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THE CAVING-INS AT OCNELE MARI IN THE VÂLCEA SUBCARPATHIANS, ROMANIA (****)

ABSTRACT: ENE M., OSACI-COSTACHE G. & TÎRLĂ L., *The caving-ins at Ocnele Mari in the Vâlcea Subcarpathians, Romania*. (IT ISSN 0391-9838, 2009).

Brine exploitation began in 1960 at Ocnele Mari for the purposes of chemical industry (chlorosodic products) at Oltchim and Govora industrial plants. Due to the increasing demand for salt and subsequently to its exploitation, huge underground cavities for the coalescence of extraction fields took place between the '70s and the '80s. Unlike other salt exploitations in the world, this is located within an inhabited area. Five extraction fields have been set up. In 2001 and 2002 a crater formed after three wells had collapsed in the extraction fields I and II, flooding and damaging twice 90 houses and over 200 people were evacuated; biodiversity of the Olt river fauna was endangered. At the moment the exploitation is planned to be continued for at least 30 years. Though, situation is difficult on a long term because other cavities could form and cause collapses, affecting 1500 people in Lunca, Ocniţa, Gura Suhaşului and Coşota villages. According to the estimates made by authorities, the ecologic cleaning of the area itself will cost over 15 million €. Research work aims at identifying and mapping the collapsed areas, as well as surveying the evolution of geomorphic processes, based on the existing data and on the measurements made between 2004 and 2006.

KEY WORDS: Brine exploitation, Extraction field, Caving-in, Collapse, Subcarpathians, Romania.

STUDY AREA

The town of Ocnele Mari lies in the Vâlcea Subcarpathians (fig. 1), more precisely in the middle and upper sectors of the Sărata catchment.

The general traits of the land are a consequence of the structural and petrographic constitution of the warped sedimentary formations in which it was carved, that is the Ocnele Mari-Govora anticline, made up especially of Miocene sandy-clayey deposits.

The study area can be roughly divided into three distinct sectors:

- the headwater sector, upstream of Lunca village, narrow and showing breaches of slope in the valley sides profile, which mark the contact between Tortonian marly formations and Sarmatian deposits;
- the erosive depressionary basin between Lunca and Ocnele Mari (about 5 km long), centered on the Ocniţa syncline and the southern flank of the Urziceni syncline and bordered by the Govora-Ocnele Mari anticline. Here, the floodplain, terraces and proluvial glacises have the greatest extension;
- the transverse sector between Ocnele Mari and Copăcelu (about 1.7 km long), where the Sărata stream intersects the hard rocks (tuffs, sandstones, microconglomerates, etc.) that make up the axis of the Ocnele Mari-Govora anticline. The valley is narrow, while the sides' profiles show many petrographic and structural scarps.

The present-day shaping of the land is determined by several factors, of which the most important are the Miocene formations intersected by the Sărata stream:

- the Lower Tortonian-Sarmatian marly complex (fig. 2), which in most cases underlies the lower half of the slopes, characterized by a moderate slant and a wide range of geomorphic processes (especially landslides);
- the Middle and Upper Sarmatian sandy complex, underlying the upper half of the slopes, which is responsible for the higher gradients and occasionally for the steep surfaces. On such formations, gullying is the most active process;

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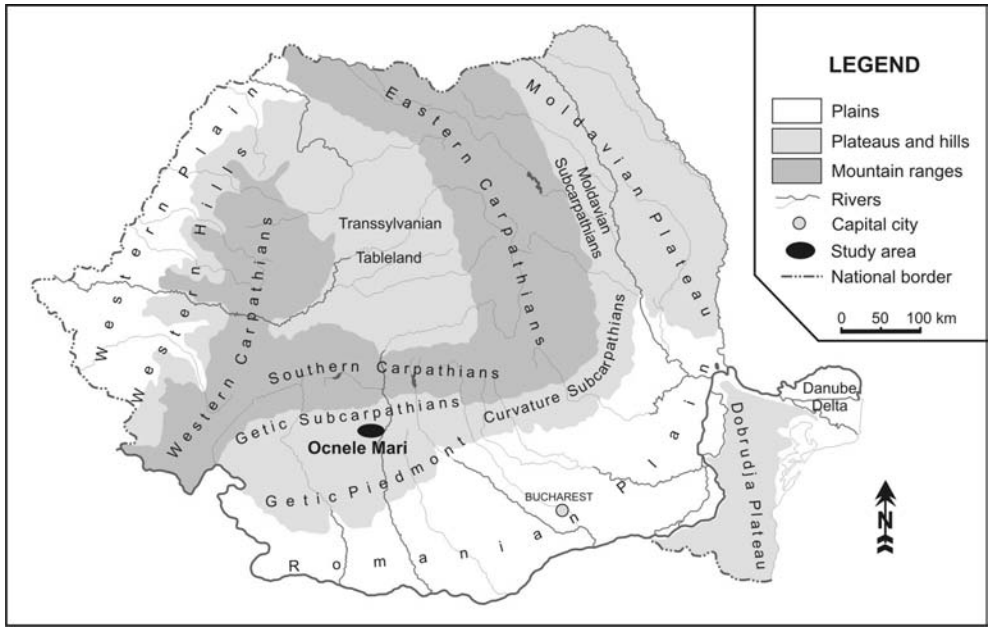


FIG. 1 - Location of Ocnele Mari town in Romania.

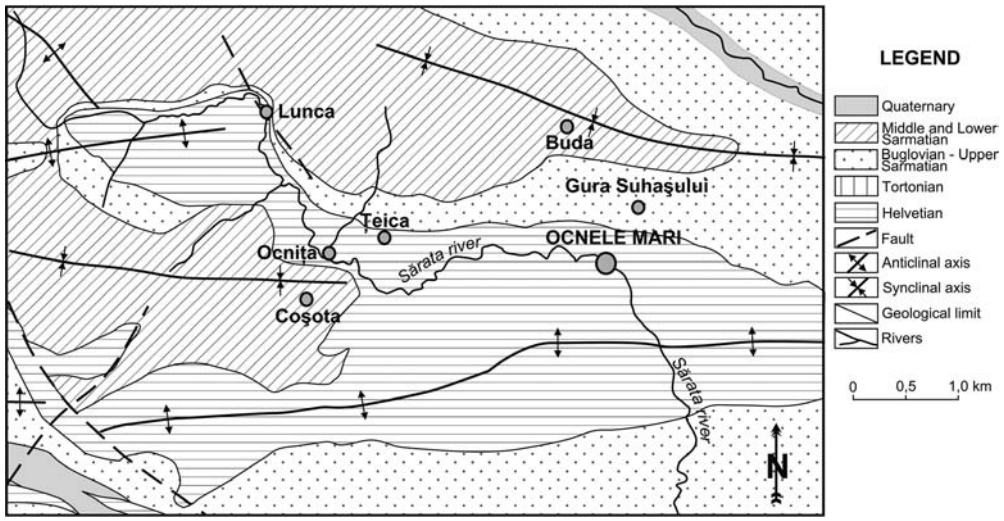


FIG. 2 - Geology of the Ocnele Mari area.

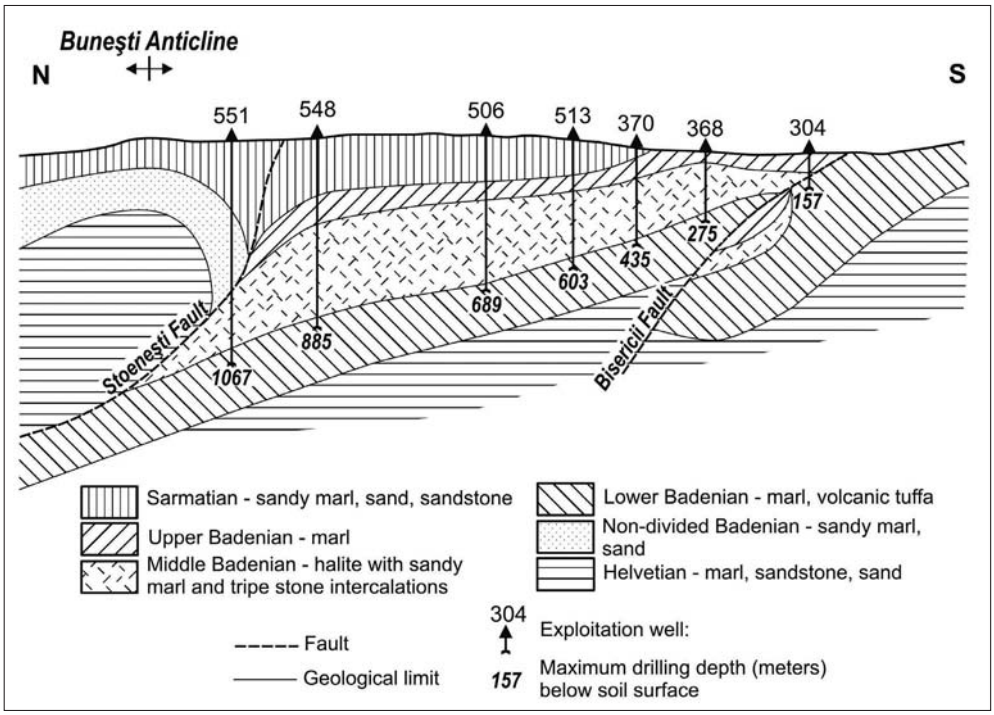
- the Middle Badenian salt deposit - a stratiform-lenticular salt plug developed on the northern flank of the Ocnele Mari-Govora anticline capped by breccias formations (salt breccia). The deposit stretches out on an east-west direction, slanting northwards by 5 to 35°. Its bed is uniform, whereas the roof is irregular, aspect generated by diapirism. Salt thickness varies from several metres on the edges to 450 m at the center. This deposit is responsible for the most recent caving-ins in the area (fig. 3).

Salt extraction here dates back to the Neolithic. At first, the exploitation was based on simpler methods: bell-shaped and trapezoidal chambers carved inside the mines. Beginning with 1953 the salt has been extracted by injecting water into the deposit and pumping out the brine solution by using wells. Consequently, with the passing of time caving-ins have occurred, which changed significantly the land surface and led to the formation of lacustrine depressions.

THE OCNITA LACUSTRINE COMPLEX

The first category includes the lakes lying in the old salt quarries abandoned at the end of the 19th century (according to the natives' testimonies). The most important are the two lakes on the right side of the Sărata stream, upstream of the Ocniţa village, namely the Lacul Sărat and the Lacul Dulce, both of them still preserving a nearly circular shape. These lakes are fed by rainfalls, snowfalls and emerging groundwaters.

FIG. 3 - Cross section of the salt layer.



A second category is represented by the caving-in lakes, which came into existence in the late 20th century and after 2001. The first caving-in lacustrine complex was formed in the immediate vicinity of the Ocniţa village, between the Pârâul Sărata stream and the Dealul Bisericii hill, shortly after the mine was abandoned in 1963 and the exploitation caves got filled with water. Initially, there were four lacustrine depressions of which only three can still be seen (Ocniţa I, Ocniţa II and Ocniţa III).

The first ceiling displacements and cracks appeared just before the mine was closed, approximately after 1950, as a result of settling processes. However, the first significant alterations began in 1968, after the mining galleries had already been flooded in 1963, and continued until 1972 (Popescu & *alii*, 1982):

- the Ocniţa «C» lacustrine depression, formed in 1968, functioned as a lake for only about three years, being subsequently silted with sediments carried by the Sărata stream during high water episodes;
- the Ocniţa I lacustrine depression, also dating back to 1968, came into existence on the site of the last mining gallery;
- the Ocniţa II lacustrine depression, smaller in size than the previous one, was formed following the caving-in of the northern part of the old mine at the end of the 1969;
- the Ocniţa III lacustrine depression, appeared in 1972, when the south-western part of the old mine and the entrance shaft collapsed. In comparison with the previous depressions this one is smaller and hanging above.

The banks of the three lacustrine depressions are still affected by landslides. At present, the settling hollows and cracks that are found on the plateau between the Sărata stream and the lacustrine deposits prove beyond doubt that in the northern sector of the new mine, as well as in other sectors where mining galleries and chambers still exist, the caving-in processes do continue to actively change the landscape.

THE ŢEICA LACUSTRINE COMPLEX

Starting in 2001, a new lacustrine complex has come into existence in the neighborhood of the Ocnele Mari town, on the slope of the Dealul Ţeica hill, to the left of the Sărata stream. The evolution processes are still active, bringing about catastrophic consequences to the local community. The caving-in phenomenon, which occurred within the Field II of the brine exploitation, stands unique in the world in what regards the size of the underground gap, with practically no supporting elements (Prida & *alii*, 2004).

Short history of the salt exploitation within Field II

In order to supply the Govora Chemical Plant (Râmnicu Vâlcea) with the necessary raw material in 1961 the exploitation works began to use another technological process, namely the extraction of brine solution by using kinetic dissolving wells. During the time, four exploitation fields (I-IV) were created (fig. 4). Activity in Field I was carried out between 1961 and 1974. In Field II the activity started in 1968 with the drilling of 15 individual wells (361-370, 376-379 and 381) placed in a triangular network, the brine extraction beginning in 1971 (fig. 5). The

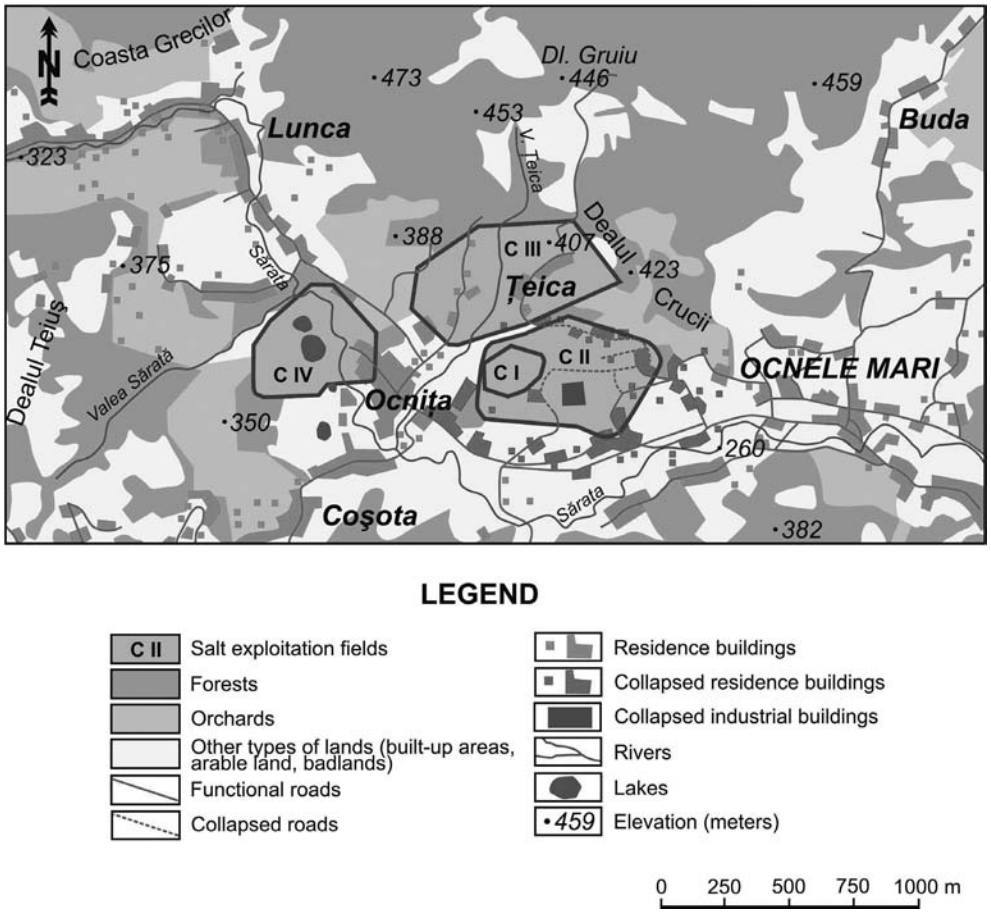


FIG. 4 - Salt extraction fields I and II in Ocnele Mari.

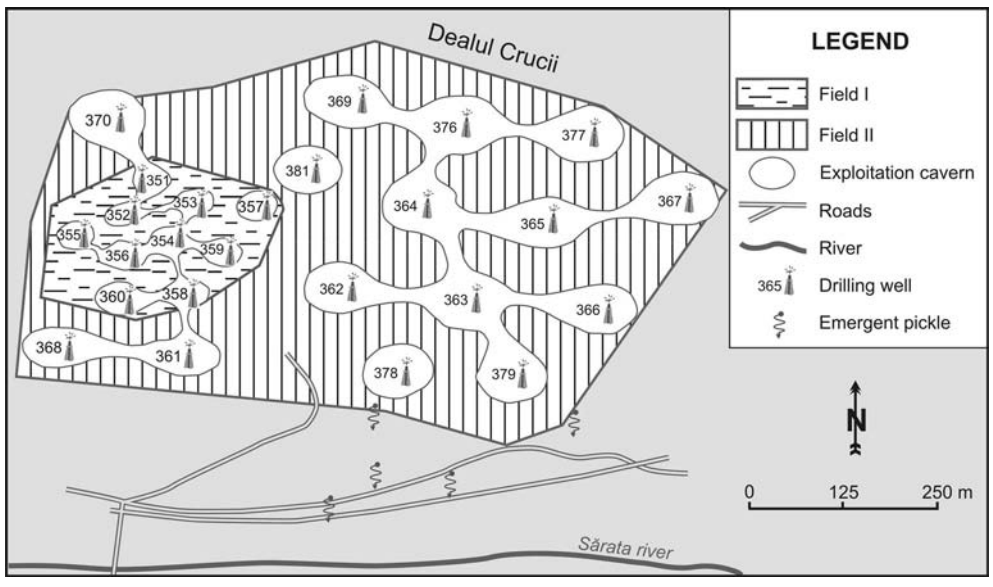


FIG. 5 - Salt extraction fields I and II on the southern slope of Dealul Ţeica hill.

cylindrical exploitation chambers with a designed diameter of 100 m should have been supported by 50 m thick cogs, which were aimed to uphold the 70 m thick ceiling. Due to the presence of some sterile intercalations within the salt plug the dissolving processes followed other routes than those planned, which made the exploitation chambers to join, at the beginning in groups of three on east-west alignments, as follows:

1. 364-365-367
2. 366-363-362
3. 377-376-169

Later on, the three alignments combined on a north-south direction including also the well 379, which was lying at the lowest elevation (285 m). This cavern was noticed in 1978, when the first measurements were made. After this joining the battery method of exploitation was employed. Water was injected along the alignment of the wells number 369, 376 and 377 and the brine was pumped out through the wells number 362, 366 and 379, after passing beforehand through the wells number 363, 364, 365 and 367. In 1993, salt exploitation from Field II stopped, being continued only in the Fields III and IV. The uncontrolled and unguided extraction strongly affected the top part of the cogs belonging to the wells number 363, 364, 365, 366, 367 and 369, which led in time to the formation of a huge cavern. The first complex measurements of its size were undertaken in 1993 by the SOCON Company (Germany). The results showed that the cavern was 60 m high, had a cross-section area of about 100,000 m^2 and a volume of nearly 4.4 million cubic metres (fig. 6). From that moment, efforts were being made in order to establish a strategy to prevent a disaster, but, unfortunately, before the specialists were able to come up with a solution, on September 12, 2004, the caving-in phenomena were triggered.

The development stages of the phenomenon

– On September 12, 2001, the ceiling of the wells number 365 and 367 collapsed, triggering the spill of about 1.7 million cubic metres of brine down the slopes of the Dealul Ţeica hill, which left behind an 8 m deep ravine. At the scene of the caving-in a lacustrine depression came into existence. If at first its diameter was 100 m, subsequently, by progressive bank cavings, it grew larger and larger until it reached a diameter of 300 m. The catastrophic event destroyed 10 households, the extraction equipment of the wells number 377 and 367, as well as several access roads. The spilled brine generated a flood on the Sărata stream, which propagated downstream as far as the junction of the Olt River, entailing serious ecological consequences. Fortunately, the more than 100 tank wagons filled with isolation liquid (diesel oil) were not overthrown, which reduced the ecological impact of the disaster.
– In the following days, based on a plan devised by two staffs of specialists (Prida & *alii*, 2004), the local authorities resettled more than 100 households of the risk area and built a retention dam meant to store 150,000 cubic metres of brine.
– During the year 2002 more than one million liters of isolation fluid were pumped out through three guided wells, as well as through the exploitation wells number 365 and 363.
– In September 2002 a new overflowing occurred triggered by the collapsing of the well number 356 (Field I thus joining Field II). Consequently, 60 households were affected and 200 people relocated.
– In 2003 the comprehensive plan of technical closing of the exploitation worked out by a group of specialists of the University of Bucharest (D.C.G.G.A.) was approved, which had the following basic objectives:
• The totally controlled collapsing of the cavern's ceiling and the evacuation of brine.
• The regulation of the Pârâul Sărat stream and the Sărata valley.

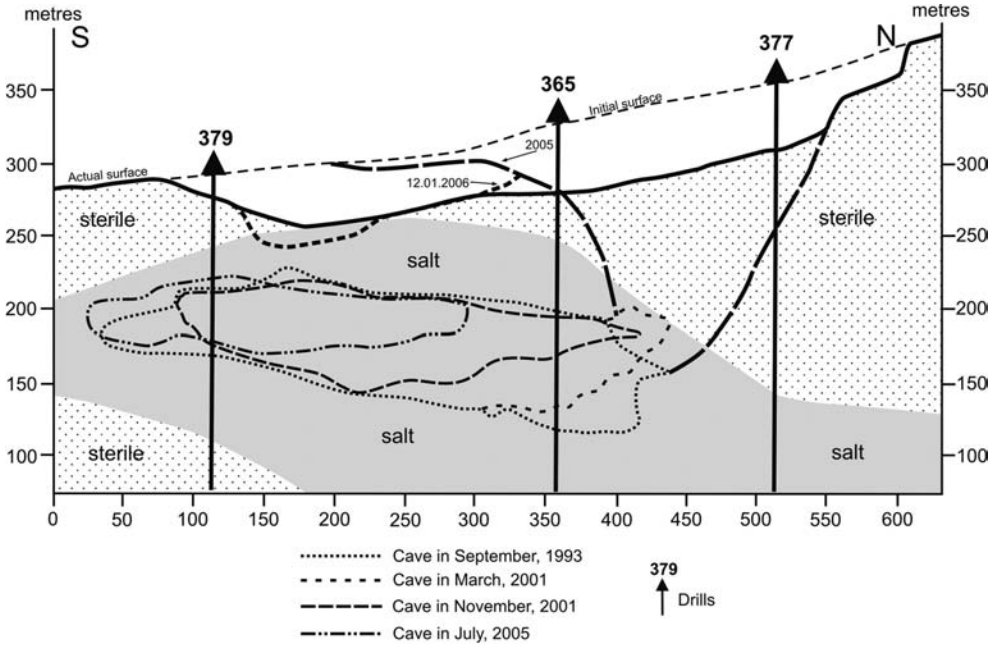


FIG. 6 - Actual S-N cross section (after Zamfirescu & *alii*, 2007).

- The mending of the brine retention dam, which had been affected by the overflowing of September 2002.
- The rebuilding of the road and water supply network that had been destroyed by the caving-in phenomenon.
- The demolition of all the houses lying in the perimeter affected by collapsing and the resettlement of their owners.
- The ecological restoration of the area.
- Other works.

– On July 13, 2004, an uncontrolled falling-in of several salt blocks detached from the safety roof led to the overflowing of about one million cubic meter of brine. Most of the amount was stored in the retention basin and only a small fraction reached the river network. The stored brine was delivered through pipes to the Govora Chemical Plant.
– As soon as this event was consumed local authorities took actions in order to implement the plan that had been approved in 2003. Therefore, controlled collapse became a priority and, consequently, the work was accomplished by December 2005.
– Between December 14 and 24, 2005, the controlled collapse that had started the same year in August began to show its first effects. Thus, on December 14 a new sinking cone was created south of the well number 363, which continued to grow northwards, reaching a diameter of 20 m. By December 24, the cone grew considerably, exceeding 130 m in diameter and totalizing an area of 105 hectares.

FORECASTS FOR THE NEXT FIVE YEARS

The measurements undertaken in the period 2005-2006 in the perimeter of the Field I exploitation area pointed out the likelihood of caving-in of the cavern estimated as having a volume of one million cubic metres.

On an area of about 3,250 m^2 (D.C.G.G.A. - University of Bucharest, 2006) the thickness of the ceiling was less than 10 m, here and there being even completely dissolved. As a matter of fact, around well number 353 a small size collapsing cone had already been formed. In the last years, the ceiling has sunk in some areas by about 1.5 m. The microseismic sensors placed after 2001 have recorded permanently underground caving-ins phenomena with a magnitude of 1-1.4. By the continuous monitoring of the area the specialists have been able to determine that the sinking speed is about 20 cm/year, which has led to the conclusion that by the year 2010 the ceiling of the cavern underlying Field I will cave-in. The controlled collapse plan stipulates that all the households lying at the base of the slope and along the Pârâul Sărata stream floodplain should be resettled and a dam should be built across the stream, using local materials, in order to avoid the overflowing of the brine and isolation liquid out of the cavern.

Taking into account that the extraction of the salt from Fields III and IV uses the same technology that led to disasters, the authorities should work out strategies for closing these exploitations in the near future, such as to minimize their negative impact on the environment.

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