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Origin of a kaolinite-NH_4-illite-pyrophyllite-chlorite assemblage in a marine-influenced anthracite and associated strata from the Jincheng Coalfield, Qinshui Basin, Northern China

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ABSTRACT

The coal from the Jincheng Coalfield, Qinshui Basin, is a medium- to low-ash yield anthracite. The mineral assemblage in the anthracite is dominated by NH_4-illite and kaolinite; with varying proportions of pyrophyllite, chlorite, pyrite, and calcite; and minor anatase, rutile, diaspore, florencite, and synchysite. Kaolinite formed during early diagenetic and epigenetic processes has been largely altered to other phyllosilicates by processes associated with the different stages of coal rank advance. The formation of NH_4-illite in the Jincheng coals is the result of illitization of an early diagenetic kaolinite precursor by interaction of kaolinite with nitrogen derived from organic matter. This reaction may have occurred at the latest stage of bituminization (subbituminous to bituminous transition). Pyrophyllite was produced by the interaction of kaolinite and quartz formed by metamorphic processes associated with anthracitization. Cookeite is relatively common in the studied coals. It may have been derived from the reaction of kaolinite with Li ions, although the source of Li is not yet clearly understood.

Minerals in the non-coal samples (partings and floor strata) appear to have responded differently to the metamorphic conditions than those in the adjacent coals. Possible mechanisms for the formation of NH_4-illite in the Jincheng non-coal rocks at least involve isomorphous substitution of NH_4 for K in the K-illite structure. The well-crystallized K-illite in the non-coal rocks probably formed from detrital K-illite, and wasrecrystallized with the coal rank advance. Absence or minor proportions of pyrophyllite in non-coal samples may be due to a lack of epigenetic kaolinite in the non-coal horizons. Pyrophyllitization occurred during a late stage of metamorphism. The general absence of chlorite in the thick non-coal interval is probably due to the low permeability of that horizon, which resulted in a lack of infiltrating Fe- and Mg-bearing fluids.

1. Introduction

The inorganic constituents in coals and associated rocks that have been subjected to metamorphic conditions generally show different mineral assemblages from that of the correlative lower-rank coal seams. A series of authigenic minerals may occur, but not necessarily exclusively, in higher-rank coals, typically NH_4-illite, illite/smectite, illite, chlorite, chlorite/smecitite, and pyrophyllite (e.g. Daniels and Altaner, 1990; Uysal et al., 2000b; Hower and Gayer, 2002; Susilawati and Ward, 2006; Permana et al., 2013). Subject to the metamorphic conditions, such as temperature, availability of ions, pH value, and heating time, various mineral assemblages may also be present in different higher-rank coals. The presence of these minerals in coals and adjacent rocks, and also their crystallinity (e.g. illite, chlorite), generally increase with rank advance (e.g. Uysal et al., 2000a; Bayan and Hower, 2012). Pyrophyllite, which occurs in very low-grade metamorphic rocks (e.g. Velde, 1968; Frey, 1970; Brattli, 1997), has also been noticed in anthracitic coals in some areas (e.g. Daniels and Altaner, 1990). Frey (1978), among others, has regarded pyrophyllite as an index mineral for the anchizone (very low-grade metamorphism/sub-greenschist facies) in very low-grade metamorphic rocks.

The Qinshui Basin (Fig. 1) is host to one of the most important

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Fig. 1. Locality map showing the Qinshui Basin and the Wangtaipu mine in the Jincheng Coalfield.

coalbed methane reservoirs in China, and also the largest region for commercial development of coalbed methane (Liu et al., 1998). The SE Qinshui Basin, which contains semi-anthracite and anthracite with vitrinite reflectance of 2.2 to 4.5%, is a favourable district for coalbed methane exploration and development (Su et al., 2005; Lv et al., 2012). Coal deformation is minor in most areas of the SW Qinshui Basin (Su et al., 2005). Although many studies have been published on the geology of coalbed methane in the Qinshui Basin, there are few detailed mineralogical studies on the coal from the anthracite region. Most mineralogical studies in the Qinshui Basin are concerned with the non-coal strata adjacent to the coal (Liang et al., 1996, 2005; Liu et al., 1996). A recent study by Zheng et al. (2016) focused on the mineralogical and geochemical characteristics of NH_4-illite in the partings of coal seams in some of the mines from the Qinshui Basin.

The present study examines the distribution and association of minerals, especially authigenic clay minerals, in anthracite and associated rock strata within the basin. Such a study has allowed evaluation of processes associated with the formation of minerals during coal rank advance, especially during anthracitization. It also provides important information about the depositional conditions and diagenetic history of coal-bearing sequences, and thus could provide important information for understanding the generation of coalbed methane in this region.

2. Geological setting of the Jincheng Coalfield

The Jincheng Coalfield is located in the SE Qinshui Basin, North China (Fig. 1). The strata in the Jincheng Coalfield dip to the northwest at < 10°. Faults are seldom developed in this area (Li et al., 2010). The coal-bearing strata in the coalfield include the Upper Carboniferous Benxi and Taiyuan Formations, Lower Permian Shanxi and Xiashihezi Formations, Upper Permian Shangshihezi and Shiqianfeng Formations, and Triassic strata (Meng, 1995; Su et al., 2005).

The Pennsylvanian Taiyuan and Shanxi Formations are the two main coal-bearing units (Fig. 2), and average 150 m in total thickness (Su et al., 2005). The Taiyuan Formation was mainly deposited in a lagoonal and carbonate platform environment (Liu et al., 1998; Su et al., 2005; Li et al., 2017). The Taiyuan Formation in the coalfield consists mainly of siltstone, mudstone, limestone, and up to 11 coal seams, with a fine quartz sandstone occurring in the lowermost part of the formation.

The major coal seam, the No. 15 coal in the lower part of the Taiyuan Formation, has a thickness of 1.2–4.7 m. The coal seam has a mudstone floor, and contains up to seven partings (though mainly one

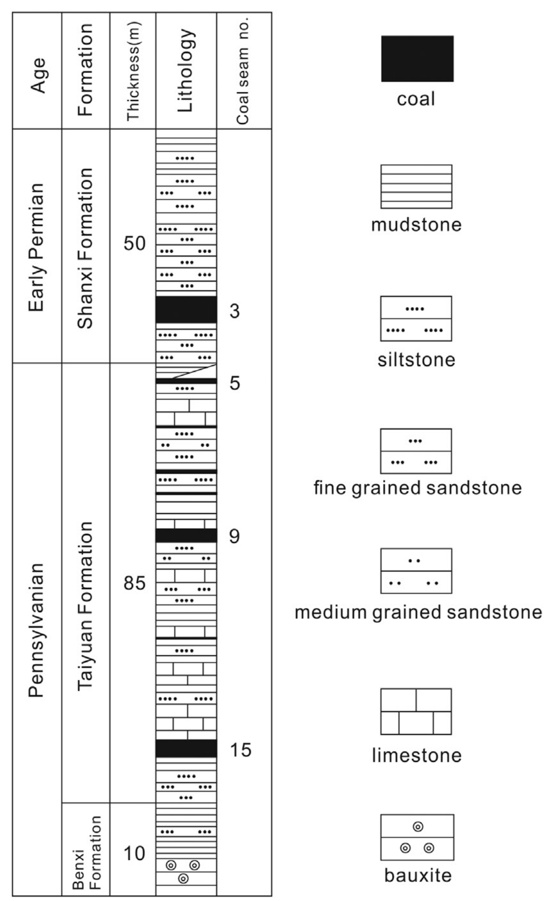

Fig. 2. Stratigraphic section through the Jincheng Coalfield (Meng, 1995).

to three partings in most areas), with the total thickness of the partings varying from 0.01 to 1.57 m. The roof of the No. 15 coal seam is a widespread thick limestone, with an average thickness of 10 m.

The Lower Permian Shanxi Formation has a thickness varying from 40 to 80 m, with an average thickness of 50 m. It mainly consists of fine to medium sandstone, siltstone, mudstone, and 1 to 3 coal seams, all of which were deposited in a deltaic environment. The No. 3 coal is the major mineable coal seam in the Shanxi Formation. Among all the coal