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OVERVIEW OF THE GEOTHERMAL ACTIVITIES IN GREECE DURING 1985-89

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ABSTRACT

Following a brief outline of the geological background in Greece, as related to geothermal exploration, the prospective areas for low enthalpy fluids are classified into four groups. These are the Tertiary grabens associated with lithospheric stretching and crustal subsidence, the Arc of the Aegean Plio-Quaternary volcanism induced by the subduction of the African plate, Central Aegean islands of distensive tectonism bordering back-arc marine basins and finally Tertiary-Quaternary sedimentary basins of various types, not classified as grabens. The geothermal regime in each of these groups is outlined, and the current status of exploration is reviewed.

INTRODUCTION

Although geothermal exploration in Greece, initially for high enthalpy, started rather late, in 1970, it has been very successful so far in discovering significant fields, both of high and lower enthalpy. This paper refers only to direct heat utilization; a companion paper deals with electrical utilization of geothermal energy.

The legal frame work ruling specifically geothermal exploration and exploitation in Greece was passed only recently (Law 1475 of 1984). Based on the experience gained, it is believed its improvement, would further stimulate geothermal exploration and applications.

The basic exploration for low enthalpy geothermal energy is conducted by the Institute of Geology and Mineral Exploration (I.G.M.E.) through the Section of Geothermal Energy of the Department of Energy Resources. On a local scale, however, the relevant Communities or Agricultural Cooperatives and privates are also involved to a lesser degree. The Industrial Bank of Greece has encouraged and financed exploration and pilot applications. The Public Petroleum Corporation of Greece has also cooperated with IGME as a drilling and financial partner on two occasions for deep wells. The Public Power Corporation is currently involved mainly with the exploration for high enthalpy geothermal energy.

GEOLOGICAL BACKGROUND

Two great geotectonic cycles can be traced in Greece, i.e. the Hercynian cycle and the Alpine one. The structures of the Hercynian cycle are found in crystalline massifs, whereas the Alpine cycle is represented by a number of isopic zones, the so called Hellenides.The massifs can be classified into: (i) the internal crystalline ones comprising the Rhodope Massif (the most internal massif), the Serbo-Macedonian Massif and the Pelagonian Massif and (ii) the external crystalline massifs, occurring on central Peloponnese and Crete.

Following the Alpine orogeny and the associated flysch deposition, molassic sedimentation started in the Paleogene, associated with fault tectonism and volcanism in northeast (NE) Greece. The volcanism started in the Eocene in the Rhodope Massif and progressively migrated southwards to its present position in the active Aegean Volcanic Arc, after a period of interruption in the upper Miocene-lower Pliocene.

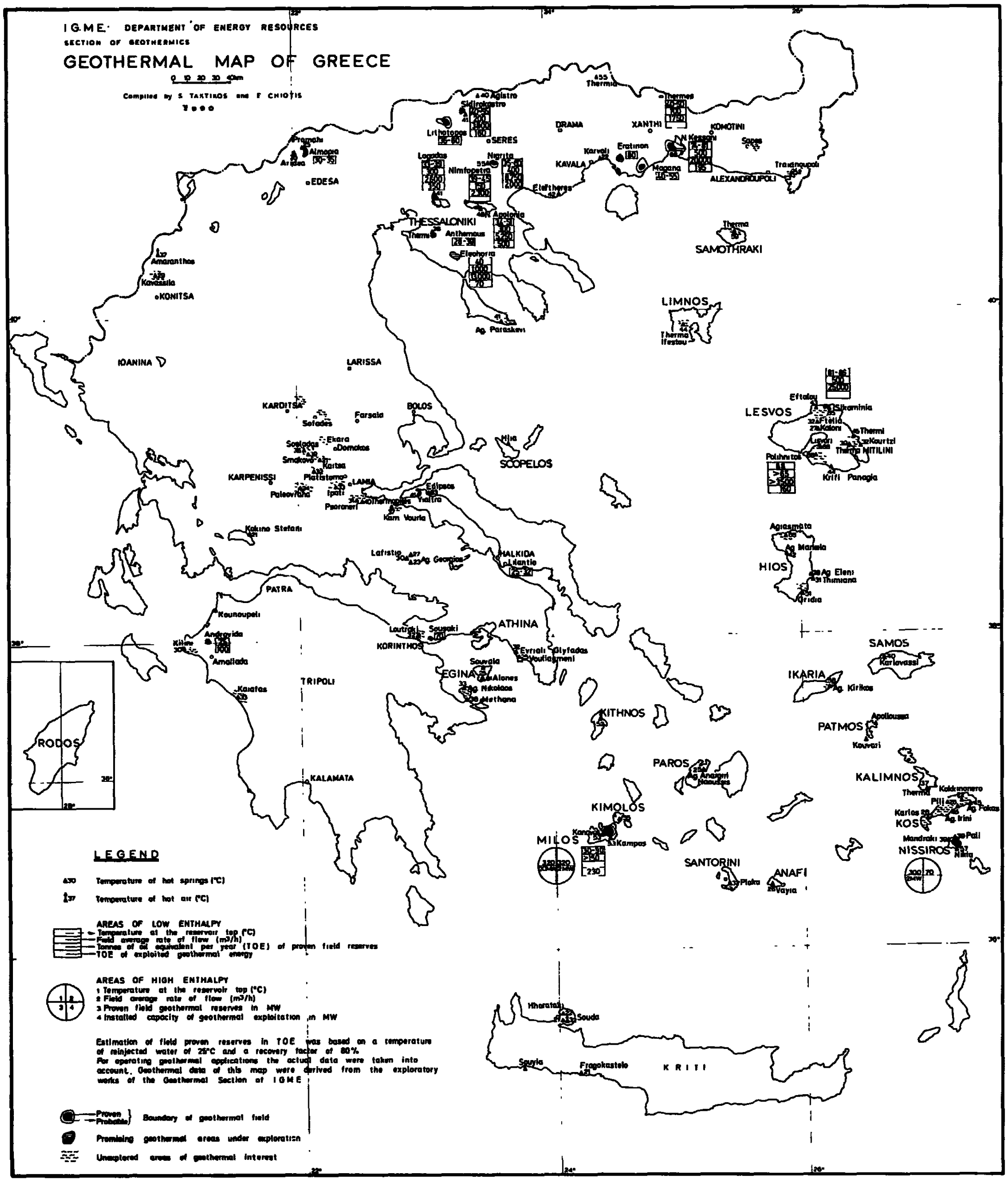
The present geothermal and geotectonic regime in Greece is controlled by the subduction of the African plate below the Aegean plate. Two contrasting regimes can be distinguished on either side of the sedimentary arc, which surrounds the volcanic one and extends along the Crete Island and the western margin of continental Greece. The external side towards the Hellenic trench is characterized by a compressive stress field and low heat flow, whereas on the internal side high heat flow and an extensive stress field prevail. This extensive tectonism apparently was initiated 10 to 15 Ma ago and resulted in the formation of sedimentary troughs with rapid and thick clastic sedimentation. Based on the tectonic subsidence history, a thinned lithosphere is inferred locally below these grabens, associated with a long lasting positive thermal anomaly (Chiotis, 1989).

On a regional scale also the Aegean lithosphere is thinned. Thus, the crustal thickness in the Cretan Sea reaches a minimum value of 20 km approximately.

GEOTHERMAL REGIME

Exploration for geothermal energy of low (100°C) and medium (150°C) enthaply was very active during the period 1985-89 as shown in Table 3 summarizing drilling activity in the various geothermal localities (Table 4). In addition to these areas where advanced exploration is in progress, preliminary exploration was also performed elsewhere, including Sperchios valley and the very prospective central Aegean islands, Lesbos and Hios.

Geologically, the areas explored can be classified as follows.



1. Tertiary-Quaternary sedimentary postorogenic grabens such as the Xanti-Komotini basin (N. Kessani field), the Delta of Nestos (Eratinon and Magana fields), the Strymon basin (Sidirokastro, Lithotopos and Nigrita fields), the Mygdonia basis (Lagadas, Nymfoptra and N. Apollonia fields), the Anthemous basin and the Sperchios valley. Troughs of this type are common in eastern Greece, developed mainly over the Serbomacedonian and Rhodope massifs.

2. Areas of recent or active volcanic activity along the Aegean Volcanic Arc, including Kos and Santorini islands. Susaki, lying at the intersection of the northwest (NW) termination of the arc with the Saronikos-Korinthian Bay graben combines both features, i.e. recent volcanism and basin formation due to intensive normal faulting.

3. Back-arc areas of active extensive tectonism in the central Aegean Sea not associated necessarily with any important sedimentation, like Lesbos and Hios.

4. Tertiary-Quaternary molassic basins of various types not classified as grabens, like Thessalia in central Greece, the Almopia basin, the Amvrakikos Bay basin and the foreland basin

of NW Peloponnese. The results of geothermal exploration in these basins are of minor importance for the time being and will not be further discussed.

Tertiary Grabens

Geothermal gradients in these troughs estimated from temperature measurements in oil wells (Ten Dam and Rouviere, 1983) are close to normal or slightly higher. It is 30°C/km in the Strymon basin, 31°C/km in the Xanthi-Komotini basin and 37°C/km in the Delta of Nestos. Thermal springs associated with normal faulting in Tertiary grabens are very common in northern Greece (see geothermal map of Greece). We mention below some of them, related to geothermal fields.

a) Lagadas (41°C) and N. Apollonia (48°C) springs in Mygdonia graben and Thermi (38°C) in the small neighboring Anthemous basin. The geochemistry of these springs indicates that the underground associated water does not exceed 100°C.

b) Thermal manifestations in the Strymon basin occur on the flanks of the basin with emergence temperatures ranging from 27° to 55°C, being 41°C at Sidirokastro and 55°C at Nigrita.

c) In Nea Kessani, the western part of the Xanthi-Komotini basin, there are thermal springs ranging from 30° to 54°C.

The geochemical characteristics of the above thermal springs indicate long circulation before rising at the surface (Minissale and others, 1989). Those of the Strymon basin belong to the Na-HCO_3 geothermal type of waters, the Nestos-Xanti and Anthemous springs are of Na-Cl type, the thermal waters in the Mygdonia basin are of the Na-Ca-SO_4 type and in the Sousaki high salinity Na-Cl waters.

The oldest sediments are transgressive and disconformable over the tectonized pre-Tertiary basement and are of Quaternary age in the area of exploration in Mygdonia, of Pliocene age in Sousaki, Miocene in Nestos and Strymon basin and of Eocene age in the Xanti-Komotini basin. The Quaternary sediments in the Mygdonia basin are a few hundreds meters thick only, whereas the Neogene sediments reach 4,000 m in the Strymon basin and Delta of Nestos. The Xanthi-Komotini basin ranks in between with a thickness approximating 2,000 m. The Tertiary clastic sediments are fluviatile, lacustrine, deltaic or marine and consist mainly of clays, claystones, shales, marls, argillaceous or clean sandstones and conglomerates. Messinian gypsum is also intercalcated in both the Strymon basin and the Delta of Nestos.

Drilling exploration so far has revealed a significant geothermal potential of low and possible medium enthalpy along the tectonic borders of the troughs or in internal horsts of the pre-Tertiary basement, covered by impervious argillaceous sediments. At the current stage of geothermal exploration, drilling is predominantly limited to a maximum depth of 500 m. This is mainly due to a combination of reasons such as: (i) rapid increase of drilling cost below this depth, (ii) scarceness of the required heavier type drilling rigs and (iii) existing geothermal applications exploits a small fraction only of the available shallow fields. Drilling exploration for shallow geothermal fields is normally carried out in two stages. Firstly, slim (2" O.D. casing) and low cost boreholes are drilled in order to get temperature measurements and stratigraphic information. Based on these data, production wells (8 5/8" to 10 3/4" O.D. casing) are drilled to determine the reservoir characteristics and evaluate its productivity.

In the Strymon basin three geothermal fields have been discovered (Sidirokastro, Lithotopos, Nigrita) in the sediments at the margins of the basin, where the reservoir depth ranges between 50 and 500 m. A geothermal potential might also exist at the bottom of the sedimentary sequence in the basement along fault zones. The deep geothermal well Serres (2,007 m) was positioned on the basis of oil exploration findings. However, temperatures encountered (~60°C) were not sufficient to justify the commercial exploitation originally planned, i.e. central heating in the town of Serres. It is worthy to mention that a shallow field (up to 50 m) was drilled in Sidirokastro within travertine, the origin of which is associated with a rhyolithic volcano penetrating the Pliocene sediments (Karydakis and Kavouridis, 1988).

In the Delta of Nestos a significant geothermal anomaly was drilled initially by slimholes over an area of 30 km^2 approximately. The anomalous geothermal gradient recorded is 3 to 4 fold in comparison to the regional one. Thereafter, the 1,377 m deep well in Nestos 1G was drilled, which after penetrating 760 m of clastic Pliocene sediments entered the metamorphic basement composed of amphibolite and gneiss. Based on temperature logs, a bottom hole static temperature of 125°C was estimated. Potential reservoir rocks are indicated by the electric logs at the sedimentary base at 550 to 650 m where the temperature is 70 to 80°C. In addition to this geothermal anomaly, which merits further exploration, the Magana geothermal field was discovered in the eastern margin of the Delta of Nestos. Temperatures about 50°C have been measured at 400 m at the base of the sediments.

A special reference should be made to the N. Kessani field because of its significance and the scaling problems it presents. It extends over area of 15 to 20 km^2 in the southern margin of the Xanthi-Komotini basin. Exploration is in the final stage of reservoir evaluation. So far 25 exploratory slim holes and six production wells have been drilled. The total yield of the field is estimated to 500 m^3/h of water at a maximum temperature of 78°C. Thermal water is produced from Oligocene sandstones and conglomerates. Underlying argillaceous Plio-Quaternary sediments act as cap rocks.

A mixture of water and CO_2 is produced due to the high content in H-CO_3 (~25 meq/l). As a result of pressure drop during well production, CO_2 is release according to the reaction:

$$2HCO_3 \text{ -----> } H_2O+CO_2+CO_3^{2-}$$

This reaction increases the concentration of CO_3^{2-}, which in turn creates conditions of oversaturation in the rich in Ca^{2+} water (~6 meq/l) and finally deposition of $CaCO_3$. These scaling problems were successfully faced by the proper chemical treatment during the experimental production of a pilot greenhouse installation.

Aegean Volcanic Arc

Santorini and Kos islands have been explored for low and medium enthalpy geothermal energy. Based on temperature measurements and geochemical analyses of thermal springs, a geothermal anomaly was located on Santorini and consequently was confirmed by slim holes. The active volcanism and the type of volcanic rocks of Santorini (latest eruption occurred in 1950) warrants the existence of shallow magma chambers. The geothermal anomaly studied is ascribed to ascending magmatic hot fluids, principally in a gaseous phase (Fytikas and others, in press). A hydrothermal system is developed in the metamorphic basement consisting of impermeable rocks, which isolate the ascending magmatic fluids from sea and meteoric water. The overlying volcanic products are in general permeable and allow percolation of cold surface waters. Therefore, geothermal targets are mostly expected below the volcanic formations within the metamorphic basement, in places near deep faults; this makes geothermal exploration relatively difficult and leads to drilling depths more than 200 to 400 m. Temperatures of 60° to 70°C have been recorded at these depths.

Similar conditions prevail on Kos Island, where a tremendous volcanic eruption took place some 120,000 years ago. Following a preliminary stage of exploration, an area with intensive hydrothermal alternation and fumarole fields was selected for drilling exploratory slim boreholes. Drilling operations started early in 1990.

Central Aegean Islands

Lesbos is the most representative of the thermal regime in the Central Aegean Islands. Three significant geothermal areas are known on Lesbos (Fytikas and others, 1989) namely Petra-Argenos, Stipsi-Kalloni and Polyhitos. Numerous thermal springs occur on Lesbos, where the hottest springs of Greece are found, with temperatures ranging from 80 to 87°C. The geochemical temperature of the thermal waters varies in the range from 115 to 125°C. Neogene volcanic rocks are widespread; they can be divided into early calc-alkaline volcanics dating between 19 and 15 Ma and shoshonitic lavas that were emitted after and/or during the deposition of lower Pliocene sediments. It is believe that the thermal systems of Lesbos are not related to shallow magma chambers or to recent volcanism in general. Geothermal anomalies are considered to be controlled by important extensional active faults, along which the thermal fluids ascend. These thermal fluids acquire their thermal content through slow percolation within the crust.

UTILIZATION OF LOW ENTHALPY GEOTHERMAL ENERGY FOR DIRECT HEAT

Utilization of direct heat is mostly limited to greenhouses in northern Greece and on the islands of Lesbos and Milos (Table 1). On an experimental basis, heating for growing fishes has also been applied with encouraging results. The chemical composition of geothermal waters varies from field to field; therefore, chemical treatment should be adopted to each field.

The biggest geothermal greenhouse unit operating on a commercial basis is found at Nigrita, in the Strymon basin. A water-water heat exchanger is used with inox plates, which must be cleaned once or twice a month due to heavy precipitation of salts, mainly $CaCO_3$.

A geothermal water-air heat exchanger is used in N. Kessani-Xanti in a demonstration unit of greenhouses installed by the Industrial Bank of Greece. The geothermal water is conveyed through a system of pipes. Air is forced among the pipes and distributed by fans through plastic channels in the greenhouses. An additional system of soil heating is also used. Chemical treatment is applied by injecting chemical inhibitors in the producing well.

Generally when the salt concentrations are not very high and severe precipitation is avoided, the direct circulation of geothermal fluids through the heating system can be possible. In these cases the chemical treatment of geothermal fluid is strongly recommended.

A small fraction of the proven low enthalpy geothermal reserves are presently used. Out of 85,000 TOE of total reserves only 4,000 TOE are exploited. This is mainly due to two reasons. First, because of a higher initial investment for geothermal greenhouses. Secondly, due to economic considerations related directly to the current oil prices. It is therefore expected that higher oil prices in the future would encourage geothermal heating of greenhouses, especially in northern Greece due to its colder climate.

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TABLE 1 - WELLS DRILLED BY IGME#
FOR DIRECT HEAT UTILIZATION OF GEOTHERMAL RESOURCES
(From January 1,1985 to January 1,1990)

*Type of well: E=Exploration, Pr=Production, A=Artesian, Pm=Pumped
**Flowing enthalpy was calculated by multiplying temperature in °C by 4.1868

Locality	Year Drilled	Well Number	Type of* Well	Total Depth (meters)	Maximum Temp. °C	Flowing Enthalpy** kJ/kg	Flow rate kg/s
Andravida	86	3	E/A	651	26		
Anthemous	85-86	3	E	867	39		
Argenos (Lesbos)	88	3	E/Pm	338	86	360	>80000
Aridea	86-88	4	E	1689	35		
Delta of Nestos	85-86	6	E	2849	72		
" "	88-89	1	E	1378	125		
Lagadas	85	3	E/A	863	39		
"	86	1	Pr/A	237	41	172	14000
Lilantio	85-86	3	E	972	30		
Magana	88-89	7	E/A+Pm	1817	63		
N.Apollonia	88	1	Pr/A	94	47	197	12000
N.Kessani	86-89	21	E/A+Pm	8270	83		
"	88-89	6	Pr/A+Pm	1073	80	335	80000
Nymfopetra	88	1	E/A	121	34		
"	88	1	Pr/A	121	41	172	14000
Santorini	85	1	E	220	51		
Serres	87	1	E	2007	56		
Sidirocastro	85-86	10	E/A+Pm	1958	50		
"	86	1	Pr/Pm	56	42	176	12500
Sousaki	88-89	5	E	901	78		
"	89	4	Pr/Pm	548	76	318	>28000
South Thessalia	86-88	6	E	2448			

IGME =Institute of Geology and Mineral Exploration

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TABLE 2 - INFORMATION ABOUT GEOTHERMAL LOCALITIES

Rock [1] = Main type of reservoir rock: B=Metamorphic basement, C=Conglomerate, G=Gravel, L=Limestone, S=Sand-sandstone, V=Volcanics.

Water [2] = Total dissolved solids,in g/kg, before flashing.

Status[3] R = Regional assessment P = Pre-feasability studies
F = Feasability studies (reservoir evaluation and engineering studies)
U = Commercial utilization

Locality	Location		Reservoir			Status[3] in Jan. 1990	Measured Reservoir Temp.°C
	Latitude	Longitude	Rock[1]	Water[2]	Area Km[2]		
Andravida	37° 54'	21° 20'	C+S	3.3	2	R	26
Anthemous	40° 30'	23° 10'		2.0		P	28 - 39
Argenos	39° 22'	26° 15'	V	11.7	4	R	81 - 86
Aridea	41° 00'	22° 04'	B	1.0	6	R	30 - 35
Eleohoria	40° 42'	23° 14'	L	1.2		R + Q	
Elatinon	40° 55'	24° 37'	S	8.0		R	80
Lagadas	40° 44'	23° 06'	G+S	0.8	6	P + U	33 - 39
Lilantio	38° 25'	23° 43'	L	8.0	2	R	25
Lithotopos	41° 22'	23° 12'	G+S	1.8	20	R	35 - 50
Magana	40° 54'	24° 43'	G+S	0.6	10	R	40 - 45
Milos	36° 44'	24° 29'	V			P + Q	30 - 90
N. Apollonia	40° 38'	23° 23'	G	1.3	2	P + Q	34 - 51
Nigrita	40° 52'	23° 33'	C		15	P + Q	35 - 61
N. Kessani	41° 04'	25° 03'	S	6.0	15	F + Q	74 - 81
Nymfopetra	40° 44'	23° 20'	G	1.0	2	P	39 - 45
Polihnitos	39° 05'	26° 13'	V			R + Q	88
Santorini	36° 22'	25° 26'	B			R	
Sidirokastro	41° 17'	23° 20'	B	1.7	10	P + Q	40 - 55°
Sousaki	37° 55'	23° 07'	C	45.0	3	P	70

TABLE 3 -UTILIZATION OF GEOTHERMAL ENERGY FOR GRENHOUSES (December 1989)

Locality	Maximum Utilization		
	Flow Rate kg/s	Temperature °C	
		In	Out
Eleohoria	110000	40	25
Lagadas	22000	35	25
Milos		40	25
N.Apollonia	28000	48	25
Nigrita	42000	50	25
N.Kessani	8000	78	53
Polyhnitos	17000	80	55
Sidirokastro	11000	50	25

TABLE 4
ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES
(Personnel with a University Degree)

1. Government
2. Public Utilities
3. Universities

Year	Man Years of Effort		
	(1)	(2)	(3)
1985	2	16	3
1986	2	21	3
1987	2	20	3
1988	2	22	3
1989	2	22	3