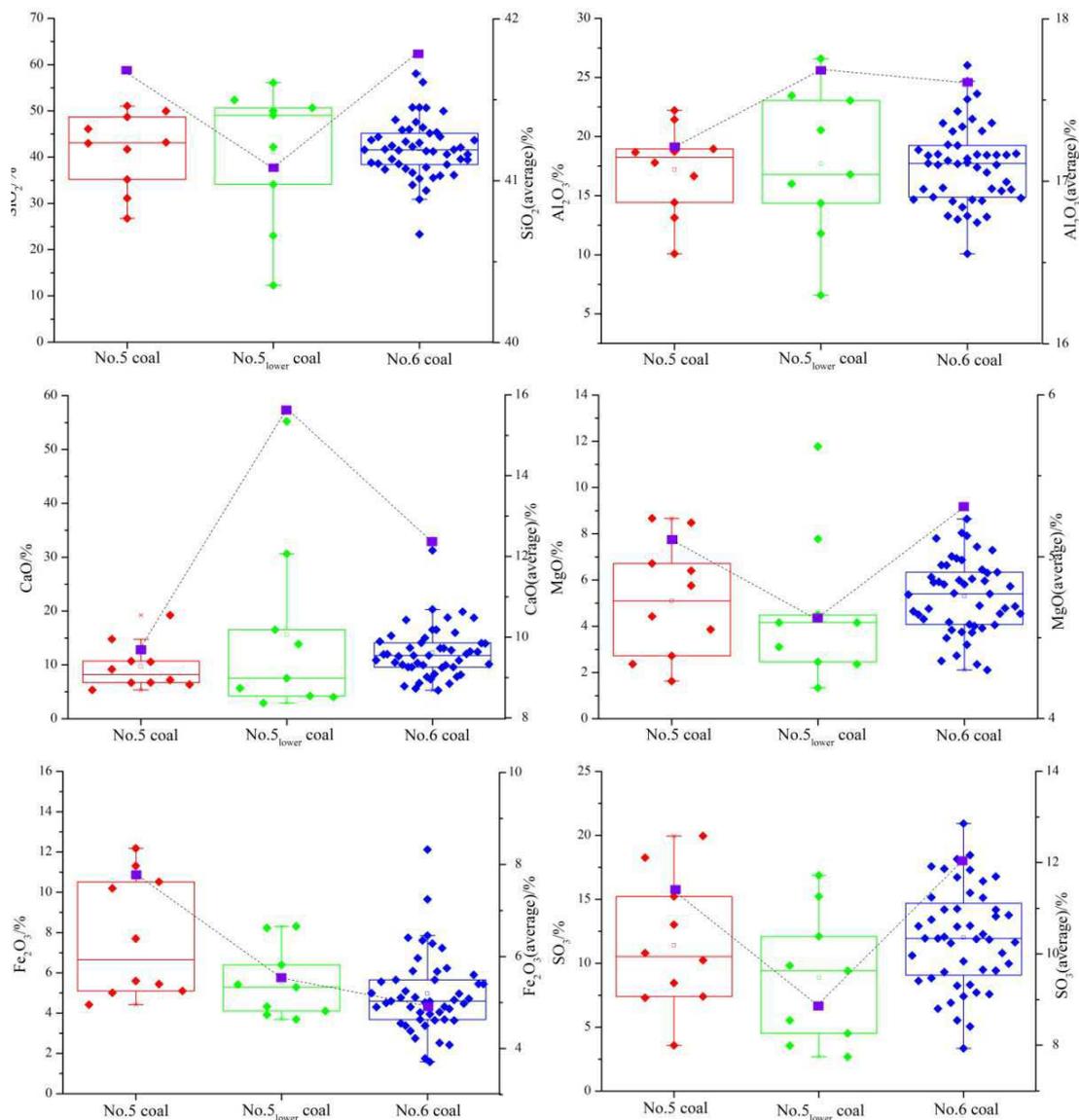


Fig.6. Vertical distribution characteristics of chemical composition of coal ash in single coal seam.

coal has a shallow water depth and high ash content, thereby indicating that the relative enrichment of ash is caused by the oxidation of coal plants.

Clay minerals in coal commonly contain kaolinite, illite, and montmorillonite. The kaolinite content of clay minerals in No.6 coal accounted for more than 90%. If the kaolinite are caused by terrestrial debris, then sufficient land-source material existed during the deposition of No.6 coal. This condition is not consistent with the low ash content, and the peat swamp environment of No.6 coal exhibits partial acidity, thereby resulting in instability of illite, which will disappear or converted to kaolinite (Jiang et al., 2009; Nayak et al., 2013). Thus, kaolinite may be mainly due to illite alteration affected by swamps. Illite is mostly a terrestrial clastic mineral that remains stable only in an alkaline medium, and the corresponding change is increased crystallinity. Terrigenous illite often represents a strong

weathering process of parent rock and lack of hydrolysis, thereby reflecting an environment of abundant terrigenous and highly settled deposits (Liu, 1994). No.5_{lower} coal has the highest illite content because of the relatively weak oxidizing environment with terrain uplift during the deposition of No.5_{lower} coal, and the large amount of cations that are carried by fresh water increased the alkalinity of the swamp water medium significantly. Mixed-layer illite/smectite is composed of illite, montmorillonite, and chlorite with regular or irregular inter bedding. Previous studies have shown that if the mixed-layer illite/smectite is any authigenic mineral, then it should be associated with illite and chlorite (Jiang, 2009). No.5 coal contains a high amount of illite and a small amount of chlorite. Thus, one can speculate that the mixed-layer illite/smectite in No.5 coal should be an authigenic mineral. Chlorite is a rare mineral in coal possibly because of metamorphic genesis or detrital terrigenous origin with the accumulation of coal-forming material at the same time. The coal in study area is lignite. Thus, the chlorite found in the sample should have formed at the beginning of the deposition in the reduction condition and retained. Thus, the chlorite can be used as the basis for the reduction of the depositional environment.

Pyrite is only developed in No.5 coal, and it occur as framboidal pyrite. Pyrite is mostly spherical under reflected light and is composed of many single particles of pyrite (Fig.9a); the particle

Table 4 Coal sulfur and other parameters

Coal	Number	St.d%	Sp.d%	Ss.d%	So.d%	Ash content	Huminite / Inertinite
No.5	5	2.384	0.564	0.234	1.21	20.99	11.2
No.5 _{lower}	7	1.73	0.36	0.16	1.13	23.47	3.45
No.6	66	1.54	0.398	0.04	1.13	16.06	4.82

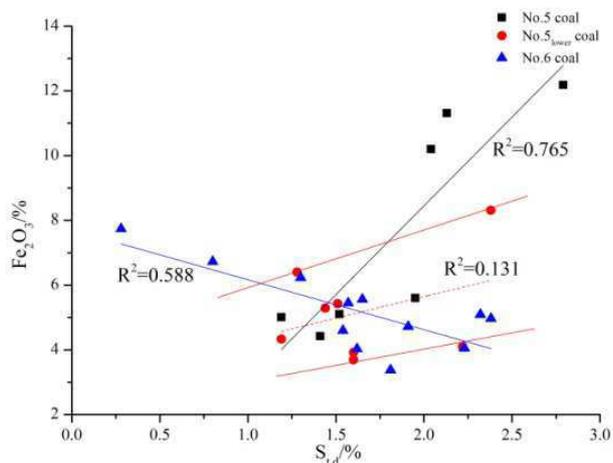


Fig.7. Relationship between Fe_2O_3 and $S_{t,d}$.

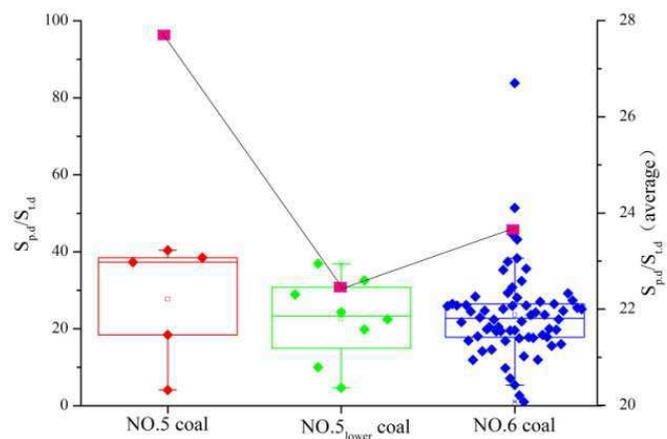


Fig.8. $S_{p,d}/S_{t,d}$ of the main coal.

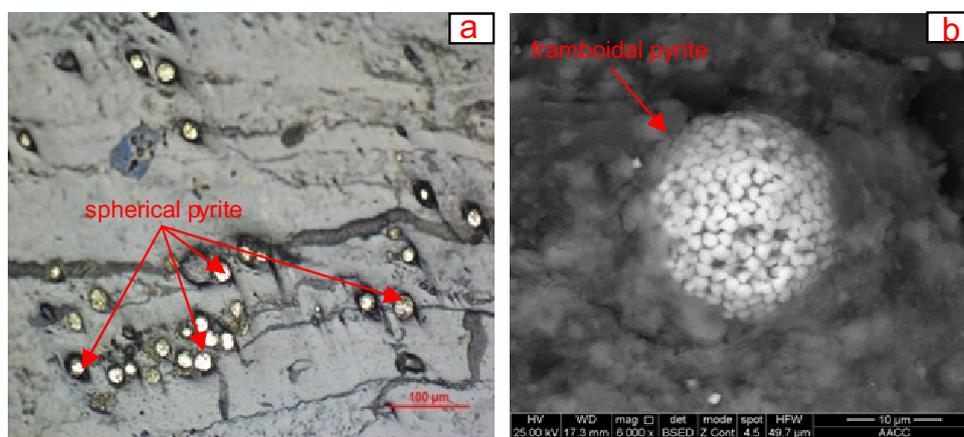


Fig.9. Distribution of pyrite in No.5 coal: a) spherical pyrite distributed in huminite in the observation of optical microscopy; b) framboidal pyrite developed in huminite in the observation of scanning electron microscopy

exhibits crystallinity under a scanning electron microscope (Fig.9b). Framboidal pyrite may be formed in the contemporaneous stage and developed in the penecontemporaneous stage with high degree of idiomorphism, and small granularity (Saikia et al., 2015). Therefore, framboidal pyrite is a contemporaneous- penecontemporaneous pyrite, the content of which can be used to indicate the oxidation-reduction potential of the water medium. Thus, the reduction of the sedimentary water medium of No.5 coal is the strongest.

Siderite is developed only in No.5_{lower} coal while as a typical syngenetic mineral developed during the peat formation, and is formed in a weak oxidizing peat swamp environment (Chen and Jiang, 2012). Calcite is less in No.6 coal because of the lack of terrigenous material and the sealing of the environment during the deposition of No.6 coal; this condition is one of the important reasons for the low ash and mineral contents in No.6 coal (Liu, 1994). Quartz content is highest in No.5 and No.6 coals, and it is usually a terrigenous mineral that is deposited at the same time as coal-forming plant debris and transported into the peat swamp by water or wind. It is scattered in organic matter in granular form and mostly a contemporaneous mineral with terrigenous detrital origin.

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