Spatial Periodicities of Structural Features of the Basement Complex of Southwestern Nigeria Deduced from Auto-Covariance and Power Spectra of Aeromagnetic Data.

G.C. Onyedim, Ph.D.[1*] **and O.O. Ocan, Ph.D.**[2]

[1]Department Physics, Obafemi Awolowo University, Ile-Ife, Nigeria.
[2]Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria.

[*]E-mail: gonyedim@oauife.edu.ng

ABSTRACT

Structural mapping in the Basement Complex of southwestern Nigeria can be difficult because of the paucity of rock exposures in a terrain that is also difficult to access in places. This paper describes the application of an alternative method of obtaining structural information, involving the computation of autocorrelation functions and power spectra for aeromagnetic profiles. The method was applied to part of Ilesha area, located in the basement complex of southwestern Nigeria. The results reveal the existence of a repetitive pattern in the spatial distribution of the magnetic structure in the rocks along the profiles examined excluding the two located in the northeastern portion. On a regional scale, the periodicities observed have wavelengths of 8.33, 4.12, 2.08, and 0.76 km, respectively. These correspond remarkably with three out of the six peaks observed in the frequency histogram of aeromagnetic lineament spacing in the study area. The success of the method in the study area means that it can also be applied to other areas underlain by Basement Complex rocks where such periodicities can be obscured by irregular or complex features.

(Keywords: magnetic anomalies, autocorrelation, power spectrum, harmonics, lineaments)

INTRODUCTION

In regional geological mapping, it is usually of interest to determine the spatial distribution of structures such as fractures, faults, joint systems, folds and alignment of intrusives. A general characteristic of the Basement Complex of Nigeria is that the crystalline rocks are extensively weathered (Faniran, 1974 and Omorimbola, 1982) and this produces a lateritic overburden, which measures tens of meters in places (Faniran and Jeje, 1983). The result is a paucity of outcrops and hence a general lack of exposure of these structures. In such circumstances, conventional field mapping techniques become difficult, time consuming and expensive especially at regional scale.

A practicable and effective method of mapping the spatial distribution of structural features and trend directions in such difficult terrain involves the computation of auto-covariance functions and power spectra of aeromagnetic data. Despite the effectiveness of this statistical method, literature on its application to real data is still dominated by studies conducted about four decades ago, for example, Horton et al. (1964) computed the spectrum and autocorrelation function of the aeromagnetic field from the north western Canadian Shield. In an earlier study, Affleck (1963) examined the statistical nature of the trends and spacings of magnetic anomalies from different parts of the American continent.

In this study, the statistical method has been applied to digitized profile of aeromagnetic data of a 784km^2 area located southeast of Ilesha in southwestern Nigeria. According to Horton et al. (1964), the method is useful for investigating areas where structural trends are either hidden or not well defined.

THE STUDY AREA

The area investigated is located southeast of Ilesha and is bounded by latitudes 7° 30'N and 7° 45'N and longitudes 4° 45'E and 5° 00'E. Rocks in the area are of Precambrian age and form part of the Nigerian Basement Complex. As shown on the geological map in Figure 1, schists and granite gneisses underlie mainly the western. The eastern part is dominated by NNE-SSW trending ridges of quartzite and granite gneisses, which rise to about 100 m above the surrounding pedeplains consisting of schists. Intrusives of the Older Granite Suite occur mainly in the south central and north central portions of the study area.

The statistical method was applied to the present study area for two basic reasons. The first concerns the difficulty involved in conducting conventional ground geological mapping in the area, due mainly to the obscuring influences of thick overburden of weathered material and dense vegetation, and the generally rugged topography that impedes accessibility.

The second is to investigate if the method can provide additional structural information or confirm results obtained previously using field based or remote sensing techniques.

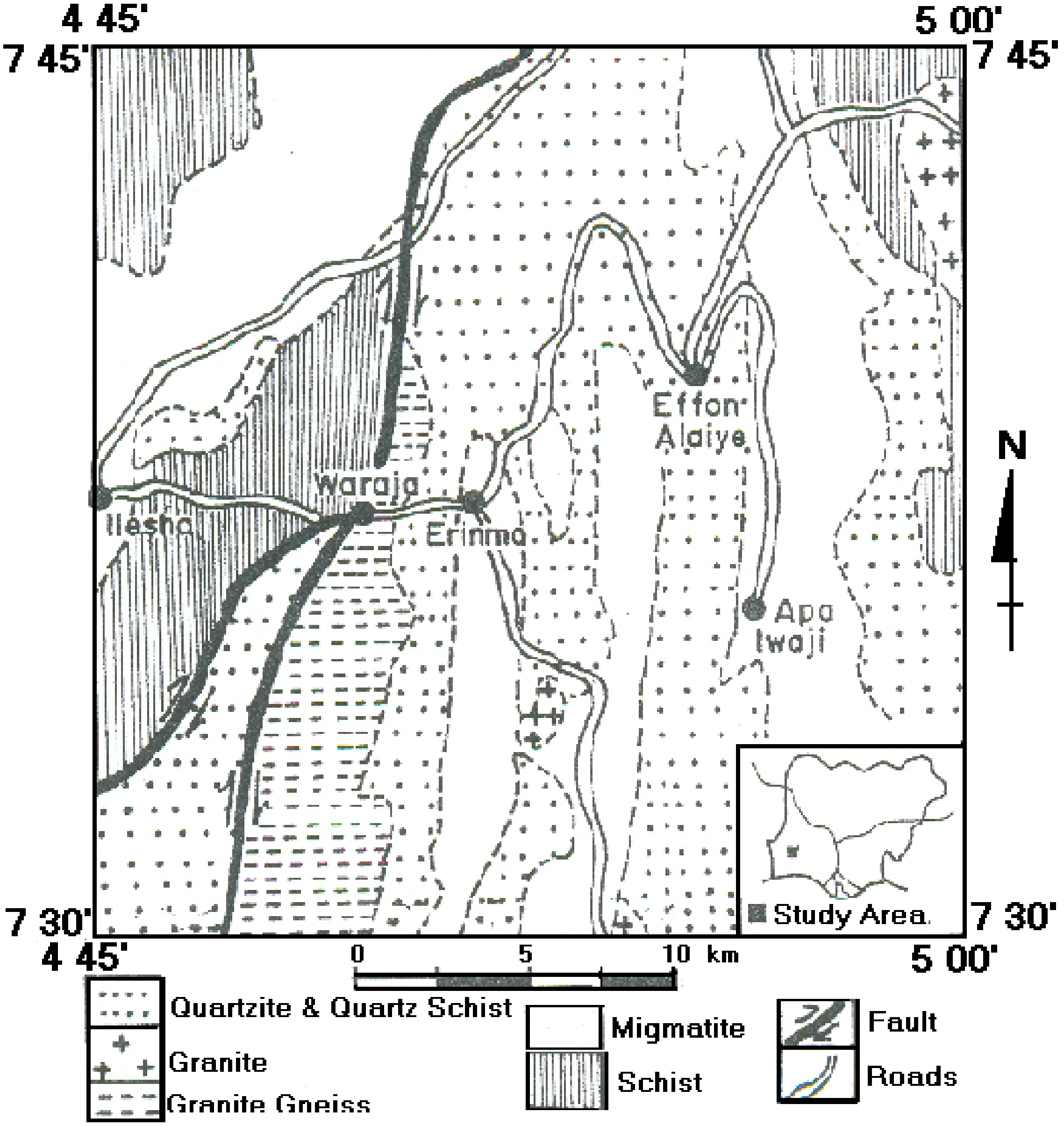


Figure 1: Geological Map of the Study Area..

MATERIALS AND METHOD

Air-borne magnetic data are available for most parts of Nigeria. They are published on half and quarter-degree sheets by the Federal Surveys of Nigeria. The data used for the study are contained in Sheet 234 (Ilesha SE) of the 1:50,000 map series.

The legend on the map indicates a normal flight height of 500 ft (approx. 152 m) above terrain. The survey consists of traverses at 1km intervals in a direction approximately NNW-SSE. The total magnetic field intensity values shown on the aeromagnetic map in Figure 2 and on the profiles in Figure 3 are relative to a 25,000 nT base value.

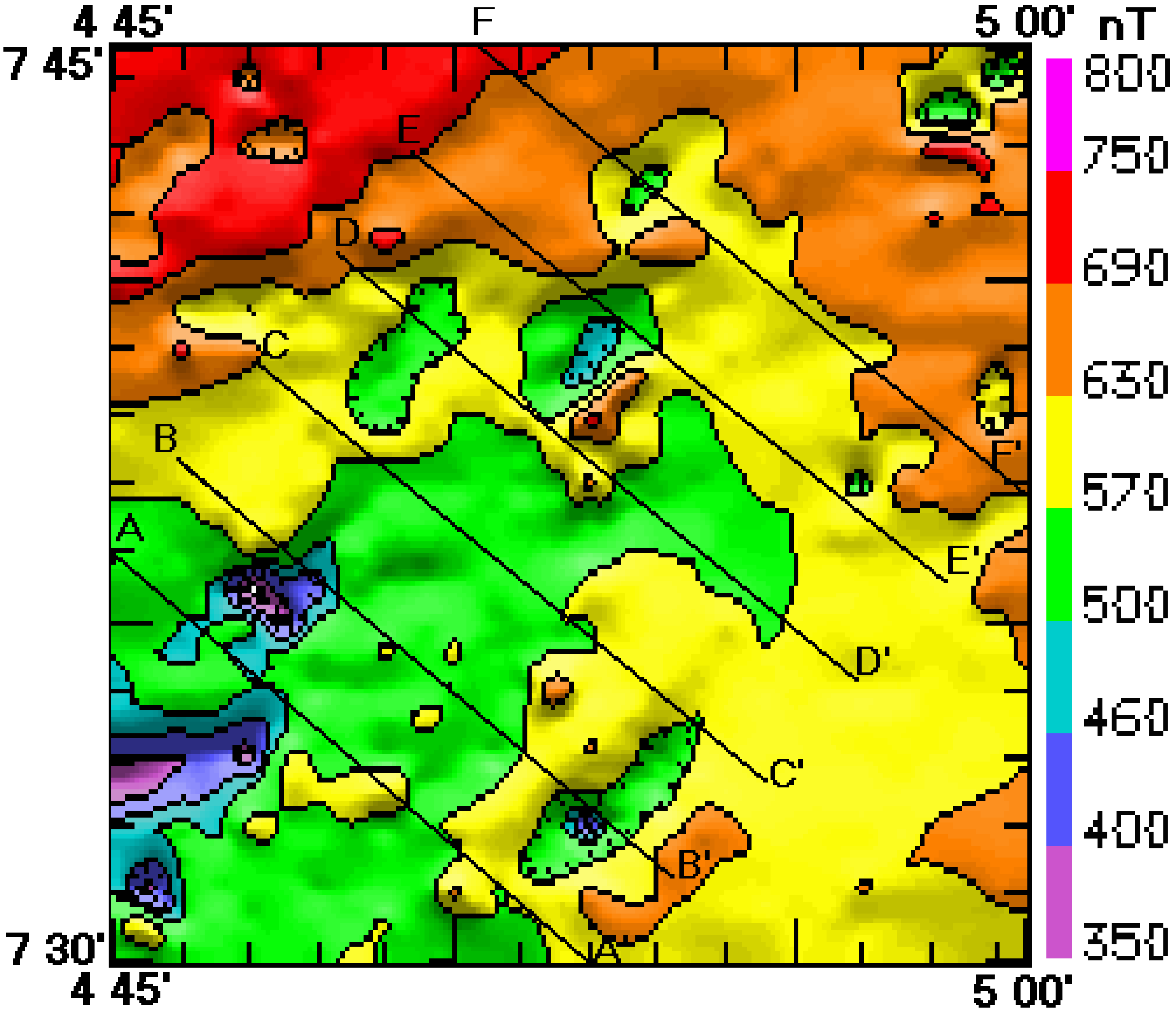


Figure 2: Aeromagnetic Map of the Study Area.
Locations of profiles AA' to FF', chosen for statistical analysis, are indicated.

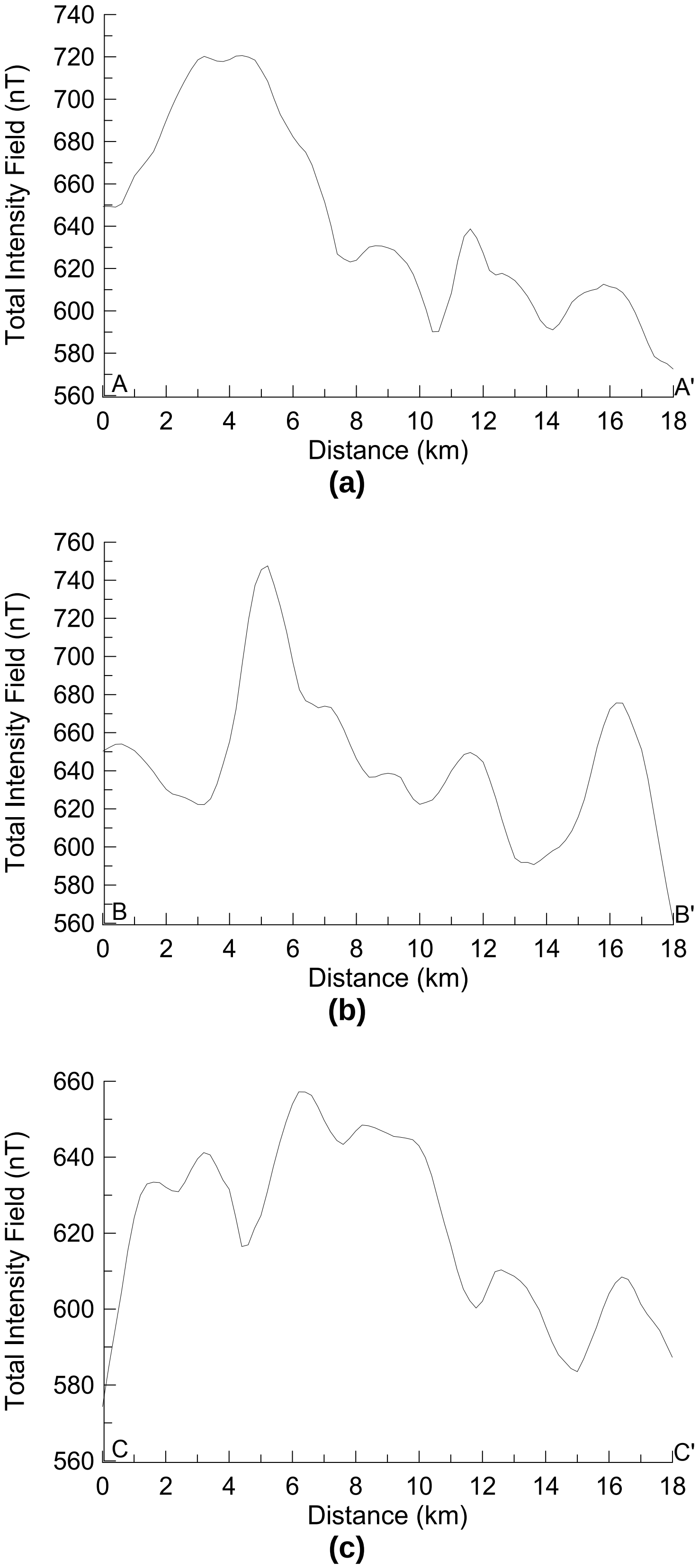
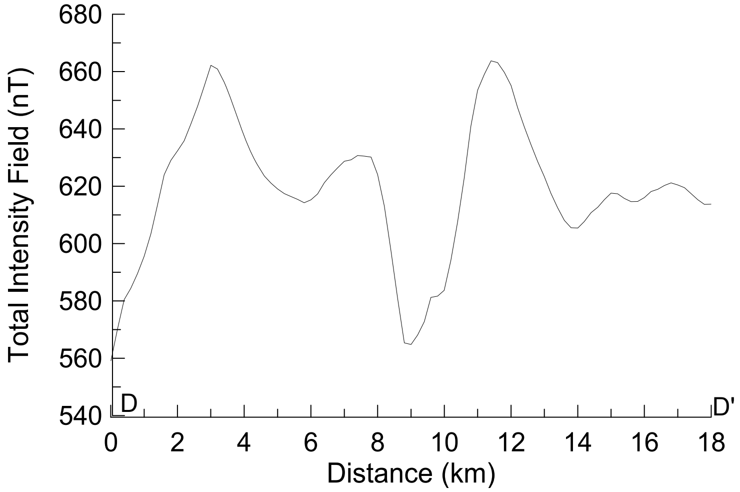


Figure 3 a, b, and c: Total Intensity Magnetic Fields along Profiles.



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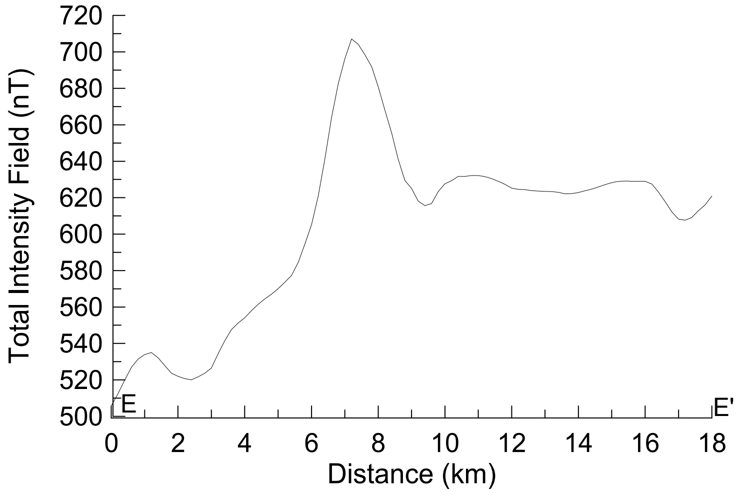

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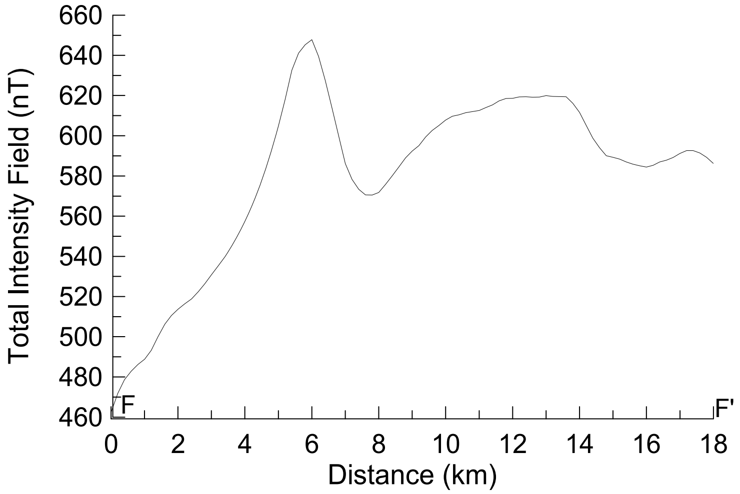

(f)

Figure 3 e, f, and g: Total Intensity Magnetic Fields along Profiles..

The aeromagnetic field is a complex phenomenon arising from complex distributions of magnetization in the earth's crust. On the aeromagnetic map of the study area shown in Figure 2, the low frequency trend has an approximately north-northeasterly orientation particularly in the western portion and NNW-SSE to N-S in the eastern portion. The high frequency anomalies, which are concentrated mainly in the western half of the area, appear to show no directional preference. It is therefore apparent that the data component corresponding to the trends and the anomalies are separable in the frequency domain. This is the basis of the statistical approach adopted by Spector and Bhattacharyya (1966) and its extensions by Naidu (1969) and also by Spector and Grant (1970). It is also possible to achieve the same results of anomaly/trend separation without leaving the spatial domain by using, for example, the autocovariance function and its spatial Fourier counterpart, the power spectrum.

Pioneer works in this area include those of Blackman and Tukey (1959), Horton et al (1964) and Gudmundsson (1966). The method proposed by Horton et al (1964) to investigate the periodicity of magnetic structure and the orientations of dominant structural trends in the District of MacKenzie, Northwestern Territory, Canada was adopted in this study because of its simplicity. Therefore, only a brief outline of the equations will be presented here, while the details can be found in that paper.

Analysis of Profiles

Data along six profiles (Figure 3) spaced about 5km apart and running approximately parallel to the flight lines, were extracted from the map in Figure 2. For consistency and unbiased statistical analysis, profiles of equal length were chosen. Each profile was then digitized using sampling intervals (Δx) equal to 0.2km.

Let T_i be the i^{th} total magnetic intensity value along the profile, with the sample points spaced Δx apart. Then the auto-covariance coefficient for the r^{th} shift is given by:

$$C_r = \frac{1}{N-r} \sum_{i=1}^{N-r} T_i \, T_{i+r}$$

$i = 1,2,\ldots\ldots,N;$
$r = 0,1,\ldots\ldots,m$

In order to include negative shifts (i.e. negative values of r), we note that,

$$C_{-r}=C_r$$

Furthermore, the auto-covariance coefficients were divided by the coefficient at zero shift (C_o), to obtain the auto-correlation coefficients whose values range between 1 and -1.

Using the auto-covariance coefficients computed from equation 2, the power spectrum for the r^{th} shift on a given profile data is given by:

$$P_r = \Delta x[C_o + 2 \sum_{p=1}^{m-1} C_p \mathrm{Cos}(pr\pi/m) + C_m \mathrm{Cos}(r\pi)]$$

$r = 0,1,\ldots\ldots\ldots\ldots\ldots\ldots m$

RESULTS AND DISCUSSION

Magnetic anomalies observed in an area reflect the variable magnetic character of the underlying rocks lying close to the surface and at unknown depths. Igneous and metamorphic terrains generate complex magnetic anomalies, which show up as short wavelength anomalies of near surface origin. High magnetic anomalies normally indicate either the presence of rocks of basic or ultrabasic composition that have relatively high iron content or structural features such as faults and folds.

Since the study area lies close to the magnetic equator, where the inclination of the ambient magnetic field is about 8^o, the magnetic anomalies produced by bodies with positive magnetic susceptibility contrast may be expected to consist essentially of magnetic lows. It is likely therefore that the prominent N-S to NNE-SSW alignments of magnetic lows in Figure 1 have their origin on such bodies

Auto-correlation Functions

Figure 4 shows plots of the auto-correlation functions computed for the 21 shifts to each of the six profiles indicated in Figure 3. Curves for profiles BB', CC' and EE' show large and sharp drops between C_o and C_1 and between C_1 and C_2.

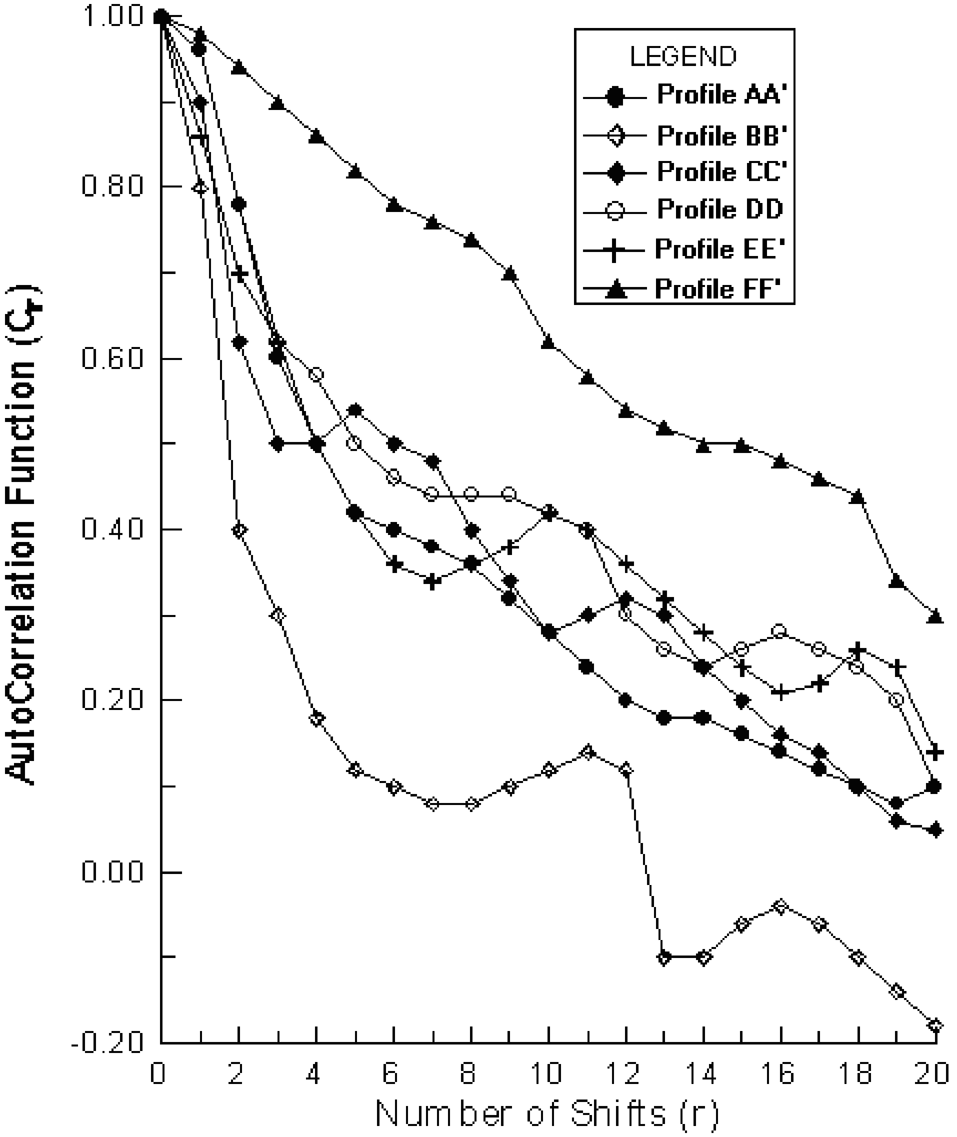

Figure 4: Autocorrelation Functions for Aeromagnetic Profiles AA" to EE'.
One shift is equivalent to 0.2 km.

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According to Horton (1964), this means that the sizes of the areas of polarization, which are randomly distributed where these profile are located, are less than 10% of the sampling interval Δx. In our case, the sampling interval is 0.2 km.

Two well-defined secondary maxima are present in the auto-correlation function for profile AA' at 10 and 18 shifts and in profile BB' at 11 and 16 shifts respectively. The locations of the maxima in AA' correspond to ground distances of 2.0 and 3.6km while those in profile BB' represent distance 2.2 and 3.2km. Profiles CC' and DD' contain one maximum each at 12 and 16 shifts respectively. These again correspond to 2.4 and 3.2km respectively. Profiles EE' and FF', which are located close to the southwestern and northeastern corners respectively of the study area, do not display any secondary maximum, at least, up to the 21 shifts applied here. In order to relate the locations of the maxima to the spatial variation of the structural and magnetic characteristic of the rocks in the area, it is necessary to examine also the nature of the power spectra for each profile.

Power Spectra

Since the autocorrelation functions for profiles EE' and FF' do not reveal the existence of a repetitive pattern of structural features or magnetic materials in the bedrock, the two profiles were excluded from the power spectrum analysis. Power spectra computed according to Eqn.3 for the four profiles AA' to DD' are shown in Figure 5.

Specifically, secondary maxima in the graph of the power spectrum for profile AA' occur at frequencies 0.24, 0.44 and 0.64 cycles per km and these correspond to wavelengths 4.17, 2.27 and 1.56km respectively. If we take 4.17km as the fundamental wavelength, then only the first two harmonics represented by wavelengths 4.17 and 2.27km are present in profile AA'. The third maximum in profile AA' does not coincide with the location of the third harmonic, which is at 1.39km.

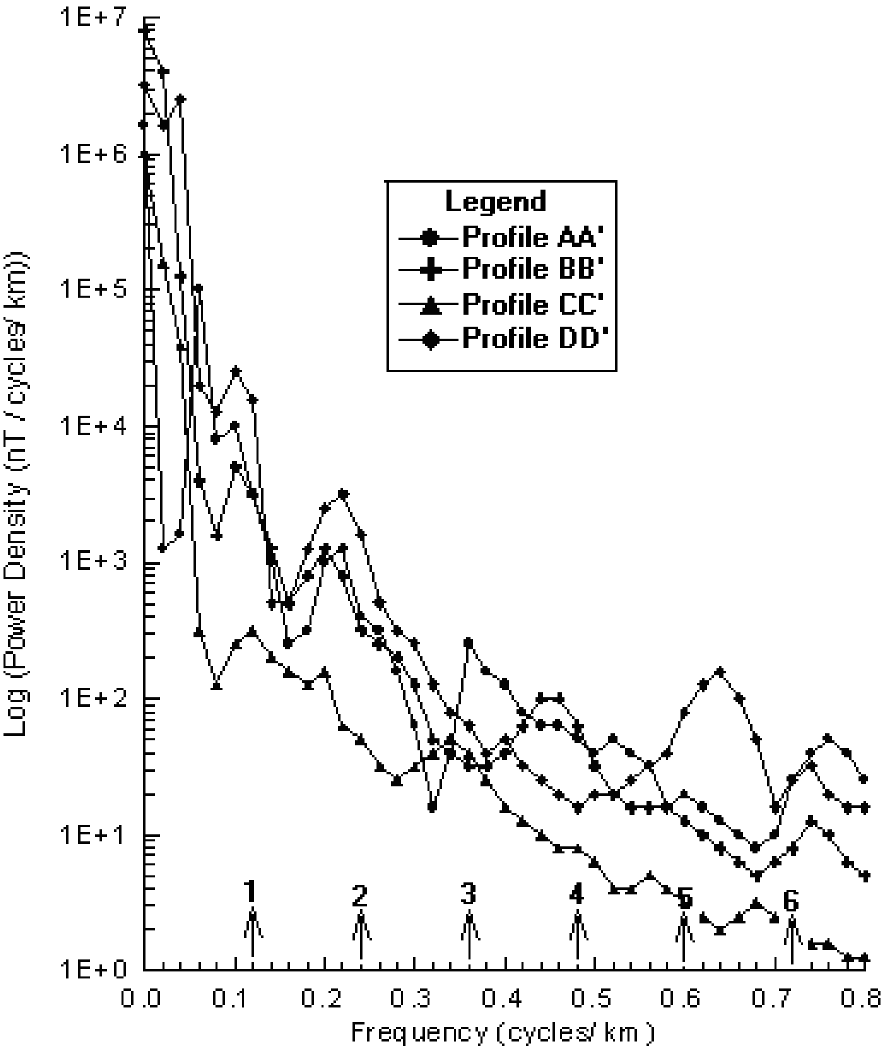

Figure 5: Power Spectra for Aeromagnetic Profiles AA' to DD'.
Arrows show locations of the first six harmonics)

The power spectral contents of profiles BB' and CC' are similar to that of AA' with the presence of the first and second harmonics only. The patterns displayed by profile DD' is different, with the only maximum present occurring at a frequency of 0.12 cycles/km or a wavelength of 8.33km. It is therefore likely that if the data from the profiles are integrated into a regional framework, a fundamental wavelength of 8.33km will emerge. In that case the fundamental wavelength of 4.17 km appearing in profiles AA' and BB' becomes the second harmonic term. Thus we notice that there is evidence of periodicity in the spatial variation of structural and magnetic characteristics of the rocks in the study area but excluding the northeastern portion.

Correlation with Structures in the Study Area

The structure of the area is dominated by flat-lying foliation associated with recumbent folds and flat-lying mylonite zones possibly related to an episode of nappe tectonics. The early foliation was affected by a major north-northeast to northeast trending fault system producing several steeply dipping mylonite zones. The most prominent one is referred to as the Ifewara Fault. These are late strike-slip faults striking parallel to lithological boundaries. According to Hubbard (1975), the faults constitute the young manifestation of repeated movements in a long established major zone of dislocation. Onyedim and Ocan (1998) conducted a lineament interpretation of the area using SPOT imagery and observed that many of the lineaments are spatially and directionally controlled by the Ifewara fault. The results also show that the lineaments represent faults, which are located within the shear zone.

The fact that the aeromagnetic profiles cut across different rock types shows that the observed similarity in the repetitive pattern for profiles BB', DD' and EE' is not a reflection of lithology but that of the magnetic structure in the area. Furthermore, since the magnetic profiles analysed above are approximately perpendicular to the trend of the strike-slip faults, it is therefore likely that the wavelengths observed in the power spectra of the profiles are indicative of the spacings between sets of faults, which are genetically related. In order to investigate the magnetic indications of structure in the study area, a lineament map (Figure 6) was constructed from the aeromagnetic map.

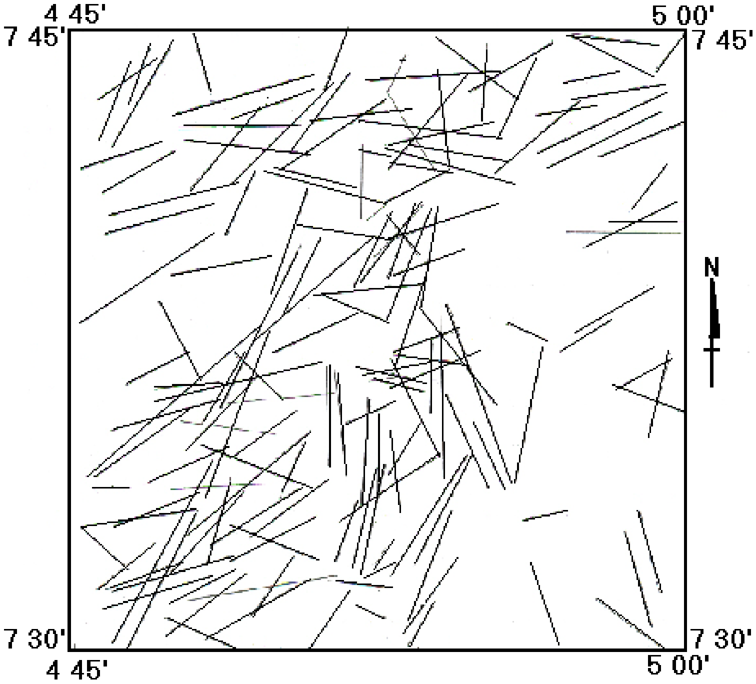

Figure 6: Map Showing Magnetic Lineaments Interpreted from the Aeromagnetic Map of the Study Area.

Such lineaments may represent faults or, in general, the alignment of magnetic materials. In the southwestern portion, for example, lineaments marking regions of high magnetic contour gradient and alignment of elongated closed contours in Figure 2 coincide with the location of the Ifewara fault.

A frequency histogram of the spacing between the lineaments is shown in Figure 7. The histogram shows that the high frequency values cluster in the region of small lineament spacing with a prominent peak centered at 1.25km. The other five peaks are located at spacing of 2.25, 4.25, 5.25, 6.25 and 8.25 km respectively. The peaks at 8.25, 4.25, 2.25 and 1.25 km correspond with the first, second, fourth and sixth harmonic wavelengths respectively and confirm the existence of the wavelengths appearing in the power spectra for profiles AA' to DD'. It is therefore possible that the sets of lineaments with spacing 1.25, 5.25 and 6.25 km, which are not similarly expressed in the power spectra, do not possess any magnetic character. Furthermore, as was also observed by Horton et al (1964), the fact that only the even harmonics are present in the patterns shows that the distribution of the magnetic properties of the rocks is not sinusoidal.

CONCLUSION

The present study has been able to reveal the relationship between aeromagnetic anomalies and the spatial distribution of structures (especially those that can be represented as lineaments) in part of the Basement Complex of southwestern Nigeria.

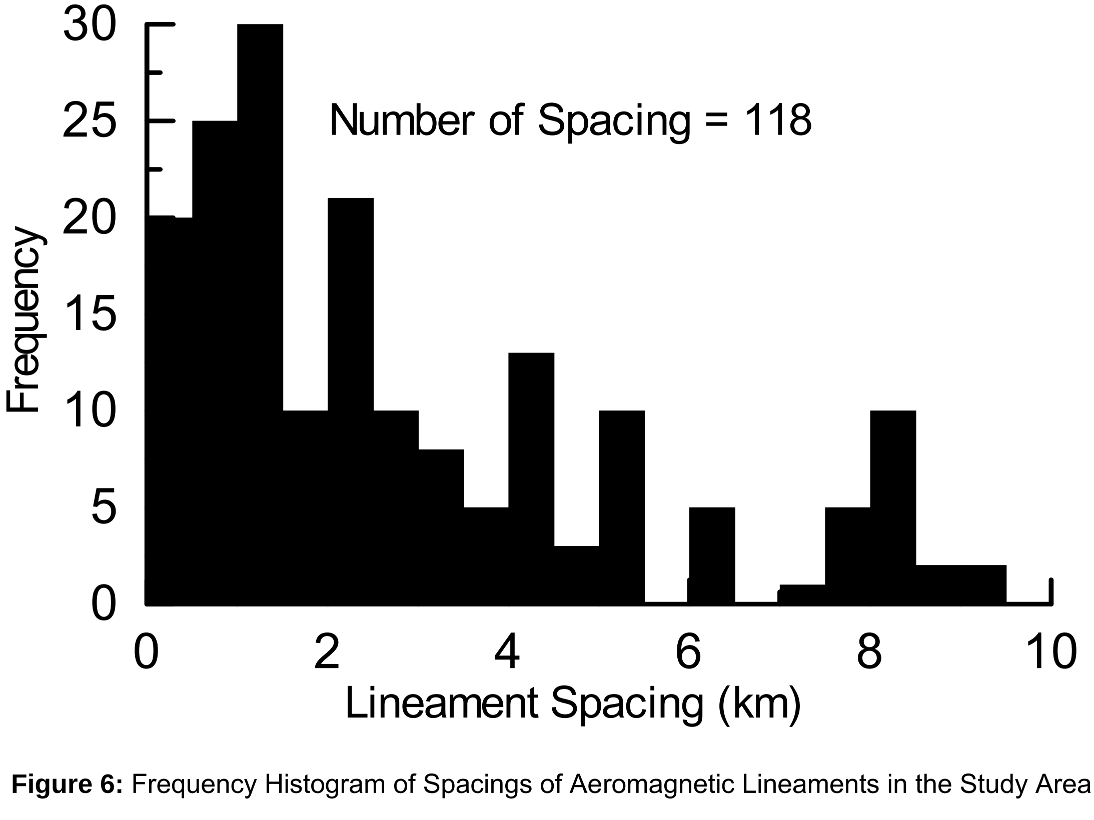

Figure 6: Frequency Histogram of Spacings of Aeromagnetic Lineaments in the Study Area.

In a regional framework, the magnetic structures in the area fall into groups whose spatial frequencies are 0.12, 0.24 and 0.48 and 0.72 cycles/km and which correspond to wavelengths 8.33, 4.12, 2.08 and 1.39 km respectively. The applicability and success of the method to the study area shows that the statistical method can be applied to other parts of the basement complex of southwestern Nigeria, where the masking effects of vegetation and thick weathered overburden on the one hand and the rugged topography on the other hand combine to make ground field investigations difficult or, in some places, impossible.

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ABOUT THE AUTHORS

G.C. Onyedim, Ph.D. and **O.O. Ocan, Ph.D.** teach and conduct research at the Obafemi Awolowo University, Ile-Ife, in Nigeria and serve in the Departments of Physics and Geology, respectively. G.C. Onyedim has interests in potential field methods of geophysical exploration and remote sensing. O.O Ocan is primarily interested in petrology and regional geology.

SUGGESTED CITATION

Onyedim, G.C. and O.O. Ocan. 2009. “Spatial Periodicities of Structural Features of the Basement Complex of Southwestern Nigeria Deduced from Auto-Covariance and Power Spectra of Aeromagnetic Data”. *Pacific Journal of Science and Technology.* 10(1):556-566

Pacific Journal of Science and Technology