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INTERPRETATION OF MAGNETIC ANOMALIES BY USING ASTA EDGE DETECTION METHOD: SAKARYA (SAPANCA) EXAMPLE

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Abstract. Derivative based methods such as Tilt Angle, Analytic Signal, Total Horizontal Derivative methods are among the most preferred methods for determining the horizontal locations of potential buried structures in geophysical research areas. These algorithms are continuously developed, and new filters are produced, which provide better results. This study aims to determine the horizontal boundaries of the fault structures on magnetic anomaly maps. To this end, the ASTA (Analytic Signal of the Tilt Angle) method, which combines the Analytic Signal and Tilt Angle methods, has been used. Edges of the potential structures have been determined for both synthetic and Sapanca Lake Basin field data.

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1 Introduction

Determining the horizontal boundaries of potential subsurface sources has a significant role in potential field surveys. Magnetic anomaly maps are frequently used to determine the consistency and location of the structures in question. These maps are created with the data obtained from the magnetometer measurements made in the survey area. Susceptibility values contrasting with the dominant magnetic susceptibility values in the region are observed as anomalies in magnetic maps.

Horizontal boundaries (location values,edges) of structures in areas where magnetic field changes are observed can be analyzed on the created magnetic anomaly maps. Therefore, it is essential to determine the horizontal discontinuities of potentially effective structures in interpreting magnetic data. To this end, many derivative based approaches have been developed. Evjen [1] introduced the vertical derivative method as the first research to determine the edges of geological sources. Verduzco et al. [2], Ma and Li [3] analyzed the maximum value of the total horizontal derivative. Miller and Singh [4] developed the Tilt angle method and compared it with horizontal derivative, second vertical derivative, and analytical signal techniques. Cooper and Cowan [5] improved and tested the Tilt angle method with applications to detect the edges of the sources that cause the anomalies. The Theta Map method has been developed as an edge detection method by Wijns et al. [6] Ansari and Alemdar [7] developed the ASTA method as a new edge detection method by combining the Analytical Signal and the Tilt Angle methods. Ferriera et al. [8] used the tilt angle of the horizontal gradient for qualitative interpretation of magnetic data.

This study aims to determine the horizontal boundaries of the geological structures by applying ASTA method on the magnetic anomaly maps created by the subsurface structure distribution causing the magnetic anomalies. To this end, the algorithms of the Tilt Angle, Analytical Signal and ASTA methods have been prepared in the Matlab environment. The accuracy of ASTA method was implemented on the synthetic model data. Noisy and noiseless anomaly maps of the synthetic model were created. After eliminating the adverse effects from noisy data by the upward continuation method, the applicability of the technique used in noisy and noiseless data was examined. The inclination angle was determined as 90^o to avoid misleading results if the inclination angle is different from the vertical. It has been observed that the results obtained by applying the method to the theoretical data are coherent with initial values. ASTA method was also applied to the real field data of Sapanca Lake Basin, and the effective geological subsurface source boundaries were analyzed.

2 Tilt Angle Method

The Tilt Angle method is one of the classical local phase filters that detect effective structures in potential field data by improving their edges [9]. This method was first developed by Miller and Singh [4]. The basis of the Tilt Angle method is the ratio of the vertical derivative to the absolute amplitude of the total horizontal derivative, which is defined as,

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

where T is the tilt angle, and M denotes the magnetic field value, $\partial M/\partial z$ represents the vertical derivative, $\partial M/\partial x$ and $\partial M/\partial y$ are the horizontal derivatives of the magnetic field.

The Tilt Angle value takes a positive value over the effective source. This value becomes zero directly above the source edge (in the region where the vertical derivative is zero and the horizontal derivative is maximum) and becomes negative outside the effective source. The tilt angle has values in the range of -90 to 90 degrees. This feature makes this method much easier to interpret than the analytical signal in the interpretation phase [5].

3 Analytic Signal Method

The Analytic Signal method was first developed by Nabighian [10]. This method is frequently used, especially in potential field data collected for near surface explorations. The advantage of the method is that it is independent of the magnetization direction of the source. It depends on the shape and location of the source structure. In this method the edges of magnetic bodies can be determined by detecting maximum value of the Analytic Signal.

The analytical signal has a complex behavior: the sum of real and imaginary parts. The horizontal derivative is a real component, and the vertical derivative is an imaginary magnetic field component in this method (Eq.2).

$$AS(x,z) = \partial M/\partial x + i\partial M/\partial z \tag{2}$$

In Equation 2, M refers to the magnetic field value, $\partial M/\partial x$ and $\partial M/\partial z$ expressions represent the derivatives of the magnetic field according to the horizontal and vertical components, respectively. Likewise, in three-dimensional cases, the analytical signal is as follows (Eq.3);

$$AS\ (x,z) = \ (\partial M/\partial x) + (\partial M/\partial y) + (i\partial M/\partial z) \tag{3}$$

where $\partial M/\partial y$ is the derivative of the magnetic field according to the horizontal component. The Analytical signal amplitude is a symmetric bell-shaped function [7] and defined as Equation 4.

$$|AS\,(z)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \tag{4}$$

Similarly, in three dimensional cases, the analytic signal amplitude can be expressed as [7];

$$|AS\,(z)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(i\frac{\partial M}{\partial z}\right)^2} \tag{5}$$

4 ASTA (Analytic Signal of Tilt Angle) Method

In the Tilt Angle method, as the structures get deeper, the structure boundaries become blurred. The interference of adjacent causative sources influence the analytical signal adversely in 3D cases. To overcome such negative effects, a new edge detection filter called ASTA has been developed by Ansari and Alemdar [7]. This method is a combination of Analytic Signal and Tilt Angle methods and can be defined as,

$$ASTA = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \tag{6}$$

In Equation 6, the Tilt Angle is shown by T. When the results obtained with the Analytical Signal and Tilt Angle methods are compared, it has been observed that the ASTA method provides much more accurate results [7].

5 Synthetic Model Applications

To test and compare the outputs of these derivative-based edge detection methods, a model consisting of 2 blocks with different depth and susceptibility values was created by preparing the programs of Tilt Angle, Analytical Signal, and ASTA algorithms (Table 1). The inclination angle of the model was determined as 90^o for the purpose of elimination the interpretation difficulties due to the inclination angle being different from the vertical. The magnetic field strength was assumed as 45000 nT. The synthetic anomalies of the model structures with and without noise were calculated (Figure 1). The noisy anomaly was created by adding 0.2 Gaussian noise to the noiseless anomaly in order to simulate the field data.

Table 1: Geometric parameters of the theoretical model.

Block No	Y Axis		X Axis		Depth Values		Magnetic
	Y1(m)	Y2(m)	X1(m)	X2(m)	H1(m)	H2(m)	Susceptibiliy (SI)
1	3	5	3	5	1	2	0.02
2	5	6	1	8	0.3	0.6	0.02

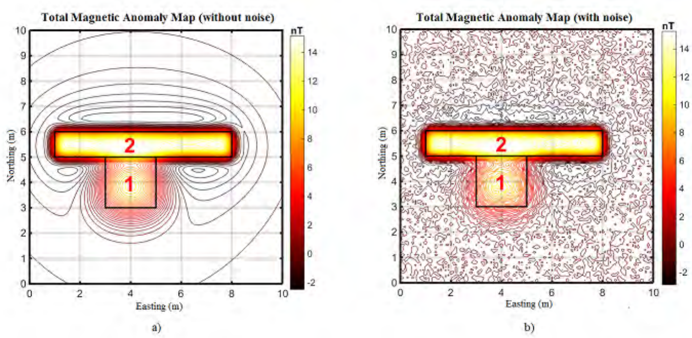

Figure 1: a) Noiseless synthetic data, b) Noisy synthetic data.

The Upward Continuation process (h=0.2 m.) was applied to eliminate the negative effects in the noisy model (Figure 2). Tilt Angle, Analytical Signal, and ASTA methods were applied to the anomaly maps in order to detect the edges of causative blocks and are shown in Figures 3-5.

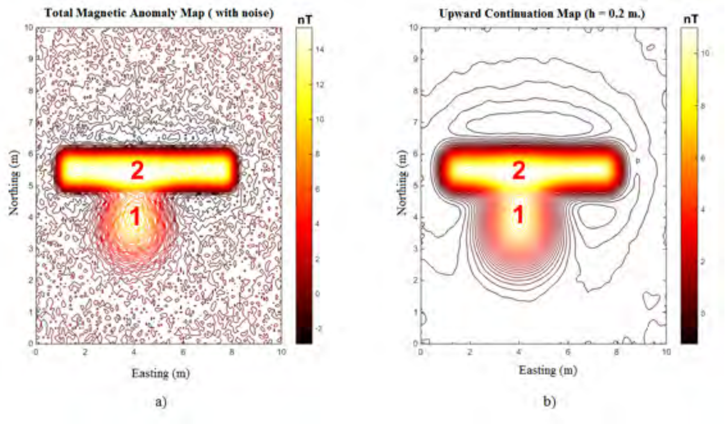

Figure 2: a) Noisy Synthetic Data (inclination angle is 90^o), b) Upward Continutaion Map (nT).

6 Field Data Applications

Sapanca Lake Basin is located in the east of the Marmara Region, within the borders of Sakarya and Kocaeli (Figure 6). The total length of the coastline is 39 km. Sapanca Lake is located in a tectonic pit that extends parallel to İznik Lake and reaches Adapazarı Plain as a continuation of İzmit Bay. Total Magnetic Anomaly map of the region was redigitized and regridded from Aydogan and Komazawa [11] (Figure 7).

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. By looking at the contour distribution in the magnetic anomaly, it is understood that the subsurface source distributions have the direction of an east-west direction. In order to eliminate the noise effect, the upward continuation was applied with the height value of 0.3 km.(Figure 8.a). During the application of the methods to the magnetic anomaly given in Figure 8a, reduction to pole was used to eliminate the effect of the inclination angle (Figure 8.b)

Tilt Angle and ASTA methods were applied to the map Reduction to pole map in Figure 8b in order to determine the geological source that causes the anomaly and are shown in Figure 9.In Figure 9a, the boundaries of the subsurface fault structure obtained by the tilt angle method are shown with zero contours. In Figure 9b, high Rad/km values as fault boundaries are indicated in red on the map obtained by applying the ASTA method.

7 Conclusions

The derivative-based edge detection methods were applied to synthetic and Sapanca Lake basin magnetic data. As a result of application of the ASTA on the field data, edges of the potential structure have been determined. According to the sections taken from the total magnetic anomaly map, it was concluded that the source distribution causing the anomalies is a fault structure.

Although the fault edges can be determined approximately in all three methods, Tilt Angle and Analytic Signal methods are not convincing due to the loss of resolution when detecting deeper structure edges when applied separately. They must be supported by another method. The results obtained from the synthetic model and field studies revealed that the ASTA method is more successful than Tilt Angle method in detecting potential structure edges and can be used as an edge detection method in future magnetic interpretation studies.

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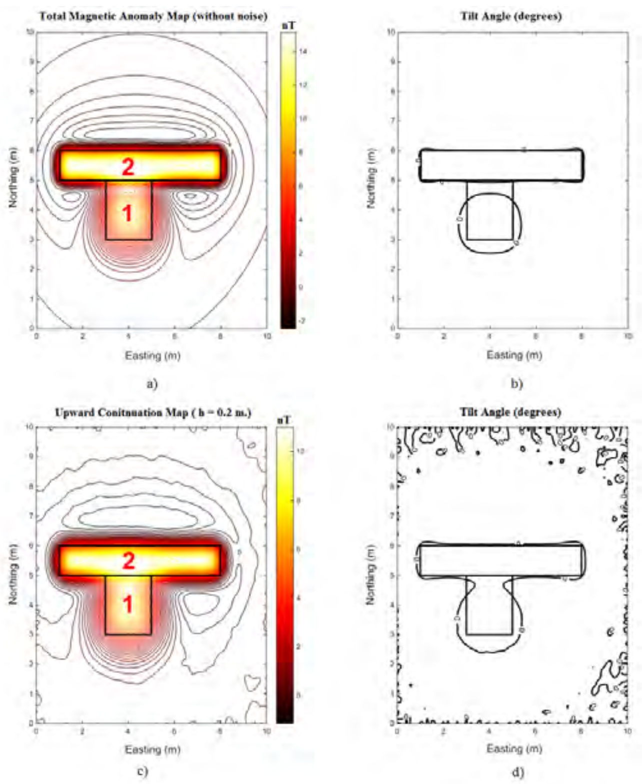

Figure 3: a) Noiseless Theoretical Anomaly, b) Tilt Angle Map of Noiseless Theoretical Anomaly, c) Upward Continuation Anomaly, d) Tilt Angle Map of Upward Continuation Anomaly.

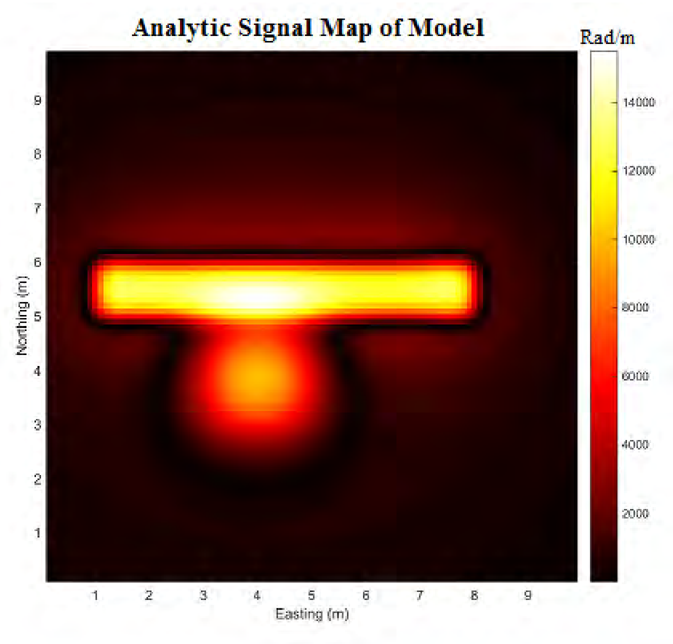

Figure 4: Analytical Signal Map of Synthetic Data.

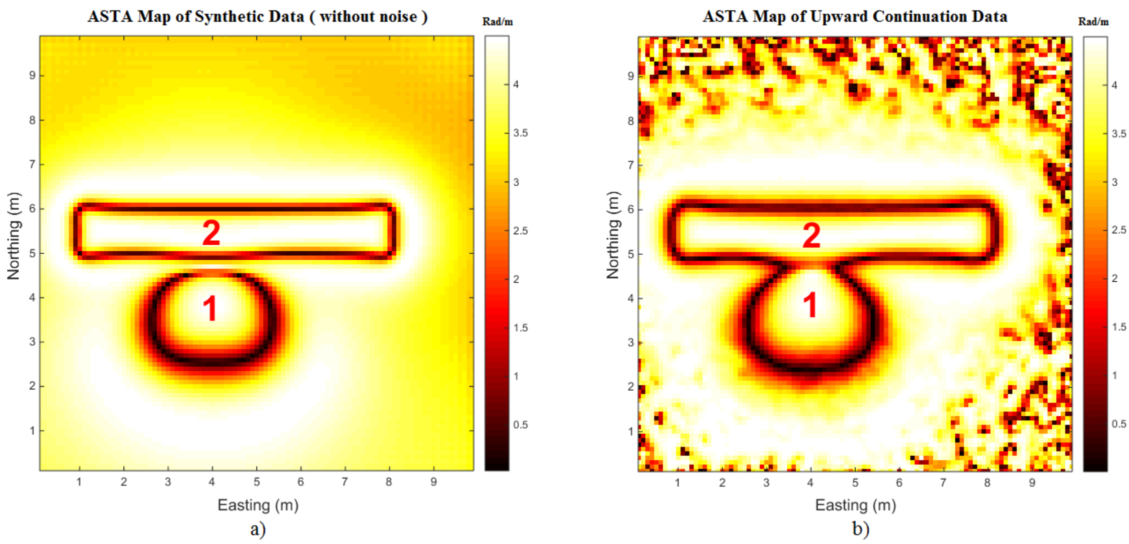

Figure 5: a) ASTA Map of the Noiseless synthetic anomaly, b) ASTA Map of the Upward Continuation data.

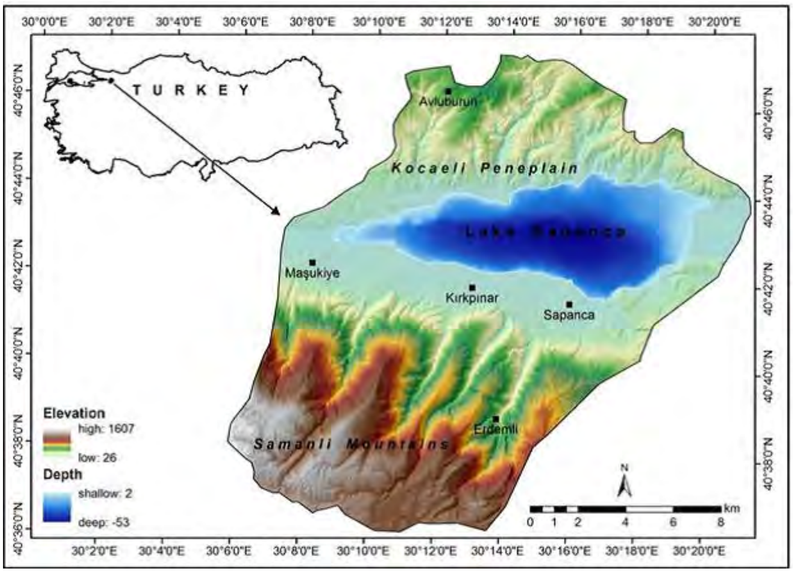

Figure 6: Location Map of survey area [12].

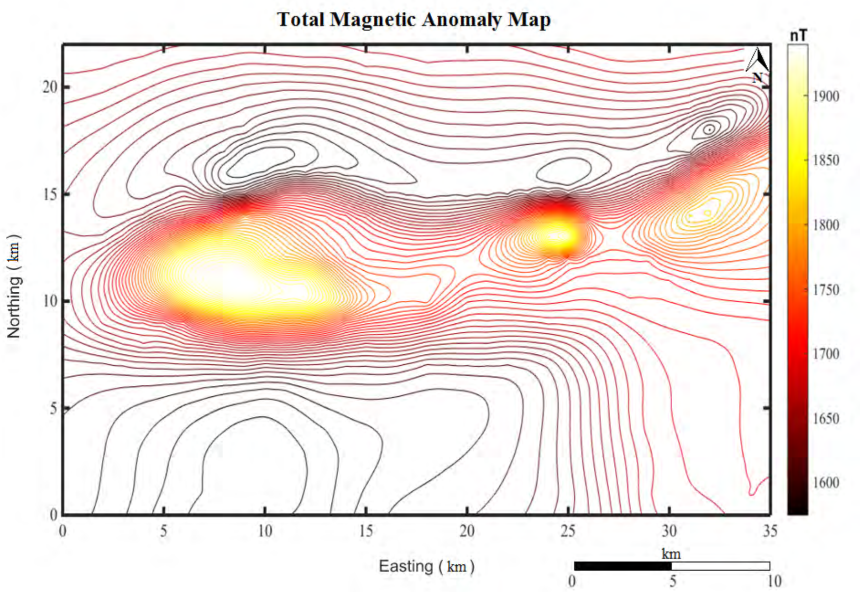

Figure 7: Total Magnetic Anomaly Map of Sapanca Lake Area.

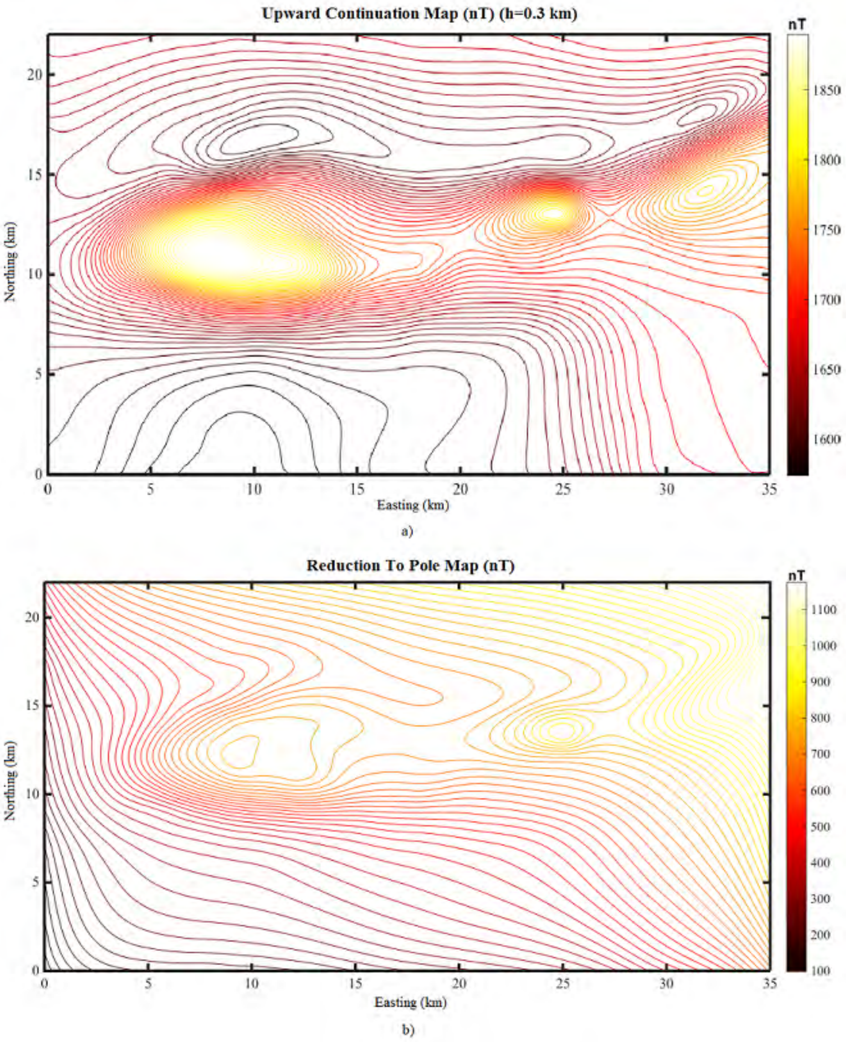

Figure 8: a)Upward Continuation Map (h=0.3 km), b) Reduction To Pole Map of (a).

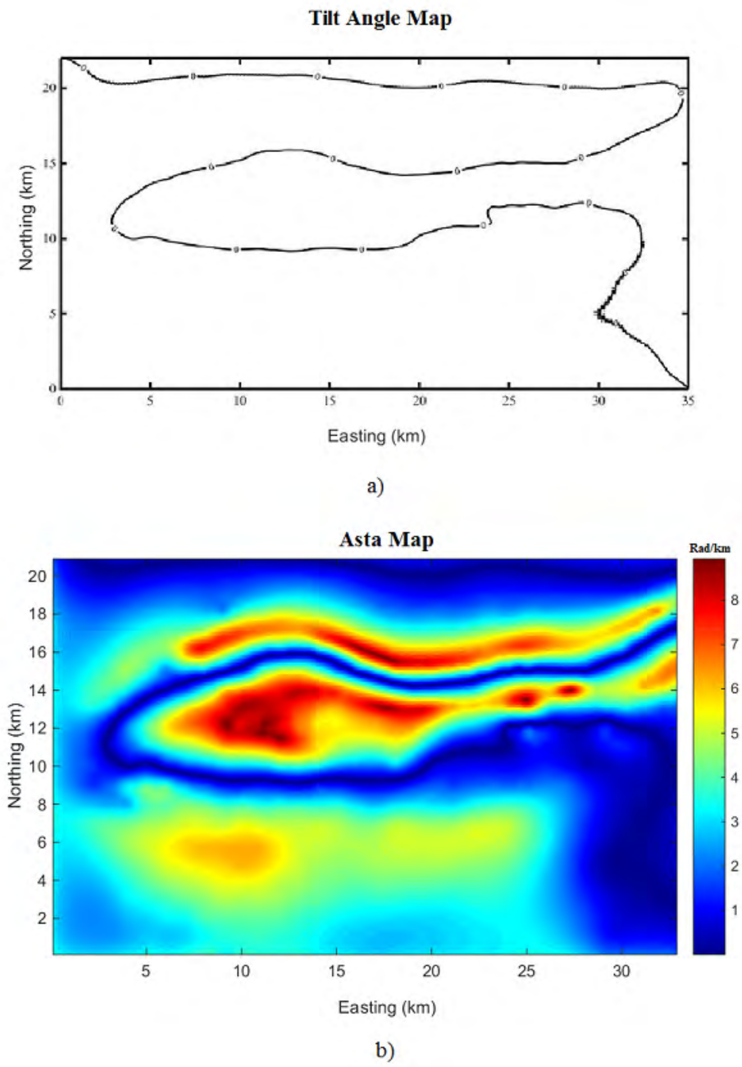

Figure 9: a) Tilt Angle Map of Sapanca Lake Basin, b) ASTA Map.

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