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Curie Point Depths Based on Spectrum Analysis of Aeromagnetic Data, West Anatolian Extensional Province, Turkey

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Abstract—The Curie point depth map of Western Anatolia was constituted from spectral analysis of the aeromagnetic data. The Curie point depth values from 53 overlapping blocks, 90 × 90 km in size, have been estimated from the band-pass filtered data. The slope of the longest wavelength part of the radially averaged log power spectrum divided by the radial frequency produced the depth to the centroid (z_0) for the deepest crustal block. The depth to the top (z_t) was obtained by the slope of the second longest wavelength part of the spectrum. From these depths, the Curie point depth was then calculated by using $z_b = 2z_0 - z_t$. The Curie point depth estimates for Western Anatolia range between 8.2 and 19.9 km.

A corresponding heat-flow map has been constructed from the Curie point depths and thermal conductivity measurements. The boundary between the areas of shallow and deep Curie point depth coincides with an active extensional system which is characterized by a complex cross-cutting horst-graben system. Deepening of Curie point depths (low heat flows) are observed at Hellenic trench axes. The shallow Curie point depths observed in the western part of the study area correspond with recent geological features such as the grabens of the Menderes Massif.

Key words: Curie point depths, aeromagnetic data, Western Anatolia, extending crust.

1. *Introduction*

Western Anatolia is one of the world's most rapidly extending provinces. The thickness of the crust decreases from 38 km in the presently unextending region in the east to 30 km in the west and to 22 km further west in the Aegean Sea, implying a variation in β factor of ca. 1.2 to 1.7 (SAUNDERS *et al.*, 1998). The β factor estimated from surface faulting and from integrating seismic strain rates yields a similar value of ca. 1.3 (EYIDOGAN, 1988; PATON, 1992). Thermal structure of an extended crust determines modes of extension, depths of brittle and ductile deformation zones, uplift/subsidence patterns and maturity of organic

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matter deposited in associated sedimentary basins. Thermal structure of such modern extensional domains is also of critical importance for better understanding the tectonic-thermal evolution of previously extended terranes now preserved in stratigraphic record.

Curie point depth estimation from magnetic data has been used extensively to estimate the thermal structure of crust in various tectonic settings (e.g., VACQUIER and AFFLECK, 1941; SERSON and HANNAFORD, 1957; BHATTACHARYYA and MORLEY, 1965; SMITH *et al.*, 1974, 1977; BHATTACHARYYA and LEU, 1975, 1977; BYERLY and STOLT, 1977; SHUEY *et al.*, 1977; BLAKELY and HASSANZADEH, 1981; CONNARD *et al.*, 1983; MAYHEW, 1982, 1985; OKUBO *et al.*, 1985, 1989; OKUBO and MATSUNAGA, 1994; BLAKELY, 1988; HISARLI, 1996; TSÖKAS *et al.*, 1998; TANAKA *et al.*, 1999; RAVAT, 2000; STAMPOLIDIS and TSÖKAS, 2002). The Curie point depth is known as the depth at which the dominant magnetic mineral in the crust passes from a ferromagnetic state to a paramagnetic state under the effect of increasing temperature. For this purpose, the basal depth of a magnetic source from aeromagnetic data is considered to be the Curie point depth.

In this paper we study the thermal structure of the West Anatolian extensional province, based on the Curie point depth estimation. A Curie point depth map of the area was constructed from aeromagnetic data and a corresponding heat-flow map was produced. We describe a thermal anomaly in Western Anatolia that coincides with the boundaries of the Menderes Massif. The Massif was first exhumed as a core complex along low-angle detachment zones during a Miocene extensional event. The area is actively extending in N–S direction at a rate of 14 ± 5 mm/yr (REILINGER *et al.*, 1997; MCCLUSKY *et al.*, 2000).

2. Regional Tectonic Setting

The main tectonic units of Western Anatolia are the Sakarya and the Izmir-Ankara Suture Zone (IASZ) in the north, the Menderes Massif and grabens in the middle and the Taurides in the south (Fig. 1; SENGOR and YILMAZ, 1981; OKAY *et al.*, 1996; BARKA and REILINGER, 1997). The area lies to the north of the Hellenic trench and is on the continuation of the trend of the Hellenic Arc and backarc region to the west (PAPAZACHOS and COMNINAKIS, 1971; WESTAWAY, 1990; TAYMAZ *et al.*, 1991; PAPAZACHOS *et al.*, 2000).

Lithospheric extension in Western Anatolia initiated in Early Miocene, following an earlier collision event along the Izmir-Ankara ophiolitic suture zone (Fig. 1; SEYITOGLU and SCOTT, 1996). Nappes of ophiolitic and continental origin (i.e., the Lycian Nappes) were emplaced over the Tauride autochthon to the south and caused deep burial and metamorphism during the collision period (COLLINS and ROBERTSON, 1997). Gravitational collapse of the thickened orogen and/or backarc extension resulted in exhumation of the metamorphics (i.e., the Menderes Massif) as a core complex, accommodated by low-angle detachment zones in

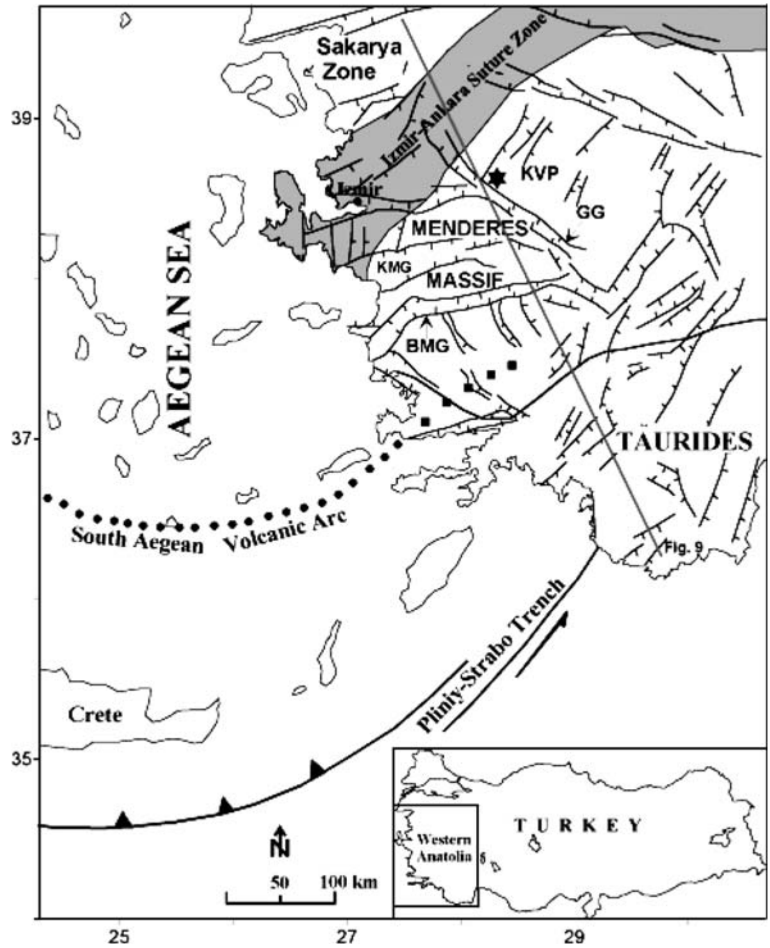

Figure 1
Generalized tectonic map of the Aegean region and Western Anatolia (modified after Papazachos and Comninakis, 1971; Dewey and Sengor, 1979; Angelier *et al.*, 1981; Okay *et al.*, 1996; Barka and Reilinger, 1997, Kocyigit, 2000). The series of large dark circles depict the South Aegean volcanic arc and stippled squares show the extension of the arc inland (Ates *et al.*, 1997). The NW-SE trending solid line indicates the cross section in Figure 9. Abbreviations: BMG Büyük Menderes Graben; GG Gediz Graben; KMG Küçük Menderes Graben; KVP Kula Volcanic Province.

Miocene. A horst-graben morphology was formed across Western Anatolia under continuing N-S extension in Mio-Pliocene (Bozkurt and Sözbilir, 2003). Fault blocks rotated along vertical and horizontal axes and were cut by new generations of E-W trending faults. The most prominent structures of the study area are therefore E-W trending grabens (Fig. 1). The highest peak in the horst blocks is ca 2000 m above sea level. The graben floors, on the other hand, are near sea-level towards the coastal areas.

Extrusive and plutonic rocks are important components of the West Anatolian extensional province. The oldests are granitoidic intrusives of Early Miocene age and are found to have emplaced into low-angle shear zones (HETZEL *et al.*, 1995) during the initial extension period. Calc-alkaline extrusives were erupted over a wide area in Late Miocene (SEYITOGLU *et al.*, 1997; ALDANMAZ *et al.*, 2000). The youngest volcanics in the area are the Plio-Quaternary alkaline lavas, known as the Kula volcanic province, located north of the Gediz graben (Fig. 1; ERCAN, *et al.*, 1985). This province comprises a number of small cinder cones and aa-type lava flows filling the present valleys. Human foot-prints on tuff horizons were discovered in this province (ARPAT, 1976). The Kula alkaline basalts of extensional origin are thought to represent decompression melting of lithospheric mantle (SAUNDERS *et al.*, 1998) or upwelled asthenosphere (ALDANMAZ *et al.*, 2000).

3. Previous Work

Several studies were carried out to determine the thermal state of the crust in Western Anatolia and the Aegean Sea. The methods used range from direct measurement of the geothermal gradients in boreholes, silica geothermometry from geothermal emanations and thermal conductivity.

Preliminary heat-flow data of TEZCAN (1979) and TEZCAN and TURGAY (1989) show some regional heat-flow anomalies exceeding 120 mW/m^2 in Western Anatolia. The mean value of heat flow for Western Anatolia is 107 ± 45 mW/m^2 based on silica geothermometry and 97 ± 27 mW/m^2 for the conventional heat flow data. These values are 60% above the world average (ILKISIK, 1995).

The General Directorate of Mineral Research and Exploration of Turkey (MTA) started a project of "Heat Flow Map of Turkey" in 1995. In this project, geothermal gradients have been measured from temperature logs in boreholes (about 150–250 m) and thermal conductivity measurements have been realized from many samples collected around the boreholes according to lithology. YEMEN (1999) studied heat flows of the Aegean region of Turkey using the geothermal gradients and the thermal conductivity measurements.

ERICKSON *et al.* (1977) show that measured heat-flow values display a stepwise increase just to the north of Crete along a N-S profile. The Aegean region is characterized by higher than average continental heat-flow values (mostly exceeding 84 mW/m^2) indicating a back-arc nature of the region similar to the western Pacific back-arc locations. This area may be interpreted as a high heat-flow zone. From three high heat-flow zones along tectonic features in the Aegean Sea, the highest heat flow occurs within and behind the Aegean volcanic arc. Seismic and volcanic activities and high heat-flow anomalies are shown in the area (FYTIKAS, 1980).

Besides these studies, magneto-telluric studies along several sections in Western Anatolia provided invaluable data concerning the variation in depth of the lithosphere-asthenosphere boundary, the Moho, and the depth to the resistive upper and conductive lower crust (CAGLAR, 1999; BAYRAK and NALBANT, 2001; GÜRER *et al.*, 2001).

4. The Method of Determination of the Curie Point Depths

Geophysicists frequently have used prism models to calculate the total magnetic field anomalies due to geological structures (BHATTACHARYYA, 1966). It is known that the bodies causing magnetic anomalies become non-magnetic above the Curie temperature of their minerals (for pure magnetite at 580 °C). Beneath this Curie temperature depth the lithosphere shows virtually non-magnetic properties. When the basal depth of the magnetic body is calculated, the Curie point depth is essentially estimated.

Analyzing statistical properties of patterns of magnetic anomalies, SPECTOR and GRANT (1970) have proven the relationship between spectrum of anomalies and the depth of a magnetic source by transforming the spatial data into frequency domain. SHUEY *et al.* (1977) implied that the method of SPECTOR and GRANT (1970) is more appropriate for regional application of magnetic anomalies. The method was introduced by SPECTOR and GRANT (1970) based on the assumption that the sources are considered to be independent collections of rectangular vertical prisms. For random magnetization, the radial average of the power spectrum of magnetization is constant. OKUBO *et al.* (1985) emphasize that the rectangular prism is a convenient geometry from which to develop the necessary theory; it is not a required geologic model. The method used here is similar to that of SPECTOR and GRANT (1970) and OKUBO *et al.* (1985).

The expectation value of the spectrum of a single rectangular prism with the average parameters for the collection is given in polar coordinates in frequency space as (OKUBO *et al.*, 1985);

$$\begin{aligned} E(r,\theta) = {} & 2\pi JA[N + i(L\cos\theta + M\sin\theta)] \\ & \times [n + i(l\cos\theta + m\sin\theta)] \\ & \times \sin c(\pi ra\cos\theta)\sin c(\pi rb\sin\theta) \\ & \times \exp[-2\pi ri(x_0\cos\theta + y_0\sin\theta)] \\ & \times [\exp(-2\pi rz_t) - \exp(-2\pi rz_b)], \end{aligned} \tag{1}$$

where $J =$ magnetization per unit volume, $A =$ average cross-sectional area of the bodies, $L, M, N =$ direction cosines of the geomagnetic field, $l, m, n =$ direction cosines of the average magnetization vector, a and $b =$ average body x- and y-dimensions, x_0 and $y_0 =$ average body x- and y-center locations, z_t and $z_b =$ average depths to the top and bottom of the bodies.

z_b is estimated in two steps as suggested by BHATTACHARYYA and LEU (1975, 1977) and OKUBO *et al.* (1985). First, find the centroid depth (z_0); and second, determine the depth to the top (z_t). Then the basal depth of a magnetic prism (z_b) is stated as the Curie point depth,

$$z_b = 2z_0 - z_t \tag{2}$$

calculated from this equation. According to OKUBO *et al.* (1985), the terms involving z_t and z_b in Equation (1) can be recast into a *hyperbolic sine* function of z_t and z_b plus a centroid term. At very long wavelengths because the *hyperbolic sine* tends to unity, a single term remains which is a function of z_0. At somewhat shorter wavelengths z_t can be obtained, because the effect of the depth to the top dominates the spectrum (TSÖKAS *et al.*, 1998).

At very long wavelengths with regard to body dimensions, a, b and z_b-z_t parameters in Equation (1) may be approximated by their leading terms, which reduced to

$$\begin{aligned} E(r,\theta) = 4\pi^2 VJr&[N + i(L\cos\theta + M\sin\theta)] \\ &\times [n + i(l\cos\theta + m\sin\theta)] \\ &\times \exp[-2\pi ri(x_0\cos\theta + y_0\sin\theta)] \\ &\times \exp(-2\pi rz_0), \end{aligned} \tag{3}$$

where V is the average body volume. Equation (3) indicates the spectrum of a dipole. To estimate z_0 from Equation (3), OKUBO *et al.* (1985) defined $G(r,\theta)$ as

$$G(r,\theta) = \frac{1}{r}E(r,\theta) \tag{4}$$

and following SPECTOR and GRANT (1970), SHUEY *et al.* (1977), and OKUBO *et al.* (1985), $G(r,\theta)$ is integrated in the frequency domain,

$$H^2(r) = \frac{1}{2\pi}\int_{-\pi}^{\pi} |G(r,\theta)|^2 d\theta. \tag{5}$$

Then $H(r)$ has the form

$$H(r) = A\exp(-2\pi rz_0) \tag{6}$$

hence,

$$\ln H(r) = \ln A - 2\pi rz_0. \tag{7}$$

Here A is a constant and z_0 can be estimated by least-squares fitting to $\ln H(r)$.

As for the estimation of z_t, OKUBO *et al.* (1985) assume that for somewhat smaller wavelengths than those ranged for estimation of z_0; after some approximations hold, the spectrum reduces to the form

$$
\begin{aligned}
E(r,\theta) = {} & 2\pi JA[N + i(L\cos\theta + M\sin\theta)] \\
& \times [n + i(l\cos\theta + m\sin\theta)] \\
& \times \exp[-2\pi ri(x_0\cos\theta + y_0\sin\theta)] \\
& \times \exp(-2\pi rz_t).
\end{aligned} \tag{8}
$$

Equation (8) describes the spectrum of a monopole and is very similar to Equation (3).

Again, the radially averaged power spectrum

$$K^2(r) = \frac{1}{2\pi}\int_{-\pi}^{\pi} |F(r,\theta)|^2 d\theta \tag{9}$$

can be computed as

$$K(r) = B\exp(-2\pi rz_t). \tag{10}$$

Here B is a constant. z_t can be obtained by least-squares fitting to the spectrum.

Consequently, the Curie point depths are estimated in three stages as follows:

1) dividing into overlapping square subregions with dimension 90 × 90 km,
2) calculating of the radially averaged log power spectrum for each subregion using the method of the above mentioned,
3) estimating of the Curie point depth from the centroid and the top depth estimated from the magnetic source for each subregion.

5. The Aeromagnetic Data

The General Directorate of Mineral Research and Exploration of Turkey (MTA) conducted in aeromagnetic surveying over all of Turkey spanning the period of 1978–1989. Aeromagnetic data were collected along flight lines spaced at 1–3 km profile intervals at an elevation of 600 m above ground level. The direction flight was perpendicular to the regional strike of Taurides (generally N-S) (AYDIN and KARAT, 1995; ATES *et al.*, 1999). The aeromagnetic data uncorrected for the International Geomagnetic Reference Field (IGRF), were provided by the MTA. Then the IGRF for the 1982.5 was removed from the anomalies using a program of MALIN and BARRACLOUGH (1981). Subsequently, the data were interpolated to a square grid with spacing 2.5 km. Figure 2 shows the total field anomaly of Western Anatolia. The aeromagnetic anomaly map has subdued magnetic anomalies, where sources are either weakly magnetic or at considerable depth.

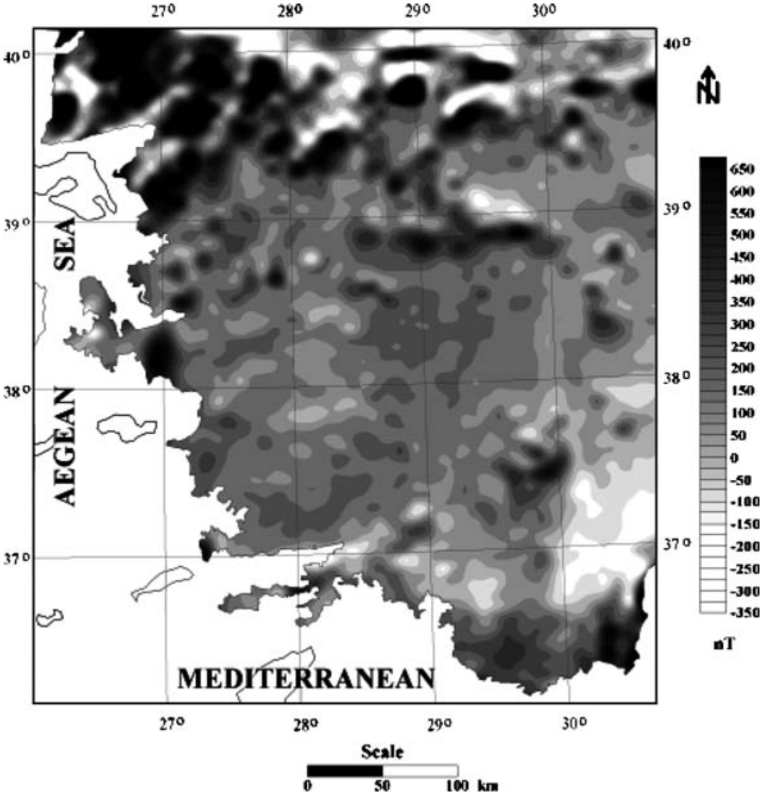

Figure 2
The aeromagnetic map of the total magnetic field of Western Anatolia of Turkey.

6. Power Spectrum Analysis and Curie Point Depth Estimates

A further investigation was carried out on the aeromagnetic anomalies to determine the possibility of Curie point depths by spectral analysis. Initially the anomaly data were reduced to the (north) magnetic pole, utilizing the FFTFIL program (HILDENBRAND, 1983). The reduced to pole aeromagnetic anomaly map is shown in Figure 3. The azimuthally averaged log power spectrum of the reduced to pole data was then computed. Figure 4a shows the azimuthally averaged log power spectrum versus wavenumber. The reduced to pole data contain both long wavelength and small wavelength anomalies. Major long wavelength components arising from topography, regional features and magnetic core fields could affect the centroid depth estimates (OKUBO *et al.*, 1985; TSÖKAS *et al.*, 1998; STAMPOLIDIS and TSÖKAS, 2002). The Curie point depth estimation requires the deepest magnetic sources. To emphasize the broad features, the small wavelength anomalies must be

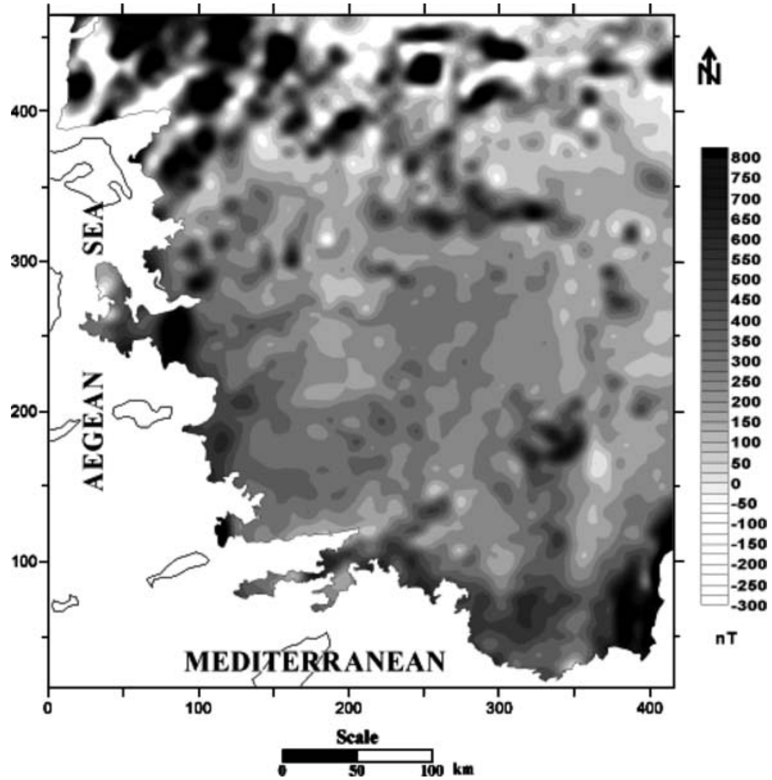

Figure 3
The reduced to pole aeromagnetic map of Western Anatolia of Turkey.

removed from the anomalies. For these purposes, a simple band-pass filter (full pass 10–65 km) (Fig. 4b) was designed from the appearance of the spectrum and applied to the data using FFTFIL again (HILDENBRAND, 1983). Its amplitude response function is shown in Figure 4b. The filtered map (Fig. 5) was used for the Curie point depth estimation.

Because of the limited depth extent of the crustal magnetization, magnetic anomalies at the Earth's surface are damped at long wavelengths and lengths of magnetic maps covering must not exceed 100 × 100 km (MAUS *et al.*, 1997). The filtered map of the study area was divided into 53 overlapping blocks, 90 × 90 km in size (Fig. 5) following OKUBO *et al.* (1985), TSÖKAS *et al.* (1998) and STAMPOLIDIS and TSÖKAS (2002). Each block overlapped the adjacent block by 50%.

Figure 6 shows examples of the power spectrum of magnetic anomaly data of a number of 6 block (Fig. 5). The depth to the centroid (z_0) of the deepest magnetic source is obtained from the slope of the longest wavelength part of the spectrum divided by the radial frequency. Thereafter, the depth to the top bound (z_t) of that

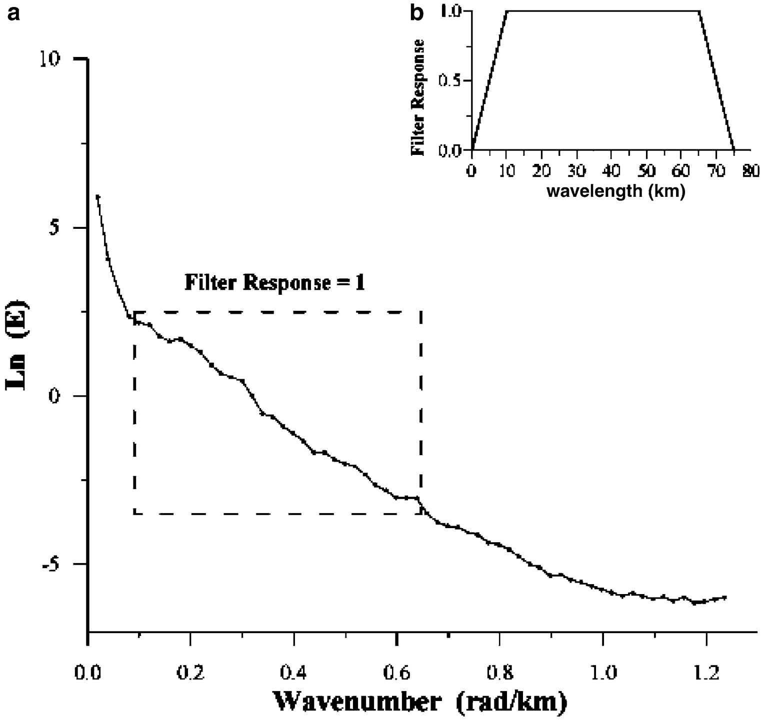

Figure 4
a. Azimuthally averaged log power spectrum of the reduced to pole data. The box represents the band-pass filter amplitude response. **b.** The response function of the band-pass filter.

distribution is estimated from the slope of the second longest wavelength spectral segment. From the centroid depth of 7.75 km and the depth to the top of 3.8, the Curie point depth is calculated as 11.7 km for this block by means of Equation (2).

In order to test the depths estimated from the analysis, the Curie depth estimations were compared with the tectonic setting (Fig. 1) and temperature data inferred from temperature logs in boreholes. The shallow Curie point depths of about 11 km obtained from blocks numbered 37, 38, 42 are compatible with the tectonic setting. From the tectonic setting, this area lies on the continuation of the trend of the Aegean arc/backarc system to the west and is characterized by a seismically active, complex cross-cutting horstgraben system and recent volcanism. For blocks numbered 23, 24, 25, 26, 30, 31, 36, 37, 38, 42 in Figure 5, a depth range of 8.2–12.4 km was obtained from the filtered data. The reduced pole data of these blocks produced a range of depth. However, the corresponding mean temperature gradients are calculated as about 5.0–7.0 °C/100 m (see Table 1) from the estimated Curie point depths. These values of temperature gradient are in good agreement with the gradient of 6.5 °C/100 m extracted from the temperature logs in boreholes (YEMEN,

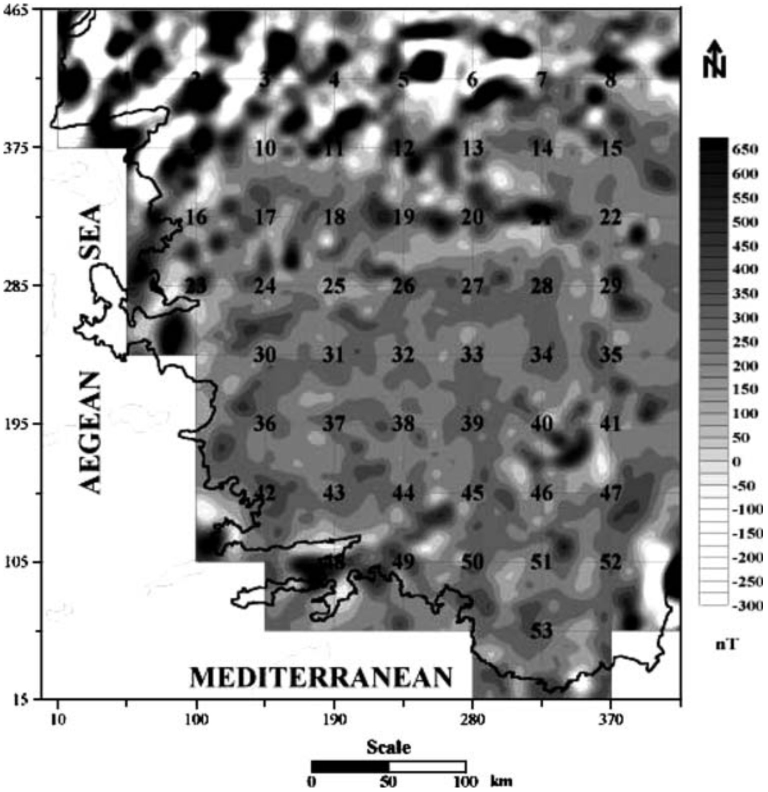

Figure 5
The band-pass (full pass 10–65 km) filtered map of the reduced pole aeromagnetic data. The map was divided into 53 overlapping blocks (90 × 90 km). Each block is denoted by a number at its center.

1999). These confirmations will be discussed in the section on Discussion and Conclusion. Figure 7 involves the Curie point depth map constituted from calculated values for each block from the spectral analysis. The fifty-three estimates inferred a range from 8.2 and 19.9 km.

7. *Discussion*

The Curie point depth map (Fig. 7) displays the presence of an east-west trending thermal anomaly in Western Anatolia. Outside the anomaly, the Curie point depth is ca. 16-km deep in the NW beneath the Sakarya Zone and slightly deeper in the SE (ca. 19 km) beneath the Tauride Mountains. The shallowest CPD is found to be 8.2-km deep within the thermal anomaly. Average thickness of the crust in Western Anatolia

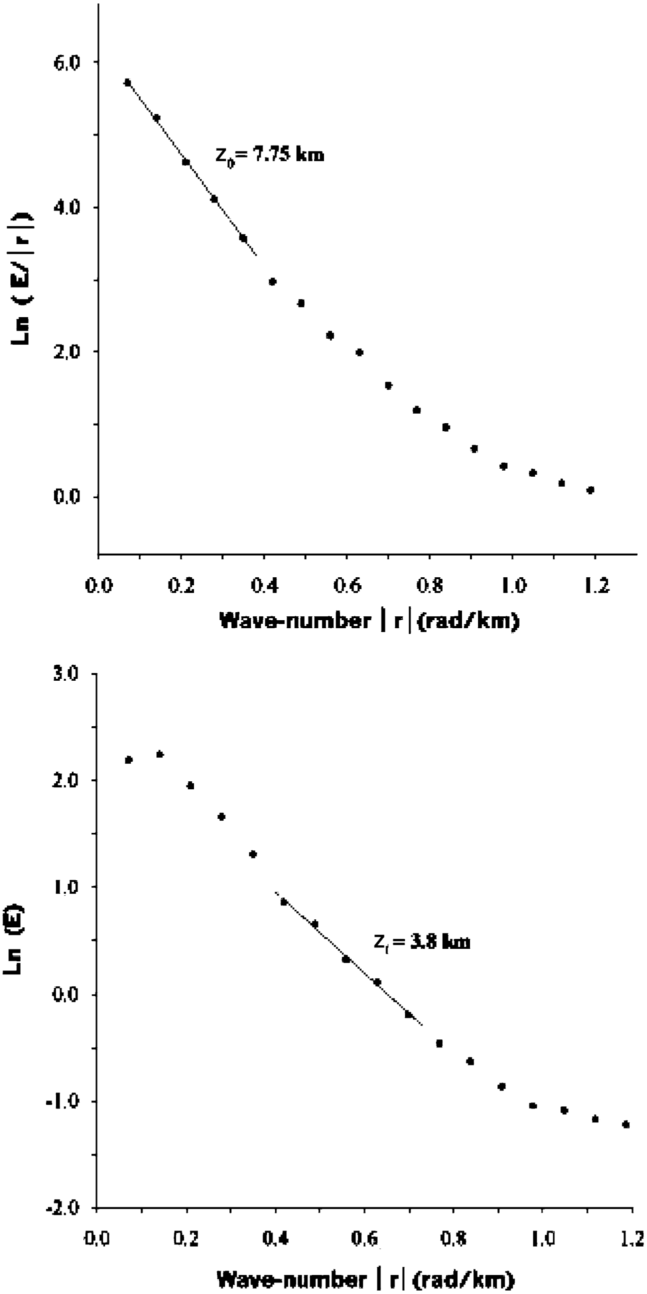

Figure 6

Examples of power spectrum for the estimation of the Curie point depth using the two-dimensional magnetic anomaly data of a number of 6 block. 7.75 and 3.8 km are obtained as the centroid and the top bound using the gradient of spectra defined as $\ln((E)/|r|)$ and $\ln(E)$, where $|r|$ is the wavenumber and E is the power spectrum.

Table 1

Curie point depths, thermal gradients and corresponding heat-flow values for selected blocks of the aeromagnetic map analyzed (Fig. 5)

Block No.	Curie point depth (km)	Thermal gradient (° C/km)	Corresponding heat flow (mWm^2)
1	13.9	41.73	89
12	13.2	43.94	93
13	11.7	49.57	105
21	12.5	46.40	99
23	8.9	65.17	139
25	8.2	70.73	150
28	9.9	58.59	125
29	9.3	62.37	133
33	11.6	50.00	106
38	11.1	52.25	111
45	16.8	34.52	73
47	19.9	29.15	62
53	16.9	34.32	73

has been estimated to be about 30 km (LE PICHON and ANGELIER, 1981; MAKRIS, 1985; AKCIG, 1988; HISARLI and ORBAY, 2000). Our estimates fall within the crust.

The West Anatolian extensional province is characterized by a high heat flow, which is 60% higher than the world average, and by the hottest geothermal fluids in Turkey (ILKISIK, 1995). The highest heat-flow values were obtained from the east-west trending Gediz and Büyük Menderes grabens in the area (ILKISIK, 1995). Therefore, we have correlated the estimated Curie point depths with geothermal gradient values and thermal conductivity measurements (YEMEN, 1999) and heat flow data (TEZCAN and TURGAY, 1989; ILKISIK, 1995). We assume that rocks are dominated by magnetite which has the Curie temperature of 580 °C. We used a mean thermal conductivity of 2.127 W/m °C which is calculated from the data of D1,..., D11 sites (Fig. 8) which range from 1.17 and 3.05 W/m °C (extracted from YEMEN, 1999). From these values, we calculated the corresponding thermal gradients (grad T = 580 °C/Curie point depth) and heat-flow data ($q = k$.grad T; here q is heat flow and k thermal conductivity). Table 1 shows Curie point depths, thermal gradients and corresponding heat-flow values for selected blocks of the aeromagnetic map analyzed (Fig. 5). From using the values, we also constructed the corresponding heat-flow map of the area (Fig. 8).

A NW-SE trending cross section is produced from the CPD map to show variation in depth of the 580°C isotherm across the region and to compare the thermal structure of the crust with the topography and geological data of the region (Fig. 9).

The cross section clearly reveals the presence of two maxima within the thermal anomaly. The first maximum is 8.2-km deep and is located in the north, under the Gediz Graben. The second one to the south is ca. 3-km deeper, forming a plateau at a

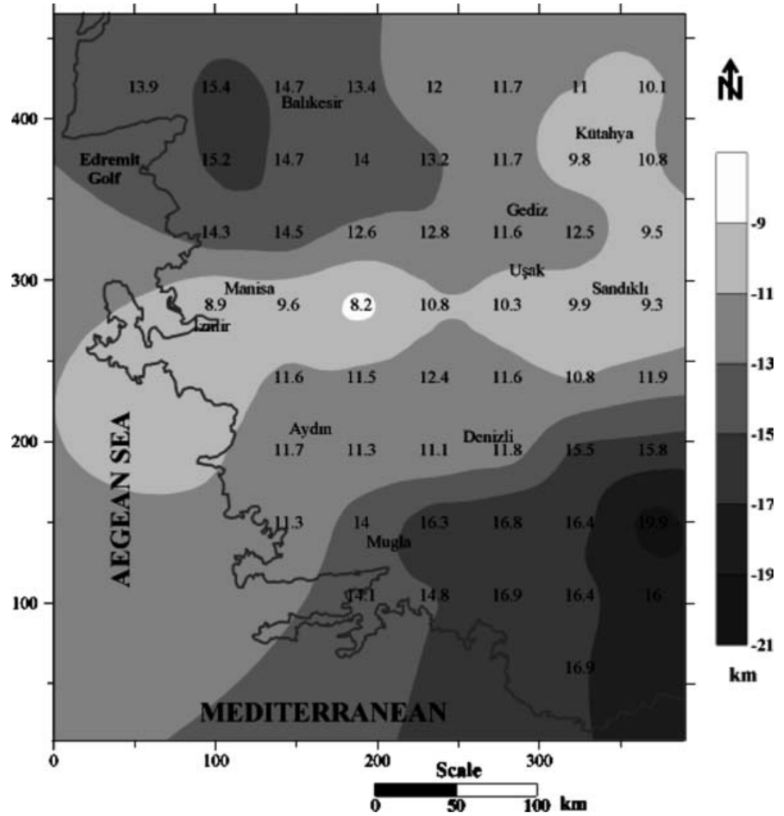

Figure 7
Curie Point Depth map for Western Anatolia. Calculated values for each block are also posted on the map (Fig. 5).

depth of 11 km and is located under the Büyük Menderes Graben (Fig. 9). The Bozdag Horst with its highest elevation across the Western Anatolian extensional province is located over the center of the thermal anomaly. The boundaries of the thermal anomaly coincide with the boundaries of the Menderes Massif core complex.

From inversion of the magnetotelluric (MT) profile data of NW-SE direction in Western Anatolia, under the Izmir-Ankara Suture Zone (IASZ), a very high resistive (> 2000 ohm m) upper crust is observed at a depth of 30–35 km while the lower crust is thinner (BAYRAK and NALBANT, 2001). Our deep Curie point depth estimates between 13.5 and 15.5 km (low heat flows) (block numbered 2, 3, 10, 11 in Fig. 5) are in good agreement with the high resistive zone. This area may be affected by the cooling effect of the resistive layer.

The southern part of the study area is characterized by a deep Curie point depth about 16–19 km (low heat flow) anomalies. This area lies on the Hellenic Trench axes. This condition is consistent with TSÖKAS *et al.* (1998) and also suits the analogy

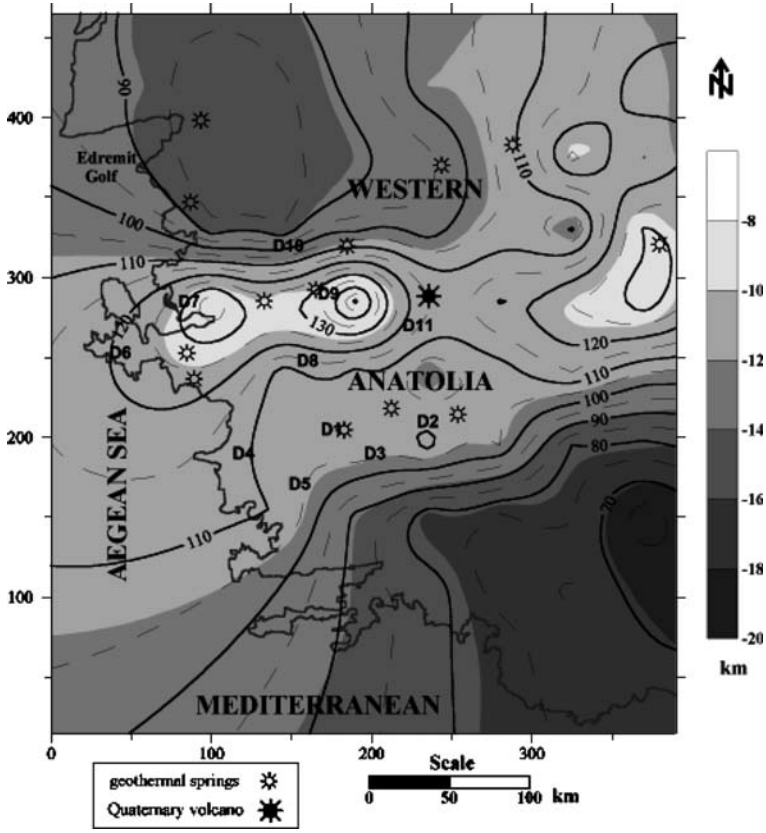

Figure 8
Inferred heat-flow contours from Curie point depths. Curie point depths are also shown in gray scale. D1...D11 show sites for geothermal gradient and thermal conductivity measurements (YEMEN, 1999). Geothermal springs and volcanic centers are illustrated also.

with other subduction areas characterized by a low heat-flow values (OXBURGH and TURCOTTE, 1971; TANAKA *et al.*, 1999).

The shallow Curie point depths of 8–11.5 km (high heat flows) on the central part of the study area (blocks numbered 23, 24, 25, 26, 30, 31) are approximately correlated with the geothermal springs (Fig. 8) except a few. Sediments deposited in the grabens are represented by low resistive and high conductive values in Western Anatolia. The top bound of the conductive lower crust is rather shallow (about 8–12 km) in this area (BAYRAK and NALBANT, 2001). The resistivity model of northeast Japan by MT data sets shows conductive zones under the geothermal field, where the Curie point depths are shallow (OGAWA, 1992).

We propose that an asthenospheric upwelling in response to lithospheric extension has created the present thermal anomaly in Western Anatolia. If we take the CPD of 18 km for a background figure in the region, the rise of the asthenosphere

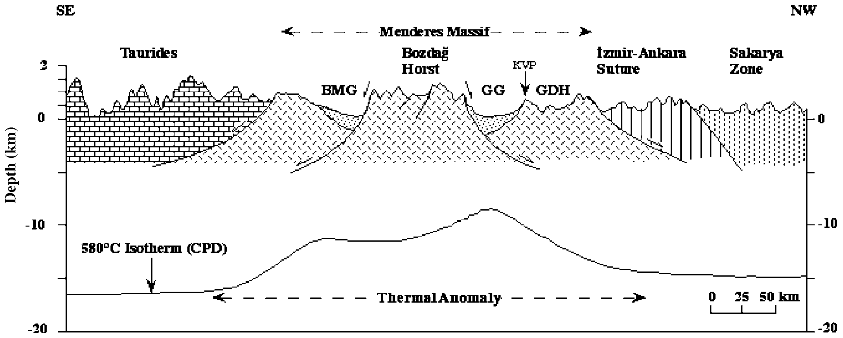

Figure 9
NW-SE cross section of the study area showing the variation of the Curie point depth and structure across the region. Note that only major high angle faults are shown. See text for explanation. Abbreviations: BMG: Büyük Menderes Graben; GG: Gediz Graben; KVP: Kula Volcanic Province; GDH: Gördes-Demirci Horst.

due to lithospheric thinning resulted in at least 8 km shallowing upward of the CPD over a 100-km wide and more than 350-km long area. Additional heat source, however, is needed to create the 3-km shallower thermal anomaly beneath the Gediz Graben. As noted above, the Gediz Graben is characterized by high heat-flow values, corresponding high geothermal gradients and Quaternary alkaline volcanism at its northern shoulder. From the evaluation of chemical, isotropic and radiometric data of *U*, *Th*, *K* in the volcanic rocks, ERCAN *et al.* (1985) concluded that partial melting had occurred in the continental crust of Western Anatolia. Further evidence for partial melting in the area was given by GÜRER *et al.* (2001). Their MT modeling revealed a conductive layer at 10-km depth underneath the Gediz Graben and the Bozdag Horst. They interpreted this layer as partially melted, visco-elastic lower crust. When the estimated high thermal gradients ($>$ 60 °C/km) in the region are taken into account, the solidus of wet granite is cut at a depth of $<$ 14 km below the surface. Adiabatic upwelling of the asthenosphere in the region may also have resulted in decompression melting. We suggest that the partial melts of asthenospheric or lithospheric sources contributed to the present thermal structure of the crust in the Gediz Graben area.

The Miocene-Quaternary sedimentary fill of the Gediz Graben is ca. 2.5-km thick. The lowermost unit comprises organic matter rich lake sediments, mainly shales and carbonates. Recently, the Turkish Petroleum Company exploited petroleum from the basin near the Alasehir Town. The high heat flows are thought to be responsible for the early maturation of the organic matter and generation of petroleum in the basin.

This study has shown that the 580° C isotherm (CPD) may rise to shallow depths during a crustal extension event that accommodates exhumation of deeply buried metamorphic massifs. 580° C is above the closure temperatures of several minerals, such as muscovite, biotite and amphibole in metamorphic rocks. These minerals will radiogenically be reset at shallow depths during an extensional event and will yield only the age of extension. Therefore care should be taken when interpreting the K/Ar, Rb/Sr and Ar/Ar ages on micas and amphiboles if the metamorphics in consideration underwent crustal extension in their later history.

8. Conclusion

The map of the Curie point depth of Western Anatolia is prepared from spectral analysis of the aeromagnetic data. The estimated Curie point depths range from 8.2 to 19.9 km. The corresponding heat-flow map constructed from the Curie point depths is almost compatible with the known heat-flow values and temperature gradient measurements and also presents new findings. Generally the new heat-flow values and geothermal gradients are significantly higher than the world average.

Variation of the Curie Point Depths across the region defines a thermal anomaly 100-km wide and 350-km long. This thermal anomaly is interpreted as a result of asthenospheric upwelling in response to lithospheric extension in Western Anatolia. Partial melting of the lower crust is also thought to have contributed to present thermal structure of the crust.

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