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HYDROLOGICAL CAUSES AND CONSEQUENCES OF THE WATER INRUSH INTO THE PRAID SALT MINE, TRANSYLVANIA, ROMANIA

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Abstract: The Praid salt mine, Romania was flooded by the Corund Creek in May 2025, which changed the hydrodynamic and environmental conditions of the site. To provide an overview of the situation, we discuss the geological processes forming the salt diapir, highlighting its hydrogeological aspects. We also present the previous mining activities, and the most probable process of the water intrusion into the mine areas. Since a new situation arose as a result of the inrush of water, we analyze the hydrodynamic processes of the recent (flooded) state and we give an outline of future possibilities.

Keywords: *Praid, salt mine, flood, salt diapir, hydrodynamics*

1. INTRODUCTION

The Praid Basin lies at the eastern edge of the Transylvanian Basin and the Gurghiu Mountains and is part of the "Salt Region." In a broader sense, the Praid Basin extends around the Salt Hill called Muntele De Sare (Sóhát) (Fig. 1) with its three settlements of Praid (Parajd), Ocna de Jos and Ocna de Sus (Alsó Sófalva and Felső Sófalva). The small, triangle shaped basin, which is no more than 2 km wide and 7 km long, points southeast towards Corund city and connects to the Sovata Basin in the northwest through the Târnava Mică (Kis-Küküllő) river's valley. In the middle of the Praid Basin lies the salt hill, with the highest point of 576 m above sea level, which is the exposed surface of a salt diapir, extending to a depth of 2.7-3.0 km. The Praid salt dome is one of the largest geological formations of its kind in Europe, with an elliptic horizontal cross-section with axes approximately 1200 and 1400 m long.

Salt mining dates back to the Middle Ages, but industrial deep mining only began in the 18th century, when the József Mine was opened in 1762 in the southwestern part of the hill, under the leadership of Austrian mining engineer Aladár Frendl (Horváth, 1998). Subsequently, mining cavities and chamber and pillar type excavations were developed on several levels down to a depth of 400-410 m below the surface.

Experts had already drawn attention to the danger of flooding of the mine areas in 2007 (Deák et. al. 2007a), and in recent years there have been several minor water ingress incidents from the Corund Creek, which were stopped by water management experts after a short or longer period of time. In one such case, the lowest mine level was covered with more than 1 m of water, which allows us to predict the likely consequences in the current situation. It was interesting to note that the flooding caused only minor damage to the mine walls, with a few centimeters of dissolution during several months of flooding period.

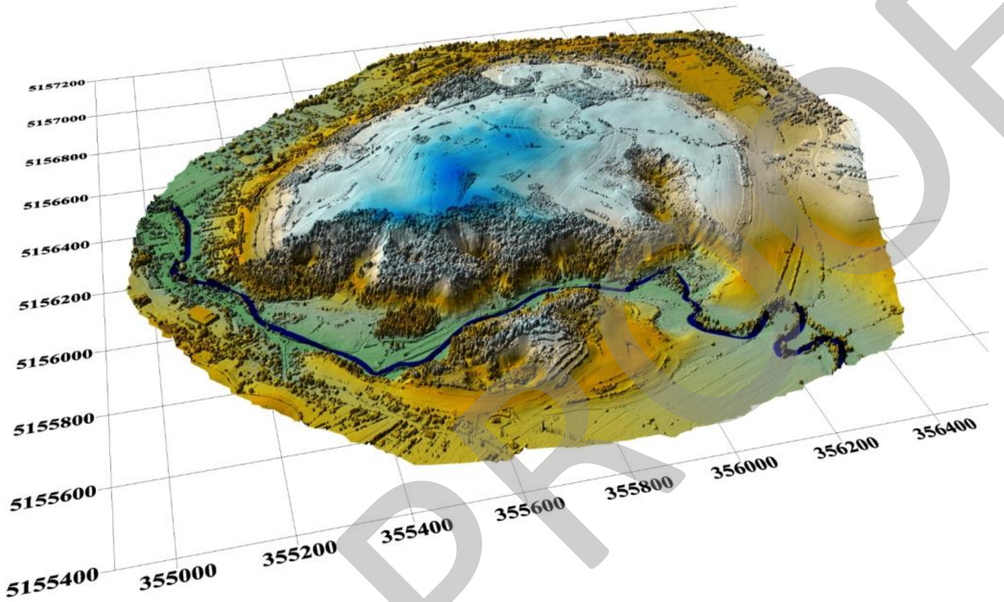

Figure 1

3D view of the Salt Hill (Sóhát, Muntele De Sare, units are given in meters)

Unfortunately, despite increasingly frequent warnings, the underground mine areas were not isolated from the Corund Creek. A flood situation developed on the Corund Creek at the end of May 2025, when the creek, which has a small catchment area and therefore capricious flow rate flux fluctuations (the creek is 19.6 km long, catchment area 137 km^2; average slope of the riverbed 24.7 m/km, 10-year (10%) frequency water discharge 70 m^3/s, 100-year (1%) frequency discharge - 200 m^3/s based on data provided by Romanian Water Authority), a flood wave with a discharge of 60 m^3/s formed, resulting in a much stronger water intrusion into the so-called “Parallel mine” from the Salt Canyon direction on 27 May 2025, than previously. During the water intrusion, the entire water flow of the stream rushed into the mine cavities, resulting in the entire underground cavity system being filled to a level of 477 m a.s.l. (the level of the Corund Creek) by 29 May 2025. The salt miners tried until the very end to prevent the entire cave system from flooding by carrying out underground work, but the underground protective structures were washed away by the flood, so these efforts were unsuccessful. Fortunately, the flood did not claim any human lives.

2. METHODS

Elevation data for the larger area are from EUSTAT website (https://ec.europa.eu/eurostat/web/gisco/geodata/digital-elevation-model/eu-dem) using the appropriate cutoff from the 30 m horizontal and 1 m vertical resolution EU-DEM grid.

Large resolution Digital Surface Model (DSM) based on LIDAR photogrammetry recordings were made by the Babes-Bolyai University, Cluj-Napoca, Romania, with a horizontal resolution of 44,3 · 44,3 mm. Due to the need of high frequency DSM recordings (1-2 DSMs/day) there was no possibility for strong post processing and recalibrating of the images that lead to large elevation errors at locations with recordings from fewer drone positions and also in absolute elevation data. To reduce these errors, we performed a subsequent recalibration based on standalone buildings and other georeferencing points. Based on cross check of several images the relative error was decreased below approx. 10 cm, the absolute error below approx. 50 cm which made the DSMs usable. In most cases we used DSMs for comparative analyses that further reduced the errors.

The maps of underground openings and cavities were digitized from ancient mine maps by the support experts of the Romanian partners. Due to different and partially unknown local reference systems used at the surveys the boundary lines are converted to world coordinates by approx. 2-5 m lateral accuracy. The schematic cross section of the underground mine areas used in several explanatory figures was presented by SALROM specialist, Szilamér J. Kovács geologist without further citation.

All Corund Creek parameters were determined by the Romanian Water Authority based on the statistical evaluation of long-term measurements of water stages and flow rates. The sodium chloride concentrations were estimated based on electric conductivity measurements measured by in situ testing devices.

3. GEOLOGY OF THE SALT DIAPIR

The formation of the Praid salt deposits is summarized based on the works of István Horváth (1998, 2011) and the website www.salinapraid.ro. The Transylvanian Basin was formed by continuous subsidence at the end of the Cretaceous period and the beginning of the Paleogene period, while the neighboring Carpathian Mountains were uplifted.

The Praid salt dome itself was formed approximately 20-22 million years ago, during the Middle Miocene, Lower Badenian geological period. At that time, the shallow inland sea that had formed in the basin was separated from the ancient Tethys Sea, and the salt layers precipitated as a result of strong evaporation were deposited in the basin, which was sinking in the meantime. The current extent of the Transylvanian salt layer is approximately 16,200 km^2, with an average evaporite thickness of around 250 m (Fig. 2).

The constant sinking of the basin resulted the formation of a nearly 5,000 m thick sedimentary formations during the subsequent geological eras, which was deposited on top of these salt layers. The salt mass therefore once lay deep below the younger layers, and the roots of the elliptical salt body in Praid is still at a depth of 2,700-3,000 m today. Under the significant pressure of the overlying rocks, the salt, like a plastic, dense liquid, was pressed towards the edges of the Transylvanian Basin. In the diapir fold zone, the plastic salt layers were compressed by enormous forces and pushed upwards towards the surface along existing fault lines in the form of salt domes. Where the salt folds could not rise to the surface, they became stuck at various depths and formed so-called crypto-diapirs.

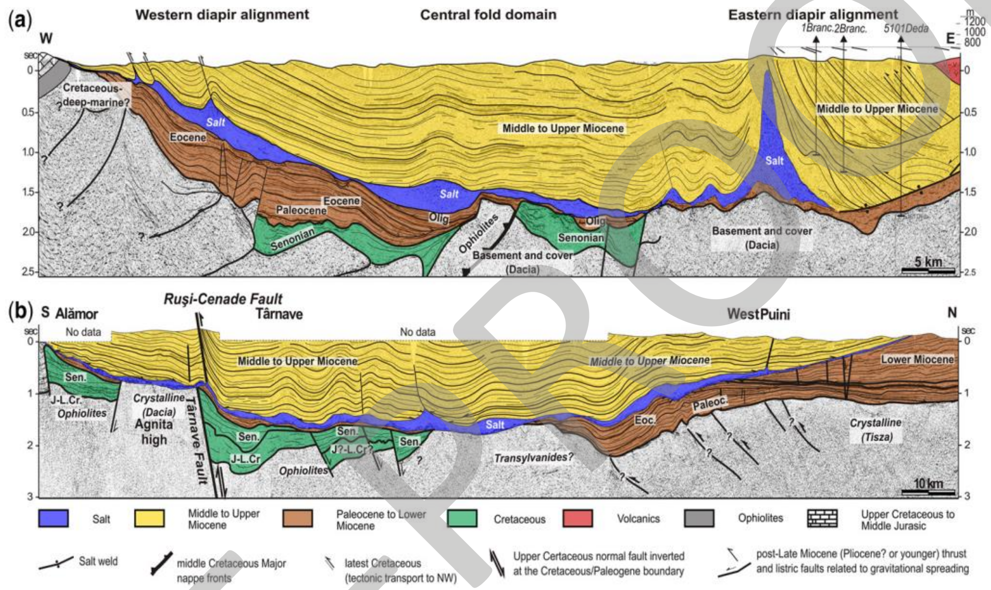

Figure 2

An E-W and N-S geological cross section through the Transylvanian Basin (Tamas et al., 2025)

Paleogene sediments are found on the edge of the Transylvanian Basin, sloping towards the interior of the basin. Within this area lies a zone of diapiric folds, where deep-seated salt domes rose to the surface and broke through the younger sedimentary layers. In the central part of the basin, there is a region of wide, circular wave folds, known as domes, in whose porous rocks considerable natural gas deposits accumulated during the Upper Badenian, Sarmatian, and Lower Pannonian geological periods.

The four important layers of the Badenian sequence, from bottom to top, are the Badenian tuff, the Globigerina marl, the evaporites (salt and gypsum layers), and finally the shale and clayey marl layer, which is the cap rock of salt diapirs.

The Pleistocene strata are discordantly deposited on the Badenian strata. These are the products of post-Pliocene Harghita volcanism, i.e., volcanic agglomerates and breccias consisting of pyroxene and amphibolite elements and grayish tuffaceous binding material. The volcanic rocks are several hundred meters thick and form the main landforms surrounding the Praid Basin. The uppermost layer consists of Holocene sediments, which consist of river sediments, alluvial cones, sand and gravel deposits, soils, and carbonate deposits (e.g., Corund aragonite spring sediments).

One of the characteristics of the Praid salt deposit is that it contains interbedded rocks (crystalline schist, dolomite, quartzite, layered sandstone, clay schist, marl) and rock inclusions. The Praid salt is densely layered, with snow-white and dark gray salt layers alternating rhythmically, and the folds of the layer lines were clearly visible on the walls of the salt chambers.

As already mentioned, the Praid Salt Dome was formed during tectonic processes when the crumpled salt dome pierced through the younger layers of the Neogene strata. This process modified the water network of the basin. The emergence of salt hill caused hydrographic changes in the area where the Târnava Mică river and Corund Creek meet. The emergence of the salt diapir formed a barrier to the flow of the Corund Creek, while the larger Târnava Mică river was able to keep pace with the emergence of the salt dome and gradually deepen its erosional valley. The Corund Creek probably broke through the diapir area in the southern part through a valley-like depression formed by the collapse of salt karst cavities along tectonic lines, thus creating the Salt Canyon (Canionul De Sare, Sószoros) in Praid.

In the salt mountain zone, numerous salt karst phenomena can be observed on the surface, where smaller and larger, partly clay-lined funnels and depressions occur, resembling the karst phenomena of limestone regions: dolines, sinkholes, potholes, and karst fields. Some of the dolines and sinkholes are constantly forming and deepening, partly due to the infiltration of rainwater and partly due to the collapse of dissolution cavities formed by underground seepage. Some larger sinkholes are traces of ancient, irregular surface mining, in some cases irregular cavities left by Roman salt mining, or more recent illegal mines from which the local population stole salt during the prohibition period.

The sodium chloride content of Praid rock salt is between 94 and 98%. Unlike the salt deposits in the surrounding area, the productive salt body contains only very small amounts of gypsum and anhydrite (www.salinapraid.ro).

4. THE HISTORY OF THE PRAID SALT MINE, GEOMETRY OF UNDERGROUND MINE CAVITIES

The website of the Praid salt mine (www.salinapraid.ro) provides a detailed history of mining based on Horváth (1998), the most important details of which are as follows:

Systematic salt mining in Transylvania began during the Roman Empire, and after they abandoned it, the so-called surface "salt cutting" was continued first by the Avars and then by the Bulgarians. After the Hungarian conquest, King Stephen's salt transport ships regularly sailed on the Mures (Maros) River after 1003.

The Transylvanians had the ancient right to freely exploit natural resources, from which their free "salt right" originated, the continuous restriction and authorization of which depended on the historical balance of power. The earliest written record of salt mining is King Andrew II's 1222 charter of privileges for the German Order of Knights of “Barcaság”, which granted them permission to operate salt-carrying ships on the Mures (Maros) and Olt rivers.

In 1405, King Sigismund of Luxembourg banned the opening of salt mines by local landowners, while in 1463, King Matthias confirmed the Transylvanians' right to use salt.

Until 1562, salt was the public property of the Transylvanian people, which meant that every household could obtain salt free of charge. Until 1562, salt was the common property of the Székely people, which meant that every Székely household could obtain salt free of charge, but this ceased after the suppression of the Székely uprisings, as King John II Sigismund confiscated the salt mine in Praid for the benefit of the royal treasury. The election conditions of Transylvanian princes Gábor Báthori (1603), István Bocskai (1605), Gábor Bethlen (1613), and György Rákóczi I (1631) included respecting the ancient freedoms of the Transylvanians and guaranteeing their free salt rights, but the free salt to which the Transylvanian people were entitled was only restored during the war of independence led by Ferenc Rákóczi II. Underground mining began in Praid in 1762, when the József Mine, which was geotechnically very stable and bell-shaped, was opened.

In 1787, the Praid salt mine became the property of the Vienna treasury. In 1864, the trapezoidal Parallel (Párhuzamos) Mine was opened, at the same time as the Nándor Mine was expanded. In 1898, the Erzsébet exploration tunnel began to be excavated in the northwestern part of Salt Hill. The medieval mining technique was reorganized after World War I, and in 1945, explosive salt mining was introduced. Between 1947 and 1949, the Dózsa György Mine was opened, but the Parallel Mine was still in operation until 1954. In 1972, work began on opening a new mining section in the north-eastern part of Salt Hill, but the work was abandoned due to quality indicators.

In 1978, new underground levels were created beneath the old mine chambers, with 12 m high, 20 m wide and 200 m long chambers, and later (in 1991) the development of the Telegdy Mine section began in the north-eastern part of the salt deposit with 16 m wide and 8 m high chambers, with square support pillars between them with a cross-section of 14 m x 14 m. The extent of the mine cavities throughout the entire Salt diapir is shown in Fig. 3, for better presentation of the underground mining areas a 3D figure taken from the work of Deák et al. (2007b), is presented (Fig. 4.)

As Figs. 3 and 4 clearly show, the bell-shaped dome of the József Mine and the pyramid-shaped ceiling of the Parallel Mine are closest to the surface. The former collapsed in a small area over time, which is why this area was covered with a larger roof structure on the surface to protect it from rainwater. There have also been minor collapses deeper in the mine. The wider pillar separating the József- and Parallel Mines collapsed in the middle section, and there have also been minor and major collapses in the ceiling of the parallel mine during water ingress. Most of these cavities were filled with concrete and clay fillings in an attempt to eliminate them.

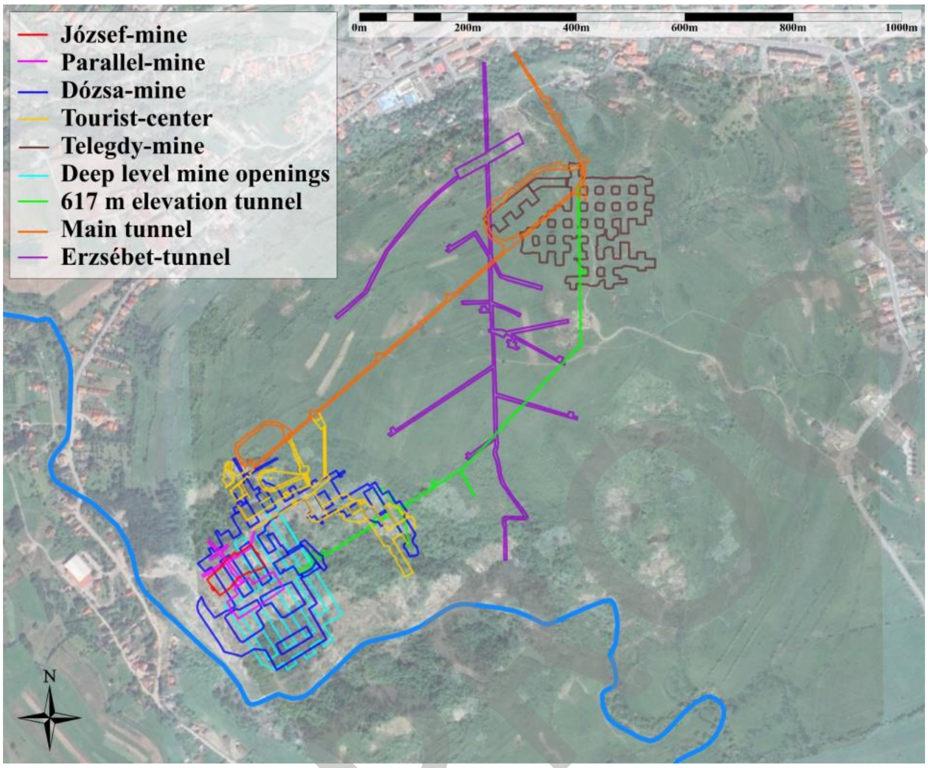

Figure 3
The location of underground mine openings (units are given in meters)

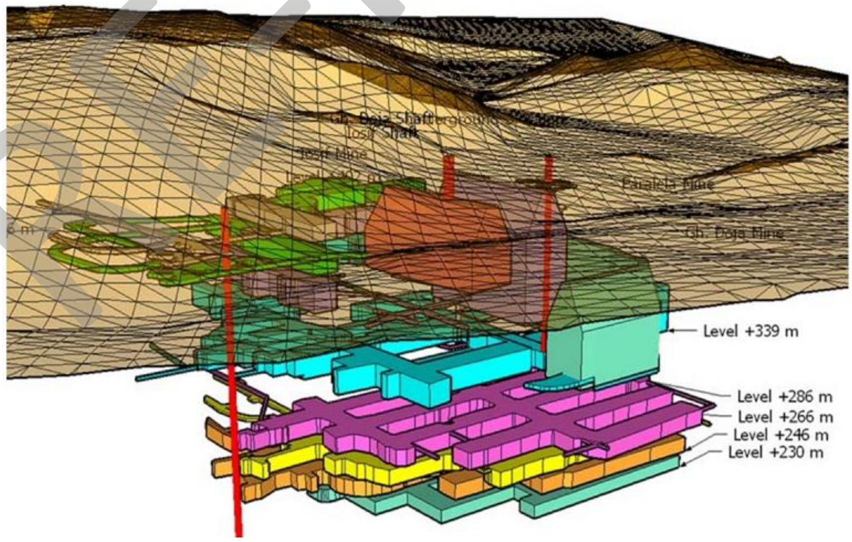

Figure 4
3D view of mine openings in the Southern part of the Salt Hill (Deák et al., 2007b)

5. Processes occurring during water inrush, hydrogeology and hydraulics of the system, stability after flooding

Over the past decades and centuries, numerous dissolution cavities and cavity systems have formed in the salt dome. Some of these were formed by water infiltrating along the fault systems in the area and, due to prolonged dissolution processes, could be as deep as 10-15 m below the surface (these are patterns of natural salt karstification).

The dissolution cavities were tapped through the vein systems by the mine cavities, and periodic "sweating" and seepage in the ceiling zones of the mines seemed natural over time, which the miners continuously pumped out from the mine areas. Occasionally, these slow dissolutions caused minor or major collapses, one of the largest of which was the collapse of part of the ceiling of the József Mine. These cavities were fed partly by sinkholes formed on the left bank of the Corund Creek and partly by fresh water slowly seeping along the veins and cracks crossing the stream, causing a continuous dissolving of salt.

In addition to this natural cavity formation, however, dissolution cavities also formed at the contact surface of the salt dome and the alluvium of the Corund Creek, as a kind of discontinuity, but these were of minor importance before the flood of the mine.

When the water broke through, the stream found its way to the former karstic cavities, where the continuous inflow of fresh water increasingly dissolved the salt formations, widened the cracks, and then broke through walls of the existing cavity system leading to the Parallel Mine’s roof level (Fig. 5). At first, this process only led to a low flow towards the mine, but with the continuous dissolution of the cavities, in its final state it was able to swallow the total discharge of the creek, which at that time was approximately 60 m^3/s.

This intruding water first spread across the floor level of the Parallel Mine, then poured down deeper and deeper levels along shafts, inclining shafts, blind shafts, and previous drill holes (Fig. 6). In this phase, not only the dissolving effect of fresh water, but also the mechanical force of the turbulently flowing water destroyed the salt rocks. According to the miners, the water rushing downwards dissolved the salt in a zone several meters wide, even exceeding 10 m in diameter, along the drill holes as it flowed towards the deeper levels. Once it reached the deepest levels, the water filled the mine from the bottom up, causing, for example, the wooden support structures of the Parallel Mine were crushed into the adjacent mine chambers, confirming that the water ingress occurred through the Parallel Mine and that any inflows into the József Mine from the surface were negligible during the water ingress process.

As a result of the water ingress, by 29 May 2025, the entire underground cavity system had filled up to the level of the Corund Creek, i.e., 477 m a.s.l. The total volume of the mine cavities can only be estimated with a high degree of inaccuracy based on the time required for flooding and the estimated average discharge of the creek. According to those calculations a total volume mine cavities of 4-7 km^3 was determined.

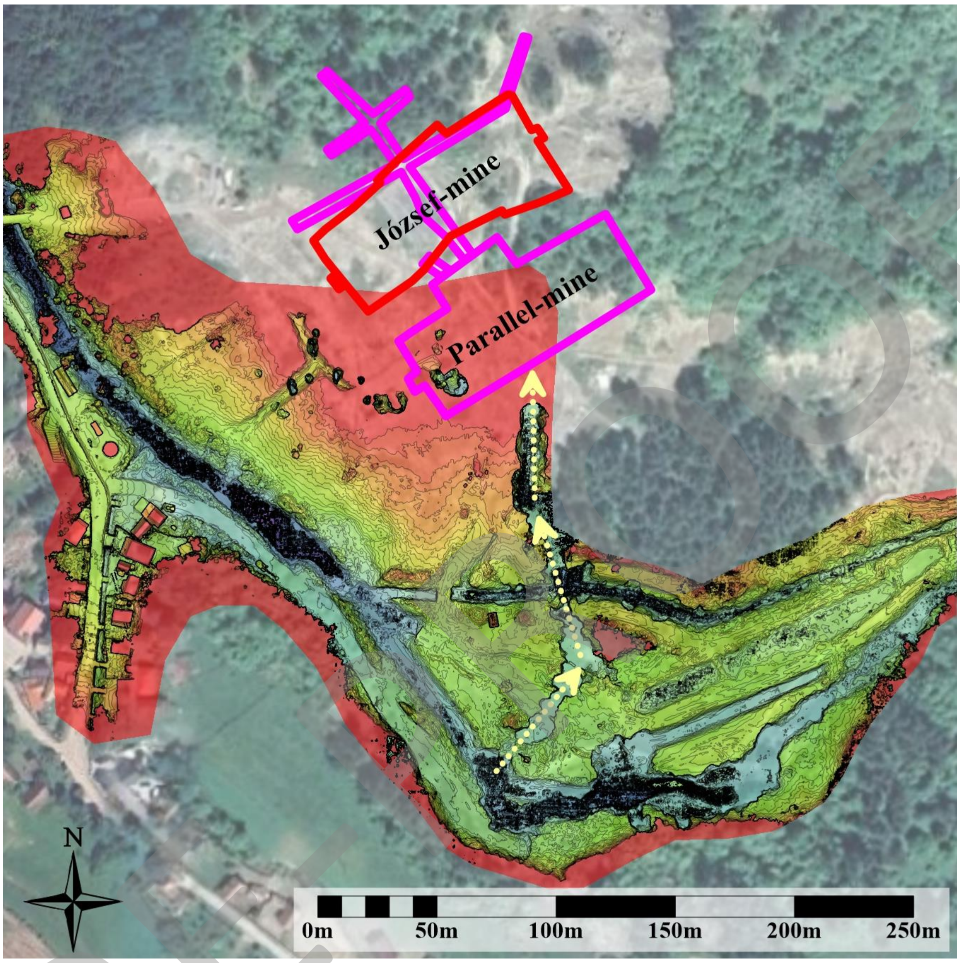

Figure 5
The direction of freshwater inflow can be easily traced on the surface relief based on the collapse of underground cavities (evaluation based on photogrammetry-based (LIDAR) DSM by Babes-Bolyai University, Cluj-Napoca made on 13.06.2025)

The fresh water entering the mine gradually dissolved more and more salt through the dissolution and erosion processes described above, and also dissolved the salt stored in the area of the former and current mining cavities. The salt deposits stored in the mine chambers are significant in that the dissolution of the mined powder and debris-like salt is much faster due to its large surface area than the dissolution of the salt walls along the pillars, which could have significantly reduced the rate of dissolution from the pillars.

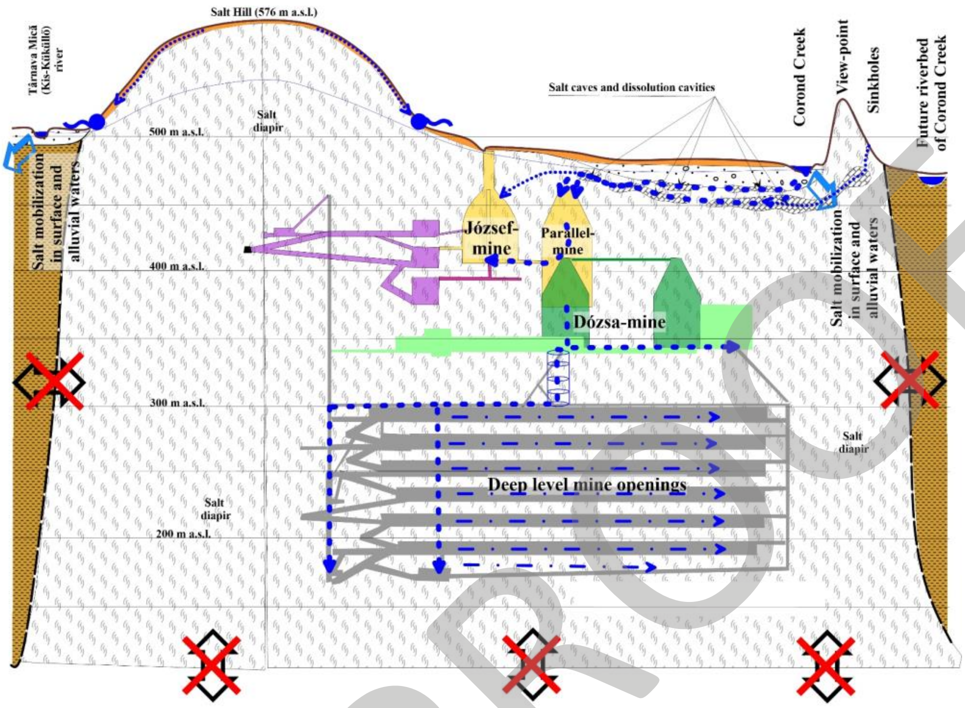

Figure 6
Schematic representation of the flooding of the studied salt mine

The saturation concentration of sodium chloride is 359 g/dm^3 at 25°C, which varies only a little with temperature (375 g/dm^3 at 60°C) and pressure. This is important because the temperature in deeper mine cavities is higher than near the surface, but at the same time, no significant change in solubility is to be expected. Considering the total filled volume of 4-7 km^3, a total of 1.4-2.5 million metric tons of salt was dissolved in the mine in a few days. According to online sources (Széchely, 2015), the mine's annual salt production was 120-150 thousand metric tons, which means that in 3-5 days, the salt equivalent of 10-20 years of production dissolved in the mine cavities. However, the density of saturated NaCl salt solution is 1170 kg/m^3, which is 17% higher than that of water, which is significant in terms of the hydrodynamics and stability of the area after filling.

According to measurements, the salt solution reached saturation in the mine chambers within a few days (by 5 June 2025) in the József Mine and in 3 weeks it the Telegdy Mine (Máthé et al. 2025) at the farthest and highest point from the water ingress point. From this point on, no further dissolution of salt could occur at the contact surfaces with the saturated salt solution. However, salt dissolution does occur after filling, wherever the saturated solution is diluted due to the infiltration of fresh water into the mine areas. Since the amount of water in the mine is nearly constant (corresponding to the current water level of the Corund Creek), a quantity of saturated salt solution corresponding to the amount of fresh water currently entering the mine escapes from the mine cavities, primarily into the Corund Creek, maintaining higher salt concentrations than before on a permanent basis.

The most typical inrush pathlines can be determined based on surface subsidence. The map shown (Fig. 7) is based on topographical surveys conducted by Babes-Bolyai University on 4 and 14 June 2025, which, due to the lack of postprocessing, remain somewhat inaccurate but are nevertheless representative. The changes in terrain clearly show the main direction of the water intrusion, as well as the alternative stream beds created during the defense measures, which are also capable of directing water in this main direction. In addition, the eastern parts also show the zones where the increasingly saturated waters from the near-surface mining areas seep out. These zones transport the waters partly from the Parallel Mine and partly from the József Mine towards the Corund Creek. The driving force behind the seepage is the water stage gradient (slope) in the Corund Creek, which reaches 2-3 m in the area (between the two ends of the Salt Canyon), depending on the water level, but also exceeds 1.5 m in the mining area. This driving force induces leakage towards the mine areas on the upstream side and discharges the mine cavities on the downstream side, which induces continuous freshwater infiltration, salt dissolution and then saltwater outflow.

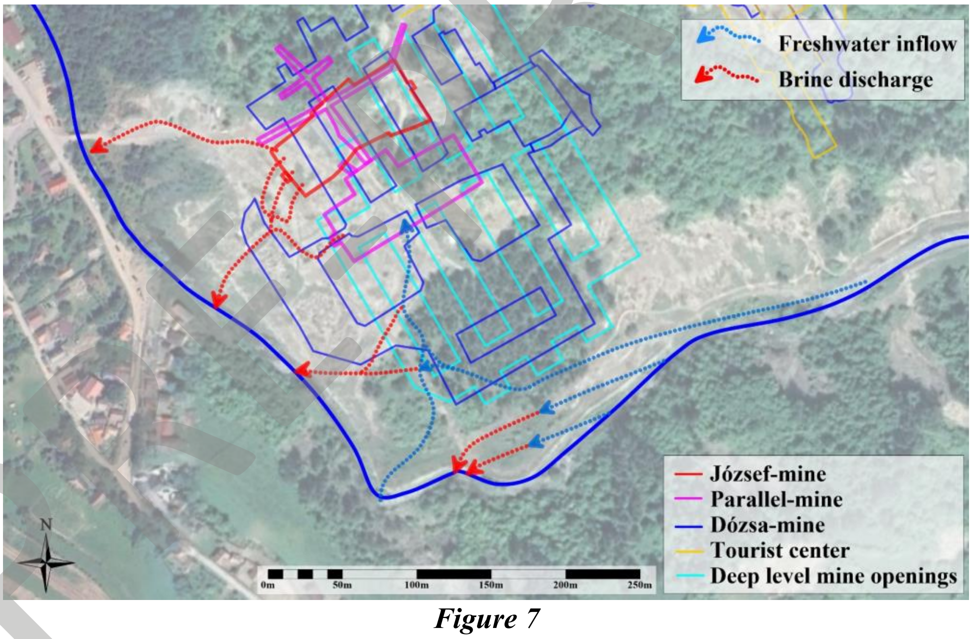

Figure 7

The recently possible directions of freshwater recharge and salty water discharge based on the surface relief survey of underground cavities (evaluation based on photogrammetry-based DSM by Babes-Bolyai University, Cluj-Napoca made on 14.06.2025)

This also means that until the water of the Corund Creek is completely isolated from the mining areas, continuous salt dissolution will occur partly from the alluvium of the Salt Canyon area and partly from the mine cavities (Fig. 7).

In addition to this constant slow salt leaching, fluctuations in the water level of the Corund Creek also generate salt yields, as the water level in the mine cavities follows the changes in the water level of the creek with a delay of at most half an hour to an hour, so that during floods, fresh water pushes towards the mine, and during low water levels, salt water seeps out of the mine cavities.

The salt loss intensity from the mine area can be estimated based on the actual discharge, sodium and chloride ion concentrations of the Corund Creek and the Târnava Mică river. The sodium and chloride concentrations can generally be determined based on electric conductivity (EC) measurements. Assuming that the change in EC is caused solely by the dissolution of sodium chloride, then 0.336 times the conductivity measured in µS/cm is equal to the chloride content in mg/dm^3, and keeping in mind that mainly sodium chloride is dissolved, then based on the molar mass ratio of Na and Cl atoms, the sodium ion concentration is 64.8% of the chloride ion concentration and the "concentration" derived from the leached NaCl is 1.366 times the chloride ion concentration. The total yield of sodium chloride dissolution from the mine can be calculated as the product of brine concentration and the discharge of the creek or river.

Based on the salt loss intensity calculations, it appeared that the initial salt dissolution rate of 1300 t/d at the end of May (just after the mine flood) had decreased to 170 t/d due to the initial measures and the trend of decreasing Corund Creek discharge and water levels, which was temporarily and suddenly raised to 3900 t/d by riverbed relocation and related construction works. This large excess dissolution caused the damage to wildlife observed in the Târnava Mică river (Máthé et al., 2025).

Máthé and his co-authors (2025) simultaneously measured the EC of the Corund Creek and the Târnava Mică river and found that the concentration of the Târnava Mică river decreased only to nearly one-fifth (21.3%) due to dilution. The brine concentration of the Corund Creek decreased from 10 g/dm^3 to 3 g/dm^3 during the initial period mentioned before, which suddenly increased to a concentration of 30-80 g/dm^3 during the initial construction works and relocation of riverbed, then decreased to between 8 and 5 g/dm^3 during the period of June 20 and 30 2025, and later fluctuated between 2-6 g/dm^3 until July 20, based on the conversion of EC data available in public communications ((Maszol.ro, Szekelyhon.ro, ZiarHarghita.ro, HargitaNepe.ro) referring to announcements of Romanian authorities. The magnitude of the mentioned concentrations is well illustrated by the fact that the average salt content of seawater is 35 g/dm^3, meaning that during peak periods, the concentration was 2-2.5 times higher than that value. Due to the nature of calculations, the mentioned values are only estimates. Máthé and his co-authors (2025) stated that above 1 g/dm^3 sodium chloride concentration there is a relevant effect on the biodiversity of invertebrate fauna, and prolonged brine concentrations exceeding 1.5 g/dm^3 caused the complete extinction of macroinvertebrates and fish populations along the affected sections of the Corund Creek and the Târnava Mică river. Drinking water standards prescribes the chloride concentration below 250 mg/dm^3 therefore all surface water discharge operations for public water supply for over 40 thousand inhabitants downstream from the mouth of Corund Creek had to be stopped (Rákóczi, 2025).

There is another interesting aspect to the hydrodynamics of the system, namely, due to the increase in density caused by the dissolution of salt, a zone with a higher potential than the surrounding area is formed in the mine cavities during dissolution, given that the hydraulic, i.e., seepage potential depends not only on the reference height of the water level but also on the density of the liquid.

As long as the salt continues to dissolve, the continuously increasing potential levels within the mine cavities are higher than their surroundings, which can be balanced out if the salt leaks out from the mine cavities through existing cracks and not completely closed fracture zones. As these waters are nearly saturated, their further dissolving effect is negligible, but they do represent a form of underground salt transport. This phenomenon may result in a local increase in the electrical conductivity of groundwater and, presumably, in its sodium and chloride content upstream in the Târnava Mică river's alluvial deposit, in the area north of Salt Hill.

Once the hydraulic balance of the mine cavities and the surrounding area is established, this salt transport ceases due to the lack of driving force. All this confirms that isolating the Corund Creek from the mining areas is critical for the environmental condition of the area, because until then, water inflow, saltwater seepage and the continuous disruption of the hydraulic balance will continue, affecting not only the Corund Creek valley and, through it, the lower reaches of the Târnava Mică river, but also the zone along the Salt Hill in the Târnava Mică valley upstream from its mouth.

However, these dissolution processes following the filling of the mine cavities only affect the uppermost zones of the shallower mine cavities near the surface, as the higher-density, saturated salt solution fills the deeper mine cavities, so no dissolution processes are currently taking place at greater depths.

The formation of the salt diapir described above and its existence over millions of years mean that the diapir is completely isolated from the groundwater laterally and from the depth below the diapir (partly due to the surrounding clays and marls, and partly due to the soluble but surprisingly impermeable salt rocks), so that the saturated water containing sodium chloride that seeps into the deeper mine cavities cannot move either sideways or downwards. Accordingly, these deeper mine cavities are stable, as further salt dissolution is theoretically impossible and the cavities previously filled with air are now filled with a high-density saturated salt solution.

This salt solution not only does not break down the walls of the mine cavities, but also supports them with its pressure. Assuming a water column height of 300 m in deep mines due to flooding, this supports the walls with a pressure of 30 bar in the case of pure water, but over 35 bar in the case of brine (Fig. 8). Since these walls were stable even under atmospheric pressure, it stands to reason that they will not collapse even with an additional 35 bar of support. As it approaches the surface, this supporting effect naturally decreases, but strangely enough, the current situation is definitely more favorable from a geotechnical (stability) point of view than the situation prior to the water inrush. For the reasons mentioned above, in the deeper mine areas (i.e., everywhere except the József and Parallel Mines), dissolution and deterioration of stability conditions are not to be expected in the current situation.

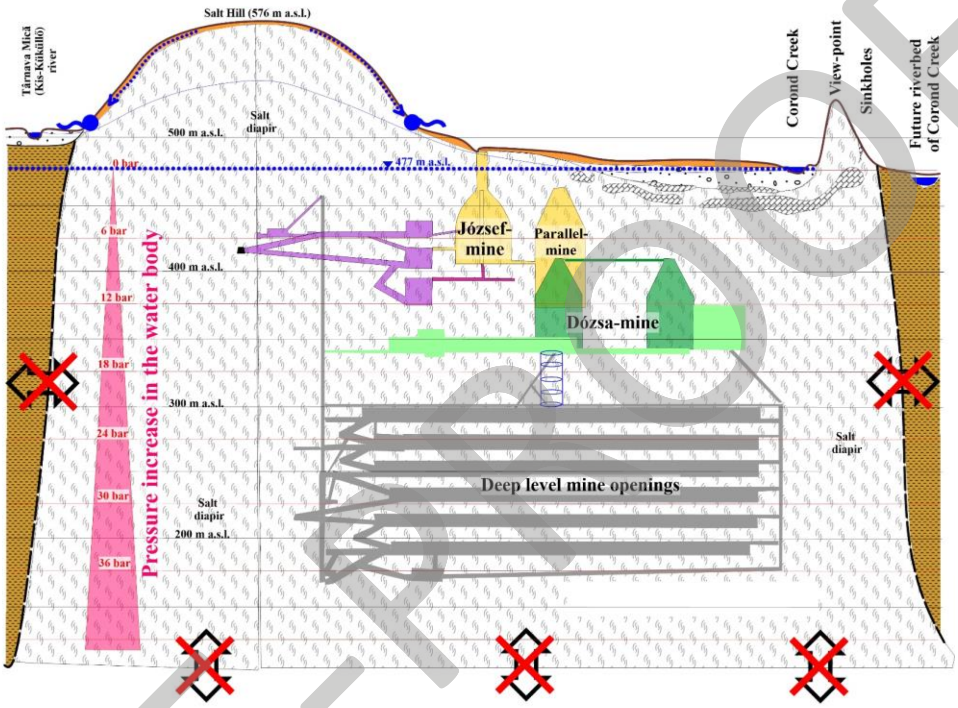

Figure 8

Explanatory chart of elevated liquid pressure in the flooded mine

Unfortunately, there may be minor or major collapses in the Parallel and József Mines, which are connected to or may be connected to surface waters, and, with very low probability, in the Dózsa György Mine due to its more direct connection to the surface and the Parallel Mine through the shafts. Dissolution near the surface is gradually eroding the salt rock of the dome and ceiling of the Parallel Mine and, to a lesser extent, the József Mine, which, as it thins, is less and less able to bear the weight of the rock above it, which could lead to collapse.

Fortunately, as Deák et al. (2009) have demonstrated with triaxial measurements, salt rocks behave differently from other rocks when bearing loads. In general, rocks undergo continuous deformation as they bear increasing loads, and then, after failure, their load-bearing capacity decreases suddenly and radically, with up to 90-95% of their load-bearing capacity being lost.

Salt rocks, on the other hand, behave differently. In the case of samples from the Praid salt mine, despite the aforementioned layering and contamination, they take loads slowly and, after reaching a maximum, are still able to bear and retain loads, i.e., most of their load-bearing capacity is retained while the salt rock undergoes deformation. The slower the loading, the greater the residual strength of the rock, and the more it is able to undergo the deformation most appropriate to the current stress state. For all these reasons, in the event of slow weakening of structures and slow increase in loads, salt rocks will be able to take on additional loads, which minimizes the possibility of sudden major collapse. Rather, slow, trend wise minor collapses can be expected.

6. Discusion and Conclusions

Solving the problems arising from the unfortunate flooding of the Praid salt mine is an ongoing challenge for hydrologists, hydrogeologists, geotechnical engineers, and environmental experts. In this study, we presented the mine and the events that took place, summarized the geological and hydrogeological conditions, and based on this, we presented the hydrodynamic and salt transport processes that occurred after the flooding.

Initial analyses predicted the rapid collapse of the mine cavities and the formation of a salty lake at the site of the mine. In addition, it was apparent that the salt content of the Corund Creek was no longer tolerable for higher organisms, and even the water quality of the Târnava Mică river was periodically intolerable for fishes and other animals. Furthermore, the drinking water supply of the settlements downstream nearby the Târnava Mică river became impossible, as the water extraction facilities had been installed on surface waters that had previously been of adequate quality. In addition to the salt content of surface waters, the salt content of groundwater has also increased locally in alluvial deposits connected to the salt dome, which also threatens the long-term use of groundwater. All these problems can be traced back to the formation and persistence of water circulation between the Corund Creek and the salt dome (Fig. 7).

Based on our analyses, the deeper levels of the flooded mine have reached a new state of equilibrium, which means that only very slow and negligible changes can occur in these areas. However, the shallower mine areas, especially the area of the Parallel Mine's roof structure, to a lesser extent the cavities near the surface of the József Mine, and least of all the parts of the Dózsa Mine close to the aforementioned mines and the shaft, are exposed to a continuously increasing level of risk over time. In these areas, fresh water seeps into the mine cavities, partly due to the fall of the Corund Creek and partly due to the driving forces caused by changes in the water level of the stream, which has a dissolving effect there, reducing the load-bearing capacity of the supporting pillars and structures, which partly causes a risk of collapse and partly causes civil protection problems through the leakage of saturated salt water corresponding to the volume of infiltrating fresh water, as well as the aforementioned environmental protection and water supply difficulties.

This dissolution of salt can only be prevented by isolating the waters of the Corund Creek from the mining areas, the ultimate solution being to divert the Corund Creek outside the Salt Hill (Fig. 9). Once the majority of fresh water, including rainwater, has been excluded, decisions can be made regarding the future of the mining areas. Based on our current knowledge, there are no scientific obstacles to the partial or complete drainage of the mining areas after the isolation of surface waters from the mine. The partial drainage of the mining areas would also be important due to the elimination of outward hydraulic potential levels, but at the same time, if the experience is favorable, it would also be possible to drain the higher-elevated Telegdy mine and the tourist center. The treatment and desalination of the extracted salt water pose a serious challenge, and an economical solution needs to be developed.

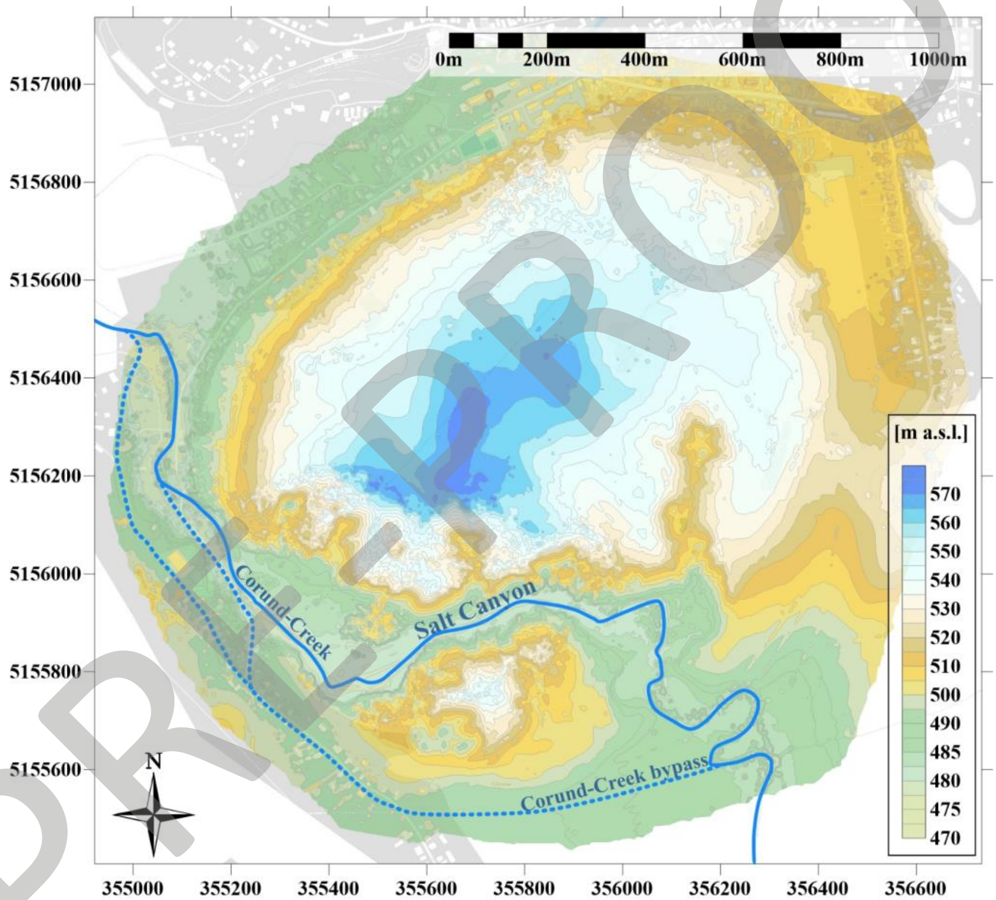

Figure 9
A possible track of Corund Creek bypass

As the current situation is clearly unfavorable for the mine, the population, and the natural environment due to the continuous leaching of salt and the reduction in the load-bearing capacity of the mine cavities, measures should be taken as soon as possible to exclude fresh water. Over time, the impact on the environment, the population, and society will increase, and the measures to be taken to mitigate them may become increasingly complex and costly.

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This paper has been prepared in accordance with the EU ERCC publication guidelines and is therefore based solely on publicly available information from newspaper articles, website information, official communications, professional publications, and basic scientific knowledge.

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