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Mapping Potential Cassiterite Deposits of Naraguta Area, North Central, Nigeria using Geophysics and Geographic Information System (GIS).

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ABSTRACT

A Geophysical and Geographic Information System (GIS) study is presented to produce a map of potential cassiterite deposits of Naraguta area, North-central Nigeria using aeromagnetic, radiometric, geological, topographic data. Each map was analysed to extract features relevant to cassiterite mineralization and hence produce evidence maps or factor maps. Index overlay method of multiple map combination was used to integrate the resultant evidence maps to produce a cassiterite potential map for the Naraguta area. The cassiterite potential map showed that most of the area within the Jos- Bukuru Complex has high to very high cassiterite mineralization potential.

Keywords: Cassiterite, Potential, Map, Evidence maps, Mineralization.

1. Introduction

Exploitation of mineral resources has assumed prime importance in several developing countries including Nigeria. Nigeria is endowed with abundant mineral resources, which have contributed immensely to the national wealth with associated socio-economic benefits. Tin mining has a very long history in Jos, Plateau state, it started in 1904 and by the mid-1920s more cassiterite (tin ore) discoveries had been made which resulted in more mechanised extraction techniques to meet the high demand for tin by 1960s. The demand increased, got to a peak and gradually declined in the late 1980s. Recently, the world demand for tin is quite steady, and is growing at about 5% a year (Cowie, 2010). Circuit-boards for televisions, computers, microwave ovens etc. contain tin because it has a low melting point which makes it ideal for this purpose. Also electronic goods, for health reasons started using solder with 97.5% tin instead of solder with 40% lead and 60% tin. This single policy change increased global tin demand by over 20% (Cowie, 2010). The rest of the tin is used for 'tin-plating' which is coating steel cans to make tin cans, for production of bronze, and various chemical processes. It is also used in lithium ion batteries. If the experiments for electric car use in countries like China are successful, this could further increase the demand for tin. Thus, the present and possible future demand for tin is high.

The Younger Granite rocks of the Jos Plateau and surrounding areas are richly mineralized with cassiterite. Cassiterite is associated with other minerals such as Columbite, monazite and accessories like zircon and topaz. Consequently, a lot of mining activities (formal and informal mining) have been carried out over the years in the area. Many of these mining activities still carried out at present is done by trial and error means e.g. (*lotto mining*). Therefore the miners may not have fully mined the cassiterite in the areas they have worked and as such some cassiterite is left untapped. These mining activities have resulted in environmental degradation and health hazards from improper waste disposal. Also revenue due to the Federal Government of Nigeria through taxation is reduced since these informal miners evade being taxed and the income earned by these miners is not included in Nigerian national income records.

The overall aim of this study is to contribute towards systematic mineral exploration in Nigeria, by using Geophysics and Geographic Information Systems (GIS) in the assessment of mineral resources. The specific objectives of this study are to prepare evidence maps of potential cassiterite mineralization from geological, topographical, aeromagnetic and aeroradiometric data and to identify cassiterite potential zones through integration of the above maps using in a GIS environment.

The study area is situated in North Central Nigeria, covering an area of about 2970.25km^2 and it is bounded by latitudes $9^\circ 30'$ and $10^\circ 00'$ and longitude $8^\circ 30'$ and $9^\circ 00'$. This area covers Jos area and surrounding towns such as Bukuru, Hoss, Vom, Barakin Ladi and others. The area is accessible by a network of roads with several major, secondary and minor roads. A railway line also passes through the area. This area is located on Naraguta sheet 168 published by the Federal Survey Department on scale 1:100 000 (Figure 1).

2. THEORY

2.1 Least Squares Method

The method consists of fitting a mathematical surface that approximates the regional component of total magnetic field data. In this study the regional field was calculated as a 2-dimensional second degree polynomial surface as shown in Equation (1).

$$Z(XY) = A_{00} + A_{01}Y + A_{02}Y^2 + A_{10}X + A_{11}XY + A_{20}X^2 \qquad (1)$$

Where X and Y are unit spacing along the two axes of the blocks and the coefficients A_{00},A_{01},A_{02},A_{10},A_{11} and constants which are to be determined. The residual (R) would be

$$R = \varphi - Z \qquad (2)$$

With φ being the observed the total field aeromagnetic data and Z the regional surface or trend. The least-squares method is known to produce both positive and negative residuals even when the true residuals are only positive (or only negative). Surfaces of various orders (a first order surface is a plane, a second order surface is a paraboloid and so on) can be computed so we can select one or more to represent the regional surface or trend.

2.2 Analytical Signal Method

The Analytical Signal method is very useful for delineating magnetic source location (Roest et al, 1992); the amplitude of the simple analytic signal peaks over magnetic contacts. Therefore it can also be used to find horizontal locations and depths of magnetic contacts. This method is very useful at low magnetic latitudes as it is independent of the inclination of the magnetic field. However, if more than one source is present, then the shallow sources are well resolved but the deeper sources may not be well resolved. The analytic signal is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly. The analytic signal function in 2-D is given by

$$a(x,z) = \frac{\partial\varphi}{\partial x} + j\frac{\partial\varphi}{\partial z} \qquad (3)$$

For the 3D case, the analytic signal is given by

$$a(x,y,z) = \frac{\partial\varphi}{\partial x} + \frac{\partial\varphi}{\partial y} + j\frac{\partial\varphi}{\partial z} \qquad (4)$$

2.3 Knowledge Driven GIS

In a very general sense, a GIS model can be thought of as a process of combining a set of input maps with a function to produce an output map.

$$\text{Output} = f\,(2 \text{ or more input maps}) \qquad (5)$$

The function *f* can take many different forms, but the relationship expressed by the function are either based on a theoretical understanding of physical or chemical principles, or they are empirical, based on observations of data, or some blend of theory or empiricism (Bonham-Carter, 2002). Various models were used for real world events simulation in GIS environment (Aronof, 1989). Integration model is one of them that is used for site selection by integrating related spatial data and effective criteria. There are two classes of integration models, the Knowledge driven model and the Data driven models.

In the knowledge driven approach experts experience and scientists' science are used for executing models while in data driven approach models, models are executed based on existent solutions and dependency value computation. There are several models but the one chosen for this study is Index overlay model. In the index overlay method, each input map (layer of evidence) to be used as evidence is assigned a different score (weight), as well as the maps are receiving different weight (Bonham-Carter, 2002) depending on the exploration model. An area that is geologically well explored with a relatively well-understood exploration model in hand (like the present study area), assignment of weight on different themes or maps ought to be through knowledge driven approach. This not only helps in developing a clear understanding of relationship between datasets (both geological or geophysical) but this also gives flexibility to an explorer to manipulate weight on different elements or evidence maps through geological knowledge about the terrain in different stages of analysis. This is advantageous for developing perhaps a variety of scenarios for different weight schemes, reflecting differences in opinion amongst experts, and allows the evaluation of sensitivity of the mineral potential maps to such differences.

It is convenient to define the scores in an attribute table for each input, evidence or factor map (some GIS provide specialized templates for inserting values in a special attribute table for all the maps being combined). After defining the score by knowledge driven approach for elements or maps, the average score (index weight) is then defined by

$$\bar{S} = \frac{\sum_i^n s_{ij} w_i}{\sum_i^n w_i} \qquad (6)$$

where $\bar{S}$ is the weighted score for an area object, W_i is the weight for the i-th input map, and S_{ij} is the score for the j-th class of the i-th map, the value of j depending on the class actually occurring at the current location (Bonham-Carter, 2002).

3. Methodology

Aeromagnetic, radiometric, geological, topographic maps were brought together into a GIS data base. This involved establishing the spatial extent of the study area and assembling the various spatial data used in the study in digital form. At this stage ILWIS 3.3 Academic was used.

The digitized maps were processed to extract spatial features like rock type (from the geologic map), magnetic susceptibility contrast (from the aeromagnetic map), intensity of radiation (from the aeroradiometric map) and elevation (from the topography map) relevant to the prediction of cassiterite deposits. This involved reclassification, selecting contacts, creating buffers, carrying regional residual separation (using SURFER 8) and analytical signal (using ASIG.FOR).

Features relevant for cassiterite mineralization were extracted from the available maps, the contours were rasterized, interpolated and contour values sliced, weighted using knowledge driven weighting and ranked based on the weights. In this study, weight assigned to each criteria were subjective and related to the importance each criteria was given. The criteria were weighted from 1 (least suitable) to 5 (most suitable). The criteria considered are magnetic susceptibility contrast, total radiometric count, elevation and rock type. The 4 evidence maps too were weighted from 1 to 4. The evidence maps are the analytical signal, aeroradiometric digital elevation model and geology evidence maps. This was achieved using ILWIS 3.3 Academic.

After completing the calculation of the weights of features indicative of the presence cassiterite for each evidence or factor map (i.e. the calculation of S_{ij}) and the weights of the individual maps (i.e. W_i), equation (6) was applied in map calculation operation in ILWIS 3.3 Academic to create the a mineral potential by combining the four maps. ILWIS 3.3 Academic was used here.

The map was then sliced to rank the weights (from very low probability to very high probability). A cassiterite potential map was produced for the study area.

4. Results

4.1 Aeromagnetic Map

The regional field of the Aeromagnetic map was calculated as a 2-dimensional second degree polynomial surface as shown in Equation 7

$$Z(XY) = A_{00} + A_{01}Y + A_{02}Y^2 + A_{10}X + A_{11}XY + A_{20}X^2 \qquad (7)$$

From this relation the regional gradients along any line were calculated. Where X and Y are unit spacing along the two axes of the blocks and the coefficients A_{00},A_{01},A_{02},A_{10},A_{11} and A_{20} are 234241.85207185, -0.42429414429893, 2.0563369505726E-7, 0.012331329012901, -4.2101522933419E-8 and 3.3797576144351E-8 respectively. The resultant regional magnetic map was observed to trend in an approximate ENE-WSW direction (Figure 2). These trends results from large features caused by the deeper heterogeneity of the Earth's crust. The magnetic residual values range from -487.828nT to +405.447nT. Negative residuals dominate the study area because the study area is close to the magnetic equator. Also from the residual magnetic map magnetic lineaments trending in NE-SW direction was identified to pass through the study area (Figure 3). This lineament (A-B) in this study is probably the Romanche paleofracture zone which, if extrapolated into the Nigerian landmass will cut across the Jos – Bukuru complex. These are paleostructures which have resulted from events like tectonic movements, intrusions, metamorphism, sedimentation, mineralization, volcanism and drainage. An ENE-WSW anomaly low has been identified in the Jos-Bukuru complex. This agrees with the study carried out by Ajakaiye (1982) that revealed a prominent ENE-WSW anomaly low is centred at the Jos –Bukuru Complex with a trend which is roughly parallel to that of the main structural feature of the Benue Trough.

Anomalies on the analytical signal map (Figure 4) trend in the NE-SW direction as can be seen by the broken lines. Some discontinuities represented by lines were also observed trending mostly in the NW–SE and NE-SW direction. This could represent short to moderately long geologic faults beneath the study area. Comparing the analytic signal map to the geological and topography maps of the study area, the high magnetic susceptibility contrasts range of 0.08 - 0.135 were observed at Vom, Bukuru, N'Gell, Rayfield and Barakin Maidiko. The result of the analytic signal indicates the probability of the presence of a magnetic source rock with high magnetic susceptibility contrast in the Jos-Bukuru Complex.

4.2 Aeroradiometric Map

From the aeroradiometric map the highest count range is between 3μR to 7μR. Some of the locations within this total count range include Dorowa, Kuru, Bisichi, Foron, Zawan, Du, Shen, Rafyield, Barakin Maiadiko, Ropp etc. See details of this in Akanbi and Makama, 2011. These values could result from the Younger Granite rocks found in these areas which host some radioactive minerals like pyrochlore, thorite, zircon and monazite (accessory elements to tin), placer deposits of weathered sediments, the by-products of tin mining which are radioactive minerals and waste products of the mining activities. These areas listed in the foregoing have experienced mining activities over the years and this has devastated residential, industrial, farmland and natural landscapes. When the Plateau State Government starts land reclamation the interpretation result for the aeroradiometric map can serve as initial guide to selecting areas badly affected by formal and informal mining activities.

4.3 Geology Map

From relevant literature on the geology of the study area, cassiterite occurs only in association with biotite-granite and the richest mineralization is in those which have suffered a higher degree of late albitization (Macleod et al, 1971, Obaje, 2009). Also Older Basalts, laterized Older Basalts and Newer Basalts preserve alluvial cassiterite deposits (Macleod et al, 1971, Obaje, 2009).

4.4 Topography Map

Detailed mapping and structural studies of the Younger Granite Complexes have revealed the pattern of tin mineralization. The cassiterite has been dispersed in multitudinous, narrow greisen veins, and quartz stringers in the roof zones of the biotite-granite intrusions, and is usually entrapped within the parent rock beneath an impermeable cover of roof rocks. The sub-horizontal form of the roof sections of the ring-intrusions and plutons has apparently favoured a lateral dispersion of mineralization. Since the greater part of the primary mineralization is concentrated in the horizontal roof sections of the biotite-granites, it follows that erosion rapidly uncovers an extensive area of tin-bearing granite and thus facilitates the wide distribution of cassiterite in the surrounding drainage system. Many of the source rocks are situated on or near major watersheds, so that a wide spread of alluvial is further enhanced. So in order to produce a cassiterite potential map, the elevation of the area needs to be considered.

4.5 Evidence Maps

After the extraction of features relevant for cassiterite mineralization from the available maps, the contours were rasterized, interpolated and contour values sliced, weighed and ranked to produce the evidence maps used in the index overlay. The attribute tables showing criteria and ranking are shown in Tables 1-4 and corresponding evidence maps are shown in Figures 5-8.

4.6 Cassiterite Potential Map

Map integration of the evidence maps of Figures 5-8 using criteria in Tables 1-4 with index overlay method produced a suitability map which was reclassified and ranked to produce the cassiterite potential map in Figure 9. The cassiterite potential map revealed that that most locations in the Jos- Bukuru Complex have very high or high cassiterite potential based on the criteria used. This information may be used by government to delineate favourable areas for future drilling of cassiterite and accessory minerals thereby contributing directly towards major industry efforts in the area and enhancing efficient mining of tin mineralization in the Naraguta area.

5. Conclusion

The integration of various data sets for the purpose of mineral exploration has become imperative for fast decision making. In this study Geophysics and GIS was used in assessing cassiterite potential zones in Naraguta area, Plateau state, Nigeria in other to contribute towards systematic mineral exploration. The aeroradiometric map revealed that areas of high total count values could result from the Younger Granite rocks found in these areas which host some radioactive minerals like pyrochlore, thorite, zircon and monazite (accessory elements to cassiterite), placer deposits of weathered sediments, the by-products of tin mining which are radioactive minerals and waste products of the mining activities. The result of the analytic signal indicates the probability of the presence of a magnetic source rock with high magnetic susceptibility contrast in the Jos-Bukuru Complex. From the cassiterite potential map, it was seen that areas with very high and high cassiterite potential correspond to areas in the Jos-Bukuru Complex where tin mining has thrived over the years. This information may be used by government to delineate favourable areas for future drilling of cassiterite and accessory minerals thereby contributing directly towards major industry efforts in the area and enhancing efficient mining of tin mineralization in the Naraguta area. With this information too, the state government can intensify her effort to organize artisanal mining so as to stop indiscriminate mining so as not to lose more State revenue. Also the mining activities experienced over the years have devastated residential, industrial, farmland and natural landscapes, when the Plateau state government start mine land reclamation this cassiterite potential map can serve as initial guide to selecting areas badly affected by formal and informal mining activities.

Suggested further work include ground truthing using ground geophysical methods to map areas with high a cassiterite potential from the study and possible drilling if result is successful.

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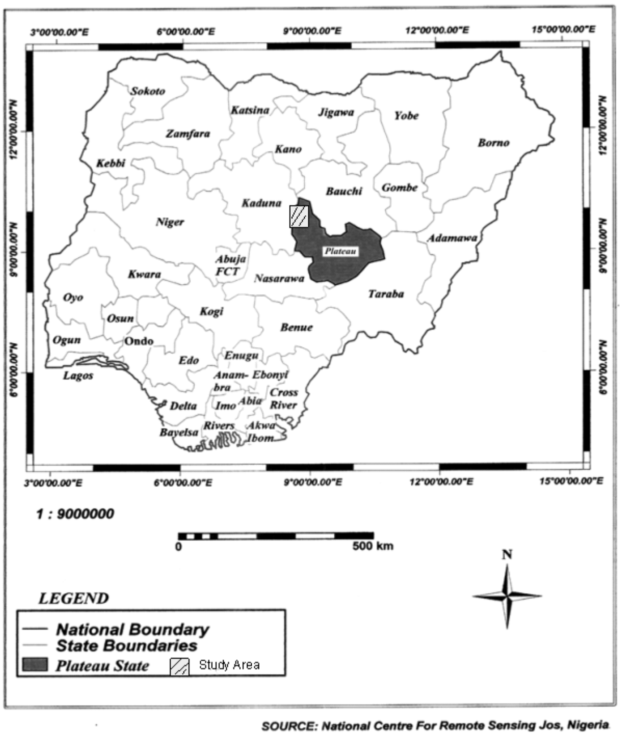

Figure 1. Map of Nigeria showing Plateau state and study area (Naraguta Area).

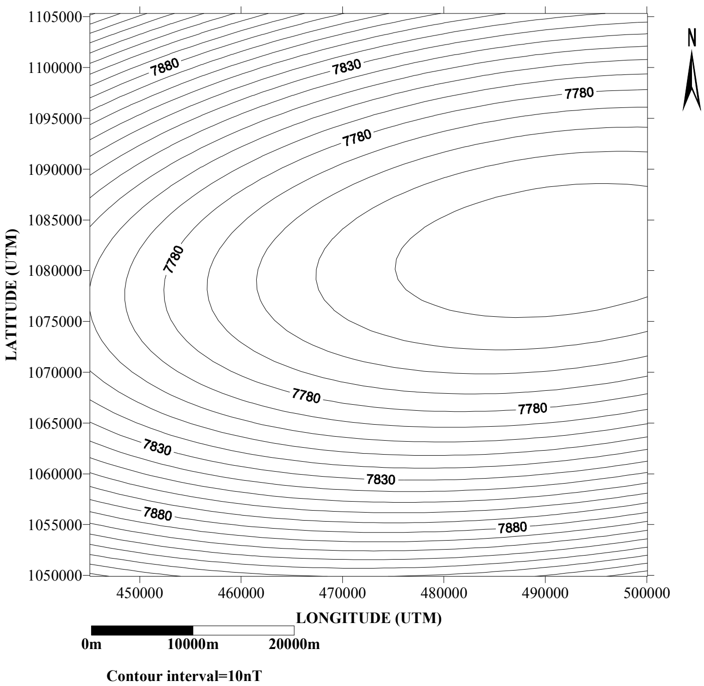

Figure 2. Regional Magnetic Map of Naraguta Sheet 168

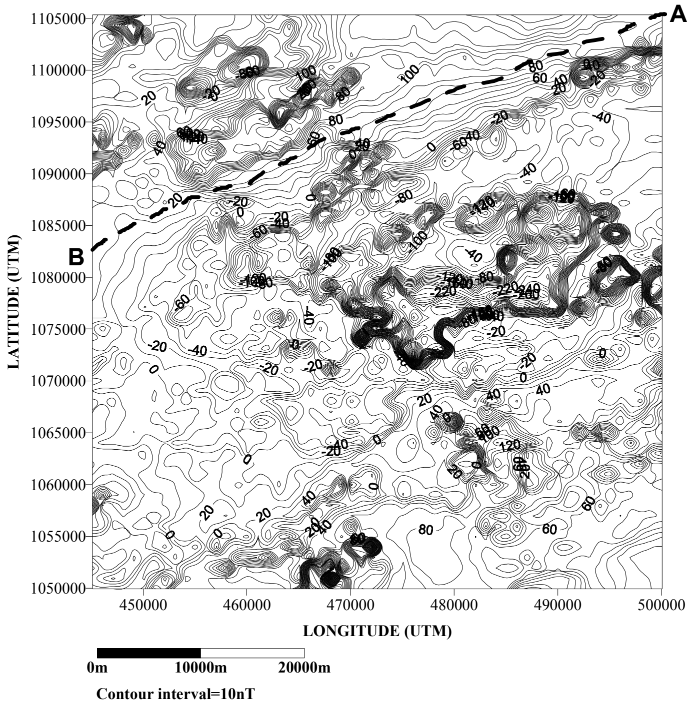

Figure 3. Residual Magnetic Map of Naraguta Sheet 168. (A-B represents Magnetic Lineaments).

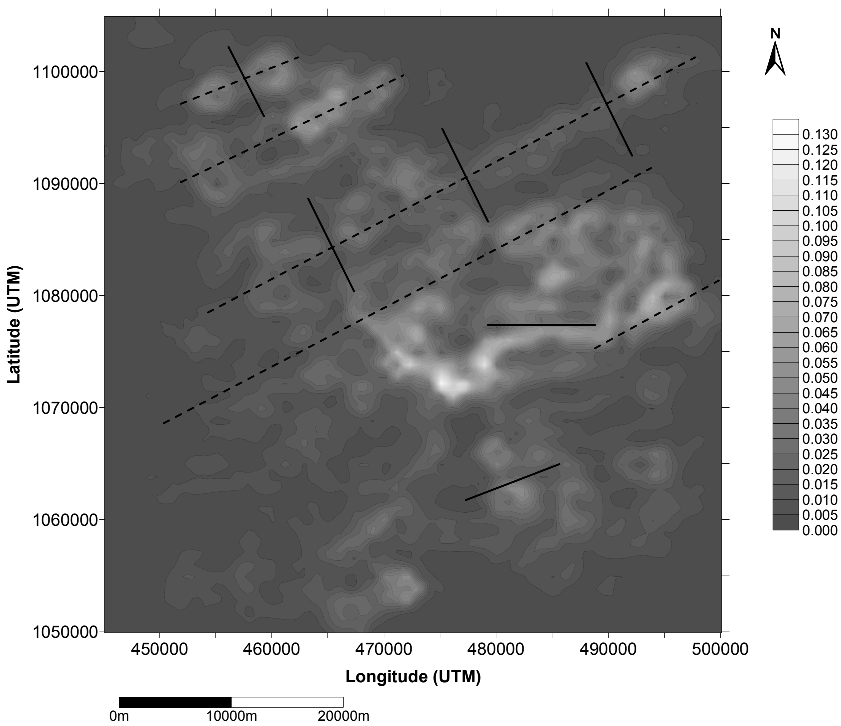

Figure 4. Analytic Signal Map of Residual Magnetic Map of Naraguta Sheet 168. Colour Scale Represents Magnetic Susceptibility Contrast. Axes in UTM.

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Table 1: The Attribute Table for Magnetic Susceptibility Contrast

Upper Boundary(Magnetic susceptibility contrast)	Group name(Ranking)	Weight
0.027	Very Low	1
0.054	Low	2
0.081	Moderate	3
0.108	High	4
0.135	Very High	5

Table 2: The Attribute Table for Total Radiometric Count

Upper Boundary(Total count in µR /h)	Group name(Ranking)	Weight
1.4	Very low	1
2.8	Low	2
4.2	Moderate	3
5.6	High	4
7.0	Very High	5

Table 3. The Attribute Table for DEM Evidence Map

Upper Boundary (m)	Group name	Weight
500	very low	1
3200	Low	2
3900	Moderate	3
4600	High	4
5300	Very High	5

Table 4: The Attribute Table for Geology Evidence Map

Rock Type	**Weight**
Aegeirine Microgranite	1
Arfvedsonite Granite	1
Biotite Granite (Grp II)	5
Biotite Granite (Grp III)	5
Biotite Microgranite (unclassified)	5
Bukuru Biotite Granite	5
Butra Riebeckite Biotite Granite	4
Daw Biotite Granite	5
Durowa Albite Riebeckite Granite	1
Fayalite Biotite Microgranite	4
Fine & Medium Grained Biotite & Biotite Muscovite Granite	5
fine grained Biotite Granite	5
Gana Biotite Microgranite	5
Granite Gneiss	1
Hornblende Biotite Granites	4
Hornblende Fayalite Granite	1
Jos Biotite Granite	5
Kassa Biotite Granite	5
Kwop Biotite Granite	5
Late Rhyolite	1

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Rock Type	Weight
Laterite	1
Miango Biotite Granite	5
Naraguta Quartz Proxene Fayalite Porphyry	1
Neil's Valley Garnite Porphyry	1
Newer Basalt	5
Ngell Biotite Granite	5
Older Basalt	4
Pegmatite & Biotite Muscovite	4
Porphyritic Biotite & Biotite Hornblende Granite	5
Porpyritic Biotite Microgranite	5
Rafin Jaki Granite Porphyry	1
Rayfield Gona Biotite Granite	5
Rhyolite & Explosion Breccia	1
Riebeckite Aegerine Granite	2
Rukuba Biotite Granite	5
S/Gida North biotite Granite	5
Shen Hornblende Fayalite Porphyry	1
Sho Granite Porphyry	1
Undifferentiated Migmatite	1
Vom Hornblende Biotite Granite	5
Yelwa Pyroxene Granite	1

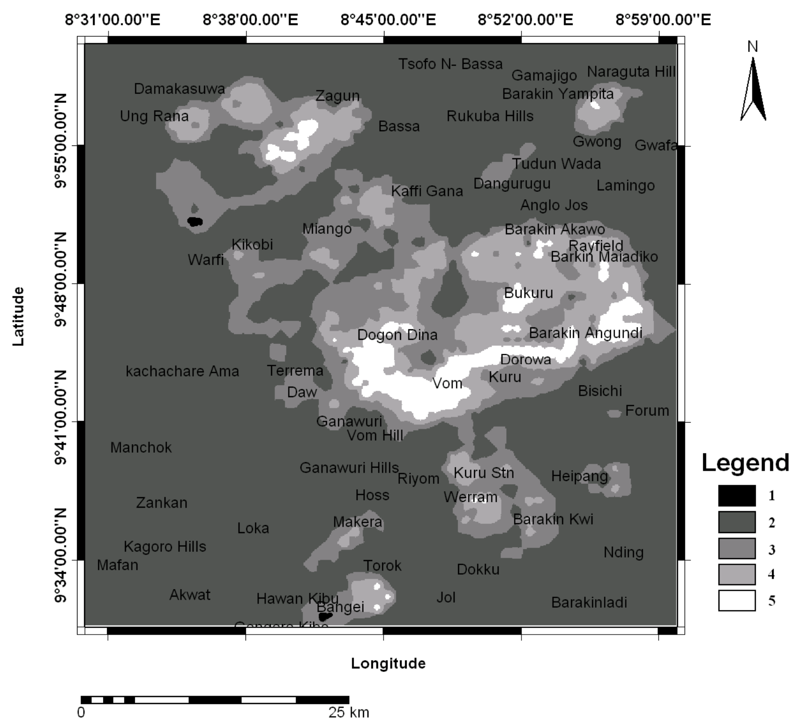

Figure 5. Analytic Signal Evidence Map for Naraguta Sheet 168. (Legend Corresponding to Weighting in Table 1).

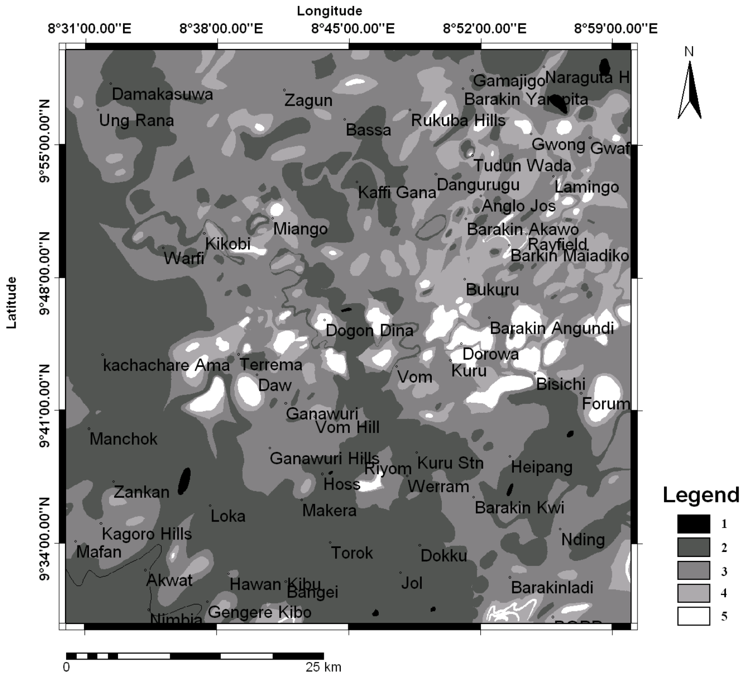

Figure 6. Aeroradiometric Evidence Map for Naraguta Sheet 168. (Legend Corresponding to Weighting in Table 2).

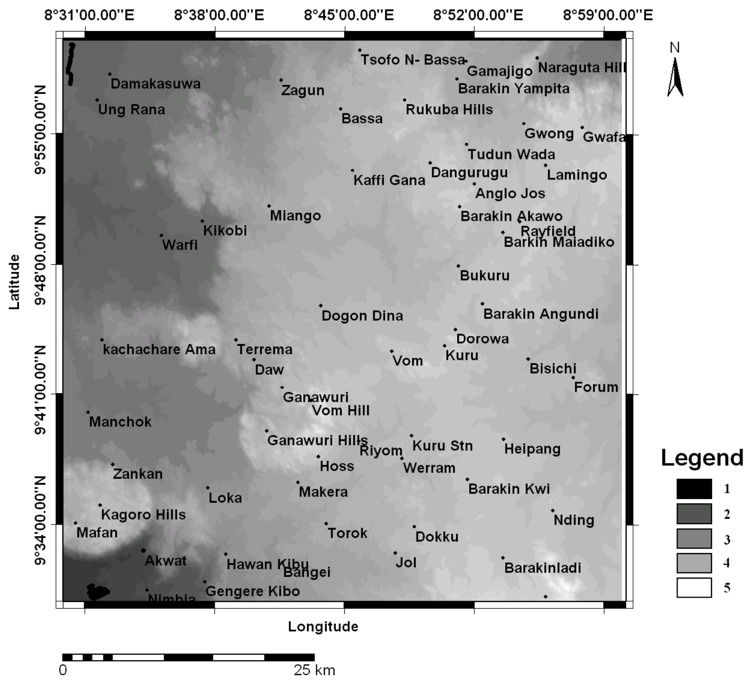

Figure 7. Digital Elevation Model for Naraguta Sheet 168. (Legend Corresponding to Weighting in Table 3).

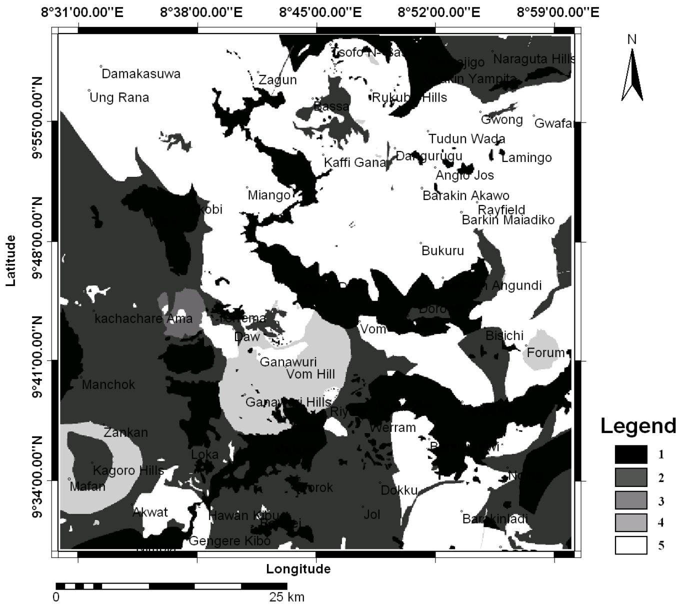

Figure 8. Geological Evidence Map showing the Weights of Rock types relevant to Cassiterite Mineralization for Naraguta Sheet 168. (Legend Corresponding to Weighting in Table 4).

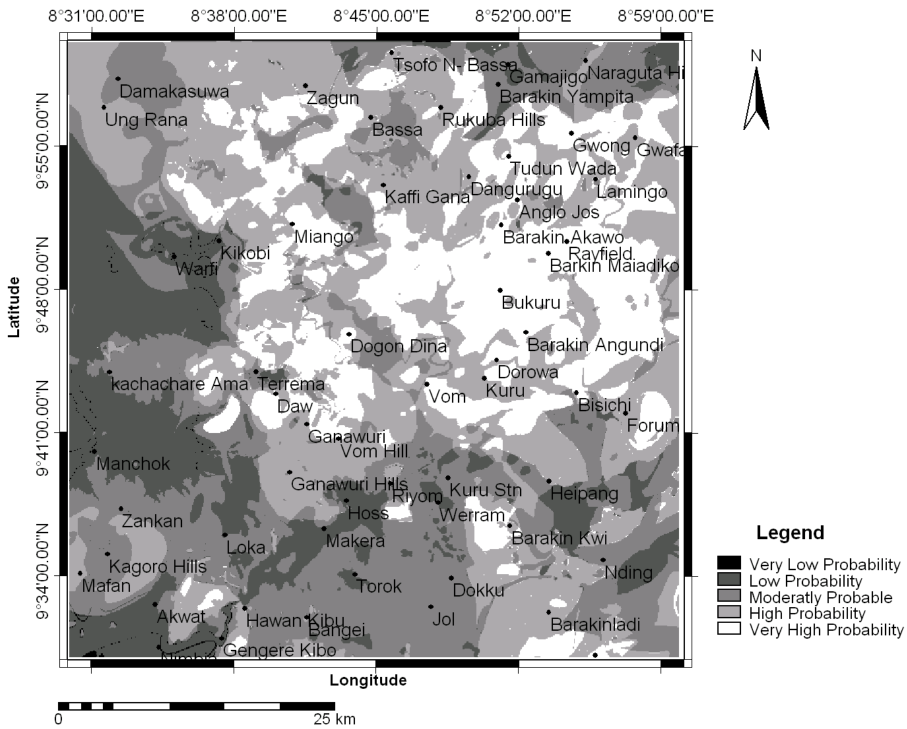

Figure 9. Cassiterite Potential Map of Naraguta Area, using index overlay method