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Full Length Research Paper

Constrained interpretation of aeromagnetic data using tilt-angle derivatives from north-western part of Bangladesh

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This paper describes the implementation of tilt-angle derivative based algorithms on the interpretation of aeromagnetic data in the north-western part of Bangladesh. With consideration of subtle contributions from both shallow/deep seated magnetic anomaly sources, analysis of magnetic data using the tilt-angle derivative technique indicates the presence of three prospective magnetic anomaly sources with depth of occurrence less than 1.00 km in the north-western part and Kishorgang upazilla of Nilphamari district, Taragong and Badargong upazillas of Rangpur district. The estimated values of magnetic susceptibility of the subsurface geologic features in such identified zones ranges from 20.00 $\times 10^{-3}$ to 26.67 $\times 10^{-3}$ SI units. The probable location of a deep-seated magnetic anomaly source at the north-western part of Chirrirbandar upazilla of Dinajpur district has also been detected and its estimated depth of 4.68 km is found to have in good agreement with the statistically estimated depth of 5.44 km. Results of the present study show that the subsurface geologic features occur at depths ranging from 0.22 to 4.68 km with magnetic susceptibility ranging from 0.12$\times 10^{-3}$ to 26.67$\times 10^{-3}$ SI. Based on the integrated borehole, geological, previous geophysical information and present findings, the present study has provided new insights on the occurrence of potential intrabasement magnetic intrusions in the north-western part of Bangladesh.

Keywords: Magnetic susceptibility, wavelength filtering, Tilt angle derivatives.

INTRODUCTION

Bangladesh and part of India (West Bengal) are situated over the Bengal Basin which is one of the thickest and largest sedimentary basins in the world. The north-western region of Bangladesh holds bright prospects for mineral resources such as coal, limestone, white clay, industrial and metallic minerals (Khan and Agarwal, 1993; Khan and Rahman, 1992).

The study area (Fig. 1) extends from latitude 25°31´N-26°5´N and longitude 88°33´E- 89°11´E. Its areal extent is 63 km × 63 km with a topographic elevation range from 30 m to 58 m above mean sea level. The topographic

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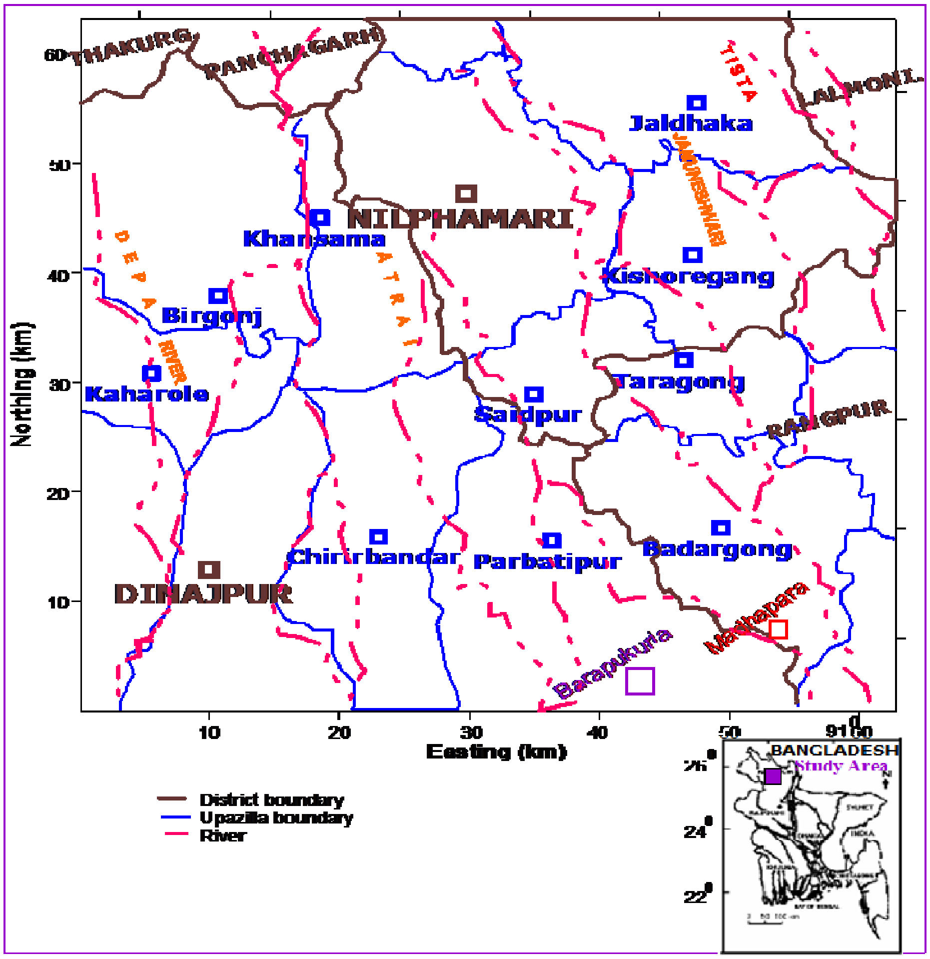

Figure 1. Location map of the study area.

height increases from north-east to south-west. The study area covers part of Nilphamari, Rangpur and Dinajpur districts of North-western Bangladesh. In 1979 –1980, an aeromagnetic survey was conducted over the greater part of Bangladesh by Hunting Geology and Geophysics Limited. The survey was commissioned by the Consultancies Department, Overseas Development Administration, United Kingdom, on behalf of the Geological Survey of Bangladesh and Petrobangla. The flight elevation was 152 m above the ground surface. It is known from the report of the results and interpretation of this survey that the basement in the greater Rangpur and Dinajpur districts of Bangladesh contain a significant number of intrusions (granitic, basic and ultrabasic) and its depth of occurrence is shallowest in Bangladesh, ranging from 0.25 km to 0.75 km. The basement slopes gently from south-east to north-west (Hunting, 1991). In 1985, the Geological Survey of Bangladesh discovered Gondwana coal of Permian age starting at a depth of 129.57 m below ground surface. In Barapukuria, an asymmetrically faulted half-graben type intracatonic basin is situated in the south-eastern part of the study area and covers Parbatipur upazilla of Dinajpur district (Fig. 1). In six boreholes (GDH–38,GDH–39,GDH–40, GDH–42, GDH–43 and GDH–44) drilled in the Barapukuria basin, the basement is encountered at depths of 513.72m, 288.11m, 655.79m, 351.26m, 473.00m and 199.08m respectively. Sharp variations of the rock type occur from one borehole to another (grandodiorite and diorite in GDH-38, diorite, gneiss and schist in GDH-39, gneiss in GDH-40 and diorite in GDH-43 and 44 are observed in the Barapukuria basin (Bakr et al., 1996). In 1995, Hossain and Cartin showed from chemical analysis that the core samples collected from borehole GDH-39 and GDH-44 contain high values of one or more valuable metals such as silver, copper, lead, tin and zinc (Hossain and Cartin, 1995).

In magnetic data interpretation one important goal is to determine the type and location of the magnetic source. Generally, intrusive (intrasedimentary/intrabasement) type magnetic sources are very much complex both in structure and physical properties. The presence of complex distributions of such intrusions causes difficulty in quantitative interpreting these data using conventional interpretational techniques.

A variety of semiautomatic interpretational techniques based on the use of derivatives of the magnetic field have been developed to determine magnetic source parameters such as locations of boundaries and depths (Blakely, 1995; Nabighian, 2005). Thompson (1982) presented first Euler deconvolution for profile data and Reid et al. (1990) for gridded data utilizing the first-order derivatives of the magnetic field. The main advantage of the Euler method is that it can provide automatic estimates of the source location requiring an assumption about the nature of the source. Nabighian and Hansen (2001) proposed an efficient approach of extended Euler method to allow structural index of the source to be estimated from the data with the calculation of Hilbert transforms of the derivatives. Thurston and Smith (1997) presented a source parameter imaging (SPI) method based on second-order derivatives of the field. The SPI method uses the local wavenumber to provide a rapid estimate of the depth of buried magnetic bodies. Utilizing third-order derivatives of the field, the SPI method was extended to estimate the structural index of the source (Smith, et al, 1998; Thurston, et al, 2002). Smith et al.(2005) and Smith and Salem (2005) advocated to use profile data as the calculation of third-order derivatives from gridded data is problematic . Fedi proposed a new approach for simultaneous determination of source depth and structural index. In this method, the field is calculated at many altitudes and scaled by a power law of the altitude. The depth and index can be obtained by finding extreme points (Fedi, 2007). Salem et al.(2005) presented an enhanced local wavenumber method (ELW) for interpreting profile magnetic data. Based on the 2D Euler equation (Thompson, 1982), Salem et al. showed that the deconvoluton of the derivatives of the local phase can provide automatic estimates of the source location regardless of the nature of the sources. The tilt angle is similar to the local phase used in the ELW method for profile magnetic data. Salem et al. (2008) proposed an efficient interpretational technique based on the derivatives of tilt angle. This technique has been used in the present study and interpretation is made on the basis of two assumptions:

I) representation of intrabasement magnetic anomaly sources by vertical sided contact models.

ii) assuming only induced magnetization due to sparseness of rock palaeomagnetic information.

The magnetic tilt angle derivatives technique provides an intuitive means of understanding the variation in depth of magnetic sources. Its main advantage is that it can be used by non specialists and is independent of any need for more advanced numerical analysis of the data.

Geology of Northwest Bangladesh

The study area is situated over the Rangpur Platform which is the shallowest tectonic unit of Bangladesh. Rangpur Platform is believed to be the subsurface continuation of the Indian Shield in the southwest and Shillong Massif in the northwest. The platform is bounded by the Himalayan Foredeep in the north and the Bogra shelf in the south. In 1992, Khan and Rahman further subdivided the Rangpur Platform into Northern Slope of the Platform, The Stable Platform, The Nawabganj-Gaibandha Intercratonic High and the Southern Part of the Platform. Whatever the tectonic divisions of the Rangpur Platform, the basement rocks of the platform are mainly gneisses and they are not strongly magnetic. There are a number of horst and graben structures in the area that are filled with Gondwana sediments and where present, underlie Tertiary sediments. Some Rajmahal group volcanic rocks of Bogra shelf area underlie Tertiary sediments (Khan and Rahman, 1992; Riemann, 1993).

METHOD OF ANALYSIS

We assume that the shallow/deep seated magnetic anomaly sources represented by vertically dipping contact models were inductively magnetized by the main geomagnetic field of 46000 nT in an inclination of 35.5°N and declination of 0.5°W. The observed magnetic data are transformed into the wavenumber domain and the two dimensional power spectrum is computed by squaring the absolute value of the 2-D Fourier transform and averaged radially to yield a one dimensional power spectrum. The radially averaged power spectrum is then used to estimate the average depth of an ensemble of deep/shallow magnetic anomaly sources (Spector and Grant, 1970). Due to the dipolar (anomalies having positive and negative components) nature of the magnetic intensity data, it makes interpretation more difficult because the magnetic body and its edges do not necessarily coincide with the most obvious mapped feature (e.g., anomaly maxima). The reduction-to-the-pole (RTP) technique transforms magnetic anomalies to anomalies that would be measured if the field were vertical (assuming there is only an inducing field). This RTP transformation makes the shape of magnetic anomalies closely related to the spatial location of the source structure and makes the magnetic anomaly easier to interpret, as anomaly maxima will be located centrally over the body (provided there is no remanent magnetization present). The RTP transformed magnetic data are further processed for suppression of noise using a Fourier transformation based upward continuation filter

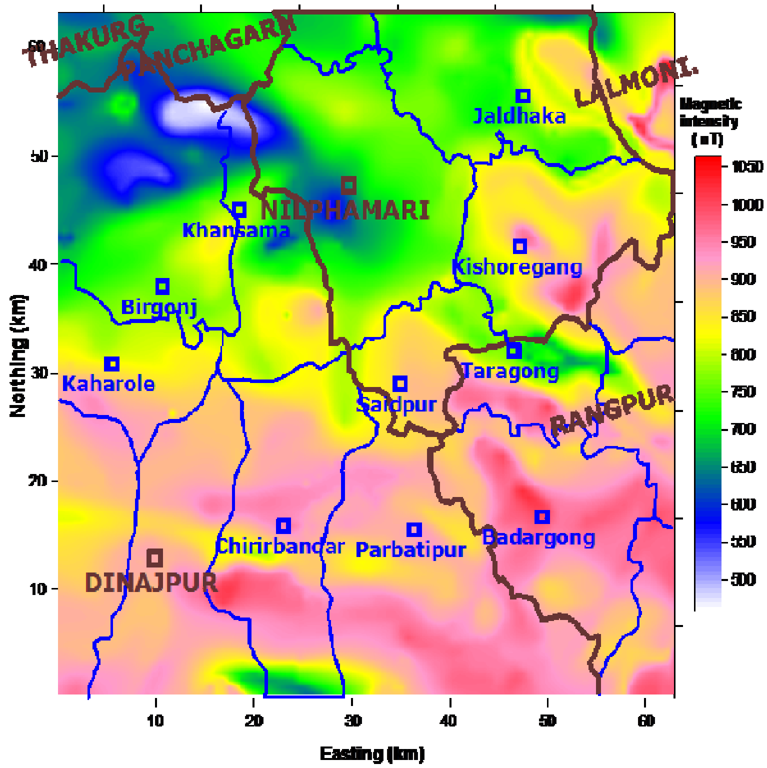

Figure 2. Aeromagnetic anomaly map of the study area.

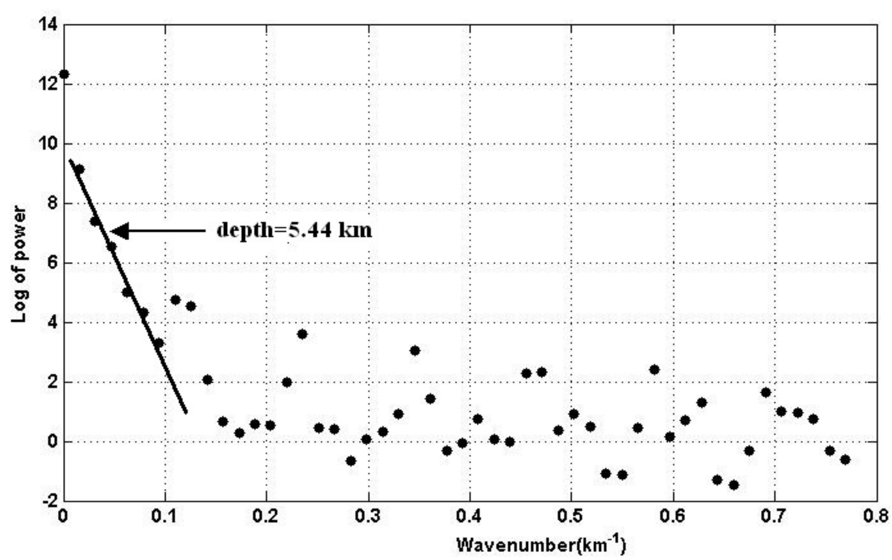

Figure 3. Radially averaged power spectrum of the aeromagnetic data.

of wavelength equal to twice the sampling interval (Gupta and Ramani, 1980; Hildenbrand, 1983). The smoothed RTP data, F can be interpreted using a newly developed interpretational technique based on derivatives of the tilt angle. The tilt angle is defined as

$$\theta = \tan^{-1}\left[\frac{\frac{\partial F}{\partial z}}{\frac{\partial F}{\partial h}}\right] \qquad (1)$$

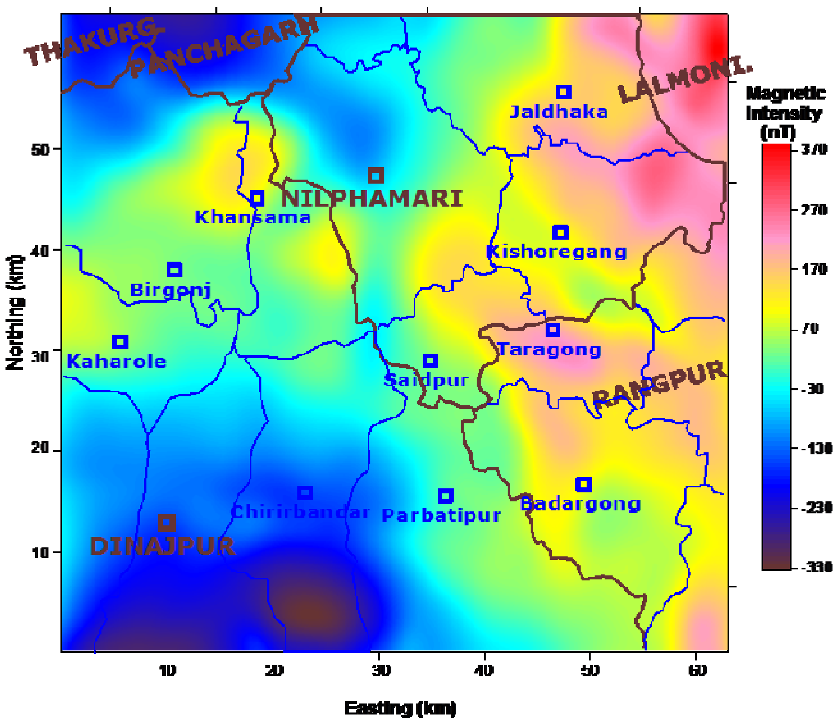

Figure 4. Smoothed Reduction to pole magnetic anomaly map of the study area.

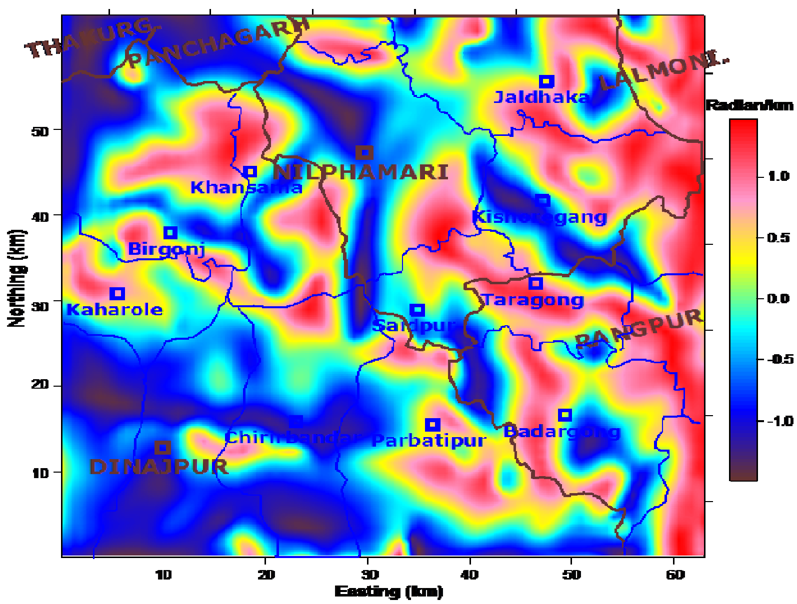

Figure 5. Map showing total horizontal derivative of the tilt angle for RTP magnetic anomaly data.

where,

$$\frac{\partial F}{\partial h}=\sqrt{\left(\frac{\partial F}{\partial x}\right)^2+\left(\frac{\partial F}{\partial y}\right)^2} \qquad (2)$$

and $\frac{\partial F}{\partial x}$, $\frac{\partial F}{\partial y}$ and $\frac{\partial F}{\partial z}$ are the derivatives of smoothed RTP magnetic data in the x, y and z directions. The rate of change of tilt angle θ with respect to x, y and z

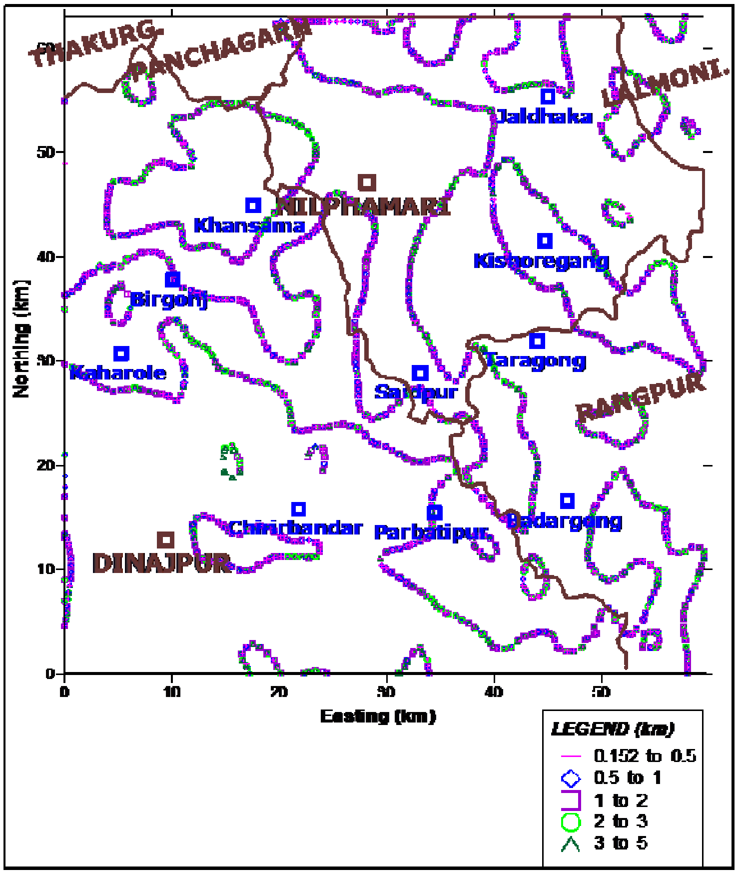

Figure 6. Estimated depths of the magnetic anomaly sources for the RTP magnetic anomaly data.

directions are defined as wavenumbers:

$$k_x = \frac{\partial\theta}{\partial x} = \frac{1}{A^2}\left(\frac{\partial F}{\partial h}.\frac{\partial^2 F}{\partial x\partial z} - \frac{\partial F}{\partial z}\left(\frac{\partial F}{\partial h}\right)^{-1} \times \left(\frac{\partial F}{\partial x}\frac{\partial^2 F}{\partial x^2} + \frac{\partial F}{\partial y}\frac{\partial^2 F}{\partial y\partial x}\right)\right)$$

(3)

$$k_y = \frac{\partial\theta}{\partial y} = \frac{1}{A^2}\left(\frac{\partial F}{\partial h}.\frac{\partial^2 F}{\partial y\partial z} - \frac{\partial F}{\partial z}\left(\frac{\partial F}{\partial h}\right)^{-1} \times \left(\frac{\partial F}{\partial x}\frac{\partial^2 F}{\partial x\partial y} + \frac{\partial F}{\partial y}\frac{\partial^2 F}{\partial y^2}\right)\right)$$

(4)

$$k_z = \frac{\partial\theta}{\partial z} = \frac{1}{A^2}\left(\frac{\partial F}{\partial h}.\frac{\partial^2 F}{\partial z^2} - \frac{\partial F}{\partial z}\left(\frac{\partial F}{\partial h}\right)^{-1} \times \left(\frac{\partial F}{\partial x}\frac{\partial^2 F}{\partial x\partial z} + \frac{\partial F}{\partial y}\frac{\partial^2 F}{\partial y\partial x}\right)\right)$$

, (5)

where,

$$A = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2}$$ is the total gradient of the reduced to pole magnetic field data.

Using 3-D form of Euler's equation (Thompson, 1982; Reid et al., 1990) and taking its derivatives in the x, y and z directions, we can write

$$k_x x_0 + k_y y_0 + k_z z_0 = k_x x + k_y y + k_z z$$

(6)

where, x, y and z are the observation coordinates, x_0 , y_0 and z_0 are the source coordinates.

The linear equation 6 is similar to the conventional 3D Euler equation, with the advantage that it does not require any prior information about the source geometry. Generally, the total horizontal derivative k_h is estimated from the relation

$k_h = \sqrt{k_x^{\,2} + k_y^{\,2}}$ and for a moving data window spanning only the x, y and z coordinates of the data points falling within the specified radial distance of the k_h peak location. In the present study, the source location parameters (x_o and y_o) corresponding to the zero tilt angle are computed from digitizing tilt angle map with mapping software. The edge depth of the geologic source

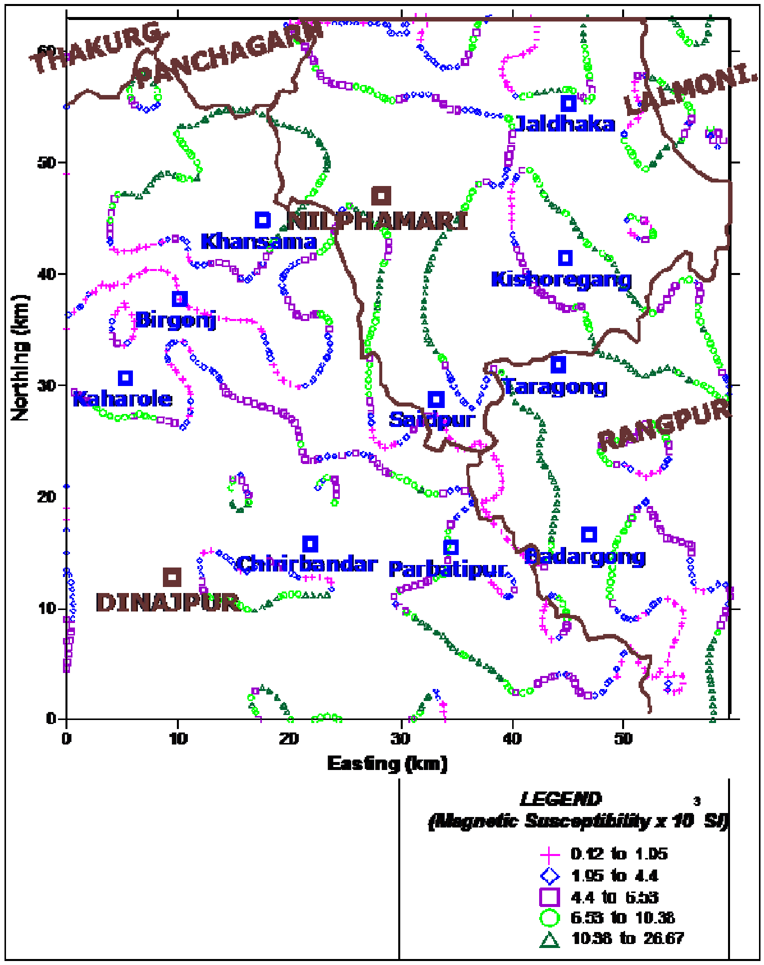

Figure 7. Estimated magnetic susceptibility for the magnetic anomaly sources.

is estimated using equation 6 after substituting source location parameter (x_o and y_o) values. The average value of the computed depths for each source location, z_o gives the edge depth at that location under consideration (Salem et al., 2008)

Assuming the intrabasement magnetic anomaly sources simulated by vertically sided contact models, the magnetic susceptibility contrast in SI units at each source location can be written as (Salem et al., 2007)

$$K = z_o \frac{\frac{\partial F}{\partial h}}{2F_0 C}$$

(7)

where, $\frac{\partial F}{\partial h}$ is the total horizontal derivative of the RTP data, F_o is the magnitude of inducing geomagnetic field, C=1–cos2i sin2A, A is the angle between the positive h-axis and magnetic north and i is the ambient field inclination.

ANALYSIS OF AEROMAGNETIC DATA

The total field aeromagnetic data were obtained by digitizing the Bangladesh Geological Survey 1:1000,0000 map on 98 X 98 grid with a spacing of 0.65 km using a sophisticated general purpose contouring program which generates the grid by constructing a smooth surface passing through every point. The resulting aeromagnetic anomaly map is shown in Figure 2. The aeromagnetic anomaly data are now transformed into the Fourier domain to compute the radially averaged power spectrum (Figure 3).

The aeromagnetic data are reduced to pole and upward continued with a continuation height of 1.30 km to produce a smoothed reduced to pole magnetic anomaly map (Figure 4). Its tilt angle map is shown in Figure 5.

The computed depths of magnetic anomaly sources and their susceptibilities are shown in Figure 6 & 7.

DISCUSSIONS AND CONCLUSION

In this work, the depths of the magnetic anomaly sources have been estimated based on the assumption of the vertical-contact model. The magnetic tilt angle is a new method, which provides an intuitive means of understanding the variation in depth of magnetic sources. The total intensity magnetic anomaly map (Figure 2) is characterized by the presence of major trend of magnetic highs and lows at the south-eastern and north-western parts of the study area respectively. These anomalies are caused by deep-crustal, sub-crustal and shallow (intrsedimentary/ intrabasement) subsurface magnetic sources whose locations are obscured due to dipolar nature of the magnetic fields. From 2-D spectral analysis, the statistically estimated average depth of the deep-seated magnetic anomaly sources is 5.44 km (Figure 3). It is quite noticeable that at wavenumbers greater than 0.1, the spectrum shows large oscillations which are probably assumed to be linked with the presence of detected shallow basement with its depth of occurrence less than grid spacing (0.65km) to some extent and intrasementary/ intrabasement intrusions (narrowly and/or widely extended). Figure 4 shows the probable spatial locations of the individually isolated magnetic sources with anomaly maxima over their centers. In the tilt angle of the magnetic data of Figure 4, the edges of the magnetic sources are well defined through zero tilt angle values (Figure 5). It is quite obvious from the estimated depths of the magnetic anomaly sources (Figure 6) that the most significant isolated magnetic anomaly sources of short aerial extent are found on the eastern side of Jaldhaka Upazilla near the Nilphamari – Lalmonirhat district boundary, north-eastern part of Kishoriganj Upazilla, south-eatern part of Taragong Upazilla, south-eastern part of parbatipur Upazilla, south-western part of Badargong Upazilla near the Dinajpur-Rangpur district boundary, west-southern part of Birgong Upazilla and southern side of the Dinajpur-Thakurgaon-Panchagar district boundary junction. These magnetic anomaly sources are occurred mostly at depths ranging from 1 to 3 km. The estimated maximum depth of 4.76 km of the isolated deep-seated magnetic anomaly source at the north-western part of chirrirbandar Upazilla of Dinajpur district is in good agreement with the statistically estimated depth of 5.44 km.

The estimated values of magnetic susceptibility for the shallow/deep magnetic anomaly sources ranges from 26.67×10^{-3} to 0.12×10^{-3} SI (Fig. 7). The magnetic susceptibility values of the deep-seated magnetic anomaly source with depth around 5.00 km range from 4.40×10^{-3} to 26.67×10^{-3} SI units. At the junction area of Nilphamari–Dinajpur-Panchagar districts, the magnetic anomaly source occurs at shallow depth less than 1.00 km with susceptibility ranges from 22.00×10^{-3} to 23.00×10^{-3} SI. In the western sides of Taragong-Badargong Upazillas of Rangpur district, the subsurface geologic feature with magnetic susceptibility ranges from 20.00×10^{-3} to 24.00×10^{-3} SI units occurs at depth less than 1.00 km.

In the north-eastern part of Taragong Upazilla, a magnetic anomaly source with similar depth of occurrence has susceptibility ranges from 20.00×10^{-3} to 23.00×10^{-3} SI. It is reported by Clark and Emerson in 1991(Clark and Emerson, 1991) that the most iron bearing minerals have magnetic susceptibility in the ranging from 0.33×10^{-3} to 450×10^{-3} SI. Due to non-availability of the sufficient borehole information and other geophysical inferences, it is not be possible to correlate the interpreted results with subsurface geology. However, based on the present findings, it can be concluded that the three identified zones of the north-western part of Bangladesh have a great potential on the availability of intrabasement intrusive type rocks.

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