Hydrogeological researches for still waters in Bihor Vlădeasa Mountains (Apuseni Mountains, Romania)

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RESUME: Afin d'identifier des sources d'eau plate dans les montagnes Bihor Vlădeasa, on a soumis un nombre de 4 sources a une recherche hydrogeologique complexe. Le programme a egalement compris l'identification des conditions hydrogeologiques dans lesquelle apparaissent la source Izvorul Minunilor de Stâna de Vale et la source Vârfuraşul, situee dans le perimetre du village Răchiţele.

La recherche hydrogeologique complexe a consiste en etablir les conditions hydrogeologiques dans lequelles appairaissent les sources, l'observation a la sources de la variation des parametres physico-chimiques pendant au moin une anee et etablir la variation dans le temp de la composition chimique et de la charge bacteriologique, sur des echantillons d'eau mis en bouteille et stockes dans des conditions de laboratoire. On a egalement analise le contenu en elements toxique et en pesticides des eaux, ansi que leur radioactivite.

Les sources etudiees ne sont pas amenagees, raison pour laquelle certaines d'entre elles presentent temporairement des charges bacteriologiques elevees, dues a une contamination locale, a la source.

Les eaux sont de type $CaHCO_3$, avec des mineralisations tres faibles, et la plupart sont non-saturees par rapport au calcite et au dolomite, sans elements toxique et non-radioactives. Le contenu en pesticides depasse ches certaines sources de 3-4 fois la concentration maximale admise par les normes de potabilite. Les eaux ont une bonne stabilite chimique.

1. INTRODUCTION

The regional hydrogeological investigations performed in the Bihor Vlădeasa Mountains, outlined the occurrence of good quality groundwater sources, some of which can be bottled as table water.

These sources were subject of a complex investigation program, conducted by S.C. Prospecţiuni S.A., over a two period of time, 1991-1992 and 1995-1996, that resulted in:

- outlining the physico-chemical parameters of the sources, by means of systematic discharge, temperature, pH, electrical conductivity, dissolved oxygen, alkalinity and redox potential measurements;
- establishing the long term evolution of the chemical composition (especially labile elements and parameters: HCO_3^-, SO_4^{--}, Ca^{++}, Mg^{++}, dissolved oxygen, total hardness, residue on evaporation at 105^0C) and of the bacteriological content, both at the source and for samples bottled and stored in laboratory conditions;
- outlining the toxic elements and pesticides content, and the global α and β radioactivity.

In the framework of the conducted study, the laboratories of Prospectiuni S.A. have performed the general chemical analyses and the toxic elements contents measurements. The bacteriological analyses have been performed at the Center for Prophylactic Medicine in Beius, under the leadership of dr. D. Mocuţa, and partly at the Food Chemistry Institute in Bucharest.

For determining the pesticides content, the water samples have been analyzed in the Central Laboratory for the Control of Animal and Vegetal Origin Products, of the Agriculture and Food Ministry, while the total α and β radioactivity has been performed by the laboratories of the Institute of Physics and Nuclear Engineering in Măgurele and in the laboratories of the Rare Metals Authority in Măgurele.

2. INVESTIGATED SOURCES

The complex hydrogeological investigations program has included 4 sources (table 1). The program was also aimed at outlining the hydrogeological framework of Izvorul Minunilor, a source that prior to our research had been assigned to the still water category by Pascu et al., 1984, and the hydrogeological condition in which occur the source Vârfuraşul.

All the investigated sources are associated to karst aquifers. It is worth mentioning that the mere occurrence of karst aquifers does not implicitly secure a good water quality; these aquifers exhibit the outstanding property of concentrating groundwater flow to a few, or just to a single source of large discharge; yet the drawback is that they are quite vulnerable to pollution and provide only very poor filtering for the surface seepage water. In order to have good quality karst water, the carbonate deposits must be overlain by either a thick cover of deposits displaying filtering properties, or by an impervious formation beneath which the saturating karst water flows slowly, in order to undergo filtering and to reach a chemical equilibrium.

Table 1. Characteristics of the springs

	Source	T	Q	ph	TDS	RE	TH	S.I.		Pest.	Bact	
		^{0}C	l/s		mg/l	mg/l	^{0}d	lms	dol	ppb	a	b
1	Aleu (Pietroasa)	6,0-6,2	9	7,55	225,6	113,1	3,35	-0,71		0,0008	+	+
2	Cuciului (Pietroasa)	7,2-7,5	10		164,2	93,0	3,9				-	+
3	Izvorul Minunilor	5,8-6,2	15,6	7,34	139,3	86,4	3,6	-0,82	-2,32		+	+
4	Murgaşu (Remeţi)	7,5-8.2	12	7,65	126,2	80,7	2,9	-0,90		0,0016	-	+
5	Izv. Rece (Padiş)	5,4-5,6	40	7,15	279,0	167,3	8,3	-0,54	-2,83	0,0009	-	-
6	Vârfuraşul(Răchiţele)	5,8-6,8	110		177,4	116,4	4,8					

Note: T- temperature; Q-mean annual discharge; RE-residue on evaporation at 105^{0}C; TH-total hardness; S.I.-saturation index (lms-limestones; dol-dolomites); Pest-pesticides (sum of α HCH, β HCH and lindan); Bact.-Result of bacteriological analysis: a- seasonal analysis; b-analysis of bottled and stored samples; (+)-bacteriological content less than maximum accepted contents for drinking water by STAS 1342-91 (m.a.c.); (-)-bacteriological content higher than m.a.c., at least at one sample.

The following general assertions are valid for the investigated sources and areas:

- the springs are either not tapped at all, or tapped in a rudimentary manner, which results in a local bacteriological contamination, mainly ensuing to runoff water inflow. Due to this fact, in some cases concentrations do not comply with drinking water requirements;

- all studied spring waters from Bihor Vlădeasa Mountains are $CaHCO_3$ type, with low mineralization;

- the water samples collected from the springs Aleu, Murgaşu and Izvorul Rece displayed a good chemical stability over the one year monitoring period. For the other sources the chemical stability was not analyzed;

- the saturation indexes, computed by Netpath program, indicate that the water of springs is undersaturated, to a larger or smaller extent, with respect to both calcite and dolomite;

- the toxic elements content, indicate Cr, Cu, Mn, Ni, Pb and Zn contents below the maximum allowed concentrations;

- for all the sources, the pesticides content exceeds up to 3 times the accepted concentration (0.0005 ppm). The waters are not radioactive.

Bihor-Vlădeasa Mountains have a rather intricate geological structure, with the crystalline formations, the sedimentary deposits and the igneous rocks forming an enormous puzzle. As a result, there is an increased probability of occurrence of karst aquifers that are well protected against pollution factors and have good quality water. For identifying new still water sources in Bihor-Vlădeasa Mountains, in a first step, several sources have been sampled and analysed for bacteriological contents (fig. 1).

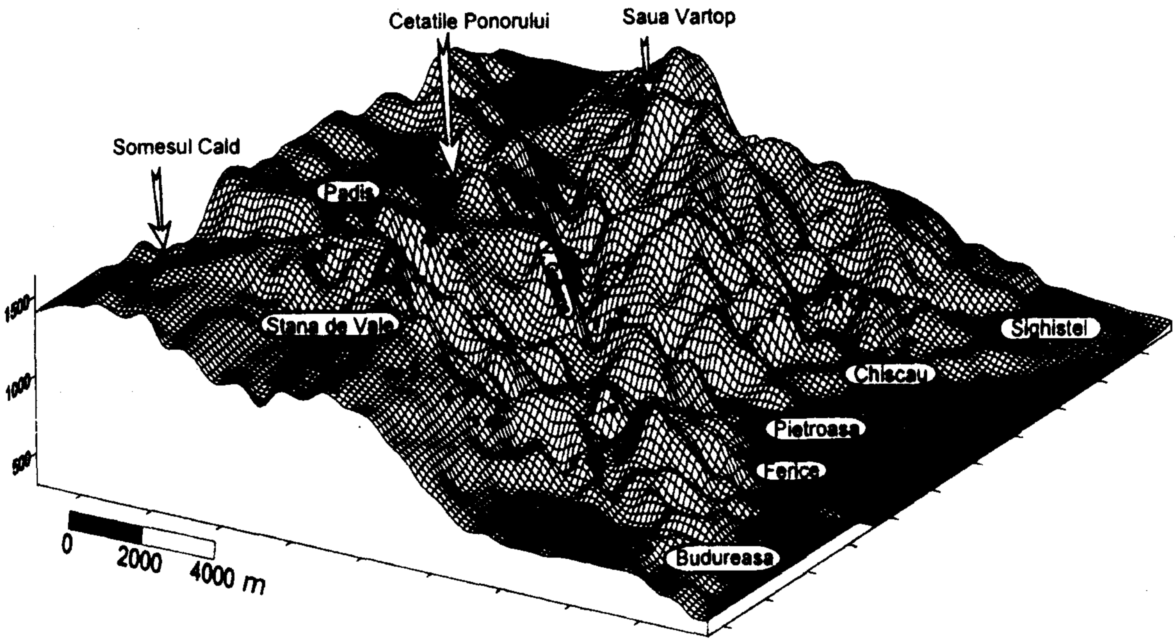

Fig.1 The central-western part of Bihor-Vlădeasa Mountains. Displays of springs analyzed for bacteriological content.

Key of the numbers: 1-Izvorul Minunilor; 2-Aleu; 3-Bulbuci; 4-Oşelu; 5-Boga; 6-Izvorul Rece; 7-Păuleasa; 8-Galbena; 9-Hidrei; 10-Blidaru; 11-Pişolca; 12-Izbucul de la Valea de Sus 13-Giuleşti; 14-Berbece; 15-Puşului; 16-Podu Cuciului; 17-Cuciului; 18-Coasta Rea; 19-Ulmului.

Figure 2 displays the total number of bacteria and total coliform bacteria contents of some karst springs, illustrating a wide range of contents, with the karst systems supplied by swallets (for example the spring Hidrei, no.9) exhibiting a higher bacteriological content, as opposed to those systems the recharge of which is diffuse and/or is taking place through an aquifer confined beneath an aquiclude (the springs Izvorul Minunilor, no.1 and Aleu, no.2), that have a smaller bacteriological load.

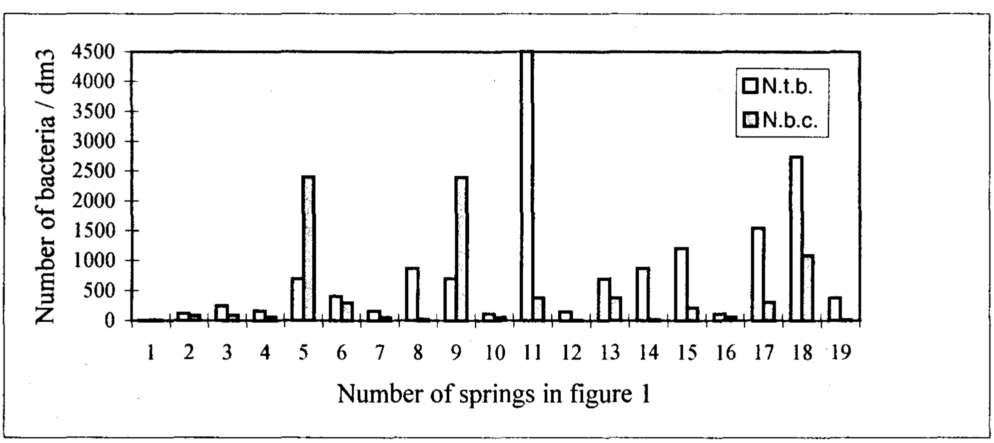

Fig.2. Displays of the total number of bacteria (N.t.b.) and of the number of coliform bacteria (N.b.c.) in some springs water in Bihor-Vlădeasa Mountains (the key of the numbers in figure 1)

Figure no. 3 displays Piper diagram with chemical composition of the springs investigated, and in figure no. 4 is presented the hydrogeological map of Ferice-Stâna de Vale area, a territory with a lot of springs with good quality spring waters.

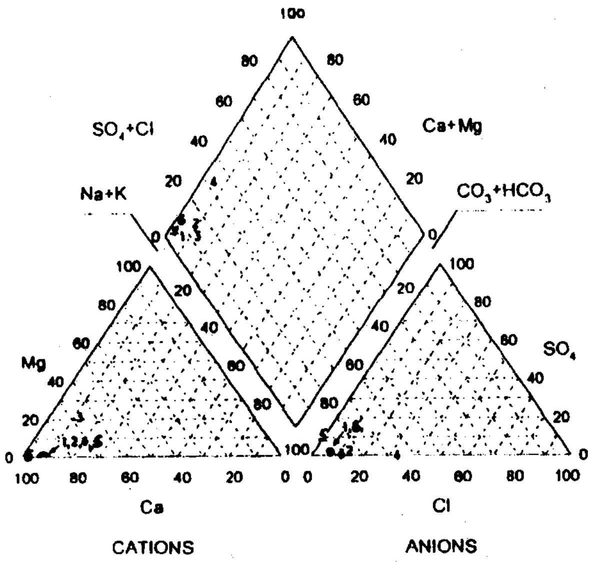

Fig. 3 Piper diagram with displays of chemical composition of studied springs from Bihor-Vladeasa Mountains (key of the numbers in table 1)

2.1 Aleu spring (figures 1, 2, 3, 4 and table 1)

It is also designated as the spring beneath Cornul Muntelui and the spring in Pârâul Popii (Apa Popii). The spring is situated beneath Cârligatele ridge, at 1140 m a.s.l., in the upper catchment basin of Aleu, a tributary of Crişul Pietros (fig. 4, no. 18). Access is provided by the Pietroasa-Padiş road, then by branching, 2 km upstream Pietroasa village, on a 10 km long forestry road that parallels Aleu stream, then further on, from 950 m a.s.l., on a steep, 700 m long forestry trail excavated on the right side slope of Popii stream.

The spring is situated on the left side of Popii stream, at 50 m relative elevation, at the extremity of a short (100 m) gully, which includes several 2-5 m high waterfalls. It emerges from a breakdown of large, black limestone blocks, in the middle of a majestic recess wall where Rhaetian limestones with virtually horizontal, decimetric bedding outcrop. In the Cornul Muntelui ridge, a thrust outlier of the Arieşeni nappe (quartzite sandstones) covers the limestone, which again outcrops immediately to the south-east, in the upper catchment basin of Sebişel stream.

In Aleu spring discharge the aquifers saturating the Late Triassic limestone of the Ferice nappe in the Cornul Muntelui area. Their supply originates mainly in runoff flowing radially on the sandstones of the thrust outlier and undergoing diffuse infiltration as it reaches the limestone surface.

2. 2. Izvorul Cuciului (figures 1, 2, 3, 4 and table 1)

Cuciului spring is located in the upper catchment area of Cohu stream, a tributary of Valea Mare of Budureasa, at 870 m a.s.l. (fig. 4, no. 5). Access to the spring is provided by the forestry road that follows the two valleys up to Podul Cuciului (9 km from Budureasa), and next by a rugged footpath that follows the course of Cuciului stream, up to the source (1 km).

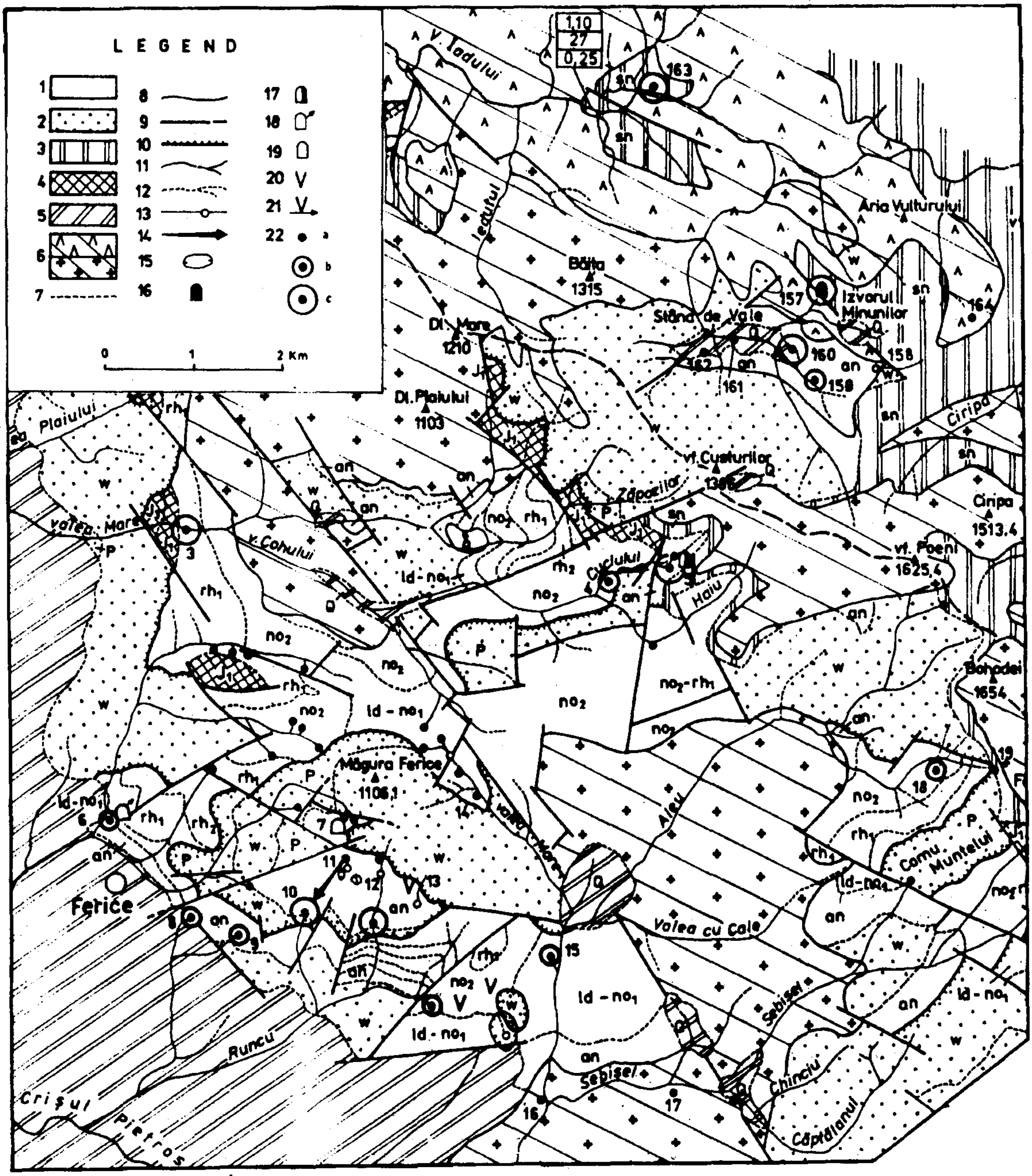

Fig. 4. Hydrogeological map of Ferice-Stâna de Vale area. After Orăşeanu, 1996 (fragment of Hydrogeological map of Bihor Vlădeasa Mountains).

Legend: 1-Mesozoic Limestones and dolomites; 2-Permo-werfenian sandstones, conglomerates and shales; 3-Senonian sandstones, conglomerates and argillaceous slales; 4-Lower Jurassic marly and argillaceous deposits; 5-Pannonian-Quaternary deposits (marls, sands, gravels); 6-Laramian magmatites: a-volcanics; b-intrusives; 7-Geological boundary between sedimentary deposits; 8-Boundary of magmatites; 9-Faults; 10-Overthrust front; 11-Course of perennial stream; 12-Course of temporary stream; 13-Subterranean capture; 14-Direction of groundwater flow; 15-Karst depression; 16-Perrenial outflow cave; 17-Temporary outflow cave; 18-Cave tapping an underground stream; 19-Inflow cave; 20-Fossil pothole; 21-Pothole tapping an underground stream; 22-Spring discharge (l/s): a-under 1; b- 1 to 10; c- 10 to 50.

Key of the numbers on the map: 3-Spring of Coasta Rea; 4-Spring of Cociu bridge; 5-"La trei izvoare" Cociu spring and cave; 6-Ferice spring and cave; 7-Peştera Vacii cave; 8-Cornilor spring; 10-Toplița spring; 11-Ponor of Groapa Budeştilor; 12-Ponor and spring of Troscău; 13-Ponor and spring of Socei; 14-Puşului spring; 15-Berbecul spring; 17-Ciurgău spring; 18-Aleu spring; 157-Izvorul Minunilor spring; 163-Murgaşu spring

Cuciului spring includes two outlets, a perennial one, that emerges in the streambed, from a limestone blocks accumulation, and a temporary one, consisting of a short cave with low entrance, situated at the bottom of the hill slope on the left side of the valley. Immediately upstream is situated a temporary spring, while further upstream the valley carries water only during flood periods.

The seasonal analyses sometimes indicate high bacterial loads, the spring being a place where wild animals use to come for drinking. In the autumn of 1992, the recorded flow rate of the spring was very low (2l/s).

2. 3. Izvorul Minunilor spring (figures 1, 2, 3, 4, 5 and table 1)

The reputation of the Stâna de Vale resort is equally due to its exceptional touristic potential and to the outstanding quality of the water discharged by Izvorul Minunilor.

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

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

Minunilor spring has a 15.6 l/s average flow rate and very small annual fluctuations of the daily average flow rate (n_v = 1.9), due to the almost exclusive contribution of the base flow component (99%) to the discharge recorded during recession periods. The strong memory effect (44 days) suggests relatively important reserves (Orăşeanu, 1996).

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

Leakage from water accumulations existing in the Senonian deposits that transgressively cover the dolomites, and from ignimbritic rhyolites that cover part of the Senonian deposits provides the main supply to the karst aquifer.

Part of the runoff collected on the western slopes of the Baia Popii ridge sinks through the Brebu swallet. In order to establish the underground drainage direction two fluorescein tracing tests have been performed, the tracer occurrence being monitored in Izvorul Minunilor and in Pastravariei springs. During the first tracing experiment (17 October 1995) the tracer was recovered in Pastravariei spring, its occurrence in Izvorul Minunilor being uncertain, as the samples fluorescence ranged in the background domain (Orăşeanu, 1996). A second tracing experiment (15 September 1997) proved that Pastravariei spring is exclusively collecting the water sunken in the Brebu swallet. Tracers experiments were performed în colaboration with meteorologist Ionuţ Varga.

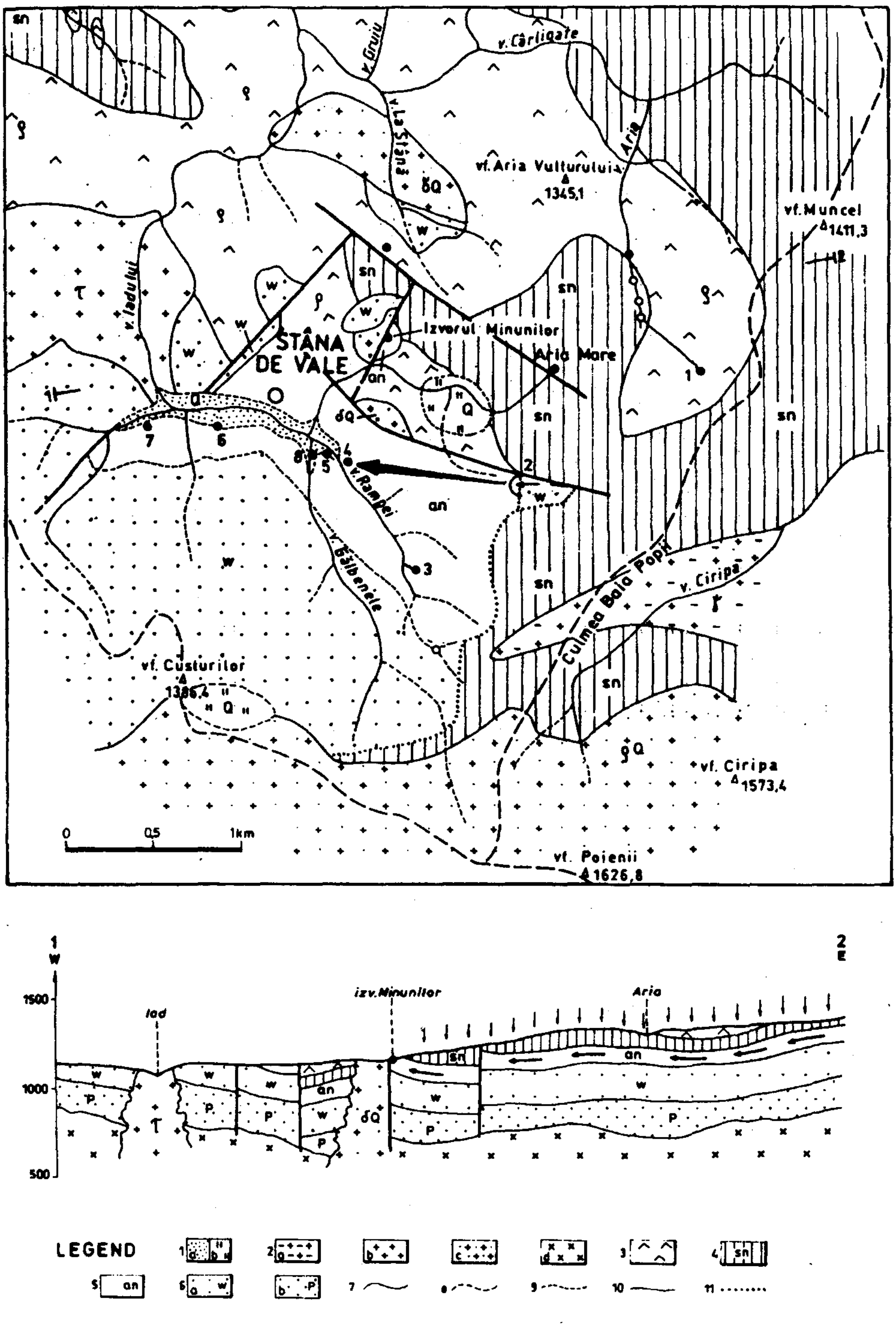

Fig.5 Hydrogeological map of Stâna de Vale area.
Geological data after Bordea et al. (1984) and Istrate (1978)

Legend: 1-Quaternary: a. alluvium; b. colluvium; 2-Laramian intrusives (second cycle): a. microgranite rhyolite; b. tonalite; c. quartz-diorite; d-granodiorite 3-Early laramian volcanics (first cycle, ignimbrite rhyolite formation); 4-Senonian (Gosau facies: conglomerates, siltstones, marls, limestones); 5-Anisian (dolomites); 6a-Werfenian (quartzitic sandstones, argillites); 6b-Permian (sandstones, shales); 7-Course of perennial stream; 8-Course of temporary stream; 9-Geological boundary between sedimentary deposits; 10-Boundary of magmatites; 11-Boundary of transgression; 12-Faults; 13-Recharge area of Izvorul Minunilor spring; 14-Subterranean capture; 15-Ponor (sinkhole);16-Watershed; 17-Direction of groundwater flow; 18-Spring; 19-Direction of cross-section Key of the numbers on the map: 1-Ariei spring; 2-Brebu ponor; 3-Rampei (Păstrăvăriei, Eremitului) spring; 4-Păstrăvăriei (Profetului) spring; 5-Meteorologists's spring; 6-Pavel spring; 7-Radu spring; 8-Izvorul Păcii spring.

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

2. 4. Murgaşul spring (fig. 3, 4 and table 1)

Murgaşul spring is located in the upper catchment basin of the Iad stream, some 6 km downstream Stâna de Vale resort (fig. 4, no. 163).

The spring occurs on the left side of the Iad stream, some 700 upstream the Murgaşul forestry hut. The spring emerges at the bottom of the steep mountain slope, from a breakdown of rock blocks, settled to some extent. For a period it has supplied a small pool hosting a trout hatchery, which is currently abandoned.

The geological setting of Murgaşul spring includes a contact between Senonian deposits and the ignimbritic rhyolites formation, with the Senonian deposits forming a small syncline surrounded by the igneous rocks (Istrate, 1978).

The average flow rate of the spring amounts to 12.25 l/s, extending over a span of 3 - 545 l/s. Worth mentioning is the wide discharge range, the maximum values being recorded after heavy rain periods, when large amounts of water burst out through the blocks on the slope above the spring.

2. 5. Izvorul Rece spring (figures 1, 2, 3 and table 1).

Izvorul Rece is situated in the southern part of the closed catchment area Padiş-Cetăţile Ponorului (fig. 1, no.6), in the catchment area of Ursului stream, which sinks in the cave at Căput. The spring emerges from an accumulation of large limestone blocks, at 1075 m a.s.l., and discharges part of the groundwater collected in the Lumea Pierdută - Valea Seacă area, that permanently provides a significant flow rate (Orăşeanu, 1996).

2. 6. Vârfuraşul spring (figures 3, 6 and table 1)

Vârfuraşul spring is located in the upper catchment area of Stanciului stream, a tributary of Henţ (Săcuieu) stream at Răchiţele, one of the most interesting - in hydrogeological terms - karst areas in Vlădeasa Mountains (fig. 6, no.5).

The geologic structure of Valea Seacă catchment area includes a very thick stack of compact and bedded limestones of Late Jurassic - Early Cretaceous age, that underwent strong thermal metamorphism induced by the Vlădeasa igneous body. The limestones are transgressively overlain by Senonian deposits featuring the Gosau formation facies and subordinately, the volcano-sedimentary formation facies (Mantea, 1985).

The products of the alpine subsequent (banatitic) volcanic activity display wide occurrences in the Stanciului valley upper catchment area, including large vertical extent bodies of quartz andesites, which pierce the limestones and the Senonian deposits (Nimăiasa, Cuciulata, Iconiţa), as well as andesite (Ţiglău) and rhyolite (Vârfuraşul) lava flows, which cover the sedimentary deposits.

Vârfuraşul spring emerges on the left side of Valea Seacă, from an accumulation of marble like limestone blocks fallen into a short recess valley, that ends in a limestone wall where the homonym cave entrance is excavated. Downstream, the flow rate of the surface course increases by 40-60%, as a result of an additional supply provided by several springs located at the bottom of the cliff on the right side of the stream.

Vârfuraşul spring emerges at 1175 m a.s.l. and it is the outlet of an underground course which runs through a 2250 m long cave (Kömives & Nagy, 1976). It provides the discharge to the karst water accumulations in the upper Valea Seacă catchment area, draining a karst system of 1445 m average topographic elevation and 6.75 km^2 area, almost entirely (97%) covered with non karst deposits. It is also supplied by streams sinking through the swallets.

The bacteriological and chemical tests are currently being performed. The karst aquifer specific recharge conditions (the presence of the Senonian deposits and of the Vlădeasa rhyolites on top of the karst aquifer), recommend Vârfuraşul spring as a best quality table water.

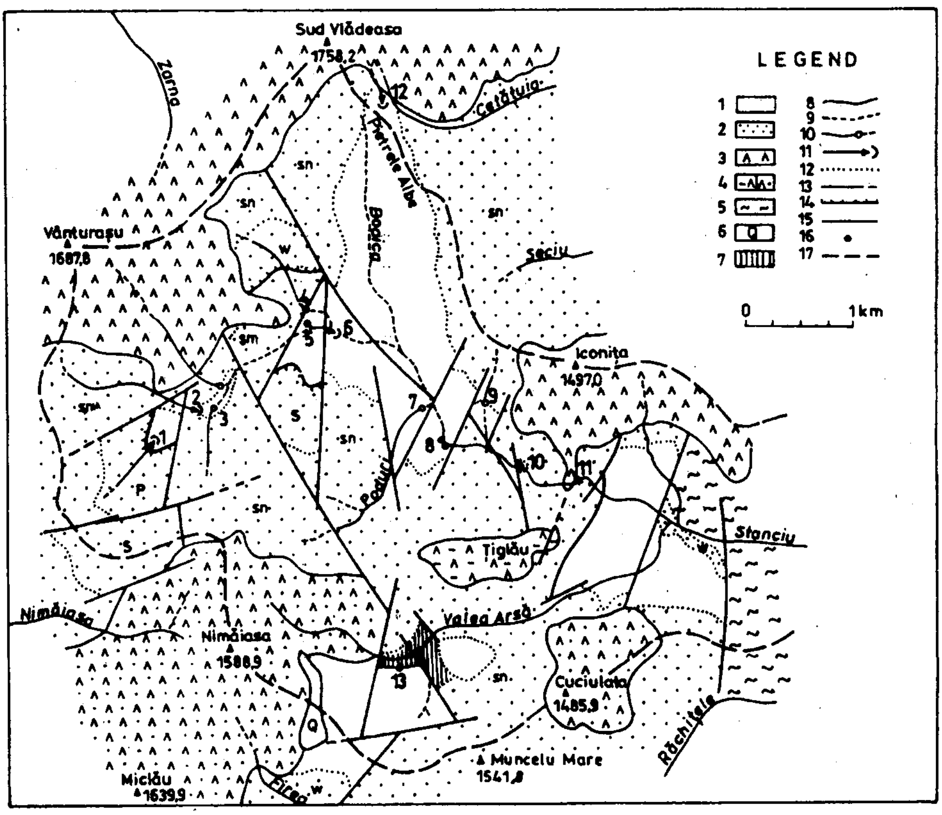

Fig. 6. Hydrogeological map of Valea Seacă area (Vlădeasa Mountains). Geological data after Mantea (1985).

Legend: 1-Mesozoic limestones; 2- Sandstones, conglomerates, argillaceous shales (S-Silurian; P-Permian; W-Werfenian; sn-Senonian); 3-Early laramian volcanics (first cycle, ignimbrite rhyolite formation); 4-Laramian quartz andesites (second cycle): a- lava flow; b-intrusives body; 5-Chrystalline schists; 6-Quaternary colluvium; 7-Lower Jurassic sandstones; 8-Course of perennial stream; 9-Course of temporary stream; 10-Subterranean capture; 11- Ponor (sinkhole); 12- Geological boundary between sedimentary; 13-Boundary of magmatites; 14-Overthrust front; 15-Fault; 16-Spring; 17-Watershed.

Key of the numbers on the map: 1-Avenul cu Spinare pothole; 2-Ponorul "La Tău"; 3-Losses of brook under Nimăiasa Mountains; 4-Losses of Făgeţel brook; 5-Vârfuraşul spring; 7-Losses of Poduri brook; 8-Izvoarele de la pârâul Sărcerului springs; 9-Losses of Cuţilor brook; 10-Izvorul de la Preluca din Vale spring; 11-Răchiţele waterfall; 12-Losses of South Vlădeasa brook; 13-Izvorul din Valea Arsă spring.

CONCLUSIONS

The investigated outlets are not tapped, and as a consequence some of them temporarily display high bacteriological loads (Cuciului and Izvorul Rece springs). We assume the phenomenon to be the result of local contamination.

The water discharged by Aleu spring is of best quality, so it can be rated as still water.

Cuciului and Murgaşul springs have very good quality water as well, yet their flow rates display large fluctuations, with drastic reductions during drought periods, which may turn to be an unfavorable circumstance in the case of intensive exploitation.

The bacteriological and chemical tests for the Vârfuraşul spring are currently being performed. Information collected so far recommend it as a very good quality water source.

Izvorul Minunilor spring has a outstanding constancy of the physico-chemical parameters of the water and a continuous lack of any bacteriologic content, as a result of favourable hydrogeological circumstances in terms of supply, flow and discharge of the karst system.

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