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RESEARCH PAPERS

Jacek Motyka
Zbigniew Wilk*

Hydraulic Structure of Karst-Fissured Triassic Rocks in the Vicinity of Olkusz (Poland)

Abstract: Hydraulic model of the Triassic karst-fissured limestones and dolomites occuring in the Olkusz zinc and lead mining district is presented. The results of observations and measurments of the geometric parameters of the fissures and karst forms exposed in mining workings and on the surface are discussed. For the convenience of mining practice a classification of open karst channels is proposed.

Introduction

Karst formations are, for different reasons, the subject of interest of researches representing various branches of geological sciences. In the course of the last two decades the interest in hydrogeology of karst-type aquifers has increased very distinctly, since as a rule these aquifers can yield large quantities of high quality water. The increasing world-wide water crisis encourages multi-directional investigations into this type of rocks. A rational development of ground-water resources occurring in karst-fissured aquifers requires a study of the dynamics of ground-water flow and due to great susceptibility of this kind of ground-water reservoirs to surface originated pollution the problem of mass migration within these rocks also demands solution.

The mining industry is strongly interested in the studies of ground-water movement within karst-fissured formations. The exploitation of karst-type mineral deposits is usually accompanied by heavy ground-water inrushes into mine workings (Plate 1, Wilk et al., 1977). They often create great hazards for both the mining operations and the crews. The inevitable draining of karst-fissured rocks around the mines results in different disadvantageous and even disastrous processes and phenomena sometimes occurring in sites located far away from the mines where ground-water extraction takes place. The improvement of forecasting methods of different hazards for both the mine workings and for the objects on the surface belongs to the most urgent tasks of modern karst hydrogeology with respect to mining industry.

According to the authors' opinion the accuracy of the respective prognoses could be improved thanks to better knowledge of the hydraulic structure parameters of the ore-bearing formations and surrounding rocks.

The authors' investigations were initiated in underground workings of the zinc-lead ore mines in the Olkusz mining district. With respect to the volume of water pumped out from these mines they belong to the top ones in Europe. The results of the authors' investigations are presented in this paper.

The Hydraulic Model of the Carbonate Rocks under Investigation

The karst-fissured rocks represent a specific type of ground-water collector. Their specificity is mainly connected with the structure of this kind of medium, within which four basic hydraulic systems can be

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distinguished, namely: pores, fissures, open karst channels and secondary filled karst forms (Fig. 1).

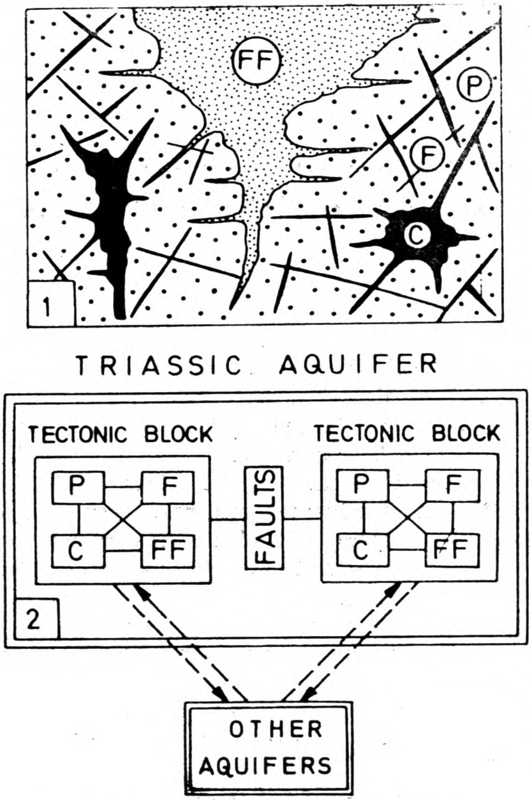

Fig. 1. Hydraulic model of the Triassic karst-fissured waterbearing horizon:
1 — scheme of a fragment of the rock massif; 2 — hydraulic scheme of ground-water circulation; **P** — pore space, **F** — fissures, **C** — open karst channels, **FF** — filled karst channels

The mentioned systems form the internal structure of the karst-fissured rock. This structure however is internally unstable as it may undergo changes resulting from chemical and mechanical action of the moving ground-water (L i s z k o w s k i, 1977) as well as from the sedimentation and from the movement of the material filling the fissures and karst forms.

Ground-water circulation within karst--fissured rocks also depends on their macroheterogeneity caused by the spatial arrangement of the strata and by the local as well as regional hydrogeological conditions. They all together create the external structure of the rocks under discussion. Both mentioned structures are connected with each other and any change within one of them causes the rebuilding of the other

The qualitative models of the interrelations between geological and hydrogeological factors and of the properties of a karstic aquifer have been proposed among others by L. K i r a l y (1975) or A. M a n g i n (1976), and a semiquantitative model in the form of an algorithm enabling to solve the water balance equations has been proposed by C. D r o g u e and A. G u i l b o t (1977).

The main element of the external hydraulic structure of the investigated Triassic aquifer are the numerous disjunctive dislocations, dividing the rock formations into separate, isolated hydrogeological units. Of great importance is also the recharge and/or discharge of the Triassic aquifer by other water-bearing horizons which occurr in the zones of hydraulic contacts (W i l k, M o t y k a, 1977) and by surface streams (Fig. 1).

The elements of the internal hydraulic structure of the discussed medium differ from each other mainly with respect to the value of hydraulic resistance. Nevertheless there exist ranges of resistance values common to different kinds of open spaces. Fissure and karst channel systems characterized by the least hydraulic resistance are the privileged ways of ground-water circulation.

Fissures

Until now the pore space of the carbonate Triassic rocks has not been investigated from the point of view of its hydraulic properties. The measurements of the main geometric elements of the fissures, i.e. width, length and spatial orientation have een carried out in the underground mine workings and in surface exposures. As a result it has been found that the most frequent value of the fissure width equals ca 0.2 mm. The maximum values reach up to 35 mm within the shallow hipergenic zone, up to 5 mm at the depth of 100 m and up to 2.5 mm at the depth of 150 m, respectively.

The values of surface fissurity indices (K_{ws}) and of the surface density of joints (Γ_F) were calculated using the formulae given below (L i s z k o w s k i, S t o c h l a k, 1976).

$$K_{ws} = \frac{\sum_{1}^{n} l_i \cdot b_i}{F}, \qquad (1)$$

$$\Gamma_F = \frac{\sum_{1}^{n} l_i}{F}, \qquad (2)$$

where:

K_{ws} — surface fissurity index,
Γ_F — surface density of fissures (m^{-1}),
l_i — length of a respective fissure (m),
b_i — width of a respective fissure (m),
F — the cross-section area of a fissured rock fragment (m^2).

The measurement results were also used for the calculation of the hydraulically equivalent fissure width of the investigated rock massif fragment. Therefore the assumption has been made that the volume of ground-water flowing through the cross-section of a real rock massif fragment for a certain time period equals the volume of ground water flowing during the same time period through the cross-section of the same size of a fragment of a fictitious massif. The authors also assume that this massif is cut with fissures of identical representative width (b_m) and that their total length equals the sum of the lengths of separate fissures of a real rock massif.

The equivalent fissure width was calculated applying the explicit Bussinesq's equation including the simplifying assumption referring to the identity of hydraulic gradient within all fissures. As a result the following formula has been derived

$$b_m = \sqrt[3]{\frac{\sum_{1}^{n} b_i^3 \cdot l_i}{\sum_{1}^{n} l_i}}, \qquad (3)$$

where: b_m — hydraulicaly equivalent fissure width (m).

The characteristic values calculated using formulae (1), (2) and (3) can be seen in Table 1.

One of the basic elements of the internal hydraulic structure is the spatial orientation of fissures since it forces the ground water to flow in this and not in the other direction.

The measurements have shown that apart from the differences in different measurement sites there exist two main fissure directions, namely 20—60^g and 320—360^g. They are in accordance with the ones observed in other localities of the same rock massif (N g u e n - K h a c - A n, 1971; K r o k o w s k i, 1974; G ó r e c k i, 1977). In some places an uniform distribution of fractures orientation has been found (fig. 2, site No 2), what is characteristic of the collapse breccia structures, in this region first described by M. S a s s - G u s t k i e w i c z (1974).

T a b l e 1

Extreme values of hydraulic properties of the fissures observed within the carbonate Triassic of the Olkusz region

Depth below the surface (m)	Surface fissurity index K_{ws} (%)	Surface density of fissures Γ_F (m^{-1})	Hydraulically equivalent width of fissures b_m (mm)
Terrain surface	0.13—4.40	3.95—15.98	0.23—14.0
100	0.0046—0.30	0.21—3.58	0.60—4.48
150	0.070—0.66	2.46—14.68	0.56—1.03

Karst Channels

The hydraulic resistance of a karst channel depends mainly on the size, shape and the variation in the size of the cross-section of the karst channel perpendicular to the direction of ground water movement. Obser-

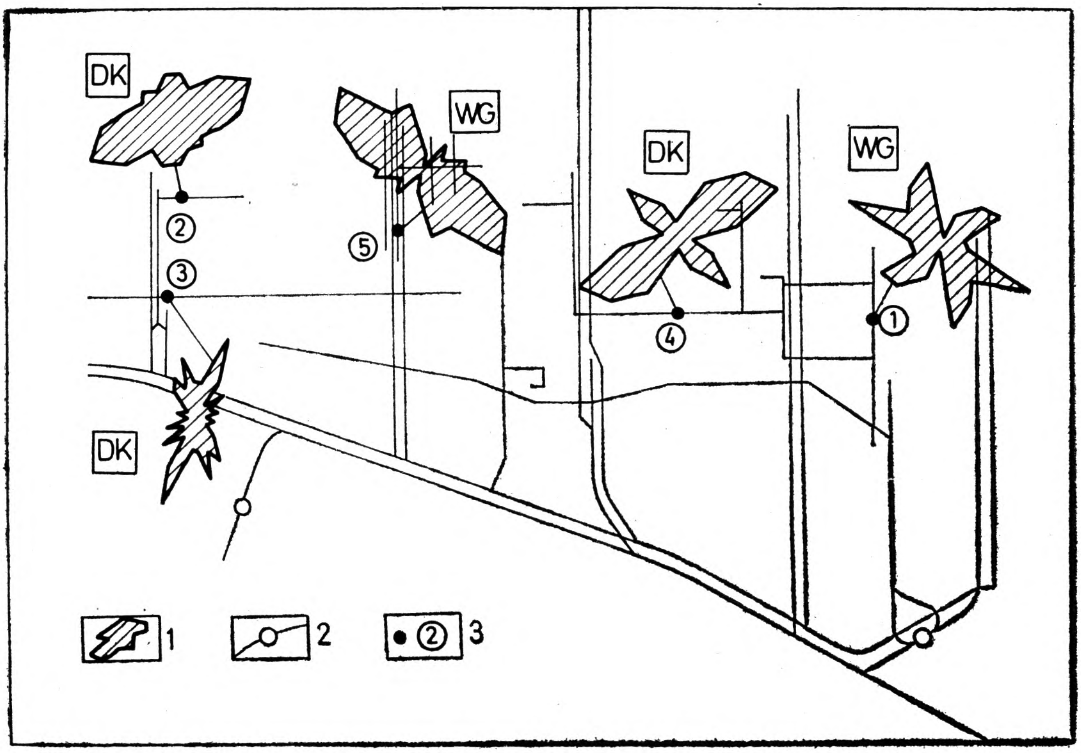

Fig. 2. Fracture orientation diagram — Pomorzany ore mine:
1 — diagram of fracture orientation, 2 — mine workings, 3 — measurement site and its current number; DK — orebearing dolomite WG — Gogolin beds, limestone

vations have shown that the shapes of the karst channel cross-sections are very irregular as a rule (fig. 3). Sporadically one can observe karst channels with smooth internal walls, beeing examples of typical karst pipes (Pl. 2). Some channels are distinctly bordered from one or two sides with bedding planes. Similar examples of cave cross--section shapes have been reported by R. L. Powell (1977).

The observed karst channel cross-sections of different shapes were transformed by the authors into ellipses of the same size. The ratio of the length of the horizontal (x) and vertical (y) half-axes of the ellipse was assumed as the measure of the regularity of this shape. Taking into account the numerical values of these ratios three main types of karst channels cross-sections have been distinguished:

1. Vertically elongated (V): x/y below 0.8
2. Regular (R): $x/y = 0.8$ to 1.25
3. Horizontally elongated (H): x/y above 1.25

The karst channels characterized by the vertically elongated shape of the cross-section participate in 40%, by the regular one — in 23%, and with the horizontally elongated cross-section in 37% in the whole population under consideration. The ratios of the equivalent ellipses are between 0.09 and 10.6.

The sizes of the karst-channels cross-sections (F_k) are located within a considerable range of values, between 0.002 and 3 m^2. With respect to size they have been divided into four following groups (Fig. 4):

1. Small F_k below 0.25 m^2
2. Medium F_k between 0.25 and 0.5 m^2
3. Large F_k between 0.5 and 1.0 m^2
4. Very large F_k above 1.0 m^2

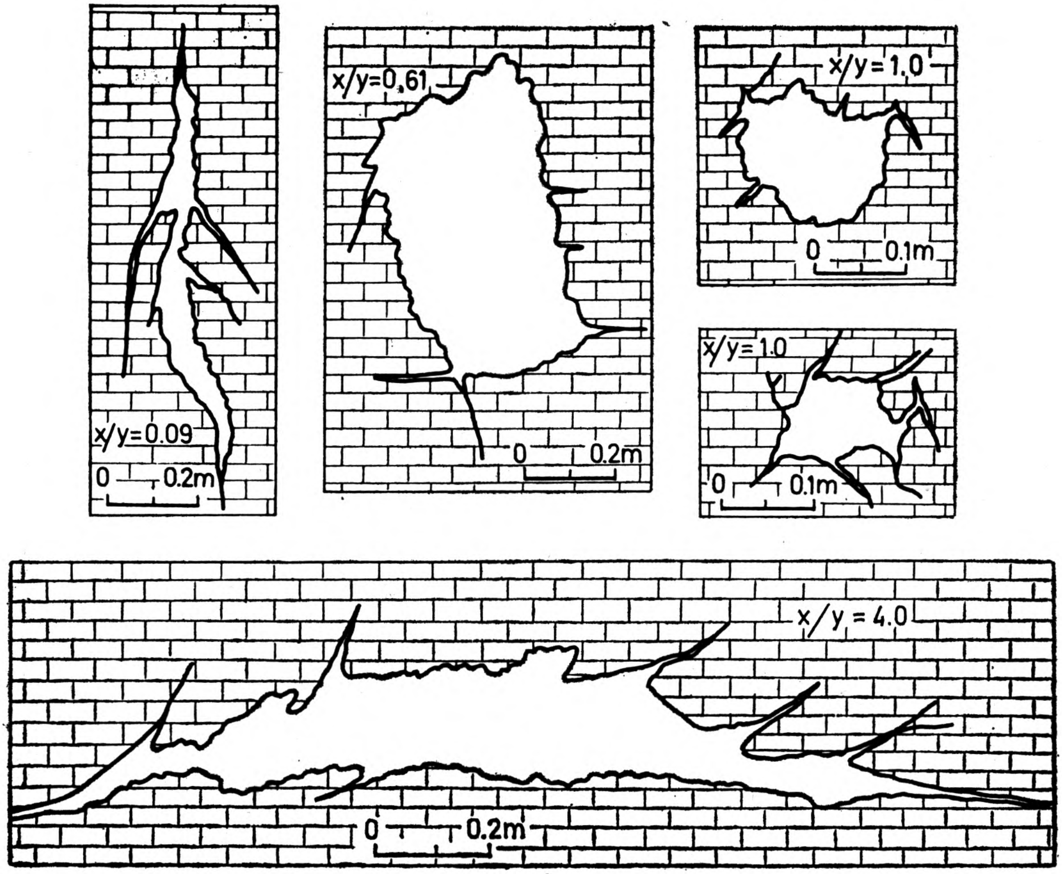

Fig. 3. Examples of karst channels cross-sections to be observed in the Olkusz ore-mine

Among the observed karst channels there prevail forms with small cross-section sizes (69%). The frequency of the remaining groups is as follows: medium — 17.7; large — 4.9%, very large — 8.0%.

The orientation of karst channels is various, what is characteristic of mature network of this kind of karst forms. Nevertheless the direction of 40—80^g is the most frequent. It corresponds to the most frequent direction of fractures and disjunctive dislocations of second range (Fig. 5).

Filled Karst Forms

On the basis of up to date observations in mine workings and in core drillings as well as in surface exposures one may conclude that the secondary filled karst forms represent a considerable portion of the Triassic rock massif under consideration. In the ore mine workings extensive secondary filled karst forms zones several hundreds of meters long are to be seen (Wilk et al., 1973). From the observations of mine workings and in surface exposures it appears that there occur all kinds of karst form fillings distinguished by M. Paloc (1977), i.e. the detritic, chemical, organic and mixed ones (Photo 4).

The detritic filling consists mainly of clayey substance and of calcareous grains (Sass-Gustkiewicz, 1977) in which there stick sharply angular fragments of mother rock (dolomite) of different size (Sass-Gustkiewicz, 1971) (Fig. 6). The-

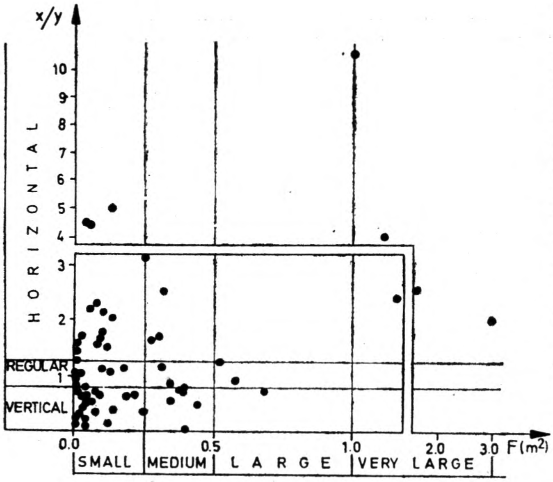

Fig. 4. Point diagram of the relationship between the ellipse half-axes ratio x/y of the karst channels cross-sections and their size (F)

re exists certain regularity in the distribution of the rock fragments of different size. The larger ones prevail in the upper part of the filled solution openings, what characterizes the typical collapse-breccia structures (Sass-Gustkiewicz, 1974). Similar regularity has also been reported from other karst regions in Poland (Gradziński, 1962; Głazek et al., 1977). Some karst openings are filled with white colloidal zinc sulphide (brunckite). The interfragmental filling is very often represented by zinc-lead- or iron-sulphide and calcite (Sass-Gustkiewicz, 1974) or even barite (Nieć, 1980). If this is the case we can define it as a detritic-chemical type of filling. Pure chemical type of filling occurs very seldom. In such case it is represented by hydratized iron oxides accompanied by hematitic pizolites. Some, usually small, solution openings are filled with organic matter, in which I. Lipiarski (1977) found numerous *Arthropoda* fragments.

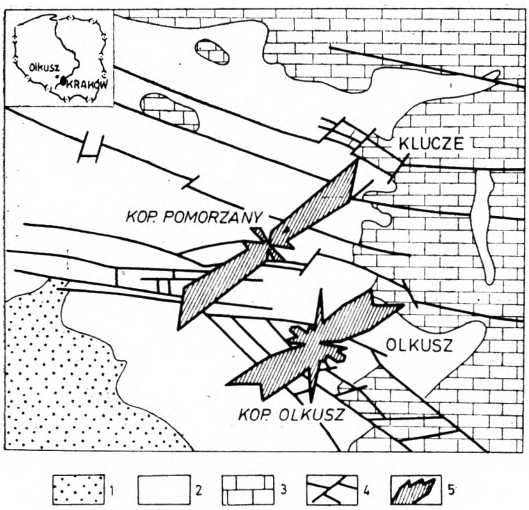

Fig. 5. Orientation of karst channels as observed in mine workings of the Olkusz ore-mining district:

1 — Permian, 2 — Triassic, 3 — Jurassic, 4 — faults, 5 — karst channels orientation diagrams

Fig. 6. Example of a filled karst channel (Olkusz ore-mine):

1 — limestone, 2 — clayey matter wih sand admixture, 3 — sharply angular fragments of limestone, 4 — blue weathered clay, 5 — clay with brunckite

Impact of Hydraulic Systems Upon the Formation of Ground-Water Flow within Karst-fissured Rock Massif

The role of the mentioned types of voids in the process of collecting and transmission of ground-water within the discussed kind of rock massif depends mainly on their total volume as well as on their hydraulic resistance. The discussion of this problem lasting for years in the hydrogeological literature is still very far from its completion. As far as the pore space is concerned most authors believe that this kind of voids is responsible only for the collectory properties of the rock massif. The hydraulic resistances within the pores are very great in comparison with those within the fissures or solution channels. For this reason while constructing the mathematical model of a fissured rock massif G. I. Barenblatt and J. P. Zheltov (1960) made the simplified assumption that the pore space does not participate in the ground-water transmission, and represents only a certain hydraulic capacity. However, T. D. Streltsova (1976) does not agree with souch a simplification, and believes that the pore space should not be neglected in the general mathematical model of ground-water flow through the discussed rock massif.

According to the authors the pore space has a considerable share in the volume of water stored within the rock massif, however within the detritic and oolitic carbonate rocks, where the size of pores is comparatively large, the significance of the pore space in the process of ground-water transmission increases.

Considering the comparatively small hydraulic resistances and the part they take in the total volume of rock massif voids the fissures represent the most important ways of ground-water transmission within fissured and karst-fissured rocks. The fissure network can be compared to the mesoporosity of the massif, where the blocks of rock separated by joints play the role of grains within a typical pore medium. The space volume occupied by the fissures within the massif is very small as a rule and usually does not exceed 1%. Hence the conclusion has been drawn that first of all the fissures play the role of conductors characterized by great hydraulic transmissivity and minute (Streltsova, 1976) or practically no hydraulic capacity (Barenblatt, Zheltov, 1960).

In comparison with other kinds of voids the open karst channels are characterized by minute hydraulic resistances, and due to their small total volume also by respectively small hydraulic capacity. As a result the karst channels are the privileged ways of ground-water circulation (Bakalowicz, 1977) which may be compared with the surface stream system. In undisturbed conditions a well developed system of karst channels represents a local, internal drainage basis for the surrounding rocks (e.g. Haładus et al., 1978). The significance of the open karst channels becomes distinctly evident in cases of natural ground-water regime disturbances. For example in case of disturbances resulting from mining operations the karst forms may be the source of sudden, disastrous ground-water inrushes into the mine workings (e.g. Wilk et al., 1977) and on the other hand they enforce the shape and extent of the cone of depression around mines and great ground-water supply plants.

The filled karst forms posses the properties of all of the above discussed kinds of voids. Depending on the kind and the stage of diagenesis of the material filling the forms under discussion their hydraulic transmissivity can be similar to that of the pore space, of the fissures or even of the open solution channels. The importance of this type of hydraulic systems increases especially when the natural regime is abruptly and seriously disturbed. The artificial lowering or raising of the ground water table causes the increase of the hydraulic gradients and of the velocity of ground-water flow, respectively. This may result in the removal of loose material filling the large sized voids and in the reconstruction of the internal hydraulic structure of the karst-fissured rock massif. A portion of the loose material is being pumped out together with the inflowing ground-water. As a result of the displacement of the sediments filling

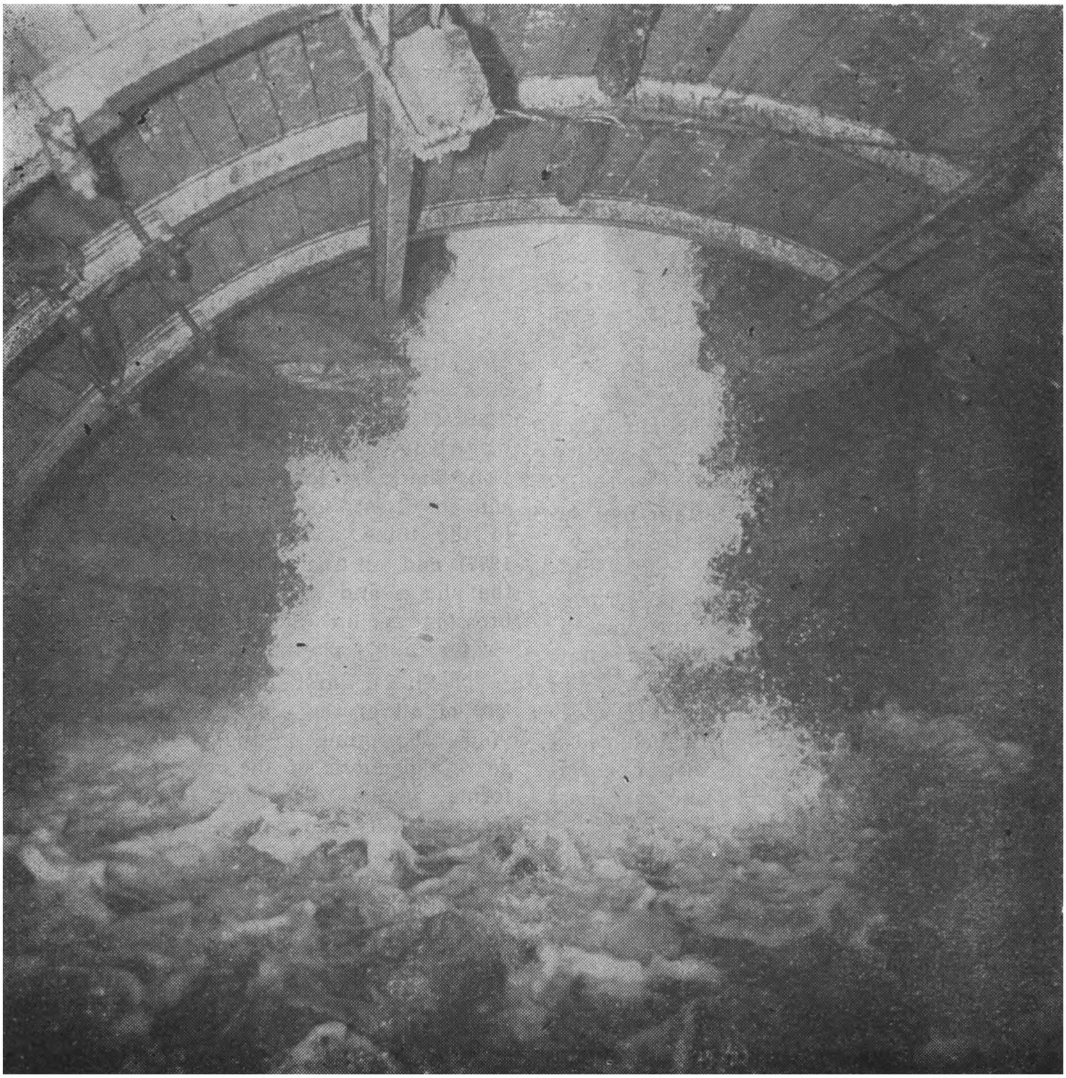

Photo 1. Example of ground-water inrush into a mine gallery, yielding ca 50 m^3/min
(*All photographs are Jacek Motyka's*)

Photo 2. Example of ground-water outflows from a fractured zone

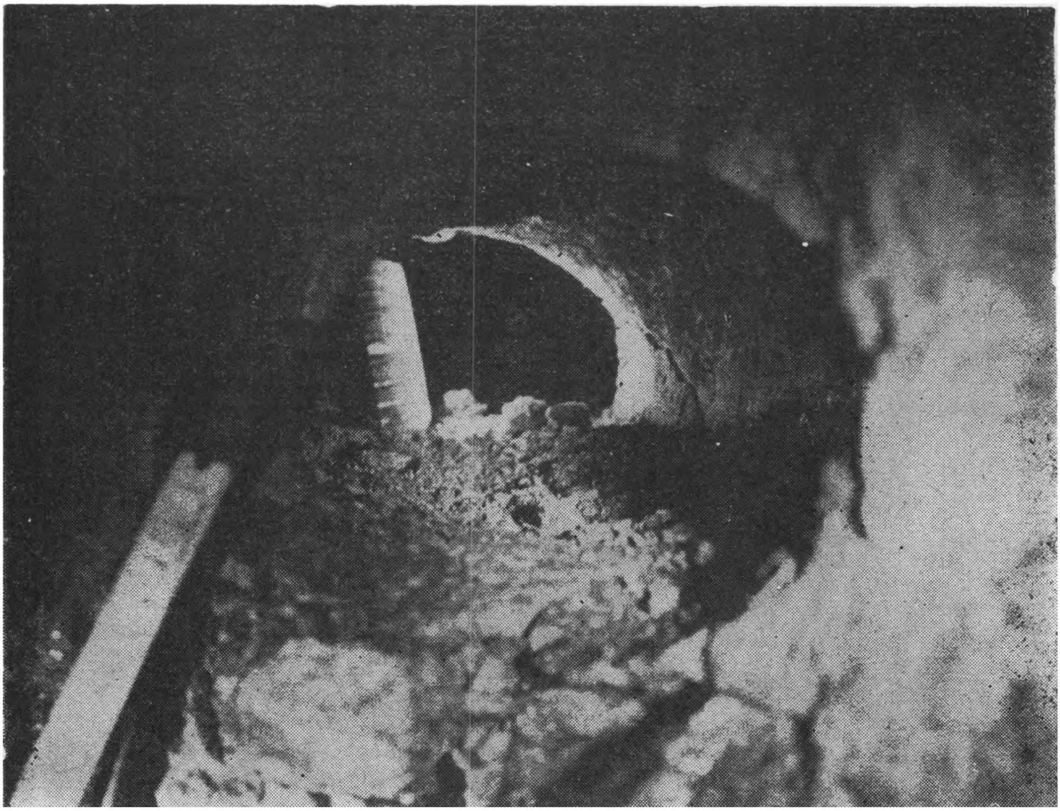

Photo 3. Example of a karst pipe

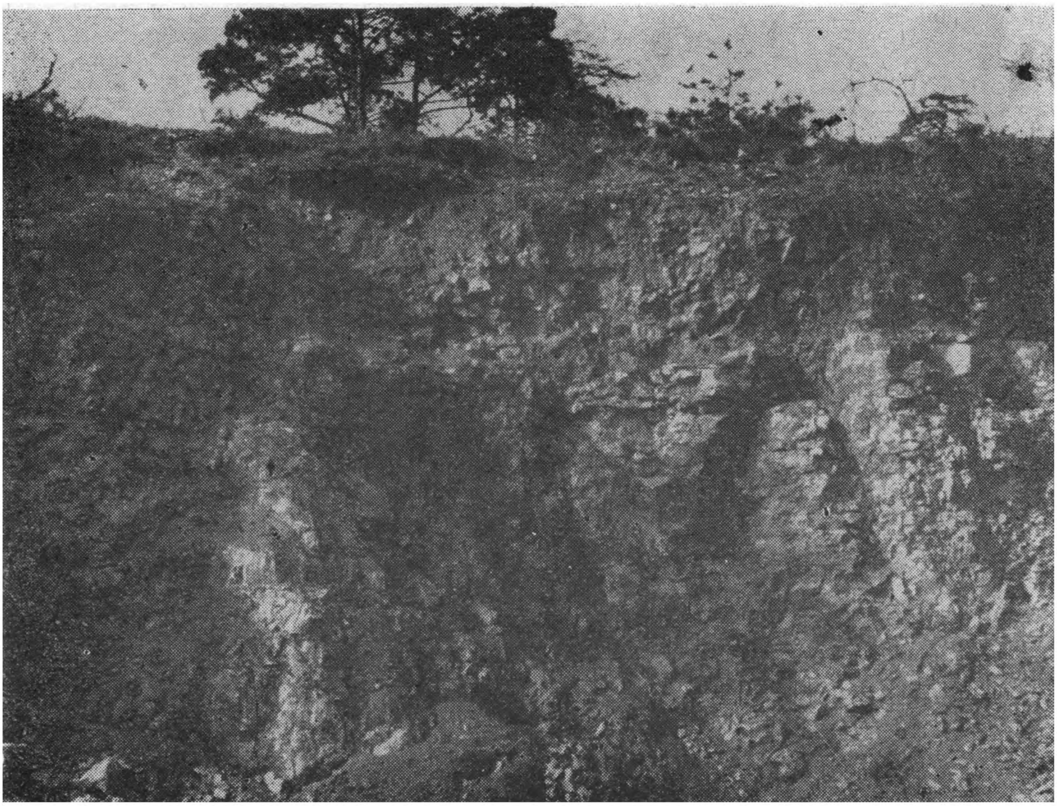

Photo 4. Example of a filled sink in Roethian dolomite

the karst forms and wide fissures new ways of ground-water circulation are created.

The drainage of the karst-fissured rock massif resulting in the replacement of the material filling large voids often causes unfavourable or even disastrous engineering-geological processes on the earth surface (e.g. Głazek, Szynkiewicz, 1979). The most common phenomena produced by them are the sink-holes, sometimes causing great damages of buildings, industrial objects, communication lines etc. within the range of intensive drainage of karst-fissured rock formations.

References

Bakalowicz, M., 1977: Étude du degré d'organisation des écoulements souterrains dans les aquifères carbonatés par une méthode hydrogéochimique nouvelle, C. R. Acad. Sci., **284**, Sér. D: 2463—2466, Paris.

Barenblatt, G. I., Zheltov, J. P., 1960: Ob osnovnych uravnenijach filtracji odnorodnych zhidkostej v treščinovatych porodach. Dokl. AN SSSR, **132**, 3: 545—548, Moskva.

Drogue C., Guilbot A., 1977: Représentativité d'un bassin témoin en hydrogéologie karstique: application à la modélisation des écoulements souterrains d'un aquifère de grande extension. Journ. of Hydrology, **32**: 57—70, Amsterdam.

Głazek, J., Sulimski, A., Szynkiewicz, A., Wysoczański-Minkowicz, T., 1977: Kopalny kras ze środkowoplejstoceńskimi szczątkami kręgowców w Drabach koło Działoszyna (Fossil with middle pleistocene vertebrates at Draby near Działoszyn (Central Poland)), [w:] Kras i speleologia, t. 1 (X), s. 42—54, Katowice.

Głazek, J., Szynkiewicz, A., 1979: Kras kopalny jako czynnik potęgujący zmiany środowiska podczas działalności inżynierskiej, [w:] Materiały z Sympozjum n.t.: „Zmiany środowiska geologicznego pod wpływem działalności człowieka", t I, s. 40—50, Warszawa.

Górecki, J., 1977: Orientacja przestrzenna i wykształcenie spękań w utworach triasowych kopalni Bolesław k/Olkusza (Spatial orientation and nature of fractures from the Triassic rocks of the Bolesław mine near Olkusz), Przegl. Geol., **11**: 556—558, Warszawa.

Gradziński, R., 1962: Rozwój podziemnych form krasowych w południowej części Wyżyny Krakowskiej (Origin and development of subterranean karst in the southern part of the Cracow Upland), Ann. de la Sociéte Géol. de Pologne, **32**, 4: 429—492, Kraków.

Haładus, A., Motyka, J., Szczepański, A., Wilk, Z., 1978: Prognozowanie metodą modelowania analogowego dopływów wody do kopalń pracujących w skałach szczelinowo-krasowych (Forecasting of ground-water inflow into mines in fissure-karst horizons using the electric analogue simulation method), Ann. de la Sociéte Géol. de Pologne, **48**, 3—4: 559—587, Kraków.

Kiraly, L., 1975: Rapport sur l'état actuel des connaissances dans le domaine des caractères physiques des roches karstiques, Intern. Union of Geol. Sci., Ser. 8, No 3: Hydrogeology of Karstic Terrains, p. 31—40, Paris.

Krokowski, J., 1974: Statystyczne opracowanie spękań ciosowych wapieni środkowego triasu i górnej jury między Krakowem a Chrzanowem (Statistic Elaboration of Joints in Middle Triassic and Upper Jurassic between Kraków and Chrzanów), Zesz. Nauk. AGH, 412, Geologia, **19**: 45—56, Kraków.

Lipiarski, I., 1971: On Fossil Remains of Arthropods and Plants and Organic Matter from Cavities in the Triassic Rocks of the Cracow Area, Bull. de l'Acad. Pol. des Sci., Ser. des Sci. de la Terre, **19**: 79—83, Varsovie.

Liszkowski, J., Stochlak, J., (red.) 1976: Szczelinowatość masywów skalnych, Wyd. Geol., Warszawa, p. 312.

Liszkowski, J., 1977: Prawidłowości i odrębności hydrauliki krasowej (Regularities and pecularities of karst hydraulics), Biul. Geol. UW, **21**: 29—51, Warszawa.

Mangin A., 1976: Les systèmes karstiques et leur méthodologie d'investigation, Ann. Sci. Univ. Besançon, Geol., **25**: 263—273, Besançon.

Nguyen-Khac-An, 1971: Zagadnienie ciosu na kopalni Bolesław. Praca doktorska. AGH, Kraków.

Nieć, M., 1980: Model of formation of Cracovian-Silesian type zinc-lead deposit at Bolesław, near Olkusz, Poland, [in:] Proc. of the Fifth Quadren. IAGOD Symposium, p. 445—457, Stuttgart.

Paloc, H., 1977: Karsts anciens et eaux actuelles. Proc. of the Twelfth Intern. Congress. Karst Hydrogeology, p. 229—238, Huntsville, Alabama.

Powell, R. L., 1977: Joint patterns and solution channel evolution in Indiana, [in:] Proc. of the Twelfth Intern. Congress. Karst Hydrogeology, p. 255—269, Huntsville, Alabama.

Sass-Gustkiewicz, M., 1971: Rudy cynku i ołowiu w kawernach krasowych

(Zinc and Lead Ores in Karst Cavities), Rudy i Met. Nieżel., **7**: 347—349, Katowice.

Sass-Gustkiewicz, M., 1974: Collapse Breccias in the Ore-Bearing Dolomite of the Olkusz Mine (Cracow-Silesian Ore District), Ann. de la Société Géol. de Pologne, **44**, 2—3: 217—226, Kraków.

Streltsova, T. D., 1976: Hydrodynamics of Ground-water Flow in a Fractured Formation, Water Res. Research, **12**, 3: 405—414.

Wilk, Z., Motyka, J., Niewdana J., 1973: Geologiczne i hydrogeologiczne uwarunkowanie powstania zapadlisk na obszarze górniczym jednej z kopalń rud cynkowo-ołowiowych (Geological and hydrogeological conditions of the origin of zinc-holes on a mine field of one of the zinc and lead ore mines), Bul. Inst. Geol., **277**: 359—378, Warszawa.

Wilk, Z., Motyka, J., 1977: Kontakty między poziomami wodonośnymi w olkuskim rejonie kopalnictwa rud (Contacts between water-bearing horizons (Olkusz ore mining region, near Cracow), Ann. de la Société Géol. de Pologne, **47**, 1: 115—143, Kraków.

Wilk, Z., Adamczyk, A. F., Biernacki, J., Motyka, J., 1977: Wykształcenie strefy uskoku Pomorzan i jego hydrogeologiczna charakterystyka (Geological and hydrogeological characteristics of the Pomorzany fault zone). Ann. de la Société Géol. de Pologne, **47**, 3: 459—481, Kraków.

Jacek Motyka, Zbigniew Wilk

STRUKTURA HYDRAULICZNA SKRASOWIAŁYCH I USZCZELINIONYCH SKAŁ TRIASOWYCH W OKOLICACH OLKUSZA (POLSKA)

Streszczenie

Przedstawiono model hydrauliczny triasowych, uszczelinionych wapieni i dolomitów występujących w obrębie olkuskich kopalń cynku i ołowiu. Przedyskutowano wyniki obserwacji i pomiarów geometrycznych parametrów szczelin oraz form krasowych występujących na powierzchni, a także odsłoniętych w trakcie prowadzenia prac górniczych. Zaproponowano klasyfikację otwartych kanałów krasowych na potrzeby praktyki górniczej.

Jacek Motyka, Zbigniew Wilk

STRUCTURE HYDRAULITIQUE DES ROCHES KARSTIFIÉES ET FISSURÉES DU TRIASSIQUE DANS LA RÉGION DE OLKUSZ (POLOGNE)

Résumé

On a présenté le modèle hydraulitique des calcaires et dolomies triassiques apparaissant dans la zone de mines de zinc et de plomb à Olkusz. On a discuté les résultats des observations et les mesures des paramètres géométriques des fissures et des formes karstiques apparaissant en surface, et celles découvertes au cours des travaux miniers. Une classification de canaux karstiques ouverts a été proposée aux besoins de la pratique minière.

Ferenc Cser
Gábor Izápy
Lászlo Maucha*

Problems of Water Chemistry of Jósvafő Terrain (Hungary)

Abstract: Chemical analyses and the discharges of waters of five springs at the Jósvafö terrain are given as series of daily measurements. The chemical composition of waters is practically constant in the whole year of 1980 except the flood periods in springtime. Then the chemical composition of the waters of the Vass Imre cave differs

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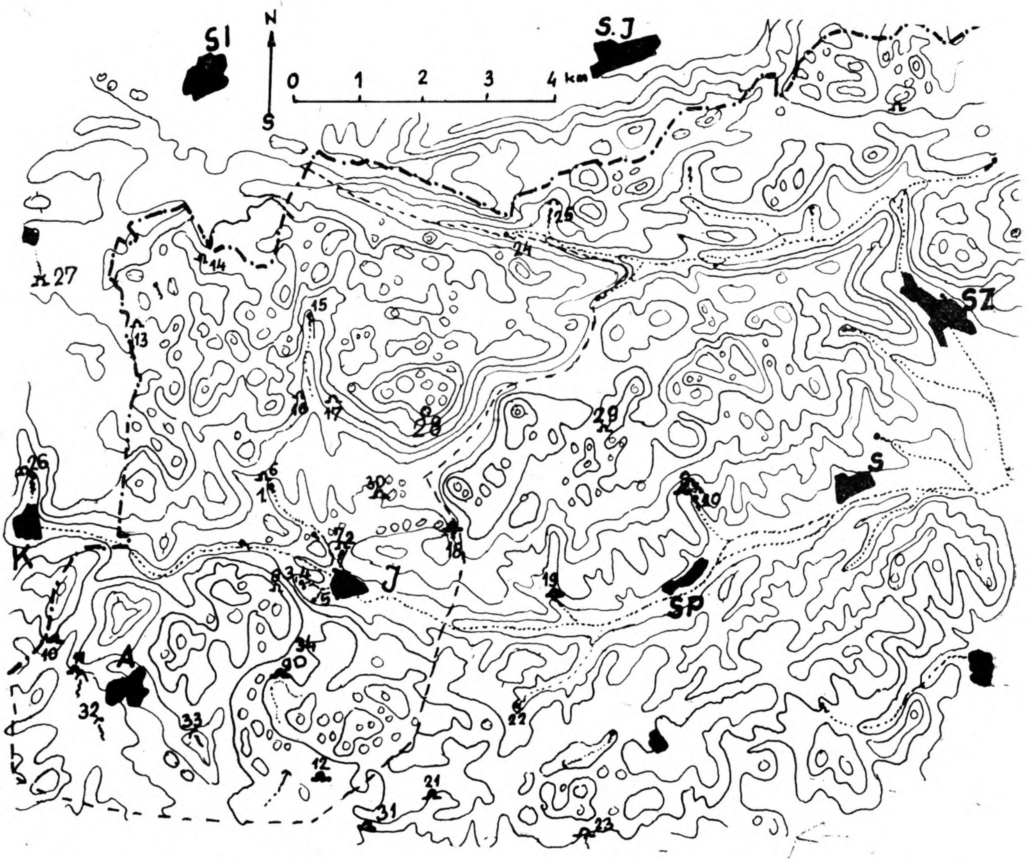

Fig. 1. The map of the representative area:
J — Jósvafő, A — Aggtelek, S — Szin, SP — Szinpetri, K — Kecovo, SI — Silice, SJ — Silická Jablonica (vilages). Numbers indicate caves springs and sink-holes referred in the text

significantly from that of the cave-spring Kistohonya. The results are interpreted according to the mathematical model of the karstic springs. The use of the equation of R. J. Fagundo and J. J. Valdes (1975) gave non reasonable saturation indices of the waters. This leads to the conclusion that solubility constant of the local rock is necessary to be known for the calculation of the saturation index.

According to the Lądek Zdrój recommendation of the UIS Commitee of Karst Physicochemistry and Hydrogeology the Jósvafő area was designated as the Hungarian representative terrain for the physico-chemical and hydrogeological investigations in the karst. This area maintains the most intensive investigations have been carried out also here in the last decades.

Characterization of the Area

The Mesosoic basement of the studied area is composed of Trias age formations (Balogh, 1950). The oldest surface sediments are Seisian sandstones. The next ones above it are Campilian marly limestones in thin layers what have a rest of solution of 0,15—0,20 p/p. Limestones and dolomites are the further stages of Trias with a rest of solution of some percents only. From the middle Cretaceous age the Triassic sediments were repeatedly creased forming out the anticlin of the Jósva valley. In the North-Western side of the anticlin is the representative terrain (on the synclinary highland) where there was no transgression since the Upper Triassic age (Bidló, Maucha, 1964). The active karstification of the area is in progress with shorter pauses from the Upper Cretaceous. The area is represented on Fig. 1.

Besides many of small caves as Porlyuk (Fig. 1, No 14), Tüscöklyuk (No 16), Szarvasól (No 14), Sehova-pothole (No 35), Nagyoldali-pothole (No 28), Kuriszlán (No 18), and sinkholes the 25 km long Baradla-cave (No 10, 11, 8, 9), the 5 km long Béke-cave (No 12, 31), the 1 km long Vass Imre-cave (No 6) and Kossuth-cave (No 7) are situating here.

The area is not closed in the sense of hydrogeology. It has no natural boundaries, it is joined to its Eastern part. The infiltration area of the numerous springs can not be defined unequivocally. The greatest springs belong to caves. Two of them: Jósva

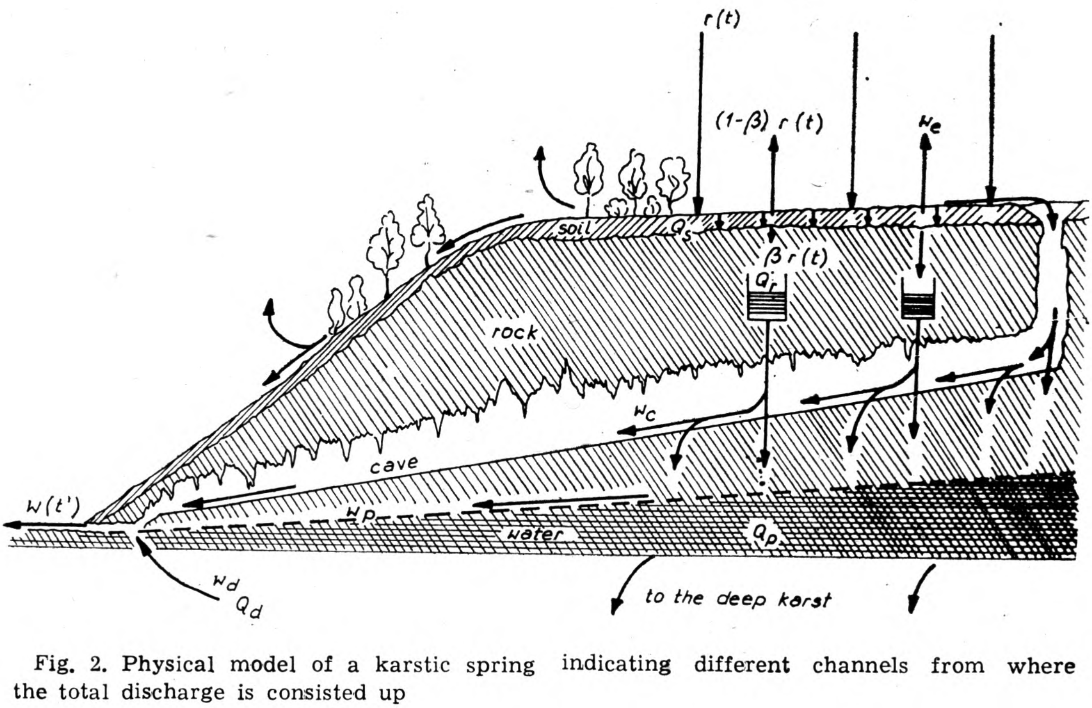

Fig. 2. Physical model of a karstic spring indicating different channels from where the total discharge is consisted up

(No 3) and Lower-cave spring (No 4) belong to the Baradla-cave. The Nagytohonya-spring (No 2) is drenaging of the Kossuth-cave, the seasonal Kistohonya-spring (No 1) was found to be connected with the Vass Imre-cave. The Komlós-spring (No 5) is the output for the waters of the Béke-cave. The Lófej-spring (No 15) must also belong to a cave but this possible cave has not been discovered at present.

Characterization of the Spring

Two of the springs have aclimatic outbursts (Nagytohonya and Lófej). The investigation of their discharge curves registrated by the VITUKI led to the theorem of the tidal effects in rocks (M a u c h a, 1968). The investigations of the discharge curves as mathematical functions using the operator technic led to the physical model of the karstic springs as represented on Fig. 2. According to this model the discharge curves can be divided into different consecutive exponential parts which belong to different stages of stored water in the aquiferous rock.

The infiltration area of the springs are situating mostly on the investigated area, but they have some small parts out of the border. The springs are mostly fed by infiltration, some of the springs: Nagytohonya, Jósva, Komlós, Kecskés-kut (No 22) etc., have well defined sink-holes. Nagytohonya have connection with the deep confined karstic area (G a d o r o s, 1971).

The discharge of the springs, Kistohonya, Nagytohonya, Komlós, Jósva and Lófej have already been registrated for many years by the Jósvafő Research Station of VITUKI. The model given in Fig. 2. makes us possible to discriminate the origin of the water coming out at different stage of the discharge process. The aim of the chemical analysis of the water at this representative area is to detect the effects of the different origin on the chemical composition of the water and to detect the dependence of the dynamics of the karstification on the moving „forces" in the karstic circulation (M a n g i n, 1976).

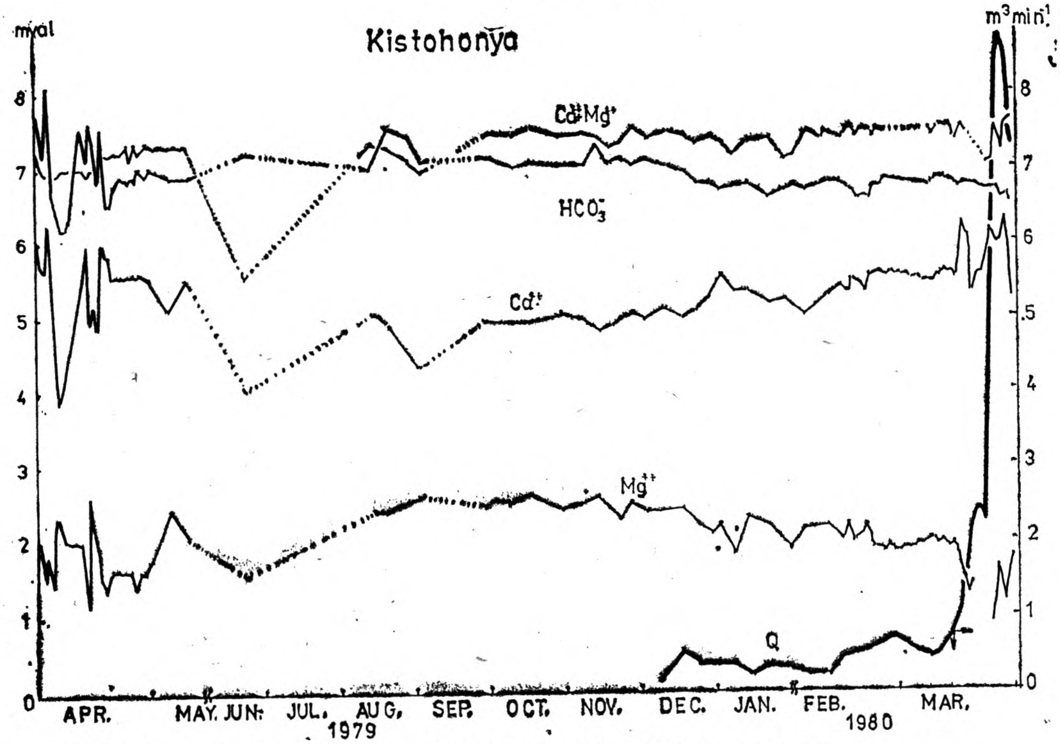

Fig. 3. Chemical composition and discharge of the Kistohonya spring

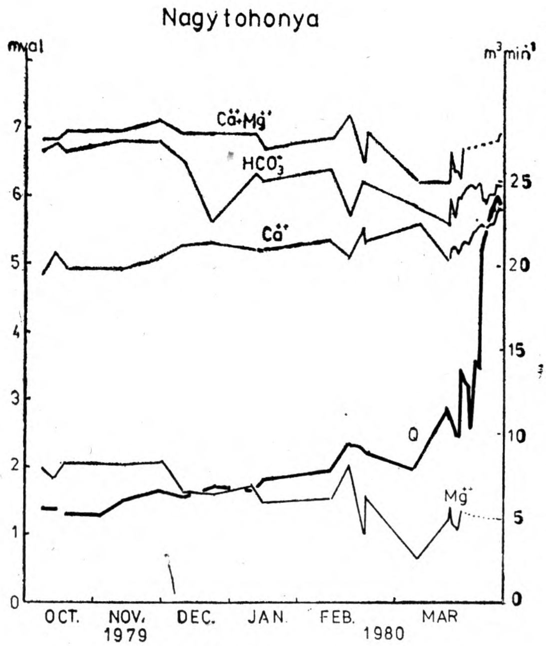

Fig. 4. Chemical composition and discharge of the Nagytohonya spring

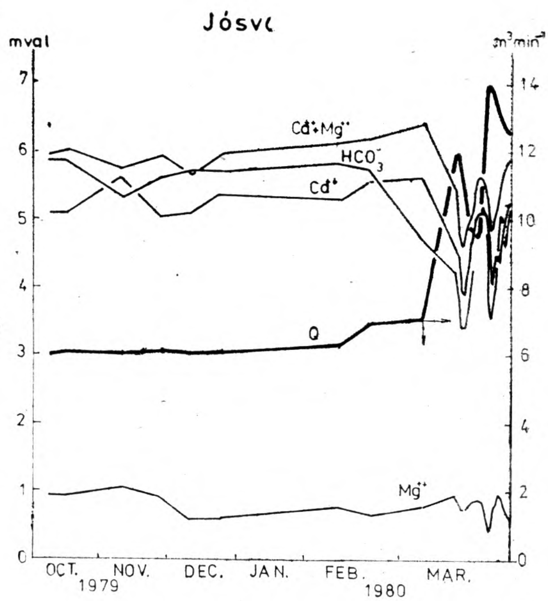

Fig. 5. Chemical composition and discharge of the Jósva spring

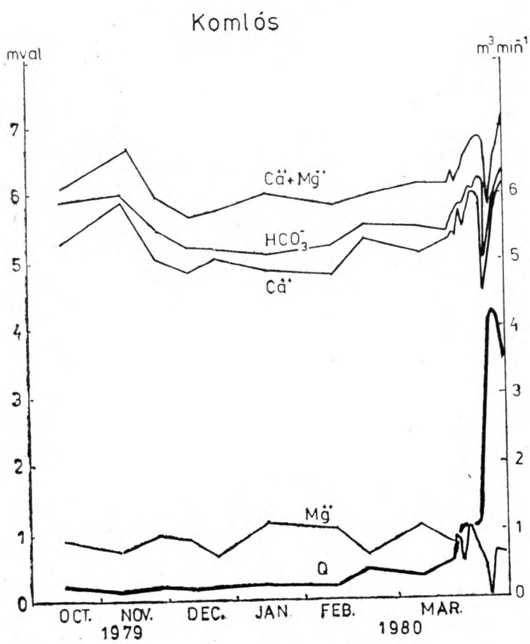

Fig. 6. Chemical composition and discharge of the Komlós spring

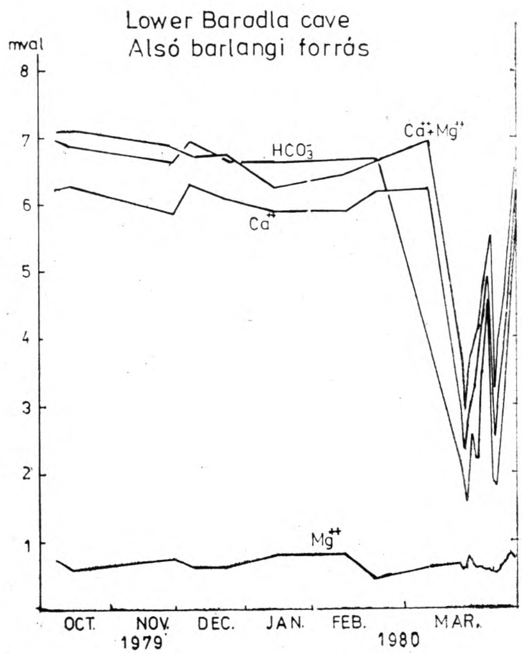

Fig. 7. Chemical composition of the Lower Baradla cave spring

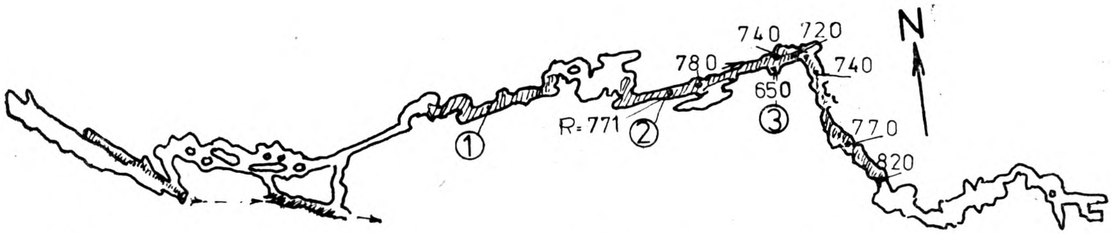

Fig. 8. Map of the Vass Imre-cave presenting the place from where samples were taken and the specific resistivity of the water of the stream

Method

The present paper is going to give some of the results obtained from the representative area in 1979—1980 years. The Ca^{++}, Mg^{++}, HCO_3^- and H^+ contents of the waters of Kistohonya, Nagytohonya, Komlós, Jósva and Lower-cave springs resp. as well as their specific resistivity, temperature were measured by the use conventional methods: taking one sample per week, and in flood periods. The composition of the waters was practically unchanged in the periodes between floods. Representative parts of the results are shown in Fig. 3—8.

Results

The two groups of springs differ from each other in their total mineralization and in their Mg^{++} content. The springs at the head of the Jósva valey have greater Mg^{++} content and lower Ca^{++} content than the springs in the Tohonya valey. All of the springs have little variations in their chemical composition in the non-floody periods, but the chemical composition varies in a great extent before and during the floods. Both of the area were covered by snow in this winter from the end of December up to the middle of February. The melting of the snow occured in two steps initiating a flood with two peaks. In general one can observe a great decrease in the mineralization some days before the floods and an increase in the falling part of them. The five springs have five different answer reactions to the change of the input. The greatest change can be observed in the Ca^{++} and HCO_3^- contents of the waters with an exception of the Kistohonya-spring, where the changes are basically slow. The two Tohonya springs have nonconstant Mg^{++} content. The decrease of the Mg^{++} in the water begins many weeks before the floods and it has a great oscillating tendency during the floods. It has to be mentioned, that the value of HCO_3^- overcomes the total concentration of the bivalent cations.

Waters of the Vass Imre-Cave

Fig. 8 shows the map of the Vass Imre-cave indicating three points from where samples were taken for chemical analyses. The results of the analyses are given in Table 1. Samples were taken also from both of the springs supposed to be belonging to the cave. The seasonal spring have a discharge varied from 0 to 15 m^3min^{-1} the unseasonal spring have a discharge varied from 0.1 to 0.5 m^3min^{-1}. Uncircled figures indicate the resistance of the water at a given time when the samples were taken (April 14, 1979). Sample 1 was taken from a syphone called Lagunás. Here the cave turns to be narrow reaching dolomite. There is a standard water level here cca 6 m above the corridor. The water does not circulate in the syphone, a thin layer of calcite covered the water surface when the sample was taken. This means, the water had to be saturated at that moment. Sample 2 was taken from the slowly flowing water of a corridor called Cidri (tremble). The water flowed in direction of a „sink hole" from where sample 3 was taken. This was a shaft from where water comes out in floods. A small streem was going from here to the direction of the cave entrance.

At the shaft two type of waters were mixed. The specific resistivity of the water indicated greater mineralization after being mixed than a continous decrease of it.

Table 1

Chemical composition of different waters of the Vass Imre cave with respect to the composition of the spring Kistohonya

Date	Source	Ca^{++} [mval]	Mg^{++} [mval]	HCO_3^- [mval]	pH	Ca^{++} $+Mg^{++}$ [mval]	t [°C]
April 11	Seasonal	5.46	2.15	7.28	7.12	7.61	9.5
	Nonseasonal	5.99	1.74	7.28	7.22	7.73	9.8
April 12	Seasonal	5.46	2.17	7.08	7.14	7.68	9.2
	Nonseasonal	5.70	2.00	7.08	7.10	7.70	9.2
April 13	Seasonal	5.46	1.90	7.04	6.63	7.36	9.4
	Nonseasonal	5.66	1.54	7.04	6.63	7.19	9.3
April 14	Seasonal	6.21	1.94	7.00	6.66	8.14	9.6
	Nonseasonal	6.30	1.79	6.92	6.63	8.10	9.4
	Lagunás 1	7.50	0.60	7.04	6.80	8.10	9.9
	Cidri 2	8.05	0.83	7.92	6.80	8.88	9.9
	Narancs 3	8.79	1.94	9.12	6.80	10.72	9.9
April 15	Seasonal	5.28	1.44	6.96	6.57	6.77	9.4
	Nonseasonal	5.50	1.70	7.11	6.70	7.20	9.3
	Lagunás 1	6.78	0.52	7.08	7.02	6.94	9.9
	Cidri 2	7.70	0.70	8.32	6.80	8.41	9.9
	Narancs 3	7.74	1.96	9.00	6.48	9.68	9.9

1 2 3 — see fig. 8.

Interpretation of Results

As the Table 1 shows, the chemical composition of the waters in different parts of the cave being not far from each other differ basically. The temperature of the waters in the cave is greater than that of the springs. The mineralization of the waters in the cave is also greater than that of the springs and is increasing in the direction of the entrance in a good accordance with the results of I. Czájlik (1961). The content of Mg^{++} in the water in the first two points is much lower than in the third one as well as in the springs. The pH value of the waters in the cave is extremaly low but decreased also in the springwater from April 11 to April 15.

The saturation index for calcite was calculated for each sample using the equation of R. J. Fagundo and J. J. Valdes (1975):

$$\log CS_C = \log [Ca^{++}] + \log [HCO_3^-] + pK_C + pH - pK_2 \quad (1)$$

Log $CS_C < 0$ was calculated for each case. Many of other data of chemical analyses obtained from samples of many different springs of this area given in Fig. 1, were then tested for saturation. Most of them were found to be also unsaturated. The samples mentioned above were analysed many days after the sample had been collected. The data given by R. Maucha (1930) resulted mostly from unsaturated waters, too. The water from sample 1 was unsaturated although it was covered by thin layer of calcite indicating a saturated or oversaturated character of the water. This is a contradiction.

Let us study eq. (1). It contains three measured data and two constants. One of the constants is independent of the place and time where it is used (pK_2) but pK_C may depend on the nature of the stone. The solubility constant of the Carrarien marble can not be used without criticism for every case. Naturally, this value determines the solubility of the calcite itself, but the rocks are not pure and precipitated calcite. Their solubility may differ from the solubility of an ideal crystalline substance. We suggest to use an individual value of pK_C what is measured for the stone of the investigated area.

The stones in our representative area contain a lot of Mg^{++} (Bidló, Maucha, 1964). We calculated, therefore, the saturation index for dolomite as well (CS_D). The results obtained here are even more irreal, since reliable pK_D data can not be found in the relevant literature. The solubility data for the dolomite are also very contradictionary. Many measurements indicate dolomite as more soluble than limestone (B a l á z s, 1965; H o d g e m a n, 1960). In contrast, there is an experience of the cavers, that a cave gets to be narrow reaching dolomite after limestone. According to the measurements of T. M á n d y (1954) carried out on different limestones and dolomites among the same conditions at 15°C, limestone gave a mineralization of 157 mg/l Ca^{++} and dolomite gave a mineralization of 132 mg/l Ca^{++} where the Mg^{++} was measured as Ca^{++}. Here $K_D \approx K_C$ can be concluded. The problem is more vivid in area where limestone containing a great portion of Mg^{++} is exsisting. This is our case. Our conclusion again is, we have to investigate the solubility of our rocks.

The work carried out recently in our representative terrain did not diminish the number of the problems to be solved, the number of the open questions were increased. We can conclude, that the waters of springs situated very near to each other may differ basically. The spring of the Lower-Baradla-cave seems to collect infiltrating waters only. This result obtained by the many year chemical analysis of the spring was recently proved by the exploatation work carried out with very great difficulties. The Jósva-spring, what is 3 m far from the previous one have more channels including the channel of the sink-holes. Different type of waters were also indicated in the Kistohonya-spring and of the Vass Imre-cave. The spring was detected as a flood spring of the sink-hole and cave Milada (Fig. 1, No 27) in Czechoslovakia. The permanent spring of this sinkhole is the Kečovo-spring (No 26) which also has a cave. The stream in the Vass Imre-cave carry infiltrating waters only. In flood periods the lower cave system, what is very narrow, is flooded hindering the flow of the infiltrating water to the lower stages of the cave. The spring shows the chemical composition of waters coming from the other area with different stones on it. The water collected in the chanels of the Vass Imre-cave comes in the spring only after running out of the flood-water. This type of model was given in Figure 2.

The second conclusion of the present paper is that the actual solubility data of the rocks in the given area must be used for the calculations of the saturation of the waters. At least, we conclude again, that chemical analyses should be carried out daily, particularly when the flood is present. The chemical composition of a karstic water did not change markedly when the springs led out infiltrated waters in the summer and autumn periods. Abroupt changes may be expected in the spring periods, when a soft water is infiltrating and being stored in the rock. More than one analyse in a day might be necessary in this periods.

References

B a l á z s D., 1965: A karsztkorrózió általános kémiai vonatkozásai (General chemical consequences of karst korrosion), Karszt és Barlang, II: 51—61, Budapest.

B a l o g h K., 1950: Az északmagyarországi trász réregtana (Stratigraphy of Nord-Hungarian Trias), Földtani Közlöny, 11—19, Budapest.

B i d l o G., M a u c h a L., 1964: A Jósvafő környéki karsztüledékek vizsgálata (Investigation on the karstic deposits in the environs of Jósvafő), ÉKME Tudományos Közleményei, 10: 71—82.

C z a j l i k I., 1961: A Vass Imre-barlang részletes hidrológiai vizsgákatának ujabb eredményei (New results of the detailed hydrological research in the Vass Imre-cave), Karszt és Barlangkutatás, III: 3—19, Budapest.

F a g u n d o R. J., V a l d e s J. J., 1975: Estudio quimica fisico del'compartimento de las aquas karsticas de la region de San Antonio de los banos (La Habana Cuba) mediante el uso de modelos matematicos, Ann. Speleol., 30: 643—653, Paris.

G a d o r o s M., 1971: A complex investigation of the Nagytohonya Spring of Jósvafő, Karszt és Barlangkutatás, VI: 79—102, Budapest.

H o d g e m a n C. D., 1960: Handbook of Chemistry and Physics, Elsevier, Cleveland.

M á n d y T., 1954: Mészkövek és dolomitok oldási vizsaálata (Investigation on solubilites of limestones and dolomites), Hidrológiai Közlöny, 34: 508—510, Budapest.

M a n g i n A., 1976: Les system karstiques et leur methodologie de l'investigation, Ann. Scien. Univ. Besancon, 25: 263—273.

M a u c h a L., 1968: Ausweise der Gezeiten--Erscheinungen des Karstwasserspiegels, Karszt és Barlangkutatás, V: 101—116, Budapest.

M a u c h a R., 1930: Az Aggteleki cseppkőbarlang vizeinek chemiai vizsgálata (Chemical analysis of waters in the Aggtelek-stalactite cave), Hidrológiai Közlöny, 10: 1—9, Budapest.

Ferenc Cser, Gábor Izápy, Lászlo Maucha

PROBLEMY CHEMIZMU WÓD W REJONIE JÓSVAFŐ (WĘGRY)

Streszczenie

W artykule przedstawiono wyniki analiz chemicznych wód i pomiarów przepływu w pięciu źródłach w rejonie Jósvafő. Skład chemiczny badanych wód okazał się praktycznie niezmienny w całym okresie pomiarowym, z wyjątkiem okresu wiosennych wezbrań, kiedy to chemizm wód z jaskini Vass Imre różnił się znacznie od chemizmu źródła Kistohonya. Wyniki zinterpretowano na podstawie matematycznego modelu źródeł krasowych. Zastosowanie równania R. J. Fagundo i J. J. Valdesa (1975) przyniosło niemożliwe do przyjęcia wskaźniki nasycenia wód; wyprowadzono stąd wniosek, że do znajomości tego wskaźnika konieczne jest poznanie współczynnika rozpuszczalności dla skał lokalnych.

Ferenc Cser, Gábor Izápy, Lászlo Maucha

PROBLÈMES DU CHIMISME DES EAUX DANS LA RÉGION DE JÓSVAFŐ (HONGRIE)

Résumé

Dans l'article sont présentés les résultats des analyses chimiques des eaux et les mesures de l'écoulement dans 5 sources dans la région de Jósvafő. La composition chimique des eaux étudiées s'est révélée pratiquement invariable, cependant le chimisme des eaux dans la grotte Vass Imre a considérablement différé de celui de la source Kistohonya. L'interprétation des résultats s'appuyait sur le modèle mathématique des sources karstiques. L'utilisation de l'équation de R. J. Fagundo et J. J. Valdes (1975) a apporté des indices de saturation d'eau impossibles à admettre. On en est arrivé à la conclusion, que pour connaitre cet indice il est nécessaire de connaitre le coefficient de solubilité pour les roches locales.

Victor Nikolayevich Dublyanskiy*

Chemical Denudation in the Karst Areas of the Ukrainian Carpathians, Crimea and the Caucasus

Abstract: The paper presents the findings of the study of the chemical denudiation degree in the areas built of the Upper Jurassic (the Ukrainian Carpathians and Crimea), and the Jurassic and Cretaceous limestones (the Causasus) — Table 2. The investigative methods were here described (Table 1). Basing on the results of the research effected in the years 1958—1979, and appling the hydrochemical method, the author obtained the values falling between 21.8—81,3 m^3/year. The lowest value reported refers to the Carpathians, and the highest one to the Akhtsu ridge in the Caucasus.

Introduction

The mountain chains of the Ukrainian Carpathians, as well as those of Crimea and Caucasus, are classified as Alpine-folded belts. According to Maksimovich's regionalization of karst in the Soviet Union (Maksimovich, 1962), the following karst areas may be distinguished: the Carpathian karst, the karst of mountainous Crimea (referred to as Crimean karst) and the karst regions of the Great Caucasus.

A typical feature of the Carpathian karst region is the development of bare mountainous karst on Upper Jurassic limestones, which form small klipp-bluffs (up to 0.5×0.2×0.1 km). This area receives yearly about 1300 mm of precipitation with an average evaporation of 500 mm. While the Crimean karst area is characterized by the development of bare and grass-covered karst, in the northern periphery there occurs covered karst on Upper Jurassic limestones. Annual precipitation measured in this region amounts to about 960 mm in the west, and 565 mm in the east, the evaporation being between 480 and 290 mm. The karst region of the Great Caucasus includes some areas which exhibit lowland, upland and mountainous karst (both covered and bare) on Jurassic and Cretaceous limestones. The annual precipitation varies from 2500 mm in the mountainous regions to 500—600 mm on the northern slopes, with an evaporation of 700 mm and 260 mm, respectively. The features of surface and underground karst are discussed in detail in the literature (Gvozdetskiy, 1954; Masimovich, 1962; Kiknadse, 1972; Dublyanskiy, 1977).

The study of chemical denudations is amongst the most efficient methods of examining karst processes (Dublyanskiy, Shutov, 1977). In that kind of investigations it is necessary to have a great number of data on the chemical denudation obtained by comparable methods.

The methods of hydrochemical investigations in karst regions were developed in the period of 1960 to 1965 at the Institute of Mineral Resources, Ministry of Geology of Ukraine (Simferopol) and published in the seventies (Shutov, Ponomarev, 1976; Dublyanskiy, 1977). The investigations were carried out in various karst areas, using different methods. The results reported by N.V. Rodionov (1949), I.G. Glukhov (1963), P.A. Kostin (1967), N.M. Yeremenko (1971), and T.Z. Kiknadse (1972) were obtained from the analysis of water mineralization and discharge of karst springs. N.I. Kochetov (1976) made

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use of the discharge modulus and of the river waters originating in, or flowing through, karst regions. D. Sh. Gabechava (1977) took into account the results obtained from analyzing the hydrographs of rivers fed by karst waters. M. Pulina (1966, 1974) and V. P. Zverev (Makarenko, Zverev, 1970) employed empirical formulae which had been derived from generalized observation data obtained in different regions.

The application of different approaches to the calculation of the chemical denudation yields different values for this same karst region.

Thus, in the Ukrainian Carpathians the annual chemical denudation values reported by F. A. Makarenko and V. P. Zverev (1970) vary from 10 do 20 m^3, whereas those published by M. Pulina (1974) fall between 30 and 40 m^3.

The chemical denudation values reported for Crimean karst vary from one investigator to another. While N. V. Rodionov (1949) gives an annual denudation value of at most 35.5 m^3, I. G. Glukhov (1963), F. A. Makarenko and V. P. Zverev (1970) say that it may be even as high as 50 m^3. In the western part, according to Glukhov (1963), chemical denudation does not exceed 22.3 m^3/year, and according to Shutov (1969) 31.6 m^3/year.

The greatest number of reports has been published on the chemical denudation in the Caucasus. After Kostin (1967) the denudation values for Pastbishchnyi, Skalistyi and Peredovoe ridges are 50.2 m^3/year, 99.7 m^3/year and 220.6 m^3/year, respectively. According to Yeremenko (1971), the chemical denudation of the Andiiskii ridge amounts to 199.5 m^3/year. These data, however, are inconsistent with those obtained by Kochetov (1976) and a number of other investigators. According to him, the degree of chemical denudation on the northern slopes of the Great Caucasus is 46 to 67 m^3/year, 124 m^3/year and 32 to 72 m^3/year in lowland, upland and high mountains, respectively. Zverev (Makarenko, Zverev, 1970) gives a denudation value of 10 to 50 m^3/year for this area. The southern slopes of Caucasus exhibit different degrees of chemical denudation which vary from 18.2 m^3/year in the basin of the Tskhenistskhali river to 148.4m^3/year in the basin of the Rechkhi river (Gabechava, 1977). The values reported by Kiknadse (1972) vary from 36 m^3/year for the Arabika massif (Black Sea slope) to 103 m^3/year (Shabashkha). The report by Pulina (1966) includes the value of 55.8 m^3/year for the litoral part of the Gagrinskii range, and the value of 137.7 m^3/year for the high-mountain part. The denudation values for upland and the high-mountain part published by N. I. Kochetov (1976) are 121 m^3/year and 68 m^3/year, respectively.

From this detailed account it can easily be seen that the problem of chemical denudation is still far from being solved univocally.

Sampling Methods and Analytical Procedures

The main objectives dealt with in classical hydrogeology are the samples of surface water from the area of feeding and the samples of spring water from the area of discharge. The hydrogeology of karst involves speleological methods in which samples are collected for atmospheric precipitation (rain and snow samples are taken at different points of the karst relief), infiltration water in grass-covered karst (with the use of a lysimeter), infiltration water in bare karst (samples are taken in solution runnels and shallow sinkholes), water of springs entering the karst relief (with sampling points at streamsinks) condensation water (samples are collected from the walls and ceilings of karst caverns with the use of a brush and a rubber bulb or by the installation of water receivers in the zone of draplet condensation), snow and ice present in the caverns (sampling is carried out along the length of the section; in this procedure it is necessary to adjust the results to he thickness and the density of particular layer), pan water (samples are taken from all of the reservoirs; consideration is given to their dimensions and origin), underground streams (downstream sampling at a distance of 20, 50 or 100 m, which depends on the aim of the investigation), karst springs (sampling is combined with discharge and temperature determinations), and waters from freatic zones (samples are collected from boreholes).

During the expedition, in areas with difficult access selected were points (caves, shafts. springs) for permanent observation which was carried out for many years' periods or for different seasons.

The methods employed in this study are conventional sampling methods (*Spravochnik...*, 1962) which have been somewhat modified to make them workable under conditions of a karst cavern. Measurements were carried out for air and water temperatures, water discharge, atmospheric pressure and CO_2 concentration in the ambient air; pH was measured in situ (with the use of a pH-meter) and so were the concentrations of labile compounds (HCO_3^-, CO_3^{2-}, and free CO_2). Chemical analyses of the water samples were usually carried out in a stationary laboratory to determine the concentrations of 8 to 12 components (Reznikov et al., 1963). The number of samples has never been less than 10, so as to provide sufficient data for statistical calculations.

Methods of Interpretation

The results of chemical analyses were converted into gram-equivalents and percentage of gram-equivalents, and then the total mineralization (sum of all ions minus 0.5 HCO_3^-) was calculated. The equilibrium of the sums of anions and cations was taken as a measure of analytical accuracy (with a 3-percent error). The results of analyses were shown in triangular and square diagrams (Durov 1961). Using Kurnakov's rule, the volumes of water of different origin at the discharge point, were calculated. The data obtained form chemical analyses were subject to statistical processing (cf. Komarov, 1972).

Individual situations (variations in the chemical composition of the water along the stream, wariation in the chemical composition of water with time at a given point) were analyzed in terms of the Brodsky diagram together with karstological and geological profiles. To establish the metamorphism of karst waters and the degree of saturation with calcium carbonate, the Tillmans-Trombe diagram was used (cf. Roques, 1967; Pulina, 1974).

Table 1

Formulae for the Calculation of Karst Denudation, K (m^3/year)

Reference	Formula	K
Kruber, 1915	$\Theta = DQ$	(30)
Rodionov, 1949	$U = \frac{V}{V_1} \times 100 \times 1000$	(30)
Corbel, 1959	$K = \frac{4ED}{100}$	32.0
Williams, 1963	$K = \frac{E(D_{Ca}+D_{Mg})}{10 \times 2.7}$	33.2
Groom, Williams, 1965	$K = \frac{\Theta}{d S \times 10^6}$	29.6
Pulina, 1966, 1974	$K = 0{,}0126\, \Delta M\, q$	31.6
Gams, 1968	$K = q\, m\, \frac{(6.6_{Na}+4.7_{Mg})\, 31.5}{10^4}$	31.0
Habič, 1968	$K = \frac{4q\, D\, 31.5}{10^4}$	32.1
Chikishev, 1973	$I = \frac{1000\, V}{S_1}$	(3.0)
Chikishev, 1973	$I = 0.0000126 q\, D$	(32.0)
Chikishev, 1973	$K = 0.0126 q\, D$	32.0
Kiknadse, 1977	$K = 0.63 q\, \Delta M$	31.0
Marinin, Abyshev, 1977	$K = 0.255\, M\, q\, m$	33.5
Gabechava, 1977	$K = 0.011\, q\, \Delta M$	27.3

Θ = annual discharge of $CaCO_3$, kg/year; I = rate of karstification, porcent/1000 years, in brackets: m^3/year; K = karst denudation, m^3 km^2/year; D = concentration of $CaCO_3$ in the water, 170 mg/l; M = mineralization of springs, 210.0 mg/l; M_1 = mineralization of precipitation, 43.0 mg/l; ΔM = defference in total mineralization between the investigated water and precipitation 167.0 mg/l; Ca, Mg = hardness, 9.36 + 0.78°; Q = discharge of water, 150 l/s; q = modulus of discharge, 15.0 l/s × km^2; X = quantity of precipitation, 800 mm; Z = evaporation, 330 mm; E = runoff (X—Z), 470 mm; S = catchment area, 10 km^2; S_1 = karst area, 10 km^2; V = volume of leached rocks, km^3; V_1 = volume of karst massif, 1.7 km^3; m = coefficient describing the degree of karstification; d = density of limestone, 2.7 t/m^3.

Methods of Calculating the Chemical Denudation Value

Many formulae are available for calculating the chemical denudation of karst. Most of them are known by the name of their authors. As these formulae involve a variety of symbols and units, their unification has become really urgent. Some of the formulae in question were verified during our study of the karst region of the Krasnaya Cave (Dublyanskiy, 1977), and the results are summarized in Table 1.

The first Russian investigator who analyzed (and calculated) the occurrence (and quantity) of $CaCO_3$ outside the borders of the karst massif was A. A. Kruber (1915). His calculations were based on the theory of ionic runoff (which is well known in hydrogeology) and yielded an annual value of 0.9×10^9 kg, corresponding with the layer of dissolved rock in the area of the investigated basin, which is 30 m^3/year. Later, N. V. Rodionov (1949) published a formula for calculating the rate of karstification (percent/1000 years). Thus, a rate of 0.017 percent/1000 years corresponds with an annual dissolved-rock layer of 30 m^3. In 1959, J. Corbel derived his climatic formulae, and four years later P. S. Williams suggested that the concentrations of Ca^{2+} and Mg^{2+} in the water should be considered separately. A calculation formula which incorporates the quantity of $CaCO_3$ carried by the stream during 12 months in a given area was proposed by G. Groom and P. S. Williams in 1965. I. Gams (1968) derived an exprsesion including water hardness (in German degrees) and modulus of discharge, whereas P. Habič (1968) employed a formula which involves the modulus of discharge, as well as the quantity of $CaCO_3$ carried by the stream.

As shown by Table 1, all of the formulae listed there give similar results. It should, however, be noted that in all of them the assumption has been made that it is only the carbonate component which leaves the mountain massif; Cl, SO_4 and Na ions being neglected. Neglected are also the mineral components of precipitation water. These disadvantages were eliminated by M. Pulina (1966, 1974) who presented a formula and a nomograph which incorporate the mineralization of both the springs and the precipitation water.

A. Chikishev (1973) proposed three modifications to Rodionov's and Pulina's formulae by including (in Rodionov's expression) the coefficient 0.1 which should, in the opinion of the author of this paper, provide a comparability of the data obtained for mountain massifs with various thicknesses of karst rocks. In fact, he has only decreased the calculated value of chemical denudation by a factor of 10. T. Z. Kiknadse (1972) suggested to make a distinction between the denudation of surface karst and that of underground karst. Such a distinction requires knowledge of the underground catchment area. P. M. Marinin and M. N. Abyshev (1977) modified this expression by introducing the parameter of carbonate hardness (in German degrees). D. S. Gabechava (1977) postulated that the chemical denudation of karst be measured in terms of HCO_3^- concentration, and not in terms of the concentration of Ca^{2+} and Mg^{2+}, as it had been practiced so far. This postulate is substantiated by the fact that, with the accumulation of Na^+ ions in a given complex of rocks, some of the Ca^{2+} ions participate in the reaction of exchange. However, Gabechava did not take into account that the reaction

$$H_2O + CO_2 = H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

yields excess HCO_3^- ions which are not equivalent to the quantity of dissolved calcite. This problem was considered for the karst waters of Poland by M. Markowicz-Łohinowicz (1972). In mountainous Crimea and Caucasus, 60 percent of events exhibit a carbonate hardness which is higher than total hardness. In such cases we take into account total hardness (*Spravochnik...*, 1962). Gabechava's formula differs from the above expression in that it includes the values of the weight-by-volume of calcite and dolomite.

All the expressions for the calculation of the chemical denudation value, which have been discussed in this Section, seem to be derived from the well known formula of ionic runoff. In what these expressions differ from one another, is the number of terms included in them, so they yield almost identical results (yearly average of 31.2 m^3, $\sigma = \pm 1.7$, $Cv = 0.05$). Assuming that the calculations of total mineralization (including precipitation waters) are correct, it is convenient to use the expression proposed by M. Pulina (1966, 1974):

$$K = 0.0126\, \Delta M\, q,$$

in which the modulus of discharge should be determined from balance investigations, and the degree of mineralization should be calculated statistically, on the basis of long-term field or stationary observations.

In the period of 1958 to 1979 hydrochemical investigations were carried out in the karst region of the Carpathians, Crimea, Western Caucasus and Abkhasia by a special karst expedition. The investigations were sponsored by the Ukrainian Academy of Sciences, the Institute of Mineral Resources of the Ukrainian Ministry of Geology, and the University of Simferopol. About 2500 water samples were collected and analyzed (of them 1342 were used for calculating the value of chemical denudation; Table 2). Moduli of discharge were determined from the results of 20-year balance investigations for mountainous Crimea (Glukhov, 1963; Pribluda et al., 1977), and on the basis of preliminary calculations of the water balance for other regions (while precipitation and discharge were determined from long-term observations, evaporation was calculated with the use of empirical formulae, Table 2).

The results listed in Table 2 are in good agreement. The value of chemical denudation increases as a function of the modulus of discharge and the altitude of the mountain massif (Ai-Petrinskij and Dolgorukovskij massifs, Alek-Akhtsu). The denudation value is also influenced by the conditions under which karst was developing, as well as by the type and character of the karst rock. E.g., the chemical denudation values for Crimea and the northern slope of Central Caucasus in the vicinity of Mineralnye Vody (28.8 and 24.7, respectively) seem to be an indication that the evolution of karst in both areas proceeded under similar conditions. In fact, this was not so. In Crimea, in the region of bare karst, the mineralization of underground water is not very high (210 to 270 mg/l), which may be an evidence of the great karstification potential in this area. In the region of Mineralnye Vody, under conditions of grass-covered karst occurrence, underground waters show increased mineralization levels (up to 390 mg/l), approaching the state of saturation. Thus, the similarity of the chemical denudation values for the massifs of Alek, Akhtsu and Gumishkhinskij cannot be considered as indicating that the karstification process has developed with a similar intensity. As will

Table 2

Calculation of chemical denudation (K) for some karst areas in the South of the Soviet Union with formula $K = 0.0126\, \Delta M \cdot q$ (Pulina, 1974)*

Karst area, Mountain massif	Number of analyses	Mineralization of water [mg/1]		ΔM	Modulus of discharge [l/s q km^2]	K [m^3/year]
		springs	precipitation			
Carpathians	48	198.0	32.0	166.0	10.4	21.8
Mountainous Crimea	470	270.6	38.0	232.0	9.8	28.8
Ai-Petri	260	233.0	33.0	200.0	24.9	62.8
Dolgorukovskii	126	210.0	43.0	167.0	15.0	31.6
North Caucasus	92	390.0	12.7	377.3	5.2	24.7
Abkhasia						
Alek	83	140.0	34.0	106.0	59.7	79.7
Akhtsu	133	140.0	35.9	104.1	62.0	81.3
Gumishkhinskii	150	556.0	35.5	520.5	11.9	78.0

* There are three different methods of formulating the degree of chemical denudation. m^3/km^2 year; mm/1000 year, and m^3/year, of which the latter seems to be the most convenient for our purpose.

be shown later, the karst of the Gumishkhinskij massif is influenced by cold and thermal waters.

In this way, making use of the chemical denudation which is an essential feature of a karst region, we lose an important part of information. To bridge this gap, we have to look for another tool, the differential analysis of hydrochemical data.

Metamorphosis of Karst Water

Based on the available data, the metamorphosis problem will be discussed for five karst regions. In the Ukrainian Carpathians the origin of karst waters is influenced by the infiltration of precipitation water. The centres of the geochemical fields of infiltration waters, waters of underground streams and springs are placed 'perpendicular' to the direction of the pH versus $CaCO_3$ concentration equilibrium curves of the Tillmans--Trombe diagram (Pulina, 1974). This is the simplest example of metamorphism without any secondary influence. All of the samples are placed in the zone of unsaturated waters. Even waters of karst springs preserve their aggressiveness at the points of discharge.

In mountainous Crimea the origin of karst waters is also influenced by atmospheric precipitation, and this influence is predominant. In those regions where covered karst developes, karst waters are transformed by mountainous meadow soils; they mix with water from snow and ice melting in karst caverns and with condensation water. Waters from catchment areas built of non-karstified (or poorly karstified) rocks exhibit increased mineralization levels. These waters mix with one another in various proportions to form an underground catchment area, and they appear on the ground surface in the form of springs. Almost all of the karst springs occurring in mountainous Crimea are characterized by a very high aggressiveness. The expansion of the geochemical area covered by spring waters substantiates the necessity of separate investigations. It was J. I. Shutov (1969) who studied this problem in detail. The centres of the geochemical areas of various karst water types occurring in Crimea lie on the broken line which intercepts the equilibrium curve at an angle of 50°.

Karst waters in the Alek and Akhtsu massifs originate under complicated conditions. While in the areas with bare and grass-covered karst their origin is influenced by precipitation water, in beech forests and brown forest soils karst waters undergo considerable transformations. In either of the two cases, pH decreases to a level of 0.2 to 0.5, thus contributing to an increase in aggressiveness. In areas built of clayey and sandy rocks of the Palaeogene age, underground streams are fed with strongly mineralized water (with mineralization levels ranging from 160 to 180 mg/l). They mix with condensation waters to give origin to cave waters which appear on the ground surface in the form of large springs. The mineralization of runnels is an important factor which indicates that corrosive processes are particularly pronounced in the upper part of the aeration zone and that the mineralization of waters in the underground catchment area is increased. In low-water periods, only those waters approach the state of saturation. The remaining types of karst waters belonging to the Alek and Akhtsu massifs are unsaturated. The centres of the geochemical fields tend to the straight line which intercepts the equilibrium curve at an angle of 70°.

In Caucasus, in the feeding area in the vicinity of Mineralnye Vody (Skalistyj and Postbishchnyj ridges), Jurassic and Cretaceous karstified rocks have formed a flat monocline. While the origin of the Upper Cretaceous waters is primarily influenced by precipitation, the origin of waters in Valanginian rocks should be attributed both to atmospheric precipitation and to the partial inflow of infiltration water from the non-karstified rocks of the Hauterivan-Albian age. The waters of Tithonian carbonate deposits are predominantly generated by precipitation, whereas those of the sulphate deposits originate due to the inflow from the Lower Cretaceous deposit series. In the case of grass-covered karst and a flat monoclinal structure of the karst rocks in the upper part of the aeration zone, underground waters are promptly saturated (in

Upper Cretaceous deposits) and even supersaturated (in Lower Cretaceous and Upper Jurassic deposits). That is why the mineralization values calculated for the waters of this region are very high, and the deposition of calcareous tufa near the karst springs is very frequent. The centres of the geochemical fields tend to the broken line, which intercepts the equilibrium curve at an angle of 50°.

In the Gumishkhinskij massif, the feed of karst waters which occur in the form of springs in the Maanikavara Valley (in the vicinity of the famous Novoafonskaya Cave) is affected by a number of factors. Some part of the outflow water originates from atmospheric precipitation both in the nearer (adjacent to the cave) and in the farther (in the Bzybskij ridge) feeding areas. In the Apsta, Tskvara, Msra and Maanikvara valleys a sinking of the surface flow is being observed, especially in its upper and lower flowage. Infiltration and condensation waters, as well as influent streams, mix with each other in different proportions to generate karst-cave water which leaves the underground area in the form of springs. Owing to the sinking process in the upstream section of the river, precipitation and infiltration waters alone are not saturated with calcium carbonate. Influent streams which originate due to the sinking process in the downstream part of the river valleys at a regiona fault, are supersaturated, whereas cave waters and karst springs represent the geochemical fields, in which occur both saturated and unsaturated waters. The centres of the geochemical fields are on the broken line which intercepts the equilibrium curve at an angle of 70°. The position of the karst spring waters outside the metagenesis line is an indication that their origin is influenced not only by the waters of the upper part of the aeration zone, but also by some other types of water. Thus, examining the position of the hydrochemical fields formed by various types of karst water enables a better understanding of the mechanism which governs the origin of underground waters in this region and permits prediction of their features. For the majority of karst areas belonging to the Alpine belt in the South of the Soviet Union, the process of calcium-carbonate saturation does not take the form of straight-line perpendicular equilibrium curves (cf. Pulina, 1974); it follows a highly complicated behavioral pattern (cf. Roques, 1967).

Downstream Changes in the Mineralization of Karst Waters

A synchronous collection of water samples in karst caves at various depths from the entrance makes it possible to assess the changes in the chemical composition of karst water inside the mountain massifs. The most intensive investigations were carried out in the Krasnaya Cave (Dublyanskiy et al., 1967) and in the Alek massif (Dublyanskiy, Brel, 1977).

The investigations of the Krasnaya Cave have revealed variations in the mineralization levels at a downstream distance of 4 km. Under low water conditions, the Krasnopeshchernaya underground river receives predominantly infiltration water feed. Mineralization behaves in the following manner: while at a distace of the first 400 meters there is an increase up to a level of 340 mg/l, the value measured at a distance of 4.5 km approaches 290 mg/l. This tendency to decrease persists, until the water leaves the underground area. However, there are four sections associated with the zones of the fault, in which the increase of water mineralization becomes very rapid (about 20 to 40 mg/l). After reaching a maximum value (for underground water) at a distance of 100 m from the ground surface, the degree of mineralization at the discharge point amounts to only 79 percent. A similar behaviour has been observed in some other water caves of Crimea (e.g., Eni-Sala-Sh, Jour-Jour, Zheltaya and Uzuniya).

A statistical interpretation of data obtained from chemical analyses of karst water samples collected at the depth of 0 to 100 m; 100 to 400 m, and 400 to 500 m from the ground surface made it possible to calculate the gradients of vertical leaching. In the upper part of the zone of epihydrogenesis (Maksimovich, 1964) the gradient of vertical leaching is 167 mg/l $\times$ 100 m, whereas that in the lower part equals 60 mg/l × 100 m. In the zone of hydrogenesis this gradient amounts to 18 mg/l × 100 m. It has often been observed that, under conditions of low water, carbonate depositions with gradients between −0.11 and −14.5 mg/l × 100 m are formed in the zone of hydrogenesis. Investigations conducted for the region of the Krasnaya Cave show the following percentage of leaching cavities which have formed in individual zones: 57% and 10% in the upper part and lower part of the epihydrogenesis zone, respectively, and 33% in the hydrogenesis zone. It is worth noting that 88 percent of these cavities appear in the period of flood, and only 12 percent under low water conditions (Dublyanskiy, 1977).

The karst streams of the Alek massif are formed by the confluence of waters from individual karst cavities belonging to one water-bearing system. They are predominantly fed with influent water from the area of non-karstified rocks of the Palaeogene age. The gradient of vertical leaching in the zone of epihydrogenesis varies from 25 to 34 mg/l × 100 m and from 12 to 17 mg/l × 100 m in the upper part and lower part, respectively. In the zone of hydrogenesis, the gradient ranges between +2 to −8 mg/l × 100 m and −5 to −45 mg/l × 100 m. The gradient of horizontal leaching in karst water-bearing systems is (on the average) 10 mg/l × 100 m and 0.2 mg/l × 100 m of passage length for the upper and lower part, respectively (Dublyanskiy, Brel, 1977).

In the region of the Novoafonskaya Cave, karst water streams are formed due to the feeding with infiltration waters and influent streams from farther and nearer areas. In the farther area of feeding, the mineralization of karst waters shows the following pattern of behaviour: it increases rapidly with a gradient of 80 to 100 mg/l × 100 m and then decreases to a level which accounts for some 40 percent of the initial value; at the point of discharge there is again a rapid increase in mineralization (up to 214 percent), and a transition from hydrocarbonate-calcium to hydrocarbonate-chloride calcium-natrium type of water. Based on these data, the hypothesis is put forward that the mineral subthermal waters of a chloride-natrium composition have a significant contribution to the genesis of karst waters in the Novoafonskaya Cave (Dublynskiy, 1977). To support this hypothesis, the results of hydrochemical investigations were interpreted with the use of the Durov diagram. As shown by this diagram, karst springs are situated on the straight line for the mixing of karst water streams with mineral waters. The proportion varies from 26 : 1 in March during snow melting to 5 :1 in November when low water conditions occur. In this way, analysis of the seasonal downstream variations in the degree of mineralization of karst waters not only gives valuable data on the occurrence of corrosive processes in given time and space, but also facilitates estimating the genesis of karst waters.

Differential Analysis of Chemical Denudation

The results obtained by the author of this report during his investigations of the hydrogeological and hydrochemical regimes in Crimea (Krasnaya Cave region), in Western Caucasus (Khostinskij rising spring, at the toe of the Akhtsu massif) and in the Gumishkhinskij massif (rising spring of the Maanikvara river at the Novoafonskaya Cave), enabled a scheme to be established for the calculation of chemical denudation. The calculation diagram is based on the observations of the regimes in given units of time (week, decade, fortnight) and includes information about the precipitation received, about evaporation (the differentiation of these parameters gives the value of discharge in the given karst massif), air temperature (which is necessary for distinguishing the types of feeding), discharge of the karst spring, and mineralization of the karst spring water. The diagram is consistent with the formula for ionic runoff and takes the form:

$$R_u = Q\,M\,a,$$

where R_u denotes ionic runoff, g/s; Q is discharge, m³/s; M indicates mineralization, mg/l, and a is a dimensional coefficient (product of Q and M of the two diagrams presented earlier).

The diagram of ionic runoff provides information on how the intensity of the chemical denudation process varies with time. Taking into account the method of feeding the underground waters of the Krasnaya Cave region, we may distinguish four characteristic periods: (1) consumption of reserves accumulated during autumn floods (December to February, duration of 62 days); (2) spring snow melting (February to March, duration of 44 days); (3) feeding by infiltration water and influent streams (March to April and October to February, duration of 91 days), and (4) feeding by condensation--infiltration (duration of 168 days).

In 1972, the ionic runoff of the Krasnopeshchernaya river (including salt deposition due to precipitation) amounted to 26 g/day. Taking into consideration the density of limestone, 2.7 t/m^3, gives 304 m^3/year. While 73 percent of the ionic runoff takes place in the cold season (from October to March), the remainder occurs in the hot period. Karst processes were found to be the most intensive in the periods of snow and rain floods (28 percent of the annual leaching of carbonate takes place during 40 days) and autumn rainfall (32 percent of the annual leaching occurs during 60 days). As the ionic runoff follows a seasonal pattern, the values of karst denudation obtained from field observations may differ significantly (by some 200 to 250 percent). It is therefore necessary to make careful comparative analyses of published data. The differences between chemical denudation values calculated from the data of long-term observations of the regime (30.3 m^3/year) and those calculated from long-term field observations (31.6 m^3/ /year; Table 2) amount to 4.2 percent.

Routine analyses of the ionic runoff diagram may also be useful in the investigations of other regions. In the case of grass--covered and sediment-covered karst of the Alek massif it would be interesting to separate from the ionic runoff some other components of various origin.

The atmospheric component is easy to calculate by multiplying the annual amount of precipitation (2396 mm) by its mineralization (34 mg/l) and the catchment area which consists of limestones (6.1 km^2). The influent-stream component can be determined by multiplying the annual amount of effective precipitation (precipitation minus evaporation, 1823 mm) by the mineralization of influent streams and atomspheric waters (143.8 mg/l) and by the catchment area which does not contain karst rocks (5.7 km^2). The total ionic runoff may likewise be calculated as a product of the discharge from the Alek massif (1885 m), of the average mineralization of spring waters (140.0 mg/l) and the overall area of the massif (11.8 km^2). The total ionic runoff from the Alek massif amounts to 3108 tons per year. Of this amount, precipitation accounts for 64.2 percent (496.4 t/year) and influent water for 48.2 percent (1495.5 t/year). Thus, the contribution of karst to the total ionic runoff is 35.8 percent (1116.1 t/year), the value of karst denudation being 35 m^3/year (and not 79.7 m^3/year, as shown by Table 2). Based on the available values of condensation discharge (62 mm) and mineralization of condensation water (108.3 mg/l), we may estimate the influence of chemical denudation as a contributing factor. In the warm season, 41.2 tons of karst rocks (15.2 m^3) are lost for the Alek massif as a result of condensational corrosion. This accounts for 3.7 percent of the total karst corrosion. Thus, the role of condensational corrosion is of less importance.

The ionic runoff from the Gumishkhinskij massif amounts to 795 g/s, which gives a chemical denudation value of 78 m^3/year (Table 2). However, in the lower part of karst discharge it is only 45 percent of that value, i.e. 35.1 m^3/year. Most of the mineral matter present there is due to the subthermal component of the underground flow.

In this way, the differential approach to the problem of chemical denudation permits important conclusions to be drawn as to the origin of karst waters in this region and the seasonal changes in the mineralization level. As yet, there is no possibility to perform calculations for other parts of the Alpine belt in the South of the Soviet Union. To overcome this difficulty, stationary hydrogeological investigations are needed.

References

Corbel, J., 1959: Erosion en terrain calcaire. Ann. de Geogr., **68**.

Chikishev, A. G. 1973: Metody izučenija karsta. Moskva.

Dublyanskiy, V. N., 1977: Karstovye peščery i šachty Gornogo Kryma. Leningrad.

Dublanskiy, V. N., Shutov, U. J., 1977: Osnovnyje problemy gidrochimii karbonatnogo karsta. Zemlevedenie, 12. Moskva.

Dublyanskiy, V. N., Shutov, U. J., Voznesenskaya, I. E., 1967: Uslovija formirovanija chimičeskogo sostava podzemnych vod v karbonatnych massivach. Dokl. Akad. Nauk SSSR, **175**, 4.

Dublyanskiy, V. N., Brel, T. M., 1977: Gidrochimija karstovogo massiva Alek, (in): Geochimija landšaftov i podzemnych vod. Krasnodar.

Durov, S. A. 1961: Sintez v gidrochimii. Rostov n. Donou.

Gabechava, D. S., 1977: K metodike ocenki chimičeskoj denudacii, (in:) Meroprijatija po povyšeniju ustojčivosti zemljanogo polotna v karstovych rajonach BAM. Krasnojarsk.

Gams, I., 1968: Some measurement of corrosion intensity in the Dinaric karst and their significance for karst geomorphology. Beograd.

Glukhov, I. G., 1963: O chimičeskom sostave podzemnych vod gornogo Kryma, (in:) Vaprosy formirovanija chimičeskogo sostava podzemnych vod. Moskva.

Gvozdetskiy, N. A., 1954: Karst. Moskva.

Groom, J. E., 1965: The solution of limestone in South Wales. Geogr. Jou., **131, 1**.

Habič, F., 1968: Kraški svet med Idrijco in Vipavo. SAZU, **21, 11**.

Kiknadse, T. Z., 1972: Karst massiva Arabika. Tbilisi.

Kochetov, N. I., 1976: Količestvennaja ocenka chimičeskoj denudacii na Zapadnom Kavkaze po gidrochimičeskim dannym. Geomorfologija, **3**.

Komarov, I. S., 1972: Nakoplenie i obrabotka informacii pri inženerno-geologičeskich issledovanijach. Moskva.

Kostin, P. A., 1967: Opyt primenenija količestvennogo metoda k izučeniju gornogo karsta. Vest. MGU, Geografija, **3**.

Kruber, A. A., 1915: Karstovaja oblast' gornogo Kryma. Moskva.

Makarenko, F. A., Zverev, V. P., 1970: O podzemnoj chimičeskoj denudacii na territorii SSSR. Dokl. AN SSSR, **192**, 2.

Markowicz-Łohinowicz, M., 1972: Próba przedstawienia składu chemicznego wód krasowych. Speleologia, **7**, 1—2. Warszawa.

Maksimovich, G. A., 1962: Tektoničeskie zakonomernosti raspredelenija karsta na territorii SSSR. Moskva.

Maksimovich, G. A., 1964: Gidrogeochimičeskie zony platform, Chimičeskaja geografija i gidrochimija, **3**(**4**). Perm.

Marinin, P. M., Abyshev, M. N., 1976: Izmienenie formuly rasčeta karstovoj denudacii, (in:) Voprosy ochrany prirody Gornogo Altaja. Gorno-Altajsk.

Pribluda, V. D., et al.: 1979: Balans podzemnych vod jugo-zapadnoj časti Gornogo Kryma. Geologičeskij Žurnal, **39**, 2.

Pulina M., 1966: Zjawiska krasowe Zachodniego Kaukazu. Czasopismo Geograficzne, **37**, 4. Wrocław.

Pulina M., 1974: Denudacja chemiczna na obszarach krasu węglanowego. Prace Geograficzne, **105**. Warszawa.

Reznikov, A. A., et al.: 1963: Metody analiza prirodnych wod. Moskva.

Rodionov, N. V., 1949: Nekotoryje dannye o skorosti rozvitija karsta v karbonatnych porodach. Trudy Laborat. Gidrogeol. Problem., **6**.

Roques, H., 1967: Chemie des carbonates et hydrogéologie karstique. Mém. et doc. CNRS, **4**.

Shutov ,J. I., 1969: Metodika rasčeta pokazatelja aktivnosti karstovogo processa. Gidrogeologia i inžiner. geolog., **6**.

Shutov, J. I., Ponomarev, E. A., 1976: Metodičeskie rekomendacii po gidrochimičeskomu izučeniju karstovych vod. Simferopol.

Spravochnik gidrogeologa, 1962. Gosgeoltechizdat. Moskva.

Williams, P. S., 1963: An initial estimate of the speed of limestone solution in Country Clare. Irish Geogr., **4**.

Yeremenko, N. M., 1971: Karst vostočnoj poloviny severnogo sklona Bolšogo Kavkaza. Manuscript of doctor. dis., Moskva.

Victor Nikolayevich Dublyanskiy

DENUDACJA CHEMICZNA W REJONACH KRASOWYCH UKRAIŃSKICH KARPAT, KRYMU I KAUKAZU

Streszczenie

W artykule przedstawiono wyniki badań nad rozmiarami denudacji chemicznej w obszarach zbudowanych z wapieni górnej jury (Karpaty ukraińskie i Krym) oraz jury i kredy (Wielki Kaukaz) — tab. 2. Dokonano przeglądu metod badawczych (tab. 1). Na podstawie badań terenowych przeprowadzonych w latach 1958—1979, posługując się metodą hydrochemiczną, uzyskano wyniki mieszczące się w przedziale 21,8—81,3 m^3/rok; najniższą wartość uzyskano w odniesieniu do Karpat, a najwyższą dla grzbietu Akhtsu w SW Kaukazie.

Victor Nikolayevich Dublyanskiy

DÉNUDATION CHIMIQUE DANS LES RÉGIONS KARSTIQUES DES CARPATES UKRAINIENNES, DE LA CRIMÉE ET DU CAUCASE

Résumé

Dans l'article ont été présentés les résultats des recherches sur l'étendue de la dénudation chimique dans les régions formées de calcaire du Jurassique supérieur (Carpates Ukrainiennes et Crimée), du Jurassique et du Crétacé (Grand Caucase) — Tab. 2. On a fait la revue des méthodes de recherches (Tab. 1). A l'aide des recherches sur le terrain, menées dans les années 1958—1979 et utilisant la méthode hydrochimique, ont été obtenus les résultats se placant dans l'intervalle de 21,8—81,3 m^3/an, où la valeur la plus petite a été obtenue dans les Carpates, et la plus grande pour la crête de Akhtsu dans le Caucase.

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Study of the Karst at the Alcorlo Dam (Spain)

Abstract: This report is a summary of the studies carried out by the Group of Scientific Speleology of the Royal Spanish Society of Natural History, in order to determine the permeability conditions of the karst discovered in the dam-site. The studies began in August 1977, the date in which the building work was at its final phase and primarily oriented to solve the problems created by a series of caverns appeared in the dam-site, on the right bank and below the maximum water level.

Regional Geology

Geologically speaking we face an area which does not represent severe difficulties, except but the inherent ones to karst.

The dam site is located in a narrow valley excavated by the river Bornoba in a monoclinal Cretaceous series of calcareous composition basically, which the river cuts ortogonally leaning on both banks at the front of the slope of these series.

This slope leans discordantly on a Paleozoic mass composed of shales and micaschists, which is limited at the top by paleogenous red clays used to build the impermeable nucleus of the dam:

— The impermeble foundation, formed by a series of kaoliniferous sands in facies Utrillas from the Superior- Medium Cretaceous.
— An inferior litted series with alternative levels of marls and dolomitic limestone in which some caverns are located, with a tendency to remain covered by landslides, and in some cases the only evidence we can get of their existence is the drop of the drill pipes during the survey bore-holes.
— A thick series of dolomitic Touronian limestones on which slopes there appear numerous pipes.
— An upper series formed by litted dolomitic limestones with a higher density of caverns in which the most important pipes system is located.

The ensemble is folded structurally speaking, dipping monoclinally southwards and cut by the Bornoba river which crosses the bundle in N-S direction giving place to an excellent dam-site as far as the topographical conditions are concerned.

Concrete Problems found in the Karst

They are focussed on the following aspects:

— Appearence of several caves in the dam-site area, at dolomitic marly-calcareous level, below the point of maximum water level.
— Existence of other caverns noticed during the survey holes.
— Presence of fillings of karstic origin at different points within the area.
— An even more developed system of caves located down stream in the same narrow valley used for the dam-site.

In general terms, we find a system of karstic pipes generated under hydraulic gradient, in conditions of freatic or semiconfined aquiferous, and whose recognition has been made difficult due to the presence of numerous clay seals which block the karstic system.

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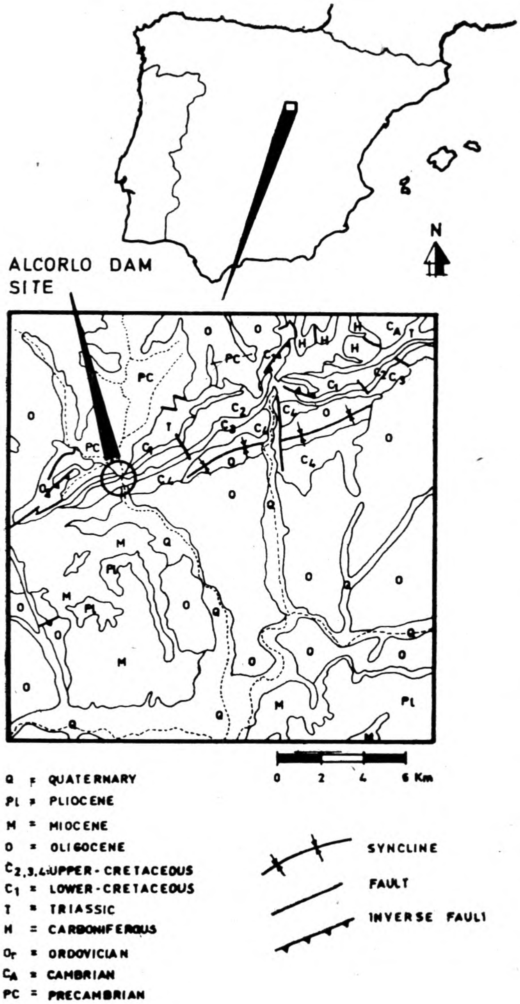

Fig. 1. Geological location of the Alcorlo dam surroundings

There is always the possibility of the extrusion of those fillings in case they are under the increasing hydraulic gradient, with the subsequent permeability problems derived in the reservoir.

Basic Criteria Followed in the Study of the Karst

The carbonatic monoclinal series represent a basin shore, of E—W direction, on which a karst has settled.

Our experience shows that in this type of karst there is a general tendency to develop at the basin shore following parallel directions, this tendency being associated in a lower degree to the trend of the layers. A greater development in the E—W direction is expected.

This tendency has been perfectly checked in the case of the dam in Patón de Oliva — Patones (Madrid), on which right bank there is a karst with more than 8 km of topographied galleries following the above mentioned patterns. The calcareous strip on which this karst is placed is an extension of the subject of our study.

The karst pipes system is the result of a selective enlargement of fissures through dissolution. The degree of development of these karst-pipes is proportional to the hydraulic gradient.

Within the fractures system which karst uses in its formation, there is a tendency to use those formed as a response to traction efforts according to perpendicular planes to the main axis of minimum efforts (σ_3).

From the geological study of the region, we conclude that a vertical uplift, responding to a tectonic one of blocks belonging to the paleozoic strip which appears to the north, and a settlement of the Tertiarious basin which lies to the south are both liable to provoke open fractures due to traction and to an E—W direction.

General Process of Karst Research

It includes:

— Study of karst-pipes.
— Mineralogical and geomechanical analysis of the fillings.

The total amount of data about karst-pipes and fractures is summed up in table 1.

For the statistical study in star diagrams of frequencies of the prevailing directions, we have associated the values to 12 types of directions, 15° each, from 0° to 180°.

General Survey of the Pipes

General survey of the pipes grouping them according to their location in the

Table 1

A = DIACLASES RIGHT ABUTMENT
B = DIACLASES LEFT ABUTMENT
C = A + B
D = KARST PIPES RIGHT ABUTMENT
E = KARST PIPES LEFT ABUTMENT
F = D + E
G = TOTAL DIACLASES RIGHT ABUTMENT (INTERNAL AND EXTERNAL)
H = TOTAL DIACLASES LEFT ABUTMENT
I = TOTAL DIACLASES OF DAM SITE

DIACLASES

	A	%	B	%	C	%	D	%	E	%	F	%	G	%	H	%	I	%
1							31	26.72			31	[illegible]	31	21.23			31	19.25
2							22	18.96			22	18.48	22	15.06			22	13.66
3	3	10	1	8.33	4	9.52	5	4.31			5	4.20	8	5.47	1	6.66	8	4.96
4			2	16.66	2	4.76	4	3.44			8	6.72	4	2.73	2	13.33	6	3.72
5	5	16.66	4	33.33	9	21.42	8	6.89			8	6.72	13	8.90	4	26.66	17	10.55
6	16	53.33	4	33.33	20	47.61	9	7.75			9	7.56	25	17.12	4	26.66	29	18.01
7	3	10	1	8.33	4	9.52	5	4.31	1	25.0	6	5.04	8	5.47	2	13.33	10	0.62
8	2	6.65			2	4.76	1	0.86			1	0.84	3	2.05			3	1.86
9							2	1.72	1	25.0	2	1.68	2	1.36	1	6.66	3	1.86
10	1	3.33			1	2.38	10	8.62	1	25.0	10	8.40	11	7.53	1	6.66	11	6.83
11							10	8.62	1	25.0	11	9.24	10	6.84	1	6.66	11	6.83
12							9	7.75			9	7.56	9	6.16			9	5.62
Σ	30		12		42		116		4		120		146		15		161	

KARST PIPES

	D	%	E	%	F	%
1	73.7	8.40	10.15	9.50	83.85	8.53
2	73.77	8.41	13.2	12.35	86.97	8.84
3	60.38	6.88	18.33	17.16	78.71	8.00
4	102.26	11.66			102.26	10.39
5	122.62	13.98	11.5	10.76	134.12	13.6
6	130.26	14.85			130.26	13.24
7	98.2	11.20	9.5	8.89	107.7	10.9
8	99.65	11.36	1.8	1.68	101.45	10.31
9	25	2.85	15.05	14.09	40.05	4.07
10	19.54	2.22	11.48	10.74	31.08	3.15
11	20.8	2.37	10	9.36	30.8	3.13
12	50.55	5.76	5.8	5.43	56.35	5.73
	876.73		106.81		983.6	

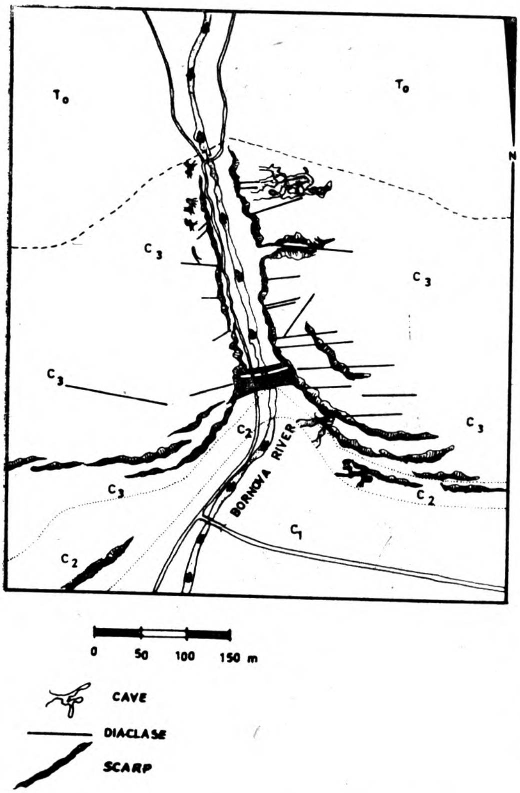

Fig. 2. General view of the dam site:
T_o — Oligocene, C_3 — Upper-Cretaceous, C_1, C_2 — Lower-Cretaceous

lithological column and depending on which buttress they are placed on, being treated as a whole afterwards. (Table 1). A total amount of 983.6 mts. of karst pipes are topographied in different caves. 90% of this amount belong to the right bank. The underground system so defined is placed in a photogrametric map at a 1 : 5000 scale (Fig. 2).

In the same way the position and situation in the column of karst pipes detected in survey holes are determined.

Generally speaking the caves of the right bank follow the expected tendency to develop in an E—W direction (Fig. 2 and 3), while the ones in the left bank go from E to NE and from S to SE. Nevertheless at this bank the pipes system cannot be considered as representative since it hardly represents 10% of the total topographied area.

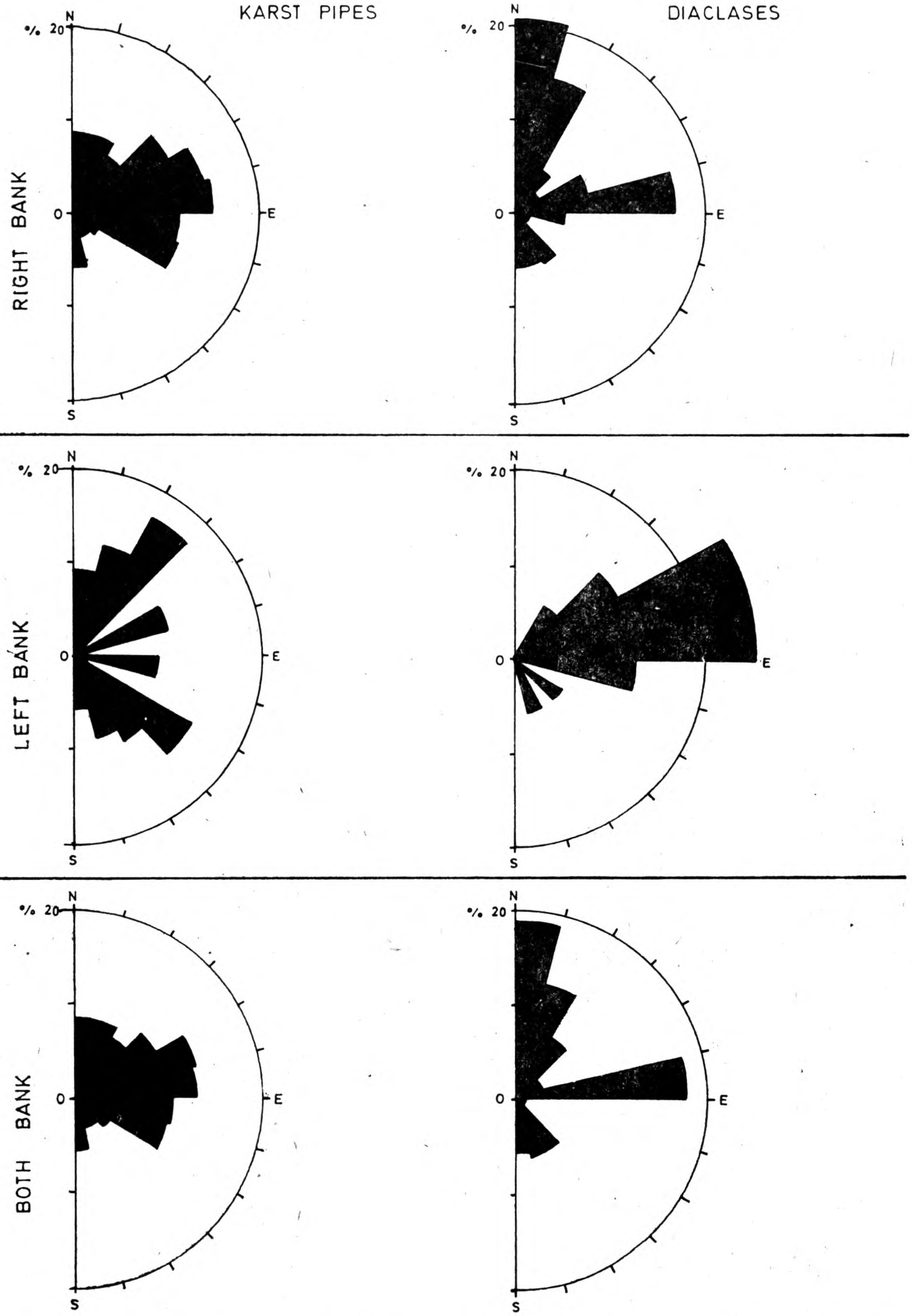

Fig. 3. Correlation between karst pipes and diaclases in the surroundings of the Alcor-lo dam

Analysis of Existing Fillings

Next step consists in a mineralogical and geomechanic study of the different samples of clays collected in the caves of the ressservoir.

Mineralogical Analysis of Clays

The general results of the mineralogical analysis of clays carried out through X-rays diffraction give high percentages of dolomite, and the presence of clay minerals is between 40—60%. Detected minerals are: high quantities of illite and chlorite, minerals of low plasticity and which are not liable to have presiovolumetric changes, in spite of the moisture variations which will take place with the water level increase.

There also appear in low proportions montmorillonite, vermiculite and interstratified clay minerals such as chlorite-montmorillonite and montmorillonite 12-vermiculite which can produce great swelling pressures.

Geomechanic Trials on the Cavern Clays

The following have been carried out:

— Atterberg limits.
— Shear stress: in natural moisture, in moisture next to liquid limit, in moisture next to plastic limit.
— Determination of swelling pressures by edometric trials.

Low values of shear stress are thus detected (0.01—0.04 Kg/cm^2) for moistures next to liquid limit ($I_L = 1$) and they point to the possibility of extrusion of karstic seals under top water level conditions. (Fig. 4).

Study of Diaclases

It has been sought from two different acpects.

External Diaclases

It has been focussed on all those fractures which have originated morphological changes in the rockbanks which are supposed to include the ones responsible for the karstification.

A field study is carried out and each

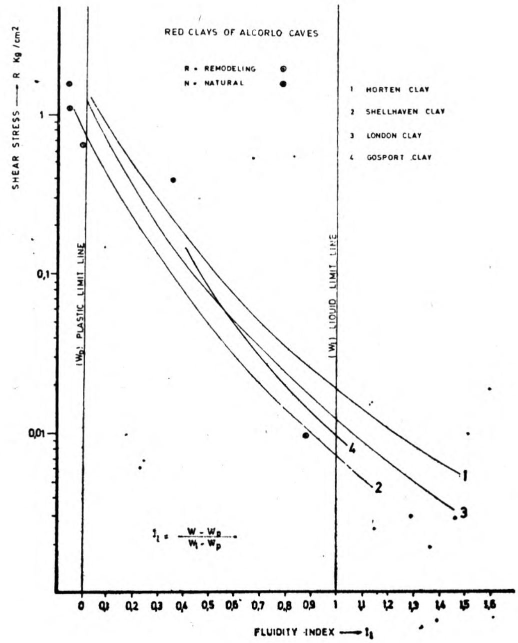

Fig. 4. Relation between shear stress R and fluidity index I, of the clays

diaclase is located in the photogrametric map 1 : 500 and these field data are accompanied by a photogeological study on a scale 1 : 5000.

Data are represented in a stereographic projection. There appear clearcut maximums with nearly 70% of the fractures being concentrated between N 60—90 E, and 48% are located between N 75—90 E (Fig. 3).

Internal Diaclases

All the fractures observed inside the pipes are registered. The method used is similar to the ones employed in the study of karst pipes, taking partial data according to the situation of caverns in the lithological column, the information being treated as a whole afterwards.

By doing so it is possible to detect those fractures that, although they do not cause any morphological alterations in the mountain they do have some influence in the interior and are responsible for the complementary directions of the karst.

The values so obtained (Fig. 3 and Table 1) detach from the external data and there appear clearcut maximums with 35% of the data around N 15 E-N 15 W direction (Fig. 3 and Table 1).

Relation Between Fracturation and Karst Pipes Directions

Turning back to Table 1 as a synthesis of the statistics of diaclases and karst pipes, there is a great similarity between both types of data, with two maximums N-S and E-W within the fracturation direction which are well represented in the karst pipes directions where the prevailing trends in the N-E quadrant show maximums in types 5 and 6 (N 60—90 E) (Fig. 3). These results agree with our work hypothesis.

Conclusions and Recommendations

The development of the karst is confirmed to follow E-W direction with a secondary pipes system going N-S. This karst forms a karst system partly filled with clays which will be affected by the water resservoir.

The hydraulic gradients, at top water level which would influence the clay fillings in caves of the right bank will be from 2,5 to 3 Kg/cm^2, that is to say, enough to provoke its reactivation due to the low values of shear stress of the mentioned clays under saturation conditions.

The possibility of leakage through the karst in the dam-site at the inflow of water is then very high and it severely affects the purpose the dam was built for.

In order to have the right information in case leakage needed to be corrected we recommend the following work to be carried out.

Digging out the clay fillings of the first matres in the caves within the reservoirs and put in its place a concrete mass which would serve as a seal (Fig. 6).

Observation of all the springs down the stream the damsite measuring the cutflows and relating these data to the water level in the resservoir in order to know not only the dynamics of the flow under different conditions, but its development as well.

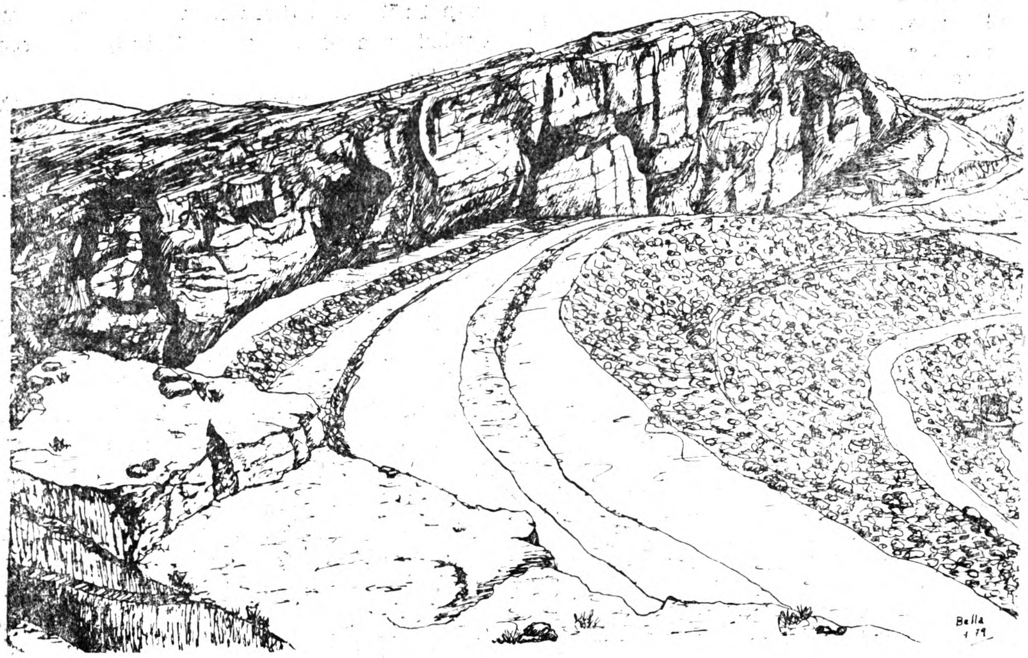

Fig. 5. General view of the dam

Fig. 6. Excavating a clay filling in a cave with bulldozer

Finally, when all the available data and information a sealing program based on grouting procedures hould be elaborated and quantified taking into account not only geometric considerations but geological and hydrogeological ones as well, that is to say, the most suitable according to technical and economical criteria.

Bibliography

Avias, J., 1969: Barrages en terrain karstique: l'exemple du barrage de Ceyrac (Gard), Rev. Géogr. des Pays Medit., 7: 75—83.

Burger, A., Dubertret L., 1975: Hydrogeology of karstic terrains, Inst. Ass. of Hydrogeol., série B, n° 3: 1—190, Paris.

Drogue, C., 1979: Application des études de magasin à l'explatation des eaux souterraines en milieux karstiques, Ass. des Géol. du Sud-Ouest, réunion Tarbes, Oct. 1978.

El Ramly, I.M., 1965: Contribution to the hydrogeological study of limestone terrains in V.A.R., Actes du Coll. de Dubrovnik sur l'hydrologie des roches fiss., AIHS — UNESCO, I, p. 348—377.

Eraso, A., 1977—1979: Conferencias de Hidrogeología karstica en el Curso Internacional de Hidrogeologia NOEL LLOPIS, F.C.G. — C.S.I.C. — UNESCO, Madrid.

Eraso, A., 1979: Vision dialectique du processus de la karstification. Analyse critique du phénomène de la dissolution, Ass. des Géol. du Sud-Ouest, réunion Tarbes, Oct. 1978.

Mangin, A. 1979: Le Karst, entité physique, abordé par l'étude du système karstique, Ass. des Géol. du Sud-Ouest, réunion Tarbes, Oct. 1978.

Mattauer, M. 1967: Introduction à la microtectonique, Science Progress. La Nature, 3383: 81—89.

Memorias del Grupo de Trabajo de Espeleología Científica de la Real Sociedad Española de Historia Natural, 1978. Presa de Alcorlo. Estudio del Karst de la cerrada. Mem. n° 3, parte 1°, GTEC de la RSEHN, Madrid.

Ramsay, J.G., 1967: Folding and fracturing of rocks, Mc Graw Hill Ed., New York, 568 p.

Therond, R., 1973: Recherche sur l'étancheité des lacs de barrage en pays karstique. These Doc., Eyrolles, Paris, 444 p.

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BADANIA NAD KRASEM W REJONIE ZAPORY ALCORLO (HISZPANIA)

Streszczenie

W artykule przedstawiono wyniki prac zmierzających do określenia zasięgu i stopnia rozwoju form krasowych napotkanych w trakcie budowy zapory Alcorlo. Stwierdzono istnienie serii jaskiń i kawern częściowo wypełnionych słabo zwięzłymi osadami gliniastymi, głównie występującymi na osi E-W, w prawym obrzeżeniu projektowanej zapory, poniżej spodziewanego poziomu spiętrzenia wód. Przeprowadzono badania strukturalnej wytrzymałości osadów i zaproponowano ich usunięcie z pierwszych kilku (kilkunastu) metrów jaskiń w strefie kontaktu z planowanym zbiornikiem oraz wprowadzenie na to miejsce masy wypełniająco-uszczeliniającej.

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RECHERCHES SUR LE KARST DANS LA RÉGION DU BARRAGE ALCORLO (ESPAGNE)

Résumé

Dans l'article sont présentés les résultats des recherches ayant pour but de définir l'étendue et le degré de développement des formes karstiques rencontrées au cours de la construction du barrage Alcorlo. On a constaté l'existance d'une série de grottes et cavités partiellement remplies de dépôts limoneux cohérents, apparaissant généralement dans la direction E-W, sur le rebord droit du barrage, au-dessous du niveau attendu du rehaussement des eaux. On a fait des recherches sur la résistance structurale des dépôts et on a proposé de les évacuer sur quelques premiers mètres des grottes, dans la zone de contact avec le bassin planifié, en mettant une masse d'étanchéité et de remplissage à la place.

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Problèmes posés par le karst dans le barrage de Tous (Espagne)
Rapport préliminarie des travaux en cours

Résumé: Ce rapport, un résumé d'une étude actuellement en cours, a pour objet de donner une vue d'ensemble des problèmes géologiques dans un barrage construit dans une région calcaire avec des signes évidents de karst, autant actuel comme fossil. Avec cette étude on tâche de déduire quelles sont les directions préférentielles du drainage souterrain du karst et quelles possibilités existent pour reactiver le paléokarst afin de pouvoir choisir le traitement d'étanchéité le plus approprié selon les critères technico-économiques.

Puisque l'étude est actuellement en cours, nous nous limiterons ici à exposer la méthode de travail utilisée, indiquant les données obtenues jusqu'à maintenant dans la première phase déjà terminée.

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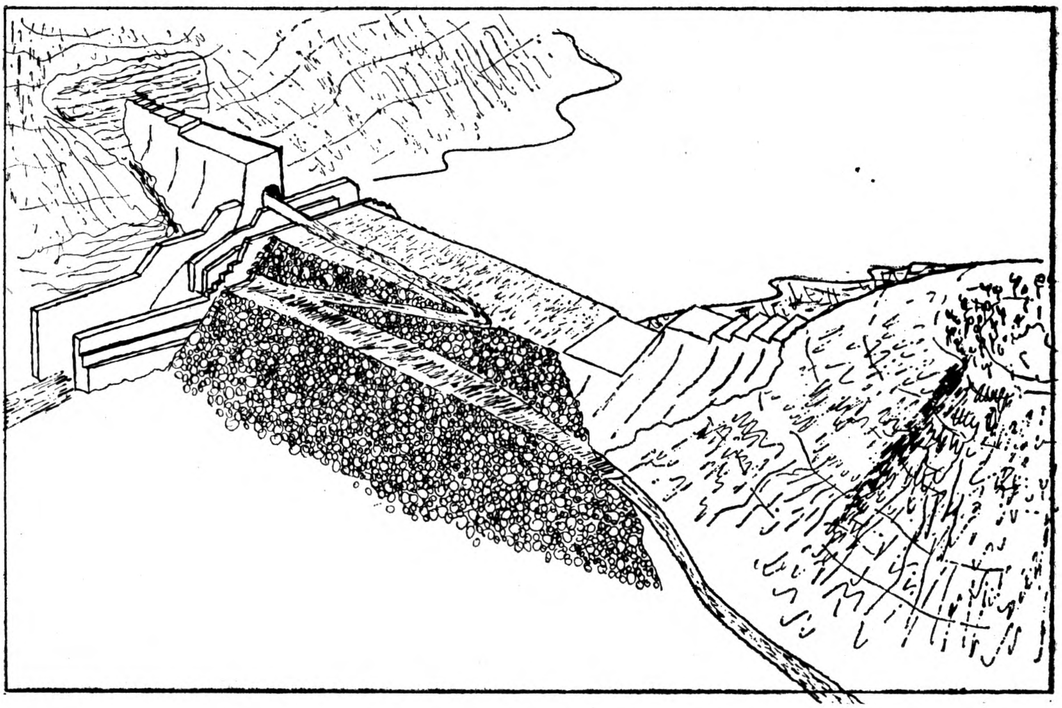

Fig. 1. Vue générale du barrage de Tous

Caractéristique du site du barrage

Le site du barrage se trouve dans une gorge formée par des roches calcaires du turonien, en aval de la confluence des rivières Jucar et Escalona. Le fond de la rivière est formé par un paléorelief avec un remplissage d'une épaisseur considérable qui posait des problèmes d'effondrement pour les charges transmises par un barrage de gravité, et ceci était la raison de modifier le projet initial, variant le corps central du barrage et construisant un barrage en enrochement avec un noyau imperméable d'argile, conservant en même temps les appuis latéraux de béton comme barrage de gravité.

Quoique le barrage soit déjà terminé jusqu'à une hauteur de 90 m au-dessus du niveau de la mer, existe le projet d'élever le barrage dans une seconde phase jusqu'à la côte de 133 m, en fonction des résultats obtenus dans la première phase. Le site du barrage est schématisé dans la figure 1.

Entourage géologique

Description de la série stratigraphique

Les matériaux les plus anciens qui se trouvent dans la zone correspondent au Trias; il s'agit de puissantes masses d'argile et marnes du Keuper en facies germaniques, avec des bancs intercalés de gypse qui présentent des signes évidents de diapyrisme. Associées à ceux-ci apparaissent des roches éruptives basiques du type ophites.

Le Jurassique se trouve dans quelques points isolés en forme de calcaires ou dolomies massives d'une épaisseur minime. La caractéristique fondamentale de la lithologie du crétacé est la formation calcaire un peu marneuse et plus souvent sableuse avec une épaisseur de plus de 700 m. Cette série est la plus abondante dans la zone du barrage et notre problème se concentre sur celle-ci.

Dans le Tertiaire, discordant avec l'antérieur, se trouvent des dépôts marins fondamentalement sableux et marneux qui correspondent au Miocène, pour passer à des dépôts lacustres, conglomérés et calcaires dont l'âge oscille entre le Pontien et le Pliocène. La série termine avec du matériel quaternaire en forme de terrasses, coluvions de versant et matériel détritique, galets, sables, limons et argile qui bordent les formations secondaires, en particulier épaisses dans la zone où se trouvent les rivières.

Tectonique

Le style tectonique présente des caractéristiques particulières, puisque nous nous trouvons dans un point singulier où convergent l'influence des chaînes ibériques avec celle des prébétiques, dont les directions SE de la première et NE de la seconde se croisent dans cette zone transitionnelle (fig. 2).

Un autre élément d'une importance considérable dans l'ensemble tectonique sur un plan plus local est la présence d'un Keuper diapyrique, qui se trouve à une distance très proche parfaitement parallèle à la rivière en question.

Il semble logique de penser que la structure de la vallée est fortement influencée par l'extrusion triasique.

La zone où se trouve la rivière est jalonnée par importantes failles de décrochement longitudinales à la rivière, quelques-unes avec de forts mouvements verticaux inverses.

Ces fractures dans lesquelles on a trouvé au moins quatre phases différentes du mouvement, sont responsables du fait que la vallée de la rivière est une zone tectoniquement élevée (quoique morphologiquement déprimée); un facteur qui peut être intéressant au moment d'évaluer l'épaisseur réelle du calcaire qu'il est à supposer au-dessous de la rivière.

Il y a également une série de fractures mineures, associées et d'une direction transversale à celles-ci, ainsi qu'un réseau de diaclasses qui se manifeste surtout dans les zones qui correspondent aux bloques isolés entre les failles importantes.

Problème concret du barrage

La première difficulté causée par le site du barrage était le remplissage au fond de la rivière qui à l'endroit exacte du barrage est d'une épaisseur d'environ 100 m. Cette circonstance donnait lieu à la costruction d'un barrage mixte, comme déjà mentionné,

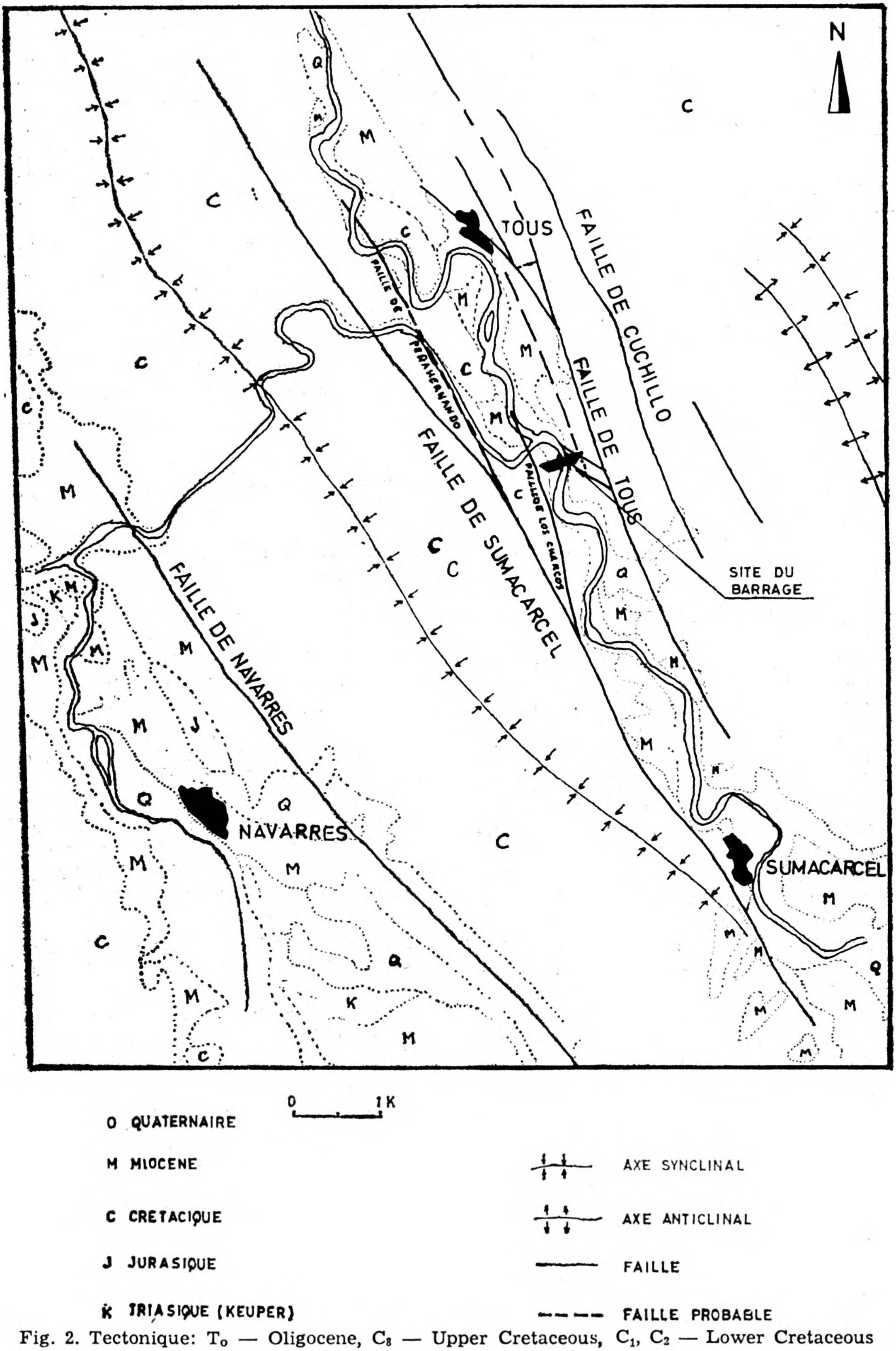

Fig. 2. Tectonique: T_o — Oligocene, C_8 — Upper Cretaceous, C_1, C_2 — Lower Cretaceous

avec la partie centrale d'enrochement et les rives en béton.

Le second problème est constitué par les fuites qui se sont formées en profitant d'un karst actuel et de l'évidence d'un paléokarst, dont les remplissages correspondent aux sédiments considérés continentaux.

En relation avec cette question on devait considérer quelques aspects fondamentaux:

— Les remplissages de ce plaéokarst sont installés fréquemment d'une manière préférentielle dans les grandes failles de la zone. Ceci semble indiquer que le paléokarst a suivi une direction d'écoulement selon les principales dirtctions tectoniques de la zone.
— Ces remplissages comprennent des matériaux variés d'une granulométrie très diverse. On trouve des sables fins, galets calcaires de différents diamètres, argiles rouges et blancs, et plus souvent des galets calcaires dans une matrice d'argile rouge.
— De l'autre côté, ces matériaux de remplissage que l'on trouve systématiquement dans presque tous les joints des failles, apparaissent très souvent reactivés et il est même possible d'observer des stries d'origine tectonique sur les galets selon les différentes directions. Ceci prouve évidemment qu'après le dépôt de ces matériaux dans la région, les failles se sont reactivées plusieurs fois.
— Le dernier aspect qu'il faut tenir en compte est l'apparition de nouvelles sources (ou l'augmentation du débit des sources existentes) dans la zone proche du barrage, due à l'augmentation du gradient hydraulique, causée par la montée du niveau d'eau dans la retenue.

Actuellement on est en train de traiter une fuite de l'eau qui a son origine dans une perte située dans la rive droite du barrage, au-dessus de la faille de Sumacarcel, qui a provoqué plusieurs sources à une distance de 2 km du barrage, en aval de la rivière, avec un débit d'environ 4,5 m³/sec.

Méthode du travail suivie

On est parti de la base qu'un karst se développe en faveur d'un réseau de fractures déjà existant dans la région et d'une manière préférentielle dans les fractures générées par les efforts de traction.

La première phase du travail consistait dans la réalisation d'une étude profonde de la tectonique régionale sous deux aspects:

— d'un côté l'étude des failles et ses mouvements pour en déduire les directions des contraintes principales et les axes de déformation globale discontinue dans la région;
— de l'autre côté la vérification simultanée du traitement statistique des systèmes de diaclasses pour en déduire leurs orientations préférentielles.

La seconde phase du travail était concentrée sur l'étude du paléokarst, tant en ce qui concerne ses morphologies que les caractéristiques et dispositions de ces remplissages.

Finalement, dans la troisième phase du travail actuellement en cours, on analyse les variations des niveaux piézométriques dans les forages en aval du barrage, en fonction des gradients hydrauliques causés par les différentes hauteurs du plan d'eau dans la retenue.

En tenant compte de la relation étroite qui semble exister entre le karst et le fonctionnement structurel de la région, on a commencé dans la première phase à se concentrer sur ce point. La première tâche réalisée consistait en l'établissement d'une cartographie détaillée à l'échelle 1 : 10 000 (appuyée d'une étude photogéologique) de grandes failles mentionnées avant, et de toutes les fractures mineures ou associées qui affectent la zone du site, de la retenue y compris une certaine partie en aval du barrage (fig. 3).

Après ce travail on a pris des données concernant les mouvements des failles qui peuvent être déduits en étudiant les terrains divers des plans de faille, et prêtant une attention spéciale à l'information reçue par les stries de friction, stries de dissolution, veins de calcite, stylolithes, etc. afin de dresser un modèle le plus proche possible du fonctionnement des failles et du mouvement global des bloques.

L'étape suivante consistait dans l'interprétation des données avec l'aide de deux méthodes selon deux points de vue à la base

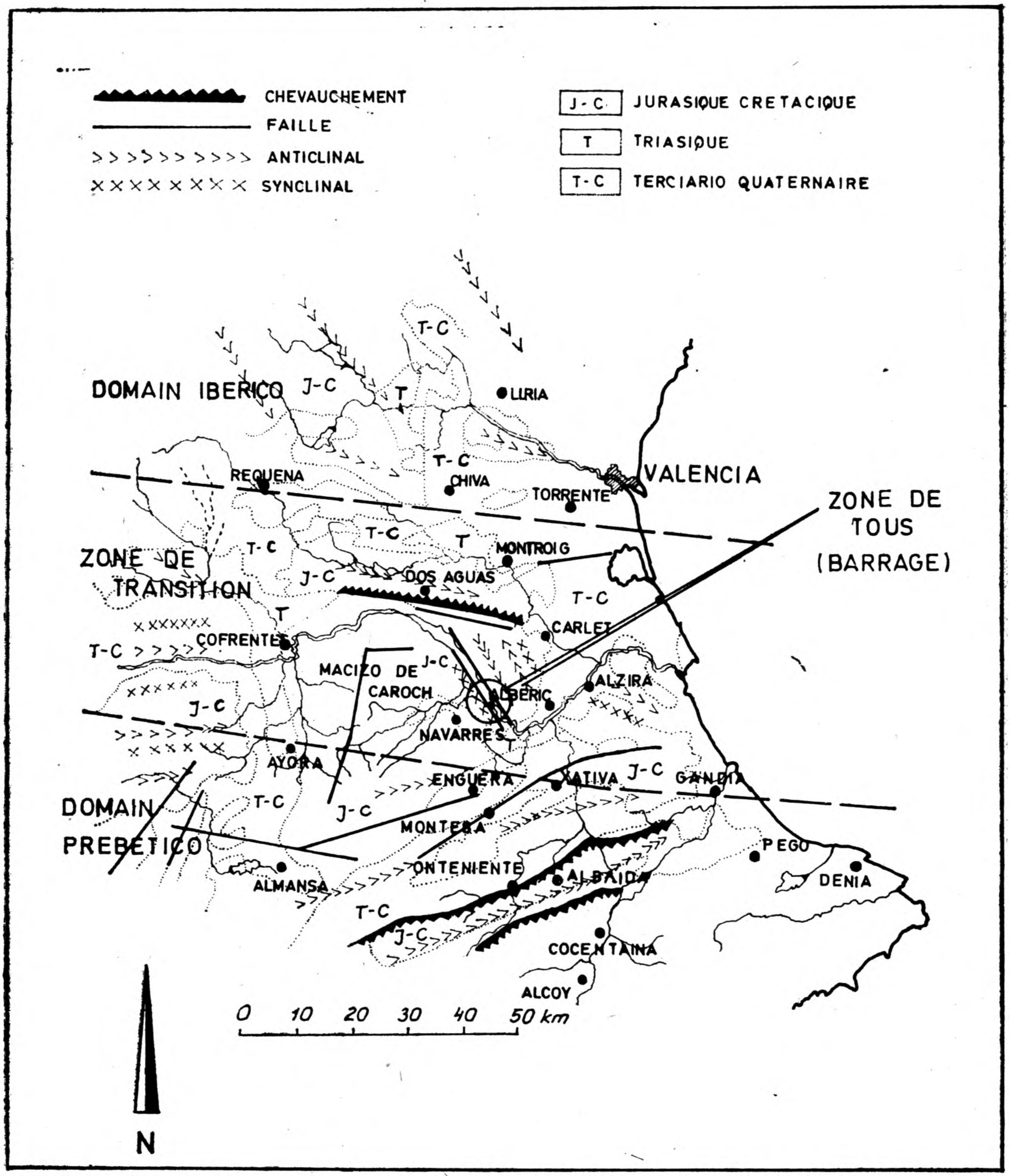

Fig. 3. Plan de situation géologique

d'une analyse structurelle: d'un côté l'identification des contraintes principales σ_1, σ_2, σ_3 et son possible évolution selon les différentes phases tectoniques observées, en utilisant la méthode d'Anderson en projection stéréographique. D'autre côté la détermination des directions principales de déformation régionale, *X*, *Y*, *Z* tenant compte de la tectonique cassante de la zone, qui selon les vérifications faites a fonctionné pendant au moins quatre phases de mouvements différents, et comme c'est logique à penser, les dernières étaient influencées par la déformation causée par les premières phases. Là

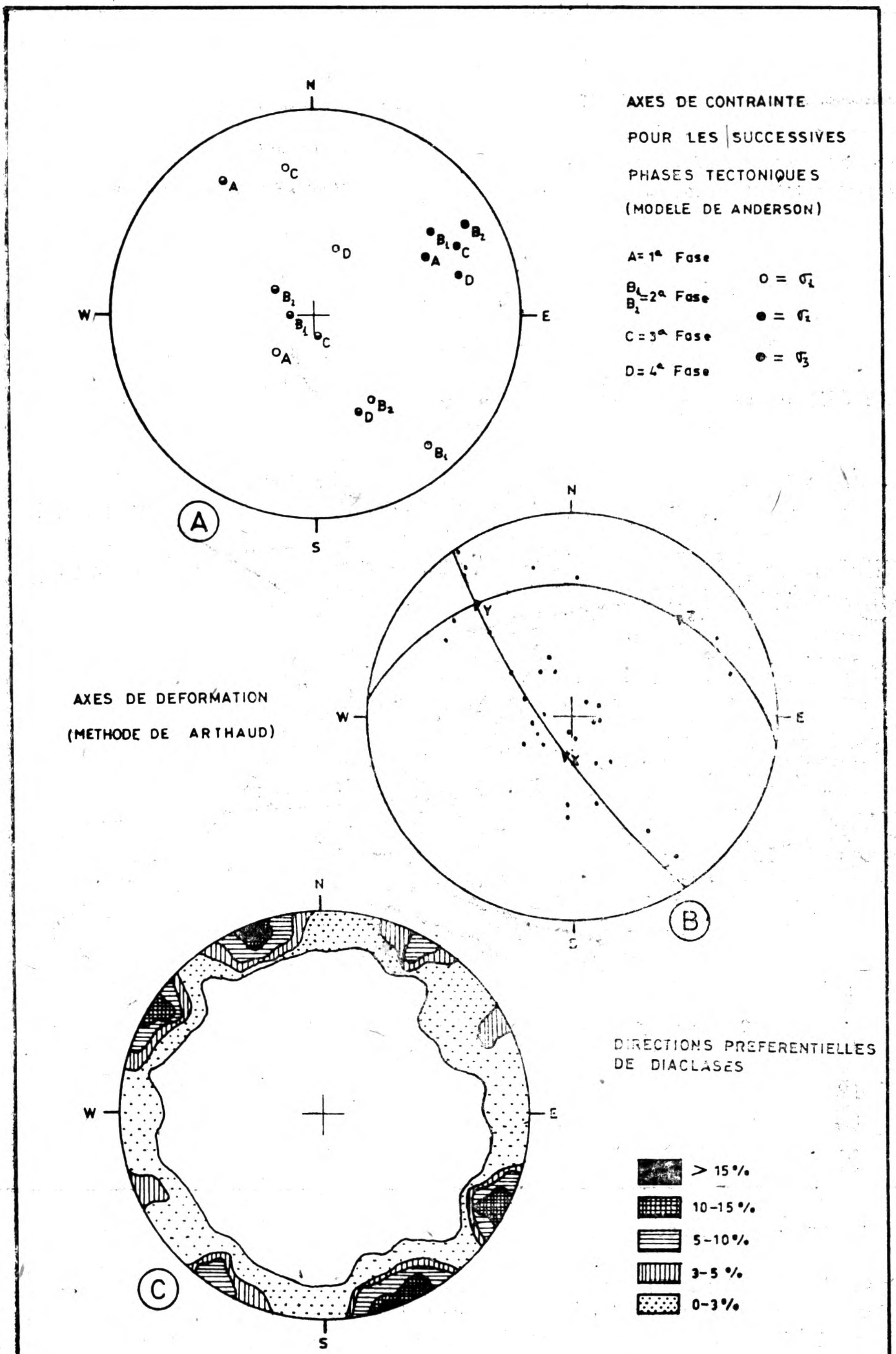

Fig. 4. Diagrammes tectoniques

on a utilisé la méthode d'Arthaud pour les régions de tectonique cassante qui semble très convenable dans ce cas.

Les résultats obtenus de cette étude peuvent être résumés dans les points suivants:

— Les directions principales des contraintes déterminent l'existence d'au moins quatre phases dont l'une peut être divisée en deux sous-phases avec un virement d'orientation de σ_1 de 26°.
— Toutes les phases de mouvement observées ont une direction commune de σ_3 environ N 60 E (fig. 4A).
— Les axes de déformation déduites pour la zone suivent les directions X: N-192°; Y: N 320°; Z: N 48° (fig. 4B).
— En comparant les deux modèles on voit que la direction de l'axe principale intermédiaire Y de déformation se trouve sur le plan formé par les contraintes qui correspondent à la première phase σ_1 σ_2. Ceci confirme l'hypothèse de départ indiquant cette direction N 320° comme la préférentielle dans la formation de l'écoulement souterrain.

Après l'étude des failles on a réalisé une étude des diaclasses. A cet effet on a choisi les zones éloignées de l'influence probable des failles et où il est possible de faire un grand nombre de mesures afin d'obtenir des résultats statistiques sûrs. Les stations de mesure, suivant les critères mentionnés avant, se trouvent distribuées sur toute la zone et principalement dans les vallées transversales à la rivière Jucar.

Les données transférées au canevas stéréographique pour son analyse statistique, permettent la déduction des directions préférentielles des diaclasses. On l'a réalisé tout d'abord partiellement pour chaque station et finalement on les a groupées dans des stéréogrammes globaux. Les stations déjà étudiées nous donnent une direction préférentielle N 154° et deux associées N 32° et N 71°, la dernière moins forte (fig. 4C).

Etude du paléokarst (actuellement en cours)

Le programme à suivre comprend:

— L'inventaire des formes autant extérieures (dôlines, etc.) qu'intérieures (conduits, etc.) en les situant dans la série stratigraphique et sur le plan géologique.
— L'étude granulométrique des remplissages.
— L'étude du comportement géomécanique en relation avec les points suivants: limites d'Atterberg, essais de cisaillements, essais édométriques, grâce auquels on espère pouvoir prévoir le comportement de ces matériaux dans les conditions de saturation, en vue des gradients hydrauliques créés par la retenue.
— De l'étude et du traitement statistique des stries observés dans les galets calcaires de quelques remplissages on peut déduire que les phases tectoniques ont été postérieures à l'installation du paléokarst, et ceci nous permet d'établir une chronologie relative dont l'utilité sera primordiale tant pour l'établissement de l'évolution régionale que pour le pronostic du comportement futur de la retenue.

Etude de l'influence du barrage sur le niveau phréatique de la zone (actuellement en cours)

En premier lieu on dressera des cartes d'isopièces basées sur les données fournies par le réseau de piézomètres installés dans la zone proche au site du barrage. Pour chaque intervalle de 2 m dans la hauteur du plan d'eau dans la retenue une carte sera établie. De son interprétation on peut déduire la variation en profondeur de la surface piézométrique, la connaissance des voies de circulation privilégiées et la détermination du mouvement de l'eau dans la nappe, qu'il faut tenir en compte au moment de corriger les fuites existantes.

Conclusions

L'objectif poursuivi sur la base de l'interprétation de toute l'information obtenue, consiste à:

— Localiser les fuites instantanées causées par le karst actuel et les quantifier en fonction de la hauteur de l'eau dans la retenue, c'est-à-dire de la grandeur du gradient hydraulique.
— Etudier son évolution dans le cours du temps, quantifiant dans la mesure possible la reactivation du paléokarst, sous les nouvelles conditions hydrauliques créées par la retenue.

— Etablir les bases pour élaborer le projet d'un traitement d'étanchéité qu'il faut définir en conditions optimales selon critères technico-économiques.

Au cours de nos travaux nous avons pu constater que la direction préférentielle du drainage du karst dans un calcaire qui est soumis à une tectonique cassante est celle qui correspond à l'axe Y de déformation (c'est-à-dire à l'axe principale intermédiaire qui ne produit ni raccourcissements ni allongements). Cette conclusion est quelque chose de tout à fait nouveau dans la prédiction du drainage dans le karst, dont on savait jusqu'à maintenant que les directions préférentielles, en reation avec l'ellipsoïde de contraintes, étaient adaptées aux plans orthogonaux à celle de σ_3 qui représente la direction de traction.

Bibliographie

Anderson, E. M., 1951: The dynamics of faulting, Oliver and Beyd, edit., Edinburgh.

Arthaud, F., 1969: Méthode de détermination graphique des directions de raccourcissement, d'allongement et intermédiaire d'une population de failles, Bull. Soc. Géol. de France, **7**: 729—737.

Boni, C.F., 1973: Lineamente hidrogeological dell'Appenino carbonatico laziale-abruzzese, ESA — AIH, Palermo, 11p.

Castany, G., 1968: Prospection et exploitation des eaux souterrainnes, Dunod. Paris, 717p.

Eraso, A., 1979: Problemas observados y plan de investigación del Karst existente en la presa de Tous. Rapport intérieur, Agroman E.C.S.A., Madrid.

Eraso, A., 1977 à 1979: Conferencias de Hidrogeolgía karstica en el Curso Internacional de Hidrogeologia NOEL LLOPIS, F.C.G. — C.S.I.C. — UNESCO, Madrid.

Hinkelbein, K., 1978: Darstellung und statistische Auswertung von Kluftmessungen mit Hilfe der Lagenkugelprojektion, Laichinger Höhlenfrenud, **13**, 26: 1—42, Laichingen.

Mangin, A., 1975: Contribution à l'étude hydrodynamique des aquifères karstiques, Thèse Doc., CNRS, Lab. souterrain Moulis, 279p.

Sonderegger, J. L., Kalley, J. C., 1970: Hydrology of limestones terrains; geological investiagtions, Bull. Geol. Survey Alabama, n° 94, part B: 1—146, Montgomery.

Therond, R., 1973: Recherches sur l'étanchéité des lacs de barrage en pays karstique, Thèse Doc., Eyrolles, Paris, 444p.

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PROBLEMY ZWIĄZANE Z KRASEM W REJONIE ZAPORY TOUS (HISZPANIA). WSTĘPNY RAPORT Z PROWADZONYCH PRAC

Streszczenie

Przedstawiono aktualny stan badań nad krasem kopalnym występującym w rejonie planowanej zapory Tous. Przeanalizowano kierunki ewentualnego drenażu wód ze zbiornika i jego wpływ na reaktywowanie się procesów krasowych w otoczeniu zapory. Przedstawiono metody badawcze które pozwoliły określić strefy i kierunki drenażu.

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KARST-INVOLVING PROBLEMS APPEING IN THE TOUS DAM AREA (SPAIN). INTRODUCTORY REPORT ON THE WORKS CARRIED ON

Summary

The authors describe the present state of the research works over fossil karst appearing at the trritory where Tous dam is designed to be built. The eventual draining directions, and the dam impact on the karst reactivating proccesses in the dam vicinity were analyzed. The researching techniques that allowed to determine the draining zones and directions were described.

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Remarques sur l'hydrogéologie des mines dans des formations karstiques

R é s u m é: L'article présente les plus importants problèmes hydrogéologiques qu'affrontent les services miniers au cours de l'exploitation dans les séries carbonatées soumises à la karstification. On a discuté les méthodes de recherches sur le régime des eaux karstiques qui sont nécessaires pour les travaux liés avec le drainage de mine.

Intérêt de l'investigation karstologique-minière

Dans les matériaux karstiques se localisent, sans doute, des aquifères de caractéristiques exceptionnelles et en même temps singulières, qui font l'objet d'un intérêt spécial pour l'hydrogéologue. Mais ces aquifères présentent, relativement fréquemment, un aspect le transcendance indubitable, qui est normalement oublié par de nombreux karstologues. Je me réfère, de façon concrète, à la complexité problématique que posent les aquifères karstiques quand il s'agit d'y placer des travaux souterrains et spécialement quand ceux-ci sont miniers. Une justification possible de cet oubli peut résider dans la bibliographie insuffisante qui traite ce thème, conséquence des difficultés de cette spécialisation, et dans les restrictions des entreprises minières pour faire connaître ces recherches. D'autre part, et jusqu'à la récente célébration à Grenade (Espagne), du I Congrès Mondial de l'Eau dans les Mines et les Travaux Souterrains (SIAMOS-78), on n'avait pas réussi à réunir une expérience mondiale sur ce thème (les Actes recueillent des apports de 23 pays).

Cependant, pour nous tous qui consacrons notre activité de recherche et professionnelle à cette thématique, il n'y a aucun doute que les problèmes miniers dans des milieux karstiques sont, en priorité, les hydrogéologiques. Et cela parce que, dans ces systèmes karstiques, l'implantation d'un travail minier suppose l'intrusion d'un élément anthropique, qui va affecter et modifier le fonctionnement hydrologique du système, et en même temps le travail minier va se trouver conditionné par la présence de cette eau.

En conséquence, l'expérience du minier le fait associer, fréquemment, la présence de l'eau aux travaux du sous-sol, en même temps que pour l'hydrogéologue l'existence d'aquifères, même à faible profondeur, est facilement compréhensible. Cependant, les spécialistes en „hydrogéologie minière" sont peu nombreaux et, en conséquence, les énormes possibilités offertes par les travaux miniers, à la recherche hydrogéologique, n'ont pas encore trouvé le cadre adéquat de développement.

Mais on peut prédire, sans aucun doute, que dans un futur immédiat va se produire un changement total de cette situation, grâce auquel l'hydrogéologie, qui, longtemps et dans de nombreaux aspects, s'est vue bénéficiée par la technologie pétrolière, va maintenant trouver dans la mine son meilleur laboratoire et son meilleur champ d'exprience, en même temps que les mines vont pouvoir faire face aux problèmes posés par l'eau, non comme s'il s'agissait d'un stérile, mais avec toutes les ressources et méthodologies que peut lui offrir l'hydrogéo-

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logue, et avec le défi d'intégrer cette eau dans le cadre global de la gestion des ressources hydrauliques (F e r n a n d e z - R u b i o et P u l i d o - B o s c h, 1978 a).

Ainsi l'hydrogéologie va trouver, dans les mines, la possibilité de contraster la théorie avec la réalité, d'appliquer des technologies d'avant-garde, de réaliser des expériences à échelle réelle, et tout cela, avec une disponibilité de moyens supérieure à celle qui jusqu'à présent a été habituelle. De là la perspective d'un futur optimiste qui doit naître de cette étroite relation entre l'hydrogéologue et le minier, sortout quand le besoin de matières premières minérales augmente de jour en jour, et les problèmes que l'eau pose dans le sous-sol sont chaque fois plus importants.

Tout cela justifie le fait que le Groupe de Travail d'Hydrogéologie de l'Université de Grenade ait centré son activité de base, depuis plusieurs années, sur les investigations relatives à l'eau dans les mines et à l'hydrogéologie karstique.

Mines et hydrogéologie karstique

Etant données la multiplicité et la variété thématique qu'offre ce domaine, je prétends seulement aborder quelques aspects de base de celle-ci, qui seront suffisants pour mettre en évidence l'interrelation mine—karst—hydrogéologie.

Dans cet exposé, je vais prêter une attention spéciale aux méthodologies de recherche hydrogéologique, aux implications imposées par la présence de l'eau dans le milieu minier et, finalement, à quelques possibilités d'intégrer ces eaux dans la gestion globale des ressources hydrauliques.

Au préalable, il convient de signaler que, directement dans des matériaux karstiques, formant partie des roches encaissantes, ou étant en raport de voisinage avec celles-ci, on peut trouver toutes sortes de gisements miniers, quelles que soient leur genèse, leur composition et leur morphologie.

On ne peut parler, pour autant, d'un type spécial de gisements du point de vue karstologique, bien que le même processus de karstification soit favorable au développement de quelques concentrations minérales. Mais ce que l'on peut affirmer c'est que le fait, pour un gisement, de se situer dans un milieu karstologique, oblige à se poser la problématique hydro-géologique spécifique de ces systèmes aquifères, imposée par l'anisothropie hydrodynamique, avec des circulations privilégiées le long de discontinuités principales, alimentées ou alimentant un système de fissures de deuxième ordre.

Un aspect qui va conditionner, en tout cas, cette conception, est celui qui concerne les relations géométriques entre le gisement et le système karstique, où l'on pourrait considérer une extraordinaire diversité morphologique de gisements (corps estratoïdes, lentilles, filons, disséminations, etc.), liés à la sédimentation, au remplissage de fractures, au processus de metasomatose, et qui à leur tour se trouvent quelquefois sous-jacents et d'autres supra-jacents aux aquifères, desquels ils peuvent recevoir de l'eau *per ascensum* ou *per descensum* sans oublier la possibilité d'un apport latéral. Tout ceci imposant une grande complexité dans le régime hydrologique.

D'autre part, le système propre d'exploitation minière a une incidence fondamentale sur le rapport eau — mine, et à son tour le système de drainage adopté agit sur le coût d'exploitation, dont dépendent la rentabilité et la survivance de la mine.

En ce qui concerne les systèmes d'exploitation, il faut signaler que, dans de nombreuses occasions, les méthodes appliquées dans une première phase des travaux, dans laquelle on ne prévoyait pas de problèmes hydrogéologiques, agissent *a posteriori*, d'une façon pratiquement irréversible, sur la présence de l'eau et sur la possibilité technique et économique du drainage. Tel est le cas, par exemple, des anciens fronts superficiels d'exploitation, qui agissent comme des collecteurs d'eaux vers les exploitations souterraines; ou c'est le cas de mines inondées abandonnées, qui peuvent être responsables de brusques irruptions dans les nouveaux emplacements des travaux; ou ce sont même les sondages d'investigation minière, à travers lesquels des aquifères peuvent établir une interconnexion avec la mine.

Il faut donc une connaissance et une planification hydrogéologique avec le maximum de garantie, depuis le commencement de la recherche, pour orienter convenablement l'ensamble des opérations minières correspondantes aux phases d'exploration, de préparation, d'exploitation et d'abandon de la mine, en tenant compte de l'incidence probable de l'eau sur toutes celles-ci.

Le système karstique minier

Un aspect qui doit toujours présider cette recherche hydrogéologique, est celui concernant l'analyse et la connaissance des systèmes aquifères affectés, et l'établissement des relations internes et externes dans le domaine minier. L'analyse qui, dans ce cas, se rapporte fondamentalement à la karstification.

Dans ce sens nous ne pouvons pas oublier que la karstification la plus active, et avec elle le développement des voies de circulation préférentielle, est conséquence d'une tectonisation intense, puisque ce processus de karstification demande l'ouverture préalable de fractures, de tension spécialement, qui vont être les conduites privilégiées pour l'accès de l'eau et la dissolution karstique conséquente (n'oublions pas que 70 à 80% des irruptions d'eau, dans les mines, se produisent par des failles, et 15 à 20% par des fractures qui y sont liées).

Mais cette circulation aquifère n'est pas seulement préférentiele le long de fractures de tension (spécialement dans des axes anticlinaux), et le long de failles dans la masse carbonatée, mais aussi, dans le cas des mines, les filons sont des voies très favorables à cette circulation.

En tout cas, de nombreuses exploitations, affectées par des venues d'eau provenant d'aquifères karstiques, profitent de ces collecteurs hydrauliques favorables pour y placer les équipements de captage, qui rendent possible le drainage de la mine, en inversant le sens de l'écoulement (Fernandez-Rubio, 1974; Morell Evangelista et al., 1978). Les autres systèmes de fractures sont, en général, moins favorables à la circulation aquifère.

Pour compléter, dans le cas qui nous intéresse, le comportement hydrogéologique se voit en général affecté par les trous miniers (effondrements contrôlés, subsidences, collapsus, etc.), qui produisent des connexions hydrauliques au sein du système karstique ou dans d'autres systèmes périphériques.

Ainsi le karst, de soi complexe, se voit altéré par la présence d'une série de conduites antropiques privilégiées, qui sont à l'origine des changements importants dans le régime hydrologique, puisque la mine joue un rôle de conducteur et d'accumulateur, et se situe ainsi avec des caractéristiques intermédiaires entre les régimes propres aux eaux superficielles et aux eaux souterraines.

D'autre part, ce rôle de drain joué par la mine, dans le système, occasionne fréquemment, la réactivation de la circulation aquifère et du processus de karstification, et spécialement son rajeunissement quand il affecte un karst géologiquement fossile, et cela en conséquence du processus de karstification qui requiert la circulation aquifère et du drainage qui entraîne les remplissages du karst. Ainsi on a vérifié, par exemple, que de nombreuses exploitations de zinc et plomb en Polonge, se trouvent en contact avec un karst fossile (Różkowski et Pulina, com. orale).

A tout ce qui a déjà été exposé, on peut ajouter, dans le cas de systèmes aquifères à multicouches, les complications inhérentes à cette circulation complexe (Medina et al., 1978). Dans ce cas il est fréquent que le milieu minier corresponde à un aquitard intercalé, auquel l'aquifère carbonaté apporte ou draine de l'eau par un effet de „drainance". Il en est ainsi dans les exploitations de fer de Ojos Negros (Teruel, Espagne), (Fernandez-Rubio, 1974).

Considérant le fait hydrogéologique, très généralisé, de l'augmentation de la pression hydrostatique avec la profondeur, on justifie que les problèmes de l'eau augmentent au fur et à mesure de la profondeur des exploitations quand, en outre, la solution de ces problèmes offre de plus grandes difficultés.

Nous pouvons aussi signaler que ces travaux dans des mines profondes, qui fréquemment, se présentent soumises à de grandes pressions hydrauliques, peuvent être sauvegardés par des matériaux de faible conductivité hydraulique. Dans ce cas il faut éviter les fractures provoquées par l'exploitation minière, puisque c'est à travers de celles-ci, et favorisées par les gradients hydrauliques élevés, que peuvent avoir lieu des irruptions catastrophiques (Wolmarans, Guise-Brown, 1978).

Quand cette circonstance se présente, et dans certaines limites techniques et économiques, de nombreuses mines utilisent le procédé de laisser des massifs imperméables de protection, afin d'isoler la mine du système karstique; tel est le cas de quelques exploitations de lignite à Megalopolis (Grèce) (Spiliotis, 1978) ou de charbon, bauxite et manganèse dans la Massif Central du Transdanube (Tettamanti, 1967).

Enfin, nous pouvons indiquer quelques autres cas, dans lesquels les systèmes karstiques ne sont pas en contact direct avec les exploitations minières, mais sont les responsables capacitifs de l'apport des eaux, à travers des matériaux intermédiaires perméables d'une autre nature (Fernandez-Rubio et Pulido-Bosch, 1978 b, Kafri et Agron, 1978).

Objectifs de l'investigation

Une investigation bien programmée, doit se concentrer à établir le modèle conceptuel du comportement complexe du système et des relations hydrogéologiques, qui permettent de prévoir et de quantifier l'effet provoqué par la mine, et effets dérivés des moyens d'action possibles, afin d'analyser les incidences réciproques mine — aquifère, et de pouvoir adopter les solutions les plus favorables.

Mais cet objectif, presque toujours, est atteint seulement à moyen et long terme, car dans une première phase, le besoin de placer des dispositifs de drainage et de calculer l'effet de ces derniers prévaut normalement, quand en réalité on ne dispose pas encore d'information hydrogéologique convenable. Cela oblige à estimer des données inconnues, sur la base de l'information partielle disponible et, surtout, de l'expérience accumulée par les spécialistes.

Au fur et à mesure que l'investigation avance, et que l'on contraste ou modifie les prévisions et les résultats, on peut atteindre un plus grand degré d'efficacité du drainage. Et cette efficacité sera d'autant plus grande que plus profonde sera la connaissance des caractéristiques de l'entourage karstoligique minier, dans lequel on ne peut obvier à la localisation de secteurs de circulation karstique préférentielle, liée de façon sélective á la fracturation, aussi bien pour réaliser les travaux miniers se protégeant de ceux-ci, que pour y programmer les travaux de captage.

L'objectif de la recherche à long terme est, fréquemment, celui d'établir le modèle analytique, qui permettra de prévoir l'évolution hydrologique future, devent de possibles planifications différentes des travaux miniers et des systèmes de drainage. Ainsi, on pourra atteindre parmi ces possibles solutions des alternatives, tenant compte non seulement de leur efficacité, mais aussi de l'évaluation économique du binôme „minerai extrit — coût du drainage", ou du dénomé „coefficient d'inondation" (Fernandez-Rubio, 1975).

Malgré ce qui a été exposé jusqu'ici, il y a des cas et des circonstances dans les quels, avec la technologie actuelle et les coûts qu'impose le drainage, on n'arrive pas à des solutions applicables; dans ce cas, l'eau peut supposer un obstacle infranchissable pour la mise en exploitation du gisement, surtout quand cette incidence est non seulement technique et économique, mais aussi qu'elle implique des aspects de sécurité, qui mettent en péril des vies humaines.

Technologie de l'investigation

En ce qui concerne les techniques à employer, dans cette recherche, leur variété est fonction de la complexité des problèmes déjà décrits.

Il en arrive de même avec l'amplitude à appliquer ces techniques, puisqu'il s'agit d'un équilibre technique et économique dans lequel le coût de la recherche ne doit pas dépasser la valeur de la réduction du risque avec laquelle on l'atteint.

On ne peut parler, pour autant de techniques spécifiques d'investigation, pour aborder ces problèmes, puisque en réalité elles couvrent une très large gamme, et dans chaque cas une sélection bien méditée s'impose.

Mais ce que l'on peut détacher c'est que les importantes implications économiques de l'eau dans les mines justifient et conseillent d'agir avec une instrumentation technologique très supérieure à l'habituelle dans d'autres domaines de l'hydrogéologie, qui permet d'augmenter la confiance dans les résultats acquis, tenant compte des implications déjà signalées auparavant. Il s'agit, sans doute, de techniques dans lesquelles la conception pratique doit prévaloir sur la scientifique, bien que celle-ci ne soit pas exclue.

En général on part (Fernandez-Rubio, 1980) de la réalisation d'études géologiques de base, avec appui de la photointerprétation de la lithostratigraphie, de la fracturation et de la karstification. L'investigation hydrogéologique détaillée, proprement dite, doit comprendre également l'information apportée par l'investaire des points d'eau; l'enregistrement piézométrique, le recueil d'échantilons d'eau et leur contrôle physique et chimique; les jaugeages d'eaux superficielles et souterraines; etc.

Ces travaux sont complétés par des sondages de recherche hydrogéologique, dans les différents systèmes aquifères impliqués, avec analyses de leur comportement pendant la performation, et avec l'installation de piézomètres, en général multiples, soit sur la surface soit à l'intérieur de la mine (verticaux ou inclinés), pour un contrôle à court et long terme des oscillations du niveau, provoquées par des causes naturelles, par le drainage, ou par les travaux miniers eux-mêmes.

La large application de diverses techniques géophysiques terrestres prête également son appui, ainsi que les diagraphies électriques, thermiques ou radioactives dans des sondages.

Une place importante est occupée par les pompages d'essai en sondages, avec des piézomètres d'observations pour la détermination de paramètres dimensionnels des aquifères, et cela malgré les limitations que dans le karst pose leur interprétation. On réalise aussi, et dans un but identique, d'autres tests dimensionnels dans des piézomètres ou dans des sondages de recherche minière.

L'emploi de techniques avec des traceurs, chimiques ou istotopiques, est fréquent, ainsi que les études de datation des eaux, pour analyser l'écoulement régional, le mélange des eaux, et les affections à leur qualité.

En général, cette technologie d'investigation, bien qu'elle s'intensifie dans l'entourage minier, doit s'appliquer à une superficie très supérieure à celle de l'exploitation proprement dite, afin d'acquérir l'information nécessaire sur le milieu hydrogéologique, déterminer l'aire d'influence et les conditions du drainage, et établir le bilan hydraulique des aquifères, avec les modifications introduites par l'exploitation minière, spécialement sur des relations d'interdépendance des subsystèmes périphériques, et la recharge possible induite motivée par le drainage.

L'intérêt dérivé de l'information que la mine elle-même offre aux spécialistes, entraîne le besoin de poursuivre le contrôle hydrogéologique, pendant l'exploitation, et d'établir, sur cette base, de véritables tests de sensibilité des hypothèses de travail.

Défense contre les irruptions d'eau

De manière générale on peut différencier systèmes de prévention et systèmes de protection (passive ou active). Les premiers ont pour objet d'éviter ou de retarder les irruptios d'eau ou de réduire leur importance, et demandent, pour leur efficacité, la présence de formations aquicludes ou aquitardes, non tectonisées, qui se localisent entre le milieu minier et le système karstique, et qui atteignent une puissance spécifique suffisante pour supporter la poussée hydraulique.

Les méthodes passives de protection consistent à isoler la zone dangereuse, au moyen d'une fermeture, lorsque l'irruption d'eau s'est produite. On peut également inclure ici le scellement des voies de circulation d'eau par des injections, ou les traitements par congélation.

De leur côté, les méthodes actives de protection consistent à déprimer le niveau potenciométrique, ce qui s'obtient normalement au moyen de pompages, à partir de puits ou de sondages, ou au moyen de galeries de drainage.

Tous ces systèmes, pour combattre la venue d'eaux souterraines, doivent se compléter par une protection efficace contre l'irruption des eaux superficielles (canaux collecteurs périphériques; déviation et canalisation des lits; etc).

La gestion de l'eau de mine

Le drainage de la mine exige, comme caractéristique spécifique, le besoin d'extraire, d'abord des ressources et des réserves du systèmes aquifère, jusqu'à obtenir la descente piézométrique sous l'aire d'exploitation. A partir de ce moment le pompage peut se réduire aux ressources et à l'apport des systèmes périphériques annexes (karstiques ou non).

Mais il est normal également que ce drainage implique une augmentation de l'infiltration, aussi bien en conséquence de l'augmentation directe à partir des eaux de pluie ou d'écoulement superficiel, que par la réduction de l'évaporation, sans perdre de vue la possibilité de que la descente des niveaux agisse sur les profits hydrauliques préexistants, et altère en tout cas le bilan hydrique.

Rappelons à ce sujet que dans de nombreuses occasions le pompage dans des mines situées dans des terrains karstique est supérieur à 2000 m³/heure. Ainsi nous pouvons rappeler les presque 30 000 m³/heure pompées dans les mines du Massif Central du Transdanube, qui correspondent à 90% de l'eau infiltrée (Tettamanti, 1967); ou le pompage de plus de 40 000 m³/heure dans des districts miniers de Pologne.

C'est pour cela que les grands volumes d'eau, qu'il est nécessaire de pomper dans le drainage des mines et qui peuvent modifier sensiblement le flux régional, doivent s'intégrer dans le cadre de la gestion optimale globale des ressources hydrauliques.

En planifiant cette gestion, on ne peut pas oublier le fait que, pour des motifs très divers, ces mines et les processus qui y sont liés, peuvent occasionner une détérioration de la qualité de l'eau, dont je me suis occupée dans un travail antérieur (Fernandez-Rubio, 1977 b). Cette contamination oblige à mettre en marche la technologie adéquate pour réduire les polluants et/ou traiter les eaux polluées pour pouvoir les utiliser, ou au moins, pour pouvoir réduire les préjudices qu'elles provoquent.

Mais le principal aspect, qui maintenant nous intéresse de détacher, est celui relatif à l'utilisation possible de ces importants débits d'eau, de bonne qualité.

A ce sujet il faut tenir compte que l'extraction minière ne se réalise pas, en général, à débit constant mais á dépression constante, vers les puisards auxquels peut s'assimiler le dispositif de drainage. Pour le calcul des caractéristiques dimensionnelles de l'aquifère, dans ces conditions de dépression constante et de débit variable (normalement décroissant et affecté par des irruptions aux causes techniques), nous avons développé une méthodologie adéquate (Fernandez-Rubio et Yague, 1978).

La gestion de ces eaux signifie, sans doute, un changement d'optique, mais non de motivation, qui est imposée par le besoin de drainage, lequel est très affecté, dans des milieux karstiques, par la variation d'apports superficiels. Cela entraîne que le régime d'extraction peut être très différent du plus convenable pour la gestion, bien qu'on arrive facilement à des conditions d'utilisation des plus favorables, face à la demande, de celles qui présentent les émergences naturelles (lesquelles peuvent arriver à disparaître ou à voir réduire leur débit).

La planification de ces pour et contre nous conduit, finalement, à la convenance de s'occuper de la demande, de façon que l'eau de drainage de mine puisse s'utiliser comme débit de base, qui se complète essentiellement, en époques d'augmentation de consommation, par des eaux d'autres provenances, comme débit de pointe (Fernandez-Rubio et Pulido-Bosch, 1978 a).

Références

Fernandez-Rubio, R., 1974: Hidrogeologia de la mina Castilla (Sierra Menera, Guadalajara), Doc. Invest. Hidrol., **16**: 139—173, Barcelona.

Fernandez-Rubio, 1975: Problemas hidrogeológicos en la mineria, Bol. Geol. Min. España, **LXXXVI** (V): 55—157, Madrid.

Fernandez-Rubio, R., 1977a: Hidrogeologia aplicada a la mineria, Industria Minera, **170**, Madrid.

Fernandez-Rubio, R., 1977b: Introducción al análisis de la contaminación de los acuiferos subterráneos por procesos mineros, Curso Contam. Aguas Subterr. Centro. Intern. Formac. Ciencias Ambient., 23 pp., Madrid.

Fernandez-Rubio, R., 1980: Investigaciones hidrogeológicas aplicadas a la mineria y trabajos subterráneos, SIAMOS. III: 1437—1451, Granda.

Fernandez-Rubio, R; Pulido Bosch, A., 1978 a: Integración de las aguas procedentes del drenaje de minas en la gestión de recursos hidráulicos. Problemas y posibilidades. 3 Conf. Nac. Hidrol. General y Aplicada. SMAGUA-78, p. 167—172, Zaragoza.

Fernandez-Rubio, R., Pulido Bosch, A., 1978 b: Problemas hidrogeológicos que afectan a la explotación de la turbera de Padul (Granda, España), Estudia preliminar. SIAMOS: I: 125—132. Granada.

Fernandez-Rubio, R., Yague Ballester, A., 1978: Drenaje de una mina hasta nivel constante. SIAMOS. II: 741—749, Granada.

Kafri, U., Agron, N. A., 1978: A proposed hydrogeological model for future lignite mining and groundwater drainage in the Hulla Basin (Northern Israel). SIAMOS. I: 173—181, Granada.

Medina Salcedo, F., Fernandez-Rubio, R., Gordillo Martin, A., 1978: Hydrogéologie de la Plaine du Marquesado et influence de son drainage méridional (Dépression Guadix-Baza, Espagne), Ann. Inst. Geol. Publici. Hungarici., **LIX** (1—4): 336—350, Budapest.

Morell Evangelista, I., Sanchis Moll, E., Barbero Sevillano, J. P., 1978: Ejemplo del aprovechamiento de la variación lateral de permabilidad de un acuifero en el proceso de desague de una labor minera, SIAMOS. I: 219—226, Granada.

SIAMOS, 1978. L'eau dans les mines et travaux souterrains. 3 vol., 1550 pp., Granada.

Spiliotis, G., 1978: Groundwater control in opencast mining of a lignite deposit in Southern Greece, SIAMOS. I: 237—250, Granda.

Tettamanti, T., 1967: Hydrological and hydraulic characteristics of waters flowing from fissured carbonate rocks into mines, Hydrol. Roches Fissured Col., Dubrovnik, AIHS, **73**: 105—118.

Wolmarans, J. F., Guise-Brown, F. H., 1978: The water hazard in deep gold mining of the far West Witwatersrand—South Africa, SIAMOS. I: 329—346, Granada.

Rafael Fernández-Rubio

UWAGI O HYDROGEOLOGII KOPALNIANEJ NA OBSZARACH KRASOWYCH

Streszczenie

Artykuł informuje o najważniejszych problemach hydrogeologicznych, z jakimi stykają się służby kopalniane prowadząc eksploatację w seriach węglanowych podlegających krasowieniu. Omówiono metody badań reżimu wód krasowych, które są niezbędne przy pracach związanych z odwodnieniem kopalń.

Rafael Fernández-Rubio

SOME REMARKS ON THE MINING HYDROGEOLOGY IN THE KARST REGIONS

Summary

The paper supplies the information on the most important hydrogeological problems that are enconutered by the mining services while minnig carbonated series karstification undergoing. The author discusses the investigating techniques adopted to the karst waters regime, imperative to mines draining works.

Pál Müller*
István Sárváry**

Effect of Mining Activity on Thermal Karst Springs (Transdanubian Range, Hungary)

Abstract: The bulk of the coal and bauxite bodies in the Transdanubian Range are laying on the Triassic karstic rocks or on fanglomerate — like permeable rock consisting of debris of dolomite. The heat-collecting area of the thermal springs consists of deeply buried (1000—2000 m below the surface) karstic rocks connected with the neighbouring open karst areas. This the mining operation leads inevitable to strong depression in the horizon of karstic water. The authors suggest that the only method for the defence of the spring-systems is the reflux of the water of the mines in wells situated in adequate points between the mines and springs.

Introduction

It is a well known phenomenon, that around big karstic areas, hot-water springs can often be find, and thermal water is available by drilling too. Many of these sites are used as tourist and recreation centers, like in Budapest, where in the time of the ancient Romans and during the Turkish invasion (XVI. c.) the thermal springs were widely used.

The discharge of the hot karstic springs was rather uniform during centuries as it was proved by the measurements and historical records. It was soon recognized by the companies charged by the management of the baths, that in a given group of springs and existing wells the discharge cannot be increased by new drillings, the total amount of hot water remains nearly the same. It was also generally accepted, that hot-water systems rest undisturbed for long periods, therefore — before and after the II. World War — a lot of investments were made (baths, recreation hotels, etc.) based on the thermal springs. And so it caused a general surprise, when the discharge of the springs decreased quickly in the early sixties.

Some great thermal springs dried up in an extremely quick manner (in one or two years). These springs, well known for ages, first turned to be cold lakes, and soon to empty craters.

The hydrogeological investigations — after some years — proved univocally, that the disappearing of the hot springs was caused by mining activities within the neighbouring karstic areas. The coal and bauxit mines caused great depressions by sinking the karstic water level.

What was the reason that the mining of sixties was connected with an abruptly increasing pumping activity?

The advance of mining production forced the operations to descend to a level, deeply under the karstic water table. The new pumping sites with their enormous discharge disturbed profoundly the hydraulic equilibrium of large karstic regions.

The infiltrating precipitation — assuring the input of the karstic water-systems — remained nearly undisturbed, but the quantity of water, originating from the above alimentation, actually leaves the karstic massive in an essentially different distribution and with different temperature. The discharges — alimenting during centuries the thermal springs — actually are pumped by the mines.

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We should like to demonstrate the origin of the thermal karstic waters, and the unfavourable effect of the mining. We should also like to call attention that there is a possibility to avoid these disagreable environmental effects of the mines.

The Origin of the Thermal Karstic Waters

The crust of the Earth is heated by the thermal flux originating from the interior of the Globe. As the thermal conductivity

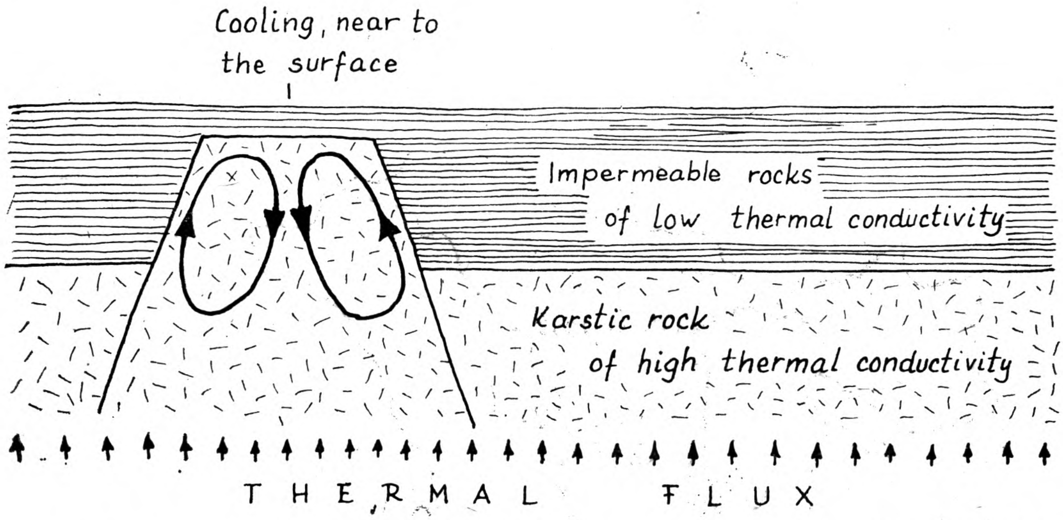

Fig. 1. Development of increased convecting cells in a horst-like karst body surrounded by clays or other low-permeability rocks

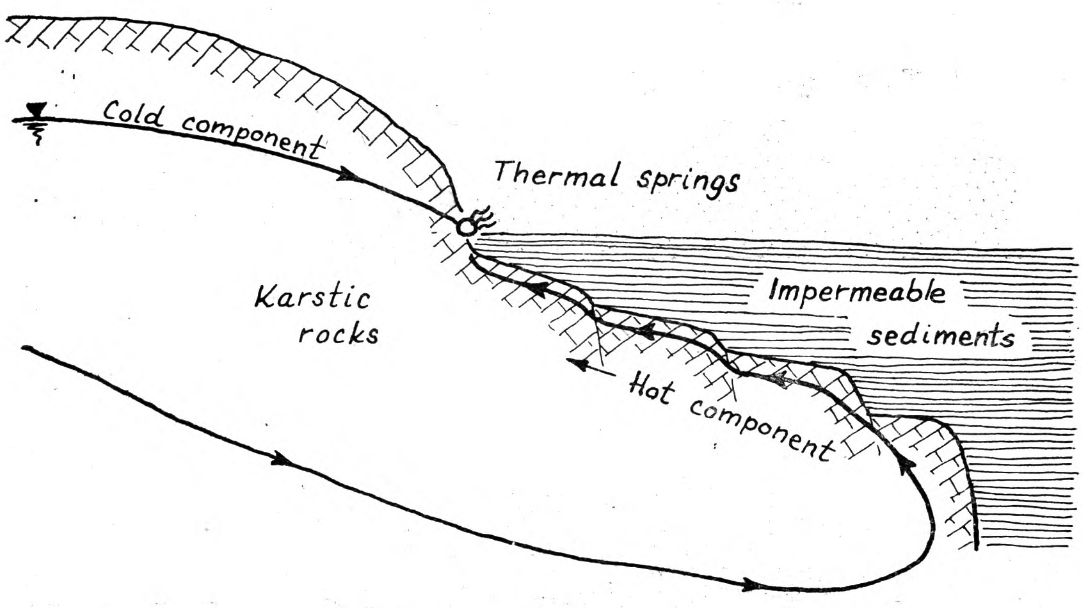

Fig. 2. Development model for the thermal spring of Budapest. After M. Vendel (1962)

of the rocks is not uniform, the heat arrives to the surface with slight differences. In the karstic rocks the propagation of the heat in increased by the heat-convecting (heat-transport) effect of the circulating water. As the water-conductivity (permeability) of the karstic rocks is very high, they can be considered as a massive of high thermal conductivity.

As a consequence, if there is a horst-like karstic body surrounded by clays or other low-permeability rocks, a group of well determined and highly increased convecting-cells develops (Fig. 1). This phenomenon was first explained by M. Vendel, and later developped by M. Vendel, P. Kisházi (1964). Naturally with an increasing thermal flux the forces acting in the convection process will be greater and the phenomenon develops more accented. In the basin of the Carpathians the geophysical investigations have proved, that the Earth-crust is rather thin, which causes an increased heat-flux.

If the karstic massive outcrops are bor-

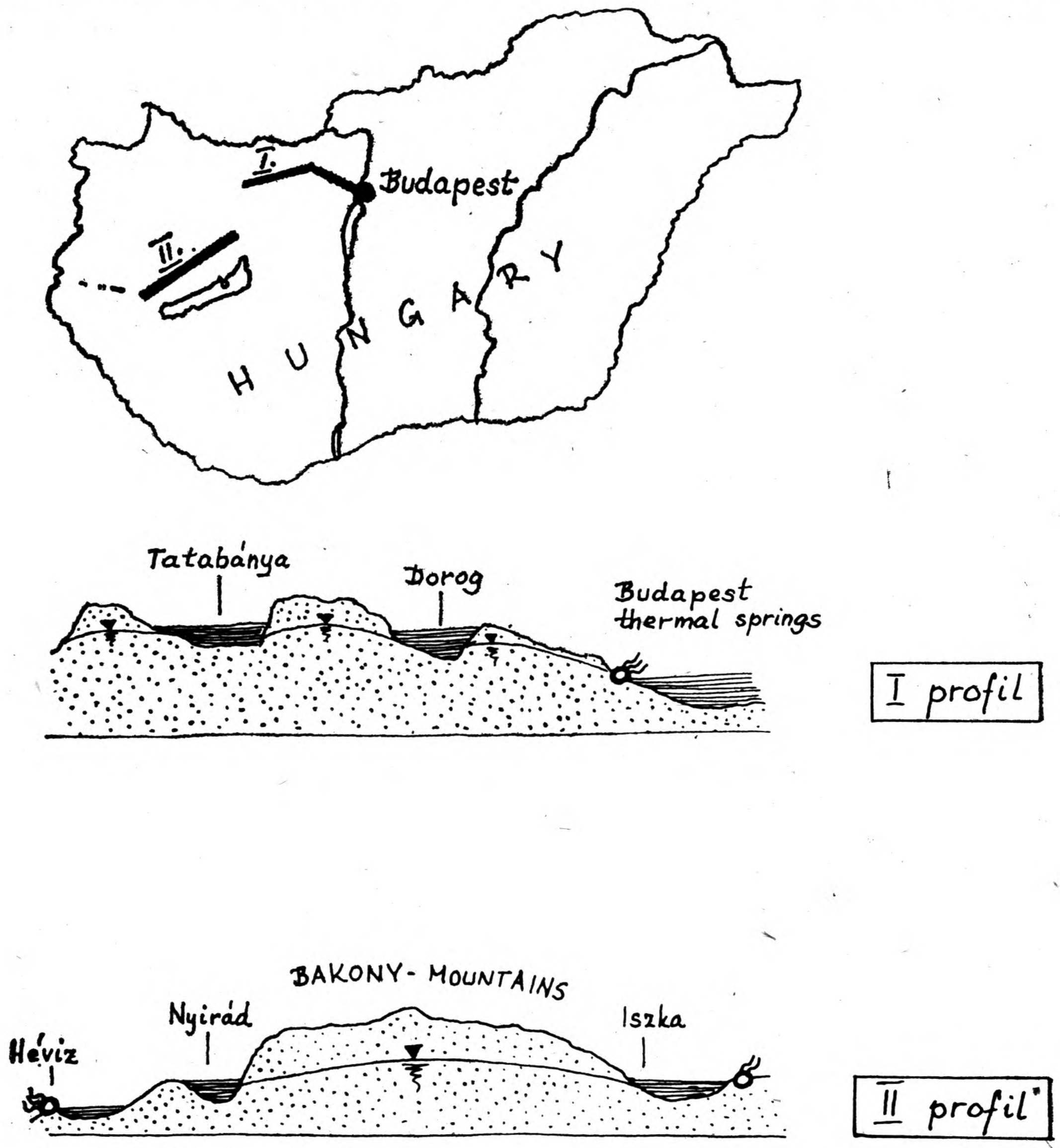

Fig. 3. Stratification of water:
A — labile balance between the cold- and hot-water layers, B — stratification of fresh-and salt-water in permeable rocks of coastal areas

dered by impermeable sediments, the heated water comes to the surface. Vendel proposed the schema of the Fig. 2 as an explanation for the development of the thermal springs of Budapest. This schema is evidently applicable for many other thermal springs of the World.

The subsequent investigations of P. Liebe, P. Lorberer (1978) proved the validity of Vandel's theory in all details, with a slight modification. The loop-like pathway of the heated water does not turn back in the same vertical profile, but makes a loop also in horizontal sense. This pathway and thus the heat-collecting area can be traced by measuring the heat-flow in the sedimentary cover. Under the open karstic areas the saturated zone is filled with cold karstic water.

In most spring areas there is a delicate balance between the cold- and hot-water layers, resulting a thermal stratification. This situation is analogical with the density stratification of the fresh- and salt-water in the permeable rocks of coastal areas (Fig. 4). It is well known, that a forced pumping causes a penetration of the heavier salt-water into the fresh-water wells. Similarly in the case of a group of thermal springs, the front of cold water advances by the forced pumping and gradually invades the area of hot water.

On natural conditions the interfaces are in an equilibrium between the hot and cold water masses. Therefore in many such sites, springs of extremely different temperature can be found in very small distances.

The Effect of Mines

The mining operations ruin the thermal springs mainly by displacing the interfaces between the hot- and cold-area in a dis favourable direction.

We demonstrate the casual connection of the mining operations and the hot-spring systems by two hydrogeological sections of the Fig. 3. The first profil shows the relationship between the thermal springs of Budapest and the Dorog and Tatabánya coal-basins. The second one is oriented parallely to the lake Balaton and cuts the Nyirád and Iszka bauxit localities respectively the hot-spring of Héviz and some other less significant thermal springs on NE.

The bulk of the coal and bauxit bodies in the Transdanubian Range are laying immediately on the Triassic rocks, or on a fanglomerate-like permeable rock, consisting of debris of dolomite. Thus the mining operation leads inevitably to a strong depression in the karstic water.

The spreading of the depression is faster in the confined aquifers (containing hot water), than in the unconfined ones (see in the Fig. 5). In the subsequent periods, marked by 1, 2, 3, 4 the cone of the depression is spreading relatively slow in the open karst (unconfined aquifer), because we have to remove important masses of water from the volume of the cone. On the other hand in the confined (buried) part of the karst, the decrease in the water pressure spreads with the speed of the sound (without removing of water-masses), and causes immediate drops of the water-level in great distan-

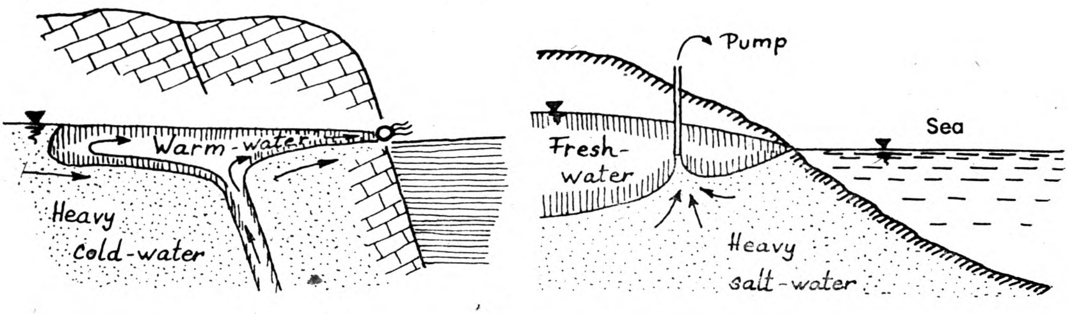

Fig. 4. Hydrogeological cross-sections with thermal springs in Hungary

ces. For instance in the Tatabánya coal-basin the increase of the water pumping dried out the Fényes-springs situated in a distance of 15 kilometres.

During the first period the cone of the depression remains mostly in the open-karst area, and so the water-level and the hydrostatic pressure (which controls the discharge of the springs) decreases only gradually. But when the cone of the depression arrives to the border of the confined area, the propagation of the depression turns to be a very rapid process, causing an immediate drop in the discharge of the thermal springs (Fig. 5).

According to the model of Vendel (Fig. 2), the hot-component of springs is alimented through the confined area (buried- karst), while the cold component comes from the neighbouring open karstic mountain. It is evident that the depression of the mining operations affects rapidly the hot-component, since it is situated in the confined system, while the cold-component remains nearly inaffected for a long period. Therefore in the spring-systems the depression is stronger in the hot water. The delicate interface between the cold- and hot-water moves towards the hot-area, allowing the inflow of the polluted, cold, alluvial- or surface-water, too (fig. 6).

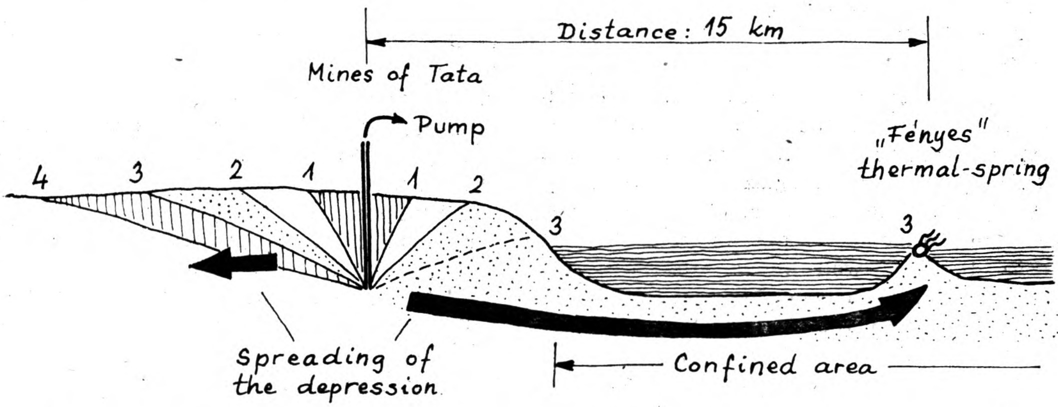

Fig. 5. Area of thermal spring occurence near the Mines of Tata

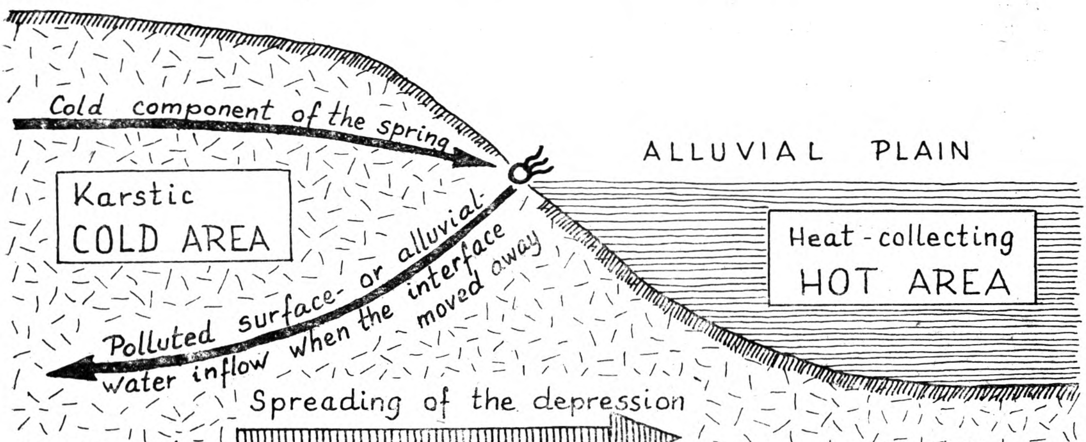

Fig. 6. Labile interface between cold- and hot-water layers (according to Vendel's model; see Fig. 2)

Protection of the Thermal Springs

According to the above considerations, the depression not only diminishes the pressure of the thermal waters, but causes their cooling and pollution too. The only method for the real defense of the thermal system is to block the spreading of the depression in a certain distance from the springs. This can be achieved by the means of a series of recharge wells, situated between the springs and the mine (Fig. 7). We have to optimize the implantation of the recharge wells, in order to avoid a too high percentage of recycling in the cone of the depression of the mines. In spite of this a certain recycling is inevitable, but this is the only process to protect our precious thermal springs. There is no other method available to avoid the drying out and the pollution of the thermal waters.

Conclusion

Before the beginning of the mining operations in karstic areas, we always have to consider their destructive effects on the neighbouring hot karstic springs. The only existing possibility to defend the springs is to recharge a fraction of the pumped water into a serie of appropriately situated recharge-wells. These wells can assure the reestablishment of the piezometric levels, necessary for the maintenance of spring-activity.

The installation and operation costs of the recharge system have to be built in the costs of the mining operations. The economy of mining has to be evaluated taking into consideration these additional costs.

References

Liebe, P., Lorberer, A., 1978: The interrelation between flow and temperature conditions in karstified rocks containing thermal water, VITUKI Proceedings, Annual Report 1975, 3/B. In hungarian: 162—175; English summary: 62—63, Budapest.

Vendel, M., Kisházi, P., 1962: Beziehungen zwichen Karstwässern und Thermen auf Grund der beobachten Verhältnisse in Transdanubischen Mittelgebirge, Mitt. d. Geol. Gesel. Österreichs in Wien, **55**, Wien.

Vendel, M., Kisházi, P., 1964: Interrelations between thermal springs and karstic waters on the basic of conditions observed in the Transdanubian Central Montain Range (in hungarian). MTA X Müszaki Tudományok Osztályának Közleményei, **32** (1—4): 393—417; **33** (1—4); 205—233, Budapest.

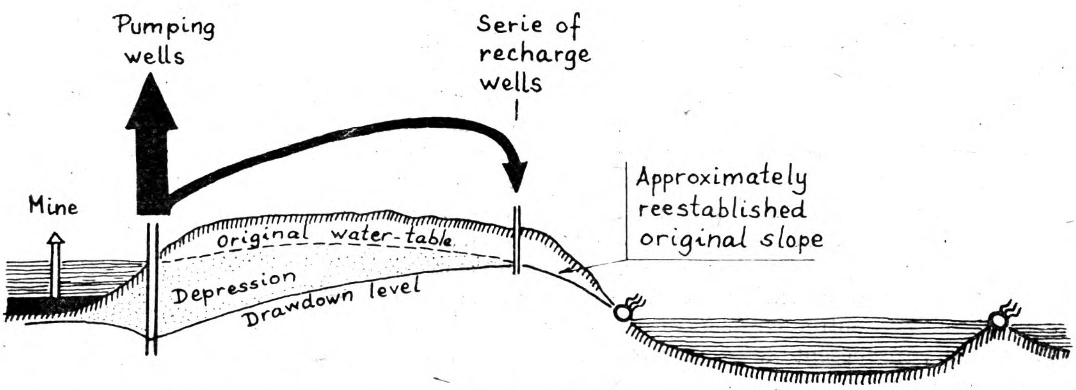

Fig. 7. Protection of the spring-systems suggested by the authors

Pál Müller, István Sárváry

WPŁYW KOPALNICTWA NA TERMALNE ŹRÓDŁA KRASOWE (PASMO TRANSDUNAJSKIE, WĘGRY)

Streszczenie

Obszar występowania źródeł termalnych w obrębie Pasma Transdunajskiego związany jest z głęboko położonymi (1000—2000 m pod powierzchnią) skałami krasowymi, które zachowują hydrogeologiczny kontakt z sąsiednimi obszarami krasu odkrytego. Wody ciepłe, których cyrkulację wymusza strumień termalny z wnętrza ziemi, kontaktują się z zimnymi wodami krasu odkrytego, co w efekcie powoduje stratyfikację termiczną tych wód. W wyniku prowadzonych prac górniczych w zwierciadle wód powstają silne depresje prowadzące do zakłócenia tej równowagi. W celu ochrony źródeł termalnych przed wpływem zimnych wód krasowych autorzy proponują przerzut wody z kopalń do studni usytuowanych w odpowiednich miejscach.

Pál Müller, István Sárváry

INFLUENCE DE L'INDUSTRIE MINIÈRE SUR LES SOURCES THERMALES KARSTIQUES (ZONE DE TRANSDANUBE, HONGRIE)

Résumé

L'apparition des sources thermales à l'intérieur de la zone de Transdanube est liée aux roches karstiques profondément situées, à 1000—2000 m sous la surface, qui gardent le contact hydrogéologique avec les régions avoisinantes du karst nu. Les eaux tièdes, dont la circulation est forcée par le courant thermal venant du fond de la terre, se mélangent avec les eaux froides du karst nu, ce qui a pour conséquence la stratification thermique de ces eaux. Il en résulte qu'au cours des travaux miniers, sur la surface d'eau apparaissent de fortes dépressions qui troublent cet équilibre. Pour protéger les sources thermales contre l'influence des eaux karstiques froides, les auteurs proposent le détournement des eaux des mines aux puits situés à des endroits convenables.

Judit Kovács*
Pál Müller**

Origin of the Hydrothermal Karstic Phenomena in the Buda-Hills (Hungary)

Abstract: There are several caves within the area of Buda-hills, created by hydrothermal activities. By analysing the various forms of caves as well as the ores and minerals developed due to the hydrothermal activity two different processes can be distinguished having been the driving forces of the development of the hydrothermal activities and the development of the caves of this way.

The Geological Development of Buda-Hills

The main mass of Buda-hills consists of carbonate rocks, the oldest rock type occuring on the surface is Ladinian dolomite with Diploporas. In the Lower Karnian stage mainly flinty-marly dolomites developed. The Upper Karnian dolomites contain generally only a small amount of unsoluble residuals. The spreading of the Norian (in few places it is partly Upper Karnian) Duchstein limestone is smaller, than that of the dolomites and it is limited mainly to the western parts of the mountain system. The stratigraphical unit is a geosynclinal formation of north-alpine features. The thickness of Triassic strata is some thousand metres, although it had not been measured yet.

Following the Triassic age, there is a gap in the deposits until the Middle Eocene, partly due to erosion. The phases of Cretaceous orogeny have caused structures of isoclinal folding at some places (mainly on the southern part of the mountain), fractures at other parts of the mountain. The transgressions of Middle Eocene have resulted in brackish and marine deposits, which contain smaller coal-series on the north-, north-west regions of the mountain.

The sea of Upper Eocene have flooded the whole area, and deposited 20—100 metres of Discocyclinan limestone overlying the corall limestone bedded by Lithotamnium (5—20 metres in thickness). The rate of development of carbonate sediments was decreased in the overlying formations, because of temperature drop and the subsidence of the sedimentary basin. The bryozoan-, and Buda-type marls (partly as a facies of the Discocyclinan limestone) are still of Eocene era. The traces of andezite volcanism of the same age can be found at many places. Laminited black clay and clayey marl mainly of euxinan facies were deposited over these strata („Tardian" formation), followed by the 800—1000 metres thick Kiscellian clay of Middle Oligocene. At some places sandstone (Hárshegyian sandstone) can be found, as a heteropian facies of the lower level of this formation. There are no younger marine sediments (sand, clay of Upper Oligocene and Lower Miocene) in the mountain. It is probable, that the area was uplifted in that time, forming an undulating country emerging from the sea.

In the Middle Miocene (Badenian stage), there had been an immense andesite volcanism, extending from Dunazug (Pilis)-hills to the northern border of Buda-

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-hills. The same period is characterised within the area of our recent investigation by a rapid uplift.

The material of the deposited clays in the valleys lying nearby testifies this hypothesis, since these clays contain a great amount of foraminifers and nannoplanctons, originating from the thick formation of Middle Oligocene (the Kiscellien clay). It is probable, a large part of the clay covering the whole mountain in a thickness of 800—1000 metres was eroded at that time. Another probable process forming the landscape in the Upper Miocene stage is the significant tectonic movement, which is indicated by faults and folds.

The Pannonian lake was able to inundate some parts of the mountains once again in the Pliocene. Since that time the mountain is raised gradually. The deposits of fresh-water limestone are the proofs of this process. The fresh-water limestone of the Upper Pannonian are lying at an elevation of 400 metres above sea-level, and those of Pleistocene can be found at 130—300 metres.

Thermal Activities within the Area Investigated

Two different thermal activities can be distinguished within the area of Buda-hills:
— phase I — one having volcanic origin,
— phase II — the other developed due to thermal flux.

The two phases (I and II) are separated even in time. It is probable, that volcanic activity was acting earlier. An effort is made in the following to establish a theoretical model describing the probable development of these thermal activities. When weighing the reliability of this modell it is necessary to consider the character of the process, and that only the final results are available in the form of karstic phenomena observable in the caves.

Characterization of the First Phase of Thermal Activity

The thermal activity due to volcanic process can be traced in two zones. The northern siliceous zone (from the Szabadság mountain till the Ezüst mountain) was developed under the influence of the Miocene andesite of the Dunazug mountain, while the southern zone was created by the andesite laccolite located in surroundings of Budaőrs in underlying position. Where the two zones contact each other, both influencing factors might have role in the development of caves, eg. Bátori cave.

In the Miocene, when the first phase of the thermal processes was acting, the carbonate rocks suitable for the development of the karstic forms was covered by thick Oligocene (Kiscellian) clay. (The andesite in the Dunazug mountain is undoubtedly a Miocene formation, while the ageing of the laccolite of Budaőrs will be further discussed). The volcanic activities around the two centres mentioned, provided both the high temperature needed for the development of thermal processes and the siliceous and gaseous volcanic materials transforming the rocks lying around. The thickness of the covering clay layer reached probably about 1000 metres, since it is still at 600 metres at some places even after the surface erosion.

The flow, maintained by the temperature difference was a confined one below the very thick covering layer and this structure ensured the possibility of the development of hydrothermal activity under a temperature higher than 100° C, as well as the continouos transport within the closed system (Fig. 1). The time of the erosion of the covering Kiscellian clay can be determined with a relatively good accuracy. The raising of Buda-hills was simutaneous with the Miocene volcanism (i.e. Middle Badenian). This uplift was gradually followed by filling up the grabens around the mountain with clay. Since these layers contain the foraminiferras, characteristic for the Kiscellian clay, but in a removed form, the erosion of the Middle Oligocene clay should have happened at the same time.

The age of the thermal activity can be estimated on the basis of the age of rocks the material of which is transformed by the thermal water. The aging in the northern zone is relatively simple, because the andesite was explored at many places on

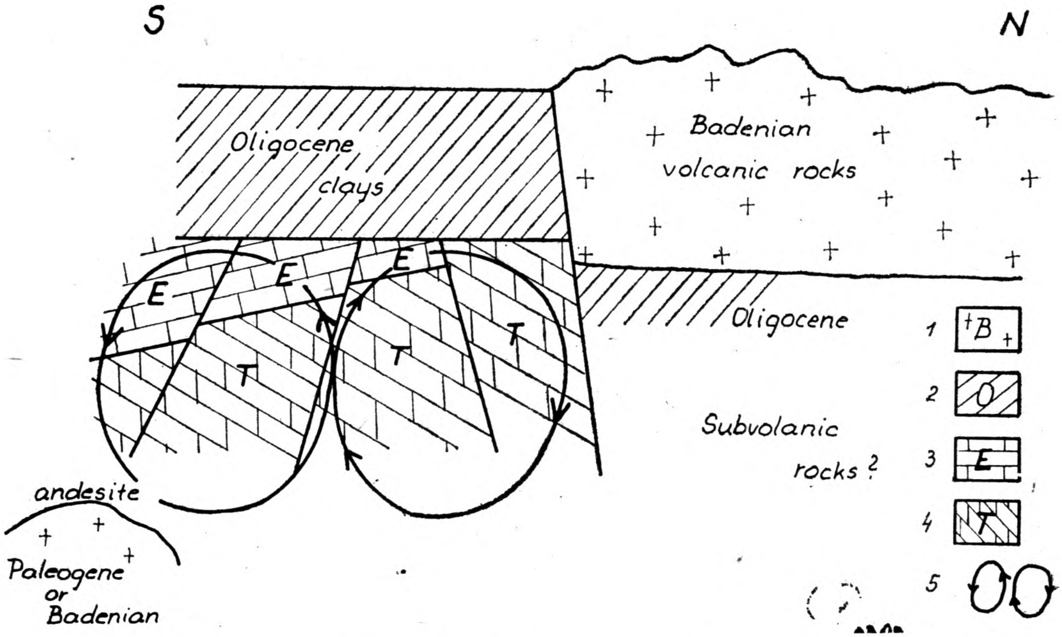

Fig. 1. Schematic profile through the Buda-hills during the Badenian (Middle Miocene):
1 — Miocene volcanic rocks, 2 — Oligocene clays, 3 — Eocene limestone and marl, 4 — Triassic dolomite and limestone, 5 — closed convective cells

the surface. Thus it is known, that the volcanism acted here in the Middle Badenian stage. The laccolite in the southern zone might have developed due to a volcanic activity either in the Paleogene or in the Middle Badenian stage, since it is interbedded between the layers of Triassic Dachstein limestone. On the other hand apart from siliceous dolomite and Eocene marl flinty layers can also be found in Kiscellian clay and Hárshegyian sandstone, the latter two having Oligocene age. It can be supposed, therefore, that the volcanism was acting after the Oligocene ie. in the Middle Badenian stage.

The passages and caves developed as the effect of hydrothermal steams and gases, since the presence of CO_2, SO_3 and other similar gases had important role to raise the capacity of water to dissolve carbonates. The development of confined flow due to the covering clay resulted in the precipitation of various minerals on the walls of caves.

There are three factors indicating the volcanic origin of the hydrothermal activities ie.:

1) presence of minerals testifying the high temperature,

2) occurence of elements transported generally by volcanism,

3) existence of the izotopes of calcite crystals.

The thermal water transported by the confined flow formed passages along the tectonic joints of the karstic rocks, boilers at the crossings of channels and spherical recesses at the higher horizons. The latter form develops generally in vertical shafts due to the lowering of the water table. The convective flow of air maintained by the temperature difference between the thermal water and the cooler rock is mentioned generally as the reason of spheric forms (Müller, 1974).

When the temperature difference is high and the passage is large the vapour is condensed from the vapour-saturated air on the wall and the water flows back in the form of thin film. Since the CO_2 content is also high the water is very aggressive. The highest amount of condensed water appears at the upper part of the large channels of caves. The solution of the rock material is very intensive here, while it is much lower in small openings, where there is not any considerable air transport. The final result of the process is the development of a sphere-shaped cell in which the movement of air can follow the most idealistic flow-pattern. At the upper part of the longer shafts more cells may develop above each other in this way.

The lower openings of the spheric cells are situated generally at the elevation of the water-table. These openings are generally narrow, because here the water flowing down on the wall and condensed from vapour is generally saturated and the fine suspended particles settle, protecting the rock against further solution. The returning water has generally high concentration, which raises the calcium content dissolved in the thermal karstic water, thus the mineralization starts instantaneously with the development of spheric cells, but it is influenced also by the changes of the position of the water-table.

The tectonic joints may be filled completely by minerals the development of which is characterised by the presence of high temperature, ie. barite, meta-cinnabarite, high temperature forms of calcite. The silification of the parent-rocks is also a consequence of the high temperature.

Development of Thermal Activity in the Second Phase

After the volcanic activity of Middle Badenian an extensive denudation started in the Buda-hills due to the regression, which initiated also the development of processes resulting in karstic forms. Only a part of the terrain was formed from karstic rocks in that period, where their raised blocks were not covered by younger sediments (Szabadság-, Nagy Szénás, Pilis-, and Kutya-mountains). This geological structure and the decrease of the thickness of the crust (which started probably at the beginning of the Lower Pliocene) resulting in high geothermic gradient made the development of the convective flow of thermal waters recharged by the water possible, which is stored in the karstic aquifer (Fig. 2).

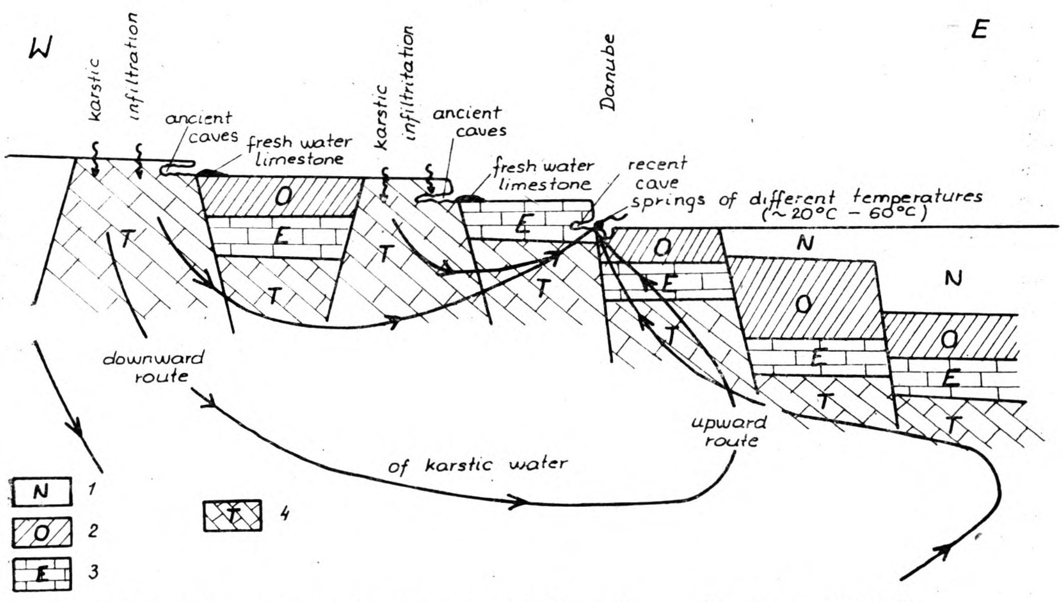

Fig. 2. Schematic profile through the Buda-hills (Late Pliocene — Recent):
1 — Neogene, 2 — Oligocene clays, 3 — Eocene limestone and marl, 4 — Triassic dolomite **and limestone**

The age of the second phase of thermal activity is estimated to be at the beginning of the Lower Pliocene. This hypothesis is supported by the fact, that the rapid development of sediments started also at that time in the basin, which process was also the result of the decrease of the thickness of the crust and the gradual lowering of the basement. Thus the karstic formations forming the basement of the sedimentary basin, were lowered to very deep position, but their recharge was maintained by the unconfined karstic blocks remained near the surface. The water transported to the deep aquifers along tectonic lines was heated by the geothermal energy being relatively high due to the anomalie mentioned before. The metamorphism of the sediments provided free CO_2 (Müller, 1971). Thus very active thermal water was raised near the surface through the draining lines. The water dissolved various minerals during this transport.

The thermal water might form hot springs or it was mixed with the cold water infiltrating through the surface and nearly horizontal galleries were formed in the mixing zone. Spheric cells might also develop along the vertical fractures, but the mineralization was considerably lower in this system, because the flow was not confined, thus the free CO_2 might live the system and the water transported also large amount of dissolved materials on to the surface through the springs.

The Marks of Hydrothermal Activities in the Caves of Buda-Hills

There are several caves in the Buda--hills the development of which was initiated by the hydrothermal activities having acted within the area. Examples are the Szemlőhegy-, the Ferenchegy-, the Mátyáshegy-, the Pálvölgyi-, the Bátori-, and the Molnár János caves. Generally the marks of both hydrothermal activities can be found in these caves (eg. the barite deposited on the wall of Ferenchegyi cave is probably the residual of the first phase, while the present corridor has developed due to the second phase, which fact is indicated by the narrow stretches, where the barite veins hindered the development of the channel). The generally observable forms can be distributed into two groups accordind to their origin. Thus the development of siliceous layers in the Pálvölgyi- and Mátyáshegyi caves may be the result of the first phase. The horizontal channels, being characteristic for the mixing zone of thermal and cold waters eg. in the Szemlőhegyi-, Ferenchegyi caves, were developed probably in the second phase. The calcite crystals, the main axis of which is parallel to the fractures, were formed during the thermal activity induced by volcanism (such forms can be formed in smaller caves of Martinovich mountain), while those staying perpendicular to the wall like teeth are probably the results of the second phase (examples of this type are around Üröm and in the quarries of Mátyás mountain).

The time of the development of the caves can be similarly groupped there are three possible variations:

a) the development of the cave was governed only by volcanic activity,

b) caves developed during the first phase, but further formed due to the second hydrothermal activity,

c) caves produced by the unconfined hydrothermal flow due to the geothermal anomaly.

The caves within the area investigated belong either to the first or to the second group. The Bátori cave and the Sátorkőpuszta cave near Dorog, can be mentioned as the very probable examples of the first group. The influence of the second phase was only very weak in these cases. This assumption is protected by the fact, that the external deposits of the open system are missing here. In the other caves (eg. Ferenchegyi-, Szemlőhegyi-, Mátyáshegyi- and Pálvölgyi caves) the marks of both phases can be found, testifying that both the volcanic activity and the second hydrothermal process influenced their development.

Comparison of Development of Caves and ore Forming Process Due to Hydrothermal Activities

As it was demonstrated in the previous chapter the hypotheses concerning the development of hydrothermal caves are based on the karstic forms and special deposits, which can be found in the caves today. The reliability of the assumptions can be provided by comparing the forms of the carbonate deposits containing ores (the ore content of which proves the hydrothermal origin induced by volcanic activity) and the appearance of similar deposits without ore, which can be found in the caves of the Buda-hills and which may have originated either from the first or the second phase of hydrothermal activities. This comparison shows a great similarity, a slight distinction can be made between the two processes following Kunsky's (1957) proposal. The term „hydrothermal karstic forms" refers to the results of hydrothermal processes in karstic formations, which did not include the development of ores, while the results of ore forming processes are called „thermomineral karstic form".

In Poland the Zn-Pb mineralization of Olkusz-mine is a typical example of the thermomineral karstic forms developed at the interface of a limestone and a dolomitic limestone, in the „caves" formed by hydrothermal activities in the latter layers (Sass-Gustkiewicz, 1975; Dżułyński, 1976). The hydrothermic vapours and gases at first transformed the limestone to dolomite. Later on they resulted in other brecciating factors ie. hydrothermal explosions and hydraulic fracturing, because the temperature of thermomineral solutions was above 100°C. One of the results of hydrothermal explosion is the rapid expansion of water into steam (Muffler et al., 1971). The hydrothermal explosions may lead to „chain reactions". For instance, with temporary increase in pressure, the solution is rammed into the enclosing rock, breaking it up by wedging the fractures open (Bridgman, 1952; Kents, 1964; Dżułyński, 1976). On the other hand, a sudden drop in pressure may brust the rocks apart and create rock fragments into which the solutions have permited under high pressure. Such phenomenon has been indicated by W. J. Phillips (1972) as „hydraulic fracturing" and is held to contribute to the formation of crackle and mosaic breccias.

The rock type developed in this way is called collapse breccia. Its character is determined partly by the properties of host-rock (eg. crystalline dolomite produced by metasomatic replacement of limestones and recrystallization of primary dolomites; Dżułyński, 1976). The pores remained between the solid matrix are saturated by hydrothermal solutions further changing the properties of the layer by mineralization. In the creation zone, pizolitic, lamellated ore formation may develop due to the relatively rapid flow of the solution (Dżułyński, 1976), which is very similar to the aragonite-calcite crystals, which can be found in the caves of Buda-hills, where the hydrothermal activity took place without depositing ores.

Comparing the thermomineral forms described previously to the karstic forms found in the caves of Buda-hills, there are many other similarities directly or indirectly proving the hydrothermal origin of those caves. In Sátorkőpuszta cave, near Dorog, eg. the relicts of collapse-breccias and so-called „box-work" features can be found on the walls and roofs of the lowest room. The parent rock is hard Dachstein limestone of Upper Triassic age, which is not suspectible to be fissured easily without hydrothermal activity. Fissures do not develop under relatively low temperature and pressure, only if the rock has been softened by solution and/or disaggregation before (Dżułyński, 1976).

One of the most characteristic features of the caves is the development of spheric cells. Their development in the contact zone of the cold rock and the warm water was already explained earlier on the basis of Müller's hypothesis (1974). The factors probably influencing the size of the cells are: the rock type, the stability of the rock and the position of the table of the thermal water, related to the thickness of the covering layer. Investigating the last factor, it can be stated, that the thin covering layer creates higher temperature gradient between the thermal water and the cold rock, thus the condensation of the vapour is more rapid, causing the stronger solution of the rock and the development of larger spheric cells.

It was also mentioned earlier, that the type of the minerals developed on the walls of the caves indicate also their hydrothermal origin (eg. the presence of barite is the proof of high temperature developed during the first phase of hydrothermal activity). In the spheric cells of the Bátori cave having lower position very rich aragonite-calcite formations of cauliflower-shape can be found, although, similar crystals can develop also from cold water, their great amount and the density lead to the supposition, that a rise of the level of the thermal karstic water followed the development of the spheric cells and the crystals were deposited by the thermal water.

In the Sátorkőpuszta cave the precipitation of gypsum is observable on the walls The presence of limonite ores in the Bátori cave was thought earlier to be of hydrothermal origin. The hydrothermal mineralization produces, however, the sulphid ores of the metals. Only the upper part of the ore vein may contain metalloxides, where the original sulphides were transformed by oxidization acting in the aeration zone. In the Bátori cave the sulphid ores are completely missing. The supposition according to which the Bátori cave was formed during the first phase of the hydrothermal activity contradicts also to the hydrothermal origin of limonite ores, viz. a confined flow system developed in this phase and the environment of such system is generally characterised by reductive activities. Thus the hypotesis stating that mineralization is younger than the development of the cave has great probability. The fact, that the contact zone between the ore and the limestone is missing, excludes also the assumption of metasomatic mineralization. It can be supposed therefore, that the limonite was deposited originally in the form of oxides and not transformed from sulphides. The aging of mineralization is very difficult. The origin of the iron may give some assistance in this investigation. The parent rock of the cave is covered by an Oligocene sandstone of Hárshegy type, which contains large amount of iron. The infiltrating precipitation percolated through the sandstone leaching it. The iron in the form of dissolved ferro-hydroxide reached the interface of the sandstone and the limestone. There the dissolved material precipitated due to the change of the pH value of the water. At present the iron ore saturates the lower layer of the sandstone, it can be found along the interface of the two different rocks or it creates apparent veins along the bedding planes of the limestone.

References

Bridgmann, P. W., 1952: Studies in large plastic flow and fracture, Metallurgy and Metallurgical Engineering Series, p. 362, Mc Graw Book Company.

Dżułyński S., 1976: Hydrothermal Karst and Zn-Pb Sulfide Ores, Ann. de la Société Géol. de Pologne, **46**, 1—2: 217—230, Kraków.

Kents, P., 1964: Special breccias associated with hydrothermal developments in the Andes, Econ. Geology, **59**: 1551—1563.

Kunsky, J., 1957: Thermomineral karst and caves of Zbrasov, Northern Moravia, Sborník Zeměpisné Československé Společnosti, **62**: 306—351.

Muffler, L. F. P., White, D. E., Truesdell, A. H., 1971: Hydrothermal Explosion Craters in Yellowstone National Park, Geol. Soc. Amer. Bull., **82**: 723—740.

Müller, P., 1971: A Metamorf Eredetü Széndioxid Karsztkorróziós Hatása (The karst corrosional effect of carbon-dioxide of metamorphic origin), Karszt és Barlang, **II**: 53—56, Budapest.

Müller, P., 1974: A Melegforrás-barlangok és Gömlofülkék Veletkeréséről (Abouth the origin and development of the spherical caverns and warm-spring-cave), Karszt és Barlang, **I**: 7—10, Budapest.

Phillips, W. J., 1972: Hydraulic Fracturing and Mineralization, Journ. of the Geol. Society London, **128**: 337—359.

Sass-Gustkiewicz, M., 1975: Stratified sulfide ores in karst cavities of the Olkusz Mine (Cracow-Silesian Region, Poland), Ann. de la Société Géol. de Pologne, **45**, 1: 63—68, Kraków.

Sass-Gustkiewicz, M., 1975: Zinc and Lead mineralization in collapse breccias of the Olkusz Mine (Cracow-Silesian Region, Poland), Ann. de la Société Géol. de Pologne, **45**: 303—324, Kraków.

Judit Kovács, Pál Müller

POCHODZENIE HYDROTERMALNYCH ZJAWISK KRASOWYCH W REJONIE WZGÓRZ BUDY (WĘGRY)

Streszczenie

W rejonie wzgórz Budy występuje kilkanaście jaskiń, których pochodzenie związane jest z działalnością hydrotermalną. Na podstawie przeprowadzonej analizy rozprzestrzenienia tych jaskiń i ich form oraz analizy występujących w rejonie kruszców i minerałów pochodzenia hydrotermalnego wyróżniono dwie fazy działalności hydrotermalnej:

— faza pierwsza jest związana z działalnością wulkaniczną w rejonie wzgórz Budy, datowaną na schyłek eocenu lub początek pliocenu, przy działalności hydrotermalnej rozgrywającej się pod warstwą przykrywającą o znacznej miąższości,

— faza druga o charakterze systemu otwartego, w którym wody były transportowane z dużych głębokości do strefy aeracji, a niekiedy i na powierzchnię przez strumień termalny związany z plioceńskimi procesami powulkanicznymi.

Analiza śladów występowania tych dwóch faz ma na celu przeprowadzenie klasyfikacji genetycznej jaskiń w rejonie wzgórz Budy.

Judit Kovács, Pál Müller

ORIGINE DES PHÉNOMÈNES KARSTIQUES HYDROTHERMAUX DANS LA RÉGION DES COLLINES DE BUDA (HONGRIE)

Résumé

Dans la région des collines de Buda il y a plusieurs grottes dont l'origine est liée à l'activité hydrothermale. L'analyse de diffusion de ces grottes et de leurs formes, ainsi que l'analyse de minerais d'origine thermale démontre qu'il y a deux phases de l'activité hygrothermale:

— la première est liée à l'activité volcanique, datée pour le déclin de l'Eocène ou le début du Plocène, et est accompagnée de l'activité hydrothermale dans la couche sous-jacente à une densité considérable,

— la deuxième est caractéristique au système ouvert, dans lequel les eaux ont été transportées de grandes profondeurs à la zone d'aération, et parfois à la surface par le courant thermal lié aux processus pliocènes post-volcaniques.

L'analyse des pistes d'apparition de ces deux phases a pour but la classification de grottes dans la région des collines de Buda.

REPORTS

V[ième] Ecole Spéléologique de l'Université de Silésie et de Wrocław

En 1975 l'Institut de Géographie de l'Université de Wrocław a pris l'initiative d'organiser une école scientifique consacrée aux phénomènes karstiques et à la spéléologie. Cette proposition résultait de l'appréciation de la situation actuelle dans la spéléologie polonaise et a été examinée durant le séminaire spéléologique organisé en automné 1974 à Lądek Zdrój par Polskie Towarzystwo Przyrodników im. Kopernika (Association Polonaise des Naturalistes) et l'Institut de Géographie de l'Université de Wrocław. L'école proposée avait pour l'objectif de permettre aux spécialistes, s'intéressant à la problématique karstique, de perfectinner leur qualifications au cours des séminaires et discussions scientifiques. Une telle école permettrait d'établir les principes de la collaboration et les programmes scientifiques communs entre les institutions scientifiques engagées dans cette thématique. Cette école assurerait également la place aux étudiants de géographie et géologie dont les thèses et séminaires seraient consacrés au karst. L'ambition des organisateurs était de publier succesivement les matériaux originaux présentés au cours de l'école.

La I[ère] Ecole Spéléologique a eu lieu dans l'intervalle semestrielle en février 1975 dans une station climatique à Lądek Zdrój (Basse Silésie). 61 personnes y ont participé, dont 11 maîtres de conférence agrégés et professeurs universitaires. Les participants représentaient les institutions scientifiques et les écoles supérieures en Pologne s'intéressant au karst, ainsi que trois principaux centres karstiques en Tchécoslovaquie: les Universités de Prague et Olomouc, et le Musée du Karst de Slovenie à Liptowski Mikulaš. En outre, parmi les participants de l'Ecole se sont trouvés les membres des organisations spéléologiques de Polonge et Tchécoslovaquie ayant des ambitions de faire des travaux scientifiques dans les grottes. Pendant la première Ecole a été établi le programme commun polono-tchèque des recherches sur le karst de Sudètes.

Les expériences d'organisation et l'apport scientifique de la I[ère] Ecole ont été mis à profit durant les écoles successives: II (1—15 II 1976 à Lądek Zdrój—Bozkov), III (1—14 II 1977 à Lądek Zdrój—Blansko) et IV (22—28 II 1978 à Lądek Zdrój). Ensuite l'organisation de ces écoles est passée dans les mains du Laboratoire de Géomorphologie Karstique, constitué à l'Université de Silésie à Sosnowiec en 1976, et ses collaborateurs étaient restés: Section Spéléologique de la Sciété Polonaise des Naturaistes „Kopernik", l'Office de Voïvodie à Wałbrzych, et l'Association Polonaise des Amis des Sciences à Varsovie. A l'Université de Silésie a été recommencée l'édition nationale de l'annuaire *Kras i speleologia,* qui est la continuation de celui *Speleologia* édité a Varsovie. Les matériaux des Ecoles Spéléologiques, y compris des comptes rendu, ont été publiés dans 5 volumes de cette publication 1(X) — 5(XIV). Au cours de l'Ecole sont organisées les expositions des plus recents travaux et publications scientifiques, on projette les films et les diapositives, on présente les expositions photographiques sur le karst et la spéléologie. L'Ecole est également l'initiateur des programmes scientifiques dans le domaine du karst et pendant son travail ont lieu des sessions des organisations spéléologiques.

Suivant la tradition, la Vième Ecole Spéléologique a été organisée à Lądek Zdrój du 5 au 12 II 1979 par le **comité d'organisation** composé de:. prof. dr Alfred Jahn (Université de Wrocław), doc. dr Vladimir Panos (Université à Olomouc), doc. dr Marian Pulina (chef de l'Ecole — Université de Silésie à Sosnowiec), mgr Andrzej Kozik (secrétaire de l'Ecole — Univerité de Silésie). Les chefs et les organisateurs des séminaires étaient respectivement: dr Adolfo Eraso (Université de Madrid), dr Jerzy Głazek (Université de Varsovie), doc. dr A. Kostrzewski (Université de Poznań), dr Alain Mangin (CNRS — Moulis), mgr Wojciech Magiera (CUPRUM — Wrocław), doc. dr Andrzej Różkowski (Université de Silésie), prof. dr Rafael Fernandez-Rubio (Université à Grenade).

Les participants représentaient les Universités suivantes: Budapest, Grenade, la Havane, Madrid, Poznań, Prague, Sosnowiec, Varsovie et Wrocław; les institutions de l'Académie des Sciences: Institut des Sciences Géologiques de PAN à Varsovie, Institut de la Protection de la Nature de PAN à Wrocław, Musée de la Terre de PAN à Varsovie et CNRS à Moulis, sections de l'Institut de Géologie à Sosnowiec, Wrocław et Varsovie; Editions Géologiques à Varsovie, Académie des Mines et de la Métallurgie à Cracovie, Ecole Supérieure Pédagogique à Kielce, Institut d'Hydrologie et Météorologie à Sofia, Water Designe Burau à Budapest, Musées à Częstochowa et Oradea; bureaux de projets miniers: POLTEGOR et CUPRUM à Wrocław, Association Polonaise des Amis des Sciences de la Terre à Varsovie, Conseil National de la Protection de la Nature; instituts et organisation spéléologiques: Ceska Speleologica Spolonost, Sprava Slovenskych Jaskyn, Circolo Speleologico e Idrologico Friulano, Magyar Karszt eś Barlangkutato Tarsulat, Institut Spéléologique à Budapest et Union Spéléologique Internationale auprès de l'UNESCO.

100 personnes environ ont pris part dans les travaux de l'Ecole, parmi lesquels: 79 participants de Pologne, 1 de Bulgarie, 10 de Tchécoslovaquie, 2 de France, 2 d'Espagne, 1 de Cuba, 1 de Roumanie, 3 d'Hongrie, 1 d'Italie.

Les travaux de l'Ecole ont été realisés en méthode de séminaires. On a organisé trois séminaires au cours desquels 36 confrences ont été présentées et communiquées. Le séminaire le mieux représenté était celui de l'hydrologie du karst où l'on a prêté beaucoup d'attention aux résultats des recherches du groupe de CNRS de Moulis sur la dynamique des eaux karstiques. Un film sur la circulation des eaux karstiques, spécialement apporté par les auteurs à Lądek, fut un supplément de cette thématique. Les deux autres séminaires, „Problèmes actuels du karst" et „Le karst et la pratique", ont abordé les plus essentiells questions dans ce domaine. Les conférences présentant des méthodes investigatrices dans le karst et des réalisations pratiques dans l'industrie minière ont particulièrement attiré attention. A part la problématique scientifique, les participants de l'Ecole ont consacré deux jours aux travaux liés à l'aménagement de la grotte de l'Ours à Kletno, aux perspectives des découvertes de nouvelles galeries et à l'organisation d'une musée de la nature auprès de cette grotte.

Durant les travaux de l'Ecole a été ouverte une exposition de la littérature karstique et spéléologique provenant de l'échange de l'annuaire „Kras i Speleologia" et apportée par les participants. En outre, dans la salle de conférence on pouvait voir une exposition de la photographie spéléologique — résultat du concours organisé par la Section Spéléologique de la Société Polonaise des Naturalistes „Kopernik" de Cracovie et la redaction de la publication „Wszechświat".

Les débats de la V^{ième} Ecole Spéléologique étaient accompagnées par les sessions du Comité de Conseil National de la Protection de la Nature discutant les problèmes d'aménagement de la grotte de l'Ours, et celles de la Commission Internationale de Physicochimie et d'Hydrologie du Karst U.I.S. Le compte-rendu de la session de la Commision U.I.S. a été publié dans le 4 (XIII) volume de *Kras i speleologia.*

Les participants ont reçu chacun 2 (XI) volumes de *Kras i speleologia* insérant les matérieux de la III^{ième} Ecole Spéléologique et le travail de M. Markowicz et M. Pulina: *Demi-microanalyse chimique quantitative des eaux provenant des régions du karst carbonaté* — édité par l'Université de Silésie à l'occasion de la V^{ième} Ecole Spéléologique. C'est un supplément N° 1 à la publication de *Kras i speleologia.*

Les cours prononcés pendant les séminaires ont été enregitrés sur la bande magnétique et sont à la disposition des intéressés.

Programme des travaux de la V^{ième} Ecole Spéléologique

6 II 1979

La séance d'inauguration de l'Ecole — ont pris la parole: mgr Z. Fedorowicz, vice-voïvode à Wałbrzych, dr A. Eraso, membre du présidium d'U.I.S, prof. A. Jahn, représentant des organisateurs de l'Ecole.

Cours d'inauguration de prof. R. Fernandez-Rubio: Etudes hydrogéologiques à Toreal de Antequera (Espagne).

En outre ont pris la parole: dr J. Głazek: Commémoration d'Edgard K. Tratman, dr P. Bosak et prof. A. Jahn: Commémoration de Józef Kunsky.

Séminaires: Grotte de l'Ours à Kletno — chefs: W. Magiera.

S. Kozłowski et M. Drzewiecka-Kozłowska: Conditions géologiques de la formation de la grotte de l'Ours.

7 II 1979

Matinée — travaux sur le terrain dans la grotte de l'Ours à Kletno et dans le Massif de Śnieżnik Kłodzki — chef. M. Pulina: présentation des résultats de recherches géophysiques dans la région de la grotte effectuées par S. Jodłowski (Institut de Géologie — Wrocław).

Après-midi a eu lieu une session de la Commission de Conseil de la Protection de la Nature présidée par A. Jahn.

8 II 1979

Séminaires: Hydrologie karstique — présidents: A. Mangin et A. Różkowski.

A. Mangin: Propositions de recherches sur le karst en méthodes physiques mettant à profit les résultats de recherches des systèmes karstiques

P. Müller, J. Kovacs (M.K.B.T. Budapest): Génèse du karst thermal dans la région des Collines de Buda (Hongrie)

F. Cser (M.K.B.T. Budapest): Modèle mathématique des sources karstiques

A. Pacholewski (Institut de Géologie — Sosnowiec): Résultats des recherches sur la dynamique des eaux fissurées-karstiques (?) dans les aquifères du Jura de Cracovie-Częstochowa

J. Motyka (Académie des Mines et de la Métallurgie, Cracovie): Prévisions des venues d'eau dans les mines exploitant les gisements de type karstique

M. Bakalowicz (SNRS — Mulis): Applications des méthodes chimiques pour déterminer les phénomènes karstiques

J. Valdes (Université à la Havane): Recherches physico-chimiques des eaux du karst tropic et leur rapport avec le milieu géologique

J. Jankowski, M. Pulina (Université de Silésie): Dénudation chimique sur les versants nord de Szczeliniec Wielki (Montagnes de Table)

J. Głazek: Résultats préliminaires des déterminations isotopiques de l'âge des concrétions en Pologne

J. Leszkiewicz, J. Wach (Université de Silsie): Problèmes hydrochimiques du bassin versant du glacier Antonia (Spitsberg)

R. Fernandez-Rubio: Etude hydrogéologiques d'une mine de minerai métallique dans la région de Ojos Negros (Espagne)

Film français: *Circulation des eaux karstiques* avec le commentaire de l'auteur du film — A. Mangin.

9 II 1979

Séminaire: Problèmes actuels du karst — présidé par A. Eraso et A. K. Kostrzewski.

A. Eraso: Nouvelle méthode de recherches sur le karst. Modèles naturels et convergence des formes

J. Rudnicki (Institut des Sciences Géologiques de PAN — Varsovie): Développement des grottes du kars thermal

P. Bosak, J. Sykora, S. Turma (Université de Prague): Nouveau type d'aragonite dans les dépôts de grottes

J. Otęska (Institut de la Protection de la Nature de PAN — Cracovie): Petites formes apparaissant à la surface des butte--temoins

W. Głazkowa (Grande Ecole de l'Agriculure, Varsovie): Recherches pionniers sur la reception souterraine radio effectuées par D. Doborzyński dans les grottes de la région de Cracovie

M. Łukasek (Université de Wrocław): Sur les phénomènes karstiques à Połom près de Wojcieszów (Montagnes Kaczawskie)

B. Koss (Université de Wrocław): Observations de la grotte Radochowska (Sudètes)

Après-midi—présentation des diapositives prises dans les régions karstiques en Polonge (Grotte de l'Ours), en Roumanie et au Cuba.

10 II 1979

Séminaire: Le karst et la pratique présidé par: R. Fernandez--Rubio et A. Różkowski.

L. Valenas (Musée Tarii Crisurilor à Oradea): Morphologie du karst de la région de Monts Bihor

P. Bosak: Influence des propriétés des roches carbonatées sur le processus de karstification

J. Řehak (Cesla Speleologicka Spolonost — Boskov): Influences anthropogéniques sur le karst en Tchécoslovaquie

A. Różkowski, T. Rudzińska (Institut de Géologie, Sosnowiec): Influence du karst sur la perméabilité des formations du calcaire coquiller dans la région de Silésie-Cracovie

T. Rudzińska: Méthodes de recherches hydrogéologiques sur les niveaux fissurés-karsques du Triassique silésien dans les formations complexes

A. Szynkiewicz (POLTEGOR — Wrocław): Influence du karst sur les travaux miniers dans les mines à ciel ouvert en Pologne

A. Pacholewski: Application des méthodes de la géophysique de surface sur l'exemple des recherches dans le bassin — versant experimental à Wiercica (Jura de Cracovie-Częstochowa)

C. Rzepa (Ecole Supérieure Pédagogique à Kielce): Propriétés physico-chimiques et errosives des eaux dans la grotte de Raj (Montagne de S^te^ Croix)

11 II 1979

Travaux sur le terrain dans les Montagnes de Table présidés par A. Jahn et M. Pulinowa.

12 II 1979

Cours de Z. Wójcik (Musée de la Terre de PAN, Varsovie): Terminologie polonaise spéléologique. Histoire de ce problème, discussion sur les problèmes présentés au cours des séminiares

13 II 1979

Débat de la Commission de Physico-chimie et d'Hydrologic du karst UIS — dirigé par A. Eraso et M. Pulina.

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