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ENVIRONMENTAL IMPACT OF MINING ACTIVITY IN THE UPPER SILESIAN COAL BASIN (POLAND)

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ABSTRACT. The coal mining industry in The Upper Silesian Coal Basin has existed for over 150 years. Recently the mining industry in the USCB has been found at a low ebb. About the thirty oldest coal mines were closed to reduce the operating costs of the mining industry. Coal exploitation over a long period in the Upper Silesian Coal Basin has caused considerable and often irreversible changes in the natural environment. After the ending of exploitation, apart from hitherto existing hazards, which are gradually decreasing, new ones may also appear. A few years ago the authorities of the Silesian agglomeration began to labour under the difficulties connected with the process of winding up mining works and with the management of former mining areas. Their revitalization requires well-planned actions and suitable financial expenditures.

Keywords: environmental impact, Upper Silesian coal basin, exploitation.

1. Introduction

The Upper Silesian Coal Basin (USCB) lies in the southern part of Poland and continues into the Czech Republic. It is a triangle shaped synclinal form with an area of 6100 km² (Fig. 1).

The geological structure of the USCB shows a lot of similarities to mountainous paralic and limnic coal basins of Variscan age in Western Europe. The Carboniferous basin was formed on a Precambrian crystalline massif (Brunne - Upper Silesia plate) characterized by considerable subsidence. The Carboniferous mudstone and sandstone complex with numerous coal seams has a thickness of up to 8000 m. In the northern part of the basin the Carboniferous is overlain by a Triassic carbonate formation. In the southern and western parts only Miocene argillaceous and arenaceous facies with evaporites overlie the Carboniferous sediments. The folded Carpathian massif of the Alpine orogeny partially overthrusted the basin along its southern margin. Within the basin Quaternary sediments form a discontinuous cover of glacio-fluvial sediments several dozen meters in thickness.

The most favourable conditions for coal exploitation occur in the north and southwest of the basin where tectonic uplifting took place exposing a part of the Upper Carboniferous coal-bearing formation.

The coal mining industry in the USCB has existed for over 150 years. At the beginning of coal mining in the 19th and 20th centuries the coal exploitation was concentrated in sub-crop zones of Carboniferous strata. The first collieries began their mining activity in the region of the Main, Kazimierz and Bytom synclines (Fig. 1). In the southern part of the USCB the exploitation had been started in the area of the Orlova-Boguszowice overthrust.

Recently the mining industry in the USCB has declined. The crisis is mainly connected with the shortage of coal resources and decreasing coal demand as well as the necessity of reducing the subsidy for coal mines. The thirty oldest coal mines operating in urbanized areas and with unfavourable mining and geological conditions, were closed to reduce the operating costs of the mining industry. A few years ago the Silesian agglomeration began to suffer difficulties connected with the process of winding up the mining works and with the management of former mining areas.

2. Coal exploitation in the Upper Silesian Coal Basin

Because of the fact that the Silesian agglomeration consists of ten large cities and a dozen or so smaller ones mostly abutting them, the development process of coal exploitation was very similar in the whole area. Sosnowiec has been selected as representative of this region.

At the beginning of the 20th century coal was exploited in open pits or collieries up to 80 meters deep but by the late 1980s the maximum depth reached was about 1200 meters. Mining was carried out over approximately 80% of the 90 km² area of Sosnowiec. In the first stage of mining a chamber-pillar system of coal extraction was applied and roof collapse was the common method of headings infill. Hydraulic filling of excavation was used for the first time in 1905. A longwall system has been applied at the coal mines operating in Sosnowiec region

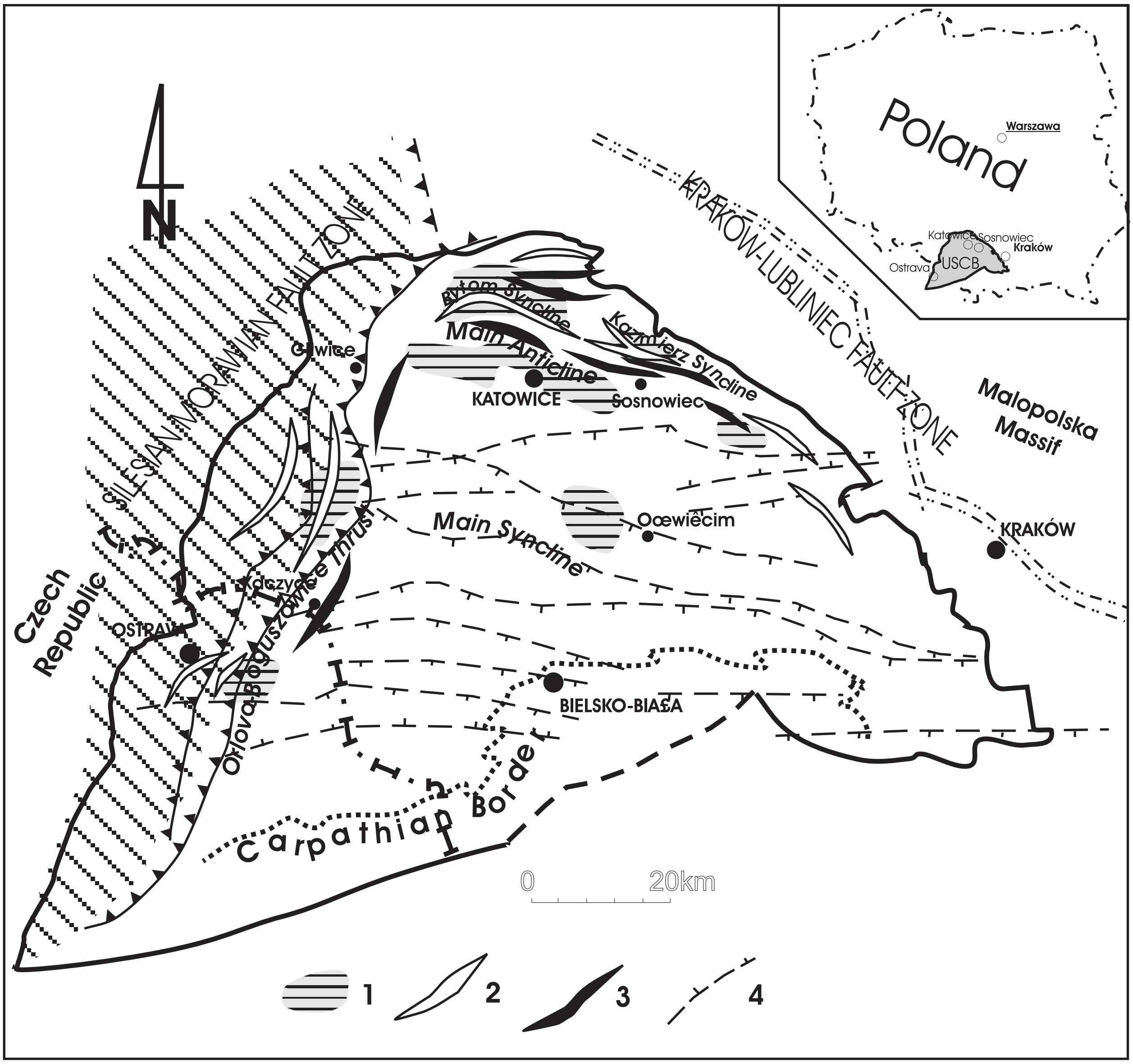

Figure 1. Geological sketch of the Upper-Silesian Coal Basin (USCB). Compiled after Jureczka & Kotas (1995): 1 – areas of intensive coal exploitation, 2 – synclines, 3 – anticlines, 4 – tectonic faults,

since 1925. The most intense development of mining in Sosnowiec took place between 1950 and 1970 and coal production has been decreased systematically since 1980. In the 1990s six collieries were closed. At the present time only one colliery operates in Sosnowiec.

3. The impact of exploitation on the natural environment

There are some negative aspects connected both directly and indirectly with underground coal exploitation:

- induced mining tremors
- discontinuous deformations of rock mass
- intensive ground subsidence owing to exploitation carried out on such a large scale.
- salty water diversion from dewatered mines into rivers and surface water reservoirs
- solid waste (barren rocks, coal cleaning waste)

After completion of mining some of the disadvantageous effects can directly disappear but some can still exist for a long time and seriously affect the natural environment. The negative events which do not exert an influence after closure of coal mines are as following:

- residual subsidence lasts for several years and for differing periods in different areas, thus it is difficult to forecast and monitor
- gas hazard in workings and gas migration towards the surface

- changes of water regime connected with a reestablishment of former ground water levels
- changes in underground water chemical composition caused by mixing of water from different aquifers
- flooding of subsided ground.

Distinctive characteristics of some of the above and their influence on the environment are discussed in further detail below.

4. Seismicity of the Upper Silesian Coal Basin

Seismicity occurring in the Upper Silesian Coal Basin is relatively well recorded and recognized. The frequency energy distribution of seismic events in the USCB has indicated the evident bimodal character. Most detected seismic events have a local magnitude not exceeding 2.3 (energy less than 1 MJ). These weak events are induced by mining activity and they occur near excavations. Since the mid 1980's it has became clear that an occurrence of events with higher local magnitude could be affected by the local geological and tectonic conditions. The strong events have to be considered as the result of mutual interaction among mining, lithostatic and tectonic stresses. The research on the structural geology together with seismological study leads to the conclusion that some of the structural elements of the USCB were related to large discontinuities in the deep crystalline basement. At present, the mining-induced stress field may interfere with the tectonic stress field causing instability of shallow fault zones and generation of strong events of magnitude larger than 2.8. The spatial distribution of strong shock epicenters is not homogeneous in the USCB. Despite the fact that mining activity is carried out all over the USCB shock epicenters group in well separated clusters corresponding to structurally different geological units. The seismicity of the USCB area has changed in space and time. For the basin as a whole the mean activity rate has generally been decreasing from 1977 up to 1996. During the last six years the activity rate has increased again. The number of events per year has returned to a level similar to that in the late 1970's (Idziak, 2002).

5. Ground surface deformation

After exploitation of the coal deposits in the Upper Silesian Coal Basin the occurrence of continuous and discontinuous deformations is very common. There are geological as well as mining factors which can influence the deformations.

Among the geological ones are:

- depth of coal seams
- inclination and thickness of coal seams
- tectonics and lithology aspects of overburden
- water content in rock mass.

Mining factors are :

- exploitation method applied to mining
- direction and operating rate
- number of simultaneously exploited seams.

Discontinuous deformations are formed as a result of breaking the original continuity of rocks and can be observed in layers both beneath and above the surface of the rock mass being exploited. Predominantly, the appearance of such dislocations takes place in the first stage of mining development when thick and shallow lying deposits were extracted. However, these types of deformations occurred rarely in the case of 50-meter-deep exploitation where the overburden includes siltstone; and also in exploitations up to a depth of 100 meters where the overburden consisted of sandstone.

It seems that the process of discontinuous deformations has stabilized. Nevertheless, original faults and fissures have influenced the phenomena appearing in the rock mass. Predominantly, they are zones of contact of underground water horizons or paths of groundwater drainage. On the ground surface the discontinuous deformations manifest themselves as vertical cone-shaped holes, trenches, irregular collapse sinks, chimneys and fissures.

Plastic strain is the most common type of rock mass deformation in mining areas. Deformation of this type can propagate a long distance from its origin. Rock layers in a roof of an extracted coal seam are deflected towards the excavation. The deflection can propagate up to the ground surface without strata continuity being broken, dependant upon local geological conditions. The deflection zone width on the surface depends on an angle of influence (γ). For the Carboniferous sandstone - siltstone complex in The Upper Silesian Coal Basin, the angle γ ranges between 55^o and 70^o. For Triassic and Miocene sediments the angle is about 45^o. The magnitude of ground surface subsidence is influenced by the system of excavation backfilling. The subsidence coefficient, defined as the ratio of maximum ground deflection to excavation height, is equal to 0.8 in the case of closing the excavation by roof falls and diminishes to 0.2 using a hydraulic filling. The time interval necessary for a new ground level to be stabilized depends on many geological and mine factors. In some mining areas the process of stabilization may last for several months but in others it may continue for several years.

Ground surface deformations occurring in the USCB are amongst the largest deformations in coal basins around the world. Remarkable deformations originated in the 1970s and 1980s during the intensive exploitation of a large part of the coal basin. In many coal fields, mining was carried out successively to extract coal seams occurring at different depths. It caused a superposition of the rock mass deformations and enlarged their destructive effect on the ground surface. Nowadays the average exploitation depth is about 650 m and it will increase by 10 m to 15 m per year. The direct influence of mining on the ground surface in the USCB can be seen over an area of 750 square kilometers but the oblique effects occur over an area of 1000 square kilometers. The total thickness of extracted coal seams was more than 30 m. Most excavations were carried out with roof caving. For this reason ground subsidence is significant and reaches 25 m - 30 m. The biggest subsidence took place in the cities of Bytom, Katowice, Zabrze and Sosnowiec (Cabala & Cmiel, 1999). In this period of intense exploitation a subsidence rate in some quarters of Bytom of up to 5 mm per day was recorded. Several subsidence troughs with depths varying from 16 m to 32 m were formed. During this period, the city center subsided about 6 m. Considerable parts of the subsidence troughs were flooded by ground water. In other urbanized regions of the USCB excavations were backfilled using hydraulic filling. It limited ground deflection but mining works carried out repeatedly in these areas brought about the occurrence of irregular subsidence troughs causing heavy damage to buildings. Under one of the quarters of Katowice , working was carried out in three stages. The ground subsidence in the area was no more than 1.91 m deep but as many as 127 buildings from the total number of 292 buildings located there were damaged (Cmiel, 1996). Much greater subsidence in Bytom generated during a single stage of mining did not cause such massive damage.

6. Changes of ground water regime

Changes of ground water regime, caused by underground mining in the USCB, were analyzed in detail by Rogoz (2001). Normally with the end of extraction in a coal mine dewatering of the excavations should also be stopped. This would result in the submergence of excavations by underground water. However, in the USCB dewatering of closed mines has had to be continued. Many of the USCB mines are connected by a complex system of galleries. Discontinuity in dewatering of a closed mine could augment a water hazard at the neighbouring mines, which were still operating. Cessation of mine dewatering will be possible after the closure of all mines of the region in about 30 years. Another serious problem is the choice of dewatering system both because of economic reasons and water quality protection. Most of the coal mines in the USCB are dewatered by stationary pumping sets. The use of stationary pumps is very expensive. For example, dewatering of closed zinc and lead ore mines belonging to the "Orzel Bialy" Mining Company cost more than 2 million US dollars in 1998. The replacement of stationary pumps with deep-well pumps located in pit shafts is now planned. The expenses of such investment are very high but operating costs of the facilities are much lower because they need no ventilated underground chambers and additional transport shafts.

Because of the continuing dewatering of closed collieries the quantity of mine water carried away to rivers will not decrease significantly. The amount of salt reaching the rivers should decrease slightly owing to a mixing of mineralized underground water with fresh water infiltrating from the surface.

After the cessation of dewatering and submergence of closed mines some parts of the subsided ground surface will be flooded by rising ground water. It may occur in areas where shallow water-bearing layers are not isolated from the carboniferous rock mass. Deeply incised river valleys are potential hazard areas especially along segments where the riverbed is silted up or embanked. The cessation of dewatering will redress the natural hydrological regime and will cause an increase in seasonal fluctuations of river flow.

Drinking water intakes exist at many collieries in the USCB. These abstractions can be preserved if they are located above the final water level appertaining at submerged workings after the cessation of pumping. Their capacity and water quality will not change. Intakes located below the water level, however, will be destroyed because fresh water will mix with mine water contaminated by the products of iron sulfide oxidation and heavy metals.

7. Gas migration

After stopping the ventilating and dewatering of closed collieries, gas emanating from the rock mass via excavations can migrate to the surface. The gas migration phenomenon has been observed in many coal basins in which collieries have been closed. The rate of migration depends on many geological, hydrogeological and mining factors. Concurrently with a rise of water level in flooded excavations gas migration is intensified because water replaces the gas contained in the rocks. The gas migrates upwards both through natural paths such as faults, fissures, and fractured zones and also through backfilled galleries, shafts etc. Migrating gas contains mainly methane and carbon dioxide. It can infiltrate into soil, drains, sumps and even to the lower floor of buildings. Considerable amounts of methane may cause unexpected explosions on the surface. The gas affects the environment undesirably influencing plant vegetation and enlarging the greenhouse effect.

During the structural changes in the Polish coal industry, six collieries with extensive gas emanations were closed. Four of them had operated in the Lower Silesian Coal Basin and the other two in the Upper Silesian Coal Basin. The research on gas migration carried out by Krause (2001) in the USCB pointed to the fact that gas emanation has been decreasing exponentially since exploitation stopped. It diminished fivefold during the first month. The gas emanation will gradually decrease to nothing over the next 10 to 15 years. Gas accumulation may occur locally during closure works. A classic example of this was a methane explosion at the shaft being filled up in the "Morcinek" coal mine.

8. Conclusion

Long-lasting coal exploitation in the Upper Silesian Coal Basin has caused considerable and often irreversible changes in the natural environment. Mining waste dumps and partly flooded subsidence of the ground has become a typical aspect of the Silesian landscape. Moreover, lowering of groundwater horizons has led to the evolution of special habitat plants in many parts of the area.

Currently, structural changes in the mining industry of the Upper Silesian Coal Basin include closure of unprofitable coal mines but thus will not lead to an immediate improvement of the natural environment. Apart from hitherto existing hazards, which gradually decrease after the cessation of coal extraction, new ones may in all probability appear. These are as follows:

- uncontrolled explosion of gas migrating from closed headings;
- flooding of consecutive parts of depressed areas due to rising groundwater levels;
- changes in the flow of surface water-courses.

Disturbances of the rock mass result from mining operations and have given rise to areas characterized by induced seismicity in which the most intensive seismic events can be compared to weak earthquakes. Taking into account the monitoring results which have been obtained over the last several years one can ascertain that the limitation of coal output did not decrease the USCB seismicity. On the contrary, the number of registered seismic events increased (Idziak, 2002). Similar phenomena occur in the part of the basin lying within the Czech Republic.

Generally, the impact of coal mine closure on the environment is difficult to predict and control. Thus, one cannot estimate the time interval necessary for environmental conditions to become stabilized.

Nowadays studies on environmental degradation are carried out in the USCB. There are three principal types of areas with differing degrees of degradation. These are:

a) areas completely devastated in which rebuilding of their environmental value is no longer possible
b) areas disturbed to some degree in which spontaneous rebuilding of environment is possible
c) areas in which the return to original state is no longer possible but an artificial ecosystem similar to the natural one can be created.

The areas mentioned in (c) seem to be the most interesting because they appear frequently in the neighbourhood of strongly urbanized regions. In future they will become recreation areas. However, their revitalization requires well-planned actions and suitable financial expenditures. Revitalization of the mining areas has been already applied in the USA and the United Kingdom. The result in these places shows that it is a good way to minimize the environmental disturbances after ending the mining activity.

9. References

CABALA, J., CMIEL, S., 1999. *Dynamics of ground surface deformation caused by mining in the period 1973-97 in USCB on the example of Kazimierz trough. Documenta Geonica of Akademy of Sciences of Czech Republic, Proc. 2 Czech-Polish Geomechanical Symposium. 243-252,Prague.*

CMIEL, S., 1996. Degradacja powierzchni terenów górniczych na przykładzie obszaru zlewni rzeki Rawy. In Migula, ed., Problemy srodowiska i jego ochrony. Wyd. Centrum Studiow nad Czlowiekiem i Srodowiskiem US, 2: 10-20, Katowice.

KRAUSE, E., 2001. Safety and environmental aspects of gas hazard in post-mining regions. In Dubinski, ed., Czlowiek i srodowisko wobec procesu restrukturyzacji gornictwa wegla kamiennego. „GEO” Edit.,: 417-430, Kraków.

IDZIAK, A.F., 2002. Migration of seismicity in the Upper Silesian Coal Basin. *Acta Montana* Series A, No 20 (124): 111-117.

JURECZKA, J. & KOTAS, A., 1995. Upper Silesian Coal Basin. In Zdanowski & Zakowa, eds., The Carboniferous system in Poland. *Publ. Polish. Geol. Inst.*, 148: 164-173.

ROGOZ, M., 2001. Forecasting the changes of water environmental with regard to the directions of restructuring process. In Dubinski, ed., Czlowiek i srodowisko wobec procesu restrukturyzacji gornictwa wegla kamiennego. „GEO” Edit.,: 211-226, Kraków.

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