

Geotechnical characterization of Beka-Gotto rock massif (Adamawa-Region Cameroon) for the use in civil engineering

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ABSTRACT

Beka-Gotto is a village of Ngaoundal located in the Adamawa region (Cameroon). The present study is carried out to determine the physical and mechanical characteristics of the local rock massifs, in order to determine their possible uses in various fields of civil engineering. The methodology used consists of petrographic and geotechnical characterization of the different massifs. The rocks crop out as domes or slabs. The rock is light gray. Under the microscope, the rock presents a grainy microstructure composed of plagioclase, potassium feldspar, biotite and quartz. Zircon and opaque minerals represent the accessory phase. With this composition, rock is granodiorite. The geotechnical study, on the other hand, made it possible to understand that, on the physical level, the rock massif has very good properties. In fact, the specific weight on class 6/10 and 10/14 obtained has mean values of 2.73 and 2.68 kN/m³ respectively. While the apparent density obtained of the class 6/10 and 10/14 has mean values 1.35 and 1.46 g/cm³ respectively. Mechanically, Los Angeles coefficient is 24-46.3% while the Micro-Deval coefficient is 7-35% and the coefficient of dynamic fragmentation is 18-30%. In accordance with geotechnical standards, with the exception of the Gbago massif, the other massifs have a choc resistance and a wear resistance of satisfactory to limited grade as well as good resistance to dynamic fragmentation and therefore usable in any type of structure.

Keywords: Geotechnics; Petrography; Beka-Gotto; Civil engineering; Rock massif

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INTRODUCTION

Cameroon is a country where the construction of buildings, roads or other masterpieces is undergoing rapidly. It cannot therefore achieve a harmonious development in the field of infrastructure if the local materials are not characterized before being exploited. This requires knowledge of their genetic type and their distribution at the local, regional, and national levels. The search for quarry borrowings has become a major priority in the execution of public works. It was with this same idea that mining and quarrying the 10th conference on the building materials construction was held in Algeria from March 27 to 28, 2018 under the theme: "Building materials construction and sustainable development", (NOMAD, 2012).

Cameroonian territory covers a large area (475,442 km²) with different sedimentary, magmatic and metamorphic rock terrains. It has been demonstrated that knowledge and geotechnical engineering characterization of construction materials in Cameroon will allow the development of several national economy sectors as well as the generation of jobs.

The study area is located in Beka-Gotto, in the

Adamawa Region, Cameroon, more precisely in the Djerem Department within Ngaoundal district. The geographical coordinates that bound Beka-Gotto is 6° 45' and 6° 65' North latitude and 13° 55' and 13° 70' East longitude with an average elevation of 1043 m (Fig. 1).

The main objective of this work is to assess the quality aggregates for civil engineering work, which may contribute to resolving the lack of building materials in the Adamawa region, particularly in the Djerem department. The study consists of a petrographic description at the sample scale and the deposit scale along with the analysis of the rock resistance parameters like Los Angeles, Micro-Deval, and Dynamic Fragmentation.

GEOLOGY AND GEOMORPHOLOGIC SETTING

The Pan-African Chain of Central Africa (CPAC) also called mobile zone of Central Africa (Lassere 1966; Lasserre and Soba, 1979; Bessoles and Trompette 1980; Affaton et al., 1991), corresponds to a wide zone that extends north of the Congo Craton and is limited to the west by the Trans-Saharan chain.

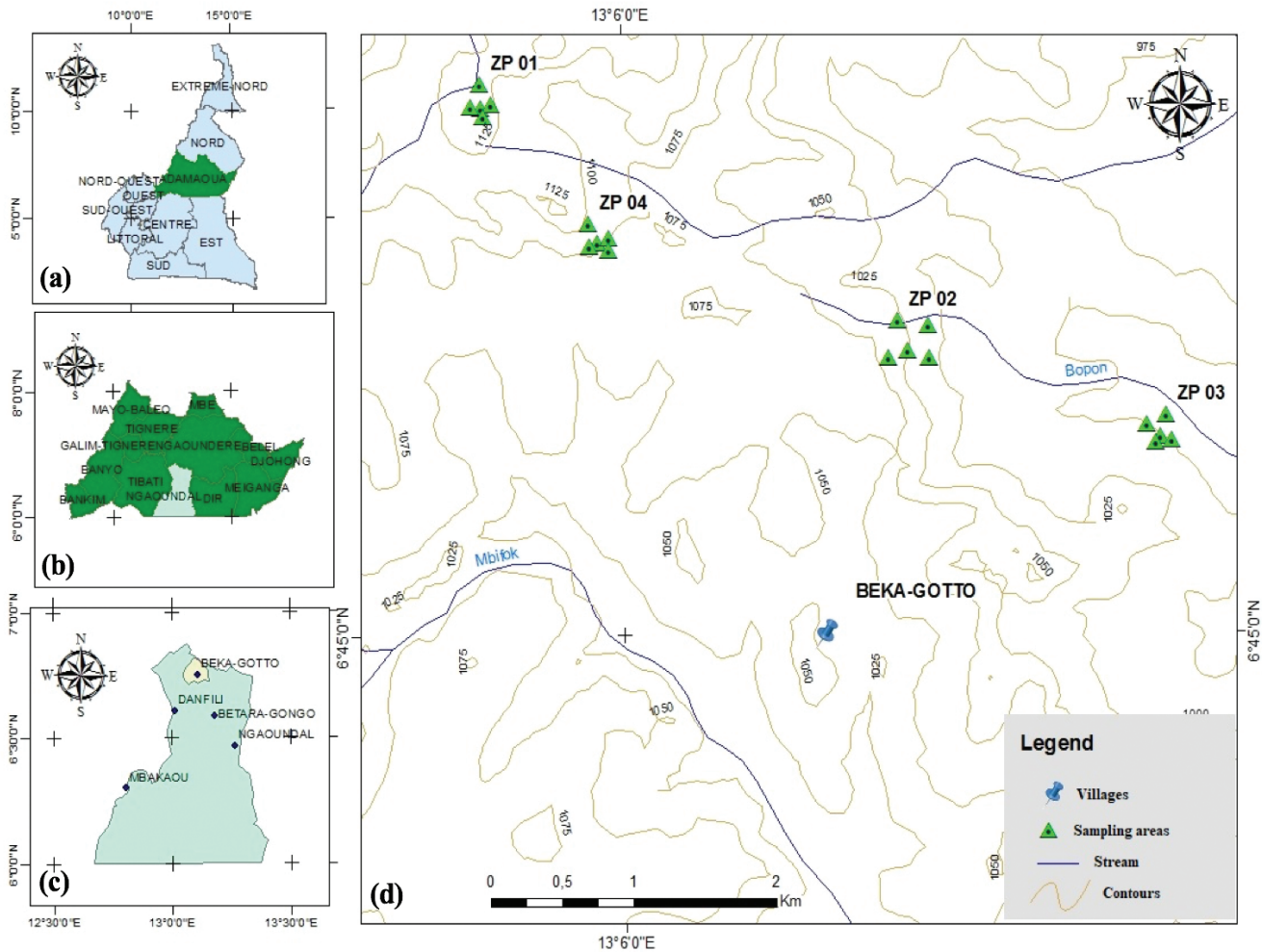


Fig. 1: Location of the study area: (a) Administrative map of Cameroon; (b) Map of Adamawa region; (c) Map of the study area in the district of Ngaoundal; (d) Topographic map of the study area.

Petrographic, structural and geochronological studies have permitted subdivision of the CPAC into three lithostructural domains: the North, Center, South Cameroon domains, (Fig. 2a) (Ngako, 1999; Toteu et al., 2004, Van Shumus et al., 2008). The study area is composed of various geological formations, including: a base granite covered in places by volcanic formations represented by anatexis derived granites and biotite anatexites (Fig. 2b).

Segalen (1967) and Kamgang K. (1998) presented a geomorphological sketch of Cameroon, which allows us to distinguish four major units' characteristics, namely, regions of low altitudes, intermediate reliefs, planing surfaces and mountains. The Beka-Gotto area belongs to the South Cameroon Plateau characterized by low-relief surfaces and mountains with altitudes that vary between 740 m and 1850 m. The map of the digital terrain model emerged from the geographical coordinates recorded in the field and digitization of the background topography, and show

that the altitudes in the study area vary between 740 m and 1300 m (Fig. 3).

The Beka-Gotto village is bounded by the following mountain ranges: Gabiskedje and Ngoulouk in the north, NgaouHOLA and Balina in the east and NgaouNdoum, in the south (Fig. 3).

An aggregate is a granular material used in the construction industry, either linked to other substances (binder, bitumen) to obtain mortar, concrete, road concretes, etc., or unbound such as railroad ballasts, aggregates for the drainage system. It is made up of several mineral grains of different dimensions in which most frequently between 0 mm and 125 mm but can go up to 150 mm. Aggregate is either natural or artificial in origin. Table 1 shows the range of granular classes and their application at various levels of construction. During this study, the 6/10 mm and 10/14 mm granular classes are the subject of our study, because these two classes are the most used in road construction.

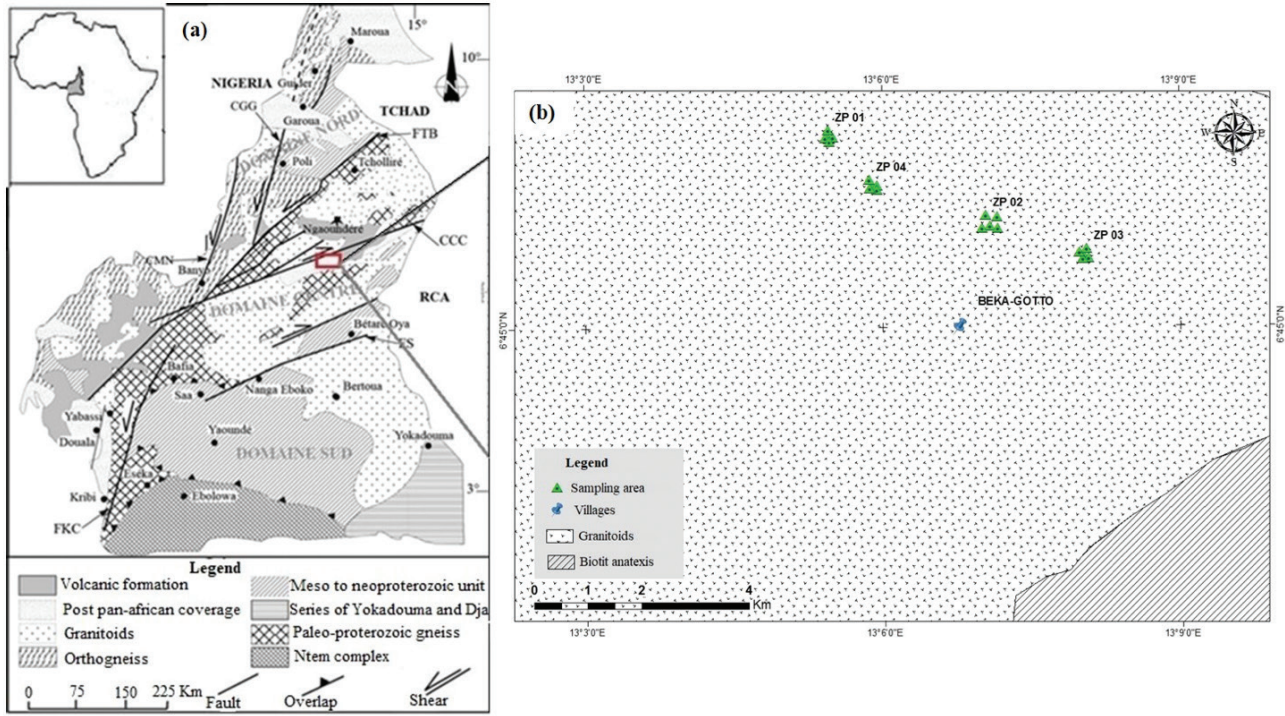


Fig. 2: (a) Simplified geological map showing the Pan-African chain from Central Africa to Cameroon indicating the three domains (Toteu et al., 2001) (b) Simplified geological map showing the study sector (Dumort (1968). FKC = Kribi-Campo fault; FS = Sanaga fault; CCC = Shear Cameroon Center; CGG = Godé-Gormayashear; CMN = Mayo-Nolti Shear; TBF = Tcholliré-Banyo fault.

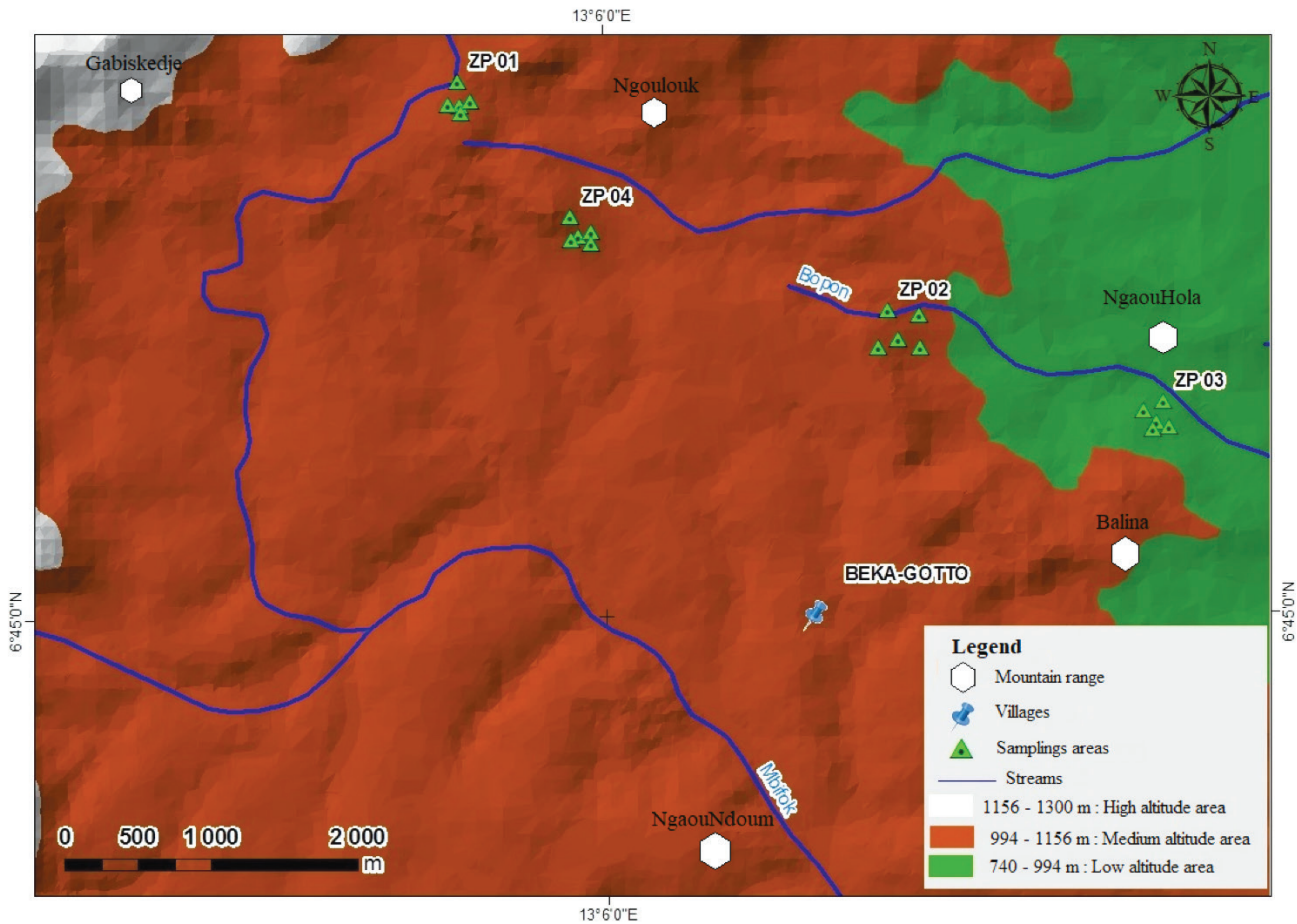


Fig. 3: Digital terrain model of the study area (After Dumort, 1968).

Table 1: The different classes of aggregates with their use in civil engineering.

Granular class (mm)	Usage					
	Concrete	Mortar	Backfill	Foundation layer	Base layer	Bearing layer
0/2	•	•				•
0/5	•	•				
4/6	•	•				•
2/6	•					•
5/10	•					•
6/10	•					•
Granite	•					
5/15	•					
10/14	•					•
10/20		•				
15/25	•					
25/50			Ballasts for railways			
0/31,5					•	
0/150			•	•		
Riprap		Hydraulic works; civil engineering works; supports.				
0/40			•			
40/125			Sanitation			

MATERIAL AND METHODS

In order to achieve the objectives, a brief study, relating to the Adamawa Region geology as well as specific study of Ngaoundal in particular was carried out. Four sampling areas were identified and samples were collected (Fig. 4). Samples were documented

according to their location, their lithology and their degree of alteration.

At each area, approximately 75 kg of material was collected in bags for laboratory analysis. Representative samples were taken and placed in plastic packaging for thin section preparation. The

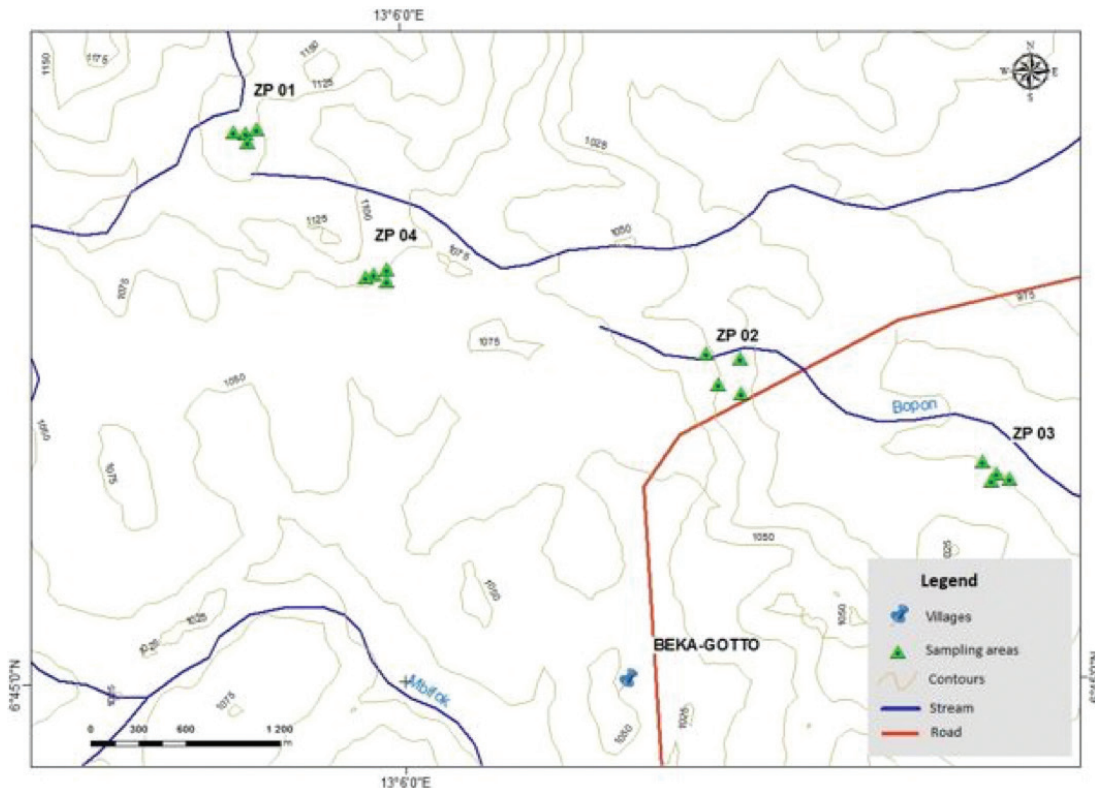


Fig. 4: Map showing the sample location.

numbering of each location are ZP01 to ZP04 for geotechnical tests in the A-Z Consulting laboratory.

In the A-Z Consulting laboratory at Yaoundé, five tests were carried out, namely:

- Bulk density;
- Specific weight (NFP 94-054);
- Los Angeles or Abrasion Test (EN 1097-2);
- Micro-Deval (EN 1097-1);
- Dynamic fragmentation.

Table 2 shows the operating mode of the various geotechnical analyzes carried out in the laboratory.

The petrographic thin sections were prepared from the most fresh, unweathered and unaltered representative samples. The description of thin sections was used to determine petrographic characteristics. In addition, geotechnical engineering tests, particle size analysis, and both the Los Angeles test and the Micro-Deval test were conducted. Crushing by dynamic fragmentation was used for the production of class 6/10 and 10/14 aggregates. Los Angeles and Micro-Deval tests were conducted to determine the respective resistances of abrasion, crushing and grinding. In addition, the Kurtosis coefficient, specific weight, and apparent density were calculated.

Table 2: Methodology of different analysis carried out in the laboratory.

Test	Principle	Operating mode
Bulk density	It is possible to determine the apparent density of the material, that is to say the quantity of materials contained in a given volume.	The principle consists of looking for 03 successive weighing values with a maximum deviation of 50 g. The material used consists of a mold of known volume, a scale, a tray and a plane. The bulk density p_a is determined using the formula $p_a = 100 \times M/V$
Specific weight NF P94-054.	It is possible to determine the real density of the material, taking into account the voids present in the rock.	The mass of solid particles is obtained by weighing, and the volume is measured with a pycnometer. The real density PS of solid particles is obtained from the formula: $P_s = P_w (m_2 - m_1) / (m_4 + m_2 - m_1 - m_3)$ Where, P_w is the density of water (1000kg / m3), m_1 is the mass of the empty pycnometer, m_2 the mass of the pycnometer + aggregates, m_3 the mass of the pycnometer + aggregates + water and m_4 the mass of the full pycnometer water in grams.
Los Angeles or Abrasion Test EN 1097-2	It is possible to measure the combined resistances to shocks and to the progressive deterioration by reciprocal friction of the elements of an aggregate.	The test is started by performing the machine 500 rotations at a speed between 30 and 35 rpm for all classes except the 25-50 mm class where the number of rotations is 1000. After the test, the aggregates are removed and collected in the tank placed under the apparatus to prevent losses of the aggregates, the opening must be made above this tank. The material contained in the tank is crushed on the 1.6 mm sieve and then the 1.6 mm residue is washed in another tank and it is poured into the perforated tank. As soon as the residue is dried in an oven then the weights of the M1 weighing are determined, and the Los Angeles coefficient is then calculated: $LA = 100X (M - M1) / M$
Dynamic fragmentation	It measures the quantity of elements smaller than 1.6 mm produced, in subjecting the material to impacts of a standard mass.	The procedure for the dynamic fragmentation test is as follows: - Placement of the sample in the mold by distributing it evenly (i.e. M). - give the number of mass blows indicated according to the granular class chosen. - Collect and sift the aggregate after testing on the 1.6 mm sieve. - weigh the refusal, or m' the result of the weighing. - the dynamic fragmentation coefficient is by definition equal to the ratio: $m = M - m' = 350 - m'$ $FD = 100X (350 - m') / 350$
Micro-Deval EN 1097-1	It determines the resistance to wear by the reciprocal friction of the elements of an aggregate.	Reproducing wear phenomena in a rotating cylinder and consists in measuring the wear of the aggregates under standardized conditions produced by mutual friction, in the presence of water and an abrasive load in a rotating cylinder. Let M be the mass of the material tested and m is the mass of the elements smaller than 1.6 mm produced during the test; wear resistance is expressed by the Micro-Deval coefficient which is written: $MDE = 100xm/M$

RESULTS

Contribution of the petrographic study

The rocks out crops occur as domes or slabs (Fig. 5a and 5b). The rock is light gray in color and the visible minerals are quartz, feldspar, and biotite.



Fig. 5: Photographs of Bahkosso and Gbago granite massifs. (a) Slab outcrop of the Bahkosso granite. (b) Slab outcrop of the Gbago granite.

In thin section, the rock shows a grainy microstructure composed of plagioclase, potassium feldspar, biotite, and quartz and some minerals are clear in hand specimens (Fig. 6a and 6b). In addition, zircon and opaque minerals represent the accessory minerals. Plagioclase (25-30%) is in the form of sub-automorphic crystals of variable size between 1 x 0.5 mm and 1.25 x 1.8 mm. These plagioclase crystals are associated with potassium feldspar crystals and sometimes contain biotite inclusions. These minerals are also associated with quartz, and biotite lamellae (Fig. 6b and Fig. 8b). Alkaline feldspar (20-25%) is represented by microcline and orthoclase. Their crystals appear as large sub-automorphic to automorphic patches. The larger ones sometimes reach 1.5 mm long and sometimes exceed 0.93 mm in the minor axis. Some K-feldspar crystals contain opaque mineral inclusions while biotite flakes mold others. Some alkaline feldspar crystals are perthitic and others are myrmeckitic (Figs. 7a and 7b).

Quartz (15-20%) occurs in the form of polycrystalline, sub-automorphic to xenomorphic plaques up to 1.6 mm long axis. Large quartz crystals are frequently associated with feldspar patches, while small sub-automorphic crystals are often clustered around plagioclase crystals (Fig. 8a). They exhibit for the most part rolling extinction. Biotite (10-15%) is in the form of flakes in the rock and may be in contact with feldspar, quartz, some biotite flakes show the start of alteration to chlorite, and others contain inclusions of zircon crystals. It is automorphic to sub-automorphic, weakly pleochroic, between light green and dark green. The association of biotite flakes, alkaline feldspar hornblende crystals, and quartz is common. Hornblende (5%) occurs as subautomorphic

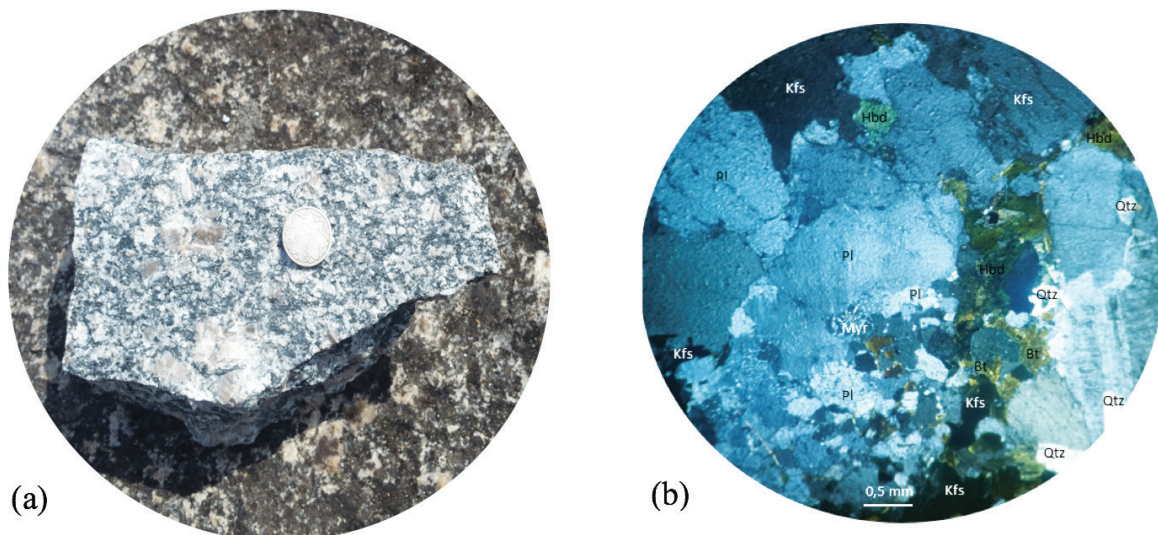


Fig. 6: Photograph and photomicrograph of biotite and amphibole granite (a). Sample of biotite and amphibole granite. (b) Microstructure showing all the minerals of the rock. Bt: Biotite; Kfs: Potassic Feldspar; Myr: Myrmeckite; Pl: Plagioclase; Qtz: Quartz.

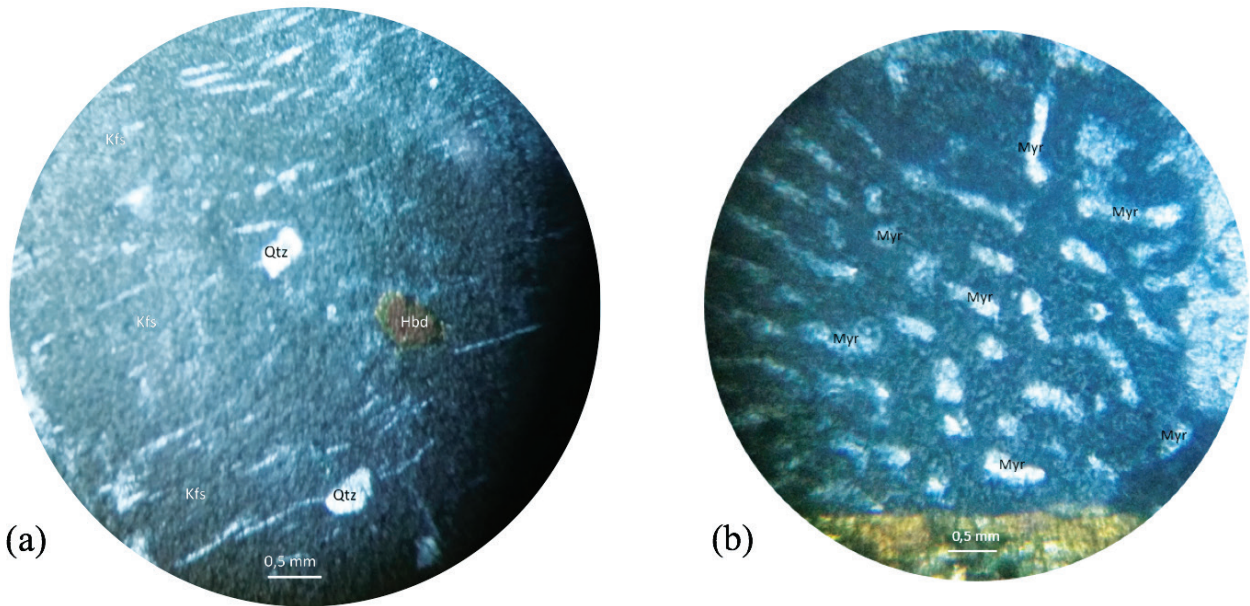


Fig. 7: Photomicrograph of biotite and amphibole granite (a) image showing perthite and inclusion of quartz and hornblende in the plagioclase (b) image showing Myrmekite texture. Hbd: Hornblende; Myr: Myrmekite; Qtz: Quartz.

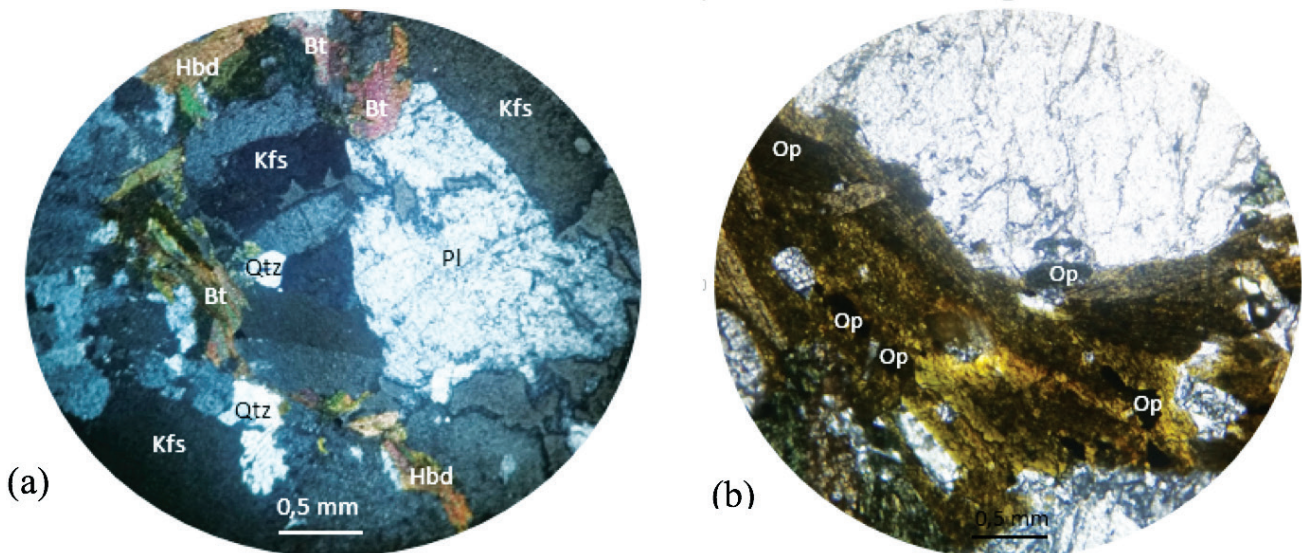


Fig. 8: Photomicrograph of biotite and amphibole granite (a) image showing the mineralogical association Pl + Kfs + Qtz + Bt. (b) Image showing inclusions of opaque minerals in the amphibole. Bt: biotite; Hbd: Hornblende; Kfs: Potassic Felspar; Op: opaque; Pl: Plagioclase; Qtz: Quartz.

to automorphic crystals up to 1.25 x 0.75 mm in size. Some feldspar crystals have inclusions of opaque minerals and others are included in plagioclase crystals. Opaque minerals (<3%) are in the form of smaller automorphic crystals included in other minerals (biotite, plagioclase) or dispersed in the matrix. Zircon (<2%), in automorphic crystals with a radioactive halo, is generally found in inclusion in biotite lamellae. Since the rock is a granodiorite, it is characterized by the following mineral association: Pl + Kfs + Qtz + Bt (Fig. 8e).

Contribution of the geotechnical study

Table 3 presents the results of physical and mechanical characterization of the samples taken from the granite massifs. The bulk density test carried out on two granular classes (6/10 mm; 10/14 mm) of four samples taken shows that the bulk density of the different samples varies between 1.42 and 1.49 as shown in Fig. 9a.

The results of the specific weight achieved on two granular classes (6/10 mm; 10/14 mm) of the four

Table 3: Geotechnical analysis results.

Samples	Granular class (mm)	Apparent density (g/cm ³)	Specific weight (kN/m ³)	Coefficient LA (%)	Coefficient MD (%)	Coefficient FD (%)
ZP01	6/10	1.42	2.61	31.5	9	20
	10/14	1.46	2.62	24.7	8	21
ZP02	6/10	1.47	2.67	43.0	35	30
	10/14	1.49	2.64	46.3	38	29
ZP03	6/10	1.42	2.67	30	7	21
	10/14	1.45	2.77	33	8	19
ZP04	6/10	1.43	3.00	28	7	18
	10/14	1.43	2.72	30	7	19

samples shows that the value of the specific weight of the samples varies between 3.00 kg / m³ and 2.61 kg / m³ as shown in Fig. 9b.

Regarding the mechanical parameters, the results of the Los-Angeles test on granular classes 6/10 mm and 10/14 mm have a variation of the coefficient from 24.7% to 46.3% as shown in Fig. 10. The results of the Micro-Deval test carried out in the two granular classes 6/10 mm and 10/14 mm with a test sample mass of 5000 g vary from 7% to 38% (Fig. 10a). The results of the dynamic fragmentation test of the rock presents the coefficients that are 20%, 30%, 21%, and 18% respectively. The coefficient is obtained

according to the granular class 10/14 and with a test setting mass of 350 g. We noticed a slight variation between the different massifs (20%, 30%, 21%, and 18%). Three quarters of the massifs studied present an almost identical resistance to fragmentation as shown in the diagram in Fig. 10b.

The results of the geotechnical tests obtained on these rock samples are interpreted based on the guide for evaluating the quality and durability of the materials is presented in Table 4.

According to the evaluation guide of a materials quality and durability, think that apart from the Gbago

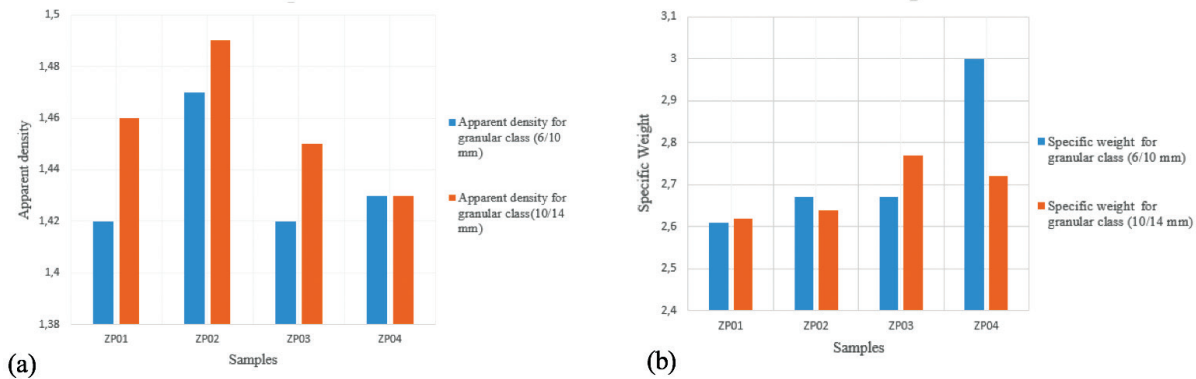


Fig. 9: Histogram of the physical tests. (a) Apparent density; (b) Specific gravity.

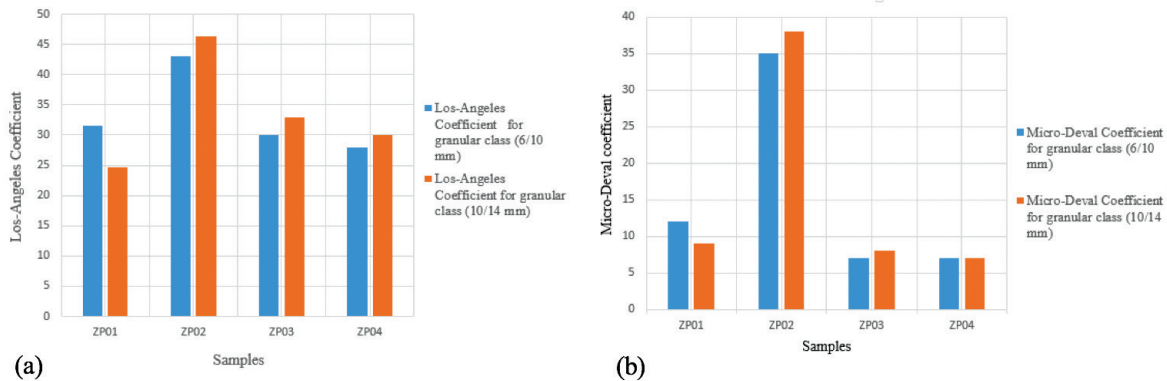


Fig. 10: Histogram of mechanical tests (a) Los Angeles coefficient (b) Micro-Deval Coefficient.

Table 4: Guide for evaluating the quality and durability of materials.

Criteria	Standard	Excellent	Satisfactory	Limited	Poor
Los Angeles test (%)	EN 1097-2	<15	15-25	25-35	>35
Specific weight test	EN 13383-2	>2,7	2.5-2.7	2.3-2.5	<2,3
Micro-Deval test (%)	EN 1097-1	<10	10-20	20-30	>30

massif (ZP02), which presents mediocre resistance, the other three massifs have limited resistance (Table 4). However, resistance to the abrasion slightly varies depending on the grain size variation and the cohesion between the grains. A rock made up of quartz or fine- to medium-grained minerals have good resistance as compared to those made up of coarse-grained minerals. Therefore, the lower the resistance to fragmentation, better the material is. A granite material with a Los-Angeles coefficient > 35% is not usable in road construction. Therefore, beside the ZP02 massive, the remaining three other massifs can be used in site construction and in the formulation of concrete and mortars. Nevertheless, the granular classes 10/14 and 6/10 can be recommended for the construction of traffic road T4-T5 because their value are less than 30.

It should be noted that the resistance of a rock is linked to its mineralogical composition and degree of weathering. A rock that is made up of ferromagnesian or weathered minerals generally gives poor results to mechanical resistance because there is inadequate cohesion between the grains. However, the lower the abrasion resistance, the more the material becomes excellent. After comparing our results to those in table 4, we can therefore say that the three massifs (ZP01, ZP03 and ZP04) could be suitable for the construction of roads, for the manufacturing of aggregates for asphalt concrete, ground concrete for pavement and aggregates for surface coatings; while the ZP02 massif presents a poor mechanical characteristic. As specified in the technical specifications, the base layer aggregates of asphalt must have an MDE<12 (Atlan, 1978).

Regarding the results obtained for dynamic fragmentation, the three massifs (ZP01, ZP03 and ZP04) have good characteristics as compared to the ZP02 massif. When the coefficient is less than 25%, the material is usable in railway construction. On the contrary, if the coefficient is greater than 25% the material cannot be used in road construction, particularly in the implementation of different layers and especially the base layer. But, the material can be crushed and used as aggregates (gravel in the formulation of concrete). The smaller the coefficient, the more resistant the rock is. Rocks containing quartz as binding materials are more resistant followed by those that contain calcite or ferruginous minerals.

Rocks that content clay are less resistant. Generally, resistance increases with the percentage of quartz (Atlan, 1978). The French geotechnical standard indicates that the Bahkosso, Na'abissa and Kaparang are good for railway construction while the ZP02 massif is not good for rail road construction, but either good for making concrete.

DISCUSSION

Our petrographic study indicates that the granodiorite formations in the study area and the different massifs of the Beka-Gotto locality share a similar source. The rocks from this magmatic group emerge in the form of balls, blocks, slabs and domes. At the outcrop, the rock is light gray in color. They are generally made of plagioclase, potassium feldspar, biotite and quartz and accessory minerals (zircon and opaque minerals). The mineralogical composition and grain size of the rocks studied play an important role in their resistance. Thus, petrography results will be valuable in the selection of resistant material for construction purposes. The geotechnical tests show that the granodiorite can be used in construction. Based on the results of physio-mechanical tests obtained, the granodioritic massif has remarkable resistance. On the base values of resistance to abrasion and fragmentation, the granodiorite can be characterized for road construction and in the formulation of concrete.

The results of the mechanical characteristics of aggregates do not agree with the work of Al-Hadj H. Z. (2014) that focused on the geotechnical characterization granites in the Ouaddai region in eastern Chad. On the petrographic level, it obtains two types of granite: biotite granite, granite consisting fine- to medium-grained quartz, orthoclase, plagioclase biotite, and biotite granite and amphibole, medium- to coarse-grained, consisting of quartz, orthoclase, plagioclase, biotite, amphibole and opaque minerals. On the other hand, in the Beka-Gotto locality we found only one magmatic set: granodiorite that does not have the same mineralogical compositions than the biotite and amphibole granite observed in the Ouaddai region. From a geotechnical point of view, the LA coefficient of the four biotite and amphibole granites samples in the Ouaddai region of class 10/14 are respectively 33%, 33%, 30%, and 29%. These show that the results are clearly satisfactory to that obtained at the level of the Beka-Gotto granodioritic

massif, with LA coefficient values over the four samples 24%, 46%, 33%, and 30%, respectively. The Micro-Deval value of 7%, 8%, 7%, and 7%, are significantly lower than that obtained value at the Beka-Gotto granodioritic massif which are 9%, 38%, 8%, and 7%. And finally the biotite and amphibole granite of the Ouaddai region presents the values of dynamic fragmentation coefficient (21%, 20%, 20%, and 15%) that is clearly lower than that obtained at the level of the granodioritic massif of Beka-Gotto (20%, 30%, 21%, and 18%).

The biotite and amphibole granite obtained in the Ouaddai region overall present better characteristics than the granodioritic of Beka-Gotto, which represents satisfactory characteristics on three quarters of all of its massifs. We think this could be a result of moderate alteration in some parts of the Beka-Gotto massifs. Youogo (2018) carried out the petrographic and geotechnical characterization of Foto-Menouet, which shows that there is a plutonic formation made up of microgranites, porphyroid granites, syenogranites and aplitic granites. While, at the level of the Beka-Gotto massifs there is a magmatic set made up of only granodiorite. From a geotechnical point of view, the materials from the Foto-Menouet deposit show a LA coefficient of 24.7 on the class 10/14, and a Micro-Deval of 9.06, a specific weight of 2600 kg/m³ and an apparent density of 1.39g/cm³. Hence, it can be seen that the results of the various geotechnical tests carried out by Youogo (2018) are practically identical to the results obtained at the granite massif of Beka-Gotto region.

CONCLUSIONS

Examination of the results shows a great homogeneity of the substratum and it highlights that the granites from the Beka-Gotto massif have excellent characteristics. However, some small irregularities were noticed in the Gbago massif (ZP02). This could be explained by the mineralogical composition, grain size, and rock fracturing, which play a significant role on the quality of the material and the weathering of the rock. In accordance with geotechnical standards, the rocky massif of Beka-Gotto has good quality and usable for civil engineering works (manufacture of any crushing aggregates for asphalt concrete, ground concrete for pavement and aggregates for surface plasters).

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AUTHOR'S CONTRIBUTIONS

A. Aboubakar and B. I. Manefouet proposed the current research, which is part of the Master thesis research work of the first author. A. Aboubakar, L. S. Komguep, E. T. Talom and Y. L. Djonthu conducted field work and sampling. A. Aboubakar, E. T. Talom, C. R. Foueze and Y. L. Djonthu wrote the paper and prepared the figures following acquiesced data. A. Aboubakar, B. I. Manefouet, L. S. Komguep contributed the work with observations and comments in analyzing data and interpretation. All the authors discussed, reviewed, and finalized the paper.

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