

# STRUCTURE OF MADAGALI HILLS NE NIGERIA FROM AIRBORNE MAGNETIC AND SATELLITE DATA

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(Received 13 September, 2005; Revision Accepted 3 January, 2006)

## ABSTRACT

Airborne magnetic anomaly data over Madagali hills of Nigeria's NE Basement Complex, show complicated arrangement of long wavelength anomalies, with significant magnetic low. These features are interpreted in terms of deep geologic structures, and /or susceptibility variations within basement rocks. The residual magnetic anomaly, and satellite imagery analyses have revealed NE-SW, N-S, E-W and NW-SE trending structures. These revelations coupled with results of ground geological mapping show that this basement region is polygenetic, and has experienced magmatism, metamorphism and structural deformations. Implications of results to Chad Basin and Tenere Rift evolution, and the relationship with the Chad Shear Zone are presented.

**KEY WORDS:** Basement, residual anomalies, lineaments and structural deformation.

## INTRODUCTION

The study area lies within the basement terrain of NE Nigeria between longitudes 13:30 E and 13:45 E, and latitudes 10:45 N and 11:00 N (Fig.1). Interest in the present work was aroused while participating in a field excursion to Gwoza area, a town at the northern boundary of Nigeria, during the 2004 Annual Conference of Nigerian Mining and Geosciences Society in Maiduguri. The work aims at studying to some detail the structure and tectonics of Madagali hills, which are part of

the Mandara Hills that extend into Cameroon Republic. An attempt is also made to relate the findings to the evolutionary tectonics of the adjoining Chad Basin, Tenere Rift in Niger Republic, and the Chad Shear Zone in Chad Republic.

Rocks in the area had been presented on the 1994 edition of the geological Map of Nigeria and published by the Geological Survey of Nigeria (GSN), generally as granitoids. Few works by Islam et al. (1989), Baba (1990), Baba et al. (1991), over Gwoza area showed the area to have migmatite - gneisses, schist, tectonized and undeformed granites.

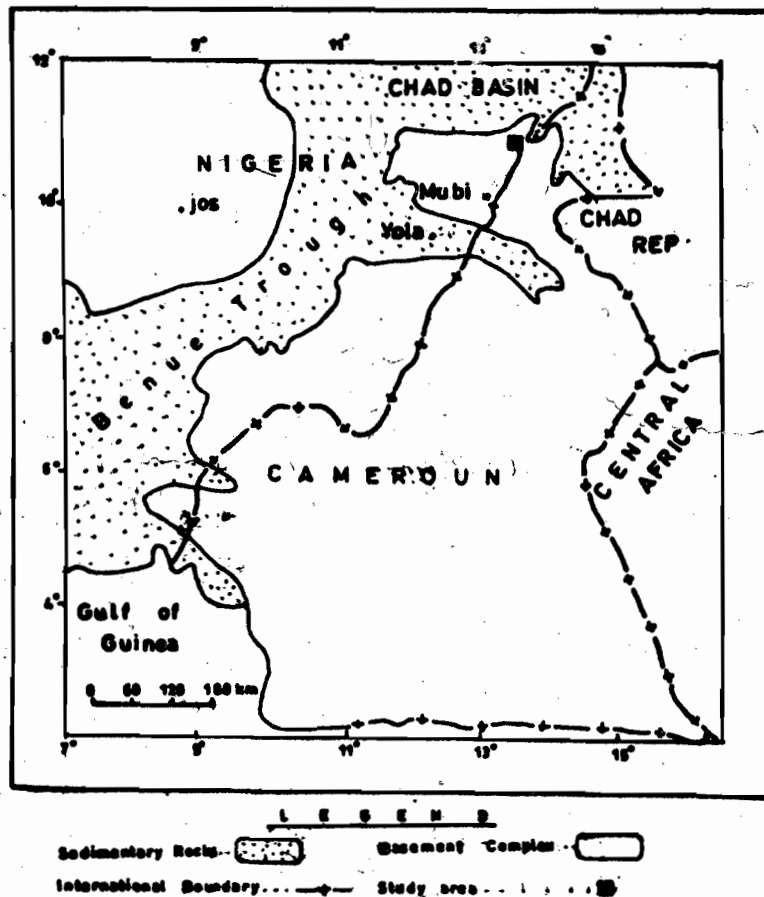


Fig.1-Location map of the study area.

Bassey (2004) was quoted by Adebayo and Daya (2004) on the geology of Mubi region which lies to the SW of the present study area (Fig.1), as having Pan African granitoids as intrusives to gneiss and migmatite rocks. Mandara hills are part of the larger Hawal Basement Complex, the northeastern segment of Nigeria's basement areas. (Fig.1). The hills terminate northwards at the Chad Basin.

**GEOLOGY**

As part of this study a geological survey of part of the area was undertaken with emphasis on structure. The following gives a brief description of the lithological units found and the structural features. The geological map is presented in Figure 2.

**LITHOLOGICAL UNITS**

**Gneiss**

The exposures of this rock are uncommon in the area probably due to weathering and erosion. A small (unmappable) outcrop

of it is found to the east of Naamtari Jambutu where river exposes it at the foot of the granite hill. Here the rock is fine grained and foliated at N140° with the foliation vertically dipping. The rock is sheared and jointed along the N-S direction. The rock is also found as xenoliths in the granite on the west bank of the river. From its field relationship with the granite it is the older rock in the area.

**Schist**

Schist seems to be the most widely occurring rock type though outcrops of it are virtually absent except to the northeast of the area where the rock outcrops. Along the river beds there is abundance of cobbles of schist probably eroded from bedrock. The rock has felsic and micaceous bands which imparts foliation along a direction N10° with vertical dip. The felsic mineral are alkali feldspars and quartz while the micas are mainly biotite and glauconitic. The rock has developed bead-like boudins along N10° direction.

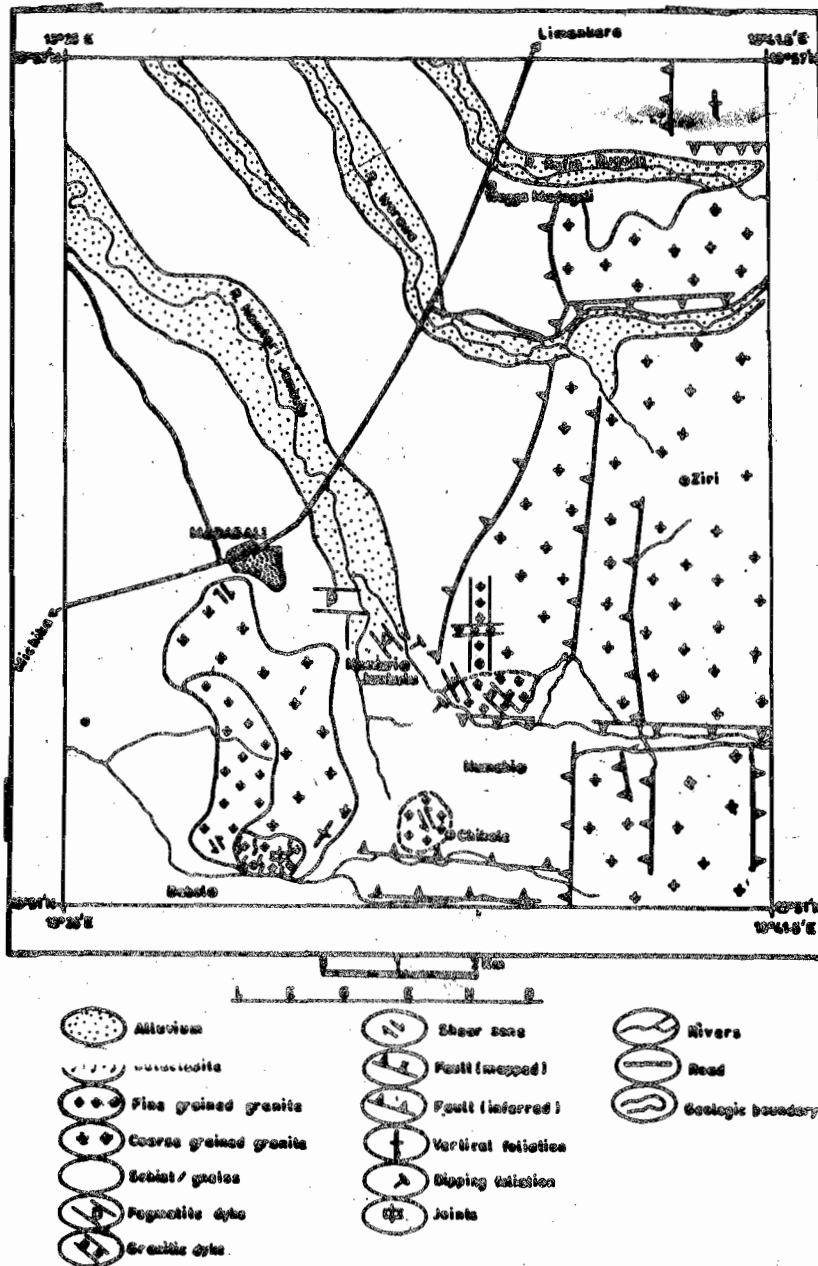


FIG. 2 : Geological map of Madagali

**Granites**

These are mainly found in the east as massive escarpment and probably next to schist in abundance. South of Madagali town an outcrop also occurs. The granites occur in two textural varieties; the coarse grained type which has a high proportion of feldspar followed by quartz, plagioclase feldspar, biotite and hornblende. The orthoclase measures up to 2 cm in grain size. The rock shows weak foliation ( $N160^\circ$ ) at Michika - Madagali road junction. Along Bebel - Madagali road the foliation is stronger and the strike changes to  $N60^\circ$  with vertical dip. At the upper course of River Naamtari Jambutu, the rock foliates at  $N140^\circ$ . The other textural variety of granite is the fine grained type. It is mineralogically similar to the former and occurs as intrusive to it. It is found north of Bebel and north of Humshi. The granites are emplaced in an N-S direction.

**Alluvium**

Alluvial deposits of sand, gravel, pebbles and cobbles derived from bedrock and the surrounding hills are found along the river courses in the area.

**STRUCTURES****Dykes and Veins**

Fine grained granitic dykes of N-S, E-W and NW - SE orientations are found on the granitic hill east of Naamtari Jambutu. One of these dykes (an N-S dyke) measures 2.0 m in width and is cross cut by an E-W dyke of 30 cm in width. The contact between both is sharp. At Chikale a  $N120^\circ$  granitic ridge is variously intruded by quartz veins and vein lets. These

veins trend between  $N85^\circ$ - $N100^\circ$ . Pegmatite dykes are commonly found at Chikale as intrusive into the granite ridge. Along the west bank of River Naamtari Jambutu a vertically dipping  $N120^\circ$  pegmatite dyke is found and its width varies between 1-3 m. The exposed length is about 62 m. A vertically dipping  $N80^\circ$  (E-W) intensely sheared pegmatite dyke whose width is about 7 m is also found SE of Madagali town, along the west bank of River Naamtari Jambutu. Close to the settlement of Naamtari Jambutu a coarse grained granitic dyke of strike  $N140^\circ$  and dip  $60^\circ$ E with an exposed length of more than 40 m and width 0.5 m is found. The dykes and veins mark the last phase of intrusive activities in the area.

**Joints**

Joints occur commonly on the granites, at Bebel the granite is tectonized developing joint system whose orientation vary from N-S ( $02^\circ$ ) to NNE ( $N13^\circ$ ). The joints seem to have been initiated by rock shearing and have developed a cataclastic texture, fragmenting along regular planes. The tectonized zone extends for about 150 m. The schist in the NE of the study area has developed joints trending between  $N110^\circ$ - $N140^\circ$ . Other joints directions on the granite are  $N18^\circ$ ,  $N50^\circ$  and  $N90^\circ$ .

**Shear deformation**

Shear deformation on the granite is common, at Chikale shear deformation on the granitic ridge which is about 90 m long is intense. The shearing has produced smooth fracture planes and slickensides on the rock indicating it is associated with faulting. The high intensity of the shear deformation is

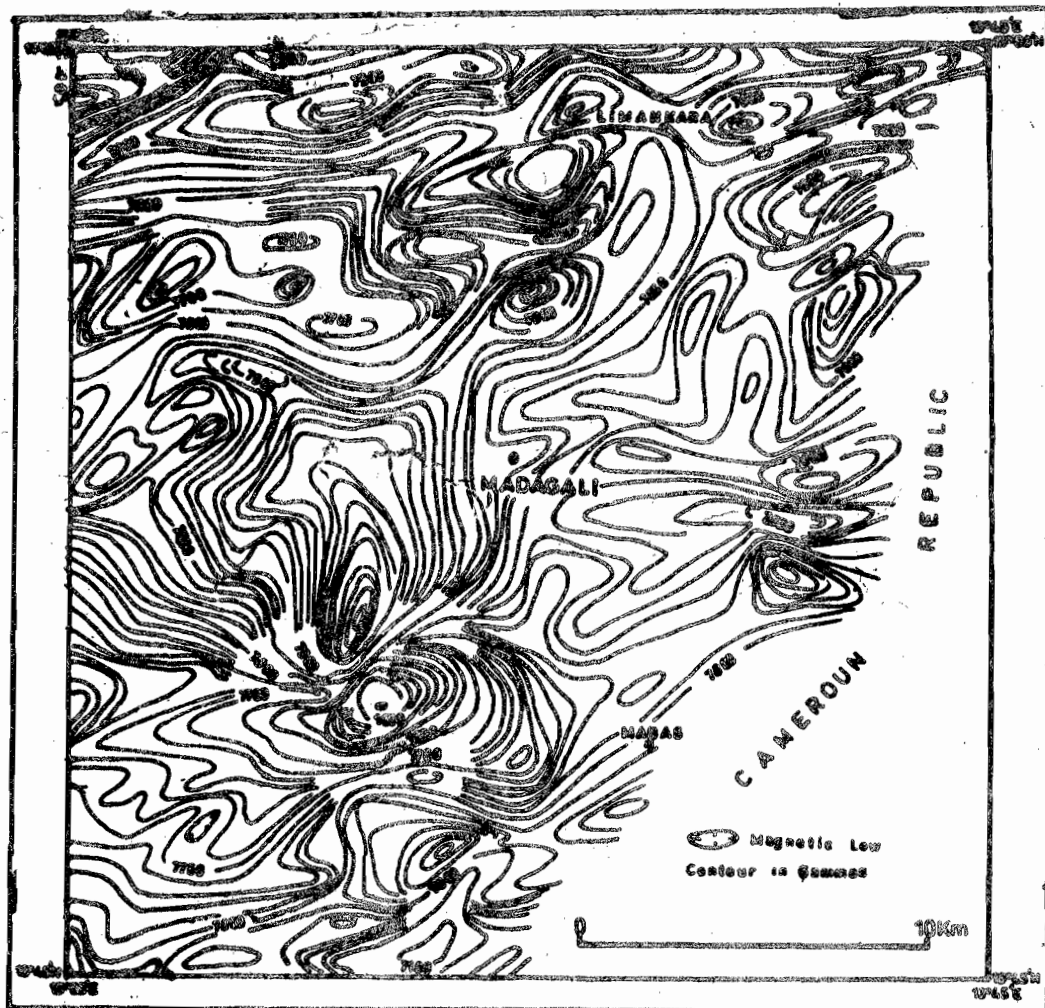


Fig. 3: Aeromagnetic map of the study area

evidenced by the presence of mylonite within the shear zone. Blocks of rock between shear planes are as small as 0.3 cm and as large as 20 cm. At least three shear deformational directions are found at Chikale: E-W (N70-N110°), NW-SE (N160°) and N-S (N170°). These reflect three shearing episodes, and from field occurrence NW-SE shearing is the oldest followed by N-S, then by E-W. These correspond to pre-Pan African (NW), Pan African (N-S), and late Pan African (E-W).

**Faults**

These are ubiquitous in the area and were recognized based on the occurrence of slicken sides on the rock surface and the presence of scarps. From the slicken sides the sense of movement and the type of fault (normal fault) was determined. At Limankara in the north of the study area shearing and faulting have altered the initially coarse grained granite to mylonite. The fault zone trends N-S and the shearing has imparted a crude foliation to the rock striking at N168° with a vertical dip. The Limankara fault zone extends southwards to the granites of Madagali area. E-W normal faults are found on the schist east of Wagga Madagali and east of Humshi (Fig. 2). Some other faults have been inferred based on similarity in topographic, magnetic and satellite imagery characteristics. The elevation from the foot of the hill east of Naamtari Jambutu and Ziri is 550 m and 1150m respectively. Intermediate elevations exist between these two. Based on the alignment of the faults between these two places the faults are considered to constitute step faults.

**MAGNETIC AND SATELLITE DATA**

Aeromagnetic map used for the present work was obtained from the GSN which had acquired maps for the entire country

between 1974 and 1980 and published them in the form of 1/2° by 1/2° sheets contoured mainly at 10 gammas interval. The maps are published on scale of 1:100,000. The present work covers part of sheet 136.

The original map was digitized at a grid of 1 km. This digitization interval was considered satisfactory as it accords with the scale of the original map. A reduced version of the original map is presented in Figure 3. The digitized data were subjected to regional residual separation process by applying a moving average filter. The technique involves the averaging of potential field data along the periphery of a regular polyhedron with its centre at the point for which the residual is computed. The average value around the polyhedron is simply the arithmetic mean of a finite number of equally spaced points about the boundary. The residual value is the observed value at the centre minus this average. In the present work the digitized values were regularly spaced and a 4- point averaging filter was applied. This was considered satisfactory as higher point averaging filters (8, 16, and 32) would have caused loss of significant details on the magnetic data. Care was taken to ensure that there were no overlaps in the computation exercise. The exercise could not be applied to the extreme SE portion of the magnetic map due to unavailability of data (Fig 3). The residual data were contoured using a computer software (SURFER 7.0) to produce residual map of magnetic anomalies. For the SE portion zeros were inputted into the contouring software programme, which automatically generated contours over the area. The residual magnetic anomaly contour map is shown in Fig.4a., its 3-D version is presented in Fig.4b.

Satellite data over the country have been prepared by Geomatics international Inc for the Federal Ministry of Agriculture and Natural Resources. It was acquired in Jan

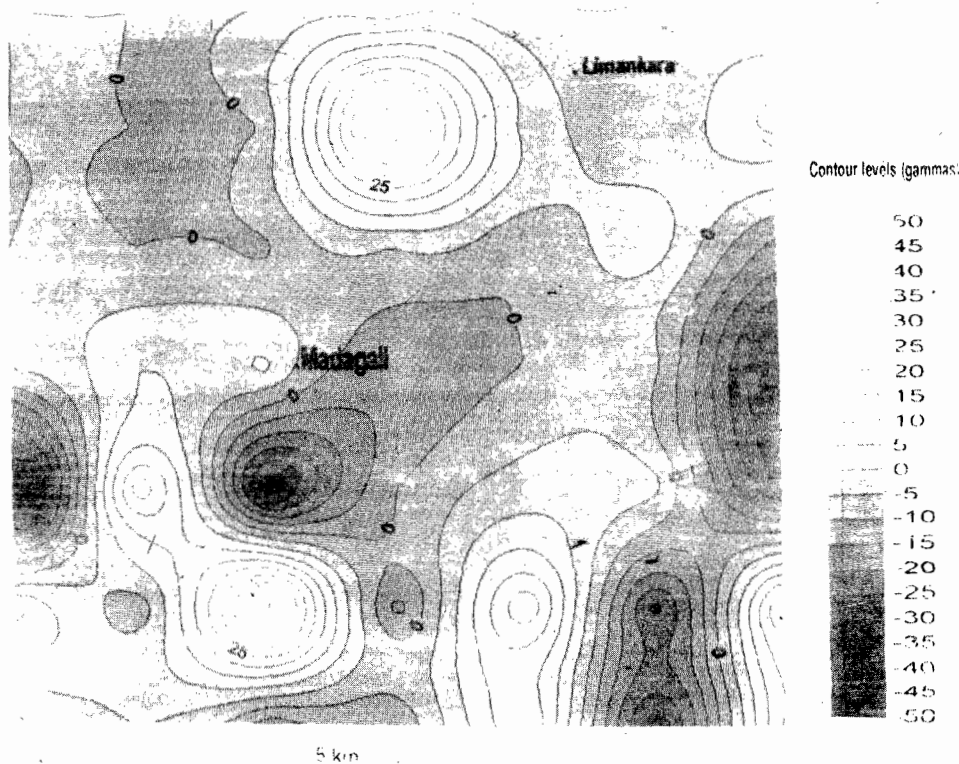
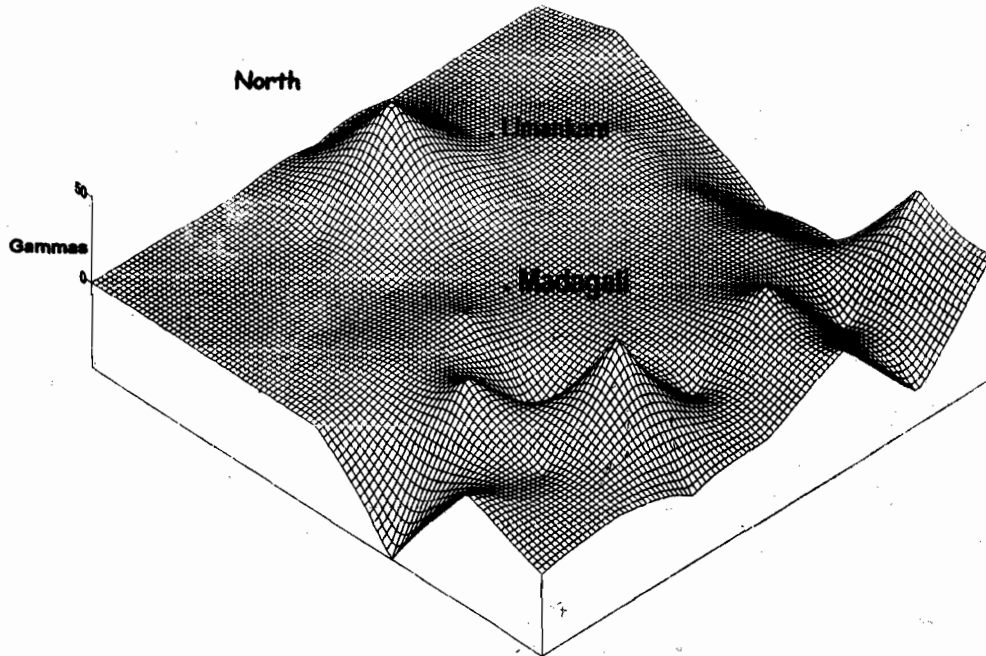


Fig.4a: Residual magnetic anomaly map of Madagali area.



**Fig.4b: 3-D Residual magnetic anomaly map of Madagali area.**

1993 with a resolution of 30 m and published on scale of 1:250,000. The present study covers part of sheet 38 of the satellite map of Nigeria. The imagery was interpreted monoscopically following classical aerial imagery interpretation techniques of Drury (1987). A transparency was superimposed on the imagery and major structural features and straight channel streams were identified and marked out. The interpretation was guided by published topographic map of the area and geological fieldwork. The satellite imagery and its interpretation are present in Figures 5a and 5b respectively.

#### DATA ANALYSIS

From the residual magnetic anomaly map, and the 3-D version (Fig.4a and 4b) there are three areas of significant positive residual anomalies. They occur to the south and southeast of Madagali, and to the west of Limankara. Their maximum amplitudes are between 25 to 50 gammas. A fourth residual positive anomaly is largely truncated is found at the SE boundary of the study area. It has maximum amplitude of 30 gammas. These residual anomalies can be explained in the light of available regional geological reports on the Mandara hills, and the adjoining basement regions (Adamawa massif in Nigeria, and the northern Cameroon basement). These regions have widespread occurrence of basalts, trachytes and trachybasalts (Avbovbo et al., 1986; Fitton, 1987; Moraueu et al., 1987; Toteu, 1990; Basseu et al., 1999; Basseu, 2005). The positive residual anomalies are attributed to these basic and intermediate rocks.

Areas of occurrence of zero or negative residual anomalies in the study area are interpreted in terms of the presence of granites, gneiss and schist in the area. They may also be due to susceptibility variations in the lithologies or a combination of both.

On the satellite lineament map (Fig.5b.) three main trends can be recognized: NW-SE, NE-SW, and N-S. E-W trend is minor. The NW-SE trending lineaments are found more in the west of the study area, where some of the river courses are controlled by them (see: Fig.2). The NW-SE lineaments are mainly found on the metamorphic basement. NE-SW lineaments are found more towards the east with some extension in the southwest of the study area. They mainly affect the pan African granites. N-S lineaments are mainly found eastwards also. They define fault zones which affect the granites. E-W lineaments occur mainly eastwards except one that occurs close to the southern boundary of the study area. Some of them are coincident with mapped faults which control river courses (Fig. 2).

#### DISCUSSION

The study area has experienced polyphase thermo tectonic events involving magmatism, metamorphism and structural deformations. From field structural data the oldest deformational features trend NW-SE. These features are foliation, shear zones and joints. The NW-SE lineaments are among the longest and invariably are of deep crustal origin (Odeyemi et al., 1999). Other geophysical evidences (gravity and seismics) exist to show these lineaments continue beneath the Chad Basin into Niger Republic, where they have surface expression as the Tenere Rift (Lake Chad Basin Commission, 1973; Cratchley et al., 1984; Nur, 2001).

Some planar bodies have been emplaced along the NW structural direction as pegmatite and granite dykes. Major streams in the area namely Rivers Naamtari Jambutu, Worawa and Rafin Bugada flow essentially NW-SE after taking their rise from the eastern hills. N-S structures observed are mainly normal faults, resistant basement ridge, dykes and foliation. From this study, they are next in relative age to the NW-SE



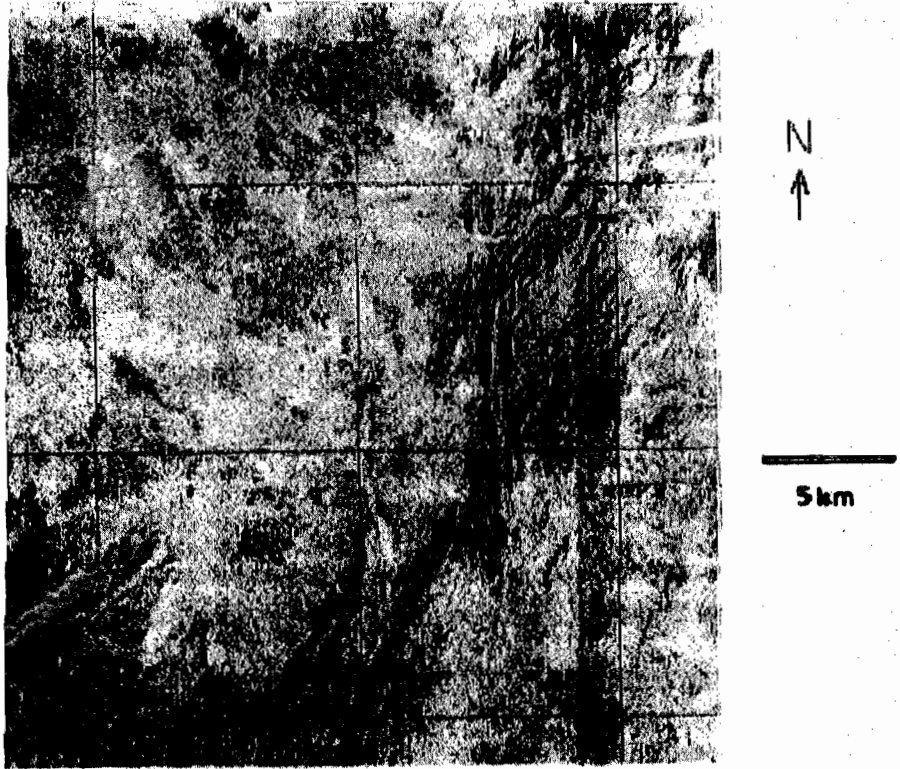


Fig. 5a: Satellite imagery of Madagali area.

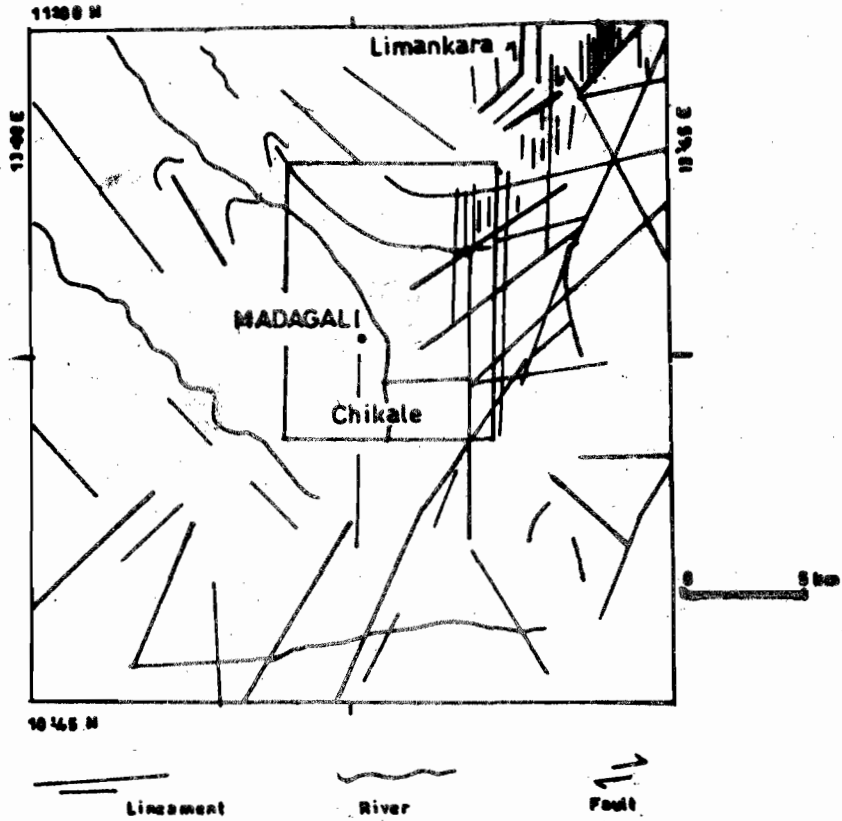


Fig.5b: Satellite lineament map of the study area.  
(Area in box is site of ground geological mapping)

structures. N-S faulting in the study area is extensive stretching for more than 20 km from Limankara to the south of Chikale (Fig.5b). The N-S faults extend into the Chad Basin where they've affected the sediments (Avbovbo et al., 1986). A general pattern of residual magnetic contours in Fig.4a is their N-S orientation. This is reflective of the deep basement structure in the area. NE-SW structures are next in relative age. The structures are found to be faults and foliation. This structural direction is related to the West African Rift System made up of the easterly Benue Trough and Cameroon Volcanic Line (Fitton, 1983). By inference it is also related to the NE trending Chad shear zone in Chad Republic (Fig 6). E-W lineaments are the youngest as they cross cut structures of all other directions. They are mainly basement normal faults, while others are granitic and pegmatitic dykes. Cornachio and Dars (1983) reported an ENE-WSW trend as a foliation direction produced as a late Pan African event. Some of the ENE-NSW lineament is seen to the south & northeast in the satellite lineament map.

## CONCLUSION

Magnetic, satellite and field studies have thrown some light on the geology and structure of this part of Nigeria's basement complex that has been relatively understudied. The major lineaments observed have been accounted for in terms of faults foliation, joints, shear zones, dykes and veins. The lineaments have regional extensions into Niger, Chad and Cameroon. The Chad basin evolution involved interplay of NW-SE, NE-SW, N-S and possibly E-W tectonics. Major Drainage channels in the area are structurally controlled. The study has revealed E-W structures as the youngest which is different from observations elsewhere in the Nigerian Basement (see: Oluyide 1988; Ene and Mbono, 1988; Ekweume, 1994, 2003). Probably for the first time surface expressions in Nigeria of basement structures which control the formation of the NW-SE trending Tenere Rift in Niger Republic have been recognized.

There is need for geochronological dating of rocks and structural events in the northeast basement of Nigeria for a better understanding of the geologic history of this area.

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