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Physical and Mechanical Features of the Quaternary Basanites of the Cap-Vert Peninsula of Dakar (Senegal, West Africa)

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Abstract

This work presents the results of geotechnical tests carried out in the laboratory on specimens of Quaternary olivine basanites from the Cap-Vert peninsula of Dakar. The samples were taken following geotechnical investigations in the Fann-PE, Mermoz-Ouakam, Yoff and Ngor areas respectively. The results obtained show a dry density between 20.45 and 29.30 kN/m^3 which corresponds to medium to high density basanites. The porosity varies between 0.33% and 4.20%. For microlitic basanites, the porosity remains low, on the other hand, for micrograined basanites; a slight increase in porosity is noticed. As for the methylene blue adsorption test value measured, it is between 0.25 and 1.10. The uniaxial compression strength (Rc) and Young's modulus (E) vary respectively from 12.19 MPa to 41.748 MPa and from 1477.6 MPa to 7699.1 MPa. The low strength values are recorded in altered and vesicular basanites. Also, a correlation was made between uniaxial compression strength and porosity and showed a gradual decrease in strength with increasing porosity.

Keywords

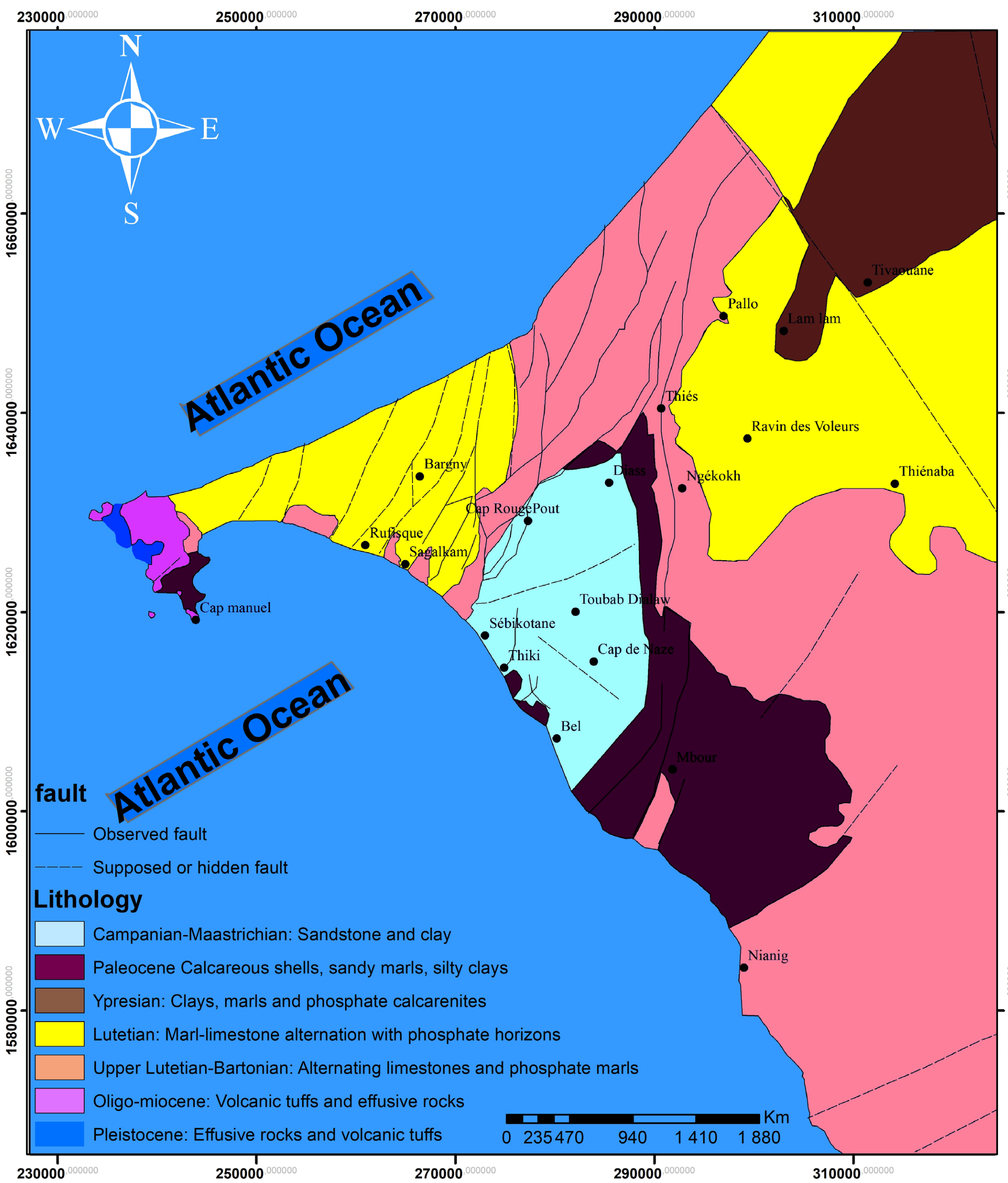
Quaternary Basanites, Cap-Vert Peninsula of Dakar, Uniaxial Compression Strength, Young Modulus, Porosity, Dry Density, The Methylene Blue Test

1. Introduction

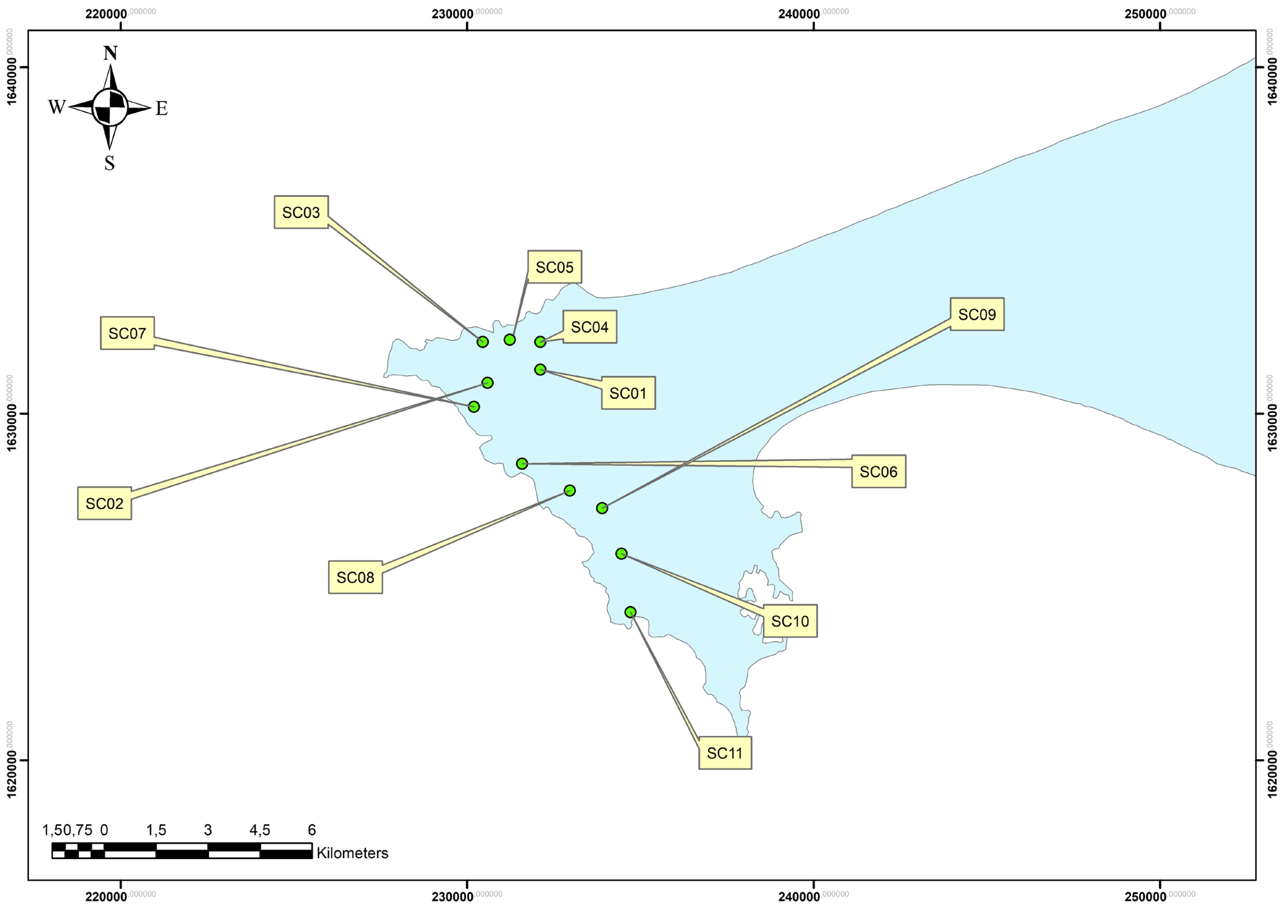
The western end of West Africa was, at the end of the Tertiary and the beginning of the Quaternary, the scene of an important basaltic volcanism [1]. This part of Senegal has a wide variety of rock combinations (tuffs, dolerites, basanites and basalts) of different nature, petrographic, mineralogical, physical and mechanical characteristics. The Tertiary and Quaternary volcanic formations of the Cap-Vert peninsula have been the subject of previous researches that have identified, mapped and helped to understand their modes of emplacement [1]-[6]. However, there are fewer geomechanical characterization studies on the area. The Dakar region is located in the Cap-Vert peninsula and covers an area of 550 km^2, or 0.28% of the national territory. It is located between 17˚10 and 17˚32 west longitude and 14˚53 and 14˚35 north latitude. It is a region that is bounded on the east by Thiès and by the Atlantic Ocean in its northern, western and southern parts [7]. The developing city of Dakar, capital of Senegal has experienced a construction and infrastructure boom over the last two decades. The basanites are used both as building materials and as foundation support. Volcanic boulders are considered as one of the facies corresponding to the shallow geotechnical components in some municipalities of Dakar. This situation presents many challenges in the construction process as recognized by geotechnicians working in this area. These volcanic facies must meet specific criteria of properties and characteristics to be used as foundation material. The behavior of any civil engineering structure depends largely on the strength and deformation properties of the geo-materials. Sarr *et al.* (2020) [8] set the basis for the study of the behavior of foundations on these basanites and other rocks through a geomechanical study in the western part of the Cap-Vert peninsula. It is important, whatever the geomechanical use that one wants to make of them, to know the geotechnical parameters of the facies in place. This geotechnical knowledge will be achieved by determining the physical, mineralogical and mechanical properties of basanites. **Figure 1(b)** below shows the location of the sampling points after a core drilling campaign. All these samples were packaged, labelled and sent to the laboratory for analysis. This article presents the results of the study on the mineralogical, physical and mechanical characterization of Quaternary basanites from the Cap-Vert peninsula of Dakar, Senegal.

2. Geographic and Geological Framework

The study area is located in the Dakar region, specifically at the tip of the Cap-Vert peninsula. The Cap-Vert peninsula constitutes the western end of the Senegalese-Mauritanian coastal basin located on the western of the West African craton. The climate is a Sudano-sahelian type, with an alternating rainy season (from July to October) and a relatively cool, windy dry season (from November to June). Its temperature varies within 17˚C - 25˚C from December to April and 27˚C - 30˚C from May to November [7]. From a geomorphological point of view, the Cap-Vert peninsula is characterized by a West-east profile of two domes framing a depression. The head of the Cap-Vert peninsula (Dakar region) is dominated by two hills, the largest of which reaches 105 m, and the Horst de Diass, which forms a slightly accentuated relief of about 100 m in altitude and plunges northward toward Kayar. United by a depressed area, the Gabren of Rufisque of low altitude (20 to 30 m) [6]. Inside the peninsula, the relatively flat relief is formed by clayey sands and sand dunes or the volcanic plateau upon which, a part of the city of Dakar is built; making it difficult to access the volcanic formations. The geological history of the study area is integrated into the overall geology of the Cap-Vert peninsula, which was the site of Tertiary and Quaternary volcanism (**Figure 1(a)**). Tertiary volcanic formations are scattered throughout the Cap-Vert peninsula and the Thiès region, while Quaternary formations are confined to the tip of the Cap-Vert peninsula [4] [5] [6]. Three successive volcanic units are interbedded in the sands, from bottom to top:



(a)



(b)

Figure 1. Illustrative maps of the study area ((a) Geological map according to Roger *et al.* (2009) [9] modified; (b) Location of core holes).

- A lower volcanic unit consisting of tuffs and highly altered lavas;
- A middle volcanic set/unit, located in the median part of the sands. It is represented by flows of dolerite and basaltic;
- An upper volcanic set to which our study refers is located at the top of the sands. It corresponds to the Mamelles volcano and to the flows which came from it.

3. Materials and Laboratory Tests

Laboratory tests such as physical and mechanical properties tests require good quality sample. The basanites tested are either altered, vesicular or sound from Quaternary volcanism.

Cylindrical samples of 80 mm and of the same height were prepared for petrographic analysis, porosity, dry density, methylene blue value and a slenderness of 2 for simple compressive strength according to the recommendations of the International Society of Rock Mechanics (I.S.R.M.). The thin plates sections are made in the laboratory of the Institute of Earth Sciences (IST) of Cheikh Anta Diop University of Dakar with several instruments dedicated to cutting, polishing and manufacturing. The process of realization of the thin plates, as follows:

- Cutting of the rock with a chainsaw equipped with a diamond saw
- Preparation of the glass slide by roughening one side of the slide and then labelling the slide
- Polishing of the pseudo-planar face of the sample to obtain a flat surface
- Drying of the sample on the hot plate
- Preparation of the resin to glue the piece of rock
- Put the resin on the glass slide then carefully place it on the sample to avoid bubbles and let it rest for at least 24 hours so that the glue set
- Cutting the basanite sugar to obtain a slide with a thickness lower than 100 µm
- Thinning of the slide by polishing with silicon carbide powder.

The dry weight of the rock was obtained by direct measurements of the volume and weight of the samples after drying in an oven at 105˚C for 12 hours to the guidelines of the NF P94 064 standard.

$$\gamma = \frac{w}{v} \quad (1)$$

With

γ: Density (kN/m^3)

W: Weight of dry material (kN)

V: Volume of the sample (m^3)

The porosity was measured by the dry density and saturation method [3] [10]. The principle of this technique is to first weigh the sample; then dry it in the oven and finally soak it. It is then weighed when all voids are filled with water (by water saturation for 72 hours in a water bath set at 20˚C (**Figure 2(b)**). After saturation, the samples are quickly wiped with a clean cloth and weighed again.

$$n = 100 \times \frac{m_w - m_s}{m_s} \quad (2)$$

With

n: porosity (%)

m_s: mass of dry material (Kg)

m_w: mass of the saturated sample (Kg)

The methylene blue value is determined according to the guidelines of the NF P94 068 standard. It is used to quantify the state of alteration of the rocks made at the end of the petrographic study. The test consists in measuring by dosage the quantity of methylene blue which can be adsorbed by the material in suspension in water. This quantity is related by direct proportionality to the 0/5 mm fraction of the fine material. The test sample is 60 g and is introduced into a 100 ml solution of blue solution. The suspension of the material is subjected to a permanent agitation of 400 revolutions per minute. The rest of the test consists of injecting 5 ml of methylene blue and gradually testing the stain on the filter paper. The stain thus formed is composed of a central deposit of dark blue

(a) (b) (c) (d)

Figure 2. Different methodological phases ((a) dry density measurement, (b) marine bath for saturation, (c) methylene blue value measurement device, (d) cylindrical rock samples for simple compression).

colored material surrounded by a colorless wet zone. Proceed with successive injections in steps of 5 ml to 10 ml (depending on the blue solution) until a light blue peripheral halo appears. The test is then said to be positive from that moment on. The execution of the blue test is fast and does not require expensive specific equipment (**Figure 2(c)**). The methylene blue value VB is determined by the following relation:

$$VB = \frac{B}{m_0} \times 100 \quad B = V \times 0.01 \tag{3}$$

With

m_0: mass of dry basanite

B: mass of blue introduced (10 g/l solution)

V: volume of blue introduced

VB: is expressed in grams of blue for 100 g of dry material

In addition to the identification tests, the simple compressive strength and the Young's modulus are determined according to the NF P 94 420 standard. The experimental device used is a 1500 kN press from TECNOTEST. The monitoring of the deformation during the test is carried out with the help of a displacement sensor equipped with a manometer of allowing to measure the axial displacement in the central third of the specimen.

$$R_C = \frac{F}{A} \tag{4}$$

With

F: is the value of the applied force

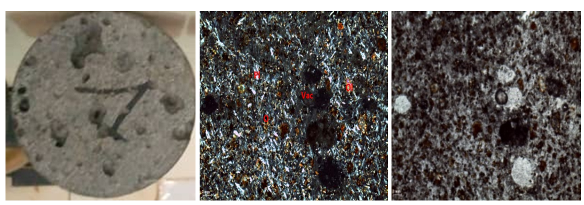
A: is the section of the rock specimen

4. Results and Discussions

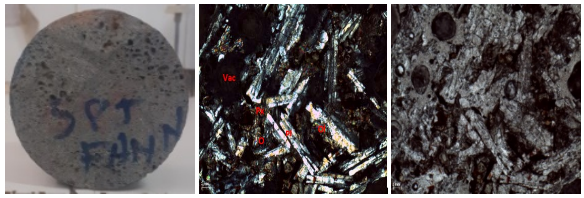
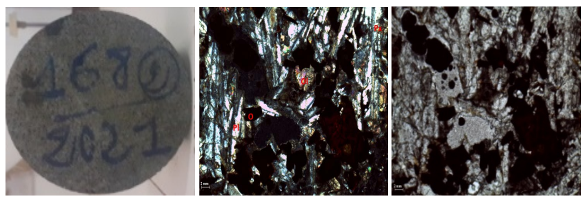
4.1. Microscopic Analysis

Thin section images revealed the presence of microstructures in the sampled basanites. Table 1 shows the mineralogical and petrographic characters of selected basanite specimens.

Table 1. Mineralogical and petrographic analysis of basanites.

Sites	Characterization	Minerals/ microstructures	Samples
Vesicular basanite **Mermoz-sacré cœur**	Healthy and little altered basanite with microlitic porphyry texture composed of plagioclase, olivine and pyroxene. Plagioclases are in microlites and phenocrysts embedded in a mesostasis. The olivines, less abundant than the plagioclases, are in the form of phenocrysts and microcrysts generally enclosed by plagioclase microlites and surrounded by a crown of iddingsite synonymous with alteration. Pyroxenes are in the form of very small crystals between the plagioclase microlites. The rock also contains opaque minerals with a vesicular aspect.	Plagioclases+++++ Olivine+++ Pyroxenes++ Opaque minerals+ -vacuoles -microfractures	 **Polarized light** **Natural light** Olivine (Ol)-Plagioclase (Pl)-Opaque minerals (O)-Vacuole (Vac)

Continued

Vesicular altered basanite **Fann-PE**	Healthy basanite with microlithic to porphyritic texture. The plagioclases are colorless in natural light but with vivid staining in polarized light. They occur in large laths and show well visible polysynthetic macles. The plagioclase crystals show the beginning of a detectable alteration. The olivines are in the form of iddingsitised phenocrysts. Pyroxenes of clinopyroxene type are of variable size. The rock contains opaque minerals with a vacuolar aspect.	Plagioclases+++++ Olivine+++ Pyroxenes++ Opaque minerals + -vacuoles -microfractures	 **Polarized light** **Natural light** Olivine(Ol)-Plagioclase(Pl)-Pyroxene(Px)-Opaque minerals (O)-Vacuole (Vac)
Healthy basanite **Ngor**	Basanite has a porphyritic texture. Plagioclase occurs as large laths with prominent polysynthetic macles. The olivines are in the form of phenocrysts and microcrysts surrounded by a crown of iddingsite synonymous with alteration. The phenocrysts show cracks that are sources of fluid passage. These fluids are at the alteration of the mineral. Pyroxenes are of variable size and are caught between the plagioclase laths. The rock also contains opaque minerals	Plagioclases+++++ Olivine+++ Pyroxenes++ Opaque minerals+ -macles -microfractures	 **Polarized light** **Natural light** Olivine (Ol)-Plagioclase (Pl)-Pyroxene (Px)-Opaque minerals (O)-Vacuole (Vac)
Healthy basanite **Ouakam-mamelles**	Poorly altered basanite with a porphyritic texture. Plagioclase is very present in large laths and shows well visible polysynthetic macles. Iddingsitized olivine is present as phenocrysts and microcrysts. The rock also contains opaque minerals and micrometric to millimetric vacuoles.	Plagioclases++++ Olivine++ Pyroxenes+ Opaque minerals -macles -microfractures -vacuoles	 **Polarized light** **Natural light** Olivine (Ol)-Plagioclase (Pl)-Pyroxene (Px)-Opaque minerals (O)-Vacuole (Vac)

4.2. Results of Physical and Mechanical Tests

The results of the samples tested during the various laboratory tests are listed in Table 2. These are the intact basanites recovered from the drill core. The mineralogical composition shows the presence of plagioclase, olivine and pyroxene.

Table 2. Physical and mechanical parameters.

Boreholes	N° Sampling	Physical parameters			Mechanical parameters		Nature of the rock
		Dry weight (kN/m³)	Methylene blue value (g/100 sol)	Porosity n (%)	Compressive strength RC (MPa)	Modulus of deformation E (MPa)	
SC01 Ngor-Almadies	ECH01	25.33	0.33	0.33	40	2586.7	Healthy basanite
	ECH02	20.50	0.66	1.50	18	2283.1	Vesicular basanite
SC02 Ngor-Almadies	ECH03	22.42	0.70	0.85	16	1803.4	Vesicular altered basanite
	ECH04	23.80	0.83	0.9	28	2632.3	Healthy basanite with few vesicles
SC03 Ngor-virage	ECH05	29.30	0.66	0.36	27	7699.1	Healthy vesicular basanite
	ECH06	24.05	1.0	4.20	18	1777.9	Vesicular altered basanite
SC04 Yoff-Aéroport	ECH07	23.40	0.50	1.08	23.83	-	Healthy basanite
	ECH08	20.45	0.33	1.46	17.59	-	Vesicular basanite
SC05 Yoff-Almadies	ECH09	25.85	0.32	0.82	32.88	-	Healthy vesicular basanite
	ECH010	26.15	0.30	0.67	41.748	-	Healthy basanite
SC06 Ouakam-mamelles	ECH11	25.78	0.33	0.48	38	2999.8	Healthy basanite
	ECH12	22.80	0.66	1.36	28	3261.2	Vesicular basanite
SC07 Ouakam-mamelles	ECH13	23.89	0.25	2.79	12.19	-	Very vesicular basanite
	ECH14	24.42	1	1.0	15.58	-	Vesicular basanite
SC08 Mermoz-ouakam	ECH15	23.34	0.89	1.46	24.27	-	Low vesicular basanite
	ECH16	23.65	0.53	2.05	25	2934.8	Low vesicular basanite
SC09 Mermoz-sacré cœur	ECH17	24.30	0.66	0.56	22.32	-	Low vesicular basanite
	ECH18	26.05	0.50	0.66	34.14	-	Healthy basanite
SC10 Hôpital de Fann	ECH19	22.86	0.75	0.63	34	3405.9	Healthy basanite
	ECH20	22.80	0.66	2.40	15	1477.6	Low vesicular basanite
SC11 UCAD, Soumbedioun	ECH21	25.16	0.48	0.50	30	3309.6	Healthy basanite
	ECH22	25.00	0.83	1.36	25	2971.5	Low vesicular basanite
	ECH23	22.15	1.10	1.02	16.15	-	Low vesicular basanite

We observed a process of olivine iddingsitization in all rocks encountered. Plagioclase and pyroxene are weakly altered. The alteration of the minerals leads to the degradation of the physico-mechanical characteristics of the basanites. The dry density is very variable according to the basanite facies and varies between 20.45 and 29.30 kN/m^3 which corresponds to low to high density basanites. Low densities are certainly observed in altered basanites. Indeed, mineralogical analyses revealed a proportion of altered olivine and plagioclase. The high densities are mostly found in the healthy basanites. The porosity of the basanites varies from very low to low, ranging from 0.33% to 4.20%. Microscopic analysis showed the presence of vacuole between the minerals which remains unconnected; this explains this low porosity despite the presence of vacuole. Basanites with a grainy texture or coarse aspect have larger porosities than other basanites. The results of uniaxial compression tests carried out on different basanite facies show a wide range of variation in mechanical characteristics (Young's modulus and uniaxial compression strength). Indeed, these parameters vary between 1477.6 MPa and 7699.1 MPa for the Young's modulus; and between 12.19 MPa and 41.748 MPa for the simple compressive strength. Healthy, low-vacancy basanites (**Figure 3(b)**, **Figure 3(e)**, **Figure 3(f)**, **Figure 3(g)**) have average simple compressive strengths. This compressive strength decreases for altered, microlitic or micrograined texture basanites with high vacuoles (**Figure 3(a)**, **Figure 3(c)**, **Figure 3(d)**, **Figure 3(h)**). The analysis of the different experimental curves (**Figures 4(a)-(c)**) show that porous to very porous and sometimes altered basanites present a linear phase of axial deformations at the beginning of loading. These curves are characterized by brittle behavior attributes. Due to the presence of vesicles and alteration of the rock, the mineral grains constituting the rock are not welded together leaving a certain volume of voids between them. The healthy basanites and little porous presents a small phase of tightening, we have a beginning of nonlinear phase or partially, represented by a light concavity. These curves are characterized by attributes of ductile behavior. This phase corresponds in fact to a reorganization of the constituents of the rock. For higher stress levels, a certain linearity between the axial deformation and the stress can be noticed. At the beginning of this second phase, the compactness of the rock is maximum, induced by the reduction of voids, pores and micro-cracks during the previous phase.

5. Relationship between Porosity and Simple Compressive Strength

Several authors have carried out tests [11] [12] [13] on the influence of porosity on the physical and mechanical parameters of geometries. We have conducted similar studies between porosity and strength on about twenty basanite samples. The results were analyzed for healthy basanites, with an absence of vesicles (low porosity basanite) or with a low percentage of pores, and on basanites with vesicles (very porous to porous basanite).

Figure 5(a) and Figure 5(b) show that the compressive strength decreases with the porosity of the rock. The correlation coefficient is 0.5644 which corresponds to an average correlation for basanites with few or no vesicles. We notice a gradual decrease in simple compressive strength with increasing porosity. In the case of the vesicular basalts, with an alteration, one notices a big dispersion. The correlation coefficient is 0.2423 which corresponds to a weak correlation. This dispersion of results with a poor correlation between these two parameters is related to the neoformation of clays that come to fill part of the voids. They decrease consequently the porosity.

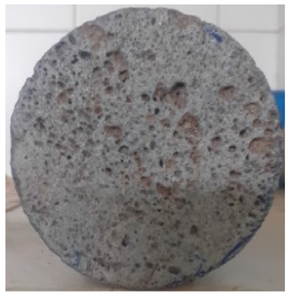
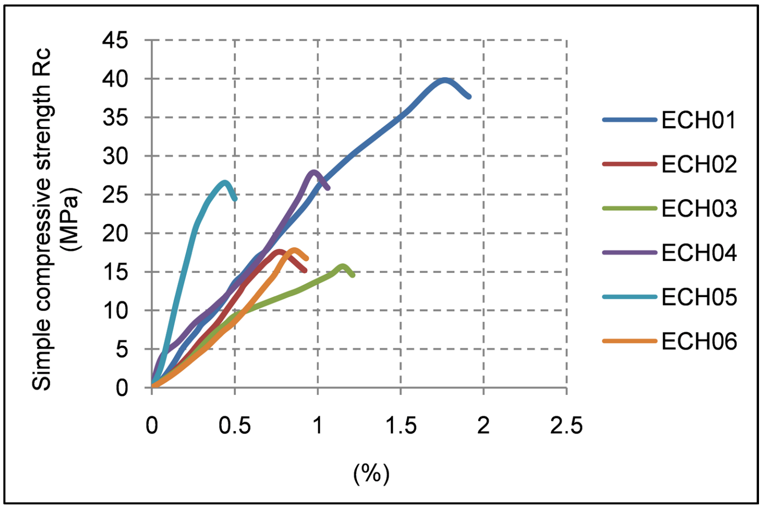
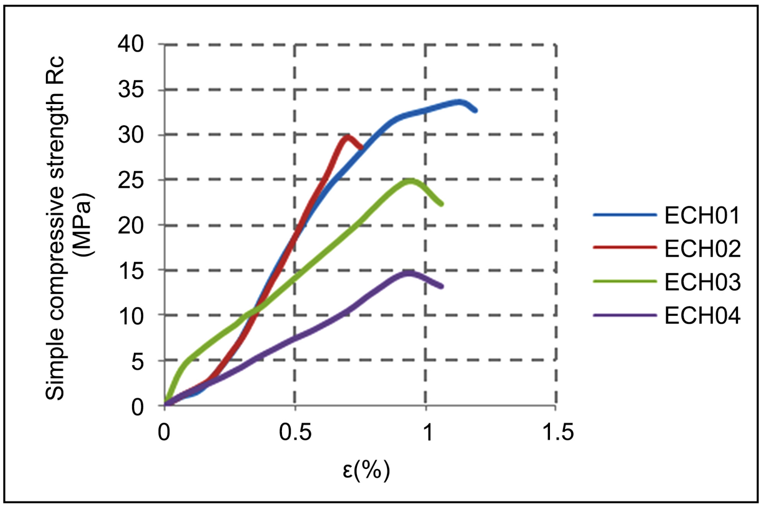
 (a) Altered basanite with presence of vacuoles. Porosity n(%): 2.79 VB: 0.96 RC: 13.50 MPa	 (b) Healthy basanite with a grainy texture without vacuoles. Porosity n(%): 1.08 VB: 0.50 RC: 28.0 MPa	 (c) Altered basanite with strong presence of vacuoles. Porosity n(%): 1.50 VB: 0.66 RC: 18.0 MPa	 (d) Very porous and altered vacuolarian basanite. Porosity n(%): 4.20 VB: 1.96
 (e) Healthy micrograined basanite without vacuole. Porosity n(%): 1.08 VB: 0.50 RC: 23.83 MPa	 (f) Healthy basanite with aphanitic texture and vacuoles. Porosity n(%): 0.66 VB: 1.10 RC: 34.14 MPa	 (g) Healthy aphanitic basanite with few vacuoles. Porosity n(%): 1.36 VB: 0.70 RC: 27.0 MPa	 (h) Basanite with micrograined microlitic texture with strong presence of vacuoles. Porosity n(%): 2.79 VB: 0.25 RC: 12.19 MPa

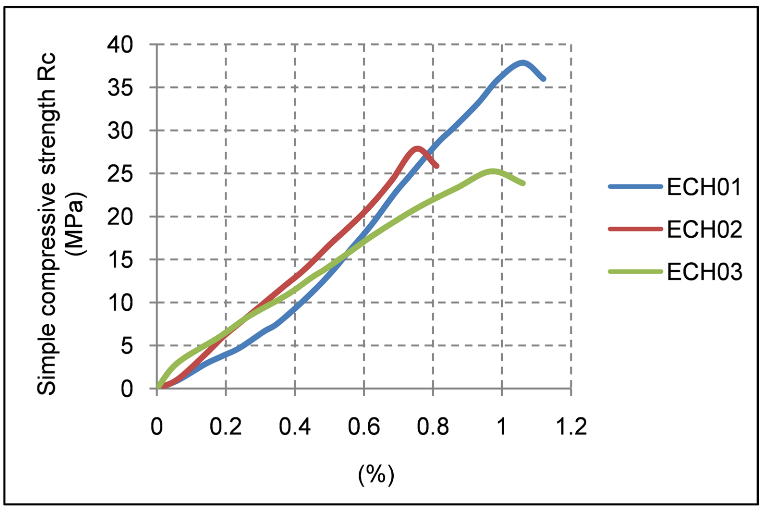
Figure 3. Influence of the petrographic character on the physical and mechanical parameters.



(a)

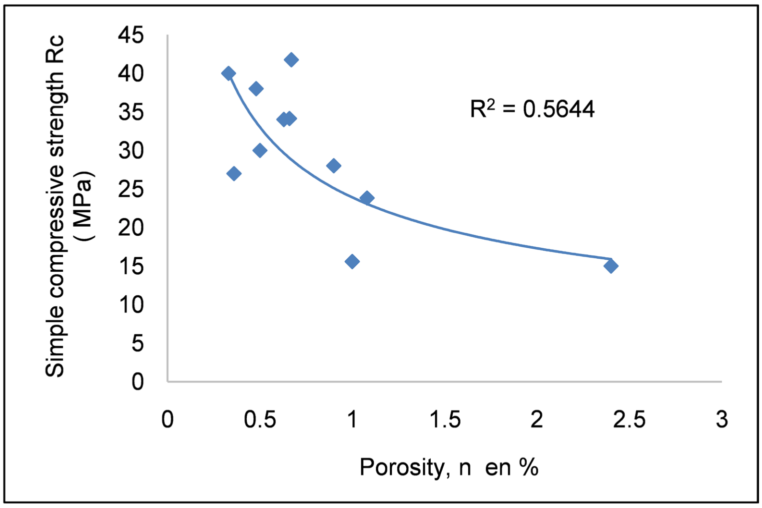


(b)

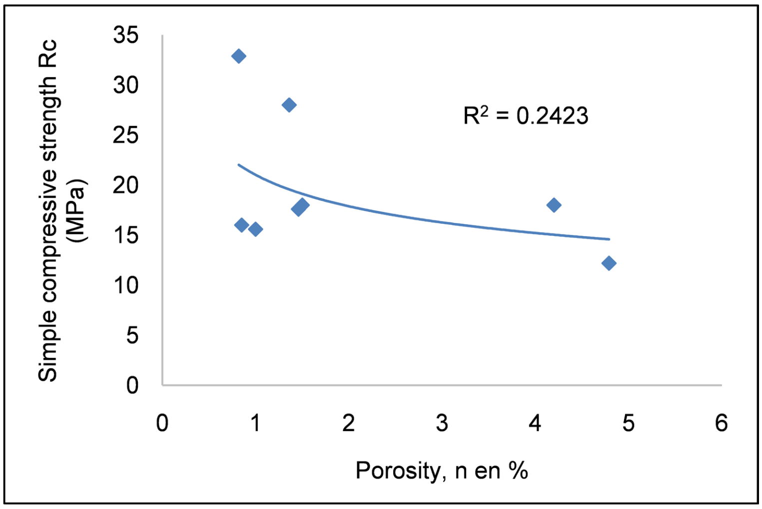


(c)

Figure 4. Stress-strain curve: (a) Ngor-Almadies-Ngor-virage, Yoff-Aeroport; (b) Fann-PE, (c) Ouakam-Mermoz.



(a)



(b)

Figure 5. Influence of porosity on simple compressive strength ((a) Healthy basanite and basanite with few vesicles; (b) Basanite with vesicles (porous) and weathered).

6. Conclusion

In this paper, the olivine basanites of the Cap-Vert peninsula of Dakar were geotechnically characterized. A series of physical (porosity, dry density and methylene blue value) and mechanical (uniaxial compressive strength and Young's modulus) measurements were performed. The physical studies showed that the porosity of the rock is variable according to its texture, its degree of alteration and the presence of vesicles. As for the mechanical results which concerned the determination of the resistance to compression and the module of elastic deformation (Young's modulus) on cylindrical specimens, these measurements revealed that the various series of basanites present a behavior of elastoplastic type. The simple compressive strengths show that the basanites are of low to medium quality. These results corroborate perfectly the structuring of the basanites of the study areas. Indeed, the results of the physical properties and the visual observations show that the altered basalts with vesicles (pores) lead to a low value of compressive strength and therefore affect the mechanical parameters. The analyses also show a decrease in compressive strength with porosity and alteration. This is related to the neoformation of the clay which gradually fills the voids.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

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