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HERCULE THERMOMINERAL SPRING. HYDROGEOLOGICAL AND HYDROCHEMICAL CONSIDERATIONS

BY

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Hercule thermomineral spring acts as the main outlet of a large aquiferous structure — Cerna syncline — including Jurassic-Cretaceous limestones. Within the limestones body mixing occurs between karstic waters of surface origin and thermomineral ascending waters. This process is responsible for a high instability of the regimes of the yields, temperature and chemistry of the spring.

1. INTRODUCTION

Hercule thermomineral spring is situated at the Northern end of Băile Herculane spa, on the right side of Cerna valley, at 150 m elevation, just 7 m above the streambed. The thermomineral water reaches the surface through an outflow cave, Peștera Hercule, explored on 94 m total length, along which 5 sumps are met, of 1—6 m depths and 2—18 m lengths. The outstanding characteristics of the spring are: (a) strong discharge fluctuations, displaying a variation range of 81 l/s, from 17 to 98 l/s; (b) water temperature and chemistry show an inverse dependence upon the discharge, temperature variation being 34°C, while that of the calculated total dissolved solids (TDS) is 2.22 g/l; (c) spring water passes from the chlorosodic to the chlorocalcic class as the discharge fluctuates with the critical point around 65 l/s.

The great importance of the spring as the main source of thermomineral waters of the spa determined the undertaking of several research programs, whose purpose was the identification of the causes of the fluctuating discharge, temperature and chemistry regimes as well as the development of some stabilization solutions. Worth to be mentioned are the following: Voitești (1918) infers the inflow in the thermal source of some cold waters, originating from the limestone. M. Pascu[1], by means of radioactive tracers, proves the link between two sinking points of surface streams and the thermomineral source and suggests three alternate possibilities to prevent further cold infiltration. N. Golopența et al.[2] start a systematic recording of the discharges and the temperatures at Hercule

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[1, 2, 3] Hydrogeological reports from the archives of "Întreprinderea balneară Băile Herculane" (1971, 1973) and of Întreprinderea de prospecțiuni geologice și geofizice, București (1974, 1977, 1978, 1981).

spring and suggest the excavation of a tunnel bore in order to collect the cold infiltrations. Vasilescu (1973) suggests the drilling of a well in the middle of a geothermal anomaly delineated in the proximity of Hercule cave. POVARĂ et al (1973), POVARĂ and LASCU (1978) and G. Simion[3] widely enlarge the acquired information on Hercule hydrostructure, with the latter also suggesting a new conceptual image on the recharge of the thermomineral structure from Băile Herculane.

2. CERNA SYNCLINE AQUIFEROUS STRUCTURE[4]

Hercule thermomineral spring emerges in the southern third of a large hydrogeologic structure — Cerna syncline — developed on the right side of Cerna river, along about 25 km. It includes sedimentary deposits beloging to the Danubian domain occuring in a synclinal disposition, with a NNW-SSE strike (Fig. 1). According to NĂSTĂSEANU (1980) the petrographic facies of the syncline are mainly carbonatic (the Dogger-Tithonic-Barremian limestone series) and flyshoide (Iuta layers and the Wildflysh). Since flysh deposits prevent any underground organized water circulation, the carbonatic facies are the only ones to host the aquiferous complex body.

At its Northern end the syncline plunges under Godeanu crystalline, while to the South, in Herculane spa area, it has a direct contact to Cerna graben. To the Eastand to the West the syncline is bordered by impervious deposits. As a consequence this hydrogeological structure is open to an underground circulation southward only, toward the syncline axis plunge. The syncline has the appearence of an asymetric trench, with its flanks overturned eastward, of a great development along the axial direction and broken by faults normal to it, with vertical as well as horizontal displacements.

The microtectonical determinations made evidence of three systems of fissures, of which the tension (W—E) and the shear (NNE—SSW) ones may be accounted for an underground water circulation.

In the southern third of the syncline only the limestones of the eastern flank, strongly overturned to the graben, outcrop. They have a continuous development in surface along about 9 km, their total surface being 0.64 km^2. Within their body some caves, with continuous steam outflow, at temperatures varying between 26.0—54.5°C are known, POVARĂ et al., 1972) namely : *Grota cu Aburi* located 400 m away and at 375 m elevation, with a steam outflow whose temperature displays seasonal and annual variations in the range of 49.5—55.5°C ; *Avenul lui Adam*, located 215 m away, at 275 m elevation, with a steam outflow of 17.5°C temperature amplitude 29.0—46.7°C) ; *Peștera de la Despicătură*, located 85 m South of Peștera Hercule, at 155 m elevation, inside which the air has temperature variations in the range 26.0—29.0°C.

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[4] Such as delineated by G. SIMION in "Raport asupra studiilor hidrogeologice efectuate în carstul văii Cerna..." (1978), Archives of the Intreprinderea geologică de prospecțiuni geologice și geofizice, București.

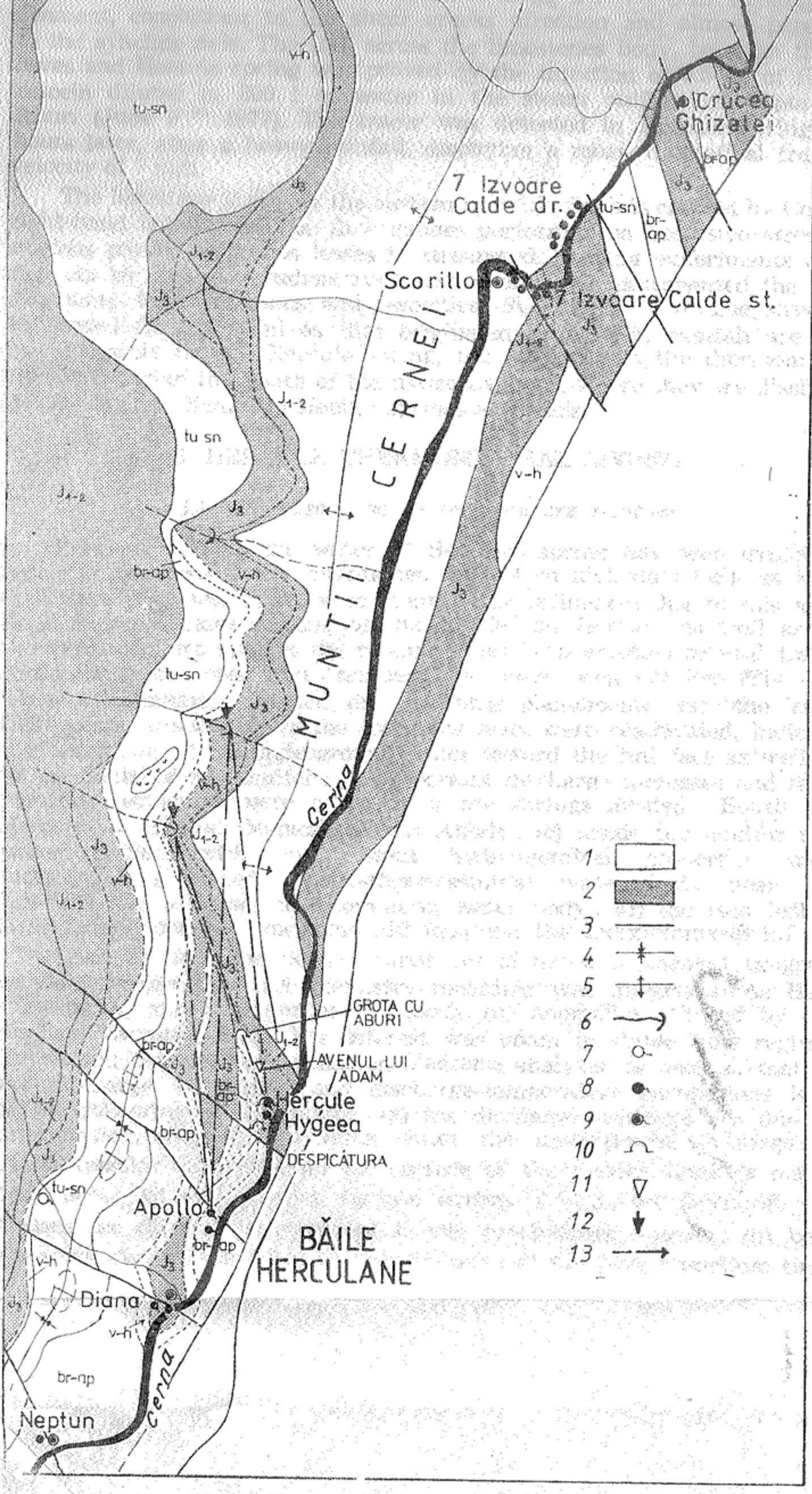

Fig. 1. Hidrogeological map of the middle Cerna river basin. Key: 1 — impervious deposits, 2 — karstifiable rocks, 3 — fault, 4 — syncline, 5 — anticline, 6 — swallet, 7 — karstic spring, 8 — thermomineral spring, 9 — drill hole, 10 — cave, 11 — pothole, 12 — tracer injection point, 13 — underground karstic drainage direction. (The geology after Năstăseanu, 1980)

The above mentioned caves are met along a NNW-SSE striking lineament, concordant to the shear cracks direction and almost parallel to the syncline axis. The link across the limestones body, between these caves and Hercule spring was proved by the injection of 0.5 kg of fluorescein diluted in 800 l of water in the steam outflow of Grota cu Aburi (June 9^{-th} 1977). The tracer was detected in Hercule spring 85 hours later, after a heavy rainfall, displaying a mean theoretical transit velocity of 7 m/h.

The limestone stripe on the eastern syncline flank is crossed by Cerna right-hand tributaries. The flow gauges performed on succesive stream-sections proved continuos losses in streambed. Tracing experiments carried out by means of radioactive isotopes and dyes documented the underground flow directions and velocities (POVARĂ, 1980). The streams infiltrated flow as well as that originated directly in rainfall are directed mainly toward Hercule spring, but also toward the thermomineral sources from the South of the hydrostructure, where they are discharged by Apollo, Diana and Neptun springs and wells.

3. HERCULE THERMOMINERAL SPRING

3.1. *The discharge — temperature relation*

Previous to 1973 the water of Herculee spring has been exploited under an increased head, maintained by a 4 m high dam built at Hercule Cave entrance. In order to identify the influences due to this artificial supplementary loading of the aquifer on Hercule as well as on the even southern springs the retention has been emptied several times, while the water yield and temperature have been checked (Fig. 2). These expriments revealed the following phenomena : (a) the karst field joints situated above the free flow level were reactivated, indicing the dispersion of the underground water toward the hill face as well as to the South of the aquifer ; (b) important discharge increases and temperature reductions were noticed at the springs located South of Hercule — Higeea, Despicătura and Apollo ; (c) inside the aquifer two water bodies, with contranstant hydrochemical properties were formed — a mixed karstic-thermomineral water body near the hill face and a deeper thermomineral water body ; (d) the cold inflow is originated from between the hill face and the thermomineral inflow.

After the dam had been brought out of use a permanent program of yield temperature and chemistry recording was undertaken at Hercule spring, mainly, in order to specify the anomalies induced by the dischage increase, while less interest was given to stable flow regime. Yields and temperatures variation diagrams analysis, as well as that of the discharge — rainfall and discharge-temperature correlations lead to the following considerations: (a) the discharge increases are due to precipitation (Fig. 3), the latter enter the underground drainage of Cerna syncline directly from the surface of the eastern flank (a maximum 30%), as well as from surface streams (70%) ; the discharge increases are directly proportional to the precipitation values ; (b) between the start of a rainfall and the increase of the flow a medium time interval of ten hours was noticed. Water infiltrated in the valley streambed nearest to Hercule spring reached the hill face in 72 hours ; (c) during 1973—1982 interval the maximum yield variation amplitude was

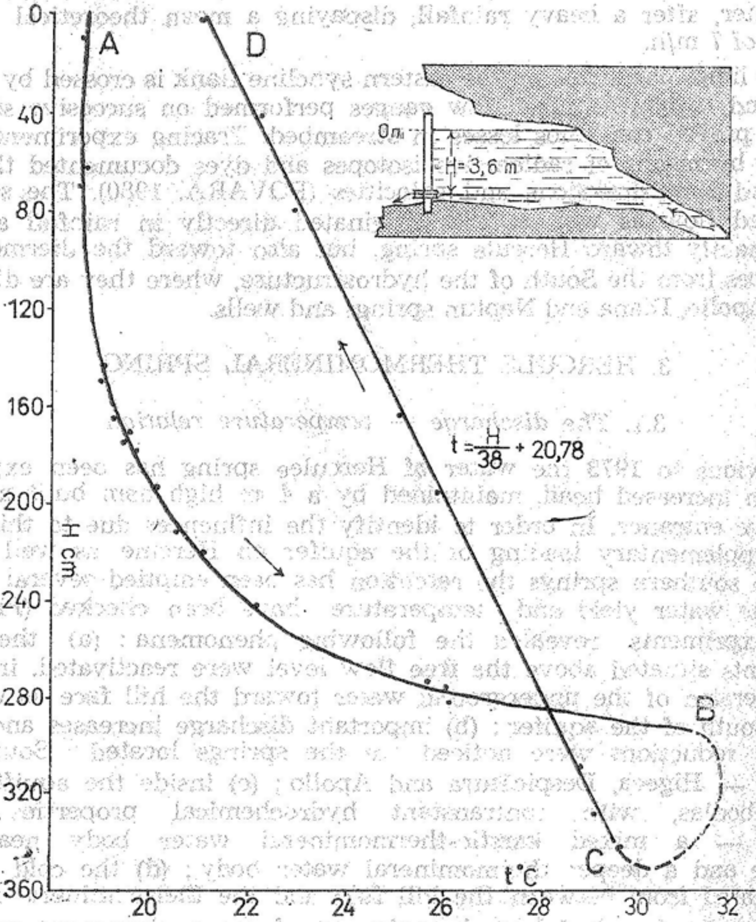

Fig. 2 — Experimental emptying of Hercule retention between 22th—30th January 1972. A—B evacuation interval, B—C free flow interval, C—D filling interval.

81 l/s, the minimum recorded discharge of 17 l/s occuring on 23 th April 1982, while the maximum, of 98 l/s, occured at November 22 ond, 1976 ; (d) the discharge increases induce a corresponding temperature diminishing (Fig. 4 and Fig. 5), which pleads for a cold inflow as their cause. The thermic energy transfer among water and limestone (or among water and air, as log as Hercule drain is concerned), would provoke deviations from this rule. Discharge increases have been no-

ticed with reduced temperature variations : between November 26th to 27th 1976, to a yield reduction of 30 l/s acordingly a 3.7°C temperature reduction was noticed.

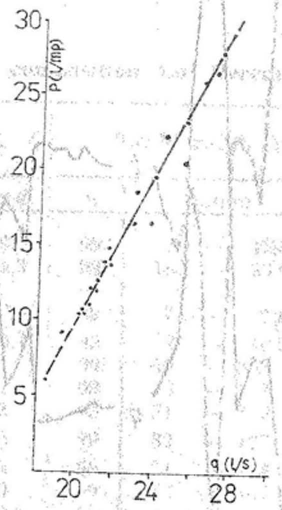

Fig. 3 — Discharge (Q) versus rainfall (P) variation diagram at Hercule spring.

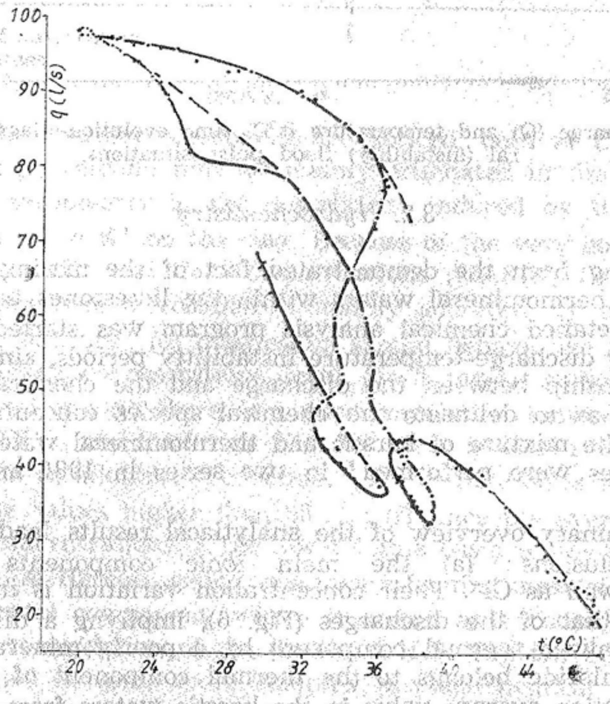

Fig. 4 — Discharge (Q) versus temperature (t°C) variation diagram at Hercule spring during December 1976.

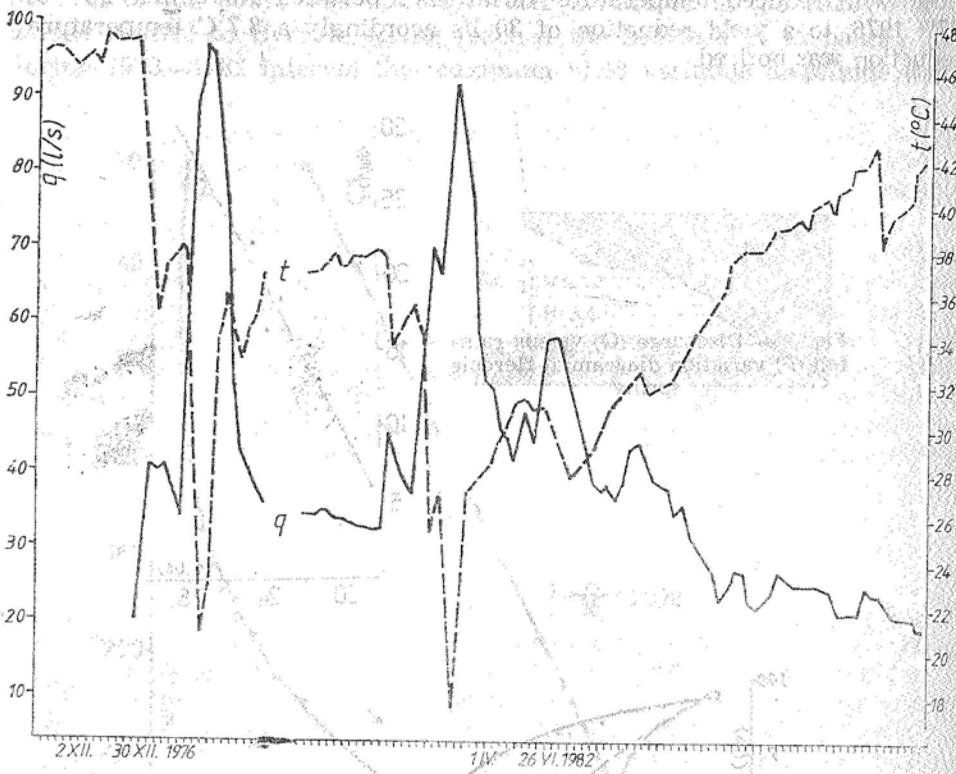

Fig. 5 — Discharge (Q) and temperature (t°C) time evolution diagrams for several (instability) flood pulse situations.

3.2. *Hydrochemistry*

Proceeding from the demonstrated fact of the mixing of the cold waters with thermomineral waters within the limestones body of Cerna syncline, a detailed chemical analysis program was started at Hercule spring during discharge-temperature instabilitty periods, aiming to draw out a relationship between the discharge and the chemical concentration, as well as to delineate the chemical species concentration variation within the mixture of karstic and thermomineral waters. The chemical analyses were performed[5] in two series in 1981 and 1982 (Table 1).

A preliminary overview of the analytiacal results leads to the following conclusions: (a) the main ionic components are Ca^{++}, Na^{+}, K^{+} as well as Cl^{-}. Their concentration variation is inversely proportional to that of the discharges (Fig. 6), impliyng a dilution of the highly mineralized thermal component by a poorly mineralized karstic water; (b) chloride belongs to the thermal component of the mixture. Its contcentration average value in the karstic waters from lower Cerna

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[5] The specified analytical methods are described by MARIN (1984).

basin in only 1.3 mg/l, versus about 900 mg/l at Hercule spring. The good, inverse, correlation between its concentration and yield values of less than 65 l/s support the idea of a stable supply of the thermal component (Fig. 7 a). At dicharge values higher than 65 l/s random deviations of the thermal component are noticed, both at Cl^- and Ca^{++}, Na^+ and K^+; (c) calcium may be mainly originated in the dissolved limestone and secondarily in the desorbtion induced by the ionic exchange of Na^+ and K^+ on the clay. Because of the very good corelation noticed between Cl^- and Ca^{++} concentrations (MARIN, 1983), one may admit that limestone dissolution is mainly achieved by thermal component of the mixture; (d) magnesium should behave like Ca^{++}, but its very low average concentrations level (4—5 mg/1) makes any interpretation uncertain; (e) there is a poor correlation between alkalinity, expressed as HCO_3^- and discharge (Fig. 7b). As a general rule, flow diminishing induces an alkalinity reduction, but this relation is stronghly disturbed at flow values higher than 65 l/s; (f) since the average value of the sulphate concentrations in the lower Cerna basin is less than 10 mg/l, versus 70 mg/l at Hercule spring, one may infer that most of it is derived from the thermal component, where it occurs as a consequence of an almost complete oxidation of the dissolved H_2S. The ion SO_4^{--} is even strongly implied in some more complex physico-chemical processes as it may be noticed from the poor corelation of fig. 7 c. The same applies to SiO_2 too.

Table 1

Variation ranges and averages of chemical composition for Hercule spring

		12th Mar.-22nd Apr. 1981			9th Mar.-2th June 1982		
		n	Range	Average	n	Range	Average
T	(°C)	110	22.1 — 36.9	30.3	99	17.4 — 43.0	35.2
Q	(1/s)	110	33.1 — 79.5	54.0	99	18.2 — 93.6	36.9
pH		110	7.20— 7.55	7.4	99	7.04— 7.62	7.3
CO_2^-	(mg/1)	86	5.6 — 10.5	8.4	99	2.7 — 10.8	6.8
Ca^{++}	(mg/1)	110	109 — 272	201	99	49 — 353	258
Mg^{++}	(mg/1)	110	2 — 6	4	99	3 — 7	5
$Na^+ + K^+$	(mg/1)	101	105 — 375	258	99	31 — 573	402
HCO_3^-	(mg/1)	101	103 — 131	116	99	82 — 127	107
SO_4^{--}	(mg/1)	110	43 — 102	68	99	31 — 120	78
Cl^-	(mg/1)	110	267 — 935	643	99	52 —1407	972
SiO_2	(mg/1)	110	9.0 — 31.0	20.0	—	— —	—
TDS	(mg/1)*	101	657 —1798	1302	99	295 —2512	1820

n = number of observations
* calculated values

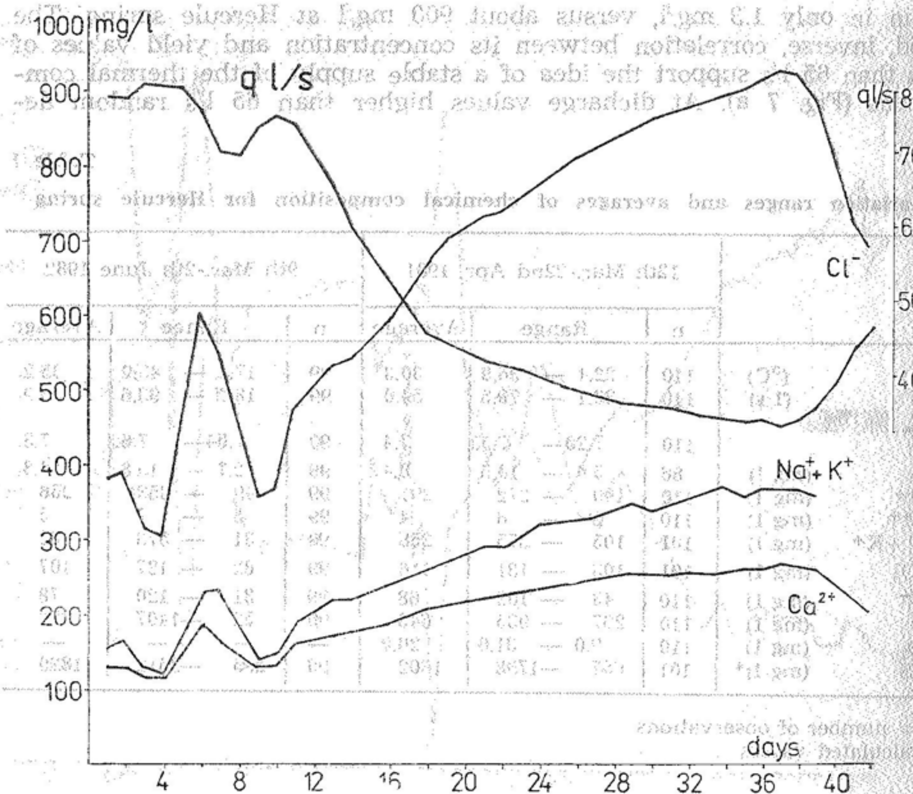

Fig. 6 — Time evolution of the main chemical species concentrations at Hercule spring (1981).

4. DATA INTERPRETATION

Underground drainage through Cerna syncline is following its axis displaying mean theoretical velocities of 7 m/h. The inputs in the aquifer are both gravitational, including cold waters of surface origin and ascensional, including thermomineral, waters (fig. 8). The concentrated underground flow along the karstic drain of Hercule cave (of which only 100 m are known) is of free surface type. In its southern third the drain crosses major transverse faults along which geothermal anomalies were outlined. These fault are the paths along which the thermomineral water penetration into the karstic waters drain occurs. The mixture of the two waters of different origin is discharged to the bull face mainly through Hercule spring and secondarily through the springs and the wells from the syncline (Apollo, Diana).

Mixing zone I (permanent) is situated along a lineament outlined by several caves, displaying steam outflows, while *Mixing zone II* shows only temporary activity triggered by the rainfall : both are met at the lowel of the free surface of the flow in the drain. The existence of the

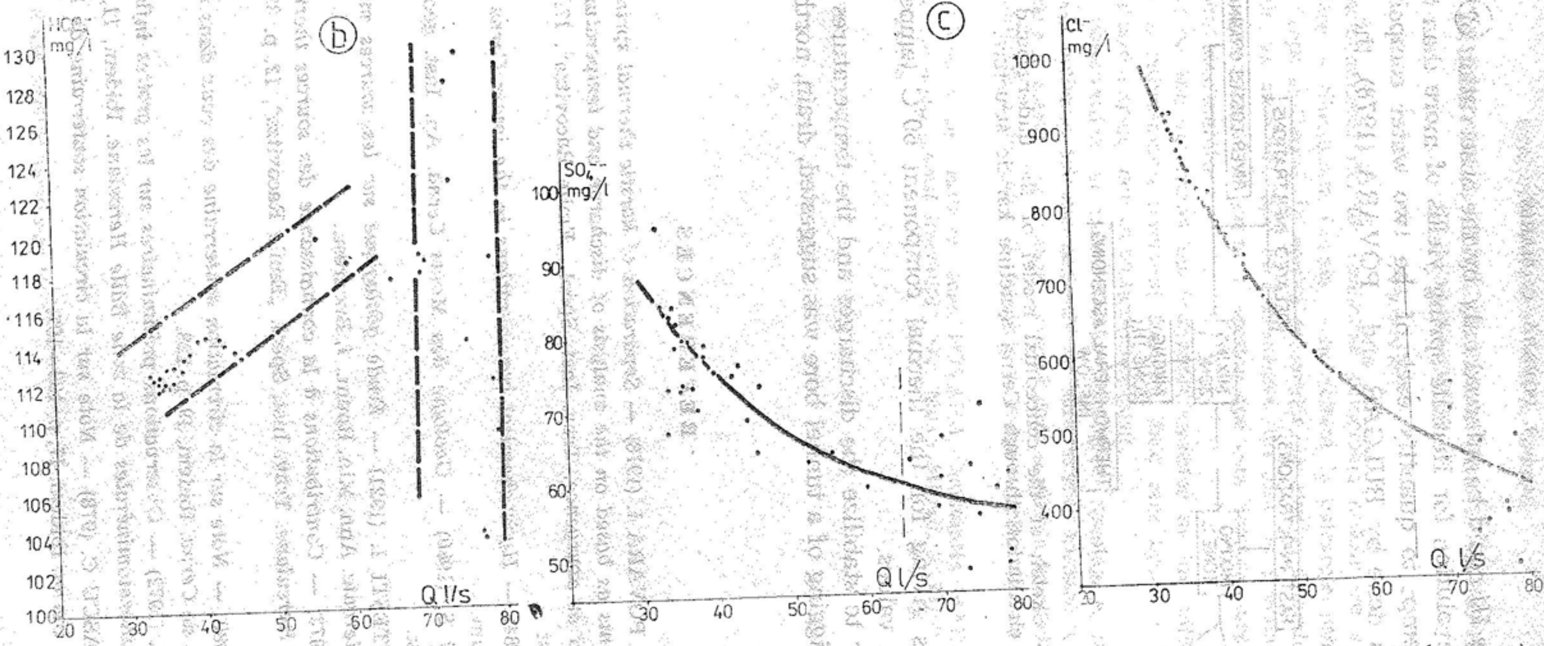

Fig. 7 — Concentrations of : (a) chloride, (b) alkalinity expressed as HCO_3^- and (c) sulphate as a function of the discharge at Hercule spring.

Mixing zone III could be inferred only by the observation of the Cl⁻ concentration evolution for Hercule spring yields of more than 65 l/s.

An attempt to quantify each of the two water components of the aquifer was done by BULGAR and POVARA (1978), the subsequent

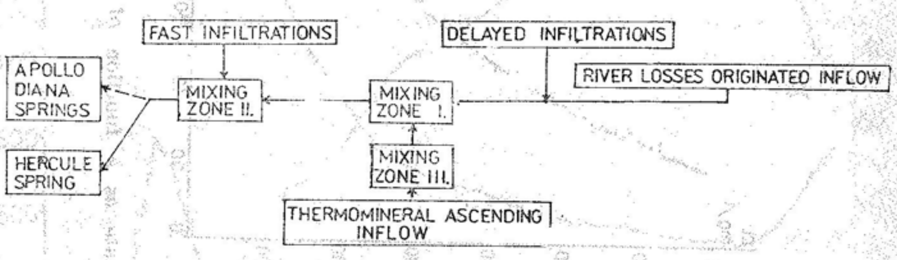

Fig. 8 — Sketch of the conceptual model of the underground waters circulation through Cerna syncline karstic structure.

computations giving for the thermal component 60°C temperature and 14,9 l/s yield values.

In order to stabilize the discharges and the temperatures of Hercule spring the digging of a tunnel bore was suggested, drain, north of *Mixing zone I*.

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IZVORUL TERMOMINERAL HERCULE. CONSIDERAŢII HIDROGEOLOGICE ŞI HIDROCHIMICE

Rezumat

Izvorul termomineral Hercule constituie principala descărcare a unei ample structuri acvifere — Sinclinalul Cernei — dezvoltată în calcarele jurasic-cretacice din versantul drept al Cernei. În corpul calcarelor, la nivelul drenului natural al peşterii Hercule, se amestecă ape reci provenite din rîuri şi precipitaţii, cu ape termominerale ascensionale. O parte a acestor ape este drenată spre izvoarele şi forajele din sudul sinclinalului.

Amestecul de ape determină un pronunţat caracter de instabilitate a debit-temperaturilor şi chimismului izvorului Hercule, fapt care produce perturbări în regimul de utilizare a apelor pentru tratament balnear.

Pe baza observaţiilor şi măsurătorilor geologice, speologice, hidrologice şi hidrochimice s-a elaborat schema generală de alimentare, amestec a tranşelor de apă şi descărcare a acestora la versant, schemă care a stat la baza elaborării unui proiect de stabilizare a debitelor şi implicit a temperaturilor izvorului.

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