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Paleoenvironmental reconstruction of the coal- and oil shale-bearing interval in the lower Cretaceous Muling Formation, Laoheishan Basin, northeast China

Yu Song [a,b,*], Zhaojun Liu [a,b,*], Achim Bechtel [c], Reinhard F. Sachsenhofer [c], Doris Groß [c], Qingtao Meng [a,b]

[a] College of Earth Sciences, Jilin University, Changchun 130061, China
[b] Key Laboratory for Oil Shale and Paragenetic Energy Minerals, Changchun 130061, Jilin Province, China
[c] Department Applied Geosciences and Geophysics, Montanuniversität Leoben, Peter-Tunner-Str. 5, A-8700 Leoben, Austria

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ABSTRACT

The Laoheishan Basin in northeast China has been filled with Lower Cretaceous coal- and "oil shale"-bearing sediments. The basin fill includes from base to top alluvial conglomerate (lower member of Muling Formation), fan delta sediments interbedded with coal and oil-prone mudstone (denominated as "oil shale") layers in the upper member of Muling Formation, and volcaniclastic rocks (Dongshan Formation). In the present study, the maturity of organic matter, oil shale quality, and paleoenvironment of the coal and oil shale accumulation are investigated based on macro- and micropetrographic data, proximate and ultimate analyses, bulk geochemical parameters, biomarkers analysis and stable isotope geochemistry.

In the Laoheishan Basin, both coal and "oil shale" layers are derived from land plant organic matter. This contrast the "oil shale" of this basin from oil shale/coal intercalations in fault-related basins, in which oil shale has been found to be of algal origin. The coal is sub-bituminous in rank, hydrogen-rich and oil-prone. The "oil shale" is of low-medium grade and the relatively low oil yield may relate to the abundant resinite and sporinite, because of their lower generation potential compared with alginite. Accumulation of the high-ash coal commenced in low-lying mire, drowned during frequent floodings. Subsequently high-ash, low-sulfur coal was deposited in a stable low-lying mire, under oxic conditions and limited bacterial activity. Afterwards the mire was drowned and formed a freshwater, dysoxic to oxic shallow lake, in which "oil shale" layers accumulated. Finally, the depositional environment returned to low-lying mire but probably with a brackish influence, as indicated by elevated sulfur contents in the uppermost samples. Petrography- and biomarker-based proxies indicate that gymnosperms dominated the paleovegetation of the mire, accompanied by variable amounts of herbaceous plants, such as ferns.

1. Introduction

During the Cretaceous age, various natural resources developed in northeast China and have been paid extensive attention by a number of researchers (e.g., Sha, 2007; Sha et al., 2008; Bechtel et al., 2012; Wang et al., 2013). The natural resources mainly comprise coal-bearing deposits (e.g. in the Jixi, Boli, Shuangyashan, Hegang, and Fuxin coal basins; RTMCFEH, 1986), oil accumulations (e.g. in the Daqing and Liaohe oil and gas fields; Ye et al., 1990) and oil shale resources (e.g. Qingshankou and Nenjiang Formations in the Songliao Basin, and Dalazi Formation in the Luozigou Basin; Zhang et al., 2007; Jia et al., 2013; Xu et al., 2015; Song et al., 2016b). Oil shale is commonly defined as a fine-grained sedimentary rock containing organic matter that will yield substantial amounts of oil and combustible gas upon destructive distillation (Dyni, 2003). Liu et al. (2009) defined the oil shale as fine-grained sediments with oil yields exceeding 3.5 wt.%, irrespective of their origin.

In northeast China, non-marine Cretaceous rocks, including freshwater, brackish-water and volcanoclastic deposits, are widely distributed throughout the time and space (Sha, 2007). Among them is the Laoheishan Basin (Fig. 1), which contains coal and oil-prone mudstone layers (reaching "oil shale" quality) in the Lower Cretaceous Muling Formation (Liu et al., 2006). Previous research related to the Laoheishan Basin mainly focused on the calculation of coal resources (Jiang, 2007). However, to date very little research has been undertaken on the paleoenvironment, which resulted in the deposition of the coal and "oil shale" layers of the Muling Formation.

* Corresponding authors at: College of Earth Sciences, Jilin University, Changchun 130061, China.
E-mail addresses: songyu1009@126.com (Y. Song), liuzj@jlu.edu.cn (Z. Liu).

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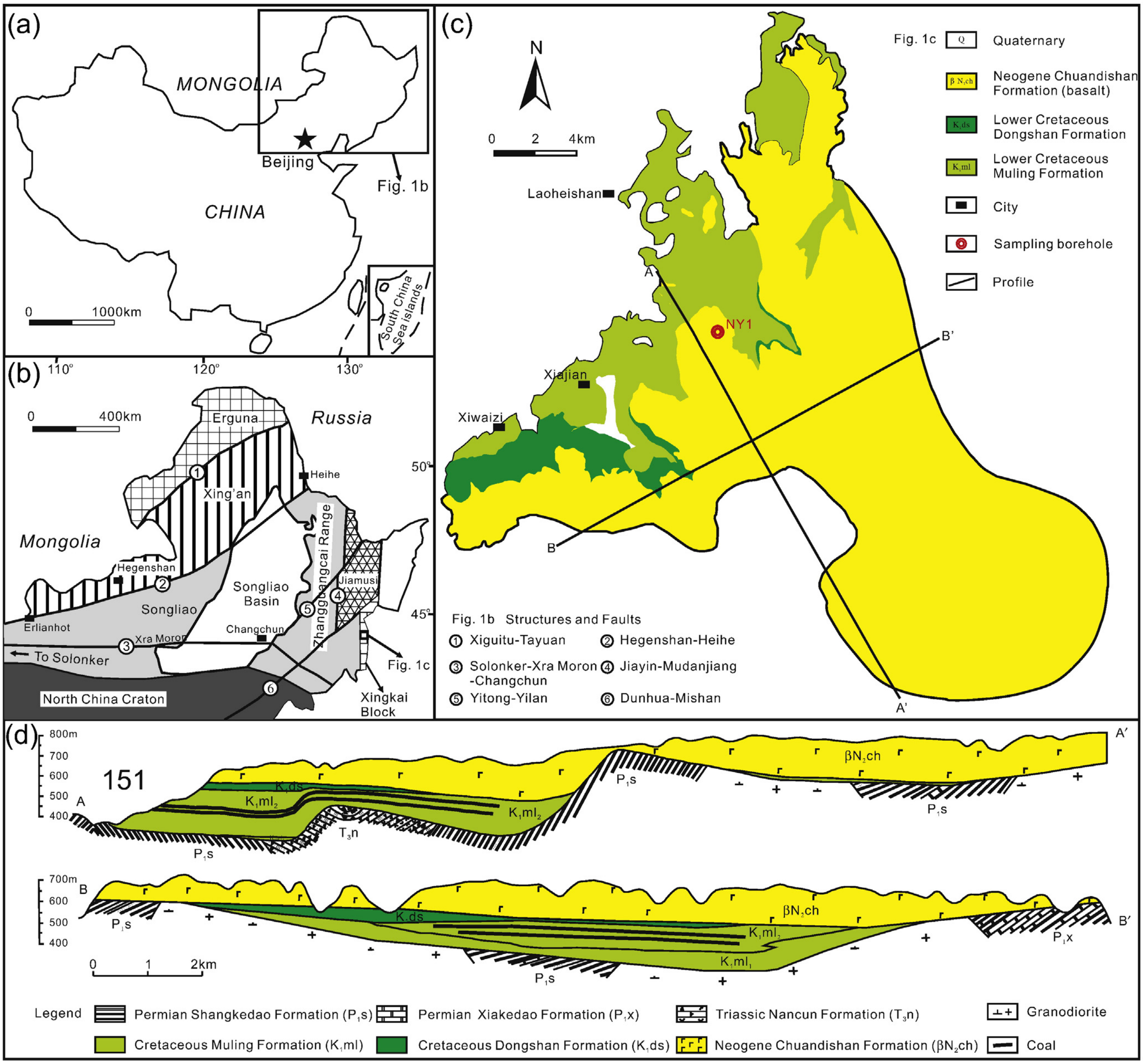

Fig. 1. (a) Location of northeast (NE) China, (b) simplified geological map of NE China, showing the position of the Xingkai Block (Wu et al., 2007; Xu et al., 2012), different symbols indicate different blocks, (c) geological map of the Laoheishan Basin and the sampling location, (d) profiles of the Laoheishan Basin showing the basin structure.

The main aim of this paper is to reconstruct the environmental conditions during coal and "oil shale" deposition. To reach this goal, biomarker data are used in combination with bulk geochemical, maceral and compound-specific analysis. Besides that, proximate and ultimate analyses are applied to determine the coal rank and oil shale quality.

2. Geological setting

Northeastern China is formed by several micro-continental blocks separated by major faults. The micro-continental blocks are (from NW to SE) the Erguna, Xing'an, Songliao, Jiamusi and Xingkai blocks (Fig. 1a, b; Wu et al., 2007).

The Laoheishan Basin is situated in the Xingkai Block composed of Precambrian metamorphic basement, partly covered by carbonate, clastic and volcanic rocks of Paleozoic and Mesozoic age (Shi, 2006; Xu et al., 2012). The basin covers an area of approximately 400 km^2. Outcrops of the Cretaceous basin fill are very rare and occur only in northwestern part of the basin (Fig. 1c). The central and southeastern parts of the basin are covered by extensive and thick basalt layers of the Neogene Chuandishan Formation.

The Lower Cretaceous basin fill is about 400 m thick and dips southeastwards with <5°. It comprises the Muling Formation and the overlying Dongshan Formation. The Muling Formation is subdivided into two members. The lower member is composed of conglomerate with interbedded sandstone and mudstone (K_1ml_1, Fig. 2). In contrast, the upper member (K_1ml_2) consists of mudstone, sandstone and limited conglomerate, with several coal and "oil shale" layers, which were deposited during periods of highest subsidence (Fig. 1d; Zhang and Ma, 2010).

3. Samples and methods

Twenty eight samples, including 18 coal, 8 "oil shale" and 2 mudstone samples, were taken from the borehole NY1 (Fig. 1c). Each sample comprises an interval of about 3 cm and is representative for a macroscopically homogenous layer, 0.03 to 0.25 m thick. The samples were fresh and the sampling positions are indicated in Fig. 3. All samples