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CAUSES AND CONSEQUENCES OF WATER FLUX ON THE EXAMPLE OF TRANSVERSE HEADING MINA IN THE SALT MINE "WIELICZKA"

PRZYCZYNY I SKUTKI DOPŁYWU WODY NA PRZYKŁADZIE POPRZECZNI MINA W KOPALNI SOLI „WIELICZKA"

The causes of disastrous water flux in the historical Salt Mine "Wieliczka" have been presented on the example of transverse heading Mina at the IV level at a depth of 175 m bsl. The complex geological setting of direct environment of the transverse heading Mina has been described paying attention to unfavorable hydrogeological conditions in the northern part of the salt deposit. The main activities oriented to limiting the water hazard in the Salt Mine "Wieliczka" and the reconstruction of inner safety pillar, which had been seriously damaged by mining activities, have been analyzed. A selection of objects inside the mine, saved from flooding thanks to protection works has been visualized in photos.

Keywords: salt mine, water hazard, Wieliczka

Na przykładzie zabytkowej Kopalni Soli „Wieliczka" przedstawiono co doprowadziło do katastrofalnego dopływu wody do poprzeczni Mina położonej na IV poziomie na głębokości 175 m ppt. Opisano złożoną budowę geologiczną bezpośredniego otoczenia poprzeczni Mina zwracając uwagę na wyjątkowo niekorzystne warunki hydrogeologiczne panujące od północnej strony złoża soli. Podano główne kierunki działań dla ograniczenia zagrożenia wodnego Kopalni Soli „Wieliczka" mające na celu odbudowę wewnętrznego filara bezpieczeństwa, który został poważnie uszkodzony wcześniejszymi robotami górniczymi. Pokazano wybrane obiekty znajdujące się wewnątrz kopalni, które dzięki pracom zabezpieczającym udało się uratować od zatopienia.

Słowa kluczowe: kopalnia soli, zagrożenie wodne, Wieliczka

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1. Introduction

The interior of the Salt Mine "Wieliczka", which was put on the UNESCO First List of World's Cultural and Natural Heritage in 1978, belongs to the most beautiful objects in the World. Its special value lies in the original geological build of the deposit, i.e. block in the upper part, and layered in the lower one, with beautiful sculptures and works of mining art. The exquisite Crystal Caves with beautiful halite crystals are the most spectacular elements of the mine.

The Salt Mine „Wieliczka" extends below the city area of Wieliczka and the neighboring villages. It has a rectangular shape (7 km × 1.5 km) with the mining area of over 9 km^2.

Over centuries there were made 9 levels and 2 interlevels in the mine. The total length of the galleries exceeds 200 km, and the volume of workings reaches about 6.5 mln m^3.

The Salt Mine "Wieliczka" has existed for over 7 centuries and now is an attraction visited by over a million tourists each year.

Getting rock salt with mining methods was very dangerous, frequently accompanied by the risk of fire, water and methane occurrence. Water fluxes in the mine several times seriously endangered both the mine and the town above it. The latest water flux of 1992 caused great damage, therefore it was necessary to undertake industrial and laboratory investigations and work out original technical and technological solutions which would protect the mine against such situations in the future.

2. Outline of geological setting and hydrogeological conditions

Geologically, the Wieliczka area is composed of the Jurassic, Cretaceous (Carpathian flysch), Tertiary (Miocene) and Quaternary strata. Figure 1 illustrates the complexity of geological setting of the deposit on the example of a cross section of the transverse heading Mina area, whereas cases of complex build of the deposit have been shown in photo 1.

The Jurassic strata are represented by rocky, compact, hard limestone with numerous silica balls.

The Cretaceous strata belong to the sub-Silesian and Silesian nappe unit, assuming the form of spotted, grey, grey-green shales, interbedded with numerous sandstone intercalations.

The oldest Tertiary strata are built of Skawina subsaline beds, represented by mudstones, marly claystones and evaporates in the form of chlorides and sulfates, as well as Chodenice oversaline beds represented by clays, mudstones and marls interbedded with brittle sandstones. Chodenice beds surround the salt deposit and their thickness ranges between some to 500 meters. The Bogucice sands occur under the Quaternary strata in the deposit area.

The Quaternary strata are constituted by Pleistcene and Holocene sediments, mainly loess and clays.

Four basic types of rock salt can be found in the deposit: green block salt, spiza salt, shaft salt and green layered salt. The salt deposit is surrounded by clayey-gypsum screen protecting it against water fluxes. Unfortunately, the protective area has been broken due to mining activities and some uncontrollable water fluxes occurred in the mine.

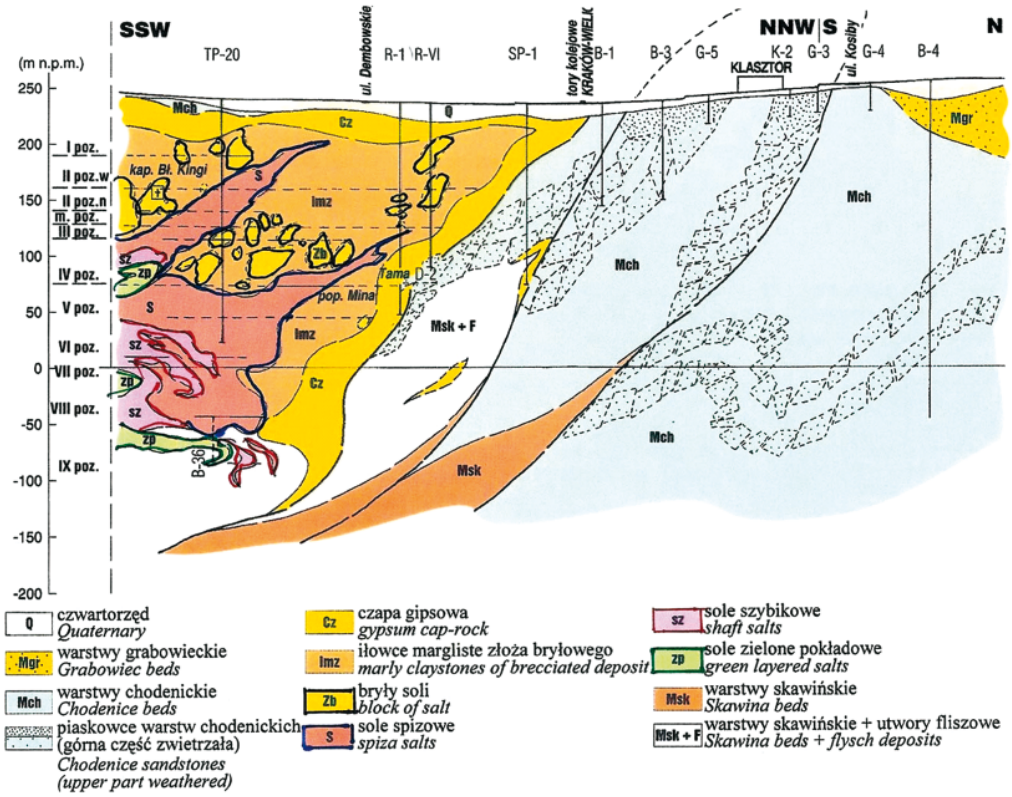

Fig. 1. Cross-section through the northern part of the mine in the transverse heading Mina area

The isotopic analyses reveal that the mine accepts water from various leaks and this is: glacial water, Holocene water, glacial water with admixed Holocene water and Holocene water with admixed recent water.

A more detailed description of geological setting and hydrogeological conditions can be found in papers by Brudnik et al., 2010, Garlicki & Wilk, 1993, Garlicki et al., 1994-95.

3. History of water leakages in the transverse heading Mina area

Before 1815 the first section of the transverse heading about 80 m long was performed between shaft Mirów and inclined heading Galicja. The works were continued, and in 1850-53 a section 240 m long was mined, stopping the front within saline Zuber of the brecciated deposit. In 1851 the name of the transverse heading Mina was used for the first time in the documentation. The last, northern section of the transverse heading was probably performed in 1908-1910 and was 30 m long. The first information about a water flux in the transverse heading Mina came from 1935; it says about water rate of 1 l/min and NaCl saturation of 240 g/l. The flux was localized

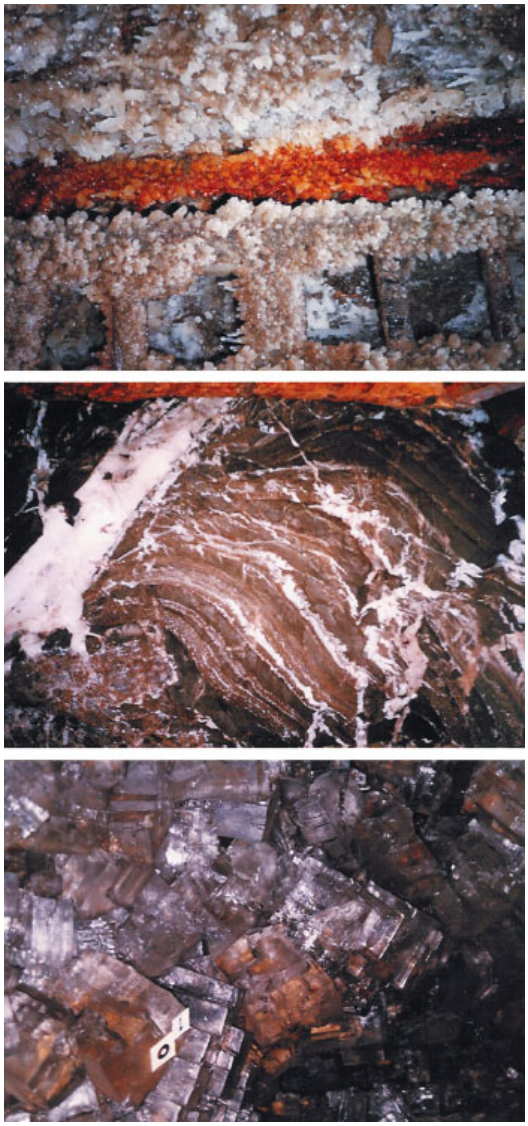

Photo 1. Examples of geological build of deposit in the Salt Mine "Wieliczka"

and intaken about 115 m from the northern head of the transverse heading. The successive data on the fluxes in the transverse heading Mina were as follows:

- 1948-51 rate 0.8 to 1.5 l/min saturation 107 g/l NaCl,
- 1957 2.2 l/min 110 g/l NaCl,
- 1969-70 1.2 l/min 300 g/l NaCl,
- 1971 (9 October) – 30 m before the northern head of the transverse heading a rapid flux and goaf of the working.

In 1989 a design was made for the end section of the transverse heading Mina. It was to be rebuilt to the area registered as W-IV-27. The works started in 1990 and in the third quarter of 1991 works were suspended for financial reasons. At that time the intensity of water flux was 4 l/min, and saturation 40 g/l NaCl. In the second quarter of 1992 the works were resumed.

On 7 April 1992 r., when the reconstruction head was 3.5 m off the end of the old working, a rapid increase of flow rate at the bottom of the working was observed. On 13 April 1992 water with solids rapidly rushed to the transverse heading Mina. The water rate at that time was estimated to be about 20 m^3/h. A rescue operation was administered immediately and the scope of necessary protection measures established, but this operation was disturbed on 17 April 1992 by another, more intense flux, which filled the transverse heading Mina with sediments almost up to the roof. In such a situation two wells were planned to be drilled from the surface to the expected zone directly feeding the water flux to the transverse heading Mina. The drilling of the rescue drainage well R-1 started. At a depth of 36 to 82 m the well R-1 reached the zone of strongly fractured sandstone and the drilling mud circulation was completely lost. After reaching a depth of 134 m the well R-1 was cased. The drilling was finished at 170 m of depth, i.e. correspondingly to the level of the transverse heading Mina. The results of investigations did not indicate any direct hydraulic connection between the flux in the transverse heading Mina and the performed well R-1. The water pumping from the well R-1 did not have any significant influence on the magnitude of flux in the transverse heading Mina, as the rate still was equal to 500 l/min. Unexpectedly on 2 June 1992 the flux to transverse heading Mina suddenly stopped, and on 4 June 1992 reappeared (200 l/min.) to completely disappear on the next day at 4.30 hrs. Between 5 June and 15 August 1992 the flux stabilized at a level of 0.3 to 1.6 l/min and saturation 50 g/l NaCl. At that time a dam in the transverse heading Mina started to be made. A block dam consisting of three segments was designed. It was preceded by a clay plug and a concrete dam, separated with a clayey-concrete segment. After the block dam was performed, 35 m^3 of water solution of clay and clayey-cement slurry were injected underneath. In 15-17 July 1992 and 3-4 August 1992 the concrete segment of the dam was construed, whereas on 19 August 1992 the space between the block dam and the concrete dam was filled with the clayey-cement slurry.

A number of injection wells were drilled around the concrete segment and the cement slurry was introduced to reinforce the rock mass around the dam.

To implement this concept, a pipeline was installed in the dam, through which water gathering behind the dam was constantly discharged. The flux rate at that time was ranged from zero to 5 000 l/min. On 9 September 1992 numerous leaks appeared behind the discharging pipe, and then over and under the dam and from the cavern a few meters before the dam.

On 11 September 1992 a subsidence trough was observed on the surface. The maximum lowering of the terrain on that day was 0.3 m, to later increase to over 2 m. The railroad (Wieliczka-Wieliczka Marketplace section) became undulated and deformed (Photo 2), and part of the wall around the Reformati monastery collapsed. Dangerous cracks appeared on the walls and ceilings of the monastery (Photo 3) and the neighboring buildings, threatening their stability. Additional factor deteriorating the situation was the fractures (Photo 4) over 1 m in width and 5 m depth in the slope on which the monastery was sited, and cracking of the main collector in the area of the subsidence trough.

Protection works lasted many years (Gonet & Stryczek, 1992, Gonet & Stryczek, 1993, Stryczek & Gonet, 1993a, Stryczek & Gonet, 1993b, Stryczek et al., 1995) and were conducted with various intensity mainly due to the financial problems. This led to closing the bar in the last

drainage well in 15 October 2007, and so shutting the inflow to the transverse heading Mina. Accordingly, the balance of fluxes to the mine since 13 April 1992 was the following:

- summaric yield from the leak – 1 037 596 m³,
- quantity of moved solids – 64 089 Mg,
- quantity of Na Cl brought by leak waters – 10 635 Mg.

The area is being constantly monitored (d'Obyrn & Brudnik, 2011).

Photo 2. A view on the railroad and wall around the monastery

Photo 3. Fragment of supported roof of the monastery

Photo 4. A view on the fractures and wall around the monastery

4. Causes of leaks

In the case of the Salt Mine "Wieliczka" we can speak of a variety of factors causing leaks. Among the most important ones are natural geological and hydrogeological conditions connected with mining activity, which is not always at the highest technological level. It should be emphasized that previously the geological recognition of the deposit was at a low level and this aspect was mainly responsible for undertaking many exploitation activities. Besides, the untight main collector in the area of most prominent subsidence in the transverse heading Mina, which was staying within the area of influence of the Chodenice layers, which were supplying water to the mine, also deteriorated the leak situation. Among the unfavorable natural conditions are:

- high watering of the northern forefield of salt deposit appearing close behind the protective clayey-gypsum screen,
- enormous water reserves gathered in the surrounding Chodenice layers, constantly supplying water to the northern forefield of the deposit,
- considerable water pressure on clayey-gypsum protective screen resulting from high water level in the northern forefield of the deposit and depth of production levels.

Among the most important causes of leaks in the mine are:

- disturbing of the northern clayey-gypsum screen around the deposit with workings,
- localization of production rooms, sited too close to the clayey-gypsum protective screen,
- existence of unidentified historical workings inside the mine and in the northern forefield of the deposit,
- disturbing the tightness of salt deposit roof with vertical workings, mainly in the form of shafts and backfilling boreholes.

Another element increasing the problem of water flux to transverse heading Mina was the lack of tightness of the main sewage collector in Wieliczka. The collector had to be closed and replaced with a new one, resistant to possible lowerings of terrain in that area.

All this resulted in weakening of the safety pillar (Fig. 2), which at a certain point in time could not withhold the pressure of water which rushed into the transverse heading Mina.

5. Activities limiting the water hazard

Works connected with working out an efficient method of sealing the rock mass, which would eliminate water flux to the salt mines, are very difficult because of unfavorable operation of brines on the rock mass and sealing slurries and require efficient cooperation of many specialists. It should be emphasized that at the time of disastrous water flux to the transverse heading Mina the closing method was not known in the World's mining practice; most of salt mines were traditionally flooded when they fulfilled their technological tasks.

This however cannot be done to such outstanding historical object as the Salt Mine "Wieliczka". There were undertaken multidirectional activities both from the surface and from accessible workings. The linking of hole injection and original pipeline injection methods turned out to be a success. Most of the operations have been presented in detail in numerous papers (Garlicki et al., 1994-95, Garlicki et al., 2004, Gonet & Stryczek, 1995, Stryczek & Gonet, 1992) therefore will not be discussed here. Figure 3 is their brief illustration.

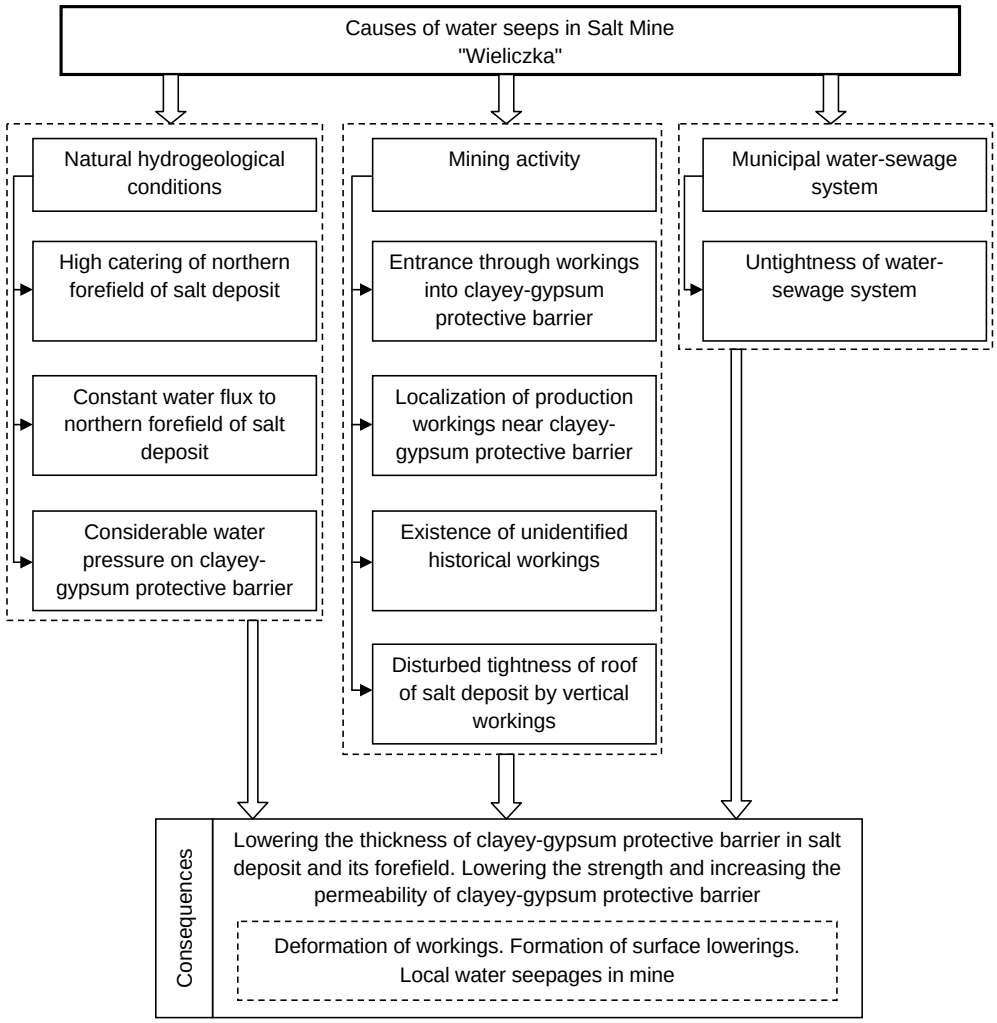

Fig. 2. Block diagram illustrating causes of water fluxes in the Salt Mine "Wieliczka"

As a result of those activities, this dangerous water flux was managed and the unique at World's scale historical object preserved for the future generations. Below are presented some saved elements of the mine (Photos 5-8), which the Reader may find worth seeing in nature sometime.

It is also worth noting that in a number of cases preventing potential water fluxes turned out to be far more advantageous than fighting with the consequences, administering very expensive rescue operations and renovation of damaged objects on surface as it was the case, e.g. in the monastery (Fig. 9).

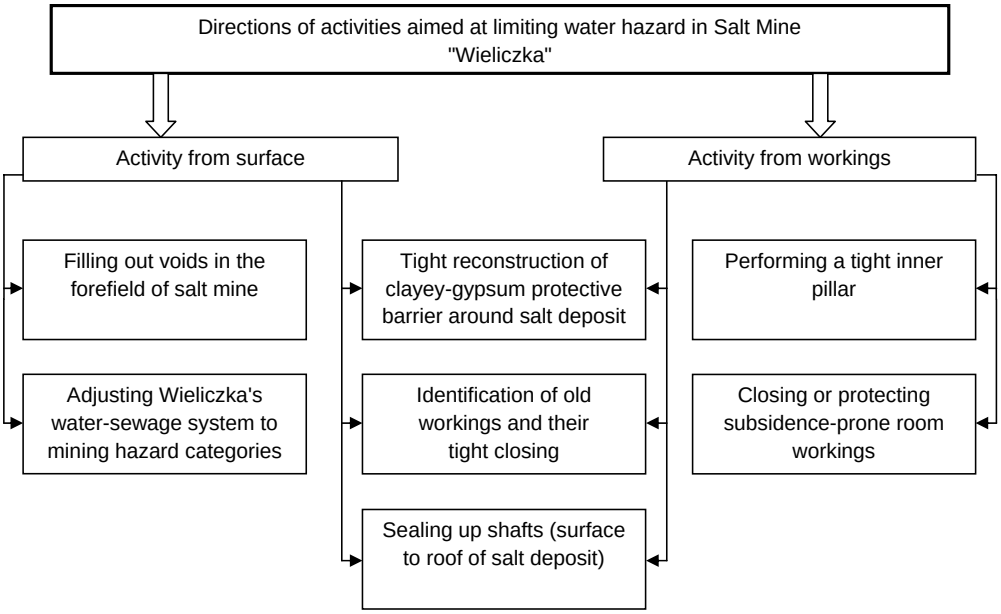

Fig. 3. Activities aimed at limiting water hazard in the Salt Mine "Wieliczka"

Photo 5. Fragment of Crystal Cave

Photo 6. Józef Piłsudski Chamber

Photo 7. St. Kinga Chapel

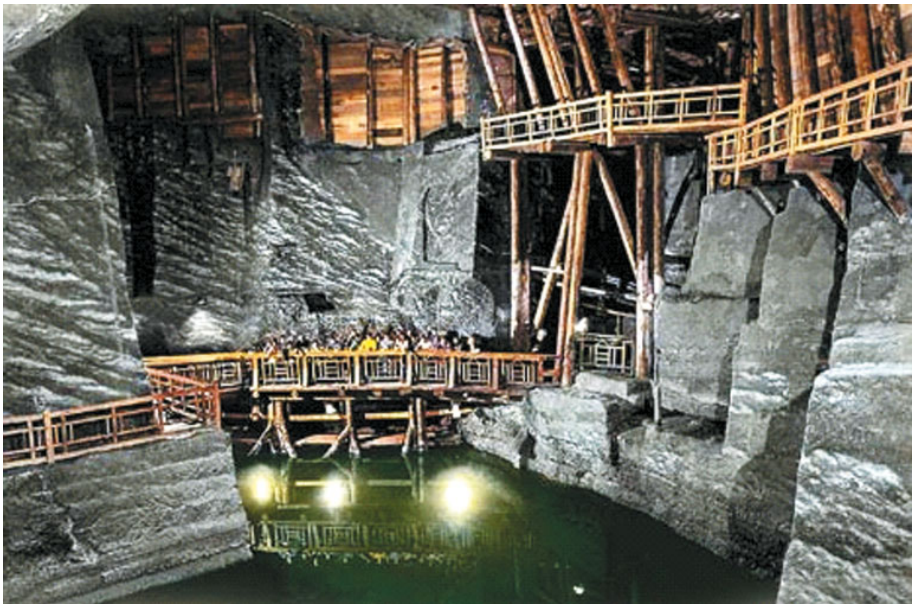

Photo 8. Erazm Barącz lake

Photo 9. View on the Reformati Monastery during its renovation after a disastrous water flux in the transverse heading Mina

6. Conclusions

1. The geological setting in the transverse heading Mina area is very complex. From the north, behind the clayey-gypsum screen, the Chodenice beds collect considerable amounts of water, which constitutes the greatest hazard for the Salt Mine „Wieliczka".
2. The main causes of water leakage in the Salt Mine „Wieliczka" are considered to be:
   – unfavorable hydrogeological conditions in the northern part of the salt deposit,
   – long-lasting mining activity, especially the one performed years ago, in the northern protective screen, lowering its thickness and strength, increasing permeability and consequently, loss of stability.
3. Consequences of uncontrollable water flux to the transverse heading Mina were visible on surface and in the workings. Thanks to the use of new technologies the leakages could be managed and the mine in the transverse heading Mina protected.

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