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AIRPHOTO INTERPRETATION AS AN AID TO LITHO - STRUCTURAL MAPPING IN TROPICAL TERRAIN - THE NEW FEDERAL CAPITAL CITY SITE, ABUJA, NIGERIA

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ABSTRACT . — The Federal Capital Development Authority of Nigeria requested that an engineering geological investigation of the proposed New Federal Capital City Site at 1: 25.000 scale be carried out for suitability purposes. Mapping with conventional field methods alone proved to be insufficient due to the concealed terrain conditions in the area. Two different scales (1: 40.000 and 1:10.000) of aerial photographs were used which have revealed three main bedrock units and the entire structural framework of the area. Airphoto interpretation data shows lithological banding running NNE — SSW and fractures developed mainly in NW — SE and NE — SW directions. Through this information a major tectonic event has been inferred, resulting from a principal stress acting WNW—ESE.The directional frequency and the length of fractures show variations according to rock type. The metaigneous rocks gave high fracture density and frequency values, whereas metasedimentary rocks yielded low values of the same parameters.

INTRODUCTION

A detailed engineering geological study of the southern section of the New Federal Capital City Site was carried out in 1979 by the Geology Department of the University of Ife, Nigeria. A similar study was performed during the same period by the University of Ahmadu Bello, Zaria, Nigeria for the northern section of the city site. Because of the particular usefelness of airphoto interpretation in the area, only the photogeological part of the entire study is presented in this paper. The other aspects of the investigation are explained in detail, in the UNIFE project report (1979). The main features, investigated in this study are surface structures, regional lithological units and fracture traces.

The work of Blanchet (1957), Lattman (1958), Norman (1976) illustrate the use and capabilities of large scale remotely sensed data for engineering applications. Most of these publications emphasize the importance, of a fracture interpretation in concealed terrain. Ray (1960) provides several stereograms as examples pertinent to terrain conditions of the type found in Nigeria. Thomas (1974) discovered that the lineaments traced from aerial photographs were the framework of large structural block patterns in Williston Blood Creek Basin (USA) and that these features were not evident on the conventional geological maps.

This paper illustrates a case in which aerial photographs have been of particular value for foundation engineering. It also provides relevant information on photo interpretation for site investigation Upon which other kinds of studies can be effectively implemented.

The study area covering approximately 200 km^2 stretches between Latitudes 8° 45' and 9°00' North and Longitudes 7° 15' and 7°30' East. The topography is mature and has a low relative relief except for hills of various sizes which rise above the general topography. Several mature profile rivers drain the area westward to the river Usuman which runs south to join the river Niger.

THE ABUJA AREA

The new Federal Capital Site lies in the tropical savannah vegetation zone where there is fairly complete soil and vegetation cover. This presents problems for geological field investigations. For example, conditions such as delineation of lithological boundaries, trace of fractures and general structural trends are difficult to solve solely by field traversing.

Initially, five geologists were sent to the field to start the preliminary geological mapping without airphoto interpretation data. Thus all that could be done was together some local geological information in accessible localities. As a result, only scattered information was assembled and no conclusion could be drawn about the main structural framework of the area. At this point, it was realized that the remotely sensed data were needed.

The field team was not able to identify the major fractures and litho-structural units but the study of aerial photographs described below identified 276 fractures and three main litho-structural divisions

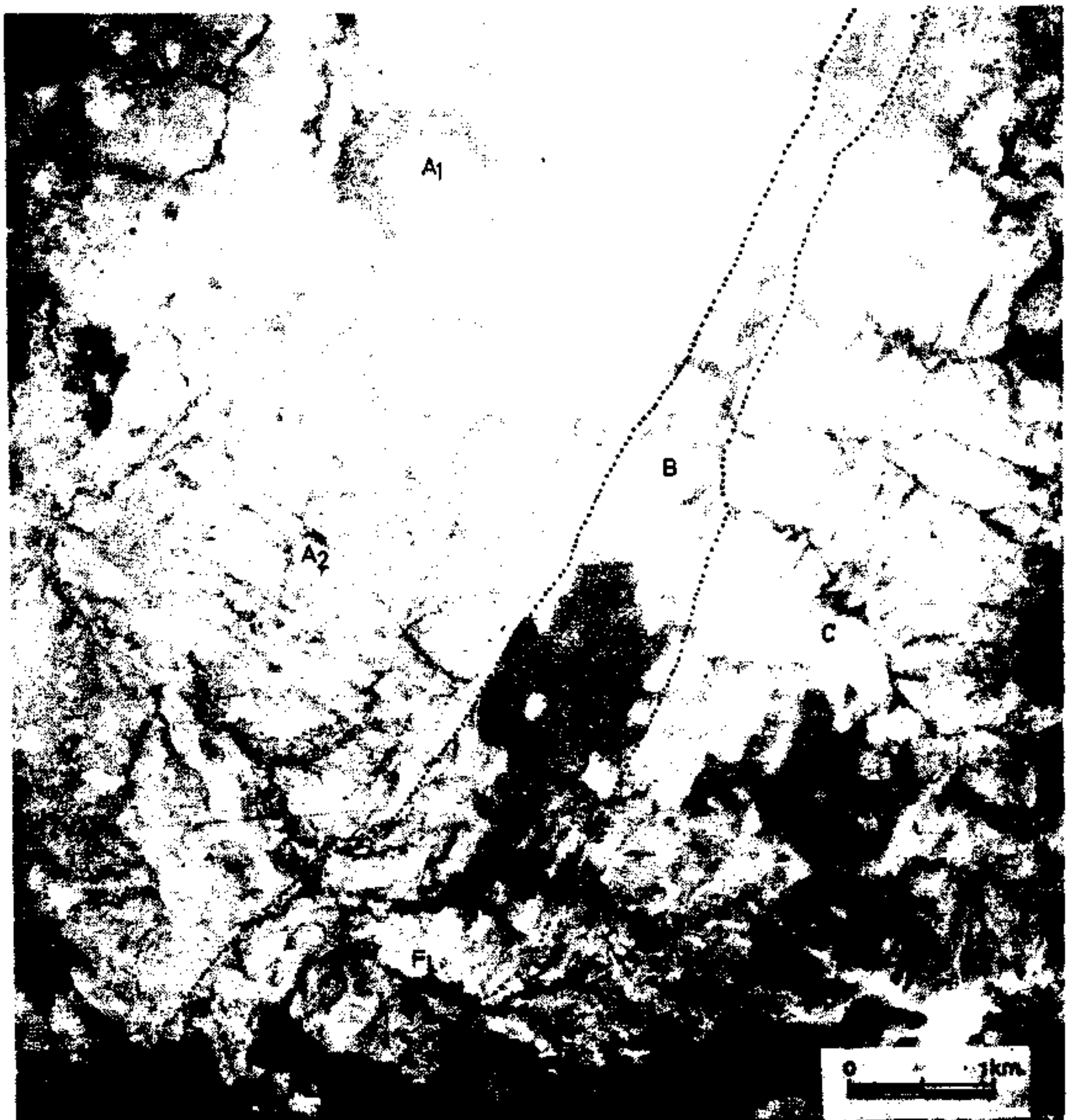

Fig. 1 — Aerial Photograph (1: 40.000) showing three Lithological units, A_1 Migmatite, A_2, Granite gneiss, B, Quartzite, Amphibolite and Banded gneiss and C, Schists. At FL, the beds show drag effect due to faulting. Line H—J is the southern boundary on the map (Fig.5). The Northern boundary of the photograph is shown on the map (K— L).

in the area. This information then enabled the field geologists both to collate the scattered field observations and to prepare a traverse plan which formed the oasis for the geological site investigation.

GEOLOGICAL SETTING AND REGIONAL TECTONIC CONTEXT

The area is underlain by Nigerian Basement Complex rocks of Precambrian age. Studies by Grant (1971), McCurry (1976), and Ball (1980)show that the Nigerian Basement Complex rocks occur in the Mobile Zone of Pan-African reactivation between the West African Craton, to the west, and Congo Craton to the southeast. Radiometric ages obtained on different rock types using several radiochronometers show that the Nigerian Basement Complex is polycyclic Grant (1971), Rahaman et al. (1983), Rahaman and Lancelot (in press). The evidence of deformation in the rocks observed in the field also confirm the polycyclic nature of this Basement Complex

Most workers agree that the Pan-African orogeny and the associated plutonic phase which is approximately 600 million years have extensive influence on the rock characterization and deformational structures in the region (Grant, 1971; Traswell and Cope, 1963; Oversby, 1975; Van Bremeen et al., 1976).

Two distinct rock groups are distinguished in the area:

1— Metaigneous and older granite group (i.e. granite gneiss, migmatite, biotite granite, porphyritic granite and granodiorite) and

2 — Metasedimentary group(i.e.quartzite,amphibolite and banded gneiss, mica schist, quartz schist and amphibolite schist).

A sharp escarpment clearly visible on both scales of aerial photographs separates the two rock groups which has been interpreted as a sheer zone (USGS, 1977) passing through the west of Kusaki (Fig. 5) in the South extending in a NNE—SSW direction (approximately N30°E). This shear zone is the extension of the shear zones observed by Ball (1980) in the Hoggar region North Central Africa, which the trend of these reasonably distant shear zones is very probably related to the deformational mechanism that is affected by the proximity and location of the cratons with respect to both areas.

Both the shear zone and the granitic plutons are cut by NW - SE and NE - SW shear faults in the area (Figs. 3 and 5). This was also observed by Ball (1980) and McCurry (1976) in the northern extent of the Pan-African Orogenic Belt. The granitic plutons

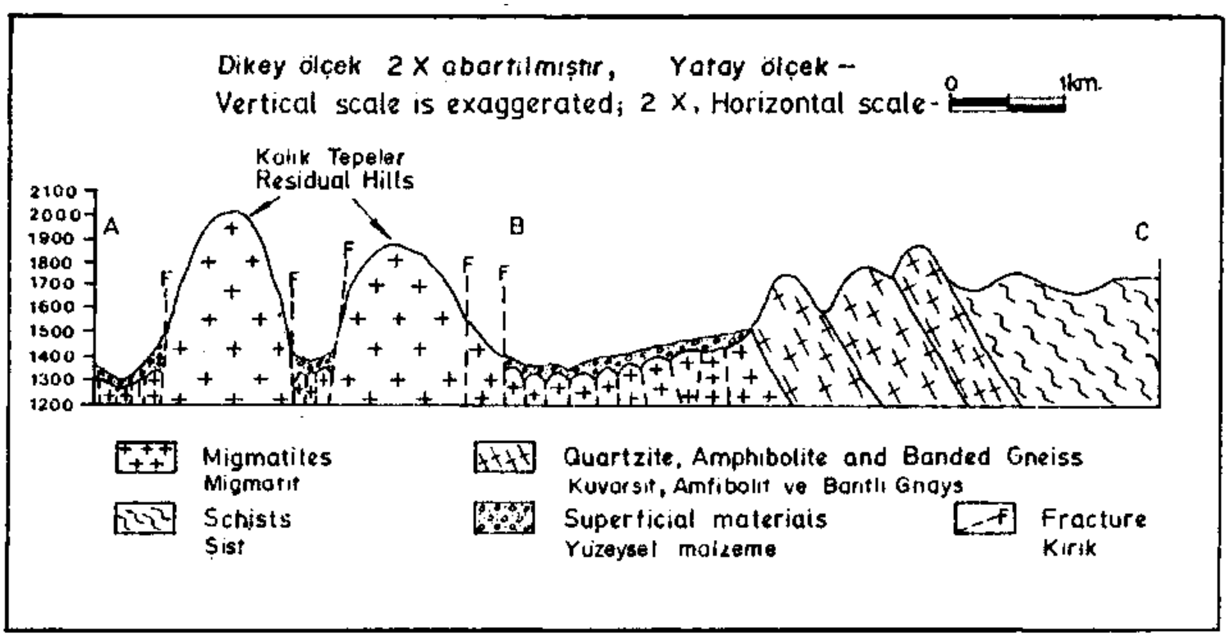

Fig. 2 — Geological cross-section along A, B and C on the map (Fig.5).

are dated as syn-to Post-Pan—African Orogeny (Grant, 1971; Traswell and Cope 1963 and Bremeen et al., 1976). Using this dating, an inference of more or less 600 my can be made as the age of the fractures. However, elsewhere in Nigeria, it was observed that the Cretaceous sediments are cut by some major faults which may have been the result of the reactivation of post Pan-African fractures (Avcı, unpublished). This faulting is the latest activity affecting the Basement Complex since the late Cretaceous period

MATERIAL AND METHODOLOGY

The remotely sensed data employed in this study are of two types :

1. 1 : 40. 000 scale black and white infra-red poor quality photographs covering a large regional area, and
2. 1 : 10.000 scale black and white panchromatic good quality photographs which covered confines of the City site.

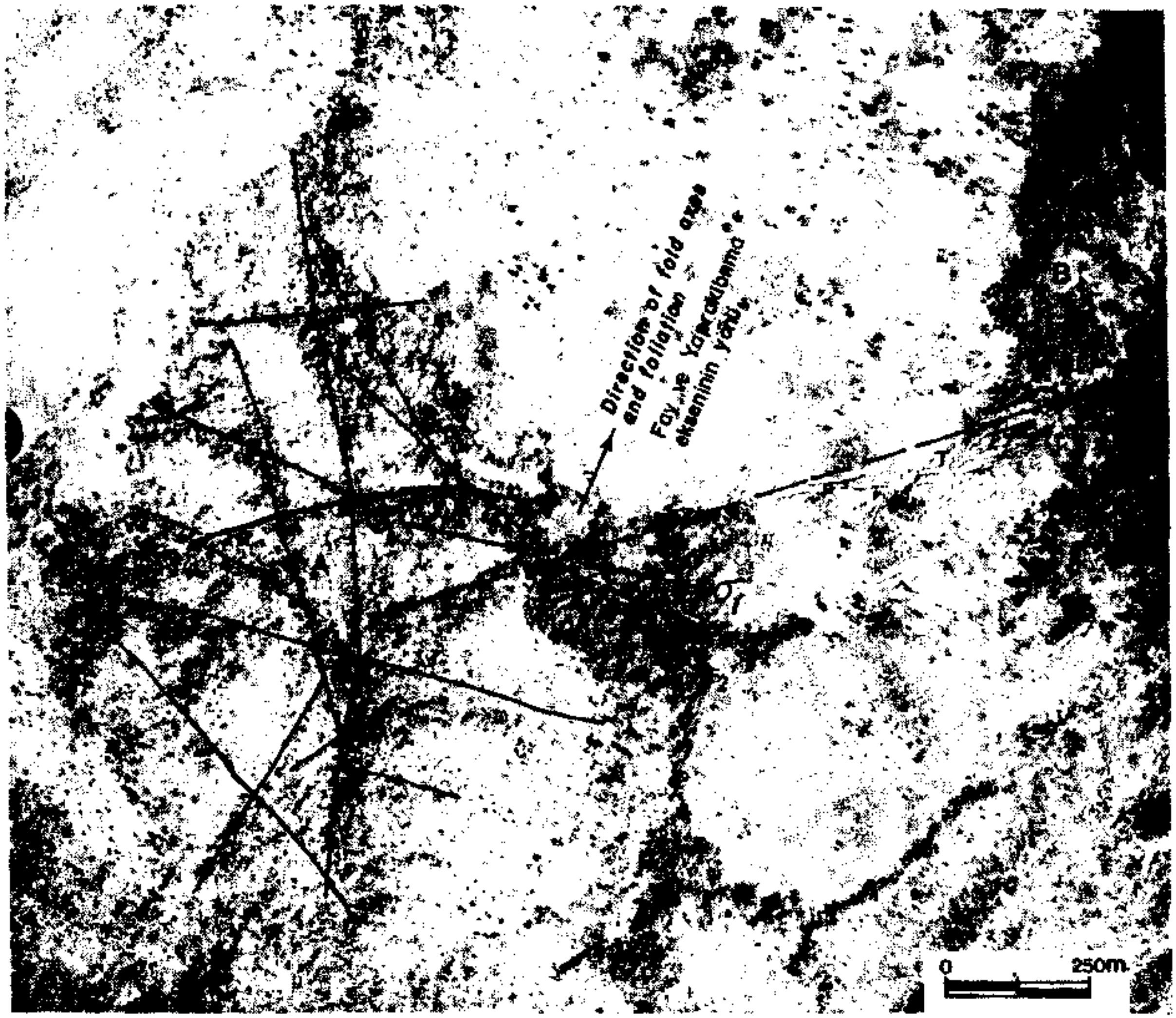

Fig. 3 — Aerial photograph (1 : 10.000) showing fractures cutting accross both the metaigneous (A) and metasediments (B) F_1 is a Shear fracture along which tin mineralization has developed. The trenching is clearly visible at T F_2 and others are also shear faults developed as a result of the same principal stress O_1

The 1 : 10. 000 scale photographs helped in solving many local scale problems. Several kinds of topographic maps also proved to be reasonably reliable when used in combination with the aerial photographs.

Geological information about the area is rather scarce. However, since the area was selected as the New Federal Capital City Site, some investigations have been carried out. These are the reports by USGS(1977), University Ahmadu Bello, Zaria (U.A.B. 1979) and the University of Ife (UNIFE 1979).

The preliminary photo interpretation started with small - scale photographs (1:40,000) in order to make a quick regional analysis of the area. This led to the identification of two major litho-structural units which have been the fundamental information of the entire study. At the 1:40,000 scale, it was also possible to discriminate some internal characteristics of each unit, and many fractures could also be traced.

The interpretation of 1:10. 000 photographs considerably improved the quantity and quality of information obtained. For example, it was possible to identify another unit within the metasedimentary group which could not be distinguished on the 1:40.000 scale photographs.

On the other hand, recognition of the. patterns representing the litho-tructural units on 1:10. 000 scale was not possible as the pattern development is poor on large scale photographs. However, the most comprehensive analysis of the geologic condition resulted from a complementary study of both photographs at both scales. For example, when an observation was made on 1:10. 000 photographs, it was necessary to examine the 1:40.000 scale photographs as well in order to correlate features with the regional structure in the area. And conversely, interpretations made with the 1:40. 000 scale were checked by 1:10.000 scale photographs for the final interpretation

AIRPHOTO PATTERN AREAS AND LITHO - STRUCTURAL UNITS

Morpho-structural units as ground features are very large. In the field it is not easy to observe and to study them, particularly when the terrain is poorly exposed on aerial photographs, the scale of these features is such that patterns are visible and reflect areas of similar morpho-structural characteristics.

In the study area, these morpho-structural patterns have evolved as a consequence of lithology and structure and determined the litho-stiwctural units. On the basis of these units, a programme for traverses and field work was prepared in such a way that each unit was appropriately field checked and sampled.

Two major litho-structural units were identified and several other subunits were distinguished as follows :

1. Area of metaigneous and older granite rocks

Granitic rocks cover 60% of the study area. The area is characterized by residual hills which are in places clustered but mostly occur as isolated individual hills. They are controlled by fractures and have slopes that are very steep (Fig.2). The tops of the hills are rounded and the process of conchoidal weathering (exfoliation) is active on all of them. The fractures across the hills have two dominant orientations (NE — SW and NW — SE) and appear as rectilinear narrow depressions which are readily identified by concentration of vegetation, a grey tonal quality on aerial photographs and by the presence of straight water courses (Fig. 1).

Three types of residual hills were distinguished which correlate with their underlying lithology :

a. Well formed, residual hills which occur in the northern area, developed in porphyritic granite, granodiorite and biotite granites all of which have similar characteristics in terms of erosion.

b. Clustered and sometimes elongated, poorly formed residual hills in the South which formed in the granite gneiss area. The formation of these hills apparently reflects the gneissic structure and are elongated parallel to the general foliation of the rock.

c. Well formed, larger, massive residual hills which have formed in migmatitic rocks. The relief of the hills in this rock type is related to the physical characteristics of the rocks which are the most resistant rock type in the area.

2. Area of metasedimentary rocks

These rocks cover the remaining part of the area and are divided into two subunits :

a. Ouartzite, amphibolite and banded gneiss : The unit consists of alternating bands of quartzite, incorporated in amphibolite and banded gneiss which are considered as one lithologic group. The thickness of the unit varies between 50 m to 1500 m.

The metasedimentary rocks display a typical trellis type drainage with a NNE—SSW trending parallel ridge and valley pattern and is readily recognised on the aerial photographs (Fig.l).

Few fractures cut across the structural trends at high angles which are the extensions of fractures developed in the metaigneous area which die out or transform into another type of deformation in this unit as a result of the different physical characteristics of the rocks. An example of this is observable along the Wosika River as a flexure at location FL in Figure 1. In this area, it was easier to trace the faults due to the off-sets produced by faulting along the structural trends (Figs.3 and 5).

b. Schists: Towards the East, beyond the unit (a), the area is underlain by mica schists and amphibolite schists which are structurally associated with unit (a) as the strike and dip of both are similar. Field measurements along a traverse from Kusaki to Buze village have shown a strike of N30°E and an average dip angle of 60°. However, deformation in these rocks has changed the trends of strike and the attitude of dips dramatically as observed in the field.

The metasedimentary unit was investigated by traverses accross the structural trends. Three traverse lines were planned along routes that were designed to retrieve the appropriate information and to collect samples.

FRACTURE ANALYSIS AND GEOTECTONIC INTERPRETATION

There is a NNE — SSW orientation of the lithological banding observable both in the aerial photographs and in micro texture of all the rock types in the area. This orientation is clearer on the aerial photographs in meta-sedimentary formations which are more readily distinguishable from the metaigneous rocks (Fig.l). In the metaigneous rock area there are only few hills with elipsoid shape and valleys which are elongated parallel to the direction of the general structural trend.

The dense fracture system and the prominent lithological orientation show that the area has been affected by a major tectonic event (Pan - African Orogeny). This event caused deformation of the rocks and produced certain strtictural features. An indication of the polycyclic nature of the Basement Complex is the chaotic micro structure imprinted in the rocks, but some minor folds are preserved with their axial planes parallel to the general lithological banding within the gneissic rocks. Major foldings, mentioned by Benkhelil in UNIFE (1979), was not observed in the area. According to the present deformations on the rocks the magnitute of Pan-African orogeny was too high to expect to find primary structural features in the area.

The analysis of photo-interpretation data and observations in the field made it possible to determine the principal stress direction in the area. Strike slip faults, oriented in NW - SE and NE - SW directions were used to elucidate this notion (Figs. 3 and .5). The strike slip sense of displacement of the faults is observable where they cut and displace the NNE — SSW lithological bandings. The proposed principal stress model, inferred from the present fracture system in the area is comparable to the models proposed both by Moody and Hill (1956) and Hobbs et al. (1976). These fractures are shown on the photogeological map (Fig. 5).

Experiments have shown that faults can represent shear fractures which develop at an angle of less than 45° to the direction of principal stress with the fold axes normal to it (Hobbs et al., 1976) . However, considering the uncertainity and the variability of the conditions (Cook, 1969; Friedman, 1972) in this principal stress, the direction of foliation and the fold axes were also used in identifying the direction of principal stress field in the area (Fig.3).

Figure 4a is a directional frequency diagram plot of 276 fractures for the whole area. The fractures oriented 140° — 165° , all of which represent the NW — SE shear fault directions, are the longest and most frequent. The small peak at 70° is the NE — SW shear faults. In this case, the very small cluster along 110° represents the extension fractures developed along the direction of principal stress (O_1). The clusters at 20° and 35° directions are the extension fractures formed along O_1 and parellel to the fold axes and foliation plane which postulates the presence of principal stress direction in a WNW — ESE trend.

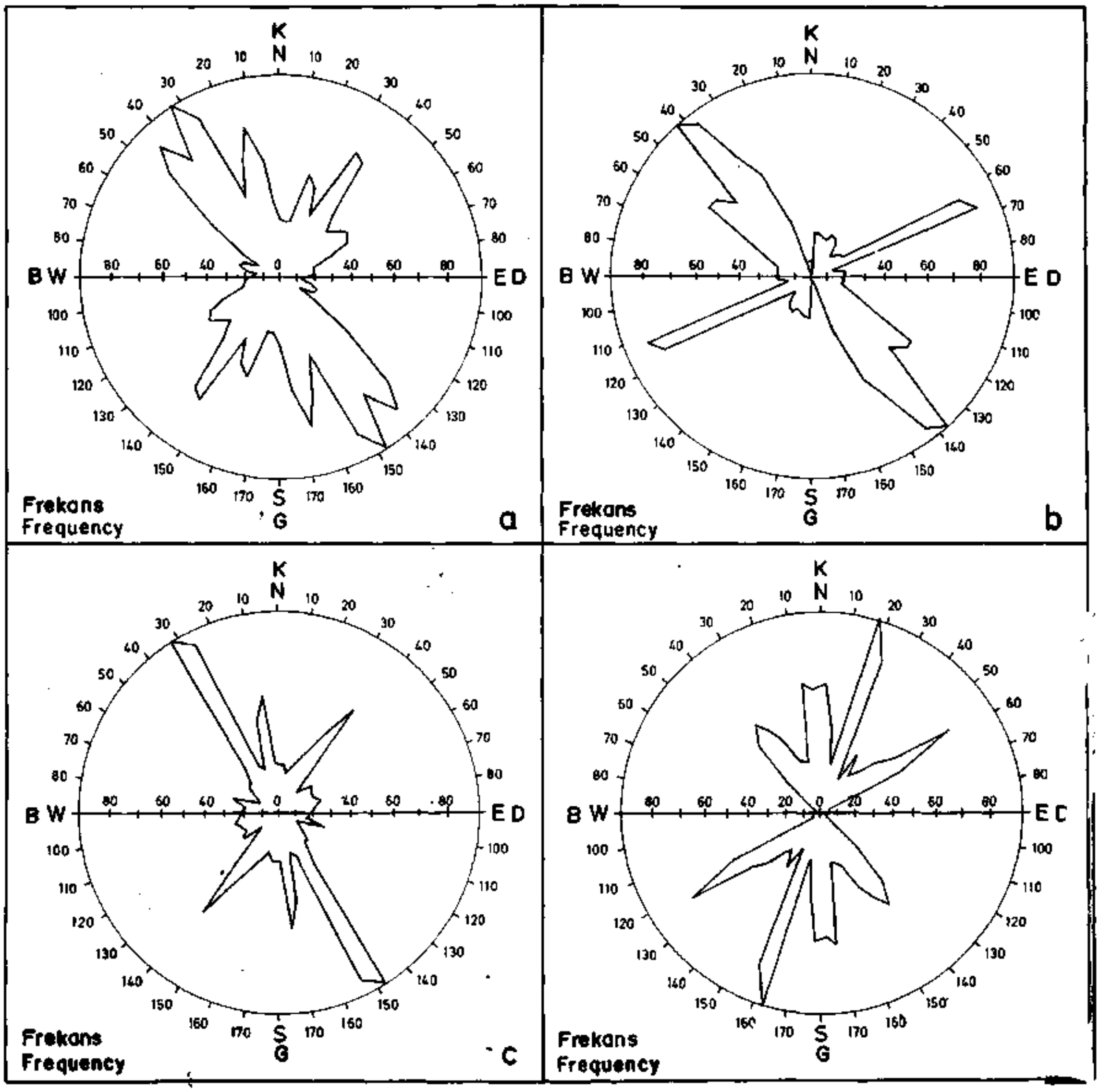

Fig. 4 — Rose diagrams plots of variable amount of fractures from different parts of the study (The class interval for each figure is 5 degrees.)

Considering the formation of Pan - African Orogeny by the movements of the two rigid craton masses as mentioned earlier, the principal stress field obtained is in concordance with the geographical location of the cratons as the sources of compression which are also in a WNW — ESE direction with respect to the Nigerian Basement Complex.

Rose diagrams (Figs. 4b, c and d) were prepared from data from the different parts of the area to observe the effect of the deformation characteristics on different rock types. A comparison of these diagrams with each other shows visible differences which are attributable to the different rock characteristics. For example, Figure 4b is a frequency diagram of 40 fractures occurring in the migmatite area. These are shown to occur in 2 clusters at 65° and 140°. However, NW — SE oriented fractures are dominant and frequent and the two main clusters on the diagram are the shear fractures reflecting the criss-cross fracturing. These indicate an unimodal rock character. The (O_1) principal stress direction can be inserted along 100° cluster set.

Figure 4c is a frequency diagram of 50 fractures from a porphyritic granite area where major faults have clustered at 150°. Clusters at 40° appears to be the representation of NE — SW shear fractures. The (O_1) direction is around 105°. The irregular distribution of the frequency directions reflects a near unimodal rock characteristic.

Figure 4d represents 51 fractures mapped in the southwest corner of the area that is underlain by granite gneiss and banded gneiss. The diagram illustrates a different trend of fracturing in this part of the area. The main frequency directions of fracture in this area are in NNE — SSW direction, the highest cluster is around 20° NE and also a great concentration in a northern direction. This change in frequency direction of fracture, is due to the strong foliation direction which parallels the direction of weakness in these rocks. The clusters at 60° and 140° are the shear fractures; hence, (O_1) principal stress direction at 100° southeast.

Directional frequency diagrams of fractures alone are not adequate information for analysis. Thust, other parameters, like fracture density and fracture frequency calculations, were also carried out.

For example, relation ship of the number of fractures and their length to surface area depends on the strength of the substrate. By calculating the fracture density and fracture frequency, the relative visible state of brittleness of an area can be more realistically determined.

The fracture density is defined as the total length of all the recorded fractures divided by the area that include these fractures.

$$Fd = \frac{\Sigma L}{A}$$

Where Fd = Fracture density
L = Total length of all fractures
A = Area

One hundred and seventy four kilometers of fractures were identified in an area of 142 km^2 within igneous rocks that underlie the area of the City Site.

$$\textbf{Therefore : } FD = \frac{174}{142} = 1.225$$

This fracture density value falls in the range of high fracture density (Vielon et al., 1976).

Another important quantitative measurement is the fracture frequency, defined as the number of visible fractures per unit area.

$$\text{i.e. } Ff = \frac{\Sigma F}{A}$$

Where Ff = fracture frequency
F = total number oı fractures
A = Area

$$\textbf{Thus : } Ff = \frac{276}{142} = 1.943.$$

This is a medium to high fracture frequency according to Vielon et al. (1976). The density and frequency calculations for metasedimentary area showed very low values that reflect their plastic characteristics.

These simple statistical analyses outlined above show that the area is fairly densely fractured. However,

PHOTOGEOLOGICAL MAP OF THE PART OF THE AREA

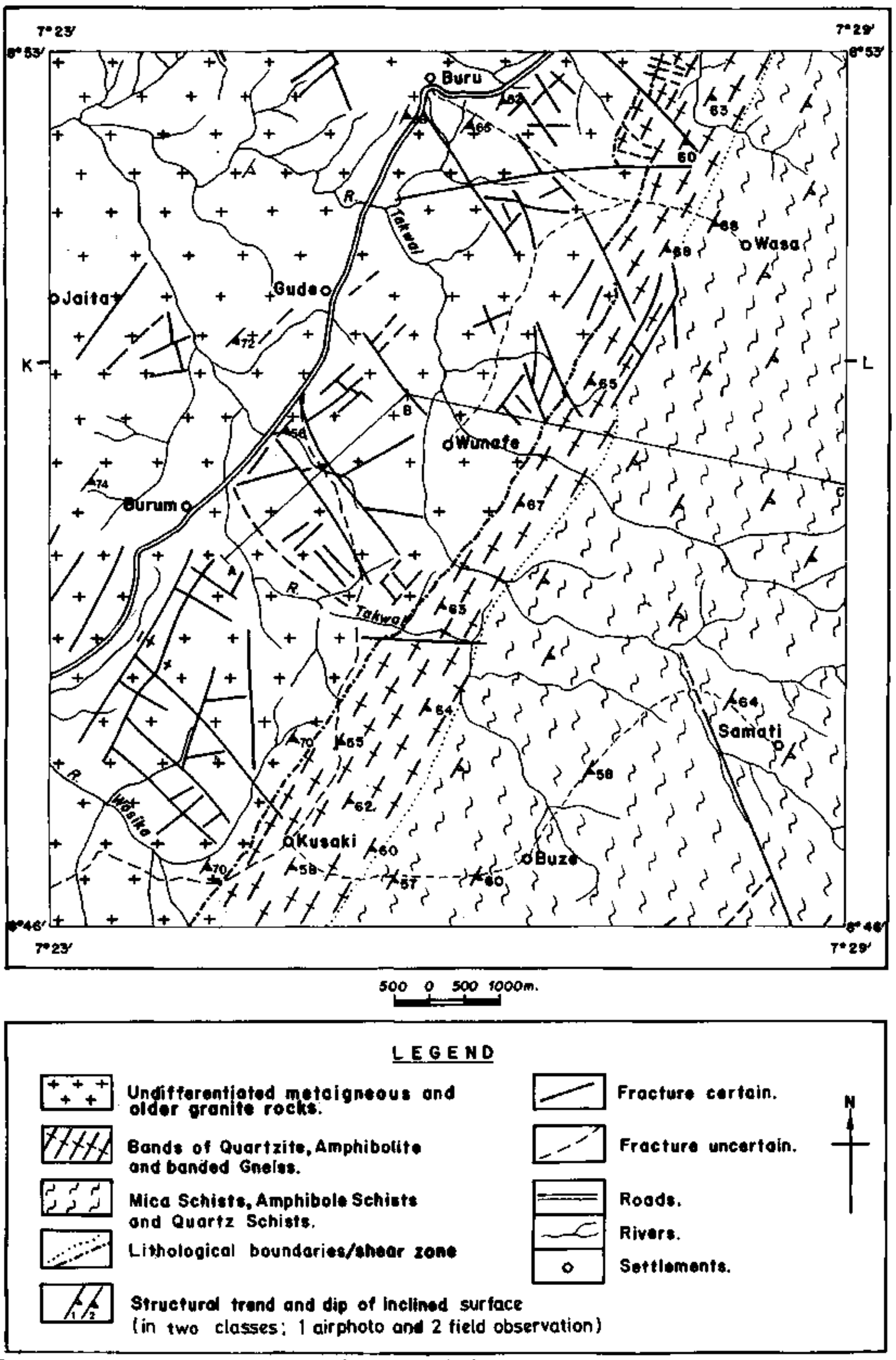

Fig. 5 — Photogeological map of the part of the area.

information on the tectonic history of the area shows that Nigerian Basement Complex rocks were stabilized after the Pan-African Orogeny (600 million years ago or less) and related plutonic phase(Grant,1971). There are no written or oral records of earthquakes in the region.

The area underlain by undifferentiated metaigneous rocks is stable, bears high strength parameters (Krynine and Judd, 1969) and has a gentle topography with occassional residual hills forming an attractive landscape.

The metasedimentary area, on the other hand, is topographically rather rugged and the section underlain by schists have a low shearing capacity (UNIFE, 1979) and thus may create unstable conditions for founding structures.

Therefore, the area underlain by undifferentiated metamorphic igneous rocks (Fig. 5) is recommended as the development site for the proposed Capital City. The infrastructure of Abuja City is now nearly completed. The Governmental offices are expected to move into the residents soon.

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