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Thermal conductivity of major rock types in western and central Anatolia regions, Turkey

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Abstract

Thermal conductivity is a key parameter in heat flow and geothermal investigations as it controls the temperature distribution within the Earth. Turkey has a significant geothermal potential yet rock thermal conductivity studies have been very limited. Here, we report new thermal conductivity values collected from 240 rock samples in western and central Anatolia regions. The data were initially classified according to lithologic descriptions; then mean thermal conductivities were determined after applying corrections from dry to saturated conditions, if necessary. The major rock types encountered in these regions are igneous metamorphic, and sedimentary rocks. Limestone is the most common lithological unit encountered both in western and central Anatolia regions. The limestones in western Anatolia show a higher mean thermal conductivity than the limestones in central Anatolia. Dolomitization has a significant effect on the thermal conductivity of limestones. Neritic limestones show a higher mean thermal conductivity compared to lacustrine limestones. The results of this study reveal large contrasts in thermal conductivity values among different rock types that can have major implications for future heat flow and geothermal modeling studies in these regions.

Keywords: thermal conductivity, western Anatolia, central Anatolia, geothermal, heat flow

(Some figures may appear in colour only in the online journal)

1. Introduction

Thermal conductivity is a thermal property that quantifies the ability of a material to conduct heat. Knowledge of thermal conductivity is essential in heat flow determinations as heat flow is calculated by multiplying the geothermal gradient with the thermal conductivity (Jaeger 1965). Thermal conductivity is also an essential input parameter in thermal modeling investigations as it controls the steady-state temperature distribution within the Earth (Blackwell and Steele 1989). In particular, the contrast in thermal conductivity between sediments and basement rocks may lead to significant temperature changes even if regional heat flow is constant (Thakur *et al* 2012, Erkan and Blackwell 2008, Balkan and Salk 2014). Rock thermal conductivity also has important implications in oil and gas exploration, thermoelastic stress analysis, and geological disposal studies (Pigford 1982, Rutqvist *et al* 2008, Feng *et al* 2013).

Although western Turkey has many medium-to-high enthalpy geothermal systems (Basel *et al* 2010), detailed thermal models have not been developed due to a lack of direct thermal conductivity measurements and insufficient geothermal gradient data. In particular, thermal conductivity information is necessary for estimating the Enhanced Geothermal System (EGS) potential of an area (Tester *et al* 2006). This study aims to fill the gap in knowledge of thermal conductivities of the major lithologic units in western and central Anatolia.

In Turkey, geothermic studies started at the beginning of the 20th century with ground temperature measurements for meteorological purposes (Tezcan 1995). The first heat flow map of Turkey was published by Tezcan (1979), and then improved by Tezcan and Turgay (1991). In these studies, heat flow values were calculated from non-equilibrium bottom-

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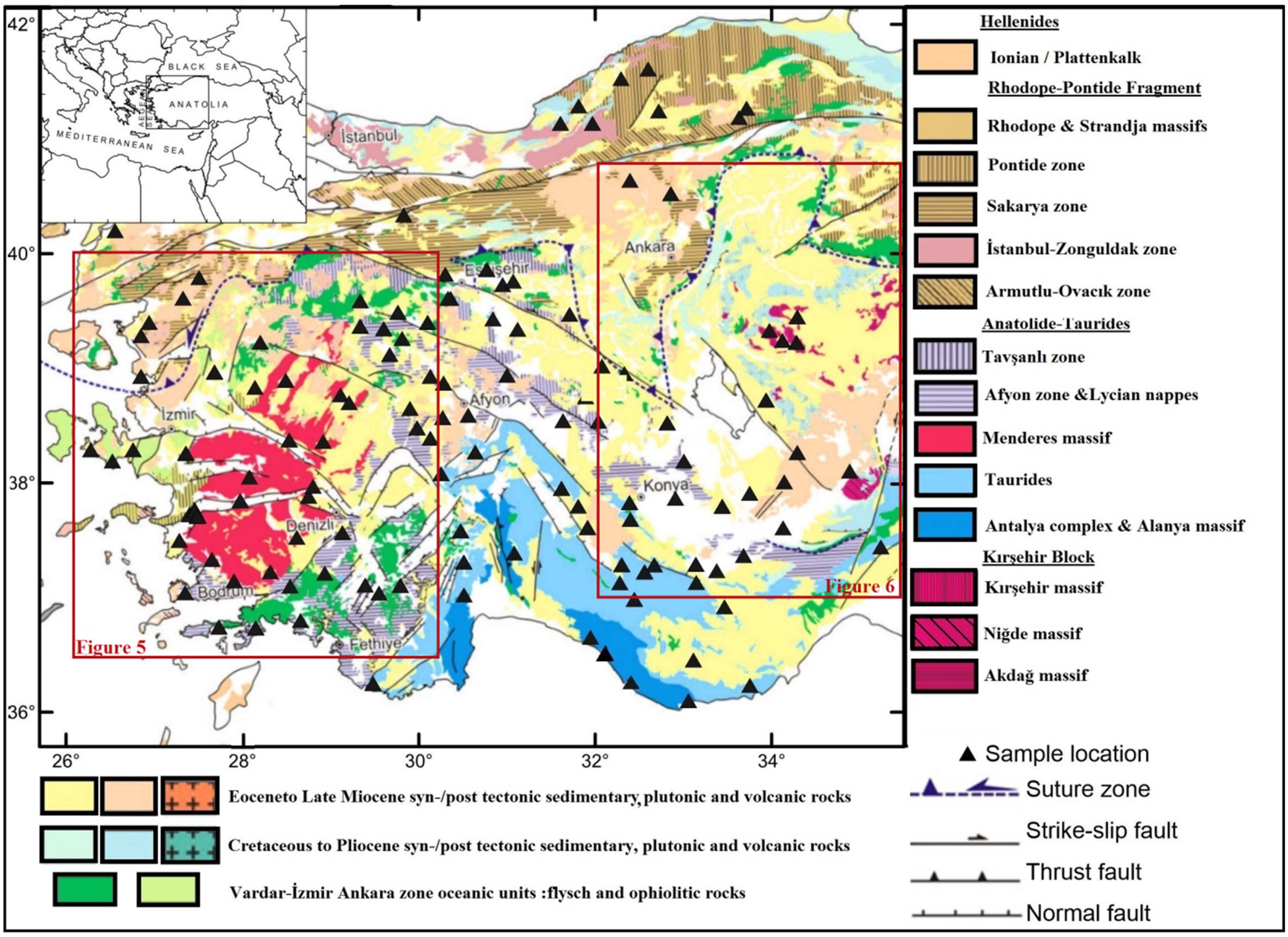

Figure 1. Simplified geological map of the study area and location of rock samples. Note that more than one type of lithologic unit were collected at the same locations. Reprinted from Çemen *et al* (2014), Copyright 2014, with permission from Elsevier.

hole-temperature data from deep (oil, gas, coal, and geothermal) wells assuming a constant thermal conductivity of 2.1 W m^{-1} K^{-1} for all well locations. Many local and large-scale attempts were made to estimate the regional heat flow from Curie point depths in Turkey (Hisarlı 1995, Ates *et al* 2005, Dolmaz *et al* 2005, Şalk *et al* 2005, Aydın *et al* 2005, Bektaş *et al* 2007, Maden 2010, Akın and Çiftçi 2011, Akın *et al* 2014, Maden *et al* 2015). However, all of these studies assumed constant thermal conductivity values between 2–2.5 W m^{-1} K^{-1} in their calculations.

The dataset used in this study is obtained from two government-funded projects in Turkey (İlkişik *et al* 1996a, 1996b), which were dedicated to construct the heat flow map of western Turkey. Data collection was carried out by the Mineral Research and Exploration General Directorate of Turkey (MTA). In these projects, thermal conductivity measurements from 240 rock samples were made and reported without further analyses and corrections. The measurements were carried out using a QTM-500 device in the laboratory of MTA (Karlı *et al* 2006). Locations of the rock samples are given in figure 1. In this study, the raw thermal conductivity data are initially sorted according to the lithologic types encountered in western and central Anatolia regions, separately. Then, the mean thermal conductivities of the lithologies are calculated for dry and/or saturated conditions. Finally, the significance of the results is discussed by comparing with the general geologic and tectonic setting of each region.

2. Thermal conductivity of rocks

The thermal conductivity of rocks depends on various parameters including mineral composition, porosity, anisotropy, and properties of pore-filling fluids. This leads to a large variability in thermal conductivities within each rock type (sedimentary, igneous, and metamorphic rocks). In this study, sedimentary, metamorphic, and igneous rocks are analyzed.

The types of rock forming minerals directly control the thermal conductivity of a rock, and have a wide variety of values. Rock-forming minerals such as quartz and hematite have high thermal conductivities whereas clay, gypsum, and organic materials have low thermal conductivities (table 1). This leads to a strong dependence of thermal conductivity on rock mineral composition (Schön 2011). Minerals with high thermal conductivities cause an increase in rock thermal conductivity. For metamorphic rocks, high values for quartzite (high quartz content) and relatively low values for schist and gneiss (low quartz content) are expected. Besides the mineral composition, grain size and texture of the rock also

Table 1. Thermal conductivity of minerals.

Rock-forming mineral	λ (W m^{-1} K^{-1})	Rock-forming mineral	λ (W m^{-1} K^{-1})
Quartz-α	7.69[a], 7.69[b] 7.7[c]	Magnetite	5.10[a], 4.7–5.3[e], 5.1[b]
Quartz-mean	6.5[d]	Hematite	11.28[a], 11.2–13.9[e]
Zircon	5.54[a], 5.7[e]	Calcite	3.59[a], 3.25–3.9[e]
Serpentine	3.53 ± 1.28[a], 1.8-2.9[e]	Dolomite	5.51[a], 5.5[b], 5.3[c]
Clay minerals	2.9[f], 1.7[d]	Anhydrite	4.76[a], 4.76[b], 5.4[d]
Feldspar	2.3[g], 2.0[h]	Gypsum	1.26[a], 1.0–1.3[e]
Apatite	1.38 ± 0.01[a], 1.4[e]	Organic materials	0.25[f], 1.0[c]

[a] Clauser and Huenges (1995).
[b] Cermak and Rybach (1979).
[c] Brigaud *et al* (1989, 1992).
[d] Clauser (2006).
[e] Melnikov *et al* (1975).
[f] Quiel (1975).
[g] Huenges (1989).
[h] Drury and Jessop (1983).

Table 2. Data for western and central Anatolia.

Lithology	Western Anatolia	Central Anatolia
Clastic rocks	16	0
Claystone	20	0
Conglomerate	0	3
Crystallized limestone	6	14
Limestone	33	47
Lacustrine	18	13
Neritic	7	29
Pelagic	3	3
Marl	8	7
Marble	9	3
Quartzite	0	3
Schist	11	2
Andesite	19	7
Basalt	0	3
Tuff	11	9
Granite	0	3
Peridotite	3	3
Total	136	104

determine how fast heat is transmitted through the rock (Clauser 2006). Anisotropy may also significantly influence thermal conductivity of sedimentary and metamorphic rocks. If the rock is layered, the horizontal thermal conductivity (parallel to bedding) is usually greater than the vertical thermal conductivity (Kappelmeyer and Hänel 1974, Gretener 1981, Popov *et al* 1995).

The thermal conductivity of a rock also varies with porosity. Porosity is the first and foremost important factor that controls the bulk thermal conductivity for almost all rock types, particularly sedimentary and young volcanic rocks whose relative porosity are greater than metamorphic rocks. Pore-filling materials (water, air, oil, gas, etc) have lower thermal conductivities than rock matrix which results in a decrease in the bulk thermal conductivity with increasing porosity (Clauser and Huenges 1995).

3. Data analysis

The data consist of 240 thermal conductivity measurements performed by a QTM-500 (Quick Thermal conductivity Meter) thermal conductivity device in the laboratory of MTA. QTM-500 is based on the ASTM C 1113-90 hot wire method. It is an effective and reliable technique for measuring thermal conductivity (Grubbe *et al* 1983, Sass *et al* 1984). QTM-500 is widely used in thermal conductivity determinations due to the advantage of rapid sampling time (Grubbe *et al* 1983, Thienprasert and Raksaskulwong 1984, Demirboğa 2003, Çanakci *et al* 2007).

In this study, the samples were initially classified according to lithological descriptions given in the dataset. Lithologic names were defined by reference to the Geological Map of Turkey (MTA 2010). A summary of the entire dataset for the western Anatolia and central Anatolia regions is shown in table 2. Out of a total of 240 rock samples, 136 of them were collected from western Anatolia, and 104 samples were collected from central Anatolia. Measurements in western Anatolia were conducted on dry samples, so they required corrections to saturated conditions for the determination of bulk thermal conductivities. On the other hand, data collected in central Anatolia were made in saturated conditions (Yenigün 2011), and did not require any further correction for porosity.

For the western Anatolia dataset, porosity measurements are not available, so for corrections to saturated conditions, a mean porosity value for each lithology was assigned based on the published data (Fuchs *et al* 2013, Baeyens and Bradbury 1994, Manger 1963, Yavuz *et al* 2005, JICA 1987, Ma and Daemen 2006). Saturated thermal conductivities were determined using the geometric mean model (Fuchs *et al* 2013). The relationship between dry (λ_d) and saturated (λ_s) thermal conductivity can be written as

$$\lambda_s = \lambda_d \left(\frac{\lambda_w}{\lambda_a}\right)^{\varphi} \tag{1}$$

Table 3. Thermal conductivity values for dry and saturated conditions in western Anatolia.

Lithology	N	λ_d (W m^{-1} K^{-1})	φ_e (%)	λ_s (W m^{-1} K^{-1})	$\lambda_{s,\min} - \lambda_{s,\max}$ (W m^{-1} K^{-1})
Clastic rocks (sandstone)	16	1.57 ± 1.10	25.0	3.08 ± 2.05	2.5–4.8
Claystone	20	0.70 ± 0.26	12.0	1.02 ± 0.38	0.9–1.2
Crystallized limestone	6	3.08 ± 1.21	4.0	3.49 ± 1.38	3.3–3.7
Limestone	33	2.62 ± 0.77	4.0	2.98 ± 0.86	2.8–3.1
Lacustrine	18	2.53 ± 0.82	4.0	2.87 ± 0.93	2.7–3.0
Neritic	7	2.91 ± 0.60	4.0	3.30 ± 0.68	3.1–3.5
Pelagic	3	3.09 ± 0.04	4.0	3.51 ± 0.04	3.3–3.7
Marl	8	1.35 ± 0.52	1.5	1.52 ± 0.50	1.4–1.5
Marble	9	2.93 ± 0.40	0.2	2.95 ± 0.40	2.9–3.0
Schist	11	2.80 ± 0.82	4.0	3.19 ± 0.93	3.0–3.3
Andesite	19	1.70 ± 0.61	5.0	1.99 ± 0.68	1.9–2.1
Peridotite	3	2.52 ± 0.45	4.0	2.86 ± 0.51	2.7–3.0
Tuff	11	1.11 ± 0.48	5.0	1.30 ± 0.57	1.2–1.4

N: number of the data, λ_d: mean thermal conductivity of dry rocks with their standard deviations, φ_e: estimated mean porosity from Manger (1963), JICA (1987), Baeyens and Bradbury (1994), Yavuz *et al* (2005), Ma and Daemen (2006), Fuchs *et al* (2013). λ_s: mean thermal conductivity of saturated rocks with their standard deviations. Standard deviation for porosity is assumed to be 20% of the mean porosity for range calculation. Ranges of expected values are also given for the saturated conditions.

where $\lambda_a = 0.025\ \mathrm{W\,m^{-1}\,K^{-1}}$ and $\lambda_w = 0.59\ \mathrm{W\,m^{-1}\,K^{-1}}$ are the thermal conductivities of air and water, respectively. Here, φ represents the porosity ratio. In order to account for uncertainty in the porosity estimations, a constant standard deviation of 20% of the mean porosities was assumed for all lithologic types. The effects of this uncertainty on saturated conditions were calculated by propagating the error in the measurements of dry conditions and the error in porosity estimations.

4. Results

We analyzed 10 different representative rock types in western Anatolia. Table 3 lists the mean thermal conductivities of the rocks. In addition to the mean values for dry and saturated conditions, ranges of expected values are also given by taking the standard deviation of the assigned porosity. Most of the rock samples belong to limestone units followed by claystone units.

In western Anatolia, thermal conductivities in dry conditions vary between $0.7\ \mathrm{W\,m^{-1}\,K^{-1}}$ and $3.09\ \mathrm{W\,m^{-1}\,K^{-1}}$ (table 3), and increase considerably after corrections to saturated conditions (table 3). Histograms for saturated thermal conductivity of certain lithologies are shown in figure 2. Claystone has the lowest thermal conductivity within all rocks. The thermal conductivity varies considerably for each rock type. Especially, clastic rocks (which are mainly sandstone units) show a wide range of conductivities as a result of variations in quartz contents as well as high porosity values. For metamorphic rocks, the thermal conductivities of schist and marble are $3.19 \pm 0.93\ \mathrm{W\,m^{-1}\,K^{-1}}$ and $2.95 \pm 0.4\ \mathrm{W\,m^{-1}\,K^{-1}}$, respectively. In igneous rocks, the mean thermal conductivity of peridotite is $2.86 \pm 0.51\ \mathrm{W\,m^{-1}\,K^{-1}}$, followed by andesite with a mean of $1.99 \pm 0.68\ \mathrm{W\,m^{-1}\,K^{-1}}$ and tuff of $1.30 \pm 0.57\ \mathrm{W\,m^{-1}\,K^{-1}}$. In this study the mean thermal conductivity of igneous rocks is lower than that of metamorphic rocks.

The results for central Anatolia are shown in table 4 with mean thermal conductivities and their standard deviations. These samples were directly measured in saturated conditions, thus no correction for porosity had to be applied. The highest mean thermal conductivity value of $5.0 \pm 0.98\ \mathrm{W\,m^{-1}\,K^{-1}}$ is found for quartzite which is attributed to the high content of quartz mineral that transmits heat efficiently. Tuff has the lowest mean thermal conductivity value of $1.05 \pm 0.35\ \mathrm{W\,m^{-1}\,K^{-1}}$ which can be associated with high porosity.

Figure 3 shows histograms for the thermal conductivity of certain lithologies in central Anatolia. Limestones are the most common rock in central Anatolia and their ranges of thermal conductivity are wider than other types.

5. Comparison with the general tectonics of the regions

Turkey is located within the Mediterranean Earthquake Belt where complex deformation has occurred due to the continental collision among African, Arabian, and Eurasian plates. This collision caused the westward extrusion of the Anatolian plate along the North Anatolian Fault Zone (NAFZ) and East Anatolian Fault Zone (EAFZ) (Bozkurt 2001). On the other hand, the convergence between African and Anatolian plates resulted in a subduction zone along the Aegean and Cyprian arcs called the Aegean Subduction Zone (ASZ) (Papazachos and Comninakis 1971, McKenzie 1978, Mart and Woodside 1994) where the African plate is descending beneath the Anatolian plate. The ongoing deformation of the region has resulted in the generation of four different neotectonic provinces in Turkey: the (1) West Anatolian Extensional Province, (2) Central Anatolian 'Ova' Province, (3) East Anatolian Contractional Province, and (4) North Anatolian Province (Şengör *et al* 1985). Each province shows unique structural components and tectonic features. The

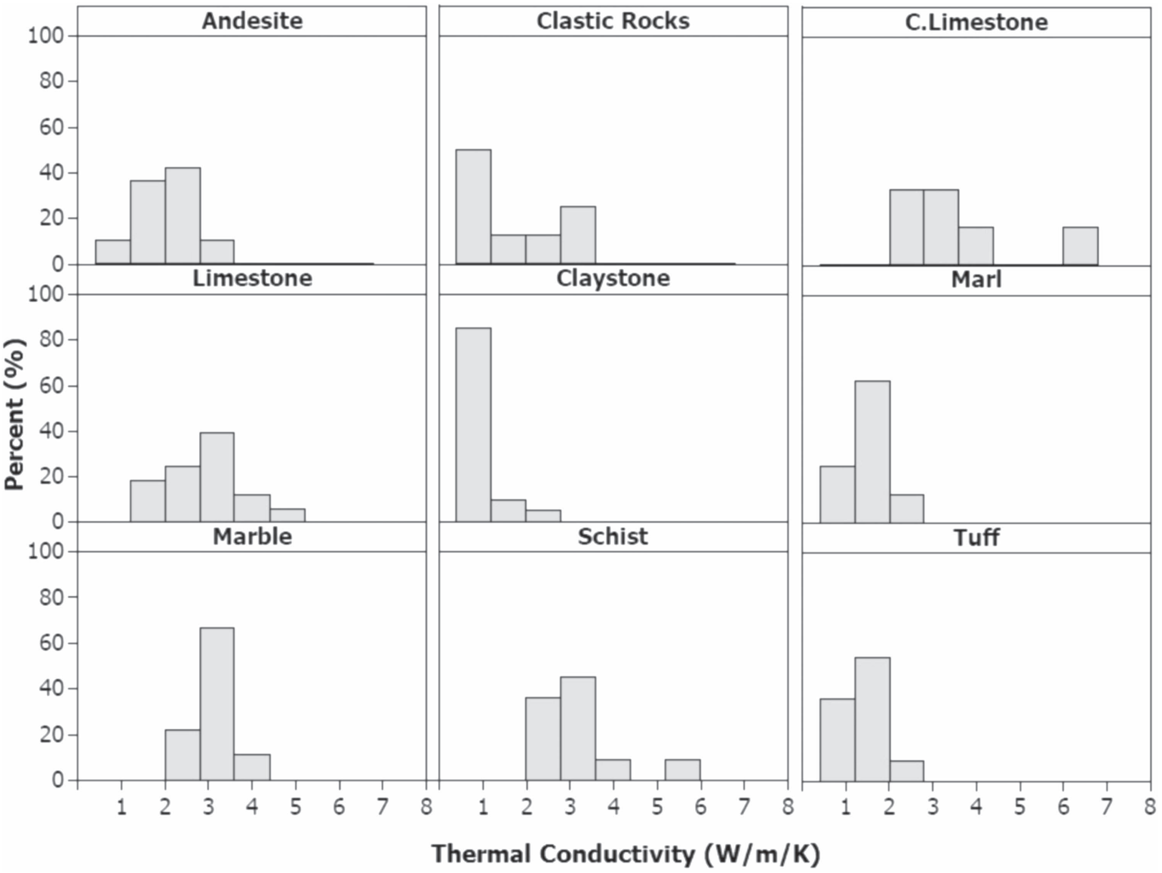

Figure 2. Histograms for saturated samples from western Anatolia.

Table 4. Thermal conductivity values of saturated conditions and their standard deviations in central Anatolia.

Lithology	N	λ_s (W m^{-1} K^{-1})	σ_{λ_s}
Conglomerate	3	2.74	0.17
Crystallized limestone	14	3.85	0.95
Limestone	47	2.64	0.68
Lacustrine	13	2.42	0.65
Neritic	29	2.88	0.50
Pelagic	3	1.83	0.89
Marl	7	1.81	0.31
Marble	3	3.29	0.30
Quartzite	3	5.00	0.98
Schist	2	1.95	0.43
Andesite	7	1.80	0.68
Basalt	3	1.40	0.22
Tuff	9	1.05	0.35
Granite	3	4.54	0.74
Peridotite	3	2.87	0.24

N: number of the data, λ_s: thermal conductivity of saturated rocks σ_{λ_s}, standard deviation of λ_s.

rock samples studied in this paper belong to western and central Anatolian provinces. The relationships of the tectonic and geologic settings along the major lithologic units encountered in these provinces are discussed below.

5.1. Western Anatolia

The western Anatolia region is noted for its long and complicated geological history. Tectonic evidence suggests that the area has experienced Cenozoic extensional tectonics (Şengör and Yılmaz 1981, Okay and Tüysüz 1999, Rimmelé *et al* 2003, van Hinsbergen *et al* 2005, 2010, Ring *et al* 2010).

The western Anatolia province includes numerous grabens filled with volcano-sedimentary sequences dissecting Menderes Metamorphic Complex (MMC) (figure 4). MMC is the oldest metamorphic terrain on the Anatolian plate, and one of the largest metamorphic terrains in the world (Bozkurt and Park 1994, Emre 1996, Işık and Tekeli 2001, Lips *et al* 2001, Çemen *et al* 2006). It includes many kinds of metamorphosed and igneous rocks from high to low grades, including gneiss, mica schists, phyllites, quartz schists, marbles, and granodiorites. We sampled two types of metamorphic rocks which are schist and marble (table 3). According to our results, marble stands out with a high thermal conductivity of 2.95 ± 0.4 W m^{-1} K^{-1}. Marbles located in Menderes massif generally have high dolomite content (Yavuz *et al* 2005), which directly increases the thermal conductivity of the marble. Western Turkey is characterized by a number of suture zones (figure 4) bearing wide areas of peridotite units. In our dataset, three peridotite samples from these suture zone show a mean value of 2.86 ± 0.51 W m^{-1} K^{-1}, which is a lower mean thermal conductivity than other the rocks of MMC.

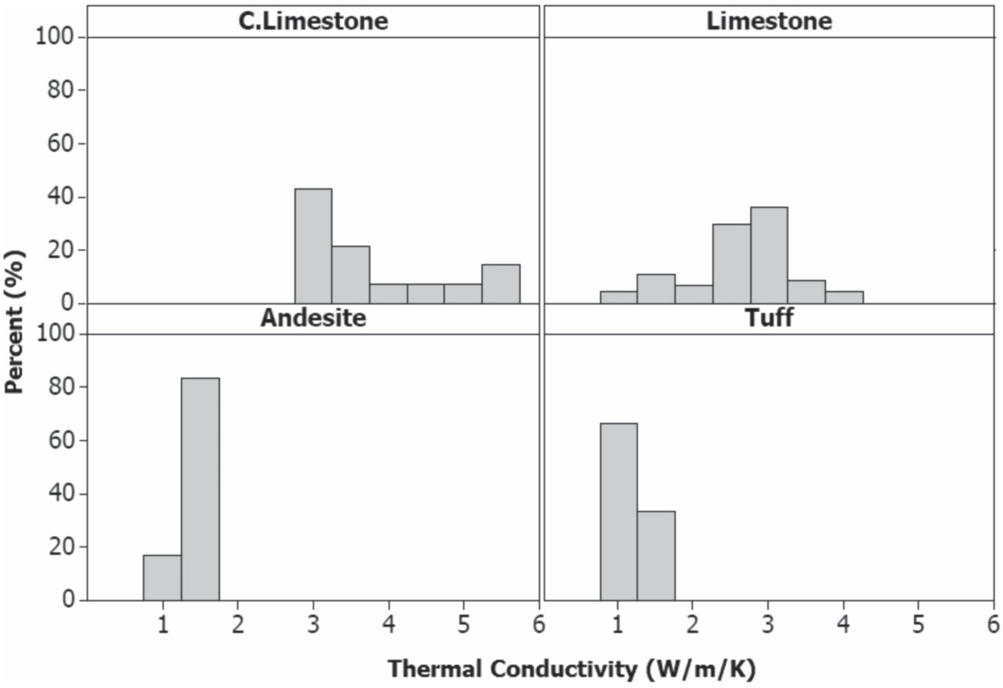

Figure 3. Histograms for saturated samples from central Anatolia.

MMC is dissected by three major graben structures (figure 4). The fills within the grabens are generally composed of two main, lower and upper, volcano-sedimentary successions. While the upper volcano-sedimentary conglomerates contain clasts from MMC, they are absent in the lower volcano-sedimentary successions (Ersoy *et al* 2014). Sedimentary parts of the successions consist of generally limestone, sandstone, conglomerate, shale, and marl (Innocenti *et al* 2005). Andesite, tuff, basalt, and rhyolite are the common volcanic rocks within typical sections (Ersoy *et al* 2014). As a part of sedimentary successions limestone, sandstone and marl units were sampled while andesite and tuff units were sampled from volcanic successions (table 3).

In this paper, we report results for three types of limestone sublithologies based on the geological map of Turkey (MTA 2010). Among the three types, pelagic limestone by far shows the highest ($3.51 \pm 0.04\,\mathrm{W\,m^{-1}\,K^{-1}}$) thermal conductivity values compared to lacustrine and neritic limestone. It is followed by crystallized limestone with $3.49 \pm 1.38\,\mathrm{W\,m^{-1}\,K^{-1}}$. Assuming that limestones generally show similar low porosity values, thermal conductivity variations may be related to the clay and dolomite contents of the sublithologies.

For volcanic rocks, porosity is the main contributor of thermal conductivity variations. The typical porosity rate of tuff ranges from 5 to 35%. The age of the rock directly controls the porosity ratio. With increasing age, exposure time to hydrothermal alteration of the rock gets longer, decreasing the porosity of the volcanic rock. Volcanic rocks older than 5 Ma have typically low porosity rate (Blackwell *et al* 1982, Blackwell and Priest 1996). In western Anatolia, volcanic rocks have ages from Oligocene to the present (Fytikas *et al* 1984). In our dataset, the ages of volcanic rocks are Miocene and older.

5.2. Central Anatolia

The central Anatolia province is situated in the middle of the Anatolian microplate and bounded by NAFZ in the north and EAFZ in the south. Multiple collisional events and extensional tectonics played a major role in the evolution of central Anatolia during the mid- to late-Cenozoic. The central Anatolia region can be defined as a steppe plateau including sediment filled basins and larger scale volcanic fields with dispersed volcanic cones (Dilek and Whitney 2000). The Central Anatolian Crystalline Complex (CACC) constitutes the basement rock of the region composed of crystalline rocks showing evidence of regional metamorphism and magmatism. It consists of the Central Anatolian Metamorphics (medium- to high-grade marbles, schists, mica-schists, quartzites, amphibolite), Central Anatolian Ophiolites (peridotites, ultramafic rocks), and Plutonic rocks of the Central Anatolian Granitoids (granitoids and syenitoids) (Şengör *et al* 1984, Satir and Friedrichsen 1986, Göncüoglu *et al* 1991, Hetzel *et al* 1995, Bozkurt and Oberhänsli 2001, van Hinsbergen *et al* 2010). Marble, quartzite, and schist units from Central Anatolian Metamorphics are investigated in this study. Quartzite has the maximum thermal conductivity of $5.00 \pm 0.98\,\mathrm{W\,m^{-1}\,K^{-1}}$. Basalt from Central Anatolia Ophiolites shows moderate thermal conductivity of $1.40 \pm 0.22\,\mathrm{W\,m^{-1}\,K^{-1}}$ (table 4).

CACC has been dissected by neotectonic structures (figure 5). In particular two main fault systems (Tuzgölü and Ecemiş fault zones) have played important roles in the neotectonic evolution of central Anatolia. These fault systems have also controlled the development of the interior basins such as Tuzgölü, Haymana, Çankırı, and Sivas basins. These basins have the best records for the evaluation of hydrocarbon and geothermal resources of the region (Görür *et al* 1998). Generally, the basins are filled with assemblages of sedimentary

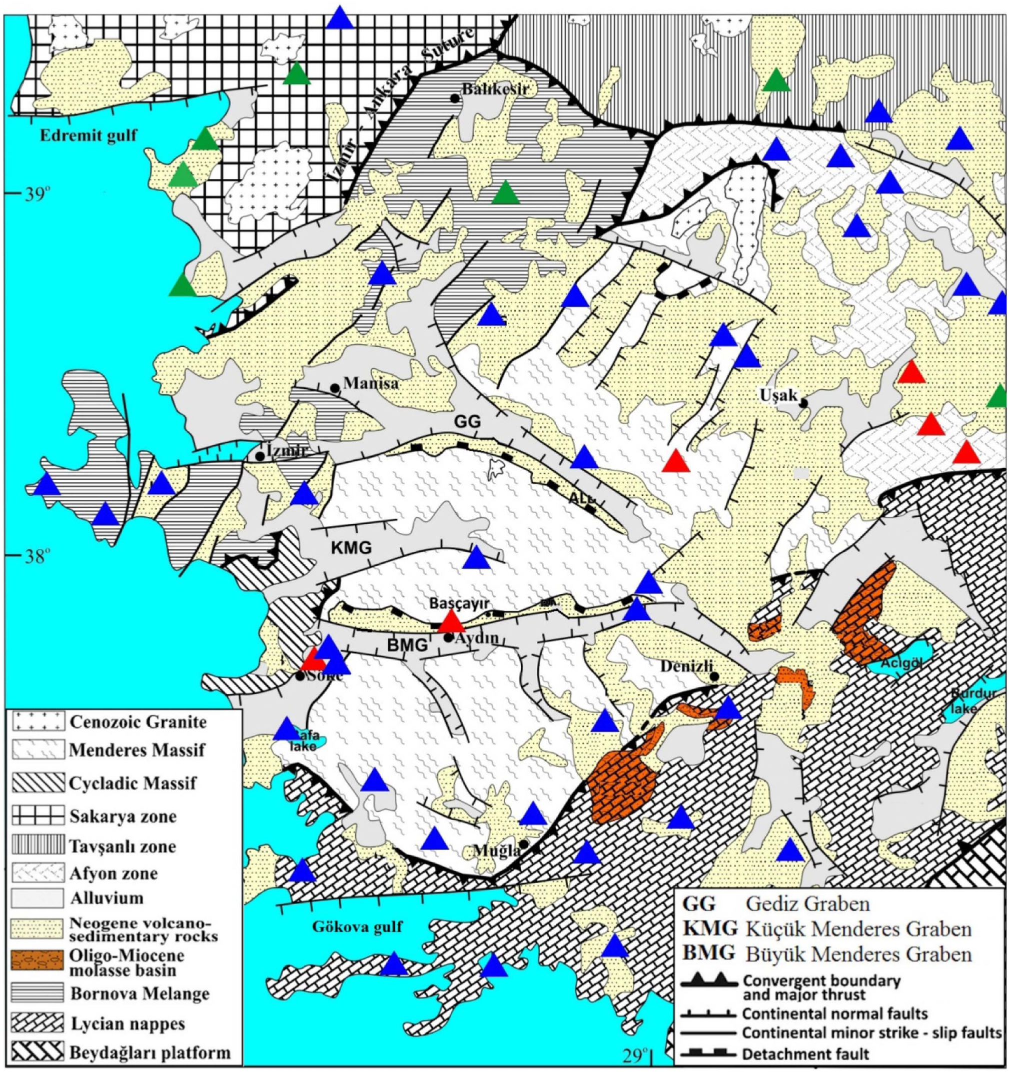

Figure 4. Geology and tectonic structures of western Anatolia. Blue, green, and red triangles symbolize measurement points of sedimentary, igneous, and metamorphic rocks, respectively. Reprinted from Sümer *et al* (2013), Copyright 2013, with permission from Elsevier.

rocks (conglomerate, sandstone, mudstone, limestone, shale, marl) with discontinuous volcanic sequences (basalt, andesite), and ophiolitic rocks (Görür *et al* 1998). Table 4 indicates that sedimentary rocks have higher thermal conductivities than volcanic rocks in central Anatolia.

Due to the local tectonic features of central Anatolia, volcanic rocks are more common in the area as compared to western Anatolia. As mentioned above, porosity is the major factor that controls the thermal conductivity of volcanic rocks, which is directly related with age. During hydrothermal alteration processes pore spaces inside rocks are filled by weathered units. Because these weathered materials have a higher thermal conductivity than water and air, the bulk thermal conductivity of the rock becomes higher. As a volcanic rock, tuff ($1.05 \pm 0.35\,\mathrm{W\,m^{-1}\,K^{-1}}$) has the lowest thermal conductivity in central Anatolia. Within the metamorphic rocks, quartzite has the highest thermal conductivity due to its high quartz content. Granite also shows a high thermal conductivity ($4.54 \pm 0.74\,\mathrm{W\,m^{-1}\,K^{-1}}$) among other rock types.

6. Discussion

All of the data for the entire study area are divided into three mega-groups as sedimentary, metamorphic, and igneous rocks. Histograms of thermal conductivity values of each group are given in figure 6. This representation enables us to see the thermal characteristics of these mega-groups individually. According to the histograms, it is possible to assign a single mean thermal conductivity for igneous and metamorphic rocks. Mean thermal conductivity values for igneous and metamorphic rocks are assigned for the entire study area as 1.88 and 3.28 ($\mathrm{W\,m^{-1}\,K^{-1}}$), respectively. On the other hand, assigning a single mean thermal conductivity for sedimentary rocks is difficult. This is to be expected by the fact that thermal conductivities of sedimentary rocks show a wide range related to their physical properties. Thermal conductivity values ranging from 0.61 to 7.12 ($\mathrm{W\,m^{-1}\,K^{-1}}$) are observed. The lowest values belong to claystones of alluvial units in western Anatolia and limestones of the Tuzgölü basin from central Anatolia. High values are derived from sandstone of neogene volcano-sedimentary rocks

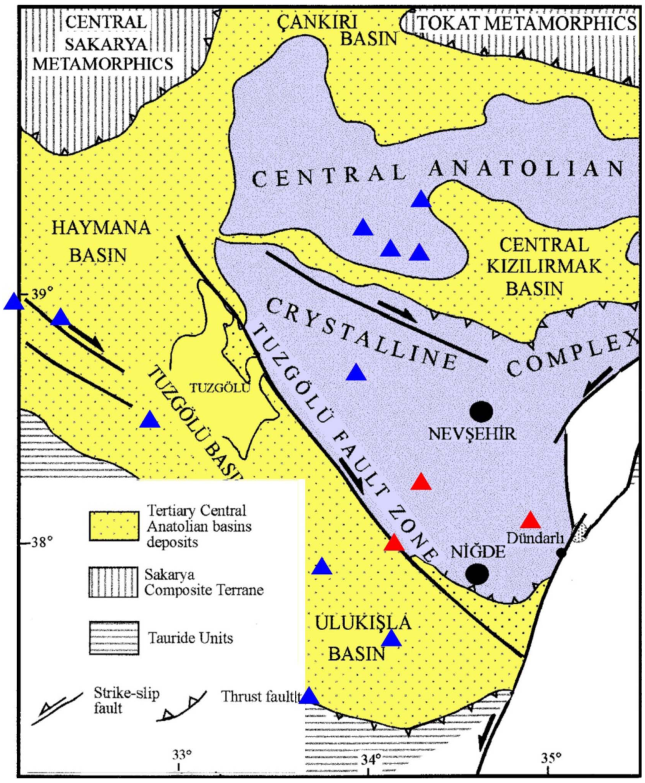

Figure 5. General geology and tectonic structures of central Anatolia. Blue, green, and red triangles symbolize measurement points of sedimentary, igneous, and metamorphic rocks, respectively. Modified with permission from Dirik *et al* (1999), Copyright 1999 John Wiley & Sons, Inc.

in western Anatolia and crystallized limestone founded in the Haymana basin from central Anatolia (figures 4 and 5).

Limestone, the most common lithological unit both in western and central Anatolia, is analyzed with its subunits, namely the neritic, lacustrine, and pelagic limestones. Figure 7 shows histograms for the four types of limestones observed in this study. Dolomite is generally prevalent within limestones but the mineral dolomite is rarely observed forming in sedimentary environments. For this reason it is believed that most dolomites form when limestones are modified by post-depositional chemical change (Schön 2011). Therefore, in our study the term 'crystallized limestone' refers to dolomitization of limestone. Crystallized limestone shows a significantly higher mean thermal conductivity than all other types due to the high dolomite content. This suggests that dolomite content has a significant effect on the thermal conductivity of carbonate rocks. Neritic limestone is also a common type of limestone in our study area. It shows a somewhat higher thermal conductivity compared to the lacustrine and pelagic limestones.

Figure 8 shows a correlation plot of the rock types that are common in western and central Anatolia regions (see table 2). Generally, mean thermal conductivities of the same units are in accordance from both regions and the correlation coefficient is calculated to be 0.82. Only the schist unit shows a significant deviation in the plot, which may be due to differences in compositions of the sampled rocks (note that only two schists were sampled in central Anatolia).

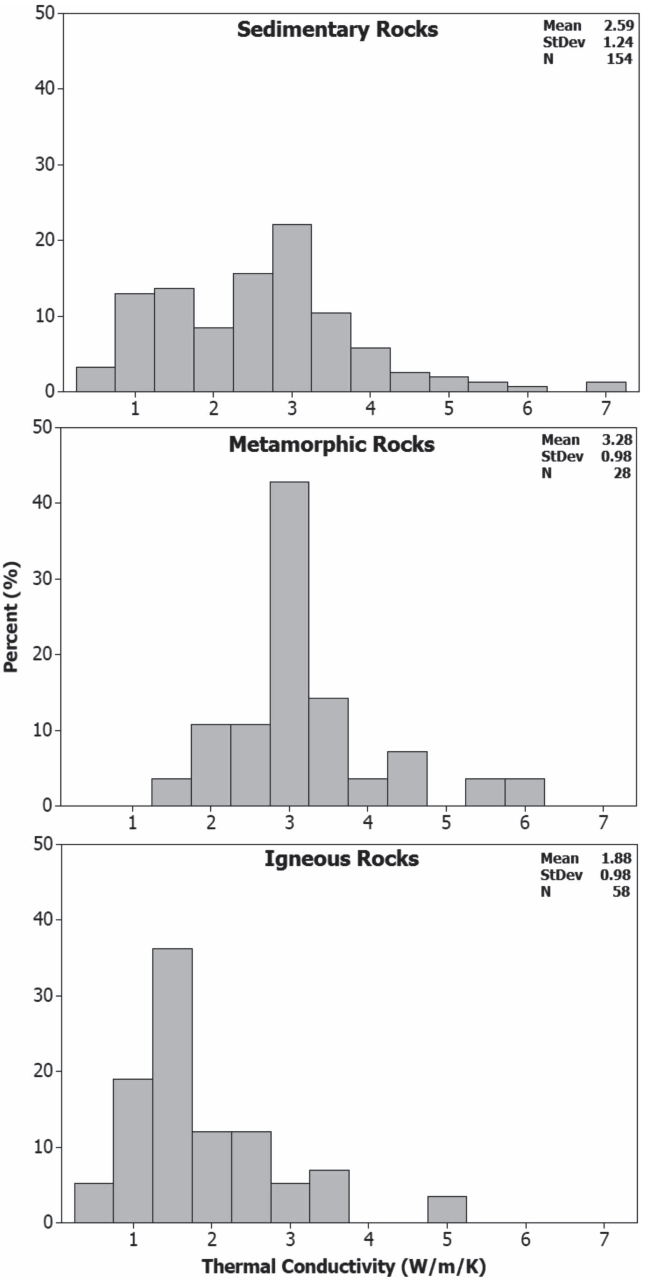

Figure 6. Histograms ofthe combined dataset of western and central Anatolia.

7. Conclusions

In this study, we analyzed thermal conductivity measurements from 240 rock samples collected in western and central Anatolia regions. The samples were initially classified according to lithological descriptions given in the dataset. Lithologic units were defined by reference to the geological map of Turkey (MTA 2010). Data from western Anatolia were corrected from dry to saturated conditions using the

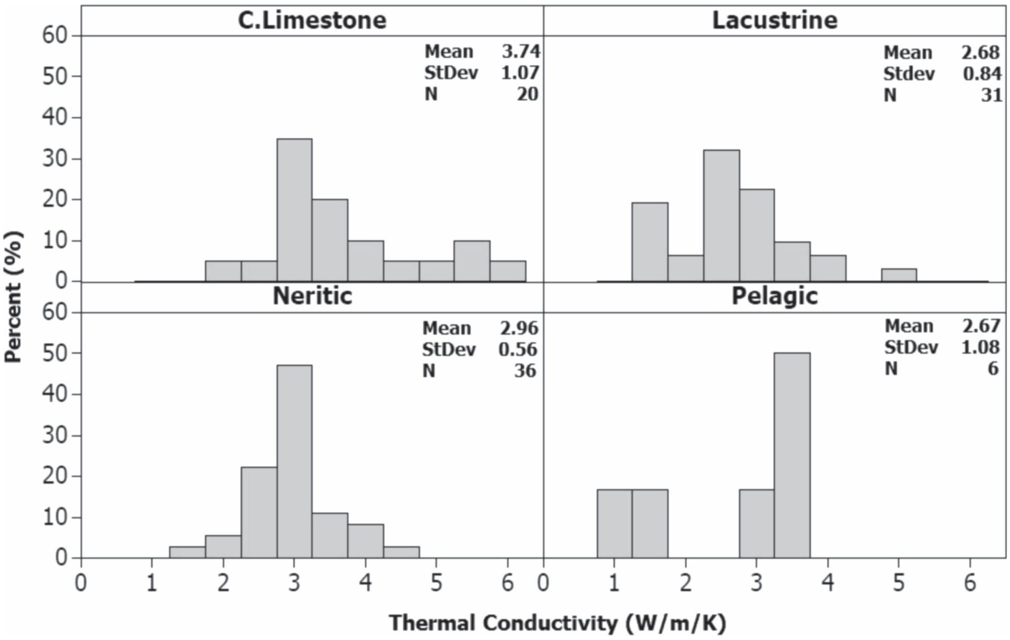

Figure 7. Histograms of the limestone samples in western and central Anatolia.

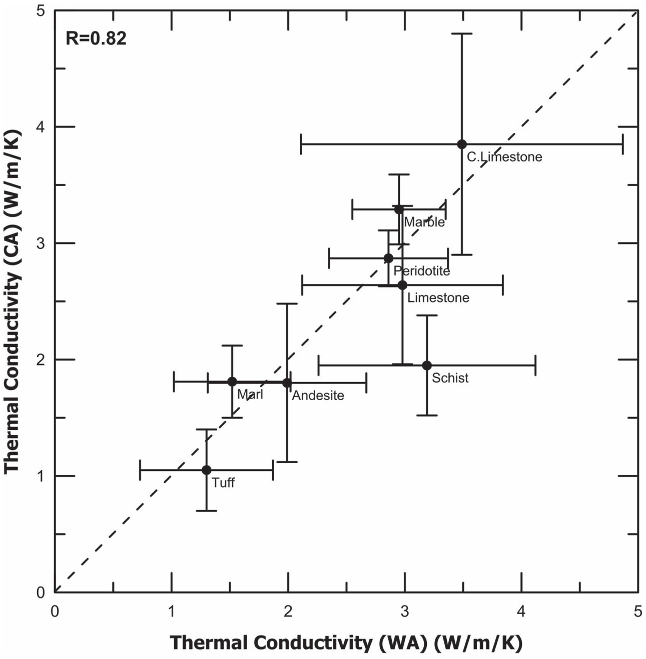

Figure 8. Correlation plot for the common rocks of western (WA) and central (CA) Anatolia.

geometric mean model. Statistical analyses were applied both for dry and saturated conditions.

Within all data, the lowest values belong to claystones of alluvial units in western Anatolia and limestones of the Tuzgölü basin from central Anatolia. High values are derived from sandstones of Neogene volcano-sedimentary rocks in western Anatolia and crystallized limestone found in the Haymana basin from central Anatolia (figures 3 and 4).

Reported mean thermal conductivities in western Anatolia are generally lower than central Anatolia. The thermal conductivity of sedimentary rocks shows a wide range of values due to a wide variety of physical properties. The high thermal conductivity of sandstones is linked with the high quartz content, whereas high thermal conductivity of crystallized limestones is linked with dolomitization. This study reveals that the range of thermal conductivity values observed for sedimentary rocks is too wide to assign a constant thermal conductivity value for heat flow and thermal modeling studies. Results of this study can be used for future heat flow and thermal modeling studies in Turkey.

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