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Petrographic, Geochemical and Geotechnical Properties of Laterites from Two Quarries in the Diass Horst (Senegal, West Africa)

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Abstract

The aim of this study is to analyze the petrographic, geochemical and geotechnical properties of laterites to optimize their exploitation. A petrographic description was first carried out on the quarry faces of two sites located in the Diass horst. Five samples, taken according to the identified horizons, were collected and sent to the laboratory. Geochemical and geotechnical tests were performed. The results show that the face of Quarry 1 reveals horizon ST2 which corresponds to the crust. In Quarry 2, horizons ST1.1 (bedrock), ST1.2 (spotted horizon), ST1.3 (crust) and ST1.4 (a mixture of crust and spotted horizon) were identified. Geochemical tests indicate a predominance of iron oxide, confirming that these laterites are ferruginous. Geotechnical tests reveal exploitable potential in horizons ST1.4 and ST2, particularly ST1.4 as a base layer for low-traffic roads and ST2 as a foundation layer.

Keywords

Laterite, Diass Horst, Petrographic, Geotechnical, Geochemical, Base Layer, Foundation Layer

1. Introduction

Laterites are among the most widely used soils in civil engineering works, particularly in road construction across most countries within the intertropical zone [1]. Laterite is defined as any weathered material derived from silicate rocks, whether indurated or not, characterized by the predominance of iron and aluminum hydroxides [2]. For a long time, laterite has been the reference material in road construction. It offers the advantage of being widely available, outcropping throughout the African tropical zone and relatively easy to exploit [3]. Due to its geographic location in the intertropical zone, Senegal possesses several lateritic deposits. Laterites occur either as gravelly materials or as continuous or discontinuous blocks [4]. Ferruginization marked the end of the Continental Terminal attributed to the Saloum Formation in the local geology [5]. Ferruginous elements appear in three forms [6]:

- As conglomerates, more or less cemented by ferruginous binders. The rock may be compact or loose. The matrix consists of ferruginous sand, and the gravel formed by ferruginous pisoliths can reach 1 to 2 cm in diameter.
- As fluvial terraces: an upper terrace where elements are agglomerated by ferruginous cement. And a lower, loose terrace or gravel terrace where crust elements become less significant toward the eastern part of the country.
- As quartz, chert or jasper fragments crust debris has been reworked and deposited as spread layers resulting in material heterogeneity.

According to [1], the great diversity of chemical compounds in laterites makes their characterization challenging. Moreover, normative documents and technical guides used for pavement design in sub-Saharan Africa are often inadequate failing to account for the specific climatic and environmental conditions of lateritic formations in road projects. However, an interdisciplinary characterization of these soils considering the factors involved in the lateritization process would allow for more precise relevant, and representative property assessments [1].

It is also important to note that current specifications in Senegal focus primarily on geotechnical parameters rather than on the petrographic nature of the materials. Numerous studies by geologists and pedologists have shown the lithological dependence of laterites on the bedrock in West Africa. These claims, though sometimes controversial, remain too general and thus lack practical relevance for road construction engineers. Similarly, engineers working in this field often overlook the value of detailed analyses [1].

Several authors [7] and [8] have studied the influence of mineralogy on the geotechnical properties of laterites. They acknowledge that mineralogical constituents and microstructure govern and influence the geotechnical behavior of lateritic soils, particularly their cohesion and compressibility characteristics. Therefore, a better interdisciplinary understanding today represents a real advancement and facilitates the search for high-quality laterite. Nonetheless, a study analyzing petrographic properties in correlation with geotechnical and geochemical characteristics would be valuable for establishing large-scale correlations and improving the prospecting of quality laterite.

2. Material and Method

The lateritic materials used in this study were extracted from two clay quarries (Sites 01 and 02) dedicated to the production of fired earth bricks. At the quarry faces, various weathering profiles were examined ranging from the bedrock to the lateritic crust.

2.1. Presentation and Geographical Location of Quarries 01 and 02

The two quarries are located within the same perimeter with the following coordinates: Quarry 01 is situated at UTM Zone 28 North X = 278,518 and Y = 1,616,501. while Quarry 02 is located at UTM Zone 28 North X = 278,130 and Y = 1,616,658. These sites are in the Thiès region approximately 70 km from Dakar (**Figure 1**) both regions belong to the Senegal-Mauritanian sedimentary basin. This extensive basin covering 340,000 km^2 is a passive margin basin along the African Atlantic coast. It stretches over nearly 1400 km from Cap Barbas (Mauritania) to Cap Roxo (Guinea-Bissau) crossing Senegal and The Gambia. Its maximum width reaches 550 km at the latitude of Dakar and it covers three-quarters of Senegal's surface area.

The basin is bounded to the north by the Reguibat Ridge. to the south by the Bové Basin to the west by the Atlantic Ocean and to the east by the Mauritanides. The clayey nature of the outcropping rocks indicates that they were deposited during a period of marine transgression in a deep marine environment. The oldest outcropping formations in the Senegalese sedimentary basin are attributed to the Upper Cretaceous and are exposed in the Diass Horst where Quarries 01 and 02 are located (**Figure 2**). The Campanian stage is identified and attributed to the Paki Formation while the Maastrichtian corresponds to the Cap de Naze Formation. These two units are grouped under the Diass Group [5].

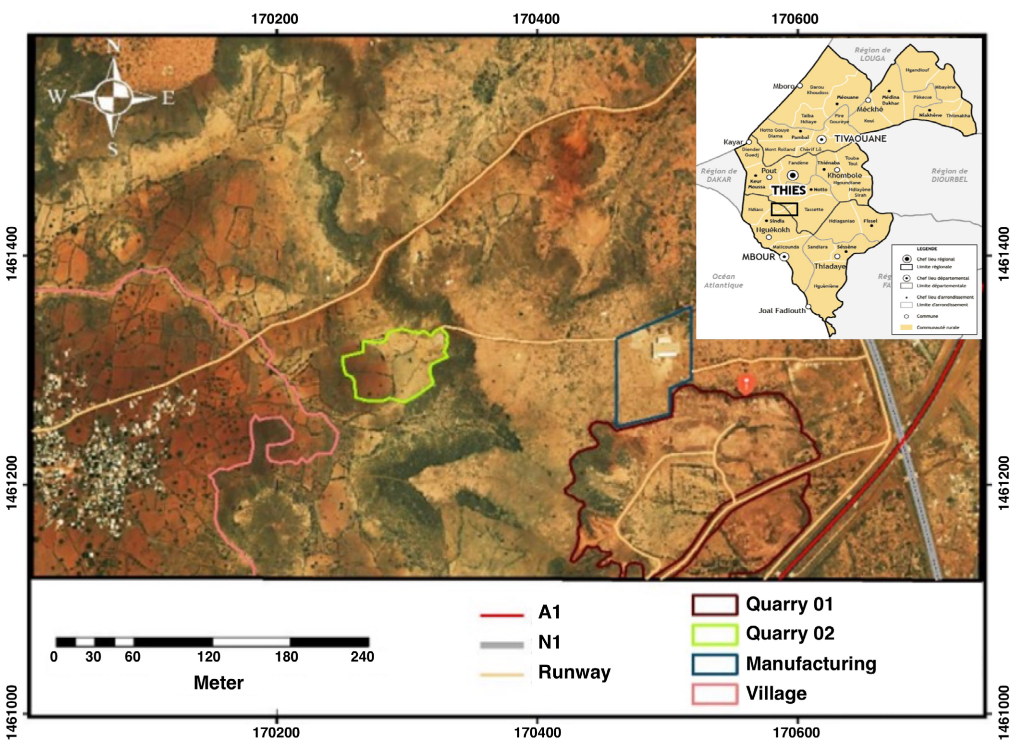


Figure 1. Location of the quarries within the study area.

At Quarry 01, a significant reserve of laterite was observed which has undergone geotechnical analysis confirming its high quality. It is important to note that this site is affected by volcanic activity which has influenced the material's properties. A weathering profile was examined at one of the quarry faces (Figure 2). The outcrops reveal a prominent lateritic crust approximately ten meters high extending over a large surface area. Other components of a typical lateritic profile are absent. From this profile, a sample labeled ST2 was collected from the crust layer.

At Quarry 02, Figure 3 illustrates the weathering profile observed at the quarry

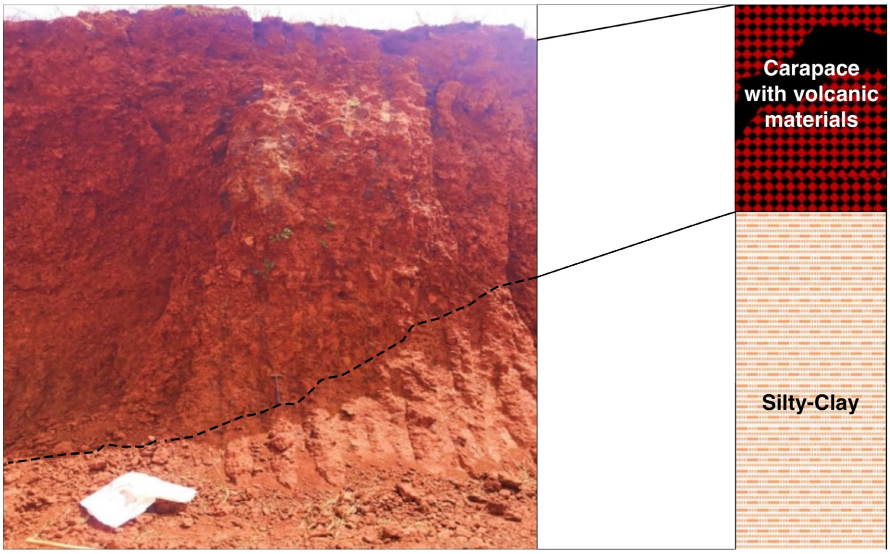


Figure 2. Lateritic crust exposure at Quarry 01 within the Diass Horst.

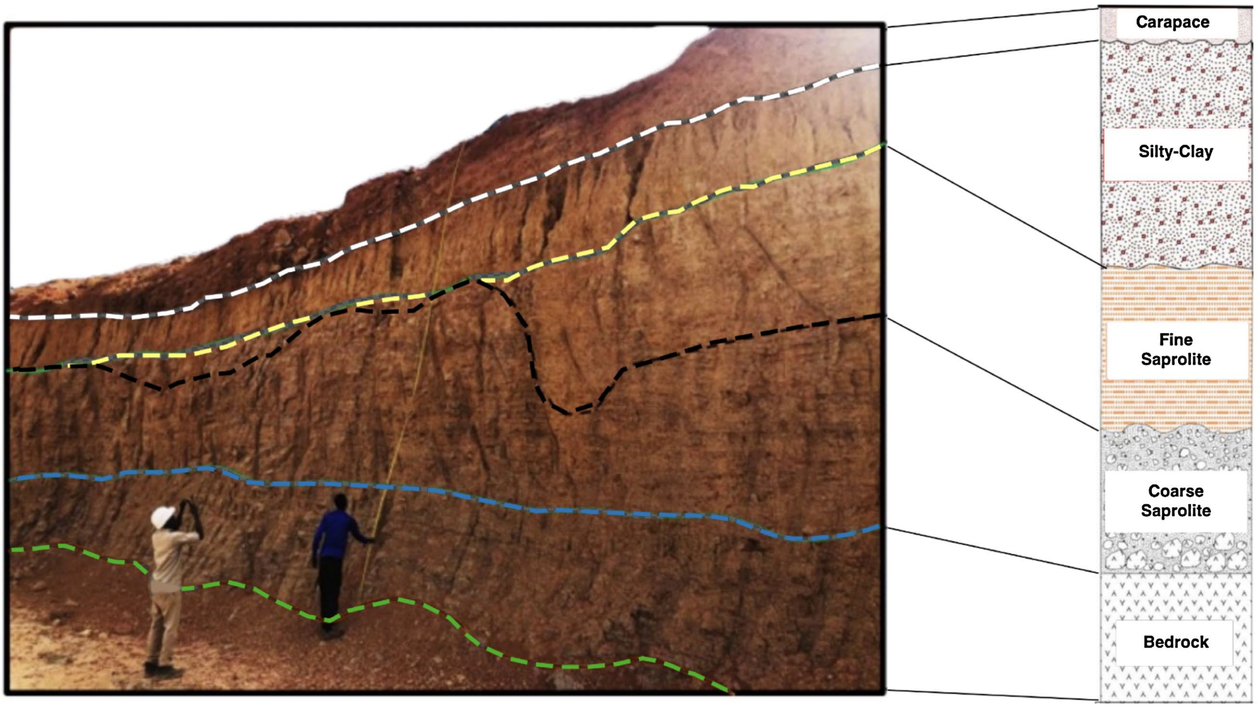


Figure 3. Vertical weathering profile from bedrock to lateritic crust at Quarry 02.

face extending from the bedrock to the lateritic crust. Four samples were collected from this profile: ST1.1 (bedrock), ST1.2 (spotted horizon), ST1.3 (crust) and ST1.4 (a mixture of crust and spotted horizon). It is important to note that, with a view to optimal exploitation, ST1.4 is sampled following mixing between the crust and the spotted horizon.

Samples were collected from these horizons and subjected to laboratory testing.

2.2. Sample Analysis Method

A total of five samples (ST1.1, ST1.2, ST1.3, ST1.4, and ST2) were collected from the two sites to perform geochemical and geotechnical tests aimed at better characterizing the intrinsic properties of the studied laterites in relation to their various stages of evolution.

Geochemical tests focused on determining the oxide composition of the samples. The geotechnical tests conducted included:

- Particle size distribution of the samples;
- Plasticity assessment through Atterberg limits;
- Specific gravity of solid particles;
- Compaction characteristics;
- California Bearing Ratio (CBR) index.

The analysis of these tests yielded the following results.

3. Results and Discussion

The geochemical tests produced the data shown in **Figure 4** which presents the

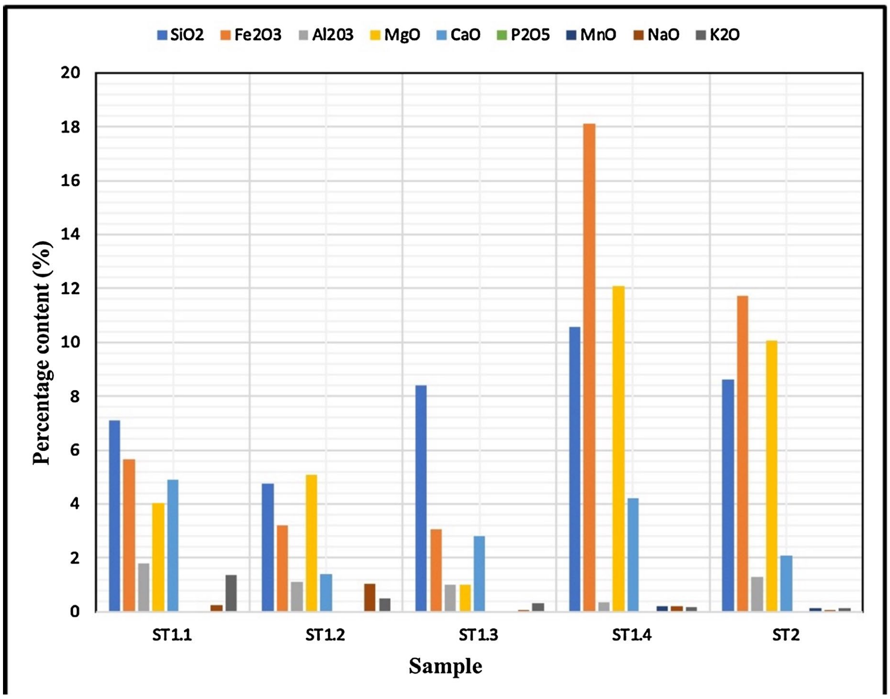


Figure 4. Geochemical composition and physico-chemical characteristics of laterite samples from Quarries 01 and 02.

physico-chemical analysis of the collected samples.

Figure 4 indicates that silica (SiO_2), hematite (Fe_2O_3) and magnesium oxide (MgO) are dominant in sample ST1.4 which corresponds to the mixture of spotted horizon and crust. The predominance of iron oxide confirms the ferruginous nature of the lateritic soils [9]. A negative trend is observed in aluminum content from the bottom to the top of the weathering profile explaining its very low concentration in sample ST1.4. Conversely, clay sample ST1.1 (bedrock) records the highest values of aluminum oxide (Al_2O_3) and calcium oxide (CaO). In the following analysis, we focus on samples ST1.4 and ST2 as they exhibit the highest oxide concentrations. Additionally, other analyzed parameters show only trace amounts—or even absence—of elements such as MnO, Na_2O, K_2O and P_2O_5.

Geotechnical studies conducted in the laboratory focused on particle size analysis. Atterberg limits, proctor compaction test and the California Bearing Ratio (CBR). The results are summarized in **Table 1**.

Table 1. Summary of geotechnical properties obtained from laboratory tests on laterite samples.

		Sample				
Designation		**ST1.1**	**ST1.2**	**ST1.3**	**ST1.4**	**ST2**
Grain size distribution	% ϕ < 50 mm	100	100	100	100	100
	% ϕ < 2 mm	97.40	96.05	96.78	15.74	20.46
	% ϕ < 0.080 mm	64.17	72.11	73.18	2.53	2.41
	Cu	-	-	-	4.30	35.57
	Cc	-	-	-	1.23	6.41
Atterberg limit	W_L(%)	53.84	32.60	31.04	29.17	35.94
	W_P (%)	8.53	11.59	12.31	18.10	15.20
	I_P (%)	45.32	21.01	18.73	11.07	20.74
Specific density	ρ_s (g/cm^3)	2.149	2.295	2.248	2.338	2.409
Modified Proctor	W_{opm} (%)	-	-	-	11.95	10.30
	ρ_d (g/cm^3)	-	-	-	1.976	1.963
CBR index at 95 % OPM	CBR	-	-		77.00	34.8
	$\rho_{d95\%}$ (g/cm^3)	-	-	-	1.877	1.865
GTR classification		A4	A2	A2	B4	B4

Particle size analysis of the clay samples shows that the bedrock (ST1.1) contains fewer fine particles than the derived samples (ST1.2 and ST1.3). This can be explained by the presence of volcanic intrusions that have hardened the affected zones leading to the formation of larger concretions. These occupy a significant volume within the clay matrix thereby reducing the proportion of fine particles.

Samples ST2 and ST1.4 show a high percentage passing through the 2 mm sieve and low fine content indicating a gravelly tendency. This suggests that sample ST2 is sandier than sample ST1.4. The determination of Atterberg limits revealed that the liquid limit decreases from the clayey bedrock to the lateritic crust while the plastic limit increases from the highly plastic clayey bedrock (ST1.1 classified as A4) toward the crust (ST1.4).

This results in a decrease in the plasticity index from the bottom to the top of the lateritic profile. However, laterite ST1.4 exhibits the lowest plasticity index value of 11 which is suitable for use as both a foundation layer and a base layer. In contrast, the clay-rich nature of ST2 makes it unsuitable for use as a base layer.

The California Bearing Ratio (CBR) test conducted on the laterite samples yielded a CBR at 95% of optimum compaction with a value of 77% for sample ST1.4 and 34.8% for sample ST2. These results further confirm the suitability of ST1.4 for use as a base layer in low-traffic roads. and ST2 as a foundation layer.

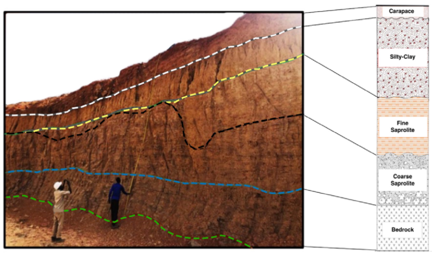
However, a synthesis based on field observations at the quarry face along with geochemical and geotechnical studies provides a better understanding of the lateritization process and allows for comparison between the two quarries. In the field, at the base of the outcrop in Quarry 2 gray laminated rocks were observed which tested negative with acid. These rocks were immediately identified as clays. The determination of the plasticity index through Atterberg limits confirmed the highly plastic nature of the bedrock (classified as A4) as well as the plasticity of the spotted horizon and the crust.

Geochemical analysis similarly indicates that these are not lateritic materials but rather clayey soils. At the top of this quarry face a red slightly plastic rock was observed. The S/R ratio obtained through geochemical analysis confirms that it is indeed a lateritic rock. With the exact nature of the studied rocks now identified their specific parameters must be assessed. Particle size analysis revealed that the clayey bedrock contains fewer fine particles than the rocks derived from its weathering.

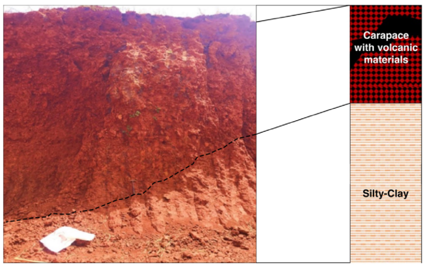
This may be explained by the fact that the bedrock is affected by volcanic activity which has locally indurated it. This feature could serve as an important marker. The laterite from Quarry 01 shows a content of iron and aluminum sesquioxides an optimal moisture content a maximum dry density and a lower CBR value compared to the laterite derived from the clayey bedrock in Quarry 02. Furthermore, both chemical and geotechnical analyses suggest that the laterite from Quarry 01 may still be undergoing lateritization. This explains why the laterite from Quarry 02 is of better quality than that from Quarry 01. The following **Figure 5** presents the results obtained from both quarries.

4. Conclusions

In civil engineering projects, it is essential to carry out a thorough characterization of laterite. Laterite is a weathering product of a bedrock of various origins formed under hot and humid tropical climatic conditions. Geological phenomena such as volcanism can also influence the intrinsic properties of laterite.



Lithology	*Samples*	*Bulk density*	*Specific density*	*Fine elements*	*Plasticity index*	*Compacting references*		*CBR to 95% of optimum*	*Sesquioxyd content*	
						Optimum water content	Maximum dry density		Fe_2O_3	Al_2O_3
Carapace	ST1.3	21.28	22.48	73.18	18.73	.	.	.	3.06	1
Top Carapace/ Top Silty-Clay	ST1.4	15.53	23.38	2.53	11.07	11.95	1.976	77	18.12	0.34
Silty-Clay	ST1.2	19.23	22.95	72.11	21.01	.	.	.	3.22	1.12
Fine Saprolite	.	.	.	.	.	.	.	.	.	.
Coarse Saprolite	.	.	.	.	.	.	.	.	.	.
Bedrock	ST1.1	20.61	21.49	64.17	45.32	.	.	.	5.67	1.81



Lithology	*Samples*	*Bulk density*	*Specific density*	*Fine elements*	*Plasticity index*	*Compacting references*		*CBR to 95% of optimum*	*Sesquioxyd content*	
						Optimum water content	Maximum dry density		Fe_2O_3	Al_2O_3
Carapace	ST2	14.41	24.09	2.41	20.74	10.2	1.962	34.8	11.73	1.28

Figure 5. Integrated petrographic, geochemical and geotechnical data from laterite samples in Quarries 01 and 02.

The study conducted as part of this work has clearly highlighted the properties of laterite within the same area while revealing physical context variations between Quarries 01 and 02. Geotechnical tests performed on samples from these sites have enabled a more accurate characterization of laterite supporting its optimal use as a base layer or foundation layer in road construction.

Conflicts of Interest

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

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