Iancu Orăşeanu

3.13.7. RAPOLT CRYSTALLINE LIMESTONES OUTCROP

(Reprint from Karst Hydrogeology of Romania, 2010)

The Rapolt crystalline limestones outcrop is located at the Apuseni Mountains southern margin, being bordered by Mureş stream to the south and by Geoagiu stream to the east. It extends westward up to Şerman hill at Hărău and up to the Vărmaga stream upper reaches, while its northern boundary runs beneath the hills Leordar and Crucii, up to Geoagiu spa. The crystalline formations has an area of about 70 km^2, out of which some 25.8 km^2 are occupied by carbonate deposits outcrops.

7.1. Physiographic characteristics of the Rapolt crystaslline limestones outcrop

Within the crystalline schists body of the Rapolt crystalline outcrop, crystalline limestones and dolomites occur as an east-west striking strip, that extends over a length of 14 km and whose maximum width, 3-4 km, is recorded in its section located between the brooks Boiu and Rapolţel. Westward of Rapolţel brook the width of the strip progressively decreases, so that in the proximity of Hărău carbonate deposits do not crop out anymore, being completely buried beneath more recent formations (Figure 7.1).

The streams Boiu, Bobâlna, Rapolţel, Şesuri and Vărmaga run across the crystalline limestone strip by dissecting land sections which occur as distinct entities in the topography of the region, as a consequence of the large elevation range (frequently of the order of 200-300 m) that separates the stream beds from the ridges which divide the individual catchment areas. When considering the entire limestone strip, one may notice that maximum elevations decrease from east to the west, from 715.9 m in Cornetu Mare peak to only 291.1 m in Şerman hill. Besides the above indicated stream courses, there occurs also Clocota stream, which runs from west to the east across the north-eastern margin of the crystalline outcrop. Before reaching Geoagiu Băi spa, this stream receives on its right side the water supplied by Clocota spring, the most important groundwater discharge in the entire crystalline area. From this junction downstream, the stream crosses the travertine terrace where Geoagiu Băi spa is built, while inflows provided by several wells drilled in that area result in doubling its discharge.

Boiu stream upper catchment area is developed within Miocene deposits. In this section, its main tributaries are Poienii brook and Iosif brook, that entirely sink into swallets located at the contact with the crystalline limestones (Fig. 1, no. 26 and 27). Further downstream, their streambeds turn into dry, grass covered, gentle slope valley that are strewn with sinkholes. Close to the contact with the crystalline schists, the course of the valley severely steepens and water flow may temporarily occur. At the bottom of this section, Boiu spring (no. 28) provides a permanent supply to the stream, which further downstream follows a course excavated in crystalline schists.

Along its section that is developed within the crystalline limestones, Bobâlna stream has a narrow, rectilinear valley, bordered by very steep hill sides which cannot be climbed. During draught periods, before reaching out of the crystalline limestone section, the stream water diffusely sinks through the alluvia and the cracks occurring in the limestones that occupies the streambed, and as a consequence the valley becomes dry. After reaching out of the crystalline limestone section, the stream valley progressively widens into a largely developed plain, which extends first on alluvia, then on the travertine precipitated by the thermal springs that discharge at Feredeu. The plain extends on the travertine plate over some 750 m in length and over 300 m maximum width, being suddenly broken by an escarpment located at the junction of Bobâlna stream with the brook that originates in the discharge of the thermal springs. From this spot downstream, down to Ciocan hamlet, the stream has entrenched a steeply descending course in the travertine, with a series of waterfalls following to one another, while bordering walls are vertical and frequently subject to intense karst processes.

Rapolţel and Şesuri streams have their upper catchment areas excavated prevalently in crystalline limestones. Along their carbonate sections, the topography is similar to that of Bobâlna stream and similarly to the latter as well, the flow regime character is temporary along the carbonate sections which occur upstream from where crystalline schists outcrops are reached, the indicated sections being completely dry during long periods of draught.

Crystalline limestones in the Şesuri stream valley is subject to extremely intense karst processes, as mirrored by the bordering hill sides which display a multitude of dissolution pockets and small cave entrances. Moreover, during low discharge periods, the stream water that runs along this section completely sinks into the limestone substratum through the opening of a vertical cavity, which is 2 m deep and has an entrance diameter of about 60 cm (no. 12).

Limestone surfaces cropping out in the area which acts as the water divide between the streams Bobâlna and Rapolţel are subject to intense karst processes, a fact mirrored by the multitude of sinkholes in that area. In the south-eastern margin of this water divide region, there is an extensive area covered with remarkable vertical tubular grikes.

In the western part of the Rapolt crystalline outcrop, the width of the crystalline limestone strip significantly decreases, reaching no more than 500 m in the sections that are crossed by the streams Vărmaga and Ţiganilor (Bârgău). The latter thoroughly sinks in its streambed during draught periods.

7.2. Previous geological and hydrogeological investigations

In the framework of their geological investigations addressing Metaliferi Mountains, T. P. GHIŢULESCU and M. SOCOLESCU (1941) have described the structure of the crystalline outcrop located south of Săcărâmb. Starting from the year 1959, Rapolt crystalline outcrop has been investigated by I. BERBELEAC with the main purpose of detecting metal ores (gold, silver, poly-metallic sulfides and iron). The results of these investigations have been exposed in geological reports and in scientific papers (1964, 1970).

In the year 1968, I. BERBELEAC has published a paper addressing the geological-structural setting associated to the thermal and the CO_2 rich mineral springs in the Rapolt crystalline outcrop.

So far, no hydrogeological investigation has specifically considered the overall carbonate deposits area in the Rapolt crystalline outcrop. Those deposits are directly mentioned in the scientific literature which addressed Geoagiu Băi spa, where thermal water discharges are directly associated to them and wells drilled in the spa have significantly contributed to understanding their hydrogeological role. A condensed presentation of the thermal water discharges at Geoagiu spa has been provided by A. PRICĂJAN (1972).

Conversely, hydrogeologists have devoted a special interest to the investigation of the areas where crystalline schists crop out, in the southern part of the Rapolt crystalline occurrence, where many discharges of thermal (Feredeu-Bobâlna, Rapolţel) and mineral (Chimindia, Banpotoc) water occur. Authors that investigated those discharges directly mentioned the crystalline limestone reservoir as potentially being in certain cases the thermal and mineral waters supply source.

In the year 1978, D. SLĂVOACĂ, M. FERU, VERONICA GEAMĂNU, G. SIMION, NATALIA GOLIŢĂ and P. LUNGU, in a paper addressing the natural occurrences of thermal water in Romania, have mentioned that between Banpotoc and Geoagiu there occurred thermal springs with flow rates ranging between 1.5-15 l/s, and with temperatures ranging between 17-32°C.

Environmental isotopes investigations performed by F. DAVIDESCU et al., 1991 and by A. ŢENU and F. DAVIDESCU, 1998, brought further information concerning the circumstances under which thermal water accumulations at Geoagiu Băi spa had been generated.

During the period 1995-1996, I. ORĂŞEANU has conducted detailed hydrogeological investigations aimed at assessing the groundwater resources potential of the Rapolt crystalline outcrop carbonate deposits.

7.3. The geological and structural setting of the Rapolt crystalline outcrop

In the proximity of the town of Simeria, the southernmost section of the Apuseni Mountains includes an isolated outcrop of metamorphic formations which could be more plausibly ascribed to the Southern Carpathians, that are located just across the alluvial plain of Mureş river. On the other hand, the relationships between this isolated outcrop and the Apuseni Mountains pre-alpine formations are rather hard to unravel, because of the significant distances that occur in-between (V. IANOVICI et al., 1976).

The geological constitution of the considered area includes crystalline schists, sedimentary formations and igneous rocks (I. BERBELEAC, 1964, 1970).

Crystalline formations. The metamorphic formations innermost stratigraphic unit consists of a compact mass of limestones generated by a reef barrier in whose proximity both carbonate and terrigenous material had been deposited, while further away deposition had included only terrigenous material. During the sedimentation an initial igneous activity occurred, out of which there resulted tuffs and tuffites, basic and acid intrusions. All this metamorphosed material is distributed into four rock complexes: carbonate, carbonate-quartzite, phyllite-conglomerate and porphiroidic rocks.

The carbonate complex is well developed in the central part of the crystalline outcrop, in the area Boiu-Bobâlna-Rapolt, becoming progressively thinner in the westward direction, to finally disappear close to Hărău village. The complex includes the following succession: compact, bedded and shaly limestones; dolomitic limestones and partly-limestone dolomites; shaly and bedded dolomites, ankeritic dolomites and ankerites.

Sedimentary formations. Before the Late Cretaceous, the Rapolt crystalline occurrence was not covered by the sea, then, during the Senonian transgression, the sea completely submerged it. Those deposits series includes at its bottom conglomerates and sandstones (the Bobâlna Beds), followed by marls, clays and sandstones (the Geoagiu Beds) and by a sandstone-marly flysch formation (the Bozeş Beds), (JOSEFINA BORDEA et al., 1978).

Quaternary deposits include the old and the recent alluvia of the terraces and of the floodplain of the Mureş river and of Geoagiu stream, as well as slope deposits, scree slopes, alluvial fans and landslides. An outstanding place among the Quaternary deposits in that area occupy the travertine and the carbonate tuff deposits. They are the result of the precipitation of the carbonates dissolved in the thermal water, and their very large extent (Geoagiu spa, Cărpiniş-Banpotoc, the streams Bobâlna and Rapolţel areas, etc.) indicates that during the Pleistocene, in that area there has occurred an intense hydrothermal activity which is still under way, although significantly less intense.

The tectonic setting of the Rapolt crystalline outcrop

The general structure of the Rapolt crystalline outcrop is that of a horst bounded by two systems of faults which strike NE-SW and NW-SE respectively (I. BERBELEAC, 1970).

The NE-SW striking faults system is older and it has displaced Late Cretaceous deposits in the eastern part of that area. Those faults have an oblique and reverse character, their thrust angles being close to the vertical. They are displaced by the faults of the second system (of NW-SE strike), whose age is Cainozoic. The faults of the first system have acted as access paths for the lamprophires and the gabbros in Cornetul Banpotocului hill and in Valea Mică, as well as for the andesites in Măgura Uroiului.

The faults of the second system strike N30-70°W and they have a north-eastern dip. They dissect the anticlinorium into several compartments, out of which a special mention deserves the uplifted block which is bounded by the faults Vărmaga-Rapolţel and Bobâlna-Săcărâmb (Figure 7.1). From the latter fault to the east, limestones in the anticlinorium axis has been downthrown in a stepwise manner by the faults Boiu and Geoagiu-Mada-Voila.

The eastern outcrop area of the crystalline limestone strip of the Rapolt crystalline formations axis is sharply broken off along the lineament Poieni stream swallet - Cornetu Cigmăului peak by the NW-SE striking Geoagiu-Mada-Voila fault. Starting from this fault toward the east, the Rapolt crystalline limestone sinks beneath Late Cretaceous deposits, which consist of a series that includes the

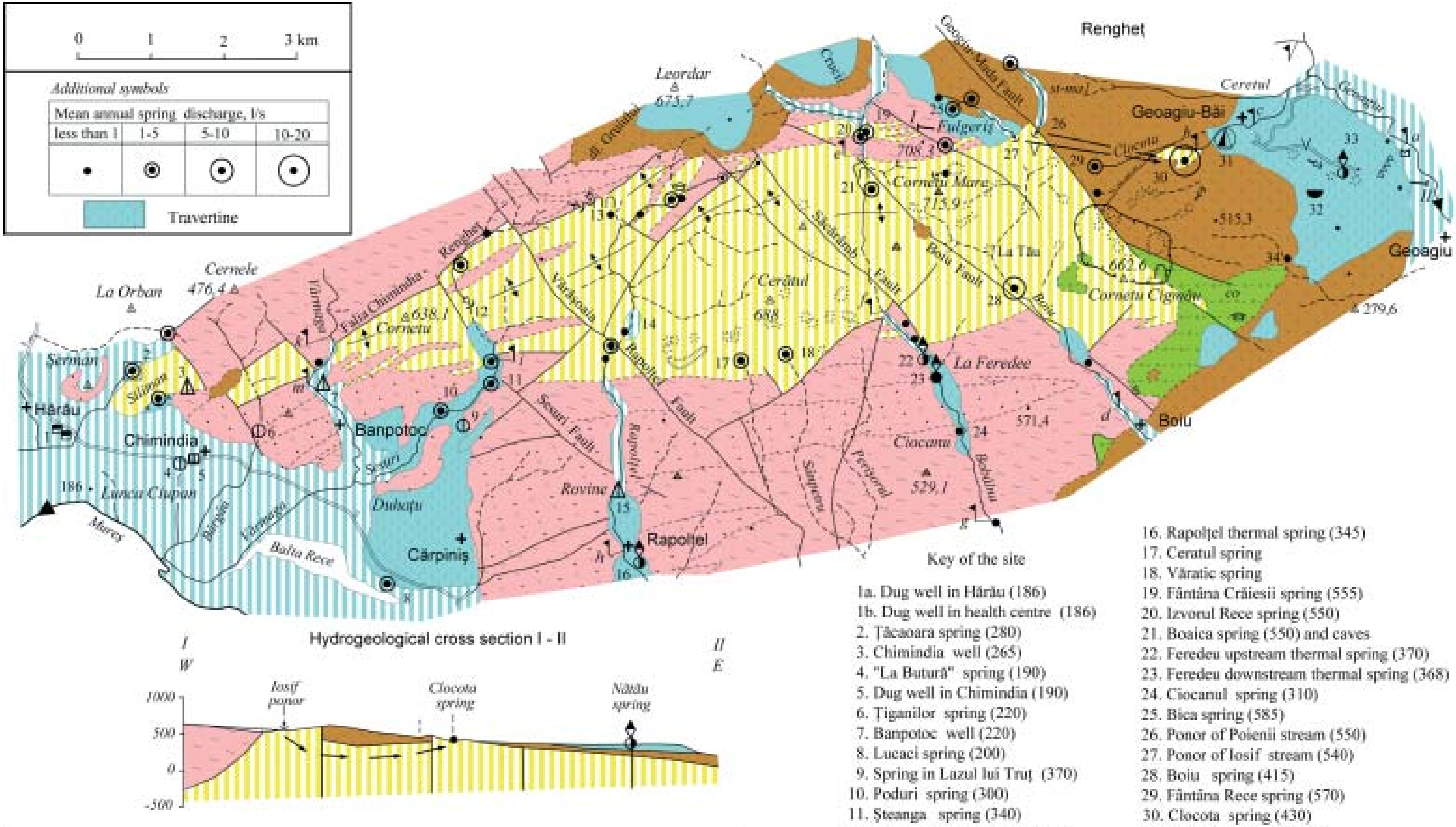

Figure 7.1. Hydrogeological map of the Rapolt crystalline occurrence.
Geological data after J. Bordea, I. Berbeleac, G. Mantea, J. Stancu, E. Rogge-Tătaru.
Legend as in Figure 1.6.

Bobâlna Layers at the bottom, followed by the Geoagiu Beds and the Bozeş Beds at the top, this latter Cretaceous unit occurring only as isolated outcrops that managed being preserved during the erosion process. Starting from Geoagiu spa toward the east, down to the valley of Geoagiu stream, Cretaceous deposits are covered by a compact plate of travertine that may be up to 120 m thick.

The Cretaceous deposits are not very thick, a slow and progressive thickening being recorded westward from the fault Geoagiu-Mada-Voila. Worth to be mentioned is the fact that Cretaceous deposits situated next to the indicated fault mimic the slightest detail of the topography of the crystalline limestones they cover, a typical example in this respect being Cigmăului Cave depression, that occurs northward of Cornetu Cigmăului peak, and whose eastern half is developed within Cretaceous formations.

7.4. The carbonate deposits hydrogeology

The cracks and the karst cavities of the limestones and of the dolomites store major groundwater accumulations, which are supplied both directly, by runoff collected on the outcrop areas, and by the surface streams that originate within the non-karst terrains which occur to the north of the carbonate rocks strip. Since impervious intercalations of regional extent are lacking in the carbonate deposits mass of the crystalline occurrence axis, inference can be made of a single, unitary karst-fractured aquifer.

In order to assess the groundwater resources potential of the Rapolt crystalline occurrence carbonate deposits, I. ORĂŞEANU, by appointment of S.C. Prospecţiuni S.A., together with PARASCHIVA and GH. HOŢOLEANU, appointed by the Institute of Meteorology and Hydrology (INMH), have set a temporary network for hydro-meteorological observations, which provided data for the hydrological year X.1995-IX.1996. There have been additionally used the hydrometric and rainfall data provided by Geoagiu hydrologic station, which belongs to the permanent network of the INMH. Table 7.1 provides physiographic quantitative data of investigated catchment areas, together with the characteristic flow rates recorded during the above-indicated hydrological year.

No	Stream	F	F lms.		H	Qmean	Qmin	Qmax	q	EM	TR
		km^2	km^2	%	m	l/s	l/s	l/s	l/s/km^2	days	days
1	Geoagiu (a)	297			582	2913	470	7340	9.81	4	5.2
2	Rengheţ	11.2	0	0	533	70.1	2	1086	6.26	5	1.47
3	Clocota (b)	1.43	0.12	8.51	516	19.9	0.35	351	13.92	4	7.7
4	Clocota (c)	2.91	0.12	4.12	486	80	50.1	388.5	27.49	14	9.3
5	Boiu (d)	7.81	5.81	74.39	548	13.4	0.9	678	1.39	2	2.3
6	Bobâlna (e)	5.75	0.62	10.8	670	55.8	6.9	845	9.15	10	6
7	Bobâlna (f)	8.81	3.43	38.9	600	40.2	0	773	4.47	10	5.3
8	Bobâlna (g)	12.49	4.49	35.95	562	84.6	9.9	993	6.61	11	6
9	Rapolţel (h)	13.75	7.69	55.93	537	30.9	2	691	2.21	9	5.4
10	Sesuri (i)	3.78	2.62		555	5.67			1.5		
11	Vărmaga (k)	30.4	0.2	0.66	509						
12	Vărmaga (m)	31	0.3	1.0	500	174	10	1550	5.6	13	12.8
13	Clocota spring					17.1	0.9	124		22	18.6

F - surface of hydrographic basin (h. b.) upstream of hydrometric gauge section; F lms. - surface of h. b. covered by cristalline limestones; H - mean altitude of h. b..; EM - memory effect; TR - time of regulation.
In brackets site of hydrometric gauge station in Fig. 7.1.

Table 7.1. Morphometric and hydrometric data of surface water streams in X.1995-IX.1996 hydrologic year

Clocota spring (Figure 7.1, no. 30) is located on the right side of the stream which bears the same name, some 300 m away from the streambed. The outlet discharges from the boulders at the bottom of a 20 m tall vertical cliff excavated in crystalline limestones that is subject to fracturing and karst processes, the spring occurrence being associated to the crystalline limestones cropping out over a small area ensuing to the Late Cretaceous deposits erosion. The spring is tapped, being used as an alternative water supply for Geoagiu spa, in addition to the water pumped from the water intake in the Mureş river floodplain.

Over the hydrological year X.1995-IX.1996, Clocota spring has discharged on the average 17.1 l/s, the recorded extreme flow rate values being 0.9 and 124 l/s. During rainfall periods, the spring water violently turns muddy. Over the flow recession period that extended between 17.05.1996-22.06.1996 and which was not subject to any rainfall influence, the spring discharge continuously declined, the recession coefficient computed for that period having an elevated value (0.0296), a fact which further illustrates the fast decline of the discharge and the intense karst processes to which the crystalline limestones is subject.

Clocota karst system is a binary type system, that extends also on non-karst terrains in the Boiu stream upper catchment area. Tracer tests conducted on 11.09.1996 at the swallets of the streams Iosif (injection of fluorescein) and Poieni (injection of rhodamine), which are tributaries of Boiu stream, have indicated that the underground flow of these streams is directed toward the Geoagiu Băi spa area. Tracers were first detected in Clocota spring 6 days after being injected, maximum recorded concentrations occurring 200 hours after the injection of the rhodamine and 164 hours after the injection of the fluorescein. Fluorescein was also detected in the thermal water discharged by the well F1 ISPIF (Fig. 7.4), the tracer occurrence being recorded as a very weak and virtually constant concentration pulse, which lasted for the time interval that extended between 180 and 350 hours after the tracer injection.

In the Boiu stream catchment area there occurs only one major karst outlet, Boiu spring (no. 28). Over the investigated hydrological year, the spring average flow rate was 7.05 l/s, with extreme values in the 0.9-678 l/s range.

Bobâlna stream follows a rectilinear course that crosses from north to the south the Rapolt crystalline limestones over a distance of about 3 km, by collecting along this section water from a 3.06 km^2 catchment area. In the stream section located upstream of the carbonate terrains, the stream catchment area extends over 5.13 km^2. During the hydrological year X.1995-IX.1996, out of the total flow rate collected by Bobâlna stream from the area located upstream of the crystalline limestones terrains, 15.6 l/s sank into the alluvia and the crystalline limestones in the streambed. In flood periods, such losses of discharge amounted to 72 l/s. During draught periods, the Bobîlna stream lower karst section was dry, the sunken flow rate amounting in those periods to 6.9 l/s.

Subsequently to exiting the karst area and until reaching Bobâlna village, the Bobîlna stream discharge is subject to a 44.4 l/s yearly average augmentation, due to the inflows provided by runoff collected on the catchment area developed within the crystalline schists, as well as, to the largest extent, to the thermal water inflows discharged by the outlets at Feredee.

The average flow rate recorded at Rapolţel gauging station during the above-indicated hydrological year amounted to 30.9 l/s, the minimum and maximum recorded flow rates being 2 and 691 l/s respectively. The specific discharge computed by considering the 14 km^2 area controlled by the gauging station is very low (2.21 $l/s/km^2$), an anomaly which can be ascribed to the intense infiltration occurring on the crystalline limestones outcrop area, a fact which results in a total absence of large discharge springs and of tributaries with permanent flow. In summer time, over long time intervals, the surface flow of Rapolţel stream ends in the section called La Stână (no. 14), as a result of complete sinking. That area is subject to significant alluvial deposition.

Vărmaga stream crosses the crystalline limestones stack over a distance of about 500m, and along this course hydrometric data indicate no significant relationships involving water supply or loss between the karst aquifer and the surface stream.

It is important to underscore that major water infiltrations occurring in the streambeds of the surface streams Şesuri, Rapolţel, Bobâlna and Boiu are located in the sections where those streams cross the faults of the second system that concerns the Rapolt crystalline outcrop, namely the more recent, NW-SE striking system. Those faults and their associated crushed zones act as actual large scale drains, which convey the surface streams water into the underground.

Processing and interpreting the data provided by the temporary network of hydro-meteorological observations and measurements which had been set in the Rapolt crystalline outcrop karst area during the hydrological year X.1995-IX.1996, resulted in deciphering the relationship between the inputs, which consisted of rainfall collected on the crystalline limestone surface and of surface water inflows originating on the terrains situated further upstream (to the north), and the outputs, which included the cold and the thermal water outlets. The relationship between the specific discharge q (expressed as l/s/km^2) and elevation was computed by means of a diagram including the daily average flow rates of three witness catchment areas located on impervious rocks, at various elevations (Vărmaga, Rengheţ and Bobâlna stream - g.s. upstream limestone). Rengheţ stream is located northward of Clocota stream catchment area. The vertical gradient of the specific discharge resulted to be 2.04 l/s/km^2 /100m (Figure 7.2).

The water budget devised for the hydrological year X.1995-IX.1996 for the Boiu, Bobâlna, Rapolţel and Şesuri streams catchment areas (Table 7.2), which were monitored by means of gauging stations, concerns an area of 37.8 km^2, out of which 20.6 km^2 are covered by crystalline limestones. Annual average infiltration that occurred in this area has amounted to 198,5 l/s and it has essentially supplied the carbonate aquifer. Groundwater outlets at the boundaries of this area include mainly cold water sources (Clocota spring -17.1 l/s, other outlets -11.5 l/s), the thermal water discharges at Geogiu spa (38.8 l/s) and the mineral water well Banpotoc (4.5 l/s). The difference between inputs and outputs amounts to almost 90 l/s. We assume that this amount of infiltrated water supplies a deeply seated karst-fracture flow which probably discharges along the NW-SE striking fractures system, which provides a direct hydrogeological connection between the carbonate aquifer on the one hand, and the Late Cretaceous permeable deposits and the Mureş river floodplain alluvia on the other.

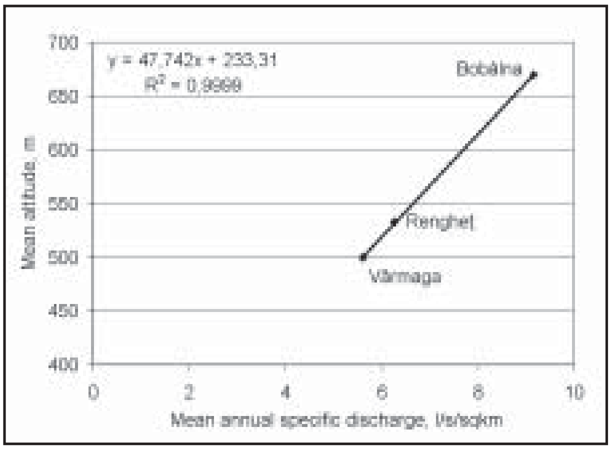

Figure 7.2. The relationship between the specific discharge and the average elevation for non-karst catchment areas.

The reversal which occurred in the hydrogeological behavior of the faults of the NW-SE striking system between the Pleistocene, when they acted as ground surface directed pathways for the up flow of thermal, bicarbonate, CO_2 rich water from which travertines precipitated, and the present-day, when they act as large scale planes that convey surface water and shallow groundwater, is a result of the change that intervened in the regional state of stress within the entire area of Apuseni Mountains, and implicitly within the Rapolt crystalline occurrence, the indicated area being involved in a process of litospheric extension, together with the Pannonian basin located to the west, and the Transylvanian basin located to the east. In Rapolt area, this change resulted in eliminating the tensions accumulated in the NW-SE striking faults system, in decompressing the rock blocks bounded by this faults, in opening the old faults and cracks systems. In terms of groundwater hydrogeology, these changes have generated pathways allowing an easy access of the surface water toward large depths, with direct consequences on the dislocation of the surface flow network.

Moreover, the extremely small specific discharge values recorded in the case of the surface streams that run on the crystalline schists terrains located southward of the crystalline limestones outcrop area, i.e. on the southern flank of the Rapolt anticlinorium, could be ascribed to the same mechanism of augmentation of the infiltration rate ensuing to the opening of old cracks and faults systems, or ensuing to the generation of new such systems, as a consequence of changes underwent by the state of regional stress.

7.5. The quality of drinking waters

The water of the surface streams Şesuri, Iosif and Poieni, that originate within sedimentary terrains (mainly of Late Cretaceous age) which are located to the north of the crystalline limestones is weakly mineralized (517.7-529.7 mg/l), of calcium bicarbonate type, highly unsaturated with respect to calcite and dolomite.

The high aggressiveness with respect to these minerals provides an explanation for the intense karst processes to which the crystalline limestones is subject. In terms of its concentration in toxic elements Pb, As and Mn, the water of Iosif and Poieni streams complies with the national regulations. Yet the copper content of Şesuri stream (103 ppb) exceeds even the maximum concentration which may be only exceptionally accepted (100 ppb).

Table 7.3 provides the results of the chemical analyses conducted on water samples collected from water outlets of the Rapolt crystalline outcrop. Spring water discharging from crystalline limestones is of calcium bicarbonate type (Figure no. 73), with total mineralizations in the range 419.30 mg/l (Fântâna Crăiesii spring, no. 19), to 710.7 mg/l (Văratic spring, no. 18). Water temperatures range between 8 and 13.5°C and pH values indicate a slightly alkaline character. Table 7.3 provides the results of the chemical analyses conducted on water samples collected from water outlets of the Rapolt crystalline occurrence.

In terms of the toxic elements contents, the karst groundwaters displays the following features:

- The concentrations of the elements Mn, Zn, Ni, Pb, As and Cr range below maximum values stipulated by STAS 1342/92 (50 ppb);
- Most samples display copper contents in excess of the maximum accepted concentration (50 ppb), some of them exceeding even the concentration which may be only exceptionally accepted (100 ppb). The high concentrations of copper are the result of the complex sulfide mineralizations occurrence within the crystalline limestones, the investigations conducted by I. BERBELEAC (1962, 1970) fully documenting the abundance of such occurrences. It is worth mentioning that also springs discharging from Late Cretaceous deposits (the spring of Poieni stream, Fântâna Rece, the spring next to David stream, Sipotele spring), display high copper contents, which are derived from the crystalline limestone occurrences as well, that in this specific case take the form of rounded gravel.

The lowest concentrations of toxic elements occur in springs that discharge from travertine and

No	Stream	F	F.lms	Hmean	Qmean	q	q 1	Δq	INPUT			OUTPUT	
		km^2		m	l/s	l/s/km^2			ER (l/s)	DI (l/s)	Total (l/s)	Source	Q (l/s)
1	Boiu (d)	7.81	5.81	548	13.4	1.39	6.7	-5.31	30.85	14.75	45.6	**Cold waters**	
2	Bobâlna (f)	8.81	3.43	600	40.2	4.47	7.9	-3.43	30.22	15.6	45.8	- Clocota spring - Boiu spring - other sources	17.1 7.05 11.5
3	Bobâlna (g)	12.4	4.49	562	84.6	6.61	7.0	-0.39	7.00		7.0	**Thermal waters**	
4	Rapolţel (h)	13.7	7.69	537	30.9	2.21	6.4	-4.19	57.61	4.06	61.7	- Geoagiu Băi spa - inflow in Clocota stream at Geoagiu Băi - Feredeu springs	3.00 35.80 26.00
5	Şesuri (i)	3.78	2.62	555	5.67	1.5	6.8	-5.3	20.01	7.66	27.8	- Rapolţel spring	3.5
6	Others		2.35				4.5		10.57		10.6	- Banpotoc well	4.00
									TOTAL: 198.5			TOTAL: 107.95	
									INPUT - OUTPUT = 90.47 l/s				

F-surface of hydrographic basin (h. b.) upstream of gauging flow section; F.lms.- surface of h. b. covered by crystalline limestones; Q_{mean} - annual mean discharge; q - mean annual specific discharge (q = Q_{mean} / F); q 1 - graphically approximate mean annual specific discharge; Dq = q- q 1; ER - effective rainfall; DI - Diffuse inflow from streams in karst section. Others = Vărmaga, Bârgău and Siliman streams.
In brackets site of hydrometric gauge station in Figure 7.1.

Table 7.2. Surface and underground waters budget in carbonate deposits of Rapolt crystalline outcrop (X.1995-IX.1996).

carbonate tuff deposits (Fântâna lui Lucaci, no. 8, Poduri, no. 10, Şteanga, no. 11 and Ciocan, no. 24). It is worth mentioning that in the tuff and travertine samples which had been analyzed, no Cu, Pb and Zn could be identified within the detection limit (10 ppb) of the equipment that was used.

Water samples collected from the springs Clocota, Boiu, Fântâna Crăiesii, Fântâna lui Lucaci and Ţăcăoara display alpha and beta radioactivity values that are largely below the maximum accepted ones (0.1 Bq/dm^3).

7.6. Thermal water discharges

A series of thermal water discharges are known within the Rapolt crystalline outcrop, both on the crystalline limestone terrains, and on terrains consisting of crystalline schists and travertines. Among them, the area of Geoagiu Băi spa is the best known, additional outlets being those at Feredee site, on Bobâlna valley, and the spring at Rapolţel.

No	Source	T °C	Cl^-	SO^{4--}	HCO^{3-}	Na^+	K^+	Ca^{++}	Mg^{++}	CO_2 free	CO_2 tot.	Dry res.	TDS	Saturation index	
			ppm											calcite	dolomite
Drinking waters															
1	Ţăcăoara spring (2)		21.30	72	366.1	11	1.60	131.90	12.80	30.80	294.80	440.70	666.80		
2	Fântâna lui Lucaci spring (8)		7.10	40.9	280.6	1.6	sld	94.00	11.60	26.40	211.20	311.80	481.60	0.568	0.393
3	Poduri spring (10)		7.10	25	902.9	25.1	1.30	228.50	36.50	369.60	1012.00	785.10	1612.10		
4	Şteanga Banpotoc (11)		7.10	44.2	707.7	18.4	1.00	194.40	26.80	228.80	730.40	655.90	1242.10	0.265	-0.131
5	Văratecul spring (18)		14.20	57.6	439.3	2.5	1.60	162.90	6.40	13.20	330.00	466.00	710.70	0.343	-0.589
6	Fântâna Crăiesii spring (19)		3.50	sld	268.4	1.8	sld	74.90	8.30	52.80	255.20	228.80	419.30	-0.386	-1.693
7	Izvorul Rece spring (20)		14.20	15.4	244	2.53	0.75	70.10	13.40	123.20	299.30	241.40	495.20	-0.218	-1.045
8	Boaica spring (21)		14.20	sld	244	1.8	0.60	64.10	13.40	61.60	228.80	222.90	415.10	-0.016	-0.615
9	Ciocan spring (24)		7.10	18.7	726	6.7	1.20	191.20	32.00	96.80	615.60	623.40	1094.50	1.143	1.514
10	Boiu spring Boiu (28)		7.10	40.6	329.5	3.7	sld	120.00	3.80	44.00	281.60	348.20	559.60	1.625	1.849
11	Clocota spring (30)		5.10	45.3	329.5	11.3	2.50	106.90	8.20	26.40	299.20	368.30	549.60	0.930	0.862
Mineral waters															
12	Dug well Hărău (1a)	11.8	673.70	177	915.2	374.2	380.50	172.00	46.20	149.60	765.60	2348.90	2957.70	0.871	1.337
13	Dug well health center Hărău (1b)	12.5	4609.8	700.8	915.2	2777	sld	326.60	180.0	167.20	818.40	9377.90	10007.5	0.816	1.571
14	Well Chimindia (3)	14.3	14.20	33.5	1769.3	86.9	6.20	407.50	71.40	1188.00	2525.60	1521.30	3594.90	0.287	0.011
15	"La Butură" spring (4)	12.3	21.30	135.4	744.3	44.4	3.50	207.80	39.50	695.20	1232.00	822.80	1900.10	-0.620	-1.790
16	Dug well Chimindia (5)	12.3	67.40	146	1000.6	75.4	12.90	292.00	40.10	457.20	1179.20	1136.50	2105.50		
17	Spring in Ţiganilor brook (6)	11.7	7.10	165.2	1427.6	46	6.30	363.10	87.60	2.20	2112.00	1407.10	4235.10	-0.730	-0.604
18	Well Banpotoc (7)	18.8	7.10	46	1342.2	39.6	2.60	340.40	53.40	1012.00	2006.40	1171.10	2857.20	0.428	0.326
19	Spring in "Lazu lui Truţ" (9)	11.5	14.20	3.8	1220.2	12	2.00	307.50	55.90	589.60	1460.80	1015.20	2220.00	0.032	-0.523
20	Well Rovine (15)	22.0	3.50	24	1195.8	7.3	1.50	310.50	52.50	704.00	1585.00	1010.10	2313.00	0.014	-0.425
21	Madei spring	12.7	35.5	30.7	768.7	44.1	3.3	216.4	17.0	352.0	915.2	742.1	1480.3		
Thermal waters															
22	Rapolţel thermal spring (16)	23.4	10.60	28.3	1121.4	1.6	1.60	293.60	51.70	212.20	1015.11	964.70	1746.70	0.489	0.522
23	Rapolţel thermal spring (16)	23,7	7.10	38.5	1281	18.9	4.50	336.7	52.00	730.40	1654.4	1113.6	2486.0		
24	Upstream Feredeu spring (22)	22.3	14.20	8.2	854.1	5.5	1.60	230.30	33.90	202.40	818.40	722.40	1357.60	0.355	0.199
25	Downstream Feredeu spring (23)	16.8	17.70	26.4	787	5.5	sld	224.40	30.90	167.20	730.40	702.60	1269.40		
26	Well no. 1, Geoagiu Băi	26.3	21.30	54.1	732.1	10.8	0.60	204.70	37.00	290.40	836.00	704.80	1363.90	0.716	1.061
27	Well no. 3, Geoagiu Băi	29.4	10.60	18.2	751.6	6	1.20	191.00	38.70	105.60	644.20	642.60	1134.50	0.626	0.963
28	Nătău warm spring (33)	21.0	7.10	39	780.9	15.4	3.80	194.00	41.00	343.20	950.40	706.50	1443.70	0.438	0.438
29	Well no. 6, Geoagiu Băi	28.0	7.10	43.5	793.1	16.6	2.70	202.00	39.50	264.00	880.00	726.20	1389.20	0.779	1.240

Table 7.3. Chemical analyses of groundwaters in the Rapolt crystalline occurrence.

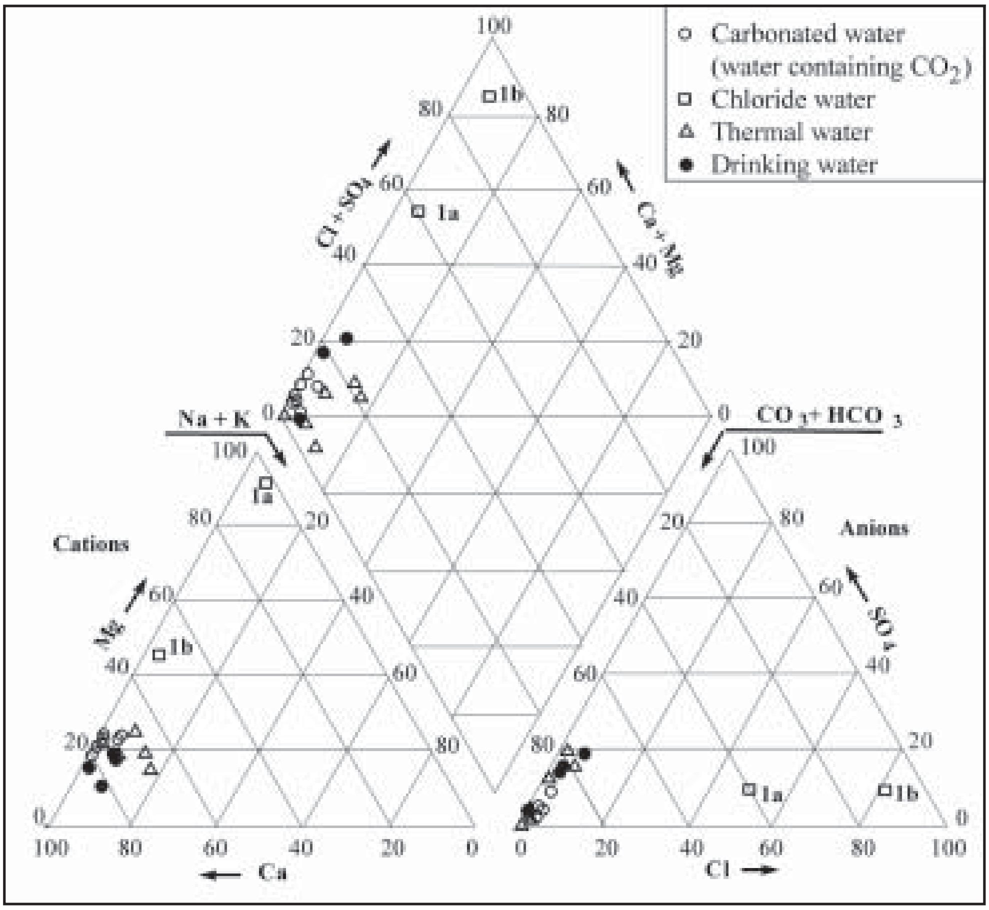

Figure 7.3. Piper diagram showing composition of mineral, thermal and drinking waters in Rapolt crystalline occurrence.

7.6.1. The Geoagiu spa area

Thermal discharges at Geoagiu Băi spa are documented since Roman times ("Thermae Dodonae"). The multitude of vestiges dating from that epoch and which have been discovered within the present-day spa illustrate the notoriety these thermal baths had in the bounds of the Roman Empire (PRICAJAN, 1972).

In geological terms, the main characteristic of Geoagiu Băi spa area is the presence of a basement consisting of Late Proterozoic - Paleozoic crystalline limestones, transgressively overlain by a sedimentary cover of Late Cretaceous and Quaternary age.

Crystalline limestones crops out along Clocota stream, where it occurs either as thick layers or as compact bodies, being hard, light-gray colored, with a fine, crypto-crystalline structure. The rock is strongly cracked and it is subject to moderate karst processes action, the main thermal aquifer in the spa being located within the corresponding cracks and karst cavities.

The Late Cretaceous sedimentary cover includes at its bottom a sandstone complex that consists of a gray and yellowish, micaferous, carbonate sandstones which exhibits centimeters-thick bedding, with sparse insertions of gray-yellowish and reddish sandy marls. At their contact with the crystalline limestones, there occurs a 2-2.5 m thick layer of breccia-type conglomerates, that may laterally turn into siliceous micro-conglomerates.

The sandstone complex that occurs at the bottom is overlain by a prevalently marly complex, which includes bedded gray, brown and yellowish marls, with centimeters-thick insertions of gray carbonate sandstones.

Considered as a whole, the Late Cretaceous deposits act as an impervious cover to the confined thermal water accumulations located in the crystalline limestones reservoir. A series of faults that displaced both the crystalline limestone and the Late Cretaceous formations provide direct hydraulic connections between these accumulations and the cold water occurring within the Quaternary travertine and carbonate tuffs reservoir.

The travertine and carbonate tuffs are generally porous, although on certain circumstances they occur as compact rocks, they are yellowish-reddish colored and have been precipitated from the thermal water. They occur as a large extent single plate, whose thickness may reach up to 120 m and which builds an actual karst plateau that extends eastward of Geoagiu Băi spa area, down to Geoagiu stream. In the central-eastern part of the plateau, travertine, which in this section is about 85 m thick, is subject to quarry exploitation.

Runoff originating on the hill slope that borders the karst plateau to the west and rainfall water has soluted the travertine plate to generate a wide range of karst landforms, such as sinkholes, swallets, potholes and karst lakes. Tăuţ lake (Figure 1, no. 32), located in the middle of a forest that includes both broad-leaves and conifer trees, occurs in a sinkhole developed within the travertine. It has about 30 m in diameter, its depth is 1.5-2 m and it never dries out, being probably supplied by underwater springs.

Nătău lake (no. 32) is supplied by the thermal spring that bears the same name, its diameter is about 40 m and it discharges by means of a brook which joins Geoagiu stream some 100 m downstream from the place where the Geoagiu-Zlatna road branches toward Geoagiu Băi spa.

A multitude of geological and hydrogeological investigations conducted by I. BERBELEAC (1962, 1964, 1969), N. GEAMĂNU et al. (1969), S. OLAH (1979), M. GAVRIŞ (1979) and D. SWOBODA et al. (1984) have addressed the Geoagiu Băi spa area.

Geoagiu Băi spa has been originally supplied with thermal water provided exclusively by natural outlets that disappeared by the present time. During the time interval 1960-1975, ISPIF has drilled in the area of the spa the wells F1, F2, F3, F4, F5, F5a and F5b, then, between 1976-1977, the company IFLGS has drilled the well F6, and finally, over the period 1983-1984 IMFBRM has drilled the wells F7, F8, F9 and F10.

During the hydrological year X. 1995-IX. 1996, the cumulated flow rate of the thermal water discharges in Geoagiu spa has been 38.8 l/s, the water temperature ranging between 26 and 32°C.

Thermal water of Geoagiu spa has a calcium – slightly magnesium bicarbonate character, with mineralizations in the range 1-1.5 g/l (Table 7.3 and Figure 7.4).

Nătău spring is located southward of the Nătău lake and farm, at the forest border. The spring is tapped in a circular pool with a diameter of about 2.5 m, its temperature is 21°C, its flow rate amounts to about 0.2 l/s and free gas is released from its water. The released gas includes 50.5 % nitrogen, 35.04 % CO_2 and 13.77 % oxygen (Table 7.4).

Environmental isotopes investigations conducted by F. DAVIDESCU et al., 1991 and by A. ŢENU and F. DAVIDESCU, 1998, resulted in formulating the following conclusions about the Geoagiu thermal water genesis:

- the thermal water is supplied by cold season rainfall, subject to climate and elevation conditions that are characteristic to the high karst plateau which occurs westward of the spa;

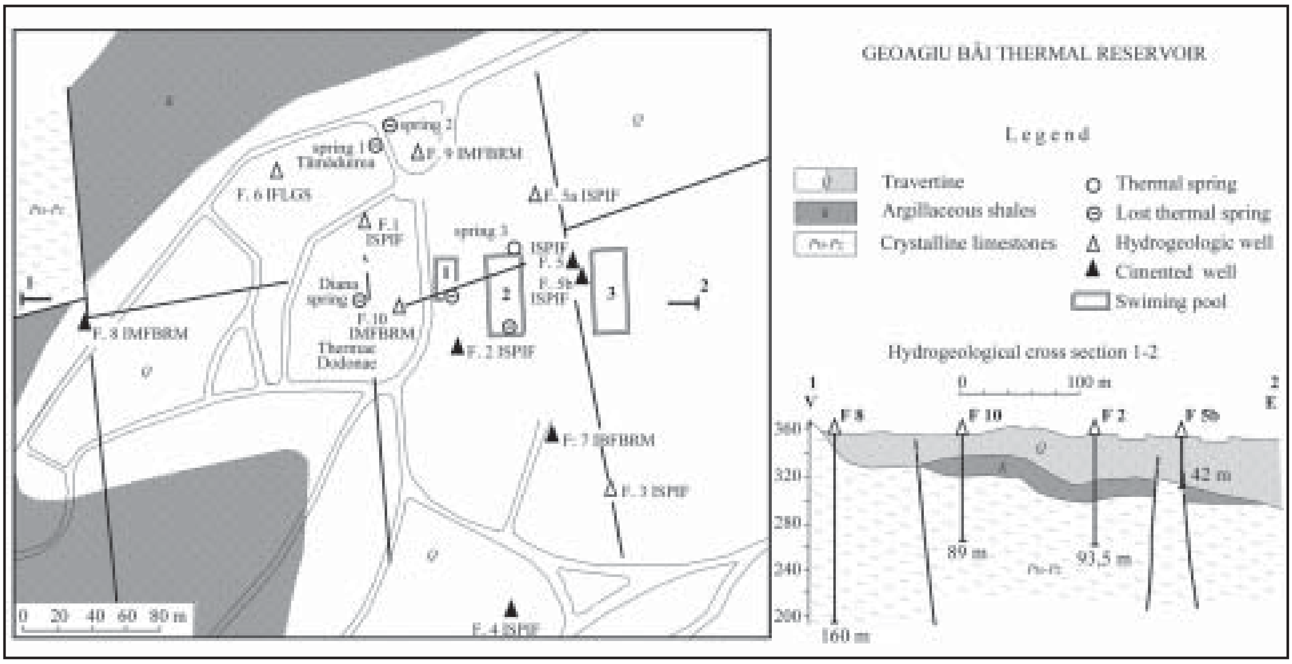

Figure 7.4. Geoagiu Băi thermal reservoir (Hydrogeological data after D. Swoboda, 1984).

- the thermal component, of 15,000 (13,000) years apparent age, up flows along Geoagiu fault in the area of the spa, where it mixes with a down flow of cold, local water, that has the same meteoric origin, yet only 5-25 years apparent age.

7.6.2. "La Feredee" springs

"La Feredee" springs occur within the median course of Bobâlna stream, in the middle of a wide alluvial plain built of travertine and tuff deposited by the thermal waters.

Feredeu upstream spring (Figure 7.1, no. 22) is tapped in a rectangular pool made of concrete, in its close proximity occurring another thermal spring of temporary character, also tapped in a rectangular, yet smaller pool. In spring time the springs flow rate is high, amounting to 25-30 l/s cumulated discharge. During draught periods, in late autumn, the spring in the small pool dries out, while the flow rate of the spring in the large pool declines down to 0.2-0.5 l/s.

The temperature of the permanent Feredeu upstream spring is 21-22.3°C and free gas is released both from that outlet, and - during discharge periods - from the temporary nearby spring. A fact worth to be mentioned is that some 40 years ago both springs were permanent and discharged abundantly, yet subsequently to the drilling of a hydrogeological investigation well in their close proximity, their flow rates drastically declined.

Feredeu downstream spring (no. 23), situated some 250 m downstream from the previous spring, is also tapped in a rectangular concrete pool. The spring is violently releasing free gas and during the observation period its temperature has varied between 16.8 and 20.2°C. Over the same period, the spring discharge has varied in the range 4-50 l/s. The average cumulated discharge of the Feredeu upstream and downstream springs, recorded during the hydrological year X.1995-IX.1996, was 26 l/s.

Some 10 m south-westward of Feredeu downstream spring, in a circular pool of about 2.5 m in diameter, there occurs another thermal spring which releases free gas and whose temperature is 19°C.

The water of the thermal springs in the area "La Feredee" has a calcium - slightly magnesium

No.	Source	Sample type	CH_4	C_2H_6	C_3H_8	iC_4H_{10}	nC_4H_{10}	CO_2	O_2	N_2	Ar
			ppm					%			
Drinking waters											
1	Fântâna Lucaci	d.g.	225	1.2	1.2	2.8	1.6	17.55	17.28	64.18	0.76
2	Poduri spring	d.g.	228	0.4	0.3	0.6	0.3	17.57	17.29	64.20	0.76
3	Fântâna Crăiesii	d.g.	199	1.6	1.2	1.6	1.1	12.31	18.38	68.36	0.81
4	Boiu spring	d.g.	187	14	12	0	0	9.30	19.01	70.61	0.84
5	Clocota spring	d.g.	148	1.2	1.2	2.8	1.1	17.32	17.33	64.36	0.77
Mineral waters											
6	Chimindia well	d.g.	7.4	0	0	0	0	89.5	2.18	8.11	0.09
7	Chimindia well	f.g.	2305	0	0	0	0	85.28	1.10	13.19	0.05
8	Banpotoc well	d.g.	873	0.3	0.4	0.6	0.3	58.12	8.75	32.48	0.38
Thermal waters											
9	Rapolţel thermal spring	d.g.	82	0.3	0.4	0.8	0.5	66.63	6.97	25.90	0.31
10	Feredeu upstream spring	f.g.	9.9	0	0	0	0	14.45	4.20	80.81	0.19
11	Feredeu downstream spring	d.g.	322	0.8	0.9	1.2	0.8	38.33	12.92	47.96	0.57
12	Feredeu downstream spring	f.g.	9.9	0	0	0	0	17.38	1.40	80.89	0.06
13	Well 1 Geoagiu Băi	d.g.	78	0.4	0.3	0.8	0.5	56.58	9.06	33.66	0.40
14	Well 3 Geoagiu Băi	d.g.	19	0	0	0	0	38.96	12.77	47.45	0.56
15	Nătău spring	d.g.	193	0.8	0.6	0.4	0.3	35.04	13.59	50.50	0.60
16	Nătău spring	f.g.	17	0	0	0	0	18.52	1.30	79.98	0.06
17	Well 6 Geoagiu Băi	d.g.	21200	0.6	0.6	1.6	1.1	52.62	9.47	35.18	0.42

Table 7.4. Composition of dissolved and free gas in water sources.
Note: d.g. - dissolved gas; f.g. - free gas. CO, H_2 1 and He are leacking

bicarbonate character, with mineralizations in the range 1200-1400 mg/l. The gas released by the springs is of nitrogen type (Table 7.4).

7.6.3. Rapolțel spring

The thermal spring at Rapolţel (no. 16) is located in the middle of the village which bears the same name, being tapped in a concrete pool from which the water discharges along a series of drains and pools that local people use for washing their clothes and for bathing.

The flow rate of the thermal outlet at Rapolţel is 3-3.5 l/s, while the water temperature fluctuates between 23 and 23.7°C. The water is of calcium bicarbonate type, the mineralizations of the two samples that we collected in the year 1996 being 1745.7 and 2486.0 mg/l respectively. The large difference recorded between the two samples is a result of the different amounts of free CO_2 in each sample, namely 212.2 and 730.4 mg/l respectively.

7.7. The mineral water occurrences

In the south-western part of the Rapolt crystalline occurrence, mainly within the crystalline schists terrains, there occur a series of natural discharges of mineral waters. Additionally, three wells drilled in this area have identified mineral water occurrences in the underground.

7.7.1. Hărău area

In Hărău village, southward of Şerman hill, along the Simeria Veche-Hărău NW-SE striking fault, whose south-western downthrown compartment is outlined as a sinking of Mureş trough, there are two sodium chloride water occurrences (Figure 1, no. 1a and 1b).

In the building of the present day clinic in Hărău there has been operating, until some 50 years ago, a public bath, a dugg well having been performed to this purpose inside the building. The water level is 2.5 m below the ground surface, the water temperature is 12.5°C, the pH value is 7.45, while the electrical conductivity is 15.84 mS. Water has a sodium-chloride character (Fig. 7.3) and a mineralization of 10 g/l.

Some 100 m westward of the clinic in Hărău, in the yard of the household of Biro Alexandru (house no. 65), there has been drilled a dugg well which at 8 m depth intercepted sodium-chloride water, whose temperature fluctuated between 10.2-11.8°C, while its pH value was 7.57. The mineralization of this water heavily fluctuates over the time span of a year, as a result of the variable mixing rates with water derived from the phreatic aquifer.

The two sodium-chloride water occurrences are located on the pathway of the previously indicated fault, which is well outlined in the local topography as a crystalline schists outcrop that forms a 1-5 m high escarpment extending over a horizontal distance of about 150 m. The water chemical character has been inferred to be the result of the leaching of deeply seated salt bodies that groundwater intercepts while flowing along the previously mentioned fault (I. Berbeleac, 1968).

7.7.2. Chimindia area

In 1997 period in Chimindia area there were 4 known mineral water occurrences:

- the mineral water spring in Ţiganilor valley (Figure 1, no. 6), situated on the right side of the stream, some 350 m upstream from the last house on the valley. The spring is tapped in a 1 m diameter concrete tube, covered with a concrete plate. At the middle of the tube there is drilled a roughly 4 cm diameter hole, by which mineral water discharges. The water temperature is 14°C and its flow rate is 0.05 l/s. In the past, the outlet has been situated on the left side of the valley, in a place where the old water intake facilities are still preserved. About 30-35 years ago, subsequently to the drilling of a hydrogeological research well located immediately upstream of the old water intake, the spring has disappeared, to emerge a few days later on the right side of the stream, in the place where it continues to exist nowadays;
- "La Butură" spring (no. 4), located some 100 m westward of the last house in the western part of the village, beneath the terrace on which the road to Hărău is built. The outlet discharges 0.3 l/s, its temperature being 15°C;
- the mineral water well in the yard of the last house of the village on the right side of the sealed road to Hărău (no. 5). The water level

is situated 11 m below ground, and the water temperature is 12.3°C;

- Chimindia old well (no. 3), located at the bottom of the southern slope of Siliman hill, in close proximity of a mineral water spring which by the present time has disappeared. The artesian discharge of the well amounts to 0.1 l/s of CO_2 rich water, whose temperature is 14.3°C, the water level for the indicated discharge conditions being situated 0.5 m above the ground surface.

The mineral water of the indicated occurrences is CO_2 rich, of calcium bicarbonate type, the largest content of free CO_2 being recorded in the mineral spring in Ţiganilor valley (2112.0 mg/l), while the lowest content is that of the domestic well in the western part of the village (457.2 mg/l).

The water discharged by the spring in Ţiganilor valley have large concentrations of Cu, As and Mn wich originates in the leaching of the cristalline limestone basement, well known for its occurence of complex sulphides mineralisation.

The gas released from the water of Chimindia old well contains mainly CO_2, accompanied by a significant amount of methane.

7.7.3. Banpotoc area

In Banpotoc area there are two mineral water discharges:

- the spring in Lazul lui Truţ (no. 9), located on the left side of Roşiile stream. The spring emerges from slope deposits, at their contact with the travertine deposits which extend further south, down to Cărpiniş village. The spring flow rate is 0.01 l/s, its temperature is 12.8°C and the discharged water is of calcium bicarbonate type, with a total mineralization of 2220 mg/l and a small content of free CO_2 (589.6 mg/l);
- the well at Banpotoc (no. 7), situated on the left side of Vărmaga stream, at the upstream end of the village, has an artesian discharge of 4.5 l/s (the water level for the indicated discharge conditions being situated about 1 m above the ground surface), and its temperature is 18.8°C. The discharged water is of calcum bicarbonate type, with a CO_2 content of 1012.0.

7.7.4. Rapolțel area

Upstream of Rapolţel village, on the left side of the stream that bears the same name, in the spot that local people call Rovine (no. 13), there is located a well discharging in artesian regime 0.01 l/s of calcium bicarbonate water of 22°C temperature, the water level for the indicated discharge conditions being situated about 0.6 m above the ground surface. The discharged water is CO_2 rich, the CO2 content being 704.0 mg/l (Table 7. 4).

Significant contents of free CO_2 have been also recorded in the karst springs Poduri (no. 10, 369.6 mg/l), Şteanga (no. 11, 228.8 mg/l), Izvorul Rece (no. 20, 123.2 mg/l) and Tantoş (no. 34, 105.6 mg/l).

References

Baciu Aurelia, Baciu P.,1988 – Valea Grădiştei. Ed. sport-turism, Bucureşti, 129 p.

Berbeleac I., 1964 – Cercetări geologice şi petrografice in cristalinul insulei Rapolt (Boiu-Rapolt-Rapolţel): D.S. Inst.Geologic, Bucureşti, v. XLIX (1961-1962), 1, p. 3-14.

Berbeleac I., 1968 – Consideraţii geologice-structurale privind izvoarele termale şi carbogazoase minerale din insula cristalină de Rapolt. Bul. Soc. St. Geol. din RSR X, 99-108, Bucureşti.

Berbeleac I., 1969 – Aspecte tectonice, magmatice şi metalogenetice in partea centrală şi sudică a Munţilor Metaliferi. St.şi cercet. de geol., geofiz., geograf., Seria geologie, v. 2.

Berbeleac I., 1970 a – Aspecte petrografice şsi metalogenetice ale insulei cristaline Rapolt. D.S. Inst. Geologic, Bucureşti, v. LIV (1966-1967),4, p. 5-22.

Berbeleac I., 1970 b – Consideraţii tectonice, magmatice şi metalogenetice în partea centrală şi sudică a Munţilor Metaliferi: St. cerc. geol., geofiz., geogr., Seria geologie, v. 15, 2, p. 329-339.

Bordea Josefina, Berbeleac I., Borcoş M., Mantea G., Stancu Josefina, Rogge-Ţăranu Elena, 1978 – Harta geologică a RSR, scara 1:50.000, foaia Geoagiu. IGG, Bucureşti.

Davidescu F. D., Ţenu A., Slăvescu Ana, 1991 – Environmental isotopes in karst hydrology. A layout of problems with exemplifications in Romania: Theoretical and Applied Karstology, v. 4, p. 77-86, Bucharest.

Lupu M., Krautner H. G., Ţicleanu N., Boştinescu S., Bandrabur T., Krautner Florentina, Horvath A. R., Nicolae I., 1982 - Harta geologică a României, scara1:50.000, foaia Deva. Inst. de Geologie şi geofizică, Bucureşti.

Pricăjan A., 1972 – Apele minerale şi termale din Romania. Ed. Tehnică, 296 p. Bucureşti.

Slăvoacă D., Feru M., Geamănu Veronica, Simion G., Goliţă Natalia, Lungu P., 1978 - Consideraţii hidrogeologice asupra ivirilor naturale de ape termale din România. Studii tehnice şi economice, seria E - Studii de hidrogeologie, ed. IGG, Bucureşti, v. 13, p. 5-15.

Swoboda D., Lupescu G., Swoboda Mariana, Niculescu M., Ignat Sanda, 1984 – Studiul hidrogeologic, hidrochimic, bioclimatic şi balneotehnic privind optimizarea exploatării zăcământului termomineral Geoagiu, jud. Hunedoara. Arh. IMFBRM.

Ţenu A., Davidescu F., 1998 – Environmental isotopic studies on mineral and thermal waters in Romania: a reviev over the last 25 years. Proceedings of the Int. Symp. Mineral and thermal groundwater, Miercurea Ciuc, Romania, 24-27 June, 1998, 271-280.