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ORIGINAL PAPER

Effect of mineralogy on physico-chemical and some geotechnical properties of soils developed over granite, schist, and migmatite gneiss: a case study of Minna, Central Nigeria

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Abstract

Results of influence of mineralogy on physico-chemical and some geotechnical properties of soils developed over granite, schist, and migmatite gneiss around Minna in central Nigeria are presented. A region around Minna was studied to obtain the structure and petrography of the rocks. Three trial pits taken to depths of 5.0, 3.5, and 4.0m were dogged within region of granites, schists, and migmatite gneiss rocks, respectively, all of which belong to Basement Complex of northern Nigeria, to study the mineralogical, physico-chemical, and some geotechnical properties of overburden soils over these rocks. In each of the trial pits, soil samples were collected at interval of 0.5m depths to terminal depths of the pits. X-ray diffraction, index properties, and compaction tests were carried out the samples, and the results were analyzed to determine the influence of mineralogy on physico-chemical and some geotechnical properties of the soils. The result showed that rate of weathering is higher in granite rocks, where primary minerals altered to secondary minerals including smectite minerals. This is followed by overburden over schists, which was observed to alter to secondary minerals like illite and kaolinite. Overburden soil over migmatite gneiss did not showed alteration to secondary minerals but conversion of the carbon element to sodium carbonate salt. Higher fines content, cation exchange capacity, and Atterberg limits, recorded from soils developed over granite rocks, probably resulted from the smectite minerals recorded within this profile. The non-plastic nature of soils, on schist rocks, despite presence of secondary minerals, and judging from the low natural moisture content observed within this profile, indicated that the minerals developed under poor drainage condition. It was therefore concluded that mineralogy of overburden soils over basement complexes and the drainage condition during formation affect their geotechnical properties.

Keywords Central Nigeria · Geotechnical properties · Granite · Mineralogy · Migmatite Gneiss · Overburden soil · Physico-chemical properties · Schist

Introduction

Tropical soils have been regarded as the most highly weathered soils on earth (Yakubu and Ojanuga, 2009). This is as a result of the climatic condition of the region, which is characterized by high temperatures and rainfall that help in promoting extreme alteration of primary minerals from the parent rock to form secondary minerals. Soil mineralogy plays important role in forming the character of a soil, such that the key features, employed to differentiate soils at the highest level, depend on mineralogy (Uehera and Gillsman 1981), which in turn depends on mineralogy of the parent rocks (Eze et al., 2020) These properties, according to Shafique et al. (2012) are responsible for all the physical properties of the overburden soils and consequently, their engineering properties. Rao (2020) highlighted age of rock, its weathering, and alteration of primary minerals to secondary minerals as factors affecting the strength of rock masses. Ko (2014) studied the characteristics of

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lateritic soils derived from different parent materials from Taiwan and stated that parent materials play pertinent roles during soil weathering process, while physical and mineralogical composition affect the development of lateritic soil. Microstructural analysis, such as mineralogy and physicochemistry, conducted on overburden soils proves to be useful in understanding the physical properties of these soils and consequently, their engineering properties (Mahalinger-Iyer and Williams 1997).

Geologists over the years have shown that rocks belonging to basement complexes differ from one position to the other in their physiochemical properties and mineralogical constituents, depending on the underlying rocks. The predominant rock complexes identified are the granitic, gneiss, and schist basement complexes. The most common of the three rocks in this basement complex is the granitic rock, whose overburden around Minna and its environs was studied by Alhaji (2008). However, the mineralogical and physico-chemical characteristic of the overburden was not considered in the study. Not much study has been carried out on overburden soils, on schist, and migmatite gneiss rocks. In this region, foundation engineers design foundation of structures in overburden over residual soils without considering the possible differences in the physical properties and consequently, the engineering properties of these soils. Ignoring the variability of mineralogical and physico-chemical characteristics of these residual weathering profiles with depth is denying the different formation factors of these soils. This may lead to misleading results and consequently, serious failure of structures erected on them. This work is therefore aimed at studying the effect of mineralogy on physico-chemical and some physical properties of overburden soils on granitic, schist, and migmatite gneiss basement complexes in north central Nigeria.

Location, Climate, and Geological Setting of Location of Studied Area

Sampling point on the granitic basement complex was located along the eastern by-pass connecting Minna-Bida road. It was about 20m from the road and was situated at 9° 32′ 20.62″ N and 6° 30′ 30.30″ E. From Figure 1, this trial pit lies on a boundary between the fine-grained granite region and migmatite gneiss region. This can possibly lead to intrusion of migmatite gneiss characteristics to this granitic overburden.

Sampling point on the schist basement complex was located close to Bosso dam and was accessed directly through the access road leading to the dam. The sampling point was located at 9° 40′ 36.28″ N and 6° 30′ 44.00″ E. From Figure 1, this point lies in the region of undifferentiated schist and positioned between the porphyritic granite region and medium to course-grained granite region.

Sampling point on the migmatite gneiss complex was located at Gadan Eregi, about 500m off Minna-Bida road. It was very close to a seasonal stream at 9° 23′ 01.0″ N and 6° 23′ 01.78″ E. There are lots of activities of local mining of gold in this area. From Figure 1, this point lies in a seam of migmatite gneiss and positioned between amphibolite schist region and Nupe sandstone region, indicating that the point is a contact zone between the Minna Basement Complex and sedimentary terrain of Bida basin.

Climate of the Studied Area

The study area lies within 9° 22′ 00″ N, 6° 20′ 00″ E and 9° 42′ 00″ N, 6° 34′ 00″ E. This area belongs to the middle belt area of Nigeria, which experiences two major seasons annually—raining season that spans from April to October and dry season that commences from November and lasts to March. The dry season is usually characterized by low humidity and is usually followed by north-east trade winds, termed Harmattan period. The raining season on the other hand is brought about by south-east trade wind. Vegetation in the area is characterized by shrubs and tall grasses as well as occasional trees of varied species. The relief of the area showed gentle topography with occasional hills, some of which can be as high as 450m. The eastern part of the studied area is characterized by rugged-type topography which runs from the north to the southern portion.

The study area is drained majorly by river Maidan, whose tributaries include Bosso dam river and Gadan Eregi river that form tributaries of Chanchaga river. These major rivers form several tributaries that spread over the study area, exhibiting drainage pattern that is dendritic in nature.

Geological Setting of the Area

The study area belongs to Nigeria Basement Complex rocks, which, according to Olarewaju et al. (1996) and Olasehinde (1999), comprises of three major Basement Complexes as shown in Fig. 1. They include the older granites, the migmatite gneiss, and the low schist belt.

Also common in the area are varied grain-sized granitic rocks that outcrop at different locations with significant fractures and joints. The joint directions are observed to range from 120–160°.

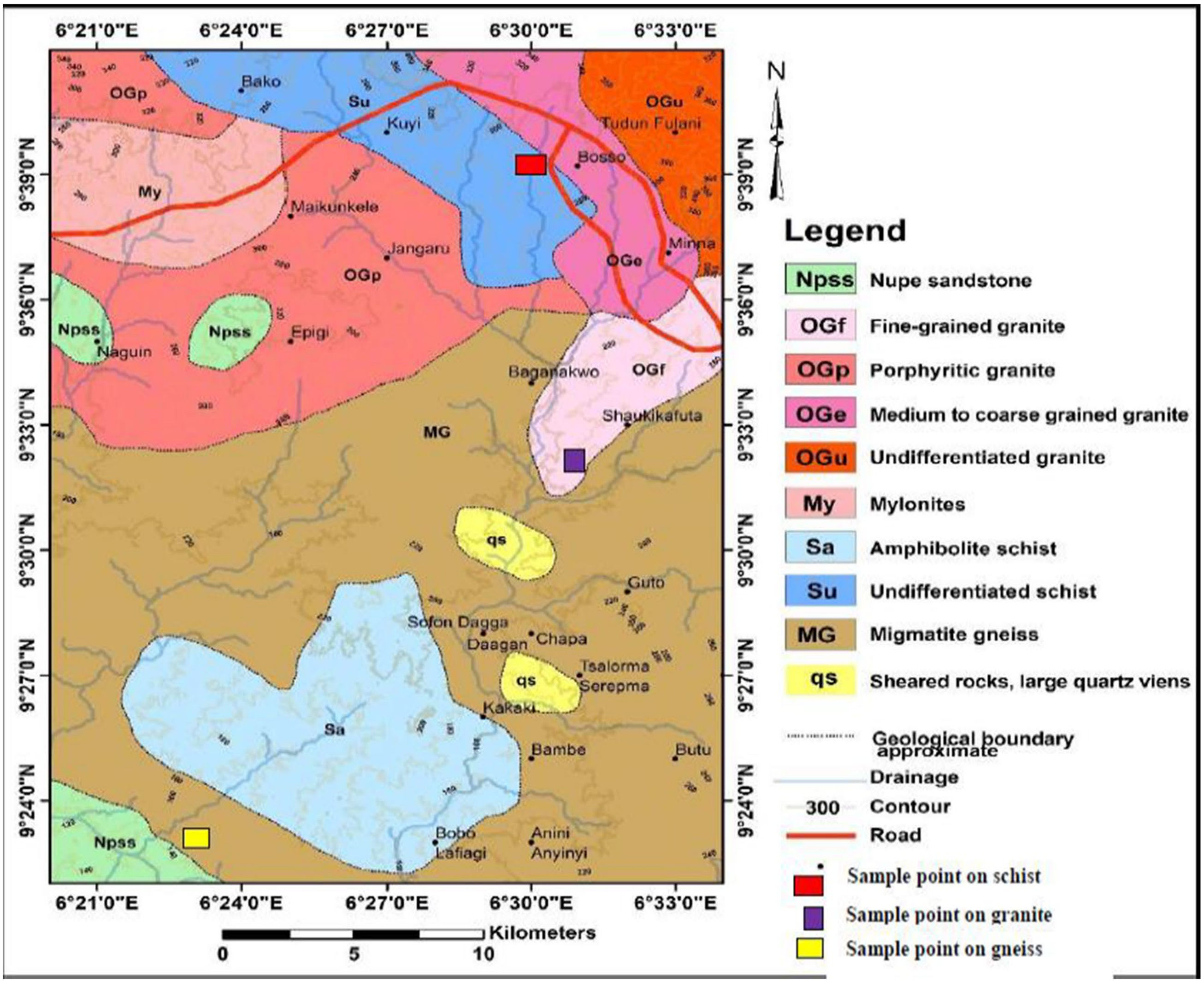

Fig. 1 Geological map of the studied area

Methodology

The method used in the study involves geological field mapping to identify various rock types. Representative fresh rock samples were collected and analyzed at the National Geosciences Research Laboratory Kaduna. The rock samples were prepared and placed on a specialized microscope. Thin slide of the rocks was placed on rotating stage of the microscope and camera set in place with light coming from under. The slides were viewed and rotated under plane polarized light (PPL) and cross polarized light (XPL) environments. Properties like color, pleochroism, relief, and texture were observed under PPL, while those observed under XPL include interference colors, twinning, and extinction.

Result of the survey was used to identify three positions (points) and their geological boundaries. Three major lithology of Granite, Schist and Migmatite gneiss were identified. From these three identified points, trial pits were conducted and the overburden soils were retrieved. In each of the trial pits, soil samples were collected at 0.5 m depth interval to maximum of 5.0 m depth or where manual digging becomes practically impossible. Physical properties including liquid limit, grain size analysis, specific gravity, natural moisture content, and compaction tests were carried out based on the methods highlighted in BS 1377 (1992). Physico-chemical tests including organic matter content, loss on ignition, cation exchange capacity, and pH were also carried out on the soil samples. Representative specimens taken from each of the samples were prepared and sent to iThemba laboratories in South Africa, for X-ray diffraction (XRD) tests. This is to obtain the major minerals contained in each of the specimen.

Results

Rock sample observation using hand lens and petrological microscope under PPL and XPL conditions

The major rock types identified in the study area are amphibolite schist, granite, and migmatite gneiss. Slide of these major rocks were prepared and observed with hand lens and under microscope as discussed below.

Amphibolite schist rocks

The amphibolite schist, which has green color and highly foliated rock, was observed to contained minerals including hornblende (amphibole), biotite, and quartz. Hornblende is the dominant mineral observed in the rock. It has predominantly green color with shades of light brown under PPL. The relief was generally high.

In many samples observed, the shape of the mineral varies from subhedral to anhedral. The cleavages were observed to be pronounced interlocking with other minerals. Under XPL, interference color of light to dark green, extinction, and twining were also observed.

Biotite mineral under PPL has brown color, low relief, and exhibit pleochroism changing from brown to greenish brown. In terms of shape, it is subhedral to euhedral. Biotite interlocked with amphibole and other opaque minerals. Under XPL, it has interference color ranging from pale green to darkish brown and showed parallel extinction.

Quartz occurred mostly as euhedral to subhedral and medium to coarse-grained crystals. It has low relief, colorless, and no cleavage under PPL. The crystal of quartz has undulose extinction under XPL. The type of quartz found in this sample is primary, because of its anhedral nature.

Granites

The granite rocks observed in the study area were granular in texture and contained feldspar, quartz, biotite, and some opaque minerals. The feldspar was observed to be almost colorless in outlook with low relief having subhedral shape under plane polar. The mineral exhibited polysynthetic twining under XPL and showed interference color of light brown. The quartz was observed to be colorless under PPL with high relief. The shape is subhedral to euhedral under XPL. It has undulose extinction. Interference colors of white to milky white are observed in quartz grain. Under PPL, the color of the biotite was observed to be brown, had moderate relief with subhedral shape having lath-like crystals. The mineral was pleotropic, changing from brown to mixtures of brown and green. In XPL, it exhibited parallel extinction and displayed an interference color of blue and yellow. Opaque minerals were also observed, as reported by Darbandi et al. (2020).

Migmatite gneiss

At microscopic scale, the migmatite gneiss rock is fine to medium grained and showed irregular foliation, marked by mineralogical bandings. The minerals observed were quartz, feldspar, hornblende, biotite, and opaque minerals. The quartz mineral was observed to be colorless with low relief under PPL. It was anhedral to subhedral in shape with texture of fine- to medium-grained crystals. Under XPL, quartz showed undulose extinction. Two types of quartz, primary and secondary quartz, were observed. Feldspar is one of the mineral observed in the migmatite gneiss rocks in the study area. The feldspar was colorless, subhedral to euhedral in shape under PPL. Two kinds of feldspar were observed and they both displayed brown interference color under XPL. The biotite mineral observed in the rocks has brown color and high relief, anhedral in shape, and pleochroic with shades of brown and green. Under XPL, it exhibited extinction which was almost parallel. Some opaque minerals were also observed. Quartzite minerals were also contained in the migmatite rock which showed porphyroblastic texture having more than 96% of quartz crystals with some opaque minerals in co-existence as accessory mineral.

Mineralogy of overburden soils collected on the three basement complexes

Results of the X-ray diffraction (XRD) tests are shown on the graphs (Figs. 2, 3, 4, and 5) with the peaks showing the predominant minerals.

Results of mineralogical composition of overburden over granite basement

Graph of the results of the representative XRD tests of soil samples, collected from overburden over granite basement, is shown in Fig. 2.

The figure shows that the major minerals grouped into strata from the stiff bedrock at the base to loose soil at the top. Weathering of rocks over basement complex must have started from the surface, since all agents of weathering, like rain water, carbon dioxide, and surface temperature, exist in the atmosphere close to the ground surface. These weathering agents attack the primary rock minerals from the surface and move gradually downwards within the profile through leaching of dissolved ions. It therefore suffices to preclude that weathering of the upper stratum of residual profile will show more results of alteration of primary rock

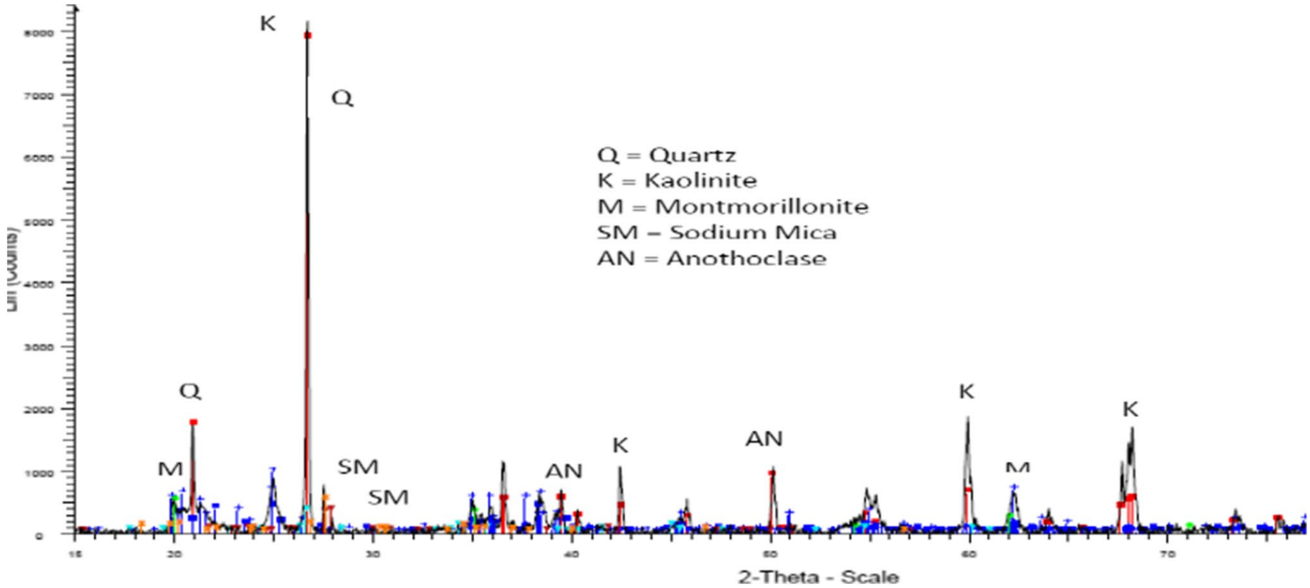

Fig. 2 Graph of representative XRD results for soils collected over granite basement at 0.5 m depth

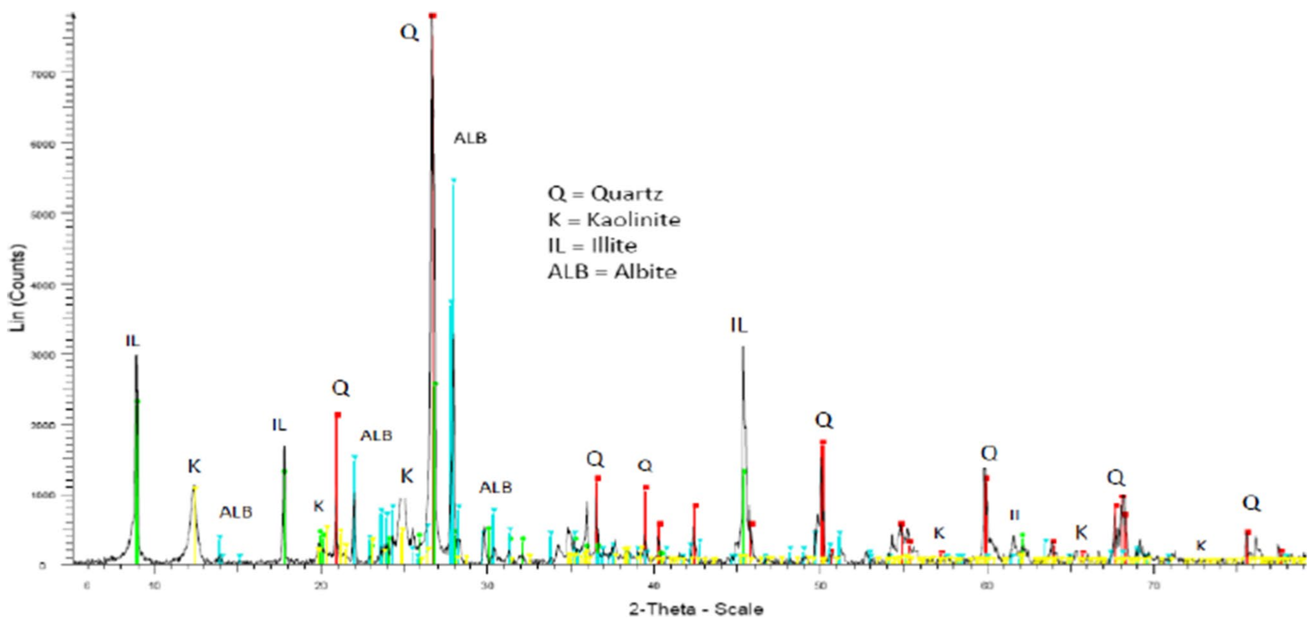

Fig. 3 Graph of representative XRD results for soils collected over schist basement at 0.5 m depth

forming-minerals to secondary minerals. The lower stratum will contain less of secondary minerals and more of primary rock-forming minerals because weathering within this stratum is still fresh.

From the XRD results and based on the major minerals observed in the soil samples collected within the residual strata, the profile can be categorized into three strata. The lower stratum between 3.5 and 5.0 m depth consists of primary minerals (quartz, phlogopite, chrysotile, potassium mica, annite, and potassium alanate) altering to secondary minerals (kaolinite, montmorillonite, and saponite). The stratum consists of large amount of primary minerals because their alteration to secondary minerals is still in process within this stratum. The presence of magnesium-rich minerals, like chrysotile and saponite that are observed in this stratum, is not expected and must have resulted from intrusion of migmatite gneiss basement, considering the position of the trial pit in relation to migmatite gneiss basement complex (Fig. 1), as opined by Ikhlef-Debabha et al. (2020). Smectites which is a common mineral in granitic

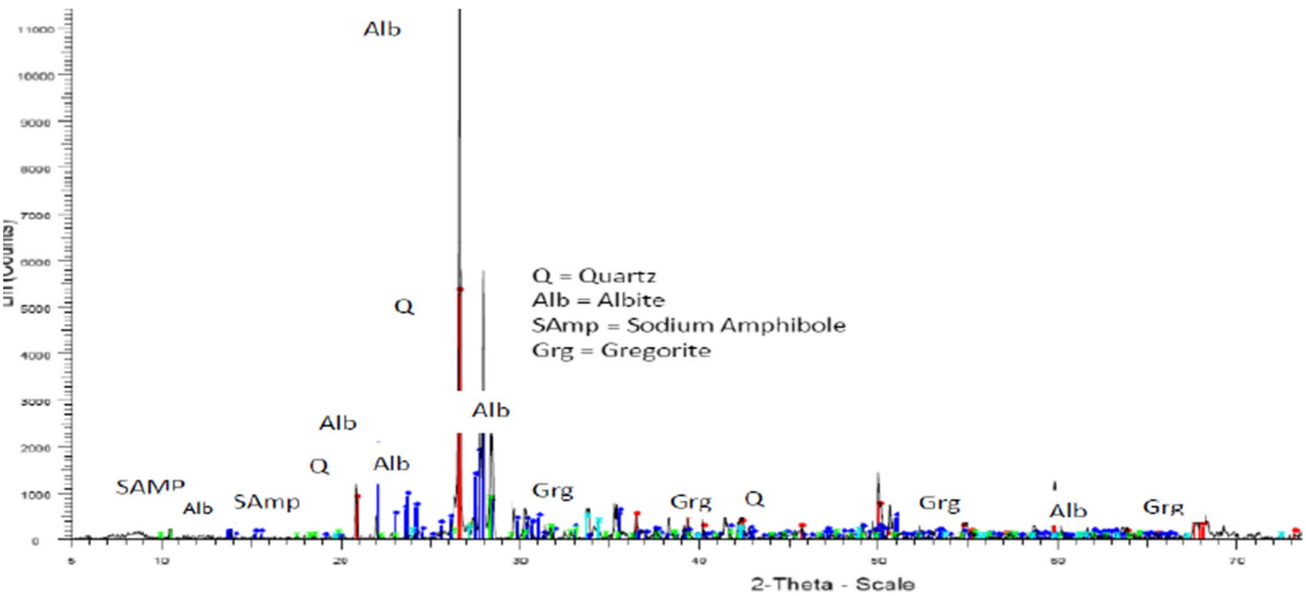

Fig. 4 Graph of representative XRD results for soils collected over gneiss basement at 0.5 m depth

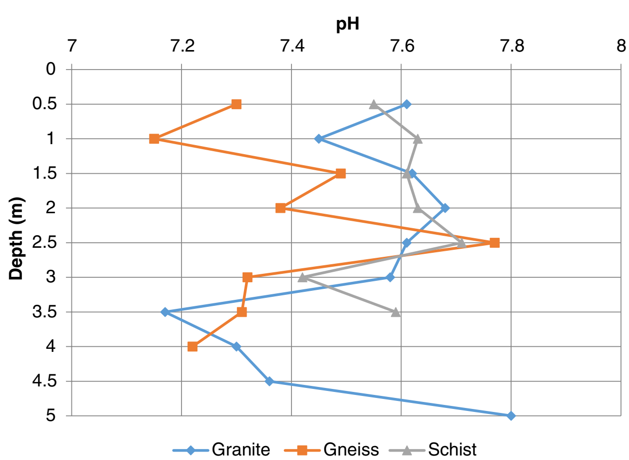

Fig. 5 Variation of pH with depth

basement is completely absent in this stratum. This mineral is probably missed at lower 2Θ values or must have developed under poor drainage condition in the subtropical climate.

The second stratum between 2.5 and 3.5 m depth has similar minerals like the lower stratum except that some primary minerals like annite, potassium alanate, and spinel have been completely transformed to secondary minerals, which is an indication of more weathering, compared to the lower stratum. The third and the upper stratum between 0.5 and 2.5 m depth recorded only quartz and phlogopite as primary rock minerals. All other primary minerals that had existed at the lower strata must have been transformed to secondary minerals (kaolinite and montmorillonite) observed in this stratum.

Results of mineralogical composition of overburden over schist basement

The graph of X-ray diffraction test results is shown in Figs. 3. Excavation to maximum depth of 3.5 m was achieved on this basement complex before intact rock was encountered.

The mineral composition within this profile grouped itself into three strata, beginning from 3.0 to 3.5 m depth, followed immediately by stratum from 1.5 to 3.0 m depth, and finally, stratum from 0.5 to 1.5 m depth. The first and the lowest stratum (3.0 to 3.5 m depth) consists mainly of quartz and albite (feldspar) as primary minerals which are in the process of alteration to illite, kaolinite, and nontronite as secondary minerals.

The second stratum from 1.5 to 3.0 m depth recorded quartz, albite (feldspar), and phlogopite (mica) as primary minerals, altering to kaolinite and illite as secondary minerals. The third stratum between 0.5 and 1.5 m depth showed higher degree of weathering, having minimal amount of primary minerals (quartz and albite) with kaolinite and illite as secondary minerals. Other primary minerals like phlogopite and biotite observed within the middle stratum have completely transformed to kaolinite and illite in this stratum.

Results of mineralogical composition of overburden over gneiss rock

The overburden on this basement complex was excavated to maximum depth of 4.0 m where intact rock was observed. The major minerals observed within this overburden were grouped into four different strata. The first lowest stratum, from 3.5 to 4.0 m, was the closest to the intact base rock and possesses major minerals including quartz, feldspar (albite), amphibole (sodium amphibole), and carbon.

The second stratum from 3.0 to 3.5 m consisted of all the minerals in the first stratum with introduction of mica (philogopite and biotite). The third stratum from 2.0 to 3.0 m consisted of the same minerals as first stratum except that carbon was completely absent. The fourth stratum ranging from 0.0 to 2.0 m consisted of same minerals as in the first stratum except the introduction of gregoryite and disappearance of carbon. Except for carbon and gregoryite, all these minerals are primary silicate minerals, while the secondary silicate minerals (clay minerals) were completely absent.

Results of physico-chemical characteristics of overburden soils on the three basement complexes

The physico-chemical characteristics investigated are pH, organic matter content, cation exchange capacity, and loss on ignition. From Fig. 5, it is observed that the pH values recorded from the three basement complexes ranges between 7.2 and 7.8, which hovers around neutral to slightly acidic.

Generally, the pH values increased from gneiss through granite to schist. However, the pH values of schist and granite basement complexes are close. The trend in pH with depth was observed to be similar for the three basement complexes, with increase in pH from 0.5 m to maximum values at 2.5 m depth after which the values dropped. The organic matter contents recorded for the three basement complexes were observed to be generally low (between 0.18 and 0.78%) which is in agreement with values recorded for residual soils. However, the trend of organic matter content with depth is similar for granite and gneiss basement complexes and showed gradual increase from 0.5 m depth to its maximum at 3.0 m depth after which the values became constant for granite basement complex, but increased for gneiss basement complex.

Cation exchange capacity (CEC) which according to Lambooy (1984) is the ion contained on the surface of soil particles. Figure 6, which showed trend of CEC with depth, was observed to have values that are lower for gneiss and schist basement complex compared to the granite basement complex. The CEC values over schist and gneiss basement range between 30 and 78cmol/kg. The values recorded for granite basement complex range between 37 and 149cmol/kg. However, the trend of CEC with depth over the three basement complexes is similar, with the values increasing gradually to 2.0 m depth after which they began to decrease (Fig. 7).

Lost on ignition (LOI) according to Konare et al. (2010) and Hoogsteen et al. (2018) is indirect measurement of organic matter content in soil mass. It is slightly related

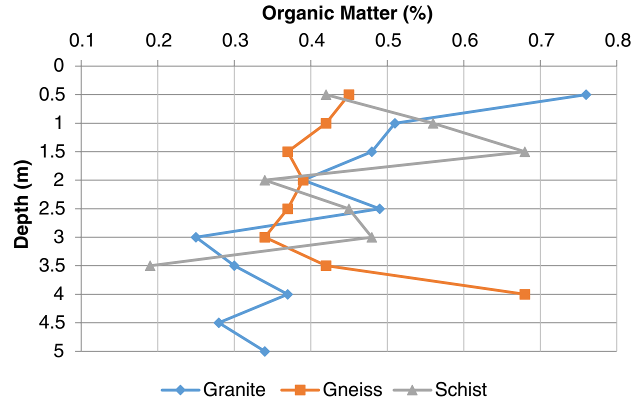

Fig. 6 Variation of organic matter with depth

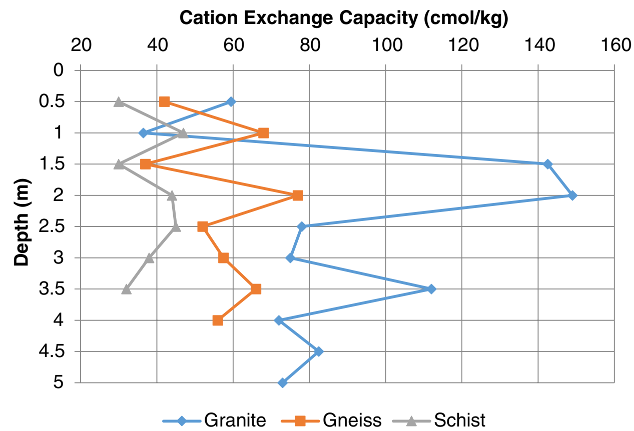

Fig. 7 Variation of cation exchange capacity with depth

to CEC of soil mass which explains the similarity in trend observed between LOI and CEC.

Generally, the LOI values over schist and gneiss basement complexes are close and range between 2.1 and 10.0%. The values obtained on granite basement were higher and range between 8.9 and 18.2%. The trends in values of LOI with depth were very close for gneiss and schist basement complexes. The trend showed increase from 0.5 to 2.5 m depth after which the values decreased (Fig. 8).

Results of some physical properties of overburden soil over three major rocks of the basement complexes

The natural moisture content (NMC) generally increased from overburden on gneiss through that on schist to that on granite basement complexes. The values were observed to be lower and closer for schist and gneiss basement complexes and the trend in variation of the values with depth is also similar. The values recorded for granite basement

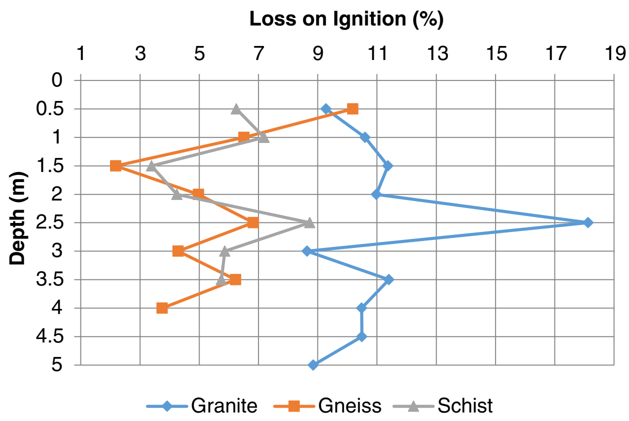

Fig. 8 Variation of loss on ignition with depth

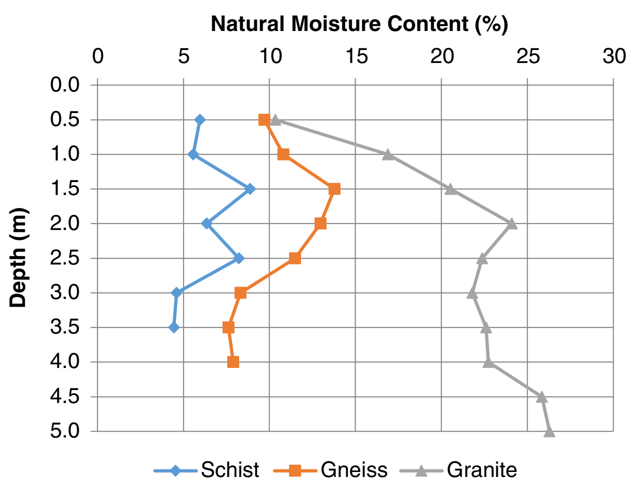

Fig. 9 Variation of natural moisture content

increased from 10.3% at 0.5 m depth to 24.1% at 2.0 m depth after which the values remained relatively constant to 4.0 m depth (Fig. 9). Beyond this, the values increased to 26.3% at 5.0 m depth.

In schist basement complex, the NMC values increased from 6.0% at 0.5 m depth to 8.9% at 1.5 m depth, after which the values reduced to 4.4% at 3.5 m depth. The values obtained in gneiss complex increased from 4.8% at 1.0 m depth to 6.5% at 2.5 m depth after which they reduced to 5.3% at 4.0 m depth.

The variation of percentage fine with depth for the three basement complexes was analyzed. Percentage fine affects physical and geotechnical properties of soil mass tremendously. The values recorded for schist and gneiss basement complexes were observed to be close and ranged between 22 and 42%. The values obtained for overburden over granite basement complex were relatively higher and ranged between 34 and 63%. The trend shows increase from 0.5 m depth to maximum value at between 1.0 and

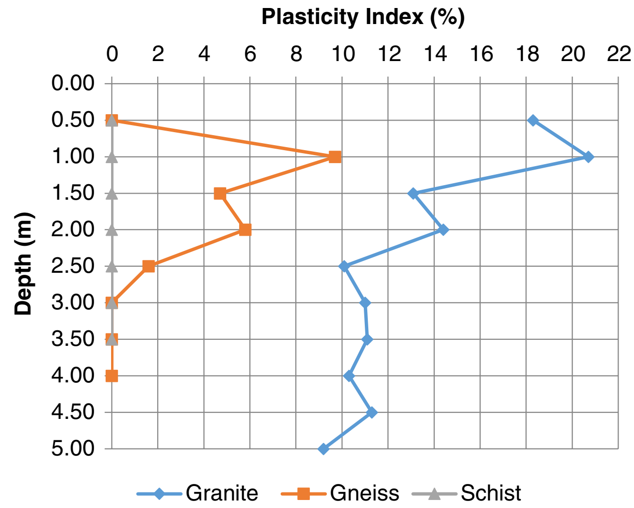

Fig. 10 Variation of plasticity index with depth

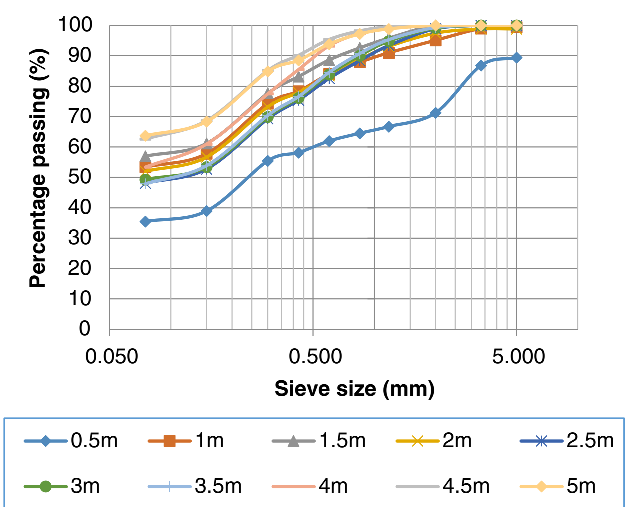

Fig. 11 Variation with depth of representative grain size distribution over granite

1.5 m depths, after which the values decreased slightly down the profile.

Overburden on schist basement complex was observed to be non-plastic over the entire profile despite presence of kaolinite and illite minerals. This is probably due to low degree of weathering of overburden over this basement complex. Overburden over gneiss basement recorded local presence of plastic material despite lack of secondary clay minerals within the profile. The values reduced from 9.0% at 1.0 m depth to 1.7% at 2.5 m depth. Soil collected from other depths within this profile was non-plastic (Fig. 10).

The grain size analysis for overburden soils within the depth studied is shown in Fig. 11 for granite basement complex. The study of grain size analysis is pertinent, especially that it is one of the major properties that affect the diffusion pattern of concrete grouting (Zhang et al. 2019). The grain size analysis for soils over granite basement, within the depth of 1.0 to 5.0 m, showed high composition of sand-sized particles with fines ranging from 47 to 63%. The soil at 0.5 m depth showed marked difference with about 10% gravel and 35% fine.

The compaction characteristics showed that the maximum dry densities (MDDs) of the soils ranges from 1.9 to 2.22 g/cm^3 over granite basement complex, from 2.06 to 2.23 g/cm^3 over schist basement complex and 2.25 to 2.46 g/cm^3 over gneiss basement complex (Fig. 12). The MDD of soils collected over granite basement complex increased from 1.95 g/cm^3 at 0.5 m depth to 2.22 g/cm^3 at 1.5 m depth. Beyond this depth, the values reduced to 1.9 g/cm^3 at 2.0 m depth, and increased gently to 1.97 g/cm^3 at 4.5 m depth.

The MDD of soils collected over schist basement complex decreased gradually from 2.12 g/cm^3 at 0.5 m depth to 2.05 g/cm^3 at 2.0 m depth, after which the values increased to 2.23 g/cm^3 at terminating depth of 3.5 m. The first reduction is attributed to higher degree of weathering at the upper stratum to form clay minerals. The increase beyond 2.0 m depth is attributed to large amount of freshly decomposed rock, retaining their primary minerals. The soil collected over gneiss basement complex demonstrated excessively higher values of MDD. The values increased from 2.27 g/cm^3 at 0.5 m depth to its maximum of 2.46 g/cm^3 at 3.5 m depth. The value reduced to 2.40 g/cm^3 at terminating depth of 4.0 m.

The optimum moisture content (OMC) values were generally lower for gneiss basement complex, followed by schist to higher values in granite. This is in agreement with Lambe (1958) who showed that OMC reduces with increase in MDD. The OMC values ranges from 6.9 to 9.4%, 10.8 to 12.8%, and 8.8 to 18.0% for gneiss, granite, and schist basement complex, respectively.

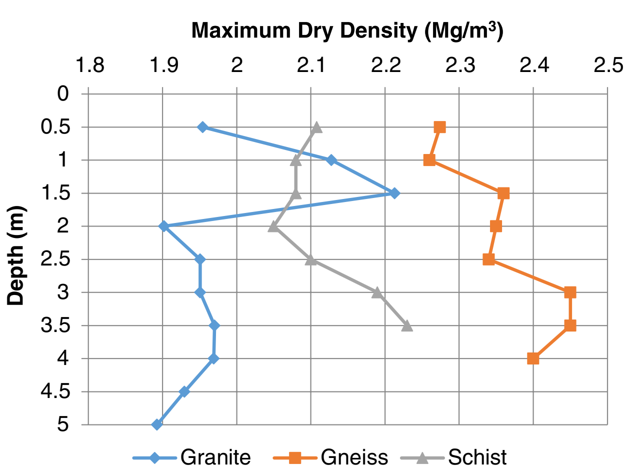

Fig. 12 Variation of maximum dry densities with depth

Discussion of results

Overburden on granitic rocks of the basement complex

Visual observation revealed that the location of the trial pit is an existing borrow pit which shows an average thickness of 0.4 m pan of reddish brown lateritic gravelly soil, followed by reddish brown fine lateritic soil to about 2.0 m depth. Beyond this depth, the reddish fine soil transforms to light soil with depth and lighter with further depth. The overburden was stiff at the surface with reduction in stiffness with depth down to 5 m depth. The lower, out of the three identified strata between 3.5 and 5.0 m, consisted of large number of primary minerals, probably because their alteration to secondary minerals is still fresh within this stratum. One of the reactions is alteration of potassium mica to kaolinite as reported by Garrels and Howard (1957).

$$2KAl_3Si_3O_{10}(OH)_2 + 5H_2O \rightarrow 3H_4Al_2Si_2O_9 + 2K^+ + 2OH^- \quad (1)$$

This is a hydrolysis reaction which involves addition of water to potassium mica to form kaolinite minerals. The water must have come from the underground water supply considering the drainage pattern of the study area. Aldega et al. (2009) noted that phlogopite joined with annite alters to kaolinite among other secondary minerals.

$$KMg_3(Si_3Al)O_{10}(OH)_2 + KFe_3(SiAl)_4O_{10}(OH)_2 \rightarrow Al_2(Si_2O_5)(OH)_4 + vermiculite + chlorite \quad (2)$$

The oxidation of annite, according to Kanamaru et al. (2018) can cause dihydroxylation through the chemical reaction:

$$K_2\left[Fe_3^{2+}\right](AlSi_3)O_{10}[OH_2] + \frac{1}{2}O_2 \rightarrow K_2\left[Fe^{2+}Fe_2^{3+}\right](AlSi_3)O_{10}[O]_2 + H_2O \quad (3)$$

On the other hand, Milanese et al. (2018) concluded that potassium alanate is a primary.

rock mineral which contributes tremendously to storage and supply of hydrogen in a weathering profile. The mechanism of dehydrogenation of alanate is given by:

$$3KAlH_4 \rightarrow K_3AlH_6 + 2Al + 3H_2 \quad (4)$$

$$K_3AlH_6 \rightarrow 3KH + Al + \frac{3}{2}H_2 \quad (5)$$

$$3KH \rightarrow 3K + \frac{3}{2}H_2 \quad (6)$$

Availability of hydrogen ions from these reactions within the stratum contributes tremendously to the reaction that alters the primary minerals to secondary minerals.

The presence of smectite minerals like montmorillonite and saponite in overburden over granite basement is responsible for higher cation exchange capacity, higher natural moisture content, higher percentage fines, higher liquid limits, and higher plasticity index, compared to the other two basement complexes (Fig. 13). Smectite minerals do not have significant effect on values of pH and organic matter within a profile. The grain size analysis of overburden over granite basement showed that soils at shallow depth of 0.5 m are gravelly with lower composition of fines, while that at 5.0 m depth has no gravel but contains higher fines. This is a clear indication of formation of gravelly lateritic soil at the upper layer of the profile. The presence of the three major clay minerals within the overburden over granite basement complex resulted in relatively lower MDD.

Overburden on schist basement complex

Road construction activities lead to excavation that conspicuously revealed the development of thick weathered schist with its characteristic flaky nature, like stacked papers. The formation showed uniformly light reddish brown overburden from the top to depth of 3.5 m where further digging became manually difficult.

The reaction of alteration of potassium feldspar to kaolinite has been shown in Eq. (1).

$$4KAlSi_3O_8 + 4H^+ + 2H_2O \rightarrow 4K^+ + Al_4Si_4O_{10}(OH)_8 + 8SiO_2 \quad (7)$$

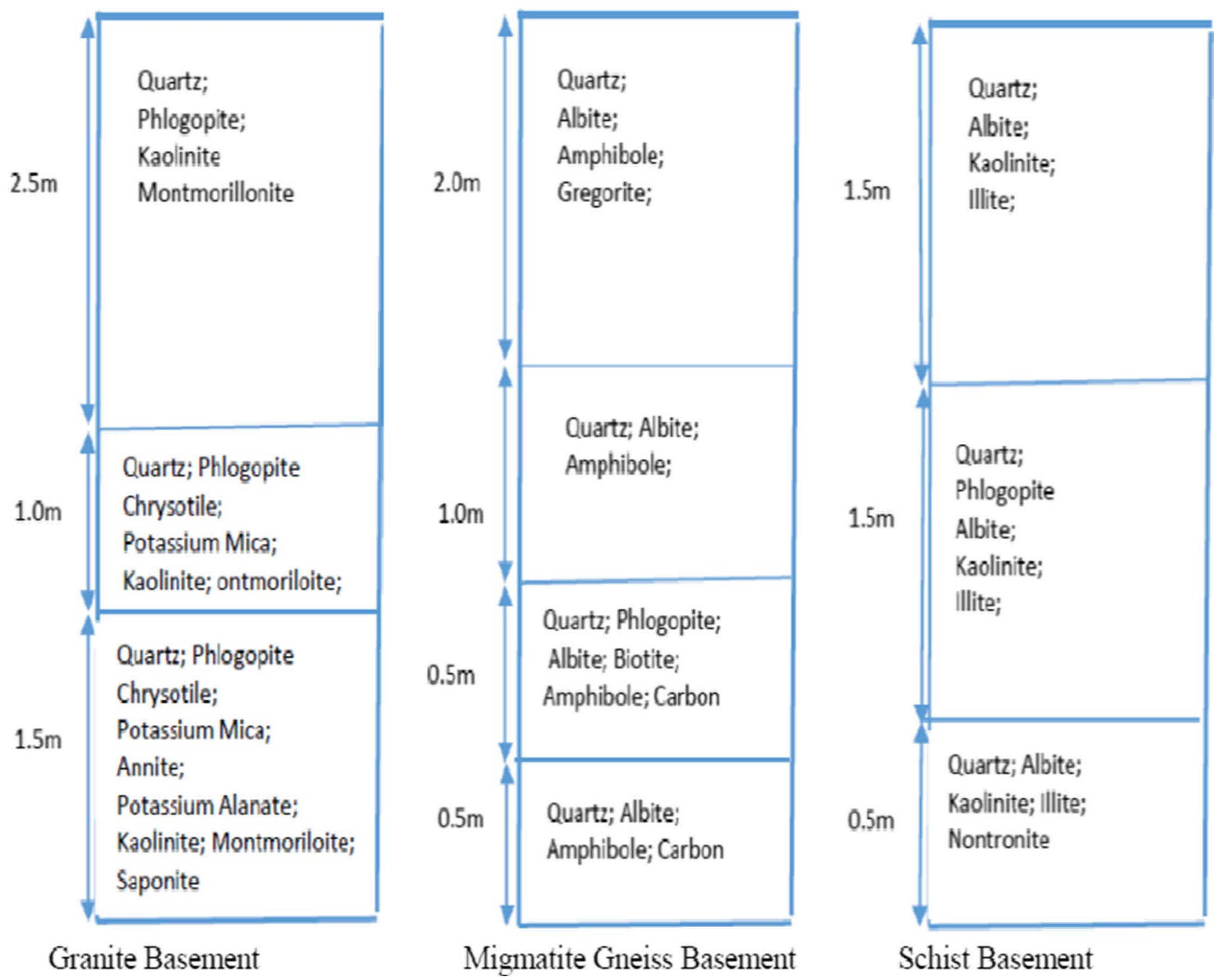

Fig. 13 Mineralogical groups forming layers in granite, migmatite gneiss, and schist basement complexes

However, albite, which is sodium feldspar, has been shown by Moayedi et al. (2011) to have reacted and altered to kaolinite as observed in this lower stratum:

$$NaAlSi_3O_8 + CO_2 + 3H_2O \rightarrow Al_2Si_2O_5(OH)_4 + Na^+ + 2SiO_2 + HCO_3^- \quad (8)$$

Similar reaction by albite to form illite was given as:

$$6NaAlSi_3O_8 + 4CO_2 + 4H_2O \rightarrow Na_2Al_4(Si_6Al_2O_{20})(OH)_4 + 4Na^+ + 12SiO_2 + 4HCO_3^- \quad (9)$$

Alteration of kaolinite minerals to illite minerals as reported by Kermani et al. (2015) is also possible and is probably taking place in this stratum through the reaction:

$$Al_2Si_2O_5(OH)_4 + {}^2\!/_3K^+ \rightarrow H_2O + {}^2\!/_3KAl_3Si_3O_{10}(OH)_2 + {}^2\!/_3H^+ \quad (10)$$

Though smectite minerals, like montmorillonite and saponite, were not formed in the overburden over this basement, the reaction of albite to form smectite minerals is possible and is given as:

$$2NaAlSi_3O_8 + 2CO_2 + 2H_2O \rightarrow NaO.3Fe_2Si_4O_{10}(OH)_2.4H_2O + Na^+ + H_4SiO_4 + HCO_3^- \quad (11)$$

Although secondary clay minerals like illite and kaolinite exist in the profile, the Atterberg limits revealed that fine soil within this overburden is generally non-plastic. This is attributed to poor development of the secondary minerals under poor drainage conditions, judging from very low natural moisture content observed.

The trend of fines and liquid limit with depth falls below that of granitic basement, but higher than that of migmatite gneiss basement. The upper part of this profile at 0.5 m depth consisted of soils with higher fines of 40%, while the medium layer at 1.5 m depth contains the lowest fine of 22%. The trend of MDD with depth is higher for these soils than those from granite basement but lower than those of migmatite gneiss basement. High specific gravity is synonymous to primary rock minerals, which are more prevalent in this overburden, compared to that over granitic basement.

Overburden on gneiss basement complex

The overburden showed relatively loose soil at the top which increases in stiffness with depth down to 4.0 m, where manual digging became difficult. Overburden over gneiss basement complex revealed profile with primary rock minerals from 0.5 to 4.0 m depth, where boring was terminated (Fig. 10). This is an indication of a very poor weathering profile which can lead to absence or minimal plasticity of the overburden soils. The presence of amphibole mineral spanning through the whole profile agrees with the findings from geological study carried out on sheet 184 (Olose et al. 2017).

The formation of gregoryite in the fourth and upper stratum is probably due to reaction between carbon that existed in the lower stratum and dissolved oxygen from rain water that leached from the surface through the soil profile to form dissolved carbon dioxide. The carbon dioxide in turn reacts with sodium from sodium amphibole to form the gregoryite mineral.

The trend of pH, organic matter content, and LOI values with depth were observed to be lower compared to that in overburden over granite and schist. This is probably due to lack of secondary minerals in the profile. The trend in CEC with depth was observed to be lower than that of granite basement complex but higher than those of overburden on schist basement. This can be attributed to carbonate salt (gregoryite), observed towards the upper layer of the profile. The trend in percentage fines and liquid limit with depth were observed to be similar and lie below the trend in both granite and schist basements. This is due to the absence of secondary mineral in the entire profile. However, the values of natural moisture content and plasticity index with depth were observed to be lower than the values in granite complex but higher than the values in schist basement. Occurrence of plasticity index towards the upper layer of migmatite gneiss basement is due to the presence of carbonic salt (gregoryite) within this layer of the basement complex.

The grain size distribution curve of samples collected from these strata showed that the finer grading occurred at depth of 1.0 m depth, while the coarser grading occurred at 4.0 m depth. The coarser grading at 4.0 m depth is a clear indication of presence of recently decomposed rock. The trend in MDD with depth gave values that are far higher than that of granitic basement complex and schist basement complex. In a similar manner, however, the trend in OMC with depth showed values that are far lower than that in granite basement and schist basement. This is expected because no secondary mineral was recorded in the entire profile.

Conclusion

From results of the study, the following conclusion is drawn:

The rate of weathering was higher in granite rocks, where primary minerals altered to secondary minerals including smectite minerals. This was followed by overburden over schists, which was observed to alter to secondary minerals like illite and kaolinite. Overburden soil over migmatite gneiss did not showed alteration to secondary minerals but conversion of the carbon element to sodium carbonate salt.

Higher fines content, cation exchange capacity, and Atterberg limits, recorded from soils developed over granite rocks probably resulted from the smectite minerals recorded within this profile. The non-plastic nature of soils, on schist rocks, despite presence of secondary minerals, and judging from the low natural moisture content observed within this profile, indicated that the minerals developed under poor drainage condition. Conversely, plastic soils observed at the upper layer on migmatite gneiss basement complex, despite complete absence of clay minerals within this profile, must have resulted from the occurrence of sodium carbonate salt (gregoryite) at the upper layer of this profile.

The pH values over residual profile in the study area generally hover around neutral to slightly acidic. The values showed that there is not much influence of mineralogy on the pH of the soils.

The organic matter contents, which range from 0.25 to 0.76% for granite basement, 0.19 to 0.68% for schist basement, and 0.34 to 0.68% for gneiss basement complexes, are generally low and in agreement with organic matter contents in residual soils.

The range of MDD values is from 1.890 to 2.22 g/cm^3 for granite basement, 2.050 to 2.235 g/cm^3 for schist basement, and 2.250 to 2.450 g/cm^3 for gneiss basement complexes. The excessively high values recorded from soils over gneiss basement are due to the predominant occurrence of primary minerals throughout the profile.

These therefore indicated that mineralogy of overburden soils over basement complexes and the drainage condition during formation affect their geotechnical properties.

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