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Preliminary Hydrothermal-Geothermal Investigations of Nigrita Serres Geothermal Fields (C. Macedonia, Greece)

Hydrogeothermale Voruntersuchungen im Nigrita Serres Geothermal-Feld (C. Mazedonien, Griechenland)

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Inhalt

1. Introduction

The local geothermal field of Nigrita (23°33'–40°54') that is established in the area by the presence of a group of hot springs (TQ) has been determined by borehole drillings to lie at a NW-SW direction of the location of the springs (Fig. 1). At the area of the geothermal field there is also occurrence of hypothermal (20.5° C) mineral springs (KQ) and boreholes (KB) that seem to be in an immediate dynamic hydraulic relation with the local geothermal field.

The purpose of the geological and hydrogeological survey of the area was the explanation of the development as well as the dynamic of the geothermal fluids of the area and also the determination of the outline of the local geothermal field. The survey should at the same time give a solution to the fact of the presence of hypothermal mineral springs between the points of hot springs occurrences.

In order to accomplish the above-mentioned aim, a geological mapping and a macrotectonic survey of the area were carried out along with measurements of physicochemical constants of the water of the springs and of the local boreholes. The

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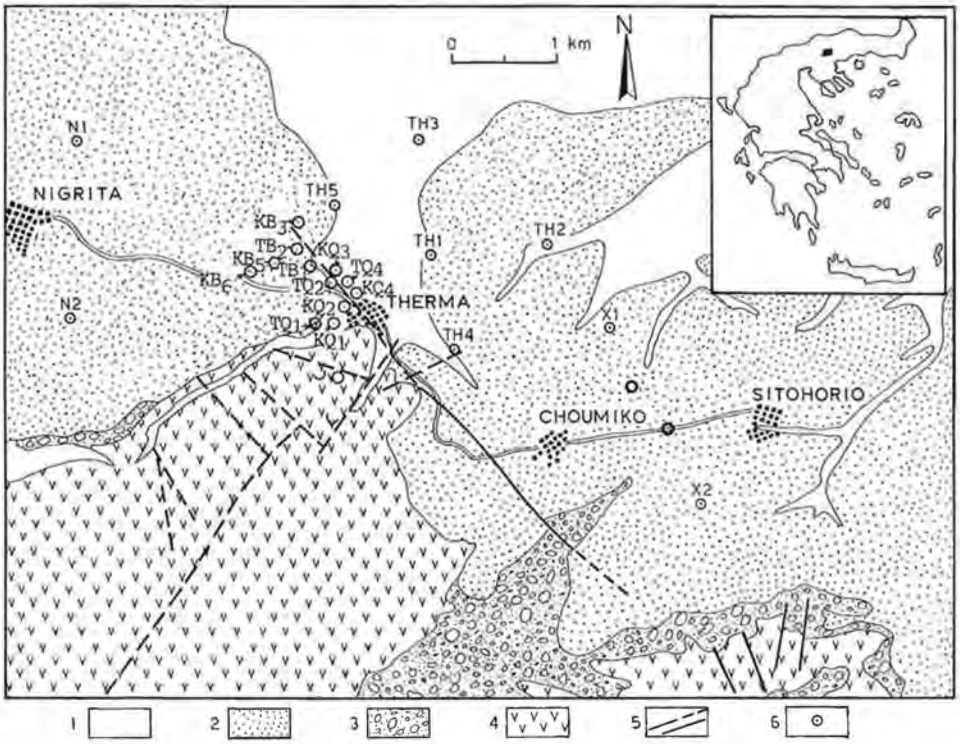

Fig. 1: Geological map of the Thermes Nigrita geothermal field (from geol. map sheet Sitahori). 1 alluvial, 2 sands and marls (Pliocene–Pleistocene), 3 conglomerates (Pliocene), 4 basement (ophiolites), 5 faults, 6 spring and borehole sites.

above-mentioned data along with the maps that were constructed and the geothermometers that were used to determine the temperature of the thermal container, in our point of view give solutions to the problems already mentioned.

2. Geological and Tectonic Situation of the Research Area

The area of development of the local geothermal field is geotectonically a part of the Serbomacedonian massif and the metamorphic system of Vertiscos (F. KOCKEL & H. WALTHER, 1965, 1968, J. MERCIER, 1966). The rocks forming the basement of the area are a series of gneiss, mica-schists and thin layers of marbles. At the upper parts of the system the predominant rocks are metagabbros, metadiabases and amphibolites. At the closest location of the springs there is an ophiolitic series which mainly consists of pyroxenic peridotites (Fig. 1).

According to H. SAKELLARIOU-MANE & N. SYMEONIDES (1968) the basement of the Serres basin at the area of occurrences of the geothermal field is covered by two systems of sediments, the first one of Neogenic age and the second the more recent of Quaternary which were confirmed further by geophysical research (Ε. ΚΥΡΙΑΚΙΔΗΣ & Γ. ΤΣΟΚΑΣ, 1987) and boring (Γ. ΚΑΡΥΔΑΚΗΣ, 1983).

The first sedimentary system of Upper Miocene-Pliocene starts with a base-conglomerate 10–15 m thick at a depth of 100–200 m which forms the main container of the hot water in the Neogene sediments and continues upwards with pure silt strata 20–25 m thick and recurring successions of silts with sandsilts, sands, sand-pebbles, marl-limestones and cobbles.

The second system of Pleistocenic age is covering the lower system with lake deposits of silts, sands and sandpebbles covered by Holocenic river and loose land sediments.

Tectonically the area of research is formed by two groups of normal faults which contributed also to the formation of the basin and many smaller faults that cut through the Neogene and Quaternary sediments. To the first group belong the two major faults (320°/75° and 335°/85°) with a NE-SW direction which are located at Megalo Revma (Fig. 1) and have affected the conditions of the basin.

To the other group of faults with a NW-SE direction belong the major normal fault of the Choumnikos area (50°/85°) that cuts through the marl-limestones of the area as well as the major fault (30°/80°) in the SW of Therma village. Besides the above-mentioned faults, geophysical research (Ε. ΚΥΡΙΑΚΙΔΗΣ & Γ. ΤΣΟΚΑΣ, 1987) along with our hydrothermal observations (G. Ch. DIMOPOULOS, 1986) determined the presence of other smaller faults which cut through the Pleistocene sediments of the basin.

3. Quality of Water of the Geothermal Field

In the area of the geothermal field of Nigrita there is simultaneous occurrence of thermal (hot) as well as hypothermal springs which appear next to one another. Their temperatures range from 21.8° C (KQ_3) up to 51.2° C (TQ_4), whereas inside borehole TB_1 a temperature of 50.4° C was measured (Tab. 1). All waters are acid (pH < 7) and their electric conductivities reach up to 3360 μS/cm (TQ_1 and TQ_4).

The yields of the thermal springs, although ranging in low levels ($Q = 0.4$–0.6 m^3/h and $Q = 2.65$ m^3/h [TQ_2]) given the presence of a neighbouring artesian (3 at) thermal water borehole (TB_1) at a lower altitude, with a yield of $Q = 80$ m^3/h (approx.) constitute the presence of a dynamic hydrothermal field. The drilling of the borehole has gradually influenced the water yields of the springs because of the decompression of the geothermal container and of the certainly existing close hydraulic relation between thermal spring-artesian borehole-container.

The hypothermal mineral springs bearing yields that range from 0.4 m^3/h (KQ_4) to 1.7 m^3/h (KQ_3) occur in the same region with the thermal springs and their mineral contents must be supplied by the hot aquifer. The hardness of the mineral waters ranges from 31.69–42.73° dGH except for the water of spring KQ_1 which presents a hardness of 15.2° dGH and is rated fairly hard (G. MATTHESS, 1973).

From the presentation of chemical values of tab. 2 on a diagram according to Piper (Fig. 2) we infer that all the values (except boreholes KB_3, KB_5, KB_6) fall inside the same regions. This certifies the common origin of the water supplying the springs, meaning that the hot as well as the cold and hypothermal waters of the area are supplied by the same geothermal fluids that originate from a common geothermal container.

Based on the classification according to K. E. QUENTIN (1969) all the thermomineral waters of the area are rated Na^+-K^+-HCO_3^--waters. The increased contents

Tab. 1: Physical characteristics (Komponente) of springs and boreholes of the geothermal field of Nigrita.

Physical parameters	Date of measurement	Temperature (° C)		pH	Electric conductivity pa µs/cm	Discharge Q (m^3/h)
		Air	Water			
TQ_1	11-6-87	29.0	49.6	6.53	3360	0.50
TQ_2	11-6-87	27.8	48.3	6.56	3340	2.65
TQ_3	11-6-87	27.2	38.0	6.30	2400	0.50
TQ_4	20-5-87	29.0	51.2	6.25	3360	0.40
KQ_1	11-6-87	33.5	24.2	6.40	3100	–
KQ_2	11-6-87	26.0	24.3	6.31	1094	0.80
KQ_3	11-6-87	26.3	21.8	6.34	1130	1.70
KQ_4	11-6-87	34.0	26.9	6.30	3180	0.42
TB_1	13-5-88	28.5	50.4	6.60	3400	80.00
TB_2	13-5-88	28.5	45.0	6.40	3400	67.00
TB_3	24-5-88	20.9	39.5	7.09	2860	–
TB_4	24-5-88	26.2	43.0	6.90	2790	–
KB_1	24-5-88	20.9	20.0	6.43	716	–
KB_2	24-5-88	20.9	17.0	6.43	1700	–
KB_3	13-5-88	20.9	22.3	6.45	880	–
KB_4	24-5-88	26.0	18.5	10.50	787	–
KB_5	24-5-88	26.0	24.0	7.30	745	–
KB_6	24-5-88	26.0	25.2	7.30	690	–
KB_7	24-5-88	24.0	18.0	10.98	612	–
KB_8	24-5-88	25.8	15.4	8.32	1790	35
KB_9	24-5-88	26.2	17.9	7.90	1410	–
TH_1			60.0			
TH_2			51.0			
TH_3			47.0			
TH_4			51.0			
TH_5			42.0			
X_1, X_2, N_1, N_2			25.0–32.0			

Tab. 2: Chemical analyses of hot and cold mineral waters of the geothermal field of Nigrita (continuation p. 138, p. 139).

	TQ_1			TQ_2			TQ_4			TB_1		
	mg/l	mval/l	mval %	mg/l	mval/l	mval %	mg/l	mval/l	mval %	mg/l	mval/l	mval %
K^+	48	1.23	4.99	100	2.56	6.19	93.75	2.4	5.9	100	2.56	6.2
Na^+	276	12.00	48.72	550	23.91	57.75	543.75	23.64	58.16	541.65	23.55	57.10
Ca^{2+}	75	3.75	15.23	88.75	4.44	10.73	93.25	4.66	11.48	99	4.95	12.00
Mg^{2+}	92	7.67	30.74	125	10.29	24.87	118.75	9.77	24.03	121.13	9.97	24.17
Fe^{2+}	0.045	2.41×10^{-3}	0.010	0.045	2.41×10^{-3}	0.006	0.114	6.11×10^{-3}	0.015	0.299	0.016	0.038
Mn^{2+}	0.087	3.16×10^{-3}	0.013	0.043	1.56×10^{-3}	0.004	0.043	1.56×10^{-3}	0.038	0.065	2.36×10^{-3}	5.72×10^{-3}
Li^+	0.663	0.082	0.33	1.153	0.167	0.40	1.153	0.167	0.41	1.085	0.157	0.38
Sr^{2+}	0.323	7.37×10^{-3}	0.03	0.559	0.013	0.09	0.676	0.015	0.035	0.676	0.015	0.036
Zn^{2+}	–	–	–	–	–	–	–	–	–	–	–	–
NH_4^+	–	–	–	–	–	–	–	–	–	0.077	0.004	9.7×10^{-3}
Al^{3+}	–	–	–	–	–	–	–	–	–	0.065	0.023	0.053
Sum	492.118	24.63	100	865.55	41.30	100	851.486	40.65	100	764.047	41.25	99.9
HCO_3^-	1262.7	20.7	92.93	2141.1	35.1	84.47	2116.7	34.7	84.24	2105	34.5	82.2
Cl^-	86.55	2.44	9.77	152.65	4.3	10.40	270.4	4.83	11.73	170.76	4.81	11.46
SO_4^{2-}	74.4	1.55	6.21	96.06	2.0	4.81	72.52	1.51	3.66	120	2.5	5.96
NO_3^-	12.85	0.21	0.84	3.124	0.05	0.12	3.614	0.068	0.14	3.383	0.055	0.13
PO_4^{3-}	0.266	0.008	0.032	0.34	0.011	0.026	0.4	0.013	0.03	0.435	0.014	0.033
S^{2-}	–	–	–	–	–	–	–	–	–	–	–	–
F^-	1.089	0.754	0.23	1.737	0.001	0.22	1.823	0.005	0.21	1.59	0.084	0.2
Sum	1437.864	34.96	100.01	2395.011	41.55	100.64	1365.257	41.18	100	2401.168	41.96	99.98
SiO_2	66.71			86.64						94.05	–	
CO_2	484	11		488	11.0			12.3		330	7.5	

	KQ_1			KQ_2			KQ_3			KQ_4		
	mg/l	mval/l	mval %	mg/l	mval/l	mval %	mg/l	mval/l	mval %	mg/l	mval/l	mval %
K^+	15.4	0.394	3.89	75.5	1.93	5.20	53.75	1.375	4.81	79	2.02	5.2
Na^+	98	4.25	42.01	48.0	20.07	53.34	302.5	13.152	45.77	493.75	21.47	55.28
Ca^{2+}	54	2.7	26.63	84.6	4.23	11.40	110.5	5.49	19.19	98.75	4.94	12.72
Mg^{2+}	33	2.72	26.32	120	9.91	26.70	103.0	8.48	29.64	175	10.32	26.57
Fe^{2+}	0.092	4.93×10^{-3}	0.049	0.092	4.93×10^{-3}	0.013	0.103	0.005	1.7×10^{-2}	0.92	4.93×10^{-3}	0.013
Mn^{2+}	0.033	1.2×10^{-3}	0.012	0.033	1.2×10^{-3}	0.003	–	–	–	0.054	1.96×10^{-3}	0.005
Li^+	0.176	0.025	0.25	1.017	0.147	0.396	0.65	0.094	3.3×10^{-1}	0.52	0.075	0.19
Sr^{2+}	0.294	6.71×10^{-3}	0.066	0.765	0.017	0.045	0.536	0.012	3.2×10^{-1}	0.706	0.016	0.04
Zn^{2+}	–	–	–	–	–	–	0.122	0.004	1.4×10^{-2}	–	–	–
NH_4^+	–	–	–	–	–	–	–	–	–	–	–	–
Al^{3+}	0.035	0.026	0.28	–	–	–	–	–	–	–	–	–
Sum	201.08	10.14	100	330.007	37.11	88.8	571.161	28.612		798.7	38.84	100
HCO_3^-	531	9.7	80.33	1860.5	30.5	82.79	1413.161	23.17	80.23	1910	31.31	79.19
Cl^-	37	1.04	9.6	153.0	4.31	11.72	104.4	2.94	10.18	135	3.8	9.61
SO_4^{2-}	51	1.06	9.79	84.0	1.75	4.75	128.0	2.77	9.59	200	4.16	10.52
NO_3^-	0.41	0.00	0.00	12.271	0.198	0.54	–	–	–	11.18	0.18	0.46
PO_4^{3-}	0.145	0.0046	0.043	0.45	0.014	0.038	0.04	0.0012	4.16×10^{-3}	0.5	0.016	0.04
S^{2-}	–	–	–	–	–	–	–	–	–	–	–	–
F^-	0.422	0.022	0.20	1.259	0.066	0.18	–	–	–	1.457	0.077	0.19
Sum	618.977	10.83	99.96	2111.480	36.84	99.94	1645.84	28.88		2258.14	39.54	100
SiO_2	32.21	–		73.45	–		59.49			81.16		
CO_2	141	3.2		600	10		335.5			678		

	KB_5			KB_4			KB_7			TB_2		
	mg/l	mval/l	mval %	mg/l	mval/l	mval %	mg/l	mval/l	mval %	mg/l	mval/l	mval %
K^+	1.09	0.028	0.33	1.636	0.042	0.5	2.8	0.072	0.8	94.5	2.42	5.82
Na^+	42.5	1.85	21.99	41.35	1.8	22.6	38.75	1.685	20.2	531.25	23.1	55.6
Ca^{2+}	87	4.34	51.6	82.76	4.13	51.8	90.1	4.5	53.4	137	6.84	16.5
Mg^{2+}	26	2.17	25.8	22	1.83	22.9	23.5	1.94	23.0	108	9	21.7
Fe^{2+}	–	–	–	2.26	0.12	1.5	3.286	0.176	2.1	0.238	0.013	0.03
Mn^{2+}	–	–	–	0.03	1.1×10^{-3}	0.014	0.094	3.4×10^{-3}	0.04	0.0625	2.3×10^{-3}	0.006
Li^+	–	–	–	0.48	0.015	0.19	0.63	0.019	0.2	1.065	0.153	0.4
Sr^{2+}	0.757	0.017	0.2	0.667	0.015	0.19	0.727	0.016	0.2	0.848	0.019	0.05
Zn^{2+}	–	–	–	–	–	–	–	–		–	–	
NH_4^+	–	–	–	–	–	–	–	–		0.424	0.024	0.06
Al^{3+}	–	–	–	0.24	0.026	0.33	0.20	0.022	0.3	–	–	
Sum	157.347	8.41	99.92	151.423	7.98	99.5	160.1	8.43	100.24	837.4	41.57	100.1
HCO_3^-	409	6.7	78.0	494	6.45	80.7	436	7.15	84.9	2074	34	81.7
Cl^-	27.3	0.77	8.97	27.3	0.77	9.6	30.7	0.86	10.2	153.6	4.33	10.53
SO_4^{2-}	39	0.81	9.4	36	0.75	9.4	19	0.39	4.6	130	2.71	2.50
NO_3^-	17.2	0.28	3.26	0.15	2.4×10^{-3}	0.03	–	–	–	1.5	0.024	6.59
PO_4^{3-}	0.022	0.7×10^{-3}	0.008	0.014	0.4×10^{-3}	0.05	0.006	0.2×10^{-3}	0.02	0.294	9.3×10^{-3}	0.0226
S^{2-}	–	–		–	–	–	–	–	–	–	–	–
F^-	0.361	0.019	0.22	0.380	0.02	0.25	0.285	0.015	0.2	1.045	0.056	0.136
Sum	492.883	8.586	99.9	557.84	7.99	100.03	485.99	8.415	99.99	2360.43	41.13	101.4
SiO_2	17			21								
CO_2	–			–								

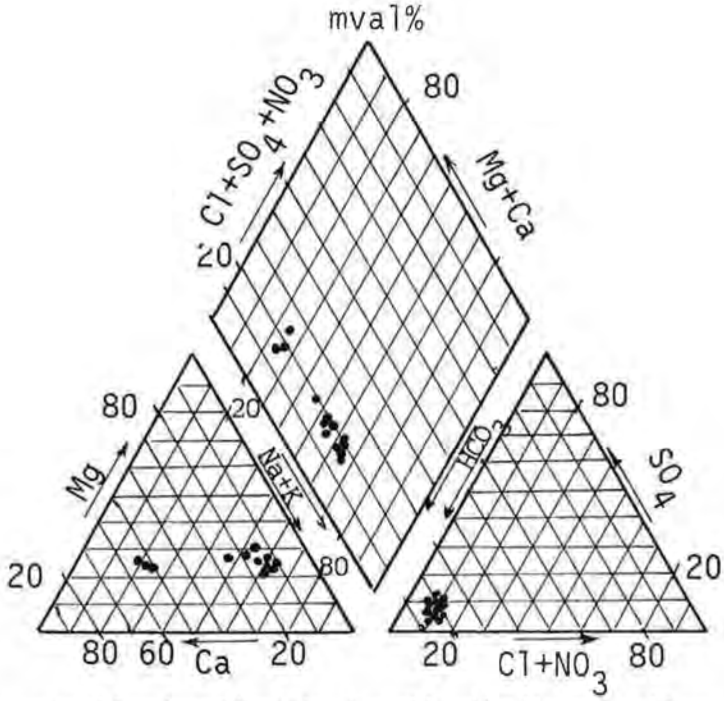

Fig. 2: Presentation of the values of chemical analyses of the cold and hot waters of the geothermal field of Nigrita on a diagram according to PIPER.

in K^+, Na^+ and Mg^{2+} is justified by the traversing and remaining of the geothermal fluids in ophiolitic rocks of the basement, whereas the locally increased contents in Li^+ (1.153 mg/l) and F^- (1.737 mg/l) is due to the traversing of the geothermal fluids through the migmatites and pegmatites of the metamorphosed basement.

4. Geothermal Condition of the Field

At the location of the occurrence and development of the local geothermal field with the help of research (ΚΑΡΥΔΑΚΗΣ, 1983) and private drillings, two series of conglomerates holding geothermal fluids have been detected. The series of conglomerates lying deeper is specified as primary container with temperatures reaching 61° C at the bottom and 59° C at the top of borehole TH_1 and holds large contents of CO_2. This series is developed in depths from 150 m to 350 m dipping 7° to the E and 5° NE. In smaller depths we come across the secondary container with conglomerate series acting somewhat like artesian.

The quality of the water in the two hot containers is identical to the quality of the water of the hot springs which certifies their common supply from the same deep primary geothermal container.

The development of these underground hot containers is in a N-NE direction (Γ. ΚΑΡΥΔΑΚΗΣ, 1983) – that is – along the axis TH_1–TH_2. From the isothermal curves map (Fig. 3) and equal conductivity (Fig. 4) isopleths as well as from aerial photograph

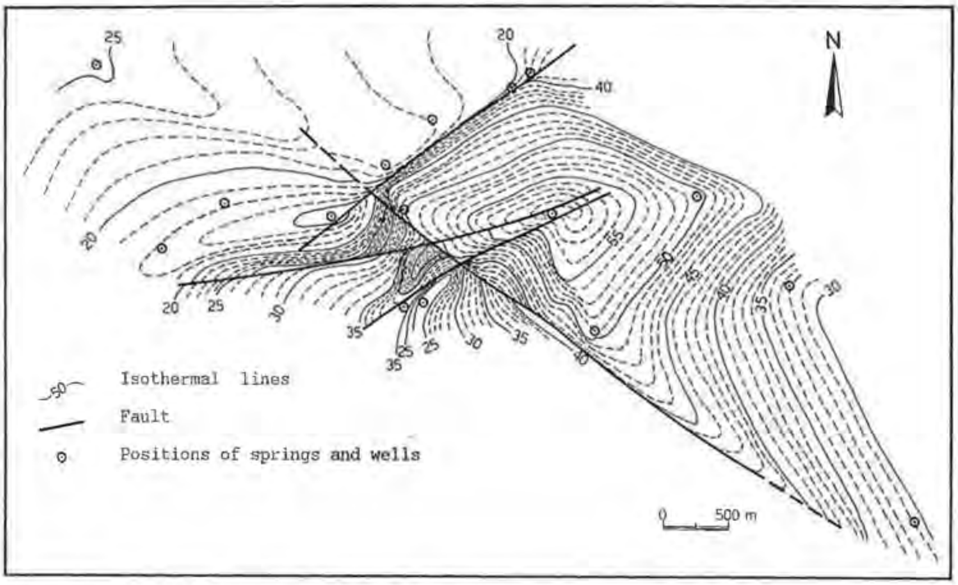

Fig. 3: Map of isothermal lines (in °C) of the Nigrita geothermal field.

the development of the geothermal field in the NW-SE direction is certified; this is the direction of increasing density of the curves and which is identical to the continuance of the large fault of Choumnikos that seems to actively take part to the surfacing of the geothermal fluids.

For the determination of the temperature of the geothermal fluid at the location of the container we tried to utilise several types of geothermometers so as to obtain the most representative value for the geothermal field in question.

As the geothermometers were mainly studied in high enthalpy fields (> 150° C) and less in low enthalpy fields (F. AMORE, R. DE FACELI & R. CABOI, 1987) we considered that in order to use them for the low enthalpy geothermal field of Nigrita certain factors like steam separation at a certain depth or merging with cold surface waters – a very common phenomenon in the Neogene basins of Greece – should be taken into account. So considering originally that there is no loss of SiO_2 during the uplifting of the geothermal fluid, the use of formula (1) and (2) (R. O. FOURNIER, 1977) for chalcedony and quartz with no vapour loss, for spring TQ_4 resulted in:

$$t_{chalzedony} = \frac{1112}{4,91 - \lg SiO_2} - 273,15 = 106,3° C \qquad (1)$$

$$t_{quartz} = \frac{1309}{5,19 - \lg SiO_2} - 273,15 = 134,5° C \qquad (2)$$

Since the waters of the Nigrita geothermal field are acid (pH < 7) and contain CO_2 we did not utilise the Na-K geothermometer as in such types of water the Na/K ratio is altered and this thermometer does not give reliable results. At the values obtained by the use of this geothermometer for the geothermal field of Nigrita we attempted a Mg correction since the presence of Mg affects the Na-K-Ca geothermo-

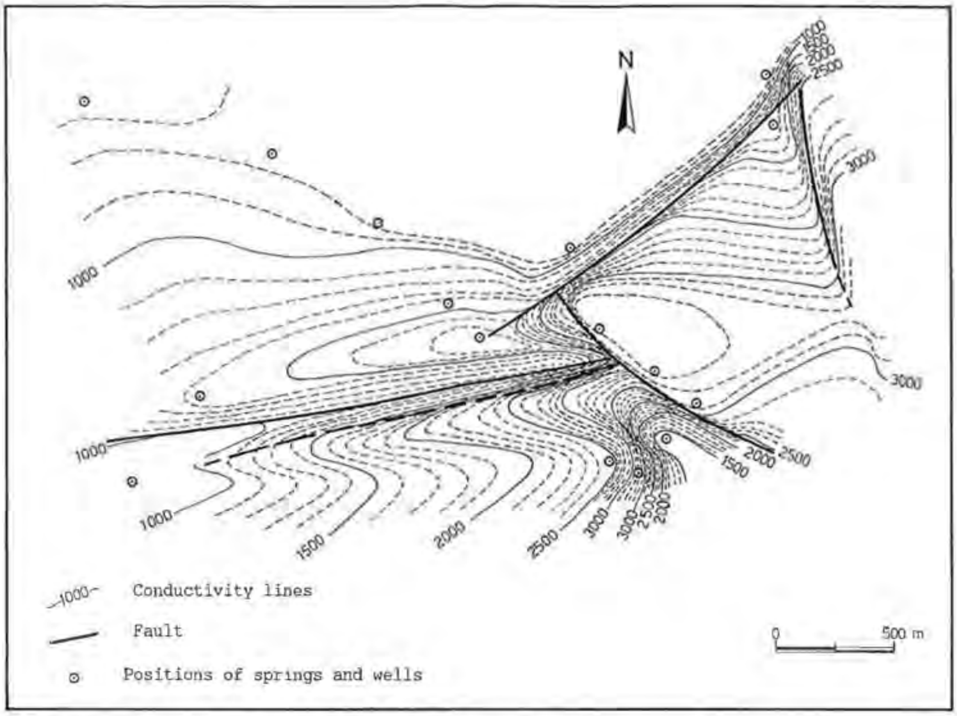

Fig. 4: Map of equal conductivity lines (μS/cm) of the Nigrita geothermal field.

meter in Mg-rich waters. The temperature values obtained by formula (3) for the Nigrita geothermal field according to the data of hot spring TQ_4 are:

$$t_{Na\text{-}K\text{-}Ca} = \frac{1647}{2{,}47 + \lg(Na/K) + 4/3\,[\lg(Ca/Na) + 2{,}06]} - 273{,}15 = 178{,}6^\circ\,C \quad (3)$$

for $\beta = 4/3$ since $[\log(\sqrt{Ca}/Na) + 2.06] > 0$.

According to R. FOURNIER & A. H. TRUESDELL (1973, 1974) the Mg correction values (ΔMg) are dependent upon the value of factor R (4) with element values meq/l which

$$R = [Mg/(Mg + Ca + K)] \times 100 = 58 \quad (4)$$

for values of $R > 50$ no corrections in the Na-K-Ca geothermometer are made.

Therefore with a value of $R = 58$ that has been determined, the value of temperature of the geothermal fluids in the container of the Nigrita geothermal field, using the Na-K-Ca geothermometer reaches 178.6° C.

According to K. MAZOR & M. A. MANON (1979) elements used as geothermometers should be active regarding temperature and inactive regarding Cl, always in relation to their condition inside the container. The terms active and inactive derive from the correlation of the elements according to temperature and Cl. If the line generated in the diagram passes through the beginning of the axes then this situation indicates inactive or concerved element that is, no significant reaction took place during the uplifting of the fluids, and thus the water conveys the information of the container. On the contrary if the extrapolation of the line intersects the other axis then the element is termed active until it reaches the surface. The above-mentioned correlations are likewise made for temperature and enthalpy and thus we acquire activity regarding these factors.

Therefore based on the admissions of K. MAZOR & M. A. MANON (1979) we proceeded in the graphic solution for the determination of the temperature of the container utilising the model suggested by R. O. FOURNIER & A. H. TRUESDELL (1974) for the cold-hot water system with no vapour loss, since the problem of cold and hot water mixture is a common phenomenon in the geothermal fluids of low enthalpy that are developed in the Neogene basins of Greece.

The correlation of SiO_2 values, temperature T and Cl^- for the geothermal occurrences in the Nigrita geothermal field (Fig. 5a, b) produced SiO_2 active in relation to the temperature and inactive in relation to Cl^- with fairly high correlation values, which, according to K. MAZOR & M. A. MANON (1979) allows for the SiO_2 to be used as geothermometer.

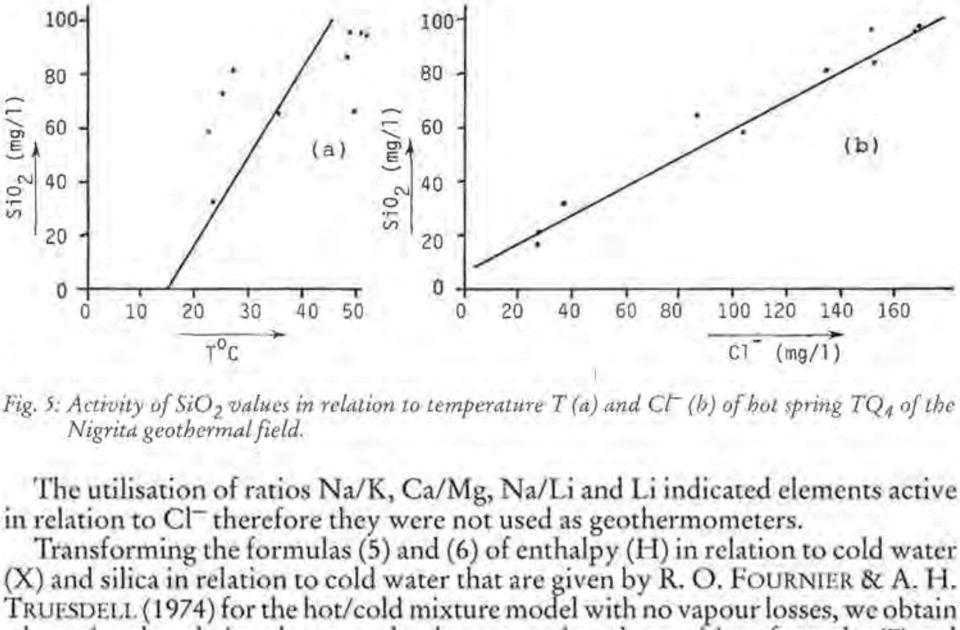

Fig. 5: Activity of SiO_2 values in relation to temperature T (a) and Cl^- (b) of hot spring TQ_4 of the Nigrita geothermal field.

The utilisation of ratios Na/K, Ca/Mg, Na/Li and Li indicated elements active in relation to Cl^- therefore they were not used as geothermometers.

Transforming the formulas (5) and (6) of enthalpy (H) in relation to cold water (X) and silica in relation to cold water that are given by R. O. FOURNIER & A. H. TRUESDELL (1974) for the hot/cold mixture model with no vapour losses, we obtain – knowing the relations between the above-mentioned quantities – formulas (7) and (8) from which applying the SiO_2 and temperature values of spring TQ_4 (95.36 mg/l/51.2° C) and of cold water borehole KB_3 accordingly (17.0 mg/l/15.0° C), and ratio X = 0.86 (Fig. 6) the deriving Si_k = 576.7 mg/l.

$$(H_k)\,(x_i) + (H_z)\,(1 - x_i) = H_{TQ} \tag{5}$$

$$(Si_k)\,(x_i) + (Si_z)\,(1 - x_i) = Si_{TQ} \tag{6}$$

$$X_t = \frac{H_z - T_{TQ}}{H_z - T_{KQ}} \tag{7}$$

$$X_{Si} = \frac{Si_z - Si_{TQ}}{Si_z - Si_{KQ}} \qquad (8)$$

where:

H_k = cold water enthalpy,
H_z = hot water enthalpy,
X = cold/hot ratio,
Si_k = cold water silica,
Si_z = hot water silica,
T_{TQ} = hot spring temperature,
T_{KQ} = cold spring temperature,
Si_{TQ} = hot spring silica,
Si_{KQ} = cold spring silica.

Based on the value of Si_z = 576.7 mg/l that was determined by formula (6) and the typical curves SiO_2/temperature T for chalcedony (A) and quartz (B) as shown

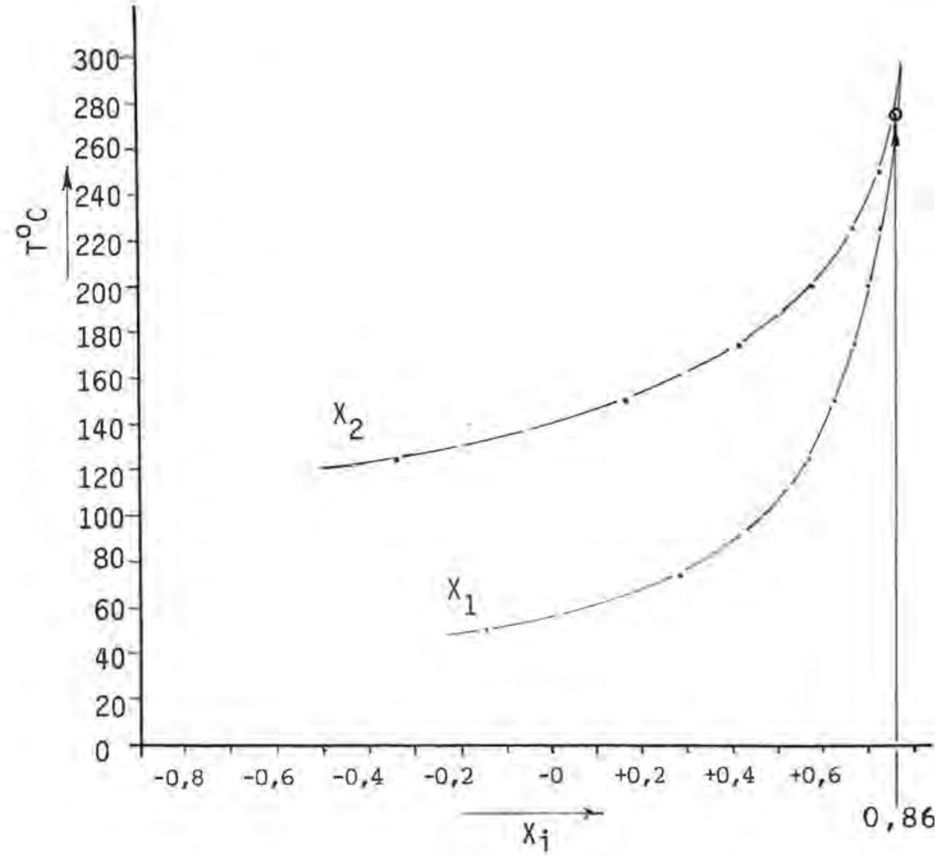

Fig. 6: Relation of analogy of temperature (T)/cold ratio (X_1) (according to R. FOURNIER & A. H. TRUESDELL, 1974) in the geothermal field of Nigrita.

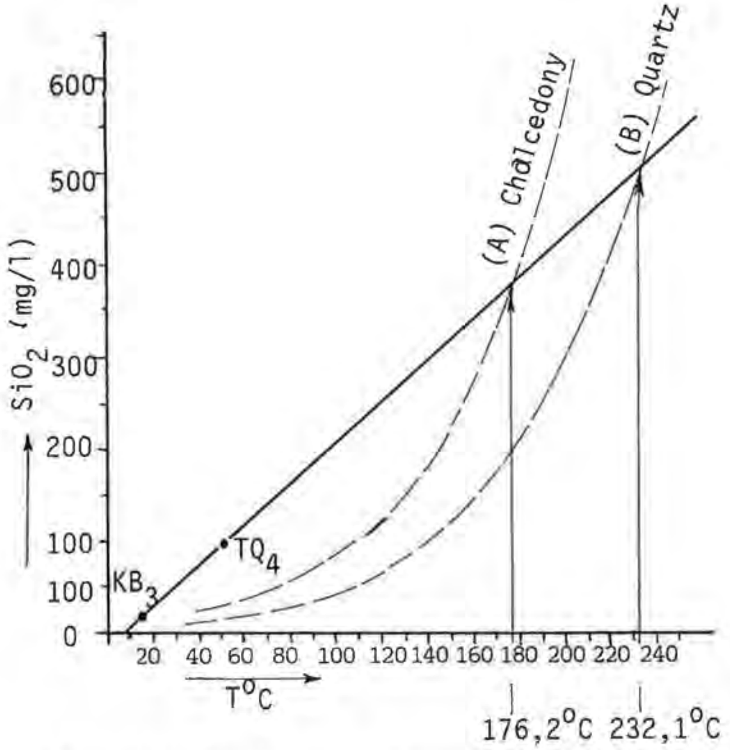

Fig. 7: Diagram of computation of the temperature of the geothermal fluid in the container from the typical SiO_2-temperature curves for chalcedony (A) and quartz (B) (according to R. FOURNIER & A. H. TRUESDELL, 1974) in the Nigrita geothermal field.

in fig. 7 we obtain temperature values for the geothermal fluid in the container $T_1 = 176.2°$ C when chalcedony is controlling the dilution and $T_2 = 232.1°$ C when on the contrary the dilution is controlled by quartz. Because the pairs of values of TQ_4 and KB_3 on the diagram of fig. 7 are closer to curve (A) of chalcedony, we accept that chalcedony is controlling the dilution of SiO_2 in the geothermal container therefore the more representative value is the one graphically determined from the chalcedony curve (Fig. 7), that is $T_1 = 176.2°$ C.

Comparing the temperature values of the geothermal fluids in the container that have been determined with the use of the Na-K-Ca geothermometers ($t_{Na\text{-}K\text{-}Ca}$ = 178.6° C) and SiO_2 (t_{SiO2} = 176.2° C) we notice an approximate equivalence, which allows as to accept the value of $T_z = 176.2°$ C as the most representative temperature of the geothermal container taking into account that the SiO_2 geothermometer provides us with more reliable results.

Based on value $T_z = 176.2°$ C for the temperature of the geothermal fluid in the container that we calculated and the data $Z_o = 72$ m, $T_{zo} = 51.2°$ C of spring TQ_4 we determine the depth of the container using formula

$$T_z = T_{zo} + 2(Z - Z_o)/100 \qquad (9)$$

for z = 423 m.

As we have established the occurence of the geothermal field on the surface with the presence of the hot springs is happening at the intersection of the two large groups of faults; the Choumnikos fault and the Megalo Revma faults (Fig. 2). We accept (Fig. 8) that the matamorphosed impervious basement of the basin along with the

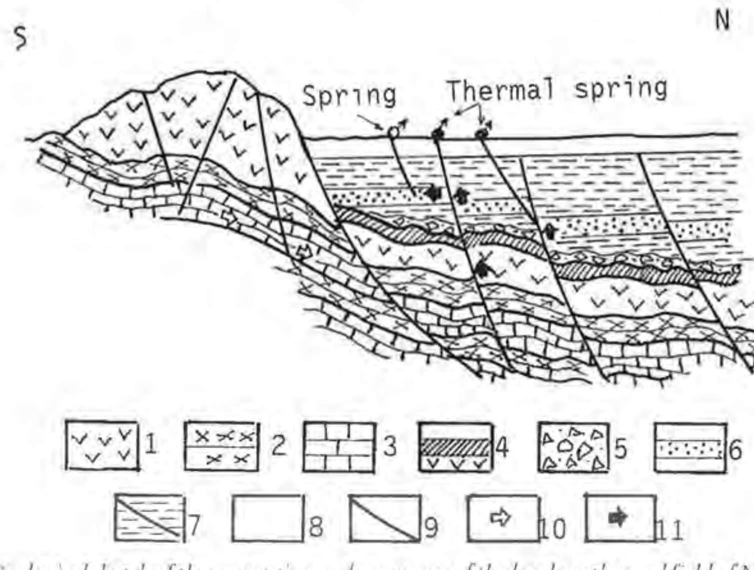

Fig. 8: Geological sketch of the generation and occurence of the local geothermal field of Nigrita on the surface. 1 ophiolites, 2 metamorphosed basement, 3 marbles, 4 abrasion mantle, 5 base conglomerate, 6 water pervious formations, 7 impervious formations, 8 Quaternary deposits, 9 fault, 10 meteoric water, 11 geothermal fluid.

overlying system of sediments that cover the container of the geothermal fluids, which is marked at a depth approx. 4200 m in water pervious formations, is being dissected by the large normal faults which have moved the northern part downwards and have accelerated the sedimentation procedures in the basin that they have generated. These NW-SE Pliocene faults that cut through the Neogene sediments of the basin allow the geothermal fluids to move upwards and fill the water pervious formations of the system, like for instance the base conglomerates and the overlying secondary conglomerate series. These faults, that were formed during the extensional stresses period of Pliocene in Greece (J. MERCIER, 1966) do not cut through the upper Quaternary sediments of the basin and they therefore do not carry the geothermal fluids on the surface. During the earlier extensional tectonic regime of the Quaternary (J. MERCIER, 1966) normal faults of NE-SW direction were generated, which have cut through the former Tertiary faults causing the geothermal fluids, moving along the intersections, to reach the surface and form the hot springs (TQ).

At the locations where these Quaternary faults did not intersect the former Tertiary faults but only the pervious strata which have been impregnated with hot water and gases, there is occurence of hypothermal mineral springs, thus creating the phenomenon of hypothermal mineral springs KQ_1, KQ_2, KQ_3 and KQ_4 being present among the hot (thermal) springs TQ_1, TQ_2, TQ_4 (Fig. 1) and close to them.

Summary

The geothermal field of Nigrita Serres is located in the western part of the Serres Basin within the boundaries of the village Therma.

Hot springs occur along a large normal fault stretching from NW to SE, and the hot springs emerge at those points where the main fault intersects with younger and smaller faults developing in the NE-SW direction.

The center of the thermal field is formed by a group of hot springs with temperatures of between 38.0° and 51.2° C. In addition, a large number of hypothermal mineral springs (21.8° C) come to the surface. According to K. E. QUENTIN (1969) the water of the springs is classified as Na^+-K^+-HCO_3^- with a pH < 7.

The geothermal waters flow along the NW-SE Pliocenic main faults and come to the surface at points where the young Pleistocenic faults intersect with one of the older faults.

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Zusammenfassung

Das Geothermal-Feld von Nigrita Serres liegt im westlichen Teil des Beckens von Serres im Randbereich des Ortes Therma (s. Fig. 1).

Die Thermalwasseraustritte sind an eine große NW-SE streichende Störung gebunden und die Austritte der Thermalwasserquellen liegen dort, wo diese Hauptverwerfung von jüngeren NE-SW streichenden, kleineren Brüchen gequert wird.

Den Mittelpunkt des Thermal-Feldes bildet eine Gruppe heißer Quellen mit Wassertemperaturen von 38,0 bis 51,2° C, daneben tritt eine größere Zahl hypothermaler Mineralwässer (21,8° C) aus. Die Wässer haben nach K. E. QUENTIN (1969) den Charakter von Natrium-Kalium-Hydrogenkarbonat-Wasser mit einem pH-Wert < 7.

Die Thermalwässer fließen in den NW-SE streichenden pliozänen Hauptstörungen und finden ihren Weg zur Oberfläche, wo die jungen, pleistozänen Bruchsysteme eine der älteren Störungen kreuzen.