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Mineralogical composition of Late Permian coal seams in the Songzao Coalfield, southwestern China

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ABSTRACT

Coals from three seam sections in the Songzao Coalfield, SW China, are mainly high-ash, high-sulphur semianthracites. Minerals within the Songzao coals are mainly kaolinite, pyrite (or marcasite in some cases), and quartz, with various proportions of non-kaolinite clay minerals, carbonates, feldspars, and anatase. The illite and mixed-layer illite/smectite (I/S) are Na-rich in some of the Datong coal samples. The I/S in the lower coals of the Datong section is most likely an alteration product of dispersed volcanic ash, due to the availability of necessary ions (e.g. K, Na, and Mg) in the marine-influenced coal swamp. Organically-bound Na, which was expelled from the organic matter with coal rank advance, especially with anthracitization, may have supplied additional Na for the formation of Na-rich illite. Authigenic I/S also occurs in a Tonghua coal ply that is overlain by a mafic bentonite and underlain by an alkali tonstein. Potassium, Na, and Mg for the formation of such I/S were probably derived from the leaching of the adjacent alkali tonstein and mafic bentonite. Although the marine water was also a possible supplier of the alkali elements, authigenic I/S is rare in coal plies that occur further away from the altered volcanic layer. Leaching of the volcanic claystones in the Tonghua coal seam probably led to the formation of relatively abundant anatase and rhabdophane in the underlying coal ply. Fracture-filling REE minerals (probably REE-hydroxides or oxyhydroxides) also occurring in that coal ply crystallized from ascending REE-rich hydrothermal fluids, probably associated with contemporaneous volcanic activity.

1. Introduction

Knowledge of the mineral matter in coal is of great significance in solving industrial problems, including difficulties associated with materials handling, boiler erosion, ash formation, and slagging, in coal processing or utilisation (e.g. Gupta et al., 1999; Ward, 1984). Knowledge of the mineral matter is also important in understanding the inorganic processes associated with coal formation (e.g. Finkelman, 1994; Ward, 2002), and thus provides important information about the depositional conditions and the geological history of coal-bearing sequences, along with the regional sedimentary and tectonic history (e.g. Ren, 1996; Ward, 2002).

Intra-seam clayrock layers with a volcanic ash origin are common in coal-bearing sequences, and have been described as tonsteins or bentonites in the literature, such as the many publications referred to herein. Leaching of tonsteins or the precursor volcanic ash by ground waters and organic acids in the peat-forming environment would be expected to result in enrichment of some elements that were released from the ash and accumulated as minerals in the coal (e.g. Crowley et al., 1989; Hower et al., 1999). The occurrence of such minerals may therefore be indicative of volcanic influence during peat accumulation and coal formation. Although the actual definition of tonsteins is still regarded in some cases as controversial, Spears (2012), among others, define tonsteins as "thin, widespread clay-altered layers of volcanic ash, dominated by kaolinite, that are commonly found in coals and associated sediments". Following Lyons et al. (1994) and Spears (2012), claystones of volcanic ash origin with a kaolinite content greater than 50% are regarded as tonsteins in this paper. Likewise, the claystones are referred to as bentonites and K-bentonites, respectively, when smectite or mixed-layer illite/smectite (I/S) exceeds 50% of the clay mineral assemblage.

Altered volcanic claystones or tuffs are widespread in the Permian strata of SW China (e.g. Dai et al., 2011; Wang et al., 2012; Zhou and Ren, 1994; Zhou et al., 2000). Although the geochemistry of many Late Permian coal tonsteins throughout the world indicates an origin from silicic to intermediate volcanic ash fallout (e.g. Kramer et al., 2001; Spears and Kanaris-Sotiriou, 1979; Zhao et al., 2012; Zhou et al., 1982; Zielinski, 1985), alkali tonsteins that developed in the early part of the Late Permian in SW China have also been reported (Zhou, 1999; Zhou and Ren, 1994; Zhou et al., 2000). Dai et al. (2011) recently distinguished three types of tonstein bands (silicic, mafic, and alkali) in the

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Songzao Coalfield, SW China, based on the distinctive chemical compositions of the materials.

This study discusses the modes of occurrence of the mineral matter and trace elements in the coal and associated non-coal strata from three individual seam sections in the Songzao Coalfield. The main purpose of the study was to investigate more fully the mineral assemblages in the volcanic-influenced coal seams in the Songzao Coalfield. The study was also expected to provide an opportunity to evaluate the geological factors responsible for the mineralogical characteristics of the coal seams, especially the relationship between the coals and intra-seam volcanic claystone bands.

2. Geological setting

The Songzao Coalfield is located in Qijiang County, SW Chongqing (Fig. 1). It is 39.5-km long (S–N) and 1.1-11-km (E–W) wide, with a total area of 140.8 km^2. It includes eight mines, the Datong, Yuyang, Shihao, Songzao, Tonghua, Fengchun, Zhangshiba, and Liyuanba mines (Fig. 1). The coalfield is located on the northwestern flanks of the Jiudianya, Jiulongshan, and Sangmuchang anticlines. The main structures within the Songzao Coalfield are three folds (Fig. 1). Faults are minor, and only those associated with the main folds affect mining conditions.

The coal-bearing sequence in the Songzao Coalfield is the Late Permian Longtan Formation, consisting (from base to top) of limestone, sandstone, silty mudstone, mudstone, coal seams, and tuffaceous sediments (Fig. 2). This unit was deposited in a tidal flat system along the western margin of an epicontinental sea basin (e.g. Dai et al., 2010). The Kangdian Oldland in the west was the major sediment source for the coalfield (China Coal Geology Bureau, 1996). The coal-bearing sequence has an average thickness of 71.8 m. The strata contain 6–11 coal seams, among which the No. 8 coal is workable through the entire coalfield and the Nos. 6, 7, 8, 11, and 12 are locally workable. The Longtan Formation is disconformably underlain by the Maokou Formation, which is a limestone unit of Early Permian age. The Longtan Formation is conformably overlain by the Late Permian Changxing Formation, which is composed mainly of thick layers of limestones intercalated with thin layers of mudstones and rich in marine fossils.

3. Sampling and analytical techniques

A total of 24 coal and non-coal samples (channel samples) were collected from three seam sections taken at the underground working faces of three operating coal mines in the Songzao Coalfield, namely, the Datong (No. 7 coal), Tonghua (No. k2b coal), and Yuyang (No. 11 coal) mines (Fig. 1). The individual samples from these sections were differentiated from each other on the basis of their megascopic lithology (Fig. 3).

Epoxy-mounted block samples were made from chips representing each coal and non-coal sample for petrographic and/or electron microscope/microprobe analyses. Each sample was also ground to fine powder (about 200 mesh) using a zirconia mill, and split into representative portions for further analyses. Proximate analysis was carried out for the Songzao coals at SGS Australia Pty Ltd. Forms of sulphur were analysed for selected coal samples. This was partly to investigate the forms of sulphur in the coals, and partly to cross check the mineralogical data, especially the percentages of pyrite and sulphate minerals.

Low-temperature oxygen-plasma ashing was carried out on the powdered coal and non-coal samples. The resultant low-temperature ashes (LTAs) were subjected to X-ray diffraction (XRD) analysis, using a Philips PW 1830 diffractometer system with Cu-Kα radiation and a graphite monochrometer, and with a tube voltage of 40 kV and current

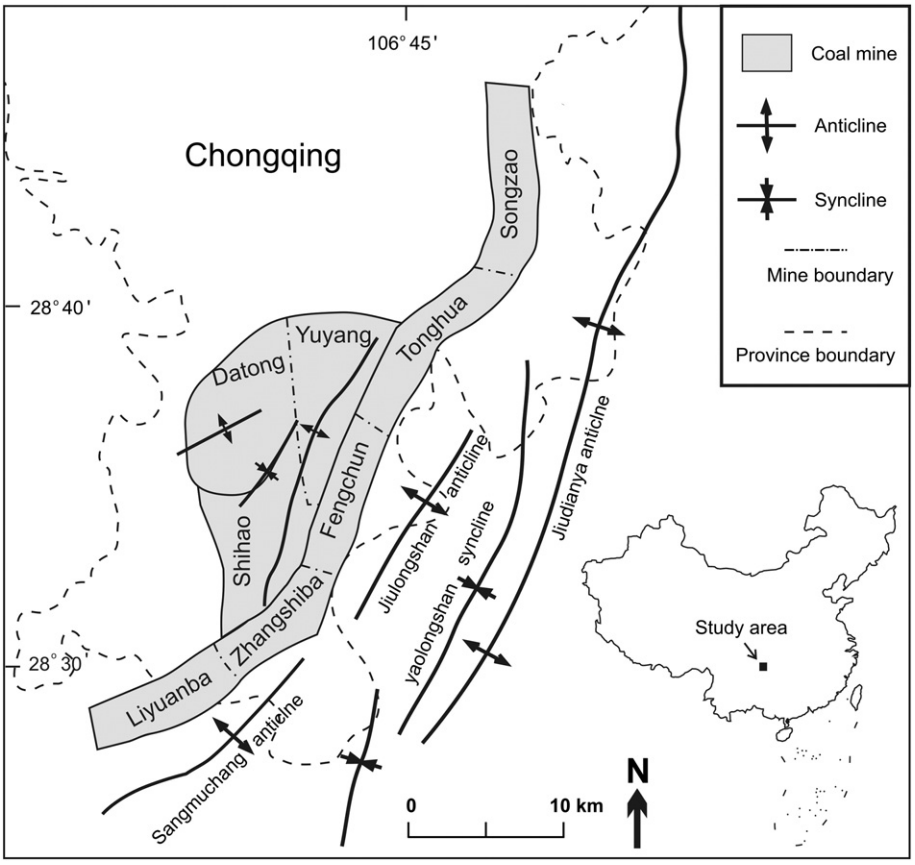

Fig. 1. Locality map of the Songzao Coalfield, China, with indication of mining areas and main structures (modified from unpublished Songzao Coalfield data).