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Petrology, mineralogy and geochemistry of the Lower Cretaceous oil-prone coal and host rocks from the Laoheishan Basin, northeast China

Yu Song[a,b,*], Zhaojun Liu[c], Doris Gross[d], Qingtao Meng[c], Yinbo Xu[e], Shuifu Li[a,b]

[a] Faculty of Earth Resources, China University of Geosciences, Wuhan 430074, China
[b] Key Laboratory of Tectonics and Petroleum Resources (China University of Geosciences), Ministry of Education, Wuhan 430074, China
[c] College of Earth Sciences, Jilin University, Changchun 130061, China
[d] Department Applied Geosciences and Geophysics, Montanuniversität Leoben, Peter-Tunner-Str. 5, A-8700 Leoben, Austria
[e] Oil and Gas Survey, China Geological Survey, Beijing 100083, China

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ABSTRACT

The coal and host rocks (mainly oil shale partings) in the Laoheishan basin (NE China) are oil-prone. This study uses petrological, mineralogical and geochemical analyses to determine the reasons of high oil yield in the coal, and the origin and modes of occurrence of the minerals and elements in the coal and oil shale partings. The obtained data show that this sub-bituminous B coal has higher oil yield (av. 10%) than oil shale partings (av. 5.7%), consistent with a higher hydrogen content in the coal. This oil-prone coal has potential for comprehensive utilization due to the relatively high gross calorific value (av. 17.23 MJ/kg) in the semi-coke. The maceral composition suggests that the relatively high hydrogen content in the coal is mainly caused by higher resinite content. Palynological analysis of coal and oil shale partings mainly proved the presence of gymnosperms and ferns, revealing that the paleovegetation is dominated by lygodiacean-/osmundacean ground ferns and cupressaceaen/taxodiaceaen canopy trees, these canopy trees would have provided abundant hydrogen rich components (e.g. resin) to the paleomire. All the identified sporopollen suggests a warm-humid subtropical paleoclimate.

Minerals in the coal include kaolinite, quartz, illite (and/or illite/smectite), chlorite, feldspar, calcite, and traces of pyrite, rutile and zircon, similar to the oil shale partings. Most of the minerals (quartz, feldspar, clay minerals, rutile and zircon) occur in layers within detrovitrinite and probably are of detrital origin. Pyrite and calcite are of epigenetic origin and probably derived from hydrothermal fluids. Compared with average Chinese coal, the Laoheishan coal is enriched in Zr, Nb, In and Sb. Zirconium and Nb mainly occur in zircon. Indium is both organically and inorganically associated, whereas antimony largely occurs in pyrite. REY (rare earth elements and yttrium) distribution patterns of coals and oil shale partings are dominated by Heavy-REY enrichment, whereas roof and floor samples are Medium-REY enriched. The M-HREY enrichment is probably caused by low-temperature hydrothermal fluids. The sedimentary input is the major controlling factor of geochemical patterns in coal and host rocks. The source rocks are probably felsic-intermediate igneous rocks from the surrounding basement, as indicated by relatively high Al_2O_3/TiO_2 ratios (7–38), cross-plot between Zr/Ti and Nb/Y, negative Eu anomalies (0.28–0.96), the presence of K-feldspar and plagioclase, and lithic fragment types (such as granite and andesite) in the samples. In addition, source rocks of sediments have caused high Zr and Nb concentrations in the coal.

1. Introduction

Coal has a complex and heterogeneous structure, composed of both organic and inorganic components with variable abundance and diverse origin (Vassilev and Vassileva, 1996; Karayiğit et al., 2000; Gürdal, 2011; Moore and Esmaeili, 2012; Dai et al., 2012a). Although the inorganic fraction typically constitutes only a small portion of the coal composition, most of the problems associated with coal utilization are related to this portion, such as mineral matter may be a source of unwanted abrasion, stickiness, corrosion or pollution associated with coal handling and use (e.g. Mackowsky, 1968; Ward et al., 1999; Ward, 2002, 2016; Gürdal, 2011; Sutcu and Karayigit, 2015; Karayiğit et al., 2017a). The inorganic matter, like the organic matter, is a product of the processes associated with peat accumulation and rank advance, as

* Corresponding author at: Faculty of Earth Resources, China University of Geosciences, Wuhan 430074, China.
E-mail address: songyu1009@126.com (Y. Song).

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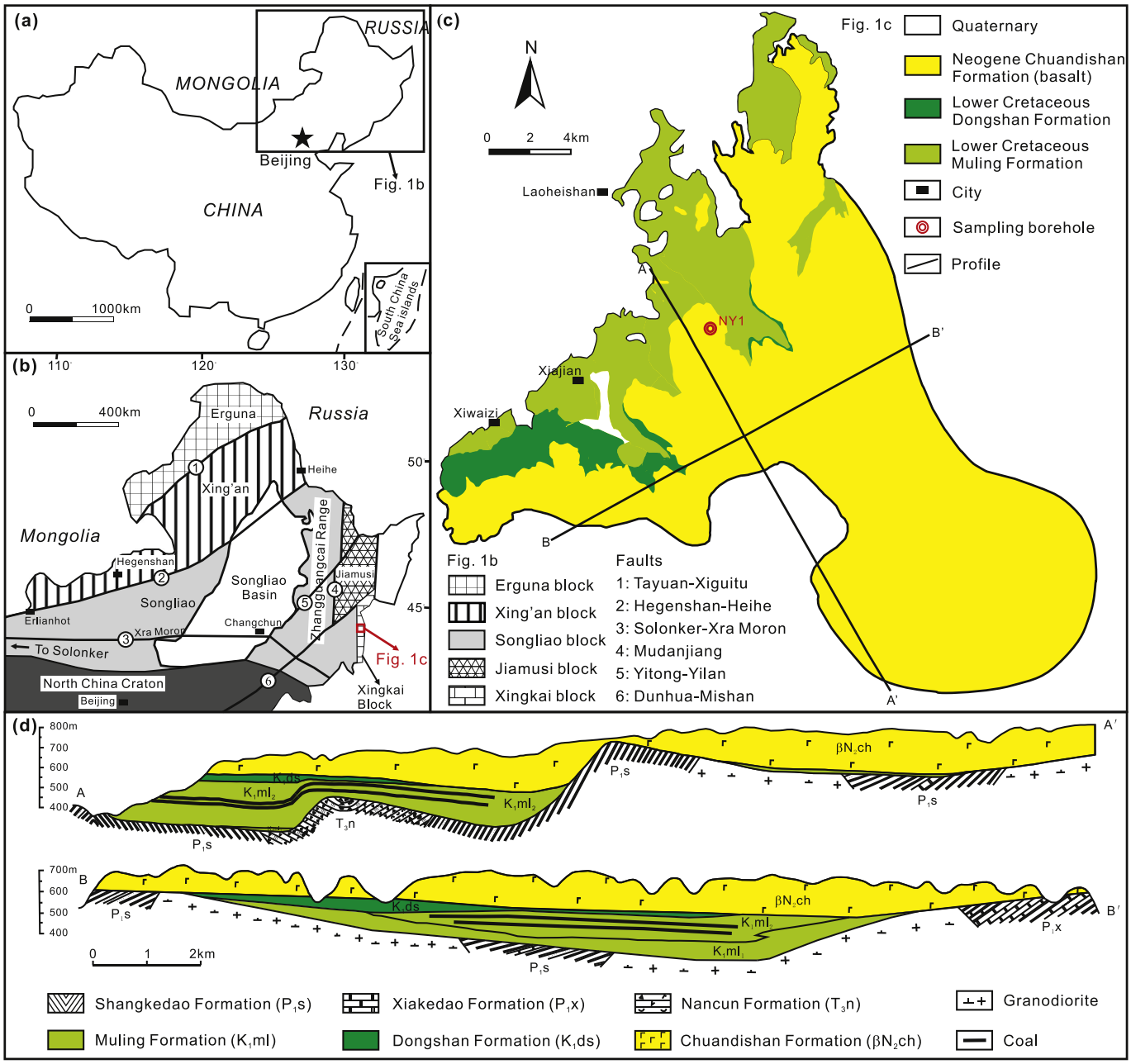

Fig. 1. (a) Schematic map of northeast (NE) China, (b) simplified geological map of NE China, showing the position of the Xingkai Block (Wu et al., 2007; Xu et al., 2012), different symbols indicate different blocks, (c) geological map of the Laoheishan Basin and the location of NY-1, (d) cross sections along the Laoheishan Basin (Song et al., 2017c).

well as changes in subsurface fluids and other aspects of sediment diagenesis (e.g. Raymond and Andrejeko, 1983; Shotyk, 1988; Susilawati and Ward, 2006; López-Buendía et al., 2007; Wüst et al., 2008; Ward, 2016; Karayiğit et al., 2016, 2017b). Recent studies indicate that the minerals in the coal are carriers of some valuable elements (such as Ge, Ga, Al, and rare earth elements), and some of these elements can be recovered from combustion waste (Seredin and Finkelman, 2008; Dai et al., 2011, 2012a; Seredin and Dai, 2012; Seredin, 2012; Dai and Finkelman, 2017; Kolker et al., 2017; Karayiğit et al., 2017c; Çelik et al., 2017).

The Lower Cretaceous coals are widely distributed in the northeast China, including Inner Mongolia, Liaoning, Jilin and Heilongjiang provinces (Ren et al., 2006). Previous studies on the mineralogy and geochemistry of coal are mainly focused on south and northwest China (e.g. Querol et al., 2001; Dai et al., 2003, 2006, 2011, 2014, 2015b, 2017; Liu et al., 2006; Zhou et al., 2010), whereas the examples from northeast China are relatively few (e.g. Zhuang et al., 2006; Dai et al., 2008, 2012a, 2015a), especially in the Heilongjiang and Jilin Provinces (e.g. Dai et al., 2018). Laoheishan Basin is situated in the eastern Heilongjiang province (Fig. 1a, b) and contains oil-prone coal and mudstone layers (reaching "oil shale" quality) in the Lower Cretaceous Muling Formation (Liu et al., 2006). Previous studies mainly focused on the depositional environment of coal and oil shale (Song et al., 2017a, 2017b). However, the causes of relatively high oil yield of the coal and mineralogical and elemental characteristics of the coal and oil shale partings in the Laoheishan basin has not been reported.

In this paper, the causes of the relatively high oil yield of the coal, and the origin and modes of occurrence of the minerals and elements in the coal and oil shale partings from the Laoheishan basin are studied for the first time.