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Valorization of Clay Soils from Traditional Quarries in the City of ATI (CHAD) for use as Fired Bricks

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Abstract

This present study deals with the clay materials of the city of Ati, chief town of the Batha Province. The aim of this study is to determine the geotechnical characteristics and mineralogical composition of clays for their use as fired bricks. For this purpose, various methods and means of identification were used, including: grain size, Atterberg limits, density parameters, compressive strength and mineralogical and geochemical analyses. The macroscopic description of the soils in the study area shows that almost all of these soils are clayey materials, with a gray, black, light gray, mottled and yellowish color, but we also note the presence of silts. It emerges from the geotechnical characterization that the materials of the quarries of the city of Ati are fine soils with an average percentage of 60% of passers by the sieve of 80µm. According to the GTR classification, these soils belong to the class of clay soils type A and have a low plasticity to plastic behavior according to the values of the plasticity index (12.2 to 23%). The values of the density of the solid grains vary from 2.17 to 2.30g/cm^3 with an average of 2.23g/cm^3. These values indicate that the density of the studied soils is medium and the particles are moderately compacted. The compressive strength of the mud bricks increases with traditional firing. From 2.1 to 2.8 MPa for unfired bricks, it increases from 2.8 to 4.8 MPa for fired bricks. Mineralogical analysis showed that the soils in the study area are composed mainly of quartz and a clayey mixture of kaolinite, smectite and illite with a predominance of kaolinites in most of the samples analyzed. The geochemistry is characterized by the dominance of potassium over calcium and the relative abundance of elements related to granitic detritic minerals: titanium, zirconium. This characterization shows that the soils of the quarries of the city of Ati are favorable for the manufacture of quality bricks, briquettes and even tiles and other ceramic objects.

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Introduction

Clays are available almost every where in the world and their exploitation does not require any particular effort or advanced knowledge (Abakar, 2018). They are of interest to most researchers in the world, because they are easily accessible in nature (Abakar *et al.,* 2017) and (Abdoulaye, 2014). These materials are valued in various fields, because of their physicochemical and mineralogical properties (Diawara, 2009), (Keita, 2014) and (Sorgho, 2013).

Chad, like other countries in the sub-region, has enormous resources of clay raw materials that can be exploited and valorized in their natural state, or improved by various additions for various uses (Al-hadj *et al.,* 2021). In addition, most buildings are built with clay bricks (fired or not). These bricks are made of uncharacterized and poorly stabilized materials, which means that the dwellings have an insufficiently long or even ephemeral lifespan. The town of Ati, the capital of the Batha Province (Fig. 1), is experiencing population growth, which naturally leads to an expansion of the town, thus increasing the demand for building materials.

Baked bricks made from clay materials have thus become the most sought-after materials for building houses. However, it is noted that these materials have not been characterized before being used.

This is largely due to the lack of knowledge of the nature of soils and geotechnical properties by the population. Faced with the high cost of durable materials (cement, steel, gravel...), the recovery of clays that are in large quantities in the locality could help the population to build their homes with a long life without difficulty. It is in this optic, that the present work was carried out. It uses the results carried out on ten samples of clayey materials at the Civil Engineering Laboratory of N'Djamena (Chad) and at the European Center for Research and Teaching of Environmental Geosciences in Aix en Provence (France). The geological context shows three main units: the Terminal Continental (composed essentially of Tertiary deposits covered by Quaternary formations), the Crystalline Basement (constituted by isolated inselberg masses that cross the sedimentary cover) and the Quaternary fluvial deposits (alternating sand and clay). The Batha River drains the granitic and metamorphic massifs of the Ouaddaï and Guéra (Wit *et al.,* 2021); one would therefore expect to find in its sediments the products of alteration of granites and schists.

From a pedological point of view, the study area presents two types of soils (Fig. 2): Arenosols and alluvial soils with the presence of intermediate states (clay, silt, sand, clayey silt, sandy-clay and clay-sandy).

Materials and Methods

Field method

In order to have representative samples of the study area, the sampling points were located in the different quarries of the city of Ati and presenting all the apparent diversities from the point of view of soil color. These are the quarries Attamaya Alkabire, Aldjazira, Makoundji, Almourhal and Woulad Issa. In addition, the sampling of unfired and fired bricks. The samples taken are intended for the determination of physical parameters (particle size analysis, Atterberg limits, density, value of methylene blue), mechanical parameters (compressive strength), mineralogical and chemical analysis.

The field work has allowed to map the different quarries of manufacture of mud bricks on the basis of clay materials and stabilized by the traditional firing which is determined by a visual appreciation of color of the fired products. The following photographs illustrate the work of making bricks and their drying until the traditional firing (Fig. 3).

Experimental protocol

The granulometric analysis of the soils was carried out by wet sieving, the principle of which is based on the (NF P 94 – 056, 1996) standard. The granulometric separation of fine particles (size less than 0.08 mm) was carried out by sedimentation according to the standard (NF P 94 – 057, 1992). The study of soil consistency was conducted on the basis of the limits of Atterberg. The plasticity limit was determined by the roller method as described by the standard (NF P 94 – 051, 1993) and the liquidity limit using the Casagrande cup. The plasticity index was determined by calculation. The density of solid grains was determined using pycnometers according to standard (NF P 94-054, 1991), and the bulk density was determined by the cutting kit method.

The chemical composition of the soils was estimated directly on compacted powder by using a Brucker tracer IV portable X-ray fluorescence apparatus in major and trace mode. This apparatus does not detect Na and has a high detection threshold on Al and Mg. Moreover the experimental conditions (porosity and surface condition of the compacted sample) make that the absolute value of the compositions is badly calibrated. We will therefore present the results normalized to the SiO_2 content. The nature of the clays was determined by the XRD method according to the classical protocol: attack of a few grams by HCl then H_2O_2 at high temperature, sieving at 125 µm, centrifugation and rinsing, suspension in distilled water by shaking and ultrasonic bath. Partial decantation, sampling and centrifugation of the fraction <2 µm for preparation of three slides per sample: one untreated slide, one slide treated with ethylene glycol for 12h, one heated at 490°C for 4 h. The slides are passed to the Philips PW 1729 diffractometer with Co cathode and double angles from 2 to 35°.

Results and Discussion

Geotechnical characteristics

Granulometric analysis

The particle size compositions of the studied samples have a variable distribution. Particle sizes below 80µm vary from 41.2% to 79.1% with an average of 60.% (Tab 1).

According to (Meriam, 2013), the granulometric study of a natural material, earth or soil, to be used in the sector of the manufacture of bricks is of capital importance because it is on it that depend the characteristics of the finished products which derive from it. The grain size is one of the main parameters to determine the suitability of a soil (Jiménez and Guerrero, 2007) and influences the suitability of the soil for shaping and drying (Moevus *et al.,* 2012).

This particle size analysis shows that the soils studied are mainly fine for most of the samples analyzed with an average of 60% of the passings of the 80µm sieve. The values obtained are lower than those found by (Narcisse *et al.,* 2017) on the stabilized earth bricks which vary between 86 and 87%, by (Ndjilbé, 2016) on the soils of the South-East sector of Ndjamena which is 82.61% and by (Al-hadj *et al.,* 2017) on the soils of Amtiman (South-East Chad) which is 76.66%.

This discrepancy is due to a higher silty and sandy fraction. The sieving carried out after suspension for the analysis of clays shows two types of samples: those where the fraction >125 µm is less than 5% (E1,2,3,5,8) and the others where this fraction is between 25 and 35%.

Atterberg limits

The Atterberg limits correspond to the proportions of water for which the clay materials go from a semi-liquid behavior to a plastic behavior and then from a plastic behavior to a semi-solid behavior (Peltier and Rumpler, 1959). In the field of bricks, plasticity is one of the desired properties, as it facilitates the manufacture (especially the shaping) of ceramic products, which ensures cohesion in the fire. Table 2 presents the results obtained.

Table 2 shows that the liquidity limit is between 42.6 and 62.2% with an average value of 52.58%. The plasticity limit varies from 30.4 to 39.2% with an average value of 34.6% and the plasticity index from 12.2 to 23% with an arithmetic average of 17.98%. From these results, it appears that the soils studied are not very plastic to plastic. (Seed *et al.,* 1962) have shown through the relationship between free swelling and plasticity index that if Ip is between 0 and 10%, the swelling potential is low, if it is between 10 and 20%, the swelling potential is medium, between 20 and 35%, the swelling potential is high and when Ip is greater than 35%, the swelling potential is very high. Based on this relationship, clayey materials from quarries have a medium to high swelling potential. More recently, (Prian *et al.,* 2000) have refined the relationship estimating the swelling potential from the plasticity index.

The thresholds are indicated as follows: when Ip> 40%, the swelling potential is very high; If Ip is between 25 - 40%, the swelling potential is high; Ip is between 12 - 25% the swelling potential is medium; Ip< 12%, the swelling potential is low. Based on this classification, the soil in the study area has a medium swelling potential because its plasticity index located in the range of 12-25%. The values obtained for the plasticity index of the studied soil (12.2 to 23% with an average of 17.98%) do not agree with those found by (Krikrou, 2018) on the Constantine clays which is 23.138% and by (Amadou, 2008) on the lateritic soils of Bafoussam which is 24%.

This discrepancy is due to the lithological nature, the percentages of fine particles, the degree of alteration and the physico-mechanical parameters.

Density

The densities are generally used to characterize the soils. They globally translate the state of compaction of the material and indirectly, the total porosity (Blake and

Hartage, 1986). They are among the most important parameters in studies of soil structure, because they are related to the nature and organization of the soil constituents (Chawel, 1977). The results of the densities are presented in Table 3. Table 3 reveals that the density of solid grains varies from 2.17 to 2.30g/cm^3 with an average of 2.23g/cm^3. Similarly, the bulk density ranges from 1.19 to 1.26g/cm^3 with an average of 1.22g/cm^3.

Table.1 Grain size analysis of soils in the study area

Designation	Particle size analysis by sieving		
	%< 80µm	%<0,2mm	%<2mm
Minimum value	41,2	98,7	99,2
Maximum value	79,1	99,4	100
Average value	60	99,9	99,7

Table.2 Atterberg limits of the soils in the study area

Désignation	w_L (%)	w_P (%)	I_P (%)
Minimum value	42,6	30,4	12,2
Maximum value	62,2	39,2	23
Average value	52,58	34,6	17.98

Table.3 Densities of soils in the study area

Designation	ρ_s (g/cm^3)	ρ (g/cm^3)
Minimum value	2,17	1,19
Maximum value	2,30	1,26
Average value	2,23	1,22

Table.4 Compressive strength of fired and unfired bricks

Designation	RC Unfired brick (MPa)	RC Baked brick (MPa)
Minimum value	2,1	2,8
Maximum value	2,8	4,8
Average value	2,5	3,8

Table.5 Mineralogical analysis of the soils in the study area

Designation	Kaolinite (%)	Illite (%)	Smectite (%)
E1	55	18	27
E2	42	26	32
E3	44	18	38
E4	61	8	31
E5	24	20	56
E6	38	19	43
E7	44	16	40
E8	32	15	53
E9	62	13	25
E10	30	36	34

Table.6 Geochemical data obtained by XRF on powders, contents normalized to SiO_2 content. Values in % up to P_2O_5, in ppm beyond. The apparent SiO_2 content varies between 43 and 64 %.

Elements	Al_2O_3	P_2O_5	K2O	CaO	TiO_2	MnO	FeO	Rb	Sr	Y	Zr
Mean	36.1	0.24	6.5	4.3	2.09	0.12	3.2	268	258	71	735
Standard deviation	5.6	0.10	0.8	1.1	0.78	0.04	2.4	84	38	32	194
Maximum	43.9	0.34	8	6.2	3.39	0.21	7.7	405	345	121	979
Minimum	25.5	<0.1	5.7	2.3	0.88	0.06	1.2	187	208	25	347

Fig.1 Location map of the study area

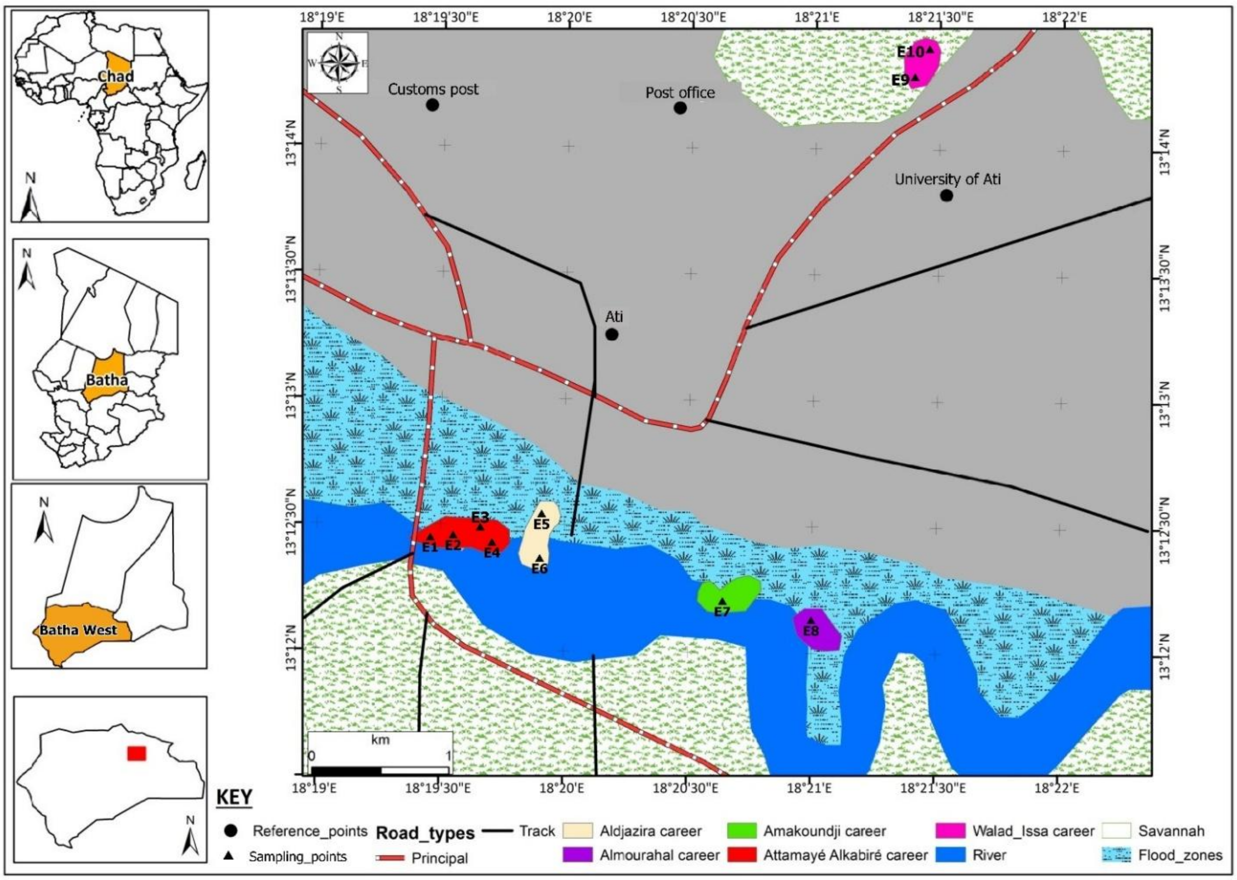


Fig.2 Soil map of the study area

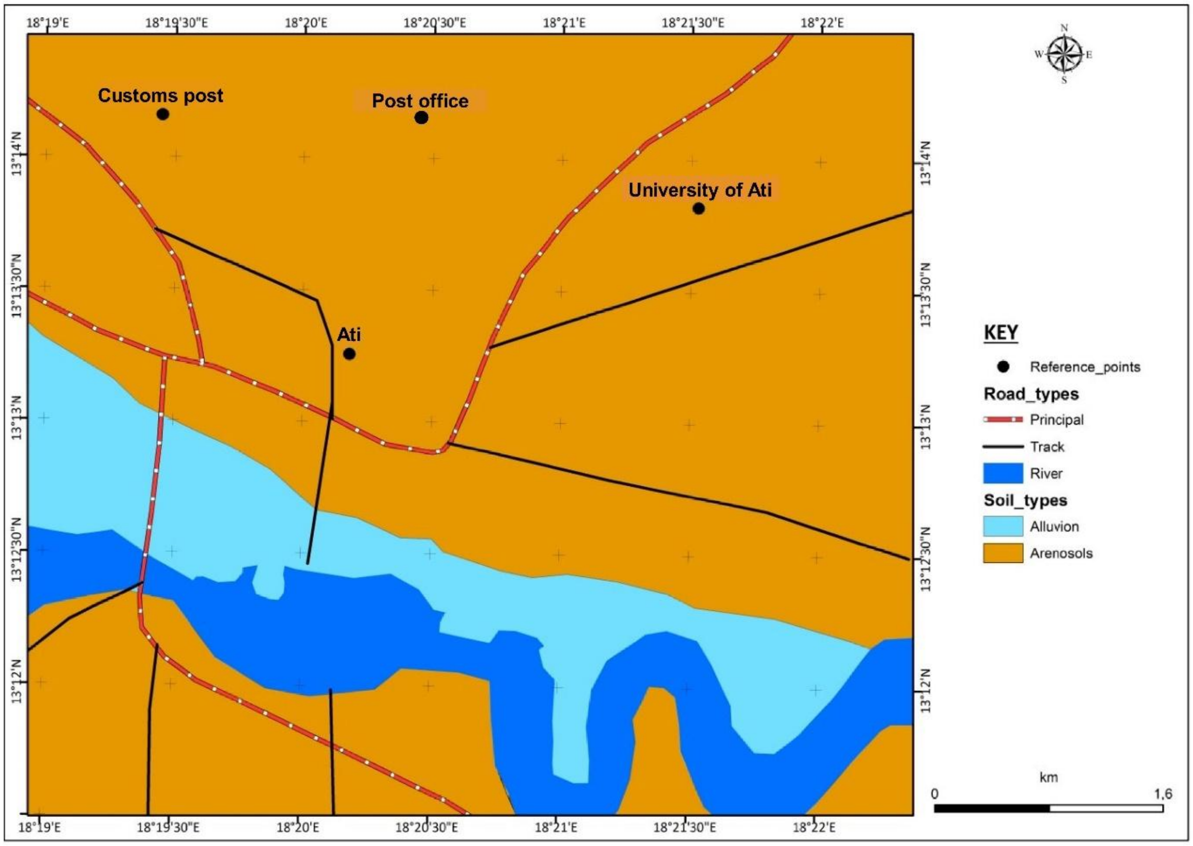
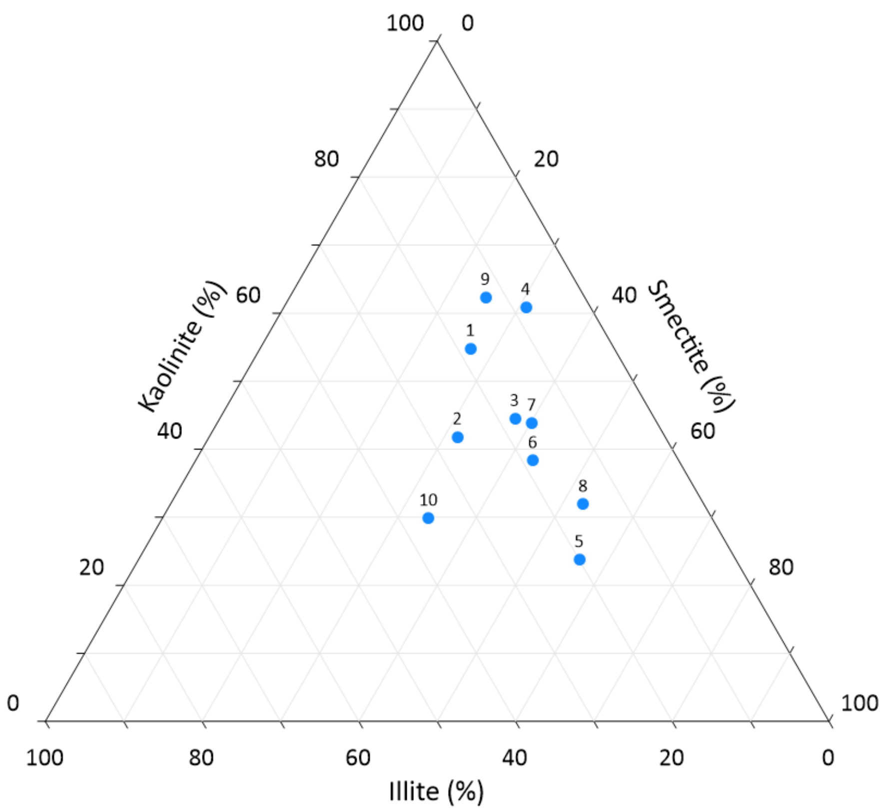


Fig.3 Manufacturing procedure of fired and unfired bricks (A, B, and C: clay materials; D, E: manufacturing, laying out and drying of bricks; F, G, H: arrangement and firing of bricks in traditional kiln).


C
D
E
F
G

Fig.4 Triangular diagram of the studied clays



The values of the densities are not so far from each other, this is explained by the this is due to the fact that most of the quarries have almost the same soil. A high density value means that the voids are reduced and the particles are highly compacted (Mermound, 2010).

Compressive strength of unfired and fired bricks

The knowledge of the compressive strength of materials is of great use. It allows to appreciate the quality and durability of the manufactured bricks. The results obtained from the mechanical strength of unfired and fired bricks are shown in Table 4.

The mechanical compressive strength values of unfired bricks vary from 2.1 to 2.8 MPa with an average of 2.5MPa. After traditional firing, the simple compressive strength increases from 2.8 to 4.8 MPa with an average of 3.8MPa. This increase due to the traditional firing is a method of stabilizing the earthen bricks.

Mineralogical and geochemical analysis

The knowledge of the nature of the clay minerals in the manufacture of bricks is very important. The mineralogical compositions were obtained from X-ray diffraction on oriented slides. The results of the mineralogical analysis of the clay fraction of the samples from the quarries of the city of Ati are presented in Table 5 and Figure 4.

The abundance of quartz in our samples is confirmed by the presence of the main quartz peak in the clay fraction, and also by the observation with a binocular magnifying glass of the fraction superior to 125 µm.

These results show that the soils of the quarries in the town of Ati are composed of a mixture of clay minerals, notably kaolinite, smectite and illite. Kaolinite and smectite dominate. Kaolinite (majority in samples 1,4,9) present in this clay exploited for the manufacture of mud bricks, is an important mineral in its composition since it does not support a phenomenon of shrinkage/swelling during drying and rewetting. It is also a refractory mineral species that limits creep at high temperatures (Bouyhyaoui, 1996).

From the geochemical point of view (data normalized to SiO_2 in Table 5), we note among the major elements the abundance of Al_2O_3 (36 ± 6%), typical of clays, a predominance of K_2O over CaO, a relatively low iron content (3.1%) and a fairly high TiO_2 content (2%). For minor elements, the abundance of Zr is notable, 720 ppm on average. Compared to average contents of 200 ppm and 0.5% for Zr and TiO_2 in regional granites (Wit *et al.*, 2021), this demonstrates a concentration of heavy minerals in the sediment.

The present work has been the subject of a study on the geotechnical characterization of clayey soils of the quarries of the city of Ati.

From the macroscopic point of view, the clayey materials present a gray, dark, light gray, yellowish and mottled color. On the surface, the texture is clayey and some materials are compact. The physical characteristics showed that the materials in the study area are essentially fine, not very plastic to plastic with a plasticity index that varies from 12.2 to 23%. The compressive strength shows that traditional firing increases the strength of the mud bricks. The mineralogical composition specified that the clay minerals in the study area consist of a mixture of kaolinite, smectite and illite. Quartz and heavy minerals bearing titanium and zirconium are abundant. These materials are favorable for the confection of bricks of qualities.

It emerges from this study that the clayey soils of the quarries in the town of Ati are favorable for the manufacture of quality bricks, briquettes and even tiles and other ceramic objects. However, the poor firing and irregular dosage of the basic materials must be reviewed to improve the quality of the bricks.

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