HYDROGEOLOGICAL ASPECTS OF THE SHUTDOWN OF THE IDRIJA MERCURY MINE

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ABSTRACT

In 1988 a decision was adopted on the definite shutdown of the Idrija Mercury Mine, where the only existing liquid metal on the globe was excavated for an uninterrupted period of more than 500 years. This paper presents the hydrogeological aspects of shutdown works. The construction of a water gate separating the Ljubevc ore deposit from the older Idrija ore deposit was an attempt to reduce inflows of water into the pumping pool. Despite our good knowledge of the geological structure and hydrological conditions, inflows from the isolated part of the deposit reappeared, reducing the level of ground water in the Ljubevc ore deposit to the level of the flooded part of the Idrija ore deposit.

Key words: shutdown of the mine, hydrogeology

INTRODUCTION

The complete and permanent shutdown of mining activities calls for the adequate liquidation of all pit facilities. For economic, technical-technological and environmental reasons, the Long-term Programme for the Gradual, Complete and Permanent Shutdown of the Idrija Mercury Mine was prepared in 1986 and adopted in 1988 (Cigale, 1988). The shutdown of the mine is progressing gradually, from the lowest, 15th level (-36 m b.s.l.), towards the surface (main shaft: 348 m a.s.l.), and is accompanied by reinforcement works, since the greater part of the mine lies directly below the town of Idrija. The ore deposit extends in the directions north-west and south-east. It is 1500 m long, 450 m deep and 400-600 m wide. The mine was comprised of 15 levels reaching a depth of 384 metres. The complex geological structure is the consequence of several tectonic phases, which divided the original ore deposit into two major sections: the Idrija ore deposit and the Ljubevc ore deposit. The hydrogeological conditions in the Idrija ore deposit were relatively favourable until the opening of new fronts and their advancement in the direction of the Ljubevc ore deposit, which resulted in increased inflows of water on the XIVth level. To prevent sudden inrushes of water from new works into the old part of the mine, a water gate was constructed. In the first phase of the mine's gradual shutdown, the water gate was closed in 1988.

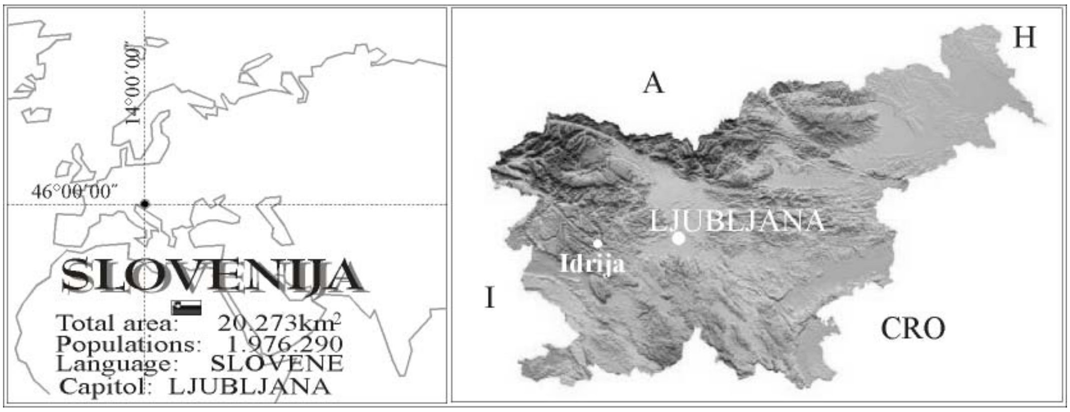


Figure 1: Idrija, geographic position

LJUBEVC ORE DEPOSIT

The Ljubevc ore deposit, discovered 40 years ago, was cut off from the Idrija ore deposit by the tertiary Idrija fault and was shifted 2.5 km south-east along the fault. An exploration shaft on the XIVth level connected the new ore deposit with the old part of the Idrija mine. This road served as the only access and communication line to the new pit (transport to and from the pit, ventilation, drainage...) To prevent and reduce the hazard of sudden inrushes of water into the old part of the mine during opening works, a water gate was constructed in 1971. The location of the water gate was selected in the geologically and hydrologically most favourable part of the road line – behind the contact between the ore deposit and the surrounding rocks (Figures 2, 3).

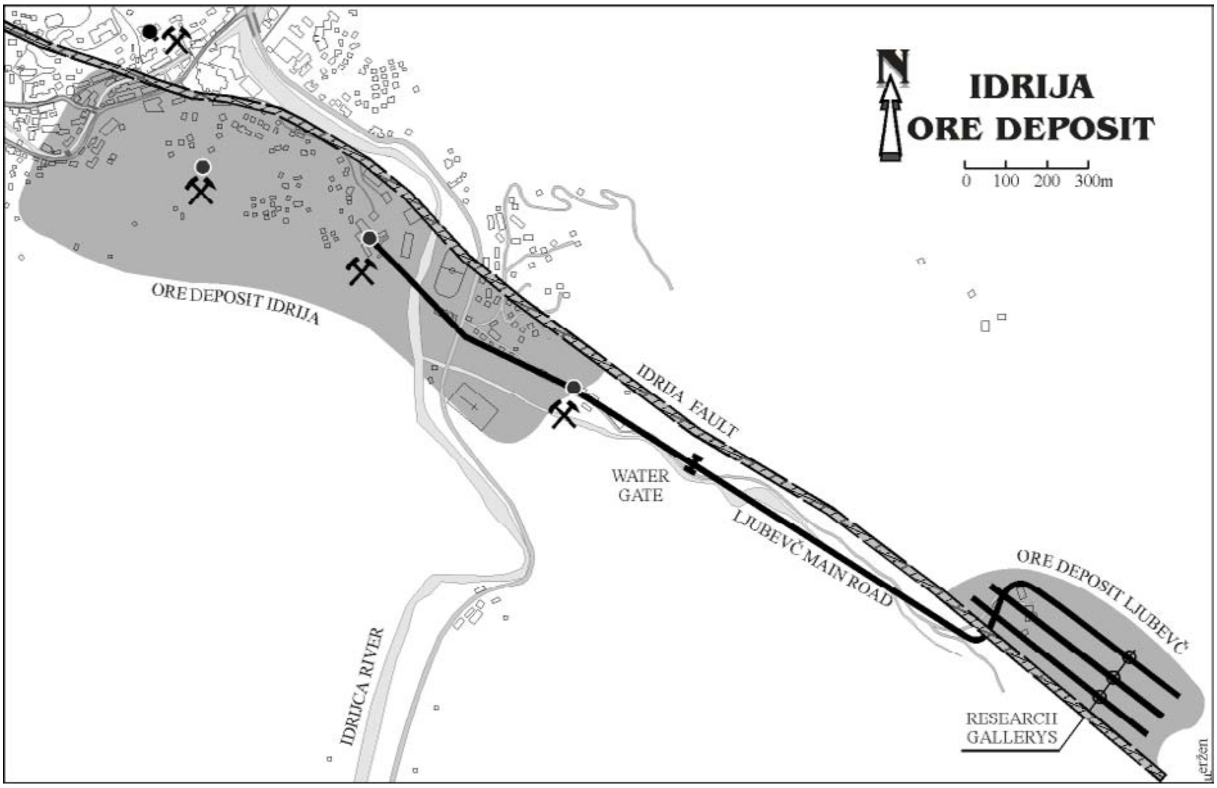
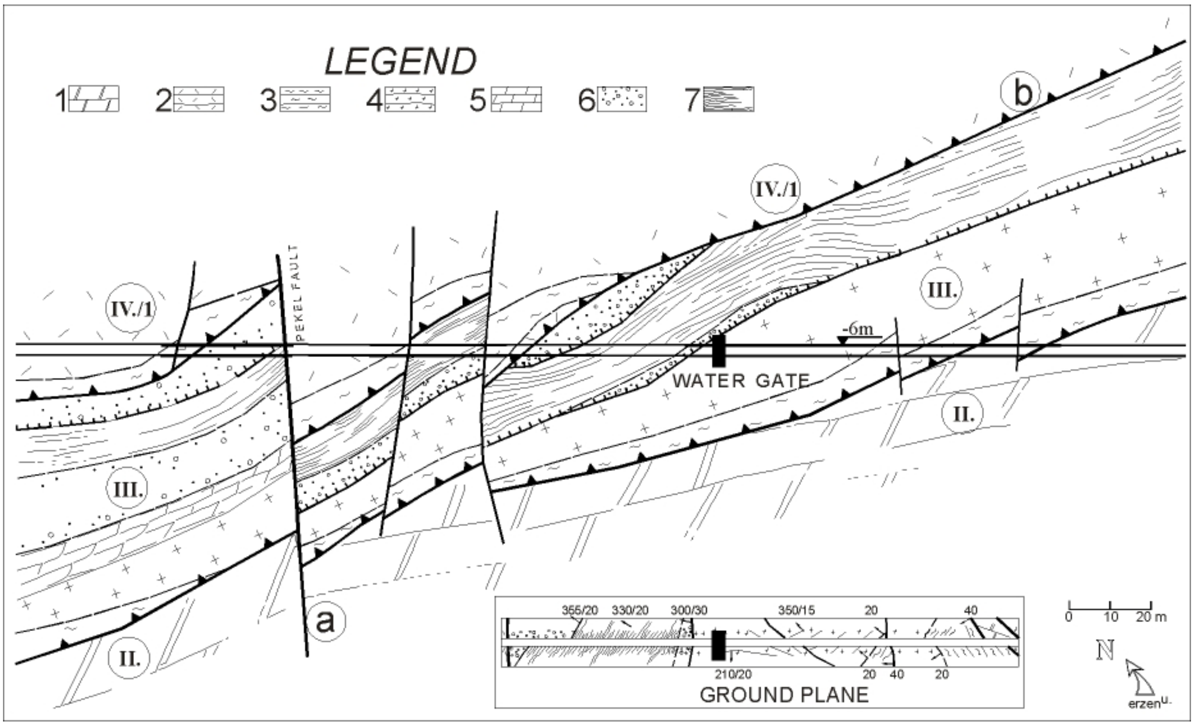


Figure 2: Positions of the Idrija ore deposit and the Ljubevc ore deposit

Geological Structure of the Water Gate Area

The first part of the road runs through rocks of the ore deposit structure comprised of lower Triassic (Scythian) dolomite with marl intercalations and gray shale (IV/1 - Idrija inner thrust sheet). Shifts near the tertiary faults resulted in multiple repetitions of individual rock strata. Below the overthrust that follows are rocks belonging to the floor rocks of the ore deposit structure, lying in inverse order (III - Kanomlja interjacent slice). The layers of Carboniferous shale are followed by Groeden sandstone. Paleozoic rocks are separated from the Lower Scythian sandy micaceous dolomite and marl by a smaller overthrust. The water gate is located directly below the impermeable Carboniferous clastites in dolomite strata, whose thickness in the road area exceeds 100m. After passing through the overthrust, the road struck Upper Triassic Norian-Rhaetian dolomite forming part of the Cekovnik interjacent slice – II. The road runs through Upper Triassic dolomite in a length of 1000 m all the way to the Idrija fault (Figure 3).

The rocks in the surroundings of the water gate are considerably crushed. These deformations are primarily the consequence of thrust geological activity. This applies in particular the Kanomlja interjacent slice (III), which is enclosed on both sides by the overthrust. Intercalated between the Carboniferous and Groeden layers are also inner thrust sheets. In the direct vicinity of the gate runs the strong tertiary Pekel fault comprised of an inner milonite zone with a thickness of a few metres and a broad external fault zone with numerous fault planes.



Legend: 1- light grey bedded dolomite ($^1T_3^{2+3}$), 2- grey granular dolomite ($^1T_1^2$), 3- calcareous micaceus clay, siltstone and sandstone ($^5T_1^1$), 4- gray sandy micaceus dolomite ($^3T_1^1$), 5- black and grey bedded dolomite ($^1P_3$), 6- grey quartz sandstone and conglomerate ($^2P_2$), 7- black shaly clay siltstone, sandstone and conglomerate (C,P) II.-Cekovnik interjacent slice, III.- Kanomlja interjacent slice, IV/1.- Idrija inner thrust sheet, a.- tertiary fault, b.- overthrust

Figure 3: Geological profile of the Ljubevc road in the water gate area

Hydrogeological Conditions in the Water Gate Area

As expected, the part of the road running through the pit structure was completely dry. The first smaller inflows appeared after breaking through the overthrust into the surrounding rocks. Behind the highly impermeable hydrological barrier of Carboniferous rocks appeared the first inflows from the crushed Groeden sandstone. The inflow of water increased substantially after the break through the Cekovnik interjacent slice (II), which is mainly comprised of Upper Triassic dolomite. During the advancement of the road towards the Ljubevc ore deposit, the total inflow of water reached 33 l/s. The area was gradually drained and before the closing of the water gate the average water flow into the pumping pool was 26.6 l/s, primarily on the account of inflows from the Upper Triassic dolomite stratum, which represents an open aquifer linked to surface waters above the Ljubevc ore deposit. The water gate was constructed in 1968, and the surrounding rocks were gradually sealed in the period up to 1972. The process was complex and long-lasting, since a pressure of up to 39 bar was expected after the closing of the gate. The injection works lowered the permeability to a range of: 10^{-6} to 10^{-7} m/s.

GRADUAL SHUTDOWN OF THE LOWER PART OF THE MINE

The works foreseen in the first phase of shutdown included the closing of the water gate and the flooding of the Ljubevc ore deposit, the abandonment of the pumping

facility on the XIVth level and the gradual flooding of the old Idrija ore deposit up to the XIth level (65 m a.s.l.), where a temporary pumping facility was set up.
On the basis of measurements of water flows into the remaining part of the ore deposit, the pump capacity was adjusted to the expected rate of 30 l/s, but with a compulsory reserve. The plans did not foresee the reoccurrence of larger inflows from the Ljubevc ore deposit in the final phase of the mine's shutdown up to the year 2006.

Flooding of the Ljubevc and the Idrija Ore Deposits

The water gate in the Ljubevc road was closed in October 1988. A manometer was installed for the purpose of measuring the rising of the water level in the abandoned pit. After the lower part of the Idrija ore deposit began to be flooded, the manometer was moved to the XIth level. The level of underground water in the Ljubevc ore deposit continued to rise until July 1997. The pressure gradually reached 30 bar (30+6.5: corresponding to the high difference between the XIVth and XIth levels), which is in line with the prognoses based on our knowledge of the geological structure of the open aquifer in Upper Triassic dolomite (Figure 4). Following the completion of the temporary pumping facility on the XIth level and the backfilling of shafts between the XVth and XIth levels with concrete, the lower part of the Idrija mine began to be flooded in October 1992 and the pumps on the XIVth level were stopped and disassembled. The rising of water in the ore deposit progressed according to the forecast (Petric, Janez, 1997). The actual rate of flooding of the area between the XIIth and XIth levels was slightly less than that forecast. The diference was attributed to the lack of available data on the size of backfills in the ore bodies excavated prior to the First World War (Rezun, Dizdarevic, 1997). During the flooding of both parts of the mine, the underground water level in the Ljubevc ore deposit rose at a quicker rate than in the Idrija ore deposit. The pumps in the new pumping facility were put into operation for the first time in November 1994, when the water reached the XIth level.

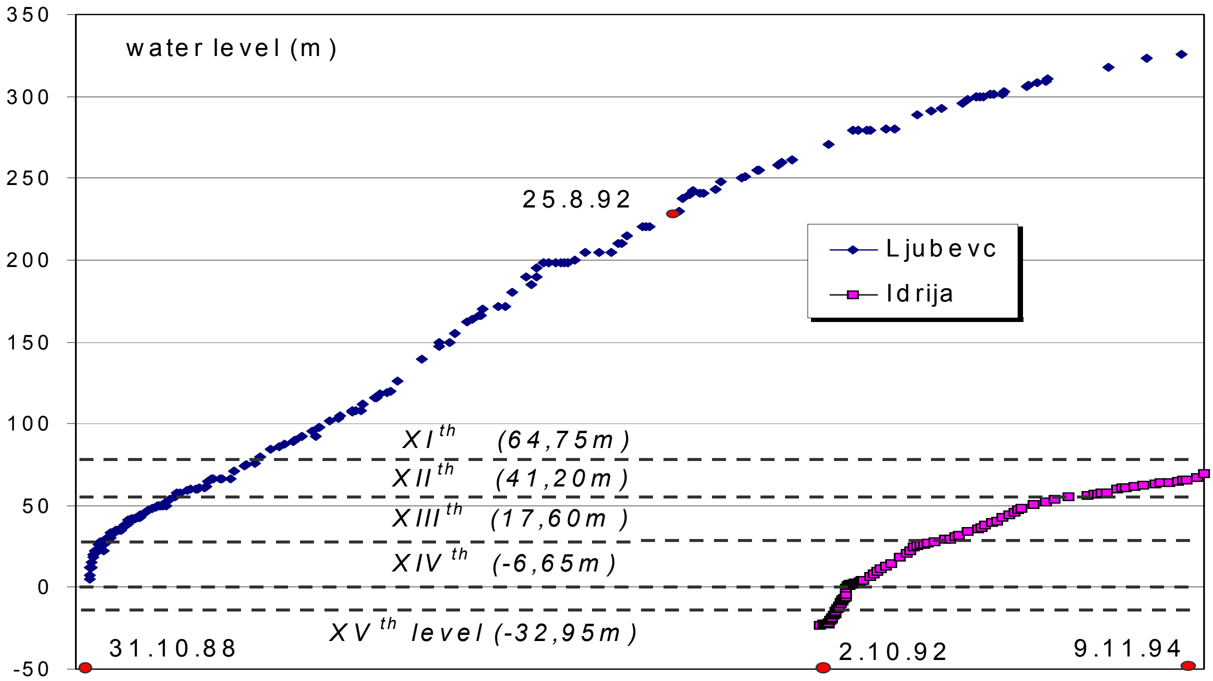


Figure 4 :Rising of underground water in the Ljubevc and Idrija ore deposits

Chemical Monitoring and Control of Discharged Pit Water

In addition to monitoring the flooding of the ore deposit, we also focused our attention on the quality of water being discharged into the Idrijca River. Pumped water has been constantly controlled since the pumps were put into operation in 1994. The first results of analyses have shown that the maximum concentrations allowed by Slovene standards for the discharge of technological waters were greatly exceeded, particularly in the case of iron and sulphates, as the consequence of the washing of old backfills made of smelting wastes. In a few years, the iron concentrations fell below the allowable limit value, while sulphates continue to remain an unsolved problem. Despite our fears, the limit values for mercury were not exceeded. In addition to samples of pumped water, the water samples from the flooded Ljubevc ore deposit were analysed. The results are below the limits applicable for pit water, and the quality has not changed significantly in comparison with the period before shutdown.

	Unit	**6-Apr-86**	**16-Feb-95**	**10-Maj-00**	**Level XI - at Ljubevc gate**	**Limit value for pit water discharges**
Water temperature	T °C	13,3	10,5	16,1	-	
pH		7,8	7,5	8,2	8,4	6,5 - 9,0
Conductivity	µS/cm	725	6.570	2.170	1.014	
Dissolved substances	Mg / l	362	3.340	1.085	507	
Iron	mg Fe / l	0,38	8,00	1,62	0,10	2,00
Sulphates	mg SO_4 / l	170	5.300	1.175	364	1.000
Mercury – total	ng Hg / l	3.200,0	25,6	230,0	-	
Total hardness	mg $CaCO_3$ / l	394	6.440	1.410	595	
Carbonate hardness	mg $CaCO_3$ / l	205	340	250	175	
Calcium	mg Ca / l	47,5	272	214,7	91,4	
Magnesium	mg Mg / l	21,0	1400,0	212,6	89,2	

Table 1: Chemical analyses of pit waters

Increase of Water Inflows into the Idrija Ore Deposit

After the closing of the water gate in the Ljubevc road, the rate of water inflow into the Idrija ore deposit ranged from 15-17 l/s. Inflows fluctuated in line with hydrometeorological conditions. Inflows into the ore deposit were calculated on the basis of data on the total operating hours of pumps in the pumping facility on level XI, where all pit waters are collected (Figure 5). In August 1998, the inflow of water into the Idrija pit unexpectedly began to increase and in November reached a rate of 27.4 l/s. After stabilizing for a few months, the water inflow began to increase in February 1999 and reached its peak in April (35 l/s), after which it decreased slightly, but still exceeded 30 l/s. Safety measures called for the enlargement of pumping capacity. At the same time, an extremely rapid fall in water pressure was registered in the Ljubevc ore deposit, which behind the water gate dropped from 28 bar in January to 9 bar in April (Car, Janez, 1999). In July 1999, the water inflow once again reached its peak, amounting to 43 l/s, and reached the same level in mid September. In between, the average inflow into the pumping facility was 35 l/s. The drop in pressure was not as drastic as at the beginning of the year. Following its last peak, the water inflow rose only slightly, but constantly, in the second half of the year, reaching an average of 35 l/s to 37 l/s in December and attaining its peak in January 2000 (40 l/s). In the period from February to April 2000, the inflows began to decrease (average 37 l/s). The falling trend continued into the period from May to July, when the mean inflow amounted to 35 l/s. The measurements of inflows into the pumping facility point to a tendency of further decrease. A constant fall in pressure was simultaneously recorded, amounting to 0.23 bar in July 2000, which points to the complete emptying of the Ljubevc aquifer to the level of the already flooded part of the Idrija ore deposit.

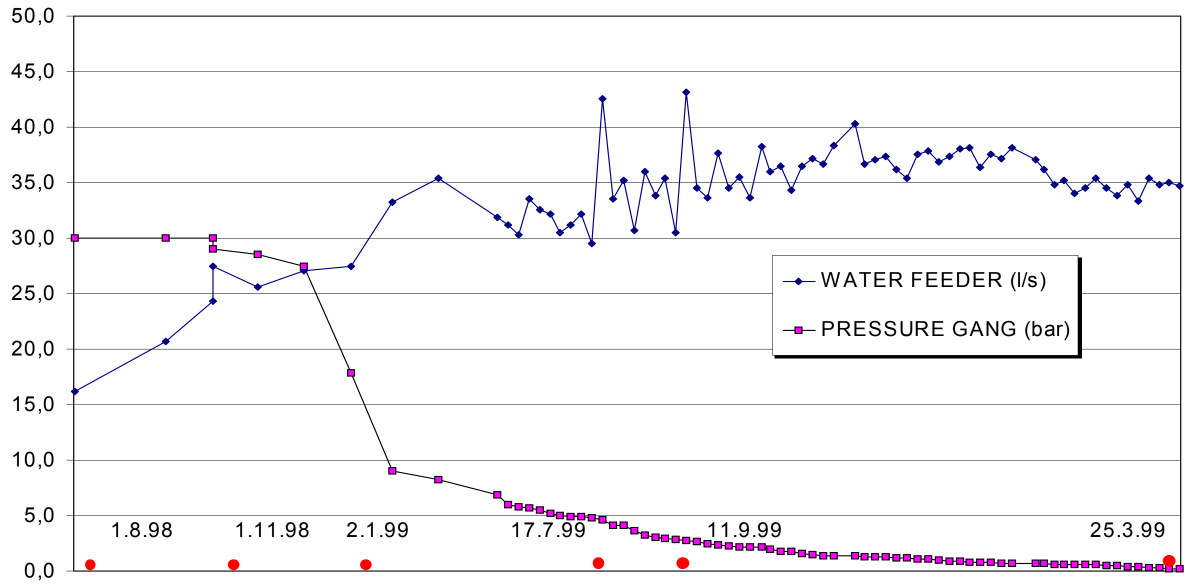


Figure 5: Manometer pressure at the Ljubevc water gate and discharges of pit water from the Idrija ore deposit

Despite comprehensive analyses of the possible consequences of flooding of the lower part of the Idrija and Ljubevc ore deposits, the events described above are both surprising and seemingly unexplainable. The main question is, what is the cause of the inflow of water from the Ljubevc ore deposit? It is possible that the water gate began to leak, or that the water penetrated through the injected rocks in the direct vicinity of the gate. Another possibility is that the filling of the Ljubevc aquifer and the increased pressure (max 36.5 bar at the water gate level) led to the washing of crushed and milonitized tectonic zones in the broader surroundings of the water gate. Irrespective of the cause, the Ljubevc aquifer, which is an open aquifer, was emptied to the XIth level, and thus a constant inflow of water between 30 l/s and 35 l/s can be expected in future.

CONCLUSION

The extensive programme of the gradual, complete and permanent shutdown of the Idrija Mercury Mine, located directly below the town of Idrija, is a complex, long-term project. The results of studies and analyses of the effects of executed shutdown works (from 1988 onward) indicate that the concept of the mine's shutdown was properly selected. The project involving the flooding of the Ljubevc ore deposit has shown that, despite our excellent geological knowledge of the area, surprises may occur at any time. Fortunately, in the case of the Idrija mine these will not have a permanent effect on shutdown works. Our experiences have repeatedly proven the significance of long-term and continuous monitoring of geological, hydrogeological and geomechanical conditions in mine shutdown projects.

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