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The impact of water-washing, biodegradation and self-heating processes on coal waste dumps in the Rybnik Industrial Region (Poland)

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ABSTRACT

Water-washing, biodegradation and self-heating impacts on coal waste features were investigated on four sample sets: fresh coal wastes (sampled less than one week after dumping), samples from gullies in coal-waste dumps, self-heated material and Bierawka river sediment mixed with coal/coal-waste particles. Rock Eval pyrolysis, petrography and gas chromatography–mass spectrometry (GC–MS) were applied to assess degree of organic-matter alteration. It was found that water-washing and self-heating did not influence the vitrinite reflectance. Rock-Eval pyrolysis results better reflected the secondary changes in organic matter, namely, S_2-TOC and HI-T_{max} allowed their extent to be defined. Changes were noted in other geochemical e.g., *n*-alkane parameters $\Sigma2/\Sigma1$ increased and n-C_{23}/n-C_{31} decreased whereas, Pr/Ph, Pr/n-C_{17} and Ph/n-C_{18} ratios increased slightly compared to fresh coal waste. The Hunt diagram allows discrimination between water-washed- and biodegraded samples from unaltered, fresh coal waste. Similarly, changes in distributions of phenols, alkyl aromatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) reflect degree of water-washing. Self-heating strongly affects distributions of some biomarkers such as *n*-alkanes, Pr, and Ph, whereas pentacyclic triterpane distributions were generally well preserved. Phenols occur in greatest amount in self-heated wastes, probably released from heated vitrinite. Domination of 2–3 ring PAH rings indicated the bitumen precipitation zone and well-differentiated burnt-out wastes. Recent organic-matter input is seen in increased CPI (Carbon Preference Index) values.

1. Introduction

As coal-waste dumps are an element of the landscape in the Upper Silesian Coal Basin (USCB) in Poland, it is important to investigate what kind of substances might be leached from them due to weathering and self-heating. In the study, relatively fresh coal waste (used as a reference) will be compared to waste from gullies eroded in the sides of the coal waste dumps, coal particles mixed with sediment from the Bierawka River (divided into two subgroups comprising different types of material) and to self-heated coal waste. The aim was to recognize the geochemical- and petrographic changes caused by secondary processes such as self-heating, self-combustion, water-washing (leaching) and biodegradation in three selected coal-waste dumps beside the Czerwionka–Leszczyny, Szczygłowice and Trachy settlements (Fig. 1) in the Rybnik Industrial Region in the western part of the USCB.

Weathering processes such as water-washing, self-heating in coal-waste dumps can create significant environmental problems. During self-combustion, high concentrations of toxic acidic gases and chemical compounds (e.g., PAHs — polycyclic aromatic hydrocarbons) are released (Lighty et al., 2000; Pone et al., 2007; Ribeiro et al., 2010). Susceptibility to self-heating is increased by climate-air temperature, wind, organic-matter rank, ash content, surface area exposed, particle size, moisture- and oxygen content, and the shape, layering and compaction of a dump. Mineral composition (especially pyrite), volatile matter, organic-matter type, direct contact with water (wetting) and storage time are also important factors (Chen, 1998; Garcia et al., 1999; Bell et al., 2001; Lyman and Volkmer, 2001; Kaymakci and Didari, 2002; Lohrer et al., 2005; Suárez-Ruiz and Crelling, 2008). Poor compaction allows easier permeation of air and water, increasing the self-heating process (Bell et al., 2001).

Permeability is an important factor determining how water passes through a coal-waste deposit and how much leachable water will be produced (Olson and Moretti, 1999). Water-washing removes lighter and more water-soluble compounds, e.g., phenols, alkylnaphthalenes, and 2–4 ring polycyclic aromatic hydrocarbons. It results in enrichment in less-soluble aliphatic hydrocarbons and heavier aromatic hydrocarbons less soluble than phenol derivatives (Palmer, 1993; Skręt et al., 2010; Misz-Kennan and Fabiańska, 2011).

2. Geological description of the USCB and the selected waste dumps

The rank of coals in the USCB ranges from subbituminous- to high-volatile bituminous coals. Maceral composition is uniform with humic coals rich in vitrinites predominating, and rare sapropelic coals (Kotarba et al., 2002). The general features of the organic matter

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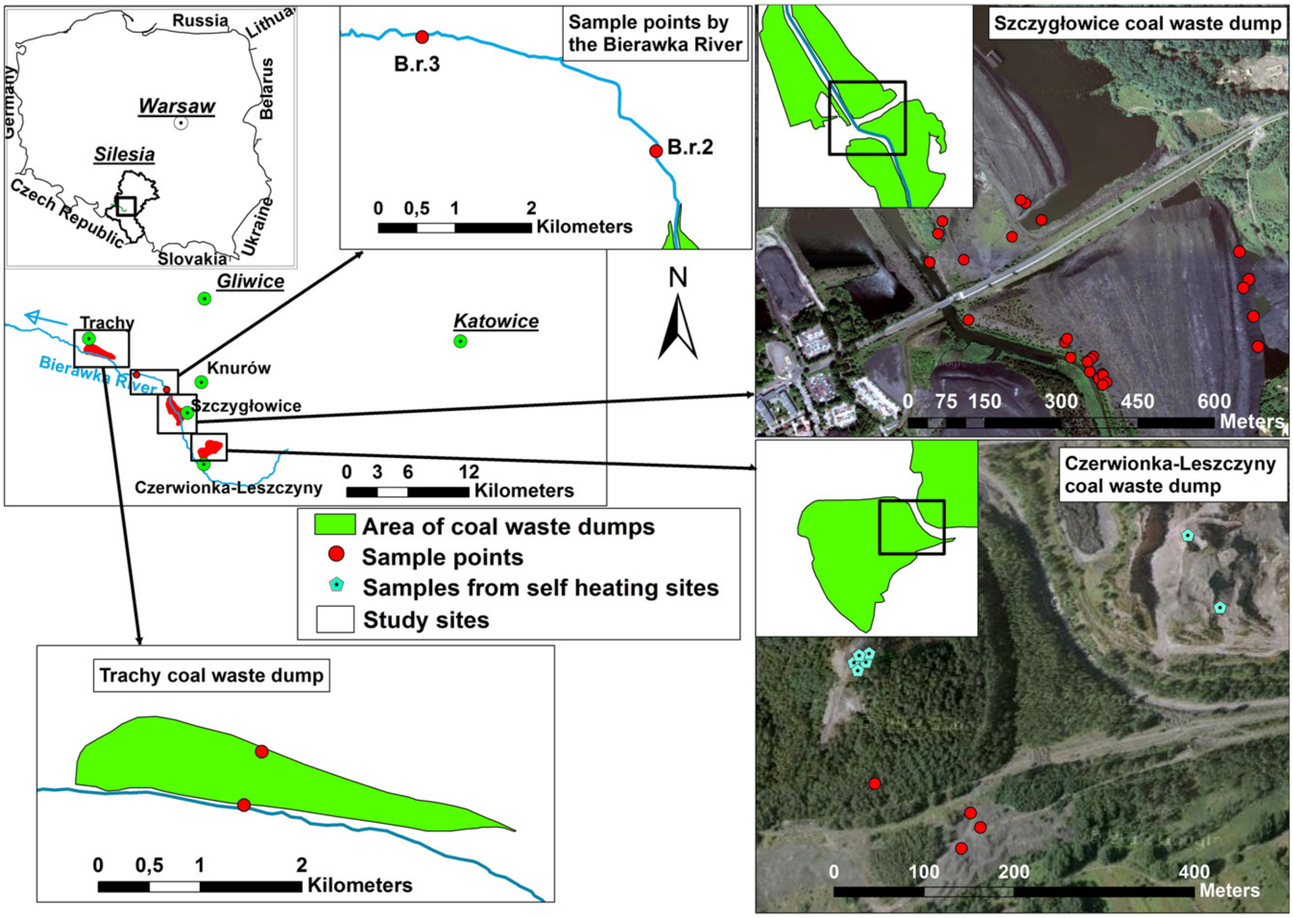

Fig. 1. The sampling points on the coal waste dumps (background map — Google Earth 2014).

contained in the coal wastes are similar to those of the bituminous coals in the Upper Silesia Coal Basin (Fabiańska et al., 2013). Most of the organic matter was deposited in an estuarine/deltaic environment with normal- to low water levels. The coals are early matured with similar vitrinite reflectance and thermal maturity corresponding to early- and medium catagenesis (Fabiańska et al., 2013). Bituminous coal seams form part of the Mississipian/Pennsylvanian sequence more than 8000 m thick infilling a flexural foreland basin. Its lower part (Upper-Mississippian) is of paralic type and comprises deposits of marine-, shore-, deltaic- and fluvial sediments. The Upper-Mississippian to Middle-Pennsylvanian part consists of non-marine deposits laid down in various fluvial systems (Kotas, 1990).

2.1. The Czerwionka–Leszczyny coal-waste dump

This dump is situated in the Rybnicki County, south-west Silesia (Grzesik and Mikołajczak, 2008) (Fig. 1). Mining companies deposited over 37 million tonnes of waste rock and tailings on the 140-hectare heap. Part of the existing dump of closed mine comprises two conical heaps, a huge flat heap and 4 tailing ponds (Grzesik and Mikołajczak, 2008). A second part is forested and consists of three cones with the highest ~100 m high. These cones cover a relatively large area of ca. 97 ha with variable morphology. Intensive pseudo-fumarolic activity occurs on the top of the steep highest cone. This part of the dump is relatively old (>30 years), and covered by forested slopes. At the self-heating site, there are visible gas vents in the surface surrounded by sulphate crusts (Parafiniuk and Kruszewski, 2010). Nowadays, the extension of the self-heating hot spot is continuously decreasing compared to earlier decades (Nádudvari, 2014).

2.2. The Szczygłowice coal-waste dump

The Szczygłowice dump is located in the town of Knurów (Fig. 1). Along the bank of the Bierawka River, there are four coal waste dumping sites where coal waste has been deposited since 1963. The waste now amounts to ca. 2.1 million tonnes. The average height of the dumps is 14–25 m with a 10° slope, favouring intensive erosion (BIP, 2015).

2.3. The Trachy coal waste dump

The Trachy dump is located in Gliwice County and close to Trachy village. The dump, opened in 1963, now comprises a large heap in the Bierawka River valley (Fig. 1; Sracek et al., 2010). The entire industrial area is 73.69 ha including 61.45 ha containing 47.54 million tonnes of waste. It is partially remediated by pine forest (BIP, 2015).

2.4. Sample sites by the Bierawka River

Four river sediments were taken from the Bierawka River, which flows between the Szczygłowice coal-waste dumps, and close to that at Trachy also. The sediments contain abundant black coal particles (Nádudvari and Fabiańska, 2015).

3. Experimental

3.1. Sampling and sample preparation

Coal waste and river sediment were sampled from May 2013 to August 2014. Each sample weighed ca. 1–2 kg. Seven are of self-heated