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KARSTIC HOT WATER AQUIFERS IN TURKEY

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ABSTRACT

The purpose of this paper is to determine the common properties of karstic hot water aquifers based on hydrogeology and drilling results of selected geothermal fields of Turkey. During the last 20 years, many geothermal fields were discovered in Turkey. Different types of hot water aquifers (geothermal reservoirs) were identified in these fields. The hydrogeological properties of the hot water aquifers such as lithology, thickness and horizontal extend have an important role in geothermal energy production. Most of the hot water aquifers in Turkey are karstic limestone (Mesozoic, Cenozoic) and marble (Paleozoic). Karstic hot water aquifers are in the Sakarya-Kuzuluk, Yozgat-Boğazlıyan, Aydın-Salavatlı, Konya-Ilgın, İzmir-Çeşme, Ankara-Melikşah, Denizli-Pamukkale and Afyon geothermal fields. These fields are characterized by high productivity, medium to low enthalpy fields, and geothermal fluid with a high CO_2 content that creates a scaling problem.

INTRODUCTION

As a result of exploration studies, many hot water aquifers (geothermal reservoirs) have been discovered by the General Directorate of Mineral Research and Exploration of Turkey (MTA). Exploration studies include prospecting, hydrogeology, geochemistry, geophysical surveys (gravity, resistivity, seismic), drilling, testing and prefeasibility studies. Many technical experiments were carried out on geothermal energy based on the results of these activities.

After the completion of the preliminary studies, drilling had been done in approximately 40 geothermal fields. The aquifers of 75% of these fields are composed of carbonate rocks, mainly limestone. The important calcareous hot water reservoirs (Fig. 1) and discovery dates are as follows: Denizli-Kızıldere (1968), Afyon-Ömer, Gecek (1970), İzmir-Çeşme (1974), Ankara-Melikşah (1975), Sivas-Sıcakçermik (1976), Konya-Ilgın (1977), Kırşehir-Terme (1987), Ankara-Haymana (1987), Sakarya-Kuzuluk (1987), Çankırı-Çavundur (1988), Aydın-Salavatlı (1988), Kütahya-Yoncalı (1989) and Yozgat-Boğazlıyan (1989).

GENERAL PROPERTIES OF THE KARSTIC HOT WATER AQUIFERS

Soluble rocks such as carbonates (limestone, dolomite, dolomitic limestone) sulphates (gypsum, anhydrite), saline rocks (NaCl and KCl) can be karstified. But these features are more common in limestone. Widespread carbonate outcrops are in the Alpine-Himalayan orogenic belt, and one third of Turkey is covered by carbonate rocks (Eroskay & Günay, 1980). Other countries too (China, Algeria, Czechoslovakia, Switzerland, USSR, Belgium, Yugoslavia, Bulgaria, Greece, Italy, Germany, France, Hungary and Israel) have karstic hot water aquifers (Boldizsar, 1976; Garagunis, 1976; Shaterev, 1976; Antonenko & Mavritsky, 1978; Haenel, 1985; Quilong et al., 1985; Arad, 1988; Luo et al., 1988; Zhang, 1988; Fekraoui, 1990; Franko et al., 1990; Konokov & Drokov, 1990; Rybach & Hauber, 1990; Vandelberghe, 1990).

General properties of karstic hot water aquifers are similar to those of cold water

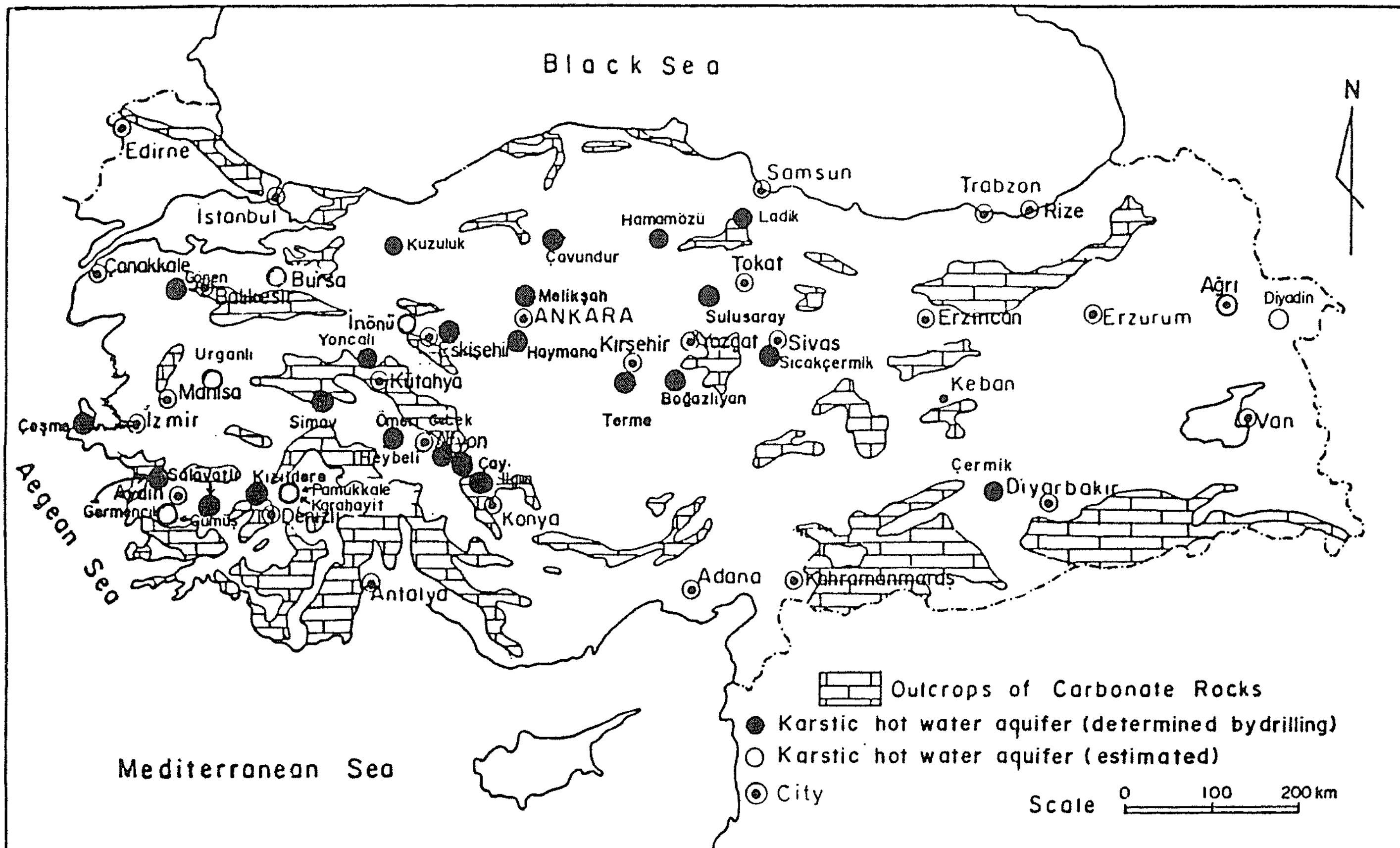


Fig. 1 - The carbonate outcrops and karstic hot water aquifer of Turkey.

aquifers, but hot water aquifers have a higher dissolution capacity due to the high temperature, pressure and chemical composition. There is an important relationship between temperature and hydrothermal cave development (Ford, 1988). As an interpretive result of the hydrogeological studies it can be that main common properties of the karstic hot water aquifer in geothermal fields are as follows: high productivity (10-300 l/s for each well) characterizes the medium (0-150°C) and low enthalpy fields (30-70

Fig. 2 - Active fault zone and travertine deposits in the Sivas-Sıcak Çermik field due to the karstic limestone aquifer.

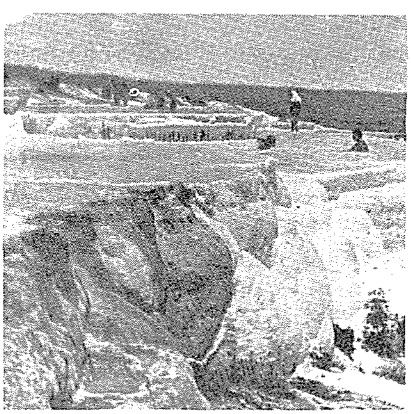


Fig. 3 - Travertine terraces and deposits in the Pamukkale Geothermal field.

Table 1 - Chemical analysis of hot springs and discharge waters from wells of some karstic aquifers.

								Concentrations in Water (ppm)																			Comparison of ions (mval/lt)	
	FIELDS	T (°C)	Q(lt/sn)	pH	CON.	TDS	HARD.	Na^+	K^+	Ca^{++}	Mg^{++}	NH_4^+	Fe	SiO_2	B	As	S^-	NO_3^-	NO_2^-	CO_3^{2-}	HCO_3	SO_4^{2-}	I^-	CO_2^{2-}	Cl^-	F^-	CATIONS	ANIONS
1	ANKARA	Hs 43	4	7.20		566	448	32	7	120	35.90	0.00	0.00	6.00	0.54	0.00		1.00	0.00	0.00	599	8.2	0.00	264	6.17	1.30	Ca>Mg>Na>K	$HCO_3>>>SO_4=Cl$
	Haymana	W 45	52	6.70	710	645	359	36	7	144	40.00	0.29	4.00	27.00	0.44	0.01	0.50	0.50	0.01		634	33.0	0.50	150	5.70	0.56	Ca>Mg>Na>K	$HCO_3>>>SO_4>Cl$
2	ANKARA	Hs 31	10	7.60		283	260	34	3	60	24.30		0.04	21.60	0.27	0.00	0.00	0.00	0.00	0.00	317	27.6	0.00	10	6.48	1.20	Ca>Na=Mg	$HCO_3>SO_4>Cl$
	Melikşah	W 39	200	7.50		436	298	49	6	67	17.30	0.00	0.00	25.00	0.54	0.01	0.19			10.08	344	49.0	0.01		10.49	2.03	Ca>Na>Mg>K	$HCO_3>SO_4>Cl$
3	AYDIN	Hs 35	6	7.00	3400	12240	772	630	46	143	29.00	1.30	0.00	44.00	6.60	0.00		0.05	0.00	0.00	942	51.0	0.00		832.00	0.90	Na>Ca>Mg>K	$Cl>HCO_3>SO_4$
	Gümüş	NW																										
4	DENİZLİ	Hs 35	500 *	6.70	1900	1510	1494	38	5	450	90.00	0.00	0.00	41.00	0.85	0.00	0.10	1.00	0.09	0.00	1060	670.0			15.00	1.90	Ca>Mg>Na	$HCO_3>SO_4>Cl$
	Pamukkale	NW																										
5	İZMİR	Hs 55	10	6.58		22240	4862	5900	396	787	703.33	0.00	0.00	16.10	4.72	0.00		0.21	0.00	0.00	183	1547.0	0.00		11971.00	1.82	Na>Mg>Ca>K	$Cl>>SO_4>>HCO_3$
	Çeşme	W 56	42	7.70		38180	3872	10075	388	1551	603.20	0.00	0.00	47.00	5.40	0.00	0.00	0.30	0.00	0.00	152	2983.0	0.47	405	20430.00	1.64	Na>Mg>Ca>K	$Cl>>SO_4>>HCO_3$
6	KIRŞEHİR	Hs 39	12	6.50	1800	1810	835	125	10	256	47.40		0.05	22.40							869	106.6			231.30		Ca>Na>>Mg>>K	$HCO_3>Cl>SO_4$
	Terme	W 52	45	7.10	2000	1368	768	200	11	237	43.00	0.10	0.10	41.00	0.10	0.01	0.10	0.20	0.20	0.00	909	114.0	103.00	115	282.00	2.20	Ca>Na>Mg>>K	$HCO_3>Cl>SO_4$
7	KONYA	Hs 41	50	6.50		702	468	49	10	130	35.00	0.00		42.00	0.72	0.00	0.00	0.00	0.00	0.00	567	90.5	0.00	287	20.00	0.40	Ca>Mg>Na>>K	$HCO_3>SO_4>Cl$
	Ilgın	W 44	110	6.80		726	476	58	11	130	37.00	0.00	0.00	38.00	0.87	0.00	0.00	0.00	0.02	0.00	598	89.7	0.00	151	22.00	0.40	Ca>Mg>Na>>K	$HCO_3>SO_4>Cl$
8	MANİSA	Hs 63	10	7.20	1800	3360	179	480	44	47	15.00	2.80	0.00	37.00	11.00	0.00	0.60	0.00	0.00	0.00	1460			79	3.40	0.00	Na>Ca>Mg=K	$HCO_3>Cl>SO_4$
	Urganlı	NW																										
9	SİVAS	Hs 45	14	6.80	1900		1088	190	42	248	114.00	0.46	0.40	22.00	2.40	0.02		0.08	0.00		1543	54.0	0.50		199.00	2.73	Ca>Mg>Na>K	$HCO_3>Cl>SO_4$
	Sıcakçermik	W 47	200 *	6.80	1850	1440	953	195	41	260	74.00	0.50	0.40	34.10	2.50	0.07		0.10		0.00	1320	33.0	2.40	334	200.00		Ca>Na>Mg>K	$HCO_3>Cl>>SO_4$
10	YOZGAT	Hs 31	25	7.80	3550	2548	961	600	14	286	60.00	0.00		46.00	0.30		0.00			0.00	787	463.0		78	883.00	2.39	Na>Ca>Mg>K	$Cl>HCO_3>SO_4$
	Boğazlıyan	W 46	225	6.40	2500	2172	981	410	11	289	63.00	0.50	0.10	30.00	0.30	0.01		1.50	0.01	0.10	848	294.0	0.50	540	576.00	2.60	Na>Ca>Mg>>>K	$Cl>HCO_3>SO_4$

W : Discharged water from well NW:There is no well in this field X : Total flow rate Hs : Hot spring water

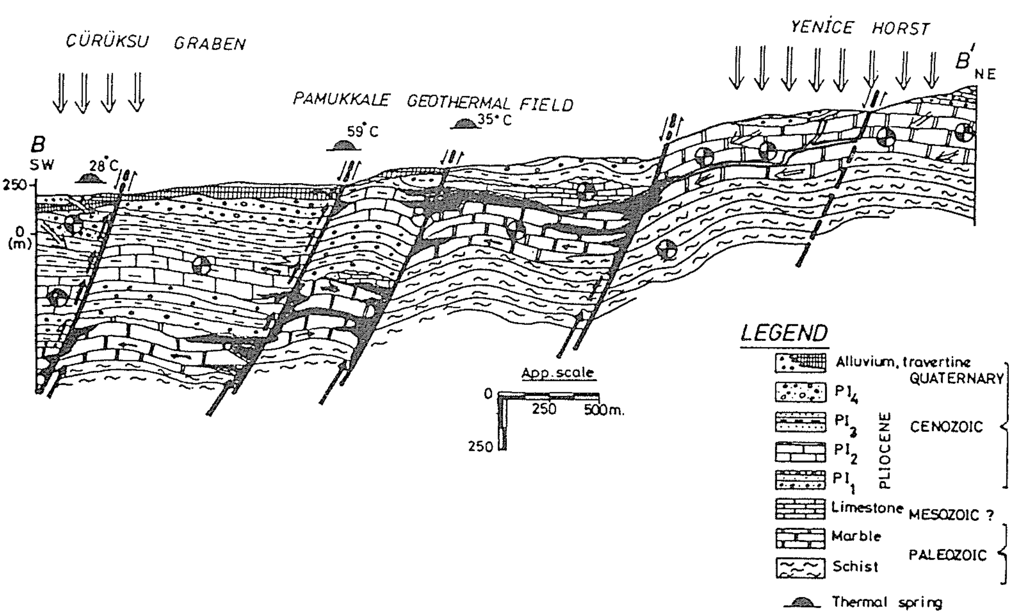
°C), geothermal fluids have a high CO_2 content that creates a scaling problem and travertine deposits around hot spring sites (Figs 2 and 3).

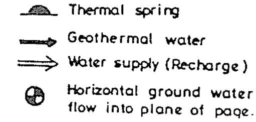
The analyses of karstic hot springs and water from wells of geothermal fields (Table 1) show high Ca^{++} and HCO_3^{2-} values are the main characteristics as follows:

$$Ca > Na \text{ or } Mg > K \text{ and } HCO_3 > SO_4 \text{ or } Cl$$

Because of sea-water intrusion at the İzmir-Çeşme field and effect of evaporitic rocks at the Yozgat-Boğazlıyan field, these fields differ from the others.

Lithology and tectonic movements are the main controls in Turkey on karstification in the crystalline limestones and marbles from Paleozoic to Cenozoic age. There is a large stratigraphic gap between aquifers and impervious cap rock units. Heating systems have developed as a result of neotectonic activity and geothermal fields have occurred along the active tectonic zones especially on graben structures. One example is the well-known tourist area of the Denizli-Pamukkale Geothermal field. According to the hydrogeological model, the main aquifers (geothermal reservoirs) in this area are limestone and marbles with high permeability characterized by a network of joints, fractures, faults and karstic features. The alternation of Pliocene claystone, marl and sandstone and Paleozoic schists acts as an impermeable cap rock in the region. The recharge rate in the area is quite large related to the permeability of the rocks forming horsts and grabens. The recharge is mainly from surface, subsurface and underground waters, which originated at rainfall, infiltrating the basin (Fig. 4).





ANALYSES OF PAMUKKALE AND MİSTUR A. SPRINGS (in ppm)

Hot spring	pH	K	Na	NH_4	Ca	Mg	Fe (total)	As (total)	B (total)	SiO_2	HCO_3	SO_4	Cl	F	S	t C°
P.Kale TermalK	6.15	18	38	0.0	450	90	0.0	0.0	0.85	41	1060	630	15	1.9	0.09	35
P.Kale MisturA	7.7	22	130	0.5	530	110	1.4	0.0	2.7	43	1415	830	34	2.5	0.06	59
Göz Pn.	6.4	8.4	54	0.0	390	104	2.0	0.0	2.3	63	915	728	20	2.0	0.12	28

Fig. 4 - Geological cross section of the Pamukkale Geothermal field.

IMPORTANT KARSTIC HOT WATER AQUIFERS AND THEIR CLASSIFICATION ACCORDING TO AGE

The simple classification based on the age of the karstic aquifers is given in Table 2.

Table 2. The age of selected karstic aquifer formations in Turkey.

CENOZOIC:	
Quaternary	Karahayıt*, Bursa
Neogene	Denizli-Kızıldere* - one aquifer, Konya-Ilgın* - partly
Tertiary	Ankara-Melikşah*
Eocene	Yozgat-Boğazlıyan*
MESOZOIC	İzmir-Çeşme*, Ankara-Haymana*, Sakarya-Kuzuluk*, Diyarbakır-Çermik*, Çankırı-Çavundur, Amasya-Hamamözü, Eskişehir-İnönü
PALEOZOIC	Sivas-Sıcak Çermik*, Denizli-Kızıldere*, Denizli-Pamukkale, Afyon-Ömer*, Gecek*, Heybeli*, Manisa-Urganlı, Kütahya-Yoncalı*, Kırşehir-Terme*, Kütahya-Simav*, Aydın-Salavatlı*, Bursa

*determined by drilling.

Cenozoic limestone formations

The main Cenozoic aquifers are Quaternary travertines and Tertiary limestone formations

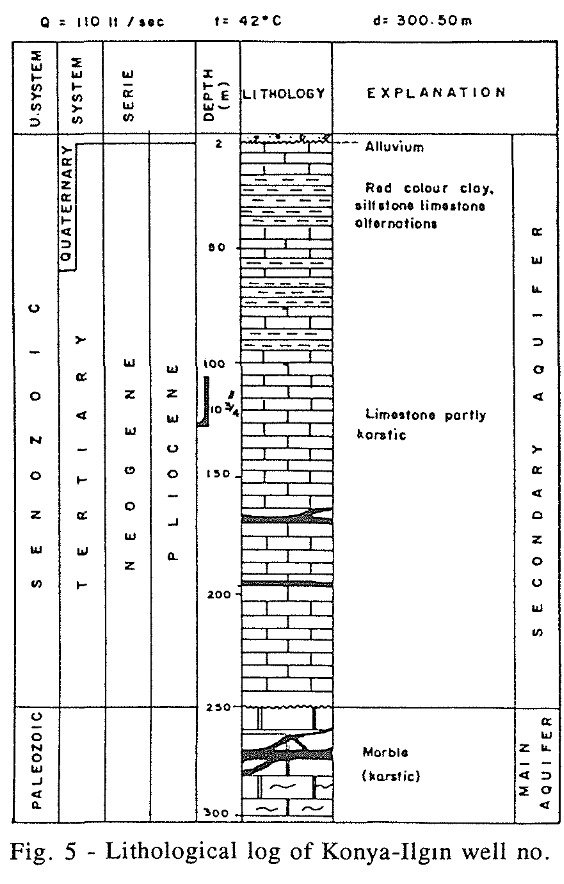


Fig. 5 - Lithological log of Konya-Ilgın well no. 1 (after Canik, 1981).

(Neogene, Eocene). The Quaternary travertine beds are karstic but generally they are secondary aquifers. The Neogene limestone formations which have widespread outcrops in Turkey are generally secondary hot water aquifers. Karstic limestones (Pliocene) form the hot water aquifer in the Konya Ilgın geothermal field (Fig. 5).

Karstic features were determined by hydrogeological survey in the region (Canik, 1981). The flow rate of the well is 110 l/s at 42°C from compressor testing. In the Denizli-Kızıldere geothermal field, Sazak limestone (Pliocene) forms a reservoir which is partly karstic. From the first well, steam and hot water mixture were obtained from a depth of 540 m at temperatures of 198°C. Also, the marble formation (Paleozoic) in this region has karstic properties. Karstic structures are determined through the bottom level of the Miocene limestone in the MH-1/A well drilled to a depth of 594 m in the Ankara-Melikşah geothermal field (Fig. 6). According to the first results from the well a flow rate of 300 l/s was obtained at 39°C output temperature.

The karstic Eocene limestone formations which are widespread in central and eastern Anatolia, are reservoirs of hot water as well as of cold water in the geothermal areas (Fig. 7). In the Yozgat-Boğazlıyan geothermal field, two wells were drilled (BB-1 and BB-2) with flow rates of 125 and 100 l/s respectively at temperatures of 32-46°C (Özmutaf & Yüce, 1989).

Mesozoic crystalline limestone formations

Some of the low temperature geothermal aquifers consist of Mesozoic crystallized limestone formations. One hot water aquifer is of Lower Triassic limestone at a depth of 282 m (Ç-1) in the İzmir-Çeşme geothermal field (Şahinci, 1988). In this well 42 l/s of hot water was produced by pumping, with a temperature of 56°C (Fig. 8).

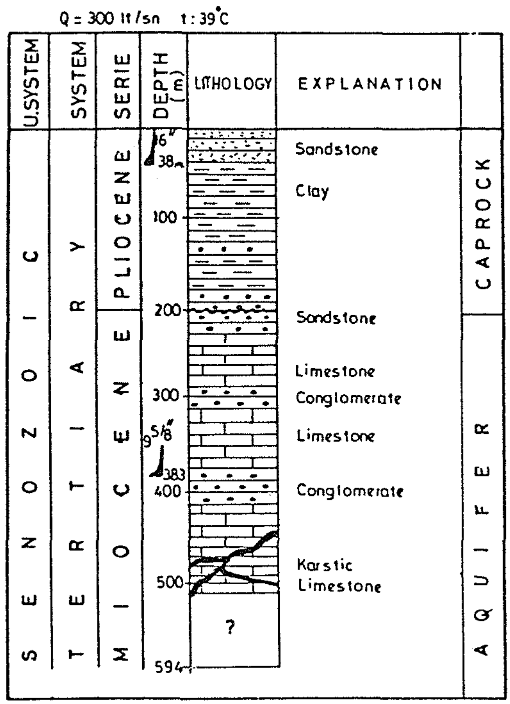


Fig. 6 - Lithological log of Ankara-Melikşah well no. MH-1A.

(a)

(b)

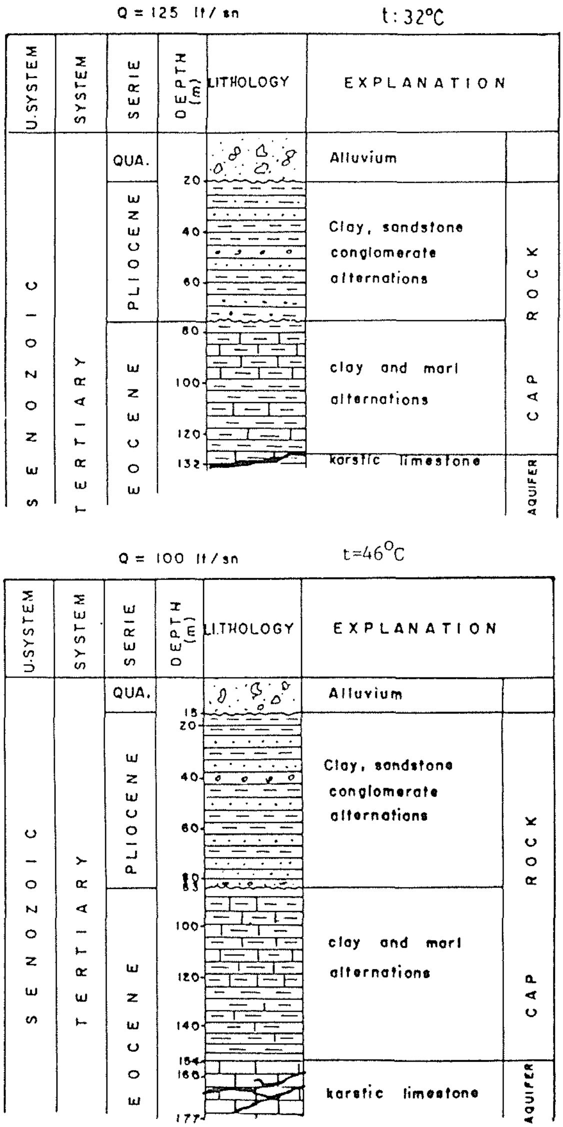


Fig. 7 - (a) Lithological log of Yozgat-Boğazliyan well no. BB.1; (b) lithological log of Yozgat-Boğazliyan well no. BB.2 (after Özmutaf & Yüce, 1989).

Another important hot water aquifer (Upper Cretaceous limestone) was discovered in the Ankara-Haymana field (Fig. 9). The H-4 well was drilled to a depth of 221 m and produced 52 l/s at 45°C temperature.

Paleozoic marble formations

In many of the geothermal fields, karst is developed in marble of Paleozoic age. In both the Konya-Ilgin and Denizli-Kizildere geothermal fields, Neogene limestone and

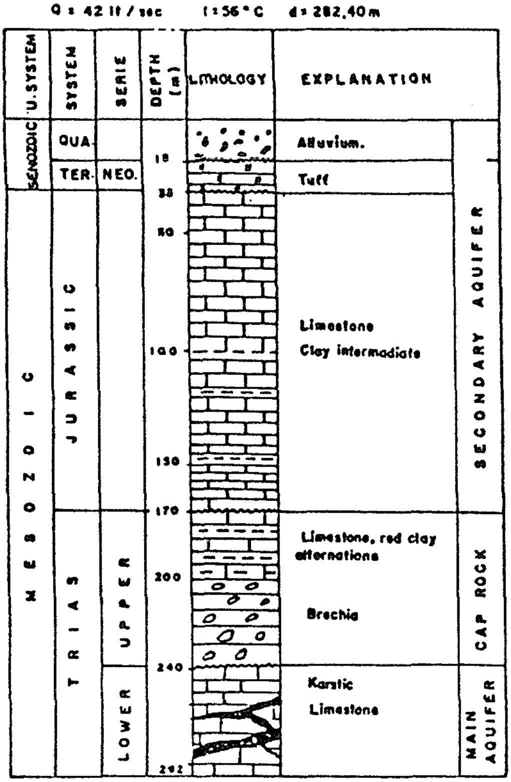


Fig. 8 - Lithological log of İzmir-Çeşme well no. 1.

Paleozoic marble form geothermal reservoirs (Canik, 1981; Şimşek, 1985). In Aydın-Salavatlı geothermal field, a marble formation has flow rates of 300 t/h at each well (AS-1 and AS-2). The wells are 1500 and 962 m deep and the temperatures are 162°C and 171°C respectively. In the Kırşehir-Terme field, a marble formation is well developed as a karstic aquifer and hot water is produced from a depth of 333 m with a flow rate of 45 t/h (Özgür et al., 1987). In Sivas-Sıcakçermik field, a total flow rate of 400 t/h hot water was produced from three shallow wells from depths of 200-350 m. Other important fields are: Aydın-Germencik (232°C), Kütahya-Simav (162°C), Afyon-Ömer-Gecek (98°C) and Heybeli (56°C).

EXPLOITATION PROBLEMS IN KARSTIC HOT WATER AQUIFERS

Among the factors affecting the production of hot water and steam, the most important problem is scaling. The most common deposition, $CaCO_3$, causes a reduction in the diameter of production and transmission pipe lines and drawdown in the reservoir. To solve this problem, downhole heat exchangers and chemical inhibitors are applied to the wells. At present, downhole heat exchangers are used in the Afyon-Ömer, Sakarya-Kuzuluk and Kütahya-Simav geothermal fields. In the Denizli-Kızıldere, Afyon-Ömer-Gecek, Gazlıgöl and Manisa-Salihli fields, chemical inhibitors have been successfully used. Thus, this important problem which is seen in karstic type geothermal reservoirs during commercial usage can be eliminated.

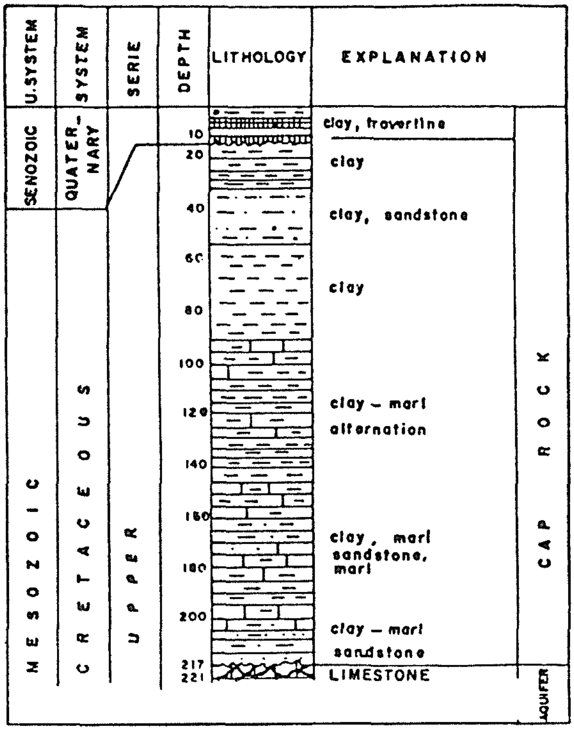


Fig. 9 - Lithological log of Ankara-Haymana well no. 4.

Another major problem that might be faced during drilling is the mud leakage into the formation, where mud cement-control is impossible. So if there are two karstic zones, only the shallower, low temperature aquifer can be used, instead of the high temperature, high flow rate deeper aquifer.

RESULTS AND SUGGESTIONS

The important characteristics of karstic geothermal reservoirs in Turkey are as follows:

- they have a high production rate,
- they generally form low and medium enthalpy geothermal fields,
- in a high enthalpy field, they produce a high rate of CO_2 for commercial usage such as the Denizli-Kızıldere field,
- scaling in the well-bore and transmission pipe lines may be a problem, but this can be resolved by using downhole heat exchangers and chemical inhibitors.

Due to their high production rates, the karstic reservoirs could be used for heating, balneological and tourist purposes.

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REFERENCES

Antonenko, G. K. & Mavritsky, B. F., 1978, The geochemical features of thermal and mineral groundwaters of the Rionion artesian basin and perspectives of their utilization. Proceeding of Hydrogeochemistry of Mineralized Waters Conference (Cieplice Spa, Poland), 263-270, Warsaw, Poland.

Arad, A., 1988, B, F and Sr as tracers in carbonate aquifers and in karstic geothermal systems in Israel. In: *Karst Hydrogeology and Karst Environment Protection* (Proc. 21st Congress of IAHS, Guilin, China, October 1988), vol. 2, 922-933. IAHS Publ. no. 176.

Boldizsar, R., 1976, Production of energy from the Pannonian geothermal anomaly. In: *Proceedings of the Int. Congress on Thermal Waters, Geothermal Energy and Volcanism of the Mediterranean*, vol. 1, 115-129. Athens.

Canik, B., 1981, Konya-Ilgın Sıcaksu Kaynaklarının Hidrojeoloji İncelemesi. S.U. Fen Fakültesi Dergisi Sayı 1. seri A.s.1-18, Konya.

Eroskay, S. O. & Günay, G., 1980, Tecto-genetic classification and hydrogeological properties of the karst regions of Turkey. In: *Proceedings of the Int. Seminar on Karst Hydrogeology* (Oymapınar), 1-41. DSI-UNDP Project Publ. DSI.

Fekraoui, A., 1990, Outline of geothermal features in Algeria. *Geothermal Resources Council Transactions*, vol. 14, Part 1, 3-8, Hawaii, USA.

Ford, D., 1988, Characteristics of dissolutional cave system in carbonate rocks, In: *Paleokarst*, 25-36. Springer-Verlag, New York.

Franko, O., Bodis, D., Fendek, M. & Remsik, A., 1990, Outline of geothermal activity in Czechoslovakia. *Geothermal Resources Council Transactions*, vol. 14, Part 1, 31-40, Hawaii, USA.

Garagunis, C. N., 1976, Geothermal areas in the Magic Gulf region in Greece. In: *Proceedings of the Int. Congress on Thermal Waters, Geothermal Energy and Volcanism of the Mediterranean Area*, vol. 1, 241-274, Athens.

Haenel, R., 1985, Present status on utilizing geothermal energy in the Federal Republic of Germany. In: *Int. Symp. on Geothermal Energy* (Hawaii, USA), 69-77.

Konokov, V. I. & Drokov, I. M., 1990, Utilization of geothermal energy USSR. *Geothermal Resources Council Transactions*, vol. 14, Part 1, Hawaii, USA.

Luo Xiangkang, Li Hongjue, Jiang Bing, Lu Duanfu, Wu Wenxun, Lin Shigui & Wang Yujie, 1988, The characteristics and resource assessment of the thermal groundwater from the Lower Triassic series karst in Chongqing Xiaoquan Hotel area. In: *Karst Hydrogeology and Karst Environment Protection* (Proc. 21st Congress of IAH, Guilin, China, October 1988), vol. 2, 983-991. IAHS Publ. no. 176.

Özgür, C., Uzel, Ö. F. & Tamgaç, Ö. F., 1987, Kırşehir-Terme Kaplıcası Terme 2-3 Sıcaksu Sondajları Kuyu Bitirme Raporu. *MTA Report no. 8222, Ankara.*

Özmutaf, M. & Yüce, G., 1989, Yozgat-Boğazlıyan-Bahariye (Cavlak) Kaplıcası Sıcaksu Sondajları (BB-1, BB-2) Kuyu Bitirme ve Korunma Alanları Etüdü Raporu. *MTA Report no. 8216, Ankara.*

Quilong, Y., Kuide, X. & Zhang Zhenguo, 1985, Preliminary assessment of the geothermal resources of China. In: *Int. Symp. on Geothermal Energy* (Hawaii, USA), 43-52.

Rybach, L. & Hauber, L., 1990, Swiss geothermal energy update 1985-1990. *Geothermal Resources Council Transactions*, vol. 14, Part 1, 239-246, Hawaii, USA.

Shaterev, K. D., 1976, Les acrotothermis de la peninsule Balkanique. In: *Proceedings of the Int. Congress on Thermal Waters, Geothermal Energy and Volcanism of the Mediterranean*, vol. 2, 519-533, Athens.

Şahinci, A., 1988, Çeşme yöresindeki kaplıcaların hidrojeolojik - jeokimyasal özellikleri ve soğuk sularla ilişkileri. Ulusal I. Hidrojeoloji Simpozyomu. Bildiriler kitabı, s. 103-109, Ankara.

Şimşek, Ş., 1985, Present status and future development of the Denizli-Kızıldere geothermal field of Turkey. In: *International Symposium on Geothermal Energy* (Hawaii, USA), 203-210.

Vandelberghe, N., 1990, Geothermal energy in Belgium: an overview. *Geothermal Resources Council Transactions*, vol. 14, Part 1, 9-14, Hawaii, USA.

Zhang Zhenguo, 1988, An assessment of karst geothermal resources of the North China basin. In: *Karst Hydrogeology and Karst Environment Protection* (Proc. 21st Congress of IAH, Guilin, China, October 1988), vol. 2, 968-974. IAHS Publ. no. 176.