Hydrogeological Processes in Karst Terranes (Proceedings of the Antalya Symposium and Field Seminar, October 1990).
IAHS Publ. no. 207, 1993.

ENVIRONMENTAL HYDROGEOLOGY OF A KARST SYSTEM WITH THERMAL AND NORMAL GROUNDWATERS: EXAMPLES FROM THE BURSA REGION (TURKEY)

THOMAS IMBACH
Dr. Werner Balderer Engineering Geology Section, ETH Hönggerberg, 8093 Zürich, Switzerland

ABSTRACT

Several earthquakes in and around Bursa, NW Anatolia, are known since historical time and are indications for present tectonic activity. Also hot thermal springs, which have been used since Roman and Byzantine times flow out on the northern slope of the Uludağ massif within a lateral zone just above the Bursa plain. These springs can be distinguished by the geographical and geological situation of the outflow zone and also by the chemical composition of the outflowing water. Based on the hydrochemical data, a conceptual model was developed which shows there is a common origin for all the thermal springs. Evidence from isotopic analyses which indicates that there is no connection between two thermal water districts is explained by a mixing with cold young groundwater.

INTRODUCTION

Within the framework of a scientific collaboration between the Mining Geology Department of the Technical University of Istanbul and the Engineering Geology Section of ETH Zürich (Swiss Federal Institute of Technology), hydrogeological, geological and geophysical studies were undertaken in the Bursa region as part of the Ph.D. thesis of the author of this paper.

Several earthquakes in and around Bursa are known since historical time and are indications for the present tectonic activity. Also hot thermal springs, which have been used since the Roman and Byzantine epoch flow out at the northern slope of the Uludağ massif within a lateral zone just above the Bursa plain. One aim of this work was to study the thermal water, the mixing processes with cold groundwater from the Uludağ massif and their relation to recent tectonic activity.

GEOGRAPHICAL INTRODUCTION

Bursa is situated south of the Marmara Sea at the northern slope of the Uludağ massif. The city is located on a huge alluvial fan and on travertine terraces which has made Bursa famous both in the past and also in recent times.

GEOLOGICAL INTRODUCTION

The northern slope of the Uludağ massif, which rises from 300 to 1700 m consists mainly of marbles, amphibolites and gneisses. This part of the massif is morphologically characterized by steep, deeply eroded narrow valleys. The central high plateau (1800 m) is formed by plutonic rocks (granodiorite). The highest peaks on the Uludağ massif (2500 m) consists of white marble. The western part of the Uludağ massif consists of deeply altered, slight metamorphic schists on which relics of sedimentary Neogene deposits can be observed (freshwater limestone, volcanic sediments and tuffs). There are also two important travertine complexes, which lie discordant on Neogene deposits (Figs 1 and 2).

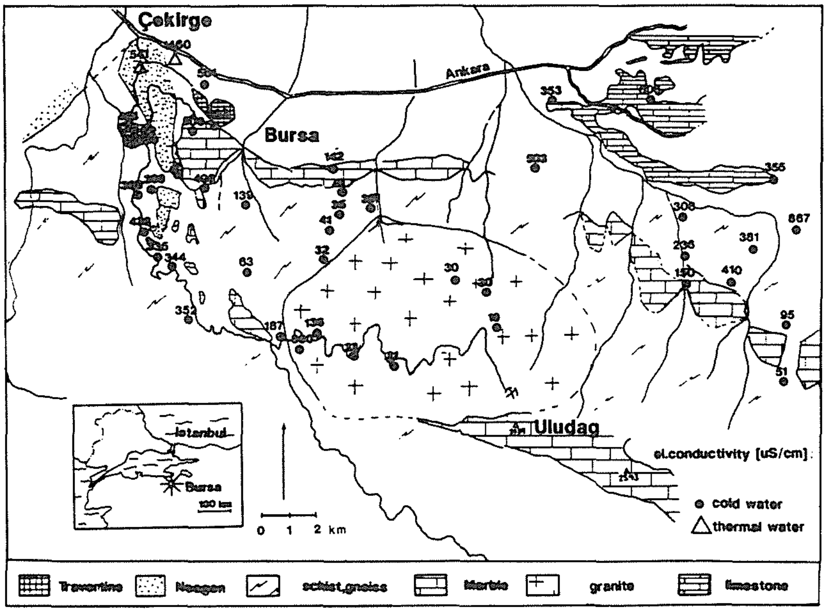


Fig. 1 - Geological units on the Uludağ massif with the most important springs and their electrical conductivity (μS/cm).

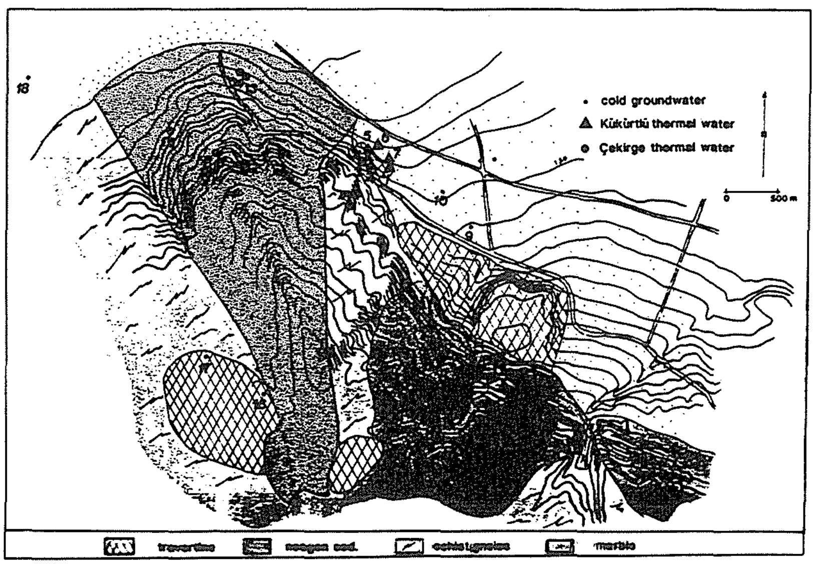


Fig. 2 - Location of hot and cold springs in the Çekirge-Bursa area. For location names see Table 1.

Further information about the geology of the Uludağ massif may be found in Ketin (1985).

Table 1. Chemical analyses from hot and cold springs in the Çekirge-Bursa area (their locations are shown in Fig. 2)

Nr.	Probe	Datum	LF uS/cm	T [C]	pH	Li mg/l	Na	K	Be *	Mg	Ca	Sr *	Ba *	Mn *	Fetot *	F	Cl	Br +	I +	SO4 *	NO3 *	PO4 *	HCO3	As *	B *	Si *
1	Yeni Kaplica	890905	1456	81.1	6.53	0.68	229	22.8	0.002	8	98	0.548	0.065	0.055	0.516	5.8	11.6	<0.2	0.080	268	<DL	0.58	531	0.128	1.697	45.37
2	Kük.I	891004	1391	80.6		0.68	223	22.8	0.002	7	93	0.581	0.068			5.5	11.4			280	0.3	0.59	529	0.125	1.778	46.71
	Kük.I	890905	1460	80.7	6.34	0.68	223	23.0	0.002	7	92	0.576	0.067	0.057	0.277	5.5	12.3	<0.2	0.060	277	0.6	0.58	529	0.094	1.775	46.37
3	Kük.III	890905	776	29.5	6.96	0.12	60	9.3	0.002	23	81	0.581	0.056	0.073	1.509	1.3	11.7	<0.2	0.050	77	<DL	0.31	433	0.056	0.107	16.04
4	Kük.II	890905	1370	73.7	6.53	0.64	210	22.8	0.002	8	99	0.562	0.066	0.063	0.626	5.2	12.5	<0.2	0.050	254	<DL	0.08	516	0.148	1.641	43.29
5	Dil	890905	1480	76.0	6.51	0.67	218	22.8	0.002	7	93	0.565	0.069	0.080	0.603	5.3	12.9	<0.2	0.050	274	0.2	0.73	534	0.090	1.725	45.57
6	Ota Kaplica	890907	1142	50.8	7.00	0.55	198	20.0	0.002	11	84	0.501	0.053	0.026	0.039	4.3	13.4	<0.2	0.040	232	5.0	0.49	468	0.106	1.467	39.36
7	Karamustafa	890906	1110	61.5	6.77	0.54	185	19.0	0.002	9	77	0.482	0.054	0.049	0.048	4.5	11.3	<0.2	0.050	226	1.6	0.38	449	0.074	1.410	39.00
8	Pinarbasi	890908	502	15.0	6.80	0.01	7	1.9	0.002	15	53	0.112	0.019	0.060	0.067	0.1	7.6	<0.2	0.040	15	2.2	0.27	215	0.032	0.021	3.76
9	Stadion	890907	561	15.5	7.11	0.02	12	4.3	0.002	9	105	0.136	0.024			0.1	9.4	<0.2	0.050	21	8.3	0.40	349	0.020	0.052	5.55
10	Kültürpark	890907	573	16.0	7.09	0.02	14	3.7	0.002	10	103	0.146	0.024			0.1	11.2	<0.2	0.040	25	10.9	0.62	331	0.020	0.054	5.67
11	Vakifbahce 1	890906	541	45.7	6.74	0.04	35	5.6	0.002	21	65	0.464	0.104	0.039	0.234	0.9	5.4	<0.2	0.050	58	0.2	0.38	296	0.035	0.070	15.35
12	Boyugüzel	890906	538	43.8	7.05	0.04	32	4.6	0.002	21	66	0.487	0.116	0.023	0.114	0.9	5.4	<0.2	0.045	57	0.2	0.25	293	0.051	0.071	16.04
13	Havuz kaynagi	891004	537	35.8		0.03	30	4.9	0.002	20	75	0.444	0.096			0.7	10.0	<0.2	0.040	61	5.8	0.28	296	0.038	0.050	13.63
14	Havuz drill.	890907	568	34.6	7.01	0.03	28	4.8	0.002	20	77	0.449	0.094			0.8	8.6	<0.2	0.040	63	0.2	0.34	301	0.055	0.053	13.15
15	Sig. sicak su	890907	531	30.8	7.70	0.04	29	6.1	0.002	22	62	0.452	0.101			0.6	9.2	<0.2	0.045	60	7.6	0.46	273	0.070	0.142	15.02
16	Villa et Bungal	890912	446	15.3	7.40	n.nb.	4	1.0	0.002	22	66	0.227	0.014	0.020	0.044	0.1	4.1	<0.2	0.040	35	<DL	0.19	264	0.021	0.004	5.24
17	Inkaya	890908	484	14.8	7.39	n.nb.	5	1.2	0.002	20	76	0.236	0.018	0.040	0.280	0.1	5.8	<0.2	0.040	35	5.0	0.25	284	0.049	0.004	5.35
18	Sig.drill.	890908	718	14.8	6.82	0.01	10	1.3	0.002	25	122	0.357	0.052			0.1	17.6	<0.2	0.040	43	19.6	0.31	406	0.081	0.004	6.73

Laboratory:
Ingenieurgeologie, ETH-Hönggerberg, CH-8093 Zürich
* Eidg. Forschungsanstalt für Wald, Schnee und Landschaft, CH-8903 Birmensdorf
\+ Mineralwasserlabor, Engimattstr. 11, CH-8059 Zürich

HYDROGEOLOGICAL INTRODUCTION

The Bursa plain groundwater within the alluvial plain aquifer is recharged mainly by water from the Uludağ massif. Fractures are the most important flow paths in metamorphic and igneous rocks. Huge karst springs on the border of the plain, the Karapnar and Pnarba springs, show the importance of the karstified marble series as a groundwater aquifer above the valley on the Uludağ massif. River water from Uludağ is artificially infiltrated into this karstified marble series to intensify the groundwater resources in the plain. Bursa itself is built on a third important aquifer.

The natural terraced morphology of this complex was used as a fortification by the founder of Bursa. But only the highest part of this karstified travertine complex is visible. Drill holes in the plain at Kültürpark and Stadion, prove the extent of 100 m thick travertine deposits, which act as an aquifer with artesian water.

On another travertine terrace not far to the west, also on the border of the plain, thermal water with a temperature of up to 82°C flows out. These thermal springs within and around the historical bath of Yeni Kapl'a (Kükürtlü district) all orginate from a travertine complex lying on metamorphic rocks. This travertine complex, which is karstified, can be distinguished from the Bursa travertine complex by a lamination structure.

The hydrogeological situation of the thermal springs within the second thermal water district of Çekirge is not well defined because the spring locations are situated in the urban area. The outcropping rock within the Çekirge district consists of Neogene sediments and limestone.

The only information about the hydrogeological situation is given by the existing spring captures and boreholes from DSI. The hot thermal water seems to originate from these rocks, as can be deduced from the old capture gallery of Byzantine or Roman times at the Vakfbah'e spring.

FIELD PROGRAMME

Geological mapping of the Uludağ massif is the basic work of the present studies. The most important springs from all over the Uludağ massif were sampled for hydrochemical analyses and some for isotopic investigations (D, T, $\delta^{18}O$) in the summer of 1989 (Fig. 1).

This hydrological information on a large scale was the basis for the geographical limitation of further detailed field programmes on a smaller scale (Fig. 2). The isotopic analyses were done at GSF Neuherberg.

RESULTS

The interpretation of the data from the hydrochemical analyses, isotopic investigations, ideal gas measurements and periodical water investigations in the Bursa-Çekirge area (Tables 1 and 2) permits the postulation of a conceptual model about origin of the thermal waters and the mixing processes.

Thermal springs in the Kükürtlü district (Nr. 17) are characterized by a Na-Ca-HCO_3SO_4 water composition. Their total mineralization is about 1 g/l and the maximum temperature is 82°C (Yeni Kapl'a).

Based on observations from the established monitoring network (through sampling on the thermal springs and boreholes by DSI) the flow path of the thermal water within a hillslope aquifer of Kükürtlü towards the plain can be distinguished from the cold groundwater within the main Bursa travertine complex, which exits also in confining layers within the plain (Nr. 910).

The thermal water in the Çekirge district (Nr. 1115) is characterized by a Ca-Mg-Na-HCO_3-SO_4 water type with a total mineralization of about 0.5 g/l and a maximum temperature of 46°C (Vakfbah'e). From the present observations the thermal water in the Çekirge district also behaves as ordinary groundwater from a hillslope aquifer.

<u>Model I</u> (based on hydrochemical analyses)

The hydrochemical analyses and physical parameters alone are misleading and postulate a common origin for the two thermal water types which have evolved along different flow paths. The Yeni Kapl'a thermal water represents the most original thermal water type and the thermal water of the Çekirge district seems to be a result of mixing of the original thermal water endmember and a cold groundwater endmember with the chemical composition of the Inkaya karst springs (Nr. 1617).

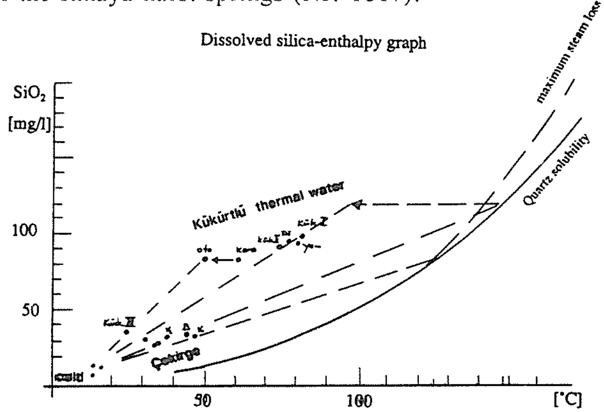


Fig. 3 - A silica-enthalpy graph (Truesdell & Fournier, 1977) for the Kükürtlü thermal water within the hillslope aquifer.

Table 2. Tritium analysis

Nr.	Probe	Datum	Tritium [TU]
1	Yeni Kaplica	890905	0.9 +-0,7
2	Kük.I	891004	
	Kük.I	890905	1.1 +-0,7
3	Kük.III	890905	3.1 +-0,7
4	Kük.II	890905	2.2 +-0,7
5	Dil	890905	1.6 +-0,7
6	Oto Kaplica	890907	4.5 +-0,7
7	Karamustafa	890906	4.1 +-0,7
8	Pinarbasi	890908	18.1 +-1,4
9	Stadion	890907	20.0 +-1,4
10	Kültürpark	890907	22.4 +-1,6
11	Vakifbahce 1	890906	1.2 +-0,7
12	Boyugüzel	890906	1.8 +-0,7
13	Havuz kaynagi	891004	5.0 +-0,7
14	Havuz drill.	890907	3.8 +-0,7
15	Sig. sicak su	890907	5.6 +-0,7
16	Villa et Mangal	890912	10.9 +-0,9
17	Inkaya	890908	12.1 +-0,9
18	Sig.drill.	890908	18.1 +-1,3

Laboratory:
Gesellschaft für Strahlen- und Umweltforschung München

<u>Model II</u> (based on a combination of hydrochemical data and the results from isotopic analyses)

The low tritium concentration in the Çekirge thermal water does not confirm the single hot water origin model. Figures 4 and 5 prove that the Çekirge thermal water did not develop from the hotter Kükürtlü area as it behaves as an ordinary groundwater from a hillslope aquifer.

The linear trend of the Kükürtlü and Çekirge data towards the Inkaya karst water data indicates there is a mixing with cold water within the hot water spring aquifer (travertine). For the hot unknown endmember of both thermal water provinces a tritium content at or below the detection limit has to be admitted.

For the interpretation of the cold water endmember data we need the tritium input function. The tritium concentration in present meteoric water is not known but the Inkaya karst water probably represent very young rainfall water. The evidence for a connection between thermal water and rainfall water is shown in Fig. 6.

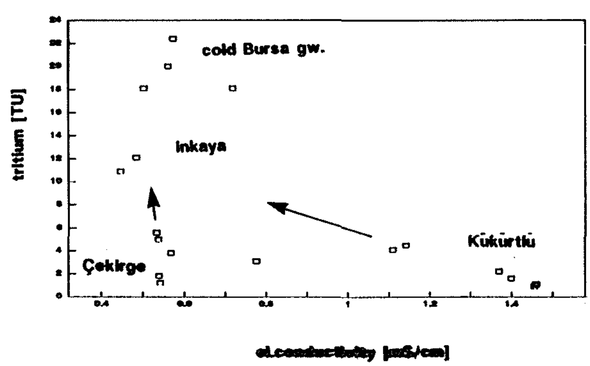
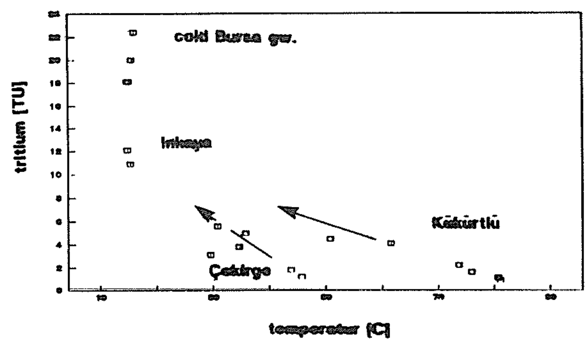


Fig. 4 - Electrical conductivity-tritium plot for sample number 1-18.



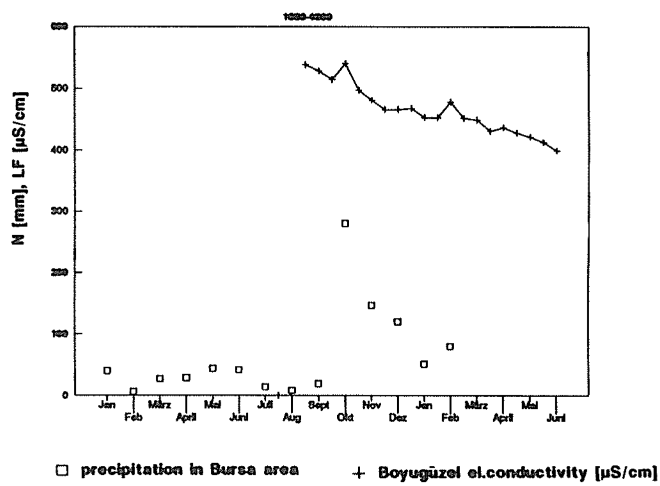


Fig. 6 - Precipitation measurements from DSI in the Bursa area, doganci barraj, compared with electrical conductivity from thermal water in the Çekirge district.

Figure 6 shows a positive correlation between rainfall in the Bursa area and electrical conductivity of the thermal water. The positive correlation without any delay proves an that the residual hot water with higher electrical conductivity (summer water) is forced out by a rapid rising of the hydrostatic pressure. The conductivity measurements were done on 18 October 1989, one day after a heavy rainfall (180 mm in 24 hours) in the Bursa area. This behaviour provides evidence for a karst or fracture aquifer.

CONCLUSION

New isotope data do not support the first model developed only on hydrochemical data. This application demonstrates the importance of environmental tritium as a tracer, especially in the case when old and young groundwaters are mixed.

ACKNOWLEDGEMENTS

We are grateful for the accommodation provided by DSI Bursa. Special gratitude is expressed to Mr E. Saker, Mr Yüksel and to Mr H. Tezel from DSI Bursa for their periodical measurements. Thanks also to WSL Birmensdorf and GSF München for their collaboration and to Prof. Yüzer and Prof. Shindler for organizing the project.

REFERENCES

Ketin, I., 1985, New developments in overthrust nappe tectonics of Turkey with the example of Uludağ. In: *Ketin Simpozyumu 20-21 February 1984*, pp. 19-36T.

Truesdell, R. O. & Fournier, R. O., 1977, Procedure for estimating the temperature of a hot water component in a mixed water by using a plot of dissolved silica versus enthalpy. *J. Research US Geol. Survey*, vol. 5, no. 1, p. 4952.