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Wavelet Analysis of High Resolution Aeromagnetic (HRAM) Data over Part of Chad Basin, Nigeria

Lawal, T. O. and Nwankwo, L. I.

Department of Physics, University of Ilorin, Ilorin Nigeria

Abstract

A High Resolution Aeromagnetic Data over part of Chad basin, Nigeria has been analyzed and interpreted with the objective of identifying the nature of magnetic source geometries responsible for hydrocarbon prospectivity using wavelet transformation technique. The technique was chosen because of the inability of Fourier transform to interpret location of features from the transform coefficients. In this work, wavelet transform coefficients were obtained using Morlet mother wavelet. The Scalogram was computed from the transform coefficients which reveal various magnetic source geometries. In other to identify the nature and location of sources geometries, a scale normalization factor was introduced on the wavelet coefficient which increases the resolution of various magnetic sources in the Scalogram plots. The result obtained from the analysis has revealed various magnetic source geometries which are important in hydrocarbon prospectivity in Chad basin, Nigeria.

Keywords: Wavelet Transform, High Resolution Aeromagnetic data (HRAM), Morlet Wavelet, Magnetic Source Geometries

1. Introduction

High Resolution Aeromagnetic (HRAM) data of the Chad Basin, Nigeria were acquired between 2003 and 2009 with the aim of assisting and promoting petroleum and mineral exploration in the basin. The basin was flown over by Fugro Airborne Services Limited, Johannesburg, with a flight line spacing of 500 m oriented in NW-SE and a tie line spacing of 2000 m (NGSA, 2010). It is believed that HRAM data are useful technique in the interpretation of igneous basin because high frequency anomalies are characteristics of shallow igneous intrusions and low frequency anomalies are characteristics of deep igneous intrusions (Yang et al. 2010).

Corresponding Author: Lawal, T.O
Email: taofeeqlawal4u@gmail.com

In order to identify these intrusions, spectral analysis is usually adopted on magnetic data profiles. However, among various spectral techniques is traditional Fourier transform, which may not be suitable for analyzing non-stationary signal like potential field data, as it is difficult to interpret location of geological features from the transform coefficients (Smith, 2000). In view of this Wavelet transforms, a recently developed mathematical tool suitable for the analysis of potential field data (e.g. aeromagnetic data, gravity data, etc.) reveals the local features present in the data (Smith, 2000; Yang et al. 2010).

Fedi and Rapolla (1997) interpreted magnetic profile data and estimated depth to source using continuous wavelet transform based on Morlet mother wavelet. Moreau et al. (1997, 1999) developed an interpretation technique based on continuous wavelet theory using a special class of wavelets called Poisson kernel wavelet. These wavelets make the corresponding wavelet transforms easy to analyze and the source parameters technique can estimate the source position and type, assuming the sources are homogeneous (Smith, 2000; Sailhac *et al.*. 2000; Sailhac and Gilbert 2003; Cooper 2005; Chamoli *et al.* 2006; Vallée *et al.*. 2004; Sailhac *et al.* 2009 and Chamoli, 2009). The depth and structural index are estimated by successively testing the least-squares misfit between a straight line and the wavelet coefficients plotted against the scale in log-log space. Yang et al. (2001) analyzed the gravity data of China using the discrete wavelet transform and applied the traditional frequency spectrum analysis technique to estimate the average depth to the source. Albora and Ucan (2001) estimated the average depth of buried bodies from the wavelet power spectrum using gravity anomaly data. Xuya *et al.* (2009) proposed the separation of the gravity anomaly using wavelet transform and average depths were estimated from the semi-log radial power spectrum. Siddiqi (2012) applied wavelet transform to determine and interpret cyclicity, zonation and abrupt changes in sedimentary successions using the well-log data of Shedgum region of Ghawar Oil Feld.

Geologically, Chad basin has been described as a broad sediment-filed depression stranding Northeastern Nigeria and adjourning parts of the Chad Republic (Fig.1).The sedimentary rocks have a cumulative thickness of over 3.6 km and consists of thick Basal continental sequence and transitional Calcareous deposit. The stratigraphic sequence (Fig.2) shows that Chad, Kerri-kerri and Gombe Formations have an average thickness of 130 to 400 m. Below these formations are the Fika Shale with a dark grey to black in color, with an average thickness of 430 m. Others are Gongila and Bima formations with an average thickness of 320 m and 3.5 km respectively (Odebode, 2010).

In this work, we have applied wavelet technique using a non-orthogonal wavelet function with a good symmetry and higher vanishing moment as the analyzing wavelet to the analyses interpretation of High Resolution Aeromagnetic (HRAM) data from the Chad basin, Nigeria in with the objective of identifying nature of magnetic source geometries responsible for hydrocarbon prospectivity.

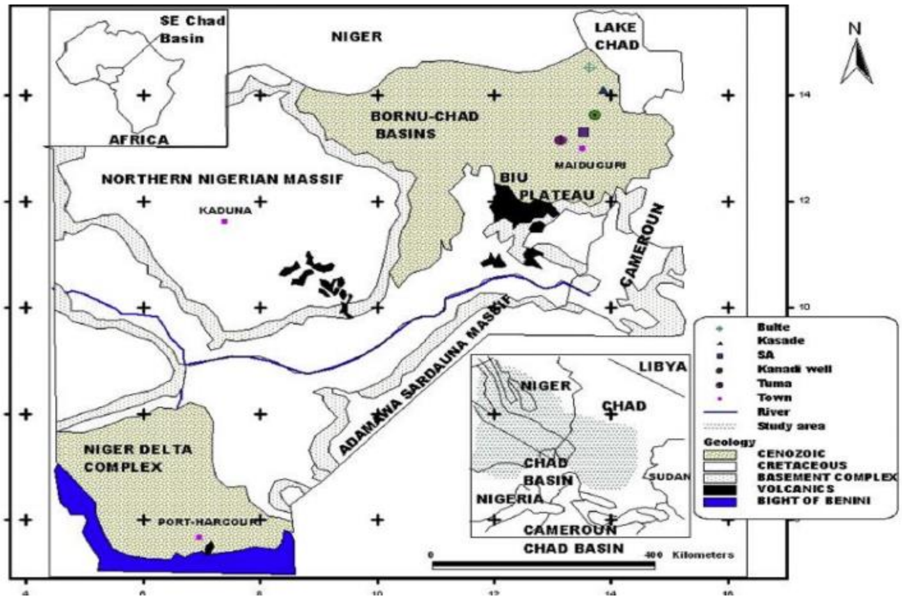
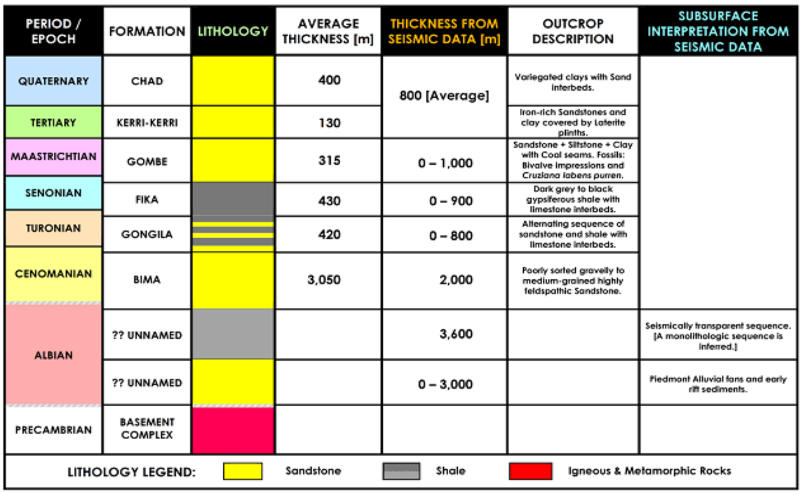


Fig.1: Geological Map of the Chad Basin Nigeria (Okonkwo *et al*.., 2012)



PERIOD / EPOCH	FORMATION	LITHOLOGY	AVERAGE THICKNESS [m]	THICKNESS FROM SEISMIC DATA [m]	OUTCROP DESCRIPTION	SUBSURFACE INTERPRETATION FROM SEISMIC DATA
QUATERNARY	CHAD	🟨	400	800 [Average]	Variegated clays with Sand interbeds.	
TERTIARY	KERRI-KERRI	🟨	130		Iron-rich Sandstones and clay covered by Laterite plinths.	
MAASTRICHTIAN	GOMBE	🟨	315	0 – 1,000	Sandstone + Siltstone + Clay with Coal seams. Fossils: Bivalve impressions and Cruziana labens purren.	
SENONIAN	FIKA	▨	430	0 – 900	Dark grey to black gypsiferous shale with limestone interbeds.	
TURONIAN	GONGILA	▨🟨▨🟨	420	0 – 800	Alternating sequence of sandstone and shale with limestone interbeds.	
CENOMANIAN	BIMA	🟨	3,050	2,000	Poorly sorted gravelly to medium-grained highly feldspathic Sandstone.	
ALBIAN	?? UNNAMED	▨		3,600		Seismically transparent sequence. [A monolithologic sequence is inferred.]
	?? UNNAMED	🟨		0 – 3,000		Piedmont Alluvial fans and early rift sediments.
PRECAMBRIAN	BASEMENT COMPLEX	🟥				

LITHOLOGY LEGEND: 🟨 Sandstone ▨ Shale 🟥 Igneous & Metamorphic Rocks

Fig.2: Generalized Stratigraphic Sequence of Chad Basin, Nigeria (Odebode, 2010).

2. Materials and Methods

The analysis was accomplished based on the mathematical developments obtain for the Wavelet transform in respect of potential field as applicable to High Resolution Aeromagnetic (HRAM) Data Processing. This is discussed below.

Wavelet Transform of Potential Fields

The Continuous Wavelet Transform (CWT) of a discrete sequence X_u is defined as the convolution of X_u with a scale s and translated version of the wavelet basis or mother wavelet is $\psi_{s,t}(u)$. The CWT as defined by Foufoula-Georgiou and Kumar (1997) is given as:

$$W_u(s,t) = \sum_{u=0}^{N-1} X_u \overline{\psi}_{s,t}(u) \qquad s > 0 \tag{1}$$

where

$$\psi_{s,t}(u) = \frac{1}{\sqrt{s}}\psi\left(\frac{u-t}{s}\right) \tag{2}$$

is the dilated and translated wavelet function, s > 0 is the scale factor, t is the translation parameter and $\overline{\psi}_{s,t}(u)$ is the complex conjugate. From equation (1), the wavelet coefficient obtained from the convolution of the discrete profile data X_u, and the dilated and translated analyzing wavelet can be viewed as the coefficient of the CWT at different scales. It is therefore important to note that the choice of the analyzing wavelet $\psi_{s,t}(u)$ is neither unique nor arbitrary but it must reflect the type of features present in the non-stationary data. Because of our interest in both amplitude and phase information and resolution in both time and frequency of a profile data, a non-orthogonal wavelet function with a good symmetry and higher vanishing moment, whose Fourier transform is a Gaussian function and is fairly ideal band-pass filter, Morlet wavelet was chosen as the analyzing wavelet in this work.

The Morlet wavelet basis function is given as

$$\psi(t) = \pi^{-\frac{1}{4}} e^{iw_0 t} e^{-t^2/2} \tag{3}$$

where w_0 is a non-dimensional frequency and is taken to be 1 in this work in other to satisfy the admissibility condition. This wavelet function of equation (3) is complex valued (Fig.3) which enables the extraction of information about the amplitude and phase of the signal being analyzed. Once the choice of wavelet function is made, it is also necessary to choose a set of scale s to be use in the wavelet transform. Torrence and Compo (1998) scaling relation is adopted in this study.

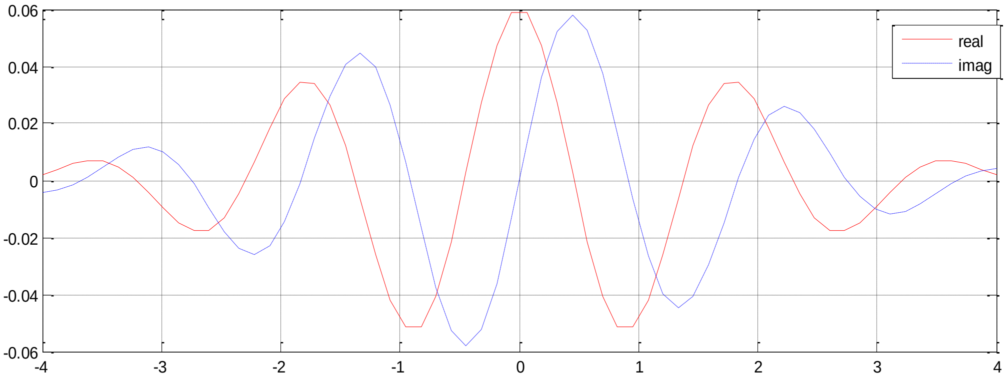


Fig.3: The Dilated and Translated Real and Imaginary Morlet Wavelet.

From the definition of the Continuous wavelet transform, the coefficient can be computed by convolution in space domain or Fourier space using discrete Fourier transform.

The coefficient of the CWT in the frequency domain is computed because it is considerably faster to do calculations in Fourier space and the implementation steps are listed below:

(i) The Fourier transform *H(k)* of the original signal *h(x)* is computed.

(ii) The Fourier transform H(k) is multiplied by the Morlet wavelet $\overline{\psi}(k)$ in the frequency domain to obtain the wavelet transform at scale s = 1.75 that is,

$$W\overline{(k)} = H(\overrightarrow{k}) \times \overrightarrow{\psi}(k)$$

(iii) The inverse Fourier transform of $W\overline{(k)}$ is computed and the coefficient of wavelet transform result $W_u(t)$ in space domain is obtained

(iv) The wavelet transform at different scales is calculated with the dilated wavelet basis and the result of the wavelet transform at different scales following steps (ii) and (iii) is obtained

From the implementation steps mentioned above, The Scalogram was computed from the transform coefficients which reveal maxima associated with larger anomalies in the plot.

However, the Scalogram plot does not provide a direct interpretation of the frequency response of anomaly sources (Yang et al. 2010). To interpret the frequency response, a Scale *S*, is stretched to an equivalent pseudo-frequency F_a. The linear relationship between this Scale *S*, and pseudo-frequency, F_a is defined as:

$$F_a = \frac{F_c}{S\ \Delta} \tag{4}$$

where F_a is the equivalent frequency of wavelet transform at Scale S , ($F_c = 1$) is the Centre frequency of the wavelet basis function, and Δ is the sampling rate.

Since magnetic anomalies caused by rocks are the superposition of several components relating to sources belonging to different positions and extents (Keary, 2002). This appears to be a problem in identifying these sources as a result of strong interference. To overcome this problem, a scale normalization factor was introduced on the wavelet coefficient which increases the resolution of various magnetic sources in the Scalogram plots (Yang et al. 2010).

High Resolution Aeromagnetic map with sheet number 65 was procured from the Nigeria Geological Survey Agency (NGSA). The study area is bounded by the UTM coordinate Northings, 1328400 mN and 1384300 mN and Easting, 826200 mE and 881200 mE. The map was windowed from the National sheet index data base delivered in Geosoft format (Fig. 4). The data was digitized for easy application and re-plotted using Surfer 9.0 (Fig. 5). In other to interpret the nature of magnetic sources present in the study area, the aeromagnetic map was carefully gridded at an equal interval of 0.875 km (Nwankwo et. al, 2011) yielding an approximate eleven (11) profiles which cut across the study area (Fig. 6). The implementation steps described above was applied to each of the eleven (11) profiles and scalogram plots of the profiles were computed.

3. Results and Discussion

The interpretation of Aeromagnetic map of the area (Fig.4) indicates that the dominant trend is in the NE-SW direction which is related to the main trend of the basin itself. Also the area shows regions positive and negative Magnetic anomalies distributed across the study area. Maximum magnetic value (147 nT) was recorded at the Central and Eastern part, while the minimum value (- 107.7 nT) was recorded at the Southern part of the study area. The high magnetic value recorded in this part of the area is highly magnetic due to their high magnetite content and rocks associated with this are Basic igneous rocks. While areas of low magnetic value are low magnetic due to their low magnetic content and rocks associated with this are Sedimentary rocks.

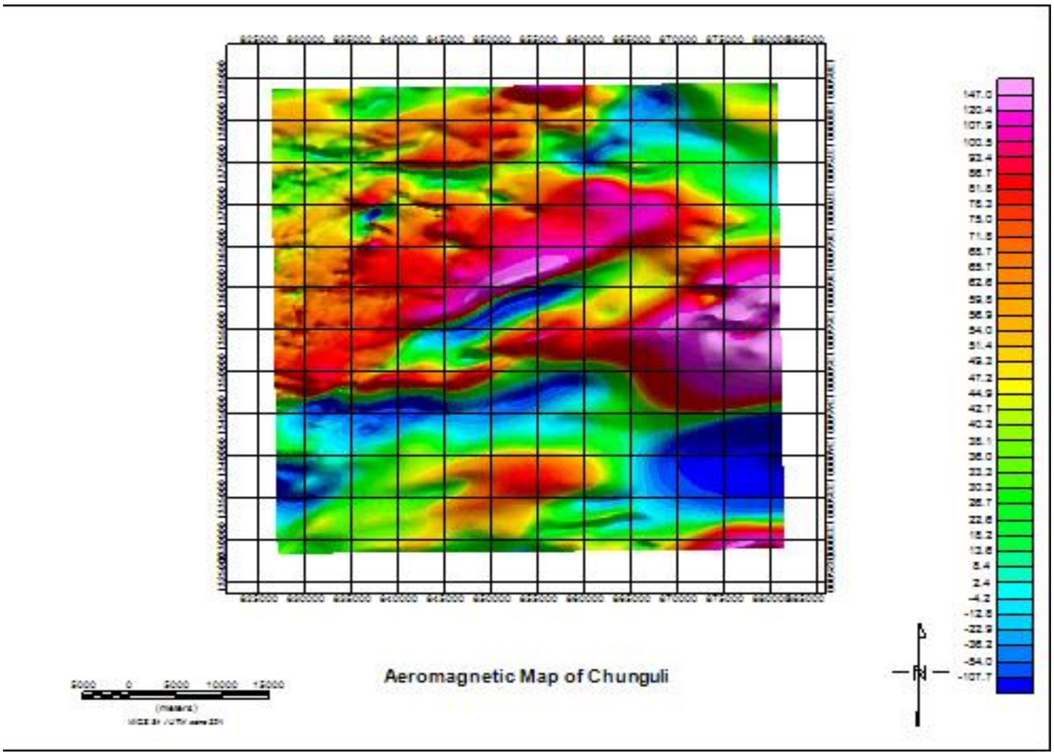


Fig.4: Aeromagnetic map in Geosoft format (NGSA, 2010)

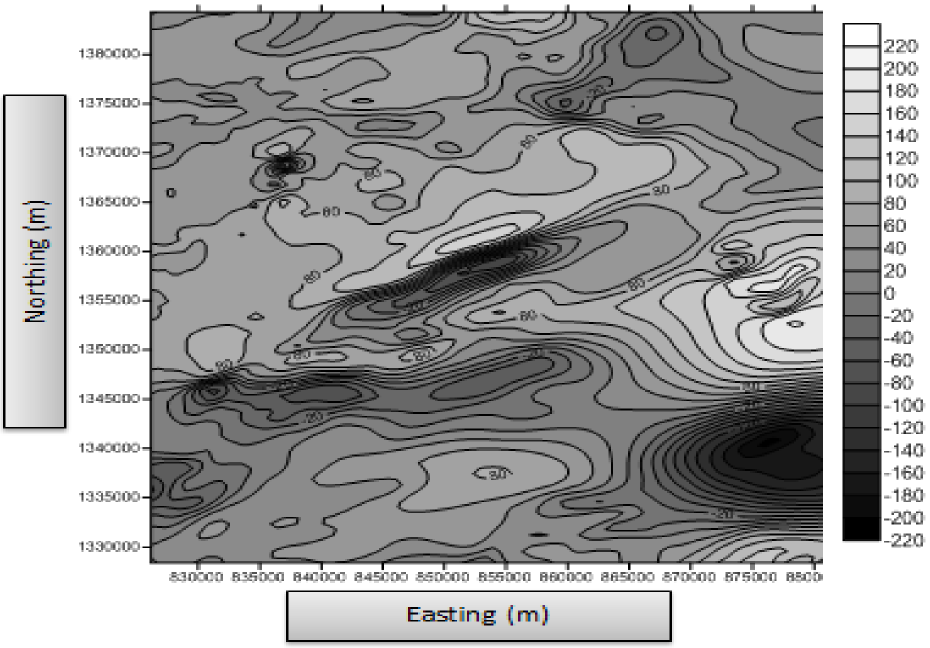


Fig.5: Re-plotted Aeromagnetic map using Surfer 9.0

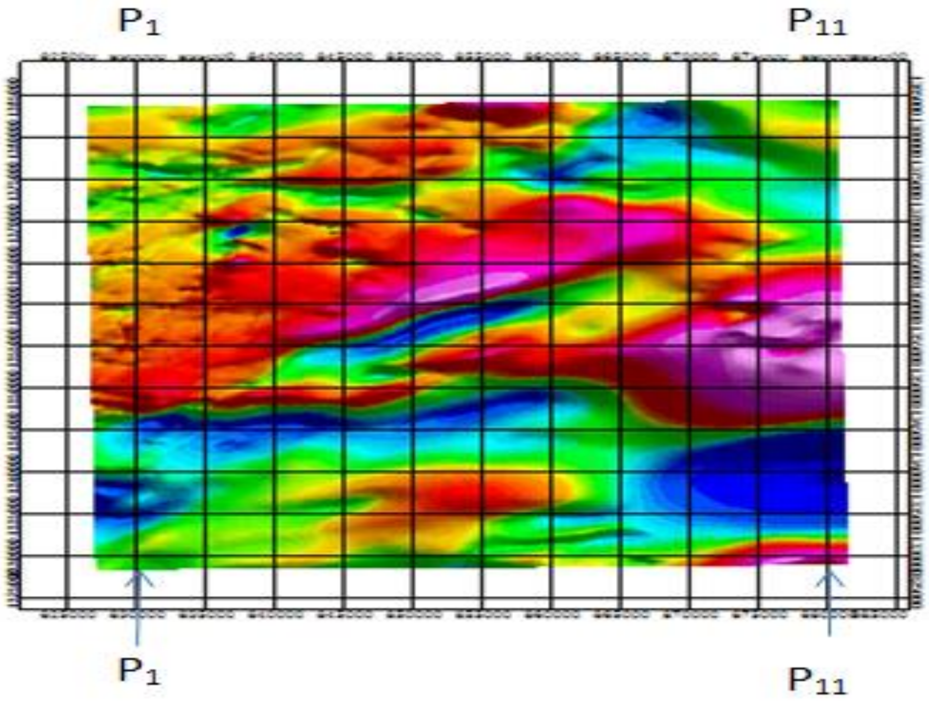


Fig. 6: Gridded Aeromagnetic Map showing Profile (P_1) to Profile (P_{11})

The results of the implementation steps described above as applied to some of the profiles and scalogram plots are shown in (Fig.7). The results shows two types source geometries, namely spheres and horizontal dykes. Profile 5 has a dyke like source geometry while other profiles are predominantly spheres. It can also be observed that majority of these sources are found at the low frequency portion of the scalogram plots and are located a varying distances in the profiles. This is an evidence to show that magnetic sources identified from this study are deep-seated structures and they can be regarded as sources responsible for hydrocarbon prospects.

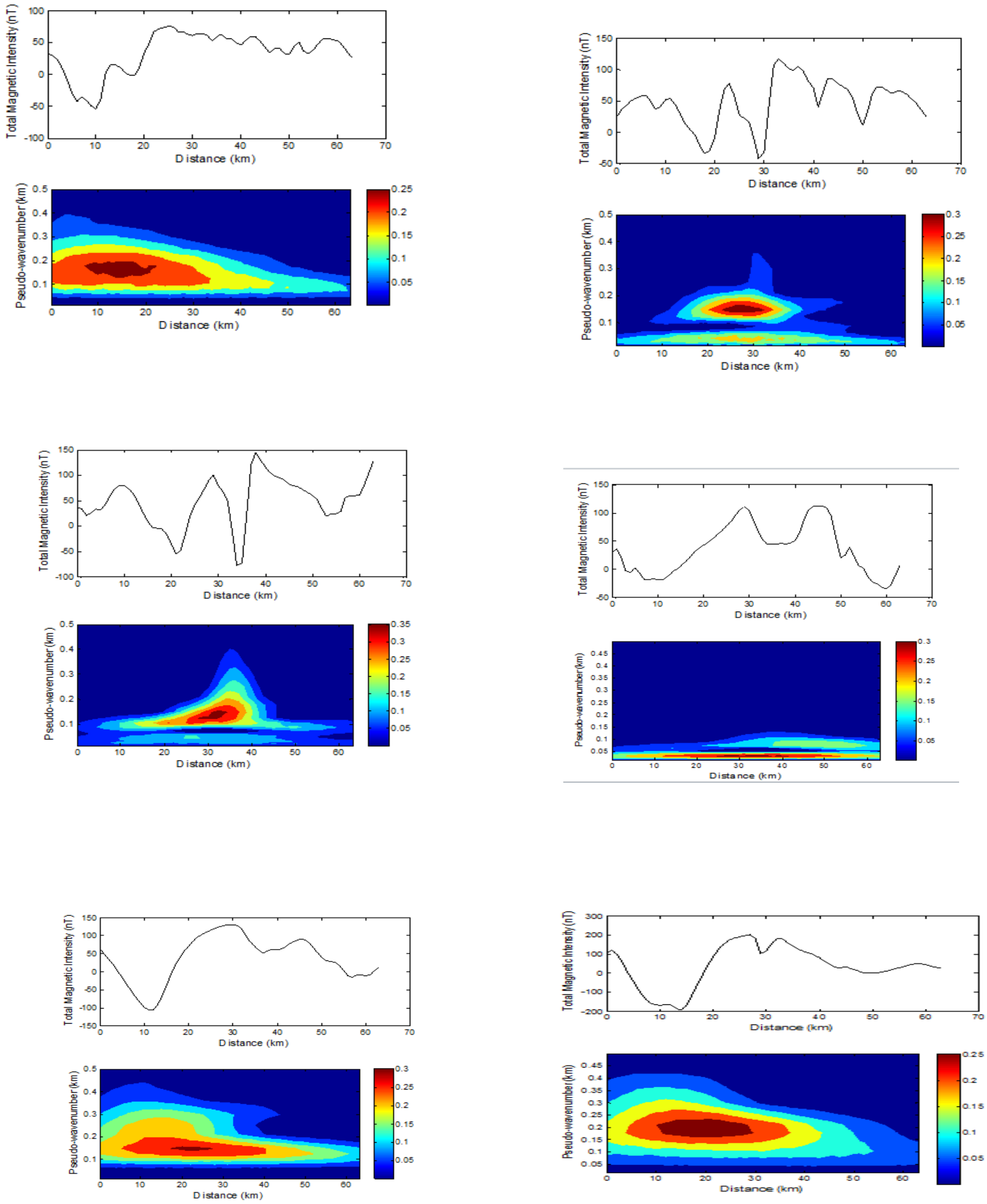


Fig. 7: Some Selected Profiles (P_1, P_3, P_5, P_7, P_9, and P_{10}) and their Scalogram plots.

4. Conclusion

Wavelet transform has been applied to the HRAM data over part of chad basin, Nigeria. It has efficiently analyzed and interprets both geometries and locations of the magnetic sources. It can therefore be suggested that these sources are responsible for hydrocarbon prospect. The technique can equally be applied to other part of the study area in other map the distribution of magnetic sources and this will serve as a guide before other methods such as Seismic can be applied for hydrocarbon exploration.

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