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T. A. K. REVIEW

WALL MICRORELIEF IN CAVES – EFFECT OF TURBULENCE

BY

M. ŞERBAN

SUMMARY

In addition to scallops and flutes, the microrelief on cave walls consists of two other forms described by Bögli (1984) as *Deckenmulden*, i.e. "ceiling troughs", and *Deckenmarken*, *i.e.* "ceiling marks". This shows that the study of these forms is not yet complete.

Given that the wall microrelief is thought to be an effect of turbulence this paper surveys the recent progress in the study of turbulence, as universal phenomenon in fluid dynamics. The turbulent motion is considered to be the primary cause of both relief micro- and macroforms like potholes, cut-off meanders and vertical undulation of the main conduits. As was shown by Wigley (1976), the whole development of the karst underground drain system, that is to the speleogenesis itself, is a turbulence process. For that reason, the author considers that the knowledge of the turbulent state is imperative for a better understanding of the interaction between water stream and soluble rock.

The paper gives the description of a complex form found in Huda lui Papară Cave (Apuseni Mountains, România), a macro-scallop bearing a great deal of smaller scallops, as a second-order relief. This form is explained as an effect of the developed turbulence *(turbulence développée)*, and so are the *ceiling troughs* described by Bögli, which are complex forms as well.

The paper discusses the possible in-cave occurrence of cavitation, which requires a very high speed of the water stream. Such velocity could have occurred in the cave Peştera cu Apă din Valea Leşului, in the lower section of the primary pressure conduit. In fact, a distinct relief, recentrly noticed on the flat ceiling of the cave, is very similar with the microrelief generated by water-propeller induced-cavitation which in shipbuilding is referred to as the "orange peel effect".

1. INTRODUCTION

We term all the concavities, of various size and shape, generated by the action o karst watern on cave walls, *wall microrelief*. They were previous classified by Bögli (1984) under the following designations :

1. Scallops, as defined by Curl (1974), *Fliessfazetten ;*

2. Flutes, as defined by Curl (1966), *Wellenfurchen ;* which occur mainly on the lower portion of the walls, reaching the floor level ;

3. *Deckenmulden* („ceiling troughs"), a name given by Bögli (1984, fig. 4) to a rare form. From Bögli's figure caption it results that the „ceiling troughs" are complex forms, their surface being covered by a second-order relief consisting of fields of much smaller hollows, called in German *Deckenmarken ;*

4. *Deckenmarken,* an original designation given by Bögli (1984, fig. 5), which could be translated as „ceiling marks". They are forms of negative relief, 1 to 3 cm in width, similar to small scallops. Such marks are often neglected by researchers because they are located on the gallery ceiling (Bögli). Şerban and Domşa (1985) recorded such forms, only 0,8 cm in average diameter, in Peştera Vîntului Cave (no. 3726/37 in Goran, 1982), which they describe as *micro-alveoli.* These microforms might be of the same nature as those designated by Renault (1958) as *cupules,* after Van Den Broeck et al. (1910).

From the already quoted photographs of Bögli, it results that the *Deckenmarken* formations may appear as a microrelief proper, or as a second-order relief, developed on the surface of a first-order relief, i.e. the ceiling troughs *(Deckenmulden).*

Desbribing the „ceiling troughs" and „marks", Bögli completes the list of the negative relief forms occurring in caves, which are not yet fully known. This shortcoming is chiefly due to the incomplete knowledge of the causes that may generate the wall relief. For a long time the main issue on debate was the erosion-*vs.*-corrosion controversy and not the primary cause which is of hydrodynamic nature. Nowadays, the microforms are known to be the result of the turbulent motion. Thus, before examining some relations between the turbulence of karst waters and its

effects, we shall review the main problems raised by the knowledge of turbulence itsefl, both as a hydrodynamic process and as a general phenomenon in the whole nature.

2. TURBULENCE AS A DYNAMIC FACTOR

Although scallops have been described already in 1894 as *Erosionsspuren* "erosion traces") by Kraus, and righteously interpretated as indicators of the water-flow direction, it was only as late as 1966 that Curl explained them im particular, the flutes, to be the result of the turbulence occurring between the boundary layer and the limestone wall. Curl also gave a method for estimating the stream velocity, based on the length of these microrelief formations.

The crucial point in explaining the making of the negative relief forms is that such forms represent traces (turbulence marks) of a turbulent motion carved on the cave walls by the karstic water streams. As was shown by White and White (1970), it is known that these streams are of turbulent flow. In other words, *turbulence,* as a general phenomenon in fluid motion, is the dynamic factor generating the marks, which we designate under the generic term of *wall microrelief forms.*

Given the large amplitude variation of the turbulent motion as a function of several parameters, especially of the water flow velocity, the wall representation will exhibit various, forms, which were designated by Bögli (1984) under the generic term *Fliessmarken,* "flow marks", which is fairly appropriate.

Until the works of Curl (1966) and Blumberg (1970), the understanding of the scallops genesis had grown slowly because the knowledge of the connection between turbulence and the negative relief it generates was poor. The turbulence itself is a highly complex hydrodynamic phenomenon (Mateescu, 1961), and the analytic study of turbulence as an universal physical phenomenon is only at the beginning (Lesieur, 1982). This explains why the genesis of certain "flow marks", as are those on the ciling (Deckenmarker), and the elucidation of some microrelief forms with complex structure as are the ceiling troughs (Deckenmulden), have been understood so late.

3. EROSION AND CORROSION AS TURBULENCE AGENTS

Admitting that turbulence is the main cause of the wall microrelief, the erosion-*vs.*-corrosion controversy is relegated to a secondary place. In principle, they both may be regarded as agents of turbulence. It only remains to find out the percentage is which one or the other process is responsible for the formation of various microrelief forms.

For a long time erosion was believed to be the modelling agent of these forms (Viehmann, 1976), as the long used terms *Erosionsspuren* (Erosion traces) by Kraus (1894) adn *Vagues d'erosion* ("erosionwaves") by Renault (1958, 1961), for the scallops suggest. Bögli (1984) took the

same view point in connection with two, out of the four forms he described, namely the scallops and the flutes. He refers especially to such formations in Hölloch Cave (Switzerland), but he also mentions, in favour of his thesis, several scallops developed on hard, insoluble rock, like the orthogneiss in the bed of he river Maggia, at Locarno (Switzerland). Our comments on this point will be given later.

On the other hand, Martel (1921) explains the scallops as being undoubtelly chemical corrosion marks *(empreintes de corrosion chimique)*, while Corbel (1963) uses systematic measurements of the "erosion" products carried off upstream and downstream the potholes to demonstrate that these negative, average-sized karstic forms, are prevailingly generated by the chemical dissolution — but not exclusively, however, in all the cases.

At Salangen, in Norwegian Lapland, the average growth of the dissolution products was over 50 mg/1, compared with less than 5 mg/1 for the transport of the mechanical-erosion products. For the potholes in Pont-des-Ouels canyon on the river Valserine, near Bellegarde (Ain, France), the ratio was more than 15 mg/1 *vs.* less than 1 mg/1, for the same products. At Pont-des-Oules, Corbel even found some potholes completely free of alluvia. In our opinion, this results, clearly stated for subaerian potholes, can be extrapolated in the case of the subterranean karstic microforms (wall microrelief).

Thus, we know many passages completely free of sand, in which scallops development is solely due to chemical corrosion. In this respect, mention should be made of the Robertson Avenue in Mammoth Cave (White and White, 1970) and the cave Peştera Neagră in Romania nr. 3444/3, Goran, 1982), visited by the author too. Bögli himself (1984) acquiesces that the "ceiling troughs" and "ceiling marks" are made only by corrosion, given that at ceiling level the water caries no stream-borne material and cannot erode. This is also valid for the scallops on a higher level of the side walls. Blumberg (1970, quoted by Curl, 1974) brought a decisive argument for the dissolution as a turbulence agent, based on the similarities between the scallops made by the hot air stream on the ice walls of the alpine glacier caverns and the wall microrelief in the limestone caves — see the pictures given by Lliboutry (1964, plate XX) and Anderson and Halliday (1969, fig, 11), the first of which shows scallops in a natural tunnel of Chardon Glacier, Oisans (France), and the second gives the view of a gallery in Paradise Ice Cave, Washington ; in both cases erosion is out of the question.

Nevertheless, from measurements made by Corbel (1963), erosion is not excluded as an agent of turbulence, although it is responsible for only 6 up to at most 10% of the process. A small amount of alluvia can increase the action of corrosion the mashing effect *(brassage)*. However, as Lange (1963) showed, larger amounts of alluvia "protect" the limestone sublayer against corrosion and prevent the bed deepening ; the whole changing geometry of cave structures is regulated by the corrosion (Lange, 1959).

The cases, quoted by Bögli (1984), of scallops developed on insoluble rock, lead us to consider erosion too as an active factor in the microrelief formation. This requires however, even according to Bögli, at

least a 10 cm/s water-stream rate and, according to Corbel, the presence of abrasive quartz sand. We believe that occurence of scallops on non-karstic rocks, otherwise rare, is an interesting research topic rather than an argument for a larger contribution of erosion to microforms making.

According to our own field research in Cerna Valley, up-stream of Herculane, the scallops on igneous rocks occur in areas where the strong water stream, permanently stirring the bottom sand, strikes directly the hard rock. Such spots are of particular topography, favouring the making of erosion scallops. Thus, the erosional process can be considered to be a particular case restricted to specific areas, whereas the corrosion covers all the soluble rock endo-harst areas.

Swinnerton (1942) mentioned that stream velocity in an important factor in estimating the limestone dissolution rate, while Kaye (1957) gave sound evidence for the value of the solvent motion for the same process. Recent studies in this direction, especially those referring to the role of thermic diffusivity, are due to Miotke (1972).

On the other hand, the part taken by the turbulent motion in pothole making has been stated already by De Martonne (1909) and experimentally proved by Viehmann (1959, 1962)) Corbel (1963) came to the conclusion that the crucial factor is : "the high acceleration and the mashing process, the abundant turbulent motions". Further, stating that : "potholes are absent in laminar-flow motion, and occur only in the areas with prevalently turbulent flow", Corbel assumes the same view on the origins of the wall microrelief, also.

From the genetic relation between microforms and potholes of diferent sizes, we draw the conclusion that the four types of marks examined by Bögli (1984), together with the potholes, form only one family of karst phenomena. It also results that the *half potholes*, termed by Bleahu (1982) *niches* ("pockets") — which are not basically different from the so-called *side-septa* of the same author — are intermediate forms between the proper potholes and the wall microforms.

The hydrodynamic control of dissolution forms considered as *turbulence marks* requires a better knowledge of this state of motion.

4. WHAT IS TURBULENCE ?

Let us consider the ideal case of a water stream flowing on an even bed and following a gentle slope. Floating objects will follow rectilinear, parallel trajectories. Objects passing by the same check points will be carried with the same speed. This is the image of a *laminar flow state* under which the future state of the moving system could be predicted.

With higher stream speed, a steeper slope and with the contribution of the conduit walls roughness, a *turbulents flow state* is established, characterized by eddies or vortices, which represent rotatory movements with different radius of curvature and unstable trajectories. A Reynolds critical number will mark the transition to the new state. Two floating objects, passing through the same points, at different time-intervals, will no longer have the same speed. And the longer the inter-

val ellapsed, the grater the speed difference. With increasing acceleration, the water motion becomes more and more irregular, the prediction of the future state of the system being impossible. *This is turbulence !*

Given that turbulence is a heavy energy-consuming process, the hnowledge of the turbulent state is of great practical importance in navigation, pipe-line liquid conveyance and plane building.

As a general phenomenon of fluid dynamics, turbulence occurs in the atmosphere as well, representing the most difficult problem in weather forecasting. Hence, in various scientific fields one must find the primary cause of the random motion, discover turbulence from its very beginning and be aware of the regular-to-turbulent-motion transition (Bergé, and Pomeau, 1980).

The first description of the turbulent motion, with applications in hydraulics, was given by the Boussinesq's theory (1877). The reports of Bergé and Pomeau (1980) and of Lesieur (1982) survey recent developments in the understanding of the turbulent motion.

5. "DISSECTED TURBULENCE"

(stages of the turbulence state)

Following Landau's (1956) unsuccessful theoretical approach, (Landau and Lifchitz, 1971), a new path in the analysis of turbulence was opened by Ruelle and Takens (1971), who used mathematical abstract entities called "odd attractors" *(attracteurs étranges)*. Thus, in order to identify the turbulent state of a physical, chemical and even biological system, a model is built, the system states being described by a certain number of parameters. A computer was used to obtain a graphic representation of the evolution of the system. If, by any reason, the system exhibits a random behaviour, i.e. a turbulent state, the graph will give an *odd attractor*, unlike other kinds of attractors, obtained when no irregular motion occurs (Ruelle, 1980).

Based on Ruelle and Takens' ideas and with some special means for fluid speed metering (laser anemometry associated with the differential interferometry), new experiments have been carried out upon the thermic convection produced in a fluid confined by two level plates subjected to a temperature gradient, through the heating of the lower plate — the so-called Rayleigh-Bénard convection (Bergé, 1975).

Cells or, more exactlly, convection rolls, will form through the rise of the heated fluid, as soon as Rayleigh's number *(Ra)* — a dimensionless number, proportional to the temperature difference ΔT between the plates — exceeds certain critical point *Ra c*.

A convection cell having a horizontal dimension *Lx* at most twice as large as the height *d* of the liquid layer is called a *small box*. This cell determines a system with a small number of degrees of freedom, which thus allaws only tho convection rolls. The system will be in a *steady, regular state*, because the velocity of the turbulent currents is uniform.

Steadily increase of the ΔT difference will result in several state changes, as follows :

1. Above a new level of Rayleigh's number, the convection speed starts oscillating at the value *Ra osc* (oscillating), with the frequency f_1; i.e. the system will have a *one-frequency steady periodical state ;*

2. Above the *Ra bip* (biperiodical) threshold, the flow will enter a *non-steady, biperiodical state,* with the frequencies, (f_1 and f_2) which generally do not have any simple relation between them ;

And, finally,

3. Overpassing the *Ra T* (turbulent) threshold, a *turbulent, wholly irregular state* is established.

The transition from a regular state to full turbulence is called *cascade* and the four jumps of the cascade are called *bifurcations ;* the first bifurcation is the transition from the state of rest to the convection state.

A three-periodical bifurcation has been recorded during a mercury aided convection test, this liquid giving additional information because of its magnetic field (Fauve, 1982).

While the two rolls in the small boxes have a wholly definite spatial scale, under the stabilizing influence of the side walls, i.e. *an intrinsic turbulence* of each roll, in the case of *large boxes* with several rolls, a different kind of turbulence occurs, in relation with the three-dimensional chaos of the structure, caused by the permanent variation of the roll position ; this non-steady state was called *phase turbulence.* An interference of distorted and disturbed rolls appears within the large boxes, because of the large number of degrees of freedom (Bergé and Pomeau, 1980).

From the above-stated we derive an important element for the study of the cave microrelief : the properties of turbulent structures are strictly dependant on the dimensions and geometry of the recipient in which the phenomenon occurs : otherwise stated, these structures are influenced by the shape and size of underground conduits.

6. CHARACTERICS OF TURBULENCE

Surveys of turbulent flows in identical macroscopic conditions — the same geometry of the recipient, the same turbulence-inducing external factors — exhibit identical statistic trends. If the means of these features are constant in time, then the turbulence is said to be *stationary (steady).* If they are invariable with spatial translation, turbulence will be called *homogeneous,* and if the means are constant with rotation, the turbulence will be *isotropic* (Lesieur, 1982).

The well-developed scallop fields, with sharp crests between the concavities, can be considered to be the result of a stationary turbulence. Curl (1974) gives several conditions for such a state. Of these, let us mention a conduit of a regular cross-section, respective of whether it is circular or rectangular, but which should be constant over a rectilinear long enough segment. We are dealing here with a certain geometry of the recipient, for which the calculation formulae for evaluating the stream velocity, based on the scallop length, can be valid but only within the limits of a stationary turbulence.

The size of the scallops also indicates that the turbulence depends on the conduit geometry (diameter or width of the gallery). For the

same mean velocity of the streams in two different size conduits, the flow velocity near the walls will be lower in the wider conduit and, hence, the scallops will be larger in the wider conduits (Curl, 1974, fig. 4) ; in other words, the scallops of given length indicate higher average speed in a wide conduit than in a narrow one.

Althogh eddies are accepted to be elementary entities of the turbulent motion, a definition of the notion of eddy is a difficult, if not impossible, matter (Lesieur, 1982). The most simplified representation of an eddy is that of a fluid particle following a circular path, as in the thermic convection rolls. In this case, the magnitude or *scale* (échelle) of the eddy is the cercle's diameter.

We shall not delate upon the analysis of the sinusoidal or even more complex structures, as are, for instance, these resulting from the interaction of the recycling eddies. We shall only state that, broadly speaking, an eddy is a structure developing in a flow of given characteristic magnitude. The magnitude of this structure is called *the scale of the eddy*. Otherwise stated, there is no definiton so far to incorporate all varieties of eddies, but we can measure the magnitude of these structures.

The smallest eddies correspond to the scale of the *dissipative structures,* a term adopted by Lesieur after I. Prigonine's terminology in the thermodynamic study of irreversible processes. We shall not go into the details of this physical phenomenon. Instead, we shall state that the *dissipation scale* is a function of the friction forces given by the fluid's viscosity. The less viscous the fluid, the smaller the diameter of the eddies. For liquid helium at temperatures near 0°K, with the viscosity tending towards zero, the dissipation scale is of the order of tens of nanometers. Photographs of such minute eddies have been taken using the special technique of d'Humières (1980). For the atmospheric air, the dissipation scale is of about one milimeter and for the water it must be somewhat greater.

Judging by the *cave turbulence marks,* the smallest forms metered in the cave Peştera Vîntului average 8 mm, with a maximum of 16 mm and a minimum of 4 mm. The largest structures are confined only by the geometry of the space in which the flow occurs. Thus, in the atmospere, the cyclones' diameter is of several thousands kilometers, whereas in the karstland the water wirlpools generating potholes can reach several meters, as far as the width of the cave galleries, or stream beds permit.

7. CAUSES OF TURBULENCE

The emergence and development of turbulence is a result of the in-time growth of the instability given by the non-linear terms of the Navier-Stokes equations in fluid mechanics. This non-linear structure entails that, in the case of turbulence, each eddy interacts *a priori* with all the other eddies. By analogy with the statistical mechanics, where the quetion of N bodies is studied, turbulence may be approached as a

problem of N eddies in strong non-linear interaction. The problem is even more difficult in the case of a non-conservative system, where the kinetic energy is dissipated through viscosity. The impossibility of a reliable forecast concerning the in-time development of a turbulent flow, because of the increase — through non-linear interaction — of the incertainties related to the small structures of the initial state, has been called *"the deterministic impredistibility of developed turbulence"* (Lesieur, 1982).

8. DEVELOPED TURBULENCE

Developed turbulence (turbulence développée, Lesieur, 1982 ; full turbulence, Mateescu, 1961), is understood as the most general from of the turbulent motion, in which the most different eddies — from the dissipation scale to the maximal structures allowed by the recipient geometry — overlap and juxtapose one another.

In this theory of developed turbulence, Kolmogorov (1941) assumes that the eddies are ordered according to a *magnitude hierarchy* (hiérarchie de taille), in which the kinetic energy is constantly transferred from the large to the small structures. He speaks of an *energy cascade*, which can schematically represented by an eddy splitted in two smaller ones. In this concept of cascade, one resorts to an analogy with hydraulics : in a steady state, the energy is assumedly introduced in the system from the large structures and then gradually passed to the ever smaller ones. When the energy reaches the scale of the dissipative structures, is is dissipated through viscosity. The amount of dissipated energy is thus equal to the introduced amount of energy in the system. Kolmogorov introduced the concept of energy cascade in order to explain the dynamics of the three-dimensional turbulence, which is likely to occur in caves as well, judging by some particular flow marks.

9. IMAGES OF TURBULENCE

Lesieur (1982) reproduces several photographs of experimental eddies, two of which are invaluable for understanding the formation of some flow marks yet under dispute. They illustrate the rolls generated in a mixing layer at the interface of a helium flow (fig. 1 A) and nitrogen flow (fig. 1 B), experimentally produced at the California Institute of Technology by G. L. Brown and A. Roshko.

Another noteworthy visualization, carried out with the aid of two coloured liquid tracers in a hydrodynamic tunnel at the ONERA Institute, France, is a high-resolution image of the so-called "von Karman alleys". These structures border a turbulent trace with vortices (eddies) rotating alternately from one edge of the trace to the other (Tarnowski, 1986). These images are useful to understand the formation of turbulent karstic marks, which will be discussed below.

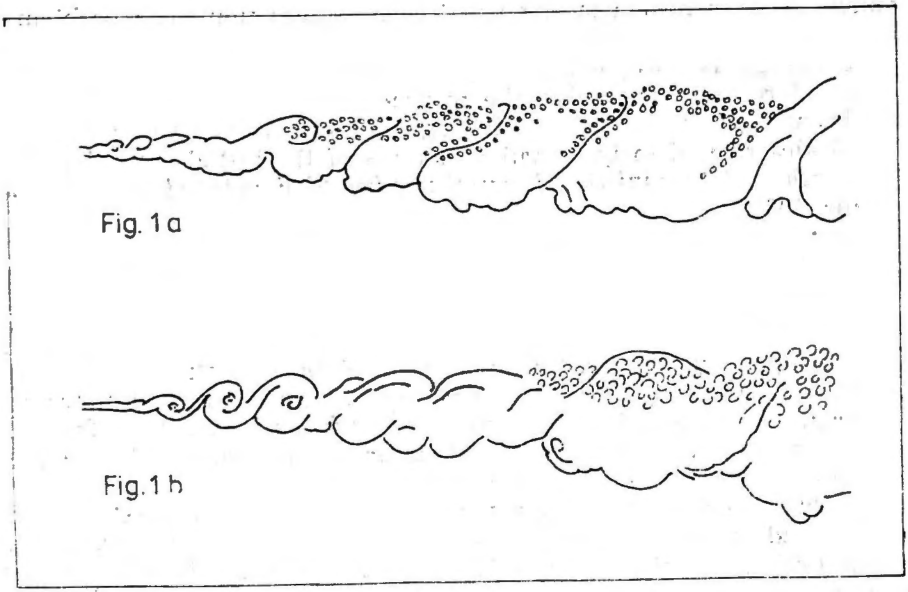

Fig. 1. Scheme after photographs of developed turbulence rolls, experimentally generated at the Pasadena Institute of Technology. 1.A. Turbulence of helium flow. 1.B. Turbulence of nitrogen flow — for which the secondary rolls are evidently bigger than those of helium flow. Helium flow has twice the Reynolds Number of the nitrogen one. (after Lesieur, 1982).

10. UNIVERSALITY OF TURBULENCE

Regarding the wall microrelief in caves, Sweeting (1973) acknowledges the turbulent origin of the karstic marks, as well as their universae character, stating that : "Both scallops and flutes, though they are (di-)solutional forms, are the result of the character of the water flow ; the rock is of secondary importance".

Turbulent processes, i.e. disordered, impredictible oscillations, occur not only in fluid flow, but also in other fields of physics, chemistry and even biology, whenever interactions between non-linear functions appear (Ruelle, 1980). A recent example is Maganza's experiment (1986) for the clarinet sounds, fron the state of rest to the acoustical chaos. This experiment goes through all the three intermediate stages of *bifurcation,* as in the case of thermic convection.

Bergé and Pomeau (1980) opine that turbulence is the most difficult issue of contemporary physics, while Lesieur (1982) pointed out that we have nowadays a deeper knowledge of the atomic nucleus than of the turbulent structures developing in one cubic centimeter of the air we breathe.

Kenneth Wilson studied the universal physical phenomena occurring in various cases when the matter changes its state. For his theory of critical phenomena, he was the sole Nobel Prize winner for physics

in 1982. "The understanding of other complex phenomena, such as the *hydrodynamic turbulence*, will very likely incorporate, some way or another, ideas somewhat akin to those of Wilson" — said one of his collaborators : Brésin (1982).

Wilson uses the concept of *chaos* for the disorderly behaviour known in hydrodynamic turbulence and declares that in all these various domains there are amazing similarities in behaviour. The matter in disordered state seems to count less than the phenomenon of disorder itself.

Wilson's ideas in physics were the basis of the mathematical studies carried out by Feigenbaum (1983). The latter discovered several regularities in the behaviour of some mathematical equations, repeatedly applied, the results being reinserted in the same equations as input data. The equations could be first made to produce regular sequences of numbers having an identifiable logic, then disorderly sequences. Investigating the passage of the numbers from order to disorder, Feigenbaum observed several particular patterns in this transition process. Feigenbaum and his collaborators were greatly astonisched to realize that some new equations, completely different from the first ones, seemed to produce the same transition patterns. Their mathematical description seemed always to include several numbers, now known as *Feigenbaum numbers*. Therefore, the patterns were likely to posses the attribute of universality, which exerts a magical influence on scientists (Gleick, 1984, 1985).

Were these regularities indeed universal, they should have also appear in actual systems governed by equations substantially more complicated than those examined by Feigenbaum, as are the equations related to fluid dynamics or to quantitative changes in animal populations. This hypothesis was confirmed in 1978, when the patterns discovered by Feigenbaum were detected during fluid experiments carried out in France (Bergé and Pomeau, 1980). For that reason, Maganza (1986) characterizes the clearly-defined sequence of state changes in his acoustical experiment as a *Feigenbaum scenario*, a sequence of events occuring with mathematical rigour.

These are the scientific premises that have to be taken into account while studying the microforms of the wall relief in caves.

11. REMARKS ON CAVE MICROFORMS

11.1. *Complex marks*

The author's first opportunity of seeing complex forms of wall microrelief is due to Bögli's photograph (1984, fig. 4), which shows "ceiling troughs" *(Deckenmulden)* associated with micro-alveoli *(Deckenmarken)*. Bögli says nothing about their formation mechanism and gives no measurements. If we admit that the micro-alveoli in Bögli's photograph have a minimal magnitude of 1 cm, given by Bögli for the small forms *(kleine Formen)*, we can estimate the large forms, i.e. the ceiling troughs, to range between 15 and 20 cm (for a cross-section, see fig. 2 A).

In August 1985 I visited Huda lui Papară Cave (No. 3221/9, Goran, 1982) to meter the scallop length, in order to estimate the flow velocity. Entering the first side gallery on the right bank of the underground stream, I was amazed by the great variety of scallops and other corrosion forms (see fig. 3).

At the first look, this lateral gallery seems to be a cut off meander of the main passageway, with stagnant water. However at a closer look, the more or less stagnant water, is the lake of sump, a karst spring actually. Hence the whole gallery is a right side affluent, consisting of two, almost parallel branches heading straight to the main passageway ; the southern, upstream branch having 40 m, whereas, the northern, downstream branch is 48 m long, the latter being the actual drain of the spring.

In flood conditions, the water from the main passageway enters the two branches of the affluent, thus generating an encounter of two contrary streams which run into each other. In these conditions, the unusual geometry given by the two branches produces a developed turbulence, which may be considered responsible for the great variety of flow marks, specially in the upstream branch.

Several *half potholes* are found in the southern branch, mainly on the North-Western wall close to the spring. On the surface of these potholes, I noticed a second-order relief consisting of large scallops, ranging between 15 and 20 cm in diameter, one of which was located about 80 cm above the gallery floor and carved in the very edge separating two half potholes. This scallops exhibits its own microrelief — of the third order — formed by units about 3 cm long. (see the cross-section in fig. 2 B).

This complex mark consisting of two microforms different in scale, resembles, by its combined character, Bögli's (1984) "ceiling troughs" both being similar to the image of a quasi-two-dimensional *developed turbulence* (see fig. 1 A and 1 B), in which quasi-two-dimensional rool of the first order are topped by much smaller second-order rolls, the later representing three-dimensional turbulent structures.

The universality of hydrodynamic turbulence makes us believe that the images of helium and nitrogen flows may serve as an explanatory model for the formation of both the "ceiling troughs" in Hölloch Cave (Switzerland) and the complex side wall mark in Huda lui Papară Cave (Romania).

11.2. *Micromarks*

The *ceiling marks* (Deckenmarken, Bögli, 1984) or micro-alveoli (Şerban and Domşa, 1985), which are likely to be corrosion forms synonymous with those decribed by Van Den Broeck et al. (1910) as *cuples*, are the smallest microforms and indicate, according to the the helium and nitrogenflow models, a high velocity of the stream. The model shows that the number of tiny thre-dimensional turbulent structures increases and the structures are smaller with larger Reynolds number. Thus the number *Re* for the small structures in fig. 1, A is about twice the number in fig. 1, B (Lesieur, 1982).

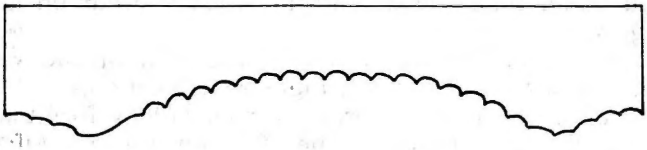

Fig. 2a

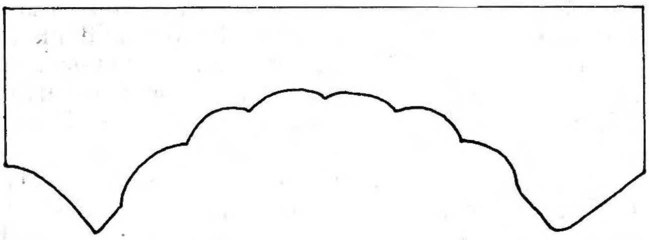

Fig. 2b

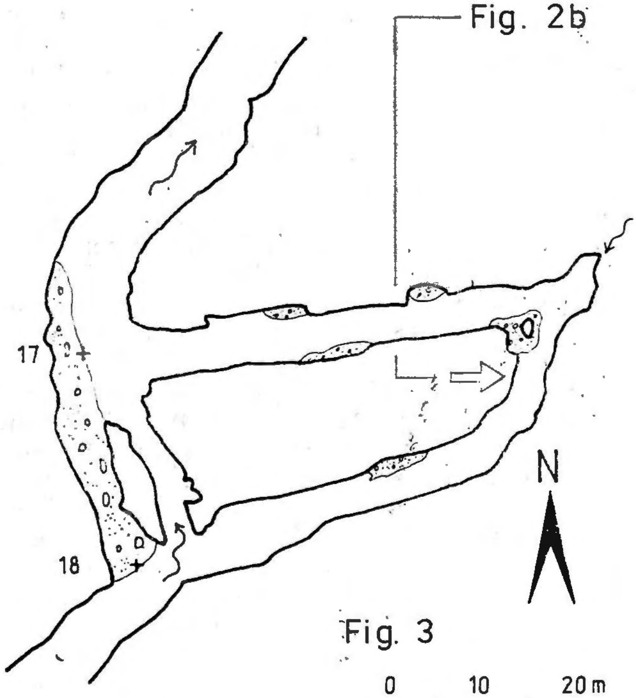

Fig. 3

Fig. 2. Cross sections through complex turbulence marks. 2 a. Schematic representation of the "ceiling troughs" described by Bögli (1984, p. 122, fig. 4) as *Deckenmulden.* 2.b. Schematic representation of the complex mark observed in the cave Huda lui Papară (Romania).

Fig. 3. Plan of the confluence of a right side affluent with the main passage in the cave Huda lui Papară (Romania). This geometry generates opposite currents at floods. It is the spot where the complex mark in fig. 2.b. is to be found. (after the survey of the "Pollaris" club, Blaj, Romania).

We assume that the micro-alveoli in the cave Peştera Vîntului have also generated under high-speed conditions. They occur on a plane, horizontal ceiling, which belonged to a cross-section of a *primary press water conduit* (phreatic tube), located at the lower loop of the vertical undulation of that conduit, hence on a highspeed location.

In the case of these microforms, Curl's (1966) formula for speed calculation yielded a rather high value of about 1,9 m/s. Of course, this rate has to taken only as a first approximation, since a comprehensive study of the relation between average water speed and the size of the micro-alveoli is not yet available. We have to mention that in the cave Peştera Vîntului, Şerban and Domşa (1985) have found micro-alveoli on the overhang of an erosion level also. This fact, together with the development of the micro-alveoli independently, or on the surface of larger forms as are, for instance, the „ceiling troughs“ in Hölloch Cave, need further research.

Concerning the formation of micro-alveoli, Bögli (1984) says : „Sie sind wahrscheinlich unter Hochwasserbedingungen umgewandelte *Kondenswassergrübchen,* die in fliessenden Wasser kleine Wirber hervorrufen und durch diese umgeformt werden“. (They are probably small cavities produced by the condensation water and altered during high floods, which in flowing water, generate small eddies and are altered by them).

Thus, Bögli (1984) states that micro-alveoli are secondary formations, conditioned by a pre-existing relief caused by the condensation water. This statement forces us to review the corrosion effects of condensation water, for wich the available data are scarce so far.

Some information on the condensation process in caves are given by Bögli (1978). However, being topoclimatic and seasonal, condensation occurs only in particular areas of cave. The location of the micro-alveoli in the cave Peştera Vîntului makes condensation unlikely. Thus, the primary character of micro-alveoli as turbulence marks seems a more plausible hypothesis.

The quantitative valus of condensation-induced corrosion in caves was noticed already by Trombe (1952, p. 120). Referring to the morphologic aspect of corrosion, he only recalled the surface weathering of the limestone walls, by which the decalcification clay is only partially removed while the underlying rock is further dissolved. In such conditions, it is hard to imagine the formation of a relief of distinctive features.

The corrosive character of condensation water was confirmed by Andrieux (1970) ,who observed the brownish colour of persistent drops unlike the limpid drops of recent formation. He scrutinized the physics of the pendent drops and established methods of calculating the amount of condensed water and measurements of vaporisation and condensation. He recorded in Sainte Cathérine Cave (Ariège, France), on July 4, 1967, 0.046 1 water/m^2 and on July 1, 1968, 0.413 1/m^2 on the same spot, the drops covering 24.9% of the 300 m^2 area of condensation. However, he dealt not with the drops detaching and the morphology of the surfaces affected by condensation has not been surveyed.

Mais (1967) describes several wall relief forms as being generated by condensation water corrosion in Schlenken-Durchgangshöhle Cave, near Hallein (Salzburg, Austria). The 100 m long tunnel-shaped cave

crosses a mountain from North to South, being ventilated by both ends. When the normal ventilation course is inverted, condensation occurs on the walls near the Southern entrance and eventually can lead to high dripping.

The mere coincidence between the corrosion relief, the condensation area and the additional lack of seepage water maks Mais assume a cause-to-effect relation between condensation and microrelief formation. He describes, among others, concave, slightly vaulted disolution forms, up to 20 cm in diameter, which present — as a second-order relief *(Subskulptur)* — a number of dimple-shaped hollows (grübchenartige Vertiefungen), up to 3 cm in diameter and up to 1 cm depth. Given their location on the open bedding faces *(Schichtfugenbruchfläche),* one can assume they are ceiling formations.

This structures, consisting of two differently sized forms of negative relief, is strikingly similar to the structures in fig. 2, A and 2, B, which we interpretated as marks of developed turbulence. Knowing from Andrieux (1970) that the condensed water drops are randomly distributed, a causal relation between the condensation process and the corrosion relief described by Mais (1976) could hardly be assumed.

We may righteously ask whether in a well ventilated cave, as this only 100 m long tunnel in Schlenkengrat Mountain, the condensation water is able to become aggresive so close to the entrance, where the meteorological conditions are the same with those outside the cave. In Cetăţile Ponorului Cave (No. 3441/18, Goran, 1982), an insurgent cave of larger proportions, the scallops occur on the stream walls only as far as several hundreds of meters downstream from the entrance.

Different corrosion effects are also associated with the condensation water (Bögli, 1978, p. 102 and 162). The small „ceiling cavities" (dimples) *(Deckengrübchen)* might be either the flat hollows resembling a fingertip print, described in Ellipsengänge of Hölloch Cave, or small, deeep hollows with sharp edges and crests (scharfen Graten und Spitzen), carved by water drops in a quick condensation („die Tropfen können bei schneller Kondensation tiefe Grübchen herauslösen"), as it happens in Dome Home Cave (Ky, U.S.A.).

The latter form is similar to the micro-alveoli described by Şerban and Domşa (1985), so much the more as it occurs : „mainly on the lower face of the almost horizontal bedings" (Bögli, 1978).

Without an opportunity to compare the above discussed microforms — at least on the grounds of photographic documentation — we cannot make a sound decision based only on the descriptions provided by various authors. From the variety itself of the karst microforms described by Mais (1976) and Bögli (1978) as effects of condensation water, it results that a cause-to-effect relation to satisfy all the cases is doubtful. We believe that this issue needs more field research, with special attention to the geometry of the underground conduits involved in the formation of the microforms under discussion. The development of the turbulence marks and of the *forms attributed to condensation water* as well must to be surveyed in their environmental and in their „ecological" conditions.

11.3. Is there any cavitation in caves?

Hjulström (1935) and subsequently other authors quoted by Warwick (1953) drew attention on the cavitation process as a possible explanation for scallop formation. Corbel (1963) showed that cavitation occurs in the following inequality is fulfilled;

$$\frac{v^2}{2g} > p + h$$

were v is the flow velocity in m/s;
g is the gravitational acceleration in m/s^2;
p is the atmospheric pressure, in water column, or 10,3 m of water;
and h is the local piezometric pressure in meters of water.

Acording to this formula, cavitation needs velocities higher than 20 m/s and piezometric values h lower than 9 m water column, while the higher velocity ever recorded was that of the underground river Timavo, Trieste district (Italy), which reached 5 or at most 6 m/s on October 6, 1908; therefore the scallops cannot be attributed to cavitation.

Bögli (1978) stated that cavitation could possibly occur under high local speed in karstic conduits, but he went on saying that forms indicating the presence of cavitation in caves are not known yet.

However, the available information on underground morphology could lead to the discovery of such forms. Based on Deike's model (1967), it has been established that in the lower bend of a vertical undulation, provided a large amplitude, i.e. a substantial level difference, the ellyptic cross-section of the press-conduit tends to flatten, becoming a horizontal slit of ample width and small elevation (Şerban and Domşa, 1985). The reduction of the conduit cross-section contributes to the local velocity increase, on the grounds of the continuity principle. Through the subsequent floor deepening, these primary slits lead to cave sections with a flat, horizontal ceiling, as are those in the cave Peştera cu Apă from Valea Leşului (No. 3720/3, Goran, 1982), surveyed by Cocean (1975, 1979).

This cave was generated by the underground drain of the Acre basin, area of 1,75 km^2, through the sinkhole Ponorul de la Acre. Down to the exurgence in Leşului Valley, there is a 165 m difference of elevation and 1600 m map distance (Rusu, 1978, 1981). If we approximate the underground drain to a circular conduit of 2 m in diameter and taking into consideration the hydraulic gradient also, the primary resurgence could have had a velocity of at least 11,6 m/s. Considering that the gallery sector with the flat ceiling had an initial cross-section of 5 m, which is the size of its present width, but a height of only 20 cm, the local speed could reached 36,4 m/s, or even twice as much, if the slit was only 10 cm high. In both situations, the conditions for the cavitation process would have been fulfilled.

During a short visit in this cave, in January 1986, I surveyed a portion of the flat ceiling, on its lowest section. The microrelief of the area under consideration exhibits fine capillary holes, like the small punctures of a needle. Their diameters vary, but average about 0.5 mm; larger holes, 1—2 mm in diameter, are few. The edges of the tiny holes

are widened in a funnel-like shape, so that minute mounds, of various diameters and little difference in elevation, appear between several neighbouring holes.

Since the surface of the ceiling is thoroughly devoid of turbulence marks and considering the high difference in elevation between the insurgence and the exsurgence of the cave, some cavitation marks can be assumed. Indeed, this microrelief in the Peştera cu Apă from Valea Leşului resembles somehow that formed arround a 1.5 cm deep *errosion furrow* (sillon d'érosion) generated on a water propeller blade by a cavitation cloud after several tens of hours of maximal speed operation. This microrelief was called after Aucher (1985, fig. 4) the *orange peel effect* with a roughness of 1 mm (en „peau d'orange" d'un millimètre de rugosité). We consider this information not complete ,but nevertheless interesting, for further sure identification of cavitation marks.

Cavitation occurs in pressure pipe-lines, on the blades of water propellers and on various turbines, and represents an important research field, given the considerable damage caused, especially in the case of high-performance equipment. In conditions of local negative pressure, vapor or gas bubbles are formed. They have a very short life, of only 10^{-4} — to — 10^{-5} seconds, and they implode (collapse) as soon as they re-enter a high pressure area. The impulsion induces a fluid microjet of less than 0. 1mm in diameter, hammering the wall with a pressure of 10^3 to 10^4 bars at the impact point for a liquid in the state of rest, and with a pressure that could reach 10^5 to 10^6 bars for the bubbles approaching the wall at a rate of 1 m/s.

The immediate question is how can the microrelieff formed on the cave ceiling be preserved ? Discussing the possibility of cavitation in karst conditions, Verdeil (1961) supports the idea that in cave cavitation occurs, the underground drainage will undergoe dramatic changes in a short time-interval. According to that hypothesis one high flood alone, which would have generated the „orange-peel"-like microrelief on the flat-horizontal-ceiling, might have made drainage so deep, that another flooding of the ceiling would never repeat.

12. DISCUSSION

We have seen in the theory of the turbulent motion that the geometry of the flow conduits affects the way in which turbulence manifests itself. Thus, the unusual turbulence marks in Huda lui Papară Cave can be attributed to the particular geometry of two active galleries. Likewise, the hypothesis of the exceptional occurrence of cavitation on the flat ceiling in Valea Leşului Cave is suggested by the geometry of the whole Acre drainage system.

Since man-made pipes for liquid conveyance are given elements with designed parameters, we can state that the effect of their geometry on turbulence is a *technical concept.*

Much to the contrary, according to the *karstic concept,* wich represents exactly the opposite relation, the geometry of the recipient is af-

fected by the turbulent flow. Much more the turbulentflow itself is the dynamic factor largely controlling the development of a karstic drain within a limestone massive. In other words, the parameters of a natural press water conduit are established by the water flow itself.

The pioneers of this point of view were White and Longyear (1962) and Howard (1964), who showed that the crucial factor in karstification is given by the *dissolution in turbulent flow conditions*. In ideal natural conduits of circular shape, the flow becomes turbulent as soon as the diameter reaches 2 cm.

Considering the widening by dissolution of a conduit as part of the mass transfer theory, Wigley (1976) demonstrates that as soon as the turbulent flow state begins, the widening rate of the process increases 30 times, compared to the case of laminar flow. This means that in an aquifer, the first conduit to have reached the turbulent-flow condition will colect more and more water and will shortly become the only main conduit.

Secondly, Wigley shows that such a main conduit, only a few kilometers long, must have a diameter of at last 2 meters.

In terms of the karstic concept, the turbulent flow state is responsible for the geometry of the conduit. This reasoning leads to the idea of hydrodynamic studies on small-scale models or through computer simulation, in order to experimentally demonstrate vertical undulation (Deike's model), as general phenomenon, characteristic of the dissolution press water conduits. This studies could furthermore verify the hypothesis of the flattening of elliptic cross-sections in the lower bend of this undulation, following an increase of the flow speed.

Considering that the formation of an undulation whithin a vertical plane and the formation of river meanders are analogous, we believe that the principle of minimal energy dissipation or of the maximal discharge, demonstrated by Hâncu (1964, 1967) for the river meanders, will be equally appliable to the *vertical meanders* in the karstic press-conduits.

In terms of the hydrotechnic concept, we may suppose that the variable geometry of karstic conduits — known as the alternative elliptic and rectangular cross sections (Deike, 1967; Vanin, 1971 Şerban, 1984) — would be the result of the principle of minimal energy dissipation. From that idea derive the prospect of applying changing geometry to the pipe-lines for conserving energy during the long liquid conveyance, and, at least, in some particular cases of high flow velocity.

In the third place, Wigley's theory (1976) makes possible the quantitative determination of the heat effect on the development of karstic conduits. Thus, it has already been established that the effects of diffusivity, which increases with temperature, prevail over the decrease of limestone solubility with temperature.

The diffusivity itself was studied by Miotke (1972) He showed that the development rate of the tropical endocarst should exceed that of temperate or cold regions. Jakucs' (1980) research in Cuba's karst confirmed this idea.

The increasing diffusivity effect with temperature is of interest not only for comparing the rate of karstification in various areas in the world, but for the analysis of the climatic variations in the same cave also, based upon a comparative study of the successive corrosion layers. The cave Peştera Vîntului in Romania could be an appropriate object for such research-works.

Lehmann's idea (1932) of applying the fluid mechanics to the flow problems of underground water streams in limestone, gains new developing prospects with the advent of supercomputers, which are able to perform one milliard operations per second, and thus simulate the Navier-Stokes equations on hexagonal networks. Such equations could not be solved by classic mathematical methods, except for some limited particular cases.

The value of the new simulation method was underlined by Tarnowski (1986), based on the first experimental attempt at a graphical representation of a turbulence structure due to the French researchers Dominique d'Humières and Pierre Lallemand from École Normale Supérieure in Paris. This representation hais been obtained with the help of a network of 1536 × 512 nodes and 9000 time-steps and illustrate a „Karman alley", simulated on a FPS vectorial computer, able to perform the operations for each node in 2 microseconds.

This experiment opened the way for designing special equipments fors such calculations and which will permit in the near future to investigate a turbulent motion, to interpret the various forms of wall microrelief as turbulence marks and to carry out research projects like those suggested above.

13. CONCLUSIONS

The complexity of corrosion microforms, like scallops, flutes and other insufficiently studied forms, call for better knowledge of the turbulence state of special parts of the underground water streams since all the forms of wall relief in the caves are effects of turbulence.

Thus, complex forms located in a larger concavity, whose face presents a second-order relief, i.e. microforms like the marks described by Bögli (1984) as *Deckenmulden,* could have been generated by a *developed turbulence.*

The study of the corrosion microforms requires knowledge of the shape and size of the gallery in which they occur, because the turbulence action also depends on the *geometry of the recipient* housing the flow. Thus, the *complex marks* was used in this paper, while the term *corrosion marks* was previously used by Martel (1921) for scallops only.

Given the particular geometry of the underground drainage from Ponorul Acre to the cave Peştera cu Apă from Valea Leşului (Bihor county, Romania), we can suppose that during the early karstification, the stream velocity could have exceded the critical level of *cavitation* in the area of the *flat-horizontal ceiling,* surveyed by Cocean (1975, 1979).

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MICRORELIEFUL PARIETAL DIN PEŞTERI — EFECT AL TURBULENTEI

Rezumat

În afară de linguriţe, sau alveole, (scallops) şi caneluri (flutes), microrelieful parietal din peşteri mai cuprinde şi alte două forme descrise de Bögli (1984) sub denumirea de *Deckenmulden*, adică „albii de tavan" şi *Deckenmarken*, respectiv „amprente de tavan", microforme a căror geneză nu a fost clar înţeleasă pînă în prezent. Rezultă că studiul acestor forme nu este încă terminat.

Deoarece formele de microrelief parietal sînt considerate a fi efecte de turbulenţă, lucrarea trece în revistă progresele recente din studiul turbulenţei, nu numai ca fenomen propriu în dinamica fluidelor dar şi ca fenomen universal din fizică, din chimie şi chiar din biologie.

Mişcarea turbulentă este considerată nu numai cauza primară a microformelor de relief parietal ci şi a macroformelor cum ar fi marmitele, meandrele incastrate şi ondulaţia în plan vertical a conductelor sub presiune carstice. După cum a arătat Wigley (1976), întreaga dezvoltare a sistemului karstic de drenaj subteran, adică însăşi speogeneza, este un proces controlat de mişcarea turbulentă. Din acest motiv, autorul consideră cunoaşterea stării de turbulenţă drept un imperativ pentru o mai bună înţelegere a interacţiunii dintre cursul de apă şi roca solubilă.

În lucrade se descrie o formă complexă găsită în peştera Huda lui Papară (Munţii Apuseni, România), şi anume o macro-linguriţă avînd, ca relief de ordinul al doilea, un număr mai mare de linguriţe mai mici. Această formă este explicată ca un efect de turbulenţă dezvoltată, la fel cum sînt considerate „albiile de tavan" descrise de Bögli (1984) sub denumirea de *Deckenmulden*, care sînt, de asemenea, forme complexe.

Se mai discută despre apariţia posibilă a cavitaţiei în peşteri, fenomen care necesită viteze foarte mari ale cursului de apă. Astfel de viteze au putut să survină în Peştera cu Apă din Valea Leşului (Munţii Apuseni), în partea inferioară a conductei primare sub presiune. Un microrelief de o formă parfticulară a fost observat recent pe tavanul plan al peşterii, relief foarte asemănător cu cel generat de cavitaţia indusă de o elice, care în construcţiile navale este denumit „coajă de portocală" (microrelief en *„peau d'orange")*.

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T. A. K. REVIEW

NATURAL AND ARTIFICIAL TRACERS IN THE STUDY OF THE HYDRODYNAMICS OF KARST

BY

E. GASPAR, I. ORAŞEANU

SUMMARY

1. INTRODUCTION

The idea of tracing the underground path of water by observations made on the surface goes back to ancient times. Straw, leaves and dyes have been introduced into one sinking point and then observed in an adjacent source, thus establishing the connection of the two and the direction of the flow.

The first remarks concerning the use of tracers to investigate underground waterflow belong to the Roman historian Josephus Flavius (A.D. 100—37) who showed in his work "The Jewish War" that in A.D. 60 Philip, the tetrarch of Trachonitis, established the origin of the Jordan river (namely the Banias spring) using chaff as a hydrological tracer. Actually, the tetrarch had introduced chaff into the Ram Crater Lake and thought he found it again in the Banias spring. Employing environmental isotopes (D, ^{18}O) 2.000 years later, Mazor (1976) demonstrated that the Banias spring is not supplied by Ram Crater Lake waters. Calculations reveal that the capacity of the lake is two orders of magnitude too small to be the feeder of the Banias spring and, furthermore, evaporation tags the lake water with chlorine, deuterium and oxygen-18 enrichments that are not found in the Banias spring. (The latter resembles the regional water recharged on the slopes of Mount Hermon). Philip's merit, however, is unquestionable as he virtually put into practice an idea the fruits of which are reaping at present.

The first through experiment conducted with tracers in a karstic area dates to 1877 when Knopp and Ten Brink used fluorescein to establish a direct connection between water losses in the Danube and the spring of the river Aach, a tributary to the Rhine — a classical example of karstic piracy (Paloc, 1975). The first labelling on a karst in Romania was made in 1904 by Romanian geologist Mihuţia who, using powdered coal as a tracer, established a hydrological link between the Cîmpenească Cave and the Boiu spring.

Numerous labellings, using fluoresceine and rhodamine B as tracers were performed by Viehmann (1966), Rusu (1979, 1981), Orăşeanu (1985 a, 1985 b,) Sencu (1986) and others.

However, the study of the hydrodynamics of karstic waters with the help of tracers has been encouraged only in the recent decades as an outcome of the spectacular development of speleology.

At present, we may say that whereas in any other area of hydrology, tracer methods may be employed along with equivalent methods of investigation, in the case of karsts the tracer-based approach is absolutely necessary owing to the unparallelled results it may yield.

The results and analysis of numerous tracer works on karsts, the recent progress made in the field of tracers and of methods used to identify and measure them, as well as the processing of the information they supply and the advancement of knowledge in general on karstic aquifers and their hydrodynamics cast clear light on the efficiency and prospects of tracing in karst (Atkinson et al., 1973 ; Gaşpar, 1973 ; Bleahu, 1974 ; Mangin, 1974a ; Mangin, 1974b ; Mangin, 1975 ; Molinari, 1976 ; Bakalowicz, 1979 ; Komatina, 1984 ; Mijatovici, 1984).

2. HYDRODYNAMIC BEHAVIOUR OF THE KARST

A karstic system that acts as a drainage unit may be divided in two zones or sub-systems — an unsaturated zone or zone of infiltration and a saturated zone or waterlogged karst (Mangin, 1975 ; Blavoux, 1980) as is schematically shown in fig. 1. In this conceptual scheme on the functioning of a karstic aquifer, imagined by Mangin, endokarstic condensation was introduced.

According to Mangin (1974), in the unsaturated zone, the flow appears in two modes, the first being two-phase (air-water), the second being an actual run-off.. The problem of capillary barriers bears an important part in the karst too.

The karst inlet represents the amount of water that seeps into the underground owing to precipitation (precipitation-evapotranspiration), to which add, with a considerable share, the infiltrations from possible non-karstic aquifers and endokarstic condensing. (fig. 1). Precipitations penetrate the whole surface of the karst in the form of either slow, diffuse infiltration or rapid infiltrations concentrated through karstic holes (fissures, faults, solution channels) woting to the runoff on the runoff on the karst surface. Furthermore, there is also the water derived from sources outside the system (rivers, lakes, ponds, leakage from aquifers) which penetrates inside through characteristic karstic forms.

Filtration seepage (or percolation water) is very important in the study of the functioning of a karstic system but may be assessed with approximation. Neither labellings on the karst surface with the help of artificial tracers nor the attempts at a mathematical modelling yielded any satisfactory results. Percolation water is defined as that proportion of runoff following precipitations in a limestone area which does not enter the channel of a surface stream, either by direct runoff or through flow," prior to sinking underground.

The relative significance of percolation waters in limestone areas will vary with geological structure, lithology, climate and degree of karstification; it will be largely a function of the degree of hydraulic homogeneity and anisotropy with respect to porosity (Drew, 1968). One

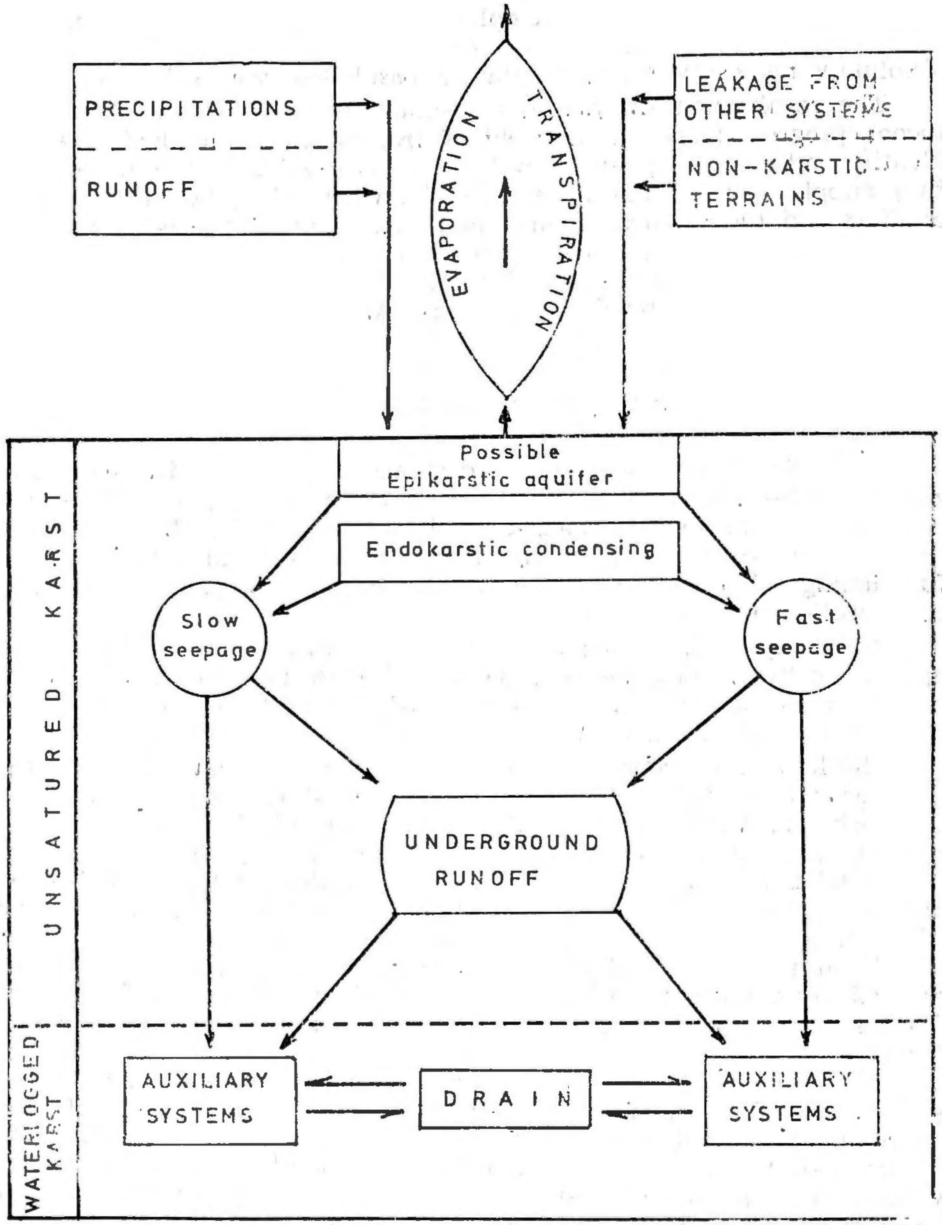

Fig. 1. Water dynamics through a karstic system. Conceptual scheme imagined by Mangin and adopted by Bakalowicz. We have introduced the endokarstic condensing.

major difference between swallet and percolation waters is that the latter will pass through the soil mantle before reaching the bedrock (except in pavement areas) and this will obviously affect its rate of flow and degree of diffusion. Suggested rates of flow of soil moisture

vary between 0.03—150 cm/h depending on the soil type, structure, state of wetness, intensity of rainfall and the nature of the overlying vegetation.

The rates of flow of percolation water vary considerably between areas of similar limestones, depending on the soil type and degree of integration and development of sub-surface channels.

Near the surface a belt of altered and cracked rock may allow temporary water storage. This epikarstic aquifer is responsible for a postponed percolation with highly mineralized waters. A conceptual sketch of a karstic aquifer was imagined by Paloc (1975) in fig. 2.

The infiltrations into the underground (percolation water and swallet water) continue their route in the epikarstic zone. In the case of abundant precipitations, this area may become saturated and thus act as a first temporary aquifer for meteoric waters.

The organization of vertical drainage in the unsaturated zone is achieved both through a fast percolation through fractures and tubular holes and through slow percolation through small fissures.

Furthermore, underground streams with a free level (sometimes under pressure) are frequently met in the unsaturated zone and some of them make a substantial contribution to cave formation.

The lower part of a hydrokarstic structure is the saturated zone or the waterlogged karst, whose constitution is heterogeneous containing a drainage network and sunken conduits in which a rapid flow develops. According to Drogue (1983), these drains are linked to reserves or slow-flow blocks, which are called sub-systems.

Mangin (1974) suggests a rather different image of the karst. This image should be understood as it accounts for the different behaviour of a karst after a number of labellings were made in different hydrogeological conditions. Thus, drains are considered to be linked to karstic formations, called auxiliary systems, wherein water moves at a lower speed. The more distant they are from the main drain, in which flow is rapid, the slower the velocity.

The auxiliary systems are groups of large-size fissures, galeries and cavities (high storage capacity reservoirs) connected to a drainage network. They develop variable flow relations with the drains, according to the hydrodynamic charge of the latter. Thus, they are supplied by drains during water-rise periods and, in their turn, supply the drains when water decreases and in periods of low flow. They are dependent on drains and the water infiltrated from the rest of the karst has a minor importance; that is why, these auxiliar systems make a whole, with the drain as their outlet. Their hydrodynamic behaviour is very different and their links with the drain entail highly different charge losses.

If there are no underground branches of the main drain to guide water to other exurgences, then the discharge it conveys will increase as the spring is being approached.

In low-flow periods the auxiliary systems supply the main drain in an upstrem-downstream direction.

During heavy rainfalls, the karstic system is put under pressure. Water velocity in the main drain increases and part of the water pene-

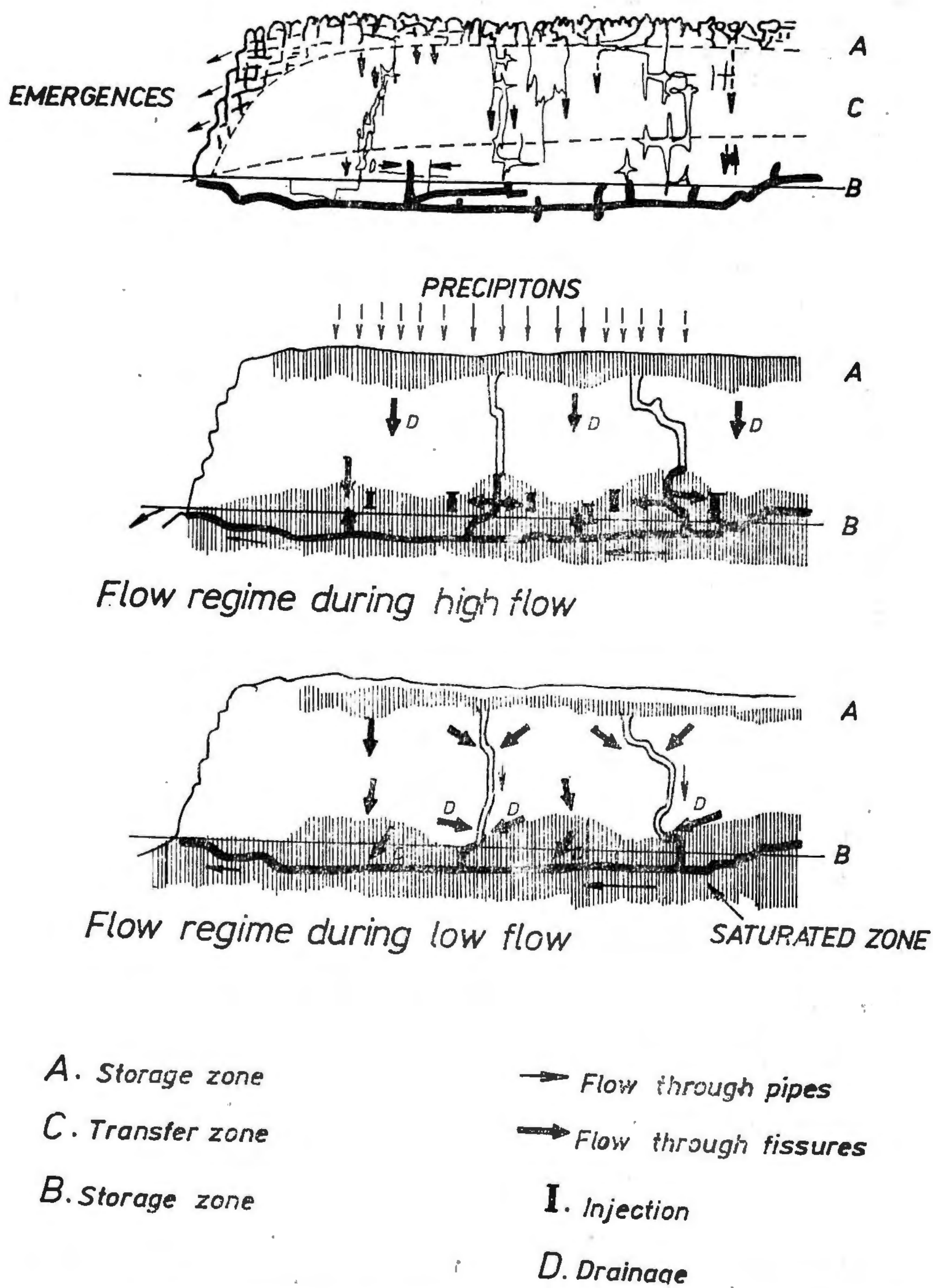

Fig. 2. A cross-section scheme of a hydrokarstic structure. Conceptual sketch of flow through a karstic aquifer imagined by Paloc.

trates the auxiliary systems. If the acces involves a charge loss (as in the case of galleries with high roughness, cavings, branches, bends, slopes, etc.), water will have to consume part of its energy to penetrate the auxiliary systems, which will first occur where energy is maximum, i.e. downstream.

The phenomenon under consideration progresses slowly upstream, according to the amount of water that penetrated the karst. Water may penetrate some of the intermediary auxiliary sysems first if its acces does not imply a high-energy consumption.

After a long period of low flow, the recharge of the sub-systems may take several years. Accumulation in the lower part of the karst depends on both supply and discharge possibilities. Recharge is not achieved after the first rainfalls that follow the low-flow period, but much later, and progressively, as discharge possibilities are saturated.

Given these circumstances, what will the fate of a tracer pulse be according to the hydrodynamic behaviour of the karst ? If during a labelling operation the tracer penetrates the auxiliary systems, the whole amount of tracer will be recovered after a long period : either continously, a large dispersion of the tracer cloud being thus achieved, or intermittently, according to the lenght of the interval of high-flood succession.

Therefore, the hydrodynamic functionning of a karstic aquifer is closely dependent on both its inner organization and the supply volume. Consequently, according to hydrological conditions, either rapid or slow flow may occur in the same karst. So, for instance, in periods of water rise, when the system is put under pressure, the network of underground channels inject water in the fissures, holes and interstices of the karstifiable rock, while in the low-flow periods they act as drains. Adding to all this are the large karstic holes wherein underground water accumulates and which can influence water transit or not, depending on the conditions that prevail at a given moment. Therefore, it is imperative to know the way auxiliary systems operate, that is whether they supply or are supplied by the main drain.

The importance of the auxiliary systems results from the fact that they provide for reserves ; their links with the drain influence the general mode of flow. The way these auxiliary systems operate is responsible for the heterogeneous behaviour of the hydrokarstic system in time and space.

The direction of flow of underground waters is the deciding factor of the karstic evolution of karstic aquifers ; variations in lithology, faults and fissures are only secondary in importance.

The direction of circulation modifies with the change in the aquifer water table. On a certain level of the underground layer water will follow a certain direction of flow. In karsts, however, when its level rises water may flow in other directions as well, according to the solution channels it intercepts.

Water circulation through karstic structures may be of several kinds :

— filtration seepage (predominantly in the upper zone of the aquifer) ;

— flow with free-surface ;

— hydraulic system under pressure ;

— combined flow (partially under pressure and partially with free surface).

Underground courses occuring in the aquifer zone obey to the hydraulic laws of the open channel flow. Groundwater flow in the waterlogged zone for the majority of the cases corresponds to flow in the pipes of systems under pressure.

The karstic springs that make the system outlet are supplied through a rapid circulation owing to the subterranean flow through the drains of the waterlogged karst, as well as through a slow circulation originating either in the drainage of karstic blocks of low permeability or in the deepest ascending channels.

The participation of each of the components of the discharge of the karstic emergence varies obviously from the hydrogeological conditions of a maximum flood wave to the severest low flow.

According to Blavoux (1980) during periods of floods the epikarstic aquifer concentrates the diffuse flow towards the vertical channels which collect part of the waters of swallow holes as of surface losses. A delayed infiltration from the epikarstic aquifer also occurs. The rapid flow continues through drains at the level of the waterlogged karst.

When flow occurs through factures, bedding planes, joints and intergranular pores, it has a diffuse and laminar character and motion is slower than that of a surface stream with a similar gradient. In the case of laminar flow, flow rate is proportional to the hydraulic gradient, permeability and effective porosity and may have a value of only several centimeters per year (Stringfield and Le-Grand, 1969).

After analysing numerous karstic structures, Atkinson (1985) suggests a third category, namely circulation through karstic fissures, that is a reticulate network of joints and bedding planes roughly 10 cm wide, which were created through dissolution. The portional contribution of each type of flow to a given karst can only be estimated.

The classification proposed by Aktinson — and suggestively renderd in fig. 3 — undoubtedly corresponds to a reality frequcntly encountered in practice.

3. GROUNDWATER FLOW ANALYSIS IN HYDROKARSTIC SYSTEMS

In general, most methods adopted for estimating water supply may be useful in studies of the hydrology of carbonate terrains but no method is applicable to all conditions. Thus, for instance, Meinzer (1932) describes some methods that are applicable chiefly tough not exclusively, to aquifers under water-table conditions and others applicable chiefly to artesian and non-artesian aquifers in which water moves at a considerable distance away from the inlet to the discharge areas.

The hydrological study of a karstic aquifer should mainly supply answers to the following questions (Stringfield and Le Grand, 1969 ; Burdon, 1967) ;

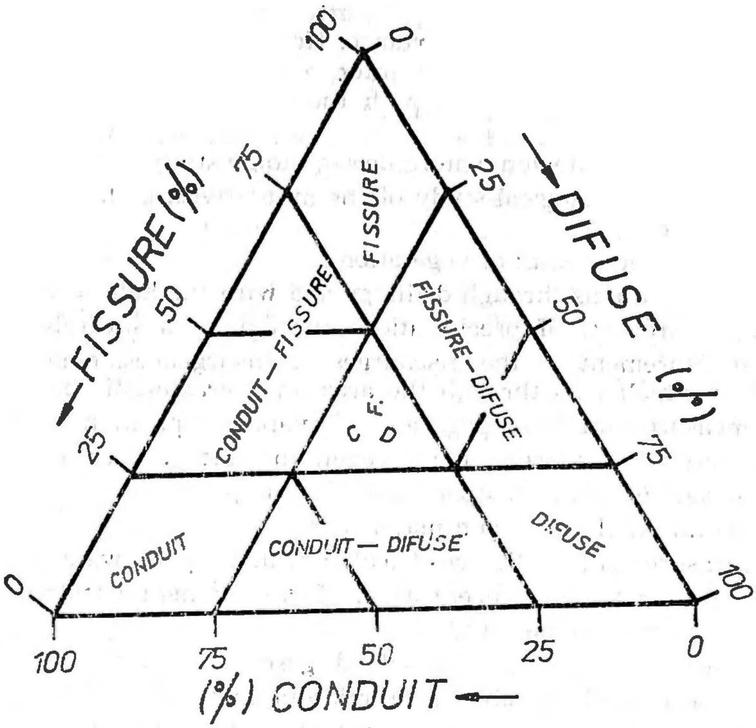

Fig. 3. Flow through a karstic aquifer. A classification proposed by Atkinson.

— the catchment area, the sources and the mode of recharge ;
— the origin of waters (meteoric, contribution by nonkarstic aquifers, contribution by surface or other sources ;
— the correlation between recharge and emergences ;
— the existence of an organized drainage, existence and functioning of the auxiliary systems ;
— the infiltration routes and their expansion ;
— water divide and diffluence areas ;
— water exchange in the underground, the nature of flow and the dispersivity of the aquifer ;
— the existence and location of underground basins, branches of the main stream, siphons, etc. ;
— the mean transit time, residence time distribution and water velocity ;
— estimation of groundwater reserves ;
— rainfall runoff analyses ;
— the behaviour of the system during flood and low-flow periods ;
— the evolution of the hydrokarstic system, phenomena of karstic piracy ;
— the quality of the water, the degree of pollution and pollution sources, the vulnerability of the karst ;

The contribution of (natural and artificial) traces in the resolution of these problems is of major importance. However, the tracer investigation of hydrokarstic systems and data interpretation are possible only within a thorough research conducted with the help of conventional methods, which include :

— the geologic, tectonic and micro-tectonic study of the area (fig. 4) ;

— the hydrogeological study of the area, caves, potholes, ponors and dolines included ;

— the characteristics of vegetation ;

— investigations through drillings and with the help of piezometers ;

— measurement of precipitations throughout a several-year cycle ;

— measurement of the discharges of insurgences, emergences and waterflows which pass through the area, in characteristic points ;

— measurement of seepage and of evapotranspiration with the help of lysimeters both in areas under vegetation and in barren zones ;

— variation in the temperature of springs ;

— evolution of minor and major ions ;

— measurement of the electrical conductivity of water ;

— variation in the concentration of environmental isotopes (D, ^{18}O, ^{3}H, ^{14}C) in the cycle under study ;

— analysis of free and dissolved gases ;

— bacterial and microbial load, microfauna ;

— measurement of the natural radioactivity of waters.

The experimental method of investigation of hydrokarstic structures with the help of tracers consists of the stimulation of the system with an input signal and measurement of the output response. The input signal is the (natural or artificial) tracer and materializes in its mode of injection which can be accidental, random, continuous, discontinuous, in the form of pulse, step, or a combination of them.

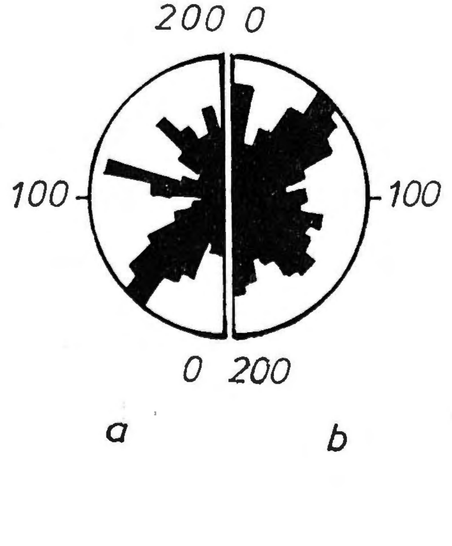

Fig. 4. Azimuthal distribution of cumulated lenghts : a — fractural features (failt and overthrusts) ; b — exokarstic features (unsymetric sinkholes, sinkhole valleys, dry active valleys, krstic capture depressions)

4. TRACER METHOD TO INVESTIGATES HYDROKARSTIC SYSTEMS

The tracer method is a technique which furnishes information about a karstic system or some part of it through observation of the behaviour of a specific substance, the tracer, that has been added to the system. The tracer method usually presupposes the use of a tracer to label a specific phase or part the system, or make them easily identifiable.

There is no such thing as a perfect tracer. Thus, for instance, rhorhodamine WT, an excellent tracer in the study of the dynamics of karstic waters, cannot be used in the study of endokarstic condensing for the simple reason that flourescent tracers cannot trace water during the evaporation-condensation process. However, the concept of an ideal tracer proves useful in the selection of artificial tracers, the search for environmental tracers and, more particularly, the development of mathematical models.

An usual classification of hydrological tracers includes natural and artificial tracers.

4.1. *NATURAL TRACERS*

Natural tracers are all the chemical or biological species, all the isotopes which can label water naturally. There is a great diversity of natural isotopes in the environment, which are also called environmental isotopes, and they label water in precipitations throughout the hydrological cycle.

4.1.1. CHEMICAL COMPOSITION OF WATER

Chemical analyses are important in understanding the rock-water interactions and thus evaluating the history of groundwater, although quantitative considerations like storage conditions and underground residence time must be backed up by hydrologic measurements and age determinations by radioistotope methods. Thermodynamic computations including saturation calculations and the calculation of the relation of the water to a specific gas phase (e.g. CO_2) are important tools for clarifying the complex reactions in natural aquifer systems (Goldbrunner and Leditzky, 1986).

The karstic aquifer is characterized by intimate relationships between its structure and functioning. Consequently, the chemical components of water may supply outstanding information on the origin of water, the probable nature of the terrains travelled by water and of the pollution between the inlet and outlet of the karstic area.

In a karstic zone, the content of dissolved ions in groundwater varies over a large range of concentrations and relative abundancies. Rainwater contains ions of dissolved sea-spray, dust and atmospheric gases, includ-

ing CO_2. While passing through the soil water becomes enriched with biogenic CO_2 which enables it to decompose and dissolve carbonates such as limestone, chalk, dolomite, marl and also silicates, olivine, orthoclase, mica and clay minerals (Mazor, 1976, Coman, 1984). These decomposition processes take place in the soil horizon, through the unsaturated zone and finally in the aquifer. Similarly, halite, gypsum and other minerals are dissolved in various amounts. Exchage reactions with silicates and carbonates and to the colourfull chemical compositions found in groundwater.

A primary step in a hydrological survey is, therefore, a chemical analysis of the dissolved ions. An essential analysis includes Ca^{++}, K^+, Na^+, Mg^{++} adn Cl^-, SO_4^{--}, and HCO_3^-.

The chemical concentrations of karstic waters are subjected, in time and in the same phases, to a two-fold influence — one which is due to seasonal climatic rhythm and the other to flow rate variations at karst outlets. That is why, the study of seasonal and episodic chemical variation during and in-between various hydrological events is very important for understanding the characteristic elements of the karst under study.

The uniformity or complexity of a karstic aquifer may be traced by chemical analysis of several water sources geographically spread over a studied aquifer, by repeated seasonal sampling or by successive sampling during pumping tests (Bakalowicz, 1979 ; Miserez, 1976 ; Marin ,1984 ; Povară and Marin, 1984).

One of the most characteristic natural tracers of karstic waters is electrical conductivity. Bakalowicz (1974) studied the relationship between the electrical conductivity of a given water and its mineralization and came to the conclusion that a linear correlation exists between them. As each ion is involved in electrical conductivity owing to both its nature and concentration, the slope coefficient of the linear regression is characteristic of the association of ions in the waters of an emergence and provides for a geochemical definition of the aquifer under study.

Müller and Plancherel (1982) studied the distribution of the values of electrical conductivity of waters in various regions and noted that a relationship exists between water mineralization and the altitude of the respective regions : mineralization increases when the altitude of the area of supply decreases.

Comparisons between karstic waters in various regions show that whereas the absolue values of water mineralization are influenced by the altitude of the supply area, the variations round the average are due to flow conditions determined by the structure of the reservoirs. Comsequently, water mineralization depends not only on altitude but also on pearmeability conditions and water residence time in the respective karstic formation.

The chemical constituents of water result from the rock-water interaction. That is why, in some cases the recharge areas of karst waters can be determined according to their chemical composition related to the drained rock type (e.g. dolomite, gypsum-magnesium, sulfate content) Zojer (1983).

Furthermore, under favourable circumstances, flow routes and interconnections may be established. Analysing the chemical composition of waters in shallow holes, drill holes and springs over a period of at least one year allows several analogies between the behaviour of certain ions or substances, the maximum and minimum of concentration being advanced or delayed in time according to hydrogeological conditions.

In this context, we should note that in ordinary chemical analyses a number of precious items of information may be overlooked. That is why, it is recommended that the water fingerprint shoud be determined with the help of activation analysis. The identification of traces of elements might allow for analogies between shallow holes and springs, and, therefore, prove aquiferous interconnections. In the case of certain karstic waters — highly mineralized ones in particular — or in case of geothermal waters, measurement of the natural radioactivity of waters may be relevant for their origin. The variation in radioactivity according to the special distribution of springs may supply data on the dynamics of the karstic waters in the area.

4.1.2. POLLUTION TRACERS

They are injected into groundwater by men, but not for the purpose of solving hydrogeological problems.

The study of the quality of the waters cotnained in karstic reservoirs may show the persistent character of certain pollutants. They may be found owing to the industrialization process undergone by the respective areas, the location of mining units, the chemicalization of agriculture, the operation of poutry rearing or animalbreeding complexes and urban developments. Pollution tracers are either injected by man in the underground or penetrate there in a natural way with the assistance of hydrometeorological factors. Besides particular pollutants, specific to certain areas, nitrates or heavy metals, which are to be found in ever larger amounts in continental waters, may be used as tracers. Adding to all this is a whole range of substances which, as an outcome of civilian and military activities, were released in the atmosphere at a planetary level and in a relatively short period and also participate in the hydrological cycle (T, ^{14}C, freon^{-12}).

4.1.3. ENVIRONMENTAL ISOTOPES IN THE STUDY OF REGIONAL GROUNDWATER FLOW

Environmental tracers are defined as isotopes or substances whose natural abundance variations may be used for hydrological studies. The environment contains a series of isotopes whose concentration varies according to the mode of production (either natural or artificial) and to environmental conditions which the investigator cannot control directly. These tracers label water naturally, tracing it throughout the hydrometeorological cycle, in atmosphere, in precipitations, in surface and underground waters.

Ideally, some of the more significant environmental isotope ration that may be used in groundwater studies include D/H, T/H, $^{14}C/^{12}C$,

$^{13}C/^{12}C$, $^{18}O/^{16}O$, $^{87}Sr/^{86}Sr$, $^{234}U/^{238}U$, $^{32}S/^{34}S$ and $^{32}Si/^{28}Si$. In practice however, for karstic waters, use is confined to the stable isotopes of water, deuterium and oxygen-18, and the radioactive isotopes tritium and carbon (Wallick and Toth, 1976).

Under ideal conditions, a study of the space distribution of stable isotopes and tritium and radiocarbon in groundwaters from karstic zones yields the following information for the groundwater regime :

— Water age at any point ;
— Mean flow velocity and drainage directions ;
— Mean residence time of water within the i-th flow system ;
— Qualitative age of groundwater at a point a given flow system ;
— Spatial and temporal distribution of recharge events ;
— Spatial extent and order of flow systems ;
— Degree of homogeneity (i.e. mixing properties) within a flow system ;
— Stagnant zones ;
— Separation of flow components.

The first studies with the help of the environmental isotopes were conducted in Turkey, where the main water resources come from karstic reservoirs with major springs of up to 50 m^3/s of discharge and benefitted from the advantage of maximum tritium concentrations in the atmosphere, which provided for a net differentiation between various water sources (Dincer and Payne, 1965 ; Yurtsever, 1979 ; Ozis and Yurtsever, 1982).

An exemple of the possibilities of the method is given by Fontes (1983) who made detailed studies of flood events in a kakrstic zone with the help of tritium and stable isotopes and established the following correlations :

— the isotope content of the flood discharge is independent of that of the rainfall causing it ;

— summer rainwater enriched with heavy isotopes accumlation in low altitude, isolated reservoirs available for storage ;

— heavy autumn rains remove summer waters as separate pulses corresponding to the discharge of isolated reservoirs ;

— when heavy rains fall during late autumn or winter, the reservoirs of the lowest part of the karst are homogeneously refilled with the water of the immediately preceding storm ;

— at the beginning of each flood, a small enrichment in heavy isotopes first reflects the discharge of waters stored at low altitude ; then, the isotope content decreases as the waters coming from higher altitude reach the outlet.

One of the largest karstic sources in the world, Fontaine de Vaucluse, was investigated with the help of environmental (and artificial tracers too) and its origin, recharge area and flow mechanisms were established (Evin et al. 1967 ; Flandrin and Paloc, 1969).

Association of other parameters of karstic waters (chemism, temperature, salt content, etc.) and the use of mathematical models to most faithfully fit experimental data will lead to a most veridical interpretation of the karstic phenomena under study (Bakalowicz et al. 1974, Blavoux et al., 1979, Siegenthaller et al., 1979). Thus for instance fig. 5 shown an

analogy of the variations in the deuterium content in time, as observed by Blaga (1979)[1] in three categories of waters the Şapte Izvoare Reci karstic springs and the Gizella and Scorillo thermal drill holes, supplied from limestone (Băile Herculane area). These springs belong to a mixture of waters described by the relation :

$$\delta D = -6{,}971.54\ d \qquad (r = -0.997)$$

where d is the average density of the salt content. Subsequent determinations with artificial tritium and fluorescein attested to the existence of a common component which supplies the two types of waters.

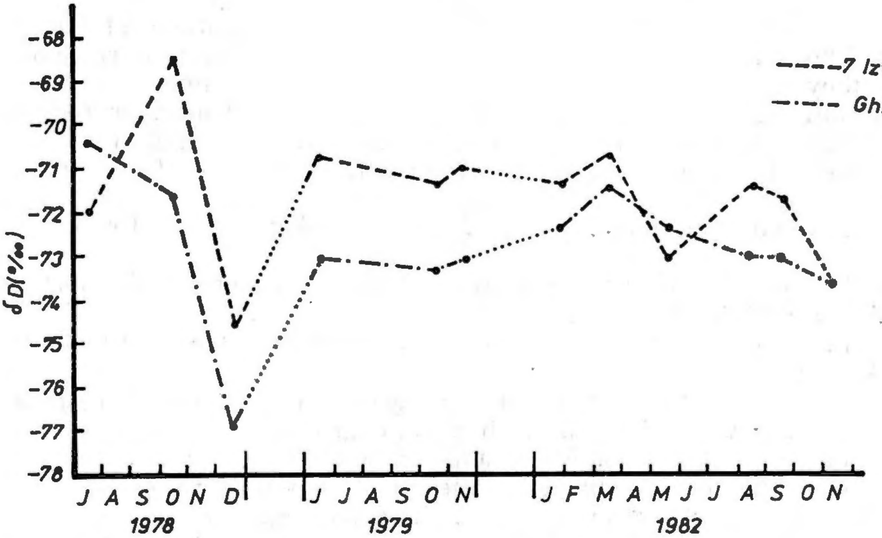

Fig. 5. δ D-time variation for Ghizela and 7 Izvoare Reci sources. A good parallelism between their δ D-time variations are shown, underlining meteoric characteristic of these waters.

4.1.4. PHYTO- AND ZOO-PLANCTON AND WATER MICROFAUNA

In certain conditions, phyto- and zoo-plancton and the live organisms that make up the microfauna of certain aqueous systems may be used as tracers. During floods, part of the microfauna which populates various karstic formations is carried by water, thus becoming a natural tracer.

In this respect, Moeschler et al. (1982) report that during a high-discharge event, the floating fauna (hydras, mollusca, crustaceans) was sampled using fine-meshed nets. A very good correlation was observed between biological and physical-chemical parameters yielding information on the discharge mechanisms.

4.2. *ARTIFICIAL TRACERS*

Artificial tracers are generally defined as those deliberately introduced into the hydrokarstic system to investigate groundwater flow.

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[1] BLAGA L. (1979) — Private communication.

An usual classification of these tracers proceedes according to the methods of detection employed. Thus, radioactive tracers (as well as activable tracers after activation) are detected and measured according to their radiation. When a tracer is detected and measured through the optical analysis of fluorescence (through *spectrofluorometry*, for instance), then we have to deal with fluorescent dye tracers.

Furthermore, the chemical composition of tracers is a basis of classification : *chemical* and *saline tracers, dyes, epilamens.*

According to their nature, tracers may also be *biological tracers* live beings (bacteria) or dead beings (spores, plants, etc.).

All hydrological tracers may be used in investigations of karstic waters. They can be selected according to the following requirements :

— they should be *conservative*, therefore stable in time, and should not deteriorate at contact with the investigated medium (water, air, rocks) ;

— they should be easily detectable and measurable in high dilutions ;

— they should not change the hydraulic conditions of the traced water ;

— they should provide for an analysis of the distribution of residence times ;

— they should not cause pollution of karstic waters of the springs beyond permissible standards in force ;

— they should not be toxic to either the population or the fauna of the karst ;

— they should not lead to the emergence of toxic or carcinogenic by-products following physical or chemical degradation ;

— they should be readily soluble in water ;

— they should be available on the markekt and inexpensive.

Naturally, not all tracers meet all these requirements.

The following tracers, however, have broad applications and, consequently, they are listed according to the methods employed for their detection and measurement, namely : chemical tracers, fluorescent dye tracers, radioactive and activable tracers, spores, bacteriaphages, etc.

4.2.1. CHEMICAL TRACERS

This category of tracers offers a wide range of possiblities, for which reason they have been extensively used in hydrology. As chemical substances may be measured according to various techniques — conductometry, chemical analysis, colourimetry, fluorometry, radiometry, activation analysis, laser analysis, olfactometry, a.o. — measurement methods are a criterion of tracer classification. On the other hand, some tracers are so important in hydrology that they make up a special category : fluorescent dye tracers, radioactive tracers, activable tracers.

The other chemical tracers, though still used in practice, have a lesser importance owing to :

— the relative high cost of laboratory detection and measurement tests ;

— difficulties in finding substitutes or compounds that can be detected in concentrations comparable with those of fluorescent dye tracers or radioactive tracers ;

— natural or artificial occurence in surface and undergrand waters in high concentrations, which limits the sensitivity of analytical methods;
— non-conservative behaviour in the traced medium;
— pollution of the karstic system ;
— toxicity for men or live beings from karst ;
— changes in the original hydraulic conditions, owing to the injection of substantial amounts of tracers as a direct result of high detection limits.

a) Sodium chloride (NaCl)

It is the cheapest of all tracers. Its solubility in 15°C water is of 360 g/l. The minimal detectable concentration is of 5.10^{-8} g/ml by measuring the Cl^- ions content in conditions of a small natural *background*. This tracer can be analysed through either chemical titration or conductimetry. Water conductivity, however, varies with temperature ±2—3 per cent for each degree centigrade so that for an accurate measurement (error ±1 per cent) the difference in the temperature of two samples included in a chain of measurements must not exceed ±0.1°C. Mention should be made that for a conductivity of natural waters of 1,000 M/cm the minimal concentration that can be measured is 10^{-5} g/ml and 10^{-6} g/ml when conductivity stands at loo MΩ cm. On the other hand, natural variations in conductivity prejudice the accuracy of measurements because of their frequency and amplitude. Nevertheless, NaCl has proved succesful in investigation of hydrokarstic structures (Gaspar et al., 1984). In such cases, however, when short water courses or *swallow holes* are labelled — which call for large amounts of tracer — labelling cannot be achieved through impoulses but through constants-discharge injection. Figure 6 gives comparative diagrams showing the variation of Cl^-, Rhodamine B and ^{131}I used as tracers to investigate the Cioroaiele Tîrcului cave.

b) Sodium dichromate ($Na_2Cr_2O_7$)

It is one of the tracers most commonly used to measure flow rates in rivers. Its main advantages are low cost, minimum measurable concentration of 10^{-6} g/ml directly on samples, and 10^{-8} g/ml after reconcentration, with an accuracy of ±3 per cent. The analysis is conducted through colourimetry (Molinari, 1969). Karstic water dynamics in Toplița brook (Pădurea Craiului Mountains) was studied by us with sodium dichromate and the transfer curve obtained is given in fig. 7.

c) Sodium iodide (NaI).

It is readily soluble in water and little retained by the medium travelled. To detect and measure it, the catalytic microdosage is employed through the kinetic method with the help of an analyser. Concentrations of 10^{-9} g/ml can be measured with an error of ±15 per cent. The *minimal detectable concentration* may be lowered to 2.10^{-10} ±50 per cent g/ml, but the limit of the method, in terms of metrology, coincides with the limit of the natural iodine content of the measured waters which, with rare exceptions, does not exceed 10^{-9} g/ml.

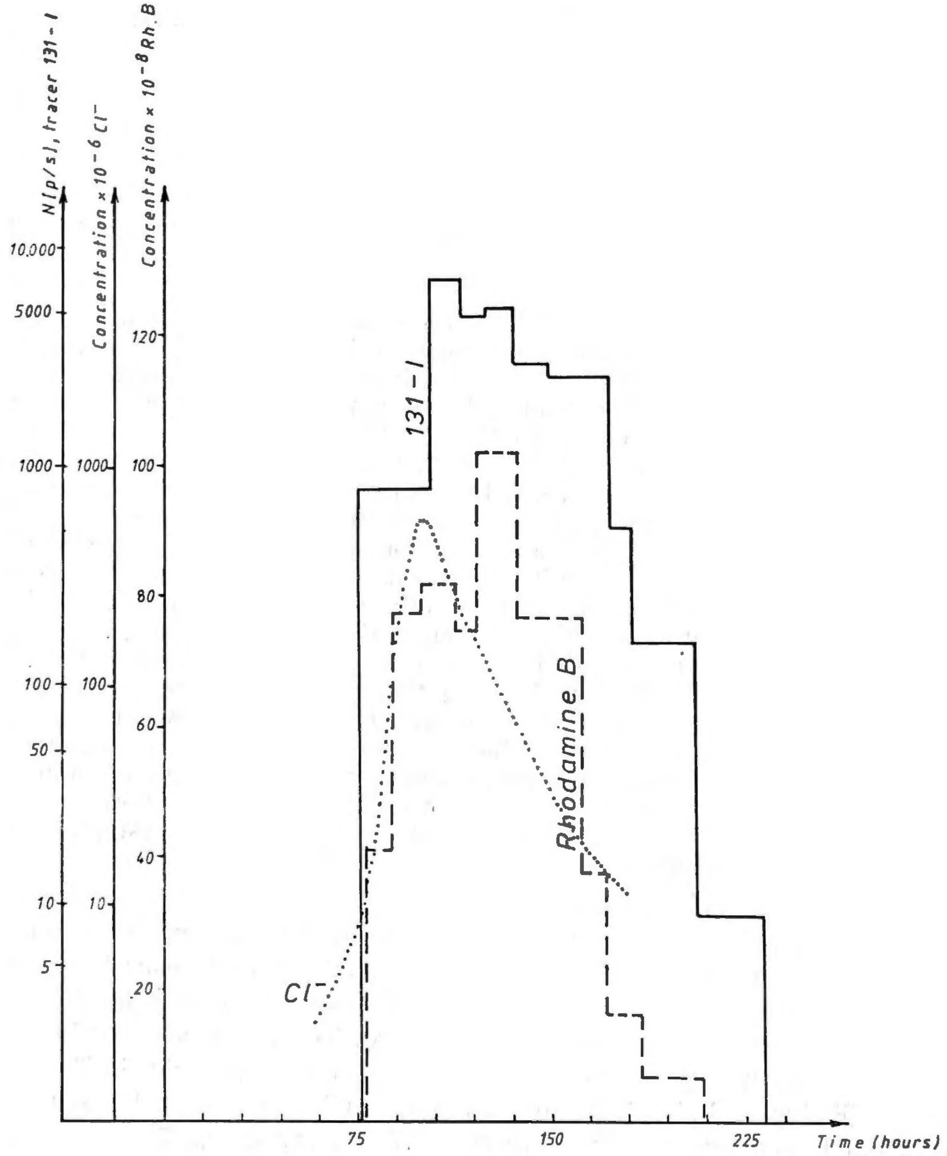

Fig. 6. Three simultaneous labellings using chemical, fluorescent and radioactive tracers. Comparative diagrams.

4.2.2 FLUORESCENT DYE TRACERS

All the fluorescent dye tracers used in hydrology and hydrogeology are organic substances ; most of them belong to the family of dyes deriving from xanthene.

The tracer properties are based on the chemical structure of special compounds consisting of the frequently occuring elements : C, H, O, N,

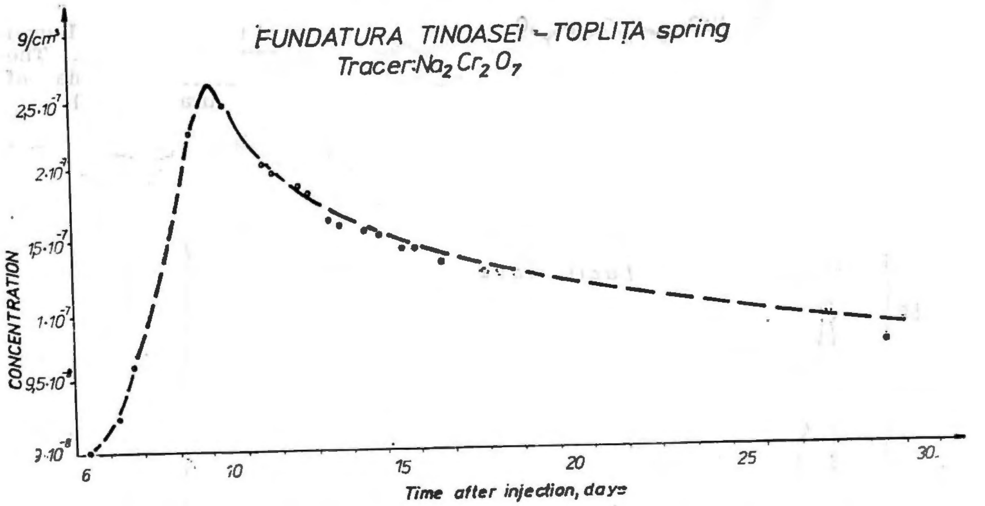

Fig. 7. The behaviour of sodium dichromate used to trace karstic water dynamics.

and S. The tracer properties can be severely changed or completely lost when the chemical structure of the dye molecules is changed or destroyed through chemical or other attacks.

Fluorescent dye tracers boast a remarkable property — they can be detected and measured *in situ* in small concentrations of 10^{-10}—$10^{-10^{11}}$ and, in some cases, even of 10^{-12} g/ml. Other advantages of fluorescent dye tracers : they are relatively cheap and not toxic, they are not mutagenic and they are fit for labelling.

a. *Uranine* $C_{20}H_{10}O_5Na_2$: It is the oldest fluorescent dye tracer used in hydrology. In point of ionic form, it is an anion with the molecular weight of 376.15. Its structural formula is given in fig. 8. It is less soluble in water : 25 g/l, but it dissolves well in water and ethanol: 300 g/l, or in water-and ammonia solution.

The minimum detectable concentration in the case of both uranine and the other tracers is obviously dependent on both the measuring device and the measurement method employed. In the case of uranine, it currently varies from 10^{-11} to 2.10^{-12} g/ml. (Feuerstein and Selleck, 1963 ; Behrens et al. 1976). Maximum excitation wave length is 431 nm and maximum emission is 512.5 nm.

b. *Rhodamine* B ($C_{28}H_{31}O_3N_2Cl$) has been extensively used as a tracer, especially after proving succesful in tracings to simulate or label pollutants in open sea. It appears in cationic form with a molecular weight of 479.02. and its structural formula is given in fig. 9. Though an organic dye which is strong and stains any material it comes into contact with, it is less soluble in water : 20 g/l. In acetone it dissolves 95 g/l, in acetic acid — 300—400 g/l and in methanol loo per cent — 800 g/l. The minimum detectable concentration in the presence of the background, at 20°C, and measured on 5 ml samples, is of 2.1×10^{-11} g/ml. Maximum excitation wave length is 553.5 nm and maximum emission is 512.5 nm.

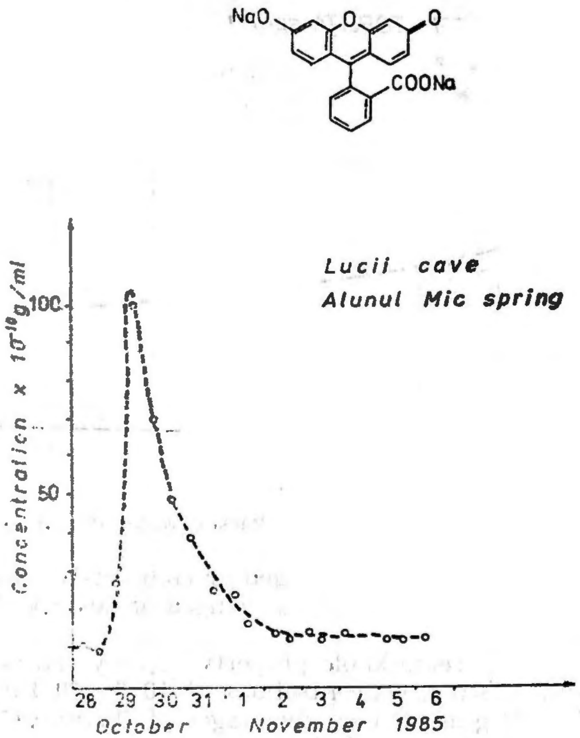

Fig. 8. Transfer curve of uranine in the Luncii cave experiment. The structural formula of uranine (up).

c) *Rhodamine Wt* $C_{29}H_{29}O_5N_3Na_2Cl$. The structural formula of rhodamine Wt is given in fig. 10. It has a molecular weight of 566.5 and appears in anionic form. Its minimal detectable concentration ranges from 5.10^{-11} to 1.10^{-11}, though possibilities exist to improve detection sensitivity. Apparently, it is the fluorescent dye tracer boasting most qualities (Laurent and Gibert, 1981).

d. *Other fluorescent dye tracers.* Noteworthy in the large family of rhodamines are other components used as hydrological tracers such as sulforhodamine B and sulforhodamine G, rhodamine 6G, amidorhodamine G. The minimum detectable concentrations in the case of these substances vary with the device and methods employed. There is a limit of $10^{-10} - 10^{-11}$ g/ml for amidorhodamine B and of $2.10^{-11} - 5.10^{-12}$ g/ml for amidorhodamine G extra.

Other xanthene dye type used for karstic waters is eosine or tetrabromofluorescein ($C_{20}H_6Br_4O_5Na_2$). It is readily soluble in watter and ethanol, in various proportions, according to the purity of the product. Minimum detectable concentration is 10^{-9} g/ml.

Other hydrological fluorescent tracers are amidoflavine, brillantsulfoflvine (stilbene derivative), lissamine (aminoketone dye type), pyranine (pyrene dye type), a.o., but they are used on a smaller scale. The minimum detectable concentration is roughly of 10^{-6} g/ml for amidoflavine and 10^{-9} g/ml for pyranine.

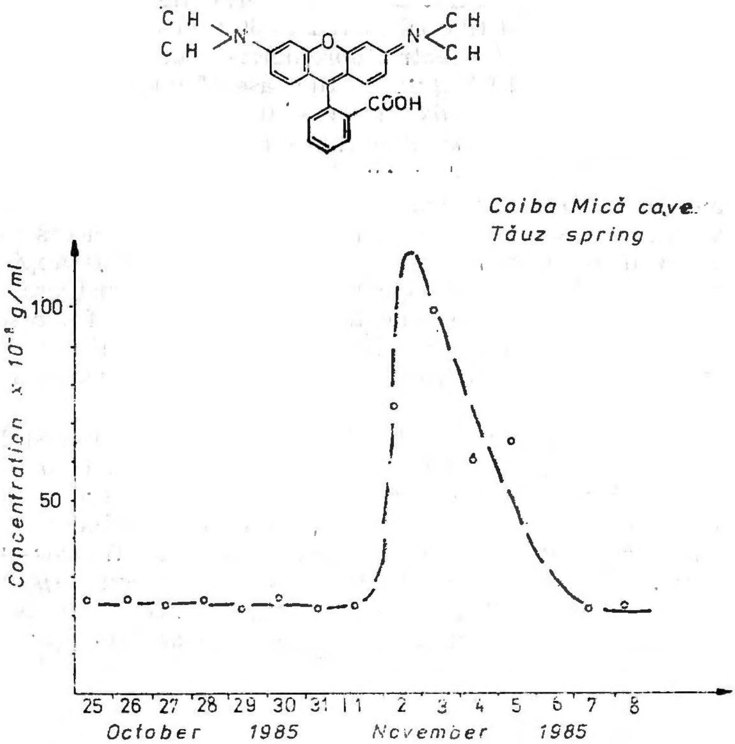

Fig. 9. The chemical formula and concentration-time variation of rhodamine B in the Tăuz experiment.

e. *Optical brighteners.* There is a number of optical agents which are used in industry to bleach paper, textile fibres, etc. Noteworthy among the tracers employed are : photine CV, fluolite BW, leocophor BS, leucophor C, chalcofluor white ST, tinopal ABP, tinoual CBS-X, stralex. They are colourless in aqueuos solution.

The detector for collection of samples is cotton (which may be detected with the help of passive detectors made of cotton wool and packed in muslin-cotton bags). At present, the minimum detectable concentration is 10^{-10} g/ml and possibilities exist to further lower it through chemical treatment of the samples. Thus, for instance if the water sample

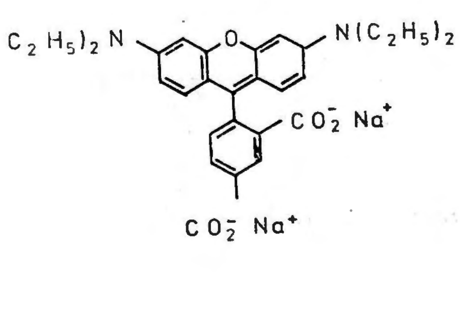

Fig. 10. The structural formula of rhodamine Wt.

that contains the tracer is dilluted with glycerol (fig. 11) in a proportion of 1 : 1, the fluorescence of tinopal increases 60 times (Schumacher, 1982). Using water samples and speotrofluorometric analysis, the detection limit may be lowered to 10^{-12} g/ml, in the case of pure waters, naturally. Unlike the other fluorescent dye tracers, the background of bleaching optical agents in surface and underground waters has been growing continuously owing to industrial pollution.

f. *Detection and measurement of fluorescent tracers.* Fluorescent dye tracers are still very sensitive and the least expensive tracers to observe underground waters in karstic terrains. The simultaneous application of various fluorescent dye tracers nearly always causes considerable analytical problems. The selective detection of individual fluorescent dye tracers in mixtures of several dyes is limited by the overlap of the spectra. Therefore additional separation steps must be introduced into the analytic procedure.

In high concentrations, all the fluorescent dyes are visible to the naked eye, separately. Various methods are employed to measure eye in concentration of 10^{-7} g/ml ; with the help of a fluoroscope, it can samples. Thus, for instance, fluorescein (uranine) is visible to the naked be detected in concentrations of 10^{-8} g/ml ; through fluorometry, the detection limit may be lowered to 10^{-10}, while through *spectrophotometry,* it drops below 10^{-11}. This sensitivity, however, may be attained in cases of independent occurence of singular tracer in pure, natural waters where no other tracers can influence the spectrofluorometric assessment (Bauer et al., 1976).

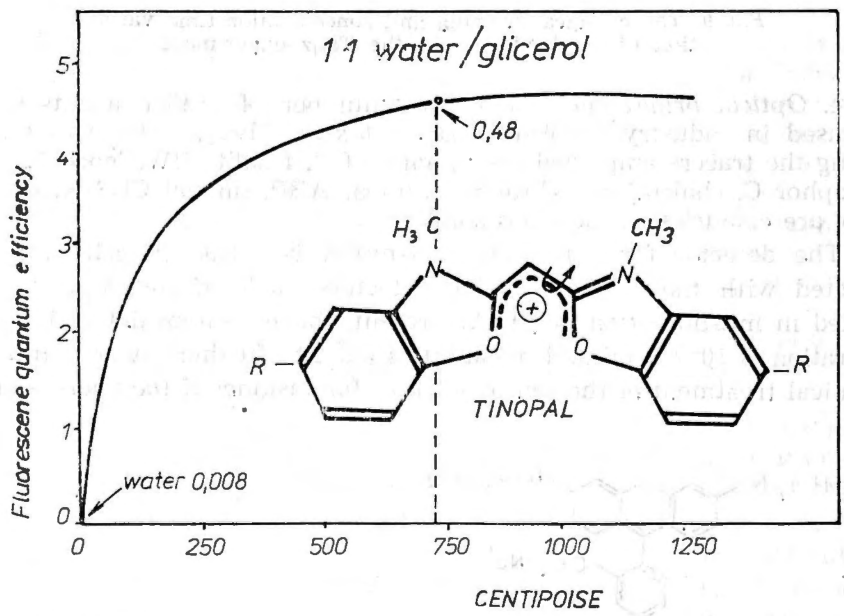

Fig. 11. Fluorescence quantum efficiency of Tinopal as a function of glycerol concentration in water. Structural formula of a tinopal-type fluorescer (Schumacher, 1982).

The relationship between the intensity of fluorescence radiation and the concentration of a fluorescent dye tracer is not rigorously the same for all tracers but it may be considered linear when first assessed. For precision measurements, the device should be standardized for all instrument ranges and recently prepared solutions, in known concentrations, should be used. These solutions alter rapidly and stable, quinine-based samples are needed for a subsequent verification of the installation.

Following the simultaneous use of several tracers, which was largely dictated by hydrological reasons (e.g. operations of multiple tracing in karsts), the question of spectral separation of dyes featuring fluorescence has been given special attention in the last few years (Behrens, 1983; Ackermann et al., 1982). With a view to measuring various tracers in the same water sample, optical and ion exchange methods, as well as thin-layer chromatography have been developed. In order to increase detection sensitivity, the fluorescent components found in water are separated and concentrated on *active coal.*

Analysing the spectral data of fluorescent dye tracers, one may note that there are tracers that can be detected and measured in fine mixtures, without mutual interference. This is the case of uranine and rhodamine, irrespective of their concentration. Likewise, tinopal can be determined independently in the presence of other fluorescent dyes because its fluorescence maximum occurs in the ultraviolet region of the spectrum. Moreover, it does not influence the assessment of any other fluorescent dye. However, the optical brightener tinopal CBS-X is disturbed by the fluorescence of organic matters in natural waters.

Relatively small disturbances occur in the following combinations of dyes: uranine-amidorhodamine G and eosine-rhodamineB; stronger mutual interference can be found in mixtures of uranine-eosine and amidorhodamine G-rhodamine B.

Recent research shows that the fluorescent dye tracers in a mixture can be measured individually through the guided application of pH modification, of adsorbtion agents and the influence of light on the solution containing the respective mixture.

Spectral analysis — in the position of both emission and excitation spectra — also supplies qualitative information, while the intensities of the spectra provide quantitative information concerning the tracers that are being measured.

Thus, in the case of two spectrally close tracers, such as rhodamine B and amidorhodamine G, superpositions occur: a correction calculus for absorbtion spectra establishes the proportions of the tracers in the respective mixture (Käss, 1976).

The method may be correspondingly applied to mixtures of several dye tracers. Errors of measurement, however, increase as the number of components rises. In the case of mixtures of spectrally extremely close fluorescent dye tracers (e.g. fluorescein-eosine of eosine-amidorhodamine G), an irreprochable analysis can be made only by resorting to a separation method (Käss, 1982).

4.2.3. RADIOACTIVE TRACERS

They proved superior to non-radioactive tracers whenever the latter were unsatisfactory from technological or economic point of view. The choice of suitable characteristics of radioactive emissions will be influenced by a number of factors including the duration of the test, the logistics of tracer supply, radioprotection requirements for the tracer prior to injection and the location and method of measurement.

Considered as an ideal tracer for water, tritium emits low-energy beta particles (0.018 MeV) and can be easily transported and handled without radiation hazards. First karst labelled using tritium as a tracer was performed by Burdon et al., 1963 in Greece. However, a major disadvantage in its use in field studies is the inhability to measure very low concentrations in the field. Samples have to be taken to the laboratory for measurement by liquid scintillation or gas-counting methods.

Radioactive tracers having penetrating gamma rays allow measurement of samples of large volumes with a correspondingly high detection sensitivity. Also, for multitracings in karst, the simultaneous detection of several different tracers may be achieved by gamma-ray spectrometry. So, in a multitracing performed in Vaşcău Plateau, two radioactive tracers, Iodine-131 and Bromine-82 appeared simultaneously in Boiu spring and were measured indeependently (fig. 12 and 13).

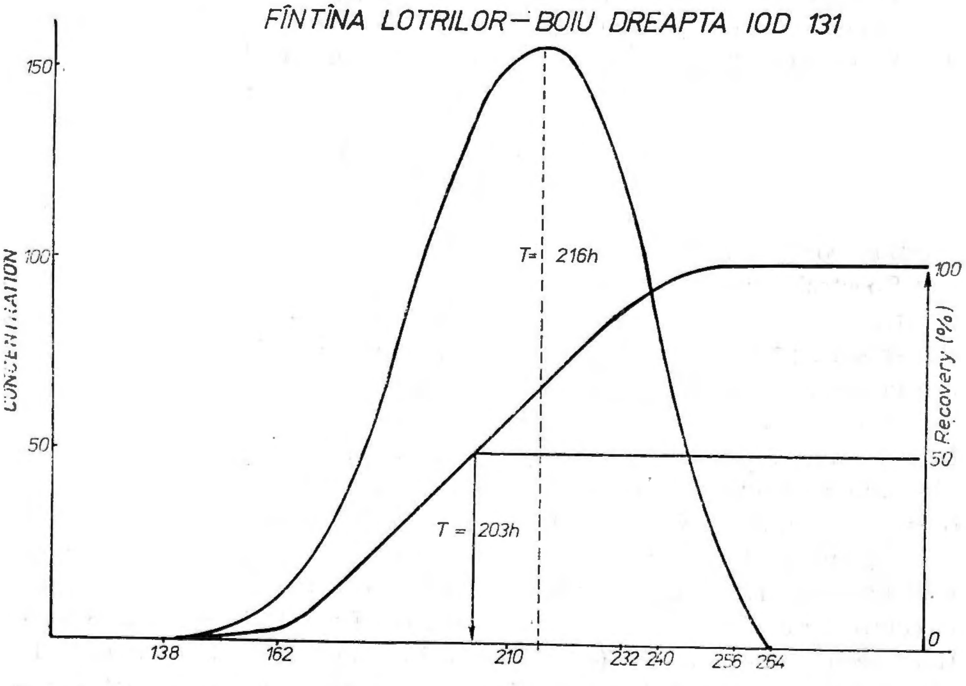

Fig. 12. Concntration-time variation of ^{131}I used as a tracer in karstic zone of Vaşcău Plateau.

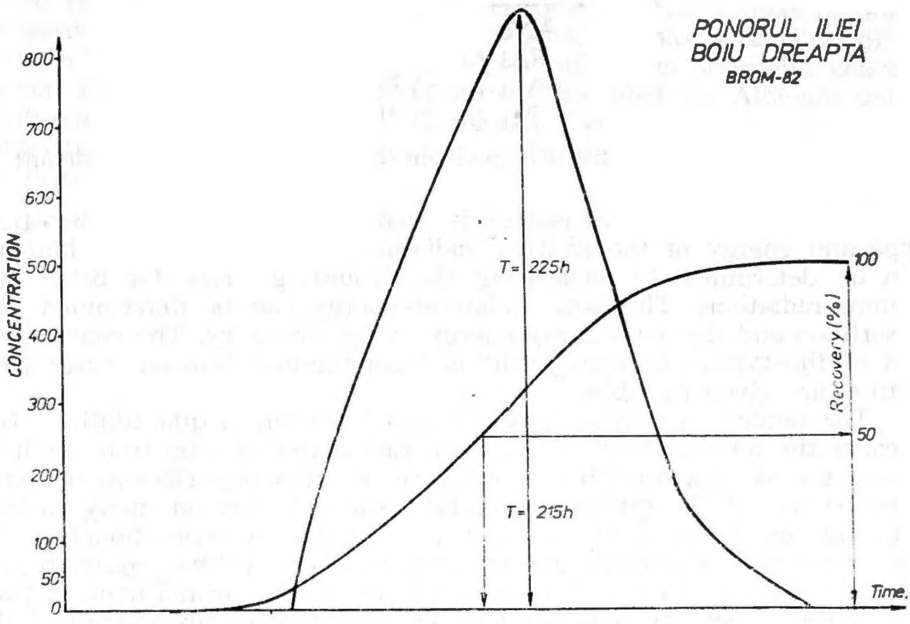

Fig. 13. Multitracing experiment in Vaşcău Plateau. A diagram representing the variation in time of the concentration of ^{82}Br used as a tracr to label the Ilii sinkhole. The tracer was concentrated on an ion exchanger, Vionit AT-1.

As possible radioactive tracers for ground water field experiment and for hydrokarstic structures in particular we agree to ^{82}Br, ^{131}I and ^{51}Cr-EDTA only.

4.24.. ACTIVABLE TRACERS

The problem of half-life in the use of radioactive tracers for investigation of hydrokarstic structures can, in principle, be avoided if inactive nuclides are used as tracers and the samples activated for analysis of the resulting radioactivity. The activation analysis is easily performed but it requires a strong neutron source (e.g. a nuclear reactor) and adequate detection equipment (a spectrometer). The atoms of most elements give rise by inrdation to radioactive species of the same elements. The elements can be identified by determining the radioactive properties of the respective radioactive nuclides produced, the activity obtaines being a measure of their concentration in the water. During water activation analysis, some typical nuclear reactions due to elements contained by the salts usually solved in water, are produced. In the case of ^{37}Cl — an element usually contained by water — the typical reaction is :

$$^{37}Cl + n \rightarrow {}^{38}Cl + \gamma$$

or

$$^{37}Cl\ (n, \gamma)\ {}^{38}Na$$

Other typical reactions for water activation analysis are :

$$^{23}Na\ (n,\ \gamma)\ ^{24}Na$$
$$^{27}Al\ (n,\ \gamma)\ ^{28}Al$$
$$^{55}Mn\ (n,\ \gamma)\ ^{56}Mn$$
$$^{40}A\ (n,\ \gamma)\ ^{41}A$$

Obviously, other reactions are possible but they are not important in the following discussion.

A certain radioactive isotope is identified by its characteristics: type and energy of the emitted radiations and half-life. The half-life can be determined by measuring the counting rate for beta and gamma-radiations. The beta radiation energy can be determined by adsorbtion and the gamma ray energy by spectrometry. The characteristics of the typical isotopes resulting from thermal neutron water irradiation are given in tables.

The neutron activation analysis may become a quantitative one because the total activity of a certain radioactive isotope from an irradiated sample is a quantitative measure of the stable element it comes from. However, the quantitative relationships depend on many factors. The induced radioactivity of the water samples is proportional to the concentration of the stable element it comes from, to the activation probability of the element and to the intensity of the thermal neutron flux. The induced activity depends also on the relative abundance of the stable isotopes of the element.

Chemical elements in this group of tracers must be present only in negligible quantities in the hydrological system under investigation to eliminate significant background. In this respect it must also be ensured that the radionuclide selected for detection cannot be formed from any element other than the actual tracer element. As an example, lanthanum used as an activation-analysis tracer is detected by activation as ^{140}La. When samples are irradiated with neutrons, however, ^{140}La is also formed by nuclear fission from the traces of uranium that are contained in most waters.

Thus, simple anions have been applied as activable tracers, whereas cations are not suitable because of their retention by ionic exchange. Of special importance are the anionic complexes of several metals; as chelating agents, EDTA, DTPA or DCTA have been used.

In actual practice, irradiation (e.g. in a nuclear reactor) is usually preceded by separation of the substances contained in the water, for example by evaporation, precipitation ion exchange. Following irradiation, radiochemical separation may be necessary to remove interfering radionuclides formed from the main substances contained in the water sample.

High-resolution gamma spectrometry with Ge(Li) detectors has greatly improved the detection of activable tracers. It permits the necessary chemical separation procedures to be reduced to a minimum.

a. Bromine is commonly used as activation analysis tracer because of its favourable tracer characteristic. Background values must be checked and a sufficiently high activation dose selected to guarantee measured tracer values that are clearly above background. This tracer is chemically stable in groundwater and sample solutions. The minimum detectable concentration of bromine is below 10^{-9} g/l.

b. Iodine is used as a rule in the form of NaI or KI. I^- may be dosed by activation analysis. Iodine-128 thus produced has a half-life of 25 minutes. In the absence of background, the minimum detectable concentration is 10^{-10} g/ml. This tracer was used to label the Albioara ponor (Pădurea Craiului Mountains — Romania), Fîntîna lui Ghiță (Vașcău Plateau) and Izoi ponor (Codru-Moma Mountains). The late labellings are presented in fig. 14 and 15.

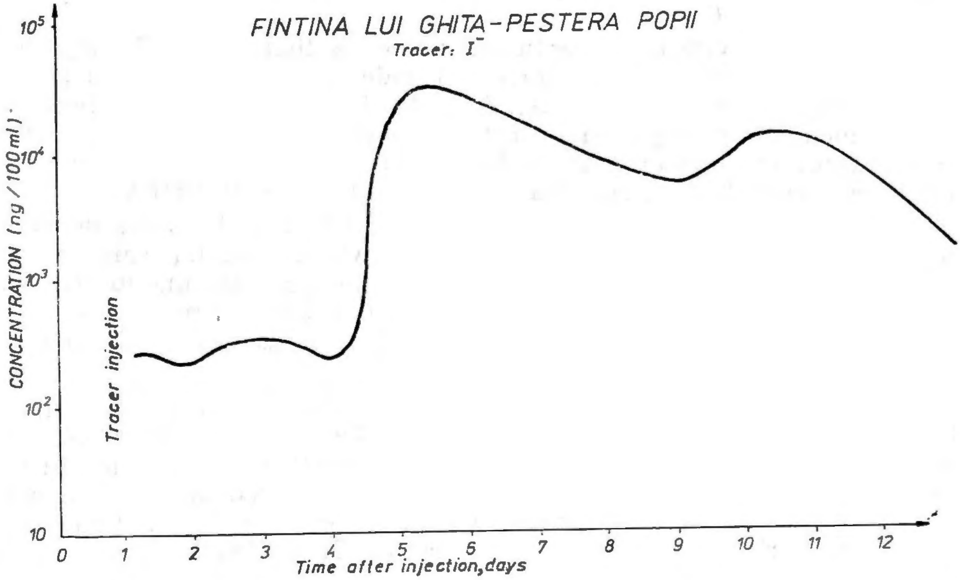

Fig. 14. Use of I- as activable tracer. The background and the concentration-time variation in a multitracing experiment performed in Plateau Vașcău.

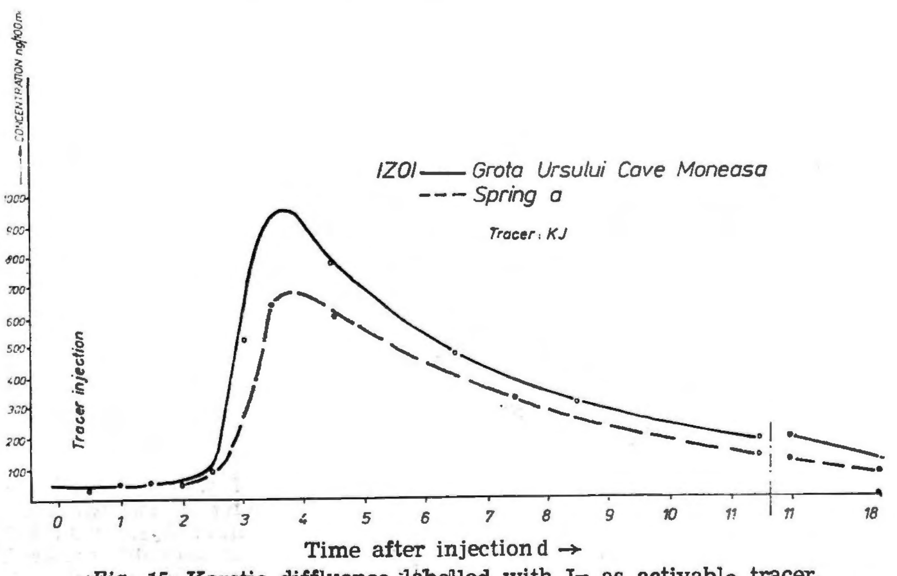

Fig. 15. Karstic diffluence labelled with I- as activable tracer.

c. *Dysprosium,* used in the form of an EDTA complex it features fine tracer characteristics and a high-sensitivity detection. The detection reaction is :

$$^{164}Dy\ (n,\ \gamma)\ ^{165}Dy$$

Its presence in underground waters is extremely rare. The minimum detectable concentration of Dy is 5.10^{-13} g/cm^3. The results of a labelling using Dy-EDTA as a tracer performed in Padiş (Bihor Mountains) are presented in fig. 16.

d. *Indium :* With the exception of the areas that contain In deposits, this element is absent from surface and underground waters. As a tracer for water in hydrological investigations. In should be used in a chemical form which is perfectly soluble in water and does not react either with the aqueous medium or with underground rocks. The chemical combination meeting all these requirements is In-EDTA or In-DPTA.

The minimum detectable concentration of indium in water depends on a number of major parameters, among which are : the amount of sampled and analyzed water, the size of the neutron flux the duration of irradiation, the number of simultaneously irradiated samples, the efficiency and resolution of the spectrometric system, as well as the nature of labelled waters.

Theoretically, for loo ml of analyzed water, in conditions in which five samples are irradiated for 20 minutes under a flux of 5.10^{11} n s.sq. cm and a spectrometric system boasting an efficiency of 7 per cent and an energy resolution of 2·7 keV is employed for measurement, the obtained detection limit of indium in water is lower than 1.10^{-12} g/ml. Figure 17 shows the variation curve of indium in the Cerna karstic spring after

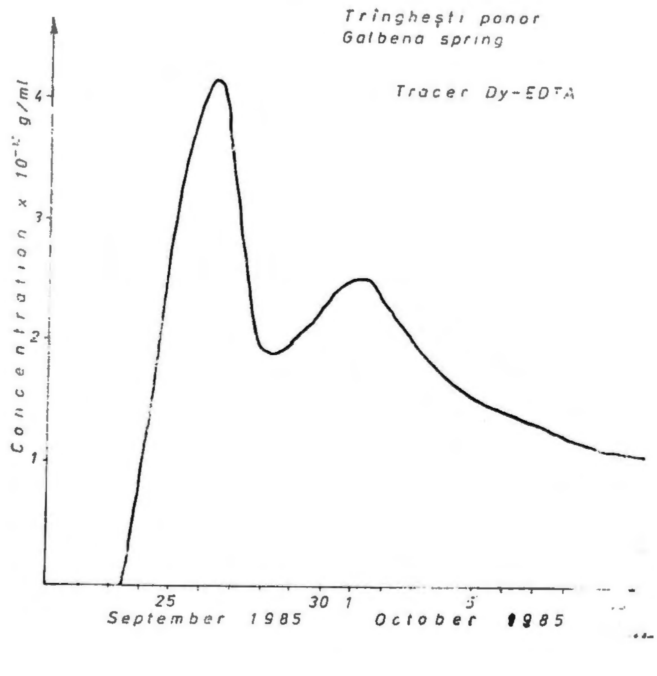

Fig. 16. A good tracer for karstic water labelling: Dysprosium-EDTA as activable tracer. The Padiş experiment.

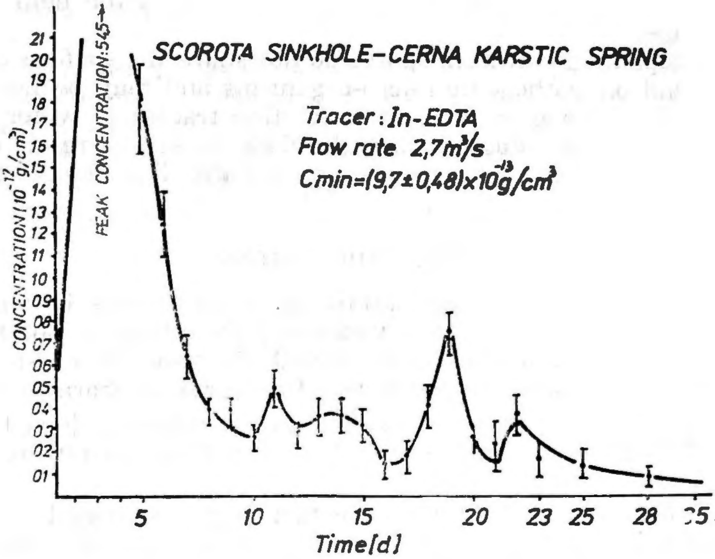

Fig. 17. **Indium-EDTA may be considered as a reference tracer to labell karstic waters. Cerna karstic spring experiment.**

the labelling made in the Scorota sinkhole. The measured values and the errors of measurement are also shown. (Gaşpar et al. 1984).

The major advantage of this tracer is that, owing to its extremely low detection limit, it can label emergences of very low flow rates which cannot be labelled by any other tracer, be it fluorescent, chemical or radioactive (with the exception of tritiated water) : an artificial lake or natural reservoir of 1 billion cu.m may be labelled using 1 kg of In-EDTA. The detection limit can be lowered below 1.10^{-12} g/ml using a volume of water larger than loo cu.cm for analysis and a larger neutron flux for irradiation (Behrens et al., 1977, Gaşpar et al., 1985b).

4.2.5. LYCOPODIUM SPORES

In 1926 the spores of club moss Lycopodium clavatum were first used as a hydrological tracer. These spores are small cellulose bodies 30—35 microns in diameter. They are commercially available and may be dyed in up to five different collours. They are employed in investigations of karstic structures, mainly in strongly corroded systems (Hötze et al., 1976 ; Gardner, 1976 ; Gray, 1976).

Lycopodium spores have densities lower than that of normal stream water and thus travel faster than the mean velocity of water.

The measuring technique employed in their case is counting. In the points of emergence the spores are collected with the help of large plancton nets. If silt is present, these nets clog up quickly ; their cloth is delicate and may be easily torn by flood waters. After collection and

washing, the spores are analyzed and counted with the help of a stereo-microscope.

The Lycopodium clavatum spores do not share the surface properties of those found on pathogenic micro-organisms and may be poor indicators of pollution travel even if they are fine tracers of water motion. Another major disadvantage is that the dust of the spores is explosive and, therefore, they must be handled with care. The detection limit is of 1 spore in 10^6.

4.2.6. BACTERIOPHAGES

Bacteriophages have proved useful as water tracers in karstic terrains. They have a number of advantages ; the phage is not toxic and non-pathogenic to man and domestic animals, it is specific for its bacteria; assay is simple and rapid, and it boasts fine survival characteristics.

Because of host specificity, phages can be mixed, injected together and then distinguished on different hosts, thereby permitting simultaneous multiple tracings.

Phages feed of the bacteria of which they are parasites, and the host organism is subsequently destroyed. This provides the means whereby the phages may be detected in the samples. A small quantity of each sample is introduced into a plate of jelly-like bacteria and is then incubated. Each phage feeds of the bacteria, multiplying itself at the same time and leaving a clear area of dead bacteria on the milky surface of the plate. A manual count of the clear patches then establishes the concentration of phages in the sample.

Methods are available for the concentration of phages from large volumes of water. Using these techniques, it is possible to detect as many as 1—2 phages in a 20-litre volume of water. Furthermore, it should be pointed out that the samples may be conserved through freezing and measured later on, according to needs.

4.2.7. GASEOUS TRACERS

The use of gaseous tracers (smoke, gas) in karstic hydrogeology and the investigation of caves is a relatively new method. In this case, the notion of tracer no longer has its conventional acceptation. These gases move mostly through the system of karstic channels whose recent activity is expressed in the form of vertical circulation and a small number of concentrated courses.

Smoke or gas is injected through wells or karstic holes situated above the aquifer zone and, with the help of an artificial circulation or of the natural circulation of the air, the tracer is guided towards the remote areas of an interconnected system of karst voids which leads to their identification.

The gases employed should be lighter than the air and slightly absorbeb by water and, with a view to facilitating detection, they shold be radioactive, highly odorized or perfectly visible. As the tracer is lighter than the air, and highly penetrating, it will be able to cut a route

of rapid acces to the surface using fractures, fissures, karstic channels and wells.

As a rule, fumigating substances that release large amounts of smoke are used as tracers; smoke may have a certain colour, that may be easily differentiated from fog. As compared to radioactive gases, it has the considerable advantage that it is not dangerous to either the experimenter or the population in the respective area.

When studying certain phenomena of karstic piracy that need labelling, des Marais (1981) resorted to volatile tracers. Thus, when a cave stream was inaccessible to water tracing, passages were delineated by use of sub-surface air flows driven by the „chimney effect", and ethanethiol vapours as a tracer. The same tracer (viz. ethanethiol had been previously used in the King Blair cave (U.S.A.) and a link with a swallow sinkhole was established (Sperka, 1969).

5. INTERACTION BETWEEN ARTIFICIAL TRACERS AND HYDROKARST MEDIUM

In karstic systems water is a complex medium which may contain ions, colloids and sediments that drift on the bottom or are held in suspension, whose origins are extremely varied, and live beings from the plant and animal kingdoms (phytoplancton, sponges, bacteria; microbes; viruses, zooplancton, microcrustaceans, plants and animals). Qualitatively speaking, waters are polluted either naturally or artificialiy with the most diverse substances, in various proportions.

The general mechanism of interaction between tracers and the rocks in the underground medium are : filtration, physical adsorbtion, chemical absorbtion, colloidal precipitation, ion exchange, chemical reactions and isotope exchange. These factors, the influence of the chemical nature of the water (degree of pollution) and the hydraulic behaviour of the karstic system contribute to lower tracer concentrations in time and space.

The interactions between the rocks in the underground and tracers are the latters general reactions with the solid phase. Other chemical reactions between tracers and the elements of the solid phase are rare. An altogether different situation develops when a tracers comes into contact with the liquid phase. Whereas, naturally, waters can have a pH value, a temperature and a salt content that are greatly varied, owing to pollution the chemical composition of water may modify to such an extent that phenomena occur conducive to either the delay or the total reduction of the tracer. An example is the use of dichromate in hydrometry (André et al., 1964). Polluted media may turn hexavalent chromium ions into trivalent ions, thus hindering dosage through colourimetry.

Radioactive or activable chemical tracers must boast a great physicochemical stability so that they may not react at contact with the traced owing to its pollution. An example in this respect is the In-EDTA tracer. Used to label kakrstic waters in a period of low flow, the tracer could be measured 180 days after labelling, as fig. 18 shows (Orășeanu et al.,

1984). Although the medium was polluted owing to the penetration of waters resulting from bauxite processing into the karst and the contact between these waters and the tracer was long enough to have favoured retention, the tracer, however, was recovered in a proportion of 85 per cent (8.5 g from the 10 g used for labelling). The retention of the 1.5 g of In-EDTA may rather be accounted for by hydrological causes, frequent in the case of labellings in low-flow periods, when the tracer is trapped by auxiliary systems of the karst.

Fluorescent dye tracers, which boast a number of altogether remarkable features also have the serious disadvantage that their behaviour is influenced by the chemical nature of the investigated medium. Noteworthy among the most frequently employed fluorescent dye tracers are xanthenic compounds.

In the group of xanthenic dyes a proton in the methylic groups is replaced by a benzenic cycles. The uranine group (uranine and eosine) is characterized by phenolic and quinonic functions of the xanthenic cycle and the carboxylic function of the benzenic cycle. In the group of rhodamines, the xanthenic cycle is the carrier of a tertiary aminic and a quaternary ammonium function. They may be carboxylic (rhodamines) or sulfonic (sulforhodamines). These features impart characteristics on fluorescent dye tracers and also influence their behaviour. So, for instance, sulforhodamines B and G behave the way anions do. Eosine, uranine and rhodamine Wt show both anionic and cationic features (Rochat et al., 1975 ; Laurent, Gibert, 1981). Rhodamines B and 6G behave as cations.

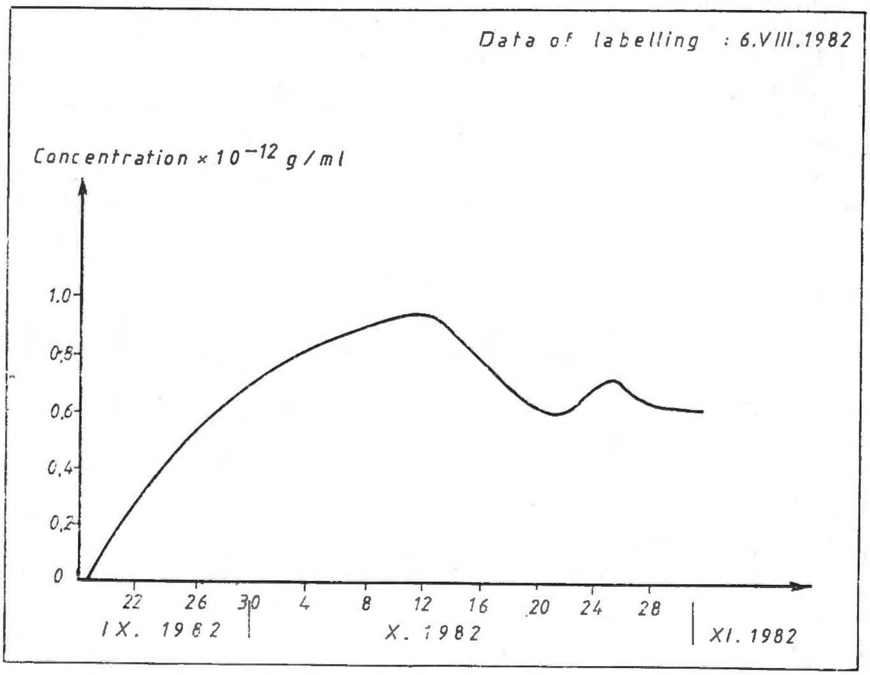

Fig. 18. The time behaviour of In-EDTA used as a tracer. The Vida experiment.

The use of fluorescent dye tracers in a medium with a strong ionic concentration may result in partial tracer loss.

Fluorescein, which may be found in five different monomeric forms, may pass to the dimeric form according to the pH value of the medium. Each of the structural forms will have different fluorescence characteristics. (Fluorescein may be also decolourized by contact with humus, clay minerals and calcite).

In exhange, the use of fluorescent dye tracers in media with high salinity (chlorinated medium) has no negative effects on them (André et al., 1976). When the medium contains sodium iodide, or when (active or inactive) sodium iodide and fluorescent dye tracers are simultaneously used, adding to the phenomena related to the rise in ionic concentration (modifications in diffusion intensity and in the absorbtion and emission spectra) are :

— a notable inhibition owing to the high sodium iodide concentrations ;

— a chemical degradation in the presence of iodine (for instance fluorescein turns into a non-fluorescent iodate derivative). The respective phenomenon also affects rhodamines : the fluorescence of rhodamine B and sulforhodamine B may be reduced in the presence of NaI (and of other fluorescence extinguishers) when its concentration exceeds 10^{-6} g/ml.

Analysing the behaviour of fluorescent dye tracers as to the chemical composition of waters (pH value, ionic charge, extent of pollution, etc.) and in interactions with the solid phase, one may note different manifestations (Feuerstein, 1963). The difference in behaviour is accounted for by the ionic nature of these tracers. Thus, the cationic form will provide for tracer fixation on most soils, on clays and colloids in particular.

Examining the absorbtion and desorbtion isotherm of rhodamine B and uranine, an excellent reversibility in uranine and a substantial, mostly irreversible, sorption in rhodamine B may be noted. Sulforhodamine and rhodamine Wt boast a behaviour similar to that of uranine.

In exchange, whereas in the case of fluorescein measurement is affected both by pH value and pollution extent, in the case of rhodamine B and sulforhodamine B the content of salts does not exert a significant influence when the pH value ranges from 5 to 10. The range of pH values is even wider — from 3 to 11 — in the case of sulforhodamine G.

Another fluorescent tracer, pyranine, shows excessive variations in fluorescence with pH changes in the range normally encountered in natural waters. This might prove a serious problem in quantitative applications to waters of variable quality.

To trace underground water in karstic systems, the tracers should be conservative (the tracer substances must be stable against physical, hydrochemical as well as microbial attacks). The basic properties of a tracers depend on their chemical and physicochemical structure. If this structure remains stable in experimental conditions, the tracer may be used in quantitative assessements.

As certain radioactive or non-radioactive isotopes (which can be detected with the help of the activation analysis), tested in their cationic form, proved an unsatisfactory behaviour, they were complexed. Nevert-

heless, the performance of anionic complex tracers is dependent on the stability of the complex. The dissociation of these complexes is characterized by the stability constant, K_s (Behrens, 1983). In table 1, MA_n is the molar concentration of the complex and M and A the molar concentration of the metal ion and of the ligand.

Table 1

The stability constants of chelate complexes in neutral aqueous solutions

Complex	Stability constant $K_s = [MA_n]/[M][A^n]$
$Co(CN)_6^{3-}$	10^{64}
Co-EDTA	10^{36}
In-EDTA	$10^{24.9}$
Cr-EDTA	10^{24}
Sc-EDTA	10^{23}
Bi-EDTA	$10^{22.8}$
La-DPTA	$10^{19.5}$
Dy-EDTA	$10^{17.6}$
La-EDTA	$10^{15.4}$
Mn-EDTA	$10^{13.8}$

A relative criterion to assess the stability of complexes is the $K_s = 10^{20}$ limit. Therefore, In-EDTA, where $K_s = 10^{24.9}$, may be considered a very good tracer.

Photochemical decay has a great importance in tracer stability, because all fluorescent dye tracers are subjected to decomposition owing to natural light. Sensitivity to light, however, differs substantially from one fluorescent dye tracer to the other (Smart, Laidlaw, 1977, Atkinson, Smart, 1981, Laidlaw, Smart, 1982). The decrease in concentration of a fluorescent dye tracer under the impact of light follows the relation :

$$I = I_o \exp - \left(\frac{0.693t}{t_{1/2}}\right)$$

where I is fluorescence after the t time of irradiation and Io denotes the fluorescence at the time t = o and $t_{1/2}$ is the half-life of fluorescence intensity.

This phenomenon has a special importance as it restricts the applications of fluorescent dye tracer to underground flow alone. On the other hand, storage of samples containig fluorescent dye tracers in areas exposed to light may lead to the degradation or total disappearance of tracers. So, for instance, uranine-containing water samples collected from karstic exurgences in day time showed lower fluorescence when compared with a reference sample, a situation which did not occur in the case of samples that had been collected at night.

The irreversible photodegradation of tracers in solutions is due to the disolved oxygen or ferric ions in particular. Owing to studies conducted on uranine (Lingvist, 1960) losses through photodecomposition could be assessed. Thus, the half-life of fluorescence in distilled water

is of 11 hours, while photochemical degradation may reach even 25 per cent per hour in polluted waters. It is noteworthy that degradation is independent of the concentration of the tracer. In exchange, degradation increases with the intensity of irradiation, being roughl 5 times higher on a clear summer day than that on a day with a cloudy sky (Molinari, 1969).

In brief, the situation of other fluorescent dye tracers is as follows : eosine decomposes under the impact of natural light faster than uranine does and has a $t_{1/2}$ of 6 hours. Rhodamines behave differently. Thus rhodamine B has a fluorescence half-life of 780 hours, but may reach values of 2.24 percent in polluted waters. In exchange, sulforhodamine B has a $t_{1/2}$ of 820 hours (the photochemical degradation of a sample exposed for a total 24 hours to strong sunshine was of only 1 per cent). From this point of view, sulforhodamine G boasts an almost identical behaviour. Among the other rhodamines, rhodamine 6G decomposes a little faster ($t_{1/2}$ = 375 hours) and then the half-life of fluorescence intensity increases under the impact of light. Amidorhodamine G has the $t_{1/2}$ = 770 hours and rhodamine Wt has the $t_{1/2}$ = 1,300 hours, which makes it a more stable tracer.

The situation of other fluorescent dye tracers is variable. Thus half-life in the case of tinopal CBS-X is of 17 hours, of pyranine is of 47 hours, while brilantsulfoflavine FF has a photochemical stability which is 200 times higher than that of eosine and a t equal to 1,200 hours (Klotz, 1982).

Not all hydrological tracers are stable at temperatures higher than that of the environment. The most relevant case is that of fluorescent tracers. So, fluorescence intensity varies inversely with temperature, though this rate repends on the dye (Smart, Laidlaw, 1977). Fon instance, degradation of fluorescein starts at 25 degrees centigrades ; at a temperature of 200°C fluorescence disappears altogether (Fabricol, Pauzancre, 1981). Degradation is not instantaneous, however. Experimentally, total degradation occurs in ten days at a temperature of 200°C. As a rule, thermal waters are higly mineralized and, in this case, the stability of fluorescein is not affected by the chemical composition of water but only by its temperature.

Radioactive and activable tracers in compounds used in hidrology are generally stable at temperatures found in practice with the exception of ^{82}Br in the $BrNH_4$ combination. As bromine volatilization starts at 18°C, it cannot be used to label thermal waters. On the contrary, ^{131}I in the form of NaI boasts fine stability at temperatures of up to 130°C. In-situ tests showed a fine percentage of tracer recovery after a 48-hour residence in the underground at a temperature of 130°C. As for the influence of the temperature of the tracer solution on measurements, it can be noted that small differences in temperature as to a reference sample may have substantial negative effects on certain classes of tracers. Fluorescent dye tracers are the most sensitive of all. Thus, rhodamine B and sulforhodamine B show a 3 per cent variation in the measured value per each degree centigrade. In exchange, hydraulic fluorescein varies only 0.4 per cent with the same temperature gradient. Sulforhodamine B is not influenced at all.

The last factor in lowering of tracer concentration in karstic systems is the interaction with biomass.

This process shows to the full in surface and karstic waters in particular where all conditions for intense biological activities are met. Of equal interest is tracer retention through other processes by algae or even through mere superficial contamination of vegetation.

Degradation of fluorescent dye tracers may occur owing to microbial activity, more particularly when they penetrate polluted waters. The most affected of them is uranine.

Iodine, a highly useful hydrological tracers, may stand a series of chemical transformations through processes induced by microbial activities in both surface freshwater and soil water.

Though not sufficiently investigated, the microbial conversion of tracers should be considered, as it leads to their gradual degradation. According to some authors, tracer biodegradability is an advantage and a criterion for selection. An example in this respect are optical brighteners which disappear from surface waters under the joint impact of sun rays and biological activities (Smart, 1982).

6. TRACER TOXICITY

Two aspects of tracer toxicity are important: first, deleterious effects on karstic and surface water life and second, the limitations which should be considered where human (and the entire ecological chain) consumption of the labelled water from karstic aquifers is a possibility. In assessing the biological risk on living organisms in karst, the amount and tracer concentration and the duration of experiment should be considered.

When tracing is achieved at high discharges, the duration of experiment is short and great concentrations may appear in karstic springs. Obviously, these springs contain water of very good quality. The tracer concentration at karstic outlets should appear below the limits pemissible for drinking water. This is very important, especially for chemical and radioctive tracers. For other tracers, whose concentrations are missing from standard in force, the toxicity of compounds to man is normally investigated on laboratory animals ; safe dosage levels are then scaled up, and an additional safety factor is incorporated.

When labelling is performed in conditions of low discharges, tending to low flow, tracer dispersion is high. The tracer penetrates into karstic holes, siphons and secondary channels where it may remain for some time, according to hydrometeorological conditions.

Tracer concentration in these zones of virtually stagnant waters with an extremely slow velocity may acquire substantial values. Having enough time to interact with the rock, the tracer will be fixed to the walls and floors of the cavities through physical and chemical processes, that is exactly at the point where the microfauna of the karst develops.

For these reasons, the tracer used should boast the features of an ecological tracer, that is, it should not lead to changes in environmental

conditions or to the emergence of mutations, and shoud not destroy the life that develops in the karst.

Of the tracers in use, radioctive tracers meet the requirement for an ecological tracing. Lower organisms are influenced only by large doses of radiation which cannot be producted by activities in use, limited by sanitation norms in force in all countries.

The only tracers that may pose ecological problems are the chemical and fluorescent dye tracers. Of the chemical tracers, certain salts, such as NaCl or KCl, call for large amounts for one labelling (more than 500 kg normally). These tracers may create a saline medium in underground cavities, a medium which might influence normal living conditions.

As for fluorescent dye tracers, they made the object of numerous studies of toxicology. The final conclusion was the need to limit the amounts of injectable tracer into the karst (Smart, 1982).

7. TRACING OF KARSTIC WATERS

7.1. *TRACER INJECTION*

The aim of the tracer injection is to stimulate the karsitc system so that an output response function apt to supply most complete information on the system may be obtained. That is why labelling must not modify the hydraulic characteristics of the karstic system.

The way in which a tracer is introduced in a ponor or sinking point may have a deciding influence on the whole experiment. The smaller the amount of tracer, the lower its impact upon hydrodynamic and ecological conditions, although tracer detection and measurement might prove a dificult metrological problem.

Of the modes of injection in use, three are worthy of mention (fig. 19).

a. *Instantaneous point injection* (by δ-input signal). The response of the system to this signal is usually a curve with a Gaussian form, as the analysis of the transfer curve obtained on an experiment plot when labelling the Valea Popii ponor (Pădurea Craiului Mountains) shows (fig. 20) Suchlike labelling cannot be performed in any conditions. For low and very low descharges, the only tracers fit for δ-pulse injection are the radioactive or activable tracers, as the amounts injected are insignificant and do not upset the hydraulic conditions of the system either at the inlet or in the underground ;

b. *Step injection.* It represents the sum of pulses, with the tracer introduced into the insurgence using a device at a constant discharge. This system is employed when large amounts of substance (the case of chemical tracers, for instance) are needed for the performance of labelling. Injection discharge, q, should be lower than a tenth of the inflow, Q_0. The introduction of the tracer takes long in the case of low-discharge insurgences and large amounts of substance are necessary. Besides being

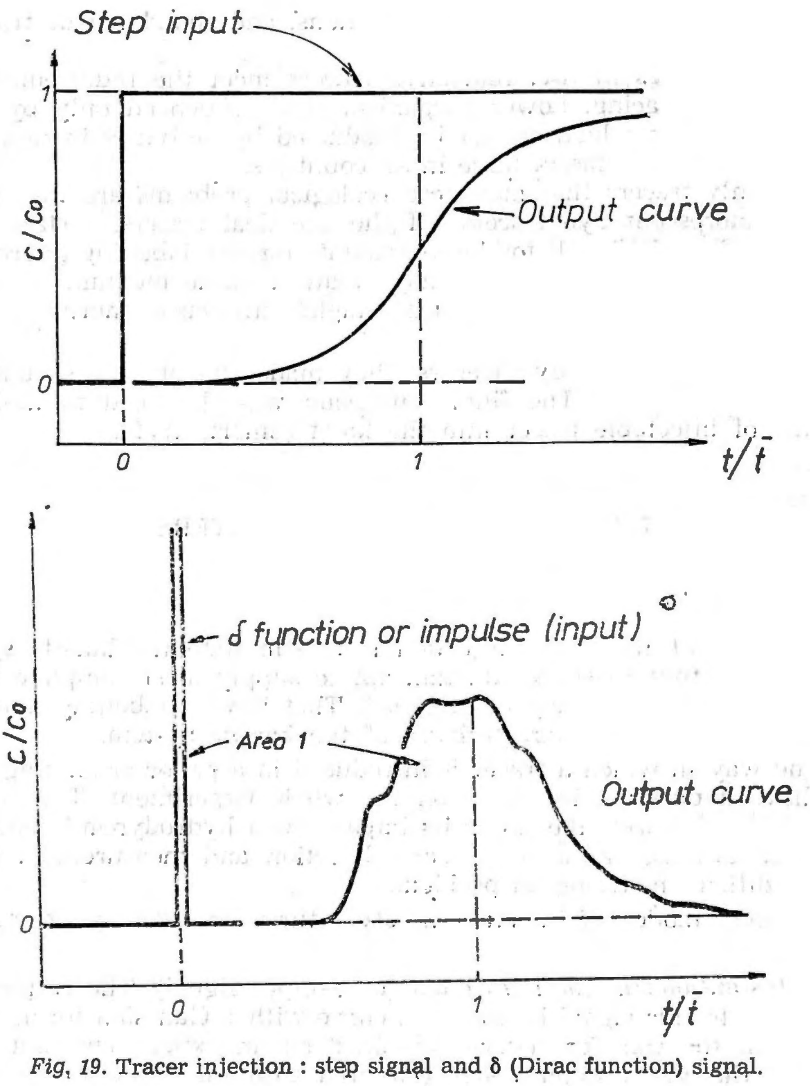

Fig. 19. Tracer injection : step signal and δ (Dirac function) signal.

uneconomical, it has the disadvantage that it may lead to negative results because of tracer dispersion below detection limits.

The response of the system to this labelling is a signal of the step type, if transit is short, or of any other form. Figure 21 shows the time variation of tracer concentration in the IAS-Mangalia mezothermal spring after the labelling of the Kara-Oban sinkhole with a constant tracer discharge (Gaşpar, 1981).

c. *Random labelling.* At present it is employed only when qaulitative results are expeted (for instance, to demonstrate the existence of an interconnection), the discharge of the insurgence is low and the tracers (dyes or salts) are available in large amounts. Tracer concentration in

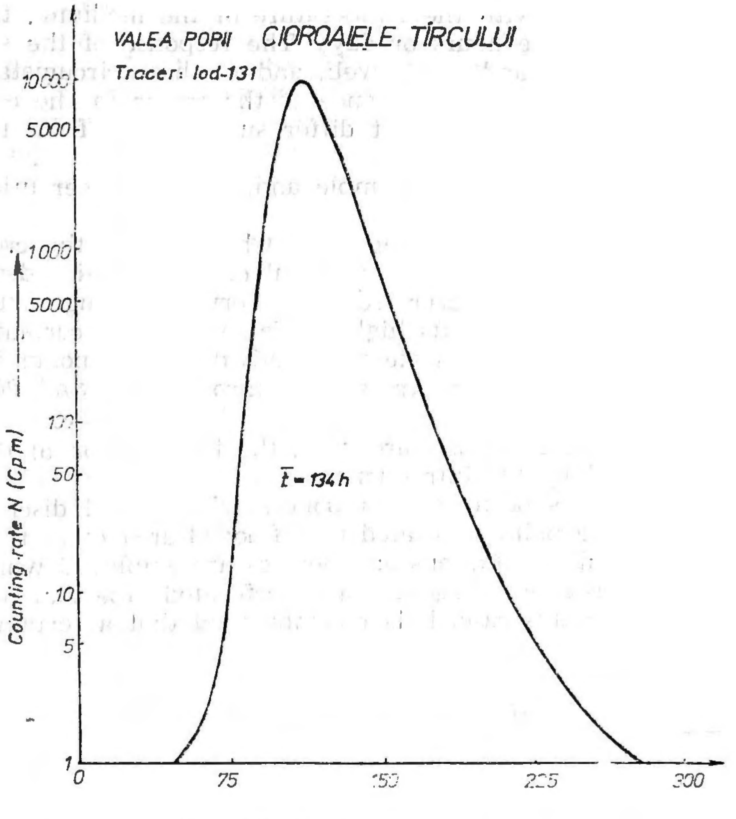

Fig. 20. Thu output curve of a tracer after labelling by δ-input signal. The flow rate of labelled ponor: 0.1 l/s.

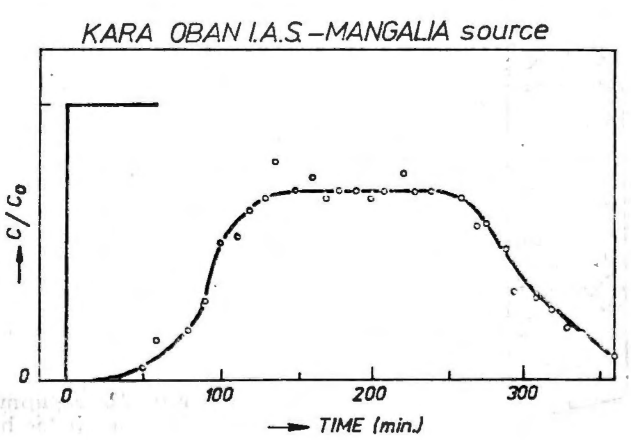

Fig. 21. Step input and tracer output curve in the Kara Oaban experiment.

the labelling points varies according to water dissolution capacity, which, in turn, varies with the temperature of the medium ; the labelling operation may take hours or days. The response of the system to such a signal will be random, as well, and in these circumstances the only aspect of interest is the presence of the tracer in the emergence under study in concentrations that differ substantially from the value of the background.

A labelling operation is not simple and, besides tracer injection, it includes :

— preparation of the labelling area, which means the creation of an access route to the ponor, the removal of the organic depositions, which tend to absorb the tracer from the very beginning in the point where its concentration is at its highest. To introduce a certain amount of water after labelling with a view to "activating" the ponor is a mistake which can only result in tracer loss through the wall effect, absorbtion reject, dispersion etc.

In case radioactive isotopes are used, the introduction of the tracer should be preceded by the introduction of the carrier.

When labelling is performed in ponors with partial discharge loss or when the sinking point is located in a flooded area or at the bottom of a lake, additional installations and devices are employed which assist tracer injection through the agency of a perforated pipe that penetrates under the layer. In this case, it is recommended that a certain amount

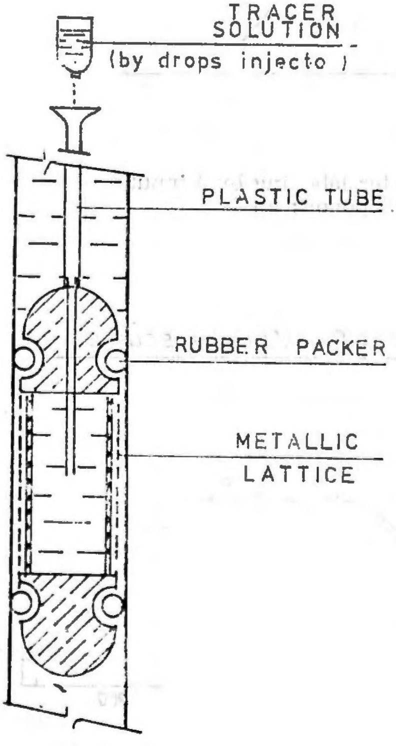

Fig. 22. Equipment for tracer injection in boreholes having vertical currents.

of water be introduced into the pipe to favour tracer penetration into the underground.

If the tracer employed is not a dye, a small quantity of fluorescein or rhodamine B can be used to verify the efficiency of the respective labelling. When the insurgence point is an estavellas (a karstic formation that may operate both as a ponor and a spring) labelling should be performed at a moment when there is no possibility that the tracer be moved backwards.

In the case of labellings in wells the existence of currents and their direction (ascendent, descendent) is determined, the areas with holes (boasting maximum permeability) are identified and isolated with packers and then the tracer is introduced (fig. 22). After the tracer has been completely injected into the borehole pipe it should be followed by the injection of the amount of water required to ascertain if the entire amount of tracer has left the pipe and penetrated into the underground.

Tracer injection may be performed in dry sinkholes too, obviously for the sole purpose of establishing certain interconnections. In the absence of a natural flow, an occasional flow is created until hydraulik links are established ; artificial flow should continue after the tracer has been injected as the probability of detecting the tracer depends on the duration of the continuity of the flow (Sencu, 1977).

— Tracer dissolution and dilution are operations that often require a large water volume. If the tracer is not dissolved entirely the inflowing amount of tracer is smaller than the amount that has been injected and, therefore, cannot be used in balance computations, even if recovery curves are obtained in emergences. Furthermore, the dissolution in time of the tracer carried by water and retained owing to the difference in density nearby the injection point will entail an artificial elongation of the tracer cloud, which conveys a false image of the hydrological characteristics under study.

— Decontamination and waste removal, which refers to individuals equipment and means of transport. Decontamination measures should be most strict. So, for instance, in case spores are used the presence of a single spore is considered sufficient to indicate the existence of an interconnection ; the possibility of conveying an erroneous information enhanges considerably if the the same individual performs both injection and the sample taking operation.

— Surveillance of emergence points, which starts when labelling operations do, or after a short interval, according to experiment conditions.

7.2. *TRACER QUANTITIES USED IN KARST WATER TRACING*

The quantities of dyes that should be injected into the water in tracer studies can only be approximately calculated or estimated. Nevertheless, such estimates can prevent gross errors. There is an optimal amount of tracer to investigate a karstic structure but it depends on a number of variable factors, such as : the labelled volume, the minimum detectable concentration of the tracer, the transit time in con-

nection of period of investigation (during low or high flow), the maximum allowable concentration of the tracer in drinking water, the outflowing discharge of springs, the background etc.

A relation that was established more recently (Leibundgut, 1974, Leibundgut et al., 1982) and has been used in numerous dye tracer tests, starts from the analysis of the tracer wave in the monitoring point :

$$M_0[kg] = \frac{T[h]C_{peak}\ [mg/m^3]Q[m^3/h]A_c\ S_c}{2 \cdot 10^6}$$

where M_0 is the injecter quantity of dye, T denotes the estimation of dye passage duration through the monitoring point, C_{peak} represents the maximum estimated concentration in the sampling point, Q is the spring discharge (in the case of determination in wells, the pumping flow rate), A is the adsorbtion coefficient and S denotes a safety coefficient.

In the case of tracers detected with the help of chemical analysis or activation analysis, Leibundgut's relation yields equally satisfactory results. In this case, however, the range of variation in the natural background, prior to, the experiment, should be known and the value of the maximum concentration expected in the measured emergence should satisfy the relation :

$$C_{peak} = 100\ Bg$$

where Bg is the value of the background for the substance used as a tracer. This metrological condition provides a fine requisite for the statistical processing of experimental data.

As for In-EDTA, used as a tracer to investigate hydrokarstic structures, the analysis of numerous trials (Gaşpar et al., 1985) has led to an empirical relation -

$$M_0 = QTPK$$

where M_0 is the In amount required for one labelling (expressed in g), S is the sum of the flow rates of the emergences where the tracer might occur (in m^3/s), T denotes the time interval, as estimated by the investigator, needed for the tracer to pass through the monitoring point and for a value of at least 10 to be attained for the maximum/minimum concentration ratio (in days), P is the loss coefficient, expressed by the M_0/M ratio, where M is the In amount recovered, and K is a safety coefficient.

The use of coefficient P is justified as a certain amount of tracer may be retained in the auxiliary systems according to the hydrodynamic behaviour of the karstic system during the testing period. On the other hand, in the case of very long transit times, determined in particular, by a lack of precipitations and the continous lowering of the water table, part of the tracer may be lost in various traps and it will be released later, after rainfall start, in general after measuring operations have ceased.

We believe that a value ranging from 1 to 3 for P may be considered as reasonable, the value of 3 not being exceeded in the abovementioned experiments. As for coefficient K, its value may be below 2.

Figure 23 shows a diagram for the optimal amount of indium needed in an experiment for cases frequently occuring in practice. So, for instance, 10 g of In-EDTA — a minimum detectable concentration of 10^{-12} g/cu.cm granted — may label a karstic structure which discharges through an emergence with an outflow of 1 cusec, the tracer cloud passing through the monitoring point for a period of 10 days if conditions are favourable. If labellings is performed at the beginning of a period of drought, the respective amount of indium would be enough only for a discharge of 150 l/s ; for a discharge of 1 cusec, 16 g are necessary.

Henceforth, it is clear that in the afore-said example the probability of obtaining a positive result, without creating ecological or financial problems, will enhance substantially of the safety coefficient is raised and an amount of 25 g used.

More complicated problems occur in case radioactive tracers are used because of strict radioprotection norms. The experimenter is obliged to take every preventive measure so that the concentration attained in the spring water should be below the permissible upper limit for drinking water.

With a view to performing radioactive labelling yielding quantitative information on the hydrokarstic structure under investigation,

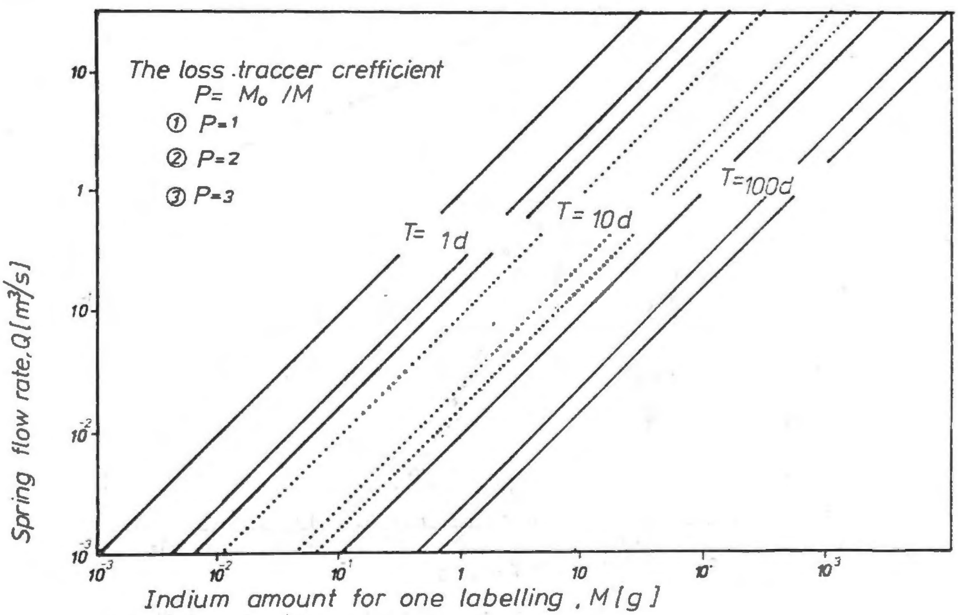

Fig. 23. Diagram to compute the Indium amount for one labelling.

it is necessary that the following conditions be achieved in the emergence point :

$$C(x,t) \geqslant C_{min} \leqslant C_{al}$$

where C_{min} is the minimum detectable concentration with the detection system employed, and C_{al}, the maximum allowable concentration of the tracer used for the population exposure. In these conditions, the maximum activity necessary, A, for the experiment is :

$$A = \Omega C_{al} D^{1/2} x^{1/2} \exp(\lambda t)$$

where λ is the radionuclide disintegration constant, D denotes the hydrodynamic dispersion coefficient, x is the distance between ponor and springs, t denotes the estimated transit time, and Ω represents the cross section of the flow (fig. 24).

Any labelling should contain a measure of risk since the activity of the experimenter depends on the hydrological conditions that prevail throughout the duration of the test. The fact should be pointed out that

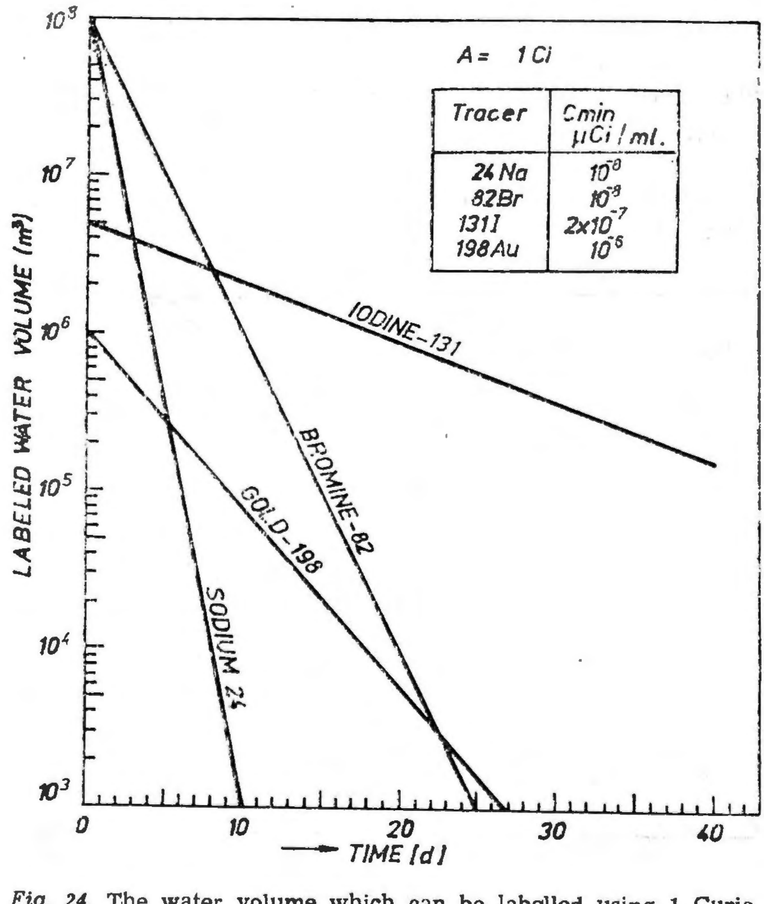

Fig. 24. The water volume which can be labelled using 1 Curie of radioactive substance.

rapid changes in hydrological conditions may either favour the experiment or cause its failure. The risk of failure appears whenever labelling is performed during low-flow periods. The tracer water may be stored in siphons, underground lakes and solution channels until the karstic structure becomes active again.

Thus, for instance, a labelling made with the help of In-EDTA in the Pădurea Craiului Mountains, in an area where average velocities of 30—40 m/day were frequent, for a transit distance of 4.8 km and a level difference of 135 m, the tracer needed 40 days to appear in the Toplița de Vida spring. Throughout this interval it penetrated deeply into the auxiliary sistems, being carried toward the outlet after it had travelled them. This is apparent in the high dispersion of results, measurable Indium amounts being released from the karst during a 150-day interval after the first occurence (Orășeanu et al., 1984).

7.3. *MEASUREMENT OF TRACERS*

The result os a labelling are primarily dependent upon an accurate inventory of all possible emergence : (continental and submarine) springs, (natural and artificial) lakes, rivers, estavellas, wells and boreholes, caves, underground mines where water inflows occur, as they all represent monitoring points.

Two methods are employed in practice : the continous procedure (in situ) and the sampling procedure.

In situ detection is used for gamma active tracers, for fluorescent dye tracers and salts. The accuracy of determinations depends on the calibration of probes and devices (in the case of radioactive tracers in particular). When salts are used as tracers, their concentration may be assessed by continously measuring either the conductivity or the resistivity of water. In case of in-situ assessements, graphic recorders are normally employed which accurately pinpoint the moment of tracer occurence.

In situ detection gives rises to two extremely difficult problems for the operators. These concern the auxiliary electronic instrumentation and the detector itself. The electronic equipment for radiation counting has to meet very high exigencies : it should enable high sensitivity determinations ; the accuracy of the measurements should be as high as that of sample measurements ; it has to be light and easily carried by one person since the medium to be investigated may be in an inaccessible region ; it should by sturdy, to resist mechanical shocks during transportation ; it should have a longer functioning independence than the duration of the investigated phenomenon, it must work in conditions within an acceptable temperature range from —5 to +40°C in temperate regions or it must be tropicalized ; it should normally function in variable conditions of humidity and pressure (e.g. in caves).

Detection on samples is a method very used in karst hydrology. The sampling must be performed with adequate apparatus, acording to a

well defined technique, and at determined time intervals, in order to observe the phenomenon all along its course.

Sampling must not perturb the hydrodynamic conditions of the phenomenon to avoid the appearance of an unexpected concentration gradient. The samples must be placed in special containers which can not be contaminated and prevent retention or contamination of the tracer. Thus, water samples are collected in plastic rather than glass bottles of a given capacity, as the latter permit an indesirable isotopic exchange.

When the sample measurement method is applied an optimal sampling interval should be found so that the information supplied by the tracer may not be lost when transit is rapid and testing should not become uneconomical when transit is long.

Analysing the results of several labellings in karsts, one may note a dependence between average transit time, $\bar{t}$, and the interval of time during which the outlet returns the tracer. T. Generally, the following relation may be expected :

$$T = n\bar{t}$$

where n ordinarily acquires values ranging from 1 to 3. T is shorter than $\bar{t}$ only in the case of recently formed karstic systems with short routes and sensible level differences.

The use of active carbon filters (for fluorescent dye tracers) and of ion exchangers (for radioactive tracers) provides for the use of very low tracer concentrations. Throughout the interval, the filters are active, the amount of accumulated tracer is large enough to be measured. This method provides for the measurement of concentrations which are not detectable through other methods (for instance, assessements of radioactive concentrations that are lower by several orders of magnitude than the maximum concentrations admitted in potable water).

When active carbon filters or ion exchangers are used, account should be taken of the fact that fixation yield depends on a number of factors such as the salt content of water, pollution degree, turbidity, discharge per unit volume and solution concentration and is inversely proportional to the last two. These filters concentrate both tracers and the fluorescent and radioactive substances regularly found in water. That is why gamma spectrometry is used to detect and measure radioactive tracers and differentiate them from natural radioactive substances accumulated on filters.

Calibration in filed conditions is of special importance in the case of fluorescent dye tracers as the intensity of fluorescenc depends on temperature, pH value and the degree of pollution of the measured water.

Because adsorbtion is continous in time, a higher background fluorescence will result if longer exposures are used. Activated carbon detectors should be replaced every three or four days, at least, as otherwise dye adsorbtion is delayed, especially in a medium rich in organic substances.

8. VARIATION OF TRACER CONCENTRATION IN THE MONITORING POINTS

At the measuring point, the concentration distribution is determined along the measuring time.

Plotting the complete curve of tracer concentration at the karst outlet provides for the interpretation of its behaviour. The aspect of curve C(t) supplies information on the phenomena occuring inside the karst and on the underground history of the waters labelled in ponors and insurgences.

Analysing these curves, Mueller (1982) assumes that the release of tracers from the karst obeys the same laws and types of exponential equations like those describing recession curves. He determined even the discharge coefficient of the recession curve, α, using the results of the experiments conducted with artificial tracers. This means that the aspects of the variation curve of the tracer according to time might be characteristic of flow conditions in a geological structure. Each structure might have its own, specific concentration-time distribution curve. If this hypothesis holds valid for the given karst, then the curve C(t) might supply additional information on the volumes of stored water wherein tracers were dispersed.

But a plot of tracer concentration against time at a spring may
Multi-peak concentration-time curves amy appear :
show one or multiple peaks under many circumstances.

— when water flows from a cave passage into the surrounding bedrock, remains there for a time and then flows in the reverse direction, back into the cave passage. Atkinson et al. (1973) suggests that water is stored in the fissure of the bedrock during the rising limb of a flood hydrograph and released on the falling limb. If traced water is stored and later released, a double peak of tracer concentration may results (figs. 25 and 26).

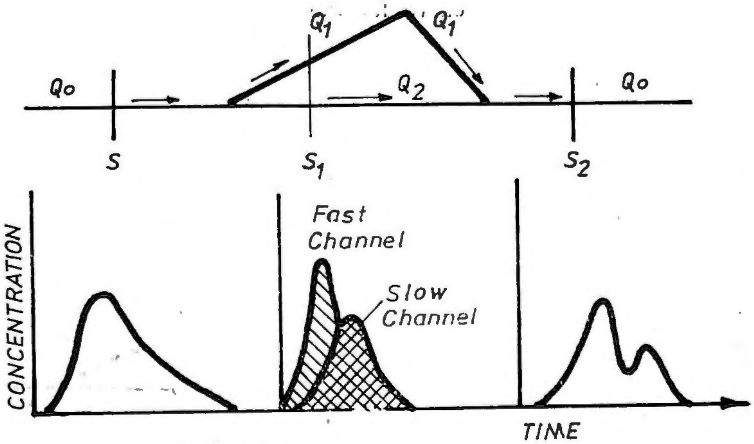

Fig. 25. Theoretical C(t) curve for two branches of the initial current in the underground.

— in certain situations when the route contains a siphon that operates rhytmically, the concentration-time distribution curve will have peaks that are equally distanced in time. The peaks must have a descending amplitude but they may also feature anomalies.

— when, at a certain moment, waters divide in the underground and take various routes towards the same spring. The peaks may be well spanned from one another, virtually representing two concentration-time curves, according to the tracer transport velocity through the two channels. If from the slow channels the tracer penetrates into cavities containing underground lakes the time distribution of tracer concentrations will be a continous curve with two peaks (fig. 27).

The intensity graphs point to certain characteristics of the karstified rock. The graph integrates these characteristics. At present, no method is available for separating on the graph the effects of hydrogeological parameters and main characteristics of karstic aquifers without doubt,

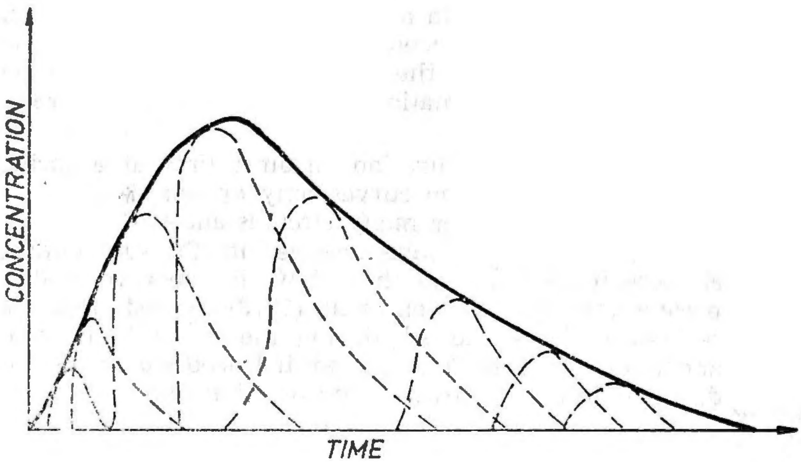

Fig. 26. Theoretical transfer curve for the case of a multichannel flow.

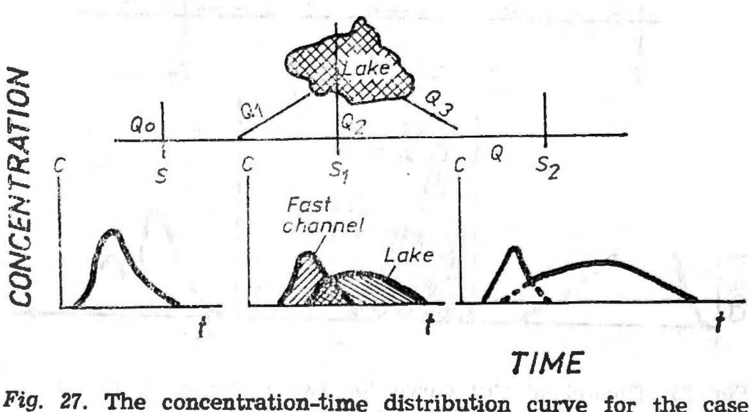

Fig. 27. The concentration-time distribution curve for the case one of the branches crosses an underground pool.

the shape of this graph primarily depends upon the geometry of the water conduit bearing the flowing water during tracing time (Milanovic, 1981).

However, considering a simplified case when the main stream divides in two on the swallet-spring route, the analysis of the residence time distribution (RTD) allows of the assessement of the amount of water that flows through the fast channel. So, for instance, in fig. 28 the area below curve C(t) may be divided in two — A and B. Under steady-state hydraulic conditions, the short circuit coefficient wll be :

$$\beta = \frac{A}{A + B}$$

The tracer concentration-distribution curve according to time provides for the quantitative processing of the pieces of information which tracers supply. Thus, if an amount of tracer M_0 in inejcted into a system and its cocnentration C, measured with time at output or another point in the system such that complete mixing has been achieved, then in steady-state conditions, consideration of mass balance requires that

$$M_0 = Q \int_0^T C \, dt$$

More often than not, however, the amount of recovered tracer is M, where $M < M_0$, as part of the tracer may penetrate into the auxiliary systems being released along with the postponed infiltration after an interval of time which is too long to allow of measurements.

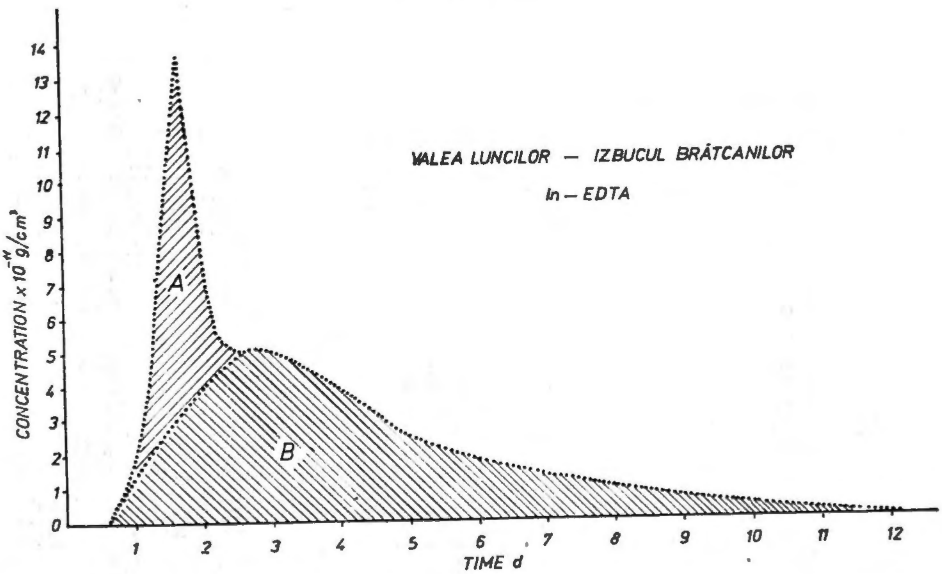

Fig. 28. The fast component of the flow may be assessed using the coefficient :

$$\beta = \frac{A + B}{A}$$

If the tracer occured in several points, then the amount recovered will be :

$$M = \sum_{i=1}^{n} M_i$$

which, for an ideal tracer, in case of a steady-state flow throughout the duration of the experiment, must be equal to the injected amount, M_0.

9. QUANTITATIVE DETERMINATIONS FROM TRACING EXPERIMENTS

Brown, Ford (1977) and Gaşpar (1972) have shown that if the values of swallet discharge Q_0, spring discharge Q, and recovered masses of tracer at spring are known, it is possible to determine one of five different types of flow networks to which the system may belong.

Let us give the schematic representation of a hydrokarstic structure characterized by an input, with the known discharge, Q_0, and an output with discharge Q. This structure may be also supplied inside with a discharge :

$$Q_x = Q_{x_i}$$

and may discharge through several emergences :

$$Q_y = Q_{y_i}$$

which may have connections with discharge Q or not.

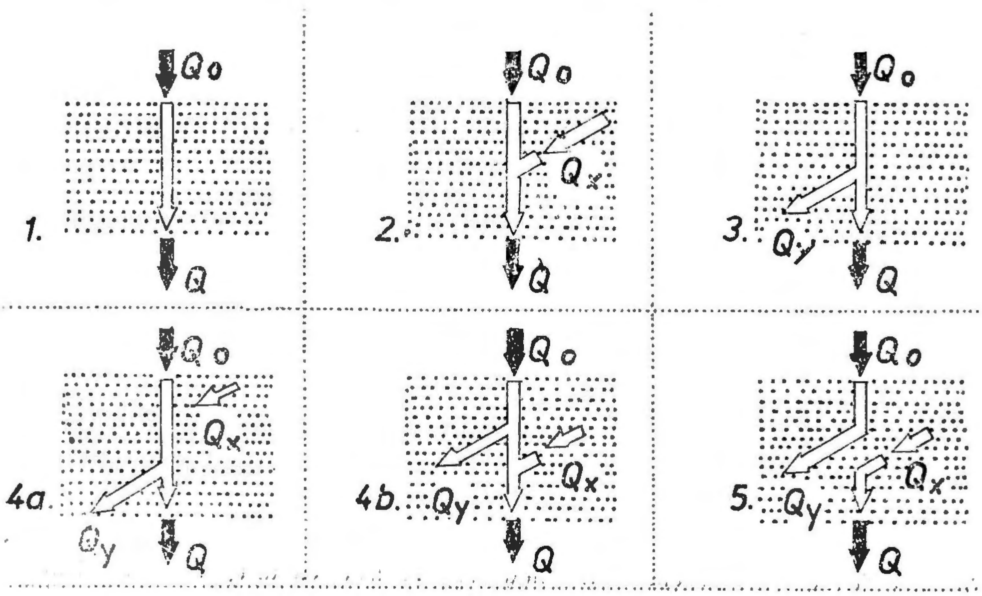

Fig. 29. Theoretical karstic flow networks.

With this image as a basis, hydrokarstic structures may be grouped in five types (fig. 29), according to the karstic networks crossing them :

— Type 1, a single input to a single output ;
— Type 2, additional, unknown input ;
— Type 3, additional, unknown output ;
— Type 4, additional inputs and outputs ;
— Type 5, an input which is not connected to the known output.

In certain circumstances, it is possible to assess the type of karstic network and the relative contributions of unknown inputs and outputs, when they exist, if all the information items available (hydrological, hydrochemical and isotopic pieces of information, investigations based on artificial tracers etc.) are processed. Let us make a brief survey :

Type 1 a of karstic network of flow corresponds to very recent karstic formations for which

$$Q_0 = Q \text{ and } M_0 = M$$

A variant of network type 1a is type 1b in which the tracer was detected in three outlets after having been injected in the inlet point A. If complete mixing has been achieved before point B it will be possible to evaluate the amounts of tracer M_1, M_2 and M_3 emerging from the outlet points if the flow rates are measured in these points (Q_1, Q_2 and Q_3).

In this case :

$$M_0 = M_1 + M_2 + M_3$$

and it will thus be possible to estimate the relative proportions of water at the outlet points originating from point A.

For a karstic network of type 2, it results that :

$$M_0 = M \text{ and } Q_0 < Q$$

In this case, the hydrochemical analyses and the data supplied by environmental isotopes may indicate the origin of the unknown discharge input. A complete study, however, calls for hydrogeological investigations through wells.

Type 3 refers to a karstic network in which :

$$Q_0 > Q \text{ and } M_0 > M$$

Therefore :

$$\frac{Q_0 - Q}{Q} = \frac{M_0 - M}{M_0}$$

In this case, other exurgences should be searched for, as they exist.

Type 4 corresponds to the situation in which the amount of recovered tracer is smaller than that injected and the discharge of the measured emergence may be smaller, equal to or larger than the discharge of the labelled insurgence :

$$\frac{Q_0 - Q}{Q} \neq \frac{M_0 - M}{M_0}$$

Very many hydrokarstic systems fall into this category. It presents only two special cases, 4a and 4b, where similar systems give different tracer budgets.

The most difficult to solve case is case 5. It represents a trap for tracer investigation for which we postulate that each labelling that does not lead to tracer occurence in the measured emergences must not be taken as a proof of lack of hydraulic continuity. Only systematic hydrochemical analyses or the study of the variation of environmental isotopes will be able to accurately assess the origin of the waters of these emergences and the inexistence of a hydraulic link with the labelled ponor. Hydrogeological investigations through wells, as well as the use of additional geophysical methods complement the range of means which lead to an understanding of the intimate structure of the respective karst.

10. FLOW MODELS

The data obtained with the help of tracers may be used either directly or in association with flow models. Generally speaking, dispersion and mixing processes taking place during flow in a real hydrological system are far too complex to be entirely described by a mathematical relation; furthermore, it is difficult, if not downright impossible, to adapt a response function corresponding to the system under study, However, though idealized, the mathematical models and the digital simulation approach, which are currently used in hydrology (Dincer, Davis, 1967, Przewlocki, Yurtsever, 1974, Yurtsever, Payne, 1978, Bulgăr et al., 1984 ,Maloszewski, Zuber, 1984) may lead, in certain cases, to a convincing description of the dynamic behaviour of the aquifer. These models originate in two basic approaches, viz. the convolution approach and the quasi-physical models employing an interconnected array of mixing cells (compartmental models).

Flow in karstic structures may be modelled if the input and the output functions are known. To obtain these functions is important as they provide for an assessement of the transfer function of the karstic system.

The input and the output functions may be the chronological series of precipitations on the one hand and the outflowing discharges on the other. The output function may correspond either to the chronological series of raw precipitations or to effective infiltrations when evapotranspiration is considered. A number of difficulties are encountered, namely that precipitations are known less accurately (as their special variability is substantial) and evapotranspiration is difficult to assess and the relations employed to compute it are not altogether satisfactory.

Other parameters (functions) related to water circulation may be considered: chemical concentrations, environmental isotope concentrations, thermal variations, solid discharge, the development of aqueous micro-fauna, as they all depend on the behaviour of the karst. For these functions to be considered and relevant, as long as possible chronological series are needed.

As they are used in the study of karst behaviour, artificial tracers may supply special information intems if successive labellings are performed in periods of low flow, of flood or in conditions of mean discharges. However, prior to applying transfer functions to the study of karst behaviour the system under investigation should be defined. There are

two methods whereby research aimed at defining a karstic system may be approached :

— knowledge of all losses and outflows from karst to establish whether it belongs to a system or not. This may be achieved through labellings within multitracing experiments ;

— research into the possibilities of existence of excess outlets (which are therefore operational only in cases of high discharges) or of uncontrolled inputs, starting from a surveillance of the main emergence of the system. This research work is conducted through both hydrological methods and labellings with tracers (which may show excess discharges, the discharges of epikarstic aquifers and the existence of karstic capture phenomena).

It is easy to determine the input function for labellings performed with the help of artificial tracers when injection is achieved through δ pulse. In the case of diffuse losses through river beds or lake bottoms, a deconvolution operation is needed for the assessment of the input function.

There are large kartic systems which contain long solution channels and in this case water re-emerges to the surface either in intermediary points or in caves. The performance of labellings in such like karst takes long to obtain the complete tracer recovery curve at the karst outlet. In this interval, hydrological conditions may change substantially and discharges may vary from low flow to flood, which renders the RTD analysis in non-steady-state conditions extremely difficult (Molinari, 1976). The solution to the problem is the performance of simultaneous labbelings in access points and the determination of tracer concentration distribution according to time, by sections. During data processing the RTD for the whole system may be obtained with the help of a convolution operation, which sensibly cuts the duration of investigations (fig. 30).

Water flow through a karstic system is far from ideal. Transfer functions may be interpreted and the age concept applied only in association with a flow pattern. The generally valid flow patterns cannot be defined as each karst boasts its own salient features and it is impossible to estimate all the parameters responsible for the behaviour of the respective karst.

These patterns are intended for understanding or simulation of the operation of the system. The lack of concordance between the results of observations and the pattern employed may be a consequence of a bad definitoin of the system, of an erroneous estimation of the input and output functions. If the flow pattern is appropiately selected then the experimental curves will superpose over the theoretical curves and all distribution parameters will be the same. In this situation, a series of important characteristics, such as static and dynamic reserve, the dispersivity of the aquifer, and, consequently, the vulnerability of the karst will be determined and, what is highly important, the behaviour of the karst in various hydrogeological conditions and it evolution predicted.

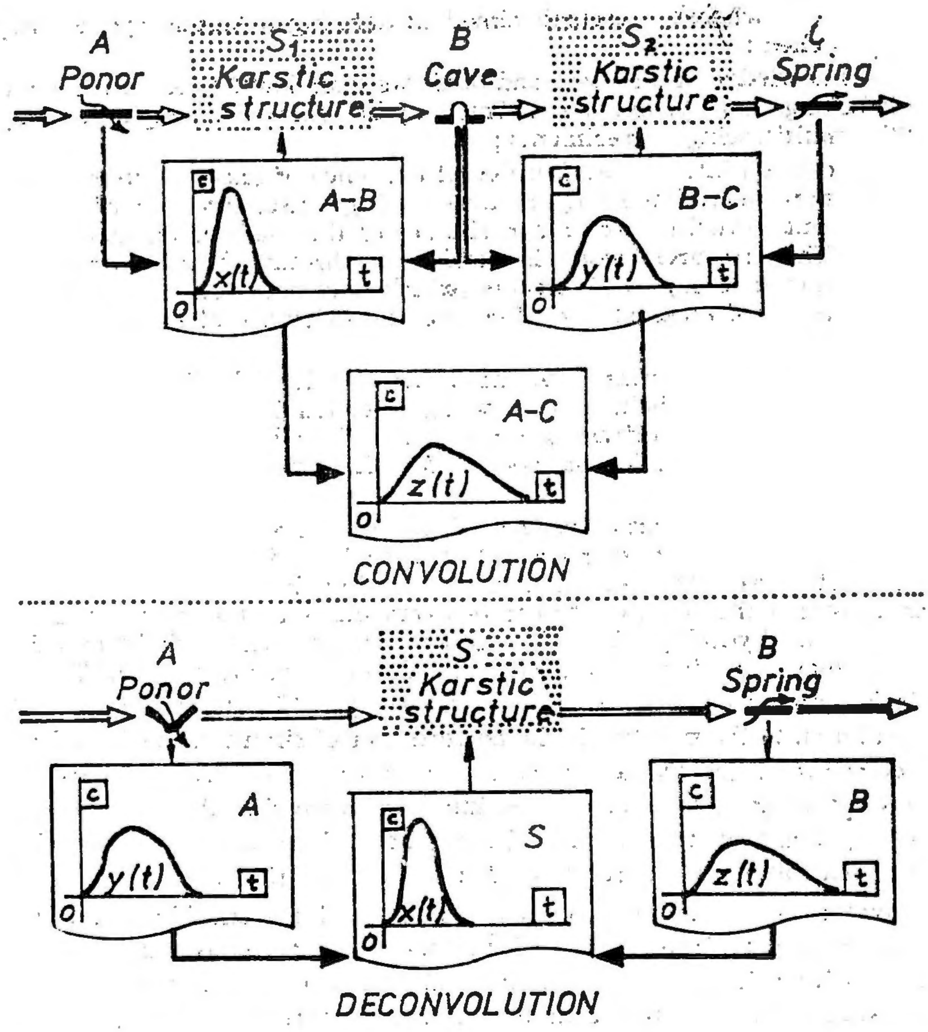

Fig. 30. Use of convolution and deconvolution for assessing an unknown component of the studied flow.

Correspondences with ideal flow models may be found in nature. A more frequently employed flow pattern is the hydrokarstic system well mixed represented by a connected group of basins. Thus, the model imagined in fig. 31 has a counterpart in reality and, with a slight deviation, represents a longitudinal section through Cueva de Boluga, Spain (Cox, 1971). The cave passage is assumed to consist of a sequence of well-stirred pools, each of volume w and a constant flow Q so that the concentration C of a solute in the water that leaves the n-th pool is the same with that of the water in the same pool. Connected basins represent a dispersion model with deviations from the piston flow (fig. 31).

The existence of a piston flow accompanied by dispersion and diffusion in the matrix (a convective-dispersive pattern) may be easily shown through a simultaneous labelling with particles (spores for instance) and a conservative hydrological tracer (either fluorescent or radioactive tracer). Thus, the outlet curve may feature a peak owing to the piston flow (materialized through spores) and a flat shape owing to the dispersion of the other tracer as in fig. 32.

In general ,experimental data (repeated labellings, multitrcing experiments) supply sufficient arguments for the selection of a flow pattern with total displacement drain or branches (short circuits, perfect-mixing zones (underground pools), stagnant zones (underground lakes, siphons), zones with dispersed, diffusion and exchange (auxiliary systems).

It should be poitned out, however, that the interpretations of flow patterns call for permanent hydraulic conditions, as two phenomena occur in this case — transport of masses of water, on the one hand, and tracer propagation on the other hand. The two phenomena are linked to each other through relations that are difficult to assess when discharge varies.

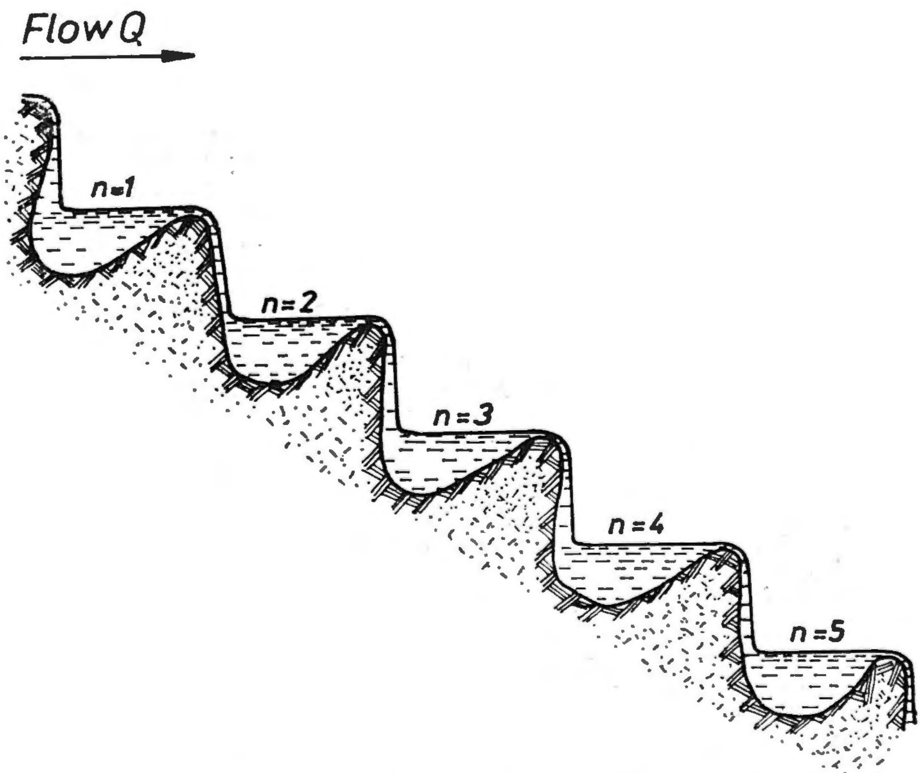

Fig. 31. Section through Cueva de Boluga, Spain (weil — stirred pools model).

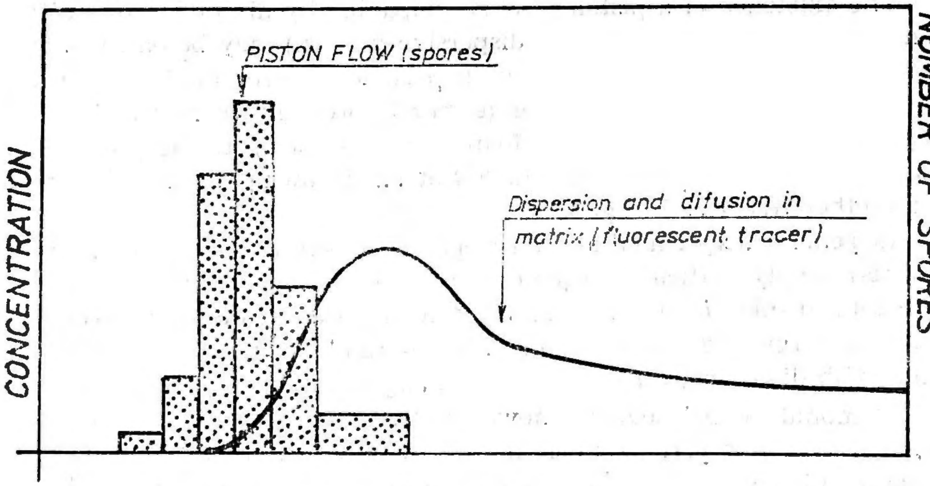

Fig. 32. **A theoretical double labelling to assess the flow through fast channel (using Lycopodium spores as a tracer) and the contribution of slow channells, using using fluorescent tracers.**

11. MULTITRACING EXPERIMENTS IN ROMANIAN KARST

11.1. *THE PROBLEM*

Inespective of its qualities, a tracer is not sufficient and cannot be used for simultaneous or repeated labellinge. Owing to the extremely different behaviour of the karst in between low flow and flood, important amounts of tracer may remain in its systems for a long time. Consequently, investigation of hydrokarstic structures should be performed through simultaneous labellings, with the help of different tracers : fluorescent dye tracers, chemical or activable tracers, radioactive or biological tracers.

Multitracing experiments are employed :

— for shortening the duration of research work by avoiding repeated trials ;

— from the necessity to perform investigations in analoguous hydraulic conditions ;

— because of the fact that the main cost of a tracing in karst depends more often than not on the intervention of the personnel that take the samples. And the spending implied by this operation is independent from the number of labellings that are performed.

Labellings in karsts supply through knowledge of the karst, facilitate validation or nevalidition of hydraulic connexions, and provide for the discovery of new connexions. They are un ideal means of studying the vulnerabiltiy of the karst to pollutants. Labellings also allow of a verification of flow patterns of the hydrokarstic structure under investigation, the performance of methodological and comparative studies concerning the behaviour of other tracers.

On the other hand, the fact should be stressed that in multitracing operations artificial tracers cannot supply information on the slightly permeable sectors of karstic systems. Such pieces of information can be obtained if water chemism and environmental isotopes are associated.

For a better understanding of the goals of artificial labellings of hydrokarstic systems a number of case studies should be outlined.

11.2. *LOCALIZATION OF GROUND WATER CATCHMENT AREAS*

Differences in the D, T, ^{18}O and salt contents resulting from the local distribution pattern of these isotopic contents within the precipitations due to continenal, altitude and other isotopic effects have been successfully used for answering the question which catchment area belongs to a specific karstic system (fig. 33). Also, labelling experiments with intentionally added tracers contributed to the definition and delimitation of catchment areas in karstic aquifers.

In karst areas, the delineation of approximate groundwater catchment boundaries is the first step in any hydrogeological study. However, if it is always difficult to place the exact limits of an emergence in karstic areas in the absence of well defined geological boundaries. The topographic supply basin and the real drainage basin are seldom in concordance. The location of catchment areas may be identified by analysing

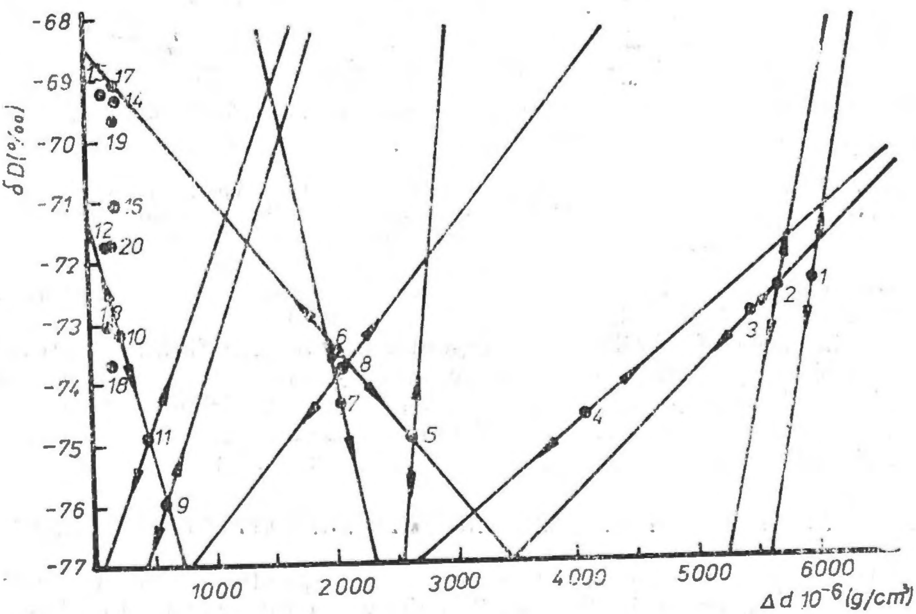

Fig. 33. Wandering lines of δD — Δd values for geothermal water types and mean values δD and Δd for all water types taken into account in Băile Herculane area. 1 — Fabrica de var ; 2 — Decebal ; 3 — Traian ; 4 — Neptun ; 5 — Diana ; 6 — Apollo I ; 7 — Apollo II ; 8 — Hercules ; 9 — Scorillo ; 10 — Ghizela ; 11 — Şapte izvoare calde ; 12 — Şapte izvoare reci ; 13 — Cerna spring ; 14 — Topleţ spring ; 15 — Poiana Beletina ; 16 — Izverna spring ; 17 — Pişetori ; 18 — Izvorul Alb ; 19 — Bîrza spring ; 20 — Ciocioare spring.

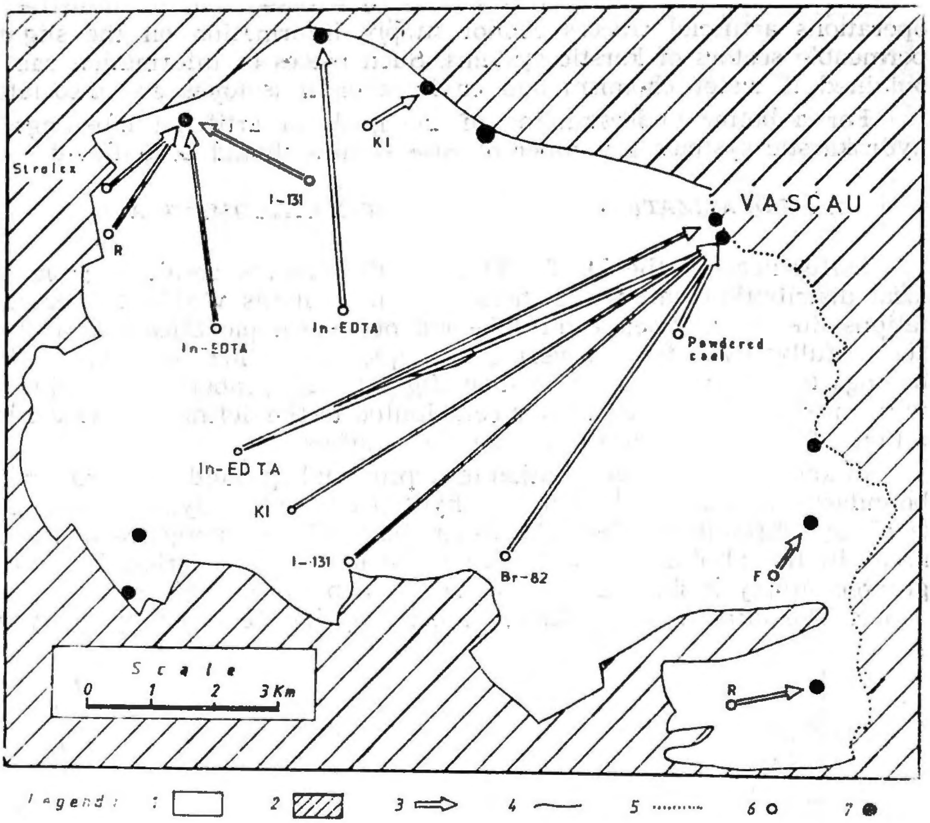

Fig. 34. Main spring and underground flow direction in Vaşcău karstic plateau. 1 — Karstic terrains. 2 — Non karstic terrains. 3 — Underground routes. 4 — Secondary barrier. 5 — Permeable border. 6 — Ponor. 7 — Spring.

hydric balance in correlation with the results of the labellings performed with the help of artificial tracers (Quinlan, 1982).

In the wake of labellings convergent and divergent flow routes result. Figure 34 shows the delineation of karstic area and drainage divides with the help of convergent labellings in Vaşcău karstic Plateau (Orăşeanu, 1985), and fig. 35, the extension of drainage area of „Peştera cu apă de la Bulz" (Rusu, 1981 ; Orăşeanu and Jurkiewicz, 1982).

11.3. *HIGHLIGHTING OF PARTIAL CAPTURES AND DIFFLUENCE SURFACES*

Phenomena of stream water piracy are specific to karstic areas ; they are characterized by the fact that the water infiltrated into a hydrographic basin and having covered a certain underground route is to be found again in a source that appears in another hydrographic basin (fig. 36).

In order to individualize the surface of the hydrographic basin upstream of the partial capture in terms of hydrogeology, the notion of diffluence surface was suggested, while to designate the phenomenon,

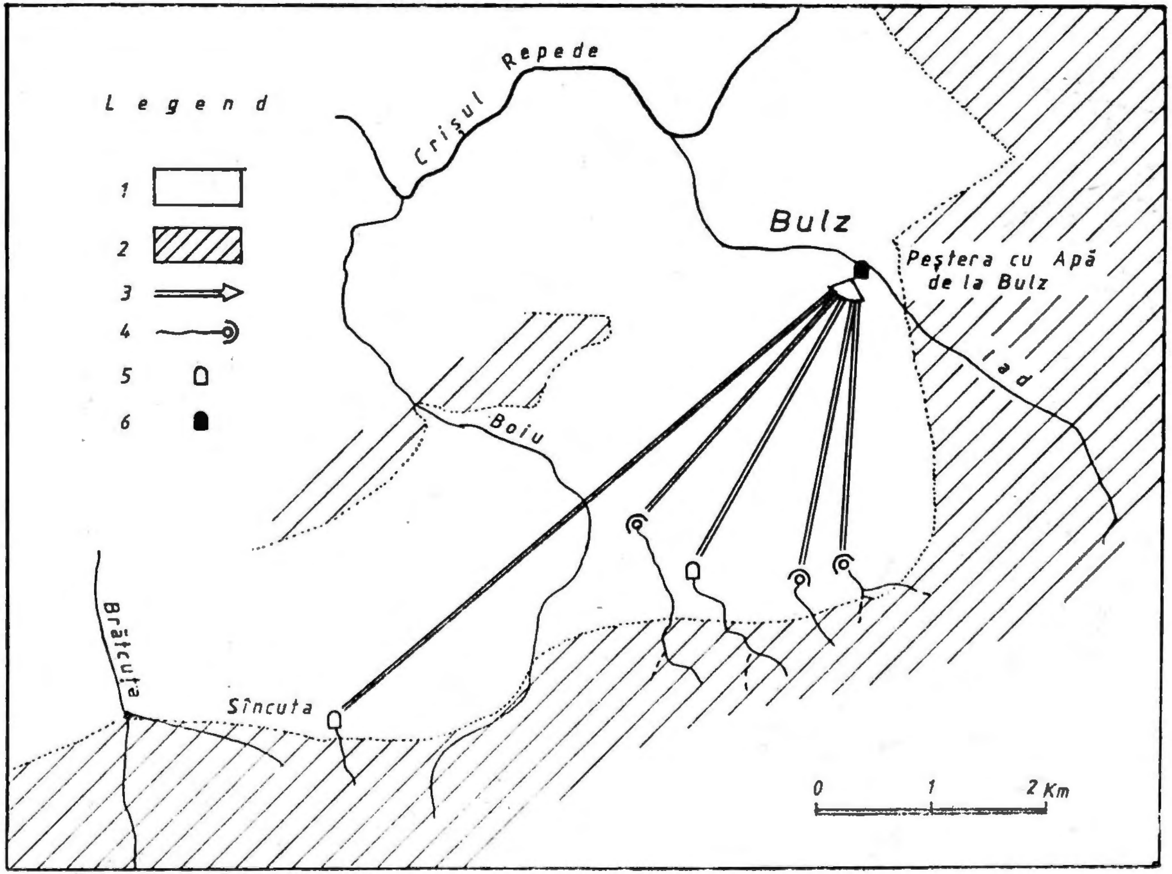

Fig. 35. Drainage area of Peştera cu Apă de la Bulz cave. 1 — Karstic terrains. 2 — Non karstic terrains. 3 — Underground routes. 4 — Ponor. 5 — Inflow cave. 6 — Outflow cave.

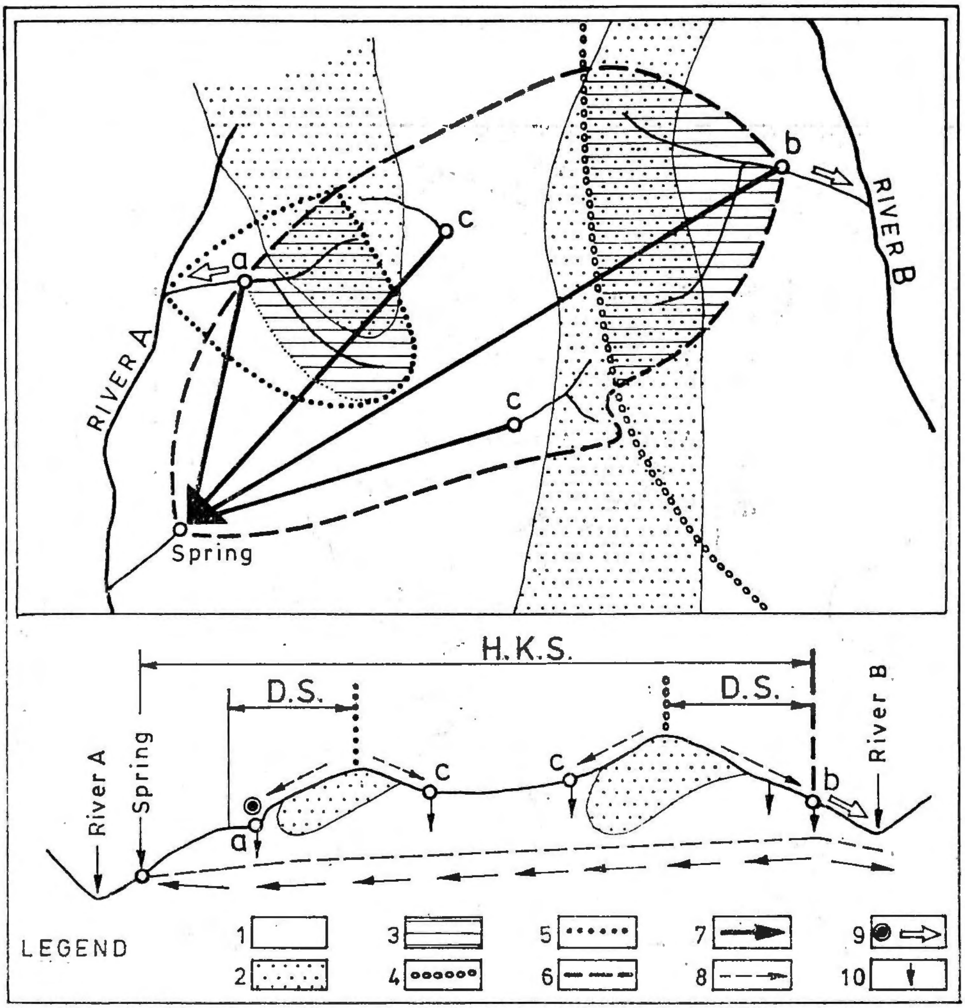

Fig. 36. Partial captures and position of the diffluence surfaces (after Orășeanu, 1985 b). a — Cohydrographic capture, b — Heterohydrographic partial capture, c — Endohydrographic (total) capture ; H.K.S. — Hydrogeological karst system, D.S. — Diffluence surface ; 1 — Karstifiable rocks, 2 — Nonkarstifiable rocks, 3 — Diffluence surface, 4 — Superficial watershed beetwen rivers, 5 — Superficial watershed between brooks, 6 — Limit of hydrogeological karst system, 7 — Underground flow direction, 8 — Efficient rain, 9 — Output from the system, 10 — Infiltrations.

the concept of basin karstic diffluence was set forth (Orășeanu and Jurkiewicz, 1982).

Hydrogeological investigations carried out in the northern part of the karstic area of Pădurea Craiului Mountains showed major developing capture phenomena, that induce a diversion in the epigean hydrographic network of karstic terrains. Fig. 37 shows the areas of karstic diffluence

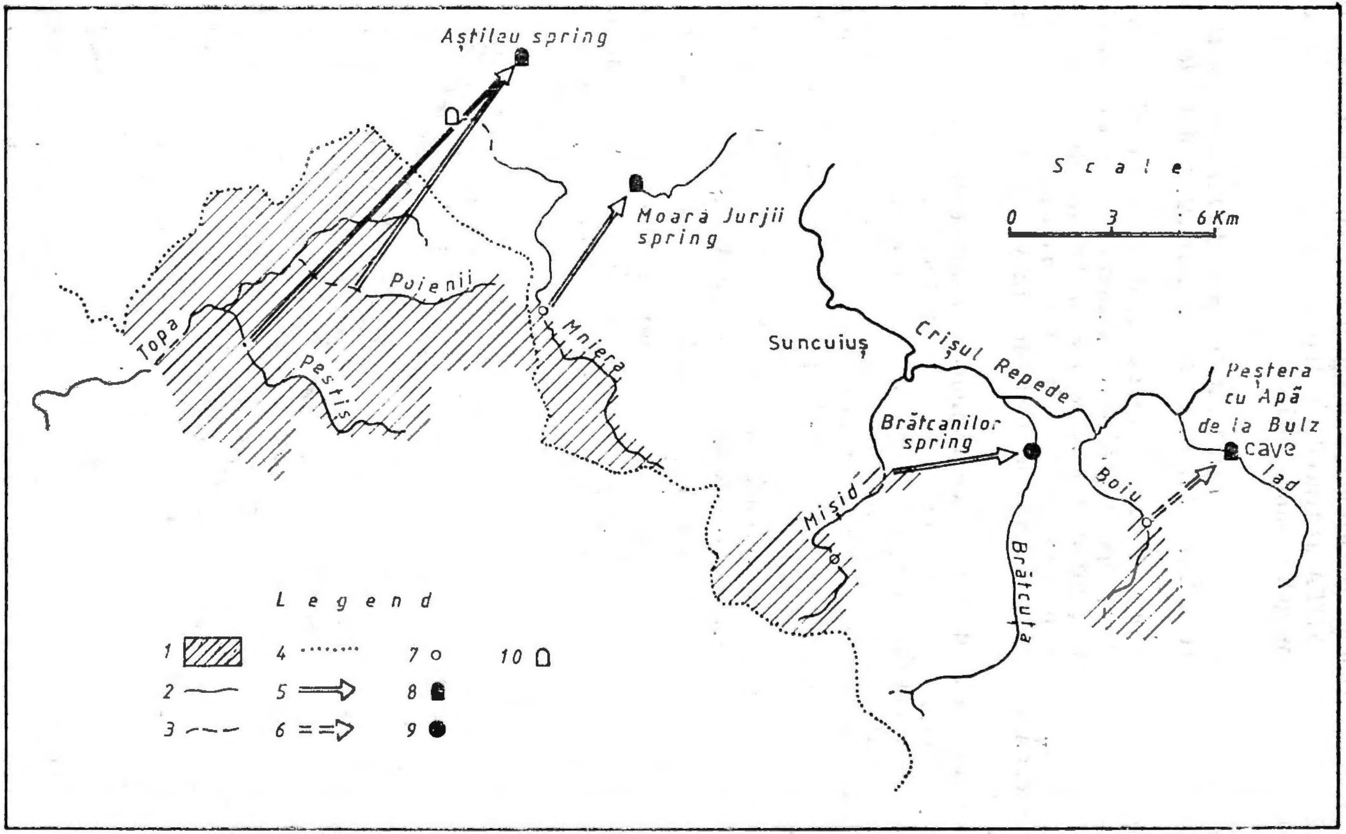

Fig. 37. Partial captures and diffluence surfaces in northern part of Pădurea Craiului Mountains (after Orăşeanu, 1985 b). 1 — Diffluence surface, 2 — Perennial river, 3 — Temporary river, 4 — Superficial watershed between Crişul Repede and Crişul Negru river; 5 — Underground connection established by tracing method, 6 — Underground connection established by budget method, 7 — Perennial partial capture, 8 — Outflow cave, 9 — Spring, 10 — Inflow cave.

set through multitracing experiments using fluorescein, rhodamine B, Iodine-131, Cl^- and In-EDTA as tracers, in the karstic area of the Pădurea Craiului Mountains (Orăşeanu 1985).

11.4. *USE OF DEUTERIUM, ARTIFICIAL TRACERS AND HYDROCHEMICAL DATA TO STUDY RECHARGE AND GENESIS OF THERMAL WATERS*

Geological and hydrogeological research carried out within the Cerna river basin indicated the deposit structural general model as well as another model concerning underground waters origin, thermal capacity, mineralization and dynamics (Simion, 1985). These models were checked by isopotic techniques, deuterium concentrations analysis, radioactive and stable tracers.

The analysis of deuterium concentrations and salt content af shallow and underground waters was performed during the 1979—1982 period by L. Blaga. The δD-time variation curves, drawn for all thermomineral sources, show that maximum or minimum deuterium concentrations reveal almost simultaneously. This fact indicates a rapid underground circulation, allowing thus the waters refreshing within the active areas of each source.

Typical for Herculane area is δD and Δ_{dens} value alignment a δD-Δ_{dens} diagram (average values) along the mixing straight line

$$\delta D = 448{,}41\ \Delta_{dens} - 75{,}45 \qquad (r = 0{,}82)$$

This fact may be considered as a unique mixing water system, generating the thermo-mineral waters in the area. So, the δD-time variations and δD average values in Cerna Valley indicate a meteoric origin of these waters (fig. 38).

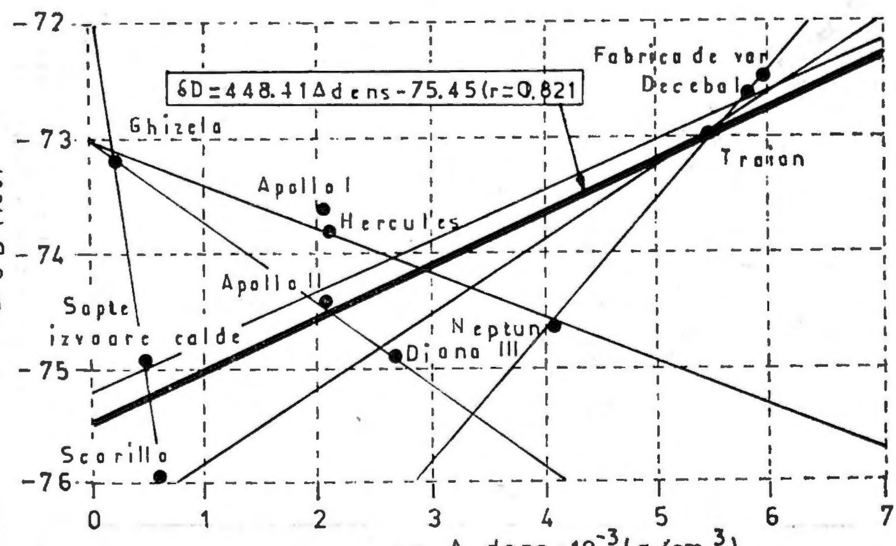

Fig. 38. Diagram of δD-time variation and δD-average values in Cerna Valley (after Blaga, 1979).

Direct investigations were carried on, labelling about 30 sinkholes and swallowholes located in the geothermal deposit recharge areas, using ^{82}Br, ^{131}I, ^{198}Au, ^{35}S as radioactive tracers as well as In-EDTA, fluorescein and other dyes.

As a result of geological, hydrogeological, hydrochemical, isotopic correlated determinations, performed also by tracers, the geothermal deposit of Băile Herculane may be considered as having an exclusively meteoric origin, with a recharge area that covers almost the entiere hydrographic basin of Cerna river.

11.5. *DETERMMINATION OF REGIONAL GEOLOGICAL STRUCTURES*

In certain hydrogeological conditions, labelligns with artificial tracers may bring valuable contributions to the knowledge on the tectonic structure of certain regions, and at a low cost too.

Thus tracers investigations performed in the Motru Sec — Baia de Aramă area estabilished a continuity of the limestone in the Danubian unit under the crystallins schists. These labellings proved through a hydrological method the existence of the Getic Nappe in this area. The hydrogeological relation between the waters infiltrated into the basin of the Gorgan brook and the springs in Baia de Aramă were highlighted with the help of ^{131}I and the relations between the diffuse losses from the Motru Sec river and the same springs with the help of In-EDTA. Figure 39 shows the two divergent labellings which contributed to the knowledge on the tectonic structure of the region (Slăvoacă, et al., 1985).

A second example is outlined in fig. 40 the area under study being located in the western part of the Bihor Mountains.

As can be seen in the section of fig. 40, a thick bridge of sandstone, conglomerates and permian shales rests discordantly over the limestone and dolomite attributed to the Autochthonous of Bihor and the Văleni overthrust. The diffuse losses in Seaca valley, a tributary of Galbena valley originating the Ruginoasa hole situated on the northern flank of the Tapu top, were labelled with In-EDTA. The presence of the tracer was detected on the southern slope on the mountain in the Criş spring; in this way, the overthrust position of the permian rocks was estabilished through a hydrogeological method.

11.6. *IDENTIFICATION OF SUB-AQUATIC SPRINGS*

This is an difficult experiment which may, however, direct to quasi-quanttative results. Two tipes of tracers were found to have a number of applications : fluorescent dye tracers, that, more often than not can be detected with the naked eye, and radioactive tracers, which can be deterted *in situ.*

Such a spring was identified under the Cerna river waters in the Piatra Puşcată point, with the help of ammonium dichromate and ^{192}Au, used as tracers. The tracers were inejcted in the Iuta valley whose confluence with the Cerna river is situated downstream of the aforesaid spring (Gaşpar and Simion, 1985).

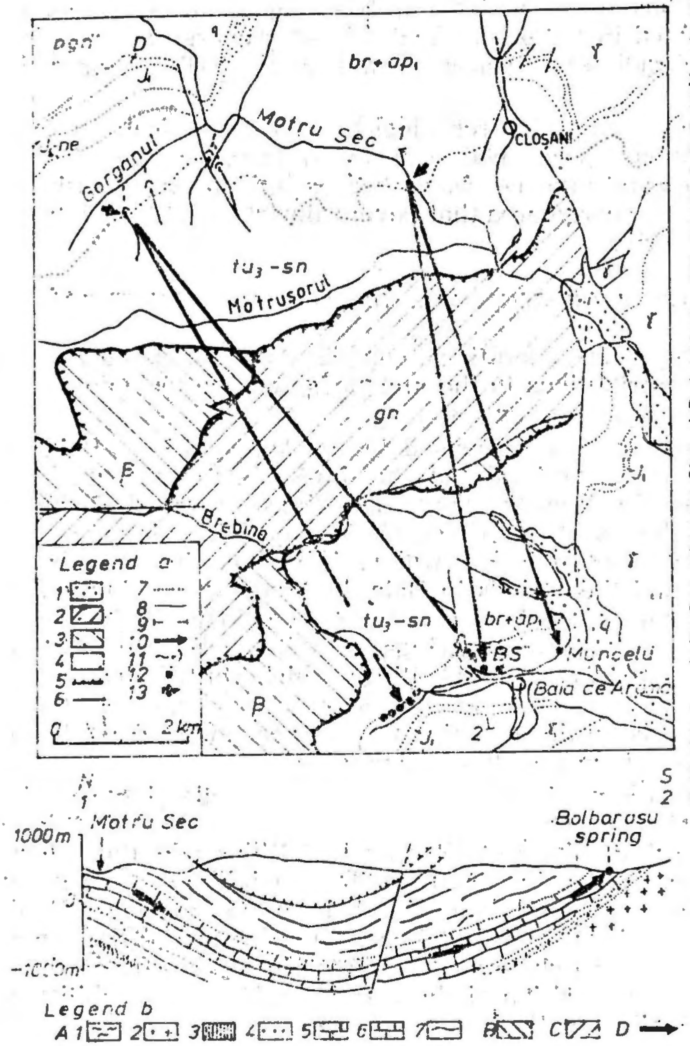

Fig. 39. Main underground drainage direction established by a multitracing experiment in Motru Sec — Baia de Aramă area. Legend a: 1 — Quaternary; 2 — Getic Nappe; 3 — Severin Nappe; 4 — Danubian Unit; 5 — Overthrust front; 6 — Geological boundary; 7 — Fault; 8 — Boundary of Quaternary formations; 9 — Geological cross section; 10 — Underground flow direction established by tracer experiments; 11 — swallet; 12 — Spring; 13 — Injection point. Legend b: A — Danubian Unit; A_1 — paragneiss; A_2 — Granite; A_3 — Chlorite shists (Devonian); A_4 — Conglomerates, sandstones (lower Jurassic); A_5 — Limestones (uper Jurassic-Neocomian); A_6 — Limestones (Barremian — lower Aptian); A_7 — Wildflysch formation; B — Severin Nappe; C — Getic Nappe.

Another labelling that led to the estabilishment of a karstic diffluence was performed with the help of ^{82}Br. In labelling the Kara Oban insurgence, part of the tracer was guided towards the mezothermal spring of Mangalia and an other part towards the gulf bearing the same name in the Black Sea (fig. 41). It is worth noting that the sinkhole was labelled with a tracer constant discharge. The shape of curve C(t) is probably due to the marine currents which prevented the maintenance of a constant measuring geometry, throughout the duration of the determinations.

11.7. THE INFLUENCE OF WATER-DEVELOPMENT OPERATION ON WATER CAPTURES IN THE KARST

When waterflows originating in non-karstic areas cross kakrstified calcareous rocks, water losses may be refound downstream in the form

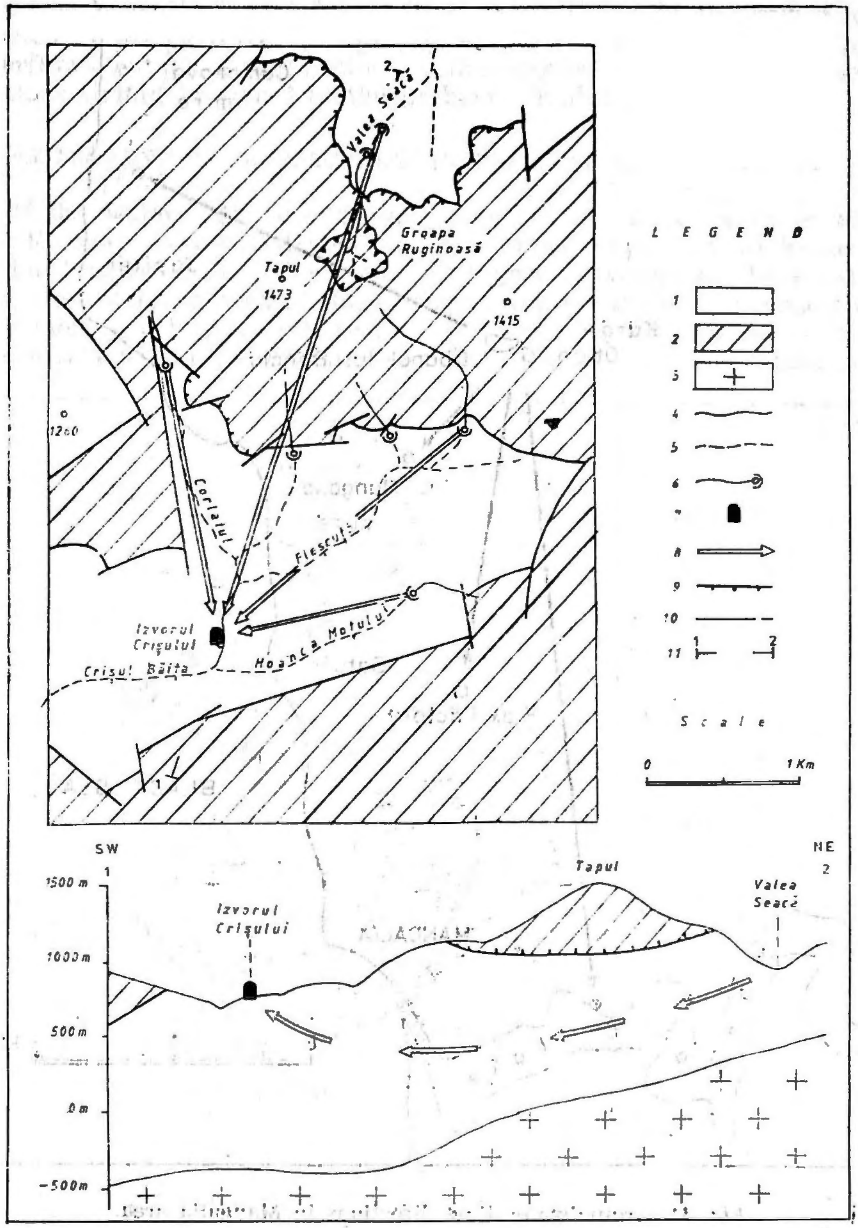

Fig. 40

Fig. 40. Extension of Izvorul Crişului catchment area in Valea Seacă basin (geological data after Borcea et al., 1975) 1 — Bihor Unit ; 2 — Arieşeni Nappe ; 3 — Magmatites ; 4 — Perennial course ; 5 — Temporary course ; 6 — Ponor ; 7 — Outflow cave ; 8 — Underground routes ; 9 — Overthrust front ; 10 — Fault ; 11 — Direction of geological cros section.

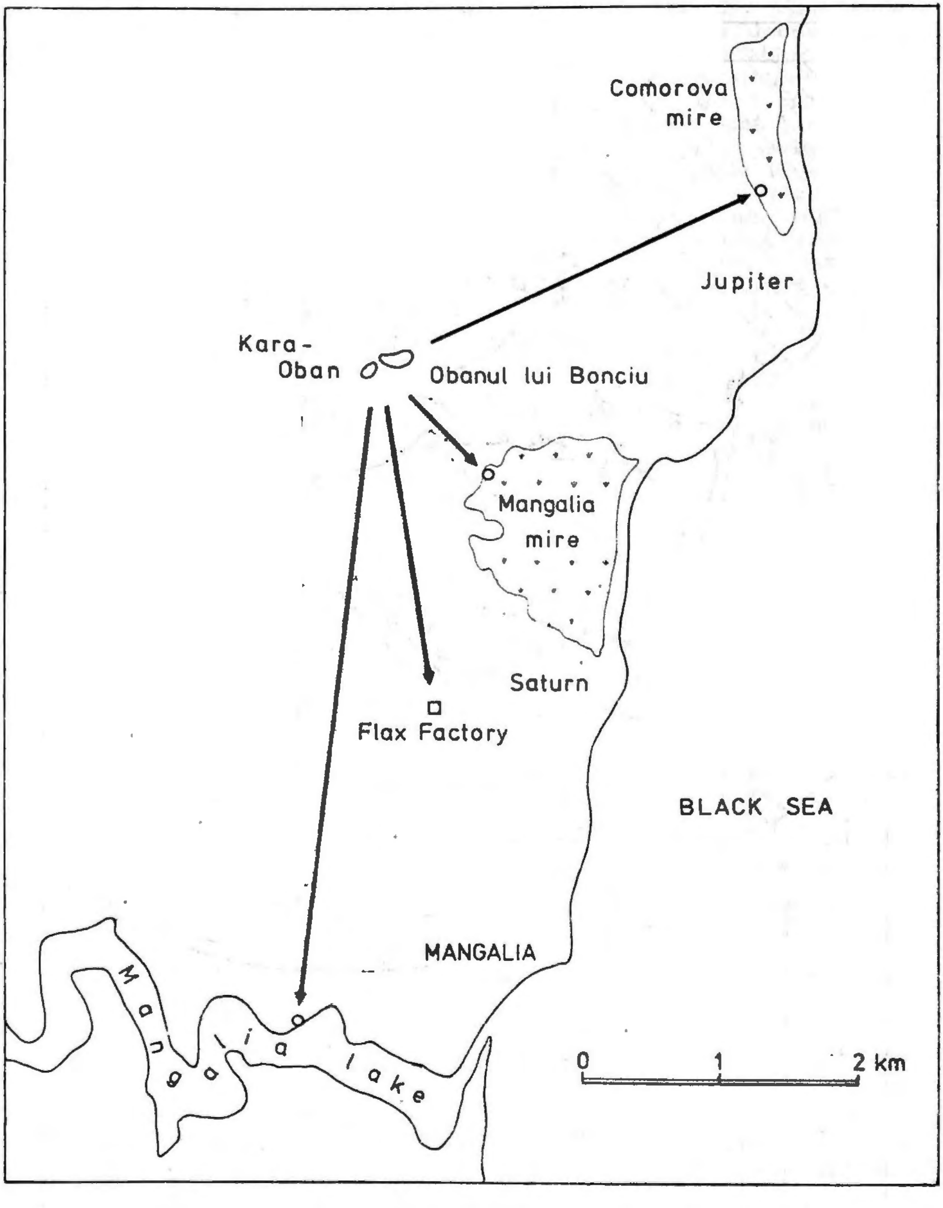

Fig. 41. Groundwater flow directions in Mangalia area.

of permanent springs. Such a group of springs, the Izvarna, with an average discharge of more than 2 m^3/s, was partially captured to provides for the water supply of the town of Craiova. The construction works on an elaborate hydropower complex in the area, which implied the building of dams to create storage lakes with waters from the rivers that cross the

zone, posed the problem of the influence these retentions exert on capture. Consequently, water losses from seven rivers in the region were detected in the captured springs (fig. 42). Therefore, as the damming of waterflows entails a diminution of the capture discharge, engineering solutions should be found to the problem. (Rădulescu et al., 1987).

11.8. *ASSESSMENT OF SEEPAGE RISK IN THE CASE OF WATER RETENTION*

If the waters of a storage lake may cover calcareous areas where karstification processes developed, it is higly important to know the relationships between surface and underground waters in the floodable area. The estabilishment of the loss areas represents a wide-scope tracer experimen twhich may asses real sizes of loss and existing risk of failure (Özis and Yurtsever, 1982). In Romania, damming of river Cerna posed

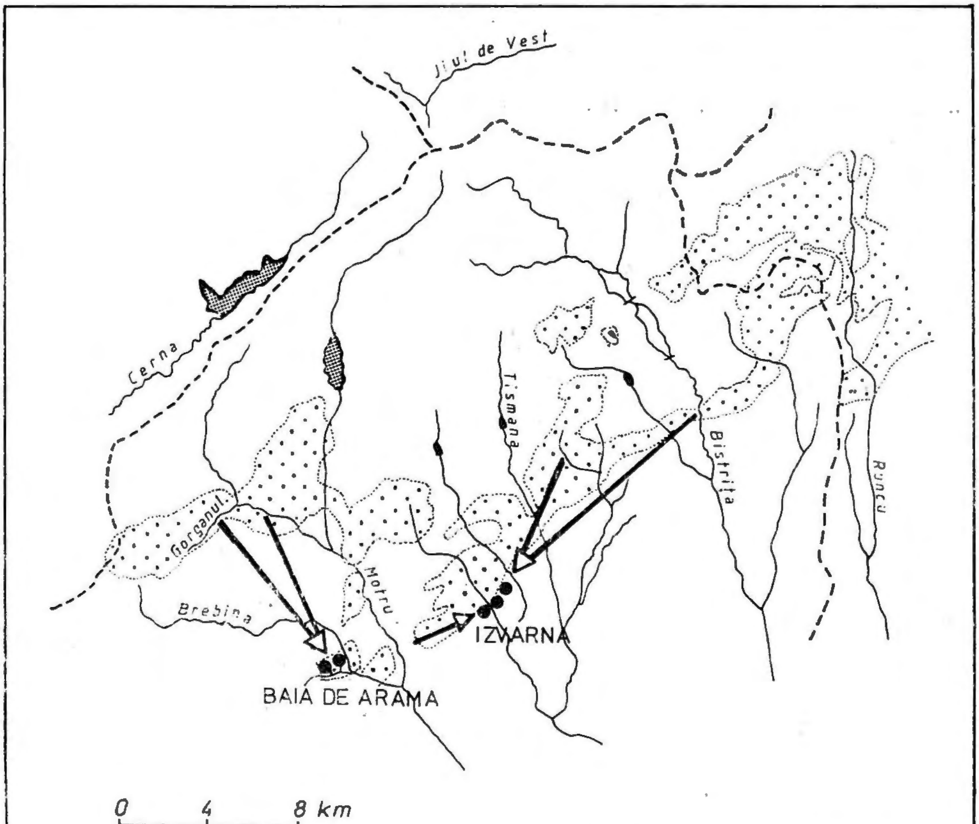

Fig. 42. Undergrond drainage directions in Baia de Aramă and Isvarna areas. 1 — Karstic terrains ; 2 — Nonkarstic terrains ; 3 — spring ; 4 — Underground flow direction established by tracer experiments.

a number of problems related to the possible water loss from the storage lake along some karstic routes. They were clarified with the help of multi-tracing experiments.

11.9. *MINE DRAINAGE IN KARST*

The Răcaş-Solavul Pleş Karstic plateau in the Pădurea Craiului mountains consists of lower tithonian and cretaceous limestone. The geological research conducted here highlighted lens-shaped accumulations of bauxite in the depressions of the paleokarst developed on tithonian limestone.

The plateau has no surface streams and the waterflows formed by th precipitations on the eastern, non-calcareous side of the plateau infiltrate into the underground through numerous ponors at the entering point in the karstic area.

Following the artificial-tracer labellings in the ponors, it was established that the underground waters moving towards Topliţa de Vida resurgence intersect the mining operations to open the deposit and substantially enhance the hydrogeological risk in the digging works (Fig. 43).

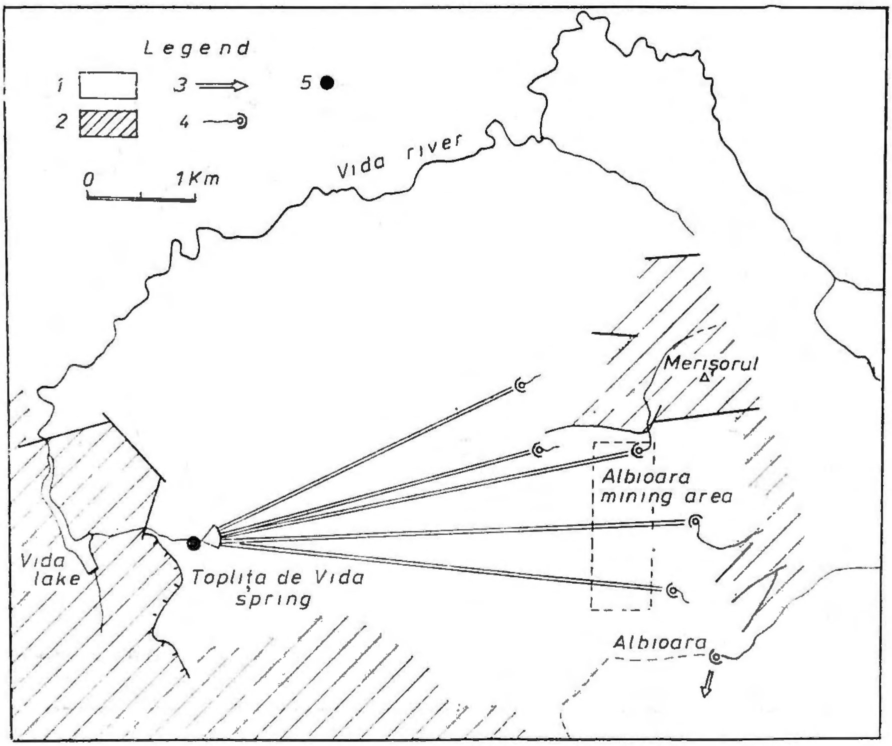

Fig. 43. Underground flow directions in Albioara mining area (after Orăşeanu et al., 1984). 1 — Karstic terrains; 2 — Nonkarstic terrains; 3 — Underground flow direction established by tracer experiments; 4 — Ponor; 5 — Spring.

The average transit velocities assessed with the help of the aforesaid tracers vary from 3.9 m/h to 20.6 m/h ; these values were used in designing the drainage gallery for the opening of the mine (Orășeanu et al., 1984).

11.10. *CAVE STREAM INVESTIGATIONS*

This is the oldest form of hydrological research and it probably dates back to the paleolithic. At present, it has broad-scale applications. Here is, for example, an experiment with radioactive tracers which highlighted the contribution of a surface stream to the supply of the underground waterflow in the Wind Cave. The respective cave has an extent of 3,000 m and its terminus is located at the confluence between the Sesii and Mișid valleys.

An important contribution to the underground stream in the Wind Cave is made by the waters infiltrated from the Recea ponor, situated at a horizontal distance of 3,185 m from the cave entrance. The labelling of this ponor with Na ^{131}I provided for the identification of the tracer in the cave with the help of ion-exchanger filters. Figure 44 shows the diagram of ^{131}I variation at the point where the underground stream in the wind cave emerges to the surface (Orășeanu and Gaspar, 1981).

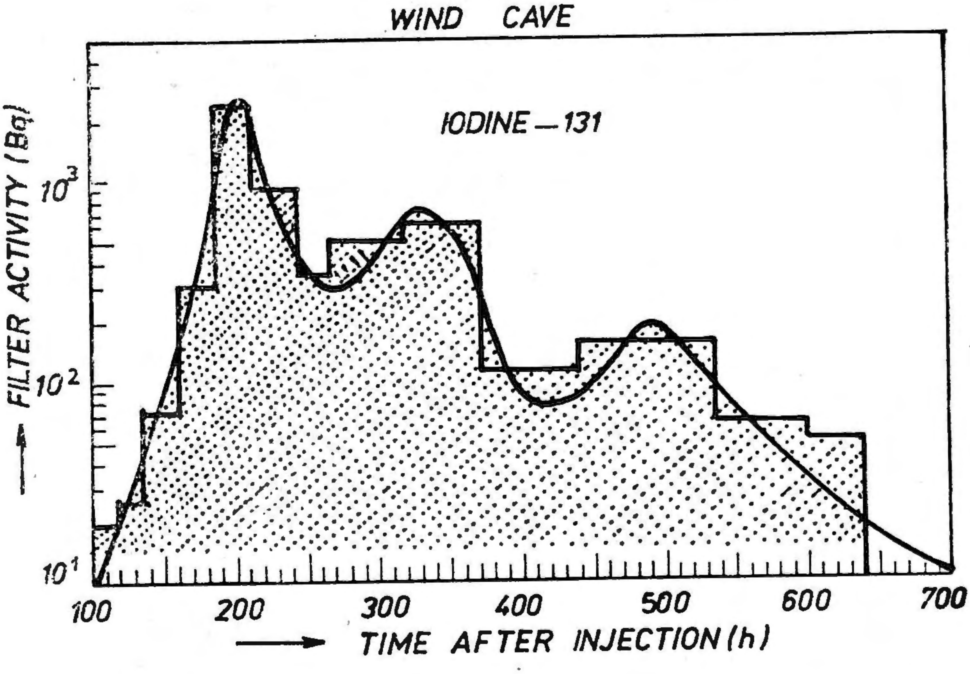

Fig. 44. The diagram of ^{131}I variation at the point where the underground course in the Vind Cave emerges to the surface.

11.11. *INVESTIGATION OF GEOTHERMAL WATERS*

The use of artificial tracers to investigate geothermal waters stored in limestones and dolomites was performed in various karstic zones. Thus, to determine the origin of Seven Warm Sources from Cerna Valley (55°C) the Tesna ponor was labelled with ^{131}I (Gaspar and Simion, 1985). The geotherfal waters from South Dobrogea was investigated with ^{82}Br. The tracer injected in Kara Oban appeared in IAS-Mangalia (23°C) mezzothermal spring, and in the thermal submarine spring from Mangalia gulf (Gaspar, 1972). In the Codru Moma karstic zone, a labelling performed with Indium-EDTA in Brătcoaia ponor was localized the water divide line and prouved a great karstic diffluence and the origin of the mezzothermal waters from Moneasa spa. The tracer appeared in Feredeu and in the geothermal wells from Moneasa (Fig. 45, after Orăşeanu, 1987).

In the geothermal field from Borş (Oradea) and in Iratoş (Arad) the tracer techniques has been particularly useful in hot water (130°C) reinjection investigations for detecting the invasion of reinjected water into the production zone, using ^{131}I as a tracer.

12. CONCLUSION

The intensive exploitation of aquiferous resources stored in karstic zones, water-development works and the location of various mining, industrial and farming units and of towns, and various ecological aspects call for a massive research work into karstic structures. The methods with artificial tracers, in association with geophysical, hydrochemical, hydrobiological and isotopic methods, are conventional methods (Gaspar, 1987).

The need for a simultaneous investigation under similar hydrogeological conditions, of all the inlets and outlets of a karstic structure through multi-tracing operations and by pluridisciplinary teams will lead to complex studies of karst area, conducted with concentrated forces, sometimes through international cooperation. Recent research, under way in various laboratories, will encourage the use of tracer methods in karst.

Tracer determinations are a common technique for the investigation of flow through karstic conduits and solution channels ; however in present no adequate models are available to describe tracer breakthrough curves in terms of hydraulics of conduit flow, turbulent dispersion and exchange with the fissure system (auxiliary system).

The future development of the application of tracers in karst hydrology will follow two directions. It will be aimed at improving the hydrogeological interpretation of tracer data and isotopic contents and at searching for new tracers (activable and fluorescent dye tracers, environmetal isotopes other than D, T, ^{14}C and ^{18}O) permitting new hydrological findings.

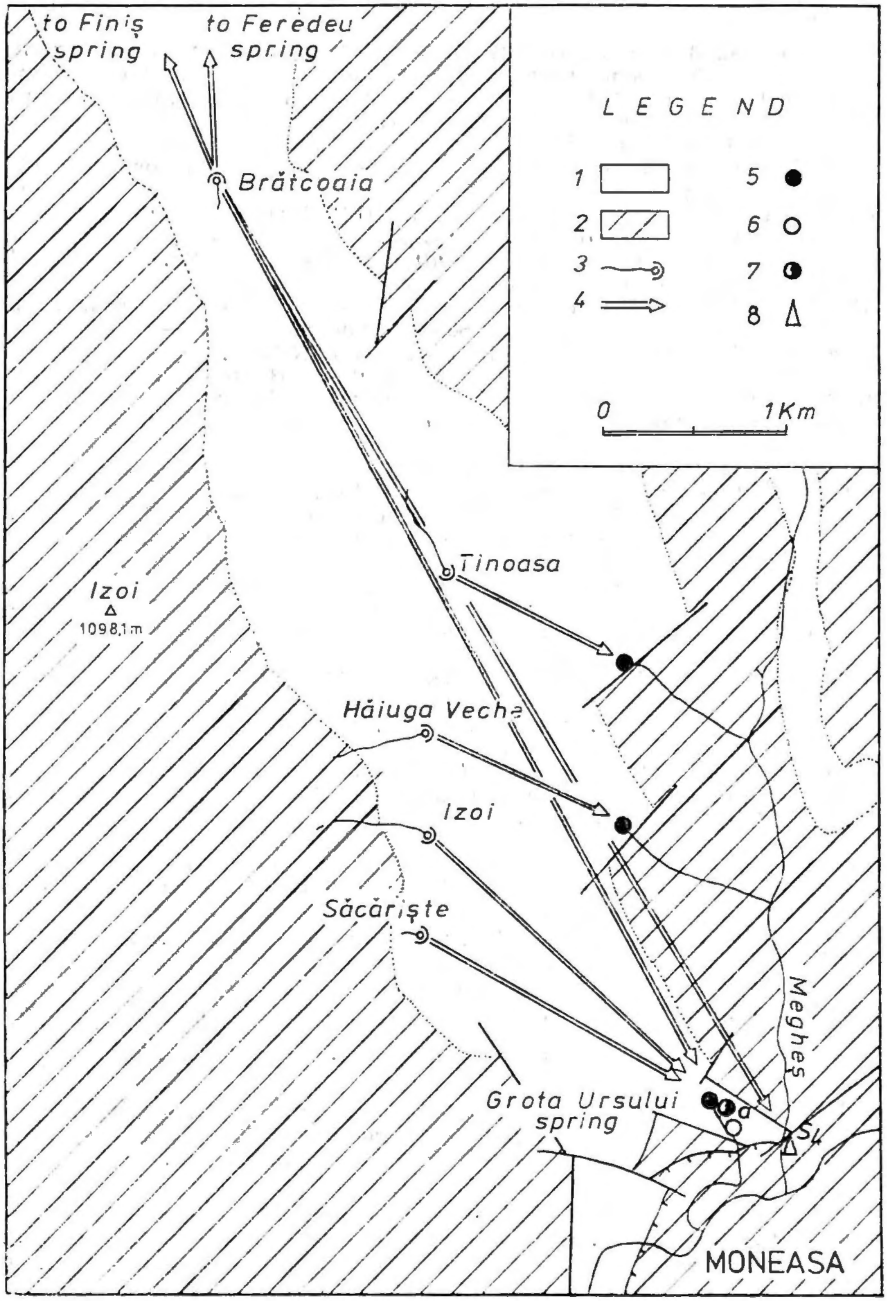

Fig. 45. Underground drainages in Moneasa area. 1 — Karstic terrains ; 2 — Non-karstic terrains ; 3 — Ponor 4 — Underground flow direction established by tracer experiments ; 5 — Cold spring ; 6 — Thermal spring ; 7 — Subthermal spring ; 8 — Hydrogeological well.

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LA GÉOLOGIE ET LA TECTONIQUE DU PÉRIMÈTRE D'INFLUENCE TE LA SOURCE THERMO-MINÉRALE „HERCULE", BAILE HERCULANE

PAR

G. DIACONU

La géologie et la tectonique du périmètre d'influence de l'émergence „Hercule" représentent un élément essentiel dans la connaissance de l'hydrostructure d'une des sources d'eau thermo-minérale les plus importantes qu'on trouve à Băile Herculane (Roumanie).

Par ce travail nous mettons à la disposition des ceux qui s'y intéressent des détails sur le sujet en question.

L'émergence „Hercule" est la principale source d'eau thermo-minérale qui est utilisée dans la cure balnéaire à l'hôtel Roman (Băile Herculane). Etant donné le fait que cette source est „contaminée" par l'eau froide provenant de la surface du sol, on cherche à trouver une solution pratique peur la conservation de la température et des particularités curatives de cette-ci. Vu le caractère organisé de la circulation des eaux à travers les roches karstifiables l'Entreprise de Prospections et d'Explorations Géologiques de l'Olténie a entrepris des travaux miniers (une galerie dans le versant avec des forages directionnés vers l'hydrostructure) pour pouvoir déceler le drain principal de l'un des deux types d'eau (chaude ou froide), en amont de leur confluence, dans le but d'éliminer le facteur thermo-polluant.

Le périmètre en étude est delimité vers le nord par la Valea Seacă, au sud par un alignement traversant la cavité karstique dans laquelle débouche la source „Hercule", à l'ouest par un alignement traversant le sommet de Ciorici (415 m) et à l'est par la vallée de Cerna.

Cette note est un résultat des travaux de cartographie géologique de surface et dans le souterrain, enrichis par les données fournies par les forages [1]. En nous fondant sur ces matériaux, nous avons dressé une carte détaillée de la géologie et de la tectonique du périmètre en question (Fig. 1), une carte géologique et tectonique au niveau des travaux miniers (galerie 403) (Fig. 2), un profil longitudinal de la structure, A—A'

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[1] Les données des forages ont été mises à notre disposition par le géoloque Mariana Mitruţiu (E.P.E.G. — Olténie) que nous remercions par cette voie aussi.

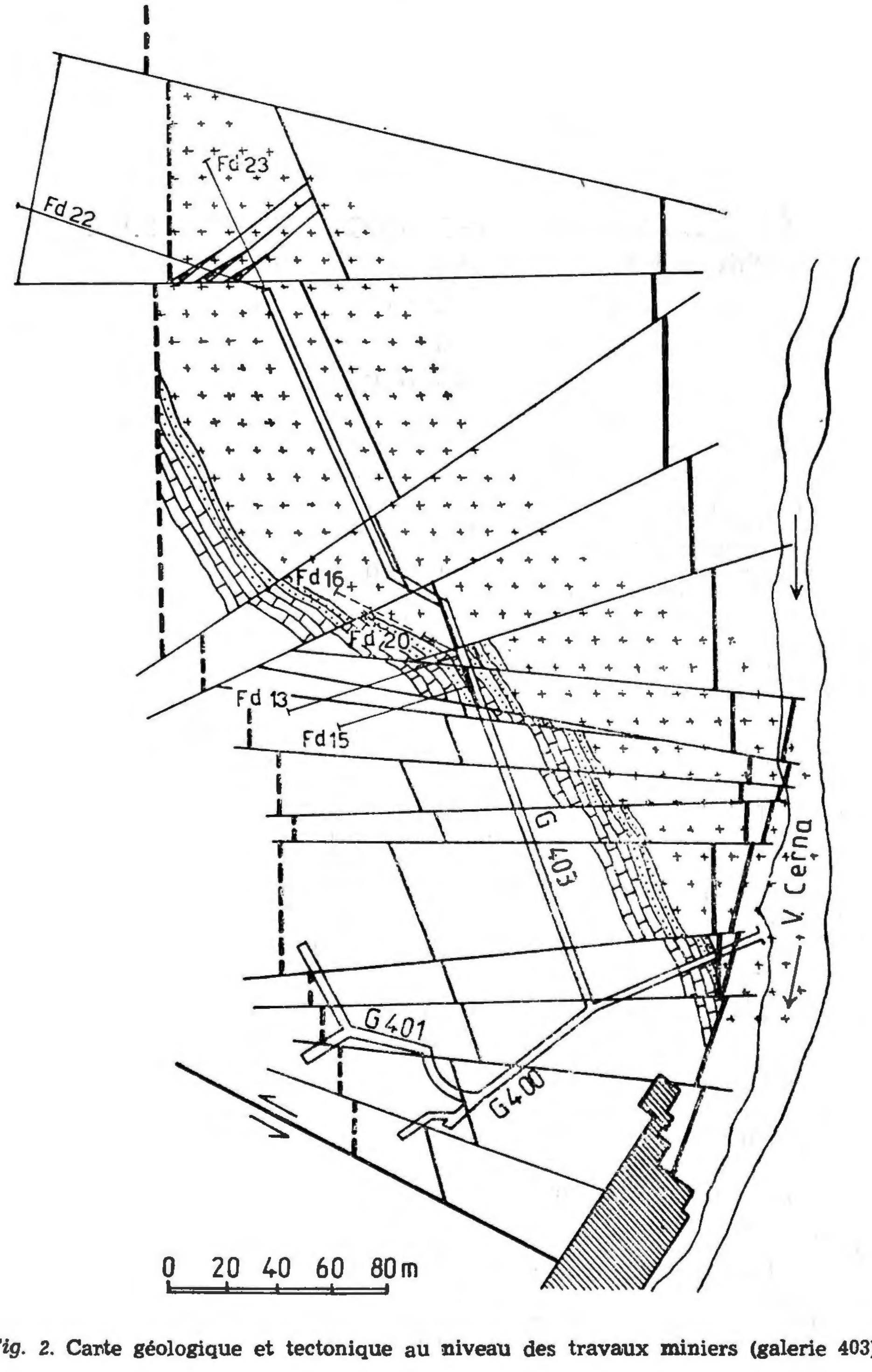

Fig. 2. Carte géologique et tectonique au niveau des travaux miniers (galerie 403).

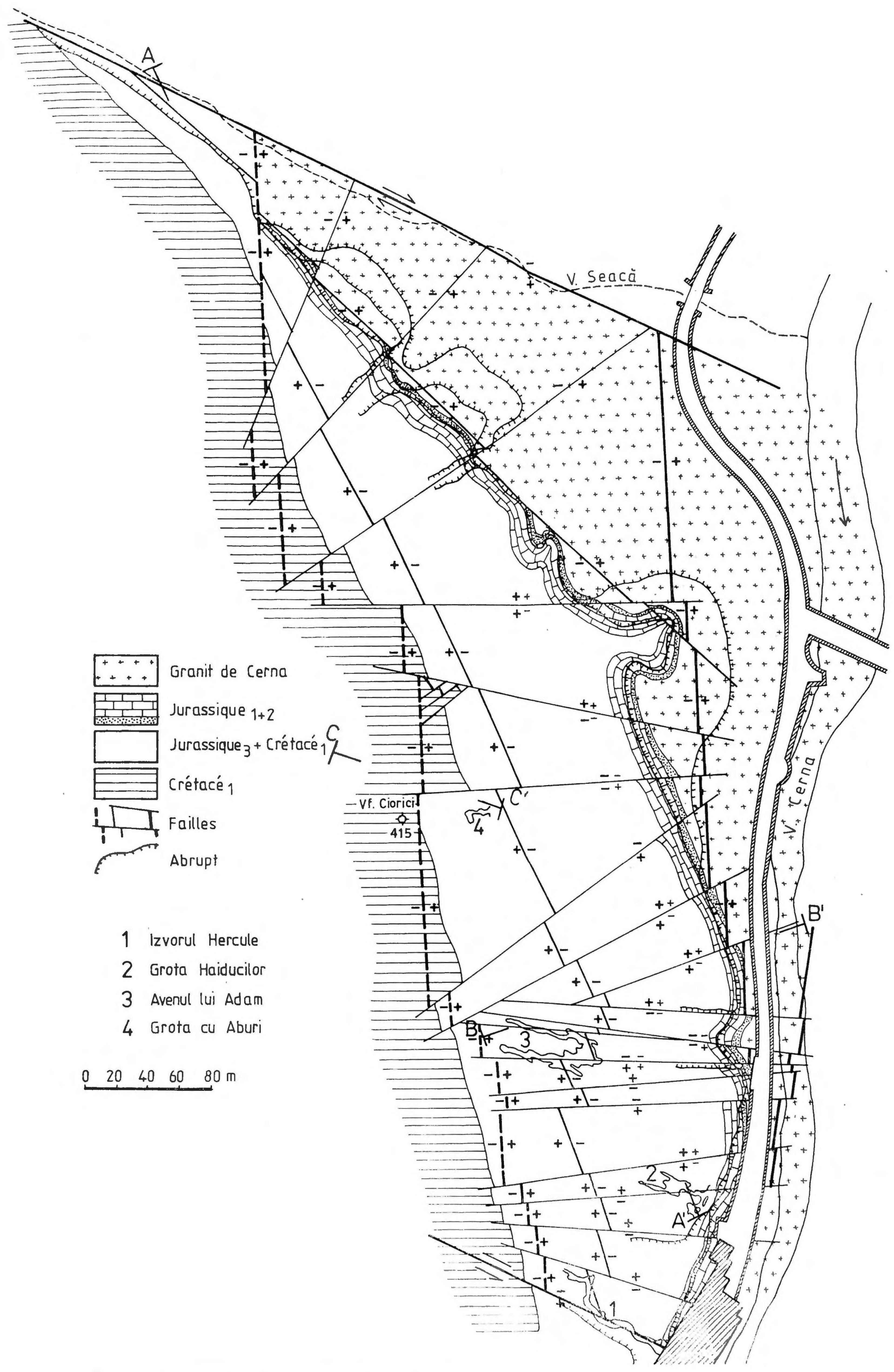

Fig. 1. Carte géologique et tectonique du périmètre d'influence de la source thermominérale „Hercule".

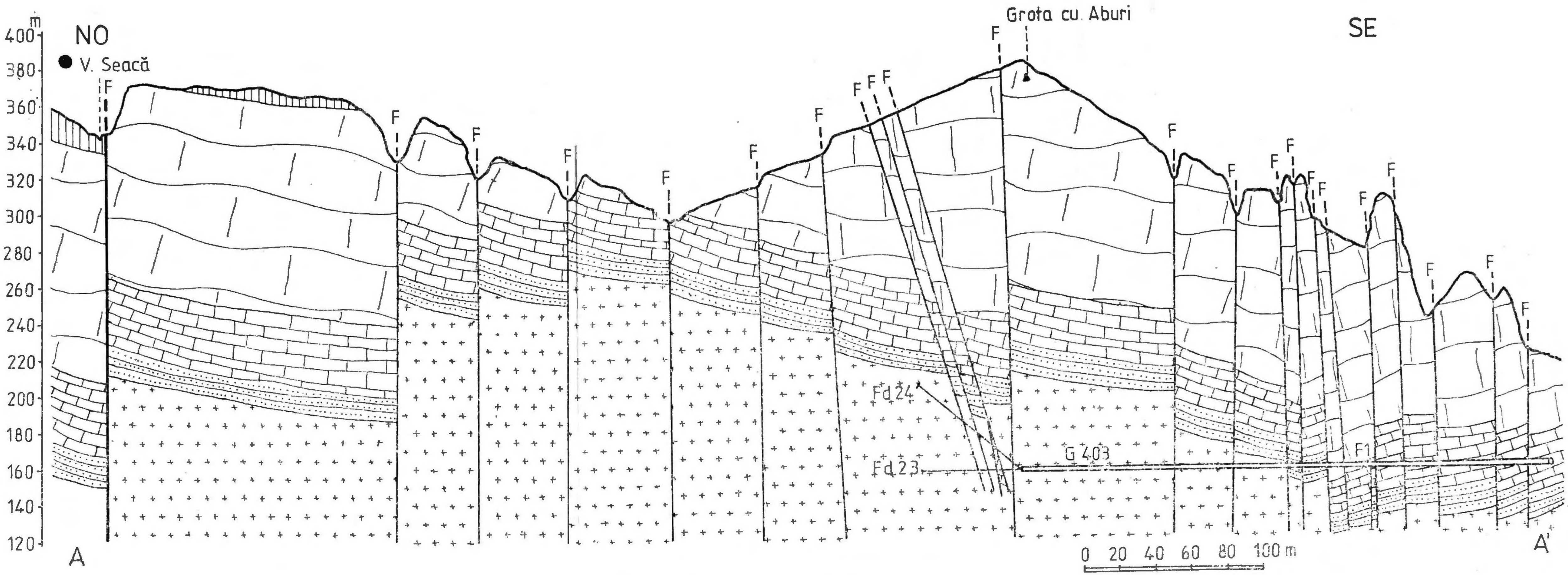

Fig. 3. Coupe géologique longitudinale, A—A .

Fig. 4. **Coupe géologique transversale, B—B'.**

(Fig. 3) et un profil transversal, B—B', orienté sur l'alignement du forage directionnel Fd 13 (Fig. 4).

Grâce au fait que la géologie et la stratigraphie des dépôts sédimentaires ont été minutieusement détaillées (et, en même temps, à un niveau scientifique élevé) par Năstăseanu (1980), nous considérons oportun à ne reprende ce sujet que sous l'aspect des variations lithofaciales compatibles ou incompatibles avec le procesus de karstification.

De ce point de vue, on distinque un complexe de dépôts sédimentés exclusivement en Mésozoïque (l'intervalle de sédimentation est compris entre le Jurassique inférieur et le Crétacé inférieur), disposés sur un subassement cristallin constitué de granitoïdes de Cerna. L'intervalle litho-facial karstifiable compris entre le Jurassique moyen (Bajocien) et le Crétacé inférieur (Berriassien) est constitué de calcaires stratifiés (détritiques et grèseux) et de calcaires massifs (à sieex, noduleux et sub-lithographiques). En ensemble, ils composent l'aquifère karstique du périmètre d'influence de la source „Hercule".

On s'est préoccupé particulièrement de la façon de diviser en compartiments tectoniques la zone en étude, en mettant l'accent sur les aspects de la tectonique disjonctive. Dans cet but, on a effectué, en parallèle avec les relevés géologiques, onze diagrammes illustrant l'orientations des fissures dans les affleurements („Izvorul Hercule", „Avenul lui Adam", „Grota cu Aburi" et le sommet de Ciorici dans les calcaires, et la Valea Seacă dans les granites) et aussi dans le souterrain (galerie

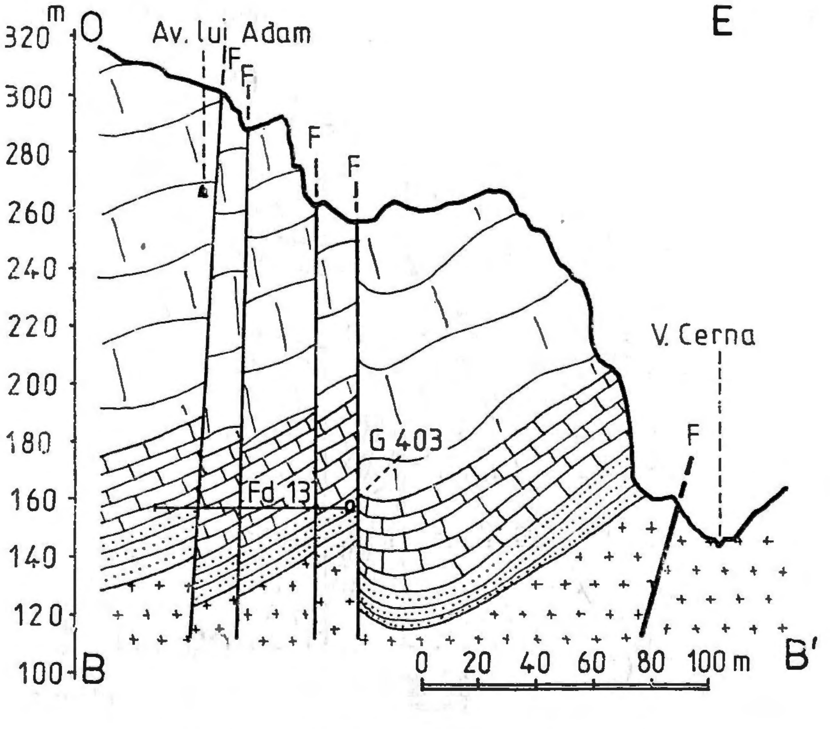

Fig. 4. **Coupe géologique transversale, B—B'.**

403 dans les calcaires, et les granites, ainsi que les cavitées karstiques connues dans la zone). On a estimé qu'une illustration sur la carte des diagrammes aurait surchargé inutilement celle-ci, de sorte qu'on a renoncé à les représenter, quoique l'orientation et l'emplecement des systèmes de fractures est une conséquence ressortant également de leur interprétation.

On présente finalement les conclusions auxquelles on a abouti en analysant la tectonique du périmètre :

1) L'aréal étudié est situé à l'extrémité sud d'interférence de trois unités tectoniques majeures mises en évidence par Năstăseanu (1980), de l'est à l'ouest : le graben de Cerna, l'anticlinal de Cerna et le synclinal de Cerna, le périmètre d'influence étant localisé sur le côté oriental du synclinal de Cerna (respectivement sur le côté occidental de l'anticlinal).

2) Les systèmes de fractures mis en évidence appartienent au moins à deux étapes orogénétiques : une étape alpine superposée à une autre étape, préalpine.

3) Le cadre des fracteures majeurs est représanté a l'est de la faile de Cerna (qui constitue d'ailleurs „la colonne vertebrale" de toute la structure) le long de laquelle, sur un alignement (dans le périmètre) N—S (l'alignement de cette faille en ensemble étant NNE—SSO), le granite apparaït à jour et, de cette façon, elle est impliquée dans l'aspect structural-géologique de la zone étudiée. Cette faille, subcrôuteuse, est envisagée par les géophysiciens comme étant associée à la faille de Mehadia (localisée à environ 5 km ONO par rapport à la faille de Cerna), considérée comme un plan de cisaillement le long duquel se produit la

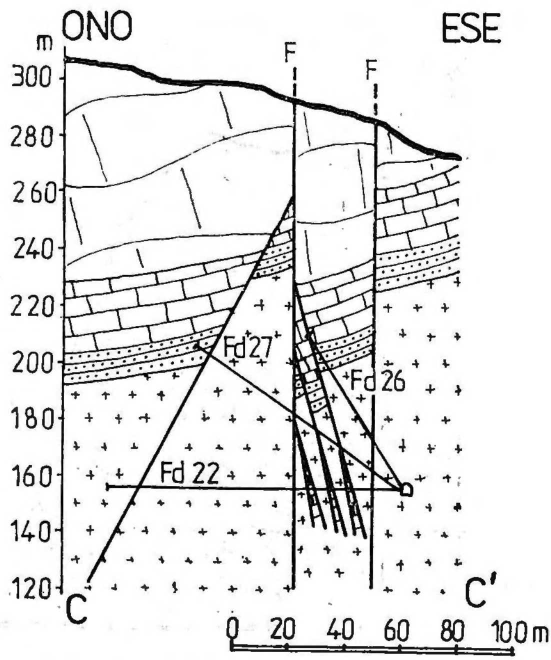

Fig. 5. Coupe géologique transversale, C—C

subduction. Dans cette situation, il faudrait estimer que l'effort tectonique a une manifestation de l'ESE vers l'ONO, par plongement du compartiment oriental au-dessous de compartiment occidental et non pas inversement, de l'ONO vers l'ESE, par chevauchement du compartiment occidental au-dessus du compartiment oriental. Beaucoup des détails méso- et microtectonique observés sur place sont d'ailleurs avérants pour la version présentée.

Du côté occidental, la délimitation tectonique de l'aréal s'effectue par une faille rélativement parallèle à celle de Cerna, en départageant vers l'ouest un compartiment bas par rapport au compartiment oriental. Cette faille a été illustrée sur la carte par une ligne interrompue, pour pouvoir la départager comme valeur majeure de celle de a faille de Cerna et non dans le sens d'une ligne de disjonction supposée. Cependant, la valeur de sa vergence vers l'ouest n'est pas certaine, les mesures effectuées n'étant pas satifaisants à cause de la présence des dépôts crétacés inférieurs non-karstifiables (marnocalcaires, marnes et grès) très friables [2]. Les deux fractures (au moins préalpines) sont alternativement affectées dans leur continuité par le système de fractures alpin superposé.

En concordance avec la dernière étape orogénétique (alpine), le périmètre est encadré au nord par la faille de Valea Seacă, orientée ONO—ESE (un élément disjonctif très important dans l'aréal, dont le rôle est non seulement d'élever le compartiment méridional par rapport au compartiment septentrional, mais de réaliser également un décrochage considérable le long du même plan à vergences comprises entre 72° et 84°N, décrochage par lequel le compartiment méridional est déplacé vers l'ouest d'environ 100 m), et au sud par la faille Hercule (élément disjonctif qui délimite l'autre côté du compartiment décroché).

4) Le périmètre est traversé par deux systèmes de fractures de cisaillement (la faille de délimitation de l'abrupt du versant droit de la Valea Seacă et a faille Avenul lui Adam — Grota cu Aburi), estimées comme préalpines, réactivées dans l'étape alpine, quand dans l'aréal il y a eu un hausse graduelle de l'ENE vers l'OSO, qusqu'à la faille occidentale.

5) Le processus de décrochage qui s'est produit dans l'étape alpine a déterminé une superposition d'un système fractural secondaire, marqué dans le secteur méridional par une série de fractures de tension orientées de l'ouest vers l'est et dans les secteurs central et septentrional par des fractures de cisaillement à orientation NE—SO, intercalé par des fractures de tension.

[2] A la suite des dernières données obtenues par des forages (novembre, 1987), la tectonique de la zone dans ce secteur a pu être interprétée comme un compartiment relevé, délimité vers ONO et ESE par un système secondaire de fractures de cissaillement associée à la faille ouest, masqués dans la profondeur de la structure (voir le profil C—C' réalisé dans la direction du forage Fd 22, respectivement la carte géologique et tectonique au niveau des travaux minières et le profil longitudinal A—A' dans le secteur du forage Fd 23.

6) Les déplacements des compartiments dans l'aréal ont eu lieu spéciálment le long des systèm de disjonction par cisaillement. Mais, d'une façon subordonné, ces déplacements se sont produits également au niveau des fractures de tension qui, par le striation des faces, ont souvent l'aspect de pseudo-fractures de cissaillement. La disposition horizontale ou sub-horizontale des striations auxquelles se superposent souvent des striations verticales déterminées par l'éboulement des compartiments (comme c'est le cas dans le secteur de la source „Hercule" ou de l'avens d'Adam), de même que leur orientation spatiale, parallèle à la direction de l'effort majeur, nous ont néanmoins permis d'en fair une estimation correcte.

7) Il serait aussi opportun de signaler le fait que, grâce au même processus de décrochage, il y a eu des déplacements même au niveau des limites de modification litho-faciale, le long des surfaces de stratification, et en raison de cette situation on a observé (particulièrement dans la galerie minière), des couches à direction et pandage atypiques à la structure, accompagnées d'évidents miroirs de friction marqués parfois de striations. En outre, secondaire par rapport au système majeur de fractures, apparaît toute une série de fractures „parasites", dont les plans varient au point de vue des valeurs de l'inclinaison entre 45° et 65°, le long desquelles peuvent apparaître des sub-compartiments, à faible importance, motif pour lequel nous ne les avons pas représenté sur les figures.

8) Un dernier aspect qu'on considère nécessaire de le mettre en évidence est celui de l'orientation dans le versant des galeries des cavités karstiques, en parallèle avec les fractures de tension. Cela est en parfaite concordance avec la théorie de la circulation hydrique à travers les systèmes de fractures d'un aquifère karstique et pourrait servir comme une information d'utilité pour l'interprétation de la circulation de l'eau à travers le massif. Mais, en profondeur, ces fractures de tension ouvertes dans les roches karstifiables sont souvent écranées par des granites, par l'intermédiaire des hausses qui se sont produites le long des systemes de cisaillement. En ce cas un apport d'eau venu par une fracture de tension sera obligé de se réorganiser le long de la fracture de cisaillement, en s'écoulant sur la direction des chutes compartimentales. Ces écranages pourraient engendrer dans l'aquifère des stokages d'eau accompagnée de drainages zigzagués sur des limites de trop-plains.

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GEOLOGIA ȘI TECTONICA PERIMETRULUI DE INFLUENȚĂ A IZVORULUI TERMO-MINERAL „HERCULE" — BĂILE HERCULANE

Rezumat

Emergența „Hercule" reprezintă principala sursă de apă termo-minerală a hotelului Roman (Băile Herculane), utilizată în cura balneară. Datorită „contaminării" acesteia cu ape reci provenite de la suprafață se fac eforturi pentru găsirea unei soluții practice de conservare a temperaturii și calității ei curative în sensul surprinderii drenului principal al uneia din cele două tipuri de ape (calde sau reci), amonte de confluența lor, în intenția eliminării factorului termo-poluant.

Arealul cercetat este amplasat la extremitatea sudică de interferență a trei unități tectonice majore puse în evidență de Năstăseanu (1980) de la est spre vest: grabenul Cernei, anticlinalul Cernei și sinclinalul Cernei, perimetrul de influență fiind localizat pe flancul estic al sinclinalului (respectiv pe cel vestic al anticlinalului).

Prezenta notă se constituie ca un rezultat al cartărilor geologice la suprafață și în subteran (galeria minieră) completate cu datele obținute din foraje. O atenție deosebită s-a acordat modului de compartimentare tectonică, motiv pentru care s-au realizat un număr de 11 diagrame de orientare a fisurilor (pe care am considerat că este inutil să le mai reprezentăm grafic atît timp cît amplasarea și orientarea sistemelor fracturale a fost o consecință derulată din interpretarea lor).

Geologia și stratigrafia depozitelor sedimentare a fost luată în discuție numai sub aspectul variațiilor lito-faciale compatibile sau incompatibile cu procesul de carstificare.

În încheiere prezentăm pe scurt concluziile care au derivat din aprecierea geologiei și tectonicei perimetrului cercetat:

1. Depozitele sedimentare din perimetru aparțin exclusiv Mezozoicului fiind dispuse pe un subasment cristalin constituit din granitoide de Cerna. Intervalul lito-facial carstificabil este cuprins între Jurasicul mediu (Bajocian) și Cretacicul inferior (Berriasian) fiind constitut din calcare stratificate și calcare masive.

2. Sistemele fracturale puse în evidență aparțin la cel puțin două etape orogenice: o etapă alpină suprapusă peste o etapă prealpină.

2. Cadrul fractural major este marcat la est de falia Cernei considerată de geofizicieni ca fiind o asociată a faliei Mehadia apreciată ca un plan de forfecare de-a lungul căruia se produce subducția. În această versiune, efortul tectonic trebuie privit ca avînd o manifestare dinspre ESE spre VNV prin plonjarea compartimentului estic sub cel vestic și nu invers, dinspre VNV spre ESE prin încălecarea celui vestic peste cel estic. De altfel, multe detalii mezo- și micro-tectonice observate în teren, pledează în favoarea acestei versiuni.

La vest, delimitarea se face printr-o falie care departajează spre vest un compartiment căzut în raport cu cel estic. Ea a fost trecută pe hartă cu o linie întreruptă în scopul de a o departaja ca valoare majoră de falia Cernei și nu în sensul unei disjuncții presupuse. Incertă este numai vergența ei spre vest măsurătorile efectuate fiind neconcordante din cauza depozitelor cretacic inferioare necarstificabile și foarte friabile. Continuitatea ambelor fracturi (cel puțin prealpine) este alternativ deranjată de sistemul fractural alpin suprapus.

Corespunzător etapei alpine perimetrul este încadrat la nord de falia Valea Seacă iar la sud de falia Hercule de-a lungul cărora s-a produs nu numai o înălțare în trepte a arealului (de la ENE spre VSV pînă la limita cu falia vestică pe planul unor fracturi de forfecare — falia din abruptul Văii Seci sau falia Avenul lui Adam — Grota cu Aburi) ci și o puternică decroșare prin care arealul cercetat a suferit o deplasare spre vest de cca 100 m.

4. Tot corespunzător etapei alpine apar în sectorul sudic al perimetrului o suită de fracturi de tensiune oreintate VE iar în sectorul central și nordic, un sistem de forfecare orientat NE—SV.

5. Jocul compartimentelor s-a făcut preferențial de-a lungul disjuncțiilor prin forfecare și subordonat la nivelul fracturilor de tensiune care adeseori apar sub aspectul unor pseudo-fracturi de forfecare.

6. Datorită subîmpingerilor s-au produs deplasări și la nivelul limitelor de schimbare lito-facială, pe suprafețe de stratificație.

7. Un ultim aspect este legat de orientarea în versant a galeriilor cavităților carstice paralel la fracturile de tensiune. Această situație este în concordanță cu teoria circulației apei prin sistemul de fracturi al unui masiv carstic. În profunzime însă, aceste fracturi de tensiune sînt ecranate adeseori de granite prin ridicările provocate de-a lungul sistemelor de forfecare și în acest caz, un aport de apă venit pe o fractură de tensiune va fi obligat să se reorganizeze de-a lungul fracturii de forfecare curgînd pe linia căderilor compartimentale. Aceste ecranări pot creea în acvifer stocări de apă însoțite de drenaje zig-zagate spațial pe limite de preaplinuri.

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ÉVOLUTIN DU RÉSEAU HYDROGRAPHIQUE DU COULOIR DÎMBOVICIOARA. NOTE 2. GENÈSE ET ÉVOLUTION DE LA VALLÉE DÎMBOVIŢA.

PAR

T. CONSTANTINESCU

L'une des conclusions de la NOTE 1 (Constantinescu, 1985) soulignait que la formation du graben (dépression) Podu Dîmboviţei n'a pas été sans déclancher toute une série de remaniements du réseau hydrographique du Couloir Dîmbovicioara. L'évolution de la vallée Dîmbovicioara, détallée dans cette première note, a constitué un exemple, permettant d'anticiper l'existence d'autres vallée dont l'évolution a été influencée par la formation du graben.

Parmi celles-ci, il est à remarquer aussi la Dîmboviţa, la principale artére hydrographique de la zone, à laqulle l'auteur consacre le présent ouvrage (NOTE 2).

Tout d'abord on fournit des arguments montrant que le grand coude fait par la Dîmboviţa dans le secteur des monts Lerescu — Tămaşul Mare — Pecineagu, est le résultat d'une capture.

L'ouvrage se continue avec la présentation de la genèse et de l'évolution du graben Podu Dîmboviţei tout en soulignant qu'il s'est formé au Miocène et qu'à partir de cette epoque-là, la dépression a fonctioné comme une forte zone d'attraction aussi bien pour les eaux de surface que pour les eaux souterraines.

La dernière partie présente *la genèse et évolution de la vallé Dîmboviţa.* Tout en niant l'hypothèse de l'existence de l'actuel trajet dans la phase initiale, l'auteur argumente que celui-ci s'est constitué par étapes et secteures, tout le precessus consistant en une série de captures, menèes à bien par les torrents developpés sur le bord des dépressions Podu Dîmboviţei et Rucăr.

La Dîmboviţa est l'une des plus connues rivières de Roumanie, qui traverse dans son secteur inférieur la ville de Bucarest, la capitale du pays. A son tour, le secteur supérieur (étudie par nous) a fait l'objet dans la dernière décennie d'une série d'aménagement hydro-énergétique, ayant produit et continuant de produire des modifications de nature surtout morpho-pydrographique.

Etant donné que notre intention n'est pas de faire l'historique des recherches, nous nous bornerons à citer dès l'abord quelques noms ayant des mérites reconnues dans la connaissance de la région. Parmi les géographes nous rappelons tout d'abord *Orghidan,* le mailleur connaisseur

de la zone (1935, 1969), *Constantinescu* (1942), *Mihăilescu* (1963), *Nedelcu* (1965), *Velcea* et *Savu* (1981), *Ielenicz* (1986). Du point de vue géologique, la région a été étudiée principalement par *Oncescu* (1943), *Dimitrescu* (1964) et *Patrulius* (1969), le dernier ayant le mérite d'apporter plus d'une donnée inédite.

Les recherches entreprises par nous durant plus 10 ans tout comme les nouvelles données géologiques nous ont permis de formuler une nouvelle hypothèse sur la genèse et l'évolution de la vallée *Dîmbovița.*

Pour être aussi explicite que possible dans la présentation de cette hypothèse, il y a lieu de mettre en discussion tout d'abord deux problèmes que nous considérons essentiels :

— la genèse du coude fait par la Dîmbovița dans le secteur des monts Lerescu—Tămașul Mare—Pecineagu ;

— la genèse et l'évolution de la dépression (graben) Podu Dîmboviței.

1. LE COUDE DE CAPTURE DU SECTEUR DES MONTS LERESCU—TĂMAȘUL MARE—PECINEAGU

Le coude de Dîmbovița et l'*ensellement* existant à NE, suggere à tout géographe une capture (Fig. 1). Malgre ceci, le phénomène de capture a été nié, en invoquant deux aspects géologiques (Orghidan, 1935, 1969) :

— la Dîmbovița a été obligée de modifier sa direction du fait de la résistance opposée par les dépôts mésozoïques qui s'étendaient à l'époque jusque dans la zone du coude et même beaucoup plus vers l'ouest ;

— l'actuelle ligne de partage des eaux entre la Dîmbovița et la Bîrsa, se maintient à partir de l'époque où les dépôts mésozoïques couvraient la région en question, vu que sur son alignement son fondement cristallin présente un soulèvement.

Les données dont nous disposons à l'heure qu'il est, nous permettent d'affirmer qu'ici a eu lieu certainement *une capture*.

A côté de l'existence du coude de capture et de l'ensellement du mont Lerescu, nous apportons à l'appui de cette hypothèse d'autres preuves :

Les arguments apportés par nous à l'appui de la capture, portent sur la nonconcordance de la ligne de partage des eaux avec la ligne des grandes hauteurs. En partant de l'Olt vers l'Est, le trait mentionné est observé seulement dans le secteur d'origine de la Dîmbovița. La Fig. 2 laisse voir que la ligne des grandes hauteurs s'éloigne de la ligne de partage des eaux., en se dirigeant vers le S, sur l'alignement des sommets Călțunu (2.207 m) — Iezerul Mare (2.462 m) — Bătrîna (2.341 m) — Păpușa (2.391 m) — Dracsinul (1.859 m), d'ou vers l'est, celle-ci est „annulée" par la vallée de la Dîmbovița, en revenant par la suite sur la ligne de partage des eaux le somet Tămașul Mare (1736 m). Ceete observation precise deux aspects.

1. *La Dîmbovița a dépassé la vieille ligne de partage des eaux*, c'est à dire la ligne des grandes hauteurs, dont nous avons déja parlé, l'actuelle ligne de partage des eaux présentant des altitudes beaucoup plus réduites que dans le cas de l'ancienne (Fig. 2). En consultant la carte hypsome-

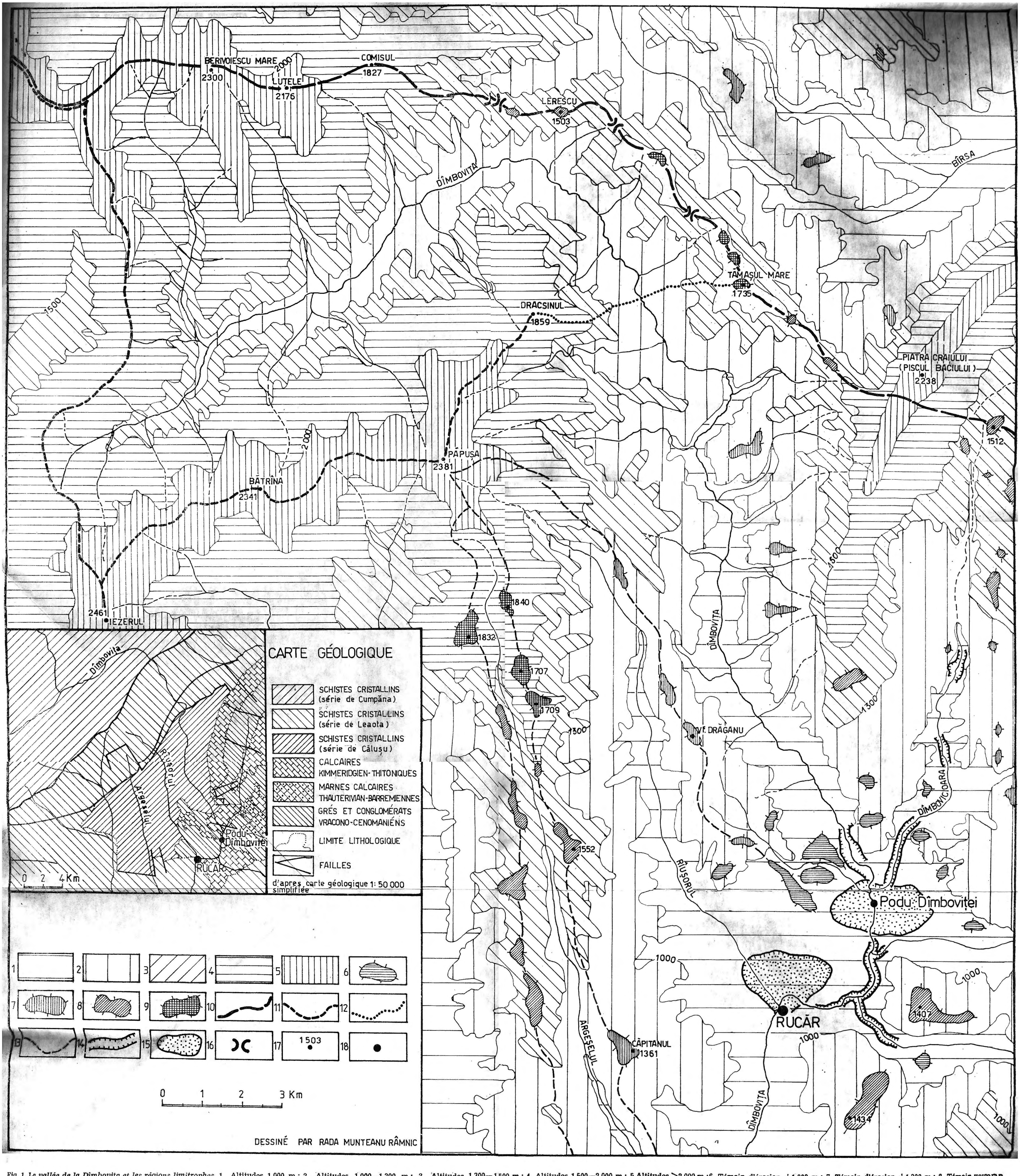

Fig. 1. *La vallée de la Dîmbovița et les régions limitrophes.* 1. Altitudes 1.000 m ; 2. Altitudes 1.000—1.300 m ; 3. Altitudes 1.300—1.500 m ; 4. Altitudes 1.500—2.000 m ; 5 Altitudes >2.000 m ; 6. Témoin d'érosion ±1.000 m ; 7. Témoin d'érosion ±1.300 m ; 8. Témoin d'érosion ±1.500 m ; 9. Témoin d'érosion ±1.800 m ; 10. Ligne principale de partage des eaux ; 11. Ligne des grandes hauteurs ; 12 Couloir de la Dîmbovița ; 13. Ligne secondaire de partage des eaux ; 14. Gorge ; 15. Dépression ; 16. Ensellement ; 17. Cote ; 18. Localité.

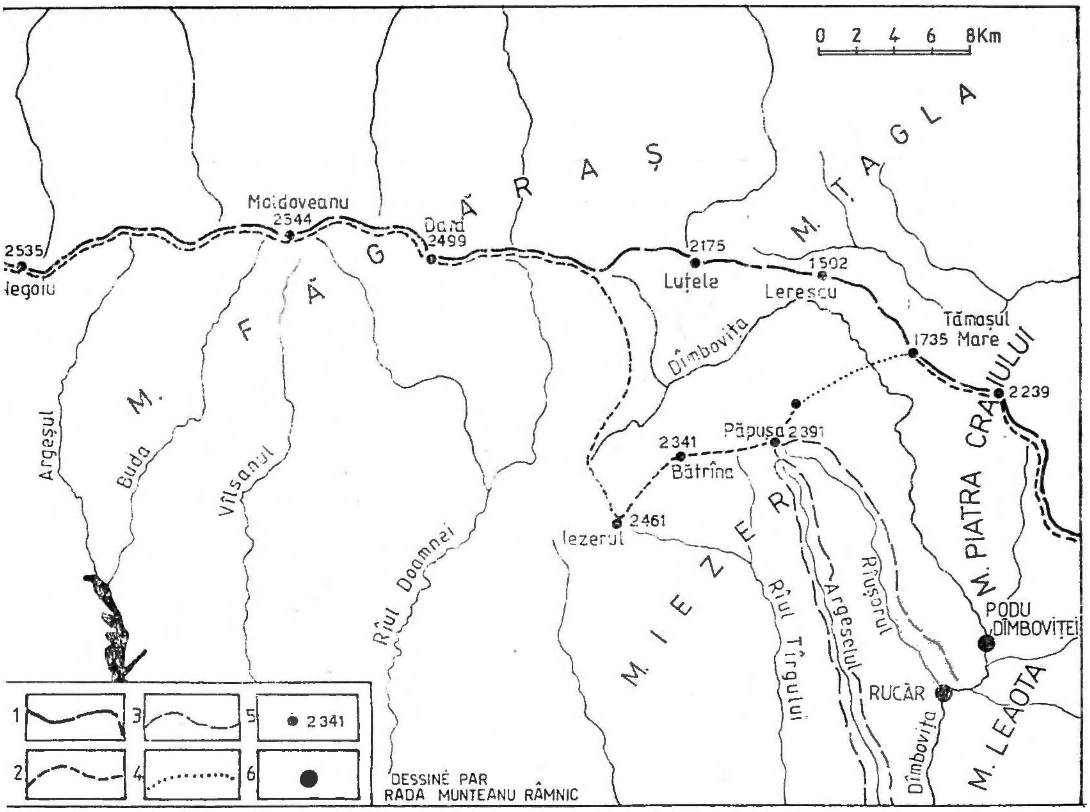

Fig. 2. La ligne principale de partage des eaux et la ligne des grandes hauteurs. 1. Ligne principale de partave des eaux (Ligne de partage des eaux carpatique) ; 2. Ligne des grandes hauteurs ; 3. Ligne secondaire de partage des eaux ; 4. Couloir de la Dîmbovița ; 5. Cote ; 6. Lotalité.

trique (Fig. 1) on constate que la partie sud (des monts Iezer—Tămașul Mare) présente aujourd'hui une altitude moyene de 1700 m, étant beaucoup plus elevée que la partie nord (de monts Țagla—Perșani), qui s'élève à environ 1.300 m. Tout en imaginant la région sans la vallée de la Dîmbovița, il resulte clairement que la rivière de l'amont du coud se continuait vers NE, par l'enseilement du mont Lerescu, du fait que celui-ci... *ne pouvait pas couler en amont !* Une eventualle inversion altimetric du Miocèn jusqu'a aujourd'hui est excluse, etant donne que la tectonique de la région souligne que dans le Pliocène-Quaternaire, la partie nord a été soulevée plus que la partie sud, dans le cadre des zones limitrophes à l'actuelle ligne de partage des eaux.

2. *Le dépassement des grandes hauteurs carpatiques pouvait se faire seulement par l'érosion regressive,* accomplis par rivière venant du S. Cette rivière a captée la vallée ayant la direction ENE, qui se dirigeait vers l'actuelle Depression de Brașov.

Et á ceci d'ajouter que les arguments contre la capture mentionnée à l'heure qu'il est ne peuvent guère être soutenus. D'ailleurs la présence

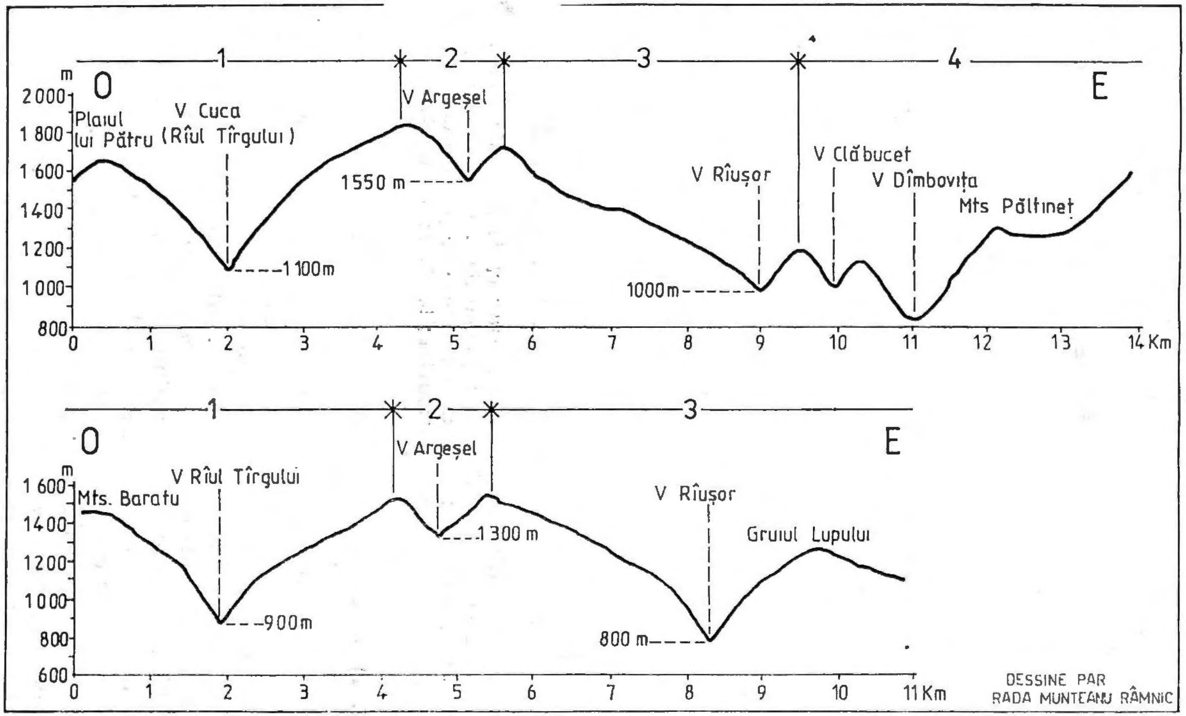

Fig. 3. Profils transversaux

des dépôts mésozoïques jusque sur l'alignement du coude de capture a été seulement supposée et non pas démontrée. Sans entrer dans le detail nous n'allons citer que quelques aspects qui, en essence, contraviennent à cette idée.

— L'extension des dépôts mésozoïques à grande épaisseur jusqu'au coude de la Dîmbovița, contravient aux connaissances actuelles portant sur la tectonique d'ensemble de la région, à savoir la distribution des grands compartiments tectoniques, problème sur lequel du moins jusqu'à présent, les géologues n'ont pas soutenus des opinions contradictoires.

— Tout d'abord, on ne peut passer sous silence, le fait que dans tout l'espece plus proche ou plus éloigné du coude on n'a trouvé jusqu'à present aucune trace quelque petite qu'elle fût (témoin d'érosion) des dépôts mésozoïque comme d'ailleurs on constate dans le S. On ne peut admettre que depuis le Crétace supérieur (alors que la région a été soumise continuellement à l'érosion subaérienne) jusqu'au Miocène (l'âge maximum qu'on peut attribuer à la Dîmbovița), les dépôts mésozoïques se soient maintenus á des épaisseurs considérables et dans le Miocène-Pliocène (une periode de temps beaucoup plus réduit que la première) ceux-ci aient été complètement érodés.

En conclusion, nous considerons que les arguments présentés mettent en évidence *une capture typique* accomplie par une rivière que évolue par érosion régressive, c'est à dire de l'aval vers l'amont.

2. GÈNESE ET ÉVOLUTION DE LA DÉPRESSION (GRABEN) PODU DÎMBOVIȚEI

Le deuxième secteur ayant un rôle essentiel dans l'argumentation de notre hypothèse est la dépression Podu Dîmboviței.

Les opinions (mises jusqu'à présent (Orghidan, 1935 ; Ielenicz, 1986) considerènt qu'antieurement à la mise en place des dépôts vracono-cénomaniens dans la zone de l'actuelle depression il s'est formé un graben qui a été rempli ultérieurement par les dépôts mentionnés. Dans le Miocène la Dîmbovița a érodé ces sédiments plus rapidement que les calcaires environnants en donnant naissance à la depression (dans les calcaires la rivière s'est approfondie de manière épigénetuque, en modelant les actualles gorges). Conformément á cett hypothèse, *la Dîmbovița serait plus ancienne que la dépression.*

La conclusion ci-dessus est infirmée par le fait que la dépression représente un véritable collecteur des rivières, vers laquelle se dirigent les vallées Dîmbovicioara, Cheia, Arșița et bien sur la Dîmbovița, trait qui *précise que le graben est plus ancien que les rivières mentionnées, du moin dans leurs secteur inférieur c'est-à-dire en amont de la depression.*

L'ancienneté plus grande de la dépression est en principe confirmée également par les arguments géologiques, vu que sa statigraphie indique le fait que dans la période antévraconienne, l'espace de l'actuelle dépression représente une zone élevée, l'inversion de relief, c'est-à-dire la formation du graben se produisant seulement durant les orogénèses intramiocène (Patrulius, 1969).

La manière dont s'est produite cette inversion n'a pas été expliquée. Vu que cette action est importante, nous allons essayer de la présenter brièvement.

Durant le diastrophisme mésocrétacé (austrique), l'actuel espace du graben fonctionnant comme une zone élevée, a été inténsement dénudé, les dépôts crétacés inférieurs (marnes et marno-calcaires) étant totalement érodés.

Mis au jour, les calcaires tithoniques-kimmeridgiens ont été soumis à la carstification en surface et en profondeur. Puis ce fut le tour de la Mer Cénomanienne durant laquelle la karstification s'est prolongée jusqu'a ce que les sédiments ont atteint une cereaine épaisseur. A partir de Crétacé supérieur la zone a été soumise continuellement à la denudation subaérienne l'épaisseur des dépôts vracono-cénomaniens diminuant considérablement dans le Paléogène. Parallelement à cette diminuation, le processus de karstification a été repris, étant donné que, comme on la d'ailleurs déjà dit, les conglomérats et les grès sont partiellement perméables, permettant de la sorte l'infiltration de l'eau jusqu'aux calcaires.

Après la formation des deux principales failles (Pleașa Nord et Podu Dîmboviței) qui ont généré le graben, au Miocéne, l'approfondisement de la dépression a été influencée aussi par le processus de karstification.

Conformément aux données géologiques, comme nous l'avons déjà, le phénomène a commencé au Miocène et s'est continue sûrement dans le Pliocène-Quaternaire.

Cela revient à dire que la formation de la dépression est due tout d'abord aux forces tectoniques, mais elle représente aussi l'effet d'un long processus karstique.

3. GENÈSE ET ÉVOLUTION DE LA VALLÉE DÎMBOVIȚA

Avant de passer à la présentation du sujet, nous rendons tout d'abord en synthèse les problèmes essentiels invoqués qui seront à la base de notre interprétation.

1. L'actuel cours de la Dîmbovița, entre les massifs de Făgăraș et Iezer, situé en amont du coude, se dirigeait dans une première étape vers la Dépression de Brașov. Celui-ci a été capté par une rivière, venant du S par érosion régressive.

2. Dans le secteur situé en amont du graben Podu Dîmboviței, la vallée de la Dîmbovița est plus jeune que la dépression.

Compte tenu des deux aspects mentionnés pour la solution du problème il nous faut partir de la présence des torrents installés sur le bord du graben, qui ont évolués par érosion régresive (Constantinescu, 1985). Tout ces torrents se sont axés sur des failles et comme il ressort de la Fig. 4, deux d'entre eux (T.D.1 et T.D.2) développés sur le trajet des actueles gorges (T.D.1 dans la Cheia Mică et T.D.2 dans la Cheia Mare) [1] ont joué un rôle décisif dans la constitution du cours actuel. Le long

[1] *Cheia Mică* (Cheia de Sus) = celle située en amont du graben ;
Cheia Mare (Cheia de Jos) = celle située en aval du graben.

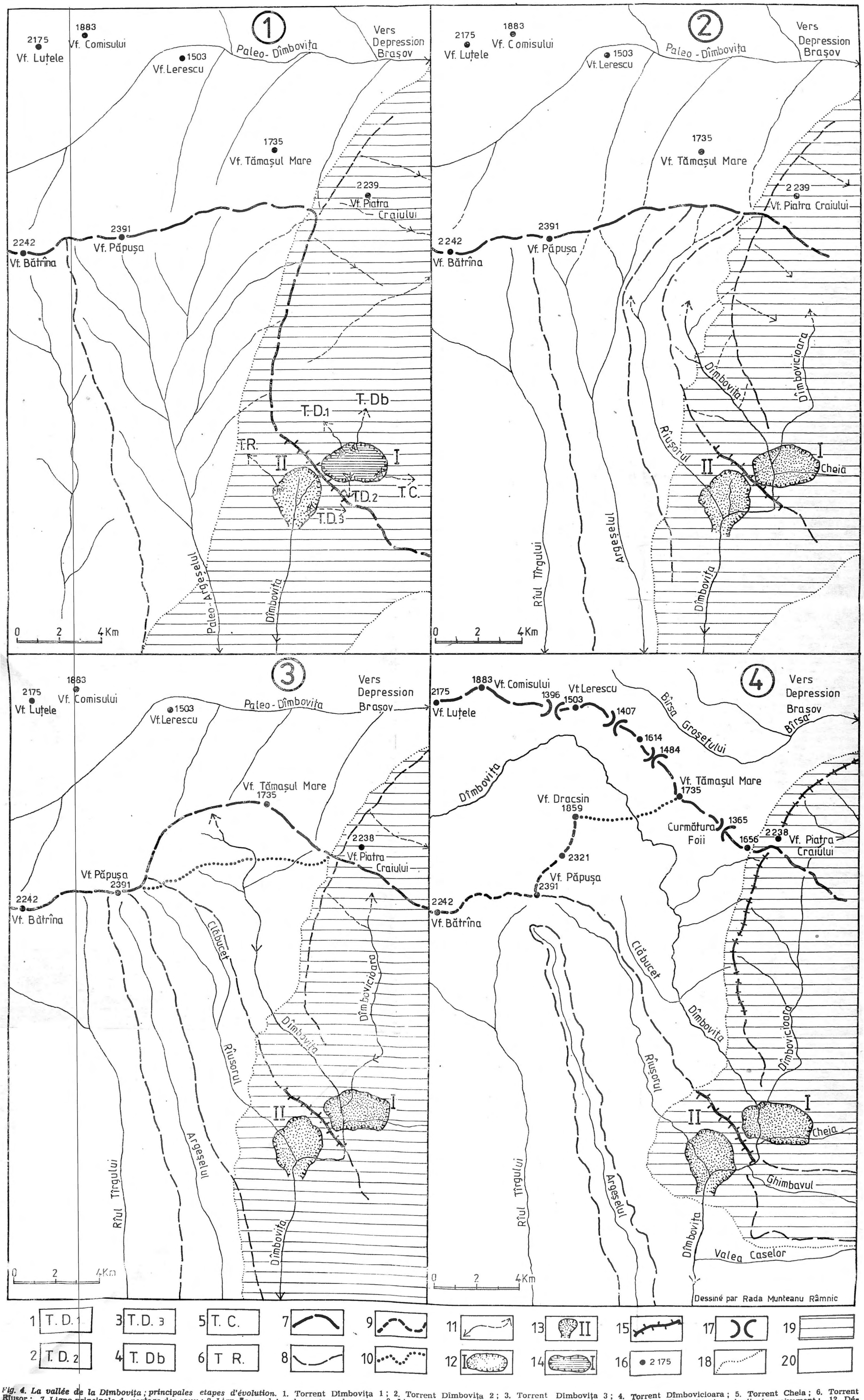

Fig. 4. La vallée de la Dîmbovița ; principales etapes d'évolution. 1. Torrent Dîmbovița 1 ; 2. Torrent Dîmbovița 2 ; 3. Torrent Dîmbovița 3 ; 4. Torrent Dîmbovicioara ; 5. Torrent Cheia ; 6. Torrent Rîușor ; 7. Ligne principale de partage des eaux ; 8. Ligne secondaire de partage des eaux ; 9. Ligne des grandes hauteurs ; 10. Couloir de la Dîmbovița ; 11. Torrent qui evoluait régressivement ; 12. Dépression Podu Dîmboviței ; 13. Dépression Rucăr ; 14. Dépression fermé (lac) ; 15. Le horst Pleașa-Posada ; 16. Cote ; 17. Ensellement ; 18. Limite lithologique ; 19. Dépôts mésozoïques ; 20 Schites cristallins.

processus dont l'essence vient d'être exposées ci-dessus nécesite toute une série d'explications.

1. *Le secteur de l'amont du graben* représente en principe la résultante du torrent axé dans la Cheia Mică (T.D.1). C'est la rivière qui a capté le cours qui se dirigeait vers la Dépression de Brașov.

Pour ce secteur on peut la question si le torrent a évolue par érosion régresive jusqu'au niveau du coude de capture ou jusqu'au N de la localité Sătic où la Dîmbovița modifie son orientation N—S en se dirigeant vers le graben dans la direction NV—SE.

Dans la deuxième variante il s'imposerait une capture efectuée par le torrent sur une rivière qui théoriquement pouvait se continuer toujours dans la direction N—S au-delà du somet Piscul Buții — l'ensellement Posada—Rucăr.

Aucune des variantes ne contravient au problème essentiel (l'installation des torrents sur le bord du graben), mais les arguments que nous allons fournir plaident en faveur d'une évolution par érosion régressive du torrent jusqu'en amont où se trouve le coude de capture.

— Premièrement nous mentionnons qu'il n'existe pas de preuve à même de justifier l'ancien cours sur l'alignement Piscul Buții-l'ensellement Posada—Rucăr. L'ensellement Posada qui suggérait un ancien cours d'eau n'est en realite que le résultat de l'érosion différenciée (calcaires, grès et conglomerats). La même chose est à dire également sur l'ensellement situé à l'ouest du précédent. A vrai dire, des preuves géographiques concluantes néexistent pas et d'ailleurs les analyses minéralogiques effectuées par nous, ne sont pas également inscrites en faveur d'un tel cours.

— Dans la période mio-pliocène, aussi bien l'espace situé entre le Massif Piatra Craiului que celui situé en amont du Massif Iezer (assez restreint d'ailleurs) était partiellement recouverts par des dépôts mésozoïques plus ou moins perméables qui ne favorisaient pas l'organisation d'une grande rivière (il s'agit de l'espace situé au S de l'ancienne ligne de partage des eaux).

— En fin, la partie sud (le Mont Pleașa — 1.072 m. Mont Vîrtoapele — 1.436 m et le Mont Ghimbav — 1.408 m) était plus élevée à cette date que celle située au N du graben. Elle conserve ce caractère aussi à l'heure actuelle, à l'E de la Dîmbovița. Consécutivement aux événements tectoniques du Miocène, lorsque se sont formés le graben Podu Dîmboviței, le semi-graben Rucăr et le horst Pleașa—Posada, ce dernier a continué à rester une ligne de partage des eaux locale et par conséquent le passage d'une éventualle rivière vers le S n'aurait pas été possible.

Toutefois, la présence d'un réseau hydrographique avec l'origine à l'ancienne ligne de partage des eaux (Iezerul Mare—Bătrîna—Păpușa—Tămașul Mare), était obligatoire. Celui-ci à d'ailleurs existé, *mais il se dirigeait vers la Valea Argeșel.* La morphohydrographie du bassin de la rivière Argeșel, ainsi que celle des bassins limitrophes, plaident en faveur de notre affirmation. Nous citerons dans ce sens, deux aspects intéresants qui attirent l'attention à la première vue.

a) Le bassin hydrographique de l'Argeșel est extrêmement étroit, par comparaison á ceux limitrophes de l'E et du V (Fig. 1).

b) La Valea Argeşel apparaît aujourd'hui suspendue par rapport aux deux vallées voisines (Rîuşorul et Rîul Tîrgului).

L'étude attentive de la carte géologique nous permet de conclure que l'Argeşel était la rivière la plus orientale axée probablement sur le contact entre le massif cristallin du Iezer et le Couloir Mésozoïque Dîmbovicioara.

Évoluant par érosion régressive, Rîuşorul et Dîmbovița „ont vole" les affluents de l'origine de L'Argeşel. Restant une rivière frêle, ce dernier a été „attaque" en continuation, ce qui a diminué considerablément son bassin hydrographique et, naturellement, sa force de creusement.

Pour en conclure, nous considéron sque les arguments présentés plaident en faveur d'*une évolution par érosion régressive du torrent axé sur Cheia de Sus (T.D-1), jusqu'au coude de capture. Ce torrent se confond, donc, avec la rivière conquérant dont nous avons déjà parlé.*

2. *Le secteur situé en aval du graben*

Dans ce secteur, la Dîmbovita fait son deuxième grand coude de 90° (Fig. 1).

Nous avons déjà anticipé que simultanément avec le graben Podu Dîmboviței, se sont formés le semi-graben Rucăr et le horst Pleaşa—Posade, le dernier fonctionnant comme une ligne de partage des eaux locale. Dans la dépression Rucăr, ouverte vers le S, s'est installé un cours d'eau à direction N—S, ainsi qu'une série de torrents qui ont évolué régressivément. Le plus actif de ce torrents a été le *Rîuşorul* d'aujourd'hui, mais au surplus, sur le bord E s'est axé un torrent (sur une faille très claire même aujourd'hui) qui avancait ver l'E (Fig. 4). Du graben Podu Dîmboviței évoluait dans la direction N—S, le torrent de Cheie de Jos (T.D.2). A un moment donné les deux se sont rencontrés, résultant ainsi une seule vallée (Fig. 4). C'est de cette manière que s'explique le grand coude de la Dîmbovița, situé entre les localités Podu Dîmboviței et Rucăr.

Ceci constituerait l'essence du phénomèn, qui nécessite une série de précisions.

Il est à souligner en premier lieu qu'après la formation du graben, il a fonctionné comme une *dépression fermée*. Etant donné que les torrents développés sur la bord du graben se sont creusés initialement dans des grès et des conglomérats (roches partiellement perméables) et que la dépression était fermée, il nous faut admettre qu'ici s'est installé pour une brève période de temps *un lac* de petite profondeur. La formation d'un lac profond n'a pas été possible parce que le bassin d'alimentation était au début assez restreint et les dépôts presentaient, comme nous l'avons déjà montré, une certaine perméabilité.

Lorsque le torrent axé sur Cheia de Jos (T.D.2) a atteint les calcaires, le lac s'est écoulé graduellement. Les traces du lac n'ont pas été dépistées parce que la grande majorité des sédiments ont été lavés, comme il était naturel, par l'action des autres torrents (Dîmbovicioara, Cheia et tout particulièrement T.D.1), qui se sont tous dirigés, après l'apparition de l'ouverture (Cheia de Jos), vers ce „canal" érodant dans leur chemin les sédiments déposés tant que le lac avait fonctionné. Les

éventuels sédiments qui y sont restés doivent être cherchés sous les terrasses de la Dîmbovița, qui s'est constituée comme une rivière unitaire aprés l'écoulement du lac. Compte tenu du fait que le développement des torrents sur le bord du graben a été, en principe, une action simultanée, après le tracé parcouru par les deux torrents à rôle essentiel dans la constitution du cours unitaire (T.D.1 et T.D.2), on peut affirmer que T.D.2 a jonctionné avec celui de la Dépression Rucăr (T.D.3) beaucoup plus vite que T.D.1, ce dernier ayant à parcourir une distance de plus 15 km, tandis que T.D.2 n'avait que 2—3 km. Ainsi *la capture effectué par T.D.1* (voir *I-er chapitre) a représente la dernière phase de constitution de l'actuel cours* de la Dîmbovița (Fig. 4). En prenant comme point de repère de base l'altitude de l'ensellement Lerescu (1.403 m), il résultait que cette capture s'est produit au Pliocène.

On peut affirmer, que le procesus de constitution de la Vallée Dîmbovița s'est accompli en *4 phases* principales synthétisées dans la Fig. 4.

Le niveau actuel de connaissance géographique et géologique de la région, exclut l'existence d'un tracé unique depuis la phase initiale. La morphologie de la zone, associée aux données géologique, nous conduit à l'interprétation exposée dans le présent ouvrage.

Le problème de la *datation exacte* du processus reste encore ouvert. Nous attribuons à ce processus l'âge Mio-Pliocène, mais théoriquement il pourrait appartenir seulement au Pliocène. Dans les deux cas, le problème essentiel, c'est-à-dire *la constitution de la Vallée Dîmbovița par secteurs et en étapes reste inaltérée.*

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EVOLUŢIA REŢELEI HIDROGRAFICE DIN CULOARUL DÎMBOVICIOARA. NOTA 2. GENEZA ŞI EVOLUŢIA VĂII DÎMBOVIŢA

Rezumat

Una dintre concluziile *Notei 1* (Constantinescu, 1985), evidenţia faptul că formarea grabenului (depresiunii) Podu Dîmboviţei, a declanşat o serie de remanieri ale reţelei hidrografice din Culoarul Dîmbovicioara. Evoluţia văii Dîmbovicioara, detaliată în această primă notă, a constituit un prim exemplu, anticipîndu-se că există şi alte văi a căror evoluţie a fost influenţată de formarea grabenului menţionat.

Printre acestea, se remarcă şi Dîmboviţa, principala arteră hidrografică din zonă, căreia autorul îi consacră această lucrare (Nota 2).

În prima parte sînt expuse o serie de argumente geografice şi geologice, care scot în evidenţă, că marele cot la Dîmboviţei ditnre munţii Lerescu — Tămaşul Mare — Pecineaga este efectul unei *captări,* săvîrşite de rîul venit din S, care a *decapitat* un curs de apă (Paleo-Dîmboviţa), ce se dirija spre NE, către Depresiunea Braşov.

Cea de a 2-a parte a lucrării, tratează geneza şi evoluţia grabenului Podu Dîmboviţei, subliniindu-se că datele geologice actuale, contrazic ipoteza clasică, conform căreia acest graben s-ar fi format anterior depunerii sedimentelor vracono-cenomaniene. Acest accident tectonic, a avut loc mult mai tîrziu, cel mai probabil în Miocen, eveniment după care arealul a devenit o puternică zonă de atracţie a apelor de suprafaţă şi subterane.

În sfîrşit, în ultimul capitol, se prezintă, ca o sinteză, geneza şi evoluţia văii Dîmboviţa. Negînd ipoteza existenţei actualului curs din faza iniţială, se subliniază că acesta s-a constituit în etape şi pe sectoare, procesul constînd într-o serie de captări, săvîrşite de torenţii dezvoltaţi pe marginea depresiunii (grabenului) Podu Dîmboviţei, torenţi ce au evoluat ulterior prin eroziune regresivă.

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LA MORPHOLOGIE DE L'EXO- ET DE L'ENDOKARST DU PLATEAU DE PURCAREŢ-MESTEACĂN (PLATEAU DU SOMEŞ)

BY

V. TODORAN, B. ONAC

Le travail traite les particularités d'un kars développé sur les calcaires éocènes et oligocènes du ***Plateau de Purcăreţ — Mesteacăn.*** On décrit des types particuliers de lapiaz, la distribution des dolines, ainsi que la présence d'un poljé de moyenne taille. On mentionne de même l'apparition dans certaines grottes du gypse se trouvant sous plusieurs formes.

L'unité géomorphologique que nous appelons le *„Plateau de Purcăreţ-Mesteacăn"* se développe dans la partie nord-est du *Podişul Someşan.* Elle est délimitée par une ligne qui unit les localités de *Purcăreţ-Vărai-Mesteacăn* au nord, par la rivière de *Someş* au sud, par le défilé de la vallée de *Purcăreţ* à l'ouest et par lo route qui relie les localités de *Răstoci* et de *Mesteacăn* à l'est.

En ce qui concerne la succession géologique des formations, nous mentionnons que les couches remontent à l'Eocène-Oligocène, étant représentées dans leur majorité par des calcaries. Afin de donner une image claire de cette succession, nous présentons dans la fig. 1 une colonne géologique synthétique à travers les dépôts qui affleurent sur ce plateau.

Ce qui caractérise la morphologie d'ensemble du *Plateau* de *Purcăreţ-Mesteacăn* est la présence de deux secteurs distincts : un secteur septentrional, plus haut et plus intensément fragmenté, et un secteur méridional, plus bas et beaucoup plus unitaire.

Le premier secteur, attaqué par les affluents du *Lăpuş,* du *Bîrsău* et du *Someş,* a été transformé en un alignement de témoins structuralo-érosifs modelés presque exclusivement dans des calcaires priaboniens et séparés entre eux soit par des dépressions, soit par de véritables défilés.

Le deuxième secteur, dénivelé de 50 à 100 m. par rapport au premier, est beaucoup plus unitaire et se distingue par une plus grande diversité du relief, fait qui est dû à la lithologie mais aussi à un réseau très dense de fractures locales. Les calcaires priaboniens de la partie nord, ainsi que les calcaires oligocènes, se prolongent dans ce secteur aussi, soulignant

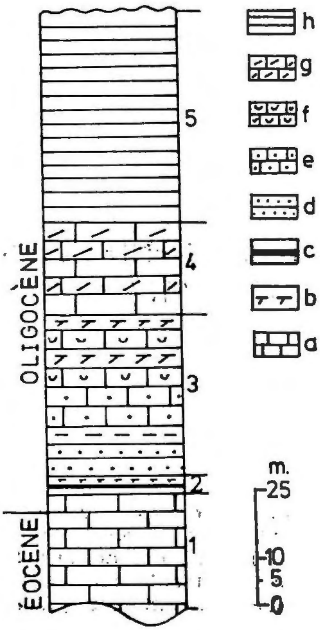

Fig. 1. Collone géologique synthétique des depôts éocènes — oligocènes de la région de Purcăreț — Mesteacăn. a — calcaires, b — marnes, c charbon, d — grès, e — grès calcaires, f — calcaires organogènes, g — marno-calcaires, h — schistes argileux bitumineux. 1. Couches de Culmea Cozlei, 2 Couches de Curtuiuș, 3. Couches de Ciocmani, 4. Couches de Bizușa, 5. Couches d'Ileanda.

de façon très prononcée le caractère structural monoclinal du plateau et générant de la sorte un karst de plateau.

Nous estimons que dans le modelage du relief du *Plateau de Purcăreț-Mesteacăn*, un rôle important revient à la fois à la lithologie et à la grande diversité des calcaires de cette zone, ainsi qu'au facteur tectono-structural qui a agi sur le relief et a conditionné la plupart des phénomènes karstiques.

1. L'EXOKARST DU PLATEAU DE PURCĂREȚ-MESTEACĂN

Le relief karstique du *Plateau de Purcăreț-Mesteacăn* est caractérisé par le développement des formes suivantes (fig. 2).

1. Les lapiaz. Ils apparaissent sur tous les types de roches du plateau (calcaires, grès calcaires, marno-calcaires), réalisant de véritables champs de lapiaz. Ils sont généralement à demi enterrés et, plus rarement, libres ou enterrés. C'est la roche sur laquelle ces lapiaz se sont formés qui leur imprime certaines particularités. Ainsi, les lapiaz qui se sont développés sur des calcaires organogènes ou algaux ont des enfoncements flanqués de petites crêtes constituées de lumachelles ou de thalles d'algues. L'apparition de ce type de lapiaz est due à la corrosion sélective. La taille de ces lapiaz est de l'ordre des décimètres.

Les grès calcaires et les marno-calcaires ont favorisé l'apparition des lapiaz creux, arrondis et en diaclase, ces derniers étant une conséquence de la sollicitation tectonique du calcaire (Bleahu, 1974). La plupart d'entre

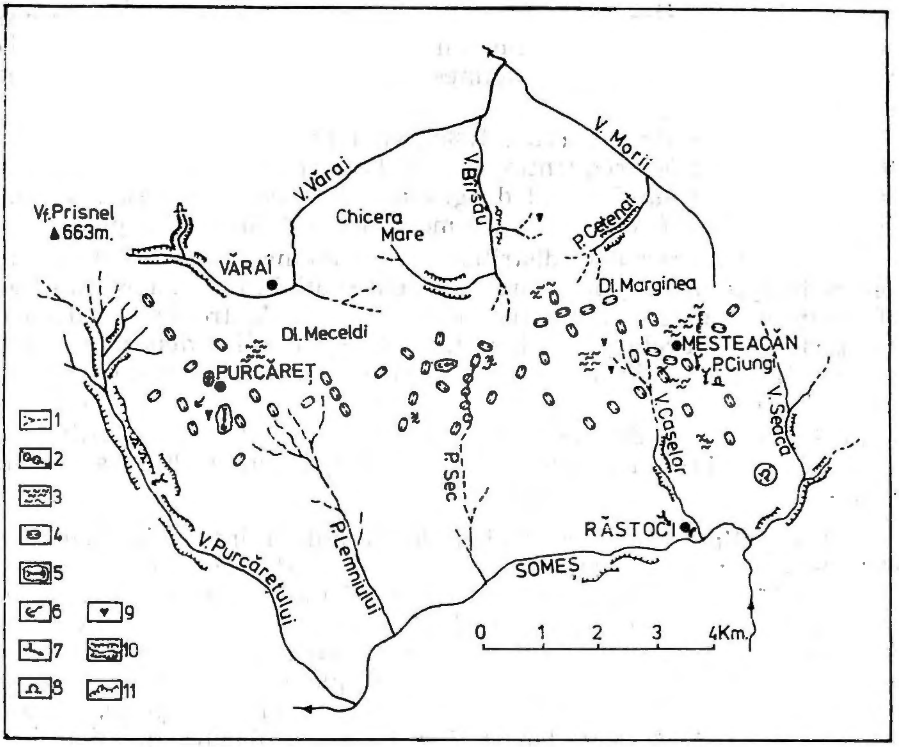

Fig. 2. Carte géomorphologique du Plateau de Purcăreț — Mesteacăn. 1. vallées à écoulement temporaire, 2. vallées dolinaires, 3. champs de lapiaz, 4. dolines, 5. poljés, 6. ponors, 7. résurgences, 8. grottes, 9. avens, 10. gorges, 11. abrupts.

eux se sont formés sous la couverture du sol et ont été dénudés par la suite. Un nombre restreint s'est formé à la surface, mais en raison des processus de pente ces lapiaz ont été partiellement enterrés.

Encore que la taille des lapiaz décrits ne soit pas très grande, ils ne s'en imposent pas moins par les particularités évoquées et par leur ample aire de distribution dans le paysage karstique de ce plateau.

2. Les dolines. Dans le karst du *Plateau de Purcăreț-Mesteacăn* nous avons rencontré trois types de dolines, à savoir : des dolines de dissolution, des dolines d'effondrement (tectoniques) et des dolines complexes. Tout comme dans le cas des lapiaz, elles apparaissent sur tous les types de roches présentes sur le plateau.

Les dolines de dissolution, qui sont les plus nombreuses, apparaissent sur les surfaces planes ou peu inclinées du plateau. Les dimensions de ces dolines varient, allant de quelques mètres pour les formes de début (de simples renfoncements) à 50—150 mètres en longueur et 10—15 mètres en profondeur, pour les formes bien développées. La majorité des dolines de cette catégorie ont un fond plat qui suit fidèlement la stratification et l'inclination du paquet calcaire.

Les dolines d'effondrement (tectoniques) sont les moins nombreusses et se développent dans la partie centrale du plateau. Par suite de l'effondrement du fond de telles dolines ont pris naissance quelques petits avens aussi.

Les pseudo-dolines (Cocean, 1980), en tant que soustype des dolines complexes, sont très fréquentes sur le *Plateau de Purcăreț-Mesteacăn*. Elles apparaissent sur le fond de grandes dolines, sous forme de petits enfoncements d'où résulte un étagement de la doline principale.

En ce qui concerne la distribution des dolines sur ce plateau, nous avons remarqué deux types d'ordonnement spatial : l'un d'après les lignes de fracture majeures — d'habitude des failles —, l'autre d'après d'anciennes directions de drainage exokarstique. C'est ce qui a déterminé l'apparition d'alignements de dolines qui s'entrecroisent, d'où résulte un véritable „échiquier".

La majorité des dolines sont riches en végétation et constitue des points de perte d'eau, en déterminant la désorganisation du réseau hydrographique.

3. Les poljés. Dans l'acception de la notion introduite par Cvijić (1893), nous avons rencontré sur le *Plateau de Purcăreț-Mesteacăn* deux poljés très bien contourés. Le premier, de 250 à 300 m. de long, est parcouru par un cours d'eau qui se perd dans un ponor au fond d'une doline ; la résurgence et le ponor sont situés dans la même dépresion fermée. Lors des débits importants, l'eau n'est drainée que partiellement et dans la doline se forme un lac temporaire. Le deuxième, un micropoljé, est beaucoup plus petit, mais possédant toutes les particularités qui définissent un poljé.

2. L'ENDOKARST DU PLATEAU DE PURCĂREȚ-MESTEACĂN

Bien que l'épaisseur du paquet calcaire de ce plateau ne dépasse pas 40 à 60 m., les grottes (5) et les avens (6) qui y sont cantonnés se signalent par des particularités distinctes. Ainsi, le calcaire organogène dans lequel sont creusées la plupart des cavités présente de riches associations faunistiques (algues, coraux, foraminifères, mollusques). Les salles des grottes ainsi que les parois des avens représentent d'authentiques musées paléontologiques, contenant la faune caractéristique de l'Eocène et de l'Oligocène.

La présence du gypse dans trois des grottes de ce plateau constitue une autre particularité. Il apparait sous les types morphologiques suivants : croûtes, anthodites, cristaux aciculaires, cristaux prismatiques maclés et agrégats de gypse. La genèse de ce dernier a été attribuée à la présence, dans les *Couches d'Ileanda* de la couverture des dépôts Oligocènes, des dépôts de gypse secondaire cantonnés sur les surfaces de schistuosité des argiles bitumineuses (Onac et Todoran, 1987).

Une autre caractéristique que nous signalons est la présence, dans la majorité des grottes, du plafond plan-horizontal. Le plus bel exemple nous en est offert par la Grotte de Ciungi (István et Zachan, 1983), où le rôle que joue la succession lithologique dans l'apparition de ce type parti-

culier de plafond est tout ce qu'il y a de plus éloquent. Nous metnionnons que la grotte en question est le plus long réseau souterrain (552 m.) qui s'est développé dans des calcaires oligocènes de notre pays.

Sans prétendre avoir épuisé tous les aspects que revêtent les phénomènes karstiques du plateau dont nous nous occupons, le travail s'est proposé de faire état de quelques particularités du karst d'âge Eocène-Oligocène du nord-est du *Podiş Someşan.*

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MORFOLOGIA EXO- ŞI ENDOCARSTULUI DE PE PLATOUL PURCĂREŢ — MESTEACĂN (PODIŞUL SOMEŞAN)

Rezumat

Lucrarea tratează morfologia exo- şi endocarstului de vîrstă Eocen—Oligocen de pe Platoul Purcăreţ — Mesteacăn, prezentîndu-i unele particularităţi.

Existenţa a două tipuri de calcare (algale, organogene) a dus la apariţia unor lapiezuri, la care canalele sînt flancate de mici creste constituite fie din thaluri de alge, fie din calcare lumaşelice.

Ordonarea spaţială a dolinelor a fost pusă pe seama factorului tectonic pe de o parte, şi pe vechile drenaje exocarstice pe de altă parte.

Sînt semnalate şi descrise două polii de talie mijlocie.

Legat de cavităţile dezvoltate în pachetul de calcar, se precizează prezenţa gipsului sub mai multe tipuri morfologice (cruste, cristale aciculare, cristale prismatice maclate, antodite, agregate) în trei dintre ele. Geneza acestor cristale a fost pusă pe seama gipsului secundar cantonat de Stratele de Ileanda.

Este menţionată prezenţa în cîteva peşteri a tavanului plan—orizontal (P Ciungi), ca o consecinţă a succesiunii litologice.

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SUR L'INFORMATION PALÉOCLIMATIQUE COMPRISE DANS LE DÉPÔT SOUTERRAIN DE GLACE DE LA GROTTE DE SCĂRIȘOARA (MONTS DU BIHOR) ET SA VALORISATION POUR UNE PROGNOSE DE LONG TERME

PAR

M. ȘERBAN, G. RACOVIȚA

On passe en revue les principaux éléments qui caractérisent au point de vue stratigraphique le dépôt de glace fossile de la Grotte de *Scărișoara* (Monts du *Bihor)*, ainsi que les essais entrepris jusqu'à présent pour en déduire les variations du climat durant les 250 dernières années. On précise les étapes qui doivent être parcourues afin d'obtenir la „clef de déchifrement" de l'information paléoclimatique comprise dans ce dépôt, en présentant les données accumulées jusqu'à présent. On établie le programme de recherches qui doit être suivi pour aboutir à la valorisation complète de cette information et, implicitement, à une prognose climatique de long terme, qui peut couvrir les 1000 ans suivants.

C'est Émile Racovitza (1927) qui a été le premier à affirmer clairement, que la glace qui compose le grand massif souterrain abrité par la Grotte de *Scărișoara* doit être fossile et se trouver en dehors des variations météorologiques externes, à l'exception de la couche superficielle, qui fond et se renouvelle chaque année. À son époque, la connaissance incomplète de la grotte rendait difficile la vérification d'une telle assertion, mais celle-ci a été pleinement confirmée après la découverte des parties profondes de la cavité (Șerban, Coman et Givulesco, 1948).

En effet, on a pu alors constater que le flanc nord-est du bloc de glace constitue une sorte d'immense section naturelle de ce massif, sur laquelle on voit facilement que la glace n'est pas homogène, mais présente une structure stratifiée. Cette structure, qui est analogue à un certain point de vue à celles des varves, résulte du fait que la glace se présente sous formes de couches plus ou moins horizontales, séparées de couches d'impuretés formées d'argile, de terre et de restes végétaux. Elles est due à l'alternance saisonnière des processus de fonte et de gel qui se succèdent à la surface supérieure du bloc de glace. La Grotte de *Scărișoara* fait partie de la catégorie des cavités à ventilation bidirectionnelle inter-

mitente (Racoviţă, 1967, 1975), ayant un caractére généralement descendant et étant fermée en cul de sac dans sa partie inférieure. En conséquence, elle est le siège d'importants échanges aérodynamiques avec l'extérieur durant l'hiver, quand la température souterraine s'abaisse bien au dessous de 0°C et toute l'eau accumulée sur la surface du bloc de glace gelle, formant une couche de glace d'une certain épaisseur. Ces échanges cessent pendant l'été à la suite d'un inversement de température entre la grotte et l'extérieur (Şerban et al., 1948) et la température souterraine augmente sous l'effet de la radiation solaire et surtout du flux géothermique, en déterminant la fonte partielle de la couche superficielle de glace et l'accumulation de tous les débris minéraux ou organiques, autochtones ou allochtones, sous la forme d'une couche d'impuretés. La structure du bloc de glace est constituée dons, en principe et en certaines conditions, d'une succession d'*unités stratigraphiques*, chacune de celles-ci comprenant une couche de glace et une mince couche d'impuretés et correspondant à une année (Şerban et al., 1967). Ce sont précisément ces paires de couches qui représentent l'élément fondamental de l'information climatique comprise dans le dépôt souterrain de glace, car tous leurs paramètres (allant de l'épaisseur et terminant avec le contenue pollinique et la composition isotopique) sont évidemment fonction des facteurs météorologiques de l'extérieur.

L'intervalle de temps auquel se rapport cette information, donné par l'ancienneté des premières couches de glace formées dans la grotte, est suffisamment grand pour pouvoir parler d'une *glace fossile* et de conditions *paléoclimatiques* d'évolution du dépôt souterrain. La datation faite à partir d'analyses polliniques attribue aux premières „unités stratigraphiques" qui apparaissent à la base accessible du bloc de glace un âge d'environ 3000 ans et place le début de la glaciation dans la Grotte de *Scărişoara* au cours d'un épisode ancien de la phase du hêtre *(Fagus silvatica)*, dans la période sous-atlantique, caractérisée par un climat plus froid et plus humide que celui de la période antérieure (Pop et Ciobanu, 1950).

Si l'âge proprement dit de ces couches de glace ne comporte pas de discussions, la date du début de la glaciation de caverne est sujet d'une certaine incertitude, car on doit avoir également en vue la posibilité d'une fonte lente mais permanente du fondement du bloc de glace (Şerban et al., 1948), ainsi que l'existence de couches de glace encore plus anciennes que celle se trouvait à la base du profil pris en considération dans l'analyse pollinique (Rusu et al., 1970). Quoiqu'il en soit, le dépôt de glace de la Grotte de *Scărişoara*, qui présente plusieurs analogies avec celui de la Grotte de *Focul Viu*, comprend un profil de l'évolution pollinique postglaciaire avec un extension bien plus grande que celle qu'on peut établir dans les gisements de tourbe, ce profil s'étandant sur une hauteur d'au moins 15 m. Le dépôt se caractérise aussi par de très bonnes conditions de conservation des débris végétaux, car on a pu mettre en évidence l'existence dans les couches d'impuretés d'une chlorophylle fossile (Pop et Ciobanu, 1950), la glacière naturelle de *Scărişoara* constituat le premier endroit de Roumanie dans lequel on a fait une pareille découverte.

Il va sans dire que, dans de telles circonstances, l'intérêt de déchiffrer l'information paléoclimatique de ce dépôt de glace pérenne est particuliè-

rement grand. Un premier essai a été fait par Şerban et al. (1948), qui ont distingué dans le profil stratigraphique trois grande paquets de couches, différents par la couleur des impuretés ; le paquet médian, comprenant d'impuretés de couleur plus foncée, a été attribué à une période plus chaude et plus humide. Cette hypothèse a été confirmée par les analyses polliniques que nous avons mentionnées et se trouve en concordance avec ce que Bleahu (1962) apelle la *transgression histrienne*. Il s'agit du fait que, à partir du premier siècle av.n.è., donc environ 2000 ans auparavant, le niveau de la Mer Noir a commencé à augmenter et cet événement coïncide parfaitement avec la période dans laquelle on a estimé que se sont déposées les couches qui forment le paquet médian, à impuretés terreuses, noires, de la Grotte de *Scărişoara* (Şerban et al., 1967).

Des conclusions plus détaillées ont pu être tirées de l'analyse microstratigraphique de deux carottes de glace, d'une longueur cumulée d'environ 1,5 m, extraites du plancher de la Grande Salle — face supérieure du massif. Quoique ces carottes ont été obtenues à des reprises différentes, séparées par un intervalle de 13 années, on peut considérer avec une approximation satisfaisante qu'elles représentent une succession stratigraphique unitaire, à partir de laquelle on a pu esquisser l'évolution climatique durant les 250 dernières années (fig. 1). Cette reconstitution met en évidence une période plus froide, qu'on a dénommée une *glaciation de caverne de forte intensité* (Şerban et al., 1967) et qui a due être comprise entre 1810 et 1850. La corrélation qui a été faite entre la microstratigraphie des deux carottes et les oscillations climatiques déduites de la variation de long terme du coefficient de température défini par Easton (1928) a pleinement confirmé cette interprétation (fig. 2), ne modifiant que la durée de la période froide : il apparait que celle-ci a commencé vers 1700 et a pris fin vers 1920 (Racoviţă, 1972), de sorte qu'elle peut mieux être superposée à la micropériode glaciare — le *„little ice-age"* de Matthes (1942) —, dont le maximum correspond aux XVII-e—XIX-e siècles.

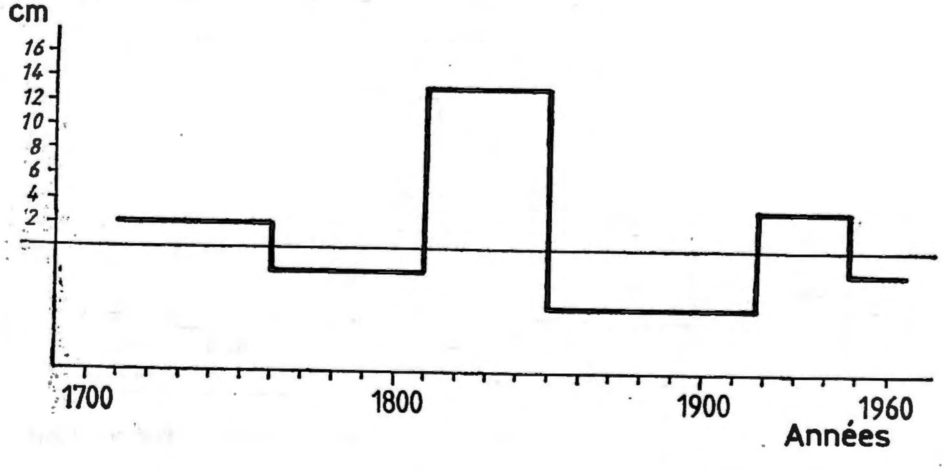

Fig. 1. Essai de reconstitution des oscillations climatiques entre 1700 et 1960, basé sur la microstratigraphie des deux carottes de glace extraites du plancher de la Grande Salle.

Outre les résultats auxquels on est arrivé par analyses polliniques et microstratigraphiques, on a également essayé de mettre en évidence la variation du contenu en deutérium et en ^{18}O des couches de glace, en étudiant à ce point de vue la deuxième carotte (Şerban, Blaga et al., 1967). Les données obtenues montrent une certaine périodicité de la quantité d'isotopes (fig. 3), mais elle relève en même temps la très grande complexité liée aux conditions qui président à la genèse de la glace de caverne. En effet, cette quantité varie suivant la nature de l'eau qui se trouve à l'origine de glace, et qui peut être soit de percolation, soit de condensation, ainsi qu'en corrélation avec les autres phénomènes physiques qui peuvent intervenir dans la dynamique de la glace, c'est-à-dire la volatilisation et la sublimation (dans l'acception de Schumsky, 1955).

Il va sans dire que les résultats résumés ci-dessus ne sont que partiels. La valorisation intégrale de l'information paléoclimatique comprise dans le bloc de glace de la Grotte de *Scărişoara* suppose d'une manière obligatoire la transcription dans les termes d'oscillations climatiques de toute la stratigraphie de ce bloc, mais celà demande d'abord la compréhension approfondie et détaillée de tous les processus physiques impliqués dans la genèse et la dynamique de la glace souterraine. Et ces processus sont particulièrement complexes.

Pour aboutir à une *„clef de déchiffrement paléoclimatique"*, il faut établir en premier lieu les relations qui existent entre les facteurs topoclimatiques souterrains et la dynamique du dépôt de glace. Les données

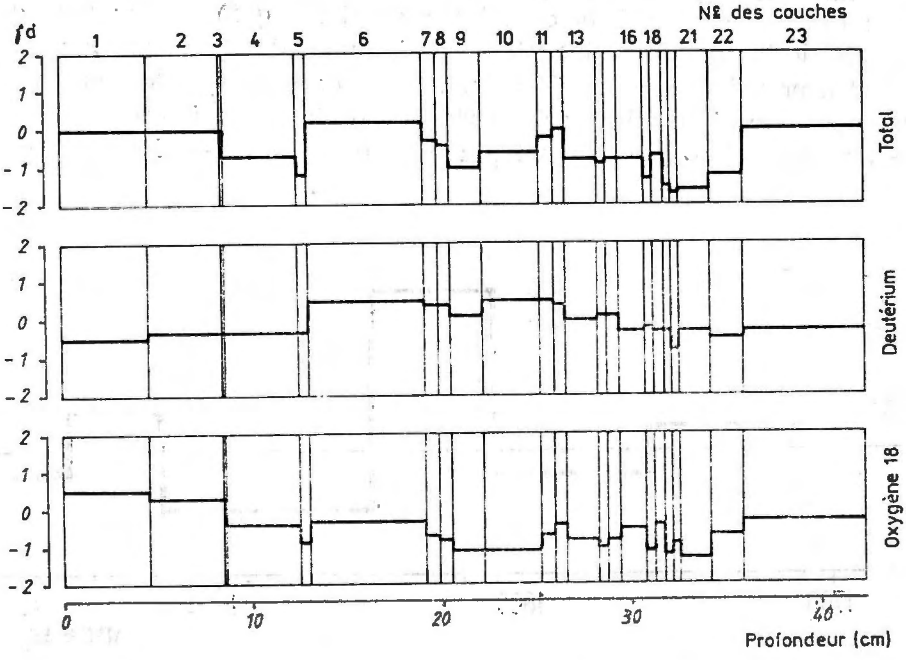

Fig. 3. Variations du contenue en isotopes des couches de glace qui composent la carotte extraite en décembre 1960. On remarque que, en général, des valeurs minima qui apparaissent tout les quatre couches impriment une certaine périodicité dans ces variations.

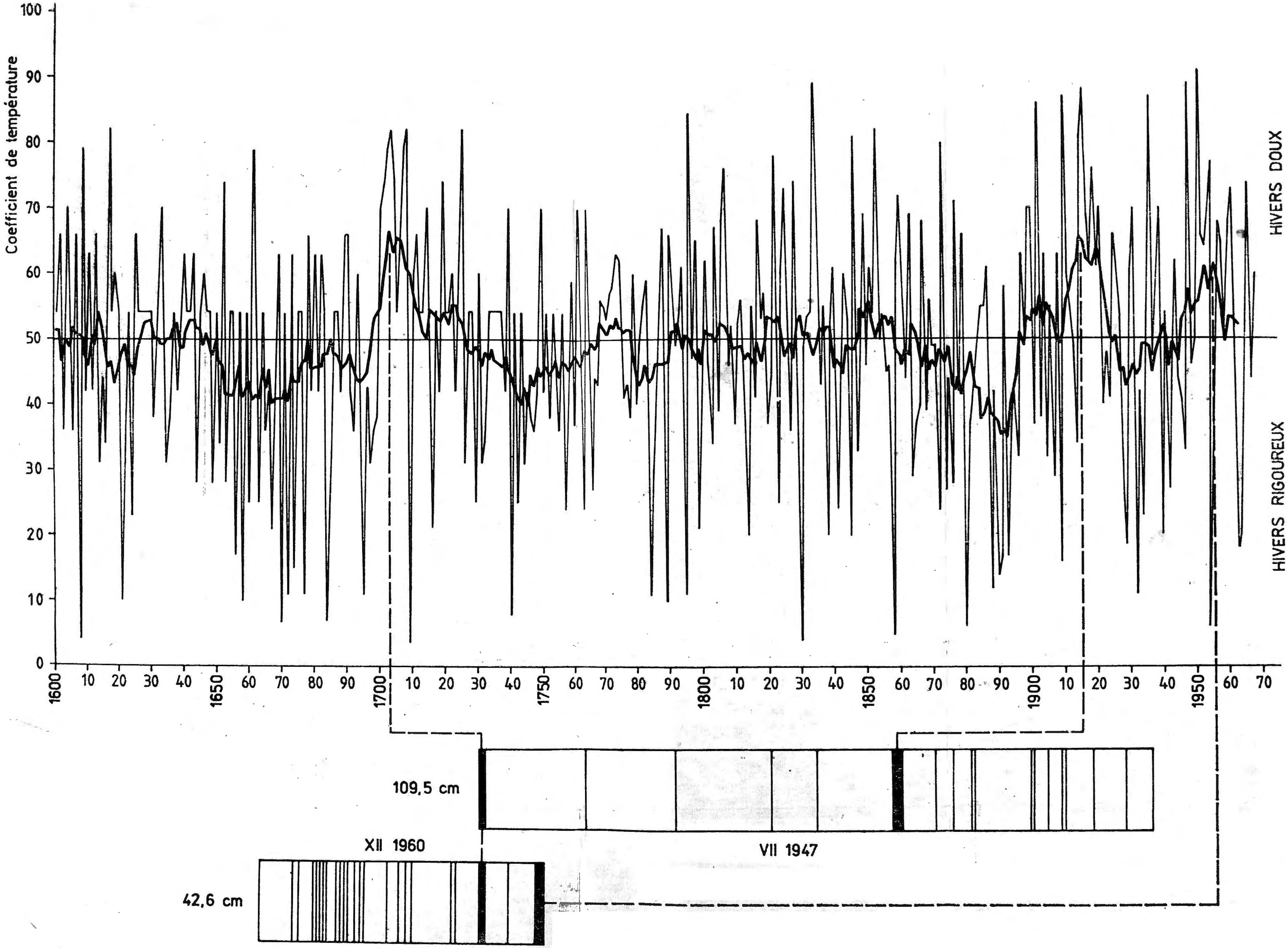

Fig. 2. **Corrélation entre les variations du coefficient de température, établies d'après les données de C. EASTON (1928), et la structure des deux carottes de glace. Les couches plus épaises d'impuretés qui apparaissent dans cette structure correspondent aux périodes d'échauffement du climat qui se sont manifestées durant les décades 1700—1710, 1910—1920 et 1950—1960.**

seulement de la durée de l'intervalle pendant lequel cette température est positive (Racoviţă et Crăciun, 1970).

En ce qui concerne la période hibernale, correspondant à la phase de criossance des formations de glace, les phénomènes sont plus compliqués. Les conditions dans lesquelles se déroulent les échanges aérodynamiques entre la grotte et la surface ont comme résultat une corrélation *parabolique* entre les valeurs journalières de la température externe et celle souterraine (fig. 5). De même, l'analyse statistique des données thermométriques montre qu'une certaine valeur de la température souterraine peut correspondre à un intervalle de plusieurs degrés de la température externe et que cet intervalle augmente justement dans la plage des valeurs optimales pour la genèse de la glace. Lorsqu'on prend en considération les moyennes mensuelles, la corrélation devient pourtant linéaire, de sorte que l'estimation de la température externe à partir d'une valeur donnée de la température souterraine devient bien plus facile à ce niveau, et il va sans dire que la précision augmente proportionnellement à celui des moyennes des trois mois de l'hiver météorologique.

Le bref exposé que nous venons de faire ne relève que la *méthodologie* qu'on peut suivre pour arriver à une valorisation complète de l'information paléoclimatique comprise dans le dépôt de glace fossile de la Grotte de *Scărişoara*. La réalisation de cet objectif demande une augmentation et une diversification considérable des données dont nous disposons aujourd'hui et, afin d'arriver à des résultats significatifs, il est nécessaire de concevoir un programme de recherches systématiques et approfondies.

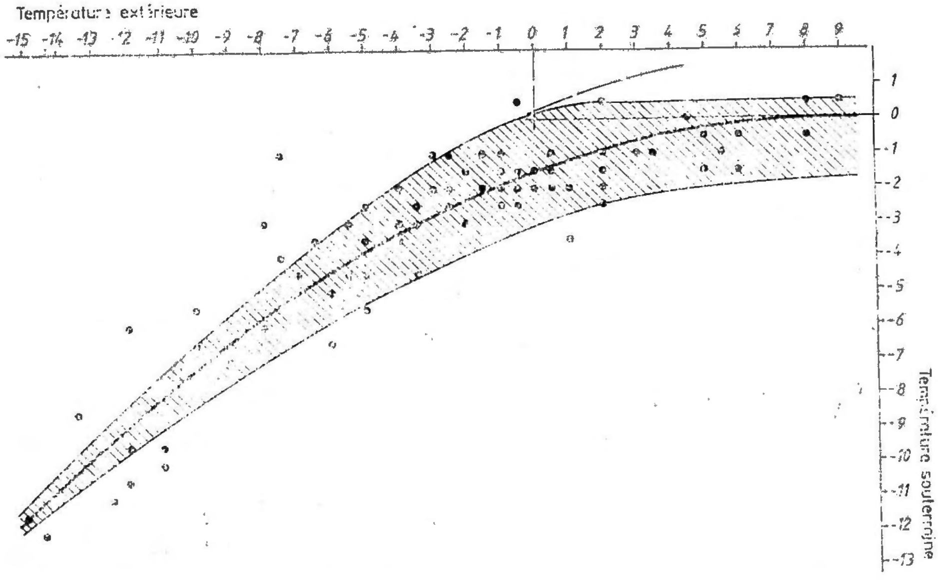

Fig. 5. Corrélation parabolique entre les température moyennes journalières mesurées à l'extérieur et dans la Grande Salle pendant l'intervalle décembre 1965 — avril 1966.

Il faut d'abord obtenir des séries complètes de mesures, échelonnées sur une longue période de temps, qui suivissent d'une part la dynamique des formations de glace et d'autre part les facteurs topoclimatiques souterrains et les paramètres météorologiques de l'extérieur, pour établir avec un degré de précission aussi grand que possible la relation quantitative qui traduit finalement l'influence du climat externe sur la genèse de la glace de caverne. Une attention particulière doit être à la thermométrie des substratums et spécialement du masif de glace, pour mettre en évidence les gradients de température et pour définir la fonction de transfert énergétique au niveau de la couche de contact entre l'air et la glace.

Il faut ensuite entreprnedre des analyses microstratigraphiques sur toute la hauteur du bloc de glace, en pratiquant des sondages en plusieurs endroits de celui-ci. Ces analyses doivent porter sur un tableau complet d'éléments morphométriques et structuraux des couches de glace et d'impuretés, comprenant l'épaisseur, le poids, les inclusions autogènes et hypergenes, les dépôt de pollen, le contenue en isotopes d'oxygène et d'hydrogène, etc. Ce n'est qu'en synthétisant toutes ces données qu'on peut obtenir une image fidèle des variations qui apparaissent le long du profil stratigraphique et des changements qui sont intervenus dans les conditions d'existence du dépôt souterrain de glace.

Il faut, enfin, réaliser un relevé topographique détaillé, à l'aide des ultra-sons, du plancher sur lequel s'appui le bloc de glace, pour vérifier en connaissance de cause les hypothèses concernant les phénomènes qui se déroulent à la base de celui-ci.

Le but majeur de toutes ces investigations est la mise en évidence des périodicités qui se sont manifestées, durant les trois derniers millénaires. dans l'évolution du macroclimat régional de la zone de *Scărișoara*. Une fois définie, cette périodicité pourra être mise en corrélation avec les résultats similaires obtenus par l'étude d'autres gisements comprenant des informations paléoclimatiques, notamment des tourbières, et par l'étude des anneaux des arbres aussi, en élargissant ainsi la zone de référence de la reconstitution climatique à une région qui pourra englober, si non tout le bassin de la Transylvanie, au moins l'unité géographique des Monts *Apuseni*.

Nous estimons que la connaissance de la périodicité qui caractérise les oscilations climatiques dans cet intervalle de 3000 ans constitue une base scientifique suffisante pour une prognose de long terme, dont l'extension pourra couvrir à un niveau satisfaisant de sûreté les 1000 ans suivants. Il va sans dire qu'une telle prognose ne peut se rapporter qu'aux grands traits de l'évolution future des paramètres climatiques, mais, même dans ces conditions, son importance pour l'optimisation de la stratégie socio-économique qui devra être adoptée est trop importante pour demander des arguments à son appui.

On ne peut pas terminer cette note sans attirer l'atention sur le caractère périssable de l'information paléoclimatique dont nous venons de souligner l'importance. En effet, l'échauffement général qui s'est manifesté durant les dernières décennies a eu comme résultat la fonte d'une grande quantité de glace, le niveau supérieur du dépôt souterrain s'abaissant d'environ 1,5 m àpartir de 1947. La tronçon du profil stratigraphique

qui correspond à la dernière période de développement du massif de glace est ansi perdu définitivement, ce que introduit une difficulté supplémentaire dans les essais de réconstitution paléoclimatique, car c'est justement ce tronçon qui aurait permis la corrélation la plus étroite entre les particularités microstratigraphiques et les variations météorologiques. Il est donc important que le programme complexe de recherches dont nous avons parlé ci-dessus débute le plus tôt possible.

Nous désirons adresser nos plus vifs remerciements au Conseil Départemental d'Alba, pour le concours qui a bien voulu nous accorder dans les études complexes effectuées jusqu'à présent dans la Grotte de *Scărişoara*.

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ASUPRA INFORMAŢIEI PALEOCLIMATICE CUPRINSĂ ÎN DEPOZITUL SUBTERAN DE GHEAŢĂ DIN PEŞTERA DE LA SCĂRIŞOARA (MUNŢII BIHORULUI) ŞI VALORIFICAREA SA PENTRU O PROGNOZĂ DE TERMEN LUNG

Rezumat

Sînt trecute în revistă principalele elemente care caracterizează din punct de vedere stratigrafic depozitul de gheaţă fosilă din peştera Gheţarul de la Scărişoara din Munţii Bihorului (judeţul Alba), cît şi încercările făcute pînă în prezent pentru a deduce variaţiunile climatului în timpul ultimilor 250 de ani, pe baza elementelor stratigrafice.

Se precizează etapele care vor trebui să fie parcurse în viitor în scopul obţinerii unei *chei de descifrare* mai exacte a informaţiei paleoclimatice cuprinsă în acest depozit, prezentîndu-se totodată datele culese pînă în prezent.

Se stabileşte programul de cercetări care va trebui să fie urmărit în vederea atingerii unei valorificări complete a acestei informaţii şi, implicit, a unei prognoze climatice de termen lung, care poat acoperi următorii 1000 de ani.

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TENDANCES DE LONG TERME DANS LA DYNAMIQUE DES FORMATIONS DE GLACE DE LA GROTTE DE SCĂRIŞOARA (MONTS DE BIHOR)

PAR

G. RACOVIŢĂ, M. ŞERBAN, I. VIEHMANN

L'analyse des observations occasionnelles et surtout des mesures mensuelles affectlées sur la dynamique des formations de glace qui se développent dans la Grotte de Scărişoara met en évidence des tendences linéaires de longue durée, qui se vérifient pour des périodes successivement plus grandes, allant jusqu'à l'échelle des six dernières décénies. Ces tendances sont négatives pour la face supérieure du bloc de glace et positives pour les formations stalagmitiques, en illustrant ainsi le phénomène de „contraste de phase" qui caractérise l'évolution des deux types morphologique sous lesquels apparaît la glace de caverne. Par ailleurs, on démontre l'existence d'une périodicité d'ordre supérieur par rapport à celle saisonnière qu ise manifeste d'une manière classique dans les variations auxquelles sont soumises les formations de glace. On conclut finalment que toutes ces particularités dynamiques peuvent être mises en corrélation avec les oscillations climatiques de l'extérieur.

1. INTRODUCTION

L'énorme bloc de glace qui se conserve dans la Grotte de Scărişoara a attiré depuis bien longtemps l'attention des chercheurs et, de ce fait, de nombreux travaux ont été consacrés à l'étude des formations de glace abritées par cette insolite cavité .Les premières observations qui nous fournissent des données morphométriques sur ces formations datent déjà du siècle passé (Schmidl, 1863), mais ce n'est qu'à partir de 1947 qu'on dispose de mesures plus ou moins systématiques concernant la dynamique de la glace de caverne. Il s'agit surtout des deux séries d'études détaillées, effectuées la première en 1963—1968 et la seconde en 1982—1985, dont le protocole a compris des mesures mensuelles sur la morphodynamique des formations de glace et sur les conditions topoclimatiques souterraines.

Les résultats obtenus à la suite de ces études ont déj à permis de tracer les traits majeurs de la variation saisonnière à laquelle sont soumises les formations de glace (Racoviţă et Viehmann, 1965, Racoviţă et Crăciun, 1970) ; il nous reste donc à essayer de mettre en évidence et

d'expliquer les tendances de long terme qui se manifestent dans ces variations et c'est justement ce que nous nous sommes proposé de réaliser dans le présent travail.

2. TECHNIQUES D'ETUDE

Les fluctuations de niveau de la face supérieure du bloc de glace, c'est-à-dire du plancher de la Grande Salle, ont été déterminées à l'aide d'une mire graduée en millimètres, enfoncée dans la glace dans la zone centrale de cette salle. Les lectures mensuelles qui ont été effectuées ne donnet, évidemment, que des résultats relatifs, se rapportant dans chacune des deux séries de mesures au niveau que la glace avait au début de celles-ci. Un repère marqué sur la paroi calcaire de la grotte en 1947 permet pourtant de traduite ces résultats en valeurs absolues, les données devenant ainsi parfaitement comparables entre elles. Notons de même que, au cours de l'étape de recherches 1982—1985, on a eu sous observation trois autres mires, placées en des endroits différents de la Grande Salle, et que les variations de niveau mises en évidence par celles-ci ont été généralement synchrones.

La dynamiques des formations stalagmitiques de glace a été étudiée sur chacun des deux principaux types sous lesquels apparaissent celles-ci et qui sont localisés en deux secteurs distincts de la grotte. Il s'agit, d'une part, des massifs stalagmitiques, concentrés dans la salle nommée l'„Eglise", et d'autre part des stalagmites plus ou moins isolées qui se développent au centre de la Grande Réserve, dans la zone „périglaciaire" de la cavité (Șerban, 1970). Afin d'éviter la dénaturation des données par suite des fluctuations que présente le fondament de glace de ces formations, leur hauteur a été mesurée à partir de repères métalliques fixes, enfoncés dans la glace. Lorsque la hauteur d'une certaine formation a été affectée par l'effondrement partiel de celle-ci, les mesures faites après cet incident ont été corrigées par interpolation, en prenant comme base les hauteurs des stalagmites à évolution normale. En chaque cas, trois ou quatre formations ont été mises sous observation, les données introduites ensuite dans les calculs statistiques représentant les hauteurs moyennes.

Les résultats obtenus durant les deux séries de mesures sont présentés dans le tableau 1.

3. TENDANCES MULTIANNUELLES DANS LA DYNAMIQUE DE LA GLACE

Outre les fluctuations saisonnières, dues au fait que la glace fond partiellement en été et se renouvelle pendant l'hiver, l'évolution de tous les trois types morphologiques de glace (bloc, massifs stalagmitiques et stalagmites) montre, au niveau de chaque série de mesures, une tendance générale de croissance ou de décroissance. Afin de quantifier ce phénomène et, par conséquent, de pouvoir comparer entre elles les tendances

Tableau 1

Variation de la hauteur des formations de glace de la Grotte de Scărioşara (valeurs absolues)

Années	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
					Plancher de glace de la Grande Salle							
1964					0,0	0,0	0,0	—3,0	—4,5	—7,5	—7,0	—6,0
1965	—4,5	—6,0	—4,5	—0,5	—0,5	0,0	0,0	—1,5	—3,0	—5,0	—5,0	—6,0
1966	—7,0	—5,0			—4,0	—5,5	—7,0	—8,5	—10,0	—11,5	—13,0	—13,5
1967	—13,5	—13,5	—13,0	—11,2	—11,2	—10,0	—11,0	—12,0	—13,0	—14,0	—16,0	—17,5
1968	—18,0	—18,0	—17,0	—14,5	—12,0							
⋮												
1982				0,0	7,7	14,6	12,0	10,1	8,6	7,1	6,6	6,6
1983	6,4	5,8	10,1	10,1	12,6	12,1	10,6	8,6	6,6	5,6	5,6	5,5
1984	5,3	4,7	4,6	7,2	7,5	8,1	7,6	5,1	4,1	3,1	2,1	2,0
1985	1,8	1,3	. .	2,1	7,4	11,6	11,9	11,6	10,3	9,1	9,1	
					Massifs stalagmitiques de l'„Eglise"							
1963					94,7	94,7	94,7	94,7	94,7	82,0	83,0	86,7
1964	90,3	89,0	90,0	92,0	91,7	91,7	90,7	89,0	88,0	81,7	78,0	81,7
1965	86,0	98,3	101,7	106,3	106,3	105,3	104,3	101,6	99,7	98,7	98,0	101,3
1966	105,3	106,7	107,0	106,0	104,3	103,7	103,3	101,3	100,0	98,3	97,0	96,3
1967	103,7	106,3	111,0	113,3	113,3	114,0	111,3	109,7	108,3	107,3	106,0	104,3
1968	105,7	111,3	119,7	121,3	122,3							
⋮												
1982				148,0	150,0	149,7	146,0	145,7	145,2	143,8	142,8	142,0
1983	144,0	149,0	155,3	155,3	155,3	155,3	153,5	151,0	149,5	148,0	146,7	146,3
1984	147,6	144,7	146,3	148,0	147,3	147,3	147,3	144,8	142,7	141,2	139,7	141,3
1985	146,5	153,3	155,3	158,0	161,0	161,3	161,3	160,0	159,7	158,3	161,0	
					Stalagmites de la Grande Réserve							
1963				128,3	141,7	138,3	131,3	130,3	129,0	126,0	117,3	121,7
1964	129,2	166,0	178,0	190,3	191,7	191,5	191,2	185,7	182,0	157,0	125,7	126,3
1965	129,0	166,7	196,7	211,3	210,0	209,7	207,0	204,3	202,0	193,0	181,0	195,0
1966	209,7	238,0	242,7	250,5	248,3	244,0	237,0	219,0	201,0	184,3	167,7	150,7
1967	150,3	205,3	231,7	238,7	236,7	234,3	231,7					
⋮												
1982				162,3	163,9	162,3	160,5	158,1	149,0	142,0	136,9	126,3
1983	130,8	157,1	179,5	179,5	179,0	171,3	167,3	163,3	156,8	151,0	142,6	150,3
1984	156,6	175,6	196,0	203,0	203,3	203,3	202,8	195,5	175,5	167,0	158,8	156,5
1985	159,8	194,3	234,3	254,0	264,0	253,5	252,8	257,5	253,5	248,8	246,0	

que manifestent les divers types morphologiques de glace, nous avons calculé pour chaque série de données la droite de régression, en employant pour cela la méthode des moindres carrés. Nous rappelons que cette droite est une fonction linéaire de la forme $y = ax + b$ et que le terme a de celle-ci a comme valeur numérique la tangente de l'angle que la droite fait avec l'abscisse ; il représente donc la mesure de la pente qui caractérise la droite de régression ou, en d'autres termes, de l'ampleur de la tendance de longue durée.

Pour le plancher de la Grande Salle (face supérieure du bloc de glace), l'équation de la droite de régression est

$$h = -0{,}3311\ n + 0{,}22 \qquad (1)$$

pour l'intervalle 1964—1968 (fig. 1 A), et

$$h = -0{,}0618\ n + 8{,}38 \qquad (2)$$

pour l'intervalle 1982—1985 (fig. 2 A), *n* étant le numéro d'ordre des mois.

Le niveau du plancher de glace présente donc une tendance négative, de décroissance, fait que se trouve en concordance avec la constatation générale que, à partir de 1947, ce niveau s'est abaissé progressivement. Mais les données plus détaillées dont nous disposons maintenant nous permettent d'affirmer que, à longue échéance, la décroissance n'est pas uniforme, le phénomène étant bien plus accusé durant le premier intervalle de temps, pour lequel le coefficient *a* a une valeur plus grande.

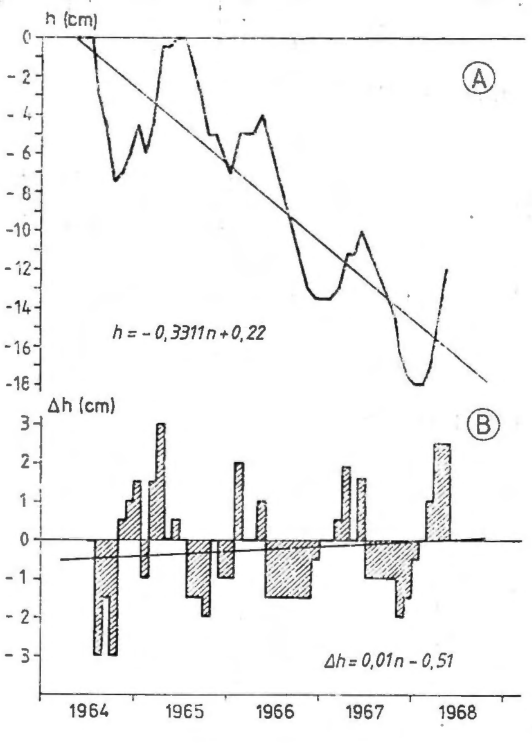


Fig. 1. Variations de niveau du plancher de glace de la Grande Salle dans l'intervalle 1964—1968. A = valeurs absolues ; B = valeurs relatives.

Pour les massifs stalagmitiques de l'„Eglise", les droites de régression ont comme équations dans les deux séries de mesures (fig. 3 A et 4 A) :

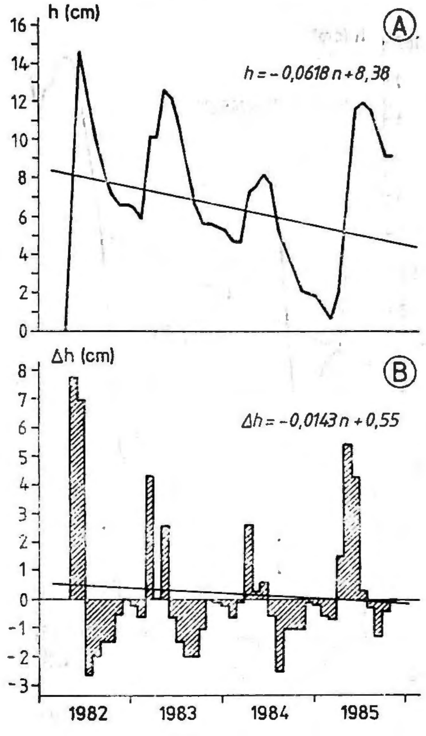
$$h = 0{,}4572\ n + 85{,}93 \qquad (3)$$

et, respectivement,

$$h = 0{,}2047\ n + 145{,}20 \qquad (4)$$

A l'encontre du plancher de glace, la tendance générale des massifs stalagmitiques et par conséquent *positive*, la hauteur de ces formations

Fig. 2. Variations de niveau du plancher de glace de la Grande Salle dans l'intervalle 1982—1985.



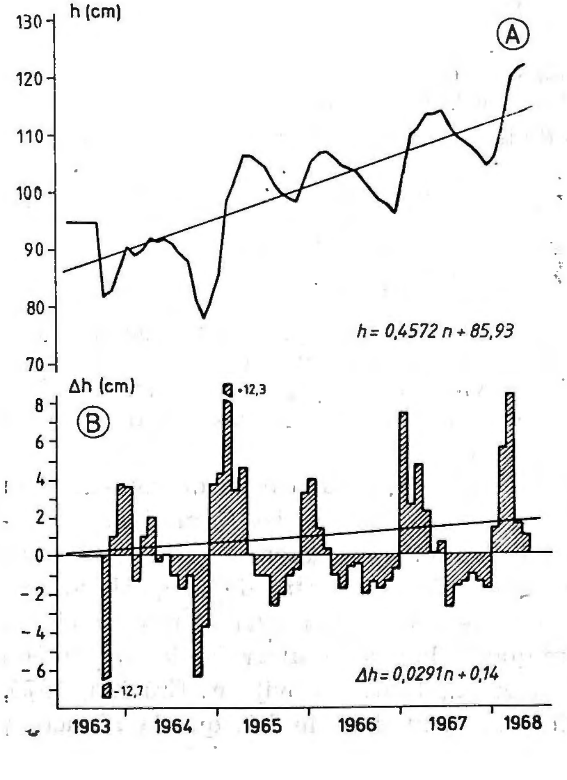


Fig. 3. Variations de la hauteur des massif stalagmitiques de glace de l'„Eglise" dans l'intervalle 1963—1968.

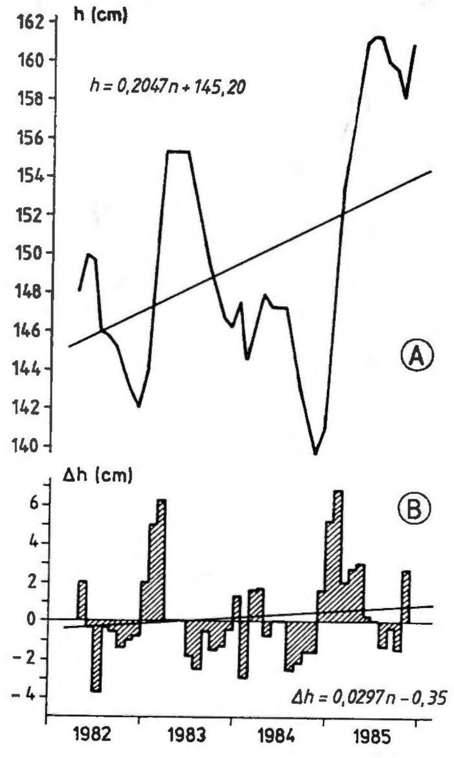


Fig. 4. Variations de la hauteur des massif stalagmitiques de glace de l'„Eglise" dans l'intervale 1982—1985.

augmentant progressivement dans le temps, et c'est toujours dans le premier intervalle que cette tendance est plus accentuée.

Enfin, pour les stalagmites de la Grande Réserve, les équations correspondantes sont (fig. 5 A et 6 A) :

$$h = 1,9373\ n + 135,37 \quad (5)$$

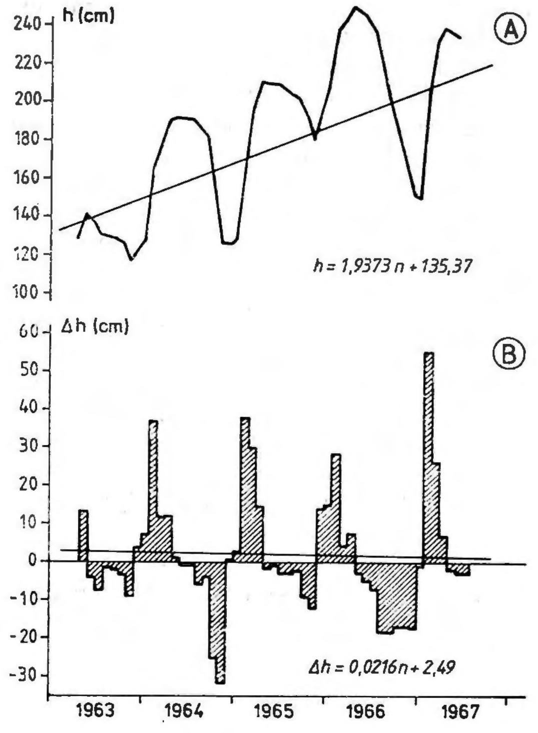
et

$$h = 2,3445\ n + 131,12 \quad (6)$$

ce qui montre une tendance de croissance encore plus forte que celle des massifs stalagmitiques. Cette fois-ci, la valeur numérique du coefficient *a* est plus grande dans le second intervalle de temps, mais on doit préciser que les stalagmites prises en considération dans les deux séries de mesures n'ont pas été rigoureusement les mêmes.

En résumant, on constate donc qu'à la tendance de décroissance du bloc de glace s'oppose une tendance de croissance des formations stalagmitiques et que cette dernière est d'autant plus accentuée que les formations en question sont plus éloignées de l'épicentre de la glaciation de caverne. On arrive ainsi à donner une expression quantitative précise à ce qu'on a appelé dans la dynamique de la glace souterraine le phénomène de „contraste de phase" (Şerban et al., 1967, Racoviță et Crăciun, 1970, Racoviță, 1972), qui réside principalement dans le fait que la réduction

Fig. 5. Variations de la hauteur des stalagmites de glace de la Grande Réserve dans l'intervalle 1963—1967.



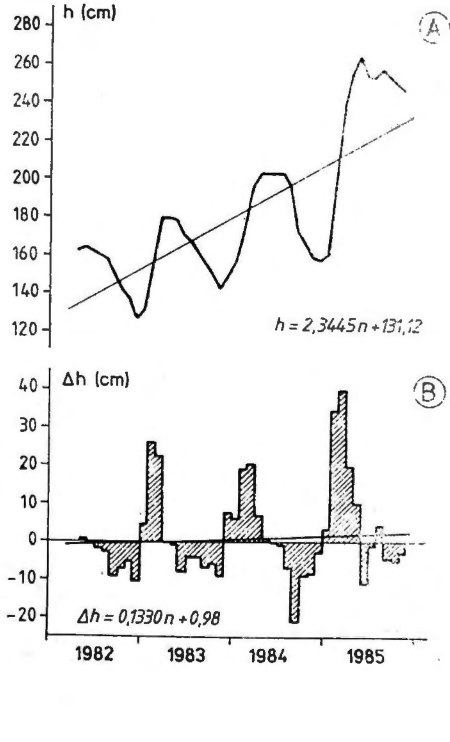


Fig. 6. Variations de la hauteur des stalagmites de glace de la Grande Réserve dans l'intervalle 1982—1985.

volumétrique du bloc de glace détermine l'augmentation de l'espace libre dans lequel peut s'accumuler l'air froid hivernal et crée ainsi des conditions plus favorables au développement des formations stalagmitiques. Mais les détails de ce phénomène restent encore assez mal connus.

En premier lieu, il ne faut nullement comprendre de ce qu'on vient de dire que les formations stalagmitiques prendent naissance à une température plus basse que celle exigée par la conservation du bloc de glace. On sait, au contraire, que la distribution spatiale des types morphologiques de glace suit de près le gradient thermique souterrain (Șerban, 1970, Racoviță, 1984), les dépôts de glace étant d'autant plus massifs que la température est plus faible. Les mesures thermométriques comprises dans le programme de recherches glaciologiques ne montrent d'ailleurs aucune particularité qui puisse fournir une explication satisfaisante au phénomène de „contraste de phase". Dans la plupart des cas, la droite de régression calculée pour les variations de température est pratiquement horizontale (fig. 7 et 8) ,la valeur numérique du coefficient a, quoique négative, étant extrêmement faible, et ce n'est que dans la Grande Salle que, durant l'intervalle 1963—1968, on constate une tendance significative dans l'évolution multiannuelle de la température de l'air (fig. 7 A) ; mais celle-ci este négative, donc exactement inverse à celle qui aurait pu déterminer l'abaissement du plancher de glace.

Si les données thermométriques ne nous permettent pas d'élucider le problème, des informations utiles peuvent un échange être obtenues de l'analyse des variations relatives de la hauteur des formations de glace,

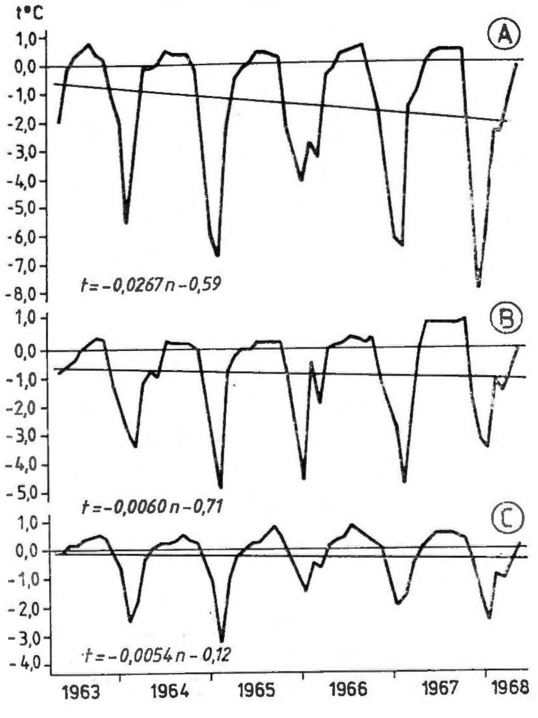
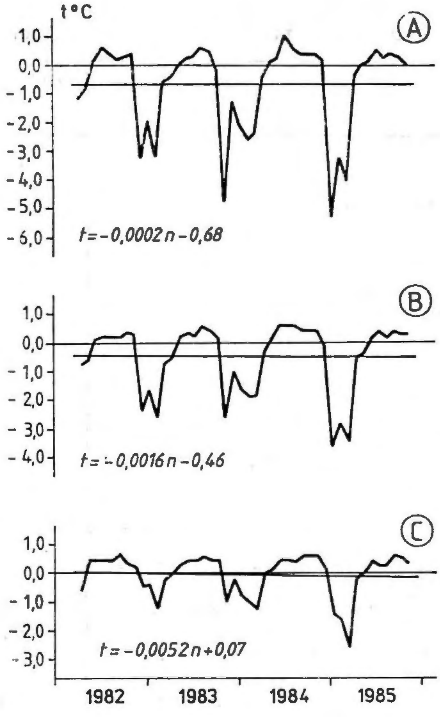


Fig. 7. Variations de la température de l'air dans la Grande Salle (A), l'„Eglise" (B) et la Grande Réserve (C) dans l'intervalle 1963—1968.

Fig. 8. Variation de la température de l'air dans la Grande Salle (*A*), l'„Eglise" (B) et la Grande Réserve (C) dans l'intervalle 1982—1985.



c'est-à-dire des quantités de glace qui se déposent ou fondent menseullement (fig. 1 B — 6 B). Ainsi, la forte tendance d'abaissement du bloc de glace qui se manifeste dans l'intervalle 1964—1968 se trouve en évidente concordance avec le fait que la valeur moyenne des décroissements [1] (1,2 cm) est supérieure à celle des acroissements (1,0 cm) ; en même temps, le nombre total des mois durant lesquels on a pertes de glace (21) est plus grand que celui des mois avec dépôts de glace (15) (tab. 2). Dans l'intervalle 1982—1985, ces relations deviennent pourtant moins claires car, si le rapport entre le nombre de mois dans chacune des deux phases conserve son sens (27 mois avec pertes de glace pour 10 mois seulement avec dépôts de glace), la valeur moyenne de décroissements (0,9 cm) est maintenant inférieure à celle des acroissements (2,2 cm). Dans ces circonstances — qui ne sont pas dépourvues de signification pour le fait que la tednance d'abaissement du plancher de glace est bien plus faible —, le paramètre avec lequel cette tendance peut être mise en corrélation reste le rapport sousunitaire d'entre la somme des acroissements et la some des décroissements (21,6 cm/24,3 cm = 0,89).

[1] Pour aboutir à des résultats aussi significatifs que possible, ce genre de valeurs ont été calculées non pas pour toute la série de données qui y correspondent, mais seulement pour un nombre entier de cycles annuels.

Tableau 2

Principaux paramètres de la dynamique des formations de glace

Paramètres	Plancher de glace	Massifs stalagmitiques	Stalagmites
Intervalle 1963—1968			
Coefficient *a* de la droite de régression	—0,3311	0,4572	1,9373
Valeur moyenne des acroissements (cm)	0,97	3,32	16,71
Valeur moyenne des décroissements (cm)	1,21	1,52	7,89
Nombre de mois avec dépôt de glace	15	20	19
Nombre de mois avec partes de glace	21	29	28
Somme des acroissements (cm)	14,5	66,3	317,5
Somme des décroissements (cm)	25,5	44,0	220,9
Rapport	0,57	1,51	1,44
Intervalle 1982—1985			
Coefficient *a* de la droite de régression	—0,0618	0,2047	2,3445
Valeur moyenne des acroissements (cm)	2,16	3,04	15,81
Valeur moyenne des décroissements (cm)	0,90	1,26	6,01
Nombre de mois avec dépôts de glace	10	13	14
Nombre de mois avec pertes de glace	27	24	20
Somme des acroissements (cm)	21,6	39,5	221,4
Somme des décroissements (cm)	24,3	30,2	120,1
Rapport	0,89	1,31	1,84

Cette situation se conserve en ce qui concerne tant les massifs stalagmitiques de l'„Eglise" que les stalagmites de la Grande Réserve, dans le sens que les valeurs moyennes des acroissemetns sont supérieures à celles des décroissements, tandis que le nombre des mois avec dépôts de glace est inférieur à celui des mois avec pertes de glace (tab. 2). En échange, le rapport d'entre la somme des acroissements et celle des décroissements est cette fois-ci supraunitaire dans tous les cas et, en plus, sa valeur est d'autant plus élevée que le coefficient *a* de la droite de régression est lui aussi plus grand. Par conséquent, la tendance d'augmentation des formations stalagmitiques de glace est visiblement due au fait que la phase hivernale de croissance, quoique plus courte, a dans leur dynamique un poids bien plus grand que celui de la phase estivale de décroissance.

Les particularités qui différencient à ce point de vue les types morphologiques de formations sont mises en évidence d'une manière particulièrement illustrative par les moyennes menseulles des acroissements et des décroissements de la glace (fig. 9). Ces moyennes montrent clairement que la proportionnalité qui existe entre les dépôts et les

pertes de glace dans le cas du plancher de la Grande Salle est fortement déséquilibrée dans le cas des stalagmites de la Grande Réserve, où la grandeur des acroissements arrive à dépasser environ 3 fois celle de décroissements. Il apparaît de même que, si la phase de croissance ne dure en moyenne que quatre moi sdans le cas du bloc de glace (de mars jusqu'en juin), elle augmente à six mois dans celui des massifs stalagmitiques (de décembre jusqu'en mai). Au phénomène de „contraste de phase" dont nous avons parlé au sujet de l'antagonisme existant entre la tendance évolutive du bloc de glace et celle des formations stalagmitiques correspond donc un décalage significatif de la phase de croissance : la comparaison entre la Grande Salle et l'„Eglise" montre un retardement de trois mois pour le début de cette phase et une prolongation d'un mois de sa durée. Il s'ensuit que dans la dynamique saisonnière du bloc de glace apparaît une période nullement négligeable (de novembre jusqu'en février), durant laquelle la glace ne se forme pas quoique la température de l'air est négative (fig. 9 A). Ceci nous amène à définir un autre élément majeur qui différencie l'évolution du bloc de glace de celle des formations stalagmitiques. Il s'agit du fait que, tant pour les massifs stalagmitiques que pour les stalagmites, on peut établir une corrélation linéaire, significative à un seuil de $5^0/_0$, entre les acroissements et les décroissements moyens mensuels d'une part et la température de l'air d'autre part, tandis qu'une telle corrélation devient tout à fait impossible dans le cas du bloc de glace (fig. 10).

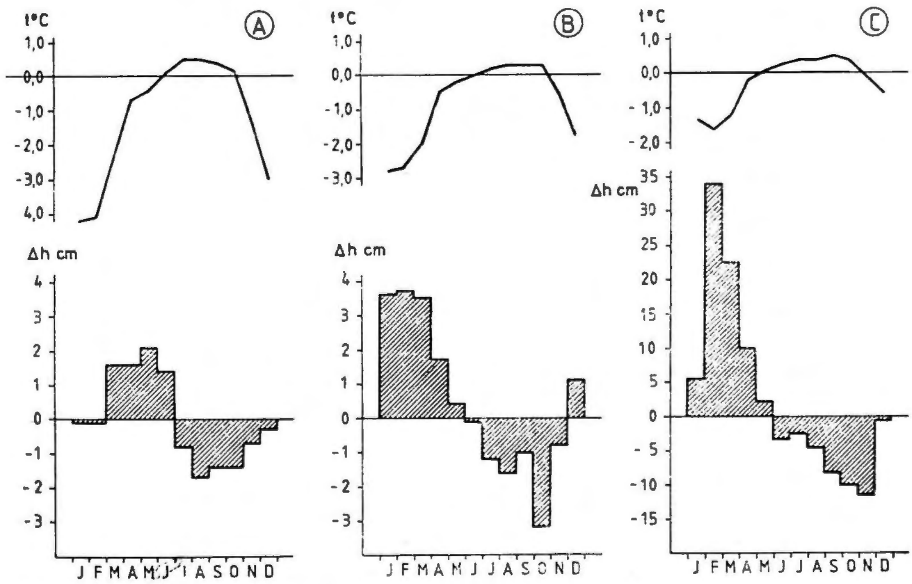


Fig. 9. Valeurs moyennes mensuelles de la température de l'air (en haut) et des acroissements et décroissements des formations de glace (en bas) dans la Grande Salle (A), l'„Eglise" (B) et la Grande Réserve (C).

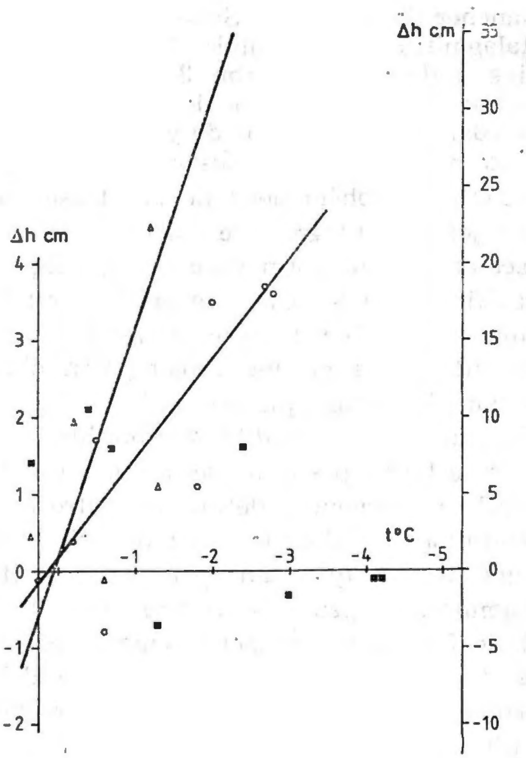


Fig. 10. Corrélation entre la température de l'air et les dépôts moyens de glace pour la Grande Salle (carrées noirs), l'„Eglise" (cercles) et la Grande Réserve (triangles).

Conformément aux observations faites dans la grotte, ce phénomène est dû en principal à un déficit d'eau d'alimentation. En effet, la formation d'une nouvelle couche de glace sur le plancher de la Grande Salle demande une quantité d'eau beaucoup plus grande que celle nécessaire pour le développement des formations stalagmitique. Or, dans les conditions climatiques actuelles, cette eau ne devient habituellement disponible qu'au printemps, lors du début de la fonte des neiges. A la fin de l'automne, quand l'abaissement de la température externe amorce la ventilation bidirectionnelle souterraine (Racoviță, 1967), l'air froid et sec qui pénètre dans la cavité détermine tout d'abord non pas le gel de la pellicule d'eau formée au cours de l'été par fonte de la glace et par percolation, mais l'évaporation de celle-ci, tandis que l'hiver, le même apport d'air arrive à provoquer des pertes de glace par volatilisation (Racoviță, 1967, 1972). On peut donc en déduire que, pour qu'il puisse avoir augmentation de niveau de glace dans la Grande Salle, il est necessaire que le surrefroidissement hivernal des substratums soit plus accentué, car c'est surtout ce phénomène qui asure la réserve de frigories indispensable à la genèse de la glace souterraine (Şerban et al., 1948). Mais ceci suppose un changement dans les conditions même du climat externe.

4. VARIATIONS DES FORMATIONS DE GLACE DANS L'INTERVALLE 1963—1985

Les informations dont nous diposons à présent sur la dynamique multiannuelle des formations de glace de al Grotte de Scărişoara, et que nous avons brièvement passées en revue dans le chapitre précédent, suggèrent l'existence des tendances de long terme couvrant des intervalles de temps encore plus grands que ceux que nous avons pris jusqu'ici en considération. Ces tendances peuvent être mises en évidence en raccordant entre elles les deux séries de mesures avec lesquelles nous avons opéré.

Pour les massifs stalagmitiques de l'„Eglise“, un tel raccordement ne soulève pas de problèmes, car les mesures ont porté sur les mêmes formations et les données concernant leur hauteur sont directement comparables. Le résultat est que, prises ensemble, ces données s'ordonnent le long d'une droite ascendante (fig. 11), dont l'équation numérique est

$$h = 0{,}2275\ n + 93{,}0 \qquad (7)$$

La tendance de croissance des massifs stalagmitiques se manifeste donc constamment durant un intervalle de plus de 20 ans.

Dans le cas du phancher de glace de la Grande Salle, le raccordement des deux séries de mesures impose — tel que nous l'avons précisé — de donner une valeur absolue au niveau de référence à partir duquel ont été établies les variations enregistrées pendant l'intervalle 1982—1985. Les mesures se rapportant au repère marqué en 1947 sur la paroi calcaire de la salle ont permis de fixer ce niveau à —65 cm. Compte tenu de cette correction, les hauteurs mensuelles du plancher de glace s'ordonnet toujours d'après une droite, mais qui est maintenant descendante (fig. 11), ayant comme équation

$$h = -\,0{,}2297\ n - 0{,}94 \qquad (8)$$

L'égalité à peu près parfaite qui apparaît entre les grandeurs absolues des coefficients a des équations (7) et (8) nous permet d'en tirer une première conclusion : *le taux d'abaissement du plancher de glace est égal au taux d'augmentation des massifs stalagmitiques.* Le complexe d'éléments qui concurent à la définition du phénomène de „contraste de phase“ s'enrichit ainsi d'un nouvel aspect quantitatif.

L'analyse des paramètres qui définissent la dynamique des formations de glace dans tout l'intervalle de temps compris entre les deux séries de mesures relève également certains éléments particulièrement intéressants concernant la périodicité des variations de hauteur auxquelles sont soumises ces formations. Il s'agit principalement des différences qui apparaissent entre la pente de la droite de régression calculée pour tout l'intervalle de 23 ans et celle des droites déterminées séparément pour chaque série de mesures. C'est ainsi que, si on se rapporte au niveau du plancher de glace, on constate que cette pente est plus acentuée dans la série 1964—1968, le coefficient a de l'équation (1) étant plus grand que celui de l'équation (8), mais qu'elle devient plus faible dans la série 1982—1985 l'équation (2) ayant un coefficient a plus petit.

Le raccordement entre les deux droites partielles de régression nous amène à tracer une ligne infléchie, dont la convexité est orientée vers le

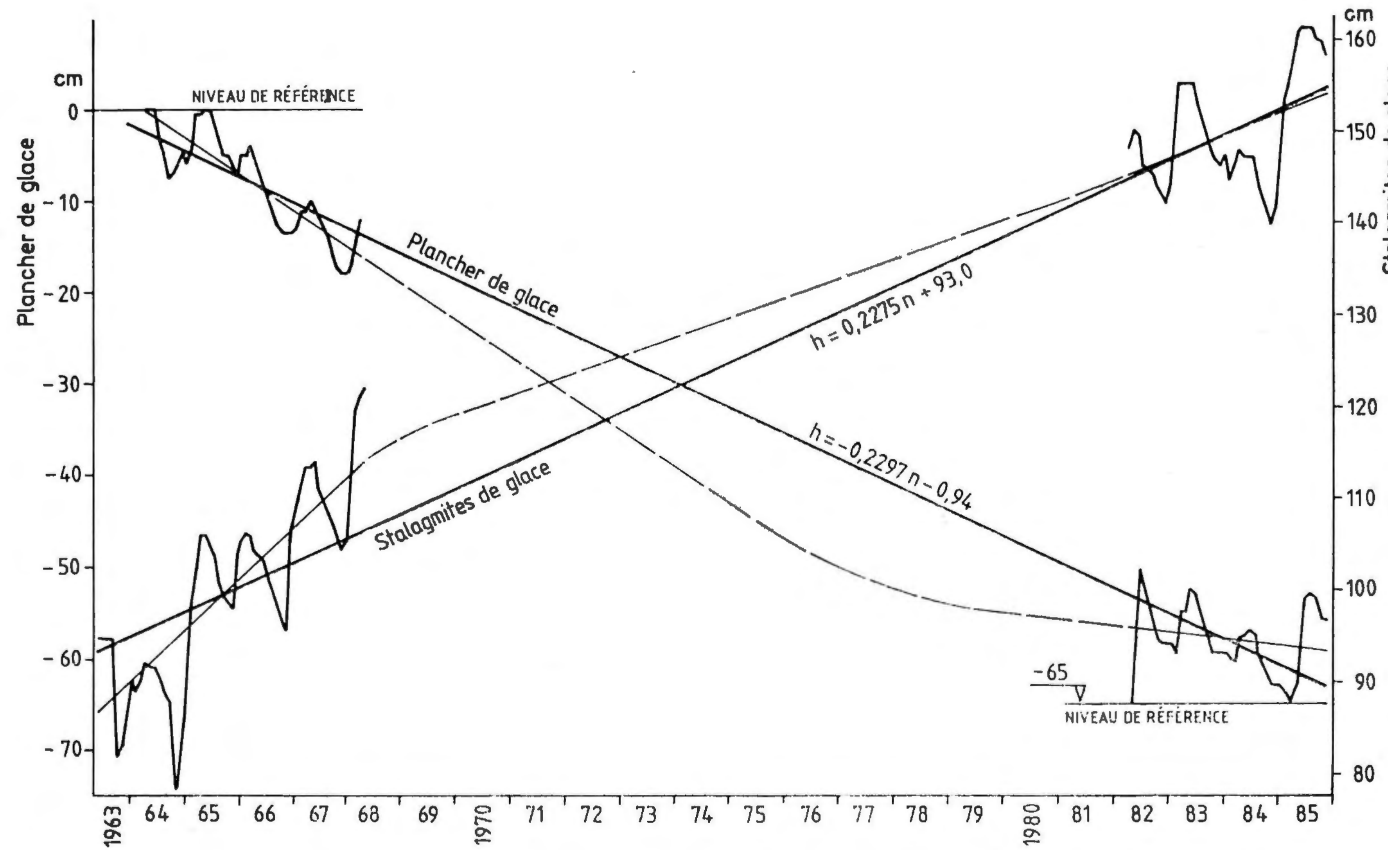


Fig. 11. Raccordement des droites partielles de régression calculées pour les variations du plancher de glace et des massifs stalagmitiques dans les intervalles 1963—1968 et 1982—1985.

bas et dont la zone d'inflexion se place vers 1977 (fig. 11). Pour les massifs stalagmitiques de l'„Eglise", la situation est tout à fait analogue mais inverse, la ligne obtenue par raccordement entre les droites partielles de régression ayant la convexité orientée vers le haut et la zone d'inflexion placée vers 1968—1969.

Les résultats auxquels ont est arrivé à la suite de ces raccordements montrent clairement que, outre l'évidente périodicité saisonnière qui caractérise la dynamique des formations de glace, celle-ci comporte aussi *une périodicité d'ordre supérieur, qui paraît correspondre aux cycles météorologiques élémentaires de 11 années*. Un phénomène analogue a été invoqué par Şerban et al. (1967) pour expliquer la similarité d'entre le „landschaft" que l'„Eglise" présentait en 1857 (Schmidl, 1863) et en 1923 (Racovitza, 1927), en opposition avec le plus grand développement des massifs stalagmitiques de glace observé en 1947 (Şerban et al., 1948), car entre 1857 et 1923 il y a 6 cycles météorologiques de 11années ou 2 cycles de 33 années. Notons, de même, que la périodicité de second ordre se manifeste d'une manière différente pour le plancher de glace et pour les massifs stalagmitiques, la comparaison entre les deux types de formations comprenant tant une inversion de sens qu'un décalage dans le temps. Ce sont là des éléments qui peuvent visiblement être compris dans le phénomène général de „contraste de phase" que nous avons déjà invoqué à plusieurs reprises. Et il va sans dire que ces mêmes éléments mettent en évidence le caractère extrêmement complexe qu'a l'information paléoclimatique inclue dans la structure stratigraphique du bloc de glace abrité par la Grotte de Scărişoara (Şerban et Racoviță, 1986), ainsi que la nécessité plus que justifiée des recherches détaillées poursuivies à longue échéance dans cette cavité.

5. VARIATIONS DU PLANCHER DE GLACE DANS L'INTERVALE 1923—1985

En dehors des données obtenues à la suite des mesures mensuelles que nous avons effectué en 1963—1968 et 1982—1985, plusieurs autres observations entreprises dans la Grotte de Scărişoara nous fournissent des renseignements concernant l'évolution de la face supérieure du bloc de glace à partir de la deuxième décénie de notre siècle.

Dans la description que Racovitza (1927) fait sur la grotte après ses visites de 1921—1923, celui-ci parle d'un seuil de 2 m de hauteur qui apparaissait dans le plancher de glace du côté nord-ouest de la Grande Salle (c'est-à-dire vers l'„Eglise") et qui séparait ce qu'il a appelé la Galerie et qu'ensuite on a nommé la Petite Salle ; il précise, de même, que le ressaut qui se trouve à l'entrée de l'„Eglise" mesurait environ 5 m. En 1947, Şerban et al. (1948) trouvent le seuil de la Petite Salle diminué à 0,5 m, mais mesurent une différence de niveau de 6 m entre le plancher de celle-ci et celui de l'„Eglise". En 1951, quand Balogh et Ujvary ont réalisé le premier plan de la grotte relevé à l'aide du théodolite, le seuil de glace était complètement effacé, tandis que la hauteur du ressaut de l'„Eglise" avait augmenter à 7,72 m ; cette dernière passe ensuite à

7,17 m en 1965 (Rusu et al., 1970) et à 7,98 m en 1985, quand les études faites en vue de l'aménagement touristique de la cavtié ont nécessité un nouveau relevé topographique.

En prenant comme point de départ les données de 1947, car c'est à partir de ce moment que nous savons avec certitude que le plancher de la Grande Salle baisse de niveau, et en tenant compte des mesures faites par rapport au repère marqué sur la paroi de la salle, on peut reconstituer les oscillations de la face supérieure du bloc de glace conformément au diagramme de la fig. 12. Ce diagramme montre que l'abaissement progressif du plancher de la Grande Salle suit une fonction linéaire, pour laquelle le calcul donne comme équation numérique

$$h = -0{,}3275\ n - 6{,}64 \qquad (9)$$

dont le coefficient *a*, ayant une valeur plus grande que celle de l'équation (8), indique un taux d'abaissement supérieur à celui qui correspond à l'intervalle 1963—1985. Cette différence, due probablement aux influences de variations saisonnières, doit être pourtant acceptée, car le coefficient de corrélation qui dérive de l'équation (9) est significatif à un seuil de 1% (r = 0,99). Compte tenu de ceci, on peut essayer d'extrapoler la fonction linéaire jusqu'en 1923, on arrivant ainsi, par rapport à 1947, à une différence de niveau positive de 0,9 m. Ce résultat est non seulement plausible, mais représente aussi la seule explication rationnelle pour le fait que Racovitza (1927) n'a vu aucune ouverture vers la partie nord de la cavité, c'est-à-dire vers la Petite Réserve d'aujourd'hui, car la glace devrait obturer à l'époque toute voie d'accès vers cette salle.

En ce qui concerne le niveau du plancher de la Petite Salle, nous constatons sur le même diagramme que celui-ci a augmenté à son tuor

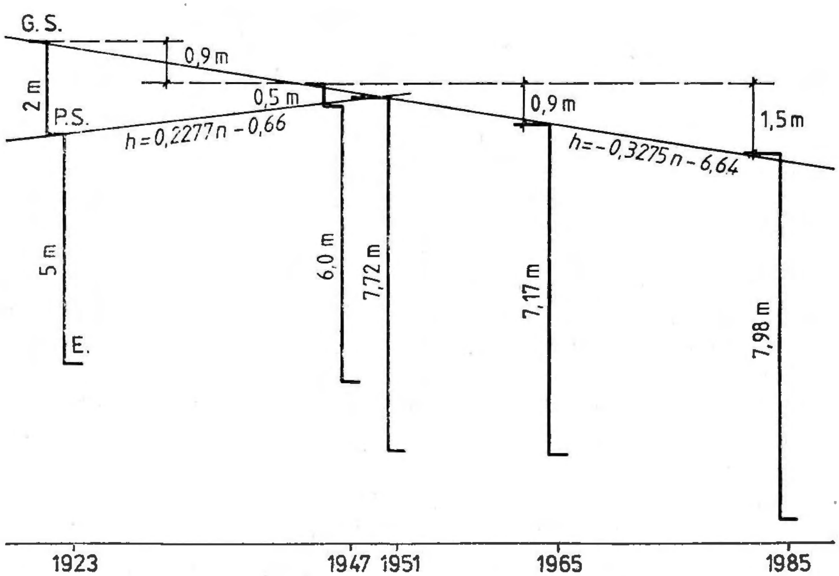


Fig. 12. Diagramme des variations de niveau de la face supérieure du bloc de glace durant l'intervalle 1923—1985 dans la Grande Salle (G.S.), la Petite Salle (P.S.) et l'„Eglise" (E.).

d'après une fonction linéaire, dont l'équation pour l'intervalle 1923—1951 est

$$h = 0{,}2277\ n - 0{,}66 \qquad (10)$$

c'est-à-dire pratiquement la même — au point de vue des valeurs absolues — que l'équation (8) calculée pour l'abaissement du plancher de la Grande Salle durant la période 1964—1985. Comme dans la comparaison avec les massifs stalagmitiques de l'„Eglise" ,on arrive donc à une égalité qui, d'une part, renforce la réalité du phénomène de „contraste de phase", mais qui, d'autre part, démontre que ce phénomène concerne aussi les différents secteurs de la face supérieure du bloc de glace. L'hypothèse conformément à laquelle ces secteurs n'ont pas eu la même évolution à longue échéance (Şerban et al., 1967) est ainsi entièrement vérifiée.

6. CORRELATION AVEC LES OSCILLATIONS CLIMATIQUES

Afin de pouvoir arriver à une interprétation complète des tendances de longue durée qui se manifestent dans l'évolution des formations de glace, il est évidemment nécessaire de connaître le contexte climatique dans lequel s'est déroulée cette évolution. Etant donné que — tel qu'on le sait — la météorologie externe influence la dynamique des formations de glace surtout pendant la phase hivernale (Racoviţă et Crăciun, 1970), nous avons défini ce contexte à l'aide du coefficient de température de Easton (1928). L'espace ne nous permettant pas d'entrer dans les détails du problème, nous ne bornons à rappeler qu'il s'agit d'un paramètre qui caractérise d'une manière synthétique les hivers et dont l'echelle de variation est comprise entre 0 et 100, un hiver normal correspondant à un coefficient de température égal à 50.

Pour atteindre le but que nous nous sommes proposé, nous avons calculé le coefficient de température à partir des températures moyennes des trois mois météorologiques d'hiver (décembre, janvier et février) enregistrées à la station de Cluj entre 1852 et 1984. Le choix de cette station est justifié par le fait que, parmi celle squi disposent d'enregistrements en série continue couvrant une période suffisamment longue, celle-ci est la plus proche de la Grotte de Scărişoara. La transcription des températures moyennes en valeurs du coefficient de température a été faite d'après la méthod préconisée par Racoviţă (1972). Les oscillations climatiques ont été mises en évidence en déterminant à l'aide des moyennes mobiles les tendances qui apparaissent dan les variations annulles du coefficient de température.

Les résultats obtenus (fig. 13) montrent que l'intervalle 1923—1984 a été généralement chaud. Il ne comprend que 4 hivers très froids (ceux de 1932, 1954, 1963 et 1964), tandis que les hivers doux sont visiblement plus nombreux. En outre, les moyennes mobiles mettent en évidence trois périodes d'échauffement plus accentué, dont le maximum se place vers 1915, 1956 et, respectivement, 1975 et qui n'ont de réplique que dans la période froide centrée autour de 1893, donc antérieure à l'intervalle qui nous intéresse. Notons, enfin, que les faibles tendances négatives que

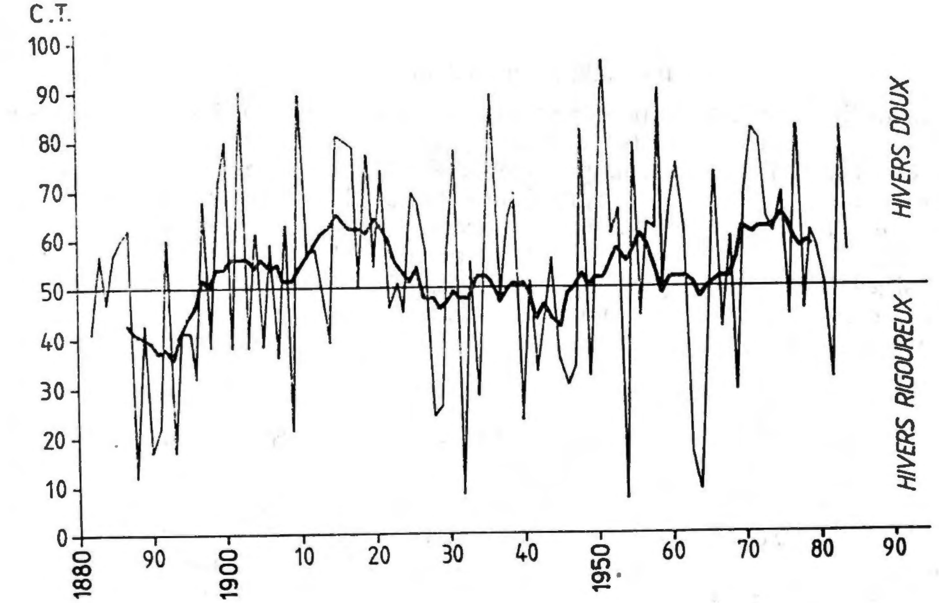


Fig. 13. Valeurs du coefficient de température des hivers dans l'intervalle 1852—1984 (trait mince) et oscillations majeures de ce coefficient déduites des moyennes mobiles (trait gras).

manifestent les températures souterraines mesurées en 1963—1968 et 1982—1985 correspondent toutes à des phases de décroissance des valeurs du coefficient de température.

En conséquence, l'abaissement progressif de niveau que le plancher de glace de la Grande Salle a présenté depuis 1923 se trouve en parfaite concordance avec le fait que, durant tout cet intervalle, le climat a été plutôt doux. A proprement parler, cette constatation n'est pas nouvelle, car on avait déjà démontré que l'actuel contexte climatique n'est pas suffisamment froid pour assurer une augmentation volumétrique du bloc de glace (Racoviță, 1972). Mais ce que nous intéresse maintenant en particulier c'est la compatibilité qui apparaît entre le caractère linéaire que nous avons accepté pour l'abaissement du plancher de glace le long de cet intervalle (fig. 12) et l'absence de tcute oscillation négative maejure dans la variation du coefficient de température. D'autre part, la périodicité d'ordre supérieur que nous avons définie dans les fluctuations de formations de glace pourrait être éventuellement liée aux trois périodes d'échauffement mentionnées ci-dessus, et auxquelles on peut ajouter celle — il est vrai, bien plus atténuée — qu'on peut déceler vers 1935, car celles-ci sont séparées par des intervalles d'environ 20 ans, donc égaux comme ordre de grandeur à deux cycles météorologiques élémentaires.

Ainsi, quoique toutes ces relations devront être normalement par des mesures faites en série continue durant au moins 22 ans, c'est-à-dire au moins deux cycles météorologiques complets, on peut affirmer en somme que, si la dynamique des formations de glace qui se développent dans la

Grotte de Scărişoara est particulièrement compliquée, c'est justement à cause de la fidélité avec laquelle cette dynamique reproduit l'ensemble du contexte climatique de l'extérieur. Une telle conclusion est de nature à augmenter d'une façon très concrète l'importance qui a été attribuée à l'information paléoclimatique comprise dans le massif souterrain de glace, mais de mettre aussi en lumière la compléxité du programme de recherches qu'on doit suivre afin d'arriver à un déchiffrement intégral de cette information.

7. CONCLUSIONS

Les données glaciologiques mensuelles dont nous disposons aujourd'hui — quoique fragmentaires — permettent de quantifier les tendances antagonistes de logn terme qui caractérisent d'une part le bloc de glace et d'autre part les formations stalagmitiques, en démonstrant que ces deux types morphologiques de glace ont un taux égal de variation dans le temps. Pour l'intervalle 1963—1985, la grandeur de ce taux est de 2,8 cm/an, soit 4,5% de la différence totale de hauteur. Ce résultat représente une expression quantitative précise du phéonmène de „contraste de phase", qui réside principalement dans le fait que la réduction volumétrique du bloc de glace, due au caractère doux que les hivers ont eu pendant les six dernières décénies, détermine l'augmentation de l'espace libre dans lequel peut s'accumuler l'air froid hivernal, en créant ainsi des conditions plus favorables pour le développement des formations stalagmitiques.

Le raccordement des droites de régression calculées pour les variations que les formations de glace ont présenté dans chacun des deux intervalles de temps pris en considération (1963—1968 et 1982—1985) relève la fait que, en dehors de la périodicité saisonnière, la dynamique de ces formations comporte aussi une périodicité d'ordre supérieur, qui paraît correspondre aux cycles météorologiques élémentaires de 11 années.

Il s'ensuit que la dynamique des formations de glace est le résultat des interactions complexes qui s'établissent non seulement entre les facteurs météorologiques de l'extérieur et la topographie particulière de la grotte, mais aussi entre ces facteurs et la géométrie variable des espaces libres souterrains.

L'analyse comparée des données glaciologiques et thermométriques montre que la régénération du bloc de glace se fait presque exclusivement sur le compte des eaux de fonte du printemps, qui gellent en fonction des paramètres du surrefroidissement hivernal des substratums, et ce sont justement ces paramètres qui restent à être déterminés par les futures études.

La connaissance aussi exacte que possible du déterminisme de la dynamique des formations de glace présente un double intérêt : d'une part, pour le déchiffrement de l'information paléoclimatique comprise

dans la stratigraphie du bloc de glace, et d'autre part, pour le contrôle du bilan thermique labile de la cavité, en vue de la conservation intégrale de la Grotte de Scărişoara dans les conditions de son futur aménagement touristique.

En conséquence, nous considérons que la nécessité des recherches détaillées poursuivies à longue échéance est pleinement justifiée.

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TENDINȚE DE TERMEN LUNG ÎN DINAMICA FARMAŢIUNILOR DE GHEAŢĂ DIN PEŞTERA GHEŢARUL DE LA SCĂRIŞOARA

Rezumat

Datele glaciologice acumulate în urma a două etape de cercetări detaliate întreprinse în Gheţarul de la Scărişoara în intervalele 1963—1968 şi 1982—1985 pun în evidenţă faptul că, în afara fluctuaţiilor sezoniere, dinamica formaţiunilor de gheaţă comportă şi tendinţe majore de termen lung, de creştere sau de descreştere progresivă. Cuantificate prin dreptele de regresie ale variaţiilor lunare de înălţime, aceste tendinţe se dovedesc a fi de sens contrar pentru cele două tipuri morfologice principale sub care se prezintă gheaţa de cavernă, ele fiind negative pentru faţa superioară a blocului de gheaţă din Sala Mare şi pozitive pentru formaţiunile stalagmitice din „Biserică" şi din Rezervaţia Mare.

Racordarea celor două seturi de date glaciologice duce la concluzia că, pentru întreg intervalul de 22 de ani cuprins între 1963 şi 1985, rata de descreştere a blocului de gheaţă este egală cu rata de creştere a formaţiunilor stalagmitice din „Biserică", ceea ce reprezintă o expresie cantitativă precisă a fenomenului de „contrast de fază" caracteristic dinamicii celor două tipuri de formaţiuni. Esenţa acestui fenomen rezidă înfaptul că reducerea volumetrică a blocului de gheaţă — corelabilă cu caracterul în general blînd pe care l-au avut iernile în decursul ultimelor şase decenii — determină un complex de factori genetici favorabili dezvoltării formaţiunilor stalagmitice.

În baza aceleeaşi operaţii de racordare, dinamica formaţiunilor de gheaţă relevă o periodicitate de ordin superior faţă de cea sezonieră, periodicitate care pare a fi determinată de ciclurile meteorologice elementare de 11 ani şi care se manifestă în cazul masivelor stalagmitice printr-un vizibil decalaj în raport cu blocul de gheaţă. Se poate deci conchide că dinamica formaţiunilor de gheaţă este rezultatul interacţiuniilor complexe care se stabilesc numai între factorii meteorologici de la exterior şi topografia particulară a peşterii, ci şi între aceşti factori şi geometria variabilă a spaţiilor libere subterane.

Concluziile desprinse contribuie la completatea cunoştinţelor privitoare la informaţia paleoclimatică înscrisă în stratigrafia blocului de gheaţă şi la precizarea paramertilor de care trebuie să se ţină cont în amenajarea turistică a peşterii pentru conservarea integrală a cadrului subteran. În acelaşi timp, ele constituie o serioasă bază de justificare a utilităţii urmăririi în Gheţarul de la Scărişoara a unui program de cercetări multidisciplinare, eşalonat pe o perioadă de timp care să acopere în mod necesar cel puţin două cicluri metorologice de 11 ani.

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GEODYNAMICS AND THE WATER CIRCULATION IN THE SALT MASSIF LAKE AREA BAIA BACIULUI—BAIA NEAGRĂ—BAIA MIRESII (SLĂNIC-PRAHOVA, ROMANIA)

BY

V. A. C. BULGĂREANU, EMILIA OLTEANU, I. RĂDULESCU, V. FEURDEAN, C. LASCU, D. SVORONOS

The circulation pattern in „Muntele de Sare" area and in the of the pipping and collapse karstic doline includes several inputs generally oriented N towards S and NE toward SW. and main outputs having the general direction NW toward SE. The circulation of relatively fresh waters originating especially fron the „Muntele de Sare" — Baia Baciului — Baia Neagră northern area, — now the main cause determining the geodynamic processes — may be controled by reducing the inputs and seepage.

The Slănic-Prahova lake area in the homonymous town, includes three lakes (Băile Verzi 1, 2 and 3) located on the left side of the Slănic valley and four lakes (Baia Baciului, Baia Neagră, Baia Miresii and Baia Roșie) on the right side of the same valley.

The lakes Baia Baciului, Baia Neagră and Baia Miresii, located in the Middle Miocene deposits of Slănic sedimentary cuvette, are either of anthroposaline origin, occupying old salt mines dug towards the end of 17th century (Baia Baciului, Baia Miresii) or of karstosaline origin (Baia Neagră, which fills a pipping doline); the ensemble, a reserve, known as "Muntele de sare" (including "Grota Miresii" — a salt "grotto" and the lake Baia Miresii) did not exist yet in the second half of the 18th century (Sencu, 1968).

From the geomorphological viewpoint (Sencu, 1968), the lakes Baia Baciului and Baia Neagră are contained in a karstic collapse and pipping doline (ca. 275×200 m), while "Muntele de sare" with lake Baia Miresii penetrates into this doline like a spur from the north. Inside this doline one notes, in addition to anthropokarstic forms (collapsed old mines), natural karstification forms of salt (lapiez, "organ tubes", karstic niches, natural bridges, collapse sinks, "ponor" and solving valleys) or settling and pipping of insoluble deposits which cover the karstificated salt (pipping dolines and settling karstic valleys). Besides this surface

karstification, the bathymetrical mapping of lake Baia Baciului [1] and the SCUBA diver investigation of lake Baia Miresii [2] have shown some submerged karstifications produced after the freshwaters filled in the two collapsed old mines ; this refers to both the 9 dissolving submerged valleys and the submerged depressions all of them on the lake Baia Baciului bottom(Fig. 1) and also to the salt overhangs, dissolving levels, dissolving grottos, salt blocks and main and secondary fissures which affect the salt lake basin Baia Miresii.

Some of above mentioned exohalokarstic elements are shown in Pl. I ; to these add the soil creep areas and partially stabilized landslides together with some works (as is the entrance gallery in Grota Miresii, beaches and other pertinent constructions).

The dynamics of the "Muntele de sare" exokarst and the pseudokarst (= refering to the insoluble deposits which cover the karstificated salt) was studied by comparing the geophotogrammetric mappings carried out in various periods (1970, 1977, 1978, 1983 ; Pl. I) ; the vertical movement rate varies between —23 and +15 $cm.y^{-1}$ (1970—1983 years), with increased episodes (—70...—120 $cm.y^{-1}$) after the March 4, 1977 earthquak (in the time span March-August 1977, the salt fissuration itself showed an "opening rate" of 4.2...15.7 $cm.y^{-1}$; Bulgăreanu et al., 1978).

The causality of the above mentioned geomorphologic changes includes solving processes induced by the fresh of relatively fresh waters circulation. It must bementioned that in the investigated area there are only local phreatic accumulations of relative fresh waters (water dry residue, RF_w =ca. 2.5 $g.l^{-1}$, domestic well denoted TV-49, Pl. I). Other water accumulations, the lakes Baia Baciului, Baia Neagră and Baia Miresii, having maximum depths of 6.62, 1.0 and 29.0 m respectively (Bulgăreanu et al., 1978) contain chlorosodic, relatively acid, saline or even hypersaline waters (Baia Baciului = 3—90 $g.l^{-1}$; Baia Neagră = 3—250 $g.l^{-1}$; Baia Miresii = 250—300 $g.l^{-1}$) [3] ; the surface waters of lake Baia Miresii, may temporarily show (after heavy rains or thawing) salinities of ca. 13 $g.l^{-1}$ (Febr. 1983). Lakes level fluctuations largely controlled by the overflows outputs or inputs and partially by endokarstic conduits, did not exceed 30—35 cm in the years 1968—1983 ; in very droughty periods, lake Baia Neagră may even dry up.

In order to establish the circulation pattern of the waters having a salt-solving effect and, hence, with geodynamic consequences, we resorted to both the hydroisotopic (using natural deuterium) and the biogeophysical (= dowsing) methods, given the lack of springs and the presence of only one relative remote domestic well (TV-49, Pl. I).

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[3] See footnote 1.

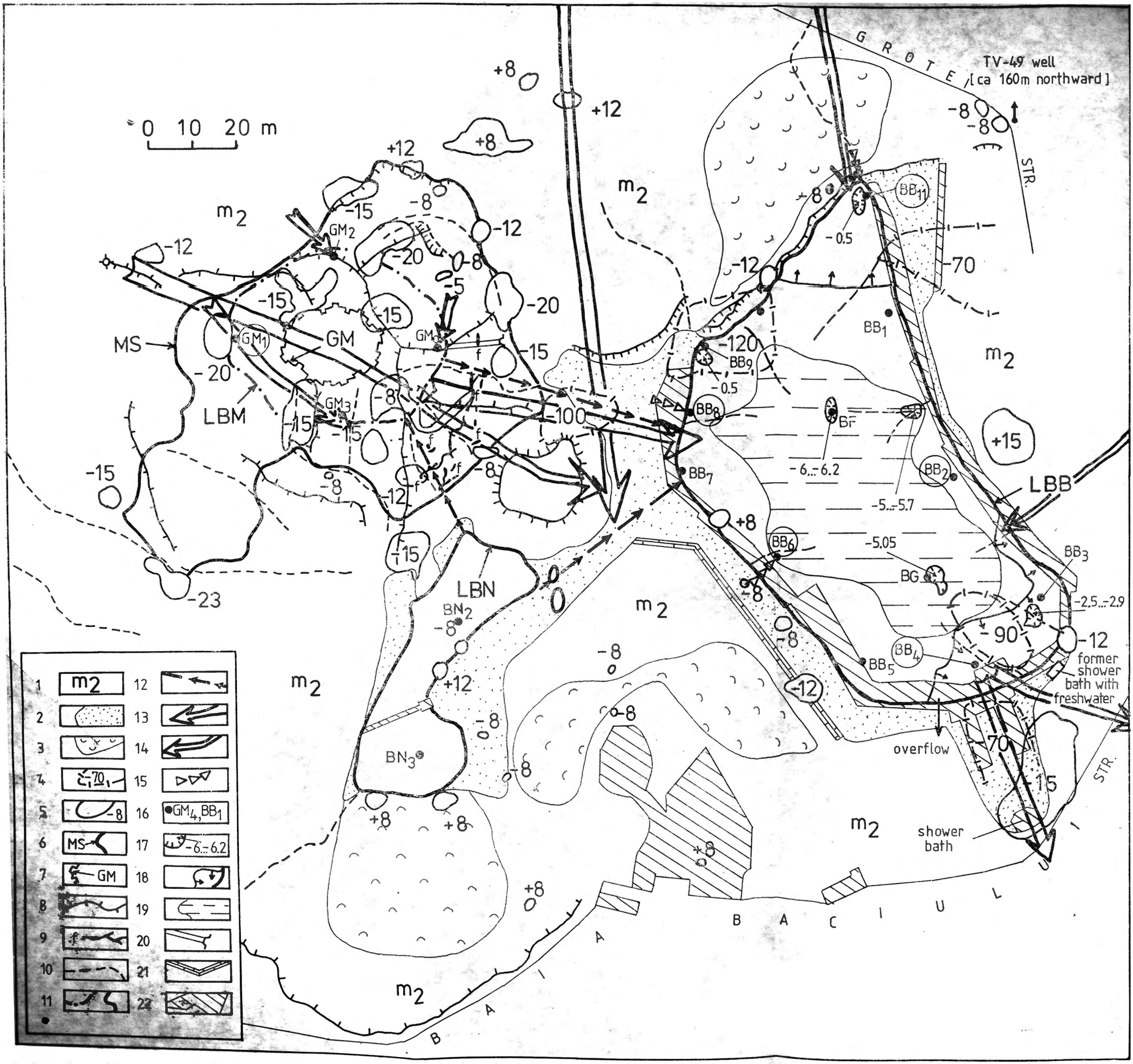

Fig. 1. Geodynamics and water circulation within the "Muntele de sare" — Baia Baciului — Baia Neagră area (Slănic — Prahova) ; 1. Salt formation (Middle Miocene) ; 2. Natural and artificial beaches ; 3. Soil creep and partially stabilized landslides ; 4. Areas with negative vertical movements (maximum values in cm.y^{-1}, June 1977 — May 1978) ; 5. Areas with maximum vertical movements $\geqslant$8 cm.y^{-1} (+, rising ; —, sinking), 1970—1983 ; 6. Salt outcrops ("Muntele de sare" boundary) ; 7. The approximate outline of the apical apertude of the "Grota Miresii" grotto ; 8. Salt crests ; 9. Fissures in the salt ; 10. Dissolving thalwegs with/without settling (submerged or at ground surface) ; 11. Outline of lakes Baia Miresii (LBM), Baia Baciului (LBB) and Baia Neagră (LBN) ; 12. Temporarily interlakes drainage (partially endokarstic), 1977—1984 ; 13. Underground drainage estimated by the natural deuterium method (1983—1984) ; 14. Idem, estimated by dowsing (1985) ; 15. Surficial runoff (1983—1984) ; 16. Water samples (1977—1984) ; the encircled symbols denote the relatively sweetening water sampling points ; 17. Submerged depressions (lake depth in m) ; 18. Areas with relatively sweetening bottom waters (water dry residue $\leqslant$ 91 g.l^{-1}, Nov. 1984) ; 19. Bottom areas with therapeutic unctuous muds ; 20. Entrance gallery dug in salt, into the "Grota Miresii" grotto ; 21. Supporting wall ; 22. Various constructions (board platforms, footbridges, snackbar, WC, etc.).

The experience gained in the use of th natural deuterium method for various lakes in the Romanian Plain and in Transsylvania already since 1976 (especially for those located on salt massifs ; Bulgăreanu et al., 1981 ; Bulgăreanu, Feurdean, 1982 ; Bulgăreanu et al., 1984) has shown that the efficiency of the method can only be achieved if the following conditions are satisfied :

— the distance between the extreme water sampling points taken into consideration should not be longer than 2 km ;

— shallow water accumulations (which frequently dry up) or those invaded by emergent (and probably by floating — leaved) vegetation should be excluded ;

— water sampling should be made at least two times a year, the distance between samples being not in excess of 500 m.

The fulfilment of these conditions excludes the misinterpretation of the variations in the natural deuterium content, variations which may be of geological, hydrometeorological, biological or other origin.

In order to establish the water circulation ways in the area, we started from the folowing premises :

— the waters having the same origin and running over relatively short distances (less than 2 km), show an almost similar natural deuterium content (denoted by CD) ;

— the CD values increase in the flow direction, fact proved both for running waters and for some lake areas (Blaga et al., 1975 ; Bulgăreanu et al., 1981 ; Bulgăreanu, Feurdean, 1982 ; Bulgăreanu et al., 1984).

For an estimation of lake supply by the relative fresh waters of local phreatic aquifer of TV-49 type (except for the littoral sweetening opint, which were established also by periodical measurements ; Pl. I), a comparison was made between the lakewater CD values and those of the phreatic aquifer, by using the Pearson variation coefficient, cv, and the formula :

$$cv = \frac{\sigma_{n-1}}{\bar{x}} 100$$

where σ_{n-1} is the standard deviation and $\bar{x}$, the arithmetic mean. For a minimum cv, the pairs of water sampling points taken into account contain similar waters and show the most probable water flow direction. The CD values and their variabilities are given in Table 1.

The examination of variation coefficients in the Table 1, shows the following :

— the phreatic aquifer (of TV-49 type) semms to supply (? endokarstic) mainly the Baia Miresii epilimnion (0—5 m depth), especially in the north-eastern littoral points GM_0 and GM_2 which confirms some earlier conclusions (Bulgăreanu et al., 1978) ;

— the distribution of CD values on the Baia Miresii lake surface shows an increase from NW (the relatively sweetening point GM_1) towards SE (GM_3 point), hence a coincident circulation within the lake epilimnion ;

— the same phreatic fresh waters seem to supply the Baia Miresii hypolimnion (24—26 m depht), which reinforce some earlier conclusions (Bulgăreanu et al., 1978) ;

Table 1

The Pearson variation coefficient (cv, %) for the deuterium natural contents (CD, ppm D/H) of the water sampling points taken in pairs from the lakes' area Baia Baciului — Baia Neagră — Baia Miresii (Slănic-Prahova); sampling data : sept. § oct. 1983 (n = 2—7)

Type of water	Sampling point (depth in meters)	CD	Type of water	Sampling point (depth in m)	CD	CV
1	2	3	4	5	6	7
Ground water	TV—49	146.90	Baia Neagră	BN_2	152.70 155.40	2.86360
				BN_3	153.15 155.45	2.91402
			Baia Baciului	BF (Om)	148.80 149.50	0.90658
				BF (1 m) BF (2 m)	149.10 149.20	0.87601
				BF (4 m) BF (6 m)	149.00 148.90	0.79898
				BG (Om)	149.35 149.15	0 91633
				BG (4.5 m)	149.20	1.09851
				BB_3	149.25 149.40	0.94406
				BB_5	149.00 149.45	0.91605
				BB_8	149.20 149.50	0.95766
				BB_{11}	149.25 149.50	0.96560
			Baia Miresii	GM_0	146 95	0.02406
				GM_1	146.75	0.07224
				GM_2	146.85	0.02407
				GM_1	147.05	0.07217
				GM_1 GM_2 GM_3 GM_0	146.75 146.85 147.05 146.95	0.07611

Table 1 (cont.)

1	2	3	4	5	6	7
				GM (1 m) GM (3 m) GM (5 m)	146.85 146.85 146.55	0.10906
				GM (7 m) GM (10 m)	146.50 146.65	0.13776
				GM (13 m) GM (15 m)	146.60 146.40	0.17163
				GM (17 m) GM (21 m)	146.50 146.45	0.16822
				GM (24 m) GM (26 m)	146.70 146.65	0.09014
Baia Baciului shower bath waters (= tap water)		145.90	Baia Baciului	BF (Om) BF (1 m) BF (2 m) BF (4 m) BF (6 m)	148.80 149.50 149.10 149.20 149.00 148.90	0.82377
				BG (Om) BG (4.5 m)	149.35 149.15 149.20	1.12455
Baia Baciului	BF (Om)	148.80 149.50	Baia Miresii	GM_0 GM_1 GM_2 GM_3	146.95 146.75 146.85 147.05	0.80394
				GM (1 m) GM (3 m) GM (5 m)	146.85 146.85 146.55	0.90936
				GM (7 m) GM (10 m)	146.50 146.65	1.0247
				GM (13 m) GM (15 m)	146.60 146.40	1.05434
				GM (17 m) GM (21 m)	146.50 146.45	1.06267
				GM (24 m) GM (26 m)	146.70 146.65	0.98530
	BF (1m) BF (2m)	149.10 149.20	Baia Miresii	GM_0 GM_1 GM_2 GM_3		0.79012
				GM (1 m) GM (3 m) GM (5 m)		0.89412

Tableau 1 (suite)

1	2	3	4	5	6	7
				GM (7 m) GM (10 m)		1.00668
				GM (13 m) GM (15 m)		1 03683
				GM (17 m) GM (21 m)		1.04530
				GM (24 m) GM (26 m)		0.96656
	BF (4 m) BF (6 m)	149.00 148.90	Baia Miresii	GM_0 GM_1 GM_2 GM_3		0.72081
				GM (1 m) GM (3 m) GM (5 m)		0.82078
				GM (7 m) GM (10 m)		0.92931
				GM (13 m) GM (15 m)		0.95952
				GM (17 m) GM (21 m)		0.96787
				GM (24 m) GM (26 m)		0.88914
	BG (Om)	149.35 149.15	Baia Miresii	GM_0 GM_1 GM_2 GM_3		0.82561
				GM (1 m) GM (3 m) GM (5 m)		0.93170
				GM (7 m) GM (10 m)		1.04642
				GM (13 m) GM (15 m)		1.07562
				GM (17 m) GM (21 m)		1.08503
				GM (24 m) GM (26 m)		1.00638
	BG (4.5 m)	149.20	Baia Miresii	GM_0 GM_1 GM_2 GM_3		0.70212
				GM (1 m) GM (3 m) GM (5 m)		0 83680
				GM (7 m) GM (10 m)		1.02909
				GM (13 m) GM (15 m)		1.05974
				GM (17 m) GM (21 m)		1.06761
				GM (24 m) GM (26 m)		0.98838

— the decrease of cv values with the increase of CD mean values from Baia Miresii epilimnion towards Baia Baciului hypolimnion seems to suggest a salt waters endokarstic circulation between the two above mentioned lakes, irrespective of the periodical output (through a canal) of the waters from B. Miresii into B. Baciului ;

— the relative high values of cv, show the lack of an existing connection between the shower bath and domestic well waters on the one hand and lake B. Baciului waters, on the other hand.

Biogeophysics (Apostol et al., 1972 ; syn. : "dowsing", „biofizitscheskii efekt", „biolokatsiya"), a modern approach of some ancient practices is based on the concept of interaction fields between a human body and some physico-geological systems, these last being characterized by continuous and actual local variations of the state of stress and considered as „biologically-disturbing geological bodies".

Upon the displacement of a human operator and during the crossing of the horizontal projection of a biologically-disturbing geological body, a succesion of biological states or signals is recorded ; the peak signals coincide with the in-plane projection of the disturbing geological bodies. The drawing of biogeophysical axes is made by joining the peaks of biological signals considered as determined by the same geological source.

Considering the types of geological bodies from the subsoil what can produce biological signals (Svoronos, 1981, 1984) as well as the signifiance given to these data in the literature (Apostol et al., 1974 ; Visarion et al., 1974), it was assessed that "Muntele de sare" — B. Baciului —B. Neagră area meets the conditions favourable to the use of biogeophysical method ; thus, the circulation of relatively fresh waters in the area determines karstification processes including geodynamic changes characterized by important variations of the state of stress in rocks ; in addition, the more or less organized circulation of waters through fissures, canals and gaps will induce the development of some pressure gradients.

In order to establish the biogeophysical axes in the investigated area, a human operator carried out 8 working profiles, considered as relevant using previously described methods and techniques (Apostol et al., 1972, 1974 ; Svoronos, 1981 ; Visarion et al., 1974). In order to eliminate the disturbing effect of salt, the measurements were made in the 1200—1430 span, which was considered the most relevant for the prevailing water circulation [4]. In our interpretation, the biogeophysical axes are the prevailing directions of fresh and salt waters circulation in the area (Pl. I). The comparison of the latter with the flow directions established by the natural deuterium method shows some similitudes in the "Muntele de sare" area ; in addition, the biogeophysical method showed 3 input (north, north-west and east of B. Baciului lake) and two output directions (both south of the same lake).

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[4] SVORONOS D. (1979), *Semnal dowsing şi informaţii geofizice produse de accidente tectonice ; analiză comparativă.* Proiect de absolvire a cursurilor postuniversitare, Facultatea de geologie-geografie, Bucharest, 40 p.

The correlation analysis of geodynamics and the water circulation pattern in the B. Baciului — B. Neagră — B. Miresii lake area, established above shows the following (Pl. I) :

— the existing dissolving valleys on the B. Baciului lake bottom correlate both with the sweetening littoral points and with the relatively sweetening area of bottom waters, established over the 1977—1984 period ;

— to the areas of high sinking yearly rates (over the 1977—1978 period), the following are associated : the overflow from B. Miresii into B. Baciului of the relatively sweetened springtime surficial waters ; the endokarstic input from the north of B. Baciului ; the past running of the bath showers (with freshwater, sometimes warm !) located on the south-eastern shore of lake B. Baciului (the showers waters usually run into the lake) ; the outside overflow of relatively sweetened waters from Baia Baciului ;

— the maximum frequency of the areas with field vertical movements (over the 1970—1983 period) is obvious in the "Muntele de sare" area, i.e. just at the place where an important input ob phreatic fresh waters has been noticed ; likewise, the most frequent salt blocks detachments are recorded from the western wall of the grotto ("Grota Miresii") where the littoral waters showed relative low salinities ;

— the early located inputs of relatively fresh waters at the epilimnion level into the B. Miresii hypolimnion (Bulgăreanu et al., 1978) are also proved by the existence of both lake slope overhangs (having some meters in size and being located at 0 m, 11—15 m, 18—20 m and (?) 22—23 m depth) and of some meters-sized solving grottos situated especially at 12—16 m depth ;

— the fresh and salt water circulation in salt is accomplished not only through various dissolving gaps but also through the N—S and NE—SW — oriented fissuring system (sometimes visible both on the "Muntele de sare" surface and inside the entrance gallery into the "Grota Miresii" grotto) rendered obvious by SCUBA diver investigation too ;

— the above-mentioned 5 flow directions, estimated only by biogeophysical method correlate with the following geodynamic processes :

— the remarkable sinkings in the area located between the "Muntele de sare" and lake B. Baciului (100—200 $cm.y^{-1}$) ;

— the karstic sinking valley and the landslides north of lake Baia Baciului and probably the sinking area having the 70 $cm.y^{-1}$ rate located NNE of the lake ;

— the important submerged sinkings (90 $cm.y^{-1}$) and the relatively water sweetening area south of lake B. Baciului ;

— the rather important sinkings of surface deposits south of lake B. Baciului which are partially dependent on the overflow output of temporary fresh waters.

In summary, the circulation pattern in "Muntele de sare" area and in the area of the pipping and collapse karstic doline (with the lakes Baia Baciului and Baia Neagră) includes several inputs generally oriented N towards S and NE towards SW and main outputs having the general

direction NW towards SE ; the long-standing circulation of relative fresh waters along these flow directions seems to be associated to the above mentioned doline formation ; a similar explanation may offer also the geodynamics of the «la Noroaie"-lakes Băile Verzi area (Bulgăreanu, Feurdean, 1982 ; Povară et al., 1982 ; Cioacă, 1967) where the relative fresh waters circulate both through an anthroposaline lake system (Băile Verzi) and along a 1 km long, halokarstic siphon having a level difference of ca. 185 m (Bulgăreanu, Feurdean, 1982).

The circulation of relatively fresh waters originating especially from the "Muntele de sare" — Baia Baciului — Baia Neagră northern area, — now the main cause determining the geodynamic processes — may be controled by reducing the inputs and seepage ; knowing that any works which imply excavations are utterly not advisable (as they facilitate the relative fresh water penetration into massif salt) only the planting of phreatophytes and of soil-stabilizing vegetation on the terrains located north of "Muntele de sare" and lake Baia Baciului seems to be adequate.

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GEODINAMICA ŞI CIRCULAŢIA APELOR ÎN SECTORUL LACURILOR PE MASIV DE SARE BAIA BACIULUI — BAIA NEAGRĂ — BAIA MIRESII (SLĂNIC-PRAHOVA)

Rezumat

Modelul de circulaţie din zona lacurilor situate pe masiv de sare Baia Baciului-Baia Neagră-Baia Miresii a fost elucidat atît prin interpretarea condiţiilor hidrochimice şi a consecinţelor de ordin geomorfologic cît şi prin aplicarea în paralel a metodei hidroizotopice cu deuteriu natural şi a celei biogeofizice („dowsing"). Astfel, în zona „Muntelui de sare" şi a dolinei carstice de sufoziune şi prăbuşire (care include lacurile Baia Baciului şi Baia Neagră), modelul de circulaţie implică o serie de influxuri cu orientare generală N către S şi NE către SW şi defluxuri principale cu direcţia generală NW către SE ; circulaţia în timp a apelor relativ dulci de-a lungul acestor trasee poate fi asociată genezei dolinei susmenţionate.

Circulaţia apelor relativ dulci provenind în special din nordul zonei „Muntele de sare" — Baia Baciului — Baia Neagră, care constituie actualmente principalul factor determinant al proceselor geodinamice, poate fi controlată prin reducerea afluxurilor şi infiltraţiilor ; deoarece orice lucrări care implică excavaţii sînt total nerecomandabile (prin faptul că facilitează accesul apelor relativ dulci la sarea masivului), pare adecuată doar plantarea de vegetaţie freatofilă şi fixatoare de teren pe suprafeţele situate la nord de „Muntele de sare" şi Baia Baciului.

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Im memory of Gabor Halasi
who knew and loved
these places so much.

HYDROGEOLOGICAL STUDY OF MONEASA AREA (CODRU MOMA MOUNTAINS)

BY

I. ORAŞEANU

The complex hydrogeological research work conducted in the Moneasa area indicated the presence in the deposits of the Finiş Nappe of a strong hydrogeological karst system, which is partially thermalized at its southern terminus, at its contact with the impermeable deposits of the Moma Nappe.

Numerous tracer labellings, pumping tests and hydrogeological balances outlined the hydrogeological features of this karst aquifer and the relationships between cold and thermal karst waters.

The Moneasa area, situated in the Apuseni Mountains, in the western-central part of the Codru-Moma massif, is well known for its thermal waters (24 to 32.8°C), which are exploited through four springs and three wells. Traversed by the same-name brook, a tributary of the Crişul Alb in Sebiş, the aforesaid area distinguishes itself owing to a great morphological variety, which is an outcome of a complex geological structure.

The terrains situated north of the Moneasa Valley, which geographically speaking, belong to the Codru Mountains, boast a varied relief, with major features facing the North-South running parallel to the direction of the geological structure. The morphology of this sector is dominated by the Izoi summit, the altitude of which top 1,000 m (1,097.7 m in the Izoi peak) wherefrom the relief collapses more than 400 m to the East to the lithologic contact depressions of Brătcoaia and Izoi-Tinoasa, continuing its fall to the East down to the Megheş valley, which is situated at an average altitude of roughly 350 m.

The left-hand slope of the Moneasa valley is exclusively made up of the rough Permian deposits of the Moma Mountains and features a rough terrain with deep torrential valleys and steep-walled slopes.

The water in the area are collected by the Moneasa brook, which run across a tectonic valley clasely folloing the overthrust plane of the Moma Nappe over the Finiş Nappe. The supply of the brook in the area under discussion is assymetrical, with tributaries which mainly feature karstifiable deposits (the Megheş, the Băilor, the Scăriţa and the Pietros brook) on right side only.

The Moneasa's meadow at the confluence with the Megheş and the Băilor brooks, situated at an average altitude of 285 m, has a maximum width of roughly 100 m and, partially, is the site of the balneal spa here.

The Megheş brook gathers its waters from under the Dîmbul Zocarului hill and the karstic depression of Izoi-Tinoasa. It boasts a norrow valley with steep-walled slopes and tributaries which are supplied by permanent karstic sources (the Viezuroiu, Răchitaru and Megheşul Sec brooks).

The Băilor brook has its major source in the Grota Ursului resurgent cave ; its downstream valley is narow and highly erosive in character. The valley upstream of the cave, known as the Feredeu valley, is dry and grassy, with stabilized slopes.

The morphology of the karstic terrains is dominated by the lithologic contact depressions Brătcoaia and Izoi-Tinoasa, adding to which are numerous other exokarst (lapies, sinkholes) and endokarst (56 caves and potholes) formations.

The lithologic contact depressions develop on Triassic limestones and dolomites at the contact with the Werfenian quartzitic sandstones partially featured by the Izoi crest. The runoff water from that crest infiltrates into the underground through impenetrable ponors, with the depressions lacking a main collector. They form an endorheic zone, that has no epigene hydrologic relationship with the neighbouring hydrologic network.

The endokarst is represented by numerous caves and potholes, noteworthy among which are :

— Peştera cu Apă de la Moară, a resurgent cave which is 2,012 m long, with a level difference of 35 m. It is through it that the waters in the cave from Merăzcric (which is 538 m long), situated 630 m to the North-East, are drained ; at present there is no speleological connection between the two caves ;

— The Grota Ursului cave is 250 m long and was discovered by G. Halasi in 1984 at the end of explorations in the 20 m long siphon wherefrom the Grota Ursului spring emerges. The cave was subsequently intercepted through a mining drift to make it suitable for tourist purposes.

The most remarkable karst feature in the Moneasa area is the pothole in the Teia valley. It is situated in the eastern part of the area, nearby a marble quarri, and is made up of red breccious limestones. It is 1,337.5 m long, has a 90 m level difference and was discovered in 1982 after the bottom of a lake formed by the sterile excavated from the quarry, which barred the course of the Teia brook, had caved in (Göpfrich, 1986).

The climate of the Moneasa area is continental, rendered moderate by median mountains, and Mediterranean influences are also felt. Over 1951—1960 a meteorological station operated in Moneasa and registered an average annual value of precipitations of 1,122.63 mm and a temperature of 9.5°C. Hydrometeorological activities were resumed in the summer of 1972, when the representative hydrologic basin of Moneasa and the Izoi Meteorological station were created.

1. A HISTORY OF HYDROGEOLOGICAL RESEARCH

The village of Moneasa is attested for the first time in the year 1200 in a sketch at the Țara Crișurilor Museum in Oradea, and the thermal springs here, which have been known ever since the times of the Romans, are mentioned in 1597 in a letter sent to the commander of the Dezna fortress, a stronghold belonging to the Transylvanian army of Sigismund Bathori, who was a supported of Michael the Brave (Coțoi, 1974).

Nendtvich Karoly conducted the first chemical analysis of the thermal springs at Moneasa in 1865 and a year later Kéry (Bittner) Imre decribed them for the first time and made a number of recommendations concerning their utilization.

The first well for thermal waters at Moneasa was drilled down to 316 m over the 1890—1895 interval; its initial discharge was of 16.6 l/s of water with a temperature of 25°C. With the building of Ward No. 1 on the Băilor brook in 1891 treatments being given for stomach complaints and rheumatism (Marki, 1895).

The first spring radioactivity measurements were conducted by Athanasiu in 1927. In 1932, Țeposu and Pușcariu referred in their book "România balneară și turistică" (Balneal and Tourist Romania) to the existence of four springs with a temperature of 20—32°C and a discharge of 14,000 to 15,000 hectolitres. The authors belive that the therapeutical value of the spa is due to the thermality of the waters there which, from a chemical point of view, are "indifferent" waters, as well as to weather conditions.

In 1951 the Balneology and Physiotherapy Institute in Bucharest released the first complete chemical analysis of the waters and in 1958 Paucă published a synthesis study concerning the thermal springs West of the Apuseni Mountains considering that the waters at Moneasa are a mixture of "hundreds-of-metres-deep waters, which rise under vapour pressure" and cold karst waters and pointing to the difficulty of deliniating the springs protection area.

As for the hydrogeological research work conducted in the past 20 years in the Moneasa area, noteworthy are the complete water radioactivity measurements performed by Szabo and Iosif in 1967, the first tracer labellings to establish the genesis of thermal waters, conducted by Slăvoacă, Orășeanu and Gașpar [1] in 1970, the first detailed hydro-

[1] SLĂVOACĂ D., ORĂȘEANU I. (1970), *Hydrogeological report.* I.P.G.G. București.

geological study of the spa made by Orășeanu in 1973 [2], the drilling of five new hydrogeological boreboles in 1972—1987 interval, a complete geophysical investigation conducted by Apostol et al. (1975), and the calculation of exploitable thermal-water reserves and the deliniation of the hydrogeologic protection area around the geothermal reservoir, accomplished by Orășeanu and Orășeanu in 1976 [3].

In 1978 Halasi published two works on the Moneasa endokarst and in 1985, together with Gisela Halasi and Birtalan, he described the exploration and morphology of the Grota Ursului cave (the cave at Băi).

2. GEOLOGICAL DATA

Opinions on the geology of the Moneasa area are closely linked to geologic knowledge of the Codru Moma Mountains. In 1936 Rozlozsnic mentioned the existence of three tectonic units, which feature the particularities of nappes, and in 1941 Paucă published the first map and the first complete geological study of the Codru Moma Mountains.

Subsequent geological research work provided for a detailed description of the structure of the Codru Moma Mountains, a structure within which authors Bleahu (1965) and Bleahu et al. (1968, 1979, 1981) distinguish the Finiș, Moma and Dieva nappes in the Moneasa area.

In 1983, as an outcome of research work conducted with a view to printing the Dumbrăvița sheet (1984), Ștefănescu et al., refer to a new tectonic unit in the Codru Mountains — the nappe of Seasa — and separate, within the Finiș Nappe in the Moneasa area, the chimeric nappes of Armanu and Seasa and the mediterranean nappe of Finiș.

From a geological point of view, the Moneasa area is situated in the area where the Moma Nappe thrust over the Finiș Nappe. The Finiș Nappe formations make up a homocline that faces the North-South, approximately, and contains Permian Rhyolitic Formation and Werfenian quartzitic sandstones in its bed. They support a thick stack of predominantly limy facies including black dolomites (Anisian), black limestones with cherts — the Roșia Formation (Ladinian), white dolomites and violet breccious limestones (Carnian), marly, argillaceous shales and silty marls interbedded with rare decimetric black limestones and quartzitic sandstones — Codru Formation (Norian), argillaceous or silty shales with rare decimetric interbeds of dolomites, limestones and quartzitic sandstones — the Carpathian Keuper (Rhaetian), massive nodular and breccious red limestones — "Moneasa marble" (Lower Jurassic) followed by a flysch-like formation consisting of interbeds of marls, shales and sandstones (Tithonic and Neocomian).

The S_5 (4666) well, drilled in the centre of the spa, indicates a rapid disappearance of the limy formations of the Finiș Nappe to the South, under the Permian silty shales and basalts of the Moma Nappe. They rise in steps to the South, under the Permian deposits, and the thickness

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[2] ORĂȘEANU I. (1973), *Hydrogeological report*, I.P.G.G. București.

[3] ORĂȘEANU I., ORĂȘEANU NICOLLE (1976), *Hydrogeological report*. I.P.G.G. București.

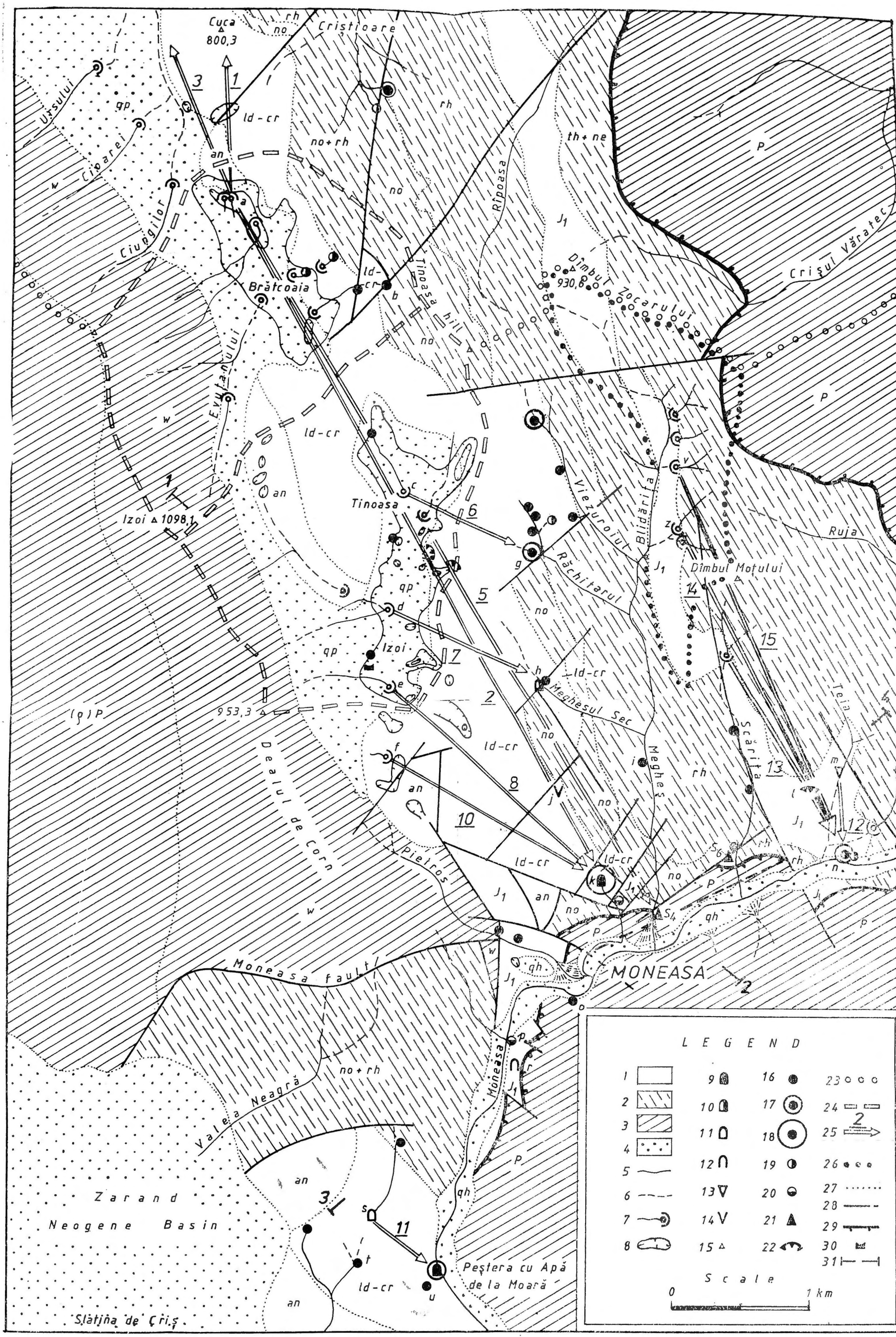

Fig. 1. Hydrogeological map of Moneasa area (geological base after Bleahu, 1965 and Bleahu et al. 1979, 1984), a — Dosul Varului ponor ; b — Popîrla spring ; c — Tinoasa ponor ; d — Hăiuga Veche ponor ; e — Izoi ponor ; f — Secărişte ponor ; g — Răchitaru spring ; h — Cave and spring of Megheşul Sec brook ; i — Cioroiul lui Petac spring ; j — Feredeu pothole ; k — Grota Ursului spring ; l — Moneasa quarry ; m — Teia pothole ; n — Piatra cu Lapte spring ; o — Mundy spring ; p — subthermal spring from stadium ; r — Liliecilor cave ; s — Merăzerie cave ; t — Fîntîna de Giurast spring ; u — Fîntîna Chiţuleşti ; v — Blidăriţa ponor ; z — Ponor of Pîrîul dintre Pietre brook ; qh — Holocen ; qp — Pleistocen ; th+ne — Tithonian+Neocomian ; J_1 — Lower Jurassic ; rh — Rhaetian ; no — Norian ; no+rh — Norian+Rhaetian ; ld—cr — Ladinian—Carnian ; an — Anisian ; w — Werfenian ; P — Permian ; (ρ)P — Permian rhiolites.

Legend : 1 — Carbonate mesozoic series (limestones, dolomites) of great thickness, highly karstified and tectonically intensely fractured, exhibiting large infiltration capacity and strong groundwater flow ; 2 — Mainly detrital and flysch-like series, including rock-complexes of variable permeability (shales, marls, sandstones, limestones) hosting occasionnaly discontinous aquifers occuring in the more permeable terms ; 3 — Detrital deposits of Permo-Werfenian age (quartzites, sandstones, shales) rhiolites and basaltes with discontinous distribution and development of permeability ; 4 — Detrital deposits of Neogene age (sands, gravels, marls) hosting limited aquifer accumulation ; 5 — Perennial river ; 6 — Temporary river ; 7 — Ponor ; 8 — Karstic depression ; 9 — Perennial outflow cave ; 10 — Temporary outflow cave ; 11 — Perennial inflow cave ; 12 — Fossil cave ; 13 — Perennial inflow pothole ; 14 — Fossil pothole ; 15 — Summit (elevation above the mean sea level in metres) ; 16 — Spring with average flow under 1 l sec. ; 17 — Spring with average flow betweeen 1 and 10 l/sec. ; 18 — Spring with average flow between 100 and 150 l/sec. ; 19 — Overflow spring ; 20 — Thermal spring ; 21 — Hydrogeological well ; 22 — Quarry ; 23 — Superficial watershed between Crişul Negru and Crişu lAlb rivers ; 24 — Limit of endorheic areas ; 25 — Underground connections established by tracing method (2 is the indicative of the tracing operation in the table No. 1) ; 26 — Meghes brook — Piatra cu Lapte spring diffluence surface ; 27 — Geological limit ; 28 — Fault ; 29 — Overthrust ; 30 — Meteorological station ; 31 — Direction of the hydrogeological cross section.

of Triassic limestones declines gradually, reaching only 65 m in the aforesaid well.

The formations of the Finiş Nappe, nearby the area of contact with the Moma Nappe, are highly tectonized and divided into a number of blocks by two fault systems — an older one facing the north-north-west — south-south-east, along the geological structure, and a newer one facing the north-east — south-west, which is perpendicular on the former.

The seismic and geoelectrical research conducted by Apostol et al. (1975) as well as the data supplied by hydrogeologic drillings show the overthrust plane of the Moma Nappe to have different inclinations, the avarage value of which is of 55° to the south. Close to the surface the inclination of the contact is grater being intercepted by the S_4 (4664) well at an angle of 70°. The F_3 well, drilled in the camping site, traversed only Permian deposits at a depth of 197 m to the bottom.

The second major tectonic element of the area is the Moneasa fault. It follows an east-west direction, perpendicular to the direction of the Finiş homocline which is cut, thus placing the Triassic limestones in the southern compartment, which was moved to the west, and the Werfenian sandstones in the northern compartment in direct contact. The fault continues under the deposits of the Moma Nappe, being responsible for the southern rise of sandstones and limestones, a rise highlighted by well S_5.

3. HYDROGEOLOGICAL CHARACTERIZATION OF THE MONEASA AREA

The great lithological variety and the different degree of fractured of the formations in the geological structure of the Moneasa area, which, from a hydrogeological poin of view, reflects in different ways of supply, accumulation, circulation and discharge of underground waters, led to the indentification of four types of formations boasting distinct geologic, structural and hydrogeologic features (fig. 1).

a. Mesozoic carbonatic succession (limestones and dolomites) which are great thickness, intensely fissured and highly karstified, and characterized by a high infiltration capacity and an active circulation of underground waters. The hydrogeology of these deposits will be enlarged upon in the following chapter.

b. Paleozoic and Mesozoic consolidated detritic deposits (sandstones, conglomerates, subordinated schists) and Paleozoic magmatites characterized by permeability through fissures and/or interstices with discontinous distribution and levelopment. Underground water circulation is limited to the alterated surface areas and to fractured zones and supplies episodic springs with low discharges of up to 1 l/s.

The Werfenian quartzitic sandstones make the bed of the aquiferous accumulations located in carbonate deposits, in relation to which they can be considered as virtually impermeable, the limit between the two types of deposits being, from a hydrogeological viewpoint, a perfect barrier. Furthermore, the quartzitic sandstones on the eastern slope of the Izoi crest play an important hydrogeological role by concentrating

the water derived from precipitation and directing surface flow to karst terrains, primarily to the Brătcoaia and Izoi-Tinoasa depressions. Owing to their contribution with surface waters, these terrains account for more than 40 per cent of the supply of karst aquiferous accumulations.

c. Norian, Rhaetian succesions and Thitonic-Neocomian flysch-like formation characterized by strong heterogeneity, made up of rock complexes of various permeabilities (clays, siltites, sandstones, limestones), which may contain discontinuous aquifers located in the more permeable elements. They form a continuous north-to-south strip east to the carbonate formations and make the virtually impermeable roof of karst aquiferous accumulation. Springs are rare on the surfaces under these deposits and they have low discharges and are linked to the sandstone-limestone intercalations.

d. Quaternary non-consolidated detritic deposits, represented by the Moneasa brook alluvia, are characterized by a notable circulation of underground waters; owing to their small expanse and thickness, their hydrogeological importance is strictly local.

The Quaternary deposits covering the karst depressions of Brătcoaia and Izoi-Tinoasa, mainly represented by blocks of quartzitic sandstones, limestones and dolomites, have small thicknesses and contain local suspended aquiferous accumulations, which have no influence on the hydrogeological conditions of karst aquiferous accumulations.

4. HYDROGEOLOGY OF KARSTIC TERRAINS

The main limestones and dolomites sequence in the area, north of the Moneasa valley, is 1—2 km in breadth and has a monocline structure. To the north the structure continues also in the Finiş brook basin and to the south it is brutally cut by the overthrust plane of the Permian deposits of the Moma Nappe.

Located in these carbonate deposits are important aquiferous accumulations, which discharge to the south mainly through the Grota Ursului spring and subordinately through the springs on the Viezuroiul, Răchitarul, Megheşul Sec and Pietros brooks. With the view to establishing the direction of flow of underground waters and flow dynamics, starting 1970 I have conducted tracer labellings here with the contribution of E. Gaşpar, Nicolle Orăşeanu, D. Slăvoacă and E. Anghel. These labellings provided for the establishment of fourteen drainage directions (Table 1).

The labellings performed in 1977 and 1986 in the Dosul Varului ponor, situated in the northern part of the karst depression of Brătcoaia, pointed to the presence of an important underground diffluence of infiltrated waters, as the tracers employed, Iodine-131 and In-EDTA, were involved in a northbound flow, to the Finiş and Feredeu springs and a southbound flow to the resurgent cave of Grota Ursului, the No. 1 ther-thermal spring and the thermal-water wells S_2 and S_4 at Moneasa. The labellings proved that in the Brătcoaia depression area the underground watershed between the basin of the Finiş brook, a tributary of the Crişul Negru, and the Moneasa, a tributary of the Crişul Alb, can be found

Table 1

Results of tracing operations on Moneasa karstic area

Numer of drainage on hydrogeological map	Ponor, H(m)		Resurgence, H(m)		L(m)/ΔH(m)	Tracer used	t hours	V m/hour	Date of labelling	Authors of tracing operations
1	Dosul Varului ponor	720	Feredeu spring	415	6000/305	Iod-131	58	103.0	10.09.1977	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
2	Dosul Varului ponor	720	Grota Ursului spring	320	5800/400	Iod-131	48	120.0	10.09.1977	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
3	Dosul Varului ponor	720	Finişului spring	490	2100/230	In-EDTA	168	12.5	19.07.1986	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
1	Dosul Varului ponor	720	Feredeu spring	415	6000/305	In-EDTA	96	62.5	19.07.1986	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
4*	Dosul Varului ponor	720	Thermal spring. No. 1	298	5900/422	In-EDTA	600	9.8	19.07.1986	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
5	Dosul Varului ponor	720	Well S_4 (4664)	296	6250/424	In-EDTA	480	13.0	19.07.1986	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
6	Tinoasa ponor	657	Răchitarul spring	525	1075/132	Fluoresceine	43	22.0	11.07.1973	I. Orăşeanu
7	Hăiuga Veshe ponor	699	Megheşul Sec spring	440	1200/220	Iod-131	1	1200.0	17.07.1974	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
8	Izoi ponor	680	Grota Ursului spring	320	2130/360	HTO	6	355.0	20.06.1970	D. Slăvoacă, I. Orăşeanu, E. Gaşpar
9*	Izoi ponor	680	Subthermal spring a	295	2180/385	HTO	6	363 0	20.06.1970	D. Slăvoacă, I. Orăşeanu, E. Gaşpar
10	Săcărişte ponor	685	Grota Ursului spring	320	1840/365	HTO	5	368,0	25 06.1970	D. Slăvoacă, I. Orăşeanu, E. Gaşpar
11	Tăul Bivolilor ponor (Merăzerie cave)	294	Peştera cu Apă de la Moară cave	250	630/ 44	Fluoresceine	8	80.0	25.07.1974	I. Orăşeanu, E. Gaşpar, N. Orăşeanu
12	Toia ponor	450	Piatra cu Lapte spring	310	650/140	Iod-131	25	16.0	1972	M. Tănăsescu et al.
13	Losses of Scăriţa brook	540	Piatra cu Lapte spring	310	1700/230	Fluoresceine	48	35.4	12.05.1987	I. Orăşeanu
14	Losses of Pîrîul dintre Pietre brook	560	Piatra cu Lapte spring	310	2680/350	Rhodamine B	70	38.3	11.05.1987	I. Orăşeanu
15	Losses of Blidăriţa brook	630	Piatra cu Lapte spring	310	3100/320	In-EDTA	72	43.0	13.06.1987	I. Orăşeanu, E. Gaşpar

H = Elevation above the mean sea level ;
L = Horizontal distance between losses and spring ;
ΔH = Difference in elevation between losses and spring ;
V = Apparent velocity ;
t = Time of first arrival of tracers ;
* Drainage direction is not drawn on the hydrogeological map.

[4] PALFY F., GROZA MARIA-ANA, CRIŞAN S., ONCEAN N., ONCEAN NUŢA, CONDEA T., ZACOI G. (1976), *Hydrological dates*, S. H. Moneasa.

The karst area limited by Brătcoaia, Tinoasa, Izoi and Moneasa, together with its slope basin that expands to the Izoi crest, forms a unique hydrogeological karst system, which is partially thermalized at its southern end. It boast a north-to-south flow of underground waters and a discharge preferentially made through the Grota Ursului spring. The waters that cannot be involved in this flow, owing to the limited conveyance capacity of channels and fissures, drain to the east through the overflow springs in the Răchitaru and Megheşul Sec valleys. The hydrogeological relations between the waters infiltrated through the Tinoasa and Hăiuga Veche ponors and the aforesaid springs were also attested through tracer labellings.

To determine the parameters of underground waters flow in the Moneasa area over October 1975 — September 1976 systematic measurements were performed, in cooperation with the collectivity at the Moneasa hydrologic station[4], of the discharges and the temperatures of the brooks Moneasa, Megheş and Pietros, of the Băilor brook up- and downstream of the thermal sources in the Ward 1 area, as well as of all the caught thermal sources(springs 1, 2, 4 and 5) and the wells S_1, S_2, S_4, and S_5 (fig. 2). Measurements were also performed of the precipitations at Izoi and Boroaia (three kms east of the spa) and of air temperature at Izoi and Moneasa.

Processing of the hydro-meteorological data, conducted at the No. 1 gauging cross section on the Băilor brook, which controls the Grota Ursului spring discharge, indicate for the mentioned spring an mean annual discharge of 121.42 l/sec. with the extreme limits ranging from 32 to 938 l/sec. The $Q_{max.\ daily}/Q_{min.\ daily}$ variability index of the spring is of 29.3, and the sensible fluctuation of its discharge is also illustred by the long fluctuation interval of the $Q_{mean\ year}/Q_{mean\ month}$ ratio shown in figure 3

The diagram of the classified flows of the Grota Ursului spring (fig. 4) shows a slope break of the line for a value of 654 l/sec., a break determined by the overflow phemomena. It is rather difficult to accurately assess the overflow sources which give birth to this phenomenon as it can be generated both by the operation of the sources in the basins of the Răchitarul and Megheşul Sec brooks, mainly of the temporary resurgent cave of the latter's valley, and by modifications occured in the distribution of the discharges of the endorheic basin of Brătcoaia, with a preferential direction to the Finiş basin.

By processing the hydrographs of the discharges measured in the No. 1 gauging cross section on the Băilor brook in periods lacking precipitations the hydrogeological parameters of the karst aquifer discharging through the Grota Ursului spring could be computed.

The recession curve of the Grota Ursului spring in the interval spanning June 4, 1976 — July 29, 1976, when it was not influenced by significant contributions from precipitations, is represented by a broken line with three slopes featuring the α_1, α_2, and α_3 discharge coefficients (fig. 5).

[4] PALFY F., GROZA MARIA-ANA, CRIŞAN S., ONCEAN N., ONCEAN NUŢA, CONDEA T., ZACOI G. (1976), *Hydrological dates*, S. H. Moneasa.

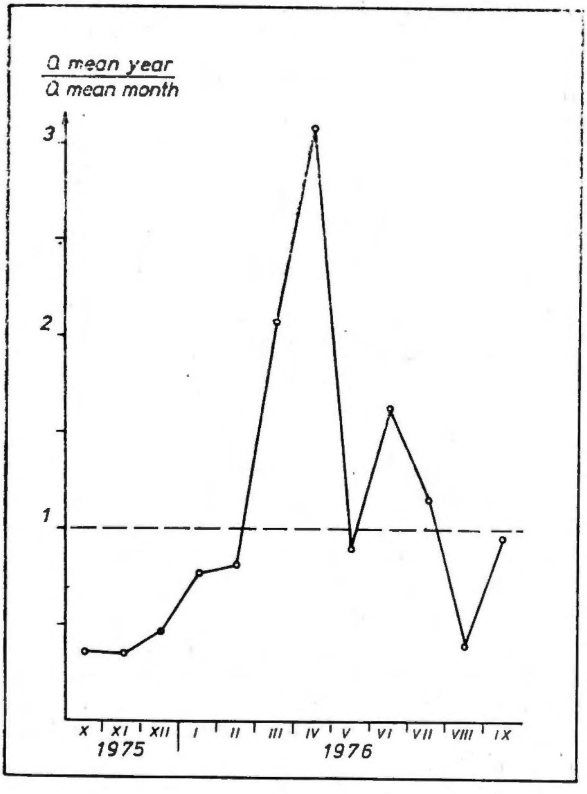

Fig. 3. Variation of ratio Q mean year / Q mean month of Grota Ursului spring.

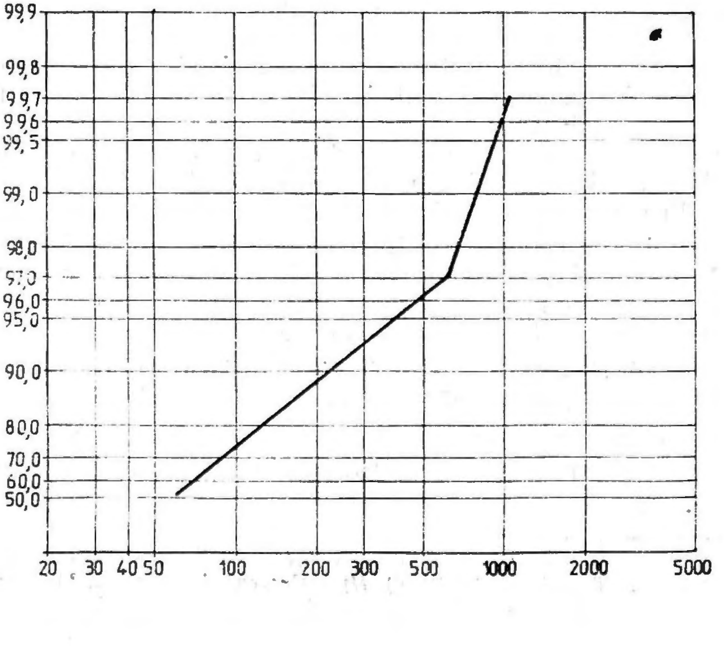

Fig. 4. The diagram of the classified flows of the Grota Ursului spring in X.1975—IX.1976 time interval (probability paper).

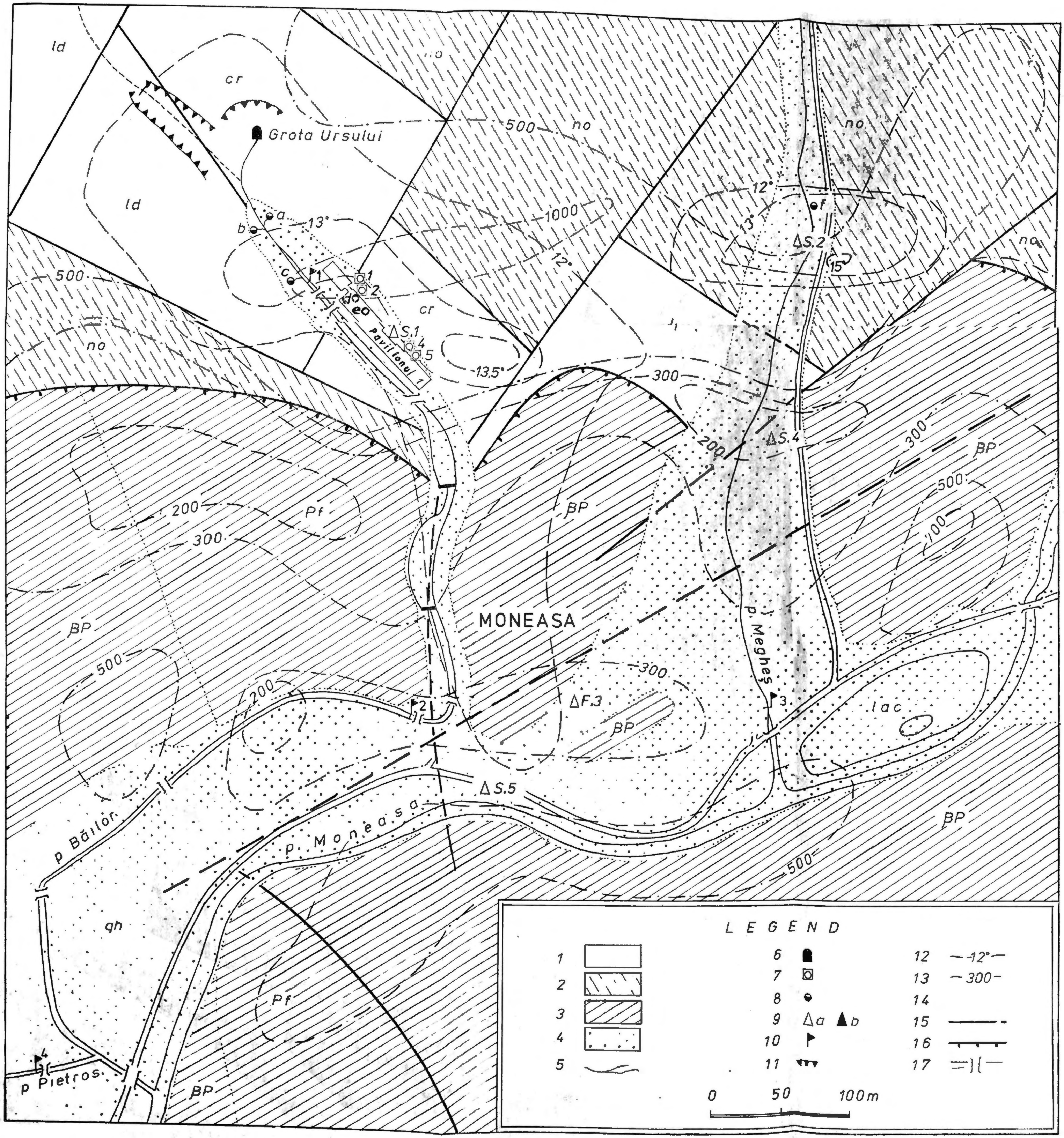

Fig. 2. **Hydrogeological map of Moneasa spa** (geological base after Bleahu et al. 1979, geophysical data after Apostol et al. 1975); qh — Holocene; J_1 — Lower Jurassic; no — Norian; cr — Carnian; ld — Ladinian; βP — Permian basaltes; Pf — Permian Feldspathic Formation.

Legend: Numbers 1 to 5 as in fig. 1; 6 — Perennial outflow cave; 7 — Caught spring; 8 — Subthermal spring; 9 — Hydrogeological well (a), Geological borehole (b); 10 — Gauging cross section; 11 — Abrupt; 12 — Isoline of equal temperature (°C); 13 — Isolines of equal apparent resistance (in ohm-m); 14 — Geological boundary; 15 — Fault; 16 — Overthrust; 17 — Bridge.

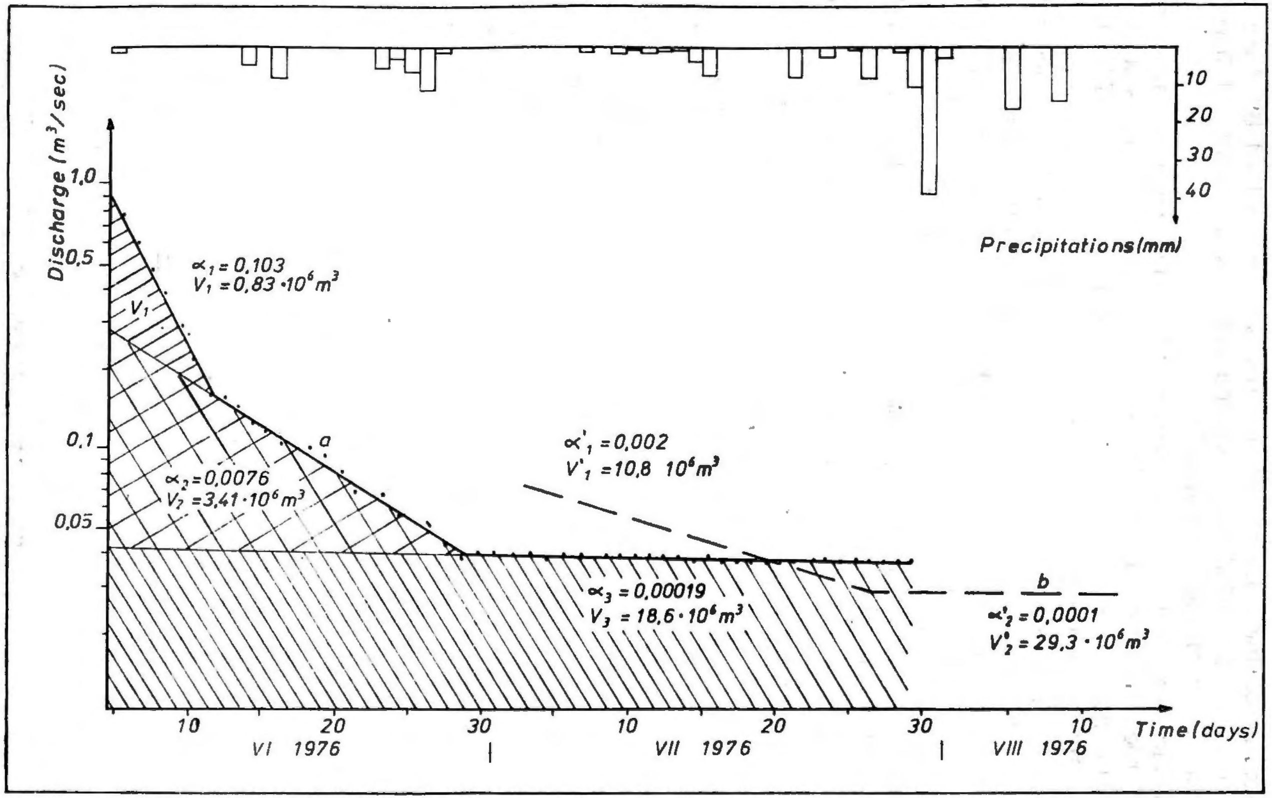

Fig. 5. The recession curve of the Grota Ursului spring (a) and of the uncaught thermal springs in Băilor brook (b) in June—August 1976 time interval.

Coeficient $\alpha_1 = 0.103$ designates the discharge of karst void spaces and channels where, in an interval of seven days, a volume of $0.83 \cdot 10^6$ cu.m. of water are discharged in turbulent conditions. The discharge of the systems of partially karstified fissures is characterized by coefficient $\alpha_2 = 0.0076$, last for 17 days or so and releases a volume of $3,41 \cdot 10^6$ cu.m. of water from the karst aquifer.

Coefficient $\alpha_3 = 0.00019$ represents the discharge of the water stored in rock fissures, in inactive subterranean void spaces and their alluvia. The most substantial value of these reservoiris is of $18.6 \cdot 10^6$ cu.m. and their discharge is prevailingly laminar.

At the southern end of the strip of Lower Jurassic limestones, which develops in the eastern part of the area — limestones which are improperly called "Moneasa Marble" — a hydrogeological karst system is located, which is mainly supplied by the waters infiltrated through the Teia, Scăriţa and Blidăriţa ponors, a system that discharges through the permanent Piatra cu Lapte spring and temporary, through the over flow sources situated immediately upstream.

The waters infiltrated through the channel of Blidăriţa brook and its tributaries are exclusively directed to the Piatra cu Lapte spring. They traverse the hydrogeological karst system in an average interval of 72 hours and follow a piston-type flow (fig. 6).

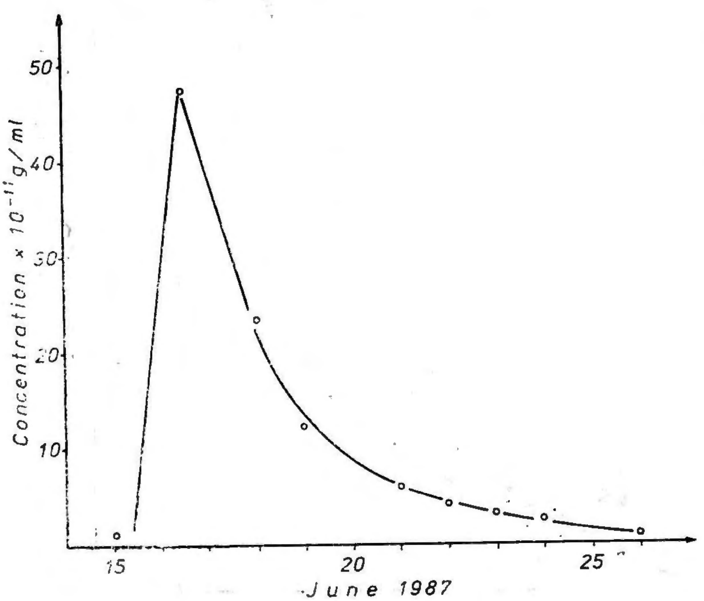

Fig. 6. Time variation of In-EDTA tracer concentration measured in Piatra cu Lapte spring after labelling the losses in flow in Blidăriţa riverbed.

5. THERMAL WATERS

The thermal waters at Moneasa — both natural emergences and those emerging through wells — are karst waters that appear in the carbonate deposits of the Finiş homocline, nearby the contact with the

Table 2

Cold and thermal water sources in Moneasa spa area

Nr. crt.	Source	Elevation a.s.l. (m)	Depth (m)	Q (l/s)	T (°C)
1	Well S_1	292,59	316,0	2,45	24,0
2	Well S_2 (4663)	302,59	604,0	0,4	28,5
3	Well S_4 (4664)	296,97	836,4	3,0	32,5
4	Well S_5 (4666)	284,95	424,6	7,0	14,0
5	Spring no. 1	293,96	—	3,29	24,0
6	Spring no. 2	293,90	—	3,32	24,0
7	Spring no. 4	292,69	—	} 4,30	31,0
8	Spring no. 5	292,59	—		31,2
9	Uncought thermal waters in Băilor brook	290,0 — 296	—	50,0	22
10	Uncought cold waters in Băilor brook	296— 320	—	40,0	10,8
	Grota Ursului spring	320	—	121,42	8,0

impermeable deposits of the Moma Nappe. They belong to the category of hypothermal (20—37°C) and subthermal (10—20°C) waters. The values of the discharges and temperatures of the sources outlined in table 2 represent the averages of a series of daily observations conducted in the hydrologic year October 1975 — September 1976 and of the expeditionary observations made in the past 20 years.

The main natural thermal-water sources are situated on the Băilor brook, downstream of the Grota Ursului spring, on a distance of 180 m before the brook enters the Permian terrains (fig. 2). Their temperature rises as they approach the contact with the deposits of Moma Nappe (fig. 7).

The average flow value of water contributions from the Băilor brook, computed on the basis of data supplied by observations made in the No. 1 and 2 gauging cross sections, are of 50 l/sec. of hypothermal waters with a temperature of 22°C, contributions of which roughly 43 l/sec. are water with a temperature of 22°C which is not caught. The value of these contributions is readily noticeable in the case of the lower discharges of the Grota Ursului spring, especially through the temperature rises registered by the Băilor brook downstream of the sources (fig. 8 and 9).

The recession curve of uncaught thermal waters on Băilor brook (fig. 5) shows presence of an important accumulations stored in partially karstified fissures and in rock fissures. The curve has two segments with different slopes and indicate a meteoric source of thermal waters. The approximate underground transit time is 30 days.

The No. 1, 2, 4 and 5 thermal springs are caught and used for internal treatment (No. 1), potable water supply (No. 1 and 2 and well S_5) and balneal treatment (No. 2, 4 and 5 and wells S_1, S_2 and S_4). The

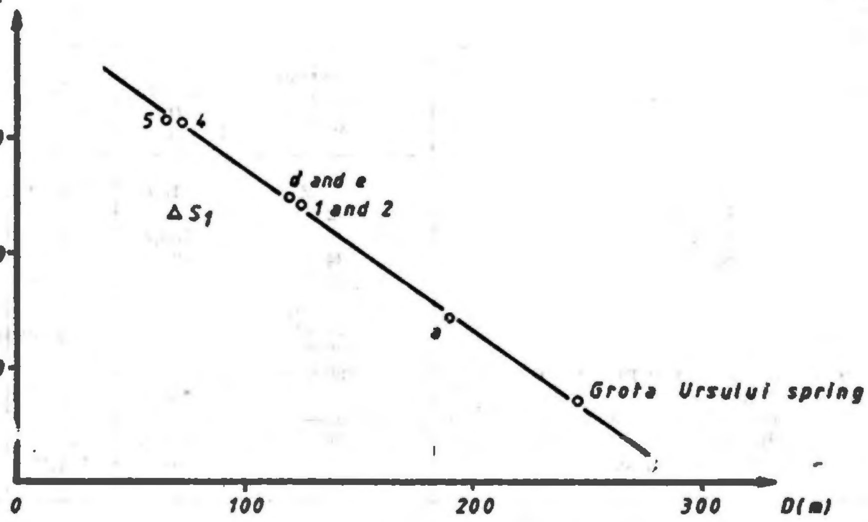

Fig. 7. The relation between sources temperatures and distance from overthrust front in Băilor brook.

"c" and "d" thermal sources (fig. 2) appear at the base of the wall of the channel situated upstream part of No. 1 Ward and they have an overall discharge of roughly 23 l/sec. and a temperature of 24.5°C. They are not caught and they represent losses from the No. 2 spring.

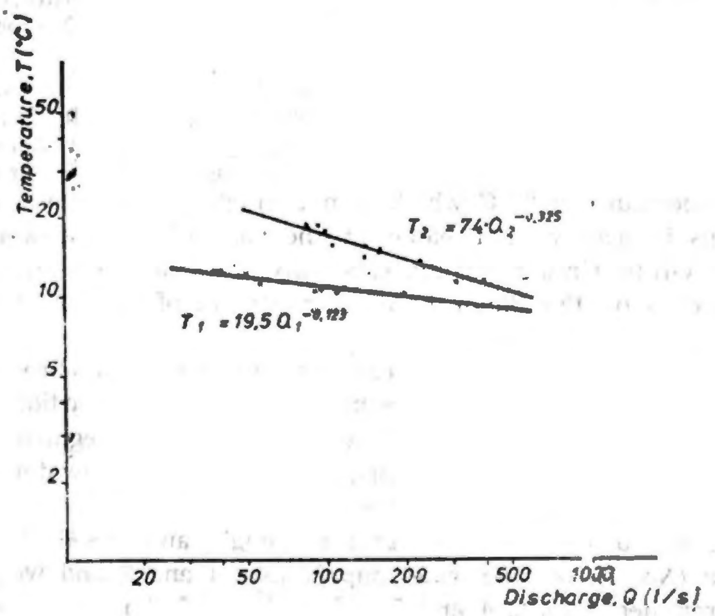

Fig. 8. The relation between mean month temperatures and mean month discharges of the Băilor brook in gauging cross sections No. 1 and 2 in X.1975—IX 1976 time interval (log-log paper).

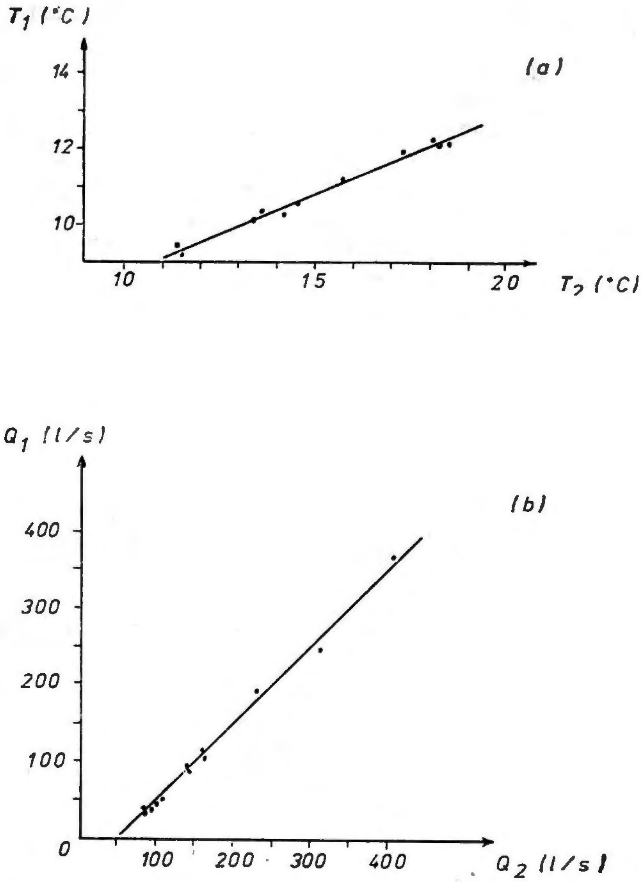

Fig. 9. The relation between mean month temperatures (a) and mean month discharges (b) of Băilor brook measured in gauging cross section 1 and 2 in X. 1975—XI. 1976 time interval

From a geothermal viewpoint, the whole area of the Băilor brook is an abnormal area with the maximum point situated close to the No. 4 and 5 sprigns (fig. 2). The anomaly follows the direction of the geological structure of the deposits of the Finiş Nappe, traverses the overthrust front of the Moma Nappe and continues, with a sensibly diminished value, along the direction of the Moma Nappe structure up to the Moneasa valley (Apostol et al., 1975).

Four boreholes were drilled between 1972—1975 with a view to investigating the area from a hydrogeological point of view and they assessed the structure of the hydrothermal reservoir at depth. In the summer of 1987 the S_6 hydrogeological well, located on the Scăriţa valley, started being drilled.

Well S_2 (No. 4663) was drilled in 1972 nearby the subthermal spring on the Megheş valley and traversed carbonate deposits along the entire depth (i.e. 604 m). The measurements conducted during drillings indicated the presence of waters with increased temperatures (30°C) in the upper part of the karst aquiferous complex and with

lower temperatures (24°C) in its lower part (Vasilescu, Avramescu, 1972 [5]).

Hydrogeological testings performed in borehole F_3 showed that throughout the entire depth (i.e. 197 m) it traversed deposits devoid of water of Moma Nappe, for which reason it was cemented.

The well S_4 (No. 4664) was located directly on the Permian deposits of the Moma Nappe, which it traversed along a thickness of 78 m; to a depth of 520 m it penetrated limestones and dolomits highly karstified and then, down to the bottom (i.e. 836.4 m), Werfenian quartzitic sandstones, a succession belonging to the Finiş Nappe.

The pumping tests conducted during drilling operations on the well S_4 indicated a sensible drop in the temperature of depth waters and a decline of the specific discharge/tested interval thickness ratio because of the reduction of the intensity of fissuration and of the size of the karst channels. Furthemore, it was noted that the discharge capacity of the intervals tested below 500 m, mainly including quartzitic sandstones, dropped substantially (fig. 10).

Wel S_5 (well No. 4666) traversed a succession including Permian schists, sandstones and basaltes belonging to the Moma Nappe (0—275

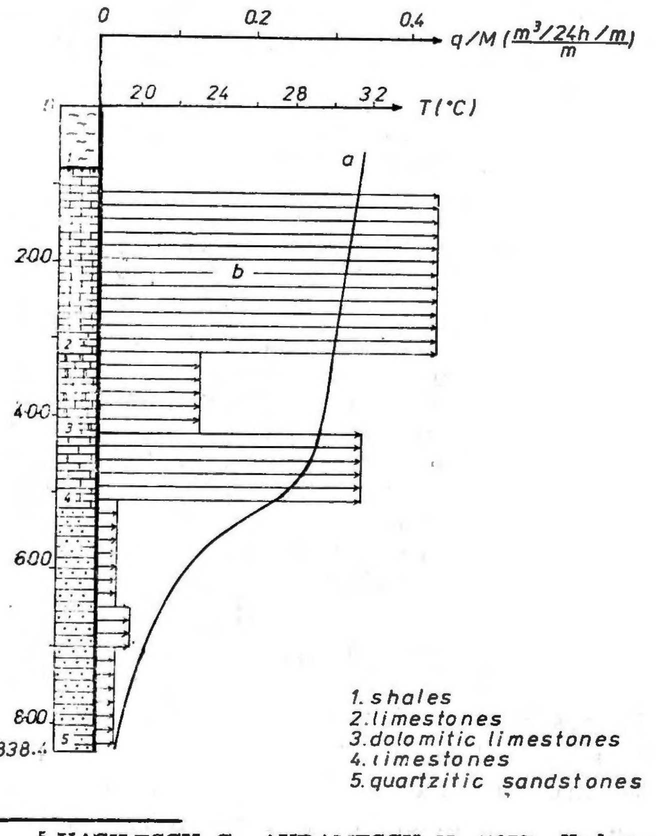

Fig. 10. The variation of temperature (a) and of specific discharge / tested interval thickness ratio (b) of the S_4 well.

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[5] VASILESCU G., AVRAMESCU N. (1972), *Hydrogeological report*, I.F.L.G.S. Bucureşti.

m), and then penetrated Triassic karstified limestones (275—340 m) and Werfenian quartzitic sandstones (340—424.6 m) belonging to the Finiş Nappe. The waters intercepted in Triassic limestones boast an artesian discharge of 7 l/sec. of water with a temperature of 17°C at a dynamic level situated 1.5 m above the ground. The hydrostatic level was of +23 m (Pîrvu, 1975 [6]). Present temperature of water is 14°C.

Besides the aforesaid thermal-waters sources, we should also refer to a spring, situated on the left-hand bank of the Moneasa river (fig. 1, p), under the embankment of a former narrow railway, near the stadium. It boast an average discharge of 0.1 l/sec. and a mean temperature of 17.5°C, values that registered great variations during rainy periods.

Others subthermal springs are situated in the upstream part of Băilor brook : spring a (14,2°C, 7,0 l/sec), spring b (10,2°C, 4,0 l/sec) and spring c (14,5°C, 3,5 l/sec). Tămăduirii spring (15—24°C, 0,3 l/sec) situated on the left-hand bank of the Megheş brook (fig. 2, f) is temporary flooded.

6. PUMPING TESTS

With a view to complementing hydrogeological image of area with data concerning the hydrodynamics parameters of the karst aquiferous complex wherein the thermal-water is located, pumping tests were performed in 1977 [7]. Water in the well S_5 was pumped at a constant discharge ($Q = 11.5$ l/sec, drawdown $s = 46.6$ m) for 120 hours and the variation of the water level in well S_1, S_2 and S_4 was observed during both pumping and in recovery. Furtermore, during the exploitation of well S_1 by the balneal spa ($Q = 2.45$ l/sec. at a dynamic level of 0.14 m above the ground) the variation of the piezometric level in well S_4 was noted.

The results obtained through pumping tests were processed and placed on a diagrams. With them as a basis, the transmissivity and the storage capacity (effective porosity) of the karst aquiferous complex were calculated. The results obtained, which are noted on the block-diagram in figure 11, bespeak a great variation, alond different directions, of the hydrodynamic features of the complex. This anisotropy is due to the bank-stratification of the limestones and dolomites, as well as to their different fissuration degree.

Thus, higher values of transmissivity and storage coefficient were obtained for the directions between wells S_1—S_5 and S_4—S_5, which correspond to the area of maximum crumbling of limestones and dolomites as a result of the Moma Nappe overthrust and to the direction of stratification of the carbonate deposits and, equally, superpose over the main direction of fissuring of these deposits.

Lower values were obtained for the S_4—S_1 direction, owing to its orientation which is perpendicular on the direction of stratification of

[6] PÎRVU MARIA (1975), *Hydrogeological report*, I.F.L.G.S. Bucureşti.
[7] ORĂŞEANU I. (1977), *Hydrogeological report*, I.P.G.G. Bucureşti.

the carbonate deposits and to their lower fissuration degree as an outcome of their more distant position as to the Moma Nappe overthrust plane.

The interference between these wells, which constantly discharge waters with different temperatures (S_5 — 14°C, S_1 — 24°C, S_2 — 28,5°C and S_4 — 32.5C), corroborated with the results of tracer labellings, which highlighted the relationship between cold karst waters and thermal waters, attests to the presence of a unique hydrogeological karst system of great expanse, boasting an extremely heterogeneous distribution of temperatures, caused by local lateral contributions in karst water of high temperatures in its southernmost part (fig. 12).

The thermal waters in Moneasa area are results of mixing between cold karst waters and karstic waters of deep circulation that rise in

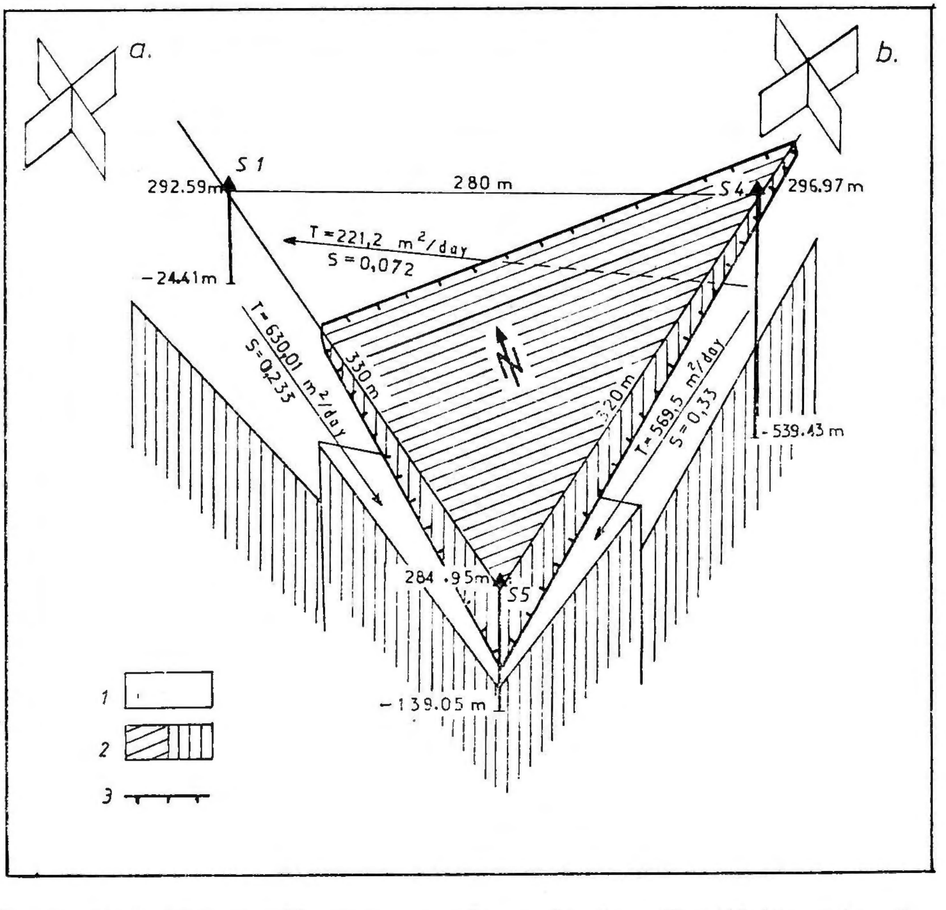

Fig. 11. Block-diagram with pumping tests results. 1 — Karstifiable rocks ; 2 — Nonkarstifiable rocks ; 3 — Overthrust front ; a, b — Main direction of rocks fissuring at Grota Ursului spring (a) and in left-hand slope of Megheş brook, near S_2 well (b).

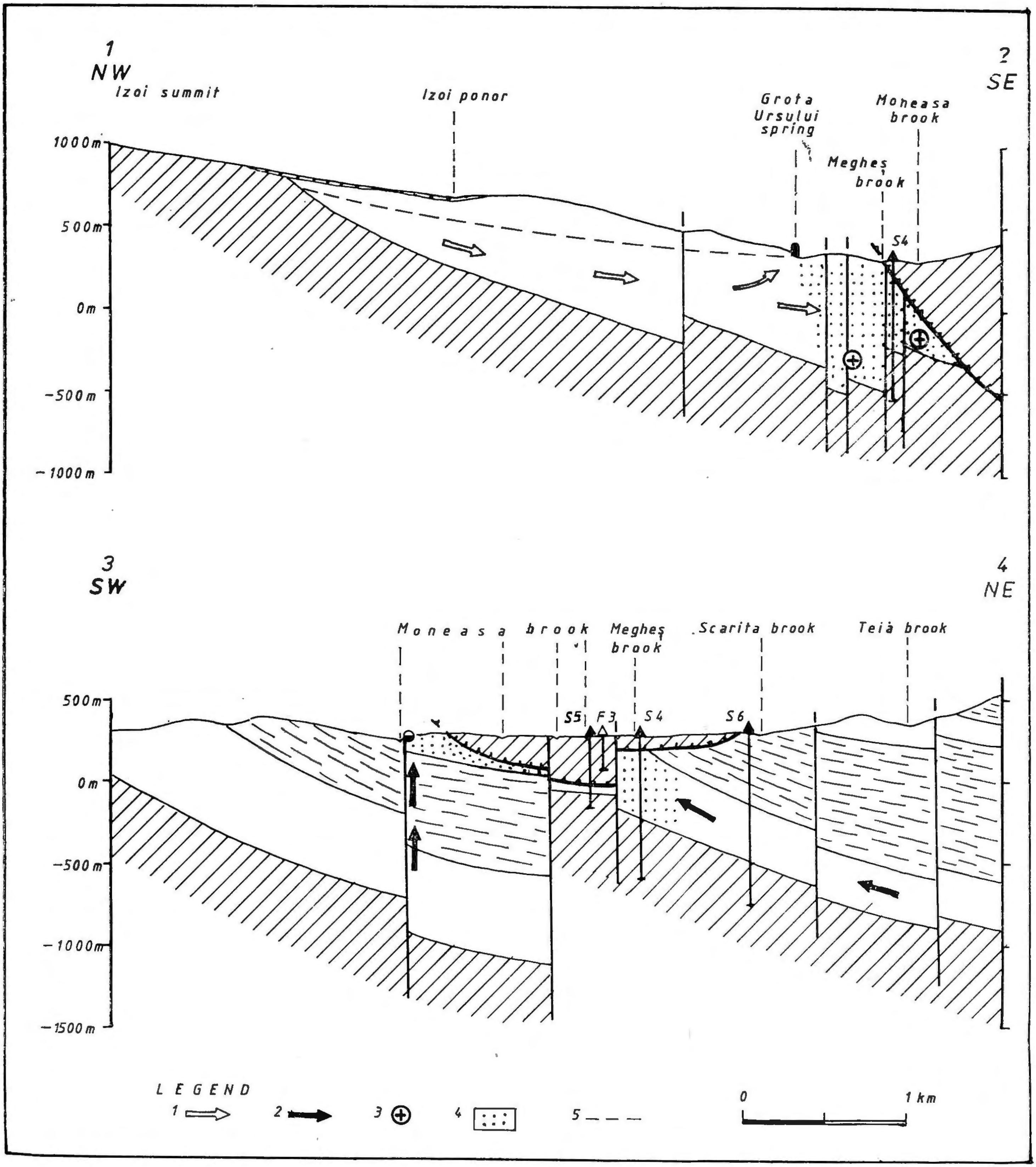

Fig. 12. Hydrogeological cross-sections in Moneasa area. 1 — Direction of cold karst waters flow ; 2 — Direction of hot karst waters flow ; 3 — Lateral contributions in hot karst waters ; 4 — Mixing zone between hot and cold karst waters ; 5 — Approximate position of water table. Others signs as in fig. 1.

calcareous interfluve at Moneasa and the localities of Slatina de Criş and Dezna, the latter being known owing to its underground thermal waters[8]. Before emerging to the surface in the Moneasa area, these waters get colder partially, which is a result of their blend with the cold waters of the Grota Ursului hydrogeological karst system.

7. HYDROGEOLOGICAL BALANCE OF THE MONEASA AREA

With a view to establishing the expanse of the hydrogeological karst system which discharges its waters to the south in the Moneasa spa area, both through the cold-water spring of Grota Ursului and through the thermal-water springs and wells, we drew up the overall balance of surface and underground water resources.

The area includes the hydrographic basin of the Meghes, Băilor and Pietros brooks and the Tinoasa—Izoi basin whose link with the exurgences in the Meghes and Băilor brooks' basins was proved through tracer labellings. The endorheic basin of Brătcoaia was not included in the balance as it is only partially drained by the sources in the Moneasa valley basin, its contribution to the supply of these sources being only indirect, as resulting from the obtained budget.

The overall balance was drown up for the whole basin and for each separate hydrographic basin with a view to establishing the supply or drainage relationships between them. To work it out, the hydro-meteorological measurements performed at the Moneasa station by Palfy et al.[9] in the Octobebr 1, 1975 — September 30, 1976 hydrologic year were taken as a basis.

Precipitations were assessed with the help of a isohyet map drawn up by interpolating the values of precipitations registered in the aforesaid hydrologic year at the meteorologic stations at Izoi (altitude 700 m), Boroaia (350 m) and Rănuşa (225 m), situated 4 km south-west of Moneasa.

Evapotranspiration was computed with the help of Turc's formula, where the mean annual temperature was assessed according to the map containing the air isotherms, worked out by interpolating the values of the mean annual air temperature measured at the Izoi and at the Moneasa.

Runoff was estimated according to the mean daily discharges measured in the gauging cross sections on the Meghes and Pietros brooks.

The emergences of underground waters (springs) are represented by the contributions of the cold and themal waters on the Băilor brook, assessed through the hydrometric measurements performed in the No. 2 gauging cross section on the Băilor brook.

Catchings of water for domestic use and for the supply of the local swimming pool are represented by the amounts of water taken from

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[8] In 1978 IFLGS drilled a hydrogeological borehole at Dezna, a locality situated roughly 6 kms south of Moneasa. Along the entire depht (897 m) it traversed carbonate deposits mainly. The well discharges 3.5 l/sec. bicarbonate calcic magnesian water with a temperature of 38.5° (VĂLENAŞ E., FASOLA V., *Hydrogeological report*, IFLGS Bucureşti).

[9] See footnote 4.

Table 3

Hydrogeological balance of Moneasa area (Hydrographic basins of Megheş. Băilor and Pietros brooks) October 1975 — September 1976 hydrologic year

Elements	U.M.	Hydrograph. basin of Megheş brook	Hydrograph basin of Băilor brook	Hydrograph basin of Pietros brook	Tinoasa-Izoi endorheic basin	Total area
Surface	km^2	6,9	1,38	1,65	4,5	14,43
Mean altitude above sea level	m	587,0	505,0	531,0	775,0	653,0
Mean annual air temperature	°C	7,4	7,8	7,7	6,7	7,1
IMPUT						
— Mean annual rainfall	mm	1.079,4	992,8	1.020,0	1.124,5	1.077,6
	x10^3 cu.m	7.448,0	1.370,0	1.683,0	5.060,0	15.561,0
OUTPUT						
— Evapotranspiration	mm	461,3	465,0	447,5	446,2	453,7
	x10^3 cu.m	3.183,0	615,0	738,0	2 008,0	6.544,0
— Runoff	x10^3 cu.m	2.336,0	—	763,0	—	3.099,0
— Emergences	x10^3 cu.m	—	5.313,0 [1]	—	—	5.313,0
— Catching of water for domestic use	x10^3 cu.m	34,0 [2]	33,0 [3] 209,0 [4]	—	—	276,0
— Output from hydrogeological karst system downstream of the gauging cross sections	x10^3 cu.m	101,0 [5]	208,0 [6]	—	—	309,0
Total OUTPUT	x10^3 cu.m	5.654,0	6.378,0	1.501,0	2 008,0	15.541,0
Variation of water resources $\pm dW$ = IMPUT — OUTPUT	x10^3 cu.m	1.794,0	—5.008,0	182,0	3.052,0	20,0

[1] Emergences in Băilor brook measured in the No. 2, gauging cross section ;
[2] The S_2 well ;
[3] Grota Ursului spring catchment ;
[4] The spring 1 and 2 caught for domestic use ;
[5] The S_4 well ;
[6] The S_5 well.

the Grota Ursului spring and spring 1, spring 2 and well S_2 thermal sources.

Exist from the hydrogeological karst system draining in the surface flow downstream of the monitoring sections are represented by the waters discharged by wells S_4 and S_5 which were not in use in the period the balance was drawn up.

The balance that could be drown shows — in the error interval of five per cent, which is acceptable in hydrometric measurements — a fine concordance between the inlets and outlets estimated for the entire area taken into consideration. It also points to a serious lack of concordance between the areas of the hydrographic and hydrogeologic basins in the zone under study (see tables 3 and 4).

The tracer labellings that have been performed render this image more intricate, in the sense that the area taken into consideration features both inlets from he Brătcoaia depresion and outlets through the Megheș—Piatra cu Lapte diffluence surface. The values of those contributions are probably equal and cannot be sensed in balance calculations.

On the other hand, this situation is relevant for the difficulties encountered in the hydrogeological research of a karst area, and highlights the need for an approach through several methods.

8. WATER CHEMISM

The chemism of the cold and thermal waters at Moneasa is calcic-magnesian with low mineralization (Table 5). Overall mineralization declines in the case of the springs on the Băilor brook as temperature rises (fig. 13) and a direct relationship may be noted between the

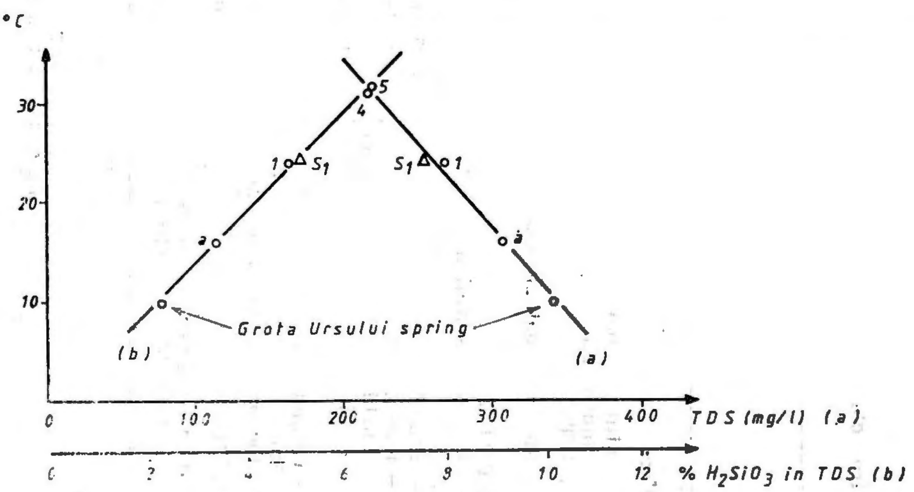

Fig. 14. The relation between TDS(a), % H_2SiO_3(b) and temperature of sources in Băilor brook.

Table 5

Variation range of chemical composition for the waters sampled in Moneasa area in 1970—1977 time interval (mg/l)

Sources	n	TDS x	T(°C)	Cl^-	SO_4^{--}	HCO_3^-	Na^+	K^+	Ca^{++}	Mg^{++}	Fe^{++}	CO_2	H_2SiO_3
Thermal spring No. 1	7	228 3	24.0	3.5		146.4	1.7	1.2	25 6	13.1		8.8	10.3
		348.1		7.1	15.3	219 6	21.0	3.1	40.0	17.0	0.1	17.6	12 9
Thermal spring No. 2	3	242.6	24.0	7.1	5 7	158.6	1.4		32.1	14.5	0.1	8.8	12 9
		246.3		7.0	7.6	159.6	4.7		33.6	14 6	0.1	8.8	12 9
Thermal spring No. 4	5	214.5	31.0	13.5		134.2	0.1	2.0	18.4	12.2	0.1	8.8	12 9
		269.8		14.2	15.3	170.8	11.5	2.6	36.4	15.0	0.2	13.2	23.3
Thermal spring No. 5	6	217.6	31.2	3.5		134.2	1.2	2.3	15.2	11.4	0.1	4.4	12 9
		252.3		14 2	17.2	170.8	10.9	2.6	28.0	22.4	0 3	8.8	18.1
Subthermal spring "a"	3	291.5	13.4	7.0		207.0	2.1		36.8	18.5	0.1	8.8	7.7
		356.1	14.9	14.2	9.6	231.8	15.9		44.1	18.7	0.1	17.6	10.5
Subthermal spring "e"	1	240.2	24.5	7.0	3.8	158.6	1.3		33.6	14.1	0.1	8.8	12 9
Tămăduirii spring	2	319.6	15 0	7.0	5.7	207.4	5.0		44.0	13.1	0.1	8.8	12 9
		329.6	24 0	7.1	11.5	219.6	10.4		52.9	14.8	0.1	13.2	15.5
Spring near the stadium	3	205.2	14.0	7.1		128.1	3.7	1.2	28.4	6.3	0.1	—	15.5
		242.2	17.5	14.2	7.7	158.6	10.8	1.2	38.4	10 2	0.1	8.8	20.7
S1 well	5	217.6	24.0	3.5		146.4	0 4	0.5	13.6	12.1	0.1	8.8	10.3
		295 5		7.1	16.3	183.0	11.5	1.7	39 2	23.8	0.2	17.6	12 9
S2 well (4662)	5	231.1	29.0	3.5		146 4	0.8	1.0	20.8	6.3	0.05	8.8	12 9
		254.5		7.1	5.7	170.8	3.1	1.6	44.6	16.0	0.5	17.6	15.5
S4 well (4664)	3	197.8	32.5	7.1	3.8	134.2	7.2	2.1	20.0	12.1	0.1	8.8	15.5
		257.7		7.1	9.6	158.6	17.1	2.4	24.0	12.9	0.2	17.6	18.1
S5 well (4666)	3	182.3	15.9	7.1		109.8	0.1	1.4	18.4	9.4	0.1	8.8	12 9
		195.3		7.1	5.7	122.0	6.8	1.6	20.2	15.5	0.2	8.8	16.1
Grota Ursului spring	5	274.7	7.0	3.4		195.2	1.4		40.0	6.2	0.1	—	3.9
		405.7	9.0	10.6	11.5	286.6	28.3		76.1	24.3	0.1	22.0	12.0

n = number of observations
* = calculated values
Note : Analysis performed in the laboratories of I.P.G.G. Bucharest.

Table 4

Surface of hydrographic and sydrogeologic basins in Moneasa area

		Hydrographic basin km²	Hydrogeologic basin km²
1.	Megheş brook	6,9	3,6
2.	Băilor brook	1,38	11,6
3.	Pietros brook	1,65	1,3
4.	Izoi-Tinoasa endorheic basin	4,5	0

H_2SiO_3 content and temperature. In time, the chemical composition of the water of the thermal springs fluctuates substantially, the most significant variation being recorded in the case of the ionic species Na^+ and SO_4^{--}. These variations show that cold karst waters are the origin of the thermal waters at Moneasa.

The No· 1 and 2 thermal springs feature low releases of gases with a composition that is identical to that of atmospheric gas. These releases are generated by the exit from solution of he atmospheric gas dissolved in cold waters as their temperature rises (Table 6).

Table 6

Chemical composition of the gas outflowing from thermal springs

Compound (%)	Thermal spring No. 1	Thermal spring No. 2
CH_4	0.3	7.7
CO_2	0.3	1.0
O_2	20.8	19.1
N_2	77.6	71.2
Ar	0.89	0.82
He	0.0	0 05

Note : Other compounds for which the gases were analyzed, C_2H_6, C_3H_8, C_4H_{10}, H_2 are lacking.

The complet measurements performed by Szabo and Iosif (1967) of the radioactivity of the thermal waters at Moneasa, indicate values ranging from 0,69 to 1.0 nCi, figures which place them far below of 29-nCi, limit which make waters radioactive.

ACKNOLEDGEMENTS

I should like to most warmly thank Francisc Palfy, head of the hydrologic station at Moneasa, for his support in processing the hidro-meteorological data needed to draw up a hydrogeological balance, as well as for our numerius talks on with the hydrology of this area.

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STUDIUL HIDROGEOLOGIC AL ZONEI MONEASA

Rezumat

Cercetările hidrogeologice complexe efectuate în zona Moneasa au evidenţiat prezenţa unui vast sistem hidrogeologic carstic (s.h.c.) în depozitele predominant carbonatice ale Pînzei de Finiş.

Marcările cu trasori şi bilanţul hidrogeologic au precizat extinderea spre nord a s.h.c. pînă în depresiunea de contact litologic Brătcoaia, apele infiltrate prin ponoarele din partea nordică a acestei depresiuni suferind o difluenţă, ele participînd atît la alimentarea izvorului Finişului şi Feredeu situate la nord, cît şi a izbucului Grota Ursului şi a surselor termale de la Moneasa situate la sud.

Izvorul Grota Ursului are un debit mediu de 121.4 l/sec., iar hidrograful debitelor acestei surse în perioadele neinfluenţate este caracterizat prin mai mulţi coeficienţi de secare, reflectînd un mod complex de alimentare, circulaţie, stocare şi descărcare a acumulărilor acvifere.

În partea sudică, la contactul cu depozitele impermeabile ale Pînzei de Moma, apele s.h.c. sînt local termalizate ca urmare a unui aport lateral de ape carstice cu temperatură ridicată. Aceste ape au la origine ape carstice reci antrenate într-o circulaţie profundă, parcurs în care temperatura lor a crescut ca urmare a fluxului termic regional ridicat (80 mW/m^2).

Sursele de ape termale captate sînt reprezentate prin cele 4 izvoare, cu temperaturi de 24—30.8°C, situate pe pîrîul Băilor şi prin 3 sonde ce debitează apă cu temperatui de 24—32.8°C. Debitul cumulat al acestor surse este de 17 l/sec. Caracterul chimic al apelor termale este bicarbonatat calcio-magnezian cu mineralizaţie mică, asemănător apelor carstice reci.

Rezervorul hidrotermal prezintă transmisivităţi de 221.2—630.1 m^2/zi şi coeficienţi de înmagazinare de 0.072—0.33, valorile mai ridicate fiind înregistrate pe direcţia generală nord—sud, corespunzătoare direcţiei principale de fisurare a depozitelor carbonatice şi stratificaţiei acestora.

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AQUIFEROUS INTERCONNEXIONS IN THE MOTRU-IZVARNA-TISMANĂ-BISTRIȚA KARST AREA

BY

D. RĂDULESCU, I. STĂNESCU, E. GAȘPAR, A. BULGĂR

The hydrologic and hydrogeologic studies conducted in the karst area situated in between the Bistrița and the Motru Sec rivers led to a number of hypotheses concerning the origin and area of supply of the Izvarna springs. These hypotheses could be verified and three different karst systems were outlined by labelling six rivers in the area with activable tracers.

1. INTRODUCTION

One of the most complex hydrogeologic structures and the karst interconnexions extending on more than 800 sq.km could be rapidly deciphered through tracer investions that were corroborated by hydrogeologic research and hydrometric measurements.

The results thus obtained allowed the computation of : water balance, permeability, transmissivity, possible water yeld, according to hydraulic gradient and the volume of stored water and in keeping with the degree of fissuration of the rock types encountered in the Izvarna springs area.

The Izvarna karst springs, with a flow of roughly 2 cu.m sec and a variation coefficient of 1.4 + 2.0, which places them among the most constant partially caught (0.9 cu.m/sec) karst springs in Europe, are a major source of potable water supply for Craiova town.

The Izvarna springs, situated some 30 km west of Tîrgu-Jiu, made the theme of both older (Constantinescu, 1980) and more recent studies, which consisted mainly of systematic measurements of flows. As for the source of supply and the circulation of groundwater, the studies lacked the support of palpable data and so were confined to mere hypotheses. The respective studies were performed on an area between the Cerna and the Motru rivers to the west, the Jaleș and the Bistrița to the east and the western Jiu basin to the north.

2. GENERAL GEOMORPHOLOGIC AND GEOLOGIC ELEMENTS

In therms of geomorphology, the area under consideration consists of two major units : a mountainous area to the north-north-west, and a depressionali area (the Getic Depression) to the south-south-east ; the springs emerge at the point of contact between the two units.

The mountainous area is situated on the outskirts of the Vîlcan mountains, with heights ranging from 1,200 to 1,400 m in the north ; to the south, these heights decline, so that at the Getic Depression limit they do not exceed 400—to—500 m.

In front of the springs, the level difference between the mountainous area and the depressional zone, whose relief is roughly 200 m in height, is poignant.

The hydrographic network includes three major rivers — the Motru (roughl 4 km west of Izvarna), the Tismana (6 km to the east) and the Bistrița (some 15 km to the east) — as well as their tributaries.

These springs, together with the Pocruia brook, form the Orlea, a right-hand tributary of the Tismana.

The main watercourses generally flow from the north-north-west to the south-south-east and run transversely to the south-eastern slope of the massif, that is to the limit between the mountainous and depressional units.

The fact is noteworthy that in the area were a passage is made from the mountainous to the depressional zone the thalweg of the rivers stands at heights superior to those of the Izvarna springs, a difference ranging from several ten of metres to more than 100 metres.

Geological conditions in the area characterized by the presence of a bed of crystalline, metamorphic and igneous rocks and a Tertiary and Quaternary Mesozoic sedimentary cover. (Fig. 1).

Metamorphic rocks develop upstream, that is north of the Motru, Tismana and Bistrița basins, in between the Jaleș and the Bistrița, and extend almost to the Getic Depression limit.

Igneous rocks mostly develop upstream and in the mid part of the Tismana and Pocruia basins and can be found on the eastern side of the Motru basins and also though in smaller numbers, on its western side. They are mostly represented by granitoid rocks, known as Șușița and Tismana type granitoids.

Mesozoic formations belonging to the Jurassic and the Cretaceous, which include conglomerates, sandstones and limestones in plates and massifs, are to be found in the western part of the Motru basin (north and South of the Motru Sec), on the right-hand bank of the Motru, between the localities of Cloșani and Calugareni and in the form of a roughly-30-km-long band situated north-west of the Getic Depression limit and crosses the Motru, the Pocruia, the Tismana and Bistrița almost perpendicularly. This band (wherefrom the Izvarna springs emerge at the point of contact with the Getic Depression Tertiary) is 1-to-4 km wide. Mesozoic deposits also occur as isolated „patches" discontinuously placed above granitic rocks. Isolated, discordant and transgressive Upper Cretaceous (marls, marllimestones and clays) is well represented west of the Motru.

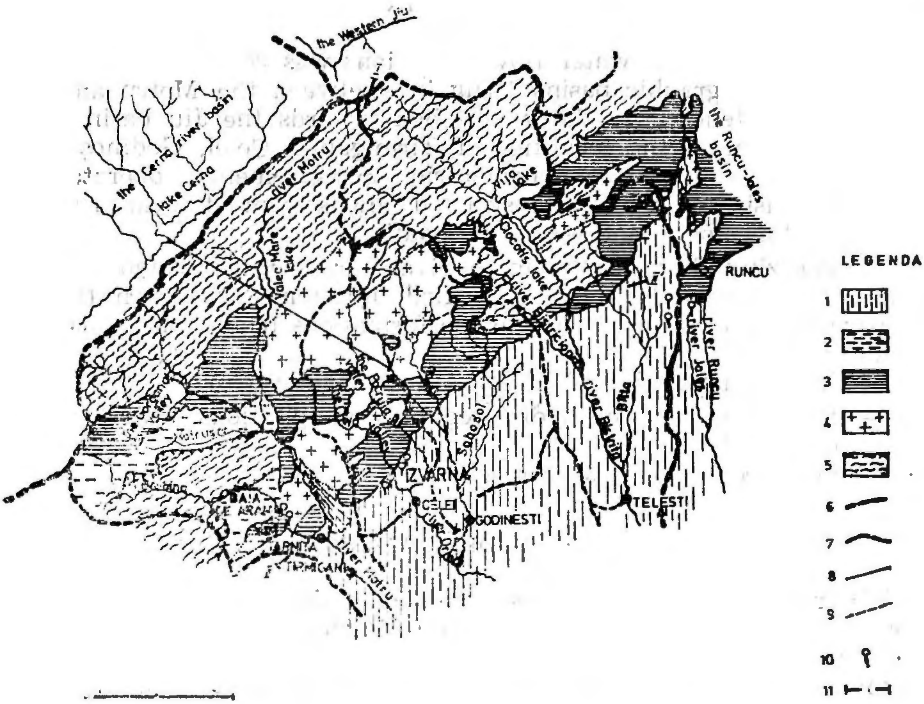


Figure. 1. Sketch showing the geological structure and a delimitation of hydrographic basins. 1. Neocene: clays, marls, sands. 2. limestones, marl-limestones; and Jurassic: conglomerates, sandstones, 4. Magmatic kocks: granitoids, 5. Metamorphic rocks: paragneisses, mica schists. 6. Limit of the area under investigation. 7. Hydrographic bassn limit. 8. Head races in operation.)9. Head races under con struction. 10. Springs. 11. Sections.

The bed and the Mesozoic sedimentary deposits on the southern side
tributions are probably equal and cannot be sensed in balance calcula-
of the Vilcan mountains are covered by the Tertiary-Neocene deposits of the Getic Depression, which include marls, clays and clayey sands in particular.

The Quaternary develops more amply on the Motru Valley in the form of a dejection cone whose width exceeds 1,5 km in the Pades area.

The Vîlcan mountains region boasts the tectonic style specific of the Southern Carpathians, the crystalline bed supporting several tectonic cycles, considering that in most cases the sedimentary deposits are solid with the bed, boasting a bed-like tectonic style characterized by numerous fractures. Most of the fractures are post-Cretaceous.

Downstream of the Motru—Motru Sec confluence on the western side in particular, a nappe formed by the Getic overthrust an extensive tectonic phenomenon which made huge masses of metamorphic rocks thrust over sedimentary formations.

3. WATERS REGIME IN THE AREA

A study of surface-water flow conditions was conducted by investigating the hydrographic basins lying in between the Motru and the Bistriţa and extending to the water-shed towards the Jiu basin in the north and down to the localities of Tirmigani, Celei, Godineşti, and Teleşti-where stations for hydrometric measurements operate on a permanent basis and which are situated downstream of Izvarna springs and of the limestone band — to the south.

Emphasizing that all the main rivers cross the metamorphic and granitic rocks as well as the karstified limestones and then flow on downstream to relatively impermeable formations (clays, marls, a.o) and considering :

— the characteristics of basins (area, altitude, a.o) ;

— the elements of the hydric regime (precipitations, runoff, evapotranspiration, a.o).

The following conclusions were reached.

3.1. THE HYDRIC BALANCE

Water balance computations showed a discharge deficit at the hydrometric measuring stations on the Motru, Tismana and Bistriţa which amounts to 2.117 cu.m/sec, accounting for roughly 15 per cent of the total flow of the discharges corresponding to basin areas. Furthermore, the hydric balance shows a surplus discharge on the Orlea (which mainly consists of the flow of the Izvarna springs), which stands at 1.44 cu.m/sec) (Table 1).

Even in the case of low discharges when the overall value of the total losses on rivers (0.662 cu.m/sec) is far lower than that resulting from the balance (2.117 cu.m/sec), the Izvarna springs discharge is a volume of underground water stored in rocks, which supplies the Izvarna springs even in longer periods of drought and is responsible for the low variation coefficient characteristic of the flow of the springs.

3.2. HYDROMETRIC MEASUREMENTS

With the aforesaid elements as a basis, expeditionary hydrometric measurements were performed in sections situated upstream and downstream of the limestone band. While measurements were performed on rivers, recordings were made of the Izvarna springs discharges.

The expeditionary measurements on flows in September and November 1984 (which was a period of drought) confirmed the losses registered when the limestone band is crossed as was highlighted in mappings.

These losses (in case of low river discharges which roughly correspond with the monthly minimal discharges, with level of confidence of 95 per cent) were :

— 0.416 + 0.383 cu.m/sec on the Bistriţa, accounting for 37—39 per cent of the river discharge upstream of the limestones ;

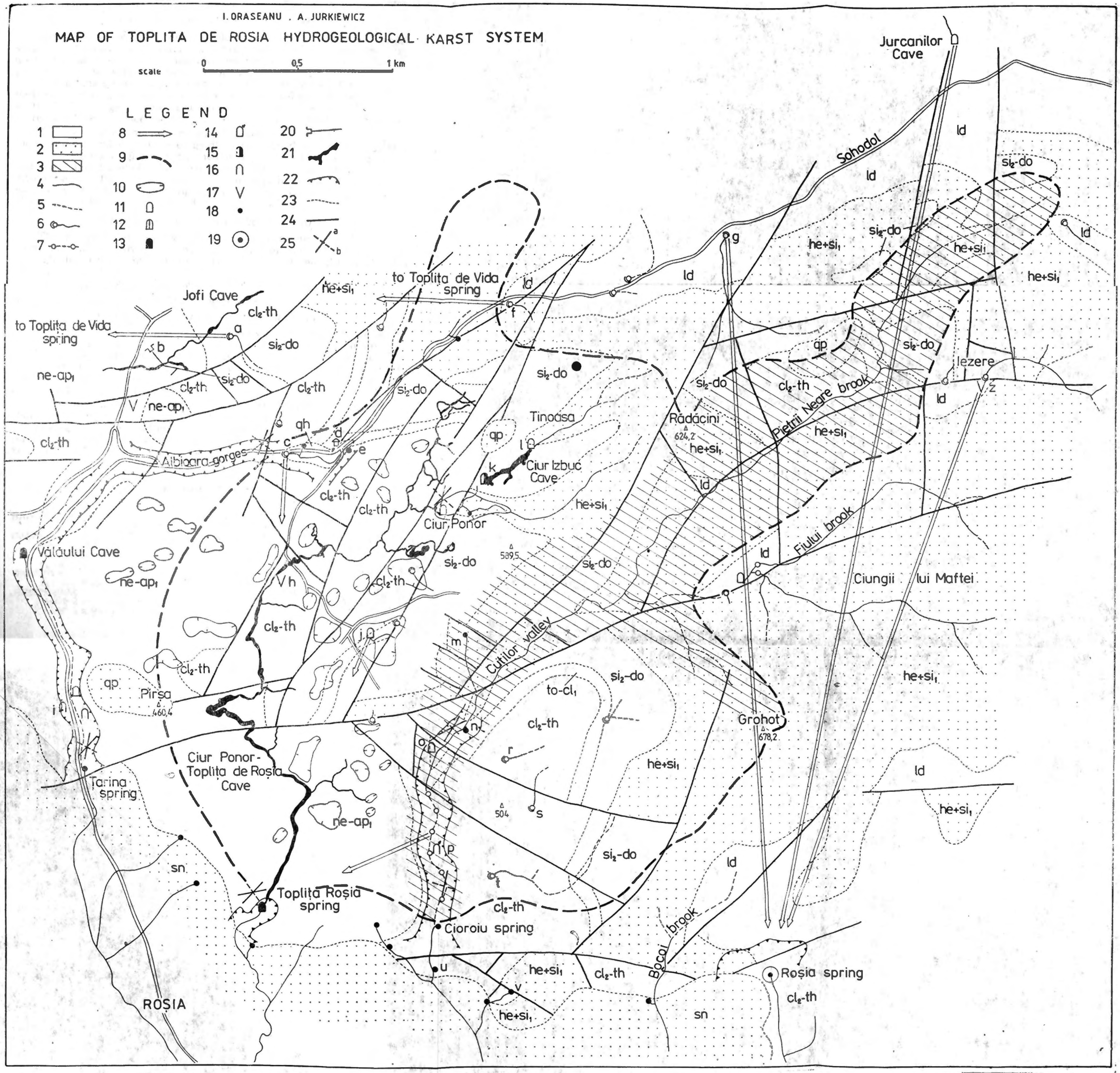


Fig. 2. Map of Toplița de Roșia Hydrogeological karst system (Geological data after D. Patrulius et al., 1983 and S. Bordea et al., 1986; Jofi cave map after I. Povară and V. Lascu; Ciur Ponor-Toplița de Roșia cave map after P. Brijan, A. Jurkiewicz, H. Mitrofan, I. Orășeanu, G. Ponta, and "Emil Racoviță", București, "Focul Viu" București, CSA Cluj Napoca, "Cristal" Oradea, GES București speological clubs). a — Baia Nișului ponor; b — Jofi mine gallery; c — Albioara ponor; d — Albioara forest range; e — Blue spring; f — Poiana Prie ponor; g — Perje ponor; h — Boului pathole; i — Vacii cave; j — Doboș cave; k — Ciur Izbuc cave; l — Tinoasa ponor; m — Ciocanul spring; n — Vilii spring; o — Vacii cave; p — Peștera care cîntă cave; r — Groapa Vilii; s — Groapa lui Oaidă; t — Tiișului ponor; u — Fîntîna Miclii; v — Cioroiul lui Mitireag; ld — Ladinian (recifal white limestones); he+si_1 — Lower Sinnemurian + Hettangian (quartzitic sandstones); si_2-do — Domerian-Upper Sinnemurian (encrinitic sandy limestones, limestones with Griphaea, limestones with cherts); to-cl_1 — Lower Callovian-Toarcian (limestones with Entolium, marls); cl_2-th — Tithonic-Upper Callovian (limestones); ne-ap_1 — Lower Aptian-Neocomian (limestones with pachyodonts); sn — Senonian (sandstones, shales); qp — Pleistocene (sands, gravels). *Legend:* 1 — Karstifiable terraines; 2 — Nonkarstifiable terraines; 3 — Diffluence surface; 4 — Permanent surface course; 5 — Temporary surface course; 6 — Ponor; 7 — Losses in flow along the riverbed; 8 — Underground connection established by tracer method; 10 — Karst depression; 11 — Permanent inflow cave; 12 — Temporary inflow cave; 13 — Permanent outflow cave; 14 — Cave tapping a underground stream; 15 — Temporary outflow cave; 16 — Fossil cave; 17 — Fossil pathole; 18 — Spring with approximate average flow under 5 l/s; 19 — Spring with approximate average flow from 20 to 100 l/s; 20 — Mine gallery; 21 — Cave passage; 22 — Key; 23 — Geological boundary; 24 — Fault; 25 — Main direction of rock fracturation, a — chear cracks b — tensile cracks.

Table 1

Synoptic table with elements of the hydric blance and the results of ba!ance computations

Basin of the river	Hydrometric station	Area "F" km²	Basin average altitude Hm (m)	Precipitation (mm)	Evapotranspiration (mm)	Surface flows Q (m³/s)	Hydric balance (m³/s) dw	Hydric balance (m³/s) Σdw
Motru	Tirmigani	302	902	1160	432	6.84	—0.318	—0.675
Tismana	Godineşti	126	501	1040	426	1.60	—0.851	
Bistriţa	Teleşti	270	721	1120	430.7	4.95	—0.948	
Orlea	Celei	61.8	573	1060	427.4	2.68	+1.441	
Total basin: Motru + Tismana + Bistriţa + Orlea	Tirmigani Godineşti Teleşti Celei	759.8	—	1125.7	430.2	16.07	—0.676	—
Tismana + Bistriţa + Orlea	Godineşti Teleşti	457.8	—	1089.8	428.9	9.23	—0.358	—

— 0.087 — 0.020 cu.m/sec on the Tismana, representing 17.6 + 5 per cent of the river discharge upstream of the limestones ;

— the Cheia Valley loses the valley flow completely (100 per cent);

— 0.159 cu.m/sec on the Motru, which accounts for 31 per cent of the river discharge at the respective date.

Total losses measured in September (less the Motru) amount to 0.529 cu.m/sec and those registered in November (the Motru included) stand at 0.662 cu.m/sec.

The discharges of the springs (including the flow conveyed to Craiova) stood at 1.682—1.793 cu.m/sec.

The results of the expeditionary measurements are given in Table 2.

Comparing the overall losses of 0.662 cu.m/sec with the discharge of the springs in the same period, a surplus worth 1.020—1.131 cu.m/sec results as Izvarna. Adding to the river losses the total seepage from the Cheia Valley and the infiltrations on the Sohodol and the Pîrgav, which amounts to 0.150 cu.m/sec, a spring surplus remains (in the respective period) of roughly 0.8—0.9 cu.m/sec.

The only explanation for this surplus, which was registered in a period of drought, is a water reserve stored in rocks (limestones, granites and metamorphic rocks).

The hydrometric measurements which confirmed substantial flow losses on the rivers that cross the limestones, led to the hypothesis that the springs are mostly supplied by the losses registered on the rivers and brooks in the east and the west-the Motru, the Tismana, the Bistrița, the Sohodol, a.o.

4. EXPERIMENTAL RESULTS

1. An insurgence on the left-hand bank of the Bistrita, at the entrance into the limestone area, was directly labelled.

The tracer could be detected only in the group of uncaught springs at Izvarna. The time dependent variation curve of the tracer concentration is given in Figure 2. The three distinct peaks suggest an organized drainage network. The short tracer transit time in the case of the uncaught springs (less than 10 days) indicates both a rapid flow through the conduit-type karst holes and the lack of a substantial underground reservoir. The auxiliary systems of the karst structures (Mangin, 1974) ca be emptied of their waters owing to a long period of drought, in which case the transited flow depends only on the water losses from surface sources.

The fact that tracer was not detected in the caught Izvarna springs does not rule out a possible link with the Bistrita as they probably belong to the same hydrocarst system.

2. The Valley of the Pîrgav, a tributary of the Sohodol, a river that belongs to the Tismana basin, was a ponor with total loss at the time of the labelling. After labelling it with In-EDTA the tracer was detected both in the caught and uncaught Izvarna springs. The tracer transfer curves are given in Figure 3.

Table 2

Flows resulting from expeditionary measurements (september—november 1984

River	Position of sections	Registered flow		Flow difference between section	
		27, 28 IX 1984 (m³/s)	15, 16 XI 1984 (m³/s)	27, 28 IX 1984 (m³/s)	15, 16 XI 1984 (m³/s)
Bistrița	Limestones—Upstream Lomestones Downstream	1.130 0.714	0.551 0.168	—0.416	—0.383
Bistricioara	Limestones—Upstream Lomestones Downstream	0.184 0.182	0.074 0.080	—0.002	+0.006
Tismana	Limestones—Upstream Lomestones Downstream	0.495 0.408	0.423 0.403	—0.087	—0,020
Pocruia	Limestones—Upstream Lomestones Downstream	0.113 0.142	— —	+0.029	—
	Limestones—Upstream Lomestones Downstream	0.138 0.144	— —	+0.006	—
The Cheia valley	Limestones—Upstream Lomestones Downstream	0.026 0.000	— —	—0.026	—
Motru	Limestones—Upstream Lomestones Downstream	— —	0.386 0.511	—	+0.125
	Limestones—Upstream Limestones Downstream	— —	0.508 0.349	—	—0.159

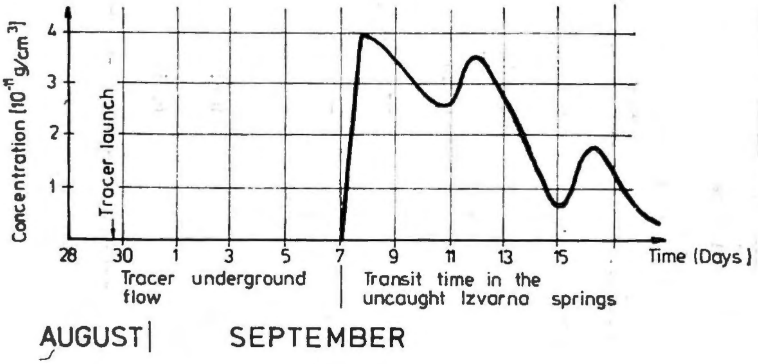


Figure 2. Tracer transfer curve at the uncaught Izvarna springs after the insurgence in the Bistrița river thalweg has been labelled with In-EDTA.

The extension of the tracer cloud for a duration of 22 days in the case of the uncaught springs (a maximum concentration being attained 17 days after labelling) leads to the assumed existence of an underground drainage network, which forms an aquiferous basin. Tracer passage though the caught springs for an interval shorter than that registered in the case of the uncaught springs is probably due to local hydrodynamic conditions.

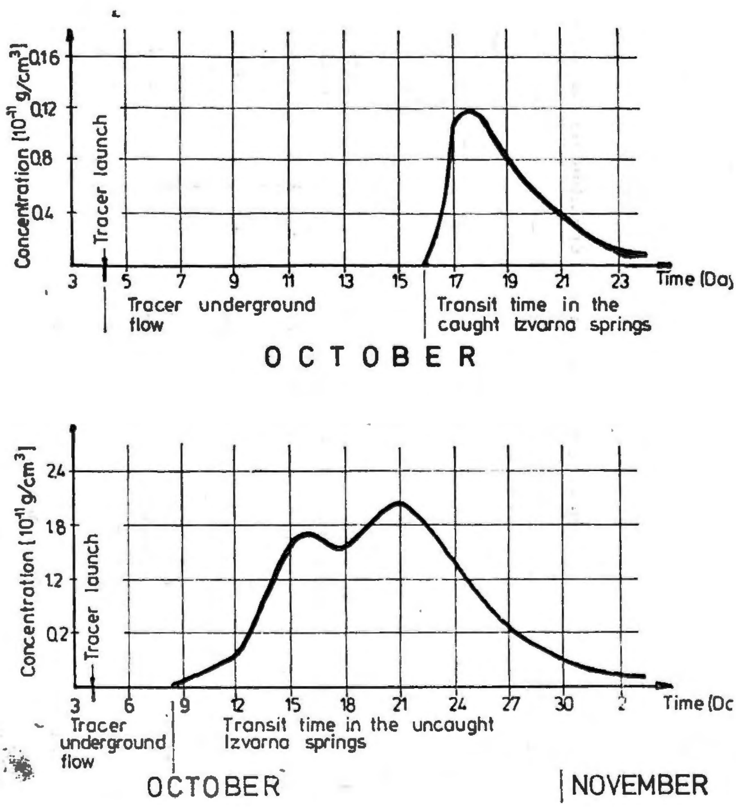


Figure 3. Trannfer curves at the caught Izvarna springs (top) ond the uncaught Izvarna springs (bottom), after the insurgences in the Pîrgav river thalweg have been labelled with In-EDTA.

3. Labelling occurred also on the Tismana springs for which hydrogeologic pointed to certain losses (20 l/sec from a flow of 423 l/sec).

That the tracer did not emerge in any of the monitoring points was considered to have been caused by launching conditions (tracer injectare occurred in a difuse area) which considerably diminished the chances detection.

4. Although the limestone zone is traversed in the Pades area by the Motru, whose minor bed is not situated directly on the rock and which flows on an alluvial bed 10 m thick and as hydrometric measurements showed a flow loss of 159 l/sec (accounting for 40 per cent of the river flow at that time) a tracer labelling was performed considering that the loss was difuse when the alluvia above the limestone are crossed.

The tracer was injected directly in the alluvial bed with the help of a special device. It was followed for a relatively long interval, though daily samples were not taken systematically. Nevertheless, the tracer was detected in a number of samples, as Figure 4 shows, which indicates the existence of a drainage between the Motru and the caught Izvarna springs.

5. The Motru Sec Area. Flow losses from both the Motru Sec and its more important tributaries were considered a pontetial source of supply for the Izvarna springs.

Consequently, a ponor in the Gorgan valley and an insurgence in the Motru Sec thalweg were separately labelled.

Both tracers were detected and measured in the Baia de Arama springs. The tracer transfer curves in the two major springs — the Bolboros and the Muncelu-resulting from an In-EDTA labelling of the insurgence in the Motru Sec are shown in Figure 5.

The labelling performed in the Motru Sec area proved that the drainage was different from previous ones. This area belongs to a different karst system and is in no way linked to the Izvarna springs.

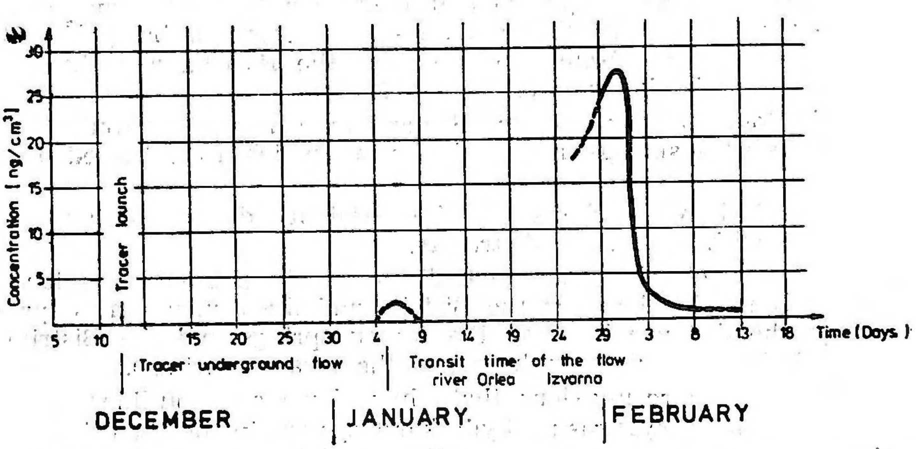


Figure 4 — Transfer curve at the Izvarna springs after the waters in the Motru river thalweg in the Padeş area have been labelled with In-EDTA.

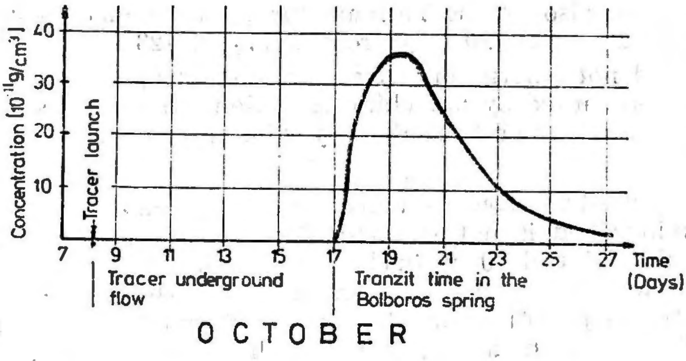
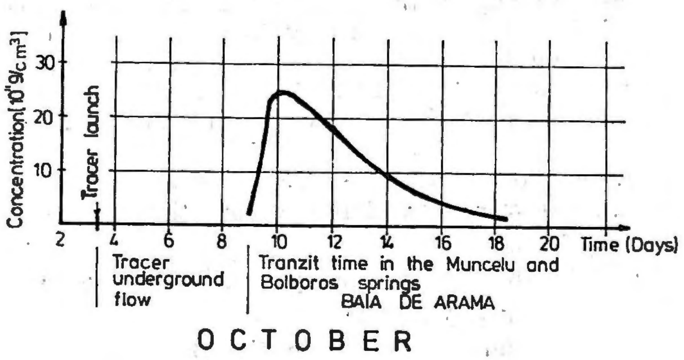


Figure 5. Transfer curves at the Bolboros spring (top) and *the Muncelu spring* (bottom) in Baia de Aramă, after the insurgences in the Motru Sec River thalweg have been labelled with In-EDTA.



Conclusions of tracer Investigations

The analysis of the geologic, hydrologic and hydrochemical data and of activable tracer labellings confirmed certain hypotheses on the existence on karst interconnexion. So, for instance belonging to different hydrographic systems are partially drained towards the Izvarna springs. These water courses are the Bistriţa — and very probably the Bistricioara, too — the Pîrgav, the Tismana, the Pocruia and the Cheia Valley (most probably), as well as the Motru.

As for losses from the Motru Sec and the Gorgan its tributary they drain towards the springs in Baia de Aramă, which are collected by the Brebina.

Figure 6 shows a scheme for the drainage directions that were established with the help of tracers.

Moreover, activable tracer labellings clearly pointed to a lack of hydraulic connexion between the Bistriţa and the Runcu—Jaleş springs (although the distance between the Runcu springs and the Bistriţa is very small in comparison with that to the Izvarna springs).

The karst interconnexions that have been set outline as many distinct hydrokarst systems : a hydrokarst system in the Baia de Arama —Motru Sec area, another in the Runcu—Jaleş area and a third, in which the Izvarna springs area included.

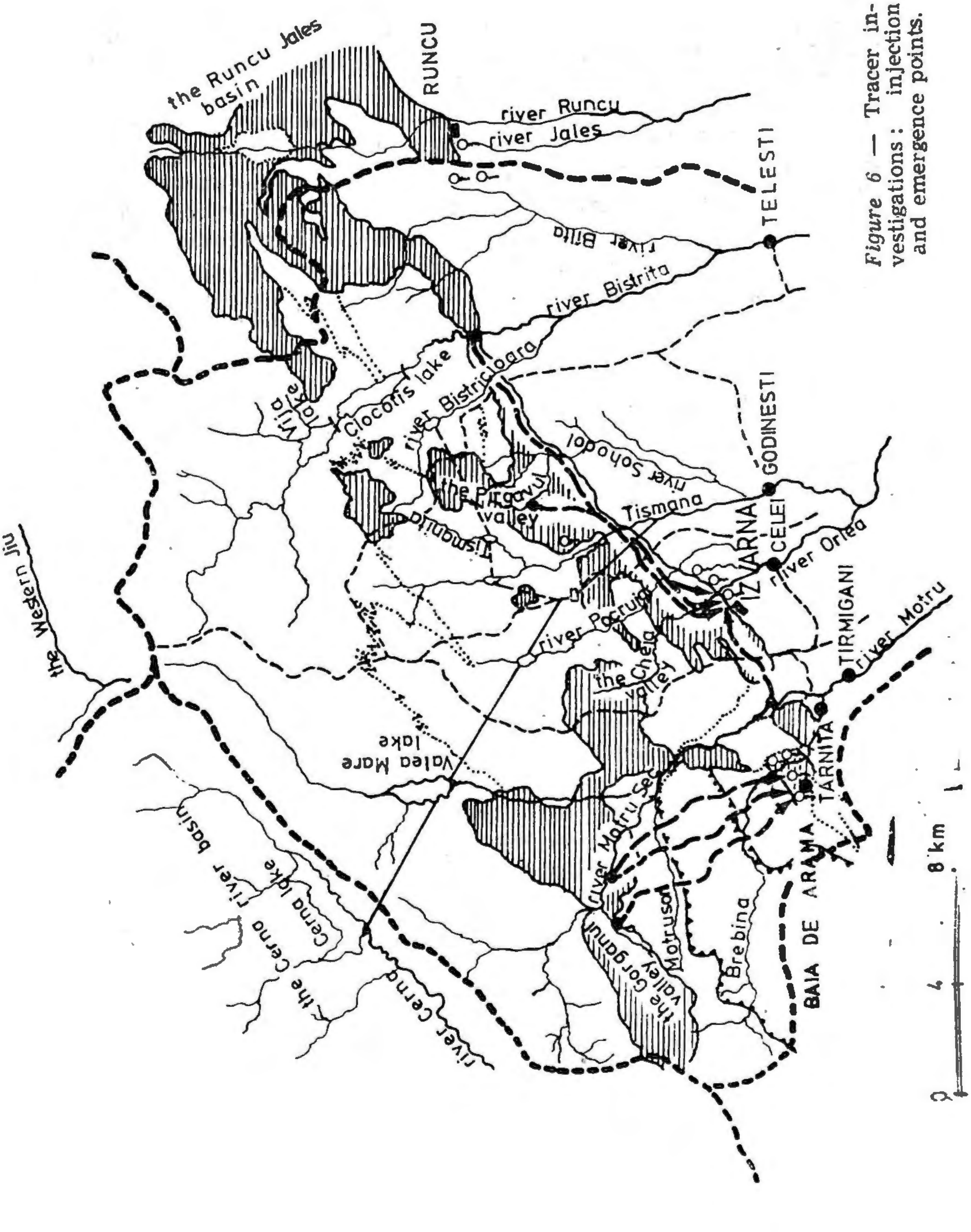


Figure 6 — Tracer investigations: injection and emergence points.

5. HYDROGEOLOGIC STRUCTURE — THE IZVARNA HYDROKARST SYSTEM

In consideration of the features of relief and of the position of various types of rocks, as well as of the height of the springs, the tendency becomes apparent of the water infiltrated into the ground at superior heights to drain towards the limestone band (Figure 7 shows the drainage of the waters infiltrated into the ground at superior heights towards the lmestone band); at the same time, water also circulates along this band, from the east and the west towards the Izvarna springs.

As the Izvarna springs are situated at the lowest height on the permeable limestone-impermeable Neocene contact, the discharge is convergent and this point acts as an over-flow of the hydrogeologic structure. Figure 8 shows the circulation of waters along the limestone band and the hydrokarst system that provides for he supply of the springs from rivers.

The conclusion is that springs are supplied from both infiltrations in the ground from precipitations (whose values and gradients are determined by rock permeability) and from the rivers and valeys that cross the limestone zone at superior heights. The infiltrations from precipitations represent a fluctuating source, while hose from rivers are

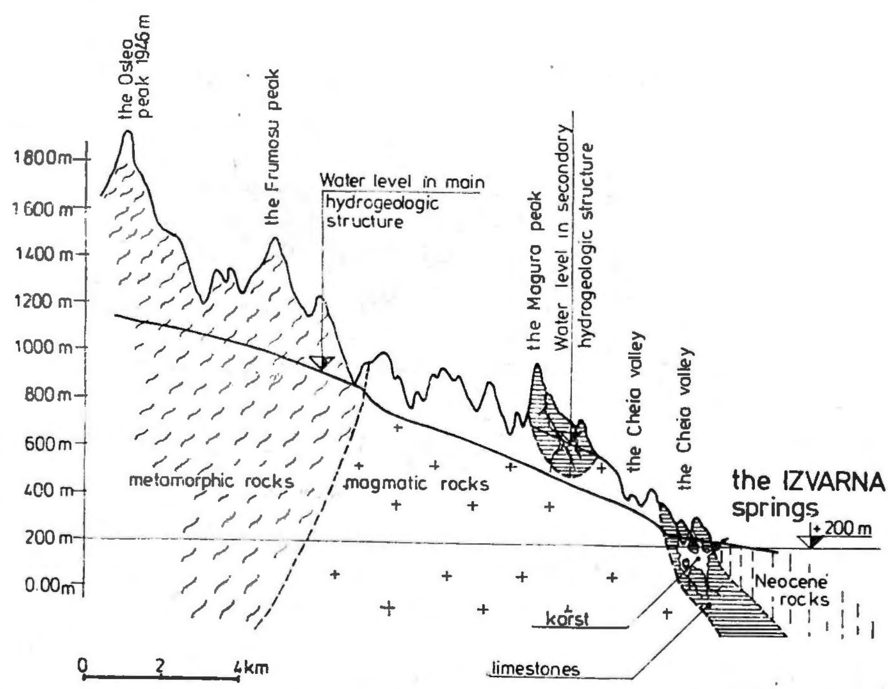


Figure 7. I—I' cross section on the limestone band (which runs parallel to the river) and a scheme of probable hydrogeologic structures.

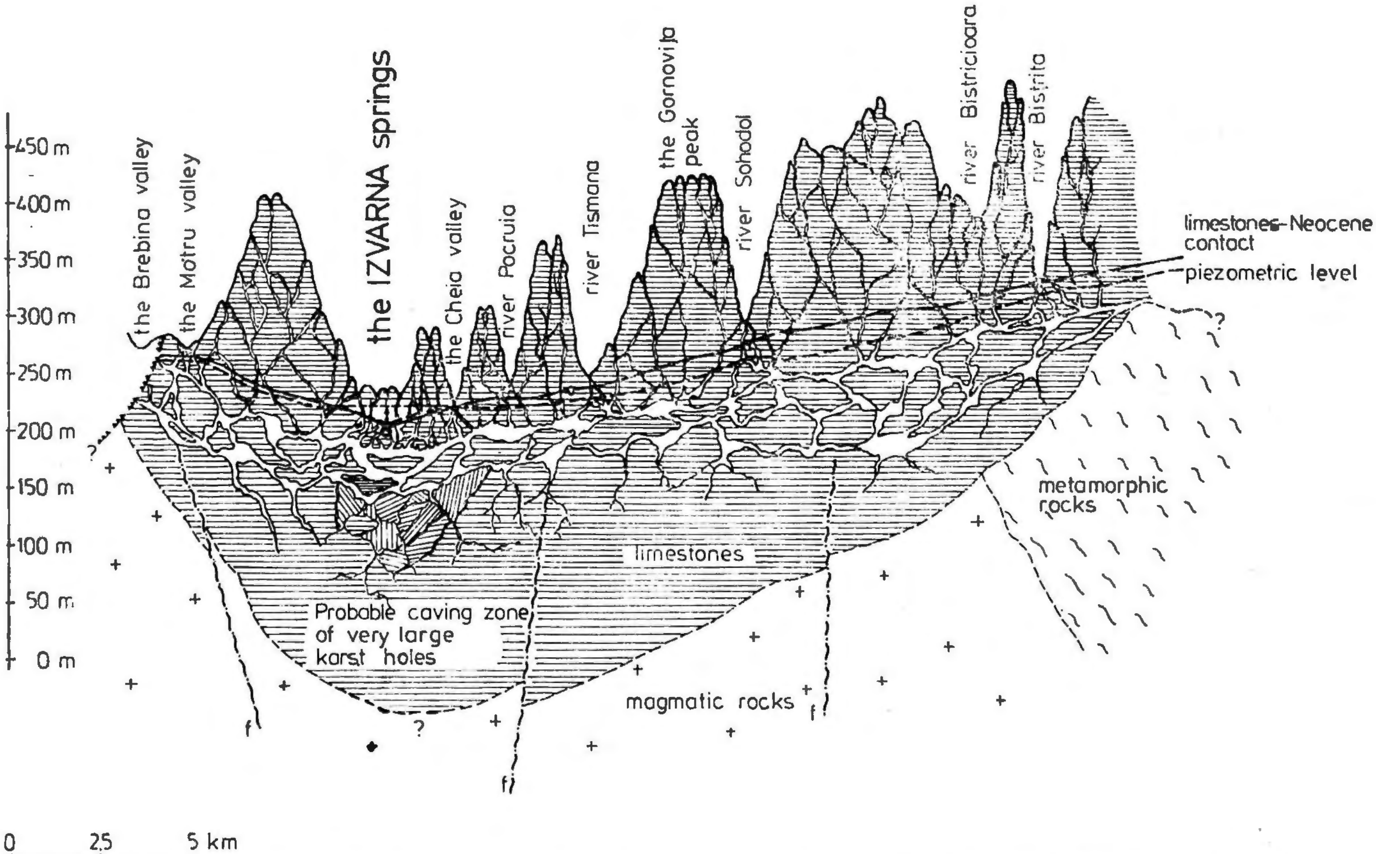


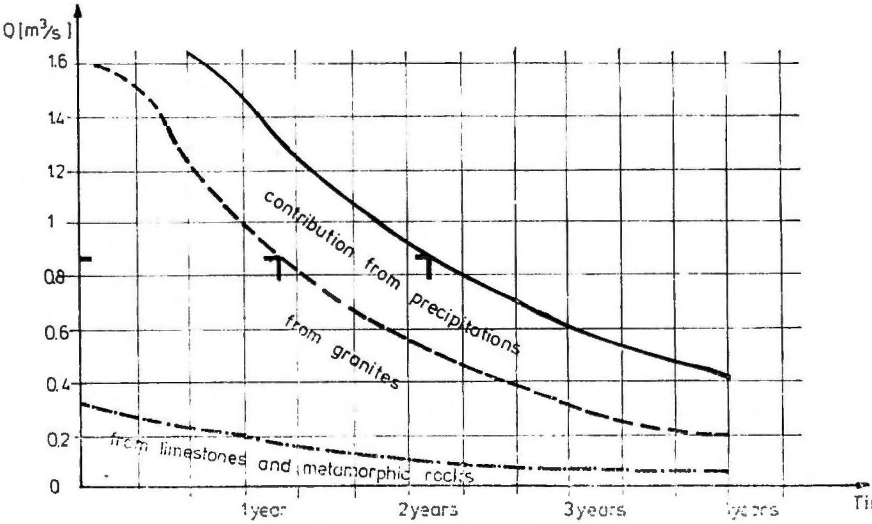
Figure 8. — II—II′ section along the limestone band (which is perpendicular to the rivers) and a scheme of the probable hydrogeologic structure.

permanent sources, responsible for the low variation coefficient of the springs.

Another explanation for the low variation coefficient of the springs is the water stored in the rock, which operates as a compensating reservoir.

This volume of water was computed on the basis of measurements and assessments conducted in both surface rock and the head races and approach tunnels of the waterpower plants under construction.

Consequently, the following mean fissurations were established :
— in granitic rocks — 0.2 per cent ;
— in limestones — 1.5 per cent.



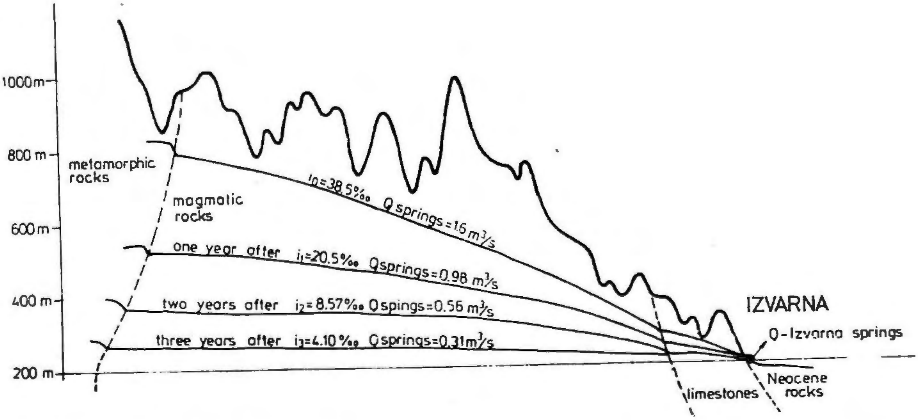


Figure 9. — Flow of the Izvarna springs supplied by the water stored in rocks (with and without the contribution of precipitations) after infiltrations from rivers (flow evolution in time) have been annulled (top). Evolution of the level of the water stored upstream and laterally to the springs and of their in-time flows assuming no contribution from other sources (i.e. rivers) or precipitations (bottom).

In keeping with the aforesaide percentages, the amounts of water in one cubic kilometre of rock are as follows :

— 1×10^6 cu.m of water/cu.km in metamorphic rocks ;

— 2×10^6 cu.m of water/cu.km in granitic rocks ;

— 15 10^6 cu.m of water/cu.km in calcareous rocks.

By limiting the outlet area of the waters placed at heights superior to those of the springs (i.e to the zone in between the Motru and the Tismana) and assuming a transit capacity of 2—3 l/sec per 1,000 squ.m of metamorphic rock, 8—10 l/sec per 1,000 sq.m of granitic rock and 15—20 l/sec per 1,000 sq.m of calcareous rock (values which were set on an experimental basis on such rocks in the pressure culverts built for hydroelectric stations both at home and abroad), the conclusion was reached that the flow currently caught at Izvarna (0.86—0.9 cu.m/sec) may be supplied, wihout the contribution of precipitations or other sources, for a year and three months and with the contribution of precipitations, though not of other sources, for two years and siv months (Figure 9 shows the amounts that can be supplied in time to the Izvarna springs from the water stored in rocks, as well as the evolution of the water level).

Applying these computations also to the area east of the Tismana, up to the Bistrita, the volume of stored water almost doubles.

The results of the studies led to the conclusion that owing to karst interconnexions, the changes induced in river flow conditions owing to waterpower developments will lead in time to a decline in the flow of the Izvarna springs, all while influencing the variation coefficient.

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INTERCONEXIUNI ACVIFERE ÎN ZONA CARSTICĂ MOTRU IZVARNA, TISMANA, BISTRIŢA

Rezumat

Începerea execuţiei unor amenajări hidroenergetice ample (baraje, galerii şi tunele de aducţiune, centrale subterane, etc.) în bazinele rîurilor Cerna, Motru, Tismana, Bistriţa, cu modificarea regimurilor de curgere, prin tranzitarea unor

debite mari dintr-un bazin hidrografic în altul, într-o zonă cu ample fenomene carstice, a ridicat problema influenţei acestor amenajări asupra mediului înconjurător.

În acelaşi timp, s-a luat în considerare preluarea unor debite suplimentare din izvoarele carstice existente în zonă (Izvarna), pentru alimentarea oraşului Craiova, care şi în prezent captează din izvoarele menţionate un debit important (0,86—0,9 mc/sec.).

Valoarea mare a lucrărilor de captare şi transport a debitelor suplimentare, precum şi riscul ca lucrările hidroenergetice să influenţeze şi să modifice debitul izvoaelor, a impus efectuarea unui studiu care să permită descifrarea eventualelor efecte.

În acest context, studiul trebuia să stabilească structurile hidrogeologice din zonă şi modul de alimentare al izvoarelor.

Rezolvarea problemei a necesitat utilizarea în paralel a unui complex de metodologii constînd din : cartări geologice şi hidrogeologice, măsurători hidrometrice, studii hidrochimice, care au permis stabilirea într-o primă etapă a unor ipoteze care şi-au găsit confirmarea, sau au fost infirmate, de rezultatele obţinute prin efectuarea unor investigări cu trasori.

După stabilirea prin tehnologiile enumerate a interconexiunilor carstice şi delimitarea structurilor hidrogeologice a fost posibilă efectuarea unor calcule, care să stabilească atît modul de alimentare al izvoarelor, să justifice debitul lor cît şi să permită explicitarea unor aspecte (coeficientul mic de variaţie, etc.) constatate.

Rezultatul studiilor ducînd la concluzia că debitele izvoarelor sînt puternic influenţate de amenajările hidroenergetice, a dus la reconsiderarea soluţiilor de suplimentare a debitului captat.

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HYDROLOGICAL KARST SISTEMS IN PĂDUREA CRAIULUI MOUNTAINS

BY

I. ORĂȘEANU, A. JURKIEWICZ

A synthesis of a large amount of pieces of information and data of a geologic, hydrogeologic and hydrometeorological nature, as well as data concerning tracer labellings provides for the identification of the expanse of the major hydrogeological karst systems in Pădurea Craiului Mountains, as well as some of their hydrogeological parameters. Furthermore, current knowledge of underground networks belonging to this system is given.

The Pădurea Craiului Mountains, situated on the western side of the Apuseni Mountains, represent one of Romania's karst areas that has been most frequently investigated from a speleological, morphological and hydrogeologic point of view. With more than 600 caves and potholes, as well as with the Vîntului Cave, which is the largest in this country (more than 33 kms. long), they also place on a leading standing as far as explored cavities in this country are concerned.

The morpholoyical features of the exo- and endo- karst in this area were accurately defined in the works of Rusu (1968, 1978), Vălenaș and Drîmba (1978), Vălenaș (1980—1981), Vălenaș and Jurkiewicz (1980—1981), Jurkiewicz and Mitrofan (1984), a.o. The tracer labellings performed by Rusu (1981), Orășeanu and Jurkiewicz (1982), Gaspar et al. (1983), Orășeanu et al. (1984), Orășeanu (1985), a.o. contributed to defining the major directions of underground water flow, while the observations made and measurements performed on the discharges of karst springs and of surface flows in the Pădurea Craiului area as well as on precipitations and air temperature, along with the works jointly conducted by researchers with the Intreprinderea de Prospecțiuni Geologice și Geofizice, Institutul de Meteorologie și Hidrologie and Institutul de Speologie "Emil Racoviță' over 1982—1983 roundied off the hydrogeologic image of these mountains.

The aim of the present work is to survey the hydrogeology of the Pădurea Craiului karst by outlining the major hydrogeological karst systems, all while reviewing knowledge about them, as well as the speleological explorations effected in this area.

We should like to point out that a hydrogeological karst system (H.K.S.) includes both karst terrains, where underground waters boast a karst-type flow, and non-karst terrains where owing to the basin karst diffluence phenomenon, surface flow contributes, either totally or partially, to supplying the same source or group of interconnected sources for a given interval.

It is extremely difficult to set the limits of H.K.S. as their is a dynamic character caused by a permanent development of karst catchment phenomena. Further more, the position of these limits may fluctuate sensibly because of seasonal variations of underground water levels.

In consideration of all these dificulties, we should like to point out that the limits of the H.K.S. given on the enclosed maps (Fig. 1 and 2) are only informative, providing for an understanding of the distribution of underground flow between the major sources. These limits were set according to the results of tracer labellings and of the interpretation of the hydrogeologic balance of surface and depth waters for the aforesaid period of observations.

1. *THE H.K.S. OF THE PEŞTERA CU APĂ DE LA BULZ CAVE*

This system, which expands in the eastern part of the Pădurea Craiului Mountains, is mainly supplied by the runoff from the impermeable terrains of the northern slope of the Preluca peak which infiltrates in the underground through the ponors of the brooks of Ponorului (figure 1.1), Popii (1.2) and Stiopului (1.4) in the karst catchment depressing of Ponoare, and through the Sîncuta ponor (1.5) in the Chicera Arsurii depression. The system is also supplied by the infiltrations in the upper basin of the Boiu brook and the diffluence surface in this area suggests a future total catchment of the Boiu brook by the Peştera cu Apă de la Bulz cave.

The system mostly consists of Anisian dolomites and limestones and its impermeable floor is made up of Werfenian quartzitic sandstones. It discharges waters that are markedly troubled during rainfalls with an annual discharge of 131 l/sec and a high variability index.

The network is accesible only through its terminal areas through the Peştera cu Apă de la Bulz cave (1,600 m in length) and the caves of Cociului (391 m length and Sîncuta (4,200 m length).

2. *THE H.K.S. OF THE BRĂTCANILOR SPRING*

The Brătcanilor spring has one of the largest H.K.S. in the Pădurea Craiului Mountains and includes rocks belonging to Upper Triassic, the whole succesion of the Jurrasic and Lower Cretaceous. The system develops North-West to South-East, a direction highlighted by the tracer labellings performed in the Ponoraş and Secătura Brătcanilor area (Rusu, 1981), and the Luncilor Valley (Mişid) by the authors (Orăşeanu, Jurkiewicz 1981). The last labelled area rounded off the image of this system, its expanse to the upper basin of the Mişidului valley accounting for the high value of the mean annual discharge (of 302 l/sec). The orienta-

tion of the system is imposed by the general tectonics of the area, with faults and geologic structures set in a North-East, South-West direction.

The system features low values of the discharge coefficient (the recesion curve discharge coefficient), (0,00244) and substantial amounts of underground waters stored early in the recession periods (4.78×10^6 cu.m). During periods of heavy precipitations, the water of the spring is markedly troubled.

Although the system's development is quite remarkable, the number of points of penetration into the possible major colector (also suggested by the high water transit velocity recorded when the Luncilor valley was labelled) is relatively low : the Ponoraș cave(figure 1.6 ; 3,800 m long and with a level difference of 211 m) the cave at Stanul Ciuții (figure 1.7 ; 611 m long and with a level difference of 41 m), the Barna pothole (figure 1,8 ; 697 m long and with a level difference of 98 m). The decolmatations effected above the Brătcanilor spring by the speleological club C.S.A. Cluj-Napoca, pointed to the presence of an underground void space roughly 50—60 m in length ; however subsequent collapses prevented further explorations.

The drain of the Macrei ponor-Moanei cave, which spans on 1,170 m and has a level difference of 104 m, is situated on the system's development area.

3. *THE H.K.S. OF THE VÎNTULUI CAVE*

The H.K.S. of the Vîntului cave, which at present, is the largest underground network in Romania, with roughly 33 kms already mapped, is characterized by a reduced developmetn area as compared with those of the other systems, as well as by an average discharge of only 30 l/sec. The research work conducted there showed that the recharge area of the underground flow in Vîntului cave was linked to the diffuse losses in the Recea brook basin (fig. 1.9), (Orășeanu, Gaspar, 1980—1981).

4. *THE H.K.S. OF THE IZBÎNDIȘ SPRING*

Situated immediately West of the Vîntului cave and probably genetically linked to it, is the H.K.S. of the Izbîndiș spring.

Consisting mostly of Anisian dolomites on which the ponors in the Cărmăzan depression (fig. 1.10) and the Groapa Blidirești hole (fig. 1.11) are located the system seems to be limited to the West by a tectonic alignment which puts Upper Jurassic (Callovian—Tithonic) limestones in contact with Anisian dolomites. However, the labellings effected in the Tomii ponor (fig. 1.12) show the influence radius of the system also extends West of that alignment.

The high discharge values (Qmed = 340 l/sec. Qmin = 49 l/sec) and the low values of the discharge coefficient (0.002—0.0037) suggest a flow through small-size fissures, supported by substantial water volumes registered early in recession periods ($1.38—4.36 \times 10^6$ cu.m.)

From an explorative point of view, this system is also linked to the presence of one of the longest siphons explored in this country, an

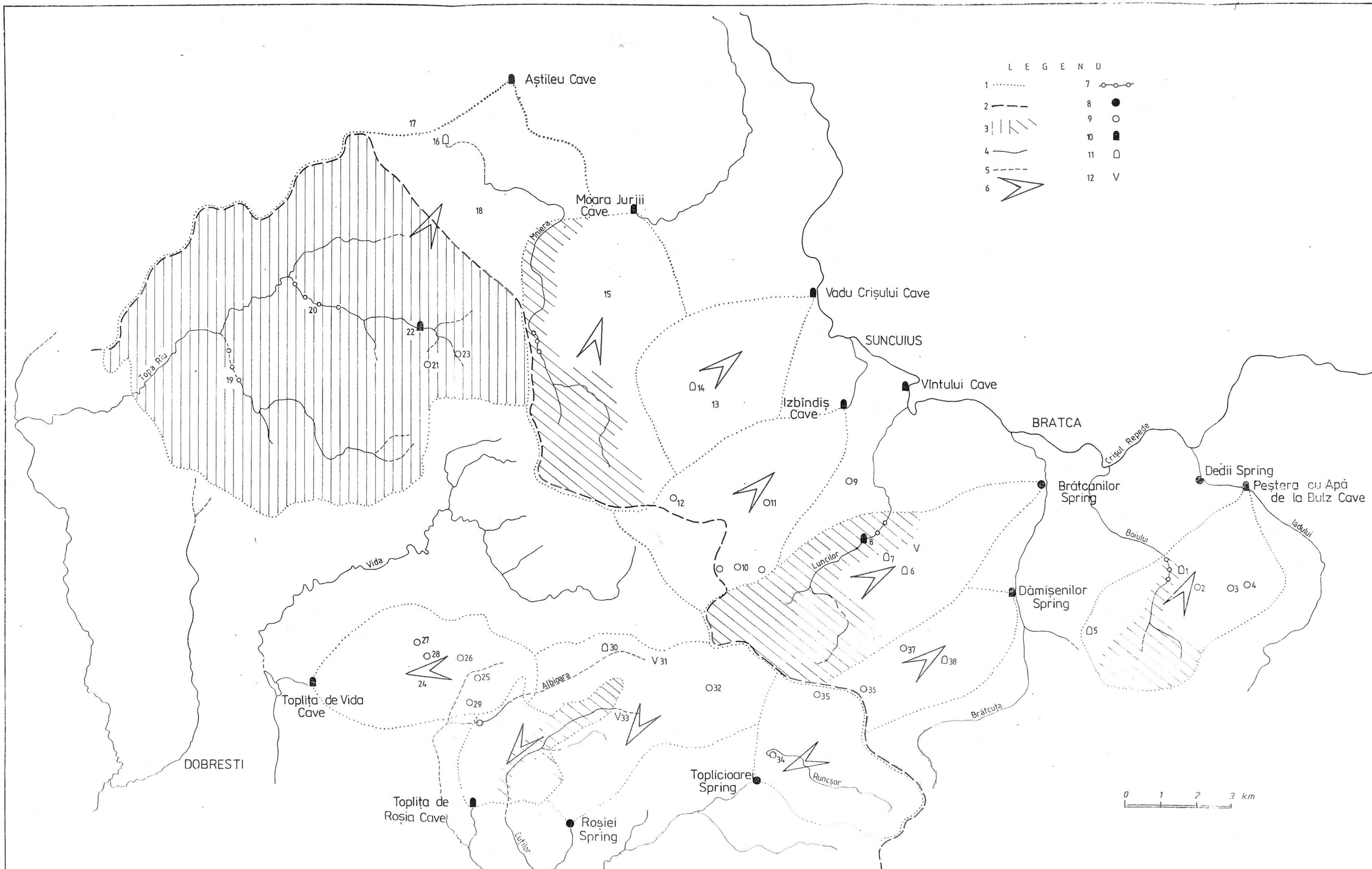

Fig. 1. Distribution of main hydrogeological karst systems in Pădurea Craiului Mountains. 1 — Approximate hydrogeological karst systems limits; 2 — Surficial watershed between Crișul Repede and Crișul Negru rivers; 3 — Diffluence surface; 4 — Permanent surface course; 5 — Temporary surface course; 6 — Direction of underground water flow; 7 — Losses in flow along the riverbed; 8 — Spring; 9 — Ponor; 10 — Out flow cave; 11 — Inflow cave; 12 — Pothole.

exploration of bad remembrance. The Izbîndiş cave, with a pan of roughly 400 m, extends above the spring and is linked to the underground flow through two wells.

5. *THE H.K.S. OF THE VADU-CRIŞULUI CAVE*

Withs the H.K.S. of the Vadu-Crişului cave we penetrate into the large karst plateaus in the norther part of the Pădurea Craiului Mountains.

The discharge of the system is strongly influenced by precipitations, while discharge coefficients are relatively high (0.008—0.0125), which bespeaks water flow and storage within a simple underground network. The volume of the water stored early in the recession periods is relatively low (0.27—0.43$\times 10^6$ cu.m.), which also points to the existence of a less branched underground network.

Contrary to expectations the karst plateau at Imaşul Bătrînului (fig. 1.13), which is entirely made up of Callovian—Tithonian limestones, provides for a penetration into the underground only through two caves (the Bătrînului cave — the Peştireu valley ponor with a span of 1,633 m and a level difference of 87 m) and the resurgent cave of Vadu-Crişului (900 m long.). The limit narrow access galleries in the terminal area of the Bătrînului cave (fig. 1.14) as well as the siphons in the cave at Vadu Crişului once again show that the lack of vigorous surface streams in the plateau areas, in the case of this massif, hinders the formation of larger-size galleries.

6. *THE H.K.S. OF THE SPRING AT MOARA JURJII*

The H.K.S. of the spring at Moara Jurjii is made up of Jurassic and Lower Cretaceous limestones of the Secătura plateau (fig. 1.15), which also represents its major suplly area. The discharge losses on the upper course of the Mniera valley, identified with the help of hydrometric measurements and labellings (Orăşeanu, 1985) attested to their belonging to this system. We once again find a karst diffluence area which develops towards a total catchment of the upper course of the Mniera valley by the spring at Moara Jurjii.

The minimal discharge registered in low-water periods in the past three years maintained round 110 l/sec. The known underground network is confined to the 200 m of galleries explored in the Moara Jurjii cave.

7. *THE H.K.S. OF THE AŞTILEU SPRING*

The largest H.K.S. system identified in the Pădurea Craiului Mountains (with an expanse of 106 sq.kms) is that linked to the Aştileu spring. Initially known to be of a limited expanse, confined to the Mniera valley basin (the loss in the cave of Potriva — fig. 1.16) and, partially, to the karst plateaus of Hîrtoape (fig. 1.17) and Zgleamănu (fig. 1.18), the research conducted of late (labellings of the ponors of the Peştiş — fig. 1.19, and Poieni valleys — fig. 1.20) doubled the known area of development by pinpointing the diffluence surface in the Topa Rîu basin (Orăşeanu, 1985).

From a geologic point of view, the H.K.S. develops along a mosaic of formations ranging from the Middle Jurasic to the Quaternary gravel of Oarzăna.

The discharge coefficients computed for various periods, which were either not influenced by precipitations, range from 0.0026 to 0.0043, according to the charge of the system at the beginning of the recession period. Both these low values and the high values of the discharges (Qmed = 365 l/s, Qmin = 74 l/s) point to the vast expanse of the H.K.S. and the impressive volume of water reserves (2—7 $\times$ 10^6 cu.m) at the begining of the recession periods accumulated in fine fissures mostly.

Besides the general drainage direction towards the Aştileu spring, a number of secondary drains : the losses of the Cordău valley (fig. 1.21) — the cave at Izvorul Gabor (fig. 1.22) — 2,707 m long and the losses in the Groapa Peşteranilor (fig. 1.23) Aurica cave —2,680 m long, are located on the diffluence area, which, from a hydrogeologic point of view, belong to the same H.K.S., with the gallery networks being, however, independent.

The main gallery system was explored both through the Mniera valley ponor known as Potriva's Cave (1,200 m long) and through the resurgence (the cave at Aştileu —2,000 m long).

Noteworthy is the fact that the long transit time in case of the labellings performed in the Topa valley indicates an underpresure flow in the most part of the system, with the exception of the terminal area, where a vadous flow was partially identified.

8. *THE H.K.S. OF THE TOPLIŢA DE VIDA SPRING*

The geologic research work, as well as mining operations performd in the Jofi—Albioara area called for detailed hydrogeologic studies. So, for instance the H.K.S. of the Topliţa de Vida spring was identified which consists mainly of Cretaceous limestones (ne-br), (massive and stratified limestones and bauxite) in the Sclavul Pleş plateau area (fig. 1.24) and Upper Jurassic limestones in the central part of the system. Towards the peripheral areas a whole package of Jurassic rocks outcrop to quartzitic sandstones (hettangian-sinemurian) on which small streams (the Bichii, the Hodişan) are formed, which, when entering the limestones, disappear through the ponors. The labellings performed (simultaneous multiple tracing with various tracers, as well as other labellings) proved that the Bichii (fig. 1.25), Merişor (fig. 1.26), Marchiş (fig. 1.27) and Fîntîna Rece ponor (fig. 1.28), as well as the ponor of the Baia Nişului brook (fig. 1.29) belong to the system (Orăşeanu et al. 1984) The general direction of the system is also shown by the system of fractures in the central area of the karst plateaus.

The average discharge for the 1982—1983 period stood at 158.2 l/sec. while the minimal discharge registered was of 26 l/sec. The low values of the discharge registered was of 26 l/sec. The low values of the discharge coefficient (0,00167 and 0.00186) point to a preferential flow through small-size fissures. The volume of stored water at the begining of recession periods for which discharge coefficients were computed were of 1.20 $\times$ 10^6 and respectively, 1.21 $\times$ 10^6 cu.m.

In point of exploration, knowledge of the underground network of this H.K.S. is rendered difficult by the relatively small size of the galleries. The most important underground void space is the cave in the 117 Jofi drift (fig. 2) which is 6 kms long and has a level difference of —130 m, while the resurgent cave at Toplița de Vida is known along 200 m, its exploration implying the surmounting of six siphons.

9. *THE H.K.S. OF THE TOPLIȚA DE ROȘIA SPRING*

The research work conducted by the EMIL RACOVIȚĂ Speologic Institute in Cluj Napoca, when prehistorical traces of footsteps were discovered in the Ciur—Izbuc cave, outlined most of the geomorphological features of the system. Previous research work led to the setting of the underground flow through the Ciur—Ponor cave (roughly 17 kms long, with a level difference of 180 m), whose galleries cross several times the entire succesion of karstifiable rocks belonging to the Jurassic and Lower Cretaceous and, sometimes, reaching quartzitic sandstones (in a number of gallery terminal areas).

The main active flow, which, as a matter of fact, is one of the most spectacular in this country, achieves an almost total penetration in between the Tinoasa ponor — Ciur Izbuc cave and the Ciur Ponor—Toplița de Roșia spring interrupted between the losses in the Ciur Izbuc and the tributaries in the gallery area called the Albioara upstream. We may also note the presence of a diffluence area on the Cuților valley, which will be probably completely caught by the Toplița de Roșia spring.

The discharge coefficients computed for the low-water periods in 1982 and 1983 amount to 0.00218 and 0.00298 for an average and minimal discharge of 72.9 and respectivelly, 11 l/sec.

The morphology of the endo-and exo-karst in this area features more than others do a perfect parallellism between the directions of the main galleries of the Ciur Ponor and Jofi caves and the directions of the Cuților, Albioara and Vida valleys which are the limits of the karst plateaus where these caves are located. This parallellism is due to both the uniform character of the fissure systems of the calcareous massif along this entire area and to a synchronous evolution, therefore, karst-forming processes at the surface and inside the massif in the same paleogeographic conditions. These conditions are mainly shown by the subsidence of the Beiușului basin, which hydrogeologically, translates into a rotation of the sense of the regional hydraulic gradient from West to South, a movement which implied a change in the same sense of the direction of flow of surface and underground courses.

The microtectonic profiles performed in the Albioara and Cuților valleys and the two inlets of the Ciur Ponor—Toplița de Roșia system highlighted a constant of the directions of the main fissure systems, therefore, of the tectonic factor of karstformation. Noteworthy is also the presence of a system of tension fissures with an average orientation N49°W/90° and of two shear fissure systems with an average orientation N27°E/81° SE and N56°E/78°SE, systems which imposed the directions of the drainage networks as well as the position of the vector of the local and regional hydraulic gradient.

10. *THE H.K.S. OF THE ROŞIA SPRING*

Situated East of the previously described system, the Roşia spring system is formed of Anisian and Ladinian limestones, covered by quartzitic sandstones (hettangian-sinemurian), which account 60—70 per cent of the system's development area.

The discharge coefficients computed for two prolonged low-water periods in 1982 and 1983 have extremely low values of 0.0017 and 0.001983 The large volume of underground water reserves at the start of recession periods seems to be mainly located on small size fissures.

The expanse of this system, which is probably very large owing to the substantial value of the average discharge (Qmed = 500 l/sec) as well as the labellings originaly performed in the Jurcanilor cave (fig. 1.30) and the Sohodol pothole (fig. 1.31), which is 1 km long and has a level difference of —100, was also shown by subsequent labellings and explorations in the Barc ponor (fig. 1.32) and the Stanu Foncii pothole (fig. 1.33), (2,700 m long ; level difference —339).

11. *THE H.K.S. OF THE TOPLICIOAREI SPRING*

This system, wich has been explored less, consists of Anisian limestones and mainly drains the waters of the Runcşor spring (fig. 1.34) through the vertical shaft at Intorsuri and the Fîntînele Huta (fig. 1.35) area in Poiana Damiş.

The system had a minimal discharge capacity of 66 l/sec in the low-water period of the 1982—1983 hydrologic year.

12. *THE H.K.S. OF THE DAMIŞENILOR SPRING*

The Damişenilor spring situated on the course of the Brătcuţa valley on the left slope and downstream of the confluence with the Groapa Tivadarului valley, has a minimal discharge of 25 l/sec. The H.K.S. of this source extends to the West in the Glimee — Toaia-Peşteruţa area within the locality of Damiş being mainly located on Anisian limestones and dolomites from the Jurassic base.

Acces to the gallery network was attempted through both the vertical shafts belonging to the system (Peşteruţa — fig. 1.36 ; Toaia — fig. 1.37, 200 m long and a level difference of —60 m and Munău — fig. 1.38) and the Damişenilor spring where narrow galleries with sunken sections extending on 2,200 m have been explored and mapped.

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SISTEME HIDROGRAFICE CARSTICE DIN MUNŢII PĂDUREA CRAIULUI

Rezumat

Multitudinea de date cu caracter geologic, hidrogeologic şi hidrometeorologic precum şi cele referitoare la marcările cu trasori au permis trasarea limitelor sistemelor hidrogeologic— castice, poblemă deosebit de dificilă datorită caracterului lor dinamic imprimat de evoluţia permanentă a fenomenelor de captare carstică.

Aceste sisteme aparţin în majoritate unor izvoare cu debite ridicate situate în general la periferia masivului calcaros. Modul de organizare a drenajelor, zonele de difluenţă carstică şi unii dintre parametrii hidrogeologici fac obiectul descrierii fiecăruia dintre cele 12 sisteme hidrogeologice prezentate. De asemenea este reliefat studiul actual al cunoaşterii din punct de vedere explorativ al reţelelor subterane aferente acestor sisteme.

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INTERPRETATION OF TRACER DISPERSION IN KARST GROUNTWATER EXPERIMENTS

BY

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Tracer dispersion in fissured rocks and in hydrokarstic structure is considered here. A nearly dispersional model is proposed for the analysis of systems with more scales of flow and mixing. A comparision of experimental data (proper as from literature) with the numerical prediction shows a good correlation.

1. INTRODUCTION

The aim of this paper is to present a new interpretation of the tracer distribution in groundwater experiments performed in hydrokarstic structures. Such structures posses complex internal flow fields resulting from large-scale flow heterogeneities. Note that the flow patterns cannot be defined as each karst boasts its own features and it is a difficult problem to estimate all the parameters responsible for the behaviour of the respective structure.

Here the well known dispersion model is improved by the use of a perturbed dispersional model proposed by Iordache et al (1987). The starting point is to assume that there exists a fundamental mechanism of dispersion which ensures the tracer transfer in the main part of the system and to consider that other processes (the flow accross large fissure sand caves, the transfer in porous matrix and so on) as perturbation of the basic mechanism taking place at other characteristic scales of mixing.

In the second part of the work, the new model will be used for interpretation of tracer experiments (activable tracers and environmental isotope data) performed in kastic zones (see Gaspar and Simion 1985). The applicability of the proposed models is also illustrated by reinterpretation of known case studies and by comparision of the results obtained by the use of purely dispersional model (see Maloszewski and Zuber 1983).

2. THE MODEL

The most common model developed for the description of solute transport in porous media and in solute channels is the dispersion equation :

$$\frac{\partial c}{\partial t} + v \frac{\partial c}{\partial x} = D \frac{\partial^2 c}{\partial x^2} \tag{1}$$

Here c is the tracer concentration, t the time, x the space, v the interstitial flow velocity and D the dispersion coeffient.

According to Iordache et al 1987 the perturbed calculated solution c_c is given by :

$$c_c = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\eta} [\Sigma q_m \cdot H_m(\eta) \exp(-\eta^2/2)] \cdot d\eta \tag{2}$$

where

$$\eta = \frac{x - v \cdot t}{\sqrt{2Dt}} \tag{3}$$

and m is the number of scales of mixing, $H_m(\eta)$ are Hermite orthogonal polynomials and q_m proportionality coefficients obtained from :

$$\int_{-\infty}^{+\infty} H_m(\eta)\, dc(\eta) = q_m \cdot m! \tag{4}$$

Here $c(\eta)$ denotes the experimental value of dimensionless concentration.

We take the truncation number m that ensure the minimum of the objective function :

$$S = \int_{-\infty}^{+\infty} (c(\eta) - c_c(\eta))^2 d\eta \tag{5}$$

3. EXPERIMENTS

Fig. 1 refers to the laboratory experiments of Grisak et al (reported by Maloszewski and Zuber (1983) in their Fig. 4), for continuous tracer injection of chloride anions in fissured rocks with porous matrix. Empirical data can be represented by a curve c(t) for fixed x. Here c(t) denotes the output relative concentration corresponding to a step input. The experimental curve c(t) is transformed in $c(\eta)$ where η is the dimensionless variable given by eq. (3). Note that we take as a first approximation $u(o)=1/2$ for $t=x/v$. Thus for $x=0.76$ m we obtained $v=1$ m/d. Taking $D=0.65$ m^2/d we obtained the objective functions 0.164 ; 0.10 ; 0.053 ; 0.064 at $m=0,1,2$ and 3 respectively. We concluded that in this case a model with three scales of mixing represents a good picture of the system. We have $q_0=0.79$, $q_1=-0.01$, $q_2=-0.11$ (see Fig. 1). Taking $D=0.8$ m^2/d

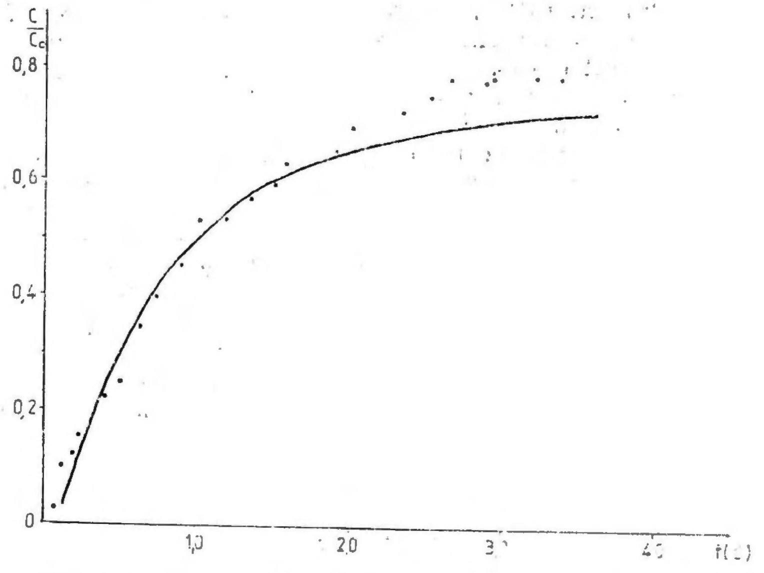

Fig. 1. Reinterpretation of laboratory experiments data of Grisak et al.

we obtain the objective functions 0.24 ; 0.11 ; 0.06 ; and 0.07 at m=0,1,2 adn 3 respectively. In this case q_0=0.79, q_1=—0.01, q_2=—0.15.

An interesting situation appears in the study of experiments concerning the dynamics of underground water in the Cerna Valley (Gaspar and Simion 1985) (see our Fig. 2). The aim of this experiment was to delineate the origin of Cerna spring (which sinkholes feed it) and the existence of complex underground piracy of surface streams (see also Ponta et al, 1983).

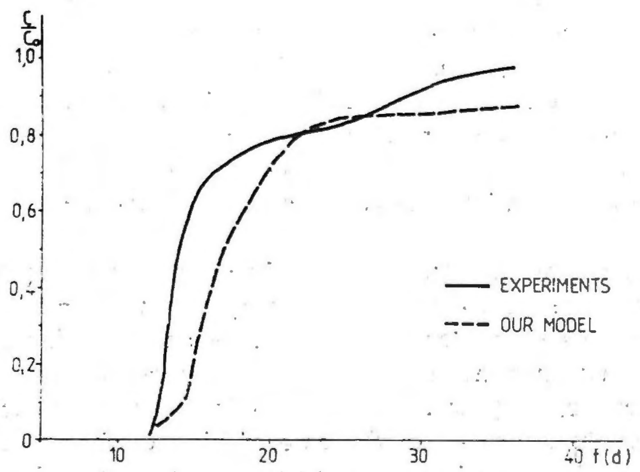

Fig. 2. Reinterpretation of Scorota—Cerna Spring experiment.

Using experimental data, the karst ground water residence time between the sinkholes and springs and dynamical volume of water stored was determined. But the experimental results may be reinterpretated to determine karst vulnerability to pollutants. Although there are notable exceptions, most groundwater flow in maturely karsted aquifers, (those in which a well-integrated conduct system has developed, like in Cerna Valley karstic structures) is analogous to flow in surface stream networks. Flow is turbulent, occurs in discrete conduits or solute channels, commonly has velocities ranging from 10 to 500 meters/hour and dispersion coeficients from 4.10^3 cm^2/s to 3.10^5 cm^2/s, and terminates at a point that for a karst is a spring (or a group of springs) which has water quality representative of the weighted mean of the groundwater basin. Using the above described procedure we obtained for x=13.550 m, v=953 m/d and $D=4.1\times10^4$ cm^2/s the best fitting at m=1. In this case $q_0=0.96$, $q_1=0.442$. Note that the value of D is comparable to that obtained in strongly fissured rocks.

4. DISCUSSIONS

An illustration of the physical interpretation of the proposed here correlations is presented in the sequel. Using (2) we obtained the average η and the dispersion δ^2 of η i.e. $\eta=q_1$, $\delta^2=q_0+2q_2-q^2_1$. The value $\eta>o$ obtained in the study of fissured rocks corresponds to the existence of a certain fraction of the feed tracer that travels more rapidly and bypass the main structure. The fact that $2q_2-q^2_1<0$ signifies that the tracer distributions is characterized by a concentration of the values around the average which is stronger than in the case of a purely dispersional distribution.

It should be emphasized that more physical models including additional mechanisms of tracer transfer are accompanied by an increase in the number of adjustable parameters (see for instance Maloszewski and Zuber, 1983). In the example presented here with a unique new parameter (m) we obtained a good correlation. Our method starts from a correct choice of v and D. Such values could be obtained in laboratory of field experiments with carefully selected sample of the karst groundwater system.

The intimate mechanisms of karst functioning and its actual vulnerability to polluants may be grasped only through repeated labellings with artificial tracers performed at low-flow and high-flow. The transit time in such experiments shows a non-linear relation with discharge, which increases rapidly as discharge declines. These clearly show the way the karst functions — in the case of high discharges it tends to a piston flow and in case of low discharges to a dispersive flow. Obviously the fit to the experimental data is not a sufficient criterion and the interpretation of tracer experiments requires further studies.

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INTERPRETAREA DISPERSIEI TRASORILOR ÎN EXPERIMENTELE PE APE CARSTICE SUBTERANE

Rezumat

În lucrare se studiază dispersia trasorilor radioactivi în structuri hidrocarstice. Se propune un model de tip dispersional perturbat pentru interpretarea experimentelor în sisteme hidrologice în care există mai multe scale ale procesului de amestecare turbulentă.

Modelul conţine o dezvoltare în serie a concentraţiei de trasor. Primul termen al seriei corespunde părţii dispersionale a transferului de trasor, iar ceilalţi reprezintă corecţii datorate abaterilor de la mecanismul pur dispersional.

Se obţine o bună corelare a modelului propus cu date proprii şi din literatură.

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PREHISTORIC HUMAN FOOTPRINTS IN ROMANIA'S CAVES

BY

I. VIEHMANN

The paper presents the inventory of prehistoric human footprints in 15 European caves. Such footprints found in two caves in Romania are described, as well as the manner in which they have been preliminarly dated: 18,000 and respectively 80,000 years.

The most ancient footprints were discovered at Laeloti in Oldwai Valley (Tanzania) by Mary D. Leakey. They are printed in the volcanic ashes and are estimated, by means of potassium-argon radioactive test, to be 3,600,000 years old (Pliocene). At present the ash stratum bearing the footprints is covered by a soilvegetation bed 22 m thick. The footprints were left by two individuals (Leakey, 1979), different in size and weight, walking in Indian file on a 23 m long path. The short man's footprints are 185 mm long and the taller's are 215 mm. The distance between two steps is 387 and 472 mm respectively. Considering the gate, the particular fashion in which the footprints were stamped and the biometrical measurements, the two individuals had a *bipedal walk,* and Dr. Donald C. Johnson (Etiopia) identified them as australopithecines. Judging by the foot size and the fact that this represents a fifteenth of the body height, the average height of these two individuals could reach 1.40 m.

Other plantar footprints belonging to prehistoric men and discovered outside the caves are those found on travertine deposits at Vértesszölös (Hngary). These are sensibly more recent, namely pertaining to the pre-Neanderthal man (Pleistocene) (Barta, 1979).

Nevertheless, the majority of the Pleistocene (Paleolithic) footprints belong to the caves. According to the literature (to the best of our knowledge), such footprints have been discovered in 15 caves, as follows ;

1. Tuc d'Audoubert (Cap Blanc, Ariège) France ;
2. Cabrerets, or Pèche-Merle (Lot) France ; footprints left by a women and a child ;
3. Montespan (Haute-Garonne) France, discovered by N. Casteret ;
4. Niaux, also called Turo, or de la Calbière (Tarascon, Ariège) France. Abbé H. Breuil discovered the footprints on calcified cláy (Bau-

rès 1958). They had been left by a short man (1.40 — 1.60 m tall) and the petroglyphs at Niaux are estimated to be Magdalenian (about 18,000 years old).

5. Aldène, also called Frauzan, Minerve or Grotte de la Coquille (Haut Minervois, Hérault) France. At this site, a round trip path made by five individuals was found. The human footprints are mixed with those of cave hyena and its coprolites.

6. Trois Frères (Ariège) France ;

7. Bédeilhac (France) ;

8. Tana della Bassua (Savona), Italy, containing footprints of Neanderthal men ;

9. Tero Amata (Italy) ;

10. Sorcière (Strega), at Toirano (Liguria) Italy. The footprints were discovered in 1950 ; they are concreted in clay and belong to the Neanderthal men estimated to have lived 70,000 years ago (Trimmel, 1968) ;

11. Ojo Guarena (Burgos) Spain ;

12. Le Portel (Ariège) France, where the footprints are covered by concretions and associated with Aurignacian grafic art work (Abel 1935) ;

13. Muierii (Baia de Fier) Romania. N. Plopşor discovered the footprints at this site but, unfortunately, before their complete valuation, they had been destroyed by the cave visitors (Muscan 1974) ;

14. Ciurului Izbuc (Pădurea Craiului Mountains) Romania. The footprints in this cave were discovered by I. Viehmann, in cooperation with T. Rusu, Gh. Racoviţă and V. Crăciun, from „Emil Racoviţă" Speological Institute, Cluj.

15. Gheţarul de la Vîrtop (Bihor Mountains) Romania. The discovery has been made by I. Viehmann, I. Bucur (a geology student) and I. Szekely-Racoviţan (an engineering-school student) in 1974, during the exploration of the cave organized by „E. Racoviţă" Speological Student Club, Cluj-Napoca. The footprints are concreted.

The author of this paper cautions against possible synonymic denominations of the caves mentioned above.

The caves are also important fort the fossils of archanthropoids and pre-Neanderthals they possess. Thus, in Northern China, 50 km away from Peking, *Sinanthropus pekinensis* was discovered in Chon-Kou-Tien Cave in 1921. Later on (1933), H. Breuil established that he had lived in the aerly Pleistocene, had used stone and bone tools and had known the fire. In South Africa (Chaline, 1972) 60 skeletons belonging to *australophithecines* have been found in Swartkrans Cave.

In Romania, the fossils of the prehistoric man were found inside and outside the caves, as follows :

a) the skull in Cioclovina Cave (Hunedoara) ;

b) the skull in Muierii Cave (Baia de Fier), older than the previous one, estimated to be 29,000 years old, according to the C_{14} test ;

c) the fossils at Schela Cladovei (Turnu-Severin), considered to be epipaleolithic ;

d) the discoveries at Valea lui Grăuceanu (Bugiuleşti), which prove to precede the aerly Paleolithic and represent the first station of the australopithecines in Europe, L. Vertes, J. Barta, K. Valoch, R. Dartt consider. (D. Nicolaescu-Plopşor 1970).

Concerning the significance of the footprints found in caves, L. Pales, Cl. Chippaux and H. Pineau (1960) state that they are „the unique living and involuntary (thus natural) document which reveal the activity of fossil human species". Such traces are taken in consideration by the sedimentary geology. D. Rădulescu and N. Anastasiu (1979) refer to these modifications of the relief (footprints ,crawling trace setc.) as „bioglyphs". Some of the above-mentioned caves excel in displaying and conserving the footprints. In Aldène Cave (Cathala 1953) a gallery contains a 20 m long accumulation of footprints, prints of knees and hands, all belonging to man. They are associated with claw scratches, prints of paws and resting quarters (Viehmann et al. 1970) of the cave bear. H. Breuil estimated that the wall drawings at Aldène belonged to the Aurignacian epoch (25,000 years ago). The footprints are impressed on the cave floor, a lightly hardened clay. They belong to adults (males and females), as well as to children. The size of the footprints is variable : 180, 200, 230, 245 and 250 m long and 30—40 mm deep. The bear nooks in this cave are among the finest ever discovered. They reach 2.50 m in diameter and 60 cm depth. In Romania such nooks were first found in Peretele Dîrnii Cave (Albac Valley, Apuseni Mountains) (Viehmann 1973).

The discovery in Ciurului Izbuc Cave occured in November 11, 1965 (Viehmann et al. 1970). The cave is located in the karstic plateau of Runcuri, in Pădurea Craiului Mountains. The "Footsteps' Room" is hidden at more than 500 m away from the actual entrance. The Paleolithic men could have had access through another entrance (clogged up nowadays), only 50 m away from the room. A layer of 1.5 mm thick telluric dust covers the "Footsteps' Room" 's argilaceous floor. The dust conceals both human and bear footprints. The analyses made by Prof. E. Stoicovici from the Laboratory of Mineralogy of the University of Cluj pointed out that the dust contains volcanic detritus that could have been brought in the cave by means of an ante-Pliocene paleohydrographic system or, more likely, carried by the air. This sediment could not originate in the neighbouring area, where volcanic rocks are absent. The powder removed from a human footprint and from a bear footprint situated 14 cm away from each other have been comparatively examined and the result showed only a 0.6% difference in composition, which means that both types of footprints had been covered by *the same deposition.*

The footprints belong to three people : a man, a woman and a child. They are chaotically scattered and mixed with footprints of *Ursus spelaeus*. This species of bear appeared in the Mousterian (50,000 years ago) and persisted until the Magdalenian (15,000 years ago) (Alimen 1965). In Romania, *Ursus spelaeus* was the most spread of the Ursidae, beginning with the Riss—Würm glaciation (Bombiță 1954). In Ciurului Izbuc Cave there are about 400 human footprints (the largest number found at a single site), out of which 230 have been marked (C .Rișcuția and I. Rișcuția 1970), and 188 have been statistically surveyed. The footprints are both static and dynamic, but because of their dissemination it was impossible to determine the intention of the Paleolithic visitors. The woman's and the child's footprints are more primitive, i.e. short, massive (wide) and little excavated. They clearly show fanned-out toes, which

attest a light adduction of the big toe (hallux). Similar small-sized Paleolithic populations have been discovered, through their footprints, in the caves Tuc d'Audoubert, Cabrerets, Montespan and Niaux in France. In Aldène Cave, besides the type of footprint described above, different footprints have been found, belonging to a man having a longer, slim foot, with a pronounced concavity. This Aurignacian footprint is very similar to the footprint of the man in Ciurului Izbuc Cave.

The man in Ciurului Izbuc Cave (C. Rişcuţia, I. Rişcuţia 1970) has been estimated to be a *Homo sapiens fossilis* belonging to the Solutrean age, presenting Cro-Magnon and partially Neanderthal characteristics.

The discovery in Gheţarul de la Vîrtop Cave, on the left bank of Gîrda Seacă Valley, in the neighbourhood of the village Casa de Piatră (Apuseni Mountains) occurred in May 1974 : I. Viehmann, I. Bucur and. I. Szekely-Racoviţan entered the first room of the cave, in which a great number of ice stalagmites develop during winter and spring. They advanced through the iron gate and the crawling way leading to "Sala Minunată" [The Wondefrul Room], discovered in 1955 by M. Bleahu and J. Bordea. In the first part of the new area, an upward turn-off, blocked by a lake, has been observed. After having crossed the lake, they climbed a wet stalagmitic drain, partially formed by *montmilch*. The end of the climb was obstructed by a fairly massive barrier of stalagmitic columns. After breaking the stalagmites, their advance ended in a final room, whose floor presented a somewhat elevated area, almost 3 m long and about 1 m wide. On the horizontal portion of that "saddle", three human footprints have been discovered : one partially preserved (the heel), another one three-quarter preserved and a complete footprint. The footprints were impressed in montmilch, which was completely solidified at the time of the discovery. Within the footprint stood a beginning of a stalagmite, grown 22 mm up from the ground and 5 fragments of "macaroni" stalagtites, stuck by concretion. The "Vîrtop Man"'s footprint is 223 mm long and 111 mm wide, with could correspond to a 1.56 m height.

The age of the footprint in Ghetarul de la Vîrtop Cave is proved by the following considerations :

1° The footprint is massive, very primitive in characteristics : it is short, wide and even, the convavity is almost completely absent. The distance between the big toe (hallux) and the other fanned-out toes clearly indicates its pronounced adduction.

2° The site of discovery is obstructed and inaccessible ; a barrier o stalagmitic columns blocked any linking passage from the rest of the cave to the footprints gallery. The footprints could have been impressed only when the floor composition was soft montmilch. It has been resolidified through a slow process of recrystallisation. At the bottom end of this room there is an earth drain from the outside : in this spot another entrance, later on collapsed, could have existed.

Hence, we consider the footprints of the „Vîrtop Man", in Gheţarul de la Vîrtop Cave, at Casa de Piatră, could possibly be pre-Neandenthal (Lower Paleolithic) with an Mousterian archaeologic age of

about 80.000 years. The whole footprint of "Vîrtop Man" has been removed together with the stalagmitic floor in which it was impressed and is conserved in the collection of „Emil Racoviță" Speological Institute in Cluj-Napoca, registered as an invaluable relic in the list of the National Patrimony.

In order to stress the great importance of studying such vestiges of the prehistoric man's life, we conclude with a quotation from Mircea Eliade (1939): "Romania has no Middle Ages, but its prehistory was equal, if not superior, to the foremost peoples of Europe".

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URME DE PICIOARE ALE OMULUI PREISTORIC ÎN PEŞTERILE ROMÂNIEI [1]

Rezumat

Lucrarea începe cu un scurt istoric al celor mai vechi urme plantare hominiene descoperite pe plan mondial, referindu-se mai întîi la paşii înscrişi în cenuşa vulcanică din Oldwai Valley (Tanzania). Acestea au fost datate prin metoda cu potasiu-argon radioactiv de către Leakey (1979), stabilindu-se că aparţin Pliocenului inferior şi că au deci o vechime de 3 600.000 de ani. Sînt enumerate apoi 12 peşteri din Europa, localizate în Franţa (8), Italia (3) şi Spania (1), care păstrează pe podeaua lor urmele unor paşi aparţinînd omului preistoric.

Pentru România sînt amintite amprentele plantare descoperite în Peştera Muierii (Baia de Fier) de către N. Plopşor, cele din Peştera Ciurului-Izbuc (Munţii Pădurea Craiului) găsite de Viehmann, Rusu, Racoviţă şi Crăciun şi cele din peştera Gheţarul de la Vîrtop (Munţii Bihor) descoperite de Viehmann, Bucur şi Racoviţan. Autorul prezintă în continuare aprecieri paleobiologice privind cohabitarea omului preistoric cu ursul de cavernă (Viehmann, Racoviţă, Riscuţia, 1970), precum şi semnificaţiile pe care le pot avea urmele umane descoperite în peşteri.

În ultima parte a lucrării sînt enumerate observaţiile care au condus la aprecierea preliminară a vîrstei omului preistoric, prin interpretarea urmelor acestuia din peşterile României. Astfel, în cazul Peşterii Muierii, urmele au fost distruse înainte de a putea fi studiate, dar datarea făcută pe un craniu descoperit în aceeaşi cavitate şi care a utilizat metoda C_{14} a stabilit pentru acesta o vechime de 29.000 de ani. La Peştera Ciurului-Izbuc s-a luat în considerare compoziţia uniformă a prafului teluric depus pe urmele labelor ursului de cavernă şi pe amprentele hominiene, faptul că picioarele omului calcă urma ursului şi invers, precum şi rezultatele analizelor antropometrice efectuate pe mai bine de 200 de amprente umane. S-a stabilit că este vorba de un *Homo sapiens fossilis*, a cărei vîrstă a fost apreciată la 18.000 de ani. Estimarea preliminară a vechimii urmelor din peştera Gheţarul de la Vîrtop, care pot aparţine unui pre-Neanderthalin de vîrstă mousteriană de acum cca. 80.000 de ani, s-a făcut prin studiul planşeului stalagmitic în care sînt ele înscrise, prin considerarea faptului că sala în care au fost descoperite a fost pentru prima dată dezobstruată şi vizitată de noi, deoarece ea fusese închisă prin cîteva colonade stalagmitice, precum şi pe baza determinărilor morfometrice efectuate de antropologul C. Rişcuţia. Una din aceste amprente a fost scoasă cu porţiunea din planşeul stalagmitic în care este înscrisă şi se află în păstrare ca obiect de tezaur în colecţiile sectorului din Cluj-Napoca al Institutului de Speologie „Emil Racoviţă" (România).

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[1] Lucrarea a fost prezentată în august 1986 la cel de al nouălea Congres Internaţional de Speologie, care a avut loc la Barcelona, în Spania.

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NOTES

PARAGENÈSE PYRITE – MARCASSITE DU KARST DES MONTS METALIFERI

PAR

M. NEDOPACA

On présente une paragenèse mineralogique, pyrite-marcassite, rencontrée dans la zone karstique Rișculița (Monts Metaliferi).

La zone karstique Rișculița des Monts Metaliferi au nord-ouest de Brad comprend des klippes de calcaire tithonique située dans la masse du flysch crétacé (Lupu et al., 1979).

Les calcaires sont à jour sur le versant gauche de la vallée Rișculița, où els paraissent sous forme d'abrupt à dépôts non stratifiés massifs, spathiques, gris-blanchâtres, intensément karstifiés à la surface.

Dans la carrière Rișculița, on remarque, dans la masse des calcaires fissurés des creux dissolution, ellipsoïdaux ou ronds, à parois recouvertes de dépôts de calcite largement cristallisées.

Les cristaux de calcite sont chimiquement corrodés selon des plans de clivage sur profondeur de 3—5 mm sous forme de petits fossés disposés en réseaux.

Dans les petits fossés de corrosion (Fig. 1) apparaissent des dépôts minéralisés de sulfures, sur une étendue de 0,3—0,7 mm, ayant un maximum de développement à l'intersection de deux systèmes de petits fossés de dissolution.

Les sulfures sont constituées par des cristaux en octaèdres bipyramidés, parfois en colonne, de pyrite et de marcassite. Elles forment, également, des groupements et des petites veinules allongées.

Sous microscope, les granules de pyrite, de 0,04 mm apparaissent écrasés, à centres de croissance radiaire autour de certains noyoau sphéroïdaux argileux. Le centre de tels noyaut est constitué par une masse argileuse à granules cryptocristallins (0,005 mm) de pyrite I. Vers les bords, les noyaux argileux sont entoures par un anenau frangé de psylomélane et de marcassite I, auquel font suite des agrégats radiaires de pyrite II (Fig. 2). Les cristaux de pyrite II à contour rhombique sont moulés et corrodés par des dépôts plus tardifs de marcassite II (Fig. 3).

Le pleocroïsme de reflexion est la caractéristique principale des dépôts de marcassite qui peut être observé surtout sous des objectifs spéciaux pour immersion dans de l'huile.

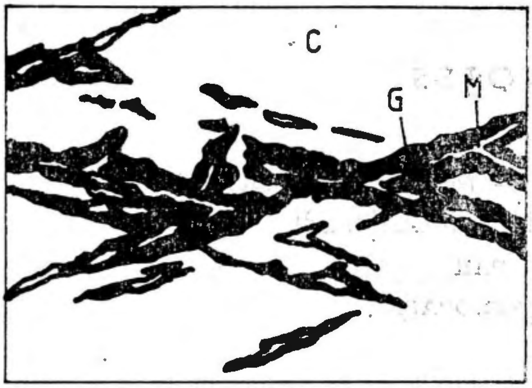

Fig. 1. Calcite (C) corrodée selon des plans de clivage (G) et depôt mineralises de sulfures (M).

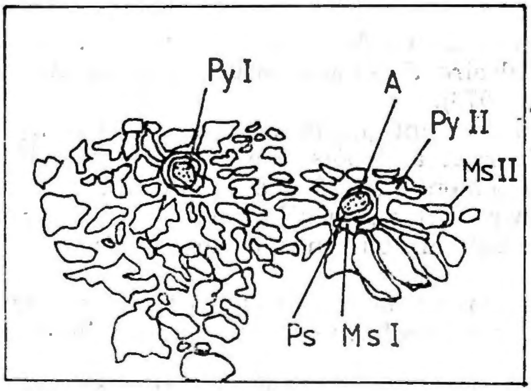

Fig. 2. Noyaux sphéroidaux argileux (A) à granules cryptocristallins de pyrite (Py I) (antoures par psylomélane (Ps) et de marcassite (Ms I) ; agregats radiaires de pyrite (Py II) moulés par de marcassite (Ms II).

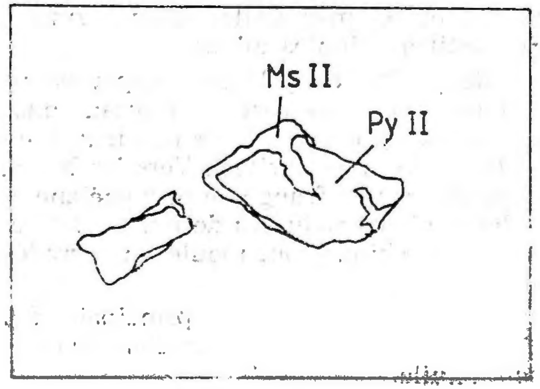

Fig. 3. Cristal de pyrite (Py II) moulée et corrodée par de

La pyrite est plus foncée, elle est isotrope et elee est plus difficilement polissable.

D'une analyse spectrale demi-quantitative faite sur ces sulfures il en ressort un modeste contenu de ces éléments mineurs : Co = 81 ppm et Ni = 25 ppm.

La faible valeur du rapport Co/Ni = 0,31 indique un régime de genèse sédimentaire, à températures basses, allant jusqu'à celle du milieu ambiant (Fleischer, 1955).

La succession de formation, décrite en l'occurrence, commence par des dépôts massifs de calcite que, ensuite, dans une étape acide, est corrodée chimiquement en des plans de clivage. Il se forme ainsi des creux où se dépose l'argile dans laquelle apparaissent les premières sulfures cryptocristallines de pyrite I, suivres de psylomélane et de marcassite I. La reprise des dépôts de sulfure débute par la formation de de pyrite II largement cristallisée, et après une courte période de broyage et de reactivité du potentiel de soufre, il se produit la périmorphose et la corrosion de celle-ci par la marcassite II.

Comme sousces d'éléments chimiques, le fer a été extrait des minéraux mélanocratés des roches environnantes, et le soufre par décomposition bactérienne. Le transport du fer est possible dans des solutions de l'acide de tanin (Hem, 1960) ou sous forme de sel stable étant dispersé dans l'eau.

L'accumulation des sulfures a été effectuée par voie bactérienne ; les faits suivants plédent en faveur de cette genèse :

— les noyaux argileux à psylomélane et marcassite se sont constitués par la diffusion du fer et du soufre à l'aide de certaines matieres organiques Berner, 1970) ;

— certaines bactéries peuvent réduire les sulfates en sulfures par des processus vitaux (Ivanov, 1968) ;

— les dépôts de psylomélane du domaine karstique sont attribués à l'action bactérienne (Coman, 1979) ;

— dans certaines organisme il existe des proteines à groupements sulphydriques (métalothyoneines) capable de précipiter les sulfures sous forme de sels insoluble (Petre, 1985).

Les structures radiaires et les cristaux en octaèdres de pyrite se sont formés aux dépends du facteur cristallographique qui a suivi la loi de sélection géométriques des germes (Petreuș, 1974).

Des paragenèses des sulfures de fer découvertes dans le domaine karstique ont été encore décrites des grottes suivantes : noyaux de pyrite recouverts de goethite dans la grotte Mamut Dacnstein — Autrich (Seeman, 1970), pyrite dans Herman Smtih Cave, Illinois, SUA (Moore, 1976) et pyrite avec marcassite dans la grotte Shor-Su-Kokanda, URSS (Hill, 1981).

La paragenèse des sulfures à pyrite et marcassite que nous venons de présenter, constitue pour notre pays une nouveauté dans le domaine karstique enrichissant aussi l'inventaire minéralogique des spéléothèmes.

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PARAGENEZA PIRITA-MARCASITA ÎN CARSTUL MUNŢILOR METALIFERI

Rezumat

Lucrarea cuprinde o descriere a unei parageneze mineralogice constituită din sulfuri metalice (pirită-marcasită) identificată pe pereţii unor cavităţi carstice deschise în Rişculiţa, Munţii Metaliferi.

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Theoretical and Applied Karstology. Vol. 8 (1987). pp. 239, to 242

NOTE SUR LA PRÉSENCE DE QUELQUES MINÉRAUX DE MANGANÈSE ET DE FER DANS L'ENDOKARST DES CALCAIRES CRISTALLINS DANS LES MONTS MÉTALIFÈRES

PAR

M. NEDOPACA

Le travail contient la description minéralogique des spéléothèems de pyrolusite et de geothite de la grotte Cila, Monts Métalifères.

La grotte Cila est cantonnée dans un bloc de calcaires qui font partie de la série des marbres de Sohodol (Dimitrescu ,1977) et elle se trouve sur le versant gauche de la Valea Morii, à 2,5 km au sud de la commune de Ponorel dans la vallée d'Arieșul Mic. La grotte a une longueur réduite (15 m) et une seule entrée ; il s'agit d'une grotte fossile, à morphologie simple, formée au contact entre des marbres et des quartzites graphiteux. Dans la grotte il y a des formes phréatiques et des spéléothèemes composés de pyrolusite, goethite, aragonite et calcite.

PYROLUSITE — MnO_2, este le principal minéral métalique qui, sous le microscope, a une couleur blanchatre claire, a faibles reflets crème, réflexion élevée et forte anisotropie. Les granules idéomorphes ou allotriomorphes présentent des fissures de dessication a disposition parallèle (Fig. 1).

Ce minéral présente des spéléothèmes sous forme de stalactites grossières, draperies, croutes parietales, etc. La pyrolusite forme des textures rythmiques avec la geothite ou apparaît en masse largement cristallisée. Parfois elle apparaît sous forme de pellicules ou d'acicules à la surface de la goethite et sur des stalactites grossières (Fig. 2).

GOETHITE — FeO.OH, est le deuxième minéral métalique, qui, sous le microscope présente une couleur grise à faible réflexion. Dans l'immersion à l'huile il y a des reflets internes caractéristiques. La goethite forme des agrégats radiaires à texture rubanée avec des petits centres divergents (Fig. 3).

Pour ce qui est des spéléothèmes, elle forme des stalactites petites, des agrégats réniformes, des clusterites et des globulites (Fig. 4) présentant une surface luisante, noir brillant.

Fig. 1

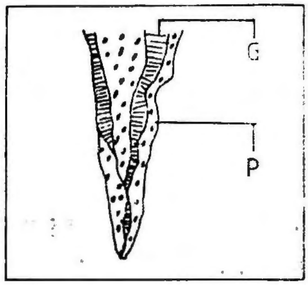

Fig. 2

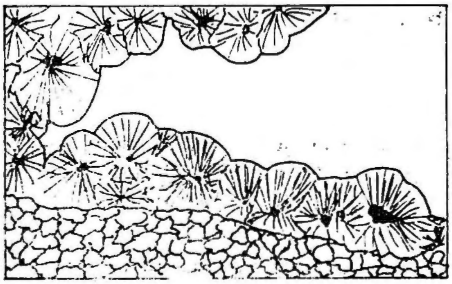

Fig. 3

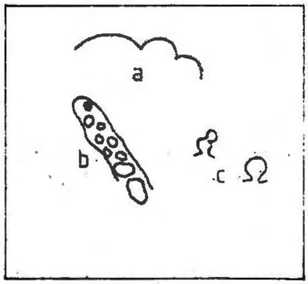

Fig. 4

Fig. 1. Pyrolusite ; agrégats cristallinen. N II, x 60.
Fig. 2. Stalactite avec d pot de pyrolusite (P) et de goethite (G), x 5.
Fig. 3. Goethite collomorphe ; agrégats radiaires. N II, x 60.
Fig. 4. Goethite ; agrégats réniformes (a) et clusterites (b, c).

L'analyse spectrale semi-quantitative a mis en évidence les micro-éléments suivants dans les concentrations de pyrolusite et de goethite : V, Cr, Ni, Co, Ti.

Les analyses en RX (Tableau I) attestent la présence certaine de la pyrolusite et de la goethite par comparaison au catalogue Miheev (1957); le diagramme d'absorbtion en IR (Fig. 5) dénote des pics caractéristiques.

Tableau 1

L'analyse en RX des échantillons

PYROLUSITE		GOETHITE	
La grotte Cila d/n	Miheev (1957) d/n	La grotte Cila d/n	Miheev (1957) d/n
3,115	3,118	4,18	4,18
2,405	2,404	2,70	2,69
2,185	—	2,45	2,45
2,110	—	2,185	2,18
1,970	—	1,794	—
1,723	1,622	—	1,72
1,556	1,555	1,706	—
—	1,302	—	—

L'aragonite se présente sous forme de fins cristaux aciculaires, déposés sur des croutes de goethite ou sur des croutes de calcite.

La source probable du manganèse et du fer est constituée par les quartzites graphiteux, lesquels dans la region de Ponorel passent dans la zone à almandine-spessartine comme degré de métamorphisme. Les deux métaux, après avoir été dissouts par les eaux superficielles acides, donnent par oxidation des composés avec des valences supérieures dont le transport se fait dans des solutions à caractèere colloidal et à l'aide de bactéries spécialisées. Sous l'action de certaine catalisateurs il résulte des dépôts rythmiques de gels ferromanganeux qui ont absorbé une série de microéléments.

Pour les spéléothèmes de pyrolusite et de goethite de la grotte Cila, nous admettons un age d'environ 1.600.000 ans qui est en corrélation avec l'age villafranchien de la karstoplaine Citera (Bleahu, Rusu, 1965). Cela est en accord avec les recherches de Bricker (1965) qui a calculé la vitesse d'oxidation des minéraux de manganèse dans le système Mn—O—H_2O jusqu'à la formation de composés finaux de type pyrolusitique.

Les spéléothèmes de pyrolusite et de goethite de la grotte Cila constituent une rareté pour la Roumanie. La goethite a aussi été décrite par Bradbury (1959) de la grotte Herman Smith (U.S.A.) tandis que la pyrolusite n'est pas citée sur la liste des minéraux des grottes publiés par Moor (1970).

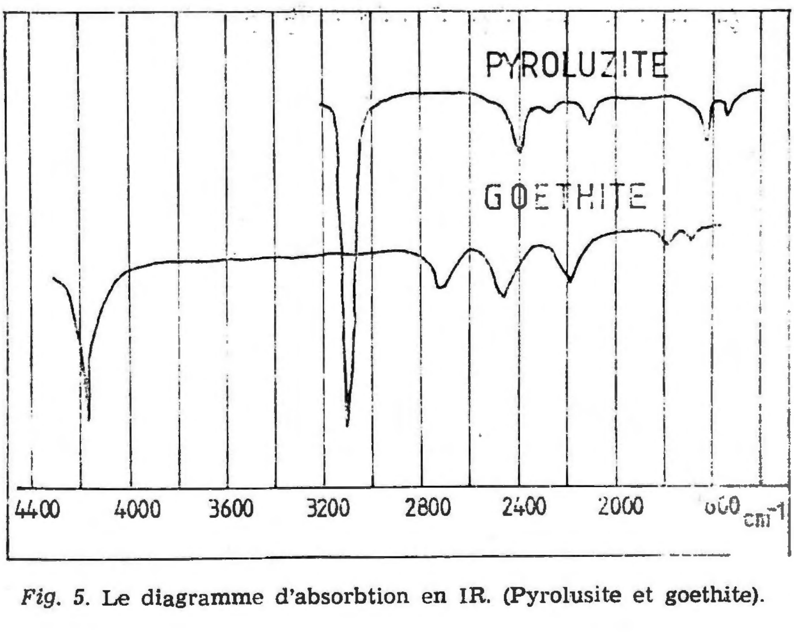

Fig. 5. Le diagramme d'absorbtion en IR. (Pyrolusite et goethite).

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NOTĂ ASUPRA PREZENȚEI UNOR MINERALE DE MANGAN ȘI FIER ÎN ENDOCARSTUL CALCARELOR CRISTALINE DIN MUNȚII METALIFERI

Rezumat

În peștera Cila din Munții Metaliferi au fost identificate speleoteme constituite din oxizi de mangan și fier. Analiza probelor la microscop, în IR și RX a confirmat compoziția lor mineralogică ca fiind alcătuită din piroluzit și geothit. Analizîndu-se și elementele minore din eșantioanele prelevate se fac aprecieri asupra surselor de proveniență a oxizilor.

În final, vîrsta speleotemelor este apreciată ca fiind vilafranchiană, în concordanță cu vîrsta carstoplenei Citera, areal în care se află amplasată peștera Cila.

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ORIGINES ET FORMES D'APPARITION DU GYPSE DANS PEŞTERA VÎNTULUI (MONTS PĂDUREA CRAIULUI)

PAR

B. ONAC, I. VIEHMANN

Les auteurs présentent le mode d'apparition et l'origine des cristaux **de gypse de Peştera Vîntului („Grotte du Vent"), département de Bihor.**

„Peştera Vîntului", le plus long réseau souterrain de Roumanie, s'ouvre sur la rive gauche du Crişul Repede, 2 km en amont de la localité minière de Şuncuiuş (départment de Bihor).

La grotte s'est développée dans l'horizon des calcaires blancs marmorées, d'âge ladinien (Triassique moyen), calcaires qui sont en général massifs, dépourvus de stratification, de teinte blanc-rose. Sur les surfaces d'altération on observe des formes de gastropodes.

Le Jurassique est disposé de façon discordante et transgressive par-dessus différents termes du Triassique moyen et inférieur. Dans la zone de Şuncuiuş le Liasique inférieur (Hettangien + Sinémurien) est représenté par le faciès de Gresten, hétérogène du point de vue pétrographique. Il y apparaît des conglomérats, des grès, des grès quartzitiques, des argiles, des argiles réfractaires, voire même des blocs de calcaires ladiniens.

Morphologiquement, le gypse apparaît dans la grotte de trois manières différentes, dont nous ferons état dans l'ordre de leur fréquence.

1) *Dépôts crustiforme*. Dans Peştera Vîntului c'est la forme d'apparition du gypse qui y est prédominante. On la retrouve en effet sur plusieur centaines de mètres dans les diverses galeries de la grotte. Les cristaux qui composent la croûte ont un habitus tubulaire à orientations diverses. Leur couleur varie du blanc mat au brun roux, en fonction des impuretés incorporées dans le réseau.

En plusieurs points de la grotte on remarque un „écaillement" de ces croûtes, le phénomène étant à remaner à l'apparition de tensions dans les roches, déterminées par divers facteurs microclimatiques ainsi que par la propriété de plasticité du gypse. L'épaisseur des croûtes varie entre 1 et 30 mm. En raison de leur aspect, ces croûtes ont été appelées „nids de guêpe".

2) *Cristaux aciculaires.* Ceux-ci se trouvent répandus dans l'argile poussiéureuse décelable dans le sol des méandres du premier étage, sous une forme semblable aux depôts de terrasse à la surface de l'écorce. Les cristaux ont une disposition chaotique dans la masse de l'argile résultée par décalcification.

La couleur de ces cristaux aciculaires varie pour les mêmes raisons que nous avons signalées dans le cas des dépôts crustiformes. Leur taille est de 0,2 à 2 mm, leur longueur variant entre 0,5 et 3 cm.

Nous estimons qu'ils se sont formés sur le plancher, dans la masse argileuse.

3) *Agrégés de cristaux.* Nous avons englobé dans cette catégorie tous les cristaux courbées ou roulés hélicoïdalement, qui, en raison de leur aspect, ont été appelés anthodites (*anthos* „fleur" en grec).

Cette forme apparaît dans les galeries des étages supérieurs de la grotte.

Le gypse qui entre dans la composition des anthodites est fibreux (variété : sélénite) ; il est d'aspect nacré et de couleur blanche quand il est pur. Tel que nous l'avons montré, dans la plupart des anthodites on remarque une courbure des cristaux, réalisant des formes semblables à la pâte dentifrice quand, sous pression, elle éferge du tube.

La courbure des „pétales" de ces anthodites a donné lieu à des controverses parmi les chercheurs, en raison des nombreuses tentatives d'expliquer la courbure, dont certaines n'ont ni fondement théorique ni appui pratique.

Les expériences de laboratoire (Huff, 1940) ont conduit à la compréhension et à l'explication des phénomènes qui ont lieu dans les pores de la roche quand une solution les traverse qui contient l'anion SO_4^{2-}. On en est arrivé à la conclusion qu'au début le dépôt est une surface mince, lisse et perlée. Si les pores sont rapprochés, il en résultera un agrégat de cristaux aciculaires qui se développe mieux dans la zone centrale, où l'apport de solution est plus important.

Par comparaison avec les hélictites de calcites, les anthodites de gypse ne se développent par à l'extrémité attachée, chaque cristal se développant à partir de la base, sur la roche à travers laquelle circule la solution, étant poussé à partir des pores par le déôt qui se forme.

Venons-en maintenant à l'expliction de l'origine du gypse de Peştera Vîntului.

Les donnes onnes géologique du plusieurs forages exécutés dans le complexe liassique inférieur ont montre que ce complexe a une épaisseur de 120 à 150 m et se développe au-dessus du paquet de calcaires ladiniens dans lequel s'est formée la grotte Peştera Vîntului.

Ayant étudié les carottes extraites de profondeurs allant jusqu'à 130,8 m, nous avons été à même de constater l'existence sur cette épaisseur de quatre niveaux distincts, appelés aussi zones oxydiques, où les argiles sableuses, les grès à ciment siliceux, l'argilite gréseux et certaines marnes sont imprégnés de minéraux du groupe des sulfures, dont les plus fréquents sont la pyrite et la marcassite.

Ces niveaux ont un développement lenticulaire, s'effilant fréquemment. L'eau d'infiltration franchit ce complexe liasique en lévigeant dans

les zones oxydiques l'anion SO_4^{2-} qu'elle charrie jusqu'au contact avec le calcaire, où elle le dépose.

Que cette hypothèse est soutenable est attesté par l'analyse de l'eau d'infiltration, qui s'écoule sur certaines portions sur les parois de la grotte. Dans cette eau, l'anion SO_4^{2-} a été déterminé en quantité nettement plus grande que dans l'actif principal de la grotte.

Nous en concluons que le complexe liasique inférieur (les zones oxydiques) est directement responsable de l'apparition du gypse dans la grotte Peştera Vîntului, apparition qui, en fonction de la morphologie et de la tectonique de la galerie ou de la salle, détermine une des trois formes de dépôt du gypse.

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ORIGINEA ŞI FORMELE DE APARIŢIE ALE GIPSULUI ÎN PEŞTERA VÎNTULUI (MUNŢII PĂDUREA CRAIULUI)

Rezumat

Peştera Vîntului, judeţul Bihor, se dezvoltă în calcare ladiniene peste care, discordant şi transgresiv, se depun formaţiuni aparţinînd jurasicului inferior.

Au fost studiate trei moduri de apariţie a gipsului, în ordinea frecvenţei lor. Crustele sînt cele mai răspîndite, apoi cristalele aciculare şi sporadic anthodite.

Geneza acestor formaţiuni de gips s-a pus pe seama unor nivele oxidice, ce apar în complexul rocilor de vîrstă jurasic inferior (Liasic) care străbătute fiind de apele de infiltraţie se încarcă cu anionul SO_4^{2-}, care în contact cu calcarul se depune sub una din cele trei forme descrise.

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SCIENTIFIC EVENTS

THE THIRD SYMPOSIUM ON THEORETICAL AND APPLIED KARSTOLOGY

CLUJ-NAPOCA, ROMANIA, 31 MAY — 2 JUNE 1985

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Institute of Speology „Emil Racoviță"
Enterprise for Geological and Geophysical Prospecting, Bucharest

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PROGRAMME

Friday morning, 31 May, 1985

OPENING CEREMONY

Keynote Address:

Dr. Natalia DUMITRAȘC, Chairman of Scientific Council, Central Biological Institute, Bucharest

Opening Statements :

Prof. Dr. Eugen NICORICI, Department of Geology, University of Cluj-Napoca
Dr. Dan SLĂVOACĂ, Enterprise for Geological and Geophysical Prospecting, Bucharest
Dr. Marcian BLEAHU, Chief of the Geological Mapping Department, Institute of Geology and Geophysics, Bucharest
Dr. Dan DANCĂU, Director, „Emil Racoviță" Speological Institute, Bucharest
Dr. Theodor RUSU, Senior Scientist, „Emil Racoviță" Speological Institute, Cluj-Napoca Department

DIAPOSIVITIVE PRESENTATION : „Speology in images"

VISIT TO THE EXHIBITION : „Traditions and Realizations in Romanian Speology" — organized at the „Emil Racoviță" Speological Institute, Cluj-Napoca Department.

SESSION 1

Friday afternoon, 31 May, 1985

Invited lecture

E. GAȘPAR and I. ORĂȘEANU : Natural and artificial tracers in the study of the hydrodynamics of karst *(Published in Theor. Appl. Karst., this volume).*

Reports

D. COMAN : Point of view on karst phenomena
M. BLEAHU : Palaeokarst in Romania
A. BULGĂR and N. SUCIU : Present-day hydrometeorological conditions in karst phenomena from Romania
C. PLEȘA : Microglossary of stygology *(Published in Theor. Appl. Karst. Vol. 2, pp. 25—45).*
M. ȘERBAN : Is there a meandering in vertical plane of the underground drainages ?

SESSION 2

Saturday morning, 1 June, 1985

Reports

T. RUSU : The Pădurea Craiului Mountains — a physico-geographic framework
T. RUSU : Exokarst in the Pădurea Craiului Mountains
A. JURKIEWICZ and H. MITROFAN : Endokarst controlling factors in the Pădurea Craiului Mountains

I. PETRESCU, E. NICORICI and D. SIMET : The role of the paleokarst in the genesis of the Sarmatian coals from the western part of the Vad-Borod basin

V. BATIN : Observations concerning the paleokarst in the Pădurea Craiului Mountains

I. COCIUBA and M. COCIUBA : Specific features of the bauxite bearing paleokarst in the Pădurea Craiului Mountains

G. IONESCU and C. IONESCU : Considerations on the morphology and genesis of the Jurassic paleokarst in the Farcu Hill area, southern Pădurea Craiului Mountains *(Published in Theor. Appl. Karst., Vol. 4, in press)*

I. ORĂȘEANU, T. RUSU, E. GAȘPAR, A. JURKIEWICZ and I. POP : Underground drainages in the Pădurea Craiului Mountains

L. BLAGA : Researches on the basis of the deuterium concentration in waters from Pădurea Craiului Mountains

I. ORĂȘEANU, A. JURKIEWICZ and H. MITROFAN : Hydrogeological karst systems in Pădurea Craiului Mountains *(Published in Theor. Appl. Karst., this volume)*

I. ORĂȘEANU, I. POVARĂ, T. RUSU, I. VIEHMANN, A. JURKIEWICZ, T. NICOLAE, V. PREOTEASA, G. HOȚOLEANU and P. HOȚOLEANU : On the ground- and surface waters balance in the Pădurea Craiului Mountains

C. MARIN : Karst hydrochemistry in the Pădurea Craiului Mountains

I. ORĂȘEANU : Hydrogeologic map of the Pădurea Craiului Mountains *(Published in Theor. Appl. Karst., Vol. 4, in press)*

P. COCEAN : Economic potential of the karst in the Pădurea Craiului Mountains

SESSION 3

Saturday afternoon, 1 June, 1985

Reports

A. BULGĂR, I. MUNTEANU and N. SUCIU : Characteristics of the hydrologic balance in karst basins

D. RĂDULESCU, I. STĂNESCU, E. GAȘPAR and A. BULGĂR : Aquiferous interconnexions in the Motru — Izvarna — Tismana — Bistrița karst area *(Published in Theor. Appl. Karst., this volume)*

C. MOISSIU, A. MOISESCU and D. MOCUȚA : Researches concerning the stability of the chacarcteristics of the flat water from Izvorul Minunilor in the Vlădeasa Massif

V.-A. C. BULGĂREANU : Geodynamisc and the water circulation in the salt massif lake area Baia Baciului — Baia Neagră — Baia Miresii ; Slănic Prahova *(Published in Theor. Appl. Karst., this volume)*

N. TERTELEAC and C. LASCU : Note concerning the transport and deposition of sediments in the sumps from the Lazului and Topolnița Cave *(Published in Theor. Appl. Karst., Vol. 4, in press)*

T. MOLDOVEANU and O. SUCIU : Contributions to the applicability of geophysical methods in the study of building foundations in karst areas

D. RĂDULESCU, I. STĂNESCU, I. GHERMAN and S. CIOCANIU : Horizons of permeability in the microkarst of the Sarmatian limestone at Mangalia

Z. R. TODEA : The karst — main water-supply in southern Dobrogea

M. NEOPACA : The pyrite-marcasite paragenesis in the Metaliferi Mountains karst *(Published in Theor. Appl. Karst., this volume)*

M. LUDU and A. BULGĂR : Peculiarities of the valorisation of the water-supply in the karst area

C. GRAMA : Problems of groundwater circulation in the Vidra-Poieni plateau (Găina massif — Bihor)

M. GĂVRUȘ : Topoclimatic researches in the Vîntului Cave

M. PETRESCU : Evolution of the relief on salt from the Valea Sărată, Turda area

SESSION 4

Sunday morning, 2 June, 1985

Reports

G. DIACONU and D. TODOR : Appreciations on a possibly new mineral species from Topolnița Cave

I. VIRAG and I. RADU : Conditions concerning the fluorescin designed for hydrokarst research syntethised from indigenous raw material

I. VIRAG : Proposals of valorisation concerning the thermic characteristic of the spring of the Ponicova creek

I. VIEHMANN and B. ONAC : Comparative study of the gypsum from the Vîntului Cave (Pădurea Craiului Mountains) and Tăușoare Cave (Rodna Mountains) *(Partly published in Theor. Appl. Karst., this volume)*

E. SILVESTRU : An active mineral : the mirabilite from the Izvorul Tăușoarelor Cave

G. PROCOPIE and I. BANU : The complex valorisation of the karst in Buila-Vînturarița Mountains

I. FILIP and M. DOMȘA : Genesis of the mirabilite in the Tăușoare Cave

N. CEANGĂ and G. CEANGĂ : Touristic valorisation of the karst in the Eastern Carpathians

A. TULUCAN, T. TULUCAN and N. PELLEGRINI : Observations on the functional and feeding system of the spring from Călugări (Codru Moma Mountains)

A. TULUCAN and T. TULUCAN : The volcano-karst relief developed on Neogene agglomerates in the Crișul Alb defile

I. BANU and C. PROCOPIE : Morphology of the similikarst in the Cretacious from the Eastern Căpățîna and Lotru Mountains

A. L. ZOLYA : Contributions to the knowledge of the genesis of the Benedek Elek caves containing mineral sources at Bățanii Mici (Covasna)

E. TERZEA : Chronology of the Upper Pleistocene vertebrate faunas in some caves and rock-shelters from south-western Romania *(Published in Trav. Inst. Spéol. „Émile Racovitza“, vol. 25, pp. 85—101)*

C. RĂDULESCU and P. SAMSON : Palaeoclimatic aspects of the Würm on the basis of micromammals from karst in Central Dobrogea
I. VIEHMANN : Inventory of bioglyphs belonging to the cave bear
A. I. DOBRESCU : Speo-palaentological Contributions on the Muscel karst

Sunday afternoon, 2 June, 1985

Small Hall of the Universitary House, Cluj-Napoca

FILM AND DIAPOSITIVE PRESENTATIONS

PARTICIPANTS

Maria ALB, Constantin AMARIEI, Gerlatin AVRAM, Radu BABOȘ, Ioan BANU, Tiberiu BĂLĂNEANU, Liviu BLAGA, Marcian BLEAHU, Iuliu BOR, Teodor BORODAN, Traian BOSDOC, Alexandru BULGĂR, Valentin A. C. BULGĂREANU, Petre BUSUIOC, Adrian CARACIONI, Maria CHIFOR, Felician CHIRILĂ, Nicolae CIANGĂ, Romică CIUTACU, Pompei COCEAN, I. COCIUBA, M. COCIUBA, Dan COMAN, Agneta CRAIOVEANU, Maria CRISTIAN, Dan DANCĂU, Istvan DANEȘ, Gabriel DIACONU, Ioan DOBRESCU, Natalia DUMITRAȘC, Emilian GAȘPAR, Mircea GĂVRUȘ, Iustin GERMAN, Dezideriu GIURGIU, Cristian GORAN, Constantin GRAMA, Radu GROIȚĂ, Walter GUTT, Mircea HORNOIU, Cătălin IONESCU, Georgeta IONESCU, Adrian JURKIEWICZ, Günter KARBAN, Mircea LUDU, Mircea MAN, Constantin MARIN, Paul MATOȘ, Horia MITROFAN, Gheorghe MOCUȚA, Alina Zoe MOISESCU, Constantin MOISSIU, Ioana MUNTEANU, Rada MUNTEANU, Livia NEAGU, Mircea NEDOPACA, Adrian NICOLAU, Eugen NICORICI, Iancu ORĂȘEANU, Mircea PESCARU, Iustinian PETRESCU, Mircea PETRESCU, Corneliu PLEȘA, George PONTA, Cornel POP, Radu POP, Ghiță PROCOPIE, Costin RĂDULESCU, Theodor RUSU, Petru SAMSON, Alfred SCHNEIDER, Georgel SIMION, Dan SLĂVOACĂ, I. STĂNESCU, Nicolae SUCIU, O. SUCIU, Mihai ȘERBAN, Emilia TALLODI, Agata TEODORESCU, Nicolae TERTELEAC, Elena TERZEA, Ion TOBĂ, Zefir Radu TODEA, Marius TOMESCU, Alina TULUCAN, Tiberiu TULUCAN, Liviu VĂLENUȘ, Romulus VENȚEL, Iosif VIEHMANN, Ioan VIRAG, Laslo ZOLYA. Bogdan ONAC

THE FOURTH SYMPOSIUM ON THEORETICAL AND APPLIED KARSTOLOGY

BĂILE HERCULANE, ROMANIA, 23—27 MAY 1986

SYMPOSIUM COOPERATING ORGANIZATIONS

Institute of Speology „Emil Racoviță"
Enterprise for Geological and Geophisical Prospecting, Bucharest

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Chairman :	Dr. Dan DANCĂU
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PROGRAMME

Friday morning, 23 May, 1986

OPENING CEREMONY

Keynote address :

Prof. Dr. Radu CĂDERE, Professor of Hydrogeology, Department of Geological and Geophysical Engineering, University of Bucharest, Bucharest

Opening Statements :

Dr. Ilie CRISTESCU, Director, Watering and Touristic Enterprise Herculane, Băile Herculane
Dr. Mihai CROITORU, Chief Geologist, Enterprise for Geological and Geophysical Prospecting, Bucharest
Dr. Dan DANCĂU, Director, „Emil Racoviță" Speological Institute, Bucharest

SESSION 1

Reports

A. BULGĂR, N. SUCIU, and I. MUNTEANU : Preliminary evaluation concerning the hydrologic potential of the main karst areas in Romania

C. MOISSIU, A. Z. MOISESCU : Potential areas containing oligomineral flat water resources in Romania

G. RACOVIȚĂ, M. ȘERBAN and I. VIEHMANN : Long-term tendencies in the dynamics of the ice formations fro mthe „Ghețarul de la Scărișoara" Cave *(Published in Teor. Appl. Karst., this volume)*

SESSION 2

Friday, afternoon, 23 May, 1986

Reports

I. CRISTESCU : Touristic valorisation of the karst phenomena in the Cerna valley

G. SIMION : Genesis of the thermomineral waters at Băile Herculane

H. MITROFAN : Considerations on the mass and heat transfer in the Băile Herculane hydrogeothermal system

G. DIACONU and M. MITRUȚIU : Geology and tectonics in the water discharge influential perimeter of the „Hercule I" thermomineral spring *(Published in Theor. Appl. Karst., this volume)*

A. TEODORESCU : Contributions to the knowledge of the endokarst hydrogeology in the „Hercule I" spring area, Băile Herculane

N. TERTELEAC : Sedimentological observations in some cave from the Cerna valley

T. JURCSÁK and E. KESSLER : Eocretacious vertebrates from Cornet and their paleozoological importance

I. VIEHMANN : Prehistoric human footprints in Romanian's caves *(Published in Theor. Appl. Karst., this volume)*

A. TULUCAN : General considerations on the limestone from the base of Pliocene on the „Turnu" structure, Pannonian Depression

SESSION 3

Saturday morning, 24 May, 1986

Reports

T. TULUCAN : Genetic classification of the endo volcano-karst phenomena in Romania. Aspects of the distribution in the Carpathian Mountains area

M. NEDOPACA : Bacterial pyrite from the caves at Risculița — Hunedoara Dist.

N. TERTELEAC, A. TERTELEAC and I. ORĂŞEANU : Microtectonic consideration concerning the groundwater drainage in the northern part of the Piatra Craiului Massif, Valea Prăpastiei-Zărneşti area

Invited lecture

C. GORAN : Consideration on the spatial configuration and development of the karst cavities *(Published in Theor. Appl. Karst., vol. 4, in press)*

SESSION 4

Saturday afternoon, 24 May, 1986

Reports

E. SILVESTRU : New data on the mirabilite from the cave Izvorul Tăuşoarelor

C. UNGUREANU : Mineralogic study of the clays from the Tecuri Cave

G. IONESCU and C. IONESCU : Considerations on some gypsum occurrences in the Ciur-Izbuc Cave, Pădurea Craiului Mountains *(Published in Theor. Appl. Karst., Vol. 4, in press)*

G. DIACONU, C. HĂDĂREANU and I. RUSU : The phenomenon of piezoelectricity on calcite *(Published in Trav. Inst. Spéol. „Emile Racovitză"; Vol. 26, pp. 87—93)*

P. BARVINSCHI : The magnetic field influence on the growth of stylolites

A. JURKIEWICZ : Considerations on the Karst in the Borşa-Fîntîna area, Rodnei Mountains

M. PREDA, T. PICIU and S. GALLÓ : Aspects of the involved pedogenetic processes in the genesis and evolution of the karst (presented by G. Racoviţă)

T. CONSTANTINESCU : Evolution of the hydrographic network in the Dîmbovicioara Couloir *(Published in Theor. Appl. Karst., this volume)*

I. POVARĂ and T. RUSU : Considerations on the genesis of the retrogressive valleys *(Published in Theor. Appl. Karst., Vol. 4, in press)*

SESSION 5

Sunday morning, 25 May, 1986

Reports

P. CHIRILĂ and S. CHIRILĂ : Aspects of the pollution in the cave of the northern part of the Hunedoara District

V. TRUFAŞ, H. MITROFAN, C. MARIN and A. IOŢA-VĂTAFU : Morphogenetic and hydrochemical considerations on the Ponorici-Cioclovina cu Apă endokarst network, Sebeş Mountains

C. MARIN : A chemical model of karst water. Preliminary consideration *(Published in Theor. Appl. Karst., Vol. 4, in press)*

E. PÎRVĂNESCU : Menagement problems concerning the waters in karst area

Invited lecture

M. ŞERBAN : Wall microrelief in caves — effect of turbulence *(Published in Theor. Appl. Karst., this volume)*

SESSION 6

Sunday afternoon, 25 May, 1986

Reports

A. FERU : New data concerning the mineral water storage at Borsec

G. BAROSI, A. SINKA and H. MITROFAN : Characteristics of the carbonate geothermal collectors in the Moesian Platform

M. FERU : Genesis of the mesothermal waters at Mangalia

V. ŞTEF : Elements of the maximum drain in the karst relief in the Geoagiu hydrographic basin

T. NICOLAE, A. BULGĂR and I. ORĂŞEANU : Characteristics of the drain regime in the Bihor Mountains karst area

I. ORĂŞEANU, E. GAŞPAR and N. ORĂŞEANU : Underground drains in the Bihor Mountains

E. G9ŞPAR, P. STĂNESCU, S. SPIRIDON, I. ORĂŞEANU and O. FĂRCAŞIU : New tracers in karst hydrology.

L. BLAGA, D. S. BLAGA, T. CIOBOTARU and V. FEURDEAN : Deuterium concentration in the groundwaters from southern Dobrogea.

Z. R. TODEA : The karst in southern Dobrogea — a water resource for the Romanian sea-shore

POSTERS

E. KESSLER : Fossil and subfossil bird material in caves of Romania

A. ADAM : Predecessors of the present-day mammals in vaces of the Hunedoara District

G. IONESCU : Hydrologic conditionning of the karst phenomena in the Rătei Cave area, Leaota Mountains

A. Z. MOISESCU and C. MOISSIU : Test of the proprieties of up to three years old bottled flat water from Izvorul Minunilor at Stîna de Vale

M. FERNOLENDT, I. RADU and I. VIRAG : Biological characteristics of an indigenously made fluorescin

EXCURSIONS

Monday 26 May, 1986

Cerna Valley, by car from Băile Herculane spa at Cerna Springs

Tuesday 27 May, 1986

A cruise on the Porţile de Fier (Iron Gates) reservoir

PARTICIPANTS

Maria ALB, Alexandru ADAM, Tatiana ADAM, Gerlantin AVRAM, Lia AVRAM, Ştefan BALOGH, Floricica BARVINSCHI, Paul BARVINSCHI, Tiberiu BĂLĂNEAN, Danil BĂDOIU, Delia Cristina BLAGA, Liviu BLAGA, Viorel BOGHEAN, Iulius BOR, Traian BOSDOC, Alexandru BULGĂR, Lucian BUŞU, Adrian CARACIONI, Ana CAPOTĂ, Radu CĂDERE, Petru CHIRILĂ, Speranţa CHIRILĂ, Cornelia COJOCARU, Traian CONSTANTINESCU, Marin COSTINAŞ, Tasiela COSTINAŞ, Ilie CRISTESCU, Mihai CROITORU, Dan DANCĂU, Gabriel DIACONU, Mirel DOMŞA, Ovidiu ENCULESCU, Dan ERENA, Marius FERNOLENDT, Adrian FERU, Mircea FERU, Emilian GAŞPAR, Cristian GORAN, Corina HĂDĂREANU, Aurel HĂRSULESCU, Mircea HORNOIU, Dan ILINA, Ion Teodor IMBRESCU, Carmen IONESCU, Cătălin IONESCU, Gabriel IONESCU, Georgeta IONESCU, Adrian JURKIEWICZ, Tiberiu JURCSAK, Günter KARBAN, Zoltan KISS, Arpad KOVACS, Gabriela LUPESCU, Iosif MAGYAR, Daniel MANUCHIAN, Constantin MARIN, Valeria MARIN, Paul MATOŞ, Olimpia MEŞTER, Horia MITROFAN, Mariana MITRUŢIU, Alina Zoe MOISESCU, Constantin MOISSIU, Ioana MUNTEANU, Virgil NĂSTASE, Mircea NEDOPACA, Adrian NICOLAU, Tudora NICOLESCU, Victor NICULESCU, Iancu ORĂŞEANU, Nicolle ORĂŞEANU, Ianoş ORBAN, Petre PANĂ, Blaziu PETER, Eugenia PÎRVĂNESCU, Aura PONTA, George PONTA, Cristian POPESCU, Ioan POVARĂ, Gheorghe RACOVIŢĂ, Mircea RASĂ, Bogdan RĂILEANU, Emil RUSU, Irina RUSU, Vasile SENCU, Emil SILVESTRU, Georgel SIMION, Ştefan SIMIONAŞ, Samuil STĂNESCU, Nicolae SUCIU, Mihai ŞERBAN, Venera ŞERBĂNESCU, Vasile ŞTEF, Emilia TALLODI, Agata TEODORESCU, Anca TERTELEAC, Nicolae TERTELEAC, Laurenţiu TIMOFTE, Zefir Radu TODEA, Alina TULUCAN, Tiberiu TULUCAN, Cătălin UNGUREANU, Radu VASILIU, Rodica VASILIU, Adriana VĂDEANU, Tarquinius VĂDEANU and Iosif VIEHMANN.