THE ANALYSIS OF THE MUDDY FLOW AND ACID DRAINAGE RISK AT ȘUIOR MINING PERIMETER, MARAMURES COUNTY

Ioan BUD, Iosif Ioan PAȘCA*, Simona DUMA*, Dorel GUȘAT**

Abstract: *Șuior mining perimeter closure involves risks related to water accumulation and evacuation. In the last time, explosive water and mud discharges occurred on Șuior - Baia Sprie tunnel, which drained to the lower operation level. Șuior Mine presents a distinctive feature compared to other mines, emphasized through combined methods for ores exploitation, in open pit and underground (via subsidence methods) and having a mineralization powerfully reactive and perishable. All these lead to the risk of the build-up of acidic waters loaded with suspension in the form of bags under pressure, subsidence on the tunnel with 6.3 km length and unpredictable breaks of dams formed by subsidence.*

Key words: *risk, muddy flow, acid drainage, stability*

1. Introduction

Within Baia Mare mining perimeter, deposits are of hydrothermal type with gold-silver mineralization and complex sulphides vein type with thicknesses varying from tens of centimetres to tens of meters.

For operations on these ores it was used a complex underground mining works network which, in most cases, involved digging under a base level that was the path for water outlet and served for the transport of mining production.

Above the base level, the underground water was partially evacuated by gravity. Below the base level, throughout the mining activity duration, underground water has been evacuated by pumping. After the mine closure, the water is no longer pumped, accumulating in operated empty spaces, existing the possibility to rise up to the base level or to move toward the surface through cracks, fractures and faults, falls or slips zones, sometimes getting an artesian waterbed character (fig. 1).

The presence of sulphides in the exploited space generates important oxidation reactions leading to a phenomenon called acid drainage, which has the effect of increased pollution of surface and underground water.

At Șuior mine, the operation was carried out by mixed methods, the upper part in open pit resulting in a sink, while the lower part involved a large network of underground mining works. The exploitation in open pit started at approximately +1,000 m and in underground, the opening work was carried out in levels of 50m up to the level +462 m. The distinctive feature of Șuior mine consists in the fact that at the level +462m it has been performed a tunnel for the mining production transport and underground water evacuation to Baia Sprie. In this way, all water from the open pit area, from the slopes around the open pit and the underground water accumulates in the operated and collapsed spaces, draining toward the tunnel area.

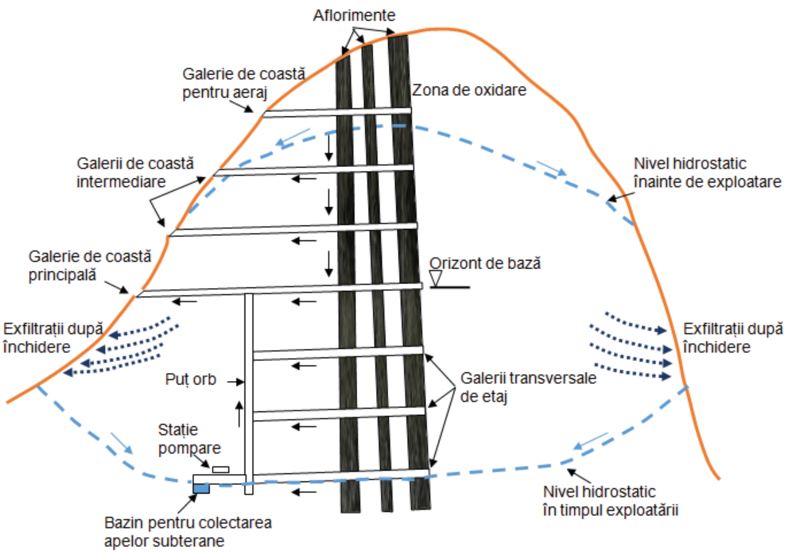

Fig. 1. **Opening and underground water evacuation system for a vein ore**

** Technical University of Cluj-Napoca, North University Center of Baia Mare*

These aspects will cause the ore and surrounding rocks weathering, chemical reactivity of Sulphur, especially pyrite and marcasite, forming important accumulations of viscous-fluid material under pressure, generating large risks of exhaust in the tunnel. Another important risk is represented by the 6.3 km length of the tunnel, with a section of 6.3 $m^{2,}$ which has a tendency of crumbling. The crumbled material forms dams that block the tunnel section and underground mining waters accumulate behind them. When the mud pressure (acid water with heavy metals and suspension) exceeds the limit value of breakage, the dams fails with an explosion effect.

In the last time, there were manifestations of explosive mining water flows - mud from Şuior - Baia Sprie tunnel - that concerned authorities, media, locals, etc., which prompted us to carefully consider such issues.

In Baia Mare mining perimeter no surveys have been carried out to estimate and assess the risks related to the water accumulation in underground spaces, the accumulation times, the escape routes and scenarios of the intervention in case of accidents. In specialized literature, there were approaches to these topics, including solutions to minimize the sulphides reactivity which should have to be adapted to the geo-mining conditions in the area.

2. Opening and operating Șuior ore deposit

Șuior ore was classified as a large deposit, with moderate potential value and a relatively small horizontal surface, but with a large extension in depth and very difficult geo- mining and tectonic conditions. These assumptions led to its mixed exploitation.

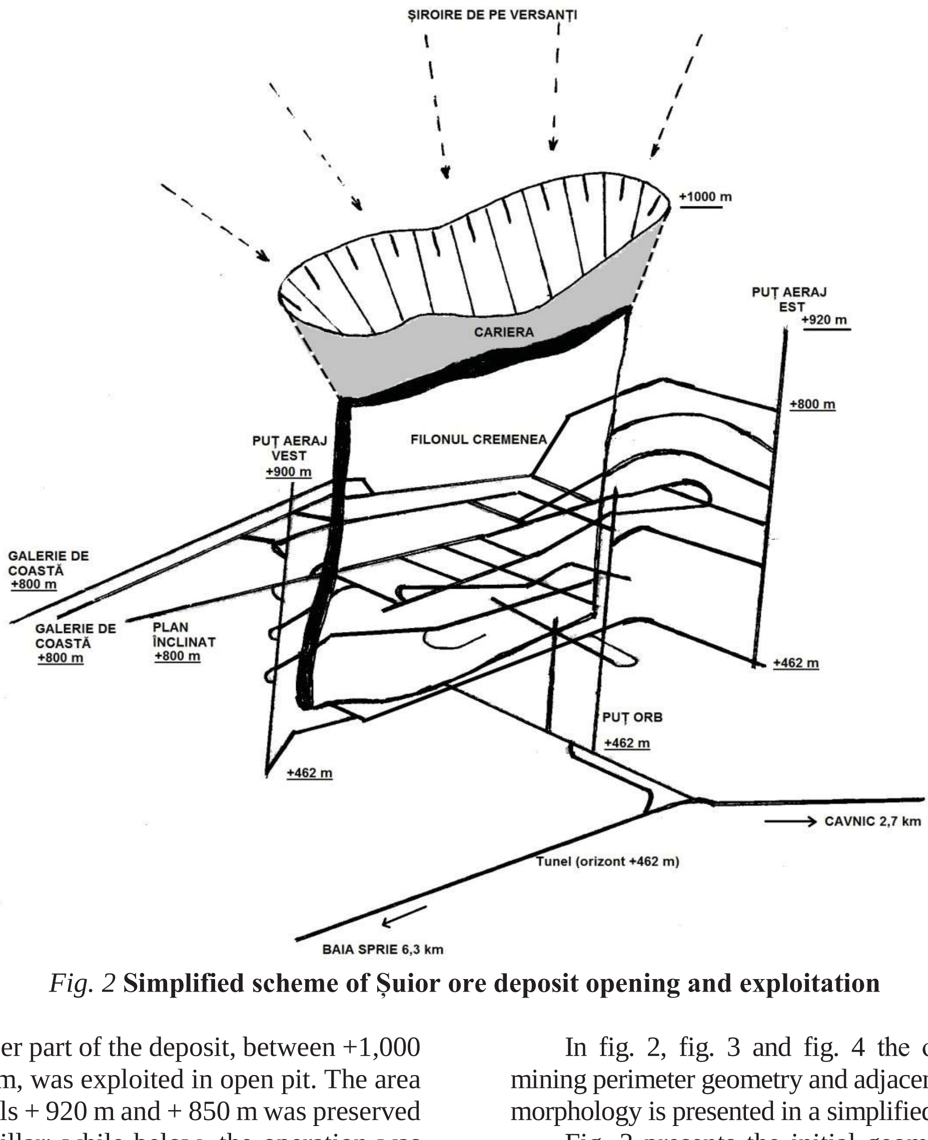

Fig. 2 **Simplified scheme of Șuior ore deposit opening and exploitation**

The upper part of the deposit, between +1,000 m and +920 m, was exploited in open pit. The area between levels + 920 m and + 850 m was preserved as a safety pillar; while below, the operation was continued in the underground through mining works. (fig. 2, fig. 3 and fig. 4)

In fig. 2, fig. 3 and fig. 4 the ore and Șuior mining perimeter geometry and adjacent surface area morphology is presented in a simplified manner.

Fig. 3 presents the initial geometry of Suior ore deposit and the formation of the pit sink and related levels.

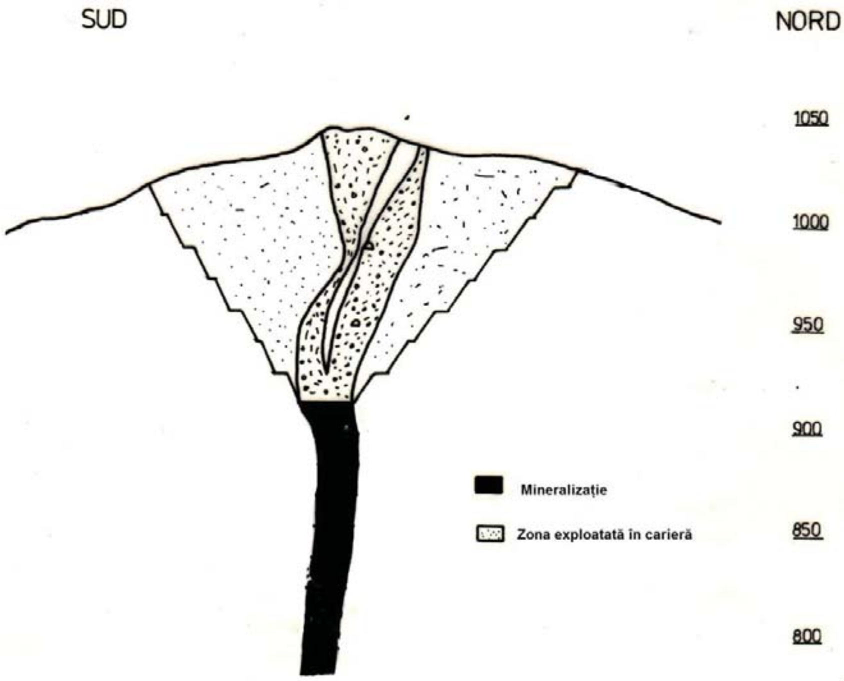

Fig. 3. **Vertical profile of Șuior ore deposit**

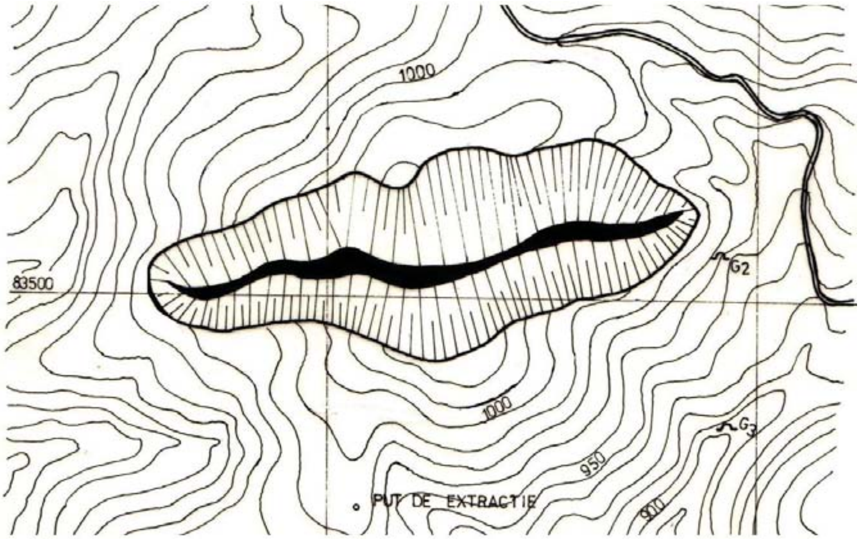

Fig. 4. **Situation plan of Șuior ore deposit**

Fig. 4 presents the situation of Șuior open pit in the moment of closure. Along the underground mining exploitation, using specific methods, this area has been transformed in a crumbling cone.

he situation plan allows an estimation of the rain water flow in the operating area.

For underground mining exploitation, a complex opening system was created with two main mining works:

- Two ventilation shaft, East and West, on the ore direction, outside its limits;
- A vertical blind shaft used to evacuate mining production by gravity to the transport level +462 m;
- Two drifts excavated at the level +800 m, for traffic, ventilation and supply;
- The declines, excavated from +800 m, with a rectilinear zone, continued with a spiral route to the base level, used for transport and supply.

As far as the underground ore deposit exploitation is concerned, it was carried out in four stages:

- Between levels +850 m and +800 m, two methods were used, with cut and dry filling and shrinkage stopping;
- Between levels +800 m and +700 m the method drift and fill was used

- Between levels +700 m and +650 m the deposit was exploited with cut and dry fill and it was created a protection pillow to pass to sublevel stopping exploitation;
- Below level +650 m the method with crumbling in sublevel stopping was used.

The particularity of sublevels stopping method consist in drilling finger raised blast holes and blasting, using important explosives charges crumbling the sublevel ore. When the ore is evacuated, the surrounding rocks will fill in the empty space.

As the exploitation level lowers, the crumbling spreads to the surface. This area, together with the open pit, form a subsidence cone which is a way for rainwater to reach in underground drifts, crossing the ore and surrounding rocks, tectonised and cracked, arriving, finally, to the base level +462 m. Accumulated water has a tendency to flow through the tunnel to Baia Sprie.

3. Geo-mining conditions which favor the phenomena of instability and accumulation of waters

Because of the complex geo-mining conditions, ICPMN Baia Mare, the Institute of Mines in Baia Mare, The Mine Institute in Petroșani, ICITPML Craiova carried out numerous studies, published as technical documents in specialized literature [1], [2], [3].

A summary of these studies is presented below in order to highlight the complexity of the conditions subject to the impact on stability over the mine life and the ability of estimation and extrapolation of such phenomena after the mining closure.

The abnormal pressure phenomena recorded in year 1984 at Șuior mine, at the exploitation levels, culminated with a partial closure of many stopes and a substantial preparatory network. These phenomena have manifested through the convergence of the mining work walls, blisters of hearts, rocks crumbling, and the mining works closure. The concerned manifestations and their scale were due to the petrographic characteristics and geo-mining conditions, both of the surrounding rocks and of vein mineralization.

The country rocks have an advanced degree of deterioration, so that feldspars have undergone major changes through switching to varied species of clay minerals. These minerals easily absorb water which weakens their cohesion, leads to blisters, accelerating rheological phenomena. Mechanical imbalance is due to the existence in the vein body of an irregular network of cracks and fractures filled with kaolin, but also due to the existence of a portion in which the mineralization is in the form of breccia, subject to alteration, too.

The alteration effect is felt both in regards of elasticity static modulus size and the Poisson coefficient, meaning that the values of the first parameter decrease and the values of the second increase, emphasizing the plastic behaviour of andesite occurring with the degree of deterioration.

The ore body and the country rocks are characterized by an advanced fissure which favours water infiltration and reduces the rock stability, showing subsidence trends and enlarging the degree of alteration. The main vein form is amygdaloidal with significant thickness in the central zone and attenuations toward the sidewalls. In the midline area, thicknesses reach 62 m and, at the ends, the size is reduced to 1.5 m and even less, up to extinction. In areas with large thickness in the ore body appreciable embedded sterile intercalations are shown. They have a lentiform aspect and are made up of pyroxene andesite powerfully transformed by hydrothermal metamorphism. The ore body geometrical characteristics are the following ones: length approximately 650 m; depth of 1200 m; area in the horizontal plane approximately 9000 m^2; the dip 85...90^o.

Mineralization is composed by:

- 21 species of sulfides and sulpha-salts: pyrite, marcasite, chalcopyrite, galena, etc;
- 7 species of nitrogen oxides and hydroxides: limonite, magnetite, hematite, oligist iron, etc;
- 2 species of sulfates: anglesite and gypsum;
- 4 species of Cu and Pb carbonates;
- 11 species of silicates.

At the first level roof, a pyroxene andesite, altered and mineralized was identified. The alteration minerals are kaolin 20%, chlorite, and sericite. Accessory minerals are pyrite (35%), complex sulphurs (blend, galena), and fine granulated pyrite.

First level, vein – pyrite ore cantoned in altered andesite: kaolinite, chlorite and montmorillonite

- Vein, quartz area
- Vein, andesitic breccia
- Vein, quartz and sulfurs: pyrite, sulfurs of Ag and As 2%
- Pyrite fine granulated

First level footwall – marl clay mineralized, pyrite

Level IV – vein, complex ore altered andesite; breccia

Clay minerals: kaolinite, montmorillonite

Pyrite fine granulated or nests in the rock body (20-25%); blende; marcasite; galena

Roof – pyroxene andesite altered and unaltered

Footwall – marl clay low mineralization, pyrite present

Level VII – vein silicified breccia, pyrite 15% in silicic body and sandstones. In footwall, marl clay low mineralized – pyrite and chalcopyrite. (2)

Significant presence of clay minerals in vein body and andesite from the roof, marl clay from footwall and important quantities of pyrite and marcasite in all structures (vein, footwall, roof) create all conditions for physical phenomena (inflation, disruption, etc.) and chemical (oxidations) phenomena that lead to the formation of a volume of material with flowing characteristics and important pressure, due to viscosity and density as well as to resulted components of sulphurs oxidation reactions (specially marcasite and pyrite) very toxic for environment.

Kaolinite appears as a feldspar and adularia alteration product and appears frequently as an accumulation of several centimetres in the complex mineralization area. The montmorillonite is present in the vein body as well as in country rocks. The average sulphur content has increasing depth tendency, reaching + 450 m level at 12.6% justifying the apparition of acid waters pH decreasing in some areas at 1,3...2,3.

At superior levels, between +700m ... +900m, in Northern and Southern sides, the vein country rocks are pyroxene andesite strongly sericite, kaolinised and fissured and transformed on large areas in a body with the aspect of clay kaolin.

In the Western area, andesitic rocks, strongly altered towards the central area, appear, with a thin strip of pyroxene andesite of 1...2 m, behind them follows the friable blackish marble and, on the Eastern side, the vein is placed in friable breccia, intensely cracked. In the Southern part, where the developing works are located, including the central shaft, the country rock is pyroxene andesite intensely altered and cracked.

At inferior levels, below 700 m, the vein is in direct contact with the marble from the footwall and below 600 m, the vein is totally cantoned in marble. The marble formations are fissured and, in consequence, crossed and affected by water.

Șuior ore deposit is crossed by a major fault called “big central fault” placed in middle area, filled with complex mineralization with thicknesses up to 2 m.

The inflow of mining water. Mining water has the following source:

- atmospheric precipitation falling on the open pit surface and surrounding area;
- the groundwater table cantoned in the superior zone of altered andesite;
- superficial waters, etc.

The waters’ movement in shall is carried out by natural rock porosity, but especially by weathering fractures and faults of the ore body and the surrounding rocks. The area with more abundant infiltrators is found in the central zone, around the "big central fault". Crossing the mountain, waters acidify, pH 5...1.5, a phenomenon facilitated in the underground by the powerful and specific bacterial flora (thyobacillus ferooxidans) [2].

The intense tectonic degree makes it easy for water to penetrate through marble, which leads to the splitting of large blocks and mudflows.

Studies performed by ICITPML Craiova in 1988 established 5 groups of rocks depending on their deterioration and alterability degree. The first group includes rocks with strong alterability, whose mechanical initial resistance reaches value 0 after 6 years and the second group includes rocks with high alterability, whose very high initial mechanical resistance decrease, after twenty years, to only 1.4...1.8% [3].

4. The estimation of risks generated by water accumulation and mudflow after Șuior perimeter mining closure

All geo-mining conditions (mineralogical, petrographic, structural and underground main mining works network) already described create premises to major risks regarding water and mud accumulation.

Geologic conditions increase two important phenomena: rocks weathering and oxidation chemical reactions. The presence, in important quantities, of clay minerals leads to total weathering in short periods of time, in the presence of water. Rocks with high initial mechanical resistance (about hundreds of daN/cm^2) get transformed, in relatively short periods of time, in a completely weathered material which, saturated in water, becomes a mudflow with tendency of accumulation in large volumes as mud bags under pressure. The presence in high quantities (tens of %) of marcasite and fine granulated pyrite, extremely reactive minerals, pyrite, arsenious pyrite and other salts lead to oxidation reactions generating acid drainage – acidic water charged in heavy metals and arsenic. As oxidation reactions are exothermic, heat dissipation accelerates these phenomena generating warm groundwater which, during the last explosive discharges, have been recorded due to the elevated temperature and the visible evaporation phenomenon, at the discharges in Săsar River and along it.

Linked to the geometry of mining perimeter, as well as through the open pit sink transformed subsequently in subsidence cone (fig. 3) and from surrounding slopes (fig. 2) rain water is drained towards underground mining work network.

Underground mining exploitation was developed around 500 m in depth, forming an empty places network resulted after ore exploitation and country rocks crumbling; in this area, water arriving from surface and underground (hydrostatic levels adjacent to mining perimeter) accumulates. In this large space, with significant size, both horizontally and vertically, weathering and oxidation phenomenon happen, forming a mixture of water and fine material called mud.

At the base of this water and mud accumulation and drainage space, the tunnel Șuior-Baia Sprie, 6.3 Km long, is an escape route (fig. 5).

This tunnel presents the instability phenomenon manifested through rocks crumbling forming digs (stoppers), which occlude partially the water and mud draining until the pressure leads to its breaking through an explosion.

These instability phenomena may occur more strikingly in the future, favoured by the mining waters with acid characteristics, pressure and elevated temperature.

All these explosive mud and mining waters may become most violent, which can no longer be controlled, administered and less cleaned.

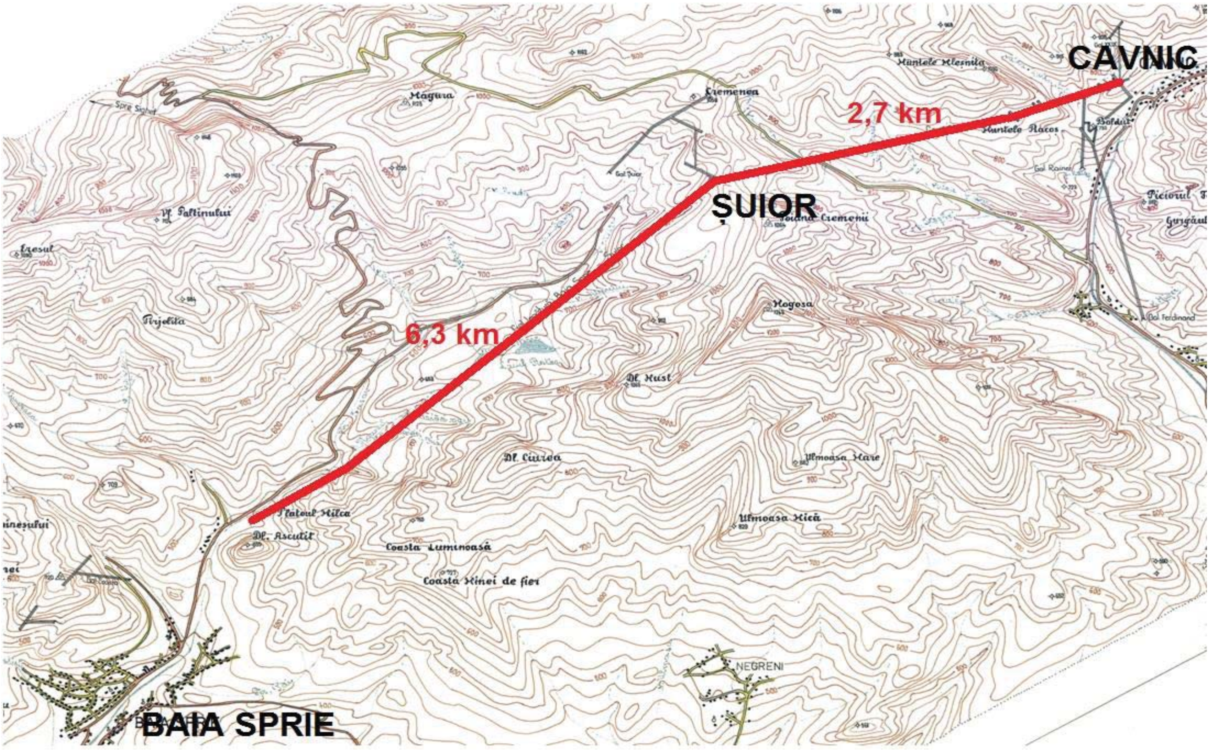

Fig. 5. **The tunnel route Cavnic-Șuior-Baia Sprie**

5. Conclusions

The analysis presented in the paper has as a goal the estimation of the major and imminent risks of mining water accumulation in Șuior mining perimeter. These waters generate acid drainage and have an important charge in clay material, weathered, leading to mudflows.

Mining water evacuation (mudflow) occurs at the base level of the mine, through a drift called, symbolically, tunnel, with a long route. All mining waters from the mining perimeter display this evacuation path. Technically, the path has a small section (6,3m^2) and poor stability.

Generally, mining closures in Romania ignored almost totally evaluation and prevention of risks generated by water accumulation and evacuation from mining perimeters.

Unlike the other mining perimeters, mining water accumulated in Șuior area becomes, practically, impossible to manage and control, evacuating stormily and unpredictable, impossible to be treated.

The analysis does not claim to be an exhaustive study as it would require more extensive resources and adequate means. Our research approach is just a warning to all those in charge with risk evaluation and management in closed or conserved mining perimeters.

References

1. Popescu, G. and others
Sinteza factorilor geominieri specifici EM Şuior și propuneri privind sistemul de deschidere, pregătire și exploatare a zăcământului sub cota 700 m – studiu 241/1995 Institutul de Subingineri Baia Mare

2. Todorescu, A.
Proprietățile rocilor, Editura Tehnică București, 1984

3. Pădure, I., Palamariu, M., Bălănescu, S., Sălăjan, C., Spătar, C.
Monografii moderne de exploatare pentru zăcămintele de minereuri, Editura Global Media Image, Deva 2001