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Characterization of the Activity, Mineralogy and Correlations between the Properties of Clayey Soils

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Abstract

The activity is related to the mineralogy and geological history of clays. Soils with the same value of the liquidity limit or plasticity index can have very different characteristics depending on the amount and type of clay minerals. The methylene blue value characterizes the activity of the clays and reflects the surface activity. Ten inactive soils contain minerals (kaolinite, illite), these soils absorb little water. Two swelling soils have normal activity and are composed of minerals (kaolinite, illite, Montmorillonite). The relationships between clayey soils properties, their activities and between the activity and the liquidity limit are defined. The correlations obtained are linear fit and exponential and sigmoidal fits. The correlations obtained with a coefficient of determination of R^2 (0.859 - 0.999) can be used to characterize and predict certain parameters of fine-grained soils as a function of clay content.

Keywords

Activity, Specific Surface Area, Cation Exchange Capacity, Mineralogy, Atterberg Limit

1. Introduction

Activity is an approximately linear relationship between the plasticity index and the clay fraction [1]. Clay soils have been classified into "inactive", "normal" and "active" clays [1]. The clay fraction indicates the variation of the physic-chemical potential of soil as a function of the plasticity index and the increase in clay fraction. In other words, the variation in soil plasticity along the line should reflect the effect of both the amount and type of clay [2]. The amount and type of clay are described by the plasticity index which is the range of water content over which a soil exhibits plastic behaviour. The behaviour of fine soils is dominated by the specific surface area [3] and the cation exchange capacity [4] [5], two intrinsic properties of fine soils [2] [6]. Specific surface area has been used to define the term relative activity as the ratio of plasticity index to specific surface area [7]. Relative activity defines the role of specific surface area on the plasticity of fine soils. The clay fraction does not identify the clay mineral species present in the soil. The specific surface area only gives an overview of the mineralogy, especially when used in combination with the clay fraction [2]. The specific surface area of clays is defined as the ratio between the specific surface area and the clay fraction [8]. The specific surface area used in conjunction with the plasticity index can help to identify the mineralogy of clay fractions [8]. Indeed, this is possible because the activity and surface activity is normalized by the clay fraction. For a variety of marine clays from around the world, the activity was equal to A = 0.005 Sc, a straight line called the "C-line" [8]. Of all the soil mineral constituents, clays contribute the greatest surface area, but their specific surface area can also vary considerably. However, the type of mineral present in the clay fractions is of major importance in determining the effect of specific surface area on the properties of clay fines [2]. The specific surface area varies considerably from one soil to another due to differences in mineralogy, organic composition and particle size distribution [6]. In this case, the specific surface area can be considered as an inherent soil property. However, the grain size distribution of a soil is one of the determining factors used to classify soils and define standards for use in geotechnics [6] [9]. For this purpose, it is important to define the geotechnical characteristics of soils on the one hand and, on the other hand, their interactions with the local environment [10]. Inorganic soils are classified on the basis of their activity according to their liquidity limit [11]. Clay soils, when in contact with water, change their volume by increasing the pore spaces or voids in the soil mass [12]. Despite the diversity of studies on clay soils, they have not exhausted the subject. The objective of this study was to characterize the activity and mineralogy of soils and to assess the relationships between activity and intrinsic soil properties.

2. Materials and Methods

2.1. Materials

Twelve soil samples known for their mud bricks were collected in 7 localities in the departments of Lékoumou, Bouenza and Niari in the south of the Republic of Congo. In these localities, there are several quarries of materials that differ in soil texture and color, which varied from yellow, grey and red. Samples were taken from the different horizons used by the brick makers, to determine the properties of soils. At each collection site, a representative sample of about 10 kg of clay soil was taken.

2.2. Methods

From the physical and chemical properties of grains, the soils are classified according to the AASHTO T88-70, (NF P-11300) and USCS classifications [13] [14].

Origin Pro 2019b software was used in the process of developing correlations between the intrinsic properties of soils. The correlation selected is the one with the highest coefficient of determination.

2.2.1. Particle Size Analysis

The granulometry represents the percentage distribution of solid grains according to their dimensions. For particle separation, two types of tests were performed by: sieving for grains of the size $\phi > 80$ µm according to NF P94-056 [15] and the sedimentation for the grains of diameter $\phi \leq 80$ µm according to NF P94-057 [16]. The grain size fraction is deduced from the recommendations of grain size nomograms, considering clays as particles < (0.002 mm), silts (0.002 - 0.06 mm) and sands (0.06 - 2 mm).

2.2.2. Atterberg Limits

The Atterberg limits are determined by the Casagrande method, in accordance with NF P 94-051 [17]. The plasticity index characterizes the extent of the water content range in which soils behave plastically. The limits of liquidity (LL) and plasticity (PL) are determined on the fraction of soil (mortar) passing a 0.40 mm sieve. The plasticity index (PI) is expressed by the following relationship:

$$PI = LL - PL \quad (1)$$

2.2.3. Blue Value of a Soil

The measurement of methylene blue adsorption capacity of a soil consists of measuring the quantity of methylene blue adsorbed by the 0/5 mm fraction of material suspended in water. This test makes it possible to characterize the clay content (or cleanliness) of a soil. It is a quantity that is directly linked to the specific surface of soil and reflects the overall quantity and quality (activity) of the clay fraction. The methylene blue value of a soil (BVS) is determined by the standard NF P 94-068 [18].

2.2.4. Specific Surface Area

Specific surface area (SSA) refers to the actual surface area of a soil particle as opposed to its apparent surface area. It is of great importance for phenomena involving surfaces, such as water adsorption and absorption. This parameter allows the interpretation of physical characteristics such as shrink-swell potentials. Depending on the geotechnical properties, the specific surface is determined by the following formula:

$$SSA = 20.93 * SBV \quad (2)$$

SSA (m^2/g)—specific surface, BVS (g/100g)—Blue value of a soil.

2.2.5. Cation Exchange Capacity

The cation exchange capacity is the number of cations in the double layer that can be easily replaced or exchanged by other cations per 100 grams of soil. It is determined by the formula:

$$CEC = \frac{BVS * 1000}{374} \quad (3)$$

CEC (meq/100)—cation exchange capacity; BVS (g/100g)—blue value of a soil.

2.2.6. Activity

The "Ac" activity characterizes the mineral constituting the fine particles. When the clay content is sufficiently high, grains larger than two micrometers are embedded in the clay and barely touch each other. The activity can be related to the mineralogy and geology of the soil and defined as the ratio between the plasticity index PI and the clay content CF [1]:

$$AC = \frac{PI}{CF(\%) < 0.002 \text{ mm}} \quad (4)$$

Ac—activity, PI—plasticity index, CF—clay fraction.

2.2.7. Relative Activity

The relative activity is the ratio of the plasticity index to the specific surface area, which defines the role of the specific surface area on the plasticity of soil [19]:

$$RA = \frac{PI}{SSA} \quad (5)$$

RA—relative activity, PI (%)—plasticity index, SSA (m^2/g)—specific surface area.

2.2.8. Surface Activity

Kaolinite and Illite minerals are defined according to the surface activity Sc which is the ratio of the specific surface area to the clay fraction CF, defined by the following formula:

$$Sc = \frac{SSA}{CF} \quad (6)$$

Sc ($m^2/g*10^2$)—surface activity, SSA (m^2/g)—specific surface area, CF (%)—clay fraction.

2.2.9. Cation Exchange Capacity Activity

The minerals Illite and Montmorillonite are defined according to the Cation Exchange Capacity Activity CECA which is the ratio of the cation exchange capacity to the clay fraction is defined by the following formula:

$$CECA = \frac{CEC}{CF} \quad (7)$$

CECA—cation exchange capacity activity, CEC (meq/100)—cation exchange capacity, CF (%)—clay fraction.

3. Results

3.1. Geotechnical Properties of Soils

Figure 1 shows the grain distribution of the twelve soils.

From Figure 1, the clay, silt and sand fractions contained in Table 1 are extracted.

Table 1 shows the particle size fractions of the twelve soils with a clay fraction of CF (32.82% - 70.54%), a silt fraction of SF (14.48% - 24.72%) and a sand fraction of SF (7.35% - 47.03%).

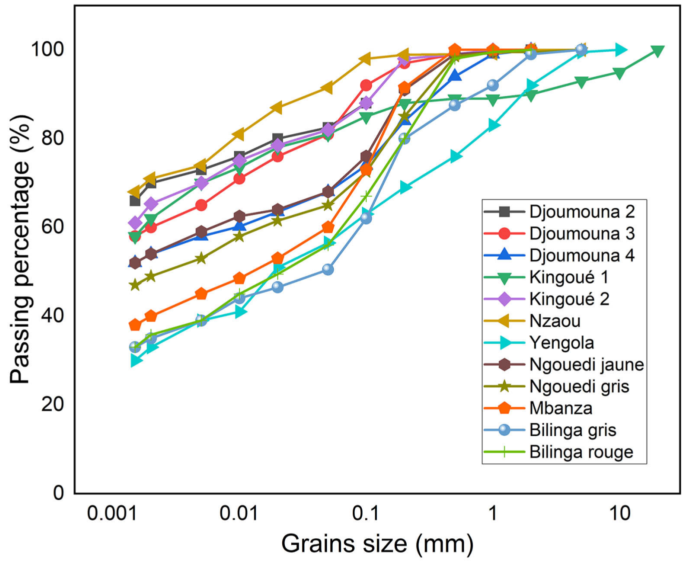

Figure 1. Particle size distribution of soils.

Table 1. Soil particle size fractions.

Soils	Particle size fraction		
	Clay (%)	Silt %)	Sand (%)
Djoumouna 2	69.13	14.48	16.39
Djoumouna 3	59.91	23.27	16.82
Djoumouna 4	53.9	15.18	30.92
Kingoué 1	61.81	19.85	18.34
Kingoué 2	64.54	18.59	16.87
Nzaou	70.54	22.11	7.35
Yengola	32.82	24.72	42.46
Ngouendi jaune	53.92	15.71	30.37
Ngouendi gris	48.87	17.65	33.48
Mbanza	39.85	22.71	37.44
Bilinga gris	34.96	18.01	47.03
Bilinga rouge	35.39	22.7	41.91

Table 2 presents the results of the laboratory tests. These are: LL—liquidity limit, PL—plasticity limit, PI—plasticity index, BVS—blue value of a soil, SSA—specific surface area, CEC—cation exchange capacity.

Figure 2 shows the characterization of the plasticity of twelve soils.

In Figure 2, eight clayey soils of medium plasticity can be distinguished, despite their clay fraction CF (32.82% - 59.91%). Three low plasticity clayey sands, with clayey fractions of CF (61.81% - 70.54%) and one very plastic clayey soil with a clay content of CF (69.13%).

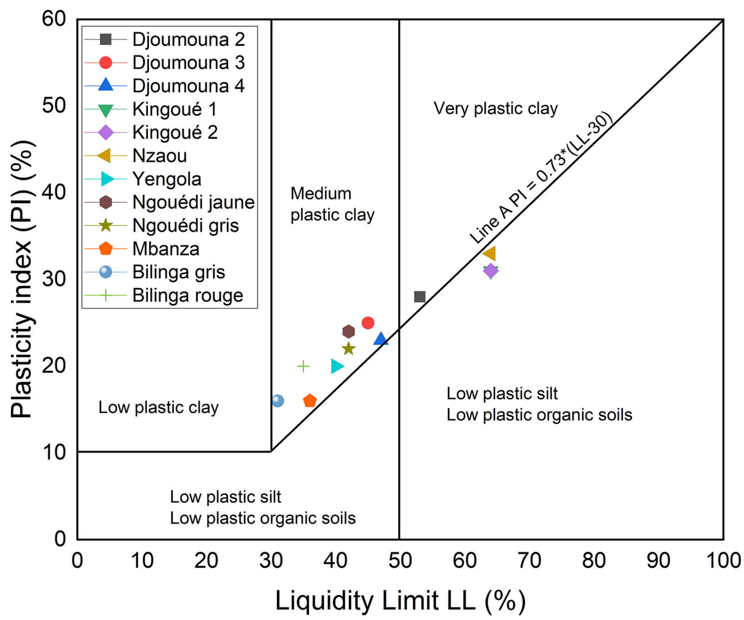

Figure 2. Plasticity of clayey soils.

Table 2. Soil properties.

Soils	LL %	PL %	PI %	BVS (g/100g)	SSA (m^2/g)	CEC (meq/100)
Djoumouna 2	53	25	28	0.81	16.95	2.166
Djoumouna 3	45	20	25	0.71	14.86	1.898
Djoumouna 4	47	24	23	0.64	13.40	1.711
Kingoué 1	64	33	31	0.913	19.11	2.441
Kingoué 2	64	33	31	0.914	19.13	2.444
Nzaou	64	31	33	0.98	20.51	2.62
Yengola	40	20	20	0.54	11.30	1.444
Ngouendi jaune	42	18	24	0.68	14.23	1.818
Ngouendi gris	42	20	22	0.61	12.77	1.631
Mbanza	36	20	16	0.412	8.62	1.102
Bilinga gris	31	15	16	0.41	8.58	1.096
Bilinga rouge	35	15	20	0.54	11.30	1.444

Figure 3 shows the swelling potential of twelve soils (variation in linear volume of the soil due to water absorption).

From **Figure 3**, the swelling potential of the soils is composed as follows: ten soils have a medium swelling potential and liquidity limits of LL (31% - 64%). Two swelling soils have liquidity limits of LL (35% - 40%).

According to **Table 3**, the soils are composed of clays of classes A_2, A_3 or A-7 and clayey sands of classes A_2 and A-2 according to the USCS, GTR 92 and AASHTO classifications [13] [14].

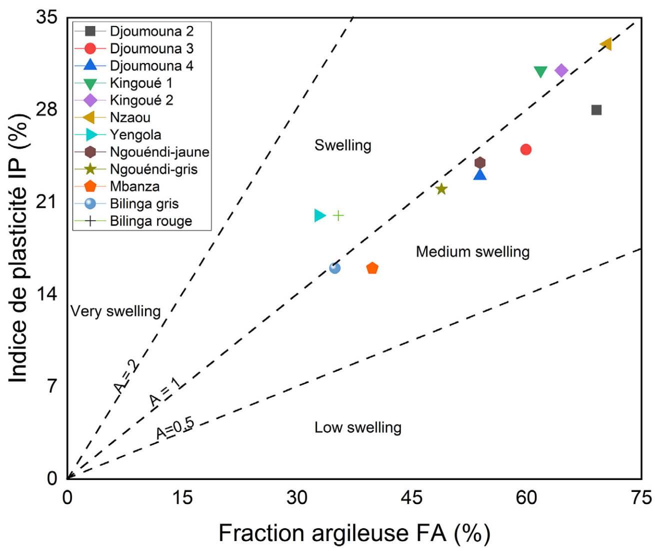

Figure 3. Swelling potential of soils. A—directing coefficients of the straight lines delimiting the areas of weakly swelling, moderately swelling, swelling and very swelling soils.

Table 3. Classification des sols.

Soils	Classification		
	AASHTO	USCS	NF P11-300 [14]
Djoumouna 2	A-7 (A-7-6)	Clay	A_2
Djoumouna 3	A-7 (A-7-6)	Clay	A_2
Djoumouna 4	A-7 (A-7-6)	Clay	A_2
Kingoué 1	A-7 (A-7-5)	Clay	A_3
Kingoué 2	A-7 (A-7-5)	Clay	A_3
Nzaou	A-7 (A-7-5)	Clay	A_3
Yengola	A-2 (A-2-7)	clayey sand	A_2
Ngouendi jaune	A-7 (A-7-6)	Clay	A_2
Ngouendi gris	A-7 (A-7-6)	Clay	A_2
Mbanza	A-7 (A-7-6)	Clay	A_2
Bilinga gris	A-2 (A-2-6)	clayey sand	A_2
Bilinga rouge	A-2 (A-2-6)	clayey sand	A_2

3.2. Activities of the Nine Clays and Three Clayey Sands

Table 4 presents the results of the activities obtained after calculation on the basis of the geotechnical properties contained in Table 1 and Table 2. These are: Ac—activity, Sc ($m^2/g*10^2$)—surface activity, RA—relative activity, CECA—cation exchange capacity activity, Ac/Sc—relationship between activity and surface activity.

Figure 4 shows the activities of active, normal and inactive soil.

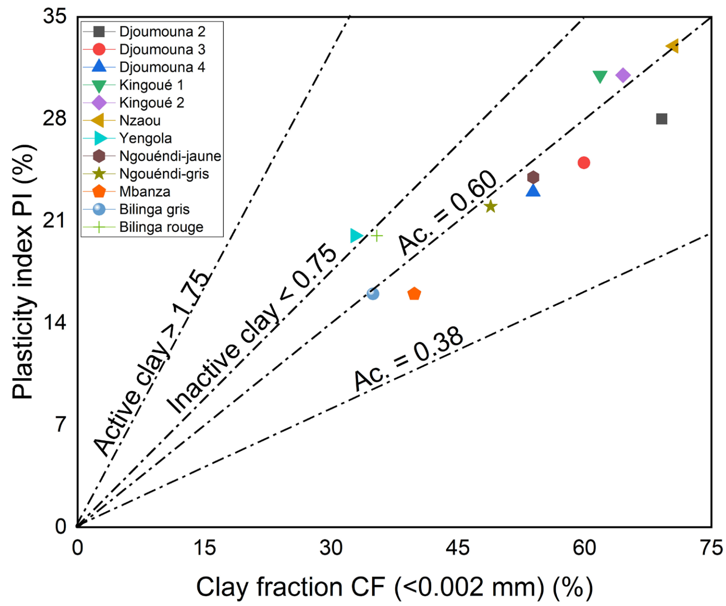

Figure 4. Clayey soils activity. Ac—are the directing coefficients of the straight lines delimiting the areas of activity (inactive, normal and active) of the fine soils.

Table 4. Soils activities.

Soils	Ac	Sc	RA	CECA	Ac/Sc
Djoumouna 2	0.405	0.245	1.652	0.031	1.653
Djoumouna 3	0.417	0.248	1.682	0.032	1.681
Djoumouna 4	0.427	0.249	1.716	0.032	1.715
Kingoué 1	0.502	0.309	1.622	0.039	1.624
Kingoué 2	0.480	0.296	1.620	0.038	1.621
Nzaou	0.468	0.291	1.609	0.037	1.608
Yengola	0.609	0.344	1.770	0.044	1.770
Ngouendi jaune	0.445	0.264	1.687	0.034	1.686
Ngouendi gris	0.450	0.261	1.723	0.033	1.724
Mbanza	0.401	0.216	1.856	0.028	1.856
Bilinga gris	0.457	0.245	1.865	0.031	1.865
Bilinga rouge	0.565	0.319	1.770	0.041	1.771

Nine clayey soils and one clayey sand are inactive, in fact their activities are lower than 0.75. The Yengola clayey sand has a normal activity, higher than 0.75, but lower than 1.75. The rouge Bilinga clayey sand has an activity close to 0.75, that is it has a normal activity.

Figure 5 shows the relative activity that defines the role of the specific surface on soil plasticity.

The relative activity values of 0.2, 0.3, and 0.4 represent the geology of soils sampling sites. These soils have geological formations that change from one sampling site to another. The relative activity depends on the mineralogy of soil.

Figure 6 shows the relationship between activity [1] and surface activity [5].

Figure 8 shows the relationship between activity Ac [1] and the surface activity Sc [8] used to delineate mineralogy, which is another way of defining relative activity [7]. Indeed, three soils (Nzaou, Kingoué 2, Bilinga rouge) have an activity Ac = 0.005*Sc. In other words, these three soils fall on the C-line [8], that is, they have mineralogy close to marine clays [8].

3.3. Mineralogy of the Twelve Soils

Figure 7 shows the Sc surface activities of the twelve soils for the determination of minerals kaolinite and illite.

Using the specific surface area as a function of the clay fraction, the new activity values can be defined. Most natural soils, generally composed of mixed mineral layers, would fall somewhere between the Sc values.

The twelve soils have surface activities Sc above 0.5, but below 3, that is, they contain the mineral kaolinite.

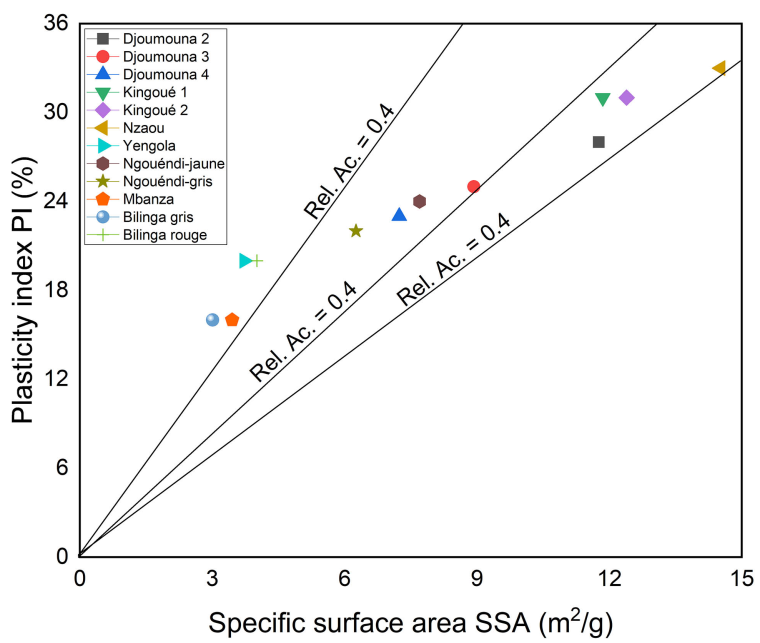

Figure 5. Relative activity of clayey soils. RA—are the directing coefficients of lines delimiting the areas of relative activity.

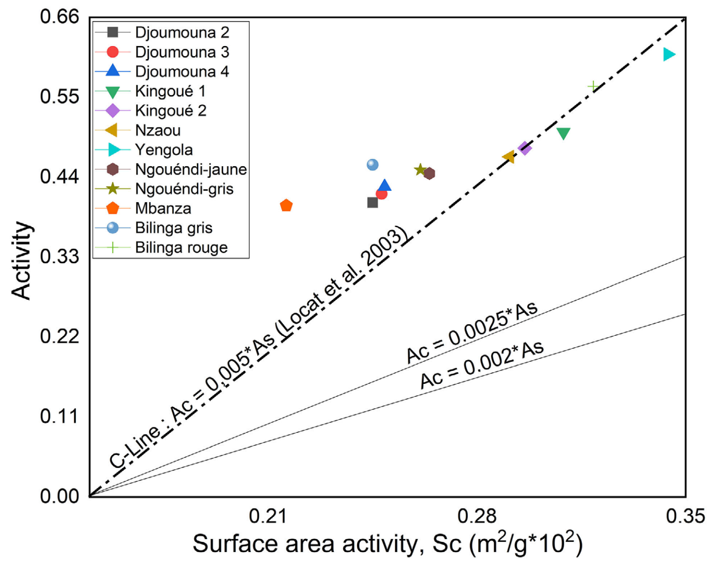

Figure 6. Relationship between activity and surface activity. Ac—are the directing coefficients of the lines delimiting the areas [5].

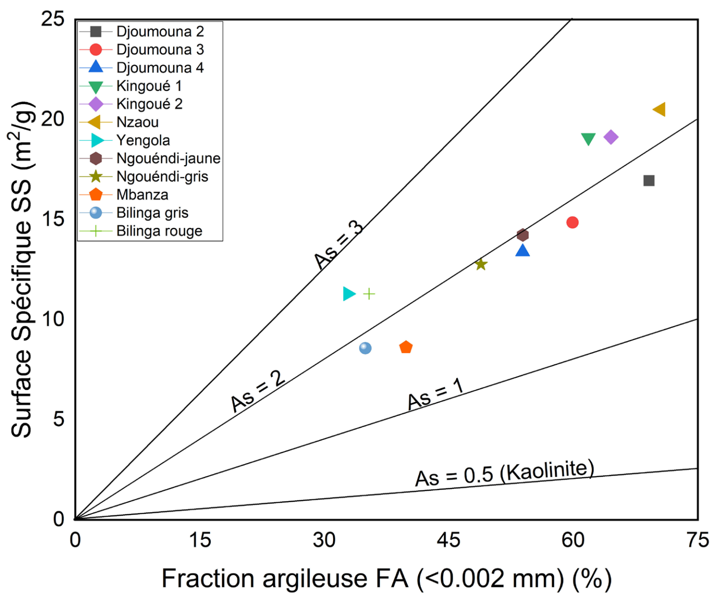

Figure 7. Surface activity of clayey fractions. Sc—are directing coefficients of the straight lines delimiting the areas of the mineralogical formations.

Figure 8 shows the cation exchange capacity normalized by the clay fraction for the determination of the minerals illite and montmorillonite.

Ten soils have a cation exchange capacity activity greater than CECA = 0.25 but, less than CECA = 1, ten soils contain the mineral Illite. In addition, the soils of Yengola and Bilinga red, have a cation exchange capacity activity CECA ≥ 1. The soils contain the minerals illite and montmorillonite. From Figure 6, Figure 7, for a given clay fraction, the specific surface area is proportional to the mineralogy following the order kaolinite < illite < montmorillonite [1].

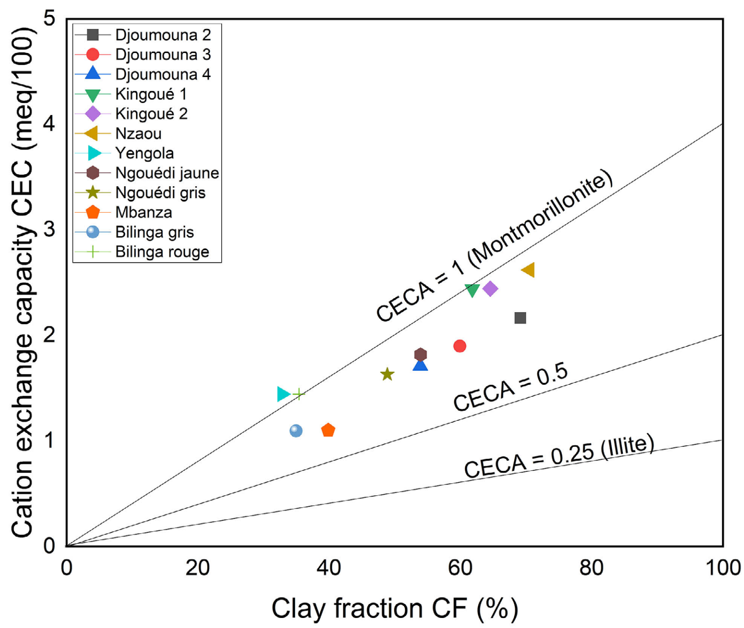

Figure 8. Cation exchange capacity activity as a function of clayey fractions. CECA—are the directing coefficients of the straight lines delimiting the areas of the mineralogical formations (Illite and Montmorillonite).

3.4. Evaluation of the Relationships between the Properties of Clayey Soils

Figure 9 shows the correlation between the surface area activity and activity.

From Figure 9, the evolution of surface activity as a function of activity is a sigmoidal fit of the slogistics model 1:

$$\mathrm{Sc} = \frac{a}{1+\exp\left(-k*\left(\mathrm{Ac}-X_C\right)\right)} \tag{8}$$

$$a = 0.36774 \pm 0.03557$$

$$X_C = 0.35148 \pm 0.01429$$

$$K = 9.8726 \pm 3.84786$$

$$R^2 = 0.881$$

Sc—surface activity, Ac—activity, R^2—coefficient of determination.

Figure 10 shows the correlations between plasticity index and blue value of a soil in function of the specific surface area.

The plasticity index is closely related to the specific surface area. The evolution of the plasticity index as a function of the specific surface is a linear fit.

Plasticity index:

$$\mathrm{PI} = a + b*\mathrm{SSA} \tag{9}$$

$$a = 3.8475 \pm 0.07801$$

$$b = 1.42208 \pm 0.00529$$

$$R^2 = 0.999$$

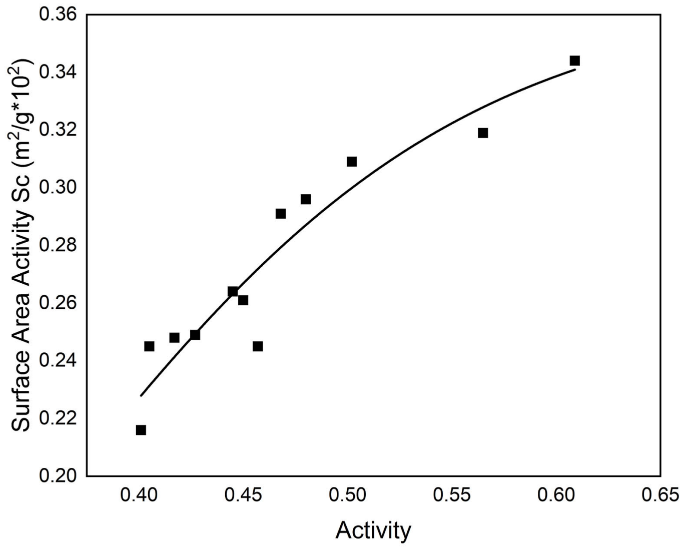

Figure 9. Evolution of the surface activity according to the activity.

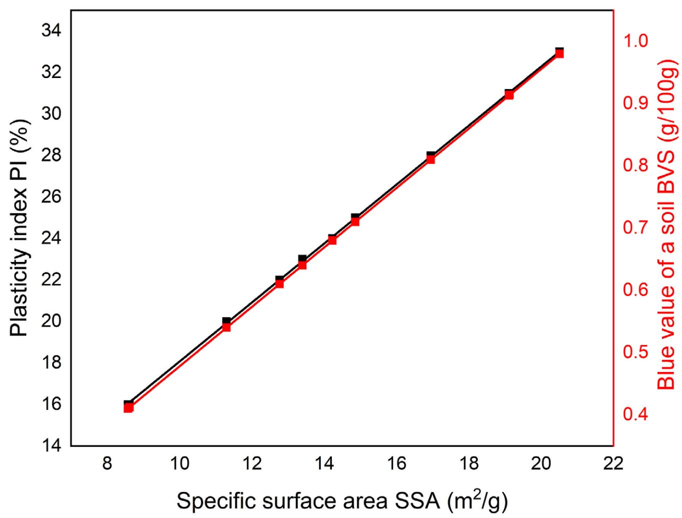

Figure 10. Evolution of the plasticity index and blue value of a soil as a function of the specific surface area.

Blue value of a soil

$$\text{BVS} = a + b * \text{SSA} \tag{10}$$

$$a = 3.84715 \pm 0.07801$$

$$b = 1.42208 \pm 0.00529$$

$$R^2 = 0.999$$

PI (%)—plasticity index, SSA (m^2/g)—specific surface area, BVS—Blue Value of a Soil, R^2—coefficient de détermination.

Figure 11 shows the correlations between relative activity and activity in function of the liquidity limit.

The evolution of relative activity as a function of the liquidity limit is a sigmoidal fit of the logistic model:

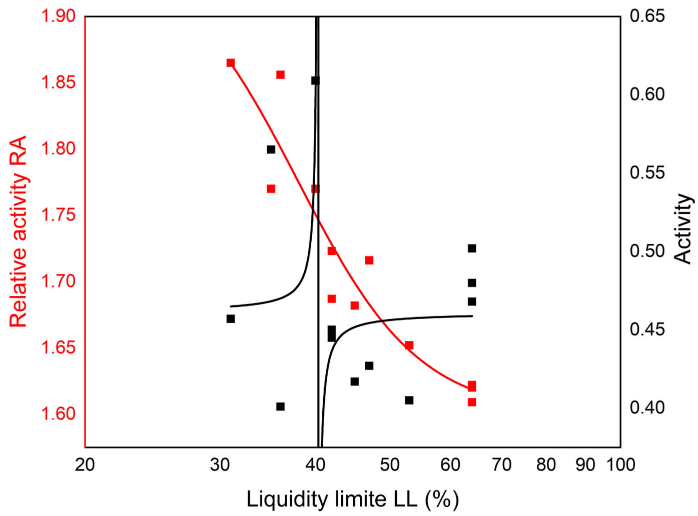

Figure 11. Evolution of activity and relative activity according to the liquidity limit.

$$\mathrm{RA} = A_2 + \frac{A_1 - A_2}{1 + \left(\frac{\mathrm{LL}}{X_0}\right)^p} \tag{11}$$

$$A_1 = 1.95232 \pm 0.23371$$

$$A_2 = 1.59978 \pm 0.05258$$

$$X_0 = 37.91619 \pm 8.69189$$

$$p = 5.47909 \pm 4.96906$$

$$R^2 = 0.859$$

The evolution of activity as a function of the liquidity limit is an exponential fit in the Exp3P1 model:

$$A_c = \exp\left(\frac{a+b}{\mathrm{LL}+C}\right) \tag{12}$$

$$a = -0.7754 \pm 0.03526$$

$$b = -0.08929 \pm 0.11079$$

$$c = -40.31886 \pm 0.42032$$

$$R^2 = 0.406$$

RA—relative activity, A_C—Activity, LL (%)—liquidity limit.

Figure 12 shows the correlation between the blue value of a soil and the liquidity limit.

From Figure 11, the evolution of blue value of a soil versus liquidity limit is a Sigmoidal fit of the Slogistic1 Model:

Blue value of a soil:

$$\mathrm{BVS} = \frac{a}{1 + \exp\left(-k * \left(\mathrm{LL} - X_C\right)\right)} \tag{13}$$

$$a = 1.09246 \pm 0.14855$$

$$X_C = 38.55063 \pm 4.0704$$

$$K = 0.07019 \pm 0.02226$$

$$R^2 = 0.923$$

BVS (g/100g)—blue Value of a Soil, LL (%)—liquidity limit, R^2—coefficient de détermination.

Figure 13 shows the correlations between specific surface area and cation exchange activity in function of the liquidity limit.

From Figure 12, the evolution of specific surface area and cation exchange capacity versus liquidity limit is a Sigmoidal fit of the Slogistic1 Model:

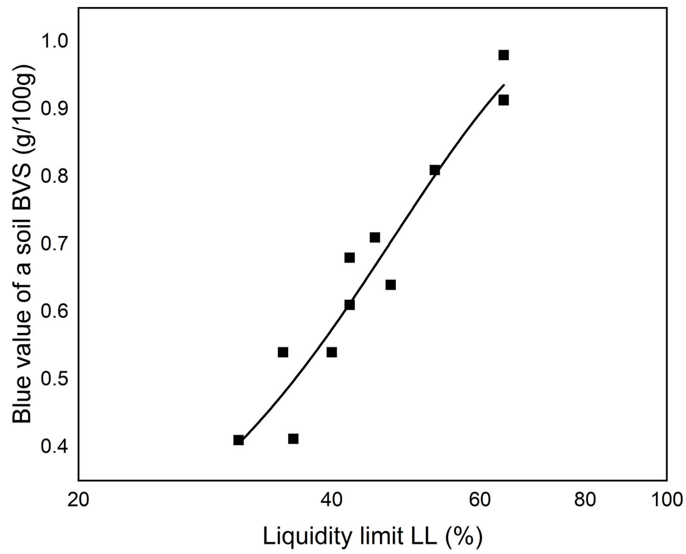

Figure 12. Evolution of Blue Value of a soil in function of the liquidity limit.

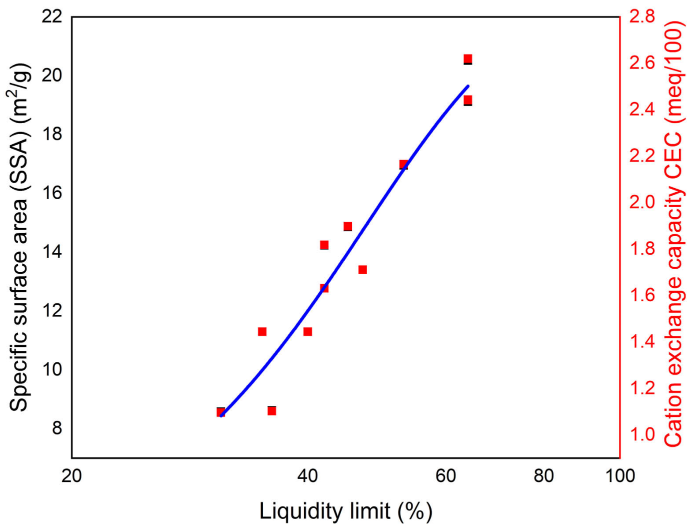

Figure 13. Evolution of the specific surface area and the cation exchange capacity in function of the liquidity limit.

$$\mathrm{SSA} = \mathrm{CEC} = \frac{a}{1 + \exp\left(-k * \left(\mathrm{LL} - X_C\right)\right)} \tag{14}$$

$$a = 2.92102 \pm 0.39701$$

$$X_C = 38.55063 \pm 4.06915$$

$$K = 0.07018 \pm 0.02224$$

$$R^2 = 0.923$$

SSA (m^2/g)—specific surface area, CEC (meq/100)—cation exchange capacity, LL (%)—liquidity limit, R^2—coefficient of determination.

4. Discussion

From **Table 1**, **Table 2**, the soils of Djoumouna 4 and Ngouéndi jaune, despite the fact that they have the same clay fraction CF (53.9%), their respective specific surface areas SSA (13.14 m^2/g, 14.23 m^2/g) are different [2] [7]. This disparity is related to the particle size distribution, mineralogical and organic composition of soils [6] [20].

From **Table 2**, the soils of Mbanza and Bilinga gris, two clayey sands that have specific surface areas of SSA (8.58 - 8.62 m^2/g). The other ten clay soils have specific surface areas SSA (11.30 - 20.51 m^2/g) which are in agreement with the SSA (10 - 40 m^2/g) [21] and SSA (15 - 26 m^2/g) [2].

From **Table 1**, **Table 2**, **Table 4**, the soils of Djoumouna 4 and Ngouédi jaune have the same clay fraction CF (53.9%), the Ngouédi jaune soil has the highest activity and plasticity index respectively of Ac (0.445, 0.427) and PI (24%, 23%) [2].

The Yengola and Bilinga rouge soils have the same plasticity index PI (20%), their respective clay fractions CF (32.82%, 35.39%) are different. Both soils have the same specific surface area SSA (11.30 m^2/g) [7]. The soils of Mbanza and Bilinga gris have the same PI (16%), their clay fractions CF (39.85%, 34.96%) are different and their specific surface areas SSA (8.62 m^2/g, 8.58 m^2/g) are close [7]. The soils of Kingoué 1 and Kingoué 2 have the same plasticity index PI (31%), their clay fractions are different CF (61.81%, 64.54%) and their specific surface areas SSA (19.11 m^2/g, 19.13 m^2/g) are close [7].

From **Table 4**, the ratio of activity [1] to surface activity [8] is just another way of defining relative activity which is the ratio of plasticity index to specific surface [7].

According to **Figure 2**, **Figure 3**, **Figure 7**, **Figure 8**, the Yengola and Bilinga gris soils are swelling clayey sands, composed of minerals (kaolinite, illite, montmorillonite). A previous study detected the minerals illite in the Yengola soil and kaolinite in the Bilinga gris soils [22].

From **Figure 6**, the C-line [8] depends on the geology and mineralogy and therefore may not be a good indicator to describe the mineralogy [2].

From **Figure 4**, **Figure 7**, ten soils containing the minerals (kaolinite, illite) are inactive, that is, they hardly absorb water. The use of these soils for brick making requires the use of a binder (stabilizer) to improve their mechanical properties [23] [24].

From **Figure 7**, the presence of kaolinite in soils is of great necessity especially for the manufacture of Adobes bricks. Indeed, clay is known for its crystallizing properties, *i.e.* playing the role of mortar especially when the soil contains organic matter [25]. It can also play a role in improving the mechanical strength of clay soils [22].

From **Figure 7**, **Figure 8**, of the twelve soils that show similar mineralogy (kaolinite, illite), only three soils fall on the C-line [8], whereas the marine clays that probably have mineralogy (mainly illite) show a linear relationship between plasticity index and specific surface area [8].

From **Figure 8**, all twelve soils contain illite which is an important mineral in the composition of soils, especially for manufacturing (bricks, tiles and pottery). Illite favours sintering at a relatively low temperature [26].

From **Figure 9**, the activity [1] and surface activity [8] are normalized by the clay fraction, both parameters are linearly correlated [7] [19].

From **Figure 7**, **Figure 8**, **Figure 10** and **Table 2**, the evolution of the plasticity index as a function of the specific surface area of twelve soils containing all minerals (kaolinite and illite), is a linear fit [6] [7] [19].

From **Figure 9**, **Figure 10**, the linear plot of activity [1] versus surface activity [8], suggests that, the range of water content from the liquidity limit to the plasticity limit is essentially controlled by the specific surface area [8], linked to the liquidity limit.

The evolution of the parameters contained in **Figures 11-13** assumes that they depend on the range of water content from the liquidity limit to the plasticity limit which is essentially controlled by the specific surface area [8].

From **Figure 12** and **Figure 13**, the evolution of the blue value of a soil as a function of the liquidity limit is none other than, the evolutions of the specific surface area and the cation exchange capacity as a function of the liquidity limit. Indeed, the blue value of a soil is closely related to the cation exchange capacity and the specific surface. Indeed, it has been shown that the specific surface as a function of the cation exchange capacity forms a linear fit [6] [19].

5. Conclusion

The laboratory results show that the particle size curves of the soils are spread out and that their particle size fractions consist of clay, silt and sand. The clayey sands and clays have a plasticity that varies from moderate to very plastic. Some soils are inactive and others have normal activity with a swelling potential that varies from medium to swelling. Ten soils contain minerals (kaolinite, illite) and two swelling soils contain minerals (kaolinite, illite and montmorillonite). The specific surface area of the clayey sands varies from SSA (8.58 - 8.62 m^2/g) and that of the clayey soils from SSA (11.30 - 20.51 m^2/g). Activity provides an approximate method for determining mineralogy, whereas the plasticity index is not really an intrinsic property of fine soils. The relationship between activity and surface activity simplifies to a relative activity. This relationship does not explain the behaviour of clays better than the relative activity. Of the twelve soils studied, only three are on the C line, defined as Ac = 0.005*As. For two soils with the same clayey fraction, the more active soil has the higher plasticity index. Two soils with the same plasticity index, but different clayey contents, have different specific surface areas depending on the clay mineralogy. Two soils with the same plasticity index, but different clay fractions, have the same specific surface. The evolution of surface activity as a function of activity is a sigmoidal fit with a determination coefficient of R^2 (0.881). The evolution of the plasticity index and the blue value of soil as a function of the specific surface is a linear fit, with R^2 (0.999). The evolution of relative activity and activity as a function of the liquidity limit are respectively sigmoidal and exponential fits with R^2 (0.859, 0.406). The evolution of specific surface area, cation exchange capacity and blue value of a soil versus liquidity limit is a Sigmoidal fit, with R^2 (0.923).

Conflicts of Interest

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

References

[1] Skemptom, A.W. (1953) The Colloidal "Activity" of Clays. *Proceedings of the* 3*rd International Conference of Soil Mechanics and Foundation Engineering*, Switzerland, 16-27 August 1953, 57-60. http://books.google.com

[2] Cerato, A. and Lutenegger, A.J. (2005) Activity, Relative Activity and Specific Surface Area of Fine—Grained Soils. *Proceedings of the* 16*th International Conference of Soil Mechanics and Geotechnical Engineering* (*ICSMGE*), Vol. 2, Osaka, 12-16 September 2005, 325-328.

[3] Dolinar, B. and Trauner, L. (2004) Liquid Limit and Specific Surface of Clay Particles 2004. *Geotechnical Testing Journal*, **27**, 580-584. https://doi.org/10.1520/GTJ11325

[4] Uchechukwu, T.O., Chukwu, U.J. and Akaranta, O. (2021) Competitive Adsorption of Metal Ions on Peanut Testa (*Arachis hypogaea* L.) Extract Using Cation Exchange Resins. *Open Access Library Journal*, **8**, Article No. e7575. https://doi.org/10.4236/oalib.1107575

[5] Mehta, B. and Sachan, A. (2017) Effect of Mineralogical Properties of Expansive Soil on Its Mechanical Behavior. *Geotechnical and Geological Engineering*, **35**, 2923-2934. https://doi.org/10.1007/s10706-017-0289-6

[6] Ahouet, L., Ngoulou, M.O., Ndinga Okina, S. and Kimbatsa, F.T. (2022) Study of the Relationship between the Fundamental Properties of Fine Soils and Those of Mathematical Models of Particle Size Distribution and Geotechnical Quantities. *Arabian Journal of Geosciences*, **15**, Article No. 1173. https://doi.org/10.1007/s12517-022-10378-x

[7] Quigley, R.M., Sethi, A.J., Boonsinsuk, P., Sheeran, D.E. and Yong, R.N. (1985) Geologic Controls on Soil Composition and Properties, Lake Ojibway Clay Plain, Matagami, Quebec. *Canadian Geotechnical Journal*, **22**, 491-500.

https://doi.org/10.1139/t85-069

[8] Locat, J., Tanaka, H., Tan, T.S., Desari, G.R. and Lee, H. (2003) Natural Soils: Geotechnical Behavior and Geologic Knowledge. *Characterization and Engineering Properties of Natural Soil*, No. 1, 3-28.

[9] Loubouth, S.J.M., Ahouet, L., Elenga1, R.G., Okina, S.N. and Kimbembe, P.L. (2020) Improvement of the Geotechnical Properties of the Soil of Lime-Treated Cubitermes Mound Soil. *Open Journal of Civil Engineering*, **10**, 22-31. https://doi.org/10.4236/ojce.2020.101003

[10] Ahouet, L., Elenga, R.G., Bouyila S., Ngoulou M. and Kengué, E. (2019) Improvement of Geotechnical Properties of Lateritic Gravel by Adding Crushed Alluvial Gravel 0/31,5. *African Journal Portals*, **3**, 1-6. http://publication.lecames.org

[11] Polidori, E. (2009) Reappraisal of the Activity of Clays. Activity Chart. *Soils and Foundations*, **49**, 431-441. https://doi.org/10.3208/sandf.49.431

[12] Onyelowe, K.C., Onyia, M.E., Van, D.B., Baykara, H. and Ugwu, H.U. (2021) Pozzolanic Reaction in Clayey Soils for Stabilization Purposes: A Classical Overview of Sustainable Transport Geotechnics. *Advances in Materials Science and Engineering*, **2021**, Article ID: 6632171. https://doi.org/10.1155/2021/6632171

[13] Chrétien, M., Fabre, R., Denis, A. and Marache, A. (2007) Search for Optimal Geotechnical Identification Parameters for a Classification of Soils Susceptible to Shrink-Swell. *Revue Française de Géotechnique*, No. 120-121, 91-106. https://doi.org/10.1051/geotech/2007120091

[14] NF P 11-300 (1992) Construction of Earthworks—Classification of Materials for Use in the Construction of Embankments and Subgrades of Road Infrastructure.

[15] NF P 94-056 (1996) French Standard. Soils: Recognition and Tests. Granulometric Analysis. Method by Dry Sieving after Washing, Association Française de Normalisation, 5-15.

[16] NF P94-057 (1992) French Standard. Soils: Recognition and Tests. Granulometric Analysis. Sedimentation Method, Association Française de Normalisation, 4-17.

[17] NF P94-051 (1993) French Standard. Soils: Recognition and Tests. Determination of Atterberg Limits. Limit of Liquidity at the Cup-Limit of Plasticity at the Roller. Association Française de Normalisation, 4-14.

[18] NF P94-068 (1998) French Standard. Soils: Investigation and Testing—Measuring of the Methylene Blue Adsorption Capacity of a Rocky Soil. Determination of the Methylene Blue of a Soil by Means of the Strain Test, October 1998.

[19] Ahouet, L., Ngoulou, M.O., Okina, S.N. and Dzaba, S. (2022) Geotechnical Characterization of Termite Mound Soils of Congo. *Open Journal of Civil Engineering*, **12**, 370-389. https://doi.org/10.4236/ojce.2022.123021

[20] Elenga, R.G., Ahouet, L., Ngoulou, M., Bouyila, S., Dirras, G.F. and Kengué, E. (2019) Improvement of an Alluvial Gravel Geotechnical Properties with a Clayey Soil for the Road Construction. *Research Journal of Applied Sciences*, *Engineering and Technology*, **4**, 135-139. https://doi.org/10.19026/rjaset.16.6017

[21] Mitchell, J.K. and Soga, K. (1976) Fundamentals of Soil Behavior. 3rd Edition, 561 p. https://kupdf.net/

[22] Elenga, R.G., Mabiala, B., Ahouet, L., Goma Maniongui, J. and Dirras, G.F. (2011) Characterization of Clayey Soils from Congo and Physical Properties of Their Compressed Earth Blocks Reinforced with Post-Consumer Plastic Wastes. *Geomaterials*, **1**, 88-94. https://doi.org/10.4236/gm.2011.13013

[23] Doat, P., Hays, A., Houben, H, Matuk, S. and Vitaux, F. (1979) Application Research

Centre—Earth (CRATTERRE), EYBENS. Alternative and Parralleles, Paris, 263 p.

[24] Guillaud, H. (2008) Characterization of Earthen Materials. Terra Literature Review. An Overview of Research in Earthen Architecture Conservation. getty.edu.

[25] Millogo, Y., Hajjaji, M. and Morel, J.C. (2011) Physical Properties, Microstructure and Mineralogy of Termite Mound Material Considered as Construction Materials. *Applied Clay Science*, **52**, 160-164. https://doi.org/10.1016/j.clay.2011.02.016

[26] Kam, S., Zerbo, L., Bathiebo, J., Soro, J., Naba, S., Wenmenga, U., Traoré, K., Gomina, M. and Blanchart, P. (2009) Permeability to Water of Sintered Clay Ceramics. *Applied Clay Science*, **46**, 351-357. https://doi.org/10.1016/j.clay.2009.09.005