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Methane contents and coal-rank variability in the Upper Silesian Coal Basin, Poland

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ABSTRACT

The process of coalification results in changes in both the chemical composition and physical properties of the coal. One of the most important stages in the development of bituminous coal is the so called "second coalification jump" corresponding to medium-volatile coals characterized by a significant decrease of volatile matter from 33% to 20% and the release of methane, carbon dioxide and water. In the Upper Silesian Coal Basin (USCB), the highest values of methane content (>12–14 m^3/t coal daf) range from 35–22% (V^{daf}) and vitrinite reflectance (R_r) values from 0.84–1.50% range—in approximate accord with values defining the second coalification jump (V^{daf}—29%; R_r—1.3%), i.e., coking coals. In the basin, the distribution of the top of high methane zone (4.5 m^3/t coal daf) is similar to that of the coking coals. That is why increasing methane contents towards the southern- and western parts of the basin can be explained by the increasing proportion of coking coals there. However, on a basin scale, correlations between present methane contents and individual parameters of coal rank are weak due, most likely, to late gas migration due, in turn, to factors unrelated to earlier coalification including, inter alia, tectonic disturbance and hydrodynamic processes.

1. Introduction

The coalification of humic coals results in changes to the coal inner structure influencing both the chemical composition and physical properties of the coal. Chemically, saturated aliphatic hydrocarbons are gradually replaced by unsaturated aromatic hydrocarbons; liptinite-group components rich in the former gradually disappear in favour of vitrinite group components rich in the latter (e.g., Chen et al., 2012; Kruszewska and Dybova-Jachowicz, 1997; Lu et al., 2001; Speight, 1994; Suárez-Ruiz et al., 2012; Taylor et al., 1998; Thomas, 2002; Vu et al., 2013). Fundamental changes involve a decrease of volatiles (V^{daf}) and atomic H/C with, at the same time, increasing vitrinite reflectance (R_r) (e.g., Kruszewska and Dybova-Jachowicz, 1997; Taylor et al., 1998; Thomas, 2002). The chemical alterations and the decreasing volatiles are reflected in the release of many products of which the most important are methane, carbon dioxide and water (e.g., Alsaab et al., 2008; Kopp et al., 2000; Moore, 2012; Semyrka et al., 1995; Taylor et al., 1998). As humic coals are very heterogeneous, both in terms of maceral content and chemical composition, they are also capable of generating and expelling non-volatile oil (Isaksen et al., 1998). One of the most important stages in the development of bituminous coal is the so called "second coalification jump" corresponding to medium-volatile coals (e.g., Kopp and Harris, 1984; Taylor et al., 1998; Teichmüller, 1989), distinguished by the decay of aliphatic bonds and the expansion of aromatic hydrocarbons in vitrinite macerals and increasing hydrocarbon orientation (e.g., Gao et al., 2012). A distinctive feature of this stage is a significant decrease of volatile matter (V^{daf}) from 33% to 20% caused by the disappearance of liptinite macerals (Kruszewska and Dybova-Jachowicz, 1997; Taylor et al., 1998). These coals are called coking coals due to their thermoplastic properties (Polish technological types 34–37). The rapid decrease in volatiles should be accompanied by an increasing release of gas products, especially methane, as humic coal represents kerogen III (gas forming) and the ending of the second coalification jump coincides with the lower boundary of the oil window stage (e.g., Kruszewska and Dybova-Jachowicz, 1997). Thus, it may be reasonable to presume that coals that have passed through the second coalification jump should have high methane contents.

The Upper Silesian Coal Basin (USCB) is characterized by a diversity of coalbed methane occurrences and a complex pattern of methane quantities in coal seams. There is no clearly-defined link between coal rank and methane content (e.g., Kędzior, 2009; Kotas, 1994). Thus, the aim of this study is to compare the spatial distribution of methane with variations of coal rank as represented by vitrinite reflectance (R_r), volatile contents (V^{daf}) and atomic H/C values so as to assess whether coals with parameters related to the second coalification jump (V^{daf} ~ 29%, R_r ~ 1.3%) are enriched in methane.

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2. Coal characterization and methane occurrence in the USCB

2.1. Geology

The USCB is located in southern Poland and in the Ostrava–Karvina region of the Czech Republic. With an area of ~7400 km^2 (Jureczka and Kotas, 1995; Kędzior, 2009), it is the largest coal basin in Poland and one of the largest in Europe.

The USCB coal deposits occur in four lithostratigraphic series of Carboniferous age (Figs. 1 and 2). In the northern- and eastern parts of the basin, the coal-bearing Carboniferous sequence is covered by Permian, Triassic and Jurassic rocks, mainly clastics but also calcareous-dolomites and limestones. The Carboniferous paleosurface is an irregular erosion surface (Kędzior, 2009). The lowermost part of a thick (100– > 1000 m) overlying Miocene sequence that covers a considerable part of the basin, especially in its central- and southern parts of the basin, comprises clays, conglomerates and claystones (Kędzior, 2009; Kotas, 1990, 1994). Carpathian nappes driven from the south over the Carboniferous rocks partly cover the Miocene sequence (Fig. 1).

The USCB (Fig. 1) is divided into a block-faulted zone in the north, centre and south and a folded zone in the west and south-west. In the block-faulted zone, the large tectonic faults of Bzie-Czechowice, Jawiszowice, Bełk and Kłodnica, with throws of 100–1000 m, are regional structures within the Main Syncline. Of likely Variscan age, these zones were probably reworked during the Alpine orogeny (e.g., Herbich, 1981; Kędzior, 2009; Teper and Sagan, 1995). The main elements in the folded zone are the Boguszowice- and Michalkovice overthrusts and the Jejkowice- and Chwałowice troughs related to tectonic stresses directed from the west (e.g., Kędzior, 2002, 2009; Kotas, 1995).

2.2. Spatial distribution of coal rank

According to Kotas (1971), coalification in the USCB occurred in two main stages:

(a) A preorogenic stage lasting through the period of basin formation in the late Carboniferous. Organic matter was heated during foredeep burial. This stage was completed in the Asturian phase.
(b) A postorogenic stage in Mesozoic- or Paleogene times resulting in coalification associated with heating in a tensional tectonic regime.

The present distribution of coal rank in the USCB was actually produced immediately after tectonic inversion of the basin and before the deposition of brown coals in the Miocene (Jureczka and Kotas, 1995). Apatite fission-track and helium dating, used to provide a temporal framework for coal rank in the USCB, reveal that coalification was mainly controlled by processes related to a deep Variscan burial event. The maximum temperature (90–100 °C) in the uppermost part of the

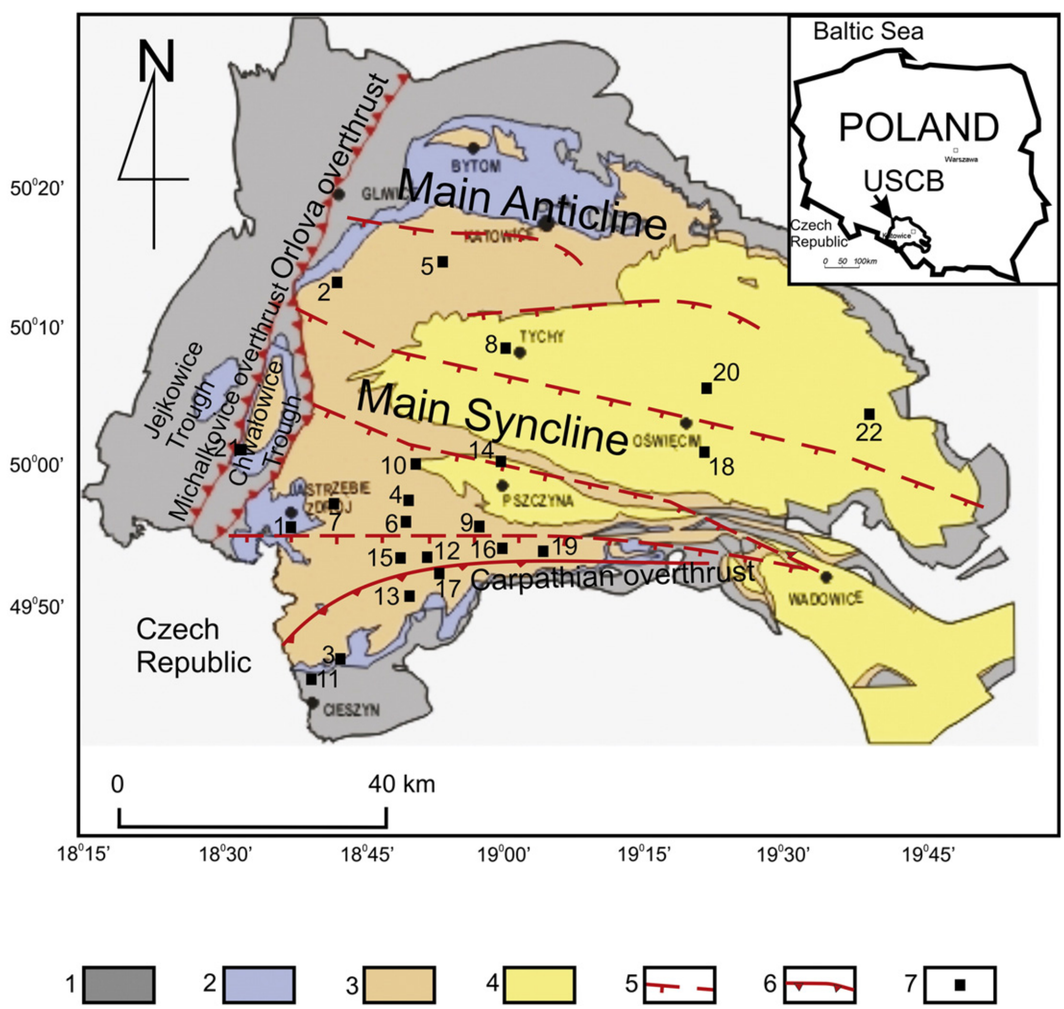

Fig. 1. Lithostratigraphy and tectonics of the USCB. Modified after Kędzior, 2009. 1—Paralic Series (upper Mississippian–lower Pennsylvanian), 2—Upper Silesian Sandstone Series (lower Pennsylvanian), 3—Mudstone Series (lower—middle Pennsylvanian), 4—Krakow Sandstone Series (middle Pennsylvanian), 5—important faults, 6—overthrusts, 7—borehole with number (see Table 1).