Protection of Salt Mines against Water Inflow Threat on the Example of Wieliczka Salt Mine

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The geological setting in Wieliczka mine and its vicinity are presented in detail in this paper. Special reference is devoted to water-bearing strata and hydrogeological conditions of the deposit. Over 700 years of exploitation resulted in physical discontinuities in the salt rocks. Mining operations entered the safety pillar of the mine at places. These activities together with unfavourable hydrogeological conditions in the salt resulted in dangerous water inflows, which could totally flood the mine. A catastrophic inflow of water to the gallery Mina" in 1992 gave an opportunity to use various methods, which allowed to overcome this disaster. Two such injection methods are described and presented in detail: borehole injection and pipeline injection. They helped to protect the Wieliczka mine against water inflows.

1. INTRODUCTION

The Wieliczka salt mine located near Krakow is one of Poland's top tourist attractions. The mine has become famous worldwide since being entered in 1978 on the first UNESCO list of 12 objects of World Cultural and Natural Heritage.

Twenty six million tons of salt have been extracted in seven centuries. In that time 26 shafts were sunk and salt removed from over 2000 chambers on nine levels reaching down to a depth of 327 metres.

In the upper part of the mine, the old exploitation area comprises a network of chambers and galleries, the total length of which amounts to about 180 km. In this part of the mine, a unique underground touring route and a museum have been arranged. The touring route leads to a depth of 135 m below the surface, passing through galleries, staircases and chapels carved out of salt blocks during the 17th to 19th centuries. One of the largest and most beautiful is the Chapel of St. Kinga. It is 54 m long, 14.5 m wide, and 10 m high.

The underground museum has several sections showing both the history of salt mining in Poland, and the geology of the Wieliczka salt deposit. In 1965, a sanatorium for patients with bronchial asthma was established, some 200 m below the surface. The microclimate in the chambers left after extraction of salt produces excellent effects and durable therapeutic results.

Due to the mining operations, which disturbed the stability of the cap rock, a catastrophic inflow of groundwaters to the mine in April 1992 took place.

2. GEOLOGICAL SETTING

In the vicinity of Wieliczka the marine Miocene sediments belong to the Badenian, and are subdivided into 4 lithostratigraphic units: the Skawina beds (sediments underlying evaporates), the Wieliczka beds (evaporates), the Chodenice beds and the Grabowiec beds (sediments overlying evaporates). The geological structure of the Wieliczka salt mine has been described in a number of published papers [1-6]. The salt deposit forms a body 1 kin wide, about 6 km long, and more than 300 m thick, consisting of two units (Figure 1). The upper unit is developed as coarse breccia composed mainly of manly claystones, with blocks of coarse-grained salt of irregular size and shape, which may reach in some places up to more than 150 m in the longest diameter. The St. Kinga Chapel is situated in one of such blocks at the second level. The lower unit is developed as a complex of strongly folded, deformed and thrust over one another salt layers alternating with anhydrite and anhydritic clays. Among that complex spina salts, shaft salts and green layered salts are most distinctive. Both mentioned units are covered by gypsum cap-rock and separated from the overlying Quaternary loams and clayey sandy Miocene strata adjacent from the north (containing flysch sediments at places). Tongue shaped wedges of flysch rocks penetrate the inner part of the salt deposit from the south.

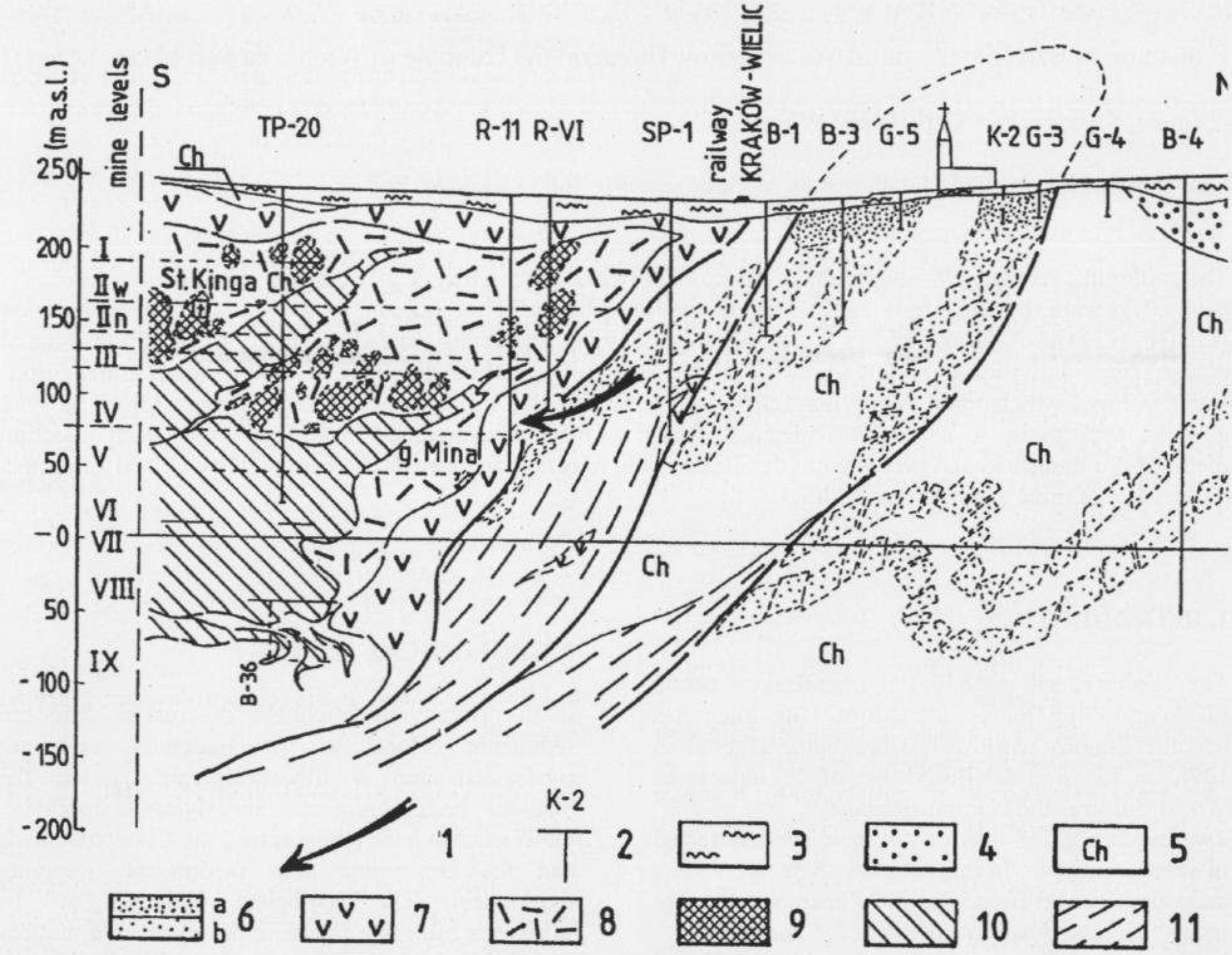

Figure 1. Cross - section in vicinity of gallery Mina (after Brudnik & Szybist, 1995)

1 - direction of inflow, 2 - borehole, 3 - Quaternary, 4 - Grabowiec beds, 5 - Chodenice beds, 6 a - Chodenice sandstones (6 b - upper part weathered), 7 - gypsum cap - rock, 8 - marly claystones of brecciated deposit, 9 - blocks of salt, 10 -spiza salts, shaft salts and green layered salts, 11 - Skawina beds (partly with flysch sediments).

3. HYDROGEOLOGICAL CONDITIONS

The youngest water-bearing strata in the area of Wieliczka are Quaternary loams, sands and gravels filling a valley of Wieliczlea and to the north reaching up to the monastery of Reformates [7-8]. Further to the north the sub-Quaternary outcrops of the Grabowiec beds occur. The main water-bearing horizon is situated within the Chodenice beds. They consist mainly of claystones, mudstones and marls. Among these prevailing sediments, two complexes of sandstones and conglomeratic sandstones can be distinguished (Figure 1). During folding and overthrust of the Carpathians onto Miocene sediments, these rigid but brittle strata were broken into blocks. Particularly their sub-Quatemary outcrops are strongly weathered and therefore they lead atmospheric waters into the subterranean zone. The gallery Mina has pierced the clayey-gypsum caprock and entered into these Chodenice sandstones adjacent to the cap-rock. This may explain enormous amount of water with mud and silt, which filled up the gallery Mina during inflows of 1992 (about 60 000 m^3).

4. CAUSES OF WATER SEEPAGES IN THE SALT MINES

Water is a serious threat to every salt mine. It manifests itself in mines when water fills the overlying strata or those surrounding the salt deposit, and rocks isolating the salt deposit lack of tightness. Keeping salt mines waterproof necessitates the use of proper methods of exploitation of the deposit and, best of all, the insurance of geomechanical stability through a defined tightness of the safety pillar.

Generally the causes of water seepages in the salt mine depend on:

- natural hydrogeological conditions
- human activity in the mine.

In case of the salt mine ,Wicliczka" the problem is even more complicated due to following factors:

- the northern foreland of the salt deposit consist of strongly aquiferous strata,
- from that northern foreland a continuous flow of considerable amount of water is possible
- hydrogeological conditions are favourable to create high water pressure onto clayey-gypsum cap-rock of the deposit,
- exploitation of salt has been carried on for over 700 years,
- there are unidentified workings of ancient exploitation,
- mining operations have pierced a safety pillar.

As a result of the above mentioned facts, the thickness of clayey-gypsum cover of the salt deposit has decreased considerably. In addition an endurance of the clayey-gypsum cap rock has decreased whereas its permeability has increased. Those changes have led to deformation of the mine workings, water inflows in the mine, and even to the development of sinkholes on the surface.

5. METHODS OF SALT MINES PROTECTION AGAINST WATER THREAT

Precisely recognized geological and hydrogeological conditions of both the salt deposit and its close neighbourhood are the prerequisite for any mining operation.

Mining operations should be carried on using professional methods. Safety pillars must be properly designed and no mining works may enter into those pillars. During exploitation it is necessary to keep mechanical stability of the mine.

When the safety pillar is not tight enough and water appears inside the salt mine even in a small quantity, protective action must be taken at once. Flushing water should be gathered and pumped out, and the rock mass should be tightened.

A general subdivision of methods which limit water inflow to the salt mines is shown in Figure 2.

Due to the leaching properties of water flowing through the salt rock mass the drainage is frequently limited as a method safeguarding the salt mine against water hazard. In certain cases, drainage is also applied as a supplementary method when using injection techniques for the sealing of the rock mass. Both these methods can be used from the surface and in the workings.

A choice of protecting methods is determined by the existing geological, hydrogeological, geomechanical and mining conditions.

6. PROTECTING WORKS IN THE SALT MINE WIELICZKA

Gallery Mina is an old working situated on the level IV of the mine. First information on a seepage year in that gallery was noticed in the year 1935, when the registered output was 1 dm^3/min and NaCl content 240 g/dm^3. Collapse of the overlying strata in 1971 prevented access to that place. In 1990 a reconstruction of the gallery Mina started, and water from the seepage was collected on mine levels V and VI. Its output was 4 dm^3/min and saturation 300g NaCl/dm^3.

About midnight of 13 April 1992 a sudden mud rush took place, with output estimated as high as 20 m^3/h The next intense inflow on 17 April 1992 filled up the gallery Mina with muddy material up to the roof At once a rescue work started, during which:

- two boreholes were drilled (drainage borehole R I and exploratory borehole R R) from the surface to the zone feeding inflow in gallery Mina;
- waterproof dam was constructed. It consisted of 3 segments (frame-dam clay packer and concrete dam);
- water gathering behind the dam was continuously removed by the pipeline.

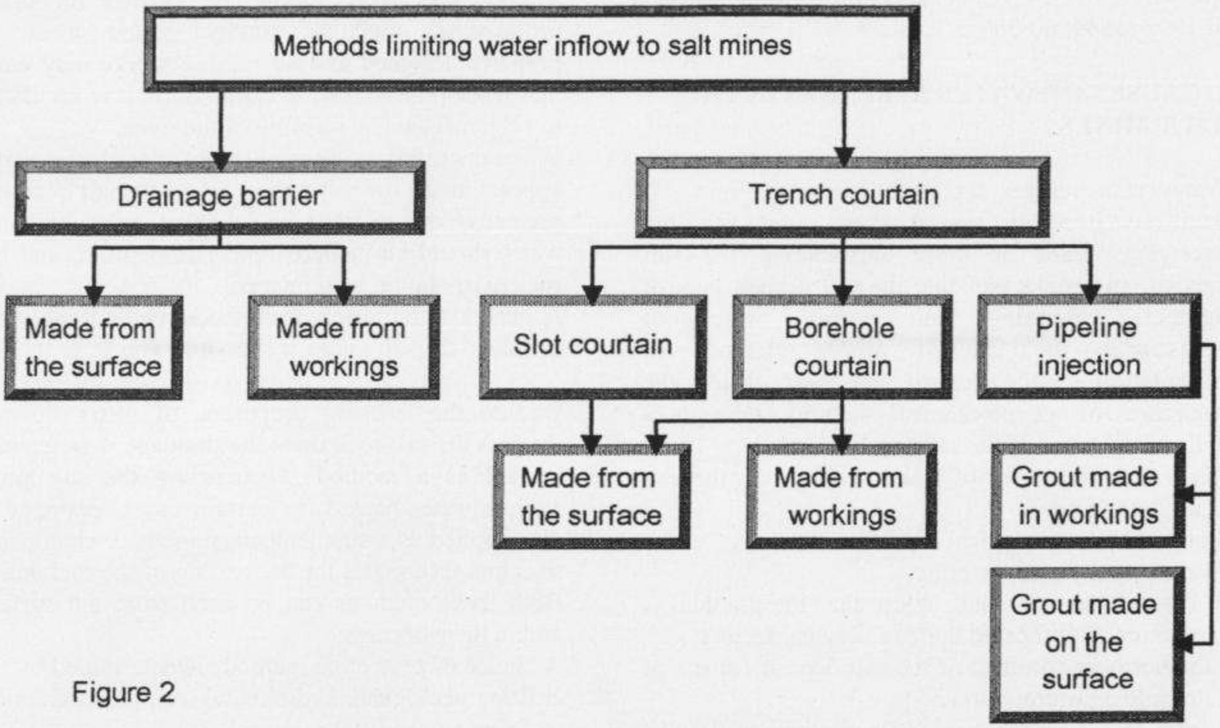

Figure 2

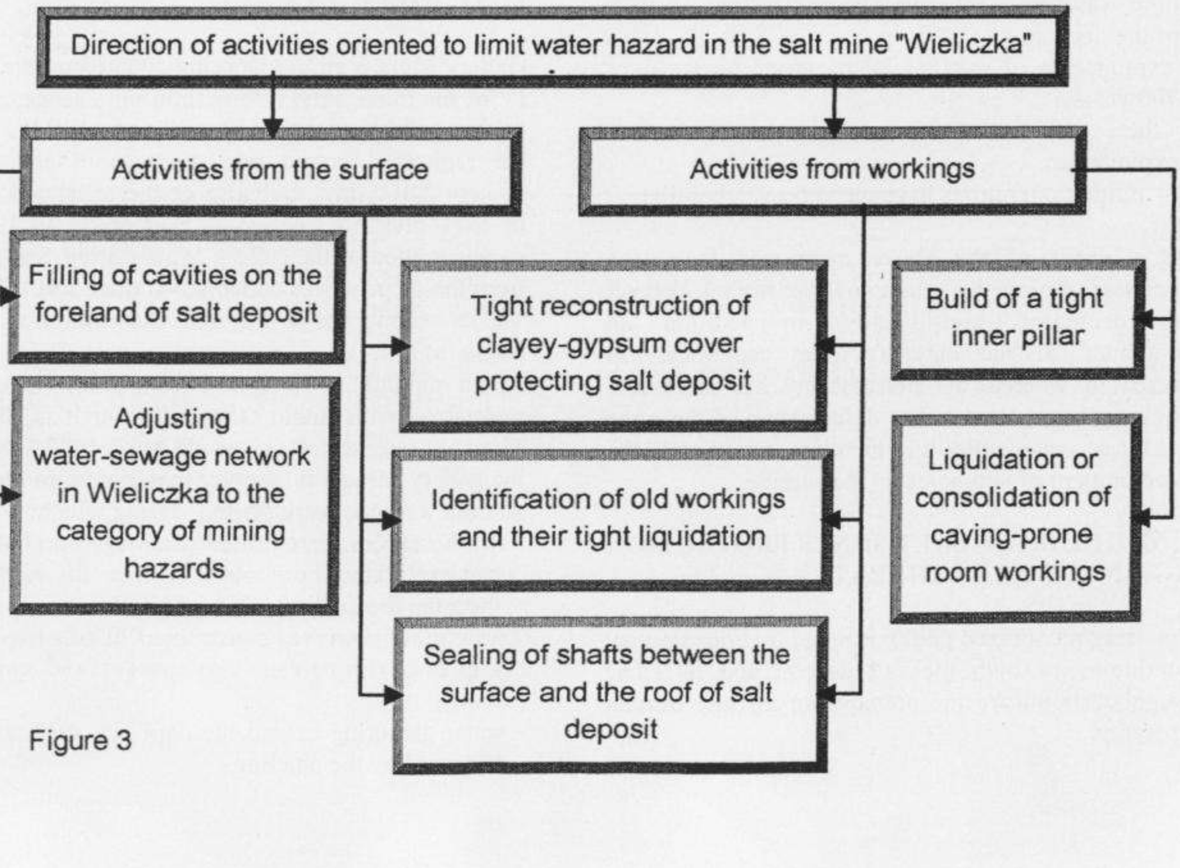

Figure 3

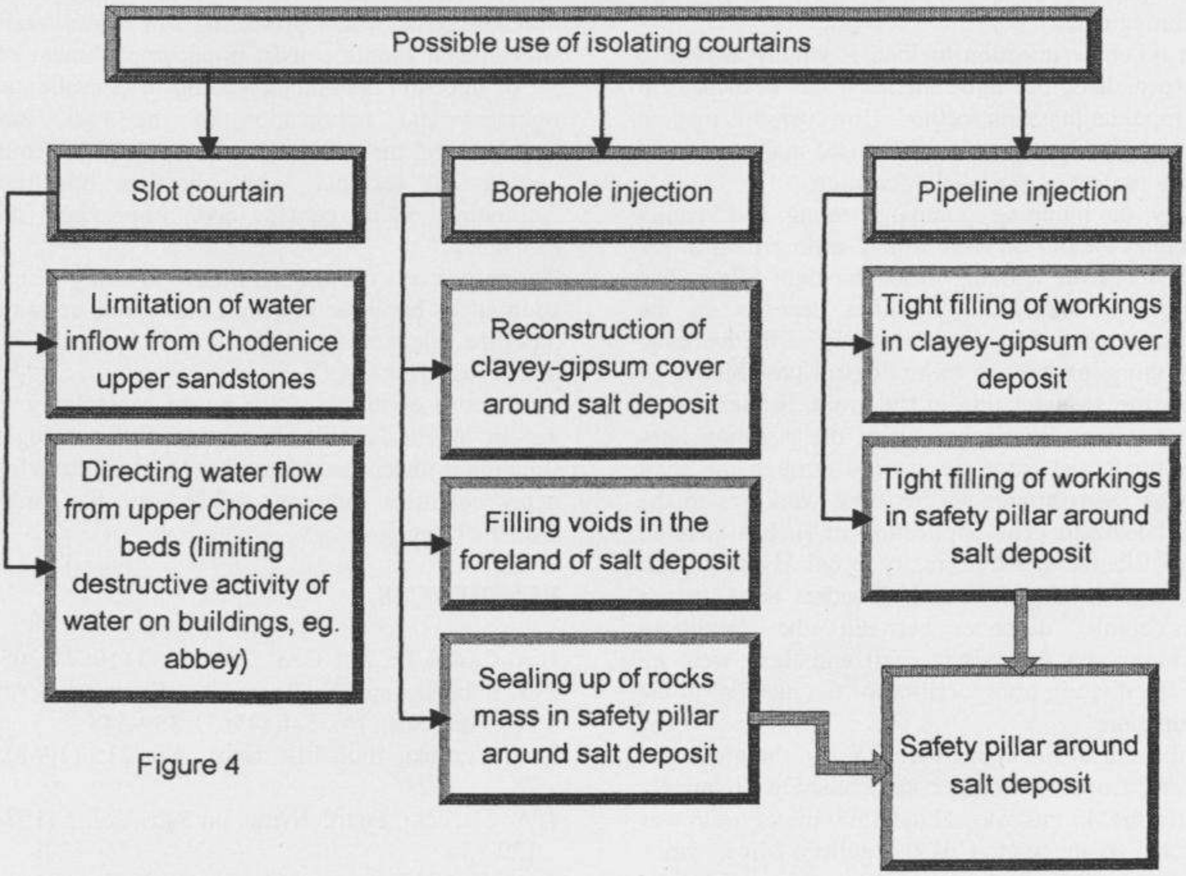

Figure 4

During those rescue operations the inflow was showing a pulsation, from 0 to 5 m^3/min. After the waterproof dam was constructed and the pipeline was shut off on 9 September 1992, numerous leakages around the dam appeared, passing into mud rush to the mine.

On the foreland of salt deposit the following phenomena were observed on the surface: subsidence exceeding 1500 mm, undulation and deviation of the railway rails, fall of the wall surrounding a monastery of Reformates and another damage of the abbey buildings, origin of the cracks and fissures within the Quaternery strata, damage of existing water-sewage system. The mentioned cracks and clefts have been filled up with clay and grout. The water-sewage system has to be rebuild with special reference to revealed mining damage and existing geomechanical conditions (Fig. 3). The clayey-gypsum cover (gypsum cap-rock shown in Figure 1) has been broken in places and needs tight reconstruction. These works together with liquidation of abandoned room workings create favourable conditions for reconstruction of a tight inner pillar in the mine.

For the rescue of the salt mine “Wieliczka” various protection works have been carried out. A general outline of these works is shown in Figure 3.

Basic works protecting the mine are injections for consolidation, tightening and stability of the rock mass. Drainage boreholes are auxiliary to create better conditions for injection works, and therefore to improve the safety of the mine.

Numerous possibilities of grout curtains are shown in Figure 4. In the salt mine “Wieliczka7” methods of borehole injection and pipeline injection are applied. Trench curtains (grout curtain) are not in use, mainly because of the existing geological and

hydrogeological conditions, as well as the high operating costs.
The borehole injection method is widely known to all specialists, but more attention has been paid to the pipeline injection method. However, this method has been rarely but successfully used in the course of works protecting the Wieliczka mine.
Firstly, the pumping, pumping-venting, and venting pipelines should be used with a sealing plug in the end part of the working meant for tight filling. The number of individual pipelines depends on the technical state of the liquidated part of the working, its volume as well as technological possibilities of preparing and injecting of the grout. In the case of the salt mine Wieliczka one of the pumping lines was conducted from the surface through the shaft Kinhga then through the existing workings to the liquidated part. The application of such a solution was attributed to the necessity to quickly secure the workings in direct hazard. Besides, there was a considerable distance between the liquidated workings and the closest shaft and there were no rails facilitating transportation of the material to the destination.
As a result of the applied technology, the grout was injected from the surface continuously in a relatively short time. In this way, about 1500 me of grout was injected in the region of the gallery Mina, which resulted in obtaining a tight filling of the ends of the galleries overlying and underlying the gallery Mina, (level IV): Badeni (level V), Poniatowski (level III), Kunegunda (level 11), the gallery to the shaft Rests („Dobudowa"- level 111) and the area of the gallery Mina (Fig. 1).

7. FINAL REMARKS

In case of the rush of water into mine, immediate drainage through the drainage borehole is advised in order to limit further leaching of salt and further destruction of rock formations in the vicinity of the borehole.Basic works protecting salt mines against water threat should consist in accomplishment of a set of injection operations leading to consolidation, tightness and stabilization of the rock mass. Drainage of the rocks should be simultaneously carried out together with injection operations, facilitating their course and improving their efficiency.
During rescue works in salt mines, in many cases in addition to borehole injection and grout curtain, a pipe-line injection should be widely applied for its numerous advantages.
As a result of the intensive works recently carried out in Wieliczka, the dangerous hydrogeological situation is under control and numerous visitors from many countries can now safely visit the famous touristic route.

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