Mineralogical and Geotechnical Characteristics of the Loose Weathered Trachytes of Fongo-Tongo (West-Cameroon)

Armand Sylvain Ludovic Wouatong
Associate Professor
Department of Earth Sciences
Faculty of Science
University of Dschang
Cameroon

William Hyoumbi Tchungouelieu
PhD Candidate
Department of Earth Sciences
Faculty of Science
University of Dschang
Cameroon

François Ngapgue
Associate Professor
Fotso Victor Institute of Technology, University of Dschang
Cameroon

Valentine Katte
Senior Lecturer
Department ofAgricultural Engineering
Faculty of Agronomy and Agricultural Sciences
University of Dschang
Cameroon

Véronique Kamgang Kabeyene Beyala
Professor
Higher Teacher Training College
University of Yaoundé I
Cameroon

Abstract

The loose materials of lower and median assemblages of soil profile developed on the Fongo-Tongo trachytes (West-Cameroon) have been the subject of mineralogical and geotechnical characterization. Mineralogical analysis reveals the presence of quartz, kaolinite, gibbsite, hematite, goethite, illite and alkali feldspar. The proportion of kaolinite decreases from the bottom to the top of the profile; while the gibbsite concentration evolves in the opposite direction. Illite and alkali feldspar coexist at the bottom of the profile. Geotechnical characterization shows that the loose material of eluvial median horizon corresponds to loamy soils of the A-6 (7) class; while the loose materials of illuvial median horizon and lower assemblages are clayed soils of the A-7-5 (17) and A-7-5 (18) classes respectively, according to Highways Research Board. Meanwhile, according to the Laboratoire Central des Ponts et Chaussées (LCPC), they are known as highly plastic silt (Lt). According to the Guide de Terrassement Routier (GTR), they belong to classA.

Keywords: Cameroon, Fongo-Tongo, trachytes, soil profile, mineralogical characteristics, geotechnical characteristics, fine soils

1. Introduction

The Cameroon Volcanic Line direction N30°E and 1600 km long, forms a series of horst and graben. The Bambouto Mountains forms the third horst and are located in the highlands of Western Cameroon and between the Manengouba and Bamenda Mountains (Deruelle et *al*., 1991). This enormous massif is a polygenic volcanic shield formed of mafic and felsic rocks with ages ranging from Miocene to Recent (Youmen et *al*., 2005). Volcanic rocks rest on the Precambrian crystalline basement (Dumort, 1968; Kwekam et *al*., 2010).

All this lithological set covers several flanks, as it happens in the south-western flank where Fongo-Tongo locality is situated and built in majority on trachytes (20-25 %) (Tematio, 2005). These are felsic volcanic rocks dating from the Miocene (Tchoua 1974; Youmen 1994; Youmen et *al*., 2005).

On petrographic plan, N'ni and Nyobe (1995) highlight three types of trachytes: (i) the "Fongo-Tongo trachyte" type formed of plagioclase phenocrysts and microcrystals, acid pyroxene, olivine, iron oxide-titanium and apatite; (ii) the fluidal quartz trachyte characterized by the abundance of alkali feldspar and (iii) the hyperalkaline trachyte consisting of phenocrysts of alkali and subsidiary pyroxene, amphibole and iron oxide-titanium feldspars. The alteration of these trachytes gives the variable thickness of supergene mantle and both loose and indurated material (bauxite). Hieronymus (1973) and Nyobe and N'ni (1990) orientated their studies solely on Fongo-Tongo bauxite breastplates. Tematio and Olson (1997); Leumbe Leumbe (2003); Tematio et *al.* (2004); Leumbe Leumbe et *al*. (2005) and Tematio et *al*. (2009) examined the loose mantle materials (soil) by studying its genesis, evolution and classification in the domain of pedology. Ananfouet Djeufack (2012) and Djuickouo (2012) for their part, carried out a geotechnical classification of the soils developed on volcanic rocks of the Dschang city but avoided those developed on trachytes. Also, Poueme Djuéyep (2012) carried out a geotechnical and mineralogical assessment of the loose weathered mantle developed on welded ignimbrites in Dschang which is used for stabilized earth bricks. Finally, the works of Ananbe Njitsop (2008) and Fobeu Nguemo (2011) on the loose supergene mantle of the crystalline basement completes the geotechnical studies on the superficial formation from different lithological groups found on the south-western Bambouto flank. Thus, the geotechnical characteristics of loose material of weathered mantle developed on Fongo-Tongo's trachytes has not been subjected to any specific study. This study therefore aims to characterize the loose materials of weathered mantle developed on the Fongo-Tongo's trachytes from a mineralogical and geotechnical point of view.

2. Materials and Methods

2.1. Natural Framework of the study

Fongo-Tongo is located on the highlands of Western Cameroon specifically the South-western side of Bambouto Mountains (Tematio, 2005). The area is characterized by low altitudes (1300-1600 m) and medium altitudes (1600-2000 m). The hydrographic network is subdendritic to dendritic. The climate is equatorial cameroonian type and is influenced by the topography and monsoon. It is characterized by an alternation of rainy season (eight months) and dry season (four months). The average annual rainfall is 1719 mm and the temperature is 20.8°C. The vegetation is strongly influenced by anthropic activities with swampy areas being occupied by raffia palm forests relics. The soils are *ferrallatic andic* and *ferrallitic* battleships according to CPCS (Centre Pedologique de Classification des Sols) classification (Tematio and Olson, 1997; Leumbe Leumbe, 2003; Tematio et *al*., 2004). The petrography of this location consists of trachytes, welded ignimbrite, non-welded ignimbrite, basalts and granites (Figure 1).

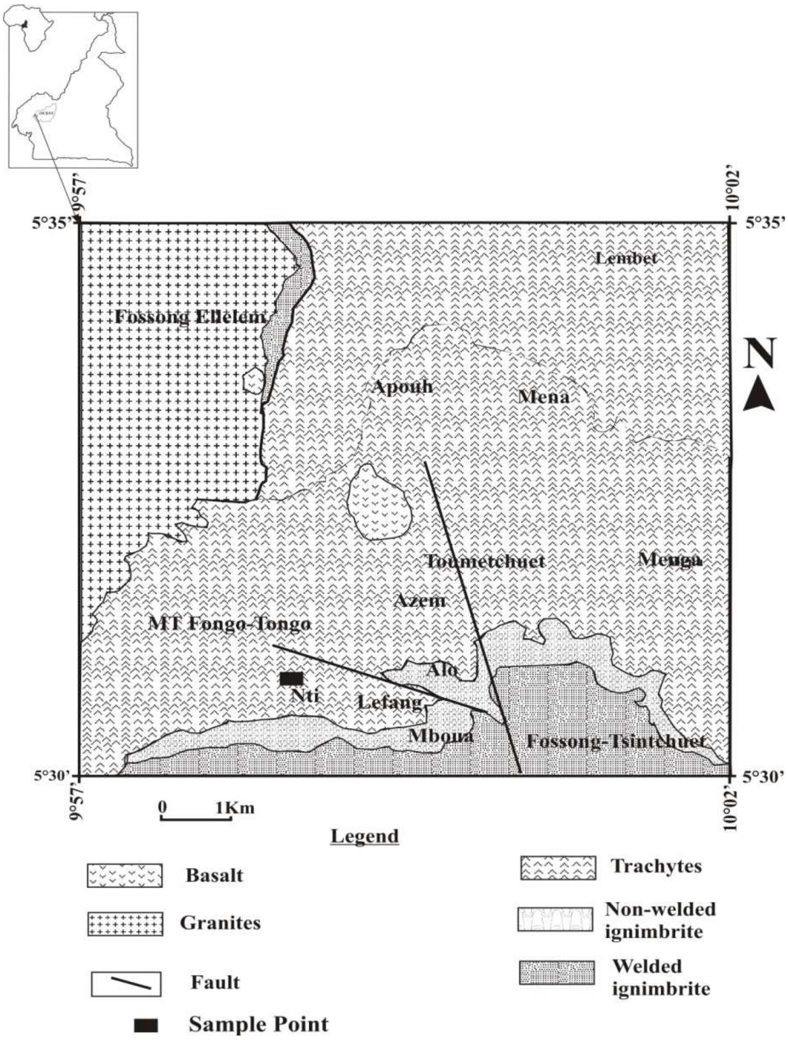

Figure1 : Location and Geological Map of Fongo-Tongo Sector

2.2-Material

Field reconnaissance survey based on topography enabled the identification of different soil profiles along the road cuts in the study area. Furthermore, macroscopic descriptions were performed on a synthesized soil profile (Figure 2). This synthesized soil profile corresponds to a slope whose coordinates are 1586 m; 05°30'50" North and 09°58'27" East (Figure 1). Finally, the samples (F-B1, F-B2 and F-C; see Figure 2) were collected at the median and lower profile assemblages for laboratory analysis.

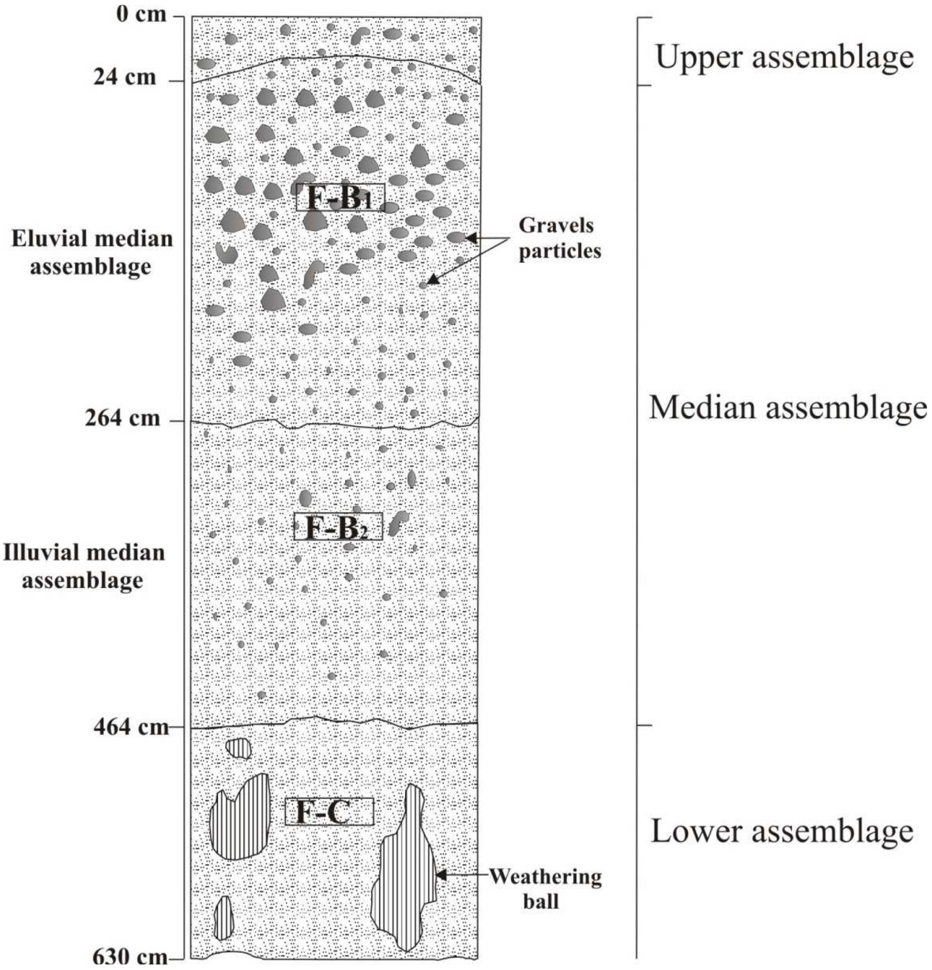

Figure 2:Weathered Soil Profile on Trachyte

The studied pedologic profile comprises three assemblages: lower, median and the upper assemblages respectively; with an approximate thickness of 630 cm (Figure 2).

The lower assemblage constitutes the lower horizon BC which is a transitional horizon, of thickness 166 cm (Figure 2). It is a polychrome weathered level. The colours range from red (10R4/6), light red (10R7/8), reddish yellow (7.5YR7/6) and pale-brown (10R8/2). Pale brown and reddish yellow characterize trachytes fragments that are in the course of weathering called weathered balls. These fragments have size fractions ranging from millimeter to centimeter, which are scattered in this level. The texture is silty clay and the structure is polyhedral. The limit between the lower assemblage and median assemblage is clear.

The median assemblage of thickness 440 cm corresponds to the horizon B. This assemblage is subdivided into eluvial median level and illuvial median level corresponding to F-B1 and F-B2 materials respectively (Figure 2). The illuvial median level has an average thickness of 200 cm, with colours ranging from dark-red (2.5YR3/6) to pale brown (10R8/2). It is silty clay having a gritty feel due to the presence of sand particles. This horizon has a polyhedral structure. Alumino-ferruginous gravels, predominantly of millimetric sizes, are scattered throughout this level. The upper limit is irregular and sharp.

Concerning the eluvial median level (Figure 2), it is 240 cm thick and has two phases: the fine and indurated particles. The fine particles are dark-red (2.5YR3/6) in colour and are classified as sandy clay. The structure at this level is particulate. Indurated gravel elements are likely alumino-ferruginous red (10R4/6). Their size fractions range from millimeter to centimeter and represent about 30 % of the particles at this level. Roots are widespread on top of this level. The limit of this assemblage with the overlying unit is sharp and irregular.

Finally, the upper assemblage with 24 cm of thickness (Figure 2) has two phases: the fine elements and indurated elements. Fine elements are dark-grey in colour (7.5YR3/1). The fragments of indurated elements (gravel) show the following colours: red (10R4/6) and yellowish-red (7.5YR6/6). The texture of this horizon is sandy loam and the structure is lumpy. Many roots are found at the base and the rootlets are concentrated at the top of this assemblage. Indurated elements as in the eluvial median level are nodular and alumino-ferruginous in nature. Their size fractions range from millimeter to a centimeter.

2.3. Methods

In the laboratory, mineralogical analysis and some geotechnical analysis (granulometry, Atterberg limits, methylene blue test) were performed at the Local Materials Promotion Authority (MIPROMALO) Yaounde. Only the soil compaction test was done in the civil engineering laboratory of the Advanced National School of Engineering (ENSP), of the University of Yaounde I.

2.3.1. Mineralogical Analyses

The mineralogical composition of the materials was studied using X-ray diffractometer. The samples were first heated at 105ºC for 24 hours before being crushed to powder of 80µ*m* diameter using a porcelain mortar. The measuring apparatus used,was BRUKER diffractometer,operating through the reflection of $K\alpha_2$ copper rays. The scanned angular domain was $5^o \leq 2\theta \leq 90^o$ with an angular space of 0.020º, within 6 seconds and at an ambient temperature of 25ºC. The apparatus was connected to a computer which directly gave the diffractograms. The different peaks of the diffractograms were determined with the aid of data automatically furnished by the Diffrac +software and controlled manually by ASTM cards.

2.3.2. Geotechnical Analyses

Concerning the grain size analysis of the different materials, it was performed accordingto the NF 18-560 (1978). Based on this specification, the grain size distribution curves were plotted with size fractions greater than 80µm obtained by wet sieving through a series of sieves of decreasing mesh sizes while the size fractions less than 80µm were obtained by sedimentation.

Atterberg limits were used to determine the plasticity index of the studied materials. The liquid limits were determined using the Casagrande apparatus while plastic limits were identified on the rods of 15 mm length and about 3 mm of thickness according to the NF P94-051 (1993) standard. According to NF P94-051 (1993), $\mathbf{I_P = \omega_L - \omega_P}$ where $\mathbf{I_P}$ is the plasticity index; $\mathbf{\omega_L}$ is the liquid limit and $\mathbf{\omega_P}$ represents the plastic limit.

The methylene blue test consists in introducing successive increasing quantities of methylene blue solution in the sample (grain size<5 mm) until the clay fraction is saturated with blue according to NF P94-068 (1993) standard. During testing, a homogeneous solution (methylene blue solution+soil) is removed with a glass rod (8 mm in diameter and 300 mm long) and put on a filter paper. At the end, if it forms a persistent light-blue halo in the wet zone around the central blue stain, the test is positive, if not, it is negative.

The modified soil compaction test aims to determine the optimum water content and the maximum dry density for a given intensity of normalized compaction. This test was performed according to NF P94-093 (1993) standard.

The geotechnical characteristics studied, have permitted the definition of the taxonomy of loose weathered materials formed on Fongo-Tongo's trachytes according to geotechnical standards (charts) like the GTR (Guide de Terrassement Routier), LCPC (Laboratoire Central des Ponts et Chaussees) and HRB (Highway Research Board).

The Group Index (I_G) is given by the equation: $\mathbf{I_G = 0,2a+0,005ac + 0,01bd}$ where **a=** that portion of the percentage passing N° 200 sieve greater than 35% and not exceeding 75%, expressed as a positive whole number (0 to 40).

b =that portion of percentage passing N° 200 sieve greater than 15% and not greater 55% expressed as a positive number (0 to 40).
c = that portion of the liquid limit (LL) greater than 40 and not exceeding 60% expressed as a positive whole number (0 to 20).
d = that portion of the plasticity index greater than 10 and not exceeding 30 expressed as a positive whole number (0 to 20).

Both the HRB and LCPC are based on the grain size and Atterberg limits, however LCPC distinguishes eight categories for granular soils. For fine soils, LCPC relies on the plasticity chart to determine the different types of soils. GTR 92 defines the classes of materials from the results of three tests categories: identification tests or nature tests, state parameter tests and mechanical tests (NF-P11-300, 1992). In this work, the classification of materials depending on GTR relies solely on identification tests or nature tests. GTR 92's classification identifies four classes of soils distributed as follows: (1) Class A: fine soils; (2) Class B: sandy and gravelly soils with fines; (3) Class C: soils with fine and coarse particles and (4) Class D: water insensitive soils.

3. Results and Discussions

3.1. Mineralogical features

The diffractograms counting of F-B1, F-B2 and F-C materials show that they consist of (i) newly formed minerals: kaolinite, gibbsite, illite, hematite, goethite and (ii) some traces of primary minerals: quartz, alkali feldspar (Figure 3). The illite crude peak indicates its state of disequilibrium and marks the transition between the alkali feldspar and kaolinite which has a more intense main peak in the F-C material. The presence of kaolinite in the BC horizon is due to good drainage at this level of profile that would result in the partial breakdown of K-feldspar to kaolinite (Tematio, 2005 and Tematio et *al*., 2009). The intensity of the main peaks of kaolinite (7.15-7.16 Å) decreases from the lower assemblage to the eluvial median assemblage while that of gibbsite (4.84-4.83 Å) increases in the same direction (Figure 3). The evolution of these two minerals is due to the transition from good to excellent drainage which causes the dissolution of the kaolinite to gibbsite with leaching of silicon (Tematio, 2005; Tematio et *al*., 2009; Tchuenkam, 2013). Goethite is absent in the eluvial median assemblage (F-B1). Nyobe and N'ni (1990) proved that the degradation of the goethite releases elemental iron (Fe), which is associated with aluminum to form alumino-ferruginous nodules. Thus, the lack of this mineral in this level of the profile can be explained by the dehydration of the mineral in favor of hematite. Very fine peaks and constant intensities of quartz are present in the whole profile, which warrants the stability of the mineral. According to Nni and Nyobe (1995) and Marzoli et *al*. (1999), the trachyte rich in quartz identified in this locality represents the parent rock on which this weathered mantle developed.

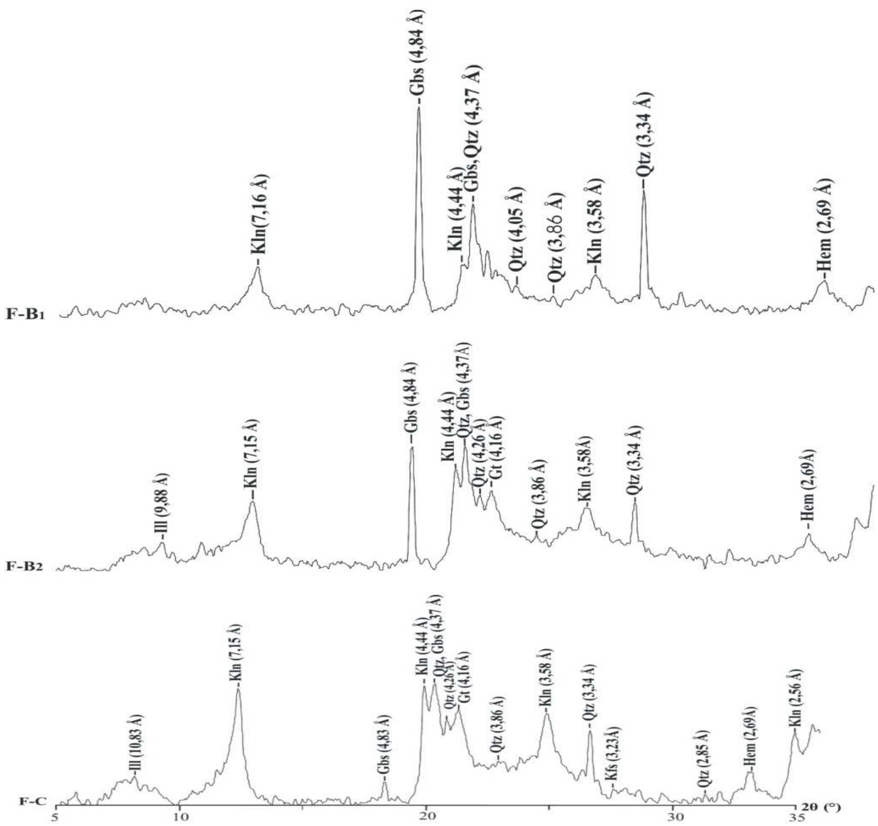

Figure 3: XRD Patterns of Mineral Constituents of Loose Weathered Materials on Trachyte

Legend: Kln: Kaolinite; **Gbs:** Gibbsite; **Qtz:** Quartz; **Hem:** Hematite; **Ill:** Illite; **Gt:** Goethite; **Kfs:** Alkaline feldspar

3.2. Granulometry

The particle sizes of less than 0.02 mm in the materials of the median illuvial horizon (F-B2) and lower assemblage (F-C) are the most important particles (Figure 4). They contain more than 80 % clay and silt (Figure 4), while gravel and sand particles are respectively less than 20 % of these materials.

The material of the eluvial median horizon (F-B1) contains 53 % of gravel and sand particles and 47 % of clay and silt particles (Figure 4). The particle size of this material seems to be identical to the indurated soil formed on basalts studied by Ananfouet Djeufack (2012) and Djuickouo (2012). Thus, the abundance of gravel and sand particles is due to a pronounced induration at this profile level. This is justified by the predominance of minerals such as gibbsite, quartz and hematite. Similarly, Djuickouo (2012) suggests that the presence of coarse particles result from precipitation process, and this is evident by the accumulation of oxides and hydroxides of iron and aluminum. However, high proportions of fine particles in the illuvial median material and lower assemblage materials can be explained by the presence of clay minerals (Poueme Djueyep, 2012; Ananfouet Djeufack, 2012). The predominance of clay minerals which are the smallest minerals in terms of size, such as kaolinite and illite (to a lesser extent) in these materials, confirm the higher percentage fine particles. Moreover, the differences between the grain size distributions curves of the different materials studied from the profile prove the differentiation of the soil profile at different horizons (Kouayep Lawou, 2006). As above, the material of eluvial median level has a predominantly gravel size fraction; while the materials of the median illuvial level and lower assemblage are fine particles.

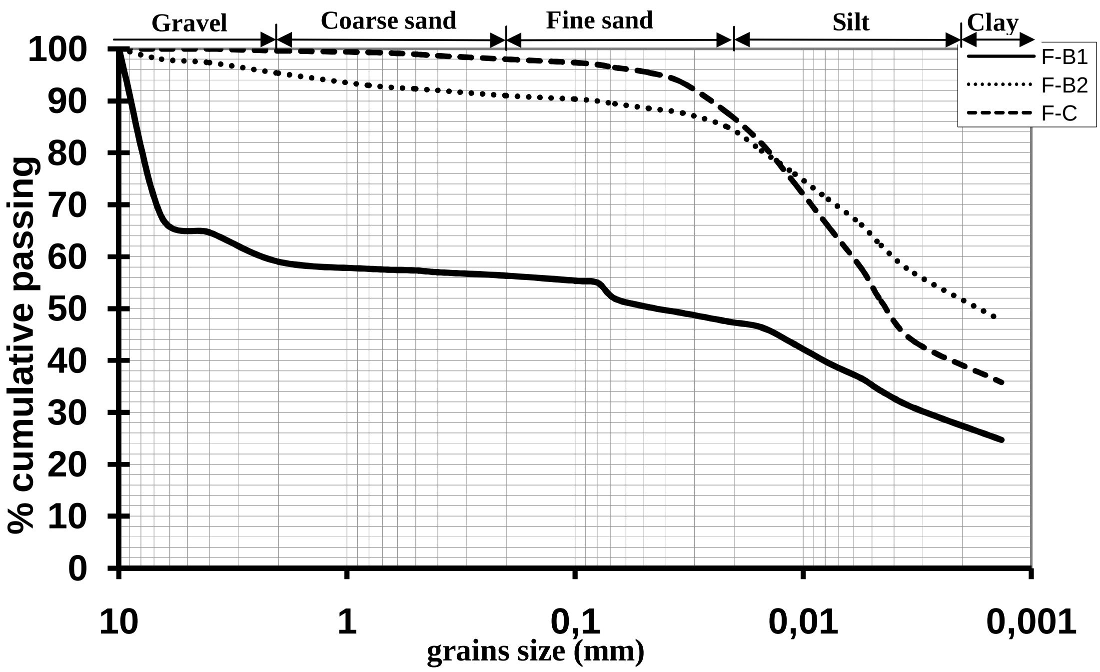

Figure 4 : Granulometric curves of Loose Weathered Materials on Trachyte

3.3. Atterberg Limits Test and Methylene Blue (See Table 1)

The values of liquid limit (ω_L) and plastic limit (ω_P) increase with depth (Table 1). The increase of fine particle proportions explains the increase of these values with the depth. The values of the plasticity index of these materials indicate that the eluvial median level material (F-B1) is of low plasticity while the materials of the illuvial median level (F-B2) and the lower assemblage (F-C) are of higher plasticity (Table 1). The high plasticity of a material is due to the presence of clay minerals like kaolinite in this material (Poueme Djueyep, 2012).

The materials of the median illuvial level and the lower assemblage contain a significant quantity of kaolinite and illite, hence an elevated degree of plasticity. Also, the different granulometric nature of these two groups of materials: (i) silty sand material for eluvial median level and (ii) silty clays for those of the illuvial median level and lower assemblage justify their rheological behavior (NF P11-300-1992).

Concerning the methylene blue test performed on weathered materials developed on trachytes, the values registered are 2.20, 2.60 and 4.27 corresponding to F-B1, F-B2 and F-C materials (Table 1). Just like the values of liquid limit (**ω_L**) and plastic limit (**ω_P**), they increase with depth (Table 1). The materials having values of methylene blue (V_{BS}) from 2.5 to 6 are silty clay soils (Duplain et *al.*, 2000). This shows that the high specific surfaces are due to the high percentage of fine particles sizes in the material of the lower assemblage and median illuvial level. The fineness of these materials is one of the properties that can explain the V_{BS} values 2.60 and 4.27 respectively. Furthermore, the combination of clay minerals (illite and kaolinite) in a material causes a high retention capacity of substances on their surfaces and therefore a high specific surface charge (Lerau, 2006). In this context, the simultaneous presence of kaolinite and illite in the studied materials explains the V_{BS} values obtained.

Table 1: Atterberg Limits and Methylene blue test Values of Samples with the Different Sampling Depths

		Paramters / **Samples and dephts**	ω_L	ω_P	I_P	V_{BS} **(%)**
Soil Profile	**Median assemblage**	**F-B1**(24 - 264 cm)	61,2	48,7	12,6	2,20
		F-B2(264 - 464 cm)	76,5	49,7	26,8	2,60
	Lower assemblage	**F-C** (630 - 630 cm)	97,1	74,6	22,5	4,27

3.4. Soil Compaction Test

The materials of the lower assemblage (F-C) and illuvial level (F-B2) of the median assemblage have their respective values of optimum water contents which are 16 % and 15 %; and 1.359 kg/dm^3 and 1.373 kg/dm^3 which represent the values of maximum dry densities of these materials (Figure 5). The values of the maximum dry density (γd_{OPM}) and optimum water content (ω_{OPM}) of median eluvial level (F-B1) are respectively equal to 11.5 % and 1.612 kg/dm^3 (Figure 5). The compaction values of eluvial level material are close to those of lateritic gravely soils of Cameroon ($\omega_{OPM} \leq$ 12 % and $\gamma d_{OPM} \geq$ 1.9 kg/dm^3) found by Sikali and Mir-Emarati (1986) and Djuickouo (2012). These values are due firstly to their low percentage of fine particles (Figure.4) and secondly, to the abundance of oxides and hydroxides (gibbsite, hematite, quartz of F-B1 given by Figure 3). However, Ngami (2012) reports that homogeneous loose materials are less favorable to compaction due to the excessive presence of fine particles (Figure 4). This confirms the results of compaction obtained on the materials of lower assemblage and illuvial level of the median assemblage (Figure 5). Moreover, the simultaneous presence of kaolinite and illite in the above mentioned materials (Figure 3) warrant their compaction behavior.

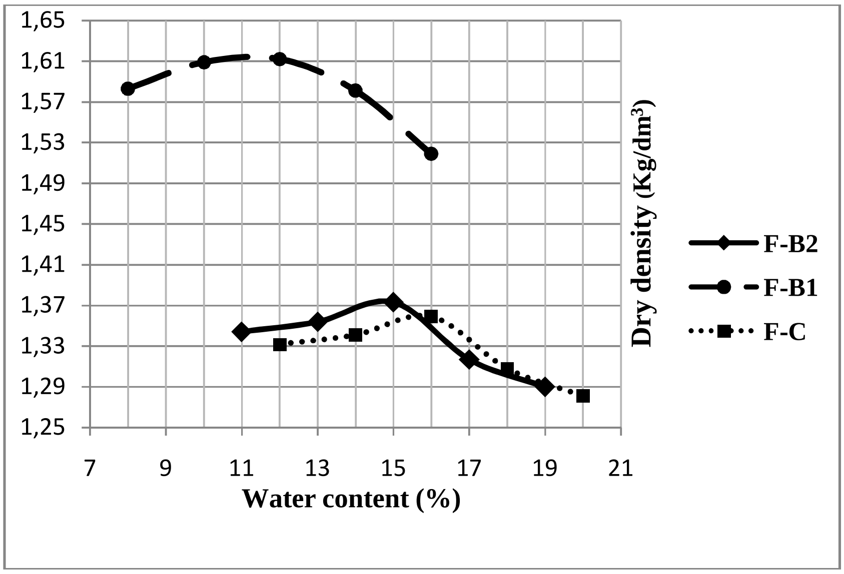

Figure 5: Compaction Test Curves of Loose Weathered Materials on Trachyte

4. Geotechnical Classification of Weathered Products Developed on Fongo-TongoTrachytes

4.1. Classification of the Highway Research Board (HRB)

Weathering materials formed on trachytes are loamy and clayed soils (Table 2). They are referred to as A-6 and A-7-5, but with different group indices. Depending on these group indices, materials F-B1, F-B2 and F-C of studied soil profile are respectively of the classesA-6 (7); A-7-5 (18) and A-7-5 (17) (Table 2).

Table 2 (a; b; c): Classification of Loose Weathered Materials on Trachyte According to Highway Research Board (HRB)

(a)

F-B_1	Sieve	2 mm	0,5 mm	0,08 mm
	% passing	59	57,3	55
	Parameters	W_L	61,2	
		W_P	48,7	
		I_P	12,6	
		I_G	**7**	
Name according to the soil types		**Loamy soil**		
Denomination		**A-6**		

(b)

F-B_2	Sieve	2 mm	0,5 mm	0,08 mm
	% passing	95,3	92,3	90
	Parameters	W_L	76,5	
		W_P	49,7	
		I_P	26,8	
		I_G	**18**	
Name according to the soil types		**Clayed soil**		
Denomination		**A-7-5**		

(c)

F-C	Sieve	2 mm	0,5 mm	0,08 mm
	% passing	99,7	99,0	97,0
	Parameters	W_L	97,1	
		W_P	74,6	
		I_P	22,5	
		I_G	**17**	
Name according to the soil types		**Clayed soil**		
Denomination		**A-7-5**		

4.2. Classification according to the Laboratoire Central des Ponts et Chaussées (LCPC)

According to the LCPC, samples F-B1; F-B2 and F-C of studied soil profile fall into the class of fine soils. Depending on the liquid limit and plasticity index, the fine soils are highly plastic loam Lt (Figure6).

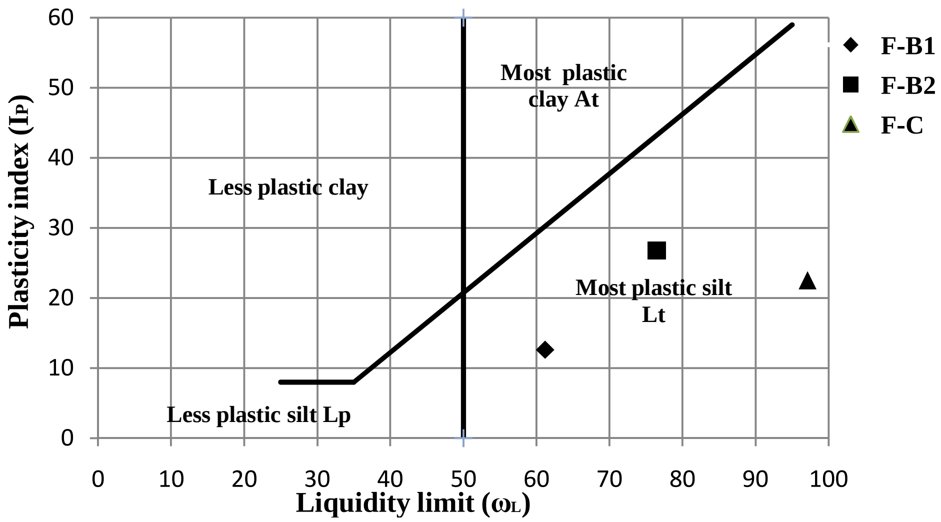

Figure 6 : Classification of Loose Weathered Materials on Trachyte According to the Laboratoire Central Des Ponts et Chaussees (LCPC)

4.3. Classification of the to Guide de Terrassement Routier (GTR)

The weathered mantle from Fongo-Tongotrachytes is part of the A Class called fine soil according to GTR (Figure7). Depending on the nature of these materials, they are A1, A2 and A3classes (Figure7).

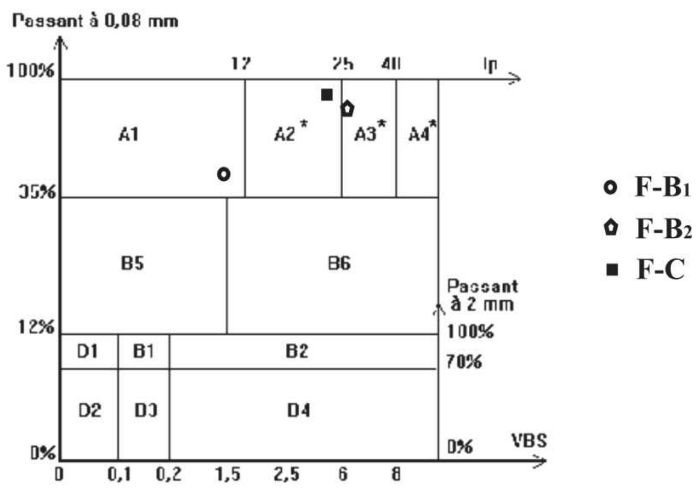

Figure 7 : Classification of loose weathered trachyte to according to Guide de Terrassement Routier (GTR)

5. Conclusion

Fongo-Tongo is an area covered by a widespread and thick loose mantle developed on trachytes and generally forming a differentiated profile (ABC type).

The mineralogy of these materials reveals the presence of newly formed minerals:illite, kaolinite, gibbsite, hematite and goethite and residual primary minerals: quartz and alkali feldspar.

The geotechnical characteristics of these loose materials from trachytes show that the proportions of fine particle sizes increase with depth. They have a percentage passing through a sieve of 80 µm greater than 35%. The values of the plasticity index of these materials indicate that the eluvial median level material is of low plasticity (12.6) while the materials of the illuvial median level and the lower assemblage are of higher plasticity (22.5 and 28.4 respectively). Thus, these values of the plasticity index increase with depth. Moreover, the values of methylene blue test (V_{BS}) which vary from 2.20 to 4.27 and the values of compaction soil tests increase also with depth. The materials of the lower assemblage and illuvial level of the median assemblage have the respective values of optimum water content equal to 16 % and 15 %; and 1.359 kg/dm^3 and 1.373 kg/dm^3 respectively, which represent the values of maximum dry densities of these materials. The values of the maximum dry density (γd_{OPM}) and optimum water content (ω_{OPM}) of median eluvial level are respectively equal to 11.5 % and 1.612 kg/dm^3.These materials correspond to loamy soils of the A-6 (7) class and clay soils of the A-7-5 class with I_G which are 17 and 18 according to the HRB. They are called highly plastic silt (Lt) according to the LCPC. Finally, they belong to the sub classes A1, A2 and A3 corresponding to A Class according to the GTR. Thus, loose weathered materials formed on trachytes are fine soils.

Acknowledgements

The authors thank Pr. Uphie CHINJE MELO, the Director of Local Materials Promotion Authority of Yaoundé-Cameroon (MIPROMALO) and the researchers of this structure, who permitted us to carry out the different laboratory analysis of which the results are here in presented

6. References

Ananbe Njitsop, B.N., (2008).Caractérisation géotechnique des produits d'altération de Menouet et Toutsang (Dschang-Ouest Cameroun) et possibilités d'optimisation de leur utilisation dans le génie-civil. Mém. Maît. DEA. Univ. Ydé I. 65p + Annexe.

Ananfouet Djeufack, C.Y., (2012). Cartographie et caractérisation géotechnique des sols développés sur roche volcaniques de la ville de Dschang (Ouest-Cameroun). Thèse M. Sc.Univ. Dschang, 65 p + annexe.

Deruelle B., Moreau C., Kambou, R., Lisson J., Njonfang E., Ghogomu R. T., Nono, A., (1991).The Cameroon Line : a review. In Magmatism in Extensional Structural Settings.A.B.Kampuzuet R.T. Lubalaeds, Springer-Verlag, p274-327.

Djuickouo. C. N., (2012).Caractérisation géotechnique des graveleux latéritiques sur basaltes de la zone de Maka (Dschang, Ouest-Cameroun). Mém. de DIPES II. ENS, Univ. Yaoundé 1.

Dumort, J.C., (1968).Carte géologique de reconnaissance du Cameroun à l'échelle 1/50000. Feuille Douala Ouest avec notice d'explicative. Imp.Nationale,Yaoundé (Cam). 69p.

Duplain, R., Lanchon, R., Saint, Arroman, J.C., (2000).Granulats, sols, ciments et bétons. Caractérisation des matériaux de génie civil par les essais de laboratoire. Collection A. Capliez, Nouvelle édition, 237p.

Fobeu Nguemo, A. (2011). Caractérisation physique des matériaux issus des manteaux d'altération des granites de Dschang en vue de leur utilisation pour la confection des bétons. Thèse M. Sc. Univ. Dschang, 54 p.

Hieronymus, B., (1973). Etude minéralogique et géochimique des formations Bauxitiques de l'Ouest Cameroun. Univ.ParisIV.Cah. ORSTOM, Ser. Géol., Vol V, n°1, pp.97-112.

Kouayep Lawou, S., (2006). Caractérisation géotechnique et propriétés des briques en terre cuite des matériaux d'altération développés sur les projections pyroclastiques de la région de Bana (Ouest-Cameroun). Mém.D.E.A. Univ. Ydé I, 75p.

Kwekam, M., Liegeois, J.P., Njonfang, E. Affaton, P., Hartmann, G., Tchoua, F., (2010).Nature, origin and significance of the Fomopéa Pan-African high-K calc-alkaline plutonic complex in the Central African fold belt (Cameroon). J. Afri. EarthSci. 57, pp. 79-95.

Lerau, J., (2006).Cours de géotechnique1. 3^e année-ingénieur de construction, Dep.Sci.et Tech. Ing. INSA-Toulouse.

Leumbe Leumbe O., (2003). Etude pétrographique, minéralogique et géochimique d'un sol ferrallitique sur trachyte de la zone moyenne du versant sud des monts Bambouto. Mém. DEA en sc. de la Terre, Univ. Yaoundé I, 93 pages.

Leumbe Leumbe, O., Bitom, D., Tématio, P., Temgoua, E., Lucas, Y., (2005). Etude des sols ferrallitiques à caractères andiques sur trachytes en zone de montagne humide tropicale (Monts Bambouto - Ouest Cameroun). Etude et gestion des sols, 12 p323-326.

Marzoli, A., Renne, P.R., Piccirillo, E.M., Francesca, C., Bellieni, G., Melfi, A.J., Nyobé, J.B., N'ni, J., (1999).Silicic magmas the continental Cameroon volcanic Line (Oku, Bambouto, and Ngaoundéré): ^{40}Ar-^{39}Ar dates, petrology, Sr-Nd-O isotopes and their petrogenetic significance. Contrib. Mineral. Petrol., 135, pp.133-150.

Ngami, P. F. (2012).Caractérisation géotechnique des sols prélevés sur le tronçon routier Tonga- Bangangté (Ouest-Cameroun). Thèse. M. Sc., Fac. Sci. Univ. Yaoundé I, 118 p+20 p annexe.

N'ni, J., Nyobé, J.B., (1995). Géologie et pétrologie des laves pré-caldeiriques des monts Bambouto : Ligne du Cameroun. Geochim. Brazil, 9, 1, 47-59.

Norme NF P18-560, (1978). Analyse granulométrique par tamisage. AFNOR., 5p.

Norme NF P94-051, (1993). Reconnaissance et essai de détermination des limites d'Atterberg. AFNOR. 15p.

Norme NF P94-068, (1993). Mesure de la quantité et de l'activité de la fraction argileuse : détermination de la valeur de bleu de méthylène d'un sol par l'essai à la tâche. AFNOR., 8p.

Norme NF P94-093, (1993). Détermination des caractéristiques de compactage d'un sol, essai Proctor normale, essai Proctor modifié, AFNOR, 14p.

Norme NF-P11-300, (1992). Classification des matériaux utilisables dans la construction des remblais et des couches de forme d'infrastructures routières. GTR 92.

Nyobe, J.B., N'ni, J., (1990).On the geology and geochemistry of the Fongo-Tongo bauxite deposit Bambouto mountains (Cameroon line).Geochemistry of the Earth's surface and of mineral formation 2nd international symposium, July, 2-8, 1990, Aix en Provence, France.

Poueme Djuéyep G., (2012).Caractérisation minéralogique et géotechnique des matériaux d'altération développés sur les ignimbrites de Dschang (Ouest-Cameroun) : valorisation dans le bâtiment. Thèse M. Sc., Univ. Dschang, 88 p + annexe.

Sikali, F., Mir Emérati, D., (1986).Utilisation des latérites en techniques routières auCameroun. Acte du séminaire régional sur les latérites; Douala-Cameroun p277-288.

Tchoua, F.M., (1974). Contribution à l'étude géologique et pétrologique de quelques volcans de la Ligne du Cameroun (Mont Manengouba et Mont Bambouto). Thèse Doct. Etat, Univ. Clermont- Ferrand, 337p + Biblio + 75 figures.

Tchuenkam, D. B., (2013).Évaluation du potentiel bauxitique du secteur Loung-Ndo zone moyenne du versant Sud des Monts Bambouto. Thèse M. Sc., Fac. Sci.Univ. Dschang, 92 p + annexe.

Tematio P.; Olson K.R., (1997).Impacts of industrialised agriculture on land in Bafou, Cameroon.Journal of soil and water conservation, p 403-407.

Tematio, P., (2005).Etude cartographique et Pétrologique des sols à caractères ferrallitiques et andosoliques dans les monts Bambouto (Ouest-Cameroun): influence de la lithologie et des facteurs du milieu sur la nature et la distribution des sols en région de montagne tropicale humide. Thèse Doct. Etat, Fac. Sci. Univ. Yaoundé I, 252p.

Tematio, P., Kengni, L., Bitom, D., Hodson, M., Fopoussi, J. C., Leumbe Leumbe, O., Mpakam, H., G., Tsozue, D., (2004).Soil and their distribution on Bambouto volcanic mountain, West Cameroon highland, Central Africa.Journal of African Earth Science,39, p 447- 457.

Tematio, P., Fritsch,E., Hodson, M.E., Lucas, Y., Bitom, D., Bilong, P., (2009). Mineral and geochemical characterization of a lepticaluandic soil and a thaptoaluandic-ferralsol developed on trachytes in Mount Bambouto (Cameroon volcanic line). Geoderma152, p.314-323

Youmen, D., (1994). Evolution volcanique, pétrologique et temporelle de la caldeira des Monts Bambouto (Cameroun). Thèse Univ. Christian Albrecht. Kiel, 274p. + 2 cartes.

Youmen, D., Schmincke, H.U., Lissom, J., Etame. J, (2005).Données géochronologiques: mise en évidence des différentes phases volcaniques au Miocène dans les monts Bambouto (ligne du Cameroun). Science Technologie Développement,11(1): p.49-57.