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Western Anatolia's (Turkey) Probable Geothermal Potential

Servet Yılmazer and Suzan Pasvanoğlu

Gayzer Yerbilimleri Ltd. Şti.

gayzerservet@gmail.com, spasvanoglu@hotmail.com

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ABSTRACT

Western Anatolia is a region where geothermal sources are densely located. Approximately 50 years ago, the probable geothermal potential of Turkey was calculated to be as 31500 MWt by MTA. In 2009, Yılmazer carried out another survey and Western Anatolia's probable geothermal potential was calculated to be 40550 MWt. Based on this result, Turkey's probable geothermal potential was reported to be in between 55000 – 60000 MWt.

In 2015, this study which is done for the western Anatolia region is updated by Yılmazer once more with the help of increasing number of deep drilling data that are obtained in the latest years.

During the calculation of Western Anatolia's probable geothermal potential, all of the cities that are located in Western Anatolia are evaluated. The data for the following cities are particularly considered on behalf of the Western Anatolia region: Afyon, Uşak, Aydın, Balıkesir, Bursa, Çanakkale, Denizli, Izmir, Kütahya, Manisa, Muğla, Sakarya and Yalova. For these calculations, the lowest temperature limit is taken as 35°C. On the other hand, as the temperature of reservoir rocks, the highest temperature data measured from the drillings are assigned. For the regions that drilling has not been performed, the temperatures of the natural hot springs are taken as the temperatures of the reservoir rocks.

The parameters that are used in the calculations, such as, temperature, reservoir thickness and porosity, are cautiously determined. With the updated parameters, the probable geothermal potential for the Western Anatolia is calculated as 75353 MWt.

1. INTRODUCTION

Western Anatolia is a region where geothermal sources are densely located. Approximately 50 years ago, the probable geothermal potential of Turkey was calculated to be as 31500 MWt by MTA (General Directorate of Mineral Research and Exploration of Turkey).

In 2009, Yılmazer carried out another survey and Western Anatolia's probable geothermal potential was calculated to be 40550 MWt. Again in 2015, this study which is done for the western Anatolia region is updated by Yılmazer once more with the help of increasing number of deep drilling data that are obtained in the latest years. Moreover, the updated calculations regarding the geothermal heat capacity potential of Turkey is concentrated in between 55000 - 60.000 MWt Yılmazer (2009), Korkmaz et al.(2010), Mertoğlu et al. (2016).

Turkey holds a significant potential for geothermal energy exploitation and is among the top ten countries producing power through geothermal energy. Research on increasing existing geothermal potential continues rapidly. On the other hand, residential heating and electricity generation activities are ongoing

This study was prepared as a result of the re-assessment and updating of previous studies on the possible geothermal potential of Western Anatolia.

All the data given by MTA inventory and also the data available for the fields studied in the literatüre including private sector and Universities as well as by our studies in various fields Yılmazer (1994, 1997, 1998, 2009, 2015), Yılmazer and Alaca (2005), Yılmazer et al. (2010), Pasvanoğlu et al. (2005), Pasvanoğlu (2015) are evaluated and used to estimate the heat capacity potential of Turkey

1.1 An Overview of Turkey's Geothermal Fields

As a geographic bridge between Europe and Asia (Figure 1), Turkey is located on the Alpine-Himalayan orogenic belt that leads to numerous tectonic, magmatic and volcanic activities. The presence of active tectonic structures such as faults, grabens, and overthrusts together with young acidic volcanic activity have given rise to the development of numerous geothermal manifestations all over the Anatolian peninsula and particularly in Western Anatolia. (Figure 2). Therefore, it has a great potential for geothermal resources.

Studies have identified more than 230 geothermal fields which can be useful at the economic scale and about 2000 geothermal and mineral water resources which have the temperatures ranging from 20 to 287°C Dağıstan et al. (2015); Mertoğlu et al. (2016). Nearly 85 % of the geothermal exploration wells have been drilled in the Western Anatolia region in Turkey.

Geothermal systems in the Western Anatolia usually have high temperatures, and found at the grabens associated with extensional tectonics. Extensional tectonism has led to the formation of several E-W trending graben systems Mc Kenzie (1978). The distribution of geothermal fields in Turkey closely follows the tectonic patterns.

The most important geothermal systems which are characterized by the occurrence of high temperature geothermal fields aligned a long E-W and NW-SE trending grabens bounding faults are formed in the Menderes and Gediz grabens. The young faults that form these grabens are active leads not only to devastating earthquakes but also to the formation of widespread geothermal water discharges (Figure 3).

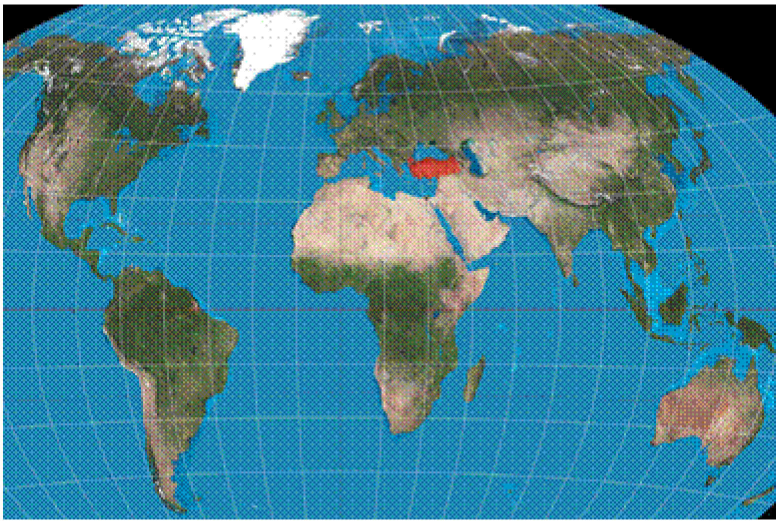

Fıgure 1: Location map of the study area on the Earth.

Turkey’s highest measured reservoir temperatures are exists within the Büyük Menderes graben and these are the Denizli-Kızıldere (242°C), Aydın-Germencik (232°C), Aydın-Salavatlı (171°C) and Aydın-Yılmazköy-Imamköy (142°C) geothermal fields (Figure 3).

Major geothermal sites of the Gediz graben are: Manisa-Salihli Caferbeyli (155°C), Manisa-Salihli-Kurşunlu (96°C), Manisa-Alaşehir-Kavaklıdere (116°C) and Manisa-Turgutlu-Urganlı (86°C) geothermal fields (Figure 3). Most of the geothermal fields are located along the southern boundary of the graben since this part of the graben is tectonically more active than that along the northern boundary.

After the year 2015, new geothermal wells have been drilled by MTA and Turkish private Sector in the Büyük Menderes and Gediz Graben geothermal systems. Reservoir temperatures of more than 250 °C are observed at the Denizli-Kızıldere, Aydın-Germencik, Manisa and Alaşehir geothermal fields that are located within the Büyük Mendres and Gediz grabens.

The Kütahya-Simav (162°C) and Kütahya-Gediz –Abide (97°C) geothermal fields that are developed within a similar graben system can also be listed amongst the high temperature fields (Figure 3).

The Gölemezli (65°C), Karahayıt (55°C) and Pamukkale (35°C) geothermal fields that are wıthin the Denizli-Çürüksu Garben, usually have low reservoir temperatures (Figure 3).

The other geothermal systems that are in the Western Anatolia exist at the NE-SW trending grabens and at the zones which have volcanic activity. These geothermal fields are the Izmir-Seferihisar (153°C), Izmir-Balçova (130°C), Izmir-Dikili (130°C), Izmir-Aliağa (96°C) and İzmir-Çeşme (62°C) geothermal fields (Figure 3).

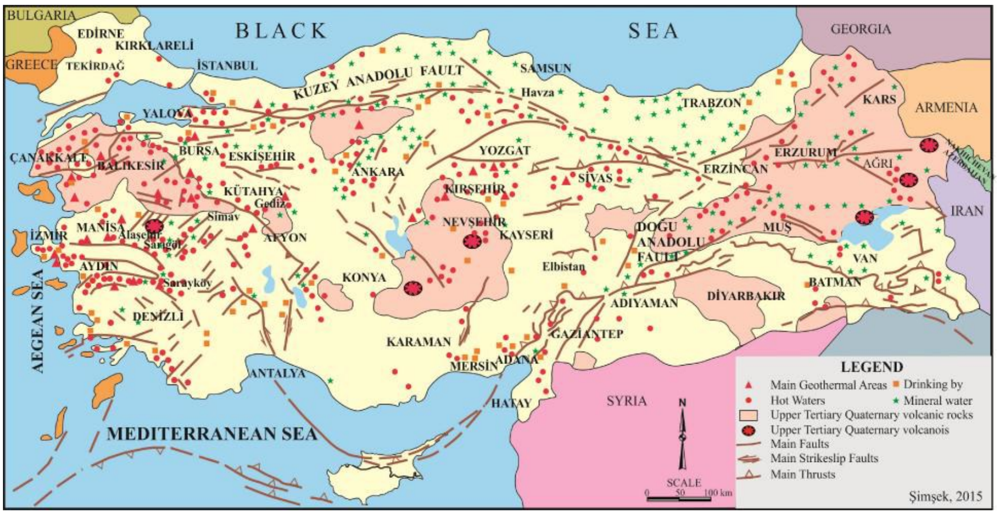

Figure 2: Distribution of hot springs and major geothermal fields in Turkey.

Apart from these fields, the other important geothermal provinces that are located in northwestern Anatolia can be listed as: The Çanakkale-Tuzla (174°C), Balıkesir-Bigadiç (95°C), Balıkesir-Hisaralan (100°C) and Balıkesir-Gönen (80°C) geotherml fields.

Additionally, there are low temperature geothermal fields in Aegean region that are related to young volcanism and compression tectonic. These fields with their reservoir temperatures are as follows: Manisa-Saraycık (74°C) and Manisa-Kula-Emir (63°C) geothermal fields (Figure 3).

The East Anatolian region (undergoing contemporary compression). and the Central Anatolian region (where the compressional regime in the east is converted to the extensional regime in the West) have moderate energy potential. Although the recently active volcanoes suggest the presence, at depth, of still cooling magma chambers that are potential heat sources, the lack of well-developed fault systems is probably responsible for the comparatively low energy potential of these regions Mutlu and Güleç (1998).

The geothermal systems in Middle Anatolia are usually linked to volcanic activities, and have lower temperatures compared to the Western Anatolia. Important geothermal fields in this region are Ankara-Kızılcahamam (86°C), Kırşehir Terme (57°C), Afyon-Ömer-Gecek (98°C), Afyon-Sandıklı (70°C), Nevşehir Kozaklı (93°C), Aksaray-Ziga (65°C), Sivas-Sıcak Çermik (49°C) and Yozgat-Sorgun (75°C) geothermal fields (Figure 2).

Due to the tectonic activities in association with volcanism the important geothermal fields in Eastern and Southerneastern Anatolia are concentrated around young volcanoes are: the Van-Erciş (80°C), The Ağrı-Diyadin (78°C), Bitlis-Nemrut (59°C), Diyarbakır-Çermik (51°C) and Urfa-Karaali (49°C) geothermal fields (Figure 2).

In the Northern Anatolia and along the Northern Anatolia Fault Zone, the low temperature geothermal fields associated with strike–slip tectonics are as follows: Sakarya-Akyazı (84°C), Bursa-Çekirge (82°C), Yalova-Armutlu (77°C), Yalova-Terme (66°C), Çankırı-Kurşunlu (54 °C), Tokat-Reşadiye (47°C) and Bolu-kaplıca (45°C) geothermal fields (Figure 2).

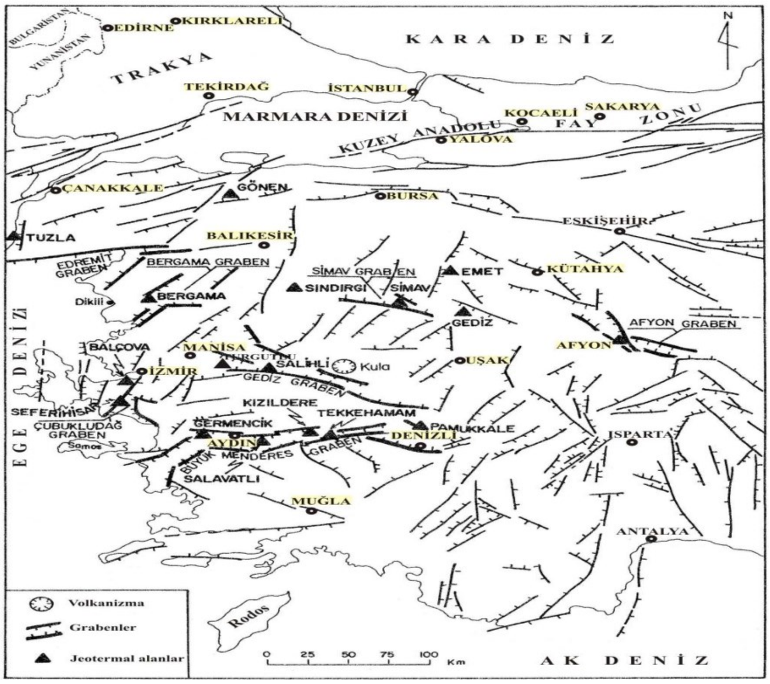

Figure 3: Geothermal fields in Western Anatolia and their structural relations Şimşek and Güleç (1994).

2. CALCULATION OF PROBABLE POTENTIAL

A conceptual model is used to calculate the geothermal potential of the Western Anatolia's following Hochstein (1975). This formula is also used by Company of WEST JEC (West Japan Engineering Consultans, INC) in their research on the feasibility study on geothermal in Turkey (2000).

The feasibility study on geothermal and fresh water resource survey for Izmir district heating system and on (Manisa, Salihli, Turgutlu, Balıkesir, Susurluk, Bigadiç) district

$$MW_t = \frac{(A.10^9.TH)(Tr - Tf)\big((1-\emptyset).\rho rC\rho r + \emptyset\rho wC\rho w\big)0{,}3 \times 0{,}95 \times 0{,}000000278}{25 \times 365 \times 24}$$

The parameters and assumptions that are used in the calculation of geothermal capacity are given below:

Assume that the area (A) is km^2, TH: Thickness (km). In order to determine the reservoir thickness, the formations that can be associated to the thermal waters are taken as a basis.

Tr: Reservoir temperature (°C), Return temperature (°C), therefore Tr-Tf is the difference between temperature of waters produced and disposed.

Φ: Porosity of the rock. Reservoir porosity is taken as: 0.1, Nevertheless, calculations are still done for the porosity values that are smaller than 0.1, however, the results did not change so much.

ρr: Density of rock (2600 kg/m^3 Goodmans (1989)), ρw: density of liquid in kg/m^3 assuming pure water , Cpr: Specific heat capacity of rock. Although the heat capacity of rock depends on lithology and porosity, the specific heat capacity of rock (0.8 kj/kg °C) is acceptable value for most areas. Cpw: Specific heat capacity of the fluid at certain temperature (for water has average value 4.2 kj/kg °C from steam table).

The potentially useable heat is an estimated of the thermal energy that is available in the reservoir. This was estimated using heat stored both in the liquid and rock and recovery method:

RF: Recovery factor is the ratio of extracted thermal energy (measured at the wellhead) to the total thermal energy contained in a given subsurface volume of rock and water Muffler and Cataldi (1978). Recovery factor, in theory it can be anywhere between 0.1 and 1.0. Commonly, a recovery factor of 25 percent is used for all identified hot-water systems to give the resource (that is, the thermal energy producible at the wellhead).

CE: Conversion efficiency (CE= 0.95), DP: Development period or life time for exploration =25 Years.

The actual power potential of the system can be estimated from the recoverable potentially useable heat using overall conversion efficiency, which is the ratio between power delivered by a utilization plant and the thermal power available at the well heads. For using heat from liquid dominated reservoir, the overall efficiency is greater than 0.5.

In this research, geology, tectonic, hydrothermal alteration, geophysical and geothermal borehole data were used in the selection of geothermal fields. Therefore, for the calculation of probable potential, the chosen fields have been quite realistic.

Based on the formula given above, the calculated reservoir capacity is evaluated as the probable potential in our calculations. Although the results obtained from our calculations express a value closer to the apparent potential, they were considered as probable potential.

3. PROBABLE GEOTHERMAL POTENTIALOF CITIES

In order to calculate Western Anatolia's geothermal potential, 18 cities that are located at the west of Turkey, are chosen. These cities are Afyon, Aydın, Balıkesir, Bursa, Çanakkale, Denizli, Edirne, Istanbul, Izmir, Kırklareli, Kütahya, Manisa, Muğla, Sakarya, Tekirdağ, Uşak and Yalova.

Among these indicated cities, 5 of them (Edirne, Istanbul, Kırklareli, Kocaeli, Tekirdağ) are not taken into consideration due to their low temperature geothermal waters.

Other than these, the geothermal potential calculation which covers the rest of the 13 cities (Figure 3) is respectively given in Table 1 to 13. Likewise, the distribution of geothermal field is given in Figure 4 and 5.

In this study, in order to determine the parameters, the data given by MTA inventory and also the data available for the fields studied in the literatüre including private sector and Universities as well as by our studies in various fields Yılmazer (1994, 1997, 1998, 2009 and 2015),Yılmazer and Alaca (2005), Yılmazer et al. (2010), Pasvanoğlu et al.(2005), Pasvanoğlu (2015) are evaluated and used to estimate the heat capacity potential of Turkey

Table 1: Probable geothermal potential of Afyon province

City	Name of the Geothermal Field	Area (km^2)	Well-spring measured T(^{o}C)	Temperature usage T(^{o}C)	Thickness (km)	Probable Potential (MWth)
AFYON	Ömer Gecek-Kızık	8	128	35	0.45	273
	Ömer Gecek-Bayatçık	7	70	35	0.3	60
	Ömer Gecek-Sadıkbey village	2	63	35	0.3	11
	Ömer Gecek-İkbal	5	53	35	0.35	25
	Gazlıgöl Afjet	3	83	35	0.3	35
	Gazlıgöl Yayladağ-bozöyük	2	70	35	0.3	17
	İscehisar	1	50	35	0.3	3.7
	Afyon Center Susuz	0.5	54	35	0.3	2.3
	Afyon Varan tesisleri	1	40	35	0.3	1.2
	Sandıklı Hüdai spring	10	83	35	0.4	158
	Sandıklı – Koçgazi	1	83	35	0.3	11.7
	Çay Heybeli	4	56	35	0.3	20
	Total Probable Potential					**619**

Table 2: Probable geothermal potential of Aydın province

City	Name of the Geothermal Field	Area (km^2)	Well-Spring measured T(^{o}C)	Temperature usage T(^{o}C)	Thickness (km)	Probable Potential (MWth)
AYDIN	Ortakçı - Horsunlu	50	161	35	0.5	2564
	Pamu kören -Kuyucak	50	191	35	0.5	3175
	Vicinity of Nazilli	60	127	35	0.5	2246
	Atça-Isabeyli	40	124	35	0.5	1489
	Sultanhisar-Salavatlı	60	185	35	0.5	3663
	Köşk- Umurlu	80	180	35	0.5	4721
	Aydın Inciliova	100	18	35	0.5	5901
	Ömerbeyli	40	240	35	0.5	3337
	Bozköy-Hıdırbeyli	50	180	35	0.5	2950
	Ortaklar-Gümüş	40	178	35	0.5	2328
	Davutlar Kuşadası	20	60	35	0.5	203
	Söke-Bağarası	50	80	35	0.5	916
	Üzümlü-Turanlı	80	150	35	0.5	3745
	Total Probable Potential					**37238**

Table 3: Probable geothermal potential of Balıkesir province

City	Name of the Geothermal Field	Area (km^2)	Well-spring measured T(^{o}C)	Temperature usage T(^{o}C)	Thickness (km)	Probable Potential (MWth)
BALIKESIR	Edremit-Güre	10	58	35	0.3	56
	Havran Davran	6	65	35	0.3	44
	Gönen	10	84	35	0.3	120
	Kepekler	3	64	35	0.3	21
	Kızık	2	50	35	0.2	5
	Balya	3	60	35	0.3	18
	Pamukçu	3	58	35	0.3	17
	Hisaralan	4	107	35	0.4	94
	Bigadiç Hisarköy	2	98	35	0.3	31
	Susurluk	3	85	35	0.3	36
	Pelitköy-Uyuz, Ayvalık-Ivrindi-Kepsut, Susurluk Gökçeler Ömerköy-Emendere	<35 was not considered				
	Total Probable Potential					442

Table 4: Probable geothermal potential of Bursa province

City	Name of the Geothermal Field	Area (km^2)	Well-spring measured T(^{o} C)	Temperature usage T(^{o} C)	Thickness (km)	Probable Potential (MWth)
BURSA	Kaynarca	3	88	35	0.3	39
	Dümbüldek	3	51	35	0.3	12
	Inegöl-Oylat	2	41	35	0.2	2
	Orhaneli	2	64	35	0.2	9
	Orhangazi-Gemlik	<35 °C was not evaluated				
	Total Probable Potential					62

Table 5: Probable geothermal potential of Çanakkale province

City	Name of the Geothermal Field	Area (km^2)	Well-spring measured T(^{o} C)	Temperature usage T(^{o} C)	Thickness (km)	Probable Potential (MWth)
ÇANAKKALE	Yenice Hıdırlar- Uyuz	10	84	35	0.5	199
	Tuzla	10	174	35	0.5	566
	Ezine Kestanbul	6	75	35	0.5	98
	Çan	2	49	35	0.2	3
	Biga-Kırgeçit	10	58	35	0.5	94
	Çan-Etili-Tepekköy-Bardakçılar	10	60	35	0.3	61
	Küçük Çetmi Lapseki-Bayramiç	<35 °C was not evaluated				

Table 6: Probable geothermal potential of Denizli province

City	Name of the Geothermal Field	Area (km^2)	Well-spring measured T(^{o} C)	Temperature usage T(^{o} C)	Thickness (km)	Probable Potential (MWth)
DENIZLI	Kızıldere	20	240	35	1	3337
	Tekkehamam -Sarayköy	20	168	35	0.6	1299
	Bölmekaya	10	85	35	0.5	203
	Yenice-Kamara	5	67	35	0.5	65
	Gölemezli	5	88	35	0.5	108
	Karahayıt Pamukkale	10	60	35	0.5	102
	Total Probable Potential					**5114**

Table 7: Probable geothermal potential of Izmir province

City	Name of the Geothermal Field	Area (km^2)	Well-spring measured T(^{o} C)	Temperature usage T(^{o} C)	Thickness (km)	Probable Potential (MWth)
IZMIR	Bayındır-Torbalı Kemalpaşa	20	60	35	0.5	203
	Menderes-Urkmez Gümüldür	30	140	35	0.5	1282
	Seferihisar-Cumali Karakoç Doğanbey	20	153	35	0.5	960
	Çeme-Şifne-Ildır-Alaçatı	20	60	35	0.3	122
	Balçova -Narlıdere Gülbahçe	20	140	35	0.5	855
	Vicinity of Dikili Kaynarca Nebiler Bademli çevresi	20	130	35	0.5	773
	Karşıyaka-Çiğli Bayraklı	20	77	35	0.5	342
	Aliağa and its vicinity	10	96	35	0.5	248
	Vicinity of Menemen	10	56	35	0.3	51
	Vicinity of Bergame	15	65	35	0.3	110
	Total Probable Potential					**4946**

Table 8: Probable geothermal potential of Kütahya province

City	Name of the Geothermal Field	Area (km²)	Well-spring measured T(° C)	Temperature usage T(° C)	Thickness (km)	Probable Potential (MWth)
KÜTAHYA	Simav-Eynal-Naşa-Çitgöl	10	162	35	0.5	517
	Gedizabide	4	97	35	0.3	60
	Şaphane	4	181	35	0.5	238
	Muratdağ	1	39	35	0.2	1
	Yoncalı-Geven	4	55	35	0.5	33
	Emet	4	49	35	0.3	14
	Hisarcık	2	51	35	0.2	8
	Emet Yeniceköy	1	41	35	0.2	1
	Emet Dereli	1	42	35	0.5	1
	Ilıca Harlek	1	41	35	0.2	1
	Göbel	<35 was not evaluated				
	Total Probable Potential					**874**

Table 9: Probable geothermal potential of Manisa province

City	Name of the Geothermal Field	Area (km²)	Well-spring measured T(° C)	Temperature usage T(° C)	Thickness (km)	Probable Potential (MWth)
MANISA	Sarıgöl Alaşehir	150	60	35	0.5	1526
	Between Alaşehir and Kavaklıdere	90	287	35	0.5	9230
	Between Kavaklıdere and Salihli	120	200	35	0.5	8058
	Between Salihli and Ahmetli	100	100	35	0.5	2645
	Ahmetli-Urganlı	40	90	35	0.5	895
	Between Yılmaz and Taytanlı	100	150	35	0.5	2238
	Vicinity of Kula	6	65	35	0.5	73
	Borlu- Saraycık	6	75	35	0.5	98
	Menteşe	2	60	35	0.5	20
	Total Probable Potential					**24783**

Table 10: Probable geothermal potential for Muğla province

City	Name of the Geothermal Field	Area (km²)	Well-spring measured T(° C)	Temperature usage T(° C)	Thickness (km)	Probable Potential (MWth)
MUĞLA	Köyceğiz-Sultaniye	4	41	35	0.3	6
	Yarağan Bozhüyük	1	37	35	0.2	0.3
	Fethiye Girmeler	2	42	35	0.3	3.5
	Bodrum Karada Gebeler Ortaca-Dutçu	<35°C was not evaluated				
	Total Probable Potential					**10**

Table 11: Probable geothermal potential for Sakarya province

City	Name of the Geothermal Field	Area (km²)	Well-spring measured T(° C)	Temperature Usage T(° C)	Thickness (km)	Probable Potential (MWth)
SAKARYA	Akyazı-Kuzuluk	4	84	35	0.5	80
	Taraklı	2	41	35	0.2	2
	Geyve	<35°C was not evaluated				
	Total Probable Potential					**82**

Table 12: Probable geothermal potential for Uşak province

City	Name of the Geothermal Field	Area (km²)	Well-spring measured T(° C)	Temperature usage T(° C)	Thickness (km)	Probable Potential (MWth)
UŞAK	Banaz	2	72	35	0.3	18
	Emirakı-Ulusaz	2	37	35	0.3	1
	Total Probable Potential					**19**

Table 13: Probable geothermal potential for Yalova province

City	Name of the Geothermal Field	Area (km^2)	Well-spring measured T(° C)	Temperature usage T(° C)	Thickness (km)	Probable Potential (MWth)
YALOVA	Termal	4	66	35	0.3	30
	Armutlu	3	66	53	0.3	23
	Total Probable Potential					**53**

Table 14: Probabale potential calculated for 13 Province

Cities	Calculated Total (MWt)
AFYON	619
AYDIN	37275
BALIKESİR	442
BURSA	62
ÇANAKKALE	1021
DENİZLİ	5114
İZMİR	4946
KÜTAHYA	874
MANİSA	24783
MUĞLA	10
SAKARYA	82
UŞAK	19
YALOVA	53
Total for 13 Cities	**75353**

4. CONCLUSION

Geothermal energy is contributing significantly to Turkey's future energy supply. Western Anatolia is one of the most important regions in Turkey in terms of geothermal energy potential

This study was prepared as a result of the re-assessment and updating of previous studies on the possible geothermal potential of Western Anatolia.The study includes 18 cities that are located at Western Anatolia.

A volumetric method is used to calculate the potential of geothermal fields following the formula described by Hochstein (1975). The volumetric methods involes the calculation of geothermal energy contained in a given volume of rock and water, but neglects all recharge to the system.

For the calculation of Western Anatolia's probable potential, the minimum applicable temperature value was taken as 35°C. The geothermal potential was calculated for the 13 cities (Afyon, Aydın, Balıkesir, Bursa, Çanakkale, Izmir, Denizli, Kütahya, Manisa, Muğla, Sakarya, Uşak, Yalova) having higher temperatures than the minimum applicable temperature value of 35°C.

The total probable potential of Western Anatolia is calculated as 75353 MWt. Based on this result and given that 70% Turkey's geothermal potential is located in Western Anatolia; the overall probable geothermal potential for Turkey can be estimated as 107647 MWt. The new result obtained for our country quite promising.

Turkey, in addition to the use of hydrothermal system, will give importance to the investigation of hot dry rock (EGS) systems for future projects.

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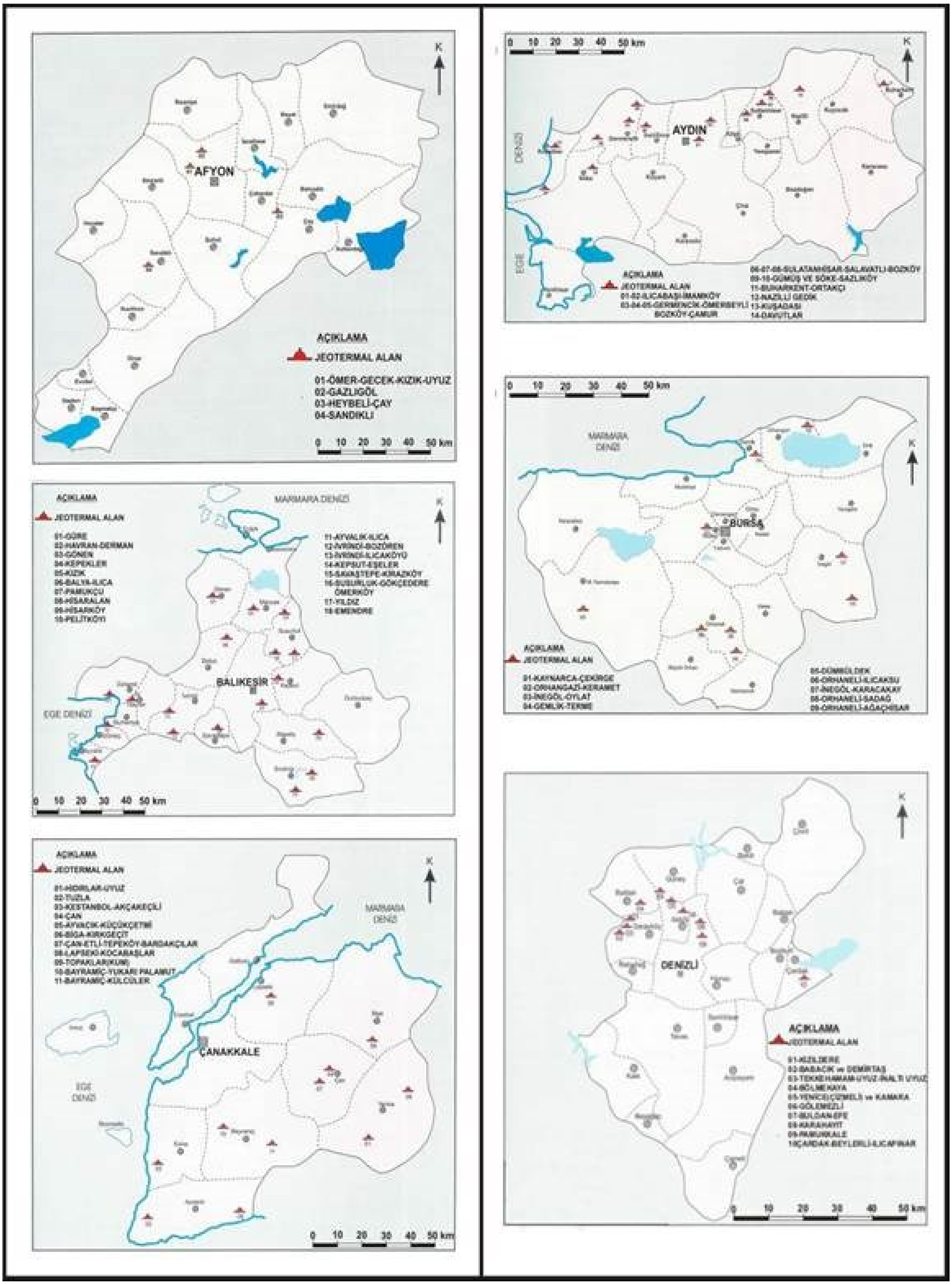

Figure 4: Geothermal fields of Afyon, Aydın, Balıkesir, Bursa, Çanakkale and Denizli provinces MTA (2005).

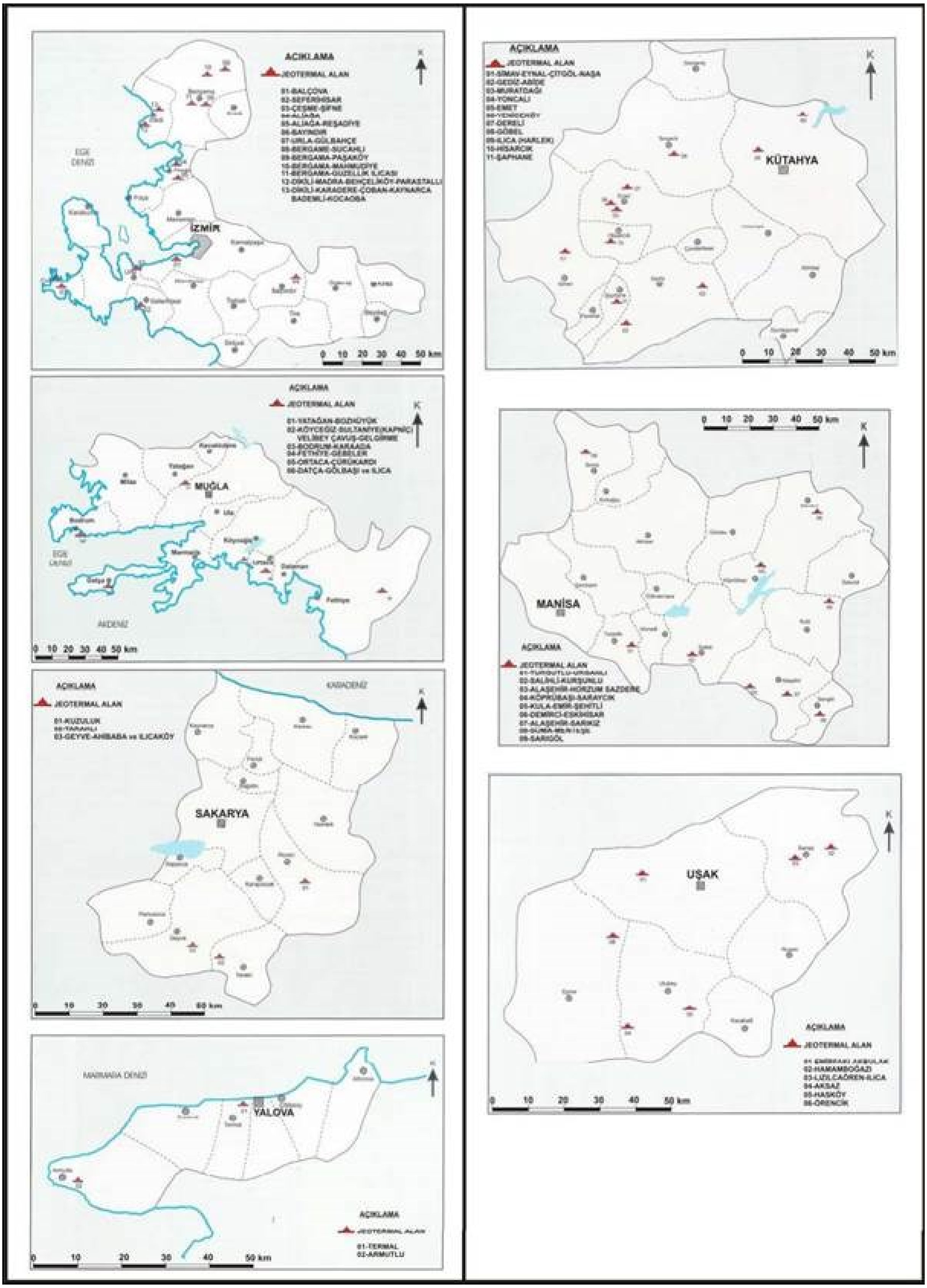

Figure 5: Geothermal fields of İzmir, Kütahya, Muğla, Manisa, Sakarya, Uşak and Yalova MTA (2005).