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CONSIDERATIONS ON THE HYDROGEOLOGY OF VAȘCĂU PLATEAU (CODRU MOMA MOUNTAINS)

BY

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Morphological and hydrogeological investigations, results of tracing experiments, hydrologic data and chemical analysis of the karst cold or thermal waters and of the gas outflowing from certain springs are used in drawing a unitary hydrogeological image of the Vașcău karstic plateau.

1. INTRODUCTION

In the southern part of Codru Moma Mountains, the carbonatic deposits occur in the form of a unitary plate, extending over some 90 km^2 at an average elevation of 600 m. This plate is geomorphologically designated as the Vașcău Plateau. Hard, noncarbonatic rocks with outstanding relief border the northern, southern and western edges of this plate, thus delineating a carbonatic-rocked amphitheatre facing Beiuș depression, where the deposits descend stepwize until they are burried under the neozoic deposits of the Crișul Negru river basin.

The orography of the plateau is dominated by some elevated hills, stretching from its north-western to south-central part (Caprelor, Ronțarul, Cristești, Chicera Ursului, Iezerul), to outline an uplifted area that sinks westward in large karstic depression (Arînda, Ponore-Pocioveliște, Bănișoara, Ponoraș, Recea) and slopes gently in the east in an extended sinkhole and dry creek plain, crossed by the Tarina-Cîmpeneasca karstic capture depression. In the proximity of Beiuș depression, over abouth a 500 meters distance, the relief again falls abruptly some 200 m, according to a fracture system striking NW-SE, covered by neozoic deposits.

Frequent karstic capture phenomena are responsible for hidrographic network diversion and hence most of the waters collected on the higher slopes bordering the plateau immediately sink through the swallets spread along the entrance in the karstic area. An exception to this is the Tarina creek which collects part of the waters from the south-eastern part of the plateau, and succeeds in carrying them 5 km over a valley carved in limestones, down to Cîmpeneasca swallet cave.

The present geologic-structural image of Vașcău plateau came off from the conjoined work of many authors, out of which special mention deserve Kutassy (1928, 1937). Pancă (1941), Bleahu (1970 [1], 1971 [1],

[1] Geological report, I.G.G. București.

1972[2], Panin and Tomescu (1974). Diaconu, Mihăilescu and Kusko (1972[2], 1973[2], 1976) and Georgescu (1978[2]). All this informations is presented on the Geologic Map of the Socialist Republic of Romania, Vaşcău sheet, edited by Bleahu et al. (1979), where the carbonatic deposits of the plateau are shown to pertain to three tectonic units : Moma overthrust, Vaşcău overthrust and Coleşti overthrust, the first being the autochthonous to the last two.

The hydrogeological frame of the plateau has been the object of the research carried out by Orăşeanu, Oorăşeanu (1978[3]), geomorphological investigations were carried out by Berindei et al. (1977) and Cocean and Rusu (1984), while Bleahu et al. (1976), Groh et al. (1976, 1978) and Halasi (1979) furnished results from the speological explorations conducted in this karstic area.

2. ASPECTS REGARDING THE TECTONIC CONTROL OF THE PLATEAU MORPHOLOGY

The lithologically, tectonically and hydrogeologically dependent karstification processes are largely active in the limestone and dolomite plate of Vaşcău plateau, where they generate many endo- and exokarstic forms. Of these, let us mention the sinkhole plains spreading throughout the surface, the sinkhole valleys (Dosul Smizii, Sohodolul Mare), the lapies (Vîrful Pietrii, Răştet, Sfăraş), the caves (Cîmpeneasca, length 1636 m), the patholes (Ilii, depth 153 m and Răştet, depth 69 m) and the contact depressions.

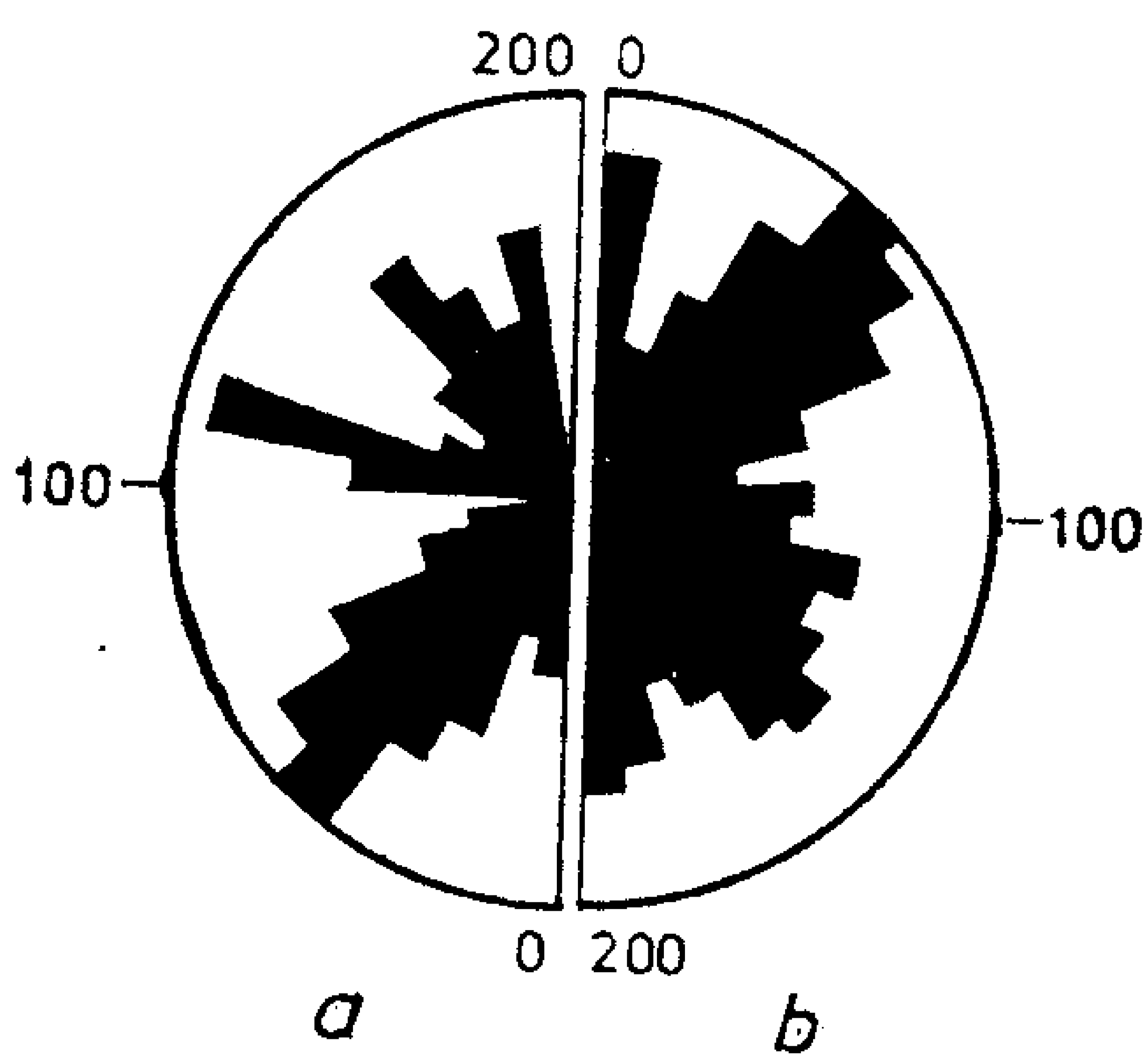

Fig. 1. Azimuthal distribution of cumulated lengths : a — fractural features (faults and overthrusts). b — exokarstic features (unsymetric sinkholes, sinkhole valleys, dry and active valleys, karstic capture depressions).

In order to outline the preferential strikes, if any, of the exokarstic features (asymmetric sinkholes, sinkhole valley, dry and active valleys, karstic capture depressions), with apparently random paths, the length of the main forms was measured on 10° azimuth intervals using

[2] Geological report, I.P.G.G. Bucureşti.

[3] Orăşeanu I. Orăşeanu Nicolle (1978) — Raport asupra studiilor hidrogeologice pentru stabilirea potenţialului de ape potabile şi termale din carstul munţilor Moma — I.P.G.G. Bucureşti.

topographic maps on the 1 : 5.000 scale for the whole karstic plateau surface. The same procedure was employed for the fractural features (faults and overthrusts) identified on the geological maps of the area. Table 1 shows the cummulated lengths of these elements distributed on strike intervals and the ploated data (fig. 1) indicate two directions of development for both fractures and exokarstic features.

The N52°E direction corresponds to the main stress axis from this area of Codru Moma Mountains and hence to the strike of the tensile cracks, which control the dominant direction of karstification because of their wide openings. The secondary N58°W direction which is normal to the direction in which regional stress develop, corresponds to the general strike of the fracture planes of Vaşcău and Coleşti overthrusts.

Whether there exists a relationship between the strikes of the fractural features, taken as an independent variable x (the cause), and the exokarstic form strikes, taken as a dependent variable y (the consequence), was chequed with the aid of the linear correlation coefficient $r_{y,x}$. The relation between the two variables is expressed by the regression equation.

Table 1

Azimuthal distribution of fractural features and exokarstic features lenght for Vaşcău karstic plateau.

Azimuthal interval	Length (km)	
	Fractural features	Exokarstic features
0— 10	9,2	18.9
10— 20	7.4	8.5
20— 30	13.2	12.3
30— 40	16·1	18.[illegible]
40— 50	22.0	22.5
50— 60	17.6	20.7
60— 70	14.1	17·8
70— 80	8.8	12.1
80— 90	5.2	8.1
90—100	3.0	12.1
100—110	11.8	10.8
110—120	20.2	14.8
120—130	7.3	12.6
130—140	5.3	14.6
140—150	8.9	16.2
150—160	15·9	15.3
160—170	12.3	11.7
170—180	9.7	9·9
180—190	14.5	14.4
190—200	3.5	16.0

The linear correlation coefficient, computed for the all data furnished in Table 1 is 0,57, but its value is insignificant since the variables under consideration are pertinent for two orthogonal groups of elements, i.e. the two preferential directions in which fractural and karstic features develop. Hence the correlation coefficient have been separately computed for the 0—100^c interval, having as a bisecting line the main stress axis of the region and the 100—200^c interval, having as a bisecting line the general strike of the overthrust planes.

For the 0—100^c interval, the correlation coefficient is 0,83. This value shows a strong tectonic control of the exokarstic feature strikes by the fault and the tensile cracks developed along the stress direction. The regression equation between these variables is :

$$y = 0,7\ x + 6,99$$

For the 100—200^c interval, the correlation coefficient has a minimum value and indicates that no clear relation is likely by exist between the overthrust plane strikes, i.e. the shear cracks and those of the exokarstic features. The time image of the situation may be yet altered by the large azimuthal dispersion of the measured values, whis is mostly due to the sinuous trace of the overthrust planes.

3. THE HYDROGEOLOGY OF VAŞCĂU PLATEAU

The geological maps drawn up by Bleahu et al. (1979), Mihăilescu et al. (1972), Diconu et al. (1973), Georgescu et al. (1978) and the author's own surveys were used in computing the hydrogeological map (Fig. 2).

The deposits involved in the constitution of Vaşcău plateau form a monoclinal structure, with a reduced eastward dip, lying on igneous and detritic rocks of permian and lower werfenian age, pertinent to Moma overthrust. These rocks are coevered by a thick carbonatic series which is tectonically pertinetnt to the upper part of Moma overthrust, to Vaşcău and Coleşti overthrusts. The whole structure is stongly faulted on the vertical and thus rock compartments of different lithological structure, are brought into contact.

The permian and lower werfenian deposits exhibit negligible underground water circulation, that is strictly confined to the fractured and altered zones. They are an actual barrier boundary for the underground water storage of carbonatic rocks with they are in contact.

Among the carbonatic series, the description of which is shown in Fig. 2, the black anisian dolomites of the Moma overthrust, with an estimated 1200 m thickness, relieve in hydrogeological importance. The second porosity of these rocks, for which dolomitization processes are responsible, subsequently folloved by a strong tectonic dislocation opened a wide field to karstification, favouring the carying of huge karst depression, that can never form in areas covered with other carbonatic deposits. In terms of morphology, outline the tectonic contact between the Moma and Vaşcău overthrusts.

The carbonatic deposits of Vaşcău plateau form an array whose thicknees increase from the west to the east, until a maximum value, estimated at more than 2500 m, is reached near the city of Vaşcău. They favor fast infiltration of rainfall and active groundwater circu-

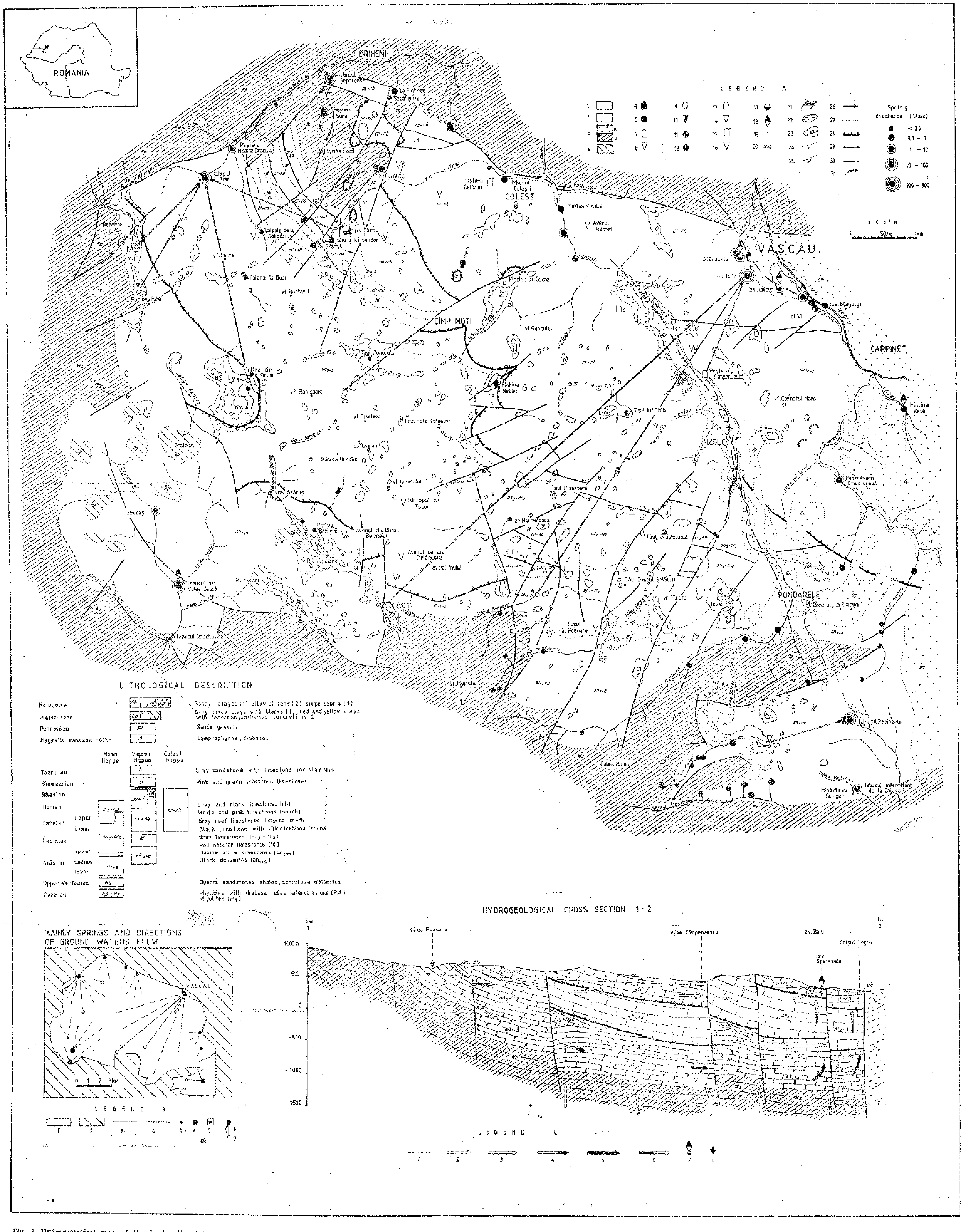

Fig. 2. Hydrogeological map of Vascău karstic plateau. a — Glemee cave; b — Cremenis pathole; c — Hirtopul cu Piatră cave; d — Hirtoape pathole; e — Dimbul Bolandului pathole; f — Coșul Dracului pathole; g — pathole of Virful Pirlitul; h — pathole of Fața Dimburilor; i — pathole of Dosul Lacului; j — pathole of Fața Delniții; k — pathole of Ograda Moții; l — Peșterii swallet; m — Cohuri swallet.

Legend A: 1 — Very thick mesozic carbonatic series, highly karstified, tectonically intensely fractured, displaying strong infiltration and active groundwater circulation; 2 — Mesozoic consolidated detrital deposits and paleozoic phyllites with igneous rocks, displaying reduced groundwater circulation almost confined to the fissured zones. They form on barrier boundary for the water accumulation of the carbonate complexe; 3 — Pannonian-Quaternary detrital deposits of reduced thickness and extension, displaying remarkable groundwater circulation: a — occurring on carbonatic rocks, with which they are in a direct recharge-drainage relation (permeably boundary); b — occurring on impervious rocks; 4 — Clay deposits of reduced thickness and extension, impervious; 5 — Outflow cave; 6 — Perennial spring; 7 — Swallet cave; 8 — Swallet pathole; 9 — Swallet; 10 — Temporary outflow pathole; 11 — Outflow-inflow cavity; 12 — Intermittent spring; 13 — Fossil cave; 14 — Fossil pathole; 15 — Cave acceding at an underground stream; 16 — Pathole acceding at an underground stream; 17 — Subthermal spring; 18 — Gas release; 19 — Exploatation well; 20 — Diffuse losses in riverbed; 21 — Perennial lake; 22 — Temporary lake; 23 — Sinkhole (vertical interval — 20 m); 24 — Perennial river; 25 — Temporary river; 26 — Underground connection established by tracing method; 27 — Geological boundary; 28 — Overthrust boundary; 29 — Thrust fault; 30 — Vertical fault; 31 — Quarry; 32 — Direction of cross-section.

Legend B: 1 — Carbonatic deposits; 2 — Non-carbonatic deposits; 3 — Barrier boundary; 4 — Permeable boundary; 5 — Spring with less than 10 l/sec yield; 6 — Spring with more than 10 l/sec yield; 7 — Catchment; 8 — Directions of ground waters flow; 9 — Tracer release location.

Legend C: 1 — Assumed piezometric level; 2 — Heat flow; 3 — Direction of cold waters flow; 4 — Cold waters undergoing a warming process; 5 — Thermal waters; 6 — Thermal waters partly cooled by mingling cold waters; 7 — Spring with gas release; 8 — Tracer release location.

lation. The recharge of the waterstorage hosted by these deposits is supplied both by the rainfall, reaching an yearly average value of 700 mm. and by the runoff and the perennial flows from the slopes bordering the karstic plateau and which sink at the entrace in the karstic area.

The discharge of he storage hosted by the carbonatic deposits is performed by a few gravitational springs with large drought yields (Fig. 2), which indicate the high degree of development of the underground karstic networks : Boiu spring — 200 l/sec., Tisei spring — 60 l/sec., Valea Seacă spring — 45 l/sec., Răşchirata spring — 25 l/sec., Sopoteasa spring — 25 l sec., the spring of Crisciorel hatchery — 20 l/sec., Pepineaua spring — 25 l/sec.

Likewise this water storage supplies the aquiferous complexes from the neogene Crişul Negru basin, between Cărpinet and Vaşcău, the limit between the two types of aquifers acting as a permeable boundary (positive boundary). Along this section, the Crişul Negru takes in an underground supply of at least 100 l/sec, and the Crisciorel creek, between the hatchery and the village of Cărpinet takes in 30 l/sec.

In addition to the above-mentioned springs, which discharge the karstic water storage directly into the peripheral hydrographic network, within the plateau, in the very karstic area, there exist some other springs of low discharge. After a very short subaerial course, the latter seeps in the carbonate bedrock through diffuse sinks (Fîntînile Bănişorii, Sfăraş spring, Sfăraşul Ligii spring, Hăiuga lui Sandor spring, Tărău spring, Fîntîna din Drum, etc.).

These springs are related to the crashed zones of the faults and from the oevrthrust planes, which act as drains for the water storage in their neighbourhood. Additionally, they are related to the impervious rock interbeddings (shalea) that favour epikarstic aquifer or to the interstitial or crack permeability difference amongst the various types of carbonatic rocks, resulting in relative barriers. These springs occur at the lowest intersections of the draining-fault, impervious bed or the relative barrier with the topographic surface, and may suplly karstic lakes hosted by sinkholes with clay-waterproofed bottom (tăul Fata Vălaielor, tăul din Poiana lui Gupi, tăul Ponorului, etc.).

Not far from the south-eastern limit of Vaşcău plateau is the intermittent spring from the Monastery Călugări. This is a temporary intermittent karstic spring, acting as the overflow of the perennial source in the immediate downstream portion. The intermittence period of the spring is rainfall-dependent and varies usually between 1 and 30 minutes. During draught periods it dries up, and the karstic aquifer network discharges only through the perennial spring downstream, whose average yield is 5 l/sec.

3.1. WATER-TRACING

Vaşcău plateau is reputed at the first place to be water traced in Romania. It was the geologist S. Mihuţia, who in 1904 injected coal powded in the water of Tarina brook, thus proving the connection between the sink in Cîmpeneasca cave and Boiu spring. The through-time of the tracer seems to have been 3—4 hours (Halasi, 1979).

In order to establish the directions in which groundwaters flows and the associated hydrodynamic characteristics, tracing operations were perfomed (July—August 1978) by means of radioactive and dye tracers, in cooperation with E. Gaşpar, the results being now partially published (Gaşpar et al., 1984). In 1984 and 1985 we performed further tracings by means of In-EDTA, Rhodamine B and Stralex (Romanian optical brightener), the data gained from all tracings performed so far being shown in Table 2.

3.2. HYDROGEOLOGICAL KARST SYSTEM

The instantaneous hydrogeological balance, obtained from the discharge of the springs and of the subaerial streams bordering the plateau recorded in cooperation with F. Palfy at the end of a long draught period (October 1978), furnished a specific underground flow of 6.6 l/sec/km^2 at the moment of interest, and the following values for surfaces of the hydrogeological karst systems of the main sources: Boiu — 30 km^2, Tisei spring — 9 km^2, Valea Seacă spring — 6,75 km^2, Pepineaua spring — 3,75 km^2, Sopoteasa spring — 3,75 km^2 and Răşchirata spding — 3,71 km^2. Corroborating these data, together with the results of the tracing operations and the strike of the carck-and-fault systems, we could outline the main underground drainage directions in Vaşcău plateau and so delineate the over-all shape of hydrogeological karsts systems (Fig. 2 B).

3.3. CHEMISTRY OF KARST WATERS

The waters of the karst aquifers are calcium-bicarbonate, with low TDS (Table 3). As the waters travel the undergrund path between the swallets and springs ,they increase in calcium and magnesium bicarbonates, whereas the sodium and potassium content, given by the washing of the confining nonkarstic areas (werfenian quartzites and alkaline igneous permian rocks). diminishes as these elements are diluted with the underground waters given by rainfall on the carbonatic deposits.

3.4. SUBTHERMAL WATERS

West of the Vaşcău town some subthermal, gas out-flowing springs develop on the neotriasic limestonen and alluvial deposits of Crişul Negru river and Boiu brook.

On the left border of Boiu brook, some 90 m upstream the Sfărăşele catchment, a spring with 17°C temperature and a 10 l/s yield issues from the grey limestones at the bottom of the slope. Two other springs with the same temperature, but very low yield and gas release, come out from the alluival deposits of the brook in the upstream portion of the above-mentioned spring. Similar gas release occurs in the riverbed of Boiu in the proximity of the two

Table 2

Results of tracing operations on Vaşcău karstic plateau

No.	Sink H(m) / Q(l/sec)	Resurgence H(m) / Q(l/sec)	Tracer used	L(m) / ΔH(m)	t hours	V m/day	Date
1.	Ponoare valley swallet 579/10	Boiu spring 300/300	Brom—82	5900/279	225	630	28.07.1978
2.	Fîntîna Lotrilor swallet 631/1,5	Boiu spring 300/300	Iod—131	7600/331	216	624	„
3.	Cîmpeneasca cave 406/10	Boiu spring 300/300	Rhodamina B	1700/106	10	4104	30.07.1978
4.	Swallet of Hăiuga lui Sandor 675/2	Tisei spring 450/110	Iod—131	2150/225	150	345	29.07.1978
5.	Swallet of Arînda (Poienile Mari) 720/0,2	Tisei spring 450/85	In—EDTA	3200/270	192	400	15.10.1984
6.	Peşterii swallet (losses of Dăneşti valley under Bîrlogel) 601/5	Tisei spring 450/150	Stralex	1500/151	15	2400	26.05.1985
7.	Cohuri swallet (losses of Pociovelişte valley) 636/4	Tisei spring 450/150	Rhodamina B	2000/186	15	3200	„
8.	Valea Ponorului swallet 499/10	Pepineaua spring 400/30	Rhodamina B	1250/99	20	1500	22.08.1978

H = Elevation ;
Q = Yield ;
L = Horizontal distance between the sink and swallet ;
ΔH = Difference in elevation between the sink and swallet ;
V = Velocity.

Table 3

Chemical composition fo the waters in the Vașcău karstic plateau *

	Cl^-	SO_4^-	HCO_3^-	Na^+	K^+	Ca^+	Mg^+	Fe^{++}	T.D.S.
	mg/l								
Ponoare swallet (under Ilii hill)	7.1	19.2	73.2	23.1	1.3	15.2	0.2	0.1	172.0
Fintîna Lotrilor swallet	14.2	21.1	61.0	24.8	1.4	14.4	0.4	0.1	178.6
Cîmpeneasca cave	10.6	13.4	195.2	4.8	3.5	26.8	25.8	0.6	299.1
Boiu spring	7.1	7.7	305.0	1.7	1.3	60.9	26.7	0.4	436.1
Tisei spring	10.6	5.8	268.4	1.3	1.3	36.1	35.5	0.3	382.8
Rășchirata spring	7.1	17.2	341.6	1.2	0.9	68.9	32.1	0.1	494.4
Valea Seacă spring	7.1	7.6	341.6	6.2	1.1	64.1	29.9	0.1	483.0
Spring of Crisciorel hatehery	7.1	17.3	317.2	25.9	2.1	75.3	10.2	0.2	492.0
Sopoteasa spring	7.1	3.8	292.8	0.4	1.1	66.5	20.9	0.2	401.5
Colești spring	7.1	5.7	329.5	20.7	0.9	95.4	0.3	1.6	505.3
Sfărășele spring (catchment)	10.6	11.5	341.6	7.5	1.6	95.3	12.2	0.4	521.1
Fintînile Bănișorii spring	7.1	2.4	219.6	1.1	0.9	39.3	21.4	0.2	306.1
Intermittent spring from the Covent Călugări	7.1	1.5	231.8	5.0	2.0	29.6	27.2	0.3	335.3
The spring under Dealul Vii	14.1	23.0	329.4	20.0	1.6	89.7	10.7	0.2	506.2
Căptălanul spring (with gas release)	7.1	3.1	372.2	0.1	1.3	57.7	40.8	0.6	502.6
Fîntîna Rece spring (Bîrza)	7.1	20.2	219.6	0.6	0.6	61.7	13.1	0.5	355.2
Sfărășele subthermal spring	7.1	4.1	292.2	35.1	1.1	44.9	14.6	0.3	444.4
Racova spring	7.1	3.8	280.6	4.2	2.2	72.9	12.2	0.3	409.7

* Analyses performed in the laboratories of I.P.G.G., Bucharest.

sources recalled above. The intensty of the gas releaise varies down to the Sfărăşele catchment, on a 350 m length.

Racova spring issues from the alluvium on the left border of Crişul Negru with a 14.5°C temperature, a 3 l/sec. yield and with strong gas outflow.

In addition to above-mentioned subthermal springs, gas outflows display also the following cold spring : the spring from the hatchery on Crisciorel valley, Fîntîna Rece spring, situated south of Cărpinet village on Bîrza valley, the spring under Vii hill near Vaşcău and the spring at the junction of Căptălanul and Seacă valley.

Subthermal waters are similar to the karstic cold waters in the terms of chemical compositon and mineralization, whereas the gases outflowing from the cold or subthermal springs are only slightly different from the atmospheric gas in terms of composition, only a slight increase in nitrogen to the detriment of the oxigen used in oxidaion processes (Table 4).

Table 4

Chemical composition of the gas outflowing from cold and subthermal springs

Source	Compound (%) *				
	CH_4	CO_2	O_2	N_2	Ar
The spring from the hatchery on Crisciorel valley	0.00615	1.540	10.32	87.5	0.459
The spring under Vii hill	0.00317	2.500	14.15	82.6	0.627
The spring at the junction of Căptălanul and Seacă valley	0.00750	3.230	15.58	80.4	0.690
Fîntîna Rece spring	0.00384	0.726	12.60	86.0	0.558
Sfărăşele subthermal spring	0.54900	1.455	12.50	84.7	0.554
Racova spring	0.0100	2.590	14.15	86.4	0.458

* Other compuonds for wiich the gases were analyzed, C_2H_4, C_3H_8, C_4H_{10}, He, H_2, are lacking.

The subthermal waters are karstic waters of deep circulation that rise in temperature because of the relatively high heat flow in this area (80 mW/m^2). The latter is not far from the Pannonian basin, which is recognized for its hyperthermal regime, more than 95 mW/m^2 (Veliciu, Opran, 1983). The waters come up to the surface on the fracture system striking NW-SE, along which Crişul Negru basin falls step-wise to the NE. On thus path they decrease in temperature as they mingle the cold karstic waters moving to the discharge areas (Boiu spring, the springs on the borders of Crişul Negru stream and the phreatic nappe in the alluvia of the stream, (Fig. 2C).

The subthermal waters occurrences Sfărăşele and Racova and the cold springs under the Viilor hill and Fîntîna Rece, with gas outflows, are situated on the same range marking the fracture system along which the neozoic basin sank.

The gas released from the subthermal and cold springs come from the cold-water-dissolved gases, that had left the solution as the temperature rose.

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CONSIDERAŢII ASUPRA HIDROGEOLOGIEI PLATOULUI VAŞCĂU

Rezumat

Platoul carstic Vaşcău este modelat într-o placă unitară de calcare şi dolomite cu o suprafaţă de cca. 90 km².

Prelucrarea statistică a măsurătorilor efectuate asupra orientării şi lungimii elementelor rupturale care afectează depozitele carbonatice (falii şi plane de încălcare) în paralel cu aceleaşi date privind formele exocarstice asimetrice majore

(doline asimetrice, văi de doline, văi seci şi active, depresiuni crastice), indică o puternică condiţionare tectonică a proceselor de carstificare, dezvoltate preferenţial pe direcţia de dezvoltare a fisurilor şi fracturilor de tensiune.

Depozitele carbonatice formează o stivă cu o grosime mare, intens tectonizată şi carstificată, caracterizată printr-o infiltraţie rapidă a precipitaţiilor şi o circulaţie rapidă a apelor subterane. În aceste depozite sînt localizate acumulări acvifere importante, delimitate la nord, sud, şi vest de depozite detritice consolidate mezozoice şi filite şi roci eruptive paleozoice, care formează pentru aceste acumulări bariere negative. La est aceste acumulări sînt limitate de depozitele neogene ale bazinului Beiuşului, cu ale căror complexe acvifere acestea sînt într-o relaţie permanentă de alimentare-drenare, limita dintre cele două tipuri de colectoare constituind o barieră permeabilă.

Acumulările acvifere carstice se descarcă printr-un număr relativ redus de izvoare cu debite ridicate, cele 8 marcări cu trasori efectuate şi bilanţul hidrogeologic întocmit, conducînd la conturarea principalelor sisteme hidrogeologice carstice.

Pe sistemul de fracturi dintre platou şi bazinul neogen al Beiuşului apar cîteva iviri de ape subtermale cu degajări de gaze, necunoscute pînă în prezent, care indică prezenţa în adîncime a unor acumulări hidrotermale.

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