AN ESTIMATE OF THE DEPTH TO THE BASEMENT UNDERNEATH THE BENUE TROUGH FROM A STUDY OF AEROMAGNETIC ANOMALIES

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(Received: July 16, 1984)
(Accepted: July 30, 1986)

RESUMEN

A partir de un estudio de anomalías aeromagnéticas sobre partes de la hondonada de Benue, Nigeria, se hace aquí un intento de estimar la profundidad del basamento bajo dicha hondonada y consiguientemente, el espesor de los sedimentos en el área. Se han determinado varios perfiles aeromagnéticos a través de la hondonada y se ha llevado a cabo una interpretación bidimensional de éstos utilizando la optimización no-lineal y técnicas interactivas en un esfuerzo por estimar la naturaleza y profundidad al basamento bajo la hondonada. Los resultados de esta interpretación muestran que bajo la hondonada Benue subyace un basamento de topografía variable. La profundidad al basamento y consiguientemente el espesor de los sedimentos que la llenan se estima que varían entre unos 0.5 km y 7 km.

ABSTRACT

From a study of aeromagnetic anomalies over parts of the Benue Trough, Nigeria, an attempt is here made to estimate the depth to the basement underneath the Benue Trough and consequently the thickness of sediments in the area. Several aeromagnetic profiles have been taken across the trough and two-dimensional interpretation of these carried out using non-linear optimization and interactive techniques in an effort to estimate the nature and depth to the basement underneath the Benue Trough. The results of this interpretation show that the Benue Trough is underlain by a basement of variable topography. The depth to the basement and consequently the thickness of sediments filling the trough is estimated to vary between about 0.5 km and about 7 km.

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INTRODUCTION

The Benue Trough is a linear Cretaceous rift structure with a northeasterly trend. It stretches inland from the Gulf of Guinea to attain an approximate length of 800 km and has an origin contemporaneous with the opening of the South Atlantic. Geological study of the trough has revealed that it is filled with Cretaceous rocks whose ages range from Middle Albian to Maestrichtian (Cratchley and Jones, 1965; Effeotor, 1974; Ayoola, 1978; Kogbe, 1981a, b; Offodile and Reyment, 1977) (Table 1 and Fig. 1   ). The Benue Trough has a coherent stratigraphic and structural condition from the southwest to the northeast as evidenced by the existence of a series of long narrow folds with ENE-WSW axes and a narrow axial zone of lead-zinc mineralization with associated intrusions.

Bordering the sedimentary rocks on either sides are the Pan-African granites and gneisses making up the basement. The basement consists of mainly quartzo-feldspathic migmatites and gneisses with occasional quartzites, marbles and amphibolites (Ofoegbu, 1985a). The basement underneath the Benue Trough is believed to have an irregular topography (Effeotor, 1974; Adighije, 1979; Cratchley and Jones, 1965; Ofoegbu, 1985a) and is exposed in a number of places and comes close to the surface at a few other places. It is further characterised by the existence of numerous Older Granitic intrusions that range in composition from granite to granodiorite, a number of dioritic intrusions and a smaller number of gabbros and syenites.

Previous estimates of the depth to the basement and sedimentary thickness in the Benue Trough have been through the interpretation of gravity anomalies over the trough (Adighije, 1979, 1981a, b; Cratchley and Jones, 1965; Ajayi and Ajakaiye, 1981), and the interpretation of local magnetic anomalies (Osazuwa et al., 1981; Ajakaiye, 1981). These authors have independently estimated the thickness of sedimentary rocks within the trough as averaging between 2 km and 6 km. An attempt is here made to estimate the depth to the basement and sediment thickness in the trough as well as investigate the nature of the basement through a detailed interpretation of aeromagnetic profiles taken over sections of the Benue Trough.

TABLE 1: STRATIGRAPHIC SEQUENCE OF THE LOWER-MIDDLE-UPPER BENUE AND CHAD BASINS

AGE	ANAMBRA BASIN	LOWER BENUE-MIDDLE BENUE	UPPER BENUE BASIN			SOUTHERN CHAD BASIN
			Dadiya-Numanha	Zambuk-Gulani	Gombe-Pindiga	
PALEOCENE and YOUNGER	IMO FORMATION	Volcanics	Lamja sandstones		KERRI-KERRI FM.	KERRI-KERRI FM.
MAASTRICHTIAN	NSUKKA FORMATION / AJALI SANDSTONE / MAMU FORMATION	LAFIA FORMATION			Gombe sand-stones	Gombe sandstones
CAMPANIAN (SENONIAN)	NKPORA FORMATION		Numanha shales	Gulani sandstones	PINDIGA FORMATION	Fika shales
SANTONIAN (SENONIAN)			SEKULE FM.			
CONIACIAN (SENONIAN)	AGBU FORMATION	AGWU FORMATION				
TURONIAN Upper			JESSU FM.			GONGILA FM.
TURONIAN Middle	EZE-AKU FORMATION	EZE-AKU FM { MAKURDI FM. / KEANA FM. / AWE FM.				
TURONIAN Lower			DUKUL FM.			
CENOMANIAN	OKOSI FM. Sandstone and Shale (ASU RIVER GROUP)	ASU RIVER GROUP	YOLDE FM.		YOLDE FM.	
MID - LATE ALBIAN			Bima sandstones	Bima sandstones	Bima sandstones	Bima sandstones
ALBIAN	Abakaliki shales					
PRE-CAMBRIAN	BASEMENT COMPLEX					

Note: ～～～ = Unconformity.

Geology of the Benue Trough Region

	Alluvium		Coal,Sandstone and shale		Felspathic sandstone and siltstone		Granite(younger)
	Basalts,trachyte,rhyolite		Sandstone shale and sandy shale		Black shale and siltstone		Grits,sand and clay
	Older basalts (Jos Plateau)		Sand,clays and shale		Shale and limestone		Shale and limestone
	Falsebedded sandstones coal and shale		Undifferentiated basement complex		Felspathic sandstone, sandy clays, calcareous sandstone and shelly limestone		Bende -Ameki group
	Shale and limestone		Felspathic sandstone		Older granites		Shale and mudstone
	Clays and shale with limestone				Sands and clays		

Fig. 1. Geology of the Benue Trough (from Ofoegbu, 1985a).

ANALYSIS OF DATA AND RESULTS OF INTERPRETATION

Aeromagnetic profiles have been taken across several sheets of the Aeromagnetic Map of Nigeria. The aeromagnetic map of figure 2 has been produced from several 1:100 000 sheets of the Aeromagnetic Map of Nigeria. The aeromagnetic survey was carried out along a series of E-W profiles 2 km apart at an average flight of 200 m and with a nominal tie line spacing of 20 km. The observed field was corrected for the regional based on the International Geomagnetic Reference Field (IGRF) epoch dated 1st January, 1974.
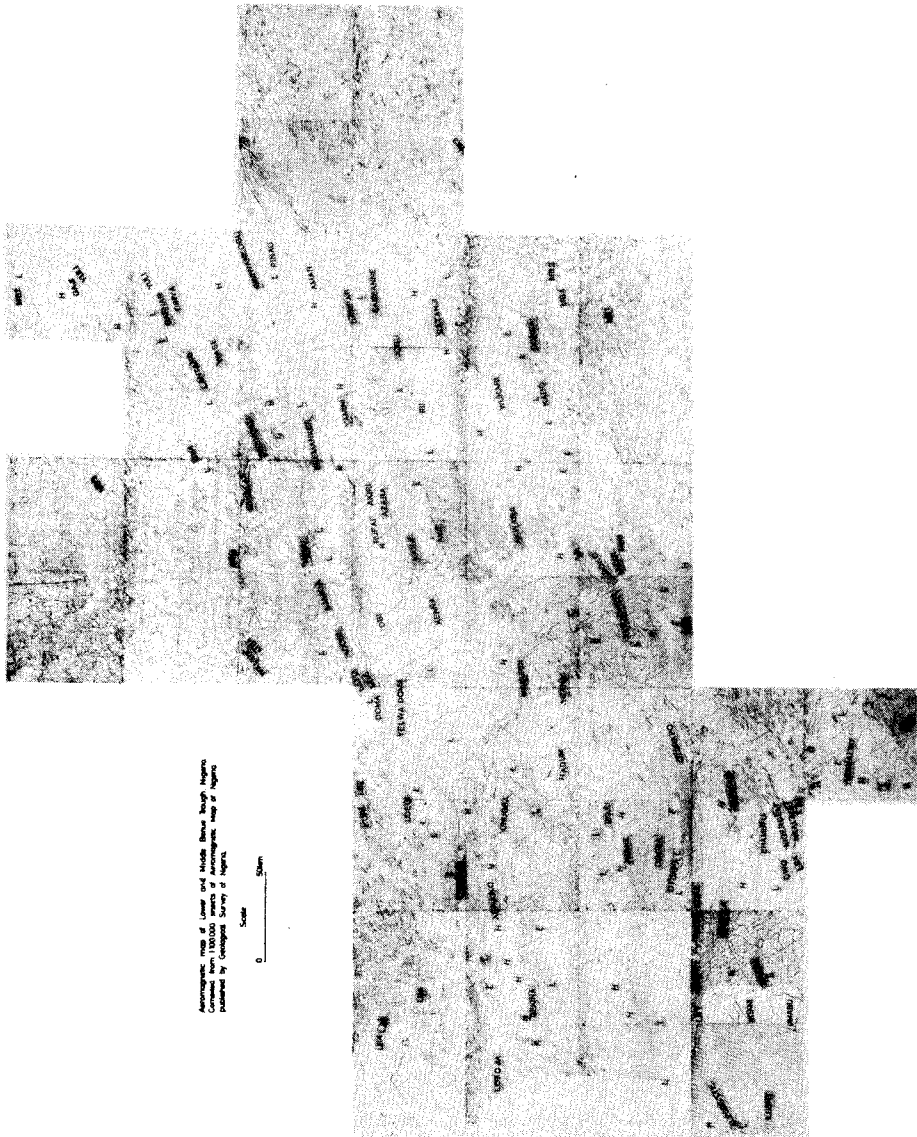
Fig. 2. Aeromagnetic map of part of the Benue Trough (from Ofoegbu, 1984).

Two dimensional interpretation of several profiles taken across the Benue Trough (Fig. 3) has been carried out using non-linear optimization and interactive techniques (Ofoegbu, 1985b). The interactive technique used here involves the computation of the magnetic anomaly due to an assumed body and its comparison with the observed anomaly. The model body parameters are then successively modified until an acceptable fit is obtained between the observed and computed anomalies. This modification of model body parameters is, however, interactively carried out through the use of specially equiped graphic oriented computer terminals with cursors.
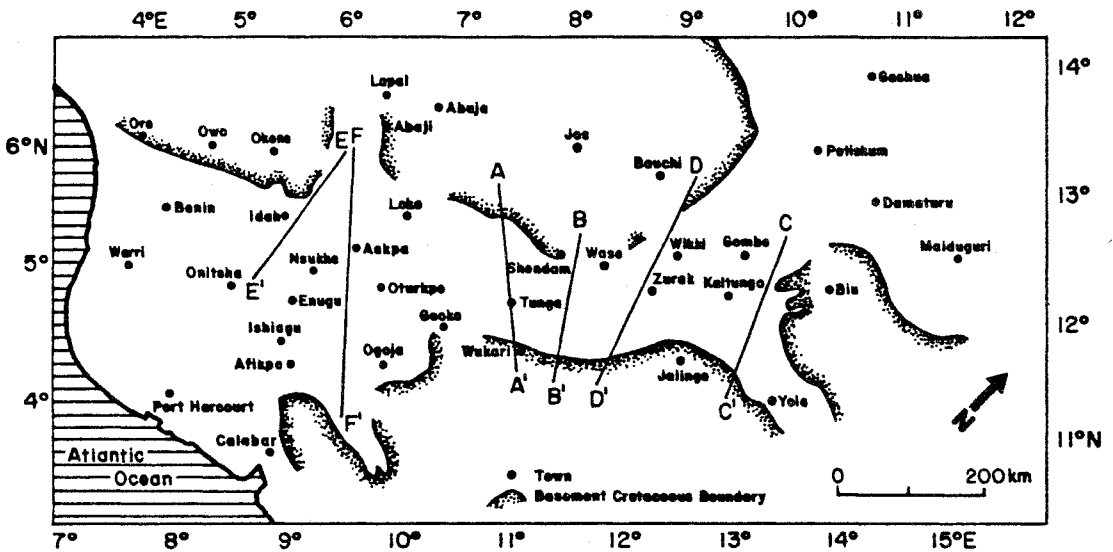
Fig. 3. The Benue Trough, showing the position of profiles interpreted.

Non-linear optimization technique on the other hand is based on the minimization of a non-linear objective function representing the difference between the observed and computed anomalies due to a given model by the iterative variation of the parameters of the model body until an optimum fit is obtained between the observed and computed anomalies (Ofoegbu, 1985b). The concept of non-linear optimization and its application to the interpretation of geophysical anomalies has been discussed by the author (Ofoegbu, 1985b) and applied to the inversion of magnetic anomalies due to dyke-like bodies (Ofoegbu and Bott, 1985; Ofoegbu, 1986a, b).

The model body used in the present study is a two-dimensional body of arbitrary cross-section (Fig. 4). The magnetic anomaly due to a body of polygonal or arbitrary cross-section ABCDEF (Fig. 4) can be evaluated by adding the effects of semi-infinite prisms for all sides of the body with due regard as to the sign (Talwani and Heirtzler, 1964). Proceeding in a clockwise direction around the body, the vertical and horizontal field strengths at a field point situated at the origin are given by

$$V = 2(J_x Q - J_z P)$$

$$H = 2(J_x P + J_z Q)$$

where:

$$Q = \frac{\mu_0}{4\pi} \sum_{i+1}^{N-1} [((Z_{i+1} - Z_i)(x_i - x_{i+1})/(Z_{i+1} - Z_i)^2 + (x_i - x_{i+1})^2)(\theta_i - \theta_{i+1})$$

$$- ((Z_{i+1} - Z_i)^2/(Z_{i+1} - Z_i)^2 + (x_i - x_{i+1})^2) \log(\frac{R_2}{R_1})]$$

$$P = \frac{\mu_0}{4\pi} \sum_{i=1}^{N-1} [((z_{i+1} - z_i)^2/(z_{i+1} - z_i)^2 + (x_i - x_{i+1})^2)$$

$$(\theta_i - \theta_{i+1}) + ((z_{i+1} - z_i)(x_i - x_{i+1})/(z_{i+1} - z_i)^2$$

$$+ (x_i - x_{i+1})^2) \log(\frac{R_2}{R_1})]$$

$$R_2 = (x_{i+1}^2 + Z_{i+1}^2)^{1/2}$$

$$R^1 = (x_i^2 + Z_i^2)^{1/2}$$

$$J_x = J \cos I_m \cos \alpha_m$$

$$J_z = J \sin I_m$$

J   =   intensity of magnetization

I_m =   inclination of magnetization vector

α_m =   azimuth of magnetization vector

N   =   number of body points with the first point counted twice.

The total field intensity T is given as:

$$T = V \sin I_e + H \cos I_e \cos \alpha_e \qquad\qquad (2)$$

where

I_e = inclination of Earth's field

α_e = azimuth of the Earth's field

An interactive FORTRAN computer program INTERGRAM which is based on the use of equation 2 to calculate the total field magnetic anomaly due to one or more bodies of arbitrary cross-section and magnetization direction is held at the University of Durham, Geological Sciences Program Library and this has been used in the course of the present study. A FORTRAN program OPMAG, however, was developed based on the non-linear optimization technique. The program OPMAG seeks to minimize an objective function (F) given by

$$F = \Sigma(T_i^1 - T_i - A_o - A_1 x_i)^2 \qquad\qquad (3)$$

where T^1 is the observed magnetic anomaly value at the ith field point and T_i represents the computed anomaly due to one or more bodies at the ith field point and is given by equation 2. $A_o + A_i x_i$ represents the zeroth and first order regional fields at the ith field point.
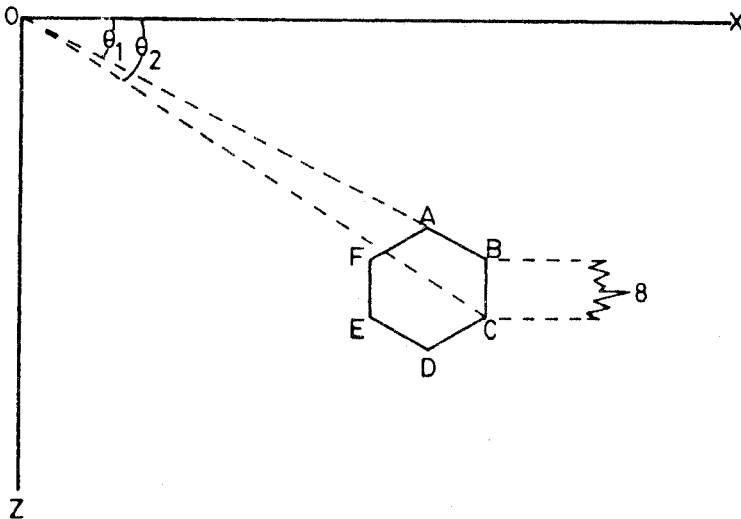
Fig. 4. Model two-dimensional body of arbitrary cross-section.

The program uses the Quasi-Newton optimization technique (Ofoegbu, 1985b) and to accomplish optimization, a call is made to the NAG Library routine EO4JAF (NAG Reference Manual, 1977). There is no limit as to the number of bodies making up the model provided the sum total of their body points does not exceed one hundred (100). In the present study however, a single body model was used.

Experience also showed that a considerable amount of time is needed to obtain convergence when the number of parameters to be optimized becomes exceedingly large as is the case in most of the models produced here unless initial estimates close
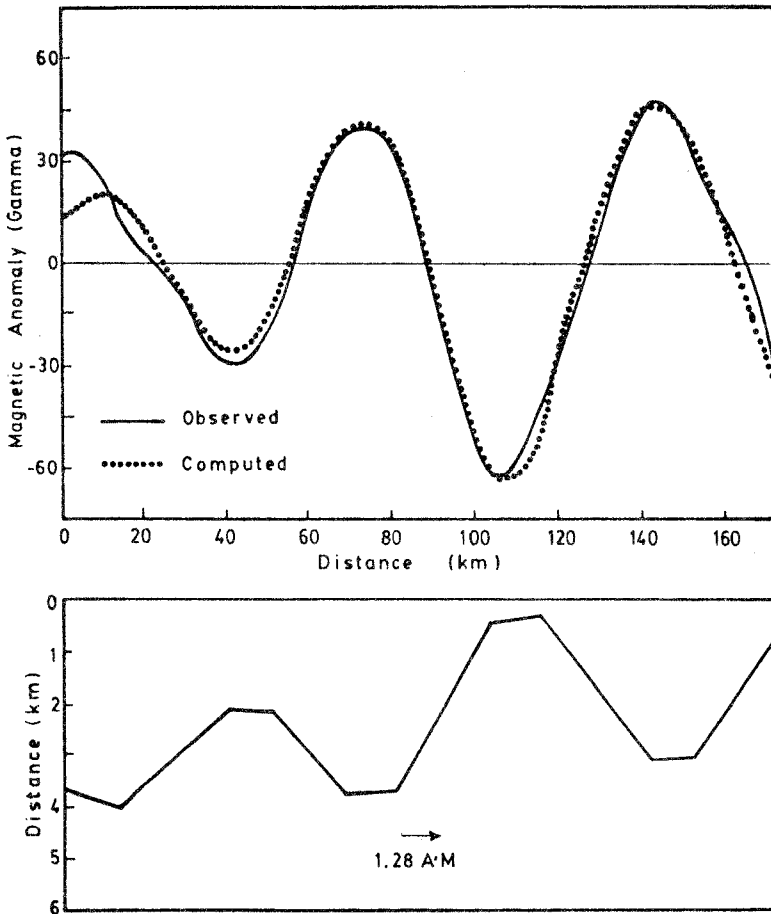
Fig. 5. Interpretation of the profile AA′.

enough to the solution are supplied. The program INTERGRAM on the other hand becomes increasingly tedious and difficult to use as one approaches a solution and its use was therefore restricted to the generation of acceptable initial estimate supplied to the program OPMAG.

The profiles taken across the Benue Trough were complicated by the presence of short wavelength anomalies (Fig. 2) and to eliminate these short wavelength anomalies, the profiles have been upward continued to heights which varied from profile to profile. It is the upward continued profiles that have been interpreted and the upward continuation has been allowed for during the interpretation.

When this work was done no known paleomagnetic studies had been carried out in the area of study. The direction of magnetization used in this work has been
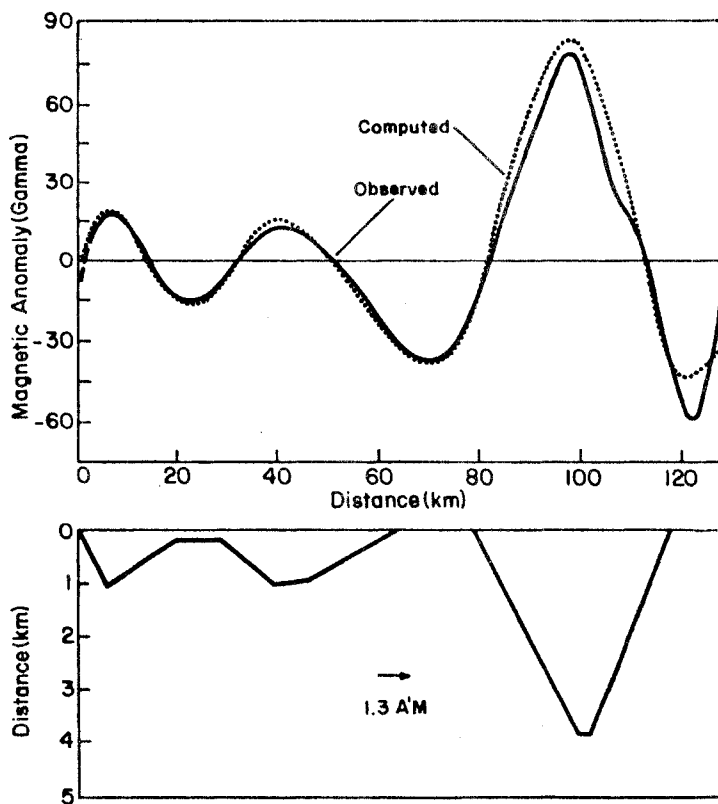

Fig. 6. Interpretation of the profile BB'.

constrained to the direction of the Earth's field which in Nigeria has an inclination of − 7⁰ and a declination of 7.4⁰. This assumption is validated by the fact that only a minor deviation has been recorded in the present position of Nigeria compared to its paleolatitude in Cretaceous times (Valencio and Daniels, 1976; D. H. Tarling, personal communication).

The profile AA' is NW-SE profile that runs through Wamba, Wukari and Kado (Fig. 3). This profile has been interpreted in terms of a basement of variable to-
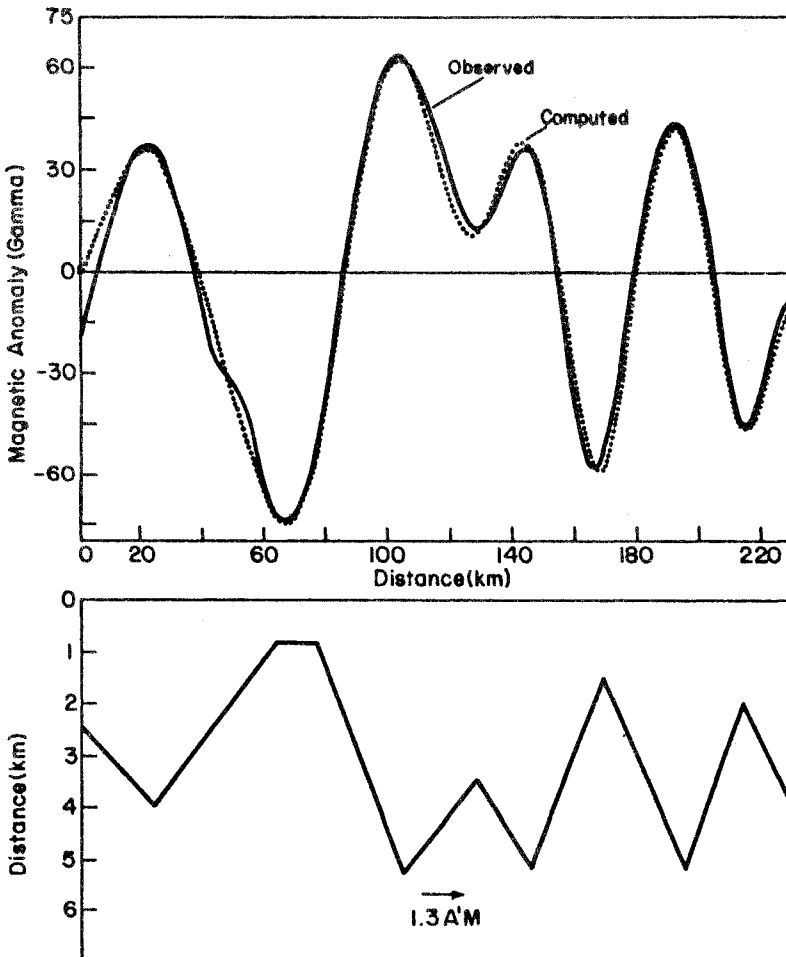
Fig. 7. Interpretation of the profile DD'.

pography and a magnetization of 1.28 A/m (Fig. 5). The maximum and minimum depths of the basement and consequently the thickness of the overlying sediments obtained for the profile AA' are about 4 km and 0.5 km respectively. The profile BB' has been similarly interpreted in terms of the underlying basement of magnetiza-
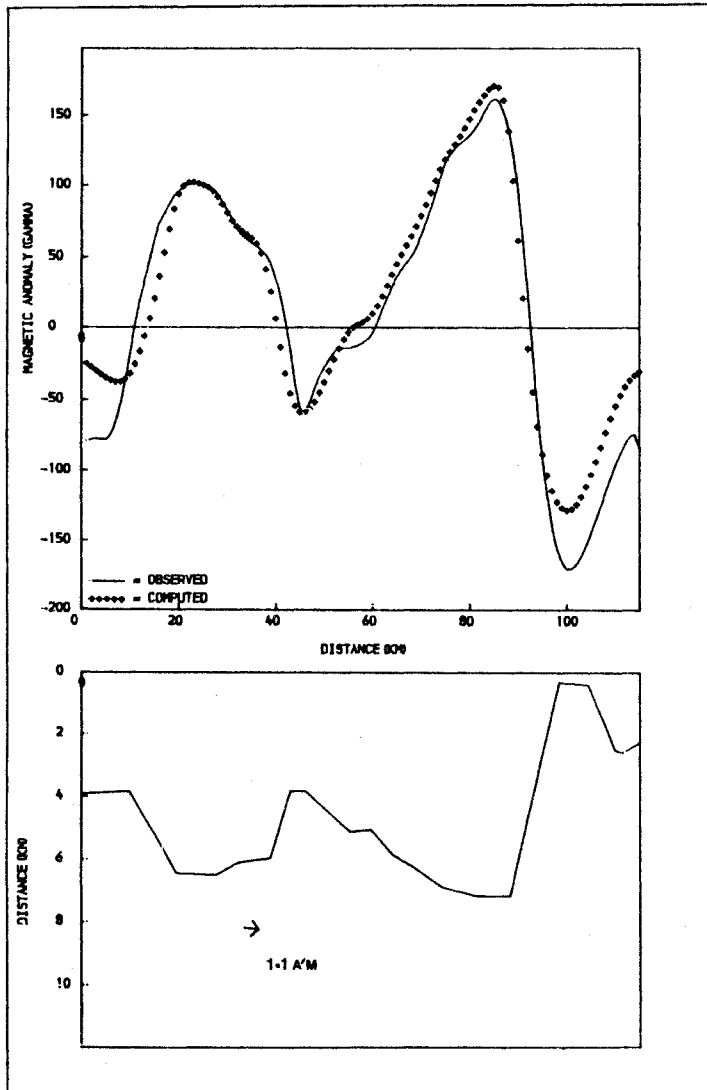

Fig. 8. Interpretation of the profile EE'.

tion 1.30 A/M and the result of the interpretation is presented in figure 6. The thickness of sedimentary cover is here interpreted to vary from about 0.2 km to about 4 km. The basement is also found to outcrop in one place while coming very close to the surface at another point along the profile (Fig. 6). Figure 7 shows
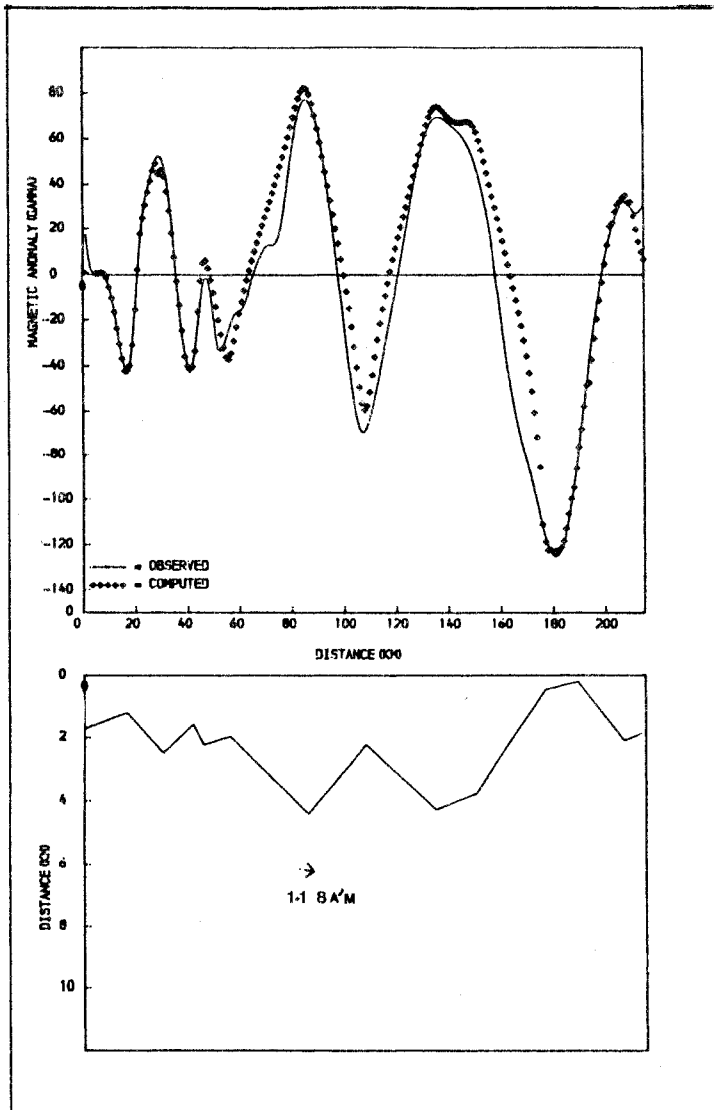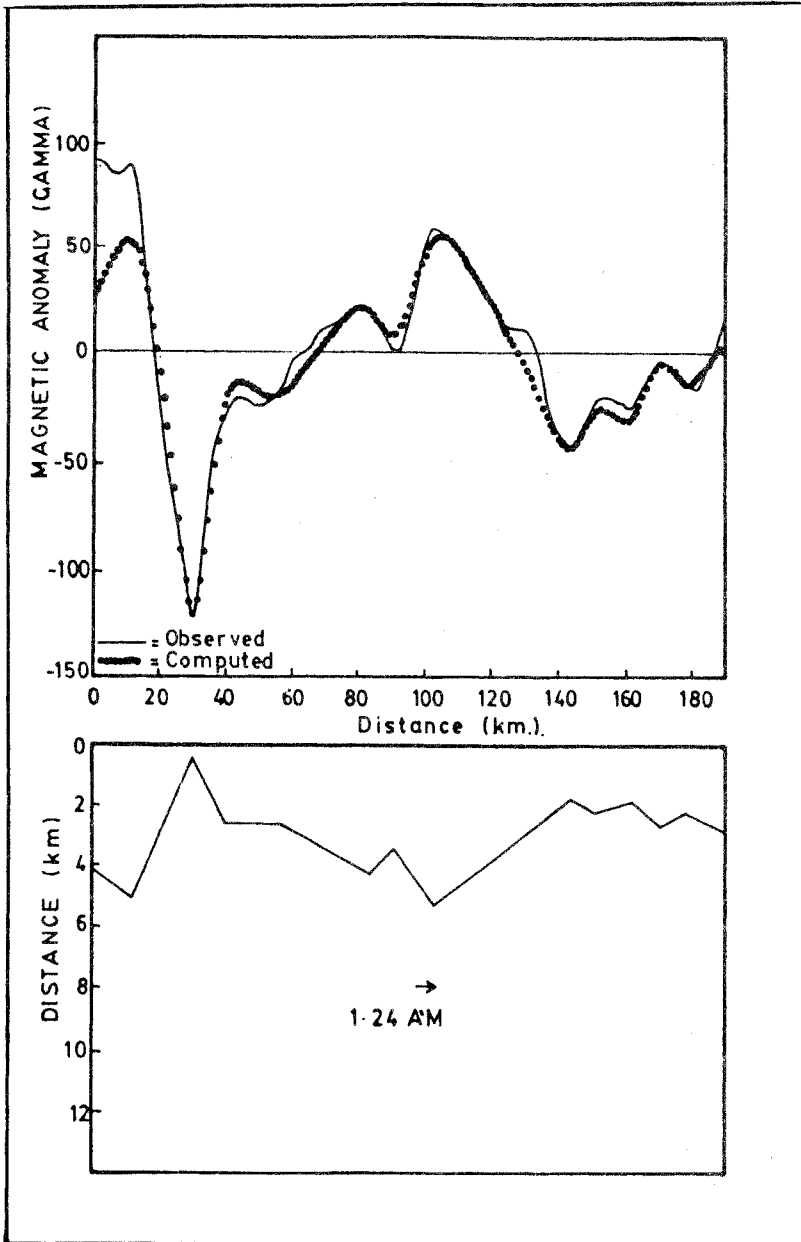

Fig. 9. Interpretation of the profile FF'.

Fig. 10. Interpretation of the profile CC′.

the result of an interpretation of the N-S profile DD′ (Fig. 3) in terms of a basement of variable topography. The model basement here is assigned a magnetization of 1.30 A/M. The depth to the basement and consequently the thickness of sedimentary cover has been estimated to vary between about 1.0 km and about 5.3 km. Results similar to the above have been obtained for the other profiles taken across the Benue Trough (Fig. 3).

The profile EE′ in the Lower portion of the Benue Trough has been interpreted in terms of a basement whose depth varies from about 7 km to 0.4 km and having a magnetization of 1.1 A/M (Fig. 8). Figure 9 shows the result of an interpretation of profile FF′ also in the Lower Benue in terms of a basement of variable topography. The model suggests a basement at a variable depth of 4.5 km to 0.4 km and having a magnetization of 1.18 A/M. An interpretation of the profile CC′ taken over the Upper Benue Trough yields a basement at a variable depth and consequently a sediment thickness of 5.4 km to 0.5 km while a magnetization of 1.24 A/M was obtained for the basement (Fig. 10).

DISCUSSION AND CONCLUSION

The results of the present study suggest that the depth to the basement underlying the Benue Trough and consequently the thickness of sedimentary cover in the area on the average vary from about 0.5 km to about 5.5 km. There are however a few places where the basement either outcrops (Fig. 6) or comes very close to the surface, while in the Lower Benue Trough it locally attains a depth of 6 km or more (Fig. 8).

The interpretation presented here is based on the assumption of a uniformly magnetized basement and as this may not be the case in all sections of the trough some degree of error may be introduced in the depth estimates made. Furthermore, the short wavelength anomalies removed by upward continuation are important in placing depth limits removal may marginally affect the resolution of depth limits obtained in this study.

A closer look at the result of the present interpretation will reveal that the fit between the observed and computed anomalies at the edges for some profiles is poor. Also basement/basin contact is not well accounted for in some of the models (e.g. figures 5 and 7). These may be due to the obliteration of the contact by sediment overstepping and erosion over the ages.

ACKNOWLEDGEMENT

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