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TECHNICAL COMMUNICATION

# Addressing the Risk of Surface Water Intrusion in Old Romanian Salt Mines

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**Abstract** In Romania, surface waters near underground salt mines represent a significant risk to the stability of the mine workings. Such problems occur in many salt exploiting facilities, i.e. Slanic Prahova, Targu Ocna, Praid. In this paper, the authors present a method of dealing with this issue at the Praid salt mine with research targeted at avoiding the hazard presented by intrusion of surface waters into old mine workings. Monitoring activities are proposed to prevent damage due to the seepage of Corund Creek water into the subsurface salt body, which could compromise and even produce collapses in the salt mine sanatorium and old and new mines.

## Introduction

The Praid Salt Mine is located in the village of Praid, in the center of Romania, in the Praid Sub Carpathian Depression, which lies between the volcanic plateau that borders the Gurghiu Mountains and Becheci Hills (1,080 m) in the East and the Şiclod Hills (1,028 m) in the West (Fig. 1). The plateau is drained by Corund Creek, which is a tributary of Târnava Mică (Deák 2006b).

The Praid Depression is characterized is characterized by two main relief levels: a peripheral one, at 600–700 m, which gives the depression a corridor-like shape 30 km long and 5–6 km wide and a lower level situated at 500 m, characterized by small erosion basins in which Corund, Ocna de Sus, Ocna de Jos and Praid settlements grew, the last of which grew to be the largest. The Praid salt structure is very well expressed within Dealul Sării, which is one of the largest diapir folds in Europe. It has an elliptical shape, and is 1.2–1.4 km wide and 2.7–3 km deep (Driga et al. 2006).

The Praid area lies in “the hilly and high plateau region” of the Transylvanian Depression, with a climate influenced by the ocean. The region’s climate is continental-temperate with a dominant western circulation throughout most of the area; there is also a shelter climate created by the proximity of the Eastern Carpathian range (Dragota and Micu 2006). Relevant meteorological stations are located at Târgu Mureş and Odorheiu Secuiesc. The annual average temperature ranges between 9 and 8°C, from west to east and from lower to highest altitudes (Târgu Mureş 309 m, Sovata 475 m, and Odorheiu Secuiesc 523 m); average annual amplitudes are over 20°C. The annual average atmospheric precipitation ranges between 400 and 600 mm in the Transylvanian Depression (Târgu Mureş) and 600–700 mm in the Subcarpathians of Transylvania (in Odorheiu Secuiesc and the Praid area).

The salt mine of Salina Praid exploits one of the largest rock salt deposits, nicknamed *Europe’s salt cellar*, located in Dealul Sării at a height of +567 m, in Praid, Harghita County. The geological reserves are assessed at about three thousand million tons of rock salt. Rock salt has been exploited in the area since the Roman Ages. The first systematic exploitation began in 1787, when the Mina Jozsef was opened; from this mine, the Karoly and Ferdinand underground exploitations were developed at a depth of 66 m from the surface. In 1864, the Mina Paralelă (see Fig. 2) was opened at a depth of 96 m, and in 1898, the mina Erzsebet was opened.

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**Fig. 1** Praid salt mine location

Until 1945, exploitation was exclusively based on manual digging. Blasting has replaced the old technology since 1947, when the Mina Gheorghe Doja (Dozsa Gyorgy, Fig. 3) was opened with large trapezoidal chambers. In 1978, the Minele Noi (Fig. 4) mine was opened, employing an exploitation technique based on multilevel rectangular long pillars and a safety floor 40 m thick in the Mina Doja.

The spatial distribution layout of the Praid salt mines is shown in Fig. 4 (Deák 2006a), which also shows the Minele Vechi (Old Salt Mines), which are now inactive (+460 to +360 m), the Salt Sanatorium Mines (+339 to +354 m), and the Mina Nouă (New Mine) (+286 to +230 m), which is currently working. We have also represented two main shafts (with a high risk of flooding) and a blind shaft that depends on the reliability of the two main shafts.

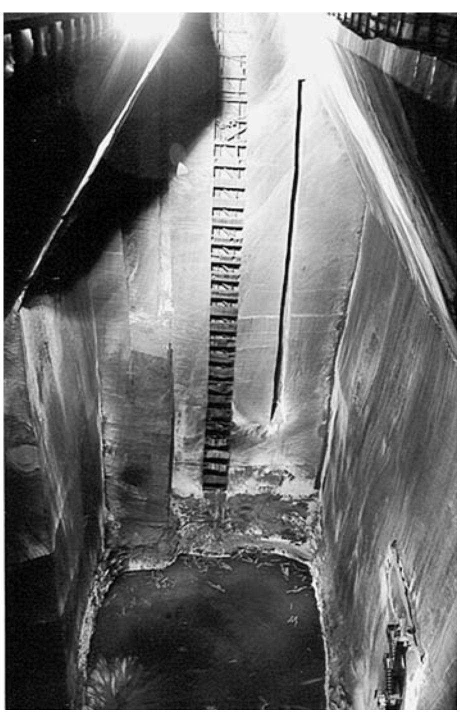


**Fig. 2** Mina Paralelă, Praid salt mine

In the following section, the authors discuss an investigation methodology to eliminate or reduce the potential hazard of flooding of the Praid salt mine through the old salt mine chambers. The research proceeded in three steps: (1) sampling points along the Corund Creek to assess water quality in the potential impact area; (2) a hydrogeological investigation to identify the potential high impact zone; and (3) a decisional analysis concerning the Praid salt mine flooding to identify potential engineering solutions.

## Methods

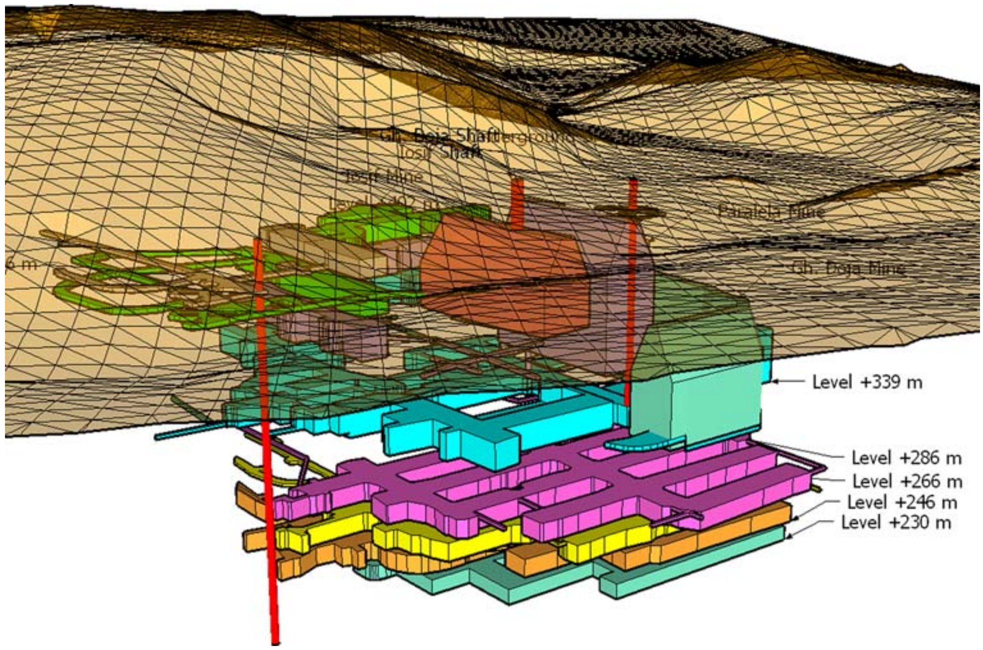
Water samples were collected for chemical analyses and beyond the potentially impacted area. In particular, they comprise: samples from three different salt springs, located south of Corund Creek, and two samples from the Corund Creek, near the salt springs confluence and 50 m downstream. Water samples were also collected near the entrance to the Doja shaft, close to the mine, and downstream of the mine area. The water sampling sites are shown in Fig. 4.

The water samples were filtered using high-density filter paper and analyzed for:

- $Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$, and Fe, using an atomic absorption spectrophotometer with a Varion lamp;
- $Cl^-$ ions, using the volumetric method;
- $SO_4^{2-}$ ions, using the gravimetric method; and
- TDS, using the gravimetric method to identify the content of NaCl, KCl, $MgCl_2$, $MgSO_4$, $CaCl_2$, $CaSO_4$, and $Na_2SO_4$.

Electric resistivity tomography (ERT) is a non-destructive method that compiles a large number of electric resistivity measurements, which we performed using a SARIS resistivimeter (SCINTREX-CANADA) (Oancea and Petrescu 2007). Using geoelectric resistivity, the apparent resistivity distribution underground can be measured using surface measurements. In practice, all devices used to determine resistivity measure the potential difference between two points. The data is then inverted using specialized software to create an image of the actual resistivity of the geological formations, which depends on various geological parameters, such as the rock type, porosity, the degree of saturation, and the salinity of the ground water. ERT is conducted using quadrupolar determination devices, which are placed on the terrain surface or in boreholes. An electric current of known intensity is introduced between two electrodes and the potential

**Fig. 3** General view of the salt mines in Praid, Romania



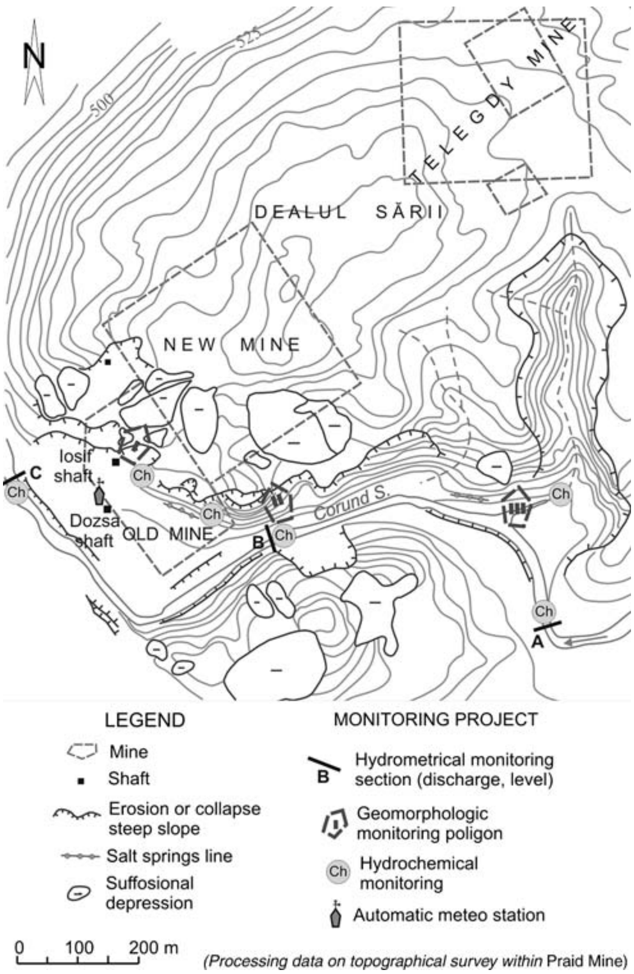




**Fig. 4** Site map with mine perimeters and hydrographic net (based on the Praid salt mine geological map), where *cross symbol* represents the location of water samples No. 1–5

difference is measured between the other two electrodes. A typical arrangement, consisting of four electrodes, is presented in Fig. 5.

For each observation point, a number of measurements are performed, while the distance between the electrodes is increased successively. The measurements are then repeated at each observation point. Many measurements are done in order to scan the investigated area or volume. Then, recorded data switching procedures are used in order to get the resistivity image, which is best fitted to the set of measurements.

In this case, the potential difference ($\Delta\Phi$) can be relatively easily determined if the investigation area is assumed to be a homogenous semi-space. In fact, the investigation space is non-homogenous and it has a three-dimensional distribution of the real resistivity.

Geoelectrical investigations were carried out through 15 profiles on the Gheorghe Doja shaft platform, using a mapping technique for the first six profiles and vertical electrical sounding (VES) for the next nine.

Decisional analysis was carried out for risk elimination/mitigation using the DKRControl method (Deák and Deák 1998, 2005). Six informational volumes, with up to 12 sub-volumes, were assembled addressing hydrology, geomorphology, geology, mining history, exploitation dynamics and techniques, salt dissolution, laboratory measurements, field observations and measurements, etc. These were analyzed by three groups of specialists: some directly involved in various aspects of the project, independent specialists, and stakeholders. After individual analysis (each specialist made a qualitative assessment/estimation, using the same predefined criteria, and indicated their score

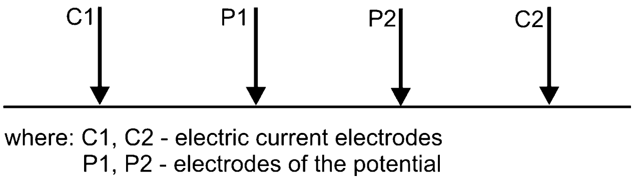



**Fig. 5** Typical layout for electrodes placement

for each informational sub-volume), the decisional matrix was assembled, and used to evaluate the likely accuracy of the database, and their specialists' confidence in the validity of the project findings and BAT (best available technologies) solutions. More detailed information is available on this procedure, on request.

## Results and Discussion

The results of the water analyses are reported in Table 1 and were used to assess the dissolution capacity of surface waters to the salt rock. The concentrations of major anions and cations were used to create the Piper diagram shown in Fig. 6 (Mihai 2006). In a Piper diagram, the ion concentrations are plotted as percentages, with each point representing a chemical analysis. The piper diagram has the potential to represent a large number of analyses and is convenient way to show the mixing of two waters from different sources (in our case, the Corund Creek water and salty spring waters). These diagrams are also useful for visually describing the differences in major ion chemistry in ground water flow systems.

In the investigated Creek section, the salt concentration in the water between samples 3 and 4 increases from 0.21 g/L NaCl to 0.44 g/L NaCl. This could show the high dissolution potential for Corund surface water in the impact zone. At the same time, samples 1 and 2 exhibit a very high salt concentration, close to that of saturated brine.

The actual hydrogeological situation on the salt breccia rock was derived using the geoelectrical data acquired on 15 profiles. These data were transformed and processed in

**Table 1** Results of chemical analyses on water samples (g/L)

| Solid residue | Sample 1 | Sample 2 | Sample 3 | Sample 4 |
|---|---|---|---|---|
| TDS[a] | 319.23 | 269.176 | 0.312 | 0.568 |
| $Na^+$ | 123.22 | 103.580 | 0.0735 | 0.168 |
| $Cl^-$ | 192.90 | 159.300 | 0.135 | 0.276 |
| $SO_4^{2-}$ | 1.882 | 2.315 | 0.069 | 0.076 |
| $K^+$ | 282.40 | 150.300 | 1.470 | 2.200 |
| $Mg^{2+}$ | 198.00 | 173.100 | 3.040 | 3.470 |
| $Ca^{2+}$ | 1063.4 | 854.200 | 12.770 | 13.93 |
| Fe | – | – | 0.030 | 0.060 |

[a] Total dissolved solids, determined at 105°C

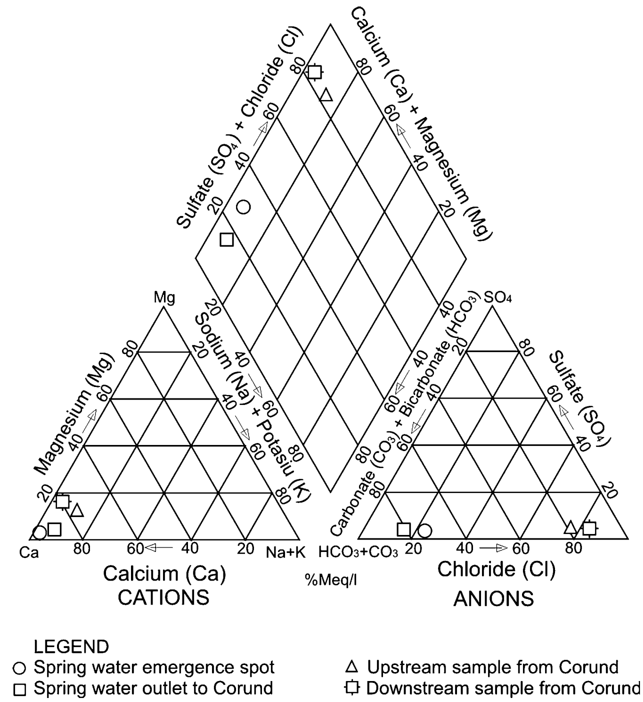



**Fig. 6** Piper diagram

order to obtain a map of the electrical resistivity in the investigation area, the platform between the two air shafts. It was assumed that the maximum investigation depth of the Schlumberger device used is equal to AB/4, considering the geological situation in the area, presented in Fig. 7, and information from the VES diagrams.

Two areas with resistivities less than 1.5 Ω at W, NW, and E of Doja (Dozsa) shaft were recognized. These areas are clearly shown in Fig. 8 on the sections from heights +480 and +475 m and are fading/superposing in depth. The geological interpretation of the geoelectrical data is based on the knowledge that minimum values of resistivity are associated with geological formations with high humidity.

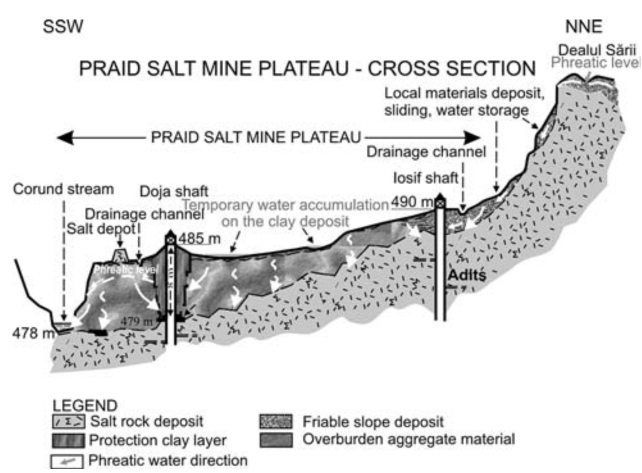



**Fig. 7** Geological structure of the investigated zone

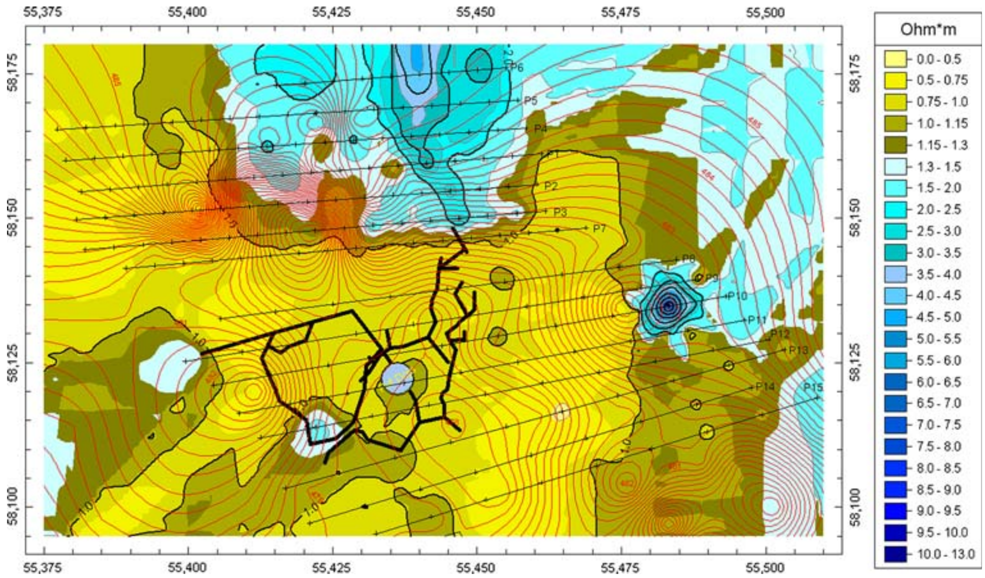



**Fig. 8** The horizontal distribution of apparent resistivity at an altitude of about +480 m

Based on the decisional analysis procedure outlined above, between 20 and 23% of the information needed to completely describe the system is lacking. The authors consider that in the case of the Dozsa shaft (the zone in the investigated area most exposed to the risk of flooding), a knowledge degree of 80% is acceptable.

## Conclusions

Our geochemical analysis indicates that the dissolution capacity of Corund surface water increases the potential risk of generating hydrogeological "windows," which would increase the likelihood of underground workings being flooded. At elevations close to the salt breccia stratum, electrical tomography already showed quite a large area of low resistivity anomalies, which is likely a high humidity zone. To prevent flooding, three hydrological and geomorphological monitoring stations should be established on Corund Creek (Fig. 4). Then, when it appears that there is an increased risk of serious damage, river diversion could be imposed.

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