3.13.4. CODRU MOMA MOUNTAINS

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Codru-Moma Mountains extend over an area of about 1200 km^2, being located in the western part of Apuseni Mountains, and they bear the shape of a NW-SE striking nappe system, bounded laterally by two Neogene basins: that of Crişu Negru (Beiuş) to the NE, and that of Crişu Alb (Zarand) to the SW. They consist of two zones which are quite distinct in terms of topography, Codru Mountains to the north, and Moma Mountains to the south, separated by Moneasa valley and by its tributary Boroaia in the western half, and by Iugii valley and Briheni brook further to the east.

Carbonate terrains of Codru-Moma Mountains occupy an area of 169 km^2, distributed as follows (Fig. 4.1):

- Dumbrăviţa de Codru-Moneasa-Dezna area (66 km^2);
- Clăptescu area (13 km^2);
- Vaşcău plateau (90 km^2).

4.1. Current status of the hydrogeological investigations

The first geographic and hydrographic information about Codru-Moma Mountains was published by A. A. SCHMIDL in its book "Das Bihar Gebirge an der Grenze von Ungarn und Siebenburgen", issued at Vienna in the year 1863. The author provided a detailed description of the Vaşcău plateau topography, also mentioning the ebb and flow spring at Călugări and the thermal water discharges at Moneasa.

The first hydrogeological observations concerning Codru-Moma Mountains are due to E. KERY, who published in the year 1866 the description of the thermal water discharges at Moneasa, together with the corresponding chemical analyses, performed the same year by K. NENDWITCH.

The Vaşcău Plateau is probably the first place in Romania where water tracing was carried out. In 1901, the geologist S. MIHUŢIA added powdered coal to the water of the Ţarina stream and demonstrated a connection between the Câmpeneasca cave (photo 1) and the Boiu spring (S. MIHUŢIA, 1904).

Starting from the year 1970, I. ORĂŞEANU has conducted detailed hydrogeological investigations in all Codru-Moma Mountains karst areas and, either on his own or in cooperation with E. GAŞPAR and other investigators, he has performed a series of tracer tests which outlined, for all those areas, the general framework of the underground karst flow. E. ANGHEL (1974), GH. PONTA and N. TERTELEAC (1977-1978) joined to the hydrological reserches.

A paper addressing the groundwater geochemistry in the Dumbrăviţa de Codru plateau has been published in 1979 by JANETA MERŢ MATYASI.

In the years 1985 and 1987, I. ORĂŞEANU has published two papers addressing the hydrogeology of Vaşcău plateau and of Moneasa area,

Photo 1. Câmpeneasca cave. Aquarelle in the book of A. A. Schmidl, „Das Bihar Gebirge an der Grenze von Ungarn und Siebenburgen", published in Vienna in 1863.

while in the year 2000, together with J. MATHER, he has published another paper concerning the origin of the thermal water discharges at Moneasa and Vaşcău.

In the year 1986, the Institute of Geology and Geophysics has issued the hydrogeological map, sheet Vaşcău, at the scale 1:50,000, prepared by PONTA GH., BLEAHU M., PANIN ŞT. and ORĂŞEANU I., where the karst terrains hydrogeology was extracted from unpublished reports of I. & NICOLLE ORĂŞEANU (1973-1978).

The Vaşcău Plateau physiography has been investigated by I. O. BERINDEI et al. (1978), M. BLEAHU (1978), and P. COCEAN and T. RUSU (1984), while M. BLEAHU et al. (1976), GROH et al. (1976, 1978), G. HALASI (1979, 1984), K. GOPFRICH (1986), S. MATYASI and L. MATYASI (1987) addressed the results of the speleological investigations carried out in Codru-Moma Mountains karst areas. A synthesis concerning the underground cavities in Moneasa area has been published by G. HALASI in 1978.

4.2. Geological and structural framework of Codru Moma Mountains

The Codru domain, where formations subsequently incorporated in the Codru nappes have been deposited, includes at its bottom a crystalline basement overlain by a sedimentary cover that consists of a thick stack of Permian-Werfenian molasse deposits, followed by a prevalently carbonate stack, whose most recent age reached the Early Jurassic. After a sea retreat episode, which had lasted during the Medium Jurassic, the Codru domain has been again covered by sea during the Tithonic-Neocomian time interval.

Between Crişu Negru stream to the north and Moneasa spa to the south, carbonate deposits form a continuous strip, incorporated in the generally homoclinal, eastward dipping geological structure of the central part of Codru Mountains. This main strip, consisting of Triassic limestones and dolomites and displaying average outcrop widths of 2-3 km, is followed to the east by a second one, which is discontinuous, displays average outcrop widths of only 50-100 m, and consists of Early Jurassic limestone. The two carbonate strips are separated from one another by thick deposits consisting prevalently of Norian and Rhetian shales and sandstones, which are virtually impervious and thus isolate the groundwater accumulations located in each of the two carbonate strips. Groundwater accumulations in the main carbonate strip are underlain by Werfenian quartz sandstones, while those in the secondary strip are overlain by flysch type deposits of Tithonic-Neocomian age. The lower half of the eastern slope of the ridge and the streambed of Ursului brook are covered by quartz sandstone scree and boulders accumulations, which frequently cover the Early Triassic deposits (Figure 5.1).

In Codru-Moma Mountains, outcrops consist of sedimentary deposits which belong to the Finiş, Moma, Vaşcău and Coleşti nappes. In devising the hydrogeological maps (Fig. 4.1 and 4.5), there has been used the geological background provided by the following sheets of the Geological Map of Romania, scale 1:50.000: Dumbrăviţa de Codru (BLEAHU et al., 1984), Petru Groza (BLEAHU et al., 1981) and Vaşcău (BLEAHU et al., 1979).

4.3. The Codru Mountains

4.3.1. The Codru Mountains physiography

The topography of Codru Mountains closely mirrors their geological structure and constitution. It includes three main mountain ridges, which strike roughly north-south and incorporate hard rocks of Permian age. Those ridges bound two depressions, which are shaped in less competent rock formations and are occupied by the upper reaches of the longest streams in those mountains, Finiş and Tărcăiţa.

The western ridge, also known as The Big Ridge of Codru Mountains, extends between the peaks Bălăteasa and Izoi. It is about 12 km long and reaches a maximum elevation of 1111.9 m in Pleşu peak. This ridge the overlooks Zarand basin to the east, forming a continuous wall which rises by almost 1000 m above the depression.

Toward the east, the Big Ridge also appears as a prominent feature, an effect of the elevation drops in excess of 400 m recorded down to the upper reaches of Finiş stream, or down to Brătcoaia and Izoi-Tinoasa karst depressions. The latter are typical karst depressions of lithological contact, shaped under the circumstances created by the underground sinking of the surface streams that originate on the Big Ridge eastern mountainsides. The depressions are flat internal drainage areas, covered to a large extent with grass, occupying areas of 3.8 and 4.1 km^2 respectively, strongly alluviated with quartz sandstone boulders, and strewn with temporary water ponds.

To the north, the Big Ridge disperses into a series of secondary ridges that smoothly descend toward Beiuş basin. Here is located Dumbrăviţa de Codru karst plateau, well known for its areas strewn with lots of large size sinkholes. It is completely devoid of surface streams and it forms a internal drainage area extending over 5.5 km^2.

Eastward from Dievii peak there occurs another karst area of Codru mountains, known as Clăptescu area, after the name of the corresponding peak (818.4 m elevation), which appears as the prominent feature of the local topography, due both to its height, and to its median position. Between the peaks Dievii (1044.0 m) and Clăptescu, a series of small depressions generated by karst stream piracy extend along a north-south direction, being shaped by runoff collected on the eastern mountainside of Dievii peak.

Water in the southern part of Codru Mountains is collected by Moneasa brook, a tributary of Dezna stream, which at its turn is a tributary of Crişu Alb river. The valley of Moneasa brook is tectonically controlled, closely following the strike of the overthrust plane of the Moma Nappe over the Finiş Nappe. In the karst area the stream supply occurs asymmetrically, its tributaries, that are excavated mainly in carbonate formations (Scăriţa, Megheş, Băilor, Pietros), coming only from the right side. Băilor brook is mainly supplied by water discharged through Grota Ursului outlet cave.

The underground cavities in Moneasa area consist of several caves and potholes, among which we mention: the cave "Peştera cu Apă de la Moară" (2012 m), "Grota Ursului" cave (250 m), and the pothole in Teia valley (1337.5 m long, and -90 m deep).

4.3.2. The hydrogeology of Codru Mountains karst areas

Groundwater accumulations in the carbonate deposits of Codru-Moma Mountains discharge through springs of relatively significant flow rates. Table 4.1 provides the hydrodynamic parameters of the main karst outlets, Table 4.2 provides the results of recession and spectral and coralative analysis, while Table 4.3. provides the tracer tests performed in Codru Mountains.

4.3.2.1. Izvorul Morii de la Borz karst system

Izvorul Morii de la Borz karst system incorporates mainly Dumbrăviţa de Codru karst area. Out of the entire karst system water supply, 95% is provided by rainfall on the limestones and dolomites outcrops, while catchment areas developed on impervious formations contribute with only 5%. Runoff collected on non-karst terrain diffusely sinks in the streambed when reaching carbonate terrains.

Izvorul Morii ("The Mill Spring") is located on territory of Borz village (site 1 in Figure 4.1), at the end of a blind valley which displays the character of a torrent, at an absolute elevation of 211 m, which is 61 m above the base level represented by Crişu Negru stream. The spring has 101 l/s average flow rate and a relatively small value of the base flow index (11.7). The extreme flow rate values recorded during the X. 1986-IX. 1987 period were 30 l/s and 350 l/s respectively, while the average temperature was 9°C. The small value of the recession coefficient (0.0065) suggests the existence of major water accumulations, stored mainly in the cracks and the bedding joints of the Anisian dolomites and of the Anisian-Carnian limestones.

The only known occurrences of groundwater in Dumbrăviţa de Codru karst plateau are related to a few domestic dug wells that tap epikarst water accumulations, of temporary and local character (Fântâna Josana, Fântâna Talpii, (sites 2 and 3 in Fig. 4.1).

The spring in Luncii Valley (site 7 in Fig. 4.1) is the second largest outlet in terms of flow rate on the territory of Dumbrăviţa de Codru village. It is the outflow of the underground stream that flows in the nearby cave in Luncii valley. The spring has an average flow rate of 12 l/s, with minimum value of 4-5 l/s, it is tapped and it provides discharge to groundwater accumulations beneath Bujorului peak and possibly to diffuse infiltration occurring in the upper reaches of Ormanului brook.

4.3.2.2. Finiș - Feredeu karst system

Tracer tests performed in the years 1977 and 1986 in Brătcoaia depression by I. ORĂŞEANU and E. GAŞPAR (Table 4.3) have outlined the existence of a major diffluence area, which concerns water that sinks in Dosu Varului swallet, located in the northern part of the indicated depression (site 17 in Fig. 4.1). Specifically, the tracers that had been used - namely Iodine-131 and In-EDTA - have been detected in the Finiş spring outlets (site 15 in Fig. 4.1) and in Feredeu spring (site 13 in

No.	Source	Q mean	Q min	Q max	n_v	B_f	Cv	Tracer tests	
		m³/sec						V, m/h	L, km
Codru Mountains									
1	Valea Morii, Borz	0.101	0.030	0.350	11.7	0.31		45.4-53.7	2.95-4.3
2	Finiş	0.289	0.025	2.300	92.0	0.15		10.8-25.0	0.8-4.05
3	Feredeu (5)	0.044	0.035	0.069	1.55	0.88	0.05	27.6-103.0	2.9-6.0
4	Grota Ursului (1)	0.058	0.017	0.657	38.6	0.40	0.64	120-368	1.84-5.8
5	Băilor stream (1, 2)	0.141	0.054	0.900	16.7	0.43			
6	Băilor stream (1, 3)	0.040	0.006	0.640	106.7	0.17			
7	Băilor stream (2, 4)	0.198	0.050	5.520	110.4	0.37			
Vaşcău Plateau									
1	Boiu	0.587	0.070	5.400	77.14	0.14	0.88	5-500	1.7-8.6
2	Şopoteasa	0.120	0.011	0.275	119.4	0.26	0.62	29.4	418
3	Crisciorel fishery	0.126	0.007	0.350	50.0	0.08			
4	Pepineaua	0.048	0.02	0.335	16.7	0.44	0.55	20	0.625
5	Coleşti	0.034	0.002	0.420	210.0	0.06	0.97		
6	Răşchirata	0.040	0.015	0.110	22.0	0.13	0.76		
7	Valea Seacă	0.077	0.023	0.250	10.9	0.32	0.51	96.3-130	0.65-1.05

n_v, (Qmax /Qmin); B_f , base flow index (the ratio between Qmin of the drought month of the year and Q mean annual). Cv, the discharge time series variation coefficient (the ratio between average deviation and the annual average of an hydrologic annual series of mean daily discharges values; (1), X. 1997-IX. 1998 time interval; (2), Băilor stream in Ciuperca gauge section; (3), Băilor stream in Pavilion 1 gauge section; (4), 1976-1997 time period.; (5), V. 2004-XII. 2007 time period.

Table 4.1. Hydrodynamic parameters of karstic springs (X.1986-IX.1987, time interval).

No	Karst system	Period	Recession curve analysis: α (day^{-1})	V dyn (106 m³)	V year (106 m³)	i	k	Corelation and spectral analysis: ME (day)	TF	RT (day)
1	Grota Ursului	X.1997-IX.1998	0.0090	0.41	0.50	0.610	0.082	18	0.192	6.9
2	Boiu	X.1986-IX.1987	0.0120	1.66	18.51	0.43	0.089	16	0.100	19
3	Şopoteasa	"	0.0050	0.40	6.74	0.52	0.060	55	0.084	36
4	Răşchirata	X.1997-IX.1998	0.0045	1.01	1.60	0.380	0.230	51	0.080	61
5	Valea Seacă	"	0.0034	1.51	1.58	0.240	0.350	60	0.100	62

α(day^{-1}) - base flow (recession) coefficient; Vdyn, dynamic volume; Vyear, annual volume; i and k, Mangin's index classification; ME, memory effect; TF, truncation frequency; RT, regulation time.

Table 4.2. Results of recession and spectral and coralative analysis.

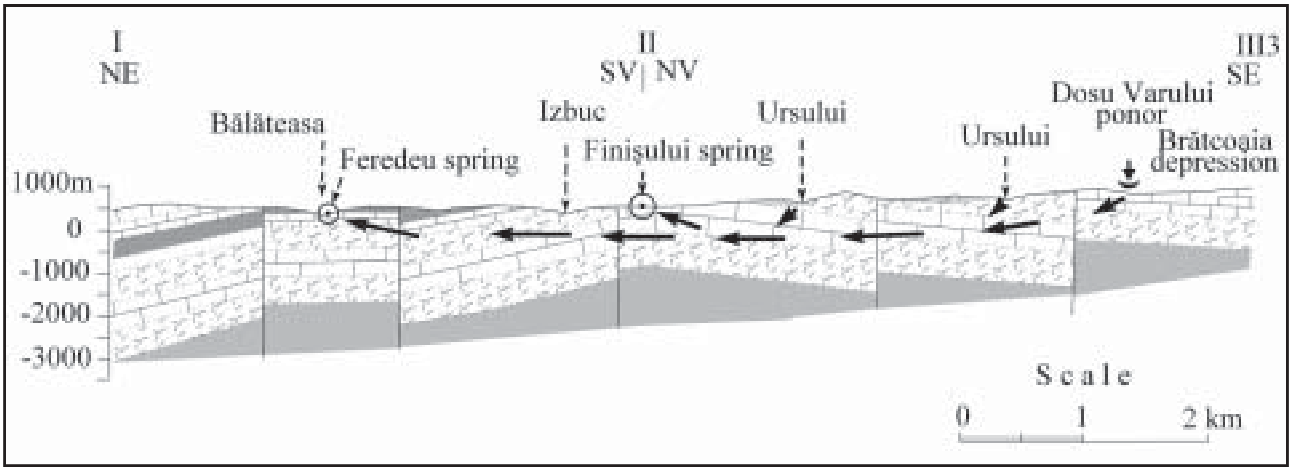

Figure 4.2. Hydrogeological cross section of Codru Mountains.
Legend as in Figure 1.6. Line of section shown in Figure 4.1.

Fig. 4.1), located to the north, as well as in Grota Ursului resurgence (site 21 in Fig. 4.1) and in certain thermal water outlets at Moneasa (the thermal spring no.1 and the thermal water wells S2 (4663) and S4 (4664)), located to the south, thus indicating that the groundwater divide between the catchment areas of Crişu Negru and Crişu Alb rivers is located in Brătcoaia area. The indicated tracer tests have additionally outlined that the springs Finiş and Feredeu on the one hand, and the resurgence Grota Ursului and the thermal water outlets at Moneasa on the other hand, all belong to unitary karst systems (Fig. 4.2 and 4.3).

During the hydrological year X.1986 - IX.1987, the monthly average flow rate of Finiş spring fluctuated between 0.025 and 2.3 m3/s. The corresponding base flow index value, n_v=92, ranges among the highest recorded for the Codru-Moma Mountains karst outlets. The wide fluctuation in terms of discharge corroborates with the large value of the recession coefficient (α= 0.01), suggesting that groundwater storage and movement occurs mainly in largely developed karst cavities, and to a lesser extent in fissures and fine joints. Spring water has an average temperature of 8.5°C and it becomes very muddy during heavy rainfall and snowmelt periods.

Feredeu spring is located on the right side of Bălăteasa brook, some 700 m upstream from its junction with Ursului brook (site known as "La Cruce", Fig. 4.4). The spring water emerges from the upper dolomite, close to the contact with Rhaetian marls. In the outlet area vegetation is abnormally abundant and a significant amount of gas is released from the spring water. The latter has a temperature of 11.2-13.0°C and it is always very clear. The spring annual average flow rate was 43.4l/s in V. 2004-XII.2007 period, with very small fluctuations ranging between 35.1 and 69 l/s , a fact which was also in accordance with the very low value of the discharge time series variation coefficient, Cv=0.05. The source being one of the first steady.

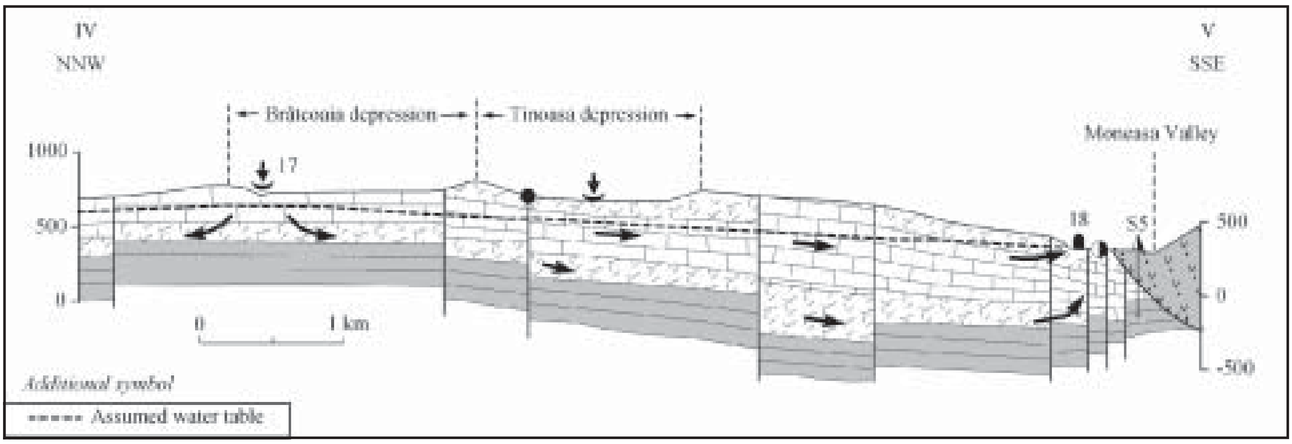

Figure 4.3. Hydrogeological cross section of Codru Mountains.
Legend as in Figure 1.6. Line of section shown in Figure 4.1.

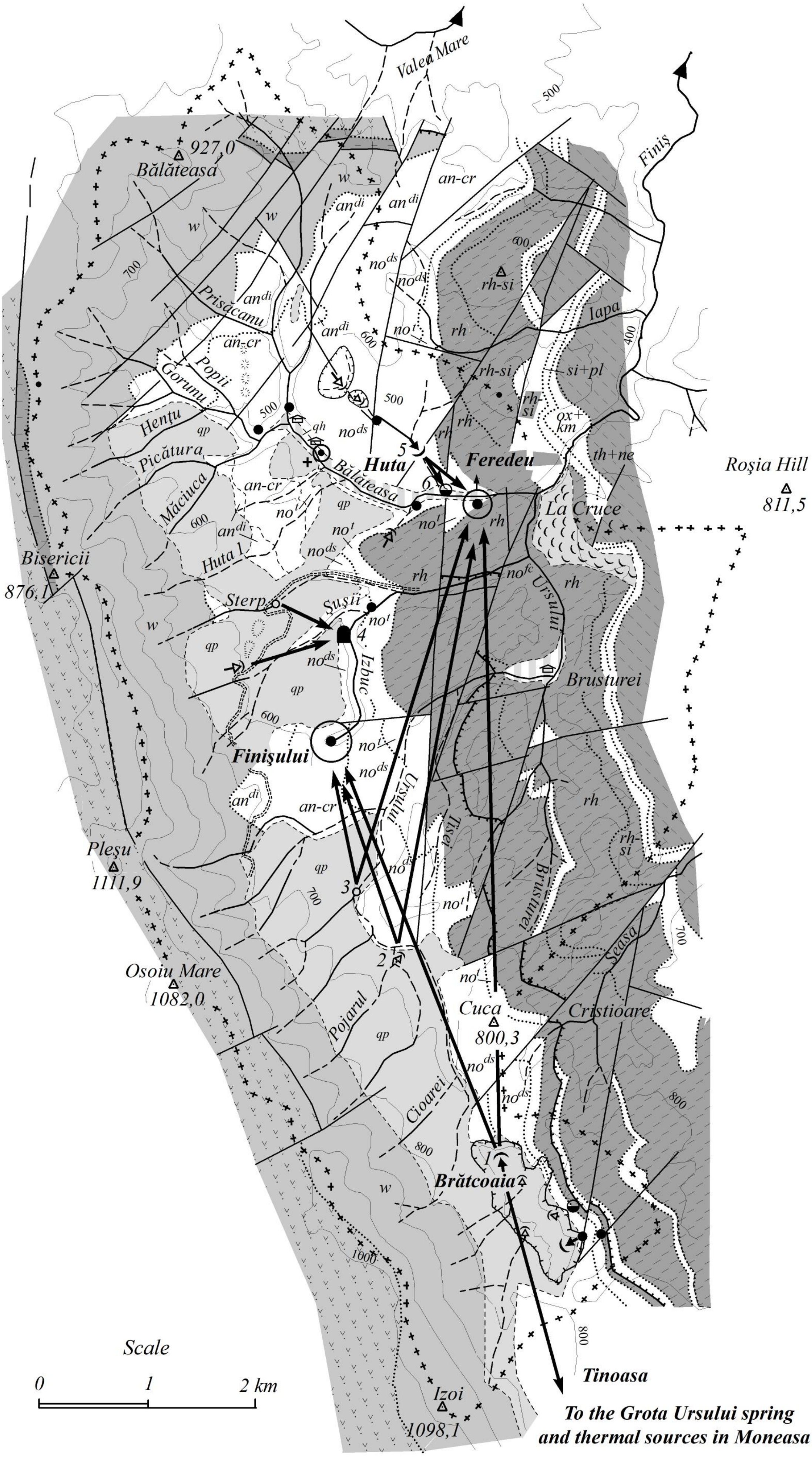

Fig. 4.4. Hydrogeological map of the upper Finiş stream watershed

Geological data after M. BLEAHU et al., 1981 and 1984. Legend as in figure 1.6

Labelling no.	Drainage no.	Insurgence	H, m	Resurgence	H, m	L, m	ΔH, m	Used tracer	T, hours	V, m/h	Date of labelling	Author(s) of labelling
1	1	Izoi ponor	680	Grota Ursului spring	320	2110	360	HTO	6	355	1970	I. Orăşeanu et al.
	2	“	“	“a” hypothermal spring, Moneasa	295	2180	385	“	6	363	“	“
2	3	Ponor of Secărişte	685	Grota Ursului spring	320	1840	365	HTO	5	368	1970	I. Orăşeanu et al.
3	4	Teia pothole	400	Piatra cu Lapte spring (fig. 4.1, no. 19)	310	650	90	I	25	41	1972	Tănăsescu et al.
4	5	Tinoasa ponor	657	Răchitarul spring	525	1075	132	F	43	22	1973	I. Orăşeanu
5	6	Losses of Haiuga Veche brook	669	Megheşul Sec spring	440	1200	229	I	1	1200	1974	I. Orăşeanu et al.
6	7	Tăul Bivolilor ponor (fig. 4.1, no. 21)	294	Pestera cu Apă de la Moară cave (no. 20)	250	630	44	F	8	80	1974	I. Orăşeanu
7	8	Dosul Varului ponor (fig. 4.1, no. 17)	720	Feredeu spring (fig. 4.1, no. 13)	415	6000	305	I	58	103	1977	I. Orăşeanu et al.
	9	“	“	Grota Ursului spring	320	5800	400	“	48	120	“	“
8	10	Călcăturii ponor (fig. 4.4, no. 2)	630	Finişului spring	490	2100	140	F	87	25	1977	I. Orăşeanu
	11	“	“	Feredeu spring	415	4250	215	”	150	28	”	”
9	12	Dosul Varului ponor (fig. 4.1, no. 17)	720	Grota Ursului spring	320	2100	230	In	168	12.5	1986	I. Orăşeanu E. Gaşpar
	13	“	“	Feredeu spring	415	6000	305	“	96	62.5	“	“
	14	“	“	No. 1, thermal spring, Moneasa	294	5900	426	“	600	9.8	“	“
	15	“	“	No. 4, thermal well, Moneasa	297	6250	424	“	480	13	“	“
	16	“	“	No. 2, thermal well, Moneasa	303	6150	427	“	460	13.4	“	“
10	17	Losses of Pârâul dintre Pietre (fig. 4.1, no. 24)	560	Piatra cu Lapte spring (fig. 4. 1, no. 19)	310	2680	350	R	70	38.3	1987	I. Orăşeanu
11	18	Losses of Scăriţa brook	540	Piatra cu Lapte spring	310	1700	230	F	48	35.4	1987	I. Orăşeanu
12	19	Losses of Blidăriţa brook	630	Piatra cu Lapte spring	310	3100	320	In	72	43	1987	I. Orăşeanu E. Gaşpar
13	20	Losses of Osoaie brook	420	Morii spring at Borz	211	2950	209	R	65	45.4	2004	I. Orăşeanu
14	21	Losses of Valea Seacă brook (fig. 4.1, no. 8)	452	Morii spring at Borz (fig. 4.1, no. 1)	211	4300	241	F	80	53.7	2004	I. Orăşeanu
15	22	Losses of Ursului brook (fig. 4.4, no. 3)	592	Finişului spring	490	1460	102	F	59.5	24.5	2004	I. Orăşeanu
	23	“	“	Feredeu spring	415	3740	177	F	144	26	“	“
16	25	Ponor of Valea Seacă brook (fig. 4.4, no. 5)	450	Feredeu spring	415	770	35	F	30	25.7	2005	I. Orăşeanu
	25	“	“	Gura Văii Seci spring (fig. 4.4, no. 6)	425	700	25	“	20	35	“	“
17	26	Ponor in Şuşii brook basin	580	Vidra spring (fig. 4.4, no. 4)	470	1000	110	F	35	28.6	2006	I. Orăşeanu

H - elevation, in meters a.s.l., L - horizontal distance between losses and springs, ΔH - vertical drop; T - time of first arrival of tracer; V - apparent velocity. Tracers: F = Fluoresceine, R = Rhodamine B, I = I-131,In = In-EDTA
Note 1: The following labellings were performed by the author in cooperation with: E. Gașpar, M. Midoiu, T. Tănase, D. I. Slavoacă and Nicolle Orășeanu - 1 and 2; E. Gașpar, E. Anghel, C. Stanca, T. Tănase and Nicolle Orășeanu - 5; E. Gașpar, M. Midoiu, T. Tănase and Nicolle Orășeanu - 7, Gh. Ponta and N. Terteleac - 7 and 8.

Table 4.3. Results of tracer tests performed in Codru Mountains.

No.	Source	n	T (°C)	CH_4	CO_2	O_2	N_2	Ar
1	Feredeu	1	13.0	0.036	7.39	0.24	92.31	0.010
2	Thermal spring no. 1, Moneasa	1	24.0	0.300	0.30	20.80	77.60	0.890
3	Thermal spring no. 2, Moneasa	1	24.0	0.700	1.00	19.10	71.20	0.820
4	Rengle	6	17.0	0.016	2.32	13.79	83.21	0.611
5	Sfărăşele	1	17.2	0.594	1.455	12.50	84.07	0.554
6	Racova	7	14.5	0.014	2.51	13.26	83.80	0.586
7	Ţucreşti	7	14.5	0.033	2.32	14.05	82.92	0.620
8	Fântâna Rece (Bârza)	1	11.8	0.004	0.72	12.60	86.00	0.558
9	Căptălanul	2	8.6	0.022	2.21	15.94	81.06	0.705
10	Crisciorel fishery	2	12.1	0.087	1.66	11.04	86.62	0.490
Athmosphere (Rankama,1970)				0	0.03	20.95	78.09	0.930

Note: Other compounds for whic the gases were analysed: C_2H_6, C_3H_8, C_4H_{10}, and He, are leacking; n = number of analysis.

Table 4.4. Chemical composition of gas outflow from springs (%vol.).

Feredeu spring water has a magnesium bicarbonate chemical character, its average mineralization is 516.1 mg/l, (35.6 mg/l Mg^{++}), it is not radioactive, and gas released from the spring consists mainly of nitrogen (Table 4.4).

4.3.2.3. Grota Ursului karst system

Considered in global terms, the karst area which extends between Brătcoaia, Tinoasa, Izoi and Moneasa, together with its catchment area that extends further to the west up to Izoi ridge, makes up a single karst system, part of which displays a thermal character in its southernmost end, and whose underground water flow is directed from north to the south, discharging mainly through Grota Ursului spring and the thermal outlets (Figure 4. 3). The water amount which cannot be carried within this flow, as a consequence of the limited transfer capacity of the karst channels and fractures, flows toward the east, through the overflow springs in the Megheş brook catchment area (Figure 4.1).

The hydrogeological relationships existing between the water sunken through the swallets in Brătcoaia and Izoi-Tinoasa karst depressions, and the cold and thermal outlets situated along Băilor and Megheş brooks, have been delineated by means of tracer tests (Table 4.3).

Băilor brook has its origin in Grota Ursului cave and it further receives, downstream from this outlet, a significant inflow of thermal water. The cumulated mixed flow rate is monitored in a systematic way in the gauging section (g. s.) installed by the National Institute for Hydrology and Water Management (NIHWM) on Băilor brook, in the area where the brook reaches the alluvial plain of Moneasa brook (Ciuperca g. s.). The gauging section operates since 1976, the average flow rate for the time interval 1976-1997 being 198 l/s, with extreme values ranging between 50 and 5,520 l/s.

In order to know the flow rate of the underground stream in Grota Ursului, a gauging station has been installed during the hydrological year X.1997-IX.1998 inside the cave, in the place where a mine passage reaches into the underground stream. Over the indicated time interval, the recorded average annual flow rate has been 58 l/s, while the average water temperature has been 8.8°C.

The karst system discharging through Grota Ursului displays rather elevated values of the recession coefficient α (0.009-0.017), a circumstance which suggests that the underground flow occurs mainly along wide cavities and that groundwater storage is not very significant. The rainfall-discharge transfer occurs rapidly, with a rather high coefficient of the cross correlation diagram (r_k = 0.342).

Out of the total amount of water discharged through Grota Ursului cave (Grota Ursului g.s.), the percentage discharged by the fast flow amounts to 10.2-18.5 %. In the case of Băilor brook at Ciuperca g.s, the percentage of water discharged by the fast flow decreases to 2.1-10.3 %, as a result of the contribution of the thermal water inflow, which discharges essentially as base flow.

According to the karst systems classification proposed by Mangin (1974, 1975), which takes into account parameters k and i, Grota Ursului karst system ranges in types II-III, that are inferred to be subject to more intense karst processes in their upstream section, to include a largely developed flooded karst in their downstream section, and to be supplied to some extent by runoff collected on non-karst terrains (binary systems).

In the south western extremity of Codru Mountains, within the territory of Dezna village, on the right side of Moneasa brook, some 200 m upstream from its junction with Zugău brook, Foradex Company has drilled in the year 1978 a groundwater well, that over its entire depth (897 m) has crossed prevalently carbonate deposits (E.Vălenaş, V. Fasola, 1978, Hydrogeological raport). The well discharges 3.5 l/s of calcium-magnesium bicarbonate water, with a temperature of 38,5°C. The water is used for treating locomotion disorders in the nearby sanatorium.

4.3.2.4. Izvorul Mare al Tărcăiței karst system

In the carbonate deposits of Clăptescu area, which is located between the streams Tărcăiţa and Crişu Văratec, there are located significant water accumulations that are supplied mainly by rainfall collected within the areas where those deposits outcrop, and subordinately from surface streams originating in the permanent springs at the bottom of the Dievii peak eastern mountainside. These surface streams sink in the underground, either through swallets where human access is not possible, or through the very thin alluvia in the streambed of Cârţala brook, which only during very abundant rainfall periods carries water over its entire length (down to the junction with Lozna brook).

These groundwater accumulations discharge mainly to the north, via Izvorul Mare al Tărcăiţei spring that is situated on the right side of Tărcăiţa brook, in its floodplain, under the Clăptescu peak northern slope which consists mainly of Ansian dolomites (site 23 in Figure 4.1). The spring average flow rate is 40 l/s and its temperature fluctuates between 10 and 10.6°C. During heavy rainfall periods, the spring water does not become muddy. The water has a calcium-magnesium bicarbonate chemical character, and an average mineralization of 687.7 mg/l.

4.4. The Vașcău Plateau

In the southern part of Codru-Moma Mountains carbonate deposits build up a single entity that extends over an area of about 90 km^2, outcropping at 600 m average elevation and being designated, in terms of physiography, as Vaşcău Plateau. Hard, non-carbonate deposits surround this entity to the north, south and west, thus bounding a carbonate rocks amphitheatre which faces east, toward the Beius depression, where carbonate deposits sink in a stepwise manner under the Neozoic filling of the depression.

The Vaşcău Plateau topography is dominated by a few peaks which follow to one another, starting from the north-west and running toward the central-southern area (Ronţaru-918 m, Iezerul-870m), thus building a high altitude zone from which the relief rapidly falls westward into a series of large karst depressions (Arânda, Ponoare-Pociovelişte, Bănişoara, Ponoraş), while to the east it gently lowers into a vast plain strewn with sinkholes and dry valleys, whose major feature is the karst stream piracy depression Ţarina-Câmpeneasca. Close to the Beiuş depression, in the proximity of Vaşcău town, the topography sharply drops by 200 m over a horizontal distance of about 500 m, along a system of NW-SE striking fractures that subsequent, Neozoic deposits obliterate (Figure no. 4.5).

The original streams network became dislocated as a result of the frequent karst stream piracy phenomena, so that most streams collected on the non-karst slopes that adjoin the plateau sink right away into the multitude of swallets which occur along the karst area boundary. The only exception is Ţarina brook, which after collecting the water on the south-western rim of the plateau, keeps flowing for 5 km along a valley that is excavated in limestones, to finally sink into Câmpeneasca swallet cave.

A compact area of internal drainage occurs in Vaşcău Plateau, extending over 73.3 km^2, one of the largest areas of this kind in Romania.

Carbonate deposits in Vaşcău Plateau occur in a stack that progressively thickens from west to the east, to reach a maximum estimated thickness of 2500 m in the proximity of Vaşcău town (M. Bleahu et al., 1979). These deposits, that in structural terms are ascribed to the Moma, Vaşcău and Colesti nappes, include at their bottom Permian-Werfenian quartz sandstones, conglomerates and shales, which belong to the Moma Nappe. The thrust planes between those units gently dip eastward, in accordance with the plateau homoclinal structure. The entire stack is intensely dissected by vertical faults, which bring in tectonic contact compartments that consist of rocks of different lithologies, as shown in Figure 4.5 and in the section in Figure 4.6.

Among the carbonate series of the plateau, a special mention deserve the Anisian black dolomites of the Moma Nappe, estimated to be about 1200 m thick. The secondary porosity of those rocks, which is a result of the dolomitization processes, together with the fracturing due to the tectonic actions, largely favored karst processes, leading to the occurrence of karst depressions of an impressive size, unparalleled in plateau areas where other types of carbonate deposits outcrop. Those

Labelling no.	Drainage no.	Insurgence	H m	Resurgence	H m	L m	ΔH m	Used tracer	T hours	V m/h	Date of labelling	Author (s) of labelling
1	1	Câmpeneasca cave	406	Boiu spring	300	1700	106	PC	3-4	500.0	1901	S. Mihuţia
2	2	Losses of Fântâna Lotrilor brook	613	Boiu spring	300	7600	331	I	216	26.0	1978	I. Orăşeanu et al.
3	3	Losses of Ponoare brook	579	Boiu spring	300	5900	279	Br	225	26.2	1978	I. Orăşeanu et al.
4	4	Losses of Hăiuga lui Şandor brook	675	Tisei spring	450	2150	225	I	150	14.3	1978	I. Orăşeanu et al.
5	5	Câmpeneasca cave	406	Boiu spring	300	1700	106	R	10	170.0	1978	I. Orăşeanu et al.
6	6	Ponor of Ponorul brook	499	Pepineaua spring	400	1250	99	R	20	62.5	1978	I. Orăşeanu et al.
7	7	Ponor of Arânda depression	720	Tisei spring	450	3200	270	In	192	16.6	1984	I. Orăşeanu, E. Gaşpar
8	8	Ponor of Dăneşti brook	601	Tisei spring	450	1500	151	S	15	100.0	1985	I. Orăşeanu
9	9	Losses of Cohuri brook	635	Tisei spring	450	2000	186	R	15	133.3	1985	I. Orăşeanu
10	10	Tăul Ponorului ponor	633	Sopoteasa spring	355	4280	272	In	144	29.7	1986	I. Orăşeanuet al.
11	11	Losses of Târsa brook	520	Spring of Peştera Popii cave	400	1200	117	I	60	20.0	1986	I. Orăşeanu et al.
12	12	Coşul de la Căldare losses	440	Căsoaia spring	375	1040	65	F	17	61.1	1986	I. Orăşeanu
13	13	Sfăraş ponor	667	Boiu spring	300	8025	367	In	1632	5.0	1987	I. Orăşeanu et al.
	14	“	“	Sfărăşele warm spring	295	8050	372	“	1704	4.7	“	“
14	15	Losses of Priga brook	640	Boiu spring	300	8090	340	I	96	82.9	1987	I. Orăşeanu et al.
	16	“	“	Sfărăşele warm spring	295	8300	345	“	168	50.6	“	“
15	17	Doboş ponor	565	Coleşti spring	400	1200	165	Dy			1988	I. Orăşeanu, E. Gaşpar
	18	“	“	Coşul de la Chietroc spring	390	1500	175	“			“	“
16	19	Ponor of Scăriţa brook	610	Spring of Valea Seacă	565	650	45	F			1994	I. Orăşeanu, E. Căpraru
17	20	Peşterelii ponor		Boiu spring		5940	255	I	12	495	1985	G.Ponta, E.Gaşpar

H - elevation, in meters a.s.l., L - horizontal distance between losses and springs, ΔH - vertical drop; T - time of first arrivel of tracer; V - apparent velocity.
Tracers: PC = charcool powder; F = Fluoresceine, R = Rhodamine B, I = I-131, Br = Br-82,In = In-EDTA, Dy = Dy-EDTA, S = Stralex; KI (activable).
Note 1: The following labellings were performed by the author in cooperation with: E. Gașpar and T. Tănase: 2, 3 and 4; C. Crăciun, E. Gașpar, I. Pop and T. Tănase: 10, 11, 13 and 14; Gh. Ponta, N. Terteleac and G. Halasi: 2, 3, 4, 5 and 6.

Table 4.5. Results of tracer tests performed in the Vașcău Plateau.

depressions trace the outcrop of the thrust plane of Vaşcău Nappe over Moma Nappe. Coleşti Nappe prevalently includes Rhaetian-Carnian limestones, while Vaşcău Nappe includes Anisian dolomitic limestones and dolomites, and to a smaller extent, Ladinian and Late Triassic limestones.

4.4.1. The carbonate deposits hydrogeology

The tracers average transit time was 85.0 m/hour, with extreme values ranging between 5 and 500 m/hour. The longest distance covered by a tracer test, 8.6 km, was recorded between the swallet in Prigă (site 22 in Figure 4.5) and Boiu spring (Table 4.5).

4.4.1.1. Boiu karst system

Boiu spring (no. 38 in Figure 4.5) is located in the western part of Vaşcău town, at the bottom of Osoiu-Corneţel hill. The spring water emerges from two outlets that do not allow human access, one of them with a permanent character, located to the north, and the other one, with a temporary character, located to the south.

Performed tracer tests have indicated that Boiu spring extends its radius of influence over the entire south-western area of Vaşcău Plateau, starting from the cave Câmpeneasca and up to Ponoraş and Sfăraş spring, in the proximity of Zugău valley. The swallets which supply the karst system are located 1.7-8.6 km away from Boiu resurgence. For tracers injected in the western extremity of Boiu karst system, transit velocities ranged in the 14.3-26.2 m/hour interval, which was much less than the velocity recorded for the flow path between Câmpeneasca cave and Boiu spring (500 m/hour).

During the hydrological year X.1986-IX.1987, the average discharge of Boiu spring was 0.588 m^3/s, with extreme values ranging between 0.069 and 6.0 m^3/s, while the discharge variation coefficient value was very high ($n_v = 77$).

The recession coefficient determined for the spring drought period is relatively high ($\alpha = 0.0120$-0.0087) and it suggests that groundwater flow and storage occur in cavities and cracks of noticeable size, thus resulting a relatively fast drainage of the aquifer. This inference is also supported by the very low value of the base flow index ($B_f = 0.142$). Out of the entire water amount discharged by Boiu spring during the indicated hydrological year, only 59.3 % originates in the base flow.

The spring water is not potable, since Ţarina brook flows across the villages Călugări and Izbuc. Further on, along the underground flow path of this stream from Câmpeneasca swallet cave to Boiu spring, transit is short and it occurs rapidly, a cir-

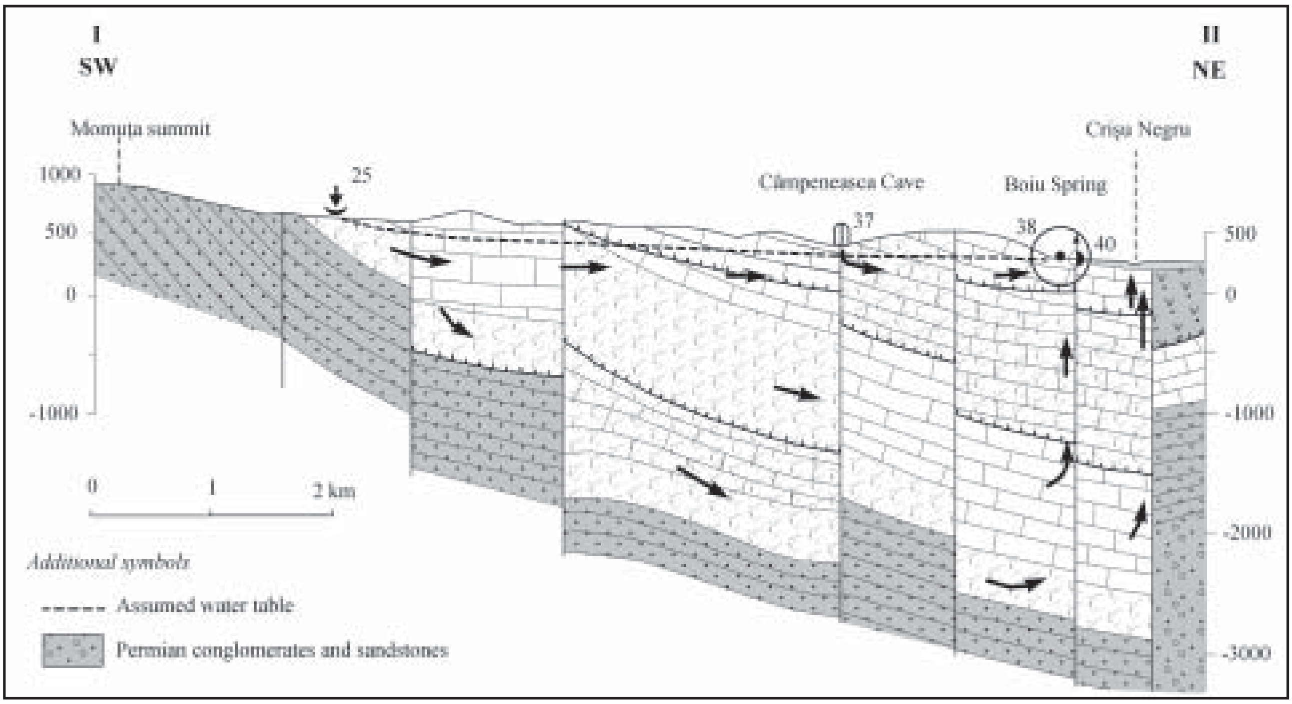

Figure 4.6. Hydrogeological cross section of the Vașcău Plateau.
(Legend as in Figure 1. 6. Line of section shown in Figure 4.5).

cumstance which does not favor water self-purification. The spring water is still used for supplying an important trout hatchery, situated downstream from the junction between Boiu spring steam and Crişu Negru river.

4.4.1.2. Șopoteasa karst system

Water in the central-northern part of Vaşcău plateau discharges in Şopoteasa spring (Figure 4.5, site 4), located on the territory of Briheni village. Spring water is up flowing along the tectonic contact between the Vaşcău Nappe limestones and the deposits of the Permian formation of the Moma Nappe. It emerges from a limestone blocks accumulation, a circumstance which prevents speleological exploration. The tracer test performed on 04.07.1986, when In-EDTA had been injected in the swallet at Tăul Ponorului (Figure 4.5, site 12), being subsequently detected in Şopoteasa spring water, has proven the continuity of the carbonate deposits of the plateau beneath the essentially impervious Toarcian deposits, which outcrop southward from the spring.

Sopoteasa spring has a rather large average flow rate, 0.214 m^3/s, and a small recession coefficient (α=0.005), a circumstance which suggests large residual dynamic resources.

4.4.1.3. Tisa karst system.

Tisa spring (Figure 4.5, site 6) provides the discharge of the groundwater in the north-western part of Vaşcău karst plateau, being supplied both by surface streams that run across Ponoare and Pociovelişte depressions, and by diffuse infiltration in Arânda and Sfăraşul Ligii-Ţărau areas. The spring emerges at the bottom of a steep, almost 100 m tall cliff, the average discharge being rather high (0.139 m^3/s), and the corresponding recession coefficient as well (α=0.0855), a circumstance which suggests that underground flow occurs prevalently through well-developed karst cavities. During rainy periods, the spring flow rate increases in a spectacular way.

4.4.1.4. Rășchirata karst system

Răşchirata spring (Figure 4.5, site 19) is located within the upper reaches of Dezna stream catchment area, on the left side of Căptălanul brook, a tributary of Dezna, at the junction with Corbului brook, in the very close neighborhood of an old furnace for melting the iron ore and of a forestry hut. The spring up flows through the scree, at the bottom of a cliff where Anisian dolomite outcrops as meter-thick layers with an abundance of karst dissolution pockets.

Over the hydrological year X.1997-IX.1998, the average flow rate of Răşchirata spring was 50.8 l/s, with fluctuations ranging between 18.6 and 144.5 l/s, the flow rates variation index (Qmax/Qmin) being 7.8, while the base flow index was 0.37. Over the indicated time interval, the spring water did not become muddy, its temperature fluctuated between 8.2°C and 8.9°C, while pH values ranged between 6.76 and 7.44.

The flow rates recession diagram constructed for the period 02.02-19.10.1998 displays a very small slope, with the corresponding recession coefficient having also a very small value, α=0.0045. The dynamic storage volume is very large and it includes only a small percentage of water, 2.1%, directly derived from the fast flow.

The significant amount of storage is also substantiated by the karst system elevated memory effect, EM=46 days. The regulation time is very long, TR=55 days, thus suggesting a significant duration of the unit transfer function.

4.4.1.5. The Valea Seacă karst system

The spring is located on the left side of Valea Seacă ("the Dry Valley"), 25 m away from the valley junction with Căptălanul brook (Figure 4.5, site 17). The spring water discharges via two closely spaced cracks of the Anisian dolomites. In 1987, the spring has been tapped in order to supply water to the pilot station built in the same year by IPEG Deva at Grajduri for the iron ore wash. By the present time the water intake isn't operating anymore.

Over the time interval X.1986-IX.1987, the average flow rate of the spring in Valea Seacă was 77 l/s, with fluctuations ranging between 23 and 250 l/s. (Table 5.1). During the above indicated hydrological year, the water temperature fluctuated between 8,5°C and 8,8°C, while its pH ranged between 6.82 and 7.39. Following very strong rainfall or fast snowmelt, the spring water becomes, for a short period of time, very muddy.

In the area of occurrence of the spring in Valea Seacă, on the terrains covered by the Anisian dolomite, there are two places where the karst aquifer receives surface water inflows: the swallet of Scăriţa brook (Figure 4.5, site 18) and the diffuse sink in the Căptălanul brook streambed, downstream from Căptălanul forestry hut.

Radioactivity analyses of the water samples collected from Răşchirata spring and from the spring in Valea Seacă have indicated that their water is not radioactive, the recorded alpha and beta concentrations being one order of magnitude below maximum concentrations stipulated by official regulations for drinking water.

4.4.2. The low-temperature thermal water at Vașcău

On the western side of Vaşcău town (Figure 4.5), four thermal spring, associated with the outflow of gas, discharge from the karstic limestones of the Coleşti Nappe and the alluvial deposits of the Crişu Negru river: Sfărăşele (no. 39), Rengle (no. 40), Racova (nr. 41), and Ţucreşti (no. 42). The temperature of the thermal springs ranges from14.5-17.2°C, and the cumulative mean discharge is 15 l/s. In addition to these thermal springs, gas is observed discharging from three cold-water spring: Blagu (no. 43), Fântâna Rece (no. 44) and spring of the Crisciorel fishery (no. 45).

The thermal waters close to Vaşcău town are similar in terms of chemical composition to the cold karst groundwaters, while the associated gas only slightly differs from the atmosphere. Sometimes, the waters exhibit iodin and even bromide character, a consequence of prolonged contact with the deposits that fill Beiuş basin, the same chemical character being recorded also for other low-temperature thermal waters in that basin (Ceica, Răbăgani etc.). A slight increase in the percentage of nitrogen is still noticeable, probably as a result of the consumption of some oxygen by the oxidation reactions (Table 4.4).

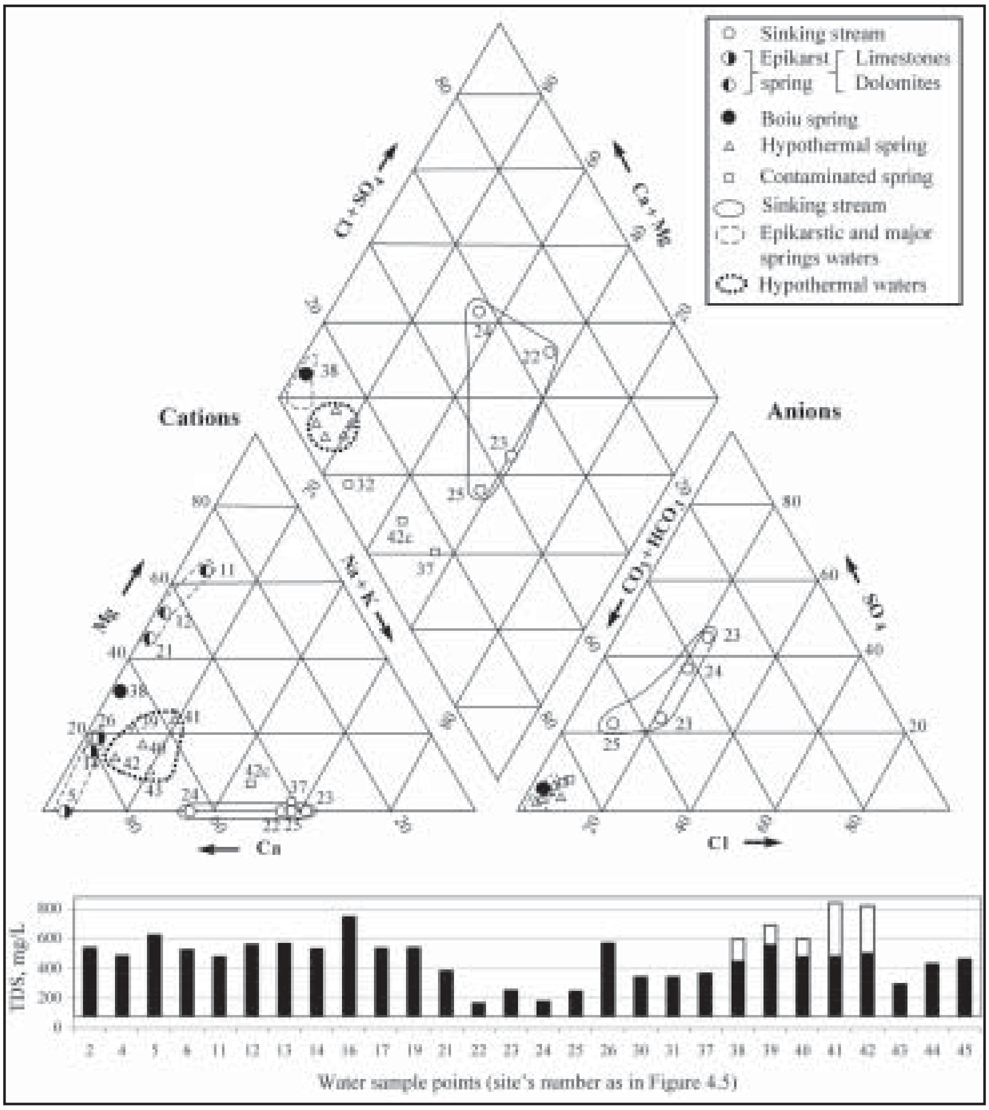

Figure 4.7. Piper diagram showing composition of waters (above) and waters TDS in the Vașcău Plateau (below)

The chemical compositions of the main groundwater types are ploted on the Piper diagram in Figure 4.7 (I. ORĂŞEANU, J. MATHER, 2000). The waters from the sinking stream in the southwestern part of the plateau are distinctive; these waters, derived from the werfenian quartzitic sandstones, have a mean TDS of only 135 mg/L, a low pH of 5.3, and no Mg. The epikarstic springs are typical karst groundwater, with a mean TDS of 421 mg/L. The main variation is in the Ca/Mg ratio, which is controlled by wheter the spring arise from limestones or dolomites. A dugg well at Oache (no. 14) yield water of a composition that is similar to the epikarstic springs.

The discharge springs on the margin of the plateau plot in the same field as the epikarstic springs and only the major Boiu spring (no. 38) is shown in Figure 4.7. Mean TDS is 435 mg/L. The thermal waters plot in a separate field and are intermediate in composition between the karstic waters and the sinking stream derived from the quartzites. However, the TDS (502 mg/L) of the thermal waters is higher than either of these waters. Three of the groundwaters are polluted. The water of the Ţarina stream it enters the Câmpeneasca cave (37) and the Pepineaua spring (31) have elevated concentrations of Na and K, probably as a result of domestic sewage pollution from the villages of Izbuc and Ponoare, and the cold spring at Ţucreşti (42) is also polluted by a small stream.

Vaşcău town, on the eastern side of the Vaşcău Plateau, is close to the faults that divide the Codru Moma Mountain Block from the Beiuş Basin. These faults a barrier to groundwater flow from the west, and most of the near-surface flow is intercepted by the Boiu spring. Deeper flow moves up to faults to mixt with the colder water to form the thermal springs. The thermal component of the waters is probably at least partly derived from the Permo-Werfenian deposits at depth of 1000 m or more beneath the surface.

Area is lie close to the Pannonian Basin, were heat flow of more than 95 mW/m^2 are recorded (VELICIU, OPRAN, 1983). The thermal water is brought to the surface by hydraulic barriers that intercept flow and allow water to move up faults and fracture and mix with cooler groundwater in the upper karstic units. This mixing accounts for the variation in temperatures among individual springs.

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4.5. Călugări ebb and flow spring

Călugari ebb and flow spring is located in the South-Eastern end of Vaşcău karst plateau, on the left side of Vulpilor brook, a tributary of Topliţa stream in the watershed of Crişu Alb river, in the area of Izbuc Monastery. It emerges from Anisian dolomites, in the neighbourhood of underlying Werfenian sandstones.

In 1863, the Austrian geographer A. SCHMIDL published "Das Bihar Gebirge an der Grenze von Ungarn und Siebenburgen" in Vienna, a first inclusive morphology and speleology study of a area on the Romanian territory. This is the work that introduces Călugări spring in the world geographical literature as an ebb and flow spring (intermittent spring). The author presents both the results based on personal observations made at its location, accompanied by a splendid watercolour image of the source (photo 1), as well as the results of previous observations made by VASARHELYI (1822), MEDVE (1823), WASTLER (1859) and CSAPLOVICS (1861).

J. VASARHELYI is known as the first researcher of this spring, being the source of its name in hungarian, that is "Dagado forras", or "the rising spring". In 1822, he says that "local people use the water as a healing force; it fills the reservoir in 2 minutes 30 seconds up to 1.5 feet (equivalent of 50 buckets). After that, the water went back fast, and it returned and went back again in 16 minutes. For one hour there was no water."

Photo 1. Ebb and flow spring at Calugari in flowing period, aquarelle in A. Schmidl's book "Das Bihar Gebirge an der Grenze von Ungarn und Siebenburgen" (Vienna, 1863).

CSAPLOVICS (1861) says that "the emergence of water in Călugari spring is preceded by loud noise. The water comes every hour or every half of hour, and while raining, event more often than that."

On 3 September 1858, Prof WASTLER notes detailed observations on the timing of eruptions, concluding that the duration of one cycle is 17'55'', while the raising of water in the reservoir from the beginning to its retraction lasts 2'16''. 4'50'' represents the time from the moment of rising to the end of the retraction, and the reservoir stays empty for 13'5''. In 1860, in autumn, he finds the spring waterless.

A. SCHMIDL had 29 observations over 24 hours in 1861, remarking the alternation of a strong eruption with a weak one. The water raised with 1 Fuss and 9 Zoll in the reservoir. He points out that the spring has a winter break in between September-March.

G. PETHO publishes "The rising spring" in 1896, in which he provides a detailed description of the flow, and comments on the feeding source and compares his own observations with those of his predecessors. On 14 August 1892, one hour and 28.5 minutes following a last eruption, "there is a shush in the evacuation tube. The water comes. In its underground route, it pushes and suddenly evacuates the air in the evacuation tube. A few moments later, the water rises up at 62 cm in two minutes. From that moment, the level goes down slowly, part of the water is drained in the riverbed on the exterior side of the reservoir, and a small fall appears, while on the other side about a third goes back in the spring. In 16.5 minutes a whole cycle takes place."

A. MIHUŢIA presents a sketch of the spring in 1904 (Fig. 1), and his observations on 14-15 July and 12 August 1901 alongside those of his predecessors. "The spring mostly emerges in early summer, in mid-summer its rise is less often, and in autumn even less often. The connection with the rainfalls is clear, respectively the amount of underground water and the amount of spring water." The author points out, as Petho did in 1869, the presence of a second source

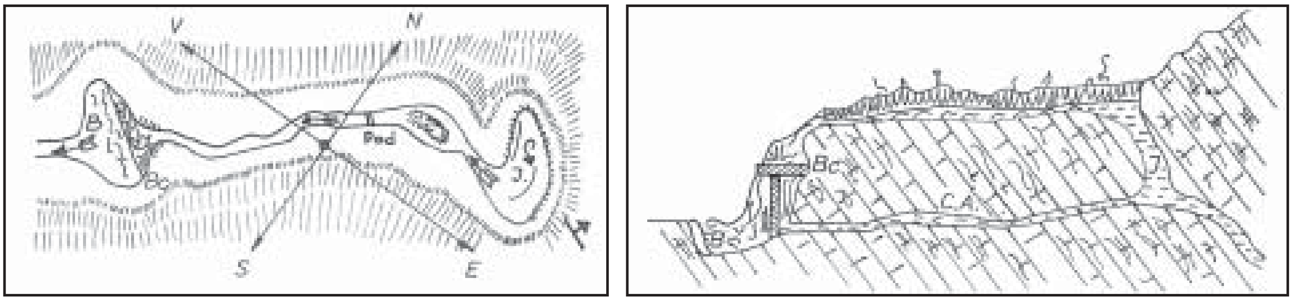


Figure 1. Sketch and cross section in the area of the of the spring (A. MIHUȚIA, 1904).

placed under the fall (Figure 1, to the right), a source by which the water of the same aquifer is discharged.

I. AL. MAXIM, in 1942, proposes a template of the spring functioning based on the siphoning principle and the observations performed on the spring run by PETHO (the 14th and 15th of August 1892) and, partially, by SCHMIDL (1st of September 1861), observations that he generalizes. From these data, MAXIM found out (?) "a grouping of the flows , i.e.: a) after two flows succeeding at short intervals, there is no flow but after a long pause; b) the long pause between the two flows is interspersed by another flow; and the second short flow oscillates in time". This functioning of the ebb and flow spring is explained by the presence of a "double siphoning", that means it has two grottos of water storage: one smaller, down, and one bigger, up (Fig. 2).

I. Al. Maxim also remarks that the secondary source under the fall, a source draining most of the spring water and affecting its operation, "was carefully plugged by the monks, so that the flow of water keeps going the same way."

Besides the up-mentioned researchers, K. SIEGMETH (1899), also wrote about the ebb and flow spring.

After the period of their visit to the spring, the authors mentioned either the existence of oscillations of the spring water and the laps of time between them, or the immobility of the water surface at its bottom. The observations are made in very short intervals of time, usually in summer, the published data being very non-homogenous. But they provide important information regarding the periods in which the spring was active.

Călugări ebb and flow spring (Fig. 3 and photo 2) comes from a 50 cm circular gallery located at the bottom of a irregular pool, rather rectangular (3.6 × 1.8 m), named by I. Al. MAXIM "Puţul de Piatră" (the Stone Pit). The pool, excavated by dissolution in dolomites, is 1 m deep, and its bottom, continuously ascending, goes on with a stone ditch, being 8.5 long in total. In the middle of the ditch, the slope turns rough, with a threshold located at 90 cm over the access of water (Fig. 4).

The water in the Stone Pit is discharged in a concrete pool shaped like a quarter of a circle, with

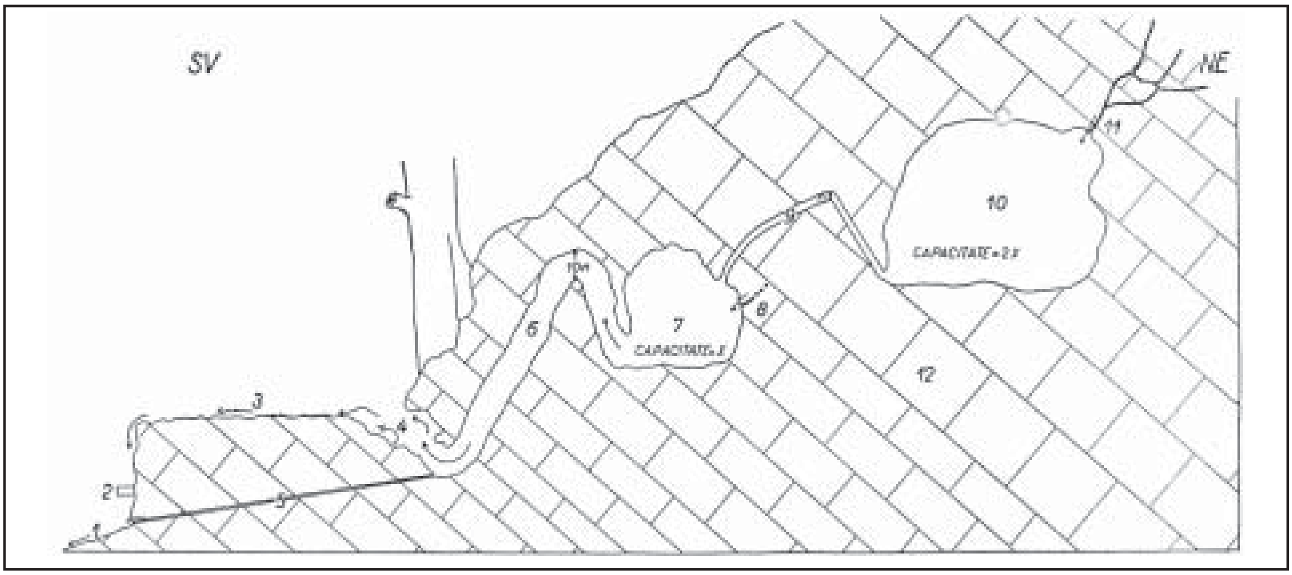


Figure 2. Principle of Călugări spring's work after I. Al. MAXIM, 1942.

4.4 m radius (¼ pool). In the concrete on the bottom of the ¼ pool, there is a hole where the water go out at high oscillations in Stone Pit (source A in Fig. 4). Other two parasite sources of a similar regime come in the ¼ pool on its Western side. A parasite and constant sources comes at the South-Eastern exterior corner and under the floor of ¼ pool.

Topographic survey were done in the area of the spring. The elevation marks presented in the text are relative altitude, being in relation with the bottom of ¼ pool, near "A" source in Fig. 4, seen as "0 m" relative altitude.

A staff gauge (100-210 cm) was put in the Stone Pit, its bottom being at -0.2 m relative altitude. The observations in Stone Pit, were irregular, based on monthly direct observations or with a shifting water level recorders (1:1 scale and 7 cm/hour paper speed). In between October 1989-November 1991, a water level recorder of 1:10 scale and 24 cm/day speed was installed. The debit of the source was almost constantly measured via a triangular weir (α = 90°C) with a water level recorder (1:5 scale and 24 cm/day speed), installed at Vulpilor brook 20 m downstream the spring. Vulpilor valley are mostly dry throughout the year.

Systematic hydrologic records, started in October 1986, and outlined that over one year, water oscillations in Stone Pit occurred in various ways (Fig. 5).

When the rainfalls were important, mostly between December and June, the water in the Stone Pit has high oscillations, of 60-80 cm amplitude, and of 9-15 minutes with about 1:7.3 ratio between the duration of water level rise and decrease, with overflows past a threshold. A clear invariance of high oscillations over long durations was remarked (Fig. 6).

Eruptions are preceded by the activation of parasite sources close to the Stone Pit and the loud evacuation of the air in underground holes. The level of the water goes up fast in the Stone Pit, over the threshold (0.64 cm relative altitude) and is discharged in the ¼ pool as a small fall. Once the maximum level is reached, the water goes down slowly, and once the threshold is reached the exterior flow stops, and the water in the Stone Pit goes back in through the access pipe and is evacuated outside by parasite sources.

Fig. 7, left, presents the shapes of high oscillations observed in various times, while Fig. 7 right indicates the debit of the source during those oscillations.

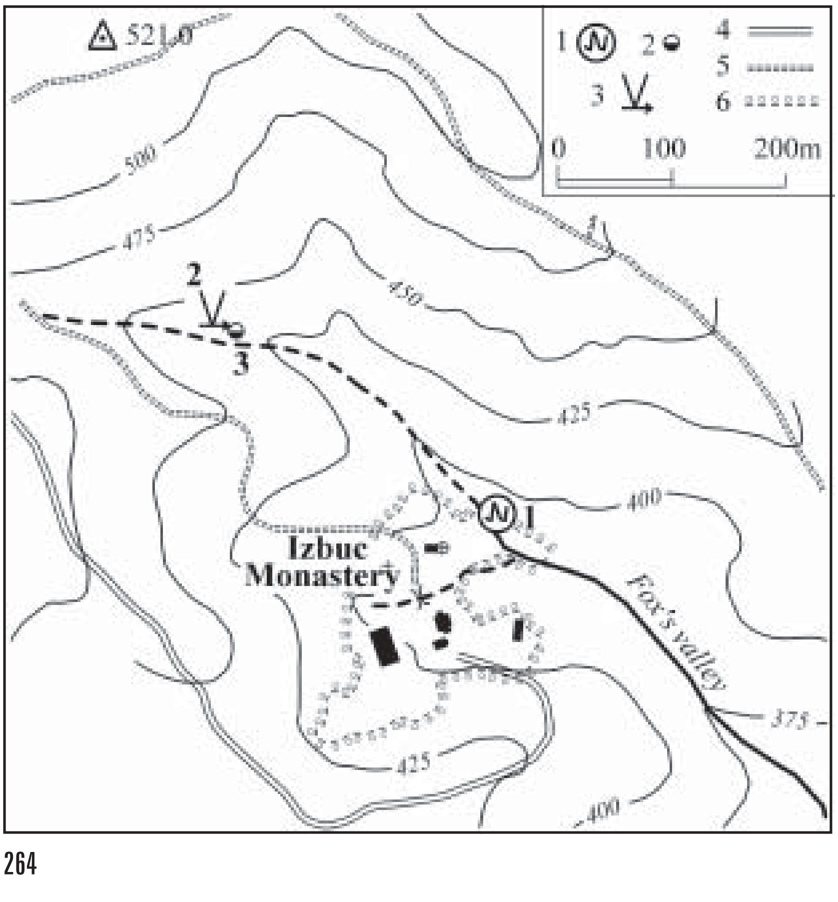


Figure 3. Site of the spring.
1 - Călugări ebb and flow spring;
2 - pothole;
3 - temporary spring;
4 - road;
5 - foot path;
6 - Izbuc Monastery area.

Photo 2. Călugări ebb and flow spring in flowing period.

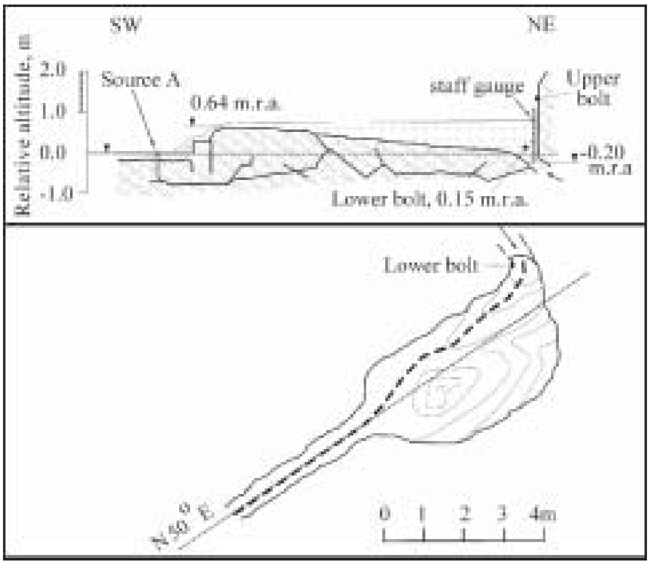


Figure 4. The Stone Pit. Cross section and sketch.

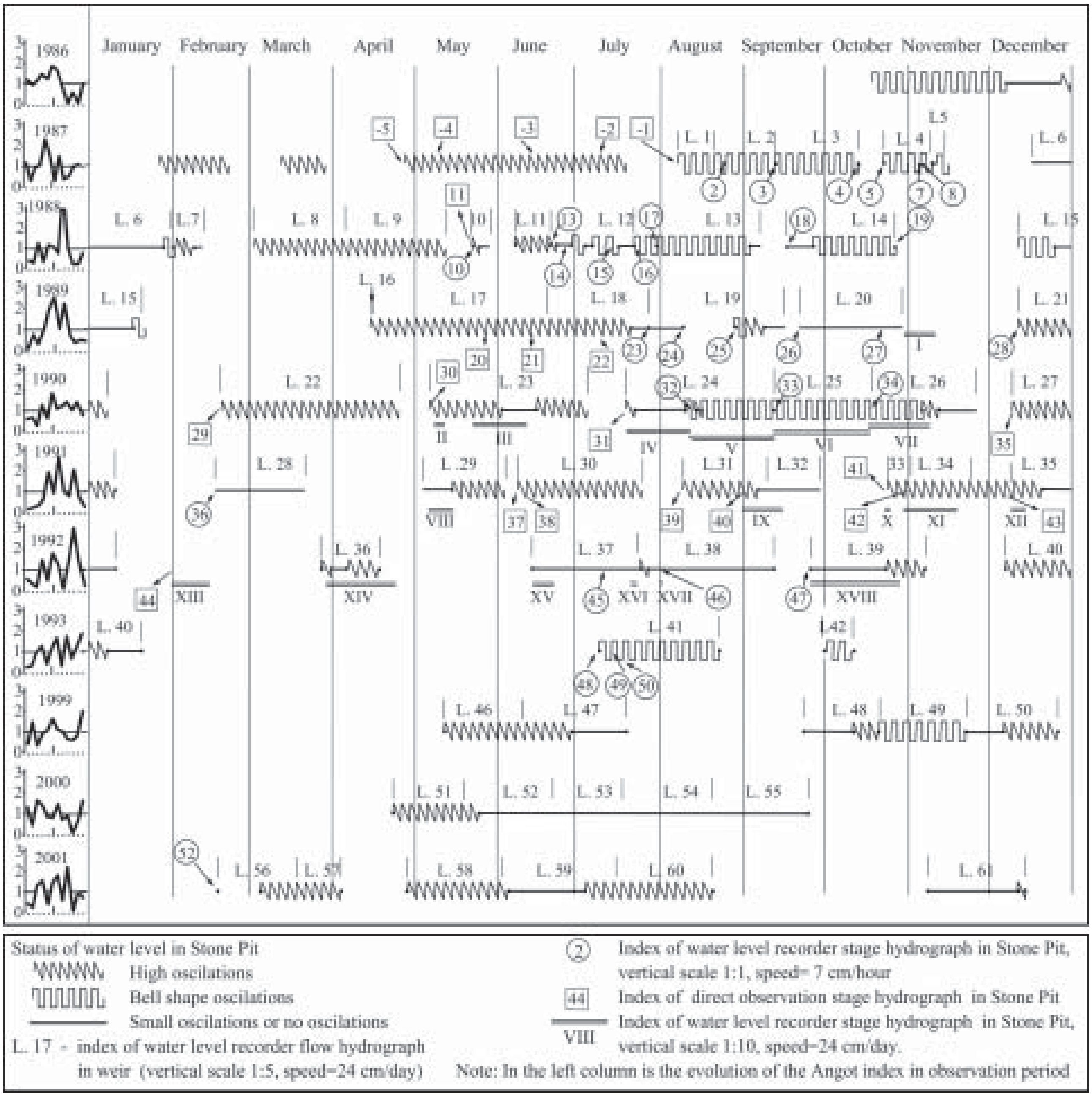


Figure 5. Observations performed at Călugări ebb and flow spring.

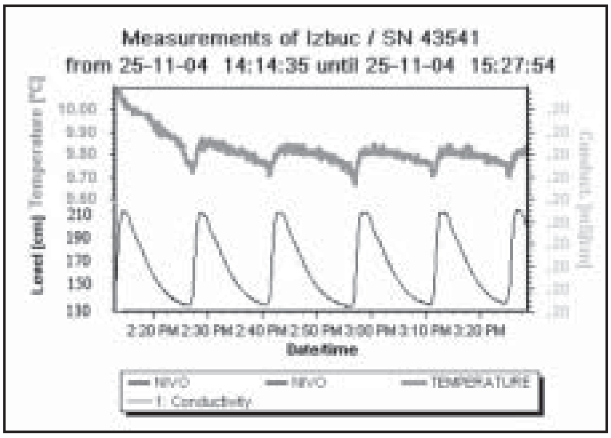


Figure 6. Water level and temperature evolution in Stone Pit during high oscillations.

The source is discharged over the threshold at medium debits of the system higher than 2.5-3.0 l/s. There were cases though when higher oscillations were noted for 1.7 l/s. The highest mean debit recorded, evacuated from the Stone Pit and the parasite sources, was 10.2 l/s, with an absolute maxim in the peak of the discharge of 33 l/s. The highest observed level, over 30 cm over the threshold, matched a maximum debit of 33 l/s. The average debit of permanent parasite sources varies between 1-5 l/s.

The height of the high oscillations goes along the medium debit of the eruption (Fig. 8). The relationship between a discharged volume of the source during the rise of the level (V1) and the decrease (V2) is of 1:3.5 (Fig. 9).

The relation between the mean discharge of the source and the duration of a high oscillation (T) is not relatively noticeable. During a time of no rainfalls, while the daily average debit goes down, the duration of the oscillations increases and this is even more noticeable at the end of high oscillations, when the duration of the oscillations, T, goes up considerably sometimes (Fig. 10).

While the flow rate decreases below cca 2.5-3.0 l/s, the amplitude of high oscillations goes down to 30-40 cm, which corresponds to 130-170 on the staff gauge, they stop abruptly (Fig. 11), the level of the water continuing to have small oscillations (Fig. 12, 13), with a 1.5 - 3 minutes ebb and flow period and with their amplitudes progressively decreasing from 8 cm to complete vanishing, together with their rarefy (Fig. 14, 15).

Further on, the spring regime exhibits a new expression, with **bell shaped oscillations** lasting about one hour and reaching 30 cm maximum

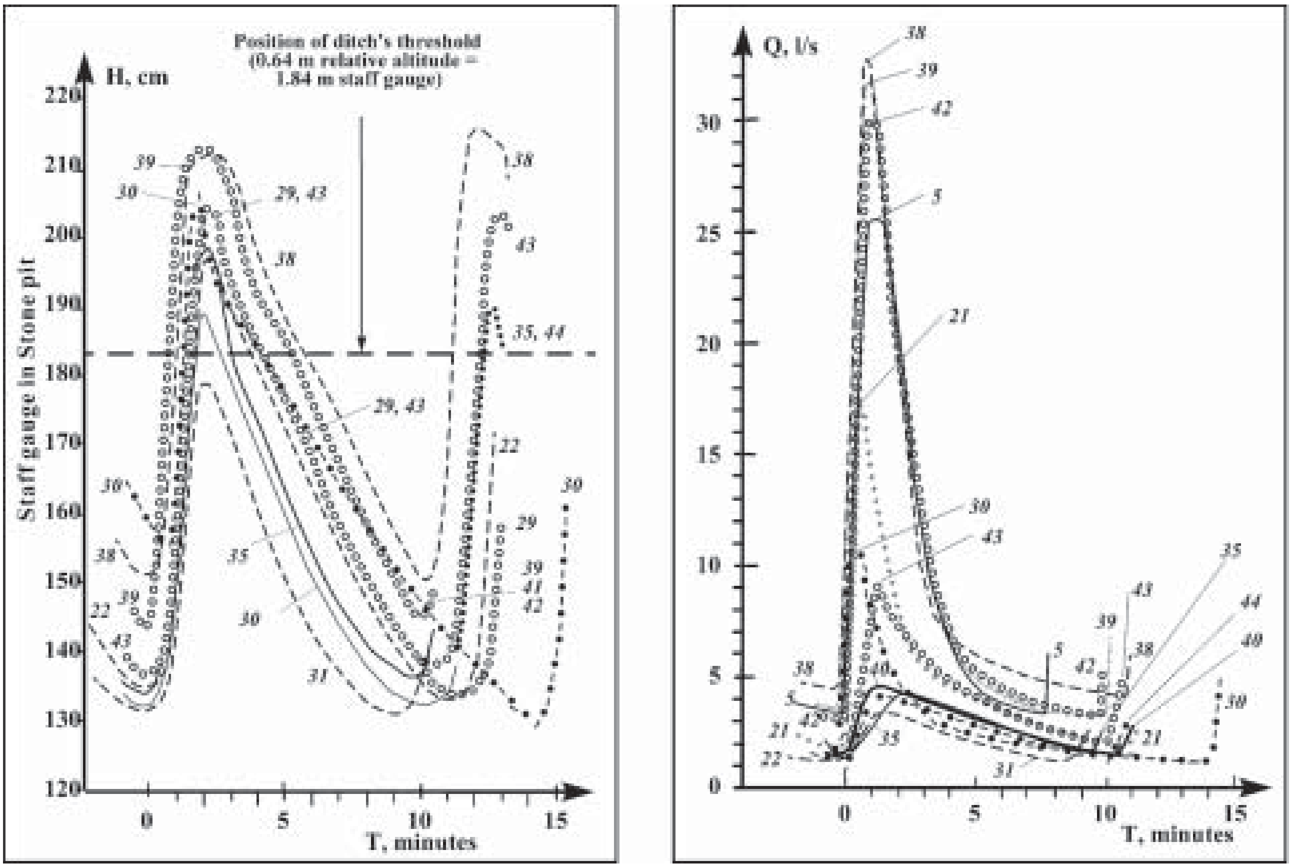


Figure 7. The shapes of high oscillations observed in Stone Pit (left) and evolution of the spring's discharge during those oscillations.

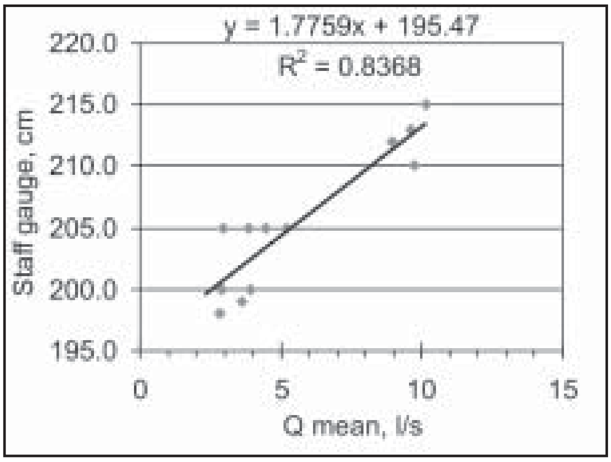


Figure 8. The amplitude of high oscilations increase with mean water discharge.

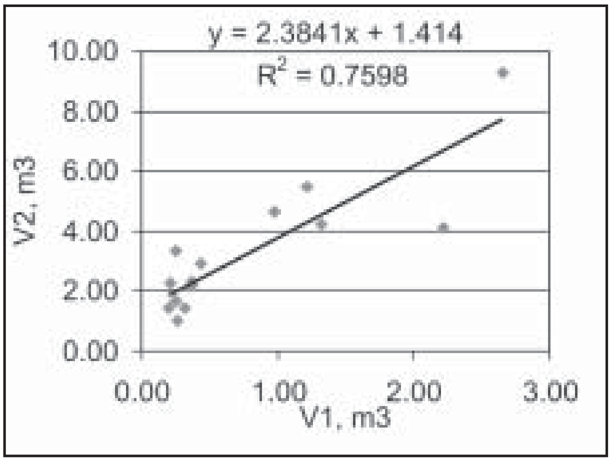


Figure 9. Relation beetwen water volumes discharged by the spring during the rise and decrease of the debit.

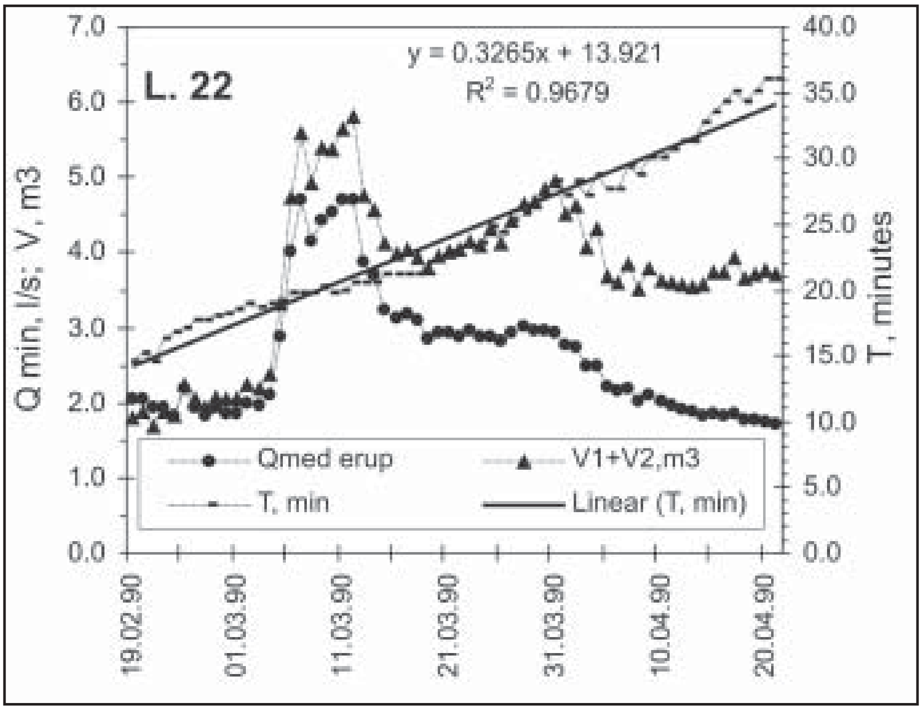


Figure 10. Results of processing the weir water level recorder flow hydrograph no. 22.

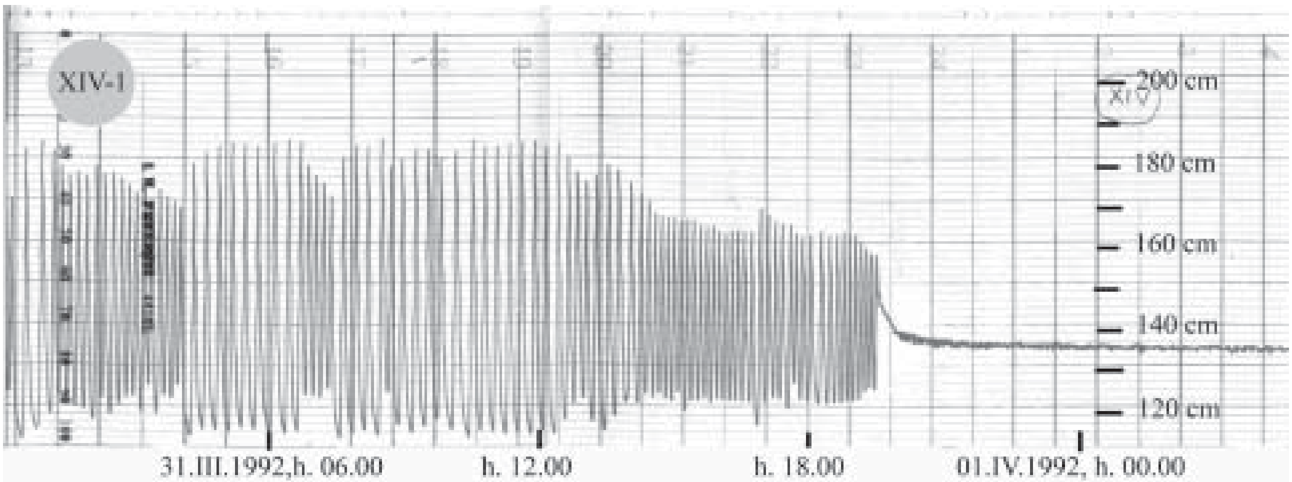


Figure 11. Stop of the high oscillations.

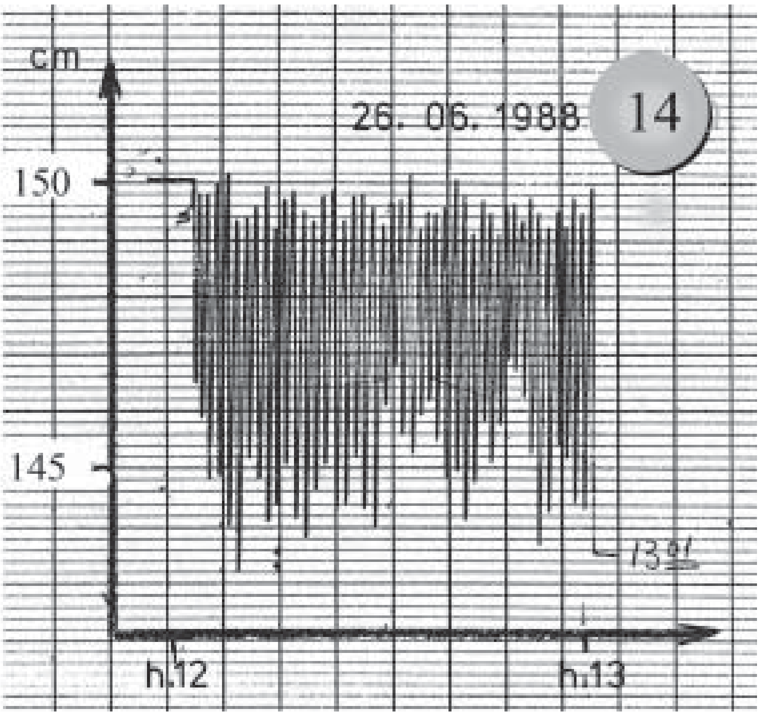


Figure 12

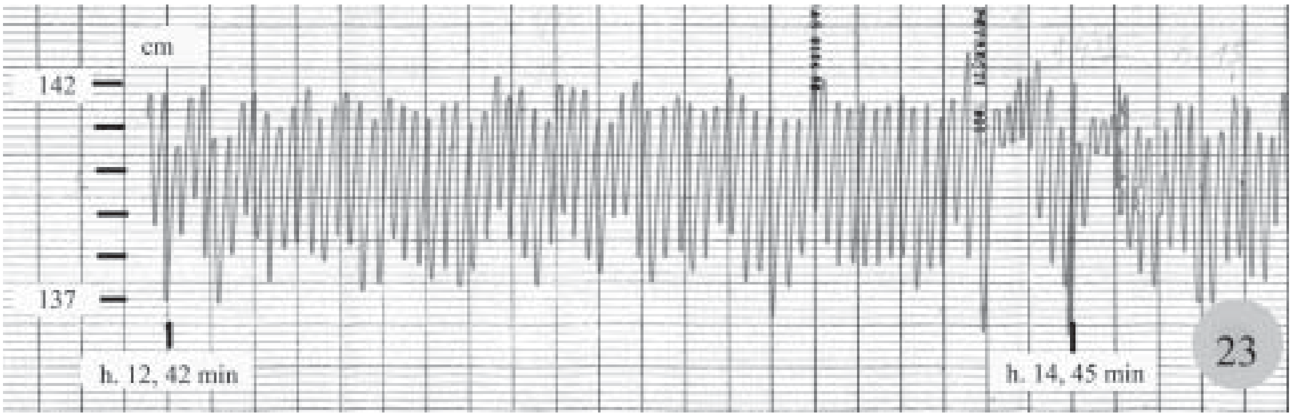


Figure 13

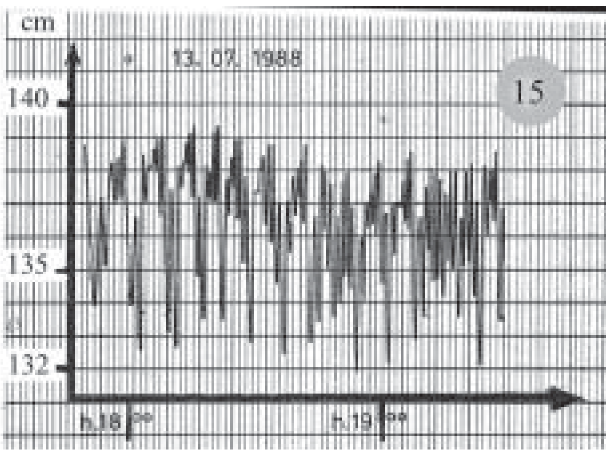


Figure 14

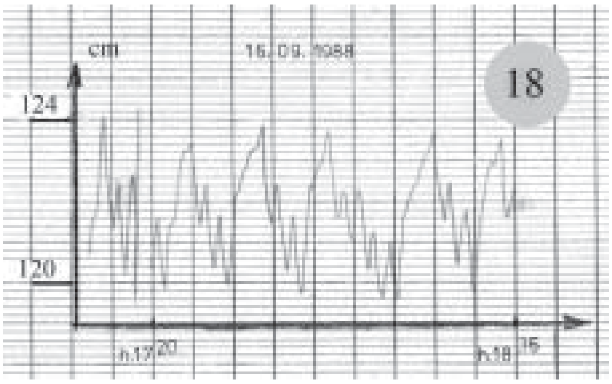


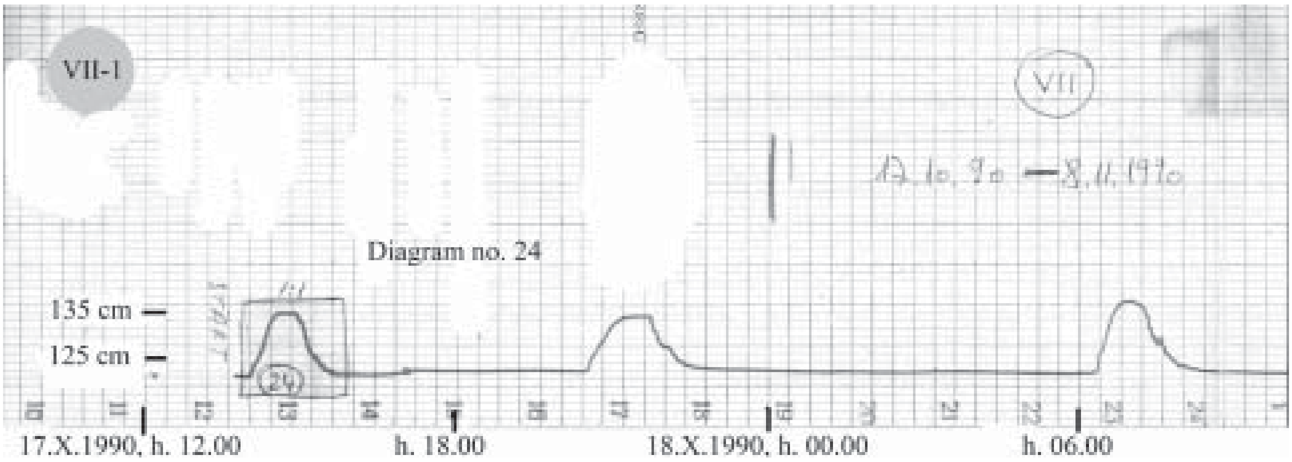
Figure 15

Figures 12, 13, 14 and 15. Different shapes of small oscillations.

amplitude (Fig. 16). In time, the interval between bell shaped oscillations increasingly large periods, ranging from 2 hours up to two oscillations or less once a day (Fig. 17), when the water level have only small oscillations.

The uneven distribution of rainfalls influences the operation of the spring, often altering the succession of oscillations previously remarked (Fig. 18 and 19).

Wet or dry character of a month within a year is illustrated by Angot index value (MARIA CRISTEA, 2004). The left column of Figure 5 present the evolution of Angot index during the years of observations at Ştei weather station, not-



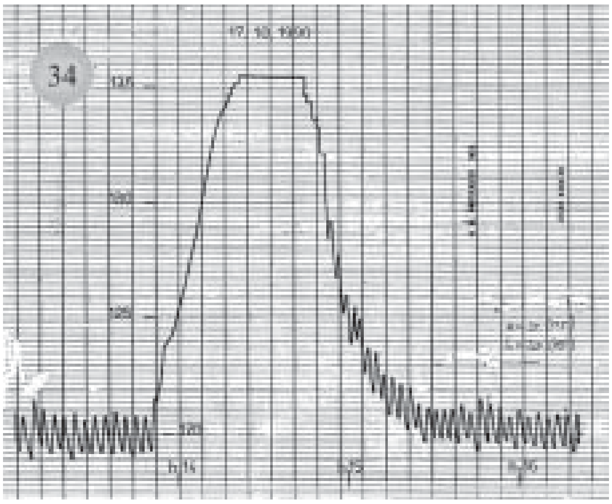


Figure 16 a & b. Sequence of bell shaped oscillations of water level observed in Stone Pit (1:10, 24 cm/day, above) and details of a bell shaped oscillation (1:1, 3.5 cm/hour, right).

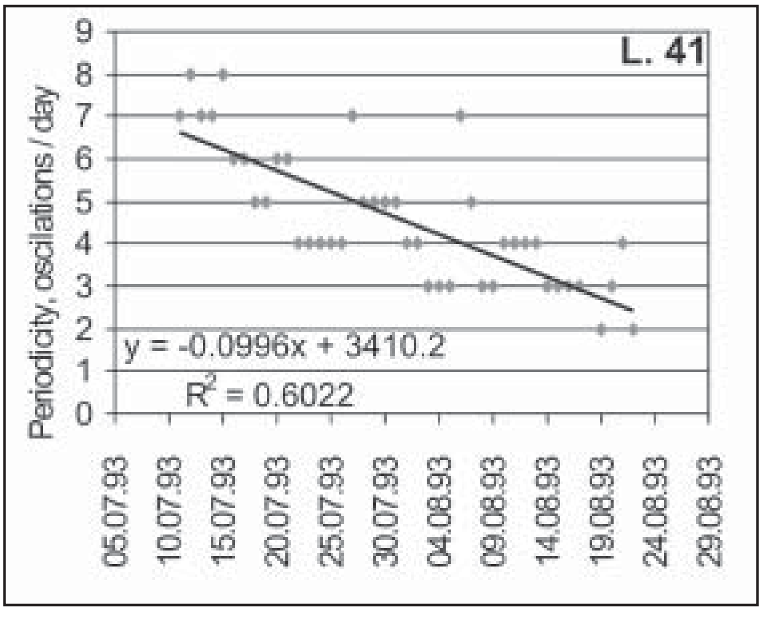


Figure 17. Rest period of bell shaped oscillations increase in time.

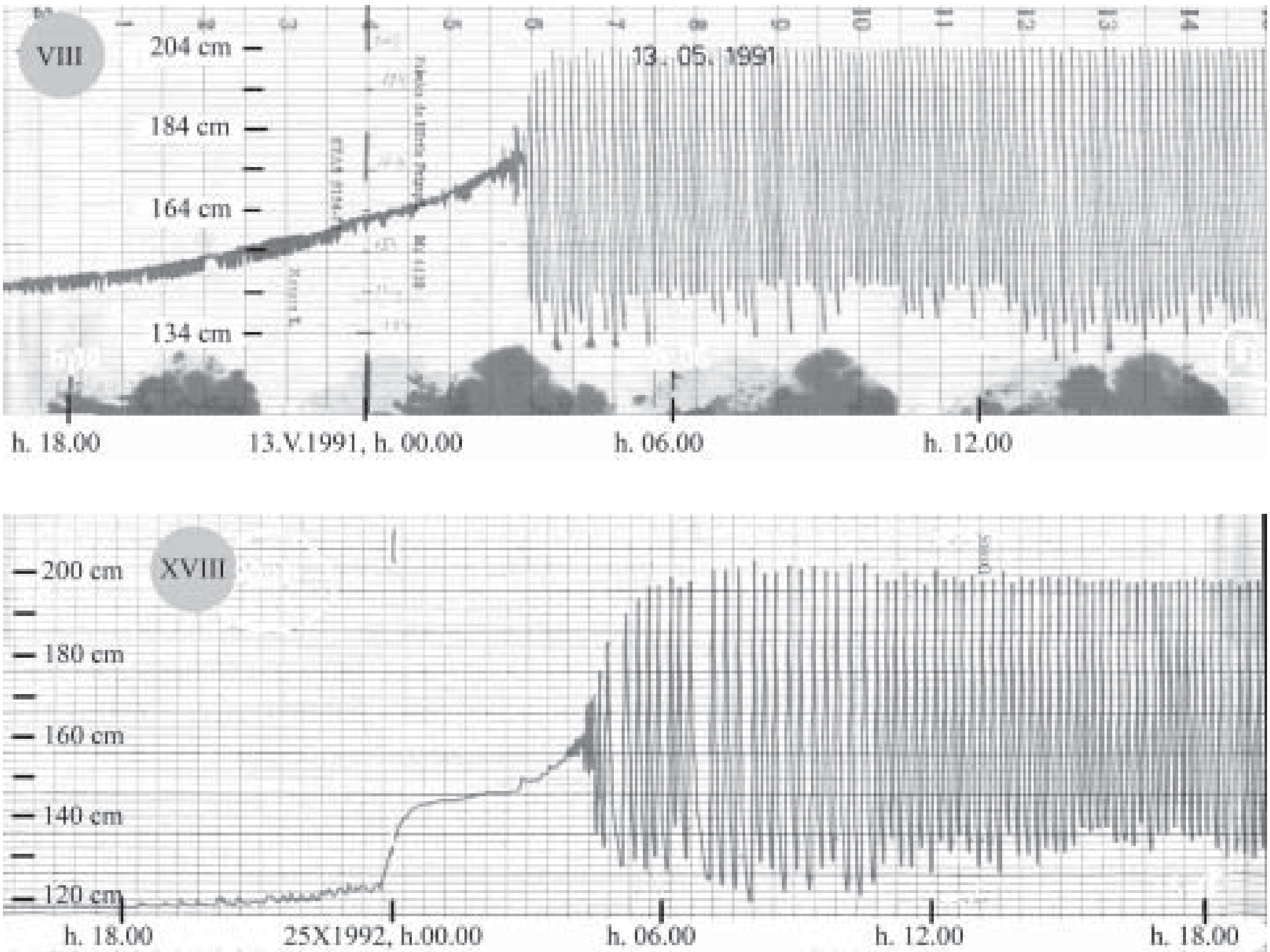


Figure 18. Different ways to start high oscillations.

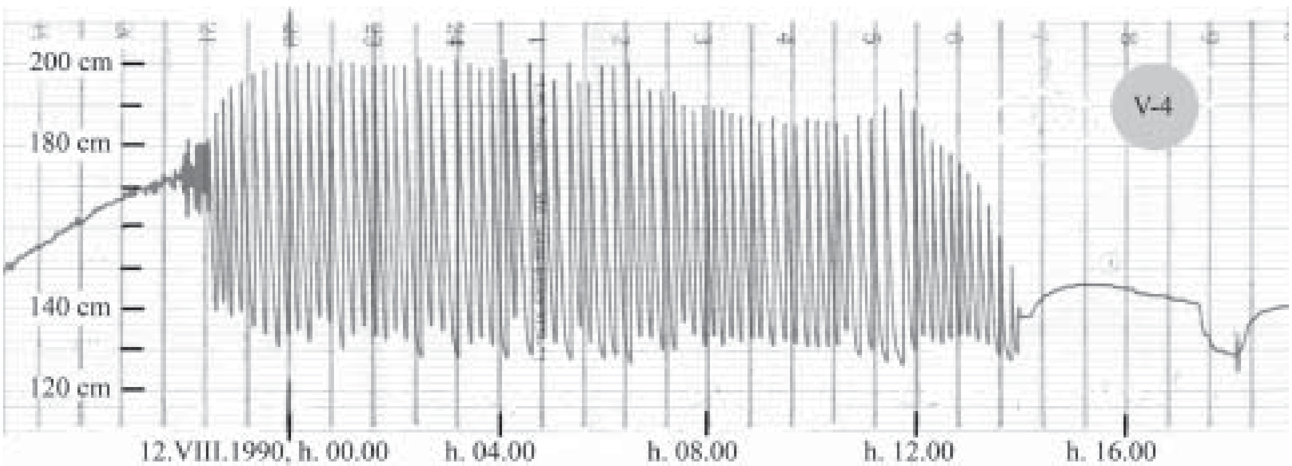


Figure 19. Framed high oscillation between small and bell shaped oscillations.

ing presence of high oscillations in Stone Pit in the rainy periods and their absence in the drought.

In spring 1985, following serious rainfalls, a 3 m diameter land collapse took place on the left side of Vulpilor brook 315 m upstream the ebb and flow spring, in the diluvia deposits with black dolomites blocks, having at the bottom a narrow descending gallery of 10.5 m long, build of the same deposits. The gallery, explored by the author in 21.10.1987, ends in the top of a karst hole with a lake 4 m below, whose surface oscillates. In 10.12.1988, GH. BRIJAN in Ştei survey the lake in pothole (Fig. 20). The observations showed that the level of water in the lake has oscillations of a similar regularity as the ebb and flow spring. The hydrological connection of those two points was proved by a fluoresceine test undertaken at 06.11.1987

The oscillations of the level of water were occasional recorded, first by sight, on a staff gauge and then on a 1:1 water level recorder for short time, and finally based on air tube method with a rubber tube. The access in the hole was difficult and dangerous. Meanwhile, the access gallery in the underground lake was slowly clogged, and in 1995 it turned unreachable.

In between 20-21 October 1990, during the bell oscillations at Stone pit, the level of the lake varied with 28 cm (water level recorder, Fig. 21). Meanwhile the debit of the ebb and flow spring varied between 0.32 and 1.51 l/s. The average volume of water evacuated from the underground lake during one eruption being 5.6 m^3, corresponding to a surface of the underground lake of about 20 m^2 (L. 26).

In Fig. 22 the recordings taken simultaneously at Stone Pit and the lake at the pothole in Vulpilor brook (air tube method) are presented on 13 July 1993. The level of the water in the pothole rises with 35 cm in 2 hours and 28 minutes, then it goes down, reaching the initial point after 1 hour and 08 minutes. If the water from the lake go direct to the Stone Pit, it travels the underground pipe between the pothole and Stone Pit (315 m) in 17 minutes and 12 seconds, with a mean speed of 0.3 m/s.

For high oscillations of water level in the Stone Pit, the level of the water in the lake of the cave has low oscillations, about 2 cm, within the error margin of the measurement. The maximum observed level of the water in the lake was 37.6 m relative altitude, when the water in the Stone Pit had high oscillations, and the overflow source (Fig. 20, a) had a debit of about 5 l/s and one could hear an underground fall.

The rare observations on the oscillations of the lake in the pothole are not sufficient to state if the lake represents a siphon mechanism or its more a appendix of the karst system. It is also to be mentioned that during the bell shaped oscillations into the Stone Pit, the oscillations of the water

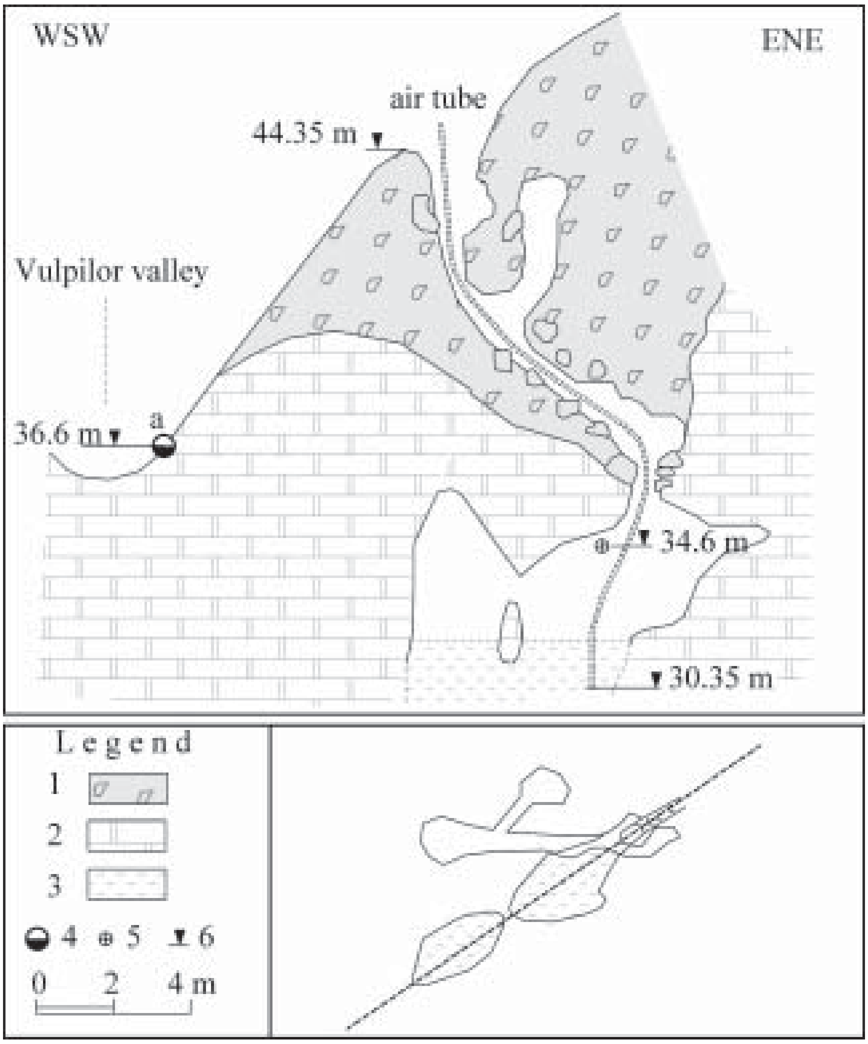


Figure 20. Pothole in Vulpilor brook.

Legend:

1. clay with blocks of dolomites;
2. dolomites;
3. underground lake;
4. temporary spring;
5. bolt;
6. mark with relative altitude

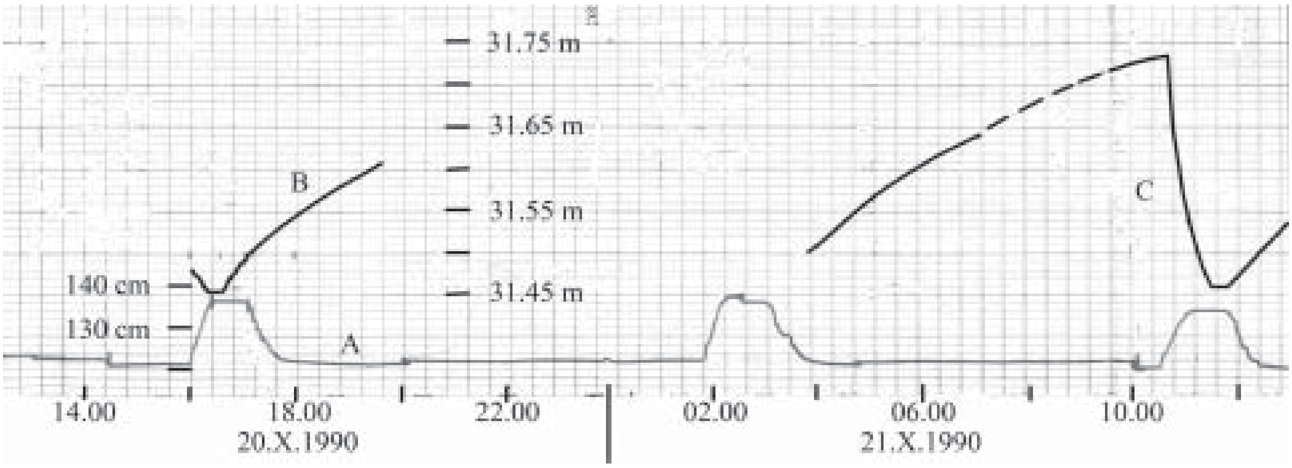


Figure 21. Oscilation of water level in Stone Pit (A) and in underground lake of pothole in Vulpilor brook (B and C).

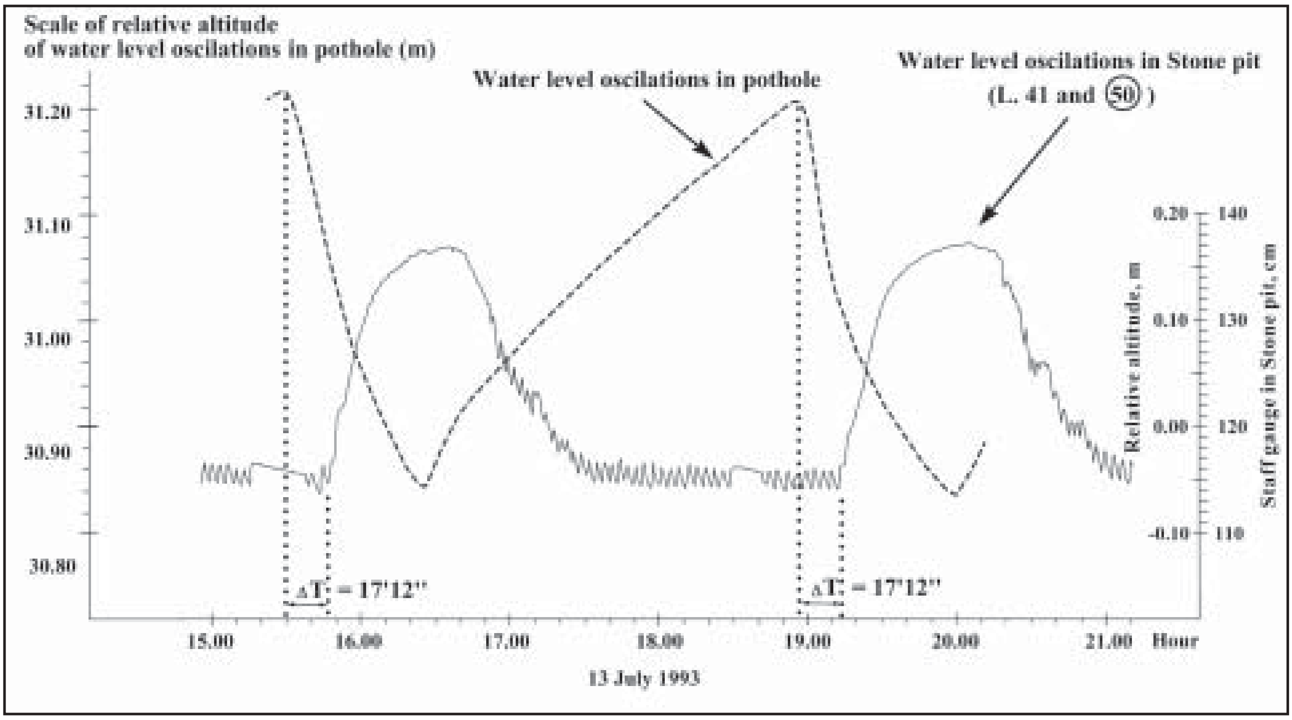


Figure 22. Simultaneous measurements of water level oscillations in Stone Pit and in underground lake in pothole in Vulpilor brook.

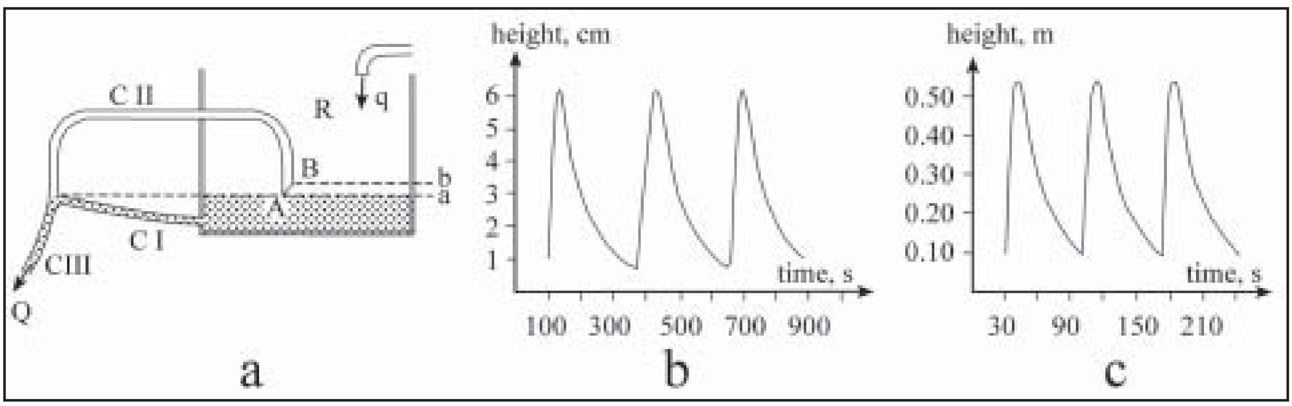


Figure 23. A. MANGIN's low scale model (a) gets oscillations of the water level (b), identical with those noted for Fontestorbes source (c).

level into the underground lake took place in different elevations.

The connection between the siphon mechanism and the Stone Pit is done by an underground flow directed on a karst pipe, with no connection to the flooded zone of the karst aquifer. The flow through the underground pipe has a free level, proved by the losses or the sources coming in the talweg of Valea Vulpilor in various times of the year. We also mention that no periodical debit variations were noticed at the overflow source "a" in Fig. 20, (no. 3 in Fig. 3).

We think the Stone Pit acts like a water stilling basin for hydro technical projects, and the oscillations of the water level are caused by the variation of the water speed into the Stone Pit. To the variation of the water speed into the Stone Pit (caused by the change from the rapid movement into the karst gallery, to the slow movement into the Stone Pit) it is associated a pressure wave that generates the movement of the water surface in Stone Pit (hydraulic jump). The variation of inflow discharge produced by siphoning mechanism are mirrored in the amplitude of hydraulic jump (by means of associated discharge wave).

In 1689 J. V. Valvasor describing spring Lintvern near Vrhnika, for the first time explained the function of intermittent spring by siphon (R. PODOBNIK, 1987). After about three hundred years, the explanation of the functioning of ebb and flow springs was approached by many researchers, among whom I. Al. MAXIM (1941), A. MANGIN (1969 a), P. HABIC (1970), A. JEANBLANC, G. SCHNEIDER (1981), J.-P. FABRE (1983), R. PODOBNIK (1987), LAZAREVIC R. (1991.

A. MANGIN (1969 a, 1969 b) notes detailed observations at Fontestorbes (Belesta-Arige, France) and published resulted data accompanied by a low scale model, which explains the mechanism of a ebb and flow source. Fonterstorbes acts as intermittent spring only in between 0.6-1.8 m^3/s debits, the duration of one oscillation varying between 48-75 minutes.

With the help of a low scale model (Fig. 23, a), A. MANGIN gets oscillations of the water at a low scale (Fig. 23, b), identical with those noted for Fonterstorbes source (Fig. 23, c).

The low scale model is made of a reservoir R connected to two pipes, a siphon CII and an almost horizontal one CI, which join in point C to result an evacuation pipe CIII. The reservoir is fed with a q debit, the debit evacuated through CIII being Q.

When reservoir R is full, the water obstructs the gap of air CII in B. The debit at CIII rises, $Q>q$, causing the emptying of the reservoir up to point A. At that moment, the activation of the air intake leads to a higher loss of the load and the reduction of Q evacuated debit which turns lower than q and the level rises in the reservoir up to the full obstruction of air gap CII. At that moment the loss of load disappears, while debit Q rises and the phenomenon restarts.

PODOBNIK R. (1987) using a model consisting of a long plastic tube of 12.3 m and a diameter of 43 mm, placed in different positions, obtained similar stage hydrograph as those of ebb and flow springs.

Starting from hydraulic intake air bases in siphons (CASTELEYN J. A. et al., 1977) and from three ebb and flow sources hydrographs flashing in the former Yugoslavia, BONACCI O. & BOJANIC D. (1991) suggest a mathematical working model of ebb and flow springs (springs called rhythmic by authors) consists of two reservoirs joined by a siphon. With the proposed model the authors have obtained identical simulated to those observed hydrographs and were possible to define the real dimensions of the siphoning mechanism.

Research on models performed by MANGIN A. (1967), PODOBNIK R. (1987) and BONACCI O. & BOJANIC D. (1991) showed that simulated hydrograph can be obtained identical to these observed at intermittent sources with very different patterns of combining pipelines, tanks and siphons, and stressing the complexity and diversity of these natural phenomena.

Călugări spring is a permanent karst source with a complex type of functioning. The high oscillations are similar to those at Fonterstorbes and may be explained based on the model proposed by A. MANGIN. They do not stop at maximum debits as the Fonterstorbes source does, but high debits are evacuated through the overflow source ("a" in Fig. 20).

Bell-shaped oscillations noticed in the Stone Pit may be explained by the way a simple siphon works, which is supported by their shape and the continuous reduction as the debits gets low.

Low series of oscillations noticed between the high and the bell ones are generated by debit perturbations between those two types of oscillations.

The water at Călugări is a Ca-HCO3 one, with a medium mineralization of about 300 mg/l (Ca^{++} = 40.1 mg/l, Mg^{++} = 18.2 mg/l).

We hope that future observations and further interpretation of collected data to bring new clarifications for Călugări ebb and flow spring.

Acknowledgements

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I would also like to thank to speleologist G. BRIJAN in Ştei, for his help to explore the pothole in Valea Vulpilor and undertaking parallel hydrological observations to the Stone Pit.

I will thank A. Schneider in Oradea for the translations from German and Hungarian of the reference papers on Călugări spring.

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