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In-situ Location of Precious Stones using Magnetic Data and Pseudo-Gravity Transforms in Parts of the Nupe Basin Area of Nigeria

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ABSTRACT

In-situ location of precious stones from the mineral-rich zones in parts of Lafiagi (Sheet 203) and Pategi (Sheet 204) areas of Bida basin, central Nigeria was carried out. It was aimed at identification of the structures that usually host precious stones and then locating them in these areas. This work involved the qualitative and quantitative analysis of aeromagnetic data and pseudo-gravity transforms using the 3-D Euler Deconvolution subroutine of Oasis Montaj^{TM} software and the geological information obtained from reliable sources in the structural interpretation and isolation work. The geological features in the studied region have been connected to the presence of gemstones known to associate with them making their location logical and easier than the hit- or-miss approach adopted by the artesian miners. The results have shown that the abundance of 2D and 3D structures that are commonly associated with precious minerals as well as the persistence and continual activities of artisanal miners explain why the study area is rich in mineral deposits.

Keywords: Precious stones, Mineral-rich, aeromagnetic, pseudo-gravity transforms, 3-D Euler.

تحديد الموقع الأصلي للأحجار الكريمة باستخدام البيانات المغناطيسية وتتحول الجاذبية الزائفة في أجزاء من منطقة حوض نوبي، نيجيريا

أولاويي أ.ك

الملخص: تم إجراء تحديد الموقع الطبيعي للأحجار الكريمة من المناطق الغنية بالمعادن في أجزاء من منطقتي لافياجي (رقم اللوحة: 203) وباتيجي (ارقم اللوحة: 204) في حوض بيدا بوسط نيجيريا. وكان الهدف منه التعرف على التراكيب التي عادة ما تستضيف الأحجار الكريمة ومن ثم تحديد مواقعها في هذه المناطق. تضمن هذا العمل التحليل النوعي والكمي للبيانات المغناطيسية الجوية وتحويلات الجاذبية الزائفة باستخدام نموذج ثلاثي الأبعاد.
نموذج Euler Deconvolution الفرعي لبرنامج Oasis Montaj TM والمعلومات الجيولوجية التي تم الحصول عليها من مصادر موثوقة في أعمال التفسير والعزل الهيكلي. وقد ارتبطت الخصائص الجيولوجية في المنطقة المدروسة بوجود الأحجار الكريمة المعروفة بارتباطها بها، مما جعل موقعها منطقياً وأسهل من أسلوب الضرب أو الخطأ الذي اعتمده عمال المناجم الحرفيين. أظهرت النتائج أن وفرة التراكيب ثنائية وثلاثية الأبعاد التي ترتبط عادةً بالمعادن الثمينة بالإضافة إلى المثابرة والأنشطة المستمرة لعمال المناجم الحرفيين تفسر سبب كون منطقة الدراسة غنية بالرواسب المعدنية.

الكلمات المفتاحية: الأحجار الكريمة، المعادن الغنية، المغناطيسية الجوية، تحويلات الجاذبية الزائفة، أويلر ثلاثي الأبعاد.

Introduction

The Gravity and Magnetic (GM) techniques have been employed worldwide by geoscientists to explore oil and solid minerals which abound in the subsurface structures of the earth. The use of Euler Deconvolution as an interpretation tool to determine source location of potential field anomalies is well established [1]. Other methods for structural study include: the estimation of structural index from low-pass filtered magnetic data [2], 2D Forward modeling and inversion [3], the estimation of the structural index [4] amongst others.

Magnetic anomalies are difficult to analyze and interprete because they are not always located in the vertical direction of the perturbing bodies. The complexity of the magnetic field and of its anomaly-to-lithology relationship often complicates interpretation. The amplitude of the anomalies is dominated by the magnetic bodies that are present in the shallowest geologic structures. Convectional filtering methods smear out the shallow sources and are not capable of separating the lower amplitude magnetic anomalies associated with the deeper magnetic source rocks [5].

On pseudogravity transformation, [6] explained the significance of employing methods to transform dipole anomalies into monopoles, aiming to enhance the interpretability of the data; [5] explained that 'Poisson's theorem relates linearly the derivative of the gravity taken along the total magnetization distributions. From this theorem, two very useful functional transformations for magnetic anomalies, the reduction-to-pole (RTP) and the pseudogravity (PSG) vertical integration, were formulated by Baranov.' However, [7] explained that, for area at low geomagnetic latitude, that is very close to the geomagnetic equator, the best practice is to reduce its aeromagnetic data to the geomagnetic equator. Consequently, the computation of a pole-reduced magnetic field, free of procedural artefacts, is problematic [8] and the best solution is to reduce the aero-magnetic data to the geomagnetic equator ([9, 7]).

Among other reasons, the global significance of this work is that gemstones (e.g. diamonds and coloured stones such as rubies, emeralds and sapphires) are rapidly gaining popularity, as evidenced by their increasing use in engagement rings, the increase in their value makes the need to verify their authenticity and source imperative. Other gemstones include: quartzite (amethyst, citine and ametrine), the garnets, moonstone, apatite, spinel, tanzanite, tourmaline, topaz and zircon. Some of these gemstones form in pegmatites and hydrothermal veins that are genetically related to igneous rocks. The jasper, malachite, opal and zircon are formed in sedimentary rocks while the beryls, jade, turquoise, spinel, ruby and sapphire are formed in metamorphic rock [10].

Analyzing the geological features in the studied region and connecting them to the presence of gemstones is the goal of this research. Some applications are well known to describe how geophysical techniques can be used in the exploration for gemstone deposits. For example, exploration and delineation of diamond-bearing kimberlites using both regional and detailed geophysical techniques has been accomplished for decades [11, 12, 13], the use of 3D Euler deconvolution in the detection or exploration for tanks and drums (or metalliferous bodies) ([13, 14], etc.

1.1 Location, Geomorphology and Regional Geology

The study area covers parts of Lafiagi (Sheet 203) and Pategi (Sheet 204) within the Bida Basin, central Nigeria (Figure 1). A Sheet comprises of ½ degree by ½ degree contour map on a scale of 1:100,000. The study area is bounded by latitudes 8˚ 40' and 8˚ 51' N and longitudes 5˚00' and 5˚ 23' E with an area extent of approx. 896.6 km^2 in a part of Lafiagi (Sheet 203) and latitudes 8˚ 30' and 9˚ 00' N and longitudes 5˚30' and 6˚ 00' E with an area extent of approx. 3,107 km^2 in the Pategi (Sheet 204) area of Bida basin, central Nigeria. The vegetation is of the Guinea savannah type with two distinct seasons (rainy and dry) [15] with tropical Guinea type climate [16].

The Bida Basin is a NW-SE trending embayment perpendicular to the main axis of the Benue Trough and the Niger Delta Basin of Nigeria. The thin sedimentary cover overlying the Basement rock in this transition environment is said to be responsible for the low depth to sources along magnetic profiles [17]. The regional structural evolution of the basin has been a subject of debate for long and satisfactory clarification about its tectonostratigraphic evolution is still in contention ([18, 19]). A possible maximum depth value of middle Niger Basin sediments has been estimated to be generally around 1000 m [20].

Lineaments are major topographical features or geological structures that could be of regional extent usually in linear or curvelinear continuous or discontinuous over an entire length. Lineaments may result from faults, joints, folds, contacts or other geological reasons, and are found in igneous, sedimentary and metamorphic rocks. Lineament-mineral association is possible through the process of mineralization [21]. Good correlation exists between areas of high lineament density and areas where there is occurrence of most minerals such as gold, iron ore, cassiterite, tantalite, clay and uranium [21, 22]. 'Southwestern Nigeria has a number of gemstone occurrences that have been noted. Pegmatite, which occurs as near horizontal or vertical dykes and intrudes earlier Precambrian lithologies, is the primary host rock. Given the significant profit margin that may be realized, investment potential in diamonds is highly favourable.

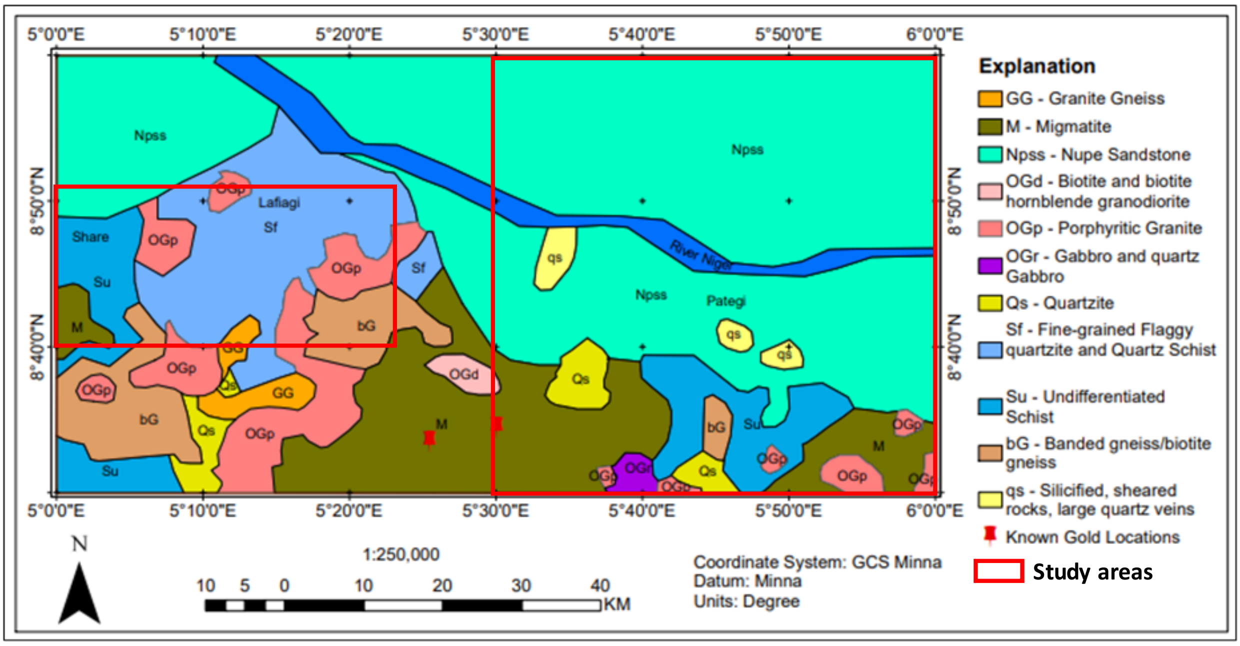

Figure 1. Simplified Geological Map of Lafiagi and Pategi regions (After [24]).

However, the current strategy for exploration and exploitation needs to be thoroughly examined in order to realize the greatest benefits' [23].

The present study has been carried out to locate the structures known to host gemstones and to estimate their depth and geometry in the Lafiagi (Sheet 203) and Pategi (Sheet 204) areas using 3D Euler Deconvolution method [25] of aeromagnetic data and their pseudogravity transforms. The present research has not only removed the hit-and-miss approach by the artesian miners but it has offered a guide to potential prospective zones where commercial deposits could be found.

2. Materials and Methods

2.1 Data Source and Analysis

The aeromagnetic data of Lafiagi (Sheet 203) and Pategi (Sheet 204) was procured from the Nigeria Geological Survey Agency (NGSA), Abuja, Nigeria. The survey which was aimed at mineral and ground water development was collected at Flight Height of 80 m, Flight line spacing of 500 m, and Tie line spacing of 2000 m. The Flight Line direction was NW - SE whereas the Tie Lines were NE - SW. For ease of processing, the data was stripped of a common value of 32,000 nT. Data collection for this area was done in 2006, so a 2005 epoch International Geomagnetic Reference Field (IGRF) was used to calculate Inclination and Declination as follows: Field Strength = 33129.9632nT; Inclination = -6.87339275; Declination = -2.51357917.

The total field aeromagnetic map of Lafiagi (Sheet 203) and Patigi (Sheet 204) (Figure 1), which is about 55.74 km by 55.74 km each in dimension were mapped and data collected at a grid spacing of 100 m yielding approx. 310,695 values per sheet. Crustal anomalies are much wider than 200 m [26] imposed by the above spacing, and therefore lie in a frequency range for which computation of errors arising from aliasing does not occur with a 100 m grid spacing. Previous works with crustal magnetic anomalies [27] show that this spacing is suitable for interpretation of magnetic anomalies arising from regional structures.

Figure 2 is the Total Magnetic Intensity (TMI) map of the study area. The map emphasizes the intensities and the wavelengths of the local anomalies that reveal information on the geometry, strike, contacts between rocks and intensities of magnetization within the study area. Several anomalies can be referred to distinct magnetic zones. Figures 3 (a) and (b) are the colour-shaded residual magnetic intensity anomaly data and colour-shaded reduced-to-pole (RTP) maps respectively.

Any three-dimensional function $f\ (x,y,z)$ is said to be *homogeneous* of degree n if the function obeys the expression [30]:

$$f\ (tx, ty, tz) = t^n\ f\ (x, y, z) \tag{1}$$

From this it can be shown that the following (known as *Euler's equation*) is also satisfied [30]:

$$x\frac{\partial f}{\partial x} + y\frac{\partial f}{\partial y} + z\frac{\partial f}{\partial z} = nf \tag{2}$$

[29] has shown that simple magnetic and gravity models conform to Euler's equation. The degree of homogeneity, *n*, can be interpreted as a *structural index* (SI). [25], have shown that a magnetic contact will yield an index of 0.5 provided that an offset A is introduced to incorporate an anomaly amplitude, strike and dip factors [30]:

$$A = (x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{\partial z} \tag{3}$$

Given a set of observed total field data, we can determine an optimum source location (x_0, y_0, z_0) by solving Euler's equations for a given index n by least-squares inversion of the data.

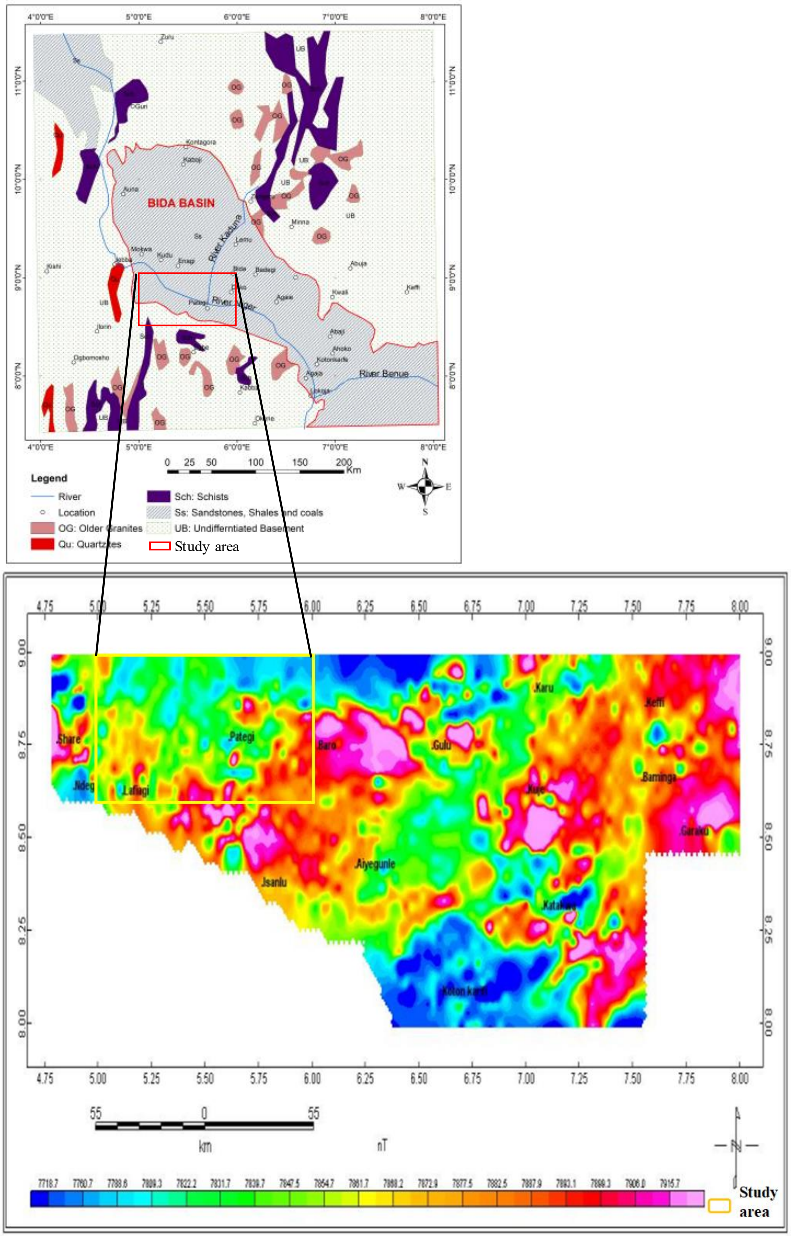

Figure 2. Aeromagnetic map of Lafiagi and Pategi study area (After [21]). (Inset is the geological map of the Nupe Basin).

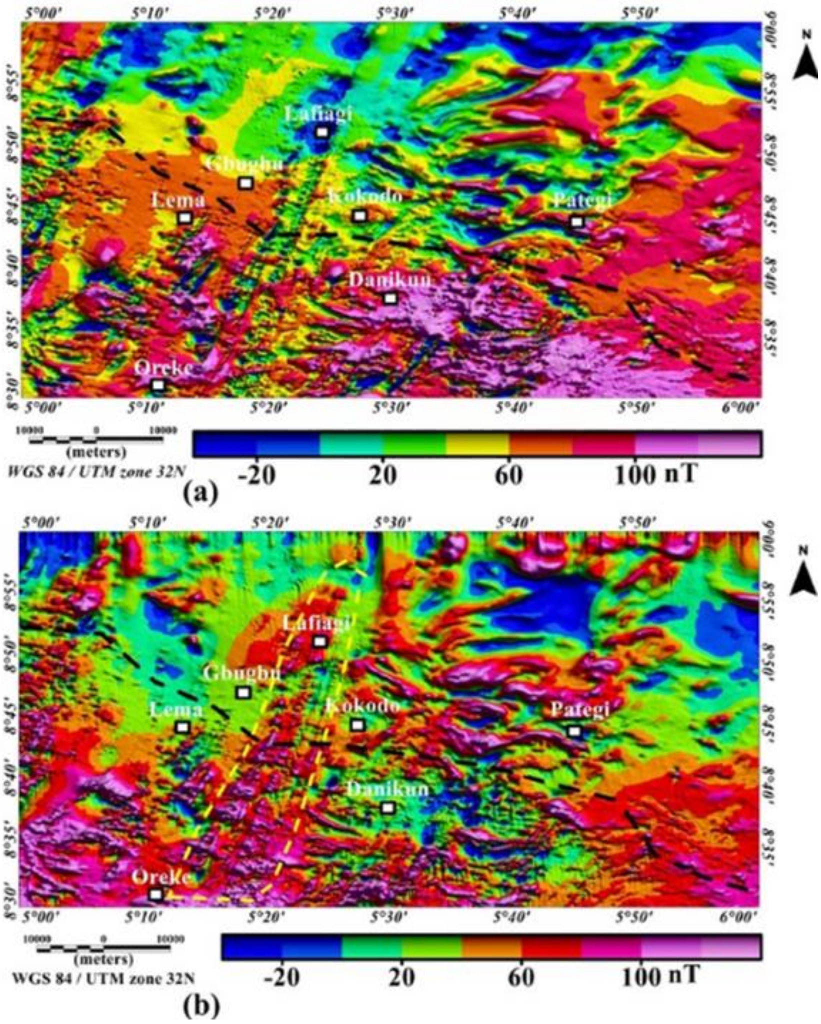

Figure 3. (a) Colour-shaded residual magnetic intensity anomaly data, with colour shading highlighting linear structural features especially at the central part of the study area (After [24]). Note, at low-latitude regions such as the study area, magnetic sources are usually characterized by magnetic low anomalies. (b) Colour-shaded reduced-to-pole (RTP) map computed from the residual total magnetic intensity map of the study area (After [24]). The colour shading highlights linear structural features which are shown in areas represented within the yellow dashed lines on the RTP map.

3. Results and Discussions

3.1 Zone Coloured Euler Solutions for Different Geologic Structures

The 3-D Euler Deconvolution processing routine is an automatic location and depth determination software package for gridded magnetic and gravity data. The depths are displayed as a grid and are based on source parameters of the following source models: contacts (faults), thin sheets (dykes) or horizontal cylinders. The relationship between structural index (η), type of magnetic/gravity model and position of the calculated depth as described by Hsu [32] is summarized as: SI (η) =0 (Contact with large depth extent (magnetic), Sill/Dyke/Step (gravity)); η = 0.5 (Contact with small depth extent (magnetic), Ribbon (gravity)); η = 1.1 (Thin prism with large depth (magnetic), Pipe (gravity)); η = 2.0 (Vertical or Horizontal Cylinder (magnetic), Sphere (gravity)) and η= 3.0 (Sphere (magnetic)). The structural index for gravity model is one less than that of magnetic and the maximum for gravity is 2.

In the Lafiagi and Pategi study areas, Figures 4a and 6a show the results obtained for structural index of 2.0 (i.e. deep seated dyke/ribbon and sill model; magnetic) of 3D Euler Deconvolution, which has been used worldwide to detect or explore Kimberlite pipe which is well known for hosting large quantity of minerals (diamonds and garnet) and rocks (peridotite and xenoliths) ([12], [13]). Figures 5a and 7a show the results obtained for structural index of 3.0 (i.e. sphere or dipole model; magnetic) in 3D Euler Deconvolution, which has been used worldwide to detect or explore tanks and drums (or metalliferous bodies) ([13], [14]). Many of these pipe-like and spherical features are found all over the area, confirming that the area is very rich in mineral resources.

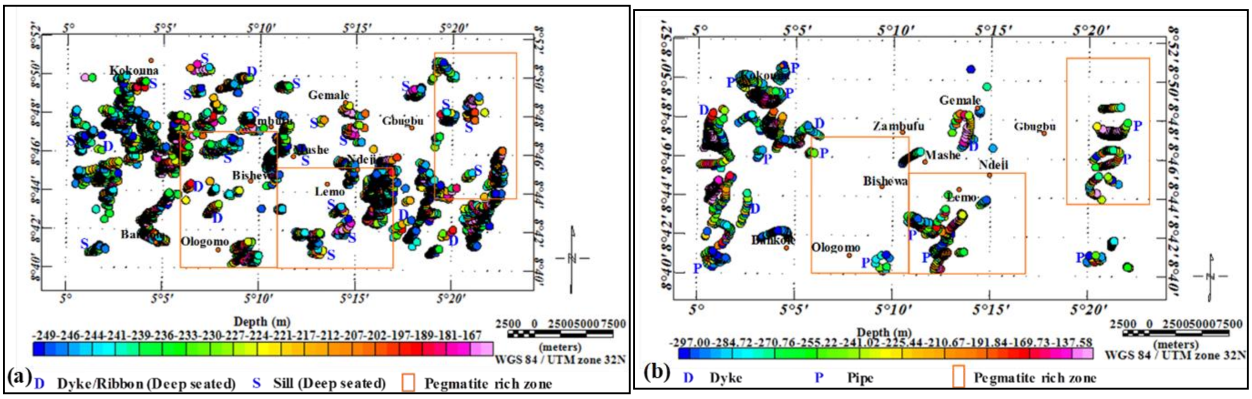

Figure 4. (a) A Typical Aero-Magnetic Euler Solutions Map for Dyke/Ribbon or Pipe (S.I =2.0), (b) A Typical Pseudo-Gravity Euler Solutions Map for Pipe (S.I =1.1) at Lafiagi.

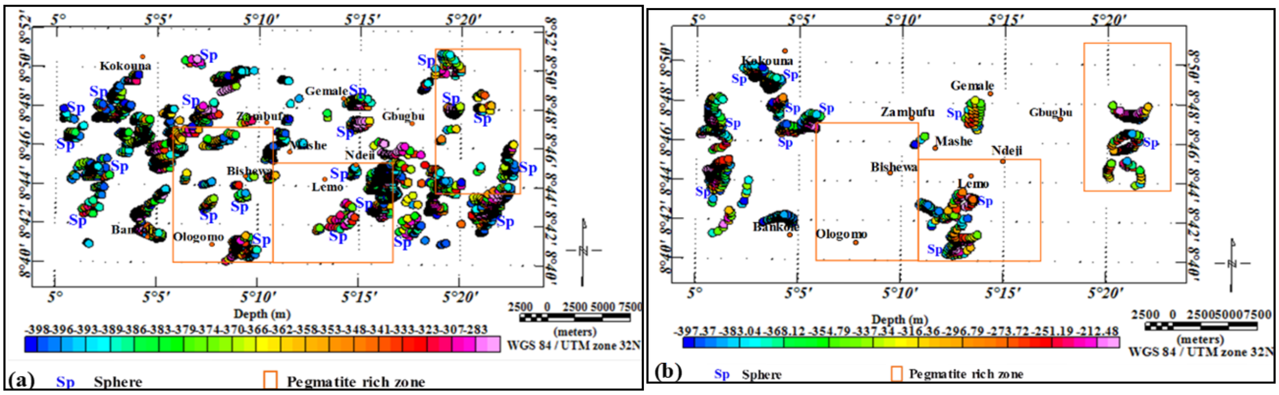

Figure 5. (a) A Typical Aero-Magnetic Euler Solutions Map for Sphere (S.I =3.0), (b) A Typical Pseudo-Gravity Euler Solutions Map for Sphere (S.I =2.0) at Lafiagi

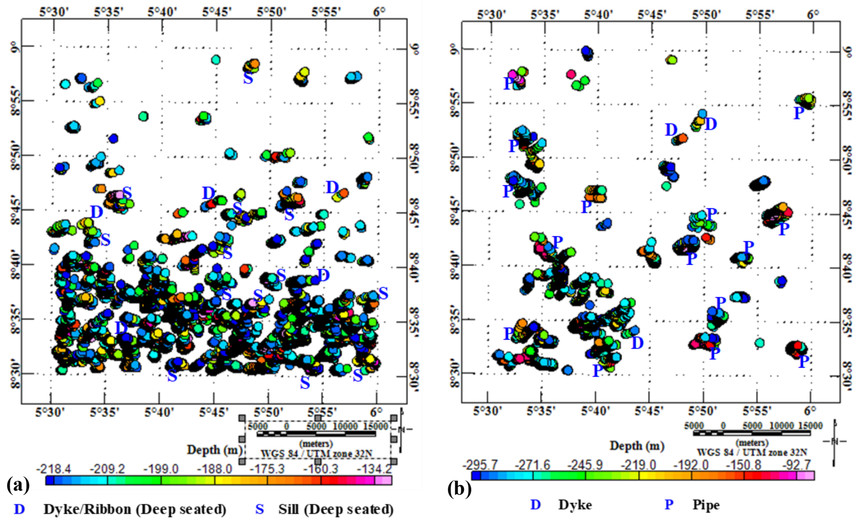

Figure 6. (a) Magnetic (REDE) Euler Solution Map for Deep Seated Dyke/Ribbon and Sill (SI = 2.0), **(b)** Pseudogravity Euler Solution Map for Dyke and Pipe (SI = 1.1) (Pategi Study Area).

In the Lafiagi and Pategi study areas, Figures 4b and 6b show the results obtained for structural index of 1.1 (i.e. pipe model: gravity) in 3D Euler Deconvolution, which has been used worldwide to detect or explore Kimberlite pipe which is well known for hosting large quantity of minerals (diamonds and garnet) and rocks (peridotite and xenoliths) ([12], [13]). Figures 5b and 7b show the results obtained for structural index of 2.0 (i.e. sphere or dipole model; gravity) in 3D Euler Deconvolution, which has been used worldwide to detect or explore tanks and drums (or metalliferous bodies) ([13], [14]). Many of these pipe-like and spherical features are found all over the area, confirming that the area is very rich in mineral resources.

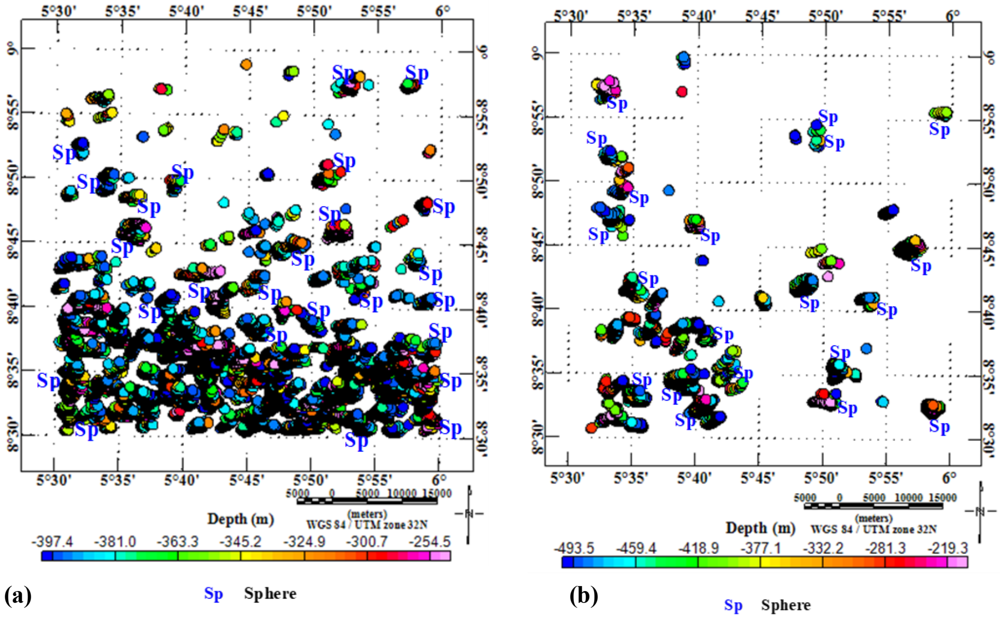

Figure 7. (a) Magnetic (REDE) Euler Solution Map for Sphere SI = 3.0), **(b)** Pseudogravity Euler Solution Map for Sphere (SI = 2.0) (Pategi Study Area).

Conflict of interest

The author declares no conflict of interest.

4. Acknowledgment

The author gracefully acknowledges the contributions of Mr Omar D.M. of Surveying and Geoinformatics Department, University of Ilorin for drawing the updated Geological Map of Lafiagi and Pategi regions, Kwara State, Nigeria.

5. Conclusions

This research has identified the structures that usually host gemstones and isolated them in parts of Lafiagi (Sheet 203) and Pategi (Sheet 204) study areas of Bida basin, central Nigeria using aeromagnetic data and pseudo-gravity transforms. The geologic structures which range from pipe to sphere are found in large quantity in the study area. The structural indices of 2.0 (i.e. vertical or horizontal cylinder model; magnetic) and 1.1 (i.e. pipe and dyke model; gravity) in 3D Euler Deconvolution have been used worldwide to detect or explore Kimberlite pipe which is well known for hosting large quantity of minerals (diamonds and garnet) and rocks (peridotite and xenoliths), while the structural indices 3.0 and 2.0 (i.e. sphere or dipole model) in magnetic and gravity respectively have been used worldwide to detect tanks and drums (or metalliferous bodies). The proximity of this area to the pegmatite rich zones and the abundance of pipe-like and spherical features in the study area confirm the likeliness of the area as a prospective zone for mineral exploration. This research has not only removed the hit-and-miss approach by the artesian miners but has offered a guide to potential prospective zones where commercial deposits could be found.

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