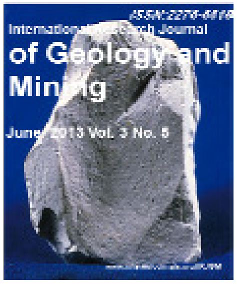

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Review

Interpretation of ground magnetic survey over Cleveland dyke of north Yorkshire, England

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Abstract

The Cleveland Dyke of North Yorkshire is one of a swarm of tholeiite dykes that radiate from the igneous intrusive complex of Mull; the dyke is an olivine-free, plagioclase and pyroxene-phyric basaltic andesite with considerable amount of magnetite minerals present. The magnetic survey profile lines trend NNE-SSW direction which crosses the E-W trending dyke approximately at right angles, series of Total Magnetic Field derivatives anomalies were constructed along profile lines over the dyke. The derivative anomalies of Analytical Signal and Total Horizontal Derivative are positive and shows two local maxima which serve as indicator of dyke edges (boundaries), thus the location of the dyke width is closed to the local maxima or on top of the local maxima. The estimated location of the dyke edges from the aligned derivatives plots falls between 22 - 32m and 18 - 33 meters along the stacked profile line from the base station, therefore the estimated dyke width range from 10-15m. The depth of the Cleveland dyke was estimated as 5 – 7.5 meters using haft maximum width manual method. These variations in width are due to power of the derivatives couple with the remanent magnetization of the dyke.

Keywords: Cleveland, dyke, olivine, magnetite, magnetic, depth, magnetometer.

INTRODUCTION

Dykes and sills of a mafic composition often have a strong, Remanent magnetisation due to rapid cooling. On aeromagnetic maps they often produce the clearest anomalies which cut discordantly across all older rocks in the terrain. Dykes and dyke swarms may often be traced for hundreds of kilometres on aeromagnetic maps, which are arguably the most effective means of mapping their spatial geometry (Fairhead, 2009). Some dyke materials have been shown to be intrinsically non-magnetic, but strong magnetic anomalies can still arise from the contact auriole of the encasing baked country rock (Fairhead, 2009). An enigmatic feature of dyke anomalies is the consistent shape of their anomaly along strike lengths of hundreds of kilometres, often showing a consistent direction of remanent magnetisation.

Magnetic survey method determines the sub-surface spatial distribution of rock magnetisation properties, (or susceptibility and remanence) which cause small changes in the earth's magnetic (Geomagnetic) field strength and direction. The magnetic field survey over the Cleveland dyke was carried out with the aim of constructing a series of Total Magnetic Field Intensity (TMI) along the profile lines and to estimate the width and depth of the dyke.

Regional Geology

The Cleveland Dyke of North Yorkshire (Figure 1) is one of a swarm of tholeiite dykes that radiate from the igneous intrusive complex of Mull. In the Cleveland Hills the dyke intrudes Upper Carboniferous Coal Measure and Millstone Grit sediments and has long been considered as Tertiary in age (Barrow, 1988). The most extensive dyke swarm is related to the Mull intrusive complex and includes the Cleveland dyke, which appears to extend some 430 km from Mull through the Scottish Midland Valley (SMV) to the coast of northeast England. Most of the area is underlain by bedrock of Carboniferous age (Barrow, 1988). In the Centre Upper Carboniferous

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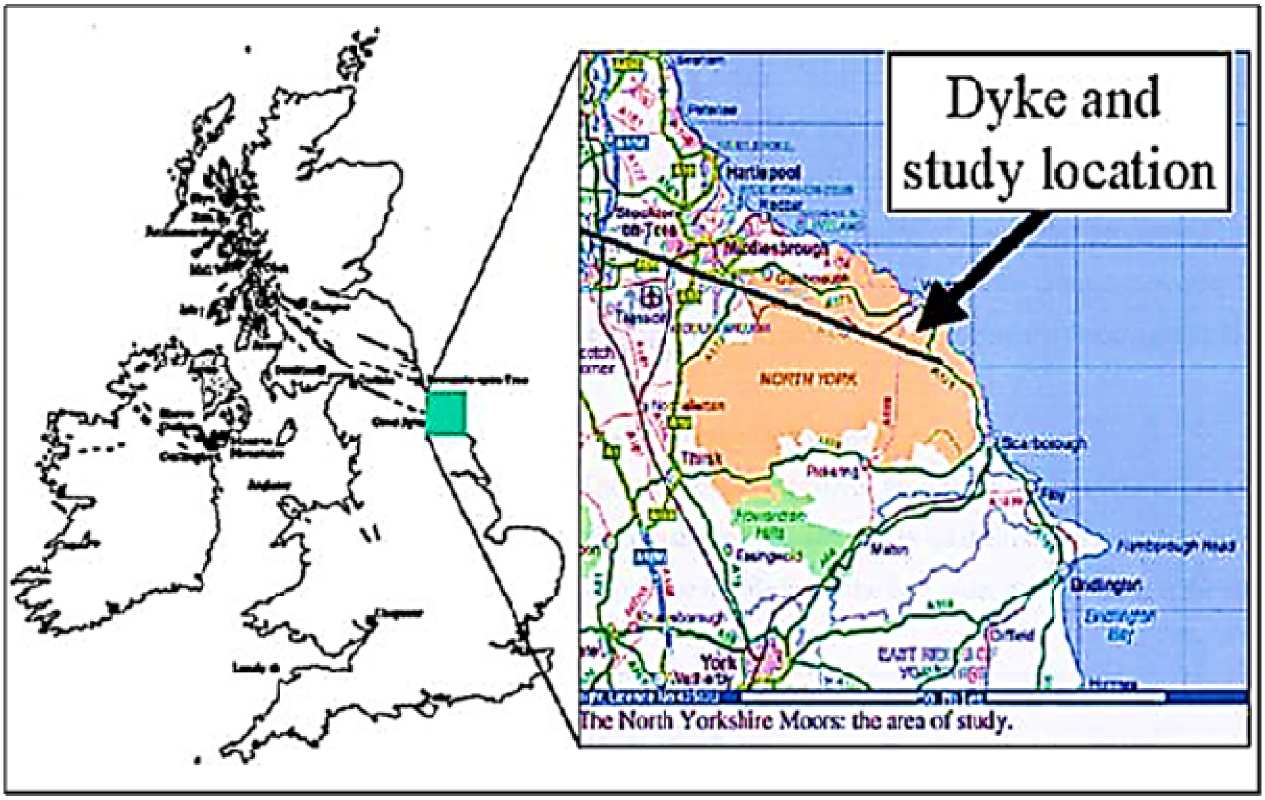

Figure 1. Location of Cleveland Dyke and Field Study Area (After Barrow, 1988)

(Pennsylvanian) Scottish Coal Measures Group sedimentary strata are overlain by the Permian Mauchline Volcanic and Mauchline Sandstone formations. Lower Carboniferous (Mississippian) rocks comprise both sedimentary strata and volcanic rocks; the Clyde Plateau Volcanic Formation and the Troon Volcanic Member (Passage Formation) are toward the base and near the top of the sequence, respectively. Carboniferous bedrock unconformable overlies rocks of Silurian and Devonian ages. The outcrop of Carboniferous and older rocks is controlled by major fault structures of north-west to east-north-east trend. Both the Inchgotrick and Bankhead faults juxtapose Lower Carboniferous strata with rocks of Silurian to Devonian ages and the Southern Upland Fault, in the south-east of the area, defines the southerly boundary of the Midland Valley of Scotland. The sequence of rocks of late Silurian to early Devonian age includes the Duneaton Volcanic Formation and is intruded by younger Devonian granodioritic and dioritic rocks of the Distinkhorn Plutonic Complex (Dubey and Holmes, 1929). The Carboniferous rocks in the area are known from mapping, incorporating coal mining data, to be intruded by many dykes, sills and volcanic vent rocks of Carboniferous to Permian age and, in addition, dykes and intrusions of Palaeogene age cut across all older rock units. The distribution of minor intrusions is less well-known in Pre-Carboniferous rocks; the Cleveland dyke is an olivine-free, plagioclase- and pyroxene-phyric basaltic andesite with considerable amount of magnetite minerals present (Barrow, 1988).

Magnetic Data Acquisition

Proton Magnetometer was utilise for the magnetic survey exercise which measures the Total Magnetic Field Intensity (TMI), the direction and orientation of profile lines and dyke were determined using 'silver' compass/GPS. The survey profile lines trend NNE-SSW direction which crosses the E-W trending dyke approximately at right angles. The Declination, Inclination of the geomagnetic field was determined as 3^{0}24'.00'' and 30^{0}24'.00'' as at 06/02/2010 respectively. Using pegs profile lines were laid across and perpendicular to the dyke direction (E-W) with station spacing set at 2m apart. The station numbering convention was same as distance along the profile line, (i.e. station 0 will be at 0m on the profile line, station 2 will be at 2m along the profile line and station 3 will be at 4m along the profile line, etc.). GPS readings (table 1) were taken at the start and end of each profile line; each profile length was set out at 62m almost equidistant on both sides of the dyke. A magnetic

Table 1. GPS Readings for all Profile lines

Profile Lines		Latitude (N)	Longitude (W)
Line A	Start	$54^0$24.657’	$00^0$40.645’
	End	$54^0$24.616’	$00^0$40.684’
Line B	Start	$54^0$24.654’	$00^0$40.623’
	End	$54^0$24.609’	$00^0$40.660’
Line C	Start	$54^0$24.647’	$00^0$40.597’
	End	$54^0$24.603’	$00^0$40.634’
Line D	Start	$54^0$24.623’	$00^0$40.543’
	End	$54^0$24.587’	$00^0$40.589’

base station was established at the first station of each profile line and total field readings and time were measured after every 20 minutes on the high pole position. Four similar profile lines (B, C, D and E) were laid out parallel to the first profile line (A) with the profile lines being 50m apart, similar processes were repeated as in the first profile line (A). Using the Proton Magnetometer, the total magnetic field at each station was measured at 1m above ground (low measurement) and 2m above ground (high measurement) and the corresponding time of measurements were also recorded. For every particular station, measurements were repeated twice or thrice in order to ensure accuracy and obtain the average readings. Finally the regional field was backed out using the first base station total magnetic value (e.g. 49268.85nT for profile line A).

Magnetic Data Processing

Processing of ground observations to magnetic anomaly is given as:

$$\text{Magnetic Anomaly} = \text{Tobs} - \text{Tth} - \text{Ttv}.$$

Tobs: Is the absolute value of geomagnetic total field measured during the survey exercise using Proton Magnetometer.

Tth. Is derived from public domain software mathematical model. Inputs are latitude, longitude, height and date of the observation point. Full field components are outputted from the Definitive Geomagnetic Reference Field (DGRF) or International Geomagnetic Reference Field (IGRF).

Ttv. All the transient variations are removed by recording their effects at based stations using Proton Magnetometer of the same sensitivity as used to measure Tobs, all measurements are relative to the Quite Night Time Values (QNTV), which occurs at about 1am to 4am when there is least interaction of the solar wind with the geomagnetic field. The variation or departures from the QNTV are added to Tobs to make all Tobs appear to be recorded at the time (i.e. QNTV).

The diurnal variation of the total magnetic field recorded at base station for profile line A at every 20 minutes is shown in Figure 2, also the Total Magnetic Field (T) recorded along selected profile lines A, C and E were shown in Figure 3, 4 and 5 respectively.

Ground Magnetic Data Interpretation

There are three stages to ground magnetic data interpretation:

i. Data Enhancement
ii. Qualitative interpretation and
iii. Quantitative interpretation.

Data Enhancement

This can be undertaken on line or grid based data with the aim of making the interpretation stage easier, which take the form of transforming and/or filtering the data and generating a range of derivatives. The prime objective is to enhance or isolate features that you wish to identify better prior to qualitative and quantitative analysis. Since magnetic and gravity anomalies are always broader than the body causing them, this creates problems of anomaly interference and make delineation of the individual sources difficult (Fairhead 2009). The range of derivatives applied to the dataset is as follows:

Horizontal Gradient (XDR) = $\left[\frac{\partial T}{\partial X}\right]$.

X Is distance along profile, T is horizontal Total Magnetic Intensity (TMI) measured in the field. The derivative can be useful in delineating magnetic contacts. It is severely affected by the inclination of the inducing geomagnetic field and is therefore not a good indicator of the true location of a contact until the magnetic data have been reduced to the pole (RTP) (Fairhead 2009). The horizontal derivative can be simply calculated in the space domain. Figure 6 shows the horizontal derivative

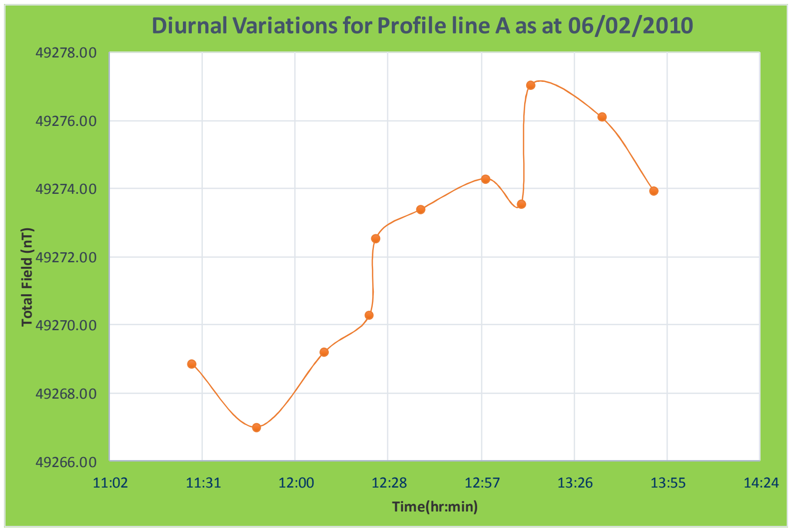

Figure 2. Diurnal Variation for Profile Line A as at 06/02/2010

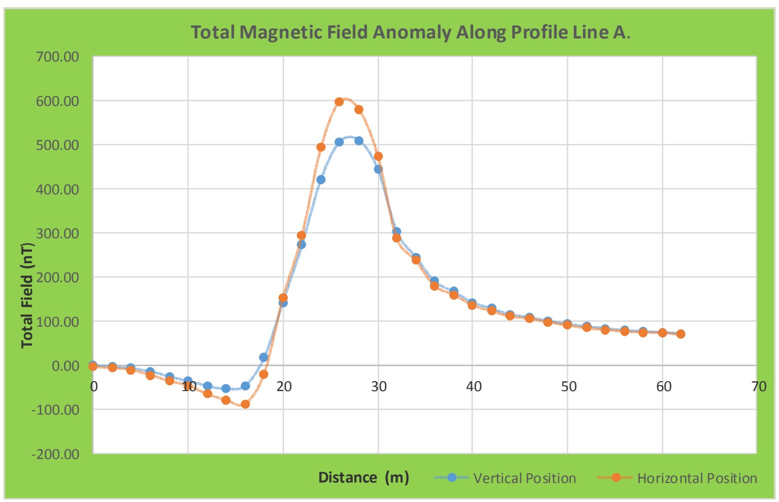

Figure 3. Total Magnetic Field Anomaly along Profile Line A

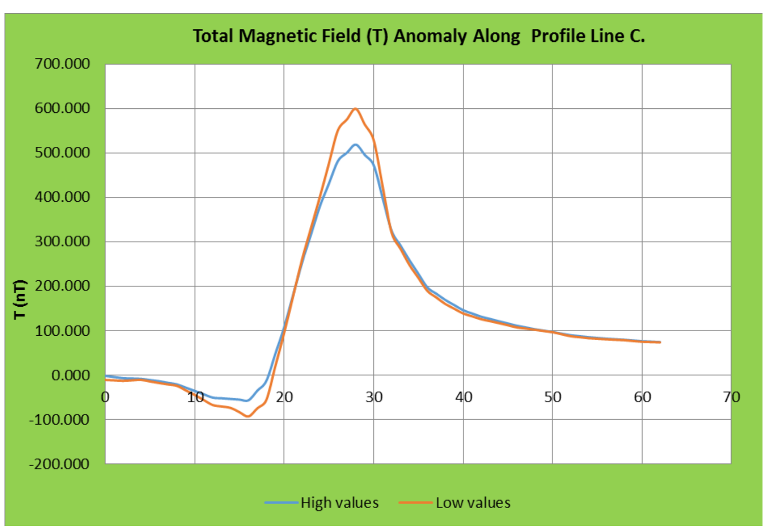

Figure 4. Total Magnetic field (T) Anomaly along Profile line C

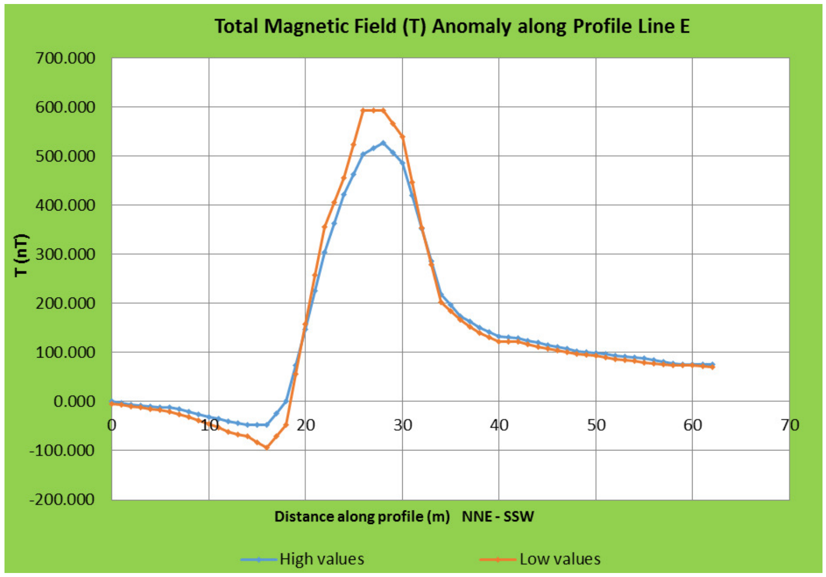

Figure 5. Total Magnetic field (T) Anomaly along Profile line E

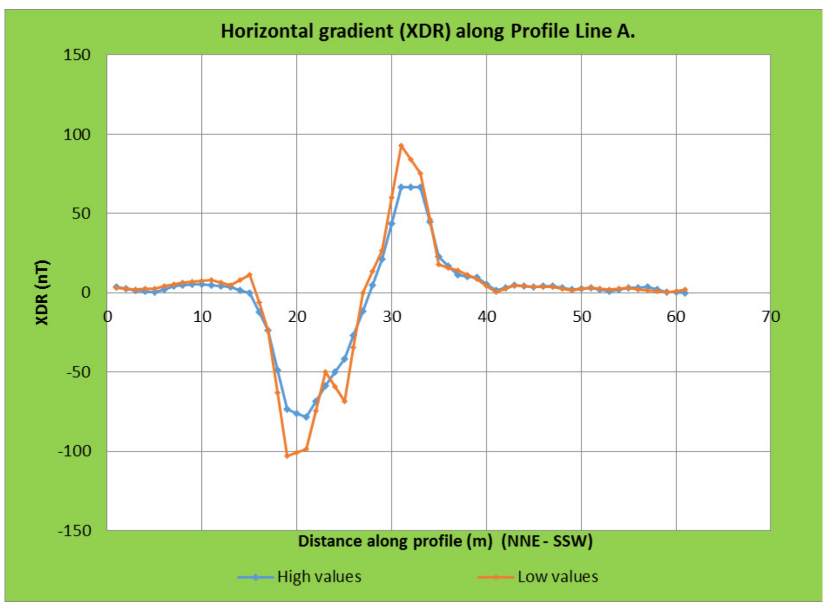

Figure 6. Horizontal Gradient (XDR) along Profile line A

(XDR) plot along profile line A.

Vertical Gradient (VDR) = $\left[\frac{-\partial T}{\partial Z}\right]$.

The vertical derivative (vertical gradient) is a good method for resolving anomalies over individual structures in total magnetic intensity data and importantly suppresses the regional content of the data (Fairhead, 2009). It also makes anomalies smaller in width and matches more closely the causative body. Figure 7 shows vertical derivative (VDR) plot along profile line A.

Second Vertical (SVDR) Derivative = $\left[\frac{\partial^2 T}{\partial z^2}\right]$.

It has the property of taking a zero value over contacts. Contour maps or images of SVDR can be noisy, because you are dealing with a 2nd order derivative which magnifies noise. In addition, zero values are not necessarily confined to regions over contacts, so that SVDR maps should be used with care. The second vertical derivative can be calculated using the 1D Fast Fourier Transform or from the space domain using

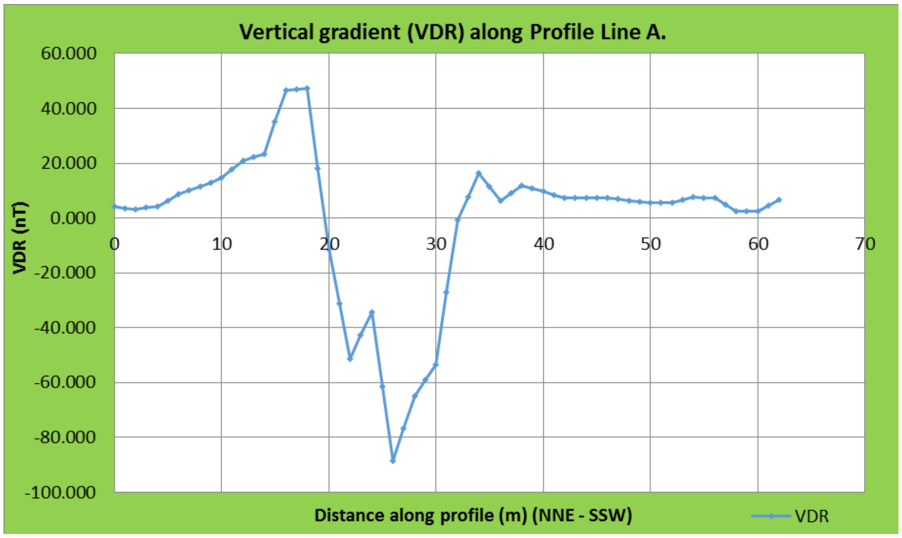

Figure 7. Vertical Gradient (VDR) along Profile line A

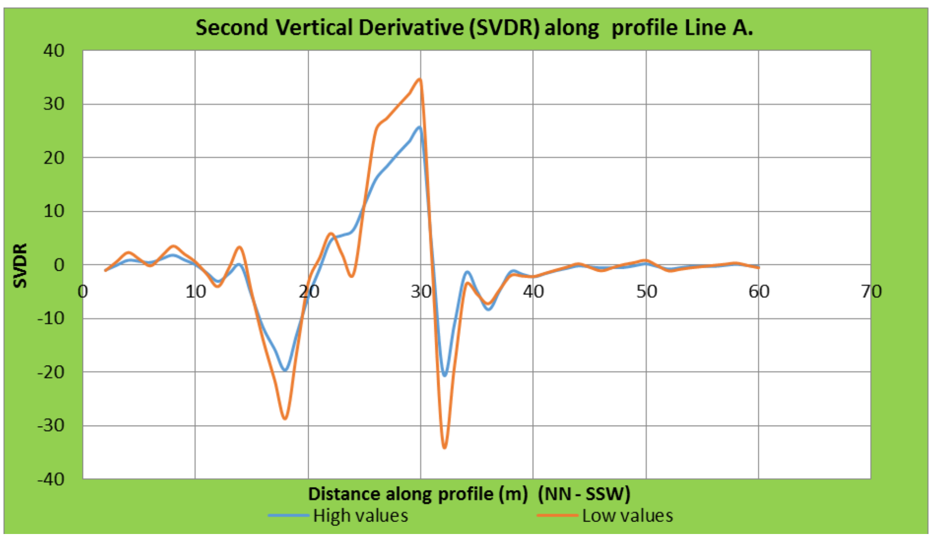

Figure 8. Second Vertical Derivatives (SVDR) along Profile line A

Laplace's equation: Figure 8 shows second vertical derivative (SVDR) plot along profile line A.

Full (Or Total) Horizontal Derivative (THDR) $= \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}$. As the name suggests it measures the full horizontal gradient. The gradients are all positive thus this derivative is easy to map. In the case of magnetic anomalies the THDR will give an indication of the boundary but due to the complexity of the anomaly will not made mapping of the edges of structures very easy. Figure 9 shows total horizontal derivative (THDR) plot along profile line A.

The Analytic Signal $|\mathbf{A}|$ Method (Or AS) is also known as the total gradient method. For the profile case in 'X' direction the expression is given as:

$$|\mathbf{A}| = \mathbf{A(X)} = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2}.$$

The total gradient is simply the Pythagorean sum of the line along horizontal derivative and vertical derivative (the resulting sum is positive). It peaks directly over the top of contacts, but is somewhat noisier and has lower resolution than the horizontal derivative. Because it requires the vertical derivative, it has to be calculated

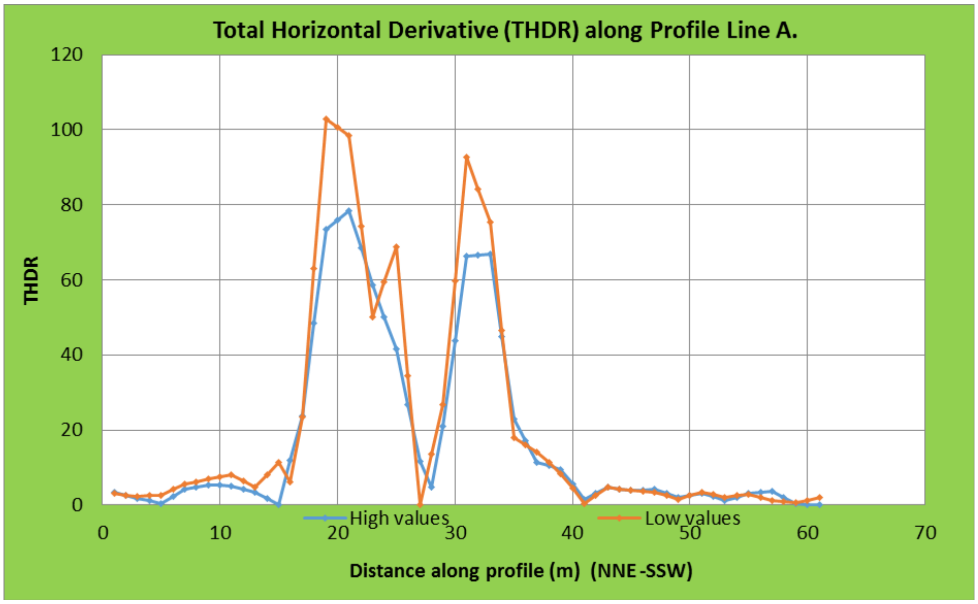

Figure 9. Total Horizontal Derivative along Profile Line A

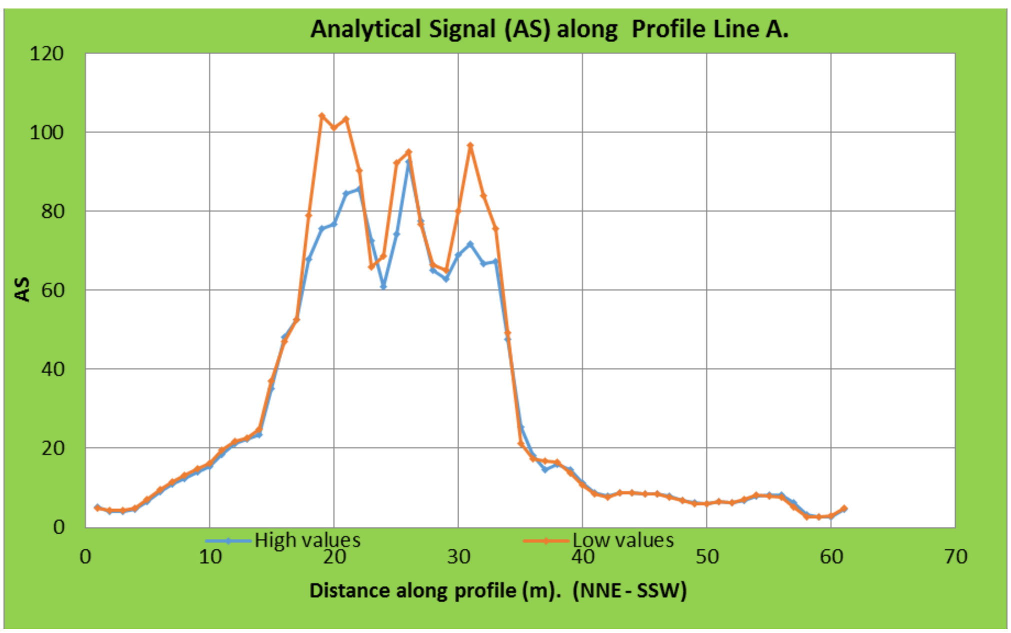

Figure 10. Analytical Signals along Profile line A

Using 1D Fast Fourier Transform methods. Figure 10 shows analytical signal plot along profile line A.

Local Phase or Tilt Derivative (**θ or TDR**): The local phase is defined as:

$$\theta = \tan^{-1}\left(\frac{\partial T}{\partial z}/\frac{\partial T}{\partial x}\right).$$

The derivative work well but have limitations in that the magnetic response is dependent on the susceptibility contrast present. If the contrast is large the anomaly will be large, if the contrast is small the anomaly will be small. This is true for Vertical Derivative (VDR), Total Horizontal Derivative (THDR) and Analytical Signal (AS). As such it may be difficult to image subtle anomalies due to the presence of large amplitude anomalies. The Local Phase, θ, or Tilt derivative (TDR) is used in seismic data analysis and was first reported for potential field studies by (Miller and Singh 1994) who used the name "Tilt". The Tilt Derivative (TDR) is defined as follows;

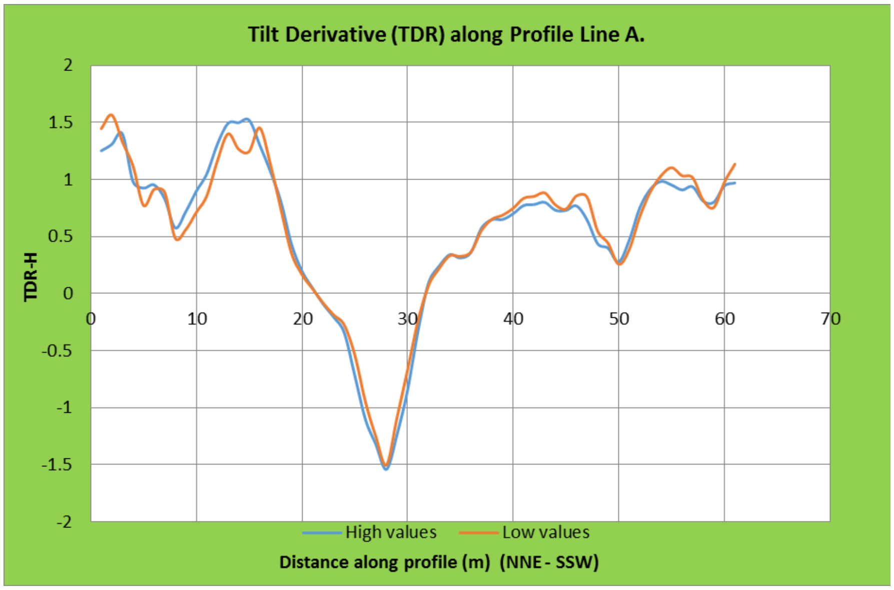

Figure 11. Local Phases (Along Profile A)

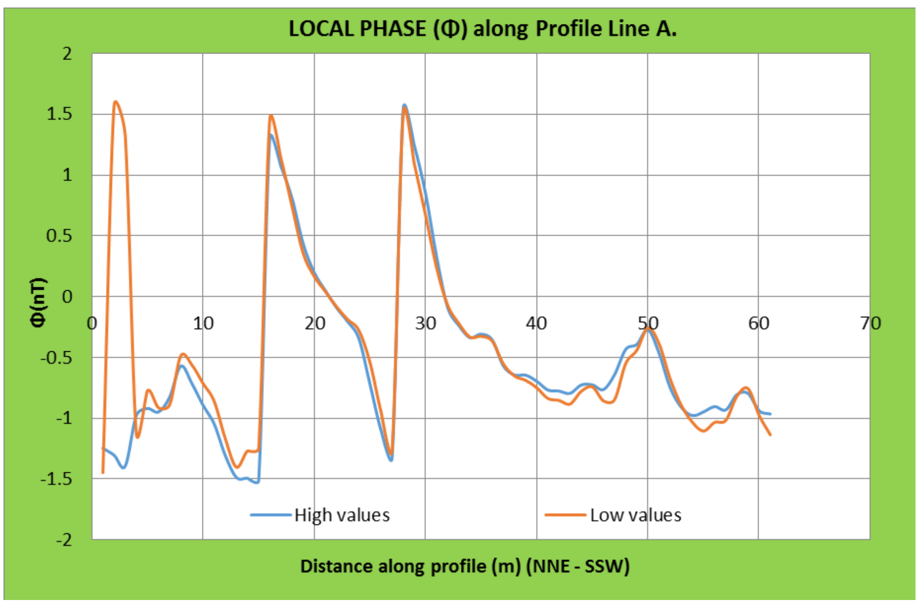

Figure 12. Tilt Derivatives (TDR) along Profile line A

Profile in X direction

$$\mathrm{TDR} = \mathrm{ATAN}\left(\frac{\partial T}{\partial z} \Big/ \frac{\partial T}{\partial x}\right),$$

Grid (x, y):

$$\mathrm{TDR} = \mathrm{ATAN}\left(\frac{\mathrm{VDR}}{\mathrm{THDR}}\right)$$

Where $\mathbf{ATAN\ is\ ARCTAN\ or\ tan^{-1}}$

The major advantages of the Tilt derivative in grid form are:

I. Its ability to normalise the signal field to within ±1.57 (or ±π/2), which are the limits of the ARCTAN (ATAN) function.

II. Its sign is controlled by the vertical derivative (VDR) since THDR is always positive. This allows easy comparison between the TDR and VDR derivatives.

Figure 11 and 12 shows the Local Phase and Tilt Derivative Plots along profile Line A.

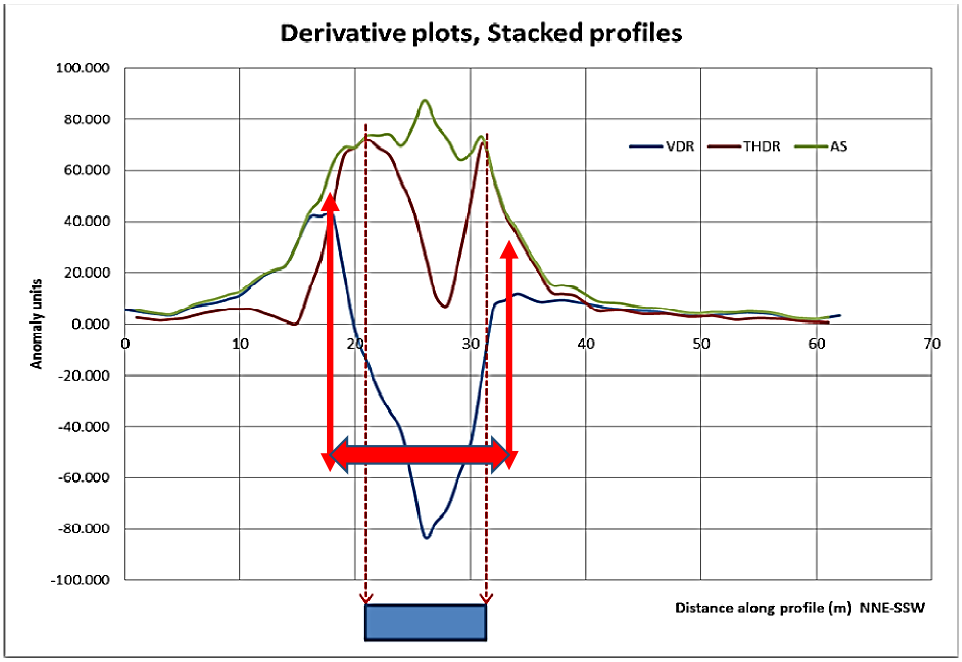

Figure 13. Estimate of width of dyke from derivatives anomalies. Width = 10m and 16m

Local Wave Number (K)

(Thurston and Smith, 1997) have gone one step further and introduced the local frequency, denoted f and the local wavenumber K. The local frequency, f, is defined as the rate of change of the local Phase with respect to X. This quantity is given by:

$$f = \frac{1}{2\pi}\frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial T}{\partial z}\Big/\frac{\partial T}{\partial x}\right]$$

In the analysis of potential fields it is often more convenient to use local wavenumber, denoted by K, rather than f where

$K = 2\pi f$.

Making this substitution and using the differentiation rule gives:

$$K = \frac{1}{|A|^2} = \left(\frac{\partial^2 T}{\partial x \partial z}\frac{\partial T}{\partial x} \quad \frac{\partial^2 T}{\partial x^2}\frac{\partial T}{\partial z}\right)$$

Width of the Cleveland dyke

The Total Magnetic Field anomalies of the profile lines over the Cleveland dyke show degree of correlation and were stacked together showing smooth noise-free derivatives anomalies. The stacked derivatives anomalies were align together to locate the edges (boundaries) of the dyke. Figure 13, 14, and 15 shows the aligned derivatives plots and estimated width of the dyke.

The derivatives anomalies of AS and THDR are all positive, THDR shows two local maxima which serve as indicator of dyke edges. The horizontal and vertical gradient shows both positive and negative single anomalies. The location of the dike width is close to the local maxima or on top of the local maxima. The estimated location of the dyke's edge falls between 22 - 32m and 18 - 33 meters along the stacked profile line from the base station, therefore the estimated dyke width range from 10-15m. These variations of dyke width might be due to the power of the derivatives couple with remanent magnetization of the dyke.

Depth of the Cleveland Dyke

Magnetic depth estimation plays an important role in magnetic interpretation. A complete quantitative interpretation of Potential field data aims to estimate three types of information about sources of geological interest: the depth, the dimension, and the contrast in the relevant physical property. There are many depth estimation methods; the number keeps growing with continual development of new algorithms. These methods include: slope (manual method), Naudy, Werner Deconvolution, analytical signal, Euler Deconvolution, Euler Deconvolution of the analytical signal, SPITM (local wavenumber) or TDR_THDR (Total Horizontal derivative of the Tilt derivative) and spectral analysis. No accepted guidelines have been established to help in the selection of a proper or optimal depth estimate method (or methods) from the many possible candidates (Fairhead,

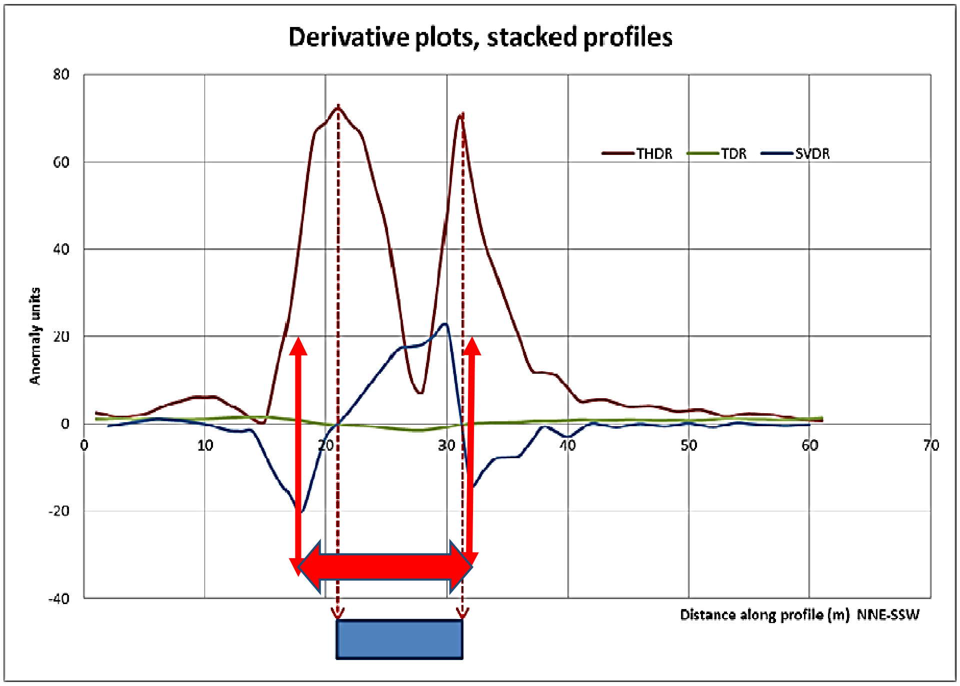

Figure 14. Estimate of width of dyke from derivatives anomalies. Width = 10m and 15m

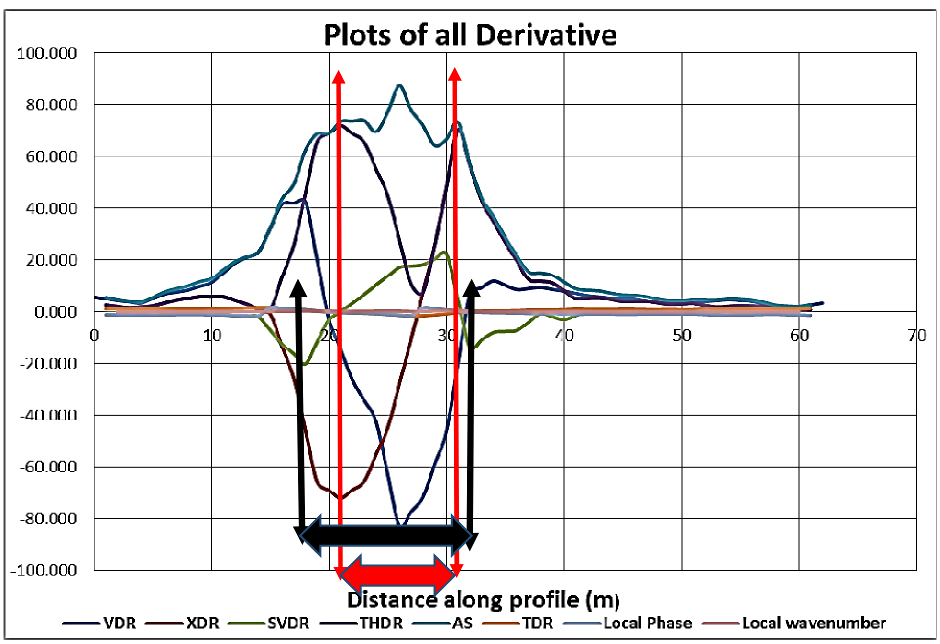

Figure 15. Plots of all Derivatives, Estimated Dyke Width = 10m and 15m

2009). The best guideline is that a proper or optimal method should be selected according to the data quality, together with experience and other geological and geophysical knowledge (Fairhead, 2009).

The width of the Cleveland dyke was estimated as 10 - 15m,using the Haft Maximum Width (W) manual method (Henderson and Zietz, 1948) in Figure 16. The estimated depth of the Cleveland dyke falls between 5 - 7.5m, these variations in depth might be due to power of the derivatives couple with the remanent magnetization of the

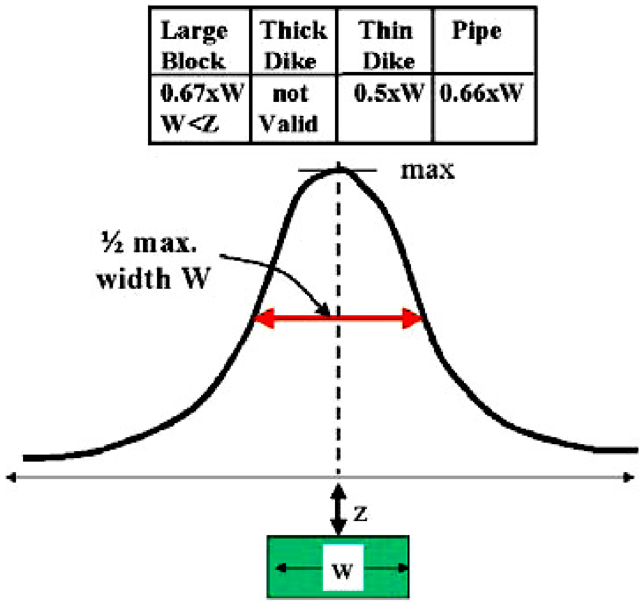

Figure16. Haft Maximum Width (W) Manual Method (Henderson and Zietz, 1948)

dyke.

DISCUSSION AND CONCLUSION

The Total Magnetic Field Intensity over Cleveland dyke produced clearest anomalies which cut discordantly across older rocks in the terrain, often have a strong remanent magnetisation due to rapid cooling and considerable amount of magnetite minerals present. An enigmatic feature of the dyke anomalies is the consistent shape of their anomaly along strike lengths, often showing a consistent direction of remanent magnetisation. The derivative anomalies of AS and THDR are all positive, thus these derivatives are easy to map magnetic contacts. THDR shows two local maxima which serve as indicator of dyke edges (boundaries), In case of AS it peaks directly over the top of contacts, but is somewhat noisier and has lower resolution than the THDR. The location of the dyke width might be closed to the local maxima or on top of the local maxima, the estimated location of the dyke edges from the aligned derivatives plots (Figure 15) falls between 22 - 32m and 18 - 33 meters along the stacked profile line from the base station, therefore the estimated dyke width range from 10-15m. The depth of the Cleveland dyke was estimated as 5 – 7.5 meters using Henderson and Zietz (1948) haft maximum width manual method (Figure 16). The estimated location, depth and width of the Cleveland dyke would assist miners to easily mine the dyke for Construction purposes.

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REFERENCES

Barrow G (1988). The Geology of North Cleveland. Memoir of the Geological Survey of Great Britain, HMSO, London

Clark DA, Emerson DW (1991). Notes on rock magnetisation in applied geophysical studies. Exploration Geophysics 22(4): 547-555

Dagley P (1969). Palaeomagnetic results from some British Tertiary dykes. Earth and Planetary Science Letters, 6:349–354

Dubey S, Holmes A (1929). Estimates of the ages of the Whin Sill and Cleveland Dyke by the helium method. Nature, 123:794–795

Fairhead JD (2009). Potential Field methods for Oil and Mineral Exploration GETECH/ Univ. of Leeds, pp. 290.

Henderson D, Zietz H (1948). Potential Theory in Gravity and Magnetic Depth Estimation – Manual Method: J. Appl. Geophysics, 84:123-129.

Miller HG, Singh V (1994). Potential Field Tilt – a new concept for location of potential field sources: J. Appl. Geophysics, 32:213-217.

Richard JB (1995). Potential Theory in Gravity and Magnetics Applications Cambridge Univ. Press.

Thurston JB, Smith RS (1997). Automatic conversion of magnetic data to dep, dip, and susceptibility contrast using the SPI™ method: Geophysics, 62:807-813.

Verduzco B, Fairhead JD, Green CM (2004). New Insights into Magnetic Derivatives for Structural Mapping: The Leading Edge, 23:116-119.