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Enrichment of Bi-Be-Mo-Cd-Pb-Nb-Ga, REEs and Y in the Permian coals of the Huainan Coalfield, Anhui, China

Mehr Ahmed Mujtaba Munir[a,b], Guijian Liu[a,b,*], Balal Yousaf[a,b], Muhammad Ubaid Ali[a], Qumber Abbas[a], Habib Ullah[a]

[a] CAS-Key Laboratory of Crust-Mantle Materials and the Environments, School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, People's Republic of China

[b] State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, The Chinese Academy of Sciences, Xi'an, Shaanxi, People's Republic of China

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ABSTRACT

This paper presents new data concerning the geochemistry and distribution of the Bi-Be-Mo-Cd-Pb-Nb-Ga, and REY in the Panyi, Xieqiao, Xinji, Zhuji, and Zhuji Xi coals of the Huainan Coalfield. The results indicate that the Huainan bituminous coals were characterized by medium ash yields and low to medium sulfur contents. The mineral assemblage present in the Huainan coals is mainly made up of quartz, kaolinite, pyrite, and calcite. The minerals, ash yield, sulfur contents, volatile matter contents, Sr/Ba, SiO_2/Al_2O_3, and $(CaO + MgO + Fe_2O_3)/(SiO_2 + Al_2O_3)$ ratio varied significantly in the Huainan Coalfield, which are attributed mainly to vertical variation in the depositional environment. These coals contain high contents of Ga, Nb, Mo, Be, Pb, Ba, SiO_2, Fe_2O_3, TiO_2, CaO, Na_2O, Al_2O_3, MnO, K_2O, and MgO, especially in the marine-influenced environment coals. The average contents of Ga, Nb, Mo, Be, and REY are higher than those of world-wide bituminous coals, thus a hidden treasure is a yet to-be-realized new economic potential. The Bi, Be, Mo, Nb, Ga, and REY have mixed organic-inorganic affinity, while Cd and Pb mainly have an organic affinity in the Huainan coals. Compared to the average Chinese coals, the REY are enriched in the Panyi, Xieqiao, and Xinji coals, slightly lower in the Zhuji coals and depleted in the Zhuji Xi coals. Compared to the upper continental crust, REY in the Huainan coal samples has medium-REY and light-REY enrichment. The average concentration of oxides (ash basis) of the rare earth elements and Y in the Panyi (on average 1120.3 μg/g), Xieqiao (1287.7 μg/g), Xinji (1148.7 μg/g), and Zhuji (1025.1 μg/g) coals are higher than the cut-off grade for industrial deposits of these elements and thus, the Huainan coals are considered as raw materials for the recovery of rare earth elements.

1. Introduction

Coal deposits containing high abundances of Ga, Ge, Li, Sc, Hf, Nb, Bi, Be, Ba, Ta, and REY have attracted significant attention in recent years as a possible new source for the extraction of these rare metals (Arbuzov et al., 2014; Seredin and Dai, 2012; Sun et al., 2012b, 2014; Vaskula, 2016; Zhang et al., 2016), which are an important source of raw materials in various high-technology applications (Sun et al., 2013, Sun, 2015). Trace elements, such as arsenic, Be, Cd, Cr, Mo, Nb, Cd, and Pb in the coal are condensed and adsorbed in the fly ash due to coal combustion in coal fired power plants. Unfortunately, coal production, utilization, and waste disposal cause various environmental problems such as emission of certain trace elements (including Be, Cr, Mo, Cd, As, Se, Zn, and Pb), greenhouse gases (Ashley et al., 2003; Fang et al., 2014; Finkelman, 1999; Flues et al., 2013; Fu et al., 2013; Jaishankar et al., 2014; Munir et al., 2018; Ribeiro et al., 2013; Streets et al., 2018; Wagner and Hlatshwayo, 2005) and exposure to these elements result in a wide range of health problems, such as cancer, cardiovascular diseases, peripheral neuropathy, neurological illness, kidney disease, encephalopathy, and impaired cognitive function even at low-concentrations (Ali et al., 2017; Dai et al., 2014a; Qi et al., 2007; Sia and Abdullah, 2017). According to several studies, coal combustion caused severe human health problems such as endemic fluorosis, arsenosis, selenosis, and lungs cancer in China (Dai et al., 2012a, 2004; Diehl et al., 2012; Ding et al., 2011; Xiong et al., 2017).

Previously conducted studies results showed that the concentrations and distributions of trace elements in organic and inorganic components impact the quality of coal combustion by-products (Alastuey

* Corresponding author at: CAS-Key Laboratory of Crust-Mantle Materials and the Environments, School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, People's Republic of China.

E-mail addresses: muju212@mail.ustc.edu.cn (M.A.M. Munir), lgj@ustc.edu.cn (G. Liu), balal@ustc.edu.cn (B. Yousaf), Ubaid@mail.ustc.edu.cn (M.U. Ali), qumber@mail.ustc.edu.cn (Q. Abbas), habib901@mail.ustc.edu.cn (H. Ullah).

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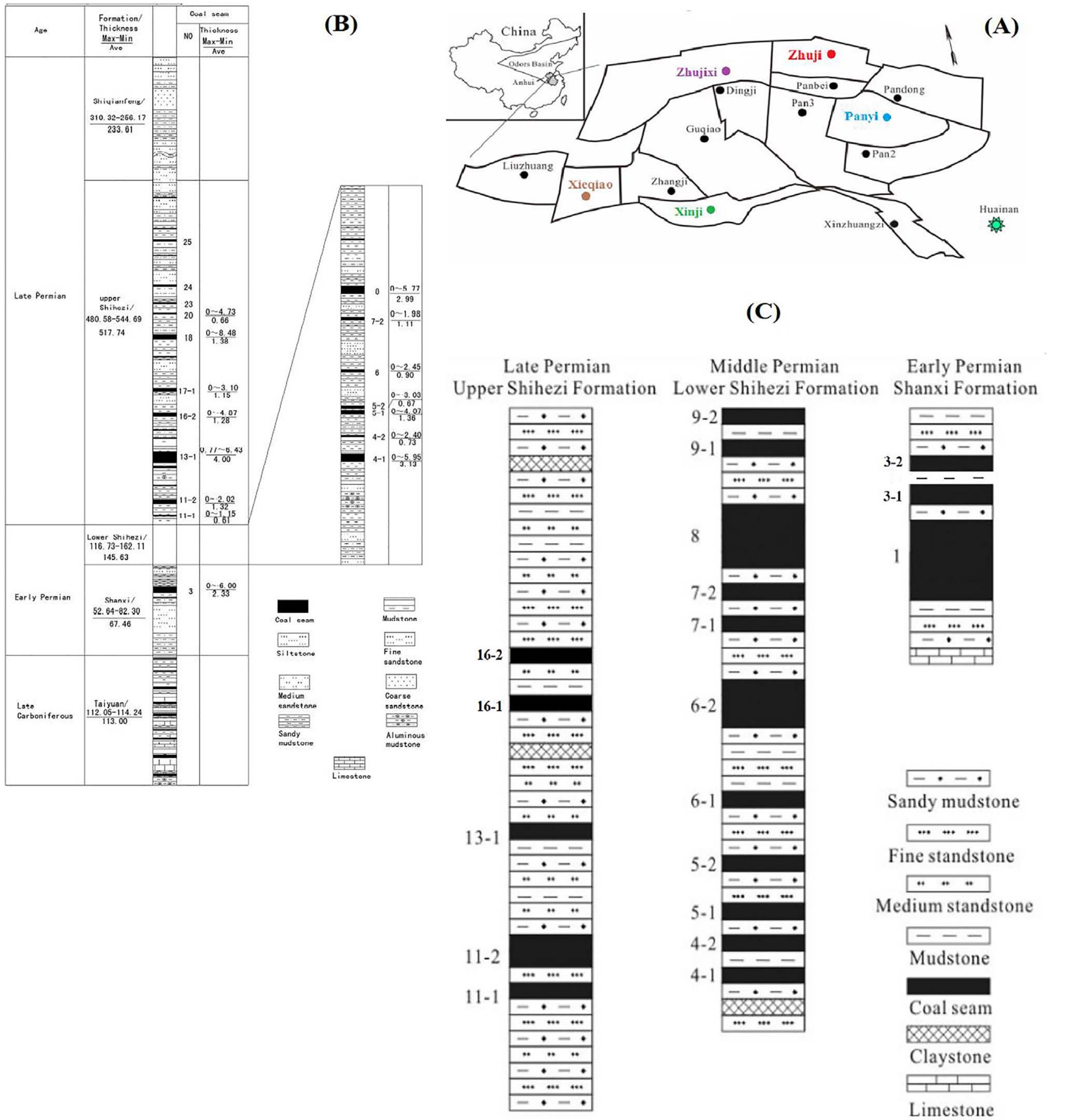

Fig. 1. (A) Location of the Huainan coalfield and main coal mines in this area (sampling sites labeled with colored dots), (B, C) Stratigraphic column and lithological characteristics of coal-bearing sequence in the Huainan coalfield, Anhui province, China.

et al., 2001; Liu et al., 2016; Mardon and Hower, 2004; Qi et al., 2007; Singh et al., 2015; Tang et al., 2009; Ward, 2016). Some valuable elements (e.g. Al, Cs, Nb, Zr, Ga, Li, Rb, Y, Ge, U, Ag, Au, and Pb) can be significantly enriched in coals or in coal-bearing strata, reaching levels equal to or even higher than their concentrations in the respective ores (e.g. Dai et al., 2017a,b; Finkelman and Tian, 2017; Seredin and Dai, 2012; Sun, 2015; Zhao et al., 2017). Several elements, such as V, B, Br, Mo, Rb, Ga, and U are generally enriched in coals deposited in the marine-influenced environment (Liu et al., 2015; Shao et al., 2003; Song et al., 2014; Swaine and Goodarzi, 2014), due to the higher contents of these elements in the seawater than fresh water. While siliceous rocks are also enriched in elements such as Mo, Cr, V, U, and Se (Jiang et al., 2015; Tian et al., 2014; Yao et al., 2015). Dai et al. (2014c) proposed that Nb, Ga, Mo, and Ta are elevated in several Chinese coals, up to the point that ashes from some of the coals may be considered as potential starting materials. These elements with important technological applications, widely used, for example, in electronics (White and Shine, 2016), and consequently have high economic values (Li et al., 2014b; Zhao et al., 2017). The rare earth yttrium (REY) mode of occurrences, distribution, and geochemical parameters are used as geochemical indicators and origin of coal accumulating materials (Jiang et al., 2016; Wang et al., 2012; Zhuang et al., 2012). The