International Journal of Coal Geology 88 (2011) 135–146

Contents lists available at SciVerse ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/ijcoalgeo

Influences of igneous intrusions on coal rank, coal quality and adsorption capacity in Hongyang, Handan and Huaibei coalfields, North China

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ARTICLE INFO

Article history:
Received 10 June 2011
Received in revised form 2 September 2011
Accepted 3 September 2011
Available online 10 September 2011

Keywords:
Igneous intrusion
Coal
Coalbed methane
Adsorption capacity
North China

ABSTRACT

Localized igneous intrusions with varying types of intrusion patterns were found in the Pennsylvanian–Permian coals in north China. Five typical patterns, including dike cut-through (pattern-I), dike cut-in (pattern-II), floor intrusion by sill (pattern-III), roof intrusion by sill (pattern-IV) and dual intrusions of roof and floor by sills (pattern-V), were investigated at five different underground profiles. It was found that the influence of localized intrusions on rank, petrology and coal quality characteristics are mainly related to the emplacement temperature, the style of heat transfer (convection or conduction), the intrusion forms (dike or sill) and size, the distance from the contact and the thermal properties of the surrounding rocks at the contact of the intrusion. Among the five patterns, only pattern-V was found to have two distinct contact metamorphic aureoles within a distance of 1–2 times of the thickness of the intrusion, whereas patterns I through IV show wave-like profiles of vitrinite-reflectance, ash and volatile matter. This resulted from the typical characteristics of "multiphasic and superimposed thermal metamorphic evolution" of north China coals. Except for the heat conduction by intrusion contact, the hydrothermal convection and tectonic-heat played important roles in heat transfer away from dike/sill. Intrusion-induced coal changes including coal rank, organic/inorganic composition and pore properties work together to influence the adsorption capacity of coals. The effect of intrusion upon the adsorption capacity of altered coals is related to the values of their altered coal ranks. Adsorption capacity is elevated from the Langmuir volume (VL) of 7.6 (pre-intrusion) to 17.5 m^3/t (post-intrusion) for altered bituminous coals and semi-anthracites with VRr<2.1%. In contrast, the adsorption capacity is moderately reduced from background levels of about 27.2 m^3/t to about 19.3 m^3/t for altered semi-anthracites and anthracites with VRr of 2.1%–3.4%. Adsorption capacity is significantly reduced (<5 m^3/t) for altered anthracites and meta-anthracites with VRr of >3.4%, because of the accumulation of coal basic structure unit and distinctly decreasing pores. The relationships between altered coal rank and adsorption capacity are different for different coals, which is mainly due to changes of pore characteristics and coal structures resulting from three important coalification jumps during contact and/or other heat metamorphism.

1. Introduction

Many key coalbed methane (CBM) basins such as the San Juan and Raton basins in the USA, the Gunnedah basin in Australia, and the Qinshui and Fuxin basins in China, have undergone contact metamorphism or thermal maturation directly or indirectly related to igneous intrusions (Cooper et al., 2007; Gurba and Weber, 2001). The igneous intrusions may have positive or negative effects on the generation and accumulation of methane gas, the physical properties of in-situ coal reservoirs and even the development of CBM (Johnson and Flores, 1998). However, studies on the influences of localized intrusions on coalbed methane reservoirs are still insufficient.

Igneous intrusions can influence the rank, type, petrographic, geochemical and stable isotopic features of coals and change the style of microstructure development in coal beds (e.g., Barker et al., 1998; Dai and Ren, 2007; Finkelman et al., 1998; Gröcke et al., 2009; Rimmer et al., 2009; Sarana and Kar, 2011; Schimmelmann et al., 2009; Singh et al., 2008; Stewart et al., 2005; Yang et al., 2011). They can also impact the CBM potential in sedimentary basins. For example, Gurba and Weber (2001) indicated that two igneous sills in the Gunnedah Basin had positive effects on the gas content and gas composition of CBM. More recently, Saghafi et al. (2008) indicated that the heating effect of a dike had enhanced not only the adsorption and porosity of metamorphosed coals, but also the gas diffusivity and trap capacities of gas storage. In the Illinois Basin, intrusion dikes changed the coal mesopore and pore properties that may have negative effects on gas migration in coal beds adjacent to the dike due to the decrease of porosity and surface area (Mastalerz et al., 2009). Few studies, however, have focused on the effects of igneous intrusions on coal in the context of different types of intrusion patterns, although these patterns are considered to be important (Murchison, 2005). In addition, as far as we know, no investigation has been conducted on

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doi:10.1016/j.coal.2011.09.004

the thermal influence of intrusion patterns to the change of adsorption capacity of coals in north China.

Various patterns of igneous intrusions have been documented in the late Palaeozoic coal-bearing strata in north China. The influences of these igneous intrusions on the exploration and exploitation of CBM in coalfields have not been adequately studied. For simplicity purposes, we describe five typical dike/sill patterns in the igneous intrusions at five underground profiles in the Hongyang, Huaibei and Handan coalfields, north China (Fig. 1). The five coalbed intrusion patterns are: dike cut-through (pattern-I, Fig. 2), dike cut-in (pattern-II, Fig. 3), floor intrusion by sill (pattern-III, Fig. 4), roof intrusion by sill (pattern-IV, Fig. 5) and dual intrusions of roof and floor by sills (pattern-V, Fig. 6). The characteristics of these patterns are given in Table 1. The aim of this study is to investigate the effects of these intrusion patterns on coal metamorphism, coal quality and methane adsorption capacity.

2. Methodology

2.1. Geological settings

The late Palaeozoic coals in north China are very important for both coal and CBM resources. In contrast to most coals in other coal-bearing basins in the world, north China coal is well known for its metamorphic complexity resulting from Meso-Cenozoic igneous intrusions, which has been described as "multiphasic and superimposed thermal metamorphic evolution" (Yang et al., 1988). The north China coals have commonly undergone three metamorphic stages, resulting in high coal ranks. In the first stage, the geothermal metamorphism increased coal rank to high volatile bituminous (HVB) with random vitrinite reflectance (VRr) of 0.8%–1.1%. In the second stage, hydrothermal metamorphism caused the coal rank to increase to low volatile bituminous coal (LVB) through semi-anthracite to meta-anthracite. In this stage, the hydrothermal metamorphism mainly resulted from multiple episodes of magma intrusion during the Jurassic–Cretaceous Yanshanian Orogeny. In the last stage, Tertiary tectonic events created local coal metamorphic zones in north China. Of these tectonic and igneous events, the Cretaceous igneous intrusions had constructive influences on CBM generation, accumulation, and improvement of permeability of CBM reservoirs, which has been confirmed in two commercial CBM basins, i.e. the Qinshui and Fuxin basins.

The Cretaceous igneous intrusions associated with the Yanshanian Orogeny had multiple episodes and orientations (Yang et al., 1988). Taking the Handan coalfield as an example, igneous events, diorite and syenite intrusions were superimposed early and late in the Yanshanian Orogeny, respectively. In addition, igneous intrusions were distributed mainly along six latitudinal tectonic zones. From north to south, the Hongyang coalfield in Liaoning Province, Handan coalfield in Hebei Province, and Huaibei coalfield in Anhui Province are located in three different latitudinal tectonic zones, i.e. the latitudes 41°–42°30′, latitudes 36°–37° and latitudes 34°–35° tectonic zones, respectively (Fig. 1).

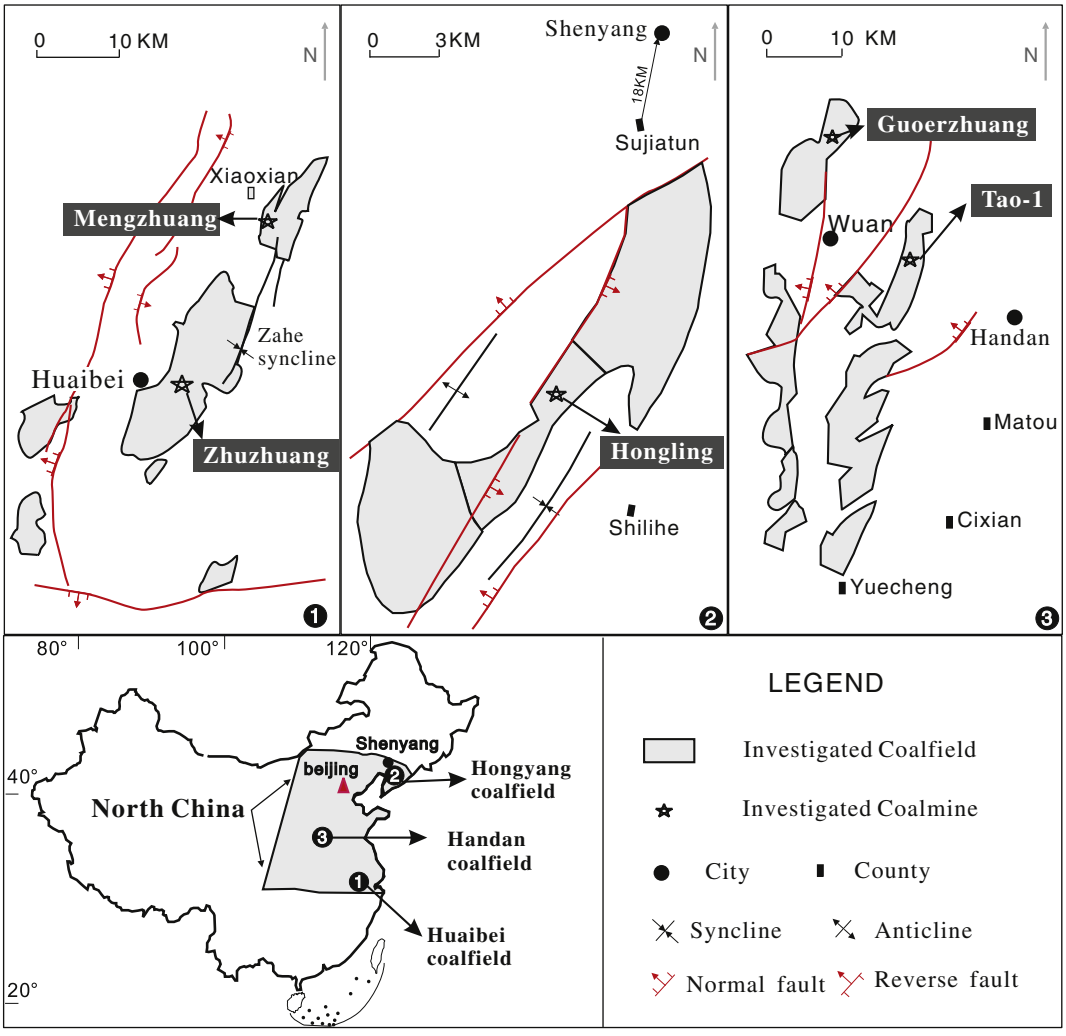

Fig. 1. Map showing five investigated coal mines in the Hongyang, Handan and Huaibei coalfields.