3.11. BANAT MOUNTAINS (REȘIȚA-MOLDOVA NOUĂ SYNCLINORIUM)

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The Banat Mountains area, located in the south-west of Romania includes more than 800 km^2 of karst zones belonging to the Reşiţa - Moldova Nouă large synclinorium. Although scientific karst investigations were initiated at the beginning of the century, the previously collected hydrogeological data were rather local and contradictory. Taking into account groundwater resources that karst areas should normally contain, "Prospecţiuni" company has completed during 1992 - 1998 a complex research program, in order to evaluate the amount of groundwater resources of this particular area.

The karst territory was divided as a result into three distinct zones (compartments), which roughly correspond to the Caraş (Northern), Miniş-Nera (Central) and Nera-Danube (Southern) catchment areas. The hydrologic, hydrodynamic and hydrochemical characteristics of the karst systems included within these zones are discussed. The water budget completed based on 1992-1998 data provides information on underground hydrologic connections between small catchment basins, and eventually for each of the above mentioned areas as a whole.

The hydrogeologic map covering all karst zones from Reşiţa - Moldova Nouă synclinorium was drowned based on hydrogeologic researches and consist of three compartments:

- Northern compartment (Fig. 3) – lying between Reşiţa (Bîrzava valley) and Anina (interfluve Miniş - Caraş valleys);
- Central compartment (Fig. 4) – located between Anina and Nera valley (Driştie - Sasca Română sector);
- Southern compartment (Fig. 5) – bordered by Nera valley (Driştie - Sasca Română sector) and Danube river (Moldova Nouă - Sicheviţa sector).

Figures 1 and 2 represent the assemblage of hydrogeologic maps as well as their legend.

1. Introduction

Within the Banat Mountains several important limestone areas occur, including the largest and most compact carbonate zone of Romania – the so called *Reşiţa - Moldova Nouă Synclinorium* which extends over some 800 km^2. The low-mountains landscape is characteristic for the entire area situated between the Reşiţa - Caransebeş Depression to the north and the Danube Gorge to the south. The northern section belongs to the morphological units of Aninei (to the west) and Semenic (to the east) mountains; its southern boundary is set along the Nera River stream bed. Between Nera and the Danube, the territory is known as Locvei (west) and Almaj (east) mountains, respectively.

Despite the fact that from a speleological point of view the carbonate area of the synclinorium has been relatively thoroughly investigated (Jeannel & Racovitza, 1929; Botoşăneanu et al., 1965; Negrea & Negrea, 1976), data concerning the hydrologic setting of karst, provided by different investigators, were isolated and sometimes contradictory.

Partial and qualitative information on the karst spring discharges and the hydrology of this area is given by Pascu (1983) and Cineti (1990). Major contributions to the investigation of the karst geomorphology in this area are due to Sencu (1970; 1973; 1986). His activity covered, with small gaps, more than 30 years. In order to identify the reciprocal relationships that exist between karst aquifers and the coal deposits from Anina area, many dye tracing experiments have been carried out by Sencu (1973) and Sencu & Cioacă (1980).

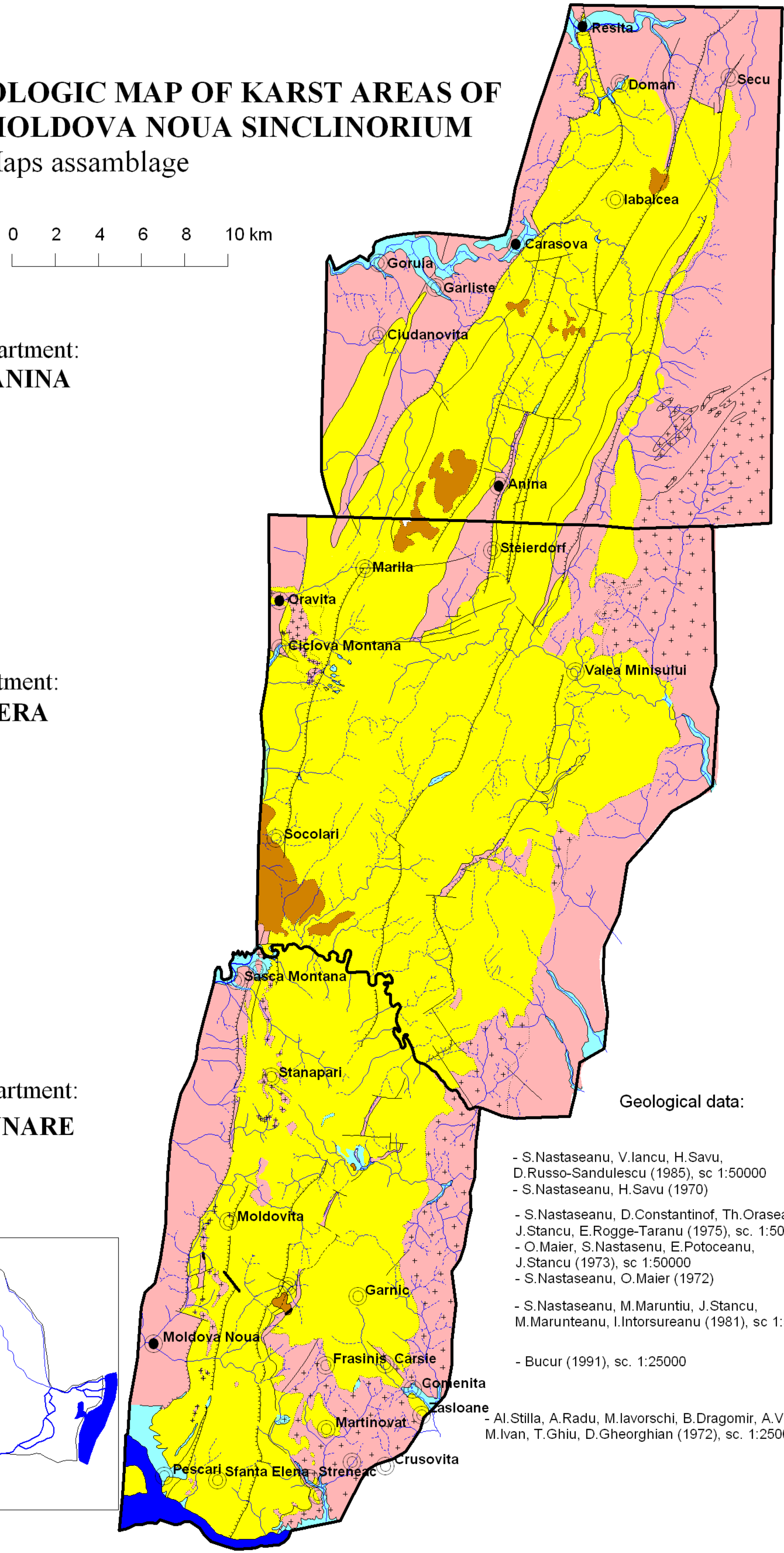
HYDROGEOLOGIC MAP OF KARST AREAS OF RESITA-MOLDOVA NOUA SINCLINORIUM

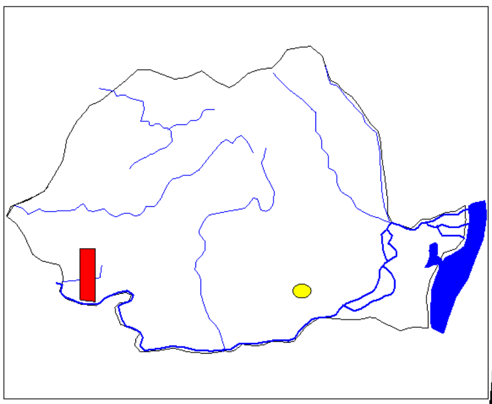
Maps assamblage

Northern Compartment:
RESITA-ANINA

Central Compartment:
ANINA-NERA

Southern Compartment:
NERA-DUNARE





Geological data:

- S.Nastaseanu, V.Iancu, H.Savu, D.Russo-Sandulescu (1985), sc 1:50000
- S.Nastaseanu, H.Savu (1970)
- S.Nastaseanu, D.Constantinof, Th.Oraseanu, J.Stancu, E.Rogge-Taranu (1975), sc. 1:50000
- O.Maier, S.Nastasenu, E.Potoceanu, J.Stancu (1973), sc 1:50000
- S.Nastaseanu, O.Maier (1972)
- S.Nastaseanu, M.Maruntiu, J.Stancu, M.Marunteanu, I.Intorsureanu (1981), sc 1:50000
- Bucur (1991), sc. 1:25000
- Al.Stilla, A.Radu, M.Iavorschi, B.Dragomir, A.Visarion, M.Ivan, T.Ghiu, D.Gheorghian (1972), sc. 1:25000

L E G E N D

Detritic deposits with reduced thickness and extension hosting local aquifers (pore flow).
(Quaternary)

Detritic deposits, indurated and non-indurated, molasse type, with reduced thickness and extension hosting local aquifers.
(Neogene, Pleistocene)

Carbonate Mesozoic series (limestones) highly fractured and karstified of large extension and thickness; exhibit high effective infiltration capacity and intensive groundwater flow. Numerous springs of 1-50l/s to 300l/s and elevated variability index
(Upper Triassic - Lower Cretaceous)

Metamorphic series, clay, sandstones and conglomerates of large extension and thickness but reduced permeability of fissures. Groundwater flow mostly confined to weathered zone. Springs with reduced flow rate (up to 1L/s).

Magmatic rocks with large extension and thickness. Permeability of fissures related to tectonised and metamorphic contact areas, with discontinuous distribution and intensity. Springs of 1-2L/s.
(Upper Ante-Proterozoic, Upper Cretaceous)

Hydrologic regime of cavity	Perennial		Temporary		Absent	
Cavity	Source	Ponor	Source	Ponor	Tapping an underground stream	Fossil cavity
Cave						
Pothole						
Impenetrable						

Losses in flow along the riverbed

a. Temporary total

b. Permanent partial

Course of perennial stream

Course of temporary stream

Karst depression

Cave passage

Spring with gas release

Groundwater flow direction

Proved

Hypothetical

Hydrogeologic well

under 1 L/s

1-5 L/s

5-10 L/s

10-50 L/s

50-300 L/s

Geologic boundary in general

Discordant boundary

Overthrust

Reverse fault

Vertical or subvertical fault

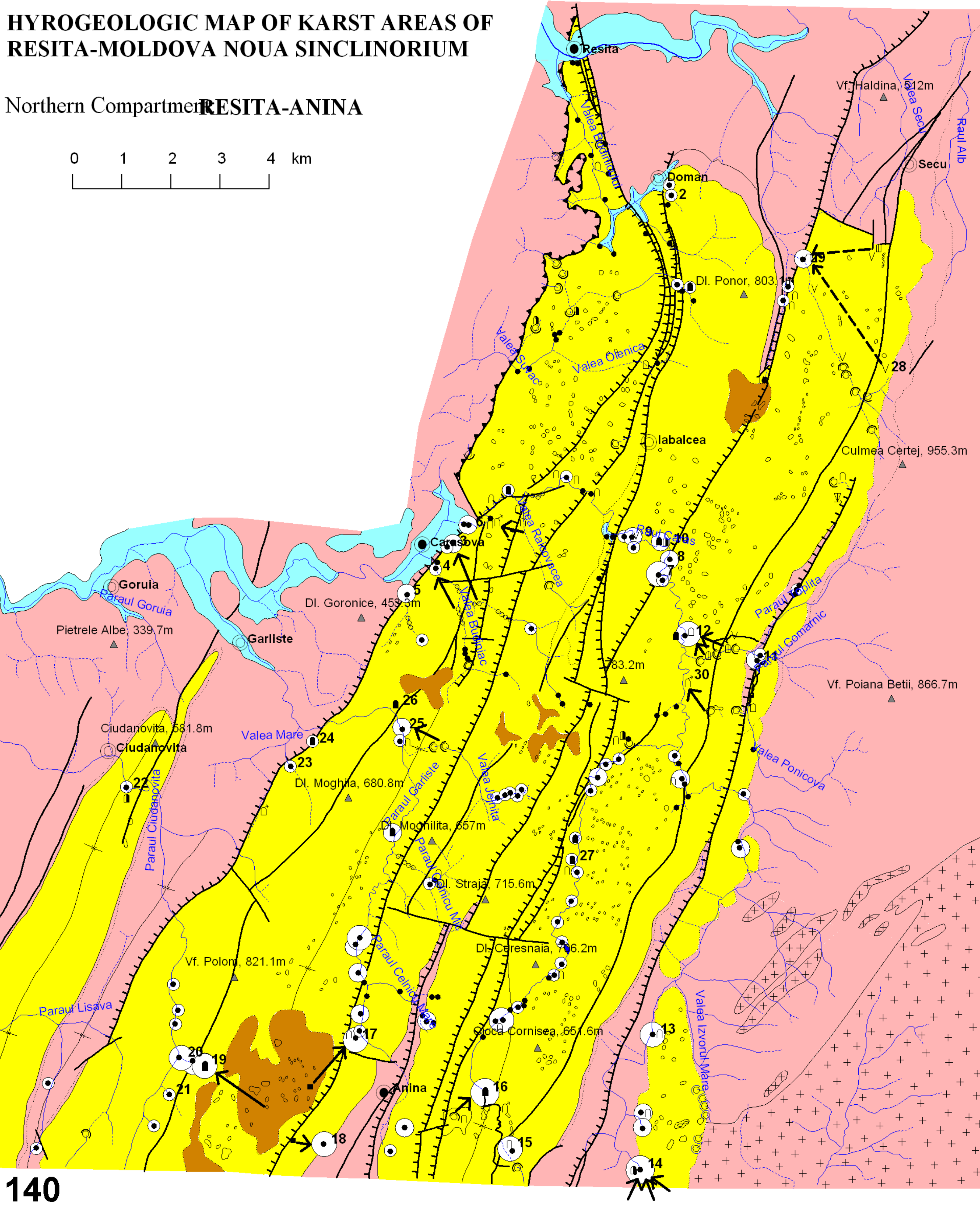
Antecline axes

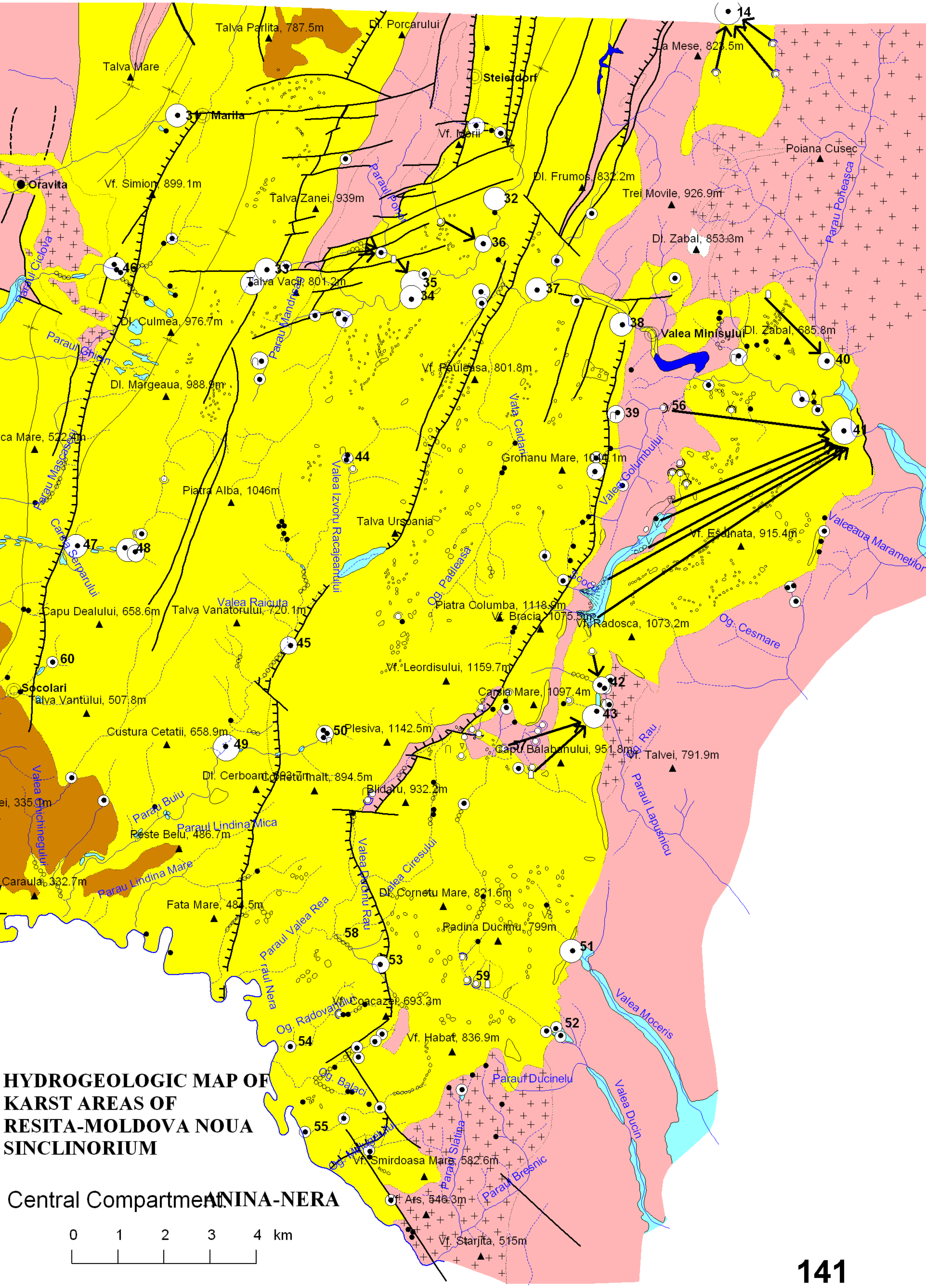
Syncline axes

78 Index of karst phenomenon (spring, ponor, cave, pothole)

HYROGEOLOGIC MAP OF KARST AREAS OF RESITA-MOLDOVA NOUA SINCLINORIUM

Northern Compartment RESITA-ANINA





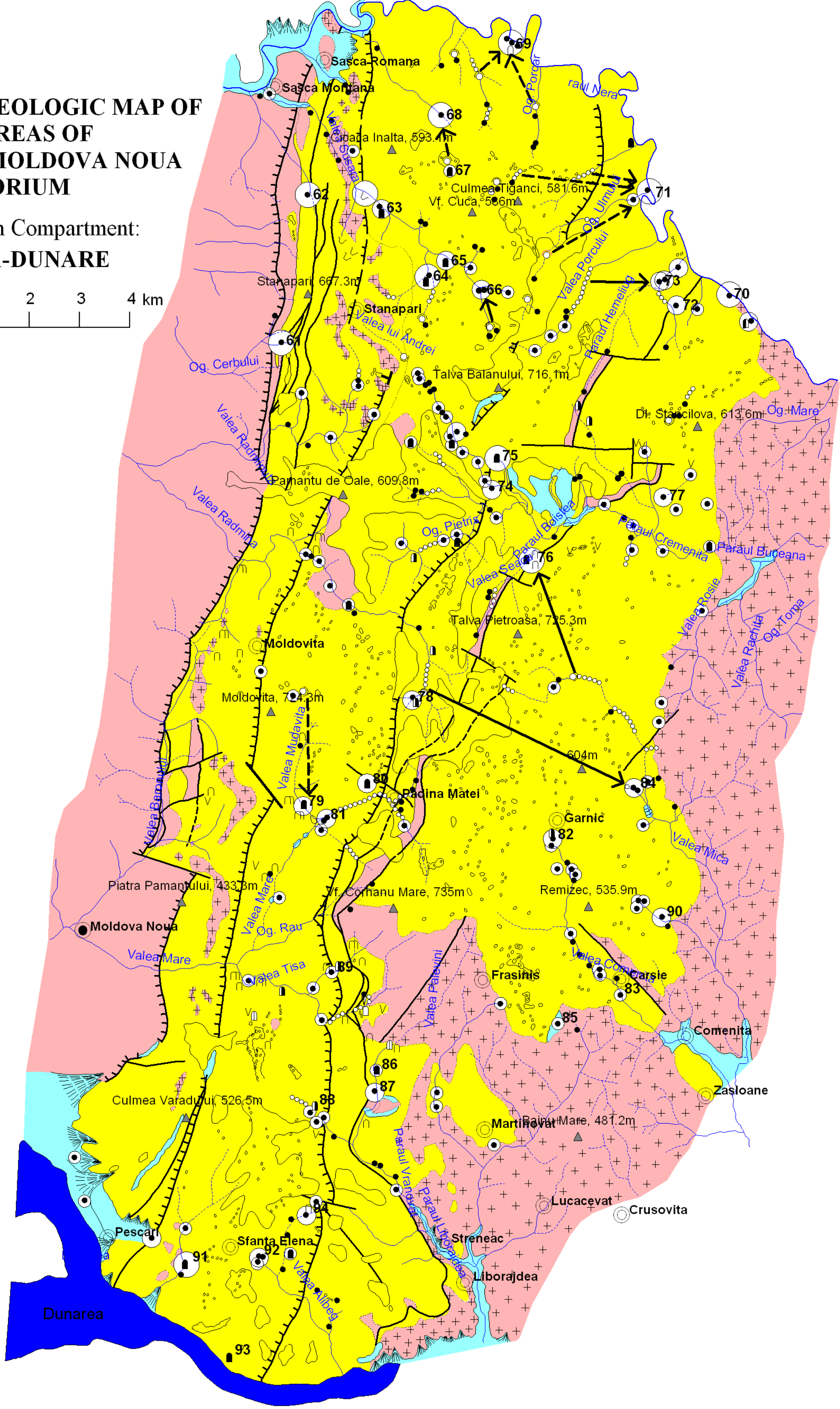
HYDROGEOLOGIC MAP OF KARST AREAS OF RESITA-MOLDOVA NOUA SINCLINORIUM

Central Compartment ANINA-NERA

HYDROGEOLOGIC MAP OF KARST AREAS OF RESITA-MOLDOVA NOUA SINCLINORIUM

Southern Compartment:

NERA-DUNARE



For the evaluation of the karst water potential of the Reşiţa - Moldova Nouă synclinorium, beginning with 1992 "Prospecţiuni" S.A. initiated a complex program comprising dye tracing tests, hydrometric records, hydrochemical analyses, etc, main results being summarized by Iurkiewicz, et al. (1996) and eventually by Iurkiewicz (2004).

2. Reșița - Moldova Nouă Synclinorium, General Presentation

The large Reşiţa-Moldova Nouă synclinorium extends over two physiographic units, *Aninei* Mountains, that occupy its northern and central section, and Locvei Mountains, lying in it southern part, with Nera valley as the boundary in-between.

The landscape includes a succession of parallel ridges and valleys striking mainly NNW-SSE, according to the overall geologic structure. The most important ridges (Pleşiva-Leordiş, Vf. Dealului-Cununa) are located south of Miniş valley, where the top altitudes are reached (1159 m, 1047 m). The eastern border of the sedimentary zone is well marked by an almost continuous escarpment that follows the limit between the crystalline schists and the Mesozoic deposits. This escarpment can be followed from the *Bigăr* Spring down to the Nera Valley. As a result of levelling, the ridges are frequently turned into karst plateaus, pierced by sinkholes and swallets.

The density of the hydrographic network is close to 0.5 km/km^2 with local differences due to karst area evolution. The main streams, Caraş, Gârlişte, Buhui, Miniş and Nera, deeply dissect the limestones, forming scenic gorge sections.

The yearly average (1964-1994) rainfall value recorded at Anina station (650 m a.s.l.) is 1005.5 mm; the same parameter recorded (1950-1994) at Oraviţa station (220 m a.s.l.) is 849.7 mm. Computed evapotranspiration values fall, at least for the northern section of the considered area, within the 475-500 mm/year range. It is worth noticing, for a proper balance computation, that the weather characteristics of the eastern slope of the massif are strongly different as compared to those from the western side, due to the Mediterranean influences.

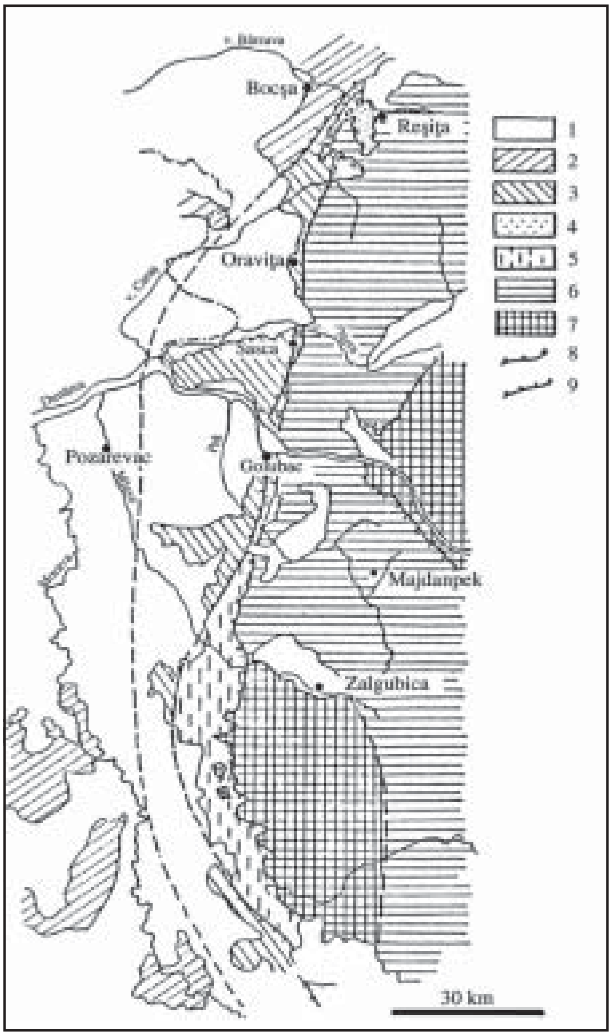


Figure 6. The main tectonic alpine units of the inner section of Southern Carpathians (Năstăseanu & Maksimovic, 1983).

2.1. Geology and Structure

As already mentioned, this zone belongs to the structural unit of the Getic Nappe. The deposits are folded as a large synclinorium with southward plunge.

The first tectonic synthesis on the Reşiţa-Moldova Nouă zone has been completed by Schreter in 1912; its main ideas are still valid and they have been additionally developed by the researchers which have been studying this area (Răileanu et al., 1957, Mutihac 1959, Năstăseanu, 1964, etc). In fact, the major structural elements established by Schreter are figured on the maps at the 1:50,000 scale completed during the last decades by the Geological Institute of Romania. The position of this unit within the general structure of Southern Carpathians has been extensively discussed (Bucur, 1991).

A relatively recent correlation of the alpine structures on both sides of the Danube (Năstăseanu & Maksimovic, 1983) led to the separation of the following units (from east to west): the *Getic* Unit, the *Sasca-Gornjak* Nappe, the *Reşiţa* Nappe, the *Dognecea-Luznica* Nappe and the *Bocşa-Morava* Nappe (Fig. 6).

The present day structural constitution is the result of the Hercynic and the Alpine tectonic cycles. The beginning of the Alpine movements is related to the Liassic transgression, while evidence concerning the various phases of this cycle of movements is provided by the Early Jurassic and the Albian-Cenomanian transgressions. As a result of these movements, the sedimentary deposits were imposed a very complicated structure, characteristic of which are the dislocation lines with thrust planes and the inclined folds, or those displaying significant attenuation of one limb.

In the synthesis on the geology of the Reşiţa-Moldova Nouă area, Năstăseanu (1964) outlines, from west towards east, the following folds displaying a jurassian style: the *Lişava-Gârlişte* Syncline, the *Natra* Anticline, the *Valea Domanului-Valea Jitinului* Syncline*,* the *Cornetul Mare-Ilidia* (*Valea Aninei*) Syncline, the *Polom* Anticline*,* the *Brădet* Syncline, the *Anina* Anticline, the *Central* Syncline (*Colonova;*), the *Beu Sec* Anticline, the *Pitulaţi* Syncline, the *Pleşiva* Anticline and the *Eastern* Syncline**.** Among them, the largest extension have the Brădet and Central synclines, the Anina Anticline and the Eastern Syncline, whose central infilling consists of Albian sandstones (Figures 7 and 9).

Many longitudinal and transverse faults, associated in some cases to important strike-slip faults, dissect this extremely folded geologic complex. The main regional longitudinal faults are *Reşiţa-Caraşova, Comarnic - Beu Sec, Prolaz*, *Terezia*, *Valea Aninei*, *Polom*, *Sodol*, *Ranchina*, *Simion*, and *West (Oraviţa) fault.*

Geologic investigations performed between 1970-1985, mainly by S. Năstăseanu, assisted by several other scientists associated to the Geological Institute of Romania, resulted into several sheets of the geologic map of Romania, at the 1:50 000 scale, which cover this area (Năstăseanu et al., 1970, 1972, 1975, 1978, 1981, 1985). The sedimentary succession includes the entire Late Paleozoic-Neozoic interval, with still several hiatuses being recorded. Within the lower half of the interval, mostly non-carbonate deposits occur, including conglomerates and sandstones of various facieses. In addition, schistose clays, black shales, coal sheds and coal layers are associated to this Carboniferous-Permian and Liassic-Early Callovian age series (Fig. 7).

The transition facies occurs in the form of an essentially marly formation, which includes marly sandstones, compact marls, marly limestones and carbonate sandstones. A carbonate series of Late Jurassic-Cretaceous age follows, which includes, chronologically (Fig. 7), *Gumpina* limestones, *Tămaşa* marls, *Valea Aninei* limestones, *Brădet* limestones, *Marila* limestones and *Crivina* marls. This carbonate series displays a typical pelagic facies. It is followed by middle shelf and reef limestones which correspond to the major transgression recorded beginning with the Barremian: *Plopa* (lower and upper) and *Valea Minişului* limestones. The carbonate sequence lasts until the end of Bedoulian (Lower Aptian) when continental conditions are recorded. During the Albian period, the sedimentation resumes with the deposition of a detritic formation (*Golumbu* Sandstone).

Within the above mentioned carbonate series, distinct lithologies (micritic and biomicritic, organic or reef limestones), and accordingly distinct ages can be separated. Although up to 1200 m thick, the carbonate stack is relatively homogeneous in what concerns its water transfer and storage properties.

The indicated tectonic and geologic factors contributed also to the current configuration of the water accumulations in the carbonate deposits. The complex role of the main fractures and of the accompanying second-order faults is outlined by their coincidence with the lineaments of swallets and springs through which the karst aquifer discharges. Besides improving drainage characteristics, the fractures also separate distinct aquifer compartments, and as a consequence they act as boundaries between the main karst areas and systems.

2.2. Premises of Karstification

Permeable Rocks

The pervious rocks complex begins with Middle Jurassic deposits - Gumpina Limestones. These are followed by the complex of the so-called

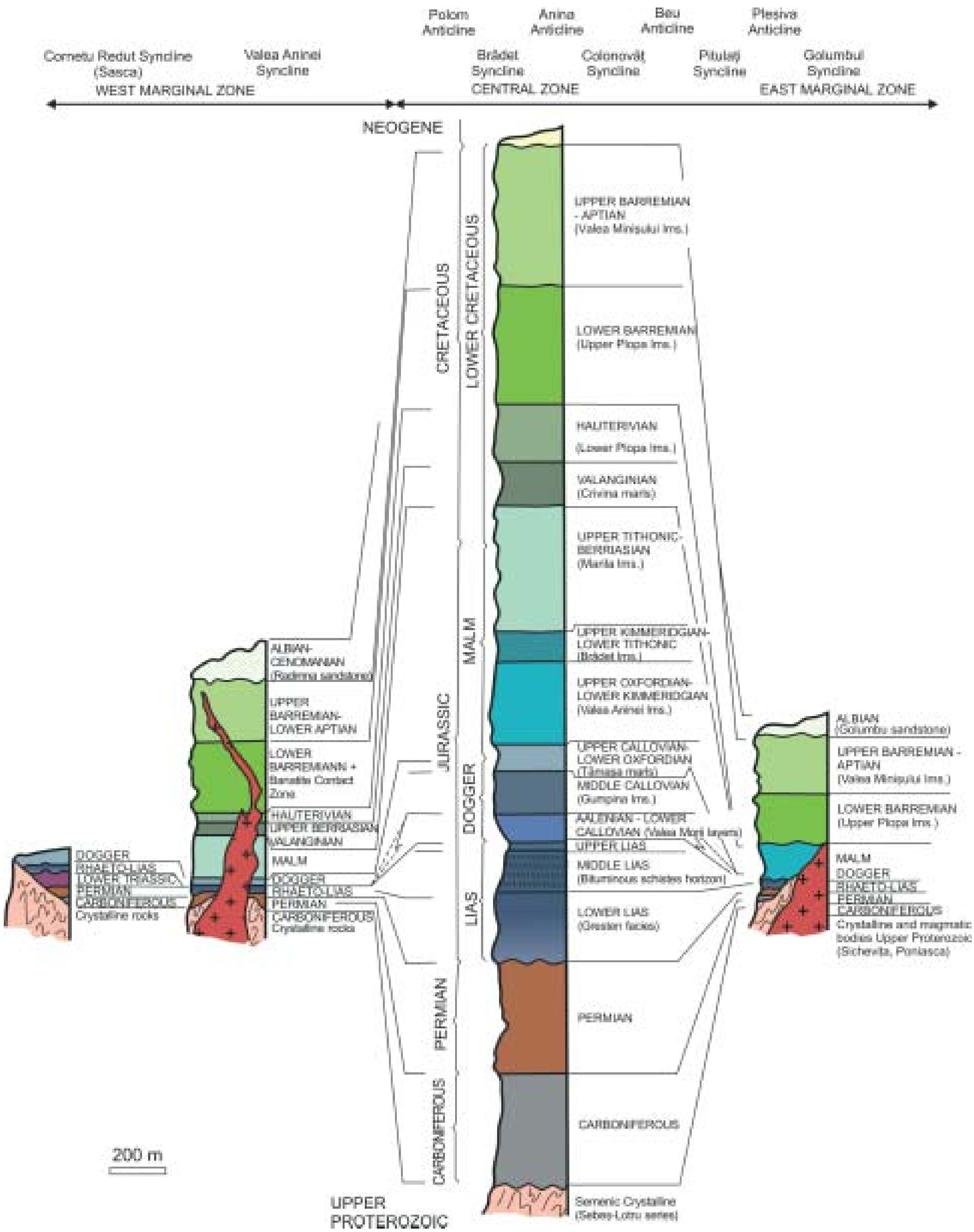


Figure 7. Lithostratigraphic column of central *Reșița-Moldova Nouă* Synclinorium and lateral facies. (STILLA et al 1972, modified).

Age (lithofacies)	Calcite (%)	Dolomite (%)	Impurities (%)
ox_2+km_1 (Valea Aninei limestone)	91.29 - 94.55	5.89 - 2.84	2.08
	86.02 - 93.1	4.60 - 16.06	1.01 - 1.84
km_2+th1 (Brădet limestone)	94.14	–	5.17
	79.85	8.62	8.71
br (Upper Plopa limestone)	88.56 - 94.90	7.53 - 2.78	1.91
	94.08 - 94.97	3.86 - 4.92	0.34 - 0.64
ap_2 (Valea Minişului limestone)	90.46 - 91.35	1.18 - 0.22	7.32
	88.2	3.94	5.03

Table 1. Mineralogical composition of four main carbonate deposits.

Tămaşa Marls which are, in fact, marls and marly limestones, which, although less-permeable, do not form an impervious screen and may be considered as 'pervious'. These deposits support the limestones of Valea Aninei (Upper Oxfordian - Lower Kimmeridgian), followed by the limestones of Brădet (Upper Kimmeridgian-Lower Tithonian) and Marila (Upper Tithonian-Berriasian). After a marly sequence belonging to the Valanginian, the carbonate series continues with middle shelf and reef limestones of the Barremian - Lower Aptian interval (Plopa and Valea Minişului limestones). Among them, the Plopa Limestones are the most pure (94.08-99.07% calcite and 3.86-4.92% dolomite).

The results of 80 chemical and 37 spectrographic analyses (Bucur & Pomîrjanschi 1986) carrried out on carbonate rock samples collected from three boreholes drilled in Doman area as well as from mining or cave galleries, assisted in procentual assessment of calcit, dolomit, clay and silicon components (Table 1). According to these results, *Valea Aninei and Upper Plopa limestone are the most propitious to karstification,* this situation being confimed by other field data.

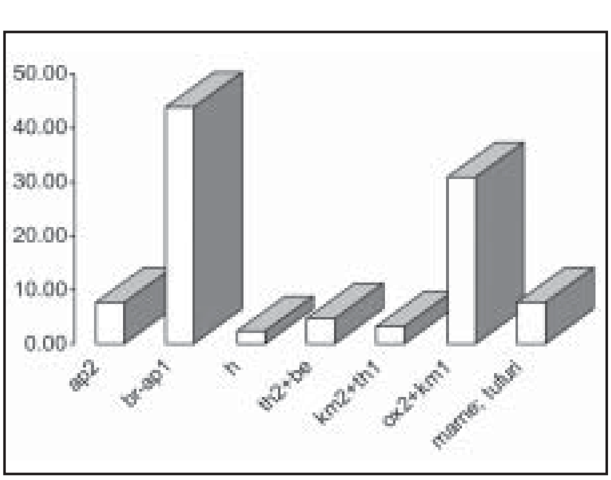


Figure 8. Karst phaenomena occurency (%) in different carbonate formations.

The various affinity to karstification of the carbonate deposits from the northern compartment of Reşiţa - Moldova Nouă sinclinorium had been revealed through surveys conducted for surface and underground karst phaenomena. Thus, based on the number of karst hole entities (caves or potholes) inventoried for ten carbonate formation, the *Upper Plopa limestone* (57.10%) *as well as Valea Aninei limestone* (30.5%), appear as most karstified (Iurkiewicz et al., 1996); similar situation was recorded for swallets and karst springs. The synthesis of the inventoried karst phaenomena in main carbonate formations is briefly presented as percentages in Table 2 and Figure 8.

In the same category (permeable rocks) could be included the thermal and chemical contact rocks (skarns and hornfels) formed at the limit with 'banatites' intrusions. The original permeabilty of these deposits have been improved on account of the intrusions that have induced a secondary permeability, leading to a karst-type water circulation. This type of circulation has been recorded at the -50 m level of the Ciclova Montana mine. Thermal waters with a temperature of 29.3°C and pressure up to 3.5 bars have been intercepted in several sites at this horizon, either in boreholes or in the galleries.

South of Nera valley, the occurency of these deposits is connected to the alignment of *banatite* intrusions (three km in width) extending from north to south between Sasca Montană and Moldova Nouă. This structure is clearly delimited by the *West* (Oraviţa) and *Simion* faults and include the carbonate deposits of Upper Triassic age

Limestone age	ap_2	$br\text{-}ap_1$	h	th_2+be	km_2+th_1	ox_2+km_1	Other rocks (marls, tufa)
Caves and potholes	4.5	57.10	0.14	3.65	0	30.52	4.07
Swalllets	8.47	30.50	6.77	8.47	6.77	35.59	3.38
Springs	9.62	44.44	0	1.48	2.96	26.66	14.81
Total (%)	7.53	44.01	2.30	4.53	3.24	30.92	7.42

Table 2. Karst phaenomena occurency (%) in different carbonate formations.

shaping out a distinct hydrogeologic compartment at the limit with the metamorhic area of the western Locva Mountains.

Good hydrogeologic properties similar to karst-type water circulation, were identified through drilling of some 10 hydrogeologic boreholes that penetrated thermal and chemical contact rocks in *Anina-Steierdorf, Moldova Nouă and Cărbunari areas.* However it must be noticed that the natural behaviour of the aquifer systems was strongly perturbated by the intensive mining activities and particularly south of Nera Valley the net western limit between the methamorphic and karst areas was practically replaced by an anthropic structure comprising hundreds of kilometers of galleries disposed vertically on around 300 m.

Deposits with ambiguous character (pervious/impervious)

It seems that the two previously mentioned marly limestone formations (Tămaşa and Crivina marls) may restrict or not the hydrogeologic continuity, depending on the component which prevails (i.e. marl or limestone) and/or on the deposit thickness. The Crivina Marls formation (Valanginian) for example has a prevalently marly character only at the stratotype zone, on the left side of Miniş valley, downstream of Crivina forestry hut.

Another formation whose hydrogeological character is a function of its thickness is the Golumbu Sandstone. Thus, in some zones of Poiana Roşchii, where the thickness of this deposit does not exceed 5-10 m, numerous sinkholes, swallets and even small potholes have been identified. They are initially developed in sandstone, subsequently continuing into the limestones beneath. The process seems to be, however, a pure mechanical one. On the other hand, within the same area, on Golumbu Valley, where the formation thickness ranges between 50 and 100 m, the sandstones have an obviously impermeable character, carrying subaerial streamcourses.

Structural-Tectonic Conditions

The faults and fissures whose main direction is NNE-SSW impose the main drainage direction. The latter is also controlled by the analogous orientation of the folds (synclines or anticlines). Besides improving the drainage properties, the fractures separate the aquifers, acting as boundaries between the main karst systems and/or zones.

The role played by the main fractures and the associated fissure systems is outlined by their coincidence with the springs lineaments by which the karst aquifer discharges. The support fissures of the regional faults may be involved in either the recharge or the discharge of the karst aquifer systems, hence water circulation may be directed in one sense or another.

2.3. Karst Morphology

The karst morphology displays the entire range of surface and underground features, for which different evolution stages are recorded. In this respect, it is worth mentioning the abundance of the sinkhole valleys, as well as that of the sinkhole plateaus. Thus, the typical evolution: active valley-swallets-dry valley-sinkhole valley is complete.

The most spectacular exokarst features of Banat Mountains are the gorges. These are usually developed transversally with respect to the general structure, with steep slopes, 150-200 m high. The most important gorges are Caraşului (19 km), Gârliştei (9 km), Minişului (14 km) and Nerei (19.6 km). The local base-level evolution is outlined by the several cave system floors (elevation range: 50-100 m) within the steep slopes of the gorges.

Finally, a special mention should be made for the associated continental carbonate deposits i.e. calcareous tufa and travertine. Although there are currently no extensive studies concerning these formations, there are wide occurrences within the entire Banat karst, which suggest that the asso-

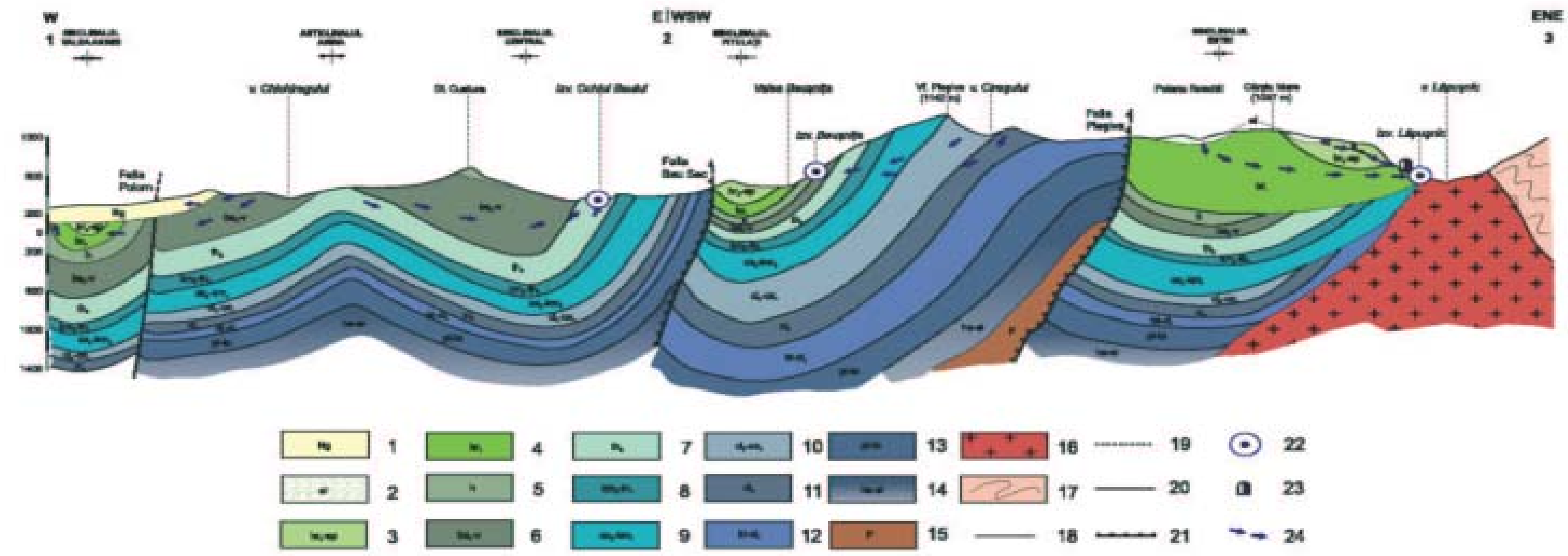


Figure 9. Hydrogeologic cross-section through the central compartment (Anina-Nera zone) of the Reșița - Moldova Nouă sinclinorium.

1. Detritiques deposits of Neogen age (Ng);
2. Golumbu sandstone (al);
3. Valea Minișului limestone (br_2-ap);
4. Upper Plopa limestone (br_1);
5. Lower Plopa limestone (h);
6. Crivina marls (be_2-v);
7. Marila limestone (th_2);
8. Brădet limestone (km_2-th_1);
9. Valea Aninei limestone (ox_2-km_1);
10. Tămașa marls (cl_3-ox_1);
11. Gumpina limestone (cl_2);
12. Valea Morii layers (bt-cl_1);
13. Bituminous schists horizon (pl-tc);
14. Deposits of Gresten facies (he-si);
15. Sandstone and red shales horizon (P);
16. Igneous rocks;
17. Metamorphic rocks;
18. Geologic boundary (generally)
19. Geologic discordance;
20. Fault;
21. Reverse fault;
22. Karst spring;
23. Temporary functional cave;
24. Underground drainage

ciated springs are over-saturated with respect to calcite.

Caves and Potholes

Although the discussed karst area is the largest of the country, the currently known caves are of moderate size (ORGHIDAN et al., 1984). An approximate inventory of the caves explored and surveyed by the speleologists associated with the Speleological Institute “Emil Racovita” and the clubs in Reşiţa[1], Anina, Oraviţa, Timişoara and Bucharest displays the following situation:

- 13 caves with lengths over 1000 m, among which 3 longer than 5000 m;
- 14 caves with lengths between 500 and 1000 m;
- 15 caves with lengths between 300 and 500 m, and
- hundreds of caves less than 300 m in length.

The usual depth of the numerous potholes which may be encountered on the karst plateaus ranges between 30-50 m and only rarely exceeds -100 m. Major caves are Buhui (7282 m in length) and Comarnic (6203 m) – both through-trips – and the pothole Poiana Gropii (-236 m in depth, 1029 m in length).

When considering this overall context, some areas like the one situated at the confluence of the streams of Comarnic and Caraş (*Comarnic Cave*: 6203 m; *Exploratorii Cave*: 5172 m) or that of Valea Mare catchment basin (*Poiana Gropii* pothole -236 m; *Cioaca Mare* pothole -137 m) might be rather considered as exceptions. They are, in fact, the results of the simultaneous occurrence of karst-favoring factors (lithological, tectonical, hydrological). Among the most important caves of Anina Mountains, *Ţolosu* cave (3040 m of large galleries but also submerged passages during flood periods) is of particular interest being entirely recharged from a karstic catchment basin while the other representative caves were formed and have a continuous evolution due to a permanent supply through swallets concentrating the surface runoff from impervious areas.

Various geomorphologic, pedologic or climatic factors reflect on chemical composition of the infiltration waters from this area, mainly oversaturated with respect to calcium carbonate, this leading to calcite precipitation as speleothemes frequently encountered in excess in Banat Mountains caves. Thus, caves as *Comarnic* (partly show cave), *“2 Mai”* (700 m in length), *Buhui* (upper level) or *Poleva* (1000 m in length) are sounding examples of well-decorated caves.

The genetic type of cavities which may be distinguished in Banat frequently depends on the position of the limestone with respect to the impervious basement. In this respect, Valea Aninei (J_3ox_2-J_3km_1) and Plopa (K_1br) limestones are strongly favored as they correspond to important transgress episodes and usually extend more than any other carbonate formation and lie directly over the impervious basin margins. The cavities resulting from such an allogenic water supply are typically sub-horizontal stream caves, often offering complete traverses along the main stream, with large-size passages along the stream-way and fossil, abundantly decorated, upper floors (*Comarnic* cave – excavated in the Valea Aninei limestones, *Buhui* cave – carved within the Plopa limestones).

Cavities associated to an autogenic (i.e. karst) water supply may be recorded either within the *recharge areas* – where the flow is predominantly vertical (potholes, steep caves) or within the *discharge* (active or inactive) *zones,* where quasi-horizontal caves may be found. Among the major caves belonging to the first type it is worth mentioning the pothole *Ponorul de la Stâna lui Ivaşcu*, with a depth of -101 m for a horizontal extension of 300 m only, and *Avenul Râurilor Suspendate* (-70 m deep), both from Poiana Roşchii area.

For the second type, the typical example is provided by *Peştera de la Captare* (near the Valea Minişului holiday-camp), with a total length of 961 m. Its 50 m depth extends between the entrance and the stream passage. This is a good example to illustrate the changes induced by the fluctuations of the local base level. During a first stage, the outflow occurred through the present-day entrance (located 60 m above the present-day spring). Following the deepening of the local base level, the drainage ran along a lower-positioned floor, so that the outflow currently uses a secondary fault, forming a Vaucluse-type spring.

[1] Most of the data concerning the caves from the northern and central parts, including the precise geographic location (using theodolite) of the main caves from Caraş basin area, are due to the “Exploratorii” Caving Club in Reşiţa.

2.4. Hydrogeology and karst systems

Catchment areas

The recharge of karst springs (or karst systems) originates either directly in rainfall or in swallets or water-loss zones. The last two situations often occur at the contact impervious/pervious formations, or within the still active sections of the valleys crossing carbonate rocks. Classical concentrated swallets, such as that of the *Golumbu* subaerial stream, allow the transfer of some 50-100 l/s that may increase to 200-250 l/s under flood conditions. The swallets associated with cave traverses (upstream cave entrances) receive average flow rates of 50-60 l/s, while the rest of the swallets rarely exceed 8-10 l/s, most of them receiving only 1-3 l/s. As we have already men-tioned, an outstanding role in the constant recharge of the karst springs have the surfaces covered by impervious rocks (crystalline schists and igneous rocks). Most of the karst networks or important springs are related to such recharge surfaces, the associated karst systems being of a allogenic-type (e.g. the karst systems of Certeje-Buhui, Caraş Spring, Comarnic cave etc).

The Golumbu Sandstone also favours the development of some perennial streams which recharge many karst aquifers, such as those discharging through the springs Ducinu, Moceriş, Lapuşnic and even one of the major karst systems of Anina Mountains namely Liciovacea-Bigar. Furthermore, the water courses formed into the Anina anticline crest continuously recharge both the Ponor-Plopa System and the Irma Spring.

In many cases, large areas within the karst plateaus (Brădet) are covered by Pleistocene residual deposits (usually terra-rosa-like clays with blocks), which persistently supply a low, yet constant rate for the springs recharge.

One may conclude as a consequence that the majority of large karst systems (including or not accessible caves) are directly conditioned by a supply originating in non-karst surfaces, one of the noticeable exceptions being *Ţolosu* cave. On the other hand, it is also true that the evolution of the karst systems supplied by perennial streams is extremely rapid, transforming them into real drains with continuously decreasing water reserves.

Subterranean Drainages

The 44 tracing experiments, out of which 25 were performed by Sencu, outline the karst systems which are concentrated in the three areas, belonging to the catchment basin of Caraş, and to the Miniş-Nera and Nera-Danube watersheds (Table 3).

Most of the subterranean connections between the swallets and the discharge areas (karst springs) have been proven by tracer tests (fluorescein). Sometimes, due to the lack of water courses *Sencu* (1973, 1980) used as dye-solvent water transported in tanks (10-20 m^3). In other cases (Anina zone), the connection has been proved by the coincidence between drilling fluid losses and a delayed pollution recorded at a neighboring spring.

One may notice that the fictitious transit velocities of the water strongly vary between 3-10 m/h for the zones of Caraşova and Liciovacea-Bigar, and 150-180 m/h in the case of the streamways running through major caves. Besides the karst systems whose configuration has been proved by tracer tests there are still many other systems whose recharge area is only inferred.

No	Swallet (Ponor)	Date	Q (l/s)	Source	Q (l/s)	ΔH (m)	Length (km)	Time (ore)	Velocity m/h
1	Pârâu Şereniac	19.07.1992	1.5	Izvorul Captat	2.5	145	1.8	192	9.4
2	Pârâu Budiniac	11.08.1992	0.8	Izvorul Şereniac	1.5	70	0.87	264	3.3
3	Ogaşul Iazomnic	21.07.1992	0.1	Izvorul Maria	3	75	0.5	144	3.5
4	Peştera Comarnic	08.04.1968	9	Comarnic	9	20	1.8	12	150
5	Ponor Popovaţ	08.04.1968	1	Peştera Popovaţ	1	95	0.7	27	28
6	Pârâu Comarnic	-	80	Izv. P. Racoviţă	40	26	0.6	20	30
7	Peştera Exploratorii	-	27	Izv. P. Racoviţa	34	36	0.7	17	42
8	Dolină (Brădet)	18.08.1967	*	Izbucul Jitin	30	50	1.5	241	6

9	Pârâu Buhui	18.11.1958	25	Peştera Buhui	25	10	2.5	18	139
10	Pârâu Izvarniţa	22.07.1977	1	Peştera Buhui	8	40	0.8	10	80
11	Pârâu Certeje	06.04.1968	8	Izvorul Certeje	12	15	0.55	3	183
12	Sonda I Brădet	-	-	Izvor Slucht	5	180	1.7	-	-
13	Sonda II Brădet	-	-	Izvor Terezia	12	30	0.7	-	-
14	Canton Cârneală	28.07.1976	15	Izv. Caraşului	250	107	0.8	62	12
15	Izvoru Roşu	06.04.1968	14	Izv. Caraşului	250	107	0.6	17	35
16	Ogaşu cu Raci	18.04.1968	1	Izv. Caraşului	250	132	1.3	72	18
17	Dolină Maial	09.04.1968	*	Izvorul Morii	14	120	1.3	44	29
18	Valea Morii	20.06.1968	30	Fântâna cu Frasini	5	30	3	12	40
19	Ponor Uteriş	09.04.1958	7	Izbucul Irma	10	100	1.2	51	23
20	Pârâu Ponor	15.08.1967	10	Peştera Plopa	10	30	0.7	16	43
21	Sonda Dl. Covăciei	-	-	Fântâna de Piatră	7	50	0.8	-	-
22	Ponor Covăcia 1	03.08.1975	1	Fântâna de Piatră	3	10	0.2	2.5	80
23	Dol. Livada Mare	10.07.1979	*	Izvoru Mare	300	90	2.2	50	40
24	Dol. Poiana Ponor	16.07.1979	*	Izvoru Mare	300	80	2.4	58	41
25	Pârâul Alb	18.07.1978	0.5	Izbucul Bigăr	300	310	4.0	205	20
26	Ponor Liciovacea	09.07.1978	0.5	Izbucul Bigăr	300	300	3.5	175	20
27	Ponorul v. Scocu	04.08.1975	2.5	Izbucul Bigăr	300	340	5.0	370	14
28	P. v. Cheia Scocu	12.06.1976	3.0	Izbucul Bigăr	300	350	6.0	154	39
29	Ponorul Cuceş	31.07.1976	4.0	Izbucul Bigăr	300	390	7.0	432	16
30	Ponorul La Ălbii	18.07.1978	0.5	Izv. Lăpuşnic	50	90	0.4	16	25
31	Ponor v. Golumbu	10.10.1994	65	Izbucul Bigăr	50	90	3.6	384	9.3
32	Og. din P. Scocului	1965	-	Izv. Lăpuşnic	-	76	1.85	280	6.5
33	Pon 4. din Pna Roşchii	09.06.95	2.0	Izv. Lăpuşnic 1	290	405	2.25	26	86.5
34	Av.din Poiana Roşchii	19.06.1995	0.5	Izv. Lăpuşnic 1	270	405	2	91	22
35	Peştera cu Zgârieturi	07.1996	2	Izv. Lăpuşnic 1	100	440	2.9	72	40
36	Izvoru Înfundat	1965	-	Izvor Poniasca	-	335	2.2	105	21
37	Valea lui Andrei	-	-	Izv. Boiştii	-		0.30	3	100
38	Ponorul din Cărbunari	-	-	Izv. Boiştii	-		0.25	-	-
39	Ogaşul Porcului	11.06.1997	1	Izv. Haimeliug 2	5	200	1.3	50	26
40	Gaura Haiducească	-	10	Og. Găurii	15	10	0.5	N/A	N/A
41	Ponorul Ascuns	01.05.1991	7	P. cu Apă de la Moară	12	60	2	21	95
42	Ponorul Polevii	02.04.1990	15	Peştera Polevii	20	50	0.35	1	350
43	Ponorul Bicii	05.06.1997	0.8	Gaura Runcii	58	126	2.6	148	17.5
44	Ponorul de la Ob. Mică	11.07.1997	1	Izv. Văii Reci	800	155	4.75	360	13.2

Table 3. Subterranean drainages in the Reșița-Nera zone.

3. Northern Compartment (Reșița - Anina Zone)

It includes Caraş cathment basin zone and part of Bârzava river basin. Karst plateaux at elevations of 400 to 600 m (Ravniştea Mare, Iabalcea, Cereşnaia, Brădet etc) oftenly occur within the investigated calcareous area that extends on around 198 km^2 (Fig. 3). The eastern boundary is well marked by topmost elevations of Certej (955.3 m) and Poiana Beţii (866.7 m), both on impervious rocks.

Within this zone, six areas with well organized karst structures were identified, namely: Caraşova, Sodol-Baciului, Certeje-Buhui, Izbucul Caraşului, Brădet Plateau, Ponicova-Comarnic (Figures 3 and 10). The underground drainage paths from the recharge toward the discharge areas are either divergent or convergent, and the fictitious tracer transit velocities range from 3.3 to 180 m/h.

The location of the springs is controlled by three factors, which acted either independently, or interconnected with each other:

- a tectonic fracture;
- the carbonate - non-carbonate boundary;
- the local erosional base.

The most important springs in this area are Izbucul Caraşului (Caraş Spring) and the springs in Caraşului Gorge (between Comarnic and Prolaz). The flow rates of the latter were estimated based on the significant difference resulted between the average discharge values recorded at two Caraş stream gauging stations, situated upstream of Comarnic junction and at Prolaz respectively (Table 4). A similar situation is that of Gârlişte stream, where the total springs inflow was estimated based on the difference between the values recorded upstream and respectively down-stream of the gorge section.

The fact that the flow rates of these springs have been measured in different periods induces a degree of uncertainty for a comparative analysis. On the other hand, the intense tectonic and karst processes underwent by the reservoir rocks resulted in high variability indexes of the karst springs. Therefore, the characteristic flow rates and the variability indexes for the considered time intervals have been synthesized, as a first estimate, in Table 4.

The minimal flow rates generally range, for all springs, between 0.001-0.030 m^3/s, while the river sections Gârlişte (downstream) and Caraş (at all measurements points) exhibit minimal flow rates exceeding 0.050m^3/s. A careful analysis of the minimal flow rates, characteristic for the drought period, highlights – for the Caraş river – the contribution of the springs from the section Comarnic-Prolaz (95 l/s) as well as the lack of any additional contribution along the sec-tion Prolaz-Caraşova. At the same time, it is worth mentioning the diffuse recharge of Gârlişte valley (downstream of Anina) whose flow rate exceeds 200 l/s during drought periods. The calculated variability indexes range between 20 and 100 for all the above mentioned springs and river sections, which is an evidence of a certain homogeneity (see Table 2). The extreme values of this index (6.6 and 105), characterize the hydrometric stations with the smallest and the largest catchment areas, respectively.

Other computed hydrodynamic parameters (depletion coefficient – α, dynamic stored water volume – V_{dyn}, Mangin 1975) also indicate mature karst aquifers (large depletion coefficients, small dynamic stored water volumes). Two kinds of systems are distinguished according to the depletion coefficients, the distinctive feature of those with values larger than 0.01 (Table 4) being a fast evacuation of the resources. The other category, including mainly the discharge from the gorge sections, displays low α values, ranging between 0.002 and 0.008 day^{-1}. A special remark deserves the spring Jitin 1, for which the depletion coefficient is 0.001, i.e. indicative of a non-karst behaviour or at least for the existence of a component with such a behaviour.

Another important parameter for the definition of the storage properties of the systems is the dy-namic stored water volume (V_{dyn}, Table 4). For the springs Lazarovăţ and Ceafarovăţ, the dynamic stored water volume is very low (less than 1×10^5 m^3), while for the springs Jitin 2, Caraş or Certeje it amounts to 1-10×10^5 m^3. For the rest of the sections, large values of the dynamic stored water volume (over 10×10^5 m^3) have been computed, the top value being recorded for the Gârlişte gorge section.

The interpretation of the results of the correlative and spectral analysis (Mangin, 1983; Iurkiewicz & Mangin, 1994) performed on flow rate histories of the springs which have been con-

Figure 10. Main karst zone and systems from the northern compartment of the Reșița - Moldova Nouă synclinorium.

1. Impervious rocks; 2. Carbonate rock outcrops; 3. Geologic boundary; 4. Fault; 5. Dolines; 6. Perennial stream; 7. Ephemeral stream; 8. Swallet; 9. Proven underground drainage; 10. Hypothetical underground drainage 11. Cave; 12. Pothole; 13. Karst network; 14. Karst spring (Q = 1-10l/s); 15. Karst spring (Q > 10l/s); 16. Borehole; 17. Water supply gallery.

Hydrometric Station	Period	Q max l/s	Q min l/s	Qmax/ Qmin	Qmed l/s	α	V_{dyn} ($\times 10^5 m^3$)	ME	TF	RT	M
Lazarovăţ	1992-93	72.5	3.6	20.13	19	0.01	0.713	32	0.136	28	B
Ceafarovăţ	1992-93	64	1	64	16.35	0.011	0.29	29	0.108	19	B
Jitin 1	1976	1320	22	60	64.6	0.001	21	4	0.288	5	A
Jitin 2	1976	162	6	27	22.135	0.017	1.05	27	0.138	16	B
Caraş spring	1992-93	599	13	46	91.38	0.017	1.62	29	0.124	29	B
Caraş spring	1976	1170	30	39	131	0.008	4.32	10	0.144	8	A
Certeje	1976	100	15	6.6	29.7	0.008	3.26	12	0.168	6	A
Comarnic Cave	1992-93	475	5	95	66.4	0.018	1.77	28	0.132	22	B
Schlucht	1992-93	398	6	66.3	45.02	0.0055	1.76	12	0.160	8	A
Caraş (Jervani)	1992-93	3266	59	55.3	404.5	0.0047	13.9	29	0.12	23	–
Caraş (Comarnic)	1992-93	4620	70	66	577	0.025	13.1	29	0.12	27	B
Caraş (Prolaz)	1992-93	7546	165	45.7	1121	0.015	50.9	-29	0.12	23	–
Caraş (Caraşova)	1992-93	16300	155	105	1621	0.013	28.8	-26	0.192	25	-
Gârlişte (Schlucht)	1992-93	910	120	7.6	270	–	–	–	–	–	–
Gârlişte	1992-93	5970	362	16.5	1041	0.0048	114	26	0.152	18	B(F)

Table 4. Hydrodynamic parameters (northern compartment).
ME = memory effect; TF = truncation frequency; RT = regulation time; M = model.

tinuously monitored over one year, indicates two major classes of springs (Table 4, Fig. 11):

- The first class includes systems more or less similar to the Aliou type, namely systems with small reserves, which only slightly modulate the rainfall information and have poor regulating capacity. The typical example could be considered the rapid component of the discharge of Jitin 1 spring which conceals the real behaviour of the system (the spectral analysis reveals that the first truncation frequency could indicate the existence of a slower component of the discharge). In the same class are also included the systems of Izvorul Caraşului (during the 1976 period), Certeje and Schlucht (at least the fast component), especially if the regulating period is consid-ered, because on the other hand, their memory effect is large, as a consequence of the supply from the surface streams. It has to be however pointed out that for short time series (< 1 year), the regulating period appears to be a much more stable criterion as compared to the truncation frequency.
- The second class includes systems the hydrodynamic behaviour of which is similar to the Baget type, namely systems with average size reserves and with enhanced regulating capacity (Lazarovăţ spring and Jitin 2 springs for instance).

The analysis of the 1992-1993 behavior of Izvorul Caraşului might suggest that the latter also belongs to this second class; yet, according to the above mentioned criteria (short time series record, relatively long freezing period), we think that such an ascription would be erroneous. In what concerns the spring Jitin 1, its first truncation frequency is characteristic for an inertial system. Nonetheless, there are several karst systems that display a rather small first truncation fre-quency, close to that identified for the **Fontestorbes** type.

Besides the previously mentioned springs, two stream sections, Gârlişte (dowstream) and Caraş (at Jervani), display characteristics similar to those of the Baget type. The memory effect of all the systems included within this class is even larger than that displayed by the Baget type, namely 24-29 days, although their regulating periods are sometimes shorter (16-23 days).

The systems included in the first class display a more or less sharp unit step response function, while those in the second class exhibit a significant

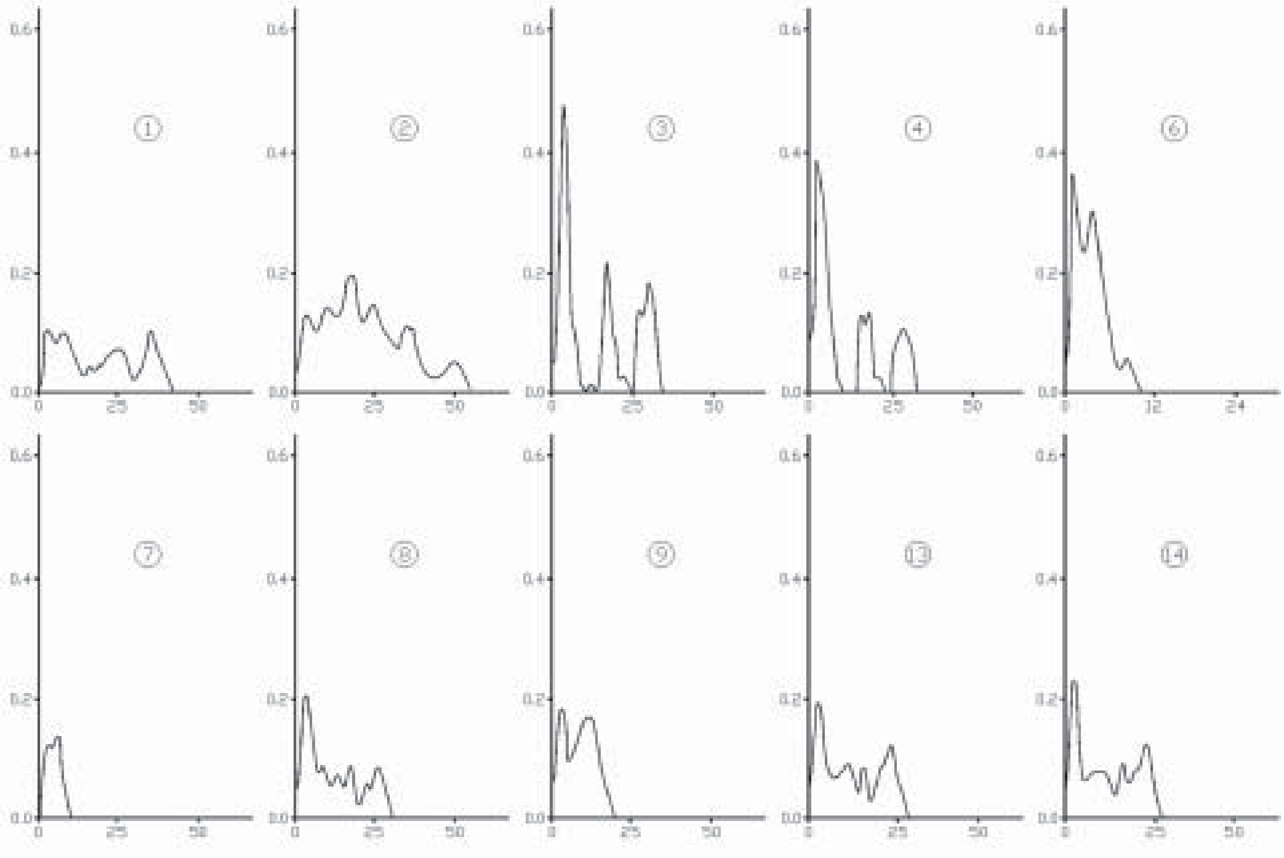


Figure 11. Unit step response function of karst systems in the northern compartment.
1. Lazarovăț; 2. Ceafarovăț; 3. Jitin 1; 4. Jitin 2; 6. Caraș spring (1976); 7. Certeje springs; 8. Comarnic cave; 9. Schlucht spring; 10. Caraș (Jervani) streamflow; 13. Caraș (Carașova); 14. Gârliște (Schlucht) streamflow.

spread out (Fig. 11). The analysis of all the considered parameters leads to the following general conclusions concerning this area as a whole:

- The fault systems striking NE-SW and the associated parallel, deep valleys resulted in a tec-tonic and topographic dissection of the carbonate aquifers, and as a result the installation of major karst systems was prevented; in addition, most of the surface streams network is totally dis-organized, the small brooks formed on the impervious substratum sinking just at the con-tact with the limestones;
- The degree of organization of the karst cavities decreases with the depth, leading to a local lack of homogeneity of the storage and transmissive properties (the karst cavities reached a highly organized stage, which resulted in very good transmissive properties, but poor storage properties);
- For the autogenic (only carbonate rocks included) karst, the lack of distinct sinking points results in systems with large regulation capacity and constant transmissive and storage properties. In the case of the Bradet plateau, the presence of the Pleistocene residual clays appears to have a major influence on the performance of an aquifer with non-karst behavior, that secures constant flow rates over long drought periods, both to the Jitin 1 spring and to the Gârlişte valley;
- The allogenic karst systems (that include surface supply from impervious areas too), are rela-tively well organized, with good transmissivity and low active storage capacity.

The **water balance** performed over the 1992-1993 period, first for small catchment areas (tributaries and stream sections), then for the entire northern section, resulted from a co-operation with INMH (actually INHGA) Bucureşti. In order to compute the input, rainfall records from the stations Caraşova and Anina have been used, which allowed a subsequent evaluation of the rainfall distribution accord-ing to elevation ranges and catchment areas surfaces.

The runoff regime has been derived from stream level records (performed continuously or twice a day) at 18 gauging stations. Evapotranspiration, computed as a first estimate (**A**) according to the Turc formula, amounts to a total value of 475 mm/year (13.5%), which results in a coefficient of 15.9 l/s/km^2 and 1.1 m^3/s water budget deficit (Table 5). A second estimate of the water bal-ance (**B**) considers equal inputs and outputs (zero infiltration) for Jervani catchment area (VII), resulting an 18.78 l/s/km^2 evapotranspiration coefficient and a deficit of only 281.5 l/s (3.38%).

Both water balance estimates (Table 5) suggests similar directions of the water exchanges between catchment sub-areas. Hydrometric mesurements performed during drought periods also substantiate this flow pattern, which can be summarized as follows:

- Groundwater transit from Nermed catchment basin (II) toward Doman (I) and Caraş (12) catchment basins;
- The hydrogeologic catchment basin which corresponds to Valea Mare river is smaller than the surface catchment basin of the same valley; hence it appears reasonable to suppose a subterranean flow from the Sohodol area to the X catchment basin (Caraş gorges between Comarnic and Prolaz);
- Downstream of Prolaz, the surface watershed is situated much closer to the valley of Caraş than to that of Gârlişte;
- Important diffuse and concentrated discharges in the median catchment basin of Gârlişte val-ley (IV) suggest that the hydrogeologic boundaries of the latter are nearer to Buhui, Caraş and Jitin valleys than its surface watersheds.

Still taking into account the measurement and estimation errors of the considered water budget elements, the resultant total deficit value according to the **A** estimate (1.1 m^3/s, corresponding to 13.5%) presumably indicates a water transfer, although not very significant, from the northern to-ward the southern zone, occurring mainly at the southern boundary of the first. (Note: the surface watershed between Gârlişte and Miniş catchment basins is conventionally outlined across the karst plateau of Anina).

4. Central Compartment (Miniș - Nera Zone)

Within this compartment, few longitudinal mountain chaines oriented NE-SW and large karst plateaux pierced by numerous dolines namely Poiana Liciovacea, Poiana Florilor, Poiana Bruscănişu or Poiana Roşchilor in-between nordest sud-vest extend on a carbonate area of around 290 km^2 drained by Miniş and Nera valleys with impressive gorge sectors of 14 km and 19.6 km respectively (Fig. 4). Within the Nera gorge sector the Beului Valley is the most important tributary (right side) either as surface of the catchement ba-

Code	Hydrometric Station	Precipit. (l/s)	Runoff (l/s)	**A**. E=15.9 l/s/km^2 l(l/s)	l(%)	**B**. E=18.78 l/s/km^2 l(l/s)	l(%)
I	Doman	43986	201	13.73	3.12	-41.17	-9.359
II	Nermed	452.657	57.836	165.93	36.65	110	24.3
III	Ciudanoviţa	532.606	140	146.32	27.47	86.129	16.7
IV	Gârlişte	1336.92	768	-79.3	-5.93	-237.71	-17.78
V	Gârlişte-Schlucht	282.391	273	-119.9	-42.48	-151.6	-53.68
VI	Mărghitaş	747.313	119.27	286.22	38.30	202.69	27.122
VII	Caraş-Jervani	933.878	404.5	104.04	11.14	0	0
VIII	Topliţa	387.927	92.339	114.46	29.5	-6	-1.54
IX	Comarnic cave	196.808	66.431	38.31	19.46	-5.163	-2.6
X	Caraş gorges	2127.716	–	–	–	–	–
XI	Valea Mare	874.703	130	322.43	36.89	219.23	25.06
Caraşova (12) VI+VII+VIII+IX+X		4393.642	1621	678.48	15.44	166.73	3.79
Total basins 12+I+II+III+IV+V+XI		**8312.78**	**3190.83**	**1127.6**	**13.56**	**281.5**	**3.38**

Table 5. Water balance of the northern compartment.

sin or the total streamflow that cumulates the strong sources of Ochiu Beului and Beuşniţa Springs.

The results of the investigations did not indicate significant differences in what concerns the setting and organization of the karst systems. Based on hydrometric measurements performed over different hydrologic cycles, the hydrodynamic parameters of ten karst systems and some karst areas were obtained. The outstanding karst sources from Banat Mountains namely Ochiu Beului (0.156-9.46 m^3/s), Bigăr (0.025-4.8 m^3/s), Beuşniţa group of sources (0.035-2.2m^3/s) and Valea Căldării spring (0.064-1.22m^3/s) are all located within this compartment.

The underground drainage paths with fictitious tracer transit velocities ranging from 6.5 to 90 m/h highlight the karstification degree that imposes a high variability rate of discharges at the outlets. The analyses were completed in the same way as for the previous zone. For most springs, the minimal flow rate values generally range between 0.0035 and 0.040 m^3/s. The exceptions are represented by *Izvorul de la valea Căldării* and the spring *Ochiu Beului,* with minimal flow rates of 0.064 and 0.156 m^3/s, respectively. The variability indexes are included into a virtually single group (0-100), which encompasses all the springs.

Table 6 indicates that most systems display a karst-type behavior, with α values exceeding 0.01 (rapid drainage of a part of the water reserve). In this group may be included the springs of *Bigăr*, *Lăpuşnic* (Fig. 12), *Moceriş* and *Beuşniţa*. Another group, with α values lower than 0.01 (0.0022–0.0095 variation range), includes the springs Izvorul de la Valea Căldării and Ducin. For the Ponor-Plopa spring the α value is strongly affected by the supply from non-karst terrains. The second parameter derived from the recession curve, the dynamic stored water volume (Table 6), displays in the case of some springs such as Lapuşnic, Moceriş or Ducin, a reduced value (0.6-2.3 × 10^5 m^3), while for Ochiu Beului, Beuşniţa or Bigăr springs the reserve is relatively high (5-13 × 10^5 m^3).

Like in the case of the Caraş catchment basin, the interpretation of the results of the correlative and spectral analysis indicates two major classes of springs (Table 6).

The first category includes the systems more or less similar to the 'Aliou type', with low reserves, which only slightly modulate the rainfall, having a low regulation capacity as well. The typical example is provided by the Ponor-Plopa system. To the same class seem to belong also the springs from the Vicinic stream, analyzed in 1974. In their case the value of the parameters is, however, affected by the reduced recording period (8 month only – no winter season values).

Within the second category are included the systems displaying a hydrodynamic behavior of 'Baget type', with medium sized reserves and large regulating capacity. This class includes, by and large, all the other springs. Two sub-classes may be still delineated. The first one displays regulating

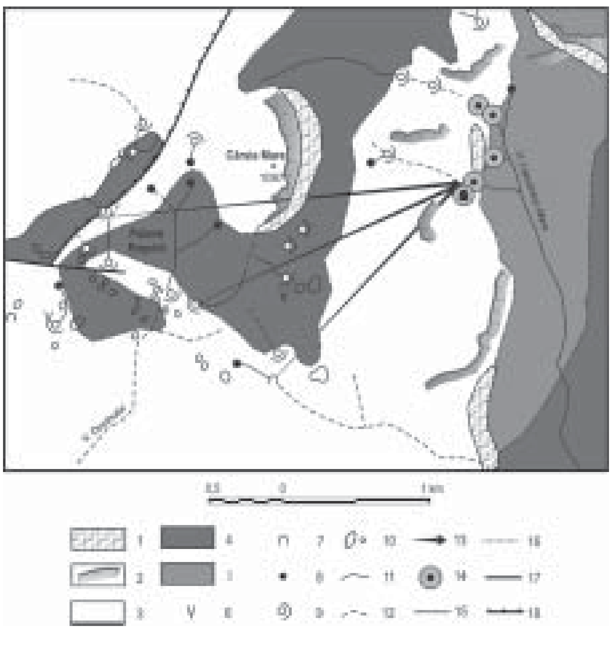


Figure 12. Poiana Roșchii - Lăpușnicul Mare karst system
1. Rock fall
2. Calcareous escarpment
3. Carbonate rock outcrops
4. Impervious rocks
5. Volcanic rocks
6. Sinkhole
7. Cave entrance
8. Karst spring (Q<1l/s)
9. Swallet
10. Dolines
11. Perennial stream
12. Ephemeral stream
13. Proven underground drainage
14. Karst spring (Q>1l/s)
15. Geologic boundary (generally)
16. Geologic discordance
17. Fault
18. Reverse fault

Hydrometric Station	Period	Q max l/s	Q min l/s	Qmax/ Qmin	Qmed l/s	α	V_{dyn} ($\times 10^5 m^3$)	ME	TF	RT	M
Plopa Cave	1973-74	3130	31	101	180.6	0.0076	7.4	3	0.268	9	A
V. Căldării Spring	1974	1220	64	19.06	192	0.0069	8.77	24	0.268	18	B
Bigăr spring	1976	4820	140	34.42	511	0.009	24.1	23	0.056	19	B
Bigăr spring	1973-74	3200	42	76	483	0.01	13.3	24	0.216	23	B
Bigăr spring	1994-95	2620	25	105	276	0.0231	3.52	43	0.144	37	B
Lăpuşnic springs	1994-95	917	11	83.16	144	0.0126	2.33	41	0.152	37	B(F)
Moceriş spring	1994-95	892	17	52.47	118	0.0108	1.92	41	0.140	39	B(F)
Ducin spring	1994-95	112	3.5	32	13	0.0095	0.63	28	0.184	30	B(F)
Vicinic (Ilidia)	1973-74	1300	32	40.6	207	0.0355	2.2	11	0.167	9	A
Vicinic (Ilidia)	1994-95	1020	18	56.6	175	0.0127	5.44	31	0.183	30	B
Ochiu Beu	1973-74	9460	156	60.6	712	0.0221	13.1	24	0.168	22	B
Beuşniţa	1973-74	2200	35	62.8	260	0.0153	5.21	26	0.168	29	B
Simion 1	1964-65	189	10.4	18.17	43.8	–	–	–	–	–	–
Simion 2	1964-65	216	7.2	30	73.1	–	–	–	–	–	–
Simion 3	1964-65	146	9.7	15.05	26.7	–	–	–	–	–	–

Table 6. Hydrodynamic parameters (central compartment).
ME = memory effect; TF = truncation frequency; RT = regulating period; M = model.

period and the first truncation frequency values similar to the 'Baget type' (the springs from Valea Căldării, Bigăr, Ochiu Beului and Beuşniţa). For all these systems, the memory effect is even larger than that of Baget, 23-30 days respectively. In what concerns the second sub-class, their parameters suggest a transition behavior between the 'Baget type' and the 'Fontestorbes type', especially in what concerns the regulating period and the second truncation frequency (Moceriş, Lăpuşnic, Ducin and Vicinic). In fact, several karst systems have a quite low first truncation frequency, close to that identified for the 'Fontestorbes type'.

The shape of the unit step response function is very sharp, without a significant spread out in the case of the first class, and composite, indicating the presence of two distinct discharge components in the case of the second class (Fig. 13).

Even though the analysis is incomplete, only partially reflecting the hydrodynamic behavior of some springs, it calls for the same general remarks as in the case of the previous zone; it can be additionally stated that:

- The presence of some impervious deposits areas within the carbonate surface allows the formation of some perennial streams (Seleştiuţa, Golumbu) which supply the most important karst systems in Aninei Mountains (Ochiu Beului and Bigar karst systems). The rest of the hydrographic network is totally dis-organized, the small brooks formed on the impervious basement sinking just at the contact with the limestones.

The results of the water budget completed for the 1994-1995 period (Table 7) supports the conclusions obtained for the previous zone:

- For the Miniş river catchment basin a supply from the plateaus Anina, Brădet and Buhui has been recorded, accounting for 6-7% of the calculated balance;
- The Nera valley catchment basin (tributaries included) displays over the limestone area a deficit of 11.3%, which might indicate a water transfer toward the Neogene deposits existing at the western limit of the synclinorium. The current data do not substantiate an older hypothesis, which assumed the existence of a groundwater flow from the central Aninei Mountains towards the Danube, passing beneath the Nera stream bed.

Estimate 1: e = 10 l/s/km^2, flow towards other catchment basins (+) 1390 l/s (19.1%);

Estimate 2: e = 18.58 l/s/km^2, according to the witness basin Poneasca (very close to the 1992-

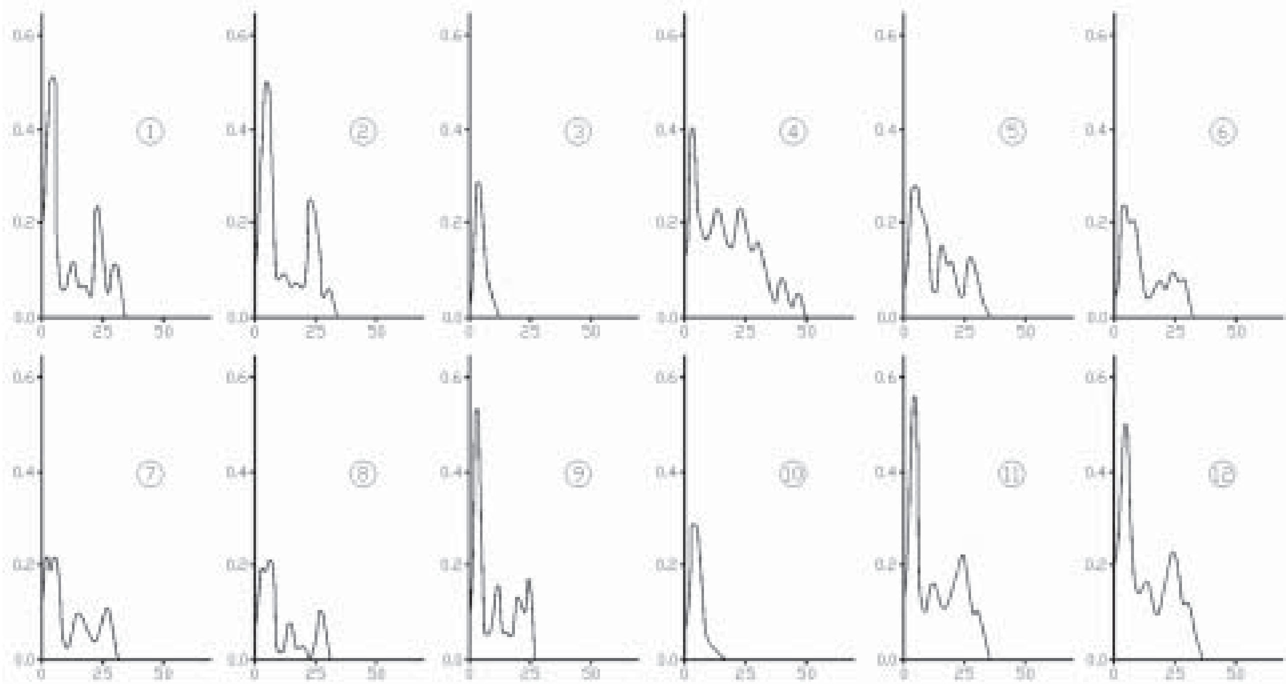


Figure 13. Unit step response functio n of karst springs in the central compartment (Miniș - Nera zone)
1. Plopa cave; 2. V. Căldării spring; 3-5.Bigăr spring (1976, 1973-74, 1994-95); 6.Lăpușnic springs; 7. Moceris spring; 8.Ducin spring; 9-10.Vicinic springs (1973-74, 1994-95); 11. Ochiu Beu spring; 12.Beușnița springs.

1993 value for Caraş-Jervani catchment basin -18.78 l/s/km^2); flow from other catchment basins (-)1310.8 l/s (-18.4%);

A possibly more realistic estimate (3) of the budget takes into account different evapotranspiration values, as a function of the specific zone where they have been calculated:

Estimate 3: NE area ⇒ e = 18.58 l/s/km^2 ; S and SE area ⇒ e = 10 l/s/km^2 .

Miniş catchment basin ⇒ inflow from other catchment basins (-)165.3 l/s (5.7%)

Total Miniş-Nera zone ⇒ losses toward other catchment basins 39.9 l/s (0.5%).

5. Southern Compartment (Nera-Danube Zone)

This compartment practically matches the eastern part of the Locva Mountains covering a carbonate surface of some 210 km^2. The sounding feature is represented by the karst plateaux namely *Cărbunari*, *La Fânețe, Nergana, Moldovița, Gîrnic, Pămînturile Albe*, and *Sfînta Elena* (*Gărîna*) occupying most of this area (Fig. 5).

Numerous karst systems were identified through hydrogelogic surveys and detailed investigations conducted on the carbonate area but only four of them namely *Gaura Runcii*, *Filipova Dira*, *Peştera de la Padina Matei, Peştera cu lacuri din*

Hydrometric Station	Precipit p (l/s)	Runoff s (l/s)	E.1 E =10l/s/km^2 I (l/s)	I (%)	E.2 E=18.58l/s/km^2 I (l/s)	I (%)	E.3 I (l/s)	I (%)
Miniş	2917.3	670.0	948.8	32.5	-165.3	- 5.7	-165.3	- 5.7
Ilidia	369.8	175.8	60.3	16.3	-54.5	-14.73	60.3	16.3
Lăpuşnic	156.8	144.0	-72.2	- 46.0	-145.1	-92.5	-145.1	- 92.5
Moceriş	130.6	188.0	-51.4	- 39.4	-105.8	-81.01	-105.8	- 81.01
Ducin	257.5	14.2	116.8	45.4	8.3	3.2	8.3	3.2
Nera	3437.5	1575.0	387.5	11.3	-878.1	-25.5	387.5	11.3
Poneasca	1405.0	525.3	405.î2	28.8	0	0	0	0
Total basins	7269.7	2697.0	1390	19.1	-1310.8	-18.4	39.9	0.5

Table 7. Water balance of central compartment.

Valea Seacă (or Mudaviţa Seacă Cave) were studied separately. Some other 20 systems were analyzed as groups based on the hydrometric records obtained on nine canyon or gorge valleys. Among systems the most important are *Gaura Runcii* (Fig. 14, 0.029-1.4 m^3/s), *Obârşia Mică - Valea Rece* (0.063-1.85 m^3/s), and *Iordan* group of springs (minimum 0.23 m^3/s).

Gaging spring discharges has and expeditionary frequency for secondary or for even some main karst systems (Cornetu Boiştii Spring or Iordan Springs) due to their isolated location or geomorphologic settings that did not allow installing a permanent flowrate gaging system.

Generally the minimal discharge values for the sources from this compartment range between 1.5-88 l/s, the only exception being represented by the affluxes of 140 l/s recorded by difference on the Nera valley gorge section during the low water season.

The variability indexes also reveal two groups of values, the first one (30-80) comprising all sources and small valleys supplied by important karst systems, while the second one (values over 100) consists of hydrometric sections from the main valleys (Radimna, Valea Mare etc).

Nine systems monitored within this area illustrate a karstic behavior highlighted by depletion coefficient values over 0.01 (quick drainage of the dynamic resources). Other four karst systems represent the second group displaying values of 0.0037 to 0.01. The dynamic volume hardly exceeds values of $0.5 \times 106\ m^3$, thus only for three sections (including also Nera gorge section) we may talk about large and very large resources (Table 8).

The interpretation of the results of the correlative and spectral analysis is as following:

- A group of systems and valleys namely *Gaura Runcii* and Peştera *cu lacuri de pe Mudaviţa Seacă*, or *Şuşara, Cremeniţa, Radimna, Valea Mare* and *Vrela* valleys are similar to *Aliou* model. Due to the rapid fluctuation of discharges on the monitored surface courses, the values resulted for the regulation time is even lower than the calculated memory effect.
- The second category refers to systems with hydrodynamic behavior similar to *Baget* type with medium resources and higher regulating capacity. In principle this category gathers the rest of sources and basins investigated in the

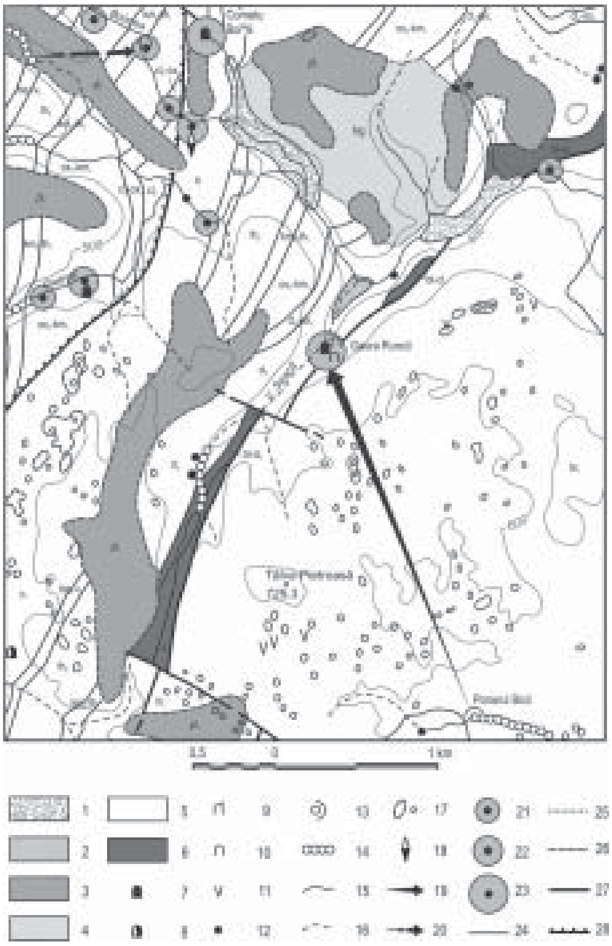


Figure 14. Gaura Runcii Karst System and surrounding area.

1. Alluvial deposits (Holocen)
2. Tuffa deposits
3. Clay and gravels (Pleistocen)
4. Neogen deposits
5. Carbonate rock outcrops
6. Impervious rocks
7. Emerging cave
8. Temporary functional cave
9. Cave intercepting a subteraneean drainage
10. Non-functional cave
11. Pothole
12. Spring (Q< 1 l/s)
13. Swallet (ponor)
14. Difuse swallet
15. Perennial stream
16. Ephemeral stream
17. Dolines
18. Thermal spring
19. Proven underground drainage
20. Hypothetical underground drainage
21. Karst spring (Q=1-5l/s)
22. Karst spring (Q=5-10l/s)
23. Karst spring (Q=10-50l/s)
24. Geologic boundary
25. Geologic discordance
26. Quaternary deposit boundary
27. Normal fault
28. Reverse fault

southern compartment characterized by memory effects exceeding 10 days. The base flow component of the above mentioned systems identified through the first cutting frequency (f_{c1}) have also similar characteristics with *Baget* type. The most important sections (systems) from this group are Filipova Dira cave system and Cameniţa, Vranovăţ, Gravensca (Obârşia Mică - Izv. Văii Reci system) and Nera valleys.

The shape of the unit step response function (Fig. 15) and the results of the recession analyses where also considered to system classification according to the similarity with one of the reference models (last column of the Table 8).

The analysis of the karst systems from the southern compartment generally partialy display similar aspects already highlighted for the other two compartments of the synclinorium.

- The fault systems striking mainly NE-SW and the associated parallel, deep valleys resulted in a tectonic and topographic dissection of the carbonate aquifers that is confirmed by the large number of the small sources and karst systems with insignificant hydric resources.
- Lack of some impervious deposits areas within the carbonate surface lead reflected in lack of important streams to contribute the development of major karst systems. The Jordan Springs apparently represent the sole exception but their location (close to river bed in a wilde section of Nera gorges) prevented proper data series gathering and consequently a quantitative evaluation of the discharge through this karst system.
- The degree of organization of the karst cavities is relatively homogenous starting with the infiltration zone up to a certain depth; consequently, a relative homogeneity of the storage and transmissive properties is common for the systems exclusively supplied from carbonate areas e.g the systems developed around the large karst plateaux of Cărbunari and Gîrnic.
- The geomorpholgical settings (lack of important streams and swalets) did not contribute to the deep karstification of the carbonate layers and equilibrated development of the karst subsystems (with the submerged karst as the main reservoir). Whenever favourable factors exist the karst systems clearly stand out from

Hydrometric Station	**Period**	**Qmin (l/s)**	**Qmed (l/s)**	**Qmax (l/s)**	**Qmax /Qmin**	**α**	**V_{dyn} ×$10^6 m^3$**	**ME**	**TF**	**R**	**M**
V. Şuşara	1996-97	22.81	118.41	954	41.84	0.0127	0.27	10	f_{c2} = 0,192	7	A
Izv.Gaura Runcii	1996-98	29.2	143.3	1392	55.23	0.0107	0.69	10	f_{c2} = 0,144	7	B (A)
V. Cremeniţa	1996-97	88	560.22	5281	60	0.0325	0.78	10	f_{c2} = 0,176	9	B (A)
V. Radimna	1996-97	22	425.19	2948	134	0.0269	0.465	10-11	f_{c2} = 0,144	5	B (A)
P. Padina Matei	1996-97	1.51	15.5	116	77.33	0.011	0.043	13	$f_c f_{c2}$ = 0,152	9	A (B)
P. Mudaviţa Seacă	1996-97	7.35	96.12	2975	404,7	0.0037	0.259	3.9	f_{c2} = 0,204	4	A
Valea Mare	1996-97	50	430.35	5450	109	0.0204	0.509	9-10	f_{c2} = 0,141	4	A
P. Filipova Dira	1996-98	12	50	352	29.33	0.0233	0.18	16-17	f_{c2} = 0,148	12	B (A)
V. Cameniţa	1996-97	32	215.67	1672	52.25	0.0216	0.508	14	f_{c2} = 0,128	10	B (A)
V. Vrela	1996-97	19.5	116.26	1182	60.61	0.0178	0.363	8	f_{c2} = 0,148	5	B (A)
V. Vranovăţ	1994-95	17	181.74	1175	69.11	0.0037	1.75	25	f_{c2} = 0,140	12	B
V. Gravensca	1996-74	53	200.63	1840	34.76	0.0052	1.89	11	f_{c2} = 0,160	9	B
V. Nera (Sasca)	1994-97	970	13330	105000	108	0.0122	58.2	20	f_{c2} = 0,136	15	B
V. Nera (gorge section)	1994-97	140	2620	24000	171						

Table 8. Hydrodynamic parameters of karst valleys and systems from southern compartment.
ME = memory effect; TF = truncation frequency; RT = regulating period; M = model.

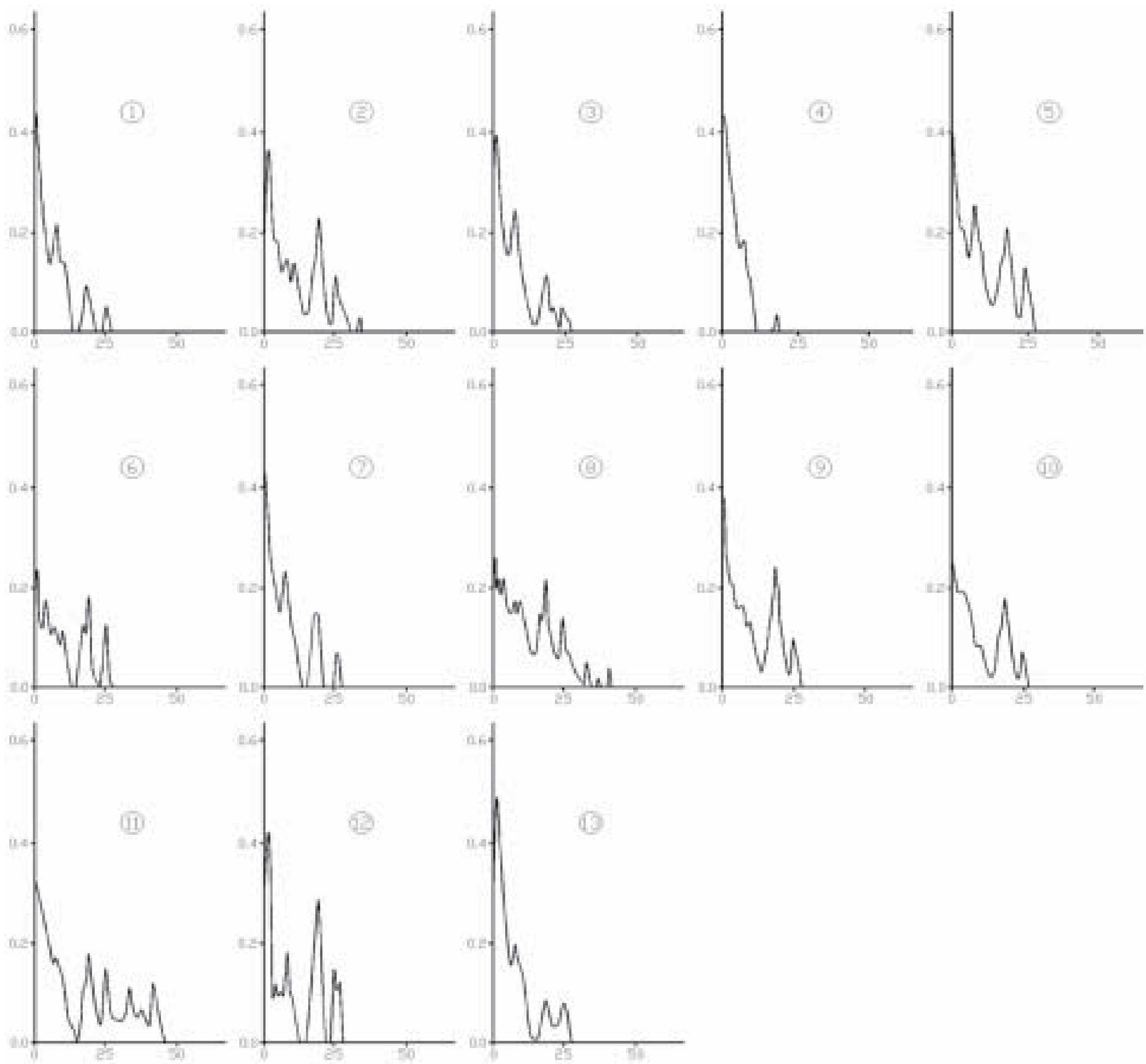


Figure 15. Unit step response function of karst systems and valleys from southern compartment.

1. Șușara Valley
2. Gaura Runcii Spring
3. Cremenița Valley
4. Radimna Valley
5. Padina Matei Cave
6. Mudavița Seacă Cave
7. Big Valley
8. Filipova Dira Cave
9. Camenița Valley
10. Vrela Valley
11. Vranovăț Valley
12. Gravensca (Cold Valley system)
13. Nera Vallley (at Sasca)

the others by the size of the dynamic resources as in case of Gaura Runcii and Izvoarele Văii Reci (Cold Valley Springs) karst systems.

Using an ETR value of 14 l/s/km^2 obtained during 1996-1997, the hydrogeologic balance carried out for the southern compartment concluded on a deficit of 0.82 m^3/s or 13.89% (Table 9). The above mentioned value of ETR eventually reflected on a coherent balance for the micro-basins located at the northern side of the compartment, in accord with framework hypothesis and tracer experiments. The surplus resulted for the southern micro-basins may originate form an underestimated ETR value (plausible considering the local climate of this area) and/or from a fast propagation of the flood waves on the canyon valleys, beyond the daily step of data recording at the temporary hydrometric station.

Hydrometric Station	Surface a(km²)	Precipitation p (l/s)	Runoff (l/s)	ETR. (l/s)	I (l/s)	I (%)
Şuşara aval	15.27	448.32	221.89	213.85	12.58	2.8
Cremeniţa	31	888.46	560.22	434	-105.76	-11.88
Radimna	31.62	906.37	425.19	442.68	38.5	4.2
Valea Mare	47.25	1354.85	430.25	661.5	263.1	19.41
Vranovăţ	18.12	592.52	181.74	253.68	157.08	26.6
Vrela	14.50	474.15	116.266	203	154.88	32.66
Cameniţa	18.50	604.95	215.67	259.95	129.33	21.3
Gravensca	20	654	200.63	280	173.4	26.5
Total	**196.26**	**5923**	**2351.8**	**2748.5**	**823.1**	**13.9**

Table 9. Water balance of southern compartment (Nera - Danube zone)

6. Water Quality

Chemical analyses performed for 68 springs indicate a calcium bicarbonate-type character. The chemical quality is generally satisfactory. Total mineralization (TDS) values range between 150 and 700 mg/l, except for the water from the Ponor-Plopa cave system, which exhibits a higher TDS value (928.2 mg/l). The excessive mineralization of this water is mainly due to the pollution induced by the former mining works of Crivina.

According to their SO_4^{2-} content, three distinct groups of springs have been separated within the central section of Banat Mountains. The first group includes the karst waters with less than 1 mg/l sulphate, discharged by springs such as Ochiu Beului, Bigăr, Moceriş, or Lăpuşnic (Fig. 16). The second group of springs (Simion 1, 2, Vicinic, Plopa) includes Crivina marls with coal interbeddings within their catchment areas, which results in an increased sulphate content (up to 30-50 mg/l, Fig. 17). The last group of springs (Fig. 17) consists of those which are strongly influenced by the coal mining activity at Anina (Ponor-Plopa, Schlucht, Terezia, Morii). The sulphate content of these waters frequently exceeds 80 mg/l, sometimes reaching values of 200-250mg/l (Ponor-Plopa 1994).

Besides pollution originating in the Anina area, karst spring waters from the western boundary are also subject to pollution due to the copper and radioactive mining activities at Ciclova and Ciudanoviţa or the Sasca - Moldova Nouă banatite alignment.

Apart from from the sample collected from Sasca mining gallery (Fig. 18, number 4) and Fântâna Seacă Spring (Fig. 18, number 3) the main sources from the southern compartment display a relatively homogeneous chemical content with a calcium bicarbonate-type character. Thus, on the same Fig.18 the other sources (18 springs) are practically indistinctively represented. The mentioned exceptions with a higher sulphate content appear however quite normal considering the transit through the thermal and chemical contact rocks (skarns and hornfels) formed at the contact with ‘banatites’ intrusions.

Comparing with the other two compartments, the trace elements analysis of the samples collected from the southern compartment specifically revealed the presence of a higher number of chemical species and and even higher content (2-3 times) for some of them (e.g. Cu). A common explanation for the higher content in Al (>50ppb) or Fe (>100ppb) could be the water transit through the residual clays largely covering the carbonate deposits on the karst plateaux. It is also likely that the surface mining activity e.g. Suvarov open pit, as well as numerous spoils (waste rock stockpile) and tailings dams resulted from periods of mininng activity covering more than eighteen centuries intermediated the transfer of some trace elements (Cu, Pb, Ni, Zn) to the karst water.

Chemical charge variation during a hydrologic year was monthly recorded monthly for seven sources located to the central (3 sources) and southern (4 sources) compartments. Discharge-

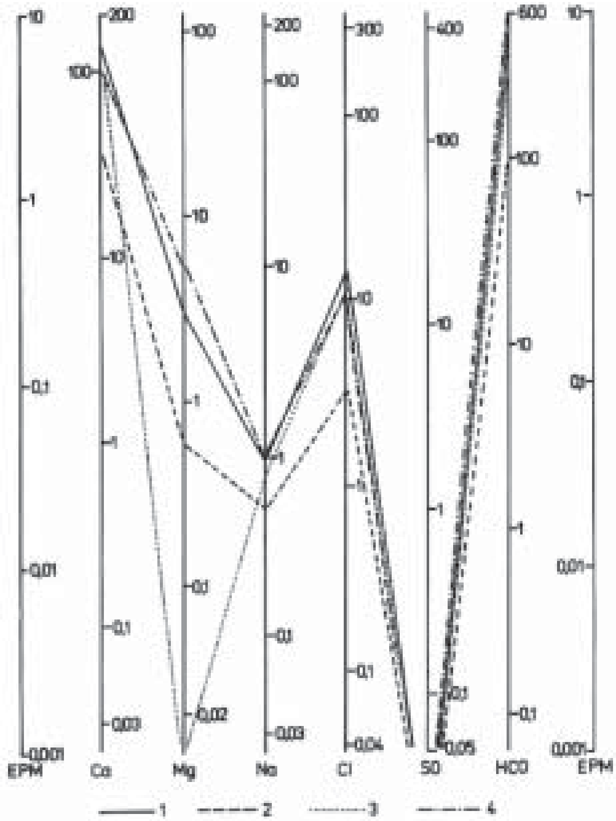


Figure 16. Schoeller diagram of low sulfate karst waters
1. Bigăr; 2. Lăpușnic; 3. Moceriș; 4. Ochiu Beu.

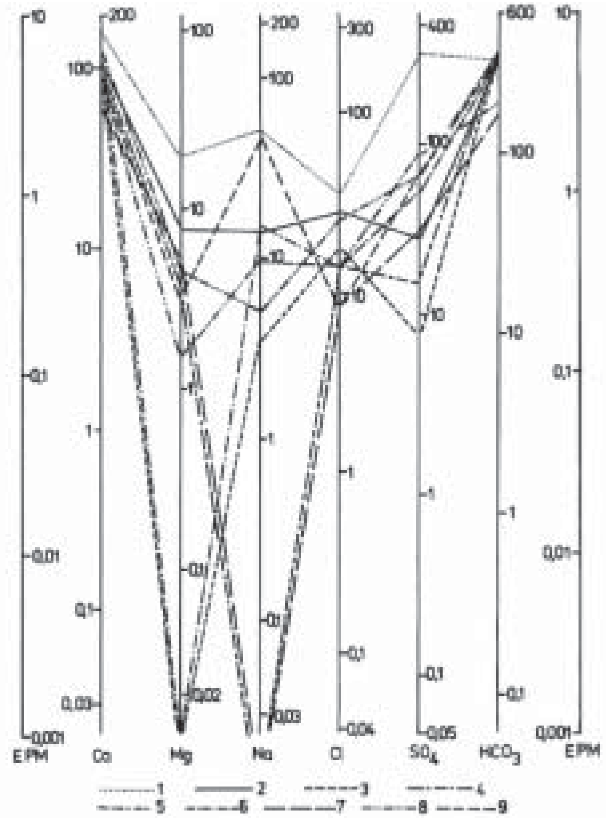


Figure 17. Schoeller diagram of medium and high sulfate karst waters
1. Plopa Cave; 2. Grota Morii cave; 3. Irma spring; 4. Plopa spring; 5. Schlucht spring; 6. Simion 1 spring; 7. Simion 2 spring; 8. Tătarului spring; 9. Terezia spring.

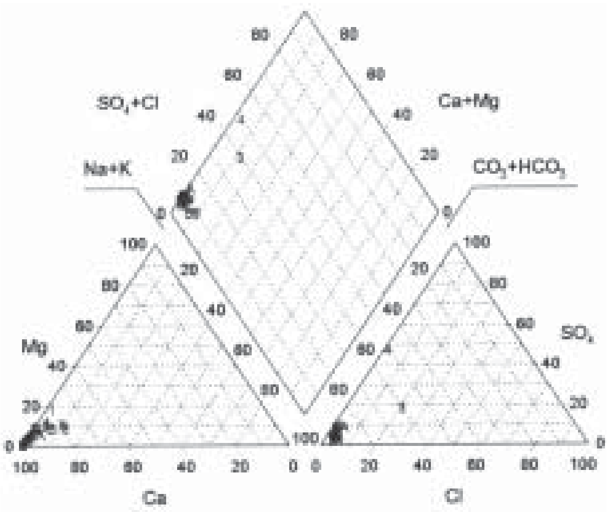


Figure 18. Trilinear diagram (Piper) of karst springs from southern compartment.
3 - Fântâna Seacă Spring; 4 - Sasca mining gallery; Group of 18 karst springs (Hot Spring from Poiana Boiștii, Vrela, Iordan, Iordan (submerged), Haimeliug, Cold Valley Springs, Alânga (second spring), Lake Spring, Big Valley (spring no. 2), Izv. de sub Cârșie, Cornetu Boiștii, Ogașul Runcii, Ogașul Găurii Spring, Beciului, Șușara as well as Padina Matei, Filipova Dira and Mudavița Seacă caves).

temperature or discharge-chemical variables correlation generally confirmed or added new information concerning analyzed system functioning mode. It is worth mentioning that during a hydrologic cycle none of the chemical parameters had been recorded with values beyond the limits imposed by the actual Romanian standard for drinkable water.

The bacteriologic analyses performed on samples from 42 karst sources revealed a relatively strong degree of microbiologic pollution. The high zones of Anina and Locva Mountains are important headwaters recharging the downstream karst systems; still within these zones, few large villages and a city i.e. Anina, Iabalcea, Cărbunari-Stinăpari or Padina Matei are hot sources of spreading chemical and bacteriological waste freely downloaded on the permanent or temporary karst valleys passing nearly through or closely nearby them.

7. Use of Karst Aquifer Resources for Water Supply

The water supply from karst springs is not very significant, as main springs are located far from major users. On the other hand, although having relatively small average flow rates, some of the accessible springs are used for towns and villages water supply.

Within the northern compartment, the three water intakes on Valea Mare (the outflow of Sodol-Baciului karst system) yield an average flow rate of some 25-30 l/s (which may decrease to 2-3l/s), to one of the districts of Reşiţa (the oldest water supply system in town).

At the downstream end of the spectacular gorges of Caraş, more then 100 l/s of the river flow rate is used for the fish hatchery in the village of Caraşova. Certeje-Buhui system is the main water supply source for the city of Anina. The recharge of the karst system is partly regulated through an artificial reservoir (the Buhui Lake) built within the swallets catchment area, which provides a virtually constant, 75-80 l/s supply. Not far from this system, at the margin of the Brădet plateau, more than ten karst springs totallising 180-200 l/s are also used for the water supply of Anina and of the Lişava colony (mining activities included).

The Simion springs, located 300 m upstream of the Ciclova Montana village, have been successively used as a supply for the brewery of Oraviţa (founded in 1865), then for the tap water supply, and currently again for the brewery (rebuilt in 1975). The main springs from the central part of Aninei Mountains, namely Bigăr and Ochiu Beului, are used only for fish hatchery.

8. Vulnerability and Protection of Karst Systems

Due to the interesting karst morphology, including important karst systems, caves and swallow holes, almost whole area of the synclinorium is protected being included in two national parks and one natural park. Thus, the National Park of "Semenic-Cheile Caraşului" covers most of northern area of the Reşiţa - Moldova Nouă Synclinorium while its central part is included within the National Park of "Cheile Nerei -Beuşniţa". The southern compartment of the synclinorium is part of the Natural Park "Porţile de Fier" (Iron Gates). The actual limits or these parks where established mostly since 1990 to present.

In most cases the protected karst areas are delimited using geomorphologic, topographic or land use criteria. However in many cases these criteria do not include the recharge areas of karst aquifer systems. The adequacy of the limits of the northern park "Semenic - Cheile Caraşului" was evaluated in order to estimate its capacity to protect the most vulnerable areas of the karst aquifer systems located in this zone.

Considering the available data and information as well as the purpose of the application, which was consultative at the initial stage, a methodology based on EPIK method concept (Doerfliger Natalie & Zwahlen 1997a and 1997b) was used for vulnerability assessment. Each of the four factors considered in EPIK method (epikarst development, protective cover properties, infiltration conditions and karst network) were separately assessed in order to analyze their influence on vulnerability (Iurkiewicz et al., 2005).

The field works, consisting in a detailed mapping of the epikarst was performed by researchers from the Speleological Institute "Emil Racoviţă", Bucharest, Romania. Data concerning karst hydrogeology were provided by Iurkiewicz (2004). Information about karst network development was obtained due to the work performed by speleologist from different clubs from Reşiţa, Anina, Oraviţa, Timişoara and Bucharest. All the necessary spatial data was digitized from different paper maps (topographical maps at scale 1:10,000 and geological maps at scale 1:50,000) georeferenced to a local projection system, Stereo70.

The evaluation of epikarst development (E parameter) was carried out by field observations (karst landforms and outcrops mapping) and the manually produced map was scanned, digitized and divided in areas belonging to the 3 categories (E1, E2 and E3) using the same criteria like EPIK method:

- E1- Areas with caves, swallow holes, do lines, karren fields;
- E2- Intermediate zones situated along doline alignments, uvales, dry valleys, canyons;
- E3- The rest of the catchments.

The subdivision of protective cover (P parameter) was possible also due to field observations. As P1 were considered areas covered by forest where epikarst has a good development and soil is less than 20 cm. As P2 areas covered by meadows and pastures where the soil is resting directly on limestone formations and has a thickness around 1 m. The areas considered to be P3 were too small to be figured at the working scale and the areas of P4 categories was considered the area with impermeable rocks.

Evaluation of infiltration conditions (I parameter) was made using slightly different criteria then the EPIK method because almost whole area is covered by forest. So, while I1 was considered like in EPIK, I2 and I3 was separated using criteria presented by Musy (2005).

- I3: Perennial or temporary swallow holes-banks and bed of temporary or permanent stream supplying swallow hole, infiltrating superficial flow etc.);
- I2: areas where slope is greater than 10 % for ploughed (cultivated) areas and greater than 25% for meadow and pastures and slope greater than 35 % for forest;
- I3: areas where slope is less than 10 % for ploughed (cultivated) areas and less than 25% for meadow and pastures and slope less than 35 % for forest;
- I4: not present as the whole are is considered to be inside of the water course catchments which is not artificially drained.

Karst network development (K parameter) was assessed taking into consideration the information concerning each hydrological basin (flow hydrograph analyses, number of springs, speleological information etc.). The whole area of each basin was considered as K1, K2 or K3.

- K1: Well developed karst network;
- K2: Poorly developed karst network;
- K3: Mixed or fissured aquifer/rocks.

The mapped vulnerability presented in Fig. 19 displays a consistent percentage of highly vulnerable zones. All these zones mainly resulted from very active karstification processes that dramatically modeled the landscape.

Generally the areas with highest vulnerability index are located inside the limits of the Park as in case of Iabalcea Plateau or Comarnic Cave area. The eastern border of the studied area that is also the limit of the carbonate outcrops is far inside the protected area therefore no potential danger would be considered.

Conversely, at the western side of the Park there is an obvious lack of consistency between the formal perimeter (along the national road Reşiţa Caraşova) and the highly vulnerable areas inferred throughout the study, largely exceeding the protected area.

Thus it was recommended that the actual western border of the National Park Semenic-Cheile Caraşului should be re-adjusted and harmonized in accordance to the obtained results. Equally, a buffer zone wherever the highly vulnerable area exceeds the limits of the Park can also be considered which eventually was proposed and accepted by the administration of the National Park "Semenic - Cheile Caraşului".

Complex aspects concerning groundwater management along the formal border of the protected territory cannot be separately treated, particularly where the water flows from outside to inside this border. The analysis results will expectedly guide further research activities followed by the completion of the protective (or restrictive) measure package already accompanying the normative document instituting this type of protection to the area.

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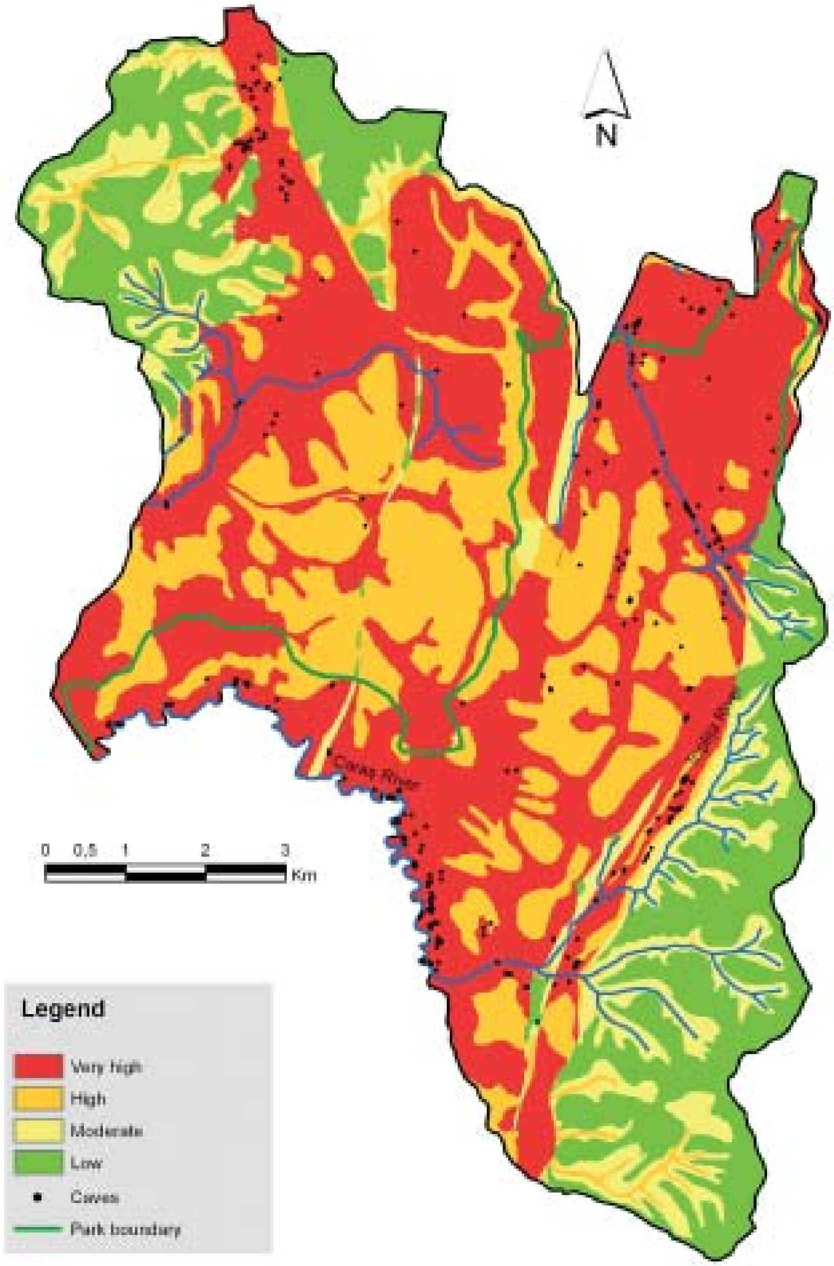

Figure 19. Vulnerability map expressed by F protection index (very high $F<20$, high $20<F<25$, moderate $F>25$, low $F>25$)

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