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EDGE DETECTION FROM MAGNETIC ANOMALY MAPS USING DERIVATIVE BASED ALGORITHMS

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Abstract. In this study, it is considered to analyze the horizontal locations of the dyke structures in vertical magnetic anomaly map of Yozgat - Sarıkaya region. To this end, the Tilt Angle method and the Automatic Gain Control method, which improves the structure boundaries, were primarily applied on the synthetic model data to determine the structure boundaries. The obtained results were analyzed and then applied on the field data. The horizontal locations of the potential dyke structures were analyzed and the images of these structures were improved.

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1 Introduction

Determining the horizontal boundaries of potential effective sources subsurface during the interpretation of magnetic data is essential to obtain maximum information from magnetic anomaly maps. In order to determine the boundaries of potential sources, edge detection methods should be applied. The presence of negative factors such as geological and physical noise, multiple sources, or errors during measurement complicates the interpretation of magnetic data. Different edge detection methods, such as derivative-based methods and local phase filters, eliminate these effects. The horizontal derivative of the potential field improves the edges of potential sources. In contrast, the vertical derivative narrows the width of the anomaly, allowing the positions of the sources to be determined more accurately.

Various methods have been proposed for interpreting magnetic data, which can derive information about the horizontal locations and depths of potential subsurface structures that cause anomalies. Evjen [1] has determined the edges of geological sources by using the vertical derivative method. Verduzco and al. [2], Ma and Li [3] have proven with their studies that the maximum value of the total horizontal derivative indicates the structure boundaries more accurately. Miller and Singh [4] put forward the Tilt Angle method and compared it with other techniques. Cooper and Cowan [5] improved the Tilt Angle method and tested it with applications to detect the edges of the sources that cause the anomalies. Wijns et al. [6] developed the Theta Map method as an edge detection method. The Least Squares method [7], Euler Deconvolution method [8], Wavelet method [9], Tilt-Depth method [10] are the examples of potential field methods that are used for determination of depth values.

In this study, to determine the horizontal boundaries of the dyke structures by using the magnetic anomaly maps, programs have been prepared in the Matlab environment of the Tilt Angle Automatic Gain Control algorithms. Synthetic models are created by constructing prismatic blocks with different depth and magnetic susceptibility values with initial parameters. The applicability of algorithms was investigated on theoretical data. In the process of interpreting the noisy data, after improving the data with the upward reach method, the applicability of the methods was tested with the application of Tilt Angle and Automatic Gain Control methods. In both cases, if the inclination angle is different from the vertical, Reduction to Pole was applied to the anomaly maps created to avoid misleading results. It has been observed that the findings obtained as a result of applying the methods to the theoretically prepared data are satisfactory. These methods have been applied to the vertical magnetic data of Yozgat - Sarıkaya, and the subsurface dyke boundaries that cause anomalies have been successfully determined.

2 Reduction To Pole Method

Reduction to the pole is a step that is especially used during the application of magnetic data processing methods on large-scale maps. This process transforms the magnetic anomaly caused by an arbitrary source into an anomaly produced as if the same source were at the pole and only in an induction magnetized medium.

Although positive gravity anomalies generally tend to be located on the source, this situation may differ for magnetic anomalies when both magnetization and ambient magnetic field are not in the vertical direction. Unless $\hat{m}$ and $\hat{f}$ are vertical, θ_m and θ_f cause lateral shifts, deformities and even phase changes up to sign change in magnetic anomaly (Figure 1) [11].

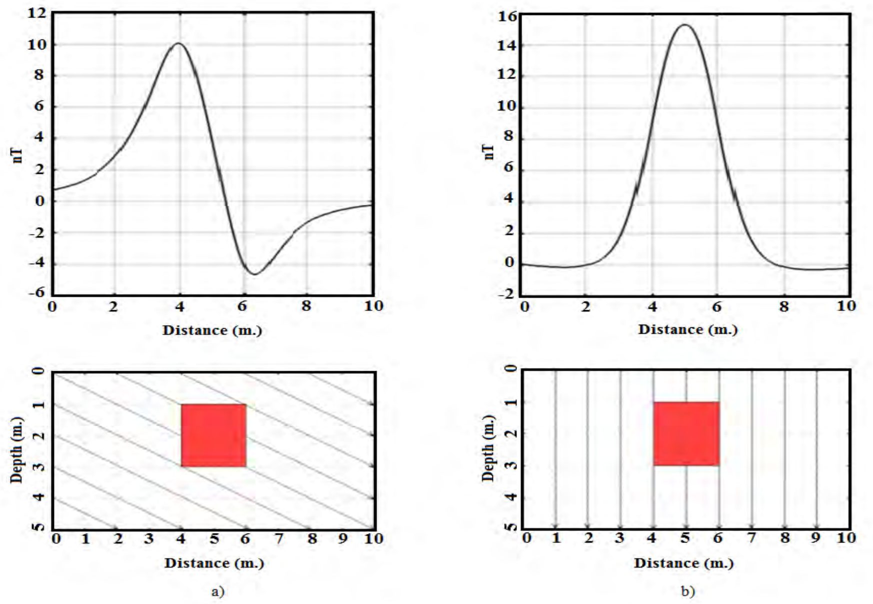


Figure 1: a) The magnetic anomaly of a vertical prismatic model with an inclination angle of 45^0, b) The magnetic anomaly obtained after the reduction of the same model to the pole [12].

Reduction to the pole eliminates the asymmetry caused by inclination by shifting the phase (assuming data is collected from the magnetic pole). Thus, centering on the source is achieved by shifting the anomaly laterally. The expression of the Reduction to Pole can be given as [11],

$$F\left[\psi_r\right] = \frac{1}{\theta_m \theta_f} = \frac{|k|^2}{a_1 k_x^2 + a_2 k_y^2 + a_3 k_x k_y + i\,|k|\left(b_1 k_x + b_2 k_y\right)}\ , \quad |k| \neq 0 \tag{1}$$

The $F\left[\psi_r\right]$ process is called Reduction to Pole due to the transformation of the ΔT_r anomaly into a measurement made at the north magnetic pole where the magnetization and geomagnetic field are vertical [13].

3 Upward Continuation Method

The results obtained in the upward continuation method are displayed as if they were measured on a surface further away from the measurement surface. This conversion tends to attenuate anomalies depending on the wavelength. There is an inverse relationship between attenuation and wavelength. Thus, this process reduces the calculated data.

The Upward analytical Continuation increases the anomalies caused by deep sources and can be evaluated according to the following equation [11];

$$F\left[\psi_u\right] = -\frac{1}{2\pi}\frac{\partial}{\partial \Delta z}\, F\left[\frac{1}{r}\right] \;=\; -\frac{\partial}{\partial \Delta z}\frac{e^{-|k|\Delta z}}{|k|} \;= e^{-\Delta z|k|}, \qquad \Delta z > 0 \tag{2}$$

4 Tilt Angle Method

The tilt angle method is one of the classical local phase filters that enable detecting potential effective sources in potential field data by improving their edges. The basis of this method, which was first developed by Miller and Singh [4], is the ratio of the vertical derivative to the absolute amplitude of the total horizontal derivative (Figure 2), and can be denoted as (Eq.3),

$$T = \tan^{-1}\frac{\partial M/\partial z}{\sqrt{\left(\partial M/\partial x\right)^2 + \left(\partial M/\partial y\right)^2}} \tag{3}$$

In Equation 3, M represents the magnetic field value, and T is the Tilt Angle value.

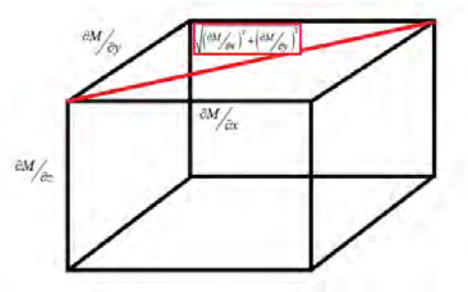


Figure 2: Schematic representation of the components on Tilt Angle method.

The Tilt Angle values can change in the range of -90 to 90 degrees. Tilt angle takes a positive value on the source of the effective source. This value becomes zero when it is just above the source edges (in the region where the vertical derivative is zero).

5 Automatic Gain Control Method (AGC)

Automatic Gain Control is a data enhancement method that balances the amplitudes of anomalies by separating the dominant wavelengths. The parameters governing this method are; the size of the sliding window from which the gain is calculated and the gain function that controls the relative amplification in the signal and noise. A standard gain function is assumed to be the inverse of the square root value in the sliding window.

For anomalies of varying wavelength (spatial frequency), choosing the window size provides preliminary information about the values between which the output data is improved. Test applications should be performed with various gain functions and window sizes to obtain the optimal result. AGC can be applied to profile and grid data [14].

6 Synthetic Model Applications

For the purpose of testing the applicability of the programs of the Tilt Angle and Automatic Gain Control algorithms prepared in the Matlab environment, two models (noisy and without noise) whose initial parameters are shown in Table 1 were created. Anomaly maps were created with the data obtained in case of different inclination angles (60^o and 90^o) (Figures 3-4). The magnetic field strength was taken as 45000 nT.

Table 1: Synthetic model parameters.

Block No	Y Axis		X Axis		Depth Values		Magnetic
	Y1(m)	Y2(m)	X1(m)	X2(m)	H1(m)	H2(m)	Susceptibiliy (SI)
1	6	8	4	6	0.7	1.5	0.020
2	3	5	3	7	0.5	1.5	0.020
3	1	2	1	8	0.5	2.0	0.010
4	2	8	8	9	0.75	2.5	0.015

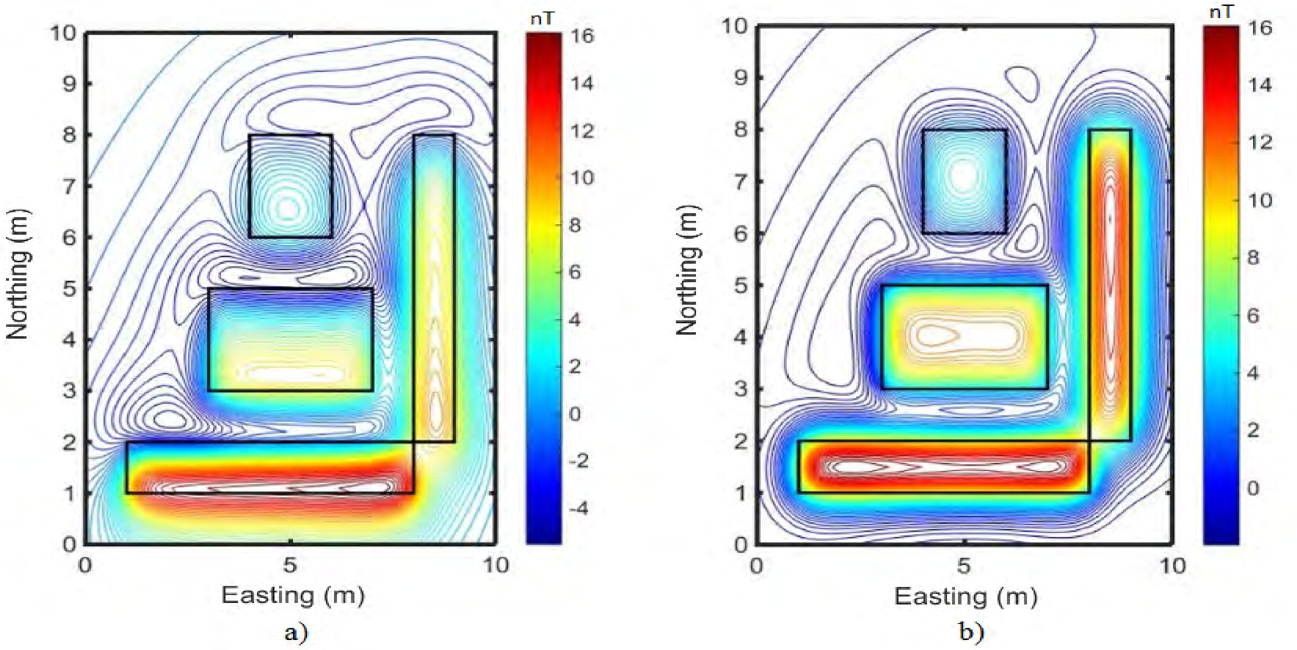


Figure 3: Noiseless Synthetic anomaly: a) with the inclination angle of 60^o , b) with the inclination angle of 90^o .

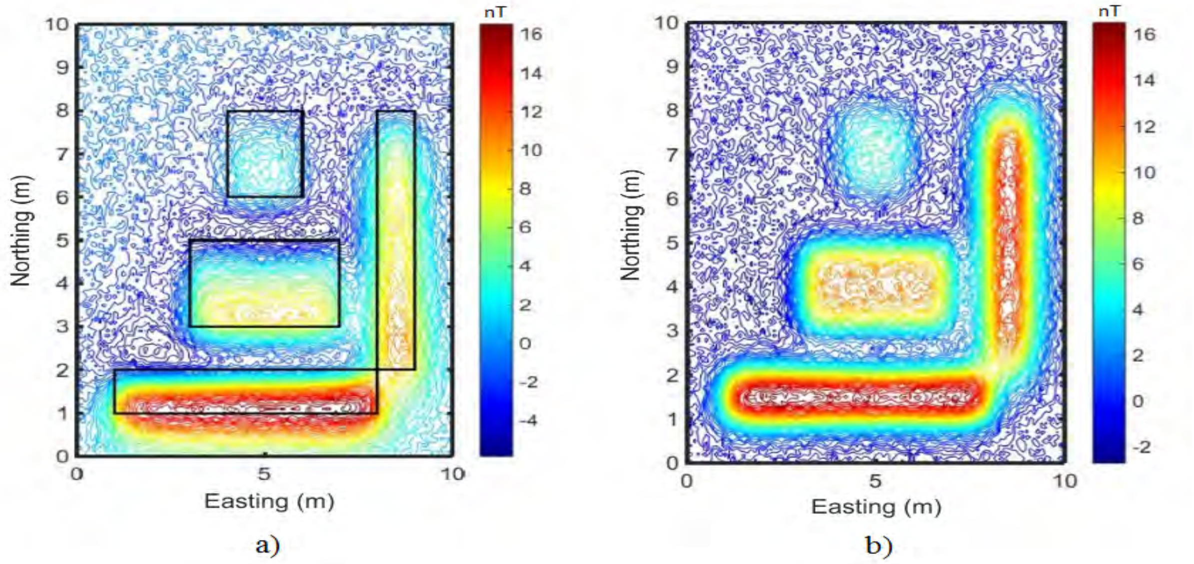


Figure 4: Noisy Synthetic anomaly: a) with the inclination angle of 60^o , b) with the inclination angle of 90^o .

The reduction to the Pole was made to ensure that the inclination angle was vertical on the model with an inclination angle of 60^o. Interpretation difficulties that depend on the inclination angle is different from the vertical in interpretation have been eliminated. In order to eliminate the noise effect in noisy models, the upward continuation method was applied. For the upward continuation operation, the height value is taken as 0.3 m (Figures 5-6-7).

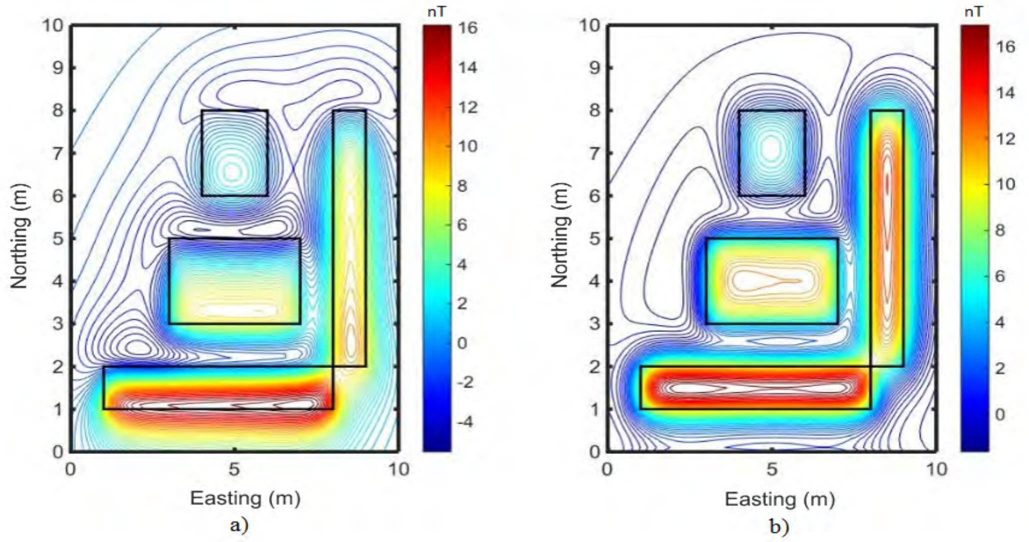


Figure 5: Noiseless Synthetic anomaly: a) with the inclination angle of 60^o , b) Reduction To Pole Map of (a).

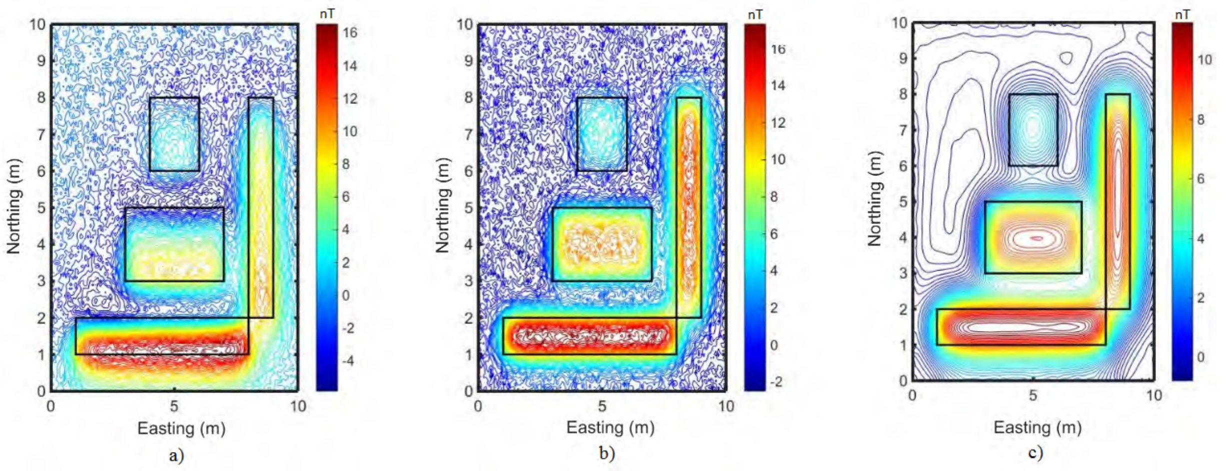


Figure 6: Noisy Synthetic anomaly: a) with the inclination angle of 60^o , b) Reduction To Pole Map of (a), c)Upward Continuation Map.

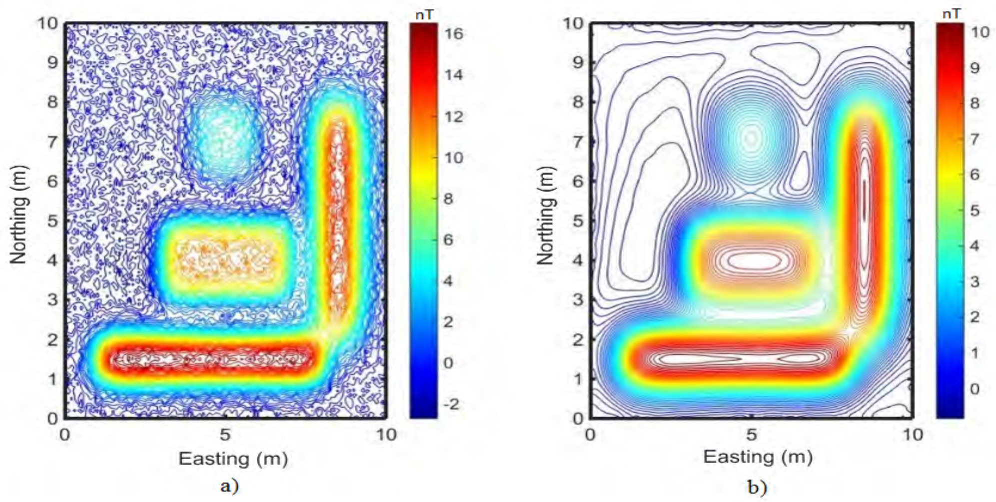


Figure 7: Noisy Synthetic anomaly: a) with the inclination angle of 90^o , b) Upward Continuation Map.

Tilt angle method was applied to the Reduction to pole and upward continuation anomaly maps in order to determine the edges of the model blocks and shown in Figure 8. The zero contours in Figure 8 refer to the structure boundaries. The shallow block boundaries can be seen more clearly. On the other hand, when looking at the deeper blocks, it is observed that there are slight deviations in the boundaries of the structure.

Finally, possible structure edges were improved with the Automatic Gain Control algorithm to improve the obtained structure boundaries (Figure 9).

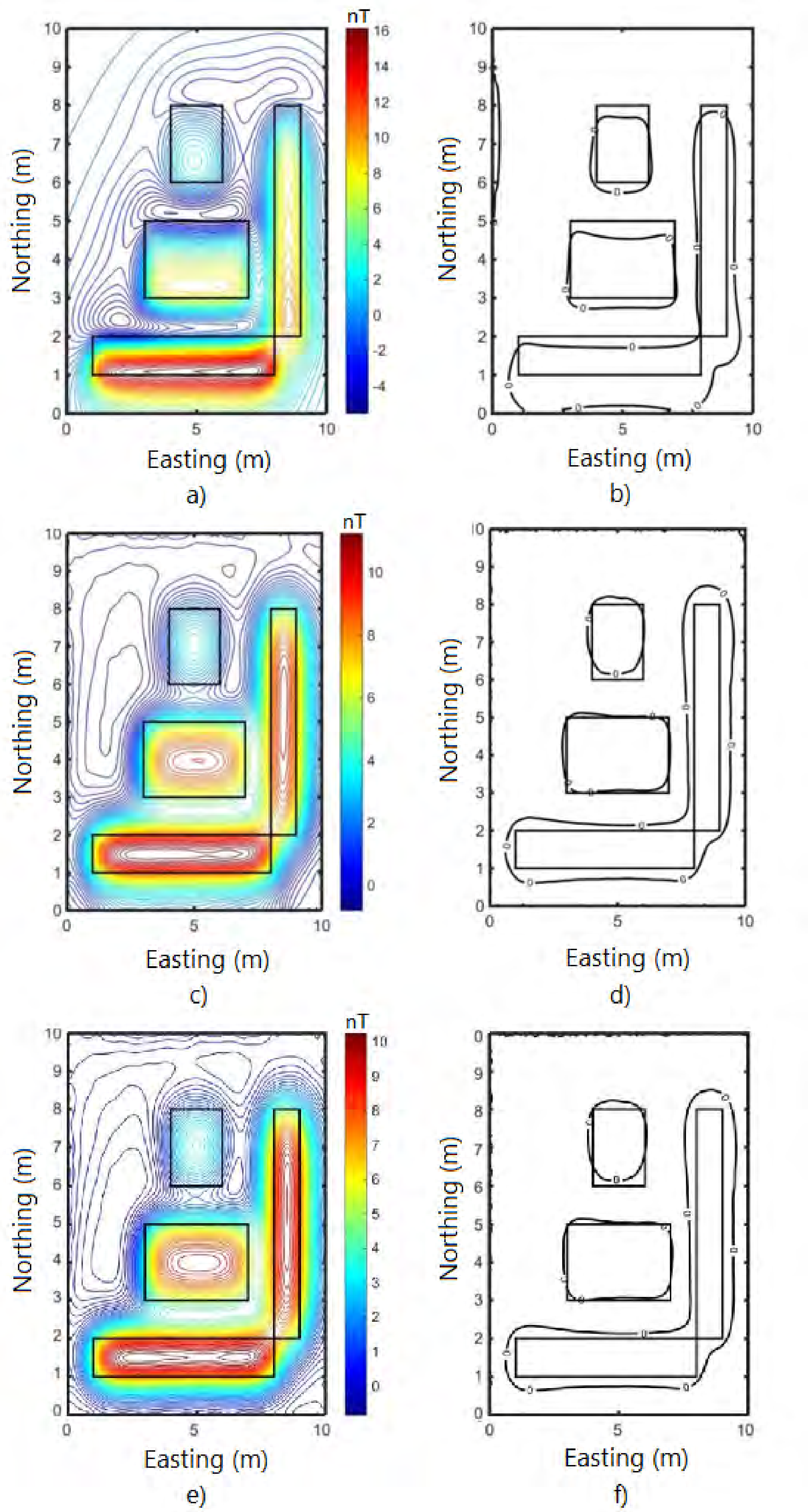


Figure 8: Noiseless Synthetic anomaly: a) with the inclination angle of 60^o , b) Tilt Angle Map (Degrees) of (a), c) RTP Map, d) Tilt Angle Map (Degrees) of (c), e) Upward Continuation Map (with the inclination angle of 90^o), f) d) Tilt Angle Map (Degrees) of (d).

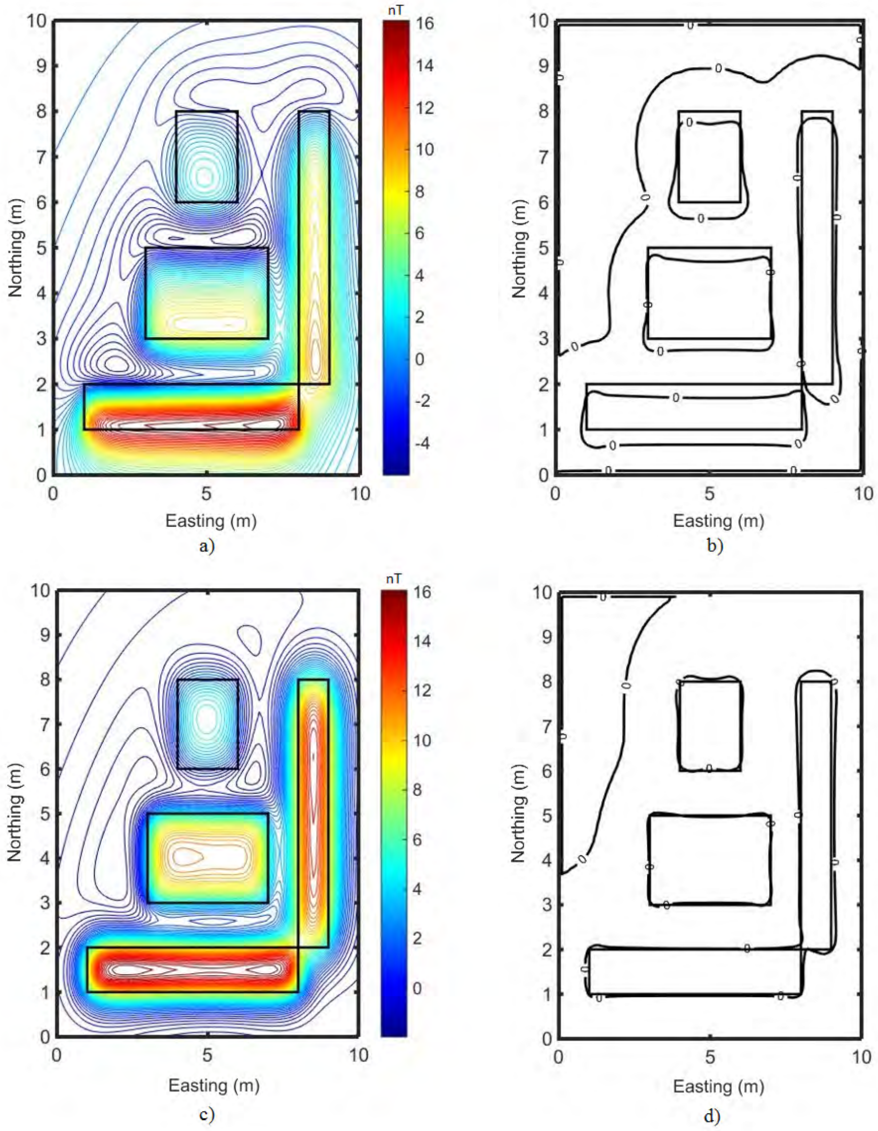


Figure 9: Noiseless Synthetic anomaly: a) with the inclination angle of 60^o , b) Automatic Gain Control Map of (a), c) a) with the inclination angle of 90^o , d) Automatic Gain Control Map of (c).

7 Field Applications

The field application was carried out in the Yozgat-Sarıkaya-Karabacak region using the vertical magnetic anomaly map obtained due to a magnetic survey conducted by MTA (Mineral Research and Exploration Institute). The location map of the study area is shown in Figure 10 (compiled from MTA Institute). A torsion magnetometer, which measures the vertical component of the magnetic field, was used in the magnetic measurements taken in the study area. The total magnetic field strength of the region is 45000 nT, the inclination angle is 56 degrees [15]. The contour map created by the magnetic data collected in the field by MTA was scaled and redigitized in the Surfer program (Figure 11). The land, located in the region where the Central Anatolian climate is dominant, has a flat structure. The area is completely covered with Neogene.

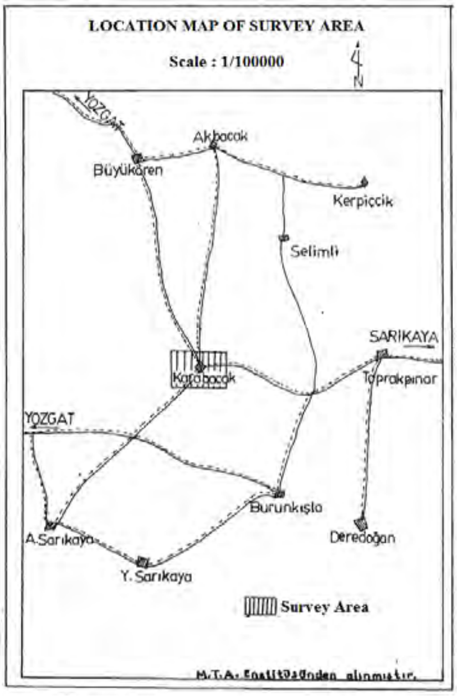


Figure 10: Location Map of Yozgat-Sarıkaya-Karabacak region (Turkey) [15].

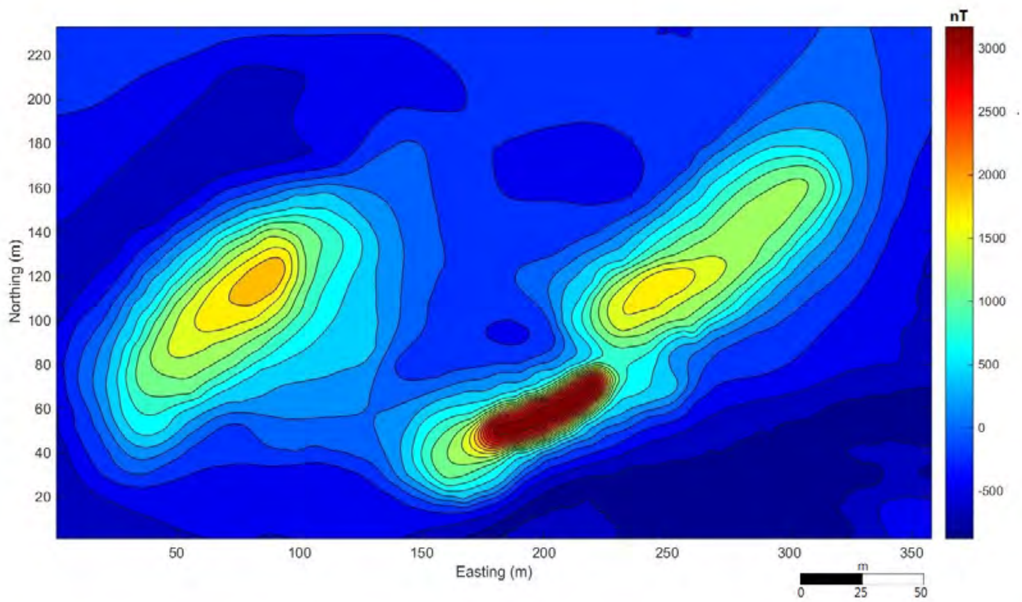
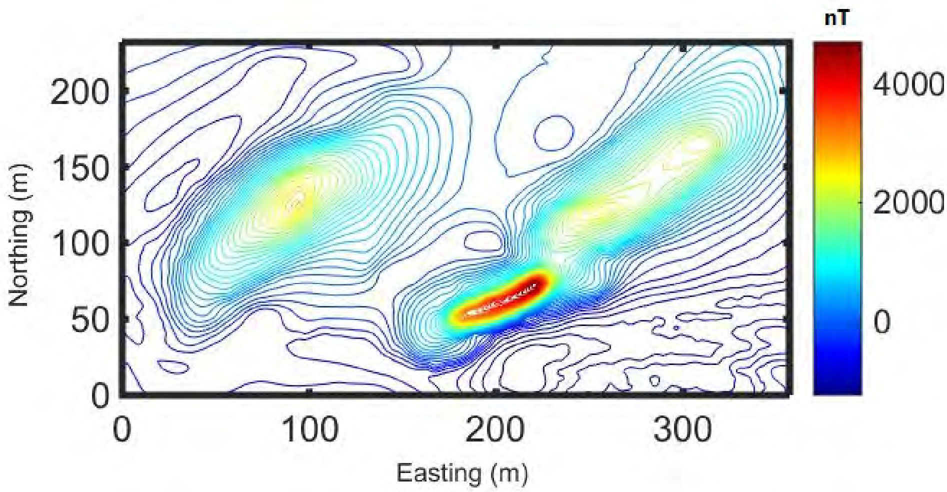
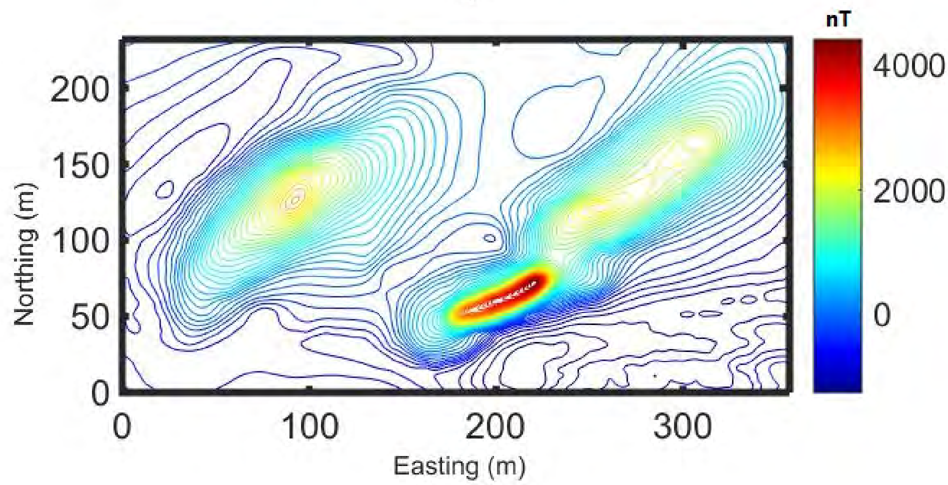


Figure 11: Digitized vertical magnetic anomaly map of survey area.

The path followed during applying the proposed methods to the field data has progressed in the order given below, and the applicability of the methods has been tried to be tested. Considering the contour distribution in the magnetic anomaly map, it is understood that the dyke distributions are in the form of a structure extending in the Northeast-Southwest direction. In order to determine the potential dyke boundaries realistically, the reduction to pole map is shown in Figure 12a. To eliminate the noise effect, the upward continuation method was applied. The height value for the upward extension operation is taken as 0.4 m. (Figure 12b).



a)



b)

Figure 12: a) Reduction Top Pole Map of the survey area, b) Upward Continuation Map of the Survey area.

The Tilt angle method was applied to upward extension anomaly map for the purpose of determining the horizontal locations (edges) of potential dyke structure distributions causing the anomalies, and they are shown in Figure 13a. Finally, horizontal boundaries were improved with the program prepared for the Automatic Gain Control algorithm (Figure 13b).

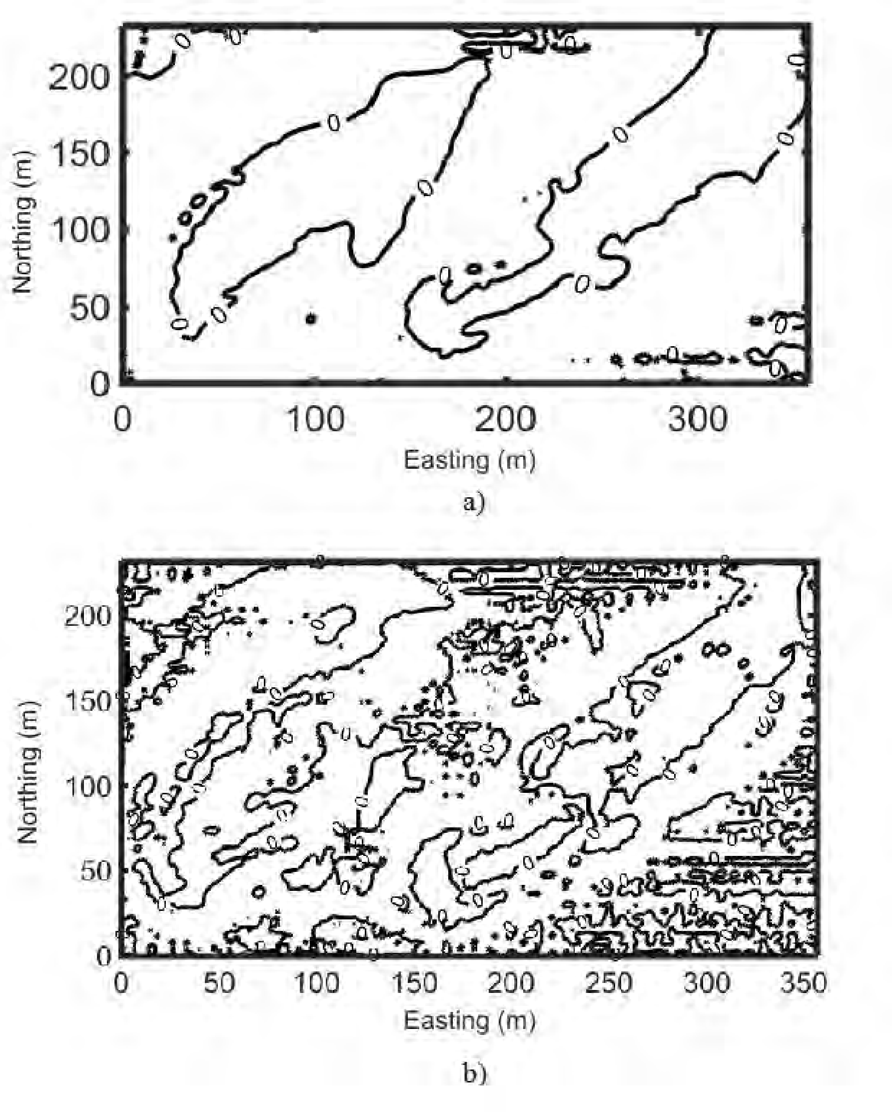


Figure 13: a) Tilt Angle Map of the survey area (zero contours indicate source edges, b) Automatic Gain Control Map of survey area.

8 Conclusions

It has been observed that the findings obtained as a result of applying the methods to the theoretically prepared data are satisfactory. These approaches have been applied to the field data, and the subsurface source boundaries that cause the magnetic anomaly maps have been successfully determined.

Consequently, the geometric positions of the blocks can be successfully obtained by eliminating the noise and inclination angle effect in the theoretical model, and the designed programs can be used in the process of determining potential sources that cause anomalies in field data. The necessity of vertical boundaries of subsurface source distributions can be a disadvantage of the methods used. As a result of the sections taken on the vertical magnetic anomaly map, it was concluded that the sources causing the anomalies were dyke structures [15]. It was concluded that the results obtained from the field application were compatible with the possible underground mass distributions of the region, and satisfactory results were obtained when correlated with the findings of various previous studies.

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