JOURNAL OF THE BALKAN GEOPHYSICAL SOCIETY, Vol. 5, No 1, February 2002, p. 3-8, 7 figs.

Determination of crustal density at the atmosphere-crust interface of western Anatolia by using the fractal method

Mümtaz Hisarli and Naci Orbay

University of Istanbul, Engeneering Faculty, Geophysics Department, Avcilar, 34850, Istanbul
E-mails: mhisarli@istanbul.edu.tr; norbay@istanbul.edu.tr

(Received 5 April 2001; accepted 6 June 2001)

***Abstract**: The crustal density at the crust-atmosphere interface is obtained by using gravity and topographic data of the Western Anatolia. There are scale-dependent and scale-independent components within the measured gravity data. Both components are related to topography and density, respectively. The fractal dimensions have been estimated from simple Bouguer anomalies, which were obtained from free air gravity anomalies for different densities. The minimum points of the fractal dimensions correspond to the density, which minimise the topographic effect. This density corresponds to the crustal density at atmosphere-crust interface for continental-scale gravity data sets. This value is found to be 2.58 g/cm^3 for the Western Anatolia.*

***Key Words**: Gravity, Bouguer Density, Fractal Analysis, Crustal Density*

INTRODUCTION

The fractal-derived density method is similar in many respects to the Nettleton profile method for determining densities (Nettleton, 1942). Aim of using this approach is to find the density of Bouguer correction, which minimizes the topographic effect. The density which minimizes topographic effect can be determined numerically, due to actually known topography. The inspiration for this methodology comes from Thorarinsson and Magnusson (1990). Chapmin (1996) made substantial changes in their approach. Chapmin (1996) applied this approach to gravity data of continental scale. Chapmin (1996) accepted the Bouguer correction density for South Africa as crustal density at atmosphere-crust interface.

In this study, fractal method was used to estimate the density that minimizes the topographic effect for the Western Anatolian region of Turkey. Free air gravity data (Figure1) with a resolution of 8 by 8 kilometers (Figure1) and topographic data with a resolution of 5 by 5 minutes (Figure 2) were obtained from the Mineral Research and Exploration of Turkey and from the National Data Center, respectively.

FRACTAL ANALYSIS AND DATA APLICATION

Classical geometry defines basic shapes such as points, lines and circles. Much of the universe around us can be explained and understood using those classical constructions. However, there are many objects in nature that cannot be represented with these simple shapes. For example, a mountain is not just a cone. There are smaller peaks and valleys of all sizes on the surface of the mountain that make it distinctly different from any simple shape (Matth, 1977). The shape of a mountain and other natural objects can be described through something called a fractal. Although there is a specific mathematical definition of fractals, for our purposes we can assume that a fractal is any object that exhibits self-similarity. Self-similarity means that any small part of the object always looks like a small copy of the whole object. The small peaks and valleys on the surface of a mountain, often look like small copies of the mountain itself. An enormous variety of natural objects can be represented with fractals. Landscapes, coastlines, trees, star clusters, moon craters, lava flows, clouds, temperature variations and also, most of geological events have fractal properties.

Fractal geometries are nothing more than scale-independent. Having fractal properties of a system scale invariance, fractal events can be determined by plotting the physical phenomenon versus the measurement. If the physical phenomenon is fractal, it will show as straight line over a variety of scales. The fractal dimension, D, which is determined from the slope of the straight line, represents fractal properties, and it is a measure of the complexity in a system and data.

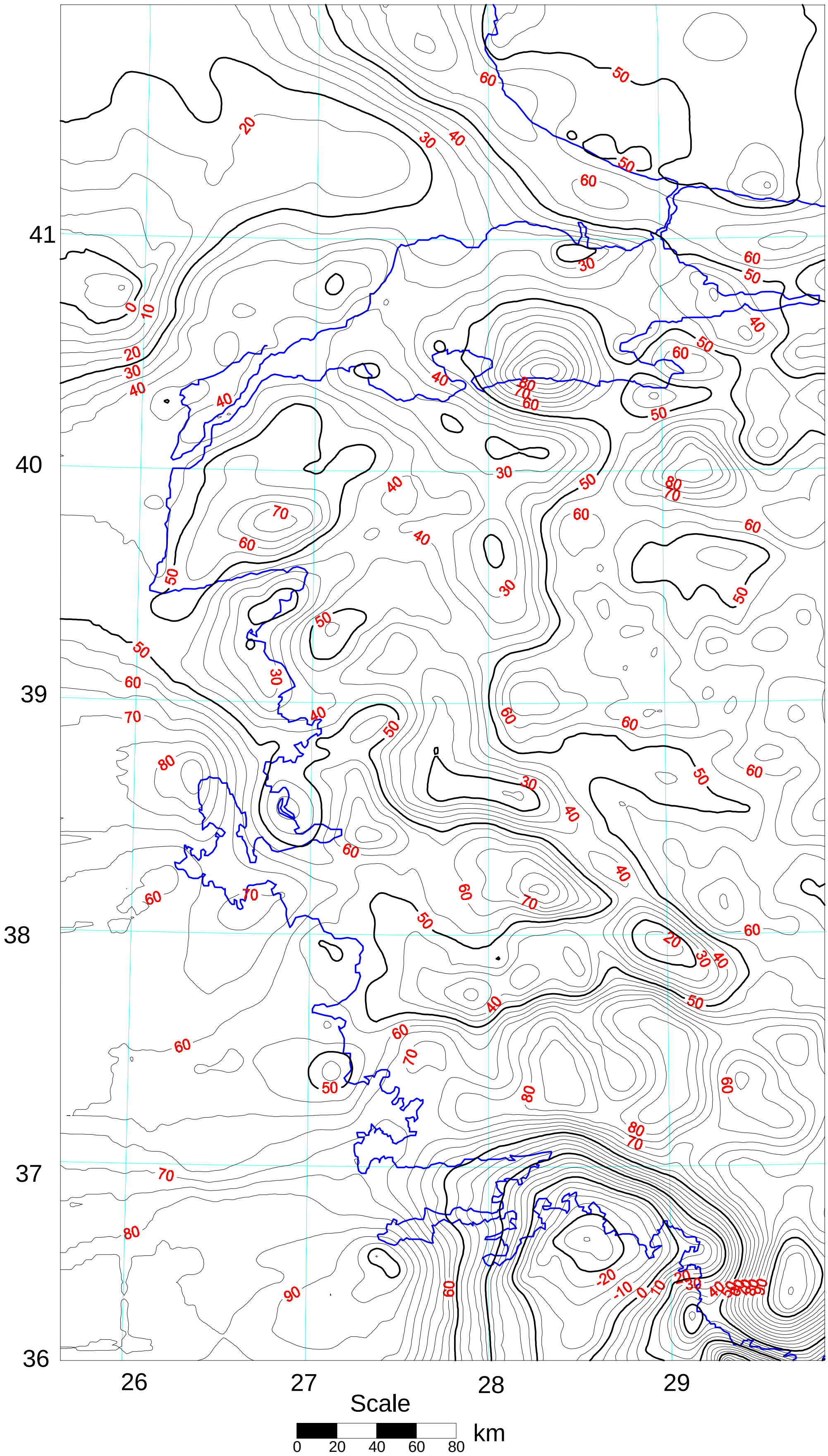

FIG. 1. Free-air gravity anomaly map of Western Anatolian obtained from MTA, resolution 8x8 km.

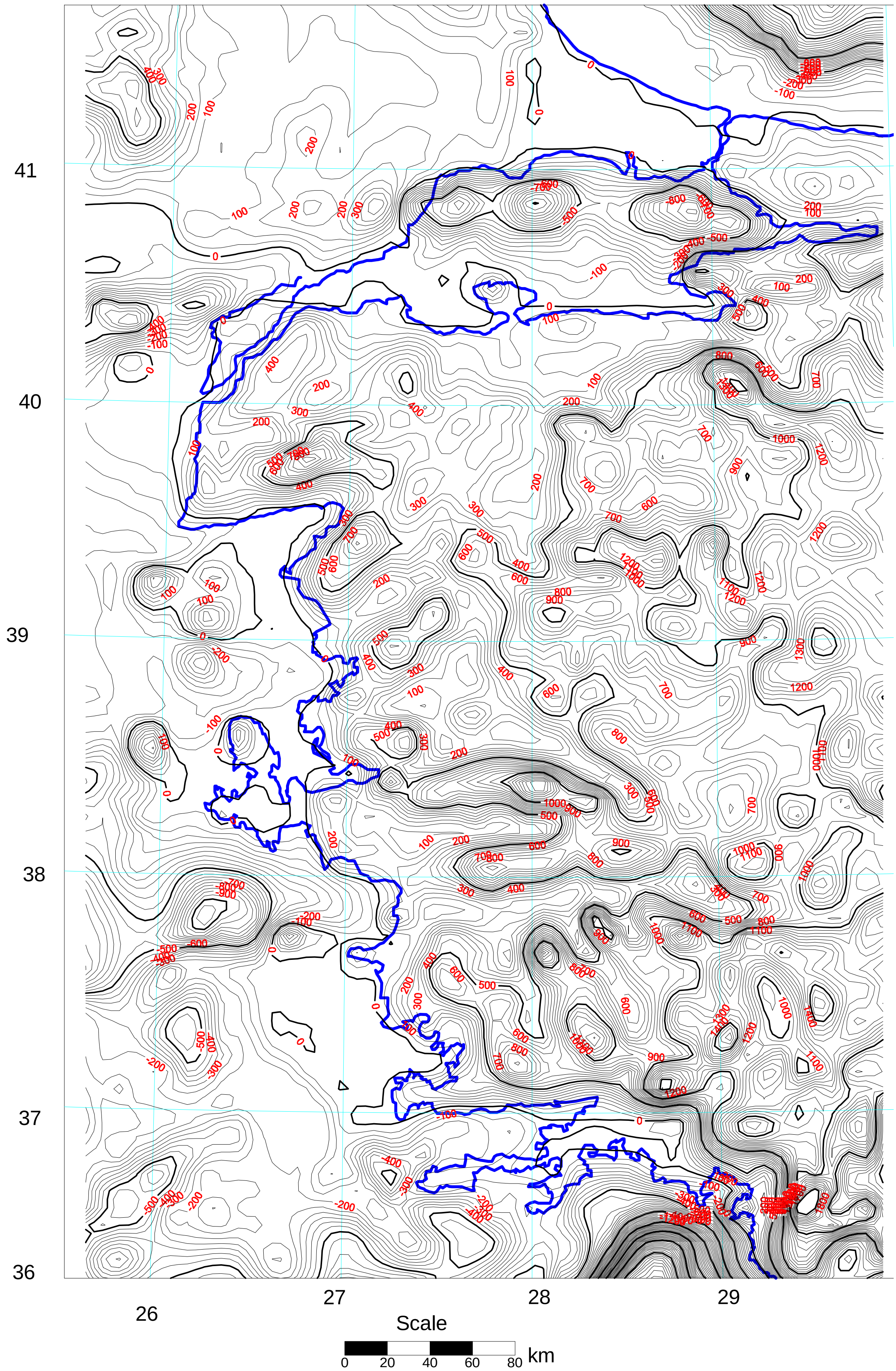

FIG. 2. Topographic data obtained from the National Data Center at resolution 5x5 minute.

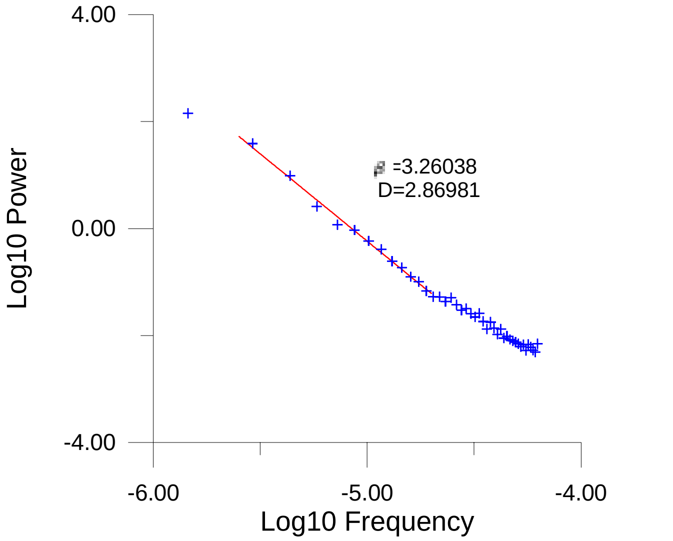

FIG. 3. Fractal power spectrum computed from simple Bouguer gravity data for 2.2 g/cm^3. b is the slope of spectrum, *D* is the fractal dimension.

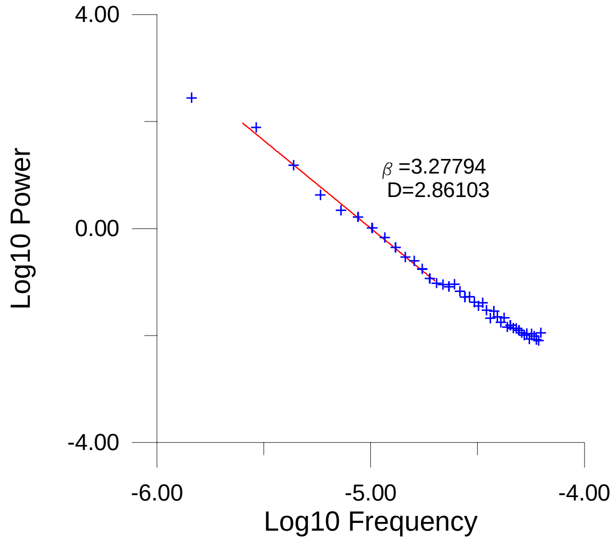

FIG. 4. Fractal power spectrum computed from simple Bouguer gravity data for 3.0 g/cm^3. b is the slope of spectrum, *D* is the fractal dimension.

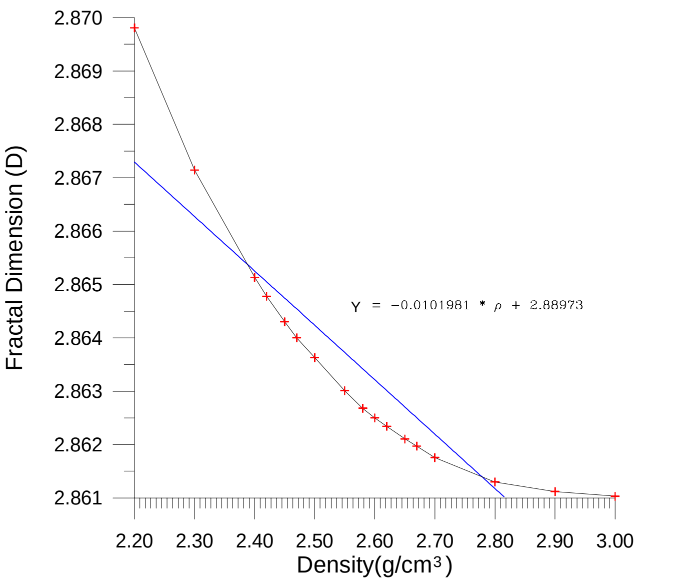

FIG. 5. Plot of fractal dimensions computed from simple Bouguer gravity anomalies for various densities versus density.

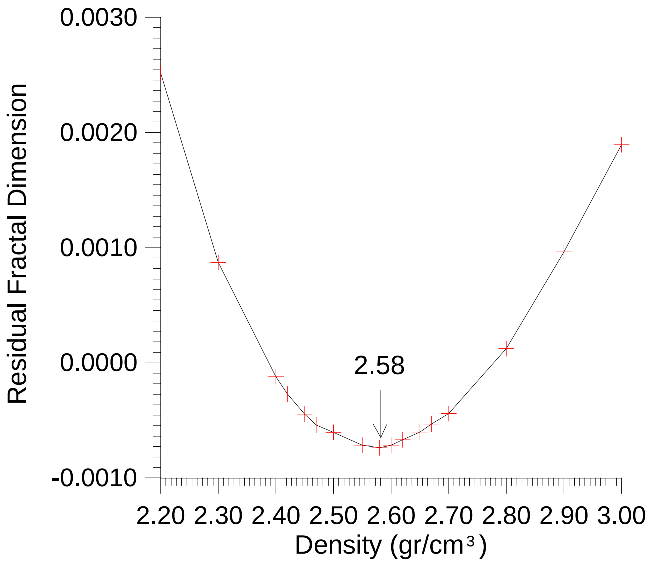

FIG. 6. Plot of residual fractal dimension versus density.

There are several methods for computing fractal dimensions. One of them is the power spectrum method (Barton et all, 1991). Fractal dimension is derived from slope, β, of the radially averaged power spectrum with log-log scale according to the following equation

$$D = (9 + \beta)/2 \tag{1}$$

Many natural phenomena are better described with a dimension part way between two whole numbers. So while a straight line has a dimension of one, a fractal curve will have dimension between one and two depending on how much space it takes up as it twists and curves (Peterson, 1984). The more that flat fractal fill a plane, the closer it approaches two dimensions. Likewise, a “hilly fractal scene” will reach a dimension somewhere between two and three. So, a fractal landscape made up of a large hill covered with tiny bumps would be close to the second dimension, while a rough surface composed of many medium sized hill would be close to the third dimension (Peterson, 1984).

Gravity data include topographic and gravity effect of geologic bodies. Since we know that topography is a fractal phenomenon (Mark and Aronson, 1984; Turcotte, 1992), fractal dimensions were used for determining how much topographic effects is contained within the gravity data. This approach is based on the concept that gravity data are a combination of scale-dependent and scale-independent components. Topography is the primary scale-independent component, while the gravity effects of the geologic distributions of density are primary scale-dependent.

Simple Bouguer gravity is given as following equation,

$$\text{Simple Bouguer Gravity} = \text{Free Air Gravity} - BC \qquad (2)$$

where *BC* is the Bouguer slab correction given by

$$BC = h(x)A\rho \qquad (3)$$

where A is the constant $2\pi G$, h is the elevation, ρ is the Bouguer density.

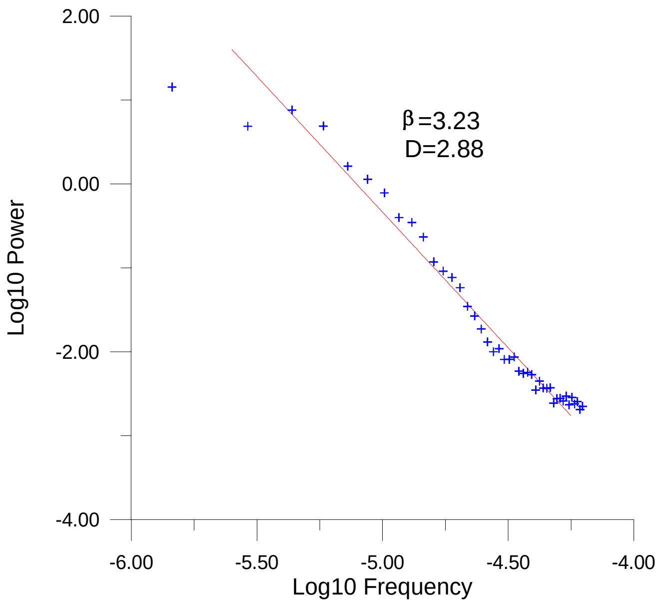

FIG. 7. Power spectrum of the free-air gravity anomalies and fractal dimension.

Simple Bouguer gravity anomalies were computed for different Bouguer densities (2.20, 2.30, 2.40, 2.42, 2.45, 2.50, 2.55, 2.58, 2.60, 2.62, 2.65, 2.67, 2.80, 2.90 and 3.00 g/cm^3) and then radially averaged power spectrum of simple Bouguer data is calculated for each Bouguer densities. The slope of the each power spectrum of the simple Bouguer gravity anomalies is used to calculate fractal dimension from Equation (1). Two power spectrums of the Bouguer gravity data are given as example in Figures 3 and 4 for example. The slopes of the power spectrums, b, and estimated fractal dimensions, D, are also seen in the same Figures and Table 1. Because topography is primary scale-independent component in gravity data, fractal dimensions of the estimated various simple Bouguer gravity anomalies are calculated as different from each other as mentioned above. In order to obtain a unique density for minimizing the topographic effect, the estimated fractal dimension versus densities are plotted in Figure 5.

Table 1. Obtained densities, slopes, fractal dimensions and residual fractal dimensions.

Density ρ	Slope β	Fractal Dimension (D)	Residual Fractal Dimension
2,20	-3,26038	2,869810	0,002516
2,30	-3,26571	2,867145	0,000871
2,40	-3,26973	2,865135	-0,000120
2,42	-3,27044	2,864780	-0,000270
2,45	-3,27140	2,864300	-0,000440
2,47	-3,27200	2,864000	-0,000540
2,50	-3,27274	2,863630	-0,000600
2,55	-3,27398	2,863010	-0,000710
2.58	-3,27464	2,862680	-0,000740
2,60	-3,27500	2,862500	-0,000710
2,62	-3,27523	2,862342	-0,000670
2,65	-3,27579	2,862105	-0,000600
2,67	-3,27605	2,861970	-0,000530
2,70	-3,27649	2,861755	-0,000440
2,80	-3,27740	2,861300	0,000125
2,90	-3,27776	2,861120	0,000964
3.00	-3,27794	2,861030	0,001894

Theoretically, the fractal dimension should decrease with increasing density as seen from Equation 3. In this equation Aρ is scale-dependent, while h is scale-independent. The scale dependent component in the simple Bouguer gravity data is going to dominate when the density ρ, increases. If the density approaches to zero, scale-independent component will be dominant. *A*ρ factor is scale-dependent, so it manifests itself as linear effect in Figure 5. Therefore, a least square regression is applied to the fractal dimension versus density to obtain the scale dependent component in the simple Bouguer gravity data. The equation of the obtained straight line after least square regression is carried out as $y = -0.0101981\rho + 2.88973$. The obtained residual fractal dimensions versus densities are plotted in Figure 6. Minimum fractal dimension corresponds to a density that minimizes the topographic effect. This density represents the best value to use for calculating the Bouguer slab correction.

DISCUSSION AND RESULTS

A least square regression was applied to fractal dimension versus density because the *A*ρ term is scale-dependent component in the Bouguer gravity data as seen in Figure 5. If we accept the density as zero in equation of the obtained straight line from Figure 5, we find a value of 2.88. This value corresponds to the fractal dimension of the free-air gravity data without making the Bouguer correction. On the other hand, the power spectrum of the free-air gravity values is given in Figure 7. The straight line is fitted from the third value of the power spectrum to eliminate the effect of isostasy. The longer wavelength is related to the isostasy in the free-air gravity data (Chapin, 1996). Fractal dimension is derived 2.88 from the slope of this straight line, as above mentioned (Figure 7). As it is seen, the fractal dimensions obtained from both ways are similar which verify the procedure.

As a result, the crustal density of the Western Anatolia is obtained as 2.58 g/cm^3 by using the fractal method. It is known that most previous workers assumed a value for density of 2.67 g/cm^3. In the Western Anatolia data set, this particular value is not seen to be valid. The 2.58 g/cm^3 value is the best density, which minimizes the gravity effect results from the topography between sea level and atmosphere-crust intersection. Therefore, this density value can be used for Bouguer reduction at the continental scale as a crustal density in the Western Anatolia.

As it is shown the obtained density value, 2.58 g/cm^3, is lower than the average density, 2.67 g/cm^3. This lower density could be related to the thermal regime of the Western Anatolia.

CONTRIBUTIONS

The authors wish to thank Prof. Dr. Demir Kolcak for his considerable improvements to be made to the manuscript. This work was supported by the Research Fund of Istanbul University, project number 1011/250897.

REFERENCES

Barton, C. C., LaPointe, P. R., and Malinverno, A., 1991. Fractal geometry and its application to the petroleum industry: Short course notes, Am. Assoc. Petr. Geol. Ann. Mtg.

Chapmin, D. A., 1996. A deterministic approach toward isostatic gravity residuals - A case study from South America: Geophysics, **61**, 1022-1033.

Mark, D. M., and Aronson, P. B., 1984. Scale-dependent fractal dimensions of topographic surfaces: An empirical investigation, with applications in geomorphology and computer mapping, Math. Geol., **16**, 671-683.

Matt, B., 1977. Fractal Pattern in Nature: http://www.stanford.edu/~mattb/fracpapr.htm.

Nettleton, L. L., 1942. Gravity and magnetic calculations: Geophysics, **7**, 293-310.

Peterson, I., 1984. Ants in Labyrinths and Other Fractal Excursions: Science News, 42-43.

Thorarinsson, F., and Magnusson, S. G., 1990. Bouguer density determination by fractal analysis: Geophysics, **55**, 932-935.

Turcotte, D. L., 1992. Fractal and Chaos in Geology and Geophysics, Cambridge University Press.