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Depth Estimation of Vertical Dyke by Applying a Simple Equation

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Abstract

A new procedure of depth estimation to the apex of dyke-like sources from magnetic data has been achieved through the application of a derived equation. The procedure consists of applying a simple filtering technique to the total magnetic intensity data profiles resulting from dyke-like bodies, having various depths, widths and inclination angles. A background trending line is drawn for the filtered profile and the output profile is considered for further calculations.

Two straight lines are drawn along the maximum slopes of the filtered profile flanks. Then, the horizontal distances between the two lines at various amplitude levels are measured and plotted against the amplitudes and the resulted relation is a sloping line. The constant values of the equation of the least square fitting to the slope line and with the maximum value of the filtered profile multiplied by an empirical factor have been used to determine the depth to dyke-like source. Low errors percentages have been obtained from the application of the present procedure to a large number of dyke-like bodies and to the field example, indicating the successful of the method.

Keywords: Magnetic interpretation; dyke-like body; Fraser filter; depth estimation.

حساب عمق القاطع العمودي بتطبيق معادلة بسيطة

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الخلاصة

تم التوصل الى اسلوب جديد لحساب العمق الى قمة المصادر المشابهة للقواطع من المعلومات المغناطيسية من خلال تطبيق لمعادلة مشتقة. يشتمل الاسلوب تطبيق تقنية ترشيح بسيطة على المسارات المغناطيسية للشدة المغناطيسية الكلية التي تسببها اجسام تشبة القواطع والتي لها عمق وعرض وزاوية ميل مختلفة. من خلال رسم خط مستقيم يمثل اتجاه الخلفية العامة للمسار المرشح وان النتيجة من هذا الرسم استخدمت في الحسابات اللاحقة.

رسم خطان مستقيمان بمحاذاة اقصى ميل لكلا الجناحين للمسار المرشح ومن ثم قيست المسافات الافقية بين الخطين عند مستويات مختلفة لمقدار الشدة المغناطيسية وبعدئذ رسمت العلاقة بين المسافات الأفقية ومقدار الشدة المغناطيسية وكانت النتيجة خطآ مستقيمآ مائلآ. ان قيم الثوابت لمعادلة افضل خط مستقيم بطريقة المربعات الصغرى مع القيمة القصوى للمسار المرشح مضروبة بعامل تجريبي قد استخدمت في

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حساب العمق للمصدر الذي يشبه القاطع. لقد تم الحصول على نسبة خطأ مئوية واطئة من خلال تطبيق هذا الاسلوب على اعداد كبيرة من الأجسام التي تشبه القواطع وعلى مثال حقلي وقد اشارت النتائج الى نجاح الطريقة التي اعطت نتائج مقاربة الى الواقع.

Introduction

The depth to a magnetic source is a piece of information of great value in geological/geophysical interpretation of subsurface structures. Many literatures on magnetic potential data are directed to estimation of depth of a source. Several methods have been developed to estimate the magnetic source depth. The number keeps growing with the continual development of new algorithms [1].

Peter's slope half-slope [2] was one of the earliest magnetic estimate techniques. This method has been developed by Bean ratio method [3]. Gay Parker [4] derived the equations for thin and thick dyke bodies and he published a standard curves for interpretation of magnetic anomalies due to these sources. The power spectrum has been used to estimate the depths of magnetic sources [5, 6]. A semiautomatic technique has been proposed by [7] through using folding technique where the magnetic field curve splits into symmetrical and antisymmetrical components. Firstly, it locates anomaly center and then estimates depth by matching the symmetric component to responses to a given vertically magnetized, two dimensional model. Werner method was originally designed to solve the dipping thin dyke problem [8]. The symmetrical curve for horizontal and vertical gradients of the magnetic field of dyke-like models is used to deduce the various parameters of the model [9].

Atchuta *et.al* [10] and [11] used the anomaly width at half the amplitude to derive the depth. Atchuta *et. al*. [10] used the characteristics of the analytical signal which they referred to as complex gradient to solve the effect of overlapping edges. They gave relationships that can be used to estimate the depths for geometric bodies. Three methods have been described by [12] to estimate source depths for magnetic anomalies arising from dipping dike models. There are several depth rules that can be used to determine a body depth [13- 15]. The depth estimates derived from any of the techniques described are seldom more accurate than 10 percent of the actual depths and sometimes as poor as 50 percent [16].

Al-Rawi [17] used three empirical relations to estimate depths of dyke-like bodies through applying three procedures to magnetic profiles after subjecting the total magnetic data to filtering technique. In the present paper an equation has been derived to ease the determination of depths for dyke-like bodies that has been described by Al-Rawi [17] previously.

Magnetic Profiles for Dyke-Like Bodies

Total magnetic intensity profiles due to dykes with various depths, widths and inclination angles of magnetic field are calculated (Figure- 1). Other parameters are kept constant. Calculations are based on a ready used computer program issued by Geophysical Software Solution Pty [pdyke] Ltd [18]. These magnetic profiles have been used to estimate the depths to these bodies by applying the present procedure of depth determination. The inclination angles for the magnetic field used are 10, 20, 30, 40, 45, 50, 60, 70 and 80 degrees.

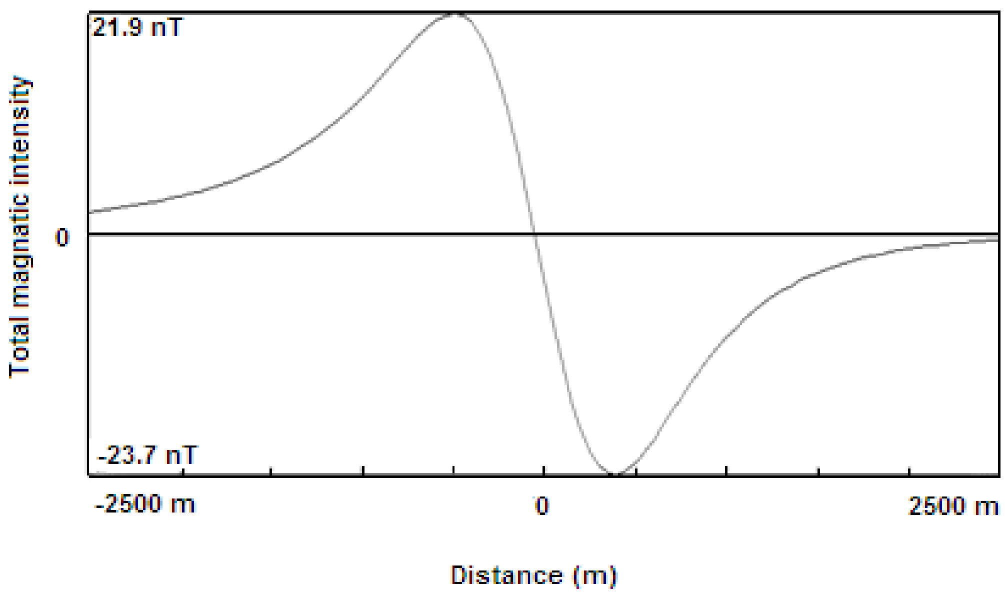

Figure 1- The total magnetic anomaly profile due to a vertical dyke-like body with inclination angle of 40^{o}, and with depth and thickness of 500m that has been treated for depth estimation.

The total magnetic values [T1, T2-----Tn] for each profile is treated by applying filtering technique that has been described by Fraser [19]. This filter consists of the sum of the magnetic data at two consecutive magnetic values [T3+T4] subtracted from two consecutive magnetic values before [T1+T2] [i.e. [T3+T4]-[T1+T2]]. The outcome of the process is the filtered profile of the total magnetic data. The first calculated value of the filtered profile should be plotted at midpoint between T2 and T3.

Depth Estimation Procedure

The filtered magnetic values are plotted against distance Figure- 2. A background trending line is drawn for the filtered profile that represents a zero level reference. The difference values between the zero level line and the filtered profile values at certain distance interval are determined such as a residual and then re-plotted in order to outline the actual shape of the profile and also to determine the maximum amplitude value of the filtered data [F_{max}] as shown in Fig.[3]. Two straight lines of the best maximum slopes are drawn along the both sides of the filtered profile. These should pass through few points that give the optimum slope, since they play a great role in depth estimation. Increasing the dyke thickness is associated with an increase of points to give a better slope lines. The two straight lines will intersect the zero level line and also intersect each other in the other ends Figure- 3.

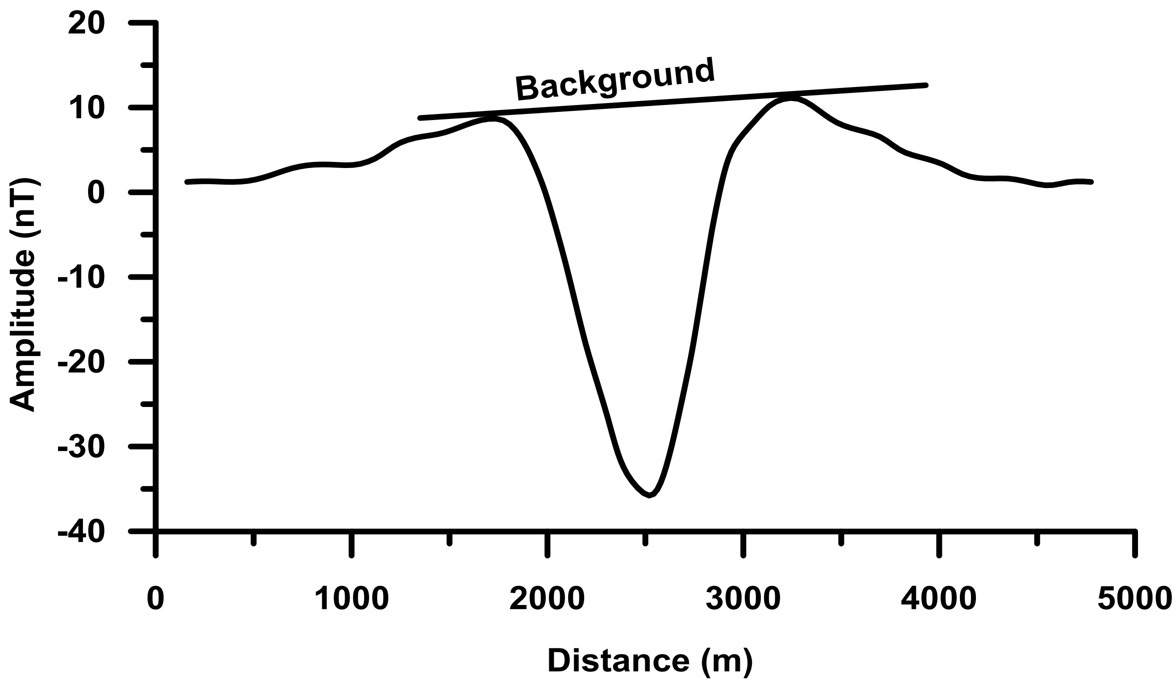

Figure 2- Filtered magnetic profile of Figure-1 with the defined background line.

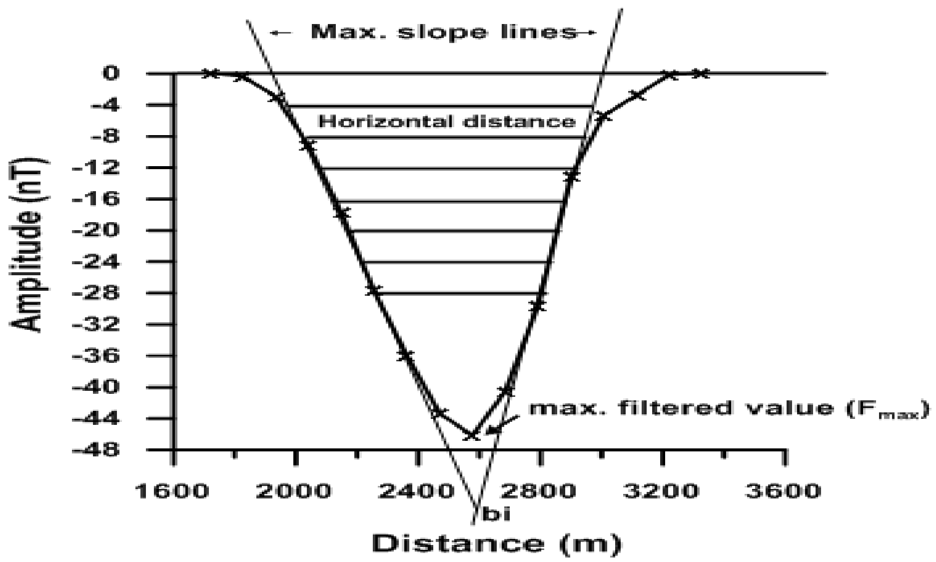

Figure 3 - Filtered magnetic profile as a result of subtracting the original filtered data from the background of Figure-2. It is exhibited the maximum slope lines along the two flanks and the horizontal distances between them.

Then, the horizontal distances between these two maximum slope lines are measured at various amplitude levels. Re-plotting these distances [x-axis] against the amplitude values [y-axis] will result in a linear relation with certain slope angle Figure-4.

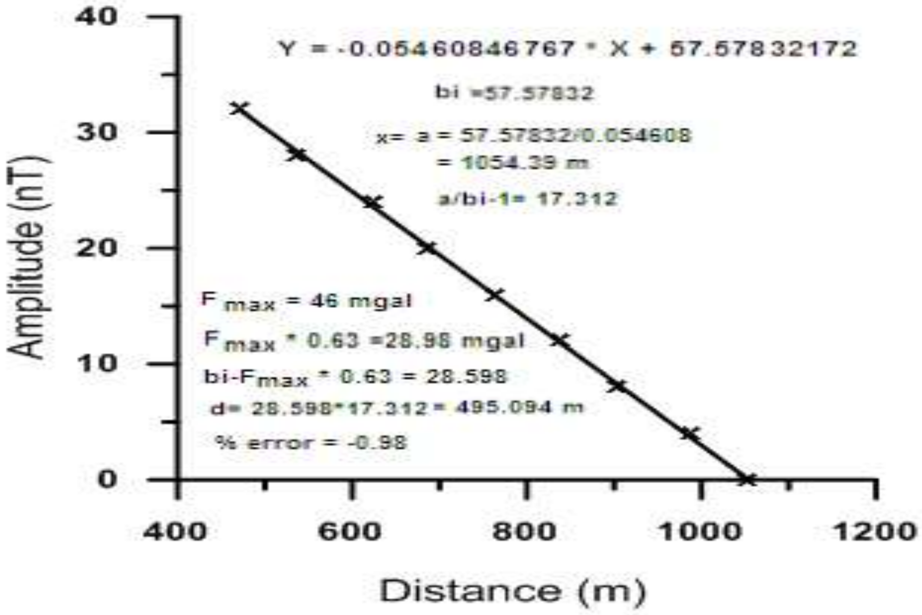

Figure 4- Least square fitting equation to the slope line resulting from the plot of the horizontal distances against amplitudes and with calculation procedure for depth estimation of dyke-like body.

This angle is varying and it depends upon the depth of the magnetic source (here dyke-like body). Shallow source has steep slope [large slope angle] while deeper source has gentle slope (small slope angle). Figure-5 Illustrates the slope lines for various inclination angles for the same source depth.

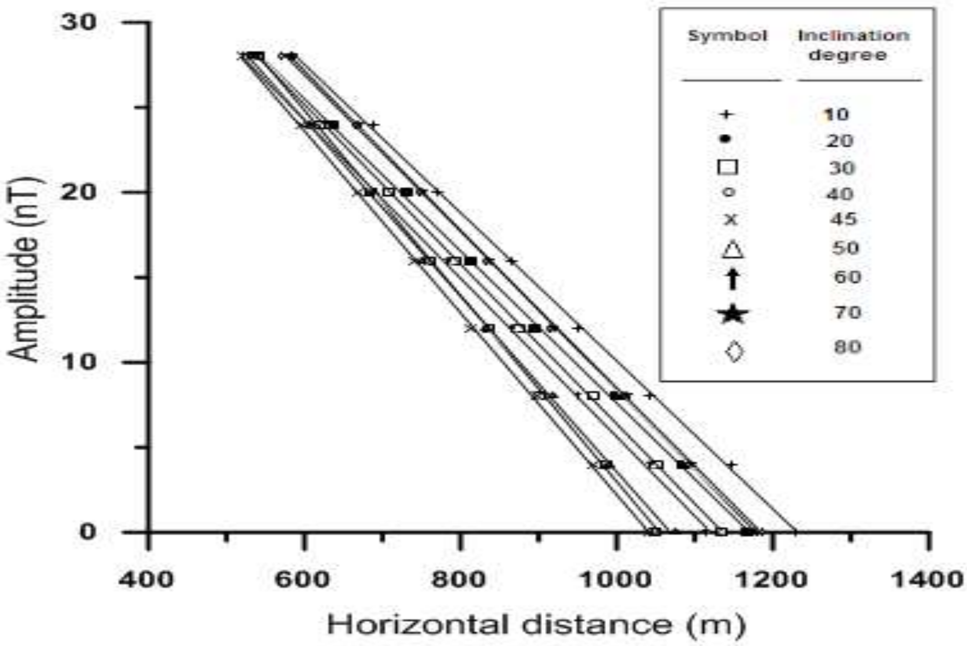

Figure 5- The slope lines plotted from horizontal distances against amplitudes for dyke- like bodies having the same depth with inclination angles 10-80 degree. It illustrates approximately the same slope angle for the same source- depth.

From this relation Figure- 4, Al-Rawi [17] has used an empirical relation where the value of 2/3 value of the maximum filtered data is defined on the amplitude axis. Then a horizontal line is drawn from this position until it intersects slope lines, where the intersection points define a position on the distance axis which is equal directly to the depth of dyke-like body. In the present procedure, an equation has been derived from the following well known relation shown in the diagram Figure- 6 of the horizontal distances against amplitudes represented on x-axis and y-axis respectively.

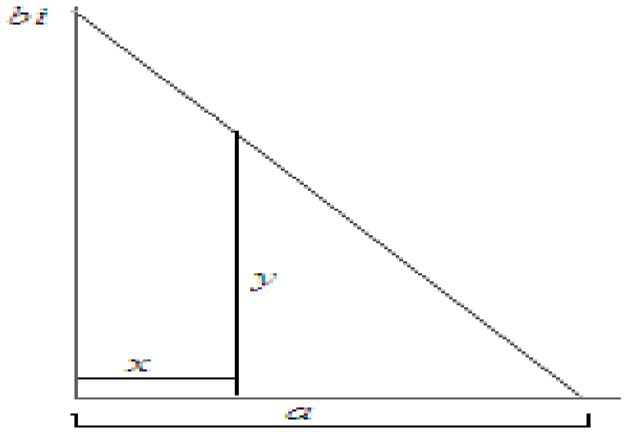

Figure 6-The diagram showing the relationship between axes that has been used to derive the equation **.**

$$\frac{y}{bi} + \frac{x}{a} = 1$$

The relation in Figure- 6 represents a first degree equation for a straight line [y=ax+b]. Derivation of this equation will lead to the following formula of depth estimation if *d*=x:

$$d = (bi - e * F_{\max})(\frac{a}{bi} - 1) \qquad [1]$$

Where
d =depth to the apex of the dyke
bi = maximum amplitude value as the result of intersection of the slope line with amplitude axis or approximately the value of intersection of the two maximum slope lines.
F_{max} = maximum value of the filtered profile data defined above.
e = an empirical factor
a = maximum horizontal distance at which the slope lines intersect distance axis or the distance between the two lines at zero level.

In order to get the best linear slope line and with [bi] and [a] values, a least square fitting line to the distance - amplitude relation, defined the equation of the straight line with its constant values. Then, the depth is estimated directly by applying the equation above and the calculation procedure is outlined on Fig. [4]. The empirical factor [e] is found to be 0.65 for most cases, but for more accurate estimation, it is possible to use values of [e] according to inclination angles. The value varies between 0.61-0.67 for most cases of dyke-like bodies at various inclination angles Figure-7 , where there is slight increase when inclination angle goes to high or low latitudes i.e. toward 10 and 80 degrees. For these angles, the estimated depths will be more accurate when empirical factor becomes 0.66 and 0.67 respectively.

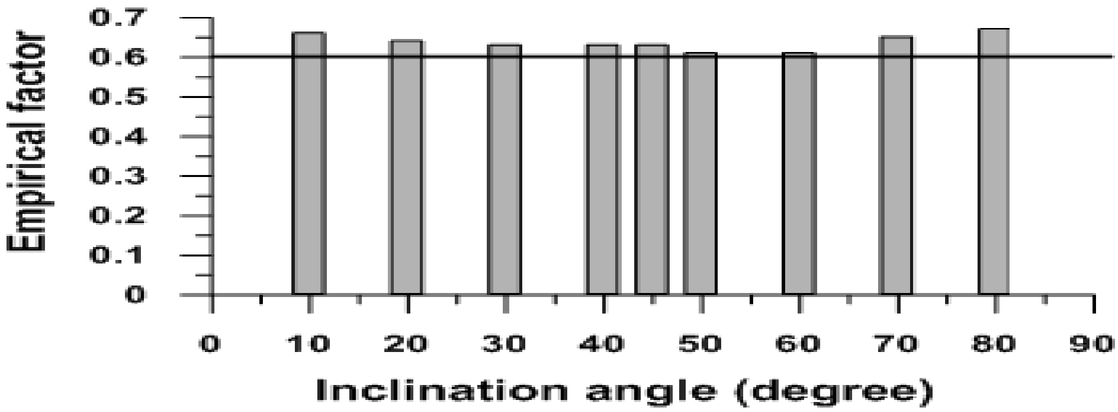

Figure 7- The empirical factors that can be used to apply the present equation of depth estimation according to the inclination angle of the magnetic field. The horizontal line at empirical factor of 0.6 illustrates the small differences at various inclination angles.

Application of the Procedure

A large number of synthetic total magnetic anomalies due to vertical dyke-like bodies of various depths, widths and inclination angles have been used to check the validity of the current derived equation of depth estimation. The mentioned procedure of depth estimation is executed on an example shown on Figures- (1,2,3 and 4) for inclination angle 40 degree and 500m depth. Low errors percent have been achieved for most cases. The synthetic magnetic profiles consist of tens of models having various parameters and have been tested by the current method which indicates the reliability of the application of the derived equation.

The maximum value of the filtered profile [F_{max}] plays an important role in the calculation, since any variation from actual value will increase or decrease the errors percentages. So, the value should be carefully measured or calculated.

Field Example

To illustrate the success of the present procedure of depth estimation, the published magnetic anomaly (Figure-8a) over the Pima copper mine in Arizona [4], where the actual given depth was equal 64.00m, has been used to check the present equation. The magnetic anomaly is digitized at interval of 45.45m and the total magnetic is calculated and subjected to the above mentioned filtering procedure (Figure-8b). The maximum slope lines of the filtered profile Figure- 9(a) are defined with horizontal distances at various amplitudes. The least square fitting equation to the slope line resulting from the horizontal distances - amplitudes relation is used Figure-9(b) and the estimated depth is 64.85m and with percentage error of 1.3%.

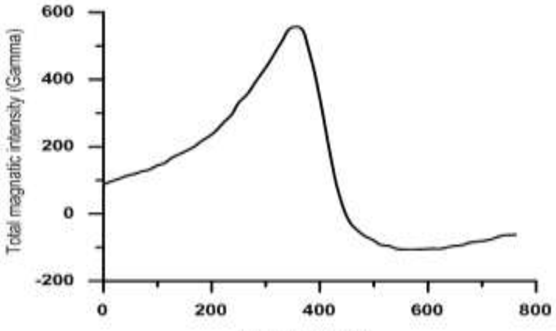

Figure 8(a) - Magnetic anomaly over the Pima copper mine in Arizona

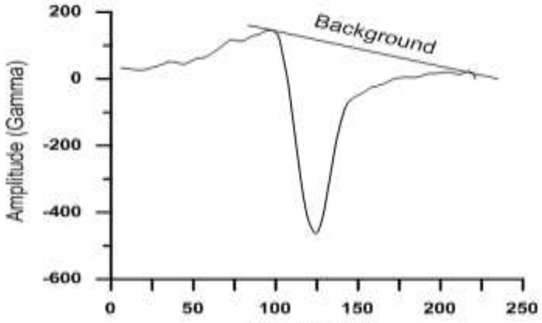

Figure 8(b)-Filtered magnetic profile of Figure7(a).

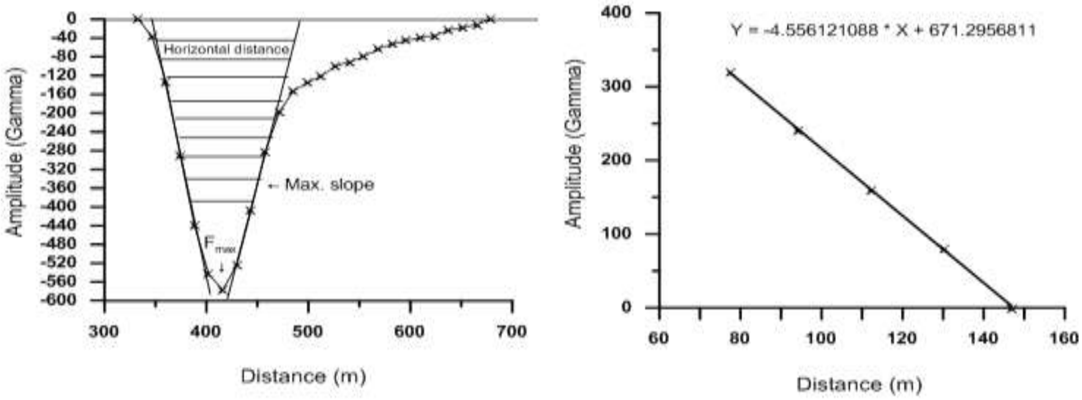

Figure 9(a). Filtered magnetic anomaly as residual with maximum slope lines and horizontal distances.

Figure 9(b) Least square fitting equation for the horizontal-amplitude relation.

Conclusions and Discussion

The outcome from the application of the present equation on magnetic anomalies, caused by vertical dykes, exhibits the success and reliability of the procedure. Low errors percents have been achieved for most cases. For shallow sources, digitizing interval should be small, and the background line for the filtered profile should be defined properly since it affects the shape of the residual profile and at the same time, the determination of the maximum value [F_{max}]. In case, there is a steep gradient this will give a negative value for the second part of the equation [i.e. a/bi-1] and in this case, when a/bi is less than one the [-1] should be omitted. This case has been found in the field example and treated accordingly.

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