Among the regional works, we have to mention those which belong to H. Stille (1953), I. Băncilă (1958), I. Preda (1959, 1964), V. Ianovici (1961), and also V. Mutihac (1964).

O. Mirăuţă and Elena Mirăuţă (1966-1967) have brought significant contributions regarding the Triassic limestones and dolomites from the Cataloi, Zebil, Agighiol regions and also on the composition of the Paleozoic and Triassic deposits in the Tulcea unit.

Making a synthesis of all the existing data, Patrulius et al. elaborates a work on the Paleozoic (Part I, 1973) and Mesozoic deposits (Part II, 1974).

Elena Mirăuţă, alone or in cooperation (1970, 1972, 1979, 1980, 1981, 1983), performs biostratigraphic studies and researches, and A. Baltreş (1981, 1982, 1984 and 1985) performs sedimentologic researches.

Micu et al. (1991) elaborates a synthetic study regarding two areas, Turcoaia-Cîrjelari-Ciucurova and Tulcea-Mihail Kogălniceanu-Babadag-Ceamurlia de Jos, in which he uses all the geological, geophysical and drilling data which have been executed until that date.

Among the first hydrogeological considerations on the Northern Dobrogea, we have to mention those made by R. Ciocîrdel and Em. Protopopescu-Pache (1958) in a paper concerning the hydrogeology of the entire Dobrogea area.

Between 1958 and 1960, The Enterprise for Drillings and Special Geological Works (I.F.L.G.S.) performed hydrogeological drills for water supply in a few regions, the obtained data being also found in reports and studies.

S.C. Prospecţiuni S.A. (1988, 1989, 1995) and PROED S.A. (1989) elaborated hydrogeological studies in smaller or larger areas, and their objective was to find out the hydrogeological conditions in some mining areas (Iulia and Altân-Tepe), or to evaluate the groundwater reserves and resources for Tulcea County, or for sectors within it (the Babadag basin).

2. Geological and structural description

Nowadays, there are two views on the structure of this area: a. overthrust nappes (which generated four units), particularly argued by geophysical data and b. scale-folds, based on the interpretation of the results supplied by the structural drillings and by some exploration drillings.

Considering the results obtained until nowadays, the pre-Upper Cretaceous formations have been assigned to two units: Măcin unit and Tulcea unit, which have had different geotectonical evolutions (Micu et al. 1991).

The Babadag basin is developing both in the Măcin unit and in the Tulcea unit (Fig. 1).

Măcin unit represents the Northern Dobrogea sector, located between the Peceneaga-Camena and Luncaviţa-Consul faults, and it mostly consists of metamorphic Precambrian formations (the Boclugea and Megina series) and ankimetamorphic Paleozoic deposits (Silurian, Devonian and Carboniferous formations) which are passed through by granite intrusions (rhyolites and granites), belonging to the pre-Carapelit age. In the southern region of Măcin unit, close to the Peceneaga-Camena tectonic line, there are Triassic

Figure 1. Hydrogeological map of the Babadag basin.
Legend:
1 - Mesozoic carbonate deposits (w_2; w_2-an_1; an_{1+2}; an_3-ld_1; ld_2+cr_3; cm; tu; co);
2 - Alluvial deposits, loess deposits (qp_3+qh);
3 - Breccia limestones, breccias, limestones (ox-kim);
4 - Sandstones, marls, conglomerates (J_2);
5 - Limy or quartzitic sandstones, argilaceous shales (cr_3+no);
6 - Basalts (β);
7 - Conglomerates, quartzitic sandstones, breccias (w_1);
8 - Breccias, conglomerates, tuffs (P);
9 - Sandstones, clays (C_1);
10 - Quartzitic rocks (D);
11 - Gray-blackish pelites, sandstones (S);
12 - Rhyolites (σ);
13 - Granites (γ);
14 - Quartzitic sericitous schists, gneisses, amfibolites;
15 - Geological boundary;
16 - Unconformity boundary;
17 - Normal fault (a-certain; b-interpretation);
18 - Reverse fault (a-certain; b-interpretation);
19 - Anticline;
20 - Syncline;
21 - Perennial surface course;
22 - Temporary surface course;
23 - Locality;
24 - Spring discharge (l/s);
25 - Water well;
26 - Group of water wells;
27 - Limit of the hydrographic basin checked by hydrometric gauging sections;

and Jurassic formations (Upper Anisian - Lower Ladinian, Middle Jurassic and Oxfordian-Kimmeridgian), and also massifs of granite and rhyolite, and their age is between Permian and Jurassic.

Most of the eastern Babadag basin is located in **Tulcea unit**. It consists of a metamorphic bedding (the Boclugea and Megina series), Paleozoic deposits, a Triassic and Jurassic sedimentary cover (where the predominant carbonate package in the superior Middle Werfenian-Carnian interval is differentiated and it can reach an approximately 1000 m thickness) and the alpine magmatites associated to the Triassic deposits (rhyolites, tuffs).

In Babadag basin, a post-tectonic cover containing Upper Cretaceous formations envelops most of the Măcin and Tulcea units.

The researches have established that the region has two distinct formations: the Iancila (Cenomanian) and the Dolojman (Turonian-Coniacian) formations.

The Upper Cretaceous in the Babadag basin presents a quite great thickness (an average of approximately 600 m) and it consists of sandy limestones, limy conglomerates (Cenomanian), yellowish limy sandstones, white sandy limestones (Turonian) and white sandy limestones, limy conglomerates, marly limestones and yellowish sandy limestones (Coniacian).

The entire Dobrogea region is characterized by the presence of the loess or the loessoid deposits (Upper Pleistocene + Holocene). The thicknesses of these deposits vary from a few meters to 150 m.

The loess – a mobile unconsolidated rock – was initially deposited on a pre-existent relief, but the subsequent erosion has removed it from the higher ground and re-deposited it in the valleys.

The deposits of the Neo-Cretaceous cover are interpreted as a weakly sinuous synclinorium, with a few sectors of brachyanticlinal and a few brachysynclinals (ex.: Uspenia-Fântâna Mare; Nicolae Bălcescu; Caugagia-Jurilovca). The gradient of the strata rarely exceeds 5-10°, but it can reach 20°.

The longitudinal (NW-SE) and transversal fracture systems (ENE-WSW) are the main tectonical elements of the region.

The most important fractures, belonging to the first system, are Luncaviţa-Consul, Meidanchioi-Iulia and Peceneaga-Camena faults.

The second system, with an ENE-WSW, E-W orientation, has triggered significant dislocations of the above-described system, the phenomenon being visible in the Consul Hill area.

The geological basis according to Szàsz et al., 1980, 1981 and Micu et al., 1991, with modifications, has been used when elaborating the hydrological map of the region.

3. Hydrogeology of the Triassic and Cretaceous carbonate deposits

The mainly Triassic and Cretaceous carbonate rocks represent the major reservoir of the Babadag region.

Although the Triassic and Cretaceous deposits are predominantly carbonate and they fill a consistent surface in the basin, the karst phenomena are almost inexistent. The causes of this absence are either the composition of the rock, in our case the passings through being permanent, from sandy limestones to limy sandstones and vice-versa, or the climate factors, which are unfavorable to karstification processes in Dobrogea (low precipitations and high temperatures).

The above-mentioned carbonate deposits have a similar hydrogeological behaviour. Being fissure permeability rocks due to their intense tectonic past, in time this leads to the accumulation of large quantities of water and facilitates its circulation.

Triassic deposits. In the northern Babadag basin, in the region between the Consul Hill (NW) and Nicolae Bălcescu village (SE), the Triassic succession, predominantly calcareous, intensely fractured, has allowed the composition of an important reservoir. This one has a NW-SE development and it is comprised between the two important fractures in the region, the Meidanchioi-Iulia (NE) and Luncaviţa-Consul (SW) faults.

The Triassic aquifer is discharging through a few springs, located in the Consul Hill and in the south of the Nicolae Balcescu village.

The springs in the Consul Hill's northern side are perennial, having a flow of up to 0.3 l/s.

The spring at Nicolae Bălcescu emerges from the fissured Lower Triassic limestones. The main fissure, with a N 40 E/70-80° NW orientation, is 5-6 meters high and 3-4 meters deep. This spring has had a particular evolution along the years. Until the autumn of 1987, when it disappeared, it had a flow of 10-15 l/s. In May 1989, it appeared again with a 6-8 l/s flow, after which it has disappeared again. All these fluctuations of the spring have been strongly related to the mining activity in the Iulia region (approximately 5 km NW of Nicolae Bălcescu). The performed mining works have encountered significant volumes of water (up to 80-100 l/s according to Iurkiewicz, 1989) which had to be evacuated. This fact resulted in the disappearance of the spring. After finishing the mining activity, in the spring of 1990, within a few months, during the autumn of the same year, the spring appeared again.

During the period between December 1993 and November 1994, the flow of the spring varied between 5.60 l/s and 9.20 l/s, but this variation has not been correlated with the precipitations recorded in the region, at least not in the surveyed period.

Although the spring appears again from Triassic limestones, its supply area is constituted, besides the above mentioned limestones, of predominantly Cretaceous limestone deposits, which can be found south and south-west of Nicolae Bălcescu (Cazu Mare Hill, Cariera Hill).

In the mining region Iulia, radioactive and radio-activable tracers have been performed in order to determine the flow directions and velocities of the groundwaters. The results show theoretical flow velocities between 10-100 m/h for the NW-SE orientation and 5-10 m/h for the SSW-NNE orientation (Iurkiewicz, 1989).

The obtained flowing directions and velocities of the groundwaters have been influenced by the mining activities, their finishing causing modifications in the above mentioned parameters.

The karst dissolution process has created dry valleys and several exokarstic microrelief zones (grikes) on the Triassic limestone areas (south of Nicolae Bălcescu, Consul Hill).

Immediately to the east of Enisala village, at the basis of the Siniş Petcu Hill's northern side, two temporary springs appear from Triassic limestones. Their flow is below 0.1 l/s.

Investigated by I.F.L.G.S. through exploration hydrogeological drills (Iulia region), the Triassic aquifer has a good flow capacity , with values between 3.10 and 5.30 l/s.

Cretaceous deposits. Taking into consideration the outcrop area (approximately 330 km^2), the thickness (approximately 600-700 m in the central area), the lythological composition and the degree of fracture and fissure of the Cretaceous deposits, one can assert that they compose a reservoir with significant possibilities for the groundwaters to accumulate and flow.

The Cretaceous deposits of the Babadag basin describe large undulations which are characteristic to the platform deposits, generally presenting a synclinorium shape, oriented NW - SE. These deposits occur beginning with Taiţa Valley (in the north) up to Peceneaga-Camena fault (in the south) and from the region of Traian village (in the west) up to the Razelm Lake (in the east).

In 1983, M. Pascu described the following hydrostructures within the basin: Nicolae Bălcescu, Başpunar (Fântâna Mare)-Uspenia, Slava Cercheză-Ciucurova, Traian (west of Atmagea) and Caugagia-Jurilovca.

In some regions, such as Nicolae Bălcescu or Fântâna Mare, where the Cretaceous deposits are close to Triassic ones, we encounter an unique aquifer.

If in the south the Peceneaga-Camena fault functions as a hydrogeological barrier, in the north the Cretaceous deposits can receive water from the Triassic limestone rocks.

The Cretaceous aquifer recharges from rainfall. In the areas where the carbonate deposits are covered with highly permeable loessoid deposits, the latter ensure a good drainage.

Considering the structure of the Cretaceous carbonate deposits for most of the Babadag basin, the main discharge of the aquifer is made by a series of submerged springs which (probably) supply the coastal lakes (Razelm, Goloviţa). In the Traian region, the structure's sinking towards the Danube makes the groundwater circulate towards NW.

Among the sources found at the northern end of the basin, we have to mention the spring at Cloşca and the springs at Babadag.

The spring in Cloşca village, of which flow has varied between 2.30 l/s and 4.30 l/s, appears from the Turonian limestones and limy sandstones which are covering the impermeable formations of Boclugea series (muscovite and quartite schists).

At Babadag, where the predominantly limestone deposits of Cenomanian make contact with the limy or quarto-feldspathic sandstones of the Alba formation (Upper Carnian + Norian), which have a lower conductivity in this region, behaving as a screen, several springs appear. Among them, more important are the spring at Geamie and the spring on Măcinului Street, both of them being permanent and with flows between 7.1 l/s and 15.3 l/s for the first spring and between 2 l/s and 3.3 l/s for the second one.

At the exit from Babadag town towards Tulcea, on the left, there is a spring with a flow about 0.6 l/s.

In the southern part of the basin, close to Peceneaga-Camena fault, there are a few more significant springs. The spring of the Slava brook, which is in fact a spring area, with a total flow of maximum 10 l/s, appears close to the Turonian (sandy) limestone deposits. In this place, these deposits lie over a marly-sandy complex (the Aiorman formation), with a low permeability.

In Fântâna Mare village, on the left side of Slava brook, there are several springs, with flow rates between 0.05 and 13.4 l/s. Among them, the most important one, used for the water supply of a part of the village, has a flow rate between 2 l/s and 13.4 l/s (December 1993 - November 1994). The spring emerges from the Coniacian carbonate deposits.

The hydrogeological basin of the Fântâna Mare springs is bordered by the Peceneaga-Camena fault line in its southern-western part and by the course of the Ciucurova valley in its northern-eastern part.

Towards the interior of the Babadag basin, the Cretaceous aquifer has very few springs, as it lies very deeply in the ground and the relief energy is rather low. A few permanent springs emerges, with flow rates between 0.1 and 2 l/s.

Although some of these springs emerge from loess deposits, they are connected to the fissural aquifer existing in the Cretaceous carbonate deposits.

The hydrogeological wells drill in the western part of the basin (Ciucurova, Slava Cercheză), which opened the Cretaceous aquifer, present piezometric levels at low depths (0-19.5 m), flow rates between 0.008 l/s and 11 l/s and drawdowns up to 26.5 m).

In the eastern part of the basin, the wells are mostly grouped in the southern part, between Ceamurlia de Jos and Jurilovca villages, close to Ceamurlia and Goloviţa lakes. Their objective was the Cretaceous carbonate aquifer and they had flow rates between 0.3 l/s and 33.3 l/s (drawdowns up to 26.7-60 m).

Several of these wells are not in service any more.

The diversity of the water flow rates values reflects both the importance of this aquifer flow capacity and its irregular extension (due to the inhomogeneous distribution of fissures).

4. Hydrogeological balanceof the Babadag basin area

Out of the de 815 km^2 surface for which the hydrogeological balance has been elaborated, the predominantly carbonate deposits (Triassic + Cretaceous) crop out on 47% (332 km^2) of the area, these ones being covered by loessoid deposits. On very restrained areas, there are crystalline, eruptive and a few consolidated sedimentary deposits.

The total rainfall for the hydrological year 01/12/1993 - 30/11/1994 recorded by the basin's rain gauging stations was relatively low: 246.7 mm at the Satu Nou (15 m elevation a.s.l.), 299.1 mm at Horia (55 m elevation a.s.l.) and 308.1 mm Ceamurlia de Jos (5 m elevation a.s.l.).

The determination of the losses through evapotranspiration at the ground surface in the concerned area, for the same period, have been performed on the basis of the data resulted from the direct measurements at the Horia station. The value of the measured real evapo-transpiration was of 266 mm.

The hydrometric measurements and observations were used to draw up a clear picture of the Taiţa, Tăiţa and Slava valleys' hydrological regime.

The Table 1 shows the following aspects:

- low values of the precipitations, also involving the low values of the runoff and of the infiltration:
- high values of evapotranspiration (close to those of the precipitations);
- the consequence of the first two aspects is represented by the low flows recorded for runoff and for infiltration;
- the negative value of the infiltration obtained for the surveyed hydrographic basin sector of Taiţa

valley suggests the existence of some underground supplies of water coming from other hydrographical basins.

For the mentioned hydrologic year, the precipitations fallen on the surface of 815 km^2 have created an availability of water for runoff and for infiltration of 437.7 l/s (319.4 l/s and, respectively, 118.3 l/s).

The infiltrated water supplies the aquifer which is partly discharged through the few springs which appear on the basin's area, the rest of them being drained by the lakes placed in the eastern area.

5. Hidrochemical considerations

The sources tested in the Babadag basin region (springs, wells), according to the type of rock the reservoir is made of, presents a calcic and/or magnesic bicarbonate water, with total mineralizations between 595 and 1205 mg/l.

The ratio between Ca^{2+} and Mg^{2+} is favourable to the first element in the case of the waters flowing through limestone deposits.

We have to mention the high values of the total hardness (15.7-49.4°dH) for most of the tested sources.

In the case of a few tests, high contents of Cl^- (287.2-638.1 mg/l), SO_4^{2-}(248.8-349.9 mg/l) and Ca^{2+}(1085.2-164.3 mg/l) have been recorded.

6. Conclusions

In the Babadag basin, the only formations able to contain aquifer accumulations are the Triassic and Cretaceous predominantly carbonate deposits, made up of fissure permeability rocks, as a result of the numerous fractures in the region.

The main flow direction of the groundwaters, eastwards, is determined by the axial sinking of the structure towards that direction.

The Cretaceous aquifer recharges mainly from precipitations.

All around the basin, except the Iulia-Nicolae Bălcescu region, where there can appear underground water supplies from the Triassic carbonate deposits placed in adjacent hydrogeological basins, there are no supplies of groundwaters.

The most important sources are located near the basin limits, where the carbonate deposits make contact with impermeable formations or tectonic accidents. Inside the basin, the Cretaceous carbonate aquifer does not communicate with the surface due to its significant distance from the ground and to the low relief energy in the region.

Despite the generalised outcrop of the predominantly carbonate deposits and their thickness, the formations' reservoir has an irregular hydrogeological behaviour. This is the result of both a low supply of water, and of the differences in tectonics – implicitly, of the collector's lack of homogeneity. The drilling data confirm the aquifer's flow capacity and its lack of uniformity.

References

Bandrabur Gh., Radu Rădiţa (1994) – Evaluarea rezervelor de ape subterane din formaţiunile carbonatice ale bazinului Babadag. Arh. S.C. Prospecţiuni S.A., Bucureşti (nepublicat).

Berbeleac I., Radu Magdalena, Proca A., Păsat T., Corneanu H., Gâdea F., Mărgărit Maria, Dobrescu Anca (1986) – Sinteza lucrărilor de prospecţiune geologică, geochimică, geofizică, minieră şi de foraj executate în unitatea de

No	Gauging station	S km²	H m	Q l/s	q_o l/s/km²	P l/s	ETR l/s	I l/s	I_o l/s/km²
1	Taiţa valley - downstream	168.0	122.0	102.7	0.6	1454.3	1417.0	-65.4	-0.4
2	Slava valley - Ceamurlia de Jos	322.0	177.0	96.4	0.3	2879.4	2716.0	67.0	0.2
3	Babadag basin - Eastern area	325.0	76.0	120.3	0.4	2978.3	2741.3	116.7	0.4
Total /*average*		815.0	*125.0*	319.4	*0.4*	*2437.3*	*2291.4*	118.3	*0.3*

S – surface of watershed; H – mean altitude of watershed; Q – runoff (at point 3 the runoff has not been measured, but it has been obtained on a graphical basis); q_o – specific annual mean discharge; P – precipitations (calculated according to the Thiessen method); I – total infiltration; I_o – specific infiltration.

Table 1. Morphometric and hydrologic data for the hydrographical basins in the Babadag Plateau region.

Măcin şi bazinul Babadag, jud. Tulcea. Arh. S.C. Prospecţiuni S.A., Bucureşti (nepublicat).
Iurkiewicz A. (1989) – Prospecţiuni pentru stabilirea condiţiilor hidrogeologice de zăcământ în zona minieră Iulia, jud. Tulcea. Arh. S.C. Prospecţiuni S.A., Bucureşti (nepublicat).
Micu C., Maxim Gh., Mihul C., Finichiu Mariana (1991) – Raport geologic privind sinteza lucrărilor geologice, geochimice şi geofizice referitoare la substanţele minerale utile solide din Dobrogea de Nord, perimetrele Turcoaia-Cârjelari-Ciucurova şi Tulcea-Mihail Kogălniceanu-Babadag-Ceamurlia de Jos, în vederea stabilirii programului de cercetare pentru treapta următoare de adâncime a mineralizaţiilor. Arh. S.C. Prospecţiuni S.A., Bucureşti (nepublicat).
Mirăuţă C., Mirăuţă Elena (1964) – Cretacicul superior şi fundamentul bazinului Babadag (Dobrogea), An. Com. Geol., Vol. XXXIII, Bucureşti.
Pascu M.R. (1983) – Apele subterane din România. Ed. tehnică, Bucureşti, pp. 358-362.
Szàsz L., Mihăilescu N., Ghenea Ana, Ghenea C. (1980) – Harta geologică scara 1: 50,000, foaia 153d. Jurilovca (L-35-118-D), I.G.G. Bucureşti.
Szàsz L., Mirăuţă Elena, Mureşan M. (1981) – Harta geologică scara 1: 50,000, foaia 153a. Babadag (L-35-118-A), I.G.G. Bucureşti.
Vâlceanu P., Vâlceanu Eliconida, Chivulescu J., Caraveţeanu Constanţa, Popescu I., Nedelcu I., Simionescu Elena, Darie Şt., Petruţ G., Proca A. (1980) – Sinteza lucrărilor de prospecţiuni geologice, geofizice, miniere şi de foraj efectuate pentru sulfuri polimetalice, minereuri de fier şi baritină în Dobrogea de Nord, în depozitele sedimentare triasice şi jurasice şi magmatitele paleozoice, în perimetrele Matca-Malcoci-v. Nucarilor şi Iulia-Mihai Bravu, jud. Tulcea. Arh. S.C. Prospecţiuni S.A., Bucureşti (nepublicat).