

Evidence of some tectonic events in the Koton Karifi area, Nigeria, from Aeromagnetic studies

¹Abdulsalam, N. N., ²Mallam, A. and ³Likkason, O.K.

^{1&2} Department of Physics University of Abuja, Nigeria

³ Physics programme, Abubakar Tafawa Balewa University, Bauchi, Nigeria

nasnaem@yahoo.com

Abstract: Total field aeromagnetic anomaly data obtained for the Koton-Karifi area, Nigeria were used for the present study. The original data were part of the aeromagnetic map of the total magnetic field intensity in half-degree sheet acquired from the Nigerian Geological survey Agency (NGSA). The superimposed ground – levelled aeromagnetic anomaly map on the geology of the area suggests a NE-SW fault line, marking a boundary between the migmatites and granitoids. It is therefore suggested that the metamorphic phase change at this boundary was a major tectonic event in the area.

[Abdulsalam, N. N., Mallam, A. and Likkason, O.K. **Evidence of some tectonic events in the Koton Karifi area, Nigeria, from Aeromagnetic studies.** *J Am Sci* 2025;21(11):1-13]. ISSN 1545-1003 (print); ISSN 2375-7264 (online). <http://www.jofamericanscience.org>. 01 doi:[10.7537/marsjas211125.01](https://doi.org/10.7537/marsjas211125.01)

Keywords: Horizontal ground level; geology; fault; fracture; super impose.

1. INTRODUCTION

The Koton-karifi area of Nigeria (Figs. 2.1 & 2.2) is part of the entire Nupe basin, Nigeria and is the SE edge of this basin lying between latitudes 8⁰:00'N and 8⁰:30'N and longitudes 6⁰:30'E and 7⁰:00'E.

This trough is filled with Upper Cretaceous sediments and is mainly occupied by the sandstones. The original rock of the area could have been subjected to considerable erosion before the Upper Cretaceous beds were laid down. The sandstones consist of unfossiliferous shallow water sandstones and pebble beds. It is possible that these sandstones could have covered a larger area (continuous to the Sokoto Basin) than now (Russ, 1957). Tertiary earth movements could have impacted low dips to this formation leading to erosion over wider areas. The youngest rocks of the area are laterites and alluvial, terrace and terrestrial deposits of tertiary and recent age (Russ, 1957).

The general stratigraphy and sedimentation processes consist of the lithologies overlying the Precambrian Basement complex. The sequence is divided into a number of formations and lithologies characteristics of the age group. The Precambrian to probably Palaeozoic rocks are the oldest rocks and form the basement complex (Adeleye, 1976).

During the upper cretaceous times, depositional cycle started with overlying of the Nupe Group (undifferentiated sandstones) in the Santonian. Adeleye (1976) gave the remaining sedimentary succession as follows. Sandstone formations of Bida and Lokoja followed in succession up to the end of Santonian. During this period, there were no severe crustal movements to alter the geometry of the layers at the end of each depositional cycle. Thus these formations overlie conformably on one another.

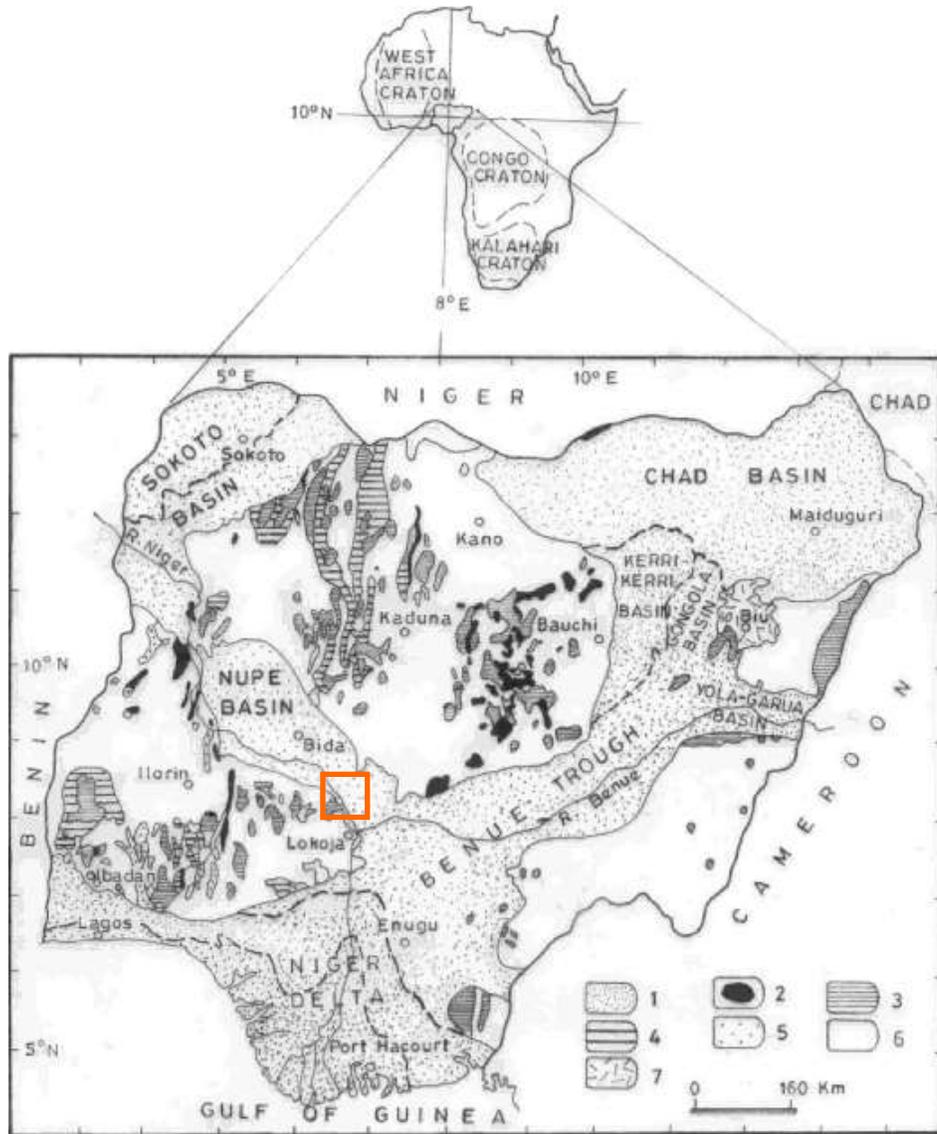


Fig. 1: Geological map of Nigeria, 1 = Cretaceous-Recent sediments; 2=Younger Granites; 3 = Older Granites; 4 = Undifferentiated Metasediments; 5 = quartzite and quartzite schist; 6 = Undifferentiated basement complex and 7 = Tertiary volcanics (From Geological map of Nigeria 1994: compiled by the Geological Survey of Nigeria). Inset is the study area: the Koton Karifi Area of the Nupe Basin, Nigeria

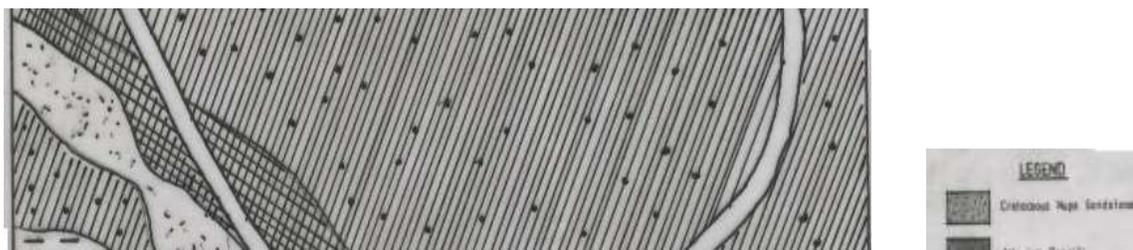


Fig: 2: Geology map of Koton – Karifi ((From Geological map of Nigeria 1994: compiled by the Geological Survey of Nigeria).

At the beginning of the Maastrichtian, the Agbaja (around Niger/Benue confluence) and Batati (around Bida) formations were deposited conformably over the Mamu formation. The Agbaja and Batati formations comprise ironstones of the minnette-type of iron ores (Adeleye, 1976). These ironstones have identical properties to the iron ores of minnette-type of Europe and America, which contain 1.3 – 0.8% phosphorus, small percentage of alumina, sulphur and silica (Adeleye, 1976). The depositional sequence is followed by Ajali sandstones and the coal seams and sandstones making the Nsukka formation. The Quarternary deposits are the recent alluvium, laterites, terrace and terrestrial gravels and sands (Russ, 1957).

The sedimentary facies of the area and the description of the major formational lithologies and structural expositions of the area have been given by Adeleye (1976), as a gently down-warped trough whose buried Basement Complex has a high relief with sedimentary formations of more than 300m thick. The epeirogenesis responsible for the basin genesis

seems closely connected with crustal movements of the Santonian orogeny of South-eastern Nigeria and the nearby Benue Valley (Adeleye, 1976). The earlier periods of sedimentation and intrusion in the Precambrian represent a complex vast period of history in the area (Russ, 1957). These earlier sediments and some minor intrusion must have been subjected to several periods of metamorphism.

2. MATERIALS AND METHODS

Total field aeromagnetic anomaly data obtained for the Koton-Karifi area, Nigeria were used for the present study. The original data were part of the aeromagnetic map of the total magnetic field intensity in half-degree sheet acquired from the geological survey of Nigeria (GSN). These surveys were conducted by consultants on behalf of GSN between 1974 and 1976 covering nearly the entire country. The main aim of these surveys was to assist in mineral and ground water development through improved geological mapping. Flight line direction was NNW-SSE at profile spacing

of 2km and tie line spacing of 20km at an altitude of about 152 m (500 ft). The lines were flown in an ENE-WEW (N60E).

The first step in the present analysis was to digitize the map (Sheet 227: Koton-Karifi) covering the survey area with a digitizing interval of 1km. Digitizing was done manually, reading values at intersections of north-south and east-west grid lines.

The next step in our analysis was to recontour the map to check for any misreading and to produce the total – field aeromagnetic intensity map (Fig. 3).

The contouring was done using the Golden Software 2D Surface Mapping Program (Surfer Version 7.0).

The removal of the broad field, particularly the normal geomagnetic field accomplishes the final stage in this step of data treatment. The application of Gauss powerful techniques of potential field theory to a detailed analysis of the Earth's magnetic field permits the description of the various complexities of the geocentric dipole field of the Earth (Cain 1968). The global model of the Earth's magnetic field, called the International Geomagnetic.

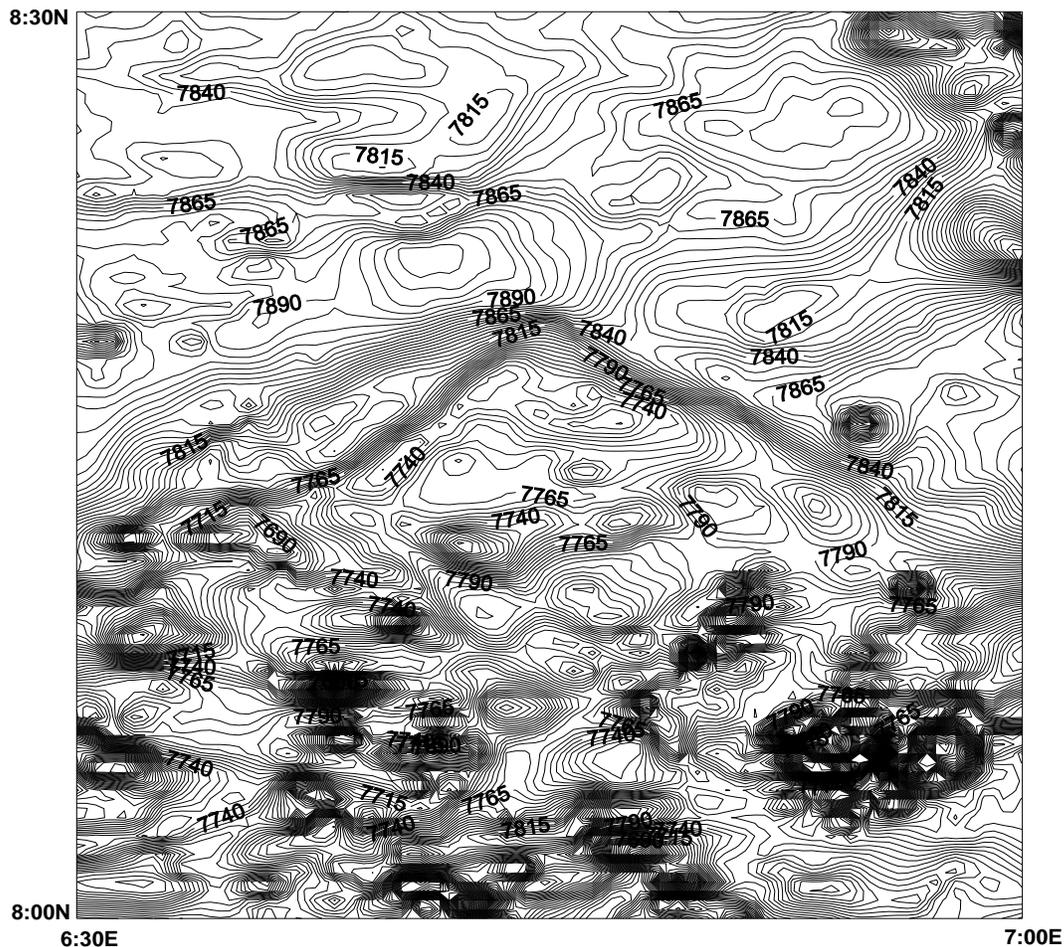


Fig. 3:

Total Field Aeromagnetic Map (Sheet 227) of Koton Karifi. Contour interval is 5 nT. Actual values are obtained by adding 25000 nT to contour values. Regional correction based on IGRF (epoch date 1st January 1974) has not been made.

Reference Field (IGRF) is based on the derivation, up to a certain degree of the so-called

Gauss coefficients in the expression of the potential of the field. Coefficients of the spherical harmonic

expansion of the magnetic field of the Earth are regularly updated to fit data from magnetic observatories or satellite data. The internationally agreed values are published every five years as the IGRF.

Magnetic surveying consists of (1) measuring the terrestrial magnetic field at predetermined points (2) correcting the measurements for known changes and (3) comparing the resultant value of the field with the IGRF value. The difference between the observed and the IGRF is called a magnetic anomaly. Thus correct removal of the IGRF from the observed field is a first step in the interpretation of magnetic data. The computation of the IGRF in the project area follows.

More than 95% of the Earth's magnetic field can be represented by the field of a theoretical magnetic dipole at the centre of the Earth inclined at

about 11.5° to the axis of rotation (Slack et al., 1967, Merrill and McElhinny 1983, Cain 1989, Lowrie 1997). The magnetic poles of the Earth are defined as the locations where the inclination of the magnetic field is $\pm 90^\circ$. The magnetic moment of this fictitious geocentric dipole can be calculated from the observed field. The residual field resulting from the difference between this dipole field and the observed field can then approximate the effects of smaller magnetic dipoles.

The Earth's core-generated magnetic field has associated with it a geomagnetic potential $U(r, \theta, \phi, t)$, which can be expressed in spherical coordinates in terms of a spherical-harmonic expansion of the following form (Quinn et al., 1995):

$$U(r, \theta, \phi, t) = R \sum_{n=1}^N \left(\frac{R}{r} \right)^{n+1} \sum_{m=0}^n \{g_{nm}(t) \cos(m\phi) + h_{nm}(t) \sin(m\phi)\} P_n^m(\theta) \quad (1)$$

Where the spherical coordinates (r, θ, ϕ) correspond to the radius from the centre of the Earth, the co-latitude (i.e., 90°-latitude), and the longitude. In equation 3.1, N is the highest degree for the chosen model as R is the mean radius of the Earth (6371.2 km); $g_{nm}(t)$ and $h_{nm}(t)$ are referred to as the Gauss' coefficients at time t , where t is the time in years (e.g., 1974.312). $P_n^m(\theta)$

represents a particular Schmidt-normalized associated Legendre polynomial of spherical-harmonic degree n and order m . These are polynomials in terms of the cosine of the co-latitude, θ . The Gauss' coefficients are slowly varying functions of time and are expressed in the form of a Taylor series expansion, where only terms up to first order in time are retained so that:

$$g_{nm}(t) = g_{nm}(T_{Epoch}) + \dot{g}_{nm}(t - T_{Epoch}) \quad T_{Epoch} \leq t \leq T_{Epoch} + 5 \quad (2)$$

$$h_{nm}(t) = h_{nm}(T_{Epoch}) + \dot{h}_{nm}(t - T_{Epoch}) \quad T_{Epoch} \leq t \leq T_{Epoch} + 5 \quad (3)$$

Where T_{Epoch} is the base epoch of the model, which for the 1975 is 1975.0. Thus $g_{nm}(T_{Epoch})$ and $h_{nm}(T_{Epoch})$ are the Schmidt-normalized Gauss coefficients of the IGRF at the model's base epoch, while the Schmidt-normalized secular variation (SV) Gauss' coefficients,

\dot{g}_{nm} and \dot{h}_{nm} (where the dot represents differentiation with respect to time, i.e., $\frac{d}{dt}$), are the

annual rates of change of the main field (MF) Gauss' coefficients g_{nm} and h_{nm} and are evaluated at the middle of the model's lifespan (i.e., at $T_{Epoch} + 2.5$). The MF Gauss coefficients and SV field Gauss coefficients are collectively referred to as spherical-harmonic coefficients.

Figure 4 shows the IGRF values computed and contoured for the Koton Karifi, Area, Nigeria at approximately 150 m above ground level for epoch date 1st January 1974 using the 1975 IGRF model. The algorithm used was based on Cain (1968) following the implementation of Cordell et al., (1992) modified for use on an IBM compatible PC.

The map (Fig. 4) shows a pattern composed of lines plunging NE-SW increasing in value with nearly uniform gradient from about 32640 nT in the NW to about 32760 nT to SE. This map is the reflection of the effect of the geomagnetic dipole field around the Koton Karifi, area, Nigeria.

The International Geomagnetic Reference Field is considered to be the best available

representation of the main field for any particular epoch (Langel 1992, Luyendyk 1998, Minty et al. 2003) and is now almost universally accepted as the background against which magnetic anomalies are reported (Tarlowski et al. 1996).

The IGRF values (Fig. 4) are subtracted from the observed magnetic field intensity values (Fig. 3) for the study area. This results in a composite aeromagnetic anomaly map shown in Figure 5.

The composite aeromagnetic anomaly map (Fig. 5) shows values ranging from -200 to 250 nT. The map shows a central linear belt which runs from the western to the eastern ends and apparently separating the area into two: with the southern dominated by convolutions and the northern dominated by smoothed network of contours. This prominent belt is likely very significant in the area and will be further investigated.

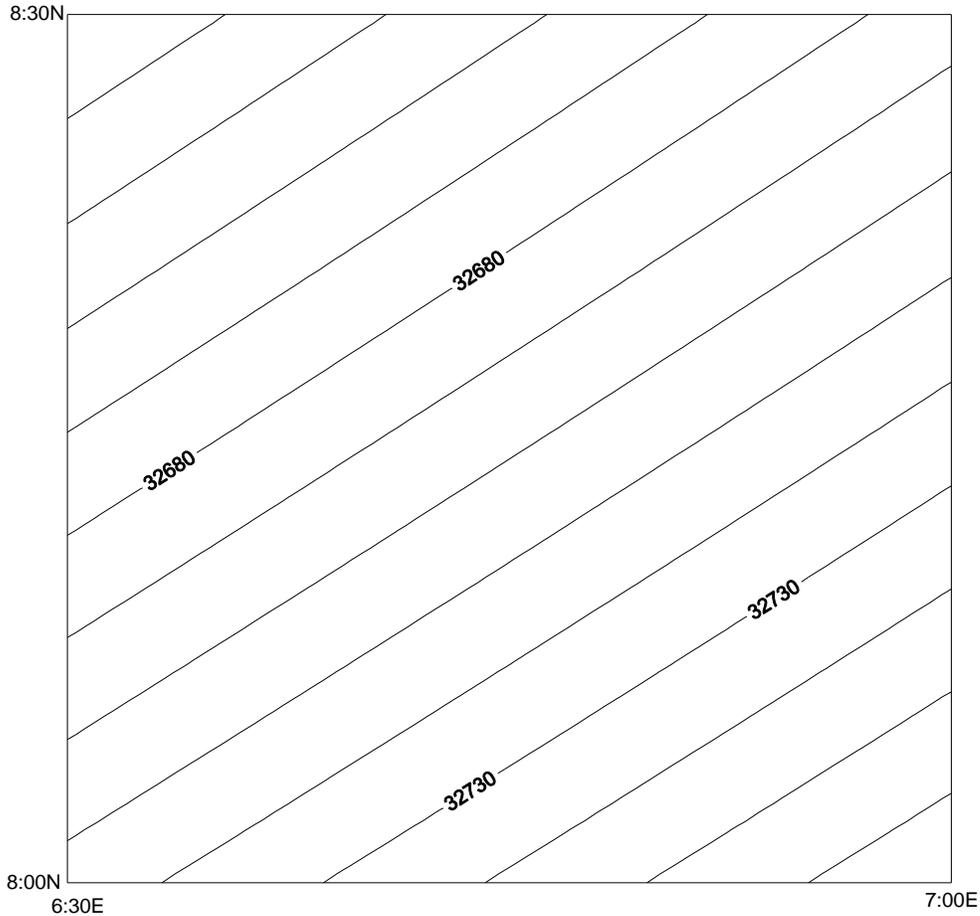


Fig. 4:

The main field (IGRF) over Koton Karifi Area. The Epoch date of 1st January 1974 was used for the 1975 IGRF model. Values of contours are in gammas (nanoteslas).

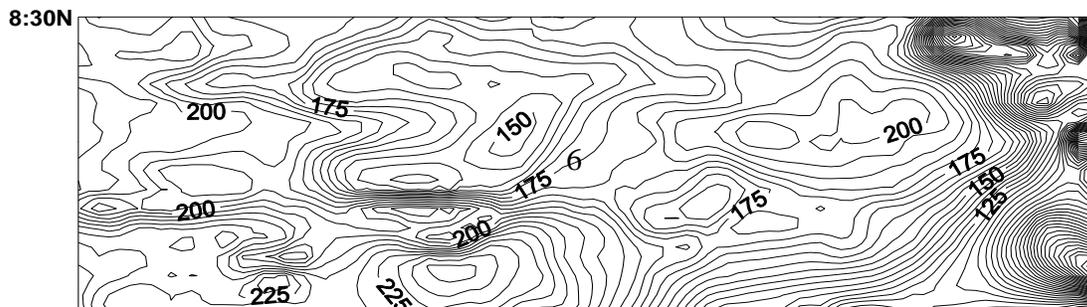


Fig. 5: Total field aeromagnetic anomaly map of Koton-Karifi area (sheet 227). The main field in form of Igrf (Igrf model 1975 of epoch date 1 January 1974) has been removed. Contour Interval is 5nT.

3. RESULTS AND DISCUSSION

The total-field aeromagnetic map of the Koton Karifi Area, Nigeria is displayed in Figure 5. This was obtained when the main field (Fig. 4) was removed from the data. This initial process in the interpretation of the magnetic data is very important and significant.

Figure 7 seems to suggest a NE-SW fault line depicted from a thresholded ground-levelled aeromagnetic anomaly superimposed on the geology. This inferred fault seems to mark a boundary between

the migmatites and granitoids. It is therefore pertinent that the metamorphic phase change at this boundary was a major tectonic episode in the area. The large arrow (Fig. 7) indicates the direction of an abrupt intervening episode that likely interrupted the continuity of the pre-existing fault. This oblique fault might be due to reported widespread Santonian episode that affected most part of eastern Nigeria culminating in the emplacement of the Abakaliki anticlinorium (Uzuakpunwa 1974).

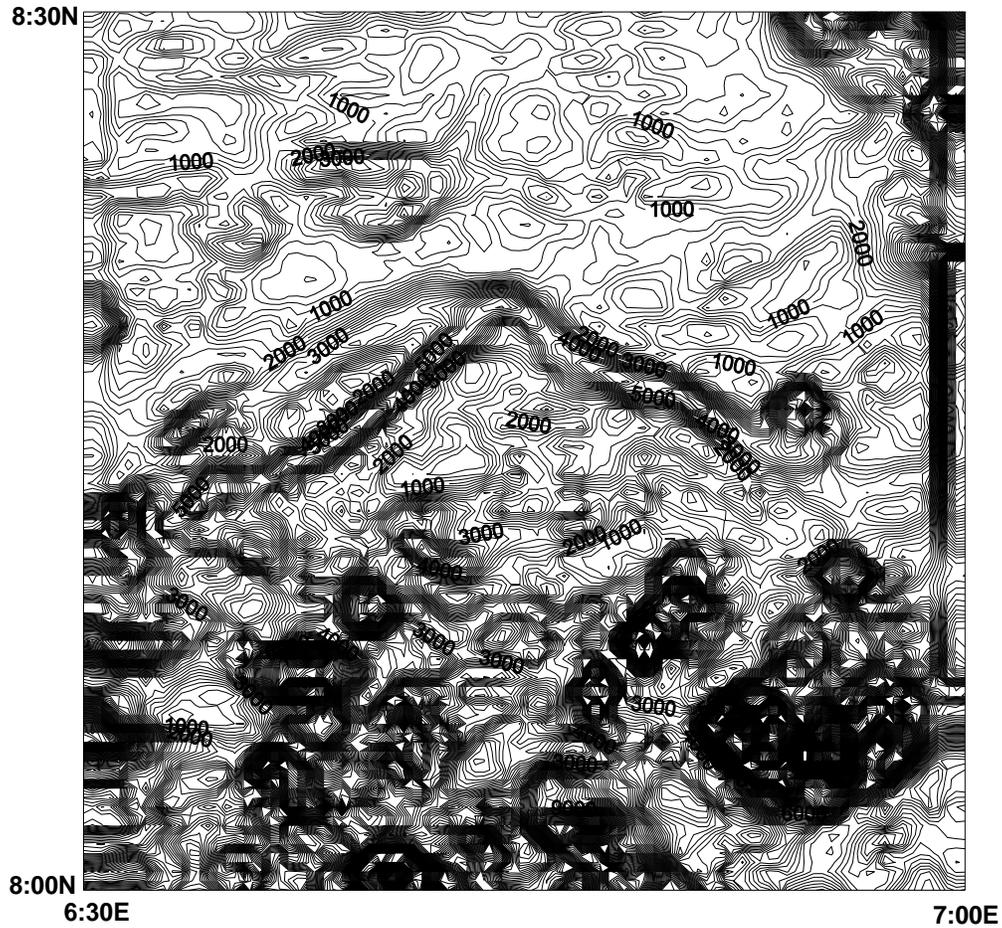


Fig. 6: Output of the horizontal gradient computation of the ground levelled residual aeromagnetic total field magnetic intensity data over the Koton Karifi Area, Nigeria. Contour interval is 200 nT/km.

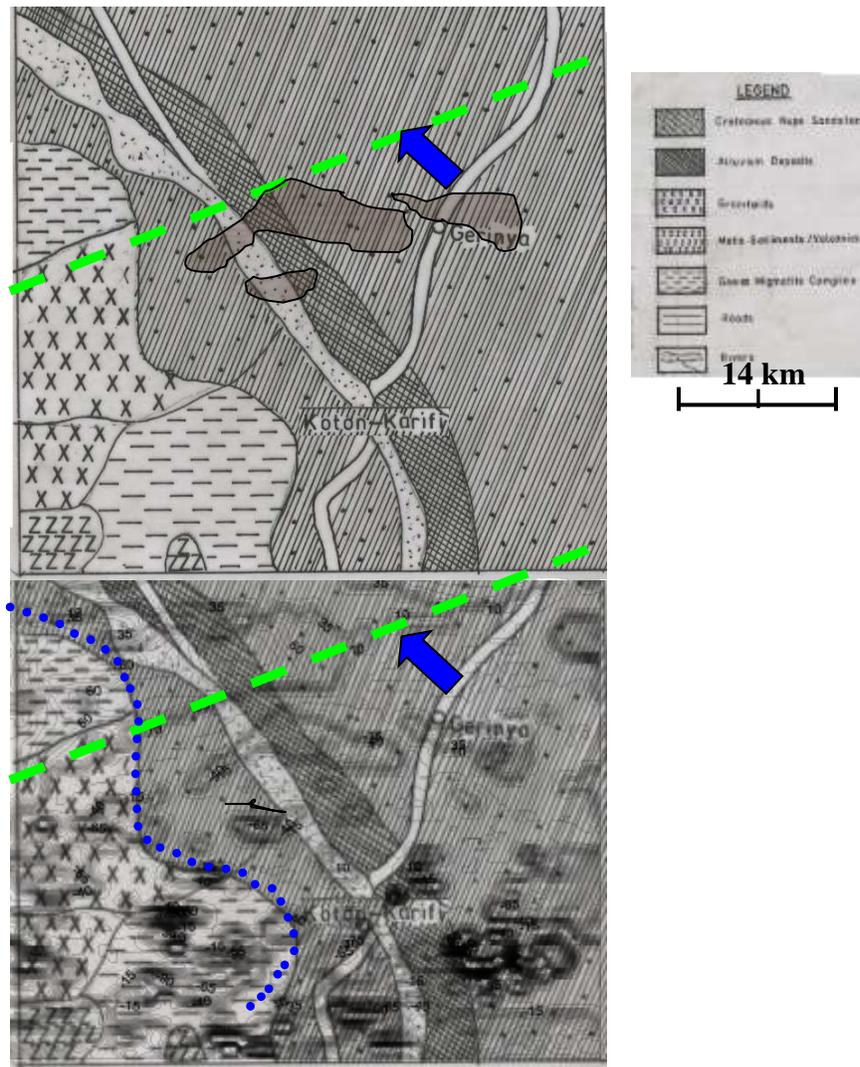


Fig 7: The ground-levelled aeromagnetic anomaly data over the Koton Karifi Area, Nigeria. Data were thresholded to emphasize the dominant contours. An inferred fault is shown (NE-SW direction) and is charted on the geology. The big arrow indicates a direction of a later distortion of this pre-existing fault.

4. CONCLUSION

The superimposed ground – levelled aeromagnetic anomaly map on the geology of the area suggests a NE-SW fault line, marking a boundary between the migmatites and granitoids. It is therefore

suggested that the metamorphic phase change at this boundary was a major tectonic event in the area. The interruption of this fault (Fig. 7) is a further evidence

of the impact of the Santonian episode which was said to have affected the greater part of eastern Nigeria.

REFERENCES

- Adeleye, D. R. (1976), The geology of the Middle Niger Basin, In: **Geology of Nigeria** (C. Kogbe, Ed.), Elizabethan Publishing Co. Lagos, 283-287
- Ajibade, A. C. (1976), Provisional classification and correlation of the schist belts of northwestern Nigeria, In: (C. A. Kogbe, Ed.), **Geology of Nigeria** Elizabethan Publishing Co. Lagos, 85-90
- Allen, J. R. L. (1965), Late Quaternary Niger delta and adjacent areas, *Bull. Amer. Assoc. Petr. Geol.* **49**, 547-600
- Avbovbo, A. A. (1970), Tertiary lithostratigraphy of the Niger delta, *Bull. Amer. Assoc. Petr. Geol.* **63**, 295-306
- Basley, J. R. (1952), Aeomagnetic surveying, In H. E. Landsberg (Ed.): *Advances in Geophysics* 1, Academic Press 313-350
- Bhattacharyya, B. K. (1965), Two-dimensional harmonic analysis as a tool for magnetic interpretation, *Geophysics* **30**, 829-857.
- Bott, M. H. P. (1973), Inverse methods in the interpretation of magnetic and gravity anomalies, In: **Methods in computational physics** (B. Alder, S. Fernbach and B. A. Bolt, Eds.), **13**, 133-162
- Brodie, R.C., (2002). Geophysical and Remote sensing methods for Regolith exploration, CRCLEME open file report 144 pp. 33-45
- Bullard, E., Everett, J. G. and Smith, A. G. (1965), The fit of the continents around the Atlantic, *Phil. Trans. Roy. Soc. Lond.* **A258**, 41-51
- Burke, K., Dessauvage, T. F. J. and Whiteman, A. J. (1970), Geological history of the Benue Valley and adjacent areas, In: **African Geology** University of Ibadan Press, Nigeria
- Burke, K. C., Freeth, S. J. and Grant, N. K. (1976), The structure and sequence of geological events in the basement complex of the Ibadan area, Western Nigeria, *Precambrian Research* **3**, 537-545
- Butler, R. F. (1992), Paleomagnetism: magnetic domains to geologic terrains, Blackwell Scientific Publ., Boston
- Cain, J. C. (1968), Computation of the main geomagnetic field from spherical harmonic expansions, NASA Data users note NSSDC 68-11
- Cain, J. C. (1989), Geomagnetic field analysis: In (James, D. E. Ed.) *The Encyclopedia of Solid Earth Sciences* Van Nostrand Reinhold, New York, pp. 517 – 522
- Cain, J. C., Hendricks, S. J., Langel, R. A. and Hudson, W. V. (1967), A proposed model for the International Geomagnetic Reference Field 1965, *J. Geomag. & Geoelect.* **19**, 335-355
- Collinson, D. W. (1983), *Methods in rock magnetism and paleomagnetism*, Chapman and Hall, London
- Cordell, L., Phillips, J. D. and Godson, R. H. (1992), U. S. Geological Survey potential field geophysical software, version 2.0. Open File Report 92-118
- Cratchley, C. R. and Jones, G. P. (1965), An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria, Overseas Geological Surveys, *Geophysical Paper* No. **1**
- Dauth, C. (1997), Airborne magnetic, radiometric and satellite imagery for regolith mapping in the Yilgorn Craton of Western Australia, *Exploration Geophysics* **28**, 199-203.
- Doell, R. and Cox, A. (1967), Magnetization of rocks, In: SEG Mining Geophysics Volume Editorial Committee (Eds.); *Mining Geophysics 2: Theory*. Society of Exploration Geophysicists Tulsa pp446-453
- Durotoye, B. (1976), Quaternary sediments of the Niger delta, In: (C. A. Kogbe, Ed.) **Geology of Nigeria** Elizabethan Publishing Co. Lagos, 347-357
- Fairhead, J. D. (1986), Geophysical controls on sedimentation within the African Rift Systems, In: (L. E. Frostick, R. W. Renaut, I. Reid and J. J. Tiercelin, Eds.), *Sedimentation in the African Rifts Geol. Soc. Spec. Publ.* **25**, 19-27
- Glatzmaier, G. A. and Roberts, P. H. (1996), Rotation and magnetism of Earth's inner core, *Science* **274**, 1887-1891
- Grant, N. K. (1971), South Atlantic, Benue Trough and Gulf of Guinea Cretaceous triple junction, *Bull. Geol. Soc. Am.* **82**, 2295-2298
- Gunn, P. J and Dentith, M. C. (1997), Magnetic responses associated with mineral deposits. *AGSO Journal of Geology & Geophysics* **17**, 145-155
- Gunn, P. J., Maidment, D. and Milligan, P. R. (1997), Interpreting magnetic data in areas of limited outcrop. *AGSO Journal of Geology and Geophysics* **17**: 175-185
- Hall, S. H. (1962), The modulation of a proton magnetometer signal due to rotation. *Geophysical Journal* **7**: 131-142
- Hartman, R. R., Tesky, D. J. and Friedberg, J. L. (1971), A system for the rapid digital

- aeromagnetic interpretation, *Geophysics* **36**, 891-918
30. Hassan, H. H., Peirce, J. W., Pearson, W. C. and Pearson, M. J. (1998), Cultural editing of HRAM data, comparison of techniques, *Canadian Journal of Exploration Geophysics* **34**, www.cseg.ca
 31. Hassan, H. H., and Peirce, J. W. (2005), SAUCE: A new technique to remove cultural noise from HRAM, *The Leading Edge* **24**, 246-250
 32. Hildenbrand, T. G. (1983), FFTFIL: A filtering program based on two dimensional Fourier analysis: US Geol. Surv. Open-File Report 83-237, 31p
 33. Hjelt, S. E. (1973), Experiences with automatic magnetic interpretation using the thick plate model, *Geophys. Prosp.* **21**, 243-265
 34. Hubbard, F. H. (1966), The association charnockite-Older Granite in southwest Nigeria, *J.Min. Geol.* **3**, 25-32
 35. Irving, E. (1964), Paleomagnetism and its application to geological and geophysical problems, John Wiley & Sons, New York.
 36. Jacobsen, B. H. (1987), A case for upward continuation as a standard separation filter for potential field maps, *Geophysics* **52**, 1138 – 1148
 37. Jain, S. (1976), An automatic method of direct interpretation of magnetic models, *Geophysics* **41**, 531-541
 38. James, W. R. (1966), FORTRAN IV program using double Fourier series for surface fitting of irregularly spaced data, *Kansas Geological Survey Computer Contribution* **5**, 19p
 39. Kearey, P. and Brooks, M. (2000), An introduction to geophysical exploration (2nd Ed.) Blackwell Science, pp. 1 – 237
 40. Klingele, E. E., Mason, I. and Kable, H. G. (1991), Automatic interpretation of gravity gradiometric data in two dimensions: vertical gradient, *Geophysical Prospecting* **39**, 407-434
 41. Kogbe, C. A., Ajakaiye, D. E. and Matheis, G. (1983), Confirmation of a rift structure along the Mid-Niger Valley, Nigeria, *Journal African Earth Sciences* **1**, 2, 127-131
 42. Ku, C. C. (1977), A direct computation of gravity and magnetic anomalies caused by 2 and 3-dimensional bodies of arbitrary shape and arbitrary magnetic polarization by equivalent-point method and a simplified cubic spline, *Geophysics* **42**, 610-622.
 43. Ku, C. C. and Sharp, J. A. (1983), Werner deconvolution for automated magnetic interpretation and its refinement using Marquardt's inverse modeling, *Geophysics* **48**, 754-774
 44. Langel, R. A. (1992), International Geomagnetic Reference Field: 1991 revision, *Geophysics* **57**, 956-959
 45. Lewis, A. (2000), Australian geomagnetic reference field, 2000 revision, Preview 85:24
 - Likkason, O. K. (1993), Application of trend surface analysis to gravity data over the Middle Niger Basin, Nigeria, *J. Mining & Geology* **29**, 2, 11-19
 46. Likkason, O. K. and Ojo, S. B. (1999), Additional evidence from gravity for a basic intrusion in the Middle Niger Basin, Nigeria, *J. Mining & Geology* **35**, 2, 171-181
 47. Likkason, O.K. Ajayi, C.O. Shemang, E.M. and Dike, E.F.C., (2005). Indication of fault expressions from filtered and Werner deconvolution of aeromagnetic data of the middle Benue Trough, Nigeria, *Journal of Mining & Geology* vol 42 (2) pp. 205-227.
 48. Likkason, O.K., Ajayi, C.O., and Shamang, E.M. (2007). A computation of IGRF Over Nigeria. *Global Journal of Geological Sciences* vol 5(1 and) pp. 107.
 49. Lilley, F. E. M. (1982), Geomagnetic field fluctuations over Australia in relation to magnetic surveys, *Bulletin of the Australian Society of Exploration Geophysics* **13**, 68-78
 50. Lowrie, W. (1997), Fundamentals of geophysics, Cambridge University Press, Lond., 354p
 51. Luyendyk, A. P. J. (1997), Processing of airborne magnetic data. *AGSO Journal of Geology and Geophysics* **17**: 31-38
 52. Luyendyk, A. P. J. (1998), Processing of airborne magnetic data, *AGSO J. Australian Geol. Geophys.* **17**, 31-38
 53. Maron, P. (1969), Stratigraphical aspects of the Niger delta, *Nig. Jour. Min. Geol.* **4**, 3-12
 54. Maus, S. and MacMillan, S. (2005), 10th generation international geomagnetic reference field: *EOS Transactions of the American Geophysical Union* **86**: 159
 55. McCurry, P. (1976), The geology of the Precambrian to Lower Paleozoic rocks of northern Nigeria-a review, In: **Geology of Nigeria** (C. A. Kogbe, Ed.), Elizabethan Publishing Co. Lagos, 15-39
 56. McCurry, P. and Wright, J. B. (1977), Geochemistry and calc-alkaline volcanics in northwestern Nigeria and a possible Pan African suture zone, *Earth Planet. Sci. Letts.* **37**, 90-96
 57. McIntyre, J. S. (1980), Geological significance of magnetic patterns related to magnetite in sediments and metasediments – a review, *Bulletin of the Australian society of Exploration Geophysicists* **II**, 19-33

58. Merrill, R. T. and McElhinny, M. W. (1983), The Earth's magnetic field, Academic Press, London
59. Merrill, R. T., McElhinny, M. W. and McFadden, P. L. (1996), Magnetic field of the earth; paleomagnetism, the core and the deep mantle, Academic Press, London, 527p
60. Milligan, P. R. M. (1995), Short period geomagnetic variation recorded concurrently with an aeromagnetic survey across the Bendigo Area Victoria, *Exploration Geophysics* **26**, 527-534
61. Minty, B. R. S. (1991), Simple microleveling for aeromagnetic data, *Exploration Geophysics* **22**, 591-592
62. Minty, B. R. S., Milligan, P. R., Luyendyk, A. P. J. and Mackey, T. (2003), Merging airborne magnetic surveys into continental-scale compilations, *Geophysics* **68**, 988-995
63. Mittal, P. K. (1984), Algorithm for error adjustment of potential field data along a survey network, *Geophysics* **49**, 467-469
64. Nabighian, M. N., Grauch, V. J. S., Hansen, R. O., Lafehr, T. R., Li, Y., Peirce, J. W., Phillips, J. D. and Ruder, M. E. (2005). The historical development of the magnetic method in exploration, *Geophysics* **70**, 33nd-61nd
65. Nagata, T. (1961), Rock magnetism, Maruzen, Tokyo, 350p
66. Naudy, H. And Dreyer, H. (1968), Attempt to apply non-linear filtering to aeromagnetic profiles, *Geophysical prospecting* **16**, 171-178
67. Offodile, M. E. (1976), A review of the geology of the Benue Valley, In: (C. A. Kogbe, Ed.) **Geology of Nigeria**, Elizabethan Publishing Co. Lagos, 319-330
68. Olarewaju, V. O. and Rahaman, M. A. (1981), Petrology and geochemistry of Older Granites from some parts of northern Nigeria, *J. Min. Geol.* **17**, 45-55
69. Ojo, S. B. and Ajakaiye, D. E. (1976), Preliminary interpretation of gravity measurements in the Middle Niger Basin area, Nigeria, In: (C. A. Kogbe, Ed.) **Geology of Nigeria**, Elizabethan Publishing Co. Lagos, 295-307
70. Ojo. S. B. (1984), Middle Niger Basin revisited, magnetic constraints on gravity interpretations, Abstract, 20th Nigerian Min. and Geosci. Soc. Conf. Nsukka, Nigeria, 52-53
71. Ojo, S. B. (1990), Origin of a major aeromagnetic anomaly in the Middle Niger Basin, Nigeria, *Tectonophysics* **185**, 153-162
72. Oyawoye, M. O. (1964), The geology of the Nigerian Basement Complex, *J. Nig. Min. Geol. and Metall. Soc.* **1**, 87-482
73. Paterson, N. R. and Reeves, C. V. (1985), Applications of gravity and magnetic: The state-of-the-art in 1985, *Geophysics* **50**, 2558-2594
74. Quinn, J. M., Coleman, R. J. and Nigro, J. M. (1995), The Joint US/UK 1995 Epoch World Magnetic Model, *Naval Oceanographic Office*, Stennis Space Center, MS; Technical Report #314
75. Rahaman, M. A. and Ocan, O. O. (1978), On relationships in the Precambrian migmatitic gneisses of Nigeria, *J. Min. Geol.* **15**, 23-32
76. Ravat, D., Hildenbrand, T. G. and Roest, W. (2003), New way of processing near-surface magnetic data: The utility of the comprehensive model of the magnetic field, *The Leading Edge* **22**, 784-785
77. Reford, M. S. and Summer, J.S. (1964), Aeromagnetics, *Geophysics* **29**, 482-516
78. Roest, W. R. and Pilkington, M. (1993), Identifying remanent magnetization effects in magnetic data, *Geophysics* **58**, 653-659
79. Russ, W. (1957), The geology of parts of Niger, Zaria and Sokoto Provinces: Geol. Surv. of Nigeria Bull. No. 27
80. Sakaba, T. J., Olsen, N. and Langel, R. A. (2002), A comprehensive model of the quiet-time, near-the-earth magnetic field: phase 3, *Geophysical Journal International* **151**, 32-68
81. Sakaba, T. J., Olsen, N., Langel, R. A. and Purucker, M. E. (2004), Extending omprehensive models of the earth's magnetic field with Oersted and Champ data, *Geophysical Journal International* **159**, 521-547
82. Schilinger, C. M. (1990), Magnetometer and gradiometer surveys for detection of underground storage tanks, *Bulletin Association Engineering Geologists* **27**, 37-50
83. Short, K. C. and Stauble, A. J. (1967), Outline of the Niger delta, *Bull. Amer. Assoc. Petr. Geol.* **51**, 761-779
84. Slack, H. A., Lynch, V. M. and Langan, L. (1967), The geomagnetic elements, *Geophysics* **32**, 877-892
85. Stacey, F. D. and Barnerjee, S. K. (1974), The physical principles of rock magnetism, Elsevier, Amsterdam
86. Stanley, J. M. (1977), Simplified magnetic interpretation of the geologic contact and thin dike, *Geophysics* **42**, 1236-1240
87. Stoneley, R. (1966), The Niger delta region in the light of the theory of continental drift, *Geol. Mag.* **103**, 385-397
88. Tackley, P. (2001), As the world churns: modeling convection in the Earth's mantle, **Research in the Geosciences**, UCLA, www.npaci.edu/envision/v14.2/tackley.ht

89. Talwani, M. and Heirtzler, J. M. (1964), Computation of magnetic anomalies caused by two-dimensional structures of arbitrary shape, In: (G. A. Parks, Ed.) **Computers in mineral industries**, Stanford Univ., 464-480p
90. Tarling, D. H. (1983), *Paleomagnetism: principles and applications in geology, geophysics and archaeology*, Chapman and Hall, London
91. Tarlowski, C., McEwin, A. J., Reeves, C. V. and Barton, C. E. (1996), Dewarping the composite aeromagnetic anomaly map of Australia, using control traverses and base stations, *Geophysics* **61**, 696-705
92. Telford, W. M., Geldart, L. P., Sheriff, R. E. and Keys, D. A. (1990), *Applied geophysics*, Cambridge University Press, London
93. Upcott, N. M., Mukasa, R. K., Ebinger, C. J. and Karner, G. D. (1996), Along-axis segmentation and isostasy in western Rift, East Africa, *J. Geophys. Res.* **101**, 3247-3268
94. Uzuakpunwa, A. B. (1974), The Abakaliki pyroclastics-Eastern Nigeria: new age and tectonic implications, *Geol. Mag.* **111**, 65-70
95. Werner, S. (1953), Interpretation of magnetic anomalies at sheet-like bodies, *Sveriges Geol. Undersok. Ser. C, Arsbok* **43** (1949), no. 6
96. Whitham, K. and Niblett, E. R. (1961), The diurnal problem in aeromagnetic surveying in Canada, *Geophysics* **26**, 211-228
97. Wright J. B. (1976), Fracture systems in Nigeria and initiation of fracture zones in the south Atlantic, *Tectonophysics* **34**, 43-7.

9/2/2025