Engineering Heritage Journal (GWK)

DOI: http://doi.org/10.26480/gwk.01.2024.26.33

ISSN: 2521-0904 (Print)
ISSN: 2521-0440 (Online)
CODEN: EHJNA9

RESEARCH ARTICLE

INFLUENCE OF THE GARNET CONCENTRATION OF METAMORPHIC ROCKS ON THE FORMATION OF LATERITIC MATERIALS AND THE VARIATION GEOTECHNICAL PARAMETERS IN ROAD BUILDING: CENTER REGION OF CAMEROON

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ARTICLE DETAILS

Article History:

Received 17 December 2023
Revised 20 January 2024
Accepted 23 February 2024
Available online 15 March 2024

ABSTRACT

This study shows the influence of garnet's content (C_g) of metamorphic rocks on the formation of lateritic materials and their geotechnical road parameters according to the standard test methods of the American Society for Testing and Materials (ASTM). Less than C_g (10 percent) involves the formation of fewer nodules, small sizes with a percentage of fines (< 80 µm) as high as 61.9 percent. 20 to 25 % of $\mathbf{C_g}$ induced the formation of more and larger nodules and low fines (17.0 to 5.9 percent) in lateritic gravel (LG). These values of fines (%fines) are opposed to the optimum dry density values of compaction γ_{dopm} (2.000, 2.430 and 2.460) at the modified Proctor optimum and bearing capacity CBR to 95 % (36, 60 and 68 %) of GL. Thus, GL can be used gradually in sub-base for T2, T3, T4 traffic and base for T1, T2 traffic. The Multiple Determination Coefficients (MCD) are 0.966 with $R^2 = 0.933$ for γ_{dopm}, 0.743 with $R^2 = 0.552$ for ω (%) and 0.961 with $R^2 = 0.924$ for CBR according to C_g and %fines. Thus, C_g influences the compaction parameters and %fines of lateritic materials derived from garnet metamorphic rocks. The higher C_g of the parent rock, the best of geotechnical properties of GL derived.

KEYWORDS

garnet content, lateritic gravel, compaction, laterites

1. INTRODUCTION

Lateritic gravels (GL) are the main natural materials used in road construction (Paige-Green et al., 2015). The formation of laterites and lateritic gravels is strongly conditioned by climatic factors prevailing in the tropics (Oyelami and Van Rooy, 2016a). These factors are bedrock, topography, vegetation and weather (Ekodeck, 1984; Duchaufour, 2001; Kamgang et al., 2001). Micas and garnet, which are the main minerals of the metamorphic basement, contribute to the formation of laterite constituents (Maignien, 1960). These two minerals alter into nodules, from oxyhydroxides in the alteration mantle, source of variation in geotechnical properties. Lithorelictual nodules observed with garnet pseudomorphosis result from metamorphic rocks in intertropical zones. In lateritic gravels (LG) they are formed by the individualization of garnet pseudomorphoses after the accretion of a cortex. Lithorelictual nodules, formed by the buildup of iron oxyhydroxides (goethite, hematite and magnetite), are in the form of globules, sea urchins, rods, nippled globules all needlelike associated (Maignien, 1960; Bogado et al., 2017).

The accumulation of ferric iron oxides (Fe_2O_3) or ferrous iron oxides (FeO) and alumina oxides (Al_2O_3) is responsible for the formation of nodules largely from minerals such as biotite of chemical formula $K(Mg, Fe)_3(Al, Fe)Si_3O_{10}(OH, F)_2$ (Bogado et al., 2017; Maignien, 1960). Similar nodules were observed in North-east Argentina on residual soils derived from granite, in South-east Paraguay on residual soils derived from gneisses, in South Brazil on residual soils derived from basalts and in South-west Nigeria on soils derived from metamorphic rocks (Bogado et al., 2017; Adekeye et al., 2021; Ale, 2023). The nodules would also result from almandine garnet with chemical formula ($Fe_3Al_2(SiO_4)_3$) by hydrothermal and meteoric alterations, with a large contribution of FeO and Al_2O_3 (Bédard, 2009).

Geotechnical characterization combined with the rock source and the degree of metamorphism were carried out on lateritic gravels (LG), from metamorphic rocks of the South Cameroonian plateau (Mengue et al., 2015). These lateritic gravels are also used in road building (Kamtchueng et al., 2015; Onana et al., 2015, 2017; Zo'o Zame et al., 2017; Ndzié Mvindi et al., 2017; Nzabakurikiza et al., 2017; Katte Yato et al., 2019; Ngo'o Ze et al., 2019; Nyassa Ohandja et al., 2020). These lateritic materials, still bearing some petrographic and mineralogical features of the parent rock, are useful for roadway and building foundations (Onana et al., 2015; Nyassa Ohandja et al., 2020). A group researcher obtained a coefficient of determination $R^2 = 0.86$ for optimum moisture ω (%) and 0.90 for optimum dry density (γ_{dopm}) (Saikia et al., 2017). On silty soils or Loess in India, obtained $R^2 = 0.96$ for ω (%), 0.96 for γ_{dopm} and 0.96 for California Bearing Ratio (CBR)) (Chindaprasirt et al., 2020). Similar results were obtained on lateritic gravels in the State of Ceara and North-east Brazil with $R^2 = 0.86$ for ω (%) and 0.76 for (γ_{dopm}) (Hohn et al., 2022).

Some researchers highlighted the variability of geotechnical parameters in lateritic gravels covering metamorphic rocks in the tropical humid area of Cameroon in function of the degree of metamorphism (Ngo'o Ze et al., 2019). These authors took no account of the petrography that is on any particular mineral in a parent rock, on the variation in geotechnical parameters of derived lateritic materials. Besides, predictions of

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compaction parameters in function of petrographic content of the materials were not presented. In the current study, the variation in geotechnical parameters is based in the petrography of rocks. The objective of this study is to show the influence of the garnet concentration (C_g) in metamorphic rocks on the formation of lateritic materials and the variation of road geotechnical parameters in road construction. This objective will be achieved through the petrographic description of metamorphic rocks and its derived lateritic gravels, the granulometric distribution, the evolution of geotechnical properties and the prediction of compaction parameters.

2. MATERIALS AND METHODS

2.1 Materials

The materials studied result from orthogneisses, micaschists, quartzites and migmatites of the Yaoundé group of the Central Africa mobile zone (Tchakounté Numbem et al., 2017). This series found in the Pan-African (Figure 1) cover is mostly composed of quartz, orthoclase, microcline, plagioclase, pyroxene, micas (muscovite, biotite), amphibole, garnet, disthene and opaque minerals (Vicat et al., 1998; Tchakounté Numbem et al., 2017). The garnet metamorphic rocks and its derived laterites sampled at Olembé, Minkan and Nsimalen (Figure 1) underwent microscopic petrographic description and geotechnical testing.

2.2 Experimental Methods

2.2.1 Sampling Method

In each sampling site, 15 kg of fresh rocks were extracted from different outcrops for petrographic analysis. 90 kg of lateritic materials were used for geotechnical analysis.

2.2.2 Confection of Thin Sections and Microscopic Obsevations

Thin sections of fresh rocks were made at the Petrography Laboratory of the Institute of Geological and Mining Research (IRGM) Yaoundé, Cameroon. They were then observed with a Leitz Wetzlar monocular polarising microscope, in Polarised and Analysed Light (PAL) ×10.

2.2.3 Geotechnical Analysis

Geotechnical tests were carried out at the National Civil Engineering Laboratory (LABOGENIE) and the Sol Solution Afrique Centrale Sarl Laboratory (SSACL) in Cameroon, using the USCS (Unified Soil Classification System) classification system. The Granulometric Analysis by sieving was carried out according to (ASTM standard D422-63, 1998). The LL and LP parameter values were determined by the Casagrande flat method and the Roller method (ASTM D4318-98, 1998) respectively. The ω (%) and γ_{dopm} were determined by modified Proctor analysis, according to the AF (ASTM standard D1557-91, 1998). The CBR test after 4 days of soaking was determined according to (ASTM D1883-99, 1999). Hallmarking was carried out using a universal press LaboTest type coupled tight with a pressure gauge to determine CBR.

Various characteristic parameters show the effects of garnet concentrations on the formation of lateritic materials. The mass of a sample necessary for each test on disrupted samples was taken according to the standard BS 1377-1 **(1990)** method. The disrupted samples were sampled at the depth of 1.5 to 5.0 m depending on the topography of the three (3) study sites. The CBR values of different materials resulting from garnet metamorphic rocks were compared with those of the different CBR classes for their use in road construction (Table 1).

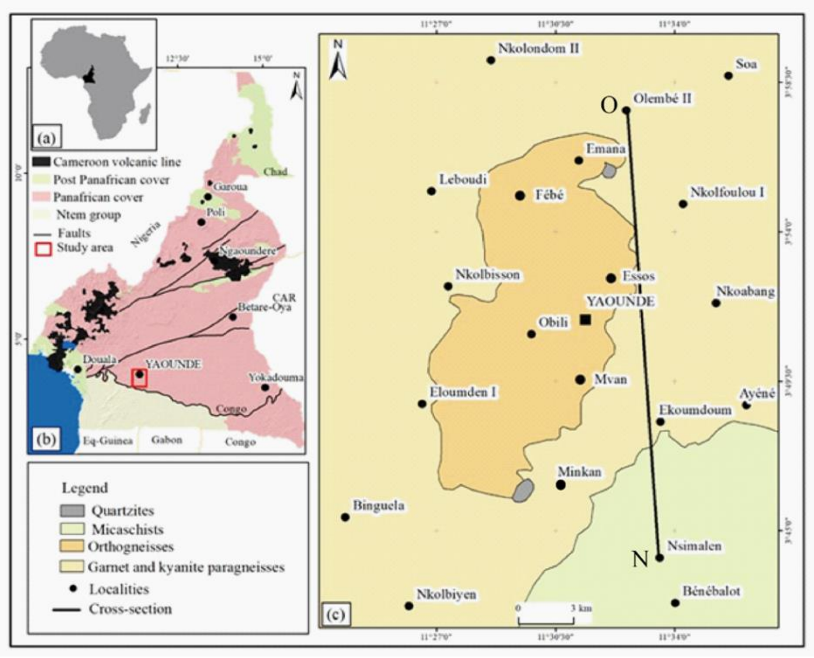

Figure 1: Geological map of (a) Cameroon in Africa (b) location in Cameroon (c) study area (Leroy and Cirotteau, 1956)

Table 1: Use of lateritic gravels according to CBR values (DEGN, 1987)

Class of CBR	Use in road construction
S_1: 0 < CBR < 5	Not suitable for road construction
S_2: 5 < CBR < 10	Fill
S_3: 10 < CBR < 15	Fill and top of fill
S_4: 15 < CBR < 30	Top of fill and sub-base for T1 traffic
S_5: 30 < CBR < 60	Sub-base for T2/T3 traffic and base for T1 traffic
S_6: 60 < CBR < 120	Sub-base for T3/T4 traffic and base for T2 traffic
S_7 : CBR > 120	Base for T3 traffic

The determination of C_g constituent of metamorphic rock was carried out by evaluating the representative percentage of garnet identified by microscopic observation in polarised and analysed light (LPA) and the space it occupies in the rock.

2.3 Data Processing

The data processing was obtained through different analyses based on diagrams and simple statistical methods. The evolution curves of granulometric (%fines) and compaction parameters according to the garnet rate were processed by the software Microsoft Office Excel 2016. Descriptive statistical methods adapted to data processing are part of the simple multiple regressions used for the sofware XLSTAT 2018. The processes help to synthesize information, without truncating them in logical reasoning (Lagarde, 1995). These processes establish relations between the petrography and geotechnical properties of laterites derived from metamorphic rocks.

3. RESULTS AND DISCUSSIONS

3.1 Geological Features

3.1.1 Petrography of Parent Rocks

Three (3) petrographic rock types were identified in the three sites: (1)

garnet migmatites at Olembé with C_g = 10 percent (Figure 2 a_1), (2) garnet and two-mica gneisses at Minkan with C_g = 25 percent (Figure 2 a_2), (3) garnet micaschists with C_g = 30 percent of garnet (Figure 2 a_3) at Nsimalen.

The other minerals accompanying garnet (5 to 10 percent) in garnet migmatites are abundant quartz (25 à 30 percent), biotite (10 to 15 percent), pyroxene (9 to 11 percent), orthoclase (8 to 12 percent), plagioclase (5 to 10 percent), muscovite (5 to 8 percent) and opaque minerals (≤ 2 percent) (Figure 2 b_1).

In garnet and two-mica gneisses the other minerals associated with garnet (15 to 25 percent) are abundant quartz (20 to 30 percent), biotite (5 to 7 percent), muscovite (3 to 5 percent), orthoclase (5 to 8 percent), plagioclase (15 to 20 percent), pyroxene (2 to 3 percent) and opaque minerals (≤ 2 %) (Figure 2 b_2).

Garnet-bearing micaschists contain abundant garnet (20 to 30 percent), quartz (10 to 15 percent), abundant muscovite (35 to 40 percent), biotite (10 to 15 percent), plagioclase (2 to 3 percent), orthoclase (2 to 4 percent), pyroxene (1 to 2 percent) and rare opaque minerals (≤ 1 percent) (Figure 2 b_3).

The garnet concentrations in the metamorphic rocks in this study are similar to those obtained in the Rowdon region in Quebec (Bédard, 2009). This garnet alters into gravels (nodules). Its morphological features and contents, and gravels are described below.

3.1.2 Lateritic Gravels

Hand specimens of Olembé garnet migmatites (OL_r) show small garnet grains of sizes between 0.8 and 2.0 mm. These grains alter into slightly indurated small size nodules ranging between 2.0 and 5.0 mm (Figure 2c_1) but larger than the garnet grains. At Minkan, garnet and two-mica gneisses show garnet grains with sizes between 3.0 and 5.0 mm less grouped. These grains are individualized in alteration, with the accumulation of iron oxides to form small nodules of sizes between 0.5 and 2.0 cm (Figure 2 c_2). Garnet (C_g = 30 percent) is abundant in garnet micaschists (NS_r) with large, tightly packed grains between 0.25 and 1.00 cm. This morpholithological aspect of grains is less identical to that in paragneisses with violet red almandine garnet in the Rowdon region of Quebec, with sizes between 0.5 and 1.0 cm and at Svratka in the Czech Republic (Bédard, 2009). The rich garnet grains led to abundant nodules of average sizes between 0.5 and 3.5 cm in the LG in the study area (Figure 2 c_3). Similar abundance in nodules on garnet micaschists was observed in lateritic soils of the Linsan plateau and of the Namou town in Guinea-Bissau (Maignien, 1960). Clearly, the C_g observed in the three (3) petrographic rock types in the study area would largely contibute to the formation and variation of the derived GL.

3.1.3 Relation Between C_g and Nodules

Petrographic obsevation of rocks shows a relation between C_g and nodules (Figure 2). Figure 2 displays the macroscopic and microscopic samples of three rock types and their derived lateritic materials. Less **C_g** (Figure 2a_1 and 2b_1) corresponds to the formation of few small nodules (Figure 2c_1), but more **C_g** (Figure 2a_2, 2a_3, 2b_2 and 2b_3) corresponds to the formation of abundant and large nodules in GL (Figure 2c_2 and 2c_3). This abundance of garnet-derived nodules may be related to the individualization of iron and aluminium oxyhydroxides from other minerals (clay, residual minerals) in chemical alteration or oxidation processes (hematite) and hydration (goethite) of iron in the garnet source (Maignien, 1960). The alteration of garnet contributes variably to the formation of nodules (Bédard, 2009). Other processes include alteroplasmation (formation of ferruginous and clayey plasma round the alteration cortex).

The formation of different GL and the size of nodules in the granulometric distribution depend on the primary minerals present in the original rock (Ngo'o Ze et al., 2019). This behavior is observed in the garnet constituent of the metamorphic rocks in the study area. Thus, garnet may influence the formation of GL nodules resulting from metamorphic rocks.

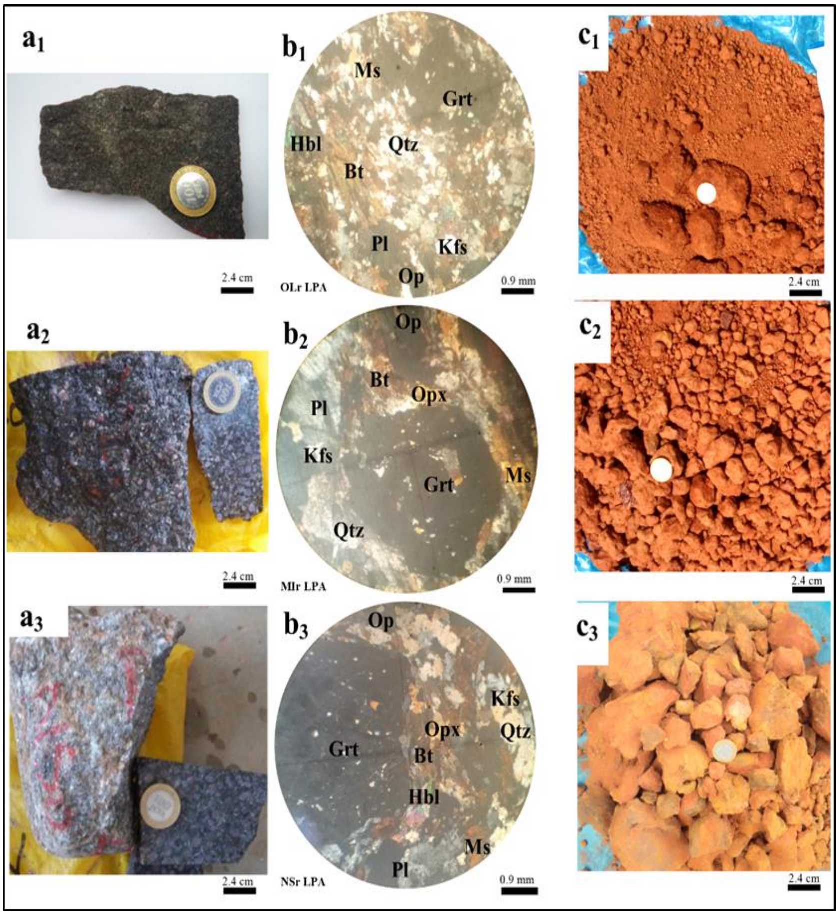

Figure 2: Macroscopic rocks: (a_1) Garnet migmatite, (a_2) Garnet two-mica gneiss, (a_3) Garnet micaschist Microscopic rocks: (b_1, b_2 and b_3) metamorphic rocks and derived laterite, (c_1) Clay laterite, (c_2) Stony and clay laterite, (c_3) Stony laterite. Pl: Plagioclase; Qtz: Quartz; Bt: Biotite; Opx: Orthopyroxene; Kfs: Potassium feldspar; Ms: Muscovite; Grt: Garnet; Hbl: Hornblende; Op: Opaque oxides (Kretz, 1983)

3.1.4 Variation of Derived Lateritic Soils

Lateritic gravels were sampled along the Olembé-Nsimalen (O-N) geological cross-section of soil layers (Figure 3) from the lower to the higher C_g zone. The horizon of sandy clay soil is thick at Olembé (~ 8.0 m) and thin at Minkan and Nsimalen (~ 2.0 m). The nodular level is thin (~ 0.5 m) at places at Olembé at the start of the cross-section and poor in nodules (37 percent). At Minkan and Nsimalen, this nodular level is very

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thick (~ 6.0 m), rich in nodules (82 to 93 percent). The type of soils explains this variation: the Olembé rocks are rich in minerals that favor argillization (feldspar, pyroxene and quartz); the Minkan and Nsimalen rocks are rich in minerals that favor induration (garnet, micas) (Maignien, 1960). There are very thick and loose clay soils at Olembé at a depth of about 8.0 m and thin at Mikan and Nsimalen at a depth of about 2.0 m, in the form of a large plateau, with the C_g and the formation of nodules (Vallerie, 1971).

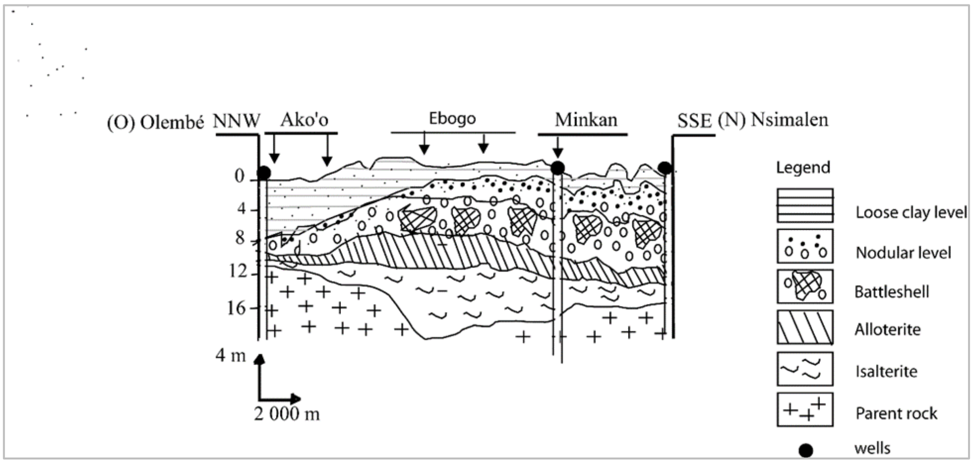

Figure 3: Geological cross-section Olembé - Nsimalen (well shown on Figure 1).

3.2 Geotechnical Properties

3.2.1 Relationship Between Nodules and Fines

The granulometric curves for lateritic materials from different metamorphic facies (Figure 4) show fines of 61.9, 17.0 and 5.9 percent for OL, MI and NS respectively. For S (silt), C (clay) and N (nodules), the calculated amount is (S+C) OL = 100-(3+11+23) = 63 percent with N_{OL} = 37 percent, $(S+C)_{MI}$ = 100-(19+47+16) = 18 percent with N_{MI} = 82 percent, $(S+C)_{NS}$ = 100-(40+42+11) = 7 percent with N_{NS} = 93 percent.

The calculated proportions of nodules are 37.82 and 93.00 percent for OL, MI and NS samples respectively. The amount of nodules increases OL (37) < MI (82) < NS (93) and the amount of fines decreases OL (61.9) > MI (17) > NS (5.9) related to garnet concentrations in rocks. At high C_g (25 to 30 percent) the amount of nodules formed is high while the amount of fines is low. The %fines values of 17.0 percent and 5.9 percent are lower than those in lateritic soils (26 percent) at Mfou in garnet free micaschists (Kamtchueng et al., 2015). GL from garnet-rich metamorphic rocks present low %fines and high amount of nodules. This corrational justification explains the evolution of compaction values at the optimum level in soils derived from rocks with lower to higher C_g values, γ_{dopm} (2.000, 2.430 and 2.460) and CBR (36, 60 and 68). Thus, the granulometry of lateritic gravels influences the optimum compaction parameters (γ_{dopm} and bearing capacity CBR).

3.2.2 Relationship Between Granulometric Distribution and Compaction Parameters

The granulometric values derived from the OL, MI and NS laterites in the study area vary (Figure 4). The granulometric curves were obtained from the data (Table 2) offset from one another. Spacing between granulometric curves indicates a heterogeneous differentiation of lateritic materials derived from garnet metamorphic rocks (garnet migmatite, garnet two-mica gneiss and garnet micaschist). The graphic shift reveals that the granulometric heterogeneity is similar on micaschists and different on gneisses and granitoids at Akonolinga **(**Ngo’o Ze et al., 2019; Ndzié Mvindi et al., 2017; Nyassa Ohandja et al., 2020; **Onana** et al., 2017; Nzabakurikiza et al., 2017).

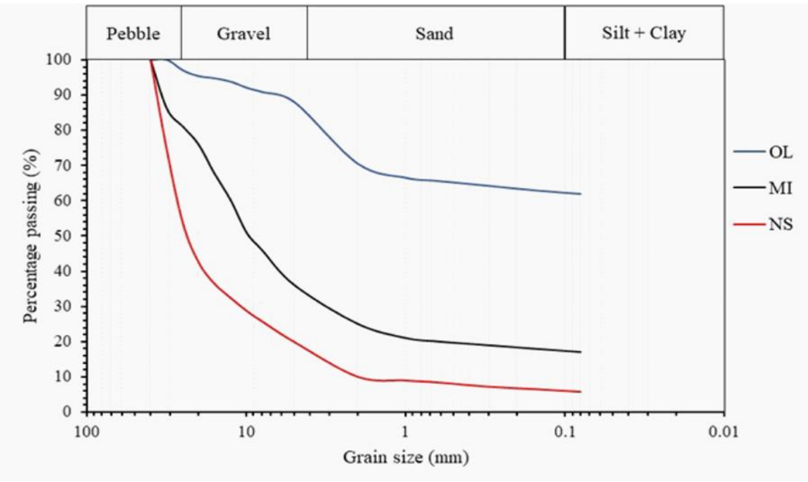

Figure 4: Granulometric distribution curves for laterite samples

The mean values of the fine fraction decrease from 71.0 to 46.5 and 33.0 percent from OL to MI and NS (Table 2), unlike the average values of γ_{dopm} (1.850, 2.046 and 2.139) of the modified Proctor optimum and the CBR (28, 39 and 44) which increase. The increasing values of γ_{dopm} and CBR conjectures the observation of coarse particles on curves MI (Minkan) and NS (Nsimalen) that pass through the sieve diameter of 31.5 and 25.0 mm at the detriment of the OL (Olembé) curve, which only begins at the sieve diameter of 20.0 mm.

3.2.3 Relationship Between C_g and Geotechnical Properties

The curve shape (Figure 5) shows varying geotechnical parameters. In curves C_1 and C_2, C_g and compaction properties (CBR at 90 percent and γ_{dopm}) increase. In curve C_3, C_g increases and %fines (< 80 µm) decreases. Thus, garnet of metamorphic rocks impacts geotechnical properties of lateritic road subgrade materials. This evolution means that from the C_g of a metamorphic garnet rock, the geological engineer will be able to estimate the type of material and the various geotechnical values (pavement compaction parameters and fines (< 80 µm)) based on figure 5, without going to the laboratory. The compaction parameters in function of C_g and fines can be predicted.

3.3 Prevision of Compaction Parameters with C_g And %Fines

The influence of garnet of metamorphic rocks on the properties of lateritic materials can help to predict compaction parameters of garnet content

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and %fines (< 80 µm). The prediction calculated by statistical processing of γ_{dopm}, ω (%) and CBR (Table 3) gave three (3) relationships from the equations (1, 2 and 3) with high values of Multiple Coefficients of Determination (MCD) 0.966, 0.743 and 0.961. The equations show a genuine relation between the compaction parameters, %fines (< 80 µm) and C_g (Table 4). The determination coefficients R^2 (0.933, 0.552 and 0.924) also justify a strong correlation at 93 percent of γ_{dopm}, approaching more the line of the saturated model (Figure 6a) with a standard error interval [+/-0.091 to +/- 0.001]. The moderate relationship of 55.2 percent of ω (%) approaches less the line of the saturated model (Figure 6b) at a standard error interval of +/- 0.207 and 92.4 percent of the relationship with CBR, and approaches the line of the saturated model (Figure 6c) with a standard error interval [+/-0.087 to +/- 7.397] of the variability model. At these R^2 values, the global link of γ_{dopm}, ω (%) and CBR with this model is the significant evidence of the value of the slope test highly significant for $p < 0.0001$. The model would express only 93.3 percent, 55.2 percent and 92.4 percent of the total variation due to the relationship between optimum compaction parameters, C_g and %fines.

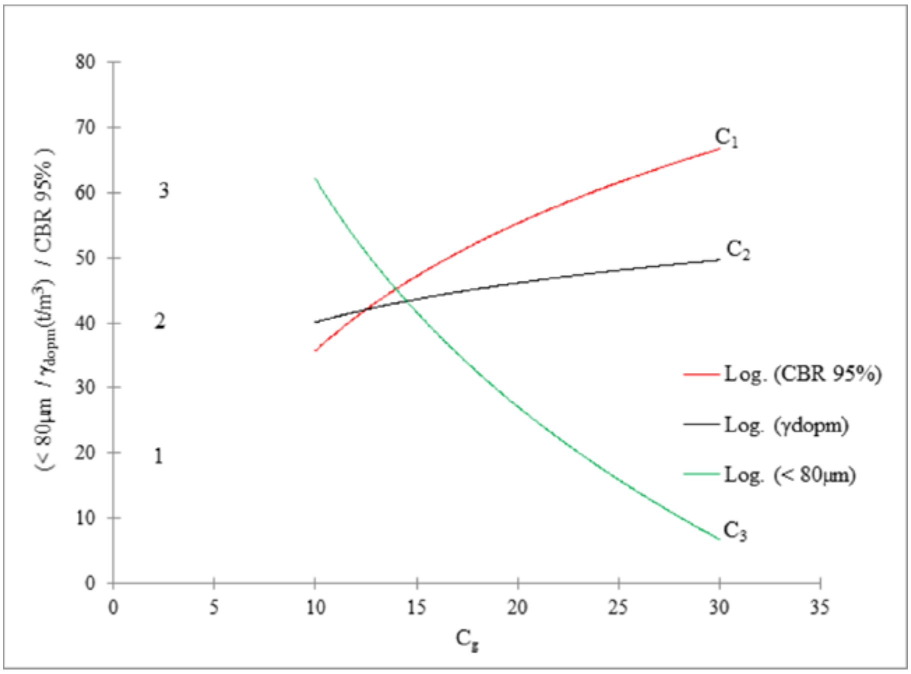

Figure 5: Evolution of CBR 95 percent, γ_{dopm} (t/m^3) and %fines lateritic gravels in function of C_g

Table 2: Geotechnical and Statistical Data on Lateritic Materials

Number Samples	depth (m)	Cg	< 80 µm	γd (t/m3)	ω (%)	CBR 95%	AASHTO
N=31	1	10	76	1.744	20.7	18	A-7-5 (12)
	1	10	67	1.636	21.2	25	A-7-5 (12)
	1.5	10	61	1.570	25.5	15	A-7-5 (14)
	1.65	10	70	1.580	24.4	14	A-7-6 (18)
	1.5	10	85	1.600	23.4	16	A-7-6 (20)
	1.6	10	85	1.580	23.5	15	A-7-6 (20)
	1.45	10	80	1.600	22.4	21	A-7-6 (20)
	1.5	10	80	1.590	22.2	17	A-7-6 (20)
	3	10	71	1.698	21.5	20	A-7-5(11)
	5	10	35	2.000	13.0	36	A-2-7(1)
	1	10	70	1.650	21.9	20	A-2-7(1)
	1	25	70	1.650	21.9	20	A-7-5(11)
	1	25	69	1.631	25.3	18	A-7-2 (12)
	1	25	72	1.700	25.7	18	A-2-7(0)
	1	25	57	1.820	12.1	19	A-7-5(12)
	1	25	76	1.665	25.5	18	A-7-5(11)
	3	25	16	2.440	14.0	61	A-2-7(2)
	3	25	18	2.332	15.7	58	A-2-7(2)
	3	25	17	2.430	13.7	60	A-2-7(2)
	3	25	16	2.433	13.5	61	A-2-7(2)
	1	25	58	1.849	20.5	27	A-2-7(2)
	1	20	63	1.879	18.1	17	A-7-5 (10)
	1	30	46	1.816	15.6	20	A-7-5 (4)
	1	30	73	1.798	16.0	15	A-7-5 (12)
	1	30	60	1.888	16.6	21	A-7-5 (10)
	1.5	30	60	1.877	18.4	19	A-7-5 (10)
	4	30	8	2.360	18.2	65	A-2-7(2)
	4	30	5	2.440	14.2	68	A-2-7(2)
	4.5	30	6	2.400	15.2	68	A-2-7(2)
	5	30	6	2.390	15.2	67	A-2-7(2)
	1	30	51	1.943	16.7	27	A-2-7(2)
Maximum		**30**	**85**	**2.440**	**25.7**	**68**	-
Minimum		**10**	**5**	**1.570**	**12.1**	**14**	-
Average		**21**	**53**	**1.900**	**19.3**	**31**	A-2-7(2)
Standard deviation		**8.75**	**27.12**	**0.33**	**4.22**	**20.30**	-

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R^2 (0.933 and 0.924) by simple regression statistic, shows a significant relation between C_g of the metamorphic rock, its derived formation and geotechnical properties. R^2 (0.933) is higher than in fine-grained soils ($R^2 = 0.90$ for γ_{dopm}) in the State of Ceará and the North-east Brazil with $R^2 = 0.76$ (γ_{dopm}) (Saikia, 2017; Hohn, 2022). But R^2 (0.552) is lower than in the fine-grained soils ($R^2 = 0.86$ for ω (%)) observed by on loess in India with $R^2 = 0.96$ and by in the State of Ceará and North-east Brazil with $R^2 = 0.86$ (ω %) (Saikia et al., 2017; Chindaprasirt et al., 2020a, b Hohn, 2022).

R^2 (0.924) for CBR in this study shows two (02) variables (C_g and %fines) and is higher than the value Katte Yato et *al.* (2018) observed R^2 (0.841) with seven (07) variables (MDD, OMC, PL, PI, %GRAVEL, %SAND and %CLAY/SILT), $R^2 = 0.04$ with LL, $R^2 = 0.10$ with PL and $R^2 = 0.00$ with PI (Table 4), on soils derived from metamorphic rocks. A group reserchers obtained a close R^2 (0.95) with five (05) variables on soil derived from volcanic and sedimentary rocks and obtained R^2 (0.957) with seven (07) variables (G, S, LL, PI, Gs, MDD, OMC) (Table 4) on fine-grained soils in India (Nyemb Bayamack et al., 2019; Hassan Jawad et al., 2021). The prediction model proposed in this study is better and shows a direct relation between the CBR and the two parameters C_g and %fines. As a result, CBR evolves with Cg and %fines.

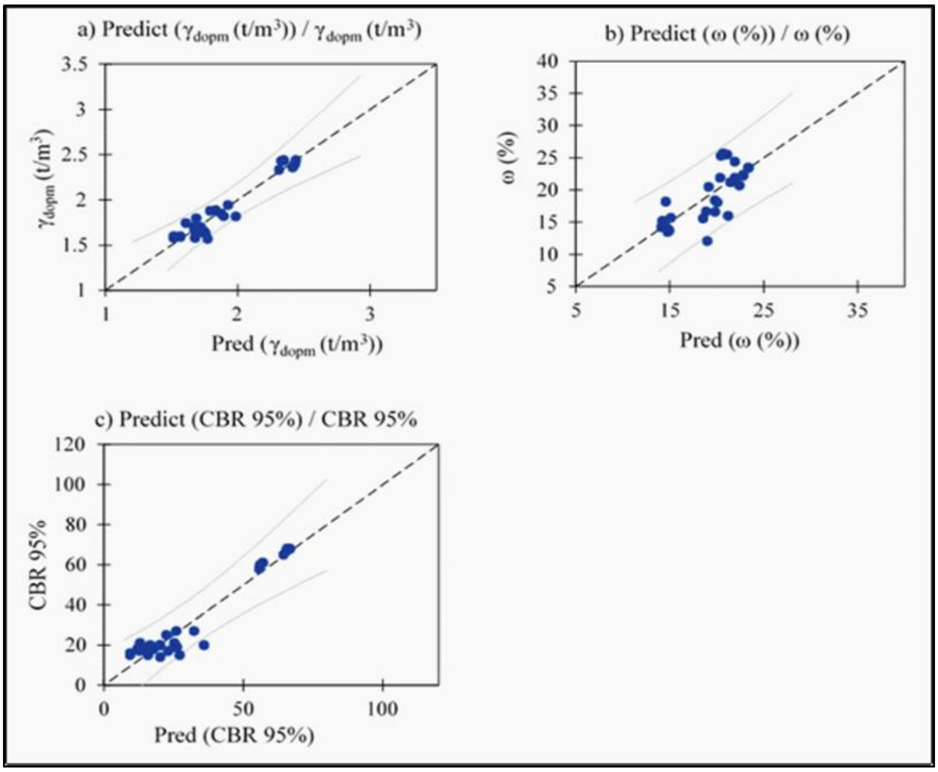

Figure 6: Predicted values of the saturated model line (a) Predict γd (t/m^3) (b) Predict (ω (%)) and (c) Predict (CBR 95%)

Table 3: Regression equations and coefficients of determination. MCD: Multiple coefficient of determination; CD: Coefficient of determination

Parameters	Variables	Equations	MCD	CD	P values	Range values
γ_{dopm}	C_g, < 80μm	γ^d (t/m^3) = 2.40717181762029+4.37189357062404E-03*C_g-1.10745577842034E-02*(% < 80 μm) (1)	0.966	0.933	< 0.0001	$\gamma^d \in [1.665-2.430]$ ω (%) ∈ [13.0-25.5] CBR ∈ [18-68] %fines(<80μm) ∈ [5.9 ;76.0]
ω (%)	C_g, < 80μm	ω (%) = 15.5313538914063-9.38741569719824E-02*C_g+0.103322970849498*(% < 80 μm) (2)	0.743	0.552	< 0.0001	
CBR	C_g, < 80μm	CBR 95% = 75.1761767070614-0.251949714358377*C_g-0.74667899391629*(% < 80 μm) (3)	0.961	0.924	< 0.0001	

4. CONCLUSION

The influence of garnet of metamorphic rocks on the formation of nodules in derived laterites and their geotechnical properties reveal the following results:

(1) The formation of GL depends on primary minerals of the original rock. High C_g favors the formation of nodules of varying shape and size in lateritic gravel used in civil engineering;

(2) C_g, γ_{dopm}, CBR and %fines values show: percentage $C_{gOL}=10$ < percentage $C_{gMI}=25$ < percentage $C_{gNS}=30$, $(\gamma_{dopm})_{OL} < (\gamma_{dopm})_{MI} < (\gamma_{dopm})_{SI}$, $CBR_1 < CBR_2 < CBR_3$ and $\%fines_{OL} > \%fines_{MI} > \%fines_{NS}$. Thus, C_g, γ_{dopm} and CBR increase while %fines decreases. The C_g of garnet metamorphic rocks influences the formation of derived laterites and compaction parameters. The more C_g is high, the more γ_{dopm} and CBR increase. γ_{dopm} and CBR depend on the variation in garnet content in metamorphic rocks and %fines. Rich garnet leads to the formation of abundant large size nodules in laterites;

(3) GL from metamorphic facies with low C_g and CBR (36 for OL class S_5) indicates a good bearing capacity. The materials can be used as sub-base for T2, T3 traffic and base or rolling surface for traffic T1. High C_g and CBR (60 for MI and 68 for NS of class S_6) indicate very good bearing capacity. Thus the GLs of MI and of NS are useful in the foundation layer for traffic T3, T4 and traffic base course T2;

(4) The MCD (0.966, 0.743 and 0.961) show the C_g in garnet metamorphic rocks, the derived alteration mantle and their compaction properties are related. Cg will help to delimit borrowing areas. Associated minerals constitute a gap in the study and participate in the formation of fines and indirectly of nodules.

(5) The evolution of C_g indicates that from a metamorphic garnet rock, the geological engineer will be able to estimate the type of material and the various geotechnical values (pavement compaction parameters and fines (< 80 μm)) without going to the laboratory. Based on the curve of CBR 95%, γ_{dopm} (t/m^3) and %fines of lateritic gravels as a function of C_g.

STATEMENT OF CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Due to the nature of the work being experimental, the data is included in the publication itself.

AUTHOR'S CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Alain Justin MENYE. Formal analysis and investigation and original draft preparation were made by Michel MBESSA and Paul BILONG. All authors read and approved the final manuscript.

ACKNOWLEDGEMENTS

The realization of this work was done thanks to the help of the laboratory SOL SOLUTION AFRIQUE CENTRALE Sarl. Authors, thank Jean Pierre TCHOUANKOUE, Plastini NGAMI for constructive comment on earlier version of this manuscript.

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