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# ANALYSIS OF THE SPONTANEOUS FLOW PHENOMENON OF THE LAND ABOVE FERDINAND SALT MINE– COŞTIUI (MARAMUREŞ)

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**Abstract:** *On July 21st 2025, a flow of rocks mixed with water took place in Coștiui (Maramureș), from the surface, in the underground excavations of Ferdinand mine (which operated between 1828-1934), at the limit of its southern shaft, which generated on the surface, in the southern vicinity of the county road DJ 186A, a collapse cone of approx. 1500m³. The article develops the geo-mechanical phenomenon and the causes that led to the occurrence of this spontaneous phenomenon, the rehabilitation measures and the safety of the affected area.*

**Keywords:** *salt mine, underground excavations, trapezoidal rooms, shaft, gallery, collapse cone, subsidence, flowing rocks, flow channel, clay rocks, reinforced concrete plate*

## 1. History of salt mining in Coștiui

The salt deposits in the north of the country extend over almost the entire area of the Tortonian deposits, on about 400 km², from north of Baia-Mare, beyond the Tisza Valley. The salt deposits in Maramureș are found at variable depths, up to 1400 m [1].

According to the chronicle "Chronologia Rei Cameralis Marmaticae", the most important documentary source for the history of the salt mines in Maramureș, found in manuscript (written between 1793 and 1811), the salt mines at Coștiui had been exploited since the period of migrations. A map from 1804 lists 14 old salt mines (Antiquarum), named after saints, Hungarian kings or Transylvanian princes, and 16 more recent mines (Recentiorum), i.e. founded in the 18th century [2].

Rona salt massif (Ronaszék) is located SE of the town of Sighet (Maramureș), on the left bank of Tisza River (about 10 km away), in a secondary valley. The massif is also in the grey facies of the salifer, being comprised of clayey marls. Intercalations of sandstone, anhydrite, dacitic tuff and coal are found in it, often forming nests. Layers of cleaner salt alternate here with others of impure salt. The massif is folded, and the folds are generally inclined towards the North. The greatest inclination is 55°, and it becomes smaller towards the depth. The direction of the massif is N-W, almost 1.5km, and the width is 0.5 km. The floor of the deposit is also observed to be formed of Paleogene sandstone. It has an exploitation area of 57,000 m², the rock salt massif is estimated at 22 million tonnes. The NaCl content is estimated at 93.199-99.946% [3].

Coștiui area has been an important place for rock salt mining since the 14th–18th centuries, through multiple bell-shaped mines and mines once opened near the town. The village of Coștiui belongs to the commune of Rona de Sus (Maramureș County), in the depression area of Maramureș, which is characterized by smooth hills. It is located between Rona de Sus (west), Petrova (east), Bârsana (south), Valea Stejarului (south-west). The area extends over Ronișoara valley, having a picturesque natural setting, with wooded hills and smooth valleys.

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In the past, at Coștiui there were at least 16 bell-shaped mines for the exploitation of rock salt, dug vertically, with the opening through shafts. The exploitation was completed in the 1930s, and some shafts are still visible on the ground, along with vestiges such as the salt lakes formed after the collapses. According to the historical data, among the documented mines are: Kurucz (1450–1707), Viz (1580–1758), Apaffi (1590–1766), Rákoczy (1703–1773), Antal I, Maria Theresa, Ferdinand and others, up to about 29 inventoried mines.

Apaffi mine is specific for its bell shape and, in the interwar period, it was still accessible. In 2003, Baia Mare Montana Speleology Club started a first research action of Apaffi cave, which is partially flooded, exploring it through an access shaft and through the adit. In the 1980's, certain repair workings were carried out, with a view to introducing the salt mine, in the future, into the tourist circuit [4].

Rona (Coștiui) rock salt mine was first mentioned in 1191. The exploitation was carried out in underground chambers in the shape of a bell, with a maximum depth of 80-100 m and a diameter at the bottom of 50-80 m. The chambers were located next to each other, separated from each other by safety pillars. In 1536, Hans Dernschwam elaborated the "Report on the exploitation of the salt mines in Transylvania", which shows that the salt mines were bell-shaped, each with three shafts: one for extraction, with a horse-driven winch, a second with stairs, for personnel and a third, with a manual winch through which the copper boiler with fire was lowered to activate the underground ventilation [1, 5].

Until the mid-19th century, most salt mines were operated in bell-shaped chambers and by a straight-step cutting system. The specific tools for cutting the salt massif consisted of simple hammers, sledgehammers, groove-cutting hammers and wooden wedges, with which the furrows were obtained and the boulders were broken. The lighting of the workplace was achieved with a lampshade, and ventilation was achieved by diffusion [5, 6].

If in the years 1720-1729, 9,858 tonnes of rock salt were extracted annually in Maramureș, in the period 1731-1751, the quantity of salt obtained here amounted to 16,000 tonnes, so that in 1791, production reached 47,453.884 tonnes [5].

The "bell chamber" mining method was replaced towards the end of the 18th century by the "trapezoidal chamber" mining method (the so-called Maramureș method), which was generalized to all salt mines in Transylvania. The chambers were 50-60 m high and 45-50 m wide. The chambers were mined in horizontal slices. In Maramureș County, at Cămara Sighet, in 1918 there was a rock salt grinding plant with a capacity of 540 tonnes in eight hours, a salt briquette plant with a capacity of 12 tonnes in eight hours and a central salt warehouse, which served Ocna Șugatag and Coștiui [6, 7].

At Coiștiu Salt Mine, extraction with a winch was used until the end of the 19th century. In 1911, an electric extraction machine with cylindrical drums and a three-phase asynchronous motor was installed at Francisc mine, which had a speed of 2.5m/s and an extraction capacity of 120 tonnes/8 hours. Rock salt exploitation was stopped in 1931, due to strong water infiltration [6, 7].

## 2. Description of Ferdinand mine

Ferdinand reserve mine dates back to 1828, according to the Map of Coștiui Mining Operations, which was drawn up in July 1912 by the Royal Salt Mine Office (Királyi Sóbányahivatal), Coștiui branch. This mine was only a reserve mine, where the trapezoidal rooms mining method was practiced.

According to a report from 1931, this mine was difficult to maintain due to groundwater infiltration, and its closure was required, because maintenance and drainage of water from the underground produced huge costs, for that time. In 1934, Ferdinand Mine was permanently closed and we can assume that at present the underground mining excavations are flooded with brine, up to a certain level.

Ferdinand salt mine was opened in 1828, from the surface, with two vertical shafts (Fig.1). One shaft was located at the northern part of the mine, 76 m in length (between elevations +391.5m and +315.5m), for ventilation; another one was located at the southern part of it, 74 m in length (between elevations +380.5m and +306.5m), for the extraction of rock salt at the surface. This represents the typical opening scheme of these salt mines exploited with trapezoidal rooms [6]. The shafts are dug, at least in the sterile rocks, at the rectangular profile of approx. 3 x 5m, with two sections and supported in oak beams joined in the tooth, with a size of 15 x 15cm. To eliminate the risk of water infiltrations beyond the support, the oak frames were sealed with animal skins and rammed clay, around the shaft support [1], [6], [7]. To prevent the support from sliding vertically, under the action of its own weight, some support systems were built at its base, anchored in the salt deposit. The southern shaft is executed 27m, in the sterile rocks and 47m in the rock salt deposit, and the northern one, is built 46m in the covering rocks and 30m in the salt deposit (as shown in the vertical sections).

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The main exploitation of Ferdinand mine was carried out with 4 trapezoidal rooms, 12 m high, arranged around a pillar in the shape of a truncated pyramid. According to the axes of the rooms, their dimensions are: in the E-W direction, 36 m, and in the N-S direction, 32 m.

In the axial plane of the western room, oriented N-S, two opening galleries are dug with the approximate dimensions of 2 m wide and 2.5 m high. The upper ventilation gallery, with a length of 112 m, is dug at approx. 7 m from the ceiling of the room and connects the two shafts. The transport gallery, 84 m in length, is dug at 4 m from the room floor; it connects with the ventilation gallery through a blind shaft executed at the southern limit of the room, with a length of 23 m, which is assumed to have been used for the development of the rooms in depth (taking into account the fact that the map shows the situation of the rooms in 1912, and the exploitation continued until 1934).

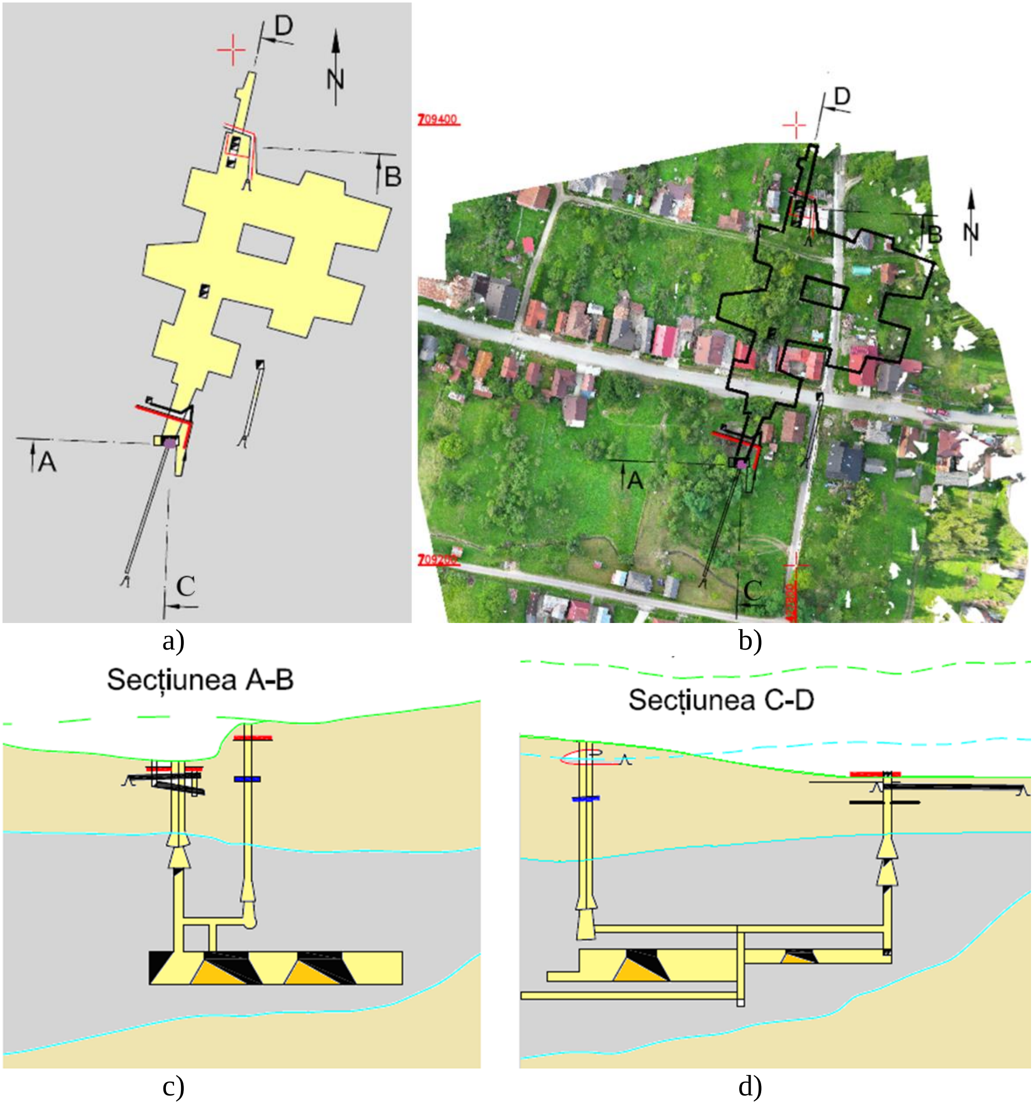


*Fig.1. Details of the Ferdinand mine (extracted from the Map of Coștiui Mines, 1912)*
*a) horizontal layout; b) mine layout, with the land and surface constructions;*
*c) vertical cross-cut A-B; d) vertical cross-cut C-D*

The placement of the opening workings on the axis of the western room may suggest that a new group of 3 rooms (mirroring the rooms system presented) was planned to be opened around another pillar in the western wing of the mine, considering the current rooms system as only the eastern wing of a supposed mine in development. Also, the existence of rooms at the airless, towards the end of each exploited room, until 1912, reveals the intention to exploit new rooms systems, around other pillars, according to the same principle.

The preparation of the rooms was carried out at an elevation of +309m (at the ceiling of the rooms), with some 2x2m section galleries, on the axis of the rooms, around the pillars. These galleries were widened to the width of the ceiling of the rooms. The extraction of the rooms was carried out in descending horizontal

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slices, with the formation of straight steps. Each slice was attacked from the centre of the rooms through a trench, 2m wide, in such a way as to develop a trapezoidal room with inclination angles of approx. 63°, up to a width of 27-30 m, at the floor [8].

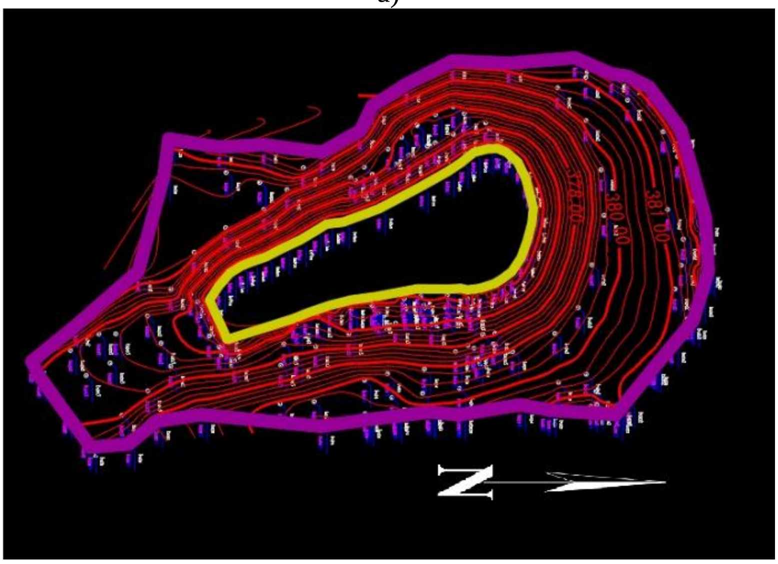
To the South, at an elevation of +306.5m, connected to the main rooms system, 4 other secondary rooms are exploited, located in a cross, connected by a gallery to the southern shaft. The rooms floor is located approx. 7 m above the main rooms floor. The height of these trapezoidal rooms is approx. 5 m, with the walls inclined at 52° and a floor width of 15-21 m.

The volume of rock salt mined from the four trapezoidal rooms on the North, with a height of 12 m, is approx. 35,000 $m^3$, and from those on the South, with a height of 5 m, is approx. 4,500 $m^3$. This means a volume of rock salt excavations of over 42,000 $m^3$ or over 20,000 tonnes extracted from the mine surface, until 1912, when the available map of the Ferdinand mine was drawn up. By 1934, when the mine was closed, taking into account the way the mine was prepared, it is possible that the rock salt reserve mined exceeded 80,000 tonnes [8].

## 3. Presentation of the event on July 21st 2025, in the area of Ferdinand mine – Coștiui

On July 21st 2025, in the area of an old shaft, at the southern limit of Ferdinand reserve mine, in Coștiui, a massive landslide occurred. It involved a flow of rocks into the underground of Ferdinand mine, as a result of which a sinking/collapse cone of approximately 20 m diameter and 12–15 m depth was formed on the surface of the land (fig. 2), affecting an area of approximately 300 m².

a)




b)

*Fig. 2. The collapse cone above Ferdinand mine*
*a) land images; b) determined by aerial photogrammetric measurements [8]*

Initially, on the orders of the competent authorities, 7 people from 5 households were evacuated as a precaution, later expanding the evacuation to 51 people from 22 homes (of which 7 were uninhabited). The authorities also delimited a safety perimeter of approximately 4,000 m² in the affected area, restricted traffic on the county road DJ 186A, decided to implement permanent monitoring of the area and took a series of measures to temporarily consolidate the land prone to landslides, from the edge of the road. The area affected by the landslide continued to be closely monitored by the authorities (ISU, Prefecture, CLSU/SVSU Rona de Sus, etc.), until the collapse phenomenon was deciphered and measures were taken to consolidate and permanently remediate the land.

On July 24th, 2025, an attempt was made to manually open, with the help of speleologists, an adit that was revealed in the northern slope of this sinking/collapse cone, an adit that develops under the national road, over a length of approx. 15-20 m, maximum. The gallery being dug a few meters from the surface, without having a technical purpose in the operating scheme of the Ferdinand mine, it can be assumed that its main role was to collect infiltration waters and, secondarily, to conduct geotechnical research on the overlying rocks (fig. 3).

Considering the relatively small section of approx. 2 m x 2.5 m of the adit and its insignificant length, evaluated at an excavation volume of no more than 100-150 $m^3$ and located a few meters above the base of the collapse cone, this can be ruled out as a cause of the rock collapse phenomenon.

On July 25th, 2025, an aerial photogrammetric measurement was carried out with a drone to develop a 3D model of the shape, dimensions and volume of this sinking/collapse cone (see fig. 2.b).

*Fig. 3. Image of the drainage adit from Ferdinand mine*

On July 26th, 2025, given that a yellow code of rain and storm was announced for the Coștiui area, the decision was made to build a sandbag dam along the national road to divert rainwater from its natural flow direction towards the sinking/collapse cone (Fig.4.a). As a temporary consolidation measure, a grid made of spruce logs was made on the bottom of the sinking cone. It was partially filled with local material, to build a “temporary support platform”; 10-15 logs, with a diameter of up to 0.8m, were placed on the northern slope of the collapse cone, at the border with the county road, to support the exposed slope with their own weight, against possible landslides (fig.4.b). The cracks oriented in the East-West direction, which appeared in the asphalt pavement of the county road, were sealed with bituminous mastic, and those on the shoulder were filled with cement, to prevent rainwater infiltration, through the fractures that appeared in the road embankment, towards the collapse cone area (fig.4.a).

In order to establish measures to restore safety to the area affected by the phenomenon that led to the formation of the collapse cone, it is mandatory to determine the causes that led to the occurrence of the phenomenon of spontaneous land instability, respectively to describe the geo-mechanical phenomenon.

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a) b)

*Fig. 4. Images of the in-situ situation, after the collapse phenomenon occurred a) temporary drainage of water and filling of fractures in the asphalt of the road b) reinforcement of the collapse cone with wooden logs*

The first team of specialists, at the request of the local and county authorities, arrived at the scene immediately after the Coștiu event. Following the analysis of the situation on the ground and the documents regarding the existence of the Ferdinand mine, it was concluded that the geomechanical phenomenon of land subsidence is typical of mining subsidence [9, 10, 11], generated by the presence of underground voids in the mine. As a first emergency measure, the decision was made to stabilize the possible development of the collapse phenomenon, with logs placed crosswise on the bottom of the collapse cone and on the slope facing the county road, followed by the pit being filled with “soil”, deposited in successive layers. In order to decipher the geotechnical phenomenon that occurred in Coștiu on July 21st, 2025, leading to the necessary measures for the rehabilitation of the affected area, expensive and long-term geological and geophysical investigations were proposed, which were not approved by the relevant ministry. In this context, there was a risk that due to the delay in taking measures, the landslide would continue and both the county road and the neighbouring buildings would be seriously affected.

About a month after the event, specialists from the Faculty of Mines of the University of Petroșani, with experience in the field of rock salt mining in Romania, were contacted. After consulting the data on Fedinand mine, analysing the situation on the ground, and comparing it with similar cases known in the country and abroad [9-15], the specialists concluded that the sudden collapse phenomenon at Coștiui is not generated by subsidence caused by underground mining excavations at Ferdinand Mine. Instead, it is a typical phenomenon of gravitational flow from the ground surface of a mixture of water-soaked rocks, in the underground of Fedinand mine, through a channel developed by the flow of underground water, over a relatively long period of time. Based on this analysis hypothesis, the spontaneous phenomenon of the collapse cone at Coștiu was described. Accordingly, urgent measures were proposed for the rehabilitation of the affected area (presented below), with further geological and geophysical investigations to be carried out after the area has been made safe, in order to find detailed information to clarify the development of this phenomenon, in order to minimize the risk of its recurrence [8].

## 4. Description of the phenomenon and the causes that led to the appearance of the collapse cone in Ferdinand - Coștiui mine area

The collapse cone is located above the underground excavations that constitute Ferdinand mine (mining rooms, opening and drainage galleries, vertical shafts and blind shaft) – fig.5.

Analysing similar phenomena developed in the area of influence of some mines in the country and abroad and especially those that occurred in the conditions of rock salt mines, the deformation and collapse of the surface land could have been caused by any of the underground excavations mentioned above. The specialists compared the shape of the collapse cone, the volume of surface rocks (over 1500 $m^3$) that leaked underground, and the relative position of the collapse cone of the mining excavations at Ferdinand mine with similar known phenomena. For example, to the phenomenon of collapsed rock flow around Carol shaft, at Slănic-Prahova Salt Mine, from 2008-2010 [13], being the only mining working that can somewhat explain

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the development of the phenomenon at Ferdinand mine represented by the southern shaft of Ferdinand mine, under the specific relief and hydrogeological/hydrodynamic conditions of Coștiui (Fig.6 și fig.7).

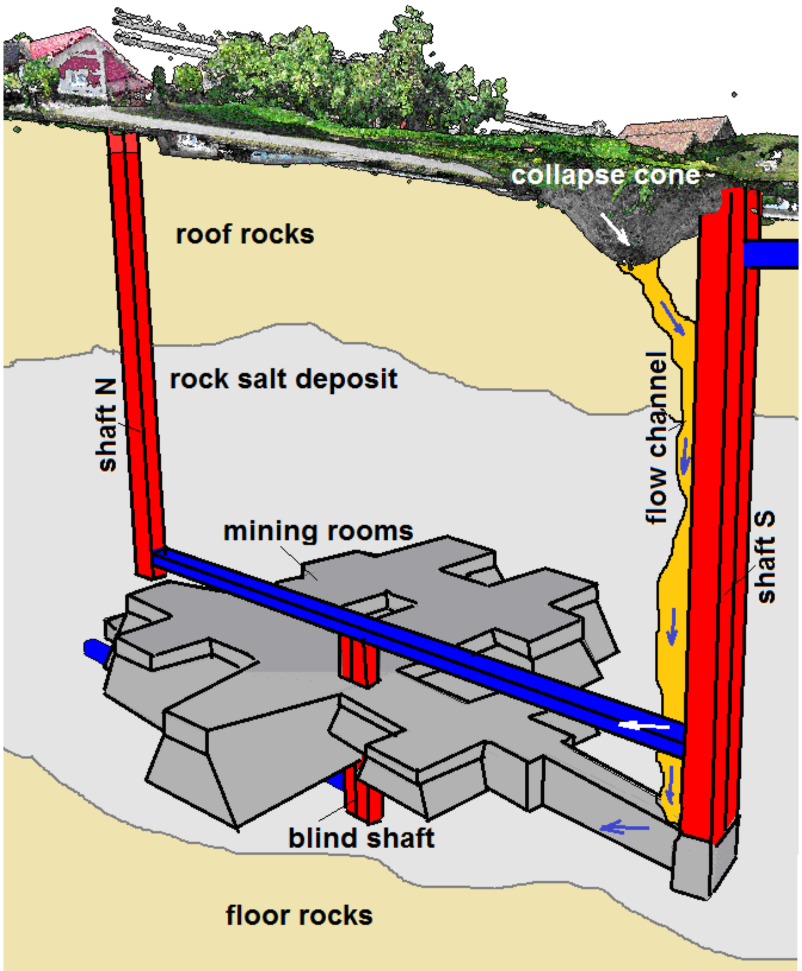


*Fig. 5. Spatial representation of Ferdinand mine and the land surface [8]*

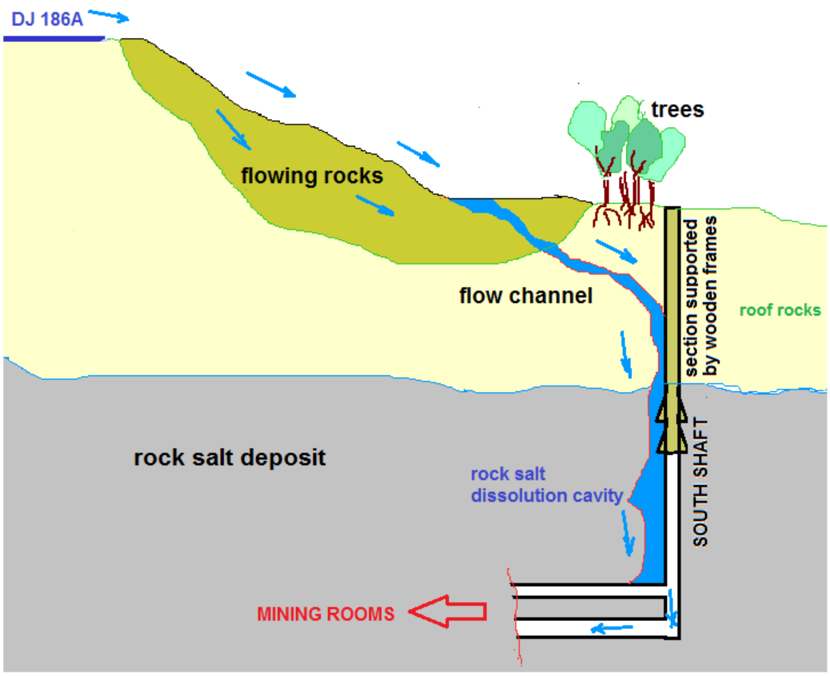


*Fig. 6. Formation over time of the flow channel and dissolution cavities in the rock salt massif, at the boundary of the southern shaft [8] (figurative representation, drawing not to scale)*

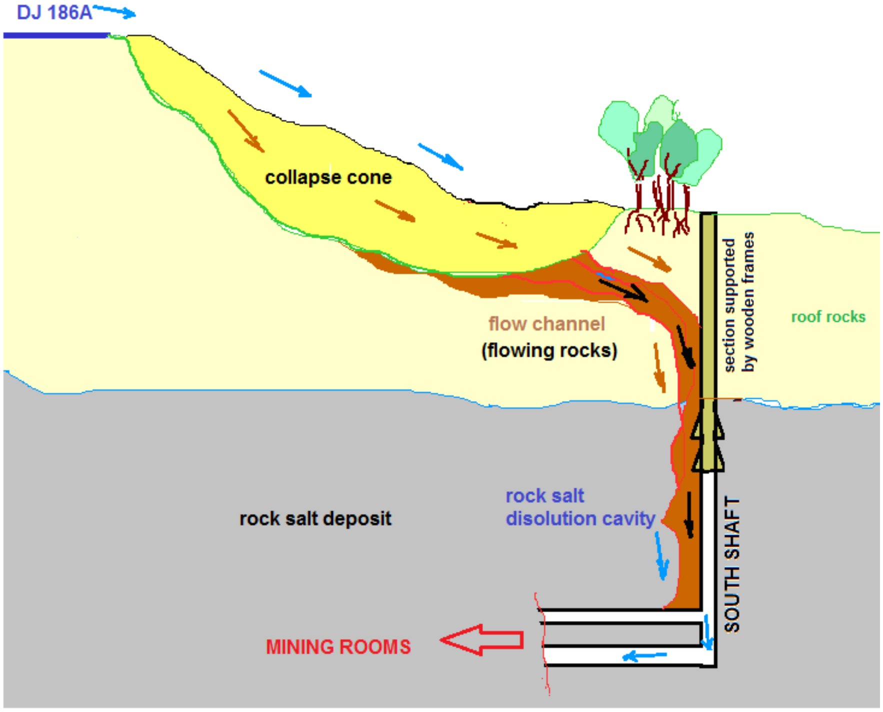


*Fig. 7. Water-soaking of rocks (formation of flowable rocks), widening of the flow channel and triggering underground rock flow/formation of the collapse cone [8] (figurative representation, drawing not to scale)*

The surface land, located between the southern shaft of Fedinand mine and the county road DJ 186A, had the shape of a sink even before the event of July 21st, 2025. The land above it had a general slope of about 10-15°, which favours the flow of surface waters, from upstream to the area subsequently degraded by the collapse cone. The hypothesis of infiltration of water from the underground water is contradicted by the fact that there is a fountain located at the upstream limit of the national road, immediately above the collapse cone, which is full of water. Otherwise, the triggering of the collapse phenomenon would have implicitly determined the emptying of water from this fountain [8].

We note that the prerequisites for the development of the hydro-geomechanical phenomenon, which led to the appearance of the collapse cone, were triggered many years earlier [8].

According to the older locals in the area, who know the history of this mining operation better, for decades, in the northern part of the southern shaft, a pond was systematically formed during the rainy seasons, from which the animals drank. Then, about 20 years ago, the water in the pond until then dried up, and the locals began to fill this pit with household garbage, soil and other plant debris. The owners of the affected land, whenever they noticed that the pit was getting deeper, tried to fill it with various materials they had at hand.

Also, one of the locals testifies that, on the evening of July 21st, 2025, he saw how the walnut tree in the centre of this land, where the sinking cone was formed, “was swallowed by the earth”. For several minutes, a specific sound could be heard, generated by the tree's movement underground and crossing an accumulation of underground water, thus causing a jet of mud, which sprayed the surrounding trees. Following the collapse, it was estimated that more than 10 fruit trees disappeared underground, and in the perimeter of the sinking cone, traces of mud can be seen on the leaves of fruit trees unaffected by the phenomenon.

The hydro-geomechanical phenomenon observed in the analysed area resulted in the formation of a collapse cone with a total volume estimated at approximately 1,500 m³ and had as its triggering mechanism the infiltration and migration of surface waters towards the northern side of the southern shaft, of the former Ferdinad rock salt mine, from Coștiui.

Taking into account the information on the spatial arrangement of underground mining excavations, the topography of the surface land and the hydrogeology of surface waters, the following will present the dynamics of the phenomenon that led to the appearance of the collapse cone on July 21st, 2025, in the locality of Coștiui, above the Ferdinand mine.

Due to the sloping terrain, surface waters flowed unhindered towards the depression area above the Ferdinand mine. It is possible that the depression in the land was also formed due to a small subsidence, determined by the presence of underground excavations, which further amplified following the systematic

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entrainment of volumes of suspended minerals by surface water currents, which penetrated through the alluvial rocks at the surface of the land.

Surface waters formed preferential flow paths through the permeable rocks located above the rock salt deposit towards the northern side of the South shaft. Because the land at the northern limit of the shaft was strongly consolidated with the roots of several trees, on an area of approx. $400m^2$, the infiltration of waters did not occur directly from the surface, next to the shaft support. Therefore, the currents created a diagonal flow path, from the centre of the current sinking/collapse cone towards the northern side of the shaft support frames. From here, over a long period, the infiltrating waters in the underground, penetrated past the well support, entrained the minerals in suspension, from the overlying rocks, forming a penetration path with increasingly larger dimensions. Once they reached the salt massif, it can be assumed that the waters began a process of dissolving the salt, forming a void at the border with the southern shaft, of at least 300-$400m^3$ [8].

At the same time, the surface waters, which reached the depression area above the Ferdinand mine, at the immediate northern limit of the southern shaft, soaked into the overlying rocks, leading to the formation of a swampy terrain, with a high water content, with a pronounced tendency to gravitational flow. In the first stage, decades ago, the phenomenon of flow of these rocks occurred in a limited way (causing the appearance of a water hole). That was due to the fact that a sufficiently wide flow channel had not yet formed in the surface rocks. With the passage of time, the increase in the frequency of rainy seasons and the volume of precipitation created favourable conditions for the occurrence of the event of July 21st, 2025. More precisely, at that time, on the surface of the land, above Ferdinand mine, near the southern shaft, an amount of about 1500 $m^3$ of flowable rocks (alluvial rocks mixed with excess water) flew through a diagonal chimney formed in the rocks, then past the support, into the dissolution voids in the rock salt deposit, and finally into the underground excavations [8].

The diameter of the mouth of the underground flow channel is several meters, with dimensions large enough to facilitate the movement of trees underground, under the action of the gravitational forces of the flowing rocks. It is possible that this phenomenon was also accelerated by the movement of heavy vehicles on the county road, which through the transmitted vibrations generated the release of part of the constituent water, trapped in certain types of rocks prone to flow. The penetration of the trees on the flow channel into the covering rocks led to the formation of a plug in the channel, which, at least for a period of time, will prevent the development of the phenomenon of water-soaked rock flow.

The northern limit of this sinking/collapse cone is in the immediate vicinity of the county road DJ 186A, which favoured the occurrence of instability processes of the cone slope and implicitly of the county road. The instability processes of the land resulted in the appearance of cracks and fissures in the structure of the roadway, some of which were visible from the moment the phenomenon occurred, and others appearing later, as the terrain movements continued.

Given the dynamic nature of the phenomenon and the risk of its expansion, it is estimated that, in the absence of immediate/effective measures to fill (backfill) and consolidate the subsidence cone, the instability process of the entire affected perimeter will increase. This evolution could lead not only to irreversible damage to the road infrastructure, but also to compromising the stability of residential buildings located in the area of influence of the subsidence cone, with possible serious consequences for the safety of the population and material assets [8].

## 5. Measures to restore the area affected by the underground rock flow

Given the urgent nature of the interventions necessary to prevent the evolution of the instability phenomenon in the area of influence of the collapse cone, based on the limited information available, it is proposed to adopt a coherent set of technical works and constructive measures, staggered in time (fig.8 and fig.9) as follows [8]:

*a) Cleaning and preparation of the work area*

From the collapse cone area, the complete elimination of vegetal mass, wooden materials, household waste and other unconsolidated materials located on the slopes or inside the cone will be carried out, as these may represent preferential paths for surface water infiltration after the rehabilitation of the area affected by the collapse.

Also, all unstable water-soaked rocks or fragments detached from the slope walls will be removed and the provisional stability of the slopes will be ensured, to prevent accidental collapses during the execution of the safety concrete plate and the filling of the collapse gap.

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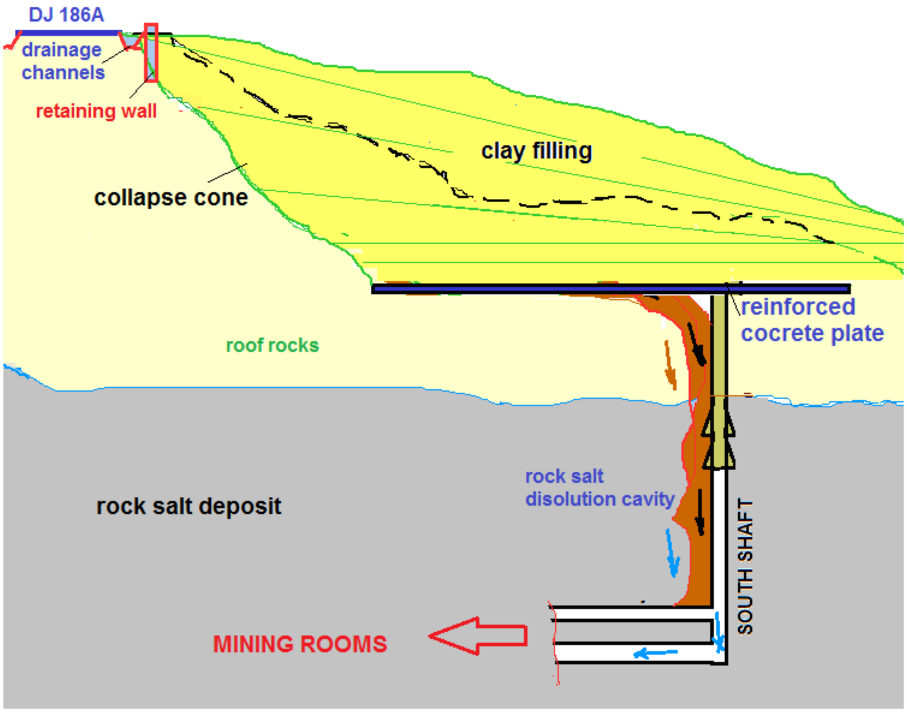
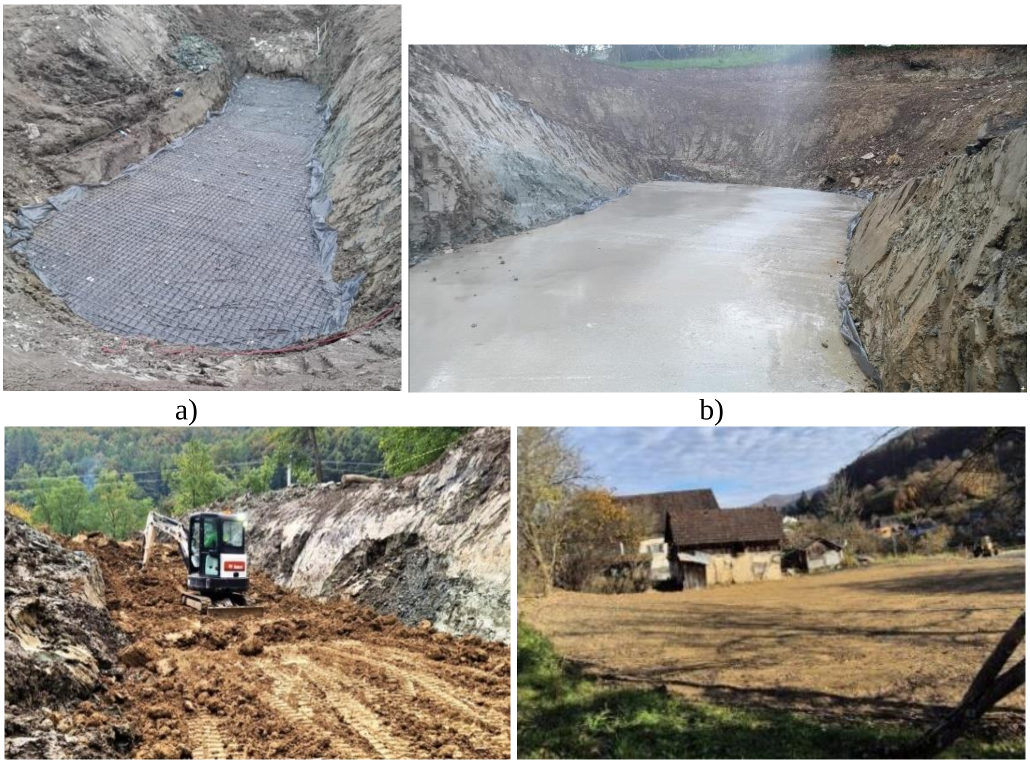



*Fig. 8. Rehabilitation and consolidation of the surface collapse area [8] (figurative representation, drawing not to scale)*



a) b)

c) d)

*Fig. 9. Filling and rehabilitation of the surface land a) steel concrete network; b) reinforced concrete plate; c) mechanized clay filling of the collapse cone; d) completely rehabilitated collapsed land*

*b) Excavation and removal of rocks from the base of the collapse cone*

Controlled excavation of the material between the lower limit of the collapse cone and the South shaft of the Ferdinand mine will be carried out, in order to eliminate any volumes of land that could favour water infiltration into the active area of the geotechnical collapse phenomenon.

The support of the South shaft will be dismantled, below the base elevation of the collapse cone, so as to prevent the redirection of infiltration waters to the underground voids of the Ferdinand mine.

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At the base of the collapse cone, a uniform surface will be provided, cleaned of loose materials, which will also include the surface corresponding to the perimeter of the shaft, on which a reinforced concrete resistance plate will be poured.

*c) Execution of the resistance concrete plate at the base of the collapse cone*

The reinforced concrete safety plate, which will be built at the base of the collapse cone, will have a minimum thickness of 0.2m, will be made of B250 concrete, added with a rapid-setting accelerator to reduce the hardening time (taking into account the urgency of the rehabilitation works). The plate will be reinforced at the bottom with 20 mm diameter concrete steel bars, placed in a grid with square meshes of approx. 0.2x0.2m, which will take over the tensile and shear stresses developed in the safety plate, after filling the void with clay.

Although the affected land at the base of the collapse cone will be removed, as much as possible, the volume and spatial position of the voids generated by the flow of water, then of the flowing rocks towards the North shaft, at the base of the cone are unknown. Therefore, the role of the concrete plate in the context of the rehabilitation measures of the affected land, consists mainly in preventing land collapses during backfilling works with the help of heavy machinery and injuries to operators, then to additionally isolate any possible water infiltrations towards the underground voids, until the maximum gravitational compaction, over time, of the backfill mass deposited in the collapse void.

*d) Filling the collapse cone with clay rocks*

The recommended material for filling the void associated with the collapse cone is clay rocks, with a high impermeability coefficient, to limit water infiltration into the filling mass. The clay must be homogeneous, free of large inclusions, stones or plant debris.

The lower layers (up to a height of approx. 2.5-3m) will be compacted manually, with a hand-held rammer, to allow careful control of the compaction density and to avoid excessive stress on the freshly poured concrete plate and the transmission of vibrations to the slope of the collapse cone.

The upper layers of clay will be deposited by mechanized compaction (with vibrating compactor plates or light-weight cylinders), progressively inclined over the slopes of the collapse cone, to form a lateral support, especially on the northern slope, from the county road, thus preventing the occurrence of local landslide phenomena.

The final level of the clay fill should be slightly convex, exceeding the elevation of the surrounding land, so that surface waters are naturally diverted away from the area of the former collapse cone. Over time, as the natural settlement of the fill material occurs, the level differences will be periodically filled with additional layers of clay, properly compacted.

*e) Rehabilitation works of the section of the DJ 186A road*

Since, along the county road DJ 186A, longitudinal fractures have appeared following the collapse of the land at its southern limit, the asphalt pavement and the foundation soil will be completely removed and the road structure will be completely rehabilitated, in particular to eliminate the fractures that may become water infiltration paths towards the underground excavations of the Ferdinand mine. It will be mandatory to build concrete ditches on both sides of the road, with sealed joints, to collect and direct rainwater to safe evacuation areas, reducing the risk of water infiltration into the surface soil.

When rehabilitating the DJ 186A road, a reinforced concrete retaining wall will be built on the adjacent side of the collapse cone, as additional protection against possible lateral movements of the terrain and clay fill.

After making the affected area safe, it is recommended to continue monitoring ground movements, the county road and nearby constructions, and the movement of water in the affected area.

Since the position, configuration and volume of the dissolution voids produced near the southern shaft, avouring the phenomenon of underground rock flow in Ferdinand mine, are unknown, it is recommended to carry out geophysical investigations and geological research drilling in the affected area, to determine the position of the rock salt roof and the geomechanical characteristics of the rock salt deposit and the overlying rocks.

Taking into account that on the territory of Rona de Sus commune there are many underground voids resulting from the exploitation of the rock salt deposit, developed over a period of over 800 years, with the help of information and old maps, a map can be drawn up with the areas of influence of the underground voids, respectively of prohibition for construction, in order to bring the General Urban Planning Project of Rona de Sus into line with the reality on the land.

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## 6. Conclusions

On July 21st 2025, in the area of the southern shaft of Ferdinand mine, in Coștiui, a massive landslide occurred spontaneously. It was associated with the flow of water-soaked rocks from the surface, into the underground excavations of the mine, resulting in a sinking/collapse cone of approximately 20 m in diameter and 12–15 m deep, with a volume of approximately 1,500 $m^3$. This geomechanical phenomenon became a risk for the integrity of the county road DJ 186A located at the northern limit of the collapse cone and the constructions in its immediate vicinity.

About a month after the Coștiui event, local and county authorities requested the support of specialists from the Faculty of Mining of the University of Petroșani who, based on the historical data about Ferdinand mine, on the information collected from the field, on their personal expertise in the field of rock salt deposit exploitation in Romania and the analysis of information about similar phenomena occurring in the country and abroad, described the geomechanical phenomenon and determined the causes that led to its occurrence, which ultimately helped establish measures to rehabilitate and secure the affected area.

The first conclusion immediately developed by these specialists who arrived in situ was that the geomechanical phenomenon was not determined by the underground mining excavations of Ferdinand mine, respectively that it is not a mining subsidence phenomenon.

Moreover, the main cause of the occurrence of this spontaneous geomechanical phenomenon was the fact that the county road DJ 186A was not equipped with rainwater drainage ditches, so that surface waters flowed freely on the surface of the sloping land, passed over the county road, infiltrating over a relatively long period of time, in a concavity of the permeable land located under this road, at its southern limit.

Also, as a secondary factor, we can mention the existence of trees with roots deeply anchored in the soil, at the downstream limit of the land affected by the accumulation of rainwater (respectively at the northern limit of the mouth of the southern shaft of the Ferdinand mine), which formed a barrier that prevented the gravitational drainage of the waters accumulated in the land. Over several years, through the land formed by permeable alluvial rocks, these waters dug a diagonal flow channel, up to the southern shaft, migrated downwards next to its support, below the level of the rock salt deposit ridge, generating a dissolution void, with a volume of the order of hundreds of cubic meters, which thus communicates with the underground excavations of the Ferdinand mine.

When the channel dug by rainwater in the permeable rocks on the land was wide enough, and the rocks on the surface were sufficiently saturated with water to form a mass of flowing rocks (probably also under the influence of vibrations produced by heavy machinery circulating on the county road), all the conditions for triggering the phenomenon of rock flow underground were met. Following the development of the flow phenomenon, a collapse cone with a volume of approx. 1500$m^3$ was formed on the surface.

The rehabilitation and safety measures for the area affected by the collapse cone were developed in the following successive stages: cleaning the collapse cone of logs, disaggregated rocks and other materials; leveling the base of the cone and building a reinforced concrete plate at this level; filling the collapse crater with well-compacted, impermeable clay rocks; rehabilitating the affected section of the county road, building rainwater drainage ditches and a retaining wall towards the boundary with the clay rock fill.

After completing the rehabilitation works of the affected land, the following recommendations were made: monitoring for a certain period of time the movements of the land, the road and the neighbouring constructions; improving the knowledge of the area affected by the collapse phenomenon, through geological and geophysical research works, in order to avoid a reactivation of the collapse phenomenon or even the occurrence of another type of phenomenon, mining subsidence (considering the presence of the dissolution void in the deposit, near the southern shaft of the Ferdinand mine).

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