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PRELIMINARY ENGINEERING GEOLOGIC REPORT ON SELECTION OF URBANSITES IN THE FEDERAL CAPITAL TERRITORY, NIGERIA

Prepared by the U. S. Geological Survey
for the Federal Capital Development Authority of Nigeria

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PRELIMINARY ENGINEERING GEOLOGIC REPORT ON SELECTION OF URBAN SITES IN THE FEDERAL CAPITAL TERRITORY, NIGERIA

CONTENTS

FIGURES

TABLES

Preliminary Engineering Geologic Report on Selection of Urban Sites in the Federal Capital Territory, Nigeria

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SUMMARY

At the request of the Nigerian Federal Capital Development Authority (FCDA), the U.S. Geological Survey (USGS) undertook a reconnaissance geologic investigation in the Federal Capital Territory (FCT) in south-central Nigeria, an area of 7,700 km^2, to provide geologic, engineering, and hydrologic data for use in the selection of a site for the proposed new National Capital of Nigeria. Reconnaissance field mapping by a team of USGS and Nigerian Geological Survey (NGS) geologists was started on March 17, 1977, and completed on June 1, 1977.

Most of the FCT is underlain by crystalline igneous and metamorphic rocks of Precambrian age. Sandstone and claystone of Cretaceous age overlie Precambrian rocks in much of the southwestern part of the Territory. Laterite of probable Tertiary age caps many hills of Cretaceous rocks and some hills of Precambrian rock farther north, and crops out near banks of streams in the eastern and northeastern plains. Alluvial sediments are found in the beds of all streams, but are of mappable size only along a few of the largest rivers. The most conspicuous structural features are a broad "U"-shaped fold traversing the eastern and central part of the Territory and a north-trending shear zone along the eastern boundary of the FCT.

The principal physiographic elements of the FCT are hills, plains, and the Gurara River along the western boundary of the Territory. Hills

in the north are the highest in the Territory, reaching 1,200 m in altitude. Heights decrease toward the south and west, and broad plains at altitudes around 200 m occupy the central and western part of the area. Flat-topped hills rising 300-400 m are a distinctive topographic feature in the south. Most of the streams drain into the Gurara River except in the extreme east where they enter the Koto River, a tributary to the Benue River.

The soils in the FCT are laterite soils; they were mapped and categorized on the basis of field tests according to the Unified Soil Classification System. Shear strengths were estimated in place by penetration tests. The soils fall into two general groups. The first group comprises poorly to well-graded sand and silty-sand soils (SW, SP, SM), which cover a major part of the Territory, provide good drainage, and provide excellent foundation material for engineering structures. The second consists of clayey sand and sand-clay mixtures (SC), which overlie the Cretaceous rocks in the southwest and metamorphic mica-rich schists in the southeast, have lower permeability and poorer drainage, and are less desirable as a foundation material.

The rock in the FCT was mapped, field tested by Schmidt hammer, and classified for its engineering properties on the basis of lithology, discontinuities, and compressive strength. The rocks are divided into three major engineering categories: (1) medium- to high-strength, massive and gneissic rock, (2) low- to medium-strength bedded rock, and (3) low-strength foliated and sheared rock. Category 2 rocks represent the Cretaceous Nupe Group sedimentary rocks of the southwest, and category 3 rocks belong to low-strength and faulted metasedimentary rocks located in the southeast. The category 1 rocks underlie the rest of the FCT.

Naturally occurring construction materials are not abundant. Alluvial and terrace sands occur in the southern reaches of the Gurara River. Coarse aggregate and riprap can be quarried from granite hills in the northern part of the FCT, and sand from the Nupe sandstone in the southwest. Fresh granite, gabbro, and the stronger unweathered metamorphic rocks can be cut for building stone. Clay-rich beds in the Nupe Group and some residual clays in the southeastern part of the FCT may be suitable for the manufacture of bricks and other ceramic products.

An area of about 800 square kilometers in the Federal Capital Territory is apparently free from potential geologic hazards, is underlain by generally competent crystalline rock covered by nonclayey sand soils, and is suitable for construction of a capital city, its environs, and supporting facilities. The area is bounded on the west by the Gurara River, on the east approximately by long. 7°15' E., on the north by lat. 9°10' N., and on the south by lat. 8°50' N. The rather flat area and the hills to the east and low mountains with inter-mountain plains to the south can provide a wide range of attractive settings for a capital metropolitan complex. The area west of the village of Gwagwalada (lat. 8°56' N., long. 7°05' E.) and north of the Usuman River has adequate flat space and approaches for an airport. No historical earthquakes have been recorded in the FCT. The closest recorded earthquake was located about 1,000 km to the west near Accra, Ghana.

Large-scale topographic and engineering geologic maps (1:10,000) should be made of any area tentatively selected for the capital site and its environs. Exploratory borings should be systematically located in the selected areas to test for soil and rock types, depth of rock weathering or alteration, and structural competency of the rock. Engineering properties of soil, rock, and aggregate should be determined by laboratory tests. Geologic, engineering, physical property, and related data should be placed in computer storage. Low-altitude large-scale (1:2,500) photogrammetric-quality aerial photographs should be taken of the selected areas for use in detailed engineering planning, surveying, and developing sources of aggregate and building materials. Geophysical surveys (seismic and resistivity) should be conducted to determine depth of soil and weathering and distance to fresh bedrock, and to provide a profile of rock and soil properties. Geomechanics investigations, including state of stress measurements, should be made where very large engineering structures or sensitive military installations are to be built. Environmental impact studies and programs should be established to minimize deterioration of the environment by urbanization of the region and to prevent culturally accelerated erosion of the Territory.

Recommendations for a program of water resources investigations have been submitted to the FCDA in a separate report by a separate team of USGS water resource specialists.

INTRODUCTION

Location

The Federal Capital Territory (FCT) comprises an area of 7,700 km^2 in south-central Nigeria having a midpoint at lat. $8^o55'$ N. and long. $7^o11'$ E. (fig. 1). The southwestern corner of the Territory is about 68 km north of the confluence of the Niger and Benue Rivers; the western edge of the Territory extends northward for 90 km immediately west of the Gurara River, a south-flowing tributary to the Niger.

Purpose and method of study

A reconnaissance study of the Federal Capital Territory was undertaken upon the request of the Nigerian Federal Capital Development Authority (FCDA) for the U.S. Geological Survey (USGS) to provide geologic and hydrologic data that could be used in selecting a site for the proposed new National National Capital of Nigeria. The program was managed by Mr. I. J. Ebong, Executive Secretary of the FCDA, and Prince Awa-Ekpo, Principal Assistant Secretary.

Administrative contacts with Nigerian and United States officials in preparation for field operations were completed by William C. Overstreet, chief of party, Lee L. Benton, and Wallace R. Griffitts between February 7 and March 16, 1977. Preliminary field work started on March 17, after

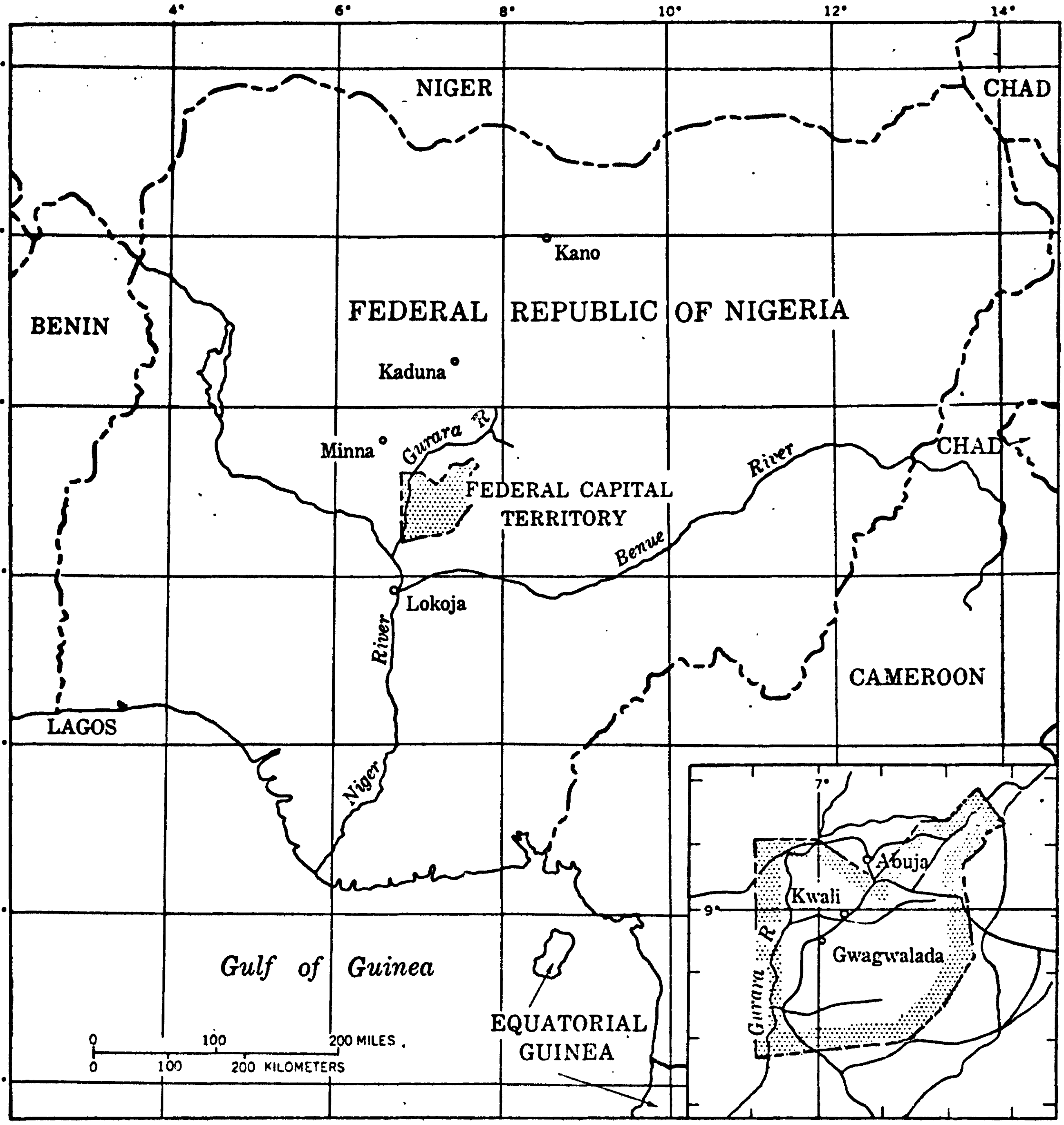

Figure 1. Index map of Nigeria showing area of study.

W. C. Overstreet and W. R. Griffitts arrived at Abuja, the field station. They were joined by John R. Ege on March 26. On April 1 intensive geologic field work began, using two Alouette III helicopters provided by Aero Contractors Company of Nigeria, under contract with the FCDA. The contractor provided full crews of pilots, mechanics, and radiomen, and furnished maintenance and fuel. On April 22, Frank D. Spencer arrived in Abuja to fill the position of logistics manager.

Between April 1 and June 1 the geologic mapping was done from helicopters. The rock units were traced from the air, and landings were frequent to permit closer examination of the rocks, to measure structures, or to take samples. The helicopter field work was preceeded by examination of aerial photographs, which also served as a base on which to plot observations where no topographic map was available. Between June 1 and June 8, maps were compiled and preliminary copies were submitted to the FCDA and to the Nigerian Geological Survey (NGS). Water supply for the FCT is discussed in a separate USGS report by L. R. Peterson and Gerald Meyer (1977).

Overstreet, Griffitts, and Ege had primary responsibility for compiling the maps of surficial features, bedrock geology, and engineering properties, (figs. 2-5) respectively, and also for preparing the corresponding parts of the report. Each geologist, however, contributed to all phases of the program.

Physical properties of soils were determined in a field laboratory in Abuja, and checked by determinations of some samples in the USGS laboratory in Denver, Colo. The strength of rocks was measured in place with a Schmidt hammer and the bearing strength of soils was determined, also in place, with a penetrometer. The field-laboratory determinations were made by J. R. Ege and by Njoku Imo and L. B. Chibogu, NGS, under Ege's supervision. Njoku Imo, L. B. Chibogu, and A. A. Obiabaka also worked with W. R. Griffitts to separate heavy minerals from sediment samples. These ultimately will be the basis of a geochemical and mineralogical reconnaissance of the Capital Territory.

During field work, field observations were recorded on a planimetric map, scale 1:100,000, published by the Nigerian Federal Surveys. A geographic map and a land-use map of the FCT, using Landsat band 7 image 1520-09181 as the image base, were prepared cooperatively by the USGS and NGS as part of this program, and have been published by the FCDA (Federal Capital Development Authority, 1977 a, b,). The surficial geology and engineering geology have been adjusted to and are published on the Landsat-image geographic base. The bedrock geology is being published in preliminary form on the planimetric base of the Nigeria Federal Surveys; publication on the Landsat base is planned when adjustment of the geologic boundaries to the Landsat-image base is completed.

Side look radar (SLAR) strips and mosaics provided by the Federal Department of Forestry, Ibadan, of the FCT yielded much information about surface and bedrock features that has been incorporated into the surficial, bedrock, and engineering geologic maps.

Acknowledgments

Local support for the field operation was given by His Excellency, the Emir of Abuja, Alhahji Suleiman Baro, the Secretary of the Local Government Secretariat, Mr. Abdu Ladan, and the Divisional Engineer, Ministry of Works and Housing, Mr. M. T. Barau. Captain E. T. Dowyaro, Commanding Officer, 30th Heavy Artillery Regiment, Nigerian Army, and staff

officers Lt. M. V. K. Kikiowo and Lt. A. J. Anetor allowed part of the Abuja barracks to be used as a helicopter base and provided a secure site for the necessary fuel dump. Finally, Mr. Haruna Tenimo, Abuja Station Manager for the FCDA, provided a wide variety of services to support the technical staff.

Through the initiative of Dr. C. N. Okezie, Director, and the effective efforts of Mr. J. I. Nehikhare, Principal Geologist, Mr. E. O. G. Muotoh, Senior Geologist, and Mr. J. D. Anozie, Mapping Coordinator, all of the Geological Survey of Nigeria, many Nigerian geologists joined the three authors in Abuja. Three of these, A. A. Obiabaka, N. I. Uduezue, and P. O. Ajayi, were engaged at least intermittently in the work from March 7 to June 1. Other geologists worked on the project for shorter times, providing the map information which they had previously obtained in the region and working with the long-term project participants to supplement it. These geologists were O. Ogedengbe, N. E. Ayi, E. Okosun, S. Adeyemi, N. O. Okoye, M. I. Odigi, B. Emeronye, B. P. Solomon, and A. C. Nnolim. The specific areas mapped by each of the geologists are shown in the index on figure 2, the geologic map.

BEDROCK GEOLOGY

Most of the Federal Capital Territory is underlain by crystalline igneous and metamorphic rocks of Precambrian age, as shown on the geologic map (fig. 2). Sandstone and claystone of Cretaceous age are widespread in the southwestern part of the Territory. Laterite, probably of Tertiary age, caps many hills of Cretaceous rocks and fewer hills of Precambrian rocks farther north. Laterite also crops out near the banks of streams in the eastern and northeastern plains.

An older Precambrian unit of metamorphosed sedimentary rocks is intruded by younger Precambrian igneous rocks. The metamorphosed sedimentary rocks form an arcuate structure that extends from the northeastern part of the area along the eastern and southern sides of the Territory, thence strikes northward into the west-central part of the Territory. This unit consists of quartzite, quartz-muscovite schist, muscovite schist, muscovite-biotite schist, biotite schist, biotite gneiss, migmatite, and marble, which define a large synformal structure that plunges north. The northern extension of the keel of this structure is intruded by plutons of biotite granite, porphyritic granite and sparse small plugs of diorite, gabbro, and syenite.

Overlying these crystalline Precambrian rocks are almost flat-lying sandstone and claystone of the Nupe Group of Cretaceous age. These sedimentary rocks are part of the Niger River embayment and occupy a graben in the crystalline rocks.

A major shear zone extends north-northeast in the Precambrian rocks along the eastern border of the Territory, and a similar trending but less conspicuous fault zone enters the northern part of the Territory near Abuja. Other prominent faults in the Precambrian rocks strike toward the northwest, northeast, and east; all these trends also characterize faults in the Cretaceous sedimentary rocks. Whereas horizontal dislocation is apparent along the faults in the Precambrian rocks, small vertical offset is the prevailing motion along the faults in the Cretaceous rocks.

Precambrian rocks

Metamorphic rocks

All the metamorphic rocks of the FCT have been altered greatly from their original form by changes that have been imposed over more than one episode. The older unit of metamorphic rocks in the FCT can be separated into two broad classes: (1) those rocks that were subjected to heating but minimum deformation, and retain enough of their original features to indicate their genesis, and (2) those rocks whose original features and origin are obscured by additional metamorphism and strong deformation.

Among category 1 metamorphic rocks are quartzite and marble beds that once were sandstone and limestone. Closely associated with these rocks are white mica schist and quartz-mica schist that represent kaolinitic and illitic clays. The mica schists grade into biotite-muscovite schists that contain minor quartzite and are derived from clays that were richer in magnesium and iron. Although the granitic gneiss is similar to many granitic rocks in composition, differing mainly in structure, it contains layers of schist and quartzite that suggest it was derived, at least in part, from sedimentary rocks.

Category 2 rocks, derived from category 1 rocks by further episodes of metamorphism, include porphyroblastic gneiss, banded gneiss, and migmatite. Under the conditions of metamorphism, alkalies and other chemical elements in the rock were mobilized, and scattered crystals of feldspar in some schists and gneiss grew in size to form porphyroblastic gneiss. In other places layers or bands of light-colored feldspathic material were injected into the host rock. During deformation, where injected material followed parallel surfaces, banded gneiss resulted. If injected material entered rocks undergoing plastic deformation, migmatite resulted. The shapes of category 2 rocks are irregular and their contacts may cut across rocks of category 1.

During mapping of metamorphic rocks, certain index minerals that are commonly associated with intensity of metamorphism were looked for. Garnet, kyanite, staurolite, and sillimanite are common high metamorphic index minerals. Red garnet was identified at about a dozen places. The aluminous minerals kyanite, sillimanite, and staurolite were not recognized in outcrop, but this may have been because the mineral grains are too small or are present in amounts too small to be seen by the unaided eye.

Stream sediment samples were gathered throughout the FCT for heavy mineral studies to supplement field mapping. A cursory examination of concentrates from these samples shows that garnet is present throughout the FCT. Most of the samples that contain coarse spherical garnet also contain staurolite; staurolite is also present in some samples containing finer grained garnet. Traces of sillimanite occur in samples taken near the granitic intrusives in the northeast corner of the FCT. This suggests that an increase in intensity of metamorphism accompanied emplacement of the granite.

Dark-brown tourmaline was found in most sample concentrates and in some cases was the dominant mineral. In outcrop tourmaline minerals occur in quartz veins as crystals 5 mm thick or more, or in rocks that consist largely of very fine silky fibers of tourmaline.

Quartzite.--Quartzite is widespread in the southern and eastern parts of the Territory, but few beds are of mappable size. Most beds are only a few centimeters thick and not more than a few meters long. A few beds are several meters thick and 8 km or more long. The rock is white, light gray, or various shades of red or brown, the darkness increasing with the iron content. Some layers are entirely quartz. These are separated by layers of mica schist. In some outcrops the quartz-rich layers contain fine mica flakes, wisps, and irregular layers.

The quartzite is commonly associated with mica schist, either white-mica schist as in the southwestern part of the Territory, or biotite-muscovite schist as in the eastern part. In either place the quartzite beds are parallel to the cleavage of the neighboring schist. Several large masses of quartzite are in biotite-rich granitic gneiss near the center of the Territory, and a quartzite mass is in migmatite farther northwest, north of Kwali. Similar rocks crop out in other places in the Territory.

Quartzite is the hardest and most brittle rock in the Territory. Where not tectonically shattered, it may yield flagstone or silica for refractory brick.

Marble.-- Marble beds, not more than 30 m thick, are enclosed in mica schist in the east-central part of the Territory. Three outcrops near Kusaki, are shown on fig. 2; others are reported farther north. The rock is moderately fine grained; individual particles generally are smaller than 1 mm. At the surface some of the rock is crumbly, but this may not persist in depth.

Amphibolite is associated with the marble, which suggests that the marble, too, may contain substantial amounts of magnesium. Fine-grained garnet rock was found near the southernmost marble outcrop near Kusaki. This rock is light brown and has a sugary texture, being made up of roughly equant garnet grains 1/4 to 1/2 mm in diameter. Black stains are common weathering products, reflecting the manganese content of the brown garnet. Similar rock was found in a few other places where marble was not known to occur.

Amphibolite and hornblende schist.--Amphibolite and hornblende schist do not form extensive outcrops in the Territory; bodies of mappable size were found only in the northwestern part. Small amounts of amphibolite are associated with marble in the eastern part of the Territory and amphibolite forms the dark component of banded gneiss and migmatite in some places, but not over large areas.

The amphibolite and hornblende schist are characterized by a high content of hornblende; hence they are dark-colored rocks. In the amphibolite the black hornblende grains are intermingled with gray to white feldspar grains. Feldspar is not prominent in the hornblende schists. The mineral grains generally are about 2 mm long. Small bodies of amphibolite associated with marble or in migmatite are much coarser, with hornblende grains as long as 5 mm.

Muscovite and quartz-muscovite schist.--Muscovite and quartz-muscovite schist are widespread in the southern and western parts of the Territory. They are distinguished by the presence of bright, shiny, light-colored flakes of muscovite as a dominant constituent. These flakes may be so tiny as to be difficult to see, or they may be several millimeters across. In either case, they are parallel to one another, causing the rocks to split readily along parallel planes. With increasing quartz content, the rock may become harder, or it may become crumbly, disintegrating into micaceous sand when struck with a hammer.

Muscovite schist is one of the less satisfactory foundation materials in the Territory; the rock has no value as a building stone. Mica can be washed out of crumbly or soft schist for use as filler in rubber, coatings on asphalt roofing, and in reflecting paints.

Biotite-muscovite schist.--Biotite-muscovite schist is most widespread in the eastern part of the Territory. The two micas are the most distinctive components and vary from place to place in relative abundance. Inasmuch as biotite weathers much more readily than muscovite, the apparent muscovite content may be high in surface materials. This is evident in the broad schist belt near the eastern edge of the Territory, where the weathered rocks at the hill tops look like muscovite schist, and the rock low on the hillsides is darker and more massive. In places the rock is feldspathic and may approach granitic gneiss in character. The broad eastern belt of biotite-muscovite schist contains vertical or steep layers of banded or granitic gneiss, generally thinner than a few meters, that probably represent zones of tectonic movement in the shear zone.

Granitic gneiss.-- Granitic gneiss is a gray rock similar to granite in composition having a marked layering and parallel alignment of biotite flakes. It generally contains substantially more biotite than most granite. In most places this biotite is rather evenly distributed through the rock. In other places, biotite is in part concentrated into layers of biotite schist that are interlayered with more normal granitic gneiss. Rocks that contain such biotite-rich layers are distinguished on figure 2 by a series of dashes from areas otherwise indicated to be underlain by granitic gneiss.

Both the granitic gneiss and biotite-rich gneiss are strong, and weather to give sandy well-drained soils.

Porphyroblastic gneiss.--Porphyroblastic gneiss is characterized by isolated crystals of feldspar imbedded in a matrix of schist or one of the varieties of gneiss. The rock also lacks the irregular, light feldspar-rich bands found in migmatite, or the parallel, sharply bounded light bands of banded gneiss, both of which also commonly contain porphyroblasts. The overall nature of the porphyroblastic gneiss differs markedly from place to place, reflecting differences in the primary rock in which the porphyroblasts have grown. From a technological standpoint, these relict features are more important than the presence of porphyroblasts.

Migmatite.--Migmatite is one of the most widespread rocks in the Territory. Its character varies greatly from place to place, inasmuch as it is, by definition, a mixture of younger light-colored rock and a darker older rock. The light-colored material commonly forms granitic layers and lenses, but much of it is coarser-grained feldspar and quartz. Layers of these light rocks do not form long parallel stripes on outcrop as do those of the banded gneiss, but are discontinuous, contorted, and pinch and swell markedly. The darker, enclosing layers are most commonly schistose and rich in biotite. Less commonly they are hornblendic granitic gneiss. The light layers locally contain fragments that resemble the darker neighboring layers. This varied lithology probably reflects the wide range of older metamorphic rocks that were impregnated with feldspathic material to form migmatite. The irregularity of banding, contortion of bands, and inclusion of fragments of older dark rock in newer young rock indicates that migmatite formed during plastic deformation.

Banded gneiss.--Banded gneiss is widespread in the eastern part of the FCT and moderately extensive in the western part, but is absent in the central part of the Territory. The rock forms long narrow bands in the eastern area, trending about N. 10°-30°E. In the western area the masses are more nearly equidimensional and are not consistently oriented.

The nature of the eastern banded gneiss reflects its position in a regional shear zone. It contains persistent sharply bounded layers of light-colored feldspathic rock separated by dark layers. Most dark layers are rich in micas and are remnants of the original schist that was injected by the light feldspathic material. Rather uncommonly the dark layers are rich in hornblende, where the original rock was hornblende schist or amphibolite. The dark layers, especially where rich in mica, may contain porphyroblasts of feldspar. The porphyroblasts tend to be imperfectly formed crystals, the imperfections ranging from rounded corners to elimination of the crystal outline entirely, producing a lens-shaped white spot.

In the western part of the Territory the banded gneiss layers are thicker than those in the eastern gneiss, the minerals are less well segregated into light and dark layers, and the layers are not as sharply bounded. In a few places a lighter layer contains pebblelike ovoids similar in lithology to the neighboring darker layers. It is likely that some of the layers are sedimentary beds. The darker layers contain much biotite and lesser hornblende. These layers locally also contain porphyroblasts of feldspar that have recognizable bounding crystal faces and show little evidence of deformation.

Serpentinite.--Serpentinite has been found in one place near the eastern boundary of the Territory. It is a very fine-grained green to yellowish-green rock having an oily or greasy luster. The green serpentine minerals contain scattered black sand-sized grains of ilmenite or chromite. Serpentinite weathers to yield a very rough, spongelike surface, but the rock itself does not soften much at the surface. The single outcrop is along the edges of a hard, iron-rich layer of laterite that may have developed from the serpentinite. The serpentinite itself probably is an altered mafic igneous rock.

Serpentinite is used as an ornamental stone, but is so soft that it is not suitable for floors or other uses subject to strong abrasion. It is unlikely that the isolated serpentinite body in the Territory would yield large blocks or be an economical source of terrazzo. It is an uncommon rock, having been found in only one other place in Nigeria.

Talc schist.--Talc schist is found in several bodies, the largest one in the northwestern part of the Territory. It is a flaky rock, gray, greenish gray, or brown in color, and has a greasy or soapy feel. The characteristic minerals are talc and minor chlorite. Other magnesium-rich silicate minerals may also be present, along with opaque black oxide minerals.

The talc schist probably also is altered ultramafic igneous rock; it might be used in such domestic activities as polishing rice.

Igneous rocks

Coarse porphyritic granite.--Coarse porphyritic granite forms several large intrusive masses in the northern part of the Territory. Most of the masses have smooth margins and are elliptical in shape, but there are a few dike-like protuberances.

The phenocrysts locally are parallel to one another, but no attempt was made to map flow structures. The larger intrusive masses are not homogeneous, but have porphyritic marginal parts and equigranular, very coarse grained centers. Some of the dark mineral grains in the coarse-grained porphyritic granite, particularly in the northwestern part of the territory, are hornblende, and the rock is a biotite-hornblende granite. Small dikes of quartz-feldspar pegmatite are near the middle of the large mass at the northeastern corner of the Territory.

Fine- to medium-grained granite.--The fine- to medium-grained granite is a gray rock containing biotite, feldspar, and quartz, in particles 1-3 mm across. The rock is generally massive, with little planar structure or cleavage. The largest bodies are bounded at least on one side by gneissic rock, as in the north-central and northwestern parts of the Territory. Smaller bodies are either in gneiss or in coarse porphyritic granite.

Charnockite is a variety of granite that contains pyroxene as its dark mineral. This difference markedly changes the characteristics of the rock. It crops out, like syenite, as a hill of boulders instead of in bare domes, as does normal granite. The rock is dark colored and commonly brownish. It is a rather minor rock in the Territory, but probably could be used for crushed rock if needed.

Syenite forms rather small bodies in the northwestern part of the Territory. Its outcrop areas tend to be hills of boulders instead of bare and solid rock. The syenite is a medium-grained, light-pink to light-gray rock made up almost entirely of feldspar, with very little dark material. Mostly eguigranular and massive, it locally contains small feldspar phenocrysts. A light-gray local variant intermixed with the light-pink syenite contains 5-10 percent of pyroxene. It grades by increase in dark minerals into dark-gray biotite-hornblende diorite.

Gabbro and diorite.--Gabbro and diorite are rather dark rocks that are composed of various proportions of black hornblende or pyroxene and gray plagioclase feldspar. On weathered outcrops the rocks are brown or brownish gray, but on fresh surfaces they are gray. Individual mineral grains are a fraction of a millimeter to 5 mm long. In some intrusive masses the texture is uniform; in others, such as the large one near Karshi near the eastern boundary of the Territory, the size and arrangement of mineral grains varies markedly from place to place.

The rocks are dark in color, hard and tough, may make excellent aggregate for concrete, and generally can be polished readily.

Jurassic Rhyolite.--Rhyolite forms a swarm of dikes along the western boundary of the Territory and small round intrusives in the north-central part. It is a fine-grained rock, most commonly consisting of phenocrysts of feldspar and quartz embedded in a very fine grained or porcellaneous matrix in which individual grains are of microscopic size. A rhyolite breccia from a plug near Karsana (lat. 9°07' N., Long. 7°21' E.) was studied in the laboratory of the USGS. Thin-section examination showed that phenocrysts of potassium feldspar, plagioclase, and quartz are in a fine-grained groundmass that has been altered, with the formation of stubby amphibole grains and abundant small biotite flakes. A chemical analysis (table 1) showed only 61.5 percent SiO_2, too low for a rhyolite, and too little K_2O in proportion to Na_2O; so the rock may be a latite or or dacite. This illustrates the difficulty of classifying fine-grained rocks in the field. A spectrographic analxsis (table 2) showed no unusual concentrations of ore metals. A K-ar radiogenic age determination (tables 1, 2) indicates a Jurassic age of 179.6 m.y. $\pm$ 10.6 m.y., similar to that of some granites of the Jos Plateau.

Cretaceous sedimentary rocks

Sandstone and claystone of Cretaceous age occupy large areas in the southern and southwestern parts of the Territory. The sandstone beds are as much as 10 m thick and consist predominantly of fine- to medium-grained sand-sized grains. Some beds contain granules of quartz as much as 1 cm across; less common conglomerates contain pebbles a few centimeters across. The sandstone beds are commonly impregnated with limonite ("ferruginized"), by some process related to development of the laterite caps found on many of the hills.

The claystone layers are comparable in thickness to the sandstone beds. The clay is nonfissile and white or gray to light brown in color.

TABLE 1. CHEMICAL ANALYSIS OF RHYOLITE SAMPLE
FEDERAL CAPITAL TERRITORY, NIGERIA

[(Lat. N. 9°07', Long. E. 7°21'). K-Ar age determination on K-feldspar gives sample age of 179.6 m.y. $\pm$ 10.6 m.y. ($\pm$ 2σ)]

(Analysis by U. S. Geological Survey)

Major Elements

Element	Amount (percent)
SiO_2	61.5
Al_2O_3	13.9
Fe_2O_3	1.1
FeO	6.7
MgO	1.9
CaO	3.5
Na_2O	4.6
K_2O	3.8
H_2O +	0.69
H_2O -	0.17
TiO_2	1.4
P_2O_5	0.41
MnO	0.10
CO_2	0.2
SUM	100.

TABLE 2. SPECTROGRAPHIC ANALYSIS OF RHYOLITE SAMPLE
FEDERAL CAPITAL TERRITORY, NIGERIA

[(Lat. N. 9°07', Long. E. 7°21'). K-Ar determination on K-feldspar gives sample age of 179.6 m.y. ± 10.6 m.y. (± 2σ)]

(Analysis by U. S. Geological Survey)

Minor Elements

Element	Amount (ppm)	Element	Amount (ppm)
Ag	< 0.1	Md	96.0
As	< 150.0	Mi	31.0
Au	< 10.0	Os	< 10.0
B	< 15.0	Pb	13.0
Ba	470.0	Pd	< 1.5
Be	11.0	Pr	< 68.0
Bi	< 22.0	Pt	< 6.8
Cd	< 32.0	Re	< 10.0
Ce	220.0	Rh	< 1.0
Co	13.0	Ru	< 3.2
Cr	39.0	Sb	< 100.0
Cu	10.0	Sc	18.0
Dy	< 32.0	Sm	< 46.0
Er	< 10.0	Sh	18.0
Eu	3.5	Sr	190.0
Ga	48.0	Ta	< 320.0
Gd	16.0	Tb	< 32.0
Ge	< 4.6	Th	< 22.0
Hf	< 100.0	Tl	< 10.0
Ho	< 10.0	Tm	< 4.6
Ih	< 6.8	U	< 320.0
Ir	< 15.0	V	80.0
La	93.0	W	< 10.0
Li	< 68.0	Y	100.0
Lu	< 22.0	Yb	12.0
Mn	1200.0	Zh	110.0
Mo	7.0	Zr	1000.0
Mb	78.0		

Tertiary laterite

Only hard, brown, iron-rich laterite is shown on figure 2. It is most prominent as flat-lying caps on hills of sandstone and claystone or, less commonly, of crystalline rocks. These caps are generally 3 m in thickness, and locally as much as 10 m thick. Composed mainly of limonite, they contain angular pieces of quartz, or locally other rocks.

Less prominent are the thinner ledges of laterite that crop out in the plains, especially along the hillsides flanking streams. These may be separated from the underlying hard rock by a few meters of clay, or they may lie directly upon hard rock. The limonite-rich layers probably do not continue far under the hill in most of the plains, and hard rock outcrops are moderately common.

Associated with the laterite--either below it or laterally away from the hard outcrops--are red to pink, rather poorly plastic clays. In places the clay is several meters thick. It is the source of clay for building the village houses and provides surfacing material for trails and roads. Some of the clayey material hardens upon exposure to the air, but it does not become as hard as the iron-rich laterite.

The most prominent laterites were formed long ago, in Tertiary time, but movement of iron and presumably other components of the laterite has continued until recent time.

Quaternary alluvium

Alluvial sediments are found in the beds of all the streams in the Territory, but they are mappable only along a few of the largest rivers. The sediment consists very largely of sand. Gravel beds are rare, and clay is only present locally.

Geologic structure

The most conspicuous structural features in the crystalline rocks of the FCT are the northerly trends of the rocks near the eastern and western boundaries, and the easterly trends in the central area. These reflect the presence of a broad "U"-shaped fold and a north-trending shear zone along its eastern limb. A smaller north-trending shear zone is just west of Abuja. Many faults and fractures that trend northwest cut the other structures and must, therefore, be younger.

Central fold

The central "U"-shaped fold is outlined by the mica schist, as it curves from northerly trends of the western limb through easterly trends in the central area to northerly trends of the eastern limb. The strata generally dip toward the center of the structure, indicating that it is a northward-plunging synclinal trough. Westerly dips at the western boundary of the Territory indicate overturning or complex folding in that area.

Eastern shear zone

The shear zone along the eastern boundary of the Territory is a major regional tectonic feature, persisting for many tens of kilometers. It broadens and changes in character southward. Near the northeastern corner of the Capital Territory it is only a few kilometers wide. The rocks in it are gneisses that contain lenses of white quartz and feldspar as much as 3 cm in length set in a strongly foliated biotite schist matrix. Nothing was seen that indicated the original structure or composition of the rock. The shear zone here is a sharply bounded belt that broadens southward to a width greater than 20 km at the southern boundary of the Territory.

In the widest area, shearing took place along planes or narrow zones that are, in places, separated from their neighbors by several meters to several hundred meters of schist. Individual shear zones commonly are occupied by vertical layers of banded gneiss, between which the intervening schist may dip westward at angles as gentle as 40° (fig. 3). From an engineering standpoint it is essential to determine the attitude of the schist and not merely that of the gneiss, which generally forms more prominent outcrops. Attitudes of foliation and discontinuities determine in large part the stability of the outcrop.

In most places the individual shear zones are in schist or granitic gneiss, but they cut other minor rocks such as amphibolite. The eastern elements of the shear zone are about parallel to the eastern limb of the "U"-shaped fold. Westward, closer to the center of the fold, the northeast-trending rock units are cut and in places truncated by individual shear units.

South of the FCT the shear zone is exposed in a window through the Cretaceous sandstone and claystone. Lineaments in the adjoining Cretaceous sedimentary rock are parallel to the shear zone, suggesting that some movements took place since Cretaceous time. The gneisses formed by shearing indicate that much, probably the dominant, movement took place in Precambrian time. The tin-bearing veins in the shear zone very likely were deposited in Jurassic time. The controlling fractures may be Jurassic or older.

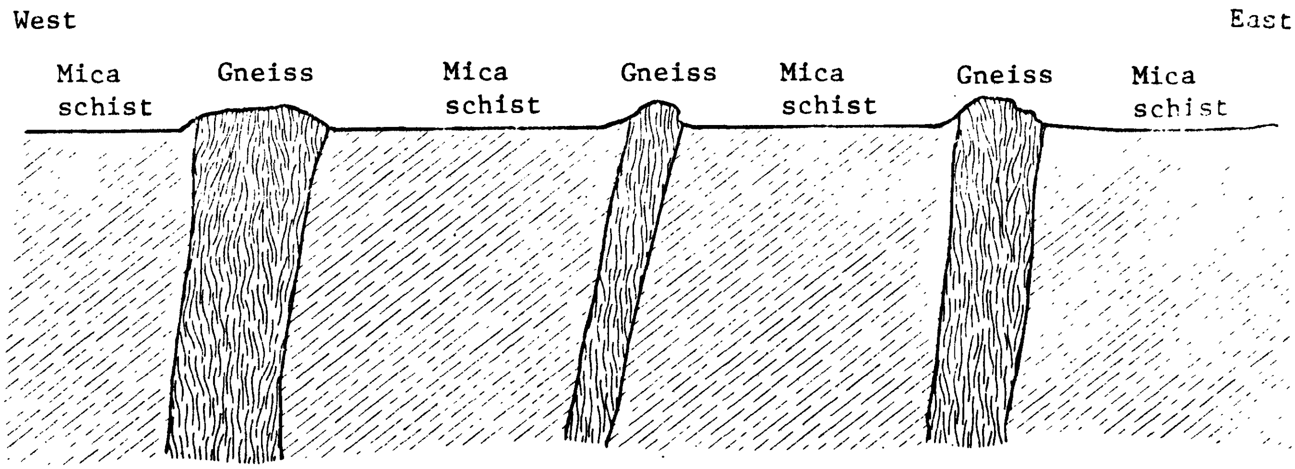

Figure 3. Diagrammatic cross section showing dip of banded gneiss layers and of interlayered mica schist.

The oldest individual shears are as resistant as the surrounding rock, and may be stronger, as they stand up as ridges above the surrounding schists. The youngest individual shears mark soft broken or altered rock that weathers readily, forming clefts and narrow valleys.

Northwest-trending faults and fractures

Northwest-trending faults and fractures are common in the FCT: the most prominent ones are shown on figure 2. These obviously are younger than the units of the shear zone that they cut. In general they seem to be in valleys, indicating that they mark belts of rather weak rock.

Mineral deposits

The mineral deposits known to be within the Capital Territory are of three general types: veins of tin or lead minerals; rock units of possible use as industrial materials--mica and talc schists; and rocks of possible use as building material--stone or clay.

Tin deposits

Tin has been sought in a few mines and prospects in a broad north-trending belt that passes through Kusaki, in the eastern part of the Territory. The veins were mined where feldspar was softened by weathering to permit easy excavation, disaggregation, and washing out of the valuable heavy minerals. Apparently little hard rock was mined. The deposits are in places where alluvial plains along streams are small or absent, so alluvial tin deposits did not accumulate. Even the broad valley south of Kusaki seems not to have accumulated much placer tin from the large veins that cross its southern edge.

Many of the vertical veins strike north, parallel to the trend of the belt as a whole, and a few are transverse, crossing the belt about at right angles. Individual veins may be 3 km in length and 30 m in width. The large veins are feldspathic, containing microcline, albite, quartz, muscovite, cassiterite, and, reportedly, columbite-tantalite. Tourmaline is common in black prisms a few millimeters to 1 cm wide and 1 cm to at least 5 cm long. Tourmaline is more abundant in quartz-muscovite greisen veins and in muscovite-rich altered walls of the veins than in the feldspathic veins.

Lead deposits

Two veins containing galena were found south of Izom, in the northwestern part of the Territory. They had been prospected by pits dug along them, exposing veins of quartz that contain galena, sphalerite, chalcopyrite, pyrite, and their oxidation products. Little or no metal seems to have been produced, and our brief examination did not show evidence of large deposits.

Mica

The white mica schist probably could yield mica suitable for use as a filler in rubber, as a coating for newly manufactured asphalt-impregnated roofing, or as a component of reflective paint and wallpaper. It could be recovered from the schist by crushing, sieving, and washing with water or air.

Major requirements for the raw material are a high content of white mica, and a low content of black mica and of tough minerals that resist crushing. These probably can be met in some of the schist areas in the southwestern part of the Territory, east of Kwaita.

Coarser mica might be obtained from greisen and altered rock near the tin veins. This might be better used to coat roofing, for which dark impurities are of little importance.

Talc

The talc schist probably cannot yield high-quality talc for French chalk or talcum powder, but may be a source for talc for other uses in which structure, color, and purity are less important, such as polishing rice or use as a filler.

Brick and tile clay

Red clay suitable for house construction and soft laterite for surfacing trails and roads are found in many places throughout the central plains in the Territory. Probably few places are more than a few hundred meters from deposits large enough to be sources of such materials for village use. Thicker and much more continuous deposits of such clays underlie plains around the northeastern corner of the Territory, and largely outside it, and in several places in the eastern part of the Territory (see fig. 5). Some of these clays may well be suitable for kiln-fired bricks and tiles as well as sun-dried bricks. The lateritic plains contain few villages, so mining the clay would not greatly disrupt farming.

Some of the saprolite or biotite-muscovite schist may also be usable for brick or tile production. Any product made therefrom would be dark colored.

SURFICIAL GEOLOGY

The principal elements of the surficial geology of the Federal Capital Territory, are shown in figure 4. These are the hills and plains on which the effects of weathering, erosion and deposition tend to control the present uses to which the land is put. This is also illustrated on the provisional map showing land use in the FCT (Federal Capital Development Authority, 1977 b).

Most of the streams in the Territory drain into the Gurara River except in the extreme east, where streams enter the Koto River which is tributary to the Benue River. The junction of the Benue and Niger Rivers at Lokoja is 68 km south of the southwestern corner of the FCT.

Hills in the northern corner of the FCT are the highest in the Territory, reaching 1,200 m in altitude. Heights decrease toward the south and west, and broad plains at altitudes around 200 m occupy the central and western part of the area. Flat-topped hills rising 300-400 m are a distinctive topographic feature in the south.

Erosional features

The distribution of the main erosional features--hills, plains, and terraces--in the FCT was compiled from 1:100,000-scale topographic maps and from 1:100,000-scale side-look radar mosaics. Some use was also made of 1:40,000-scale aerial photographs and 1:100,000-scale mosaics of the photographs.

Highland areas

On the basis of relief, shape, and lithologic and tectonic control, highland areas have been divided into four classes of hills: Inselbergs;

high tectonic ridges; rounded hills; and flat-topped hills. These high areas are dissected, but they rise from even more dissected terrain. Together, the highland areas and associated dissected terrain form the margins of the lowest planation surface in the Territory. Within these high areas are preserved relicts of older planation surfaces. The difference in altitude between the lowest planation surface in the Territory and the highest hills is as much as 800 m, but the local relief of the hills ranges from 50-500 m.

Inselbergs supported by granitic rocks are the characteristic forms of hills in the northern part of the territory. They rise with steep walls and bluntly rounded tops from pavement-like surfaces and low, rounded hills (whalebacks) of seemingly similar granite, or of gneiss and migmatite. A few inselbergs having crests about 600 m in altitude are capped by concretionary laterite that rests directly on almost unweathered granite. Other high planation surfaces in the region of inselbergs are relicts of denudational plains having average altitudes of 500-600 m, 600-700 m, and 700-800 m. The inselbergs are about 90-120 m higher than these relict plains. The tops of these inselbergs are probably the oldest erosional features in the Territory, but the absolute age was not determined. They may represent at present a pre-Cretaceous land surface.

High tectonic ridges enclosing parallel valleys and narrow relict plains extend north-northeast along the eastern edge of the Territory. The shape and distribution of these linear hills are controlled by a shear zone of regional magnitude that strikes at angles of 15° to 20° to the trend of layering in metamorphosed sedimentary rocks. Where the sedimentary rocks are intruded by plutons of granite, the shear zone cuts across the granite as well. Mylonite and hard banded gneisses formed by the shearing are the principal rocks supporting the linear ridges. Locally, however, the metasedimentary rocks include beds of quartzite and quartz schist that form ridges. The linear valleys and relict plains tend to be underlain by less resistant rocks such as mica schist, gneiss, and foliated granite. Concretionary laterite is scarce but present on the crests of a few of the linear ridges.

Rounded hills are common in the south-central part of the Territory, where they are developed on migmatite, biotite gneiss, and granite. The higher of these hills locally are capped by concretionary laterite. Low rounded hills are scattered on the plains and in the strongly dissected northern part of the Territory.

Distinctive flat-topped hills are present in the southwestern part of the Territory where the sedimentary rocks of the Cretaceous Nupe Group (Adeley and Dessauvagie, 1972, p. 182) overlie the Precambrian basement. The tops of these hills are essentially parallel to the horizontal bedding of the sedimentary rocks, but variations in altitude of as much as 100 m in the tops of the hills suggest that their present heights are controlled by block faulting. However, detailed stratigraphic studies to correlate the sedimentary beds in adjacent hills are needed before the present differences in relief can be ascribed to block faulting with assurance. Many of the flat tops are capped by concretionary laterite. Less commonly the cap is ferruginized sandstone or siltstone of the Nupe Group. Although the differences in the elevations of the caps of laterite might appear to lend substance to the inference of post-lateritization block faulting, the present relicts of laterite could equally well have formed on a surface of uneven relief.

Plains

At least four general levels of denudational surfaces are present in the plains of the FCT. The oldest and highest are in the northern and eastern parts of the Territory and have general altitudes 700-800 m, 600-700 m, and 500-600 m. They are relicts of earlier cycles of erosion than the main plain that occupies the western and central parts of the Territory at altitudes of 150-450 m. Owing to the present importance of the main plain for agriculture and for future urban development, most of the following discussion relates to it.

This main plain, the largest erosional plain in the FCT, occupies the western and central parts of the area and divides the Territory into northern and southern tracts of steep relief (see fig. 4). For identification in this report, the feature is called the Gwagwalada plain after the town (8°56'N., 7°05'E.) of that name in the central part of the area. The Gwagwalada plain is the eastern part of the denudational surface described as the Gwi Plains by Rackham (1972, p. 433). The Gwagwalada plain extends many kilometers west of the western boundary of the FCT.

The southwestern margin of the Gwagwalada plain enters the Territory near Ruwaza (8°50'N., 6°51'E.) on the Gurara River. The plain extends northward for 45 km along the west margin of the Territory to the northwestern corner of the Territorial boundary, thence another 5 km to a zone of hills. The altitude of this plain increases gradually northward from about 150 m near Ruwaza to about 250 m in the northwest. From Ruwaza the southern boundary of the plain extends eastward to the northern base of the Kuku Hills south of Kwali (8°49'N., 7°02'E.), thence eastward along the valley between Pima Hill, the Kaho Hills, and the Zango Hills on the south and the Dafara Hills and Bamshi Hills on the north. Along the east side of the Bamshi Hills (8°52'N., 7°17'E.) the margin of the plain turns northward for about 10 km thence leads easterly to the vicinity of Sabon Pigba (8°57'N., 7°29'E.) north of Wasa hills, where the Gwagwalada plain reaches its easternmost limit. At Sabon Pigba the margin of the plain turns northward and northwestward to Wuse (9°04'N., 7°28'E.), whence it extends northwesterly to the Zuma Hill area at Kuba (9°10'N., 7°19'E.). There, the northern boundary of the Gwagwalada plain curves to the south of Abuja and follows the southern side of the steep hills west of Abuja until it passes northwestward out of the Territory near Gwele (9°12'N., 7°06'E.).

From the Gurara River to Sabon Pigba the Gwagwalada plain is about 80 km wide, and rises in altitude from about 150 m at the river to about 450 m in the extreme northeastern part of the plain near Wuse; thus the general slope of the Gwagwalada plain is southwestward into the Niger embayment (Adeleye and Dessauvagie, 1972, fig. 1). This southwest gradient should provide satisfactory drainage for engineering planning.

Scattered rounded hills, whalebacks, and inselbergs rise as erosional relicts above the planation surface of the Gwagwalada plain. The largest of these relicts are the granitic hills in the northwestern corner of the Territory that preserve remnants of an old, concretionary laterite-capped planation surface at 600-650 m. Other large remnants are the rounded hills in the southeastern part of the plain 10 km east of Gwagwalada, and the Bamshi and Dafara Hills, where caps of concretionary laterite are absent.

The morphological changes marking the northern and eastern borders of the Gwagwalada plain are well defined by strongly dissected zones of steep relief that contrast with the low relief of the flat to gently rolling surface of the plain. A sharp escarpment a few kilometers north of the northern territorial boundary forms the margin of the plain as far east as Gwele, where the boundary of the Territory intersects the escarpment. Thence the escarpment is present within the Territory to the south of Abuja and to the north of Kuba and Wuse. Away from the Gwagwalada plain altitudes rise across this escarpment to 500-600 m on a denudational plain north of the escarpment and of the Territory. To the east of Abuja in the north-eastern part of the Territory, the escarpment broadens into a wide dissected zone of steep relief from which rise many granitic inselbergs There, also, the northern side of the zone of steep relief gives way to denudational plains: a high, narrow, and dissected plain (general altitude 700-800 m), that, along breaks in slope on its northern side, yields a slightly lower but broader plain at an altitude of 600-700 m in the extreme north-eastern part of the Territory. Inselbergs rise 90-120 m above these plains.

The eastern edge of the Gwagwalada plain is defined by a zone of steep relief caused by the high, north-northeast-trending tectonic ridges where altitudes exceed 900 m. Within these ridges are narrow, north-northeast-trending valleys at about 600 m altitude. To the east of these ridges and valleys, and well outside the Territory, are broad denudational plains about 300 m in altitude that are part of the Lower Benue Plain drained by the Okwa River.

The southeastern border of the Gwagwalada plain is also well defined by areas of steep relief in the Zango Hills, Kaho Hills, and Kuku Hills. These rounded hills attain altitudes of 600 m, and locally, as about 15 km east of Kwali, are capped by concretionary laterite.

The southwestern border of the Gwagwalada plain is formed by flat-topped hills composed of Cretaceous sedimentary rocks. Many of these hills are capped by concretionary laterite. Altitudes as great as 300 m are attained by some hills, but most have altitudes of only 200-250 m and stand about 100 m above the plain.

Terraces and rapids

Erosional terraces are lacking along streams in the FCT except on that part of the Gurara River that flows in Cretaceous sedimentary rocks (see fig. 4). The upstream end of the erosional terrace on the Gurara River is north of the village of Guredi ($8^{\circ}46'$N., $6^{\circ}48'$E.), and the downstream end is opposite the confluence of the Afara Bokwai River with the Gurara River ($8^{\circ}34'20''$N., $6^{\circ}51'25''$E.). This erosional terrace is a stripped surface on the bedding of the nearly horizontal sandstone and claystone of the Nupe Group. The surface is geologically young. It is formed through erosion of the sedimentary rocks by water from the Gurara River during overbank floods of recent Holocene age.

Rapids and rocky channels are present along the Gurara River upstream from Ruwaza. Although the banks of the river are quite shallow (1-6 m) and the floodplains are very narrow in the Gwagwalada plain, the river has cut down to the Precambrian bedrock and flows on unweathered crystalline rock at many localities, including the reaches from Ruwaza to Gomani ($8^{o}50'40''$N., $6^{o}52'30''$E.), from Sabon Gida ($8^{o}52'15''$N., $6^{o}52'$E.) to the confluence of the Usman River ($8^{o}53'$N., $6^{o}54'$E.), the vicinity of Guruza ($8^{o}58'$N., $6^{o}54'$E.), and intermittently upstream to Izom. The low rapids from Ruwaza to the Usman River appear to reflect active downcutting in the crystalline rocks immediately upstream from the easily eroded Cretaceous sedimentary rocks. Doubtless the actual bed of the Gurara River downstream from the contact between the Cretaceous and Precambrian rocks is entrenched below the apparent bed, and the valley thus formed is filled with alluvium to the present level of the bed.

In most of the smaller streams, pools and rapids alternate with meandering courses in shallow alluviated valleys. Along the tectonic ridges in the eastern part of the Territory, rudimentary hanging valleys are locally present.

Weathering and surficial materials

The term weathering is here used to refer to the alteration of rocks near the earth's surface. The products resulting from weathering depend on the kind of climate, duration of climatic stages, kinds of rocks at the earth's surface, shape of the land surface subjected to weathering, and vegetational cover. The products formed in the area of the Federal Capital Territory through rock weathering include laterite and saprolite, and the soils associated therewith.

Laterite

The laterites shown on figure 4 are mappable dark reddish-brown concretionary and cellular masses of hard ferric iron oxides that locally incorporate angular to subround fragments of quartz. Where present on granitic inselbergs, the laterite rests on fresh rock; where present on ridges, rounded hills, and flat-topped hills, it rests on weathered rock; on the flat-topped hills the laterite locally grades downward into ferruginized sandstone or claystone. This laterite is as much as 20 m thick and where it lies within the block-faulted hills in the Nupe group hills, exact altitudes of the iron-cemented layers are unknown. Blocks and fragments of this laterite form short talus slopes below the rim of the outcrop.

The concretionary laterite in figure 4 indicated by letter symbol but not defined by boundaries in the plains, is also dark brown, concretionary, cellular, and commonly is rich in inclusions of quartz. Exposures are most common along the upper slopes of low banks of streams, where the laterite forms thin sheets (as much as 2 m thick) that uncomformably overlie the eroded surfaces of crystalline rocks (Alexander and Cady, 1963, fig. 3). Fine- to medium-grained sand overlies this laterite and prevents tracing the continuity of the laterite onto local interfluves. Pitting or drilling toward the interfluves and away from the exposed laterite would be needed to determine if the laterite forms persistent sheets under the sand. At many localities nodules and pisolites of concretionary laterite are mixed in the upper surface of the soil. They probably represent individual centers of growth of concretionary laterite in the soil, but some may be fragments of degraded sheets of concretionary laterite.

The thin sheets of concretionary laterite are more common along streams in the plains in the northeastern part of the Territory than in the Gwagwalada plain.

Fans of concretionary laterite are very locally present in gullies at the break in slope at the base of the hills in the Cretaceous sedimentary rocks. They tend to be present where the upper part of a hill contains beds of ferruginous sandstone.

Saprolite and soil

The term saprolite was introduced by Becker (1895, pp. 289-290) "...as a general name for thoroughly decomposed, earthy, but untransported rock... substantially in place...such deposits can be worked with pick and shovel." Where a full profile of the residual products of weathering is present, saprolite underlies hard ferruginous laterite (Alexander and Cady, 1963, fig. 2; Carroll, 1970, pp. 55-56). Saprolite is soft, clayey and has a high content of quartz in comparison with the iron-rich, hard, concretionary laterite, and is the commonest product of weathering in the plains areas as well as in the valleys and on the lower flanks of hills. Saprolite is the source of the soft clayey material used to surface the "laterite" roads and to make air-dried bricks and plaster for the walls of dwellings. Much of the "laterite" referred to by construction engineers, agricultural specialists, and others in the FCT is in reality saprolite.

Residual, colluvial, or alluvial soils cover the saprolite in the plains areas. Colluvial soils cover saprolite along the lower slopes of hills, and alluvial soils lie on unweathered rocks or saprolite in the valleys of streams. Locally, alluvial soils occupy the abandoned channels of streams, as in the area between the Gurara River and Dewu ($9^{o}14'30'N$, $6^{o}55'E.$) in the northwestern part of the Territory.

The residual and colluvial soils are sandy except where they are derived from mica schist and Cretaceous sedimentary rocks. The residual soils overlying saprolite are classic examples of lateritic soils found in West Africa. Where the residual and colluvial soils are close to exposures of unweathered rocks, the soils are stoney. Patches of such stoney soils are dug and sieved on a small scale to provide aggregate for construction.

Underlying the residual and colluvial soils is as much as 65 m of laterite and saprolite. In the plains areas, flat pavements of unweathered rock are exposed. The interspersal of these pavements with soil and weathered rock materials shows that the interface between fresh and weathered rock forms shallow ridges and valleys. Because the pavements of unweathered rock may be in any part of the present topography, the distribution of ridges and valleys on the surface of the bedrock does not necessarily reflect control of topographic form by weathered versus unweathered rock. Thus, the thickness of soil and weathered rock cannot be estimated from topographic position. The possibility also exists that the apparent upper surface of unweathered bedrock may locally be the top of a lenticular mass of unweathered rock preserved in an envelope of saprolite. Although individual lenticular masses of unweathered rock may be 10-20 m thick, another zone of saprolite may underlie the lenticle. Where weathering extends to great depths, it is possible that two or three lenticles of unweathered rock may lie in the saprolite above the lowest interface between weathered and unweathered rocks. Data were not available to show that this condition exists in the FCT.

Depositional terraces and alluvium

Depositional terraces consisting of alluvial sand are present along the Gurara River and the lower reaches of the Afara Bokwo River in the southwestern part of the Territory where these streams flow on Cretaceous sedimentary rocks. These terraces are seldom more than 4-5 m above the bed of the Gurara River. Locally, permanent or intermittent lakes occupy a terrace.

Below the terraces, the bed of the Gurara River is filled with alluvial sand, and transient sandbars and sandbanks are present. Similar transient sandbars are present upstream along the Gurara River in reaches between rocky outcrops. Elsewhere in the Territory, alluvial deposits of mappable size are scarce.

Aeolian deposits

Diatoms, microscopic fresh-water or marine siliceous plants, were found to constitute a substantial part of harmattan dust and were found in soil samples gathered between 15-30 cm depths in the FCT. The presence of the diatoms indicates that material brought in by air has been added to the soil. The obvious transport mechanism is the dust-laden land wind known as the harmattan which is prevalent during the dry season in the FCT. Aeolian deposits formed in earlier parts of the Quaternary are described for Nigeria (Burke and Durotoye, 1972, p. 329, table 5) at localities as far south as Ilorin. It is possible, therefore that some of the fine sandy soil overlying concretionary laterite in valleys protected from severe sheet-wash erosion may be aeolian in origin.

Geologic interpretation

The surficial features of the Territory are interpreted to have formed subsequent to the intrusion of the rhyolite near Karsana and subsequent to the deposition of the sandstone and claystone of the Nupe Group. An isotopic age acquired in this investigation shows that the rhyolite is Jurassic. The Nupe Group has been assigned a Late Cretaceous age (Adeleye and Dessauvagie, 1972, p. 184). Oldest of the surficial features are the deposits of concretionary laterite on the Nupe Group in the south, on the granitic inselbergs in the north, and on the highest plains, at 600-800 m, also in the north. These laterite deposits may be Tertiary in age. Youngest of the surficial features are Holocene erosional and depositonal terraces and alluvium along the Gurara River. During the interval between the formation of the Tertiary concretionary laterite and the Holocene terraces, erosion reduced the surface of the Territory to the level of the Gwagwalada plain, leaving the hills, higher plains, and hanging valleys as relicts of former surfaces. The rate of weathering tended to outstrip the pace of erosion, which caused thick saprolite to form on the crystalline rocks of the Gwagwalada plain and allowed thin sheets of concretionary laterite to be developed locally over the saprolite, possibly under a cover of residual sandy soil. The record of these events is complex and can only be resolved by detailed geologic mapping on topographic base maps at scales of 1:25,000 or 1:10,000, supplemented with drilling and test pitting.

Present land use

Preparation of map

The provisional map showing land use in the FCT (Federal Capital Development Authority, 1977 b) is based on an interpretation of the relation between the vegetative cover of the Territory and the distribution of color patterns on the false color composite of bands 4, 5, and 7 of Landsat scene ID 1520-09181 imaged December 25, 1973. During road traverses in March 1977, W. C. Overstreet and A. A. Obiabaka observed seven correlations between natural features on the ground and patterns of colors in the image:

1. Forest. Dense trees and brush mainly on rough stoney ground on areas of rock outcrops, or at the base, slope, and/or crest of steep hills, and also including tree cover in uncultivated areas of gentle relief, are correlated with the bright deep red of the false color composite.
2. Riverine forest. Dense trees and brush along intermittent and perennial streams are correlated with sinuous patches of bright deep red that follows the obvious courses of streams as shown by the image.
3. Burned areas. (A) recently burned areas appear as black on the composite, and (B) older burned areas in which plant growth was re-established appear as less deep black, tending toward dark blue, partly constituting a transition to cultivated fields. The two classes of burned areas for 1973 were inferred from the appearance of different burned areas in 1977.

4. Tilled fields. Farmland having scant vegetation, under cultivation, lying fallow, or in preparation for planting; and including the villages, correlated with white on the composite, but also include pale blue areas around the white areas.
5. Mixed fields and savannah. Interspersed fields and savannah used for small plantings, fallow land, or pasture, and partly covered with grass, low brush, and second growth trees. These features correlate with lighter to darker blues on the composite that grade into or are sharply defined from the very dark blues of the old burns. These areas are mainly savannah. The tilled fields are too small to resolve.
6. Mixed forest, fields, and savannah. Areas where large trees are present but the land is partly cultivated and partly savannah, cultivated fields are too small to resolve, and pasture correlate with whitish pink, bluish pink, pink and dark blue with purple or pink cast on the composite.
7. Alluvial deposits. Sandy uncultivated alluvium in floodplains of main streams correlates with white areas in beds of streams.

Relation of land use to surficial features

The main forested areas of the Territory are the regions of steep relief bordering the Gwagwalada plain, the hills in the eastern part of the plain and southeast of the plain, and the 600-700 m plain in the extreme northeastern part of the Territory. The largest agricultural tracts are in the Gwagwalada plain and in the area underlain by the Nupe Group in the southwestern part of the Territory. Perhaps as much as half of the burned areas are not used for cultivation. These areas are pasture or are woodland that was burned to reduce undergrowth.

Culturally accelerated erosion and sedimentation

The establishment of cities in what are now agricultural lands, savannah, and forest (Federal Capital Development Authority, 1977a and 1977b) will inevitably lead to culturally accelerated erosion whereby the stability of the present land surface is lost and gullies are extended laterally and headward from the present streams; ultimately a bad-lands type of topography could develop, with loss of soil and the swamping of small streams and valleys (Montgomery, 1940; Happ and others, 1940; Happ and others, 1940; Trimble, 1974). Culturally accelerated erosion can be retarded, or largely prevented, by prior planning of land use and by the preservation of tracts of forest and sparsely cultivated savannah as greenbelts around and in the area that is to be developed.

Use could be made of synoptic observation of the Territory by satellite imagery and interpretation to aid in the evaluation of the effectiveness of programs to prevent culturally accelerated erosion. Instruction in the interpretation of remote sensing imagery is part of the program of the Federal Department of Forestry at Ibadan. Graduates of this program might be employed in land management in the Territory.

ENGINEERING GEOLOGY

Engineering geology is the application of the geological sciences to engineering practice for the purpose of assuring that the geologic factors affecting the location, design, construction, and maintenance of engineering works are recognized and adequately provided for (American Geological Institute, 1962).

In the reconnaissance study of the engineering geology of the FCT, five principal considerations were identified: 1) Adequate ground and surface water supplies to support a metropolitan area (see Peterson and Meyer, 1977); 2) topography and land forms as engineering factors to be considered in the planning and design of a city, its environs, and supporting facilities (see surficial geology discussion); 3) the use of soil and rock as construction media, either as foundations for buildings, surface structures, underground structures, highways, or airfields; 4) the availability of suitable construction material such as aggregate, fill, riprap, brick clay, cement materials, and building stone; and 5) identification of potential geologic hazards, such as landslides, flood areas, or earthquakes.

Ground and surface water supply

An adequate water supply to support a capital city, its environs and supporting facilities is a priority factor in the planning of a metropolitan complex. Peterson and Meyer (1977) have discussed and recommended a preliminary hydrological program for the FCT.

Topography and landforms

Topography and landforms can influence the planning of a city in many diverse ways. A few problems are siting of buildings; foundation stability; locating airports, roads, and transportation routes; planning drainage, water supply, and sewage disposal; zoning of residential, commercial, industrial and recreational areas; location of sources of aggregate and other building materials; and designing military and security installations.

Rock and soil as a foundation

Two factors to be considered in choosing the type of foundation to be used in construction are the function of the structure and the loads it must carry, and the surface and subsurface condition of the soil and rock under the foundation. In both soil and rock a foundation may experience bearing-capacity failure and/or settlement. Bearing-capacity failure results when a foundation breaks into the ground because the soil or rock in which it is constructed is incapable of supporting the load. Bearing-capacity failure is more rare in rock than in soil but can occur where bedrock is severely altered or fragmented. Settlement takes place when the supporting soil or rock deforms under the applied load. It can occur as absolute deformation under the entire structure or as relative deformation between points on the structure, and can be so great as to cause the superstructure to become damaged.

Highways and airfields have similar engineering requirements, although airfield criteria are more exacting because of the greater hazards and the higher stresses imposed on the runways. Airfields and highways need level, smooth, and well-drained surfaces, sufficiently firm to permit construction of pavement. Proper drainage and subgrade conditions are, therefore, critical. The best subgrade materials are well-graded gravels or coarse-grained materials that provide good bearing capacity and free drainage. Heavy airplanes can extend stresses deeper than 1 meter, upon landing, and soil conditions beneath any proposed airfield should be explored to a depth of at least 2 meters. Highways and, in particular, airfields should be located over low water tables and away from areas of potential flooding, which can weaken the base.

Underground structures can include storage chambers and vaults for water, petrol, gas, noxious materials, critical government documents or materials, food, precious metals, defense installations and military command centers, underground transportation systems, water-supply and sewage systems, housing, offices, factories, mines, and power stations. An underground structure should be built in massive, strong rock in which there are as few joints, faults, and other discontinuities as possible. In particularly large excavations or openings in the foundation material, the state of stress and in-place deformation characteristics of the rock mass should be measured. If a relatively incompetent rock medium must be used, then a thorough rock mechanics study should be made of the rock mass to determine engineering procedures needed to strengthen the rock.

Construction material

Construction material is a basic commodity of any engineering project. The location, identification, and classification of construction materials is essential before any engineering design and construction can proceed. Construction material can be classified as impervious materials, pervious materials, riprap and rockfill, brick clay, cement materials, and building stone. Table 3 lists engineering uses of these various classes. The presently located potential sources of construction materials (see fig. 5) provides a framework for further detailed exploraton and testing. Exploratory methods for locating and evaluating suitable construction materials include detailed site mapping, exploratory borings, test pits, trenches, and tunnels, and testing of the materials themselves.

TABLE 3. CLASSIFICATION OF CONSTRUCTION MATERIALS
(U. S. Bureau of Reclamation, 1974)

Material	Examples of sources	Examples of use
Impervious	Silty and clayey gravel, and sand; silt; clay	Prevention of water or fluid leakage--canals, dams, reservoirs, storage vaults
Pervious	Sand and gravel	Concrete aggregates Road surfacing and base course Subbase for airfields Fillers and drains Blankets under riprap Drainage blankets
Riprap and rockfill	Rock fragments	Protection of earth embankments or exposed excavations from the action of water such as waves, turbulent flow, or heavy rain fall
Brick clay	Low shrinkage, low-magnesium clay; clay-rich shales; adobe	Building material
Cement	Low-magnesium limestone mixed with low-alkali clay and shale or quartz sandstone; "cement rock" (clayey limestone)	Building material
Building stone	Fresh granite; well cemented sandstone, limestone, marble; weakly foliated fresh granite gneiss	Building material

Geologic hazards

Potential geologic hazards should be identified during the reconnaissance and site exploratory phase and prior to final design and construction. Weak, sheared, and fragmented rock, swelling clay soils, landslide and rockfall areas, flood plains, and potential earthquake damage zones are examples of geologic hazards. These potential hazards, if they exist, must be recognized and avoided if possible. If the potential hazards cannot be avoided, then they should be designed "around" rather than "through" in any overall plan.

Soil properties

Laterite soils are essentially products of tropical or subtropical weathering. The chemical composition and morphological and geotechnical characteristics of these products are influenced by the degree of weathering of the parent material. M. D. Gidigasu (1976), Senior Research Officer and Head of Soil Mechanics and Foundations, Building and Research Institute of the Council for Scientifc and Industrial Research, Ghana, defines laterite soils as "all the reddish residual and non-residual tropically weathered soils, which genetically form a chain of materials ranging from decomposed rock through clays to sesquioxide-rich crusts, generally known as cuirasse or carrapace." This definition will be used in this report and is most appropriate for West Africa and Nigeria.

Gidigasu (1976) further divides laterite soils into ferruginous and ferralitic soils, and into "normal" and "problem" soils. Ferruginous soils are formed in dry tropical areas under savannah vegetation that have an average rainfall of less than 1,200 mm (50 in.) per year. In these areas evaporation exceeds precipitation during the dry season, which lasts more than 8 months a year. Ferralitic soils, on the other hand, are formed in the humid tropical rain forest areas, which have an annual rainfall in excess of 1,200 mm.

Normal soils are those laterite soils that yield reproducible results both from particle-size distribution and plasticity tests made by standard laboratory procedures. In general the Unified Soil Classification System (Casagrande, 1948) is adaptable to this group of normal laterite soils. Conversely, the problem soils are very sensitive to pretest preparation and test procedures, and may not yield reproducible results from standard testing procedures.

The relationships between soil texture and parent-rock types are particularly significant in the textural classification and behavior of residual laterite soils. In the textural classification of residual fine-grained soils, the relationship to parent-rock type, weathering conditions, degree of laterization, and geologic origin are crucial factors. The tendency is for sandy parent rocks to produce sandy soils, and for clayey parent rocks to produce silty clay soils. Leaching of dissolved materials in the alteration zone is also an important laterite-soil forming process and causes a widespread reduction in density of decomposed rocks. The strength within a laterite profile can vary considerably with depth at least in part as a result of the leaching process.

Soil properties of the Federal Capital Territory

The soils in the FCT were mapped and field tested, where possible, for engineering purposes and categorized according to the Unified Soil

Classification System. The concretionary laterite, classified as a surficial material under the discussion in surficial geology, is included as a soil-type foundation material here. The concretionary laterite was not amenable to field testing with the equipment available during the reconnaissance mapping phase.

Procedures.--Soil samples from 15- to 30-cm depths were collected on a grid having a maximum spacing of 8 km. The samples were subjected to color analyses based on the Munsell Soil Color Chart and to two testing procedures performed in a field laboratory set up at the base camp in Abuja. Gradational analyses were made on 50-g samples that were passed through U.S. standard 10-, 40-, and 200-mesh sieves. The fine fractions, the fractions passing the 40-mesh sieve, were then tested for dilatancy (reaction to shaking), toughness (consistency near plastic limit), and dry strength (crushing characteristics) following the visual test method outlined in the Earth Manual (U.S. Bureau of Reclamation, 1974). Based upon the size analyses and plasticity tests, each sample was assigned a classification in the Unified Soil Classification System (table 4).

Shear strengths were estimated in place by making penetration tests at depths ranging between 15-30 cm. A hand-carried spring-loaded piston penetrometer (Model CT-700, Soiltest, Inc., Evanston, Illinois) calibrated in bars and tons/ft^2 was used.

The results of the soil tests were plotted (fig. 5) at each sample location as soil group symbols, GW, GP, SW, SP, SM, SC, and the corresponding dual symbols (table 4). The soil pentrometer values were also plotted at each sample locality in units of bars or tons/ft^2.

TABLE 4. SOIL CLASSIFICATION AND ENGINEERING USE
(U. S. Bureau of Reclamation, 1974)

Group symbol	Typical names	Description	Value as subgrade	Value as subbase	Value as base	Value as foundation
GW	Well-graded gravel, gravel-sand mixture, little or no fines	Wide range in grain sizes and substantial amounts of all intermediate particle size	Excellent	Excellent	Good	Good bearing value
GP	Poorly graded gravel, gravel sand mixture, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing	Good to excellent	Good	Fair to Good	Good bearing value
SW	Well-graded sand, gravelly sand, little or no fines	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	Good	Fair to good	Poor	Good Bearing value
SP	Poorly graded sand, gravelly sand, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing	Fair to good	Fair	Poor to not suitable	Good to poor bearing value depending on density
SM	Silty sand, sand-silt mixture	Non plastic fines, or fines with low plasticity	Fair to good	Fair to good	Poor	Good to poor bearing value depending on density
SC	Clayey sand sand-clay mixture	Plastic fines	Poor to fair	Poor	Not suitable	Good to poor bearing value

TABLE 4. (CONT.) SOIL CLASSIFICATION AND ENGINEERING USE
(U. S. Bureau of Reclamation, 1974)

Group symbol	Important properties: Compressibility & expansion	Drainage characteristics	Dry strength	Permeability when compacted 1/	Shearing strength when compacted and saturated	Compressibility when compacted and saturated 1/	Workability as a construction material 1/	Relative desirability for various uses (Number 1 is considered best): Foundations, Seepage important	Foundations, Seepage not important	Roadway surfacing
GW	Almost none	Excellent	None	Pervious	Excellent	Negligible	Excellent	-	1	3
GP	Almost none	Excellent	None	Very Pervious	Good	Negligible	Good	-	3	-
SW	Almost none	Excellent	None	Pervious	Excellent	Negligible	Excellent	-	2	4
SP	Almost none	Excellent	None	Pervious	Good	Very low	Fair	-	5	-
SM	Very slight	Fair to poor	Very slight to medium	Semipervious to pervious	Good	Low	Fair	3	7	6
SC	Slight to medium	Poor to practically impervious	Medium to high	Impervious	Good to fair	Low	Good	4	8	2

1/ Equipment recommended for the soil types is as follows: GW, Crawler-type tractor, rubber-tired roller, steel-wheeled roller; GP, Crawler-type tractor, rubber-tired roller, steel-wheeled roller; SW, Crawler-type tractor, rubber-tired roller; SP, Crawler-type tractor, rubber-tired roller; SM, Rubber-tired roller, sheepsfoot roller; close control of moisture; SC, Rubber-tired roller, sheepsfoot roller.

Discussion and results.--Climatically, the FCT lies in a dry tropical, savannah-vegetation region having a long dry season. According to Gidigasu (1976, p. 76), ferruginous lateritic soils tend to form under these conditions. The majority of the soils examined fell in the reddish-brown color group, as would be expected of a ferruginous soil.

The soils and concretionary laterite in the FCT have been divided into three engineering groups that are representative of near-surface conditions. The first group (fig. 5), consists generally of poorly to well-graded sand and silty sand, belonging to the SW, SP, SM category. This class of soils, which covers a major part of the Territory, provides good drainage and is an excellent foundation material for engineering structures. No major near-surface engineering problems are anticipated for this soil group. A summary of the soil types and their physical properties and engineering uses is shown on table 4.

The second soil group (fig. 5) comprises clayey sand and sand-clay mixtures of the SC category. This SC group is associated generally with clay-bearing parent rocks, the Cretaceous sand-, silt-, and mudstone located in the southwest part of the Territory, and with altered mica-rich schist in the southeast. This soil group can be expected to have lower permeability and poorer drainage, and in general, less desirable properties as a foundation material (table 4). Confirmation of the lower permeability of this soil group was observed after rainstorms. Water ponded at the surface for 24 hours or longer after rain fell in the SC areas, whereas, in SW, SP, and SM areas, the water drained very rapidly.

The third group, annotated as "1c" on figure 4, is designated as concretionary laterite and was not amenable to testing with existing laboratory facilities at the base camp. The exposures showed great vertical variation in density and strength and, therefore, may be problematic in predicting the engineering properties at depth without careful site examination. Values based on in-place measurements with soil penetrometer and rock test hammer suggest shear strengths ranging between 5 and 40 bars (75-600 lb/in). The concretionary laterite forms hard crusts at the surface, yet may be weak and friable underneath. It is most widespread as cappings on highland hills and mesas.

Rock properties

Rock mechanics is the science of the mechanical behavior of rock; it is the branch of mechanics concerned with the response of the rock to the force fields of its physical environment (Natl. Acad. of Sci.-Natl. Res. Council, 1966).

Rock as a material possesses certain physical characteristics which are a function of its mode of origin and of subsequent geologic processes that have acted upon it. The sum total of these events in the geologic history of a given area leads to a particular lithology, to a particular set of geologic structures, and to a particular in situ state of stress. Variations in all of these do occur regionally and, of even greater importance, may also occur locally within the confines of a given engineering site.

Engineering planning procedure involves the selection of a tentative design and a prediction of expected behavior. The behavior of a rock mass subjected to a change in stress is governed both by the mechanical properties of the intact rock and by the nature and number of the geologic discontinuities present in the mass.

Lithology can indicate the engineering behavior of a rock as an engineering material. Igneous intrusive rocks such as granite, where fresh and unweathered, are characterized by high crushing and shear strengths; however, weathering and alteration can lower their competency considerably. The hardness, crushing strength, and shearing resistance of sedimentary (clastic) rocks depend mainly on degree of consolidation and cementation; such rocks can range from competent (quartzite, dense limestone, cemented sandstone) to incompetent (porous sandstone or limestone, soft clay shale). Metamorphic rocks have a wide range in physical and chemical properties and, therefore, a corresponding range in engineering properties. Most gneisses are hard and tough and are characterized by high crushing and shearing strengths; many mica, chlorite, or talc schists are soft and, therefore, are unsuitable for high-unit loading.

From the viewpoint of rock mechanics, any geologic structure that influences one of the mass properties of the in-place rock, such as strength, modulus of deformation, or permeability, is highly significant. The most common significant structural features are joints, bedding plane and foliation surfaces, and "shears" or faults. The frequency, orientation, and nature of these geological discontinuities reduce the effective shear strength of the rock mass to a value far below the intact rock strength, at least in directions parallel to the discontinuities, and they determine to a great extent the compressibility of the rock mass. Because the discontinuities are planar or near-planar features, the shear strength and compressibility of *in situ* rock is highly anisotropic. For example, when the directions of loading are such that the potential failure surfaces must cut across the structural features, the shear strength will approach that of the intact rock material. Conversely, where the direction of loading is parallel or subparallel to the structural features, the shear strength is governed by the shearing resistance along the rock surfaces of the discontinuity and will generally be much lower.

The state of stress at any given depth at a particular site is a required factor for many problems in applied rock mechanics, particularly in design of large surface or underground engineering structures, or for studies involving geologic hazards. The natural state of stress that exists at a point within a rock mass is a result of *all* previous geologic processes that have acted on the mass; therefore, the *in situ* stresses cannot be ascertained solely from a knowledge of the current geology of the area, nor, in the present state of knowledge, from computations using equations from mechanics. The only practical means of obtaining an estimate of the stress state is by means of field measurements (D. U. Deere, A. J. Hendron *in* Stagg and Zienkiewicz, 1968; Schultz and Cleaves, 1955).

Rock properties of the Federal Capital Territory

The rock in the FCT was mapped, field tested, and classified for its engineering properties on the basis of lithology, discontinuities and compressive strength (fig. 5).

Procedure.--The rock in the Federal Capital Territory was examined for lithology, weathering, alteration, and character of discontinuities, and was tested for in-place compressive strength. The lithology, weathering alteration, and discontinuities were categorized by geologic mapping and by interpretation of aerial photographs, SLAR (sidelooking airborne radar imagery), and Landsat imagery. The strength properties of the in-place rock were estimated by testing rock outcrops throughout the Territory with a Rock Test or Schmidt hammer. The rock-testing hammer is a hand-carried spring-loaded impact instrument that measures the magnitude of rebound of a plunger impacted against a rock surface (fig. 6) (Ege, Miller, and Danilchik, 1970). Deere and Miller (1966) have correlated the magnitude of rebound and rock density with compressive strength (fig. 7). The rebound value (R) is obtained by impacting 25 blows to the rock at different points on the outcrop and using the median value of the highest 13 measured values as the rebound number for the sample locality. The instrument used in the FCT produces 0.075 m-kg (0.54 ft-lb) of impact energy and is available as the L-type Schmidt hammer (Eisenhut, Basle, Switzerland) or Rock Test Hammer RM-710 (Soil Test, Inc., Evanston, Illinois).

Representative samples of rock types impacted by the Schmidt hammer were tested for densities in the Rock Properties Laboratory of the Nigerian Geological Survey, Kaduna, and an average density of 2.55 g/cm^3 (160 lb/ft^3) was calculated for use with the rebound numbers to estimate compressive strengths from figure 7.

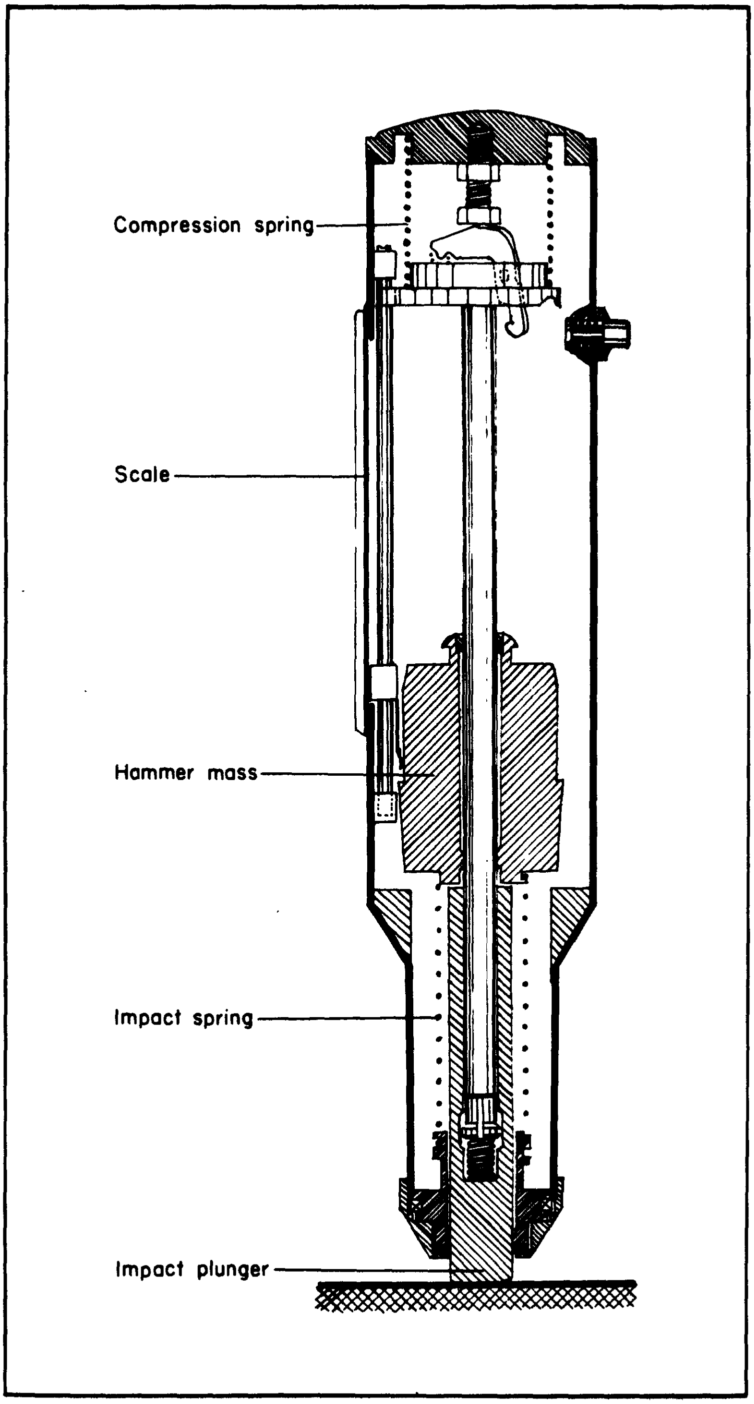

FIGURE 6.—Schematic drawing showing Type-L Schmidt hammer.

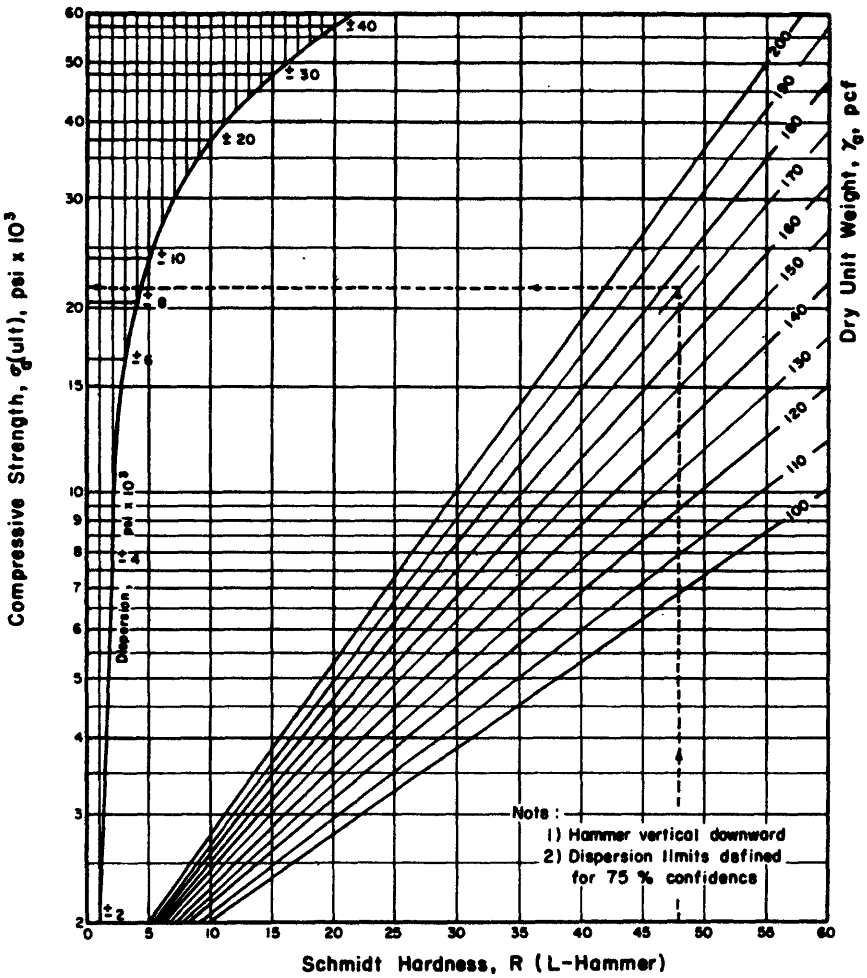

FIGURE 7.—Rock strength chart based on Schmidt hammer rebound number (R) and rock density. Average density of 2.55 g/cm^3 (160 lb/ft^3) used for FCT rocks (Deere and Miller, 1966).

Discussion and results.--The distribution of rock types is shown on figure 2. The rock-strength classification and rock testing hammer rebound number, designated by block letters and numbers, are plotted below sample localities on figure 5. The rock-strength categories, A-E, follow a geometric progression that divides common rock strengths into ranges. Table 5 defines the categories and describes typical lithologies for each range. The rebound value is representative of near-surface weathered and jointed rock conditions and probably translates to a conservative estimate of the compressive strength of a rock.

The rocks of the FCT are divided into three major engineering categories: (1) medium- to high-strength, massive and gneissic rock, (2) low- to medium-strength, bedded rock, and (3) low-strength, foliated and sheared rock (fig. 5). The medium-to high-strength massive and gneissic rock includes most of the granite, granite gneiss, and migmatite. The spacing of joints is mostly wide (>1 m), and gneissic structures where present are not expected to appreciably lower the competency of the rock. This category of rock should present a minimum of engineering problems and should provide a favorable medium for engineering structures.

The low- to medium-strength bedded rock consists of flat-lying Cretaceous sandstone, siltstone, and mudstone and is located in the southwestern part of the FCT. These sedimentary rocks form mesas or table lands many of which are capped by concretionary laterite. Joint spacing is wide (>1 m), and the rock stands as steep vertical cliffs where it has been cut through by the Gurara River. The alternating beds of sandstone, siltstone, and mudstone have different engineering properties and permeabilities; so some vertical anisotropic

TABLE 5. ROCK STRENGTH CLASSIFICATION (Deere and Miller, 1966)

Class	Description	Uniaxial compressive strength (lb/in^2)	(bars, approximate)	Typical lithologies
A	Very high strength	over 32,000	over 2,000	Quartzite, diabase, dense basalt
B	High strength	16,000 - 32,000	1,000 - 2,000	Igneous rocks, stronger metamorphic rocks, well-cemented sandstones, hard shales. Most limestones and dolomites
C	Medium Strength	8,000 - 16,000	500 - 1,000	Many shales, porous sandstones, and limestones, schistose metamorphic rocks.
D	Low strength	4,000 - 8,000	250 - 500	Friable sandstones, porous tuff, weak schists, clay shale, rock salt, and weathered or chemically altered rock of any lithology
E	Very low strength	less than 4,000	less than 250	

behavior of the material can be expected. The lower-strength beds may cause some foundation problems, possibly excessive settlement, or even failure. The more clayey parts of the rock can create drainage problems. These low-strength bedded rocks would not be generally favorable for major urban development because of their isolated highland character, and less desirable engineering properties.

The low-strength, foliated, and sheared rock forms a J-shaped belt that enters the FCT from the northeast and swings westward near the southern boundary (fig. 5). The belt is composed mainly of mica schist and is part of a large regional synform or syncline. Much of the area consists of steep hills and valleys. The eastern part of the belt is cut by a major east-northeast-trending shear zone that is subparallel to the strike of the metasedimentary rocks. The foliation planes dip from 30° off the horizontal to vertical. The inherent low strength, nonhorizontal foliation planes, and fragmented condition of the rock can be expected to create engineering problems related to foundations, stability, and drainage. No recently active landslides were noted during reconnaissance mapping; however, improper excavation or cutting of slopes, particularly in areas where geologic discontinuities are inclined toward valleys at angles of 30°-70° from the horizontal, could destabilize the region. Low-strength foliated and sheared rocks are not generally favorable for large-scale construction or engineering structures.

Structure

Lineaments, interpretated by S. J. Gawarecki (USGS) from Landsat-imagery, are plotted on figure 5. Most of the lineaments probably represent fracture zones in the bedrock and, therefore, are indicators of the density and orientation of discontinuities in the rock mass. Discontinuities within a volume of rock determine to a great extent the in-place strength of the rock. A careful examination of the lineaments shown on figure 5 should be made and related to field conditions prior to design and construction of large-scale or sensitive engineering structures, and particularly of underground excavations.

The lineaments may be useful in exploration of sources of ground water. Most of the groundwater in crystaline and metasedimentary rocks is stored in fractures. Areas of closely spaced lineaments, and especially lineament intersections, may be favorable locations for fracture-stored water.

Construction materials

The reconnaissance survey of the FCT did not reveal an abundance of naturally occurring construction materials. Alluvial sand and some quarryable sand, clay, granite and metamorphic rocks are available. Cement raw materials are not present.

Sand

Alluvial and terrace sands occur in the southern reaches of the Gurara River within the boundaries of the Territory (figs. 4 and 5). Some sandstone beds in the Cretaceous Nupe Group, located in the southwestern quadrant of the Territory, may be economical to quarry. Exploratory borings or trenching will be required to prove extent of these beds.

Coarse aggregate and riprap

In the northern half of the Territory granite hills can be quarried for aggregate and riprap (figs. 2 and 5). The granite should be drilled out to determine the depth of weathering, and tested for durability and toughness. Some granite gneiss and migmatite may be suitable for such uses but should be tested for specifications.

Building stone

Fresh granite, gabbro, and the stronger fresh metamorphic rocks, (granite gneiss and some migmatites) can be cut for building stone (figs. 2 and 5). Tests should be made to determine crushing and shear strengths, toughness, and durability.

Brick and ceramic clays

Clay-rich beds in the Nupe Group and some residual clays, classified as SC, in the southeastern part of the FCT (figs. 2 and 5) may be suitable for the manufacture of bricks or other ceramic products.

Cement

No acceptable cement raw materials were found in the reconnaissance survey. Magnesium-free limestone and low-alkali shale or clay are common cement-making materials.

Pervious and impervious materials

Pervious and impervious fill materials are available, mostly in the southwestern quadrant of the Territory. Sand and silt from the Gurara River and rocks of the Nupe Group can provide pervious material. Clayey and silty sand soils (SC, SM) (fig. 5) overlying the Nupe Group could be processed for impervious material. Hydrometer size analyses performed on seven SC soil samples from the FCT gave an average clay-size particle content of 20 percent and a range of 14-36 percent for all samples (table 6).

TABLE 6. CLAY SIZE HYDROMETER ANALYSIS OF CLAYEY AND SILTY SAND SOIL SAMPLES FEDERAL CAPITAL TERRITORY, NIGERIA

[Sample fraction size used is less than 40 mesh sieve (<0.42 mm)
(Analysist: Jill Leitner, U. S. Geological Survey)]

Field number	Group symbol	Soil name	Total sample weight (g)	Percent passing 0.42 mm	Clay fraction of <40 mesh (percent)	Clay fraction of total sample (percent)
W-57	SC	Clayey sand	50	74	48	36
OT-110	SC	Clayey sand	50	44	48	21
OT-108	SC	Clayey sand	50	66	33	22
OT-104	SC	Clayey sand	50	66	26	17
JE-27	SC	Clayey sand	50	66	24	16
JE-15	SC	Clayey sand	50	74	20	15
OT-134	SC	Clayey sand	50	88	16	14
OT-148	SM	Silty sand	50	60	12	7
OT-139	SM	Silty sand	50	74	12	9
JE-22	SM	Silty sand	50	78	12	9
JE-33	SM	Silty sand	50	68	9	6
OT-162	SM	Silty sand	50	54	9	5
JE-71	SM	Silty sand	50	82	8	7
JE-65	SM	Silty sand	50	90	8	7
JE-110	SM	Silty sand	50	44	6	3

Geologic hazards

Geologic hazards result from geologic conditions that can be triggered by natural or man-induced activities. In many cases the knowledge that a potential hazard exists will allow a planner or designer to avoid, or at least accommodate, the danger in engineering and other programs.

Foundation failure or settlement

The areas outlined on figure 5 as foliated and sheared rock and clayey sand soil (SC) are regions of potential foundation problems, either through bearing strength failure or by excessive settlement.

Drainage

The clayey sand (sc) soils may present difficulties in slow drainage characteristics.

Landslides

Although no recent landslides were observed during reconnaissance mapping, the potential exists for slope failure in the weak, sheared foliated schists in the eastern part of the Territory (figs. 2 and 5). The danger is especially severe in the region of hills and valleys where discontinuities in the slopes dip into the lowlands at angles between 30°-70° from horizontal. Such areas should be examined carefully before excavating foundations or cutting into the slopes for roads or other structures.

Floods

The Gurara River and other perennial streams have mostly low banks and, therefore, do not have the ability to store large volumes of water within their valleys. Flooding near the rivers in the Territory is possible, although apparently not common. Large-scale construction sites such as buildings, air field, railroads, or highways should not be placed on flood plains next to rivers. If it is unavoidable that highways or bridges be placed in areas subject to flooding, the foundations should be designed to survive occasional water-logging.

Earthquakes

No earthquakes in historical time have been recorded in the area of the FCT. Only two earthquakes within a 1,000 km radius of the center of the Territory have been recorded, one at a distance of 942 km and the other at 873 km. Both were near Accra, Ghana (Carl A. von Hake, written commun., July 13, 1977, U.S. National Geophysical and Solar-Terrestrial Data Center, Boulder, Colo.).

RECOMMENDATIONS

Capital city site

An area of about 800 square kilometers in the FCT is apparently free of potential geologic hazards and is suitable for construction of a capital city, its environs, and supporting facilities. This area is bounded on the west by the Gurara River, on the east approximately by long. 7°15' E., on the north by lat. 9°10' N., and on the south by lat. 8°50'N. This rather flat area, the hills to the east, and the low mountains with intermountain plains to the south can provide a wide range of attractive settings for a Capital metropolitan complex.

Airport site

The area west of the village of Gwagwalada (lat. 8°56' N.; long. 7°05' E.) and north of the Usuman River has adequate flat space and approaches for an airport having a runway oriented northeast-southwest. This orientation will take advantage of the northeasterly winds of October to March and the southwesterly winds prevailing April through September (Netting 1968, p. 64).

Further studies

A massive, wide-ranging hydrologic exploration and testing program by water experts should be made of the FCT and surrounding region to determine availability of water supplies for a capital city and its supporting facilities.

Large-scale topographic and engineering geologic maps (1:10,000) should be made of any area tentatively selected for the capital site and its environs. For any one area a series of derivative maps should show the following: genetic and engineering rock types; geologic structures including orientation, extent and description of joints, fractures, faults, bedding planes, foliation, and folds; engineering and genetic soil types; hydrologic data; landforms and stream patterns; surface gradients and slope angles; and areas of potential geologic hazards. Exploratory borings should be systematically located in the selected areas to test for soil and rock types, depth of rock weathering or alteration, and structural competency of the rock. Soil and rock core samples taken from the borings should be tested in the laboratory for physical and engineering properties.

All geologic, engineering, physical property, and related data should be placed in computer storage. The USGS has a computer program designed specifically for engineering geology and geomechanics programs: the geologic and engineering properties data storage, retrieval, and statistics system. This system will store data, retrieve, and print them on a variety of formats, and analyze the data statistically.

Low-altitude large-scale (1:2,500) photogrammetric-quality aerial photographs should be taken of the selected areas for use in detailed engineering planning; surveying; siting of buildings, roads, airfields, water lines, and other structures; and locating and developing sources of aggregate and building materials.

Areas identified on the geologic maps (figs. 2, 4 and 5) as sources of aggregate and buildings materials should be thoroughly investigated by detailed geologic mapping; test borings, pits or trenches; and standard laboratory tests on selected samples. Immediate attention should be directed to the granite hills in the northern part of the FCT and the river sediments and the sandstone and mudstone beds of the Nupe group in the southwestern part of the Territory.

Geophysical surveys (seismic and resistivity) should be conducted in the selected areas to determine depth of soil and weathering, and distance to fresh bedrock, and to provide a profile of rock and soil properties.

Geomechanics investigations should be made in areas selected for very large engineering structures such as reservoirs, dams, buildings, underground excavations, and sensitive defense installations. The state of stress in the rock should be determined using the overcore stress relief technique or hydrofracture method, available in the USGS and some engineering and mining firms.

Environmental impact studies and programs should be established to minimize deterioration of the environment by urbanization of the region and to prevent culturally accelerated erosion of the Territory. A well-coordinated program involving the geologist, engineer, biologist, architect, and planner can avoid many problems that otherwise might arise.

BIBLIOGRAPHY

Adeleye, D. R., and Dessauvagie, T. F. J., 1972, Stratigraphy of the Niger Embayment near Bida, Nigeria, in Dessauvagie, T. F. J., and Whiteman, A. J., eds., African Geology: Univ. Ibadan, Conference on African Geology, Proc., p. 181-186.

Alexander, L. T., and Cady, J. G., 1963, Genesis and hardening of laterite in soils: U .S. Dept. Agriculture, Soil Conservation Serv. Tech. Bull. 1282, 90 p.

American Geological Institute, 1962, Dictionary of geological terms: New York, Doubleday and Co. Inc., 545 p.

Becker, G. F., 1895, Reconnaissance of the gold fields of the southern Appalachians: U. S. Geol. Survey 16th Ann. Rept., pt. 3, p. 251-331.

Buchanan, Francis (F. Buchanan-Hamilton), 1807, A journey from Madras through the countries of Mysore, Canara, and Malabar, performed under the orders of the most noble the Marquis Wellesley, Governor General of India, for the express purpose of investigating the state of agriculture, arts, and commerce; the religion, manners, and customs; the history natural and civil, and antiquities, in the dominions of the Rajah of Mysore, and the countries acquired by the Honourable East India Company, in the late and former wars, Tippoo Sultan: London, T. Cadell and W. Davies, 3 vols.

Burke, K. C., and Durotoye, A. B., 1972, The Quarternary in Nigeria, in Dessauvagie, T. F. J., and Whiteman, A. J., eds., African Geology: Univ. Ibadan, Conference on African Geology, Proc., p. 325-347.

Carroll, Dorothy, 1970, Rock weathering: New York, Plenum Press, 203 p.

Casagrande, Arthur, 1948, Classification and identification of soils: Am. Soc. Civil Eng. Trans., v. 113, p. 901-992.

Coates, D. F., 1967, Rock mechanics principles: Canadian Dept. Energy, Mines, and Resources, Mines Branch Mono. 874, Queen's Printer, Ottawa.

Deere, D. U., and Miller, R. P., 1966, Engineering classification and index properties for intact rock: U. S. Air Force Weapons Lab. Tech. Rep. AFWL-TR-65-1167.

Du Preez, J. W., 1949, Laterite: a general discussion with a description of Nigerian occurrences: Bul. Agr. Congo Belge, v. 40, p. 53-66.

Ege, J. R., Miller, D. R., and Danilchik, Walter, 1970, Schmidt hammer test method for field determination of physical properties of zeolitized tuff: U. S. Geol. Survey open-file rept. Rainier Mesa-11, 40 p.

Faniran, A., 1972, Depth and pattern of weathering in the Nigerian Precambrian basement complex rock areas: a preliminary report, in Dessauvagie, T. F. J., and Whiteman, A. J., eds., African Geology: Univ. Ibadan, Conference on African Geology, Proc., p. 379-393.

Farmer, I. W., 1968, Engineering properties of rock: London, E. and F. N. Spon Ltd., 180 p.

Federal Capital Development Authority, 1977a, Landsat-image geographic map, Federal Capital Territory, Republic of Nigeria: Nigerian Federal Capital Devel. Authority, Landsat Image Map, scale 1:100,000.

Federal Capital Development Authority, 1977b, Provisional map showing land use based on the interpretation of vegetation, Federal Capital Territory, Republic of Nigeria: Nigerian Federal Capital Devel. Authority, Landsat Image Map, scale 1:100,000.

Gidigasu, M. D. 1956, Laterite soil engineering: Amsterdam, Elsevier Scientific Publishing Co., 554 p.

Goodman, L. J., and Karol, R. H., 1968, Theory and practice of foundation engineering: New York, Macmillan Co., 453 p.

Goodman, R. E., 1976, Methods of geological engineering: St. Paul, Minnesota, West Publishing Co., 472 p.

Happ, S. C., Rittenhouse, Gordon, and Dobson, G. C., 1940, Some principles of accelerated stream and valley sedimentation: U. S. Dept. Agriculture Tech. Bull. 695, 134 p.

Hough, B. K., 1957, Basic soil engineering: New York, Ronald Press Co., 513 p.

Jaeger, Charles, 1972, Rock mechanics and engineering: Cambridge Univ. Press, 417 p.

Jaeger, J. C., and Cook, N. G. W., 1969, Fundamentals of rock mechanics: London, Methuen and Co. Ltd., 513 p.

Krynine, D. P., and Judd, W. R., 1957, Engineering geology and geotechnics: New York, McGraw-Hill.

Montgomery, P. H., 1940, Erosion and related land use conditions on the Lloyd Shoals Reservoir watershed, Georgia: U. S. Dept. Agriculture, Soil Conservation Service, 26 p., Washington, D. C.

National Academy of Science - National Research Council, 1966, Rock mechanics research: Natl. Acad. Sci., Natl. Res. Council, Washington, D. C.

Netting, R. M., 1968, Hill farmers of Nigeria: Seattle, Washington, Univ. Washington Press, 259 p.

Obert, Leonard, and Duvall, W. I., 1967, Rock mechanics and the design of structures in rock: New York, John Wiley and Sons, Inc., 650 p.

Ollier, C. D., 1969, Weathering: Edinburgh, Oliver and Boyd, 304 p.

Peck, R. B., Hanson, W. E., and Thornburn, T. H., 1953, Foundation Engineering, New York, John Wiley and Sons, Inc., 410 p.

Persons, B. S., 1970, Laterite genesis, location, and use: New York,

Peterson, L. R., and Meyer, Gerald, 1977, Hydrologic reconnaissance evaluation of the Federal Capital Territory and surrounding areas, Nigeria: U. S. Geol. Survey open-file rept. 77-596, 30 p.

Rockham, L. J., 1972, The planation surfaces of a part of the basement complex of northern Nigeria--an interim report, in Dessauvagie, T. F. J., and Whiteman, A. J., eds., African Geology: Univ. Ibadan, Conference on African Geology, Proc., p. 427-535.

Reiche, P. A., 1945, A survey of weathering processes and products: Univ. New Mexico Pubs. in Geol., no. 1, 87 p., Albuquerque, New Mexico

Schultz, J. R. and Cleaves, A. B., 1955, Geology in engineering: New York, John Wiley and Sons, Inc., 592 p.

Sowers, G. B., and Sowers, G. F., 1951, Soil mechanics and foundations: New York, Macmillan Co., 284 p.

Stagg, K. G., and Zienkiewicz, O. C., eds., 1968, Rock mechanics in engineering practice: London, John Wiley and Sons, Inc., 442 p.

Terzaghi, Karl, and Peck, R. G., 1968, Soil mechanics in engineering practice, 2nd ed.: New York, John Wiley and Sons, Inc., 729 p.

The Asphalt Institute, 1964, Soils manual for design of asphalt pavement structures: The Asphalt Institute, College Park, Maryland, 261 p.

Trimble, S. W., 1974, Man-induced soil erosion on the Ankeny, Iowa: Soil Conserv. Soc. America, 185 p.

U. S. Bureau of Reclamation, 1975, Concrete manual, 8th ed.: Superintendent of Documents, U. S. Govt. Printing Office, Washington, D. C. 20402, 627 p.

U. S. Bureau of Reclamation, 1974, Earth manual: Superintendent of Documents, U. S. Govt. Printing Office, Washington, D. C., 20402, 810 p.