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Upward continuation of total magnetic field intensity data over Sokoto basin, north-western Nigeria

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High-resolution aeromagnetic data covering the Sokoto basin, north-western Nigeria were acquired and analyzed using regional enhancement techniques, upward continuation and second order regional. The objective was to delineate major geological structures. The data, which are in form of a grid, were knitted using Oasis Montaj software to obtain the magnetic total field intensity map. The composite grid was reduced to a magnetic equator to align the peaks of magnetic anomalies over the center of their causative bodies. The reduced grid was continued at various planes of observation to understate anomalies due to shallow features. The planes were at 10 km, 20 km, 30 km, 40 km, 50 km, 70 km, and 100 km above the surface. Upward continuation maps produced greatly enhanced the long-wavelength (low wavenumber) anomalies associated with deeper subsurface regional structures. The continuation revealed a high magnetic intensity anomaly in western parts of the area and low magnetic intensity anomalies in the eastern parts. The low magnetic intensity in the eastern part is interpreted as a sedimentary deposit. The residual field was removed from the total magnetic field data using the second-order least square method to get the second-order regional field. The regional field analysis agrees with the upward continuation result.

Keywords: Magnetic field intensity, reduction to the equator, upward continuation, second order regional, and Sokoto Basin.

1. Introduction

The Sokoto Basin is a sector of the larger Iullemmeden Basin (Kogbe, 1979; Kogbe, 1981) located in its south-eastern region (Shehu *et al.*, 2017). The Iullemmeden Basin itself is a border sedimentary basin covering significant portions of Libya, Algeria, Mali, the Republic of Benin, Niger Republic, and the north-western part of Nigeria (Sokoto Basin) (Ibe *et al*., 2018). The Sokoto Basin, constituting mainly the Sokoto, Kebbi, and Zamfara States of Nigeria (Figure 1), is an out-baying marginal basin with reducing sediment thickness and stratigraphic age from the thickest and oldest in Niger while younging towards Nigeria (Obaje *et al.,* 2013; Kamba *et al.,* 2018). The Basin is predominantly a gently undulating plain, underlain by metamorphic rocks (Sheu *et al.,* 2004) with an average elevation varying from 250 to 400 meters above sea level which is sometimes interrupted by mesas (Ezekiel *et al.*, 2019). A low escarpment, called the Dange Scarp is the most prominent feature in the basin and it agrees closely with the geology (Obaje *et al.,* 2013). The basin can be subdivided into the following formations: Gwandu Formation, Gamba Formation, Klambaina Formation, Dange Formation, Wurno Formation, Dukamaje Formation, Taloka Formation, and Gundumi/Illo Formation (Obaje, 1987; Obaje, 2009).

The petroleum system of the basin is explained based on the assumption that some lacustrine carbonaceous shales within the Continental Intercalaire could constitute some potential source rocks, while the sandstone faces are candidates for reservoir rocks (Bonde, *et.al* 2019). In the Rima Group, continental lacustrine shales in the Taloka and Wurno Formations and marine anoxic shales of the Dukamaje Formation constitute potential source rocks (Shehu *et al.,* 2017).while faces in all formations are potential reservoir rocks. The Dukamaje Formation (Maastrichtian) can be correlated to the Nkoporo Shale in the Anambra Basin and the Enagi/Patti Formation in the Bida Basin. Within the Sokoto group, the Dange Formation could not be assumed to have the maturity level to be a petroleum source rock but could constitute good seals in any stratigraphically lower plays. The Kalambaina carbonates are potential reservoirs while the Gamba shales may constitute regional seals (Offodile, 1976).

Despite these features, the Sokoto Basin is the least studied of all Nigeria's inland frontier basins in terms of prospecting evaluation. This is because not a single exploratory well has penetrated the sequences in the basin (Obaje *et al.,* 2013). Nevertheless, the basin has received the attention of some researchers over the years. One of which is the preliminary interpretation of gravity and magnetic data over the Sokoto Basin by Umego (1990). His results showed that the maximum possible thickness of the sedimentary region of the basin does not exceed 2 km. Adetona *et al.* (2007) estimated an average value of 1.45 km as the sedimentary thickness of the basin using aeromagnetic data. The upper part of Sokoto Basin has exclusively been studied by Sheu *et al.* (2004), their result revealed an average value of 1.386 km as the sedimentary thickness. More recently (Muhammad et al., 2014) carried out the spectral analysis of aeromagnetic data across Kebbi State, Nigeria (the south-western part of the basin), and obtained 1.72 km as the highest depth in the area. These and many others concluded that the basin is too shallow for any petroleum prospecting based on the assertion made by Wright *et al.* (1985) that, for any sedimentary basin to host hydrocarbon, its thickness cannot be less than 2.3km. Major geological structures for hydrocarbon and other minerals resources potentials were delineated.

2. Methodology

High-resolution aeromagnetic data covering the study area (Sokoto Basin) were obtained from Nigerian Geological Survey Agency (NGSA). The study of Sokoto Basin covers thirty (30) aeromagnetic maps of $0.5^0 \times 0.5^0$. An equatorial distance of 111 km to 1^0 latitudes was used in this work. The interpolated data were merged together to produce a unified dataset used to generate the composite aeromagnetic map of the study area.

The total magnetic field data were then gridded and plotted after coordinates' conversion (degrees to meters) in preparation for the upward continuation, using Oasis montaj software package. The upward continuation method was suitably employed due to the fact that the magnetic field (as a potential field) obeys Laplace's equation which allows us to determine the field over an arbitrary surface if the field is known completely over another surface. This process is referred to as continuation (Telford *et al.,* 2004). To reduce the effect of short wavelength features due to shallow sources and noise in grids to a certain level, thereby enhancing large-scale (usually deep) features in the area and consequently representing valid regional fields for an area (Jacobsen, 1987), upward continuation were applied to the total magnetic field intensity anomaly (Ezekiel et al., 2019) of the study area at various planes of observation. The planes were at 10 km, 20 km, 30 km, 40 km, 50 km, 70 km and 100 km. The method tends to accentuate anomalies caused by deep sources at the expense of anomalies caused by shallow sources (Mekonnen, 2004). We have for upward continuation, the following relation.

$$F(x', y', -h) = \frac{h}{2\pi} \iint \frac{F(x,y,0)\,dx\,dy}{\{(x-x')^2+(y-y')^2+h^2\}^{1/2}} \quad (1)$$

The left side of the equation is the total field at the point $F(x', y', -h)$ above the surface on which $F(x, y, 0)$ is known. The calculation procedure is to replace the integral with a weighted sum of values taken on a regular grid (Telford, 2004). Upward continuation is useful in the interpretation of magnetic anomaly fields over areas containing many near-surface magnetic sources such as dykes and other intrusions (Kearey and Brooks, 2000).

Regional-residual separation (second order) was also applied to the total magnetic field data to obtain the second order regional magnetic field intensity map, for comparison with the upward continuation results.

3. Results and Discussion

Figure 1(a) shows the composite map of the total magnetic field intensity (TMI) of the study area. Portions on this map that are colored red represent areas of high magnetic intensity, whereas those in blue correspond to the areas of low magnetic field intensity. Superimposed with these portions are areas of intermediate field intensities represented by colors of yellow and pale green that appear everywhere on the study map. The data were further reduced to the magnetic equator to shift anomalies exactly above their causative bodies (Figure 1(b)). The effect is not appreciable of the fact that the study area is only a few degrees away from the magnetic equator.

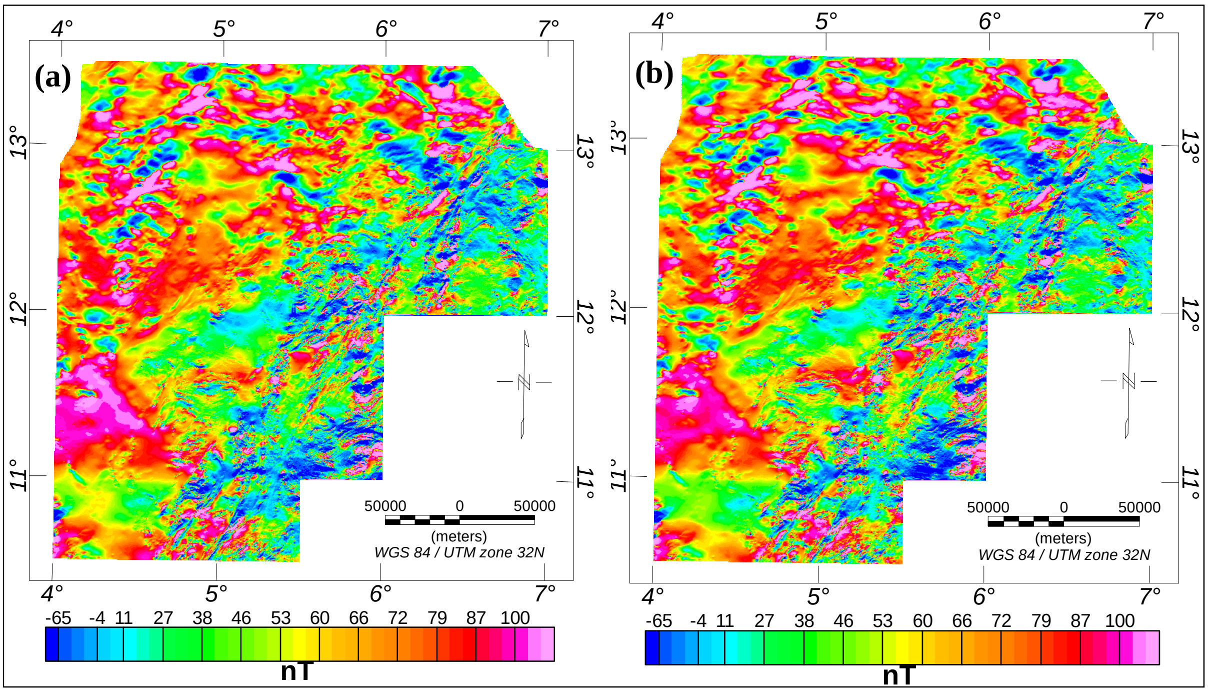

Figure 1: (a) Total magnetic field intensity map and (b) reduction to the equator of a total magnetic field intensity map.

The total magnetic intensity map of the study area was upward continued at 10 and 20 km firstly to produce Figure 2. At such heights, the shorter wavelength anomalies are visible, though slightly refined compared to that of the total magnetic intensity map (Figure 1) before the upward continuation processing. The deep blue coloration in the eastern part of the map suggests that the area is having the highest sedimentary thickness, in contrast to the red coloration in the western part, which is indicative of the presence of high magnetic intensity rocks. Pink-colored anomalies, with few traces of yellow, observed virtually in the middle of the map correspond to the highly magnetized crystalline basement rocks (migmatite-gneiss-granite complex) in the area.

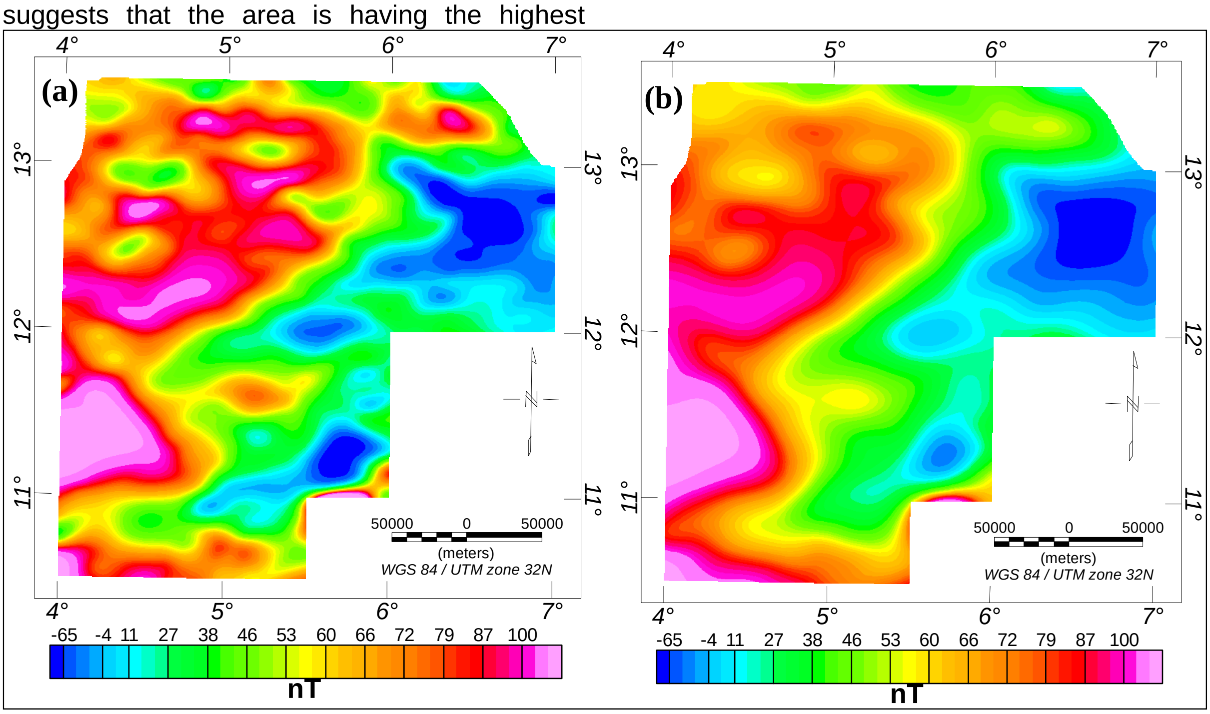

Figure 2: (a) Upward continuation at 10 km and (b) upward continuation at 20 km

The process further continued at 30 km, 40 km, 50 km and 70 km as shown in Figures 3(a), 3(b), 4(a), and 4(b) respectively. In each case, the image resolutions are better refined than in the preceding plane.

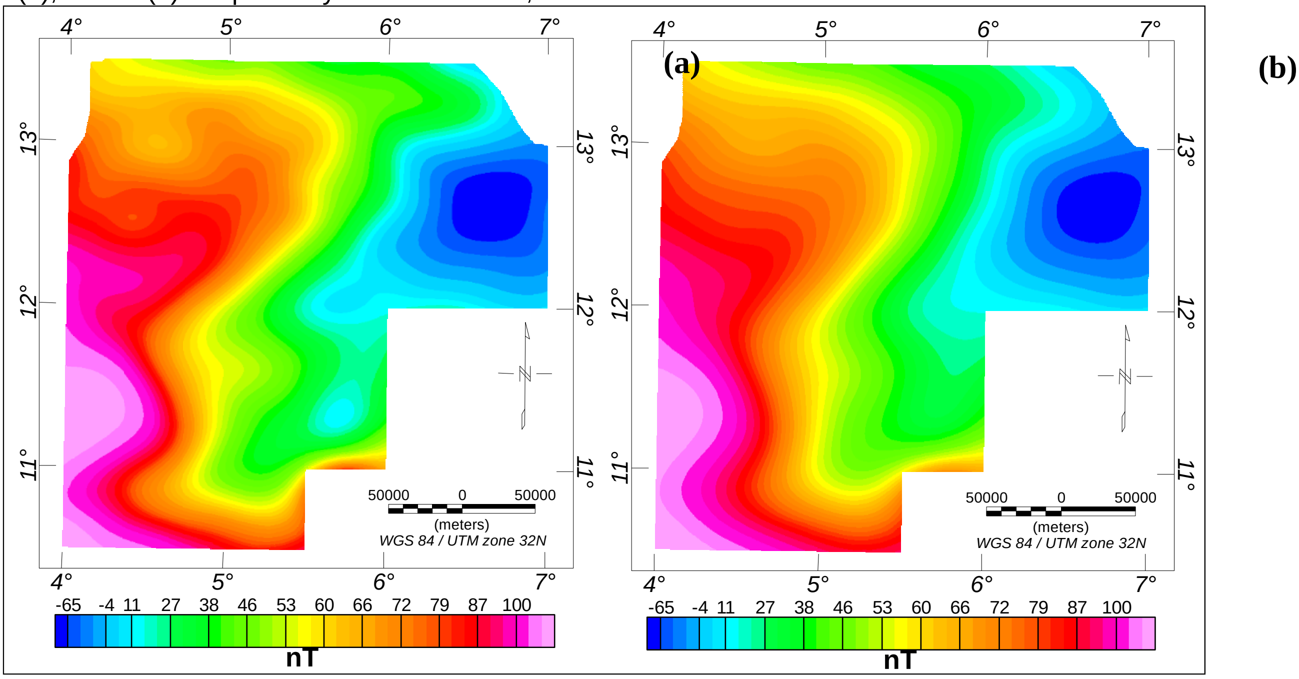

Figure 3: (a) Upward continuation at 30 km and (b) upward continuation at 40 km.

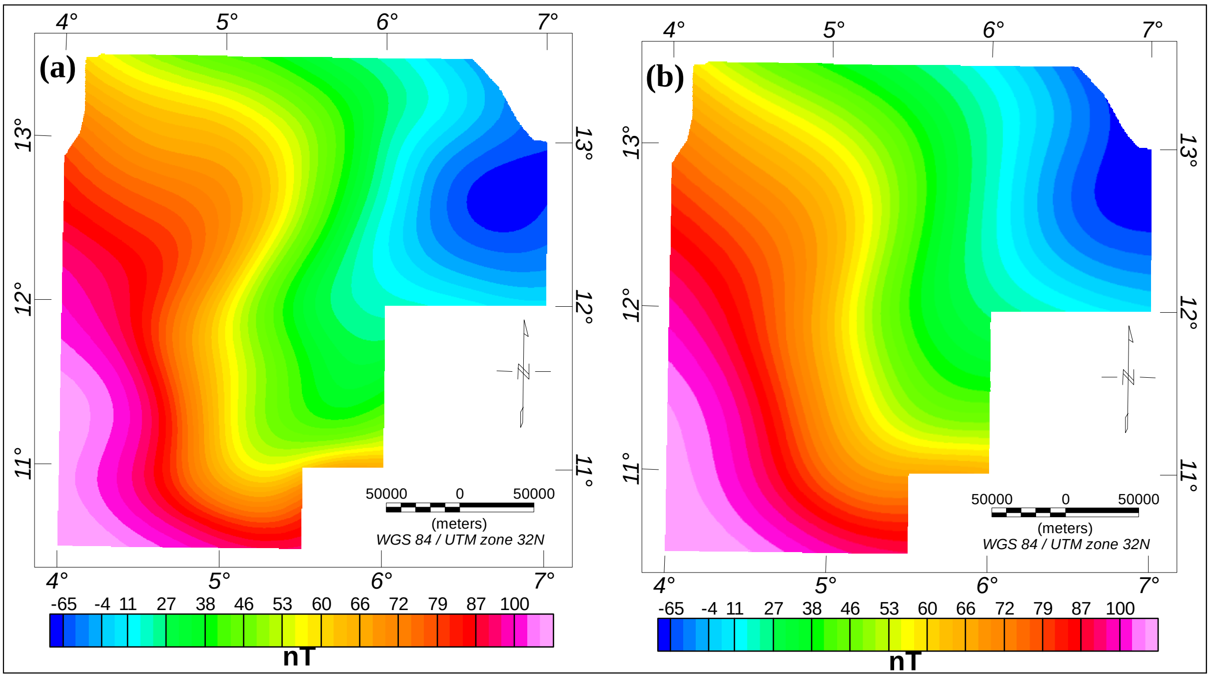

Figure 4: (a) Upward continuation at 50 km and (b) upward continuation at 70 km

At 100 km (Figure 5(a)) however, the short wavelength anomalies were completely removed, leaving behind the deep-seated long anomalous structures, which compare closely to the regional field (Figure 5(b)). It is, therefore, safe to say, from the results, that when prospecting for sedimentary related structures, such as hydrocarbons, emphasis should be given to the eastern parts of the area, while other high minerals may be traced in the western parts.

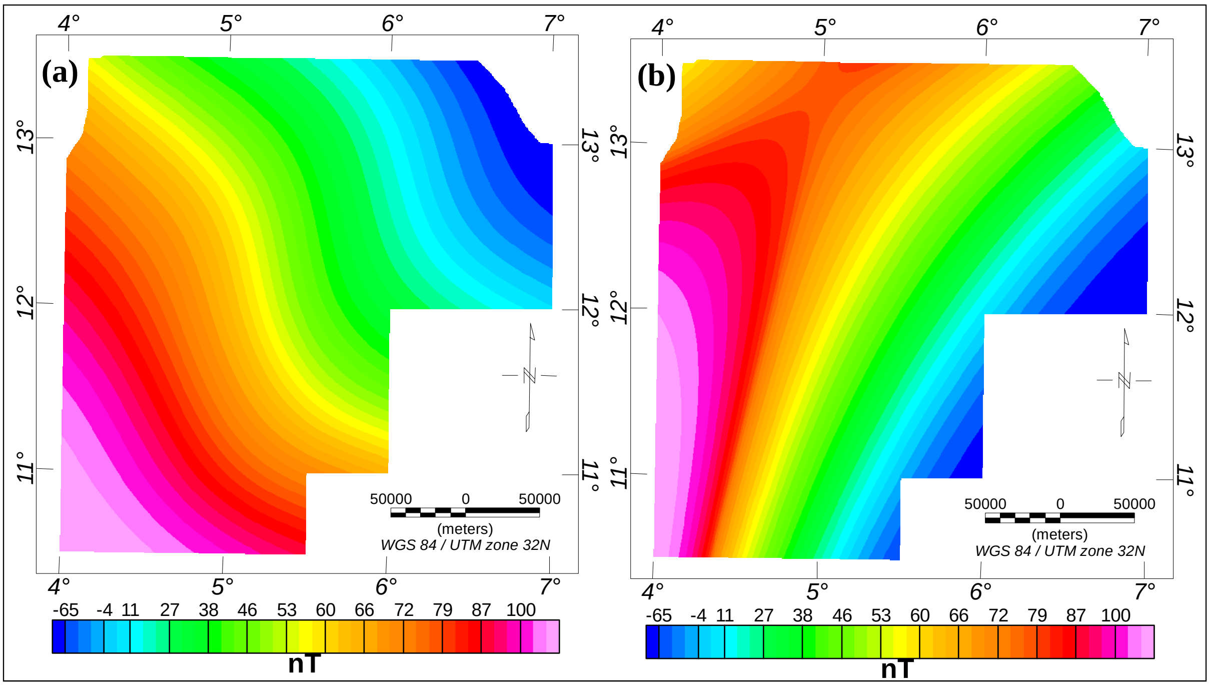

Figure 5: (a) Upward continuation at 100km (b) Second order regional magnetic field intensity map.

4. Conclusion

Thirty aeromagnetic data maps covering part of the Northern Nigeria basement complex were analyzed and interpreted in this paper. The total magnetic field was continued at various planes of observation. The planes were at 10 km, 20 km, 30 km,40 km,50 km,70 km, and 100 km above the surface of the Earth to remove short wavelength anomalies. The continuation process showed a well-seated highly magnetized structure in the eastern part of the study area. The persistence of this high intensity may indicate an upliftment of the basement or the presence of ferruginous minerals. This information will help Nigerian Geological Survey to update the existing regional geology map of the country or provide a guide for future exploration studies in the area.

Conflict of Interest

The author declares that there is no conflict of interest.

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