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Contributions to the hydrogeology of the karst areas of the Bihor–Vlădeasa Mountains (Romania)

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ABSTRACT

The Bihor Vlădeasa Mountains are ones of the most important karst regions in Romania. They have important groundwater resources, unexploited till now. On the hydrogeological map there are pointed the main karst springs with their magnitude of discharges and the directions of the groundwater flows. More than 45 tracers labellings were performed and an average of 45 m/hour of flow velocity was recorded in 42 of these.
As a consequence of the great diversity of the geological constitution and intense fracturation of the rocks, the karst systems are of binary type, with a large variety in size and hydrological parameters distribution. Due to the consistent observations and the hydro-meteorological measurements, the groundwater resources were evaluated and the processing of the flow rates series outlined a great diversity of the karstic systems.
The quality of the groundwater is very good as indicate the results of the chemical and bacteriological analysis and the potential sources of pollution are leaks.

Key words: hydrogeology, karst, analysis of the flow rates series, groundwater quality, Bihor Vlădeasa Mountains, Romania.

Contributions à l'hydrogéologie des régions karstiques des Monts de Bihor–Vlădeasa

RÉSUMÉ

Les Monts Bihor–Vlădeasa occupent l'une des premières places parmi les régions karstiques de Roumanie. En même temps, ils disposent d'importantes ressources d'eaux souterraines non exploitées jusqu'à présent. Sur la carte hydrogéologique ci-jointe, sont indiquées les principales sources karstiques, l'ampleur de leur débit et les directions de déplacement des eaux souterraines mises en évidence par plus de 45 marquages aux traceurs. La vitesse moyenne enregistrée dans 42 marquages atteint 45 m/heur.On a localisé aussi les plus grands avens et grottes cartés.
Suite à la constitution géologique variée et à la fracturation accentuée des formations géologiques, les systèmes karstiques sont, pour la plupart, de type binaire, de dimensions très différentes et à compartaments hydrogéologiques distincts. Un programme rigoureux d'observations et de mesurements hydro-meteorologiques a mené à l'évaluation du potential global d'eaux souterraines et l'étude des données acquises par différents moyens (l'étude des courbes de récession, l'analyse corrélative et spectrale des séries de débits, etc.) a permis de mettre en évidence la grande diversité de functionnement des systèmes karstiques.
Les analyses variées chimiques et bactériologiques ont évalué la potabilite des eaux karstiques de toute la région étudiée, en établissant la présence d'une eau de bonne qualité et l'absence totale des sources de pollution, qui pourraient conduire à la dégradation de la qualité de l'eau.

***Mots clés:** hydrogéologie, karst, analyse des séries d'écoulements, qualités des eaux souterraines, monts Bihor Vlădeasa, Roumanie.*

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INTRODUCTION

The Bihor mountains occupy a central position within the Apuseni mountains range, extending in a longitudinal direction between the Beiuş basin to the west and the Gilău mountains to the east, and transversely between the Crişul Repede valley to the north and the Arieşul Mic valley to the south. They consist of three distinct transverse compartments, that are well defined in what concerns both their topography and their geologic framework: Vlădeasa, Bihor and Biharia massifs (IANOVICI *et al.*, 1976).

The Vlădeasa massif consists mainly of intrusive and of igneous ophiolitic formations, which induce an overall heavy-looking topography. The southern half of the intrusive body is surrounded by sedimentary formations, within which carbonate formations occupy a pre-eminent position: the karst area Meziad-Ferice-Valea Rea to the west and south-west, and the graben of Someşul Cald to the east and south-east.

The central compartment, for which the "Bihor mountains" denomination should be preserved, due to the fact that here the karstic topography, characteristic for these mountains, is widely developed, is separated from the Vlădeasa mountains by Someşul Cald and Crişul Pietros stream courses. To the south, the Arieşul Mare and Crişul Băiţa streams delimit this compartment with respect to the Biharia massif, made up of crystalline schists.

The present paper is an introduction to the hydrogeology of the carbonate deposits occurring within the central compartment - the Bihor mountains, as well as within the southern half of the Vlădeasa mountains, areas that for the sake of the current analysis are reunited under the denomination of Bihor Vlădeasa mountains. The central compartment is simply referred to as "Bihor mountains".

I. OROHYDROGRAPHY OF BIHOR–VLĂDEASA MOUNTAINS

The complex geological constitution of the Bihor Vlădeasa mountains, that includes a puzzle of rocks, with limestones and dolomites prevailing, followed by sandstones, conglomerates and igneous rocks, results in a multitude of topography types, among which the most outstanding is clearly the karstic type, which considering its extent, variety and amplitude of the karstic landforms, ranks this specific area in the top position among all Romania's karstic territories.

Due to the presence of many ridges and isolated massifs, and to the absence — in the case of the large karst platforms — of major topographic leading lines, it is difficult to perform a systematic description of the orohydrography of this area, and as a result the presentation will follow the river catchment areas. This choice is also supported by the occurrence in the Bihor mountains of the most important water divide from all Apuseni mountains, wherefrom the rivers Crişul Negru, Someşul Cald and Arieşul Mare originate.

The origins of those three major catchment basins are separated by two mountain ridges: one, striking north-south, marked by the summits Băiţa–Custurilor–Poienii–Bohodei–Fântâna Rece–Măgura Vânătă–Biserica Moţului–Glăvoiu–Vârtop–Piatra Grăitoare, borders Crişul Negru catchment basin to the west; the other one, striking west-east, branches perpendicularly to the previous one at Biserica Moţului summit, to continue westward along Bătrâna summit–Clujului Summit–Ursoaia saddle. The latter separates the catchment basin of Someşul Cald, situated to the north, from that of Arieş, situated to the south.

At the junction of those three major catchment basins is situated the closed catchment area Padiş–Cetăţile Ponorului, surounded by a belt of ridges which preclude it from being included in any of the three previously mentioned basins.

Westward from Fântâna Rece summit branches the main ridge of Vlădeasa mountains, that along the section Cornul–Miclău–Muncelu Mare forms the divide between the catchment basins of Crişul Repede, situated to the north, and that of Someşul Cald, situated to the south.

CRIŞUL NEGRU CATCHMENT BASIN

Between the valley of Meziad to the north, and that of Crişul Băiţa to the south, Crişul Negru receives from the Bihor Vlădeasa mountains a series of major tributaries: Beiuşele, Valea Mare, Ferice, Crişul Pietros, Crăiasa and Sighiştel. Those streams, together with the main tributaries of Crişul Pietros (Aleu, Bulz, Galbena), isolate a series of west-east striking ridges, that branch from the main ridge of Bihor mountains, to smoothly connect in the end to the hilly topography of the eastern part of the Beiuş Basin.

North of Crişul Pietros, the topography is dominated by the imposing Dealul Mare, built up of banatites and carrying the road that leads to Stâna de Vale, and by the solitary summit of Măgura Ferice, as well as by the narrow and steep valleys of Zăpodie, Cohuri, Aleu and Sebişel, the fountain-heads of which reach up to 1600 m. Among the caves existing in that area noteworthy are the ones at Cresuia (Cornilor cave) and Ferice.

Bulz valley, forming the upper reaches of Crişul Pietros, collects its water from beneath the main ridge of Bihor, between the summits Cârligatele and Bălileasa, via a series of steep tributaries, some of which display inaccessible waterfalls (Boga, Oşelu, Bulbuci), while others benefit of less rugged courses (Valea Rea, Valea Plaiului). The topography of Bulz valley is dominated by the majestic Boga escarpment, with vertical, over 300 m high walls in its upper part, climbing just beneath Piatra Boghii peak. The landscape also includes many abundant springs (Boga, Oşelu, Bulbuci), peaks and bluffs, which make this area the wildest of the entire Bihor massif.

The median section of the Crişul Negru catchment basin situated within the Bihor mountains, that extends between Crişul Pietros to the north, and the ridge Vârtopul–Ţapul–Prislop to the south, is broken by the intermediate ridges Ţapul–Tătăroaia and Ţapul–Dosurile, into three subordinate catchment basins, namely Galbena, Crăiasa and Sighiştel. The first of those two ridges displays characteristic steep slopes in its median section and a small karstic plateau around Tătăroaia peak, strewn with sinkholes and having a pothole entrance just next to the summit.

Galbena valley originates between the peaks Borţigul and Glăvoiul, in terrains consisting of sandstones and conglomerates of the Arieşeni unit. When entering a limestone substratum, north of Vârtopul summit, the valley, that from here downstream is called Luncşoara, flows between the steep walls of a canyon, eventually to sink into the streambed fissures, most of the time of the year completely, some 2 km downstream of the junction with the Crişanului valley.

Two km downstream of this swallet, Luncşoara receives a powerful right hand tributary that originates in the Galbenei Spring, one of the major outflows of the closed catchment area Padiş–Cetăţile Ponorului. From here downstream the valley is called Galbena and assumes a perennial character, while receiving only left hand tributaries (Valea Seacă, Păuleasa, Budeasa). Before the junction with the Păuleasa valley, the flow rate of Galbena doubles, as a result of the inflow of Păuleasa spring. Along its entire course, from beneath Vârtop peak and down to the site called Între Ape, the junction with the Bulz stream, Galbena valley displays a rectilinear course, tectonically controlled by the major Galbena fault.

Valea Seacă, the origin of which is located in Groapa Ruginoasă, beneath Ţapul peak, has the most extensive catchment basin of all Galbena valley tributaries. In spite of this, due to the multitude of karstic stream piracy processes that occur both in its own catchment basin, as well as in that of its main tributary, Ţiganului valley, Valea Seacă carries water only during heavy rainfall periods, and, as a consequence, its direct contribution to the Galbena valley flow rate is small.

Groapa Ruginoasă is a huge, still active ravine, 125 m deep and almost 700 m in diameter, opening toward Valea Seacă, excavated in the Permian sandstones, shales and conglomerates of the Arieşeni nappe thrust outlier located on Ţapul peak. During rainy periods, a yellow-reddish mud stream flows out of Groapa Ruginoasă. The associated sand suspensions are deposited downstream, on the Galbena beaches, and further on, on those of Crişul Pietros, almost down to the junction with Crişul Negru.

Among the remarkable karstic features existing in the catchment basin of Galbena valley, we mention the 288 m deep pothole in Hoanca Urzicarului, one of the deepest in Romania, and the virtually inaccessible Jgheabului gorge, excavated by Galbena stream in the massive limestones next to its junction with the Bulz stream.

Crăiasa valley catchment basin extends west of that of Galbena and collects its water from beneath the Tătăroaia–Giunaşul ridge, via the streams Fagului, Sibişoara and Pietrele Roşii. In this catchment basin are situated three of the most beautifully decorated caves of Bihor mountains: the commercial Pestera Urşilor at Chişcău, Fagului cave, intercepted by a mining gallery excavated on the left side of Fagului valley, and Micula cave, whose underground stream emerges in the Giuleşti spring.

The Sighiştel catchment basin extends mostly on limestone deposits where the stream has excavated a deep valley, which in its upper reaches has a canyon appearance. The summits of the ridges that surround it are covered by quartzite sandstones ascribed to the Arieşeni nappe. Those deposits favor the organization of a scanty runoff, that when reaching limestone terrains sinks underground via a multitude of swallets, to supply a well developed karstic aquifer. The intense karst processes of this area resulted in the development of a large number of caves (about 70), out of which Măgura, Coliboaia, Pişolca and the pothole in Secătura are worth mentioning.

Crişul Băiţa catchment area, extending west of Piatra Grăitoare peak and south of the Ţapul - Prislop ridge, displays a high energy environment and steep slopes, across which the streams -most of them temporary (Hoanca Moţului, Fleşcuţa, Corlatul Coşuri, Hoanca Codreanului), have incised deep, canyon-like valleys, broken by many waterfalls which make progression extremely difficult. Outstanding karst features of this catchment basin are the outflow cave Izvorul Crişului, as well as the temporary stream cave Poarta Bihorului, the latter especially due to the size of its entrance porch.

The flow regime of both surface streams and groundwater in the karst area of the upper Crişul Băiţa catchment basin is dramatically influenced by the existing mining activities.

PADIŞ–CETĂŢILE PONORULUI CLOSED CATCHMENT AREA

Padiş–Cetăţile Ponorului closed catchment area extends over a surface of 37.2 km^2 and is surrounded by a belt of ridges that prevent surface flow connections with any of the adjoining catchment basins. However, tracer tests have proven that its groundwater flow discharges into the Crişul Negru catchment basin.

The origin of the closed basin is intimately related to the geological constitution of the area, specifically to the alternating karstic and non-kartsic substratums. The sandstones and shales on MăguraVânătă allow a scanty organization of the rainfall water into perennial streams, which sink when entering a limestone substratum, with a resulting dissection of the terrain, leading to the existence of 9 subordinate closed basins, within the overall Padiş–Cetăţile Ponorului closed catchment area: Vărăşoaia, Padiş, Bălileasa, Groapa de la Barsa, Valea Cetăţii, Barsa Cohanului, Paragina, Lumea Pierdută and Poiana Ponor.

SOMEŞUL CALD CATCHMENT BASIN

Characteristic of Someşul Cald upper reaches are the outstanding morphology and karst topography of Cetăţile Radesei and the associated spectacular canyon.

When reaching out of the canyon, the river receives four main, left hand tributaries: Alunul Mare, Alunul Mic, Ponorul and Valea Firii, all of which cut across the prevalently carbonate deposits of the Someşul Cald graben, displaying a characteristic karst topography, with karst plateaus (Piatra Altarului, Humpleu, Onceasa, etc.), potholes, springs and swallets.

From the Bihor mountains karst area, Someşul Cald receives two main, right hand tributaries: Bătrâna and Beliş. The first one originates in the junction of the streams Izbuc and Călineasa, the flows of which are collected from the karstic plateaus Bătrâna and Călineasa, while the second one, Beliş, has its fountain-head east of Călineasa plateau and receives as its main tributary Apa Caldă, the source of which is located beneath Ursoaia Saddle (the latter stream is delimiting Bihor from Gilău mountains).

ARIEŞUL MARE CATCHMENT AREA

A significant part of the carbonate terrains in Bihor mountains occurs in the Arieşul Mare catchment area, more specifically on the left side of the river, between its source area and the junction with Albac stream. From the fountain-head situated beneath the Vârtop pass and down to the village of Arieşeni, where it receives the Cobliş tributary, the river is called Râul Alb. Along this section it crosses exclusively terrains consisting of sandstones, conglomerates and shales, ascribed to the Arieşeni unit and displaying a characteristic topography of rounded ridges and steep mountain slopes.

The most important tributary of Arieşul Mare in the Bihor mountains karst area is Gârda Seacă. The latter is almost 20 km long, having its fountain-head beneath Şesul Gârzii, close to Padiş, while its first significant inflow is provided by the spring at Gura Apei. After a rectilinear course along a narrow valley, where the flow rate doubles via the Coliba Ghiobului and Apa din Piatră springs inflow, the entire flow of the stream—that in this section is called Gârdişoara, sinks into the cave Coiba Mică. Further on, from Casa de Piatră hamlet downstream the valley is called Gârda Seacă. It enters a narrow gorge section and receives the left hand tributary Vulturul, then next to Fileşti, via Tăuz spring, the valley recovers the flow sunk in Coiba Mică. When leaving that gorge section, the flow rate of Gârda Seacă increases on account of the discharge provided by the Coroaba spring, whichafter follows a long course across Permian-Werfenian sandstones and conglomerates, interrupted by the Ladinian limestones at Coteţul Dobreştilor hamlet, where the homonym outflow cave is located.

Before reaching the course of Arieşul Mare, in the center of the village Gârda de Sus, Gârda Seacă valley receives from the left side its most important tributary, Ordâncuşa, the course of which is parallel to, yet shorter than that of Gârda Seacă. Between the valleys of Gârda Seacă and Ordâncuşa is perched the second closed catchment area in the Bihor mountains, Ocoale–Scărişoara. Ordâncuşa flows, on its first 4 km upstream of the confluence with Gârda Seacă, through a narrow canyon, with up to 200 m high walls, cut into the limestone substratum. Within the canyon, Ordâncuşa stream receives its most important supply, the discharge of the cave Peştera lui Ioanel.

The closed catchment area Ocoale–Scărişoara, situated at 1100–1300 m altitude, is traversed in its upstream section by Ocoale brook, that when passing from quartzite sandstones on a limestone substratum gradually sinks, eventually to disappear completely. The valley downstream assumes the appearance of a wide depression, with its bottom strewn with sinkholes, where also the entrance of the Şesuri pothole is located.

On the divide between the closed catchment basin and the actual Gârda Seacă stream basin opens the wide entrance of the shaft that leads to the Scărişoara Glacier, while westward, beneath the divide, is located one of the most beautifully decorated caves in Romania, Pojarul Poliţei.

Table 1. The main karstic cavities in the Bihor Vlădeasa Mountains.
Les principale cavernes des monts Bihor Vlădeasa

Nr. crt.	The name of the cavity	Horizontal development (m)	Vertical development (m)	References
1	Pothole of Poieniţa, (146)–Cave of Humpleu hill, (150)	35.600	347.6	PAPIU, FRĂŢILĂ
2	Cave of Pârâul Hodobanei stream, (103)	22.142	181 (–211; +60)	VĂLENAŞ, 1982)
3	Cave of Zăpodie (80) - Peştera Neagră cave (81)	12.048	178 (–162;+16)	VĂLENAŞ, 1977-1978
4	Valea Rea system (Adrian pothole, 54)	11.718	–264	DAMM
5	Cornilor cave, (1)	10.140	+112	BRIJAN, 1987
6	Coiba Mare cave, (97)	5.680	121 (–76;+45)	VĂLENAŞ, 1978
7	Dârninii cave, (122)	5.645	–112	SILVESTRU
8	Zgurăşti cave, (114)	5.210	–75	CIUBOTĂRESCU
9	Cerbului cave, (137) - Avenul cu Vacă pothole	5.094	–125	SILESTRU et al., 1995
10	Pothole of Şesuri, (107)	4.010	240 (–220;+20)	LUDUŞAN
11	Cave of Fântâna Roşie, (59)	3.550	129 (–40;+89)	VĂLENAŞ, 1977-1978
12	Colţului cave, (138)	3.526	167 (-86;+81)	SIVESTRU et al., 1995
13	Lumea Pierdută system, (70-71)	3.322	–137	VĂLENAŞ, 1984
14	Cetăţile Ponorului cave, (75)	3.214	–117	BRIJAN, 1978
15	Ponorul din Cuciulata cave, (131)	3.140	85 (–75;+10)	VĂLENAŞ, 1978
16	Gheţarul de la Barsa cave, (79)	3.010	–112	VĂLENAŞ, 1977-1978
17	Peştera cu Peşti (Micula) cave, (25)	3.000 (?)		
18	Peştera de după Deluţ cave, (99)	1.480	–142	VĂLENAŞ, 1976
19	Cave of Secăturii hill, (36)	1.450	–230	HALASI
20	V5 pothole (Faţa Muncelului), (55)	1.446	273	DAMM, 1994
21	Pothole of Hoanca Urzicarului, (89)	1.125	288 (–286;+2)	VĂLENAŞ et al., 1982
22	Pothole of Cuciulata, (132)	925	–186	VĂLENAŞ, 1978
23	Zăpodiei ponor	705	122 (–112;+10)	VĂLENAŞ, 1977-1978
24	Sohodol 2 pothole	507	–193	VĂLENAŞ et al., 1982
25	"Gaura care Suflă" pothole, (Petit Tibi, 24)	241	161 (–160;+1)	KOPACZ, LAZAR, 1996

*Data compiled in colaboration with H. MITROFAN

CRIŞUL REPEDE CATCHMENT BASIN

Valea Seacă (Pârâul Stanciului) karst area and the carbonate deposits at Stâna de Vale area occur respectively in the catchment basins of Henţ and Iad streams, tributaries of Crişul Repede.

Pârâul Stanciului collects its water from the eastern slopes of the Vlădeasa massif. In its fountainhead area, in a high energy environment, the stream crosses a succession of compartments risen and sunken along fault lines, with Triassic and Jurassic limestones and dolomites outcrops in the elevated blocks and Senonian deposits in the downthrown blocks. From a hydrologic point of view it is worth mentioning the presence of Vârfuraşul spring, of the temporary dry section of the Valea Seacă stream between the swallet "de la Tău" and Nimoioasa springs, and the karstic stream piracy features along Valea Podurilor. Several caves and potholes have been explored, among which the outstanding 2250 m long Vârfuraşul cave (KÖMIVES & NAGY, 1976).

The presence close to Stâna de Vale of a little compartment consisting of limestones and dolomites resulted in shaping a karst topography of modest dimensions, yet including varied landforms (sinkholes, dry valleys, swallets, caves and springs). Outstanding among them is Izvorul Minunilor, a source of still water of excellent quality, that emerges from a small cave excavated in Anisian dolomites.

The large number of karst cavities, their dimensions and their impressive beauty place the Bihor Vlădeasa mountains in the top position among Romania's karst areas. In Table 1 are indicated the largest caves and potholes surveyed in the area.

II. GENERAL HYDRO-METEOROLOGICAL DATA

Rainfall across the Bihor Vlădeasa mountains area has an uneven distribution. Records performed during hydrologic year October 1984–September 1985, as well as multiannual average values display an increase of the annual amounts from the Beiuş basin (Budureasa—941.3 mm, Pietroasa—948.6 mm, Băiţa—884.2 mm) eastward, up to the Stâna de Vale–Piatra Grăitoare ridge area (Stâna de Vale—1608.5 mm), while further east a decrease intervenes (Vlădeasa—943 mm, Smida—

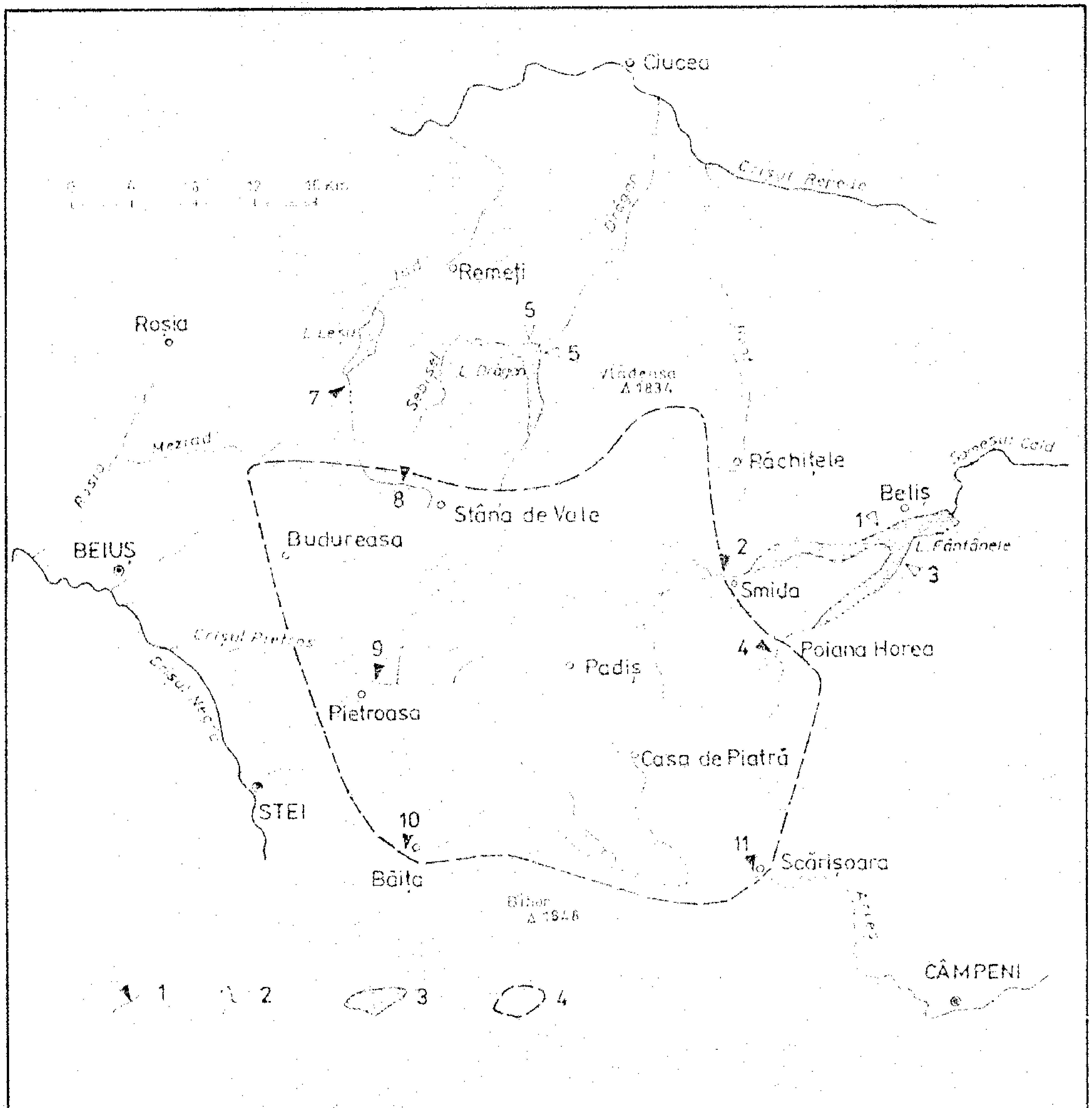


Fig. 1. Distribution of discharge gauging stations in the Bihor lădeasa Mountains: 1. discharge gauging stations (DGS) in the INMH national network; 2. suppressed DGS; 3. manmade reservoir; 4. study area.

La distribution des stations hydromètriques dans les monts Bihor Vlădeasa: 1. stations hydromètriques (SH) dans la reseau nationale du INMH; 2. SH suprimées; 3. lac artificiel; 4. zone étudiée.

952.3 mm, Poiana Horea—714.5 mm, Casa de Piatră—836.5 mm, Scărişoara—746.8 mm).

Within Bihor Vlădeasa mountains are included a series of stations of the national stream gauging network, under the authority of INMH (National Institute of Meteorology and Hydrology) (Fig. 1 and Table 2). They are generally located at the border of the mountain massifs and gauge runoff originating in catchment areas of varied lithologic constitution (limestones, dolomites, crystalline schists, igneous rocks, Permo - Werfenian molasse deposits, etc.). The distribution of the multiannual specific discharge of those streams mirrors the rainfall distribution, ranging from 31.4 l/s/km^2 in the case of Drăgan river, at the gauging station Pârâul Crucii upstream, with a high altitude catchment basin, to 19.4 l/s/km^2 in the case of Someşul Cald river, at the gauging station Beliş, in the eastern part of the mountains.

The memory effect (MANGIN, 1981a, 1981b, 1982, 1984) of the catchment basins (Table 2, Fig. 2), reflecting the groundwater reserves that sustain the runoff, has large values (47-123 days) in the case of basins extending on igneous rocks and/or crystalline schists, and low values (15 days) in the case of basins extending prevalently on limestones or Permo-Werfenian molasse deposits. The large memory effect values in the case of the igneous and crystalline rocks are due to the advanced development of the wheathering layer, that acts as a storage reservoir which slowly delivers the rainfall derived water. A quite distinct category form the Vlădeasa ignimbritic rhyolites, that occur under a variety of facieses and form a major reservoir, most of which is drained by the Drăgan river and by its tributary, the Sebişel stream.

The knowledge of the runoff characteristics has an outstanding importance in the case of the binary karst systems, since together with rainfall this is the input function to the system. Interpreting the system output function (the springs flow rates hydrograph), without considering the parameters of the non karstic catchment area (provided by correlative and spectral analysis) may result in erroneously ascribing filtering properties to the karst aquifer.

Since the springs hydrographs of the binary karst systems preserve in their memory the hydrologic characteristics of the non karstic catchment basins, especially for small and medium size systems, use of graph k/i (MANGIN, 1975) in establishing the degree and the places of the karstification must be performed with caution.

Table 2. Morphometric and hydrometric data of the main rivers of the Bihor Vlădeasa Mountains.
Les données morphométriques et hydrométriques des principales rivières des monts Bihor Vlădeasa.

River	Gauging station	F km^2	H m	Q m^3/s	q $l/s/km^2$	Bf	EM days	TR days	TF
1	2	3	4	5	6	7	8	9	10
Someşul Cald	Beliş	320	1247	6.22	19.4	0.24	48	37.1	0.196
Someşul Cald	Smida	110	1293	2.92	26.5	0.25			
Beliş	Beliş	119	1249	2.32	19.5	0.268	47	34.2	0.208
Beliş	Poiana Horea	83	1259	1.80	21.2	0.28			
Drăgan	P. Crucii am.	119	1228	3.74	31.4	0.25			
Sebişel	P.Crucii	39,4	1172	1.19	30.2	0.25	123	81	0.092
Iad	Leşu	101	979	2.83	28.0	0.205			
Iad	Stâna de Vale	27	1210	1.21	44.8	0.25	24	24.7	0.192
Crişul Pietros	Pietroasa	123	956	4.15	33.7	0.215	15	21.4	0.208
Crişul Băiţa	Băiţa	36	892	0.94	26.5	0.19			
Arieş	Scărişoara	200	1099	5.45	27.25	0.27	35	28,9	0.232

Notes: Data in columns 5, 6 and 7, after C. Diaconu et al., 1971;
Discharges for 1950-1967, time interval;
F, surface of catchment area; H, mean altitude (asl); Q, mean annual discharges; q, specific discharges; Bf, base flow index; EM, memory effect; TR, regulation time; TF, truncation frequency.
Data in columns 8, 9 and 10 for 1971–1975 time interval, except for the Drăgan and Sebişel rivers (1970–1973) and Beliş and Someşul Cald (g.h. Beliş) rivers (1971–1974).

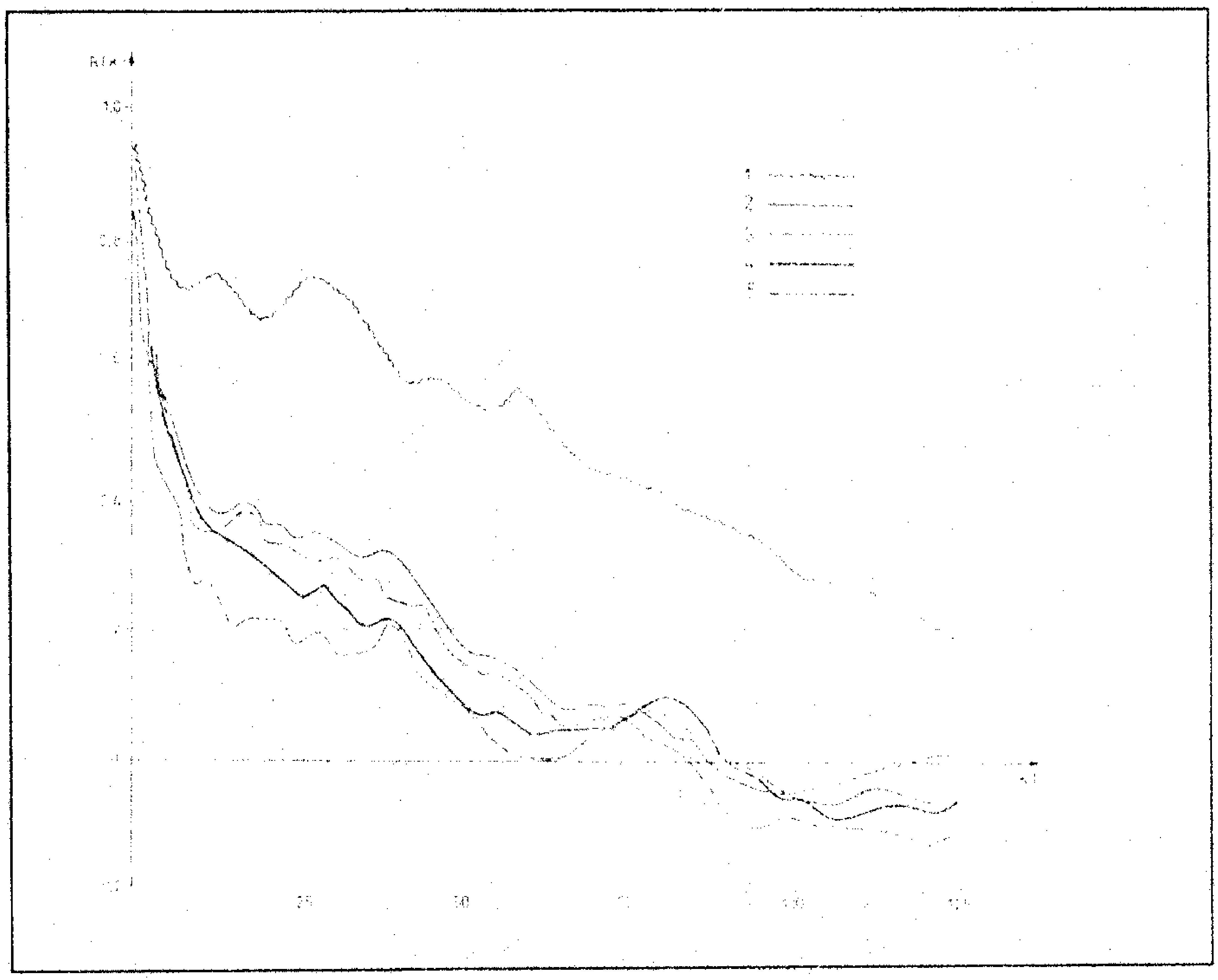


Fig. 2. Analysis of discharge time series of five rivers: 1. Sebişel (Pârâul Crucii DGS), 2. Someşul Cald (Beliş DGS), 3. Beliş (Beliş DGS), 4. Arieş (Scărişoara DGS) and Crişul Pietros (Pietroasa DGS). Simple correlation of the flow rates (*m*=125 days, *k*=1).

Analyse des chroniques de debits de cinq rivieres: 1. Sebişel (SH Pârâul Crucii), 2. Someşul Cald (SH Beliş), 3. Beliş (SH Beliş), 4. Arieş (SH Scărişoara) and Crişul Pietros (SH Pietroasa). Correlogramme simple de debits (m=125 days, k=1).

III. HYSTORICAL REVIEW ON THE BIHOR MOUNTAINS KARST HYDROLOGY INVESTIGATION

The investigations on the Bihor Vlădeasa mountains karst have been inaugurated in 1863, by the printing of Adolf Schmidl's monograph "*Das Bihar Gebirge*", the first extensive geographic study on the karstology and speleology of a specific area of our country. The work includes the geographic results of a geological-geographical scientific expedition performed in the Codru Moma, Bihor and Metaliferi mountains during 1858-1862. Detailed descriptions of a series of caves, including the Scărişoara Glacier are provided, as well as a table where the caves are listed into two categories, "*breakage*" (swallet) caves and "*eruption*" (outflow) caves, which witnesses an accurate knowledge of the water movement through karst massifs (p. 33).

In the introduction to the chapter concerning the hydrography, Schmidl provides a vivid characterization of the Bihor mountains: "*The crystalline igneous rocks of the main ridge are those where from the considerable amount of springs spout, even the weak ones. The water springs out, partly from beneath the stone, not unfrequently from the actual cliffs with cracks, from the mountain ridge, often straight from beneath the meadow, from the smooth streambeds of the ridge, from beneath small marshes, as well as from other spots. On the contrary, the upper areas of the limestone territory are characterized by water shortage, there the springs are scarce and weak, yet at the feet of the limestone formations vigorous springs burst out, exceeding the flow abundance of those in crystalline areas, frequently forming streams that might even drive water-mills*" (p. 34). In this chapter the author provides two tables including the cold and the warm springs in the mountain domains of the Cris-es, Someşul Cald and Arieş catchment basins, indicating for each of them the geologic substratum of the emergence, the temperature, the date and the author of the observations. A brief presentation of this monograph has been published by VĂLENAŞ in 1980–1981.

An important contribution to the hydrologic investigation of the karst in Bihor Vlădeasa mountains is provided by the scientists of the Institute of Speleology in Cluj Napoca, D. Coman, M. Şerban and I. Viehmann, together with the geologist M. Bleahu, team that will be subsequently joined by T. RUSU and Gh. Racoviţă, and which during 1946–1956 conducted explorations that led to the discovery of major caves (Pojarul Poliţei cave, the pothole in Şesuri, Peştera Neagră de la Barsa, Căput cave, the cave networks in Lumea Pierdută and Cetăţile Ponorului). Still during that period, the first fluorescein tracing experiments have been performed by ŞERBAN *et al.* (1957), RUSU *et al.* (1970) and VIEHMANN (1966), the flow connections between Ocoale closed catchment area and the springs at Coteţul Dobreştilor, respectively the existence of the underground flows along the Padiş

–Poiana Ponor–Cetăţile Ponorului–Galbenei Spring lineament being outlined as a result.

In 1957 BLEAHU publishes the paper "The karstic stream piracy and its importance for the morphologic evolution of the karstic regions", which exposes the methodological approach for the morphologic and hydrologic investigation of the karst areas and proposes a systematization of the corresponding terminology. The entire approach of the author is supported with examples taken from the Bihor mountains karst.

During 1976–1985, VĂLENAŞ, alone or in cooperation, publishes in a series of papers the results of speleological investigations, which assumed a definite hydrologic character too, conducted in the karst of Bihor - Vlădeasa mountains and which have brought important contributions in this domain, as an outcome of the exploration of Groapa de la Barsa cave system (1977–1978), of Coiba Mică–Coiba Mare cave system, of the cave in Pârâul Hodobanei (1982), of the karst at Casa de Piatră (1976), in the upper reaches of Someşul Cald (1978), Lumea Pierdută (1982) and in other areas.

Many of the published papers are dedicated to karst areas or objectives that are representative for the karst in Bihor Vlădeasa mountains, papers where the authors bring informations concerning the present day or the original, (i.e. the landform engendering) hydrologic context: VIEHMANN *et al.* (1980) (Cetăţile Ponorului), RUSU (1981) (Peştera Urşilor de la Chişcău), COCEAN (1988) (Gorges and defiles), BRIJAN (1978; 1982; 1987) (the pothole in Hoanca Urzicarului, Valea Bulzului-Fânaţe area, Cresuia area).

The hydrogeologic investigations in the Bihor Vlădeasa mountains have been initiated in 1983 through the activities conducted by I. Orăşeanu and N. Orăşeanu. During 1983–1985 they prepare the first hydrogeologic map of the karst areas, as well as the groundwater reserves evaluation, and perform some 36 new tracer experiments. The hydro-meteorological data acquisition has been performed in co-operation with G. and P. Hoţoleanu from INMH, while E. Gaspar and I. Tănase from IFIN (Institute of Physics and Nuclear Engineering) and I. Pop from the University in Baia Mare have taken part in the completion of the tracer tests, the results of which have been published in 1991.

In 1992, I. ORĂŞEANU and N. ORĂŞEANU performed a hydrogeologic study concerning the evaluation of the still water potential in the Apuseni mountains; the existence of still water sources in Bihor Vlădeasa mountains is outlined as a result, and a detailed investigation of the identified sources and of Izvorul Minunilor at Stâna de Vale is performed during 1995–1996.

In 1995 SILVESTRU *et al.* published the preliminary results of hydrogeologic studies performed in the upper reaches of Someşul Cald.

IV. GEOLOGIC-STRUCTURAL FRAMEWORK OF THE BIHOR MOUNTAINS

Within the overall structural setting of Bihor and Padurea Craiului mountains (see insert within the enclosed map), the lowest position is occupied by the Bihor Unit, that is usually called the "Bihor Autochthonous". It includes metamorphic formations, ascribed to the Arada and Someş series, and a sedimentary stack consisting of Mesozoic pre-Senonian formations, locally with detritic Permian deposits at their bottom.

Out of the Codru nappes system, in this specific area have been outlined the following units (starting from the lower one): the Vălani nappe, the Gârda nappe, the Ferice nappe and the Sebişel and Tătăroaia wedges, the Batrânescu nappe, the Următ nappe, the Vetre nappe and the Arieşeni nappe. Out of the second nappes system in the Bihor mountains, i.e. the Biharia nappes system, at the southern boundary of the considered map, south of the valley of Arieşul Mare, crystalline schists and gneiss belonging to the Muncel-Lupşa nappe occur, while in the area of Piatra Grăitoare summit, albitic gneiss ascribed to the Biharia nappe outcrop.

The legend of the hydrogeologic map indicates the stratigraphic correlation of the Bihor Unit formations and of the Codru nappes, according to the works of BLEAHU *et al.* (1981) BORDEA & BORDEA (1973) and to the sheets Pietroasa (BLEAHU *et al.*, 1985), Răchiţele (MANTEA *et al.*, 1987) and Biharia (BORDEA *et al.*, 1988) of the geologic map of Romania, scale 1:50,000.

THE BIHOR UNIT

The sedimentary formations of the Bihor Unit include at their bottom Permian deposits, that consist of breccia with crystalline schists fragments, with a red matrix, and of ignimbritic rhyolites. The Permian deposits, or directly the crystalline schists, are transgressibely overlain by a thick stack of Mesozoic deposits, that display two detritic episodes—one within the Werfenian (the

Werfen Formation) and one within the Early Jurassic (the Gresten Formation), a stratigraphic hiatus in the Late Triassic and another one at the beginning of the Cretaceous, and the occurrence of three major carbonate depositions, in the Early–Middle Triassic, in the Kimmerirdgian–Tithonic and in the Barremian–Aptian respectively.

The first carbonate series includes either grey and white dolomites, locally with black limestone interbeddings, or black limestones (Gutenstein and Vida limestones), with grey-yellowish shales (Pestis shales) at their top. This series, ascribed to the Anisian, is overlain by Late Anisian–Early Carnian deposits, consisting of white reef limestones (Wetterstein limestones) and white, tiled limestones (Padiş limestones), locally with polygenic breccia and red shales, interbedded with white limestones or quartzite sandstones (the Zugai formation) at the lower part.

In the south-eastern part of the Bihor mountains, in the median section of the deposits that are ascribed to the Late Anisian–Early Carnian interval, the Ordâncuşa formation occurs, consisting of white, tiled limestones and red shales at its bottom, and of sandstones and violaceous shales at its upper part.

In the Triassic limestones and dolomites are incised the large karstic platforms Padiş, Bătrâna, Mărsoaia, as well as the closed basin Ocoale Scărişoara.

The Late Triassic has a strictly local occurrence west of Padiş, where it consists of the deposits of the Scăriţa formation, that includes fine limestones and red shales, with sandstone-clayey cement.

The Early Jurassic formations of the Bihor Autochthonous transgressively overlie the Triassic deposits, occurring in a typical Gresten facies which includes quartzite sandstones and conglomerates, with Hettangian–Early Sinnemurian shales interbeddings, of 200–300 m overall thickness.

The upper part of the Early Jurassic (Late Sinnemurian–Toarcian) includes at its bottom encrinitic reddish and greyish limestones and pink quartzmarly sandstones (Late Sinnemurian–Carixian), overlain by marly limestone and grey marls with cherts (Domerian) and black marls and limestones, with or without phosphatic nodules (Toarcian), the thickness of the entire stack ranging between 6 and 80 m.

The Early Jurassic of the Bihor Unit includes locally, at its bottom, either a conglomerate with fragments of Middle Triassic limestones and with a carbonate matrix with oolitic iron (Scăriţa), or a carbonate welded mega-breccia (east of Gârda).

The Middle Jurassic includes a succession of red oolitic iron limestones, yellow spotted limestones and encrinitic limestones, of about 10 m maximum thickness.

The next major stack of carbonate deposits has been deposited during the Late Jurassic, which includes exclusively a carbonate facies, consisting at its bottom of white, reef, partly Stramberg type limestones (Farcu limestones) of Oxfordian–Early Tithonic age, and of layered limestones with blackish onchoids (Albioara limestones) of Tithonic–Berriassian age at the top.

The continental regime which occurred during the Early Cretaceous resulted in a paleo-karstic topography and in the accumulation of bauxite pockets, that trace this hiatus. During the following stage, in the Early Cretaceous, a submerged limestone platform provided the environment for the deposition of the last major carbonate series, which included fenestral lamination limestones, limestones with miliolids and limestones with orbitolins (Barremian–Early Aptian).

Along the MăguraVânătă—Poiana Horea—Ocoale lineament, the entire sedimentary series of the Bihor Unit occurs as a homocline, with an overall NW–SE strike, between Poiana Horea and Ocoale. In its northern half the structure dips southwestward, while in its southern part a westward dip is recorded. As a general rule, there are neither recurrences of the succession due to reverse strike-slip faults, nor folds. These structures have been built during the Turonian or the Middle Cretaceous, before the nappe of the Codru nappes.

The Someşul Cald graben is the northernmost compartment of the Bihor mountains. It is bordered to the south by crystalline formations, which are juxtaposed via the Someşul Cald fault, and to the north by the igneous formations of the Vlădeasa mountains, the latter contact being sometimes overlain by Late Cretaceous formations. The Someşul Cald fault is one of the major faults of the Bihor mountains, prolonged westward beyond the main ridge, up to the Bulz fault. The graben is filled mainly with Jurassic and Early Cretaceous deposits, and its structure includes a succession of transverse faults, that delimit a series of compartments with overall westward dip (MANTEA, 1986).

THE CODRU NAPPES SYSTEM

In the constitution of the Codru nappes system, carbonate deposits display different weights and lithologic compositions (see insert within the hydrogeological map).

Within the Vălani nappe, carbonate deposits closely parallel those of the Bihor Unit, with the occurrence of the same three distinct limestone and dolomite series. The Ferice and Batrânescu nappes, consisting of Permian and Triassic deposits, include at their bottom (Anisian) dolomites with sandstones and dolomitic schists, overlain—within the Ferice nappe—by black limestones with cherts (the Roşia Formation, Ladinian–Early Carnian), while in the case of the Batrânescu nappe the upper term consists of black limestones with cherts (Ladinian) and white limestones (Carnian–Norian).

Within the Următ nappe, a limestone stack occurs within the Late Jurassic, while within the Vetre nappe the carbonate deposits consist of the Frăsinel dolomites (Norian) and the Băiţa marble (Early Rhaetian). The Arieşeni nappe includes black dolomites (Anisian) and limestones and dolomitic limestones (Ladinian–Carnian).

POST-TECTONIC COVER

At the end of the Cretaceous, three major geologic events have taken place: a) the overthrusting of the Codru nappes, during the Turonian; b) the formation of fracture systems, along which the subsidence of sedimentary basins of epi-continental facies took place, with associated accumulation of Gosau type Senonian formations; c) intense subsequent volcanic activity.

The Senonian deposits featuring a Gosau facies form the Late Cretaceous post-tectonic cover of the Bihor Unit and of the Codru nappes system. Such deposits outcrop over relatively restricted areas in the Someşul Cald graben, as well as on the terrains covered by the Vlădeasa igneous formations.

The succession of the Senonian deposits in the Someşul Cald graben begins with conglomerates with arenitic matrix and well rolled embedded gravel, that includes crystalline schists, limestones and sandstones. Dark grey–reddish clayey marls and micaferous yellow–green sandstones follow. The reef facies of the Senonian consists of limestones with many corals, while the volcanic-sedimentary formation includes alternating ashes, tuffs, tuffites, sandstones, micro-conglomerates, breccia and conglomerates with terrigenous-volcanic matrix (MANTEA, 1985).

ISTRATE (1978), in a paper dedicated to the petrographic study of the Vlădeasa mountains (the western part), distinguishes within the Senonian series a lower, sedimentary complex and a volcanic-sedimentary formation. The lower sedimentary complex (the Gosau formation) includes a succession consisting of three sections: a bottom, conglomeratic one, a median, marly, sandy, micaferous one, and an upper, micro-conglomeratic one.

ALPINE SUBSEQUENT IGNEOUS ROCKS AND ASSOCIATED PRODUCTS

The alpine subsequent (banatitic) magmatic activity is documented in the western part of northern Bihor mountains and along the northern border of this unit, by means of a large variety of rocks.

Within the Pietroasa–Aleului valley area, and further north, up to Budureasa, granodiorites outcrop. They are part of a single batholitic body, that within Bihor mountains extends, both at the surface and in the underground, up to the Galbena fault. An exception is recorded in the Bulz valley area, where an igneous body having penetrated along the previously mentioned fault outcrops. A multitude of veins of andesitic or basaltic composition, that have been identified especially in the upper reaches of Crişul Băiţa, along the valleys Hoanca Moţului, Corlatul and Fleşcuţa, as well as in the Valea Seacă catchment area, are of hypoabissal origin, being associated to the indicated banatitic intrusion.

Vlădeasa mountains are built up of rhyolitic rocks of different facieses, ranging from massive to vitrophyres, as a function of the place where the rhyolitic magma solidification has occurred (i.e. under the Senonian sedimentary cover or at the surface). In the evolution of the magmatic activity of this area there have been two outstanding events, namely the setting of the ignimbritic rhyolites formations and the setting of the intrusive bodies.

The intrusion of the banatites has resulted in contact processes that concerned the sedimentary deposits being traversed. At the contact of the banatites with the limestones, marbles and various types of calcic skarns have been formed, while at the contact with the detritic and pelitic rocks, hornfels, garnet skarns, etc. are met.

NEOGENE FORMATIONS

On the western rim of the Bihor mountains, Pannonian (Malvensian) deposits consisting of clays with coal interbeddings, sands and gravel from the Beiuş Neogene Basin filling outcrop. In the close neighbourhood of the mountains border coarse deposits prevail, that are however rapidly substituted by a pelitic facies, of wide occurrence across the entire Beiuş Basin.

Quaternary formations consist of sands, gravel, boulders and, subordinately, clays. They occur in the terraces of Crişul Pietros and of the other streams that originate on the western slopes of the Bihor mountains, in the present day streams alluvia, in the ancient and the recent deluvial and colluvial deposits. A noteworthy extent have the deposits on the elevated karstic platforms Padiş–Cetăţile Ponorului, Bătrâna and Apa Caldă–Beliş divide. They consist prevalently of sands with quartzite sandstone fragments, which have been carried away by runoff originating on the nearby slopes, then left in place, once the surface streamlets had taken an underground course through the carbonate substratum.

V. HYDROGEOLOGICAL FEATURES OF THE BIHOR–VLĂDEASA MOUNTAINS

The deposits included in the geological framework of the Bihor mountains display a wide variety of lithologies and different intensities of tectonic dislocation. As a result, distinct hydrogeologic features occurred, which allowed the hydrogeological separation of five types of deposits, with specific groundwater recharge, flow and discharge characteristics (enclosed hydrogeological map):

1. Carbonate Mesozoic series (limestones, dolomites), highly fractured and karstified, characterised by very high effective groundwater flow. Numerous karstic systems of various size and prevelent by of binary type . Spring flow rates up to 550 l/s. Important water resources in large karstic systems;
2. Subsequent alpine magmatites (banatites) and metamorphites with permeability of fisures with discontinuous distribution and intensity. The weathering zones are well developed and provide a continous and important supply to the rivers (memory effect is 55–120 days for 0.2) and to the binary karst systems;
3. Prevalent by detritic Permo-Mesozoic deposits (sandstones and conglomerates with argilaceous shales and rhyolites) with different permeabilities. The groundwater flow is mostly confined to the fissured areas. They act as an caprock impervious barrier for karst water reservoirs and frequently form bedrock and/or of the caprock of the latter;
4. Senonian postectonic deposits (sandstones, conglomerates and less frequently argilaceous shales) with local extension in the northern part of the map area. Senonian reservoirs supply springs with discharge up to 3 l/s, and also subjacent karstic reservoirs from the north and north-eastern part of the map area;
5. Marly and argillaceous deposits, devoid of groundwater flow, and flysch-like series, including rock-complexes of variable permeability (marls, argillaceous shales sandstones, limestones), hosting occasionally discontinuous aquifer accumulations occuring in the more permeable terms.

VI. HYDROGEOLOGY OF CARBONATE TERRAINS

Karst systems in the Bihor Vlădeasa mountains are generally of binary type, those extending exclusively over carbonate terrains being less frequent, with their occurrence mainly restricted only to the Apa Caldă–Hoanca Seacă area. They display a wide variety of dimensions, lithologic constitutions and performance mechanisms, that are mirrored by the physical, chemical and hydrogeological characteristics of the springs.

Table 3 indicates the major springs in the Bihor Vlădeasa mountains, as well as the formation from which they emerge, their in situ measured temperature and pH, the saturation index with respect to calcite and dolomite, the TDS content, the Mg/Ca ratio and the measured or estimated annual average (over October 1984–September 1985) discharge.

The karst springs are situated at different elevations, as a result of the pronounced dissection of the carbonate deposits and of the rugged topography. At the scale of the entire karst region a general base level cannot be outlined, each specific karst area having its own base level. The karst springs flow rates extend over a very wide range, with a 550 l/s maximum multiannual average value recorded in the case of Galbenei Spring over the hydrologic year October 1984–September 1985.

TRACER TESTS

In spite of a large amount of investigations completed and of papers published prior to 1984 on the Bihor Vlădeasa mountains karst morphology and hydrology, only a small number of tracer tests (6) have been performed in order to outline the groundwater flow paths. Out of those tests, two have been performed by VIEHMANN *et al.* (1958, 1961) and the other by ŞERBAN *et al.* (1957), RUSU *et al.* (1970), VĂLENAŞ (1974), HALASI & PONTA (1984).

Starting with 1983, 36 new tracer tests have been performed by ORĂŞEANU, in co-operation with GAŞPAR, POP and TĂNASE, with rhodamine B, fluorescein, stralex (optical brightener agent prepared in Romania), radioactive tracers (I-131, Br-82) and activable tracers (In-EDTA, Dy-EDTA), within the framework of a complex investigation program concerning the hydrogeology of the Bihor Vlădeasa mountains karst, initiated by the company "Prospecţiuni S.A.". The results of the tracer experiments have been published by ORĂŞEANU *et al.* in 1991.

Considering the tracer tests performed prior to 1991 as a whole, an average groundwater flow velocity of 45 m/hour has resulted, the longest identified underground flow path, 4500 m, being that between the pothole in Hoanca Urzicarului and Păuleasa spring, while the largest elevation range covered, 665 m, was that between Muncelu cave and Blidaru spring.

HYDROGEOLOGIC WATER BUDGET

In order to evaluate the budget of surface water and groundwater in the Bihor Vlădeasa mountains, during the hydrologic year October 1984–September 1985 the national hydro-meteorological observations network has been filled in with discharge gauging sections, set up on the main streams, at sites where they left the carbonate terrains, and at the main karst springs. For filling in the meteorological observations network, rainfall gauging devices have been installed at Padiş, Runcu Ars and Vârtop. Additionally, a meteorological platform, provided with equipments for gauging rainfall, evaporation next to water surface and evapotranspiration by means of lysimeters has been built at Casa de Piatră.

The discharge gauging stations located at the outskirts of the karst areas in Bihor mountains have provided control over a 527 km^2 surface area. Those stations are: Sighiştel valley (Sighiştel d.g.s.), Crăiasa valley (downstream Giuleşti spring d.g.s.), Galbena valley (Intre Ape d.g.s.), Bulz valley (Boga forestry hut d.g.s.), Someşul Cald river (Smida d.g.s.), Beliş river (Poiana Horea d.g.s.) and Arieş river (Scărişoara d.g.s.).

For the considered area, the rainfall recorded over the hydrologic year October 1984–September 1985 has amounted to 1220 mm. This value was computed by taking into account the data provided by rainfall gauging stations of the INMH network (Băiţa, Pietroasa, Stâna de Vale, Vlădeasa, Smida, Poiana Horea, Scărişoara), the values transmitted by Padiş gauging station correlated with Stâna de Vale gauging station, and the data provided by the previously mentioned rainfall gauging stations.

During the same period, the evapotranspiration value obtained by processing the lysimetric data provided by the temporary meteorological station at Casa de Piatră amounted to 374.6 mm. The available water amount (845.6 mm), distributed between runoff and seepage, has been recovered at the discharge gauging sections at the outskirts of the karst areas, which indicates that within the range of error of the primary data, there are no significat water transfers from or toward ajoining structural units.

GROUNDWATER QUALITY

Observations, measurements and analyses performed at the main springs of the Bihor Vlădeasa mountains result in the following considerations concerning the groundwater quality:

A. The temperature of the karst springs ranges between 5.4 and 10°C, directly related to the elevation of the supplying karst system. Some springs discharge higher temperature flows, as a result of deeper underground circulations along nappe or fault planes. These specific springs are: the warm spring at Valea Neagră (Şapte Izvoare, no. 29) — 17.2°C, the warm spring at Coteţul Dobreştilor (Feredeu, no. 112) — 16.2°C and Izbucul Mic at Gârda de Sus (no. 142) — 14.4°C;

B. The pH of the discharged water is slightly alkaline, ranging between 7.15 and 7.86;

C. Five karst springs display gas outflows: the warm spring at Valea Neagră (Şapte Izvoare, no. 29), the warm spring at Coteţul Dobreştilor (Feredeu, no. 112), the spring at the confluence of Pârâul Sec with Someşul Cald (no. 140), the warm spring in Alunul Mic valley (no. 142) and Izbucul Mic at Gârda de Sus (no. 116), the chemical composition of the outflowing gas being indicated, for the first 4 springs, in Table 4.

Table 3. Characteristics of the main springs in the Bihor–Vlădeasa Mountains.
Les caractéristiques des principales sources de monts Bihor–Vlădeasa

No	Source	H (a.m.s.l.)	Lithology	T (°C)	pH	Gase	S. I.		T.D.S (mg/l)	Mg/Ca	Q	
											M	E
1	2	3	4	5	6	7	8		9	10	11	
	Hydrographic basin of Crişul Negru river											
1	Groşi spring (2)	1000	granodiorites	8.5	6.39		-2.437		63	0	2	
2	Cuciului spring (5)	830	lms. (no+rh)	7.5					156.5 ; 172.0	0		10
3	Cornilor spring (8)	425	lms. (J_3)	8.8					330.0	0.201		10
4	Cerbasca spring (10)	570	dol. (an)	8.1								35
5	Puşului spring (14)	675	lms. (rh)	8.5								4
6	Berbece spring (15)	485	lms. (ld-no$_1$)	7.9 -10	7.6		-0.303	-1.417	225.2	0.126		4
7	Spr.of Aleu-Sebişel confl.(16)	435	granodiorites	10.2	7.87		0.282	-0.307	317.1	0.059		3
8	Aleu spring (18)	950	Mg-lms (rh$_1$)	6.0 -6.2	7.55		-0.710		125.9 - 349.3 (4)	0	9	
9	Spr. of Valea Popii stream (19)	1300	rhiolites	6.6	7.6		-1.498	-4.038	62.5	0.08		2
10	Ulmului spring (20)	575	ss (w)	7.8	7.77		-0.616	-1.779	121.5	0.236		3
11	Giuleşti spring (25)	505	dol. (an)	8.5					381.7 - 465.0 (5)	0.457	79	
12	Warm spring. Valea Neagră (29)	375	dol. (an)	17.2	7.3	+	0.145	-0.720	415.4	0.074		2
13	Cold spring. Valea Neagră (29)	376	dol. (an)	10.6	7.6		0.112	-0.773	320.7	0.055		3
14	Hidrei spring (30)	390	lms. (ox-v)	8.7					271.1	0	55	
15	Blidaru spring (32)	435	c (ox-v)	8.6					269.7	1.229	70	
16	Pişolca cave (33)	500	c (ox-v)	9.4					453.0	0	25	
17	Coliboaia spring (35)	515	lms. (ox-v)	9.2					302.3	0		20
18	Spring of Fânaţe (43)	450	dol.(cr$_3$-no$_2$)	8.9								15
19	Springs of Topliţa valley (45)	525	dol. (an)	8.7								20
20	Crişului spring (50)	700	dol.(cr$_3$-no$_2$)	7.0					208.7 - 272.1 (4)	0.440	215	
21	Boga spring (56)	675	dol. (an)	6.8					258.0	0.118	500	
22	Oşelu spring (57)	910	dol. (an)	7.0					396.5	0.163	50	
23	Bulbuci spring (58)	900	lms. (an$_2$-cr$_1$)	6.5					294.8	0.237	100	
24	Izvorul Rece spring (68)	1075	lms. (br-ap$_1$)	5.4 - 5.6	7.15		-0.537	-2.853	247.7 - 306.5 (4)	0.036	40	
25	Izbucul Ursului spring (69)	1095	lms. (an$_2$-cr$_1$)	6.3							20	
26	Galbenei spring (83)	860	lms. (br-ap$_1$)	5					286.8 ; 275.0	0.380	550	
27	Păuleasa spring (84)	570	lms. (br-ap$_1$)	6.6					255.4 ; 262.5	0.100	462	

Table 3. (continued)

No	Source	H (m.a.s.l.)	Lithology	T (°C)	pH	Gase	S. I.		T.D.S (mg/l)	Mg/Ca	Q M	Q E
1	2	3	4	5	6	7	8		9	10	11	
Hydrographic basin of Arieş river												
28	Gura Apei spring (90)	1125	dol. (an)	6.0					372.2 - 442.6 (3)	0.439	61	
29	Apa din Piatră spring (93)	1100	dol. (an)	6.2					302.5 ; 362.4	0.098	23	
30	Coliba Chiobului spring (94)	1100	dol. (an)	6.2					332..8	0		30
31	Vulturului spring (101)	1040	lms. (an_2-cr_1)	6.8					326.7 ; 390.8	0	75	
32	Tăuz spring (104)	850	lms. (ox-be)	7.5					255.4 - 373.0 (4)	0.056	530	
33	Corobana spring (105)	800	lms. (an_2-cr_1)	7.1					286.1	0.165		55
34	Coteţul Dobreştilor spr. (111)	770	dol. (an)	7.2-7.5	7.5		-0.009	-0.381	344.2 - 470.5 (6)	0.314	280	
35	Warm spr Coteţul Dobreştilor (112)	757	dol. (an)	16.2	7.54	+	-0.095	-0.089	296.7	0.134		5
36	Morii spring (113)	760	dol. (an)	7.2-7.5					386.0 ; 447.7	0.332		20
37	Poarta lui Ioanel cave (114)	810	dol. (an)	7.7	7.51		0.069	-0.300	274.6 - 436.0 (5)	0.165	90	
38	Izbucul Mic spring (116)	730	lms. (an_2-cr_1)	6.8	7.74	+	-0.092	0.056	285.9 ; 464.9	0.892		10
39	Izbucul Mare spring (117)	725	lms. (an_2-cr_1)	6.2	7.38		-0.044		348.1 ; 463.8	0.083		45
Hydrographic basin of Someşul Cald river												
40	Apa Caldă spring (123)	1120	dol. (an)	8.0					444.3	0.149		40
41	Spring of Hoanca Seacă (124)	1150	dol. (an)	6.3					529.7	0.270		10
42	Călineasa (Rece) spring (127)	1170	dol. (an)	6.5					461.2	0.337		25
43	Izbucul Mic spring (129)	1255	dol. (an)	6.5					363.4	0.363		40
44	Alunul Mare spring (136)	1180	lms. (ox-be)	5.6	7.72		-0.322	-2.170	177.3 ; 218.5	0.013		110
45	Peştera Pepii cave (139)	1125	lms. (ox-be)	5.6	7.86		0.159	-1.667	264.9 ; 320.1	0		20
46	P.Sec-Som.Cald conf.spr (140)	1095	aluvia (Q)	8.8	7.8	+	-0.223	-1.574	171.4 ; 345.5	0.054		30
47	Alunul Mic spring (141)	1100	lms. (ox-be)	9.0	7.64		-0.390	-2.245	167.6 ; 322.1	0.011	180	
48	Warm spring Alunul Mic (142)	1065	lms. (T3)	14.4	7.77	+	-0.035	-0.832	206.2 ; 247.0	0.074		6
49	Springs of Şurile din Firea, 149	1070	lms. (br-ap_1)	7.5					372.4	0		100
Hydrographic basin of Crişul Negru river												
50	Vârfuraşul spring (156)	1175	dol. (an)	6.0	7.47				166.5	0.033	105	
51	Izvorul Minunilor spring (157)	1150	dol. (an)	5.8 - 6.2	7.34		-0.820	-2.323	139.3	0.190	15.6	
52	Rampei spring (159)	1145	dol. (an)	5.4 - 5.6	7.37		-0.744	-2.509	187.4	0.087		15
53	Izvorul Păstrăvăriei spring (160)	1100	dol. (an)	5.4 - 6.0	7.53		-0.555		180.5	0	50	
54	Pavel spring (161)	1085	dol. (an)	6.1	7.44		-0.597	-1.915	211.3	0.158		7
55	Murgaşu spring (162)	930	ss, ρ (sn)	7.8 (7)	7.65		-0.900		99.8 - 160.2 (6)	0.008	12	
56	Radu spring (163)	1085	dol. (an)	6.4	7.24		-0.613	-1.481	278.0	0.508		2
57	Ariei spring (164)	1325	rhyolites	5.8	7.63		-4.472	-9.437	65.0	0.285		1

Note: In brackets: Column 2 - number of the spring on the hydrogeological map; Column 4 - age of deposits; Column 5 - number of measurements; Column 9 - number of samples analysed.
Abbreviations: S.I. - saturation index; Q - mran annual discharge (X.1984-IX.1985); M - measured discharge; E - estimated discharge; lms. - limestones; dol. - dolomites; ss. - sandstones; ρ - rhyolites.

The gas outfows have a composition similar to that of atmospheric gas, hence they consist of the air dissolved in the water of the springs, that leaves the solution ensuing to the increase of the water temperature.

D. The computed saturation indexes (Table 3) indicate that the water of most karst springs in Bihor Vlădeasa mountains is undersaturated, to a larger or smaller extent, with respect to both calcite and dolomite.

The warm and cold springs at Valea Neagră (no. 29), the stream emerging from Pepii cave (no. 139) and the spring Poarta lui Ioanel are supersaturated with respect to calcite, the latter spring having large associated travertine deposits. Izbucul Mic at Gârda de Sus has saturation indexes very close to equilibrium, its water being slightly supersaturated with respect to dolomite.

The water of the springs in the catchment areas of the binary karst systems is strongly undersaturated with respect to calcite and dolomite, inducing as a result of its aggressivity an intense dissolution of the carbonate deposits. Quite typical in this respect is the water of the springs originating in igneous formations (for instance the spring of Valea Popii, no. 19 and Ariei spring, no. 164), which explains the intense development of the karst within the carbonate deposits in the Someşul Cald graben induced by runoff water originating on the southern and south-eastern slopes of the Cornul-Miclau-Vlădeasa ridge.

The water of the karst systems is of calcium bicarbonate, calcium-magnesium bicarbonate and magnesium-calcium bicarbonate type, depending on the chemical composition of the traversed formations (limestones and/or dolomites), with TDS values ranging between 125 - 529.7 mg/l.

Stiff chemical composition diagrams for water (Fig. 3) indicates a larger TDS content for the springs that either have their supply derived exclusively from large extent carbonate formations, or include a small nonkarstic catchment basin that supplies part of a large karst system (for example the karst systems in Ocoale–Gârda de Sus and Apa Caldă–Hoanca Seacă areas). The karst systems of small dimensions and with a larger contribution of the nonkarstic catchment basins have lower TDS content (for example the karst systems on the western slopes of the Vlădeasa mountains).

E. The major elements contents of the karst springs water in the Bihor Vlădeasa mountains range below the maximum accepted concentrations stipulated by the STAS 1342-91 regulation for drinking water. For some of these springs however, the bacteriological and the toxic elements content does not comply with the requirements of the regulation.

F. In order to evaluate the bacteriological content of the karst springs, specific analyses have been performed at the Preventive Medical Center in Beiuş, under the leadership of dr. Mocuţa.

Table 4. Chemical composition of gases leaks associated with waters.
La composition chemique des gaz dégages associés avec les eaux.

No.	Source*	Q l/s	T (°C)	T.D.S. mg/l	CO_2 % vol	O_2 % vol	N_2 % vol	Ar % vol
1	Warm spring of Valea Neagră (29)	1.5	17.2	415.4	6.90	19.42	72.80	0.86
2	Spring of conflence Someşul Cald -Pârâul Sec (140)	15.0	8.8	171.4	1.27	20.20	77.59	0.89
3	Warm spring of Alunul Mic stream (142)	5.0	14.4	206.2	0.31	20.26	78.15	0.91
4	Warm spring of Coteţul Dobreştilor (112)	2.5	16.2	252.3	0.54	17.83	80.81	0.79

*In brackets number of spring on hydrogeological map
Other compounds for which the gases were analysed, C_2H_2 , C_3H, C_4H_{10}, He and H_2, are lacking.

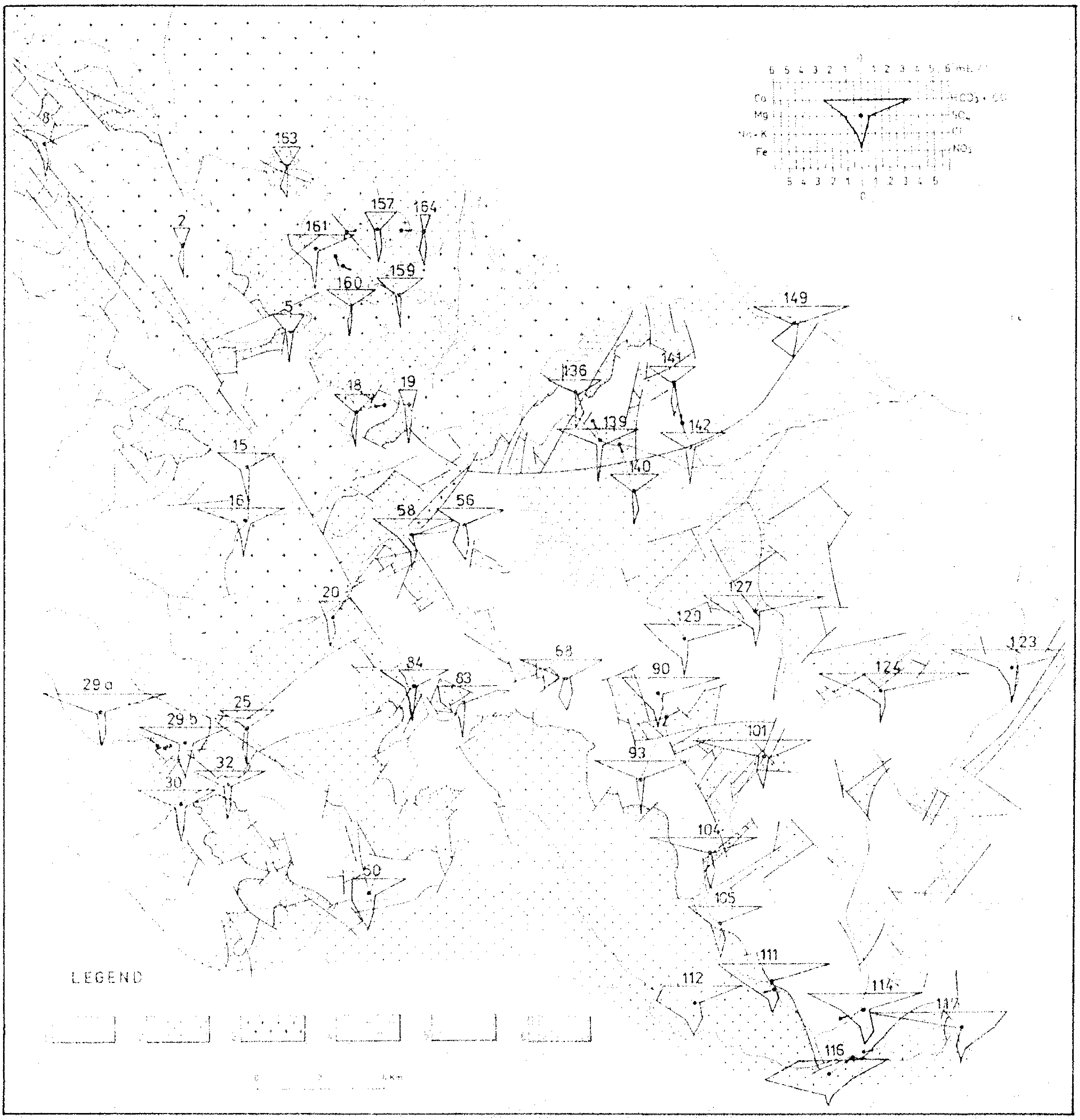


Fig. 3. Stiff chemical composition diagram. Legend: 1. Mesozoic limestones and dolomites; 2. mainly detritic deposits of Permian, Werfenian, Lower Jurassic and Senonian ages (sandstones, conglomerates, shalles and les frequently rhyolites); 3. Banatitic rocks; 4. Crystaline schists; 5. Marls, argillaceous shalles and sands of Pliocene–Quaternary ages; 6. Mesozoic marls and argillaceous deposits.

La composition chimique évidentiée par les diagrames Stiff. Legende: 1. Calcaires and dolomies mesozoïques; 2. Depôts predominants detritiques d'ages Permien, Werfenien, Jurrasic inferieure et Senonien (gres, conglomerats, schists et, subordonés, rhyolites); 3. Roches banatitiques; 4. Schistes cristalines; 5. Marnes, schistes argileuses et sables Pliocene–Quaternaire; 6. Depôts marneuses et argileuses Mesozoïques.

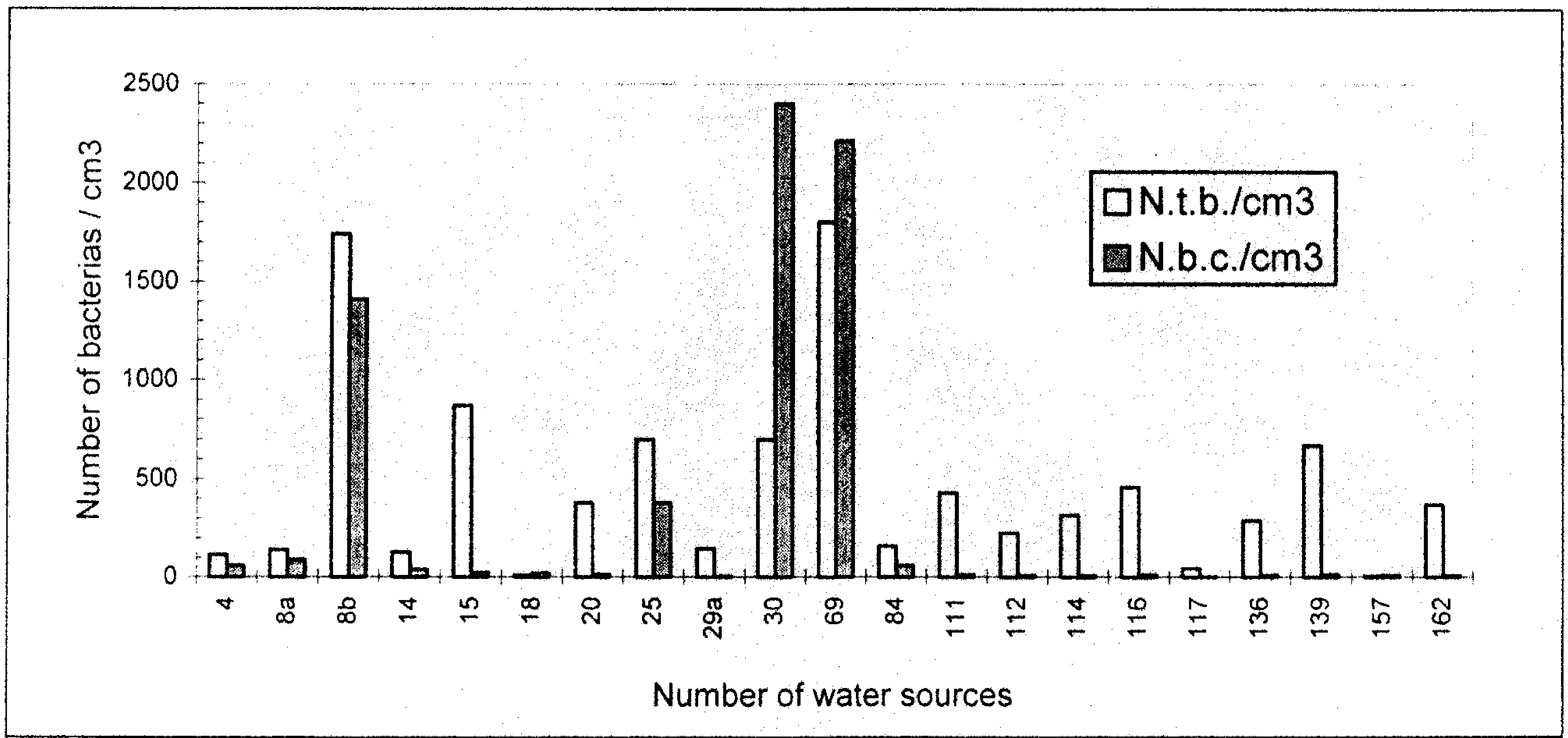


Fig. 4. Displays of the total number of bacteria (N.t.b.) and of the probable number of coliform bacteria (N.b.c.) in spring water.
Le contenu bacteriologique total et le numero le plus probable des bacteries colliformes dans les sources karstiques.

For drinking water provided by local sources (wells, springs, etc.), the STAS 1342-91 regulation stipulates the following maximum accepted bacteria contents:

- the total number of bacteria, (N.t.b.), developing at 370C/cm^3 should be less than 300;
- the probable total number of coliform bacteria/dm^3, (N.c.t.), should be less than 100;
- the probable number of coliform fecal bacteria/dm^3, (N.c.f.), should be less than 20.

Figure 4 displays the total number of bacteria and total coliform bacteria contents of some karst springs, illustrating a wide range of contents, with the karst systems supplied by swallets (for example the springs Cornilor, Hidrei, Cameniţa) exhibiting a higher bacteriological content, as opposed to those systems the recharge of which is diffuse and/or is taking place through an aquifer confined beneath an aquiclude (the springs Aleu, Murgaşu, Izvorul Minunilor, etc.), that have a smaller bacteriological load (*see* ORĂŞEANU, 1994).

Along one year time span, the bacteriological content of the karst springs water is subject to important fluctuations, relatively high contents being associated to the rainy or snowmelt periods, as compared to drought periods.

G. Toxic elements content. The STAS 1342-91 regulation stipulates that in drinking water maximum allowed concentrations are 50 ppb manganese, copper, chromium and lead, 100 ppb nickel, and 5000 ppb zinc. Exceptionally allowed concentrations are 300 ppb manganese, 100 ppb copper and 7000 ppb zinc.The analyses of 26 water samples, performed by means of the ICP equipment of the "Prospecţiuni S.A." laboratories, indicate Mn, Cr, Ni and Zn contents below the maximum allowed concentrations. On the contrary, in the case of many springs the maximum allowed lead concentrations are exceeded up to two times, while those of copper are exceeded up to six times (Fig. 5 and 6). The springs Aleu (18), Izvorul Minunilor (157), Izvorul Rece (68) and Izvorul Radu (162) display extremely low contents of the considered microelements. Relatively high Cu, Pb and Zn concentrations occur in the springs Groşi (2) and Ariei (164), that emerge from banatites, and in the springs emerging from the dolomites that outcrop in the southern end of the study area: Coteţul Dobreştilor (111), the warm spring at Coteţul Dobreştilor (112), Poarta lui Ioanei (114), Izbucul Mic (116) and Izbucul Mare (117).

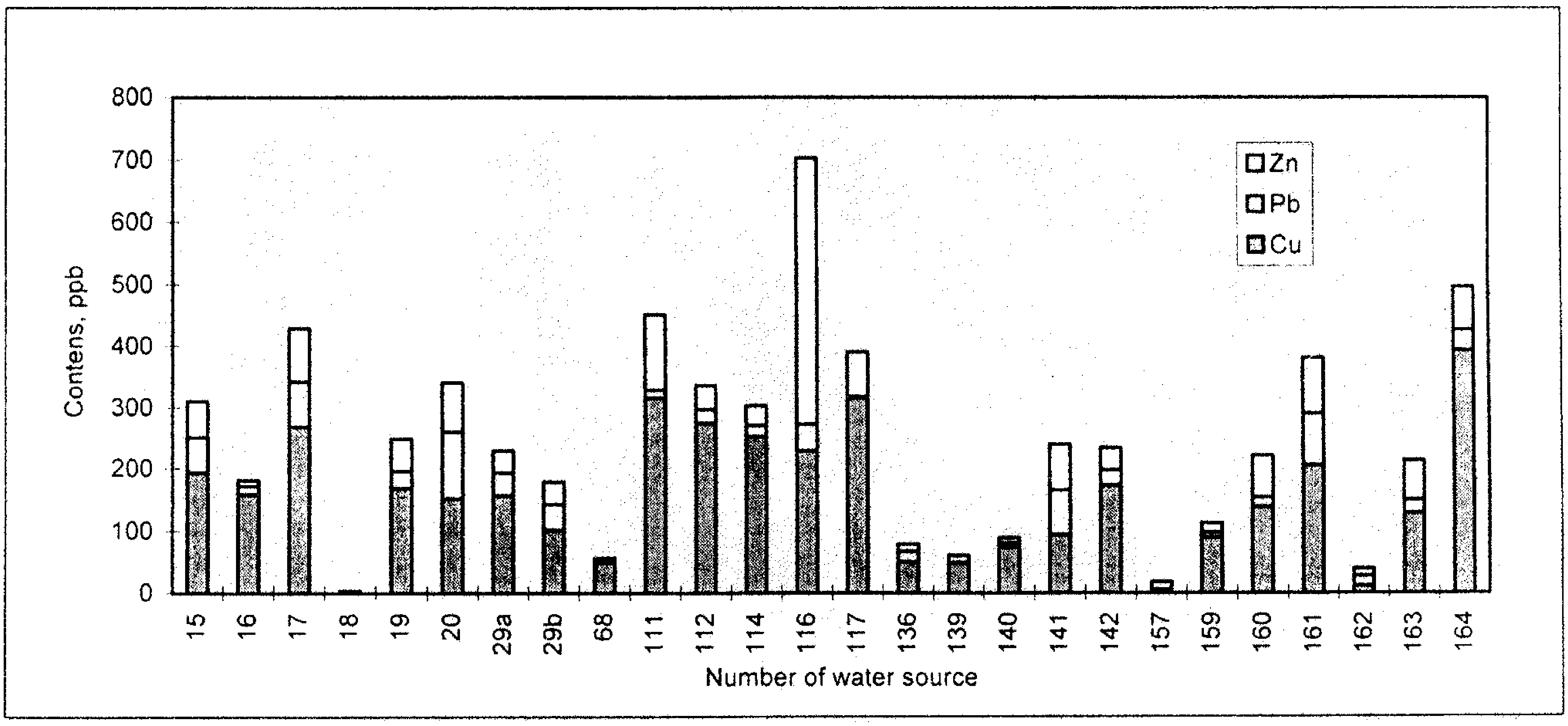


Fig. 5. Contents of the spring water in Cu, Pb, Zn.
Le contenu en Cu, Pb, Zn des sources karstiques.

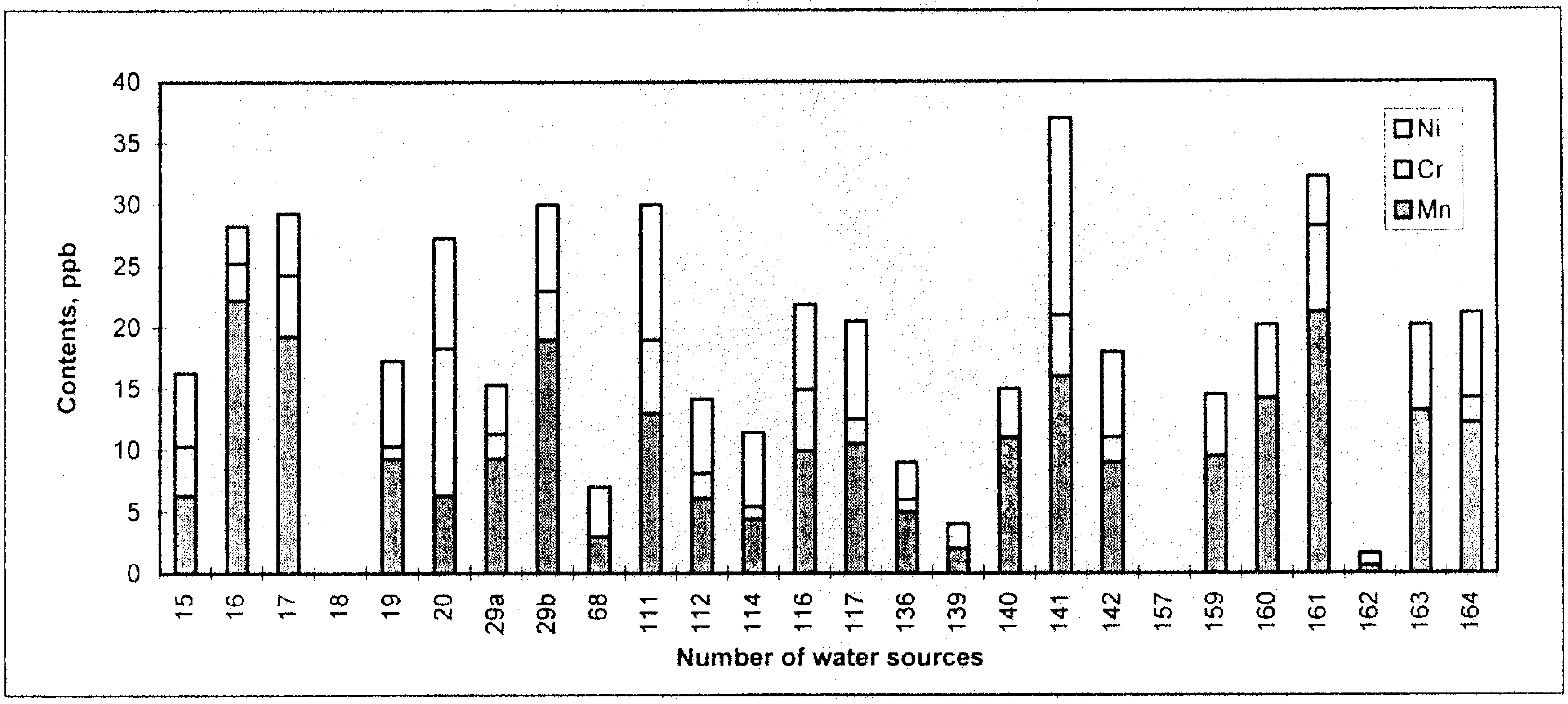


Fig. 6. Contents of the spring water in Mn, Cr and Ni.
Les contenu en Mn, Cr et Ni des sources karstiques.

VII. MAJOR KARST SYSTEMS

The puzzle-like distribution of the domains occupied by carbonate deposits in the Bihor mountains had as a result the occurrence of several distinct karst areas, each one characterised by its own groundwater dynamics regime, and including, as a general rule, several karst systems.

The hydrologic regime of 7 outlets has been continuously monitored over the hydrologic year October 1984–September 1985. Table 5 indicates average, minimum and maximum annual flow rate, flow rates variability index and results of correlative and spectral analysis of daily average recorded flow rates series, while Table 6 indicates the main parameters that characterize the flow rates recession period over the same observation.

Table 5. Characteristic discharges of the springs and results of the correlation and spectral analysis.
Les débits caractéristiques des sources et les résultats de la corrélation et de l'analyse spéctrale.

Source Parameter	Tăuz	Păuleasa	Alunul Mic	Cotețul Dobreştilor	Izvorul Crişului	Giuleşti	Izvorul Minunilor
Q_{mean}, l/s	529	477	306	274.7	217.9	77.7	19.2
$Q_{minimum}$, l/s	68	180	2	0	58	3	15.6
$Q_{maximum}$, l/s	4640	1920	3160	2120	826	571	30.0
n_v (Q_{max}/Q_{min})	62.2	10.7	1580		14.2	190.3	1.9
ME, days	18	31	16	31	37	7	44
RT, days	24.6	42	23.8	34.5	42.7	12.3	46.4
TF	0.208	0.092	0.112	0.160	0.172	0.420	0.096

n_v, index of variability; ME, memory effect; RT, regulation time; TF, truncation frequency

Table 6. Main parameters characterizing the recession
Les principaux paramètres qui caractérisent la récession.

Source Parameter	Tăuz	Păuleasa	Alunul Mic	Cotețul Dobreştilor	Izvorul Crişului	Giuleşti	Izvorul Minunilor
Period of recession	26.06.85 30.09.85	24.01.85 04.03.85	22.06.85 06.08.85	06.10.84 19.11.84	09.08.85 30.09.85	20.11.84 19.12.84	31.12.95 04.06.96
Q_0	1490	670	560	368	349	124	29.7
q_0^b	290	316	283	106	100	73.8	21.6
α	0.0116	0.0093	0.0231	0.0495	0.0078	0.0549	0.0034
q_0^*	1200	354	227	262	248	50.2	8.2
t_1	32	13	15	14	17	9	32
η	0.0313	0.0769	0.0667	0.0714	0.0588	0.1111	0.0313
ε	0.114	0.339	0.046	0.446	0.394	0.025	0.042
V_0^b	2.16	2.94	1.06	0.185	1.290	0.116	0.556
V_0^*	o.87	0.97	0.15	0.066	0.073	0.018	0.008
V_0	3.03	3.91	1.21	0.251	1.363	0.134	0.564
V_0^b / V_0 %	71	75	88	74	95	87	99
V_0^* / V_0 %	29	25	12	26	5	13	1

Q_0, total discharge at the beginning of the recession, (l/s); q_0^b, discharge at the beginning of the recession for the baseflow, (l/s); α (day $^{-1}$), baseflow coefficient; q_0^*, discharge at the beginning of the recession for the quickflow, (l/s); t_1, duration of the quickflow, (days); η and ε, parameters adopted for the curves of the quickflow, (day^{-1}),; V_0^*, initial volume which will be drained during the quickflow (10^6 m^3); V_0, initial total volume stored in the aquifer, (10^6 m^3); V_0^b, initial volume that will be drained during the baseflow (10^6 m^3).

In the correlative and spectral analysis of the flow rates, we used the methodology proposed by MANGIN (1981a, 1981b, 1982, 1984) and in the study of the recession, the papers published by MANGIN (1975) and PADILLA *et al.* (1994) (Fig. 9).

TĂTĂROAIA KARST AREA

Tătăroaia karst area is developed in Anisian dolomites and Ladinian limestones that occur as a strip extending between Crăiasa and Galbena valleys. Most of this karst area overlies the karst system of Giuleşti spring, that is supplied almost exclusively by rainfall and does not include a non-karst catchment basin.

The relatively scarce exokarst landforms are restricted to the sinkholes in the Vârcioroagele plateau; in contrast, there are several significant cavities, among which it should be mentioned the pothole "Gaura care suflă" and two major stream caves, Micula and Fagului, the latter being discovered ensuing to the excavation of a geological exploration mining gallery.

The stream in Fagului cave emerges in Giuleşti spring, as indicated by the rhodamine tracing experiment performed on 7 October 1984. Figure 7 illustrates the simple correlograms and Figure 8 the variance density spectrum of the flow rates series.

Some additional supply to the system might also originate in the sinking stream of Valea Căuşii. During heavy rainfall periods the water transfer capacity of the cracks and channels network of Giuleşti spring is exceeded, so that part of the flow is discharged through the entrance of Micula cave, that behaves as an overflow to the system.

Besides Giuleşti spring, the aquifer located in the carbonate deposits of the Tătăroaia wedge discharges also through the springs at the fountain-head of Fagului valley, of 10 l/s average cummulated flow rate, and through the IPEG mining gallery excavated eastward from Prelucilor valley, along 3 km, that discharges on the average some 15 l/s of 15 °C water.

To the north, this aquifer supplies the springs at the fountain-head of Păuleasa and Buteasa brooks (Bonciului and La Scoici springs), the latter area being designated by the locals by the name "Ape Calde" (Warm Waters).

The global interpretation of the data concerning Giuleşti spring contained in Tables 3, 4 and 5 indicates that its discharge is derived from a karst system of very poor inertia, subject to intense karst development, prevalently conductive and much less in what concerns its storage capacity. The reserves of the system are small, the weight of the fraction discharged by the fast flow amounting to 13%. There is no significant filtering of the rainfall induced information, so that heavy rainfall is immediately followed by intense floods. The discharge of the springs quickly declines after the rains stop, and as a consequence the prolonged draught periods result in a drastic reduction of the flow rate, occasionally till the discharge ceases completely.

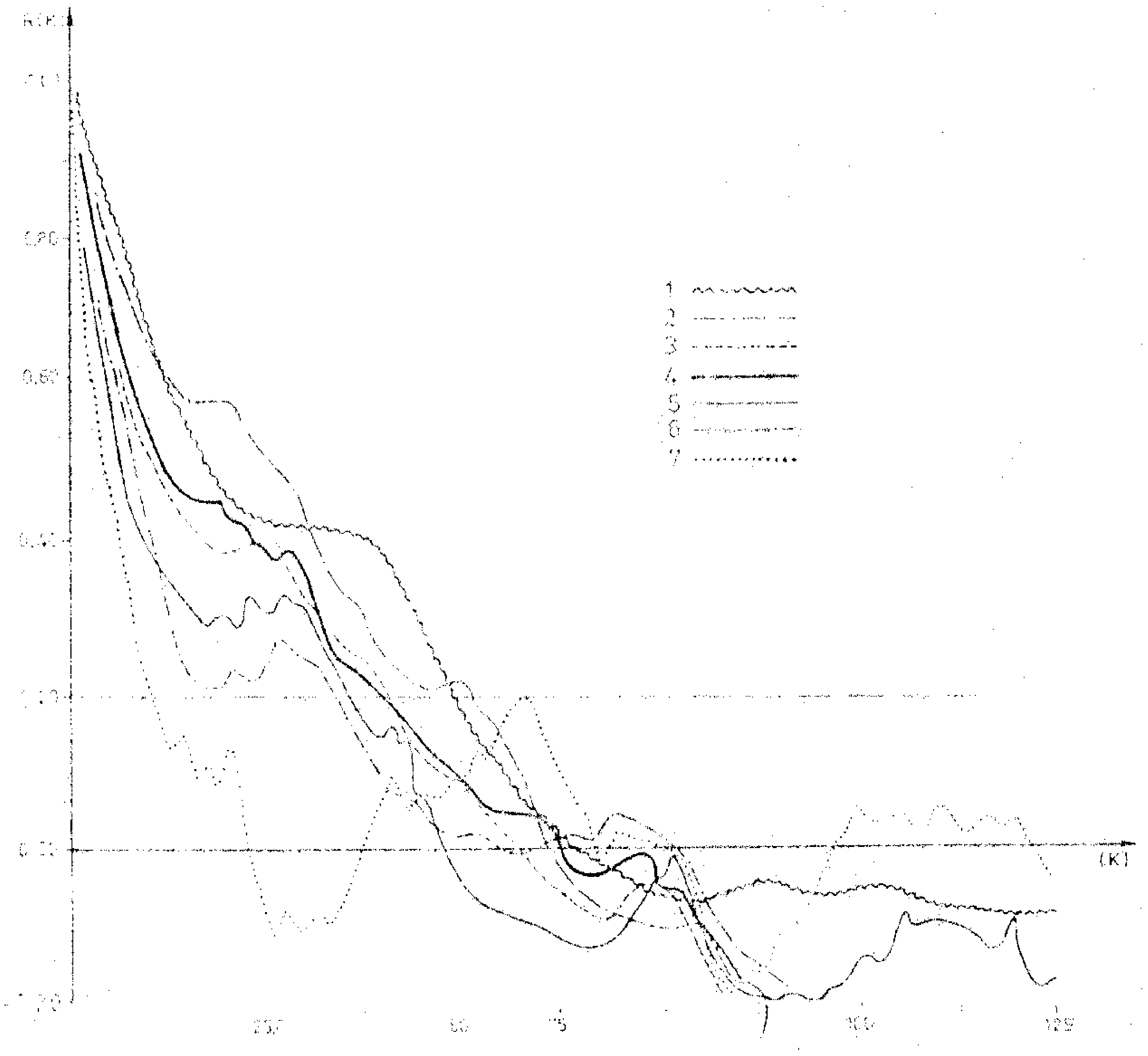
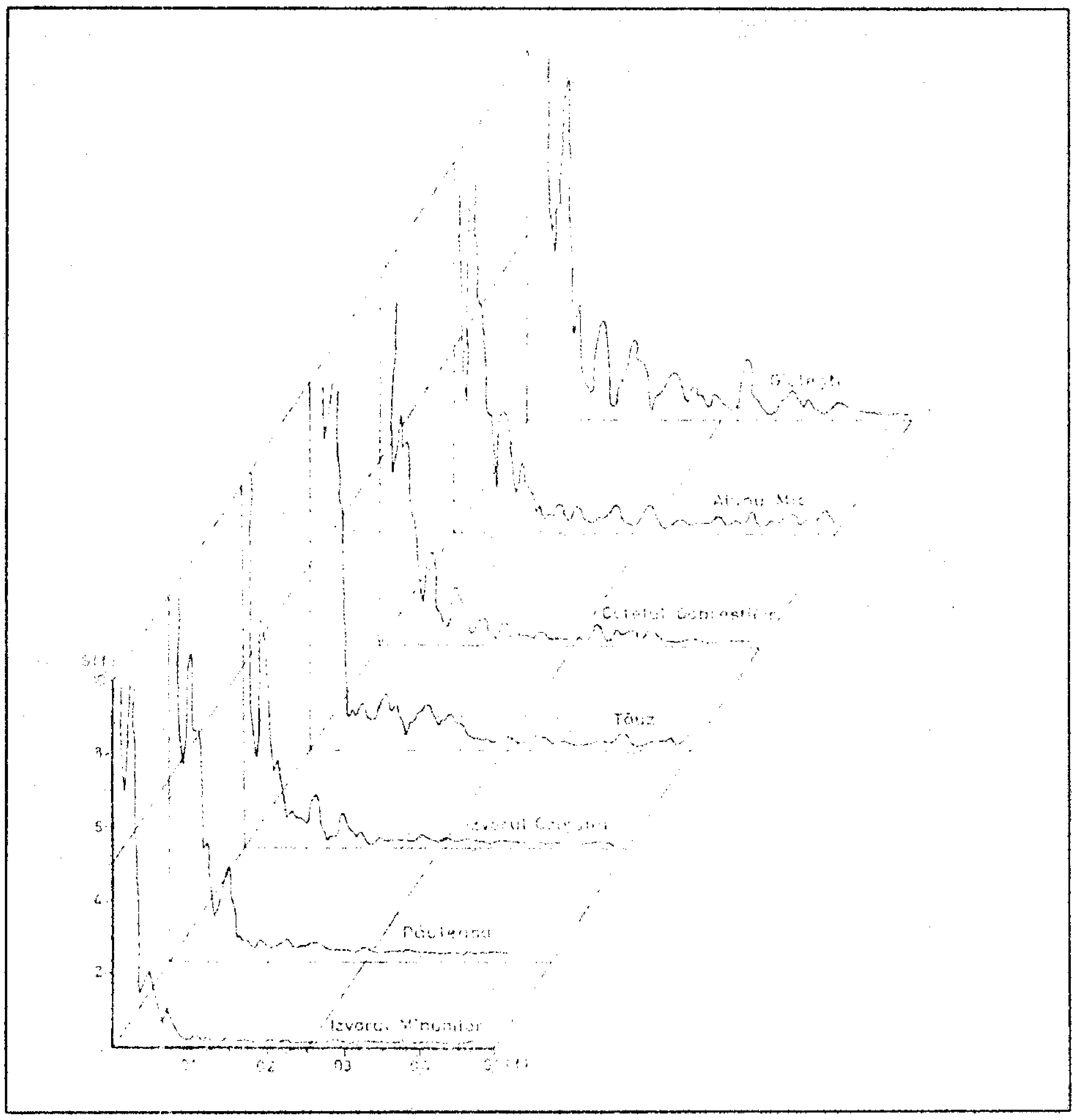


Fig. 7. Analysis of discharge time series of seven karstic systems: 1. Izvorul Minunilor; 2. Izvorul Crişului; 3. Păuleasa; 4. Coteţul Dobreştilor; 5. Alunul Mic, 6. Tăuz; 7. Giuleşti; Simple correlation of the flow rates (m=125 days, k=1).

Analyse des chroniques de débits de sept systèmes karstiques: 1. Izvorul Minunilor; 2. Izvorul Crişului; 3. Păuleasa; 4. Coteţul Dobreştilor; 5. Alunul Mic; 6. Tăuz; 7. Giuleşti. Corrélogramme simple de débits (m=125 jours, k=1).

Fig. 8. Comparative analyses of seven karstic systems. Variance density spectrum of the flow rates (m=125 days, k=1).

Analyse comparative de sept systèmes karstiques. Spectre de densité de variance (m=125 jours, k=1).



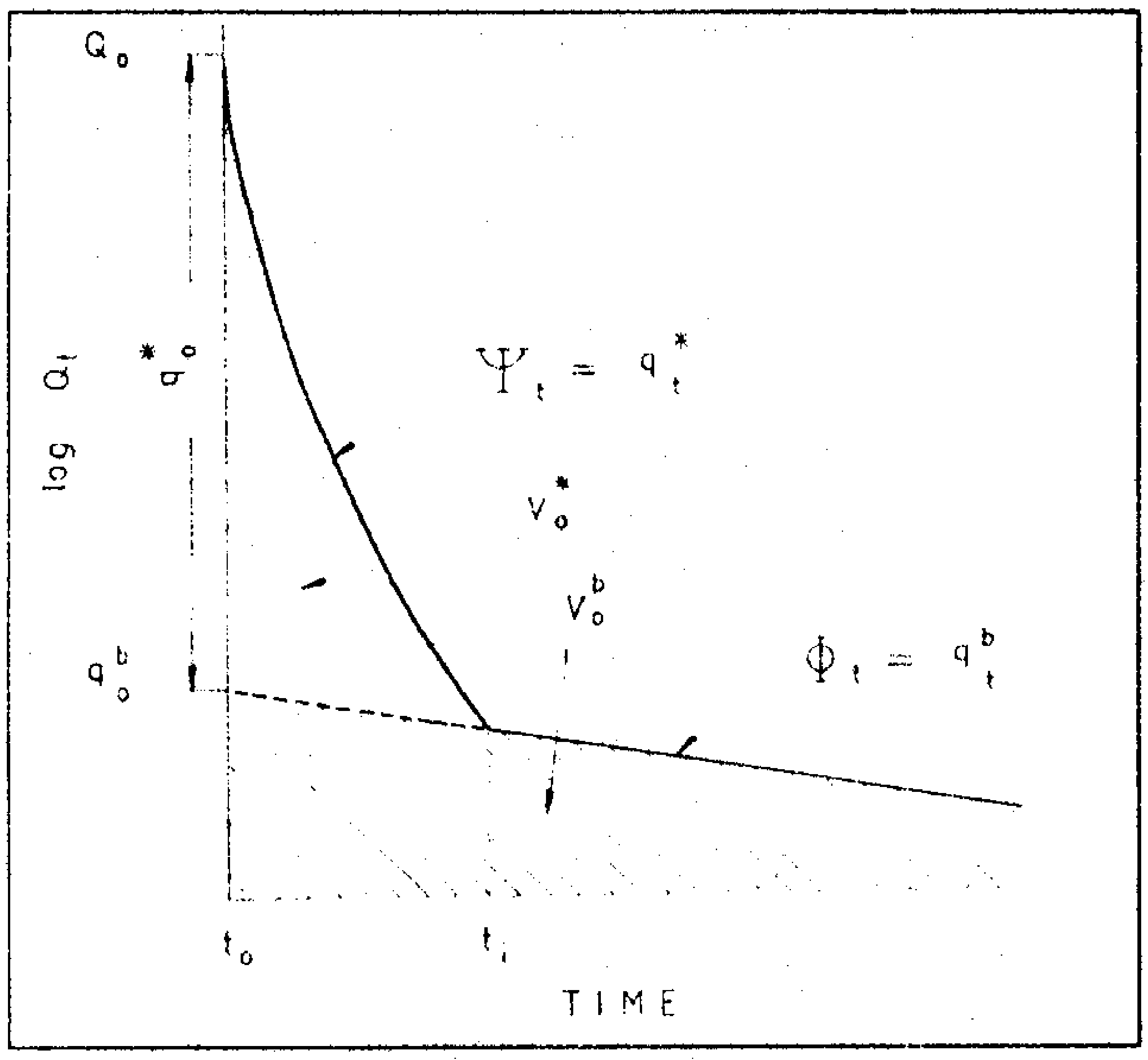


Fig. 9. Idealized diagram showing quickflow and baseflow components of the recession curve according to MANGIN'S equation (after PADILLA et al. 1994). ***Diagramme idéalisé montrant les composants d'ecoulement dans la periode de récession conformément à l'équation de MANGIN (d'après PADILLA et al. 1994).***

CHIŞCĂU–SIGHIŞTEL–FÂNAŢE KARST AREA

This karst area, that extends between Crăiasa and Crişul Băiţa valleys and is traversed along its main axis by the Sighiştel valley, is dominated by the central position of the Arieşeni nappe thrust outlier located on Prislop peak, marked by a multitude of swallets through which the runoff water sinks in the underground at its entrance on carbonate domains. When additionally considering the aquifer concentrated supplies originating on the western slopes of the Târlau peak (Secătura valley, Cheia Rea valley, Muncelului valley) and those in the area of Dosurile peak, a realistic image is obtained on the multitude of the impact points between surface water and limestones, that over the ages resulted in the excavation of an impressive number of caves.

Ensuing to the intense tectonic dislocation of the area, one karst aquifer occurs, the resources of which are subject to competition between many large flow rates springs. In the Sighiştel valley upper reaches, on its right hand side, are located the caves Coliboaia and Pişolca. Access in the first of those caves does not follow the streamway, which in turn emerges via a group of 20 l/s average flow rate springs, at the bottom of the scree slope beneath the cave entrance. The 25 l/s average flow rate stream in Pişolca cave is probably supplied through the karst area next to Grohotilor peak and through the diffuse sinking of Pietrele Roşii valley.

The most important karst spring along Sighiştel valley is Blidaru. It has 70 l/s average flow rate and during flood periods the cave Răsuflătoarea Blidarului, located 5 m upslope, acts as an overflow to the karst system.

Tracer tests have indicated that Blidaru spring discharges the entire amount of water derived from the north-western slopes of Prislop peak and from the western slopes of Târau–Pietrele Negre ridge. The tracer has been injected at the diffuse sinking points along Preluca Nasului valley (fluorescein), Secătura valley (rhodamine) and in the surface stream that enters Muncelului cave.

The tracking of the tracer has been performed by means of active coal filters immersed in the main springs on the Sighiştel valley (Coliboaia, Pişolca, Blidaru, Hidrei), in the spring of Crişul Băiţa and in the underground mining works of the Băiţa Molibden mine. While the fluorescein and the I-131 have been carried only toward Blidaru spring, rhodamine injected in the sinking section of Secătura valley has been carried, due to an underground diffluence, both to Blidaru spring (most of the tracer amount) and to Coliboaia cave. We presume that originally Secătura swallet had discharged via Coliboaia cave, the pothole in Secătura (Arago) and the above mentioned cave forming a unitary karst system. Coliboaia cave currently acts as an overflow to Blidaru spring.

Some 20 m downstream Blidaru spring there is another spring of 10 l/s average flow rate. The fact that small tracer amounts have been recovered from this spring too indicates that it belongs to the same aquifer system.

Hidrei spring is the second largest outlet (35 l/s average flowrate). It is impenetrable and occurs at the bottom of a 15 m high Tithonic limestones cliff, discharging mainly the water originating on the western slopes of Prislopul peak, as indicated by the fluorescein tracing experiment completed on 28 September 1984 at the diffuse sinking point along Sodolul Tomeştilor valley.

Considered as a whole, the karst springs in Sighiştel catchment basin are supplied by a single karst aquifer that is subject to an intense contemporary evolution of the karst processes. The large number of completed tracer tests (ORĂŞEANU, 1991) indicate that groundwater flow currently concentrates toward Blidaru spring, with an obvious tendency to abandon outlets situated upstream (Coliboaia and Pişolca) and to augment of the flow rates discharged by Hidrei spring, located at the bottom of the erosional level of the considered karst area.

During the previously indicated observation period, Sighiştel stream had an average flow rate of 456.5 l/s, with the extreme values ranging between 2130 and 110 l/s.

The most outstanding underground feature on the western water divide between Crăiasa and Sighiştel valleys is Urşilor cave at Chişcău, with a small stream running along its bottom floor. In the same area, at the fountain-head of Izbucului valley, in a small grassy depression on its left hand side, at the site called by locals "Şapte izvoare", occurs a group of springs, the one situated downstream displaying gas outflows, a temperature of 17 °C and a flow rate of 4 l/s. In its close neighbourhood, immediately upstream, two other springs of 8 °C and 5 l/s cumulated flow rate emerge from the scree.

PADIŞ–GALBENA–BULZ KARST AREA

The Werfenian deposits on the south-western slopes of Măgura Vânătă mountain, the Hettangian-Sinemurian ones occurring north of Iezere and in Groapa de la Barsa, and the Permian ones in the area of the Glăvoiu and Borţig peaks, favour the organization of a well-defined surface drainage, among which worth mentioning are, due to their large flow rates and their perennial character, the valleys Cuţilor, Renghii, Arsurii, Trîngheşti and Ursului.

When entering carbonate terrains, the surface flow is abandoned for alternative underground paths, directed toward the springs in the catchment basins of Bulz and Galbena valleys.

The tracer tests performed in order to identify the destination of the streams sinking through the multitude of swallets in Padiş–Cetăţile Ponorului closed catchment area, have outlined underground flows from Vărăşoaia subordinate closed basin and from the northen half of Padiş subordinate closed basin, toward Boga spring.

The surface streams in the southern half of Padiş subordinate closed basin, Arsura, Trânghieşti and Gârjoaba, enter first an underground course down to the spring in Poiana Ponor, wherefrom they take another, about 500 m long, surface course, eventually to sink again into an impenetrable swallet and to emerge shortly afterwards in the outlet next to the entrance in Cetăţile Ponorului cave, where from they continue their underground course down to Galbenei spring. To the supply of this latter spring also contribute, directly or via the underground course in Cetăţile Ponorului, the water collected by the subordinate closed basins Paragina, Barsa Cohanului, Cetăţilor valley and Lumea Pierdută, the latter having a significant impact due to the contribution of Pârâul Sec and of Izvorul Ursului brooks, that sink in Căput cave. The inclusion of Bălileasa subordinate closed basin is open to debate, since there is no perennial stream course to be traced.

The karst system of Galbenei spring and that of Tăuz are the systems with the largest extent in Bihor mountains. They are complex karst systems, that include in their constitution several karst drainage units (i.e. simple karst systems). The average annual flow rate of Galbenei spring during the considered hydrologic year has been 550 l/s.

The left side of Galbena valley, upstream of the junction with Păuleasa stream, displays advanced karstic stream piracy phenomena, especially in the catchment areas of Valea Seacă and Crişanul. Subsequently to diffuse sinking in a swallet located downstream of the boundary with the Permian sandstones of the Arieşeni overthrust, the water of Ţiganului valley, a tributary of Valea Seacă, emerges in Păuleasa spring, as indicated by an In-EDTA tracing experiment. Păuleasa spring is also supplied by Luncşoara stream, that sinks underground before the junction with Galbenei spring.

Valea Seacă has its fountain-head located in Groapa Ruginoasă and displays a temporary flow regime, both upstream and downstream of the banatite body that outcrops in its median section. In August 1984 the water sinking in the upper section of the valley has been traced with In-EDTA. For identifying the subsequent groundwater flow direction, the springs Păuleasa, Gileşti, Izvorul Crişului, all from southward located Crişul Băiţa catchment area, as well as the water discharged by the 3 km long Valea Seacă directional gallery, that runs from Băiţa Molibden mining area southward, down beneath Ţapul peak, have been monitored by means of adequate methods. The tracer has been identified at the latter two monitoring stations, in an advanced degree of dilution, over the time interval 2-25 October 1984 (at Izvorul Crişului), and over the time interval 24 August - 10 September 1984 (in Valea Seacă gallery). The tracing experiment has proven the continuity of the Tithonic limestones of the Bihor Autochtonous beneath the Permian quartzite sandstones, substantiating by means of a hydrogeologic investigation method the napping position of the quartzite sandstones. At the same time, it has proven that the radius of hydrodynamic influence of the minig works in the upper catchment basin of Crişul Băiţa trangresses the surface water divide of this stream.

Păuleasa spring has a 477 l/s average flow rate, with a 25% contribution of the fast flow to the water volume discharged during recession period. The relatively long duration of the rain unitary impulse influence (42 days regulating time) and the significant memory effect (31 days), indicate Păuleasa system to have important groundwater reserves, while the small values of the cut frequency (0.092) mirror the influence of the surface runoff in the spring supply.

The flow rate gauging performed along Galbena stream has identified underground sinking, that occurred between the junction with Luncşoara valley and Păuleasa spring. For instance, on 12 July 1985 the flow rate between the two gauging sections diminished from 426 to 370 l/s, while on 9 October 1985 it decreased from 130 to 90 l/s. We presume that water sinking is related to the position of Galbena fault, that in this section acts as a drainage path. The hypothesis that those stream losses might be recovered at Păuleasa spring has not been confirmed by the tracer tests. Between Păuleasa spring and the junction with Bulz stream the flow rates of Galbena have a normal evolution, no significant inflows or outflows being recorded within the error range of the gauging methods.

Upstream of the junction with Valea Rea stream, Boga stream has an annual average flow rate of 700 l/s, provided by Boga spring (500 l/s), Oşelu spring (50 l/s), Bulbuci spring (100 l/s), and by the other springs, of secondary interest, existing in the catchment basin (50 l/s).

Along a section where no tributaries exist, between the junction with Valea Rea and the junction with Plaiului valley, Boga valley displays significant sinking into the streambed, amounting to about 20 % of the entire flow rate. The topography of this specific zone appears as a wide valley section, abundantly covered with alluvial deposits, where Boga cottages settlement is located. The abundance of the alluvia is the result of the deposition of part of the suspended solids carried by the stream, which occurred when the latter diminished its flow ensuing to underground sinking. The sinking is related to the presence of the major draining fault of Bulz, along which the valley is incised. Except for this specific section, the hydrogeological role of the fault is not known; it can be only stated that gauging performed down to the site called "Între Ape" has indicated that the flow which sinks upstream is not recovered along this section.

GÂRDIŞOARA–TĂUZ KARST AREA

The geologic structure in Gârda Seaca upper reaches, that includes extensive carbonate terrains occurring as a monoclinal structure, subject to intense tectonic dislocation and covered by the detritic deposits of the Arieşeni nappe, favoured the occurrence of several large flow rate karst systems (Gura Apei, Apa din Piatră, Coliba Ghiobului, etc.). The discharge of those systems supplies Gârdişoara, the most upstream section of Gârda Seacă stream, that sinks in the cave Coiba Mică, to eventually emerge in Tăuz spring.

Downstream the cave Coiba Mică, starting from Casa de Piatră hamlet, Gârda Seacă valley carries water a new and additionally receives a strong left hand tributary, Vulturului valley, supplied by the spring with the same name, of 75 l/s average flow rate.

The complex Tăuz karst system has an annual average flow rate of 529 l/s and a 68.2 ratio between the extreme daily average flow rates recorded over the observation period (October 1984 –September 1985). When all described springs are considered, it can be observed that the fast flow of Tăuz has the highest weight (29%) with respect to the water volume discharged by the spring during the considered period of flow rates recession, which is normal if the prevalent supply of the aquifer via Gârdişoara stream is taken into account, and which is also corroborated by the large cut frequency (0.208), characteristic to systems that are highly inertial and that have undergone intense karst development. The relatively small value of the memory effect (18 days) indicates relatively small groundwater reserves, compared to the very large surface area of the system. The rain has a smaller influence period (26.4 days) than in the case of the other springs (Table 5).

OCOALE–SCĂRIŞOARA–COTEŢUL DOBREŞTILOR KARST AREA

The water divide between Gârda Seaca and Ordâncuşa valleys, dominated by the Ocoale–Scărişoara closed catchment basin, was the object of many speleological investigations, stimulated by the existence of the Scărişoara glacier, the largest cave glacier in Romania. Those investigations have been paralleled by observations concerning the groundwater flow directions, the hydrogeological connection between the pothole in Şesuri and Pojarul Poliţei spring, as well as that between the Ocoale valley stream losses and Coteţul Dobreştilor and Morii springs being outlined by means of fluorescein tracer tests.

Coteţul Dobreştilor spring is the main outlet of the Ocoale–Coteţul Dobreştilor karst aquifer. The average flow rate recorded over the previously indicated hydrologic year has been 280 l/s, while the maximum monthly flow rate has been 1.06 m^3/s. During draught periods the spring flow rate declines progressively to complete dry out, the outlet being actually an overflow of the system. The perennial outlet is Morii spring, located some 100 m downstream, and the springs that occur along the left side of Gârda Seaca valley, over the specified 100 m distance, at stream level or below. The cumulated flow rate of those springs and of Morii spring has been occasionally gauged during periods when Dobreştilor spring had dried out, resulting a value of 85 l/s.

The parameters provided by the correlative and spectral analysis indicate the karst system Coteţul Dobreştilor to have relatively important groundwater reserves. The variance density spectrum displays amplified cycles (due to the rain) for cut frequencies lower than 0.16, amplification that is due to the regulating capacity of the system. On the right side of Gârda valley, opposite the junction with Coteţul Dobreştilor spring, a sub-thermal spring (Feredeu), of 15.8–16.2 °C and with intense gas outflows emerges from the alluvia of the flood plain next to the stream channel. Its occurrence is related to the deep flow of the karst water along the nappe plane of the Arieşeni nappe.

The southern part of the Ocoale–Scărişoara closed catchment basin discharges via Poarta lui Ioanel spring. Over the previously mentioned hydrologic year, the average flow rate value has been 90 l/s, and that of the variability index has been 17.2.

PRELUCA KARST AREA

This name has been used to designate the limestone water divide between Ordâncuşa and Arieşul Mare valleys, the topography of which is marked by the sinkhole plain in the area of Preluca hamlet and by the gorge of Ordâncuşa. The dominating hydrogeological feature of this area is the massive diffuse, temporary complete sinking of Ordâncuşa stream along its last 2 km section before the junction with Gârda Seaca stream. The water is recovered in Izbucul Mic and Izbucul Mare springs, on the left side of Arieşul Mare.

Izbucul Mare emerges at the contact of the Wetterstein limestones with the Permian deposits of the Moma nappe, and discharges an average flow rate of 45 l/s, derived from seepage across Preluca sinkhole plateau and from diffuse sinking, that occurs along the median course of Preluca stream at crossing the above mentioned limestone area.

BELIŞ–APA CALDĂ KARST AREA

The easternmost occurrences of carbonate deposits in Bihor mountains are located in Beliş–Apa Caldă area. They consist of Triassic dolomites and limestones, that occupy a synclinal structure with quartzite sandstones at the bottom. The supply of the structure is derived from rainfall and its discharge is directed eastward, mainly toward Apa Caldă, a 50 l/s and 7°C spring. In the catchment basin of Beliş stream, the only significant karst spring is that in Hoanca Seacă. The latter discharges a 10 l/s average flow rate, derived from water accumulations in the northern part of Clujului peak.

The upper section of Beliş streamcourse displays a temporary flow regime, while its left side tributaries, running on non karstic terrains, are sinking in the streambed when penetrating in the karst domains.

SOMEŞUL CALD GRABEN KARST AREA

Runoff originating on terrains consisting of igneous rocks of Vlădeasa massif and of Werfenian and Senonian deposits existing in the northern part of Someşul Cald graben, supplies a widely developed karst aquifer that discharges through important flow rate springs. An outstanding position among them occupy, as a result of their significant flow rates, the springs Alunul Mic, Alunul Mare and the springs in the area Şurile din Firea.

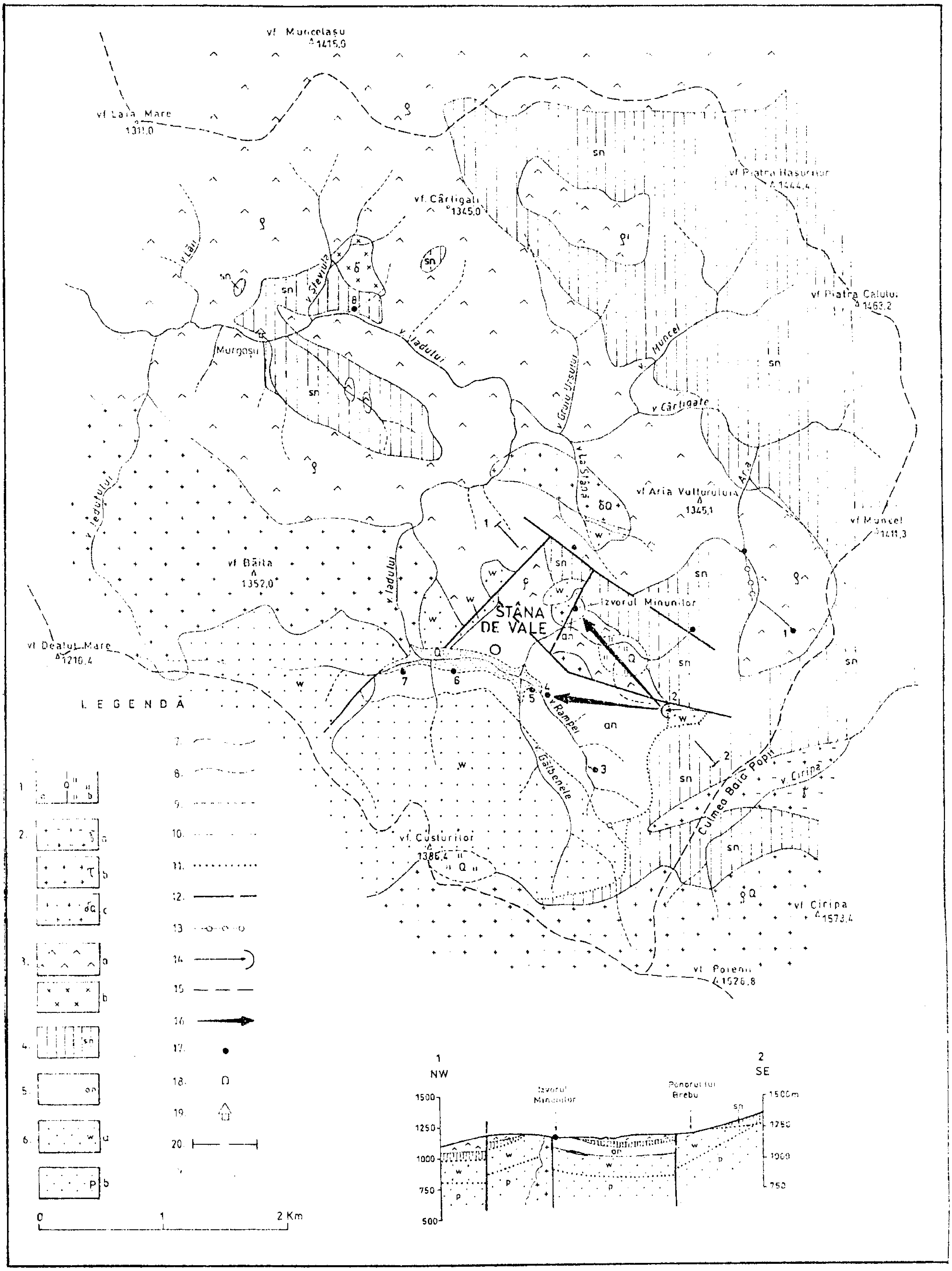
Alunul Mic spring has a karstic system that extends northward to the upper reaches of Ponorului valley, an area that for most of the time of the year supplies the system via the swallet of Ponorului valley. The tracer tests performed by injecting In-EDTA in the streamway of Diaclaza cave, fluorescein in that in Lucii pothole and rhodamine in the swallet of Ponorului valley have indicated an active karst flow. Alunul Mic spring has a flow rate that fluctuates over a very wide range (2-3160 l/s), with an average of 180 l/s. The base flow is prevalent (88%) in the water volume discharged by the spring during recession periods. The system has undergone intense karst development, it has a very poor inertia and small groundwater reserves.

Between Ponorului valley to the west and Firii valley to the east stretches Humpleu karst plateau. The plateau is built up in Barremian-Aptian limestones and has as an outstanding speleological mark the presence of the cave with the same name, one of the largest in Romania (ONAC, 1995). The cave extends from Firii valley up to the environs of the swallet in Ponorului valley, and provides a major drainage path for the water accumulations in the plateau. The tracer experiments we performed have indicated that the surface streams running down the southern slopes of Miclău peak, which sink through the swallets in the area Vârtoapele–Ponorul cu Pod, also belong to this system. The system discharges through the springs and the cave at Şurile lui Firea, of about 80 l/s average flow rate.

Fig. 10. Hydrogeological map of Stâna de Vale area (geological data after BORDEA *et al.*, 1984, and ISTRATE, 1978): 1. Quaternary: a-alluvium; b-diluvium; 2. Laramian intrusives: a–microgranite rhyolite; b–tonalite; c–quartz-diorite; 3. Early laramian volcanics: a–ignimbrite rhyolite formation; b–biotite-hornblende dacite; 4. Senonian (Gosau facies: conglomerates, siltstones, marls, limestones); 5. Anisian (dolomites); 6. Werfenian (quartzitic sandstones, argilites); 7. Perennial stream; 8. Temporary stream; 9. Geological limit between sedimentary deposits; 10. Magmatites limit; 11. Transgression limit; 12. Faults; 13. Diffuse losses in stream bed; 14. Ponor; 15. Watershed; 16. Direction of groundwater flow; 17. Spring; 18. Outflow cave; 19. Chalet; 20. Direction of cross-section.

Carte hydrogéologique de la zone karstique Stâna de Vale (les données géologiques d'après BORDEA et al., 1984, et ISTRATE, 1978): 1. Quaternaire: a–alluvions; b–diluvium; 2. Roches intrusives laramiques: a–rhyolite microgranitique; b–tonalite; c–diorite quartzifère; 3. Roches volcaniques (début du cycle laramique): a–formation de rhyolite ignimbritique; b–dacite avec biotite et hornblende; 4. Senonnien (faciès de Gosau: conglomérats, siltites, marnes, calcaires); 5. Anisien (dolomies); 6. Werfenien (grès quartzitiques, argilites); 7. Ruisseau permanent; 8. Ruisseau temporaire; 9. limite géologique entre les depôts sédimentaires; 10. limite de magmatites; 11. limite de transgression; 12. failles; 13. pertes diffuses dans le thalweg de ruisseau; 14. ponor; 15. ligne de partage des eaux; 16. direction d'écoulement souterrain; 17. source karstique; 18. grotte émergente; 19. hutte; 20. direction de section transversale.

Numbers key: 1. Ariei spring; 2. Brebu ponor; 3. Rampei spring; 4. Păstrăvăriei spring; 5. Meteorologist's spring; 6. Pavel spring; 7. Radu spring; 8. Murgaşu spring.


vf. Muncelașu 1415,0
vf. Laia Mare 1311,0
vf. Cârligați 1345,0
vf. Piatra Hasurilor 1444,4
vf. Piatra Calului 1463,2
vf. Aria Vulturului 1345,1
vf. Muncel 1411,3
vf. Băița 1352,0
vf. Dealul Mare 1210,4
vf. Custurilor 1386,4
vf. Ciripa 1573,4
vf. Poienii 1526,8
Murgașu
v. Lăii
v. Sleviuța
v. Vadului
v. Gruiu Ursului
v. Muncel
v. Cârligate
v. La Stână
v. Aria
v. Iedului
v. Iadului
v. Rampei
Gălbenele
Culmea Băii Popii
v. Ciripa
ȘTÂNA DE VALE
Izvorul Minunilor
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LEGENDĂ
1. Q a, b
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1 NW
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Izvorul Minunilor
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Two springs displaying gas outflows occur in Someşul Cald graben:

- in the catchment basin of Alunul Mic stream, next to the major fracture that delimits the graben deposits with respect to the crystalline schists, emerges a 14.5 °C sub-thermal spring, that has a flow rate of about 5 l/s and gas outflows;
- on the left bank of Someşul Cald stream, opposite to the junction with Pârâul Sec, from the alluvia of the flood plain next to the stream channel emerges a spring of about 50 l/s flow rate and 9.8 °C temperature, that displays violent gas outflows.

IZVORUL CRIŞULUI KARST SYSTEM

Izvorul Crişului karst system is located in the upper reaches of Crişul Băiţa stream, in an extremely rough topography area, that had been also subject to intense tectonic dislocation and where carbonate deposits outcrop in the streambed and on the right side of the previously mentioned streamcourse, being nappeed in their northern, southern and eastern parts by the Permian deposits of the Arieşeni nappe.

The outcrop area of the carbonate deposits does not have a permanent surface runoff: the multitude of streams running down the adjoining non karstic mountain slopes (Corlatul, Corlăţelul, Fleşcuţa, etc) sink diffusely, at their entrance on carbonate terrains. Before the excavation of the underground mining works, those groundwater flows ran to Izvorul Crişului spring, but currently a significant part of the flow is drained by the galleries of Băiţa Molibden mine. The tracer tests have indicated that the radius of influence of those mining works has extended over the entire Crişul Băiţa upper catchment basin, as well as in the upper reaches of Valea Seacă, a tributary of Galbena stream. The spring ensuingly underwent a drastic decline of its discharge, to such an extent that during draught periods it is not able to meet the drinking water supply demand of Nucet town, located downstream.

Izvorul Crişului karst system has a strong inertia, a significant regulating capacity and important water reserves, 95% of the goundwater flow during recession periods being provided by the base flow.

STÂNA DE VALE KARST AREA

In the area of Stâna de Vale climateric resort, carbonate terrains outcrop over a small area (about 2.5 km^2). The area (Fig. 10) includes several karst springs, supplied mainly by diffuse seepage of runoff originating in surrounding non karstic terrains. Springs have relatively large flow rates, supported by the abundant rainfall, the most important in such terms being Păstrăvăriei spring, followed by Minunilor spring.

Minunilor spring emerges from a small cave, excavated in a little outcrop of Anisian dolomites that protrude from beneath Senonian deposits and ignimbritic rhyolites, at the contact with a quartz rhyolites body penetrated along a fracture.

Minunilor spring has a 15.6 l/s average flow rate and very small annual fluctuations of the daily average flow rate (n_v = 1.9), due to the almost exclusive contribution of the base flow component (99%) to the discharge recorded during recession periods. The strong memory effect (44 days, Fig. 7) suggests relatively important reserves.

Minunilor spring karst system displays a typical "pass below filter" behaviour (MANGIN, 1982), completely suppressing the high frequency fluctuations (Fig. 8). The long period of influence of the rainfall phenomenon (46.4 days) accounts for the very small flow rate fluctuations. Strong rainfall does not result in a major increase of the spring discharge, increasing in turn the stored reserves. The system is inertial, i.e. very capacitive and only slightly transmissive.

Leakage from water accumulations existing in the Senonian deposits that transgressively cover the dolomites, and from ignimbritic rhyolites that cover part of the Senonian deposits (Fig. 10) provides the main supply to the karst aquifer. Subordinately, the karst aquifer is also supplied by the surface stream course that sinks into the dolomite substratum through Brebu swallet and by the seepage that occcurs across the dolomites outcrop area.

The Brebu's ponor was labelled with fluoresceine at 17.10 1995. The tracer was detected in large amount in Păstrăvăriei spring with the maximum intensity after 90 hours. In the same labelling test, in Izvorul Minunilor Spring, the level of fluorescence was situated near that of the blank (0.2 ppb) which do not prove the arrival of the tracer at the source (observation time: 5 days).

The outstanding constancy of the physicochemical parameters of the water of the spring and the continuous lack of any bacteriologic content, qualities that rank Minunilor spring among Romania's best still water sources, are the result of outstandingly favourable hydrogeological circumstances in terms of supply, flow and discharge of the karst system.

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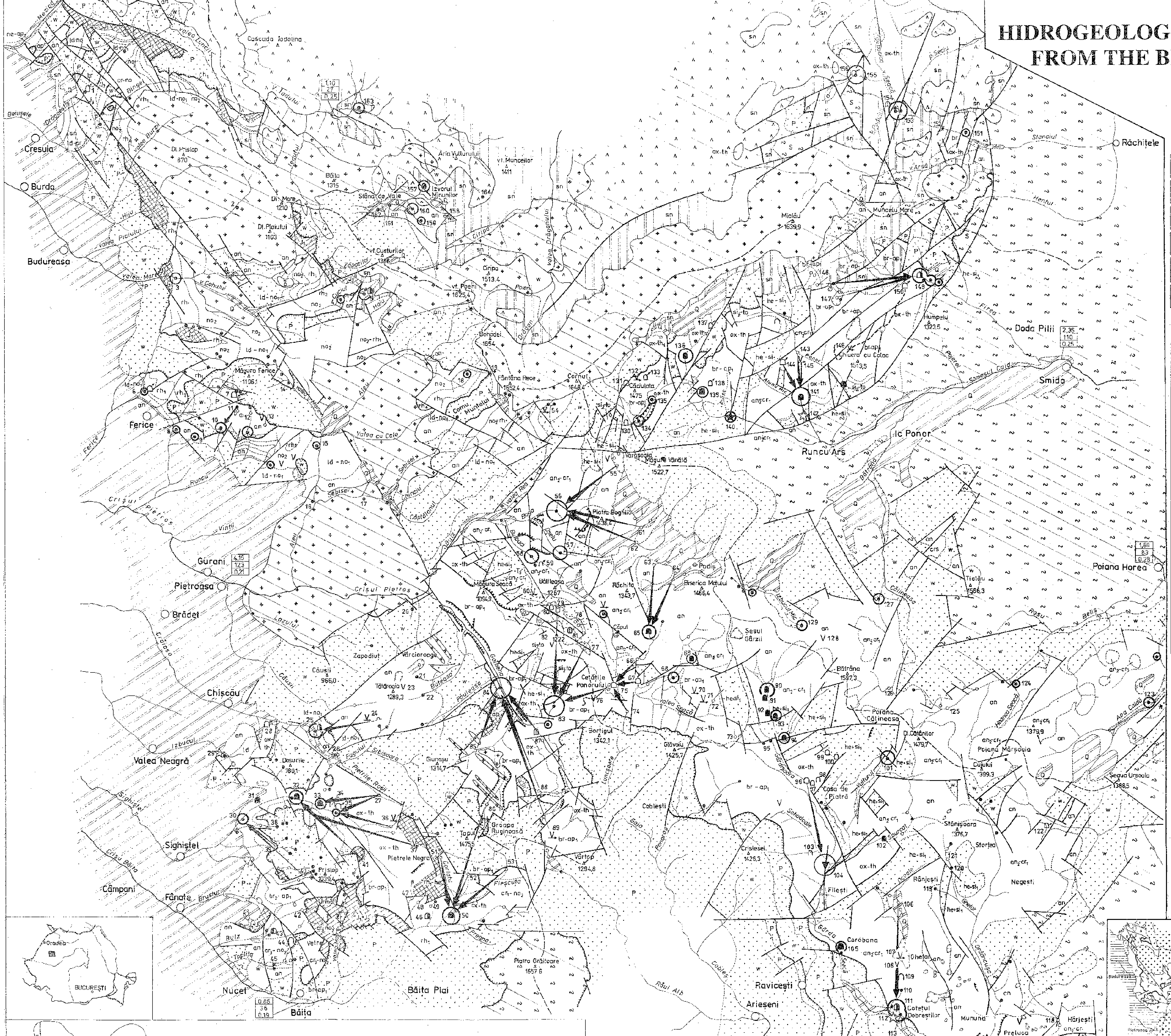
◆

IANCU ORĂŞEANU

HIDROGEOLOGICAL MAP OF THE KARST AREAS FROM THE BIHOR VLĂDEASA MOUNTAINS



Legend of the numbers on the map

In brackets, altitude of the points in metres a.s.l.

Hydrographic basin of Crişul Negru river

1. [illegible] Cave (375 m) and spring (370 m)
2. Groşi spring ([illegible] m)
3. Spring of [illegible] (475 m)
4. Spring of [illegible] bridge (710 m)
5. "[illegible]" cave and spring (870 m)
6. Ferice spring ([illegible] m) and cave (370 m)
7. Peştera [illegible] cave (892 m)
8. [illegible] spring (425 m)
9. Topliţa spring (475 m)
10. [illegible] spring (570 m)
11. Ponor of [illegible] (675 m)
12. Ponor (820 m) and spring (600 m) of [illegible] stream
13. Pothole (860 m) and ponor (800 m) of [illegible]
14. [illegible] spring (675 m)
15. [illegible] spring (455 m)
16. Spring of Aleu-Sebişel confluence (435 m)
17. [illegible] spring (545 m)
18. Aleu spring (under Cornu Muntelui, 1225 m)
19. Spring of Valea Rogii stream (1300 m)
20. [illegible] spring (575 m)
21. [illegible] spring (1540 m)
22. "[illegible]" spring (1600 m)
23. Pothole of [illegible] (1250 m)
24. "[illegible]" (Petit 1981) pothole (900 m) and IPEG entrance mining gallery
25. Spring of [illegible] (505 m) and [illegible] cave (510 m)
26. Valea [illegible] IPEG mining gallery (620 m)
27. Losses of Pietrele Rogii stream (800 m)
28. Peştera Urşilor cave of Chişcău (440 m)
29. Warm spring and Cold spring of Valea Neagră ("Şapte Izvoare", 375 m)
30. [illegible] spring (390 m)
31. Cămăruţa cave (420 m)
32. Blidaru spring (Răsuflătoarea Blidarului cave, 435 m)
33. [illegible] cave (500 m)
34. Măgura cave (565 m)
35. Coliboaia cave (530 m) and spring (515 m)
36. Secătura pothole (930 m) and losses of Secătura stream (925 m)
37. Pothole of Dosul Muncelului (1100 m)
38. Losses of Sohodol Pietrei stream (550 m)
39. Losses of Sohodol Tomeştilor stream (550 m)
40. Losses of Crăciune stream (880 m)
41. Losses of Preluca Neguţului stream (815 m)
42. Losses of Sohodol Gheţarului stream (740 m)
43. Cave (500 m) and spring of [illegible] (450 m)
44. Secătura cave (610 m)
45. Springs of Topliţa stream (525 m)
46. Poarta Bihorului cave (640 m)
47. Losses of Hoanca Ocheanului stream (850 m)
48. Losses of Coşuri stream (750 m)
49. Elena pothole (845 m)
50. Criţului spring (700 m)
51. Losses of Corlatul stream (1040 m)
52. Losses of Corlăţelel stream (1150 m)
53. Losses of Fleşcuţa stream (1150 m)
54. Adrian pothole (Valea Rea, 1275 m)
55. Ponor of Vărăşoaia (1290 m) and V5 (Piţa Muncelului) pothole (1400 m)
56. Boga springs (675 m)
57. Oşelu spring (950 m)
58. [illegible] spring (900 m)
59. Fîntîna Roşie spring (975 m) and cave (980 m)
60. [illegible] stream springs (1060 m)
61. Ponor of [illegible] stream (1260 m)
62. Ponor of Neagra stream (1235 m)
63. Ponor of [illegible] stream (1245 m)
64. Ponor of [illegible] stream (1270 m)
65. Spring of Poiana Ponor (1100 m)
66. Ponor of Poiana Ponor ([illegible] m)
67. Peştera de la Căput cave (1051 m)
68. Izvorul Rece spring (1075 m)
69. Izbucul Ursului spring (1095 m)
70. Gemănata pothole (1205 m)
71. Avenul Negru pothole (1220 m)
72. Losses of Pîrîul Sec stream (1205 m)
73. Ponors of Iezere (1250 m)
74. Losses of Barsa Cohanului stream (1090 m)
75. Cetăţile Ponorului (950 m)
76. Gheţarul Borţigul pothole (1300 m)
77. Ştevia Lupei ponor (1125 m)
78. Groapa de la Barsa (1100–1150 m)
79. Gheţarul de la Barsa cave (1125 m)
80. Cave of Zăpodie (1100 m)
81. Peştera Neagră cave (1100 m)
82. Gheţarul Focul Viu (1170 m)
83. Galbenei spring (815 m)
84. Păuleasa spring (570 m)
85. Losses of Ţiganului stream (820 m)
86. Losses of Valea Seacă stream (1100 m)
87. Losses of Lumpăoara stream ([illegible] m)
88. Losses of [illegible] stream (975 m)
89. Pothole of Hoanca Urzicarului (1165 m)

Hydrographic basin of Arieş river

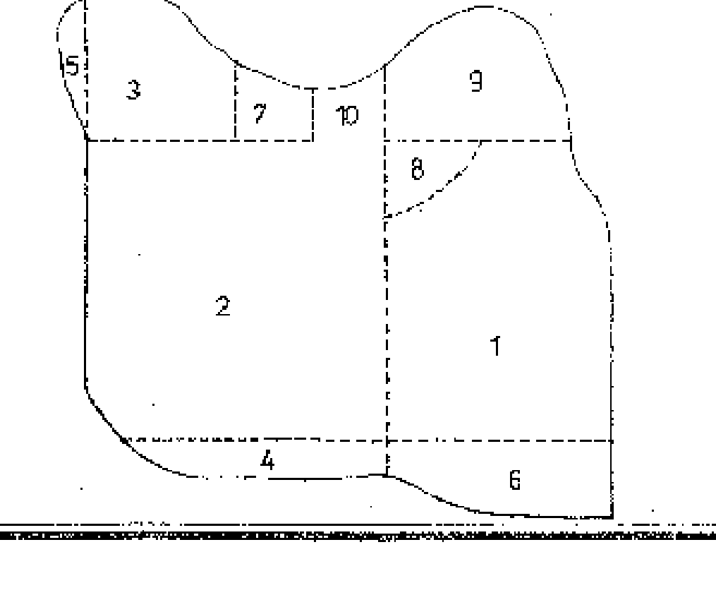
90. Gura Apei spring (1125 m)
91. Peştera cu Apă din Faţa [illegible] cave (1115 m)
92. Şura Boghii cave (1105 m)
93. Cave of Apa din [illegible] (1100 m)
94. Spring of Coteţul Chiobului (1100 m)
95. Fîntîna Tălharilor spring (1210 m) and spring of Poiana Gîrdişoara (1145 m)
96. Coiba Mică cave (1015 m)
97. Coiba Mare cave (1030 m)
98. Gheţarul de la Vîrtop (1130 m)
99. Peştera de [illegible] cave (1270 m)
100. [illegible] cave (1260 m)
101. [illegible] spring (1040 m)
102. Peştera cu Apă cave of [illegible] stream (1095 m)
103. Hodobana cave ([illegible] m)
104. [illegible] spring ([illegible] m)
105. Corobana cave ([illegible] m)
106. Losses of [illegible] stream ([illegible] m)
107. Pothole of Şesuri ([illegible] m)
108. Gheţarul de la Scărişoara (1175 m)
109. Pojarul Poliţei cave (975 m)
110. Poliţei spring (920 m)
111. Spring of Coteţul Dobreştilor (770 m)
112. Warm spring in Coteţul Dobreştilor (Feredeu, [illegible] m)
113. Morii spring ([illegible] m)
114. Zgurăşti pothole (880 m) and Poarta lui Ionele spring (810 m)
115. Losses of Ordîncuşa stream (745 m)
116. Izbucul Mic spring (750 m)
117. Izbucul Mare spring (725 m)
118. Ponor of Pleşa stream ([illegible] m)
119. [illegible] spring (1205 m)
120. [illegible] spring (1195 m)
121. Ponors of [illegible] ([illegible] – 1250 m)
122. [illegible] cave (1260 m)

Hydrographic basin of Someşul Cald river

123. Apa Caldă spring (1120 m)
124. Spring of Hoanca Seacă (1150 m)
125. Losses of Beliş stream (1220–1160 m)
126. Ponor of Călineasa (1305 m)
127. Călineasa spring (1170 m)
128. Pothole of Bătrîna Mountain (1485 m)
129. Izbucul Mic spring (1255 m)
130. Cetăţile Rădesei (1280 m)
131. Ponorul din Cuciulata cave (1480 m)
132. Pothole of Cuciulata (1400 m)
133. Peştera Neagră cave (1327 m)
134. Moloh spring (1210 m)
135. Izbucul cu Cascadă spring (1200 m)
136. Aiurul Mare spring (1180 m)
137. Cerbului cave (1300 m)
138. Coteţului cave (1260 m)
139. Peştera Pepii cave (1125 m)
140. Spring of Someşul Cald–Pârâul Sec confluence (1095 m)
141. Aiurul Mic spring (1100 m)
142. Warm spring of Aiurul Mic stream (1065 m)
143. Ponor of [illegible] stream (1130 m)
144. [illegible] cave (1235 m)
145. [illegible] pothole (1340 m)
146. Poienita pothole (1395 m)
147. Ponor of Poiana Vîrtopului (1322 m)
148. [illegible] cu pod ponor (1315 m)
149. [illegible] din Perete (1070 m)
150. Humpleu cave (1175 m)

Hydrographic basin of Crişul Repede river

151. Lespezi spring (950 m)
152. Răchiţele waterfall (1000 m)
153. Nimăiasa springs (1100 m)
154. Peştera cu Şase Intrări cave (1140 m)
155. Ponor and cave of Tău (1150 m)
156. Vîrfuraşul spring and cave (1175 m)
157. Izvorul Minunilor spring (1130 m)
158. Brebu ponor (1200 m)
159. [illegible] spring (1145 m)
160. Piştrăvăriei spring (1100 m)
161. Pavel spring (1185 m)
162. Radu spring (1085 m)
163. [illegible] spring (930 m)
164. [illegible] spring (1325 m)



Geological data :

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L E G E N D

HYDROGEOLOGICAL CHARACTERISTICS OF THE MAIN FORMATIONS

☐	Carbonate Mesozoic series (limestones, dolomites), highly fractured and karstified, characterised by very high effective infiltration and intensive groundwater flow. Numerous karst systems with various size and prevelant binary type. Spring flow rate up to 550 l/s. Important water resources in large karst systems.
a + / b ∧ / c S	Laramian magmatites (banatites: a-intrusives; b-volcanics) and metamorphites (c) with permeability of fissures with discontinuous distribution and intensity. The weathering zone is well developed and provide a continuous and important supply of rivers (memory effect is 55–120 days for 0.2) and of binary karst systems.
⁘	Prevalent detritic Permo-Mesozoic deposits (sandstones and conglomerates with argillaceous shales and rhyolites) with different permeability. The groundwater flow is mostly confined to the fissured areas. They act as an impervious barrier for karst water reservoirs and frequently form bedrock and/or the caprock for these.
▥	Senonian post-tectonic deposits (sandstones, conglomerates and less frequently argillaceous shales) with local extension in northern part of map area. Senonian reservoirs supply springs with discharge up to 3 l/s, and also, in north-east, subjacent karst reservoirs.
▩	Marly and argillaceous deposits, devoid of groundwater flow, and flysch-like series, including rock-complexes of variable permeability (marls, argillaceous shales, sandstones, limestones), hosting occasionally discontinuous aquifer accumulation occurring, in the more permeable terms.
▨	Pannonian Quaternary deposits (marls, argillaceous shales, sands, gravels) hosting discontinuous water accumulations in the more permeable terms.

CORRELATION OF THE BIHOR UNIT AND THE UNITS OF THE CODRU NAPPES SYSTEM OF THE BIHOR VLĂDEASA MOUNTAINS

(compiled after BLEAHU *et al.*, 1981; BLEAHU *et al.*, 1985; BORDEA *et al.*,1988 and MANTEA *et al.*, 1987)

		BIHOR UNIT	CODRU NAPPES SYSTEM						
			Vălani Nappe	Gîrda Nappe	Ferice Nappe	Bătrînescu Nappe	Următ Nappe	Vetre Nappe	Arieşeni Nappe
CRETAC	Aptian	Ecleja Form. Urgonian limestones	Urgonian limestones						
	Barremian								
	Hauterivian								
	Valanginian		limestones						
	Berriasian								
JURASSIC	Tithonic	darkish lms.	white & grey reef limestones				black & gray limestones (J3)		
	Kimmerid.	light-coloured reef massive lms.							
	Oxfordian								
	Callovian	limestones, marls, sandstones					black argillaceous shales & sandstones (Următ Form) (J1+J2)		
	Aalenian								
	Toarcian								
	Domerian								
	Carixian								
	Sinemurian								
	Hettangian	Gresten Form.			ma-s.ss.lms (J1)				
TRIASSIC	Rhaetian		Coşuri Beds Carpth.K		Kössen Form. V.F. Form.		Kössen Form. Carpath.Keuper	Băiţa marble	
	Norian				V.F&C.Form. Codru Form.	white limestones		Frăsinel dolomites	
	Carnian	Scăriţa Form.	white dolom. limestones		black lms. with cherts (R.F.)				gray lms. & dolomitic limestones
	Ladinian	black limestones with cherts (R.F.)	black limestones with cherts(R.F.)			gray bedded limestones & lms.with cherts			
	Anisian	Zugăi Form. white dolomites black lms.	gray dolomites ss. & shales		gray dolomit. gray lms. ss.&dol.shales	black dolomites ss.&dol.shales			black dolomites
	Werfenian	Werfen Form.	WerfenForm	Werfen Form	Werfen Form.	Werfen Form.			Werfen Form.
PERMIAN		breccia, rhyolites	breccia rhyolites	breccia, argill. shales, rhyolite	sandstones argill. shales	argill. shales rhyolites			ss,argil.shales rhyolites
CARBONIFER									
DEVONIAN									
SILURIAN									chloritic shale
ORDOVICIAN									
CAMBRIAN		Arada Series							
VENDIAN		Someş Series							

Carpathian Keuper - argillaceous shales and marls with gray dolomites; **Codru Formation** - argillaceous shales, breccias, limestones; **Coşuri Beds** - ortoquartzites, sandstones and argillaceous shales in pyrometamorphic facies; **Ecleja Formation** - marls, sandstones, limestones; **Gresten Formation** - quartzitic sandstones and conglomerates, argillaceous shales, limestones; **Kössen Formation** - limestones, black marly shales; **R.F.** - Roşia Formation; **Scăriţa Formation** - limestones, argillaceous shales, breccias; **Valea Fruntii Formation** - magnesian limestones, sandstones, conglomerates, black marly shales; **Zugăi Formation** - breccias, argillaceous shales, limestones, quartzitic sandstones; **Werfen Formation** - ortoquartzites, quartzitic conglomerates, argillaceous shales; **lms** limestones; **dol** dolomites; **ss** - sandstones; **ma-s** - marly argillaceous shales.

- - - - - - bauxites.

EXPLANATION OF LINES AND SYMBOLS USED IN THE CENTRAL MAP

Geological boundary

Geological boundary of magmatites

Fault

Overthrust front

Course of perennial stream

Course of temporary stream

Watershed

5,45
200
0,27

River gauging station with mean discharge in m³/s (top), surface water catchment area in square kilometres (middle) and base flow index (bottom)

Cave passage

Karst depression

Abrupt

Selected gas leaks associated with:

★ - cold springs;

☆ - subthermal springs

➡ Proved groundwater flow direction

Mine gallery

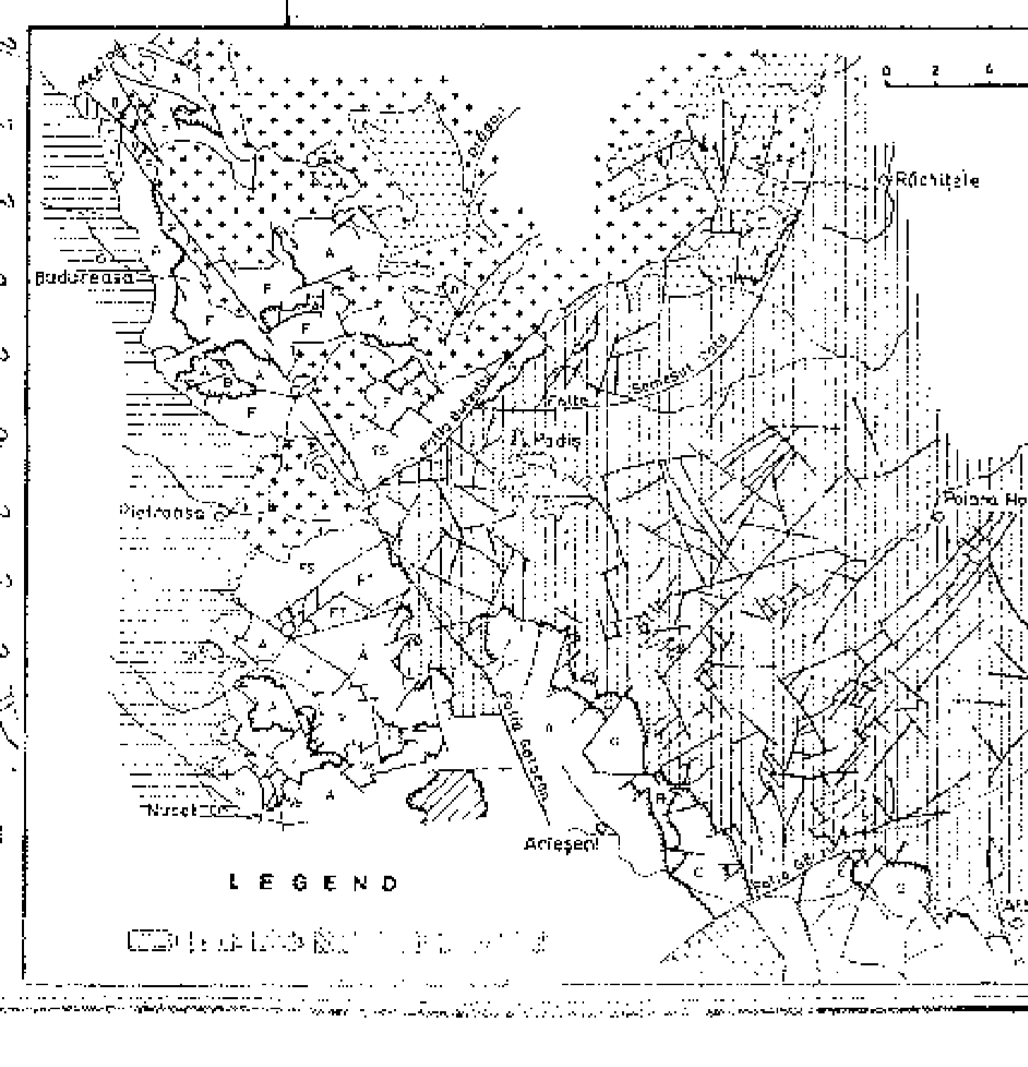
HYDROLOGIC FEATURES OF KARST CAVITIES

Hydrologic regime of cavity entrance / Cavity	Perennial		Temporary		Absent	
	Source	Ponor	Source	Ponor	Tapping an underground stream	Fossil cavity
Cave	■	∩	◧	◫	⊓	∩
Pothole	▽	▽	▽	▽	V	V
Impenetrable	●	○				

MEAN ANNUAL DISCHARGE OF THE SPRINGS (l/s)

(Hydrologic year X.1984–IX.1985)

under 1	1–10	10–50	50–100	100–300	300–600
•	⊙	⊙	⊙	⊙	⊙



Structural map of the Bihor Vlădeasa Mountains
after geological maps of Romania, scale 1:50.000, edited by the Geological Institute of Romania

Legend: 1-Neogene sedimentary cover; 2-Banatitic magmatites; 3- Senonian; 4-Muncel–Lupşa Nappe; 5-Biharia Nappe; 6-Codru Nappe system; 7-Bihor Unit