# Regional Groundwater Studies Using Aeromagnetic Technique*

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## Abstract

Geophysical techniques have played a major role in subsurface investigation. These techniques include seismic, electrical, ground penetrating radar, gravity, electromagnetic, magnetic, etc. The problems that have been buffeting the geologist or geophysical researchers are in the wide coverage of any area of interest when investigating subsurface using these ground geophysical techniques. But the aeromagnetic technique has proven to be successful in this regard. Although the magnetic technique (aeromagnetic) has been applied successfully for mineral resources and hydrocarbon exploration, this study examins in detail the uniqueness of this technique (in terms of universality, acceptability and coverage) and its application to regional groundwater studies, especially where hydrogeophysical related equipment is not available. Furthermore, this aeromagnetic technique has been applied to determine the depth to magnetic source of Ado-Ota and environs in southwestern Nigeria. The result revealed that there are two geological environments in the study area, namely sedimentary and basement complex terrain which are very significant in groundwater studies. The shallow sources characterized the basement complex with depth ranges from 102.8 m to 246.1 m, and deep sources characterized sedimentary terrain from 710.0 m to 1,980 m.

## Introduction

The difficulty facing the geologist and geophysicist specializing in groundwater exploration has been the area of coverage as a result of limitations of hydrogeophysical equipment such as terrameter, etc., and the cost. But the aeromagnetic survey has proved to be successful in this regard by mapping geological structures relating to groundwater occurrence on a regional scale. This is because aeromagnetic survey has the advantage of covering region of about 500 to 5000 square kilometers (Atkinson, 1989) and it can be integrated with other geophysical techniques for groundwater exploration. Traditionally, aeromagnetic techniques have been used primarily in sedimentary terrain for the purpose of mapping faults relating to hydrocarbon accumulation, in crystalline Basement Complex for mapping faults which is in connection with groundwater occurrence due to high magnetizations of rock types that consists of Basement Complex (igneous and metamorphic rocks) and for mineral resources investigation.

Series of studies have been carried out using aeromagnetic techniques. In Basement Complex of the world, the aeromagnetic technique has been successfully used for hydrogeological structural mapping (Olasehinde et al., 1990; Annor et al., 1990; Olasehinde and Annor, 1991; Grauch et al., 2001; Olasehinde and Awojobi, 2004) and as well in sedimentary terrain (Grauch, 1999; Grauch, 2001; Ndougsa-Mbarga et al., 2012; Chinkwuko et al., 2012; Bemensen et al., 2013; Bonde et al., 2014). Aeromagnetic techniques have shown to be a tool that can provide inexpensive reconnaissance exploration (Atkinson, 1989) compared to other geophysical techniques. Although the magnetic method is not commonly used for hydrogeological studies in alluvial environments (sedimentary terrain) but the recent high resolution surveys have proved to be successful in locating geological features such as faults that offset the aquifers within the sedimentary terrain and delimiting the igneous rock buried in the subsurface (Grauch, 1999) and these are important parameters in understanding the hydrogeology of the subsurface. This is made possible through the interaction of the earth magnetic field with the subsurface (Figure 1). Therefore, this present study examines the aeromagnetic technique to groundwater studies in sedimentary terrain of the Dahomey Dasin in Nigeria as an application.

## Dahomey Basin

The Dahomey Basin extends from southeastern Ghana through Togo and Benin Republic on the west side, to the Okitiputa Ridge/Benin Hinge Line on the east side, in the southern part of Nigeria (Adekeye and Akande, 2006). The basin is bounded in the north by the Precambrian basement rock, and the Bright of Benin in the south. The stratigraphic setting of the basin has been discussed in detail in the works of Lehiner and Ruiter (1977), Omatsola and Adegoke (1981), and some others. During the Late Cretaceous, a substantial amount of sediments were deposited in fault-controlled depressions in the Dahomey Basin, bringing about the Coastal Plain sands. Post-Santonian marine trangression accompanied the subsidence and drowning of continental margins which brought about the deposition of a very thick sequence of continental grits and pebbly sands over the entire basin (Lehner and Ruiter, 1977). In some places, mudstones and shales with thin limestones were depostied. This lithostratigraphic formation is referred to as the Abeokuta Formation (Omatsola and Adegoke,1981). During the Paleocene, a continuation of the marine transgression led to the deposition of shallow marine limestones of the Ewekoro Formation and the shales of the Akinbo Formation. Above this Paleocene sequence are the Eocene shales of the Oshosun Formation and the sandstones of the Ilaro Formation (Figure 2), which are the most recent deposition (Okosun, 1990).

## Aeromagnetic Surveys

Aeromagnetic survey involves the use of aircraft to a conduct magnetic survey in order to investigate the subsurface. This technique makes use of variation in the Earth’s magnetic field as a detecting tool. Magnetic field variations are often use as diagnostics of regional structures. In magnetic prospecting, the main target for application is the main field which varies slowly and is of internal origin, the small field which varies rapidly and originates outside the earth, and spatial variations of the main field which are smaller compared to the main field (Telford et. al., 1990). This is usually constant with time and place and is caused by local magnetic anomalies in the near surface of crust of the Earth (Telford et. al., 1990). In this research, aeromagnetic data collected by Fugro Airborne Surveys from December, 2006 to May, 2007 for Nigerian Geological Survey Agency was acquired and processed accordingly (Figure 3).

## Aeromagnetic Data Interpretation

There are two major interpretation procedures that exist on aeromagnetic data, namely qualitative and quantitive. Qualitative involves largely on map view inspection in relation to geological maps of any particular study area that contains shapes, trends of anomalies, delineation of structural trends, etc. Figure 3 shows the total magnetic field map of the study area after processing. Qualitative interpretation involves subjecting the aeromagnetic data to interpretation techniques such as analytical signal, first and second vertical derivative, source parameter imaging, etc. In this present work, processed aeromagnetic data was subjected to the following interpretation procedures, namely first and second vertical derivative, analytical signal, tilt derivative and source parameter imaging for the purpose of inferring the groundwater occurrence features and morphology.

## Vertical Derivatives

Mathematically, the first and second vertical gradients are defined as follows:

$$FVD = -\frac{(\partial F)}{(\partial Z)} \qquad (1)$$

$$SVD = \frac{(\partial^2 F)}{(\partial Z^2)}) \qquad (2)$$

where FVD and SVD are first vertical derivative and second vertical derivatives respectively. The map of first and second vertical derivatives is shown in Figure 4 and Figure 5.

## Analytical Signal

Analytical Signal (ASIG) is known as total gradient and is defined as the square root of sum of vertical derivatives of total magnetic field intensity in the x, y and z directions. This requires the horizontal (x, y) derivatives of the total magnetic field, the first-order vertical derivative (z). Roest et al. (1992) and Macleod et al. (1993) described that analytical signal can be computed in a 3D format from three orthogonal derivatives of the total magnetic field intensity using the expression:

$$|ASIG(x,y)| = \left[ (\frac{\partial}{\partial x}F(x,y))^2 + (\frac{\partial}{\partial y}F(x,y))^2 + (\frac{\partial}{\partial z}F(x,y))^2 \right]^{1/2} \qquad (3)$$

Where ASIG is analytical signal and F is observed total magnetic field at (x, y).

Space domain analysis using splines are used in horizontal derivatives computation, and wave number domain using fast Fourier transform is used for vertical gradient computation (Al-Garni, 2010). The analytical signal map of the shown some causative bodies is shown in Figure 6.

## Source Parameter Imaging

This is a powerful, easy and quick method for determining magnetic sources depth.  It has an accuracy of about (+/-) 20% which is similar to that of Euler deconvolution. But source parameter imaging (SPI) has benefits in that it can produce a more complete set of coherent solution points and it can easily be used (Figure 7).

## Tilt Derivative

Tilt derivative also known as tilt angle derivative **(**Miller and Singh, 1994; Verduzco et al., 2004) is defined as

$$\theta = \left[ \frac{\frac{\partial F}{\partial z}}{\frac{\partial F}{\partial h}} \right] \tag{4}$$

Where

$$\frac{\partial F}{\partial h} = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2} \tag{5}$$

and ∂F/∂x, ∂F/∂y and ∂F/∂z are the derivatives of the magnetic field F in the x, y and z direction. Figure 8 shows the tilt derivative map of the study area.

## Lineaments Extraction

The tilt derivative analysis map was further enhanced using remote sensing technique and ArcGIS software was used to extract the faults. This is because remote sensing is a powerful tool that can pinpoint an overview of an area. The map of lineament extracted is shown in Figure 9.

## Results and Discussion

The magnetic field intensity map is presented in Figure 3 and shows the variations in the intensity of magnetics that reflect the susceptibility of various rocks across the different terrains as displayed on the map. The variations are in three categories, namely magnetic highs, magnetic intermediates, and magnetic lows. The magnetic highs values of intensity ranging between 56.0 – 80.0 nT are the most dominant in the southern and southwestern part and partly in the eastern part of the study area. This indicates the presence of rocks of high magnetic susceptibility of typical Basement Complex. Magnetic intermediates range from 48.0 – 55 nT dominated the eastern part of the study area, which also formed the boundaries for shallow sources in the western part. This indicates the presence of metamorphic rocks. Magnetic lows with magnetic intensity value range between -4.8 – 47.0 nT is mainly dominated in the western and northwestern part of the study area, signifying the presence of materials of low magnetic susceptibility which is of sedimentary rock origin. Figure 3 clearly shows three major rock types that exist in the study area, namely sedimentary rock which is of high dominance in western and northwestern part of the study area, metamorphic rock dominates in the central part, and igneous rock as an anomaly in the western part of the study area. Also, the acute shap of a positive anomaly (80 nT) is visible in the western area. The basement to sedimentary terrain area are characterized by elongated positive east to west trending anomalies with amplitude range of 5.0 – 80 nT. The western (absolute sedimentary) part relatively displays low magnetic intensity value of -4.8 nT around the Papa, Ilugboro and Idiroko areas. Prominently, the total magnetic intensity map (TMI) revealed two major geological terrains underlie the study area, namely sedimentary terrain and Basement Complex. Sedimentary terrain dominates the western part of the study area, while Basement Complex is in the eastern part with total magnetic value ranges from -4.8 nT – 45.5 nT and 48.0 nT – 79.7 nT respectively, as shown in Figure 3. This Basement Complex covered more than half of the study area and this confirmed the geological investigation carried out by Offodile (2002) that more than half the Dahomey Basins is covered by basement rocks. The Abeokuta Formation, being the oldest outcropping sedimentary formation, appears to overlie the Basement Complex directly and this in turn is overlain by the Ewekoro Formation, Ilaro and Benin formations. The Basement Complex found in the supposed sedimentary terrain was a result of intrusion of Basement Complex into the basin and this offset the thickness of basin.

According to Telford et al (1998), the first vertical derivative (FVD) and second vertical derivative (SVD) anomaly maps are the most usual types of vertical gradient (or derivative) maps produced during aeromagnetic magnetic data analysis. Figure 4 and Figure 5 showed the first and second vertical derivatives of the total magnetic intensity (TMI) anomaly maps produced from magnetic data. The high wave number anomalies associated with surface, near-surface and local geological structures (such as groundwater channel) are the major emphasis of first and second vertical derivatives and are greatly enhanced. Figure 4 shows the surface features of a groundwater channel controlled by faults, while Figure 5 shows enhanced clarity of the groundwater channel.

Analytical signal map is shown in Figure 6. Ridges or peaks in analytical signal total magnetic intensity anomaly map occurs mostly on geological targets such as faults, volcanic plugs, dykes, shear zones, lithological contacts, discrete bodies and their edges, magnetization's directions nothwistanding (Anudu et al., 2014). Analysis of analytical signal over the aeromagnetic data of the study area confirms the anomalies peaks existence in the form of causative bodies (Figure 6). The causative bodies that represent faults, lithologic contacts, etc., are found where groundwater channels exist (Figure 4 and Figure 5) and this suggests that the groundwater of the area that falls within the zones of causative bodies may likely be controlled by hydrogeological targets such as faults.

Source parameter imaging (SPI) is used mostly for determining depth to magnetic source when interpreting aeromagnetic data over an area. Figure 7 shows the major geological sources in the study area, namely shallow sources (purple, red, yellowish, and green colour) and deep sources (blue colour). The shallow sources originated from Basement Complex and range from 102.6 – 663.0 m (0.1026 - 0.6630 km). Shallow sources clearly dominated in the eastern, southeastern, and partly southern areas. Deep sources are mainly located in the west (southwest and northwest) of the study area with thickness of sediment ranges from 710.2 to 2000 m, and most pronounced in the northwestern.

As a result of this magnetic basement mapping in sedimentary terrain, we see that groundwater in both the southern and eastern part of the study area are largely controlled by faults (Figure 9). These faults also may serve as recharging conduit for groundwater system within the study area.

## Conclusions

In this study, it was observed that aeromagnetic techniques proved to be useful in studying groundwater occurrence and structures where there is an absence of hydrogeophysical equipment. Furthermore, due to the heterogeneity of the subsurface, the technique has been able to unravel the hidden basement complex (sedimentary basins) contrary to geophysical researchers' opinion relating to sedimentary basins and depth to magnetic source. However, further geophysical studies are recommended by integrating other geophysical techniques such as geoelectric methods (for groundwater potential investigation in the areas with more faults), and seismic methods (for investigating faults in the study area) with magnetic techniques (whether ground magnetic or aeromagnetic).

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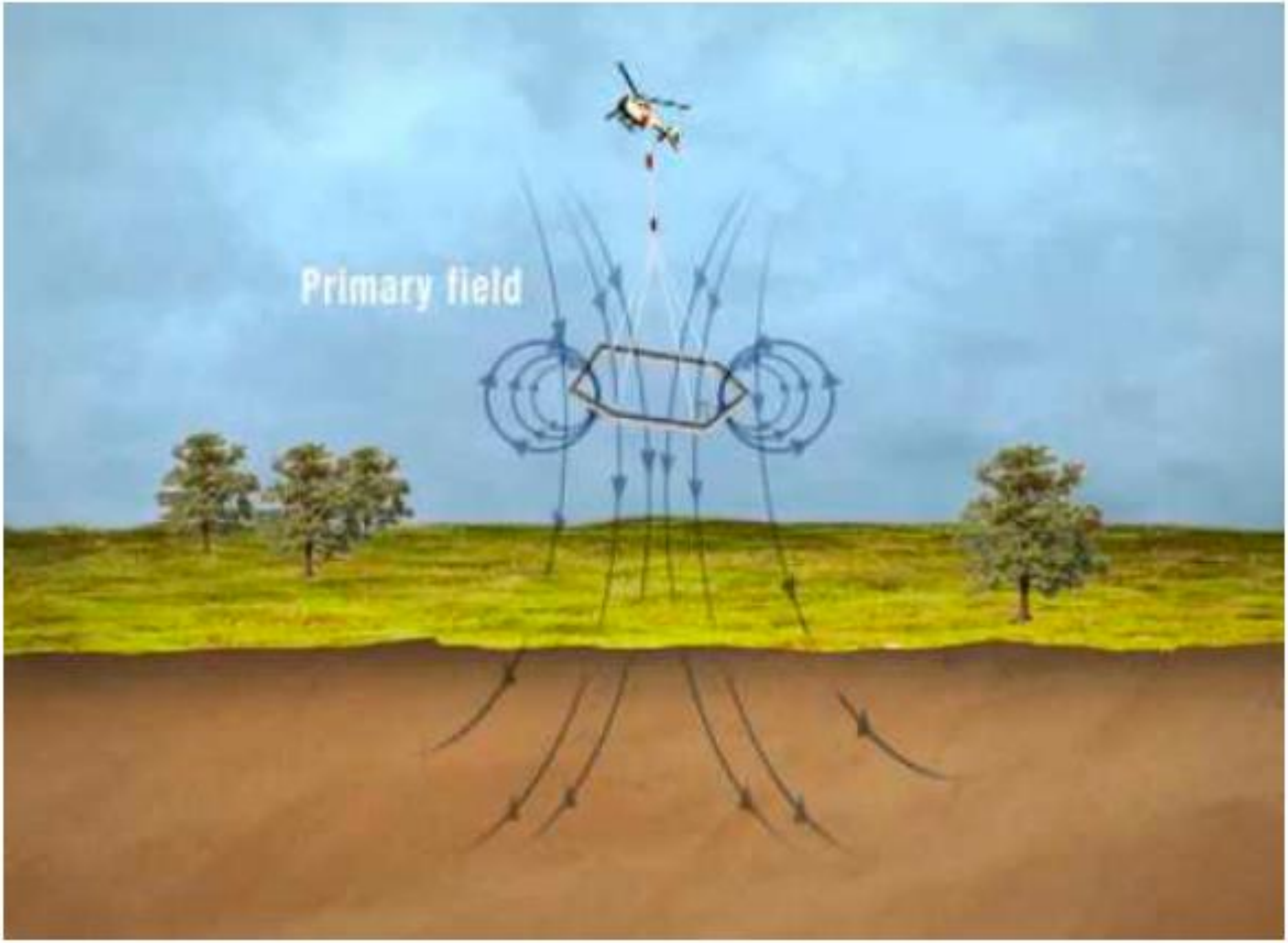


Figure 1. Earth magnetic field interactions with subsurface (SkyTEM systems, 2013).

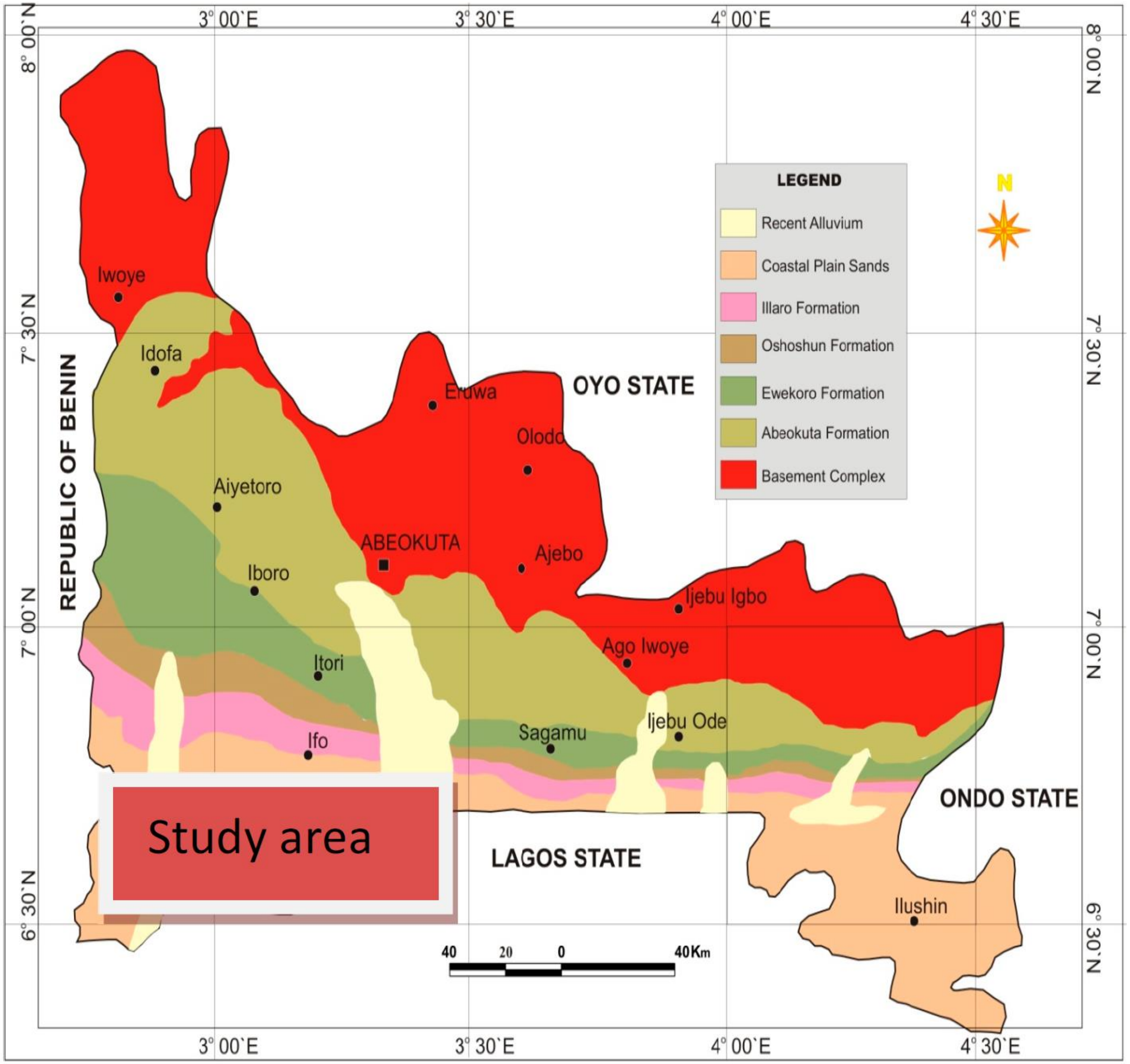


Figure 2. Geological map of Ogun State showing Dahomey Basin and the extracted study area (NGSA, 2006).

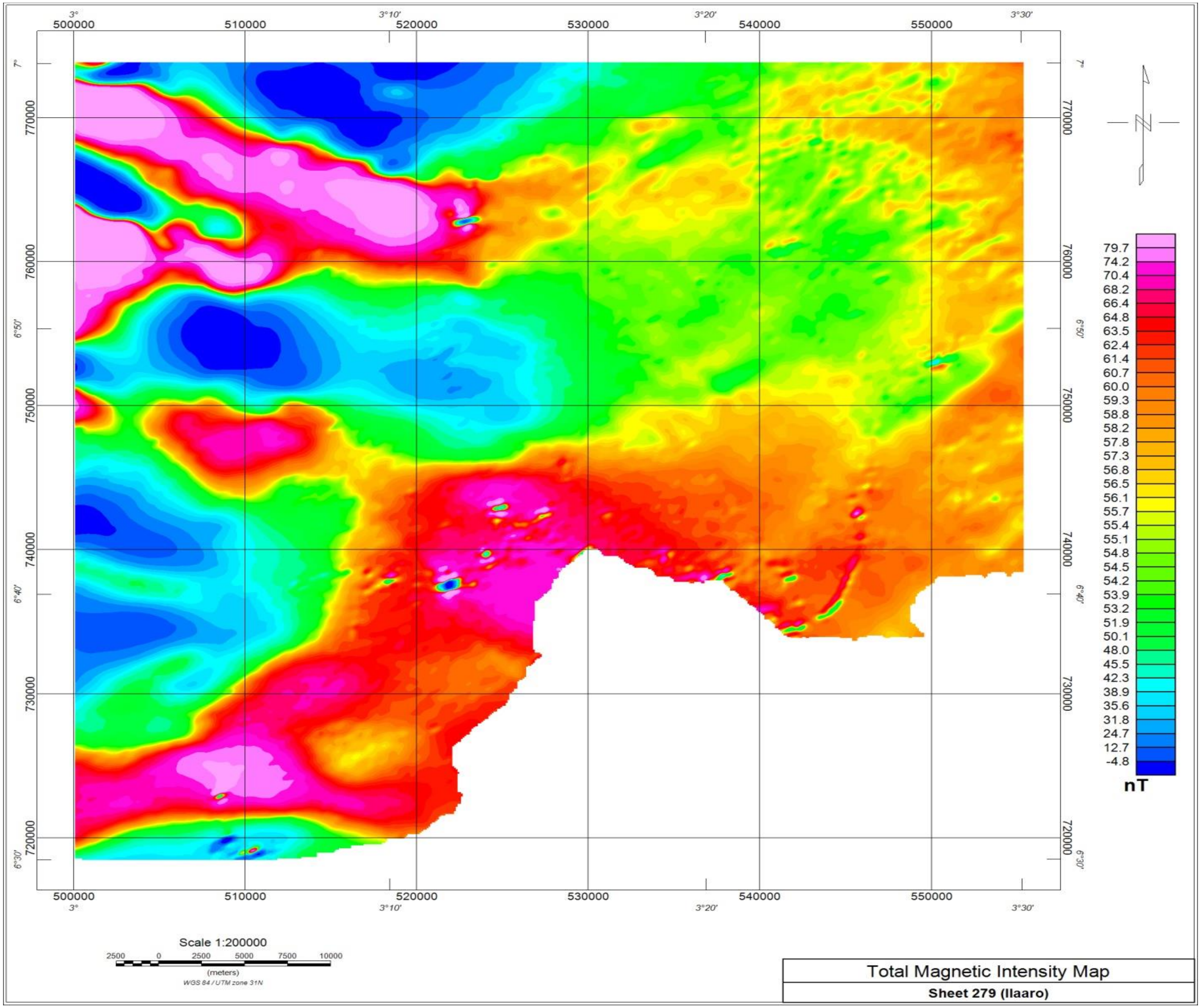


Figure 3. Total Magnetic Field map of the study area.

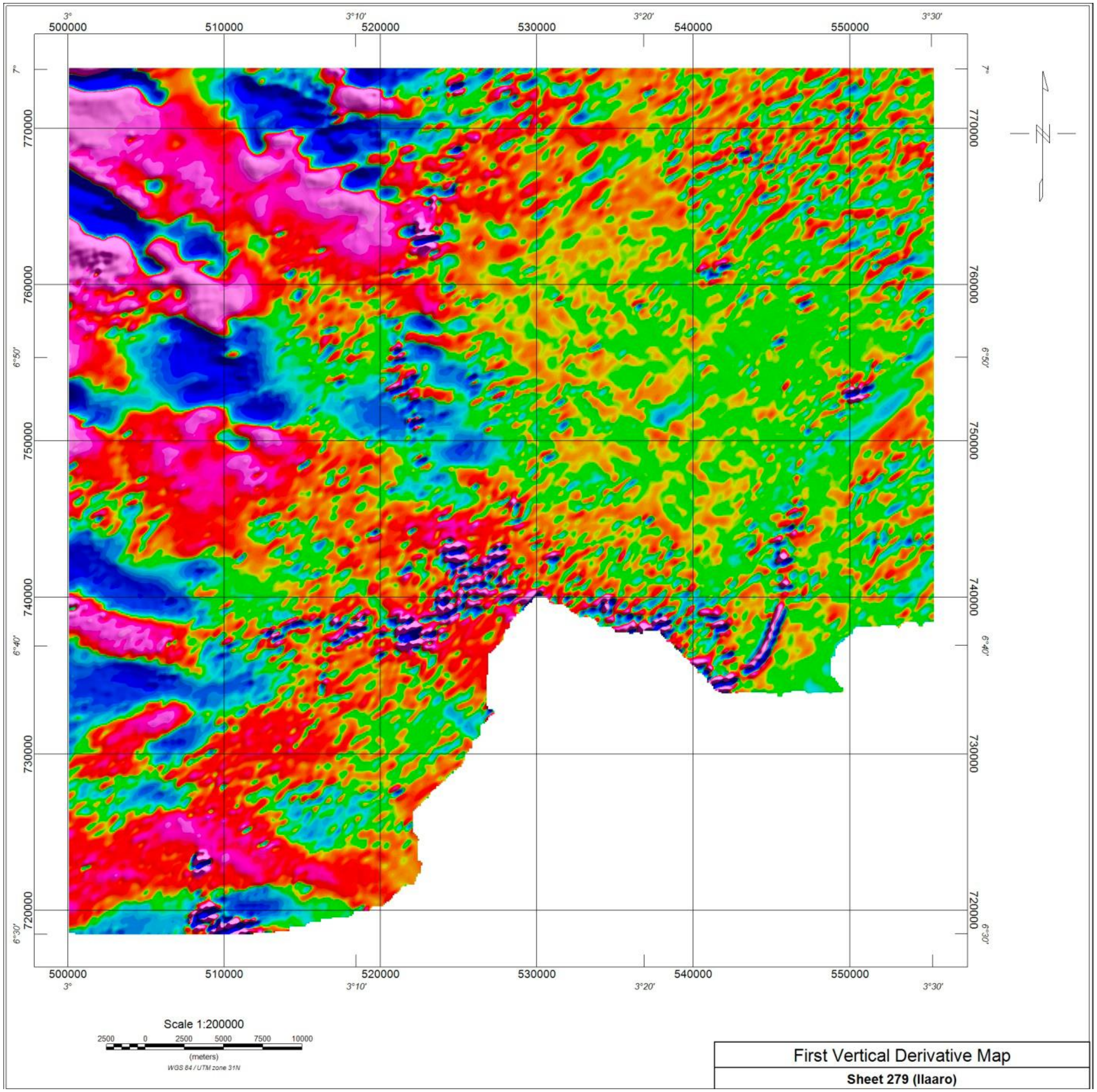


Figure 4. First vertical derivative map.

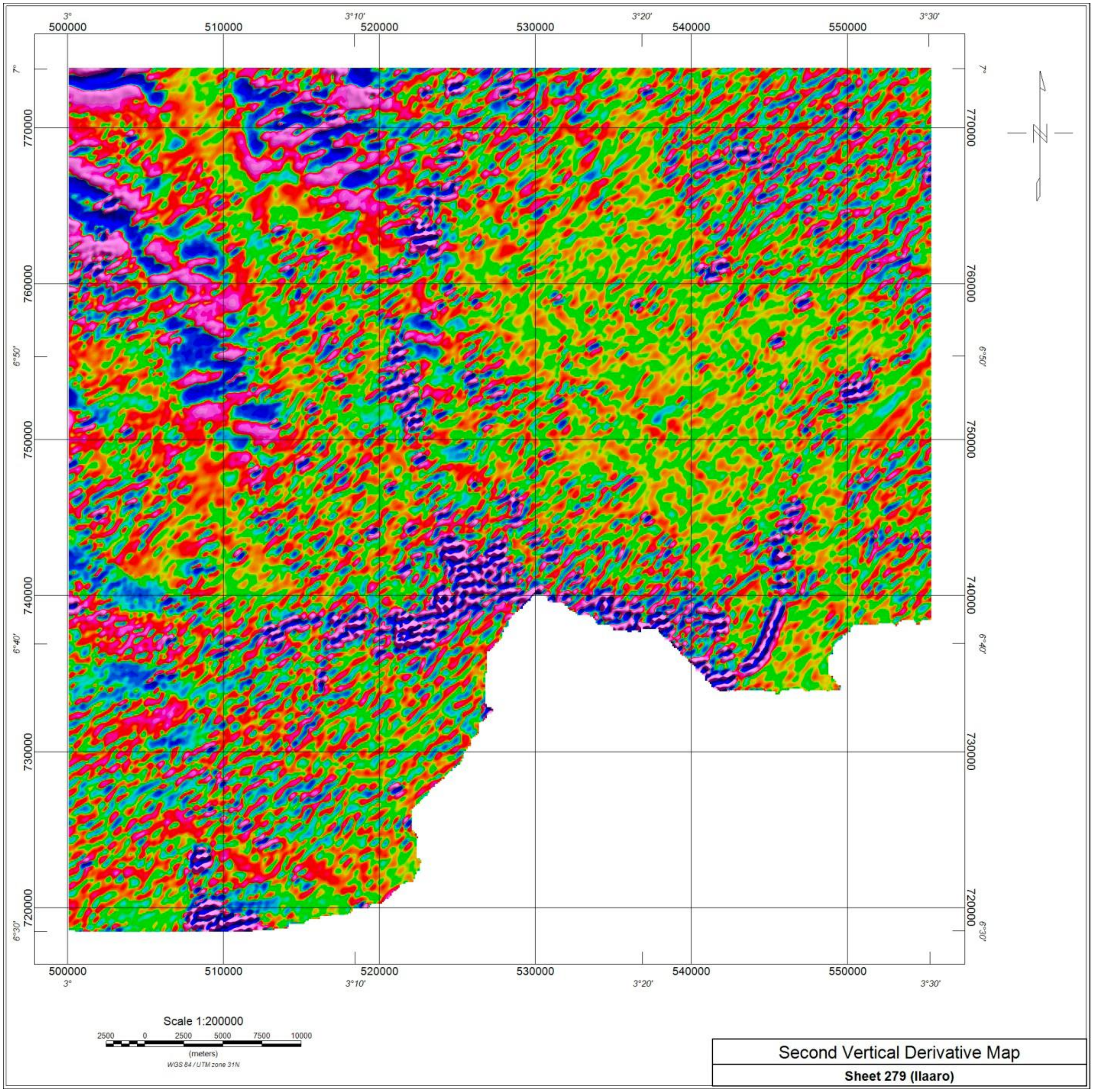


Figure 5. Second vertical derivative map.

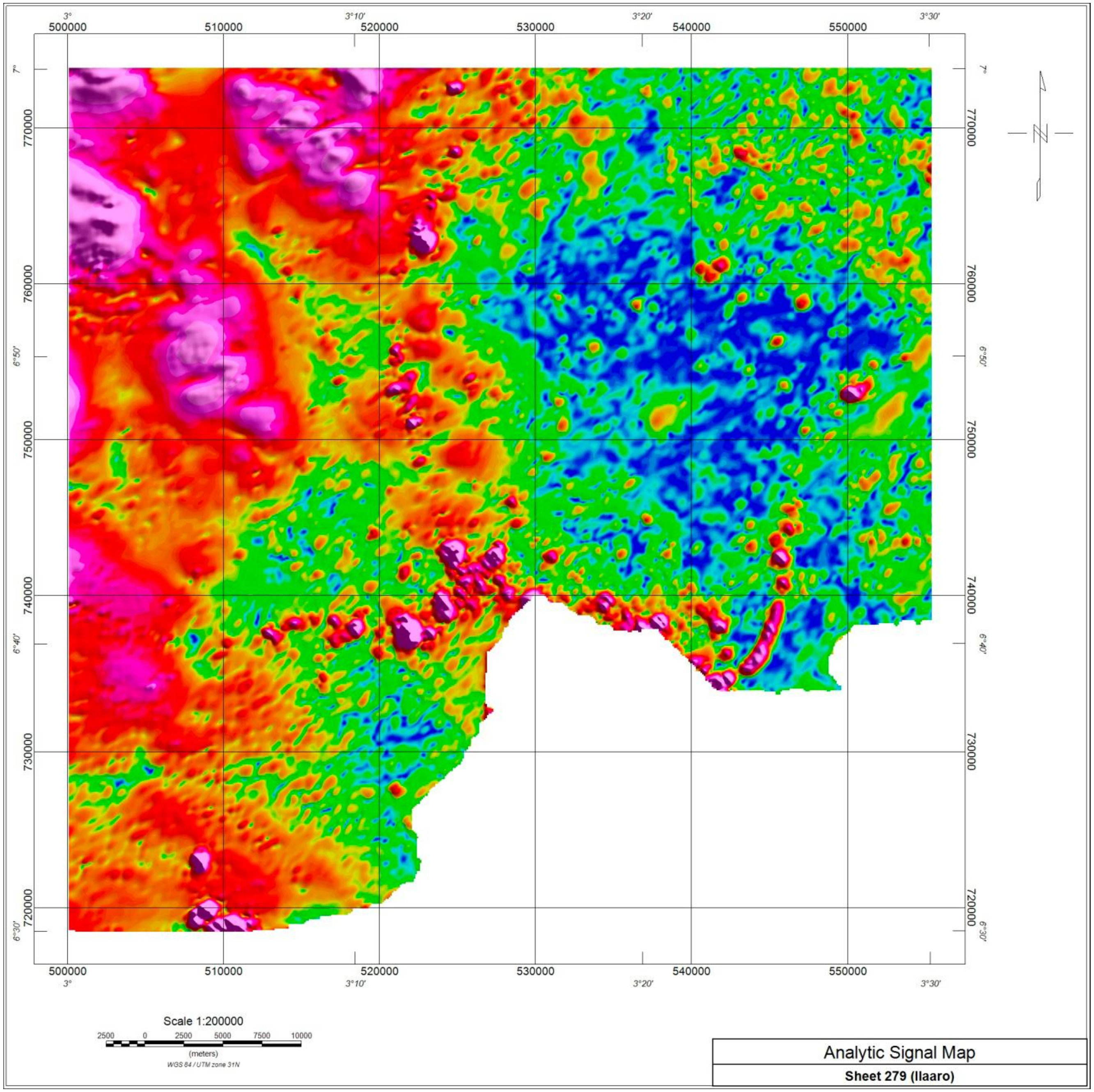


Figure 6. Analytical Signal Map showing some causative bodies.

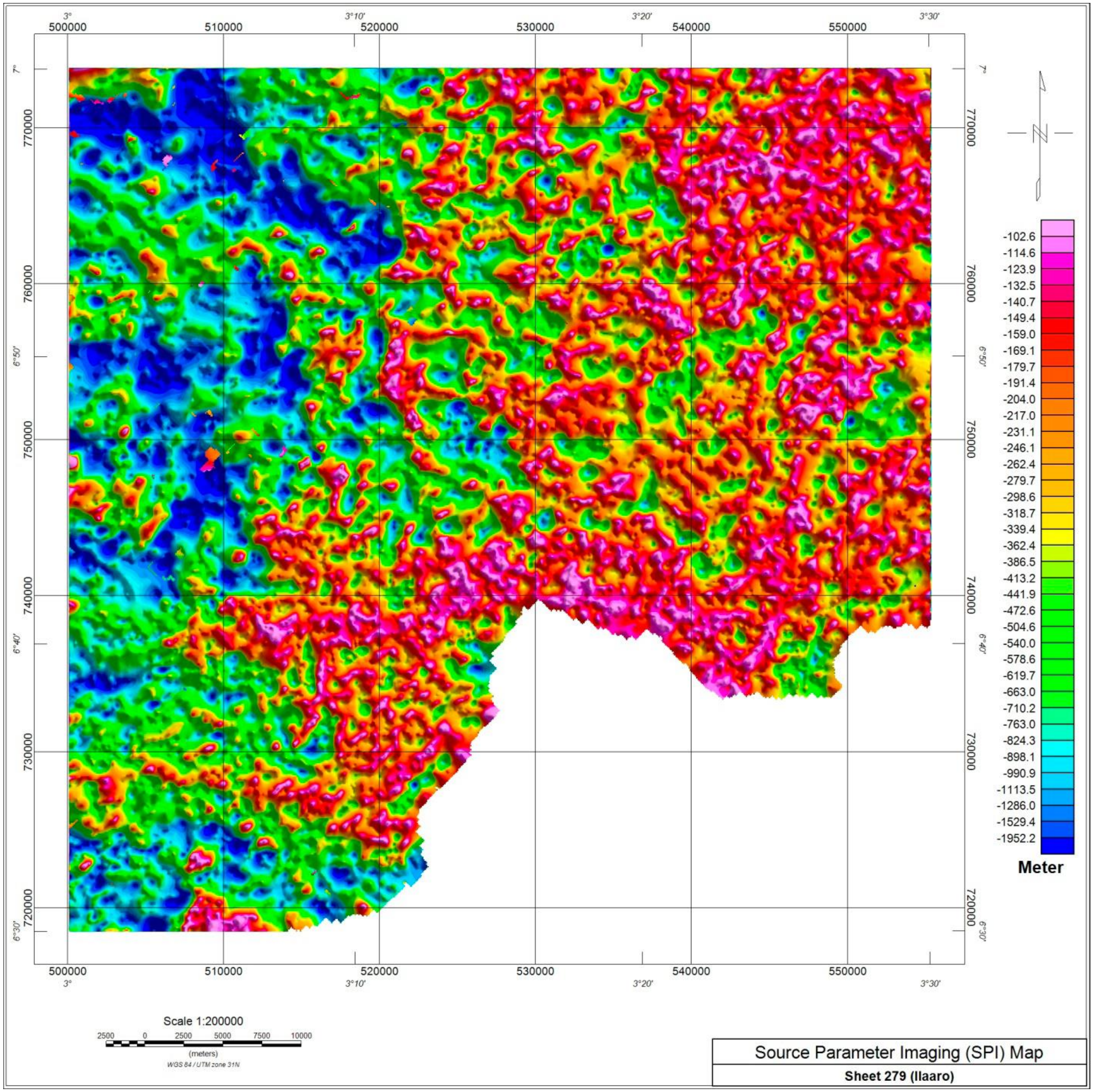


Figure 7. Map of Source Parameter Imaging for depth to magnetic source.

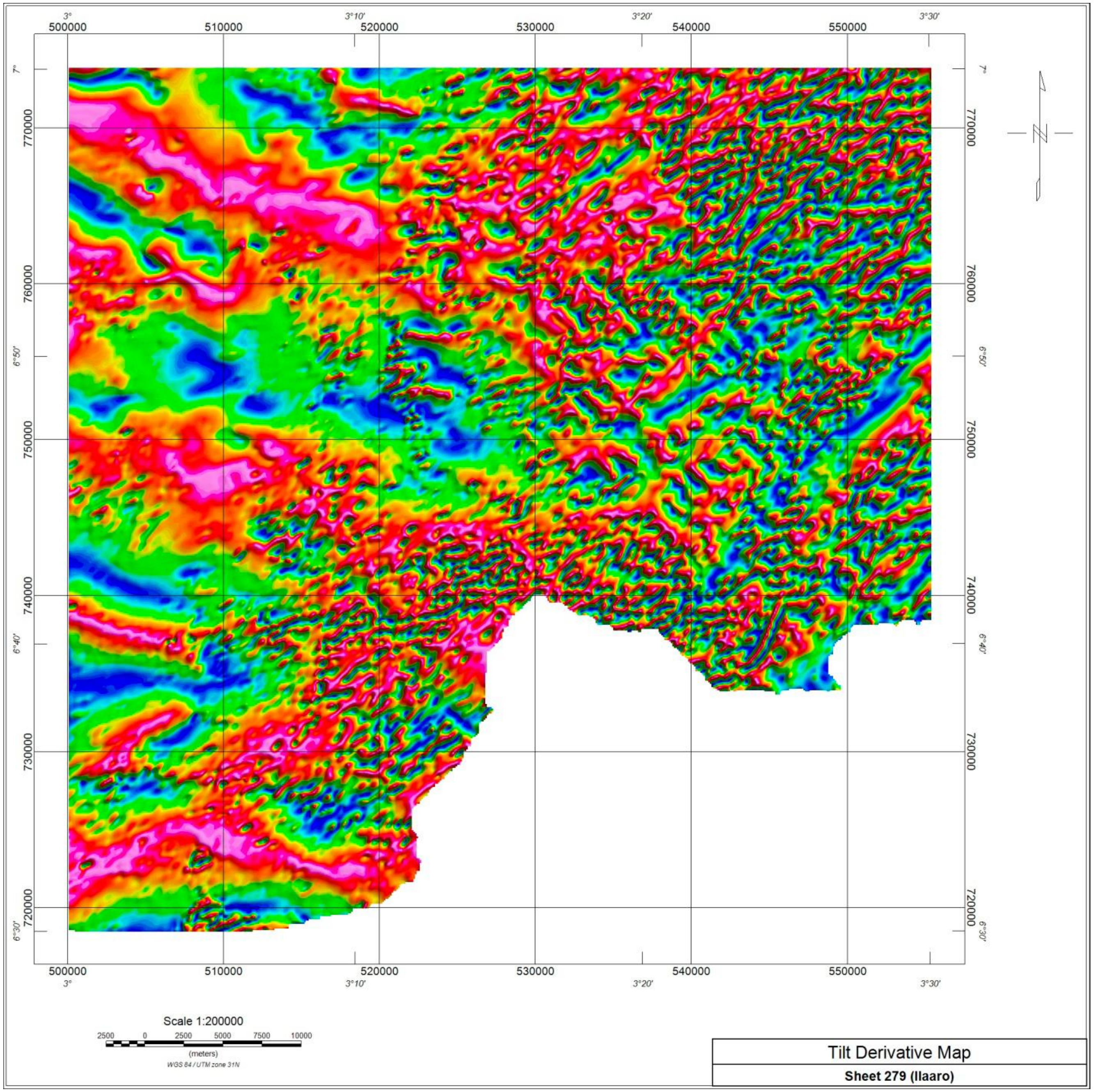


Figure 8. Tilt derivative map showing lineament features.

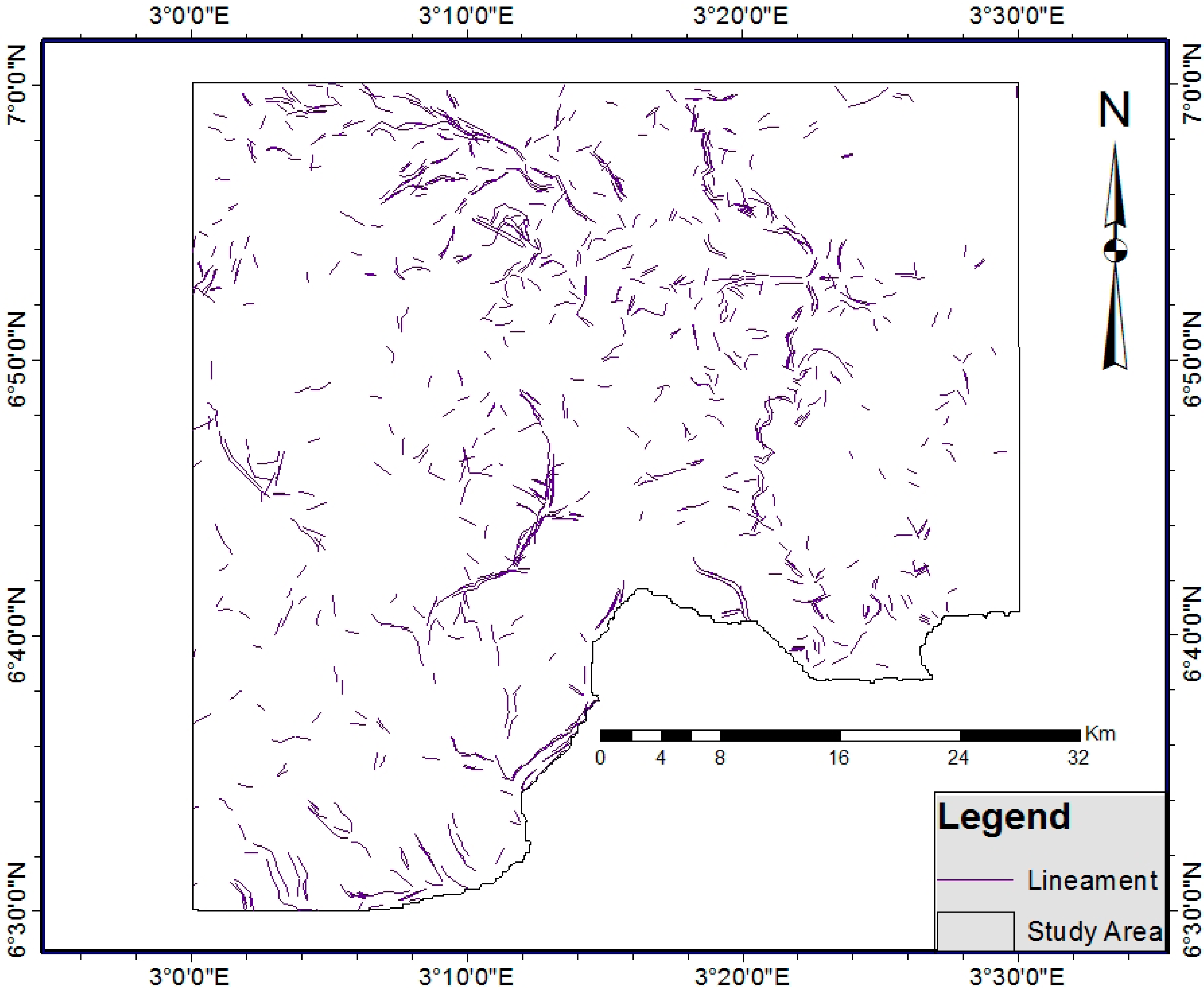


Figure 9. Lineament map of the study area.