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Telex : 42426 TPAO. TR, Ankara, Turkey

To: Dr. Joseph N.Moore
Section Manager-Geochemistry
Earth Science Laboratory
University of Utah Research Institute
Research Park 391 Chıpeta Way Suite C
Salt Lake City, UTAH 84108

U.S.A.

Dear Dr. Moore,

Since You left Turkey after finishing the geothermal seminar, we have worked at many geothermal fields in Turkey, so we are trying to find a very good geothermal potential area that contains high enthalpy fluids to produce electricity. As you know, for this purpose we have worked with UNOCAL as a joint venture participant, so we have some experiences about the geothermal exploration, but we need to have more experimental studies or applied works at a laboratory or at a university to develop our data interperatation of the geothermal works (geochemical exploration and reservoir geology and engineering), so that we can interprate our geothermal data more accuratly and solve our geothermal problems easily.

When you were here, we had talked about this kind of training for our engineers at your institute and you had told us to help about the training for us. We are sure that you can help us for this matter, but we do not know about the training program and when it is going to be available for us. Also we are not sure about your institute policy about this kind of purpose. For sure, all expenses of the studens will be paid by the Turkish Petroleum Corporatino (TPAO).

Could you please inform us about the advanced geothermal training for the data interpretation (geothermal exploratino and reservoir aspects) at your institute. If you help us for this purpose we will be very happy. From now, thank you very much for your considerations.

Best regards.

Sincerely yours,
Hacı SAVCI
Geothermal Manager

TP-Stok No.: 78:130.030 (10.000 Adet)

TELEFAX

LAWRENCE BERKELEY LABORATORY
EARTH SCIENCES DIVISION
1 Cyclotron Road
Berkeley California 94720
TeleFax: 415-486-5686

DATE: Aug 23, 1989

TO: Mike Wright

UU.R.I.

Number of Pages Following: 2

Comments:

FROM: Gudmundur Bodvarsson

Telephone: 415) 486-7348

If transmission is not complete, please advise sender.

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Address : Müdafaa Cad. No. 22 P. O. Box 209 Bakanlıklar, Ankara, Turkey
Cable : Petrol Ankara, Turkey
Telex : 42426 TPAO. TR, Ankara, Turkey

To: Mr.G.S.BODVARSSON
Earth Sciences Division,
Lawrence Berkeley Laboratory
University of California, Berkeley,
California 94720

U.S.A.

Dear Mr. Bodvarsson,

I am the geothermal manager of Turkish Petroleum Corporation. We had met at the geothermal seminar at Antalya, Turkey in 1987 and we had talked about some special advanced course or research program on the geothermal exploration and reservoir engineering subjects at your univer for our engineers as a training course that can be in a two months perio

Since that time, we have worked at many geological, geophysical, geochemical and drilling data for every field of Turkey, so we are tryin to find a very good geothermal potential area that contains high enthalp fluids to produce electricity. For this purpose we have worked with UNOC as a joint venture participant, so that we have some experiences about the geothermal project, but we need to have more experimental studies or applied works at a laboratory or at a University to develop our interperatation on the geothermal data of the geothermal works (geochemi exploration, reservoir testing and engineering), so that we can interper our data more accurately and solve our geothermal problems easily.

As I know your institute deals with that kind of experimental studies; for this purpose, would you like to help us, if some people from here come to your institute with their surface and subsurface data (geological, geophysical, geochemical and drilling) to train about the geothermal data interperatation. For sure, all expenses of students will be paid by Turkish Petroleum Corporation that is a major national oil an geothermal Company of Turkey. But we are not sure that you can accept ou request and we do not know your institute policy about this kind of matt

Could you please inform us about this kind of training for us is available and what we need to have this training at your institute.

./..

TURKISH PETROLEUM CORPORATION

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Telex : 42426 TPAO. TR, Ankara, Turkey

If you help us for this matter, we will be very happy. From now, thank you very much for your consideration.

Sincerely Yours,

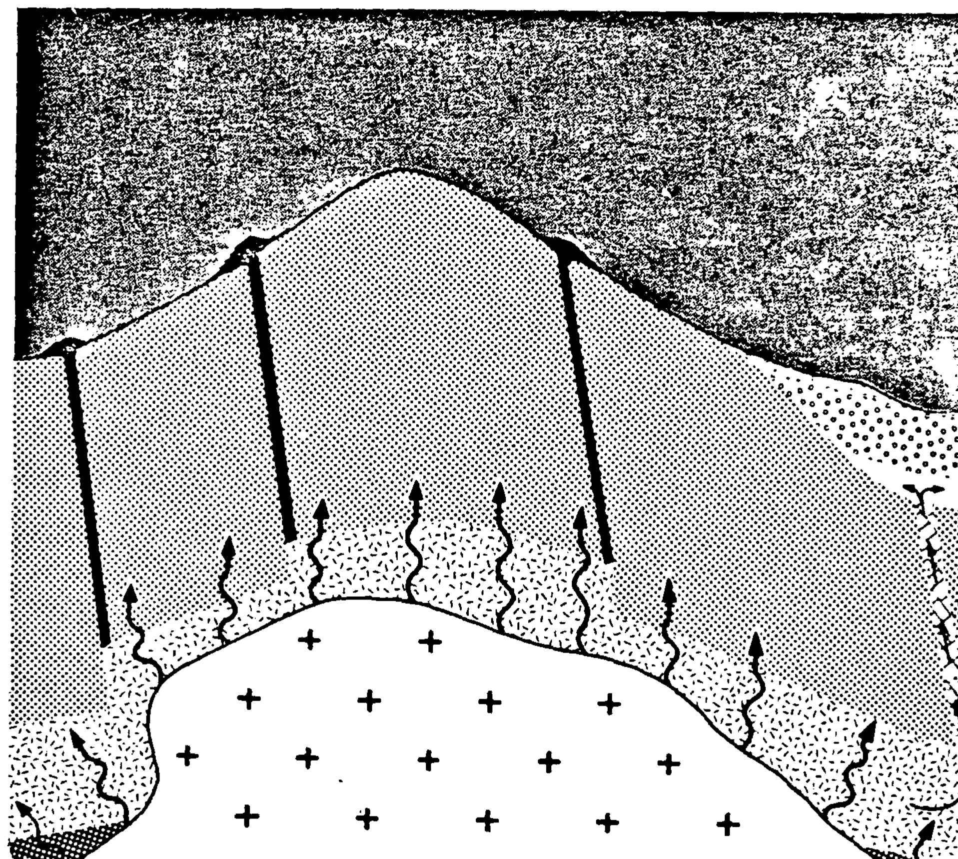
Hacı Savcı
TPAO Geothermal Manager

TP-Sicak No. : 78.13.036 (20.000 Adet)

Yugoslavia

GEOTERMALNA POTENCIJALNOST PODRUČJA AVALA-KOSMAJ-BUKULJA -RUDNIK

J. Perić
M. Milivojević



UNIVERSITY OF BEOGRAD
TRANSACTIONS OF THE FACULTY OF MINING AND GEOLOGY

Special Issue No. 4.

On Geothermal resource possibilities in the Avala-Kosmaj-Bukulja-Rudnik area

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BEOGRAD
1981.

UNIVERZITET U BEOGRADU
ZBORNIK RADOVA RUDARSKO-GEOLOŠKOG FAKULTETA

Posebna izdanja, sv. 4.

Geotermalna potencijalnost područja Avala-Kosmaj-Bukulja-Rudnik

Dipl. inž. JOVAN PERIĆ, docent
Mr. dipl. inž. MIHAILO MILIVOJEVIĆ, asistent
OOUR — Grupa za hidrogeologiju
Rudarsko-geološkog fakulteta

BEOGRAD
1981.

2. Unutar područja sa pozitivnim anomalijama sile teže i geomagnetskog polja može se očekivati regionalni toplotni tok velike gustine.

3. Kontaktno metamorfne zone otkrivenih i posebno pokrivenih intruzija kiselih magmatskih stena predstavljaju veoma potencijalna ležišta i izvorišta hidrogeotermalne energije.

4. Područja sa pojavama tercijarnog vulkanizma predstavljaju veoma perspektivna područja za eksploataciju geotermalne energije.

5. Područje Avala — Kosmaj — Bukulja — Rudnik spada u najperspektivnija područja u SR Srbiji, pa i jednog od najperspektivnijih u SFRJ za intenzivno korišćenje geotermalne energije. Procenjujemo da će se u njemu pronaći takva ležišta i izvorišta iz kojih će se geotermalna energija koristiti i za proizvodnju električne energije.

Summary

On Geothermal Resource Possibilities in the Avala — Kosmaj — — Bukulja — Rudnik Area

J. Perić and M. Milivojević, Hydrogeological Division of the School of Mining and Geology, Đušina 7, Beograd, Yugoslavia

The monograph is a presentation of the analysis and synthesis of all the data obtained by earlier regional and detailed geological, hydrogeological and geophysical research in the area extending from Beograd as far south as Gornji Milanovac, i. e. in the mountain range Avala — Kosmaj — Bukulja — Rudnik, covering about 3600 km². The purpose of the analysis was to obtain an insight into its general geothermal potential in order to assess the possibilities of this area to become a geothermal energy resource. The area lies between 20° 8' and 20° 45' east of Greenwich, and between 43° 55' and 44° 50' north of the Equator (Fig. 1). It comprises the southern peripheral part of the Pannonian basin and the northernmost part of the so-called Vardar zone, well-known in the geological literature.

The area of study is characterized by numerous occurrences of Neogene volcanics indicating the presence of still hot acid granitoid intrusions. They constitute the highest geothermal potential in this area. Incidentally, mountain Rudnik constitues the youngest volcanic area in the Socialist Republic of Serbia.

As mentioned above, the mountain range Aval — Kosmaj — Bukulja — — Rudnik represents the northernmost part of the Vardar zone. This zone and, therefore, also the area of study borders with the Dinarides on the west and the Carpatho-Balkanides on the east.

Prior to the development of the new global tectonics and the plate tectonics, the geotectonics of the mountain range Avala — Kosmaj — Bukulja — — Rudnik was generaly associated with the Vardar zone. The origin of the Vardar zone and its relative position has been variously interpreted from the standpoint of the traditional geotectonic theory. From the standpoint of plate tectonics views likewise differ, but most researchers agree that the Vardar zone is a subduction zone and that it belongs in the Serbo-Macedonian Benioff system.

The thickness of the Earth's crust in the mountain range Avala — Kosmaj — Bukulja — Rudnik and its importance as a factor in the development of geothermal energy — have not been studied in detail. A general statement can, however, be made on the basis of earlier measurements of the Earth's crust in the neighboring areas. Thus, going soutwards of Beograd, i. e. from Avala to Rudnik, the thickness of the Earth's crust increases (Fig. 4); to be more precise, its thickness near Beograd is about 25 km, and reaches 36 km in the Rudnik area.

The geological composition and structure of the area of study is of a highly complex character. This is reflected in a great stratigraphic-facial diver-

sity, and a large number of extrusions and intrusions of all kinds of igneous rocks, mostly of Neogene, perhaps, also of Quarternary age, as well as in very complicated tectonic relations (Fig. 5). As mentioned above, granitoid plutonics represent the main geothermal potential. These rocks fall into the zone which extends along the eastern and northeastern periphery of the Inner Dinarides from Kopaonik in the south to Avala in the north. The characteristics of the igneous activity in the area of study indicate that some granitoid plutonics are associated with the same magmatic melt. The plutonics are of Late Miocene age.

The neotectonics in the mountain range was rather active, as could be deduced from the occurrence of seizmic centers. Seismicity is most strongly manifested in the area of Rudnik mountain which is at the same time the area with strongest seismic activity in the whole of Serbia, its intensity falling in class IX of MCS. Another area of very strong seismic activity is that around Lazarevac, where earthquakes reach the same intensity: class IX of the Mercalli-Cancani scale (Fig. 10). Hypocenters generally occur in the shallower parts of the Earth's crust (Fig. 11). The epicenters of the most intensive and intensive earthquakes occur in the areas in which Tertiary igneous rocks are present; close to, or, along rather large discontinuities. The epicentral zones coincide with the zones of upward neotectonic movements of the Earth's crust, as recognized on the basis of accurate surveying.

Regional geophysical gravimetric and geomagnetic explorations made it possible to distinguish principal tectonic and geological units. The isogal map is very complex (Fig. 12). Most of the area between Avala and Kosmaj displays positive values of gravimetric anomalies (Fig. 12). The positive gravimetric maxima can be accounted for by the presence of basic rocks. The presence of Tertiary and Cretaceous Flysch sedimentary basins is manifested in remarkably high negative anomalies.

Numerous occurrences of thermal, mineral and thermo-mineral waters hav been estabilished in the area of study; they are found either as natural springs, or in boreholes (Fig. 22). The maximum temperature of natural springs is 31° C. The comparatively low temperature values can be attributed to unfavorable hydrogeological features of the terrain in its shallower parts rather than to the existing geothermal conditions.

Geothermal characteristics have not been studied in any great detail so that no data are available on the terrestrial heat flow. There is comparatively little evidence on geothermal gradients and/or temperature gradients, most measurements being taken in Neogene sedimentary basins. The geothermal gradients in these basins vary between 12 and 18 m/° C, which suggests that the heat flow values exceed 100 mW/m². The highest geothermal anomalies recorded to date are those measured in the vicinity of Mladenovac, i. e. in the area of the granitoid pluton of Kosmaj, and at the foot of Maunt Avala near Beograd, where there is another granitoid pluton, most likely linked with that in the Kosmaj area. According to these anomalies, the geothermal gradients avarage 5 m/° C. These anomaly values indicate that the buried granitoid intrusions of Avala, Kosmaj, Bukulja and Rudnik constitute the highest geothermal, i. e. petrogeothermal potentials. In their vicinity the heat flow values should exceed 200 MW/m².

The significance of granitoid plutons as the most important resources of geothermal energy in the area of study is also indicated by numerous paleohydrogeothermal siliceous and carbonatic occurrences. These are direct indicators of the presence of young palehidrogeohthermal high-temperature systems, of which the paleohidrogeothermal system of Avala has been studied in greatest detail. In this locality near Beograd, a temperature of 200—250° C can be expected at a depth of 1.5 — 3 km.

The analysis of results of all explorations to date warrants the conclusion that the Avala — Kosmaj — Bukulja — Rudnik area is highly likely to contain geothermal energy resouces which can be utilized. The explorations should be concentrated around the Neogene granitoid intrusions of Avala, Kosmaj, Bukulja and Rudnik, because they offer the possibility to utilize geothermal energy by applying the Hot Dry Rock (NDR) system.

Translated by mr Z. Stojadinović.

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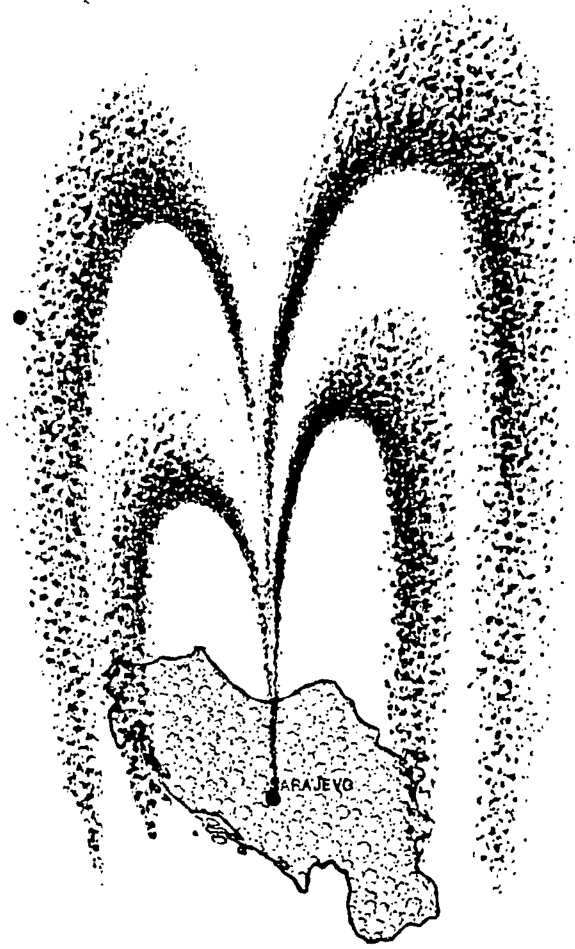


GEOTERMALNI POTENCIJALI ILIDŽE SARAJEVO

GENERAL CONCLUSION

On the basis of available information and Yugoslav and international experience in this sphere the thermal-mineral spa od Ilidža seems to deserve an exceptional professional and scientific attention.

The participants in the Programme as well as other associate members have expressed great pleasure in the fact that favourable atmosphere has been created and an approval obtained for the commencement of utilisation of geothermal power and thermal-mineral water of Ilidža for various purposes such as power supply, heating, agriculture, balneology, sports and recreation, chemical and chemical-technological purposes.

Hereby we wish to acknowledge all those who have incited a wider action of elaborating documents concerning the exploitation of this spa in economic purposes. Also, we would like to express our gratitude for the support obtained for this regional Programme. It is an exceptional pleasure to know that our social, scientific and professional idea has blossomed and born fruit enriched by the desire for this natural resource to be finally utilised and explored.

However, it is a long-term assignment and provided there is a thorough overall Programme it will have to be constantly supplemented and gradually implemented.

The Ilidža spa yields at present approximately 240 liters/s of thermal-mineral water of 58°C awaiting its valorisation. The incrustation problem has already been successfully resolved ba the Yugoslav experts in this field. It was a problem which had been earlier solved by the experts in Wester Germany, the USSR, Hungary and other countries as well. The solution has opened enough space for substituting classical fuels which is a great achievement from the social point of view.

Utilisation of thermal-mineral water resources of Yugoslavia and Ilidža has certainly improved our esteem in European scientific circles since the pilot plant and the degassing system are an original solution designed by Yugoslav experts.

The geo-thermal macro region of Ilidža is an integral part of the macro area of the so-called Busovača thermal zone which has a planetary character and where numerous indications exist concerning the presence of various natural resources of thermal, thermal-mineral, mineral, highly mineral water and CO_2 gas. Today, when we are compelled to turn to the geo-thermal energy we have to systematically and persistently investigate this inexhaustible heat resource.

It is the right moment now and for this reason we are advocating a long-term prospecting in order to find out as best as possible all the facts concerning this resource and to begin its exploitation.

It is necessary to continue with the geological and hydrogeological investigations as well as with the suplementary deep boreholes. Scientific research work and the most recent international achievements in this field have to be incorporated in this action since they will certainly be of great help in our resolution and persistence to attain this potential.

Activities concerning this subject conducted in Italy, France, the USSR, the USA and other countries should be closely followed in order to include all the pertinent information into this exceptionally responsible task of ours.

In addition to the geological investigation work it is necessary to closely follow the technology of utilisation of such waters in agricultural, heat-supply, balneological and chemical purposes as has been concluded by the specialists-associates in their valuable contributions.

Our aim has been to apply multidisciplinary and scientific experience on a whole range of utilisation of thermal and thermal-mineral waters in order to keep up with the international attainment, regardless of the fact whether we might be able to exploit these resources to a wider extent.

There are objective possibilities of obtaining new quantities of water of considerably higher temperature and pressure, as well as with a lower content of mineralisation. For this reason we have to conquer this particular matter step by step and achieve its realistic exploitation and utilisation.

The structure of the terrain as well as all the acquired data from various parts of the world where intensive drilling works have been performed indicate that here we can expect the temperature of the thermal-mineral water to be between 80 and 90°C which would satisfy our expectations to the full.

The most significant manner of water enthalpy utilisation is generation of electricity, heat supply intended for heating of residential quarters and hotels in the sense of the production of municipal hot water supply for which only the „EHOS" hotels at Ilidža have been spending considerable funds annually.

Application of hot water in agriculture promises significant results particularly since there are still ample fields available at Butmir, Ilidža and Blažuj which could be utilised for the production of food stock, mushroms and fisheries based on hot water supply.

Water chemistry can serve fot the extraction of various macro and micro elements such as fot instance B, Na, Li, Sr, S, Ce, G and other on the basis of which a chemical industry could be started as is the case in Toscana ba Larderelo in Italy as well as in other places in the world. Even potable water can be produced as a by-product using the method of dry remnant condensation.

New deep boreholes may reveal new types of water which would thus open up new domains of utilisation and application. Since this is a renewable and inexhaustible energy, it can be utilised in the region of Ilidža and Sarajevo for the conditions are ideal in the sense that they are economically feasible. For this reason the geo-thermal exploitation should commence at once. Experimental models which would prove the possibilities of hot water application in agriculture are justified indeed. Such an application would give a significant contribution in substituting imported fules for industrial purposes as well.

Activities concerning a wider usage of the geo-thermal energy from the aspect of the protection of the human environment should also be developed including them into the social planning in the Republic of Bosnia and Herzegovinia.

The present state at Ilidža concerning the reserves of thermal-mineral water offers a significant onset of experimental investigations in energetics, agriculture and chemistry and for this reason we should not await new results but utilise the already existing ones as well as permanently searching for new ones.

This Programme is a consequence of many years of scientific research work concerning the possibilities of application of geo-thermal waters from Ilidža whose total harndess is 85°dH accompanied by high release of carbonates and large quantities of erruptive gasses CO_2 and H_2S. Such and similar types of geo-thermal waters are to be found in Yugoslavia and a positive solution of the problem of heat transfer will certainly intensify the application of geothermia as an alternative heat source. The general-geo-tectonic relations indicate that Ilidža and Sarajevo are located within a wider region of exceptionally rich hydro-geo-thermal resources which has been confirmed by geological prospecting works executed during the past years and which are still in progress.

The interdisciplinary approach in the solution of a complex subject matter concerning the geo-thermal waters with a high hardness degree and large quantities of aggressive erruptive gases has attained a new technology which has yielded exceptional results such as the pilot plant for the heating of residential buildings. This plant has eliminated the incrustation problem and the problem of erruptive shocks creating favourable conditions for heat transfer while at the same time establishing suitable materials, effects of corrosion and testing of the structure.

The Assemblies of the Ilidža County and of the city of Sarajevo have engaged institutions and research workers in new contemporary technologies for the purpose of further investigations and provison of funds intended for future programmes of research and exploitation of geo-thermal and thermal mineral waters at this location.

This has resulted in a scientific-research cooperation between designers institutions and work organisations, a s well as in an elaboration of a whole range of very profitable and attractive programmes connected with the application of geothermia as an alternative and replenishable power resource.

The cyty of Sarajevo having realised its great chance in the economic-development through the application of these programmes has chosen to implement the technology from a number of fields using thermal water as its source of energy.

Heating of residential and municipal facilities of Ilidža, the highly productive industrial production of food in enclosed premises, the aquaculture for the production of fish spawn and consumable fish, the sports recreation and balneology, as well as the production of gasses and minerals are only a part of the possibilities selected by the city of Sarajevo in the form of the pilot plant and its exploitation.

Such an activity of the Sarajevo experts, as well as of the economy and the Assembly, will certainly have an impact aimed at achieving a forseable introduction of geothermy as an alternative power resource in Yugoslavia which is exceptionally rich in this type of energy. This would certainly have a favourable effect on the economic power of Yugoalvia offering a higher grade of security by the production of food stock. A possibility has been created for the inclusion of this type of technology in the international market, particularly in the Third World Countries which are abundant in geo-thermal water resources.

The present day as well as the future investigations ought to be accepted since the Programme has been favourably evaluated by experts of various profiles. It should be continuously supplemented taking into consideration all technical and scientific achievements from the surrounding countries of Europe in order to remain in the centre of all the events which might contribute to our prosperity.

It is necessary to make a study visit to Larderelo where it is possible to see everything ranging from investigation work to the chemical exploitation, and in particular the application of geothermal power in the production of electric energy. The scientific work concerning the overall utilisation of thermal-mineral waters for various economic purposes should be nurtured and supported.

F A O

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
COOPERATIVE NETWORK ON GEOTHERMAL ENERGY USE IN AGRICULTURE

first CNRE workshop on the use of
geothermal energy in agriculture
Skopje 30.03. to 01.04.1987

GEOTHERMAL ENERGY RESOURCES EXPLORATION, DEVELOPMENT AND UTILIZATION IN SR MACEDONIA, YUGOSLAVIA

ABSTRACT

This paper gives a brief survey of the results obtained in almost a ten year period of geothermal energy resources exploration, development and utilization in SR Macedonia, Yugoslavia. The teritory of SR Macedonia is characterized by numerous thermal springs thus represents an area of potential sources for geothermal energy. The distribution of hot springs is shown in Fig. 1. In most cases the springs are located at the margins of fault-bounded valleys and it is possible that deep circulation of meteoric water in these fault zones is responsible for the elevated temperature of the springs. The heating effect of deep circulation is believed to be enhanced by an abnormally high regional heat flow from the earth's crust.

Although the hot springs of Macedonia have been used as spas since the Roman times, it has been only ten years that investigation has shown that the water flow rates can be augmented by drilling not only at the spring sites but also in sedimentary basins with which the springs are associated. The geothermal activity is found in more than 20 localities, 10 of which have maximum temperature of 50 to 80 °C.

The geothermal fields are mostly located in the south-east, east and north, including the western part of the Republic as well. Among geothermal fields, investigations of Kočani, Vinica, Gevgelia, Strumica, including Skopje valley are most advanced.

Todor Novkovski, Fund for exploration and development of mineral and energy resources of SR Macedonia, Skopje, Yugoslavia

1. Introduction

The drilling exploration programme which was initiated by the Fund for exploration and development of mineral and energy resources in SR Macedonia and prepared by the Institute of Geology, Skopje and the Institute of Geology, Ljubljana, started to be carried out in the second half of the 70s, in three main geothermal areas, such as: Kočani-Vinica valley, Gevgelia-Valandovo valley, Strumica valley, including Skopje valley as well. In addition, the exploration work on the regional scale, including

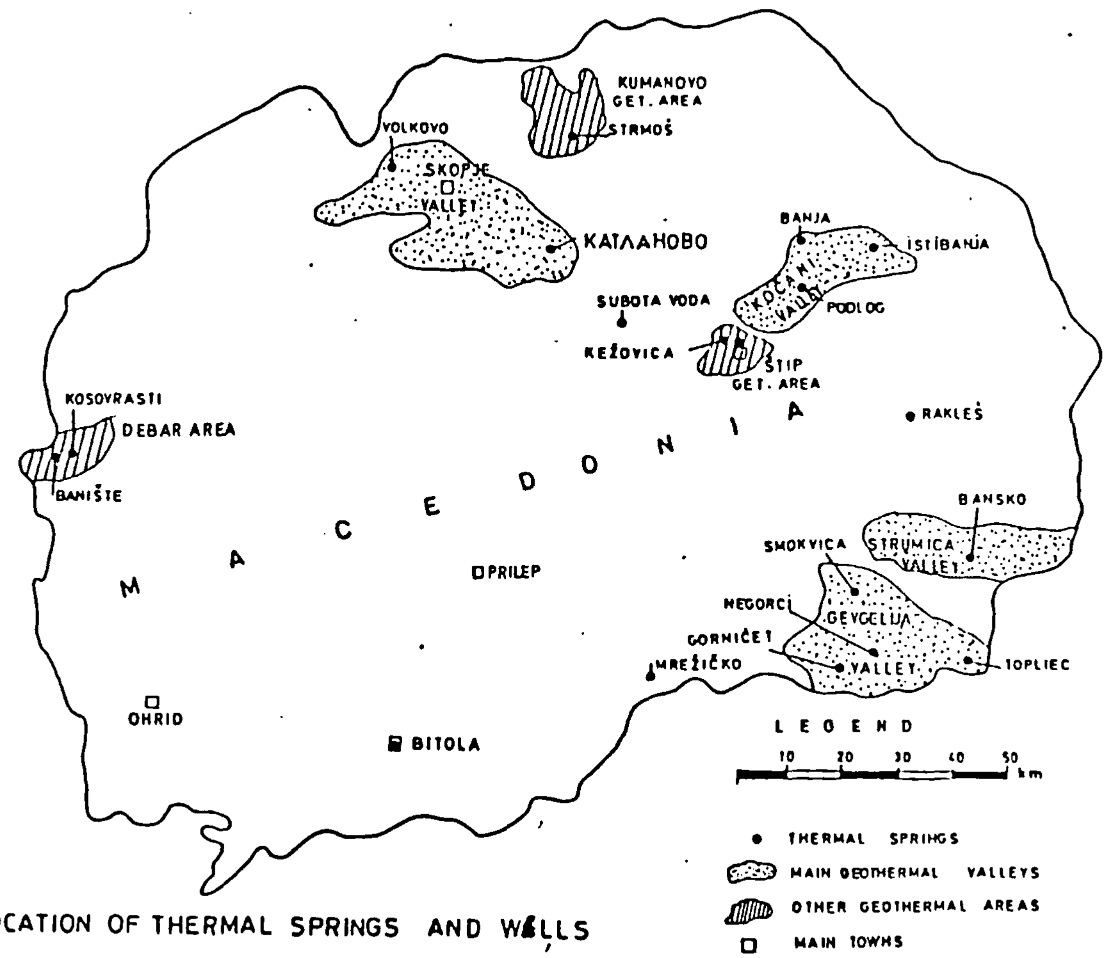


FIG.1 LOCATION OF THERMAL SPRINGS AND WELLS

drilling of gradient drillholes, was carried out ~~in~~ in Štip geothermal area /Kežovica/, Kumanovo geothermal area /Strmoš-Pčinja/, Debar geothermal area /Banjište and Kosovrasti/, Subotavoda, Toplec-Gevgelia-Dojran and Kosel-Ohrid, shown in the map above.

In this article, only the first four of them are considered. The necessary knowledge about their geological and geophysical nature is drawn from unpublished data as well as data published in Macedonia and Yugoslavia, given on the last page.

2. The Present Status

A successfull prospecting,development and utilization for geothermal water has mostly been limited to known geothermal localities. The production wells in individual geothermal areas, however, are comonly sited by aid of geological,geochemical and geophysical exploration methods, including gradient drillholes, at some distance from the natural hot springs.

Around forty shallow and deep exploratory and development wells with depths of 50 m to over 1000m, have been completed in a 10 year period. The maximum temperature encountered in drill holes is 85 °C. 15 wells are production with an average flow rate of over 1000 l/s by free flow and pumping.

The chemical composition of the thermal water is much affected by the rock types through which the water flows, so the mineralization is relatively low in eastern and southern Macedonia, where the thermal water flows through the christaline basement rocks but very high where it flows through limestones as it is the case in northern and western Macedonia. Therefore heat exchangers are needed in the limestones areas for any other use than bathing, where as the thermal water can in most cases be used directly in the christaline basement areas. Carbonate precipitation from the water is a big problem and the water is corrosive for steel as well. A chemical survey carried out in Smokvica geothermal field has shown that the well instalations and pipes are highly damaged in four years period of production only.

Large scale utilization of geothermal water for heating green houses started only few years ago. The green houses located in Gevgelia geothermal area-24 ha, Kočani 20 ha and Isti Banja-12 ha have been heated b y oil, have gradually been converted to geothermal heating. In addition, 4 ha of green houses located in Strumica geothermal area have been heating by geothermal energy for a long time now. So Macedonia has already become the largest user of geothermal energy for green houses in the world. At present, over 50 ha of green houses are being heated by geothermal energy. In addition, tests have been performed for using the geothermal water for heating the hotels in Negorska Banja, Gevgelia.

3. Geothermal Areas

3.1 Kočani Valley

The Kočani valley is located in the eastern part of the Republic ,see Fig. 2, on the contact of the two big geotectonic inits, the Serbo-Macedonian Massif and Vardar Zone.

The Kočani Valley is tectonically a depression formed by subsidence during Neogene and Quarternary periods of blocks at the intersection of the two of Macedonia's major geological zones. The two major faults in the area are oriented E-W, but the subsidied blocks, Fig. 2, between them is thought to be subdivided by smaller faults into a mosaic of small blocks. Both of the major faults are seismically active.

There are three main geothermal localities in the Kočani Valley, namely Podlog, Banja and Isti Banja.

-Podlog is located in the middle of the Kočani valley. There are thick sediments of Neogen and Quarternary age in the valley underlain by schist. Pyroclastic sediments originating in the adjacent volcenic area Kratovo-Zletovo, are the cap rocks.

Prior to drilling there were warm springs known in Podlog with a total discharge of about 0,5 l/s and temperature of 30 - 40 °C. The hot springs are thought to be associated with a N - S fault that intersects both Podlog and Banja. The first drill hole was drilled in 1967 to a a depth of 70 m. It yielded 5 l/s free flow of 60 °C. In 1980 a 320 m deep well, EBMP-1, was drilled close to old well. At a depth of 307 m an aquifer was cut yielding over 150 l/s free flow water in the begining, but after stabilization it yields about 100 l/s of 79 °C water.

In the period 1980 - 1986, around 18 exploratory and production wells with a total metrage of 8 000 m have been drilled in this area. The temperature of the water varies from about 57 to 79 °C, while the total flow rate is estimated to be over 600 l/s, both free flow and pumping.

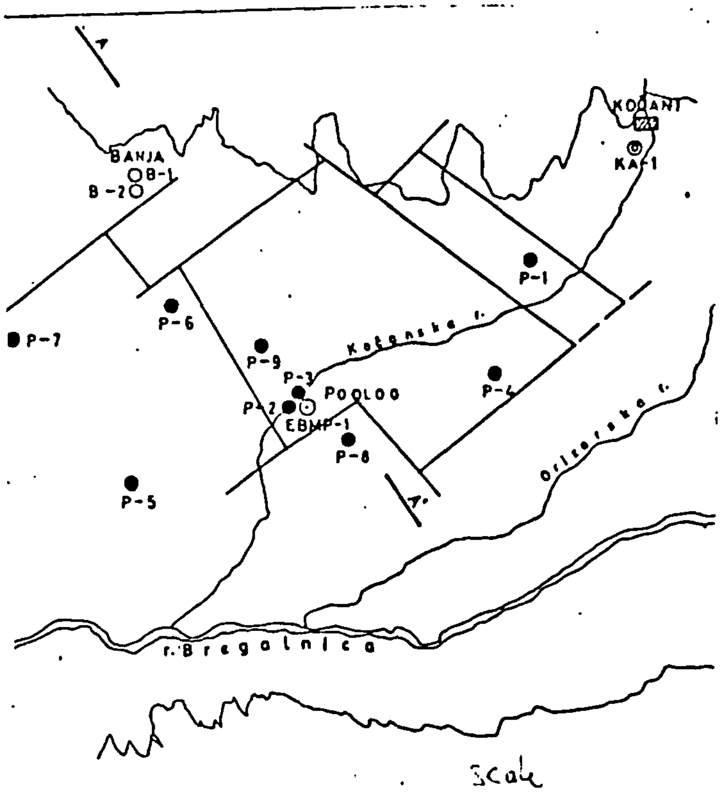


Fig. 2 KOČANI GEOTHERMAL FIELD
LOCATION OF THE WELLS AND TECTONIC BLOCKS – KOČANI GEOTHERMAL FIELDS

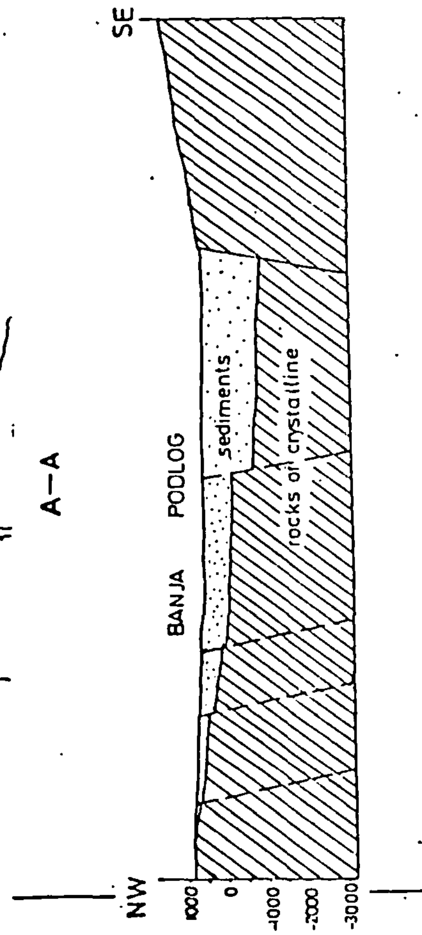


Fig. GEOLOGIC CROSS SECTION KOČANI GEOTHERMAL FIELD BANJA AND PODLOG

In 1986, the production well drilled to a depth of around 340 m, which intersected the N-W fault, yielded at the begining an estimated free flow rate of 400 l/s water, which later was stabilized to 200 l/s free flow rate. The water is of sodium bicarbonate type with variation in silica from 19 ppm to 48 ppm. The silica enthalpy mixing model indicates base temperature near 120 to 130 °C. A feasibility study on this geothermal field is prepared, showing that a total of 460 l/s , both free flow and pumping rate can be obtained from the three wells /EMBP-1,P-3 and P-a/ in the next 20 years without the need of drilling other wells.

In the Fig. 4 are shown the temperature profile of all drill wells in the area Podlog-Banja. The hot water is mainly used for heating the nearby green houses for which a 3 km long pipe was constructed to suply about 120 l/s warm water for heating around 20 ha.

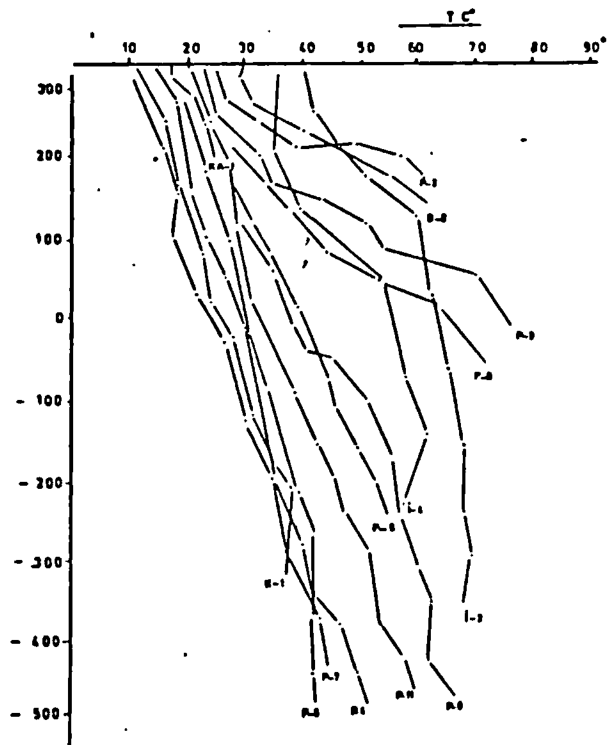


FIG. 4 TEMPERATURE PROFILES OF ALL EXPLORATORY DRILL HOLES AND PRODUCTION WELLS KOCANI VALLEY

There are no problems with precipitation or corrosion from the thermal water, so it is used directly, without using the exchangers.

- Banja is located on the E-W master fault on the northern rim of the Kočani graben about 5 km north of Podlog and about 14 km west of Isti Banja, the third geothermal field in this area. The flow rate of the Banja hot springs was reduced when the powerfull well EMBP-1 was drilled. Prior to drilling in Banja, the natural springs gave about 5 l/s of 60 °C water. The water has been used for treatment of illness since ancient times. A small health spa has been operated since 1970. The thermal water is taken from a well that gives about 50 l/s of 65 °C water. Only a small amount of this water is used for the thermal baths and heating ~~the~~ the house of the health center. A new well was drilled in 1984 to 450 m depth, but was negative.

- <u>Isti Banja</u> is north of the main subsided block, and the hot water comes out of basement rocks composed of gneisses and mica schists of Precambrian age. Several warm springs

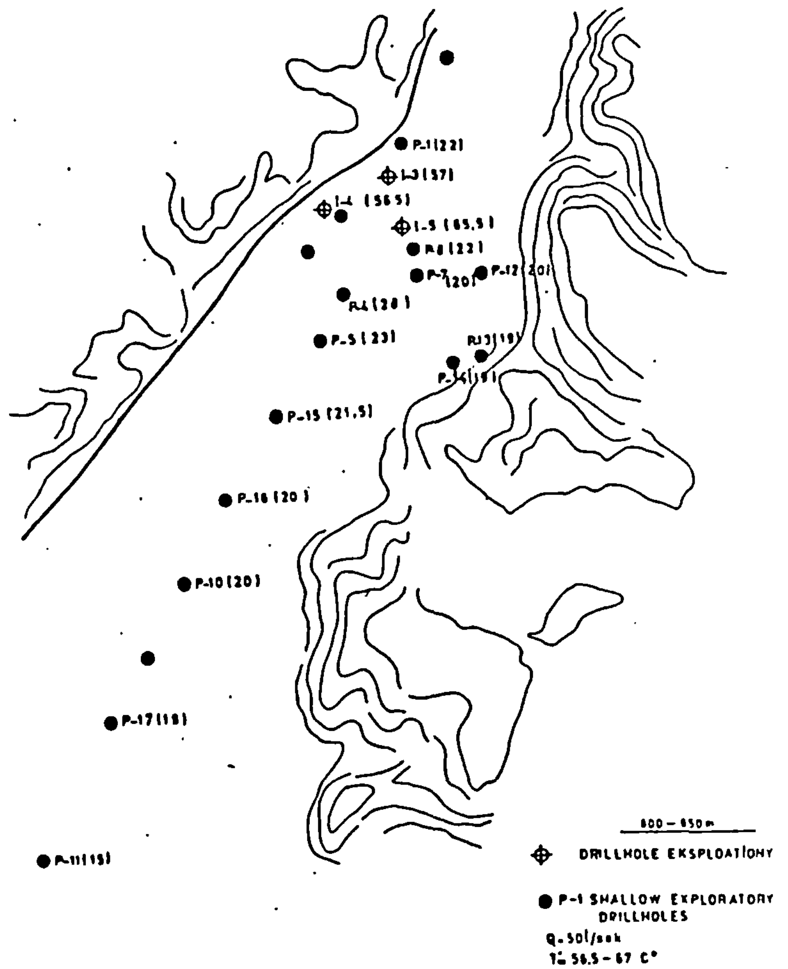


FIG 5 VINICA GEOTHEPMAL FIELD LOCATION OF THE WELLS AUD EXPCORATORY OPILLHOLES

were found in the river . After electrical resistivity measurments, 12 shallow wells (30 m) were drilled to locate an upflow zone. All gave 30 to 40 °C. A 180 m deep well gave 2 l/s of 60 °C water, and a 190 m deep well gave 6 l/s of 60 °C water. Few more drill wells have been drilled to a depth from 200 to 350 m , with a total flow rate of around 60 l/s of 65 °C water, by pumping.

In 1983 an insulated steel pipe was constructed to transfer the water from the geothermal wells, see Fig. . The water from the three production wells is collected in two open tanks and goes into the pipeline to heat the 6 ha green houses located 3 km away, see Fig. 5

According to the chemical analysis, the water is of sodium-bicarbonate type. The silica concentration is in the range 47 - 82 ppm. The water is fluorite saturated and slightly supersaturated with calcite. Temperature in excess of 120 °C might be expected according to the silica geothermometers.

3.2 Gevgelia Valley,

The three geothermal localities, Smokvica, Negorska Banja and Gorničet are located in this valley. Smokvica is about 10 km north-west of Gevgelia, while Negorska Banja and Gorničet are only 3 km west from the same town.

The Gevgelia valley is within the Vardar zone, which is considered to be a subduction zone and extends from Turkey , Bujuk Menderes graben, through Thessalonika, Macedonia and further near Belgrade into Hungarian Basin. Both , Smokvica and Negorska Banja are located near active faults, and it is an area of high seismic activity. Gorničet is the third geothermal locality associated with a N-S fault.

The Smokvica geothermal field is exploited by the Vinojug Agricultural Complex, for heating 24 ha of green houses located 7 km south of Smokvica.

Geothermal exploration started in 1979 and after an intensive period of exploration in which total 7 production wells, and more than 15 shalow drill holes and wells have been drilled to a depth of 30 m up to 850 m, with a total metrage of cca 4 000 m. All wells are drilled in a diabase intrusive. The diabase is highly altered , clay minerals and epidote are common alteration products. The strongest aquifer with the highest temperature was found at 350 to 400 m in a 500 m well. The total flow rate by pumping from 4 production wells is about 200 l/s with an average temperature of 68 °C. Pumps are instaled in 4 wells, Fig.

with a total present capacity of 120 l/s, but new downhole pumps are purchased and are to be instaled with a total capacity of 200 l/s in 4 production wells. Short time and long time interference tests have been performed among wells spaced in an area of 2,5 ha, Figs 6 .

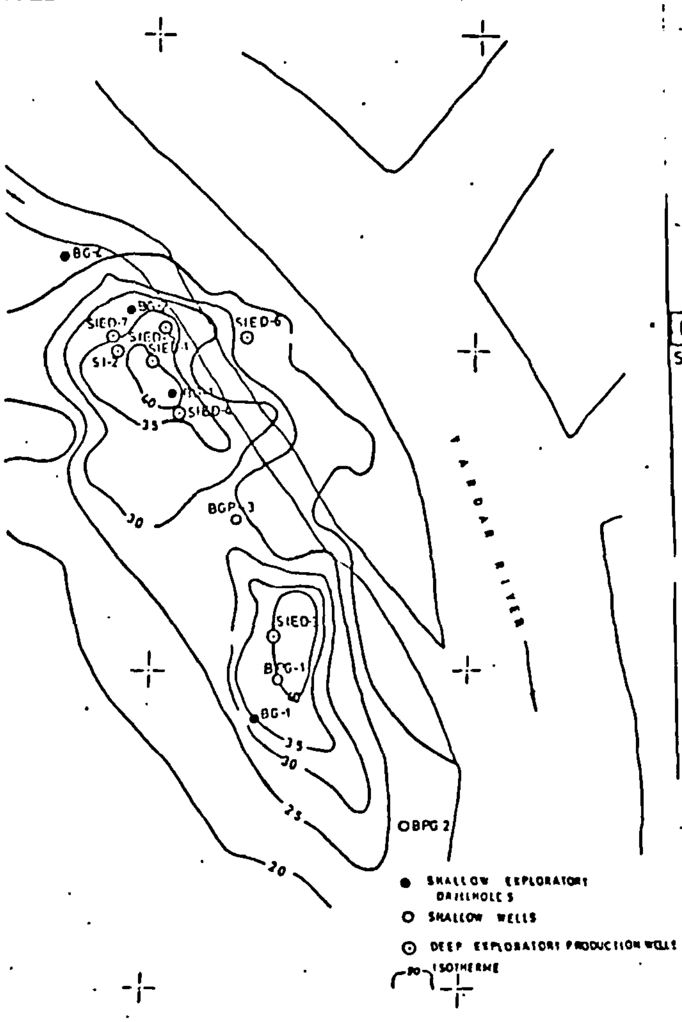


FIG 6 SMOKVICA GEOTHERMAL FIELD

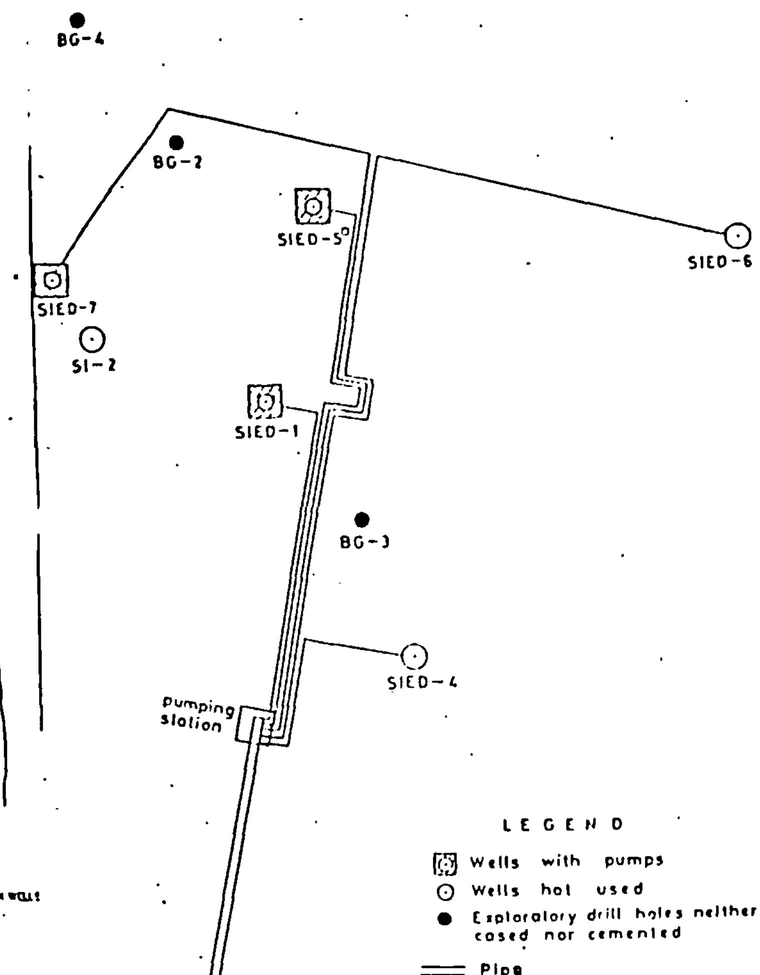


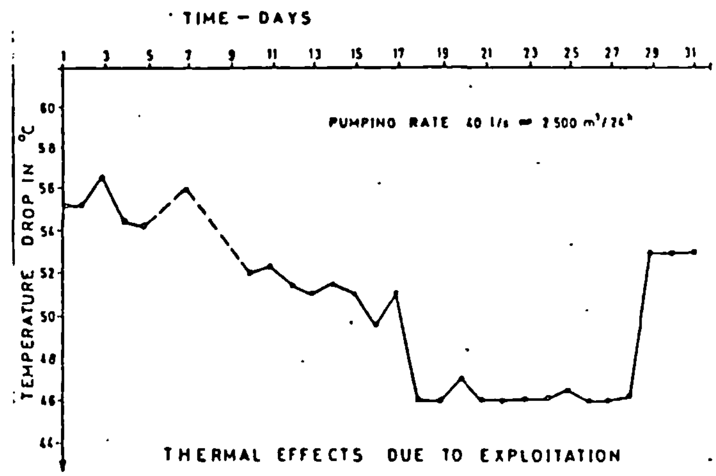
Fig.6 Location of thermal wells Smokvica geothermal field

They have given rather high permiability. The draw-down tests of this field suggests that the high permiability zones may be bounded by rather impermiable wells in one or more directions, and model studies have been made with this assumption. The short time interference tests are primary affected by fractures in the vicinity of the wells within the spilites , but at depths below 500 m, the aquifers are associated with near vertical faults and fractures, but there the primary fractures have largerly been filled with secondary minerals.

The draw-down of the water level during pumping is about 50 m, but after several hours of resting some of the wells become artesian again.

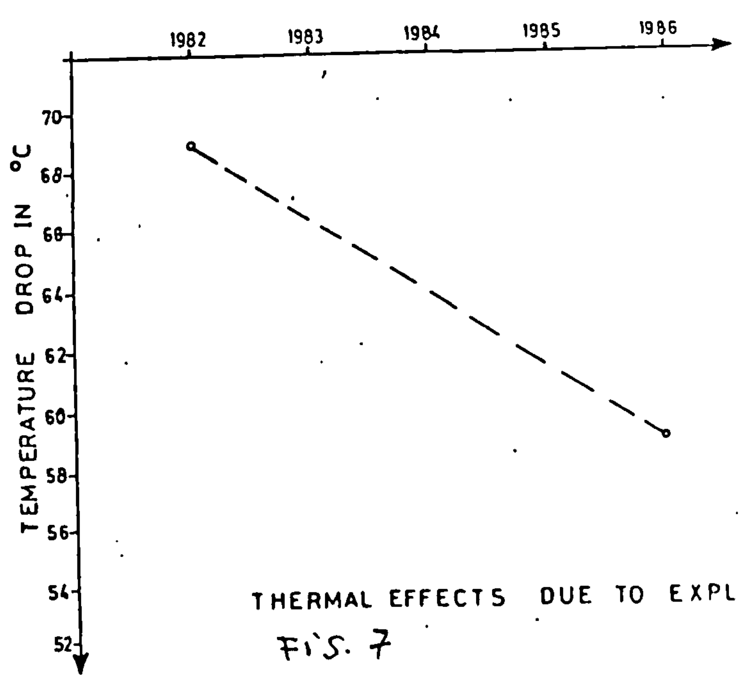
Some cooling up to 10 °C has been observed in wells at Smokvica geothermal field. It is belived to be caused by infiltration of colder water from the srroundings, or Vardar river, Figs. 7 , or by downflow of colder water in non-producing wells which are not cemented and sealed. Ground water seeps into the geothermal reservoir both through natural cracks and through old drill wells with faulty casing or not cased and cemented at all.

PRODUCTION WELL SIED-1
MARCH - 1986



THERMAL EFFECTS DUE TO EXPLOITATION
SMOKVICA - GEVGELIA

PRODUCTION WELL SIED-7
SEPT.1982 — APRIL 1986



THERMAL EFFECTS DUE TO EXPLOITATION

Fig. 7

Due to the nature of geothermal system in this field shows evidence of recharge whose rate may even appoach that of the production itself. The temperature of the recharging fluid is usually lower than that of the initial reservoir fluid. The recharge thus cools the reservoir and lowers the energy content of the fluid produced.The recharging water reaches the wells quickly, and this may couse the usual life of the reservoir to be shortened appreciably. This is especially noticed in SIED-1 well, Fig. 7 , that shows considerable recharge and changes in chemistry of the produced fluid. The geothermal fluid composition hasn't been monitored in all the wells, but the chemical composition of the water is of sodium natrium-calcium sulfite type, with a high corrosion to the steel.

Negorska Banja is located 5 km north-west of the town of Gevgelia. The water has been used for a long time in baths and from about 1950 a health spa has been operated using the thermal water . The geology is characterized by steeply diping diabases of Tertiary age and by numerous dykes and granite intrusions trending approximately E-W. Several shallow wells -20 to130 m, have been drilled in 1983 to deliniate a fault that is considered to carry the hot water. During 1984-85, two 600 m each wells have been drilled which yielded 40 l/s each hot water with temperature of 52 °C of water, by pumping. A total flow rate of 80 l/s is expected to be pumped according to short time pumping tests. The production horizons seem to be associated with spilites at a very shallow depth, 100 to 150 m from the surface, and at intersections of faults.
In 1986 , another gradient drillhole was sited, on the basis of the Head-On Resistivity profiling method, applied for the first time in Macedonia. The drillhole, which was drilled to 300 m intersected a permiable fault at about 250 m, as a result of which the temperature has increased to 62 °C, which an increase of 10 °C in this area. The water from the two wells will be used for heating the green houses located 3 km away in Gevgelia.

The water is of sodium chloride type. During 1986-87 winter sezon, tests were performed on using the warm water for heating the hotels located at the spa. The tests were successfull, and this is for the first time , where the warm water is used for heating the hotels.

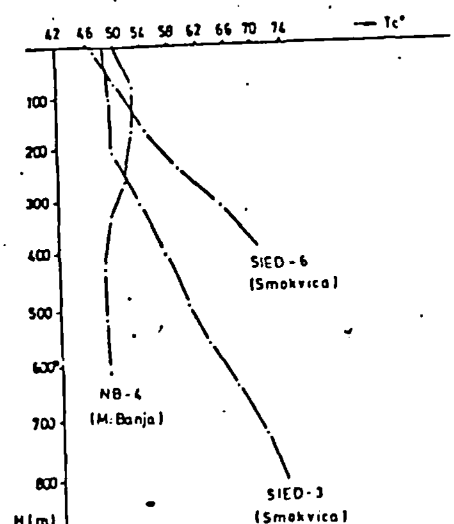


Fig. 8

<u>Gorničet</u> is the third location in Gevgelia geothermal area. It is found 5 km west of Gevgelia. There are two springs, with about 5 l/s free flow and a temperature of 25 °C of w water. The springs ara associated with N - S fault. The geothermometeres showed 150 ° C of water in the base. This geothermal field is still not explored.

3.3 Strumica Valley

This area has a thermal spring at Bansko locality only, with a free flow rate of around 35 l/s and a maximum temperature of 72 °C. The springs are located on seismicly active faults with E-W and NW-SE orientations. 30 l/s of this water has been used for green houses heating since long time, 5 l/s of hot water is used for the spa (thermal baths).

The area has been explored for many years by application of geological, geophysical, hydrogeological methods in order to sellect a site for drilling the gradient drillholes. On the basis of these surveys, a 500 m deep drillwell was sited, close to the natural springs. This well however, was drilled to a depth of 254, due to the strong erruption that hapened at this depth. It entered in a very fractured zone, which gave a free flow rate of 90 l/s during the erruption, but stabilized to a flow rate of 55 l/s with a temperature of the water of 69,5 °C.

The 838 m well was drilled at Saraj locality, but it was negative. Another drill hole was drilled to a depth of 425 m, also negative. The third deep drill hole to 510 m was drilled at Banica locality , but without much success, this gradient well was negative as well.

There are no problems with precipitation from the water. The green houses are about 3 ha and there are other 2 ha under plastic cover. The hot springs at Bansko were used for heating green houses on a large scale since 1950. It is the first locality to use the g eothermal water for heating the green houses in Macedonia.

3.4 Skopje Valley

The Skopje valley is a depression filled in with sediments of Neggen and Quarternary age including recent sediments as well. The basements rocks are of Precambrian to Mesozoic age. The Skopej valley tectonicly is an individual block that have been formed by subsidence during the Neogen-Quarternary period.

There are two geothermal localities, known as Katlanovo and Volkovo, both associated with E-W faults.

Katalnovo is located 25 km east of Skopje on the boundary of the valley near the small occurences of young vulcanic rocks. The warm water at this locality issues on the top of the ridge and at different elevations down the slopes to the Pčinja river. Aquiferes ara associated with near vertical faults in the limestones of Triassic and Cretatious age, underline by Paleozoic schists.

On the basis of the electric resistivity measurments, two exploratory and production wells were drilled in 1981, to depths of 100 m and 250 m respectively. The 100 deep drill well gave around 3 l/s free flow water with temperature of 40 °C, while the second drill well intersected a permiable fault and yielded 10 l/s of 52 °C water. This water from the drill well is used for the thermal baths in Katlanovo spa. The water is carried out in plastic pipes, and since the carbonate precipitation inside the peipe is high it must be mechanically cleaned every two to three weeks. ANother problem is the drill well itself, due to precipitation problems, it seals up in a very short time too.

Due to this problems, another well was drilled to a depth of 120 m. The drill hasn't intersected the expected permiable fault, which was located by electric resistivity survey.

Volkovo Is found on the west side of the valley, about 15 km west from Skopje.

The natural warm springs at this locality are known for a long time. Warm water with about 20 °C issues along a fault in several places. The electric surveying started in 1978, applying resistivity survey. On the basis of this measurments, a 98 m gradient drill hole was drilled in 1976. The drill hole intersected a peramiable fault which gave 15 l/ s in free flow.

In 1986, a detailed project for exploration of Skopje valley was prepared, including Volkovo locality as well. On the basis of this project, a 170 m deep drill hole was drilled , which entered the aquifer at 168 m, and the water errupted. The free flow rate stabilized at 70 l/s with temperature of 25 °C.

At the end of last year another deep well to 1000 m has started to be drilled, at this locality.

The deepest well to 1655 m was drilled in the central part of the valley, but unfortunately it hasn't reached the bedrock, due to dificulties that were experienced during drilling.

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DOE F 1325.8
(12-84)

United States Government | Department of Energy

memorandum

DATE: DEC 16 1987

REPLY TO ATTN OF: CE-342

SUBJECT: Information Exchange with Yugoslavian Researchers in Geothermal Energy

TO: Distribution

I am writing to enlist your cooperation in providing information to geothermal researchers from Yugoslavia.

In November 1987 I visited Yugoslavia under the auspices of the United States - Yugoslavia Joint Board on Scientific and Technological Cooperation. The Joint Board administers a fund whereby cooperative research grants are awarded. Cooperative research proposals are submitted by a Yugoslav organization (e.g., university, research institute) with a Yugoslav scientist designated as principal investigator and one or more US scientists named as co-principal investigators. The actual research may be carried out in either or both countries. In general, grants are limited to three years and annual budgets in dinar equivalents of $2,000 to $100,000. The Board sponsored my visit as an invitational trip to exchange information about geothermal energy in each country.

I was impressed with the degree of geothermal development underway or planned in Yugoslavia. Thus far, the strategy has been to explore near known hot springs. Resources discovered thus far range in temperature from 20°C to 96°C with flow rates up to 200 l/s. The wells are often artesian, and the water quality is usually quite good (100-2000 ppm TDS). The prospects of finding hotter resources appear favorable as exploration proceeds.

During the course of my visit I received numerous papers and reprints which describe geothermal resources and development in three Yugoslav republics: Serbia, Bosnia-Hercegovina, and Macedonia. English language summaries of those publications are attached for your information. If need be, I can obtain selected translations of the papers from which the summaries are drawn.

The Yugoslav researchers I spoke with were anxious to learn more about geothermal activities in the United States. Their interests, of course, parallel the problems they are currently facing. These include choosing appropriate exploration strategies, siting exploratory wells, conducting resource assessments, providing incentives for development, handling carbonate scale, designing efficient production facilities, and disposing of spent fluids. I am in the process of sending the Yugoslavs selected publications in these problem areas.

In addition, I have taken the liberty of identifying you as a point of contact for additional information on certain topics (see attached list). Consequently, you may receive inquiries in the future from Yugoslav researchers. I ask that you respond directly to any requests for additional information; please provide them only with currently available publications in the public domain. If you are contacted to participate in a cooperative project under the Joint Board, refer the inquiry to me. Do not make any commitment to conduct cooperative research with the Yugoslavs. Any proposed project will need to be carefully considered by DOE.

I appreciate your help in this matter.

Allan Jelacic
Geoscience Team Leader
Geothermal Technology Division

Attachments

Distribution:

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U.S. Department of Energy
Researchers in Geothermal Technology

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Dr. James C. Dunn Sandia National Laboratory P.O. Box 5800 Albuquerque, New Mexico 87185 telephone: 505-844-4715	Drilling Technology Instrumentation Magma Energy Extraction - Exploration techniques - High-temperature materials
Dr. Susan Stiger Idaho National Engineering Laboratory P.O. Box 1625 Idaho Falls, Idaho 83415 telephone: 208-526-0457	Fracture Flow Well Testing Reservoir Analysis Geopressured-Geothermal
Dr. P. Michael Wright University of Utah Research Institute 391 Chipeta Way, Suite C Salt Lake City, Utah 84108 telephone: 801-524-3439	Tracer Development Geochemistry Exploration
Dr. Marcelo J. Lippmann Lawrence Berkeley Laboratory Earth Science Division, Building 50E Berkeley, California 94720 telephone: 415-486-5035	Well Testing Reservoir Analysis Geophysical Techniques
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Lawrence Kukacka Brookhaven National Laboratory Department of Applied Science Upton, Long Island, New York 11973 telephone: 516-282-3065	Materials - Polymer concrete - Elastomers - Lost circulation materials - Cements
Dr. Hugh Murphy Los Alamos National Laboratories P.O. Box 1663 Los Alamos, New Mexico 87545 telephone: 505-667-3880	Hot Dry Rock - Hydraulic fracturing - Fracture mapping

GEOLOŠKI GLASNIK HERALD GEOLOGICAL BULLETIN GÉOLOGIQUE

To Mr. A. Jelinić from Neven Miošić, Dr., 13.11.87

Neven Miošić

HIPERALKALNE NOVOOTKRIVENE TERMALNE VODE U BOSNI

pH - 12

GEOLOŠKI GLASNIK	VOL. 30	№ 1	1-229	Sarajevo, maj 1987.

Vode imaju širok diapazon primjene u balneologiji, terapeutici, zdravstvenom turizmu, rekreaciji, regeneraciji, sportu zbog svojeg sumporovitog karaktera, niske mineralizacije, visoke alkalnosti i blagog radioaktiviteta, a centri ovakvog sadržaja su potrebni naročito danas u zdravstvenoj prevenciji i rehabilitaciji.

SUMMARY

HYPERALKALIC NEWLY DISCOVERED THERMAL WATERS IN BOSNIA

In 1985, by hydrogeological prospecting of a terrain, we discovered new springs of hyperalkalic thermal waters (pH>11), simillar by their physical and chemical features to already known waters of Kulaši spa and others in the surroundings. These are Banja Vlajići near Teslić, Vaićeva voda and Savina voda near Gračanica. These springs are located in ultramafic rocks of Uzlomac and Ozren mountains of the central ophiolite zone of Bosnia.

Characteristics of these waters are: high pH, low mineralization (150—275 mg/l), mild radioactivity, hypothermal charaster, N_2 gaseous composition and sulphur character. Such waters have not yet been discovered in the other parts of Yugoslavia, while in the world they also represent a rarity.

Hyperalkalic waters are formed in almost closed, hydrogeological structures in reduction horizons, they are of slow circulation and exchange of water, representing old, »pre-nuclear« waters and being of atmosferic origin, while CH_4 in them would be thermogenetic and hydrolitic. As distinguished from numerous thermomineral waters of the Spreca fault zone and ophiolites (Slatina, Teslić, Boljanić, Sočkovac, Bokorić, Živinice), they don't contain CO_2, from which one can conclude, ex contrario, that in this area there are not carbonate deposits in deeper beds, that is there are not thermomineral waters with CO_2. This was ascertained in Kulaši by drilling as far as 200 m under the surface of the terrain.

Accumulation of the waters wells out allong yuong tectonic fault lines in the quoted location. In these places there exists constant convection of waters out of deeper layers through, otherwise water impervious cap-rock barriers of ultramafic rocks.

Investigation with the aim to discover waters of high temperature and greater yield, in comparison with springs, especially in order to solve geological structure, structural composition and hydrogeological relations of ophiolites, have their professional justification.

The waters have wide application in health resorts, therapeutics, rehabilitation, regeneration, recreation and sports. Facilities with these purposes are scarce and needed in desease prevention and rehabilitation.

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»GEOINŽENJERING« — SARAJEVO

SAFET ČIČIĆ
NEVEN MIOŠIĆ

GEOTERMALNA ENERGIJA BOSNE I HERCEGOVINE

SARAJEVO
1986.

govini, već više geotermalnih rejona, uslovljenih različitim geološko-hidrogeološkim faktorima. Cijeni se da se značajni geotermalni potencijali u Bosni i Hercegovini nalaze u geopresiranim ležištima — sistemima. Oni mogu biti sljedeći objekat istraživanja, čemu moraju prethoditi obimna multidisciplinarna proučavanja.

Termoenergetski potencijal postojećih izvora i bušotina iznosi 166 MW termalnih, i on se može privesti korištenju bez ikakvih novih istražnih radova. Energetski obnovljivi potencijal hidrogeotermalnih sistema, proračunat raznim metodama, do dubine 3.000 m iznosi 125×10^{6} TJ, a od 3.000 do 5.000 m oko 150×10^{6} TJ, u svih 9 hidrogeotermalnih regiona. Ove procjene treba uzeti s rezervom iz više razloga i one mogu biti znatno viših, ali i nižih vrijednosti. Bušotine bi imale različite snage za razne dubine. Raspon snaga bi bio 3—15-ak MW termalnh po bušotini, uzimajući u račun dubine od 300 do 2.000 m.

Pristup istraživanju geotermalnih resursa u Bosni i Hercegovini treba biti polidisciplinaran i induktivan kako bi se sa što više postojećih podataka ukazalo na indikativne kriterije i zone istraživanja. Budući da su istraživanja geotermalne energije dugotrajna i skupa, to ih obavezno treba sinhronizovati sa istraživanjem nafte i gasa, uglja, nuklearnih sirovina, ležišta metala i nemetala, naročito.

Opravdanost istraživanja i korištenja geotermalne energije određuje postojanje geotermalnih eksploatabilnih resursa u Republici, i dosta nizak stepen njihove istraženosti, zatim prednosti korištenja ovog obnovljivog i ekološki pozitivnog energenta, njihova konkurentnost sa konvencionalnim izvorima energije, moguća brza aplikacija rezultata i druge prednosti.

Polivalentno i adekvatno kvalitativno i kvantitativno korištenje ovih resursa, zahtijeva rješavanje brojnih institucionalnih, legislativnih, kadrovskih, tehničko-tehnoloških i organizaciono-finansijskih pitanja i problema. Istraživanja trebaju obuhvatiti niz disciplina, jer su možda najkompleksnija od svih geoloških istraživanja, a uz to geotermika je mlada nauka sa još neriješenim modelom istraživanja, naročito u složenim geološkim sredinama kakva je skoro cijela teritorija Bosne i Hercegovine. Zato je nužan kontinualan transfer znanja i tehnologije iz drugih dijelova Jugoslavije i svijeta, gdje su postignuti značajni rezultati u sličnim geotermalnim sredinama, te koncentracija materijalnog i kadrovskog potencijala u cilju polivalentnog istraživanja i korištenja geotermalnih resursa.

Bosna i Hercegovina ima centralni geografski položaj u Jugoslaviji. Zbog toga, a posebno radi racionalnijeg korištenja raspoloživog, veoma oskudnog kadra i opreme, treba inicirati zajedničke programe sa susjednim republikama. Oni bi dali znatno veću efektivnost uloženim sredstvima i doprinijeli bržem upoznavanju i kvalitetnijem rješavanju mnogih krupnih problema iz geologije i geotektonike ovog dijela Dinarida, što bi se neposredno odrazilo i na efikasnost hidrogeotermalnih istraživanja u nas.

Sarajevo, jula 1986. godine

SUMMARY

GEOTHERMAL ENERGY OF BOSNIA AND HERZEGOVINA

Vivid shortage of the conventional energy resources, constant rise of their prices, enormous consumption increase, dependence of our country and the republic on expensive imported, espacially liquid, primary, energy raw materials, as well as aspects of environmental protection, impose not only strict rationality in exploitation of existing conventional resources but actualize special investigation and utilization of new renewable alternative resources of energy. One of the most important new and renewable energy resource, that might be partially a supstituation for conventional resources, is geothermal energy.

In order to investigate and utilize these resources, an interdisciplinary approach in their programming, investigation, intaking, exploitation and protection is neccessary. Only by realization of long-term, expensive and complex interdisciplinary investigations, carried out by stages, it is possible to diminish risks, as well as to extend spectrum of application of these potentials. Principal characteristics and advantages of this resource are: it is of enormous total potential applicability, it is widespread over many regions in the world, in most cases it is renewable and unexaustible, there is a possibility of its polyvalent exploitation, it has permanent energetic level, as distinguished from conventional fuels, high degree of energetic utilization and positive ecological aspect, economically it is effective and competitive with conventional fuels.

Some of the limitations in utilization of this energy are of technical and technological nature, such as expensiveness of a drilling rig, corrosion and incrustation of fluids and accordingly, lasting of intake structure, then utilization by heat exchangers and conversion of energy. The other ones are lack of money and experts, unpreparedness of consumers and investors, and their distrust of this new type of energy. But one can readily conclude that all these open questions are not an unbridgeable obstruction that could throw doubt upon justifiability of carrying out of investigations and utilization of geothermal energy, both in the world and in our country.

This work deals with general geological and hydrogeological probleme of geothermal energy in the world, in Yugoslavia and Bosnia and Herzegovina. Scope and possibility of utilization of geothermal resources in the light of actual meetings, held from 1971 to 1984, are presented, as well as many data from certain, published papers of domestic and foreign authors. Special attention is paid to the survey of types of geothermal energy geposits, then to resources and possibilities of utilization of this energy potential at present and in future. Development of utilization in some countries ad modern methods of investigation of geothermalni energy are also worked out details, having in mind a great need for these investigations to be established in our country, especially in Bosnia and Herzegovina.

Geothermal energy, with regard to investigated and estimated potentials, is classed among the most important resources of energy on our planet. They come to 10^{26} joules. This energy is greater for several thousands than any capacity that can be estimated as a need of mankind at present and in future. That quantity of energy is found to a depth of 10 km which is by drilling, even now approachable and which is found in various types of deposits: hydrogeothermal (liquid fluids, steams

and mixture water - steam), dry geothermal deposits and geopressured deposits of geothermal energy.

Significant characteristic of this type of energy is in its occurence in all parts of the earth's crust, either on the surface or at different depths. Its superficial manifestations (mofettes, fumaroles, solfataras, geysers and the like) can be found only in younger volcanic areas. That is proportionally small part of the earth's surface, in the region of Alpine orogeny, in western parts of the northern and southern America, on the islands in the Pacific, Atlantic and Indian Ocean. Considerably larger deposits of geothermal energy are found in sedimentary basins in various parts of the world, in which, on the surface or below, there exist inserted, huge masses of granite and its rock derivatives.

Development of applied geothermal energy, especially during the last three decades, pointed to extensive possibilities of utilization of this energy resource. It began with hot springs utilization even several thousands of years ago, then with extraction of sulphur, alaun and other minerals (XVIII century) and production of electricity (1912, Larderello — Italy), to be expanded in our age, practically to all spheres of human life: centralized heating of flats, basins and different kinds of public buildings, in fishing, stock - breeding, poultry farming, fruit and vegetables growing, flower growing, wine - growing and various branches of industry. Every year, new areas of geothermal energy application are discovered, so that its application in spas, which used to be primary and the only one, hardly occupies a small part of these resources.

Total consumption of geothermal energy in the world (1978) came to 8.600 MW. Of that, capacities for production of electric power covered 1.458 MW while for centralized heating, agriculture and industry it made 7.153 MW. In relation to production and consumption of conventional types of energy (oil, coal, natural gas) and to hydroenergy too, these are really symbolic quantities. Only by realization of ambitious programmes and projects, we dealt with in the above text, geothermal energy is going to play a prominent part in energy balances of many countries and consequently, become one of decisive factor in meeting future needs of mankind.

Within the former scientific and exploratory efforts, special attention was paid to complex problems of total utilization of this resource: water, steam and mineral components, that can be concentrated in hot solvents even to 30%. In USA, Mexico, Italy and some other countries, remarkable successes have been attained, especially in the process of desalination of hot waters. Adequate solutions of entire utilization of all components, contained in hydrothermal and geopressured deposits, in coming decades, will essentially contribute to valorization and further development of utilization of geothermal energy.

Geological investigation of geothermal energy deposits become more intensive and extensive. They have been carried out in over 60 countries of the world. More than half of those projects have been realized in the framework of the UN programmes. This has been lasted for near two decades in the form of financing of certain phases of investigations and sending consultants and experts. Outstanding successes have been attained so far in several countries (Salvador, Turkey, Indonesia etc.). In UN there is a standpoint that expeditious winning and extended utilization of geothermal energy resources give excellent chance to numerous undeveloped countries to compensate the shortage of oil and coal and so accelerate their development.

Investigation of geothermal energy deposits appears as a complex scientific and technical - technological process. Methods of geological prospecting together with infra-red and other remote sensing techniques are applied, then regional and detailed geological, structural, petrological, geochemical and geophysical investigations. In the first phases of work, shallow drillings are performed in order to define particular lithostratigraphic, structural, thermometric and hydrogeological parameters, condition and states and afterwards, exploratory drill holes of optimal depth are designed. Application of logical succession of methods is insisted on, as well as on specialty of geological — geochemical and geophysical works, in order to diminish the risk, for geophysics and drilling are the most expensive part of the research and therefore have to be designed on the adequate documentation.

Deposits found at a depth of about 2.000 m are currently being exploited in the world. Investigations were performed even to 6,5 km in dry geothermal and geopressured deposits. Within this, special attention is paid to improving and enlargement of efficiency of drilling methods, better treatment and exploitation of different types of deposits, their complex utilization and environmental protection. Numerous technical and technological difficulties are present on the way of intaking of the most abundant resources of geothermal energy at great depths or under high pressure. But many of them have already been eliminated, so possibilities have been continuously increasing. Rapid growth of needs for energy in the whole world, then exhaustion of conventional energy resources and permanent raise of their prices, diminishing of drinking water resources, need for increase and improvement of food production and the like, will make the interest for geothermal energy continuously grows.

Countries that realized the situation earlier, have already a remarkable profit of it, for they substituted expensive imported energy for much cheaper one, and that is especially important, for lasting domestic resources.

Surveys dealing with origin, type, distribution, evaluation and possible applicability of geothermal potentials, as well as attained results of investigations and exploitation of this resource in certain countries, point to great possibilities of its present and long-term application in the world and our country as well. In numerous countries, low level of investigation, technical and technological difficulties in intaking of this energy, cause its very low and one-sided applicability, while on the other hand, significant results, concerning its application, have been attained in the countries like: The USA, Mexico, Salvador, Nicaragua, Chile, Iceland, Italy, Turkey, Hungary, the USSR, China, Japan, Indonesia, New Zealand etc., although mentioned resources are used in the said countries far less than the real possibilities allow.

In the world, in numerous countries and also in some neighbouring ones, significant results in investigation and utilization of this resource have been attained, especially in Italy which has a long tradition of investigation and complex utilization of fluids, then in Hungary, Romania, and less in Austria and Bulgaria. This fact, among other things, has to be a stimulus for our engagement in investigations and utilization of geothermal resources.

Geothermal energy is a chance not only for developed, but also for numerous developing countries which don't have sufficient, own conventional energy resources.

Estimations of presence of applicable geothermal resources on the basis of various inquiries, studies and UN world conferences, point to low level of investigation on wide spaces and predict utilization as far as 2.020 year in far less extent than the real possibilities allow.

Great possibilities of application of this resource are in agriculture, for heating of flats, in industry, for spas and recreational activities and in extraction of mineral raw materials from fluids. The most important application is in production of electricity. There are data showing that 70% of totally installed capacities of geothermal resources with temperature below 180°C are used for spas and recreation. This means that heat is not sufficiently exploited and indicates its possibility of wide application. The fundamental element which expands its application is knowledge that the modern society uses, especially in the urban areas, approximately 50% of total energy with the temperature rising to 100°C or that in general consumption, 80% of total energy is used for low temperature processes. These data indicate that low enthalpy fluids also have a large economic value, which means that it is profitable to carry out researches even in the zones with the temperature much lower than 50°C.

Existing programmes in numerous countries and estimation of utilization indicate that intensification of investigations and intakings of this energy in coming 40 years will increase according to slight exponential dependence on time.

Even today, a half of the countries having geothermal resources and even those with enormous reserves of conventional fuels are carrying out programmes for extensive geothermal researches. In order to utilize higher energetic levels than the existing ones, as well as to expand the spectrum of application, it will be necessary to solve a great many institutional, organizational and financial problems, to improve technology of investigation, intaking, utilization and conversion of geothermal energy.

Speed of geothermal energy development will depend on geological conditions, degree of investigation and on the risk of investigation, possibility of financing, on the price of alternative resource, increase in consumption of energy, institutional factors, as well as on investigated application. One should have in mind that investigation, intaking, production, plant maintenance and environmental protection represent a continuous technological process.

Fundamental, regional and systematic investigations of geothermal energy in Bosnia and Herzegovina were not carried out until eighties, although, during various geological, geophysical, hydrogeological and oil investigations, certain elements that indicate geothermal potentiality were provided.

During several last years complex investigations of mineral, thermal and thermomineral waters of Bosnia and Herzegovina have been intensified in numerous occurences. Within study of fundamental geological and hydrogeological investigation, we have come to the certain cognitions about presence of positive geothermic anomalies and justifiability of their investigations on numerous localities and broader zones of Bosnian territory. So in 1980, systematic regional investigations of geothermal energy have commenced in Bosnia and Herzegovina, that is, in the region of Bosanska krajina, as one of the most promising zones in our republic. The works have been carried out by »Geoinženjering« — Sarajevo (investigator in charge was N. Miošić) with Republic Committee for Energy and Industry, as an investor. By this investigation we shall come to a relative geothermal valorization and zoning of the terrain according to geothermal energy potentiality. Afterwards we are going to set out with detailed investigations in our zones, locating and performing deep test holes and exploitational intake of higher temperature fluids.

Even now we are able to ascertain that in Bosnia and Herzegovina there exist high-grade potentials that can be exploited. They can be often found on numerous locations near great consumers of energy and in that sense represent a new economic categorization too, they condition a higher degree of development and effect on including indifferent natural goods into economic cycle and give a chance to activities to be developed, which hasn't been realizable earlier.

In Socialist Republic of Bosnia and Herzegovina, the degree of geothermal investigation is on a low level, but it is evident, on the basis of former geological data, geophysical, hydrogeological, oil investigation, geothermal and other investigations, and on this book as well, that it is justifiable to carry out complex investigations of geothermal potentials and initiate programmes for their realization. Therefore, the book is not only a final statement but encouragement for deep consideration of the problemme in order to set out with fundamental regional and detailed geothermal investigations in Bosnia and Herzegovina, as soon as possible.

Investigations of geothermal energy, already carried out, are of interdisciplinar and fundamental character and they define the most important geothermal factors in order to assess perspective, priority and justifiability of further investigations in Bosnia and Herzegovina.

For the first time we have made regional distribution of geothermal zones forming, on the basis of analysis and reinterpretation of existing geological, geophysical, geomorfological, neotectonic, geochemical, petrogenetic, seismological and hydrogeological data, all from the aspect of geothermal energy. By method of elimination and induction we have come to direct manifestations of geothermal potentiality and so zoning of priority zones for geothermal investigations has been carried out. Relative values of geothermal and other parameters and potentials have been obtained but they also may be a reliable base for realization of further investigations with diminished risk.

Owing to other performed investigations during the last 3—4 years, new data in treating geothermics, have been obtained. Starting from this aspect, all relevant data of different disciplines have been reinterpreted for the first time, then isotope analyses of the rocks, waters, gases. have been made, indicating geothermal potentiality of particular environments and also heat conductivity of the rocks has been experimentally determined. On the basis of measured temperatures and reckoned gradient, as well as on experimentally determined heat conductivity, on several locations there has been defined, for the first time, the most important geothermal parameter-heat flow. The first maps of the most important geothermal parameters (geothermal gradient and heat flow) have also been elaborated and there has been registered interdependence of various geological, geophysical, seismological, neotectonic, hydrogeological and other parameters on the one, and geothermal factors on the other hand.

We have proved that there are sufficiently concentrated geothermal resources to be exploitable, that hydrothermal systems are the most optimal type of a resource for investigation and utilization and that a big regional positive geothermal anomaly doesn't exist. There are only several independant hydrothermal zones. We have also proved that there is an ascendant convection and that the temperatures of the resources will be higher than those at springs, that about 95% of waters are renewable and of meteoric origin and that representative geothermal and other parameters can be obtained anly by deep drilling. Zone of potential investigations spreads northwards of approximate line Bihać — Bosanski Novi — Sanski Most — Mrkonjić-Grad — Gornji Vakuf — Hadžići — Praća — Foča — Čajniče and in this region, on the present stage of investigation there are 10 zones ranked according to geothermal perspective and potentiality (artesian basins of Posavina, Sarajevo — Zenica basin, massifs of ophiolite zone, massif of the Central Bosnian schist mountains, Bihać — Kladuša basin, flusch zone of Banja Luka — Sarajevo, massif of the Una — Sana Paleozoic, ultramafic massif of Višegrad, Paleozoic massif of S-E Bosnia and Paleozoic and Neogene massif of Srebrenica).

On the territory of the republic, investigation methods from the country and the world have been applied selectively, open questions arising from the present stage of work have been pointed to. These questions have not yet been solved, neither in geothermics nor in fundamental scientific disciplines contiguous to it, and thereby function as a limiting factor in investigations of these resources.

By this monograph the objective of the investigations is fulfilled, comprising defination of indicative parameters, existence of geothermal resources, positions, energy potentials and zoning of the terrain according to priority zones of further investigations. We have pointed to directions of further geothermal investigations, approach to the researches and utilization, then to concretely quoted measures in order to initiate and intensify explorations, intaking and polyvalent application of geothermal resources.

Applied method of the work is, by its nature, sufficiently comprising and may serve as an initiative model for further investigations of geothermal resources in Bosnia and Herzegovina.

Utilization of this resource in the world, degree of its cognition and application in our country, imposes urgent initiation and intensification of the programme for the research and universal application of geothermal potentials. Organized and systematic study of all aspects of this problem, together with transfer of knowledge and technology from other countries, where significant results have already been obtained, and their application to our conditions, will make possible accelerated and polyvalent utilization of geothermal resources in near future.

Sarajevo, 1988

Safet Čičić

Neven Miošić

GEOLOŠKI GLASNIK HERALD GEOLOGICAL BULLETIN GÉOLOGIQUE

To Mr. A. Jelenić
with pleasure
Sar., 13.11.87 from N. Miošić

Miošić Neven

GENEZA HIDROGEOTERMALNIH KONVEKTIVNIH SISTEMA H_2O — CO_2 U NEKIM PODRUČJIMA POJAVA MINERALNIH I TERMOMINERALNIH VODA BOSNE — NOVIJE INTERPRETACIJE

GEOLOŠKI GLASNIK	VOL. 30	№ 1	1-229	Sarajevo, maj 1987.

1. Gata — SB-1	6—9. 12. 84.	— 13,05	— 12,35	92	6	37,5
2. Tomina II. SB-3	14—15. 9. 82.	— 9,24	— 12,30	95	4	31
3. Grujići	28—30. 4. 85.	— 7,30	—	—	—	24,4
Laktaši Banja	25. 8. 81.	— 8,04	— 25,00	78	13	29,5
4. Laktaši Banja	25—27. 10. 83.	— 8,09	— 11,82	80	13	29,5
5. Laktaši Banja	28—30. 4. 85.	— 6,74	—			29
6. Laktaši L-1	28—30. 4. 85.	— 6,79	—	—	—	29
Laktaši L-3	25. 8. 81.	— 8,05	— 25,00	77	15	29
7. Šeher	28—30. 4. 85.	— 4,93	—	—	—	33
8. Domaljevac	6—9. 12. 84.	— 7,36	— 10,73	49	34	88,5
9. Dvorovi	6—9. 12. 84.	— 3,50	— 16,98	76	12	61,1
10. Dvorovi	6. 11. 85.	— 2,42	— 15,80	64	15,9	69
11. Tičići, buš. IT-1	7. 11. 85.	— 3,76	—	—	—	54
12. Tičići, buš. IT-2	7. 11. 85.	— 4,56	— 13,50	64,8	34,0	39,2

SUMMARY

GENESIS OF HYDROGEOTHERMAL CONVECTIVE SYSTEMS OF H_2O-CO_2 IN SOME AREAS OF MINERAL AND THERMOMINERAL WATERS IN BOSNIA — TENTATIVE INTERPRETATION

In the last ten years, at complex investigations of mineral and thermomineral waters of Bosnia, new data have been achieved. These data give us contemporary interpretation of generation of hydrogeothermal convection systems of H_2O-CO_2 together with application of the results in the world.

Following the data in this paper, it is tried to give the tool for the preliminary prospection of thermomineral waters and CO_2.

CO_2 in the carbon acid waters of Bosnia is supposed to be from thermometamorphic origin from sedimentary carbonates. This gas is renewable and there have been the same conditions of CO_2 forming nowadays. It can be created in horizons of the different depths with water and it's possible to be found in very deep horizons without water. The gradient content trend value of CO_2 with its depth remains open.

There are occurences with common thermogenesis system of H_2O and CO_2 (Slatina, Teslić, Sočkovac, Bokorić, Ilidža), but different generating of CO_2 and H_2O (Sočkovac — Kiseljak, Osivica, Ljubače) too, although all waters are of meteoric origin.

However, we can come to conclusion, that it's difficult to separate different ways of forming CO_2 in N_2-CO_2 waters, especially safe evidences of a common generating system of H_2O-CO_2. It's also necessary to solve the numerous open questions. Thus, the investigators should solve new tasks especially in a predrilling phase to confirm the indicative parameters of fluid genesis. Only the complete knowledge of genesis system gives us possibilities finding the new accumulations of carbo acid thermomineral waters and CO_2 and determining the optimal regime of utilizing and enlargement of these resources application diapason.

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11/11/87

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GEOTERMALNA POTENCIJALNOST MAČVE, SEMBERIJE I SREMA

1. UVOD. Od načeg otkrića geotermalne anomalije u mačvanskom selu Dublje u 1982. godini do početka 1986. godine izučili smo rezultate regionalnih geoloških i geofizičkih istraživanja i posebno rezultate dubokog istražnog bušenja za potrebe istraživanja nafte i prirodnog gasa na područjima Mačve, Semberije i Srema,a u cilju izučavanja njihovih regionalnih geotermalnih karakteristika. Rezultate do kojih smo došli takvim izučavanjima smatramo da su za SFR Jugoslaviju veoma interesantni sa gledišta obezbedjivanja znatnih količina čiste i obnovljive energije. Zato smo odlučili da rezultate geotermalnih izučavanja terena Mačve, Semberije i Srema prvo saopštimo geolozima Jugoslavije na 11. kongresu. Ovo činimo i zato što samo naučni skup takvog ranga može najnepristrasnije da oceni vrednost i značaj po narodnu privredu geotermalnog potencijala Mačve, Semberije i Srema.

Ukoliko učesnici 11. geološkog kongresa Jugoslavije pozitivno ocene rezultate naših geotermalnih izučavanja, onda očekujemo od Kongresa preporuku da geotermalna istraživanja Mačve,Semberije i Srema proglasi prioritetnim jugoslovenskim projektom geotermalnih istraživanja i korišćenja geotermalne energije u toplifikacione svrhe gradskih i seoskih naselja, za proizvodnju hrane i za sportsko-rekreacione i balneološke svrhe.

2. PRIKAZ I ANALIZA REZULTATA DOSADAŠNJIH ISTRAŽIVANJA. Istražno područje se prostire na teritoriji Mačve i Posavo-Tamnave (na području 5 opština), zatim na teritoriji Semberije (na području 4 opštine) i Srema (na području 3 opštine). Ukupna površina istražnog područja iznosi oko 6000 km^2.

U geološkom sastavu Terena Mačve, Posavo-Tamnave, Semberije

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GEOTHERMAL POTENTIAL OF MAČVA, SEMBERIA, AND SREM

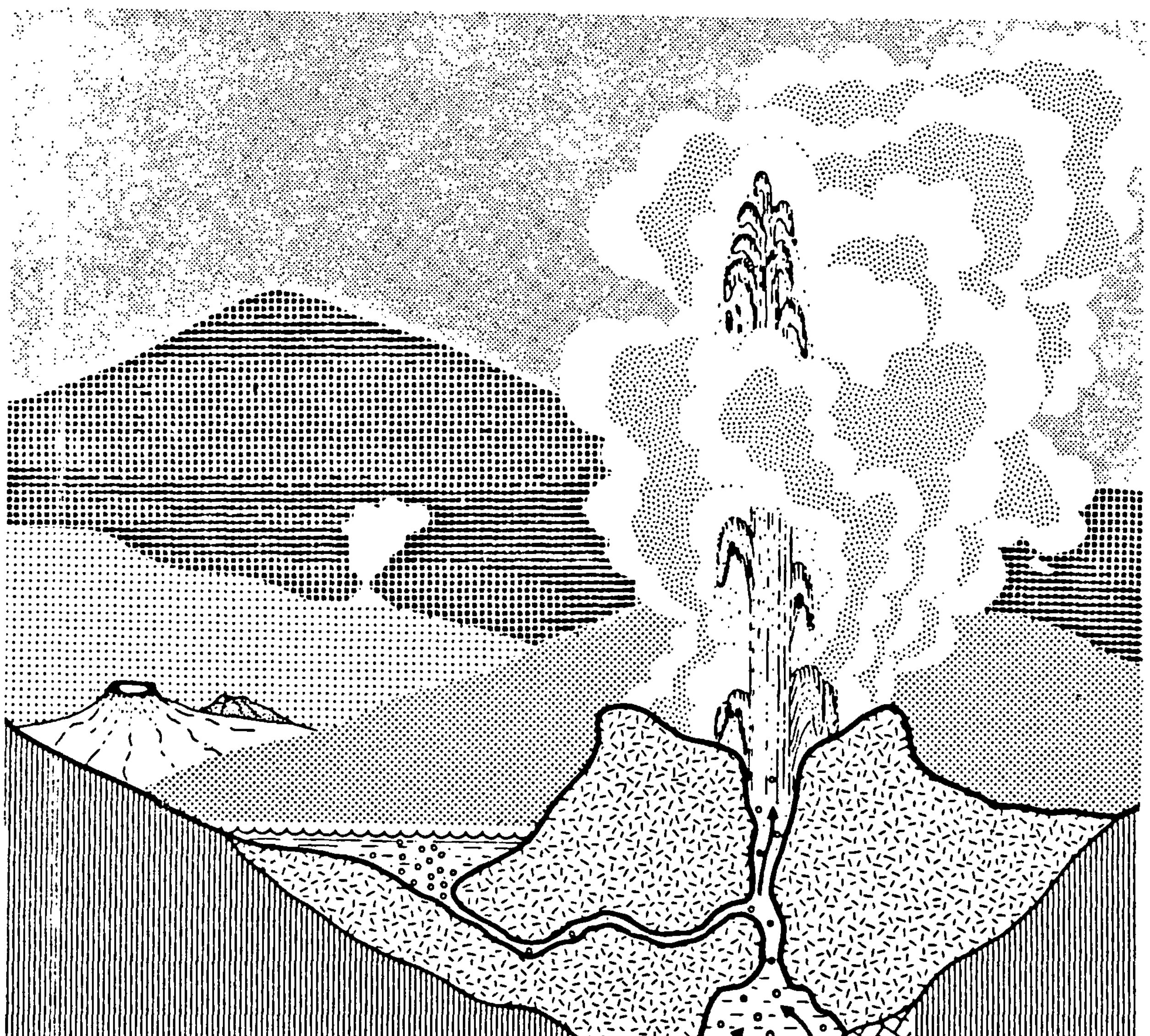
Summary

The hydrogeothermal potentials of Mačva, Semberia, and Srem, under a total surface area of about 6000 square kilometres, are preliminary assessed. The three districts are the part of the southern Pannonian margin. Neogene sediments lie in most of the area over a Mesozoic sedimentary complex composed of Upper Cretaceous flysch and thick carbonate and karstified Triassic and Upper Cretaceous deposits. The Earth a crust is thick between 24 and 26 kilometres in the region. Miocene magmatic and volcanic activites are identified in the basin and its margin. These two factors are responssible for high values of the heat flow of 112 mWm^{-2}. Ceontrolled by all the mentioned relations, an enormous hydrogeothermal system has developed in the Mesozoic karstified carbonate complex, consisting of large thermal water reservoirs at depths from

200 to 1500 metres. Water temperatures range from 50°C at 200 metres of depth to 130°C at 2500 metres. The mineral content in the thermal waters is very low, from 500 to 1000 ppm, and they may be used for drinking purpose after the thermal use. These data are collected from deep exploratory wells for oil and geothermal energy. The potential of hydrogeothermal resources within karstified carbonate deposits of Mesozoic age is assessed at some $7{,}6\cdot10^{15}$ KJ, or a heat equivalent to about $146\cdot10^{6}$ ton of oil.

PALEOHIDROGEOTERMALNE POJAVE AVALE

Mihailo G. Milivojević



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PALAEOHYDROGEOTHERMAL OCCURRENCES OF AVALA

Mihailo G. Milivojević

Beograd, 1982.

6
PALEOHYDROGEOTHERMAL OCCURRENCES OF AVALA

INTRODUCTION

Palaeohydrogeotermal occurrences* of Avala, studied in period 1975–1979, are presently considered. The direct reason for the investigation was a high hydrogeothermal anomaly noted in the Zavojnička Reka valley and palaeohydrogeothermal occurrences within their extent.

GEOLOGICAL COMPOSITION AND FEATURE OF AVALA ENVIRONS

Geological investigation and prospecting in Avala and its surrounding started a long time ago, mostly due to mercury, lead and zinc deposits, the mercury deposit being known about in prehistorical era, and later due to the vicinity of Belgrade (Fig. 1) and the fast development of geology in Serbia.

* Palaeohydrogeothermal occurrences are all occurrences of mineral deposition in past or recent geological history from hydrogeothermal fluids in places of their otuflow on ground or under water and filling rock cavities within the Earth's crust; those occurrences within the Earth's crust which were also formed in past or recent geological time by interaction of these fluids and rock masses, and anomalous values of heat filed in domains of the once circulating hydrogeothermal fluids.

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Sedimentary Rocks

These rocks compose most of Avala and its surroundings (Fig. 4). The rocks are Mesozoic (Jurassic and Cretaceous) Tertiary (Neogene) and Quaternary.

The oldest of sedimentary Mesozoic rocks are Jurassic and the most widespread are Cretaceous rocks. Jurassic, or rather Upper Jurassic, sediments are recognized west and southwest of Avala. Within them three facies are separated: diabase–chert formation, facies of reef and subreef (brachiopod) limestones and facies of aptychus beds. The largest coverage of the three facies has diabase–chert formations in which sandstone–chert and schistose–chert formations are distinguished. Jurassic sediments also include Malm (Tithonina)–Neocomian flysch, characterized by alternating sandstone and marl and shale.

Cretaceous sediments are the most widespread Mesozoic rocks near Avala. The Cretaceous is developed in all stages of the Lower and Middle Cretaceous. As for lithological composition, it is very diverse. Within the range of Cretaceous sediments the greatest distribution is that of Upper Cretaceous, the so–called Avala flysch, which was deposited from the Upper Turonian to the Middle Campanian.

Tertiary sedimentary rocks near Avala are of Neogene age – the Middle and Upper Miocene and Pliocene. Upper Miocene sediments have the largest distribution. The oldest Miocene sediments are Tortonian in age. They include clay, sand and limestone. Sarmatian sediments have a greater extent than the Tortonian and consist of clay, marl, limestone and sand. Pannonian sediments are the most widespread of Neogene sediments in Avala surroundings. They consist of clay, marl and sand. Pliocene sediments have a small coverage and are represented by sand, clay and gravel.

Magmatic Rocks

The most important magmatic rocks are of Teriary age. Occurrences of these rocks are frequent on Avala and its close proximity. They are eruptive and have the form of numerous veins varying int thickness (Fig. 4). These rocks were studied most in detail by P. Dimitrijević. These are unaltered lamprophyre, andesite, quartz microdiorite, i.e. dacite, quartz latite, and microgranite. Volcanic rocks are grading from the mineralogical aspect from one type to another indicating, according to B. Dimitrijević, their derivation from the same magma which solidified at subvolcanic level (8). Lamprophyre occurrences and the most important, microgranite occurrences are the main evidence of granitoid pluton under Avala, equivalent to granodiorite (8), (14), (6). As for the age of the above mentioned magmatic rocks, the instrusion of Avala granitoid pluton is supposed to be an event from before the Tortonian, that volcanic rocks were formed until the Middle of the Sarmatian, or that magmatic solution existed until then (46). This age is only relative and approximate, determined only in relation to the Avala magmatism as a part of Tertiary magmatism of Šumadija.

Metamorphic Rocks

Metamorphic rocks recognized on Avala and the surrounding area are serpentinite and thermometamorphic rocks, the former prevailing and composing the extreme north of the Šumadija ophiolite zone. M. Anđelković wrote (1) that they were formed before the Upper Jurassic. Thermometamorphic rocks are distributed over Avala within the Upper Cretaceous flysch (fig. 4) and consist of skarn, calc–silicate and quartz–feldspathic hornfels, epidozoite, marble, contact–altered sandstone and shale, axinite and tourmaline veins (63), (8). These rocks nonambiguously indicate the presence of a shallow mass of granodioritic pluton which accounted for the occurrence of the mentioned rocks on ground surface.

Structural–Tectonic Features

Avala and the surrounding country, situated on the periphery of Pannonian depression, belongs to the geotectonic „Vardar Zone". This peripheral position is responsible for its complex structural–tectonic composition which is a consequence of a complicated and yet unexplained and unknown evolution of the „Vardar Zone" in the geological past. The main tectonic forms are various faults and the present structure of Avala can be considered a consequence of their relationship.

METHODS OF INVESTIGATION

Palaeohydrogeothermal occurrences are quite abundant in modern geothermal regions. Where modern sources of hydrogeothermal fluids are not located but there are palaeohydrogeothermal occurrences, the latter are indicative of an active hydrogeothermal system in the geological past.

Palaeohydrogeothermal occurrences are recognized near Avala, where there are not natural hydrogeothermal occurrences in the form of thermal water springs, but there is thermal water encountered by exploratory drilling in the Zavojnička Reka valley (Fig. 3). This drilling revealed also palaeohydrogeothermal occurrences within the aquifer of the mentioned thermal water.

Palaeohydrogeothermal occurrences on ground surface were studied before the Second War by B. Dimitrijević (8) and after this war during the exploration of Šuplja Stena mercury deposit (17), (43), (50).

Data concerning the position and characteristics of these palaeohydrogeothermal occurrences were old, so that all the described occurrences had to be reconstructed and located. Until the present work, twelve occurrences had been known. Some of them were studied in detail, while some were only marked on geological maps. Therefore, the first thing to be done was a detail reconnaissance, when four more palaeohydrogeothermal occurrences were recognized.

The area of each occurrence was mapped in detail and rock was sampled for mineralogical, petrological and palaeontological, and chemical analyses. Same analyses were made for palaeohydrogeothermal occurrences noted on rock samples from exploratory boreholes. Temperature of water was measured in each discharging well using mercury thermometer during the well tests. Some of wells were temperature logged through the full length of the well. Samples of each occurrence were also examined to determine the temperature of gas–fluid inclusion homogenization. Besides the mentioned examinations, isotope analysis was made in the Jožef Štefan Institute, Ljubljana, on carbonate samples of palaeohydrogeothermal occurrences.

INVESTIGATION RESULTS

As mentioned before, I recognized sixteen palaeohydrogeothermal occurrences on surface, assembled in three zones: the Zavojnička Reka valley, the valley side and valley of the Topčiderska Reka, and the hill ridge dividing drainage areas of these two rivers (Fig. 3).

Mode of Occurrence and Appearance of Palaeohydrogeothermal Occurrences

Deposits of all palaeohydrogeothermal occurrences are differentiated by the mode of occurrence and the appearance of rock mass surface, and separated into two groups. One group consists of quartzite type occurrences conspicuous outcropping in the relief. These occurrences look like hillocks 15–20 m high, mostly as nests in serpentinite and in its contact with Upper Cretaceous flysch. Rock mass of such occurrences is composed of large blocks up to 10 m in height or diameter. The blocks are full of cavities varying in size from a few centimetres to one metre (Fig. 4). The largest cavities look like small caves or cave channels. Cavities of whatever size have different shapes, mostly irregular. Generally, rock masses of these occurrences resemble very much tufa. This mode of quartzite occurrence is a consequence of its origin and high resistance to erosion. The colour of rock is dirty yellow, gray–green or dirty white. It is greatly fractured, the

cracks mostly separating blocks up to 10 cm apart. Some of fractures or cracks are filled with crystalline quartz.

The other group consists of carbonate occurrences. Due to high carbonate content and poor resistivity to erosion these occurrences are not rising above ground surface but can be recognized only by colour. Blocks are small, to one metre in diameter, and most of outcrops consist of detritus. Other morphologic characteristics distinguishing quartzite occurrences are not possessed by carbonate ones for the same reason.

The palaeohydrogeothermal occurrences located by drilling in the Zavojnička Reka valley consist of partly or fully fractured quartz or carbonate filling in serpentinite (Fig. 5), cement of Tertiary (Sarmatian) breccia and conglomerate, siliceous film on cavern or small cavity inside surface in Middle Sarmatian limestones or crystalline pyrite in the above mentioned rock masses and in Pannonian sandstones (33).

Mineral Composition of Palaeohydrogeothermal Occurrences

The mineral composition of deposits of palaeohydrogeothermal occurrences is determined by microscopy. This examination was needed for study of chemical composition of hydrothermal fluids from which deposits were formed of palaeohydrogeothermal occurrences of Avala, and for tracing the chemistry, physical conditions of circulation and temperature change of the fluids through the time.

Microscopy for mineral composition was used to separate three zones of palaeohydrogeothermal occurrences. First zone comprises siliceous or quartzite occurrences with quartz as main mineral and chalcedony. Second zone consists of carbonate occurrences with calcite, dolomite and ankerite prevailing over quartz. Third zone comprises mixed occurrences in which microscopy could not reveal the dominating mineral. These are the mentioned newly discovered occurrences in the Zavojnička Reka valley predominantly composed of quartz and calcite. The separated zones are shown in Fig. 4.

The exploration of Šuplja Stena mercury deposit revealed within the quartzite palaeohydrogeothermal occurrence of the same name, at its deep levels, according to D. Jadranin (17) the following minerals: cinnabar, pyrrhotine, arsenopyrite, chalcopyrite, sphalerite, pyrite, marcasite, millerite, schwazite, polydymite, chloanthite, ramelsbergite, calomel, natural mercury and gold, quartz, baryte, dolomite, and avalite

Chemical Composition of Rock Mass Deposits of Palaeohydrogeothermal Occurrences

For an approximate reconstruction of the chemical composition of hydrogeotherma fluids from which derived the palaeohydrogeothermal occurrences of Avala it was necessery to study their chemical composition. Results of the chemical analysis are given in Tab. 1 and Fig. 6. The main characteristic of chemical composition of Avala palaeohydrogeothermal occurrences is the domination of one constituent. Such dominating constituents are silica (SiO_2) and Ca and Mg carbonates. Silica was dominating constituent in eight of the analysed surface occurrences, and Ca and Mg carbonates in five occurrences.

Homogenization Temperatures of Gas–Fluid Inclusions

The homogenization method of gaseous and fluid inclusions of the mentioned fluids in minerals was used to find approximate temperatures of palaeohydrogeothermal fluids from which derived the present palaeohydrogeothermal occurrences of Avala. This method was used by N. Blečić for all tests on samples from eight palaeohydrogeothermal occurrences with suitable inclusions (4).

From among the surface occurrences, the highest temperature of about 400^0 was that of palaeohydrogeothermal fluids from which originated the siliceous, i.e. quartzite palaeohydrogeothermal occurrences. Temperatures of secondary inclusions were lower by 25–50% than the primary ones and indicated the temperatures of palaeohydrogeothermal fluids which circulated subsequently. Carbonate occurrences on ground surface had lower homogenization temperature (100–150^{0}C) than the quartz occurrences. Homogenization temperatures of inclusions in quartz from silicified Sarmatian sediments and serpentinite in the Zavojnička Reka valley were very high, from 400^{0}C in the beginning to about 100^{0}C.

Isotopic Composition of Carbonates of Palaeohydrogeothermal Occurrences

Isotopic composition of carbonates in palaeohydrogeothermal occurrences was analysed for additional information on the genesis of these occurrences. Six isotope analyses of carbonate samples from five palaeohydrogeothermal occurrences were made for $\delta^{13}C$ and $\delta^{18}O$. (The results are given in Tab. 8).

Newly Discovered Thermal Water Occurrences in the Domain of Palaeohydrogeothermal Occurrences in the Zavojnička Reka Valley

During detail hydrogeological prospecting in the Zavojnička Reka valley in 1975 and 1976, very important occurrences of thermal water were discovered within the above mentioned Sarmatian sediments and serpentinites with palaeohydrogeothermal occurrences (Figs. 2 and 7), (33), (34). The temperature of the thermal water was relatively high for the depth of its occurrence, i.e. in relation to the known geothermal conditions in the region of Avala, and as such indicated the presence of geothermal, or hydrogeothermal, anomaly.

The localized thermal aquifer is formed in karstified and silicified Sarmatian limestones, silicified serpentinite conglomerates, and serpentinites (Fig. 7).

INTERPRETATION AND DISCUSSION

Main results of investigation and exploration in palaeohydrogeothermal occurrences so far recognized in Avala region are presented in the preceding text. The principal question that can be raised after the consideration of the results is: What is the importance of palaeohydrogeothermal occurrences of Avala and of thermal water occurrences within the zone of geothermal anomaly, or should these occurrences be considered an indication of concealed deposits and sources of geothermal energy? Before answering the question as the ultimate goal of the present paper, first, solutions should be offered of partial problems and these solutions integrated for a single answer to the above question.

The first partial problem to be solved is: Are the palaeohydrogeothermal occurrences of Avala what we take them to be, i.e. are they a consequence of the once present and circulating hydrogeothermal fluids? The answer is affirmative, because the palaeohydrogeothermal occurrences of Avala may certainly be taken to had orginated from hydrogeothermal fluids. It is best evinced by its texture and the appearance of deposits of palaeohydrogeothermal occurrences, their mineral, chemical and isotopic composition. Namely, primary minerals with the chemical elements derived from accumulations of palaeohydrogeothermal fluids were minerals of quartz group. carbonate minerals and sulphide minerals. They were deposited only by independent chemical reactions in the mentioned fluids. Minerals containing nickel and chromium resulted from the reaction of palaeohydrogeothermal fluids and serpentinite through which they moved up to the surface. The order and mode of deposition of individual minerals indicate a staged formation of palaeohydrogeothermal deposits. The occurrence of quartzite type was formed starting with fast deposition of a huge mass of fine–grained quartz composing most of the palaeohydrogeothermal deposit. The next deposition of mineral took place only in fissures and cracks, and in cavities of the primarily formed fine quartz mass until the end of fluid circulation. The situation with carbonate occurrences was the same (33).

Some ore occurrences within the palaeohydrogeothermal deposits, depending on the time of their formation, i.e. the geologic age, are excellent indication of hidden accumulations of hydrogeothermal fluids and of young palaeohydrogeothermal systems. This foremostly refers to mineral occurrences and mercury deposits, as has been proved and used as one of important geochemical indications in modern geothermal areas. Mineralization occurrences and mercury ore deposits are present in the scope of siliceous palaeohydrogeothermal occurrences of Avala. The best known is the deposit and old mercury mine of Šuplja Stena (17), (43), (50).

The study of the origin and importance of palaeohydrogeothermal occurrences of Avala, while objective was to decide on how justified the detail geothermal exploration in this area would be for search of geothermal energy deposits, required first a reconstruction of all palaeogeological conditions which were responsible for the formation of present--day palaeohydrogeothermal and newly discovered hydrogeothermal occurrences in the form of thermal water.

It has been explained above that hydrogeothermal fluids were the source of derivation of palaeohydrogeothermal occurrences, from which could be inferred that two main conditions: (1) accumulation of hydrogeothermal fluids of certain chemical composition, temperature and pressure, and (2) transit paths or channels through which hydrogeothermal fluids communicated with surface or with some other porous medium situated between primary accumulation and Earth's surface, controlled the formation of palaeohydrogeothermal occurrences. Hydrogeological structure which included the environments bearing hydrogeothermal fluids must have been confined or semiconfined forming, together with suitable (high) temperature, geothermodynamic conditions only for upward extrusion of fluids, to Earth's surface. Another condition was created by tectonic dislocation or intrusion of magma when fault or mylonite zones were formed in rocks lying over the formation bearing hydrothermal fluids. The porosity in these zones was much greater than that of country rocks which were impermeable for fluids from their underlying rocks and therefore fault zones were transit paths for hydrogeothermal fluids. All the above mentioned conditions were fulfilled in Avala area (Figs. 9 and 10). An interesting question in this connection is: Why palaeohydrogeothermal occurrences of Avala are formed only in serpentinites, i.e. in interesections of fault zones in them and in their contact with Cretaceous flysch, and not in flysch? The reason is the physical and mechanical characteristics of serpentinites and their behaviour during the formation of fault zones so unlike those of flysch sediments.

Another important question is related to the depth of supply channels. Mineral and chemical composition of palaeohydrogeothermal deposits showed that the mineral mass had least derived from serpentinites. It implied the depth of palaeohydrogeothermal fluid supply channels at least equal to serpentinite thickness, i.e. to their floor or deeper.

What could be inferred from all the above and from the study of palaeohydrogeothermal occurrences is that an active hydrogeothermal convective system existed in Avala region several millian years ago.

An accurate and detail reconstruction of all components of the old hydrogeothermal system, or of present palaeohydrogeothermal system of Avala, is not possible in absence of deep geothermal prospecting. Only the most probable model can be made of the old hydrothermal or present-day palaeohydrogeothermal system of Avala. This is one of the most important objectives of the study of palaeohiydrogeothermal occurrences. The model is intended to help estimating the present geothermal potential of the palaeohydrogeothermal system of Avala. In fact, this prediction model should serve as a data base for developing the concept of geothermal exploration aimed at establishing the geothermal potentiality of Avala.

Basic elements of the prediction model of the old hydrogeothermal convective system of Avala are shown in Fig. 63. Study results of the isotopic composition of calcite from carbonate palaeohydrogeothermal occurrences (Tab. 8) show the semblance of the hydrogeothermal system of Avala to the modern hydrogeothermal convective system of Larderello in Italy.

The modern palaeohydrogeothermal system of Avala, as deduced from the study of palaeohydrogeothermal occurrences and above discussion, was formed in the period when hydrothermal fluids ceased to flow in a once active convective hydrogeothermal system, when the conditions changed. The changed conditions were temperature through the depth of the system, and even more in the basin of hydrogeothermal fluids, and pressure. Since the formation period of the palaeohydrogeothermal system to the present day, the canges in it mainly consisted of slow cooling, or the temperature decline. The pressure has not much changed, because the system practically passed into a static state.

The greatest problems, which remain to be solved in future exploration, are: the depth of palaeohydrogeothermal occurrences distribution, the depth to the basin of hydrogeothermal fluids, present temperature in the basin, if it still exists, and the existence of hydrogeothermal fluids that could be exploited. All these, in addition to the discussed in section 4.6.1, are parts covered by the model of the modern palaeohydrogeothermal system of Avala.

The depth reached by palaeohydrogeothermal occurrences was discussed in section 4.2.1. and it is most probably the depth of the once existing basin with hydrogeothermal fluids. This depth is not known and cannot be predicted in absence of enough reliable indications. It can be referred only in relative terms as in section 4.6.1.

As to the „confined" hydrogeothermal fluids and their temperature, the hypotheses can be made based on the assumption about the origin and on the chemical composition of the discovered thermal water in the Zavojnička Reka valley. The origin of this water is discussed in section 3.5. Based on the modern hydrogeological conditions and on the described palaeohydrogeothermal occurrences in the Zavojnička Reka valley where thermal water was discovered, the most probable assumption is that the mentioned thermal water was condensed vapour, or cooled thermal water which reached present aquifers through the fault zone in serpentinite and peridotite. This is partly suggested by the chemical composition of this water, in which total mineral content is only 200 p.p.m. and dry residue 180 p.p.m.

Hydrothermal thermometers, used to determine temperature in the old basin of hydrogeothermal fluids in relation to SiO_2 and Na–K–Ca content in fluid outcrops, cannot efficiently be used because SiO_2 deposited in the form of the described palaeohydrogeothermal occurrences. The same refers to Ca. Therefore, the supposed temperatures of hydrogeothermal fluids in their parent basin can be related only to Na/K geothermometers (27). According to this geothermometer, water temperature in the basin of the hydrogeothermal fluid origin should be about 150°C. For the geothermal gradient value of 100°C/km the basin should be at a depth of about 1500 m.

Other components of the modern palaeohydrogeothermal system of Avala are same as when it was an active hydrogeothermal system described in section 5.6.1 (Fig. 64).

The greatest importance of the modern palaeohydrogeothermal system of Avala, which is in transition to a petrogeothermal HDR system, is the heat preserved in the granitoid intrusion which caused the formation of the old hydrogeothermal system of Avala. A temperature of about 250°C can be expected at a depth of 3 km in its contact zone.

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GEOTHERMAL ENERGY IN AGRICULTURE IN YUGOSLAVIA

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Abstract—SFR Yugoslavia has natural hot water springs practically all over its territory, indicating the presence of geothermal reservoirs underground. There is no final estimate of how much energy can be expected from this new resource, except for figures based on the results of studies and investigations.

The first use of geothermal energy in Yugoslavia in numerous spas dates back to the 19th century. Some remarkable examples of central heating are known, but the most widespread use is in agriculture (in greenhouse heating, farm heating and drying of agricultural products).

GEOTHERMAL SETTING IN YUGOSLAVIA

SFR Yugoslavia is situated in a belt richly endowed with geothermal resources. This belt starts in Hungary in the north and Italy in the west and stretches from Yugoslavia to Greece and Turkey. Four geothermal areas can be distinguished in Yugoslavia: Alpian, Dinarids, Pannonian and Bosnian–Serbian–Macedonian.

The most investigated sector is the Pannonian area, situated in the southern part of the Pannonian basin. In this area the Moho discontinuity lies at a depth of about 20 km; thick sand–clay sediment of Tertiary age, and thick sediments of Mesozoic and Paleozoic age containing hot geothermal fluids can be found in the south-western part.

The Dinarids and the Alpian areas are of less interest.

The Bosnian–Serbian–Macedonian geothermal area is situated within the Inner Dinarids, Serbo–Macedonian massif and Carpathian–Balkan chain. The earth crust in this area reaches a thickness of 40 km and there are good prospects for geothermal resources.

GEOTHERMAL ENERGY POTENTIAL OF YUGOSLAVIA

Assessment of the geothermal energy potential of Yugoslavia is rather difficult, because it is one of the few European countries that has not investigated systematically its terrestrial heat flow.

Assuming an average heat flow in Europe of about 60 mWm^{-2}, and considering the intense tectonic and magmatic activity during the Cenozoic, the average value in Yugoslavia should be in the range of 80–100 mWm^{-2}. For an average heat conductivity of 2.1 $Wm^{-1}\ K^{-1}$, the geothermal gradient can then be estimated at 50°C km^{-1}, in some parts of the country these values are much higher.

The following estimates have been made of energy potential: for the Pannonian part of SR Croatia 6.57×10^{17} kJ, SR Bosnia and Herzegovina 6×10^{17} kJ, SR Serbia proper 5×10^{13} kJ and SAP Vojvodina 6×10^{15} kJ.

GEOTHERMAL UTILIZATIONS

Numerous hot springs have been known for centuries all over the country (Fig. 1). Temperatures of 25–85°C are very convenient for balneological uses.

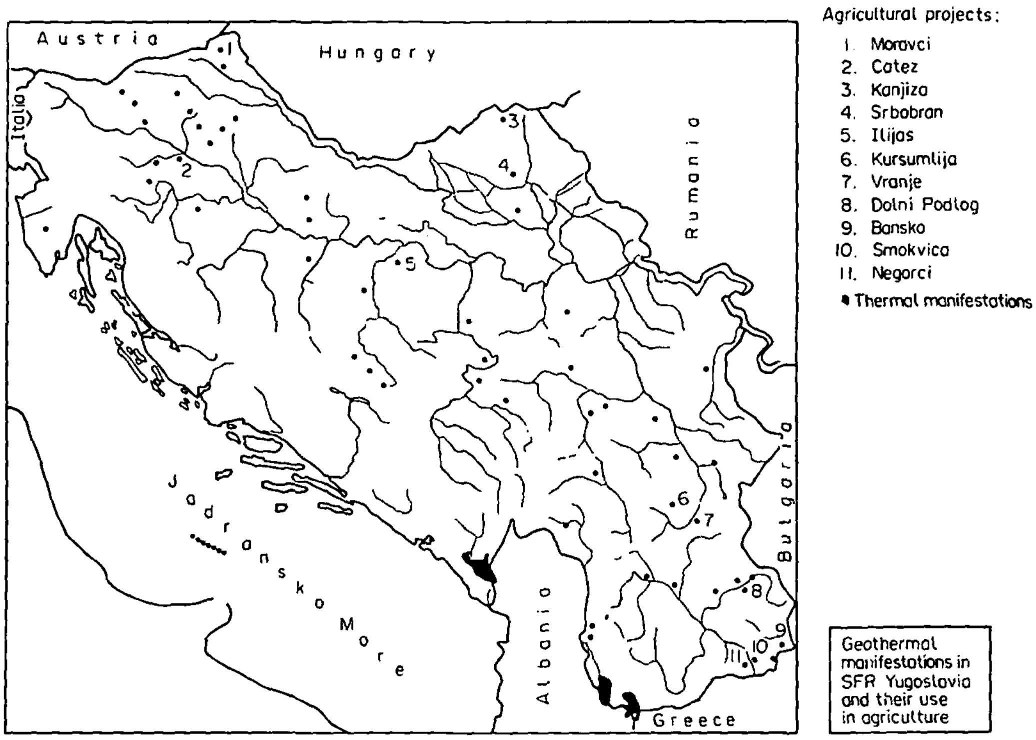

Fig. 1. Geothermal manifestations in SFR Yugoslavia and their use in agriculture.

There are several hotel heating installations using geothermal energy. Some very successful installations (one with a heat pump) are in operation and many others are under construction.

The use of geothermal energy in agriculture started in Bansko, near the town of Strumica, in southernmost Yugoslavia (9 in Fig. 1). An old-fashioned glasshouse of 2.2 ha is heated by the fluid from a thermal spring with a flow rate of 48 l s^{-1} and temperature of 72°C. The water is of low aggressivity and is used directly in the steel-pipe heating installation. Manual regulation of flow enables temperature to be regulated in the greenhouse. The annual utilization of energy is about 5000 MWh directly in the glasshouse, and about 6000 MWh in the older plastic constructions lying behind the glasshouses.

The second agricultural project was in the town of Brezice, in the north (2 in Fig. 1), where a 5 ha glasshouse produces flowers. The thermal spring (80 l s^{-1} at 59°C) produces a non-aggressive water that is used directly in the heating installations of the hotel and greenhouse. The annual utilization of energy is about 18,000 MWh.

A third geothermal greenhouse was built in Vranjska Banja (7 in Fig. 1). This 6.03 ha glasshouse, producing mainly flowers, is heated by a thermal spring with 60 l s^{-1} of water at 72°C. The water is very aggressive so heat exchangers of chemically resistant steel are in use. The annual energy utilization is approx. 17,000 MWh.

At Brezice and Vranjska Banja boiler plants of 6 and 12 MW respectively are used during peak periods. In Ilijas, near Bosanski Samac (5 in Fig. 1) a greenhouse of 2.5 ha is heated geothermally. The thermal spring (22 l s^{-1} and temperature of 85°C) produces very aggressive water. After exhaustive studies the system was put into operation with the addition of chemicals, but the problems have still not been satisfactorily solved.

In the region of Kotchany (8 in Fig. 1) 18 ha of glasshouses have been heated geothermally since 1982, as well as a rice-drying plant. Non-aggressive water at 78°C permitted a simple technical design and successful results.

In Gevgelija 22.5 ha of greenhouses have been using geothermal energy since 1983 (10 in Fig. 1). Unfortunately, the primitive design and unfinished project led to the destruction of the heating installation. Reconstruction is now under way.

Finally, near the town of Srbobran (4 in Fig. 1) a greenhouse of 0.5 ha has been heated by geothermal energy since 1984, exploiting a geothermal well of 11.6 l s^{-1} and temperature of 60°C.

All three complexes are provided with automatic temperature regulation, but without outlet temperature limitations. All of them use heavy-oil boiler plants during peak periods. A geothermal energy utilization of 85,000 MWh yr^{-1} can be estimated for the last three greenhouse complexes.

Apart from some small projects for farm heating, work is now under way to exploit geothermal energy in Gevgelija (5.2 ha of greenhouses and a laboratory, using a geothermal well of 80 l s^{-1} and temperature of 56°C; 11 in Fig. 1), in Radenci (1 in Fig. 1) and Kursumlija (6 in Fig. 1).

Altogether, about 70 ha of greenhouses are heated with geothermal energy in Yugoslavia, a rice-drying unit is in use and some farms are heated. As a consequence the average energy utilization can be estimated at about 150,000 MWh yr^{-1}.

Rice drying unit in Kotchany (Fig. 2)

Heating fluid: geothermal water of Dolni Podlog (Kotchany). Temperature 75–78°C, low mineral content, no scaling problems, no corrosion problems. Direct use in the heating pipes.

Manufacturer:	CER-Tchatchak, Yugoslavia.
Type:	VSP-10.
Capacity:	10 t h^{-1} rough or milled rice.
Heating power:	1.36 MW.
Installed electric power:	45 kW.
Moisture content of rice:	— inlet, 20%
	— outlet, 14%.

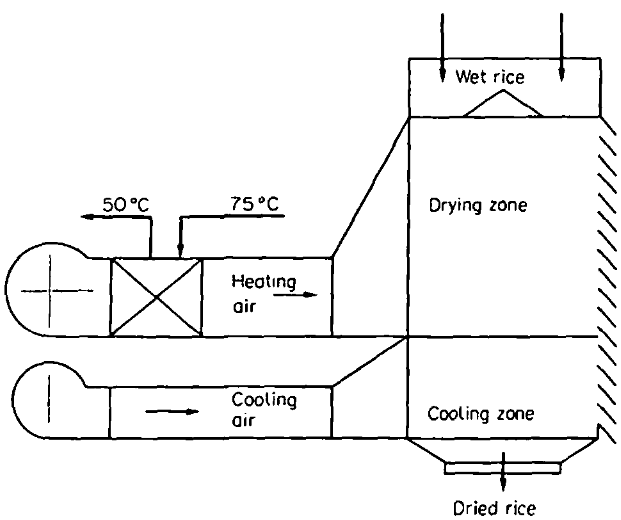

Fig. 2. Rice-drying unit in ZIK "Kotchansko pole", Kotchany.

Temperature of the heating air:	35°C.
Outdoor design conditions:	— temperature, 15°C, — relative humidity, 60%.
Drier:	Crossflow continuous system.

The rice moves downward at a constant velocity by gravity at all points of the cross-section. In order to prevent the rice from cracking, the temperature of the warm air is kept to a maximum of 40°C. The heating fluid is geothermal water between 50 and 75°C.

The drying unit is in use during the months of October, November and December during daytime, when the heat is not required in the greenhouse. The unit has been in use for four years and has proved satisfactory.

Pig farm heating

Heating fluid: geothermal water from a well in Mokrin with a temperature of 50°C. Direct use in the heating pipes.

Deaerated geothermal water is passed from a tank at a temperature of 50°C to a pump and then on to a three-way mixing valve. In the mixing valve the geothermal water at 50°C is mixed with return water at 25°C, depending on the inside air temperature. The water yields heat to passing air through the heat exchanger in the air chamber. A fan pushes the warm air into the distribution air channels and through vents into the pig-styes.

Temperature in the heated rooms is regulated electronically. The signals from the outside and inside temperature sensors pass to the regulator, which controls the servomotor of the three-way valve and the electromotor of the air chamber.

Total capacity of the installation is 372 kW; 186 kW is used in the piglet sector and 186 kW in the breeding sector.

Geothermal heating of 0.5 ha of greenhouses

Heating fluid: geothermal water at a flow-rate of 11.6 l s^{-1} and 60°C. Direct use in the heating pipes.

The heating installation is for a commercial greenhouse of 0.5 ha covered with filon. A total capacity of 1.23 MW is designed to cover a temperature difference between inside and outside air of 30°C. The system operates with two temperature regimes plus heating of the irrigation water by the return water after soil heating. The temperature regimes are as follows:

- 60–30°C: aluminium heating pipes plus "fan-jet" air heating installation; 900 kW.
- 35–25°C: polypropylene on-the-ground heating and soil heating installation; 330 kW.
- 25–20°C: heat exchanger for irrigation water; 70 kW.

Automatic regulation of the heating installations takes place through:

- Sensor for outside air temperature.
- Sensor for inside air temperature.
- Sensor for heating water temperature.
- Electronic regulator.
- Servomotor of the three-way mixing valve.

This system is a good example of how a good idea can be ruined by bad design. Mistakes were made in the allocation of the aluminium heating pipes, the vents of the "fan-jet" air heating installation were badly designed. Regulation of inside air temperature is difficult because of an inappropriate combination of the various elements of the installation.

In addition the geothermal water is aggressive and destroys the iron circulation pipes and the steel pipes of the heat distribution station.

Horticultural results are positive in the case of lettuce, but negative as regards paprika and tomatoes.

Geothermal heating of 12 + 6 ha of greenhouses (Fig. 3)

Heating fluid: geothermal water of variable flow-rate 285–0 l s^{-1}, variable pressure 65×10^4–0 Pa, both depending on the discharge period; non-aggressive water of pH = 6.8; temperature of 78°C.

Two greenhouse complexes are heated by the same borehole: "Kotchansko pole" of 12 ha and "Mosa Pijade" of 6 ha. The complexes consist of separate blocks of 1.5 ha with independent climates. The greenhouses are 3.2 m Venlo constructions with automatic regulation of temperature and humidity (Fig. 4).

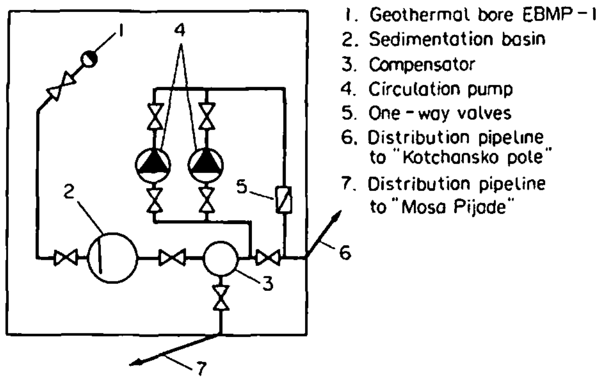

Fig. 3. Connection of the heating systems of the greenhouses to the geothermal bore.

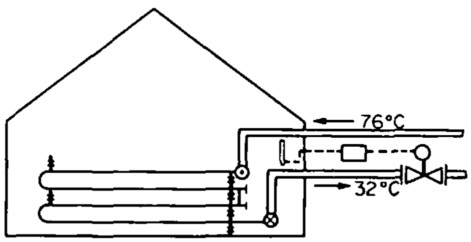

Fig. 4. Scheme of the temperature regulation in "Kotchansko pole".

"Kotchansko pole" greenhouse complex is connected to well EBMP-1 by pipeline No. 300 of 3600 m length, insulated by 70 mm of glasswool. The heating installation consists of 2 in. steel pipes in groups of four. Originally, the installation was designed for heat supply from the heavy-oil boiler plant only.

The boiler plant is now used to meet peak heat demand. Thus 85% of the total heat demand of an average climatic year is met by geothermal energy. The installed capacity is 42 MW.

On the whole this complex has given good results during the five years it has been in use. A lack of uniformity in temperature distribution, however, is a consequence of mistakes in the design of the greenhouse. The Tichelman distribution system is the wrong size and the location of the heating element is not convenient for high plants. The outlet temperature of the heating geothermal water is another problem. Because the geothermal water is not pressurized, the user tends to meet higher heat demands with an increase in water flow-rate (higher mean temperature in the installation); thus the outlet temperature is high and, because it is still not used in other applications, this energy is wasted.

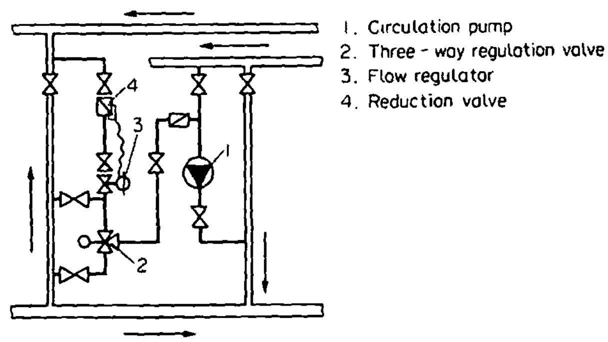

Fig. 5. Scheme of the temperature regulation in "Mosa Pijade".

"Mosa Pijade" greenhouse complex (6 ha) is connected to the same borehole EBMP-1 by a 150 m long pipeline (Fig. 5).

Compared with the heating installation in "Kotchansko pole", the heating surface is 43% larger, so that the entire heat demand for a temperature difference up to 25°C can be met by geothermal water alone. This complex was built when fuel costs were very high, justifying higher investment costs.

This installation provides a much better horizontal temperature distribution, but the same observations about high plants can be made. Complete automatic regulation of ventilation, inside air temperature and humidity creates reasonable cultivation conditions in the protected space. The results of four years of exploitation are good. This is one of the rare greenhouses that wastes no energy. With some improvement to the technology of cultivation, it should be possible to achieve much higher profits.

Geothermal heating of 22.5 ha of greenhouses in Gevgelija (Fig. 6)

Heating medium: geothermal water from borehole Smokvica near the town of Gevgelija; flow-rate about 120 l s^{-1} and temperature of 65°C. The water is rich in free O_2 and sulphur, and so it is very aggressive.

Orginally this complex was operated with four heavy oil boilers. When fuel costs increased dramatically, an attempt was made to exploit the fluid from a new borehole about 7 km away. The success of the Kotchany geothermal project encouraged a rapid development of this project, even though the borehole had still to be completed. A pipeline was built to carry the expected 350 l s^{-1} discharge and the water was temporarily used directly in the heating installations and boiler plants. Unfortunately, the funds ran out very fast, the borehole did not produce the expected flow of hot water and aggressive water destroyed the heating installation. Optimization studies are now under way.

The existing heating system, originally designed for a temperature regime of 90–110°C, is capable of meeting only 19% of the heat demand when geothermal fluids are utilized. Direct circulation of the water through the heating installation and boiler plants caused rust, scale deposits and disturbances to the circulation, due to the presence of gases. The system is out of order at the moment.

To increase the contribution of geothermal heat to meeting the total heat demand of 22.5 ha of the greenhouse complex, and to avoid scale deposits and the destruction of the steel elements of the installation, reconstruction of the entire heating system is recommended with the following modifications:

— Introduction of a closed-loop heating circuit with a heating regime of 30–60°C.

— Introduction of an additional system of steel heating pipes (existing system =2,884 m^2 1.5 ha^{-1} + 1 × 436 m^2 1.5 ha^{-1}.
— Introduction of an additional air-heating installation.
— Redesign of the boiler plant for a regime of 90–100°C.

This reconstruction and creation of several closed-loop heating circuits should permit optimal utilization of the available geothermal heat (Fig. 7).

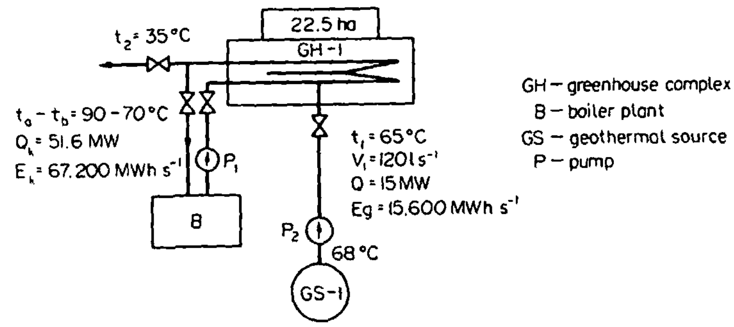

Fig. 6. Simplified scheme of the existing heating system of greenhouse complex "Gradina" in Gevgelija.

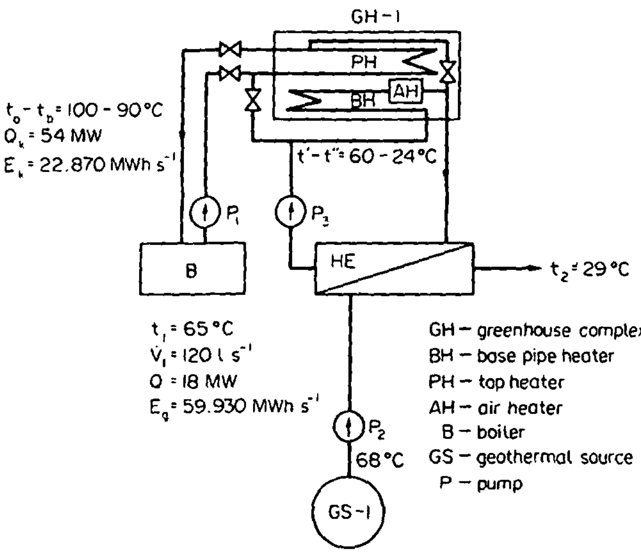

Fig. 7. Simplified scheme of the proposed reconstruction of the heating system of greenhouse complex "Gradina".

When all circuits are in use with geothermal water, a total capacity of 17.79 MW can be achieved, which means about 72% of the total heat demand of an average climatic year. The rest should be met by the heavy-oil boiler plants.

Detailed analysis of local climatic data and the 120 l s^{-1} continuous flow of geothermal water, together with the solar energy available during the day have suggested that, by installing daytime hot water accumulators, it should be possible to increase the real geothermal flow to 200 l s^{-1} during the night (Fig. 8).

The cost of this project is justified by the high fuel costs in Yugoslavia nowadays.

This solution could also solve the problem of primary degassing of geothermal water. The system could be further improved by installing a heat pump to exploit the geothermal water to 15°C (Fig. 9).

Further studies and drillings are under way to increase the flow rate to 180 l s^{-1}, which should make it easier to optimize the geothermal heating system in the "Gradina" greenhouse complex in Gevgelija.

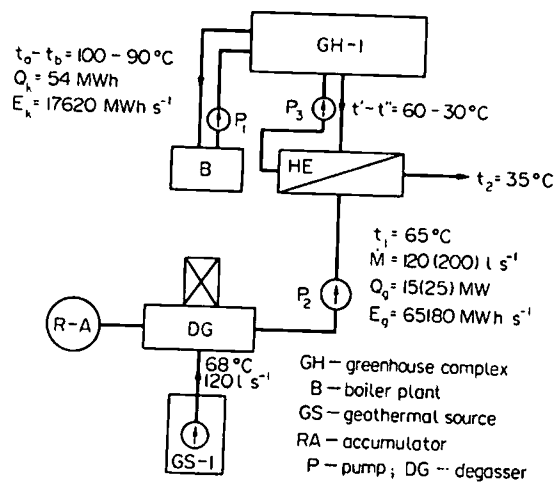

Fig. 8. Simplified scheme of the heating system with additional daily heat accumulators.

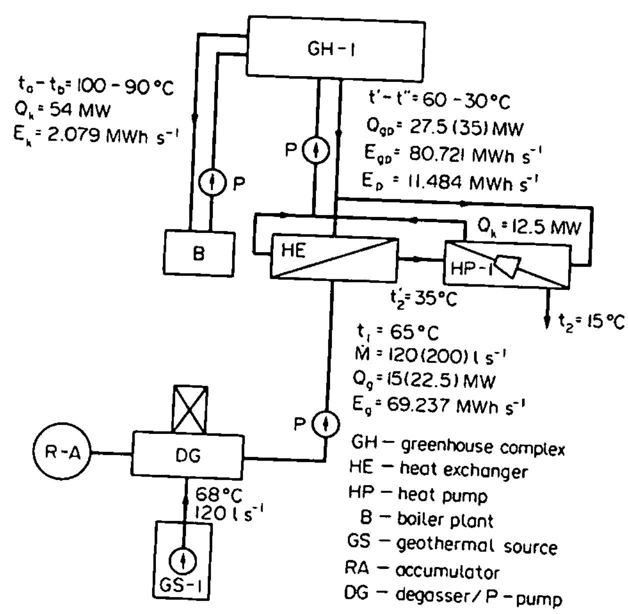

Fig. 9. Simplified scheme of the heating system with heat pump incorporated to optimize heating system of greenhouse complex "Gradina" in Gevgelija.

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GEOTHERMAL SITUATION IN GREECE

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Abstract—Exploration for geothermal resources in Greece started in 1970.

The Institute of Geology and Mineral Exploration (IGME) was responsible for implementing the exploration programme. Initially the programme covered areas considered to contain high enthalpy resources, and was financed by the State and Public Power Corporation (PPC). During the last eight years, following on the energy crisis, the programme has been extended to the medium and mainly low enthalpy fields.

At the same time as PPC launched an exploitation and power-station programme, the Banks for Industrial and Agriculture Development, as well as national and local authorities and private enterprise started a programme for exploitation of low enthalpy resources.

INTRODUCTION

Greece has, on the whole, geological conditions that are very favourable for geothermal resources, especially the active volcanic arc of the South Aegean. Due to active distensive tectonics that facilitated the rise of deeper hotter fluids to the surface, there are numerous areas with positive anomalies. The combination of adequate geological structures has created reservoirs of hot fluids at relatively small depths, that are commercially exploitable (Fig. 1).

GEOTHERMAL EXPLORATION

Known high enthalpy geothermal fields exist on Milos and Nisyros, with other potential fields on Santorini, Lesbos and Kos islands. Of minor priority are Sousaki and Methana areas on mainland Greece (Fig. 2).

Milos

On Milos island (Cyclades) there are five productive boreholes about 1000–1400 m deep, four drilled in Zephyria plain, into reservoirs in the crystalline basement, and one in Adamas area, in a reservoir of lava and Neogenic limestone and crystalline rocks. The temperature in the reservoir is 300–325°C (200–220°C at the well head) and total flow is 350 t h^{-1}. The fluids are a steam–water mixture, at a ratio 1:1, and can generate 20–25 MW_e.

There are also some interesting shallow hot acquifers on Milos (i.e. 40–100°C at 20–100 m) and some "hot grounds" too (100°C at 1 m depth) with more than 500 kcal h^{-1} m^{-2}.

Nisyros

At Nisyros (Dodecanese) there are two deep boreholes at 1500 m that produce high enthalpy geothermal fluids from limestones or volcanic formations. The produced fluids, a mixture of steam and water, could feed a 5 MW power-plant and be utilized for other purposes, such as space-heating, etc.

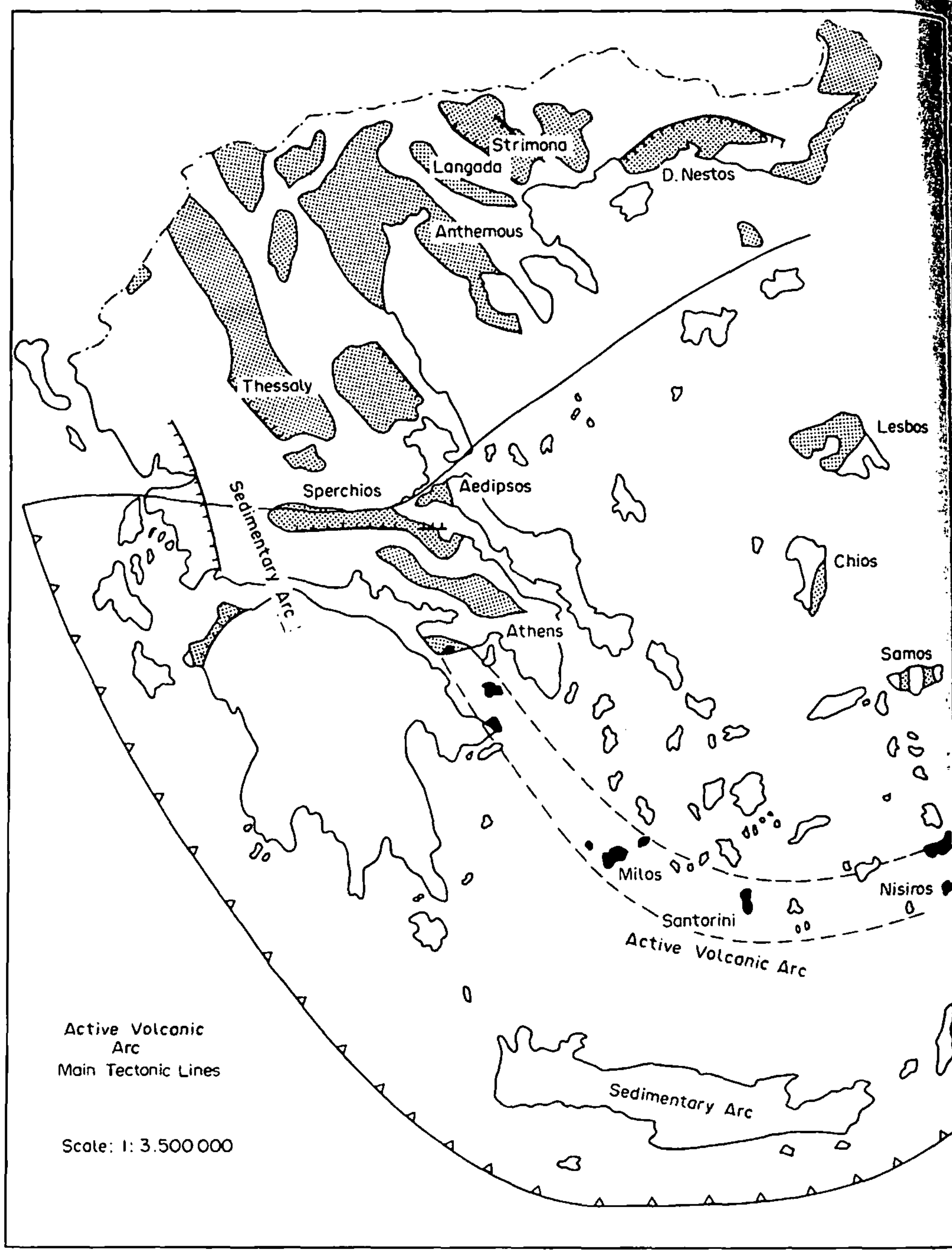
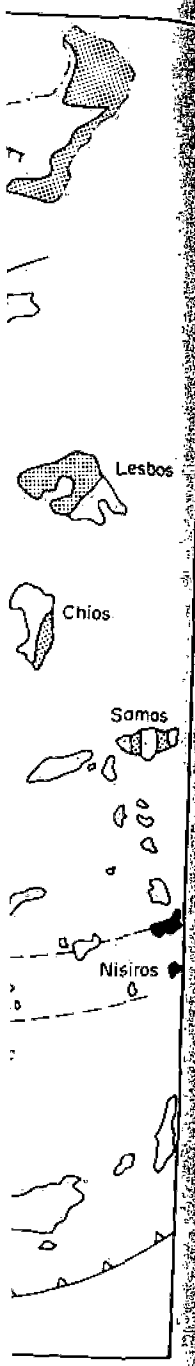


Fig. 1. Sketch map of Greece showing areas of geothermal interest.



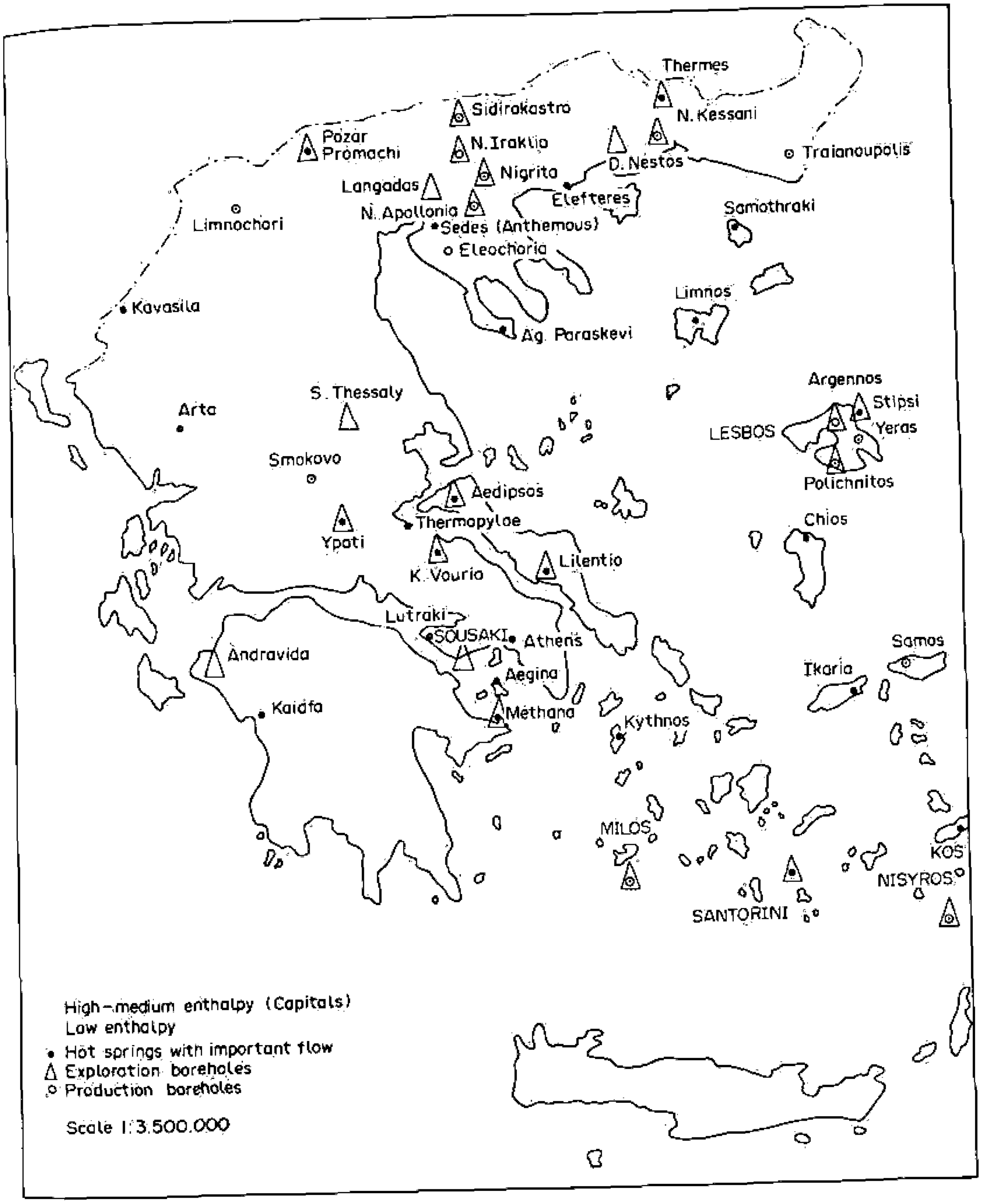


Fig. 2. Main areas of geothermal interest in Greece.

Lesbos, Santorini and Sousaki

Exploration conducted so far gives encouraging results for medium and high enthalpy exploitation.

No deep wells exist yet in these areas, but some decisions should be taken very soon.

On Lesbos island, near Polichnitos, there are five production wells 150 m deep that encountered reservoirs of hot water at 70–95°C and total flows of more than 100 l s^{-1}. The entire potential of this area is much higher. Hot water of up to 70°C is produced by wells in Stipsi–Kalloni area, while springs of up to 86°C exist on the northern coast (Argennos area). The island of Santorini with active volcanism has an interesting area in the central–southern part with temperatures up to 70°C recorded in shallow exploration boreholes.

Sperchios valley and northern Euboea grabens

This area of central Greece is rich in thermal waters that flow to the surface through natural springs and artificial wells (Thermopylae, Ypati, Platystomon, Kamena Vourla, Aedipsos, Yaltra etc.). The temperature of these waters reaches 78°C.

Other areas

Good possibilities of recovering low enthalpy geothermal resources exist in many other areas. Exploration of low enthalpy resources has so far been directed at some very favourable areas of northern and central mainland Greece, in agricultural and sometimes industrial and urban zones.

Interesting thermal acquifers and considerable quantities of hot waters have been recognized or will probably be recognized in the areas of Traianoupolis, Nea Kessani, Mangana, Thermes (Thrace), Delta Nestos, Nigrita, Iraklia, Sidirokastron, Langadas, Nea Apollonia, Eleochoria, Almopia (Macedonia), Sofades (Thessaly), Andravida (Peloponnese).

In these areas, the temperatures of the waters reach 80°C at relatively shallow depths (100–500 m).

Preliminary data for many other areas have already been collected. To facilitate the development of low enthalpy utilizations, systematic research has begun on hot water reservoirs at small depths (100–500 m) that are easily and economically accessible. Some exploration wells have also been drilled to 50–200 m.

EXISTING USES OF GEOTHERMAL ENERGY

High enthalpy

On Milos island a 2 MW_e pilot plant was installed and began operating at the end of 1986.

This pilot plant utilizes about 15 t h^{-1} of steam from borehole M-2 and the separated brine is pressured and reinjected into well M-1, 1 km away.

Various technical problems arose during preliminary tests mainly caused by scaling at wellhead and reinjection of brine with high SiO_2 contents. The PPC plans in the near future to install some larger power units (30 MW) by utilizing steam from existing or future wells.

The PPC also plans to install a pilot plant on Nisyros island for electricity generation, utilizing the steam (about 23 t h^{-1}) from an existing well.

Low enthalpy

Interest has been concentrated mainly in northern Greece and the islands of Lesbos and Milos. So far the main use of low enthalpy geothermal resources has been in heating greenhouses. The breeding of fish in a small experimental plant is also giving encouraging results.

The quality of the geothermal water differs considerably from place to place. Technical solutions must be adapted to each specific area, to prevent scaling (in the boreholes) or the precipitation of salts and corrosion in the heating equipment.

The diversity of technical solutions has delayed progress in greenhouse heating with geothermal energy. Thus, the area of geothermal greenhouses in operation in northern Greece is estimated to be 6.65 ha (2.3 ha are glasshouses), while 1.1 ha will be installed in the near future. On Lesbos and Milos islands 0.56 ha are installed (Table 1).

The chemical composition of the fluids changes from place to place. In northern Greece we have mainly carbonatic waters, with relatively low salinity. Corrosion is negligible and some scaling problems are avoided by utilizing adequate inhibitors. Experimental use of these chemicals in N. Kessani has been successful. The operational cost of using these chemicals is estimated at about U.S. \$1000 yr^{-1}.

In the case of Lesbos, Milos, etc. where corrosion is important, plastic materials are used in the main equipment. When the temperature of the geothermal fluid is above 70°C, the thermal load for the greenhouses is usually totally met, even in northern Greece. In other cases the thermal load is either partially met or geothermal energy is used in antifreeze systems. If the climatic conditions are mild (e.g. Milos island) water at 40°C can completely meet the thermal needs of the greenhouse units.

As can be seen from Table 1 the total energy savings are estimated at about 2500 OET per year.

The technical solutions applied so far, in order to exploit geothermal energy for agricultural uses in Greece, are described below.

Severe precipitation in the heating systems can be avoided by the use of heat-exchangers.

The biggest geothermal greenhouse unit operating on a commercial basis (at Nigrita) uses a geothermal water–water heat exchanger with inox plates. It has been reported that, due to precipitation on the heat exchanger plates, cleaning once or twice a month has been necessary.

The investment cost for the above-mentioned application is considered high for agricultural uses, mainly because the heat exchangers are imported.

Another type of heat exchanger is in operation in N. Kessani. A geothermal water–air heat exchanger has been constructed specifically for this project. In the heat exchanger the hot fluid is conveyed through a system of finned pipes (18 mm diam.). Air is forced between the pipes, is heated and then transported by fans through plastic channels in the greenhouses. An additional system of spiral PE pipelines is placed on the soil of the greenhouse. The geothermal water on leaving the heat exchanger is circulated through the above-mentioned system. Chemical treatment consists of injecting inhibitors into the well. Double protection against precipitation of salts has been considered necessary for the safe operation of the unit. The system can later be simplified if several safety features are proved unnecessary. Investment cost for this type of heat exchanger is also high for the moment. Industrial production of the equipment could lower the cost.

Where salt concentrations are low and severe precipitation avoided, the direct circulation of the geothermal fluids through the heating system could be achieved. Chemical treatment of the geothermal fluid is strongly recommended in this case.

The following heating systems are in operation in several greenhouse units.

(i) Galvanized finned pipes, placed on the ground of the greenhouse. This method has a rather low efficiency when the geothermal fluid temperature is below 70°C (N. Apollonia).

(ii) Specially constructed aerotherms to avoid oxidation and facilitate cleaning (Polichnitos, Lesbos).

(iii) Polyethylene or polypropylene spiral pipes placed on the ground. This system is used when the temperature of the geothermal water is lower than 50°C.

Table 1. Geothermal direct uses in Greece, as on 31 December 1986 (prepared by C. Sommaruga in 1986)

Geothermal site	Greenhouses: Model*	Greenhouses: Covered area (×1000 m^2)	Used mass flow ($m^3 h^{-1}$)	Temperatures: Geothermal water (°C)	Temperatures: Used ΔT (°C)	Geothermal energy: Load factor (%)	Geothermal energy: Installed capacity (MW)	Geothermal energy: Energy saving† (OET)	Status*	Notes
Macedonia–Thrace										
Nea Kessani	P	3.5	30	78	25	20	0.5	95	O	Starting } fish and dryers
	GT	2.5			30	25	0.45	100	O	Starting } planned
Nigrita	GT	21	180	47	25	30	5.25	1500	O	3 wells
	P	4	20	40–55	25	20	0.8	150	O	
Nea Apollonia	P	2	20	48	25	20	0.35	65	O	
	P	1					0.2	30	Pl	
	P	3	20	48	25	20	0.6	100	O	
	P	5	40	40–48	20	20	0.9	170	O	
Siderokastro	P	10				20	1.75	330	Pl	
Langadas	P	12		20					O	Anti-freeze
	P	12	>10			20	1.5	280	O	
Eleochoria	P	1.5		34	15	20	0.25	50	OE	Well mass flow: 300–600 $m^3 h^{-1}$
Aegean Islands										
Lesbos	P	0.33	3.3	72	20	18	0.07	12	OE	
	PT	4	60	87	20	18	0.9	100	C	Well mass flow >60 $m^3 h^{-1}$
	GT	1				24	0.2	45	C	
Milos	P	0.28	5	40	15	15	0.06	8	OE	
		6.5			20	20	1.2	225	Pl	
Total O		55.1					10.7	2530	O	
Total C		5					1.1	145	C	
Total Pl		17.5					3.2	585	Pl	
Greece		77.6				23.1	15.0	3260		8 sites; 14 operations

* G = glass cover; P = plastic; T = auxiliary fuel-fired thermal plant; O = operating; C = under construction; Pl = planned; E = experimental.
† 1 OET = 8,000,000 kcal (efficiency 0.8).

(iv) Polypropylene or polyethylene transparent pipes buried in the ground near the root system of the plants. This method is used with geothermal water of less than 35°C.

(v) Transparent PE tubes of large diameter, placed between the lines of plants. This system also exploits solar energy during daytime.

(vi) A plastic geothermal water–air heat exchanger has been tested in Eleochoria.

(vii) Another type of heat exchanger has been used to exploit the heat content of the ground on Milos island (ground temperature of approx. 100°C). The heat exchanger consists of a system of iron pipes (2 in. diam.) buried at a depth of 1 m. It has been calculated that 35 m^2 of hot ground are capable of meeting the thermal needs of a 350 m^2 greenhouse unit.

A special type of greenhouse construction is also used in northern Greece. It consists of a double arch-shaped galvanized steel-frame. The greenhouse is covered by two PE films placed on each of the two frames. The distance between the two films is 20–30 cm. The geothermal water is sprayed between the two films.

A small experimental unit for intensive breeding of eels (Langadas) uses 10 m^3 of water at a temperature of 37–38°C from a 50 m well. The water has a low salt concentration. The unit breeds about 10,000 eels per year.

FUTURE DEVELOPMENTS

The following low enthalpy geothermal wells are scheduled for drilling, mainly in northern Greece, in 1987.

(i) IGME intends drilling seven exploratory and production wells to depths of 100–220 m in the geothermal fields of Langadas, Nymphopetra, Nea Apollonia and Nea Kessani.

(ii) Local authorities plan to drill two boreholes to depths of 150 m in the Sousaki area. Greenhouses will use the geothermal fluids for heating.

(iii) The Public Petroleum Enterprise (DEP), in cooperation with IGME, plans to drill to a depth of 800–1000 m at D. Nestos.

(iv) A joint project IGME–ETVA to drill a series of 500–600 m holes around the area of N. Kessani–Xanthi should begin at the end of 1987.

(v) In the Langada–Volvi area, a series of wells will be drilled for agricultural uses (greenhouse heating).

(vi) On Milos island five wells will be drilled by IGME for irrigation, greenhouse heating and aquaculture (ETVA project).

The above-mentioned projects (except for the first) receive financial support from the EEC.

Several wells will also be drilled in 1987 by private individuals for greenhouse applications. Exploitation wells are expected to be drilled in the near future by the PPC on Milos, Nisyros and Lesbos islands for high enthalpy fluid recovery. There are also some proposals to install binary cycle units on islands (e.g. Lesbos) for electricity generation.

CONCLUSIONS

The new Geothermal Law (1475/84), promulgated in Greece three years ago, stipulates that geothermal energy belongs to the State, while the rights of exploration and exploitation can be transferred, by priority to local authorities and cooperatives.

Application of this Law has not sufficed to promote either the development of geological research, or the implementation of many applications, mainly because of the lack of incentives, appropriate enterprises and the means of covering the mining risks.

The organizations dealing with the exploitation of geothermal energy resources in Greece are:

(1) The Institute of Geological and Mineral Exploration (IGME), mainly in research and shallow productive drillings.
(2) The Public Power Corporation (PPC), for exploitation of high enthalpy geothermal resources.
(3) Industrial Development Bank (ETVA) plays an important role, conducting feasibility studies on the exploitation of geothermal resources.
(4) Local authorities, cooperatives and private companies are actively involved in the development of commercial applications in agriculture.

Technical and financial support for these enterprises is given by ETVA, the Agricultural Bank and the Ministry of Finance through the law promoting development investments.

Technical studies are carried out by different research institutes and universities, especially the Agricultural University of Athens and Thessalonika and the Research Institute of northern Greece. Future applications will be promoted by the EEC which will provide partial financial assistance.