DELINEATING THE LINEAMENTS WITHIN THE MAJOR STRUCTURES AROUND EASTERN PART OF LOWER BENUE TROUGH FROM 2009 AEROMAGNETIC DATA

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Abstract: Magnetic susceptibility in the area ranged from -689 nT to 613 nT, positive magnetic anomalies were observed at the Northern end of the area above Kwalla and Wamba in Plateau and Nassarawa States, respectively However susceptibility ware generally low below Wamba down to Akira and Katsina-Ala in Benue State. The IGRF filtered residual data for the study area was reduced to the pole (RTP) before being subjected to Vertical Derivative, Source Parameter Imaging and CET grid analysis. All these were aimed at estimating depth to magnetic rocks and delineate the lineaments within the area. The first vertical derivative that sharpens the edges of the anomalies reveals that the Northern part of the study area consist of basement rock outcrops with various degrees of deformations as seen from the distortion to the magnetic signatures which represents the Granite Gneiss at Kwalla and the Migmatite Gneiss at Wamba. Similar features were obtained around Akwana, Gboko and Katsina-Ala which depicts weathered porphyritic homblede Granite. Depth to magnetic rocks estimates within the study area is generally shallow though some noticeable depths in the range 3 – 3.5 kilometers were obtained around Akira just above river Benue and below Akwana on latitude 7º30´N. The phase symmetry from CET grid analysis, mapped the geologic boundaries which equally coincided with ridges within the area as thick pink bands enclosing major magnetic highs, these features are predominant within the outcrop basement rocks. Valleys were observed within regions of long wavelength anomalies which could be found from the 1VD map around Makurdi, Lafia and Akira. Lineament map obtained from CET shows linear structures that trend in the NW-SE and E-W directions these could be interpreted as veins that are host for minerals within the area, they are predominant around Kwalla in Plateau State and Wamba in Nassarawa State and also in Katsina-Ala and Gboko in Benue State.

Keywords: CET, imaging SPI, IGRF, vertical derivatives

Introduction

The continuous search for mineral and petroleum (hydrocarbon) deposit has been a major challenge that will continue to be faced not only in Nigeria but also all over the world. Nigeria is a country that is blessed with lots of mineral resources, but yet to explore most of these resources. The reason for this negligence is vested on the fact that Nigeria is being faced with some economical challenges, political challenges, and over reliance on some specific mineral deposit leading to the negligence in some others, which may yield large economic potentials to the country at large.

Considering the fact that the hydrocarbon (petroleum) which presently has been a great source of revenue generator in the country will not always be there forever, holding to the fact that it is a source of energy that is non-renewable in nature, and might one day in the nearest future get exhausted, as a result of continuous exploitation. To that effect, attention needs to be shifted to other basins (sedimentary basins) which have some of the geological potentials of having some useful minerals, be it solid minerals or hydrocarbons.

Recently, some countries have been discovering petroleum from their inland basins, which are similar to that of Nigeria's inland basin in terms of time. Subsequently the Nigerian government through the Nigeria National Petroleum Co-operation (NNPC) and other oil companies deem it necessary to run heavy investments in the inland basins, which have being prospected for hydrocarbon and other minerals. This till today remains exclusive (Salako and Udensi, 2013).

Such a Basin is the Benue Trough, which comprises of, Upper, Middle and Lower Troughs and has the prospect of not just hydrocarbon deposit but also some minerals. Never the less effort and money is still been pumped into the research carried out, based on reconnaissance for minerals and hydrocarbon being prospected in the area (Salako, 2014).

The study area is located between latitudes 7º00´N and 9º00´N and longitude 8.5 ºE and 9.5º E in north central Nigeria (Fig. 1). The area is part of the Middle Benue Trough that is noted for hosting economic minerals, it covers an approximate area of 24,200 km^2, and covers farmlands, villages, towns, game reserves, and natural reserves. The area lies east of the Federal Capital, Abuja. Topographically, the study area is hilly at the northern fringes and drained mainly by river Benue and its tributaries in the southern part, it is characterized by moderate relief with high granitic hills generally extending several kilometers, having the NE – SW direction and forms several peaks of relatively higher elevation than the surrounding rocks. Despite the hilly nature of some part of the study area, there are still good road networks, foot-paths and tracks in the area. Major roads found in this area provide access road to the southeastern part of Nigeria and some other communities in the study area such as Akwanga, Nasarawa-Eggon, Lafia, Keana, Awe, Doma, Shendam, Pankshin to mention few. There are other minor roads that provide access to smaller settlements, farms, rivers and streams. The area is marked by two distinct climatic conditions; temperatures in this area range from 20 - 27°C, while at night, temperatures could be as low as 10°C. Months of March to June experienced increasing temperatures as the rainy season set in; sometimes, daily temperature could be above 35°C. The rainy season lasts usually from May/June to September/October depending on the rainfall pattern for the particular year, with mean annual rainfall of 1560 mm. The dry season is usually heralded annually by the dry, cold harmattan winds and occurs between November and March. After the departure of the harmattan and in the absence of rain, the hot sunny season with temperatures exceeding 27^{o}C sets in (Balogun, 2003). The mean annual temperature of the area is 20^{o}C.

This study is an attempt to determine structures and lineament pattern by enhancing the magnetic signatures of shallow and deeper geologic features simultaneously to reveal magnetic anomalies that could show edge boundaries and contacts that are linear and continuous in the study area to aid mineral exploration, it is believed that, this will contribute to a better understanding of the geology and tectonic history of the area.

Geology of the study area

The study area lies within the Basement complex of North-Central Nigeria and the Cretaceous sediment of the Middle Benue Trough (MBT). The Basement complex of North-Central Nigeria, is part of the Pan-African mobile belt extending from Algeria across the south Sahara to Nigeria, Benin and Cameroon Republics (Fig. 1). Evidence from the eastern and northern margins of the West African Craton indicates that the Pan-African belt evolved by plate tectonic processes which involved the collision between the passive continental margin of the West African Craton and the active continental margin (Pharusian Belt) of the Tuareg shield about 600 Ma. It is believed to be accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses.

The basement complex rocks units in the area include granulitic gneisses, migmatite and older granite. The Jurassic (145-210Ma) Younger granites in the study area are high level, anorogenic granites; they mainly consist of microgranites and biotite granites, porphyries and rhyolites which outcrop at the northern fringes. The geology of the Middle Benue Trough has been described in some details by Offodile (1976). The oldest rocks belong to the Asu River Group: a mixture of lava-flows, dykes and sills representing the first middle Albian episode into the Benue Trough. The Awe Formation marks the beginning of the regressive phase of the Albian Sea, it consists of transitional beds of flaggy, whitish, medium to coarse-grained sandstones interbedded with carbonaceous shales or clays from which brine springs issue continuously (Offodile, 1977). The Keana Formation resulted from the Cenomanian regression, which deposited fluvio-deltaic sediments in the Lafia-Awe area. This formation consists mainly of crossbedded, coarse-grained feldspathic sandstones.

The sandstone is generally poorly sorted and occasionally contains conglomerates and bands of shales and limestones towards the top. Eze aku, Agwu and Lafia Formations are also present and these represent the Turonian to Early Maastrichtian sediments in the MBT. The Ezeaku Formation comprises essentially of calcereous shale, micaceous fine to medium-grained friable sandstones, with occasional beds of limestone. The Conician Agwu Formation consists mainly of black shale, sandstones and local coal seams. The Maastrichtian Lafia Formation is the youngest formation reported in the Middle Benue Trough and consists of coarse-grain ferruginous sandstones, red loose sand, flaggy mudstones and clays (Offodile, 1976). Tertiary- Recent volcanic rocks which consist of the Basalts, Trachyte, Rhyolite, and newer basalts of volcanic line also occur in the area.

Materials and Methods

The high resolution aeromagnetic data (HRAM) used for this present work was obtained from the Nigerian Geological survey agency Abuja, which had acquire digital data for the entire country between 2005 and 2009. The airborne survey was carried out for the Nigerian Geological Survey Agency by Fugro airways services. The surveys was flown at 500 m line spacing and at an average flight elevation of 80 m along NW – SE direction, and published in form of grid (digital form) on 30` by 30` sheets. The IGRF has been removed from the data.

Eight sheets numbering 210, 211, 231, 232, 251, 252, 2271 and 272 were assembled for this work with each square block representing a map in the scale of 1:100,000. Each square block is about 55 x 55 km^2 covering an area of 3,025 km^2, the digital data was acquired as merged unified block and were extracted from the map using Geosoft Viewer software. The study area is located within the Eastern part of Lower Benue Trough, it include the basement complexes bounding it at the Eastern and Northern edges, Fig. 1. The area is bounded by Latitude 9.0^0 N to 9.5^0 N and Longitude 7.0^0 E to 8.5^0 E

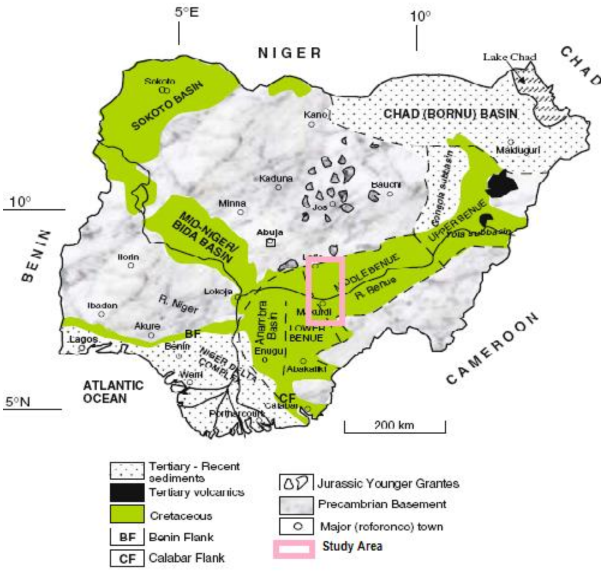

Fig. 1: Geology map of Nigeria showing the study area

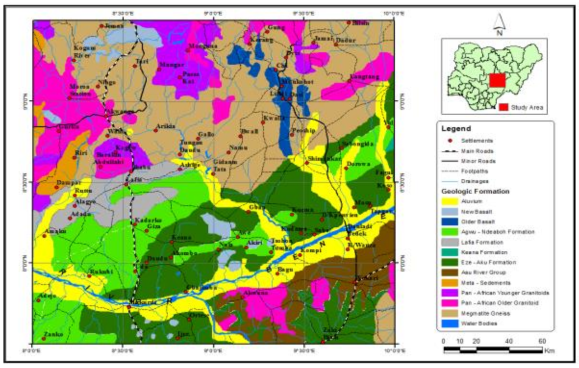

Fig. 2: Geological map of the study area (Adapted from NGSA, 2006)

Methodology

In this research four main analytical processes ware used to obtain the final lineament map.

1. Reduction of the TMI to Pole
2. Computation of the Horizontal Derivative of the Field
3. Computation of the Source Parameter Imaging and
4. Computation of the CET for the Field

Theory of method

Magnetic pole reduction

Reduction to the pole is use in low magnetic latitudes to change an anomaly to its equivalent as would be observed at the north magnetic pole. This transformation simplifies the interpretation and visualization of anomalies from low magnetic latitudes.

The reduction to the pole is:

$$L(\theta) = \frac{1}{(sinI_a + icosI.\cos(D-\theta))^2}$$

Where: I = geomagnetic inclination Ia = Inclination for amplitude correction (never less than I) D = geomagnetic declination

Horizontal gradient (HG)

Horizontal gradient is a simple approach to locate linear structures such as contacts and faults from potential field data. For magnetic field *M(x,y)*, the horizontal gradient magnitude *HG(x,y)* is given by (Cordell and Gdelrauch, 1982, 1985)

$$HG(x,y) = \sqrt{(\frac{\partial M}{\partial x})^2 (\frac{\partial M}{\partial y})^2} \qquad (1)$$

This function peak over magnetic contacts under certain assumptions: (1) the magnetic field and source magnetization are vertical, (2) the contact is vertical and (3) the sources are thick (Phillips, 1997). Violation of the first two assumption leads to shift of the peaks away from the contact location. Violation of the third assumption leads to secondary peaks parallel to the contacts. In order to partially satisfy the first two assumptions, the method was applied to the regional component of the reduced to the pole magnetic data. When these assumptions are satisfied, the method is effective in detecting lineaments that may correspond to basement faults and contacts. Moreover, the method is less susceptible to noise in the data, because it only requires calculation of the two first-order horizontal derivatives of the magnetic field.

Source parameter imaging

The basics are that for vertical contacts, the peaks of the local wave number define the inverse of depth. In other words;

$$Depth = \frac{1}{K_{max}} = \frac{1}{\left(\sqrt{(\frac{\partial Tilt}{\partial x})^2 + (\frac{\partial Tilt}{\partial y})^2}\right)_{max}} \qquad (2)$$

$$Tilt = arctan\left(\frac{\frac{\partial T}{\partial z}}{\sqrt{(\frac{\partial T}{\partial x})^2 + (\frac{\partial T}{\partial y})^2}}\right) \qquad (3)$$

The Source Parameter Imaging (SPI) method calculates source parameters from gridded magnetic data. The method assumes either a 2-D sloping contact or a 2-D dipping thin-sheet model and is based on the complex analytic signal. Solution grids show the edge locations, depths, dips, and susceptibility contrasts. The estimate of the depth is independent of the magnetic inclination, declination, dip, strike and any remanent magnetization. Image processing of the source-parameter grids enhances detail and provides maps that facilitate interpretation by non-specialist (Kovesi, 1997).

Estimation of source parameters can be performed on gridded magnetic data. This has two advantages. First, this eliminates errors caused by survey lines that are not oriented perpendicular to strike. Second, there is no dependence on a user-selected window or operator size, which other techniques like Reid *et al.* (1990) and Euler methods require. In addition, grids of the output quantities can be generated, and subsequently image processed to enhance detail and provide structural information that otherwise may not be evident.

The centre for exploration targeting (CET) grid analysis plug-in for structures

The aim of this structural analysis is to:

1. Locate the contact between the basement at the north and western part and the sedimentary region of the study area
2. Locate the extent and position of the outcrops and intrusive bodies (into basement and sedimentary formations) within the study area
3. Detect fracture or any fault that may exist within the area
4. Interpret entire the lineaments detected.

Starting with the **Standard deviation** that provides an estimate of the local variations in the data at each location in the grid, it calculates the standard deviation of the data values within the local neighborhood. Features of significance often exhibit high variability with respect to the background signal. For a window containing *N* cells, whose mean value is μ, the standard deviation σ of the cell values x_i is given by:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \qquad (4)$$

When interpreting the output, values which approach zero indicate very little variation, whereas large values indicate high variation (Kovesi, 1991). The next stage is to apply **Phase Symmetry;** this property is useful in detecting line-like features through identifying axes of symmetry. It is also known that the symmetry of a signal is closely related to the periodicity of its spatial frequency. Consequently, it is natural to utilize a frequency-based approach to detect axes of symmetry. This plug-in implements the phase symmetry algorithm developed by Kovesi (1991).

The result from phase symmetry is passed through **Amplitude Thresholding,** in conjunction with non-maximal suppression (NMS). The NMS is useful for finding ridges since low values are suppressed whilst points of local maxima are preserved, it also takes into account the local feature orientation so that the continuity of features is maximized and can be used to remove noise and highlight linear features

Finally **Skeleton to Vectors** is applied. The Skeleton to Vectors plug-in is for vectorising the skeletonised structures from the skeletonisation plug-in via a line fitting method described below. This vectorised data can then be used as input to the structural complexity map plug-ins. For each structure in the grid, a line is formed between its start and end points. If the structure deviates from this line by more than a specified tolerance the structure is divided into two at the point of maximum deviation and the line fitting process is repeated on these two new structure segments. This process is continued recursively until no structure segment deviates from its corresponding line segment by more than the specified tolerance. These line segments form the vectorised representation of the structures within the grid (Kovesi, 1991).

Result and Discussion

The IGRF corrected TMI map (Fig. 3), the positive anomaly belts are shown around the western edge of the map which are the old granites rocks of the Eastern parts of Nigeria and the northern edge that represent the young granitic rocks of the central part of Nigeria. Magnetic intensity in the area ranges from -689 nT to 613 nT, positive magnetic anomalies were observed at the Northern end of the area above Kwalla and Wamba in Plateau and Nassarawa states respectively while magnetic intensity are generally low below Wamba down to Akira and Katsina-Ala in Benue state. Other regions showing positive or high magnetic intensity are Gboko, around Akwana from latitude $7^0.45'$ N to 8.0^0 N and around Makurdi in Benue state.

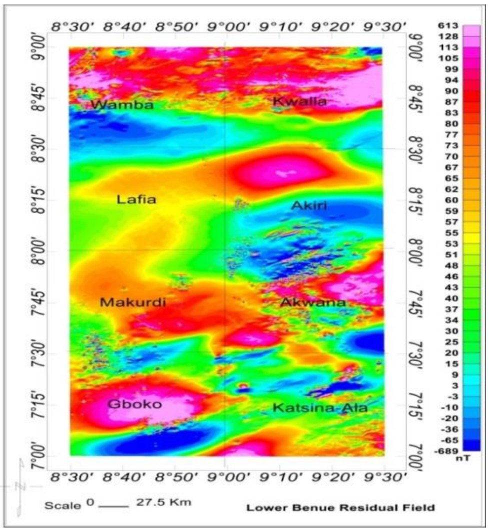

Fig. 3: IGRF filtered total magnetic intensity of the study area

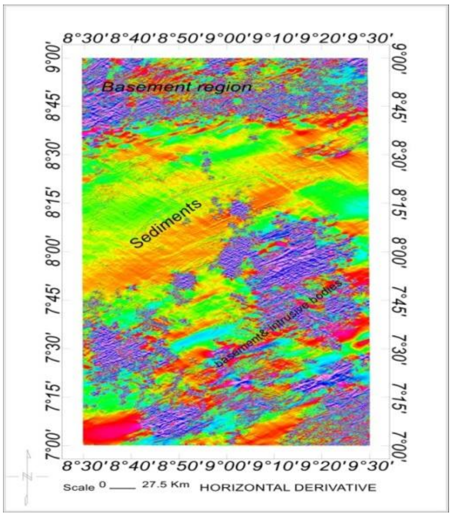

Fig. 4: Horizontal derivative of the study area

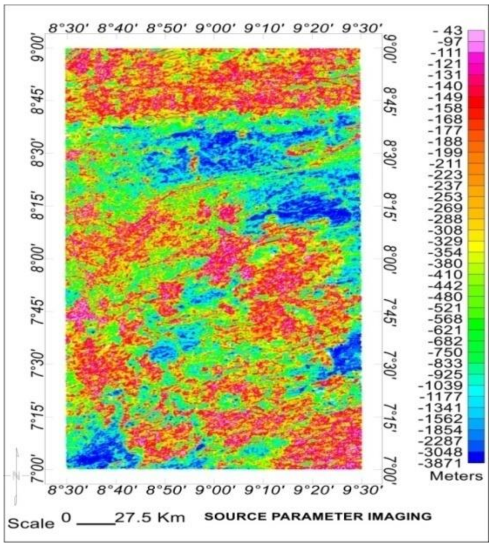

Fig. 5: Source parameter imaging of the study area

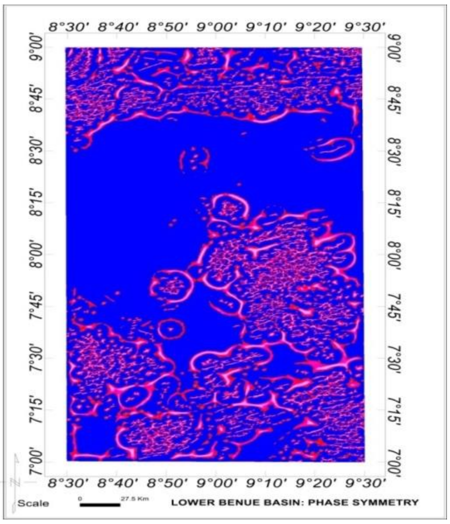

Fig. 6: Phase symmetry from CET for the study area

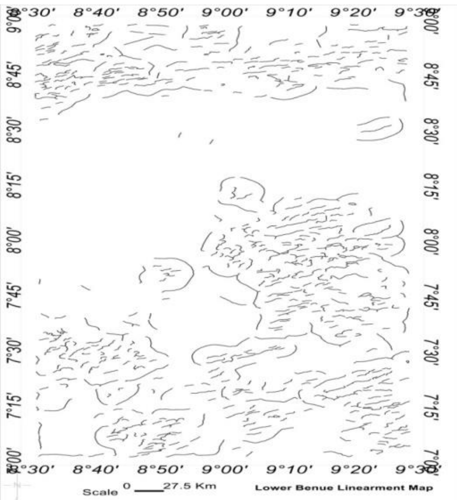

Fig.: 7: Lineament map of the study area

The horizontal derivative of the field shown in Fig. 4 enables us to locate and map the major anomalies within the study area as it is illustrated in the degree of distortion to the magnetic signatures. Rock type at the western portion of the study area is identified as undifferentiated Older granite, mainly porphyritic granite granitized gneiss with porphyroblastic granite. Rock type at the Northern portion is identified as Biotite gneiss. False bedded sandstone, coal, sandstone and shale are the lithologic units at the surface within the sedimentary basin. River Alluvium deposition identified along the river channel above and below the river Benue. Undifferentiated granite mainly porphyritic granite granitized gneiss with porphyroblastic granite covers Kwalla in Nasarawa State. Akwana, Lafia and Makurdi in Benue State are covered by false bedded sandstone (Ajali Formation).

These are observed all over the study area except on Lafia and Makurdi sheets, and between Akiri and Kwala, are characterized with average sedimentation. The second image from the CET analysis shows the linear structures referred to as lineament map, Fig. 7, most of these features are located within the basement or outcrop regions and areas where sedimentation is generally very shallow or regions where magnetic rocks intrude into the sedimentary formation. It is observed that most of these lineaments are trending in the NE-SW and E-W directions which can be traced to the origin of the Basin. This corresponds to the shear stress created when the American plate was separated from the African plate (Ajakaiye *et al.*, 1991). They are observed within the Northern and Southern ends of the study area. These lineaments depicting faults, fractures and contacts represent veins of mineralization within the study area.

Computing the Source Parameter Imaging of the field gives us a fair idea of the thickness of overburden within the study area which will help in estimating the depth of the anomaly investigated. Result of the SPI, Fig. 5 shows that the depth to magnetic source rocks in the area is generally shallow, though isolated depths to the tune of 3 km are observed just below Kwande and on Akira between latitude 8.13^0 to 8.30^0, other points of note are on attitude 7.30^0, below Kwana and just below Gboko at the South-western corner of the study area. Shallow sedimentation in the range of 40 to 180 meters dominates the Northern end of the study area around Kwalla in Plateau state and Wamba in Nassarawa state, equally shallow sedimentation is observed on Akwana and bellow Katsina-Ala.

The SPI results agreed largely with the results of Nur *et al.* (1994), who obtained 1.6 to 5 km for deeper source around middle Benue, while 60 m to 1.2 km was obtained for shallow magnetic source; Nwogbo (1997) got 2 to 2.62 km for deeper source and 70 m to 0.63 km for shallow source from spectral analysis of upper Benue trough; Nur (2000) obtained depth range of 625 m to 2.219 km for deeper source and an average of 414 m for shallow source at upper Benue trough; Nur (2001) got a depth range of 420 m to 8 km southwest of Chad basin. Other workers whom this present work had largely corroborated include: Likkasson *et al.* (2005), Nur *et al.* (2003), Nur (2001), Osazuwa *et al.* (1981), Ofoegbu (1984a) and Ofoegbu (1988).

Conclusion

The IGRF Total Magnetic Intensity data was reduced to the pole so as to reduce the effect of angles of inclination and declination and to remove the effect due to dipolar nature in magnetic data. This operation enabled us to obtain perfect symmetry and to place the magnetic signature directly above the causative body. The result is mapped as shown in Fig. 3. The result is further subjected to Horizontal Derivative which revealed two main regions, the first showing short wavelength magnetic signatures that are a mixture of both high and low magnetic susceptibility, which is the characteristic features of basement/outcrop and or regions of intrusive bodies at shallow depth. These could be found at the Northern end of the study area and just below the river Benue (at the Western end) and the extreme South-Easter corner of the study area. Secondly regions with long wavelength magnetic signatures, represent regions of relatively high sedimentation, these could be found around Makurdi, Lafia and upper part of Akira sheets. Depth estimates are generally low except isolated cases that ranges from 2.2 km to 3.8 km. Linear structures dominate the Northern and the Southern part of the area, these are structures that are host to mineral deposits.

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