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Karst terrains and major karst systems in Romania

Adrian Iurkiewicz & Iancu Orăşeanu
Prospecţiuni S.A., Bucureşti, Romania

ABSTRACT: Hydrogeological features of the Romanian karst are specific for each of the main geostructural units of country. Such differences supported by field data resulted in identifying four hydrogeologic types of karst, the *Carpathian Orogen karst type, the North Dobrogea karst type, the platforme karst type* and *the Carpathians post-tectonic cover karst type*. Various investigation methods (tracing tests—more then 150, water budget analysis, etc.) have been used for the delineation of 17 major karst systems. The hydrodynamic and hydrochemical features of these systems are synthetically outlined. The average discharge of these systems ranges from 500 to 1200 l/s, many of them being tapped for water supply of some major Romanian cities.

1. HYDROGEOLOGICAL TYPES IN ROMANIAN KARST

The carbonate rocks in Romania outcrop on a surface of 5900 km^2 and consist of sedimentary and metamorphosed limestones and dolomites, carbonate sandstones and conglomerates with limestones fragments. To this area a surface of 4600 km^2 with limestones covered by loess deposits in Southern Dobrogea (4200 km^2) and in Babadag Basin (400 km^2) can be added.

The carbonate deposits are included in a geologic structure which belong to the Alpine Orogene (the Carpathian Orogene and the Northern Dobrogea Orogen) and to the Moesian Platform. The Carpathian Orogene consists in deformed units which outcrop in the Carpathians Mountains and in Apuseni Mountains and in post-tectonic units (foredeep, molassic depressions, post-tectonic covers and alpine subsequent magmatites), which bound the folded units (Sandulescu, 1984).

The various tectonic, structural and morphologic conditions in which the carbonate rocks occur are directly reflected in the recharge, circulation and discharge of the groundwater, which lead to distinguishing four types of karst in hydrogeological terms: Carpathian Orogene karst (folded units karst), Northern Dobrogea Orogene karst, platform karst and Carpathian post-tectonic cover karst (Orăşeanu, 1993, Fig. 1).

The Carpathians Orogene karst. Within the folded units of the Carpathians, the carbonate deposits are included in intricate geological structures, intensely fractured and often drawn into large systems of overthrusts. These features associated with a high value of the hydraulic gradient imposed by topography, favoured an intense karstification of rocks. The carbonate rocks from the Carpathians Orogene are represented by sedimentary and metamorphosed limestones and dolomites (2625 and 835 km^2, respectively) and by carbonate sandstones and conglomerates with limestone fragments (975 km^2), (Sencu, 1968). These rocks outcrop over the whole area of the Carpathians Orogene, generally as a dispersed small surfaces. Large areas are developed only in the Western half of the Southern Carpathians and in the Apuseni Mountains.

The mean annual value of rainfall in Carpathians Mountains varied from 500 mm in low (300 m) altitude areas, to 1500 mm in high mountains at 2000 m altitude. In the same interval of altitude, evapotranspiration value varies between 600 mm and 300 mm.

Surface water courses in karst areas of the Carpathians Mountains often have a temporary character, but sinking in riverbed and simultaneous downstream flow are frequent suggesting the complexity of the relations ships between the surficial and the underground waters as well as the difficulty in performing a water budget. For a pertinent hydrogeological particularization, the catchment area

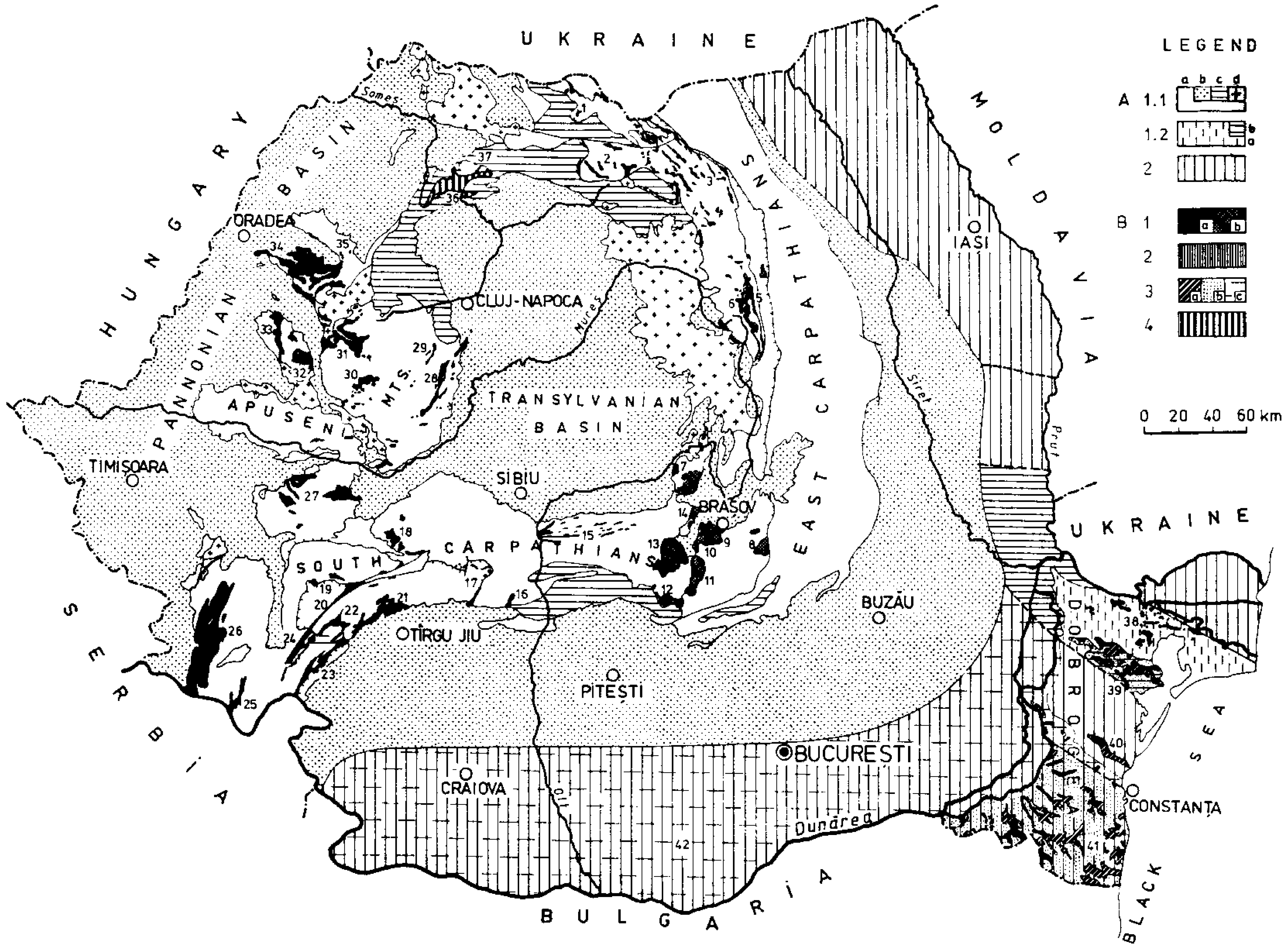

Figure 1. Distribution of the hydrogeological karst types in Romania (after Orăşeanu, 1993).
A. Geotectonic major units: 1.1. Carpathians Orogene: a) Orogenic formations; b) Foredeep and molassic depressions; c) Post-tectonic covers; d) Subsequent alpine magmatites; 1.2. North-Dobrogea Orogene: a) Orogenic formations; b) Post-tectonic covers; 2) Platforms. B. Hydrogeological karst types: 1) Carpathians Orogene types: a) Limestones and dolomites; b) Calcareous sandstones and conglomerates; 2) North-Dobrogea Orogene type; 3) Platforme type: a) Limestones in outcrops; b) Limestones covered by loess; c) Limestones covered by Pre-Quaternary deposits; 4) Carpathians post-tectonic covers type.
Morphologic units numbered on the map: 1: Maramureş Mts., 2: Rodna Mts., 3: Rarău Mts., 4: Giurgeu Mts., 5: Ceahlău Mts., 6: Hăghimaş Mts., 7: Perşani Mts., 8: Ciucaş Mts., 9: Piatra Mare Mts., 10: Postăvaru Mts., 11: Bucegi Mts., 12: Leaota Mts., 13: Piatra Craiului Mts., 14: Codlea area., 15: Făgăraş Mts., 16: Buila-Vânturariţa Mts., 17: Lotru and Căpăţânii Mts., 18: Sebeş Mts., 19: Retezat Mts., 20: Cerna-Jiu passage, 21: Vâlcan Mts., 22: Mehedinţi Mts., 23: Mehedinţi Plateau, 24: Cernei Mts., 25: Almăj Mts., 26: Banat Mts., 27: Poiana Ruscă Mts., 28: Trascău Mts., 29: Gilău Mts., 30: Poeni Plateau (Metaliferi Mts.), 31: Bihor Mts., 32: Vascău Plateau (Moma Mts.), 33: Codru Mts., 34: Pădurea Craiului Mts., 35: Rez Mts., 36: Someşan Plateau, 37: Preluca Mts., 38: Tulcei Mts., 39: Babadag basin, 40: Casimcea area, 41: South-Dobrogea, 42: Moesian Platform.

developed upstream of a point of partial stream sinking was designated as *diffluence surface*, while the concept of karst basin diffluence was suggested for the phenomenon itself (Orăşeanu & Iurkiewicz, 1982). The karst basin diffluence is a process by which the effective rainfall associated to a hydrographic basin is separated as a consequence of the partial capture, into an infiltrated fraction supplying an underground flow directed outside the hydrographic basin and a fraction that continuously or temporarily flows along the river channel downstream of the partial capture point (Orăşeanu, 1985).

The karst hydrogeological systems display various stages of development, beginning with an incipient one that of the underground flow organization, up to a single drain of the system. Mean of groundwater flow velocity is relatively high, tracing operations performed in different seasons and places indicating average values of 45 m/h in Bihor Mountains (42 experiments), 46 m/h in Pădurea Craiului Mountains (78 experiments) and 53 m/hour in Vaşcău Plateau (8 experiments).

The largest karst springs in Carpathians Mountains have a mean annual discharge of 1 to 2 m^3/sec, and their occurrence is related to the presence of a large limestone area as well as of a binary hydrogeological karst system with a great extension of non-karst terrain. The first case includes Barza spring from Mehedinţi Mountains (Fig. 1, no. 22) and the sources from Cheile de Jos ale Dâmboviţei in Piatra Craiului Mountains (Fig. 1, no. 13). The second case includes Izvarna spring from Vâlcan Mountains (Fig. 1, no. 21) and Cerna spring from Cerna-Jiu trench (Fig.1, no. 20), the largest karst source from Romania, with a mean annual discharge of 2 m^3/sec., variations flow from 0,5 to 10m^3/sec.

Limestones and dolomites are also developed over large areas in Apuseni Mountains, but an intense fracturation has led a mosaic type structure, with outcrops of carbonate and non-carbonate rocks. This structural framework did not favour the organization of extensive karst aquifers with high flow rate springs. In exchange there are numerous sources with discharges ranging between 300 and 600 l/sec.

The Northern Dobrogea Orogene karst. This type of karst is characterized by the same fractured and folded geological structure as the previous type, but here it is cut off by a flat relief, with a low table land aspect. The carbonate rocks are represented by Triassic dolomitic limestones and they outcrop in the northeastern part of Northern Dobrogea (Tulcea zone), looking as isolated small size massifs with a quite important development in depth. The small hydraulic gradient of the groundwater, as well as the dry pluviometric regime of the area (400–500 mm/year), result in reduced spring discharge, under 10 l/sec.

The main direction of the groundwater flow is toward Razelm Lake (East-South-East), a zone where the hydrokarst structure lapse in an axial way.

The platform karst. The Northern part of the Moesian Platform is developed on the territory of Romania, in the Romanian Plain (30800 km^2) and in Southern Dobrogea (4500 km^2). In its geological constitution it has a thick, up to 1500 m succession of Malm-Barremian limestones.

In the Romanian Plain these rocks outcrop within limited areas along the Danube bank, at Giurgiu, and dip Northward, exceeding 2000 m in depth North of Bucharest, where the karst reservoir is occupied by thermal water. The carbonate deposits in Southern Dobrogea outcrop only along the main valleys and at the Black Sea shore, being covered almost everywhere (4200 km^2) by a thick layer of loess.

In Southern Dobrogea, the geological, structural and morphological conditions have favoured the development of a karst aquifer of platform type, characterized by the large thickness of the carbonate stack with a quasi-horizontal position, by the lack of folded tectonic style and by the presence of vertical faults affecting the whole mass of the limestones.

The flat topography of the region has imposed a small hydraulic gradient to the Malm-Berriassian and Sarmatian aquifers, which resulted in a slow groundwater flow, with a mean velocity value of 2.6–5.4 m/year for the deep aquifer and of 0.8 m/year for the shallow one (Davidescu et al., 1991). This aquifer system is the most important in Romania, because its water resources as a whole are 12–14 m^3/sec. There are some hydrodynamic interferences and interactions not only between the two aquifers, but also between them and the water of the Danube, of the lakes, of the Danube-Black Sea Channel and the irrigation network (Zamfirescu et al., 1994).

The Babadag Basin includes the post-tectonic cover of the Northern Dobrogea Orogene. According to its evolution and geological constitution (installed upon a consolidated basement, large thickness, tabular structure) it forms a platform type cover, with the same type of karst. The basin consists a NNW–SSE striking synclinorium with an area of 732 km^2, and an east axial dip below the bottom of the Razelm Lake and the Black Sea. The filling of basin is made up mainly of upper Cretaceous limestones and sandy limestones, reaching 1000 m in thickness. A large area of 400 km^2 is covered by loess deposits. The karst reservoir has a low hydraulic gradient which induces a slow movement of the water to the East, through underwater sources into Razelm Lake.

The Carpathians post-tectonic cover karst. The post-tectonic covers throughout the Carpathians Orogene have been deposited in sedimentary basins with unconsolidated labile basement (submitted intermittent subsidence) and have been formed by the alternation of deposits with various lithological constitutions, where extent carbonate rocks are frequent. The structure is slightly inclined and the tectonic displacements are of limited amplitude. The carbonate series often reach tens of meters in thickness and contain aquifer accumulations with local importance.

2. GENERAL FRAMEWORK OF KARST SYSTEMS AREAS

In **Apuseni Mountains** the carbonate deposits outcrop over large areas and can be found in the geological constitution of all the main tectonic systems of this mountains: Bihor Autochtonous, Codru Nappes System and Biharia Nappes System from Northern Apuseni Mountains and the Nappes System in the Southern Apuseni Mountains.

Three major carbonate series separated by impervious rocks occurs within the Bihor Autochton in Pădurea Craiului Mts. and in Bihor Mts.: the Triassic series, up to 1500 m in thickness, the Jurassic-Cretaceous series, 200–550m, and Cretaceous series, 50–350m.

Endorheic areas and diffluence surfaces are large developed and make water budget computation difficult. The diffluence surfaces are resulted in basin karst diffluence processes, by which the available water amount of a specific catchment area, as a consequence of partial captures is divided into a fraction that seeps and is directed by underground flow outside this catchment area, and another fraction that permanently or temporarily follows the surface flow, downstream the capture area (Orăşeanu & Iurkiewicz, 1982). In Pădurea Craiului Mts. endorheic areas cover 224 km^2 and diffluence surfaces are developed on 107 km^2.

The overall hydrogeologic picture of Pădurea Craiului Mts., without Remeţi graben, is characterized by the presence of an unitary karst aquifer in which there is a deep circulation from East to the West overlay by numerous shallow ones which discharge at the northern and southern periphery of the massif (Orăşeanu & Iurkiewicz, 1987). The karst water with deep flow are thermalized as a consequence of the hyperthermal regime of the area adjacent to the Pannonian basin and are partially discharged by the sources in Felix-Oradea-1 Mai zone, which is part of the large karst aquifer (Orăşeanu, 1985).

Vâlcan Mountains (systems 14-16) are included in the group of the western ranges of the Southern Carpathians which all have a similar tectonic pattern, dominated by the overthrust of the Getic Domain over the crystalline and sedimentary formations of the Danubian Domain.

The limestones, the thickness of which may reach 1000 m, are of Dogger-Aptian age and are layered (the lower sequence) or massive (the upper sequence).

The surface stream-network supplies the carbonate reservoir through diffuse or concentrated swallets, which may be either partial or total losses. The inflows vary between 5–300 l/s, which account for 50–100 % of the total flow rate of a stream. The mean runoff displays significant variations, between 12.5 and 45 $l/s/km^2$, according to the season and to the considered elevation range. Another component of the aquifer recharge includes the rainfall on the limestones outcrops, which varies between 700 mm/year (at 250–300m elevation) and 1100 mm/year (at 1500 m elevation).

Banat Mountains (systems 12–13), includes one of the largest and most compact limestone areas in Romania, situated in the western part of these mountains, where it extends over some 800 km^2.

The sedimentation area, corresponding to the well-known Reşiţa-Moldova Nouă synclinorium (9 major structures as synformal and antiformal folds occur across a total width of 21 km) includes a carbonate series of Late Jurassic-Cretaceous age, up to 1200 m thick, within which distinct lithology (micritic, biomicritic or reef limestones), and accordingly, distinct ages can be separated. Many longitudinal and transverse faults dissect this extremely folded geologic complex.

The yearly average (1964–1976) rainfall value recorded at Anina (in the middle of the area) is 997 mm. Computed evapotranspiration values fall, at least for the northern and central section of the considered area, within the 475–500 mm/year range.

3. SYSTEMIC ANALYSIS PARAMETERS

The flow rate evolution, for most of analyzed sources is closely connected to the seasonal character of the climate. For this reason, after the high spring flood pulses, when the maximum discharge values are frequently reached (Table 1) for many karst systems a long recession period begins (2–4 months). At the end of the recession period, the decline in the spring flow rates is severe the minimum discharge values being reached (Table 1). As a consequence the high variability indexes are due in a certain extent to the climate. On the other hand, it's the geological and the structural setting as well as an important degree of karstification which controlled the range of the variability.

Recession curves analysis. According to Mangin (1994) the analysis provides some important quantitative parameters, such as the dynamic volume, the depletion factor, and two dimensionless parameters ranging between 1 and 0. The results of such a type of analysis may be expressed both numerically (Table 2) and graphically (Fig. 2).

The depletion factor α describes the depletion of the flooded zone. In our cases it is easy to identify two such modalities for the depletion process. For the considered karst systems, the depletion process displays two distinct behaviors. In the systems 2, 3, 9,12 and 6, with larger values of α (0,01–0,037) the reserves are more rapidly evacuated. Alternatively, in the rest of considered systems the evacuation of the reserves, occurs much slower, as indicated by the

Table 1: Hydrometric parameters of major karst systems.

1	Source	Period	Surface km²	Q_{min} m³/s	Q_{max} m³/s	Q_{mean} m³/s	$\frac{Q\,max}{Q\,min}$	B_f	Tracing exp. S(m/h)	D (km)
1	Aştileu	1982–83	25.0	0.074	2.55	0.354	34.46	0.303	5.6 – 262	2.62 – 11.5
2	Brătcani	1982–83	22.0	0.068	2.412	0.305	35.47	0.406	42.2 – 211	1.7 – 5.7
3	Izbândiş	1982–83	16.3	0.049	3.98	0.347	81.22	0.171	7 – 82.3	3.4 – 5.65
4	Topliţa de Roşia	1982–83	3.8	0.011	0.873	0.073	79.36	0.176	25.8 – 72.8	1 – 3
5	Topliţa de Vida	1982–83	8.0	0.022	3.6	0.162	163.64	0.174	3 – 141.7	3.37 – 6.8
6	Roşia	1982–83	26.5	0.078	11.150	0.516	142.95	0.201	7 – 34.6	2.1 – 5.7
7	Păuleasa	1984–85	—	0.02	1.92	0.477	96.00	0.574	15.3 – 83	1.9 – 4.6
8	Tăuz	1984–85	—	0.068	4.64	0.529	68.24	0.309	8.2	2.65
9	Boiu	1986–87	3.8	0.07	5.4	0.587	77.14	0.142	5 – 500	1.7 – 8.15
10	Şopoteasa	1986–87	7	0.011	1.314	0.214	119.45	0.203	29.4	4.28
11	Grota Ursului	1982–92	13.6	0.062	2.0	0.180	32.25	0.366	120 – 368	1.84 – 5.8
12	Bigăr	1973–74	30	0.042	3.2	0.483	76.00	0.200	12 – 39	3.5 – 7
13	Ochiu Beului	1973–74	32	0.156	9.46	0.712	60.6	0.219	—	—
14	Izvarna	1957–64	310	0.722	4.055	1.571	5.6	0.5–0.9	42	10 – 19.7
15	Vâlceaua	1957–64	264	0.240	3.2	1.181	13.3	0.25–0.7	42 – 250	1 – 10.7
16	Pătrunsa	1971–72	—	0.146	5.62	1.490	38.49	0.240	42 – 84	3.1 – 5.7
17	Morii	1988–89	—	0.063	1.7	0.229	26.98	0.362	25.4 – 104	4.5 – 6.7

Base flow index $B_f = b/a$ where *b = mean discharge of the driest month* and *a = annual mean discharge*

small α values (α = 0.001–0.009). A small depletion factor may not necessarily indicate important reserves: sometimes it is related to a supply provided mostly by sinking streams, that collect their water from noncarbonate terrains. This is for instance the case of Topliţa de Roşia outlet part of a several kilometers long stream that provides an entirely accessible connection with Ciur Ponor swallet.

The dynamic volume of the flooded zone *Vdyn* (Mangin 1994) is generally remarkable, between 1 and 5 millions m³; yet the two karst systems in Vâlcan Mountains have even larger dynamic volumes. In spite of a low α value, it is for Topliţa de Roşia spring that the lowest *Vdyn* was computed (no. 4, Table 2) which confirm that the reserves of this system are small. As indicated above, the slow decline of its discharge is the result of a supply originating mostly in noncarbonate terrains.

The recession curve analysis results were used to draw a diagram based on the two dimensionless parameters mentioned above: *i*, related to the characteristics of the infiltration zone, and *k* that provides an estimate of the importance of the flooded zone.

The diagram (Fig. 2) indicates that systems in Pădurea Craiului and Banat mountains underwent the most intense karst processes, which resulted in well developed cave systems, that sometimes reach important flooded zones (no. 1, 5). According to the same criteria, the systems in Bihor and Codru Moma Mts. are included in the same class with those in Vascău and Poieni plateaus, the underground karst networks in their upstream part inducing delays in the supply: for instance, the system of Tăuz spring explored by cave divers down to 74 m depth, and which includes in its upstream section a complex, 22 km long maze cave.

Correlation and spectral analyses. The systemic and functional approach of the karst, that uses the karst systems as a reference is based on the study of input-output relationships (Mangin, 1983; 1994). The method is similar to time series analysis, consisting of a descriptive investigation of the series of discharge and rainfall values. The longer the chronological series is, the better are the results. Unfortunately, data collected from only three systems (no. 11, 14 and 15) complied with the necessary duration requests. Even under those circumstances, the results (Table 2) corroborate the information.

For a suggestive interpretation of the computed parameters it is necessary to consider a reference classification, relying on four simple and very well studied karst systems (Mangin, 1994). In this classification each "archetype" (Aliou, Baget, Fontestorbes and Torcal) was defined using four principal descriptive tools:

– the "memory effect" derived from the correlogram, which provides some information on the amount of the reserve, as well as on the extent of the underground drainage;

Table 2: Hydrodynamic parameters of major karst systems

No	Source	Recession curves analyses					Correlation and spectral analyses			
		α (day^{-1})	*Vdyn* $10^6 m^3$	*Vyear* $10^6 m^3$	*i*	*k*	memory effect (day)	truncation frequency	regulation time (day)	model
1	Aştileu	0.007	1.35	11.16	0.21	0.12	46	0.120	32	B⇒F
2	Brătcani	0.037	0.5	9.61	0.31	0.05	20	0.168	24	A⇒B
3	Izbândiş	0.01	0.7	10.94	0.23	0.06	15	0.124	18	A⇒B
4	Topliţa de Roşia	0.004	0.29	2.3	0.14	0.12	29	0.168	25	A
5	Topliţa de Vida	0.0017	1.22	5.1	0.013	0.24	12	0.184	9	A
6	Roşia	0.008	1.23	16.27	0.08	0.07	13	0.21	10	A
7	Păuleasa	0.009	2.02	15.04	0.47	0.13	40	0.092	32	B⇒F
8	Tăuz	0.006	1.96	16.68	0.44	0.117	33	0.05	25	B
9	Boiu	0.012	1.66	18.51	0.43	0.089	16	0.100	19	B
10	Şopoteasa	0.005	0.4	6.74	0.52	0.06	55	0.084	36	F
11	Grota Ursului	0.0017	4.99	5.67	0.473	0.88	22	0.124	27	B
12	Bigăr	0.012	1.3	15.23	0.257	0.085	24	0.168	23	B
13	Ochiu Beului	0.022	1.31	22.45	0.182	0.058	24	0.168	21	A
14	Izvarna	0.0003	80	50	0.8	> 1	78	0.088 (0.196)	57	F⇒T
15	Vâlceaua	0.006	17	40	0.75	0.44	66	0.088	65	F⇒T
16	Pătrunsa	0.019	1.51	47.088	0.68	0.032	41	0.144	35	B
17	Morii	0.002	4.39	7.22	0.56	0.6	28	0.064	20	B

Models: A, *Aliou*; B, *Baget*; F, *Fontestorbes*; T, *Torcal*.

– the truncation frequency which describes the filtering effect of the aquifer.

– the regulation time, which is identified by the duration of the impulsive response (i.e. the unit hydrograph).

– the shape of the impulsive response of the system, obtained from the cross-correlogram function.

The parameters summarized in Table 2 indicate a remarkable resemblance of the karst systems in Pădurea Craiului mountains (except no. 1, the Aştileu system) to Aliou "archetype" of well karstified systems with a functional karst structure. According to the peak value of the cross-correlogram, which is the highest in the range, as well as to other additional elements, Ochiu Beului outlet from Banat mountains (no. 13 in Table 2) belongs to the same class of the non-inertial systems. The shape of the impulsive response of such systems is very sharp, without any significant spread out (Fig. 3).

Another distinct group of springs (nos. 7, 8, 9, 11, 12) display a more inertial behavior, similar to that of Baget system (Table 2, Fig. 3).

The above mentioned exception in Pădurea Craiului mountains, the spring at Aştileu has an impulsive response typical for the Aliou "archetype", while other parameters place him in an intermediate position between the Baget and Fontestorbes "archetypes". The spring is supplied both from a extensive underground catchment area, and from a high flow rate swallet, Potriva cave, that provides a fast (262 m/h) connection to the outlet. As a result, under certain conditions the faster response of the composite recharge component seems to obscure the general response of the entire system.

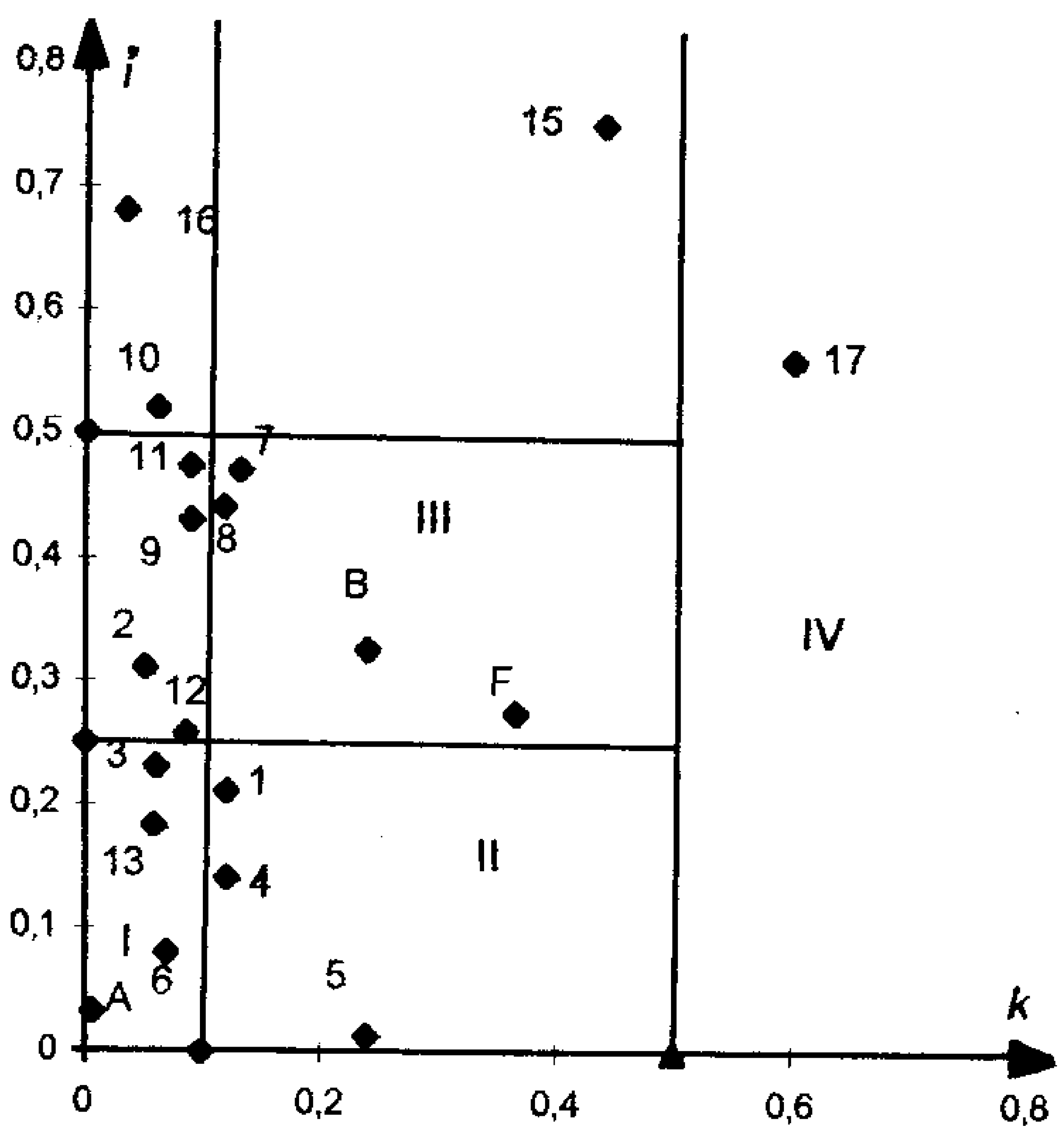

Figure 2 Position of major karst systems according to Mangin's classification (1975).
Models: A, *Aliou*; B, *Baget*; F, *Fontestorbes*.

3. COMPLEX AQUIFER SYSTEMS

Detailed studies of the karst aquifer systems in Vâlcan mountains (Iurkiewicz, 1994) indicated that two of them (nos. 14 and 15 in Tables 1, 2) exhibit a complex organization, consisting of sub-systems with various degrees of interconnectiveness.

Vâlceaua karst system includes, in addition to its main outlet (no. 14 in Table 2), three more outlets, with average flow rates ranging between 20 and 1000 l/s. The hydrologic water budget performed over the period 1980–1990 for several catchment areas belonging to this system indicates that 130–150 l/s are diverted from the karst aquifer toward a detritic reservoir that consists of Miocene and Lower Meotian gravel and sand formations, located to the south.

The analysis of 9 recession periods included in the interval 1958–1964 reveals two distinct sets of depletion factor (α) values. The first set with α ranging between 0.0046–0.0060, corresponds to a karst behavior of the system, which occurs during periods when even the draught flow rate does not fall below 600 l/s. The second set of α values (0.0014–0.0026 days^{-1}) was recorded during more severe draught periods, when the flow rate falls below 500 l/s. In the latter case the system behavior is almost non-karstic, which is characterized by sudden drops on the recession curves, due to the water transfer toward the Miocene-Meotian aquifer. The computed dynamic volume resulted to be the order of $15–17\times10^6 m^3$.

The separate examination of each hydrologic cycle within the general frame of the correlative analysis indicates that the reserves of the system are affected by rainfall impulses for long periods, that may extend over up to two years. In this respect, it has been observed that the recurrence of comparatively "dry" hydrologic cycles every 1 or 2 years results in draught flow rates lower than 500l/s, and implicitly in the occurrence of the sudden drops in the discharge series.

As a general conclusion, the computed values of the four descriptive parameters position Vâlceaua system between the Fontestorbes and Torcal "archetypes" (Table 2, Fig. 3).

Izvarna karst system (no. 15 in Table 1) ranges among the most constant large discharge springs in Romania. The system is developed in a low and elongated limestone bar, dissected by many surface streams. There is morphologic and hydrologic evidence (Iurkiewicz, 1994) that an upper underground karst drainage level is overlying the main deep drainage. It has been also inferred that the karst system receives an additional underground supply

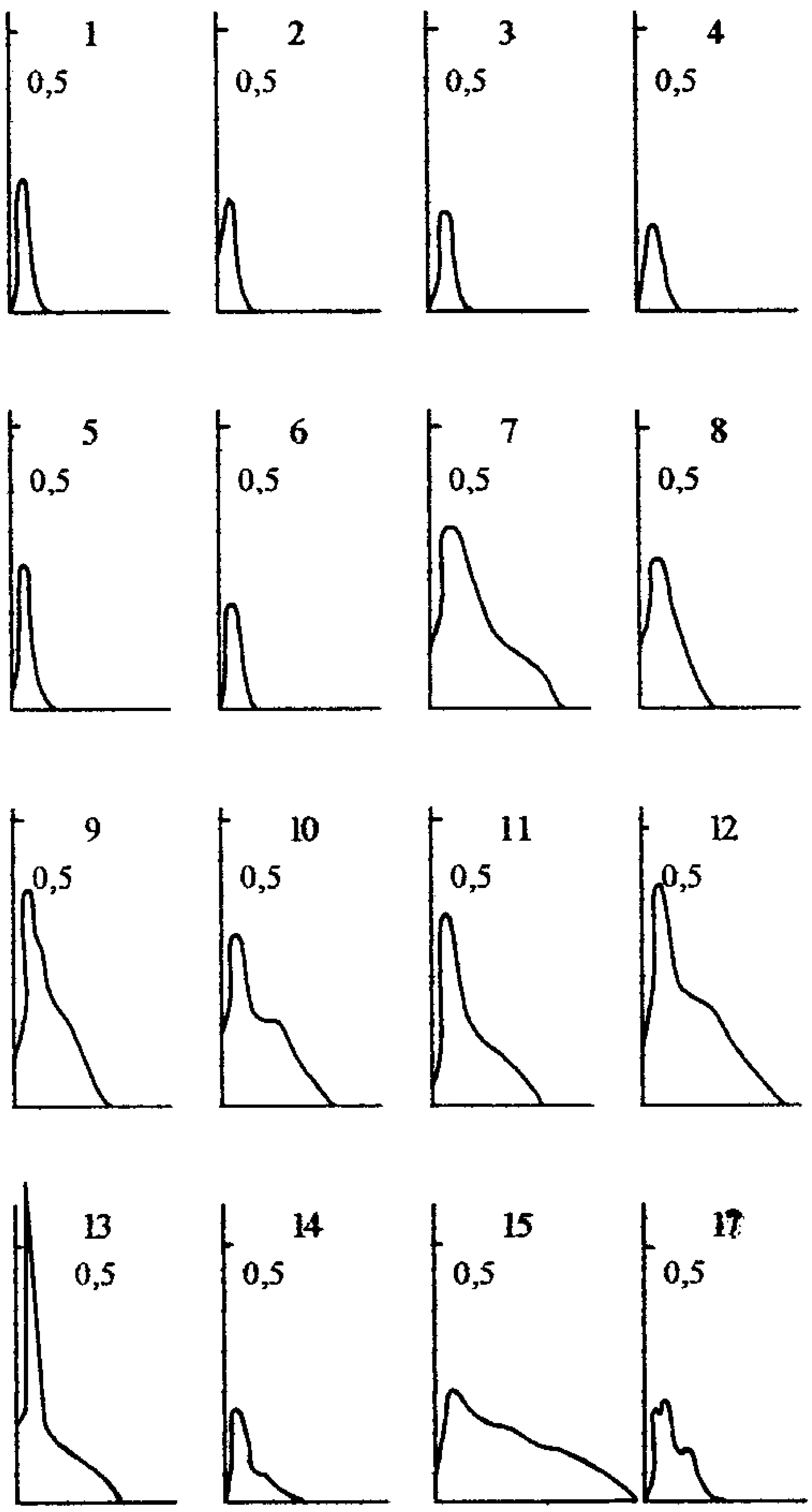

Figure 3: Unit hydrograph of major karst systems.

provided by a fissured aquifer occupying a granitic body located to the north (Rădulescu et al., 1985)

The recession curves display a very steep initial, post rainfall decrease, which features the response of the shallow component of the discharge, i.e. the fast depletion of the unsaturated zone. Long depletion periods follow, when the discharge, provided mainly by the deep component of the system, slowly decreases.

*V*dyn, α, *i* and *k* parameters interpretation is awkward, since depletion occurs in a rather non-karstic flow regime: the computed α values are abnormally low (0.0003 day^{-1}), while *V*dyn is correspondingly large. Anyway, according to the *i* and *k* parameters the system doesn't fit anywhere the diagram in Figure 2, which implies that the its behavior is resembling more that of a porous aquifer.

The recession curves sometimes display sudden drops, the origin of which is analogous to that identified by means of the correlative analysis for the spring Vâlceaua.

According to the values of the descriptive parameters, the hydrodynamic behavior of each of the two underground drainage levels (i.e. shallow and deep) can be identified. In this respect, the deep component of the spring discharge can be included between the Fontestorbes and Torcal "archetypes", poorly karstified aquifers with high "memory" effect and long regulation time. At the same time, the shape of the impulsive response (Fig. 3) and the second value of the cutting frequency (0.196) outline the hydrodynamic behavior of the shallow drainage, quite similar to that of the Aliou "archetype".

4. CONCLUSIONS

The importance of all the previously discussed parameters lies in the manner in which they are used. An obvious application is to rely on the evaluation of the dynamic volume of the flooded zone in assessing the available amount of water which can be supplied to consumers. The vulnerability to the pollution may be estimated as well, from information on the internal structure and on the hydrodynamic behavior of the system. In this respect, the analyzed karst systems call upon the following remarks:

- All karst systems in Pădurea Craiului Mountains are non-inertial, without significant regulation of the inflow, so that both miscible and immiscible pollutants are easily transmitted to the outlet. On the other hand if the pollution is not important a reasonably fast self-treatment can be expected.
- The other systems (except nos. 14 and 15) are more or less inertial, with moderate filtering effect for immiscible pollutants, yet without significant filtering effect for miscible pollutants.
- Nos. 14 and 15 are the two large systems in Vâlcan mountains with a complex organization. Their main discharge component displays a non-karstic behavior, with a strong regulation capability. This component will be little influenced by immiscible pollutants, and even a short time pollution with miscible pollutants will not be critical (10–14 days), although its traces may still remain detectable for many years. The other discharge component is much smaller quantitatively, but its transit through the system is virtually instantaneous, which makes it highly vulnerable to pollution.

Another fact worth being pointed out is that most of the systems in Pădurea Craiului and Vâlcan mountains are connected with to regional scale aquifers like the one discharging thermal at Băile Felix spa and respectively the Miocene aquifer in the Carpathian Foredeep. The vulnerability to the pollution of the discussed karst systems has to be considered therefore in a broader, regional scale context.

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