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THERMAL WATERS FROM THE ISLANDS OF THE AEGEAN ARC (GREECE)

ABSTRACT. — Several islands in the Aegean arc are characterized by thermal anomalies, connected with their past of present volcanic activity, which can give rise to an inflow of gaseous species of deep origin into shallow aquifers.

Samples of thermal waters collected in the islands of Santorini, Milos, Nysiros and Kos, have been analysed with respect to fundamental and minor constituents, with the aim of identifying the main characters in their chemical composition which can be referred to the above mentioned input.

The emergence sites of the studied manifestations, mostly near the seaside, seem to be mainly responsible of the observed sodium-chloride composition, but the silica, boron and lithium concentrations, along with the presence of noticeable quantities of iron and manganese, appear a clear hint of hydrothermal influence.

RIASSUNTO. — Alcune isole dell'arco Egeo sono caratterizzate da anomalie termiche, connesse coll'attività vulcanica passata o presente, che possono dare origine ad un apporto negli acquiferi subsuperficiali di specie gassose di origine profonda.

Sono stati analizzati sia i costituenti fondamentali che quelli in tracce di 24 campioni di acque termali, raccolti nelle isole di Santorini, Milos, Nysiros e Kos, allo scopo di identificare i caratteri principali della loro composizione chimica che possono essere riferiti all'apporto profondo suddetto.

I punti di emergenza delle manifestazioni studiate, per la maggior parte vicini al mare, sembrano essere la causa della composizione clorurato-sodica osservata; le concentrazioni di silice, boro e litio e soprattutto la presenza di quantità significative di ferro e manganese sembrano essere chiari indizi di influenza idrotermale.

Introduction

The volcanic activity occurred in the Aegean area during recent times until present gave rise to widespread thermal anomalies, with still active fumaroles and thermal springs.

Several investigations have been carried out on chemical compositions of this kind of manifestations, mainly because of their geothermal and ore-forming importance (PUCHELT, 1973; DOMINCO and PAPASTAMATOKI, 1975; BUTUZOVA, 1976; PEETERS, 1976).

This paper is aimed to verify the enect of possible inflows into shallow aquifers of chemical species of deep origin, sensitive to changes in the thermal and physico-chemical conditions of the environment.

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As a result of this process, an enrichment in surface water is expected for volatile constituents as well as for other elements leached from the confining rocks.

Beside the fundamental chemical composition, the distribution of several minor constituents has been thus investigated in samples of natural waters from Santorini, Milos, Nysiros and Kos.



Fig. 1. - Location of the investigated islands.

Volcanological features

The Aegean arc area represents an active converging system, consisting of a typical arc-trench structure (BOCCALETTI et al., 1974; NINKOVICH and HAYS, 1972). This system is the result of the northwards movement of the african plate, which dips under the aegean microplate producing an active seismic zone with a surface of earthquakes inclined at a mean angle of 30° (PAPAZACHOS, 1972).

The depth of the earthquakes under the volcanic arc is about 150 Km.

The volcanic arc lies on the southern margin of the Attic-Cycladean massif, and started its activity about 3 million years ago (FYTIKAS et al., 1976); it consists of a series of centers extending from the gulf of Saronico on the west to the island of Nysiros on the eastern side (fig. 1). Some volcanic centers are still active (Santorini and Nysiros), while fumarolic manifestations only are present in others (Sousaki, Milos, Kos; GEORGALAS, 1962).

Among the investigated areas, Nysiros and Santorini represent central apparatuses, whit a summit caldera at Nysiros and a caldera produced by the famous Minoan eruption (1480-1450 b.C.) at Santorini; the intracalderic volcanoes of Palea- and Nea-Kameni subsequently formed, for the latter a discontinuous activity, beginning in 197 b.C. and lasting till 1950, is recorded (GEORGALAS, 1962).

The volcanic centers of the other islands mainly consist of small edifices with associated pyroclastic products, and lava flows.

Some tuff cones representing the last stage of activity are present at Milos.

The volcanic centers of the other islands mainly consist of small edifices with series, consist mainly of andesites and dacites, with minor quantities of rhyolites and basalts.

Basalts, along with basaltic andesites, are sufficiently widespread at Santorini only, while at Nysiros basaltic andesites represent the early products.

Rhyolites are present at Nysiros and Milos.

Experimental

Table 1 gives a description of the investigated samples, while tables 2 and 3 provide the values obtained, beside the fundamental constituents, for SiO_2 , B, NH₄, F, Sr, Li, Br, Fe, Mn, Rb.

The analytical procedures used are:(HCO3, Br)Volumetry(SiO2, B)Colorimetry(Ca, Mg, Na, K, Li,
Rb, Sr, Fe, Mn)Potentiometry(Cl, SO4, NH4, F).

Analysis of the results

By the square diagram of fig. 2, two groups of samples can be distinguished. Most of the studied waters are characterized by an alkaline chloride composition, which appears quite reasonable because some of them have been directly collected from seawater, while for the others pertaining to manifestations located near the shoreline a marine influence is to be expected.

The few samples of different chemical type have been collected at higher elevations, do not show any possible connection with seawater and substantially reflect the leaching of the confining rocks.

With reference to the first group, when considering the parameters normally assumed as chemical indicators of thermal anomalies, the above mentioned marine influence forces us to rule some of them out of our consideration; in fact the actual values of Na/K ratio and of NH₄ concentration are strongly overshadowed

TABLE 1

Description of the samples

No.	sample	Locati	on	Description	Date of collection		
	1	Palaea Kameni	(Santorini)	Submarine spring	September 1980		
	2	Nea Kameni	(Santorini)	Submarine spring	September 1980		
	3	Nea Kameni	(Santorini)	Submarine spring	August 1978		
	4	Nea Kameni	(Santorini)	Submarine spring	September 1980		
	5	Caldera	(Santorini)	Seawater	August 1978		
	6	Palaea Kameni	(Santorini)	Seawater	September 1980		
	7	Vlikhada	(Santorini)	Thermal spring	August 1978		
	8	Vlikhada	(Santorini)	Thermal spring	September 1980		
	9	Agios Georgios	(Santorini)	Dug well	August 1978		
	10	Agios Nikolaos	(Santorini)	Dug well	August 1978		
	11	Akrotiri	(Santorini)	Dug well	August 1978		
	12	Plaka	(Santorini)	Thermal spring	September 1980		
	13	Pali	(Nysiros)	Spring	September 1978		
	14	Mandraki	(Nysiros)	Thermal spring	September 1978		
	15	Kokkino nerð	(Kos)	Spring	September 1978		
	16	near Kokkino nerð	(Kos)	Spring	September 1978		
	17	Vromotopo	(Kos)	Dug well	September 1978		
	18	Agios Focas	(Kos)	Thermal spring	September 1978		
	19	Agios Soulas	(Kos)	Thermal spring	September 1978		
	20	Agia Irene	(Kos)	Thermal spring	September 1978		
	21	Kalamos	(Milos)	Dug well	September 1980		
	22	Halyki	(Milos)	Pond	September 1980		
	23	Kanava	(Milos)	Pond	September 1980		
	24	Charos	(Milos)	Dug well	September 1980		

TABLE 2

Fundamental constituents of the analysed samples; values are in milliequivalents per liter (epm). Conductivity values are in $m\Omega^{-1} \cdot cm^{-1}$

No.	sample	T°C	pH	Cond.	ca ²⁺	Mg ²⁺	Na ⁺	к+	нсо3	C1	so ₄ ²⁻
	1	36	5.4	47	29	117	535	12	8.6	636	53
	2	40	5.5	47	31	115	528	14	5.9	606	52
	3	27.5	6.3	44	29	110	551	11	5.4	648	58
	4	27	6.0	47	28	121	524	13	5.1	626	55
	5	24	7.95	45	26	109	518	12	3.2	647	64
	6	24	8.1	47	26	123	513	12	3.5	658	56
	7	31	6.9	5.3	5.7	9.2	49	0.64	3.3	52	7.6
	8	30	7.95	5.6	6.1	9.3	43	1.2	2.8	50	6.2
	9	21	6.75	1.8	4.3	2.6	11	1.1	4.0	14	3.0
	10	23.5	6.65	2.4	3.5	1.0	20	1.2	2.5	22	2.4
	11	22	6.75	3.4	9.6	5.7	23	0.60	4.2	32	4.0
	12	35	7.2	14	14	21	116	2.6	4.0	129	21
	13	27.5	6.9	18	38	27	163	5.5	2.9	226	16
	14	49	6.7	42	87	52	487	16	4.4	592	32
	15	23	6.6	0.81	21	5.5	0.98	0.058	19	1.2	6.4
	16	23	6.7	0.85	33	7.6	1.0	0.087	23	1.3	9.6
	17	20	3.1	2.0	7.1	1.3	6.1	0.62		4.8	10
	18	45	6.45	44	84	82	509	14	22	611	70
	19	34	7.55	0.71	6.2	1.5	1.3	0.076	5.2	1.2	2.4
	20	43	7.3	20	45	12	209	4.4	3.6	244	10
	21	29	8.0	0.68	3.4	0.84	2.1	0.31	3.8	1.7	1.8
	22	25	7.3.	30	57	13	280	33	5.9	355	17
	23	44	5.8	30	51	13	289	30	6.8	366	16
	24	47	6.4	3.9	13	4.1	35	3.7	13	35	6.0

by the composition of seawater, and do not seem to provide any support to the present study.

Useful information appears instead to arise from the distribution patterns of silica, boron, lithium, iron and manganese, of which a brief account is given.

TABLE 3

Minor constituents of the analysed samples; values are in milliequivalents per liter (epm) for NH⁺₄, F⁻, Sr²⁺, Li⁺, Br⁻, Rb⁺, Mn²⁺ and Fe²⁺, and in millimoles per liter for SiO₂ and H₃BO₃

No. sample	Si02	H3BO3	NH ⁺ ₄	F_	Sr ²⁺	Li ⁺	Br ⁻	Rb ⁺	Mn ²⁺	Fe ²⁺
1	1.2	0.60	0.050	0.071	0.25	0.056	1.1	0.0049	0.024	0.55
2	1.3	0.51	0.065	0.071	0.27	0.086	1.0	0.010	0.072	0.43
3	1.1	0.67	0.033	0.096	0.24	0.057	0.97	0.0046	0.017	0.082
4	0.72	0.48	0.055	0.056	0.24	0.045	0.86	0.0038	0.075	0.22
5	< 0.0001	0.65	0.010	0.072	0.22	0.023	0.97	0.0015	0.0015	0.0075
6	< 0.0001	0.51	0.029	0.079	0.25	0.023	1.1	0.0016	0.023	0.018
7	0.70	0.017	0.017	0.017	0.050	0.009	0.11	0.0006	<0.0001	<0.0001
8	0.81	0.028	0.015	0.036	0.057	0.010	0.079	0.00023	<0.0001	<0.0001
9	1.0	0.023	0.030	0.085	0.029	0.008	0.0011	0.0006	<0.0001	<0.0001
10	0.40	0.020	0.019	0.028	0.029	0.0005	0.0019	0.00095	<0.0001	<0.0001
11	1.1	0.013	0.027	0.034	0.042	0.006	0.035	0.0006	<0.0001	<0.0001
12	1.6	0.10	0.042	0.041	0.092	0.016	0.14	0.0011	<0.0001	<0.0001
13	2.0	0.54	0.057	0.014	0.17	0.082	0.33	0.0070	<0.0001	0.0035
14	1.5	1.1	0.16	0.039	0.47	0.22	0.86	0.023	0.15	0.0075
15	0.23	0.0065	0.0064	n.d.	n.d.	0.0005	n.d.	<0.0001	0.0075	0.052
16	0.13	0.001	0.020	n.d.	n.d.	0.0005	n.d.	<0.0001	<0.0001	<0.0001
17	1.8	0.0075	0.080 .	0.0085	0.029	0.0005	0.033	0.00075	0.0075	0.066
18	0.28	0.62	0.0033	0.13	0.39	0.034	0.92	0.0019	<0.0001	0.008
19	0.90	0.018	0.024	0.037	0.18	0.0005	0.001	<0.0001	<0.0001	0.0015
20	0.35	0.70	0.026	0.040	0.26	0.21	0.37	0.0054	0.00075	<0.0001
21	0.63	0.019	0.042	0.0035	0.035	<0.0001	0.0045	<0.0001	0.0033	<0.0001
22	2.8	2.1	0.035	0.030	0.39	2.0	0.31	0.092	0.077	0.023
23	2.9	1.8	0.25	0.031	0.39	1.9	0.30	0.085	0.15	0.027
24	2.9	0.13	0.38	0.015	0.10	0.060	0.045	0.0056	<0.0001	0.010
Silica	: bes 23, 14 en	side the 24, als are vironme	e overs so the to be ents.	aturatio lower consid	on va conce lered	lues pe ntration anoma	rtainir s of s lous	ng to sa amples for ma	amples n no. 1, 2 arine or	o. 13, 22, , 3, 4, 12, brackish
Boron	: val no by	lues of . 5 and sample	the B 6, assu es no.	/Cl rat umed a 13, 14,	tio at as uno 20, 2	least tr contami 2, 23, 2	wice t nated 4 (fig	hat per local se . 3).	taining t awater, a	o samples are shown
Lithium	 anomalous values for Li/Cl ratio, in comparison with the same standards of reference, are observed for almost all the samples (fig. 4). 									
lron	: concentrations higher than 0.2 ppm Fe pertain to samples no. 1, 2, 3, 4, 5, 6, 14, 18, 22, 23, 24.									
Manganese	e : concentrations above 0.1 ppm Mn are observed for samples 1, 2,									

Among the samples of the second group, no. 21 appears as typical surface solution without special chemical features; nos. 15, 16, 17, 19, all from Kos, reflect the influence of gaseous input, directly detectable for nos. 15, 16, 19



Fig. 2. - Square-diagram of the fundamental chemical composition.



Fig. 3. - Boron vs. chlorine concentrations in the studied samples.

characterized by bubbling CO₂, and easily deduced for no. 17, acid and located in a fumarolized area.

Significant concentrations of Fe and Mn are observed for samples no. 15 and 17, this latter being also oversaturated with respect to SiO₂.

Anomalous concentrations of silica, boron and lithium can be strictly connected to thermal anomalies, but they can also represent the results of past activities, whose declining effects are still lasting.

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The presence of iron and manganese requires instead physical-chemical conditions which can prevent their precipitation as insoluble hydroxides; these conditions, low values of pH and redox potential in a surface environment, can only be produced and maintained by a continuous inflow of chemical species of anaerobic origin.

In a volcanic system it is rather easy to ascribe this phenomenon to the influence of hydrothermal fluids, that is, when iron and manganese are detected an input of reducing species can be derived accordingly (Cellini-Legittimo et al., 1980).



Fig. 4. - Lithium vs. chlorine concentrations in the studied samples.

So, taking into account the samples for which anomalous values of the considered parameters are observed, along with their locations, it appears that the fulfilment of the conditions possibly related to the influence of chemical species of deep origin is mainly revealed at Nysiros (no. 14), Milos (nos. 22 and 23), Kos (no. 17) and Santorini (no. 1, 2, 3, 4).

The sample from Kos refers to an area where low temperature fumaroles were still active few years ago, while for the other islands the above mentioned anomalies are observed where the erosion by sea waves cut the volcanic structures, so allowing the emergence of deep fluids.

Conclusions

The investigations on the chemical characters of natural waters from the islands of Santorini, Milos, Nysiros and Kos allowed to detect the influence of hydrotheremal fluids, mainly expressed by significant concentrations of iron and manganese, which only can persist in a surface environment if a continuous inflow of reducing species occurs.

This circumstance while representing a chemical witness of the «active»

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character of the area, cannot provide direct information about the stage of activity, with volcanological implications.

However, since any change in the intensity of the observed surface anomalies could be produced by some degree of modification in the deep system, a survey of that kind of manifestations seems advisable.

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