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Full Length Research Paper

Appraising the structural geology of Kakuri Sheet 144: Implications for the tectonic evolution of the basement complex

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The appraisal of the structural geology of Kakuri Sheet 144 using integrated analyses of remotely sensed lineaments, aeromagnetic anomaly, micro and macro structures show a tectonic framework expressed by a mainly NW – SE ductile vertically dipping foliation of transpressed tectono-metamorphic possibly pre-Pan African (S1) trend which has been overprinted by a set of NE – SW (L2) fracture system cut obliquely by an E-W (L3) sinistral shearing with a dextral sense. Magmatic activity might have exploited these north-easterly fracture systems which are consistent with the regionally deep seated north-easterly fault systems that define the limits of the schist belts, the younger granites and Benue Trough.

Key words: structural geology, structural fabric, geological map

INTRODUCTION

Olasehinde (1989) observed that elucidating structural fabrics, especially the fracture pattern in the Nigerian basement is a problem due to poor exposure. Beyond this, elucidating them is useful in mineral and water exploration programs. Aeromagnetic data are useful in overcoming such problems and aeromagnetic coverage of continental areas has been helpful in reconstructing the tectonic evolution on a global basis (Mita and Anand, 2003). The structural and tectonic framework of the Nigerian Basement Complex has been reported as comprising northeast – southwesterly and northwest – southeasterly lineaments superposed over a dominant north-southerly trend (Olasehinde et al., 1990), and NW – SE and NE – SW pair superposed on a N - S joint set (Annor et al., 1990; Annor and Freeth, 1985). Olasehinde et al. (1990) confirmed Ball's (1980) presence of NW – SE aeromagnetic signature. These conclusions have chiefly been based on aeromagnetic anomaly studies on a more or less regional scale and which coincides with the regional patterns recorded on the basement (Figure 1).

Tying these structural patterns to particular episodes of deformation has been difficult in nearly all the basement exposures in Nigeria. This paper attempts to study the structural and tectonic history of the basement by reappraising the magnetic anomaly and satellite data, and comparing these with field structural and micro-structural signatures of the basement rocks using the Kakuri Sheet 144 which represents a contact area between the meta-sediments to the west and a transition into the gneissic basement to the right (Figure 1). The Nigerian Basement Complex is located in the Pan African Mobile belt sandwiched between the West African Craton to the west and the Congo Craton to the southeast. The basement is predominantly amphibolite - grade quartz-feldspar-biotite + hornblende gneisses and migmatites (Wright et al., 1978). It is a polycyclic ensemble of heterogeneous migmatites and gneisses, meta-sediments and granites that have undergone a complex evolutionary history spanning through the Archaean (>2.50 Ga) to the Pan-African (550+100 Ma) (Rahaman, 1988; Ogezi, 1977; Ajibade et al., 1981; Dada, 2000, 2008). Several unanswered questions continue to trail the

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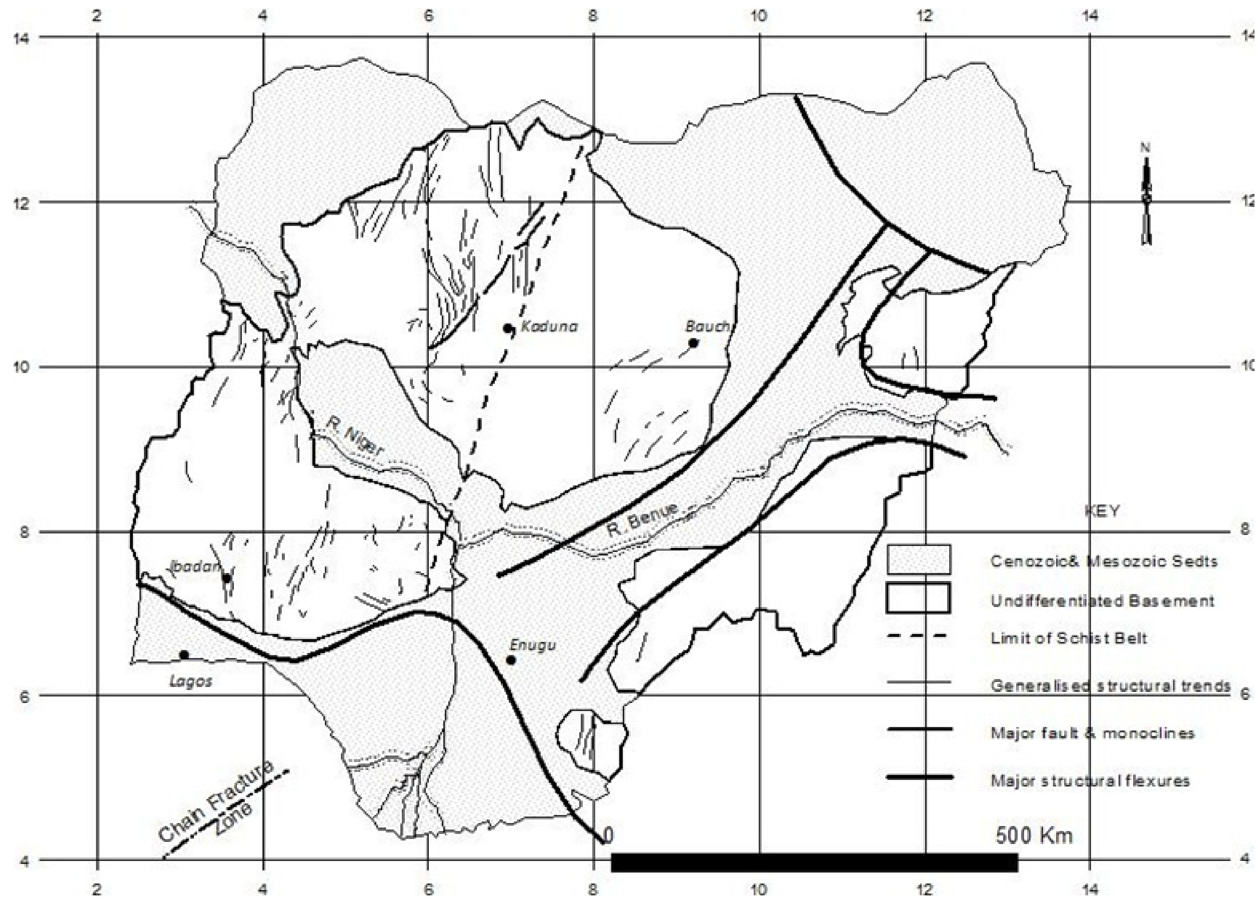

Figure 1. Generalised geological map of Nigeria showing the western Nigerian metasedimentary trends, after Oyawoye (1972) and location of Kaduna.

tectonic history of the basement such as whether they were formed as a result of ensialic or ensimatic processes related to plate tectonics (Wright et al., 1978; Rahaman et al., 1988; Ajibade, 1987) and the thermo-tectonic control on the distribution of the supra-crustal and granitic rocks within the basement. Using major and trace element geochemistry, Dada (1999) studied the petrogenesis and evolution of the basement around Kaduna. He assigned the amphibolite facies related to subduction-related magma generation of volcanic arc settings for the gneisses of the basement based on the high Rb, Sr, K/Rb, K/Sr, low Ca and chondrite normalized negative anomalies of Nb, P, Ti coupled with a high Al_2O_3/TiO_2 while the amphibolites are of the low Mg-tholleites and poorer in LILE but enriched in P. This pattern tends to support a multistage evolution that involved an early basaltic crust transformed to amphibolite.

Field relations as well as regional tectonics seem to favour the gneisses as the primary basement that was in part intruded by basic dykes that were subsequently sheared and deformed. This complex tectonic history has not only resulted in a complex rock composition but a complex structural pattern. Such structural patterns are a major control to mineral resources in Nigeria and elucidating the history of these fractures will help our understanding of the basement metallogeny. Figure 2 is a regional structural map produced from satellite imagery. The tectonic patterns such as the shear zones highlighted, correspond well with mapped structures such as Kwaga gold belt (west of Kaduna) which was mapped by Truswell and Cope (1963) and modified by Garba (2002). This is the southern prolongation of the Birnin Gwari metasedimentary belt. These patterns which is replicated in the Kakuri area of study therefore requires a closer reappraisal in confirmation of the theory of the late Pan-African brittle deformation proposed by Ball (1980) and Garba (2002).

METHOD OF STUDY

Datasets used in this study include satellite imagery, aeromagnetic data, geological map and field measured data all of which were processed in that order, to correspond to the conventional reconnaissance - detailed field - scale approach. The Kakuri Sheet studied lies within Latitudes 10°00''N and 10°30''N and Longitude 7°00''E and 7°30''E (Figures 1 and 2). Geometrically rectified dry

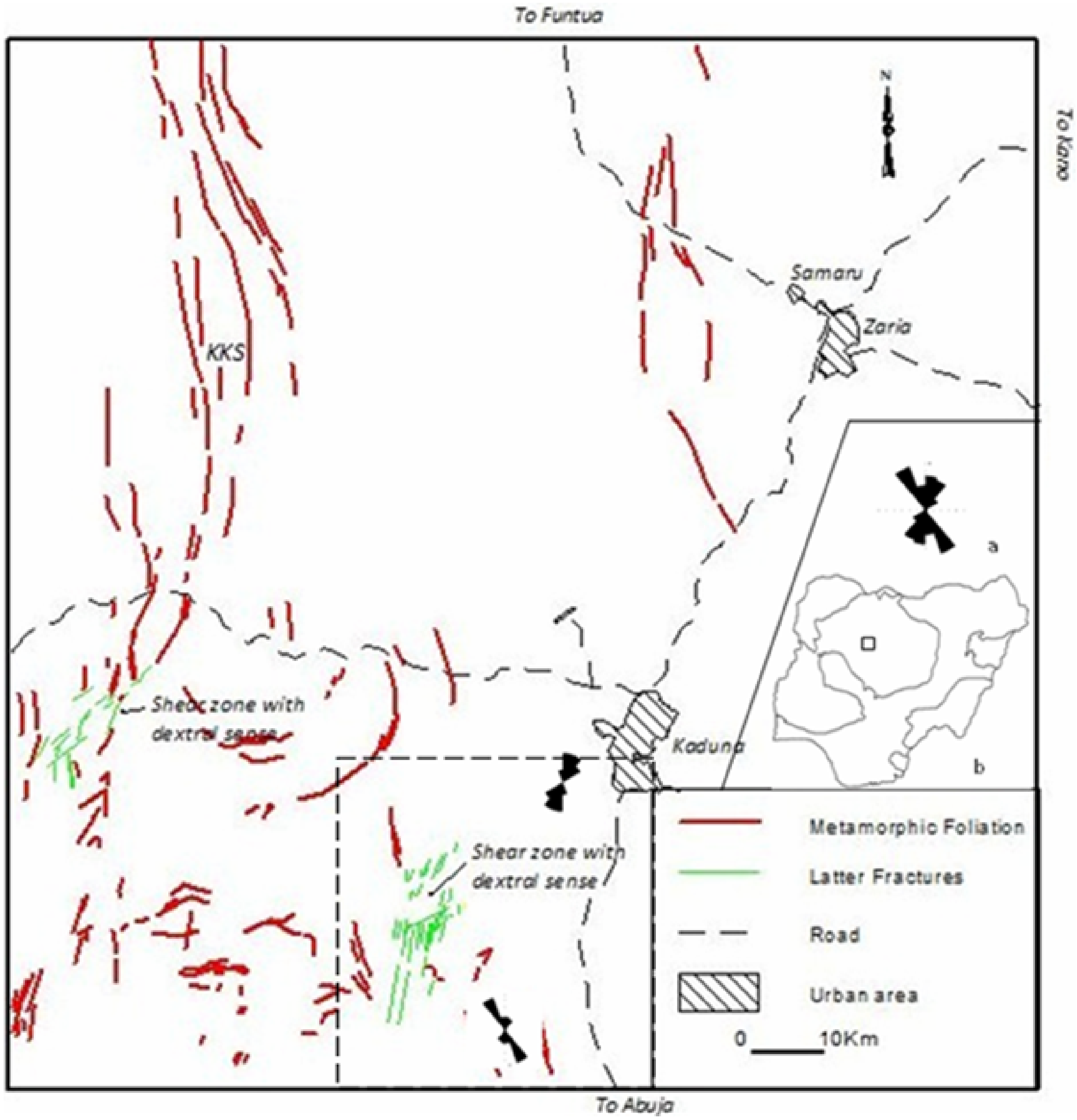

Figure 2. Regional fracture patterns of Kaduna - Zaria area generated from Landsat5 TM imagery, Kakuri Sheet 144 in set.

season Landsat5 TM imagery acquired from National Centre for Remote Sensing Jos, was subset from the Landsat5 main scene, to correspond to the Kakuri 144 Sheet. RGB 543 composite provided sufficient enhancement from which lineaments were screen digitized in Ilwis Academic 3.1 utilizing the UTM projection, Clark 1880 Spheroid and Minna datum all of which served as the georeference parameters for subsequent maps. Lineament generation automatically creates their orientations and saved in an attribute table from which the frequency azimuth rose was obtained.

Lineament density map utilized 2 x 2 km grid, which calculates the total length of lineaments within this box. The map returns a graduated scale of least to highest lineament density in meters.

Published aeromagnetic map for the area was screen digitized using 1.85 squared grids. The resultant point map with a value domain was interpolated, using the nearest neighbour algorithm in which each output pixel returns Euclidean distances towards all points. The value of the point with the shortest distance towards an output pixel is assigned to this output pixel. Subsequently, the raster map was sliced along bounding values of < 7,789 (Low), 7,780 to 7,860 (intermediate) and > 7,860 (high). This procedure is analogous to the modified upward continuation filtering of Ajakaiye et al. (1986). At least 100 fracture measurements were plotted and compared with the imagery and aeromagnetic trends for the sheet.

RESULTS AND DISCUSSION

The meta-sedimentary lithologies dominated by migmatized and schistose rocks (Figure 2) expectedly gave darker shades on the satellite imagery while the

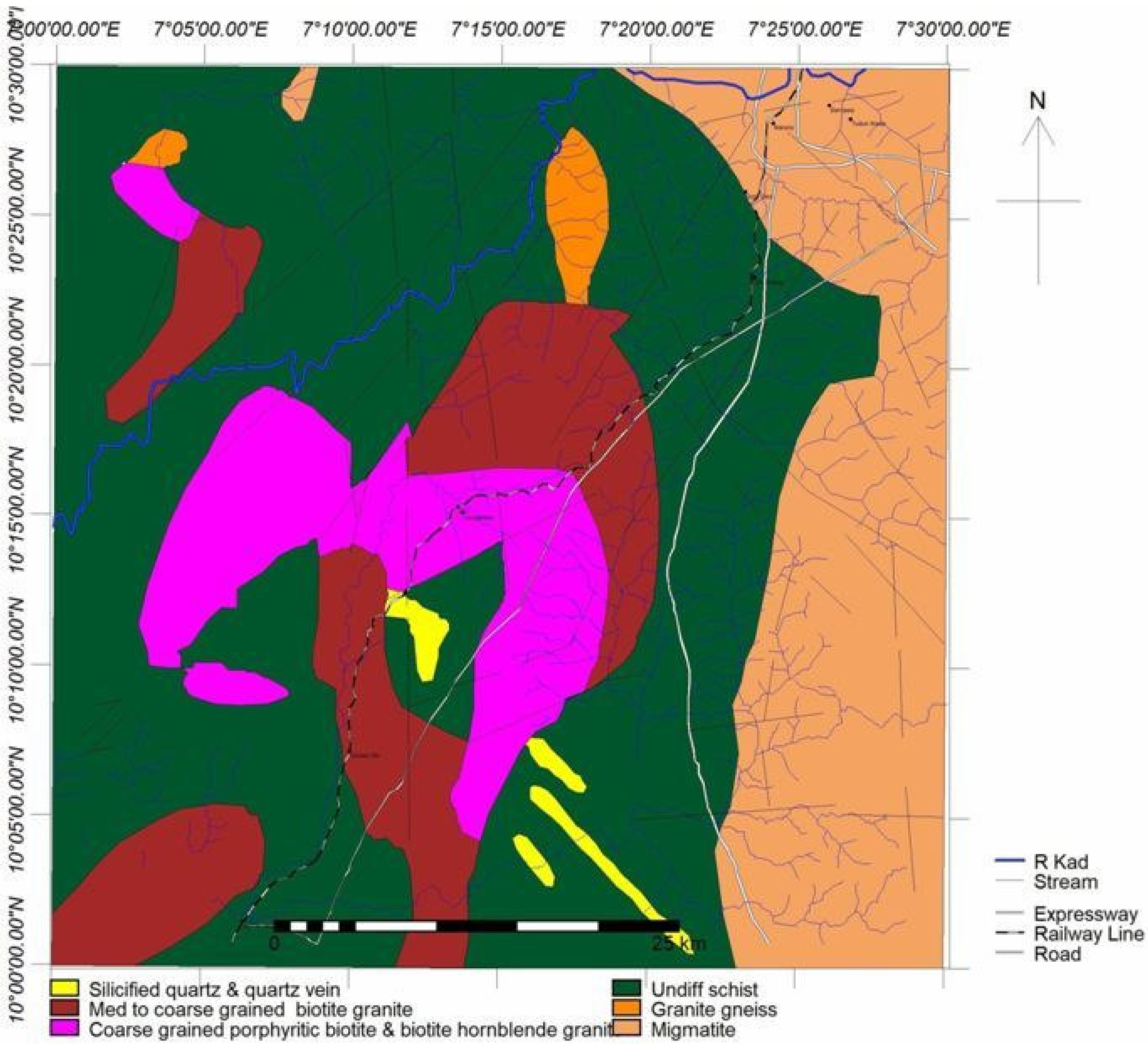

Figure 3. Geology of Kakuri Sheet 144 (modified after geological survey).

more granitic terrains gave lighter shades (Figure 3). This is because the meta-sediments have more of the mafic minerals which together with the lateritized clays contribute to the staining of band 3 and absorptions of the clayey components at or around 2.2 µm of the EM spectrum which corresponds to band 5 of Landsat5 TM. It is apparent from the imagery (Figure 4) that the lineaments display a wide scatter in orientation. NW – SE trends that stretch from the lower central area and extend to the north-western corner, represents the uplifted metamorphosed gneisses and quartzite ridges. These bodies and trends were mapped by the geological survey published map. This ridge appears to have been truncated by apparently NE – SW shearing with a dextral sense. This stepped NE – SW trends have been exploited by the River Kaduna system.

The Landsat5 TM generated lineament map shown in Figure 5, shows a preponderance of two major conjugate trends. Approximately 285 lineaments that summed up to 523,814.5 m, but some were considered negligible and thus discarded leaving a total of 111 orientation data which gave a mean resultant direction of 028-208. The NE – SW trend and the NW – SE trend and the sub-optimal N-S and E-W trends were apparent. As explained earlier, the NW – SE trend represent metamorphosed bodies that are sufficiently exposed at the surface to be captured by satellite imagery. The high density of lineament at the central portion represents a fracture

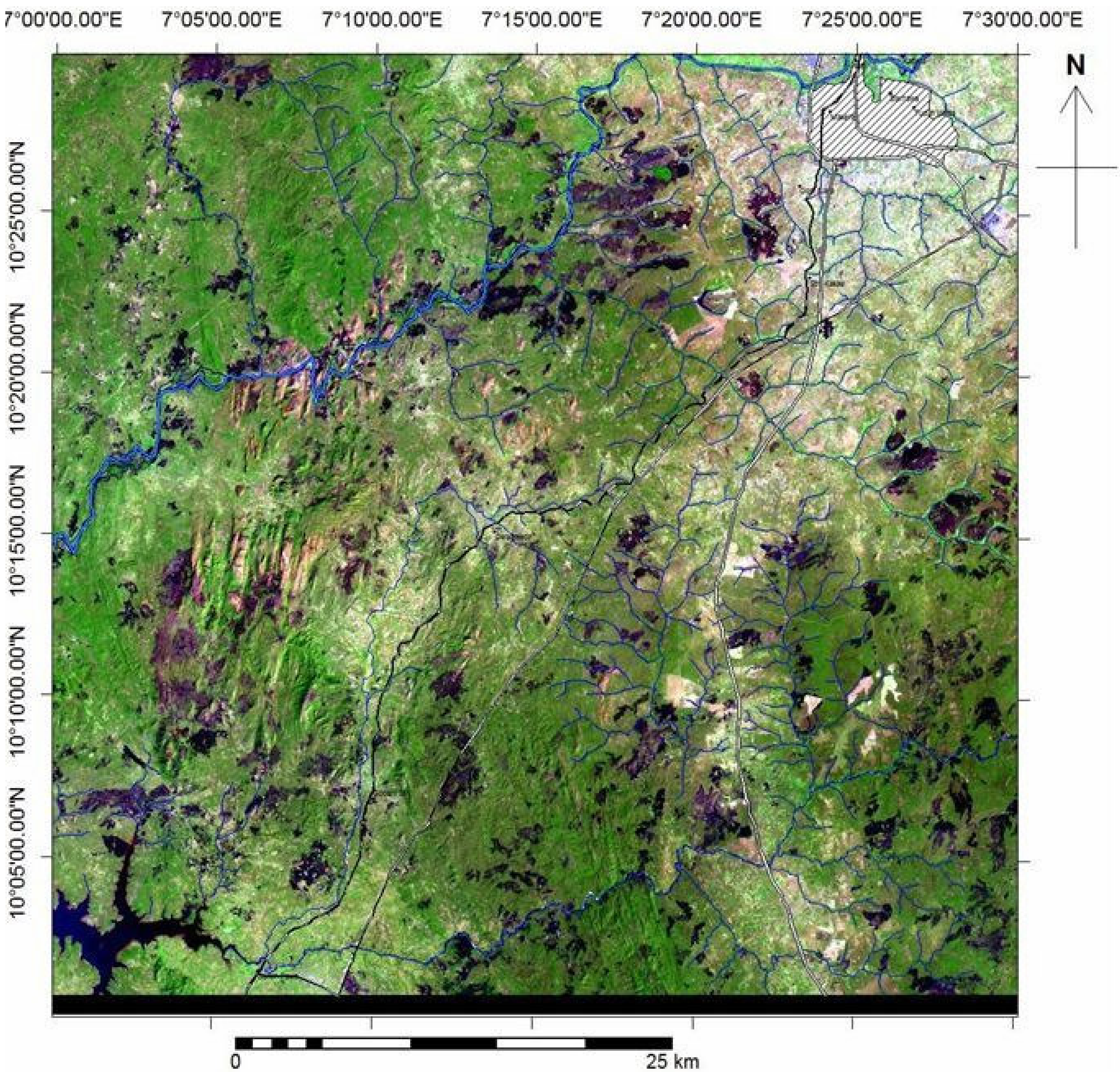

Figure 4. RGB543 colour composite of Landsat5 Tm imagery of Kakuri Sheet 144.

system that is predominantly NE – NW trend.

The 3-D analysis of the lineament shows that, three major successions of trends were preserved. The main older NW-SE metamorphic lineament which is expressed by banded and quartzitic ridges. The second is the suboptimal NNE to N-S heading of linear fractures which have been obliquely truncated by a NE-SW trends which have been here related to dextral faulting. The trend of these faults has been reported by Oyawoye (1972). These last set appear interestingly deeper and which have been exploited by the River Kaduna and Sarkin Pawa depressions. For exploration purposes, these last set may be the most interesting. This has been confirmed by the deep seated magnetic trends (Figures 6, 7, 8 and 9). Even though lineaments generated from the satellite imagery recorded a wide scatter, two bimodal peaks can be depicted as follows (Figure 8):

a) 0° - 10° (8.1% of data) and 010° – 019° (7.2% of data) = NNE – SSW trend.

b) 060° -070° (8.1% of data) and 050° – 060° (7.2% of data) = ENE – WSW trend.

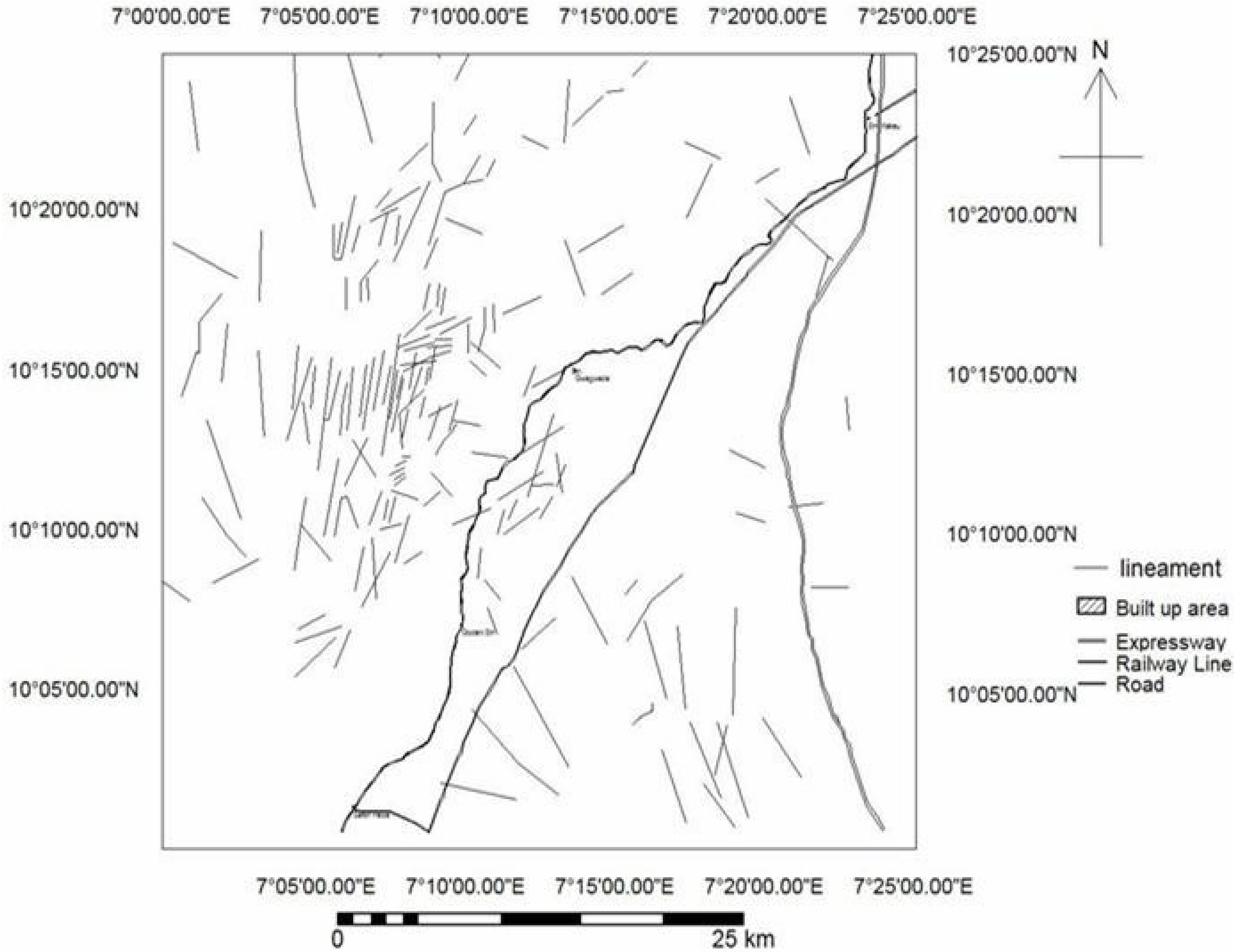

Figure 5. Landsat5 TM generated lineaments including both fractures, as well as foliation surfaces for Kakuri Sheet 144.

The rose plotted for the Landsat5 TM generated orientations is generally comparable to that obtained by Ananaba and Ajakaiye (1989) for the basement rocks of Nigeria. The field data plot gave a single peak uni-modal trend with a NNW – SSE (Figure 7b). A statistical summary of the frequency of orientations plotted against number of lineaments (Figures 8,9,10) gave about 43 lineaments in the ENE (60-90), constituting 38.73% of the total data plotted. NE-SW trends are apparent in Figure 7 which is consistent with the observations of Ajaikaye (1986), Olasehinde et al. (1990) in which they related such trends with deep seated basement lineaments. The near absence of NW – SE trends is very instructive especially when magnetic signatures are supposedly deep seated signatures. Deep seated fractures are zones of weaknesses where granititic materials such as the younger granite trends (Ajakaiye et al., 1986) take advantage of. The high magnetic materials are the migmatites, gneisses and meta-sediments. The Intermediate range is the granitoids while the low range represents the more basic geological materials (Olasehinde et al., 1989). In this terrain, geological mapping have not revealed such materials but the possibility of mapping such materials at deeper depths is here discovered.

An attempt was made at assessing the deformation recorded on these rocks by carrying out preliminary strain measurement on the rocks. Caution is here advocated because the number of data is not sufficient at the scale of the work considered, but it sure gave an idea of the recorded deformation at the micro-structural level. Axial ratio of the ellipsoids range between 1.71 and 2.34 with only one ellipsoid having an extreme 3.8 (Figures 11, 12 and 13). This indicates moderate to intermediate strains. The trends are generally north-westerly, since strain measures were performed on the steeply and near vertically dipping gneisses. These interpretations were however non-conclusive, since it was not conducted on

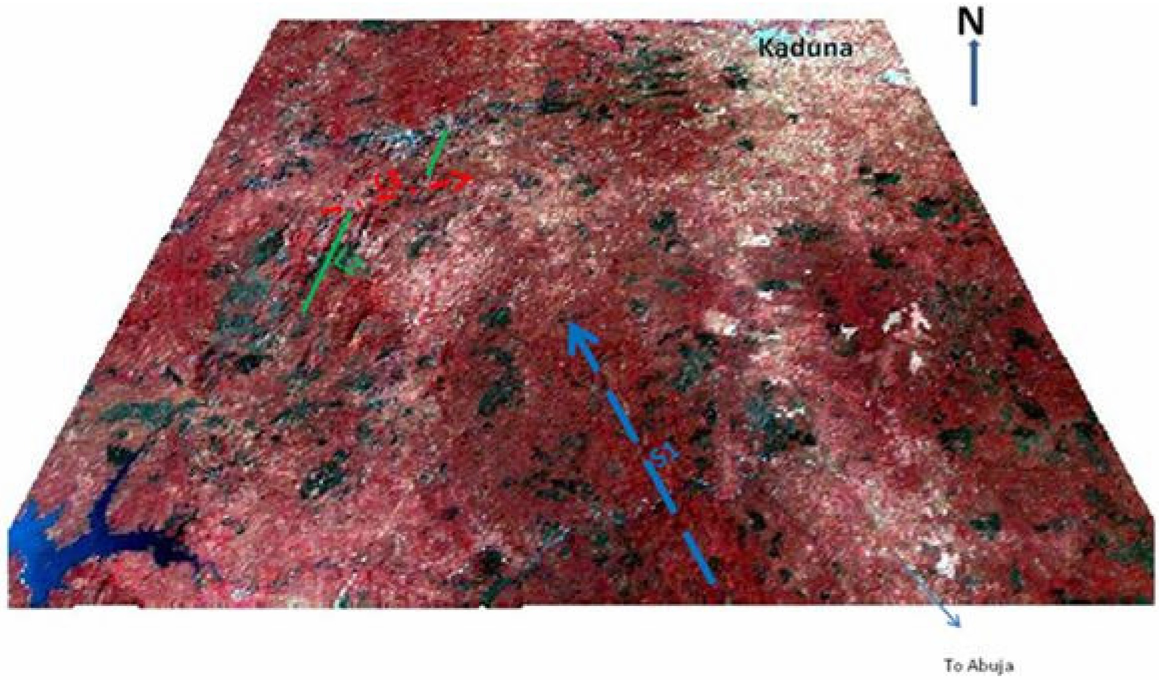

Figure 6. 3D view of the area showing the three major trends and episodes. S1 is gneissose foliation trends on ridges of gneisses and quartzites, L1 is fracture trends and L3 is fault systems.

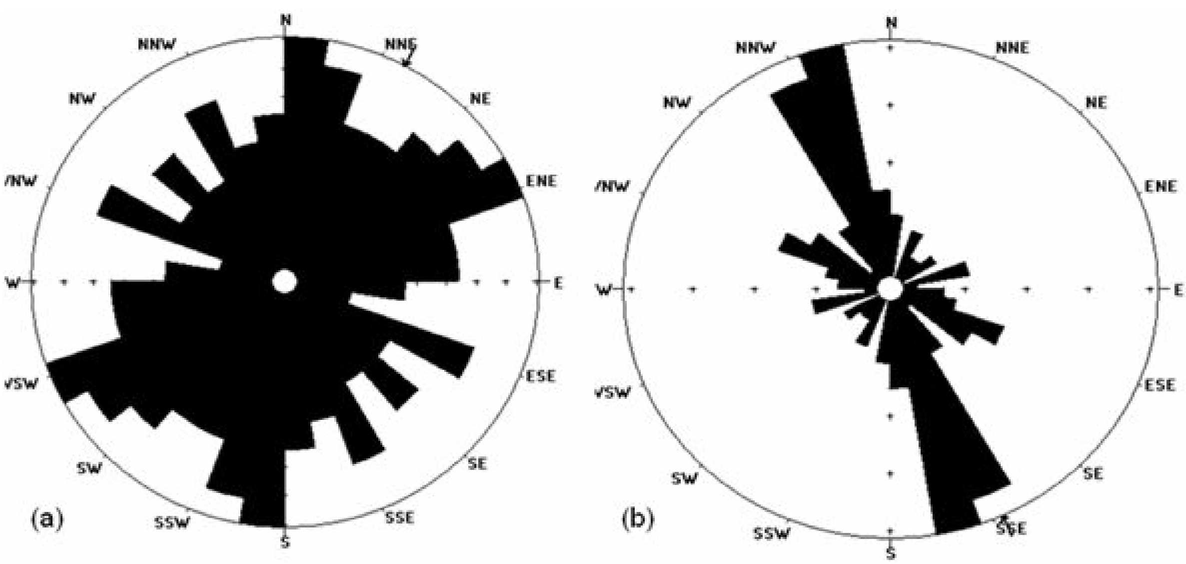

Figure 7. A comparison of the Frequency azimuth rosette diagrams for fracture trends of Kakuri sheet 144 (a) generated from Landsat5 TM (n=111) and (b) field measurements scattered over the same area (n = 92).

non-deformed granites, to ascertain the homogeneity of the original bodies. It however gave useful orientation data for comparison.

Summary of findings

A good understanding of the structural patterns in the Nigerian Basement Complex is critical to the understanding of the tectonic evolution of this part of the Pan-African terrain. The problem associated with mapping these fractures include poor exposure and masking by surface weathering processes. This problem is further accentuated by a rather unclear chronology of these patterns. Though regional fracture patterns have

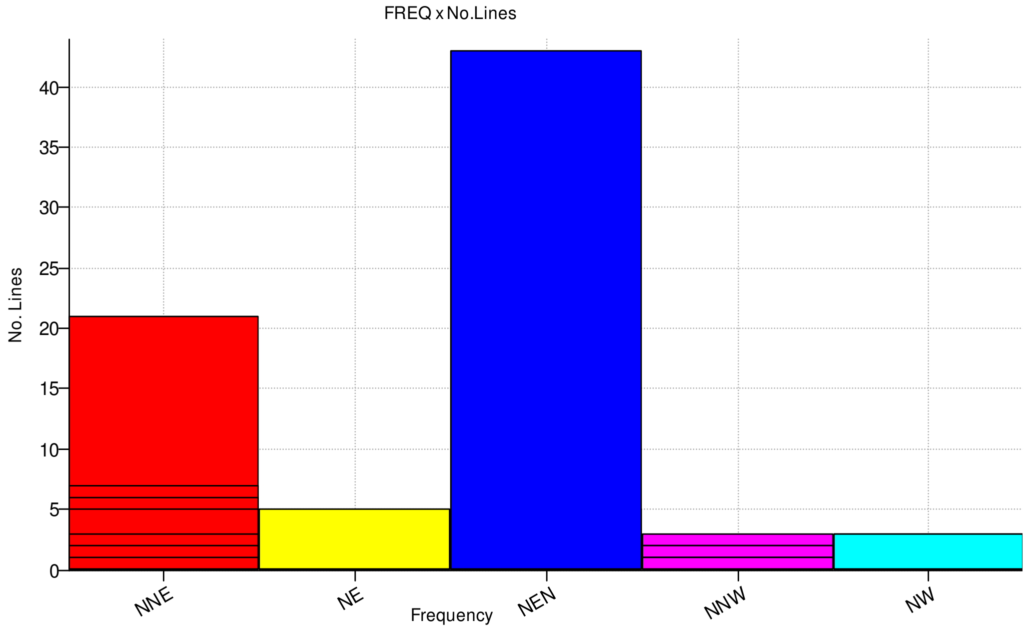

Figure 8. Statistical histogram showing the variation of the trends.

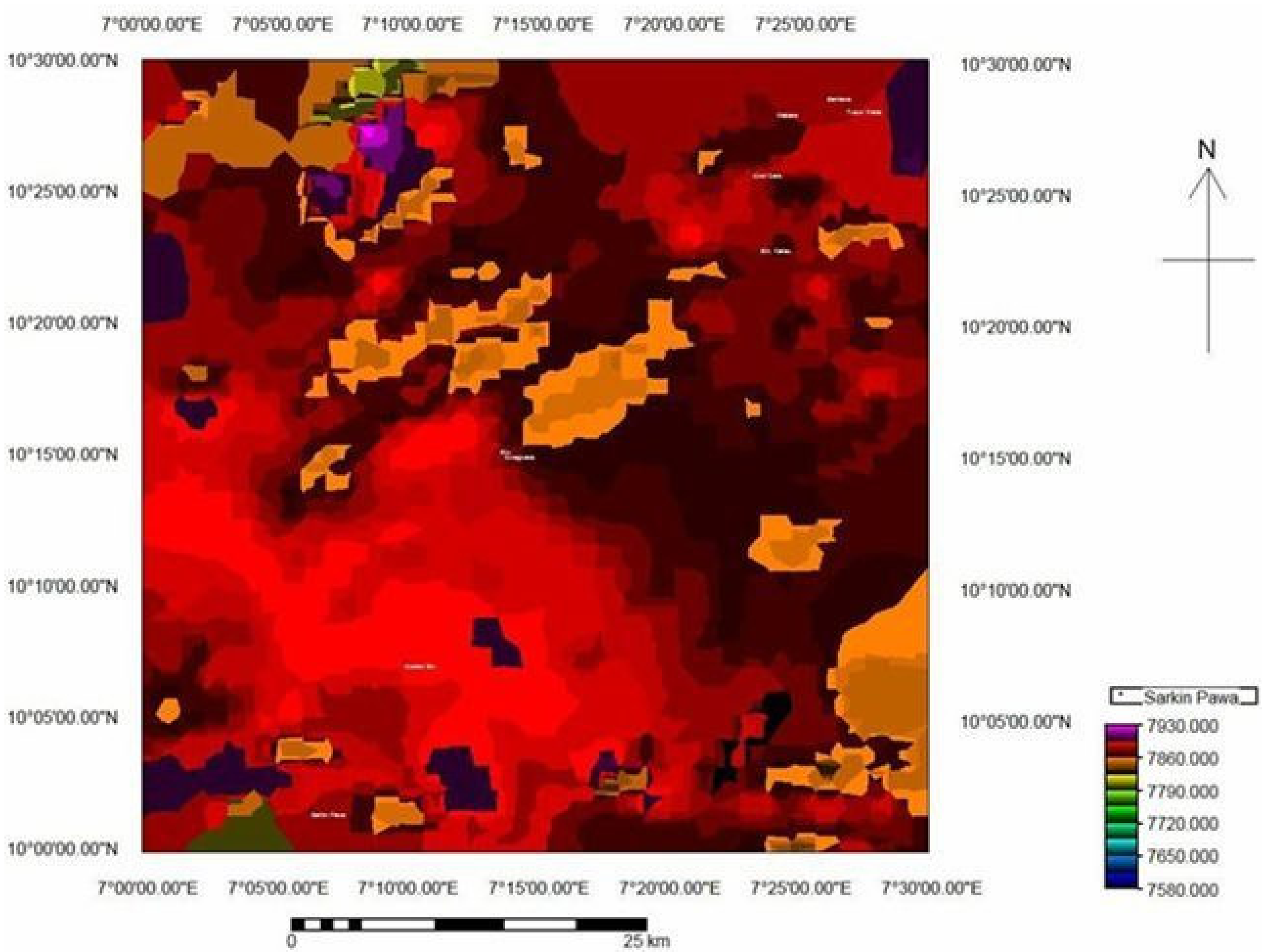

Figure 9. Digitized aeromagnetic map of Kakuri sheet 144.

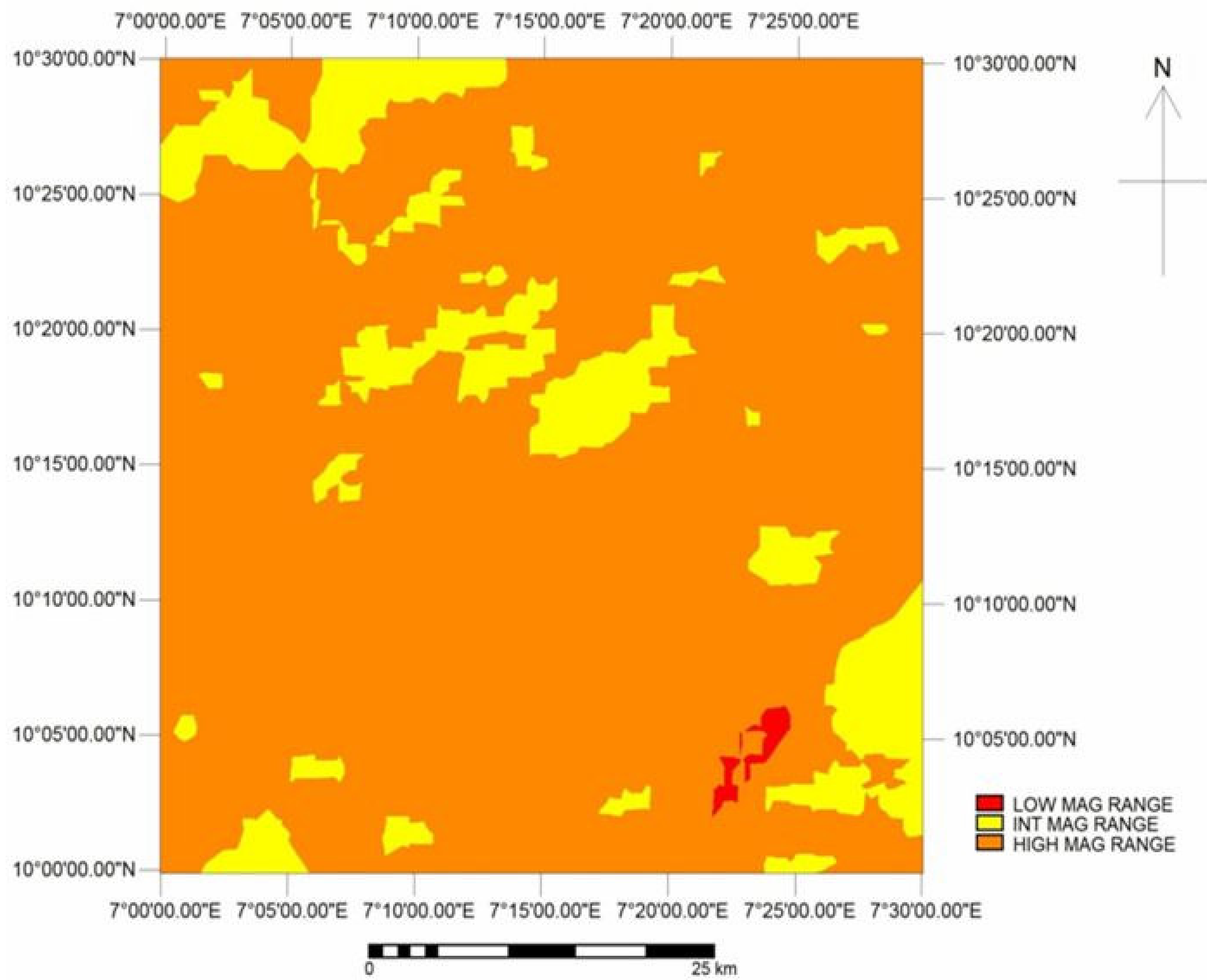

Figure 10. Reclassified colour map of magnetic range.

been amply documented (Ball, 1980; Ajakaiye, 1986; Annor et al., 1990, Annor and Freeth, 1985, Olasehinde et al., 1990, Olasehinde, 1989), these patterns have not been closely compared with micro tectonic patterns. Aeromagnetic lineaments are normally deep seated and often, non – fracture lineaments such as metamorphic trends are not taken into account. Additionally, field geological mapping of structures are extrapolated. These observations have informed the focus of this research.

Two main trends have been captured by the Landsat5 TM study and include NW-SE longer lineaments and a second pair of NE-SW and NNE-SSW trends which appear statistically abundant but spatially discontinuous and shorter. These trends coincide well with deep aeromagnetic trends, which have been attributable to an extension of Atlantic fracture zone that extends into the Nigerian Basement Complex (Olasehinde et al., 1990). The north-westerly trends are however not apparent in the aeromagnetic trends, even though they are very pronounced in the landsat5 TM study. These in the authors' opinion may be supra-crustal signatures and not related to deep seated aeromagnetic trends of Ball (1980). The micro-structural trends confirm the near absence of the north-easterly trends in the gneisses. A close study of regional map (Figure 2) which represents about nine 1:100,000 sheets, show that, the same pattern is replicated in the metasedimentary trends which obviously predate the subsequent shearing with a dextral sense which possibly were exploited by the Pan-African magmatism. If we subscribe to the suggestion that deformation may not have been synchronous with magmatism (Grant, 1978; Rahaman et al., 1991), then we equally subscribe to the assumption that, these NW – SE pre- Pan African did not probably assume significant

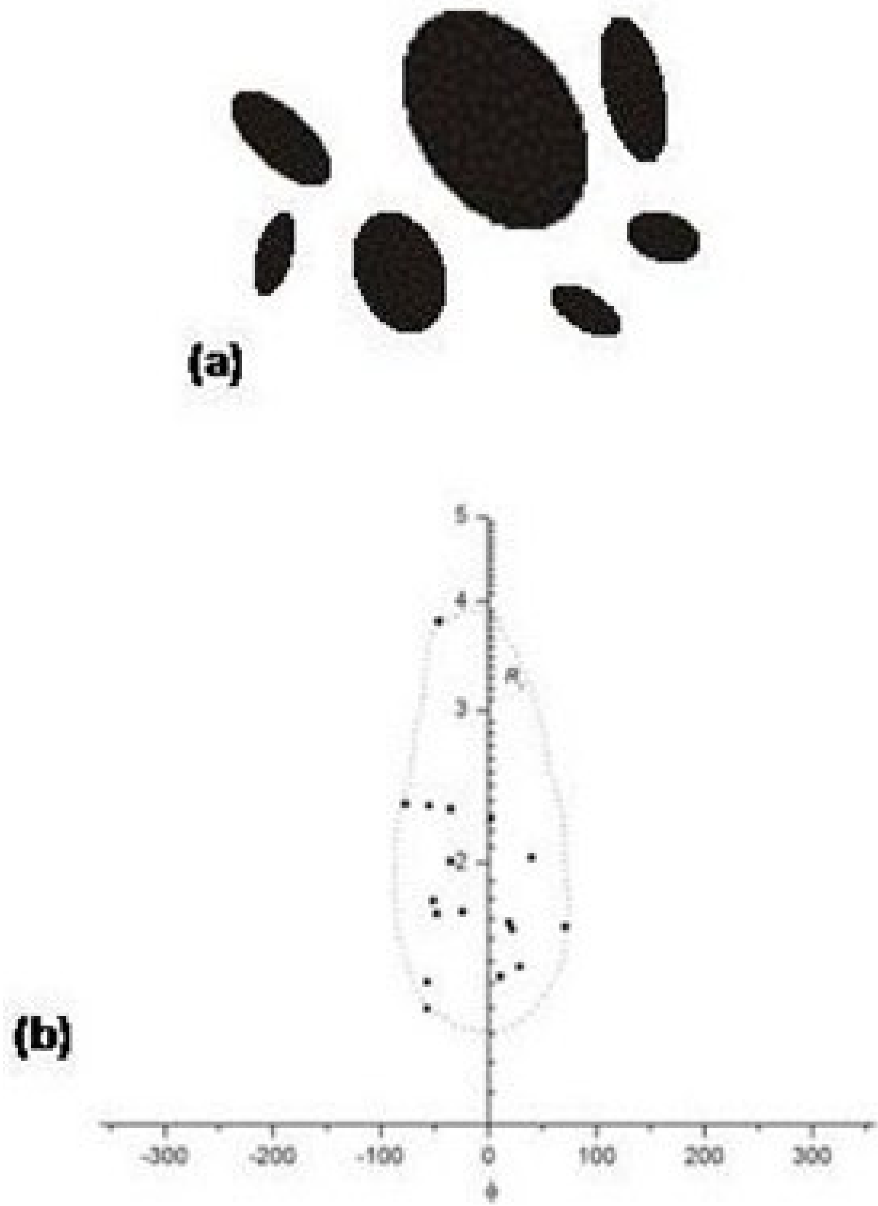

Figure 11. (a) Strain ellipsoids obtained from gneisses showing inconsistent orientations, (b) Rf / θ diagram of the axial ratios of ellipsoids in the same area.

proportions.

Regionally, it appears D1 deformation is typified by F1 surfaces oriented approximately 3500 to N-S both in the gneisses and shaft-like enclaves of the concordant schist with nearly vertical and gentle dips. Locally, intense shearing developed D2 penetrative surfaces which cut the N-S axial folds creating N-S, NW-SE crenulation surfaces.

Meso- and micro-structural data and significance

A similar scatter was also noticed in the strain ellipsoids which generally gave a NNW SSE trends with strain axial ratios approximately.

Conclusions

The following conclusions can be drawn about the tectonic framework:

1. An early, mainly NW – SE ductile vertically dipping foliation of transpressed tectono-metamorphic possibly pre-Pan African (S1).
2. A latter overprinting by a set of NE – SW (L2) fracture

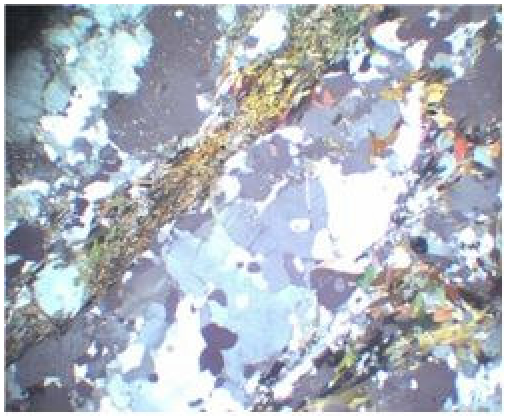

Figure 12. XPL of the banded and strained gneiss cut normal to foliation planes.

Figure 13. Dark thick bands are thick shafts of biotite schist. Pen at the top central part of the picture is north oriented.

trend cut obliquely by an E-W (L3) sinistral shearing with a dextral sense.

3. Magmatic activity exploited these north-easterly fracture systems which are consistent with the regionally deep seated of north-easterly fault systems

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