International Journal of Coal Geology 116–117 (2013) 1–16

Contents lists available at ScienceDirect

International Journal of Coal Geology

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

Distribution of methane and carbon dioxide concentrations in the near-surface zone and their genetic characterization at the abandoned "Nowa Ruda" coal mine (Lower Silesian Coal Basin, SW Poland)

Henryk Sechman [a,*], Maciej J. Kotarba [a], Janusz Fiszer [b], Marek Dzieniewicz [a]

[a] AGH University of Science and Technology, Faculty of Geology, Geophysics and Environment Protection, al. A. Mickiewicza 30, 30-059 Krakow, Poland
[b] Wrocław University of Technology, Faculty of Geoengineering, Mining and Geology, ul. Wyspiańskiego 27, 50-370 Wrocław, Poland

ARTICLE INFO

Article history:
Received 22 November 2012
Received in revised form 6 April 2013
Accepted 21 May 2013
Available online 25 May 2013

Keywords:
Soil gas
Methane origin
Carbon dioxide origin
Stable isotope
"Nowa Ruda" coal mine
Polish Lower Silesian Coal Basin

ABSTRACT

The closure of hard coal mines in the Lower Silesian Coal Basin (SW Poland) resulted in migration of coal-bed gases (mostly methane and carbon dioxide) towards the surface. The gases were driven out by rising groundwater table in the Pennsylvanian aquifer (so-called "water piston effect"). Because such migration may be a hazard for inhabitants living in the post-mining lands a surface geochemical survey was carried out in the area of the closed "Nowa Ruda" hard coal mine. The research aimed at: (i) evaluating the distribution of methane and carbon dioxide concentrations in the near-surface zone, (ii) determining the genetic characteristics of soil gases and (iii) comparing their characteristics with that of coal-bed gases. The surface geochemical survey included sampling of soil gases and chromatographic analyses of samples for methane and carbon dioxide concentrations and for stable carbon isotope composition in samples of increased methane and carbon dioxide concentrations. Samples were collected along 8 sampling lines located in the mining fields "Piast", "Słupiec" and "Wacław". In total, 390 soil gas samples were collected from 1.2 m depth. Maximum methane and carbon dioxide concentrations were 7.8 and 5.8 vol.%, respectively. Almost all methane encountered in the analyzed samples of soil gases are of microbial origin and were generated during recent anaerobic processes in the near-surface zone. High concentration of carbon dioxide was generated by aerobic biodegradation of organic matter in abandoned mines. Moreover, carbon dioxide was originated during the near-surface oxidation of methane. Only sometimes insignificant thermogenic component of coal-bed methane and carbon dioxide which migrated to near-surface zone from Pennsylvanian coal-bed strata occurs. Moreover an insignificant component of endogenic carbon dioxide also migrated though the faults from deep-seated volcanic chambers and/or even from upper mantle in the "Piast" mining field. The results of our research revealed that the changes of soils gas concentrations in the "Słupiec" field do not indicate "water piston effect". The highest state of gas emergency by inflow of deep-gases to near-surface zone could take place in the years 2008–2010 therefore much later than the near-surface measurement sessions in 2004. In the "Piast" field a relatively high number of anomalous concentrations of methane and carbon dioxide were measured. Such values results from degassing of groundwaters, the table of which stabilized within the Pennsylvanian aquifer in 2000. Gases migrated towards the surface along the fracture systems and faults, particularly along the Main and the Great faults. A great number of anomalously high carbon dioxide concentrations were measured in the "Wacław" field, which is an effect of groundwater table stabilization within the Pennsylvanian rocks. Carbon dioxide migrates towards the surface along the bedding planes of Pennsylvanian coal-bearing strata and along the linings of remediated "Wacław" and "Wanda" shafts. The highest state of gas emergency by inflow of deep-gases to near-surface zone caused by the uprising of Pennsylvanian water table ("piston effect") could take place in "Piast" mining field in the years 1998–2000, and in "Wacław" mining field in the years 1978–1980, therefore much earlier than the near-surface measurement sessions in 2004.

1. Introduction

The Nowa Ruda mining district is a part of the Lower Silesian Coal Basin located at the margin of the Intra-Sudetic Synclinorium in SW Poland. It is one of the largest geological structures in the Central Sudety Mts. The coal-bearing Pennsylvanian strata forms elongated

* Corresponding author. Tel.: +48 12 617 38 89; fax: +48 12 633 65 04.
E-mail address: sechman@agh.edu.pl (H. Sechman).

0166-5162/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.coal.2013.05.005

exposures, up to several kilometers wide, extending along the margins of the depression. The Lower Silesian Coal Basin includes two mining districts: Wałbrzych and Nowa Ruda.

In the years 1991–1997 the hard coal mines in the Wałbrzych mining district were closed due to economic constraints and safety measures, both controlled by complicated geological structure and hydrogeological conditions, high gas and rock outburst hazards, and difficult mining conditions (Kotarba, 2002).

The main components of coal-bed gases in the Lower Silesian Coal Basin are methane and carbon dioxide accompanied by smaller amounts of higher methane homologues, helium and hydrogen (Kotarba, 1988, 1990; Kotarba and Rice, 2001). After the closure of coal mines both drainage and ventilation systems were shut down, which resulted in the restoration of the groundwater table. Consequently, the rise of groundwater table caused the "water piston effect", which pressured the coal-bed gases towards the surface (Kotarba, 2002; Fiszer et al., 2002). Intensive migration of coal-bed gases from closed mines towards the surface is proceeds mostly along the tectonic zones (faults and/or overthrusts), mining-induced fracture zones, bedding planes and old mine workings (adits, winze and shafts) (Dzieniewicz et al., 2002; Kotarba et al., 2002). Migration of coal-bed gases (mostly methane and carbon dioxide) towards the near-surface zones may cause a significant hazard for residents of post-mining areas. Methane, which is lighter than air, accumulates in the upper parts of closed spaces, particularly those insufficiently ventilated, (e.g., cellars, basements, garages, water wells and underground drains), where it can form an explosive mixture in air at levels as low as 5% (LEL — the lower explosion limit). Usually the maximum allowed limit for mining operations etc. is 20% of LEL (1 vol.%) (Noack, 1998). On the other hand, carbon dioxide is heavier than air. It can accumulate in terrain depressions as well as in fractures, canals, water wells and basements and cause an atmosphere unsuitable for breathing (e.g. Kotarba, 2002). Usually the threshold limit value for CO_2 (for long term occupational exposure) is 5500 ppm (0.55 vol.%). At a concentration of 3% the respiration of humans is increased by 100%. 3% is the short term exposure limit (STEL). A concentration between 7 and 10% causes unconsciousness; a concentration larger than 10% can result in respiratory paralysis and death (e.g. Cable, 2004; Kozłowski, 1980; Nelson, 2000).

During the years 1997–2001 the working group from the AGH University of Science and Technology in Kraków, Poland ran comprehensive geochemical studies of gas hazard in the Wałbrzych mining district (Dzieniewicz et al., 2002; Kotarba, 2002; Kotarba et al., 2002; Sechman et al., 2002). The results led to the development of methodology to evaluate the hazard caused by the closure of hard coal mines (Korus et al., 2002; Kotarba et al., 2002; Sechman et al., 2006).

In the Nowa Ruda district the mining operations ceased in 1976, 1995 and 2001 in the fields: "Wacław", "Piast" and "Słupiec", respectively. After closure, a surface geochemical survey (Fig. 1), similar to the Wałbrzych district was carried out. Sampling lines were positioned in relation to main tectonic lines in the region, to outcrops of coal seams and to inundated areas resulting from the rise of groundwater table in the Pennsylvanian aquifer and to urban areas.

The aims of this paper are to evaluate the distribution of methane and carbon dioxide concentrations in the near-surface zone, to determine their genetic characteristics and to compare the soil gases with the coal-bed gases. These data enabled us to evaluate the distribution of coal-bed gases in the near-surface zone of the former "Piast", "Wacław" and "Słupiec" mining fields, to localize the zones of anomalous concentration of methane and carbon dioxide, and to determine the most important factors controlling their migration.

2. Geological setting and hydrogeology

The coal measures of the Nowa Ruda mining district occur in three separated, sedimentary basins, each of them being the individual coal deposit of different geological setting. The basins are filled with Pennsylvanian and Permian strata resting upon the Lower Paleozoic metamorphic structure of the Sowie Góry Mts.

The Nowa Ruda mining district includes: two depressions separated by a Lower Paleozoic diabase-gabbro massif, Dzikowiec elevation, and the Great Fault with a vertical displacement of about 1000 m. In the eastern depression of the synclinal Czerwieńczyce Graben two coal deposits were discovered in the villages: Ludwikowice Kłodzkie, Jugów ("Wacław" mining field) and Przygórze, Wolibórz ("Bolesław" mining field). The western depression (Nowa Ruda depression) comprises two coal deposits, one within the Nowa Ruda town boundaries ("Piast" mining field) and a second one in Słupiec ("Słupiec" mining field) (Fig. 1).

Generally, the Pennsylvanian coal-bearing succession in the Nowa Ruda district dips towards the southwest at 18° to 35° except for some parts of the Słupiec deposits where dip angles up to 90° were noticed.

Hydrogeological conditions of the Nowa Ruda district are controlled by four groundwater horizons. Three of them occur in the coal deposits and their overburden in Quaternary sediments, Permian and Pennsylvanian strata, and whereas the fourth horizon is in the older Paleozoic basement.

The Quaternary horizon comprises alluvial sands and conglomerates which are up to several meter thick. Due to low thickness and limited occurrence, this horizon is unimportant for the hydrogeology of the region. The outcrops of Rotliegend strata recharged by meteoric waters cover about 70% of mining fields. The thickness of this aquifer is 200–800 m. Rotliegend lithology includes low-permeable sandstones and conglomerates intercalated by impermeable shales. Hence, water-bearing capacity of this horizon is low and its role in recharging the underlying Pennsylvanian aquifer is insignificant.

The Pennsylvanian aquifer comprises sandstones and conglomerates interbedded with coal seams and clayey-quartz shales of total thickness about 450 m in the "Piast" field and 200 m in the "Słupiec" field. Outcrops of Pennsylvanian coal-bearing strata in the "Nowa Ruda" and "Słupiec" fields are located in their central parts and form a morphological depression between Nowa Ruda and Słupiec, which provides favorable conditions for infiltration of groundwater into the rock formations.

The basement of the "Piast" and "Słupiec" mining fields is formed by Lower Paleozoic gabbro and diabase as well as gabbroic and diabase conglomerates of low water-bearing capacity.

The mining systems with roof collapse in the coal mines disrupted the rock formations. Mining-induced fracture systems provide favorable conditions for infiltration and circulation of groundwaters. Mine drainage during the exploitation of coal deposits developed a vast and deep depression cone, mostly within the Pennsylvanian strata. In the "Piast" field mining operations the depression cone extended down to about 700 m depth (−260 m a.s.l.) with the discharge of 2.0–4.2 m^3/min. In the "Słupiec" field exploitation descended down to 900 m depth (−515 m a.s.l.) at the discharge of 3.0–3.6 m^3/min. Depth of coal exploitation in "Wacław" and "Bolesław" mining fields was approximately 600 m (−110 m a.s.l.).

The coal exploitation ended first in the "Bolesław" mining field (in 1972). In 1976 the exploitation from the "Wacław" mining field also ended. Up till 1980, the underground water table has stabilized in this area at the level of 470 m above sea level in "Bolesław" mineshaft and at the level of 460 m above sea level in "Ludmiła" shaft. The impact of the Pennsylvanian waters on the ground surface takes place through these mineshafts by the use of technological adits. In 1995 the exploitation of "Piast" mining field stopped, as well as the exploitation in "Słupiec" mining field (since 2001). At present, the stabilization of underground water table of Pennsylvanian aquifer has been achieved together with their impact on the ground surface. Since the November 2000, in the former "Piast" field the water drains through the shaft "Anna" and it achieved the level of 392.8 m above