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Effects of rapid thermal alteration on coal: Geochemical and petrographic signatures in the Springfield (No. 5) Coal, Illinois Basin

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ABSTRACT

Igneous intrusion into a coal bed can change the geochemical and petrographic properties of the coal including vitrinite reflectance, maceral petrographic composition, optical texture, mineralogy, stable isotope composition, trace element composition, and bulk geochemistry. The intent of this study was to evaluate petrographic and geochemical changes in an intruded coal and compare them to trends seen in coals altered by normal burial maturation, thereby evaluating whether or not the intruded coals followed a different maturation pathway. The current study reports petrographic, bulk geochemical (proximate, ultimate), Leco total organic carbon (TOC), and Rock-Eval pyrolysis data for a suite of samples from the Springfield (No. 5) Coal (Pennsylvanian, Desmoinesian) in the southern part of the Illinois Basin where the coal had been intruded by a Permian-age peridotite dike.

Petrographic analysis shows an increase in vitrinite reflectance (R_m) from background levels of 0.55–0.63% up to ~4.80%, a loss in ability to differentiate liptinite macerals, formation of isotropic coke and, at the dike/coal contact, development of fine-grained mosaic anisotropic coke texture. Volatile matter (VM) content decreases and fixed carbon (FC) content, ash, and mineral matter (Parr formula) increase approaching the intrusion contact. Carbon increases whereas nitrogen, hydrogen, and oxygen decrease approaching the intrusion. The presence of carbonate minerals (confirmed by X-ray diffraction and petrographic analysis) has a significant impact on proximate and ultimate data. However, even after removal of carbonates, trends for VM vs. R_m, %C vs. R_m, and H vs. C do not follow typical trends associated with normal burial coalification. Approaching the contact, Leco TOC, Rock-Eval free oil content (S_1), remaining hydrocarbon potential (S_2), CO_2 from pyrolysis of the organic matter (S_3), and hydrogen (HI) and oxygen (OI) indices decrease whereas thermal maturity (T_{max}, °C) increases. S_2 vs. R_m and T_{max} vs. R_m diverge from the pathways seen in previous studies of coals that have undergone normal burial maturation.

Geochemical data from this study suggest that the intruded Springfield (No. 5) Coal may have followed a maturation track that differed from that seen under normal burial maturation, perhaps due to the geologically rapid, high heating event associated with the emplacement of the intrusion. It is also suggested here that the natural coke textures produced by this rapid geological heating may differ from those observed for metallurgical cokes produced under standard industrial coking conditions. Typically, in an industrial coke oven, a coal of this initial rank (Ro = ~0.6%) would produce an isotropic coke, rather than the fine-grained circular anisotropic coke seen here. However, as variations in heating rate, duration of heating, maximum temperatures attained, hydrothermal conditions, and pressure are mostly unknown for the intrusive event, it is not unreasonable to suggest that differences in these variables contributed to the higher anisotropy of the coke. Alternatively, the development of this texture may reflect "pre-heating" of the coal during the intrusion event.

1. Introduction

Igneous intrusions can change many properties of coal and organic matter (OM) including vitrinite reflectance, petrographic composition, mineralogy, stable isotope composition, trace element composition, and bulk geochemical properties (Finkelman et al., 1998; Golab and Carr, 2004; Golab et al., 2007; Mastalerz et al., 2009; Rimmer et al., 2009). The effects of igneous intrusions on organic and inorganic constituents in coal have been studied in the USA (e.g., Clegg, 1955; Cooper et al., 2007; Crelling and Dutcher, 1968; Finkelman et al., 1998; Mastalerz et al., 2009; Meyers and Simoneit, 1999; Rimmer et al., 2009; Schimmelmann et al., 2009; Stewart et al., 2005; Thorpe et al., 1998), Australia (Gurba and Weber, 2001; Kisch and Taylor, 1966; Saxby and Stephenson, 1987), Antarctica (Schopf and Long,

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1966), South Africa (Gröcke et al., 2009; Saghafi et al., 2008), China (Dai and Ren, 2007; Dai et al., 2012), and Europe (Murchison, 2004; Pearson and Murchison, 1999). Other studies have focused on the effect of igneous intrusions on organic-rich sedimentary rocks (Aarnes et al., 2011; Clayton and Bostick, 1985; Dennis et al., 1985; Saxby and Stephenson, 1987; Simoneit et al., 1981). Rimmer et al. (2009) provided a useful review of petrographic and geochemical studies of thermally intruded coals/organic matter (OM).

The role of temperature and the duration of heating on the kinetics of thermal alteration of coal/organic matter (OM) have been debated (e.g., Barker and Pawlewicz, 1994; Hood et al., 1975). Rapid alteration of coal due to igneous intrusion may result in different relationships between chemical composition and vitrinite reflectance than occur during burial maturation (Murchison, 2004, 2006; Murchison and Raymond, 1989; Pearson and Murchison, 1999; Rimmer et al., 2009). In the current study, a suite of closely spaced coal samples was collected from the Pennsylvanian-age Springfield (No. 5) Coal at a site in southern Illinois where the coal seam had been intruded by a dike determined to be Permian in age (Fifarek et al., 2001). We present whole-coal petrographic, bulk geochemical (proximate and ultimate analyses), Leco total organic carbon (TOC), and Rock-Eval pyrolysis data and compare trends in these data to those seen for coals that have undergone normal burial maturation. By doing so we will evaluate the hypothesis that accompanying the rank increase, both physical and chemical properties of coal macerals change in response to the rapid thermal alteration associated with an intrusion but that the coals demonstrate a maturation trend that differs from that seen under normal burial maturation conditions.

2. Methods

A series of closely spaced samples was collected approaching a coal/intrusion contact from the Pennsylvanian-age Springfield (No. 5) Coal seam (Carbondale Formation) from a mine in southern Illinois (Fig. 1). The thickness of the dike at this location is unknown as mining stopped once the contact was encountered. Sample numbers (WCM) indicate distance from the intrusion (Table 1): WCM1 was collected at the coal/intrusion (dike) contact and WCM44 was collected from unaltered coal furthest from the dike. In this area, the unaltered rank of the Springfield Coal is high volatile bituminous with localized increases in rank due to intrusion by Permian-age ultramafic peridotite dikes (Fifarek et al., 2001; Mastalerz et al., 2009; Rimmer et al., 2009; Stewart et al., 2005). Due to the extreme hardness of the highly metamorphosed coal adjacent to the intrusion, whole-channel sampling was not possible and, therefore, the coal was collected as "grab" samples. Following removal of rock dust, 44 samples were collected. Samples (100–300 g) were chipped from the coalface into collection bags. The sampling interval close to the intrusion was approximately 0.1 m, increasing to 0.3 m at a distance of approximately 2 m from the contact. The last two samples were collected at approximately 7 and 15 m to assess background levels considerably beyond the alteration halo. Due to limited exposure time of the cut and removal of the exposed coal prior to sampling, the samples were deemed to be unweathered (and subsequent analysis showed no evidence to the contrary). Samples were crushed and sieved to minus 20-mesh for petrographic analysis, minus 60-mesh for geochemical analysis, and minus 100-mesh for Leco TOC and Rock-Eval analysis. A representative split of minus 20-mesh, air-dried coal was

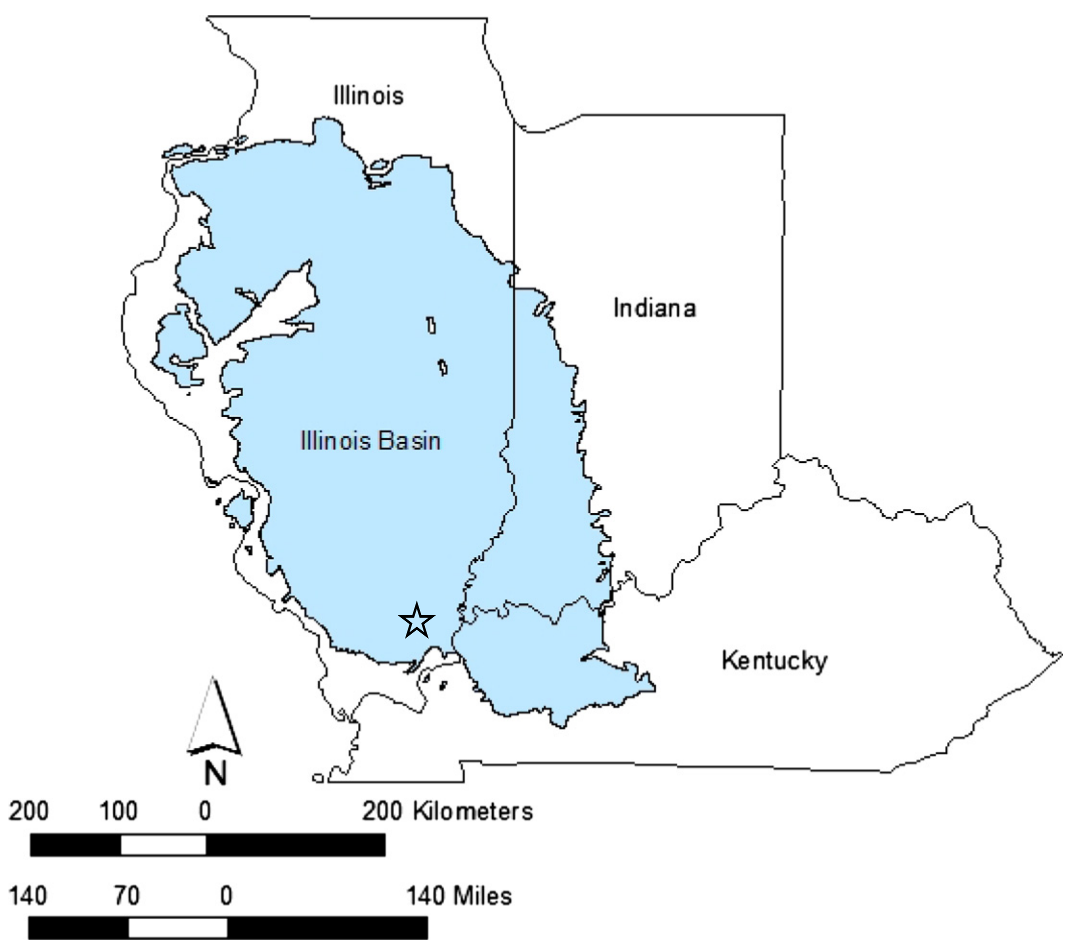

Fig. 1. Sampling location for the intruded coal series, southern Illinois, USA. Shaded area shows the extent of the Pennsylvanian strata.