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Petrological, mineralogical, and geochemical compositions of Early Jurassic coals in the Yining Coalfield, Xinjiang, China

Yaofa Jiang [a,*], Lei Zhao [b], Guoqing Zhou [a], Xibo Wang [b], Lixin Zhao [b], Jianpeng Wei [b], Hongjian Song [b]

[a] Jiangsu Institute of Architectural Technology, Geological Survey, Xuzhou, Jiangsu 221116, China
[b] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology, Beijing 100083, China

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ABSTRACT

The petrological, geochemical, and mineralogical compositions of 10 coal seams (Early Jurassic) from an exploratory borehole (Hole ZKJ502) in the Jieliangzi mining area of the Yining Coalfield, Xinjiang Uygur Autonomous Region, China, were investigated, using optical microscopy and field emission-scanning electron microscopy in conjunction with an energy-dispersive X-ray spectrometer (FE SEM-EDS), as well as X-ray powder diffraction (XRD), X-ray fluorescence (XRF), and inductively coupled plasma mass spectrometry (ICP-MS). The Yining coals are of subbituminous to highly volatile C bituminous in rank (vitrinite reflectance, average 0.49%) and are characterized by low sulfur content (average 0.45%), low ash yield (average 4.10%), high volatile matter (average 38.82%), high proportion of inertinite (average 49.5%), and low concentrations of most trace elements. Relative to the upper continental crust, the rare earth elements and yttrium in the Yining coals are mainly characterized by light and heavy REY enrichment. The minerals in the Yining coals are dominated by quartz, kaolinite, and siderite, followed by pyrite, bassanite, and hexahydrite, along with small proportions of illite, calcite, dolomite, gorceixite, goyazite, ankerite, marcasite, diaspore, florencite, hematite, and millerite. The similarity between the Yining coals and the magmatic rocks from the peripheral mountain area of the basin in terms of the Al_2O_3/TiO_2 ratio, the REY enrichment type, the REY distribution patterns, and the Eu anomalous fractionation suggest that the sediment source region was mainly Carboniferous volcanic rocks (andesite and basalts) on peripheral mountains. The acid conditions and lowered water table during peat accumulation may have caused detrital minerals to be leached, leading to the relatively low ash yield. Another reason for the low ash yield may be the simple coalfield structure and poor groundwater migration channels in the rocks and coal seams in the central zone of the basin, which would limit the minerals carried by the groundwater into coals. A number of authigenic minerals (quartz, kaolinite, siderite, and gorceixite) occur as cell-fillings and elevated concentrations of Li, Be, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Zr, Nb, Mo, Cs, Hf, W, Pb, Th, and REY occur in Nos. 26 and 27 coals, indicating that there was an injection of a small-scale solution.

1. Introduction

Coal resources are abundant in the Xinjiang Uygur Autonomous Region of China, and the approved coal reserves were estimated to be 231.2 Gt by the end of 2009 in Xinjiang, of which 25% is located in the Yili basin (Editor of Coal Engineering, 2012; Wu, 2011). Almost all of the coal resources in Xinjiang occur in Jurassic strata (Mao and Xu, 1999).

For the past several years, a large amount of data on paleo-structure, paleo-geography, basin evolution, igneous activity, sequence stratigraphy, and coal-accumulation process, which were obtained during coalfield prospecting-exploration in the Yili coal basin, have been reported (Chen et al., 2006, 2008; Li et al., 2010, 2012, 2013, 2014b; Long et al., 2008; Lu and Jiang, 1999; Ma et al., 2012; Qiu et al., 2014; Shi et al., 2011; Sun et al., 2012; Wang and Chen, 2004; Zhang et al., 1999; Zhu et al., 2014; Zhuang et al., 2013). In contrast, the research data on the maceral composition and character of the Yili coals, the concentrations, modes of occurrence, and origins of trace elements and minerals in the coals are relatively far less.

A number of studies have been devoted to a sandstone-hosted roll-type uranium deposit that was discovered in the Yili basin in the early 1990s. The geological characteristics and metallogenic mechanisms of the sandstone type uranium ore deposit have been reported by Han et al. (2008), Liu and Jia (2011), Min et al. (2001, 2005a,b), Wang et al.(2005, 2006), and Zhang et al. (2006). A recent study by Dai et al. (2015b) revealed the geochemical and mineralogical characteristics for the coal-hosted uranium deposit that is hosted in the middle Jurassic Xishanyao Formation (J_2x) on the southern margin of the Yili basin.

These data have shown that the coal-seam thickness is not evenly distributed across the entire Yili basin; the thicker coal seams (3.5 m

* Corresponding author at: Jiangsu Institute of Architectural Technology, Geological Survey, 26, Xueyuan Road, Xuzhou City, Jiangsu Province 221116, China.
E-mail address: jiangyaofa-xz@163.com (Y. Jiang).

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to 8.0 m thick) and ultra-thick coal seams (greater than 8.0 m thick) are distributed mainly in the marginal parts of the basin. Moreover, the coal-formation period of the thicker coal seams is also different. For example, in the southern margin of the basin, the thicker and ultra-thick coal seams occur mainly in middle Jurassic Xishanyao Formation (J_2x), whereas in the northern margin of the basin, the thicker and ultra-thick coal seams are hosted mainly in the early Jurassic Badaowan Formation (J_1b) (Li et al., 2014b; Wang and Chen, 2004).

To reveal the petrological, mineralogical, and geochemical characteristics of the main coal seams in the Yili basin and to provide data for better evaluating the potential for utilizing its coal, 10 coal seams hosted in the Badaowan Formation (J_1b) and Sangonghe Formation (J_1s) in the Yining Coalfield were sampled and measured in this study. The results may be significant from both an academic and practical perspective.

2. Geological setting

The Yining Coalfield (located in Xinjiang Uygur Autonomous Region of north-western China) forms part of the Yili Basin (Fig. 1). The Yili Basin is a composite intermontane basin formed in the Tianshan Mountain orogenic belt. The basement of the basin is Proterozoic metamorphic rocks and Paleozoic deformed sedimentary and igneous rocks (mainly Carboniferous volcanic rocks). The depositional strata on the basement include sedimentary series dating to the Late Permian.

Based on structural features, five secondary tectonic elements (three sub-basins, an uplifted fault-block, and a compressed nappe mountain) have been recognized (Fig. 2A) within the Yili Basin (Chen et al., 2006, 2008; Li et al., 2010; Liao, 1992; Zhang et al., 1999; Zhu et al., 2014). The Yining sub-basin is the largest of the sub-basins and is named Yining Coalfield in coalfield prospecting-exploration. As shown in the NS profile of the basin (Fig. 2B), the northern margin of the Yining sub-basin is the Keguqin mountain where the main body of the orogenic belt is composed of Proterozoic metamorphic rocks (gneiss, schist, marble, and marbleized limestone), Ordovician marine clastics and carbonatite, Silurian continental sedimentary rocks, Carboniferous volcanic rocks (andesite, quartz porphyry, and rhyolite), Permian continental detrital rocks, and Hercynian granite intrusions. The southern margin of the Yining sub-basin is the Qiapuqiale compressed nappe mountain consisting mainly of Carboniferous (Mississippian) intermediate-acidic volcanic rocks and Permian detrital rocks. These outcropping rocks on lateral mountains built the sediment-source region of the Yining depression.

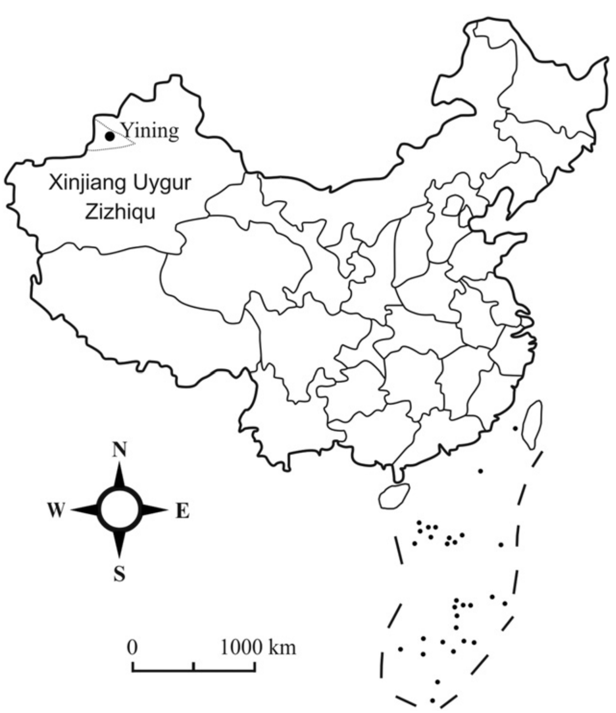

Fig. 1. Location of Yining city and the Yining Coalfield.

From the early Jurassic to middle Jurassic period, detrital sediments were deposited in an alluvial, fluvial, and lacustrine depositional environment (Ma et al., 2012; Mao and Xu, 1999; Shi et al., 2011; Zhuang et al., 2013). The dominant sedimentary facies in the Yining sub-basin are alluvial fan deposits, fluvial deposits, river deltas, and shallow-lake sediments. Optimal coal-forming conditions were present during the early–middle Jurassic. Among the three sub-basins the Yining Basin holds the greatest developmental potential in terms of coal seams. The Jurassic coal-bearing strata in the Yining Coalfield are composed of the early Jurassic Badaowan Formation (J_1b), early Jurassic Sangonghe Formation (J_1s), and middle Jurassic Xishanyao Formation (J_2x) (Fig. 3). The thickness of the Badaowan Formation across the coalfield varies from 95 to 298 m, the thickness of the Sangonghe Formation varies from 150 to 200 m, and the thickness of the Xishanyao Formation varies from 120 to 280 m. There are 14 coal seams in the Badaowan Formation, five coal seams in the Sangonghe Formation and 12 coal seams in the Xishanyao Formation in the basin. As mentioned above, the thicker coal seams and ultra-thick coal seams are hosted mainly in the Badaowan Formation (J_1b) and Xishanyao Formation (J_2x). Further, the thicker coal seams in the Badaowan Formation and Xishanyao Formation were mainly formed in a river-delta depositional environment (Ma et al., 2012; Mao and Xu, 1999; Shi et al., 2011; Zhuang et al., 2013).

3. Samples and analytical procedures

A total of 10 coal seams (16 core samples) were taken from an exploratory borehole (Hole ZKJ502) located in the Jieliangzi mining area in the Yining Coalfield (Fig. 2). These include nine coal seams (Nos. 18 to 29) hosted in the Badaowan Formation (J_1b) and one coal seam (No. 13) hosted in the Sangonghe Formation (J_1s). There are only two very thin coal seams hosted in Xishanyao Formation (J_2x) in this borehole (Fig. 3). Because splitting the core for archiving was not required in this exploratory program, entire seams were collected from the drill cores. For the thin coal seams (Nos. 13, 18, 23, 24, and 29 coal, respectively), the entire drill cores were collected, and for the thicker seams (Nos. 21, 22, 26, 27, and 28 coal, respectively), stratified sampling of the coal core was performed, separating the coal from the parting according to ASTM Standard D5192-09 (2011). The rock partings, which are greater than 0.01 m thick, have been selected from the coal seams according to Chinese Standard MT/T 1090-2008 (2010). All collected samples were stored individually in polyethylene bags that were packaged and taped securely for transport.

All samples were pulverized, screened, mixed, divided, and air-dried in the laboratory. Three types of the particulate coals were prepared; the first one (<1 mm) was prepared for petrographic analysis, the second (<0.2 mm) was prepared for proximate analysis and testing, and the third (<0.075 mm, passed a 200 mesh sieve) was prepared for geochemical analysis following ASTM Standard D2013/D2013M-11 (2011).

Proximate analysis of the coals was carried out according to ASTM Standards D3173-11, D3175-11, and D3174-11 (2011). Total sulfur and gross calorific value of the coals were determined following ASTM Standard D3177-02 (2007) and D5865-04 (2005). The ultimate analysis of the coals was carried out following ASTM Standard D3178-89 (2002) using an elemental analyzer (Vario MACRO). The microscopic analysis in reflected light was carried out according to ASTM Standard D2797/D2797M-11a (2011). The maceral classification of coal and terminology used in the petrographic study are based on Taylor (1991) and the ICCP System 1994 (ICCP, 1998, 2001). Mean random reflectance of vitrinite (percent R_r) was determined using a Leica DM-4500P microscope