Δελτίο της Ελληνικής Γεωλογικής Εταιρίας τομ. XXXX, 2007
Πρακτικά 11ου Διεθνούς Συνεδρίου, Αθήνα, Μάιος 2007

Bulletin of the Geological Society of Greece vol. XXXX, 2007
Proceedings of the 11th International Congress, Athens, May, 2007

ORIGIN AND QUALITY OF THERMAL GROUNDWATERS IN THE REGION OF FARSALA (E. THESSALY/GREECE)

Stamatis G.[1*], Parpodis K.[1], Lambrakis N.[2], and Zagana E.[2]

[1] *Institute of Mineralogy-Geology, Agricultural University of Athens, Iera Odos 75, 118 55 Athens, Greece; stamatis@aua.gr*

[2] *Laboratory of Hydrogeology, Department of Geology, University of Patras, 261 10 Rio, Patras, Greece; nlambrakis@upatras.gr*

Abstract

Farsala Basin presents a remarkable geothermal interest. Areas exhibiting geothermal potential are directly related to faulted zones, represented mainly by cross-faulted systems of E-W, NW-SE and NNE-SSW direction. Thermal waters occur in the areas of Ampelia and Krini in boreholes of 420 m depth. Their temperature ranges between 20,5° and 39,1° C. Thermal waters originate from meteoric waters, which have been infiltrated and heated in great depths, moved towards the surface through faults and hosted in the aquifers of coarse - grained formations find in the area. Their chemical composition is controlled by their contact with the volcanic parts (pillow lavas) of the ophiolithic series. They show alkaline character and low salts concentration. Waters of Ampelia region, which belong to Na-HCO_3 type, exhibit temperatures from 27,9° to 39,1° C and low salt concentrations (405-607 mg/l TDS). On the contrary, waters of Krini area present lower temperatures (20,5° –26,2° C) and higher salt concentrations (734-1850 mg/l TDS). These waters belong to Na-Mg-Ca-HCO_3 and Na-SO_4-Cl-HCO_3 types. According to chemical geothermometers the study area can be classified to low enthalpy geothermal field, since the estimated thermal liquids temperature in great depths varies from 50° to 70° C.

Key words: *Thermal waters, Hydrogeochemistry, Geothermometry, Farsala basin, Greece.*

Περίληψη

Η λεκάνη των Φαρσάλων παρουσιάζει αξιόλογο γεωθερμικό ενδιαφέρον. Οι περιοχές όπου εντοπίζονται οι γεωθερμικές ανωμαλίες, παρουσιάζουν άμεση σχέση με τις ρηξιγενείς ζώνες της λεκάνης και κυρίως με διασταυρούμενα συστήματα ρηγμάτων διεύθυνσης Α-Δ, ΒΔ-ΝΑ και ΒΒΑ-ΝΝΔ. Τα θερμά νερά εντοπίζονται στις περιοχές Αμπελείας και Κρήνης, εντός γεωτρήσεων βάθους έως 420 μέτρα και κυμαινόμενης θερμοκρασία 20,5° -39,1° C. Πρόκειται για κατεισδυόμενα μετεωρικά νερά τα οποία στα βάθη αυτά φιλοξενούνται προφανώς στα ηφαιστειακά μέλη της οφιολιθικής σειράς, pillow λάβες, από τα οποία έχουν αποκομίσει την ποιοτική τους σφραγίδα. Τα διαλύματα διακρίνονται για τον αλκαλικό τους χαρακτήρα και την περιορισμένη *περιεκτικότητα σε άλατα. Στην περιοχή Αμπελείας εμφανίζονται τα θερμότερα διαλύματα (27,9° -39,1° C), με χαμηλή συγκέντρωση αλάτων (405-607 mg/l TDS) και επικράτηση του υδροχημικού τύπου Na-HCO3. Αντίθετα στην περιοχή Κρήνης εμφανίζονται διαλύματα χαμηλότερων θερμοκρασιών (20,5° - 26,2° C) αλλά υψηλότερων συγκεντρώσεων αλάτων (734-1850 mg/l TDS) και επικράτηση των υδροχημικών τύπων Na-Mg-Ca-HCO3 και Na-SO4-Cl-HCO3. Βάσει χημικών γεωθερμομέτρων εκτιμάται ότι η θερμοκρασία των ρευστών στο βάθος είναι της τάξης των 50° -70° C και ως εκ τούτου η περιοχή έρευνας κατατάσσεται στα γεωθερμικά πεδία χαμηλής ενθαλπίας.*

Λέξεις κλειδιά: *Θερμά νερά, Υδρογεωχημεία, Γεωθερμόμετρα, Λεκάνη Φαρσαλών, Ελλάδα.*

1. Introduction

The basic aim of this work is the study of the chemical characteristics of groundwater hosted in different hydro-lithological units of Farsala Basin. The existence of thermal groundwaters mainly in deep boreholes of particular areas of the basin was confirmed during the fieldwork. According to the record of water-occurrences, the water temperature measurements and the results of chemical analyses, two characteristic areas of different thermal groundwater quality were detected. The geology of the study area presents a variety of lithological types and an intense tectonic activity, which is reflected on several faulted zones. The circulation of meteoric waters in deep stratigraphic horizons and high temperature environments, in which ground thermal liquids are finally hosted, is obviously accomplished through the abovementioned-faulted zones. There is a lack in thermal liquids surface activities in the study area. This is also observed in Spercheios Basin (located southern from Farsala Basin), where a great number of thermal springs and regions of intense geothermal activity exist (Sfetsos 1988, Papadeas 1996, Gartzos *et al.* 1996). Since the local economy is based on agriculture and farming, geothermal waters, if exploited properly, could support several activities such as glass houses, farming, siccative activities and spa establishments. The paper presents the geothermal status of the area, describes the chemical character of thermal waters, interprets their origin, explains the processes taking place within the geothermal system and evaluates the temperature of the geothermal reservoir.

2. Study Area

2.1. Geological Setting

The study area takes part of the East Greece Geotectonic Unit and includes alpine and post- alpine formations (Fig. 1). The youngest post-alpine formations of the study area are consisted of a) recent Holocene deposits, alluvial sediments and talus cones, which cover the lowland of the basin, b) Neogene formations mainly of fluvio-lacustrine and lacustrine-brakish-marine origin that occupy a large area in the north part of the basin and c) Plio-Pleistocene terrestrial deposits, which are developed at the lower topographic parts of the south and east margins of the basin. The alpine formations form the sub-basement of the sediments in the major part of the basin. They consist of:

a) Flysch of Upper Cretaceous age: mainly fine-, mid- grained and in some places coarse–grained clayey sandstones, conglomerates and intercalations of marly and sandy limestones. It is located mainly at the east and north margins of the basin overlaying the Cretaceous carbonates (Bornovas *et al* 1969, Katsikatsos *et al* 1983).

b) Limestones: Upper Cretaceous transgressive limestones mainly mid – plated and in some places thick- and thin-plated, microcrystalline, karstified with marly intercalations, located mainly at the east and west margins of the basin.

c) Ophiolites: They consist of serpentinites, dunites and peridotites, underlying by the upper Cretaceous limestones and overthrusting the metamorphic formations of the Triassic-

Jurassic platform. They form the Pre-Upper Cretaceous tectonic nappe. The ophiolites consist mainly of volcanic rocks (pillow lavas) in Farsala area and in some cases of ultrabassic intense serpentinised formations. In the broad area of Orthris, pillow lavas present high alkaline concentrations (Na_2O: 3,4-5,4% και K_2O: 0,1-1,7%) (Ferriére 1982). Intense fractured and seprentinised ultrabasic bodies with important chromite concentrations appear in the east part of the basin (Eretria area). The Ophiolite masses overlay the Jurassic Schists (Katsikatsos *et al* 1983, Migiros 1990).

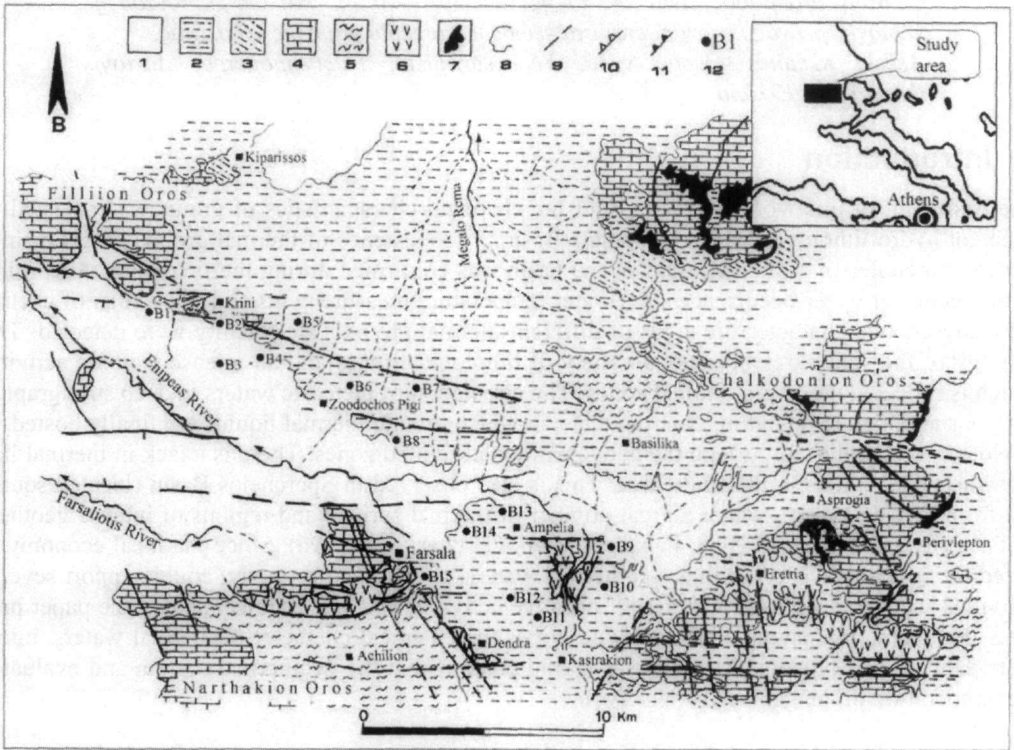

Figure 1 - A simplified geological map of the study area (Bornovas *et al.* 1969, Katsikatsos *et al.* 1983, Mariolakos *et al.* 2001b), (1: Holocene deposits, 2: Neogene formations, carbonates, marls, conglomerates, sands, etc, 3: Flysch of Upper Cretaceous, 4: Limestones of Upper Cretaceous, 5: Schists and phyllites of Upper Cretaceous and Jurassic, 6: Ophiolites of Pre-Upper Cretaceous tectonic nappe, 7: Paleocene Olistholiths and Olisthostromes "Krini formations", 8: Geological boundary, 9: Fault, 10: Overthrust pre-uppercretaceous, 11: Overthrust post- uppercretaceous, 12 : Sampling boreholes for chemical analyses

d) Schist – formations: The southern part of Farsala Basin is covered by schist and hornfels formations, which consist of clayey schists and cherts with conglomerates and limestones intercalations. The schists in the east part of the study area are chloritic–sericitic– epidotic, intensively alternating with marbles, sipolines and crystalline intercalations. Their visible thickness is approximately 400 m and they are probably of Jurassic Age (Bornovas *et al.* 1969, Katsikatsos *et al.* 1983).

e) Olistholiths and Olisthostromes: They consist of serpentinites, diabasic-dioritic-grabbro rocks, carbonate and dolomite parts, which have been deposited unconformably on the above-mentioned formations. They form a particular tectonic unit known as "Krini formations" (Katsikatsos *et al.* 1983). These formations are restricted northern of Chalkodonion Mounatin and east of Eretria.

The tectonic structure of the study area is characterized by E-W trending faults, which mainly control the basin development and by NNW-SSE trending faults (Fig. 1).

2.2. Hydrogeology

Three different aquifer types occur in the study area, which are related with the various lithological units. An unconfined aquifer of important potentiality is developed in the unconsolidated deposits of the basin and suffers from overexploitation due to the supply of the irrigation needs of the area. The thickness of the unconsolidated deposits ranges from a few meters eastern of the basin to a few ten meters westwards, to more than 200 m in the central and northern parts of the basin, particularly within the tectonic grabens (Mariolakos *et al.* 2001a, 2001b). Groundwater flows from the east to the west parts of the basin. The absolute groundwater level reaches 140 m asl in the east part, whereas in the west part is 110 m asl. Generally, due to the overexploitation of the unconfined aquifer, a groundwater level decrease is observed, which is calculated at 3-6 m/a. (Kallergis *et al.*1970, Mariolakos *et al.* 2001a, 2001b). A karst aquifer of important potentiality is developed within the karstified carbonate formations. The major karst springs of the region, such as Vrisia and Chtouri springs, located west of the Farsala city, are fed from the carbonate formations of Narthakio and Filio Mt in the west part of the basin. The discharge of these springs shows an obvious decrease and falls dry in hot periods. This could be also attributed to the overexploitation of the karst aquifer (Mariolakos *et al.* 2001a, 2001b). The carbonate masses developed in the east part of the basin probably feed laterally the unconsolidated formations of the basin. An aquifer of low potentiality is developed in the fractured crystalline formations. The discharge of the deep boreholes in the ultrabasic rocks does not exceed 30 m^3/h. Within the Neogene sandy and carbonate horizons an aquifer of low potentiality occurs. The discharge of the boreholes, when the formation thickness and structure are favourable, reaches the 20-30 m^3/h.

3. Methodology

All boreholes in the study area were recorded during July and August 2005. In a network of 95 equally distributed boreholes in the study area, temperature measurements were taken during their pumping. Samples for chemical analyses were collected from 15 boreholes, according to their temperature and origin region. Physicochemical parameters were measured in situ with the use of portable devices: T^0C and EC (WTW/LF-330), pH (WTW/pH-330i) and dissolved oxygen DO (WTW/OXI-96). Titration methods were used for the determination of CO_2, and H_2S concentrations. Samples were collected in plastic polyethylene bottles and analysed for Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, NH_4^+, PO_4^{3-}, I^-, F^-, Br^- B^-, SiO_2, total and carbon hardness. For the determination of Fe, Mn, Cu, and Zn samples were collected and preserved in the field. They filtered, acidified to pH<2 with upltrapure HNO_3 and then collected in 100 ml plastic polyethylene bottles. All chemical analyses were conducted in the laboratory of Mineralogy-Geology Institute at the Agricultural University of Athens. Cations were determined using atomic absorption (GBC-908AA), while anions apart of Cl^-, were measured with spectrophotometer (HACK-DR/3000). For the assessment of total and carbon hardness as well as Cl^-, titration methods were applied: Titriplex-Lösung A, HCl 0,1N and $AgNO_3$ 0,1N respectively (Höll 1979).

4. Results

4.1. Geothermal study

The study area takes part of the broader area of East Sterea, where a heat flow increase is observed, related to the late orogenetic volcanism and the creation of the South Aegean Volcanic Arc (Fytikas *et al.* 1979). The late orogenetic volcanic centers of Lichades (North Evoikos Gulf) and Mikrothives (NE Orthis Mt) evidence the northwest end of the Volcanic Arc into the study area. Figure 2 presents the groundwater temperature distribution according to the measurements from a 95-borehole network. The temperature was measured during the pumping of groundwater samples.

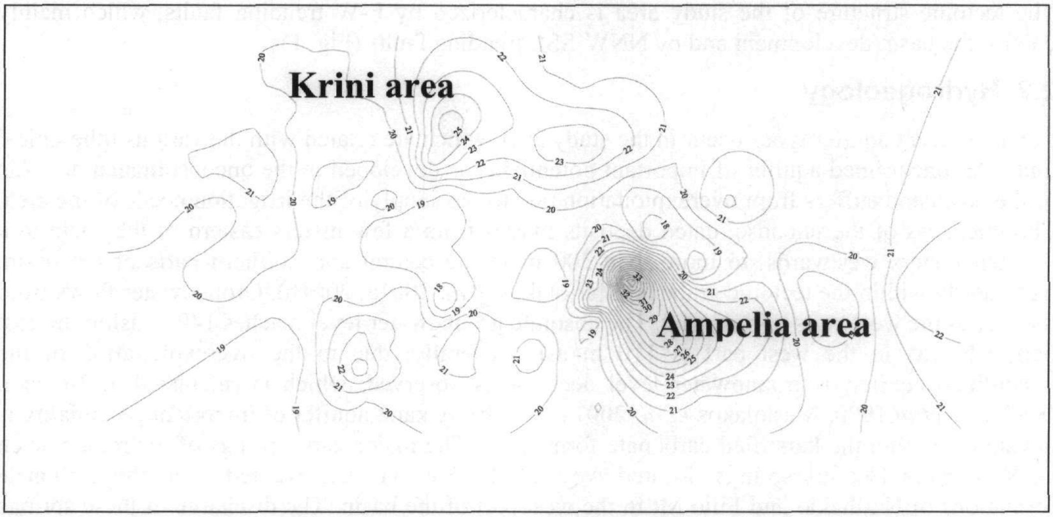

Figure 2 - Groundwater temperature distribution in Farsala Basin

The lowest temperatures ranging from 16,5° C to 19,5° C are observed in boreholes in central and west parts of the alluvial basin. These boreholes are located in depths from 45 to 312 m and many of them reach negative levels up to –170 m (below sea level). Thermal waters in boreholes located in depths between 100 and 150 m reveal temperatures from 16,5° C to 18,5° C, while thermal waters of greater depths exhibit temperatures from 18,5° C to 19,5° C. This temperature increase indicates the presence of geothermal activity in deeper aquifers. The groundwater temperature of the region between Krini and Zoodocho Pigi communities (Fig. 1) in the northwest part of the study area reaches 26,2° C (borehole B5). The borehole B5 is located in a 350m depth and reaches negative levels up to -130 m (bsl). Temperature increase is also observed along the zone of the north slopes of the basin, which coincides with the fractured zone of the area. The groundwater temperature in the boreholes of this area ranges from 21,2° C to 24,2° C. Thermal groundwaters of 39,1° C temperature are recorded in the region between Dendra and Ampelia communities (Fig. 1) in the central-south part of the study area. The borehole B13, where the highest temperature value is observed, is located in a depth of 400m and reaches -200 m bsl. According to Thurner (1967) and based on the temperature measurements, thermal waters of the study area are classified as slightly thermal (20 ° -25 ° C), thermal (25 ° - 32 ° C) and very thermal (>32 ° C). Thermal waters from B13 belong to the third type, whereas B3, B5, B11, B12 and B15 boreholes belong to the second group. The rest of the boreholes belong to the first type.

4.2. Chemistry of thermal waters

Chemical data from all samples of the study area are provided in Table 1. Thermal groundwaters of Krini and Ampelia areas display differences not only in temperature but also in their chemical character.

In Krini region, the groundwater temperature ranges from 20,5° C to 26,2° C. Thermal waters exhibiting the highest temperature of 26,2° C (borehole B5) in this region, present also the highest conductivity (2170 μS/cm) and the highest TDS value (1850 mg/l). Electrical conductivity and TDS values of the rest thermal groundwaters vary from 795 to 1146 μS/cm and from 734 to 979 mg/l respectively. They present alkaline character (7,3-8,1 pH) and low O_2 concentration (1,6-5,7 mg/l). The CO_2 concentration ranges from 18 and 32 mg/l, whereas the H_2S concentration varies between 0,3 and 1,8 mg/l. The Borehole B13 with the highest temperature (39,1° C) of the study area is located in Ampelia region. In the other boreholes of Ampelia region the groundwater temperature ranges between 22,4° C and 28,8 ° C. Thermal groundwaters of Ampelia area are characterized by low TDS values (405-942 mg/l TDS), low electrical conductivity values (366-

1091 μS/cm) and high pH values (7,8 and 8,7). They present low O_2 concentration (0,2 – 5,4 mg/l). The CO_2 concentration ranges from 14 mg/l to 30 mg/l, whereas the H_2S concentration varies between 1,2 mg/l and 5,6 mg/l. The thermal waters (borehole B16) with the highest temperature of 39,1° C present the lowest TDS value (405 mg/l). In figure 3 is shown thermal waters of Krini and Ampelia region in a Piper diagram. Thermal waters of Krini region present the following hydrochemical types: a) Mg-Na- HCO_3 (B3, B6, B7, B8), b) Na-Mg-Ca- HCO_3 (B2, B4) and c) Na-SO_4-Cl-HCO_3 (B5). The most thermal waters of Ampelia region present an indeterminate type of Mg-Ca-Na-Cl-HCO_3 (B9, B10, B12, B14, B15). Thermal waters from B11 and B13 exhibit the types Na-Cl-HCO_3 and Na-HCO_3.

Table 1 – Results of chemical analyses

	Thermal waters of Krini area T: 20,5-26,2^{0}C								**Thermal waters of Ampelia area** T: 22,4-39,1^{0}C						
Boreholes	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
Sampling	12.7.05				13.7.05				14.7.05						
Abs. Allt. (m)	133	152	131	162	223	182	215	181	212	262	273	264	203	194	212
Depth (m)	250	100	220	180	350	80	420	100	160	100	300	400	400	200	250
Q (m^3/h)	30	40	30	50	70	80	55	40	45	50	60	70	110	65	55
T ^{0}C	20.5	21.2	25.2	23.2	26.2	23.2	24.4	21.2	22.4	23.6	28.8	27.9	39.1	24.3	26.2
EC μS/cm	795	1146	795	868	2170	1050	960	970	587	865	675	655	366	1091	434
pH	7.3	7.4	7.6	7.5	7.9	7.6	8.1	7.7	7.8	7.1	7.9	7.8	8.7	7.2	7.8
O_2 mg/l	5.7	5.2	4.1	4.5	..	1.7	..	1.6	5.4	4.8	0.7	0.4	0.2	1.4	0.6
CO_2 mg/l	18	22	28	20	32	24	28	20	24	22	14	30	20	28	32
H_2S mg/l	0.6	1.6	1.4	0.8	1.8	1.2	1.2	0.6	1.4	1.2	4.2	2.1	5.6	2.4	1.8
Tot. Hardn. ^{0}dH	21.8	28.1	13.6	17.2	24.2	23.7	22.5	20.0	11.2	22.0	5.0	9.5	1.8	27.4	11.0
Temp. " ^{0}dH	17.6	17.1	17.4	21.8	17.9	24.4	23.2	21.3	12.9	16.8	11.2	14.3	8.4	19.6	10.6
Perm. " ^{0}dH	4.2	11.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	7.8	0.4
Ca^{2+} mg/l	77.6	92.0	36.0	46.4	84.0	44.8	48.0	32.0	33.6	108.0	23.2	36.8	8.1	92.0	30.4
Mg^{2+} mg/l	47.5	66.1	37.2	46.5	53.9	75.8	68.7	67.5	28.4	30.0	12.2	19.1	3.1	63.0	29.5
Na^+ mg/l	38.8	59.8	100.2	96.9	413.0	99.6	100.0	107.2	60.4	60.4	130.0	103.5	89.6	69.0	25.3
K^+ mg/l	1.1	10.0	3.0	1.4	4.0	4.0	3.6	3.6	1.4	2.8	2.5	2.0	1.4	1.2	0.6
NH_4^+ mg/l	0.01	0.65	0.98	0.15	..	7.43	1.51	0.21	0.00	0.04	0.19	0.17	0.26	0.52	0.00
HCO_3^- mg/l	384.3	372.1	378.2	475.8	390.4	530.7	506.3	463.6	280.6	366.0	244.1	311.1	183.1	427.1	231.8
Cl^- mg/l	53.2	92.2	67.4	53.2	319.1	85.1	53.2	81.6	53.2	85.1	95.7	63.8	39.1	99.3	28.4
SO_4^{2-} mg/l	44.0	103.2	80.0	38.1	510.0	98.2	100.4	80.8	10.4	41.6	47.2	32.2	20.1	79.1	51.3
NO_3^- mg/l	53.2	83.6	13.6	24.2	28.6	13.6	29.9	24.6	32.5	43.1	11.4	12.3	7.5	80.1	7.9
PO_4^{3-} mg/l	0.38	0.38	6.21	0.34	0.11	0.18	0.19	0.28	0.24	0.24	0.33	1.25	0.32	0.31	0.21
I^- mg/l	0.02	0.11	0.04	0.04	0.04	0.01	0.02	0.06	0.01	0.00	0.05	0.18	0.13	0.15	0.44
F^- mg/l	0.00	0.00	0.00	0.00	0.01	0.01	1.22	0.00	0.00	0.00	0.27	0.36	0.69	0.76	0.00
Br^- mg/l	0.04	0.08	0.02	0.03	0.06	0.01	0.02	0.04	0.01	0.00	0.10	0.10	0.02	0.01	0.28
SiO_2 mg/l	33.4	33.2	20.8	24.4	46	19.2	21.6	21.8	27.6	34	25.7	23.5	51.4	29.2	33.2
Fe^{2+} ppm	<0,001	<0,001	<0,001	0.151	..	<0,001	<0,001	<0,001	<0,001	<0,001	0.094	0.202	<0,001	0.228	<0,001
Mn^{2+} ppm	<0,001	<0,001	<0,001	<0,001	..	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001
Zn^{2+} ppm	<0,001	0.460	<0,001	<0,001	..	<0,001	0.003	<0,001	<0,001	0.125	<0,001	<0,001	<0,001	<0,001	<0,001
Cu^{2+} ppm	0.035	0.045	0.044	0.049	..	0.037	0.060	0.054	0.061	0.058	0.052	0.050	0.067	0.069	0.047
TDS mg/l	734	914	745	807	1850	979	935	884	529	772	593	607	405	942	440

The concentrations of the surface pollutants present a significant decrease in relation to the groundwater concentrations of the above-mentioned boreholes. NO_3^- and NH_4^+ concentrations range from 7,5 mg/l to 12,3 mg/l and from 0,19 mg/l to 0,26 mg/l respectively. In borehole B12, thermal waters present the highest PO_4^{3-} concentration (1,25 mg/l). This group of alkaline thermal waters exhibit also high concentrations of I^- (0,05-0,18 mg/l), F^- (0,27-0,69 mg/l) and Br^- (0,02-0,10 mg/l). These waters originated from the mixed group of thermal waters infiltrating at great depths hold their HCO_3^- concentration and deposited a great amount of earth-alkaline (Ca^{2+} and Mg^{2+}). After that, they were enriched mainly with Na^+ ions and secondarily with Cl^- and SO_4^{2-} ions. The lithology of the aquifer, the tectonic structure of the greater area and the temperature status contributed to the creation of these waters. The direct participation of seawater in the

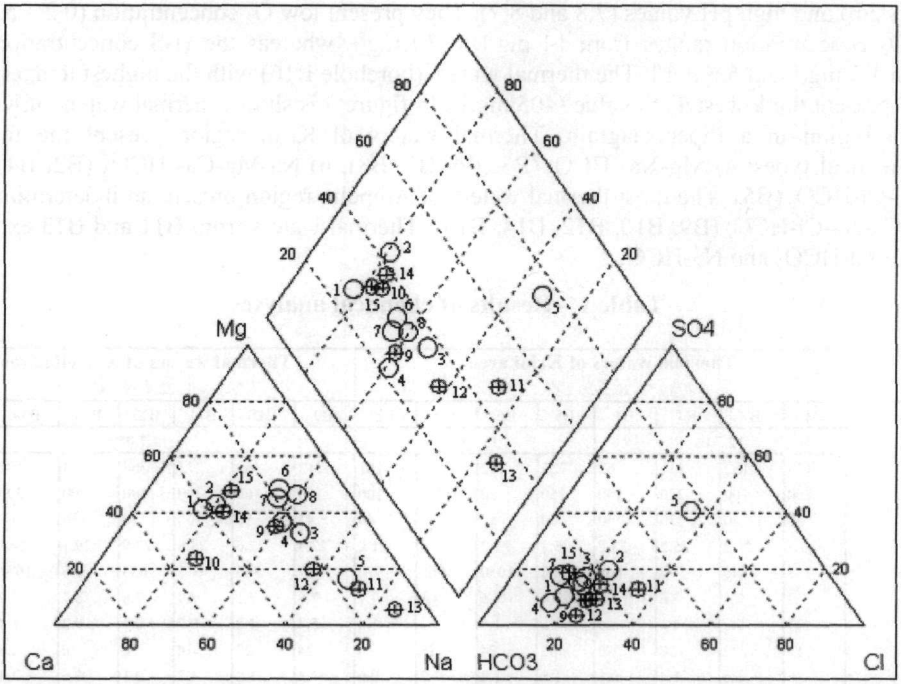

Figure 3 - Classification of thermal waters in Piper Diagram (○ : thermal waters in Krini area, ⊕ : thermal waters in Ampelia area)

establishment of the quality character of the solutions is under question despite the observed increase of Na^+ Cl^- and SO_4^{2-} ions especially in Krini area. The high concentrations of these ions are mainly attributed to the dilution of evaporates of the Neogene formations developed in the area and less to the seawater intrusion. The Neogene deposits of the area are of lacustrine and marine origin and probably contain evaporates (Bornovas *et al.* 1969). In Ampelia area, where pillow lavas are dominated, the presence of minerals enriched with Cl^- ions is also not excluded. These pillow lavas were created in sea environment and the contribution of halogens to the crystal structure of clay-silica minerals is considered to be viable. The presence of $SO^{2-}{}_4$ ions is related to oxidation of iron-pyrite, which is contained in pillow lavas and dilution of secondary hydrothermal gypsum, which coexist in limited concentrations within volcanic rocks. The Piper diagram in fig. 3 confirms that besides sample from B5 borehole, SO_4^{2-} concentrations are gradually decreased compared to Cl^- and HCO_3^- ones. This is a characteristic phenomenon of thermal and seawater mixture. From the Cl/Na correlation diagram (fig. 4), it is also shown that all types of waters tend to mix with seawater. Nevertheless, this is not confirmed from the Cl/ HCO_3^- relation diagram.

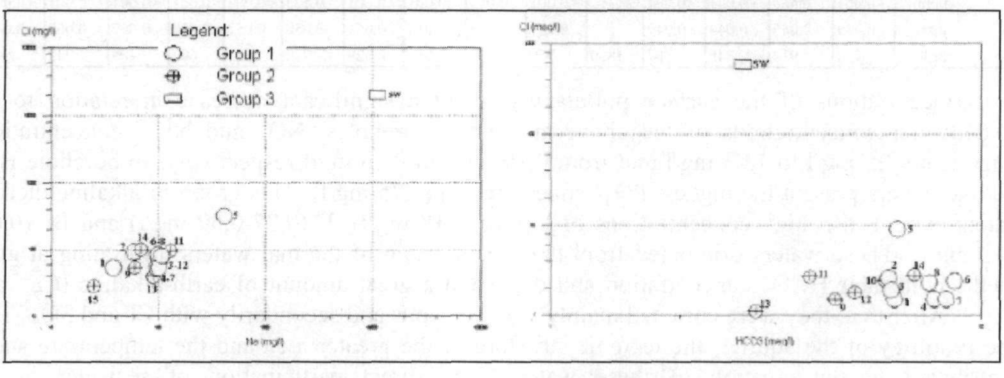

Figure 4 - Ion ratios: Cl/Na and Cl/ HCO_3^-

The ion ratio Na/Cl>1 and especially the ratio Cl/Br one, which is the most certain indicator of seawater intrusion (300 seawater indicator) consist a basic parameter supporting the questioning about the seawater intrusion in the hydrothermal reservoir of the area. Cl/Br ratio appearing in thermal waters of the area range from 638 to 5316, displaying rather a dilution of evaporates than seawater intrusion.

Table 2 - Ion Ratios of the thermal waters of the study area (meq/l)

Ion Ratios	B3 (25,1 °C)	B5 (26,2 °C)	B7 (24,4 °C)	B11 (28,8 °C)	B12 (27,9 °C)	B13 (39,1 °C)	B14 (24,3 °C)	B15 (26,2 °C)
Na/Cl	2,302	1,917	2,910	2,110	2,521	3,519	1,075	1,377
Cl/Br	7600	12000	6000	2160	1440	4400	22400	229

4.3. Geothermometry

The present temperature status of the geothermal reservoir is not clear. Table 3 presents the estimation values of geothermal reservoir temperatures for those boreholes exhibiting higher temperatures according to SiO_2 and Chalcedony (Fournier 1977), Na/K (Fournier and Potter 1979), K/Mg (Giggenbach 1988) and Na/K/Ca (Fournier 1979) geothermometers.

Table 3 - Temperature estimation (^{0}C) of the original geothermal reservoir according to geothermometers

Geothermometers	B3 (25,1^{0}C)	B5 (26,2^{0}C)	B11 (28,8^{0}C)	B12 (27,9^{0}C)	B13 (39,1^{0}C)	B15 (26,2^{0}C)
SiO_2	65	97	73	69	102	83
Chalcedony	33	67	41	37	73	52
Na/ K	143	82	105	117	89	-
K/Mg	56	54	53	58	53	-
Na/K/Ca	113	55	49	39	46	-

According to silica geothermometer, the calculated temperatures range from 65° C, for the less hot sample, to 102° C, for the hottest sample. According to Chalcedony geothermometer, the estimated temperatures are much lower from the silica ones, ranging between 33° C and 73° C. K/Mg and Na/K/Ca geothermometers suggest similar temperatures with Chalcedony geothermometer.

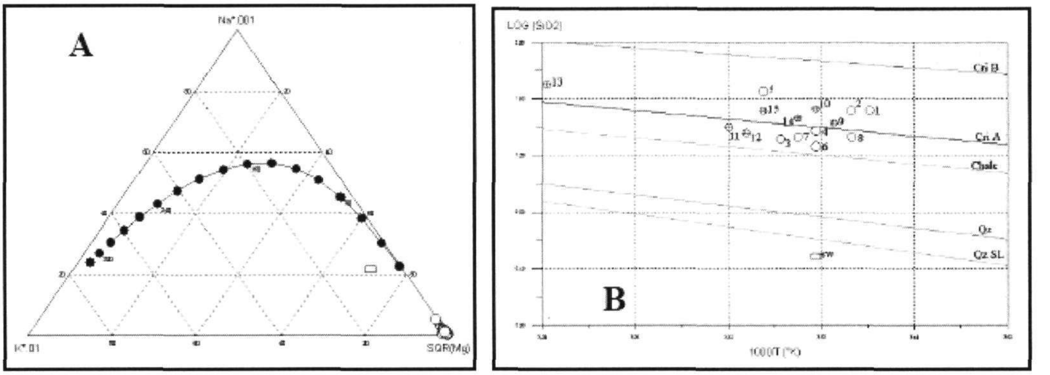

Figure 5 - Na/K/Mg (A) and SiO_2 (B) geothermometer diagrams

According to Giggenbach's (Fig. 5A) triangle diagram, hot samples from surface waters are classified to the "non-equilibrated" group, meaning that groundwaters do not equilibrate with minerals in the reservoir rock. Therefore, the origin temperature could not be clearly estimated.

However, according to anticipated temperature values from the geothermal reservoir, a rather possible value could be found in the field from 50 ° C to 70° C, which comprises the estimated, values from K/Mg and SiO_2 geothermometers. Thus, the study area can be classified to geothermal fields of low enthalpy. These waters have not been circulated in great depths and mixed with marine water as it can be concluded from the chemical composition of the examined hot waters of the area. The acquisition of temperature of these waters could be attributed to the temperature transmission through induction. Therefore, a geothermal system must probably exist, where the heat source is in greater depth and is covered by impermeable formations. Through these formations, heat can be transmitted towards the surface, where the aquifer that hosts the studied waters is located.

5. Conclusions

The fractured tectonic in Farsala Basin, combined with the existence of permeable and impermeable formations, create appropriate conditions for the development of an active geothermal system. The geothermal activity observed in the study area is directly connected to the fractured zones of the sub-basement formations. Thermal water temperatures range from 20,5° C to 39,1° C. These waters belong to Na-HCO_3, Na-HCO_3-Cl and Na-SO_4-Cl-HCO_3 hydrochemical types. The relatively shallow aquifer is characterized by high alkaline concentrations compared to earth-alkaline, suggesting that circulation takes place mainly within volcanic formations, i.e. pillow lavas of the ophiolithic series developed in the broader area of Farsala. The chemical composition of the aquifer is related to processes of hydrolysis of clay-silica minerals, which occur within ophiolithic formations, as well as to dilution of evaporates, which obviously coexist within Neogene formations. The thermal liquids mixture originating from deeper aquifers has not been theoretically validated. The presence of SO^{2-}_4 ions is related to oxidation of pyrite, dilution of secondary hydrothermal gypsum, which coexists in limited concentrations within volcanic formations and dilution of Neogene evaporate formations. The limited Ca^{2+} concentration is obviously related to the precipitation of calcite. The origin of Cl^-ions is mainly attributed to the dilution of evaporates and surface influences. According to geothermometric estimations, the possible temperature values of the geothermal reservoir range from 50 to 70° C and therefore the study area is classified to low enthalpy geothermal field.

6. References

Bornovas, I., Filippakis, N., and Bizon, J.J.G., 1969. Geological Map of Greece 1:50.000, Farsala Sheet. Publication IGME Athens.

Ferriére, J., 1982. Paléogéographies et tectonigues superposées dans les Hellénides internes: les massifs de l΄Othrys et du Pelion (Grèce continentale), *Thèse*, Univ. des Sciences et Techniques de Lille, S.G.N. N° 8, vol. I.

Fournier, R.O., 1977. Chemical geothermometers and mixing models for geothermal systems, *Geothermics*, 5, 41-50.

Fournier, R.O., 1979. A revised equation for the Na/K geothermometer. Geoth, *Resources Council, Trans*., 3, 221-224.

Fournier, R.O., and Potter, R.W., 1979. Magnesium correction to the Na-K-Ca chemical geothermometer, *Geochim. Cosmochim. Acta*, 43, 1543-1550.

Fytikas, M., and Kolios, N., 1979. Preliminary Heat Flow Map of Greece. In V. Germak and L. Rybach (eds), Terastrial Heat Flow in Europe, Springer, 197-205pp.

Gartzos, E., and Stamatis, G., 1996. Genesis of the thermal springs of the Sperchios graben, Greece, *N. Jb. Geol. Paläont. Mh*., H2. 91-115.

Giggenbach, W.F., 1988. Geothermal solute equilibria.-Derivation of Na-K-Mg-Ca geoindicators, *Geochim. Cosmochim. Acta*, 52, 2749-2765.

Kallergis, G., Morphis, A., Papaspyropoulos, Ch., and Christodoulou, Th., 1970. Hydrogeological investigations in the Western Thessaly basin, *Hydrological and Hydrogeological Investigations*, IGME Athens, No8, 166pp.

Katsikatsos, G., Mylonakis, E., Triantaphyllis, E., Papadeas, G., Psonis, K., Tsaila-Monopoli, S., and Skourtsi-Koroneou, V., 1983. Geological Map of Greece 1:50.000, Velestino Sheet. Publication IGME Athens.

Mariolakos, E., Lekkas, S., Alexopoulos, A., Fountoulis, I., Spyridonos, E., Badekas, I., Mariolakos, D., and Andreadakis, E., 2001a. Τεχνητός εμπλουτισμός του υπόγειου καρστικού υδροφορέα του Φυλλήιου όρους στην περιοχή των Φαρσάλων (Θεσσαλία), *Proc. of the 9th Intern. Congr. Athens, September 2001, Bull. Geol. Greece*, vol. XXXIV/5, 1843-1850.

Mariolakos, E., Lekkas, S., Papadopoulos, T., Alexopoulos, A., Fountoulis, I., Alexopoulos, I., Spyridonos, E., Badekas, I., Mariolakos, D., and Andreadakis, E., 2001b. The subsurface tectonic structure of the Farsala basin (Thessaly) as determining factor of the Hydrogeological conditions of the region, *Proc. of the 9th Intern. Congr. Athens, September 2001, Bull. Geol. Greece*, vol. XXXIV/5, 1851-1858.

Mariolakos, E., Fountoulis, I., Alexopoulos, I., Spyridonos, E., Badekas, I., Mariolakos, D., and Andreadakis, E., 2000. The geometry of the aquifer in the Narthakion Mt. (Thessaly) as a result of the neotectonic deformation, *Proc. of the 8th Panhellenic Congr. of EYE*, 343-350pp.

Migiros, G., 1990. The lithostratigraphic-tectonic structure of Othris (Central Greece), *Bull. Geol. Soc. of Greece*, XXVI, 107-120.

Papadeas, G., 1996. Geological and Geothermal exploration in the Sperchios basin (Greece), *Energy resources investications*, IGME Athens, No3, 80pp.

Sfetsos, K., 1988. Inventory of thermal and mineral springs of Greece, III Continental Greece, *Hydrological and Hydrogeological Investigations*, IGME Athens, No39, 667pp.