INFLUENCE OF PARENT ROCK FACTOR ON SOME GEOTECHNICAL PROPERTIES OF TWO GENETICALLY DIFFERENT SOILS FROM NORTHCENTRAL NIGERIA

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Modal mineralogy and some geotechnical properties of sandstone derived soil samples were compared with those of migmatite - gneiss derived ones. This was done with a view to determining the influence of parent rocks on their engineering properties. This was achieved using the statistical method of student's t – test. The test helps to decide if the observed difference in two measurements is legitimate or just due to randomness.

Thin sections showed that the migmatite - gneiss derived samples are rich in feldspars and mica with up to 40% and 25% modal estimates respectively. Sandstone derived samples which contain essentially quartz grains have lower plasticity and shrinkage, better grading and compaction characteristics, higher compressibility, California bearing ratio and permeability coefficients than the migmatite - gneiss derived ones.

Better engineering properties exhibited by the sandstone derived soil can be linked with high quartz content in its parent material. The feldspars and micas in the migmatite - gneiss weathered into clay minerals which are plastic and hydrophilic. Statistical treatment of the determined parameters showed that the observed differences were significant in all cases except for permeability and compressibility.

Key words: Modal mineralogy, Sandstone, Migmatite – gneiss, Statistical student's t – test.

Introduction

Factors such as climate, mineral composition of parent rock, degree of weathering, vegetation and drainage affects soil formation. Adeyemi et.al., (1999) investigated two genetically different lateritic soils in Southwestern Nigeria and concluded that if all other pedogenic factors are kept constant, significant differences in engineering properties of residual soils can be caused by difference in their parent rocks. Bayewu et al., (2012) studied the petrographic and geotechnical properties of four genetically different soils in southwestern Nigeria. He noted that the observed difference in the geotechnical properties of these soils were related to the mineralogy of their parent rocks. Many other researchers such Badmus (2010), Adebisi (2010), have worked on the influence of parent rock factor on the geotechnical properties of soils from Southwestern Nigeria but research of this nature is not common with Northcentral Nigerian soils. This part of Nigeria has a drier and warmer climate when compared with the Southwest. There is therefore need to investigate the extent to which parent rock factor will influence the geotechnical properties of residual soils from this climatic region.

Residual soils derived from the weathering of igneous or volcanic rock in areas where drainage is good are generally believed to possess good engineering properties (Wesley 2009). Also, it is generally assumed that residual soils derived from the weathering of sedimentary rocks are generally less likely to have good engineering properties, regardless of the topography in which they are found. These assumptions should be subjected to the composition of parent rock irrespective of parent rock origin. This paper investigates the influence of parent rock factor on some important geotechnical properties of two residual soils from similar climatic environment in Northcentral Nigeria. One of the parent rocks is of sedimentary origin while the other is of metamorphic origin.

Study area

The location of the two study areas is shown on a geologic map in Figure 1. Figure 2. shows coarse to medium grain sandstone outcrop which is the parent rock of the soil samples taken from a study area in Mokwa. Figure 3. shows migmatite - gneiss outcrop which is the parent rock of the soil samples taken from the second study area in Ilorin. The Mokwa sandstone outcrop shown in figure 2 belongs to the Cretaceous Sandstone Formation of the Northern Bida Basin, while the migmatite – gneiss outcrop is part of the Precambrian Basement Complex rocks. The study areas are accessible through the highway linking the Nigerian Southwestern region with the Northcentral region. These two sampling sites were selected such that they both fall in the same climatic zone and similar topographic settings as shown by figure 4. This will help eliminate the possibility of attributing the observed differences in the geotechnical characteristics of these residual soils to other pedogenic factors other than their parent rocks.

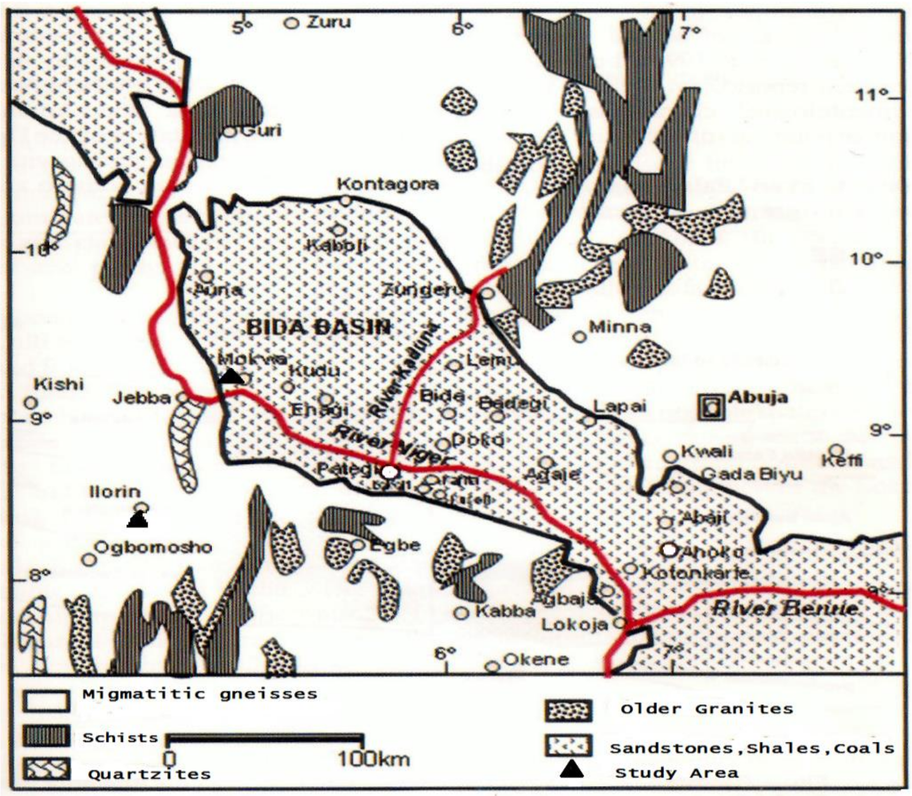

Fig 1: Geological map showing location of study area. (Modified after Kogbe 1989)

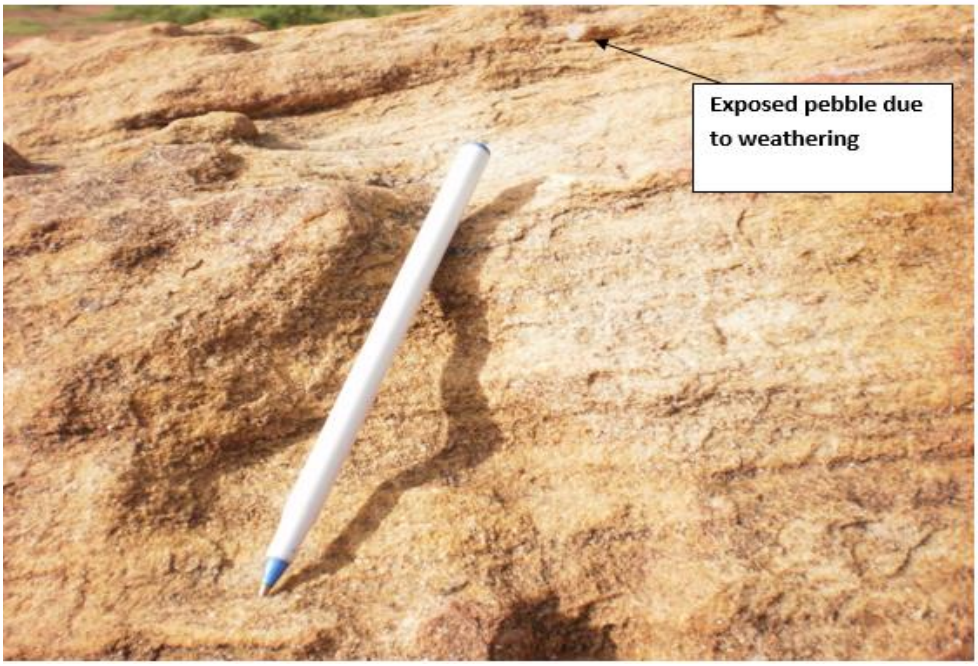

Figure 2: Pebbly arkosic sandstone outcrop with fine laminae at Mokwa sampling location.


Figure 3: Migmatite- gneiss outcrop about 2 km from Ilorin

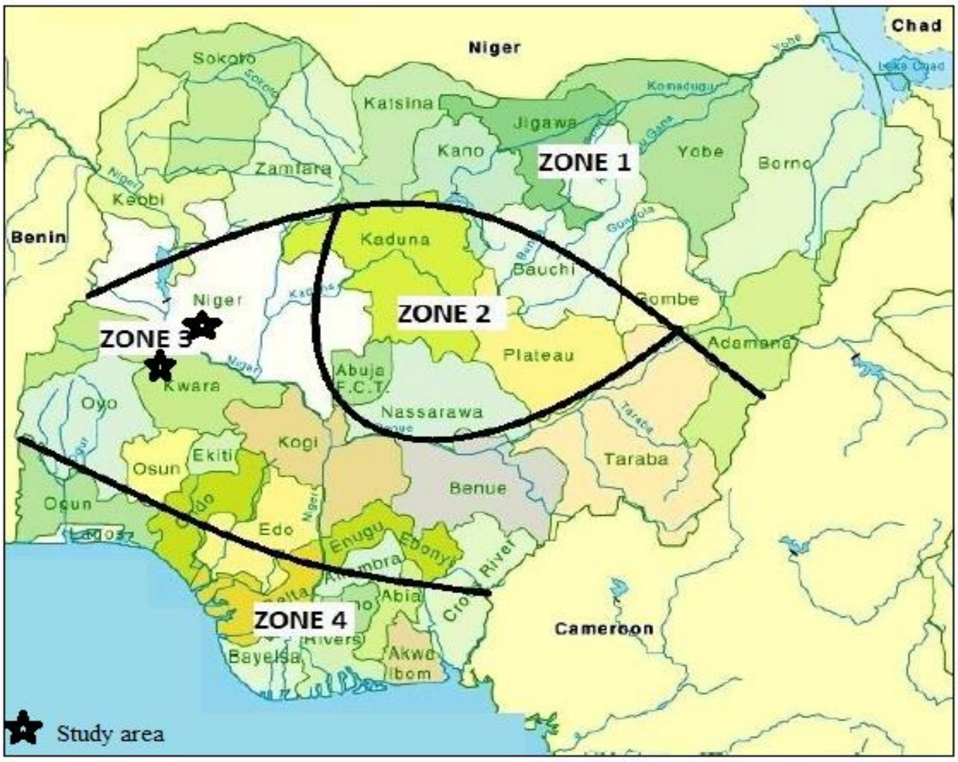

Figure 4: Map of Nigeria showing the climatological zones in Nigeria (Adapted from Federal ministry of works 2013).

Method

A preliminary pedologic mapping was carried out in the area in order to study the different rock types in the study area. This helped in making the choice of sampling area and method of sampling. Sixty-four bulk samples were collected with the aid of digger, hand shovel and head pan from two selected locations along the Ilorin – Mokwa highway. These two locations have similar topography and relief but varying bedrocks.

Index and engineering design tests including consistency limits, grain size analysis, California bearing ratio, compaction, permeability and consolidation tests were carried out on samples from both study areas. The moisture dry density relationship was determined using the modified AASHTO mold and 6kg of soil. Falling head permeameter was used to carry out the permeability test. All tests were carried out following the British Standards (BS-1337). Thin sections of samples of the parent rocks were made and careful examinations under plane polarized light and crossed nicols were carried out in order to determine their mineralogical composition. Modal analysis of the varying mineral grains present in the slides were also done.

The average values of each determined parameter were compared in order to determine if there is influence of parent rocks on their index and engineering properties. This was done using the statistical method of student's t –test. This test helps to decide if the observed difference in two sets measurements is legitimate or just due to randomness. When t – stat is higher than t - critical, the observed difference is said to be significant or legitimate.

RESULTS AND DISCUSSIONS

Petrography of Parent Rocks

Minerals identified in thin sections of the migmatite - gneiss include quartz, feldspars, mica and hornblende. While the migmatite - gneiss samples are rich in feldspars, mica and hornblende, the sandstone derived samples consist essentially of medium grained sub angular to sub rounded monocrystalline quartz grains. Based on this mineralogy, the sandstone derived soil is expected to have better engineering properties compared to the migmatite derived soil. Migmatite – gneiss which is high in feldspar and mica content will decompose into clay particles which have affinity for water. On the other hand, quartz would be almost retained as the weathered products of the sandstone, making the resultant soil coarser grained and less hydrophilic. Modal mineral composition of the parent rock samples as presented in table 1 therefore, explains the difference in the classification and engineering properties of the soils derived from them.

Figure 5 shows the photomicrographs of sandstone under cross polarized light while figures 6a and 6b show the photomicrographs of sandstone under cross polarized light. Figure 6c. shows figure 6b under plane polarized light with the clear segregation of the felsic minerals from the mafic ones.

Table 1. Modal Composition of parent rock material of the studied

Mineral constituent (%)	Migmatite – gneiss				Sandstone samples		
	M1 (m)	M2 (m)	M3 (m)	M (f)	SS1	SS2	SS3
Quartz	25	30	30	40	95	96	95
Microcline	10	8	5	15	-	-	-
Plagioclase	15	20	30	25	-	-	-
Biotite	25	15	15	5	-	-	-
Muscovite	-	5	-	15	-	-	-
Hornblende	25	22	20	-	-	-	-
Accessory mineral					5	4	5

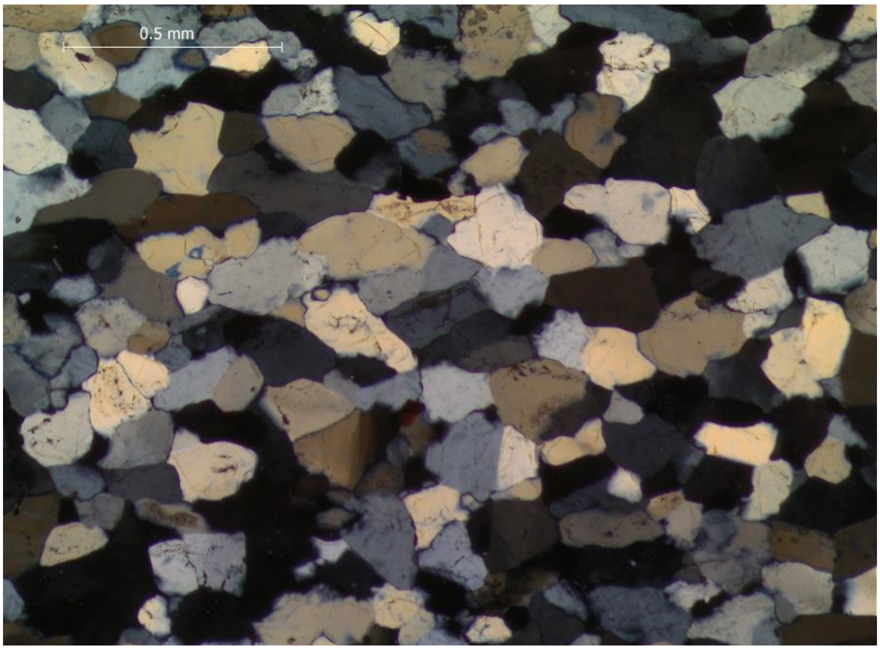

Figure 5. Photomicrograph of sandstone under XPL× 40

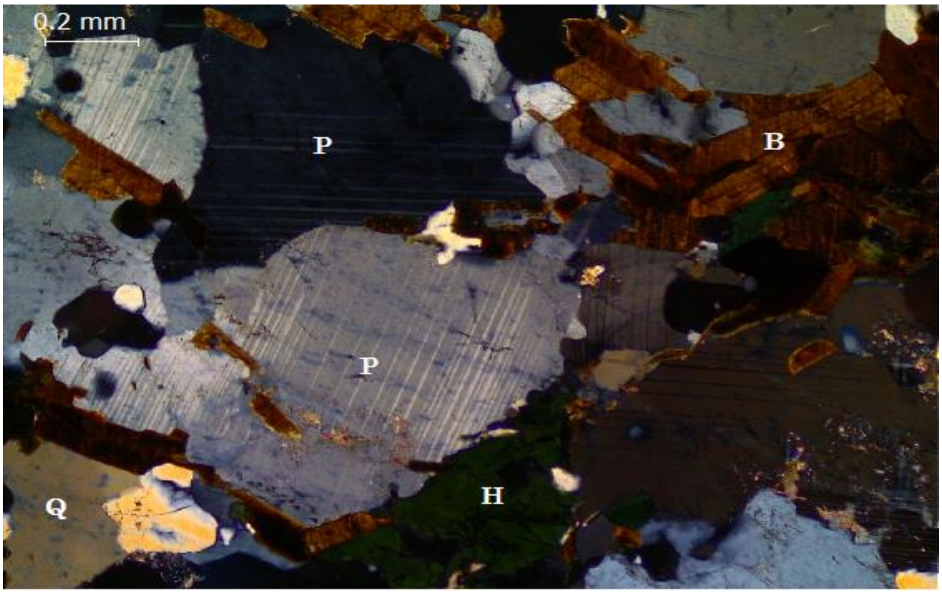

Figure 6a. Photomicrograph of Migmatite gneiss under XPL× 100

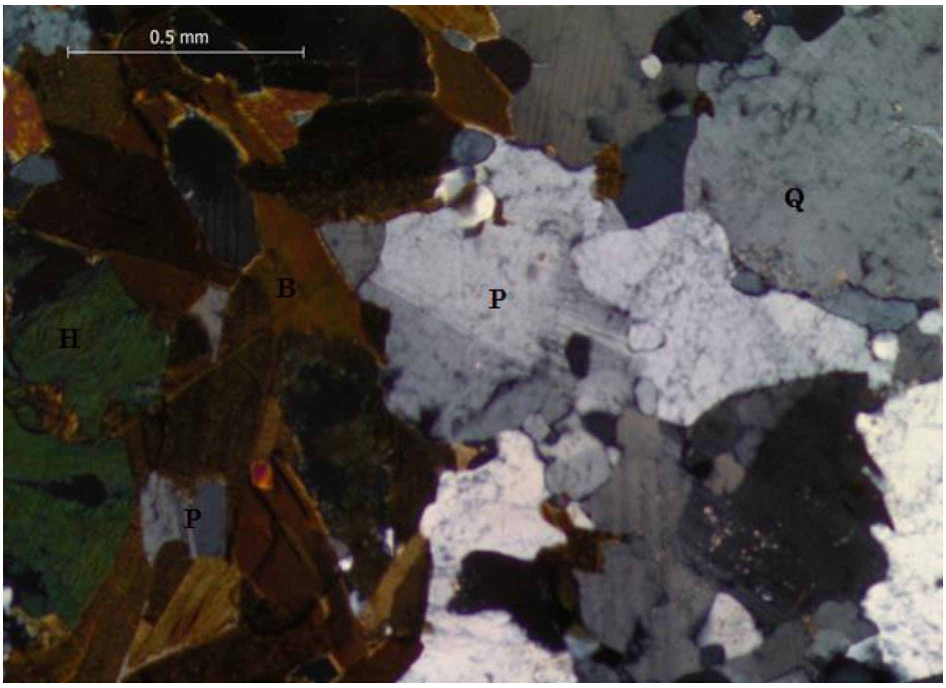

Figure 6b. Photomicrograph of Migmatite gneiss under XPL× 100

Figure 6c. Photomicrograph of Migmatite gneiss under PPL× 100

Influence of Parent Rock on the Atterberg Indices of the Studied Soils

The liquid limit values of the migmatite derived soil samples are averagely higher than those of the sandstone derived soil samples. Plasticity chart (Figure 7) indicates that migmatite derived soil samples are of medium plasticity while the sandstone derived ones are of low to medium plasticity. The migmatite derived soil samples also have plasticity index values that are higher than that of the sandstone derived samples. Soils with high plasticity index are usually more plastic than those with low plasticity index.

The sandstone derived soil samples have lower liquidity index than the migmatite derived ones. This implies that the migmatite derived soil samples are softer and also have remolded strength lower than the sandstone derived soil samples (Mitchel and Soga 2005). The sandstone derived soil has lower flow index values than the migmatite derived ones. This indicates that the sandstone soil has shear strength higher than that of the migmatite soil. Table 2 presents the average values of the Atterberg indices of the two set of soils while table 3 presents the results of the statistical t – test conducted on the Atterberg indices data of the studied soils.

The student's t - test was used to check if the observed differences in the index properties of this soil are significant. The result showed that the observed differences are significant in all cases.

Table 2: Average values of the Atterberg indices of the two set of soils.

Atterberg Indices	Sandstone derived soil		Migmatite derived soil	
	Average	Range	Average	Range
Liquid Limit	33.2	20.76- 4.2	40.18	28.38 -48.8
Plastic Limit	20.09	10.92 -27.66	23.43	17.38 -29.58
Plasticity Index	16.68	11.03 - 19.09	18.47	7.31 -26.61
Liquidity index	0.77	(-2.7) - 0.5	0.49	(-2.2) - 0.4
Flow Index	16.59	7.36-24.90	19.97	16.90-24.94

Table 3: Result of the statistical t – test conducted on the Atterberg indices data of the studied soils.

Atterberg indices	t - Stat	t- Critical	Nature of difference
Liquid limit	**5.69**	**1.67**	**Significant**
Plastic limit	**3.00**	**1.67**	**Significant**
Plasticity Index	**5.42**	**1.67**	**Significant**
Liquidity index	**1.72**	**1.67**	**Significant**
Flow Index	**3.40**	**1.67**	**Significant**

Other classification properties

The migmatite derived soil samples have higher natural moisture content than the sandstone derived ones. This can also be related to the fine contents of these soils. The amount of fine grained materials in the migmatite derived soil ranges from 20% to 54%, while the fine content of the sandstone derived soil ranges from 11% to 35%. However, the Federal Ministry of Works and Housing (1997) specifies an amount of fines not more than 15% for subbase materials. The sandstone derived soil samples have significantly lower fine grained content and lower plasticity than the migmatite derived ones as a result of the direct impact of the geology of the parent rock from which they are derived. Usually, fine grained soils have high affinity for water. Soils with high fine grained content also tend to have high plasticity index and hence perform poorly as foundation soils.

The linear shrinkage of the sandstone derived soil ranges from 1.5% to 7.3%, while that of the migmatite-derived soil ranges from 2. 2% to 10.1%. According to Ola (1980), the sandstone derived soil samples classify as soils with marginal degree of expansion, while the migmatite-gneiss derived ones classify as soils with marginal to critical degree of expansion. Averagely, the magmatite derived soil has linear shrinkage higher than the sandstone derived soil. This indicates that the migmatite soil samples are more susceptible to shrinkage and expansion than the sandstone derived ones. Madedor (1983) recommended a linear shrinkage not more than 10% for good subgrade materials and a value not more than 8% for good subbase materials. On this basis, soil samples from the two parent materials are suitable as highway subgrade materials while most of the sandstone derived samples are also suitable as subbase materials.

Table 4 presents the classes of the studied soil according to the Unified Soil Classification system and the American Association of State Highway and Transportation Officials (AASHTO) classification. The sandstone derived soil samples mostly belong to group A-2 of the AASHTO classification. The group index for this soil ranges from 0 to 1. They consist of transitional granular materials all of which have fines that are less than 35 percent that are silty. It is rated as good to fair road subgrade.

The migmatite derived soil classifies as A - 7 soil and possess group index higher than 20. Soil belonging to this class is usually very elastic and plastic, subject to high volume change with variations in moisture content. Strength can be low to high but all A – 7 soils are quite impermeable. This type of soil should be utilized only where nothing else is available.

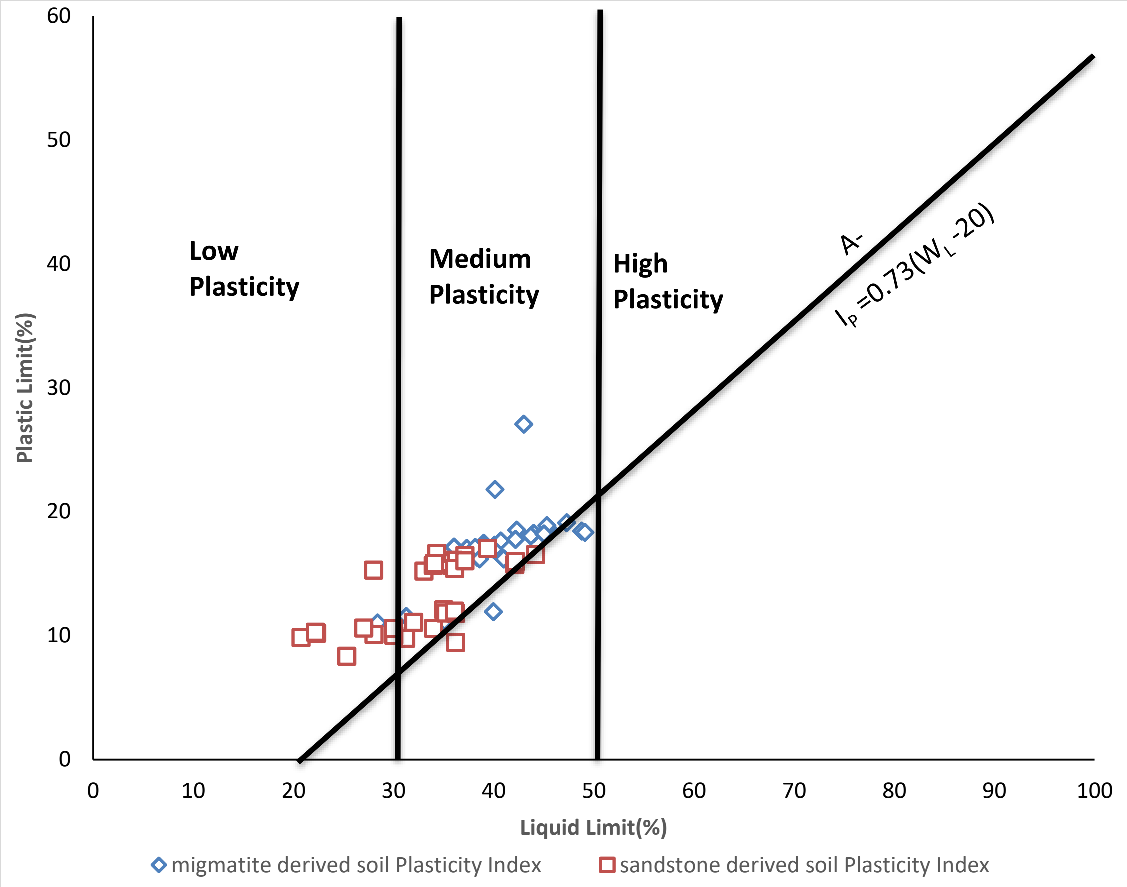

Figure 7. Casagrande Chart comparing the plasticity of the studied soils.

Table 4. ASHTTO and UCSC Classification of the studied soils

Sample number	USCS group name	AASHTO classification	Sample number	USCS group name	AASHTO classification
BMS1	Silty Sand	A-2-4(0)	BMB1	silty clay	A-7-6(18)
BMS2	silty gravel	A25(0)	BMB2	silty clay	A-6(5)
BMS3	Clayey sand	A-2-4(0)	BMB3	silty clay	A-7-6(21)
BMS4	Clayey sand	A1B(0)	BMB4	silty clay	A-7-6(20)
BMS5	Clayey sand	A26(0)	BMB5	Clayey sand	A-2-6(0)
BMS6	Clayey sand	A26(1)	BMB6	Clayey sand	A-2-6(0)
BMS7	Clayey sand	A26(0)	BMB7	silty clay	A-6(7)
BMS8	Clayey sand	A26(1)	BMB8	silty clay	A-6(11)
BMS9	Clayey sand	A26(1)	BMB9	silty clay	A-7-6(23)
BMS10	Silty sand	A26(0)	BMB10	silty clay	A-7-6(22)
BMS11	Silty sand	A-2-4(0)	BMB11	silty clay	A-7-6(10)
BMS12	Silty sand	A-2-4(0)	BMB12	silty clay	A-6(10)
BMS13	Clayey sand	A26(0)	BMB13	Clayey sand	A-2-6(1)
BMS14	Clayey sand	A26(0)	BMB14	Clayey sand	A-2-6(0)
BMS15	Clayey sand	A26(0)	BMB15	silty clay	A-6(4)
BMS16	Clayey sand	A-2-6(0)	BMB16	silty clay	A-7-6(15)
BMS17	Silty gravel and sand	A-2-4(0)	BMB17	silty clay	A-7-6(20)

BMS18	Silty gravel and sand	A-2-4(0)	BMB18	silty clay	A-7-6(3)
BMS19	Clayey sand	A-2-6(0)	BMB19	silty clay	A-7-6(21)
BMS20	Clayey sand	A-2-6(1)	BMB20	silty clay	A-7-6(21)
BMS21	Clayey sand	A-2-6(1)	BMB21	clayey gravel with sand	A-2-6(0)
BMS22	Clayey sand	A-2-6(1)	BMB22	clayey gravel with sand	A-2-7(0)
BMS23	Clayey sand	A-2-6(0)	BMB23	silty clay	A-7-6(8)
BMS24	Clayey sand	A-2-6(1)	BMB24	silty clay	A-7-6(10)
BMS25	Silty sand	A-2-6(1)	BMB25	silty clay	A-7-6(18)
BMS26	Silty sand	A-2-6(0)	BMB26	silty clay	A-7-6(16)
BMS27	Silty sand	A-2-6(0)	BMB27	silty clay	A-7-6(8)
BMS28	Silty sand	A-2-4(0)	BMB28	silty clay	A-7-6(8)
BMS29	Clayey sand	A-2-6(1)	BMB29	Clayey sand	A-2-6(1)
BMS30	Silty sand	A-2-6(0)	BMB30	Clayey sand	A-2-6(0)
BMS31	Clayey sand	A-2-6(0)	BMB31	Clayey sand with gravel	A-2-7(1)
BMS32	Clayey sand	A-2-6(1)	BMB32	silty clay with gravel	A-7-6(16)

Influence of parent rock on the grain size distribution parameters of the studied soils

Figure 8 shows bar charts comparing the relative proportions of the component grain sizes of the studied soils. Although, soils from both parent rocks are well graded, migmatite derived soil samples are richer in fine grained materials than the sandstone derived ones which are richer in sand sized materials. This is a direct reflection of their parent rock mineralogy. The abundant feldspars and mica in the migmatite - gneiss are expected to weather faster into fine grained silt and clay sized materials while quartz in the sandstone is expected to weather into sand grains. The result of the grain size distribution analyses of the studied soil were treated using the statistical student's t – test and the result is presented in table 5. It is observed that the coefficient of curvature which is descriptive of soil texture is not significantly different based on parent rock factor. On the other hand, the coefficient of uniformity which is descriptive of soil grading and percentage composition of different grain sizes varies significantly with parent rock factor. This indicates that keeping other pedogenic factors like climate and topography constant, significant difference in the grain size distribution parameters of residual soils can be caused by difference in parent rocks.

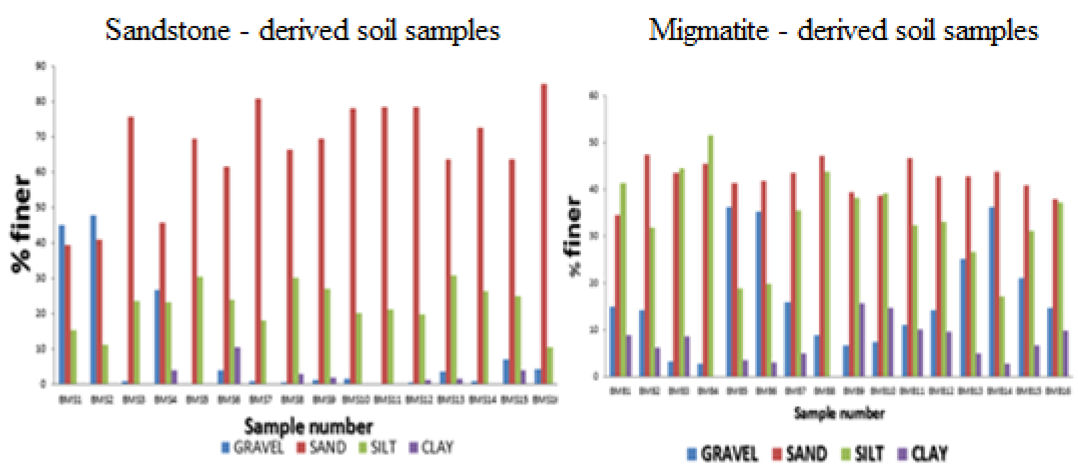

Fig 8: Bar charts showing the summary of the grain size distribution result for both set of soil.

Table 5. Result of the statistical treatment of the grain size distribution parameters of the studied soil

Parameter	t- Stat	t - Critical	Nature of difference
Amount of gravel sized particles	3.36	1.67	significant
Amount of sand sized particles	10.65	1.68	significant
Amount of silt sized particles	6.42	1.67	significant
Amount of clay sized particles	1.30	1.67	Insignificant
Amount of fine particles	7.25	1.67	significant
Coefficient of uniformity	3.89	1.70	significant
Coefficient of curvature	0.72	1.68	Insignificant

Effect of parent rock factor on consolidation parameters of the studied soil.

Table 6 presents the summary of the statistical treatment of the coefficient of volume compressibility (m_v) data. Although, comparison of the average m_v values for both parent rocks shows that the sandstone samples exhibit higher compressibility than the migmatite derived ones, student's statistical t- test however show that the observed difference is not significant at any pressure range. Since m_v is a measure of soil compressibility, this implies that parent rock factor does not have significant influence on the compressibility of the studied soils.

Table 7 shows the result of the student statistical t- test of the coefficient of consolidation of the studied soils. Despite the seemingly observed higher rate of consolidation in the sandstone derived soil, statistical t- test shows that there is no significant difference in the coefficient of consolidation for soils of both origins. Since coefficient of consolidation is a measure of rate of consolidation, this implies that the parent rock factor does not have significantly impact on the rate of consolidation of the studied soils.

Table 6. Summary of the result of the student statistical t- test of the coefficient of volume compressibility values of the studied soil

Pressure range (kPa)	**t -Stat**	**t -Critical**	**Nature of difference**
32-64	**1.19**	**1.70**	Insignificant
64-128	**1.21**	**1.71**	Insignificant
128- 256	**0.39**	**1.70**	Insignificant
256- 512	**0.79**	**1.70**	Insignificant

Table 7: Summary of the result of the student statistical t- test of the coefficient of consolidation values of the studied soil.

Pressure (kPa)	**t - Stat**	**t - Critical**	**Nature of difference**
32kPa	0.23	1.70	insignificant
64kPa	0.45	1.70	insignificant
128kPa	0.81	1.70	insignificant
256kPa	1.57	1.70	insignificant
512kPa	0.74	1.70	insignificant

Influence of parent rock factor on the compaction parameters, California bearing ratio and permeability coefficients of the studied soils

The sandstone derived soil samples possess higher maximum dry density (MDD) and lower optimum moisture content (OMC) than the migmatite derived ones. The OMC and MDD values of the studied soil samples were compared with the classification of Krebs and Walker (1972) which classified compacted densities and optimum moisture content according to AASHTO classification system. Base on his classification, the migmatite derived soil exhibits OMC and MDD typical of silty sands and gravels of low plasticity belonging to class A-4 of the AASHTO classification system, while the sandstone derived soil exhibits OMC and MDD typical of silty or clayey gravel and sand mixture belonging to class A-2 of the same classification system.

The unsoaked California bearing ratio (CBR) of the sandstone derived samples ranges from 43% to 127% while the soaked CBR ranges from 17% to 46%. The unsoaked CBR value for the migmatite derived soil ranges from 22% to 89%, while the soaked CBR ranges from 13% to 36%. The minimum CBR recommended by the Federal Ministry of Works and Housing 1997 for base course material is 80% unsoaked CBR and 30% soaked CBR using modified AASHTO compaction standard. On this basis, the compacted sandstone derived soil is suitable as highway subbase material while the migmatite derived soil is not suitable. Also according to this specification, both soils meet up with the minimum soaked CBR requirement for highway subgrade materials but sandstone derived soil is more suitable.

The permeability coefficient of the migmatite derived soil ranges from 9.2×10^{-9} m/s to 3.5×10^{-8} m/s while that of the sandstone derived soil ranges from 1.0×10^{-8} m/s to 3.4×10^{-8} m/s. According to Terzhagi and Peck (1967) and Kedi (1974), the permeability coefficient of soils of both origins are typical of very low permeability fine sand, sandy silt and silt. Their drainage properties are described as poor. The federal ministry of works and housing (1997) recommends that foundation materials must possess coefficient of permeability not less than 1×10^{-2} m/s to be termed free draining. Since the soils from the study area are not free draining, provision of adequate drainage is necessary if the ingress of water and subsequent weakening of these soils will be prevented when used as foundation materials.

Table 8 presents of the statistical t-test results of the OMC, MDD, CBR and permeability coefficients of the studied soils. These results indicate that parent rock factor have control over the OMC, MDD, soaked and unsoaked CBR of the studied soils. Although, the average permeability values of the sandstone derived soil are slightly higher than that of the migmatite derived ones, statistical t- test indicates that the observed difference is not significant. This implies that parent rock factor does not have significant impact on the permeability coefficients of the studied soils.

Table 8. Statistical t-test results of the OMC, MDD, CBR and permeability of the studied soils.

Parameter	t -Stat	t -Critical	Nature of difference
OMC	9.47	1.70	significant
MDD	1.81	1.75	significant
Unsoaked CBR	9.73	1.71	significant
Soaked CBR	4.02	1.69	significant
Permeability	0.40	1.70	Insignificant

Conclusion

Soil samples derived from sandstone was found to be geotechnically better than the Migmatite - gneiss derived ones despite their parent rock is of sedimentary origin. This can be attributed to high feldspar and mica content in the migmatite – gneiss samples. Student's t-test confirmed that there was significant difference in the geotechnical properties of the soil samples derived from the two parent rocks except for permeability coefficient and compressibility. These two parameters are closely linked with each other because compressibility is controlled to a large extent by permeability. Lack of significant control of parent rock factor on permeability can be attributed to similar grading characteristics of soil samples derived from both parent rocks. This implies that the geotechnical properties of the lateritic soils from study area are directly related to their parent rock mineralogy. Therefore, their evaluation and use as foundation materials should be with recourse to the geology of their parent rocks.

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