DETERMINATION OF SEA WATER INTRUSION RATE AND POSSIBLE AQUIFER ROCKS BY MEANS OF HYDROCHEMICAL AND ISOTOPIC (^{18}O, D, T AND $^{87}Sr/^{86}Sr$) TECHNIQUES (GÖKOVA KARSTIC SPRINGS, SW TURKEY)

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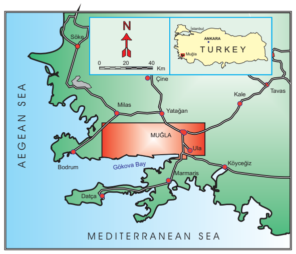
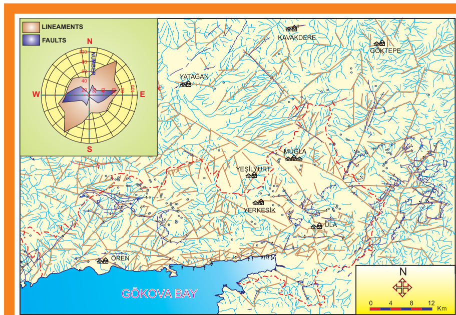


INTRODUCTION

Gokova Bay located at the southwestern Turkey is among the major tourist resort areas. Sustainable touristic development is based to a great extend on the availability of fresh water which is mainly supplied by karstic limestone aquifer that is in direct contact with sea water in many places.

Varying degrees of sea water contribution is observed in most of the springs that are currently being used as water supplies for drinking purpose. Increasing need for fresh water supplies within the last 15 years resulted in the expanding use of available water resources which in turn caused more salinization.

Within the scope of a regional survey carried out by UKAM, hydrogeological structure and the mechanism of fresh water salinization by sea water has been investigated by means of hydrochemical and environmental isotopic techniques.



CLIMATE & DRAINAGE PATTERN

Climate is of Mediterranean type with hot and dry summers and mild and wet winters. Most of the precipitation is in the form of rainfall, but sporadic snowfall is also observed at the peak areas extending over 1000m.Based on 50 years meteorological records the mean annual precipitation is 1185 mm. Mean annual temperature is 14.8 °C, and the maximum and minimum temperatures are 28.1 °C and 2.4 °C, respectively. Relative humidity is about %62. Dominant wind direction is WNW-NW and the length of the sunny days are 8.5 months.

Almost all of the precipitation is drained by the carbonate formations as implied by the presence of a poorly-developed drainage pattern and scarcity of perennial streams. All perennial streams, though their discharge is limited to a few l/sec are located over impermeable formations. The main groundwater flow direction at the plateau (i.e. in the northern part) is from north to south. It is inferred that the precipitation in the plateau part infiltrates rapidly into the deeper parts of the carbonate aquifers where it gets concentrated around the fault lines and is conveyed towards coastal part.

Throughout the aquifer system, groundwater flow is controlled by tectonic structures. All springs are located along the fault lines or at their intersections.

INFERRING AQUIFER ROCK BY MEANS OF $^{87}SR/^{86}SR$ DATA:

The $^{87}Sr/^{86}Sr$ ratio of the marine carbonate rocks are assumed to be identical to that of seawater at the time of their deposition if the following situations did not happened: alteration of rocks after diagenesis, dedolomitization inaccurate age assignments or,high amplitude and short period variation of the oceanic $^{87}Sr/^{86}Sr$ ratio (Faure, 1986).

The variation of $^{87}Sr/^{86}Sr$ ratio of the oceans during Phanerozoic time is given in the Figure which is based on the data of Burke et. al. (1982). Because of the reasons mentioned above $^{87}Sr/^{86}Sr$ ratio of the groundwater should be identical to the $^{87}Sr/^{86}Sr$ ratio of the aquifer rock if there is no other source of Sr.

Limited number of samples have been analysed for the Sr isotope ratio contents in this study. These are GK-14 Sea water, GK-13 Bagyaka plateau spring which is not affected by seawater, and three coastal springs that were affected by seawater in different rates (GK-3 Cennet Restaurant, GK-7 Deniz Restaurant II ve GK-9 Akbük).

Sea water effects were substracted from measured $^{87}Sr/^{86}Sr$ ratio of the groundwater samples and remaining sample contents were compaired with those of aquifer rocks. Hydrogeological map points out that all springs analysed for $^{87}Sr/^{86}Sr$ ratio are in contact with allochtonous and autochthonous units. Most of the groundwaters are in contact with the Triassic-Middle Jurassic limestone and dolomite, Tertiary conglomerate except the spring numbered GK-13 Bagyaka which is in contact with the Silurian-Permian schists (see Table 4).

Final conclusions for Sr isotope ratios are made as follows;

GK-3 Cennet Restaurant is recharged by Triassic-Middle Jurassic aged Gereme formation and Tertiary aged Kopruçay formation,

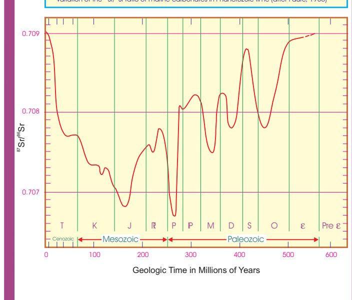
GK-7 Deniz Restaurant II springs aquifer rock is Tertiary aged Köprüçay formation,

GK-13 Bagyaka spring is fed by Mesosoic Yilanli formation,

GK-9 Akbuk spring's aquifer rock is Gereme formation and sandy, clayey layers of Tertiary Yatagan formation.

Sea water sample from the Gokova Bay is diluted by freshwater, thus $^{87}Sr/^{86}Sr$ ratio of this sample lower than the standard ocean water's value given by Faure (1983) as 0.70812.

Sr contents and possible aquifer rock of the water samples



Variation of the $^{87}Sr/^{86}Sr$ ratio of marine carbonates in Phanerozoic time (after Faure, 1986)

HYDOGEOCHEMISTRY

Springs, wells and seawater have been surveyed for chemical composition variations for a period of two years. Regional hydrogeochemistry comprises of three chemically distinct type of waters, namely two end-members, sea water and fresh karstic ground water and the mixture of these two. Fresh karstic ground water and sea water are characterized by Ca-HCO3 and Na-Cl facieses, respectively. Mixture waters usually belong to the part of Na-Cl facies close to Ca-Cl facies. Fresh karstic groundwater (samples 11, 12 and 13) discharging at high altitudes (in the plateau part) are located in the Ca-HCO3 region. Well in Gokova coastal plain (16 A and B) discharge also fresh water from a buried stream channe.. Although located nearby the sea, artesian flow conditions dominating in this part of the alluvium aquifer limits the extend of sea water intrusion. Specific conductivity measured in these wells is slightly higher than those of plateau springs and varies around 750 microS/cm.

Since sea water in the Gokova Bay (14) is mixed with fresh water, two more sea water samples (17 and 18) have been collected to represent original sea water. These are plotted on the right corner of the central diamond of Piper's diagram. Other sampling sites located to the north of Gokova Plain and along the northern coast line are plotted between sea water (14, 17, 18) and fresh water (plateau springs; 11, 12 and wells in Gokova Plain; (16 A and 16B). Depending on the amount of sea water contributed, some waters (coastal springs) are located close to sea water whereas, the springs in plain are located closer to the wells in the plain. Calculated sea water contribution rates are given in the Table.

CHEMICAL AND ISOTOPIC PARAMETERS OF THE WATER SAMPLES

AVERAGE VALUES

Code	Sample Name	Type	Cl meq/l	ISOTOPES ^{18}O (%oSMOW)	D (%oSMOW)	T (TU)
GK-1	Azmak(duvar dibi)	Sp.	13.74	-6.45	-33.23	6.30
GK-2	Azmak-Kümes	Sp.	17.84	-6.32	-33.58	6.63
GK-3	Cennet Restaurant	Sp.	23.02	-6.38	-33.35	6.57
GK-4	Halil'in Yeri Rest.	Sp.	10.12	-6.75	-35.08	10.03
GK-5	Belediye Kuyular›	W	8.32	-6.79	-35.95	10.40
GK-6	Deniz Rest.-1	Sp.	72.86	-5.51	-30.30	7.47
GK-7	Deniz Rest.-2	Sp.	59.40	-6.07	-32.88	9.43
GK-8	Ç›naralt›	Sp.	52.80	-6.07	-32.20	9.30
GK-9	Akbük Liman›	Sp.	88.04	-4.76	-23.73	6.60
GK-10-A	Ören (Ac›su) I	Sp.	96.75	-4.58	-22.78	5.10
GK-10-B	Ören (Ac›su) II	Sp.	86.50	-4.50	-23.10	-
GK-11	Alg› Köyü	Sp.	0.63	-6.16	-31.60	6.17
GK-12	Yeniköy	Sp.	0.90	-6.36	-31.78	6.90
GK-13	BaŸyaka Köyü	Sp.	0.61	-6.74	-34.57	8.33
GK-14	Gökova	SEA	427.49	-0.91	-5.03	4.87
GK-15	Akçap›nar Köyü	Sp.	0.90	-5.05	-24.63	7.33
GK-16-A	Kuyu - I	W	1.92	-6.31	-32.70	6.50
GK-16-B	Kuyu - II	W	1.11	-6.40	-33.90	0.00
GK-16-C	Kuyu - III	W	1.25	1.56	6.55	1.45
GK-17	Marmaris	SEA	813.31	1.82	10.90	0.9
GK-18	Ören	SEA	590.00	-	-	-

Code	Sample Name	Date (d/m/yy)	Type	$^{87}Sr/^{86}Sr$	Error
GK-3	Cennet Restaurant	12/5/95	Sp.	0.79800	± 0.00006
GK-7	Deniz Rest.-2	12/5/95	Sp.	0.70875	± 0.00005
GK-9	Akbük Liman›	11/5/95	Sp.	0.70879	± 0.00004
GK-13	BaŸyaka Köyü	11/5/95	Sp.	0.70934	± 0.00006
GK-14	Gökova (Sea)	12/5/95	SEA	0.70853	± 0.00007

PRECIPITATION (MuŸla Observation Stations)

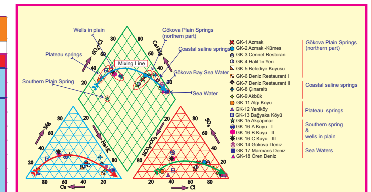
Date	TYPE	Altitute (m)	^{18}O (%0 SMOW)	^{2}H (%0 SMOW)	^{3}H (TU)
September-94	P	646	1.31	5.5	-
October-94	P	646	-6.53	-35.5	4.6
November-94	P	646	-7.45	-43.0	4.8
December-94	P	646	-8.38	-49.5	3.5
January-95	P	646	-5.98	-28.2	3.9
February-95	P	646	-4.63	-25.7	4.5
March-95	P	646	-5.33	-28	5.0
April-95	P	646	-8.23	-52.5	8.3

All isotopic analyses have been carried out by IAEA Headquarters' Laboratories
Except:
Tritium analyses in bold letters done by Environmental isotope Lab. in Jordan
Sr isotope analyses in the Mass Spectro. Lab. At The Hacettepe University
TYPE : Sp.: Spring, W: Well, SEA: Sea water, P: Precipitation

Average seawater contribution to groundwater

Code	Sample Name	Average Cl mmol/l	Sea water %	Fresh water %
GK-1	Azmak(duvar dibi)	13.74	2.22	97.78
GK-2	Azmak-Kümes	17.84	2.92	97.08
GK-3	Cennet Restaurant	23.02	3.8	96.2
GK-4	Halil'in Yeri Rest.	10.12	1.61	98.39
GK-5	Belediye Kuyuları	8.32	1.3	98.7
GK-6	Deniz Rest.-1	72.86	12.26	87.74
GK-7	Deniz Rest.-2	59.4	9.97	90.03
GK-8	Çınaraltı	52.8	8.85	91.15
GK-9	Akbük Limanı	88.04	14.83	85.17
GK-10-A	Ören (Acısu) I	96.75	15.41	84.59
GK-10-B	Ören (Acısu) II	86.5	14.41	85.59
GK-11	Algı Köyü	0.63	0	100
GK-12	Yeniköy	0.9	0.04	99.96
GK-13	Bağyaka Köyü	0.61	-0.01	100.01
GK-14	Gökova (sea)	427.49	72.43	27.57
GK-15	Akçapınar Köyü	0.9	0.04	99.96
GK-16-A	Kuyu - I	1.92	0.22	99.78
GK-16-B	Kuyu - II	1.11	0.08	99.92
GK-16-C	Kuyu - III	1.25	0.1	99.9
GK-17	Marmaris (sea)	813.31	100	0
GK-18	Ören (sea)	590	100	0

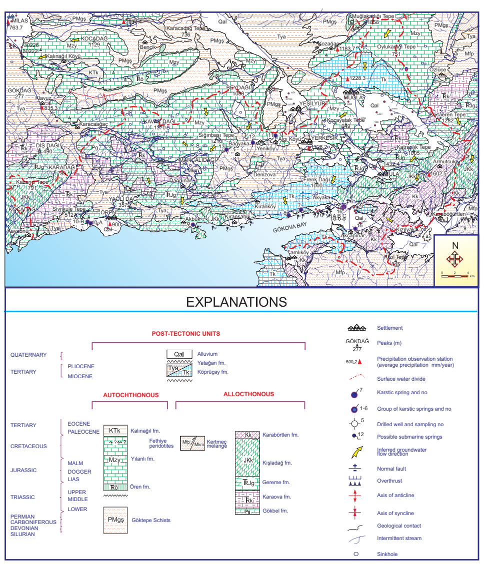
Cl contents of the freshwater is 0.649 mmol/l (average value of the plateau springs GK-11, GK-12, GK-13)



CALCULATED RECHARGE ELEVATIONS OF THE SPRINGS

Code	Name	Spring. Elev. (m)	SEA WATER CONTRIBUTIONS NOT EXTRACTED ^{18}O	‰ 0.15	‰ 0.20	‰ 0.25	AVE.	EXTRACTED ^{18}O	‰ 0.15	‰ 0.20	‰ 0.25	AVE.
GK-1	Azmak	1.7	-6.45	930	698	558	729	-6.67	1080	810	648	846
GK-2	Azmak-Kümes	1.0	-6.32	847	635	508	663	-6.60	1033	775	620	809
GK-3	Cennet Restaurant	0.8	-6.38	885	664	531	693	-6.72	1113	835	668	872
GK-4	Halil'in Yeri Rest.	0.6	-6.75	1132	849	679	886	-6.90	1233	925	740	966
GK-5	Belediye Kuyulari	2.0	-6.79	1157	868	694	906	-6.89	1227	920	736	961
GK-6	Deniz Restaurant I	0.4	-5.51	307	230	184	240	-6.43	920	690	552	721
GK-7	Deniz Restaurant II	0.5	-6.07	677	508	406	530	-6.94	1260	945	756	987
GK-8	Çinaralti	0.5	-6.07	678	509	407	531	-6.87	1213	910	728	950
GK-9	Akbük Limani	0.5	-4.76	195	146	117	153	-5.83	520	390	312	407
GK-10-A	Ören (Acisu) I	1.0	-4.58	317	238	190	248	-5.50	300	225	180	235
GK-10-B	Ören (Acisu) II *	1.5	-4.50	367	275	220	287	-5.51	307	230	184	240
GK-11	Algi Köyü	660.0	-6.16	740	555	444	580	-6.15	733	550	440	574
GK-12	Yeniköy	850.0	-6.36	875	656	525	685	-6.36	873	655	524	684
GK-13	Bagyaka Köyü	600.0	-6.74	1129	847	677	884	-6.74	1127	845	676	883
GK-14	Gökova (sea)	0.0	-0.91	-	-	-	-	-6.54	-	-	-	-
GK-15	Akçapinar Köyü	9.0	-5.05	<400	<400	<400	<400	-5.05	<400	<400	<400	<400
GK-16-A	Kuyu - I	2.0	-6.31	842	631	505	659	-6.31	840	630	504	658
GK-16-B	Kuyu - II *	2.0	-6.40	900	675	540	705	-6.40	900	675	540	705
GK-16-C	Kuyu - III *	2.0	-6.37	880	660	528	689	-6.37	880	660	528	689
GK-17	Marmaris (sea)	0.0	1.56	-	-	-	-	1.56	-	-	-	-
GK-18	Ören (sea)	0.0	1.82	-	-	-	-	1.82	-	-	-	-

* Calculated from the values of December 1994 field campaign



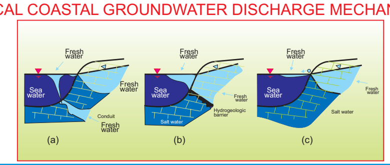
Hydrogeologicall map of the study area (modified after Meşhur et. al., 1995)

HYDROGEOLOGY OF THE STUDY AREA

Regional geological structure of Gökova Bay area comprises of autochthonous, allochthonous and post-tectonic units. Main components of the regional geology and their structural relationships are shown in the map. During the geologic history, this area has been subject to compressional and tensional tectonics. At the time of compressional tectonics, allochthonous units mainly comprising of various types of carbonates thrusted over metamorphic basement, the "Menderes Massive". These carbonate series, in turn, overthrusted by an ophiolite nappe of which only a small part outcrops in the study area. After the completion of compressional tectonics at the beginning of Tertiary, post-tectonic units of mainly detritic nature have deposited especially in the present day's high lands located to the northern part. Following their deposition, tensional tectonic activities which are still active became dominant and resulted in the formation of large-scale horst-graben type faults. The Gokova Bay is, actually, a graben which is still sinking.

From the geomorphological point of view, the area comprises of three major parts; A coastal plain and a steep fault line along the northern coast of Gokova Bay, a slightly undulating plateau extending at an elevation of 600m, a mountainous part with peaks up to 1750m to the northeast of plateau. There are a number of karst plains which have been former poljes scattered on the plateau part. The presences of these karst plains indicates that the area has experienced more humid conditions just as happened in the coastal part of the Taurids karst range during the Pliocene period.

TYPICAL COASTAL GROUNDWATER DISCHARGE MECHANISMS



CONCLUSIONS

Sea water contribution calculated by Cl content increases toward west along the coast line in the Gokova plain groundwater basin. The seawater at the eastern end of Gokova Bay is diluted by freshwater discharges, and consequently exhibits a seawater contribution rate of 74% suggesting that 26% of seawater is of freshwater origin. Groundwater water samples collected from other sites have contribution rates between 1% and 17%.

As the seawater contribution increase, the error on the recharge elevation estimated from ^{18}O data increases. This is clearly seen on GK-9 Akbük, GK-10-A and B sampling points which have the highest seawater contribution rates among the others. Calculated elevations after substracting the seawater contributions provided plausible results.

87Sr/86Sr ratio of groundwater was proven to be a useful to to estimate the sea water contribution rate and to infer potential aquifer rock(s).