Comparison Between Second Vertical Derivative and Tilt Angle Methods in Detecting Edges of Gravity Anomaly

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Abstract- Edge detection is very important in description of subsurface structures. Interest is usually placed on boundaries or edges especially during exploration minerals. Second vertical derivative and tilt angle methods are among the most commonly used methods in detection of lithological boundaries. The choice of which method to select in edge/boundary detection is very vital and that is why this paper addresses the two methods. Satellite gravity data of Hadejia segment of chad basin Nigeria acquired from Bureau Gravimetric International (BGI)was used as case study. The area is a contact region between Chad sedimentary formation and cretaceous northern basement complex. Second vertical derivative and tilt angle maps were plotted on surfer software to produce maps that shows boundaries between the two formations. Comparison was made between the two results pointing out some similarities and differences between the two results. This will guide an individual researcher while making choice of which among the two methods will suit his research based on his interest.

Indexed Terms- Second vertical derivative, Tilt angle, Edge detection, Gravity anomaly.

I. INTRODUCTION

Reasonably, many methods have been established for the analysis of gravity anomalies instigated by simple bodies (Essa k. S., 2012). Derivatives increase the power of the linear dimension in the denominator to amplify sub-surface features. That is, because the gravity effect varies inversely as the distance squared, the first and second derivatives vary as the inverse of the third and the fourth power, respectively, for the three-dimensional bodies.

By taking the derivative of g along the $x and y$ axes, we obtain the components of the horizontal gradient of gravity.

Numerous theoretical solutions are continuously possible. This made interpretation of anomalies non-unique mathematically. The label of "non-uniqueness" can result to the inaccurate impression that no single interpretation is better in a geologic sense than any other. (Richard and Blakely, 2011). The "non-uniqueness" of potential-field studies is relatively close to the more general topic of scientific uncertainty in the Earth sciences and beyond. Nearly all the results obtained in the Earth sciences are issues to noteworthy uncertainty because problems are mostly addressed generally with incomplete and imprecise data. The growing requirement to combine results from multiple disciplines into integrated solutions in order to address complex global issues requires special attention to the appreciation and communication of uncertainty in geologic interpretation.

Second Vertical Derivative (SVD) tends to emphasize local anomalies and isolate them from local background. The calculation of gradients is anticipated to boost subtle features of gravity data that otherwise cannot be visually noticed from the original data. High gradients can be associated with a high contrast of physical properties of the subsurface and vice-versa. (Putra *et al*, 2019). The second vertical derivative is frequently employed in gravity interpretation for isolating anomalies and for upward and downward continuation. Many researchers have used second vertical derivative for boundary location (Aku, 2014; Wahyudi *et al.*,2016; Justia *et al.*,2018). The tilt angle derivative on the other hand is also used to infer about geological edges. Tilt angle has been used as the basis for a variety of methods for edge enhancement of potential field anomalies (DOĞRU *et al.*,, 2017; Fikret *et al*., 2017; Putri *et al*., 2019).

Because of the fact that both second vertical derivative and tilt angle methods are known and recognized as good edge detectors, this research aims to compare the two methods to help figure out which is better at a particular case. Comparison between two the methods will guide an individual researcher while making choice of which among the two methods will suit his research based on his interest. Reviewed literature has revealed that little or no research paper has compared the two methods. Although some have taken too many methods for comparison (Ismail *et al.*, 2019), it might not picture the similarities and differences between these two methods particularly as presented in this paper.

II. MATERIALS AND METHODS

The materials used for the research include Microsoft excel software, Grapher software, Surfer software, Satellite gravity data.

- The Study Area

Hadejia and surrounding whose satellite gravity was used is part of Nigerian chad basin which lie between latitude 11^0 -13^0E and longitude 8^0 - 14^0N. The area is underlain by rock and younger sediments of the Chad formation. (kwaya et al 2018).

Figure 1: Nigerian map showing the chad basin area

- Second Vertical Derivative Method

The SVD of the vertical component of gravity, g_z, can be calculated in the spatial domain from the horizontal gradients by using the Laplace's Equation.

$$\frac{\partial^2 g_z}{\partial z^2} = -\left(\frac{\partial^2 g_z}{\partial x^2} + \frac{\partial^2 g_z}{\partial y^2}\right) \quad (1)$$

(Aku, 2014)

For an elongated anomaly along the y-axis, the SVD can be approximated by the second horizontal derivative of the gravity data along the x-axis in Equation (2). :

(Prihadi*et al*, 2018; Putra *et al*, 2019)

$$\frac{\partial^2 g_z}{\partial z^2} \approx -\frac{\partial^2 g_z}{\partial x^2} \quad (2)$$

In the wave-number domain, or Fourier domain, the SVD is usually calculated

by using the following Equation (3). :

$$\frac{\partial^2 g_z}{\partial z^2} = F^{-1}(|k|^2 G_z) \text{ with } |k|^2 = k_x^2 + k_y^2 \quad (3)$$

(Putra et al, 2019)

- Tilt Angle Method

In gravity, Tilt angle is defined as the ratio of the vertical derivative of anomalies to their horizontal derivative.

Total horizontal component is defined as:

$$HGM = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \quad (4)$$

The vertical gradient of the gravity values $\partial g/\partial z$ is the ratio of the change in the magnitude of the gravity vector at a point on two different vertical points to the spatial separation between them. It is derived from the idea that the gravitational field vector g is derivable from the gradient of gravitational potential U as

$$g = -\nabla U \quad (5)$$

Which obeys Laplace equation (Ibe and Iduma, 2018)

$$\nabla^2 U = \nabla . \nabla U = -\left(\frac{\partial g}{\partial x} + \frac{\partial g}{\partial y} + \frac{\partial g}{\partial z}\right) = 0 \quad (6)$$

and thus

$$\frac{\partial g}{\partial z} = -\left(\frac{\partial g}{\partial x} + \frac{\partial g}{\partial y}\right) \quad (7)$$

The tilt angle filter is defined as

$$\theta = arctan \frac{\frac{\partial g}{\partial z}}{\sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2}}, \quad (8)$$

Where θ is tilt angle and g is gravity anomaly.

III. RESULTS AND DISCUSSION

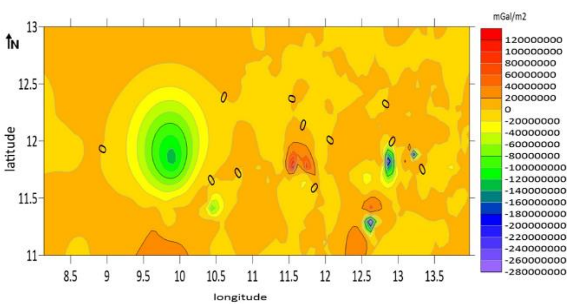

Figure 2: The svd map of the study area.

The second vertical derivative map in figure 2 shows the values of second vertical derivative which ranges from -280000000 mGal/m^2 to 12000000 mGal/m^2. The zero values show the edges of deeper feature. As defined earlier, the portion with less density is considered to contain more sediment. The map shows that density distribution is decreasing inward between 11.5^{0}N to 12.5^{0}N and 9.3^{0}E to 10.2^{0}E. The same thing happens between 11.8^{0}N to 12^{0}N and 12.7^{0}E to 13^{0}E. However, the area with highest density can be seen in the middle of the map between 11.7^{0}N to 11.9^{0}N and 11.5^{0}E to 13^{0}E.

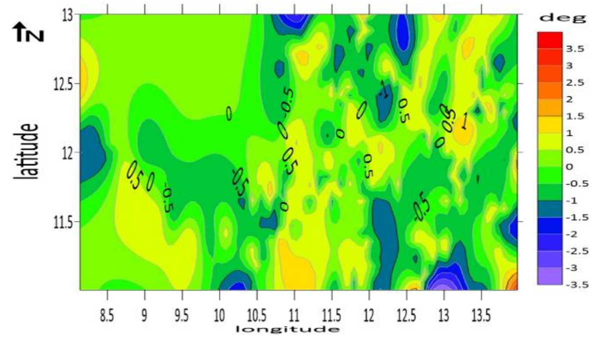

Figure 3: The tilt angle map of the study area.

From figure 3, the tilt angle ranges between between -3.5 degrees to 3.5 degrees with major edges considered to be at angle zero. This describes the edges of the deeper and shallower feature.

The Second Vertical Derivative map in Figure 2 shows that the 'polarity' of the anomaly can still be recognized, i.e. the low density in the central part relative to its surroundings. The second vertical derivative method of gravity anomaly illustrates the amplitude of gravity anomaly that is caused by fault structure that appears as residual anomaly. The map of second vertical derivative method in this study shows that the method is useful in enhancing weaker local anomalies, edges of geologically anomalous density distributions were defined and geologic units are identified. The map produced extended zero contours which corresponds to the edges of local geologically anomalous structures. The quantity zero mGal/m^2 remarkably coincides with most of the lithological boundaries when compared with the major geologic contacts.

The tilt map shows the tilt derivative data which noticeably show the orientation structure of fault that correlates with the geological structure. Tilt derivative technique was not only map of the geologic structure which has a regional characteristic, but also in a minor fault which has the residual anomaly. The tilt angle map shows the angle between portions that have different values of density. The angle ranges between between -3.5 degrees to 3.5 degrees with edges at zero degrees. This describes the edges of the deeper and shallower feature.

When we compare the tilt angle map with the second vertical derivative map, we can observe that there are similarities especially at the edges although the edges are more enhanced in second vertical derivative map in figure 4.2 than tilt angle map in figure 4. This is because of the fact that double differentiation (equation 12) is expected to have more enhancement of the local features than the single differentiation (equation 19).

The importance of the second vertical derivative arises from the fact that double differentiation with respect to depth tends to emphasize the smaller, shallower geologic anomalies at the expense of larger regional features.

The second vertical derivative image is thus often seen as a perfect and better resolved image of the type of anomalies which are significant in oil and gas or mineral exploration than in the gravity image. The second vertical derivative has enhanced the shallower effects at the expense of deeper effects to completely remove the regional effects to determine the sense of contacts. The advantage of the tilt derivative method is well suitable to all source condition of the subsurface; shallow and deep sources. (Yanis *et al*, 2019).

Based on figure 4, the tilt angle anomaly is the inference response over the geological source in the positive value, while the zero data is represented over or near the source, and negative data is outside from source. This technique is useful for simplicity and quickly detecting between the geological structure and host in the research area

IV. SIMILARITIES

The positions lebelled A,B,C and D on both Second vertical derivative and tilt angle maps in figures 2 and 3 respectively are typical similarities between the two methods. Both graphs are showing edges at those points (A,B,C and D) which have the same cardinal points.

V. DIFFERENCES

Tilt angle method describes the edges of both deeper and shallower feature while the second vertical derivative enhances the shallower effects at the expense of deeper effects to completely remove the regional effects to determine the sense of contacts.

The second vertical derivative uses double differentiation with respect to depth which tends to emphasize the smaller, shallower geologic anomalies at the expense of larger regional features while tilt angle derivative is based on the angle of contact between different formations.

Second vertical derivative is suitable for only deeper sources while tilt derivative method is well suitable to all source condition of the subsurface; shallow and deep sources.

CONCLUSION

The second vertical derivative and tilt angle techniques are two important methods used in edge detection especially in potential field studies. We can say that one method is better than the other in some cases but not in all cases. This paper has pointed out some advantages of each of the two methods over the other. This will serve as a guide to a researcher to make choice of boundary/edge detection method based on his interest of anomaly. But it is advisable for a researcher to merge the two methods or include more because of their individual differences and the advantage of one over another. Using multiple methods will add more certainty and efficiency to the result.

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