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Occurrence of analcime in the middle Jurassic coal from the Dongsheng Coalfield, northeastern Ordos Basin, China

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A R T I C L E I N F O

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A B S T R A C T

This paper describes the occurrence of significant authigenic analcime ($NaAlSi_2O_6 \cdot H_2O$) in the middle Jurassic coal from the northeastern Ordos Basin and discusses its origin. Twelve coal samples from borehole ZK31-19 in the Dongsheng Coalfield were collected and analyzed. The coals are characterized by a low-medium ash yield, high volatile matter and low sulfur contents. The major-element oxides in the studied coals are mostly at similar or much lower concentrations compared to the averages for Chinese coals. Similarly, most trace elements are depleted or in concentrations close to the respective averages for world low-rank coals. Based on Seredin-Dai's classification, the REY (rare earth elements and Y) in the coal mainly display N- and H-type distribution patterns, with no Ce and Eu anomalies. Coal sample ZK31-19-12 from the lower Zhiluo Formation contains analcime up to 23 wt%, with a high Na_2O concentration of 1.23% (both on a whole-coal basis). The analcime occurs as lath, as subhedral granular crystals in fissures or pores and as anhedral crystals in the organic matrix. Furthermore, significant analcime has also been observed by SEM in coal from the upper Yan'an Formation (sample ZK31–19-10), which mainly occurs as anhedral crystals. No evidence of analcime forming from precursors of volcaniclastic material, alkali zeolites or other silicates was detected, therefore, it is deduced that the analcime in the studied coals formed by authigenic precipitation. The Na_2O content in the studied coal seams displays a vertical variation different from that of the ash yield (A_d) and those of the detrital-dominated elements, such as SiO_2, Al_2O_3, TiO_2, Zr, Nb and Th, indicating a different origin of Na compared with other detrital materials of terrigenous origin. Combined with the evidence of the obvious Na peak in authigenic amorphous material and gypsum mineral by SEM, it can be inferred that the source of Na may derive from the fluids. The paleoclimatic change (from subtropical warm and humid to semi-arid and arid hot, during the deposition period of the Yan'an to the Zhiluo Formation) may provide favorable conditions for analcime authigenesis, leading to its abundant precipitation in the lower Zhiluo Formation and its limited occurrence in the upper Yan'an Formation. Such paleoclimatic change is also significant for the U mineralization in the lower Zhiluo Formation.

1. Introduction

Analcime, a sodium zeolite with an ideal structural formula of $Na_{16}Al_{16}Si_{32}O_{96} \cdot 16H_2O$, is a common authigenic silicate mineral in sediments and sedimentary rocks (Remy and Ferrell, 1989). Its occurrence has mineralogical importance because, in general, analcime is believed to be formed through the reaction between volcanic glass and saline solutions (English, 2001). The correlation between alkalinity and zeolite composition in sedimentary environments has been noted and experimentally explained (Mariner and Surdam, 1970). Furthermore, Hartley et al. (1991) and Hay and Sheppard (2001) have concluded the specific requirements on environmental conditions (such as water chemistry, temperature and pressure, etc.) for analcime formation. Analcime, however, was not formed directly from volcanic glass (Hay, 1978). The reaction of volcanic glass with saline solutions to form analcime may be a complex dissolution-precipitation process (Hay and Sheppard, 2001), in which gel-like material and/or alkali zeolite precursors may act as intermediate phases (Hartley et al., 1991).

Significantly, analcime may be formed in an environment devoid of volcaniclastic material. English (2001) has identified the authigenic occurrence of analcime from amorphous aluminosilicate material in lacustrine sediments, with no volcanic rocks or pyroclastic sediments

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involved. Campo et al. (2007) suggested that analcime in a fluvial-lacustrine sequence from northwestern Argentina was formed by direct authigenic precipitation or through the reaction between interstitial brines and clay minerals or plagioclase. Karakaya et al. (2013) also noted the formation of analcime either by direct chemical precipitation or by the reaction of montmorillonites and Na-rich feldspars or other non-zeolite precursors in a closed basin.

Although the formation of analcime has been widely observed in sediments as well as in sedimentary rocks, analcime is not a common mineral in coal. Some studies have identified its presence as being closely related to volcanic ash (Dai et al., 2017a and references therein). Whateley et al. (1996) and Querol et al. (1997) have described the occurrence of several different zeolite minerals, including analcime and clinoptilolite/heulandite, in a Turkish lignite deposit, possibly derived from the interaction of volcanic ash with Na-rich formation waters under alkaline conditions. In the present study, analcime occurrence has been identified in colas from the lower Zhiluo Formation and upper Yan'an Formation.

The lower Zhiluo Formation has gained significant interest for hosting the largest sandstone-type uranium deposit in China, located in the Dongsheng area (Akhtar et al., 2017). The genesis of sandstone-hosted uranium deposits is generally considered to be the interaction of epigenetic oxidizing uranyl-bearing fluids with reducing agents within permeable sandstones, where soluble U(VI) can be reduced to insoluble U(IV) by detrital plant debris, humates, hydrocarbons and sulfides (Zhang et al., 2017a,b and references therein). The U in these deposits generally is accumulated within the medium to coarse-grained sandstone beds in localized reduced environments, typically in curved zones known as roll-fronts (Dai et al., 2015a). Based on the geochemical evidence and hydrodynamic modeling, Xue et al. (2010, 2011) indicated that the U mineralization in the Ordos Basin was resulted from mixing between uranium-bearing, oxidizing fluids and hydrocarbon-carrying, reducing fluids. The occurrence of both analcime and U mineralization in the lower Zhiluo Formation makes us question whether there is a connection between the two. The aims of the present study are to (i) report the occurrence of analcime in coal and discuss the sedimentary environment that leads to analcime authigenesis in coal, (ii) find the potential linkage between analcime formation and U mineralization, providing insights into the geological settings of U accumulation in the study area.

2. Geological setting

The Ordos Basin is located to the west of the Northern China Platform (Dai et al., 2006). This platform, which is dated from the Precambrian, provided a stable setting upon which Cambrian and Middle Ordovician marine rocks were deposited (Johnson et al., 1989). It extends across five provinces in northern China (i.e., Shaanxi, Gansu, Ningxia, Inner Mongolia, and Shanxi, Fig. 1), covering an area of approximately 250,000 km^2. The Ordos Basin is surrounded by the Yinshan mountains to the north, the Qinling mountains to the south, the Helan and Liupan mountains to the west, and the Lvliang mountains to the east (Yuan et al., 2007; Zhang et al., 2018 and references therein). Controlled by the basement configuration, the Ordos Basin can be subdivided into six structural domains, including Yimeng uplift, Weibei uplift, Jinxi fault-fold Belt, Shanbei slope, Tianhuan depression, and the western thrust-fault belt (Luo et al., 2007). The study area is located on the northeastern margin of the Ordos Basin (Fig. 1).

As the second largest sedimentary basin in China, the Ordos Basin is well known for its vast coal, oil, gas and uranium resources (Akhtar et al., 2017 and references therein, Fig.1). There are three sets of coal-bearing sequences in the Ordos Basin: Carboniferous-Permian, Triassic, and Jurassic (Wang, 1996). The Carboniferous-Permian coal seams, which are widely distributed throughout the whole basin, mainly occur in the Taiyuan and Shanxi Formations. The Triassic coal seams mainly occur in the Wayaobao Formation and are distributed in Hancheng,

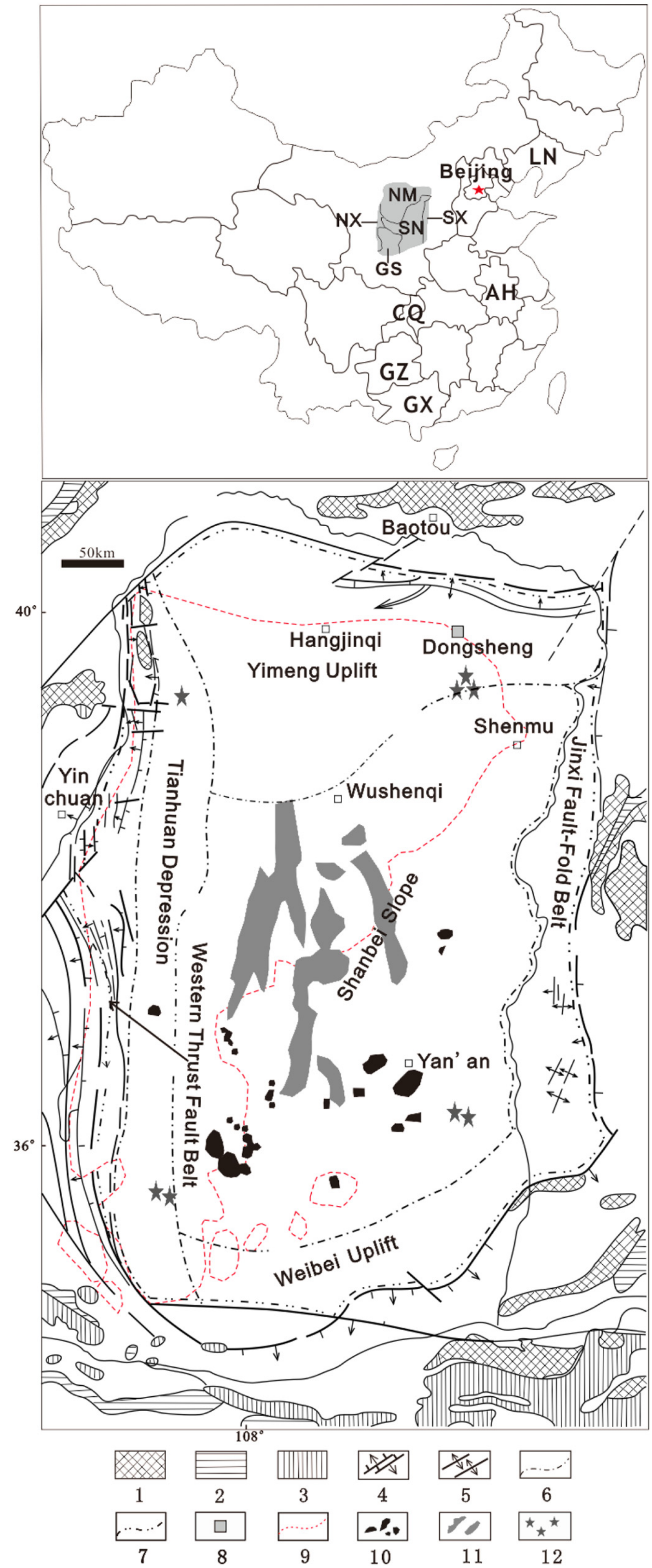

Fig. 1. Tectonic division of the Ordos Basin and locations of study area (1. Archean; 2. Lower Proterozoic; 3. Upper Proterozoic; 4. Normal fault, Reverse fault; 5. Anticline, Syncline; 6. Tectonic unit boundary; 7. Basin boundary; 8. Study area. 9. Mesozoic coal[a]; 10. Oil field[b]; 11. Gas field[b]; 12. Uranium deposit[b]. NM: Inner Mongolia; NX: Ningxia; SN: Shaanxi; SX: Shanxi; GS: Gansu; AH: Anhui; CQ: Chongqing; GX: Guangxi; GZ: Guizhou; LN: Liaoning). Modified from Luo et al. (2007). [a] from Yang et al., (2010); [b] from Akhtar et al., (2017).

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