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Changes in optical properties, chemistry, and micropore and mesopore characteristics of bituminous coal at the contact with dikes in the Illinois Basin

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ABSTRACT

Changes in high-volatile bituminous coal (Pennsylvanian) near contacts with two volcanic intrusions in Illinois were investigated with respect to optical properties, coal chemistry, and coal pore structure. Vitrinite reflectance (R_o) increases from 0.62% to 5.03% within a distance of 5.5 m from the larger dike, and from 0.63% to 3.71% within 3.3 m from the small dike. Elemental chemistry of the coal shows distinct reductions in hydrogen and nitrogen content close to the intrusions. No trend was observed for total sulfur content, but decreases in sulfate content towards the dikes indicate thermochemical sulfate reduction (TSR). Contact-metamorphism has a dramatic effect on coal porosity, and microporosity in particular. Around the large dike, the micropore volume, after a slight initial increase, progressively decreases from 0.0417 cm^3/g in coal situated 4.7 m from the intrusive contact to 0.0126 cm^3/g at the contact. Strongly decreasing mesopore and micropore volumes in the altered zone, together with frequent cleat and fracture filling by calcite, indicate deteriorating conditions for both coalbed gas sorption and gas transmissibility.

1. Introduction

Coals affected by igneous intrusions are relatively common and have been described from many localities worldwide. Physical and chemical effects of intrusion on coal vary depending upon heat exposure, time of igneous emplacement, pressure, hydrology, as well as coal rank, lithology of the surrounding rocks and other local factors. The zone of affected coal depends on the temperature of the intrusion and the size of the intruding body (Crelling and Dutcher, 1968; Bostick and Pawlewicz, 1984). Although the extent of the altered zone is usually close to the thickness of the intrusion (Gurba and Weber, 2001; Cooper et al., 2007), this may vary significantly depending on the type of intruding material and local emplacement conditions (Murchison, 2005), ranging from the fraction of the thickness of the intrusion (Mastalerz and Jones, 1988; Raymond and Murchison, 1988; Murchison and Raymond, 1989) to over several times the intrusion thickness (Jones and Creaney, 1977).

Typical optical changes in coal caused by intrusion involve microbrecciation, disappearance of liptinite macerals, increase in vitrinite reflectance, development of devolatilization vacuoles, coke texture, and the presence of pyrolytic carbon (e.g., Kisch and Taylor, 1966; Jones and Creaney, 1977; Goodarzi and Cameron, 1990). These alterations are accompanied by chemical changes in coal such as a decrease in hydrogen and nitrogen contents (Thorpe et al., 1998) as well as changes in inorganic geochemistry (Ward et al., 1989; Finkelman et al., 1998; Golab and Carr, 2004).

Intrusions into Pennsylvanian coals in the Illinois Basin are rare and, therefore, few studies are available (Clegg, 1955; Stewart et al., 2005). A temperature of ~600 °C has been suggested for a ~10-m-thick peridotite dike intersecting the Springfield Coal Member in Illinois, where the altered coal zone has been estimated to be 1.2-times thicker than the thickness of the intrusion (Stewart et al., 2005). In this paper, we discuss contact-metamorphic changes in the Springfield Coal in Illinois (Fig. 1), in a location close to that described by Stewart et al. (2005). In addition to chemical and optical changes resulting from intruding magma, we discuss changes in mesopore and micropore characteristics and their implications for the gas content in the coal.

2. Methods

Freshly exposed, unweathered coal was sampled several days after the dikes were discovered by underground mining activity. One dike was up to 1.2-m-thick (termed “small dike” in this paper), whereas the other was significantly larger (termed “large dike”);the large dike had not been penetrated, and only one of its margins could be observed in the mine. Samples of coal were collected close to each dike and identified in terms of their distance from dike contacts (Fig. 2).

Data for vitrinite reflectance (R_o), proximate and ultimate analyses, sulfur speciation, and pore characteristics are listed in Table 1 for

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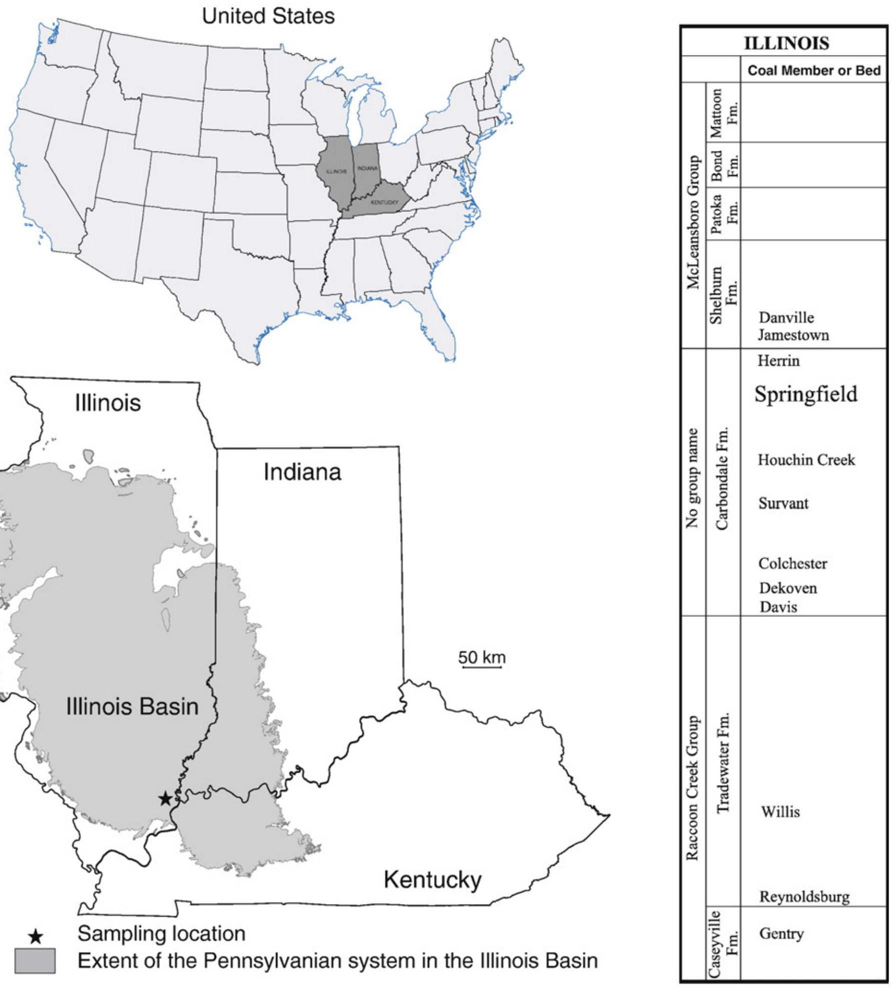

Fig. 1. Location of the dikes on the extent of the Pennsylvanian System in the Illinois Basin and lithostratigraphic position of the affected coal bed (Springfield).

samples from the vicinity of the large dike, whereas R_o and pore characteristics for the small dike are shown in Table 2. Proximate and ultimate analyses followed ASTM standards (ASTM, 2007).

Porosity characteristics include BET specific surface area, BJH mesopore volume, mesopore size, D-R micropore surface area, D-A micropore volume, and micropore size. Definitions of these parameters are given in Gregg and Sing (1982). All of these parameters were determined using an ASAP 2020 porosimeter. Mesopore characteristics were determined using nitrogen gas as the adsorptive at the boiling point temperature of liquid nitrogen (77.35 K at atmospheric pressure), whereas micropore volume, micropore specific surface area, and micropore size distribution were determined using low-pressure CO_2 at 273 K.

3. Results and discussion

The two peridotite-type dikes that intersected the coal were mostly dark brown with some light grey sections (Fig. 3A). Not all their boundaries could be observed; those that were accessible were irregular and some pockets of mixed coal/peridotite material was present in the vicinity of all contacts.

3.1. Changes in optical properties of coal

Unaltered coal samples, #15 from the large dike and #2 from the small dike (Fig. 2), are of high-volatile B bituminous rank with R_o of ~0.6% (Tables 1, 2). Petrographically, they are high in vitrinite (Fig. 3B), which is typical of the Springfield Coal in general (Mastalerz et al., 2004). Liptinite is represented dominantly by sporinite and, rarely, cutinite (Fig. 3C), and inertinite is dominated by semifusinite and, rarely, fusinite. Coals in close vicinity to the intrusions show clear indications of thermal alteration expressed by the absence of liptinite macerals (Fig. 3D–F), development of devolatilization vacuoles in vitrinite and inertinite (Fig. 3D, E), "strain anisotropy" (Fig. 3F), and abundance of carbonates in the form of veins or cell fillings (Fig. 3G). Coal directly at the contact with the large dike only occasionally developed fine-grained mosaic texture, but failed to develop typical natural coke texture, high anisotropy, or pyrolytic carbon. In the coal at the contact with the small dike, mosaic texture was not observed at all.

The absence of liptinite macerals indicates that the temperature of coal at the intrusion contact was >300 °C. Liptinite macerals undergo devolatilization and vitrinization shortly above 300 °C (Mastalerz and Mastalerz, 2000). The absence of well-developed coke texture, on the other hand, suggests that the temperature did not exceed 500 °C (Taylor, 1961; Brooks and Taylor, 1965) because coke texture is diagnostic for bituminous coal carbonization at 500 °C and higher. However, the occasional development of a very fine-grained mosaic texture at the contact with the large dike suggests that the maximum temperature was close to 500 °C. Temperatures of 320 °C for the small dike and 360 °C for the large dike were calculated from R_o using the equation of Barker and Pawlewicz (1994) and appear to underestimate the actual temperatures reached during contact metamorphism, perhaps because R_o expresses limited reliability as a geothermometer