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# INTERPRETATION OF A LINEAR MAGNETIC FEATURE NEAR MUTUM-BIYU, NIGERIA

C.O. OFOEGBU *

*Department of Physics*
*University of Port Harcourt — P.M.B. 5323, Port Harcourt — Nigeria*

A linear magnetic feature which runs continuously for 56 km from around Kambari in the SW to around Bimari in the NE is here interpreted in terms of a dyke-like body which does not reach the surface. Several profiles have been taken across its length and interpreted using non-linear optimization techniques, giving an excellent fit to a dyke having an average width of about 0,70 km. The depth to the upper surface of the interpreted dyke varies between 0.15 km and 0.79 km to give an average depth to the top surface of about 0.30 km. An average magnetization of about 0.40 A/m was estimated for the dyke on the basis of the present interpretation. It is suggested that the postulated dyke may have been part of the suite of igneous intrusive bodies whose emplacement played an important role in the evolution of the Benue Trough.

Uma feição magnética linear, com uma extensão de 56 km entre as proximidades de Kambari no SW até as proximidades de Bimari no NE, é interpretada neste trabalho como um provável dique que não aflora na superfície. Vários perfis transversais foram construídos e interpretados através de técnicas não-lineares de otimização, resultando num bom ajuste com um dique com largura média de aproximadamente 0,70 km. A profundidade até a superfície superior do suposto dique varia entre 0,15 km e 0,79 km, com uma profundidade média de perto de 0,30 km. Com base nesta interpretação, foi estimado para o dique uma magnetização média de cerca de 0,40 A/m. É sugerido neste trabalho que o provável dique possa ter sido parte de um conjunto de corpos ígneos, cuja intrusão teve um papel importante na evolução da Fossa Benue.

## INTRODUCTION

On sheet 214 of the Aeromagnetic Map of Nigeria is a remarkable linear anomaly running from around the town of Kambari in the southwest to about 6 km east of Bimari in the northeast, a distance of about 56 km (Fig. 1). The linear magnetic anomaly analysed here occurs over an area which lies within the sedimentary Benue Trough of Nigeria.

The Benue Trough is a linear sedimentary basin of subsidence which extends deep into the African continent and was associated with the separation of Africa from South America and the opening of the South Atlantic (Ofoegbu, 1984a) (Fig. 2). It trends northeasterly and houses a thick succession of shales, sandstones, limestones, coal and evaporites whose ages range from Aptian to Maestrichtian (Ofoegbu, 1985a). The Benue Trough is characterized by an axial zone of lead-zinc mineralization and numerous mafic and feldsic intrusives and basaltic lavas. Bordering the sediments on either sides are the Pan African granites and gneisses which make up the crystalline basement. In the Mutum Biyu area of the Benue Trough, there is no geological evidence for the existence of a sill, lava sequence or a major fault. A detailed account of the geology of the Benue Trough within which the area of study lies has been presented elsewhere (Ofoegbu, 1985a).

The relatively smooth magnetic anomalies of rather gentle magnetic gradient which flank the linear magnetic anomaly on either sides are attributed to the presence of a thick sequence of non-magnetic sedimentary rocks of Cretaceous and younger ages. Adjacent to this region of smooth magnetic anomalies are short wave-length anomalies which can be seen to the left of a line running from Gunduma through Mutum Biyu, Bade Kwoshi-Wurkum and Barin-Buba liman (Fig. 1). These short wavelength anomalies are probably caused either by susceptibility changes within the basement or by near surface intrusives or a combination of both.

The existence of the linear magnetic anomaly near Mutum-Biyu has not been reported elsewhere in the literature and this paper presents a detailed interpretation of the continuous section of the Mutum-Biyu magnetic anomaly. The anomaly is here interpreted as being caused by a dyke-like body on the basis of the excellent fits between observed and calculated profiles obtained by non-linear optimization techniques. The dyke-like body here called the Mutum-Biyu dyke does not appear to have reached the surface.

## METHOD OF INTERPRETATION

Usually, the magnetic anomaly due to a parallel sided, flat topped, uniformly magnetized dyke (Fig. 3) can be interpreted in terms of its width, depth and location with respect to the centre using such methods as curve fitting techniques, method of characteristics (Åm, 1972; Bruckshaw & Kunaratnam, 1963; Gay, 1963) and automated techni-

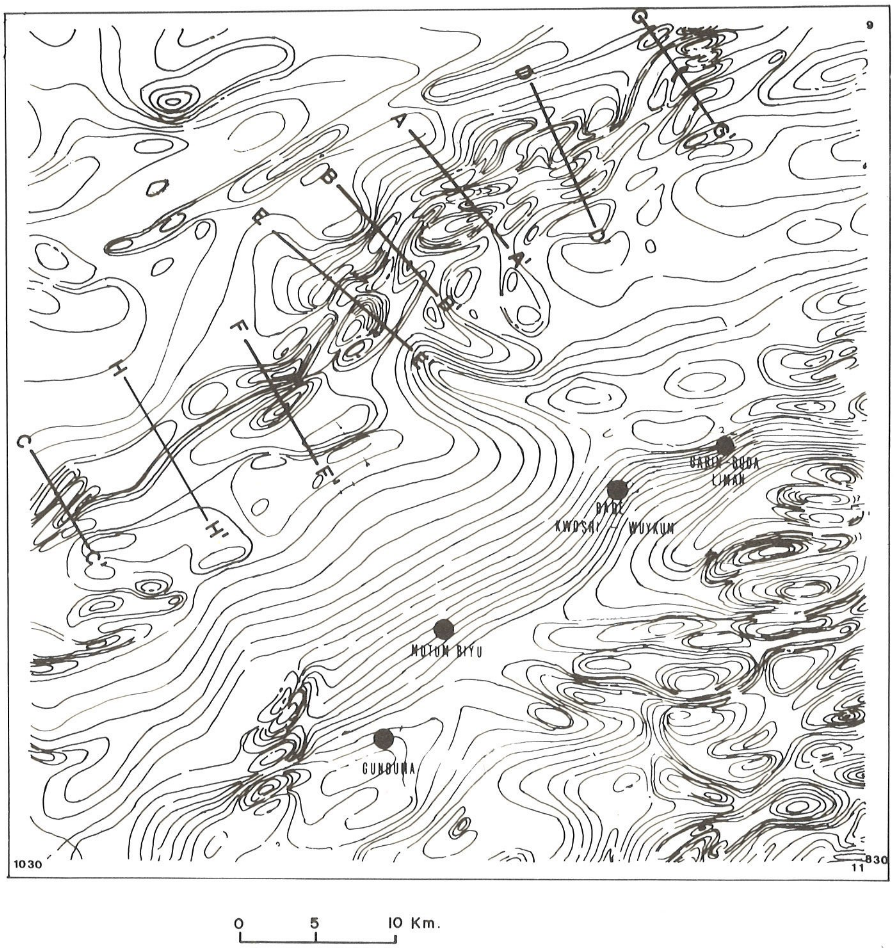


Fig. 1 Sheet 214 of the Aeromagnetic map of Nigeria showing the Mutum-Bivu linear magnetic feature.

ques (e.g. Khurana et al., 1981; Rao et al., 1981; Won, 1981; Ofoegbu, 1982; Koulomzine et al., 1970).

A method of combined least squares analysis and non-linear optimization technique has been used in the present study. The method seeks to minimize a non-linear objective function representing the difference between the observed and computed anomalies due to a dyke by iteratively varying the non-linear parameters of the dyke, while obtaining optimum values of the linear parameters by least squares analysis until an acceptable fit is obtained between the observed and computed anomalies.

The objective function to be minimized is:

$$F = \sum_{i=1}^{N} (T_i - T_i^1 - A_o - A_1 X_i - A_2 X_i^2)^2 \qquad (1)$$

Where $T_i^1$ is given by the equation for the magnetic anomaly due to a two-dimensional parallel sided, flat topped, uniformly magnetized dyke of dip d (Fig. 3).

$$T_i^1 = 2k\phi\psi \, J \sin(d) \quad \theta \sin(\beta) + \log\left(\frac{r_2}{r_1}\right) \cos(\beta) \qquad (2)$$

$A_o + A_1 X_i + A_2 X_i^2$ represent a quadratic regional field at the ith field point.

$T_i$ = observed anomaly at the ith field point

$J$ = intensity of magnetization of the dyke

$k = \dfrac{\mu_o}{4\pi}$

$\beta = I_e' + Im' - d$

$I_e' = \tan^{-1} [\tan(I_e)/\cos(\alpha_e)]$; $I_m' = \tan^{-1} [\tan(I_m)/\cos(\alpha_m)]$

$\phi = [1-\cos^2(I_e) \sin^2(\alpha_e)]^{\frac{1}{2}}$; $\psi = [1-\cos^2(I_m) \sin^2(\alpha_m)]^{\frac{1}{2}}$

$I_e$ = Inclination of Earth's field

$I_m$ = Inclination of direction of magnetization

$\alpha_e$ = Angle between the positive and direction of magnetic north

$\alpha_m$ = Angle between the positive x and horizontal projection of the direction of magnetization.

The angle $I_m'$ represents the dip of magnetization of the dyke in the plane perpendicular to the strike of the dyke. This angle can however only be computed if some assumption is made about the inclination of the dyke (d).

Combining equations (1) and (2), the objective function F is given as:

$$F = \sum_{i=1}^{N} (T_i - J_i P(x_i) - J_2 Q(x_i) - A_o - A_1 x_i - A_2 x_i^2)^2 \qquad (3)$$

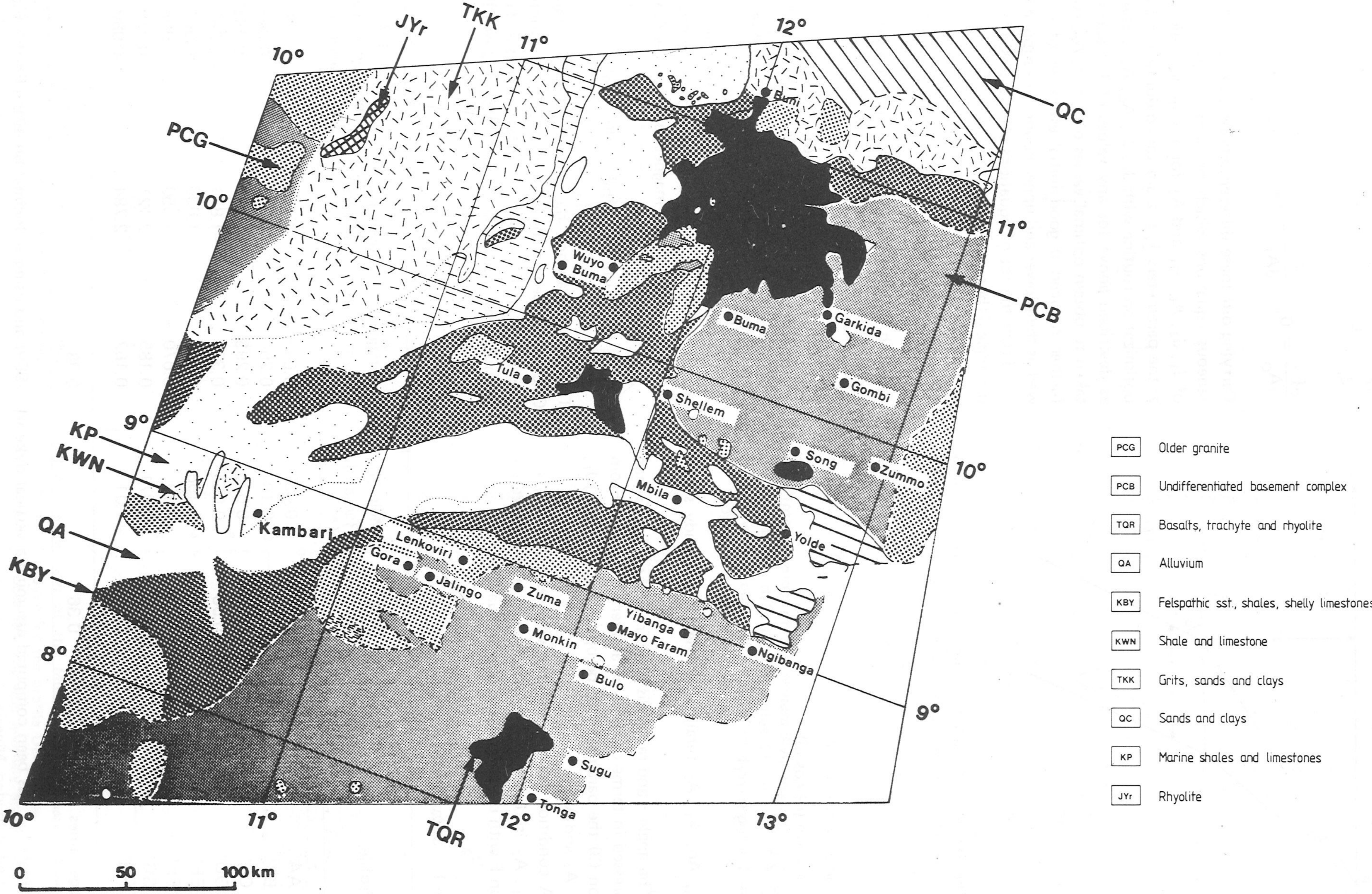


Fig. 2 Geology of Benue Trough region.

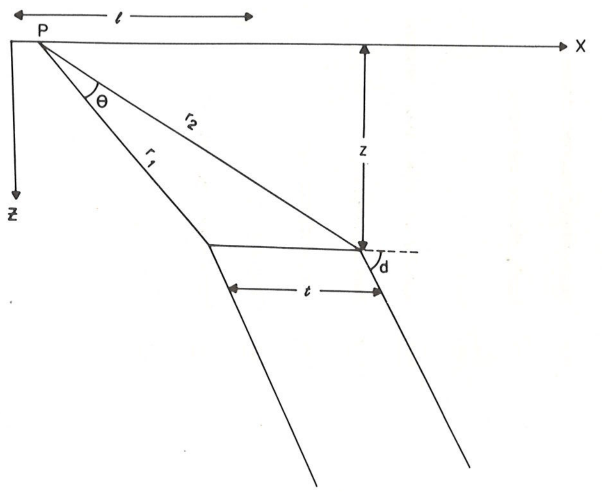


Fig. 3 The geometry of a uniform infinite two dimensional dyke in relation to the field points where the magnetic anomaly is observed.

where

$$J_1 = J\phi\psi \sin(d) \sin(\beta)$$
$$J_2 = J\phi\psi \sin(d) \cos(\beta)$$
$$P(x_i) = 2k\,\theta \qquad (4)$$
$$Q(x_i) = 2k \log(r_2/r_1)$$

and $T_i$, Ao, $A_1$, $A_2$ retain their meanings already stated above.

The angle θ and radial distances $r_1$ and $r_2$ (Fig. 3) can be expressed in terms of dyke parameters ℓ, t and z. From equation (3) the parameters to be optimized are ℓ, t, z, $J_1$, $J_2$, $A_o$, $A_1$ and $A_2$.

A condition for a minimum with respect to $J_1$, $J_2$, $A_o$, $A_1$, $A_2$ is that the partial derivatives of the objective function F with respect to each one is equal to zero.

$$\frac{\partial F}{\partial J_1} = 0; \quad \frac{\partial F}{\partial J_2} = 0 \qquad (5)$$

$$\frac{\partial F}{\partial A_o} = 0; \quad \frac{\partial F}{\partial A_1} = 0; \quad \frac{\partial F}{\partial A_2} = 0$$

Carrying out these differentiations gives a set of five simultaneous equations which on solution give optimal values of $J_1$, $J_2$, $A_o$, $A_1$ and $A_2$ for any given values of ℓ, t, and z; the parameters 1, t, z are varied during the course of the optimization routine with $J_1$, $J_2$, $A_o$, $A_1$ and $A_2$ obtained as described above for any values of 1, t and z. The time taken to obtain optimal values of ℓ, t, z, $A_o$, $A_1$ and $A_2$ is further reduced if good initial estimates of ℓ, t and z as well as their lower and upper bounds are supplied.

From the set of equations (4) it is possible to compute the angle β thus:

$$\beta = \mathrm{Tan}^{-1}(J_1/J_2) \qquad (6)$$

and with slight rearrangement of equation (4), a new term J′ could be derived.

$$J' = (J_1^2 + J_2^2)^{\frac{1}{2}} = J\phi\psi \sin(d) \qquad (7)$$

J′ is the magnetization of the dyke in plane perpendicular to the strike of the dyke.

If further internal control exists for the angular terms αm and d, then it will also be possible to compute $I_m$ and J′ and consequently the magnetization of the dyke given as:

$$J = J'\left[\cos^2(I_m)\sin^2(\alpha_m) + \sin^2(I_m)\right] \qquad (8)$$

The present author has developed a Fortran program OPDYE 2 based on the mathematical formulation discussed above. The program was found to be rapid and convenient to apply and requires less than one second of CPU time to

Table 1: Summary of Results

| Profile | Thickness (km) | Depth (km) | Angle (β) (Radians) | Magnetization A/m | Angle ($I_m$′) (Radians) | Coeff. of Correlation observed vrs calculated anomalies |
|---|---|---|---|---|---|---|
| AA′ | 0.80 | 0.45 | −0.432 | 0.640 | −2.189 | 0.976 |
| BB′ | 0.59 | 0.15 | −0.184 | 0.254 | −1.943 | 0.991 |
| CC′ | 0.66 | 0.15 | 0.028 | 0.293 | −1.731 | 0.984 |
| DD′ | 1.12 | 0.58 | −0.064 | 0.329 | −1.871 | 0.993 |
| EE′ | 0.60 | 0.79 | 0.158 | 0.530 | −1.636 | 0.961 |
| FF′ | 0.20 | 0.21 | 0.19 | 0.670 | −1.550 | 0.998 |
| GG′ | 0.91 | 0.15 | −0.371 | 0.185 | −2.121 | 0.979 |
| HH′ | 1.14 | 0.28 | −1.01 | 0.162 | −2.784 | 0.980 |
| Average values | 0.75 | 0.36 | | 0.38 | | |

* The angle $I_m$′ has been computed assuming a vertical dyke (d = 90°) and using an inclination of the Earth's Field of – 9° as measured at Ibadan, Nigeria.

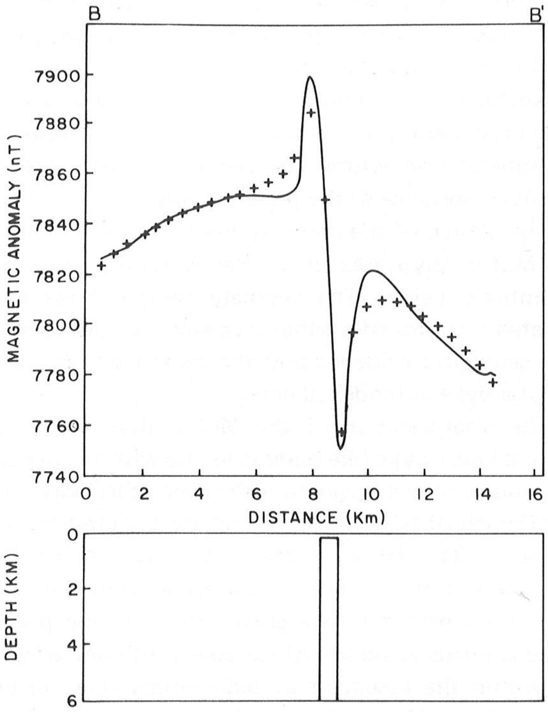


Fig. 4 Interpretation of the Mutum-Biyu magnetic anomaly in terms of a dyke for the profile BB' of Fig. 1. The profile shows the observed magnetic anomaly and a selection of points on the computed curve.

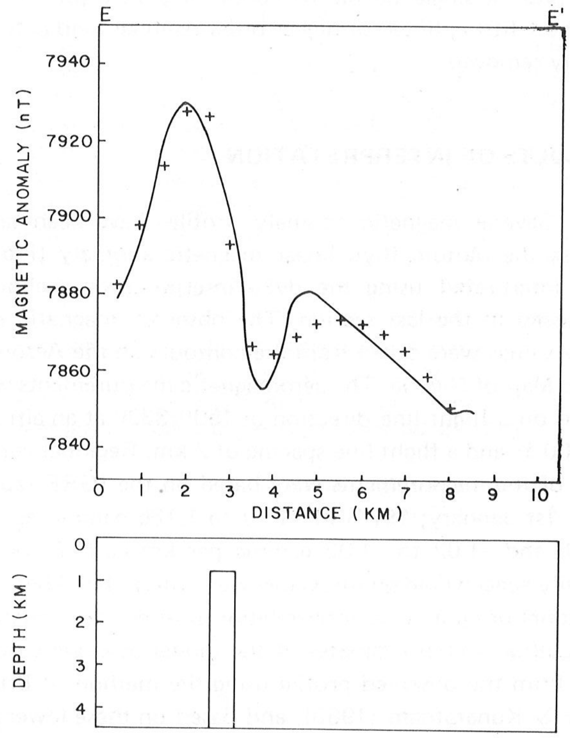


Fig. 5 Interpretation of the Mutum-Biyu magnetic anomaly in terms of a dyke for the profile EE' of Fig. 1. The profile shows the observed magnetic anomaly and a selection of points on the computed curve.

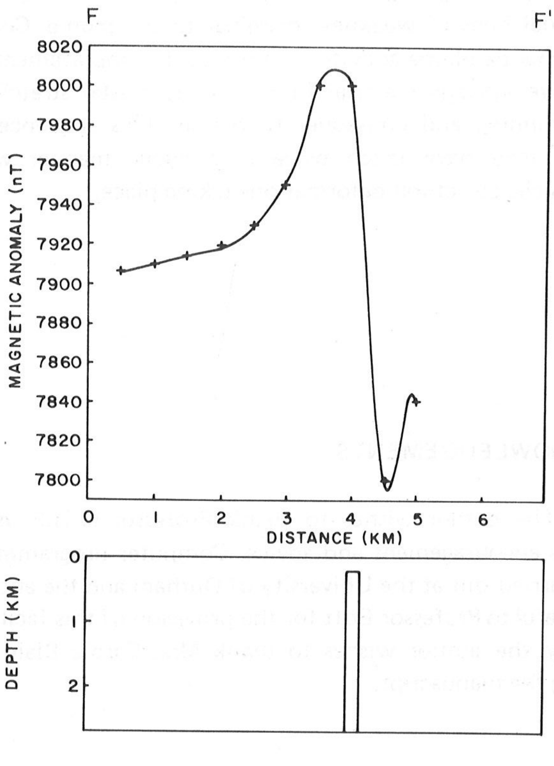


Fig. 6 Interpretation of the Mutum-Biyu magnetic anomaly in terms of a dyke for the profile FF' of Fig. 1. The profile shows the observed magnetic anomaly and a selection of points on the computed curve.

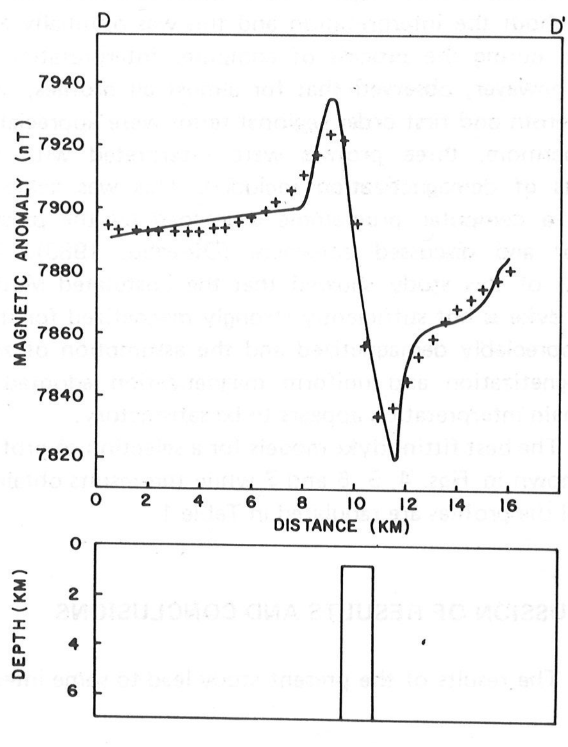


Fig. 7 Interpretation of the Mutum-Biyu magnetic anomaly in terms of a dyke for the profile DD' of Fig. 1. The profile shows the observed magnetic anomaly and a selection of points on the curve.

interpret a single profile of about fifty field points with the best fitting linear or higher order regional field automatically removed.

## RESULTS OF INTERPRETATION

Several magnetic anomaly profiles have been taken across the Mutum Biyu linear magnetic anomaly (Fig. 1) and interpreted using the dyke interpretation technique discussed in the last section. The observed magnetic anomaly values were taken from the contours on the Aeromagnetic Map of Nigeria. The aeromagnetic measurements were based on a flight line direction of $150^o/330^o$ at an altitude of 500 ft and a flight line spacing of 2 km. Regional correction of the measurements were based on the IGRF (epoch date 1st January, 1974) of -1.10 to 1.166 gamma per km north and -1.02 to -1.03 gamma per km east. To obtain equally spaced field points, values were interpolated between contours using a curve interpolation routine, developed by the author. Initial estimates of the model dyke were obtained from the observed profile using the method of Bruckshaw & Kunaratnam (1963), and based on these lower and upper bounds were placed on permissible values of the location, width and depth of the dyke. The computer method based on non-linear optimization was then used to determine the best fitting geometrical and magnetic parameters of the postulated dyke beneath each profile.

A second order regional field (quadratic) was assumed throughout the interpretation and this was optimally estimated during the process of computer interpretation. It was, however, observed that for almost all profiles, only the zeroth and first order regional terms were appreciable. Furthermore, three profiles were interpreted with the effects of demagnetization included. This was achieved using a computer programme developed by the present author and discussed elsewhere (Ofoegbu, 1983). The results of this study showed that the postulated Mutum Biyu dyke is not sufficiently strongly magnetized for it to be appreciably demagnetized and the assumption of zero demagnetization and uniform magnetization adopted in the main interpretation appears to be satisfactory.

The best fitting dyke models for a selection of profiles are shown in Figs. 4, 5, 6 and 7 while the results obtained for all the profiles are tabulated in Table 1.

## DISCUSSION OF RESULTS AND CONCLUSIONS

The results of the present study lead to some interesting points. The interpreted anomaly occurs within the Benue Trough and with a trend close to that of the trough. The existence of a dyke as modelled here could well have some tectonic implications. The Mutum-Biyu anomaly may also represent a linear sequence of mineralization or a linear mineral vein within the Benue Trough; hence the economic importance of the present study.

The source of the anomaly lies within the sediments of the Mutum-Biyu area of the Benue Trough rather than being entirely below. The anomaly cannot, however, be interpreted in terms of a sill or lava sequence owing to lack of any geological evidence and the most likely possibility is that of a dyke as modelled here.

The interpretation of the Mutum-Biyu anomaly in terms of a linear dyke-like body is in line with the results of earlier studies of the magnetic field over other parts of the Benue Trough of Nigeria carried out by the present author (Ofoegbu, 1984a, 1984b; 1984c, Ofoegbu, 1985b). These studies showed that magnetic anomalies over the trough are best accounted for to a great extent by the presence of igneous intrusive bodies of variable depth and occurring either within the basement of sedimentary rocks or both. The postulated Mutum-Biyu dyke-like body could well have been part of the suite of igneous bodies whose emplacement played an important role in the tectonic evolution of the Benue Trough (Ofoegbu, 1984d; Ofoegbu & Amajor, 1985). According to these authors the evolution of the Benue Trough is thought to have involved the rise of a mantle plume giving rise to updoming and development of initial lines of weakness marginal to the plume. Continued mantle plume activity gave rise to the emplacement of intrusive igneous material in the crust, crustal stretching and thinning and consequently rifting. This sequence of events may have taken place in a cyclic manner with intercyclic structural deformations taking place.

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