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Aspects of Geology of Ganawuri Area of North Central Nigeria: Evidence from Field, Petrographic and Geotechnical Studies

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Abstract

Geological and geotechnical investigations involving detailed geologic mapping and composite soil sample laboratory tests respectively, have been carried out at Ganawuri, North Central Nigeria with a view to delineating the different rock units in the area and their Engineering significance. The area is underlain by the Crystalline Basement rocks composed of Granite Gneiss with late Diorite, Basalts and Pegmatite intrusions. The older units have been intruded by the Biotite Granite of the Younger Granite province, occurring as a ridge bordering the northeastern margin of the area. Structures observed in the area include fault/shear zones, pegmatite dykes, basaltic dykes and fractures. The dominant trend is in the NE-SW direction with local deviations in NNE-SSW, WNW-ESE, NW-SE and NNW–SSE. The joints are generally vertical with few dipping steeply to the SE or SW. Thus it is evident that the early NNW-SSE trending foliation in the granite gneiss guided the regional structural development in the area. This feature thus controlled all the other structures (anticline, shear zones, fractures and the river channel), all of which are oriented in the same direction. This dominant NE-SW trend may be associated with development of the Benue Valley of Nigeria. Composite soil samples were obtained at different points around the area and laboratory analysis carried out on them. Using the Unified soil classification system (USCS), soil sample I was classified as SM soils with zero plasticity, samples 2 and 3 soils were classified as SC, CL and SC, OH soils with medium and high plasticity respectively. Results also showed that while sample 1 soil has low potential expansiveness, samples 2 and 3 soils have medium and high potential expansiveness respectively. The Specific Gravity values range from 2.53 to 2.64 and decreases towards the Northeast. The Natural Moisture Content and Coefficient of Curvature variations in the area show similar trend. Both decrease towards the Southwest and have values ranging from 4 to 12.5% and 0.86 to 1.09 respectively. The Uniformity Coefficient increases towards the south and decreases towards the Northwest with values ranging from 11 to 19.5. The 3-D display of both the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) shows opposing trend in variations as MDD decreases towards the North while OMC increases towards the North. In both soil samples, the values of the Skewness lies between 0.5 to 1.0 and as such can be said to be positively Skewed (strongly fine Skewed). Moreover, the value of Kurtosis for the three samples lies between 1.11 to 1.66 and can be said to be Leptokurtic. They can be said to be well to moderately well sorted because of the range of values for sorting (Standard Deviation) lying between 0.35-0.71 indicating competence for engineering works. Based on the investigations carried out, it is suggested that further analysis through coring at the shear zones be carried out and consolidation grouting may be needed to reduce deformability and increase mechanical strength at these zones.

Keywords: Biotite Granite, Foliation, Ganawuri, Geotechnics, Petrography, Shear zone.

Introduction

Many authors have studied extensively the Younger Granites of Nigeria. The most prominent of these authors was Falconer (1903) who made the distinction between the Younger and Older Granites. He opined that the Older Granite is supposed to be 550m years old (Pan–African), while the average age of the Younger Granite is 165 +5m years (Jurassic). Jacobson et al (1958) had a thorough study of the mode of emplacement of the Younger Granite taking Ririwai ring complex as case study and proposing two different cycles of emplacement (Volcanic and plutonic phases). The earliest geophysical work carried out on the Plateau area were for exploitation purposes and was said to cover an area of not more than 500km^2 (Ajakaiye, 1976). Electrical Resistivity and Magnetic methods were used to locate the channels of old rivers buried by volcanic/alluvial materials thus enabling a reduction in the amount and cost of exploitation and drilling in the search of tin minerals (Shaw, 1951). An aeromagnetic map (sheet 168, Naraguta, S.E.) covering a limited part of the Younger Granite province has also been published (Canadian Aero–Service Limited, 1963). Gravity, Seismic, Resistivity and Magnetic techniques were used in the study of sub-basalt deposits (Mason-Smith, 1965). The results show that Gravity and Seismic methods were equally useful. Detailed Gravity work on a 122m^2 grid was recommended in using both shallow (Shot holes and hammer) test surveys were carried out with the main purpose of finding the relative usefulness of these methods in mapping the bedrock topography under the hard basalt (Ajakaiye 1975). Ibe (1983) studied the Zaranda Younger Granite and concluded an emplacement through a pre-existing structure within the Basements. Any construction work within a given area normally requires adequate and thorough understanding of the subsurface geology and engineering properties of the materials occurring in the area (Ibe 1999). The geological investigation involved detailed geological, structural and petrographic studies. This was followed by a geotechnical investigation which involved the determination of engineering properties and characteristics of the soils underlying the Ganawuri area. Ejeh I.O and Ugbe C.F (2010) observed that the jointing features on the younger granite rocks around Fobur, northern Nigeria occurred in an anorogenic setting. They stated that the joint structural trend in the Younger Granite rocks replicated those found in the surrounding orogenic basement rock exposures. This could reflect the likely existence in the host Migmatite-gneiss-quartzite complex imposed residual stresses of the Pan-African event that were not fully relieved.

The Study Area

The area of investigation is located within latitudes 9°37.473'N and 9°37.58'N and longitudes 8°38.763'E and 8°39.072'E. It is covered by the Federal surveys of Nigeria topographic map (Naraguta sheet 168SW) of scale 1:50,000. The area can be reached through a motorable road that branches at the Riyom town along the Jos – Kafanchan express way. It is located at about 60km SW of Jos and 9km West of Hose Railway crossing. The Ganawuri area is sparsely populated and dominated by people of the Angas tribe. They live in thatched houses which are mainly based on topographic advantage as same are erected on the low land areas. Their major activity is farming. Their major cash crops are millet and Sorghum; these are favoured by the presence of flood plain vegetative cover in the area. There are also settled Fulani cattle men and some Berom-speaking people. The study is aimed at mapping the geologic units and associated structures underlying the Ganawuri area and determining the geotechnical properties of the soils in the area.

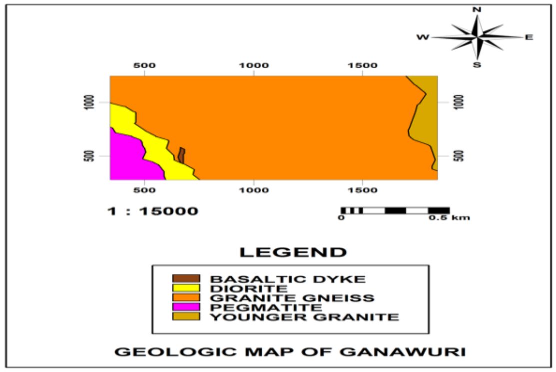

Figure 1. Geological Map of the study area.

Methodology

Geological Studies

The two major rock units observable in the Ganawuri complex which reveal two clearly defined cycles of intrusions are the Crystalline Basement and the Younger Granite. The Cystalline Basement comprises largely of Granite Gneiss, Diorite, Basalt and Pegmatite as the major rock types. This order, from Granite Gneiss through Diorite, Basalt to Pegmatite indicates younging direction. The only rock type of the Younger Granite is the Biotite Granite. These are shown on the geologic map of the area (figure 1). The field occurrence, hand specimen and microscopic studies of these different rock types are as discussed below:

Crystalline Bassement Rocks

Granite Gneiss

Field occurrence

The Granite Gneiss forms the main rock unit in the area and acts as country rock. Outcrops of the Granite Gneiss in some places show intense and ptygmatic folding (Plates 1 and 2). In some areas, they show parallel quartz dykes and enclaves to the intruding basaltic matter (Plate 3).

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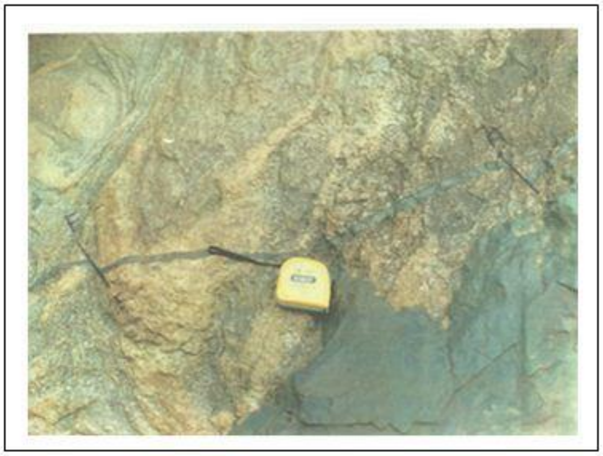

Plate 1. Ptygmatic folding on the Granite Gneiss (Note both structural control and NE Micro Faulting)

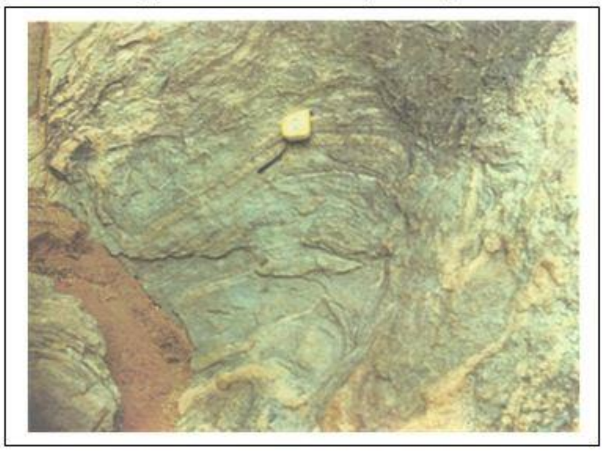

Plate 2. Intense folding on the Granite Gneiss indicates high pressure in the NE-SW direction

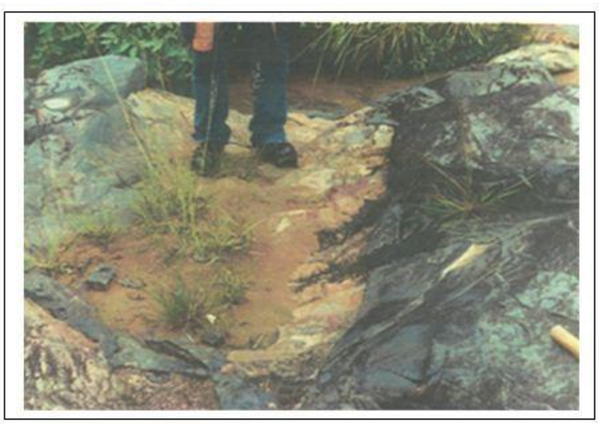

Plate 3. Enclave of the older Granite Gneiss in the intruding Basaltic matter

Hand Specimen Study

This rock unit is grey to dirty white in colour. Texturally, it is medium grained with coarse porphyroblastic feldspar grains seen as crystalline patches on its surface. It is a mixed rock and as such referred to by many authors as Migmatite.

Microscopic Study

Under the plane light, biotite, ferromagnesian minerals and hornblende are arranged in definite directions and are alternate to the leucocratic minerals. Biotite has relative higher relief with rounded pleochroic halos typical of mica from basement areas (Plate 4). Under crossed nicols, the banding between light and coloured minerals is distinctively shown (Plate 5). In the plate, the different extinction-angles for grain of quartz signify not only metamorphic characteristics but of possible straining occasionally of high pressure. Mineralogical association is as follows: Quartz–Mica–Hornblende–Feldspar. This is indicative of medium grade metamorphism. Also with this association, the original rock is probably Granite. The presence of late Pegmatitic and basic intrusive bodies near this body probably raised the grade of metamorphism from low to medium.

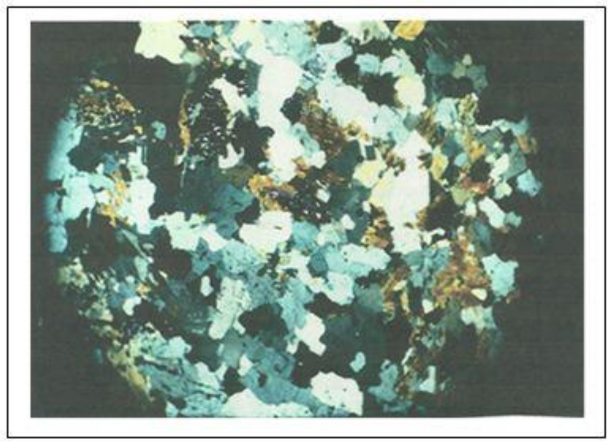

Plate 4. Photomicrograph of the Granite Gneiss showing mineral affiliation/orientation under PPL

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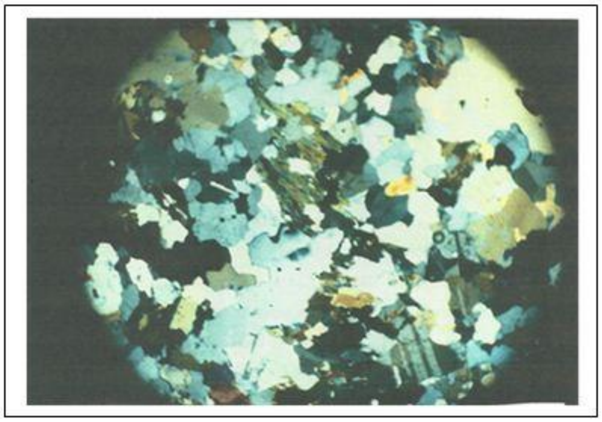

Plate 5. Photomicrograph of the Granite Gneiss showing mineral affiliation/orientation under XPL

Diorite

Field Occurrence

This rock unit occurs as dyke intruding the older Granite Gneiss. In some places, occasional thin stringers and veins of Leucocratic Granite or Pegmatite cut the Diorite; thus the Diorite is older than the Pegmatite from the cross cutting relations. It trends nearly NE-SW.

Hand Specimen Study

The Diorite is pale grey in colouration. It is medium to fine grained in texture and the grains are equiangular. Ferromagnesian minerals and minute feldspar –filled cracks are observable.

Microscopic Study

Under the plane light, strands of Labradorite are set in a ground mass of augite, iron oxide, pyrite and smaller feldspar grains shown in Plate 6. Sections of the microscopic views indicate more fine-grained nature probably resulting from chilled margin. It weathers in spheroidal manner similar to that of dolerite. Under the crossed light (Plate 7), a modal estimate of the mineralogy is given as Feldspar 50%, Iron Oxide 20%, Quartz 5%, Augite 15%, Pyrite 5% while Accessory minerals make up to 5%.

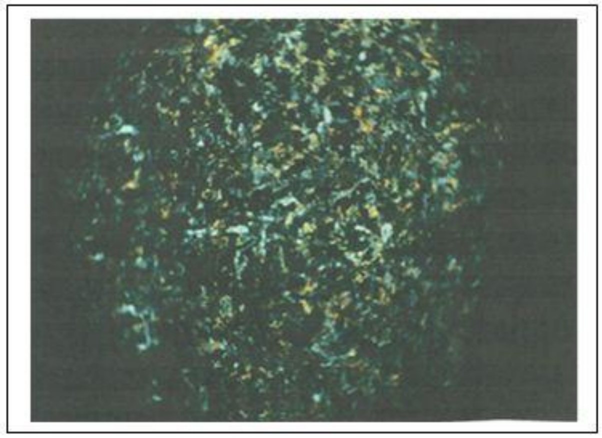

Plate 6. Photomicrograph of Dioritic dyke under PPL (Note chilled marginal effect and Feldspartic veins)

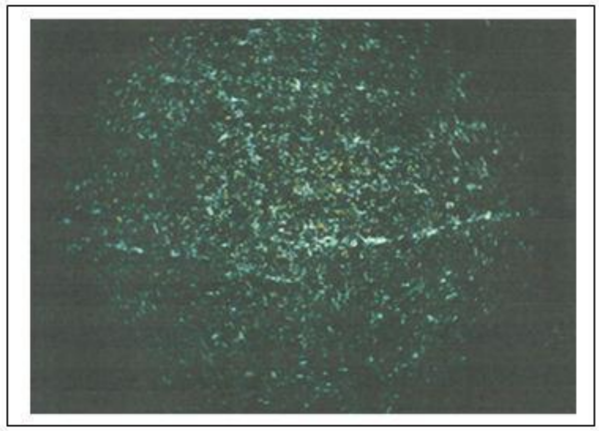

Plate 7. Photomicrograph of Dioritic dyke under XPL (Note chilled marginal effect and Feldspartic veins)

Basalt

Field occurrence

This, like the Diorite, occurs as dykes mainly cross-cutting the older Granite Gneiss particularly along the stream bed in the area. The major trend is N20^{o}E (NE-SW) and dipping 65^{o} to the SE. The width of the basaltic dyke along the axis ranges from 1.4 to 1.5 meters as measured in the field (Plate 8). There are vertical joints and micro-faulting on the surface of the basaltic dyke (Plate 9). Its relationship with the Granite Gneiss suggests that the Basalt is a later event, unlike Pegmatite and Dioritic rock units.

Plate 8. Forceful injection of Basaltic matter into the pre-existing Granite Gneiss

Plate 9. Joint pattern typical of the newer basalt that acts as a dyke (Note the micro faulting)

Hand Specimen Study

The Basalt is grey in colour. It has strands of plagioclase minerals occupying a particular lineation on the rock mass. Texturally, it is medium grained. Large grains of Feldspar measuring up to 1.5cm are rimmed with greenish minerals possibly Olivine.

Microscopic Study

Under the microscope, strands of Labradorite are set in a ground mass of smaller grains of augite, Iron oxide, pyrite and accessory minerals (Plates 10 and 11). The Ophitic texture is typical of Dolerite and has been interpreted as having association with Younger Granite that outcrop NE of the survey area. It is worthy of note that the basic rocks are confined to the southern and southeastern ends of the area. To the North and north east, the terrain gives way to relatively high weathering. Modal estimate for the dolerite is as follows: Feldspar 55%, Augite 5%, Iron Oxide 20%, Pyrite 5%, Olivine 2-5% while others are less than 5%.

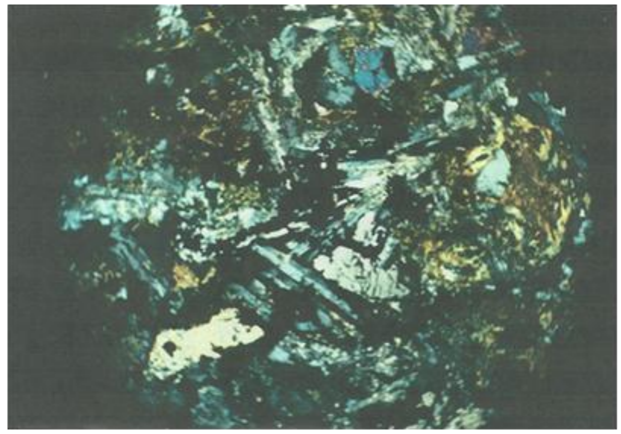

Plate 10. Photomicrograph of Basaltic dyke under PPL (strands of Labradorite are seen in Augite and Pyrite Ground mass)

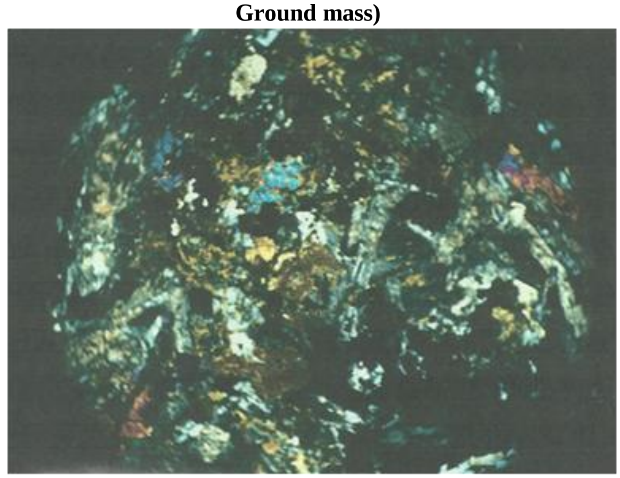

Plate 11. Photomicrograph of Basaltic dyke under XPL (strands of Labradorite are seen in Augite and Pyrite Ground mass)

Pegmatite

Field occurrence

This occurs as massive dykes mainly in the western and central parts of the area. In some places, it occurs as quartz-tourmaline pegmatite in association with Granite Gneiss (Plate 12).

Hand Specimen Study

The Pegmatite is creamy white in colour. It is coarse grained and as such cannot be studied under microscope. The pegmatites have zoned microcline, quartz and muscovite as the major mineral components. The marginal parts are aplitic and/or feldspathic while the core contains mainly quartz, muscovite and black tourmaline

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Plate 12. Quartz-Tourmaline Pegmatite associated with the Granite Gneiss

The Younger Granite rocks

The Biotite Granite

Field occurrence

This occurs as ridge (ring dyke) bordering the Northeastern margin of the area. There are equally large boulders along the base of the ridge. Some parts of the Younger Granite have been fractured and weathered to some degree and these planes act as sediment receptacle and as such support luxuriant vegetation observable at the flanks of the Ganawuri Hill (Plate 13). There is a clear geologic contact between the Biotite Granite ridge and the Granite Gneiss (Plate 14).

Plate 13. Shear zone acting as sediment receptacle (Note luxuriant vegetation at the flank of Ganawuri hill)

Plate 14. Geologic contact between Granite Gneiss and Ganawuri complex

Hand Specimen Study

The Biotite Granite is coarse-grained in texture. Its colour grades from light brown to straw yellow. It has dark patches and disseminated shinny particles on its surface which can be linked to the presence of Biotite and Quartz respectively as the major minerals.

Microscopic Study

Under plane light, apart from hornblende and biotite, all other minerals have very low relief. Grain sizes ranging from 1mm to over 1cm make the granite porphyritic. Minerals identified are Microcline, feldspar, quartz, biotite, hornblende. Accessory minerals include Zircon and Garnet. The presence of garnet makes the granite rich in alumina. The modal composition of the Ganawuri Biotite Granite is as follows; Quartz 20%, Hornblende 5%, Feldspar 65%, Biotite 5% and Accessory minerals less than 5%. Intergrowth of quartz and feldspar is common as seen in the northern part of Plates 15 and 16. There appears to be recrystallization of Biotite inside the feldspar.

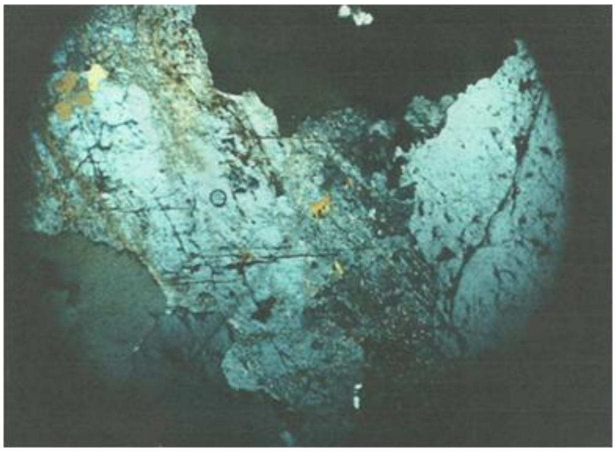

Plate 15. Photomicrograph of the Ganawuri Biotite Granite under PPL (Microcline, Biotite and Quartz are evident)

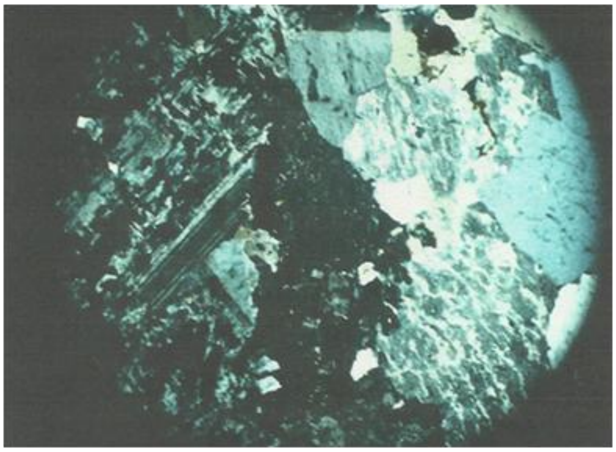

Plate 16. Photomicrograph of the Ganawuri Biotite Granite under XPL (Microcline, Biotite and Quartz are evident)

Structural Geology

The area under investigation lies entirely within the migmatitic Granite Gneiss complex that is foliated and deformed into ptygmatic folds. The foliation trends N160^o with moderate dip (about 50^o on the average) to ENE or WSW (Figure 2a), thus defining a local NNW-SSE trending anticlinal axis. The foliation is defined by the alignment of quartz veins, schistose enclaves and the ferromagnesian minerals. Other structures observed in the area are fault/shear zones, Pegmatite dykes, Basaltic dykes and fractures.

Fault/Shear Zones

Two major trends of fault zones were observed in the area. The first one occurs in the western part of the area, and trends N165^o on the average, with an average dip of 50^o to the WSW (Figure 2d). Crushed and recrystallized rocks of pegmatitic character with horizontal striation planes occur, indicating a possible strike–slip feature, characterizing the zones. The width of this zone was estimated to be 100m with the length cutting across the entire area of study. A transitional zone grading from crushed rock to foliated Diorite and to undeformed Granite Gneiss characterizes the eastern contact of this zone. The second one trends N15 ^{o} and within a sheared and recrystallized Granite Gneiss. Tourmaline–Pegmatite was also observed in this zone which measures about 30cm by 15cm (Plate 12).

Pegmatite and Basaltic Dykes

Pegmatite dykes occurs in the western and central parts of the area of investigation. Its dominant trend is NE-SW with steep to vertical dip (Figure 2b). Massive dyke of Basalt crosscut the Granite Gneiss outcrops observed within the river channel. The major orientation is N20^o (NE-SW) and dipping 65^o to the SE (Figure 2b); the width is in the range of 1.4 to 1.5 meters.

FRACTURES AND JOINTS

Series of fractures and joints were observed to affect all the major rock units in the area including the dykes. The dominant trend is in the NE-SW direction with local deviations in NNE-SSW, WNW-ESE, NW-SE and NNW–SSE. The joints are generally vertical with few dipping steeply to the SE or SW (Figure 2c). Thus it is evident that the early NNW-SSE trending foliation in the Granite Gneiss guided the regional structural development in the area. This feature thus controlled all the other structures (anticline, shear zones, fractures and the river channel), all of which are oriented in the same direction. Finally, this dominant NE-SW trend may be associated with development of the Benue Valley of Nigeria (Ajakaiye 1976).

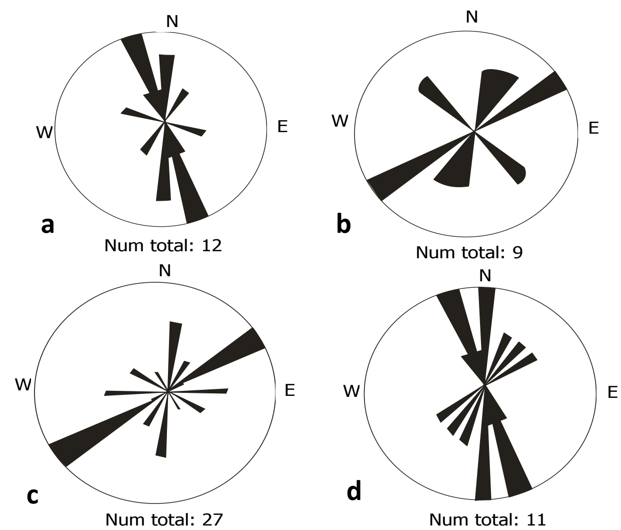

Figure 2. Rose diagrams showing trends of structures in the area (a) Foliation in Rocks of Ganawuri (NNW-SSE) (b) Pegmatite and Dolerite dykes (NE-SW) (c) Fracture (NE-SW) (d) Shear zones NNW-SSE)

Geotechnical Studies

Three soil samples were collected from pits dug up to a depth of 2m in the area. The samples were taken at different depths to ensure heterogeneity and to obtain a complete representative and fresh sample of the soil. They were put in air tight sample bags and then taken to the laboratory for analyses. To ascertain the physical and mechanical properties of the soil and to evaluate their potentials as construction materials, the following tests were carried out: Grain size analysis, Atterberg limit, Compaction test and Specific Gravity test. The results are summarized in Table 1 below:

Table 1. Results of the Geotechnical Study

Geotechnical Parameters	1	2	3
Natural Moisture content, (W)	4.3	10.7	12.1
Specific Gravity, (Gs)	2.60	2.64	2.54
Optimum Moisture Content (OMC) (%)	10.1	14.4	16.3
Maximum Dry Density (MDD) (Kg/m³)	1540	1490	1510
Liquid Limit (LL) (%)	35.5	40.8	55.8
Plastic Limit (PL) (%)	/	17.9	30.4
Plastic Index (PI) (%)	/	22.9	25.4
Liquidity Index (LI) (%)	/	-0.31	-0.71
Compressibility (λ)	/	0.131	0.14
Void ratio (e)	11.2	28.2	30.7
Activity of clay (A)	/	1.12	0.78
Coefficient of Uniformity (Cu)	19.44	11.25	17.33
Coefficient of curvature (Cc)	0.87	0.96	1.08
Mean (X)	0.32	0.49	0.34
Median	0.23	0.25	0.16
Standard Deviation (SD)	0.39	0.65	0.43
Skewness (Sk)	0.55	1.05	0.73
Kurtosis (K)	1.36	1.65	1.36

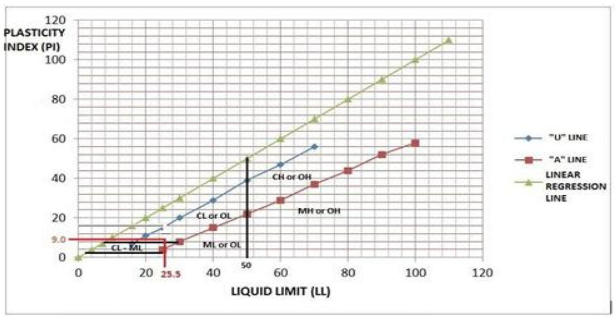

Figure 3. Plot of Plasticity index against Liquid Limit (Casagrande Chart)

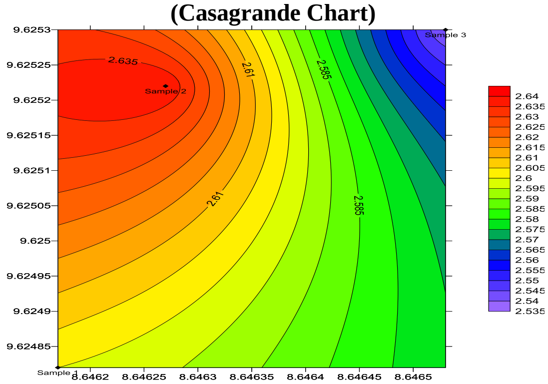

Figure 4. Variations of Specific Gravity in the area

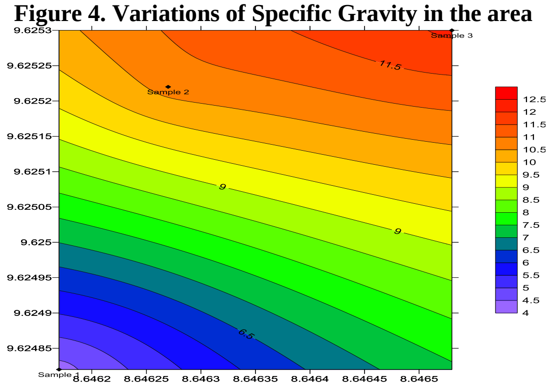

Figure 5. Variations of Natural Moisture Content in the area

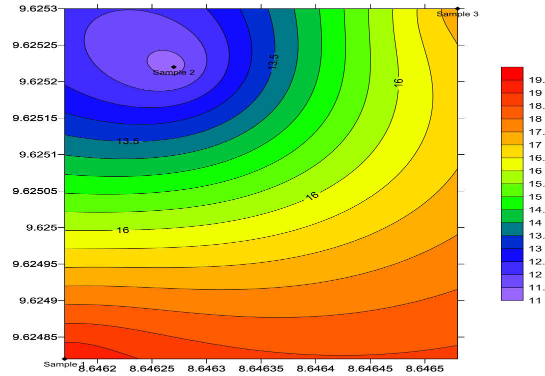

Figure 6. Variations of Coefficient of Uniformity in the area

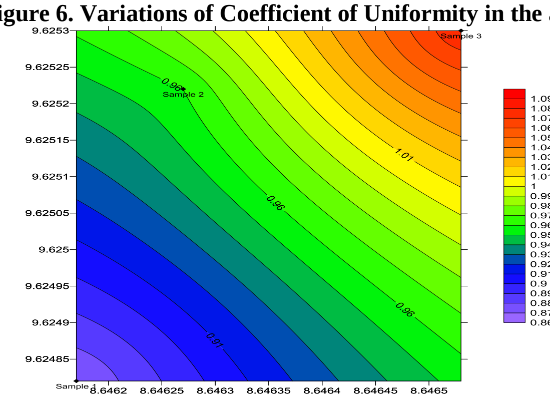

Figure 7. Variations of Coefficient of Curvature in the area

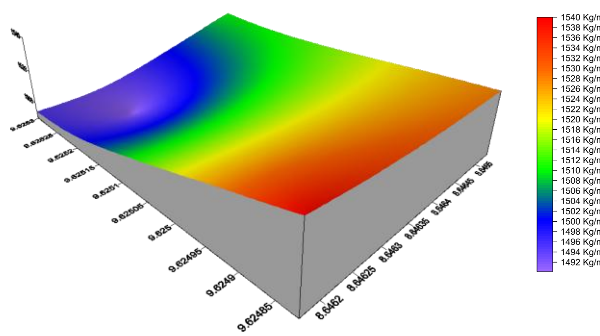

Figure 8. 3-D display of Maximum Dry Density variation in the area

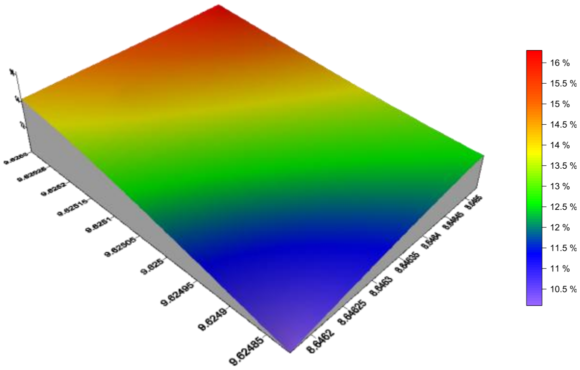

Figure 9. 3-D display of Optimum Moisture Content variation in the area

Discussion of Results

Geology

The result of the geological investigation reveals five major rock units viz: Granite Gneiss, Diorite, Basalt, Pegmatite and the Biotite Granite. There are structural features like fault/shear zones, fractures, Basaltic and Pegmatite dykes. These structures, along their major directions, are weak zones that may permit fluid infiltration and structural failures. Also, percolation of water may be facilitated through these structured directions, removing filler materials which may be occupying the fractures. This in turn could lead to differential settlement of the foundations. Slight opening of joints on excavation may lead to sliding of large boulders to appreciably reduce the strength of the rock mass. The trend of these structures suggests both activities through pre-existing pathway and forceful emplacement.

Geotechnics

From the result of the dry sieve analysis and computation, one can regard the soil underlying the Ganawuri area as being well graded sequel to the fact that the Coefficient of Uniformity (Cu) in each case is greater than four (4), and also the coefficient of curvature in each case lies between 0 and 3. On the Unified soil classification system adopted after Casagrande (1948), sample 1 can be classified as SM soil, sample 2 as SC, CL soil; sample 3 is SC, OL soil. From the plot of plasticity chart (Figure 3), sample 2 fell above the A-line and within the intermediate range and as such can be classified as inorganic clays of medium (intermediate) plasticity. Sample 3 fell below the A-line and within the high plasticity range and thus can be classified as inorganic silts of high plasticity. Because of its non-plasticity index value, Sample 1 did not plot on the graph and as such can be said to be non-plastic. This can be attributed to the presence of Pegmatite and low weathering grade within the area. The liquid limit, plastic limit, as well as the plasticity index of sample 3 is greater than that of sample 2 (Table 1). This shows that sample 3 soils have greater tendency to swell or shrink than sample 2 soil. Also sample 3 has higher tendency to resist being compressed based on its comparatively higher compressibility than sample 2. The Specific Gravity values range from 2.53 to 2.64 and decreases towards the Northeast (Figure 4). The Natural Moisture Content and Coefficient of Curvature variations in the area show similar trend (Figures 5 and 7), both decreasing towards the Southwest and having values ranging from 4 to 12.5% and 0.86 to 1.09 respectively. The Uniformity Coefficient increases towards the south and decreases towards the Northwest with value ranging from 11 to 19.5 (Figure 6). The optimum moisture content for sample 3 is greater than that of sample 2 which is in turn greater than that of sample 1. This means that to compact and load the soils in the field, sample 1 needs to smallest amount of water to bring it to its maximum dry density than sample 2; whereas sample 3 requires the higher moisture content than sample 2 which in turn has higher moisture content than sample 1. The 3-D display of both the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) shows opposing trend in variations as MDD decreases towards the North while OMC increases towards the North (Figures 8 and 9). The void ratio is the ratio of the volume of voids to the volume of solid. High void ratio means high permeability (Bell 1980). Sample 3 has the highest value of void ratio followed by sample 2 and then sample 1. Thus permeability decreases in this order. The negative value of liquidity index in both samples 2 and 3 shows that the in-situ water content (natural moisture content) is less than the plastic limit and the soils can behave brittly. Sample 2 has somewhat high percentage of active clays than sample 3 and the former can be said to have some amount of illite while the latter can be said to have mainly clays of Kaolinitic content. The statistical parameters like the Mean, Median, Skewness; Standard Deviation and Kurtosis are higher in sample 2 than sample 3 which in turn has higher values of the aforementioned statistical parameters than sample 1. In both soil samples, the values of the Skewness lies between 0.5 to 1.0 and as such can be said to be positively Skewed (strongly fine Skewed). Moreover, the value of Kurtosis for the three samples lies between 1.11 to 1.66 and can be said to be Leptokurtic. They can be said to be well to moderately well sorted because of the range of values for sorting (Standard Deviation) lying between 0.35-0.71 (After Folk and Ward 1957).

Conclusion and Suggestions

Although the Ganawuri area is located on the crystalline Basement (Migmatite–Gneiss), which is a good foundation, foliation, fracturing, shearing, pegmatization and jointing may reduce the bearing capacity of the soil. These zones may become more pervious to allow gradual build-up of water pressure, which will in turn, lead to increased fissuration and further weakening, and so may permit sliding of structures constructed on them. It is recommended herein that sealing mechanisms (grouting) be introduced to control percolation of water through these structures. Percolation of water along the major structures and weathered zones should be assessed in detail in order to design the appropriate grout curtains and drainage system. And since most of the structures are vertical or nearly so, it is also recommended that grout holes must be appropriately inclined to intersect and seal the major joints and other structures at depth. The fault zone that trends NW/SE appears to dominate the area. Movement along the fault plane may be possible if load is put on this place. Coring may be necessary at these locations to determine any possible mobile parameters. Again, consolidation grouting may be needed to reduce deformability and increase mechanical strength at these zones.

Intensive weathering has provided possible construction materials at the area. The engineering properties have ascertained the suitability of these materials (soils) as construction materials. The sandy matter along the channel means possible greater seepage and must be addressed.

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