

**Investigations and Evaluations on the
Technical, Economical and Ecological
Situation of the
Brine Fields of OCNELE MARI, Romania**

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**Dr. Andreas Reitze
Hartmut von Tryller**

SOCON Sonar Control Kavernenvermessung GmbH, Giesen

Ralph Gaertner

DEEP. Underground Engineering GmbH, Bad Zwischenahn

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Abstract

The cavern fields of OCNELE MARI are located at the southern edge of the Transylvanian Alps in Romania near the town of RIMNECU VALCEA. Since 1959 SALROM have been operating brine leaching caverns in five cavern fields. The brine is supplied exclusively to a nearby chemical plant. SALROM also operates a mine for exploiting rock salt in Rimnecu Valcea; this salt is mainly used for spreading on roads in winter, but is also exported. SALROM is the state salt exploitation company and operates other fields in Romania.

Since 1959 a total of about 66 brine caverns have been created in four brine leaching fields. Only fields III and IV are still partly in operation. The first signs of surface damage occurred in 1968. As a result, Romanian institutes carried out subsidence measurements and more extensive rock mechanic investigations. Sonar surveys carried out in the nineties provided the first indications of disproportionally large voids.

Following various studies carried out in Romania, this cavern field was more closely investigated in 1997 and 1998 by the SOCON/DEEP consortium during a comprehensive study. The study was funded by the European Community and investigated and evaluated the technical, economic and ecological situation of the OCNELE MARI brine field. Within the framework of this study a large cavern system that had been formed from six individual caverns by uncontrolled leaching was brought to light.

1. Introduction

The cavern fields of OCNELE MARI are located on the southern boundary of the Transylvanian Alps in Romania, near the city of RIMNECU VALCEA (recently in the news because of the 1999 miners' revolt there).

In 1997/98, after different companies had already carried out studies in Romania, this cavern field was more closely investigated by the consortium SOCON/DEEP in the course of an extensive study. The study was financed by the European Community and its aim was to investigate and to evaluate the technical, economic and ecological situation of the brine field OCNELE MARI, and then to recommend measures to be taken in order for it to achieve economic viability. Within the framework of this study there was, firstly, an evaluation of the technology in use from the point of view of western European standards and, secondly, proposals on how state-of-the art technology for brine production and sonar surveying might be introduced.

Since 1959 SALROM had erected and operated a total of approximately 66 brine production caverns in five cavern fields here. The brine produced was sent by pipeline exclusively to an adjoining chemical works. The production capacity of OCNELE MARI was 210,000 t brine per year, corresponding to approximately 54,000 t of salt. In addition, in RIMNECU VALCEA a mine is operated by SALROM for the extraction of rock salt, used mainly for the production of de-icing salt, also for export (approx. 200,000 t capacity per year). SALROM is the state-run company for salt production and operates still other salt-mining facilities in Romania.

Between 1959 and 1974 there was brine production in 10 caverns in Field I of the OCNELE MARI brine field. The first signs of damage appeared on the surface in the year 1968.

Field II was operated in the years 1970 to 1993, during which time there was brine production in a total of fifteen caverns. From 1973 to 1979 there was brine production in Field III TEICA with its eleven caverns. During this same period there was also brine production in Field III LUNCA (a total of 22 caverns). Some of these caverns are still in operation or serve as a strategic reserve.

The newest field is Field IV with eight caverns and is still in operation.

By means of echo measurements taken in 1993 and 1995 by SOCON disproportionately large voids were detected. More intensive echo measurements, pressure tests, brine level checks and a joint interpretation of all measured caverns within the framework of the SOCON/DEEP study in 1997/98 brought a caverns system in field II and its true dimensions to light.

This cavern system resulted from uncontrolled brine production in the caverns to the extent that the safety pillars between the caverns were partially or even entirely swept away by the brine. The result was a (brine-filled) gigantic cavern of 4 million m³, with a diameter of approximately 300 m. Although brine activity in Field II was discontinued in 1993, subsidence can still be clearly observed. Many experts have declared that the caverns are in serious danger of caving in.

2. The situation in the OCNELE MARI brine fields

The cavern fields of OCNELE MARI are situated under hilly countryside with a maximum surface elevation difference of 120 meters within the cavern field area. Above the caverns the land surface is used agriculturally as well as for housing. Fig. 1 shows in the foreground some typical housing as well as the drilling rigs which are characteristic for Romanian cavern fields and which are permanently installed above each cavern.



Fig. 1: View of an OCNELE MARI cavern field

In OCNELE MARI there are five cavern fields with a total of 66 caverns. The first cavern field was put into operation as early as 1959. Currently only the caverns in field III TEICA and field III LUNCA are in operation. Production in all the other fields has been shut down.

The caverns in OCNELE MARI are situated at depths between 100 and 450 m. The overburden above the rock salt deposits has a thickness of just 50 meters in the south and up to several hundred meters in the north of the area.

At the beginning of the '70s subsidence resulted in noticeable damage at the surface, which made it necessary to carry out regular levelling checks. Fig. 2 shows typical damage to a house. Cracks in the walls are quite evident and it can be seen that a cavern is in close proximity.



Fig. 2: Damaged house

3. Taking stock of the situation and investigations carried out

3.1 Sonar cavity surveys

Echometric cavern surveying in the cavern fields of OCNELE MARI were carried out in spring of 1997. During this period 28 caverns in the fields II, III TEICA and III LUNCA were surveyed. 21 of these caverns were uncased during the surveys so that all the measured sections could be magnetically oriented. The remaining seven surveys were measured through one or two casing strings. SOCON's new gyro compass system was used in these seven surveys to ensure that the absolute orientation was obtained. All surveys were executed using the BSE echo tool developed by SOCON [1,2].

After completing interpretation of the echometric survey data, the cavern fields were jointly interpreted and presented as plans and sections as well as three-dimensional views taking into consideration all the data available. The interpretations were performed on the basis of the current German mining regulations and standards governing the graphic presentation of cavern fields.

All graphic displays were based on the coordinates of the individual caverns made available by SALROM. As echometric surveys always refer to the position of the casing shoe it is necessary in order to present the cavern field correctly to have the results of borehole logging that indicate the position of the casing shoe referred to the surface position of the respective borehole. However, as deviation surveys were not carried out for the wells in OCNELE MARI the coordinates of the borehole surface positions were used for the casing shoe coordinates. Consequently the calculation of the shortest distance between the individual caverns may be erroneous owing to the boreholes not being completely vertical. Such possible errors have to be considered accordingly.

A plan view of the cavern field III LUNCA is shown in figure 3. Specific information is indicated for all the caverns surveyed up to now by SOCON: the maximum radii plot, i.e. the projection onto a single horizontal plane of the largest radii measured in each direction, the largest leached out individual area as well as a topographic map. This plan view was created using the CavMap program, the centre piece from SOCON's CavInfo Software Suite [3].

During the project numerous detailed displays have been prepared based on the three dimensional cavern field models that have been set up. These detailed displays have been used when working on various task areas. Some examples of this are given in Section 4.

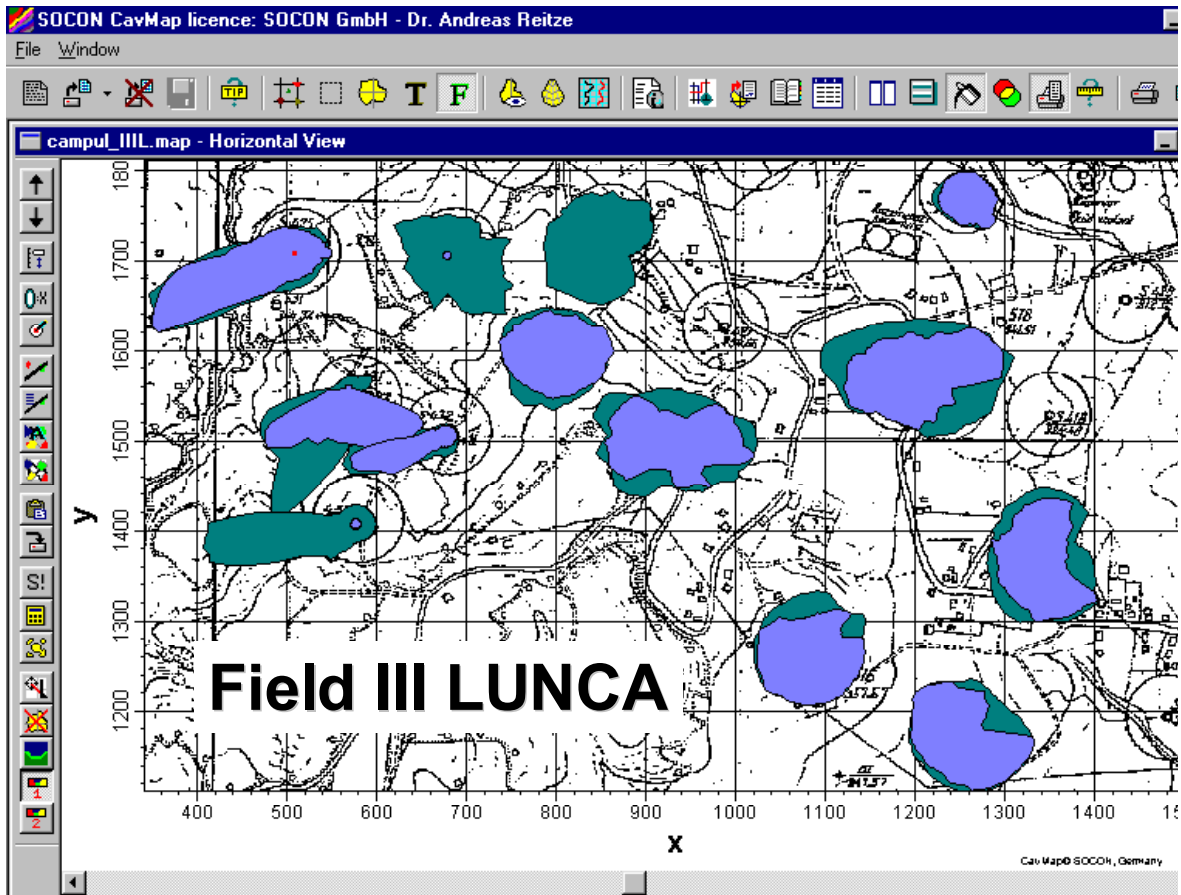


Fig. 3.: Plan view of field III LUNCA

3.2 Subsidence analysis

Within the framework of the study it was necessary to tackle two basic problem areas in connection with subsidence:

- 1.) Verification, evaluation and analysis of past measurements of surface subsidence.
- 2.) Determination and assessment of the effects of subsidence on the social environment, i.e. on residential buildings.

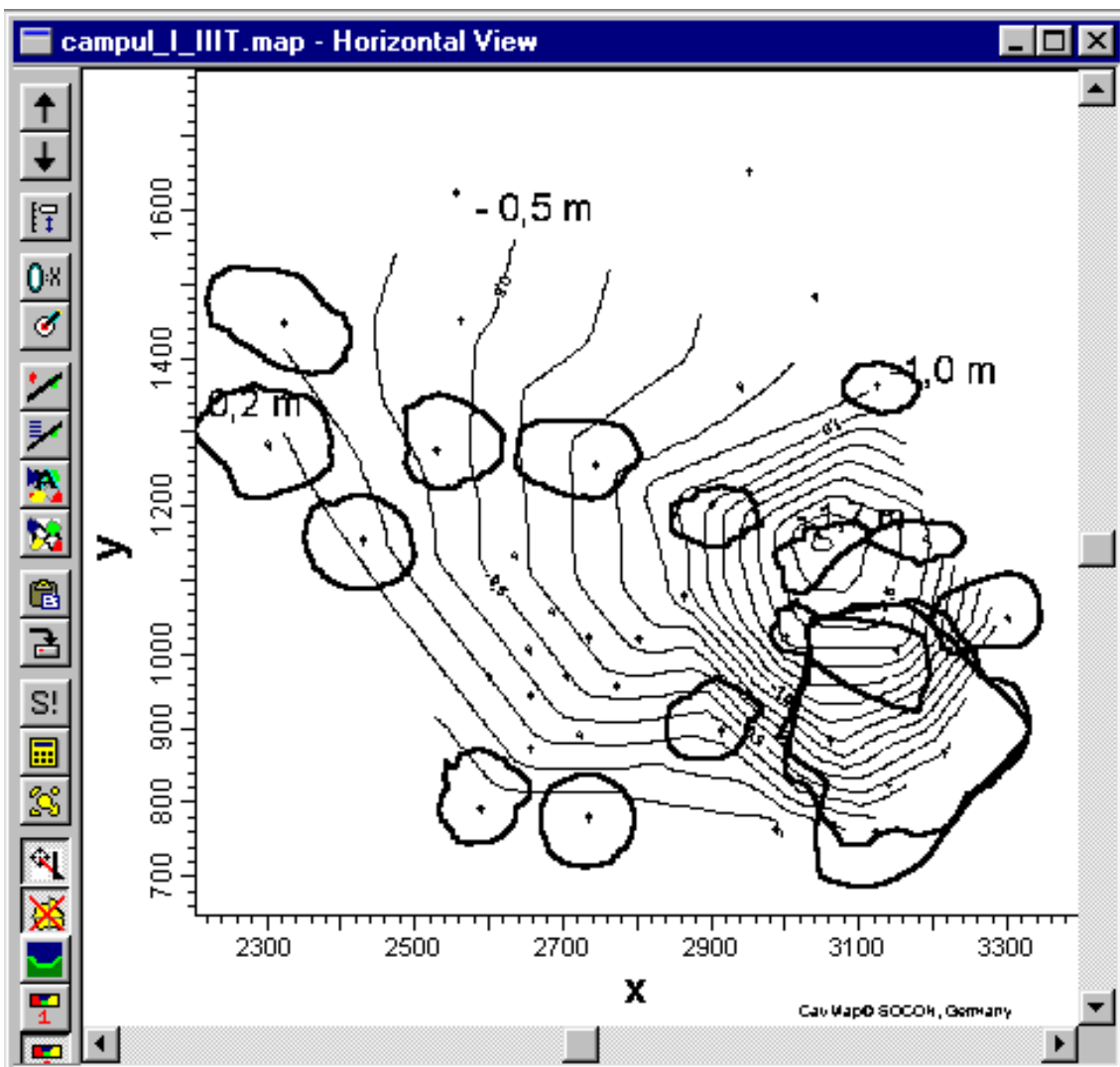
The data available at the start of the project consisted of numerous lists and tables in analogue form only. After every follow-up survey, these tables were updated in the past by hand. The manual approach adopted in the past for evaluating the survey data is possible in principle, but in view of the mass of data available, does not permit the economical determination of all possible and especially the most relevant prognoses. In order to be able to perform a maximum number of analyses within the scope of the project, it was first decided to store all existing subsidence data with the aid of a computer for further processing. Digitalisation of the data was therefore carried out.

On the basis of the data inventory established in this way, it was then possible to carry out evaluations and analyses at reasonable cost. Within the framework of the project, this

permitted the realization of a wide variety of possible representations, ranging from the derivation of subsidence curves to the plotting of contours for entire cavern fields.

The subsidence curves provide an indication of temporal behaviour. Such curves provide a fair indication of the acceleration or deceleration of the subsidence process. As a digital data inventory is now available, it will be relatively simple in the future to also determine and graphically represent derived values such as e.g. subsidence rates.

In order to jointly represent and analyse subsidence behaviour above the cavern fields contour maps were derived from the subsidence data. Figure 4 shows the resulting subsidence trough over the time period 1972 to 1997 for the fields I, II and III TEICA.



4: Subsidence trough (1972 - 1997)

Fig.

The damaged and specially monitored objects in Field II have also been inspected on site and the damage has been documented by photographs (see Fig. 2). On the basis of the available measurements, the inclination changes for each side of all of the monitored buildings were computed and normalised over one year (up to 20 mm per m and year!). These results were correlated with the derived maximum inclination in the subsidence basin. The damage in some cases is so severe that living quality is greatly impaired. Open cracks in some cases give rise to unacceptable living conditions especially during the cold season. Repair measures are no longer possible in most cases.

As further subsidence is expected in the future, and especially because a direct threat to residents is given owing to the combined caverns in Field II (see 4.3), resettlement of the residents presently living in the area of direct and indirect influence of cavern field II will be unavoidable.

3.3 Solution mining aspects

During several on-site visits the surface and subsurface equipment used for solution mining were examined and described.

The operational leaching data for the past years has been compiled as far as available and compared to the real cavern shape development of the caverns as surveyed in May 1997.

In order to allow for any statements concerning the economic residual life span of the caverns the basic data for different caverns was compiled and assessed with respect to the rock mechanical investigations. Based on the results three different runs with the DEEP.-3 D-leaching simulation program have been performed. The caverns chosen are located in the cavern fields still under operation. It was not intended to do history matches for caverns which had already exceeded any one parameter that came out of the rock mechanical analyses, since the technical life span of those caverns should be limited.

As a result of the leaching simulation it could be affirmed that an additional salt production of approx. 2.5, 4.0, and 4.5 million t respectively would be recoverable, although it is required to adhere to the proposed leaching concept quite closely, i. e., frequent blanket interface controls and regular echometric surveys will be necessary.

The leaching simulation results have been used in order to compare them to other caverns already surveyed in order to group them according to their estimated residual life. The result of the simulation study was that in the near future no extra wells would be necessary, owing to the fact that even some spare wells were available.

3.4 Rock mechanical aspects

In order to restrict the expenditure to an economically feasible level the caverns were divided into groups with the intention of not evaluating each cavern of the salt mining field separately. Furthermore the three-dimensional load bearing behavior of the caverns has to be simplified in 2D-models.

Geometry is an important parameter in the dimensional analysis of a cavern. For this reason the caverns were divided into several groups with respect to their geometrical shape, i.e., roof shape, diameter and height of the cavern .

The first group shows its maximum diameter in the roof, the second one has got the maximum diameter at the bottom. The third group is made up of caverns with a height of more than or equal to 150 m. The fourth type of cavern shows a marked elliptic shape in the horizontal plot. In the fifth type caverns are grouped which are connected with each other and therefore show an irregular geometrical shape and have great extensions.

In a second step further important parameters for the dimensional analysis of a cavern for mineral extraction were taken into account as criteria for the division into groups:

- the depth of the cavern
- the minimal distance ba from the cavern to the neighboring caverns
- the rock salt roof thickness

The larger the diameter and the higher the overburden rock mass layer on the top salt, the greater the load the roof has to bear. The thickness of the roof is an important parameter concerning whether tensile stress will occur on the bottom side of the roof or not. The shorter the distance ba , which represents the pillar width, and the taller the pillar, the greater it will be under stress.

The objective is to determine caverns which could be used as representative calculation models for the other caverns. The selection of these representative caverns should take into consideration the variables with great influence on their stability.

In relation to the other caverns a representative model has to have maximum values, with reference to the diameter and the height, or minimum values, with regard to the distance ba and the roof thickness, in the parameters influencing the analysis. In this way a statement about the stability of other caverns can be made.

In case the geometrical shape of a cavern makes it impossible to undertake an axisymmetric analysis, a different calculation model has to be chosen.

The axisymmetric analysis is not possible if the geometrical shape of the cavern in the horizontal plot differs much from a circle and looks like an ellipse with a ratio of $b/a < 0,4$, with b and a being the two different diameters of the ellipse. In this event, for some caverns a plain stress or a plain strain model represents the situation of the cavern more adequately.

If two or more caverns are connected, their specific situation has to be considered because of their irregular shapes and their extreme dimensions. In order to consider the three-dimensional effects a plain stress or a plane strain model should be used.

Some caverns have to be analyzed individually, as each cavern has a maximum or a minimum value in the parameters, and this has a great influence on the analysis.

As a result of these conclusions it became evident that an evaluation of the stability of the salt mining field OCNELE MARI is difficult because of missing information (some caverns have not been measured), the irregular shapes of the caverns and their differing geological situations.

Representative Calculation Model

The attempt to divide the caverns into groups has shown that they should be treated as isolated cases, or that in order to undertake a final evaluation parameters were not available at the moment nor will they be available. For this reason a representative field cavern was determined for a salt mechanical analysis taking into account the specific geological situation of the salt mining field OCNELE MARI.

Under the given assumptions the maximum permissible diameter and maximum permissible height of this cavern as well as the minimum rock salt roof thickness and minimum pillar width were determined. The dimensioning of this representative cavern takes into account the state of the art in salt mechanics and contains sufficient safety reserves in load-bearing capacity to satisfy international demands.

With this representative cavern it was possible to compare the existing caverns of the salt mining field OCNELE MARI with regard to their deviation from the configuration of the representative cavern.

3.5 Environmental aspects

During the study an extensive investigation into the environmental damages in the salt mining area was carried out. The use of gasoil as a blanket medium over the long period of time has resulted in quite some oil spills through low environmental consciousness in combination with some larger accidents (ruptured casings and pipelines). The consortium SOCON/DEEP conducted a drilling program for taking soil samples through hand drilled bore holes for three different brine fields. These samples were then chemically analysed and marked on the location map

With the used method contamination sources were detected. It was possible to point out contamination paths. Based on the results measures for rehabilitation and regeneration of the contaminated areas have been given.

4. Potential hazards in field II

4.1 Size of the cavern system

In the plan view of fields TEICA I, II and III (Fig. 5) a vast void is evident in the eastern part of field II around cavern 365. This is in fact a cavern that has been formed from what was originally six individual caverns. The pillars between the caverns were dissolved during the '70s and '80s by uncontrolled leaching processes. At that time the cavern operator could not detect this uncontrolled cavern development using the sonar equipment at his disposal. Cavern surveys carried out in this field by SOCON in 1993 and 1995 provided the first indications of disproportionately large voids. At that time reliable coordinate information was not available so it was impossible to display the caverns in a single view. It was not until the whole cavern field was evaluated and graphically displayed within this study that the true dimensions of the cavern system were brought to light.

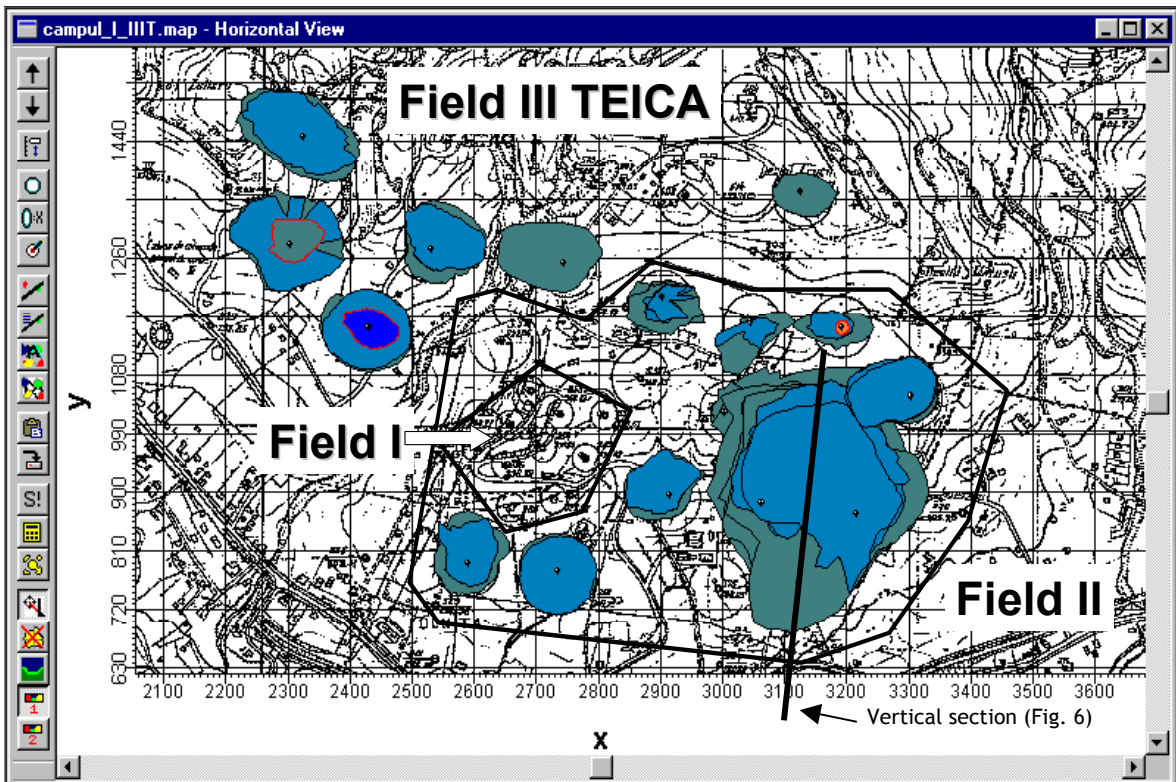


Fig. 5: Plan view of fields I, II and III TEICA

The cavern diameter of up to 350 meters and its volume of approximately 4 million cubic meters makes it one of the largest caverns in the world. It is not possible to determine the exact volume because the cavern could not be completely surveyed as some of the boreholes are no longer accessible. Moreover it is uncertain whether there is a connection to the adjacent field I. The caverns there are all connected to one another, however, they cannot be surveyed as there is no access to any of the boreholes.

Fig. 6 shows a vertical north-south section through the cavern system. The exact location of the section can be seen in Fig. 5.

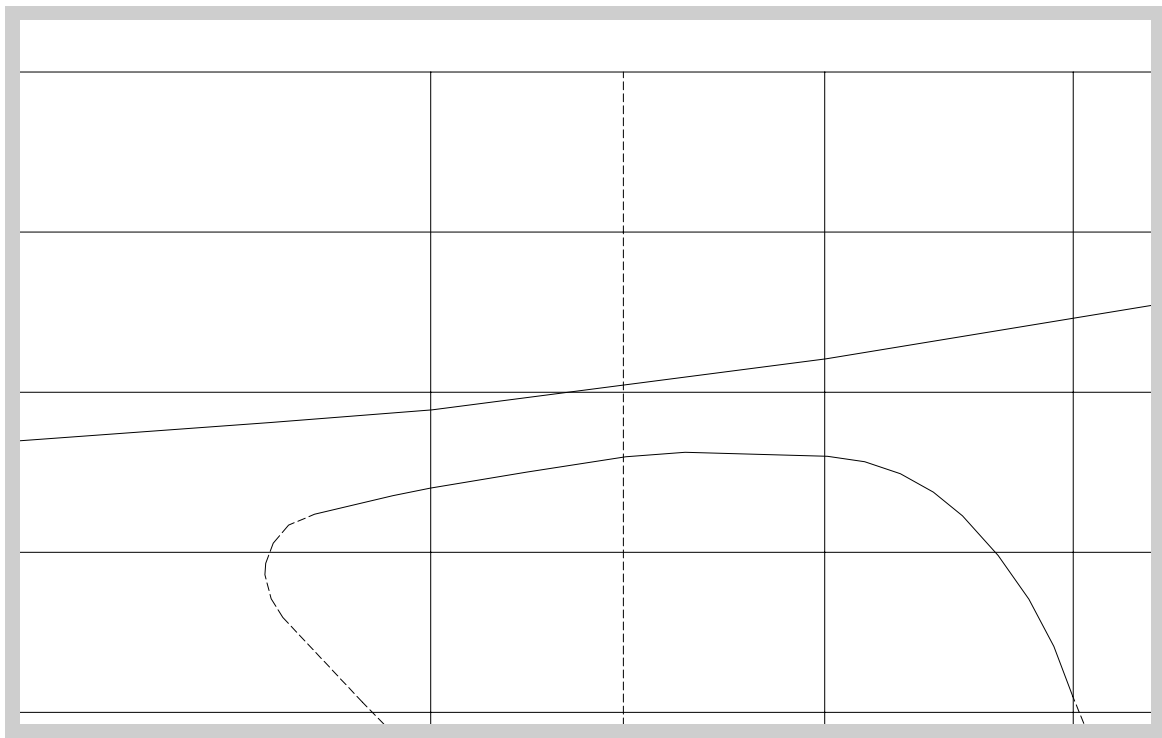


Fig. 6: Vertical section

4.2 Subsidence

The 15 caverns in field II (361 - 381) were mined between 1970 and 1993. Measurements are only available from 1972 onwards, however. Figure 7 shows the subsidence curves based on the average value at the four foundation points in each case. A noticeable feature in this case is the fact that the subsidence values are evenly distributed between almost zero and 1.722 m.

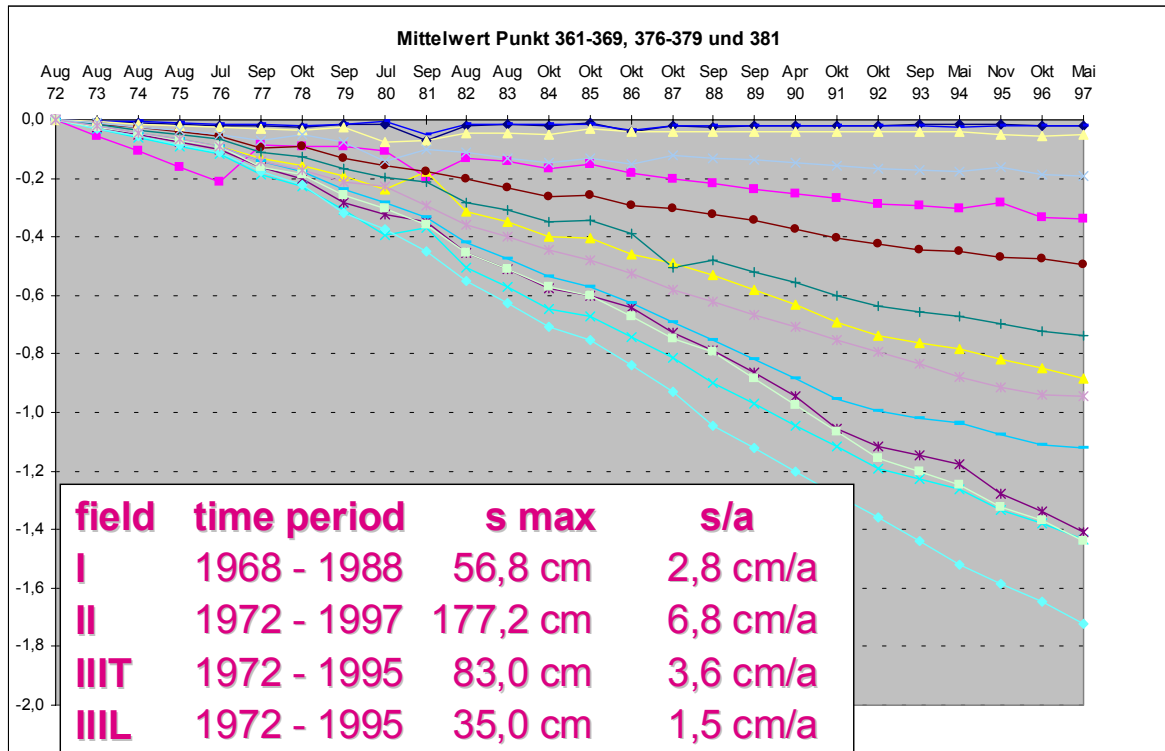


Fig. 7: Subsidence curves for field II

A linear subsidence rate is observed in this field at almost all points. Maximum subsidence occurs in this field above caverns 376, 377 and 365 with values of between 1.41 m and 1.72 m. This corresponds to an average subsidence rate of up to 69 mm/year. The least amount of subsidence is above caverns 361, 368, 378 and 379, which are all located on the southern boundary of the cavern field. The reason for the very low subsidence values, e.g. only 1.9 cm in 25 years above cavern 361, may also be explained by the superposition of subsidence movements by downward displacements on the incline, resulting in a deposition of material at the bottom of the incline which compensates the subsidence due to solution mining. The existing level and displacement measurements seem to suggest this type of phenomenon. On the other hand, an unknown level change of the reference bench mark may possibly lead to erroneous results in boundary regions experiencing only slight subsidence. A slight drop in the bench mark level would, for example, result in the detection of very slight or no subsidence in zones experiencing small displacements. In areas with large subsidence, on the other hand, a change in the level of the bench mark would have a less noticeable effect.

4.3 Possible consequences

Considering the shape, size and depth of the cavern system as well as the continuous subsidence processes it must be assumed that sooner or later the cavern system will

collapse. From the data available it is not possible to determine when such a collapse will occur. As the geological information is very vague – for example there are no drilling cores – and the connections to adjacent caverns are uncertain, predictions of what will happen cannot be made with the necessary thoroughness so as to be reliable. Collapse can therefore be expected to take place at any time.

Consequently further investigations must take into consideration the immediate effects of a collapse. Here the priority must be the protection of the local population, because owing to the hillside location such a collapse will result in a flood wave of at least 2 million cubic meters of brine (Fig. 8) gushing down onto the village of OCNELE MARI and other inhabited areas.

The SOCON-DEEP consortium has been working intensively on possible solutions. For instance a three dimensional model of the cavern system and the earth's surface has been set up to enable the collapse and the resulting effect on the surface and the valley to be simulated. The results of these investigations cannot be presented yet.



Fig. 8: Brine outflow after a cavern collapse

5. Bibliography

- [1] REITZE, A.; VON TRYLLER, H.:
Accurate echometric surveying of caverns - The physics and tool technology, SMRI Fall 1995 Meeting, San Antonio, Texas, USA, October 1995.

- [2] REITZE, A.; VON TRYLLER, H.:
Techniques and practical use of the new tool generation for the echometric surveillance of caverns, SMRI Spring 1996 Meeting, Houston, Texas, USA, April 1996.

- [3] REITZE, A.; VON TRYLLER, H.:
Mapping of cavern fields using the CavMap program - an information system for cavern operators, SMRI Spring 1998 Meeting, New Orleans, Louisiana, USA, April 1998.