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**GÖNEN VE EKŞİDERE (BALIKESİR) TERMAL SULARININ
HİDROJEOLÖJİK İNCELEMESİ**

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HYDROGEOLOGICAL INVESTIGATION
OF
GÖNEN AND EKŞİDERE (BALIKESİR) THERMAL WATERS

PhD THESIS

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PREFACE

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SUMMARY

This dissertation is one of the separate element but also an integrated part of the İTÜ-ETH multi-disciplinary Marmara Project which investigates the active tectonics of NW Turkey and its interrelation to groundwater circulation, heat flow and seismicity.

The investigation area is located in Gönen town of Balıkesir city. In this study the 82°C discharging Gönen thermal water and 42°C discharging Eksişidere thermal water were investigated from hydrogeologic, chemical and isotopic points of view.

The investigated area is situated geologically in the Sakarya Zone of Pontides. The Karakaya Complex is the oldest unit in the investigation area. This unit is unconformably overlain by the Jurassic-Cretaceous aged Bayırköy Formation, Bilecik Limestone and Vezirhan Formation. Neogene lacustrine sediments, volcanosedimentary and volcanic rocks overlie all these formations. The overlying superficial deposits principally consist of Quaternary alluvium laid down by the Gönen River and its branches. The main faulting in the investigation area is the western extension of the North Anatolian Fault Zone (NAFZ).

Hydrologic characteristics of the investigation area were examined through calculation of evapotranspiration and runoff by evaluation of meteorological data in Penman's water budget table, calculation of base flow, surface runoff and evapotranspiration by separation of hydrograph components of Gönen River and Keçi Stream. The alluvia of Sarıköy Plain and northern side of Gönen Plain were classified as rich and extensive aquifer. Consolidated formations such as Jurassic-Cretaceous karstic limestone and Neogene fractured volcanic rocks were classified as local and individual aquifer. The alluvium of central and southern Gönen Plain was classified as poor aquifers. Some alluvia of the Gönen Plain, Neogene sedimentary rocks and Triassic Karakaya Complex were classified as very poor aquifers. The discharge of groundwater was computed to be $48.10^6 \text{ m}^3/\text{year}$. The groundwater discharges by the streams ($30.10^6 \text{ m}^3/\text{year}$), evapotranspiration ($4.10^6 \text{ m}^3/\text{year}$), springs ($2.10^6 \text{ m}^3/\text{year}$) and artificial discharge ($12.10^6 \text{ m}^3/\text{year}$). The groundwater samples collected from the area were grouped into 4 as $\text{Ca} \cdot \text{HCO}_3$., $\text{Na} \cdot \text{HCO}_3$., $\text{Na} (\text{SO}_4)(\text{Cl})(\text{HCO}_3)$ and other types.

The origin of the Gönen thermal water was found to be meteoric water infiltrated during the Pleistocene at a low temperature of about 0°C ($\approx 10,000$ years ago). The infiltrated water flows most probably through the Kazdağ Metamorphic Unit, and reaches a depth of 3-4 km and is heated to approximately 100°C in the reservoir. The emergence of the water at the surface takes place where the permeability is increased due to fault zones. The origin of the Eksişidere thermal water is shallow circulating meteoric water associated with karstic system. The infiltrated water from the hills located at the southern side of the thermal water emerges at the surface through the fault zone between volcanic and sedimentary rocks of the Neogene. The impermeable sedimentary rocks cause the emergence of water above the plain level.

ÖZET

GÖNEN AND EKŞİDERE (BALIKESİR) SICAK SULARININ HİDROJEOLJİK İNCELEMESİ

Ülkemiz sıcaqsu kaynakları açısından oldukça zengin olup, son yıllarda bunlardan tedavi amacının yanısıra, alternatif bir enerji kaynağı olarak da yararlanılmaktadır. Fakat bu doğal zenginliğimiz yeterince araştırılmadığı için potansiyeli tam olarak bilinmemektedir.

İTÜ-ETH Marmara Projesi'nin bir parçası olan bu doktora tezi çalışmasında Gönen bölgesi hidrojeolojik açıdan incelenmiş, Gönen ve Ekşidere termal sularının kökeni araştırılmıştır. Gönen termal suyu günümüzde, kaplıcalarda ve yaklaşık 1000 konutun ısıtılmasında kullanılmaktadır. Termal su tüketimi ortalama olarak 50 lt/sn'dir. Gönen, kaplıcaları sayesinde iç turizm açısından oldukça hareketli olup ve 550 yatak kapasitesine sahiptir. Ekşidere termal suyunun kullanımı ise, gelişmekle birlikte, oldukça sınırlıdır.

Çalışma alanı Balıkesir iline bağlı Gönen ilçesi sınırları içerisinde Gönen ve Ekşidere termal sularının civarındadır. Bölge coğrafik olarak Marmara Bölgesi'nde yer almaktadır. Gönen'in antik ismi Artemea olup Gönen isminin Germenon'dan kaynaklandığı iddia edilmektedir[2]. Çalışma alanı 187 km² yüzölçümlü ve deniz seviyesinden 30m yüksekliğe sahip olan Gönen ovasıdır ve civarıdır. Çalışma alanındaki drenaj ağı, antik adı Aisepos olan Gönen Çayı ve onun kolları tarafından oluşturulmuştur. Bölgede, Karadeniz ile Akdeniz iklimlerinin geçiş iklimi olan Marmara iklimi hüküm sürmektedir. Yıllık ortalama yağış 700 mm ve yıllık ortalama sıcaklık 14.5°C'dir.

Arazi çalışmaları sırasında, inceleme alanındaki jeolojik birimler ve tektonik hatlar belirlenmiş ve ayrıntılı hidrojeolojik bilgilerin toplanmıştır. Sıcak ve soğuk suların fiziksel, kimyasal, izotopik ve gaz özelliklerinin saptanması için arazide ve laboratuvarında çalışmalar sürdürülmüştür. Suların debi, pH, elektrik iletkenlik(EC), redoks potansiyeli(Eh), sıcaklık, alkalinite ve asidite değerleri kaynak veya kuyu başında ölçülmüştür. Kimyasal, izotopik ve gaz analizlerinin büyük bir kısmı ETH-Zürich laboratuvarlarında ve Almanya'da yapılmış veya yaptırılmıştır.

Çalışma alanının en altında bulunan birim gnays, amfibolit ve mermerden oluşan içinde Permiyen yaşlı kireçtaşı olistolitleri bulunan Karakaya Karmaşığı'dır. Bu birim Sarıköy Ovası'nın güneyinde ayrılmış, yapraklanmış yeşil renkli olarak gözlenmektedir. Birim mermer ve siyah çört ile aratabakalı olup kuvars-albit-muskovit şist, kuvars-feldispat-muskovit şist ve metatüf olarak tanımlanmıştır. Birim içerisinde fosil bulunamamıştır fakat bölgesel tektonik verilerden hareketle [30] Triyas yaşı önerilmiştir. Bu birimin üzerinde uyumsuz bir şekilde Alt Jura yaşlı Bayırköy Formasyonu yer almaktadır.

Bayırköy Formasyonu Gündoğan, Hafızhüseyinbey ve İncirli civarında sarımsı-kahverengi, ince-kalın tabakalı, karbonat çimentolu konglomera, silttaşı, kumtaşı ve marn serisi olarak gözlenmektedir. Bu birimin üzerine Orta-Üst Jura-Alt Kretase yaşlı Bilecik Kireçtaşı uyumsuz olarak gelmektedir.

Bilecik Formasyonu Hafızhüseyinbey, Dereköy, Çıgılmış, Babayaka, Akçapınar ve İncirli civarında gözlenmektedir. Birim tabanda beyaz-krem renkli, kalın tabakalı ve onkolitik köşeli çakıllı kireçtaşı; ortada siyah-açık kahverenkli orta tabakalı, oolitik aratabakalı çörtlü sparitik kireçtaşı; üstte gri-siyah renkli, orta kalınlıkta tabakalı mikritik kireçtaşı şeklindedir. Bu birimin üzerine Üst Kretase yaşlı Vezirhan Formasyonu gelmektedir.

Vezirhan Formasyonu Üçpınar civarında beyaz-açık kahverenkli, ince-kalın tabakalı, çok çatlaklı killi kireçtaşı olarak gözlenmektedir. Birimin tabanı çalışma alanında gözlenmemekle birlikte birim, Biga Yarımadası'nın birçok yerinde Bilecik Kireçtaşı'nın üzerinde yer almaktadır [30]. Bu birim uyumsuz olarak Tersiyer yaşlı tortullarla örtülmüştür.

Miyosen yaşlı volkanik kayalar, göl çökelleri ve Kuvaterner yaşlı akarsu çökelleri çalışma alanının birçok yerinde gözlenmektedir. Volkanik kayalar genelde andezitik olup hyalokristalin porfirik dokuda, bol plajiyoklas, biotit, piroksen, amfibol ve opak mikrokristaller içermektedirler. Yer yer feldispat mineralleri çok ayrılmış olup kaolenleşmişlerdir. Silisleşme yaygın olarak gözlenmektedir. Tüfler, tüfit, kumlu tüfit, aglomeratik tüf ve tüflü kumtaşı şeklinde gözlenmektedirler ve kahverengimsi sarı, beyaz ve gri renkli olup, bazen gevşek bazen de sıkı, kil, silt, kum ile plajiyoklas, biyotit ve amfibol içeren tüflerden oluşmuştur. Gölsel çökeller linyit içeren kil, kireçtaşı, konglomera, kumtaşı ve marn içermektedirler.

Bu birimlerin üzerine Gönen Çayı ve kolları tarafından taşınmış alüvyon gelmektedir. Alüvyonun ortalama kalınlığı 20 m. civarında olmakla birlikte yer yer 100 m.yi bulmaktadır. Tersiyer çökellerinin toplam kalınlığı ise 400 m. dolayındadır.

Metamorfik (yeşilşist) olan Karakaya Karmaşığı'nda yapraklanma gözlenmektedir. Uyumsuzluklar Karakaya Karmaşığı, Bayırköy Formasyonu, Bilecik Kireçtaşı, Vezirhan Formasyonu, Noejen birimleri ve alüvyon arasında gözlenmektedir. Bayırköy Formasyonu, Bilecik Kireçtaşı ve Vezirhan Formasyonu arasındaki uyumsuzluk açısal değil, zaman boşluğundandır. Yukarıdaki üç birim kıvrımlıdır. Tabaka doğrultu ve eğimlerinin değerlendirilmesi sonucu ortalama olarak K7D doğrultulu ve 35NE dalımlı bir kıvrım eksenini saptanmıştır.

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Çalışma alanı dışında gözlenen ve bazı araştırmacılara göre Karakaya Karmaşığı'nın altında yeralan Kazdağ Grubu ve çalışma alanı içinde yer alan jeolojik birimlerin hidrojeolojik özellikleri yaşlıdan gence doğru aşağıda tanımlanmaktadır.

Gnays, amfibolit ve mermerlerden oluşan Kazdağ Grubu, mermerlerinde gözlenen erime boşlukları ve çatlakları sayesinde suyu iletecek yeterli geçirimsiliğe sahiptir. Zayıf bir akifer ortam olarak tanımlanan bu birimin Gönen termal sularının oluşumunda önemli olduğu düşünülmektedir. Kazdağ Grubu'nu üzerleyen Karakaya Karmaşığı ise çok zayıf akifer olarak sınıflandırılmıştır. Bu birim de, çok düşük geçirimsiliğinin olması ve Kazdağ Grubu üzerinde örtü kaya işlevi görmesi dolayısıyla, Gönen termal sularının oluşumunda oldukça önem taşımaktadır.

Bayırköy Formasyonu'nu oluşturan taneler sıkı çimentolu olduğundan permeabilitesi düşüktür. Birim, çatlaklı yapısı sayesinde ikincil porozite kazanmış olup yerel akifer niteliği göstermektedir. Bilecik kireçtaşı da yerel akifer niteliğindedir fakat karstik yapısı sayesinde bölgedeki en önemli kaynakları oluşturmaktadır.

Neojen tortul kayaçları zayıf ve çok zayıf akifer, çatlaklı volkanik kayaçlar ise yerel akifer niteliğindedir. Sarıköy Ovası'nda ve Gönen Ovası'nın kuzey kesiminde bulunan alüvyonlar yaygın ve zengin akiferlerdir. Bu birimin özgül verimi 2 lt/sn/m'nin üzerindedir ve permeabilitesi 16 - 86 m³/day/m² arasındadır. Gönen ovasındaki diğer alüvyonlar ise çok zayıf akiferlerdir.

Çalışma alanı içerisinde yeralan su noktaları kimyasal açıdan Ca..HCO₃..., Na..HCO₃..., Na..(SO₄)(Cl)(HCO₃) karakterli ve diğer tip sular olarak sınıflandırılmıştır. Gönen termal suyu Na..(SO₄)(Cl)(HCO₃), Ekşidere termal suyu Ca..HCO₃... türünde sulardır.

Gönen termal suyu SOLMINEQ.88 bilgisayar programı kullanılarak jeokimyasal açıdan modellenmiştir. Bu program yardımıyla suyun değişik sıcaklık ve basınç koşulları altında iyon cinsleri ve doygunluk indisleri hesaplanmıştır.

İlk modelleme soğumuş termal suyu yansıtan 25°C sıcaklıkta ve 0 bar basınç altında yapılmıştır. Bu durumda su aragonit, kalsit, kalsedon, kristobalit, dolomit, kuvars ve talk bakımından doygun bulunmuştur. İkinci modelleme suyun kuyudan çıkış anını yansıtan 82°C sıcaklıkta, 0 bar basınç altında ve kuyu başında titrasyon yöntemiyle ölçülen CO₂ miktarının suya eklenmesi ile yapılmıştır. Bu durumda suyun kuvars haricinde hiçbir mineralce doygun olmadığı gözlenmiştir. Üçüncü modelleme ise suyun yaklaşık 1 km derindeki durumunu yansıtan 100°C sıcaklık ve 100 bar basınç altında yapılmıştır. Yalnızca dolomitin doygun olduğu, kuvarsın ise dengede olduğu görülmüştür.

Bu modelleme sonucu kuvars açısından dengede olan suyun rezervuar sıcaklığının hesaplanmasında kuvars jeotermometresinin doğru sonuç verebileceği bulunmuş ve kuyu civarında gözlenen aragonit kristallerinin de varlık nedeni açıklanmıştır.

Sıcak sularının kökenlerinin anlaşılmasında çok gerekli olan stabil izotop (Döteryum ve Oksijen-18) analizleri çalışma alanı içindeki ve dışındaki çok sayıdaki su noktasından alınan su örneklerinde yapılmıştır. Bazı örneklerde ise yaş saptaması için

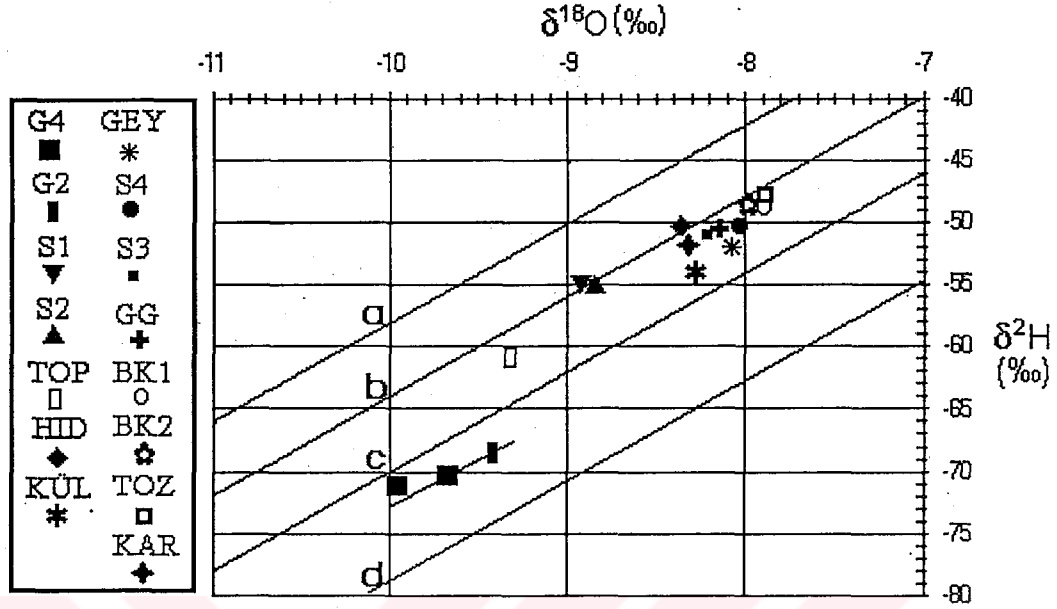
radioaktif izotoplardan trityum ve Karbon-14 analizleri de yapılmıştır. Sularda genellikle çözünen gazlardan olan metan, azot, oksijen, argon ve karbondioksit miktarları da gaz analizleri yardımıyla saptanmıştır.

Gönen ve Eksişidere Termal Sularının Kökeni

Çalışma alanı içinden ve dışından toplanan su örneklerinin stabil izotop konsantrasyonları (Çizelge 1), Anadolu, Akdeniz, Marmara meteorik su hatlarını ve paleoklimatik su hattını içeren $\delta^2\text{H}$ - $\delta^{18}\text{O}$ diyagramına işlendiğinde, Gönen termal sularının paleoklimatik su hattı ile Anadolu meteorik su hattı arasında kaldığı görülmektedir (Şekil 1). Bu durum Gönen termal suyunun yaşlı bir meteorik su olduğunu işaret etmektedir. Eksişidere termal suları ve diğer su noktalarından alınan sular meteorik su hatları arasında bulunduğu bunların kökeni de kesin olarak meteoriktir.

Çizelge 1 Örneklenmiş suların izotop analizi sonuçları

Örnek Adı	Örnekme Tarihi	$\delta^2\text{H}(\text{‰})$ Döteryum	$\delta^{18}\text{O}(\text{‰})$ Oksijen-18	$^3\text{H}(\text{TU})$ Trityum	Sıcaklık (°C)	pH	EC ($\mu\text{S}/\text{cm}$)
S1 Eksişidere Batı	Ağ.27, 1992	-55.1	-8.84	<1.1	42.0	8.0	389
S2 Eksişidere Doğu	Ağ.27, 1992	-54.6	-8.92	<0.7	28.1	7.7	400
S3 Gençlik Suyu	Ağ.27, 1992	-51.0	-8.21	11.6±1. 2	19.0	4.3	256
S4 Hafız- hüseyinbey	Ağ.26, 1992	-50.3	-8.04	20.0±1. 4	14.4	7.3	600
G2 Gönen	Ağ.26, 1992	-68.9	-9.41	<0.7	78.8	7.8	2530
G4 Gönen	Ağ.26, 1992	-70.5	-9.68	<0.7	73.8	8.0	2455
Gey Geyikli	Ağ.27, 1992	-52.1	-8.07	12.3±1. 2	25.2	4.2	213
G4 Gönen	Eyl.3, 1994	-71.4	-9.95	<1.7	75.0	7.1	2455
Hıd Hıdırlar	Eyl.4, 1994	-50.3	-8.37	<0.7	84.2	6.6	980
Top Topaklar	Eyl.4, 1994	-60.8	-9.31	<0.7	67.3	8.0	1700
GG Gobaklı- gediği	Ağ.14, 1996	-50.4	-8.18	-	8.5	6.3	92
BK1 Orman Bekçi Kulubesi 1	Ağ.14, 1996	-48.0	-7.89	-	10.5	7.7	65
BK2 Orman Bekçi Kulubesi 2	Ağ.14, 1996	-48.8	-7.96	-	7.5	8.4	65
Toz Tozlu	Ağ.15, 1996	-48.6	-7.90	-	4.6	8.4	122
Kar Kartalpınar	Ağ.15, 1996	-51.8	-8.32	-	6.5	7.4	79
Kül Külcüler	Ağ.15, 1996	-54.0	-8.29	-	34.7	6.9	1020



Şekil 1 Alınan su örneklerinin $\delta^2\text{H}$ - $\delta^{18}\text{O}$ diyagramı

(a - Doğu Akdeniz meteorik su hattı $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 22$)

b - Marmara meteorik su hattı $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 16$

c - Dünya ve Orta Anadolu meteorik su hattı $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 10$

d - palaeoklimatik su hattı $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 1.2$)

Gönen termal suyunda analizi yapılan argon gazının çözünürlüğü ile ortam sıcaklığı arasındaki ilişkiden ve soy gaz olması nedeni ile yeraltında reaksiyonla miktarının değişmeyeceğinden yararlanarak Gönen termal suyunun süzülmesi sırasında ortam sıcaklığının 0°C olduğu bulunmuştur. Bu sonuç da bizi Gönen termal sularının süzüldüğü zamanda çok soğuk iklim koşullarının hüküm sürdüğünü ve Buzul Çağı'nda süzölmüş bir su olabileceğini düşündürmektedir.

Gönen termal suları ile Kazdağ arasında bulunan sıcak ve soğuk sular arasında uzaklığın bir fonksiyonu olarak izotopik ve kimyasal açıdan bir korelasyon bulunmuştur. Bu ilişki Gönen termal sularının süzölme bölgesinin Kazdağ civarında olduğunu düşündürmektedir fakat bu durum kesin olarak ispatlanamamıştır.

Gönen G-4 kuyusundan elde edilmiş [31] sıcaklık logundan yararlanarak termal suyun hızı tahmin edilmeye çalışılmıştır [49]. Hesaplama sonuçlarına göre Gönen termal suyunun görünür hızı 0.17 m/yıl ve porozitenin $\%2$ olduğu varsayımına dayanılarak gerçek hızı 8.5 m/yıl olarak tahmin edilmiştir. Bu hıza göre Kazdağ yakınlarından süzölen su 10.000 yılda Gönen'e ulaşacaktır.

Gönen termal suyunun rezervuar sıcaklığı kuvars jeotermometresi yardımıyla 97.9°C olarak hesaplanmıştır.

Elde edilen hidrojeolojik sonuçlar yardımıyla Gönen termal sularının hidrojeolojik modeli oluşturulmaya çalışılmıştır.

Ekşidere termal suları ise sığ dolaşımli ve Gönen termal suyundan çok daha genç meteorik kökenli bir su olarak saptanmıştır. Süzölme bölgesi muhtemelen kaynağın güneyinde yer alan yükseltilerdir. Ekşidere termal suyunun rezervuar sıcaklığı kuvars jeotermometresi yardımıyla 61.9°C olarak hesaplanmıştır.



CHAPTER 1 INTRODUCTION

Turkey is one of the richest country in the world having a lot of thermal water springs. Most of these springs have not been investigated in detail and the potential of them is not very well known. In 1992 the Gönen geothermal region was selected for the detailed investigation of hydrogeologic conditions, origin and the potential of the Gönen and Eksidere thermal spring groups.

Since that time, the investigation consisting of geologic mapping by aiming to present geologic units and major tectonic lines, and collecting detailed hydrogeologic information about water-bearing properties and distribution of formations, recharge-discharge relationship, general characteristics of the hydrogeologic regime and reservoir rocks for thermal water. In-situ and laboratory works were carried out to determine the chemical, physico-chemical and isotopic characteristics of thermal water. This PhD dissertation is one of the separate element but also an integrated part of the İTÜ-ETH Northwest Anatolia Poly-Project.

The investigation area is located in Gönen Town of Balıkesir City geographically in Marmara Region.

Water samples for chemical and isotopic analyses were collected from hot water wells, hot and cold springs in different locations in and in the vicinity of the investigation area. The pH, EC(electric conductivity), temperature, alkalinity and acidity values were measured in the field. Chemical and isotopic analyses were mainly carried out in Switzerland (laboratories of ETH) and Germany.

CHAPTER 2. GENERAL INFORMATION ABOUT THE INVESTIGATION AREA

2.1. Location and Transportation

The investigation area is located geographically in Marmara Region in Gönen Town of Balıkesir City (NW-Turkey). It includes the Gönen thermal springs (500m north of Gönen town) and the Eksidere thermal springs (13 km south-west of the town). The investigated area is about 400 km² (Figure 2.1).

Gönen town is one of 16 towns of Balıkesir City. The town has 3 sub-districts and 90 villages. The total area of the town is 1152 km² (8% of the Balıkesir City) and it is located on 46'06" North latitude and 27'38" East longitude. The town is bordered by the Marmara Sea (Erdek Bay) in the north, Bandırma town in the north-east, Manyas town in the east, Balya town in the south, Yenice town in the south-west and Bigger town in the west.

It is possible to reach the investigation area all seasons via state highway Nr.2. Regular ferryboat line is also available between Istanbul and Bandırma with a railway connection to İzmir.

2.2. Topography, Flora and Climate

The center of the investigation area is the Gönen Plain which is surrounded by mountains in the west and the south. The plain is separated by small Neogene hills from Tahirova Plain in the north and Manyas Lake in the east. The highest points are Kocayurt Peak (634 masl) in the west, Akçalı Peak (579 masl) in the south and Asar Peak (374 masl) in the west.

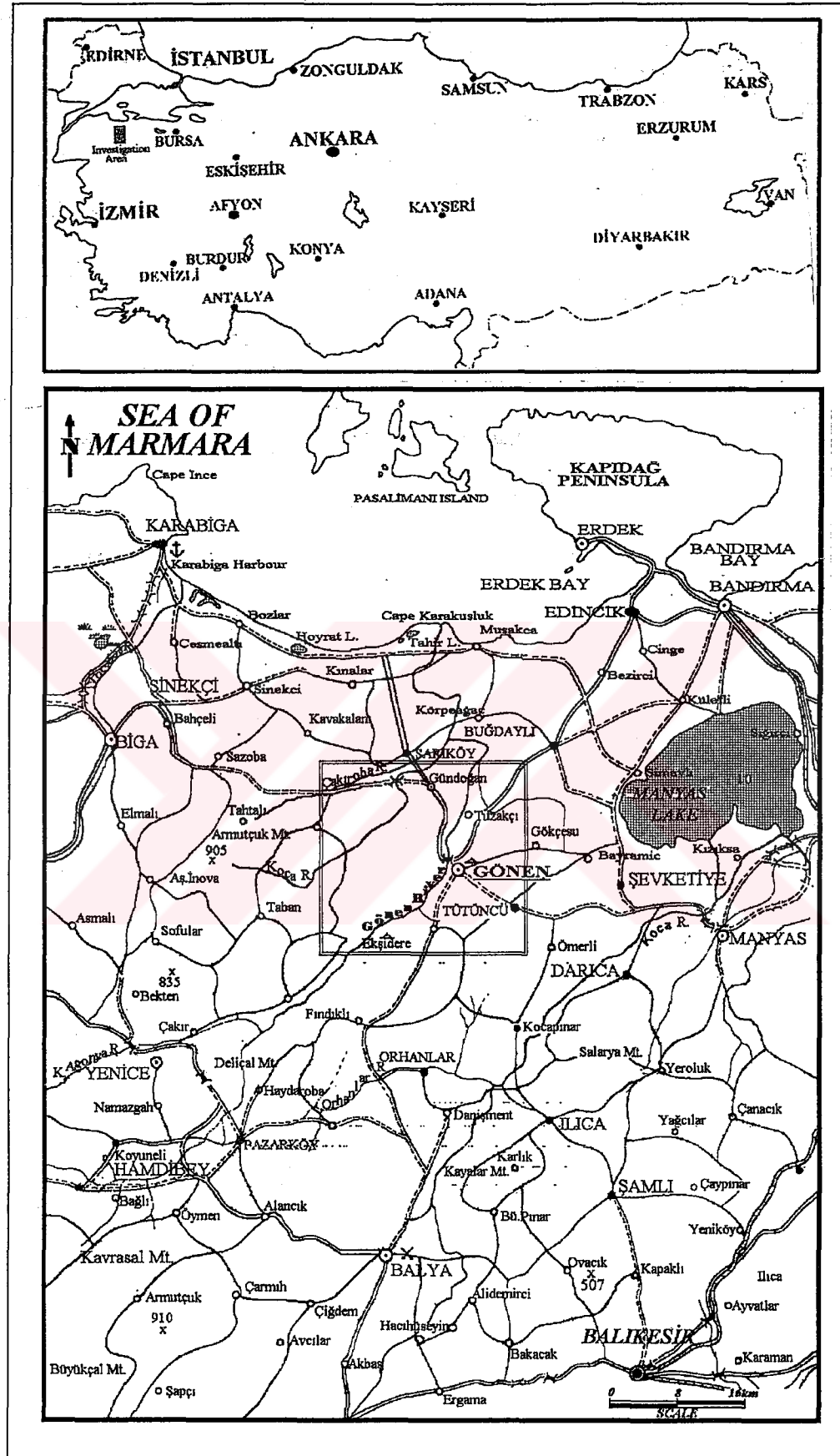


Figure 2.1 Location map of the investigation area

In the investigation area the stream pattern was formed by the Gönen River (antique name Aisepos) and its branches. The Büyük Agonya and the Küçük Agonya Rivers reach to the Gönen Plain by crossing the valley among Evgi, Kaplan, Göklen and Karlık mountains and from this point the river is called as the Gönen River. From the west, Kocadere and Keçi Streams and from the east, Çaylak, Keten and Çerpes streams join the river and after this junction the river leaves the plain through the epigenetic Ayvalıdere Gorge and enters to the Tahirova Plain formed by the delta of the river and reaches into the Erdek Bay (Figure 2.2 and Figure 2.3).

The total length of the Gönen River is approximately 135 km, and the lengths of the river on the Gönen Plain and the Tahirova Plain are 42 and 8 km., respectively.

In the north of the investigation area, a couple of small lakes (generally lagoons and abandoned channels) are seen in the Tahirova Plain that cover a surface area of 1 km². The lakes are temporarily connected to the sea during the tide.

The surface area of the Gönen Plain (including the Sarıkoy Plain) is 187 km² and its average altitude is 30 masl. The surface area and the average altitude of Tahirova Plain are 55 km² and 10 masl.

The forests are confined to the mountainous periphery. Although the dominant plant is bush there are also extensive stands of pine, poplar, chestnut and walnut trees. Only agricultural plants, such as rice, wheat, tomato and other vegetables, are cultivated in the plain.

The Marmara type climate prevails in the investigation area which is a transitive regime between Mediterranean and Black Sea climates. The annual average precipitation is 706.1 mm and average temperature is 14.5°C (average of 1950-1970). The maximum precipitation is seen in November, December and January. Table 2.1 shows the climatic characteristics of Gönen for the period 1980-1989.

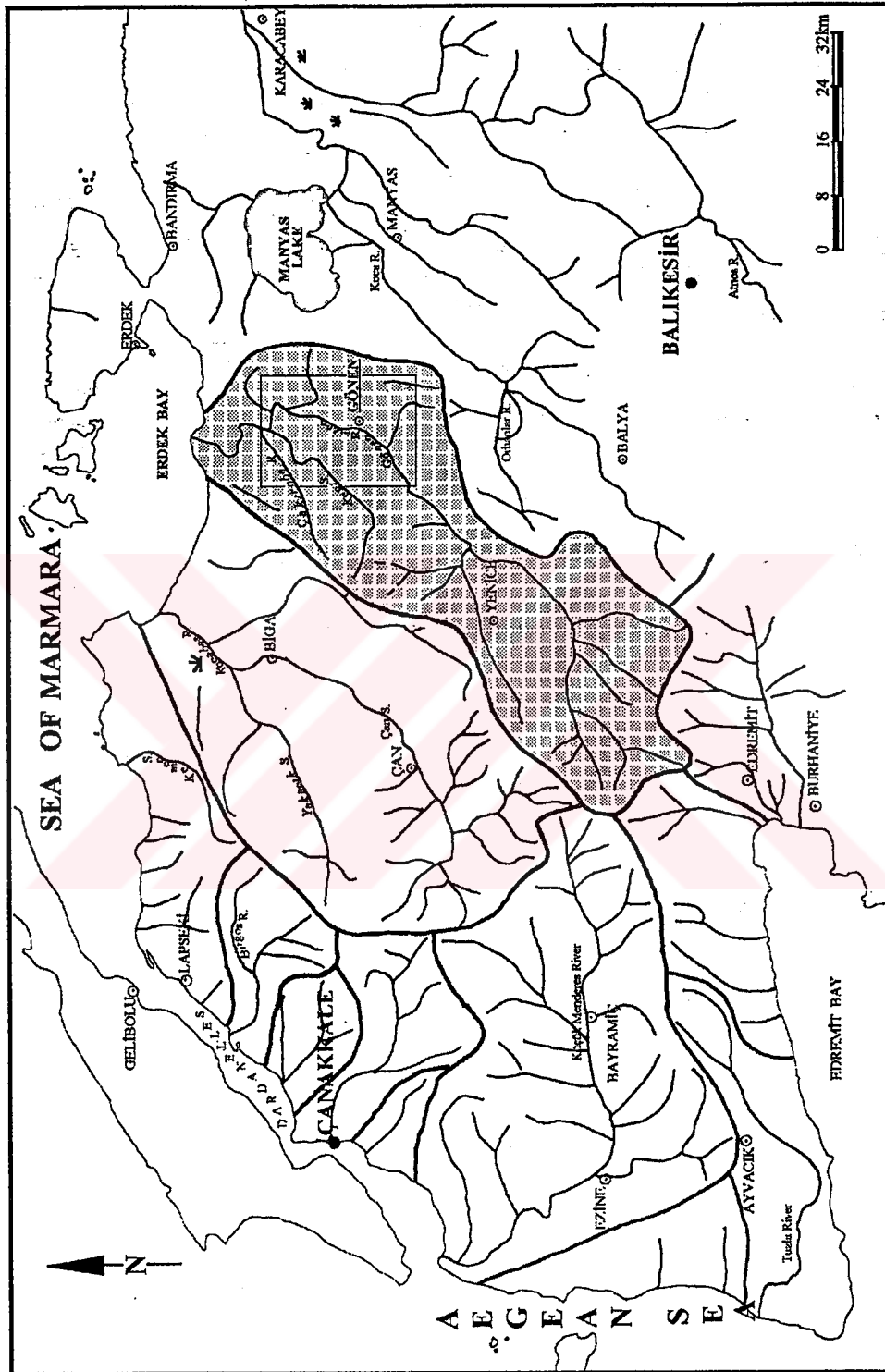


Figure 2.2 Stream patterns and watershed lines of the Biga Peninsula and studied part of the area

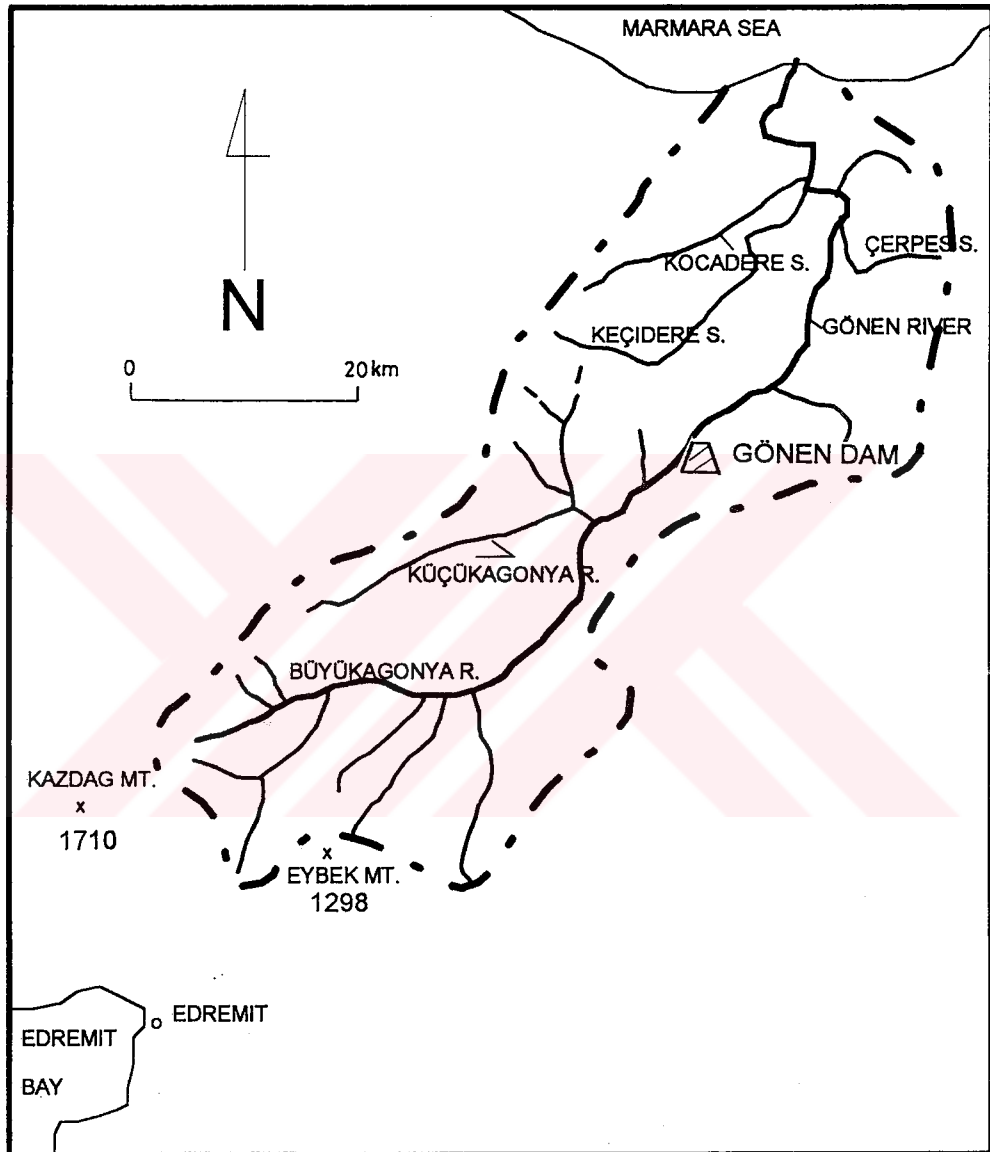


Figure 2.3 Catchment area and branches of the Gönen River

2.3. Population and Settlement

The population of Gönen mainly consists of Muslim immigrants from Bulgaria, Greece and Caucasia(Circassians and Georgians). The number of inhabitants of the whole town and of the town centre is shown in Table 2.2.

Table 2.1 The climatic characteristics of Gönen (mean values of 1980-1989) compiled from the Gönen Meteorology Station

Months	Temperature (°C)	Humidity (%)	Precipitation (mm)
Jan.	5.4	80.8	113.3
Feb.	5.0	78.0	63.8
Mar.	7.2	77.7	53.2
Apr.	12.0	76.0	51.0
May	16.2	75.0	40.0
June	21.0	67.3	28.8
July	22.9	65.9	15.6
Aug.	22.6	68.9	9.6
Sept.	19.2	70.8	8.4
Oct.	14.3	75.9	45.4
Nov.	9.3	80.3	123.2
Dec.	7.2	81.1	110.2
Average	13.5	74.8	55.2
Total			662.4

Table 2.2 The number of inhabitants of the Gönen town and of the town centre according to censuses for the period 1950-1990 and estimation for 2000 (records of the Gönen Governorship)

Year	Gönen Town	Town Centre
1950	23,000	9,983
1955	25,000	9,581
1960	27,000	10,890
1970	34,620	13,922
1980	36,934	14,750
1990	67,600	26,850
2000	100,000	40,000

2.4. Economy and Mining

Agriculture plays an important role for the economy of the town. Fertile and irrigated soil is cultivated generally two times in a year. Mountainous areas are generally used as pasture. Milk is processed in dairies. There are 1 food and 6 leather factories, 2 flour mills and more than 50 dairies.

Table 2.3 shows the important ore deposits of the Gönen town. The lignite of Sebepli is still under exploitation and mercury of Hodul had been exploited in 1960's [1].

Table 2.3 Ore deposits and reserves of Gönen [1]
(1) Measured, (2) Indicated, (3) Inferred

Location	Ore Type	Reserve(ton)	Grade(%)
Gaybular	Lead	45,000 (1)	10
Hodul	Mercury	25,000 (2+3)	0.19 Hg
Sebepli	Kaolin	150,000 (2+3)	22-37 Al ₂ O ₃
Ilcaoba	Clay	250,000 (3)	-
Sebepli	Lignite	570,000 (3)	-

2.5. History

The antique name of Gönen is Artemea. The name of Gönen was derived from Germenon according to some historians such as Hasluk, Wiegand and Philippon [2]. The town was captured in 1334 by Ottomans during the reign of Orhan Ghazi. Gönen became crowded and constituted as a town after the Russian War (1878) by the people immigrated from Trinovo and Pleven. The antique bridge (Alexander's Bridge) was constructed by Alexander the Great in 400 BC to cross the Gönen River before the Iran War. The remains of two Byzantine castles can be seen in Babayaka and Alacaoluk villages (Figure 2.4). Figure 2.5 shows an inscription panel of a fountain from Ottoman time.

2.6. Tourism

The town is very active in domestic tourism due to the Gönen Spa. There is a three-star hotel (Yıldız Otel) out of four in the spa. Almost all houses around the spa are used as pensions. The hotels are 100% full in summer season. The number of curists are between 700-1200 per day. Total bed capacity of hotels is around 555.

The cure centre helps to cure muscle rigidity commonly seen after surgery and accidents, various types of rheumatism and calcification, gynaecological diseases, mental stress, children's development disorders and gastrointestinal problems.

2.7. The Gönen Dam

Brief information is given below about the Gönen Dam (still under construction) which will play an important role for the development of the town.

Type	Earth fill
Catchment area	1,116 km ²
Aim	Flood control + irrigation + energy
Thalweg	94 masl
Min. water level	125 masl
Ave. water level	158.30 masl
Max. water level	162 masl
Crest	164 masl
Height	70 m
Total volume	210,000,000 m ³
Ave. annual water flow	512,540,000 m ³
Annual regulated water	148,936,000 m ³
Max. area of reservoir	14 km ²
Max. length of reservoir	27.2 km
Irrigation area	175 km ²
Power	11 MW
Annual production	63,000,000 kWh



Figure 2.4 The remains of a Byzantine castle in Alacaoluk



Figure 2.5 Inscription panel of an antique fountain

(Transcription: Bu dilcu çeşme-i baki, nam-ı hümayun yaptuktā

Zalal-ı lütfü Gönen halkını etti reyyan

Translation: After the construction of this captivating and everlasting fountain on behalf of Empire
Kindness of the pleasant water satisfied the people of Gönen with drink)

CHAPTER 3. PREVIOUS STUDIES

Various hydrogeological and geological aimed investigations were conducted in the Gönen Plain and its surrounding area and some of them are in connection with the Gönen and Ekşidere thermal springs.

The region was formerly studied by TCHIHATCHEFF [3] in 1853, PHILIPPSON [4] in 1918, PENCK [5] in 1918 and CHAPUT [6] in 1936.

R.REMAN [2] studied Gönen thermal water in 1942 for balneological purposes.

K.Ö. ÇAĞLAR [7] studied Gönen and Ekşidere thermal springs in 1948 for the inventory of "Mineral and Thermal Water Springs of Turkey".

İ.KETİN and F.ROESLI [8] carried out macro-seismic research work on the earthquake of Gönen-Yenice (18.3.1953). It is stated that the main features of these fault lines were a horizontal displacement of 3.5 to more than 4 meters and a vertical displacement of 0.4-1 meters. The horizontal displacement was always 'right lateral' and their course was marked by a series of open fissures arranged 'en echelon' to the general fault strike.

H.WEDDING [9] has attempted first outline of the Neogene sequence of Biga Peninsula in 1960. He distinguished 'Lower Andesite' and 'Upper Agglomerate' including sedimentary unit and agglomerate-tuff unit

O.SALTIK [10] prepared a report on hydrogeology of Gönen-Sarıköy Plain in 1964.

M.GÖRAL [11] reported ground water reserve of Gönen-Sarıköy Plain in 1967.

GİZBİLİ Engineering Company [12] studied Gönen Plain and surrounding area in 1967, for feasibility of Gönen Dam.

M.V.ALKAN [13] studied mercury (cinnabar) mineralization around Hodul village in 1970. He divided geological units into series such as Palaeozoic Series (phyllite, quartzite, quartz-sericite schist, graphite-calc-sericite schist, quartz-sericite-chlorite-mica schist, clayey schist and slate), Mesozoic Series (partly recrystallized limestone), Tertiary Series (andesite and dacite, and their tuffs). He stated that the cinnabar mineralization occurred due to volcanic intrusion and was seen inside limestone and schist near the fault zones.

L.BENDA [14,15] carried out palynological and radiometric age determinations of the Neogene in NW Anatolia in 1971 and 1974. He stated that coal occurrences in this area have shown that the coal development and consequent lacustrine-volcanoclastic sedimentation over the entire area took place in the same time. The studies show ages of 18.3 ± 0.3 - 19.8 ± 0.3 ma.

T.KARTAL [16] prepared a hydrogeological report on Gönen thermal springs in 1973.

İ.ÜLKER and N.ÇEKİRGE [17], in 1973, prepared the Gönen thermal water city, regulating reconstruction plan report.

E.BİNGÖL *et al.* [18] described rock units of Biga Peninsula in 1975, as follows;
The Pre-Permian aged metadunite, metagabbro, pyroxenite, amphibolite, gneiss, marble,

Lower Triassic aged, generally Permo-Carboniferous and recrystallized limestone blocks containing low grade metamorphosed spilite and grauwacke (the Karakaya Formation),

Middle-Upper Triassic aged no block containing clastic rocks,

Granite and granodiorite and their metamorphic aureole (contact zone) younger than Upper Triassic,

Lower Jurassic aged sandstone,
Upper Jurassic aged limestone with chert nodules,
Eocene aged volcanics and grauwacke,
Neogene aged volcanics, marly limestone and volcanosedimentary rocks.

They also reported that low-grade metamorphosed spilite and grauwacke that contains Permo-Carboniferous and other blocks, lies between eastern side of Kazdağ and Balya in SW-NE strike to the Marmara Sea, and from Manyas Lake to Bilecik, north of Sivrihisar and Ankara.

E.ÖLMEZ [19] prepared the Gönen 1 (G1) and the Gönen 2 (G2) hot water drilling report in 1976.

N.ÇEKİRGE [20] prepared "the Gönen Thermal Water City Project" in 1977.

N.KELEŞ [21] prepared the geophysical resistivity report of Tahirova-Gönen-Sanköy Plains in 1980.

M.GÖKÇEN [22] carried out photogeological studies of Gönen Plain and its surrounding area in 1981.

A.AYGÜN and A.ÇAKIR [23], in 1985, studied clay and kaolinite reserves around the Balıkesir-Gönen-Balya region. In this study, Paleozoic and other base rocks divided into four groups;

1-Epimetamorphics, 2-Permian limestone, 3-Triassic detritics and 4-Cherty limestone.

Miocene aged volcanics and lacustrine sediments were also mapped in this study and it was stated that these units were horizontally and vertically transitive.

T.ERCAN et al [24] studied the volcanic rocks of Biga Peninsula in detail in 1986.

Ş.CENGİZ [25] investigated the fault zone across the Gönen River by using the geophysical resistivity method in 1986. He found a border between measurement points indicated by closing of contour intervals indicating an inferred fault.

ORME Company [26] prepared the feasibility report for the geothermal central heating of the Gönen town in 1987.

A.ALTINAY *et al* [27] studied the Susurluk-Manyas-Gönen-Yenice-Kalkım region in 1989, for the purpose of lignite exploration.

In this study the Paleozoic-Mesozoic aged metamorphic rocks, recrystallized limestone and Paleocene aged granite-granodiorite were described as base rocks of the region which are overlain by the Upper Oligocene-Pliocene aged volcanic and sedimentary rocks.

M.SIYAKO *et al* [28] studied the Tertiary geology and hydrocarbon potential of the Biga and Gelibolu Peninsulas in 1989. It is stated that the Tertiary rocks of Biga and Gelibolu Peninsulas were grouped into four sequences separated by major erosional unconformities. They are the Maastrichtian-Early Eocene, the Middle Eocene-Oligocene, the Miocene and the Pliocene-Quaternary sequences. It is also stated that all the Oligocene sediments were eroded during the regional uplift at the end of Oligocene in the Biga Peninsula, wide areas were covered by andesites, dacites, rhyolites and acidic tuffs, and several large granodiorite plutons were placed during Early-Middle Miocene, during the Pliocene and Quaternary fluvial sediments and lacustrine carbonates were deposited. With the inception of the North Anatolian Fault in the Early Miocene large number of NE-SW trending dextral faults had formed and 8 km long dextral offset were determined across the İnova-Sarıköy Fault plane.

E.HERECE [29] studied the fault trace of 1953 Yenice-Gönen earthquake and the westernmost known extension of the NAF system in the Biga Peninsula in 1990. It is stated that the main faults exhibited a clockwise en-echelon pattern from

Manyas-Danişment in the east, Yenice-Gönen in the centre and Sarıköy-İnova in the west. The nature of grabens, as pull-apart basins, during Late Pliocene to Quaternary time in an essentially strike-slip regime had been quantified in the Bursa-Gönen graben apparently moved 3.4 km West-Southwest along these faults, while E-W normal faults developed in the graben that account for some 8.2 km of North of South extension.

A.İ.OKAY *et al* [30] investigated geology and tectonic evolution of the Biga Peninsula in 1990. In this study four distinct NE-SW trending zones were recognised in the Biga and Gelibolu Peninsulas, which from NW to SE were; the Gelibolu, the Ezine, the Ayvacık-Karabiga and the Sakarya zones; the Sakarya zone was made up of the Triassic Karakaya Complex overlain unconformably by the Jurassic-Cretaceous sedimentary rocks, in the west, the gneisses, amphibolites and marbles of the Kazdağ Group occurred tectonically below the Karakaya Complex while in the east low grade metamorphic rocks intruded by a granite form the stratigraphic basement to one of the Karakaya units (the Hodul Unit). Four tectonostratigraphic units were distinguished in the Karakaya Complex: The Nilüfer Unit, the Hodul Unit, the Orhanlar Grauwacke and the Çal Unit. It is also stated that all the four Karakaya units were strongly deformed during the late Triassic Karakaya orogeny.

Z.ERZENOĞLU and A.ULUŞAHİN [31] prepared the Gönen G-4 and the G-4/A thermal water well drilling report in 1990.

CHAPTER 4. GENERAL GEOLOGY

4.1 Introduction

The knowledge of geological setting around thermal water springs is necessary for better understanding of the hydrogeological and geothermal conditions. It gives valuable information about the distribution and characteristics of cold and hot water aquifers.

The investigated area is situated geologically in the Sakarya Zone of Pontides. The Sakarya Zone corresponds approximately to the Mysisch-Galatische Scholle [32], to the Inner Pontides [33], and to the Sakarya Continent [34]. In western Turkey the Zone occupies roughly the area between the North Anatolian Fault and the İzmir-Erzincan suture (Figure 4.1). The Sakarya Zone consists of a pre-Liassic metamorphic basement and a cover of Mesozoic and Tertiary clastics and carbonates.

Basic geological data were compiled from the maps and investigations of Mineral Research and Exploration Institute (MTA), Bingöl *et al.* [18] and Okay *et al.* [30] in Biga Peninsula.

Most of geological studies in Gönen have been confined to explorations of industrial raw materials, lignite, investigations of Yenice-Gönen strike-slip fault zone and thermal water.

Geological studies in the investigation area were carried out in summer times for the period 1990-1993. 1/25.000 scaled topographic maps (Bandırma H19-d1,d2,d3,d4) were used .

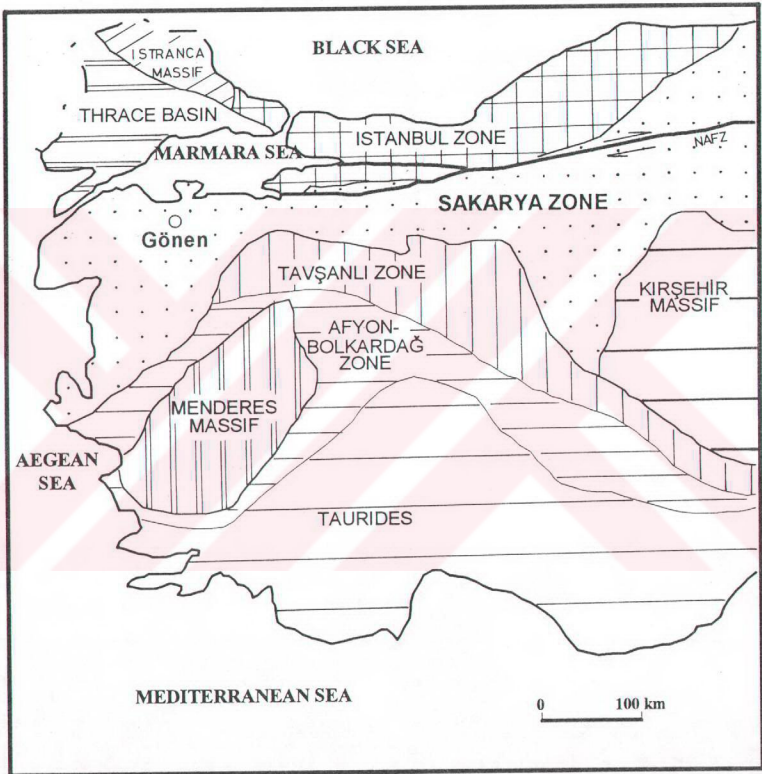


Figure 4.1 Tectonic units of western Anatolia [35]
(NAFZ - North Anatolian Fault Zone)

4.2 Stratigraphy and Lithology

The Karakaya Complex is the oldest unit in the investigation area. This unit is unconformably overlain by the Jurassic-Cretaceous aged Bayırköy Formation, Bilecik limestone and Vezirhan Formation. Neogene lacustrine sediments and volcanic rocks overlie all these formations. The overlying superficial deposits principally consist of Quaternary alluvium laid down by the Gönen River and its branches (Figure 4.2 and Figure 4.3).

4.2.1 The Karakaya Complex (K.K.)

The name of Karakaya is first given by Bingöl *et al.* [18]. The Karakaya Zone has a very wide distribution in the Pontides and extends from Edremit on the Aegean coast to Ankara, and further east of Tokat and the Ağvanis Massifs.

The Karakaya Complex tectonically overlies the gneisses, amphibolites and marbles of the Kazdağ Group and is overlain unconformably by the Jurassic-Cretaceous sedimentary rocks. Four tectono-stratigraphic units were distinguished in the Karakaya Complex (Figure 4.4 and Figure 4.5)[30];

- | | | |
|----------------------------|---|--|
| 1-The Nilüfer Unit | : | Green schist metabasic rocks and marble |
| 2-The Hodul Unit | : | Arkosic sandstone, black shale and siltstone with Permian aged limestone olistoliths |
| 3- The Orhanlar Greywacke: | | Monotonous greywackes with subordinate shale and small Lower Carboniferous limestone olistoliths |
| 4-The Çal Unit | : | Basic volcanic and pyroclastic flows, olistostromes with spilite and Upper Permian limestone fragments and olistoliths, volcanogenic sandstone and minor amounts of red radiolarian chert, calcarenite and pelagic limestone |

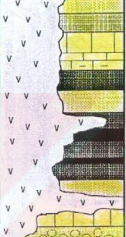
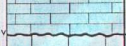
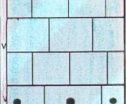
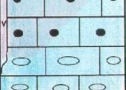
ERA THEM	S Y S T E M	S E R I E S	N A M E	S y m b o l & T h i c k n e s s	LITHOLOGY	E X P L A N A T I O N S
C E N O Z O I C	QUA.			Qal 20-40 m.		Alluvium UNCONFORMITY
	N E O G E N E	M I O C E N E		nv nla 250-400 m.		Claystone (with lignite), limestone, conglomerate, sandstone, marl and tuffite(nla) Andesitic lava, tuff and agglomerate (nv)
						UNCONFORMITY
M E S O Z O I C	CRE.	UPPER	VEZIRIAN FORMATION	Kv ~80 m.		Pelagic limestone UNCONFORMITY
		LOWER				
	J U R A S S I C	MALM	B İ L E C İ K L I M E S T O N E	Jb ~800 m.		Micritic limestone
		DOGGER				Oolitic intercalated nodular (chert) spartic limestone
						Oncolitic limestone UNCONFORMITY
		L I A S	B A Y I R K Ö Y F O R M A T I O N	Jba ~1000 m.		Carbonate cemented conglomerate sandstone, siltstone, marl and shale UNCONFORMITY
O I C	T R I A S S I C		K A R A K A Y A C O M P L E X	TK >3 km.		Permian aged recrystallized limestone olistoliths Quartz-albite-muscovite schist Quartz-feldspar-muscovite-chlorite schist Metasiltstone, metasyenite Marble and black chert

Figure 4.2 Generalized stratigraphic columnar section of the investigation area

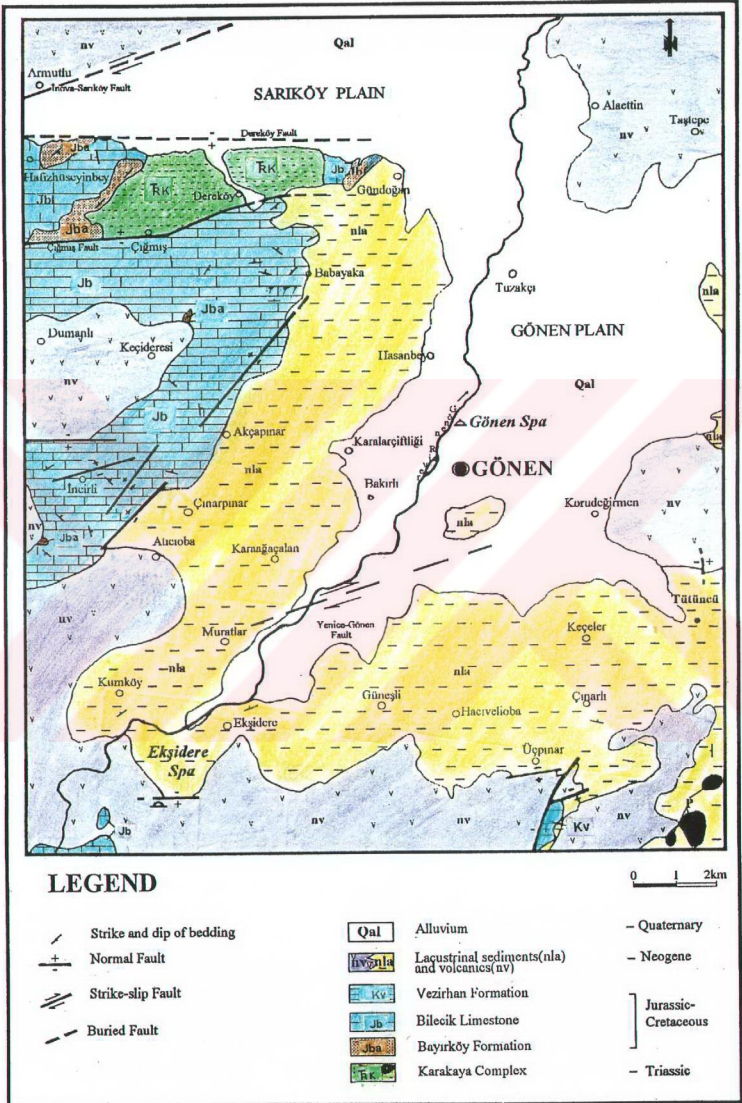


Figure 4.3 Simplified geological map of the investigation area

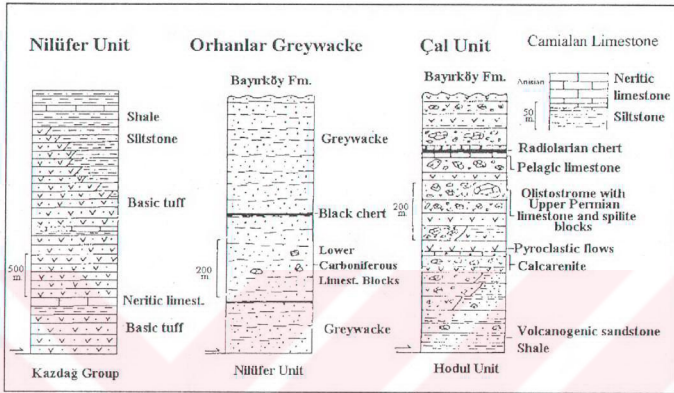


Figure 4.4 Stratigraphic columnar sections of the Karakaya Complex units with the exception of the Hodul Unit [30]

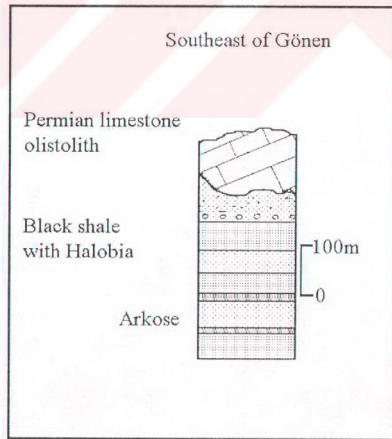


Figure 4.5 Stratigraphic columnar section of the Hodul Unit for the southeast of Gönen [30]

The Karakaya Complex seen in the investigation area corresponds to the Nilüfer Unit and crops out on the south of the Sarıköy Plain around Dereköy in an area of approximately 7 km². The best observation of this unit can be done only along the road-cuts in the field because of dense bush covering and lack of well exposed crops due to alteration.

The unit is observed as altered, foliated, green colored (Figure 4.6) with intercalation of marble and black chert, and identified as;

Quartz-albite-muscovite schist

that consists of muscovites orientated parallel to schistosity, a few lepidoblasts of biotite and granoblasts of albite (pertaining to a secondary texture due to diagenetic change),

Quartz-feldspar-muscovite-chlorite schist (metasyenite porphyry)

that derived from a magmatic origin having muscovites orientated to schistosity, and lepidoblasts of chlorite, porphyroblasts of quartz and feldspar, and granoblasts of quartz and feldspar,

Metasiltstone (metatuff)

that has abundant sericite and biotite orientated parallel to schistosity, cryptocrystals of quartz and secondary calcite crystals along the cracks, and is laminated,

according to thin section examinations collected from the field. Only quartz veins and muscovite minerals are recognisable in hand specimens.

It is the lowest tectonic unit of the Karakaya Complex that made up metatuffs and metavolcanic rocks with intercalation of marble and phyllite [30]. The bottom of this unit can not be seen in the investigation area.

Marble lens of the unit can be best seen in the quarry on the way from Dereköy to Babayaka village (Figure 4.7). Marble is observed as white colored with brown colored veins, fine grained and mostly foliated in the field. It consists of completely



Figure 4.6 The Nilüfer Unit of Karakaya Complex near Dereköy



Figure 4.7 The marble lens of Nilüfer Unit observed in the marble quarry near Dereköy

recrystallized microcalcite crystals and fissures are filled by secondary calcite and limonite.

Black cherts (metachert) are seen in the area between Dereköy and Çıgırmış villages. The cherts widely cover this part of area due to resistance of rock. They even keep their original folded structure in some places without any layer on the top and the bottom of it. It is low grade metamorphosed chert and hematite intercalated, and contains secondary quartz veins that also metamorphosed (Figure 4.8).

The thickness of this unit is more than 3 km as a result of syn-metamorphic thrusts and it contains no fossils but Triassic age has been asserted for the unit according to results of regional tectonic considerations [30].

This unit resembles to deposits of intra-arc or/and fore-arc basins developed on oceanic or transitional crusts [30].

The Permian limestone olistoliths of Karakaya Complex is exposed in south-east (around Çiftlikalan, Çobanhamidiye and Atagölcük) of the investigation area. It is not clearly seen whether the outcrops of olistoliths are connected to each other or separated blocks because of the covering of the Neogene sediments the area among them. The olistoliths belong to the Hodul Unit[30] but the unit itself is seen out of the investigation area (Figure 4.9)

The olistoliths are grey colored and recrystallized limestone containing coarse calcite crystals. They contain light-brown coloured cracks filled by limonite and white colored calcite veins. Their primary texture is micritic. The limestone displays an absence of layering, e.i. it is in a massive form.

The samples collected from limestone olistoliths in the Hodul Unit in different locations have yielded Early Carboniferous, Middle-Late Carboniferous, Late Carboniferous-Early Permian and Late Permian ages [30] (90% Upper Permian). But the samples collected from the investigation area have no fossils.

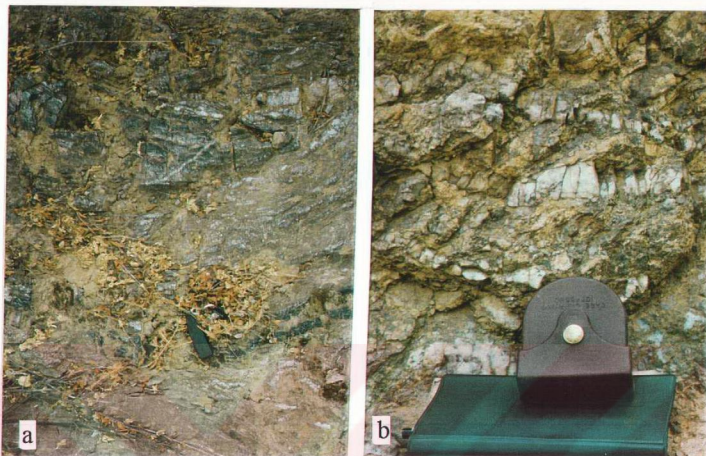


Figure 4.8 Metamorphosed chert(a) and quartz(b) boudins in the Karakaya Complex near Dereköy



Figure 4.9 The olistoliths of Karakaya Complex

4.2.2. The Bayırköy Formation (Jba)

The name of this formation, that consists of mainly sandstone, is given after Bayırköy village in west of Bilecik by Granit [36]. The unit crops out around Hafızhüseyinbey, west of Çığmı, Gündoğan and in the valley of Keçi Stream.

The unit is observed as yellowish-brown, thin to thick bedded, carbonate cemented conglomerate, sandstone, siltstone, marl (Figure 4.10). Quartz and muscovite fragments are seen in hand specimens. The samples collected in the field are described as;

Clayey limestone

that contains microfossil and quartz grains united by clayey carbonate cement,

Marl

that contains clayey micrit with secondary calcite filling solution openings,

Sandstone

that contains angular crystals of quartz, feldspar, muscovite and biotite with small amounts of limestone fragments in sand size and the grains are united by limonitic carbonate cement.

Silty limestone

that consists of laminated quartz, microfossil and volcanic rock grains in silt size united by clayey micritic cement,
according to thin section examinations.

Bed thickness of conglomerate is around 100 cm, and 10-15 cm at siltstone levels.
The bedding is graded.

The formation unconformably and transgressively overlies the units of Karakaya Complex and overlain by Bilecik Limestone with a non-depositional unconformity (diastem). The thickness of the formation was not measured in the investigation



Figure 4.10 The Bayırköy Formation observed in the valley of Keçi Stream

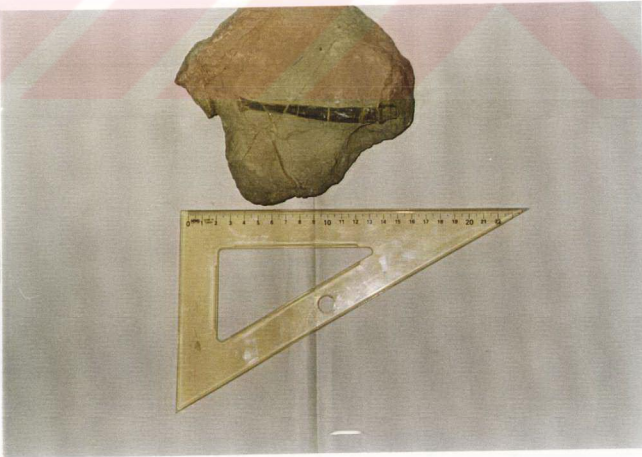


Figure 4.11 The Belemnite fossil found in the Bayırköy Formation

area. Along the Bayırköy section it is 1112 m. thick [37]. The formation is poorly fossiliferous and only one Belemnite fossil (Figure 4.11) is found inside collected samples. But it is known that the formation contains locally abundant crinoids and ammonites. The age of this formation have been established as Lower Pliensbachian (Lias) [30].

The fauna included and coarse grained detrital material indicates a shallow sea depositional environment for this formation.

4.2.3 The Bilecik Limestone (Jb.)

The Bilecik Limestone named after Bilecik City by Granit [36] and Eroskay [37]. It is the largest outcrop of the Mesozoic aged rocks in the investigation area.

This formation is observed as white-cream colored, thick-bedded and oncolitic-angular pebbly limestone at the base; black-light brown colored, medium-bedded and oolitic intercalated nodular (chert) sparitic limestone in the middle; and grey-black colored, medium-bedded and micritic limestone on the top (Figure 4.12 and Figure 4.13). The samples collected in the field are described as;

Fossiliferous oolitic limestone

that consists of ooliths and microfossils united by sparry calcite cement and fractures are filled by secondary calcite and dolomite,

Biopelsparite

that consists of ooliths, fossil fragments, fossils and intraclasts united by sparry calcite cement,

Oncolitic microfossiliferous limestone

that contains ancooids made up by limestone fragments (nucleus size varies between 1-15 mm), cataclastic quartz volcanic rock fragments (as lithoclast) and microfossils united by micritic cement,



Figure 4.12 The outcrop of the Bilecik Limestone near Hafızhüseyinbey



Figure 4.13 The general appearance of the Bilecik Limestone at south of Ekşidere

Sparite (sparry limestone)

that is made up by sparitized cryptocalcite crystals, scarce dolomite and fossil fragments, its primary texture is micritic and fractures are filled by secondary calcite,

Micritic limestone

that contains more than 90% micrite,

Didolomitic limestone

that is partly (50%) converted to dolomite by the replacement of the original calcite then converted to calcite again, its primary texture was micritic and contains abundant rhombohedral crystal shapes of dolomite filled by sparry calcite and fractures are filled by secondary calcite,

Altered calcite fill

that contains altered and oxidised calcite crystals united by carbonate cement and is a recemented hydrothermal carbonate rock,

Fossiliferous limestone

that contains abundant fossils inside micritic texture, according to thin section examinations.

The formation is fossiliferous at the base. Tintinnidae, Textulariidae and some other foraminifer fossils (det. E.Meriç) are found in collected samples that are not characteristic to for the age of the formation. But in general the Bilecik limestone is Middle-Upper Jurassic-Early Cretaceous aged [30].

The Bilecik Limestone was deposited in continental shelf while lower parts of it indicating high energy and shallow sea, upper parts indicate low energy and deep sea conditions.

4.2.4 The Vezirhan Formation (Kv)

The name of the formation that consists of pelagic limestone, is given by Eroskay [37]. The Vezirhan Formation crops out around Kocataş Peak, at the south of Üçpınar. It is seen as white, light-brown and pink colored, thin to medium bedded, intensively fractured and identified as clayey limestone.

The bottom of the formation is not seen in the investigation area. This formation overlies the Bilecik limestone in several parts of the Biga Peninsula [30]. It is overlain by the Tertiary aged rocks in the investigation area but around Bilecik abundantly fossiliferous Maestrichtian aged sandstone (the Gölpaşarı group) overlies the Vezirhan Formation with a diastem [37].

The fossil fauna of samples collected from various localities in Biga Peninsula and Bilecik gives Upper Cretaceous age [30,37]. The total thickness of the formation is stated as 80 m. around Bilecik [37].

The limestone was deposited in an open sea environment.

4.2.5 The Tertiary Deposits (nv, nla, Qal)

Miocene aged volcanic rocks (nv), lacustrine sediments (nla) and Quaternary aged fluvial deposits (Qal) are observed almost all over the investigation area.

Lavas commonly have andesitic composition, are dark grey and red, and consist of abundant plagioclase, biotite, pyroxene, amphibole and opaque microcrysts in a hylocrystalline porphyritic texture. Typical flow structures are formed in some places. Feldspar crystals are coarse grained. Alteration is observed along fractures. Altered lavas are reddish-brown and white-yellow colored. Feldspar minerals are extensively altered to form kaolin. Silicification and silicified zones are often observed.

Tuffs are in form of tuffite, sandy tuffite, agglomeratic tuffite and tuffaceous sandstone (Figure 4.14). They consist of brownish-yellow, white and grey colored, commonly loose and sometimes compacted clay, silt, sand and tuff having plagioclase, biotite and amphibole crystals. The bedding varies from thick to thin. Tuff-tuffite interfingers with agglomerates and lacustrinel sediments. Agglomerates consist of rounded, sub-rounded and angular andesite gravels.

Lacustrinel sedimentary rocks in the investigation area consist of claystone with lignite, limestone, conglomerate, sandstone and marl.

Lacustrinel sediments with lignite are seen locally within the volcanic rocks. Claystone is thin to medium bedded, brownish-yellow, nearly white colored and contains quartz and aragonite veins, semi-silicified and semi-coalificated wood, and in some places economical lignite (≈ 10 m.) beds. Limestone is light grey colored, thick bedded, siliceous limestone with silica-band intercalations. Some layers of limestone contain gastropod fossils. Conglomerate is well-cemented, medium to thick bedded, poorly sorted and coarse grained at the bottom. The gravels are rounded, sub-rounded and angular. Sandstone is generally observed loose but sometimes consolidated.

The volcanic, volcano-sedimentary and lacustrinel sedimentary rocks are overlain by Quaternary aged alluvium that laid down by the Gönen River and its branches. The thickness of alluvium is generally 20 m. but in some places reaches up to 100 m.

The total thickness of Tertiary deposits is around 400 m.



Figure 4.14 The exposure of tuffites at the southern part of the investigation area

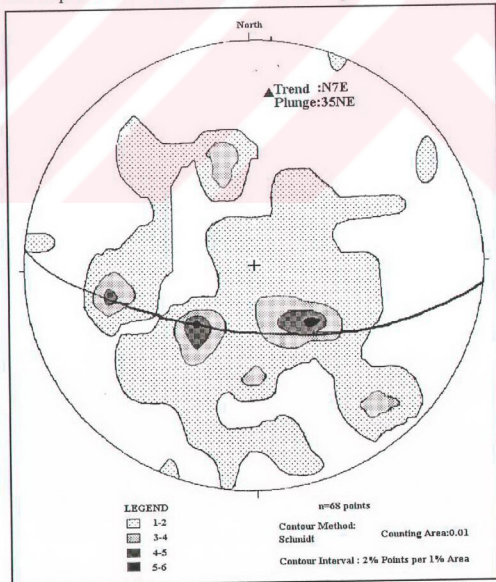


Figure 4.15 Schmidt diagram showing average fold-axis and plunge of the Bayırköy Formation and the Bilecik Limestone

4.3 Tectonics

Structural features of rock masses and seismicity of the investigation area are discussed in this section.

4.3.1 Structural Geology

Schistosity is observed in the Triassic aged Karakaya Complex which is metamorphosed in greenschist facies (low grade dynamothermal metamorphism). There are quartz and chert boudins in accordance with schistosity having 2-10 cm thicknesses. Shear zones are evident in the contacts of marble and schist. The major strikes and dips of foliation are N 10-20 W, 35-70 NE and N10-20E, 45-60 SE.

Unconformities are seen among Karakaya Complex, Bayırköy Formation, Bilecik limestone, Vezirhan Formation, Neogene aged units and alluvium. The Bayırköy Formation of Lower Jurassic age overlies the Karakaya Complex transgressively and with an unconformity. The unconformity among Bayırköy Formation, Bilecik Limestone and Vezirhan Formation is a diastem. Unconformity represents break in the stratigraphic sequence and an important tectonic event if it is large. Only the unconformity between Jurassic-Cretaceous aged formations and Neogene aged units can be classified as a large unconformity and indicates an erosion caused by uplift at the end of the Oligocene in the region.

Gently folded structure is seen in Jurassic-Lower Cretaceous aged Bayırköy Formation and Bilecik limestone. The strikes of fold-axes are N30E near Hafızhüseyinbey, N40-45E between Babayaka and Çıgırmış, N50E near Gündoğan and approximately N-S at the south of İncirli. The evaluation of measured strikes and dips, in the Schmidt diagram, has given an average trend of fold-axis about N7E, and a plunge about 35NE (Figure 4.15). Generally flat-lying Neogene aged sedimentary rocks display monoclines where the dips are locally steeper due to high angle faults in basement rocks.

The NE-SW striking Sarıköy-İnova strike-slip fault forms the northern border of the Sarıköy Plain. The Dereköy Fault is a E-W striking, buried but easily interpreted normal fault that forms the southern border of the Sarıköy Plain. At the footwall of the fault, Triassic aged Karakaya Complex, Jurassic-Lower Cretaceous aged Bayırköy Formation and Bilecik limestone crop out. This fault belongs to neotectonic period and occurred due to movement of the Sarıköy-İnova strike-slip fault. At the footwall of E-W and NE-SW striking Çıgırmış Fault (Figure 4.16) Triassic aged Karakaya Complex, Jurassic-Lower Cretaceous aged Bayırköy Formation and Bilecik limestone are found. Only Bilecik limestone is found at the hanging wall. In the northern part of İncirli the contact between Jurassic-Lower Cretaceous aged Bilecik limestone and Neogene aged volcanic rock is faulted. There are NE-SW striking normal faults in Bilecik limestone that lie on İncirli, at SE of İncirli, NW of Akçapınar and Pehlivanhoca, NW of Çınarınar. These faults most probably belong to neotectonic period. The breccia produced during movement of the fault which lies at NW of Akçapınar and the parallel scratches and grooves on slickensides of the fault that lie on İncirli (Figure 4.17a,b) are clearly seen. The strike and dip of this fault is measured as N35E,30SE.

The Yenice-Gönen strike-slip fault is located between Muratlar and Gönen inside investigation area and buried under alluvium. The main features of this fault were examined by Ketin and Roesli [8] after the earthquake took place on March 18,1953. The horizontal displacement has been found 3.5-4 meters and vertical displacement 0.4-1 meter.

The Ekşidere hot springs are located on E-W striking normal fault between Neogene aged volcanic rocks and lacustrine sediments. The E-W striking normal fault located at south of Üçpınar is also the contact between volcanic rocks and lacustrine sediments. Another fault located at south of Üçpınar lies along the valley striking NNE-SSW and NE-SW. This normal fault is on the contact between Upper Cretaceous aged Vezirhan Formation and Neogene aged volcanic rocks. At the north of Tütüncü N-S striking local normal fault is found inside an abandoned coal mine.



Figure 4.16 The extension of Çığırış Fault at south of Dereköy and the valley of Keçi Stream



a



b

Figure 4.17 a,b The slickensides of the fault that seen at the west of İncirli village

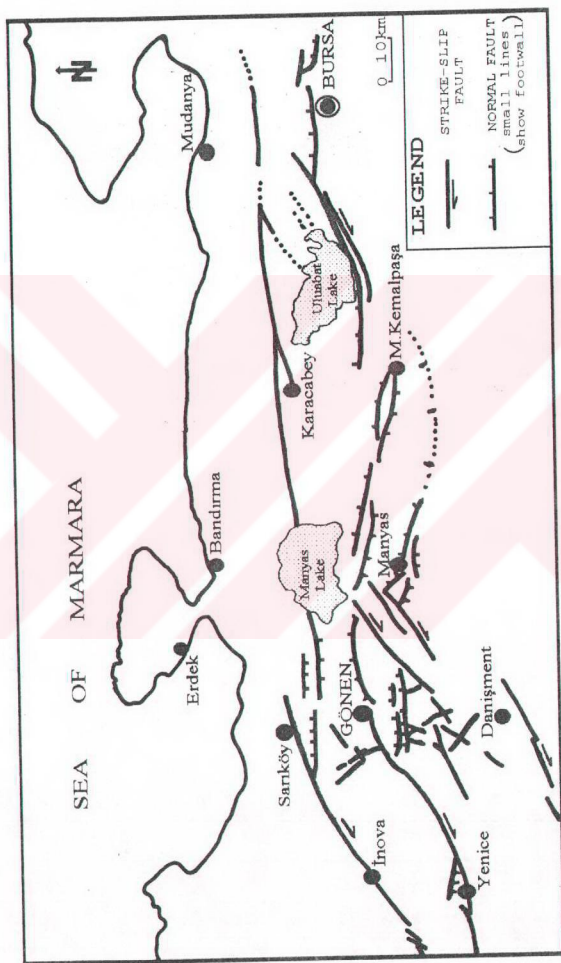


Figure 4.18 Bursa-Gönen Graben and Quaternary Faults [25]

The buried faults that formed the Gönen Plain and caused the discharge of Gönen thermal water, are inferred after evaluating the geophysical studies carried by MTA.

The main faulting in the investigation area is the western extension of the North Anatolian Fault system. The main strike-slip faults of the Bursa-Gönen Graben are the Manyas-Danişment Fault in the east, the Yenice-Gönen Fault in the center and the Sarıköy-İnova Fault in the west (Figure 4.18). The strike-slip faults mentioned above move in W-SW direction and E-W to NE-SW striking normal faults develop the graben as a pull-apart basin [29].

4.3.2 Seismicity of Gönen and Vicinity

Gönen and vicinity are a seismic active region that suffered structural damages and casualties at several recent earthquakes. The main cause of the earthquakes in this region is the movement of the North Anatolian Fault Zone.

The most destructive earthquake of recent years is the Yenice-Gönen Earthquake that occurred on March 18, 1953. The intensity (I_0) of the earthquake had been measured as X in Gönen. The total damaged area covered 30,000 km². It caused 16 casualties; 738 buildings collapsed and 570 buildings had been non-habitable out of 2449 buildings in Gönen. The length of the fault that caused earthquake was 80 km between Çan and Manyas. The depth of focus had been measured as 40-50 km [34] but recent evaluations of data show that it is less than 10 km (H.Eyidoğan, pers. comm.). The fault is a dextral strike-slip fault according to focal mechanism solution (Figure 4.19).

The Manyas Earthquake occurred on October 6, 1964, and 23% of the buildings collapsed in Gönen. The maximum damage had been seen in Bostancı around Gönen. The intensity (I_0) of the earthquake had been measured as VIII and depth of focus as 34 km [34] but recent evaluations of data show that it is around 10-12 km (H.Eyidoğan, pers. comm.). The fault is an NW-SE striking normal according to focal mechanism solution (Figure 4.19).

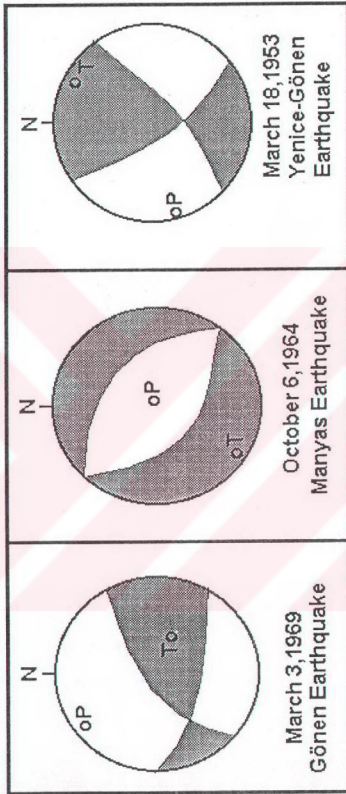


Figure 4.19 Focal mechanism solutions of the Gönen Earthquake, the Manyas Earthquake and the Yenice-Gönen Earthquake [38]

The Gönen Earthquake occurred on March 3, 1969. Nine buildings collapsed and twenty buildings had been non-habitable in Gönen. The intensity (I_0) of the fault had been measured as VII in Gönen and the depth of focus as 40-50 km[34] but recent evaluations of data show that it is less than 10 km (H.Eyidoğan, pers.comm.). It has a reverse fault character with strike-slip component according to focal mechanism solution (Figure 4.19).

Nearly 1750 earthquakes were recorded for the period 1900-1990, between longitudes 30.0E-28.5E and latitudes 39.0N-40.5N (Figure 4.20). The number of earthquakes greater than 4.0 (Ms) are plotted in Figure 4.21 and the list of earthquakes between 4.5 and 8.0 (Ms) is given on Table 4.1. Distribution of focus depths for the period 1986-1990 is given on Table 4.2.

Table 4.1 The number of earthquakes between 4.5 and 8.0 (Ms) for the period 1900-1990 (H.Eyidoğan, pers.comm.)

Magnitude (Ms)	Number
4.5-5.0	22
5.0-5.5	23
5.5-6.0	16
6.0-6.5	14
6.5-7.0	7
7.0-7.5	0
7.5-8.0	3

Table 4.2 Distribution of focus depths for the period 1986-1990 (data from H.Eyidoğan, pers.comm.)

Year	Number of earthquake	Depth of focus (km)							
		Undefined	0.1-2.5	2.6-5.0	5.1-7.5	7.6-10.0	10.1-12.5	12.5-15.0	>15.0
1986	208	21%	3%	11%	10%	49%	4%	1%	1%
1987	171	21%	3%	5%	7%	53%	5%	4%	2%
1988	144	29%	5%	8%	6%	45%	3%	2%	2%
1989	193	22%	5%	9%	3%	48%	5%	5%	3%
1990	106	4%	8%	15%	12%	45%	3%	5%	8%
Ave.	165	20%	5%	10%	7%	48%	4%	3%	3%

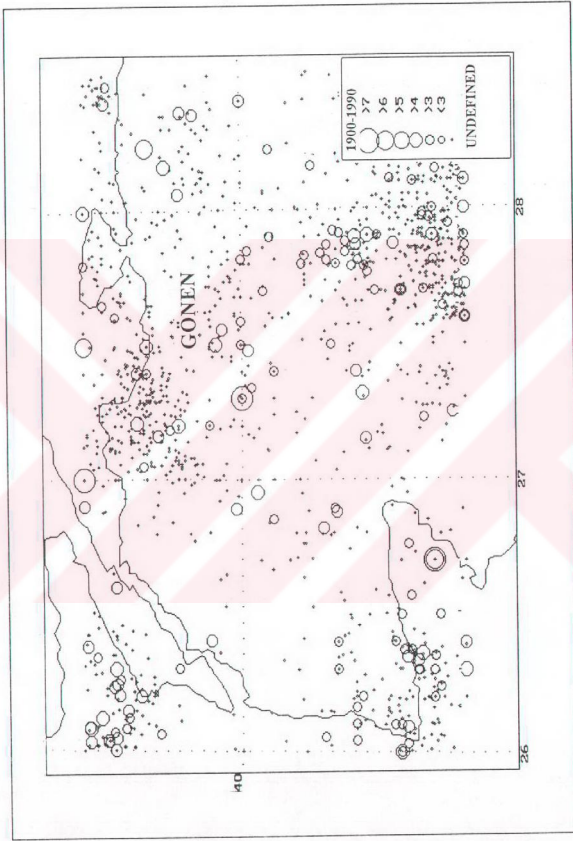


Figure 4.20 Epicenter map of earthquakes for the period 1900-1990 (H.Eyidoğan, pers. comm.)

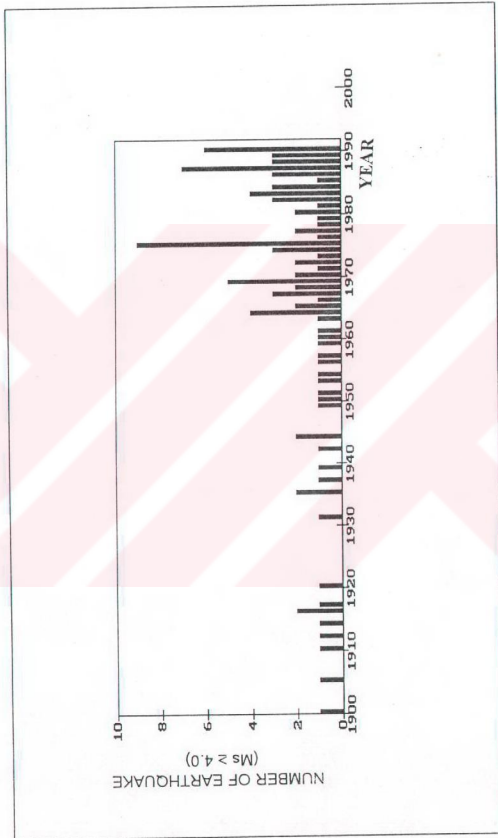


Figure 4.21 The number of earthquakes greater than 4.0 (Ms) for the period 1900-1990 (H. eyidoğan, pers comm.)

CHAPTER 5. HYDROGEOLOGY

Hydrologic characteristics of the investigation area are examined through calculation of evapotranspiration and runoff by evaluation of meteorological data in Penman's water budget table, calculation of base flow (groundwater flow), surface runoff and evapotranspiration by separation of hydrograph components of Gönen River and Keçi Stream.

Hydrological and hydrogeological data obtained from this study are discussed in this chapter.

5.1 Hydrology

5.1.1 Meteorological Data

Necessary meteorological data, for calculation of evapotranspiration and runoff, are obtained from Meteorological Bulletin of 1974 for the period 1950-1970 (Table 5.1) and from Gönen Meteorology Station (located at 40°06' longitude and 27°40' latitude) for the period 1980-1989 (Table 5.2).

Table 5.1 includes precipitation (P) in mm, temperature (T) in °C and relative humidity (R_H) in percent. Table 5.2 includes maximum temperature (T_{max}), average temperature (T_{ave}) and minimum temperature (T_{min}) in °C, relative humidity (R_H) in percent, precipitation (P) in mm, wind speed at 10 meter (U_{10}) in m/sec, sunshine duration (n) in hours/day.

Table 5.1 Meteorological data for the period 1950-1970 from Meteorological Bulletin of 1974

Months	P(mm)	T(°C)	R _H (%)
Jan.	103.6	5.0	77
Feb.	74.2	6.7	72
Mar.	74.6	8.2	70
Apr.	51.2	13.0	65
May	32.9	17.4	62
Jun.	29.2	21.8	54
Jul.	15.8	23.8	54
Aug.	13.0	23.2	56
Sep.	39.8	19.8	62
Oct.	65.2	15.4	68
Nov.	74.5	11.6	70
Dec.	132.2	8.6	74
Total	706.1		
Average		14.5	66

5.1.2 The Drainage Basin

The boundaries of basins and drainage patterns inside the area between Kumköy (entrance point of the Gönen River into the Gönen Plain) and Ulukır (exit of the Gönen River out of the Gönen Plain) are given in Figure 5.1. The general type of the drainage pattern is dentritic. This pattern generally develops when the rock resists as uniform material against to erosion.

Table 5.3 shows the drainage densities of the adjacent basins A, B, C and D. The drainage density (D_d) is calculated by $D_d = \Sigma L / A_d$ where ΣL is the total length of streams in the basin and A_d is the drainage area. Poorly drained basins have a drainage density less than 0.6 km/km^2 and well-drained basins have greater than 3 km/km^2 [39].

Table 5.2 Meteorological data recorded by the Gönen Meteorology Station for the period 1980-1989

	1980												1981											
MONTHS	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
T _{max} , °C	-	-	-	-	-	-	-	-	-	-	-	-	17.4	19.1	22.6	27.4	26.3	35.1	35.2	32.6	30.4	29.0	24.0	19.2
T _{ave} , °C	3.1	4.4	6.7	10.9	15.9	20.2	22.7	22.3	17.2	16.1	12.0	7.2	4.1	4.9	9.2	11.5	14.6	22.1	22.1	22.3	19.1	16.9	7.7	10.5
T _{min} , °C	-	-	-	-	-	-	-	-	-	-	-	-	-8.4	-4.2	-2.4	-3.4	1.3	8.6	11.6	8.6	7.0	6.6	-3.4	-0.4
R _H , %	82.5	80.3	80.2	80.2	78.4	73.2	68.7	70.4	74.6	69.4	79.5	78.4	79.7	80.0	75.0	80.4	79.5	62.4	63.9	68.7	72.9	74.0	77.1	77.6
P, mm	141.0	57.9	112.8	58.9	57.7	50.5	11.3	5.3	37.5	12.3	105.0	116.2	221.6	124.6	54.2	10.5	78.6	12.7	35.6	0.9	16.7	51.2	176.7	270.0
U ₁₀ , m/sec	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
n, hours/day	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1982												1983											
T _{max} , °C	20.2	16.4	22.5	29.3	27.6	40.6	31.0	34.0	32.0	27.6	21.3	20.0	16.6	22.3	21.9	28.3	29.6	31.7	36.3	33.3	33.0	26.6	20.8	17.7
T _{ave} , °C	5.9	3.1	6.5	10.9	15.1	21.3	21.7	22.3	20.9	15.2	8.1	8.5	4.0	5.3	8.3	13.4	17.9	19.6	23.2	21.3	18.5	12.9	9.4	7.9
T _{min} , °C	-8.0	-5.0	-6.1	0.7	3.2	6.6	10.6	13.1	8.5	1.5	-5.4	-6.4	-7.4	-7.6	-4.6	1.4	2.4	8.3	9.5	10.0	3.0	2.1	-2.7	-3.9
R _H , %	79.7	80.0	75.0	80.4	79.5	62.4	63.9	68.7	72.9	74.0	77.1	77.6	78.0	73.0	73.2	72.9	70.8	68.5	68.5	69.4	72.8	77.6	82.2	81.7
P, mm	104.1	36.9	20.9	95.6	74.1	1.7	24.6	1.4	2.0	36.8	19.8	90.5	103.4	78.4	9.9	46.5	41.3	44.8	38.7	54.4	6.5	29.9	96.1	83.3
U ₁₀ , m/sec	2.6	2.9	3.7	2.0	1.9	1.5	2.2	2.6	2.7	2.5	2.3	3.1	2.5	3.7	3.4	2.1	2.1	2.5	2.6	2.9	2.6	2.2	2.8	2.3
n, hours/day	-	-	-	-	-	-	-	-	-	-	-	-	3.6	3.9	4.5	6.9	7.9	8.7	9.2	9.0	7.6	4.7	1.8	2.7
	1984												1985											
T _{max} , °C	17.7	14.9	21.4	22.4	33.5	34.3	40.0	32.4	36.2	35.3	22.7	17.0	18.4	20.7	20.3	31.5	30.8	36.1	37.3	38.6	30.3	24.1	26.2	21.2
T _{ave} , °C	6.9	6.3	7.1	9.4	17.8	20.6	22.0	21.1	20.1	15.4	10.8	5.5	7.4	1.2	6.0	13.2	18.2	20.8	22.1	23.4	18.6	12.2	12.0	8.2
T _{min} , °C	-3.7	-0.9	-2.4	-1.2	2.5	7.0	10.3	10.0	6.6	-0.4	-1.4	-6.8	-3.6	-15.1	-5.3	-1.6	-0.7	9.0	9.0	12.4	7.4	-1.3	-0.1	-3.0
R _H , %	81.9	84.9	81.2	82.6	72.9	62.2	62.1	66.5	64.8	72.5	82.4	80.7	80.6	73.3	79.7	69.8	73.6	60.0	56.4	66.0	64.7	75.7	80.1	83.0
P, mm	81.7	51.9	70.3	89.1	13.2	5.9	18.3	13.9	3.7	25.8	53.2	9.2	144.7	59.8	38.3	34.8	23.2	4.4	2.9	1.6	1.4	79.3	169.4	43.7
U ₁₀ , m/sec	2.2	2.5	2.6	2.0	1.9	2.6	3.1	2.8	2.4	2.0	2.1	2.2	3.3	3.3	2.6	2.3	1.9	2.1	3.0	3.2	2.9	2.7	2.4	2.4
n, hours/day	2.0	0.8	2.6	4.0	7.9	9.5	9.6	8.7	9.0	6.2	2.6	2.4	1.9	3.4	2.8	6.3	8.2	10.2	10.9	9.0	8.7	4.6	2.8	2.2
	1986												1987											
T _{max} , °C	18.9	20.0	22.3	29.2	31.2	34.5	35.2	37.3	32.9	26.6	15.9	17.4	20.0	20.9	23.6	26.0	30.2	36.8	41.6	37.2	34.8	34.7	22.6	19.0
T _{ave} , °C	7.6	7.2	6.4	13.4	15.1	23.0	23.3	24.2	19.6	14.0	6.9	5.1	6.2	6.6	3.7	10.3	15.6	20.8	23.8	21.6	19.9	13.3	11.0	6.6
T _{min} , °C	-4.3	-2.0	-3.2	0.9	0.2	8.8	12.1	12.7	7.0	1.9	-5.0	-6.9	-6.3	-7.2	-8.4	-3.7	0.0	7.4	11.8	9.0	5.0	-1.4	-3.5	-4.8
R _H , %	83.1	80.8	80.6	73.5	71.0	66.0	67.8	69.3	71.4	75.9	80.6	79.6	78.9	78.5	76.8	72.6	71.0	66.4	67.4	69.0	69.4	78.6	79.8	84.9
P, mm	184.6	136.6	34.3	39.7	9.4	52.5	3.0	0.0	3.1	37.7	73.9	58.1	140.7	28.3	64.8	55.5	32.7	38.7	15.3	1.2	0.2	32.2	123.0	157.1
U ₁₀ , m/sec	2.8	3.4	3.0	1.8	2.5	2.1	2.6	3.4	2.9	2.8	2.1	2.6	3.8	2.6	3.3	2.8	1.9	1.9	3.0	2.4	2.4	2.5	2.0	2.3
n, hours/day	2.3	1.8	2.4	7.9	8.2	9.0	10.2	8.6	6.5	3.9	2.8	2.2	2.0	2.4	3.5	5.5	7.4	9.4	9.6	9.2	8.4	4.2	3.1	6.3
	1988												1989											
T _{max} , °C	11.4	10.5	14.1	16.1	22.8	23.0	31.3	30.1	26.6	18.8	11.2	10.5	7.4	12.2	15.4	23.4	23.0	27.3	28.8	30.2	26.7	18.6	14.4	10.9
T _{ave} , °C	6.5	5.6	8.6	11.1	15.9	21.8	25.2	23.7	18.8	13.9	6.2	6.6	2.4	5.6	9.4	15.5	16.2	20.2	23.3	23.4	19.6	13.5	8.5	6.3
T _{min} , °C	2.1	1.1	3.8	6.5	8.9	14.2	18.0	17.0	12.1	9.5	3.2	3.0	-2.1	-0.3	3.8	8.0	9.7	12.0	17.2	16.7	13.1	9.1	3.9	2.3
R _H , %	83.2	80.2	76.4	81.1	77.0	77.9	69.4	69.3	71.7	79.0	81.2	82.1	80.2	69.0	78.8	66.5	75.9	74.1	70.8	71.2	72.4	82.0	83.0	85.3
P, mm	7.0	51.4	91.7	60.3	22.3	28.6	6.2	1.2	12.6	34.4	313.5	125.7	4.6	12.5	34.3	19.0	47.3	48.1	0.0	16.5	0.3	114.6	101.7	148.1
U ₁₀ , m/sec	2.6	2.8	2.3	2.1	1.7	1.4	2.8	2.8	2.1	2.8	2.3	2.2	2.5	2.9	2.2	2.2	2.0	1.5	3.3	2.6	2.0	2.3	2.0	2.3
n, hours/day	2.6	2.5	4.7	3.4	6.6	9.2	10.1	9.4	7.6	4.3	2.7	2.7	3.3	5.4	4.7	7.5	6.9	8.6	9.5	9.2	7.0	3.8	3.3	2.8

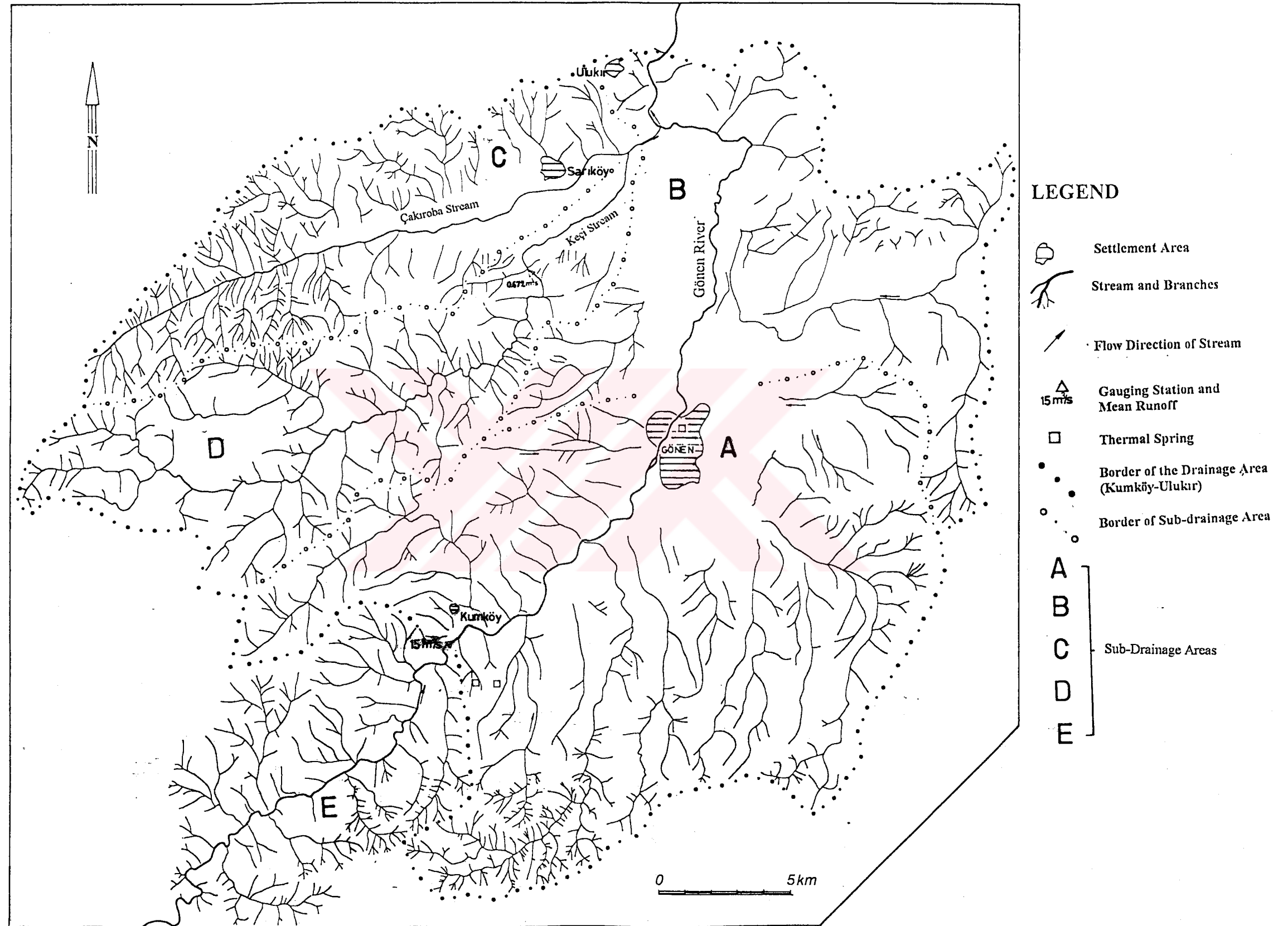


Figure 5.1 The boundaries of drainage basins and drainage patterns between Kumköy and Ulukır

Table 5.3 The drainage densities of the basins A,B,C and D

Basin	Total length of stream (ΣL ,km)	Drainage Area (A_d , km ²)	Drainage Density (D_d ,km/km ²)
A	400	300	1.33
B	145	180	0.80
C	220	120	1.83
D	205	130	1.57
A+B+C+D	970	730	1.33

5.1.3 Precipitation

The average precipitation value of Gönen (at 36.94 masl) is 706.1 mm/year for the period 1950-1970 and 662.5 mm/year for the period 1980-1989. The seasonal distribution of precipitation is as follows;

<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>
44%	22%	8%	26%

The estimation of precipitation at higher altitudes should be taken into consideration while the drainage area of the Gönen River extends to the Eybek Mountain (1298 masl; west of the Kaz Mountain). The gauging of stream discharges show that runoff-precipitation ratio reaches up to 91% (Table 5.5). This result is due to taking amount of precipitation for lower altitudes. For this reason correction should be done to find the actual precipitation amount. This estimation can be done from the formula given by Erinç [40];

$$Y_{h2} = Y_{h1} + 0.54\Delta$$

where Y_{h2} is precipitation in mm at h_2 meter, Y_{h1} is measured precipitation in mm at h_1 meter, Δ is the elevation difference between h_2 and h_1 .

The estimation of precipitation for the summit of Eybek Mountain is

$$Y_{h2}=662.5 + 0.54(1298-36.94) = 1343.5 \text{ mm.}$$

Figure 5.2 shows the cumulative departure from average precipitation (682.26 mm) from 1960 to 1994 and the graph indicates a relative drought for the period 1981-1994.

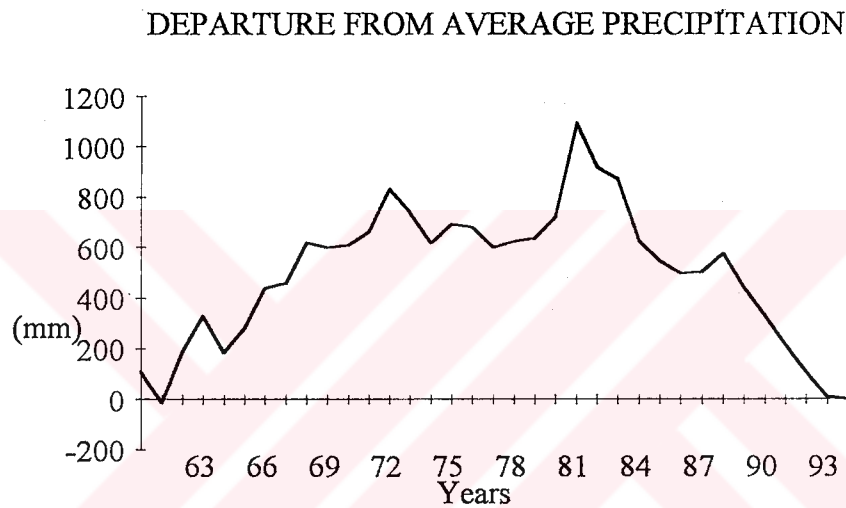


Figure 5.2 Cumulative departure from average precipitation

5.1.4 Evapotranspiration

The amount of potential evapotranspiration (E_p) is calculated 824.3 mm/year by using necessary meteorological data in Penman's formula and Table 5.4 shows Penman's water budget table that is used to calculate the actual evapotranspiration (E_a). The value of actual evapotranspiration is found 434.5 mm/year which is 65% of precipitation for the conditions in the plain.

Runoff measurements of Keçi Stream can also be used for the estimation of evapotranspiration in mountainous parts of the investigation area by considering evapotranspiration equals to the difference of precipitation and runoff. By using the

Table 5.4 Meteorological water budget of Gönen Area (Penman's method)

Values	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
Temperature (T), °C		5.4	5.0	7.2	12.0	16.2	21.0	22.9	22.6	19.2	14.3	9.3	7.2	13.5
Potential evapotranspiration(EP),mm		20.7	31.7	44.4	67.8	95.3	126.6	143.2	126.1	83.0	46.6	23.5	15.4	824.3
Precipitation (P), mm		113.3	63.8	53.2	51.0	40.0	28.8	15.6	9.6	8.4	45.4	123.2	110.2	662.5
P-Ep, mm		92.6	32.1	8.8	-16.8	-55.3	-97.8	-127.6	-116.5	-74.6	-1.2	99.7	94.8	-161.8
Reserve water, mm		100.0	100.0	100.0	83.2	27.9	0.0	0.0	0.0	0.0	0.0	99.7	100.0	-
Actual evapotranspiration(Ea), mm		20.7	31.7	44.4	67.8	95.3	56.7	15.6	9.6	8.4	45.4	23.5	15.4	434.5
Deficient water, mm		0.0	0.0	0.0	0.0	0.0	69.9	127.6	116.5	74.6	1.2	0.0	0.0	389.8
Excess water, mm		92.6	32.1	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.5	228.0
Runoff, mm		70.0	51.0	29.9	15.0	7.5	3.7	1.9	0.9	0.5	0.2	0.1	47.3	228.0
Deficiency of runoff according to precipitation, mm		43.3	12.8	23.3	36.0	32.5	25.1	13.7	8.7	7.9	45.2	123.1	62.9	434.5

runoff measurements of Keçi Stream from Table 5.5 and precipitation measurements that calculated for hydrologic years;

<u>Precipitation</u>	<u>Runoff</u>	<u>Evapotranspiration</u>
636.6 mm/year	389.6 mm/year	247 mm/year
100%	61%	39%

5.1.5 Runoff

The portion of the precipitation that returns to the sea and appears in surface streams is described as runoff. It consists of in varying proportions surface runoff and base flow (various terms such as groundwater runoff, effluent seepage or sustained flow have been used to designate this outflow from subterranean storage). The base flow is generally observed during a rainless period.

Runoff value is taken from gauging stations (the Gönen River and Keçi Stream) of Eİİİ(Directorate of Electricity Works) for the period 1979-1989(hydrologic years). Surface runoff and base flow are found by the separation of hydrograph components. This separation is based on drawing a line at minimums of every rising and falling limb (Figure 5.3). Table 5.5 shows precipitation, total runoff, surface runoff and base flow of Keçi Stream and Gönen River. The total runoff is 389.6 mm/year for the Keçi Stream and 400.5 mm/year for the Gönen River.

The runoff found from Penman's table is 228 mm/year. That is 35% of the total precipitation.

5.1.6 Infiltration

The estimation of groundwater potential is an important step in hydrogeologic studies. The estimation or measurement of infiltration gives an input data about the groundwater potential.

Table 5.5 Precipitation, runoff, surface runoff and base flow values of the Keçi Stream and the Gönen River for the period 1979-1989(hydrologic years)

Hydrologic Year	Precipitation (mm)	Runoff (mm)	Surface Runoff (mm)	Base Flow (mm)
KEÇİ STREAM				
79-80	-	-	-	-
80-81	789	717	530	187
81-82	859	476	306	170
82-83	571	242	121	121
83-84	557	404	272	132
84-85	400	195	114	81
85-86	756	393	238	155
86-87	547	416	256	160
87-88	594	228	137	91
88-89	656	435	362	73
Average	636.6	389.6	259.6	130.0
GÖNEN RIVER				
79-80	752	425	182	243
80-81	789	596	298	298
81-82	859	694	392	302
82-83	571	251	115	136
83-84	557	310	134	176
84-85	400	181	81	100
85-86	756	591	373	218
86-87	547	386	193	193
87-88	594	242	108	134
88-89	656	329	199	130
Average	648.1	400.5	207.5	193.0

In virgin areas, evapotranspiration and discharge of water from the zone or zones of saturation into stream channels (base flow) should be equal to the recharge of groundwater (infiltration). If the rate of base flow is known, then the rate of net infiltration is also known. Table 5.5 gives the rates of base flow calculated for the Keçi Stream and Gönen River.

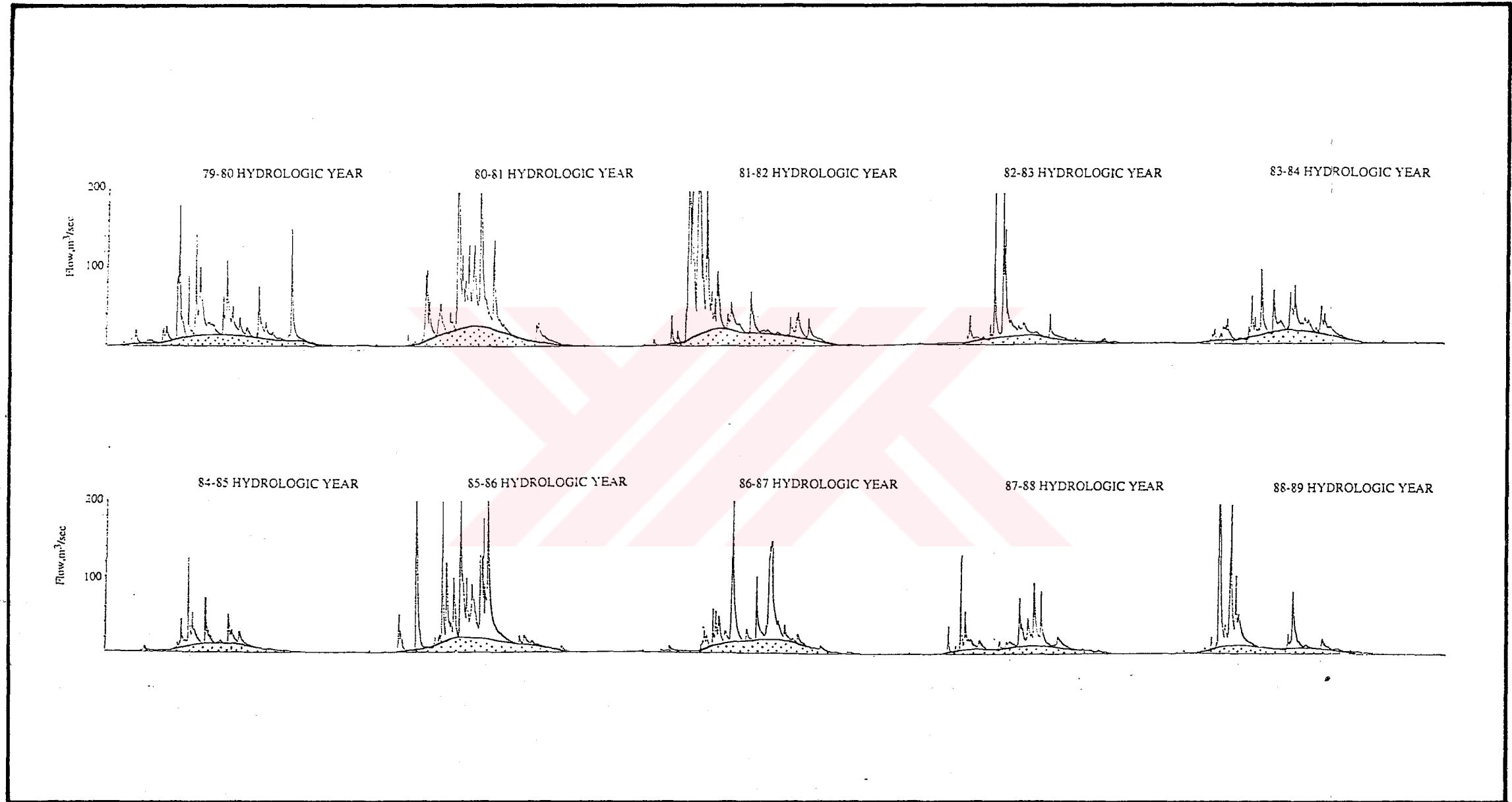


Figure 5.3 Hydrograph of the Gönen River that is used to find base flow and surface runoff by the separation of hydrograph components. Dotted areas indicate base flow. (Total runoff values are taken from EIEI Bulletins for the Kumköy Gauging Station)

5.2 Water Points

5.2.1 Streams

The Gönen River is the most important stream of the investigation area. The sources of the Gönen River are the Eybek Mountains (1298 masl). The Küçük Agonya branch joins the river after it runs through the Pazarköy Plain. The river flows through a 12 km long canyon and then reaches the Gönen Plain. It meanders in the Gönen Plain until the Ayvalidere Gorge. Çakıroba and Keçi streams join the river from western and Çerpeş Stream from eastern. Finally the river discharges into the Erdek Bay (Marmara Sea) over its delta called as the Tahirova (Figure 2.3). The catchment area of the river above the Kumköy measurement station is 1192.8 km². The average runoff of the river for the period 1979-1989 is 15.15 m³/sec.

The sources of the Keçi Stream are Karlık Mountains (900 masl). It runs in the west-east direction between Dumanalan and Keçidere villages within the investigation area. But after Keçidere it turns to the south-west direction and runs to the Sarıköy Plain first to join the Çakıroba and then the Gönen River. The catchment area of the stream above Dereköy measurement station is 130 km². The average runoff of the stream for the period 1980-1989 is 1.6 m³/sec.

The sources of the Çakıroba Stream are the surroundings of the Tahtalı village (750 masl, west of Sarıköy). The stream flows in the southwest-northeast direction, in the valley located on the Sarıköy-İnova strike-slip fault. The stream enters to the Sarıköy Plain near Hafızhüseyinbey village and join the Gönen River near Sarıköy. The catchment area of the stream above west end of the Sarıköy Plain is 51.2 km². The total catchment area of the stream is 111.5 km². The average runoff of the stream is 0.22 m³/sec. The source of the Çerpeş Stream is Dumanlı Hill (650 masl). Çaylak and Keten streams are the branches of the Çerpeş stream. The total catchment area of the stream is 223.7 km².

Table 5.6 Some runoff measurements carried out by DSI*
(* data taken from unpublished DSI records)

Date	Name of stream	Location	Runoff (m ³ /sec)
Nov.11,1980	Gönen	Ayvalidere Gorge (north end of the Gönen Plain)	9.105
Nov.6,1981	Gönen	Ayvalidere Gorge (north end of the Gönen Plain)	3.192
Nov.11,1980	Gönen	Balcı village (south end of the Gönen Plain)	6.578
Nov.6,1981	Gönen	Balcı village (south end of the Gönen Plain)	1.775
Aug.26,1972	Gönen	Gönen Bridge (middle of the Gönen Plain)	0.265
Oct.11,1972	Gönen	Gönen Bridge (middle of the Gönen Plain)	4.593
Nov.11,1980	Keçi	South of Ayvalidere Gorge	0.712
Nov.11,1980	Çakıroba	South of Ayvalideve Gorge	0.453
Nov.11,1980	Çerpeş	South of Ayvalidere Gorge	0.086

5.2.2 Springs

The springs observed in the investigation area can be grouped as karstic springs that are found in limestone due to solving action of groundwater; fracture springs that are generally found in fractured (practically unsoluble) volcanic rocks; depression springs [41] that are generally found in Neogene aged lacustrinal sediments where the land surface cuts the water table and hot springs that are due to faults and fissures extending deep into the earth. Table 5.7 shows the list of springs and their locations are given in App. B.

5.2.3 Wells

Dug-wells are widely used for irrigation and domestic demands in the Gönen Plain. Water level, electrical conductivity and depth of dug-wells were measured by DSI in October 1981. Their static water level vary from 0.5 to 6.5 m. Figure 5.4 shows the water level contours and flow directions of groundwater drawn according to data obtained from measurements of DSI. The hydraulic gradient of groundwater

is 3/1000 in the Gönen Plain and 6/1000 in the Sarıköy Plain. The flow direction of groundwater is generally toward NE in the Sarıköy Plain and western part of the Gönen Plain.

Table 5.7 Important springs observed in the investigation area

Number of Spring	Name of Spring	Type	Measured Discharge (lt/sec)	Electrical Conductivity (μS/cm)	pH	Temperature (°C)
S1	Ekşidere west	Hot	5.4	390-434	7.68-8.03	41.5-42.8
S2	Ekşidere east	Hot	1	390-400	7.02-7.67	28.1-35.4
S3	Gençlik suyu	Fracture	<0.1	256-330	3.59-4.31	18.8
S4	Hafızhüse-yinbey	Karstic	7	550-600	7.14-7.33	14.4-16
S5	-	Karstic	0.4	462	7.50	16
S6	Muharrem Çiftliği	Karstic	0.3	475	7.45	22
S7	Dumanalan	Karstic	-	425	-	-
S8	Akçapınar	Karstic	0.37	625	-	16
S9	-	Fracture	0.2	270	-	24.5
S10	-	Depression	0.18	650	-	18.5
S11	-	Fracture	0.15	330	-	23.5
S12	-	Fracture	<0.1	275	-	22
S13	-	Fracture	<0.1	275	-	24
S14	-	Fracture	<0.1	270	-	-
S15	-	Fracture	0.11	420	-	24
S16	Tütün Çeşme	Depression	<0.1	-	-	-
S17		Depression	<0.1	-	-	-
S18		Fracture	<0.1	115	-	-
S19	-	Depression	<0.1	550	-	21.5
S20	-	Depression	<0.1	700	-	17.5
S21	-	Depression	<0.1	600	-	20
S22	-	Fracture	<0.1	495	-	26

Electrical conductivity values of most of the water seen in dug-wells are between 350-850 μS/cm but some of them reach up to 6500 μS/cm. Temperatures are measured 14.5-18.5°C. Depths of dug-wells are between 3-9 meter and their diameters are generally about 70 cm.

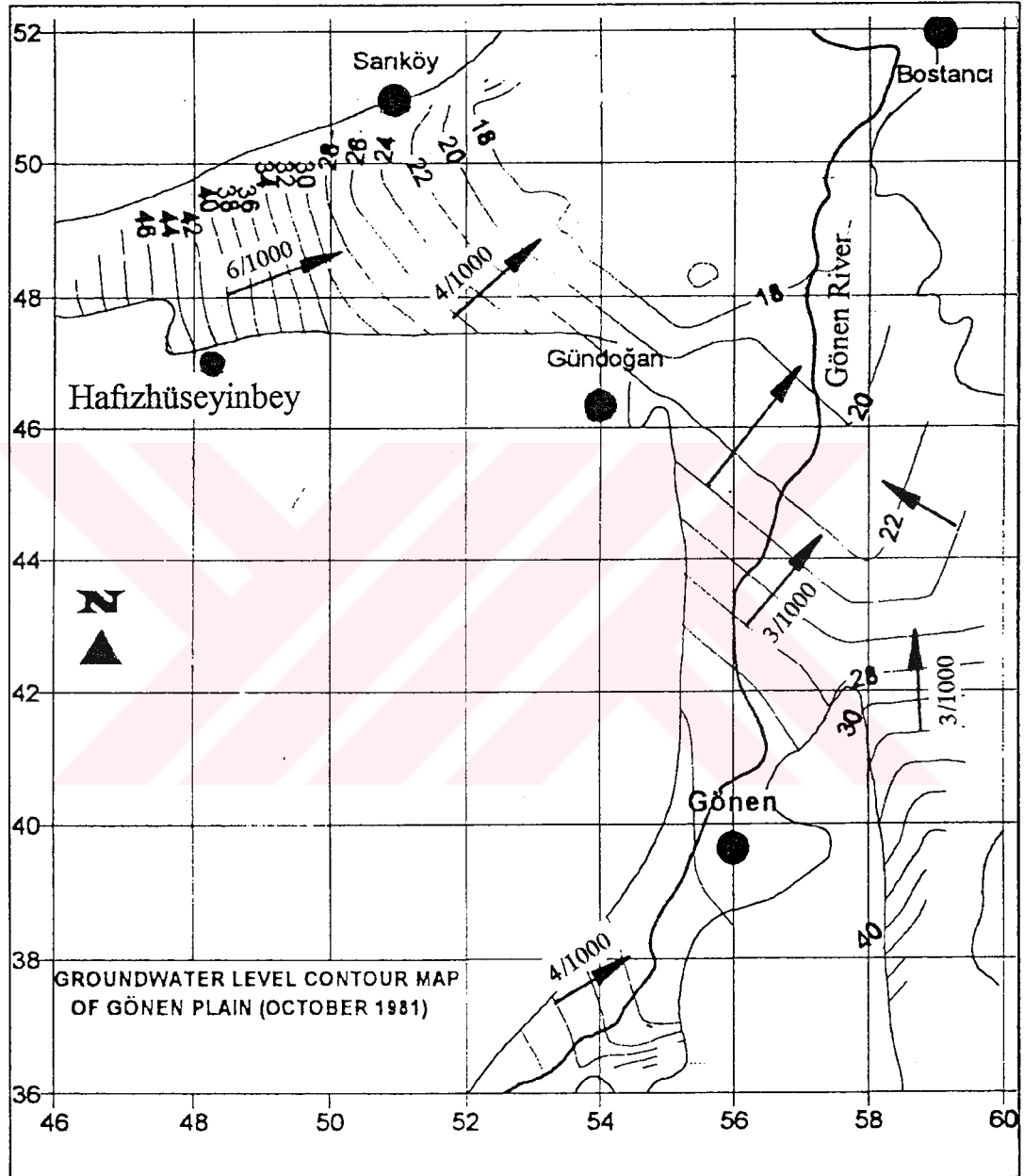


Figure 5.4 Groundwater level contour map of the Gönen Plain drawn according to measurements of DSI on October 1981. (Arrows show the flow direction of groundwater)

Table 5.8 Some data of wells drilled by DSİ in Gönen and Sarıköy Plains (unpublished records of DSİ)

Number	Location	Purpose	Date of Drilling	Depth(m)	Static Level(m)	Discharge (l/sec)	Drawdown (m)
7469-A	Tuzakçı	Exploration	May 1966	236.0	2.71	15.1	14.89
7470-A	Gündoğan	Exploration	Jun. 1966	85.8	1.92	48.0	1.15
7470-B	Gündoğan	Exploration	Jun. 1966	293.0	2.30	44.3	9.51
7471	Gönen	Exploration	Jul. 1966	300.0	2.71	4.0	11.74
7472	Gönen	Exploration	May 1966	213.2	-	dry	-
7473-A	Alaattin	Exploration	Jun. 1966	27.0	22.29	1	21.33
7473-B	Alaattin	Exploration	Jun. 1966	250.4	6.07	15.1	20.79
7474-A	Sarıköy	Exploration	Jun. 1966	40.0	1.73	24.5	6.86
7474-B	Sarıköy	Exploration	May 1966	236.0	2.61	2.4	19.83
7475	Balcı	Exploration	Jun. 1966	281.1	1.64	2.8	25.28
7933-A	Hafızhüseyinbey	Exploration	Jul. 1966	45.0	2.41	17.3	9.33
7933	Hafızhüseyinbey	Exploration	Jul. 1966	172.0	-	dry	-
24775	Gönen	Exploration	Oct. 1978	58.0	3.50	0.5	36.5
O27	Taştepe	Industrial	Oct. 1977	200.0	22.60	3.0	49.4
O28	Taştepe	Industrial	Oct. 1976	190.0	31.10	1.8	51.7

Table 5.9 Lithology of formations cut by some exploration drillings carried out by DSI in the Gönen Plain (unpublished records of DSI)

Well no:7475	Location: Balci	Well no:7471	Location: Gönen	Well no:7473B	Location: Alaattin	Well no:7933B	Location: H.hüseyin
<u>Depth(m)</u>	<u>Lithology</u>	<u>Depth(m)</u>	<u>Lithology</u>	<u>Depth(m)</u>	<u>Lithology</u>	<u>Depth(m)</u>	<u>Lithology</u>
0-2	soil	0-1	soil	0-1	soil	0-1	soil
2-11	gravel	1-27	boulder	1-3	clay	1-15	boulders of limestone and andesite
11-281.1	clay, clayey gravel, clayey sand	27-29	clay	3-27	clay, gravel	15-25	clay
		29-44	coarse gravel	27-33	clay	25-32	clayey sand
		44-68	clay	33-43	andesite gravels	32-90	clay
		68-123	marl clay	43-250.4	andesitic gravel, tuff	90-102	sandy clay
		123-128	clay, gravel			102-112	altered limestone
		128-148	marl, clay			112-160	clayey limestone
		148-150	clay			160-172	limestone
		150-171	sandy clay				
		171-180	clay				
		180-200	sandy clay				
		200-220	clay				
		220-262	sandy clay				
		262-300	marl				

Table 5.9 cont'd

Well		Location: Tuzakçı		Well		Location: Gönen		Well		Location: Sarıköy		Well		Location: Gündoğan	
no:7469A	Depth(m)	Lithology		no:7472	Depth(m)	Lithology		no:7474B	Depth(m)	Lithology		no:7470B	Depth(m)	Lithology	
0-1	0-1	soil		0-3	0-3	clay		0-3	0-3	soil		0-2	0-2	soil	
1-7	1-7	clay		3-8	3-8	gravels of andesite		3-5	3-5	gravel		2-6	2-6	sand	
7-9	7-9	sand		8-10	8-10	sand		5-10	5-10	clay		6-7	6-7	clay	
9-22	9-22	boulder		10-13	10-13	sandy clay		10-20	10-20	gravel		7-19	7-19	sand	
22-48	22-48	clay		13-17	13-17	clay		20-29	20-29	clayey sand		19-34	19-34	gravel	
48-54	48-54	gravel		17-21	17-21	gravel		29-30	29-30	gravel		34-38	34-38	clay	
54-102	54-102	clay		21-40	21-40	clay		30-38	30-38	clayey gravel		38-55	38-55	gravel	
102-126	102-126	marl, clayey sand and gravel		40-44	40-44	sand		38-106	38-106	clay		55-60	55-60	clay	
126-336.6	126-336.6	marl, clayey sand, andesitic tuff		44-99	44-99	clay		106-202	106-202	marl, clayey and sandy gravel		60-71	60-71	sandy clay	
				99-101	99-101	sandy clay		202-236	202-236	andesitic tuff		71-80	71-80	sand, gravel	
				101-153	101-153	clay		236-239	236-239	andesite		80-103	80-103	clay	
				153-213.2	153-213.2	marl, andesitic tuff						103-112	103-112	sand, gravel	
												112-116	112-116	clay	
												116-120	116-120	sand, gravel	
												120-125	120-125	clay	
												125-138	125-138	sand, gravel	
												138-282	138-282	sandy clay	
												282-293.3	282-293.3	sandy clay, tuff, gravel	

Table 5.10 Information about the geothermal wells used for exploitation of hot water[31]

Well Nr.	Date of Drilling	Well Diameter(in.)	Casing Diameter(in.)	Lithology	Explanations
G1		0-37 m. 37-130 m..	17½ 12¼	0-110 m. 97.6-119.6 m. 119.6-129.6 m.	85/8 65/8 65/8(screen)
G2	March-June 1976	0-40 m. 40-216 m. 216-534.1 m.	22 17½ 8½	0-40 m. 40-55 m. 55-216 m. 216-534.1 m.	17½ 85/8 85/8(screen) 65/8(screen)
G3	June-July 1985	0-41 m. 41-108 m. 108-308 m.	17½ 11½ 8½	0-41 m. 0-56 m. 56-108 m. 108-308 m.	12¾ 10¾ 85/8 65/8 (screen)
G4	April-June 1990	0-204.6 m. 204.6-422.2 m. 422.2-432.5 m.	12¼ 8½ 7 3/8	0-202 m. 196-202 m. 202-394 m. 394-402 m.	95/8 65/8 65/8(screen) 5½(screen)
				0-23 m. 23-59.6 m. 59.6-74.1 m. 74.1-113 m. 113-115 m. 115-210 m. 210-276 m.. 276-534.1 m.	clay-sand-gravel tuffite silt-limestone tuffite limestone tuff-tuffite altered andesite metadiabase
				0-16 m. 16-51 m. 51-67 m. 67-68 m. 68-84 m. 94-102.5 m. 102.5-215 m. 215-296 m. 296-308 m.	clay-sand-gravel tuff agglomerate clay agglomerate tuffite limestone tuffite recrys. limestone
				0-74 m. 74-99 m. 99-104 m. 104-111 m. 111-133 m. 133-142 m. 142-213 m. 213-232 m. 232-432.5 m. 432.5m	clay-sand-gravel agglomerate clayey limestone claystone clayey limestone claystone tuffite limestone (no cuttings) meta sandstone
					cavity in 210th meter
					circulation loss in 140.1-140.2 m.
					core sample is limestone between 244.3-246.7 m. bit sample

Drilled wells are also extensively used for irrigation in the Gönen Plain. Only a little information is known about the private drilled-wells. But exploration drillings of DSİ in the Gönen and Sarıköy plains give enough information about groundwater and water-bearing properties of rocks drilled in the plains. Table 5.8 gives the list and some properties of these wells drilled between 1966 and 1978 and Table 5.9 gives the drilled lithologies.

For the exploitation of hot water 5 geothermal wells drilled by MTA. They are named as G1, G2, G3, G4 and G5. Table 5.10 gives information about the geothermal wells except G5.

5.3 Water-Bearing Properties of Rocks

5.3.1 Rich and Extensive Aquifers (rea)

Unconsolidated formations (nonindurated sediments) which have a specific capacity greater than 2 liter/second/meter in drilled wells, were classified as **rich and extensive** aquifers. This type of aquifers are observed in alluvium of Sarıköy Plain and northern side of the Gönen Plain. The permeability of these aquifers ranges between 16 and 86 m³/day/m². The thickness of the aquifer varies between 40-100m. Table 5.11 gives the list of drilled wells in this aquifers.

Table 5.11 Exploration wells drilled by DSİ in rich and extensive aquifers

Location	Number	Depth (m)	Specific capacity (lt/sec/m)	Transmissibility (m ³ /day/m)	Thickness of Aquifer (m)
Sarıköy	7474-A	40	3.5	455	28
Gündoğan	7470-A	86	42.6	5538	64
Gündoğan	7470-B	293	4.6	598	13
Hafızhüseyinbey	7933-A	45	2.0	260	-

5.3.2 Local and Individual Aquifers (la)

Consolidated formations such as Jurassic-Lower Cretaceous aged karstic limestones and Neogene aged fractured volcanic rocks which have specific capacity between 0.5-2 liter/second/meter in drilled wells, were classified as **local and individual** aquifers. The permeability of these aquifers ranges between 0.4 and 2.6 m³/day/m². Table 5.12 gives the list of drilled wells in these aquifers.

Table 5.12 Exploration wells drilled by DSİ in local and individual aquifers

Location	Number	Depth(m)	Specific capacity (lt/sec/m)	Trans-missibility (m3/day/m)	Thickness of Aquifer (m)
Tuzakçı	7469	236	1	130	50
Alaattin	7473-B	250	0.7	91	222

5.3.3 Poor Aquifers (pa)

Alluvium of central and southern Gönen Plain and Neogene sedimentary rocks which have specific capacity between 0.1-0.5 liter/second/meter were classified as **poor** aquifers. The permeability of these aquifers ranges between 0.2 and 0.7 m³/day/m². Table 5.13 gives the list of drilled wells in these aquifers.

Table 5.13 Exploration wells drilled by DSİ in poor aquifers

Location	Number	Depth(m)	Specific capacity (lt/sec/m)	Trans-missibility (m3/day/m)	Thickness of Aquifer (m)
Gönen	7471	300	0.3	29	41
Balcı	7475	281	0.1	5.2	18
Sarıköy	7474-B	236	0.1	13	59

5.3.4 Very Poor Aquifers (vpa)

Some alluvia of the Gönen Plain, Neogene sedimentary rocks and Triassic Karakaya Metamorphic Unit which have specific capacities less than 0.1

liter/second/meter were classified as very poor aquifers. The permeability of these aquifers is around $0.2 \text{ m}^3/\text{day}/\text{m}^2$. Table 5.14 gives the list of drilled wells in these aquifers.

Table 5.14 Exploration wells drilled by DSI in very poor aquifers

Location	Number	Depth(m)	Specific capacity (lt/sec/m)	Transmissibility ($\text{m}^3/\text{day}/\text{m}$)	Thickness of Aquifer (m)
Gönen	24775	58	0.01	1.3	-
Taştepe	O27	200	0.06	7.8	-
Taştepe	O28	190	0.03	3.9	-
Alaattin	7473-A	27	0.04	5.2	24

5.4 Recharge and Discharge of Groundwater

5.4.1 Recharge of Groundwater

Groundwater is derived chiefly by downward seepage (infiltration) of surface water, either directly from precipitation or from streams supplied by precipitation.

The theoretical maximum recharge can be the amount of excess water (228 mm) found from Penman's table (Table 5.4) if all the water infiltrates into the ground. Runoff measurements of Keçi Stream is used in this study to calculate the recharge of groundwater instead of assuming an infiltration ratio. The average annual runoff of Keçi Stream is 386.6 mm and the average annual base flow (groundwater runoff) is 130.0 mm (Table 5.5). The average annual base flow can be said as the net recharge amount of groundwater neglecting artificial discharge and evapotranspiration from groundwater. The total catchment area of the basin is approximately 730 km^2 between Kumköy and Ayvalıdere Gorge (Figure 5.1). But the aquifer type (local and individual aquifer) along the Keçi Stream and extensive and rich aquifer is nearly 50% of the whole drainage area. The rest of the drainage area is poor and very poor aquifer. The recharge amount of water is found by multiplication of infiltration amount and 50% of the drainage area.

$$\text{Recharge} = 0.130 \text{ [m/year]} \times 0.5 \times 730 \times 10^6 \text{ [m}^2\text{]} \cong 48 \times 10^6 \text{ [m}^3\text{/year]}$$

5.4.2 Discharge of Groundwater

The discharge of groundwater from the zone of saturation generally occurs by the hydraulic processes such as discharge by the streams, springs, and evapotranspiration, including both evaporation from soil and transpiration of plants in areas having a shallow water table.

For calculation of discharge by the streams, runoff measurements of streams in the entrance and exit of the Gönen Plain are used (Table 5.6). Table 5.15 gives the discharge amount through streams.

Table 5.15 Discharge amount of groundwater through streams in the Gönen Plain

Date	Runoff (m ³ /sec) in the entrance of the Gönen Plain	Runoff (m ³ /sec) in the exit of the Gönen Plain	Difference
Nov.11,1980	6.578	9.105	2.527
Nov.6,1981	1.775	3.192	1.417

The discharge of groundwater through streams between the two gauging stations is equal to 1.417 m³/sec. The minimum value is chosen on purpose that the effect of rainfall is thought to be minimum. In November evapotranspiration and artificial discharge do not happen or happen in small amounts. So this value should give the total discharge of groundwater to the Gönen River (note that the recharge of groundwater is found 48x10⁶ m³/year). But in summer because of evaporation and artificial discharge (pumping from wells and directly from Gönen River in the Gönen Plain) for irrigation, the river can not discharge groundwater. The discharge of groundwater by the streams is computed as 30x10⁶ m³/year for the period of 8 months.

Evapotranspiration from the soil happens between June and October where the depth of water table from surface is between 0-2 m. This area is around 20 km²

(generally in northern part of the Gönen Plain and in eastern part of the Sarıköy Plain). The deficient water is 398.8 mm/year (Table 5.4). The evapotranspiration from groundwater is found by multiplication of deficient water, area and evapotranspiration coefficient which is generally taken as 0.5 for such calculations.

$$\begin{aligned}\text{Evapotranspiration from groundwater} &= 0.3988 \text{ [m/year]} \times 20 \times 10^6 \text{ [m}^2\text{]} \times 0.5 \\ &= 4 \times 10^6 \text{ m}^3/\text{year}\end{aligned}$$

5.4.3 Water Budget

Water budget of the investigation area is prepared according to recharge and discharge amount of groundwater. The artificial discharge is computed from the difference of recharge and discharge amounts.

Table 5.16 Water budget of the investigation area

Recharge of groundwater(m ³ /year)		Discharge of groundwater(m ³ /year)	
The average annual base flow $\cong$ the net recharge amount of groundwater		by the streams	30x10 ⁶
		by the evapotranspiration	4x10 ⁶
		by the springs	2x10 ⁶
		Artificial discharge	12x10 ⁶
Total	48x10⁶	Total	48x10⁶

5.5 Water Chemistry

During the water cycle, water may appear in many environments and under different conditions. The chemical quality of surface or groundwater is the resultant of the geologic, hydrogeologic, biologic and cultural environment of the water and varies time to time as well as from place to place.

Determinations of the temperature, pH, alkalinity, acidity, dissolved oxygen and electric conductivity (EC) were carried out in the field, in order to avoid changes occurring by the time the samples reach the laboratory. Analyses of anion and cation concentrations of water samples were carried out in the laboratories.

5.5.1 Field Measurements

Field measurements of pH, electric conductivity(EC) and temperature of water resources were conducted by pH-meter(HACH) and EC-meter(HACH). Amount of dissolved oxygen were found by the Winkler method using Aquamerck 11107.

Total acidity and total alkalinity were determined by titration. Total acidity is the capacity of a water for neutralizing base to pH 7.0. In order to determine the total acidity, 0.0227N NaOH or Aquamerck 11109 were used in titration procedure. Total alkalinity is the capacity of water for neutralizing strong acid to pH 4.5. For the determination of the total alkalinity 0.02N HCl or Aquamerck 11108 were used in titration procedure. Table 5.17 shows the results of field measurements of water resources.

5.5.2 Chemical Composition and Classification of Water Resources

Water samples are collected and analyzed to ascertain chemical characteristics of water resources. Cation and anion concentrations of water samples were determined in the hydrogeology laboratories of ETH and İTÜ. The results of analyses made by MTA and DSİ are also given in this section. Table 5.18 gives the results of all chemical analyses.

For the classification purposes of water resources, units of cation and anion concentrations were converted from mg/l to mval%. Cations and anions were separately sorted in descending order. The values more than 10% were used in classification. The ions found in the water samples more than 50 mval% are underlined and those between 20-50 mval% are shown in parenthesis [42,43].

Table 5.17 Some physical and chemical properties of water resources measured in the field

Date	Name or number of water resource	T(°C)	EC (µS/cm)	pH	Eh (mV)	Dissolved O ₂ (mg/lt)	Alkalinity (mg/lt CaCO ₃)	Acidity (mg/lt CaCO ₃)	Discharge (lt/sec)
Aug.24,1990	Gönen River*	-	600	-	-	-	-	-	-
Aug.30,1990	S3	19.0	230	-	-	-	-	-	0.01
Aug.30,1990	S1	39.0	440	-	-	-	-	-	7
Aug.27,1991	Geyikli Spring**	21.3	197	3.75	189.6	-	70	-	-
Aug.28,1991	Gönen City Water***	-	425	-	-	-	280	71.3	-
Aug.29,1991	S5	16	462	7.50	-23.5	-	320	135	0.4
Aug.29,1990	S4	16	550	7.14	-3.2	-	390	135	7
Sep.04,1990	G3	70	2260	7.18	-6.9	-	297	140	-
Sep.04,1990	G1	-	2320	7.13	-4.5	-	135	-	-
Sep.04,1990	G4	62.8	2420	7.00	5.4	-	550	166	-
Sep.04,1990	G2	70.3	2370	7.13	-3.4	-	500	166	-
Mar.05,1992	S3	-	330	3.59	197.7	-	-	-	0.01
Mar.06,1992	S2	28.1	390	7.02	5.1	-	-	-	-
Aug.26,1992	G2	78.8	2530	7.80	-	0.8	550	90	-
Aug.26,1992	G4	73.8	2455	8.00	-	2.6	610	100	-
Aug.27,1992	S2	35.4	400	7.67	-	2.3	270	30	1
Aug.27,1992	S1	42.8	389	8.03	-	1.4	290	70	-
Aug.27,1992	S3	18.8	256	4.31	-	-	0	230	0.025
Aug.27,1992	S4	14.4	600	7.33	-	7.1	610	70	-
Aug.27,1992	Geyikli Spring**	25.2	213	4.20	-	5.2	-	210	-

* EC value is measured near the Gönen Bridge

**this spring is on the way to Geyikli village out of the investigation area

***Gönen city water comes from the Dumanalan Spring(S7)

The major cation and anion concentrations can easily be seen by using this classification.

Table 5.19 gives the type of water according to the classification mentioned above and in Figure 5.5 the semi-log (Schoeller) diagram of cation and anion concentrations of water resources is given.

The groundwater samples were gathered into 4 different groups.

I) Ca..HCO₃.. Type

Groundwater samples collected from the Ekşidere hot springs (S1 and S2) and karstic cold spring (S4) of Hafızhüseyinbey, and samples of water wells 7933A, 7471, 7473A, 7473B and 7470A belong to Ca..HCO₃.. Type water group. The Schoeller diagram of this group is shown in Figure 5.6.

II) Na..HCO₃.. Type

Groundwater samples of water wells 7933B and 7470B belong to Na..HCO₃.. Type water group. Figure 5.7 shows the Schoeller diagram of this group.

III) Na..(SO₄)(Cl)(HCO₃) Type

Water samples collected from the Gönen thermal water wells belong to Na..(SO₄)(Cl)(HCO₃) Type water group. Figure 5.8 shows the Schoeller diagram of this group.

IV) Other Types

The water sample collected from Gençlik Suyu (S3) is (Na)(Ca)SO₄ Type. This sample is a low mineralized acidic cold water. The water samples from water wells 7475, 7474B, 7469A give (Mg)(Ca)HCO₃.., (Ca)(Na)(Mg)HCO₃(SO₄), (Ca)(Mg)(Na)HCO₃(Cl) types in order. Schoeller diagram of these types is shown in . Figure 5.9.

Table 5.18 Cation and anion concentrations of water resources of the investigation area

Sample No	Date	CATIONS(mg/l)										ANIONS (mg/l)						
		B	Li ⁺	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	Ba ⁺⁺	Fe (total)	Al ⁺⁺⁺	NH4 ⁺	Cl ⁻	HCO3 ⁻	SO4 ⁼	NO3 ⁻	F ⁻	I ⁻	SiO2
G1 ⁽³⁾	1974	7.6	-	460.0	24.0	46.0	2.2	-	0.1	-	1.1	262.0	354.0	473.0	-	3.8	0.4	68.0
G2 ⁽³⁾	1976	-	4.0	440.0	22.0	49.0	1.6	-	0.2	-	1.2	270.0	394.0	491.0	0.3	4.3	-	46.0
G2 ⁽²⁾	1992	7.2	-	403.0	25.6	43.2	2.4	0.051	0.2	0.2	-	209.7	-	381.4	0.3	-	-	-
G3 ⁽³⁾	1985	7.6	-	460.0	26.2	48.0	3.2	-	0.1	-	0.3	261.0	397.0	459	0.8	3.4	-	80.0
G4 ⁽¹⁾	1991	3.0	1.5	365.6	26.5	49.0	2.9	-	0.5	-	1.4	252.0	384.3	-	-	-	-	68.0
G4 ⁽²⁾	1992	7.1	-	414.0	26.4	45.8	3.1	0.044	0.1	0.2	-	209.3	-	380.2	0.3	-	-	-
S1 ⁽³⁾	1985	0.4	<0.1	10.6	1.5	50.0	15.0	-	-	-	<0.1	12.0	195.0	28.4	2.1	0.3	-	35
S1 ⁽²⁾	1992	<0.1	-	11.0	3.1	47.3	10.7	0.3	<0.1	0.3	-	9.6	-	17.8	0.3	-	-	-
S2 ⁽³⁾	1985	<0.1	<0.1	11.4	2.1	49.0	11.0	-	0.1	-	0.1	14.7	177.0	41.0	2.0	0.4	<0.1	37
S2 ⁽²⁾	1992	<0.1	-	10.8	2.9	47.3	9.4	0.2	<0.1	0.2	-	14.2	-	29.4	0.3	-	-	-
S3 ⁽²⁾	1992	<0.1	-	7.6	1.6	6.6	2.0	<0.1	0.1	3.9	-	15.9	-	59.8	0.3	-	-	-
S4 ⁽²⁾	1992	<0.1	-	6.0	1.7	76.0	12.8	<0.1	<0.1	0.2	-	11.3	-	9.3	8.2	-	-	-
7933A ⁽⁴⁾	1966	-	-	27.4	2.7	84.0	11.4	-	-	-	-	41.2	260.9	39.0	-	-	-	-
7933B ⁽⁴⁾	1966	-	-	207.0	2.7	24.0	8.4	-	-	-	-	42.6	388.5	132.0	-	-	-	-
7471 ⁽⁴⁾	1966	-	-	16.8	2.7	46.0	13.2	-	-	-	-	12.8	212.3	17.3	-	-	-	-
7473A ⁽⁴⁾	1966	-	-	54.0	3.5	90.0	14.4	-	-	-	-	69.6	286.5	60.5	-	-	-	-
7473B ⁽⁴⁾	1966	-	-	32.9	16.4	76.0	15.6	-	-	-	-	42.6	298.6	25.4	-	-	-	-
7469A ⁽⁴⁾	1966	-	-	49.9	3.5	76.0	28.8	-	-	-	-	100.8	295.2	37.5	-	-	-	-
7470A ⁽⁴⁾	1966	-	-	19.8	3.1	66.0	13.2	-	-	-	-	34.8	208.4	34.5	-	-	-	-
7470B ⁽⁴⁾	1966	-	-	64.4	2.3	24.0	13.2	-	-	-	-	16.3	174.1	68.1	-	-	-	-
7475 ⁽⁴⁾	1966	-	-	19.8	2.7	38.0	25.2	-	-	-	-	23.4	190.0	39.8	-	-	-	-
7474A ⁽⁴⁾	1966	-	-	27.8	3.5	86.0	20.4	-	-	-	-	53.9	319.6	25.9	-	-	-	-
7474B ⁽⁴⁾	1966	-	-	64.4	3.5	67.0	19.8	-	-	-	-	49.0	283.0	89.8	-	-	-	-

(1) ITU Hydrogeology Lab.

(2) ETH Ingenieurgeologie Hydrolab.

(3) MTA

(4) DSI

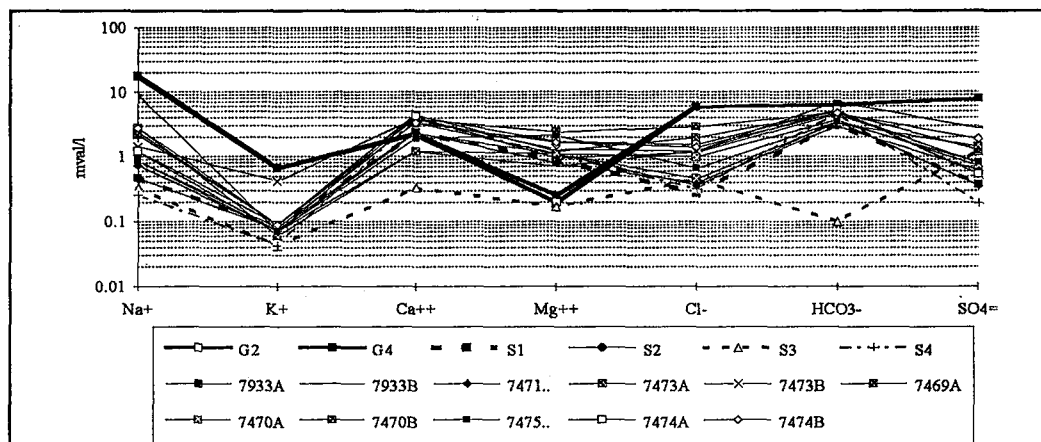


Figure 5.5 Schoeller diagram of analyzed water resources of the investigation area

Table 5.19 The classification of analyzed water resources of the investigation area

Number of water sample	Type of water
<i>Cold groundwater</i>	
S3	(Na) (Ca) Mg SO_4 Cl
S4	Ca (Mg) HCO_3
7933A	Ca Na Mg HCO_3 Cl SO_4
7933B	Na HCO_3 (SO_4) Cl
7471	Ca (Mg) Na HCO_3
7473A	Ca (Na) Mg HCO_3 (Cl) SO_4
7473B	Ca (Na) Mg HCO_3 Cl
7469A	(Ca) (Mg) (Na) HCO_3 (Cl)
7470A	Ca (Mg) Na HCO_3 (Cl) SO_4
7470B	Na (Ca) (Mg) HCO_3 (SO_4)
7475	(Mg) (Ca) Na HCO_3 SO_4
7474A	Ca (Mg) Na HCO_3 (Cl)
7474B	(Ca) (Na) (Mg) HCO_3 SO_4 Cl
<i>Hot groundwater</i>	
G1	Na Ca (SO_4) (Cl) (HCO_3)
G2	Na Ca (SO_4) (Cl) (HCO_3)
G3	Na Ca (SO_4) (Cl) (HCO_3)
G4	Na Ca (SO_4) (Cl) (HCO_3)
S1	Ca (Mg) Na HCO_3
S2	Ca (Mg) Na HCO_3 Cl

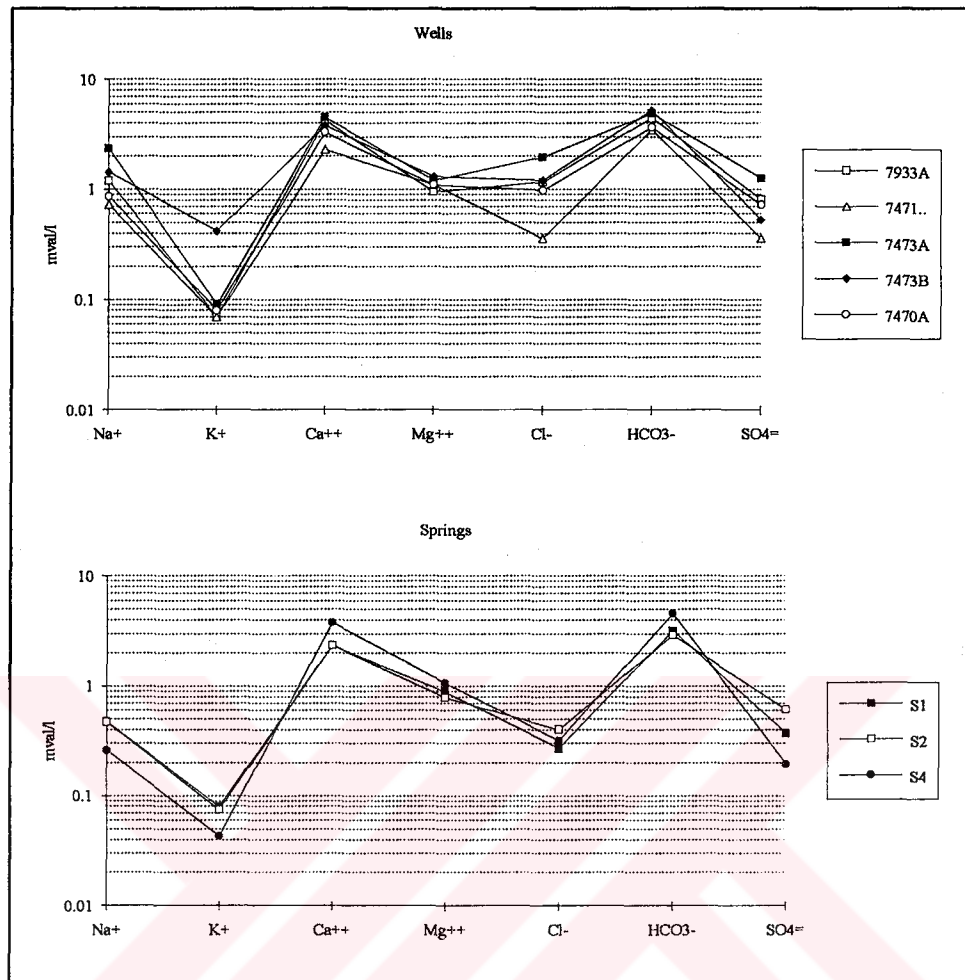


Figure 5.6 Schoeller diagram of Ca..HCO₃.. Type waters

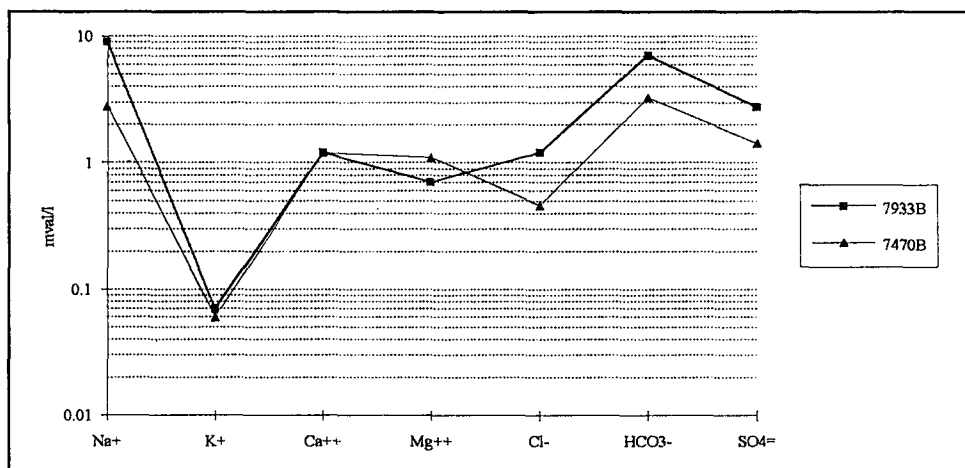


Figure 5.7 Schoeller diagram of Na...HCO₃.. Type waters

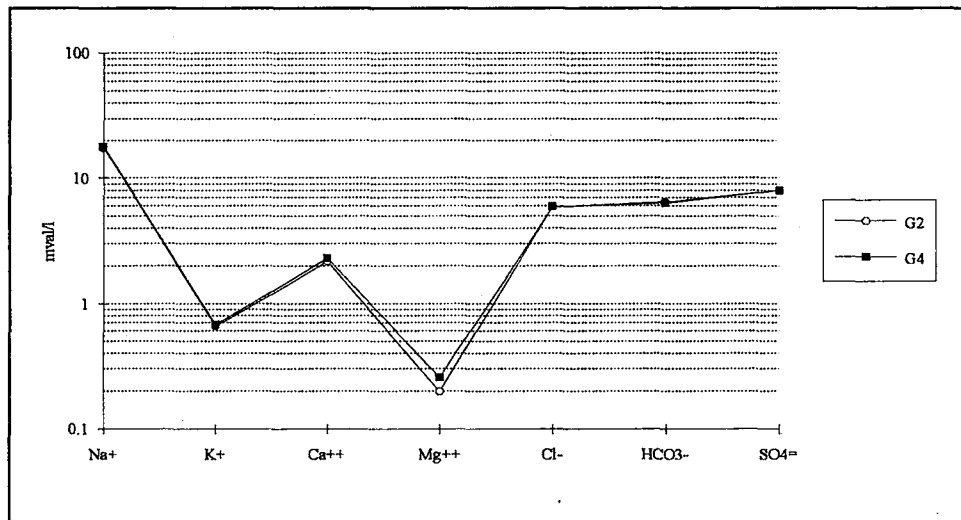


Figure 5.8 Schoeller diagram of Na..(SO₄)(Cl)(HCO₃) Type waters

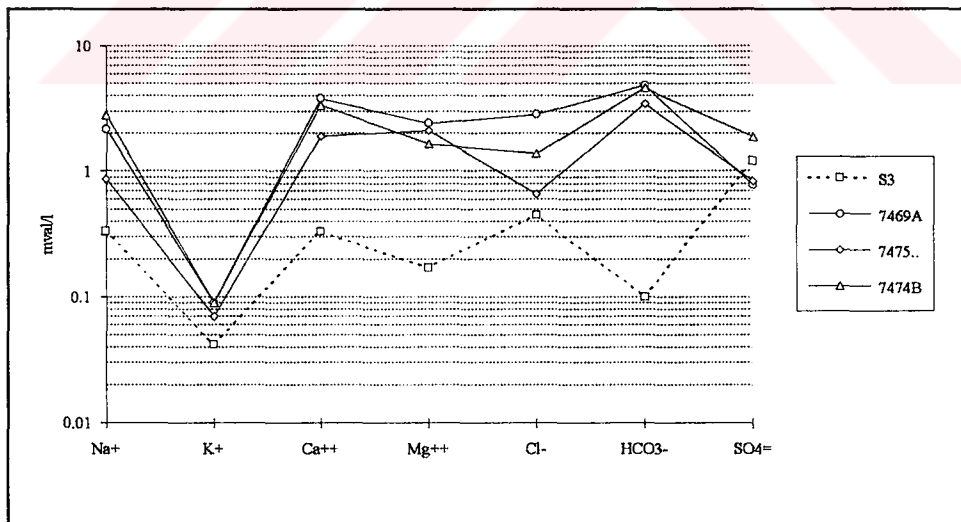


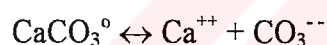
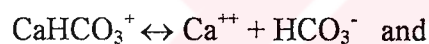
Figure 5.9 Schoeller diagram of waters grouped as Other Types

5.5.3 Geochemical Modeling of the Gönen and Ekşidere Thermal Waters

Geochemical modeling based on equilibrium and irreversible thermodynamics is a well recognized tool for understanding the process of water-rock interaction and predicting their consequences. For this purpose, a computer program, SOLMINEQ.88, was used in this study. This program computes the activity coefficients using Pitzer equations, pH and mineral solubilities. The principal computations carried by this program are aqueous speciation and saturation states of minerals[44].

The distribution of aqueous species for a given composition of water at specified pH and temperature is computed by solving a set of mass-action, oxidation-reduction and mass-balance equations based on the ion-association model.

For example, the dissociation reactions for CaHCO_3^+ and CaCO_3^0 are;



for which the respective mass-action equations are;

$$K_{\text{CaHCO}_3^+} = \frac{m_{\text{Ca}^{++}} \cdot \gamma_{\text{Ca}^{++}} \cdot m_{\text{HCO}_3^-} \cdot \gamma_{\text{HCO}_3^-}}{m_{\text{CaHCO}_3^+} \cdot \gamma_{\text{CaHCO}_3^+}}$$

$$K_{\text{CaCO}_3^0} = \frac{m_{\text{Ca}^{++}} \cdot \gamma_{\text{Ca}^{++}} \cdot m_{\text{CO}_3^{--}} \cdot \gamma_{\text{CO}_3^{--}}}{m_{\text{CaCO}_3^0} \cdot \gamma_{\text{CaCO}_3^0}}$$

where m_i and γ_i , are respectively, the molality and activity coefficient of the subscripted species and K is the dissociation of the subscripted aqueous complex.

The saturation state of a mineral in a given solution determines its interactions with that solution. In this program, two saturation indices are used to test for possible dissolution or precipitation of minerals. The program computes the Gibbs free energy (ΔG_{diff}) between the actual and equilibrium states of a mineral in a given subsurface water as well as the saturation index (SI) given by;

$$SI = \ln(Q/K)$$

ΔG_{diff} is given by;

$$\Delta G_{\text{diff}} = RT \ln(Q/K)$$

where R is the gas constant, T is temperature in degrees Kelvin, Q is the reaction quotient, and K is the equilibrium constant at the specified temperature and pressure.

At equilibrium, $Q=K$ and $\Delta G_{\text{diff}}=0$. In this case, the subsurface water is in equilibrium with the mineral and no dissolution or precipitation should take place. Where $\Delta G_{\text{diff}} > 0$, the mineral will not dissolve because of oversaturation, but rather will likely precipitate if kinetic factors allow.

During sampling of subsurface fluids, volatiles (including CO_2 , H_2S , NH_3 and CH_4) may be lost before the solution pH is measured. These gases can have a significant impact on the calculated, in-situ pH of the solution and must be included in the analyzed composition of the fluid. The program has options for titrating the lost gases back into solution. When the amount of lost CO_2 is known, the amount of CO_2 lost is added to the concentrations.

In-situ CO_2 concentrations of waters were measured by acidimetric titration using 0.0227N NaOH to the phenol phthalein end point, $\approx \text{pH } 8.3$ (Figure 5.10). An average of 14 ml titrant were spent for the titration procedure of Gönen (G1, G2, G3 and G4) samples and CO_2 concentrations were found as 140 mg/l (≈ 3.2 mmol/l).

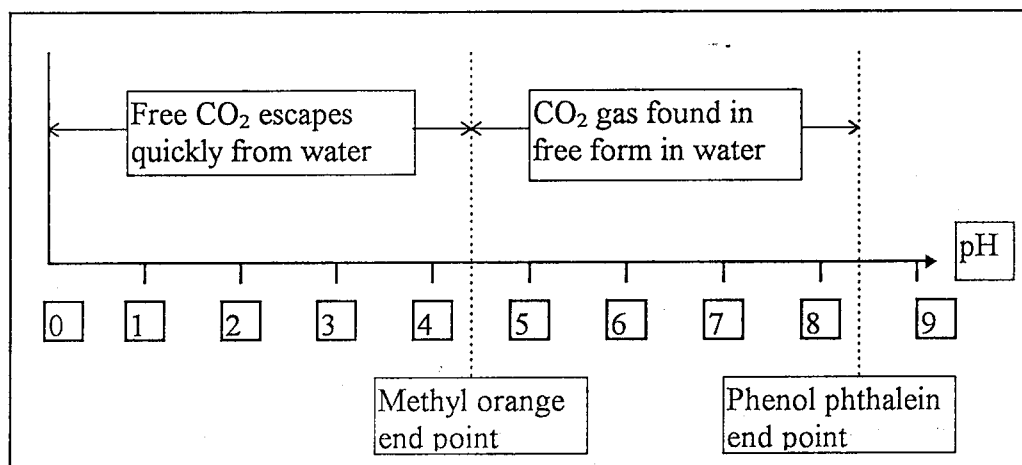


Figure 5.10 Availability of CO₂ in water in different pH values

The program was used to compute ionic species (Table 5.20) and saturation indices (Figure 5.11, 5.12 and 5.13) of the Gönen thermal water at different temperatures and pressures. First computation was made for 25°C and under atmospheric pressure ($P=1$ bar) reflecting the conditions of cooled thermal water. As a result of this computation the cooled Gönen thermal water (sample of G2) was found as oversaturated in aragonite (CaCO_3), calcite (CaCO_3), chalcedony (SiO_2), cristobalite (SiO_2), dolomite ($\text{CaMg}(\text{CO}_3)_2$), quartz (SiO_2), and talc ($\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$) (Figure 5.11). Second computation was made for 82°C, 1 bar pressure and by adding CO₂ lost to the concentration found by titration, reflecting the conditions of thermal water just before flowing out of well. Under these conditions, oversaturated minerals mentioned above become undersaturated except quartz (Figure 5.12). Third computation was made for 100°C and 100 bars pressure with the CO₂ amount added before reflecting the conditions of thermal water at 1000 m depth. Only dolomite becomes oversaturated and quartz is in equilibrium under these conditions (Figure 5.13).

The modeling helps to interpret the reason of low magnesium content in the Gönen thermal water while it can not dissolve dolomite (or may precipitate from

thermodynamic point of view) at depth. Due to the equilibrium with quartz at depth, the quartz geothermometer should give reasonable results for the computation of reservoir temperatures. Around thermal water well drillings aragonite is observed by the author which is one of the oversaturated mineral found by computations.

The same modeling was applied to the Ekşidere thermal waters. At 25°C chalcedony, cristobalite and quartz become oversaturated. After adding of CO₂ lost (2.5 mmol/l) at 42°C, only quartz become oversaturated. At 70°C (reservoir temperature computed by quartz geothermometer) and under 250 bar pressure all the minerals found undersaturated. The modeling shows that the Ekşidere thermal waters can not reach the equilibrium with minerals at the reservoir. The application of chemical geothermometers should be found doubtful.

Table 5.20 Analyzed and calculated ionic species and pH for different conditions of Gönen thermal water (G2) by using SOLMINEQ.88

TDS 1480.75 mg/l	T=25°C P=1 Bar	T=25°C P=1Bar	T=82°C P=1Bar	T=100°C P=100Bar
CO ₂ added (mmol/l)	0.0	0.0	3.2	3.2
pH	7.80	7.80	6.52	6.55
Ionic species (mg/l)	Analyzed	Calculated		
Ca ⁺⁺	43.24	34.22	30.34	28.32
Mg ⁺⁺	2.39	1.81	1.67	1.64
Na ⁺	403.00	390.60	381.30	379.0
K ⁺	25.56	25.19	25.11	25.05
Cl ⁻	209.66	209.30	209.10	209.10
SO ₄ ⁻	381.40	315.30	273.50	263.10
HCO ₃ ⁻		353.30	354.50	350.90
SiO ₂		-	-	
CaCO ₃		1.20	0.38	0.74
CaHCO ₃ ⁺		3.68	8.07	10.01
CaSO ₄		24.03	32.42	36.18
MgHCO ₃ ⁺		0.26	0.35	0.34
MgSO ₄		2.43	3.02	3.18
NaSO ₄ ⁻		57.45	101.10	110.40
NaCl		0.61	0.84	0.84
NaCO ₃ ⁻		0.38	0.44	1.08
NaHCO ₃		3.45	6.48	7.20
KSO ₄		1.20	1.47	1.64
CO ₃ ⁻		1.59	0.11	0.13
H ₄ SiO ₄		78.15	79.00	78.92
H ₃ SiO ₄		1.02	0.18	0.25
H ₂ CO ₃		10.97	205.30	206.30

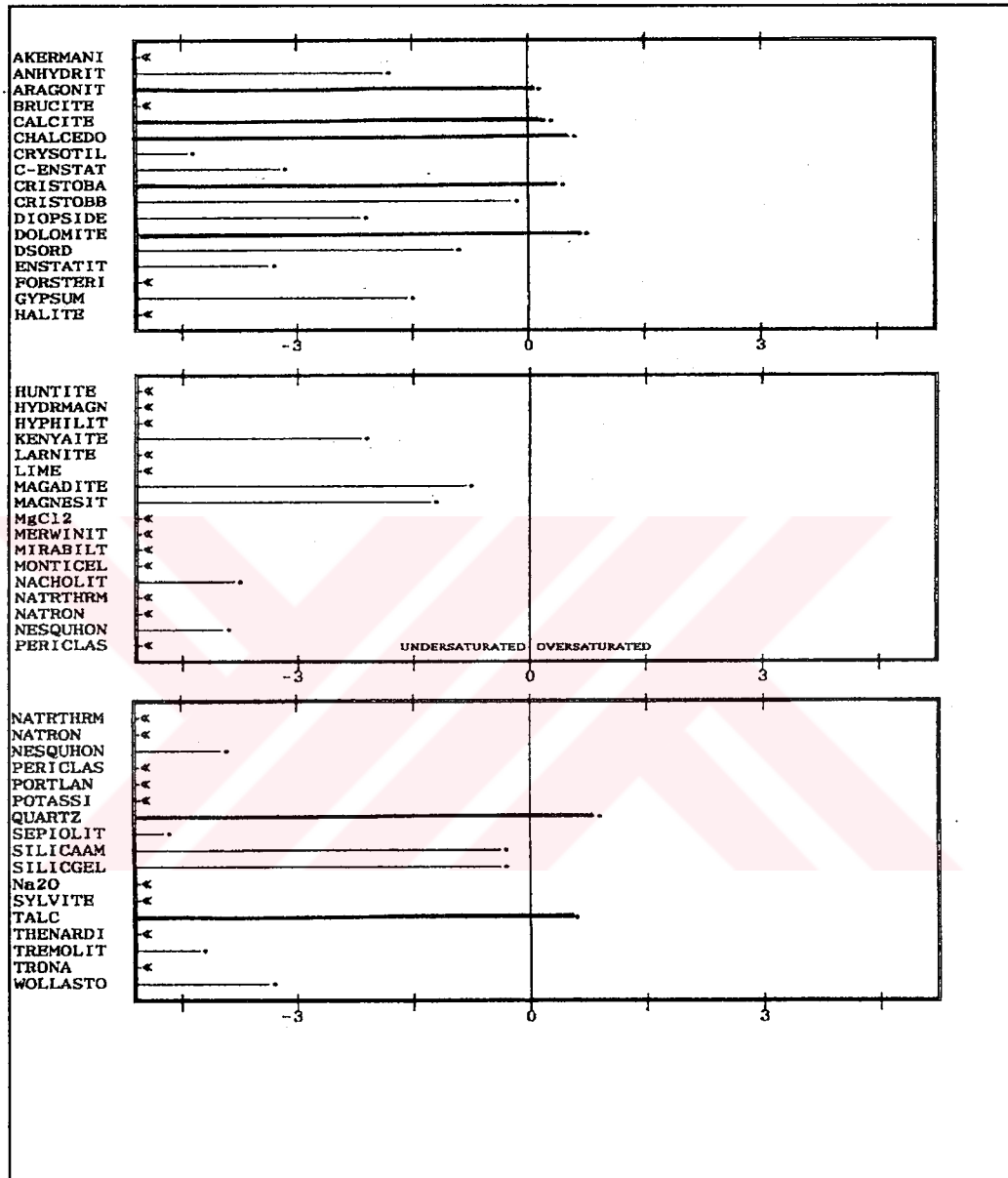


Figure 5.11 The saturation index plot of the Gönen thermal water at 25°C

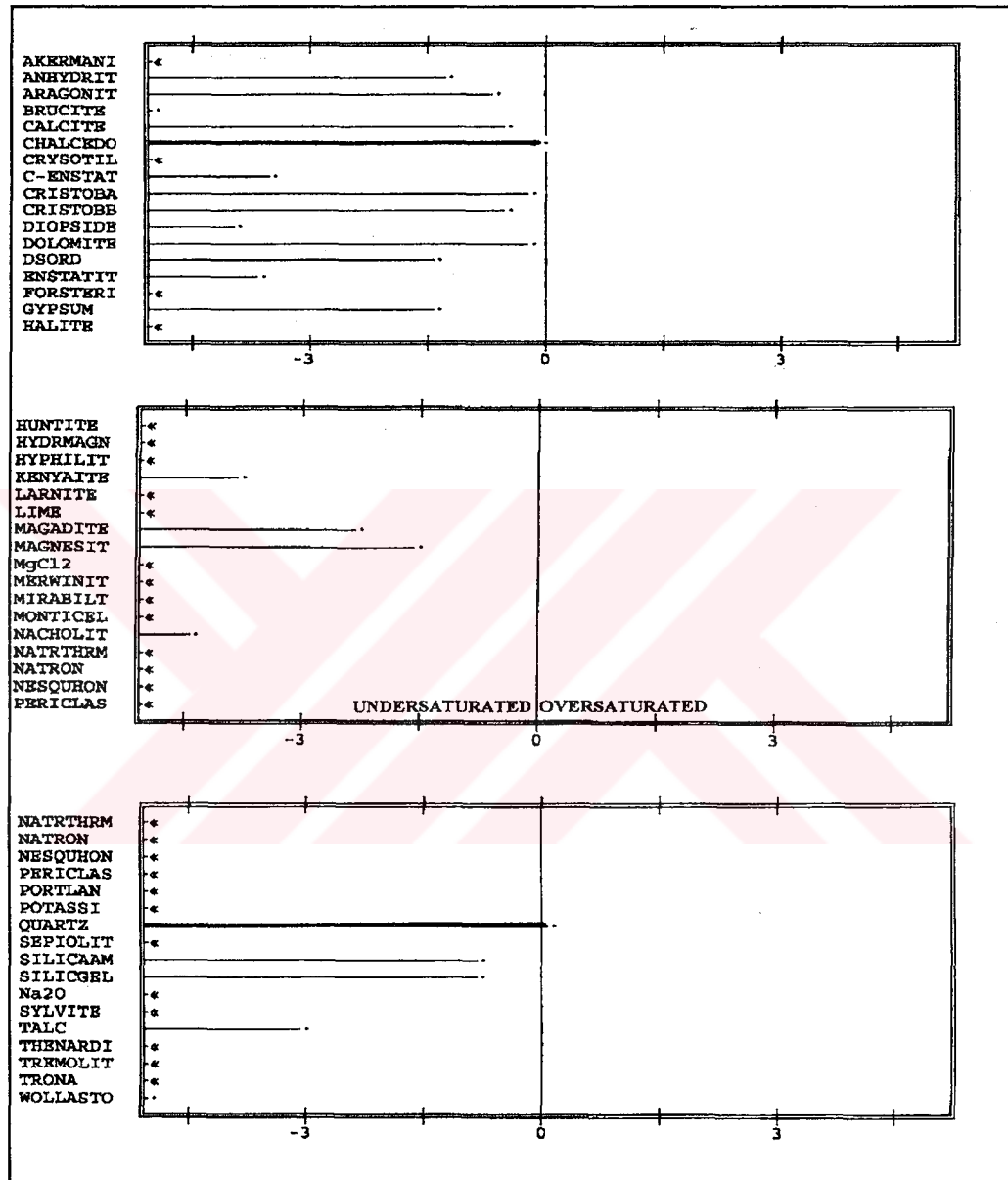


Figure 5.12 The saturation index plot of the Gönen thermal water at 82°C

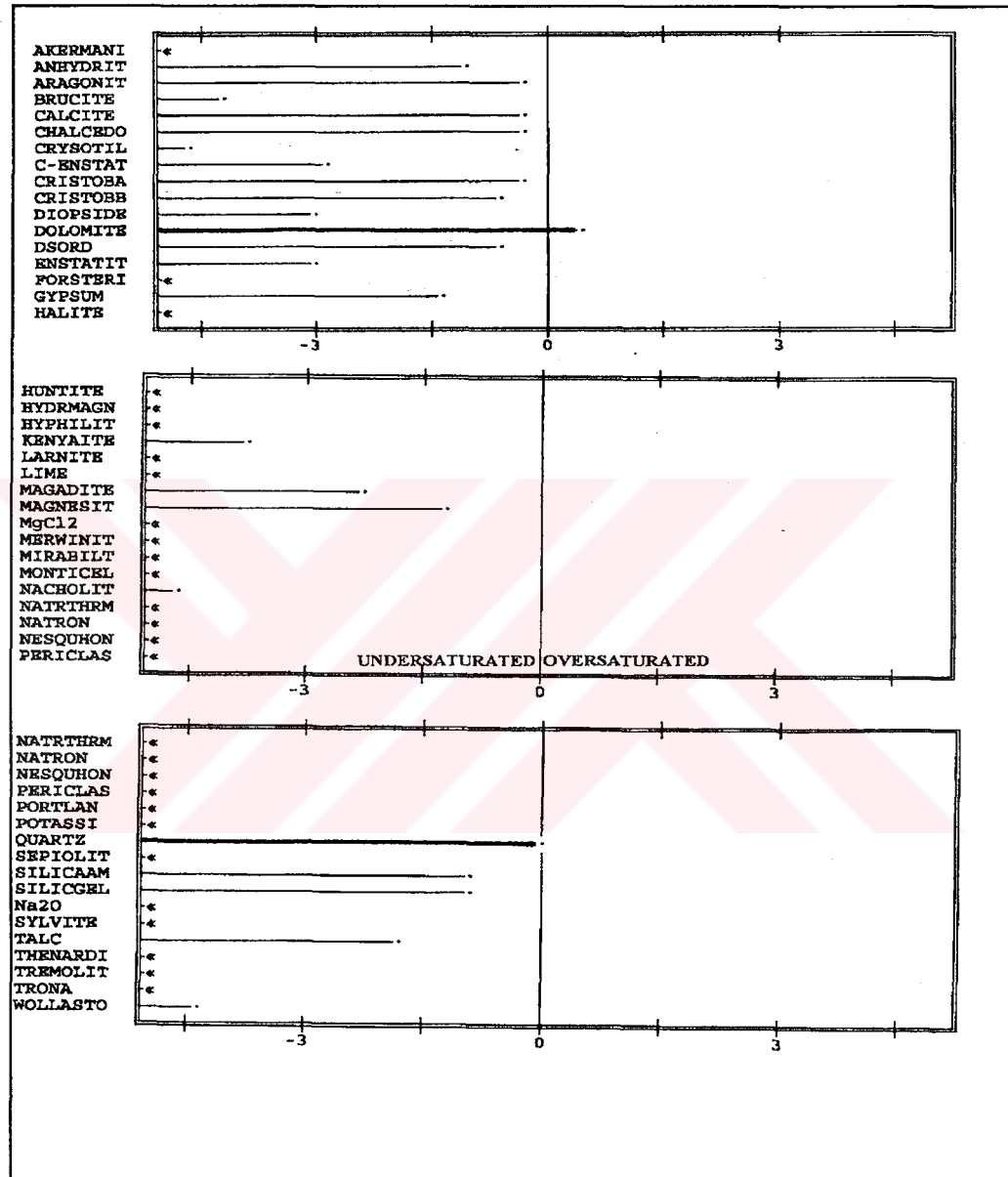


Figure 5.13 The saturation index plot of the Gönen thermal water at 100°C and 100 bars

CHAPTER 6 THERMAL HYDROGEOLOGY

In this chapter, the origin, the recharge temperature, the infiltration area, the age, the circulation depth and reservoir temperature of the Gönen and Ekşidere thermal waters, will be discussed. Results of available chemical, gas and isotopic analyses of the Gönen and Ekşidere thermal waters were used as well as some other cold and thermal waters located in and out of the investigation area.

6.1 Stable Isotope Composition of the Sampled Thermal Waters

Water molecules are built of hydrogen (H) and Oxygen (O). Different varieties of atoms with different numbers of neutron in their nucleus are called isotopes. The stable isotopes present in water are light hydrogen, ^1H (1 proton); heavy hydrogen called deuterium, ^2H or D (1 proton+1 neutron); light oxygen, ^{16}O (8 protons+8 neutrons) and heavy oxygen, ^{18}O (8 protons+ 10 neutrons).

Oxygen and hydrogen isotope analyses are extremely useful in the study of the origin of thermal waters. Applications of stable isotope analyses of oxygen-18 and deuterium were used to study the origin of Gönen and Ekşidere thermal waters together with regional hydrogeology, chemical and gas composition of the waters.

The water resources sampled for isotopic analyses in 1992 were S1, S2 (Ekşidere thermal waters), S3 (Gençlik suyu-acidic cold water), S4 (karstic cold spring), G2 (Gönen G2 thermal water well), G4 (Gönen G4 thermal water well) and Gey (acidic cold water near Geyikli village out of the investigation area). The water samples from Gönen thermal water wells were found to be significantly lighter isotopically than other sampled waters. This difference has been the cause of sampling thermal waters extending to Kazdağ Mountain. In 1994, thermal water samples were taken from G4, Hıd (Hıdırlar) and Top (Topaklar). Finally, in 1996,

samples were taken at different altitudes (1000-1700 m a.s.l.) of Kazdağ Mountain designated as GG (Gobaklıgediği), BK1 (Forester Hut 1), BK2 (Forester Hut 2), Toz (Tozlu) Kar (Kartalpinar) and from Kül (Külcüler thermal spring) near Kazdağ Mountain. The locations of sampled waters are shown in Figure 6.1 and their isotopic composition are given in Table 6.1.

The isotopic composition of water is expressed in permil (‰) deviations from the SMOW (Standard Mean Ocean Water). These deviations are written for δ^2H and $\delta^{18}O$:

$$\delta^2H(‰) = \frac{(^2H/^1H)_{sample} - (^2H/^1H)_{SMOW}}{(^2H/^1H)_{SMOW}} \times 1000$$

and

$$\delta^{18}O(‰) = \frac{(^{18}O/^16O)_{sample} - (^{18}O/^16O)_{SMOW}}{(^{18}O/^16O)_{SMOW}} \times 1000$$

6.2 Gas Composition of the Gönen and Ekşidere Thermal Waters

Gases dissolve in water in quantities varying with the nature of gas, the temperature, and the pressure. During infiltration, the water generally attains equilibrium with the air and dissolves atmospheric gases at the recharge area in the aeration zone of soil. Some gases of metamorphic and mantle origin may be dissolved in water during deep circulation. The samples were collected in August 1992 and the analyses were carried out at the Paul Scherrer Institute in December 1992. Table 6.2 gives the CH_4 (methane), N_2 (nitrogen), O_2 (oxygen), Ar(argon) and CO_2 (carbon dioxide) concentrations of the Gönen and Ekşidere thermal waters. Nitrogen and carbon dioxide predominate in these waters.

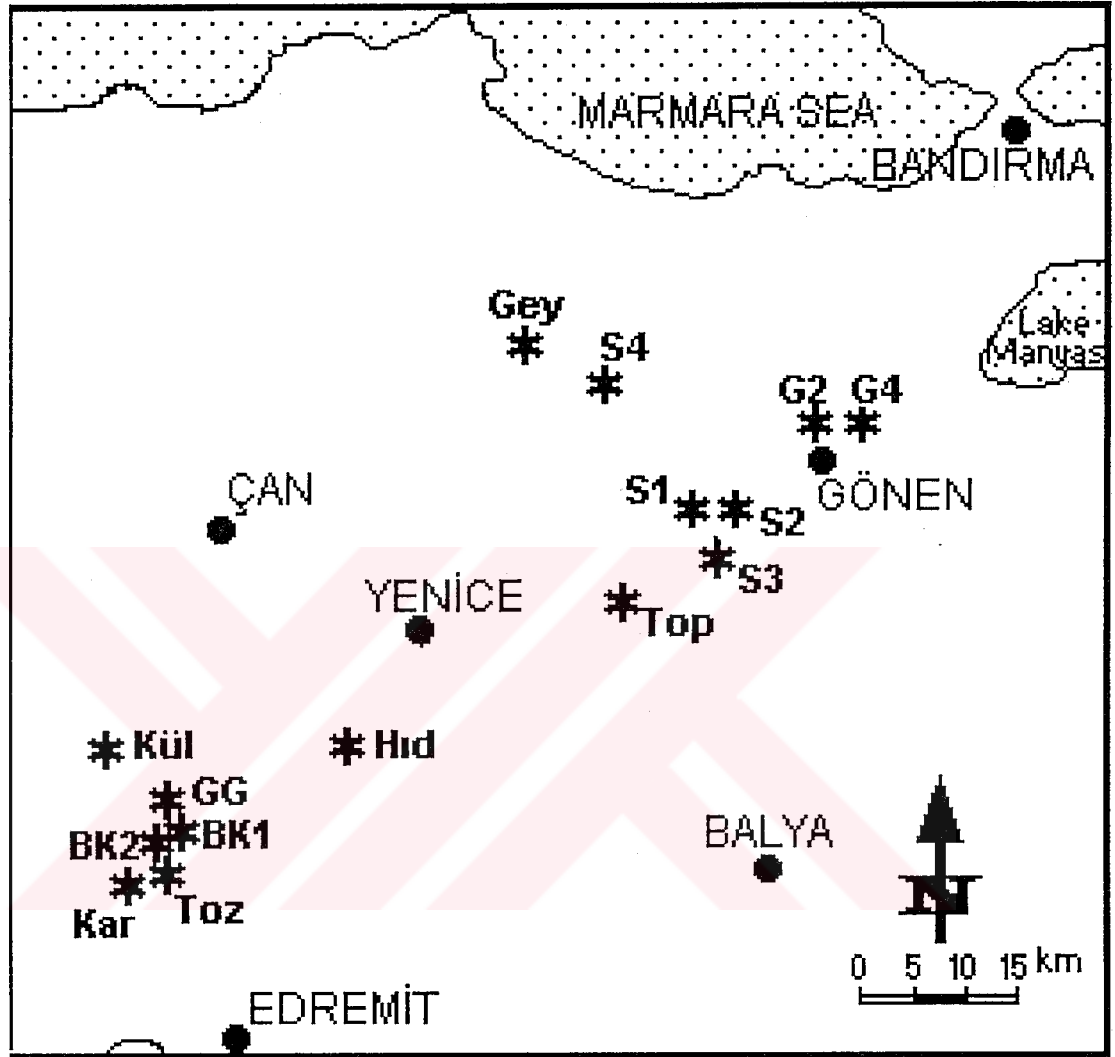


Figure 6.1 Location map of sampled water resources for isotopic analyses

(Gey-Geyikli spring, Top-Topaklar thermal water, Hıd-Hıdırlar thermal water, G2 and G4 -Gönen thermal water, S1 and S2- Ekşidere thermal water, S3-Gençlik suyu spring, Kar-Kartalpınar spring, Toz-Tozlu spring, BK1 and BK2- Forester hut springs, GG-Gobaklıgediği spring, Kül-Külcüler thermal water)

Table 6.1 Results of the isotopic analyses of the sampled waters
(isotope analyses carried out by GSF, Neuherberg, Germany)

Sample name	Date of sampling	$\delta^2\text{H}(\text{‰})$ Deuterium	$\delta^{18}\text{O}(\text{‰})$ Oxygen18	^3H (TU) Tritium	Temperature (°C)	pH	EC ($\mu\text{S}/\text{cm}$)	Discharge altitude (masl)
S1 Ekşidere West	Aug.27, 1992	-55.1	-8.84	<1.1	42.0	8.0	389	200
S2 Ekşidere East	Aug.27, 1992	-54.6	-8.92	<0.7	28.1	7.7	400	200
S3 Gençlik Suyu	Aug.27, 1992	-51.0	-8.21	11.6±1.2	19.0	4.3	256	200
S4 Hafız- hüseynbey	Aug.26, 1992	-50.3	-8.04	20.0±1.4	14.4	7.3	600	200
G2 Gönen	Aug.26, 1992	-68.9	-9.41	<0.7	78.8	7.8	2530	35
G4 Gönen	Aug.26, 1992	-70.5	-9.68	<0.7	73.8	8.0	2455	35
Gey Geyikli	Aug.27, 1992	-52.1	-8.07	12.3±1.2	25.2	4.2	213	100
G4 Gönen	Sep.3, 1994	-71.4	-9.95	<1.7	75.0	7.1	2455	35
Hıd Hıdırlar	Sep.4, 1994	-50.3	-8.37	<0.7	84.2	6.6	980	300
Top Topaklar	Sep.4, 1994	-60.8	-9.31	<0.7	67.3	8.0	1700	150
GG Gobaklı- gediği	Aug.14, 1996	-50.4	-8.18	-	8.5	6.3	92	1000
BK1 Forester hut 1	Aug.14, 1996	-48.0	-7.89	-	10.5	7.7	65	1220
BK2 Forester hut 2	Aug.14, 1996	-48.8	-7.96	-	7.5	8.4	65	1260
Toz Tozlu	Aug.15, 1996	-48.6	-7.90	-	4.6	8.4	122	1480
Kar Kartal- pınar	Aug.15, 1996	-51.8	-8.32	-	6.5	7.4	79	1700
Kül Külcüler	Aug.15, 1996	-54.0	-8.29	-	34.7	6.9	1020	400

Table 6.2 The gas concentrations of the Gönen and Ekşidere thermal waters and volumetric composition of air at sea level

	Concentration										Total extracted gas volume cm ³ /kg
Sample Nr	CH ₄		N ₂		O ₂		Ar		CO ₂		
	mg/kg	Vol%	mg/kg	Vol%	mg/kg	Vol%	mg/kg	Vol%	mmol/ kg	Vol%	
G2	0.79	1.53	39.8	44.1	-	-	1.00	0.78	1.7	53.6	72.1
G4	0.65	1.19	40.0	42.3	2.70	2.50	0.96	0.71	1.8	53.3	75.7
S2	-	-	16.0	42.0	1.82	4.20	0.56	1.04	0.7	52.7	30.4
Air at sea level		0.0002		78.804		20.946		0.934		0.032	

6.3 The Origin of the Gönen and Ekşidere Thermal Waters

At present, almost no problem concerning the origin of groundwater can be solved without the use of environmental isotope determinations.

The isotopic composition of present-day surface waters are well-known and lie on a “meteoric water line” that can be described by the general equation:

$$\delta^2\text{H} = x \cdot \delta^{18}\text{O} + d$$

where the value of x is equal to 8 in all meteoric waters if it is not under effect of evaporation, but d-parameter which is described as deuterium excess, is equal to 10 in global¢ral Anatolia meteoric waters, 22 in eastern Mediterranean meteoric waters, 16 in Marmara meteoric waters [45] and 1.2 [46] in palaeoclimatic waters.

The isotopic compositions of sampled waters are plotted on $\delta^2\text{H}$ - $\delta^{18}\text{O}$ diagram, where global¢ral Anatolia, eastern Mediterranean, Marmara and

palaeoclimatic water lines are also drawn (Figure 6.2). The samples of the Ekşidere thermal water (S1 and S2), the karstic spring (S4), Gençlik Suyu (S3) and the Hıdırlar thermal water (Hid) are related to local meteoric water because their isotopic composition lie close to the Marmara meteoric line. The samples of the Topaklar thermal water (Top) and the Geyikli acidic spring (Gey) lie in-between global¢ral Anatolia and Marmara water lines. The isotopic composition of the samples mentioned above lie in between meteoric lines and the origin of them is certainly meteoric, therefore.

The meteoric water derives from rain, snow and water bodies of surface water that percolates in rocks. The majority of the meteoric waters are generally recharged at high elevations in the margins of the basins. Recent evidence from stable isotope ratios of water indicates that meteoric water can percolate to great depths (up to 10 km) in geothermal systems[47] and their circulation time may exceed thousands of years. This type of waters are called old meteoric water.

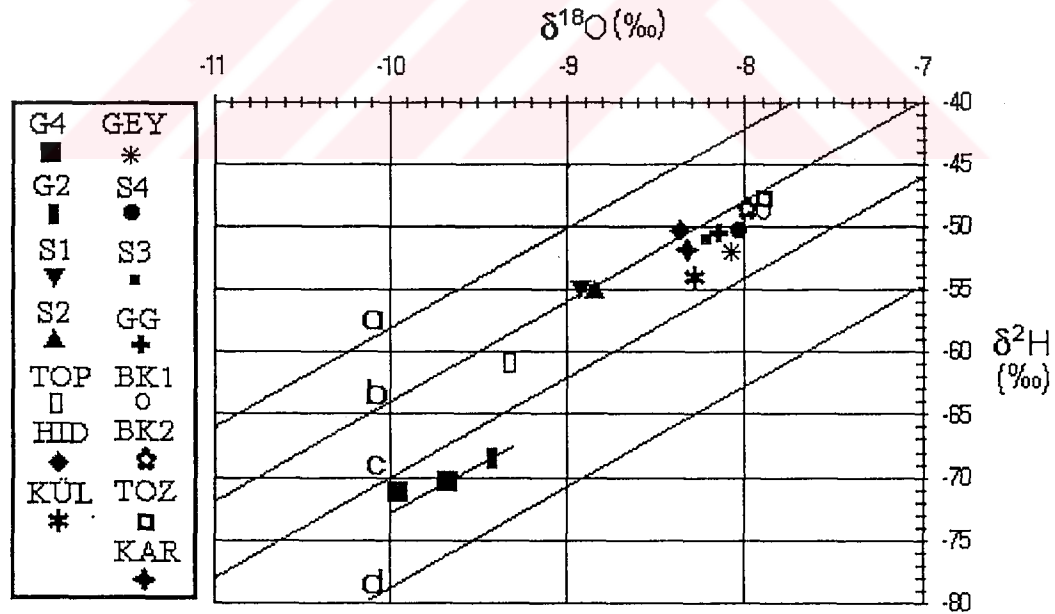


Figure 6.2 The $\delta^2\text{H}$ - $\delta^{18}\text{O}$ plot of sampled waters

(a - eastern Mediterranean $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 22$

b - Marmara meteoric water line $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 16$

c - global¢ral Anatolia meteoric water line $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 10$

d - palaeoclimatic water line $\delta^2\text{H}(\text{‰}) = 8\delta^{18}\text{O} + 1.2$)

The $\delta^2\text{H}$ content of the Gönen thermal water is the lowest among sampled waters. The $\delta^2\text{H}$ and $\delta^{18}\text{O}$ composition of the Gönen thermal water is related to old meteoric water. Depleted $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values indicate cold climate conditions and/or higher recharge altitudes.

The isotopic composition of most deep geothermal waters is related to that of the local meteoric water but does not lie on the meteoric water line while they are usually enriched in ^{18}O . $\delta^{18}\text{O}$ shift (Figure 6.2) in the Gönen thermal water is due to isotopic exchange that occurs between water and minerals at elevated temperatures (water-rock interaction). In waters, $\delta^{18}\text{O}$ shifts are more common than $\delta^2\text{H}$ shifts because hydrogen atoms are rarely found in minerals. The magnitude of oxygen isotope shift depends on the mineralogy of rock, the temperature, the water/rock ratio, and the time of contact.

6.4 Recharge Temperature and Recharge Area of the Gönen and Ekşidere Thermal Waters

The solubility of Argon in water is strongly temperature dependent. In other words, recharging water gets the temperature information when it equilibrates in the saturated zone. The recharge temperature of water can be found by using temperature dependent solubility of Argon. This method is first described by Mazor [48]. The Ar concentration of the Gönen and Ekşidere thermal waters is given in Table 6.3.

Table 6.3 The Ar concentration of the Gönen and Ekşidere thermal waters

Sample Nr	Ar, in mg/kg	Ar, in $\text{cc}_{\text{Ar}}/\text{cc}_{\text{water}}$
G2(Gönen)	1.00	5.6×10^{-4}
G4(Gönen)	0.96	5.4×10^{-4}
S2(Ekşidere)	0.56	3.1×10^{-4}

In order to compute the ambient temperature (or palaeotemperature) in the water-recharge zone, the solubility diagram of atmospheric argon was used (Figure 6.3). It is assumed that there is no excess air dissolved in these waters (normally Ne is used for the correction). The solubility of Ar in Figure 6.3 is given for 760 mm Hg or at sea level. The recharge of the water should be at higher altitudes and a correction factor must be used before using Figure 6.3. The correction factor to sea level is given in Figure 6.4.

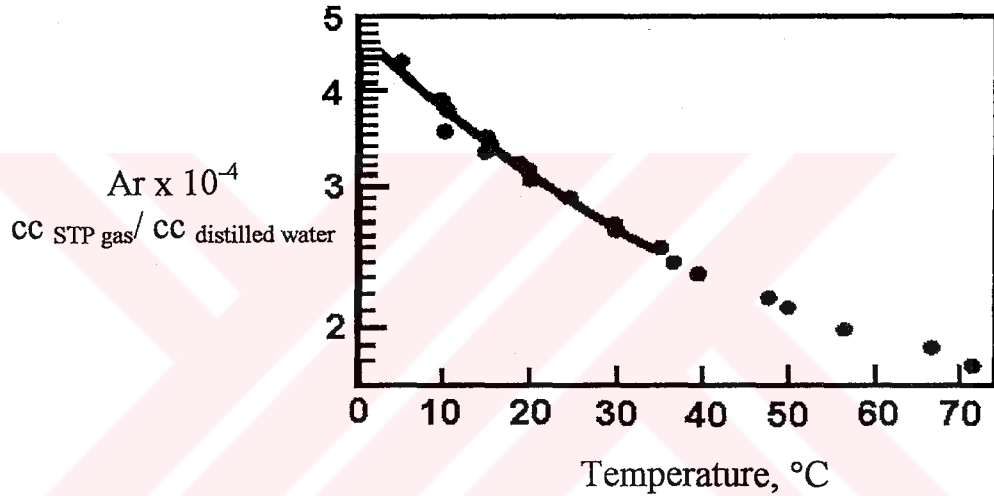


Figure 6.3 Solubility of atmospheric argon in fresh water at sea level, as a function of the ambient temperature [48].

In the samples of the Gönen thermal water $5.4\text{--}5.6 \times 10^{-4}$ $\text{cc}_{\text{Ar}}/\text{cc}_{\text{water}}$ were found. The altitude selected was 1500 masl (considering Kaz Mountain as the possible recharge area) and correction factor of 1.19 was found from Figure 6.4. The Ar concentrations were divided by 1.19 and 4.7×10^{-4} $\text{cc}_{\text{Ar}}/\text{cc}_{\text{water}}$ was calculated as an average value for 760 mm Hg. From Figure 6.3, the ambient temperature (or palaeotemperature) at water recharge zone was found to be about 0°C.

For the computation of ambient temperature at the water recharge zone for the Eksidere thermal water the Ar concentration (3.1×10^{-4} $\text{cc}_{\text{Ar}}/\text{cc}_{\text{water}}$) was divided by 1.055 (the altitude selected was 500 masl) and 3.0×10^{-4} $\text{cc}_{\text{Ar}}/\text{cc}_{\text{water}}$ was found. The

1.055 (the altitude selected was 500 masl) and $3.0 \times 10^{-4} \text{ cc}_{\text{Ar}}/\text{cc}_{\text{water}}$ was found. The ambient temperature was found to be 23°C from Figure 6.3. This temperature is 10°C higher than the actual mean annual temperature of Gönen. The reason of this can be loss of the gasses just before sampling.

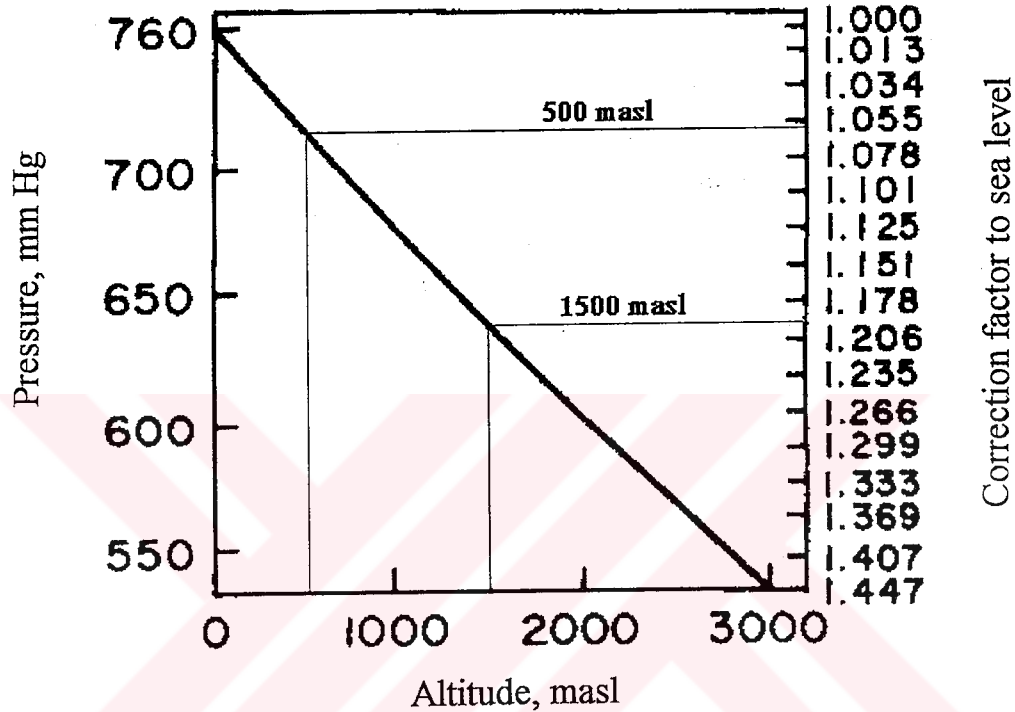


Figure 6.4 Atmospheric pressure variations as a function of altitude. Correction factor on the right axis serve to convert solubility values at sea level to values at desired altitude (dividing by the factor) or to normalize data at given altitude to the corresponding value at 0 masl (multiplying by the factor [48]).

The recharge area of the Gönen thermal water is thought to be Kazdağ Mountain which is the only area of high elevation around the Gönen thermal water. As the clouds move on into the continent or up a mountain, the produced rain becomes progressively depleted of the heavy isotopes. But isotopic composition of sampled waters (GG, BK1, BK2, Toz and Kar) from different elevations do not show a significant trend with respect to altitude. The stable isotope contents of young cold waters are almost the same over the whole area. Because of this result, it is not

possible to define the recharge area as a function of altitude. The origin of depleted deuterium can only be explained by cold weather because the ambient temperature at the recharge zone was found to be about 0°C by using argon concentration.

A trend was found in chlorine content and electrical conductivity among samples from Gönen, Topaklar, Hıdırlar and samples of Kazdağ (GG, BK1, BK2, Toz and Kar) as a function of distance from Kazdağ Mountain (Figures 6.5 and 6.6). This trend indicates that chlorine concentration and electrical conductivity increase along the flow path from Kazdağ Mountain to Gönen. Figure 6.7 shows that waters containing low chlorine and high deuterium, such as Hıdırlar (Hıd), Külçüler (Kül), Ekşidere (S1 and S2) and cold waters, indicate actual recharge conditions. In this case, Hıdırlar and Külçüler should be close to their recharge area, which are also close to Kazdağ Mountain.

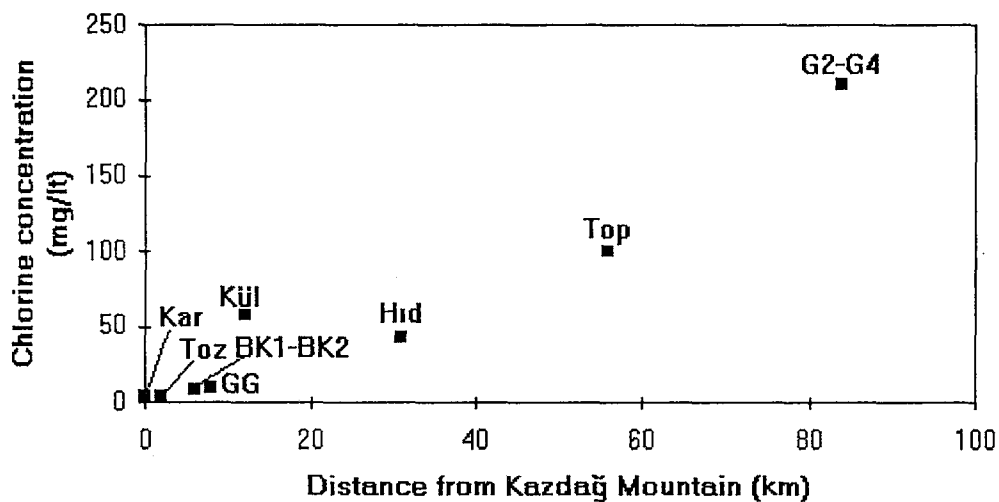


Figure 6.5 Plot of the chlorine concentration versus distance from Kazdağ Mountain

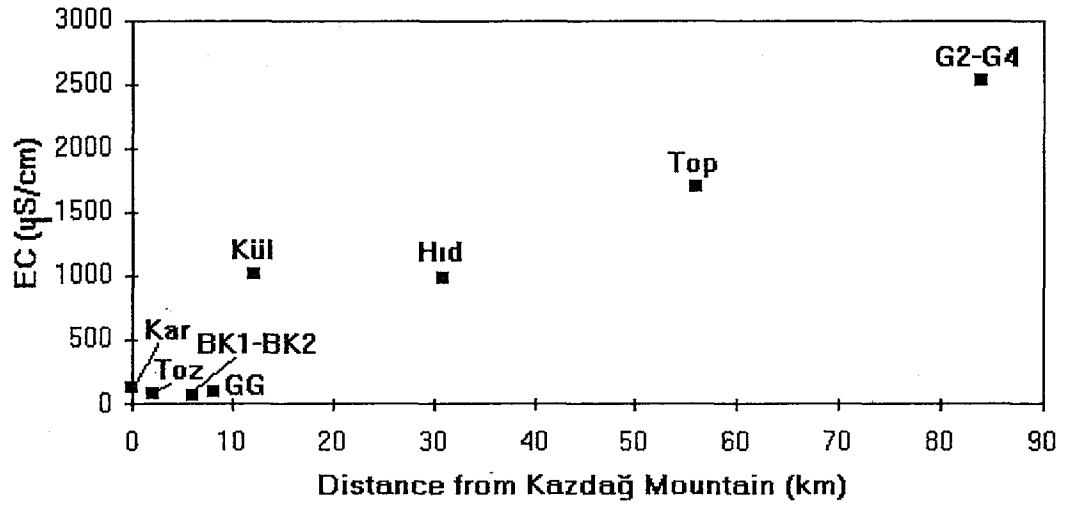


Figure 6.6 Plot of electrical conductivity versus distance from Kazdağ Mountain

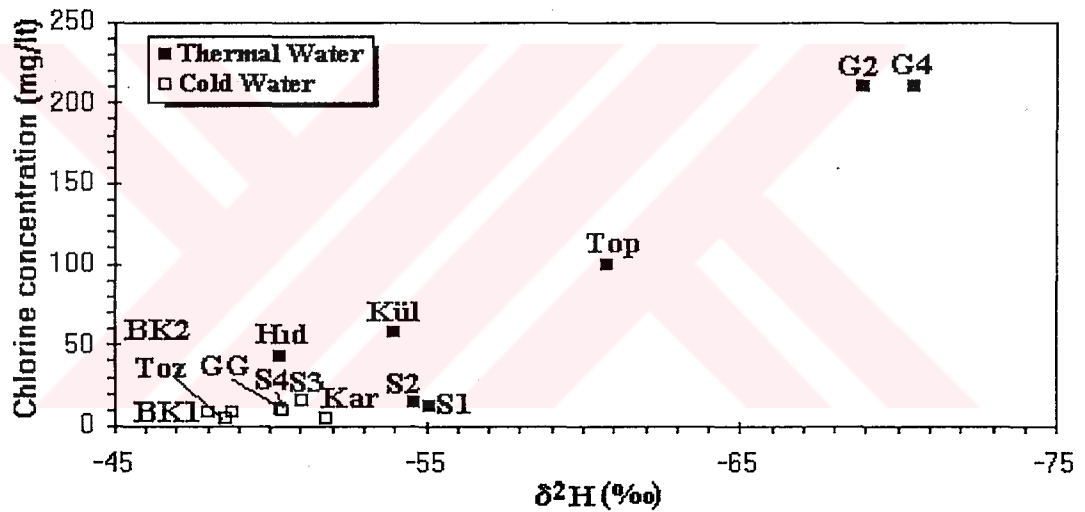


Figure 6.7 Plot of deuterium versus chlorine content

The Ekşidere thermal waters are different in temperature, chemical and isotopic composition from the Gönen thermal water. Its chemical composition (Ca HCO_3 Type) and temperature ($28.1\text{-}42.8^\circ\text{C}$) point to a shallow circulating system rather than to a deep circulating system. The ambient temperature found from argon concentration indicates a warmer climate if there is no loss of Ar during sampling.

As a result, the recharge area of the Ekşidere thermal waters can be thought the hills seen at the southern edge of the thermal waters, where the average altitude is around 500 masl.

6.5 Flow Velocity and Transit time of the Gönen Thermal Water

The best method to calculate the age or the transit time of water is the ^{14}C isotopic measurement method within 40,000 years. If the recharge area is known then the calculation of flow velocity is also possible.

The samples for ^{14}C determination were collected from the Gönen, Hıdırlar and Topaklar thermal waters. A 30 liter carboy was used to precipitate CO_2 as BaCO_3 by using a saturated BaOH solution. The uncorrected age of the Gönen thermal water is $22,970 \pm 200$ years and that of the Hıdırlar thermal water is $16,640 \pm 140$ years according to ^{14}C and $\delta^{13}\text{C}$ values. (^{14}C and $\delta^{13}\text{C}$ analyses:

Institut für Teilchenphysik,ETH).

The tritium (^3H) concentration of water gives age information within 40 years. Tritium is the radioactive isotope of hydrogen. The concentration of tritium (^3H) in water is expressed by the ratio of ^3H atoms to ^1H atoms; a ratio of $^3\text{H}/^1\text{H}=10^{-18}$ is defined as 1 tritium unit (1 TU). The tritium concentrations of all sampled waters are given in Table 6.1. All of the sampled thermal waters have tritium concentration below the detection limit. This indicates that the sampled thermal waters are at least older than 40 years.

An attempt was made to estimate the velocity of thermal water by using a thermal profile (or temperature log) of the G4 thermal water well. The detailed temperature measurements in the well were carried out by MTA after completion of the drilling [31]. The temperature log of the G4 thermal water well is given in Figure 6.8.

The velocity estimation method using temperature logs obtained from thermal water wells is described by Dumlu&Yalçın [49] according to theory of Bredehoeft&Papadapulos [50]. They developed an analytical solution to estimate the rate of vertical groundwater movement by using thermal profiles. They used the following formula for heat and fluid which flows through an isotropic, homogenous and fully saturated porous medium;

$$\frac{\partial^2 T}{\partial z^2} - \frac{c\delta v}{K} \cdot \frac{\partial T}{\partial z} = 0$$

For boundary conditions ($T_z=T_0$ at $z=0$ and $T_z=T_L$ at $z=L$) the equation can be solved as;

$$f\left(\beta, \frac{z}{L}\right) = \frac{T_z - T_0}{T_L - T_0} = \frac{1 - e^{-\frac{\beta z}{L}}}{1 - e^{-\beta}} \quad \left(\beta = \frac{c\delta v L}{K} \right)$$

where T is the temperature at any point ($^{\circ}\text{C}$), z is the depth (cm), c is specific capacity of the fluid (cal/gr. $^{\circ}\text{C}$), δ is density of the fluid (gr/cm^3), v is vertical velocity of the fluid (cm/sec), K is the thermal conductivity of the solid-fluid complex (cal/cm.sec. $^{\circ}\text{C}$), T_z is the temperature measurement at any z depth ($^{\circ}\text{C}$), T_0 is the uppermost temperature measurement ($^{\circ}\text{C}$), T_L is the lowermost temperature measurement ($^{\circ}\text{C}$), L is the vertical distance between T_0 and T_L (cm).

In this method, β and v are estimated by matching type curve $[z/L; f(\beta, z/L)]$ and field curve $[z/L; (T_z - T_0)/(T_L - T_0)]$, and using the above mentioned equations.

The modification was done by choosing $\beta \geq 4$. If β is chosen greater than 4 than $e^{-\beta}$ becomes 0.0183 which can be accepted as 0 and then the equation can be rewritten as;

$$1 - e^{-\left(\frac{\beta z}{L}\right)} = \frac{T_L - T_0}{T_L - T_0} \Rightarrow 1 - \frac{T_z - T_0}{T_L - T_0} = \frac{T_L - T_z}{T_L - T_0} = e^{-\left(\frac{\beta z}{L}\right)} \Rightarrow \frac{\beta \cdot z}{L} = \ln \frac{T_L - T_0}{T_L - T_z}$$

If specific heat of water (c) is equal to 1 cal/gr and density of water 1 gr/cm³

$$\beta = \frac{v \cdot L}{K} \Rightarrow \frac{\beta}{L} = \frac{v}{K} \text{ . If we multiply both sides by } z \frac{\beta \cdot z}{L} = \frac{v \cdot z}{K} \text{ is found.}$$

The equation $\frac{\beta \cdot z}{L} = \ln \frac{T_L - T_0}{T_L - T_z}$ can be written as $\frac{v \cdot z}{L} = \ln \frac{T_L - T_0}{T_L - T_z}$ by substitution

$\frac{\beta \cdot z}{L}$ with $\frac{v \cdot z}{L}$ and $v = \frac{K}{z} \ln \frac{T_L - T_0}{T_L - T_z}$ is found.

So if T_0 , T_L and T_z at any z depth is known then the vertical velocity (v) can be estimated. For thermal conductivity (K) an average value $5 \cdot 10^{-3}$ can be used if it is not known.

From the temperature measurements of G4 well $T_0=29.1$ °C, $T_L=90$ °C, z and T_z are chosen as variables. Velocities were computed for every T_z at z depth by using the following equation.

$$v = \frac{5 \times 10^{-3}}{z} \ln \frac{90 - 29.1}{90 - T_z}.$$

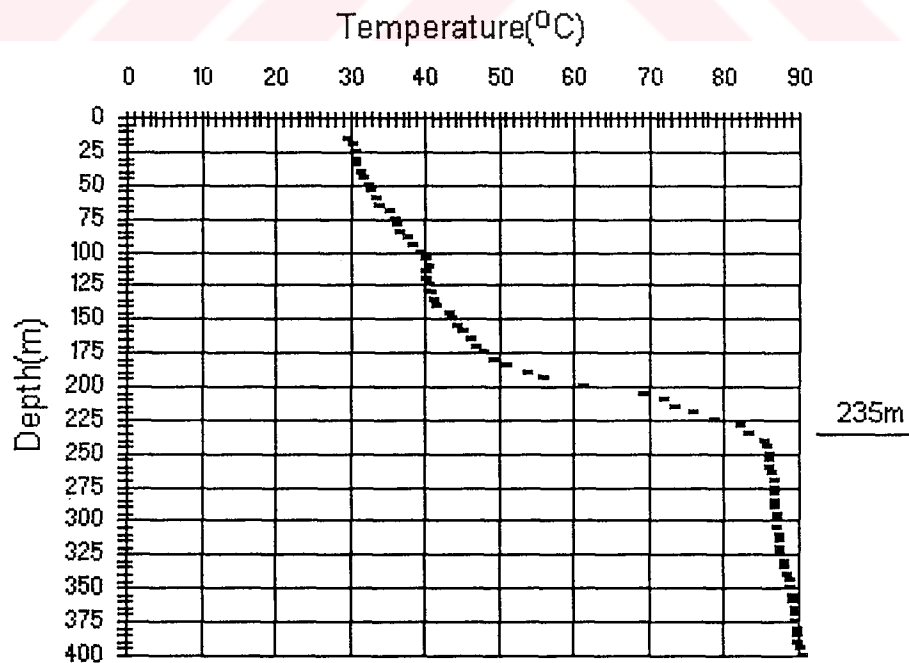


Figure 6.8 Temperature log of G4 thermal water well drilling

The β value was checked for every computed v value. The velocities where $\beta \geq 4$ was taken into consideration and the average velocity was found as $5.42 \cdot 10^{-7}$ cm/sec (Table 6.4) which equal to 0.17 m/year.

The actual groundwater velocity (v_a) assuming the porosity of rock as 2%;

$$v_a = \frac{0.17}{0.02} = 8.5 \text{ m/year}.$$

Table 6.4 Estimated velocities and average velocity calculated from temperature (T_z) at z depth where $\beta \geq 4$

Depth (z) m	Temperature (T_z) °C	Velocity (v) $\times 10^{-7}$ cm/sec	$\beta = vL/K$
240	85.0	5.20	4.16
245	85.3	5.22	4.18
250	85.4	5.16	4.13
255	85.5	5.10	4.08
260	85.5	5.00	4.00
265	86.0	5.13	4.11
270	86.1	5.08	4.07
275	86.2	5.04	4.03
280	86.3	5.00	4.00
340	88.0	5.02	4.01
345	88.3	5.18	4.14
350	88.4	5.19	4.15
355	88.6	5.31	4.25
360	88.8	5.40	4.36
365	88.9	5.49	4.39
370	89.0	5.55	4.44
375	89.2	5.77	4.62
380	89.3	5.87	4.70
385	89.4	6.00	4.80
390	89.4	5.92	4.73
395	89.8	7.23	5.79
average velocity=		5.42×10^{-7}	

Another approximation on the velocity estimation was made by using the discharge and pressure tests carried out by ORME [26] in the G2 thermal water well. They measured maximum pressure as 1.1 kg/cm² when the well was completely closed. When water-gate was open then the discharge of the well was measured as 16.4 lt/sec and the pressure was 0 due to flowing. The transmissibility can be estimated by applying the theory of Dupuit;

$$Q = \frac{2 \cdot \pi \cdot T(H-h)}{\ln R - \ln r} \Rightarrow T = \frac{Q \cdot (\ln R - \ln r)}{2 \cdot \pi \cdot (H-h)}$$

where T is the transmissibility, H-h is the drawdown, Q is the rate of discharge, R is the radius of cone of depression, r is the radius of well.

From the measurements, the drawdown (H-h) was 11 meter because 1.1 kg/cm² of pressure is equal to 11 meter water column, and the rate of constant discharge was 16.4 lt/sec (1417 m³/day) while pressure was zero. R is assumed as 1000 meter and the diameter of the well is 8' 1/2 thus the radius of the well is 0.1 meter.

$$T = \frac{1417 \cdot (\ln 1000 - \ln 0.1)}{2 \cdot \pi \cdot 11} = 188.6 \text{ m}^2/\text{day}$$

Aquifer thickness (m) should be known to calculate the hydraulic conductivity (K). The measured maximum temperature in the well was 90°C which corresponds to approximately 3000 meter according to mean geothermal gradient (1°C/33m). The aquifer thickness was roughly taken as 3000 meters.

$$K = \frac{T}{m} = \frac{188.6}{3000} = 0.06 \text{ m/day or } 21.9 \text{ m/year}$$

The flow velocity (v) of water can be calculated from Darcy's equation; $Q=K.A.I$ where Q is equal to multiplication of the velocity (v) and the area (A). If Q is substituted the equation becomes $v.A=K.A.I$ and $v=K.I$, where I is hydraulic gradient.

The elevation difference between G2 thermal water well and the recharge area (considering the recharge area is around the Kaz Mountain) is roughly 1500 meter and horizontal distance is 85 km. Thus, hydraulic gradient(I) is

$$I = \frac{\Delta h}{L} = \frac{1500}{85000} = 0.0176 \text{ m/m.}$$

The flow velocity of water (v) is found;

$v = K.I = 21.9 \times 0.0176 = 0.38 \text{ m/year}$ and the actual groundwater velocity (v_a) assuming the porosity of rock as 2%;

$$v_a = \frac{0.38}{0.02} = 19 \text{ m/year}$$

The transit time (or residence time) was calculated to be between 4,500-10,000 years by using the two different estimated flow velocities for 85 km distance. For the water of the Gönen thermal wells G2 and G4, with respect to stable isotope values of $\delta^2\text{H}$ and $\delta^{18}\text{O}$, all characteristics of a palaeowater are fulfilled [51]. The palaeowaters reported by Gat and Magaritz [52] are with ^{14}C ages between 9,000 and 13,000 years. As a consequence, residence times of more than 9,000 years must be taken into consideration for palaeowaters.

6.6 Reservoir Temperature and Circulation Depth of the Gönen and Ekşidere Thermal Waters

Heat source of thermal waters may be the geothermal gradient or various magmatic activities. Although volcanic rocks are widely seen in and around the investigation area, the heat source of the Gönen and Ekşidere thermal waters must be the geothermal gradient because of their low content of Boron and Fluorine which are abundantly dissolved by waters heated by volcanic rocks. Thermal water

ascending to the surface may cool by various processes. The cooling may be conductive, adiabatic, boiling, mixing with cold water or combination of these processes.

The important parameter to distinguish adiabatic and conductive cooling processes is the flow rate of thermal water. The calculations of the maximum rates of flow for conductive cooling and minimum rates of flow for adiabatic cooling [53] were used to understand the cooling process of the Gönen and Eksidere thermal waters. Figure 6.9 shows the extrapolated correlation of the maximum rates of flow for conductive cooling versus depth and Figure 6.10 shows the extrapolated correlation of the minimum rates of flow for adiabatic cooling versus depth.

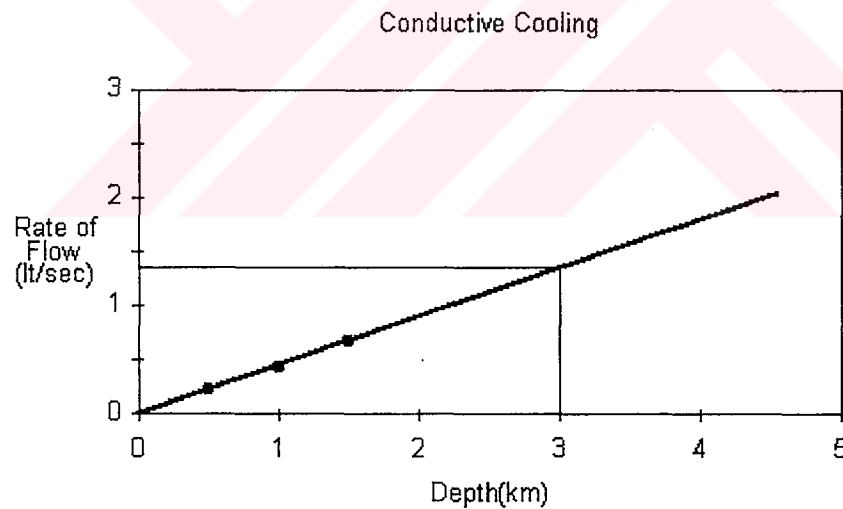


Figure 6.9 The extrapolated correlation of the maximum rates of flow versus depth for conductive cooling (dots are the calculated values [53])

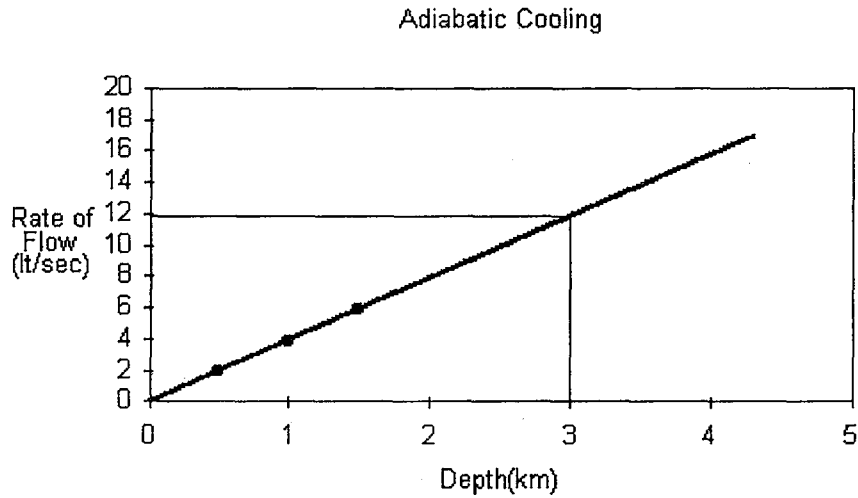


Figure 6.10 The extrapolated correlation of the minimum rates of flow versus depth for adiabatic cooling (dots are the calculated values [53])

As stated in previous sections the measured maximum water temperature is around 90°C and natural rate of flow is around 15 lt/sec in Gönen thermal water wells. The circulation depth of the Gönen thermal water can be calculated as 3 km by using geothermal gradient (1°C/33m) if the initial temperature in the recharge zone is 0°C and measured maximum temperature is 90°C. The maximum rate of flow is found 1.25 lt/sec for conductive cooling and the minimum rate of flow is found 11.5 lt/sec for adiabatic cooling for 3 km depth in Figures 6.9 and 6.10. These figures indicate that the cooling process of the Gönen thermal water may be adiabatic because the rate of flow of the Gönen thermal water is too large for conductive cooling.

The rate of cooling due to expansion of water was calculated by Schoeller [46] as 0.57°C at every 100 meters. By the help of the calculation the cooling of the Gönen thermal water for 3 km depth can be calculated as 17°C. The addition of cooling to the measured maximum temperature gives the minimum reservoir temperature of the Gönen thermal water as 99°C.

The rate of flow of the Ekşidere thermal waters is around 7 lt/sec. Figures 6.9 and 6.10 indicate that the cooling of the Ekşidere thermal waters can also be adiabatic unless if there is no horizontal flow in shallow depths.

Another and widely used method in calculation of reservoir temperatures is chemical geothermometers. The calculated reservoir temperatures are given in Table 6.5. The quartz geothermometer yields the most reasonable reservoir temperature to be 97.9°C for the Gönen thermal water and 61.9°C for the Ekşidere thermal water.

Table 6.5 The calculated reservoir temperatures of the Gönen and Ekşidere thermal waters by use of chemical geothermometers

Chemical Geothermometer	Equation	Calculated Reservoir Temperature (°C)	
		Gönen(G2)	Ekşidere(S1)
Quartz	$t = \frac{1309}{0.41 - \log k} - 273.15 \quad k = \frac{\alpha H_4 SiO_4}{\alpha H_2 O}$ α -activity	97.9	61.9
Na-K-Ca($\beta=1/3$)	$t = \frac{699}{\log(Na/K) + \frac{1}{3}[\log(\sqrt{Ca}/Na) + 2.06]} - 273.15$	120	147.3
Na-K-Ca($\beta=4/3$)	$t = \frac{699}{\log(Na/K) + \frac{4}{3}[\log(\sqrt{Ca}/Na) + 2.06]} - 273.15$	180.9	325.7
Na-K	$t = \frac{1180}{\log(Na/K) + 1.31} - 273.15$	169.5	-
Mg-Li	$t = \frac{2200}{\log(\sqrt{Mg}/Li) + 5.47} - 273.15$	68.5	-

6.7 Hydrogeological Circulation Model

The circulation model of thermal waters is based on the regional hydrogeology, chemical, isotopic and gas composition of the sampled waters.

The origin of the Gönen thermal water is meteoric water infiltrated during the Pleistocene at a low temperature of about 0°C ($\approx 10,000$ years ago). The infiltrated water flows most probably through the Kazdağ Metamorphic Unit, and reaches a

depth of 3-4 km and is heated to approximately 100°C in the reservoir. The thermal water is in equilibrium with quartz and dolomite is oversaturated at a depth of 1 km. The emergence of the water at the surface takes place where the permeability is increased due to fault zones. The cooling process is adiabatic. The surface temperature and rate of discharge are 82°C and 15-20 lt/sec. The circulation model of the Gönen thermal water is illustrated in Figure 6.11.

The origin of the Eksidere thermal water is shallow circulating meteoric water much younger than the Gönen thermal water. The infiltrated water from the hills located at the southern side of the thermal water emerges at the surface through the fault zone between volcanic and sedimentary rocks of the Neogene. The impermeable sedimentary rocks cause the emergence of water above the plain level. The water does not equilibrate with any mineral during circulation. The surface temperature and rate of discharge are 42°C and 7 lt/sec.

6.8 Comparison of Hydrogeological Models of Investigated Groundwater Systems Within the Frame of the Marmara Project

The results of the individual study areas (Tuzla-Çanakkale, Bursa, Kuzuluk-Akyazı, Gönen-Balıkesir, Yalova-Armutlu and Bergama) were presented in the study of W.BALDERER [51] with conclusions on groundwater circulation. The hydrogeological models summarized in the above mentioned study are presented below;

Kuzuluk area

The mineral and thermal waters of the Kuzuluk area, arising within a topographically well defined subsidence basin, are with respect to their stable isotope contents clearly disconnected not only from the meteoric waterline showing a marked oxygen shift but also disconnected, as proved by their much lower $\delta^2\text{H}$ values, from the actual local groundwater of recent recharge. The isotopic signatures would lead to a conceptual model where a deep seated fluid

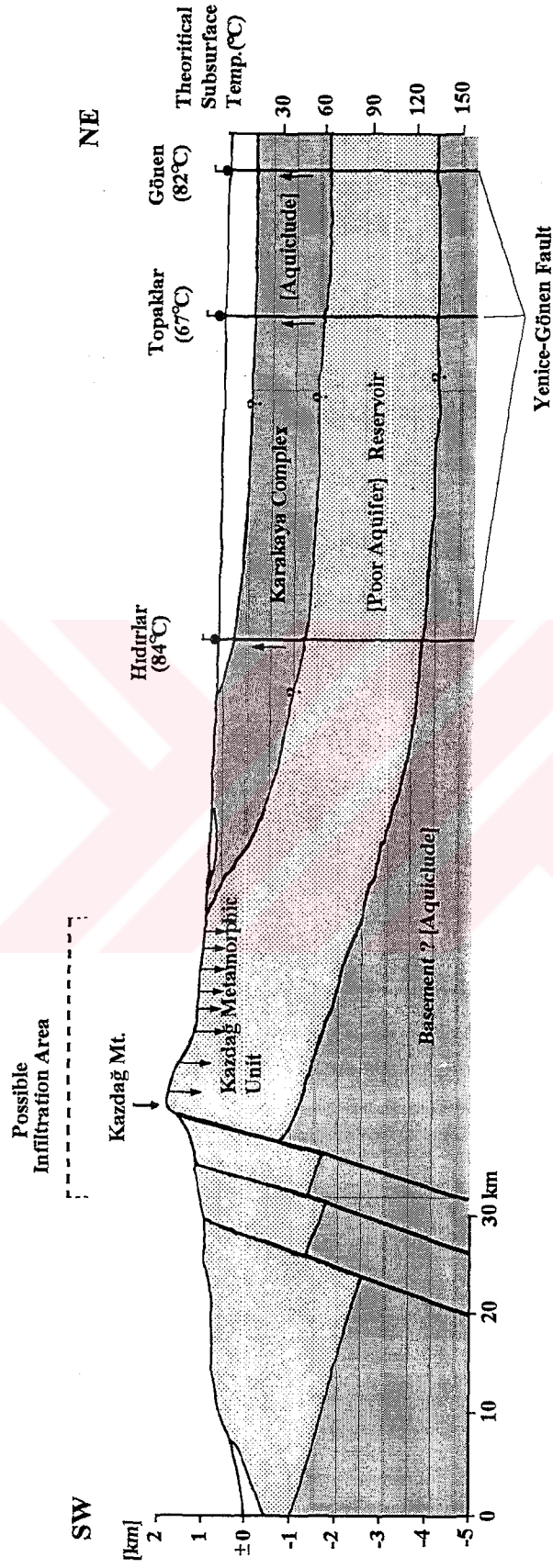


Figure 6.11 Circulation model of the Gönen thermal water

exists, which is disconnected from actual recharge and is outflowing through fractures of the low permeable top layers of volcanic rocks and ignimbrites and silicified gravels [55] not because of the usually admitted mechanism of the hydrologic cycle but because of the local tectonic configuration of the pressurising effect of the uprising CO₂ (Figure 6.12).

Bursa area

From the presented results of isotope, hydrochemical and hydrogeological investigations and in consideration of the historical records [42] it results that the Bursa area represents a region of a stable thermal system. Normal regional terrestrial heat flow builds a boundary condition [56]. Recharge in the fissured and partly karstified rocks of the Uludag massif, deep vertical circulation due to tectonic structure and a high hydraulic gradient lead to the observed hot waters. These naturally occur at intersections of two fault systems [42]. By the cooling process of the outflowing hot water, travertine deposits were formed by calcite precipitation beginning from the uppermost spring origins. The fact that the springs used today all originate within the altitude range of these travertine deposits indicates a decrease of hydraulic head with time. This area is good in agreement with the traditional model of regional groundwater flow with the properties needed for geothermal systems: long and deep groundwater circulation which is favoured by open fractures due to extensional tectonics, and fast ascent of the hot fluid by a high permeable regional fault zone.

Yalova/Armutlu/Gemlik area

The occurrences of the hot springs at Yalova and Armutlu are related to fault zones intersecting with morphological low level zones (within erosional valleys or canyons). They represent nearly unmixed deep groundwaters which evolved mainly by water-rock interaction processes. The Gemlik Orhangazi subthermal to thermal waters originate by the special tectonic structure of karstic systems below

the valley level and rise up through tectonic fault zones [45] (Figure 6.13). Karstic processes of limestone dissolution are enhanced through uprising CO₂ along the fault zone.

Gönen area

Very old groundwaters exist within the Gönen graben area, as evidenced by the thermal waters G2 and G4 accessed by boreholes. The natural conditions are disturbed through the intense exploitation by the Gönen geothermal power plant. According to the presented results, the Gönen water originates from recharge during a period of Pleistocene climate, as evidenced by stable isotopes but also by the extremely low recharge temperature of about 0°C (probably infiltration of meltwater) resulting from the dissolved argon content and also in agreement with the resulting ¹⁴C model age range in the order of 20'000 years. Compared with the thermal waters of Topaklar, Hidirlar and Külçüler, an actual mixing process is assumed where younger recharged groundwaters occur within intermediate flow paths (Figure 6.11). Such a process is in agreement with the actual recharge conditions, as evidenced by the cold water springs of different altitude ranges of the Kazdag massif. For the waters of Ekşidere, a different evolution mainly in contact with karstified carbonate rocks is admitted .

Bergama/Kozak area

According to chemical and isotopic composition, the thermal waters of the Bergama/Kozak area reflect active flow systems with infiltration in the areas of the Kozak massif and with individual outflow zones in the plains of Bergama, Kocaoba, Kaynarca [57]. According to the very high NaCl concentration a mixing process with a highly mineralised formation water or sea water is assumed for the Bademli water. The discharge zones of the investigated hot waters are related to the combined effect of the intersection of fault zones combined with favourable areas of low topographic height, as in eroded valleys or gorges. The water of Bergama is outflowing along fault zones within the underlying bedrock also and

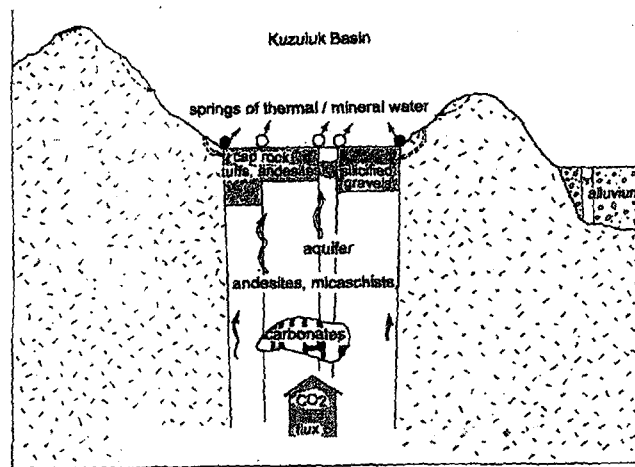


Figure 6.12 Hydrogeological model of the Kuzuluk thermal waters [55]

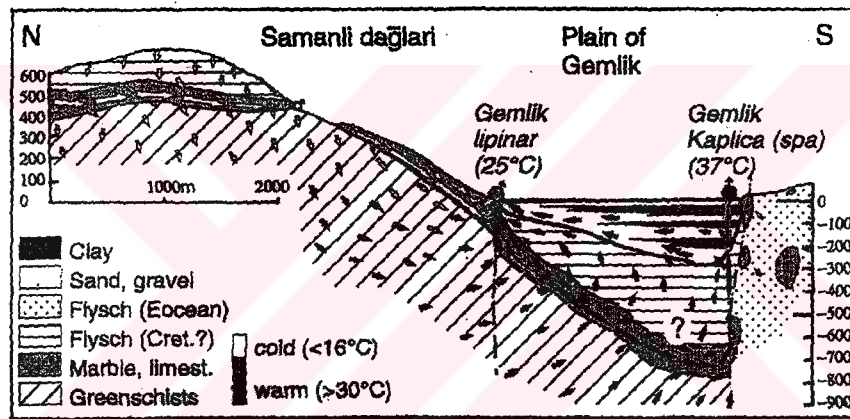


Figure 6.13 Hydrogeological model of the Gemlik thermal waters [45]

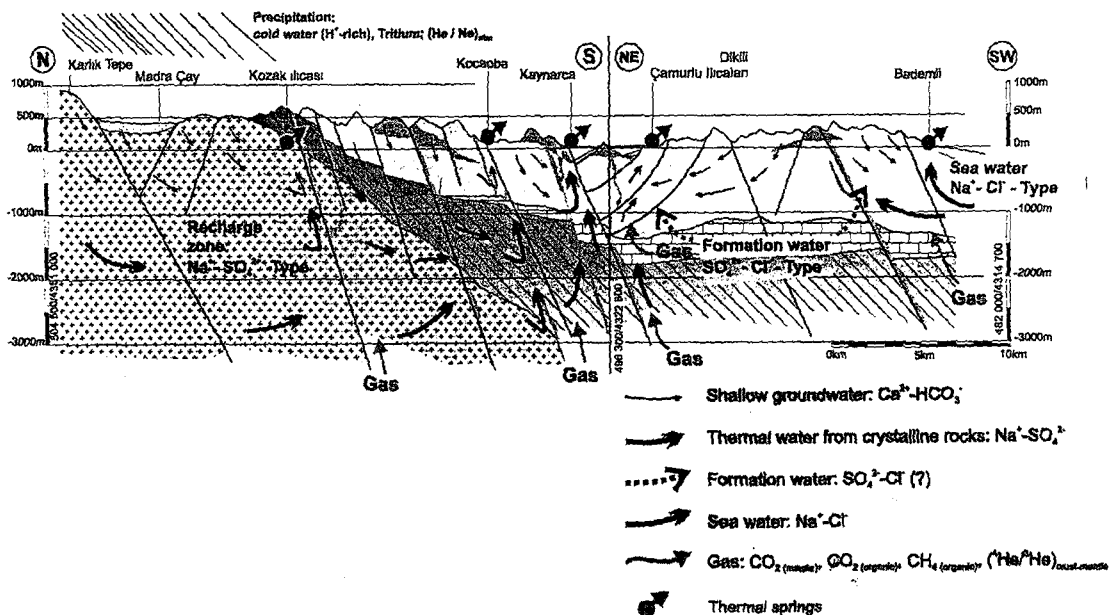


Figure 6.14 Hydrogeological model of the Bergama thermal waters [57]

accumulated within the sedimentary layers of higher hydraulic conductivity within the alluvial plain of Bergama. Therefore, hot water in different levels of these unconsolidated sediments of the infilling of the Bergama plain/graben structure exists. The conceptual hydrogeological interpretation model is shown in Figure 6.14.

Tuzla/Kestanbol area

In the Tuzla/Kestanbol area on the Biga peninsula, the outflowing high concentrated thermal waters can, by their chemical and isotopic composition, be neither directly derived from infiltrated meteoric water nor from recent sea water [58]. From the observed chemical and isotopic composition of the water, it seems most probable that they represent mixtures between a deep lowly mineralised groundwater (containing no anthropogenic produced tritium) and a deep brine situated as connate water of probable marine origin at even greater depth. The mixed and heated water at greater circulation depth is driven to the surface by a buoyancy effect along the hydraulically conductive zones along the intersections of three major fault systems (Figure 6.15).

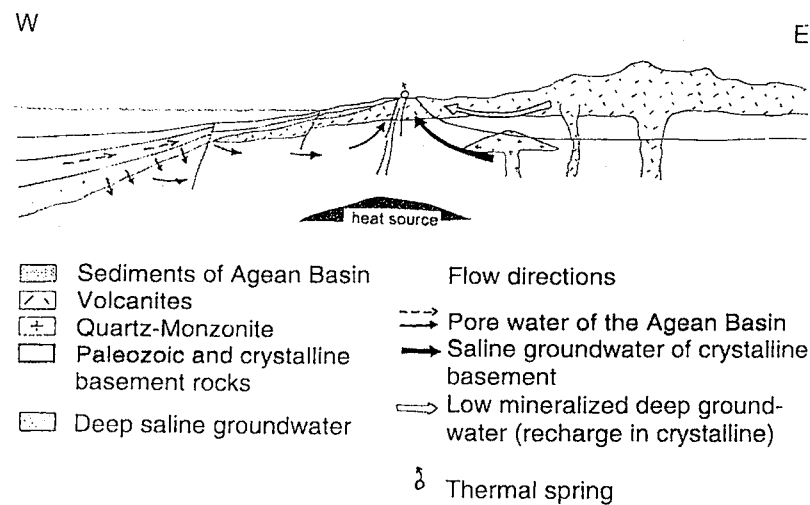


Figure 6.15 Hydrogeologic model of Tuzla thermal waters [58]

CHAPTER 7 CONCLUSIONS

The investigation area is situated geologically in the Sakarya Zone of Pontides. The Karakaya Complex is the oldest unit in the investigation area. This unit is unconformably overlain by the Jurassic-Cretaceous aged Bayırköy Formation, Bilecik Limestone and Vezirhan Formation. The Neogene aged lacustrine sediments and volcanic rocks overlie all these formations. The overlying superficial deposits principally consist of the Quaternary alluvium laid down by the Gönen River and its branches.

The buried faults, that formed the Gönen Plain and caused the discharge of the Gönen thermal water, were inferred after evaluating the geophysical studies carried out by MTA. The main faulting is the North Anatolian Fault System in and around the investigation area.

Gönen and its vicinity are seismically active region that suffered serious structural damages during several recent earthquakes. The main cause of the earthquakes is the movement of the North Anatolian Fault Zone in this region.

The dominant type of the drainage pattern is dendritic. This pattern generally develops when the rock is uniform in its resistance to erosion.

The value of actual evapotranspiration was found 434.5 mm/year by using Penman's formula which reflects the conditions of the plain. But by using runoff measurements of the Keçi Stream the evapotranspiration was found 247 mm/year which reflects the conditions of the mountainous areas.

The recharge of the groundwater was found $48.10^6 \text{ m}^3/\text{year}$. The rate of artificial discharge was computed around $12.10^6 \text{ m}^3/\text{year}$. Dug and drilled wells are widely used in the plain for irrigation.

Aquifers were classified according to their specific capacities found from the drillings of DSI.

The springs observed in the investigation area were grouped as karstic springs, fracture springs, depression springs and hot springs.

The groundwater samples were gathering into 4 different groups such as $\text{Ca}.\text{HCO}_3$ Type, $\text{Na}.\text{HCO}_3$ Type, $\text{Na}..(\text{SO}_4)(\text{Cl})(\text{HCO}_3)$ Type and other types.

The geochemical modelling of thermal waters is useful to estimate the possible chemical changes in water between the reservoir rock and the discharge point.

The stable isotope composition of both thermal waters indicate a meteoric origin, but the Gönen thermal water is related to an old meteoric water (palaeowater).

The argon concentrations of thermal waters show that the Gönen thermal water infiltrated in a cold climate but that the Ekşidere thermal water infiltrated in a warmer climate (if there is no loss of Ar during sampling).

The recharge area of the Gönen thermal water is not certain, but Kazdağ Mountain, which is 85 km away from the discharge area, is the most possible recharge area. The possible recharge area of the Ekşidere thermal water is near the hills located at the southern edge.

The cooling process of the Gönen thermal water is adiabatic. The rate of cooling due to expansion was calculated as 17°C and the reservoir temperature was found to be 99°C . The reservoir temperature was also calculated to be between 68.5 and

180.9°C by using chemical geothermometers. The quartz geothermometer gives a reservoir temperature of 97.9°C

All the sampled thermal waters inside and outside of the investigation area are at least older than 40 years due to absence of tritium.

The flow-velocity estimation method has given reasonable results. The estimated flow velocity of the Gönen thermal water was calculated to be 8.5 m/year by using the thermal profile method. The calculated age of the Gönen thermal water is 10,000 years by using a flow velocity estimation supposing that the water is recharging near Kazdağ Mountain. The ^{14}C isotopic dating method gives 23000 years as an uncorrected age.

The upflow mechanism of the thermal waters is mainly due to a piston effect (hydraulic pressure). The emergence of the water to the surface takes place where the permeability is increased due to the fault zones.

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