4.4. THERMAL AQUIFERS IN MESOZOIC KARSTIFIED LIMESTONES FROM ORADEA - BĂILE FELIX & 1 MAI AREA, WESTERN ROMANIA

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1. Regional background

The presented area, adjacent to the Crişul Repede River, is situated in the north-western part of Romania, next to the border with Hungary (Fig. 1). Morphologically, from the bordering area until close by Felix and 1 Mai resorts is a plain area; eastward it is continued with a low hill area.

The altitudes go from about 100 m in the western part to about 400 - 500 m in the eastern area, towards Aştileu - Vârciorog; in the mountainous area, but out of the map frame in Fig. 2, the altitudes increase towards the Pădurea Craiului Mountains, characterized by exo-karstic relief.

The annual mean temperature in this area is +10°C.

The precipitation quantity during normal years is 600 - 700 mm, but towards the high areas could exceed even 1000 mm.

2. Short history of the thermal aquifers knowledge evolution

The existence of the **Felix & 1 Mai thermal aquifer** (Băile Felix and Băile 1 Mai area) has always been known due to the natural emergences

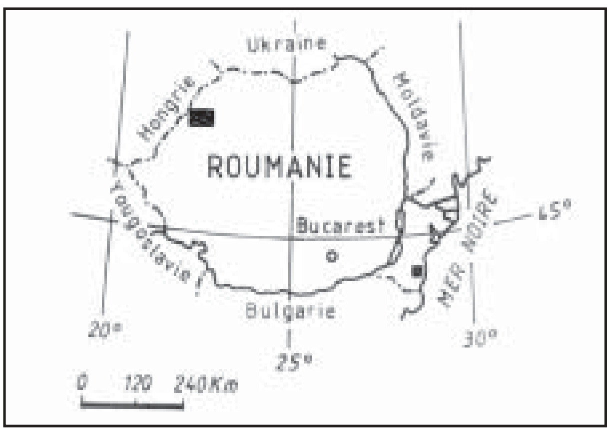


Figure 1. Location of the study area.

such as the Felix spring (within Băile Felix area) but particularly through the sub-lacustrine springs disposed along the Peţa stream, that generated – within the area become Băile 1 Mai – the lakes named Ochiul Mare, Ochiul Pompei and Ochiul Ţiganului. Due to these warm waters some flora and fauna relic species have survived since the ice age, such as *Nymphaea lotus var. thermalis* and some species of *buccinidae,* which are protected nowadays in a natural reservation. The documents prove that the waters from this area were used even since 1221 for balneary treatments; the two spas are internationally famous at the present time.

The first drillings date since 1885 („Balint” well in Băile Felix) and respectively since 1886 („Izbuc” drill in Băile 1 Mai), at a depth of 47.2 m and respectively 101.7 m. After 1962, with the spas development and the increase of necessary water for balneary treatments, an ample drilling and research program has started. At present, there are 9 wells which are exploited in the two spas, but in order to know the deposits extension, more exploring drillings were executed, including a reference one (F 4768) to 3170.5 m depth.

Oradea thermal aquifer is situated in the north-western part of the Felix-1 Mai aquifer and is extended approximately in the area of the town with the same name (Fig. 2). The drillings were performed beginning with 1963, at depths of 2500-3200 m; nowadays, 12 drillings are functioning (among them, an extraction-injection doublet, F 4797-F 4081) through which the thermal water (67-91°C) is exploited, used for energetic purpose and subordinated for balneary purpose.

The hyper-thermal aquifer Borş is situated in the northern part of the Crişul Repede River, in the north-western part of the Oradea aquifer and near of the locality having the same name (Fig. 2). Starting with 1977, 18 boreholes were drilled, 6 of them are in use nowadays, including the doublet system (extraction-injection) or for various experiments; due to the very high mineralization and to water temperatures up to 130°C at the mouth of the hole, this water has an energetic use.

3. Geological and structural background

From **geological** point of view, Oradea - Băile Felix &1Mai area is situated in the eastern part of the Pannonic Depression, next to the contact area with Apuseni Mountains.

The geological formations from this area belong mainly – although developed especially in depth – to the “Bihor Autochthon”; in the eastern half of the territory outcrops small Permian patches and formations belonging to the other major structural unit, the so-called “Codru Thrust Sheet” (Fig. 2).

Over the autochthonous deposits and also over the thrust sheet from the areas where this one was developed, a post tectonic cycle was deposed, constituted by Senonian deposits which cover discontinuously the basement.

The Mesozoic deposits of the Bihor Autochthon, descending in depth towards west, constitute the basement of the nowadays Pannonic Depression. This large depression, formed by reactivating some old crustal fractures (especially G12), as a result of the laramic diastrophism movements and subsequent phases, was gradually replenished with Neogene and Quaternary very thick deposits; these deposits cover, of course with small thicknesses, also the marginal areas of the depression, so that is the case of the intra-mountains basins or Felix - 1 Mai area.

The basement of the Pannonic Depression in this area is constituted by epizonal and mezozonal metamorphic formations and by presenonian Mesozoic sedimentary formations, represented by Triassic, Jurassic and Lower Cretaceous.

All these formations were intercepted by drillings both in the Felix - 1 Mai and Oradea areas and towards west till the border, at Borş. Within the Băile Felix - 1 Mai perimeter, only the Lower Cretaceous appears, as a calcareous heel (Şimleu Hill) which is interposed between the two spas. Moreover, this is the most western appearance of the limestone (Fig. 2), which is strongly developed toward east, in the Pădurea Craiului Mountains.

Structurally, these Mesozoic deposits constitute a big faulted monocline, with fallings in steps westward, where it is covered by newer deposits.

Litologically, the whole Mesozoic series of the Autochthon is mainly made by limestone and dolomites, strongly karstified both in the Pădurea Craiului Mountains and towards west, in the Felix - 1 Mai, Oradea and Borş areas, where these formations appear at depths bigger and bigger. Regarding the thicknesses, it is estimated that the Mesozoic series is very thick, of about 3500 m. The Jurassic formations have thicknesses of 150-200 m in the Oradea area (about 600 m in the Felix area) and the lower cretaceous ones have between 200-870 m at Oradea and 350-600 m within the Băile Felix-1 Mai area.

The post tectonic cover, a sedimentary replenishment of the Pannonic Basin, is constituted in the Oradea - Băile Felix & 1 Mai area from upper cretaceous, Neogene and Quaternary deposits.

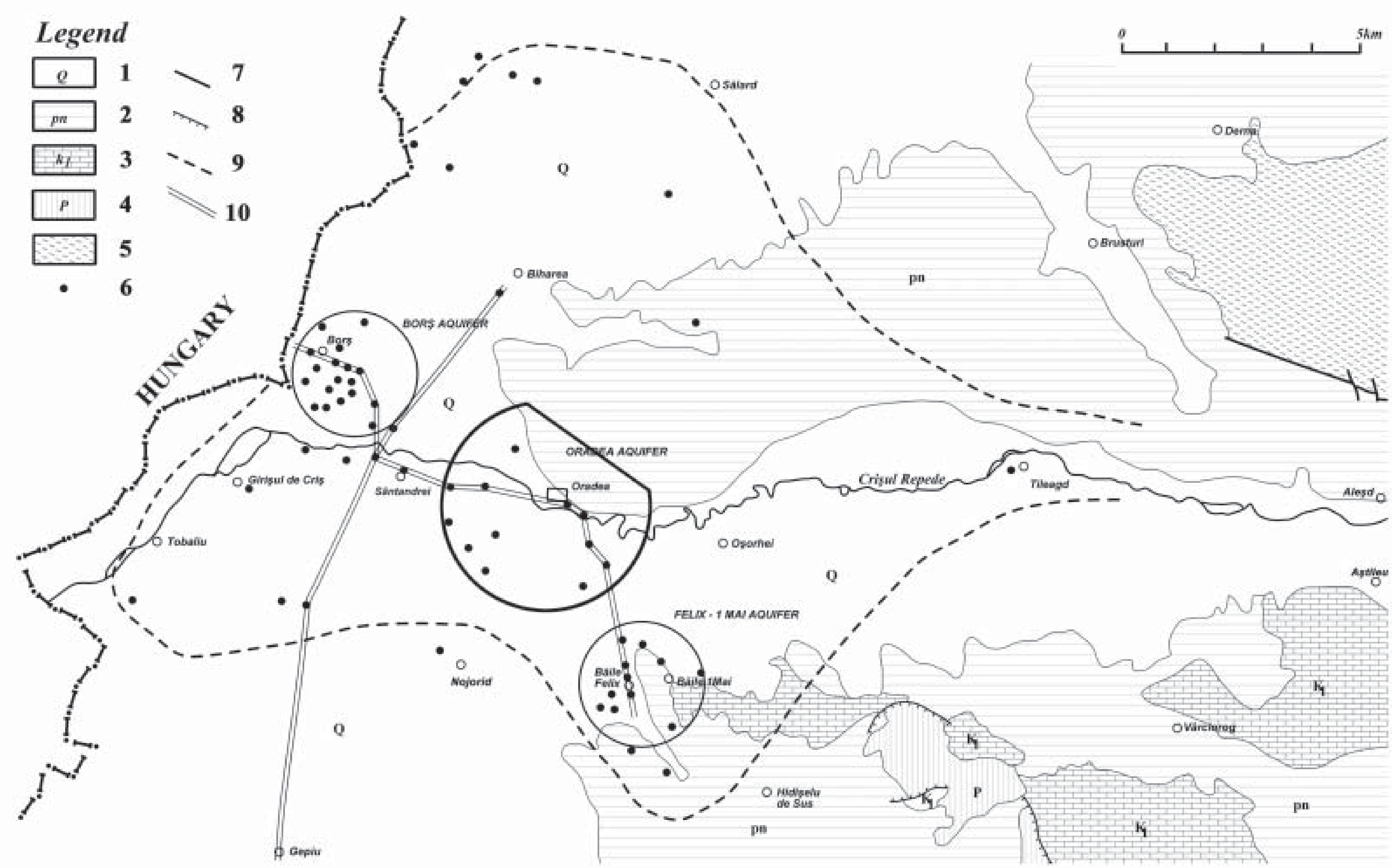
Senonian, intercepted in drills only in Oradea area, is deposed in Gosau facies (a large range of rocks, especially carbonated), discordant overlapping the Bihor Autochthon.

Neogene stands overlapping and discordantly over older deposits and is represented by Miocene (Badenian and Sarmatian) and Pliocene in pannonic facies.

Miocene is detrital, with thicknesses of tens or even hundreds of meters in the Oradea area, but in the Băile Felix - 1 Mai area is completely pinched out.

Pliocene, represented by Pontian, is developed especially within the depression, reaching

Figure 2. Synthetic geological map of the Oradea - Băile Felix & 1Mai area.
Legend: 1 - Quaternary: alluvia deposits from flood plains and four terraces levels; 2 - Pontian: sandy clays and sands; 3 - Lower Cretaceous: barremian-apțian stratified and massifs limestone; 4 - Permian: breccias, conglomerates, shale (from the system of the Codru Thrust Sheet); 5 - Proterozoic: metamorphic rocks (mica schist and para gneisses); 6 - Structural geological drillings, boreholes for exploration and/or exploitation (extraction / injection) of geothermal water; 7 - Fault (outcropping or covered); 8 - Thrust sheet; 9 - Approximately developing limit of the Mesozoic limestone deposits and of geothermal water occurrence; 10 - Geological cross-section.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Băile 1Mai
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Hidişelu de Sus
Vărciorog
Gepiu

Oradea in north (Sânnicolau de Munte) a thickness of 2933 m. It is constituted by two litostratigraphic series: a lower complex predominant pelitic and an upper complex predominant psamitic (which represents an important collector for the thermal water).

In Oradea - Băile Felix/1 Mai area, the thicknesses of the Pliocene formations, intercepted through drillings decrease rapidly from about 1000 -1200 m in the western part of Oradea-city, to only 15-20 m at Băile Felix and even less than 10 m in Băile 1 Mai.

Quaternary is represented by alluvia deposits – with thicknesses of meters grade – which forms flood plains and an important system of four terraces and also by some sporadic diluvia deposits.

From ***tectonic and structural*** point of view, the basement of the Pannonic Depression in the Oradea - Băile Felix & 1 Mai area, is compartmentalized in blocks, function of two faults systems that are almost perpendicular (Fig. 3):

- pannonic system, of orientation NW-SE; the main fault of this group is the crustal fracture G12 (Socolescu et al., 1975) that crosses the western part of the Oradea-city and is continued on the Hungarian territory. This is the marginal fault of the Pannonic Depression, because it delimits towards east the pannonic basement;
- carpathian system, with an approximate direction E-W, represents the system that conditioned and fragmentized the western mountainous massifs. G10 crustal fracture is the most important from our area that crosses, in the northern part of Oradea the marginal fault of the Pannonic Depression.

As structural elements that are more important in this region we mention the intra-mountains basin of Borod – developed along the Crişul Repede River, the Beiuş Basin – intra-mountains basin situated in the southern part of Băile Felix and the Velenţa faults system, being N-S orienta-

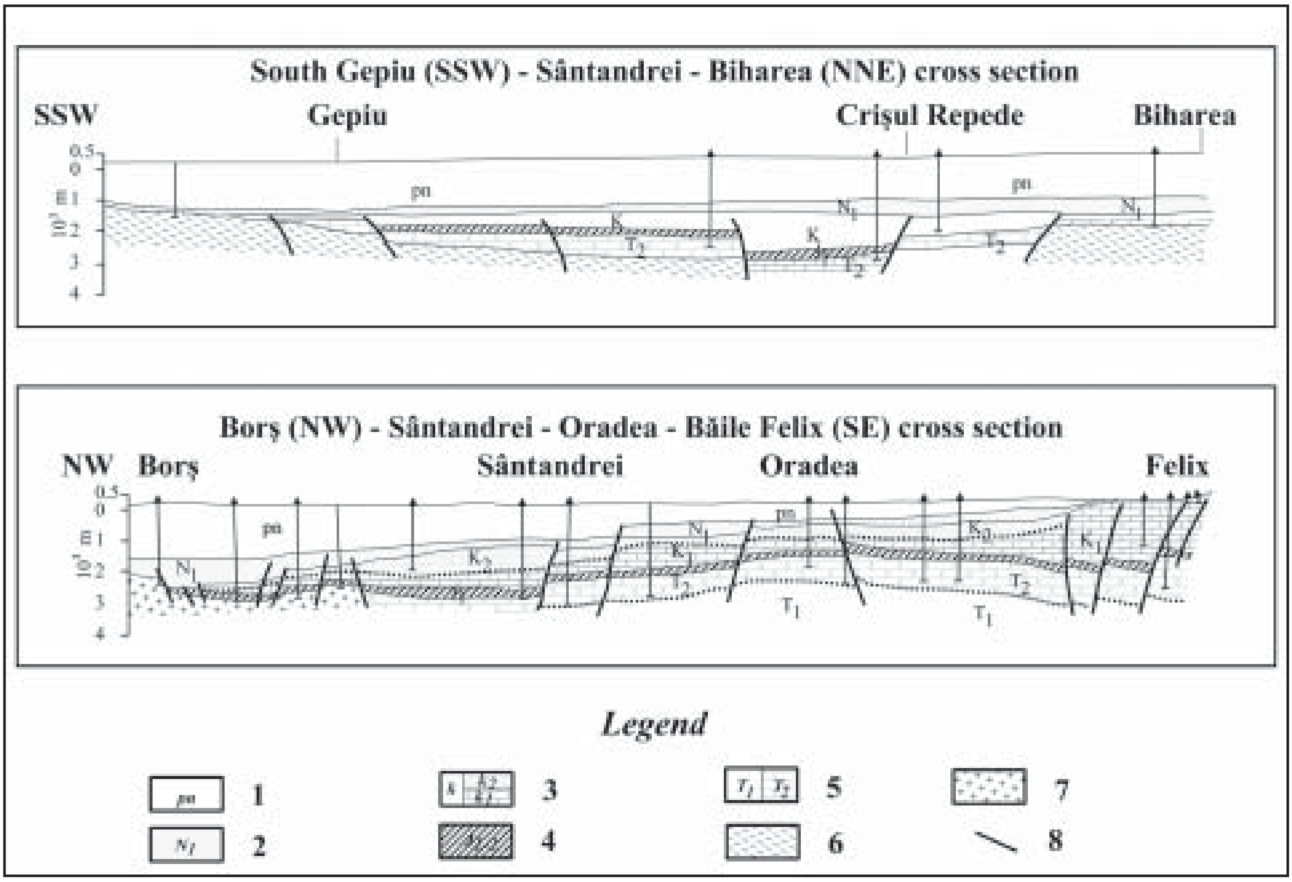

Figure 3. Geological cross-section through the Oradea - Băile Felix area.
Legend: 1. pn - Ponţian: pelito-psamitic series; 2. N_1 - Miocene: marls, sands, sandstones; 3. K - Undifferentiated Cretaceous [3.a. K_2-Senonian: marls, fine sandstones, conglomerates, clayey shale; 3.b. K_1- Lower Cretaceous (with J_3 in base): limestone, marl-limestone]; 4. J_{1-2} - Lower and Medium Jurassic: clays, sandstones, compact marl-limestone: 5. Triassic (5.a.T_2 - Medium Triassic: limestone, dolomites; 5.b. T_1 - Lower Triassic: conglomerates, sandstones); 6. Proterozoic: metamorphic rocks; 7. Proterozoic: granites; 8. Fault.

tion and the routing of the main fracture of this system, Oradea - Băile Felix - Hidişel Valley.

4. Geothermic characteristics

Borş - Oradea - Băile Felix & 1Mai region is situated on the north-eastern flank of a regional geothermic anomaly centered upon Tisa River, which also is part of a sub-continental anomaly developed within the Alpine-Carpathian inter-arch of the Pannonic Depression. The thermal flux in this area is very strong, its average value is 2.4 $\mu cal/cm^{2}*s$ (comparing to the global average which is of 1.5 $\mu cal/cm^{2}*s$), what means high gradients of temperature, 50-70°C/km.

A detailed geothermal study having thermal water as objective has been carried-out in the Oradea - Băile Felix &1Mai area by Veliciu, 1986. The map with measured temperatures at the depth of 40 m shows a differentiated effect of the thermal convection in the region of the two aquifers. Thus, comparing with regional background value of 11.8°C, in the region of Oradea – where the thermal water is deeply situated – the temperatures are of 13.5 -13.9°C, and in the Felix and 1 Mai areas, a very clear individualized anomaly occurs, of 15-20°C, due to the 1st thermal complex which is situated to a small depth. The morphology of this anomaly suggests a tight connection with the disjunctive tectonics; thus, clearly may be identified the E-W fault, along the Peţa Creek and the N-S fractures bundle associated to Velenţa fault, along the Hidişel Valley.

5. Hydrogeology of thermal aquifers

In the presented area there are geothermal waters stored within the entire package of Mesozoic carbonate rocks, but only the Triassic and Lower Cretaceous are practically interesting.

In this region, three aquifers could be delimited, namely: Felix -1 Mai aquifer, Oradea aquifer and Borş aquifer (Fig. 2). In the case of the first aquifer, the thermal waters are in the Lower Cretaceous, while in the case of the two other aquifers the collector is represented by the package of the Triassic rocks.

The most important aquifer formation is represented by the Triassic that constitutes the main thermal waters collector of energetic interest, while the formations of the Lower Cretaceous present a special interest from balneary-therapeutic point of view in the Băile Felix -1 Mai area.

5.1. Lower Cretaceous aquifer in the Băile Felix - 1 Mai area

5.1.1. General hydrogeological data (depths, levels, discharges, temperatures)

This aquifer is situated in the fissure system, sometimes even karstic, well developed in the upper part of the Barremian-Aptian, which is calcareous only in the Băile Felix & 1 Mai area. Tectonically, the area is placed on a fallen compartment, broken from the most eastern branch of the Pădurea Craiului Mountains; it is strongly affected by deep fractures that assure the ascending ways of the warm water from the depths. The impermeable roof, constituted by Pliocene deposits with thicknesses of about 50 m in the Felix area and of about 5-10 m in the 1 Mai one, allows the conservation of the aquifer potential and also explains the thermal lakes genesis on the Peţa Creek and the existence of a difference of layer pressure between the spas. Together with the exploitation development of the Felix spa, this difference decreases from 6 m in 1886, to 4 m in 1969 and to only 2 m in 1971 (Ţenu, 1975). The discharge of the Peţa Creek that collects the natural thermal springs from the 1 Mai spa also decreased gradually from over 190 L/s in 1970, to 143 L/s in 1977 and to only 50-60 L/s in 1986. These are mean discharges; they have a seasonal variation, they decrease towards autumn, so that it was demonstrated through the hydrograph of the "Izbuc" drill, between 1967 and 1971 (Ţenu, 1975).

Vertically, the Felix - 1Mai aquifer is a system structured on three complex aquifers, belonging only to the Lower Cretaceous and positioned as follows:

- complex I, till about 300 m depth, manifested either by springs (only in the perimeter of 1 Mai spa, at present with a total discharge of 40 L/s), or by drills (within the both spas, with artesian piezometric levels up to +14 m and discharges in eruptive regime between 25 and 100 L/s). F2 Rontău drill, cemented at present in order to protect the aquifer, produced in an eruptive way to the execution 260 L/s. The water of this complex has surface temperatures of 45-50°C in the Felix spa and 35-40°C in 1Mai; this complex is exploited at present in the Felix perimeter through the F 4087, F Balint, F 4003, F 4011 drills and in the 1 Mai perimeter through Fp2;

- complex II, between 300 and 650 m, with piezometric levels between +4.5 and +5.2 m and discharges in eruptive regime or through pumping of 25-67 L/s, with surface water temperatures of 33-36°C (in the 1 Mai perimeter) and of 43°C (in the Felix perimeter); it is exploited at present through the Fp4 drills (in the Felix perimeter), Fp1 and Fp2 (in the1 Mai perimeter);
- complex III, between 650 and 1316.5 m, with piezometric levels of +8 m, discharges in eruptive regime of maximum 3 L/s and surface water temperature of 34°C, unexploited.

A drill of reference (F 4768) executed recently in Băile Felix emphasized, under the complexes from the Lower Cretaceous, only the presence of some poor accumulations of thermal waters in the Jurassic limestone little fissured (the interval 1589-2080 m) and in the Triassic limestone and dolomites (the interval 2204-3170 m).

5.1.2. Hydrochemistry

From hydro-chemical point of view, the waters of this aquifer are, within the areas of both aquifers, of hydrogencarbonate-sulphate-calcium type, with the ratio HCO_3/SO_4 of 1.4-1.6 in the 1 Mai spa and with a decreasing tendency in the Felix spa to 1.2-1.3. The data collected in the last 120 years show that the mineralization degree does not exceed 1 g/L, there are not important changes in time (seasonal or multi-annual) of the chemistry (except some major earthquakes), but that it is a constant differentiation between spas regarding the mineralization degree. Thus, a comparison of the analysis between 1886-1969 for F „Balint" (Felix spa) and F „Izbuc" (1 Mai spa) shows, in the first case, a total mineralization, of about 1000 mg/L and in the second case, of about 850 mg/L (Ţenu, 1975).

The specific electrical conductivity measured in 1987 for 9 samples of water from this aquifer is situated between 221-773 $\mu S*cm^{-1}$, and the mean is 603 $\mu S*cm^{-1}$.

An observation that could be relevant and could be the consequence of a too intense exploitation is that during the last years of 90[s], for the „Balint" drill (Felix spa) it was observed a continuous increasing of the HCO_3 content (from 190 to 410 mg/L), while in the „Izbuc" drill (1Mai spa), this one remained constant, at 350 mg/L (Ţenu, 1981).

In order to complete the image of the chemical composition of this aquifer we mention the fact that two analyses, made in 1961, in order to determine the dissolved gases, show a mean content of 4.0% CO_2, 58% N and the rest is air.

5.1.3. Microelements, radioactivity

Within the microelements group (minor elements or „traces") analyzed in the Lower Cretaceous aquifer, we can classify the metallic and radioactive microelements.

Regarding the metals, only one analysis exists, made in 1976 by a spectrophotometer in atomic absorption on water from F 4003 Felix for 10 metals (Ţenu, 1981). All detectable contents for Cu, Mn, Zn, Cr, Pb, Cd, Ni, Co etc are infinitesimal, situated under the maximum concentrations admitted (CMA) by the Law 458/2002 regarding the quality of the potable water.

Concerning the waters radioactivity, this issue was analyzed in the Felix & 1 Mai area, at more time moments, during about 50 years (Athanasiu, 1927; Szabó, 1959; Vasilescu & Nechiti, 1970; Ţenu. 1975) for Ra, Rn, U and the total activity β, γ. The contents in Rn were generally situated under 400 pCi/L, that of Ra-226 under $9,0*10^{-12}$ g/L, U under 0.001 mg/L and the total activity β, γ is of tens order of pCi/L, without observing important seasonal or multi-annual variations. These contents in radioactive microelements, characteristic for a way through carbonated rocks, do not confer to the waters of these spas, according to the standard in force, the quality of radioactive waters, from medical point of view.

It is remarkable the fact that the shallow waters along the Peţa Creek contain more Rn than the waters from the thermal aquifer.

5.1.4. Environmental isotopes

The thermal aquifer from Băile Felix & 1Mai was investigated by isotopes (deuterium, oxygen-18, tritium, radiocarbon and carbon-13) in four periods: 1969-71, 1976-78, 1987 and 2005; the most complete investigation was made between 1976 and 1978 (Ţenu, 1981) and we will further refer especially to it.

In Fig. 4 there were correlated the annual mean isotopic compositions for δD and $\delta^{18}O$ since 1976 for the main water types from this area. L-MWL was obtained as a result of determinations made on a time period of 4 years, on samples of monthly means precipitation and calculated as weighted annual means and L WL is the regression line corresponding to the mean isotopic composition of the figured local water points.

As a general remark, in the diagram the position close to the points that represent the thermal aquifer are observed, on one hand, and those of the shallow and surface water, on the other hand, as well as the isotopic composition of all groundwater is situated between winter input function and annual input function. This means that the recharge of the thermal aquifers results from another season than the classical cold one or they are even a precipitation mixture from the whole year. In a detailed diagram δD - δO (Fig. 5) the analysis from 1976 for this aquifer, are almost parallel to the abscise and lead to an equation typical for the thermal waters; this line crosses the W-MWL line and let two points from five on the left, to values more negative than those expected.

The tritium determinations were synthesized, for both thermal aquifers in Table 1. Regarding the Băile Felix & 1Mai aquifer, it has been ascertained a normal decreasing in time of the average values, from 16 TU to 0.7 TU. The analyses are significant only for the first study interval (1969 = 19 TU; 1970 = 16 TU; 1971 = 12 TU) and they allowed a quantitative assessment of the young recharge participation, evaluated to about 1/8 from the total recharge of the mountainous area (Ţenu, 1975). The water of this "young recharge" is infiltrated through areas close to the spas.

In Table 2 there were written the analysis of ^{14}C and ^{13}C, which are significant for the Băile Felix &1Mai aquifer; an analyses ^{13}C made on a rock sample of Lower Cretaceous limestone from the Felix area indicated $\delta^{13}C = 0.0$ ‰ vs. PDB.

Table 3 shows that during 18 years it was a continuous decreasing of the mean apparent ages on aquifer to about 2/3 from that initially evaluated. This tendency, namely the "rejuvenation" of

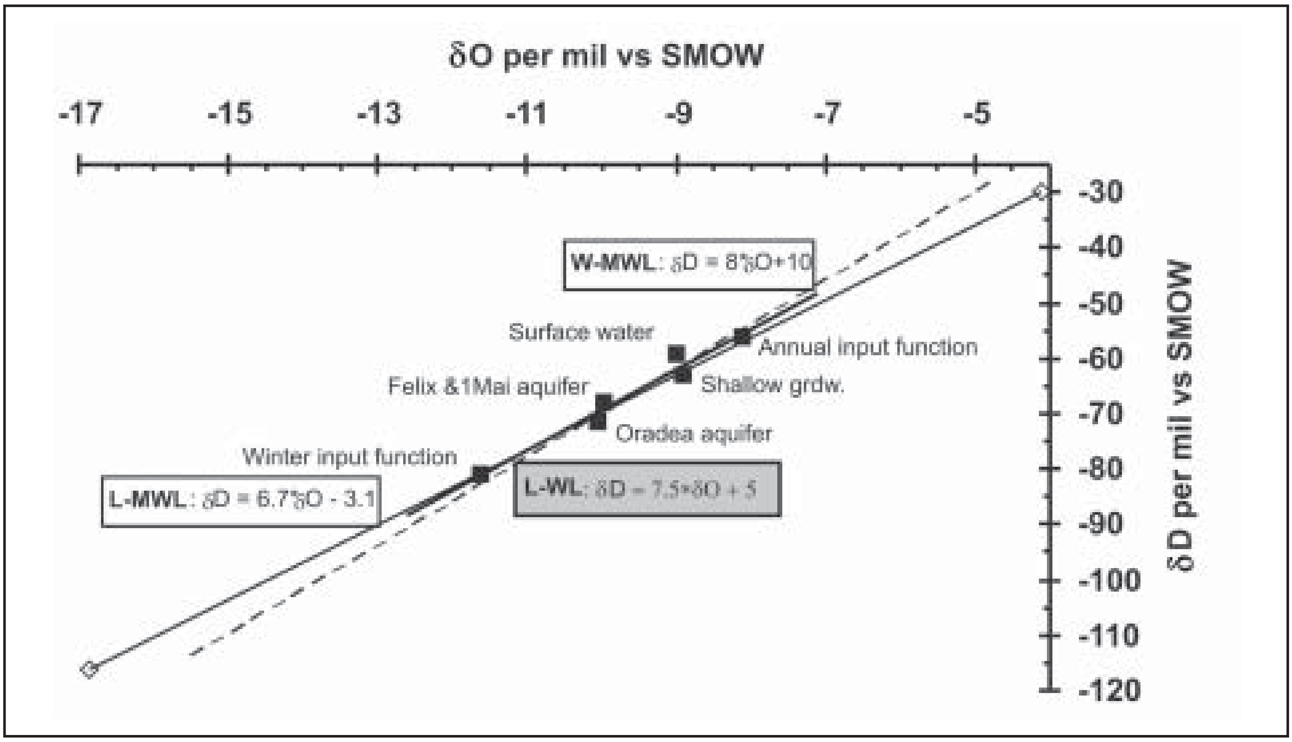

Figure 4. δD-δO diagram of the main water types (averages values in 1976 year) from Oradea-Băile Felix -1 Mai area, including thermal aquifers.

Legend: W MWL - world meteoric water line; L MWL - local meteoric water line with its end terms (empty diamond); L WL - equation of averages (black squares) water points; Winter input function - the isotopic content of meteoric waters in winter season; Annual input function - the isotopic content of meteoric waters over the entire year.

C-14 ages, is accompanied by the decrease of the concentrations in ^{13}C registered in 1987 comparing with the period 1976-78. These findings have a unique but interesting explanation, namely the fact that through the increasing of the exploitation in the area of the two spas, an equilibrium lack of the natural recharge regime occurred, expressed by activating the underground dynamics. Concerning the radiocarbon, this was concretized by radiometric ages, smaller and smaller and so the steps of water lying in the underground are shorter; regarding the ^{13}C, the reflex consisted of the impossibility of a normal equilibrium water-rock, due to the shortening of the direct contact time in the underground.

An analyze of the evolution in time of the individual values for each drilling emphasizes the fact that, while within some drillings, for example F Izbuc and F 4087, it was a constant decrease – even important – of the apparent ages in others, as F 4012, this parameter remained quasi-constant. This finding can be connected to the underground dynamics, as a consequence of the tectonic local compartment.

5.2. Triassic aquifer from the Oradea area

5.2.1. General hydrogeological data (depths, levels, discharges, temperatures)

Although the Mesozoic deposits and even the thermal water development area are much larger, especially extending towards north (Figure 2), an aquifer of economical importance was outlined only in the Oradea-city area.

This aquifer is situated in the Campillian sup-Anisian aged calcareous-dolomite complex which has favourable conditions of thermal water accumulation at depths ranging between 2000 and 3000 meters, with a slight tendency of arching in the central part and sinking towards East and West. It was investigated by 14 hydrogeological drillings and is exploited at present by 11 wells from which an injection-extraction doublet (F 4797 - F 4081) in the neighbourhood Nufărul of Oradea-city.

The aquifer is artesian, with heads from 3.0 bar in its south-eastern side (F4081) to 9.0 bar in the North-Western part (F4767); the discharges vary pretty tightly, from approx 600 m^3/day to 1100 m^3/day.

The water temperature at the mouth hole vary between 67°C and 91°C and the geoisotherms at the base of the Triassic collector have values that start at 80°C in the eastern extremity of the aquifer and reach 120°C in the western extremity.

5.2.2. Hydrochemistry

The Oradea aquifer has sulphate-calcium waters, with a double TDS (approx 1.4 g/L), as compared to the waters from Lower Cretaceous aquifer; the analyses are well individualised in the field of the anions as opposed to all the other water types in the region (especially due to high concentration of sulphates) but are similar in cationic proportions with the waters of Felix and 1 Mai Lower Cretaceous aquifer. After the great earthquake on March 4th, 1977 it was observed, as in the case of the Lower Cretaceous aquifer, a tendency of chemistry modification, namely the diminishing of the $rSO_4/rHCO_3$ ratio.

Specific electrical conductivity measured in 1987 for 9 water samples from this aquifer is between 935 - 1703 μS*cm^{-1}, with an average of 1265 μS*cm^{-1}.

A comparative, but global characterization of the chemistry of these two aquifers is given in Table 4.

Aquifer	n	Year	TU
Felix / 1 Mai: thermal waters in lower Cretaceous	27	1969-71	16
	18	1976-78	0.2
	9	1987	< 5
	2	2005	< 0.7
Oradea: thermal waters from Triassic	9	1976-78	< 0.5
	9	1987	< 5

Table 1. Time evolution of tritium averages activity (TU) per aquifer (the results are from Țenu,1975, 1981 and 1987). n - number of analyses.

Lab. name	Sampling location	Sampling date	C-14 DIC (pMC)	δC-13DIC (‰)	Apparent age (years)
Univ. Bordeaux	F Izbuc / 1 Mai	15.07.1969	5.5 ± 4.0		18,250
Univ. Bordeaux	F 4003 / Felix	14.07.1969	5.3 ± 3.5		18,550
IIRG Pisa	F Izbuc / 1 Mai	15.08.1976	7.2 ± 0.5	- 4.3	16,020
IIRG Pisa	F 4012 / Felix	15.08.1977	11.1 ± 0.4	- 5.3	12,440
IIRG Pisa	F 4087 / Felix	16.08.1976	6.3 ± 0.6	- 3.3	17,120
INMH Bucureşti	F 4087 / Felix	12.09.1987	16.9 ± 2.9	- 9.9	8,970
INMH Bucureşti	F Izbucul Nou / 1 Mai	13.09.1987	8.5 ± 1.2	- 12.6	14,650
INMH Bucureşti	F 4012 / Felix	13.09.1987	10.6 ± 1.4	- 13.5	12,820

Table 2. Carbon isotope analyses performed for thermal waters in Băile Felix & 1Mai area (from Țenu, 1975, 1981 and 1987).
The apparent ages were recalculated according: t = 8267*ln A°/A, where T½ = 5730±40 years; A° = 50 pMC.

5.2.3. Microelements, radioactivity

As the microelements are concerned, in the case of the Triassic aquifer, there is only one 1976 spectrophotometer in atomic absorption analysis made on Oradea F 4004 water for the same 10 metals as in the case of the Lower Cretaceous aquifer (Ţenu, 1981).The detected contents for all the analysed metals are – as in the previous – minute, except the Mn which was found with a quantity of 0.140 mg/L.

Thermal water radioactivity determinations (Vasilescu & Nechiti, 1968) indicated higher contents for this aquifer (F 4005 and F4006 Oradea) than for the Lower Cretaceous aquifer, namely: Rn=1.2-1.96 nCi and Ra=0.78-38.75*10^{-12}g/L. An analysis of the global ß activity made in 1970 on salts extracted from F 4005 water (Ţenu, 1975) indicates 2.3 pCi/L.

5.2.4. Environmental isotopes

The thermal aquifer in the Oradea area was investigated through environmental isotopes (deuterium, oxygen - 18, tritium, radiocarbon, and carbon -13) in two stages: 1976-1978 and 1987 (Ţenu, 1981); in this case the most complete investigation was made between 1976 and 1978 and that's why we are especially referring to it.

The 1976 deuterium and oxygen-18 analyses are aligned in the δD - δO diagram from Figure 5, practically parallel to the abscise, under the Felix and 1Mai aquifer line, with some more negative values for deuterium; they lead to a typical equation for thermal waters, which intersects though the W-MWL line suggesting an isotopic composition for the recharge waters, which has the following equation δD = 6.7*δO + 4, as it was determined based on thermal water content from the Cotiglet well in Triassic, situated towards the mountain area (Ţenu, 1981). This observation is also valid for the Felix and 1 Mai thermal aquifer and demonstrates, together with the concordant sensibility to major earthquakes, the uniqueness of the supplying of the thermal system at a regional level.

The tritium was absent in all determinations made for Oradea thermal aquifer (Table 1) indicating the fact that residence times of ground water are superior to the dating possibility of this radioisotope which is limited to a maximum of 50 years.

Aquifer	n	Year	Ages
Felix/1 Mai: thermal waters in lower Cretaceous	2	1969	18,400
	3	1976	15,190
	3	1987	12,150

Table 3. Time evolution of radiocarbon averages apparent ages.
n - number of analyses

Aquifer	Anionic index	Cationic index	Characterization
Thermal waters in Lower Cretaceous **(Felix/1 Mai aquifer)**	$HCO_3^- > SO_4^{2-}$ $rSO_4/rHCO_3=0.4$	$Ca^{2+} > Mg^{2+}$ $rCa/rNa = 6.4$	Water from limestone; likewise of shallow groundwater.
Thermal waters in Triassic **(Oradea aquifer)**	$SO4^{2-} > HCO_3^-$ $rSO_4/rHCO_3=4.1$	$Ca^{2+} > Mg^{2+}$ $rCa/rNa = 8.1$	Water from limestone and dolomites, sometimes with gypsum.

Table 4. Hydrochemical types of both thermal aquifers (from A. Țenu, 1981).

In Table 5 the results of the ^{14}C and ^{13}C analyses significant for the Oradea aquifer were written; the Triassic limestone which is the host rock was analyzed on a rock sample from that area and has a typical content for the marine environment: $\delta^{13}C$ = +0.5 ‰ vs PDB.

Analyzing the evolution in time of mean apparent ages on this aquifer, evaluated by radiocarbon in 1976 and respectively 1987, it was noticed that it has decreased from 20.300 years to 13.740 years. At the same time there was a “negativation” of ^{13}C values, certified and discussed in the case of the Băile Felix and 1 Mai aquifer.

As in the case of Lower Cretaceous aquifer, the structural and tectonic frame generated a different comportment of wells as regard the temporal evolution of individual radiocarbon measured values. Thus, while in F 4767 was noticed a constant and strong apparent ages diminution in F 4005 this parameter remained quasi-constant.

5.3. Triassic aquifer in the Borș area

5.3.1. General hydrogeological data (depths, levels, discharges, temperatures)

The hyper-thermal aquifer from the Borş area is a hydrodynamic unit with reduced extension, with little static reserves, with a very slow recharging because of the tectonic block configuration. It is practically a hydrodynamic closed structure, being tectonically isolated in a sunken graben between two crystalline compartments, raised to the east and west.

It is situated in the fissured limestone formation of Triassic age (Anisian) and the depth is between 2500 and 2800 meters. The volume of the voids and cracks doesn’t exceed 2%, excepting the superficial, karstified area of the collector. The aquifer is artesian.

The temperature of the geothermal water that reaches the surface varies according to the exploita-

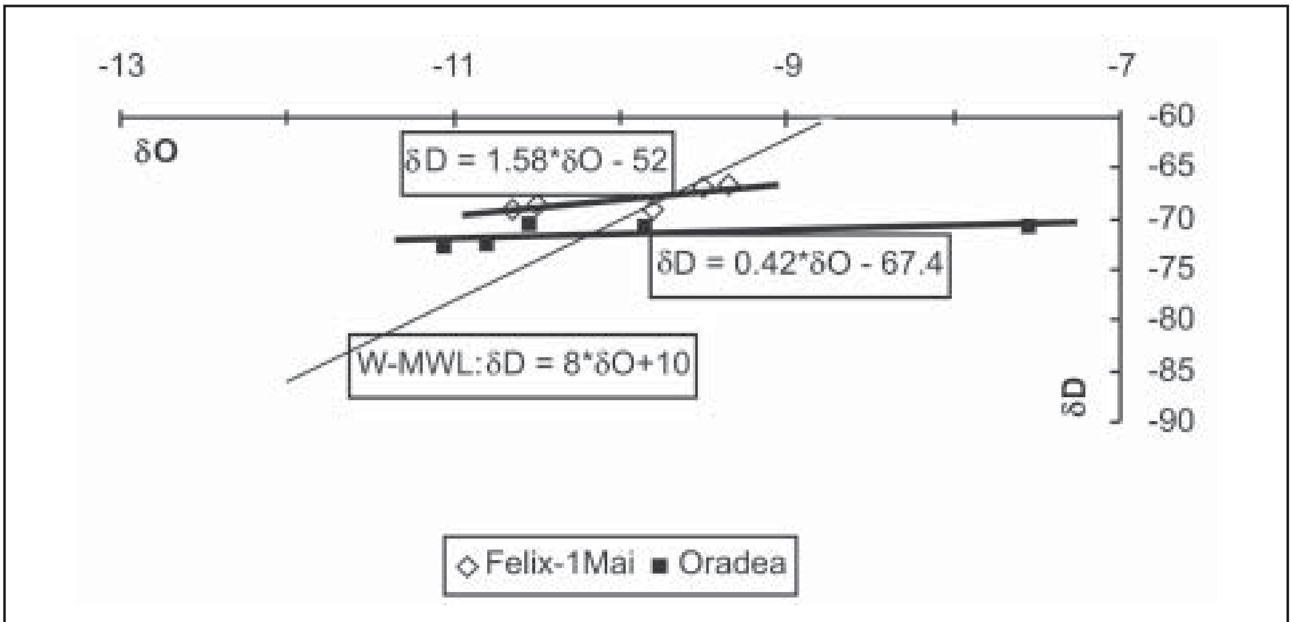

Figure 5. δD - δO diagram with the individual analyses in 1976 year for Oradea and Băile Felix & 1Mai thermal aquifers.

Lab. name	Sampling location	Sampling date	C-14 DIC (pMC)	δC-13DIC (‰)	Apparent age (years)
IIRG Pisa	F 4081 / Oradea	17.08.1976	5.4 ± 1.2	- 3.6	18,400
IIRG Pisa	F 4006 / Oradea	18.08.1976	5.8 ± 1.3	- 3.7	17,800
IIRG Pisa	F 4004 / Oradea	19.08.1976	5.3 ± 0.9		18,550
IIRG Pisa	F 4005 / Oradea	20.08.1976	5.1 ± 1.1	- 3.5	18,870
IIRG Pisa	F 4767 / Oradea	21.08.1976	1.7 ± 0.6	- 3.2	27,950
INMH Bucureşti	F 4767 / Oradea	10.09.1987	9.6 ± 3.1	- 20.2	13,640
INMH Bucureşti	F 4005 / Oradea	11.09.1987	5.5 ± 4.6	- 15.0	18,250
INMH Bucureşti	F 4797 / Oradea	12.09.1987	16.2 ± 7.6	- 15.0	9,320

Table 5. Carbon isotope analyses performed for thermal waters in Oradea area (from Țenu, 1981 and 1987). The apparent ages were recalculated according: t = 8267*ln A°/A, where T½ = 5730 ± 40 years; A° = 50 pMC.

tion discharge from 75°C at a discharge of 3-4 L/s to 130°C at a discharge of over 20 L/s. A temperature of 152°C was recorded at a depth of 3000 m (well 4157).

As after the start of the exploitation, in 1977, the pressure of the aquifer was dropping fast, they experimented for a period of 15 years the doublet type exploitation regime by re-injecting thermally used water or even mixed up with fresh water.

The aquifer is exploited in an energetic purpose (for the warming of green houses) but has limited economical perspective.

5.3.2. Hydrochemistry

From the chemical point of view, the geothermal waters from Borş aquifer are strongly mineralized, of chlorine-sodium-hydrogen carbonated type, with a high organic charge (235 mg/L) and little content of phenols (0.4 -2.7mg/L). They have a moderate toxicity. In the case of pressure drop below 12 bars, they have the tendency to deposit a $CaCO_3$ crust; the maximum deposition intensity is at 3-4 bars. The chemical parameters listed below can better define the hydro-chemical particularities of this aquifer:

Dry residue: = 7.4 – 12.7 g/L;
SO_4^{2-} =120 – 440 mg/L;
HBO_2 = 223 – 414 mg/L
Cl^- = 3000 – 7600 mg/L;
Na^+= 2700 – 5000 mg/L;
Ca^{2+} = 100 – 180 mg/L
HCO_3^- = 1500 – 2100 mg/L;
Volatile substances = 400 mg/L

Within the aquifer the pH is 7, but at the surface it stabilizes itself to 6-6.5, the water becoming aggressive and corrosive to metals.

5.4. Arguments for the model of a unique hydro-geothermal system Oradea - Băile Felix and 1 Mai

Our fundamental knowledge on geothermal aquifers in Oradea - Băile Felix and 1 Mai area are coming almost totally from two decades, 1968-1988.

From the geological point of view, we have to take into account the existence of a thick layer of Mesozoic limestone deposits, partially fissured and karstified, which continue from the mountain area Pădurea Craiului – where there are exokarstic phenomena – to the west, deepening tectonically and monoclinally under the deposits of the Pannonic Depression (Figures 2 and 3). These limestone deposits are deeply affected by two fissure systems which direct, mainly towards west, the recharge waters infiltrated in the mountain area, but facilitate, after their warming in the deep layers of the aquifer, the convective redistribution in the area.

The Borş hyper-thermal aquifer lies next the border with Hungary, near the locality with the same name; it is situated within Triassic limestone but is practically a hydro-dynamically closed structure, being tectonically isolated in a sunken graben between two raised crystalline compartments, to the east and west. The water has high temperatures (75-130°C) but is also highly mineralized (7.4-12.7 g/L). The aquifer is exploited for energetic purpose, but has a limited perspective, because it necessitates re-injection.

The Oradea and Băile Felix &1 Mai thermal aquifers, although they are situated in formations with different ages (Triassic and Lower Cretaceous) and are situated at completely different depths (2000-3000 meters, 50-300 meters respectively) forms a unique and open system, being tightly interconnected. Without presenting the characteristics again, we will succinctly stop on the systematization of arguments that sustain the uniqueness and openness of the system and also the interconnection of the two thermal aquifers.

The uniqueness of the system was proven by two elements, namely (Ţenu,1981):

- Stable isotopes, which pointed out for both aquifers an identical recharging component from the isotopic composition point of view;
- The unitary reaction of the two aquifers after the major earthquake in Vrancea area from 04.03.1977, which manifested through:
  - increase in total mineralization and a modification of ionic proportions (the increase in the HCO_3/SO_4);
  - clearly "negativation" in the ^2H and ^{18}O contents.

The open character of the system, which implies the existence of a continuous recharge, is sustained by two categories of arguments (Ţenu, 1975, 1981):

- by radioactive isotopes, ^3H and ^{14}C, which demonstrated:
  - the fact that thermal waters of the both aquifers, although being relatively old waters according the evaluated residence times, are part of the active hydrological cycle;
  - the existence of a recent recharge component, by about 1/8 of the resource, which can occasionally activate and can be felt especially in the 1 Mai resort area;
- by the good time stability of the physical and hydro-chemical parameters as well as the exploited yields (as long as they maintain in the recharging limit).

Interconnectivity of the aquifers was especially demonstrated by interference tests made on both aquifers, during 1979 by Paal, (cf. Cohut, 1986) and respectively during 1984 by Paal and Cohut (cf. Bretotean et al., 1998), establishing:

- the prompt and unique reaction of the whole system to quantitative impulses;
- the total exploitable resources of the system at 300 L/s (210 L/s in Felix and 1 Mai resorts and 90 L/s in the Oradea area).

As a consequence of the open system character and also following of an exploitation rate next – sometimes probably over – to the limit of exploiting resources are to be noted:

- continuous diminishing of apparent averages ages evaluated by radiocarbon;
- progressive "negativation" of carbon-13 in both aquifers with more than 10 δ units in 10 years;
- progressive increasing, over the last 100 years, of HCO_3 ion quantity in the waters from Felix spa.

A periodic monitoring of these geochemical indicators should be an useful tool in order to maintain, on the one hand, the equilibrium between recharge and total exploited yields in the system and, on the other hand, between the two aquifers yield rates.

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