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Preliminary mineralogical and geotechnical characteristics of Zogbodomey clays in the coastal sedimentary basin of Benin (West Africa)

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The Benin coastal sedimentary basin is filled with deposits of clays of diverse nature. This study focused on the characteristics of clayey materials of Zogbodomey in sight of their valorization in the construction and ceramics sectors. The clay deposit is covered by a lateritic layer of 2.5 m thickness around. The reserve updated of the deposit is estimated at 53,198,437 tons. The Clays are composed of 56.7% of kaolinite, 31.96 smectite and 6.79% of quartz. The plastic and liquid limits are 38% and 118%, respectively, with a plasticity index of 80%. Drying and firing shrinkage of the bricks of 3.125% and 3.25%, respectively, are acceptable. The compression strength of the bricks of 10 and 15, hollow block 15 and facing bricks is 1.3; 1.5; 2.7 and 8.6 MPA, respectively. These values are consistent with the standards recommended by the National Test Center and Research of Work Public (CNERTP). The characteristics of Zogbodomey clays are favourable for their use inr the manufacture of baked bricks.

Keywords: clays, compression, liquidity, mineralogy, plasticity, Zogbodomey

Introduction

The clays are sedimentary rocks mostly composed of more or less hydrated phyllosilicate minerals. They have a wide variety of compositions, properties, nomenclature and industrial applications. The clays which are mainly rich in SiO_2 and Al_2O_3, are important industrial minerals with numerous applications, especially in the manufacture of ceramics, for building constructions, industrial and craft ceramics, the pharmaceutical industry and pottery (El Ouahabi 2013; Pialy 2009; Marsigli and Dondi 1997; Reeves, Sims, and Cripps 2006).

In Benin, the coastal sedimentary basin in the East, Center and West of the country contains significant and varied deposits of clays. Among these deposits, that at Zogbodomey in central Benin is used for a semi-industrial exploitation in the construction sector and that at Sè in the West is exploited for pottery.

The clays have technological requirements that are often based on grain size, chemical and/or mineralogical composition and physical properties which make them viable for use (Blanco et al. 2005; Celik 2010; Khalfaoui and Hajjaji 2009; Murray 2007).

This study aims at evaluating the potential suitability of Zogbodomey clay materials as raw materials in various ceramic applications by investigating their chemical, mineralogical and geotechnical characteristics. The findings have the advantage of contributing to the promotion of local building materials.

Material and methods

Material

For this study, in addition to the materials generally used, one topographic map at 1/50,000 scale (Zagnanado 1d) and two geological maps at 1/200,000 scale (Abomey-Zagnanado and Lokossa-Porto- Novo) were used. The laboratory materials comprised:

- an oven for the drying of specimens;
- a precision balance;
- a Casagrande apparatus for the determination of the Atterberg limit;
- a mechanical press for the realization compressive strength tests.

Methods

Data collection

The logs of pits realized in 1983 during the project of geological reconnaissance of clays of the coastal sedimentary basin of Benin financed by the United Nations Development Programme (UNDP) and those realized by Slansky in 1962 were collected. The x-ray diffraction and geochemical analysis data produced for this project were also obtained and interpreted.

In the field

Two pits A1 and A2 of 4 and 4.5 m depth respectively were dug in Aoundomè and Zado. The samples were selected according to clay facies variation. The samples were also taken from the quarry of 'Nature Brique Sarl' society at a depth of 7 m. These samples were described to clarify their colour, structure, and mineralogical composition. The logs of the pits were realized.

In the laboratory

The samples were collected and some bricks produced by 'Nature Brique Sarl' society were subjected to analyses and laboratory tests. The water absorption test was realized at the Department of Earth Sciences (DST) and the geotechnical tests (Atterberg limits and compressive strength) at the Laboratory of Testing and Research in Civil Engineering (LERGC) of the University of Abomey-Calavi.

- Determination of water absorption (NBN B 24-203).

The water absorption test was carried out according to the Belgian procedure. After preliminary measurements at the end of firing and cooling, the specimens of each batch were kept dry in an oven until their submission to water absorption. Each dry and cool specimen was weighed (A) and the three were then immersed into clean water at 25°C for 24 h. The specimens were removed from the water, their surfaces were wiped off and the weight (B) of each was measured immediately. The water absorption capacity was calculated as:

$$\text{Water Absorption } (\%) = \frac{(B - A)}{A} \times 100$$

- The Atterberg limits (Standard NF P 94-051)

These tests were carried out on the clay samples taken from the quarry. The tests consist of determining the liquid limit (WL), which marks the passage of a sample of the plastic state to the liquid state; the plastic limit (WP), which corresponds to the passage of the sample from the solid state to a plastic state shrinkage; and, E finally, the plasticity index (IP), which provides information on the extent of the plastic field soil (Feinberg 1986; Sadik, El Imrani, and Albizane 2012).

- Determination of compressive strength (NBN EN-771-1)

These tests were carried out on the bricks of 10, 15, the hollow block of 15 and the bricks of facade. These bricks were placed and centred on the base plate of a mechanical press. A uniformly distributed load was applied and increased continuously until failure. The compressive strength is given by the equation:

$$Fc = \frac{F}{Ac}$$

where: Fc (N/mm^2) is the compressive strength;

(N) is the maximum load applied
Ac (mm^2) is the area of the section of the brick on which the compressive force is exerted.

Data processing

- Realization of the geological section and the thickness map

The geological section was realized through the correlation between the wells dug during this study and those dug in the field work of the United Nations Development Programme (UNDP) project in 1983 and by Slansky (1962). The geographical coordinates of pits were collected using a Garmin type GPS. These coordinates, once converted, were introduced with the thickness of clay into the Surfer 8 software to produce a thickness map.

- Reserves estimation

The reserve was estimated on the basis of the average thickness of the clay layer and the studied area. The average thickness of the clay layer considered was 7.275 m, taking into account an exploitation going to 10 m of depth. The specific weight of the clay was 2 t/m^3.

$$\text{Reserve} = \text{Area}\,(m^2) \times \text{Thickness}\,(m) \times \text{Specific weight}\,(t/m^3)$$

- Estimation of the proportion of each mineral identified

The estimation of the proportion of each mineral identified was computed by combining the chemical compositions with the mineral composition following the method developed by Njopwouo (1984). This method consists of writing for each element (a) the relation (1):

$$T(a) = \sum_{i=n}^{n} Mi.Pi(a)\ ; \quad (1)$$

with: T (a); mass expressed as a percentage of the oxide of the chemical element a in the sample;

Mi; mass expressed as a percentage of mineral **i**;
Pi (a); mass proportion of the oxide of the element **a** in the mineral **i** deduced from the ideal formula attributed to this mineral **i**.

The indeterminate **(I)** is obtained from Equation (2):

$$I = \Sigma c - (\Sigma m + \Sigma o) \quad (2)$$

where: **Σc** is the sum of the results of chemical analysis; **Σm**, the sum of the calculated mineral phase contents and **Σo**, the proportion of oxides not taken into account.

- Atterberg limits and compressive strength

The values of the plastic index (IP) and liquid limits (WL) were projected on the Casagrande's abacus to determine the extent of the plastic field of these clays.

The results of the compressive strength tests carried out on the different types of brick were compared with the standards recommended by the CNERTP which are 12–25 Kgf-cm^2 (1.18–2.45 MPa) for the breeze-block of a load bearing wall and 25–35 Kgf-cm^2 (2.45–3.43 MPa) for the breeze-block of a non-load bearing wall (Afouda 2002).

- Water absorption

The results of the water absorption tests realized on the bricks were compared to the allowable limit. According to Melo, Kamseu, and Djangang (2001), the percentage of water absorption of baked bricks should not exceed 20%.

Results and discussion

Geological study of the deposit

The Zogbodomey clay deposit is covered by a lateritic layer of 2.5 m thickness around. The clay is massive, plastic with various colours from beige to whitish or yellow to reddish. The clay layer is more homogeneous at the West than the East, where we note the presence of lateritic nodules. The correlation between the pits enabled to establish the East–West geological section of the deposit. This geological section shows a lateral continuity of the clay layer (Figures 1 and 2). The presence of an important reserve makes no doubt. This reserve is updated and estimated at 53,198,437 tons over an area of 3656250 m^2.

The thickness map of clays layer established shows lower thicknesses (6–7 m) at the East of the deposit while in most another region it more than 7 m (Figure 3).

Mineral characterization

The chemical analyses realized in two different laboratories (the laboratories of the Institute of Geology of Louis Pasteur University in Strasbourg in France and the X Ray Assay Laboratories in Ontario, Canada) by the UNDP project are presented in Table 1. The mineralogical analyses have been realized by x-ray diffraction in the same laboratories. The results of these analyses are summarized in Table 2.

These results show that the dominant clay mineral is kaolinite ($Al_2Si_2O_5(OH)_4$) (mineral of the kandide group) which is accompanied by smectite. The proportion of each mineral contained in the clays has been estimated on the basis of these results (Table 3).

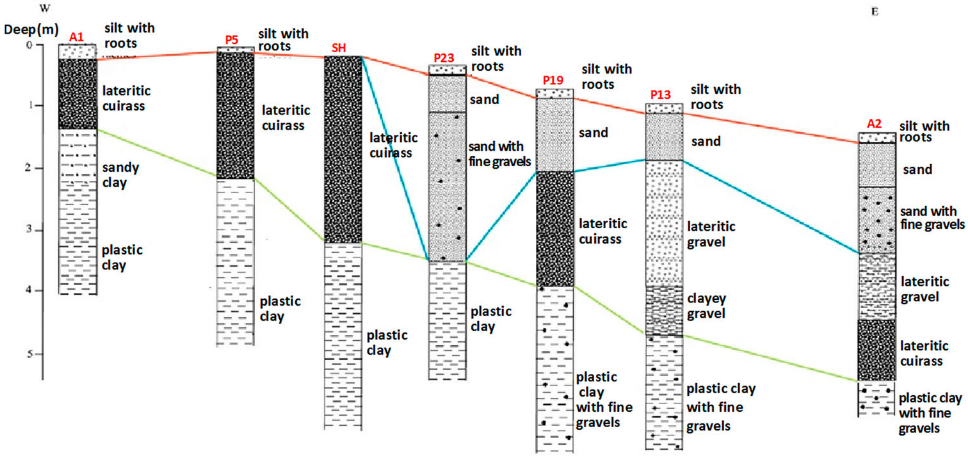

Figure 1: Correlation between the lithostratigraphic sections of the wells.

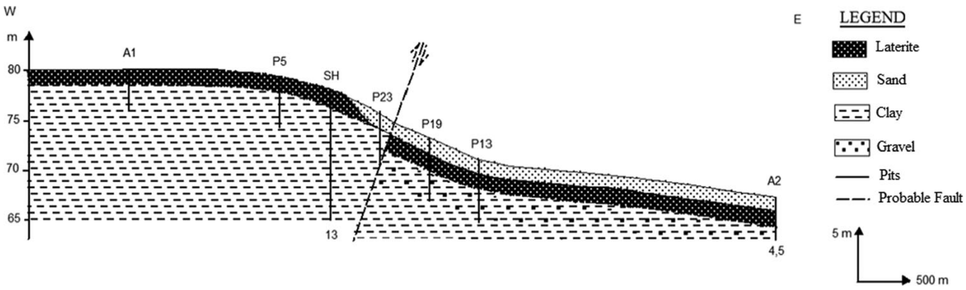

Figure 2: W-E geological section of the deposit.

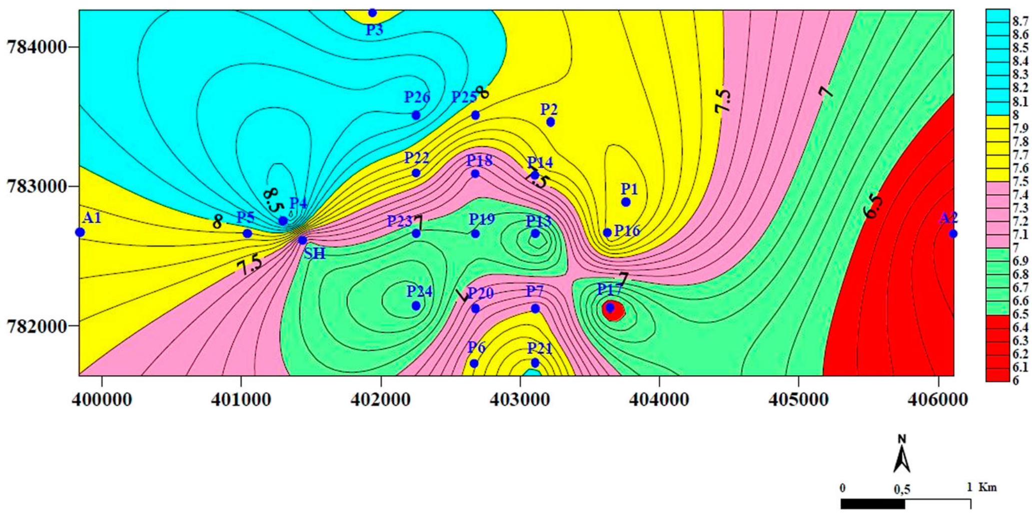

Figure 3: Map of clay level thicknesses based on well data.

Table 1: Average results of chemical analyses of the laboratories of the Institute of Geology of Louis Pasteur University and X Ray Assay Laboratories.

Oxydes	SiO_2	Al_2O_3	MgO	CaO	Fe_2O_3	MnO	TiO_2	Na_2O	K_2O	PF 1000°	Σc
Laboratoires											
University of Louis Pasteur	61,4	23,7	0,6	0,4	2.5	–	1,39	0,05	0,61	8,74	99,39
X Ray Assay Laboratories Ontario	61,6	21,7	0, 63	0, 2	2,75	0,01	1,59	0,12	0,6	9,54	98,74
Average	61,5	22.7	0,615	0,3	2,625	0,01	1,49	0,085	0,605	8,74	99,065

Table 2: Results of the mineralogical analyses carried out in the laboratory of the Institute of Geology-Louis Pasteur University and the X Ray Assay Laboratories.

Minéraux	Laboratoires
Quartz (Assez fort), Kaolinite (Fort), Smectite (Faible)	Institut de Géologie-Université Louis Pasteur
Quartz, kandide et smectite (Minéraux par ordre décroissant d'abondance)	X Ray Assay Laboratories

Table 3: Estimation of the percentage proportion (%) of each mineral present in Zogbodomey clay.

Sample	Quartz	Kaolinite	Smectite	Σm	Indét (I)
Pits N°1	31,96%	56,70%	6,79%	95,45%	−1,51%

From the analysis of this table, the Zogbodomey clay is composed of 56.7% of kaolinite, 31.96% of quartz and 6.79% of Smectite. The high proportion of kaolinite clay enabled to consider Zogbodomey clay like kaolinitic clay (containing at least 50% kaolinite). Its mineralogical composition is approximately the ideal composition of ceramic pastes proposed by Pialy (2009). The undetermined are estimated at −1.51%. They may be due to not taking into account K_2O because illite, sanidine or microcline was not detected by XRD.

Physical characterization of the clay

The results of the Atterberg limit tests carried out on the clay samples are presented through the semi-logarithmic diagram (Figure 4). The values obtained are the averages of three tests.

The parameters of this curve are as follows:

- plastic limit WP = 38%
- liquid limit WL = 118%

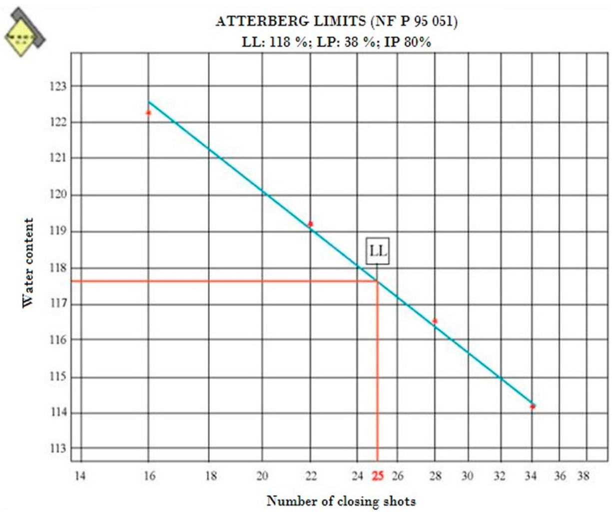

Figure 4. Determining the liquidity limit.

- plasticity index IP = 80%

To determine the extent of the plastic field of this clay, we projected the results on the Casagrande diagram (Figure 5).

The projection on the Casagrande diagram shows that the plasticity of Zogbodomey's clay is very high. This high plasticity is linked to the presence of kaolinite and especially smectite. According to Allaoui et al. (2005) and Guerraoui, Zamama, and Ibnoussina (2008) the plasticity of clays depends on the nature of their clay minerals and is inversely proportional to grain size (ASTM). The highest index values are obtained with montmorillonites (Callaud 2004). The high value of the liquid limit proves that this material has a high affinity for water and a very high absorption capacity (Louafi and Bahar 2017).

Physical characterization of bricks

Water absorption

The results of the water absorption tests show that the average water absorption coefficient of the bricks is 16.22%. According to Melo, Kamseu, and Djangang (2001); the percentage of water absorption of clay bricks should not exceed 20%. This percentage must not be too low. Following this line of reasoning, we could conclude that the water absorption coefficient of the bricks produced is within the allowable limits.

Drying and firing shrinkage

The value of the drying shrinkage (3.125%) is within the limits tolerated by the regulations (AFNOR 1983), which is 10% at the most. As for the value of the firing shrinkage (3.23%), it slightly exceeds the accepted limits, which vary from 0.5 to 3%. This justifies the very high plasticity of the clay.

Mechanical resistance

The results of the compressive strength tests are indicated in Table 4. A wide range of compressive strength was found ranging from 8.6 MPa to 1.3 MPa. These values

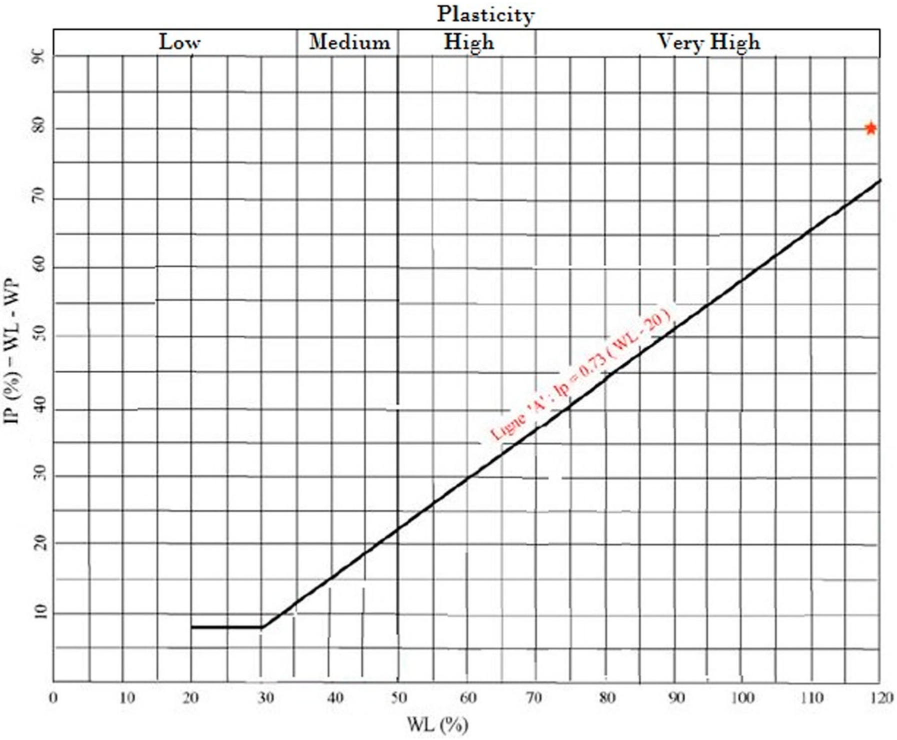

Figure 5: Classification of fine soils on the Casagrande diagram.

Table 4: Average compressive strength of brick.

	Bricks of 15	Bricks of 10	Hollow block of 15	Bricks of facade	Nervure
Dimensions (mm)	300 × 200 × 150	300 × 200 × 100	380 × 320 × 150	220 × 110 × 70	320 × 140 × 50
Average compressive strength (MPa)	1,5	1,3	2,7	8,6	1,6

are consistent with the standards recommended by the National Test Center and Research of Work Public (CNERTP) which are 12–25 Kgf-cm^2 (1,18–2,45 MPa) for the breeze-block of load bearing wall and 25–35 Kgf-cm^2 (2.45–3.43 MPa) for the breeze-block of non-load bearing wall (Afouda 2002).

Conclusion

Zogbodomey clays are a kaolinitic clay of very high plasticity whose probable reserve is estimated at 53, 198, 437 tons. Its mineralogical composition is approximately the ideal composition of ceramic pastes. Its drying and firing shrinkage allow good industrial profitability. The water absorption coefficient of the bricks produced is within the allowable limits. These results show that the Zogbodomey clay deposit has physicochemical and mineralogical characteristics that are favourable for use in the manufacture of fired bricks. They meet the standards required for profitable industrial operation. However, it would be interesting to carry out laboratory tests and semi-industrial trials in order to develop an industrial technology suitable for the manufacture of sanitary ware, earthenware pottery and tiles.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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