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title: **Hydrogeology monitoring results obtained at the "Wieliczka" Salt Mine following the elimination of water inflow in the Mina traverse at Level IV**

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The threat of water is considered the biggest natural hazard to the Wieliczka Salt Mine. Currently, this threat is posed by water inflows called mine leaks. The sources of these leaks are the Chodenice layers localized in the northern part of the salt deposit. Hydro-geological monitoring consists of measurements of water capacity inflow and chemical testing. Isotopic investigations are also performed, as well as gravimetrical measurements in the northern border zone of the deposit. Gravimetrical measurements have been conducted temporarily, since the emergency inflow to the Mina Gallery on Level IV. This inflow, during 1992–2007, was considered as the biggest hazard for the mine and to the city of Wieliczka. Results of the monitoring concluded, that after closure of inflow to the Mina Gallery, the quantity and quality of other mine inflows (Fornalska 2 Gallery on Level VII and Z-32 Chamber on Level VI) have not changed. Observations of pressure in the D-2 and D-3 drain holes and water level in the B-3 piezometer indicate that water levels in the deposit are returning to pre-1992 levels. This process has also been confirmed by gravimetrical measurements.

Monitoring of hydro-geological phenomena, within which measurements of the efficiency of all registered water inflows to underground excavations and also chemical analysis of incoming waters, is conducted. Hydro-geological phenomena observed in the excavations of the Wieliczka Salt Mine called mining leakages are natural inflows of brine from behind the deposit or brines circulating within the deposit, due to inaccurate intake of inflows on the higher levels of the mine (Brudnik et al., 2006).

The dimensional layout of all hydro-geological phenomena registered on mining maps indicates (Brudnik et al., 2006):

- the occurrence of leakages of the lowest salinization in the northern border of the deposit;
- the presence of NaCl unsaturated leakages in the vicinity of the northern border of the deposit and in the region of under-saline layers occurrence;
- the localization of leakages of the highest capacity in the vicinity of the northern border of the deposit;
- the presence of numerous leakages of high NaCl salinization over 300g/dm^{3}and diverse capacity in the central part of the deposit.

Table 1. presents a sheet with mine leakages on several levels with a specification of the range of their capacity, according to data from 31.12.2009

Table 1. Leakage sheet in the Wieliczka Salt Mine.

Inflow volume [dm^3/min.]	**Number of leakages on mining levels**										**Total number of leakages**
	I	IIh	IIl	III	IV	V	VI	VII	VIII	IX	
< 0,1	26	13	16	17	9	12	4	2	1	1	**101**
0,1 - 1,0	3	4	4	9	10	3	11	6	3	-	**53**
1,0 - 10,0	1	-	-	1	2	-	1	1	-	-	**6**
> 10,0	-	-	-	-	-	-	2	1	-	-	**3**
Total	**30**	**17**	**20**	**27**	**21**	**15**	**18**	**10**	**4**	**1**	**163**

Hydro-geological conditions of the "Wieliczka" deposit, showed in details in the hydro-geological documentation (Górka et al., 2009) indicate that the highest inflows to the mine are supplied by the sandy Chodenice layers, classified as of Middle Miocene origin, occurring in the

northern forefield of the rock salt deposit. A number of these inflows, in time of their formation, had a catastrophic character endangering the mine's existence.

These leakages appeared in the Kloski and Colloredo traverses on levels V and IV in the 19th century and to the 6-67 hole in the Kosocice longtitude on level VI, to chambers Z-32 on level VI and Fornalska 2 on level VII and also to the Mina travers on level IV in the 20th century.

Inflows to the Kloski and Colloredo traverses are seized at present in the Regis longtitude on level VI, and their total capacity does not exceed 3 dm^3/min. Whereas the inflow to the 6-67 hole has been dammed by means of water dams nr. 3 in the Gussmann longtitude on level V and nr. 4 in the Kosocice longtitude on level VI.

The largest active inflows are at present inflows captured under the Z-32 chamber on level VI and in the Fornalska-2 chamber on level VII.

In October 2007, after a 15 year old period of conducting protective works in the Mina traverse, the valves on drainage holes, used for water seizure, have been closed. This inflow, symbolized in the mines leakage evidence as WIV-27, supplied by the Chodenice layers, was considered the most dangerous water inflow into the underground excavations of the "Wieliczka" Salt Mine in the years 1992–2007. The pulsative character of this inflow differentiating from a few to a few thousand dm^3/min. and the variable content of solid fractions elevated by water, maximum 1593,16 g/ dm^3, caused danger to the safety of the underground "Wieliczka" Salt Mine and to the city located above the mine (Garlicki, Wilk, 1993).

Protecting the mine from the water inflow into the Mina traverse was aimed at constructing a dam against water consisting of timber, clay and concrete segments closing the periphery of the excavation, drilling drainage bores D-1, D-2 and D-3 enabling water drainage from behind the dam and also sealing the orogen with the hole injection technique in order to generate a spatial bowl sealing the peripheries of the Mina traverse (Gonet et al., 1997).

Completion of works aiming at sealing the orogen surrounding the peripheries of the Mina traverse allowed to liquidate the drainage hole D-1 and then to close the valves on the drainage holes D-2 and D-3 (Bromowicz, Brudnik, 2007). Complete closure of the water inflow into the Mina traverse was the result of the undertaken measures.

After closing the water inflow into the Mina traverse the inflows in the Fornalska 2 chamber and beneath chamber Z-32, symbolized as WVI-16 and WVI-32 in the mining leakages register, have the largest share in the total inflow into the underground excavations of the Wieliczka mine.

In 2006, ergo before closing the inflow into the Mina traverse, those inflows constituted jointly 54% of the total natural inflow into the mine's excavations, which totalled in 202.566 m^3. In 2008 those inflows represented 81 % of the total natural inflow, amounting 135.834 m^3, whereas in 2009 these inflows presented 80 % of total natural inflow amounting 134.028 m^3.

Analysis of conducted measurements of the capacity of inflows in the Fornalska 2 chamber and beneath the Z-32 chamber and also of chemical determination allow to state that closing the water inflow into the Mina traverse did not cause changes in those inflows. The dimension of the inflows in the Fornalska 2 chamber and beneath the Z-32 chamber uphold within the limits registered before closing the water inflow into the Mina traverse (Fig. 1).

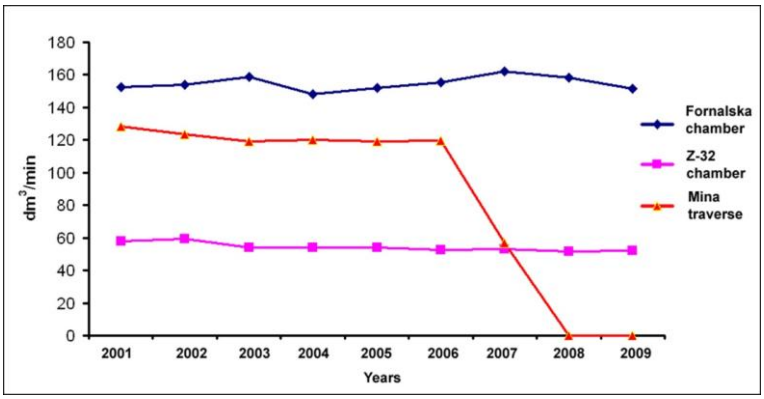

Figure 1. Average dimension of the water inflow into the Fornalska 2 chamber, the Z-32 chamber and into the Mina traverse in the years 2001 – 2009.

A similar tendency is noticed in reference to salinization of these inflows. No significant changes of NaCl content in the inflow into the Fornalska 2 chamber and in the inflow into the Z-32 chamber are observed (Fig. 2).

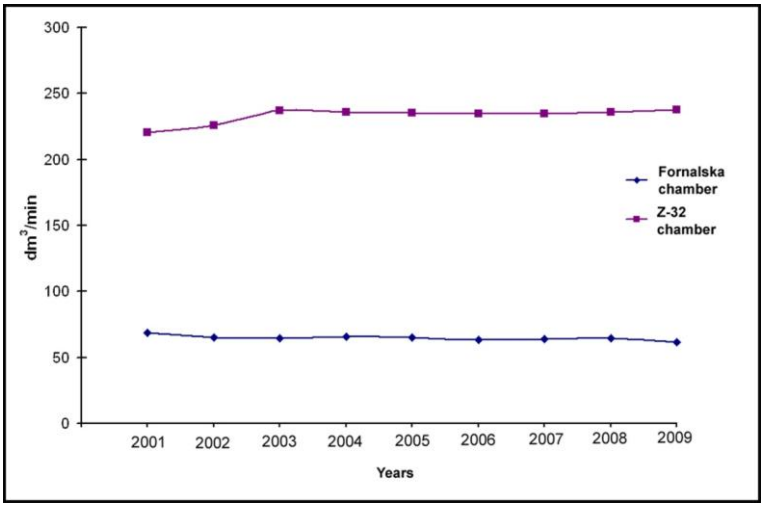

Figure 2. Average NaCl content in the inflow into the Fornalska 2 chamber and the Z-32 chamber in the years 2001–2009.

Registration of pressure changes observed on manometers built on closed drainage holes D-2 and D-3 is conducted within the hydro-geological monitoring in the Mina traverse, whereas from the surface level measurements of the water table in the piezometric bore B-3 are conducted. This bore registers changes of the position of the water table within the sabulous Chodenice layers formations located in the northern forefield of the Mine traverse.

Readings of the pressure of manometers installed on the drainage holes D-2 and D-3 have shown its rapid growth after closing the inflow in the Mina travers and stabilization on the level of 1,5 MPa (Fig. 3).

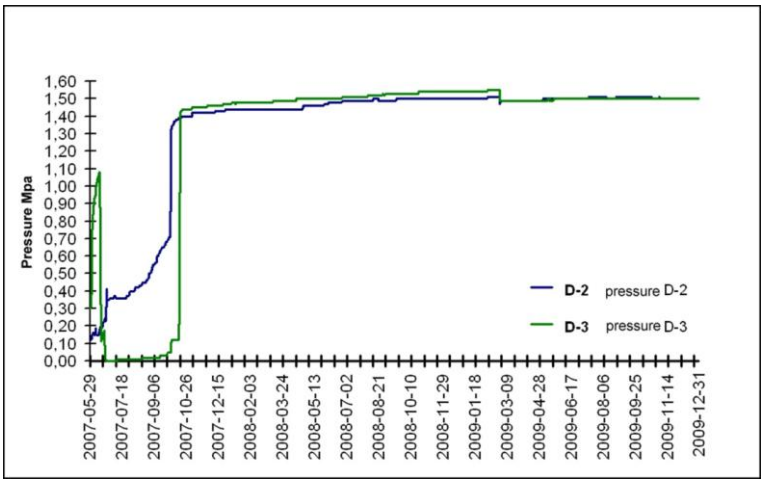

Figure 3. Pressure changes registered on drainage holes D-2 and D-3 and in the Mina traverse in the period 29.05.2007–31.12.2009.

Rapid growth of pressure indicates lack of free spaces in the sealed orogen area on the northern forefield of the Mina traverse. On the other hand stabilization of pressure indicates complete restoration of the level of waters in the orogen to the condition from before 1992. This state is confirmed by measurement data from registering the position of the water table in the piezometric bore B-3 (Fig. 4).

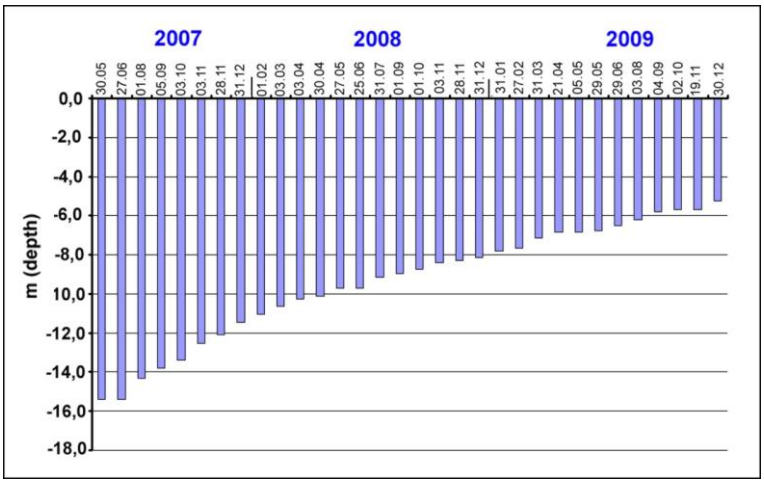

Figure 4. Position of the water table in the piezometric bore B-3 in the period May 2007–December 2009.

The state of restoration of the water level has been proved with gravimetrical research conducted on the northern forefield of the deposit in the area of the Mina traverse in the years 1992-2007 (Madej et al., 2008). Gravimetrical research conducted in 2006 and 2007 have shown the restoration of state of the orogen in the area of the Mina traverse forefield to the state from 1992. The research proved the thickening of the orogen in depleted areas due to

water inflow into the Mina traverse. The area closest to surface of the orogen was influenced by this process in particular (Madej et al., 2008).

The results of hydro-geological monitoring conducted in the Wieliczka mine, indicating lack of relevance between the closure of the water inflow into the Mina traverse and the dimension of the inflow and NaCl salinization of the main mining leakages supplied as the inflow in the Mina traverse by the Chodenice layers, are convergent with the results of isotopic research conducted annually since 1973 on water sampled from mining excavation inflows (Zuber, Duliński, 2004). The authors of this research claim that there is a large number of water subsystems in the Chodenice layers, which despite the presumably existing general hydraulic link, are clearly separate.

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