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KARSTIC PHENOMENA IN CALCAREOUS-DOLOMITIC ROCKS AND THEIR INFLUENCE OVER THE INRUSHES OF WATER IN LEAD-ZINC MINES IN OLKUSZ REGION (SOUTH OF POLAND)

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ABSTRACT

The results of a detailed statistical survey of the karstic features in the Olkusz region are described. The data has been obtained from surface boreholes and mine galleries. Although the karstic features studied were vertical, its main development is from the first 200 metres. The main hydrogeological problems are also described in relation to mining, emphasising that the greatest danger of sudden inrushes of water are in relation to the contact zones between limestones and dolomites.

INTRODUCTION

Some lead and zinc ore bodies, occur within limestones and dolomites from the Middle and Lower Trias in the North-Western edge of the Upper Silesian Coal Basin. The three mines which exploit these mineral beds have the greatest inflow of ground water of all Polish mines. The total inflow of water to these mines, which are very close to one another, is almost 5 m^3/s, and a relatively stable, pumping depression area, was created several years ago. The existence of a karstic network in the triassic rocks surrounding the lead-zinc ores, is one of the most important reasons for the quantity of the water flow, together with other geological factors and factors connected with the permeability of the aquifer. These associated karstic shapes, capable of carrying large quantities of ground water, represent a serious danger to the main galleries. On several occasions during the long history of the mining industry in the Olkusz region, the mine galleries have run into karstic channels and inrushes have occurred [6]. The flow rates have been in the order of 0.3 to 0.7 m^3/s, with a maximum of 1.5 m^3/s.

Up to the present time efficient methods for finding karstic formations, for example channels, which may present a potential threat to the mine galleries excavated in the saturated area, have been impossible to determine. The application of such methods would allow more economic and safer mining in karstic rock. In the authors' view, it is necessary to determine, first of all, the geometrical properties of the karstic features and their location inside the rock mass. The paper presents the results of the research carried out in this field.

THE KARSTIC CAVITIES

The carbonate rocks from the Middle and Lower Trias surrounding the mines in Olkusz, are 100-150 m thick and form a massif which regularly dips towards the North-East. The general trend of faults in two different directions, NW-SE and SW-NE.

The karstic cavities have been studied in boreholes, surface outcrops, small open cuts and mine galleries. In boreholes, the depth of the cavity has been measured, as well as its dimensions with reference to the axis of the hole. In surface outcrops, open cuts and mine galleries, the area and lineal dimensions of the external sections of the cavities have been measured. The directions of the karstic channels have also been measured.

In the Olkusz region several thousands of boreholes have been drilled; in these boreholes more than 400 karstic cavities have been intersected, with a thickness which varies from 0.1 m to 18 m. Almost half the drilled cavities were less than 1 m in thickness and more than 36% were between 0.5 and 1 m thick. The distribution of thickness of the cavities is lognormal. Although without drawing the conclusion that there is therefore, a relation between cause and effect, we emphasise that unitary specific yield of many karstic aquifers and even hydraulic conductivity, within the non-saturated zone, follow a lognormal distribution [8,4].

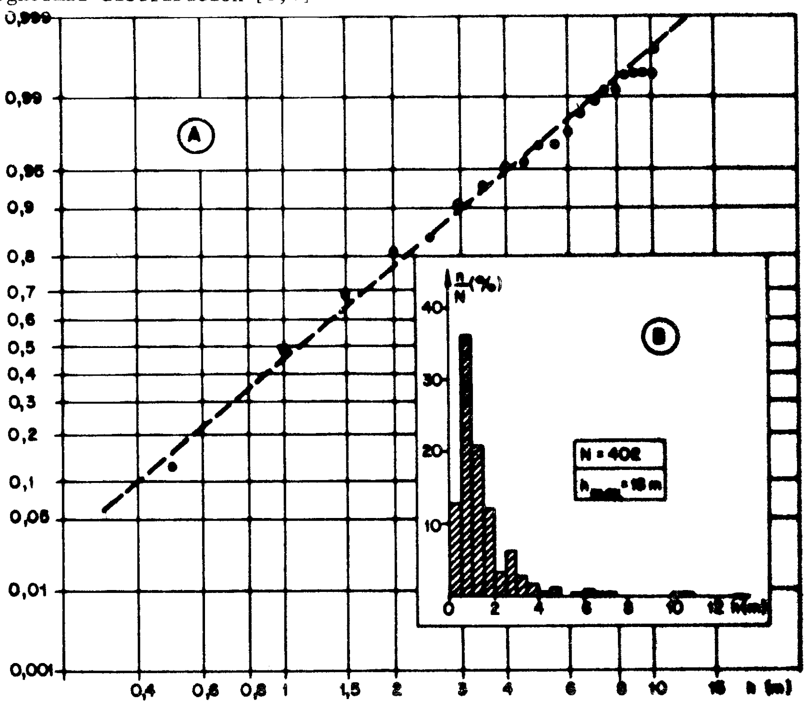

Figure 1. Distribution of thicknesses (h) of karstic cavities intersected by boreholes. (A) accumulated frequencies in logarithmic abcisses) and densities of probabilities (in ordinates), (B) histogram.

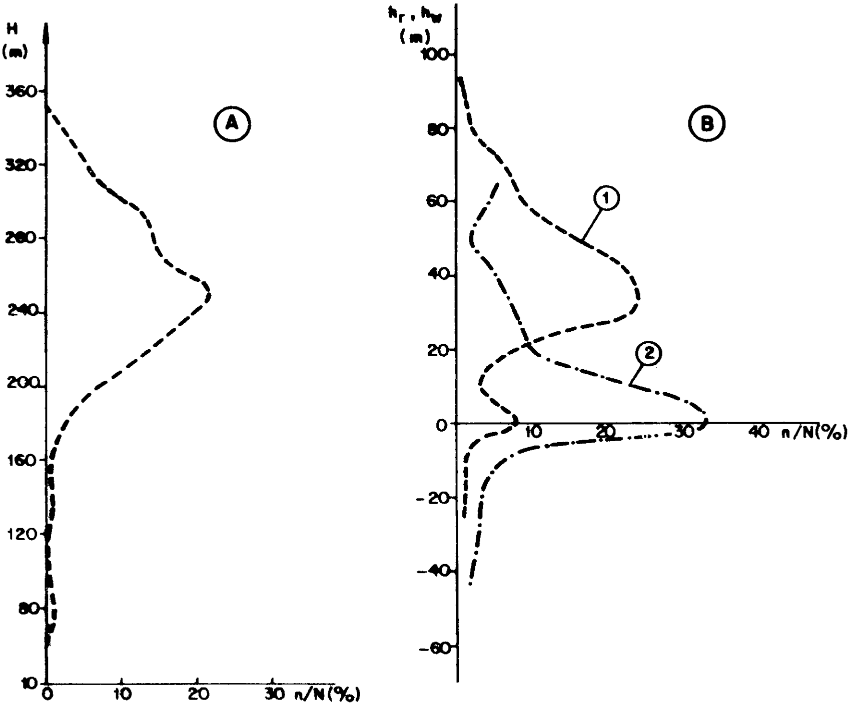

Figure 2. Frequencies of karstic cavities intersected in boreholes. (A) regarding height (H), (b) regarding limits between beds of limestones and dolomites. 1. Curve showing the position of the holes regarding the limit between dolomites from the Lower Trias and limestones from the Middle Trias (hr : distance from this limit to a hole; + : above the limit; - : below the limit). 2. As curve 1 but with reference to the limit between limestones and dolomites from the Middle Trias (hr : distance between this limit and a cavity).

The sequence from the Middle and Lower Trias is essentially made up of dolomites, with limestones, marl and calcareous marl intercalations. It has been verified that 33% of the intersected cavities in boreholes are immediately located in the contact between dolomites and limestones (Figure 2(B)). It has also been noticed that the cavities are between a few metres and 320 m in depth (Figure 2(A)), and 98.5% of them are less than 200 m deep.

In the case of surface outcrops, small open cuts and mine galleries, in addition to area and lineal diametres, regularity in the section has also been noted. As a measure of this regularity, the ratio has been taken of the lengths of the horizontal semi-axis (x) and the vertical semi-axis of the equivalent ellipse of the same area. These measures have been taken in 181 karstic channels.

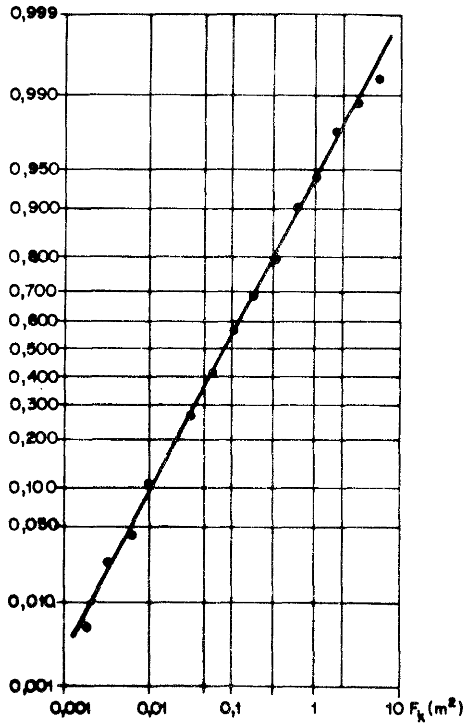

Figure 3. Distribution of the areas of the transversal sections (Fk) of the cavities seen in the open cuts and surface outcrops of the triassic rocks and in mine galleries.

The area of the sections of the cavities is between 0.0013 and 8.4 m^2 and only 5.5% are over 1 m^2 (Figure 3). It has been noticed that the distribution of the semi-axis of the equivalent ellipse of the transversal section of the karstic channels, has values which vary from 0.055 to 10.6. 16% of the holes have regular sections ($0.8 \leq x/y \leq 1.25$); 37% have an x/y relationship lower than 0.8 and 46% higher than 1.25. It has been noticed that the cavities with sectional areas higher than 1 m^2 are regular or horizontally elongated.

Such cavities develop along bedding joints, especially in contact zones between limestones and dolomites. Other large cavities are found in the surrounding zones of vast areas of breccia, having, in this case, the tops in the shape of an equilibrium arch (Figure 5). The small and medium cavities generally belong to formations firstly developed along a bedding plane, or along vertical fissures or intersections of several of them.

With respect to the directions of the karstic channels, there can vary even in the same mine; however it can be observed that some directions are more frequent. In the Bolestaw mine the channels of direction 140-160° and 40-60° predominate, but in the Olkusz mine the direction

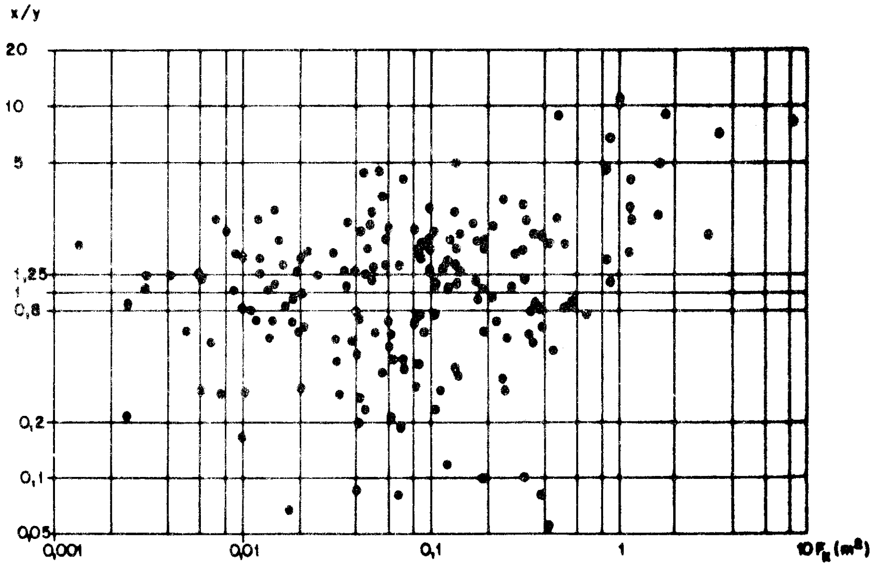

Figure 4. Relationship between the area of the transversal sections of the holes (Fk) and the ratio between the semi-axis of the equivalent ellipse. x : horizontal semi-axis; y : vertical semi-axis.

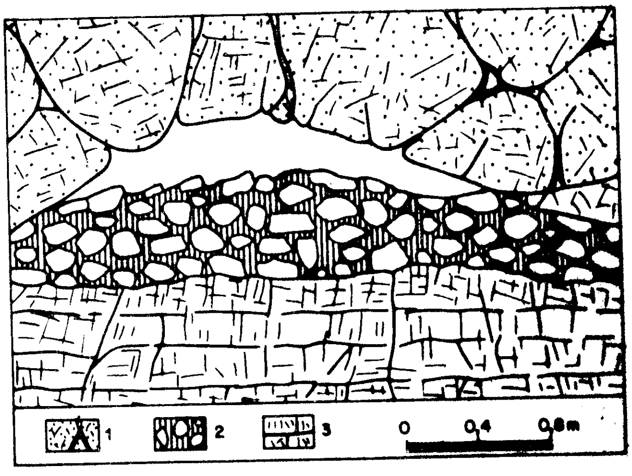

Figure 5. Example of a hole with equilibrium arch. 1 : blocks of dolomites; 2.: breccia cemented by sulfates of lead and zinc; 3 : fissured limestones.

60-80° predominates, and in the Pomorzany, 20-40°. In the latter case the direction 120-160° has a peak frequency less pronounced than in the former (Figure 6). It has also been noticed that the predominant directions of the karstic channels and the directions of the predominant fissures in the carbonate massif in the Olkusz region coincide. This is a fact which has been verified in many other areas [3] even in karst in evaporites rocks [7].

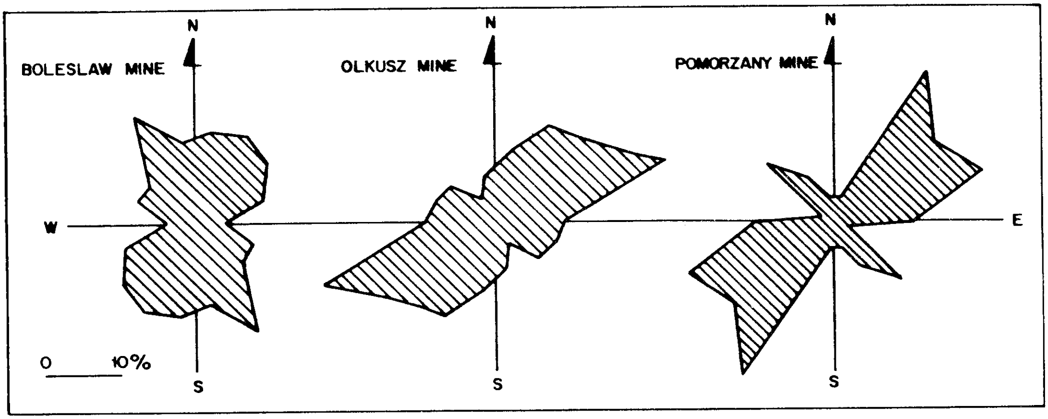

Figure 6. Directions of karstic channels seen in mine galleries and in the surface of the ground in the region of Olkusz.

FILLED KARSTIC FORMATIONS

Filled karstic formations have been found along the whole of the triassic sequence. Two types of filled formation were found in the area : small funnels, and those running along the bedding joints. In boreholes filled formations of 320 m in depth have been found. 37% of these are found in the first 200 m, similar to the karstic cavities. It has also been noticed, very frequently, that the filled formations are found very close to the contact zones between dolomites and limestones (Figure 7).

The formations which have been found in boreholes can be divided into three different groups. The first group consists of those developed along the boundaries between layers. These can reach some hundreds of metres in length and several metres in height (Figure 8(A)). The second group includes the formations running vertically in a funnel or hole shape. They have vertical dimensions of about ten metres and horizontal dimensions of several metres (Figure 8(B)). Formations with large horizontal and vertical dimensions belong to the third group (Figure 8(C)). The smallest of these are probably karstic funnels filled in subsequently by deposits of allochthones or of residual origin. The largest formations probably come from paleovalleys filled after the action of important karstic processes.

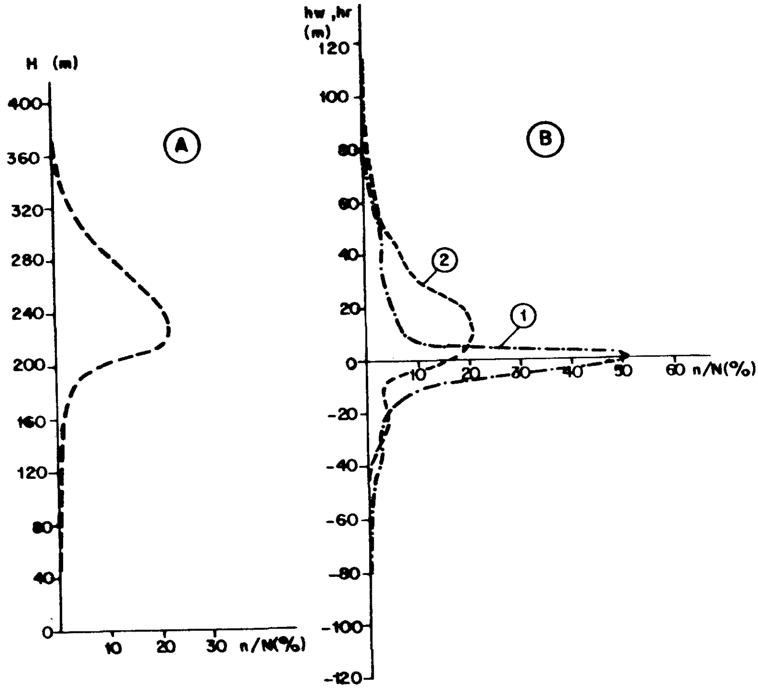

Figure 7. Frequencies of filled karstic forms found in boreholes.
A : showing height (H), B : showing the limits between beds of dolomites and limestones.
1. Curve which shows the situation of forms regarding the limits between limestones and dolomites from the Middle Trias (hw : distance from this limit to a shape).
2. As curve 1, but showing the limit between dolomites from the Lower Trias and the limestones from the Middle Trias (hr : distance between this limit to a formation).

UNDERGROUND AND SURFACE HAZARDS IN RELATION TO KARSTIC FORMATIONS

There are three main types of dangers in relation to karstic formations in the Olkusz region : (1) Inrushes of ground water into the mine galleries, suddenly and unexpectedly, and even catastrophically.
(2) Raising of the artificial funnels up to the surface of the ground as a consequence of the collapse of the ceiling of the galleries in the most abundant and therefore weaker karstic areas [10].
(3) Easy pollution of the ground water running towards mines, due to industrial and farming activities.

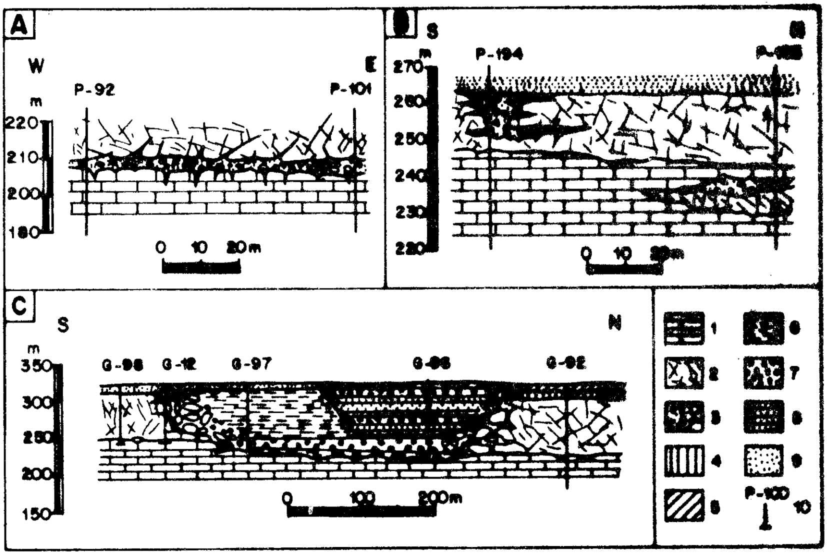

Figure 8. Examples of filled karstic formations found in boreholes.
A : Formation developed along the limit between beds of dolomites and limestones. B : Karstic funnel. C : Formation of large dimensions. Middle Trias : 1. Limestones, 2. Dolomites, 3. Breccia. Upper Trias : 4. Clay, 5. Sand Clay. Lower Jurassic : 6. Clays, 7. Conglomerates, 8. Sandstones. Quaternary period : 9. Sands, 10. Boreholes.

In karstic rocks most of the water runs through channels (units of transmission; [1,2,5] and due to the dimensions of these and to the pressure of water it can reach a high speed and heavy flows. This is why when a mine gallery intersects a karstic channel with heavy flow of water there is danger of flooding the gallery or even the whole mine. This has happened several times in the Olkusz region. The flow through these channels is very often 0.5-1.0 m^3/s. This maximum flow has at times been kept up for approximately ten hours, and as a consequence the total flow of water was above 5 m^3/s, thus the flow is greater than the pumping capacity. The excess water was diverted into a system of special sump holes designed for such cases of catastrophic inrushes. This type of threat exists especially close to the non-filled karstic channels, although it can also happen in filled karstic formations, when material is carried by the water, increasing the inflow up to ten times.

The essential problem posed in mining in saturated karstic rocks is to foresee the place where a mine gallery may intersect a karstic channel containing water under pressure and to estimate the flow of the inrush. Up to the present time, a method of forecasting in Olkusz has not been found. It has also been noticed that the highest probability of inrushes of water can be found close to the boundaries of limestones and dolomites, or at the boundary itself, where most of the channels and filled karstic formations of large dimensions can be found.

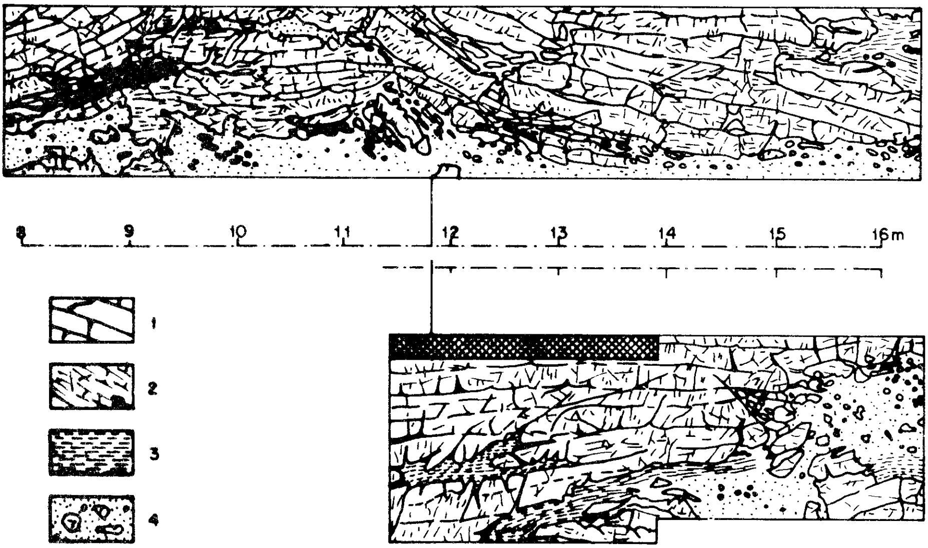

Figure 9. Example of a filled karstic form found in a mine gallery.
1. Limestones, 2. Marl limestones of small thickness,
3. Sandy clays, 4. Pudding breccia.

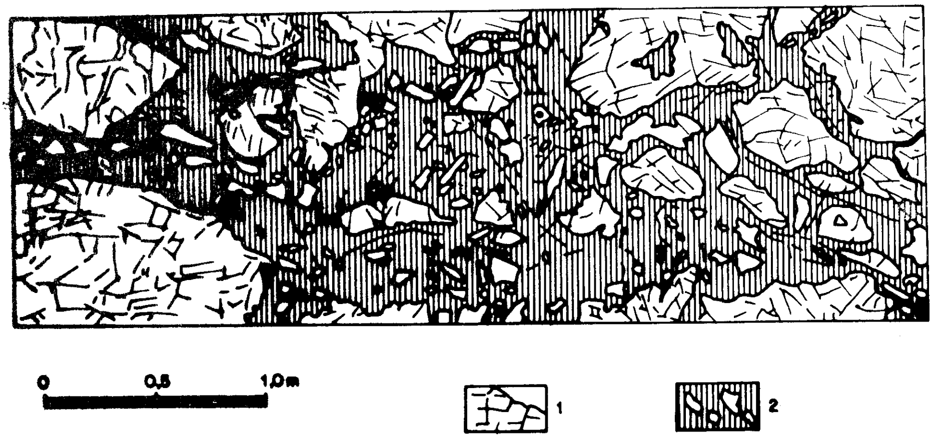

Figure 10. Example of a zone of breccia cemented with calcite.
1. Dolomites, 2. Calcite with fragments of dolomites.

It has also been seen that the areas of karstification weaken the resistance of the rocky massif. In Olkusz, the horizontal dimensions of these areas reach several hundres of metres [9]. In its surroundings there are, very often, deposits of lead and zinc, so that mine galleries have to be excavated. Within the filled formations the mechanical resistance is low in relation to limestones and sound dolomites. This implies that the gallery has to be lined and so the total cost is increased. It may happen that the lining is not sufficient and the ceiling of the gallery may sink with the load of the material; this may even affect the surface. Sink-holes appear outside. The biggest is more than 100 m in diameter and almost 30 m in depth. Smaller sink-holes also form outside the mining area as a consequence of erosion of the material which fills the karstic formations provoking its collapse.

The existence of karstic channels through which water runs at a high speed facilitates the inflow and migration of pollutants into the aquifer. In Olkusz there is a factory of cellulose and paper which has been working for many years and which is located 7 km away from one of the lead-zinc mines. Since its opening, this factory has been discharging polluting substances (lignino-sulfonide acids) over sands which cover triassic carbonate rocks. As a consequence of dewatering due to mining, the water table of the area has been depressed and so the water from the sands feeds the triassic carbonate rocks; 1.5 years later polluted water can be found in the mine galleries. 70% of water previously used as drinking water, is polluted; the attempt to separate the non-polluted water from the polluted would require extra and extremely expensive mining work. In addition to which, within the partially drained karstic cavities, a dense bacterial fauna develops and metabolizes the polluting agents. As a result of this metabolism and putrefaction of these bacteria, large quantities of methane have been created. This gas can easily reach the mine galleries, through the karstic channels and fissures, and is also carried by the ground water. As a consequence this has caused explosions with fatal casualties. This has required extra safety measures and, consequently, the cost of mining has increased.

CONCLUSIONS

From a detailed statistical study of the karstic cavities in the Olkusz region it has been shown that both the thickness of the cavities and the area of their transversal sections have log-normal distributions. The maximum development of karstic cavities and filled formations are found in the first 200 m below ground, although the maximum depth to which karstic phenomena can be observed is greater.

The control of these formations and the resulting incidence in mining dangers by the presence of water are not well understood, although from the study of the formations we may conclude that the contact zones between limestones and dolomites, as well as fractures, represent probable places for the development of channels.

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