# USE OF VOID SPACE IN ABANDONED MINES IN THE UPPER SILESIA COAL BASIN (POLAND)

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## Abstract
The natural variation of free voids within the Upper Silesian Coal Basin (USCB) has been determined by physical and mechanical analyses of rock properties. This paper presents some possible uses of the free voids that occur in Polish coal mines.

## Introduction
By the end of 2006, nearly 30 coal mines in the Polish part of the Upper Silesian Coal Basin (USCB) were abandoned. There were various reasons for abandonment, of which the most important were economics factor and depletion of coal resources. Of these abandoned mines, only two closed mines and one isolated part of one active mine have been allowed to completely flood. The rest of the abandoned mines are still being either partially or completely dewatered, to protect the active mines connected with the abandoned ones (Fig. 1).

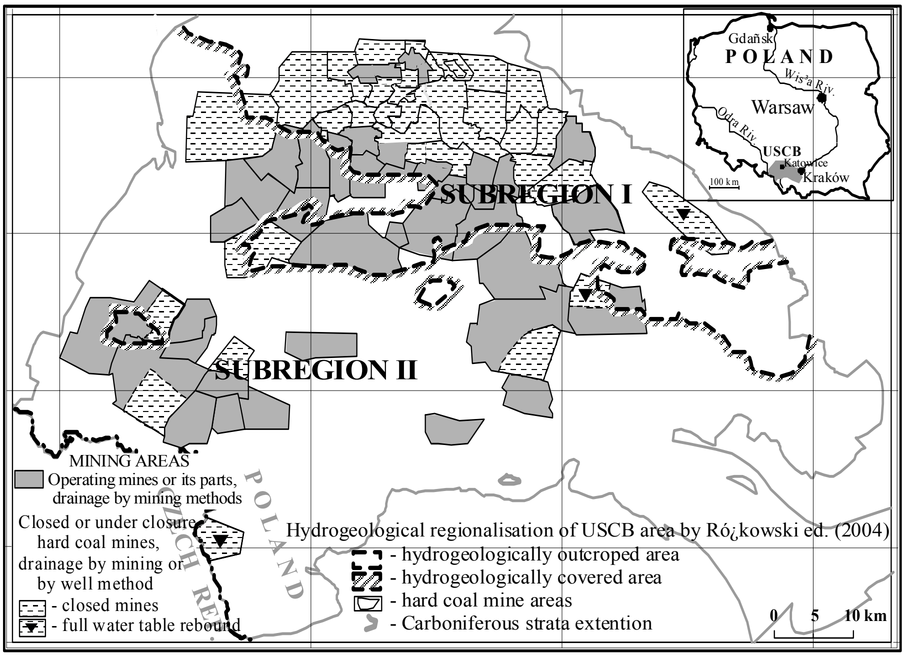


**Figure 1. Location of coal mines in the Upper Silesian Coal Basin (USCB).**

The abandoned mines in the USCB region are characterized by diversified and complicated mining conditions. While the lithostratigraphic structure of the Carboniferous deposits (sandstones, mudstones, siltstones with coal seams) is not particularly complicated, the deposits vary significantly in terms of their physical and mechanical properties. The complexity of these conditions, especially the hydrogeological ones, has been characterized by several Authors (Bukowski, 2002, 2006; Wagner, 2002).
Despite the diversity of the geological and mining conditions, the capacity of the voids which were created during mining operations is almost always large. Volumes in excess of one millions of cubic meters ($m^3$) are typical, including both already flooded and currently un-flooded void volume. These void spaces represent a chemical, gas, and geomechanical hazard; however, under particular conditions they can be successfully and practically used.

## Characteristics of void spaces within abandoned mines in the USCB

In Polish coal mines the volume of the void spaces in the mine workings (goafs, galleries, shafts, headings and post-exploitation fissures) is usually estimated in accordance with the methodology developed by Rogoż (1978). The capacity of the rock mass is estimated by two methods: 1) using hydrogeologic parameters, or 2) using the water-storage capacity of the rock mass. The water-storage capacity of the rock mass consists of the rock mass storage capacity within the extent of the mining excavations and above them, and the additional capacity of the rocks and fissures situated outside the mining excavation area but within the cone of depression (Bukowski, 2002; Bukowski and Grzybek, 2005). The nature of the void spaces (as well as their behaviour and the stability of their capacities) depends on geomechanical conditions and factors affecting the rock mass parameters. The characteristics of the geomechanical conditions in USCB have recently been presented by Bukowska (2005).

Mines in the western part of the USCB (most of Subregion II, Fig. 2) have been developed in older and deeper Carboniferous strata, which are predominantly mudstones and claystones overlying sandstones. These strata are characterized by relatively low values in permeability and porosity (Witkowski, 1987). These rocks also have relatively high strength and low strain. After water saturation (leading to capillary saturation), changes in the strength of sandstones and claystones are not significant. As a result of these mechanical characteristics, void spaces created by mining (such as caved goafs) do not undergo intensive closure even under high geostatic pressure (Bukowski et al., 2006).

The strength of the sandstones and mudstones in this part of the USCB region are not very sensitive to the presence of water. However, problems with the stability of mining excavations and the preservation of mining excavations exist; they are caused by the combined effects of very changeable stratification and high tectonic and geostatic pressures. Water inflow into mines of this part of the USCB region is smaller than water inflow to mines in Subregion I, due to the protection provided by the covering of low permeability rocks in Subregion II. However, mine inflow in Subregion II is much more mineralized and saline.

Looking at the rock mass from the perspective of the ability of water retention, it is a non-water-storing rock mass, made of rocks with a very low effective porosity and with specific yield approaching zero. Void space capacity is mostly created by the capacity of preserved mine workings and fissure spaces of tectonic or post-mining origin (Fig. 2).

The eastern part of the USCB region, including most of the hydrogeologically outcropping area (Subregion I) and the south-east part of the hydrogeologically covered area (Subregion II) is characterized by younger Carboniferous deposits and different natural conditions than those described above. In the mines in this area sandstones with high porosity and permeability predominate. Also the petrographic structure of the Carboniferous sandstones is different, consisting of high percentages of argillaceous binder and, very often, swelling minerals. As a result the mechanical properties of sandstones are characterised by low strength and high strain, and these rocks are sensitive to the influence of water.

The water capacity of voids within the water reservoirs in the eastern and south-eastern mines of the USCB region is linked mainly with the high aquifer properties of the rocks. The water capacity of goafs and galleries (Fig. 2, positions 1 and 2), and post-mining fracturing (Fig. 2, position 3) play a minor role in the total water capacity of reservoirs.

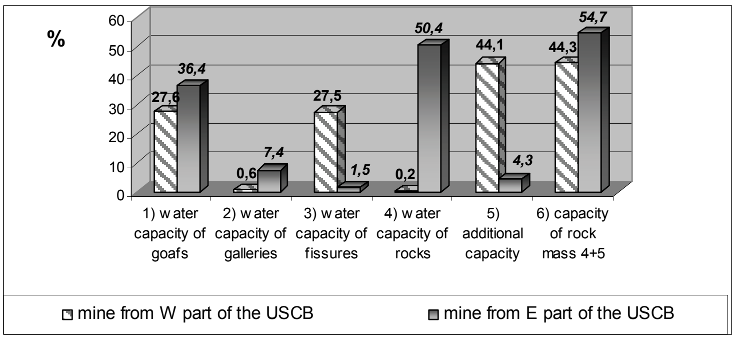


**Figure 2. Source of void capacities in selected reservoirs in the western and eastern Polish USCB (after Bukowski, 1999, 2002).**

Water storage capacity of the rock mass (Fig. 2, positions 4 and 5) is similar for both the east and the west part of the USCB region, but the properties and character of free voids in post-mining rock mass show large variations. The goaf capacity and the fissure capacity (Fig. 2, positions 1 and 3) dominate in the west part of the USCB

region, while the goaf capacity and the intergranular capacity of rocks (Fig. 2, positions 1 and 4) dominate in the eastern part. Galleries have a low influence on the total voids capacity in all Polish coal mines.
Because of the very different distribution of each component in the reservoir capacity within the Polish USCB mines (Fig. 2), free voids in each mine should be considered separately, particularly for the assessment of free voids, which could be used for economical and environmental purposes.

## Prior uses of free mining voids in the USCB

Underground voids in abandoned mines have been rarely used in the Polish USCB. When used, the most popular method was backfilling with waste rock or fine sand obtained from waste rock. The majority of abandoned mines underwent flooding due to natural inflow. Natural flooding has been limited by dewatering, to limit water hazard and inflow into neighbouring active mines. The water capacity of flooded mine workings has been used to provide protection against water inrushes to active mines, especially in those excavations and rock masses where flooding processes can occur. This protection is a key factor for the security of active mines (Fig. 3).

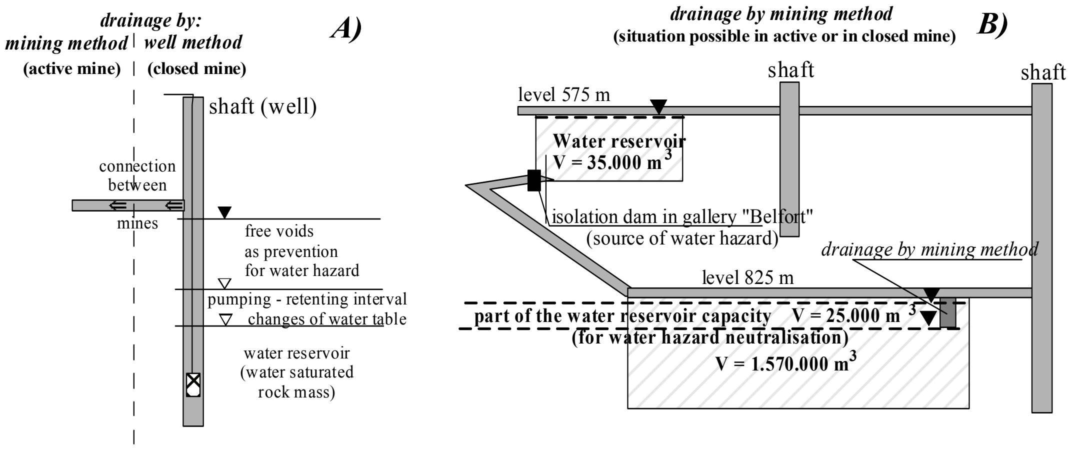


**Figure 3. Models of use of free voids as a protection against water hazard (after Bukowski et al., 2006): A) Closed mine with well drainage, B) Active or closed mine with in-mine drainage.**

In the mines where excavations are dewatered by wells, special depth ranges (working and emergency) are established. The volume of voids affects not only the security of adjacent working mines but also the economics of the dewatering process (Fig. 3A). The proper assessment of the volumetric components of water reservoir permits safe and optimal selection of the limiting values for the water levels in the reservoir. In dewatered mines, there is generally any use of free voids than as a water reservoir. Under favourable geological and geotechnical conditions, the free voids above the water level could be used as the gas reservoir.
For abandoned mines where underground access is available, dewatering by mining methods (stationary pump-stations) is feasible. In this case, free voids within the mining workings and rock mass are used as the emergency water reservoirs. In abandoned mines where the stationary drainage system has been interrupted, the only way for maintaining and using the mining voids is dewatering by wells operating at ground level, or by the reventilation and the rehabilitation of some mining workings (mainly galleries) situated near the shafts.

## Advantages and disadvantages of using the underground mine voids in the USCB

A variety of projects are currently being evaluated for the possible use of the free voids in abandoned mines, including:

- Reserve (back-up) water reservoirs (in the east and northeast part of the USCB);
- Disposal sites for fine-grained wastes derived from mines and power stations (mainly in the west of the USCB);
- Reservoirs for gas and liquid fuels;
- Storage reservoirs for salt water and brine to protect surface waters (south-eastern part of the USCB); or
- Geothermal reservoirs (south-eastern and north part of the USCB).

So far, mainly due to economic reasons, none of these projects has been fully accomplished.
Current restructuring of coal mining industry makes it possible to evaluate more effective use of free mine voids only with reference to those mines which will be closed in the future. Previously, one of the mines in the Lower

Silesia was considered as potential gas storage reservoir. However due to the unfavorable natural conditions in this part of the country, the project was not undertaken.
Polish experience in terms of gas storage in mining excavations has been linked closely with oil mining and in one case with salt mining. Today in Poland there are 7 gas storage projects. Among the most recent ideas, it has been considered to transform two coal mines into low-pressure gas or liquid-fuel storages, or to select some portion of the excavations for medium- and high-pressure reservoirs. The abandoned "1-Maja" mine is one of the sites where free voids can be used in various ways. It has been observed that relocating waters from the adjacent active mines into the 1-Maja excavation can result in a number of benefits (Karwasiecka et al., 2005). This idea is in the implementation phase since July 2006. The 1-Maja mine is currently being flooded with natural inflow and additional inflow from an adjacent active mine (Fig. 4).

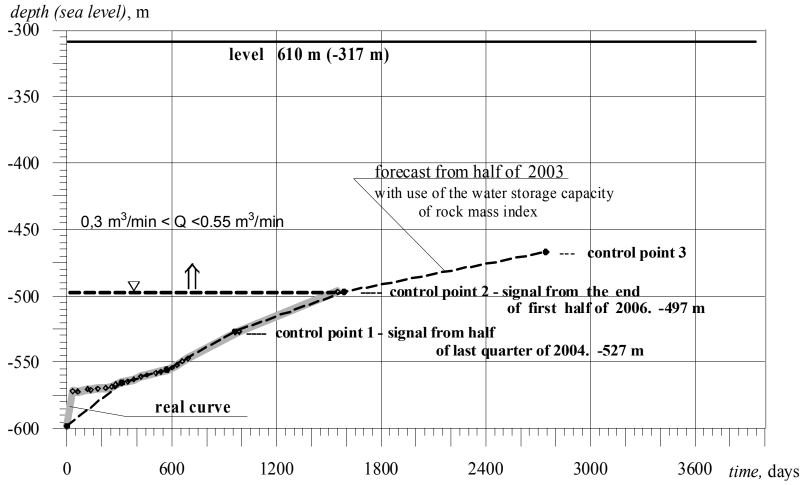


**Figure 4. Changes of groundwater level in mine workings in the abandoned "1-Maja" mine up to the second half of 2006.**

The "1-Maja" mine was abandoned in 1997. The natural inflow to its dewatering system was estimated at approximately 0.55 cubic meters per minute ($m^3$/min), decreasing to 0.30 $m^3$/min. Taking into consideration the capacity of the free voids in the mine workings and natural inflow to the mine, the time of flooding up to the 610 m level (i.e., the "safety level") was estimated at approximately 8.5 years. This estimate was refined using monitoring data collected during rebound of the lowest levels in underground workings, as well as with new hydrogeological data on the properties of rocks (Motyka and Józefko, 2000), as shown in Figure 4. According to the new evaluation, water table rebound to the safety level of 610 m will last for 25-30 years. Recent data on rebound at this mine show that the void capacity of the mine workings and the rock mass could be used for the storage of brines or gas. Because of the presence of geothermal anomalies in the region (rock mass temperature up to 40-55$^o$C), the use of mine voids as a geothermal water reservoir was also taken into consideration.
Recently, because of the possibility of sudden water inrush, it was necessary to dewater the water reservoir in the 1-Maja Mine to the new planned mine working level in a neighbouring active mine. The volume of water within this reservoir is estimated to be approximately 0.8-1.0 million $m^3$ of highly mineralized water. Discharge of this large amount of saline water into stream waters would cause a significant negative environmental impact, as well as financial losses for the mine. Accordingly, it was decided to dewater the reservoir and to pump its waters to goafs of an abandoned neighbouring mine (Fig. 5). This operation led to some advantages, namely:

1. Elimination of water hazard in the neighbouring active mine;
2. Reducing the dewatering costs in the reservoir which is causing a water hazard;
3. Reducing negative environmental effects by decreasing the discharge of saline waters;
4. Generating renewable energy;
5. Creating future geothermal energy recovery opportunities from high-temperature rockmass.

## Summary

At the present stage of coal mine restructuring in Poland, the wider use of free voids in abandoned mines is complex, but this does not mean that there are no such possibilities. The authors of the paper believe that the example of "1-Maja" mine and other similar mines demonstrate the feasibility of diverse beneficial uses of free voids in abandoned mines, despite highly variable natural conditions.

The permanent closure of underground workings by refilling and sealing is very expensive, particularly for deep mines. However, the avoidance of this cost by the productive alternative use of the mine voids provides an economic opportunity, particularly in mines within Sub-region II of the Polish USCB, where the greatest possibility of utilisation of existing underground mine infrastructure occurs. In this region the controlled flooding of closed, isolated mines and related underground workings was feasible, as shown in the example of “1-Maja” mine. Mine voids can also be used for gas storage, waste storage, or as a source of geothermal energy. Such methods might result in important positive environmental and economic advantages.

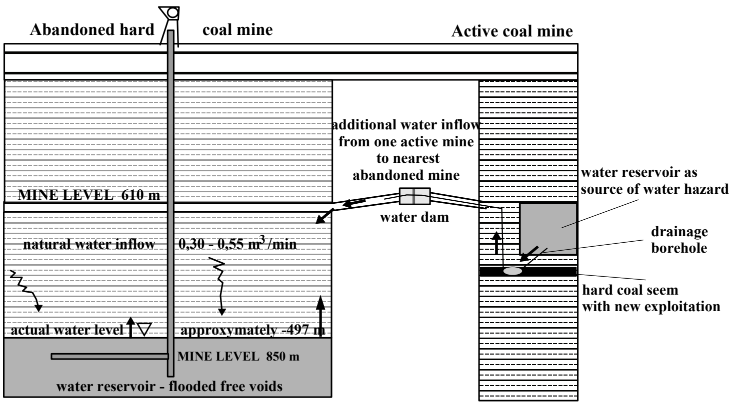


**Figure 5. Scheme of using the free voids in abandoned mine by the active coal mine.**

The use of underground workings as water storage reservoirs (mainly in the northeast and east part of the Polish USCB) may also protect the active mines against water inrush hazards. Free voids above abandoned mines’ reservoirs can be only partly used for water storage because of the protection of safety in active mines (water hazard prevention). Nevertheless, the available reservoirs in USCB mine voids represent an economic groundwater resource. The water reserves accumulated in mine workings during rebound are significant; this water does not fit the drinkable water standards, but it can be used for industrial purposes (in shallow mines with easy water recharge) or to recover geothermal energy (in deeper mines with good thermal conditions).

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