JURNAL OF BALKAN GEOPHYSICAL SOCIETY, Vol. 7, No.2, August, 2004, p. 12 - 22

Estimation of the paleopole positions from potential field anomalies of a local area in northern central Turkey

F. Bilim[1] & A. Ates[1, *]

Jeofizik Müh. Böl., Ankara Universitesi, Besevler, Ankara 06100, TURKEY

***Corresponding Author**
E-mail: ates@eng.ankara.edu.tr, Fax: 90-312-2120071

Abstract: *Gravity and aeromagnetic anomalies of a local area in northern central Turkey obtained from the General Directorate of Mineral Research and Exploration of Turkey (MTA) used to estimate the source body magnetization, which can also reveal the remanent magnetization component. Rocks collected from the outcrops suggest a mafic origin for the gravity and magnetic anomalies. Possible paleopole positions of latitude from –44.05° N to –27.48° N and longitude from 11.95° W to 23.40° W are calculated for varying induced intensity ranges. Koenigsberger ratios (Q) are calculated for inclination and declination angles of remanent magnetization for paleopole ranges to monitor the reliability of the paleopole positions. The present day geomagnetic pole position using the proposed method is estimated at approximately geographic latitude and longitude of 84.9° N and 72.8° W, respectively. This demonstrates the reliability of the existing mathematical algorithms. Calculated paleopole positions in the study area indicate that these formations are rotated about 50° in an anticlockwise direction as suggested by previous researchers in central Turkey.*

Keywords: paleopoles; potential field anomalies; northern central Turkey; Koenigsberger ratio.

1. Introduction

Calculation of paleopole positions is useful for locating the ancient geomagnetic poles. There are several ways of calculating positions of the ancient geomagnetic poles. For example; McElhinny (1973); Tarling (1983); Butler (1992). All of these methods are based on palaeomagnetic work on the samples collected from the field. Schnetzler and Taylor (1984) developed an observational method for estimation of remanent magnetization. Roest and Pilkington (1993) investigated the remanent magnetization effect in magnetic data using the analytic signal and horizontal gradient of the pseudogravity. Ates and Kearey (1995) demonstrated that the total field magnetization can be estimated by maximum correlation of aeromagnetic and gravity anomalies and thus paleomagnetic pole positions can be estimated. Bilim and Ates (1999) wrote a computer program to estimate the direction of the source body magnetization. They applied the method to a local area in northern central Turkey. Results showed that the region rotated in an anticlockwise direction as suggested by previous researchers.

In this paper, the palaeopole positions for northern central Turkey are estimated using the existing mathematical background. An anticlockwise rotation and northwards drift of the study region are demonstrated.

2. Mathematical background

In case of presence of remanent magnetization of the causative body, the direction and intensity of the total field magnetization is different from that of the Earth's field. In this case, the total magnetization vector can be separated into horizontal and vertical components as induced and remanent elements. Horizontal and vertical components of remanent magnetization can be calculated by using horizontal and vertical components of the total magnetization. The horizontal component of remanent magnetization can be given by;

$$J_{ry} = \sqrt{(J\cos\beta)^2 + (J_i\cos\alpha)^2 - 2J\cos\beta J_i\cos\alpha\cos\theta} \tag{1}$$

The vertical component of can be given by

$$J_{rd} = J\sin\beta - J_i\sin\alpha \tag{2}$$

Where;
J_{ry} = the horizontal and J_{rd} vertical component of remanent magnetization (A m^{-1}), respectively. J = total magnetization (A m^{-1}), J_i = induced magnetization (A m^{-1}), α = inclination angle of the total magnetization (degree), β = inclination angle of induced magnetization (degree), θ = angle between horizontal component of total magnetization and horizontal component of induced magnetization. Intensity of remanent magnetization can be calculated easily by means of Equations (1) and (2). Paleopole latitude and longitude can be calculated as below (Tarling 1983)

$$\lambda_p = \sin^{-1}\left(\sin\lambda_s \sin\lambda + \cos\lambda_s \cos\lambda \cos D\right)$$

and

$$\psi_p = \psi_s + \left(\sin^{-1}\left(\cos\lambda \sin D / \cos\lambda_p\right)\right)$$

Where; λ_p = paleopole latitude, ψ_p = paleopole longitude, λ_s = normal geographic latitude, ψ_s = normal geographic longitude, λ = magnetic latitude and D = declination angle of remanent magnetization.

Magnetic latitude is $\tan I = 2\tan\lambda$
λ is the magnetic latitude and I is the inclination angle of remanent magnetization.

Consequently, paleopole position can be estimated by the steps as follows:
i.) Estimation of the direction of the total magnetization, ii.) Estimation of the inclination and declination angles of the remanent magnetization, iii.) Estimation of the paleopole position.

3. Estimation of the paleopoles in northern central Turkey

In central Turkey, paleomagnetic and tectonic works were carried out by Sanver and Ponat (1981); Rotstein (1984) who suggested an anticlockwise rotation. Recently, Bilim and Ates (1999) estimated the source body magnetization direction of a body which supported the anticlockwise rotation of the region. Their method search for the maximum correlation between the pseudogravity and observed gravity anomaly data. The correlation procedure is carried out making use of the root-mean-square equation. In this paper, we further, support the anticlockwise rotation by means of estimating the magnetic paleopole positions by the aforementioned processes. We also suggest a northwards drift of the central Turkey.

Simplified geological map of an area in northern central Turkey is shown in Fig. 1.

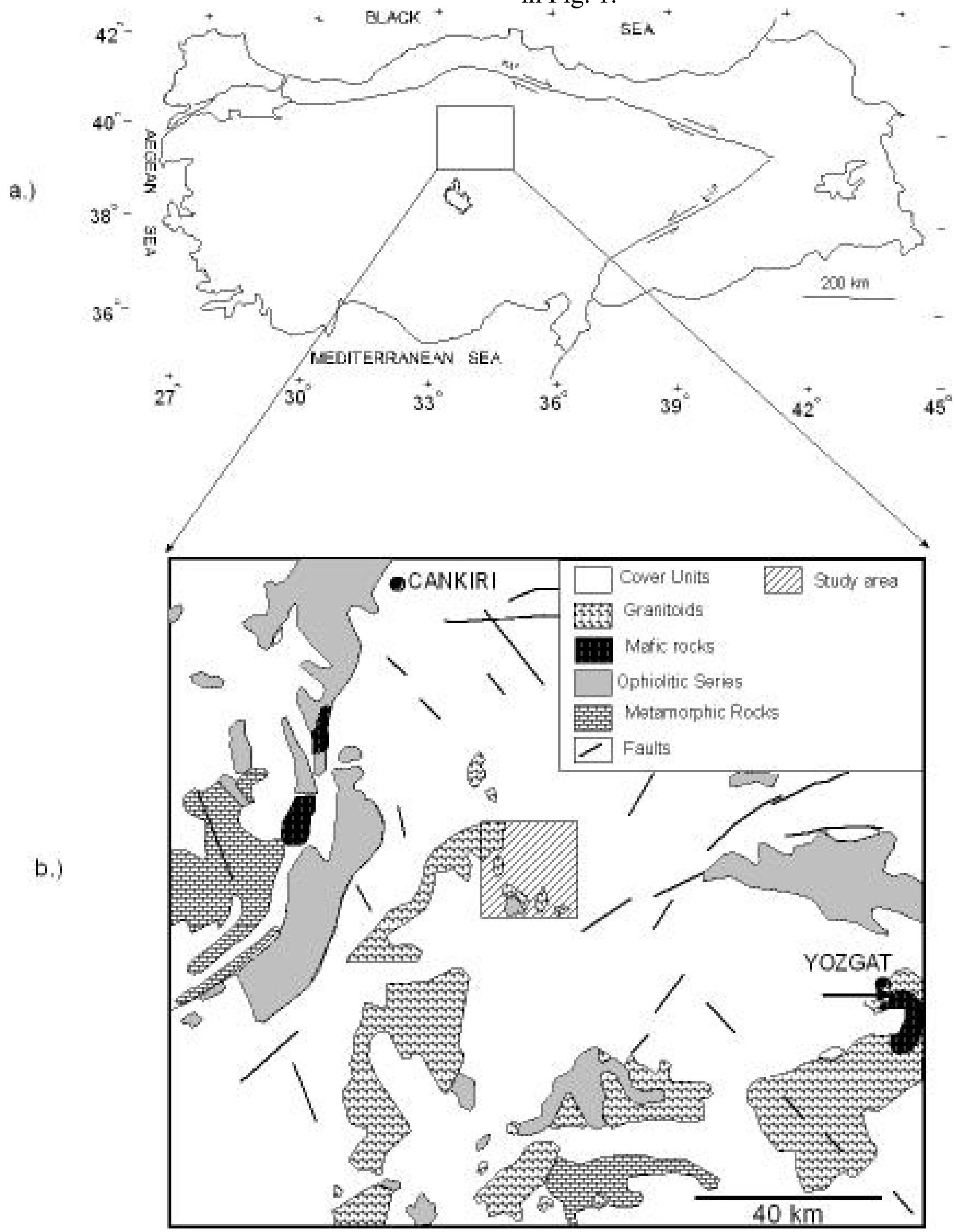

Figure 1. a) Location map. b) Simplified geological setting of the study area. Arrow shows location of the rock samples collected site.

Most of the region in Fig. 1 is covered with young sedimentary units. Granitoids, metamorphic rocks and ophiolitic series can be seen at several places. Intrusive mafic rocks outcrop at small locations in the southeast and northwest. Previous researchers have suggested that, in the region, only mafic rocks are magnetized and all other rock formations are not magnetized or have little magnetization (Kadıoğlu et al. 1998). Moreover, rocks collected from outcrops of mafic and granitoidic formations near town of Yozgat, listed in Table.1 and 2, show that gabbroic rocks give mean density of 2.88 Mg m^{-3} and maximum susceptibility of 26×10^{-3} SI. Mean density of granitoidic rocks is 2.62 Mg m^{-3} which is quite close to literature densities of the sedimentary rocks (Telford et al. 1990). In the study area, large amplitude of gravity and magnetic anomalies can be seen (Ates et al. 1999) and sources of causative bodies of the anomalies appear to be the same. Interesting gravity and aeromagnetic anomalies can be seen at a location shown by box at the center of Fig.1.

Table 1. Rock densities. Location of the sampling site is shown by an arrow in Fig.1.

Rock type	Location	No of samples	Mean density (Mg m^{-3})	Standard deviation	Range (Mg m^{-3})
Granitoids	[+]	3	2.62	0.013	2.60-2.64
Gabbro	[×]	4	2.88	0.14	2.64-2.99

Table 2. Rock susceptibilities. Location of the sampling site is shown by an arrow in Fig.1.

Rock type	Location	No of samples	Maximum susc. $\times10^{-3}$, SI	Standard deviation
Granitoids	[+]	2	1.26	0
Gabbro	[×]	2	26	0.0012

Fig. 2 and 3 show the gravity and aeromagnetic anomalies of the region shown by a box in Fig.1. The gravity (Fig.2) and aeromagnetic (Fig. 3) anomaly data were obtained in digital form with 2.5 km grid intervals from the General Directorate of the Mineral Research and Exploration Company of Turkey (MTA). The gravity data were surveyed at 1-3 km intervals. Bouguer and terrain densities of 2.4 Mg m^{-3} were used in the reduction. The aeromagnetic data were surveyed at an altitude of 600 m with 1 to 3 km profile intervals.

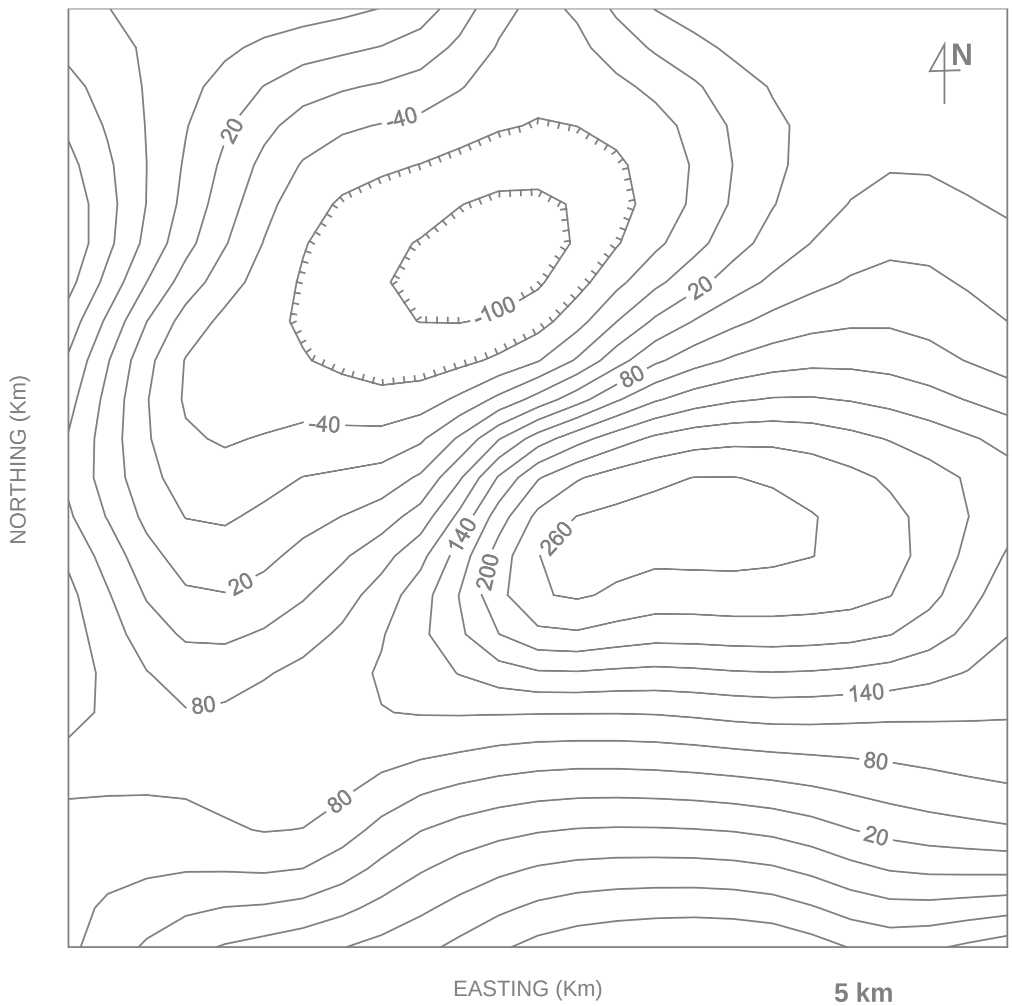

Figure 2. Aeromagnetic anomaly map of Northern Central Turkey. Flight height is 600 m above sea level. Contour interval is 30 nT.

Shape of the aeromagnetic anomaly (Fig. 3) suggests that the magnetization direction is different from that of the Earth's present field (dip=55º N, azimuth=4º E).

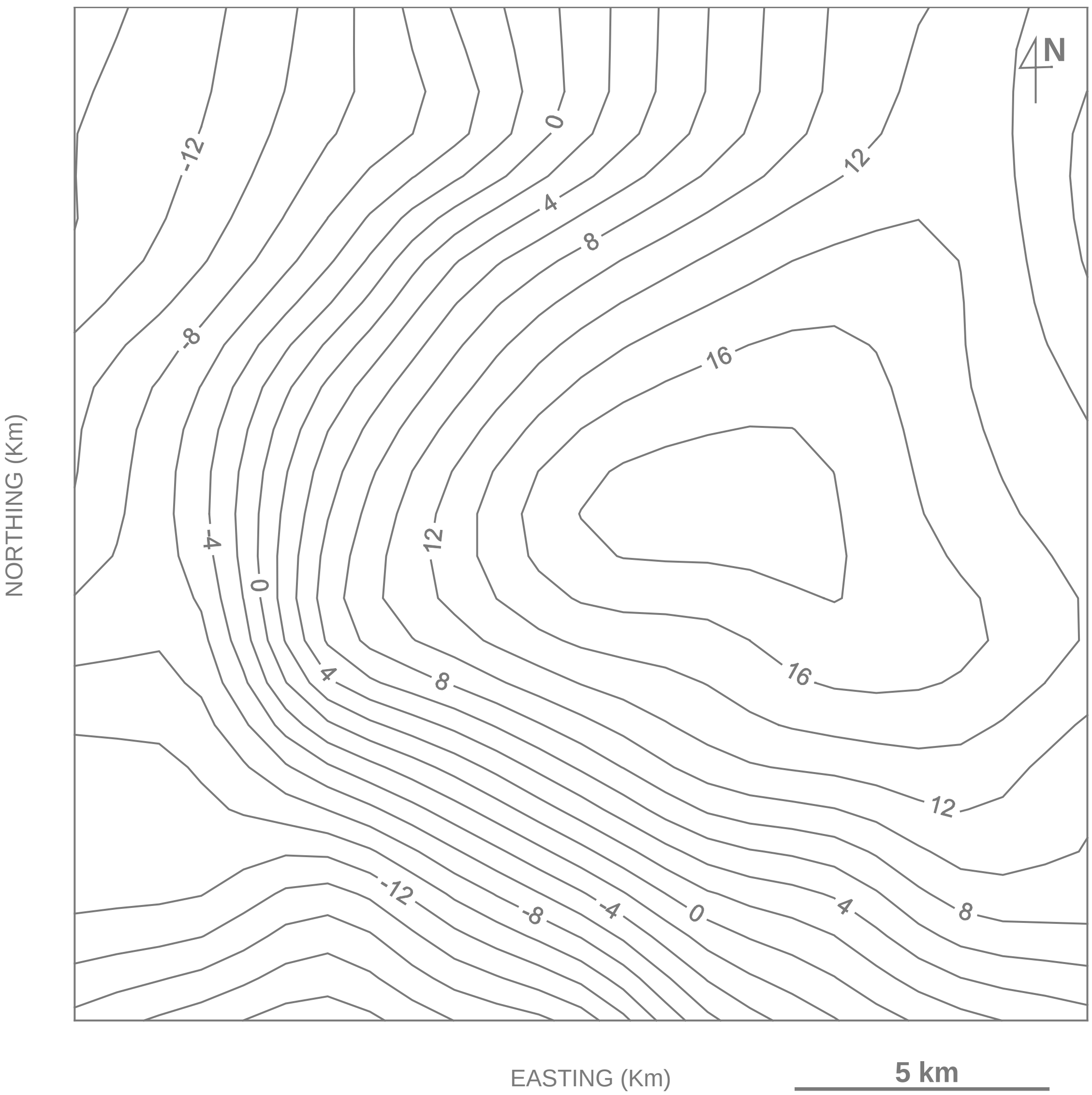

Figure 3. The gravity anomaly map of near Yozgat, Central Northern Turkey. Contour interval is 2 gu.

The total magnetization vector was determined from gravity (Fig. 2) and aeromagnetic (Fig. 3) anomalies (Bilim & Ates, 1999). Figure 4 shows the contoured plot of C_{RMS} in which the inclination and declination of the total magnetization vector (J) varies from 70º to 100º and from -90º to -5º, respectively. It can be seen from Fig. 4 that the estimated inclination and declination angles of the total field magnetization are 81º N and -53º W, respectively. The total intensity of magnetization of the source body was estimated as 0.3A m^{-1} from the amplitude difference of the maximum and minimum contours in Fig. 3. The intensity and the direction of remanent magnetization were calculated for a range of J_i (intensity of the Earth's field) varying from 0.4-0.8A m^{-1}.

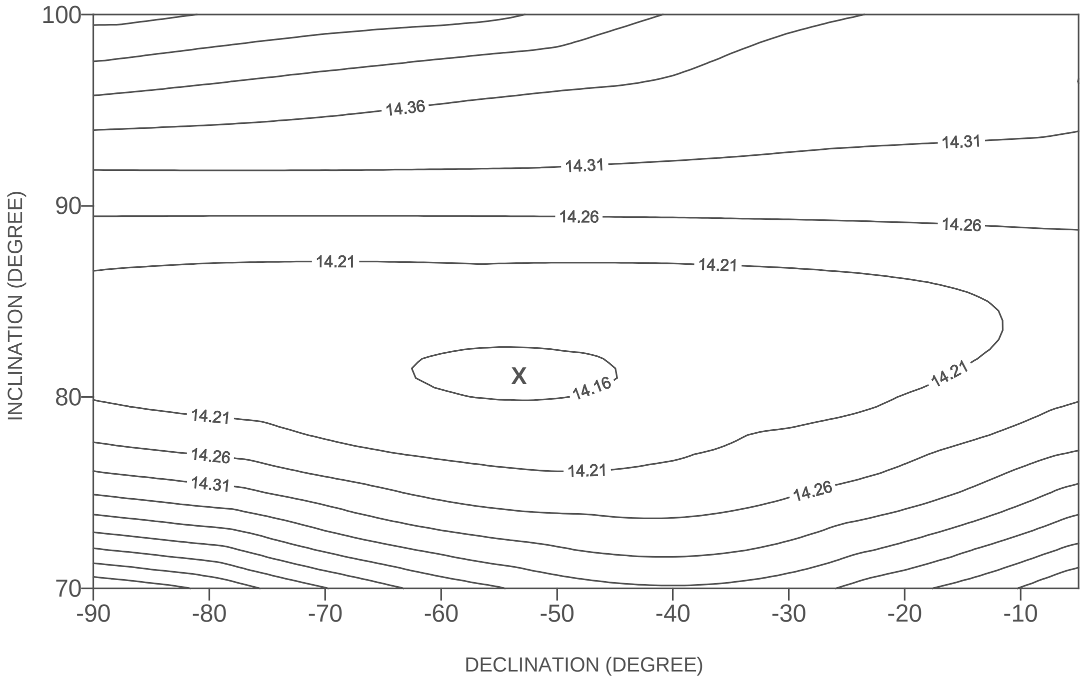

Figure 4. Contour map of RMS correlation function C_{RMS} for ranges of inclination and declination of the total magnetization vector for Figures 1 and 2. X sign shows the estimated angle of the total magnetization vector.

Using the remanent magnetization angles for J_i varying from 0.4-0.8A m^{-1} and today's geographic coordinates, differences in the latitude and longitude of paleopole were calculated (Table 3). In addition, the Koenigsberger ratio (Q) (Koenigsberger, 1938) of remanent to induced magnetization was calculated for given range of J_i (Intensity of the Earth's field) and calculated values of J_r (Intensity of the remanent magnetization). Table 3 shows the calculated paleopole positions and Q values. It can be seen from Table 3 that the location of the paleopole varies from –44.05º N to –27.48º N and from 11.95º W to 23.40º W (shown in Fig. 5 with + signs). Q values varies from 0.5 to 0.7 and are seem reasonably large and thus indicative a substantial presence of remanence.

To provide further support on the efficiency of the method, present geomagnetic pole location was calculated. The induced component of magnetization has a declination of 4º E and an inclination of 55º N in central Turkey for excluding the effect of remanent magnetization from calculations. The total component of magnetization was also taken same as the induced component of magnetization. Both the induced intensity of magnetization and total intensity of magnetization were taken 0.6 A m^{-1}.

Normal geographic latitude and normal geographic longitude of central Turkey are 39.5º N and 33º E. North geomagnetic pole latitude and longitude are about 79.1º N and 71.1º W (Blakely, 1995), respectively, which is shown in Fig. 5 with an open circle.

Table 3. Calculated paleopole positions and Koenigsberger ratio (Q), which was applied to the aeromagnetic and gravity anomalies (Fig. 2 and 3) of an area around northern central Turkey. The intensities and the directions of remanent magnetization were calculated for a range of intensity of the Earth's field (J_i) varying from 0.4-0.8Am^{-1}.

Range of intensity of induced magnetization ($A\ m^{-1}$)	**Intensity of remanent magnetization ($A\ m^{-1}$)**	**Inclination angle of remanent magnetization (degree)**	**Declination angle of remanent magnetization (degree)**	**The ratio of remanent to induced magnetization, Q**	**Magnetic paleopole latitude (degree)**	**Magnetic paleopole longitude (degree)**
0.40	0.20	8.58	195.00	0.50	-44.05	11.95 W
0.50	0.28	23.20	192.57	0.57	-37.08	17.52 W
0.60	0.37	31.30	191.05	0.62	-32.65	20.42 W
0.70	0.46	36.24	189.98	0.65	-29.64	22.20 W
0.80	0.56	39.52	189.20	0.70	-27.48	23.40 W

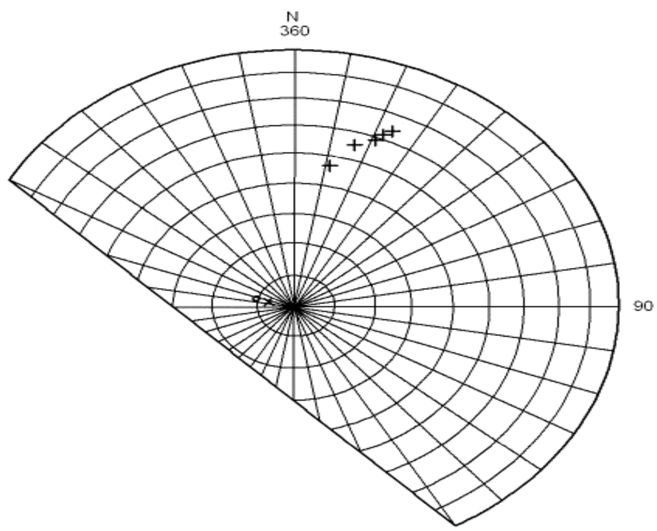

Figure 5. Location of the paleopole positions on a polar projection. Open circle shows the location of the north geomagnetic pole at located at about 79.1ºN and 71.1ºW. X sign shows the location of the calculated present geomagnetic pole position at 84.9ºN, 72.8ºW. + Signs show the location of the paleopoles varying from –44.50ºN to –26.53ºN and from 19.10ºW to 26.23ºW for latitudes and longitudes, respectively. J_i varies from 0.4-0.8Am^{-1}.

Using Equation (3) and (4), present geomagnetic pole latitude and longitude were calculated 84.9º N and 72.8º W, respectively (Table 4).

Table 4. The true (from IGRF 1990 (Blakely, 1995)) and calculated geomagnetic poles.

North Geomagnetic Pole (IGRF, 1990 (Blakely, 1995))		The Calculated Geomagnetic Pole		Relative error (%)	
Latitude (degree)	Longitude (degree)	Latitude (degree)	Longitude (degree)	Latitude	Longitude
79.1ºN	71.1ºW	84.9ºN	72.8ºW	7	2

Results of the calculated geomagnetic pole and relative error are also given in Table 4. The location of the calculated present pole position is shown in Fig. 5 with X sign. Calculated relative error in the latitude and longitude are 7 % and 2 %, respectively.

4. Conclusion

Correlation of gravity and magnetic anomalies of same source bodies can reveal the direction of the total magnetization vector. Furthermore, calculations can be extended into estimating the location of the magnetic pole position. Remanent magnetization associated with tectonic orientation can often reveal the paleopole position. Correlation of the gravity and aeromagnetic anomalies of a local area in central Turkey, where covered with non-magnetic sedimentary units, revealed paleopole positions and that the study area was rotated about 50° in an anticlockwise direction. It can also be deduced from the mean paleopole latitude that the study area was located at low latitudes of about 35° north of Equator and drifted some 45° northwards.

The declination and the inclination angles of remanent magnetization-Konigsberger ratio (Q) diagram is shown in Fig.6.

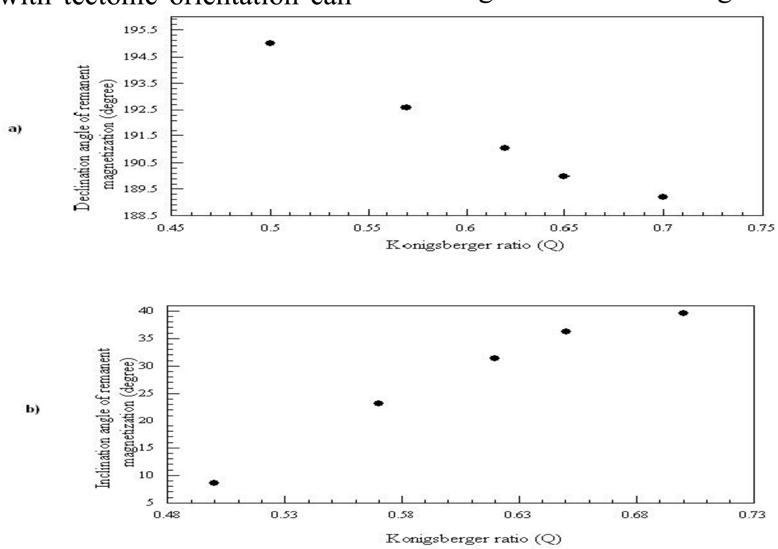

Figure 6. The declination (a) and the inclination (b) angles of remanent magnetization-Koenigsberger ratio diagram.

Koenigsberger ratios (Q) calculated for ranges of intensities of the Earth's magnetic field and remanent magnetization were indicative of considerable amount of remanent magnetization. Location of the present north geomagnetic pole calculated for central Turkey also puts emphasis on the validity of the method.

Acknowledgments

This work was financially supported by the Scientific and Technical Research Council of Turkey (TUBITAK) under grant no: YDABCAG-118. We thank Geophysical Surveying Department of MTA for the provision of gridded aeromagnetic and gravity data.

References

Ateş, A., Kearey, P. and Tufan, S., 1999. New gravity and magnetic anomaly maps of Turkey, Geophysical Journal International, Research Note, 136: 499-502.

Ates, A. and Kearey, P., 1995. A new method for determining magnetization direction from gravity and magnetic anomalies: application to the deep structure of the Worcester Graben. Journal of the Geological Society, 152: 561-566.

Bilim, F. and Ates, A., 1999. A computer program to estimate the total field magnetization direction of a body causing magnetic anomaly. Computers and Geosciences, 25: 241-250.

Blakely, R. J., 1995. Potential Theory in Gravity and Magnetic Applications. Cambridge University Press, Cambridge.

Butler, F. R., 1992. Paleomagnetizm, Blackwell Scientific Publications, Boston.

McElhinny, M. W., 1973. Palaeomagnetism and Plate Tectonics, Cambridge University Press, London.

Kadıoğlu, Y. K., Ateş, A. and Güleç N., 1998. Structural interpretation of gabbroic rocks in Ağaçören Granitoid, central Turkey, Geological Magazine, 135: 245-254.

Konigsberger, J. G., 1938. Natural Residual Magnetism of Eruptive Rocks, Terrestrial Magnetism and Atmospheric Electricity, 43: 119-130, 299-320.

Roest W. R. and Pilkington, M., 1993. Identifying remanent magnetization effects in magnetic data. Geophysics, 58: 653-659.

Rotstein, Y., 1984. Counterclockwise rotation of the Anatolian block. Tectonophysics, 108: 71-79.

Sanver, M. and Ponat, E., 1981. Kırsehir ve dolaylarına iliskin paleomanyetik bulgular. Kırsehir Masifinin rotasyonu. Istanbul Yerbilimleri, 2**:** 231-238.

Schnetzler, C. C. and Taylor, P. T., 1984. Evaluation of an observational method for estimation of remanent magnetization. Geophysics, 49: 282-290.

Tarling, D. H., 1983. Palaeomagnetism: Principles and Applications in Geology, Geophysics and Archaeology, Chapman and Hall.

Telford, W, M., Geldart, L. P. and Sheriff, R. E., 1990. Applied Geophysics (2nd ed.) Cambridge University Press.