

Comparative Study of Graphical Methods and Velocity Analysis of 2-D Seismic Reflection Data with Application to Niger Delta

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ABSTRACT

A comparative study of graphical methods and velocity analysis of 2-D seismic reflection data has been carried out and presented in this paper. The anomalies on which these studies were tested were taken from the Niger Delta. The depths to the Benin, Agbada, and Akata formations were estimated employing both graphical methods as well as velocity analysis of 2-D seismic reflection data. The results indicate that the two separate methods applied yielded approximately the same value for the depths to the top of the subsurface. This work has further reconfirmed the importance of some graphical methods in interpretation of data such as the one used in this work. It is interesting to note that the applied graphical method estimated the depths to the bottom of these structures which could not be estimated using only 2-D seismic reflection data.

(Keywords: geological analysis, Benin formation, Agbada formation, Akata formation, comparative analytical methods, aeromagnetic anomalies, oil field identification, petroleum occurrence)

INTRODUCTION

The release of aeromagnetic maps by Geological Survey of Nigeria (GSN) has stimulated interest in research in the interpretation of aeromagnetic anomalies over different parts of the country. A number of oil fields have been discovered entirely or primarily through aeromagnetic surveys. A more conventional relationship between magnetic anomalies and petroleum occurrence is encountered when an oil trap is associated with structural features in the underlying basement rocks. Structures both regional and local have a very important role in the emplacement of mineralization (Domzalski, 1958).

Several investigations have been carried out by many authors around the area of Niger Delta in Nigeria (Short and Stauble, 1967; Kogbe, 1976; Hosper, 1965; and Ofoegbu, 1985). The activities involved in the search for subsurface structures that contain minerals have continued to grow and assume greater importance; hence, the research in this area continues to gain more attention (Ekweozor and Daukoru, 1994; Haack et al., 1997; Reijers et al., 1997 and Nwachukwu et al., 1995).

The primary aim of this study is to determine the depth to top of Benin, Agbada and Akata formations using velocity analysis of 2-D seismic reflection data and graphical methods and the two results compared.

GEOLOGY OF NIGER DELTA

The geology of Niger Delta has been presented by several authors (Reyment, 1965; Short and Stauble, 1967; Whiteman, 1982; Stoneley, 1966). The Niger Delta is situated on the gulf of Guinea on the west coast of Central Africa. It extends from longitude 3°E to 9°E and from latitude $4^{\circ}30'1\text{N}$ to $5^{\circ}20'1\text{N}$. The area included within the Niger Delta comprises sediments that began to be deposited during the upper Cretaceous in the area partly delineated to the north by the present-day confluence of the Niger and Benue Rivers. Its development appears to have been centered around two major subsiding basements; the Anambra embayment, in which 6,000 to 7,000 meters of sediments accumulated, and a younger, more southerly region, where subsidence was more extensive and some 1,200 meters of sediments were deposited (Reyment, 1965).

The major tectonic framework of the Delta consists of two intersecting structural elements. One is the zone of subsidence of the Benue trough, running from NE-SW. The other is the

zone of subsidence of the middle Niger trough. Three main formations have been recognized in the subsurface of the Niger delta (Frankl and Cordry, 1967; Short and Stauble, 1967). These include Benin formation, Agbada formation and Akata formation. Table 1 summarizes the stratigraphy of the Niger Delta.

Table 1: Stratigraphical Succession of the Niger Delta.

Formation	Lithology	Age	Thickness (M)
Benin	Continental, fluvialite gravels and sands	Eocene – Recent	0 -2100
Agbada	Paralic Sequence of interbedded sand and shales	Eocene – Recent	300 -4500
Akata	Pro-delta Marine Shales and clays with some turbidites and sand bodies	Eocene – Recent	600 - 6000

(Modified from Short and Stauble, 1967).

The seismic reflection data used in this study is a 2-D seismic survey. A 1,500km strike line that cuts across rubber plantations, swampy/dry forest, farms, and roads were employed in this study. The refractor velocities ranged from 1,605m/s to 1,744m/s, and averages of 1,677m/s and 550m/s were used, respectively, as elevation and weathering velocities. The thickness of the weathered layer ranged from about 2m to about 9m while surface elevation values ranged from about 14m to about 21m. Static values trend smoothly down the line and tied favourably at intersections to within limits of $\pm 2m/s$. The recording parameters used include a record length of 6 seconds, sample rate of 2milliseconds, high cut filters between 125Hz – 72db octave and low cut-out.

The energy source used was dynamite including a charge of 2.5kg. The shot point interval was 50m and 5 holes shot pattern was used. The shot point space was between stations and the shot point depth was 3 meters. The distance between single shot points was 5meters.

The geophone pattern was 2x5 geophones in-line and the spacing was 2.5 meters. The receiver

station interval was 25 meters. The number of channels and a fold coverage of 120, and 30 – fold (300%) were used respectively. Figure 1 shows the detector pattern and the source pattern used during the acquisition of the data.

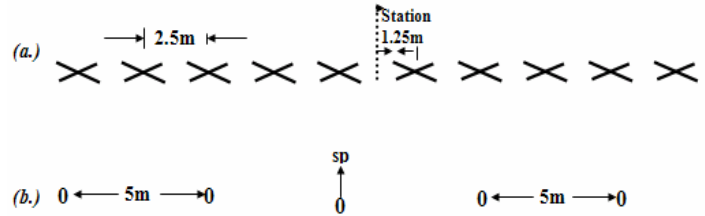


Figure 1: Source-Detector Pattern: (a) Detector Pattern (b) Source Pattern. **X** represents the single geophone point, **0** represents the single shot point.

GRAPHICAL METHODS APPLIED

The maps were on a scale of 1:100,000. The nominal flying height during data acquisition was about 752m above the surface around Agbor.

The graphical methods applied are discussed below in detail. Rambabu and Rao (1983), presented a method for rapid manual evaluation of magnetic anomalies for a thin dike. The method is based on the characteristic distances $X_{3/4}$, $X_{1/2}$, $X_{1/4}$ at which the anomaly falls off to $3/4$, $1/2$, and $1/4$ of the maximum value. Simple mathematical expressions using the characteristic distances are presented to estimate the depth and dip of the sheet. This method does not require prior knowledge of the base level and the origin.

The magnetic anomaly over a sheet along a line perpendicular to its strike, which is given by:

$$F_{(x)} = p \left[\frac{X \sin Q + H \cos Q}{x^2 + h^2} \right]$$

From the above, the authors deduced that:

$$h = \frac{X_M + X_{1/2}}{2(X_M^2 + X_{1/2}^2)}$$

$$\text{or, } h = \frac{X_{1/4} \cdot X_{3/4}}{3(X_{1/4} - X_{3/4})}$$

Bean (1966) developed a method for determining the depth to magnetized bodies from the analysis of aeromagnetic anomalies. In this method, a few specific points are used to obtain the parameters of the magnetized body. This method uses the inflection and half maximum slope points of anomalies having either two flanks or single high gradients. Ratios of distances between these points are used to obtain a solution. He simplified the problem by combining angles of dip, magnetization direction, and the inclination of the geomagnetic field in the plane of the profile into an apparent inclination angle.

By use of Bean's graph, the depth, width and apparent inclination angle can be determined rapidly from only a few simple measurements. Finally, charts are used in determining δ'' width/depth ratio and theoretical half maximum slope distance.

Rao and Rambabu (1981) developed a method of estimating depths of magnetic anomaly due to long tabular bodies using monograms. This method is based on the positions of the maximum and minimum of the magnetic anomaly due to a long tabular body. Characteristic ratios, D and A, involving distances and amplitudes of the maximum and minimum points on the anomaly curve are defined. Monograms showing the variation of D and A with the parameter are used for the evaluation. The parameters of the caustic source are evaluated from the two ratios D and A and the monograms, using some simple analytical relation are presented by:

$$A = \left| \frac{F_M + F_m}{F_M - F_m} \right|$$

and

$$D = \left| \frac{X_M + X_m}{X_M - X_m} \right|$$

Stanley (1977) applied a simple procedure to the interpretation of magnetic profiles. The practical procedure for manual interpretation of Stanley, involves graphically differentiating the anomaly curve, then a straight line is drawn joining the maximum (M) to the minimum (m), and the vertical axis ($X = 0$ and $T_x(0)$) is located by its interception with the curve. The baseline is constructed a distance $M - T_x(0)$ above the

minimum. The interception of the base line with the profile locates X_0 . He finally listed equations, which link the coordinates of the four characteristic points with the unknown parameters of the dike or contact.

Grant and Martin (1966) used some dimensional quantities called "characteristic estimators" in fitting simple models such as prism or tabular bodies to magnetic anomaly pattern. They used characteristic curves as a concise graphical presentation of the behaviour of characteristic estimates with change in the parameters of the model.

The procedure for a prism model requires two estimators, one for determining the parameter H/T and the other for determining L/T. These estimators are; $S.X W_{1/2} / \text{Amp}$ and $YW_{1/2} / XW_{1/2}$. Then a set of characteristic curves are used and $YW_{1/2} / XW_{1/2}$ and $S.XW_{1/2} / \text{Amp}$ are fed into the curves and corresponding H/T and L/T values are obtained. Finally, other complementary curves are used in determining $XW_{1/2} / T$ using H/T and L/T values from where the depth h is calculated.

METHOD OF DATA ANALYSIS

The processing sequence used in this study is summarized in Table 2. The data in multiplexed format was de-multiplexed and resampled at 4 milliseconds for more convenient processing. The de-multiplexed data was then transferred to another tape and recorded. The field geometry information contained in a log book was fed into the computer containing the de-multiplexed data. Both receiver and source static values were recorded. Reflections on the record were disrupted by ground roll energy that is characterized by its low frequency and high amplitude appearance.

Yilmaz (1987) observed that a progressive decrease in the signal-to-noise ratio at late times is true for almost all seismic records. In suppressing noises, the data was subjected to various processing techniques. The program for picking velocity was designed such that picking from velocity spectrum or constant velocity stacks of each panel implies automatic picking from either of them. The values of velocities picked were employed in correcting (NMO correction) the central CMP gather in order to flatten the primary events.

Table 2: Processing Sequence.

INPUT DATA PARAMETERS					
RECORD LENGTH:	600 2MSEC	SAMPLE INTERVAL:	4 MSEC		
DATA TRACES/RECORD:	120	ORIGINAL FORMAT:	SEGD		
PROCESSING PARAMETERS					
INPUT DATA: SHOT GATHER					
01.	LABELLING AND GEOMETRY UPDATING				
02.	SPHERICAL DIVERGENCE CORRECTION: $T * \text{EXP}(0.5 * T)$				
03.	MUTE				
04.	FK FILTERING 1750 M/S CUTS COS TAPER				
05.	FK FILTERING				
06.	CDP GATHER				
07.	PREDICTIVE DECONVOLUTION				
	DESIGN GATE	OPERATOR	GAP	WHITE NOISE	APP GATE
	0. 6-2. 5 S	180MS	20 MS	5 PERCENT	0. 0-2. 0 S
	1. 5-3. 5 S	180MS	24 MS	5 PERCENT	2. 0-6. 0 S
08.	FIELD STATICS CORRECTION				
09.	APPLICATION OF FIRST RESIDUAL STATICS W400-2500, (P-20, 20)				
10.	NMO CORRECTION USING VELOCITIES FROM OLD SECTION				
11.	DYNAMIC EQUALISATION:	OP. LENGTH	WINDOW		
		1500MS	0-6000MS 50% OVERLAP		
12.	STACK				
13.	KIRCHHOFF MIGRATION USING 100 PERCENT VELOCITIES				
14.	FILTERING:	FREQUENCY		WINDOW	
		08 - 60HZ		0- 1500MS	
		08 - 50HZ		1800 – 2500MS	
		08 – 40HZ		3500 – TMAX	
15.	DYNAMIC EQUALISATION:	OP. LENGTH	WINDOW		
		1000MS	0 – 6000MS 50% OVERLAP		
16.	TRACE SELECTION :	EVERY 2 CDPS DISPLAYED			

During the first stage of velocity analysis, the estimated residual statics corrections are applied to the original CMP gathers without any NMO correction. The velocity analysis is performed to improve the velocity picks, after which another velocity spectra and constant velocity stacks plot were generated. The second phase of velocity determination was carried out repeating the same procedure as in Phase 1. This helped in improving the data and enhanced velocity convergence and stacking quality. The data was migrated with the final value of velocity picks. This migration brought the reflection energy from

their CMP position to their true subsurface location and diffraction invariably was collapsed.

INTERPRETATION AND DISCUSSION OF RESULTS

The migrated section (Figure 2) shows good events and continuous reflections. The time window shows that there is no reflection from 0 to 0.5 second. From 0.5 to 1.5 seconds, there are strong continuous reflections. From 1.5 to 2.0 seconds, reflections were not observed.

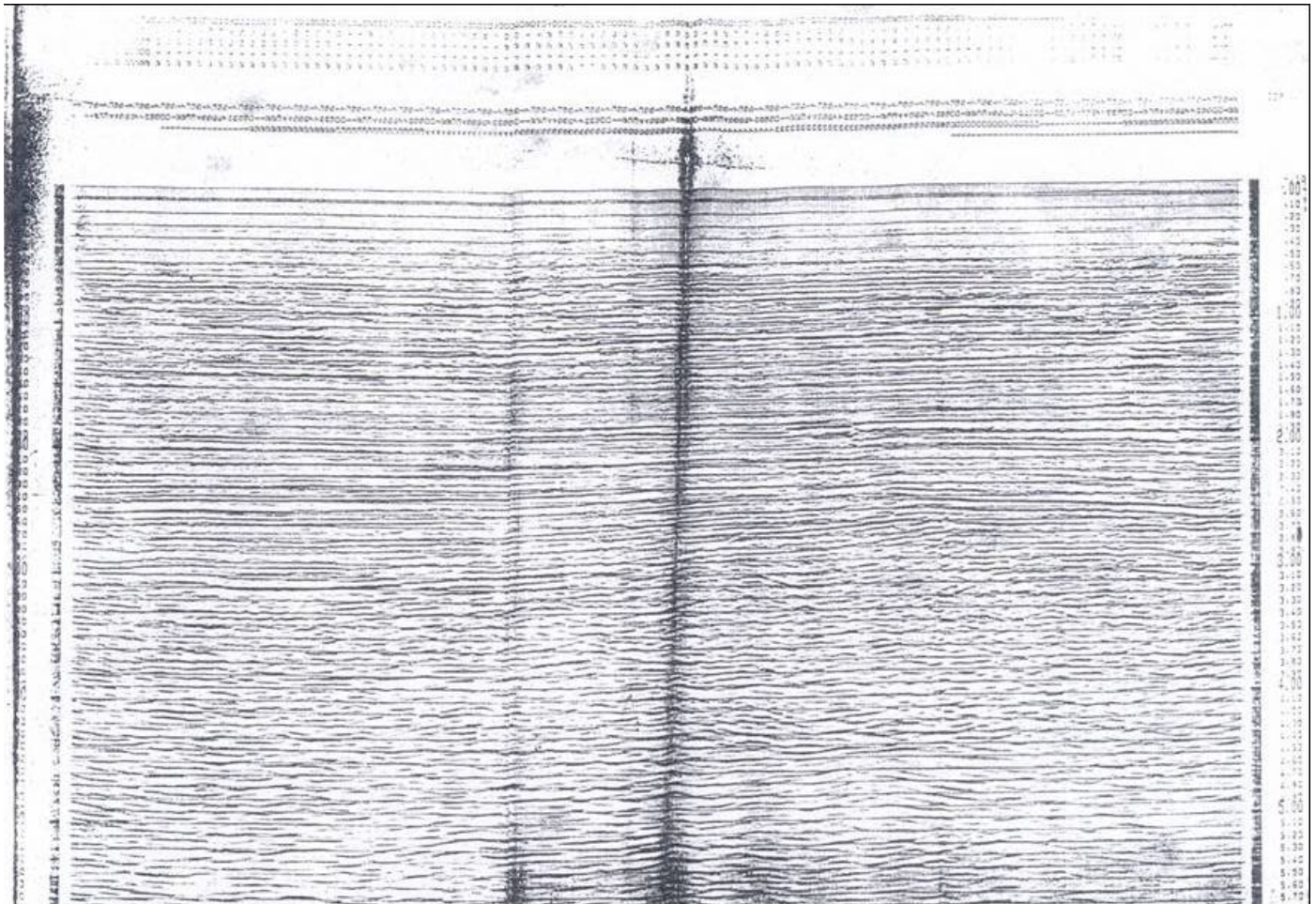


Figure 1: Migrated Section.

From about 2.0 to 6.0 seconds, there were discontinuous transparent reflections.

The interpretation using stratigraphic indicators shows that the Benin formation terminates at about 1.0 second, Agbada formation terminates at about 2.9 seconds, and Akata formation extends downwards. The geological interpretation carried out using the migrated section depicted four faults. Three of those faults were identified as synthetic faults, while the remaining one is an antithetic fault. The antithetic fault was dictated between 1.0 to about 6.0 seconds, while two out of the three synthetic faults were dictated between 1.1 to 6.0 seconds. Hence, the antithetic and synthetic faults lie within the Agbada and Akata formations.

From the stratigraphic interpretation and the time-depth conversion, it was observed that the Benin formation, which terminates at about 1.0 second, corresponds to a depth of about 1,087 meters. The Agbada formation, which is the major hydrocarbon bearing/marine sequence of the Niger Delta started from about 1.0 to 2.90 seconds, corresponds to a depth of about 4,184 meters. Hence, the thickness of Agbada formation is about 3,097m. The Akata formation starts from about a depth of 4,184 meters and continues downwards. It was not possible to reach the basement of the Akata formation from this study. The values of the thicknesses of the various formations of the Niger Delta obtained from this study are compared with those of previous researchers as shown in Table 3. They are in fair agreement.

Table 3: Formations and Corresponding Thicknesses of the Niger Delta given by Various Researchers.

Benin	Agbada	Akata	Researchers
1,200m	2,300m	3,100m	Short and Stauble, 1967
2,000m	5,000m	8,000m	Weber and Daukoru, 1973
1,087m	3,097m	Not possible to reach the base of Akata formation from this study	Present Study

The results in Table 3 were compared with the result in Table 4 obtained from interpretation of aeromagnetic data using different graphical methods by Okeke (1992).

Table 4: Results of the Graphical Methods used for the Interpretation of Aeromagnetic Data (Okeke, 1992).

Method Used	Depth Obtained (km)
Rambabu and Rao (1983)	6.70
Bean (1966)	2.45
Rao and Rambabu (1981)	0.42
Stanley (1977)	5.05
Grant and Martin (1966)	2.85

Comparing the results in Table 3 and Table 4, the depth obtained using the Rambabu and Rao (1983) method reaches the base of Akata formation when compared with the thicknesses of the formations of Niger Delta as shown by the result of Short and Stauble in Table 3. When compared with the results of Weber and Daukoru, the depth calculated using the Rambabu and Rao method will not reach the base of Agbada formation. Comparing the result with the depths calculated from the present study, the depth will penetrate into the Akata formation. The depths calculated using Bean's method and that of the Grant and Martin will only

penetrate into the Agbada formation, but will not reach its base when compared with the result in Table 3. The depth calculated using Stanley's method will penetrate into the depths of Akata formation when compared with the results of Short and Stauble and the present study, but will stop at Agbada formation when compared with the result obtained by Weber and Dankoru. The depth obtained using Rao and Rambabu, when compared with the results in Table 3, will only penetrate into the Benin formation, but will not reach its base.

CONCLUSION

Most efforts made in improving data quality in seismic exploration starting from data acquisition through data processing are aimed at aiding interpretation of seismic sections that will yield a reliable understanding of the geology of the study area. The inferred structures are mainly faults and the stratigraphy comprises of Benin, Agbada, and Akata formations. The estimated sediment thickness values computed from the data used are Benin, 1,087m; Agbada, 3,097m; and Akata, whose base could not be estimated from this study.

The calculated depths from the graphical methods of aeromagnetic data yielded results which are comparable with those obtained from the seismic data. The graphical methods are easier to apply and they are faster. Although some precautions have been taken in this study to ensure high accuracy and neat production, there is room for further measures to be taken in future work. It is therefore, suggested that aeromagnetic data covering most parts of Niger Delta be applied in future work for more robust result.

ACKNOWLEDGEMENT

I am grateful to Shell Petroleum Development Company (SPDC) for the seismic data and the facilities used in this study. I would also like to thank Prof. (Mrs.) F.N. Okeke for the aeromagnetic data and useful suggestions.

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SUGGESTED CITATION

Obiora, D.N. 2006. "Comparative Study of Graphical Methods and Velocity Analysis of 2-D Seismic Reflection Data with Application to Niger Delta". *Pacific Journal of Science and Technology.* 7(2):204-210.