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TWO EXAMPLES FOR IMAGING BURIED GEOLOGICAL BOUNDARIES: SINKHOLE STRUCTURE AND SEYİT HACI FAULT, KARAPINAR, KONYA

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[a] *Maden Tetkik ve Arama Genel Müdürlüğü Jeofizik Etütleri Dairesi Başkanlığı*
[b] *Maden Tetkik ve Arama Genel Müdürlüğü Maden Etüt ve Arama Dairesi Başkanlığı*
[c] *Maden Tetkik ve Arama Genel Müdürlüğü Jeoloji Etütleri Dairesi Başkanlığı*

Keywords:
Sinkhole, gravity, hyperbolic tilt angle, edge zone, derivative, tilt angle, anomaly, Seyit Hacı Fault, Karapınar, Konya.

ABSTRACT

Once anomalies with positive and negative circular closures are assessed together in potential field maps, the ones which have meaningful geometric structure appear as more distinguishable. When the edge detection is applied, the preliminary geological model about the geological structure may or may not be verified. When it is not verified then it is understood that the predicted geological model should be reconsidered and discussed again. In this study, the edge detection was introduced and the success of the method was tested in an artificial data. Following that, its effect on sinkholes was studied applying the method on detailed gravity data collected in Karapınar (Konya) region. At the same time, this method was applied on data related to active Seyit Hacı Fault zone. It was detected that the fault had shown continuity towards SW and these evidences were discussed.

1. Introduction

Edge detection methods in data processing stages of the potential field data can rapidly be applied rather than consuming time due to developments in computer technology. Derivative methods in edge detection processes (Euler deconvolution, tilt angle and their combinations) give good results in detecting boundary structures on data. The gravity anomaly occurs depending on the environment in which the target structure exists. It gives a negative value if the target structure exists in a denser geological environment than it. However; it exhibits a positive value if it is located in a less dense geological environment that it. The sensitivity of tilt angle in detecting especially the plutonic intrusions in gravity and magnetic methods and decoding buried ones have been studied by many investigators (Oruç, 2010; Akın et al., 2012; Toker, 2014; Toker and Çiftçi, 2014). In the method of hyperbolic tilt angle (HTA), as the ratios of variables in vertical and total horizontal derivatives are expressed hyperbolically different than the method of tilt angle, the result is not a vectorial but a scalar magnitude.

The detection of the edge boundaries of the horizontal derivative, the vertical derivative to localize the anomaly at a certain area and the analytical signal to give high values on edges of geological structures contribute a lot in terms of detectability. In previous studies, the 2nd order vertical derivative of the analytical signal (Hsu et al., 1996), total horizontal derivative of the tilt angle (Verdusco et al., 2004), hyperbolic tilt angle and 2nd order vertical derivatives of the tilt angle (Cooper and Cowan, 2004) were used in edge detection data processes.

In this article, the success of the edge detection method was examined in modelling the volumes of environments which show a clear edge relationship with the surrounding geological environment as it was in sinkhole boundaries. In this study, "shifting by a scalar" method was applied in order to make

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boundary transitions to be more distinctive image using HTA method on a model. After the application, it was seen that more detectable images were obtained and the application was tested with actual field data.

2. Hyperbolic Tilt Angle (HTA) Method

Hyperbolic tangent function was expressed by Cooper and Cowan (2006) below as;

$$HTA = Tanh^{-1} = \frac{\frac{df}{dz}}{\left[(\frac{df}{dx})^2 + (\frac{df}{dy})^2\right]^{1/2}} \qquad (1)$$

where; *f* is the potential field, *df/dz* is the first order vertical derivative of potential field (f), *df/dx* is the first order vertical derivative of the potential field (f) in x direction, *df/dy* is the first order vertical derivative of the potential field (f) in y direction. The operand in denominator is the amplitude of the horizontal derivative.

According to Zhou et al. (2013) who studied the consistency and limits of the method;

$$Z = tanhx = \frac{sinhx}{coshx} = \frac{e^x + e^x}{e^x - e^x} \qquad (2)$$

The Equation 3 is obtained using the transformation in the formula (2) by means of single and double function characteristics of this function.

$$X = tanh^{-1}Z = 0.5 * \ln\left(\frac{1 + z}{1 - z}\right) \qquad (3)$$

and when the function is rearranged using Equations (1) and (3), the following equation is obtained (Zhou et al., 2013) as below;

$$HTA = 0.5 * \ln \frac{\left[(\frac{df}{dx})^2 + (\frac{df}{dy})^2\right]^{1/2} + \frac{df}{dz}}{\left[(\frac{df}{dx})^2 + (\frac{df}{dy})^2\right]^{1/2} - \frac{df}{dz}} \qquad (4)$$

The "vertical derivative" in above equation can take positive and negative values. Local end values belonging to vertical derivative remove the equation from being stable (Zhou et al., 2013). Cooper (2103) suggests shifting negative contrast by a scalar. At the statement of the function given below, it is aimed at making the equation stable by adding a constant such as "k".

$$Tanh^{-1} = \frac{\frac{df}{dz}}{\left[(\frac{df}{dx})^2 + (\frac{df}{dy})^2\right]^{1/2} + k} \qquad (5)$$

In the application, while the edge detection process of relatively negative circular closures is performed, the data process image can be made more accurate and understandable by shifting the residual negative contrast by a scalar such as "k".

When the hyperbolic tilt angle method is applied it is sufficient to make shifting as much as the amplitude of negative lines in the image. Within this respect, when selecting parameters of data process one should be careful about the advantages and disadvantages of this method as the wrong parameter might cause some details to get lost. Accordingly; if "k" parameter is selected greater than normal then data of the process may become poorer than normal. On the other hand, if "k" is selected smaller than normal, then the expected detection may not be achieved. Thus, it is very important to select the most suitable and confidential parameter that will remove negative oscillations originating from the density contrast of the environment.

In sample model study, the stable HTA image of the model was calculated by 0.3 mgal shifting oscillations in vertical derivative of the potential field data belonging to the gravity anomaly of the prism at 5 km depth which has 0.1 gr/cm^3 contrast (Figures 1a, b, c). The gravity effect of the model prism, the response of this gravity effect to HTA application and vertical derivative in 3D view were given in figures 2a, 2b and 1c, respectively.

In figure 2b, except the edge zone effects of the model prism it is seen that moirés observed in cross shapes are negative oscillations. As these oscillations are the effect of negatives of vertical derivative in 3D which is shown in Figure 1c, the anomaly which occurs by (k) 0.3 mgal shift of the vertical derivative is shown in figure 3b.

Figure 3 a) the gravity effect of the model prism in figure 1, b) HTA image shift in positive direction.

In model application given by Cooper (2013), ±0.1 gr/cm^3 gravity anomaly of prismatic structures

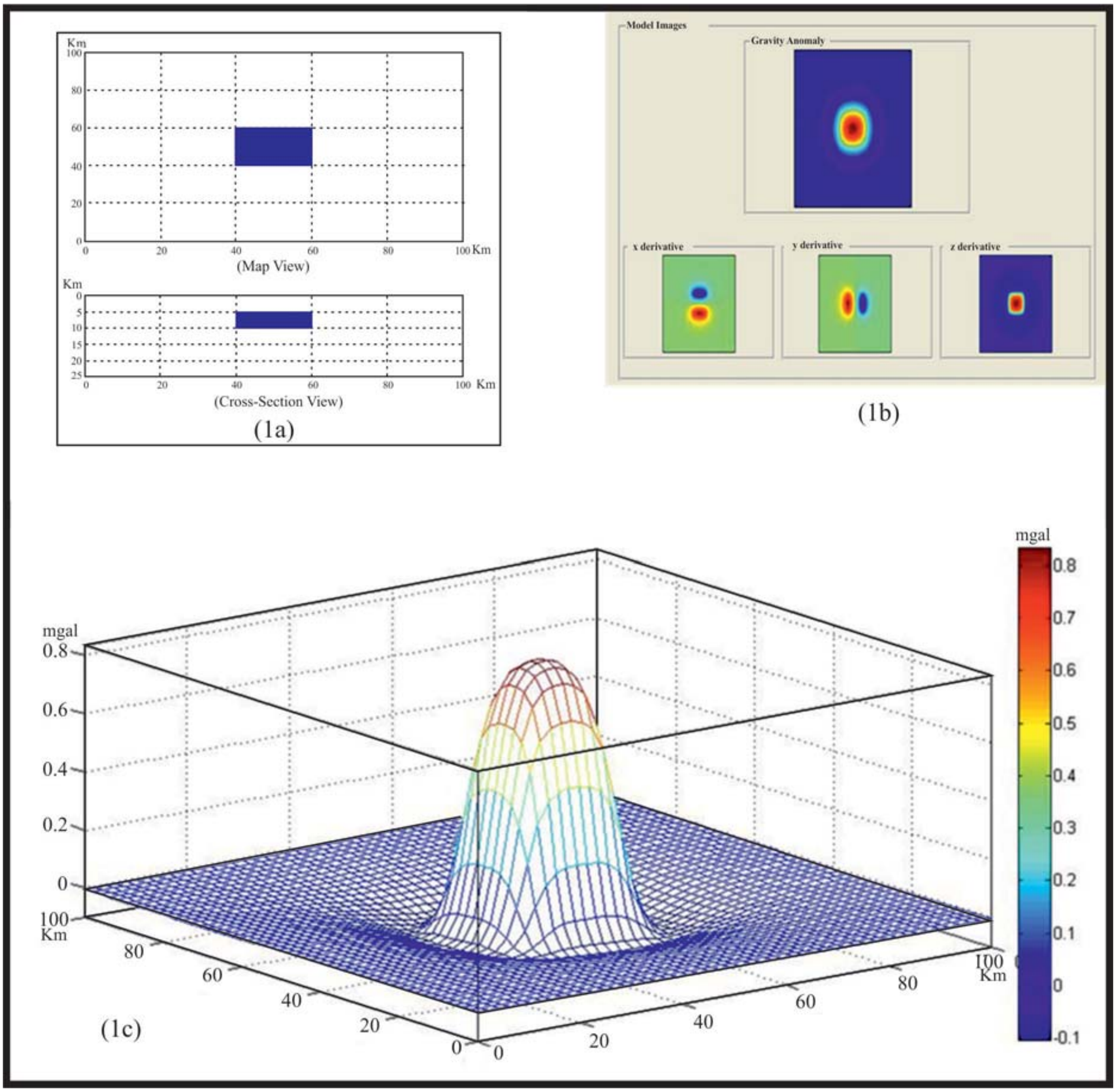

Figure 1- a) View of the model from top and side, b) The gravity effect of the model and its derivative components, c) Vertical derivative in 3D view.

at 5 km depth and negative-positive oscillated boundary imaging are given in figures 4a and 4b, respectively. Model structures which are seen on the lower left and on the upper right corners in Figure 4a and cause anomaly were remarked by black square line. The boundary imaging shift (k=0.3) according to Cooper (2013) was given in figure 5.

3. The Application of The Model On Field Data

The application defined above and examined on a model prism (Figure 5) was tested on actual field data and the results were compared. To do that, gravity data generated in Karapınar-Konya by Törk et al (2009) were used. The image obtained as a result of the hyperbolic tilt angle edge detection process applied on Bouguer gravity data was given in figure 6a.

Negative anomaly areas became apparent as independently or geometrically being associated with each other in some places on this image. Places which tend to form sinkhole structures became apparent in the form of negative circular closures on this map after performing HTA process. As this map was generated by applying only one data process on raw gravity data, many other processes which are applied during data simplification become unnecessary and

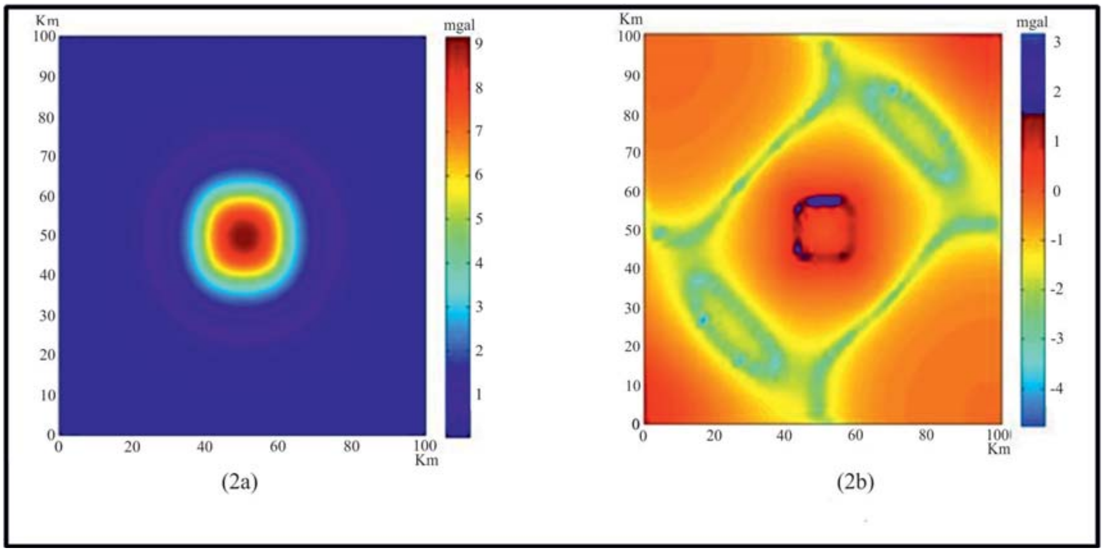

Figure 2- a) the gravity effect of the model prism in figure 1, b) hyperbolic tangent view.

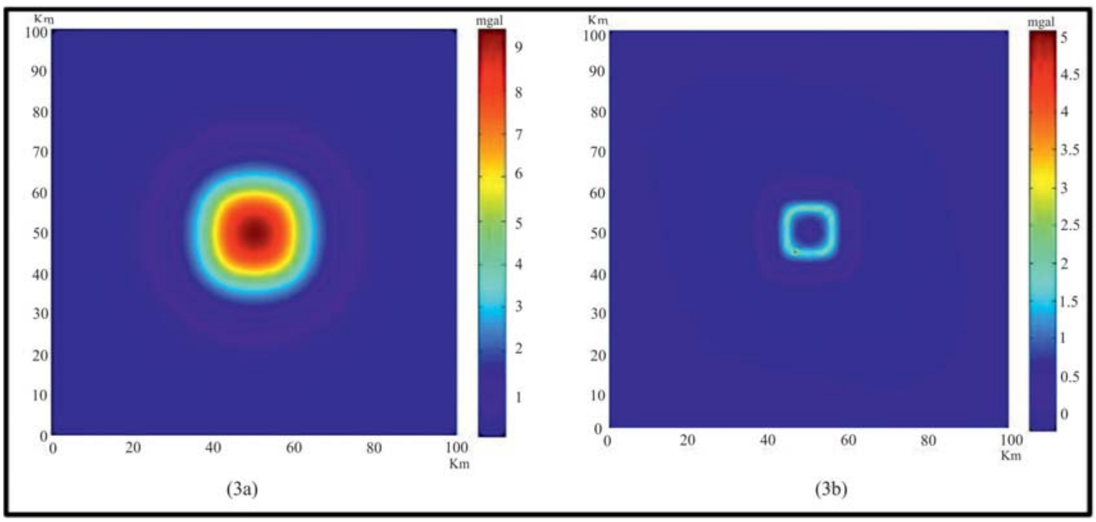

Figure 3- a) the gravity effect of the model prism in Figure 1, b) HTA image shift in positive direction.

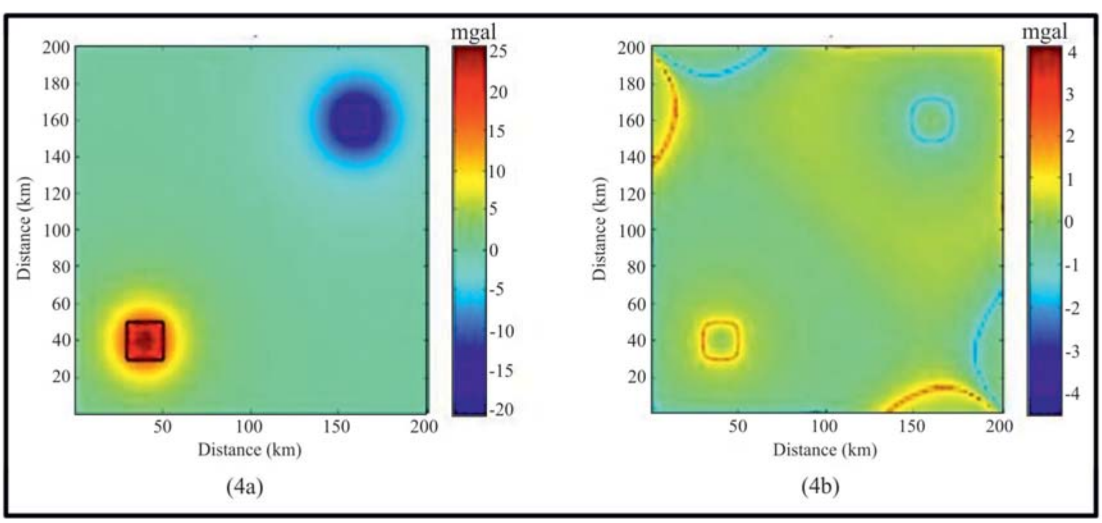

Figure 4- a) positive and negative anomalies of prismatic structures, b) negative-positive oscillations in boundary imaging.

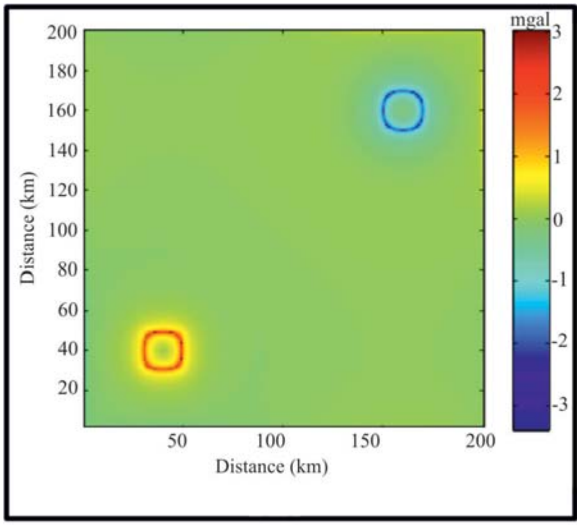

Figure 5- Boundary imaging shift by 0.3 k. (Cooper, 2013).

timesaving. The probability of error also decreases significantly as the process is simple. Thus, this map shows that this method can safely be used in edge detection processes of negative bodies. Suggestions asserted by Zhou et al. (2013) regarding the disadvantages of this process were responded by Cooper (2013) in the same volume of the journal and it was clearly shown that it is possible analytically and on model based (see Figure 5).

Figure 6b was obtained applying a series of processes in order to clearly reveal the sinkhole structures of the same field data.

3.1. Sinkhole Structure

Western and northwestern parts of Karapınar where the study area takes place is located in the main geomorphological region of the Central Anatolia namely the “Sinkhole Plateau” (Erol, 1990). Erol (1990) stated that sinkholes located in the sinkhole plateau developed in late Pleistocene, especially during the recent pluvial period (Würm) and there was a karstification in the region even earlier than this formation (middle-lower Pleistocene). When the Konya Lake was on pluvial level in Pleistocene, karstic underground erosion occurred along the detachment fault in SE-NW starting from high levels of Pleistocene Konya Lake (1030-1010 m) towards lower levels of Tuz Lake basin (1010 – 905 m). The groundwater flow has decreased during interpluvial period and the development of sinkhole has been interrupted until next phase. Findings in this study also support that block faulting played an important role on the development of sinkhole. Hence, all sinkhole structures in the region take place on the foot wall of Seyit Hacı Fault (Figures 7 and 8).

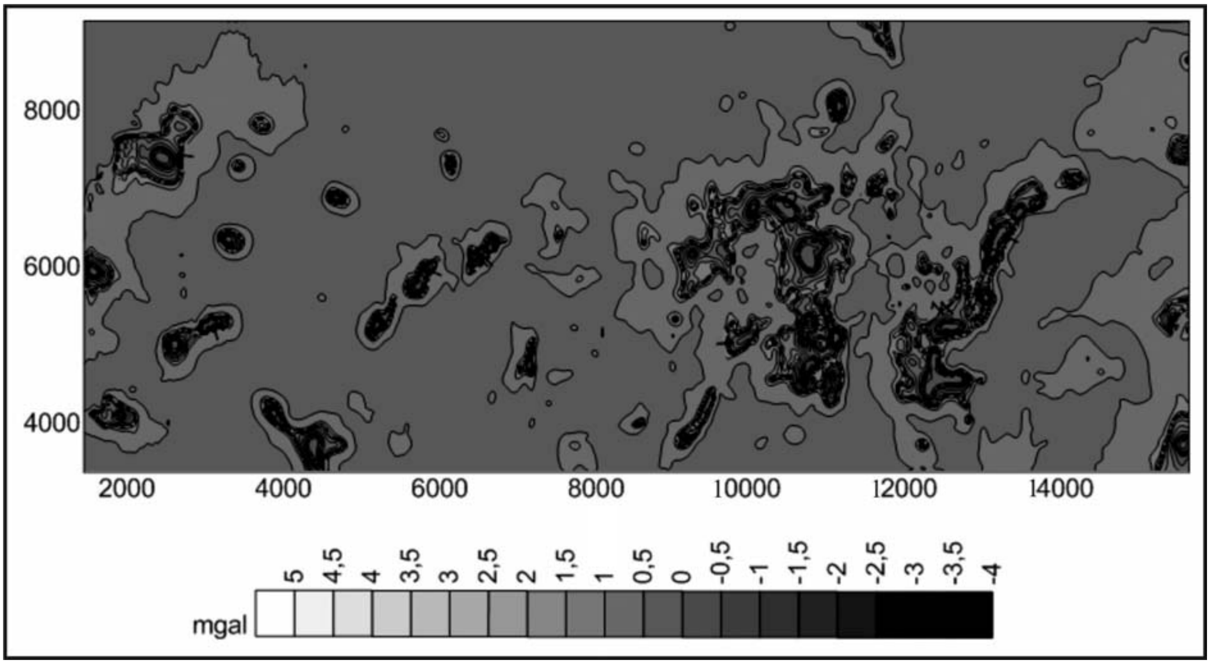

Figure 6- a) Image obtained as a result of the hyperbolic tilt angle edge detection process which was applied to Konya-Karapınar field data (field data were taken from Törk et al., 2009; see figure 8 for location, relative coordinate was used).

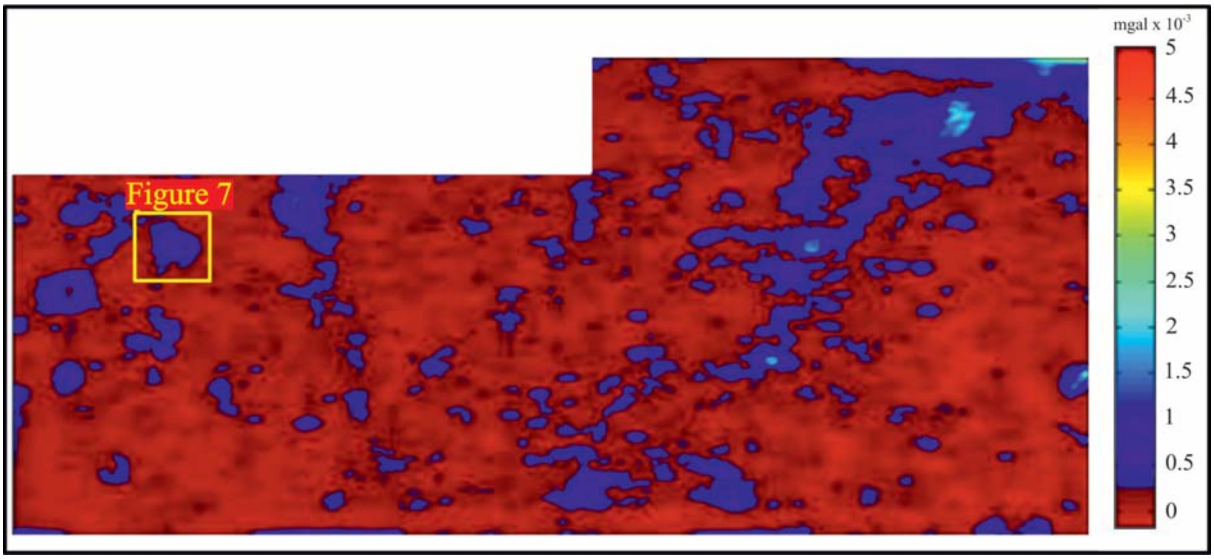

Figure 6- b) Field data with high pass filter, blue areas probably coincide with areas of sinkhole/karstic structures (relative coordinates are as in figure 6a, see figure 8 for location).

When these structures reach the surface following the advanced karstification/cave formation period, they are called as "sinkhole". Sinkholes which are geomorphologically formed in the form of smooth circular and cylindrical volumes in 3rd dimension often occur as in irregular geometry. Sinkholes due to the surrounding geological formations create a negative density difference.

Following the field application (as shown in Figure 6b) one sinkhole was selected on the field and shifting was applied in order to increase the distinguishability of boundary transitions of this structure. More detectable image was obtained as a result of the processes of which related results were shown in figures 7a, b and c.

The actual field data is seen in figure 7a. A collapsed structure in the field which is relatively low dense compared to surrounding environment and one of the zone at west in which dark blue colored negative values exist is observed. The source body of the data was foreseen as a shallow geological structure starting from a few meters at the surface and the edge detection technique was tested by HTA method (Figure 7b). However; it is seen in figure 7c that oscillations decrease and the collapse structure becomes localized in the application by selecting k as 0.3 (Figure 7c).

3.2. Seyit Hacı Fault

The study area is located in Konya-Eskişehir section of the Central Anatolia Neotectonic Region (Koçyiğit, 2000). This area is represented by structural elements (normal faults, horst and grabens) of the extensional tectonic regime products. The Karapınar graben which orients in NE-SW direction,

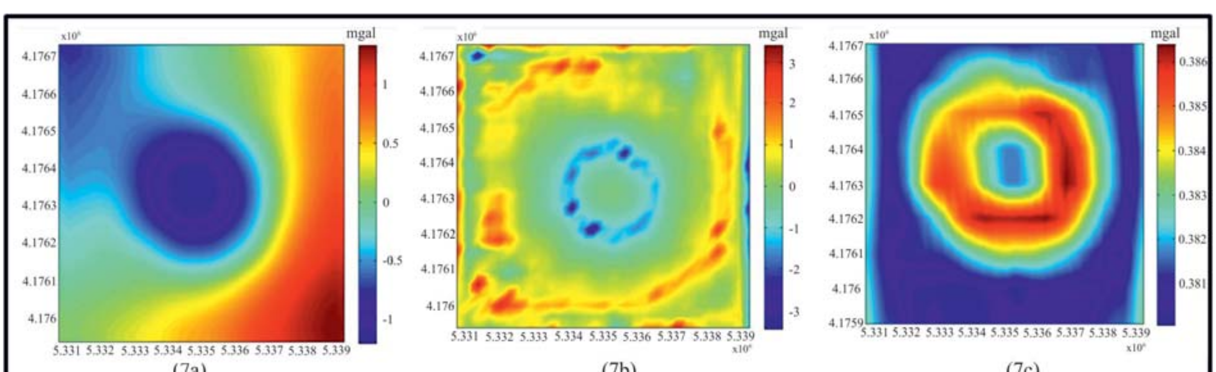

Figure 7- a) Negative anomaly, b) HTA view of the anomaly, c) shifted HTA image (see figure 6b for location).

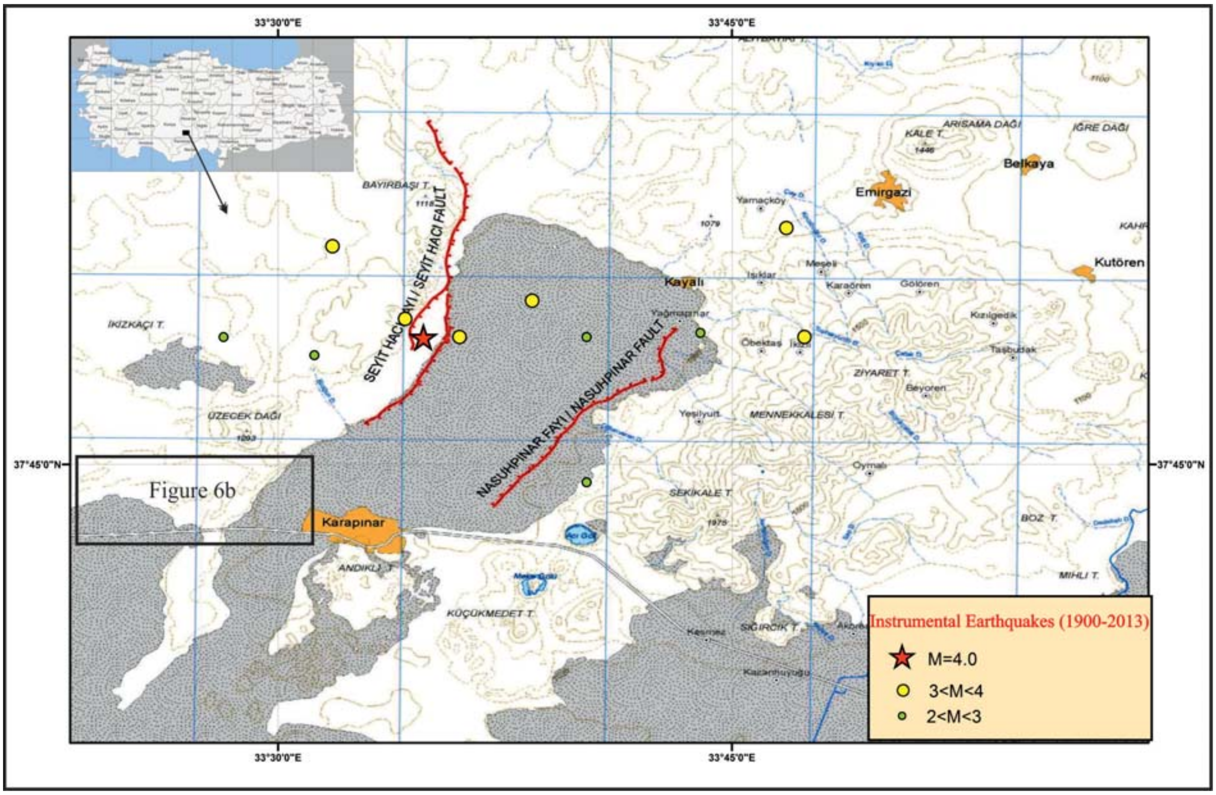

Figure 8- Location of the Karapınar Graben and Seyit Hacı Fault in 1/250 000 scaled Karaman sheet (NJ 36-11), series of Active Fault Map of Turkey (Emre et al., 2011).

24 km long and 8 km wide is one of these structural elements. The eastern and western borders of the Karapınar Graben are restricted by Nasuhpınarı and Seyit Hacı faults, respectively (Özalp et al., 2011). Emre et al. (2011) defined Seyit Hacı Fault as 18 km long, active normal fault which is formed by 2 segments (northern and southern segments) (Figure 8).

The northern segment is formed by two sub segments (fault section). The orientation of the northern segment is N15°E and 2.8 km long. The southern segment is totally 12 km long and has orientation in NNW, N-S and NNE directions.

In this study, the probable sinkhole structures which are considered to have occurred in western part of the Karapınar Graben were investigated by the Hyperbolic Tangent Method and subjected to the edge detection process. It was seen that there were many sinkhole structures which formed or probably to occur within different sizes in the region and these exhibited a linearity in NE-SW directions (Figures 6a, b). In order to discuss the relationship of this detected lineament with active faults in the region, high pass filtered field data (Figure 6b) of the investigated area was coordinated and plotted on 1/250 000 scaled Active Fault Map of Turkey, Karaman sheet (NJ36-11) (Emre et al., 2011) (Figure 9).

Anomaly which exhibits linearity in NE-SW directions corresponds to SW continuation of the Seyit Hacı Fault (Emre et al., 2011) (see Figure 8). It is considered that probable sinkhole structures seen in high pass filtered field data were developed on the hanging wall of another 3rd segment of the SE continuation of the Seyit Hacı Fault. The segment in question was named as "Seyit Hacı Fault, Segment 3". This segment is formed by 3 fault sections which are 8 km long, parallel to sub parallel in N40°E direction (Figure 10).

Tectonomorphological characteristics of the Seyit Hacı Fault segment 3 defined in this study can also be clearly observed in satellite images. Tectonomorphological elements (Figure 11) such as; linear fault scarps, alluvial fans arranged along the fault and hanging valleys indicate the activity of this segment of the fault.

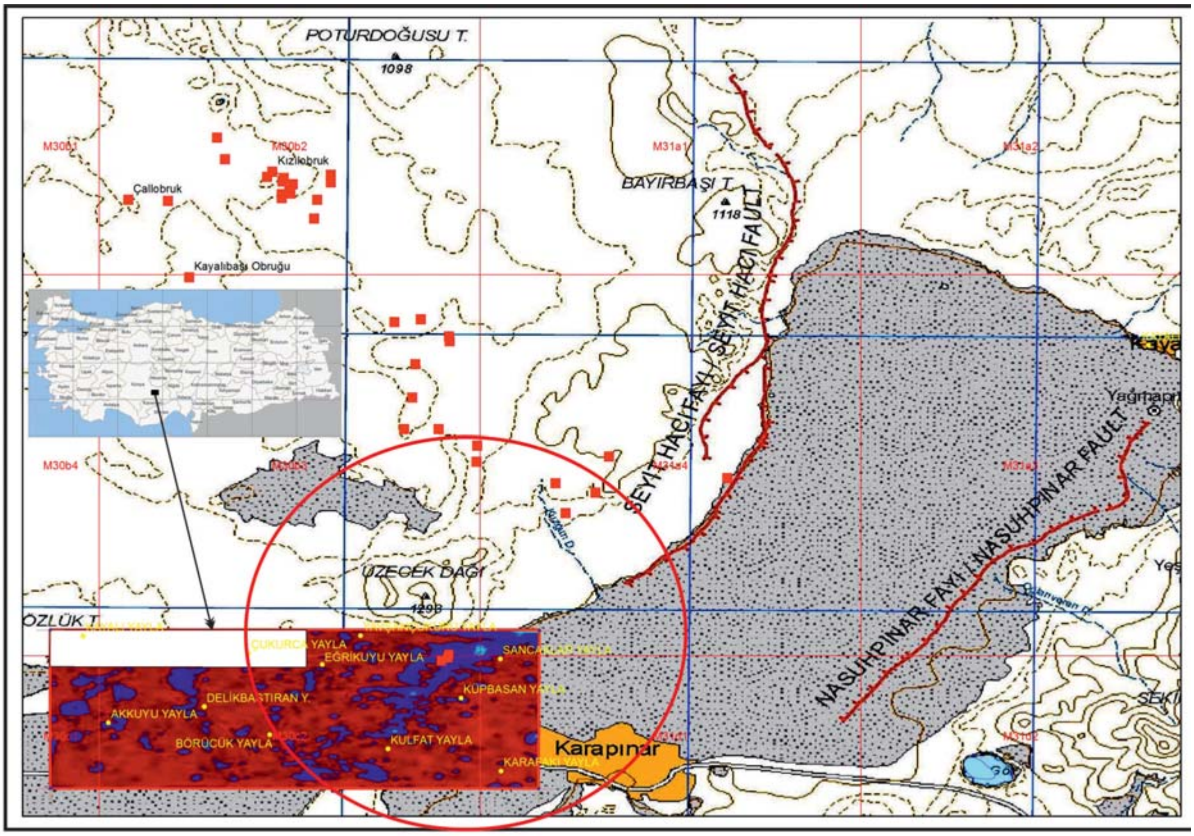

Figure 9- Location of high pass filtered field data of the study area on Active Fault Map of Turkey Series, 1/250.000 scaled (NJ 36-11) Karaman Sheet (Emre et al., 2011) (Red points represent recent sinkhole structures. All these structures were digitized using 1/250.000 scaled topography map and are located on the hanging wall).

Figure 10- Locations of Seyit Hacı Fault segments in Googleearth view. Seyit Haci fault segment 3 was mapped as a result of this study. Segments 1 and 2 were taken from Emre et al. (2011). (x3 vertical exaggeration, looking north with oblique angle).

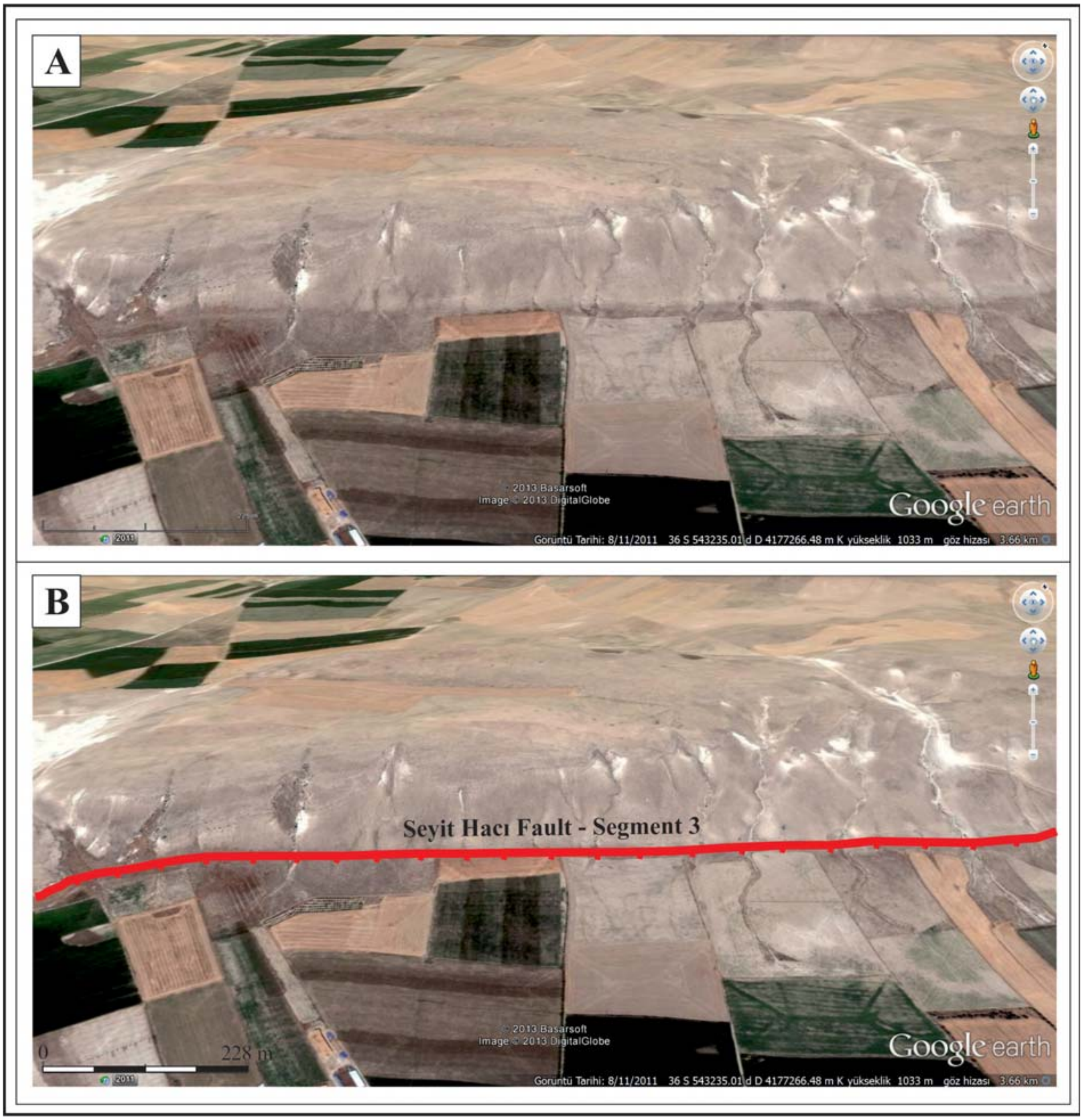

Figure 11- Googleearth view of Seyit Haci Fault, Segment 3. A: non-interpreted, B: interpreted (x3 vertical exaggeration, looking northwest with oblique angle).

4. Results and Discussion

In this article, Hyperbolic Tilt Angle (HTA), which is one the method applied in imaging buried geological structures by processing the potential data was introduced and tested on actual field data. First, the edge detection method of HTA was introduced. Then, in order to query the usage of this technique in detecting sinkhole or similar structures, model responses to edge detection processes which the buried prismatic model structures give were studied. And in the last stage, the application was tested by the actual field data and the edge detection of a sinkhole structure in Karapınar (Konya) region was realized. Besides, it was discussed that the neotectonic structure of the Seyit Hacı Fault which is located just at the NE section of the study area, orienting in NE-SW directions should continue towards SW as the 3rd segment by studying the anomaly type obtained in this investigation.

HTA method is one the methods used in this purpose and the image obtained is actually quite complicated compared to other derivative and phase filters in terms of detectability. However, the weak point of the method was stated by Zhou et al. (2013). Nevertheless, Cooper (2013) said that it will be enough to shift by a scalar like "k" in order to stabilize this method and showed it on a model as well. Toker and Çiftçi (2014) discussed model responses belonging to all other edge detection techniques and this method in their articles called "Simav grabenin yapısal jeofiziği" (the Structural Geophysics of the Simav Graben). They established that the map (of which its vertical and horizontal amplitudes are proportioned) which is easily simplified in one step by being shifted with HTA method could produce quite useful results in detecting the boundary transitions of geological structures which cause negative anomaly for distinguishability. The same issue was discussed in more detail by Toker (2014). Consequently; it was shown in this article that shift process by a scalar makes HTA method more advantageous compared to the other derivative and phase filtering methods.

Vertical derivative to create negativity in total caused the stability of the method to be questioned (Zhou et al., 2013). In addition, it was understood that sinkhole structures which create 0.2 mgal relative difference within sediment (as it was in salt dome anomaly) and form 0.2 – 0.4 mgal negative differences with respect to its surround could be shifted by a scalar like "k" and their edge detection processes can safely be performed.

This article does not intend to show the comparison of skills of HTA method with respect to other edge detection methods but to show how the edge detection ability of HTA could easily be remediated. In addition, it was pointed out that most of the edge detection processes containing vertical derivative had a problem of depth. The environment of formation of sinkholes, which are indicated as the target structure in this study, to be in shallow depths has not created any problems in terms of the discrimination of process in vertical derivative in HTA method.

In this article, HTA method in edge detection techniques was also tested from the point of detectability of tectonic structures which associate a boundary relation with the surrounding geological structures as it was in sinkholes and quite successful result were obtained. Seyit Haci Fault is one the neotectonic structures of the Central Anatolia Region. The 3rd segment of this fault which has the characteristics of SW continuation has not been detected so far and has first been defined in this article. The anomaly lineament which is easily seen in figure 9 should represent the line in which deformations such as; fracturing/breaking developed on the 3rd segment of the fault and karstic/sinkhole type dissolution structures which developed as a result of the severe groundwater activity triggered by a sudden rise of block. Undoubtedly; this finding should be supported by paleoseismological studies in order to reinforce this information.

HTA method used in this study should be applied to geological bodies (dyke, layer, intrusive structure, mineral deposit, etc.) that have sufficient size, regular geometry, more definite density and susceptibility difference compared to surrounding geological environment. The model should be tested and the success of the method should be questioned in doing so. The success of the method will give way such a useful instrument to be used especially in the exploration of mineral deposits.

Acknowledgement

Model calculations in this study were made by modifying Potensoft Proses software developed by Arısoy and Dikmen (2011).

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