Mining Impact on Ground Water of Uranium Mine Zirovski Vrh

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Abstract

Past activity in Uranium mine Zirovski vrh has affected above all on the quality of the air and water in its surrounding. There are three outlets which have contaminated the surface and ground waters: mine run off water has enlarged content of uranium, the drainage from the mine waste disposal beside uranium still SO_4, Ca, Mg in Cl ions has increased and outlet from the mill tailings radium and SO_4, Ca, Mg, Cl, NH_4 ions. All this mine waters have been strongly diluted when they discharge to the local streams. In comparison with other uranium mines the level of contamination in our case is low. Ground water appears in the alluvial fans and in the dolomite background in the bottom of the valley. Because of low permeability of the alluvial sediments the ground water is just slightly contaminated with these pollutants a few hundred meters bellow the discharge. The permitted authorised limits for mine waters after closure works has been established by the Ministry of the Health. Proposed remediation works should have resulted in diminishing of uranium content in the mine run off water and drainage water of the mine waste disposal only.

1. INTRODUCTION

The ore deposit was discovered in the massif of Zirovski Vrh in the western Slovenia in 1960. After the start up of the explorations and tests, the ore mining started in 1982 and uranium ore processing began in 1984. The mine ceased with the production in the year 1990 due to economic reasons and under the pressure of some ecological movements as a result of the society changes in the Republic of Slovenia.

The ore deposit was opened in the length of 2000 m, width of 200 m and in the height of 150 m. During this time 1.5 million tons of mine waste, 620 000 tons of ore were produced and 450 tons of U_3O_8 extracted. Mine waste was deposited at the mine waste pile Jazbec, the mill tailing at the mill tailings site Borst (Figure 1).

2. GEOLOGICAL STRUCTURE

Žirovski Vrh massif is presented by older Carboniferous and Permian strata on the younger Triassic rocks (Figure 2). Permian clastic strata are of fluviatil origin and are divided into lower grey and into upper red formation. Uranium mineralisation appears only in the lower grey formation and it is of diagenetic origin. The ore appears as cement in sandstones, the ore bodies are lens shaped and elongated in belts. The thickness of the ore bearing zone is 150 m, the thickness of the grey formation is 400 m. The main uranium minerals are uraninite and coffinite.

The northwestern part of the ore deposit is folded and has a shape of double »S« fold as a consequence of overthrusting. In the southeastern part of the ore deposit the strata dip toward south-west under the angles of 30^0 to 50^0. The massif Zirovski Vrh is cut by several Dinaric faults in NW-SE direction with displacements of a few hundred meters. In the open part of the mine some minor faults with displacement up to 20m can be found only.

Carboniferous strata in the base consist of clay schists. Together with Groeden strata they were overthrusted on younger Upper Triassic strata. These are represented by mudstones, tuffites, sandstones, limestone lenses and dolomites. The mine waste pile and the tailings have been located on these strata. The rivers and brooks have deposited also the youngest alluvial layers in the valleys.

3. HYDROGEOLOGICAL CHARACTERISTICS OF THE ROCKS

Listed rocks, which appear in the ore deposit and in the base of tailings and mine waste pile, have different hydrogeological characteristics.

The oldest Carboniferous strata are composed of clay schists, sometimes they also included sandstones. Older authors stated that they have only capillar porosity and are good insulator. Our studies have not confirmed this general understanding about practically impermeable strata. Due to strongly developed schistoisity and frequent tectonic fractures, these rocks have low permeability or are impermeable, coefficient k has value from 1.10^{-7} m/s to 1.10^{-9} m/s.

Middle Permian clastic sediments (Groeden strata), are presented by sandstones, minor conglomerates, and siltstones. The mineralization with uranium occurs in these strata. Novak (1974) indicated, that they are strongly fractured, the cracks are mainly filled with clay. Petrovic (1969) stated 2 % porosity. Examination of more samples in year 1980 showed 1.4 - 3.6 % porosity of the schists and 2.5 - 6.5 % porosity for sandstones and conglomerates as well the rock itself is low permeable or impermeable. With the water permeability measurements in different parts of the mine we have proved that coefficient of permeability ranges in very broad limits from $k = 1.10^{-5}$ m/s in tectonically fractured zones to $k = 1.10^{-10}$ m/s and less in unaffected areas. In the folded part above the mine deposit a Jazbec scale was overthrusted. Veselic (1996) estimates, that it represents an impermeable barrier with coefficient $k = 1.10^{-9}$ m/s.

Carnian clastites and Noric dolomites are presented in Triassic strata by. Carnian clastites consist of gaily coloured siltstones, sandstones, tuffites, and some limestone developed in lenses. Fractured porosity is developed in clastites. We have observed caverns and karst caves inside these strata in limestone at the Boršt and Jazbec sites. Fracture porosity is also typical of Upper Triassic dolomite, Petrovic (1969) stated also karstification of the dolomite. His statements were accurate, we have noticed a bigger cave in dolomite at the confluence of the Brebovscica and the Todrascica flows.

The youngest are alluvial sediments at the bottom of both valleys. Intergranular porosity is typical of these strata that are water bearing. Novak has observed that these strata are poor acquifer, due to high content of silt and clay in these sediments.

4. UNDERGROUND WATER IN THE EXPLOITATION AREA

Referring to the different geotectonic units, where the ore deposit appears and also the mine waste pile and the mill tailings are located, we have to discuss their underground waters separately. To determine the levels of the underground water and its contaminants, a grid of piesometers have been placed in the area of waste piles and in the valleys of the surface water flows.

4.1. Underground Water in the Ore Deposit

The ore deposit is located in the succession of the clastic rocks of Groeden age, which have been deposited on older Carboniferous strata. Referring to the relative low permeability or impermeability of the Carboniferous strata respectively, Groeden strata are poor acquifer. The springs or permeable zones appear close to the faulted zones and to the cracks connected to these faults. We observe stronger fracturing also in the northwestern part of the ore deposit as a consequence of fold structure. We have already mentioned that we have found impervious rocks inside unaffected blocks.

There were a lot of water inflows in some areas during the opening of the mine, which have dried up with continuation of the work. The biggest water inflows appear at the lowest level, where the drying funnel has not been lowered yet under the level of this horizon.

The springs were very interesting in the stopes, which were made under the lowest level. Water inflows give a few tenths of litre per second from the cracks in the floor and walls. At the end of the production in year 1990 these ramps were flooded almost to the top e.g. to the level 448 m. This shows the free level of the underground water in this part of the ore deposit.

The mine water percolates over the mineralised surfaces on its way through the ore deposit. Uranium well dissolves in oxidising water and dissolves on the walls of cracks. The springs in the highest part of the mine are still clean ($c < 10\ \mu g\ U_3O_8/l$), the concentrations of uranium increase in the mine water toward the lowest horizon. The most contaminated water comes from the stopes and mineralised boreholes. All the mine water outflows through the lowest adit P-10 into the Brebovscica river. Uranium concentrations range from 200 - 300 $\mu g\ U_3O_8/l$, the flow vary from 18 - 35 l/s.

4.2. Underground Water in the Mine Waste Pile Jazbec and in its Base

Underground water in the mine waste pile has been studied in details (Cadez, 1996). Since that time it is continually controlled and sampled in seven piesometers (Gantar 1998). Underground water is formed above the bottom of former ravine and rock base in the thickness up to 5 m in the lower part and up to 2 m in the upper part and dip parallel to the former ravine (Figure 3). Due to low permeability of the mine waste in its lower part the underground water level minimally vary. Primary well permeable mine waste has become less permeable close to the grounding, due to washing away of the fine mine waste fractions and of red mud.

Underground water in the waste pile is rather contaminated with uranium, also with sulphates. It is less contaminated in the upper part of the mine waste (a few 100 $\mu g\ U_3O_8/l$) in the lower part it reaches over 1000 $\mu g\ U_{-3}O_8$ /l.

Contaminated water flows into the culvert of the Jazbec brook from the parallel drainage and the perpendicular drainage as well. Particular measurements show that uranium content at discharge vary from 200 to 1400 $\mu g\ U_3O_8$ /l. Analyses of monthly composites that represent continual sampling, show yearly average of 327 $\mu g\ U_3O_8$ /l (year 1995) and 575 $\mu g\ U_3O_8$ /l (year 1992).

Continual underground water in the bedrock of the mine waste pile exists only in dolomite. Anticipations that contaminated underground water from the mine waste pile percolates also into dolomite (Figure 3) have been proved with implementation and measurements in the piesometer BS-27. In this piesometer which is located a few ten meters under the mine waste pile at the Jazbec brook, it has been ascertained that the underground water in dolomite contains over 200 $\mu g\ U_3O_8$ /l and also several times bigger sulphate concentrations.

4.3. Underground Water at the Mill Tailings Borst and in its Base

At the mill tailings Borst we observe two underground waters: in the tailings body itself and in its base. Underground water is formed in the lower third of the tailings and dips parallel to the former hill slope (Figure 4). It occur as pore fill among fine grained tailing (fraction of mud) that is very low permeable due to fine grind ($k = 2.\ 10^{-9}$ to $3.\ 10^{-10}$ m/s). The level has oscillated slightly during the past years.

The bedrock is composed from stained coloured Carnian clastic sediments, the siltstones prevail among sandstones and tuffites. The siltstones have very low permeability, ground water is bounded about all on seldom fractured zones. Upon the data from piesometric grid the ground water appears in major part of the piesometers close to the former surface of the ground. The level of the underground water has decreased in the lover part of the landslide after the construction of the drainage tunnel (Figure 4). Sandstones, which appear in the background part of the tailings ground, are more permeable, include systems of cracks, which are wider, more frequent and more permeable. This has been proved by measurement of the permeability in the boreholes with siltstones ($k = 7.3 - 8.1\ .10^{-7}$ m/s) and boreholes with sandstones ($k = 6.2.\ 10^{-6}$ m/s). In the presence of water the tuffites swell and change into clay. This originated the slide plane of paleo landslide and its reactivation after deposition of the mill tailing on its surface.

Underground water in the tailings itself is heavily contaminated with uranium, sulphates, calcium, and also with ammonia and radium. These underground water seeps over the drainage system into common drainage outflow (SDIJ) and through separated channel system into the tailing pond. With these the outflows from the tailings affects the surface waters (the Todrascica brook) and its environment. The discharge SDIJ has flow from 0.2 - 0.9 l/s, the water is contaminated.

A slight increase of the concentration of the pollutants has been observed in the piesometers, which reach the bedrock. These effects are more noticeable just in some piesometers, but they are at the lower values of analytical determination limit.

4.4. Underground Water in the Valley of the Brebovscica and the Todrascica rivers

Apart from the mine space and both waste piles the underground water appears inside the exploitation area also in the valley of the Brebovscica river and her main tributary in this part the Todrascica brook. We can separate two sorts of underground water: underground water in alluvial deposits and in the dolomite bedrock.

The thickness of alluvial sediments vary from a few meters to 15 m. The piesometers boreholes show that these sediments are composed from gravel and sand that include also considerable amount of silt and even clay. For this reason they are poor acquifer, the layers with higher permeability have the shape of a lens. They have intergranular porosity. Continual underground water is limited to their lower part and is slowly renewed.

The underground water in the dolomite is continual where observed and declines in the direction of the valley (Figure 5). We observe great changes of the level to 10 m in it during the rainfall and dry seasons. Such fast and great reactions to the rainfall are typical of Karstic acquifer. With high levels the underground water rises into upper alluvial deposits.

Underground water in alluvial sediments is partially contaminated, but due to small permeability of these sediments, the contamination has not reached considerable values. Uranium and sulphate ion concentrations have risen 2 - 3 times in these boreholes and are typical, and have been confirmed with long lasting observations. These values are compared with natural background and do not reach maximal permissible concentration limits for drinking water.

We have succeeded to prove that the underground water in dolomite ground is directly contaminated by seepage waters from the mine waste pile Jazbec. Uranium and sulphate content have risen more than 100 times or 10 times in the borehole BS-27 respectively. The boreholes lies close to the Jazbec mine waste pile. The concentrations decrease fast toward borehole BS-29 because of fresh water inflow parallel to the main valley, then slower toward the borehole BS-30. The impact of the mining is scarcely anything perceived in the borehole BS-30.

5. MEASURES TO MINIMIZE THE UNDERGROUND WATER CONTAMINATION IN THE EXPLOITATION AREA

For the run of mine water and for the outflows from the mine waste pile and the mill tailings Borst and periodically from the tailings pond is typical that they contain raised concentrations of uranium and also other contaminants (SO_4 , Ca, Mg, ammonia, ^{226}Ra) in view of natural background (J. Lenart et al., 1995). The results of the measurements are summarised in the Table 1.

Table 1: Results of the water measurements in the mine waste pile Jazbec and from the mill tailings Borst for year 1994, average monthly measurements

Monitoring point	Flow in year Total m^3/year	NH_4^+ Mg/l	U_3O_8 µg/l	^{226}Ra Bq/m^3	Ca^{2+} mg/l	Mg^{2+} mg/l	C1⁻ mg/l	Fe mg/l	SO_4^{2-} mg/l
MPL for chem. Subst. in effluents		1	-	-	-	-	-	2	700
MPK for chem. Subst. in potable water		0.1	50	-	200	50	200	0.3	200
Derived conc. For potable water		-	420	1000	-	-	-	-	-
JAZBEC	477964	0.2	372	22	72	25	19	<0.1	218
SDIJ	37073	21.4	246	98	134	30	175	<0.1	447
BORST PRELIV	7802	25.3	1346	6339	447	28	127	<0.1	1272
BORST IZPUST	18970	35.2	1570	5563	513	38	162	<0.1	1267
DRENAZA	1269	6.0	1117	940	370	42	120	<0.1	840
BORST POTOK 1	73604	0.2	13	145	22	4	9	<0.1	44

The concentrations of contaminants are a few times higher in the bodies of the mine waste pile and tailing itself, but they are diluted before discharging. Impact of the contaminated water from the mine and mill onto underground water of the bedrock is evident at Jazbec area. The impact decreases very fast down flow to the values that are a little greater than the background.

The biggest source of contamination are direct effluents from the mine, mine waste pile and mill tailings to the surface water flows (Jazbec, Todrascica brooks and Brebovscica river). Full scale of these pollution is monitored continually. A part of this water leaks into the underground water and might represent bigger source of pollution of the underground water. The contents of pollutants in the Brebovscica river are so diluted that they do not exceed the limits for potable water.

Bigger part of the effluents from the waste piles will have diminished effluent flows after its covering and long-term remediation. With successfully implemented works, the levels of underground water will decrease in the waste piles and the leaching of the contaminants will drop as well. The same is valid for successfully implemented works in the underground mine and for pollution of the mine water. At this opportunity we would like to note the need to backfill old stopes referring to the results of the mine study on roof caving process. In this way the subsidence and the mine water contamination will be prevented (Veselic, 1995) due to fresh water inflow into the mine. Today's pollution in some cases exceeds the permitted concentration limits at the point of discharge, which will not be the case after successfully implemented remediation plans. For that reasons, we believe, there is no need for any additional measures to minimise future water concentrations of the discharges from remediated mine objects.

6. References

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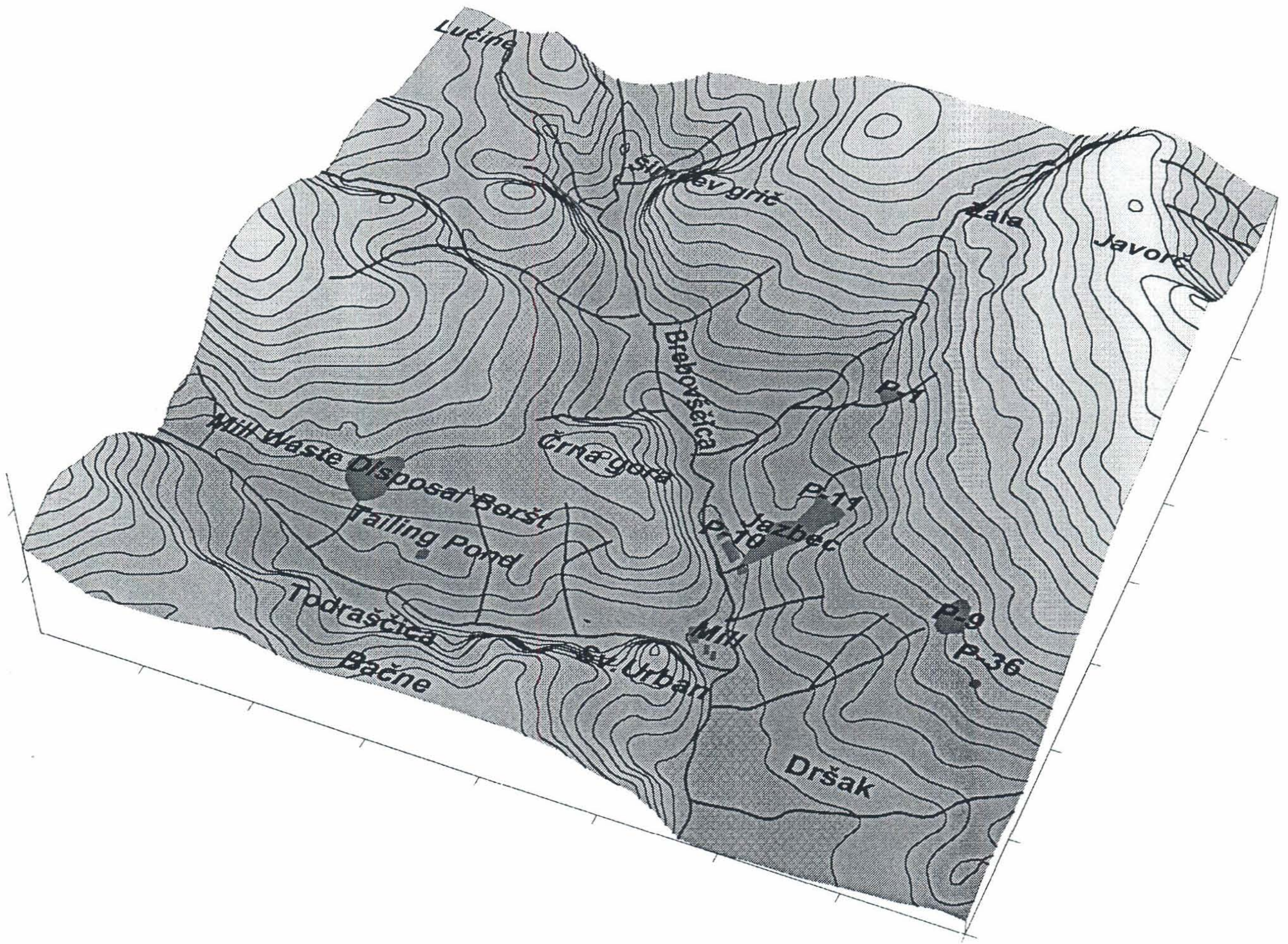

Figure 1: Location of the mine object (by T. Beguš)

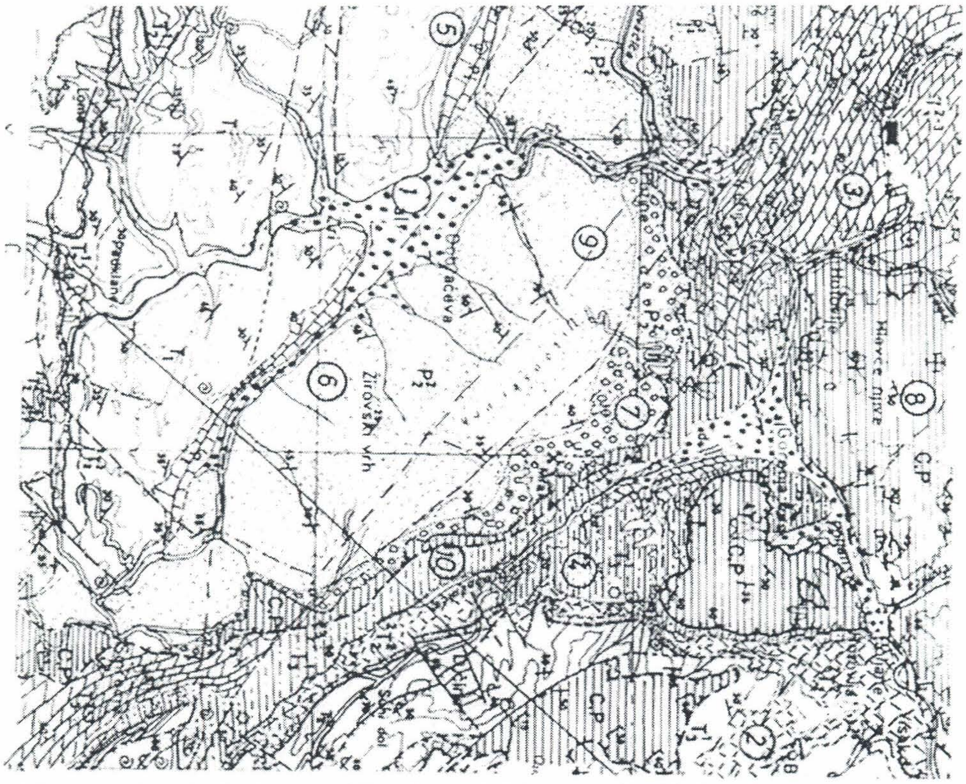

Figure 2: Geological map of the Zirovski Vrh area (by K. Grad)

1. Alluvium 2. Cordevolian dolomites 3. Norian dolomites 4. Carnian clastic rocks
5. Upper Permian Limestones 6. Red middle Permian formation
7. Grey middle Permian formation (with U mineralisation) 8. Carboniferous schists
9. Faults 10 Overthrusts

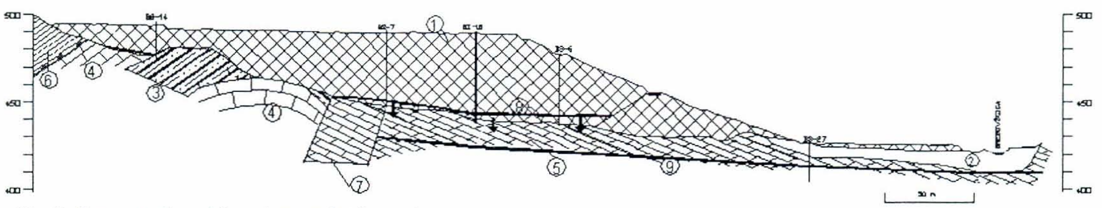

Fig. 3: Cross-section of the mine waste disposal

1 Mine waste 2 Alluvial sediments 3,4 Upper Triasic (Carnian) siltstones and limestones 5 Upper Triasic (Norian) dolomite 6 Carboniferous schists 7 Fault zone 8 Ground water tabel in mine wast 9 Ground water tabel in dolomite

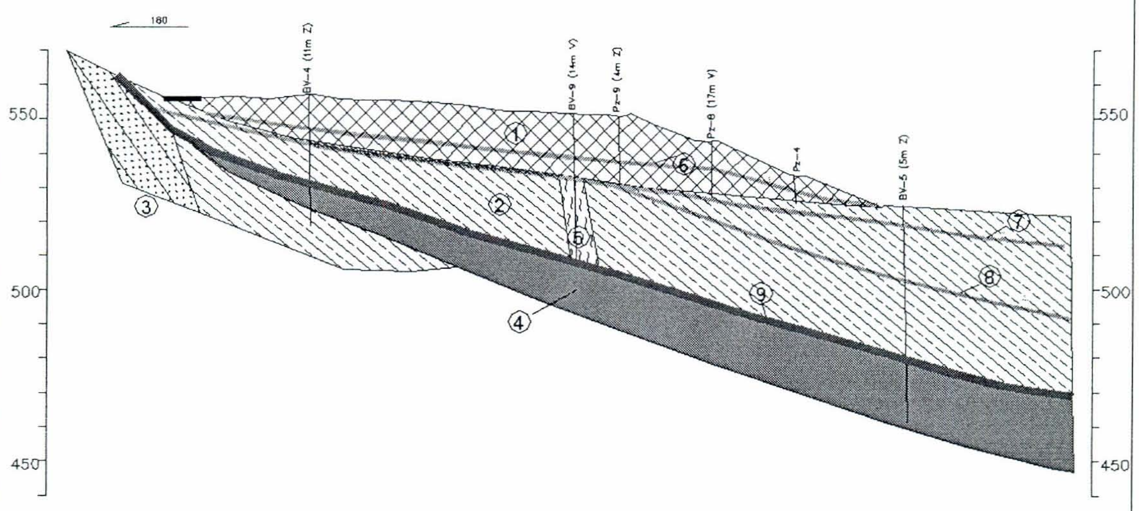

Fig. 4: Cross-section of the mill tailing disposal

1 Mill waste 2,3,4 Upper Triasic (Carnian) siltstones, sandstones and tuffites 5 Fault zone 6 Ground water level in the mill waste
7,8 Ground water tabel in bedrock before and after excavation of the drainage tunnel 9 Sliding plane

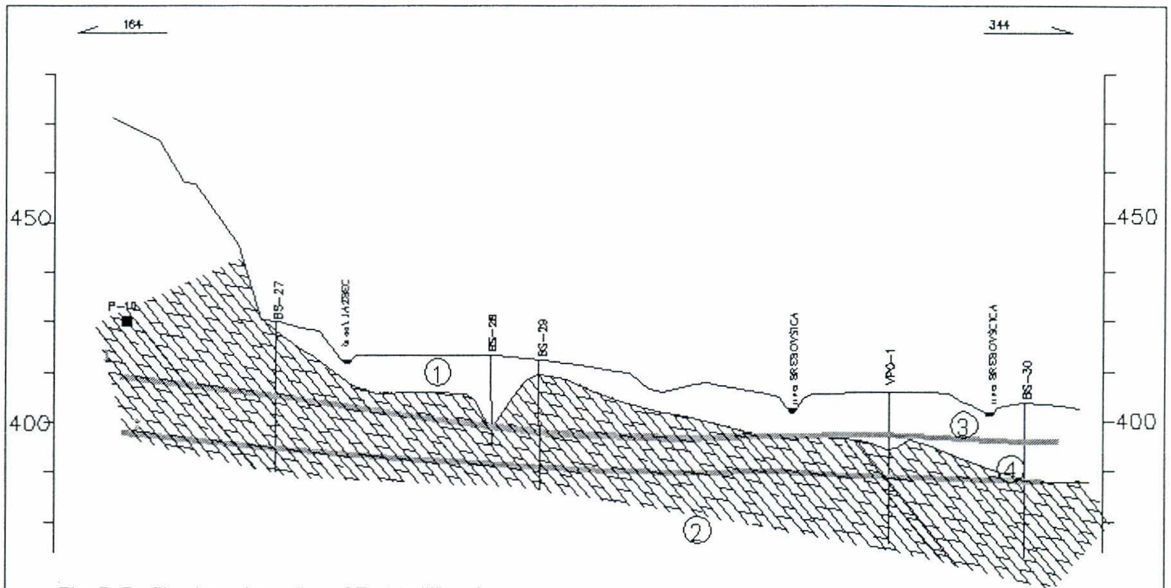

Fig. 5: Profile along the valley of Brebovščica river

1 Alluvial sediment 2 Upper Triasic (Norian) dolomite 3,4 Upper and lower ground water level in dolomite