3.9. SOUTHERN VÂLCAN MOUNTAINS

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During centuries, the presence of *Izvarna - Celei* swamps at the base of the calcareous slopes of the Vâlcan Mountains couldn't be ignored by the local inhabitants attracted by the amount of clear water constantly emerging from the ground or by the pilgrims passing through northern Oltenia region. Information on Tismana Monastery that is one of the oldest, and the most beautiful in Romania dates back to the fourteen century and also includes a reference on its own water supply source that may be thus considered as one of the first information on a centralized water supply system in the area.

The Vâlcan Mountains extends over more than 900 km^2 from *Motru* valley to *Jiu* deep valley with altitudes that mainly ranges between 400-500 and 1800 m. Integrated within the western group of Southern Carpathians, the Vâlcan Mountains have a longitudinal ridge oriented WSW – ENE, lowering abruptly to the NNE (Petroşani Depression) and in steps towards the south. To the southern slopes of these mountains important calcareous areas are located, where all representative karst features as dolines, ponors, caves and sinkholes largely occur.

Specific surveys and researches as well as regular discharge gauging were conducted throughout the years by different companies and governmental institutions. These have concluded around 1964 to start tapping the main karst springs of the area namely Izvarna and Vâlceaua for the water supply of the cities of Craiova and Tg. Jiu respectively. Further informations on main karst systems of Southern Vâlcan were offered among others by Ilie (1970, 1973), Sencu (1967), Constantinescu (1975) as well as Vintilescu et al. (1970). Many other data were gathered and included in unpublished reports or researches conducted for the implementation of the so-called *Cerna - Motru - Tismana* hydropower project. Key underground connections between the main surface water inflows and karst springs of Southern Vâlcan Mountains were presented by Rădulescu et al. (1987).

Based on previous data and extensive surveys conducted on the southern slope of the Vâlcan Mountains the overall hydrogeology of the karst systems of this area was thoroughly investigated and described by a "Prospecţiuni" Company team (Iurkiewicz A., Ruxandra and D. Slavoacă, 1991, 1992) and concluded by Iurkiewicz & Mangin (1994), Iurkiewicz et al. (1996) and Iurkiewicz (1994, 2004). A detailed analysis has been dedicated to Izvarna karst system by Iurkiewicz (2010).

Recent interpretation of the structural evolution of the western ranges of South Carpathians commonly accept a structural edifice composed by three groups of tectonic units, i.e Getic-Supragetic Units, Severin Nappe and Danubian Units (Berza, 1997). The similar tectonic pattern of the whole group including also the Vâlcan Mountains is thus dominated by the overthrust of the Getic Units over the crystalline and sedimentary formations of the Danubian Units. According to the model proposed by Pop (1973) Pop et al. (1975), Marinescu et al. (1989), Stan et al. (1979) within the *Geologic Map of Romania* (1:50,000), sheets of *Tismana*, *Peştişani* and *Câmpu lui Neag*, the overall geological structure of Vâlcan Mountains (Figures 1 and 2) include a crystalline basement, consisting of crystalline schists and granites of Precambrian age, and a sedimentary cover starting with Lias formations (sandstones, shales and conglomerates).

The limestone deposits may reach a thickness of 1000 m and are of Dogger-Aptian age. The lower sequence of these deposits is mostly layered, while the upper one is massive. The whole carbonate package is unconformly covered by a flyschoid series of Cenomanian-Senonian age. From a structural point of view the limestone mostly occupy a normal position between the Lias age sandstones and the Upper Cretaceous flysch, while some parts are thrusted over the flysch and largely occur, yet as relatively thin (<200 m) bodies (Figs 1, 2). Still, the major shafts of the region (some of which count also among the deepest in Romania, Cârca Părăţeilor, -121 m) are located in such bodies, which occupy the summit of mount Pleşa.

The carbonate formations are located in three distinct morpho-geologic settings:

a) In the northern part, near the main ridge, thin crystalline limestones (not indicated on the map) occur, interbedded within. However, one of this narrow (~100 m) limestone layers hosts the currently deepest cavity of the mountain range, Cartianu (-142, +23 m), inside which an underground stream of about 15-20 l/s flows.

b) In the south-eastern part, Jurassic-Cretaceous limestones with a low degree of crystallinity occur on a large and rather compact area. Deep valleys flowing from north to south and their tributaries delineate several isolated summits: Pleşa, Plescioara and Ştersura-Bordul Dobriţei. Devoid of surficial runoff, these areas preserve old morphologic surfaces, perched several hundred of meters above the contemporary streambeds.

c) In the south-south western part, limestones of Urgonian facies frequently display a massive, reef character, and build a low and elongated barrier, crossed by many surface streams. The existing fault systems of regional amplitude and the overall high degree of fracturing favored the organization of remarkable underground drainages.

Among the top karst phenomena from southern Vâlcan Mountains we should mention *Pârgavului Cave* (L=3600 m, D=120 m), *Râpa Vânată Cave* (L=2100 m, D=47 m), *Tismana Monastery Cave* (L=1000, mostly submerged), or *Gârla Vacii Cave* (1460 m in length) as well as the main potholes *Clocoticiul 1 din Scoaba Sărăturii* (L=150, D=98), *Clocoticiul din Cârca Părăţeilor* (149 m in depth), and the impressive *Urloi* pothole (62 m in depth). Tables summarizing the most important karst phenomena located to the southern Vâlcan Mountains (caves, potholes, springs and ponors) and their index on the map are presented at the end of this chapter.

The surface stream-network supplies the carbonate reservoir through diffuse or concentrated swallets, which may be either partial or total losses. The inflows vary between 5-200 l/s, which account for 50-100% of the total flowrate of a stream. The mean runoff displays significant variations, between 12.5 and 45 l/s/km^2, according to the season and to the considered elevation range. Another component of the aquifer recharge includes the rainfall on the limestone outcrops, which varies between 700 mm/year (at 200 m elevation) and 1100 mm/year (at 1500 mm elevation).

Granites and granitoides of Şuşiţa and Tismana, also largely occur on the southern slopes of Vâlcan Mountains. These rocks have good fissural permeability, which favors the storage and circulation of the groundwater, thus contributing to the constant recharge of the carbonate aquifer however a real assessment of water volumes transferred from an aquifer to another was not possible even some attempts in this direction were made.

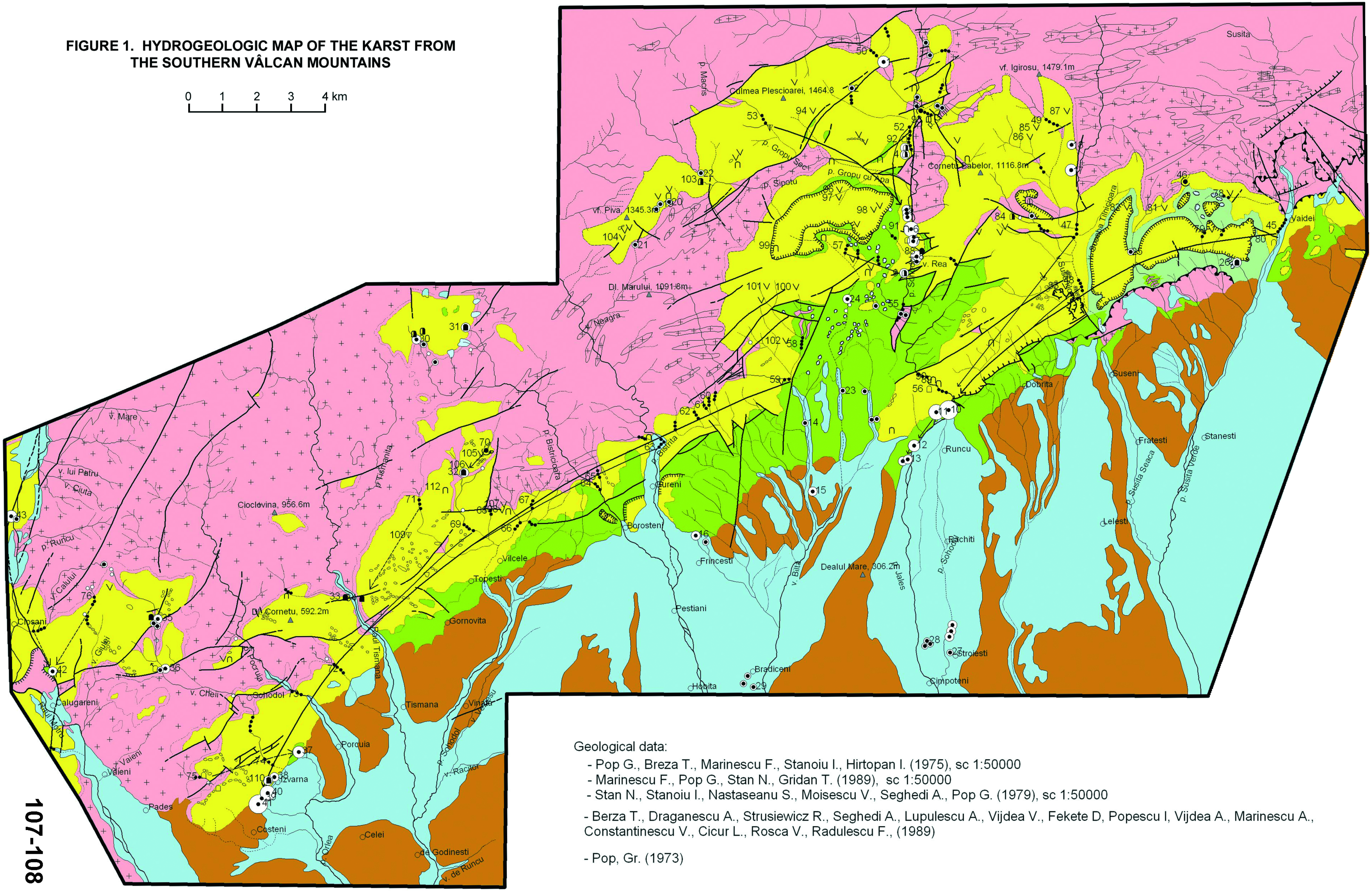
The upper cretaceous flyschoide deposits, with quite a different lithology, display the same hydrogeologic behavior, which includes low discharge springs (1-3 l/s), yet of permanent and constant character. The metamorphic rocks and the stack of marls and clays of Meotian-Pontian age have no significant permeability and no water.

In Vâlcan Mountains three major hydrokarstic systems are organized (Figs.1, 2), the characters of which are:

1. The northern system (Pătrunsa-Picuiel) includes three lineaments of permanent springs, Pătrunsa, Picuiel and Valea Rea (1), with flowrates of 100-300 l/s, 100-160 l/s and 70-100 l/s respectively, as well as a lineament of temporary springs acting as an overflow, Prilejele, with flowrates of 0-200 l/s. The concentrated inflows are located in Gropu Sec valley (2), where 10-50 l/s sink, in Gropu cu Apă valley (3), where 100-300 l/s sink, and in Sohodol valley (4), where losses of 200-300 l/s have been recorded.
2. Eight km downstream are located the resurgences of the second system, Jaleş-Vâlceaua (5), the main spring of which, Vâlceaua, provides one of the main water supplies to the city of Târgu Jiu (150,000 inhabitants). All the springs in Runcu area, Vâlceaua (Q=100-700 l/s), Jaleş (Q=0-300l/s), Albuleşti (Q=80-100 l/s) and Balaure (Q=15-20 l/s) were proved by means of radioactivable tracers to be included in this system. The sinking points are located in Şusiţa Verde streambed (6) (losses of 170-200 l/s), in Şusiţa Seacă streambed (7) (losses of 120-150 l/s), and in Gârla Vacii cave, on the right side of Sohodol valley (8) (losses of 0-100 l/s). Tracer veloci-

FIGURE 1. HYDROGEOLOGIC MAP OF THE KARST FROM THE SOUTHERN VÂLCAN MOUNTAINS

0 1 2 3 4 km



Geological data:

- Pop G., Breza T., Marinescu F., Stanoiu I., Hirtopan I. (1975), sc 1:50000
- Marinescu F., Pop G., Stan N., Gridan T. (1989), sc 1:50000
- Stan N., Stanoiu I., Nastaseanu S., Moisescu V., Seghedi A., Pop G. (1979), sc 1:50000
- Berza T., Draganescu A., Strusiewicz R., Seghedi A., Lupulescu A., Vijdea V., Fekete D, Popescu I, Vijdea A., Marinescu A., Constantinescu V., Cicur L., Rosca V., Radulescu F., (1989)
- Pop, Gr. (1973)

L E G E N D

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 (Middle Jurassic -Lower Cretaceous)

Detritic deposits poorly indurated with medium extension hosting important pore flow when draining karst aquifer; (Lower Meotian, Kersonian, Bessarabian, Badenian)

Upper Precambrian granitoids, of large extension and thickness. Permeability of fissures related to tectonised areas with discontinuous distribution and intensity; springs of 1-5L/s. Inferred role to karst aquifer recharge.

Detritic deposits, with reduced thickness and large extension, hosting local aquifers (pore flow); numerous intermittent terace springs of low discharge, 1-2 L/s. (Holocene-Pleistocene)

Metamorphic series, sandstones and conglomerates of large extension but reduced permeability of fissures. Groundwater flow mostly confined to weathered zone. (Upper Precambrian, Devonian and Lower Jurassic)

Detritic deposits, indurated, widflysch type of variable thickness and extension. Occasionally, discontinuous aquifer units occurring in most permeable terms. (Senonian, Middle-Upper Turonian and Cenomanian)

Detritic deposits (marls and clay) with aquitard role between aquifers occurring in plain areas (Pontian-Portaferian and Odessian as well as undifferentiated Meotian

Hydrologic features of karstic cavities:

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

Course of perennial stream

Course of temporary stream

Karst depression

Quarry

Groundwater flow direction

Proved

Hypothetical

Mean annual discharge of the springs (L/s)

under 1 L/s

1-10 L/s

10-50 L/s

50-100 L/s

100-200 L/s

over 200 L/s

Geologic boundary in general

Discordant boundary

Geologic boundary

Fault

Reverse fault

Overthrust

Duplication structure

7 Index of karst phenomenon

ties of 50-100 m/h were recorded in both previously described systems.

The hydrologic budget performed between 1980 and 1990 for several catchment areas belonging to this system indicates a water transfer of 130-150 l/s, from the karst area toward a detritic reservoir located to the south, which includes miocene age and lower meotian age gravel and sand formations and discharges by the group of springs at Stroieşti-Câmpofeni.

3. The most important hydrokarstic system, flowing from north-east to the south-west, ranges among the most constant large discharge springs in Romania and discharges through the group of springs at Izvarna (9, Fig.1), 70% of which are tapped and piped for water supply to the city of Craiova (300,000 inhabitants). The system is developed in a low and elongated limestone bar, dissected by many surface streams. There is morphologic and hydrologic evidence (Iurkiewicz & Mangin, 1994) that an upper underground karst drainage level is overlying the main deep drainage (Fig. 3). It has been also inferred that the karst system receives an additional underground supply provided by a fissured aquifer occupying a granitic body located to the north (Rădulescu *et al*. 1985).

The main flow-inputs to the system[1] include (from east to the west) Bâlta valley (Fig.1, 10) (losses of 10-30 l/s, 20 km far from the main spring Fig. 4), Bistriţa valley (losses of 200-400 l/s) and Pârgavu valley (12) (losses of 10-50 l/s). Losses were also identified along the valleys of Bistricioara (50-70 l/s) and Pocruia (10-15 l/s), most probably included in the same system.

Above the longitudinal drainage (which covers a distance of 20 km between the extreme points which tracing experiments proved to be connected), several other systems exist, apparently independent with respect to the main one. Some of the most important cave systems in the area are associated to these systems: *Tismana* (1 km long), *Râpa Vânată* (2.1 km long) and *Pârgavu* (3.6 km long and 119 m deep).

Tables of representative karst phaenomena located to the southern Vâlcan Mountains and their index on the hydrogeologic map of the area

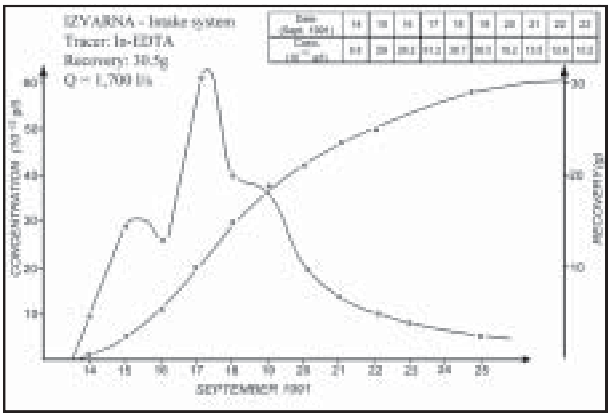


Figure 4. Tracer experiment of Balta inflows.

(Figure 1) were included at the end of this chapter.

Water quality has been assessed throughout complete chemical analyses performed within *SC Prospecţiuni* laboratories. The results indicate the presence of calcium bicarbonate and calco-sodium water types routinely occurring in carbonate areas with mostly a very low chemical charge. From chemical data it can be also inferred a good homogeneity of the aquifer lithology and most likely a relatively short transit of the groundwater throughout the systems.

To obtain additional data for surface - groundwater relationship and other aspects concerning regional hydrogeology isotopic researches of the main emergences were carried out (contents of tritium deuterium and oxygen 18). On the short term (one year) the temporal variation of the isotopic contents is less significant while the electric conductivity highlights some peculiarities of the hydrodynamic behavior of the karst systems.

The plot of stable isotope contents (δD $^o/_{oo}$, versus $\delta^{18}O$$^o/_{oo}$) suggests the existence of two main karst aquifer zones:

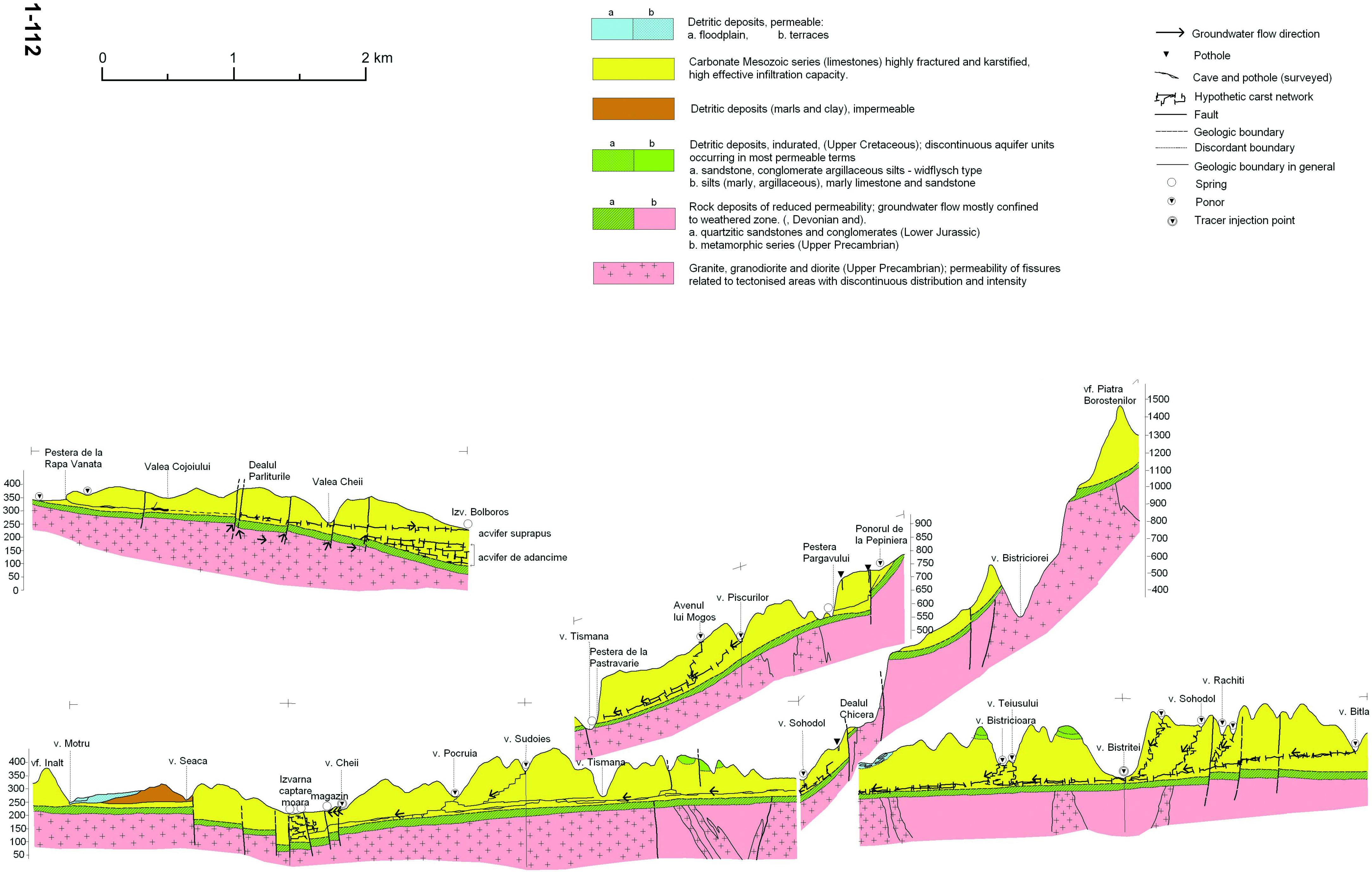
- Upper karst zone (ZCS) – that extends mainly to the north-eastern part of the limestone area (Pleşa Hill, Vaidei)
- Lower karst zone (ZCI) – longing the southern border starting from Runcu springs passing through Izvarna up to Baia de Aramă.

The second zone also includes Bâlta, Râuşor, Brădiceni and Stroieşti group of springs, fitting the western extremity of ZCI thus highlighting a preponderantly karstic recharge of these sources.

The microbiologic content of Runcu group of springs (Balaure, Albuleşti and Vâlceaua intake structure) is particularly high due to the water tape

[1] *Labelled with radioactivable tracers.*

FIGURE 3. HYDROGEOLOGIC CROSS-SECTION



point (small lake and pipe) upstream Sohodol gorges that facilitate germs development. Towards the western border of the karst zone the bacteriologic content of the springs draining the upper part of the Izvarna system (Bolborosu, Izvorul de la Magazin) is also remarkable high. In the same time it is worth mentioning the low bacteriological content of the main Izvarna spring draining the bottom part of the system this reflecting once again the distinct origin of this component of spring's discharge.

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

Series of rainfall and discharge data recorded during 1956-64 and 1971-72 were obtained courtesy of INMH and ISPIF. Data interpretation performed on the basis of relevant methods of systemic analysis (Mangin 1975, 1982, 1984) lead to the following results:

Pătrunsa spring; The hydrologic cycle 1971-1972 is the only available period of records; the mean discharge for this period is 1.493 m^3/s. The overflow sources of the system (Prilejele or Prajele springs) start functioning only when system discharges over 2.5 m^3/s. However the analysis shows that time interval with such high discharges (total flowrate over 2.5 m^3/s) is relatively short.

Jaleş spring; the parameters obtained for this source are mainly similar with the ones for the above mentioned system thus leading to quite identical interpretation. These parameters change according to the hydraulic charge of the system, while the spring reflects either the general behavior of the system or its own hydrodynamic behavior. The relevant low-water regime of the spring starts for discharges under 0.5 m^3/s - 0.7 m^3/s. Actually, due to the recent changes at the intake structure taping the main outlet of the system (excavation lowering the discharge base) the low water period is replaced by a total loss of discharges at *Jaleş* spring.

Vâlceaua spring; the discharges of the low-water period range in case of this source below 0.7 m^3/s. The overflow sources are functional over discharges of 1.1-1.3 m^3/s.

The recession coefficient α resulted from the analysis of 11 recession periods recorded for this source shows two main groups of values (0.002 and 0.006-0.008) that characterize system functioning over and behind a discharges interval of 0.5 - 0.6 m^3/s. This interval is very important because it shows the moment and the manner in which the system passes from a karstic behavior to a less or even non karstic one (Fig. 5 and 6).

On the recession curves the last mentioned situation is marked by sudden drops of discharge

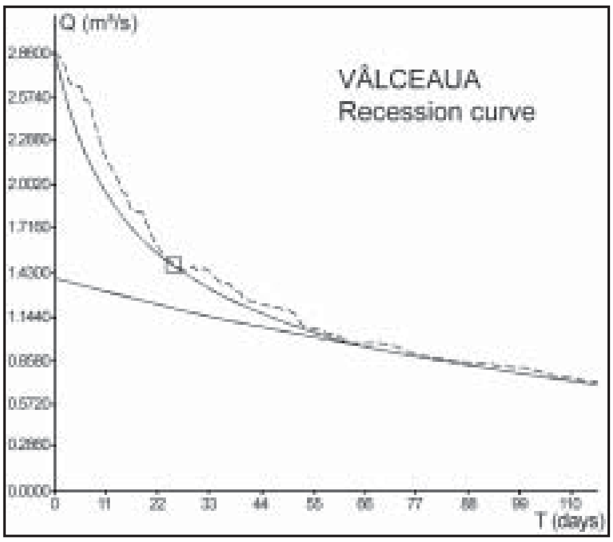


Figure 5. Karstic behavior of Vâlceaua spring; Recession curve 11.06 - 04.10.1961.

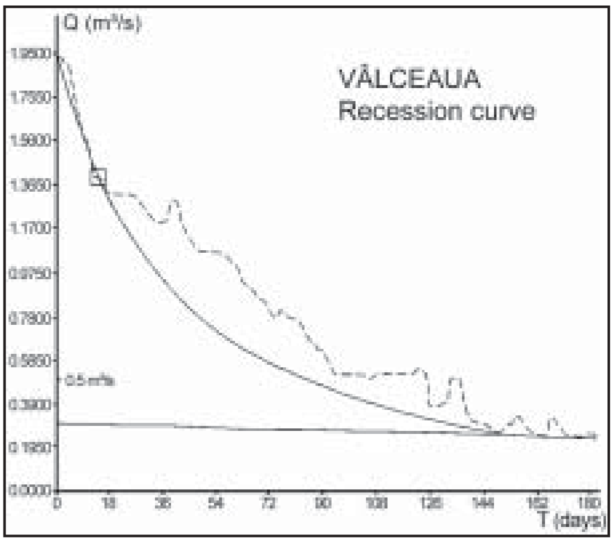


Figure 6. Non-karstic behavior of Vâlceaua spring; Recession curve; 05.05 - 03.11.1958.

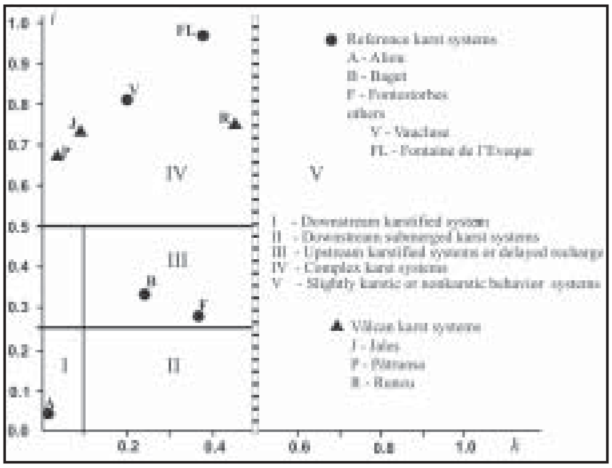


Figure 7. Hydrodynamic classification of Southern Vâ lcan karst systems.

values that correspond to water transfer to the granular aquifer (of Miocene - Meotian age) located southern to the karst system. The difference is also highlighted by the large variation interval of the water volumes drained during the quick flow (6-30%) or base flow. Still the calculated dynamic volume (V_{dyn}) and implicitly the magnitude of the flooded karst zone, is particularly high i.e. 15 - 17×10^6 m^3.

Izvarna spring; Discharges below a threshold interval of 1.2 m^3/s -1.3 m^3/s characterize the low water regime of the system; during the high water seasons, whenever the system discharges over 2.4 m^3/s the upper drainage level contribute with additional flowrate to the main outlets.

Hydrograph analysis during recession (flood and baseflow) periods provides insights to the functioning manner of the system components. Thus the flood recession part of the curve (initial post rainfall decrease) is very steep, and features the contribution of the shallow component of the discharge, i.e. the fast depletion of the highly karstified but less extended unsaturated zone. The long depletion period that follow (baseflow recession), is characterized by a very slow and constant decline of the discharge, supplied mainly by the deep component of the system. Consequently, it can be considered that the depletion period represents a rather non-karstic flow regime with computed α values (Mangin, 1975) uncommonly low (0.0003 day^{-1}), while the dynamic volumes (V_{dyn}) is correspondingly very important. Eventually, the resulted values for the *i* and *k* (>>1) parameters classify the behavior of the system much closer to that of a porous aquifer than of a karstic one. Unexpected and abrupt oscillations reaching 200-500 l/s, that occur in the discharge series during the depletion period, seem to suggest that Izvarna spring is only the overflow of a deep drainage possibly extending further south-westward.

For both Izvarna and Vâlceaua systems the dynamic resources identified through recession curve analysis were very high over 10-15 millions cubic meters. Still, these values only reveal the magnitude of the flowing resources through the flooded zone and does not represent the real volume of reserves.

According to *k* values in the classification proposed by the method (Fig. 7), Pătrunsa-Picuiel system and Jaleş spring have similar behavior with *Aliou* model. Using the same parameter the behavior of Vâlceaua (Runcu) spring could be considered as close to the *Fontestorbes* model. However considering both parameters (*i* and *k*) Izvarna system does not even match with classification limits while all other systems are classified as complex ones.

The separate examination of each hydrologic cycle within the general frame of the correlative and spectral analyses indicates that the reserves of the system are affected by rainfall impulses for long periods, that may extend over up to two years. In this respect, it has been observed that the recurrence of comparatively "dry" hydrologic cycles every 1 or 2 years results in draught flowrates lower than 500 l/s, and implicitly in the occurrence of the sudden drops in the discharge series. However this also explain the presence of high resources even during medium term drought seasons. Similar but even tight relationship was identified for Izvarna system spring. This characteristic that is similar for both systems is very important for the sustainable management of the groundwater resources of the area: it prove that dramatic falls *of the discharges* occurring suddenly *on both systems hydrographs are the very effect of two essentially dry hydrologic cycles (low rainfall amount) that may succeed at maximum two years interval.*

As a general conclusion, the computed values of the four descriptive parameters position Vâlceaua system between the Fontestorbes and Torcal "archetypes".

According to the values of the descriptive parameters, the hydrodynamic behaviour of each of the two underground drainage levels (i.e. shallow and deep) can be identified. In this respect, the

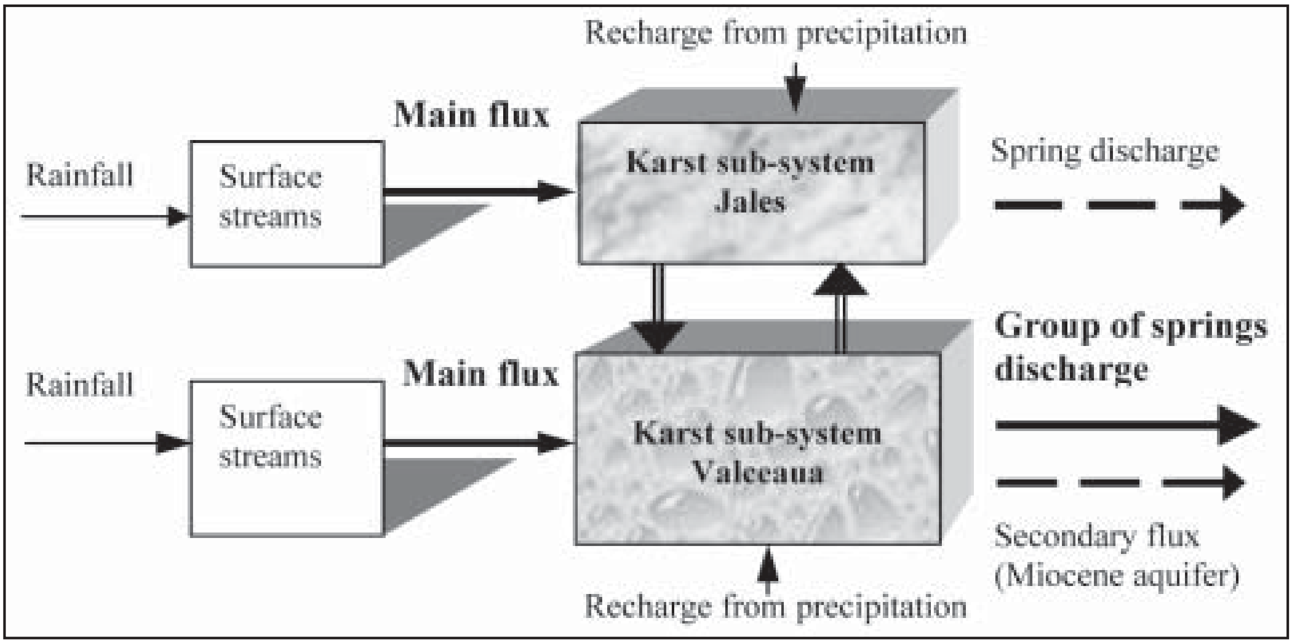


Figure 8. Schematic representation of the Jaleș - Vâlceaua karst system.

deep component of the spring discharge can be included between the Fontestorbes and Torcal "archetypes", poorly karstified aquifers with high "memory" effect and long regulation time. At the same time, the shape of the impulsive response (unit hydrograph) and the second value of the cutting frequency (0.196) outline the hydrodynamic behavior of the shallow drainage, quite similar to that of the Aliou "archetype".

Taking in account the values of the descriptive parameters, the hydrodynamic behavior of each system in respect with the reference systems is as following:

- The behavior of the main group of emergences of Pătrunsa - Picuiel system (Pătrunsa springs), is similar to *Baget* model.
- The deep component of Izvarna spring discharge can be included between the *Fontestorbes* and *Torcal* "archetypes", poorly karstified aquifers with high "memory" effect and long regulation time. At the same time, the shape of the impulsive response and the second value of the cutting frequency (0.196) outline the hydrodynamic behavior of the shallow drainage, quite similar to that of the *Aliou* "archetype" .

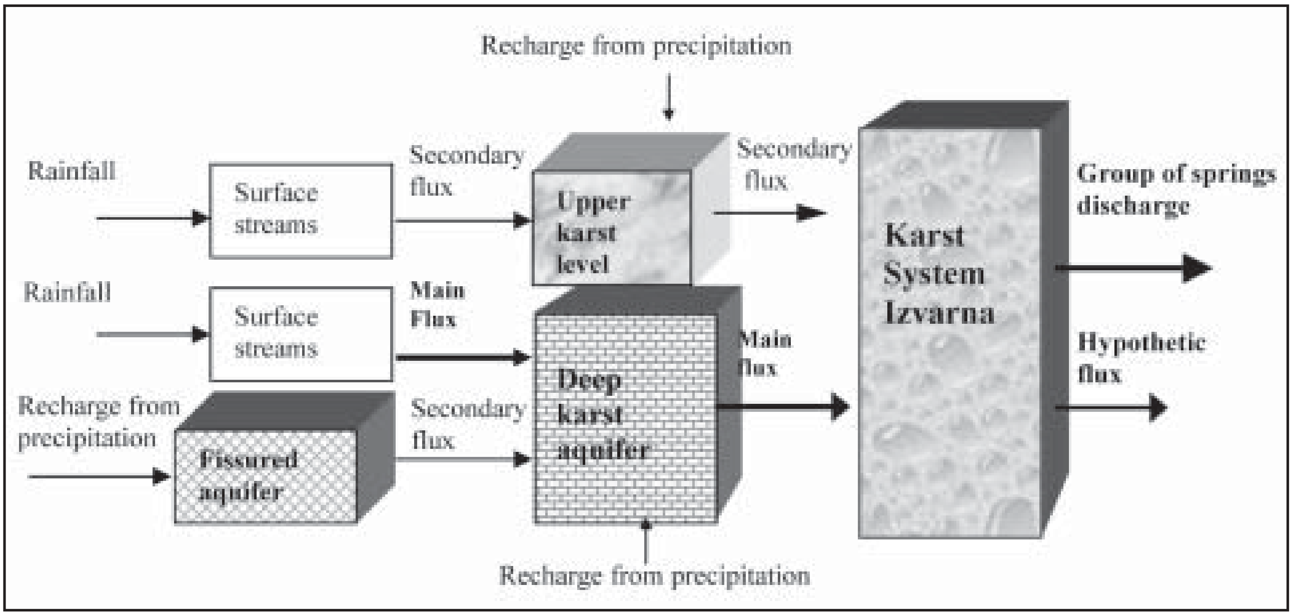


Figure 9. Schematic representation of the Izvarna karst system.

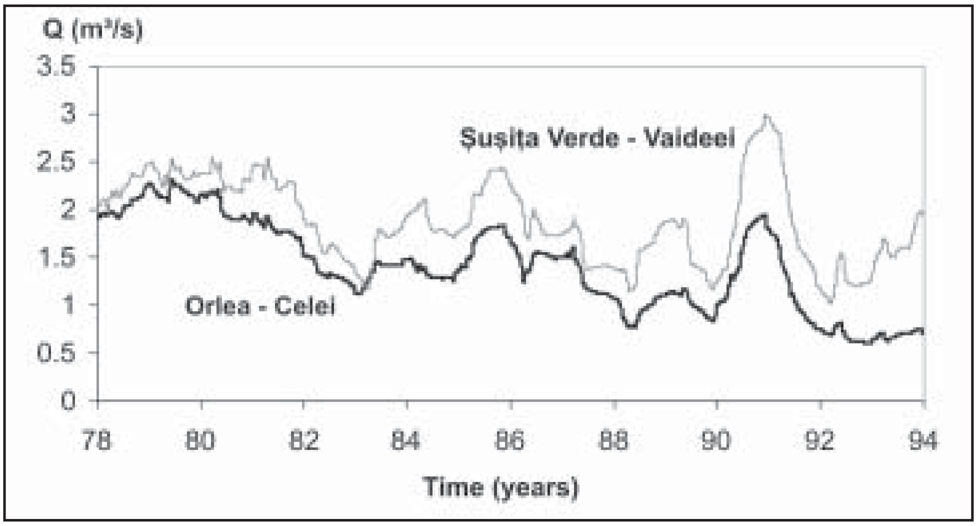


Figure 10. Trend analysis: *Şuşiţa Verde* valley (left) and *Orlea* valley (right).

- In case of Jales spring the shape of the unit hydrograph is mainly similar to the *Aliou* model while the computed values of the four descriptive parameters position Vâlceaua system between the *Fontestorbes* and *Torcal* relevant models.

The detailed studies of the karst aquifer systems in Vâlcan mountains indicated that two of them exhibit a complex organization, consisting of sub-systems with various degrees of interconnectiveness. Systemic analysis identified the relationships between sub-systems and provided an overall characterization of each system behavior.

Thus the upper karst level of the Izvarna system or any of the sub-systems composing Jales-Vâlceaua (Runcu) system could be considered *serial subsystems* or in *cascade without feed-back*, (one of the component is connected with near subsystems but in one way, Fig. 8).

The karst system Runcu is a system *in cascade with feed-back*, where the system components interrelate among them in both ways. Eventually the Izvarna system as a whole consist of *parallel subsystems* that only interact within the global function of the system (Fig. 9).

In order to identify the possible interference of the hydropower system with the karst system a trend analysis on Izvarna springs discharges was conducted. Stream discharges on *Orlea* valley (out of which Izvarna group of springs is representing around 80%) and *Şuşiţa Verde* valley as non karstic catchment area preserving a natural flow regime were analysed and compared using available data for more than 15 years period. Main aspects resulted from the analysis of the filtered hydrograph performed on the discharge time series of both valleys (Fig. 10, filter amplitude of 365 days) can be summarized as following:

- a five years periodicity, is present on both charts, due to the long-term climate features;
- similar decreasing trend of both series is visible during 1978-1983 period;

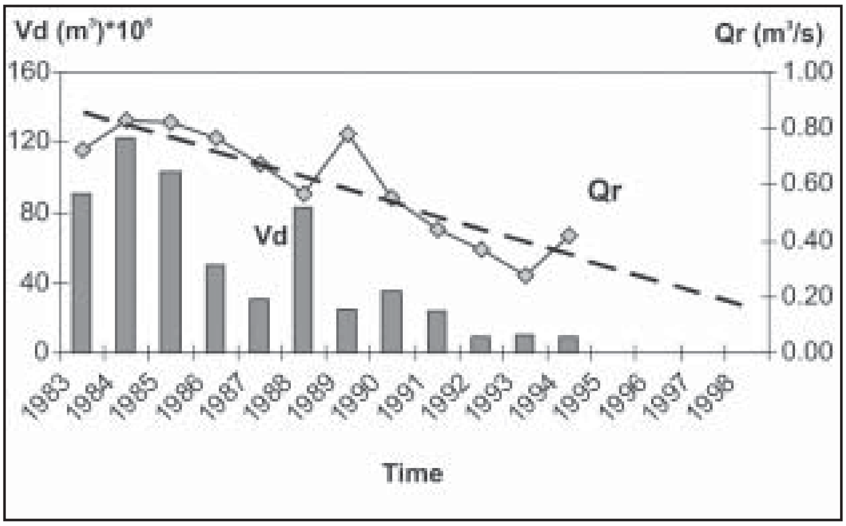


Figure 11. Izvarna system – trend of the dynamic volume, Vd (columns) and the discharge at the end of the recession, Qr (line).

- The decreasing trend associated only to the Orlea series continues after 1983 while over the same period the *Şuşiţa* series maintains a cyclic evolution above a virtually constant value of 1,1 m^3/s; it can be assumed that the degradation of the dynamic resources of Orlea system become effective starting with 1983;
- Commencing with 1992 despite a visual similarity of both curves the steeper downward slope of the Orlea series is noticeable; according to the important "inertia" identified for the Izvarna system this decline might reflect either the drought of that year and/or the filling of the Vija reservoir; the latter is built on the upper Bistrita river tapping important flow rates and directing it to the Cerna-Motru-Tismana hydro-power system; its *upstream* location *with respect to the main swallet which supplies the karst aquifer* (*$Q_{ins.}$ = 300-400 l/s*, Fig. 1) clearly threatens the main recharge point of the Izvarna system.

Several recession curve analysis performed yearly during 1982-1994 period indicates a dramatic reduction of the dynamic volume (V_d), from $123\times10^6 m^3$ in 1984 to $9.16\times10^6 m^3$ in 1994 (Fig.11). Despite the relative stability of the considered parameters during 1993–1994 and even an increase of the flow rate recorded at the end of each recession period (Q_r), the analysis of the cyclic (five years periodicity) behavior indicates that in case of a continuous decline, beyond the end of the 1993-1998 cycle (Figure 11, dashed trendline) the flow rates of the tapped karst springs during the low water periods might be insufficient if compared to the yield that is continuously diverted to the city of Craiova (800 l/s).

The importance of all the previously discussed parameters lies in the manner in which they are used. Due to different water supply and hydropower projects the hydrodynamic behavior of Izvarna and Jaleş-Vâlceaua systems were radically changed comparing with main data series (1957-1964) previously presented.

However some general remarks extracted from the analyses of the mentioned data remain still actual. An obvious application is to rely on the evaluation of the dynamic volume of the flooded zone in assessing the available amount of water which can be supplied to consumers. The vulnerability to the pollution may be estimated as well, from information on the internal structure and/or the hydrodynamic behavior of the system. Thus:

- **From an ecological point of view**. The deep structure of the Izvarna system shows mostly a non-karstic hydrodynamic behavior identified via the quasi-constant discharge component resulting from a strong regulation capacity. Thus, it may be stated that the base component of the system will be less influenced by a physical pollution (immiscible pollutants) and within first stage (10-14 days), even by a chemical pollution (miscible pollutants). Conversely, it can be assumed that even in case of a more or less accidental pollution the same component will suffer the consequences of it over a quite long period most likely extending to few years.
- The upper karst drainage level is representing a much less significant and highly variable discharge component, but the groundwater transit through the system is virtually instantaneous, and consequently makes it highly vulnerable to pollution

After the excavations performed inside the small tapping chamber of Vâlceaua spring, part of the quick discharge as well as the base discharge of Jaleş spring were diverted to the new lower base of discharge represented by Vâlceaua spring. Consequently the main concerns expressed for Izvarna spring are actual also for Jaleş-Vâlceaua system bearing in mind that proportionally the contribution of each component (quick/base) are different from Izvarna system.

Another fact worth being pointed out is that these two systems are connected with a regional scale aquifer i.e. Miocene aquifer in the Carpathian Foredeep. The vulnerability to the pollution of the discussed karst systems has to be considered therefore in a broader, regional scale context.

- **From an economical point of view.** Obviously, the sources draining the two main systems from Vâlcan Mountains partially control the amount of the resources stored or in transit through the karst aquifer. Another important component most likely larger than the analyzed ones supplies the Miocene aquifer or other aquifer structures located south-westward.

Thus the schematic image of the two systems suggests o possible exploitation of the resources

Tables of representative karst phaenomena located to the southern Vâlcan Mountains and their index on the hydrogeologic map of the area

Cave / Pothole	Hydrographic Basin	Dimensions		Index
		L	D	
Peştera cu Ciur	Şuşiţa Verde	185	80	78
Bidăroaia din Bordul Dobriţei	Şuşiţa Seaca	—	88	87
Peştera de la Gârla Vacii	Sohodol	1460	—	56
Peştera Laptelui	Sohodol	637	—	89
Peştera Pârlazului	Sohodol	1149	—	90
Peştera de la Izbucul Muşchiat	Sohodol	1036	—	9
Peştera din Valea Rea	Sohodol	721	24	88
Peştera de la podul Picuiel	Sohodol	580	30	7
Peştera aval de v. Fuşteica	Sohodol	2200	—	92
Avenul Urloi	Gropu cu Apă	—	62	95
Clocoticiul 1 din Scoaba Sărăturii	Sohodol	150	98	96
Clocoticiul 2 din Scoaba Sărăturii	Sohodol	268	72	97
Clocoticiul din Cârca Părăţeilor	Sohodol	—	149	98
Clocoticiul din Cracul ăl Scurt	Bâlta	—	97	101
Peştera din pârâul Pietrele Albe	Scărişoara	642	—	031
Peştera Pârgavului	Pârgavu	3600	120	32
Peştera de la mânăstirea Tismana	Tismana	1000	—	33
Peştera Fuşteica	Orlea	750	—	110
Peştera de la Râpa Vânată	Orlea	2107	47	75

Ponor	Index	Q (L/s)	Ponor	Map Index	Q (L/s)
Şuşiţa Verde	45	250	V. Bâlta	59	25
Şuşiţa Seacă - upstream	47	100	V. Bistriţa	63	350
Şuşiţa Seacă - downstream	48	75	V. Bistricioara	64	60
V. Poienii	49	15	P. Sohodol	66	5-9
V. Macriş	50	30	P. Albului	67	5-9
V. Grijii	51	40	V. Pârgavului (afluent)	68	5-9
V. Sohodol (Fuşteica area)	52	250	V. Pârgavu	69	20
V. Gropu Sec	53	25	V. Pocruiei	73	15
V. Gropu cu Apă	54	150	V. Cheii	74	15
V. Sohodol (Vidra gorges)	55	80	P. Orzeştilor (Râpa Vânată Cave)	75	1-9
V. Sohodol (Gârla Vacii cave)	56	250	V. Calului	77	5-9

Spring	Map Index	Q (L/s)	Spring	Map Index	Q (L/s)
Prilejele (Prajele)	5	0-400	Bordu	18	5-100
Pătrunsa	6	100-500	Brădiceni (grup)	29	20-40
Picuiel	7	100-200	Pârgavu	32	10-80
V. Rea	8	80	Tismana Mânăstire	33	5-50
Muşchiat	9	0-150	Tismana Păstrăvărie	34	5-50
Vâlceaua	10	200-900	Bolborosu	37	10-150
Jaleş	11	0-500	Izvarna Moară	40	200-400
Albuleşti	12	50-150	Izvarna	41	1400
Balaure	13	10-20	Călugări	42	10-40
Cucute	17	50-100	Izvorul de la Scuteala	43	5-50

Dictionary: Peștera – Cave; Clocotici, Bidăroaie (local names) – Pothole

locate downstream the discharge zone. The main goal of such work could be a controlled exploitation (quantitatively but also qualitatively) and additional water provision to the city of Craiova as well as compensating the water supply of the city of Târgu Jiu particularly during critical seasons.

Another option should focus on a complex exploitation (tourism and leisure, mini hydro-power etc) of the high potential offered by the Southern Vâlcan Mountains karst areas. Among others, the system discharges could be controlled upstream ponor's line or infiltration sectors. In case of Jaleş - Vâlceaua the alternative supposes carrying out three dams. The validity of the solution could be tested through surface and groundwater flow optimization models and scenarios aiming to a regulated discharge at the Vâlceaua intake chamber (Runcu village).

Selected References

Berza T.,1997, A hundred years of tectonic studies in South Carpatians: The state of the art. In: A. Grubic & T.Berza (Eds): Geology of Djerdap Area, Geoinstitut, Belgrade, pp 271-276.

Constantinescu T., 1975, Considérations sur les grottes situées entre les rivieres Susita Verde et Sohodol (Monts Vâlcan-Carpates Meridionales), Trav. Inst. Speol. "Emil Racovita", tom XIV, pp169-188.

Ilie D.I., 1970, Carstul din nordul Olteniei, Teza de doctorat, Arhiva Universităţii Bucureşti.

Ilie D.I., 1973, Resurgenţele din zona Tismana - Izverna, (NV Olteniei), Analele Universităţii Bucureşti, XXII.

Iurkiewicz A., 1994, L'interet de l'analyse systémique dans l'evaluation de la vulnerabilité à la pollution des systèmes karstiques des Monts Vâlcan, Proceedings of the International Symposium "Impact of industrial activities on groundwater", 23-28 May 1994, Constantza Romania.

Iurkiewicz A., 2004, Analiza sistemică în investigarea hidrodinamică a acviferelor carstice (exemple semnificative din România), PhD Thesis, University of Bucharest, 280 vp.

Iurkiewicz A., 2010, Hydrogeology and exploitation of Izvarna Spring, Romania, in "Groundwater hydrology of springs: engineering, theory, management and sustainability", Eds: Kresic N., Stevanovic Z., Elsevier, pp 442-456.

Iurkiewicz A., Slavoacă D., Slavoacă Ruxandra, 1991, 1992, Studii pentru stabilirea potenţialului hidrogeologic al depozitelor carbonatice din muntii Vâlcan, judetul Gorj, Arhiva S.C. Prospecţiuni-S.A., Bucureşti.

Iurkiewicz A., Mangin A., 1994, Utilisation de l'analyse systémique dans l'étude des aquiferes karstiques des Monts Vâlcan, Theoretical and Applied Karstology, 7, Ed. Academiei Române, Bucureşti, pp 9-96.

Iurkiewicz A.,Voica Mariana, Bulgăr A., 1996, Indirect evaluation of the Izvarna Karst System Discharge Trend (Romania), Theoretical and Applied Karstology, 9, Bucureşti, pp.113-119.

Mangin A., 1975, Contribution a l'étude hydrodynamique des aquiféres karstiques, These Doct. Sci. Nat. Dijon, in *Ann. Spéléol.*, 29, 3, pp 283-332, 29, 4, pp 495-601, 30, 1, pp 21-124.

Mangin A., (1982) Determination du comportement hydrodynamique des aquiferes karstiques a partir de l'étude des informations fournies par leurs exutoires, Colloque national en hommage a Castany, Orléans la Source, pp 397-403.

Mangin A., 1984, Pour une meilleure connaissance des systèmes hydrologiques a partir des analyses correlatoire et spectrales, *Journ. of Hydrology*, 67, pp 25-43.

Marinescu F., Pop G., Stan N., Gridan T., 1989, *Peştişani*, Harta Geol. RSR, Sc. 1:50,000, Ed.I.G.G., Bucureşti.

Pop Gr., 1973, Depozitele mezozoice din Munţii Vâlcan, Ed. Academiei, Bucureşti, 155p.

Pop G., Berza T., Marinescu F., Stănoiu I., Hîrtopanu I., 1975, *Tismana*, Harta Geol. RSR, Sc. 1:50,000, Ed.IGG, Bucureşti.

Rădulescu D., Stănescu I., Gaspar E., Bulgar Al. 1987, Aquiferous interconnexions in the Motru-Izvarna-Tismana-Bistrita karst area, Theoretical and Applied Karstology, 3, Bucureşti, pp199-214.

Sencu V., 1967, Cheile Runcului, Observaţii geomorfologice, St. Cerc. Geol. Geof. Geogr., Seria Geografie, 19, 1.

Stan N., Stanoiu I., Năstăseanu S., Moisescu V., Seghedy A., Pop G., (1979) *Câmpu lui Neag*, Harta Geol. RSR, Sc. 1:50.000, Ed.I.G.G., Bucureşti.

Vintilescu I., Constantinescu Tr., Diaconu G., 1970, Grottes, phenomenes karstiques et situation hydrologiques dans la valée de la Şuşiţa Verde (Monts de Vâlcan), Trav. Inst. Speol., IX, pp 9-34.