3.13. APUSENI MOUNTAINS

by Iancu ORĂȘEANU
Romanian Association of Hydrogeologists, ianora@hotmail.com

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3.13.1. The Physiographic, Geological-Structural and Hydrogeological Setting of the Apuseni Mountains Karst Areas

Apuseni Mountains are situated at the inner part of the arc traced by the Eastern Carpathians and by the Southern Carpathians, forming a connecting bridge between that two mountain units and acting as a barrier which closes the Transylvanian Basin to the west. They occupy an area of about 10.750 km^2, their average elevation being 700 m, figures which indicate them to be the smallest unit of the Romanian Carpathians.

In the general framework of the Romanian karst, the salient features of Apuseni Mountains are the high frequency of the karst areas and the outstandingly diverse and beautiful relief. Carbonate deposits outcrop over a total surface of 1132 km^2, they occur within the entire mountains area and occupy compact surfaces within the mountains Pădurea Craiului, Bihor Vădeasa, Codru Moma, Trascău, within Poieni Plateau and within the Rapolt crystalline limestones outcrop (Fig. 1.1). When the overall streams network of Apuseni Mountains is considered, one can easily notice that the most important rivers of those mountains, namely Crişu Alb, Crişu Negru, Crişu Repede, Someşu Cald and Arieş, have their headwaters located in karst areas.

1.1. The physiographic setting

The topography of Apuseni Mountains is dominated by Gilău mountains body. It is built of old crystalline formations and of granites, with just sporadic occurrences of crystalline limestones. The ridges of those mountains are leveled at an average elevation of 1700 m, a circumstance which indicates them to belong to the erosion platform Cârligaţi. That mountains body reaches it maximum elevation, 1827 m, in Muntele Mare peak.

The other topographic units of Apuseni Mountains are distributed around this central body, at lower elevations and with different appearances. To the west there occur "Bihor Mountains", a denomination which local people in Beiuş region use in order to designate the whole highly-elevated front which dominates Beiuş Basin to the east. In this general sense, "Bihor Mountains" extend longitudinally between Gilău Mountains and Beiuş Basin, and transversally between Arieşu Mic valley in the south and Crişu Repede valley in the north. In fact, "Bihor Mountains" include three transversal compartments which are quite different in terms of their structure and landforms: the mountains body Vlădeasa, the actual Bihor Mountains and the mountains body Biharia (V. IANOVICI et al., 1976). Ancient Romans used to designate this whole area as "Tierra Biharia" (A. SCHMIDL, 1863).

Vlădeasa Mountains body, whose name has been taken from that of its highest peak (Vlădeasa, 1836 m), includes mostly banatitic intrusive and volcanic formations, and as a consequence the corresponding topography has a compact appearance. The southern half of those mountains igneous body is externally bordered by sedimentary formations, a significant fraction of which are carbonate deposits that display characteristic landforms: Remeţi graben to the north-west, Meziad-Ferice karst area to the west, Someşu Cald graben to the south and Stanciu brook karst area to the south-east.

The boundary between Bihor Mountains and Vlădeasa Mountains body follows mostly the stream courses of Someşu Cald and Crişu Pietros, crossing the water divide between those two streams south of Cârligatele peak. The southern boundary of Bihor Mountains, which separates them from Biharia mountains body, is provided by the stream courses of Arieşu Mare and of Crişu Băiţa. The salient features of the Bihor Mountains topography are controlled by carbonate deposits, a special mention deserving – within the karst topography as a

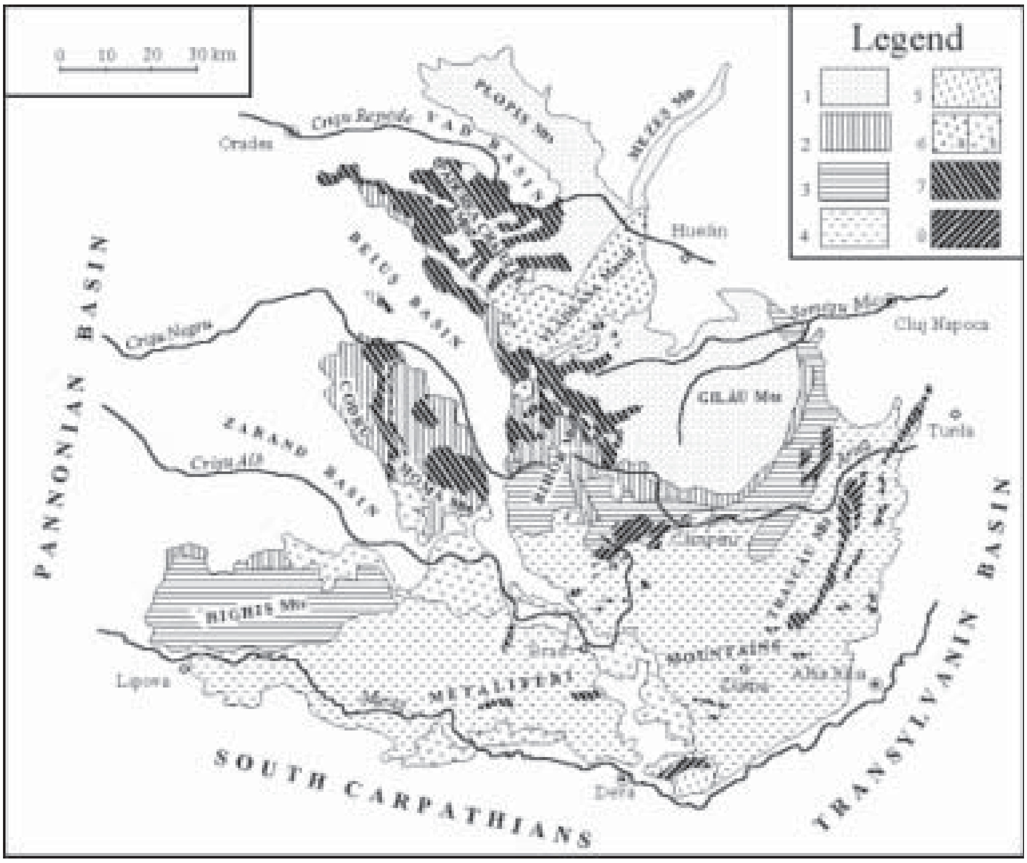


Figure 1.1. Tectonic sketch of the Apuseni Mountains with carbonate deposits outcrop areas (after Bleahu et al., 1981, modified). Legend:
1. Bihor Autochtonous;
2. Codru Nappe System;
3. Biharia Nappe System;
4. Metaliferi Mountains;
5. Getic Nappe;
6. Magmatites:
a. Banatitic,
b. Neogene;
7. Sedimentary limestones and dolomites;
8. Crystalline limestones and dolomites.

whole – the region of Padiş-Cetăţile Ponorului, one of Romania's first-ranking karst areas.

Codru Moma Mountains consist of two distinct topographic units, Codru Mountains to the north, which include two north-south striking main ridges that are separated from one another by the karst trough of Finiş stream to the north, and by the Brătcoaia and Tinoasa karst depressions to the south, and Moma Mountains situated to the south, the salient topographic feature of the latter being the Vaşcău karst plateau.

In the Metaliferi Mountains, a Southern Apuseni Mountains structural unit which extends between the valleys of Arieş and of Mureş, carbonate deposits occurs as two compact areas, in Poieni Plateau and in Trascău Mountains respectively. Poieni Plateau is a vast erosion platform shaped in crystalline limestones and uplifted at elevations of about 1000-1200 m. In Trascău Mountains limestones occurs as a continuous narrow strip that extends between the streams Arieş and Ampoi, perched almost 500 m above the surrounding topography. Eastward of that limestone strip, limestones occurs as olistoliths that form isolated topographic bodies.

In the southern part of Apuseni Mountains there occur crystalline limestones outcrops which in terms of structure belong to the Getic Nappe. Geologists designate that specific area as the "Rapolt crystalline limestones outcrop".

Rainfall has an uneven distribution across the various areas of Apuseni Mountains, the maximum value, in excess of 1400 mm/year, occurring over the Vlădeasa-Stâna de Vale-Biharia lineament, a barrier against the wet fronts which arrive from the west (Fig. 1. 2). In the east, it is only along the Apuseni Mountains main ridge, which extends between the peaks Cîrligatele - Clujului Peak - Muntele Mare, that rainfall amounts remain elevated (in excess of 1200 mm/year). Northward and southward of that ridge, dramatic drops are recorded in the annual rainfall amounts. Values in excess of 1000 mm/year are again recorded just along the Trascău Mountains ridge, while on the eastern slopes of those mountains rainfall amounts steeply decline, to fall below 600 mm/year at the border of the mountains area, in the neighborhood of Turda town. The rainfall gauging station at Stâna de Vale, in Vlădeasa mountains body, is the one which records Romania's largest amounts of rainfall, the recorded multi-annual average being 1563.8 mm (as computed for the 1950-2003 time interval), and 1635.9mm (when computed only for the 1973-2003 period).

The Apuseni Mountains stream-network is dense, a consequence of the fact that those mountains build up a major topographic knot from which water is supplied to streams carrying significant multi-annual average flow rates.

Runoff mirrors both the Apuseni Mountains uneven rainfall regime, and their complex geological constitution. As a result, catchment areas positioned at similar average elevations may display contrasting values of their multi-annual average specific discharge. Specifically, the specific discharge declines from 31.4 l/s km^2, as recorded for the stream Drăgan positioned in the western part of the mountains, to only 16.5 l/s km^2, recorded in the case of Someşu Rece stream, positioned in the mountains eastern part. When Apuseni Mountains are considered as a whole, the highest multi-annual average specific discharge is that of Crişu Pietros river (33.8 l/s km^2 at Pietroasa gauging station). Elevated values of that parameter are also recorded in the case of the streams Iad and Crişu Negru, located in the western part of the mountains (Fig. 1.3).

In order to assess the Apuseni Mountains carbonate deposits groundwater potential, hydrogeological investigations have been conducted during the 1981-1996 period, hydrological-meteorological observations and measurements being performed in each major karst area for at least one hydrological year. During those periods, the rainfall regime and implicitly the runoff and the underground flow regimes diverged quite a lot with respect to the average values recorded over the 1979-1998 time interval. Figure 1.4 illustrates the Crişu Negru (Beiuş gauging station) and Arieş (Scărişoara gauging station) cumulated annual average flow rates deviation, expressed as percents with respect to the multi-annual average of the corresponding cumulated flow rates (the 1978/79-1997/98 period). We specifically took into account flow rates recorded along those streams since they collect runoff from vast areas where carbonate deposits outcrop.

The catchment areas lithological constitution is mirrored in the surface and underground flow configuration, the inter-relationships between

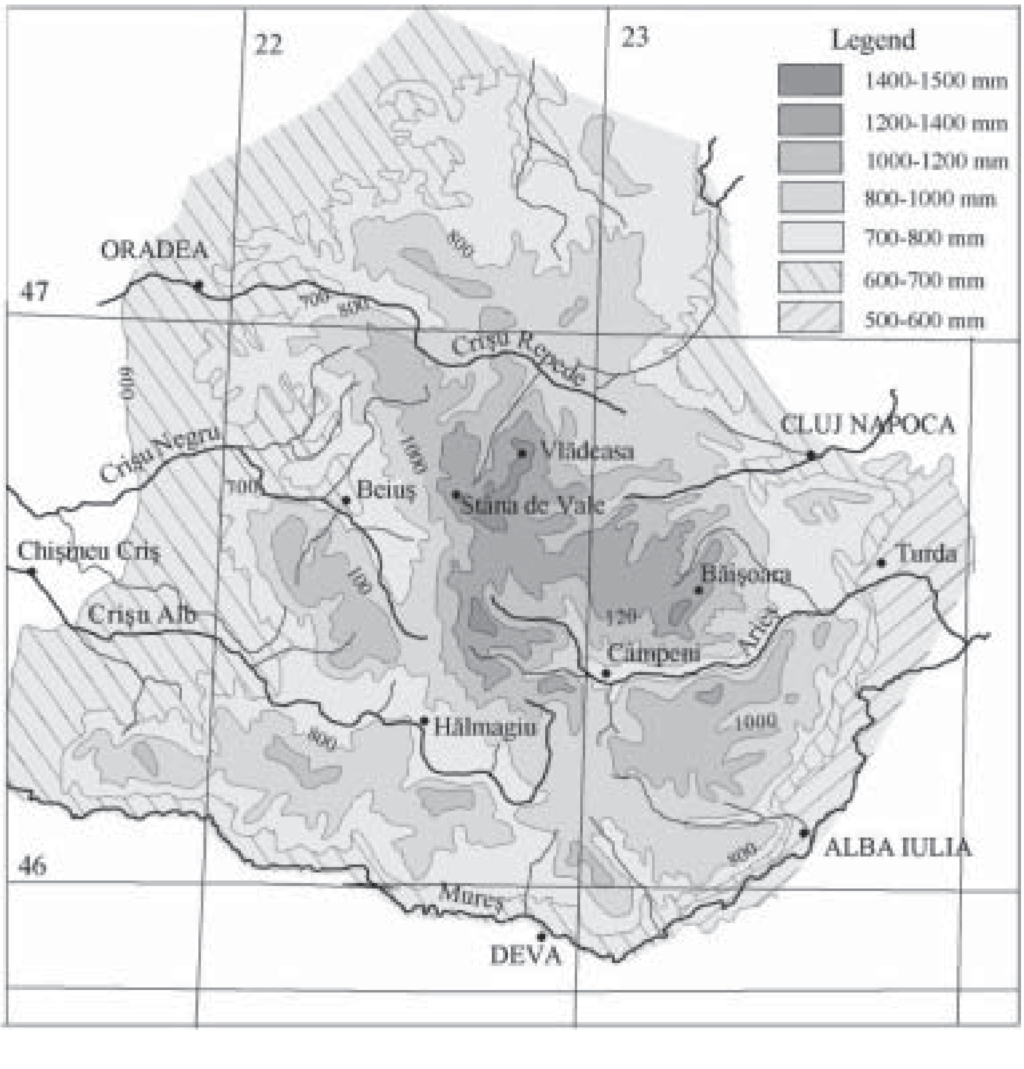


Figure 1.2. Rainfall contour map (after Geographic atlas of Romania).

those factors being highlighted through discharge time series data processing, performed by means of the correlative and spectral analysis methods. One can thus rank the geological formations according to their memory-effect, a parameter which to a certain extent corresponds to “storage” defined in the conventional hydrogeology. The method has been proposed by A. MANGIN (1981) in order to assess the karst systems amount of structuring. A large value of that parameter indicates a system possessing significant reserves, whose storage properties are large, while its conductive properties are poor. Conversely, a small value is characteristic to a system with poor reserves, whose storage properties are also poor, yet its conductive properties are high.

In order to outline the part played by lithology in the generation of runoff, there have been selected 10 major catchment areas of Apuseni Mountains, with contrasting lithological constitutions, yet with similar areal extents and vegetation covers (Table 1.1). The analysis has considered daily average flow rates recorded during the period 1971-1975.

The memory effect mirrors the importance of the part played by underground flow in generating surface flows. It increase with altitude of hydrographic basin, that mean with rainfall, and also it is dependent of lithological constitution of the area. Its value is very small (6-15 days) for catchment areas developed on limestone and impervious rocks (alternating shales, marls and sandstones), being conversely large (47-123 days) for a substratum which includes molasse type deposits, crystalline schists, paleozoic granites and Vlădeasa ignimbritic rhyolites.

The very small memory effect of the streams that collect their water from catchment areas including in their lithologic constitution large fractions of carbonate deposits is a result of the fast groundwater drainage, a consequence of carbonate deposits being subject to intense karst processes. In the case of the binary karst systems it is outstandingly important to know the surface flow characteristics, since together with rainfall they provide the system input function.

1.2. The geological-structural setting of Apuseni Mountains

Apuseni Mountains are the result of a long evolution, achieved through several tectonic cycles, their present-day structural configuration (Fig. 1.1) being mostly the result of the Alpine Cycle evolutions. The previous tectonic cycles formations are metamorphosed and they build-up the crystalline basement of the Alpine sedimentary cover (V. IANOVICI et al., 1976, M. BLEAHU et al. 1981).

Sedimentary deposits in Apuseni Mountains have been deposited in two sedimentary basins

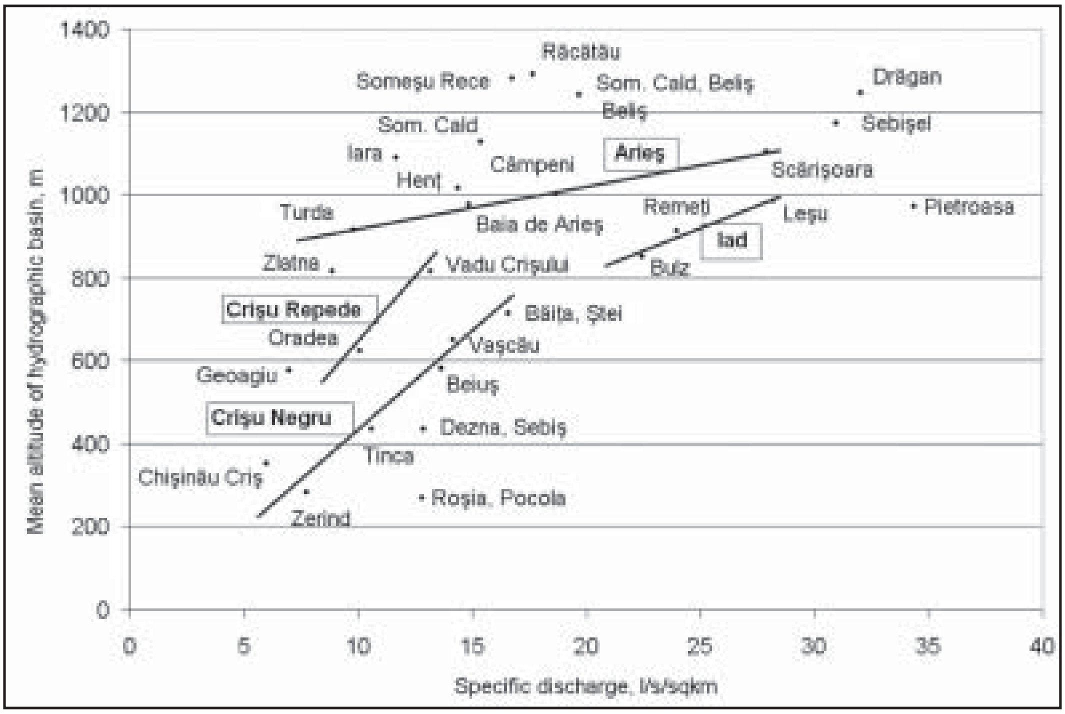


Figure 1.3. Relationship between multi-annual average specific discharge and the catchment areas average elevation (after I.N.M.H. data).

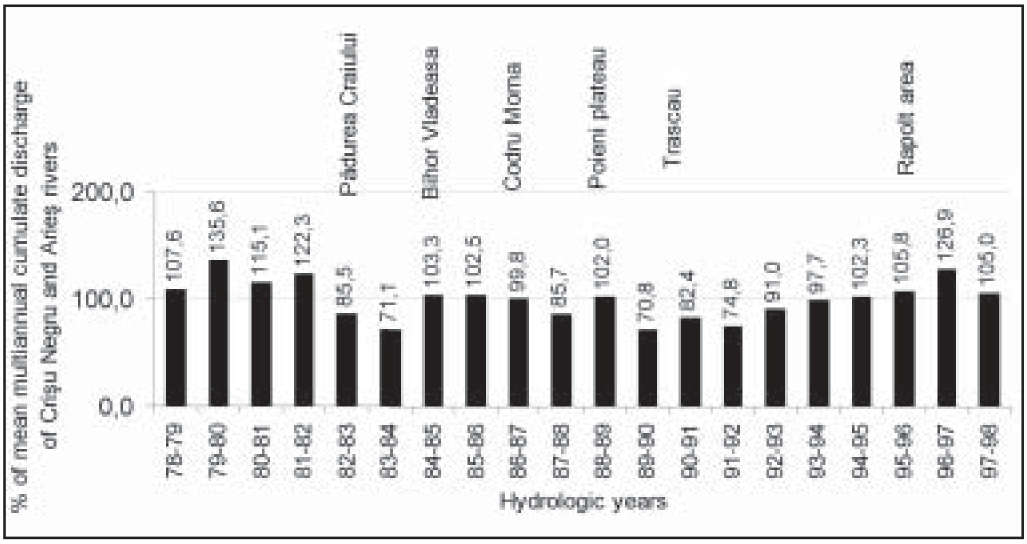


Figure 1.4. Crișu Negru (Beiuș gauging station) and Arieș (Scărișoara gauging station) cumulated annual average flow rates deviation, expressed as percents with respect to the multiannual average of the corresponding cumulated flow rates (the 1978/79-1997/98 period).

with distinct evolutions, a circumstance which for this area resulted in outlining two tectonic units with distinct sedimentation and tectono-genetic processes developments, namely the Northern Apuseni Mountains and the Southern Apuseni Mountains (the Metaliferi Mountains), units that are enclosed in two of the Carpathians majors units, the Internal Dacides and the Transylvanides.

1.2.1. The Northern Apuseni Mountains

The Northern Apuseni Mountains include an almost complete sedimentary series of Permian-Mesozoic age, with Permian formations consisting of clastic and molasse deposits, the Triassic and Jurassic facieses being, with scarce exceptions, carbonate and clastic, while the Cretaceous formations, mostly carbonate at their lower part, become shaly, then clastic toward their upper part.

The mountains exhibit a nappes structure, each nappe being defined by its own cristalline series and sedimentary sequences. Their structural build-up has been completed during the Cretaceous orogenesis, subsequent tectonic movements resulting in the delineation of post-tectonic basins that had been former gulfs of the Pannonian Depresssion. These movements have been accompanied by a Laramic intense magmatic activity, with intrusive and volcanic products.

Within the Northern Apuseni Mountains structure there can be outlined three zones with distinct paleo-geographic and tectonic evolutions, distributed from north to the south as follows: Bihor zone, where sedimentation occurred in shallow water and has been interrupted by many exondation episodes, Codru zone, with sediments deposited in deep sea basins divided into several tectonic units (the Codru Nappes System), and Biharia zone, which is a relict of the old Hercynian structures (Cambrian and Paleozoic metamorphic formations), preserved within the Alpine structures. The tectonic units are distributed from north to the south, with Bihor Unit positioned at the bottom and bearing the role of an autochtonous unit for the other two, while Biharia unit is positioned at the top.

Deposits ascribed to the Bihor Autochtonous Unit are widely developed in Pădurea Craiului, Bihor and Gilău mountains. Codru Moma Mountains are entirely built of deposits ascribed to the Codru Nappes System, the same type of deposits building also a belt which surrounds to the west, south and east the compact body formed by the mountains Pădurea Craiului, Vlădeasa, Bihor and Gilău, the maximum width of that belt reaching 5 km. At its outer part, the belt is overthrust by the units ascribed to the Biharia Nappes System.

The lithological constitution of Northen Apuseni Mountains are shown in Table 1.2.

1.2.1.1. Post-tectonic formations

The Late Cretaceous cover. After the nappes emplacement, the Northern Apuseni Mountains have been subject to a tectonic activity consisting mainly of fracturing, which resulted in generating a series of sedimentation basins of small-extent, the so-called "post-tectonic basins" in which Late Cretaceous deposits were accumulated (subsequently

River	Sebişel	Răcătău	Someşu Rece	Iara	Drăgan	Ampoi	Abrud	Crişu Pietros	Vida	Topa
Hydrological station (h.s.)	Pârâul Crucii	Răcătău	Răcătău	Valea Ierii, aval	Valea Drăganului	Zlatna	Abrud	Pietroasa	Luncasprie	Vârciorog
• River course upstream of gauging station (g.s.)										
lengh, km	16	26.9	32	19	42	19	14	18	19.4	13
slope, %	28.6	25	28	52	27	35	40	56.5	22	22.3
altitude, m	1327	1396	1565	1775	1622	1060	1142	1342	608	589
s.h. altitude, m	870	660	660	778	468	406	587	325.24	181.6	299
mean discharge, m^3/s	1.225	2.140	3.405	2.55	6.958	1.432	1.474	4.637	1.106	0.436
minimum discharge, m^3/s	0.138	0.120	0.480	0.284	0.442	0.006	0.025	0.478	0.097	0
maximum discharge, m^3/s	38.8	63.2	47.0	86.0	175.0	75.0	52.0	110.0	48.5	24.9
q, $l/s/km^2$	31.4	21.2	22.3	23.6	27.4	9.68	8.37	37.7	19.9	7.14
base flow index, Bf	0.25	0.22	0.22	0.25	0.19	0.06	0.10	0.19	0.11	0.01
• Hydrographic basin upstream of g.s.										
Surface,	39	101	153	108	254	148	176	123	55.5	72.5
Mean altitude, m	1174	1242	1365	1372	1124	818	881	959	508	474
Forest surface, %	62.6	59.5	56.5	56.9	55.8	54.1	41.3	69.1	70.0	25.2
Litology, %										
- limestones								50	75	50
- granites		33	84	11				18		
- rhyolites	75				84			2		
- neogene volcanites						10	8			
- chrystaline schyst	9	67	16	89	16					
- molasse deposits	15					52	20	27	18	
- impermeable and flysch-like deposits						38	72			20
- Pannonian + Quaternary								3	7	30
• Memory effect, days	123	57	56	52	47	35	14	15	10	6

Note:
- Hydrologic data after "Anuarul hidrologic", 1970-1975, edited by I.N.M.H.
- Morphometric data after "Atlasul cadastrul apelor din România", 1992.
- Lithology after geological map of Romania, scale 1:50,000, edited by I.G.R.
- Observation period: 1971-1975, except Sebișel and Someșu Rece, 1970-1973

Table 1.1. Morphometric, hydrometric, litology and correlative and spectral analysis data of surface streams from Apuseni Mountains.

to the nappes emplacement), and which afterwards, during the Cainozoic, continued to act as gulfs of the Pannonian Depression (V. IANOVICI et al., 1976).

In the Northern Apuseni Mountains, the contact between the Autochtonous and the nappes is overlain by Senonian deposits. The latter occur in the Gosau facies, with variations in terms of lithostratigraphy from one depression to another, the corresponding occurrences being extensively met in the graben Remeţi, in Roşia basin and in the high regions of Vlădeasa mountains body, where they

CORRELATION OF THE BIHOR UNIT AND THE UNITS OF THE CODRU NAPES SYSTEM
OF THE NORTH APUSENI MOUNTAINS

Table 1.2

(after geological maps of Romania, scale 1:50.000, edited by Geological Institute of Romania and M. Bleahu et al., 1981)

		Bihor Unit		Codru Nappes System									
				Valani Nappe	Finis-Gârda Nappe	Ferice Nappe	Dieva Bătrânescu Nappe		Moma Nappe	Vascau Nappe	Colesti Nappe	Urmat Nappe	Vetre Nappe
		Padurea Craiului Mts.	Bihor Mountains				Codru Moma Mountains	Bihor Mountains					
CRETACEOUS	Turonian med.	sds, s, a-s											
	Vraconian												
	Albian	sds lms											
	Aptian	Ecleja lms Form Gugu breccia	Ecleja Form. urgonian limestones	sds, a-s									
	Barremian	limestones		urgonian limestones									
	Hauterivian			xxxxxxx	marly limestones		marly limestones						
	Valanginian	XXXXXX bauxites	XXXXXXX	limestones	sandstones		sandstones						
	Berriasian				shales		siltstones						
JURASSIC	Tithonian	reef lms.	black lms. white	white and gray									
	Kimmeridgian	reef lms.	massive,	reef	lms with								
	Oxfordian	and	reef lms.	limestones	silicifications								
	Callovian	peletal lms.	red oolitic										
	Aalenian	marls	limestones										
	Toarcian	marly-lms.	marls, lms.							black ss, lms		q-sds	
	Domerian	limestones	marly lms.								red lms and	arg-s	
	Carixian	and	marly. sds		Moneasa limestones						siltstones	carbonate sds	
	Sinemurian	marly-lms. quartz sds.	sds. and	q-sds arg.s	siltstones					bedded pink and green lms		(Urmat Form.)	
	Hettangian	with arg. int.	conglomerates	Cosuri Beds	sds. lms	arg-m,sds(J1)							
TRIASSIC	Rhaetian		fine lms,	ss, sds	black lms ss,sds	Kossen Form. V.Frunzei F.	white lms black lms			gray and black lms	loferitic limestones		Baita lms
	Norian		red arg-s (Scarita Form.)		carbonate sandstones white lms	V.Frunzei F. and Codru F.	dol, dol-lms siltstones reef lms,white & red dol-lms	white limestones with red	light gray reef limestones	white and pink limestones	reef limestones		white dolomites (Frasinei dolomites)
	Carnian		white dol. b. lms, sds (Zugai Form.)	white dol-lms and	white lms dolomites	black lms with cherts		matrix		black lms with cherts			
	Ladinian	white reef limestones (Wetterstein)	reef white lms.b. white bedded lms. (Waterstein)	black lms with cherts (Rosia Formation)	black lms with cherts (Rosia Formation)	(Rosia limestones)	black lms with cherts, yellow siltstones	bedded gray lms (Rosia limestones)	gray pink limestones	red and pink lms with ammonites			
	Anisian	black lms. white dol.	black lms. grey dol	gray dolomites	black dolomites	gray and white dolomites	black lms and gray dolomites	dolomites	dolomitic lms black dolomites	dolomitic lms white dol			
	Werfenian	q-sds,arg-s	q sds, arg-s,c	sandstones	q-sds	q-sds	sh,q-sds,dol	q-sds	cg, sds, a-s				
Permian		shales and sandstones	breccias rhyolites	q-sds shales	sds, congl. rhyolites	q-sds arg shales	q-sds, congl. basalts,rhy	argillaceous shales	basalts,rhy.				
Carboniferous													
Devonian													
Silurian													
Ordovician													
Cambrian		crystalline	crystalline										
Vendian		schists	schists										

Codru Formation:argillaceous shales, breccias, limestones; Ecleja Form.:marls,carbonate sandstones; Kossen Form.: limestones, black marly limestones; Valea Frunzii (VF) Form.: dolomitic limestones, sandstones, conglomerates, black marly shales; Zugai Form.: breccias, argillaceous shales, limestones, quartz sandstones. Urmat Form.: black argillaceous shales, carbonate sandstones, quartz sandstones.

Abbreviations: lms-limestones, dol-dolomites, sds-sandstones, q-sds-quartzitic sandstones, cong/c-conglomerates, arg-int- argillaceous intercalations, arg-s/a-s-argillaceous shales, arg-m-argillaceous marls, b-breccias; ss-siltstones, sh-shales, rhy-rhyolites.

Note: Significance of colours as in Figure 1.6

have been by preserved from being eroded. In Roşia depression, those formations are about 1500 m thick and they consist of sandstones, conglomerates and clays. The cover deposits series continues with alternating limestone, sandstones and marls (Santonian), marly sands with tuffs intercalations (Campanian) and essentially terrigenous deposits that include in their upper part the volcano-sedimentary formation (Maastrichtian).

Late Senonian-Paleogene Igneous formations (Banatites). The products of the Alpine subsequent magmatic activity are widely developed in the Northern Apuseni Mountains, occurring as intrusive bodies, lava flows, ignimbrites, cinerites and dykes. They display extensive outcrops in the areas Pietroasa, Budureasa, Valea Seacă and in the mountains body Vlădeasa, where they consist of intrusive bodies which include granodiorites, diorites and porphiric diorites, as well as rhyolite effusive bodies crossed by dykes with various petrographic constitutions.

The Neogene cover. Starting from the Neogene, more specifically from the beginning of the Badenian, descendent vertical movements resulted in an invasion of the Apuseni Mountains low areas by the surrounding seas, thus being generated intra-mountains depressions filled with sedimentary formations consisting of complete series of detritic rocks, occasionally associated with tuffs, limestones and coals.

1.2.2. The Southern Apuseni Mountains

The Southern Apuseni Mountains have been generated within a sedimentation basin that acted as a eugeosyncline and whose evolution has been fast, specifically restricted to the Jurassic-Cretaceous time interval. Those mountains include large bodies of intrusive rocks and sedimentary complexes characteristic to a geosyncline environment, with prevalent occurrences of flysch, wildflysch and molasse formations, carbonate sequences being on the other hand scarce. A mark of the tectonic instability that accompanied the sedimentation of the deposits building the Southern Apuseni Mountains is provided by the occurrences of formations including olistoliths at several levels, the Late Cretaceous tectonic movements generating a nappes structure, with specific lithologic constitutions and tectonic evolutions.

1.2.2.1. Post-tectonic formations

Late Senonian - Paleogene igneous rocks (Banatites). Those rocks include a large variety of types, ranging from granodiorites and diorites up to effusive rocks, like andesites and rhyolites.

The intra-mountains Neogene molasse deposits and the associated igneous rocks. Neogene sediments in this area have been deposited in several NW-SE striking depressions, first in the south-eastern part of the region. Deposits include sandstones and conglomerates with intercalations of marls with andesite tuffs (Early Badenian), shaly sands and volcano-sedimentary deposits (Late Badenian), covered by shaly formations deposited during the sea recession stage. Pannonian deposits include gravel, sands and shales. Besides the Laramic magmatic activity, that had been manifest in the Northern Apuseni Mountains as well, in the Southern Apuseni Mountains there has additionally occurred a strong Neogene magmatic activity, accompanied by intense metallo-genetic processes, a circumstance to which the name "Metaliferi" given to those mountains is directly related (M. BLEAHU et al., 1981).

1.3. The carbonate deposits occurrence areas in Apuseni Mountains

In Apuseni Mountains, carbonate deposits consisting of limestones and of dolomites of sedimentary and crystalline types outcrop over areas of various extents, unevenly distributed at the overall scale of the mountains unit (Fig. 1.1). Sedimentary carbonate deposits display their largest extent in Pădurea Craiului Mountains and in Bihor Mountains, the large majority of those deposits being ascribed to the Bihor Unit.

Within the sedimentary formations series of the Bihor Autochtonous Unit there occur three large carbonate series, of outstanding hydrogeological interest:

• *the Triassic carbonate series*, up to 1500 m thick and consisting of Anisian limestones and dolomites and of Ladinian limestones, underlain by the Permian-Werfenian detritic series. The Werfen Formation, of Early Triassic age, is 150-200 m thick and it consists of quartz conglomerates, quartz sandstones and shales with dolomite inter-beddings at the upper part;

• *the Jurassic-Early Aptian carbonate series*, 200-550 m thick on the average and consisting of a limestone series ascribed to the Midle (8-75 m) and the Late (120-150 m) Jurassic and to the Early Barremian-Aptian (the pachiodonta lower limestone, 50-350 m thick). That series is underlain by prevalently detritic deposits of Early Jurassic age, up to 70 m thick and consisting of shales and quartz sandstones (the Gresten Formation), the latter deposits separating it from the Triassic carbonate series.

Subsequently to the deposition of the Late Jurassic limestones, the Bihor Unit domain has been uplifted above the sea level, and as a result a widely developed paleo-karst and associated bauxite lenses occurred on the indicated limestones surfaces. There has then followed the deposition of the characeea limestone (0,5-1 m thick) and of the gasteropoda limestone (2-4 m thick), each of them of Neocomian age, after which the pachiodonta lower limestone, of Early Aptian age and 300 m thick has been deposited. The carbonate series has been overlain by a monotonous, 100-700 m thick series consisting of gray marls (the Ecleja Layers).

• *the Late Aptian carbonate series*, which consists of the pachiodonta medium limestone, 60-350 m thick. That limestones is overlain by the glauconitic sandstones and by the pachiodonta upper limestone complex (700 m thick, of Aptian-Late Albian age). The limestones belonging to that complex occurs as lenses.

In Pădurea Craiului Mountains, carbonate deposits of the Bihor Autochtonous Unit outcrop over an area of 304 km^2, out of which 29 km^2 occur within the Remeţi graben.

Carbonate series within the tectonic units of the Codru Nappes System occur mainly in Codru Moma Mountains, occupying an area of 165 km^2. In Vaşcău plateau they build a compact plate that extends over 90 km^2. Also the tectonic units of that system which occur on the western slopes of Vlădeasa Mountains Body and of Bihor Mountains include in their lithologic constitution carbonate sequences of significant development.

In the Southern Apuseni Mountains, carbonate deposits prevalently occur in Trascău Mountains, within the Fundoaia, the Bedeleu and the Râmetea nappes. The crystalline basement of the Fundoaia Nappe consists of quartz schists and of limestones of Late Devonian - Early Carboniferous age. Within the Bedeleu nappe, the lithologic succession includes at the bottom the keratofiric formation with micritic limestones inter-beddings (of Oxfordian - Early Tithonic age), then chert limestones (of Oxfordian - Early Tithonic age), compact limestones (of Late Tithonic - Berriasian age), and micritic, red and green limestones (of Valanginian - Hauterivian age). Within the Râmetea Nappe the carbonate sequence consists of compact limestones (of Late Tithonic - Berriasian age), underlain by andesitic rocks and keratofires, and overlain by unconformably deposited detritic flysch-like deposits.

Southward of Arieşu Mic stream, the karst plateau Poieni extends over an area of 88 km^2, between Câmpeni and Avram Iancu, being developed in the crystalline limestones of the Muncel-Lupşa Nappe.

Crystalline limestones and dolomites outcrops also occur in the Gilău Mountains south-eastern extremity, in the Poşaga and Ocoliş streams catchment areas. Limestones occurs there as narrow strips (1-3 km in width), that are clearly delineated in the local topography and are transversally dissected by the main streams network.

The Apuseni Mountains southernmost occurrences of carbonate deposits are met in Rapolt area, to the north of Mureş river. The deposits belong to the Rapolt crystalline limestones outcrop, they consist of crystalline limestones and dolomites, and in structural terms they belong to the Getic Nappe.

1.4. The hydrogeological map of Apuseni Mountains

In terms of lithology, Apuseni Mountains exhibit a large diversity, being at the same time highly complex in structural-tectonic terms, circumstances which result in various patterns of groundwater recharge, flow and discharge. In devising the legend of the hydrogeological map in Fig.1.5, the lithologic constitution has been assumed to be the main factor which controlled the hydrogeological characteristics of the geological formations. Since no quantitative measurements of the hydrogeological parameters had been performed either “in situ”, or in the laboratory, the author has expanded the description of the characteristics by adding detailed observations he has collected in the field. The geological formations involved in the Apuseni Mountains geological build-up have been categorized into the following hydrogeological entities (Fig. 1.5):

- Mesozoic (a-sedimentary limestones and dolomites) and Paleozoic (b-crystaline limestones and dolomites) carbonate series, highly fractured and karstified, characterized by very high effective infiltration and prevalently conduit porosity with intensive groundwater flow. A large number of karst systems of various extents and prevalently of binary type. Important water resources in large karst systems.
- Prevalently molasse deposits (sandstones, conglomerates and less frequently shales) with double porosity. The groundwater flow is mostly confined to the fracture and stratigraphic joints, and to a lesser extent to the inter-granular pores. When they are thick, they act as an impervious barrier for karst water reservoirs and frequently form bedrock and/or caprock for the latter: a-Permo-Mesozoic molasse; b-Upper Cretaceous cover and Miocene transgressive deposits.
- Paleozoic granites (a1) and rhyolites (a2), mesozoic ophyolites (b), Laramic intrusive (c1) and volcanic (c2) magmatites, Neogene volcanites (d) and metamorphytes (e) with extensive fracture networks and well developed weathering zones providing a continuous and important supply to rivers and to binary karst systems;
- Pannonian and Quaternary deposits (marls, shales, sands, gravels), hosting discontinuous water accumulations in the more permeable terms;
- Marly and argillaceous deposits, devoid of groundwater flow, and flysch-like series including rock-complexes of variable permeability (marls, shales, sandstones, limestones), occasionally hosting discontinuous water accumulations occurring in the more permeable terms.

On the hydrogeological map there are also indicated the drinking water discharges with annual average flow rates in excess of 30 l/s, the thermal and mineral water (still water included) discharges that are genetically related to carbonate rocks, as well as the most significant caves and potholes.

Signification of the colors, lines and symbols on the hydrogeological maps in this chapter are shown in legend in Figure 1.6.

1.5. A short history of the karst research in Apuseni Mountains

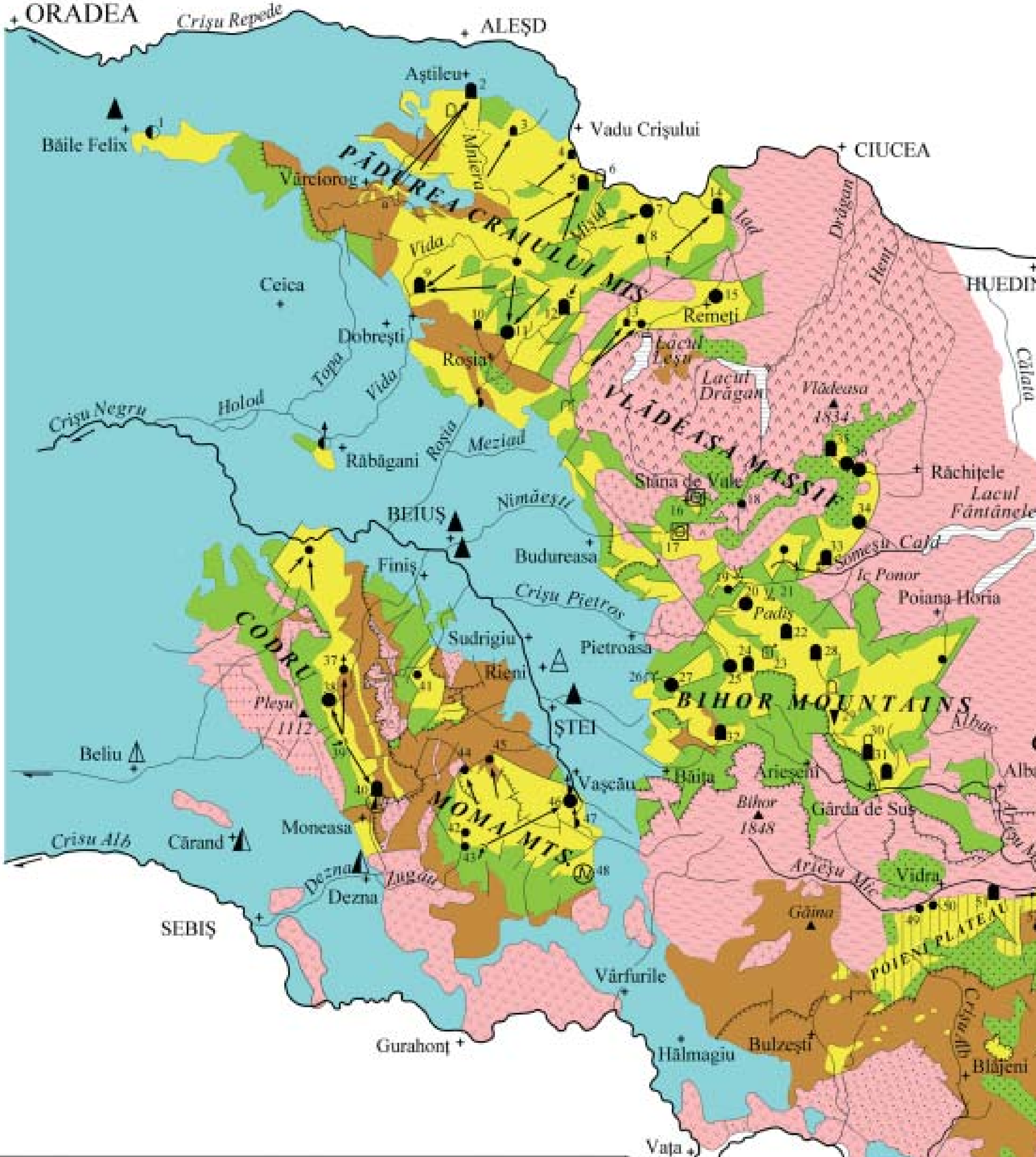
In the Apuseni Mountains karst areas, the oldest pieces of information about karst springs and groundwater pathways have been provided by geographers, geologists and cavers.

In the year 1863, Austrian geographer A. SCHMIDL published in Vienna the book "Das Bihar Gebirge an der Grenze von Ungar und Siebenburgen" ("Bihor Mountains at the border between Hungary and Transylvania"), the first geographical and speleological study of major extent that addressed a specific area located on the territory of our country.

In the year 1901 there has been conducted the first tracer test addressing an underground stream course located on Romania's territory. The experiment has been performed by the Romanian geologist S. MIHUŢIA, who injected coal powder in the brook Tarina, up in Vaşcău plateau, and thus ascertained the hydrological connection between the swallet cave Câmpeneasca and the spring Boiu, in the proximity of Vaşcău town (Fig. 1.7).

During the period 1946-1956, researchers of the Institute of Speleology in Cluj-Napoca, D. COMAN, M. ŞERBAN and I. VIEHMAN, together with M. BLEAHU and later on accompanied also by T. RUSU and Gh. RACOVIŢĂ, have conducted explorations that resulted in discovering the large karst cavities of Bihor Mountains, Pojarul Politei cave next to Scărişoara Glacier Cave, the pothole in Şesuri, Peştera Neagră de la Barsa Cave, Căput cave, the cave networks Lumea Pierdută and Cetăţile Ponorului.

In the year 1957, a fluorescein tracer test performed by M. ŞERBAN, D. COMAN and I. VIEHMAN outlined the hydrological connection relating the underground stream course in the pothole in Şesuri with the spring Pojarul Poliţei, then in the year 1970, T. RUSU, G. RACOVIŢĂ and D. COMAN published a paper addressing the Karst Complex Scărişoara, in which they men-



Iancu Orăşeanu

BRAD

DEVA

Figure 1.5. HYDROGEOLOGICAL MAP OF THE APUSENI MOUNTAINS

0 5 10 15 km

Site key

1. Peţa lake
2. Aştileu spring
3. Moara Jurjii spring
4. Cave at Vadu Crişului
5. Izbândiş spring
7. Brătcanilor spring
6. Vântului cave
8. Dămişenilor spring
9. Topliţa de Vida spring
10. Topliţa de Roşia spring
11. Roşia spring
12. Toplicioara spring
13. Peştera cu Apă din v. Leşului cave
14. Peştera cu Apă de la Bulz cave
15. Tăul fără Fund spring
16. Minunilor spring (Wonder spring)
17. Cuciului (Hera) spring
18. Ciripa spring
19. Valea Rea cave andspring
20. Boga spring
21. Vărăşoaia V5 pothole
22. Spring from Poiana Ponor
23. Cetăţile Ponorului cave
24. Galbenea spring
25. Păuleasa spring
26. Bears cave at Chişcău
27. Giuleşti spring
28. Gura Apei spring
29. Tăuz spring
30. Gheţarul de la Scărişoara
31. Coteţul Dobreştilor spring
32. Crişului spring
33. Alunu Mic spring
34. Şurile din Firea springs
35. Vârfuraşu spring
36. Spring of Sărcerului brook
37. Feredeu spring from Huta
38. Finişului spring
39. Dosu Varului ponor
40. Grota Ursului spring and group of spring and wells at Moneasa
41. Izvorul Mare al Tărcăiţei spring
42. Spring of Valea Seacă
43. Răschirata spring
44. Tisei spring
45. Şopoteasa spring
46. Boiu spring
47. Crisciorel spring
48. Ebb and flow spring at Călugări
49. Lerţii spring
50. Pişoaia Vidrii spring
51. Morii spring
52. Feredeu spring at Sohodol
53. Bujorul ebb and flow spring
54. Huda lui Papară cave
55. Iezerul spring
56. Feredeu spring at Băcăia
57. Tămăduirii spring
58. Apa Acră spring
59. Thermal sources at Geogiu Băi and Clocota spring
60. Feredeu spring at Bobâlna
61. Warm spring at Rapolţel
62. Bampotoc well
63. Mineral waters at Chimindia

Verso A3

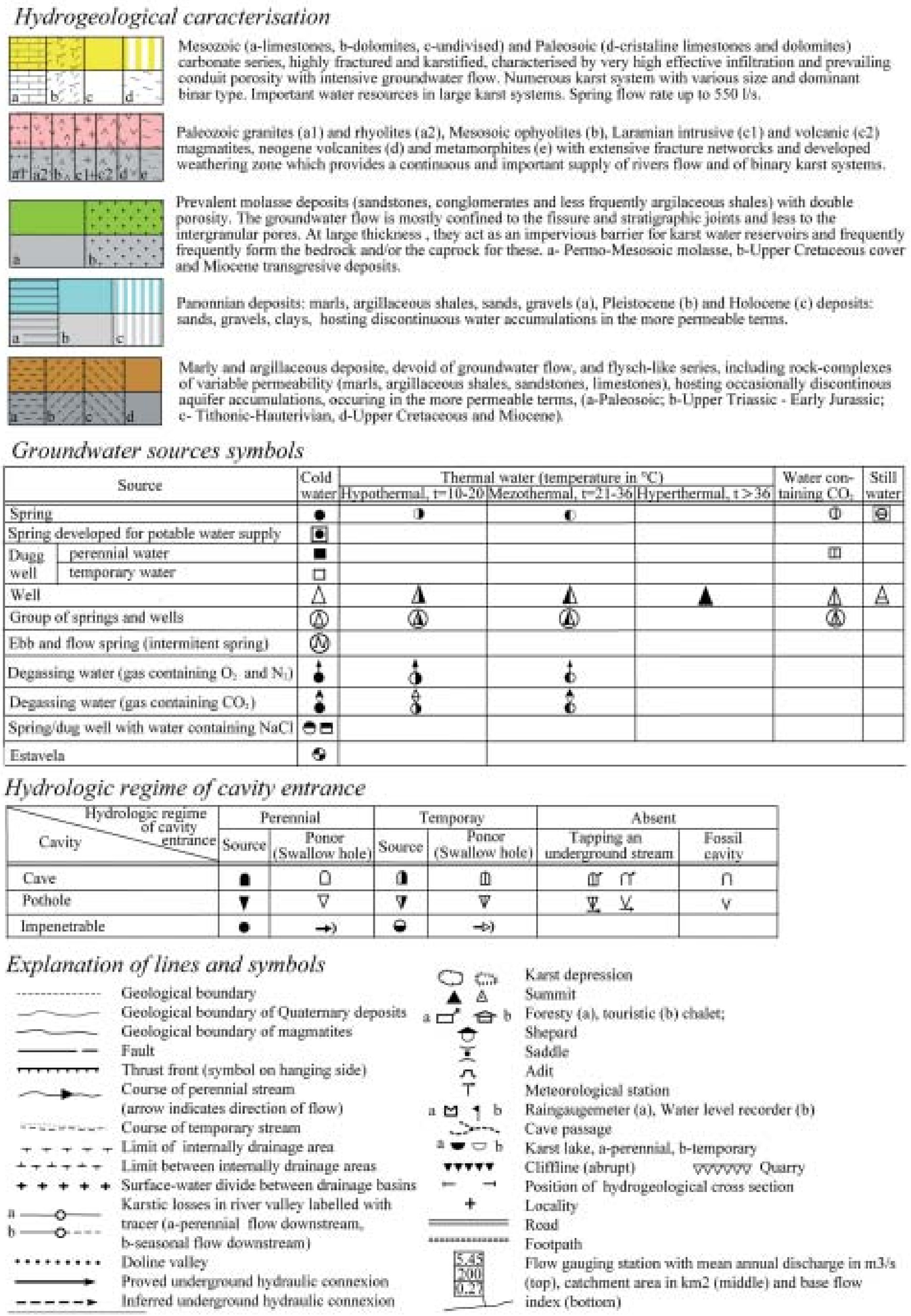


Figure 1.6. Explanation of lines, symbols and colours used on the hydrogeological maps.

tioned a tracer test they had performed in the year 1964 and by which they had outlined the underground flow of Ocoale stream toward the spring at Coteţul Dobreştilor (Fig. 1.8).

A tracer test performed by I. VIEHMAN in the year 1958 has outlined the underground connection between the sinking points of Tămaşa brook, in the proximity of the burned up chalet in Padiş, and Ponorului spring. Three years later, the same author together with T. RUSU, C. PLEŞA, C. RISCUŢIA and A. ROHRICH have traced the surface stream that sinked in Poiana Ponor (Râturile Ponorului), the fluorescein reaching Galbena spring after 66 hours (I. VIEHMAN, 1966, Fig. 1.9).

In the year 1980, I. VIEHMAN, E. CRISTEA, M. ŞERBAN, O. CUC and S. GHITEA, have published a paper in which they traced the history of the explorations in Cetăţile Ponorului Karst Complex and provided descriptions of the associated flowpaths network and of the giant sinkholes and underground passages.

Over the time interval 1960-1988, the Pădurea Craiului Mountains karst areas have been subject to detailed karst topography and hydrology investigations conducted by T. RUSU, who performed a multitude of fluorescein tracer tests, by which he outlined the main karst flow directions. The integral publication of those results occurred in the year 1988.

During the 1970-2001 period, hydrogeologists of the Geological and Geophysical Prospecting Company (the present-day "Prospecţiuni" S.A. company) have carried out a systematic an continuous investigation of all the karst mountain units belonging to Apuseni Mountains: Pădurea Craiului, Bihor Vlădeasa, Codru Moma, Poieni Plateau, Trascău and the area of Rapolt. The performed investigations aimed at assessing the groundwater resources, at studying the thermal water accumulations, at outlining the hydrogeological settings of the Pădurea Craiului Mountains bauxite accumulations and of the complex mineral ores in Băiţa Bihor area, at assessing thermal and still water prospects. Over that entire time interval, investigations have been performed by I. ORĂŞEANU and NICOLLE ORĂŞEANU, with E. ANGHEL joining in for the Apuseni Mountains thermal water occurrences investigation during the year 1974, Gh. PONTA and N. TERTELEAC presence in Codru Moma Mountains hydrological research in 1977-1978 period while A. IURKIEWICZ and H. MITROFAN joined in for the investigation of the hydrogeological setting of the Pădurea Craiului Mountains bauxite accumulations, over the time interval 1981-1982.

In the framework of the activities aimed at groundwater resources assessment, there have been set up temporary networks for collecting hydrometeorological data. Building up those networks, performing the specific observations and measurements and processing the obtained data have been conducted by the author in cooperation with GHEORGHE & PARASCHIVA HOŢOLEANU and with LUMINIŢA TIBACU of the INMH, for Pădurea Craiului Mountains (over the hydrologic years 1981-1982 and 1982-1983), for Bihor Vlădeasa Mountains (over the hydrologic year 1984-1985) and for Rapolt area (over the hydro-

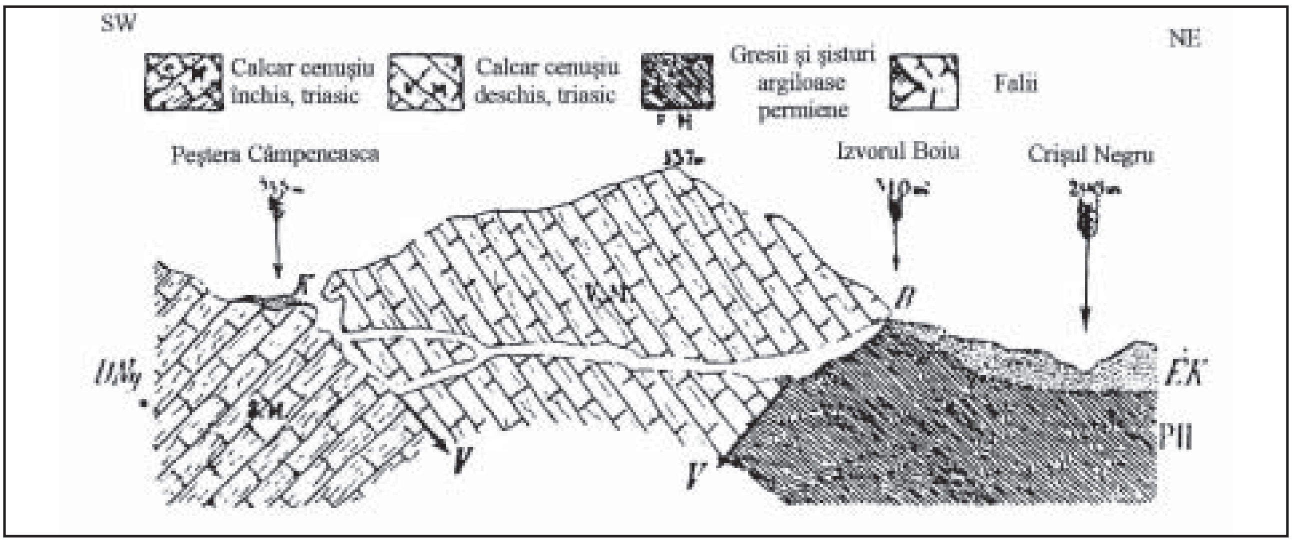


Figure 1.7. Geological cross-section between Câmpeneasca cave and Boiu spring (MIHUȚIA, 1904).

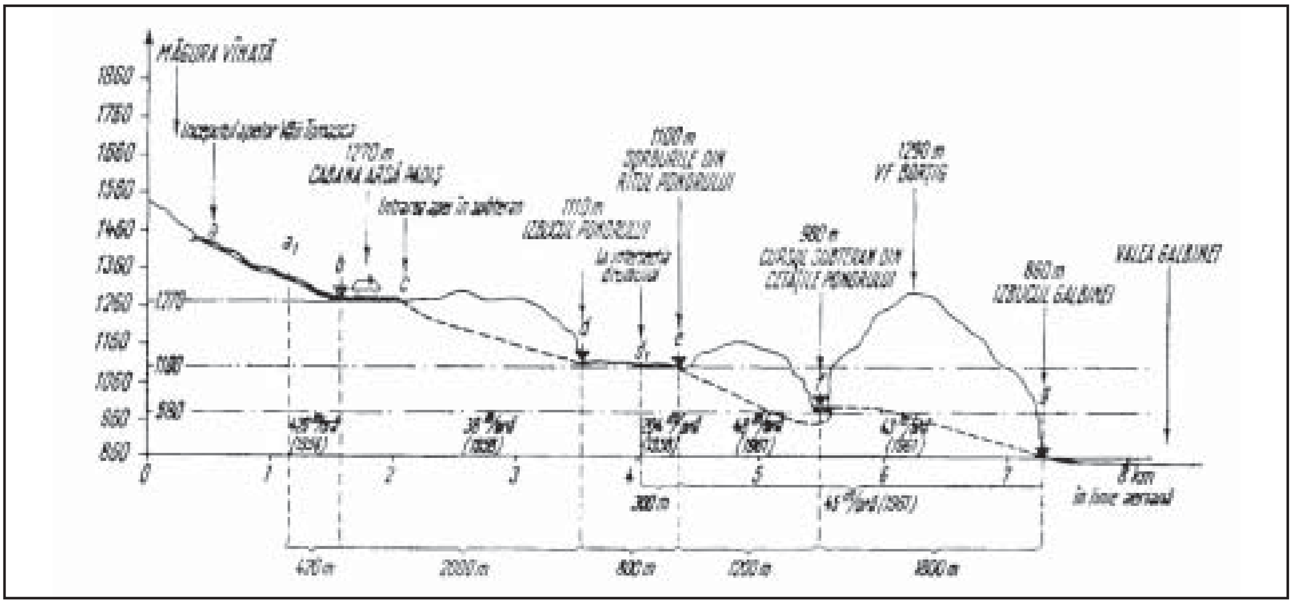


Figure 1.8. The mixed (sub-aerial and subterranean) pathway of the stream course in Padiș - Cetățile Ponorului - Galbena Valley (after I. VIEHMAN, 1966).

logic year 1995-1996), and together with I. POVARĂ, TH. RUSU, C. MARIN, MARIA ALB, G. DIACONU, I. VIEHMAN, V. CRĂCIUN and P. COCEAN of the Institute of Speleology E. Racoviţă for Pădurea Craiului Mountains (over the hydrologic years 1981-1982 and 1982-1983).

Over the time interval 1970-2009, the author has conducted, either on his own or in cooperation with other investigators, more than 100 tracer tests, many of them performed together with E. GAŞPAR, a researcher of the Institute for Nuclear Physics at Măgurele, with I. POP, a professor at the High Education Institute in Baia Mare, and with A. IURKIEWICZ, a hydrogeologist of "Prospecţiuni" S.A. Part of those investigations results have been published in a series of papers.

A significant contribution to the knowledge of the Apuseni Mountains karst topography and hydrology has been provided by the papers of L. VĂLENAŞ, B. ONAC, P. COCEAN, E. SILVESTRU and P. DAMM.

There has to be also acknowledged the major contribution of the amateur cavers clubs in exploring and investigating the Apuseni Mountains karst. In many cases, the caves and potholes discovered by amateur cavers have attracted the scientists' in-

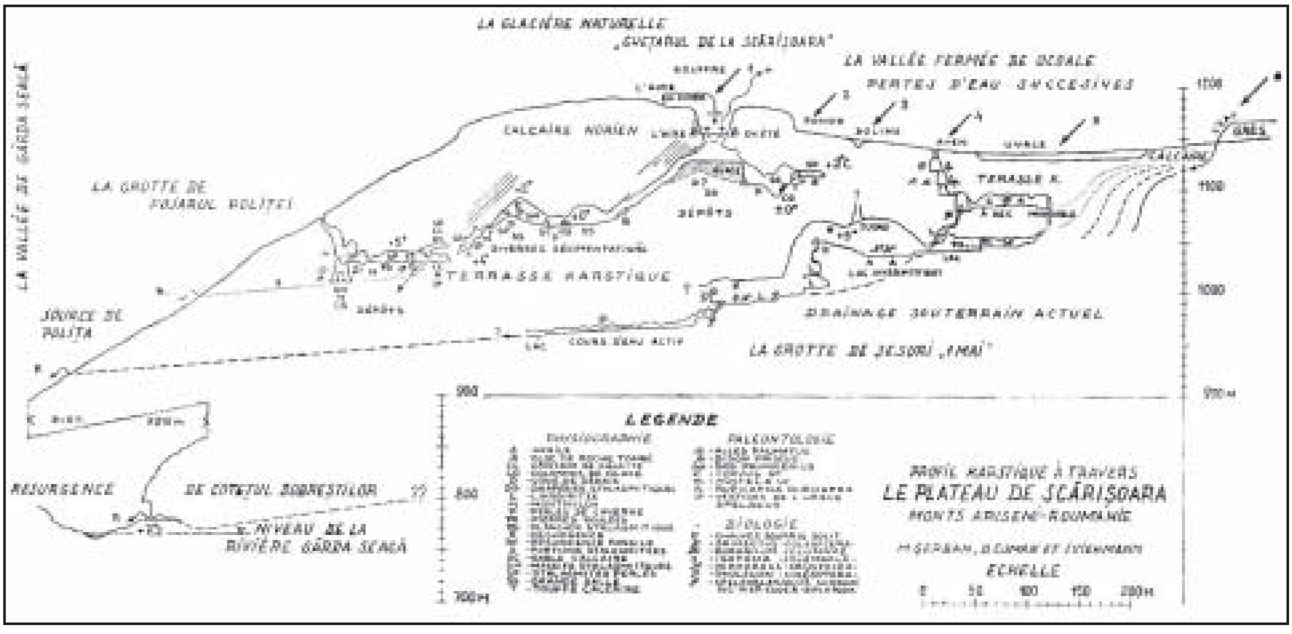


Figure 1.9. Karst cross-section across Scărișoara plateau (after M. ȘERBAN et al., 1957).

terest, and together with the latter, amateur cavers have contributed to the scientific investigation of this invaluable treasure of Apuseni Mountains.

The contributions of various investigators to the knowledge of the Apuseni Mountains karst hydrology shall be described in detail in the sections devoted to the presentation of the main karst areas.

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