

Physicochemical and Mineralogical Characterization of Clay Materials in the Douala Coastal Sedimentary Sub-basin (Cameroon, Central Africa)

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Abstract This study is focused on the physicochemical and mineralogical characterization of five different clay materials of Eastern part of Douala sub-basin. It aims to know the nature and geotechnological properties of the clay raw materials in order to raise the idea of their potentialities in industrial applications. The samples were subjected to several analyses such as geotechnical tests notably the particle size distribution, the Atterberg limits, the swelling index, the chemical (cation exchange capacity, pH-H₂O and pH-KCl, X-ray fluorescence) and mineralogical (X-ray diffraction) analyses. These clay materials showed high fine fractions (up to 99%) and high plasticity index (15 to 63%). The swelling index is medium (16 to 20) and the CEC moderate (30 - 40), indicating the presence of a small proportion of swelling 2:1 type clays. The clay materials are predominantly constituted by kaolinite (32 – 72%), quartz (20.2 - 50.7%) and illite (4.6 – 10%), which are characteristic of the sedimentary environment and morphoclimatic conditions of the Douala coastal sedimentary sub-basin. The predominant oxides in clay materials are SiO₂ (34.05 - 51.18%) and Al₂O₃ (16.05 - 23.98%). Iron oxide Fe₂O₃ is moderate (1.55 - 11.22%) and alkali and alkaline earth oxides are weak less than 2%. The physicochemical parameters associated with mineralogical and geochemical data make them suitable for ceramic applications and also serve as backfilling materials in building constructions when improved by adding sand.

Keywords: clay materials, Douala coastal sedimentary sub-basin, mineralogical, physicochemical, Cameroon

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1. Introduction

Several physicochemical and mineralogical properties of clay materials give them a wide spectrum of applications in industrial fields [1]. In addition to the manufacture of building materials, they are used for example, for the development of polymeric materials or the refining of edible oil, cosmetics or medicine [2,3,4,5,6]. Clays are part of industrial materials, minerals and rocks, which have economic value and whose physical or chemical properties are used in various uses, products or industrial processes. They can be used in the raw state or modified by some treatments in industry after their extraction. However, several studies have been conducted on clay materials in Cameroon. On the one hand, they concern their genesis and paleo-environment of deposits [7-13] and their characterizations to several and

varied applications [3,14-20]. Thus, the valorisation of local clay materials less expensive and available in developing countries can have a very positive impact on the development of the economy both locally and nationally. The satisfaction of local or national demand can not only promote the development of supply by multiplying production units and thus the creation of jobs, but can also slow down imports of finished or semi-finished clay-based products. In the coastal region of Cameroon, the clay raw materials of Yansoki (Eastern part of Douala sub-basin) are exploited by the local population for backfilling the shallows in construction. These materials of continental and marine sedimentary origin are in abundance in the locality and easily exploitable [21,22,23,24].

The interest of these clay raw materials is therefore not known to all by the local population through their uses as base layers for construction. In the context of the implementation of a sustainable approach using local clay

resources and less expensive for several industrial needs, the present study seeks to determine the physicochemical and mineralogical characterization of the clays materials of the Douala coastal sedimentary sub-basin in order to conclude on the possibility of their valorisation to industrial applications.

2. Geological and Geographical Setting

The study area has geographical coordinates of $3^{\circ}10' - 4^{\circ}12' N$ latitude and $9^{\circ}50' - 9^{\circ}52' E$ longitude and is located on the south-eastern edge of the Douala coastal sedimentary sub-basin. The Douala sub-basin is interspersed between the Kribi-Campo sub-basin to the south and the Rio Del Rey basin to the north. The outcropping geological entities are composed of continental and marine sedimentary formations of Cretaceous, Tertiary and Quaternary ages locally covered with lateritic cuirasses [25,26,27,28] (Figure 1). They consist of: (1) the Mundeck Formation (Aptian Cenomanian), (2) the Logbadjeck Formation (Cenomanian-Campanian), (3) the

Logbaba Formation (Maastrichtian), (4) the N'kapa Formation (Paleocene-Eocene), (5) the Souellaba Formation (Oligocene), (6) the Matanda Formation (Miocene) and (7) the Wouri Formation (Plio-Pleistocene). Sedimentary formations are related to the three stages of geodynamic and sedimentary evolution that have affected basins since the opening of the South Atlantic Ocean [25,26,27,29].

The study area is characterized by a low erosion area (< 200 m altitude) under the action of climate, which is humid tropical and promotes the weathering of the materials to the formation of ferrallitic and hydromorphic soils. Ferrallitic soils are thick and mainly made up of kaolinite, quartz, gibbsite, hematite, goethite and accessory minerals such as rutile, muscovite-illite, smectites, and magnetite [30,31,32]. The local geology of Yansoki and its surroundings corresponds to the N'kapa Formation (Paleocene-Eocene), the Matanda Formation (Miocene) and the Wouri Formation (Plio-Pleistocene) [7,29]. These formations are composed of clays, silts and sands sometimes associated with organic matter.

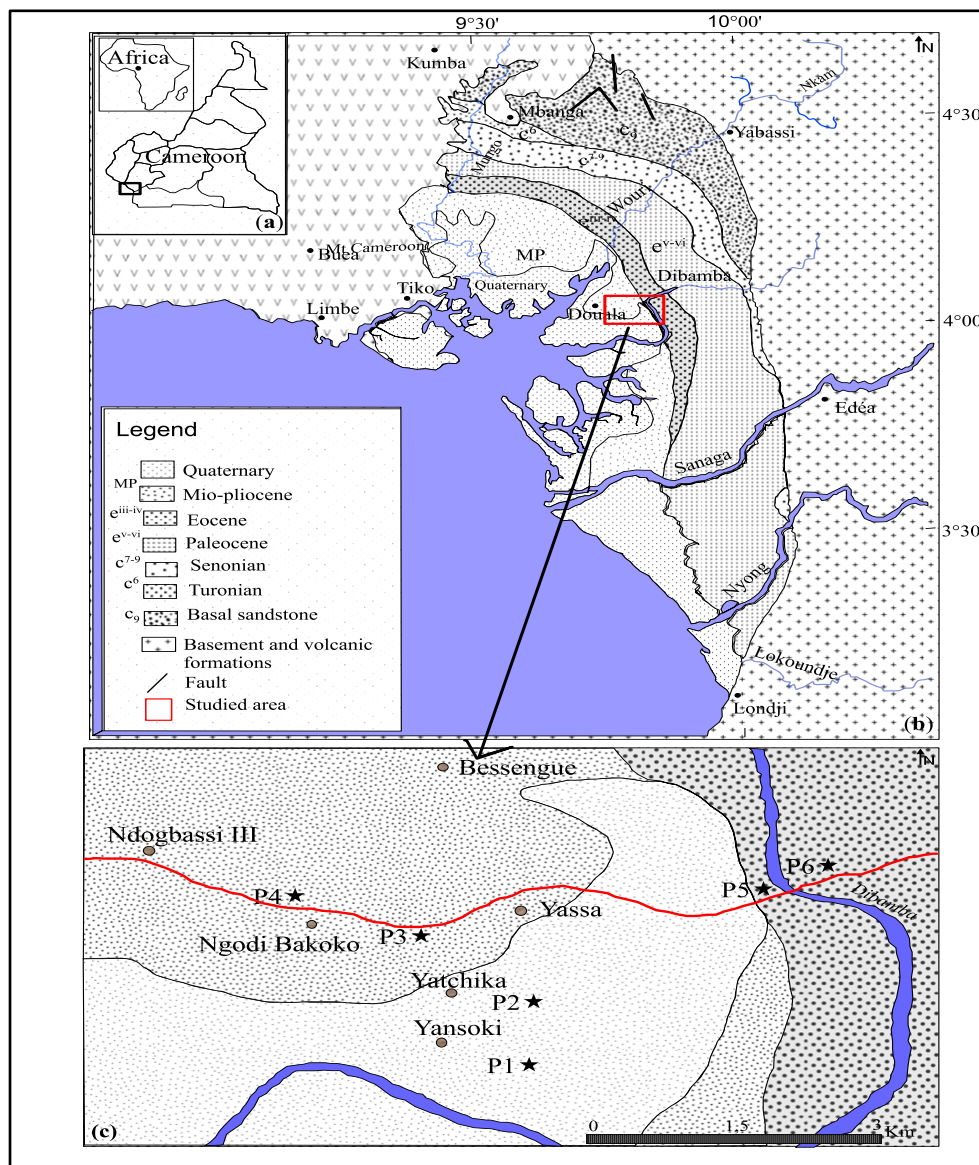


Figure 1. Geological map of Douala modified [29]: (a) Location map of the Douala sub-basin in Cameroon; (b) Geological map of the Douala sub-basin including the study site; (c) Geological map of the study area

3. Materials and Methods

3.1. Sampling Techniques

The lithological sections of Yansoki were made on continental and marine sedimentary formations origin. These formations are composed of layers with sands, silts and clays fractions covered by nodular gravel, clay-sandy and sandy-clay horizons. Six (06) profiles were made during the excursions and only two representative profiles of the study area have been presented in this study (P1 and P4) (Figure 1C). Profiles were made according to their morphology in the study area and the available positions. After the careful description of the profiles carried out,

samples were taken manually using the trowel as sampling material in the center of the different clay layers identified. Samples were taken according to their colour, texture and structure. Five clay facies have been identified: dark grey clays, light grey clay, purplish clay, colourful clay and yellow clay (Figure 2). The samples collected were prepared for laboratory analysis. This made it possible to homogenize different samples belonging to the same facies and to have five representative samples named as follows: Fgc (light gray facies), Fvi (purplish facies), Fja (yellow facies), Fgs (dark gray facies) and Fba (coloured facies). On the five samples representing these facies underwent extensive analyses, namely the physicochemical, mineralogical (DRX) and geochemical (XRF) analysis.

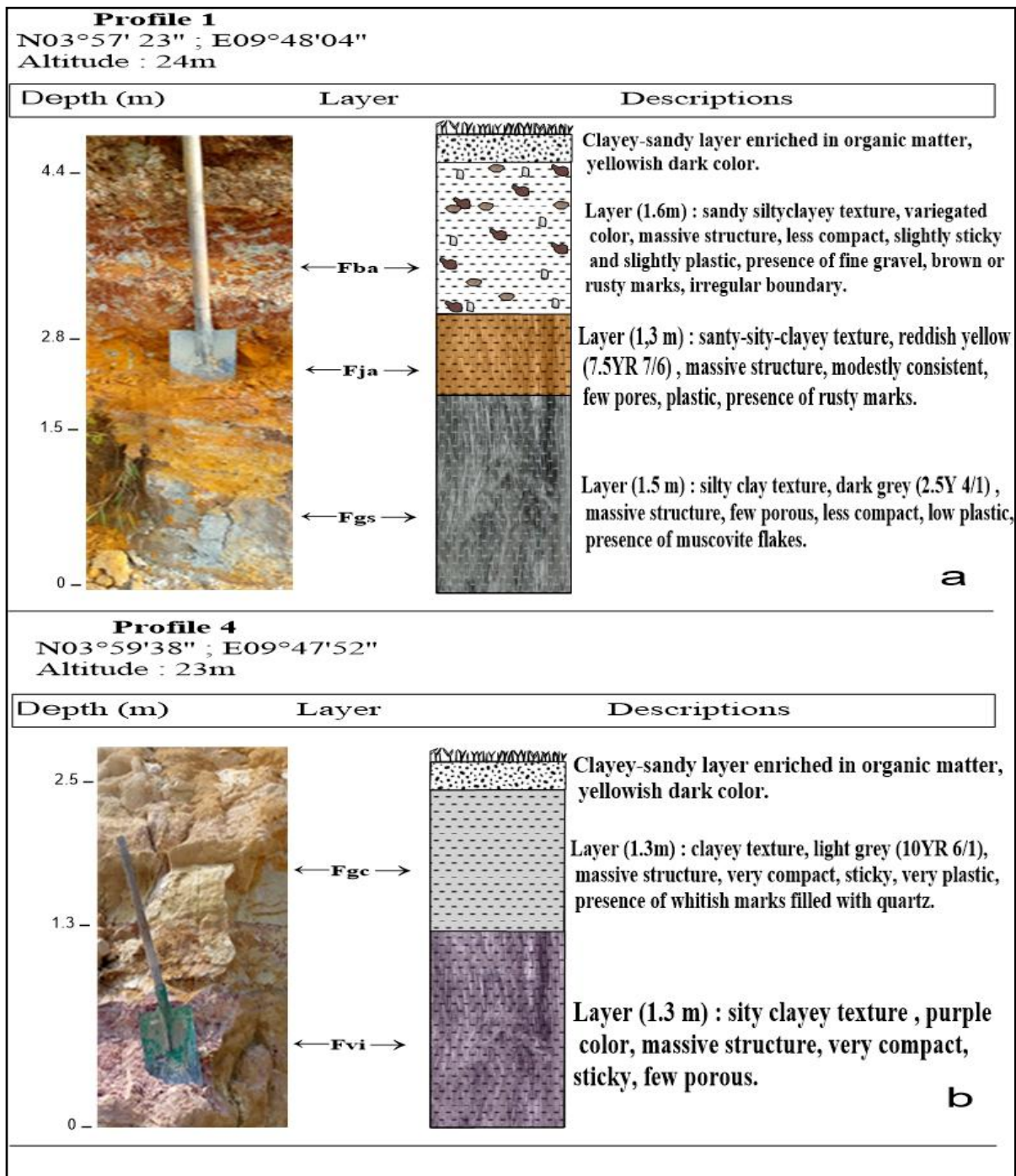


Figure 2. Profiles of the studied area showing the disposition of different layers: a) profile 1; b) profile 4

3.2. Analytical Techniques

The physicochemical properties have been determined at the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang and Local Materials Promotion Authority (MIPROMALO) in Yaoundé, Cameroon. They concern: particle size, Atterberg limits, swelling index (T), Cation Exchange Capacity (CEC) and Organic Matter (OM).

The particle size distribution of clay materials was obtained by wet sieving, according to NFP 94-093 French standard [33], using the sodium hexametaphosphate (NaPO₃, 5wt%) as dispersive agent. The plastic behaviour of clay materials was determined using the Atterberg limits according to NFP 94- 051 French standard [33]. Liquid limit (LL) and plastic limit (PL) were measured by the Casagrande apparatus for the size under 400µm. The plasticity index was determined by arithmetic difference between LL and PL following the formula:

$$PI(\%) = LL - LP \quad (1)$$

The swelling index (T) was obtained by measuring V1 volume of 20g of steamed powder at 105 °C for 24 hours and the V2 volume of the same powder in 100 mL of distilled water for 24 hours. The rate of swelling index is thus obtained by the equation:

$$T = 100 * (V2 - V1) / V1 \quad (2)$$

The Cation Exchange Capacity (CEC) was obtained by the [34] method, using ammonium acetate at pH 7 in three phases : saturation of the absorbent complex by NH₄⁺ ions and extraction of exchangeable bases; washing the floor with alcohol to remove excess NH₄⁺ ions; determination of NH₄⁺ by Kjéldahl distillation after desorption from a KCL solution.

pH measurement took place in two steps: firstly, measuring the active (or real) acidity (pH in water or pH-H₂O) and secondly, measuring the potential acidity (pH-KCl). For pH-H₂O, 10g of the specimen was mixed with 25ml of water and agited and there after left to stand for 24 hours before using a pH meter to measure the pH values. For the pH-KCl, 10g of the specimen was mixed with 25ml of a solution of KCl, agitated and left to stand before measuring the pH with a pH-meter. The pH-KCl is generally less than pH-H₂O. The gap between these two pH values makes it possible to determine the reserve (or total) acidity of clayey materials.

The Organic matter (OM) was determined using the [35] Method. The organic matter content is obtained by multiplying the organic carbon content by the Sprengel factor which is 2.

The mineralogical analyses was done precisely in the clay, geochemistry and sedimentary environments (AGES) research unit of the University of Liège in Belgium. The Bruker Advance D8 diffractometer (copper radiation K α 1, $\lambda = 1.5418\text{\AA}$, V = 40 kV, I = 30 mA) was used in this study according to the methodology of [36]. The diffractograms are obtained from the total fractions of the disoriented powders (the measurements in 2 θ range from 2° to 45° with a scanning pitch size of 0.02° and a time per step of 2s). The mineral phases present in the studied samples were better identified with the Origin Pro.9.

Qualitative and semi-quantitative estimates were obtained by the Biscaye method in [37].

The geochemical composition of the bulk clay materials was carried out at the Laboratory of Cimencam of Figuil in Cameroon, Lafarge group, France by X-ray fluorescence spectrometry using a philips XRFSPW1404 spectrometer. The Chemical Index of Alteration (CIA) [38] is calculated by the following formula:

$$CIA(\%) = \left[Al_2O_3 / \left(\frac{Al_2O_3 + CaO}{+Na_2O + K_2O} \right) \right] * 100 \quad (3)$$

4. Results and Discussion

4.1. Morpho-structural Organisation of Weathering Profiles

The study area is constituted by sedimentary deposits and dominated by silty-clays with different colours. The choice of sampling was mainly done for clay materials. The two representative profiles were described following their colour, texture and structure:

Profile P1 (Figure 2a) with coordinates N03°57'23" latitude and E09°48'04" longitude comprises three layers from bottom to top: the first layer (1.5m thick) is dark grey (Fgs: 2.5Y 4/1), weakly compact and has silty-clay texture, massive structure, low plasticity, moderately porous, muscovite platelets. The second layer (1.6m thick) is yellow (Fja: 7.5YR 7/6), and has sandy-silty clayey texture, massive structure, moderately consistent, weakly porous plastic with rust marks. The third layer (1.3m thick) is colourful or multicolour (Fba: 10YR 6/4 for gray nodules; 10YR5/6 for yellowish-brown nodules), weakly compact, slightly sticky and has silty-clay texture, massive structure, some gravels, brown or rusty markings, irregular boundary. The whole of the three layers is covered with a soil of sandy-clay texture, yellowish black color, with the presence of plant roots, traces of microorganisms and organic matter;

Profile P4 (Figure 2b) with coordinates N03°59'38" latitude and E09°47'52" longitude includes two main clay layers consisting from bottom to top: the first layer (1.3m thick) is purplish (Fvi: 2.5Y 4/1), very compact, very plastic, strongly sticky, moderately porous and has silty-clay texture, massive structure. The second layer (1.2m thick) is light gray colour (Fgc: 10YR 6/1), very plastic, very sticky and has clay texture, massive structure, low porosity, regular boundary with the previous layer. All the layers are covered with a soil of sandy-clay texture, yellowish black color, with the presence of plant roots, traces of microorganisms and organic matter.

4.2. Physicochemical Properties

Particle size distribution and plasticity index of clayey materials are very important factors to determine suitability for various applications and peculiar attention should be given to the finer (< 2 µm) fraction for ceramic [39,40]. Table 1 gives the particle size distribution of the studied clay materials. It is therefore important to note that the studied clay materials in general have a different

particle size distribution from one facies to another and a wide distribution with an abundance respectively (30.50 - 44.50%) of clay, (40.10 - 53.70%) of silt and (14.50 - 16.90%) of sand. The exception of the Fgc facies which is almost respectively made of 97.50% of clay, 1.50% of silt and 1% of sand. The Belgian textural classification diagram [41] makes it possible to define different fields of applications of ceramic clay materials. The projection of particle size in this textural classification diagram of clay materials shows that the Fja, Fgs and Fvi facies are heavy clays; Fba is a silty-clay and Fgc is considered very heavy clay. This demonstrates the predominance of clay proportions in these clay materials. Particle size data were also projected in [42], which shows the suitability of materials for ceramic use. The positioning of the samples in the Winkler diagram, shows that they can be used for the production of bricks and tiles but the addition of degreasing materials are necessary to optimize their properties in the ceramic manufacturing process. The Fgc facies is considered as an unsuitable material because of its richness in clay particles.

According to [43,44], kaolin's are materials with a purely clayey texture, very low in sandy sized particles (about 2%), low in silty sized particles (about 8%) and very rich in clay sized particles (about 90%). Referring to [43], the Fgc sample is a kaolin strong of its purely clayey texture has a strong plasticity and a large specific surface. This kaolin can be good in geophagy and beneficial to consumption by its ability to absorb moisture, thus reducing salivation and subsequently nausea associated with pregnancy [45]. It is also important for internal organs by absorbing bacterial toxins and undesirable substances [46,47].

Plasticity is one of the most important parameters for manufacturing clayey products [48,40]. The liquidity limit (LL), plasticity limit (PL) and plasticity index (PI) are reported in Table 1. There are high levels of liquidity limits compared to plasticity limits. However, the values of plasticity index (PI) deducted from those of liquidity limit and plasticity limit vary from 16.7 to 63.9. The high value of the plasticity index is in agreement with the fine particle size identified in the clay materials. All the plasticity index values are greater than 10 which is the threshold limit under which the raw material is no longer suitable for the using in ceramic industry [49]. In fine

ceramics, plasticity is one of the properties sought after because it facilitates the shaping of manufactured products and ensures their cohesion. According to [50], clay materials with a plasticity index (PI) < 10% can cause cracks of products manufactured during the extrusion process and are not welcome in ceramic production related to the construction of buildings due to the possible variation in the amount of extrusion water. However, those with an IP greater than 10% can be used in the raw state for structural ceramic products obtained by extrusion. In view of the results of this work, the analysed samples have a plasticity index well above 10% and can be used as good building materials.

The positioning of the different samples in the [53] plasticity diagram of clay materials shows that the Fvi sample belongs to the field of mineral clays of medium plasticity while the other samples Fgc, Fja, Fgs and Fba are found in the field of organic clays and mineral silts of high compressibility. However, particle size and plasticity are two extremely related parameters. According to [51], the plasticity of a clay material depends on both the particle size distribution and the mineralogical composition. In the same vein, [52] showed that the plastic character of clays is attributed to their dominance in kaolinite and their high organic matter content. Based on this earlier work and the positioning of the samples in the [53], it can be said that the studied clay materials have a kaolinitic nature and are plastic. Several other studies have shown that particle size distribution significantly influences the plasticity of clay raw materials and therefore influences rheological properties [54,55]. This justifies the high water retention capacity and the high values of the liquidity limit of the studied materials. In the study area, clay materials are used by the local population for backfilling. Based on the previous results and according to the work of [56,57], studied the materials have a high plasticity and can be considered as marginal backfill materials. However, for better base layer performance, an adequate stabilization method would be recommended by including coarse-grained materials such as sand to improve the properties of clay soil used as backfill material. This method has been proven according to [57] indicating that stabilizing compressible clays with locally available sand can be one of the cost-effective and rapid methods to improve the properties of these materials.

Table 1. Physicochemical characteristics of the studied clay materials

Sample code	Fgc	Fvi	Fja	Fgs	Fba	
Clay ($\phi < 0.002$ mm) %	97.50	44.50	33.20	32.00	30.50	
Silt ($0.02 > \phi > 0.002$ mm) %	01.50	40.10	52.30	51.10	53.70	
Sand ($2 > \phi > 0.02$ mm) %	01.00	15.40	14.50	16.90	15.80	
Liquidity limit	94.40	50.50	65.50	73.30	82.60	
Plasticity limit	45.20	27.10	43.80	50.40	61.40	
Plasticity index	49.20	23.40	21.70	21.90	21.20	
Swelling rate	13.00	10.00	11.40	13.60	13.60	
Cation exchange capacity	26.00	19.74	23.6	27.12	24.66	
Organic matter	02.06	02.04	02.50	04.00	02.60	
pH	pH-H ₂ O	4.7	5	4.8	3.4	4.9
	pH-KCl	3.9	4.1	4	2.9	3.9

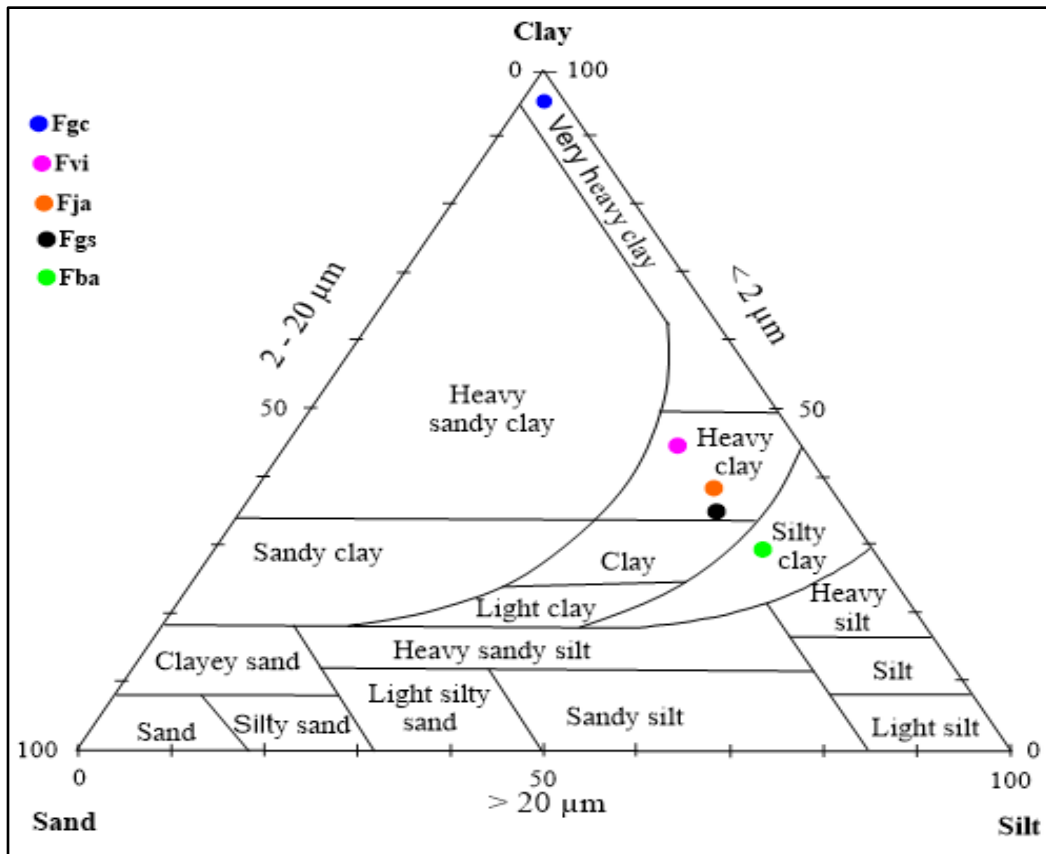


Figure 3. Classification of studied clay materials according to the Belgian triangle of textures [41]

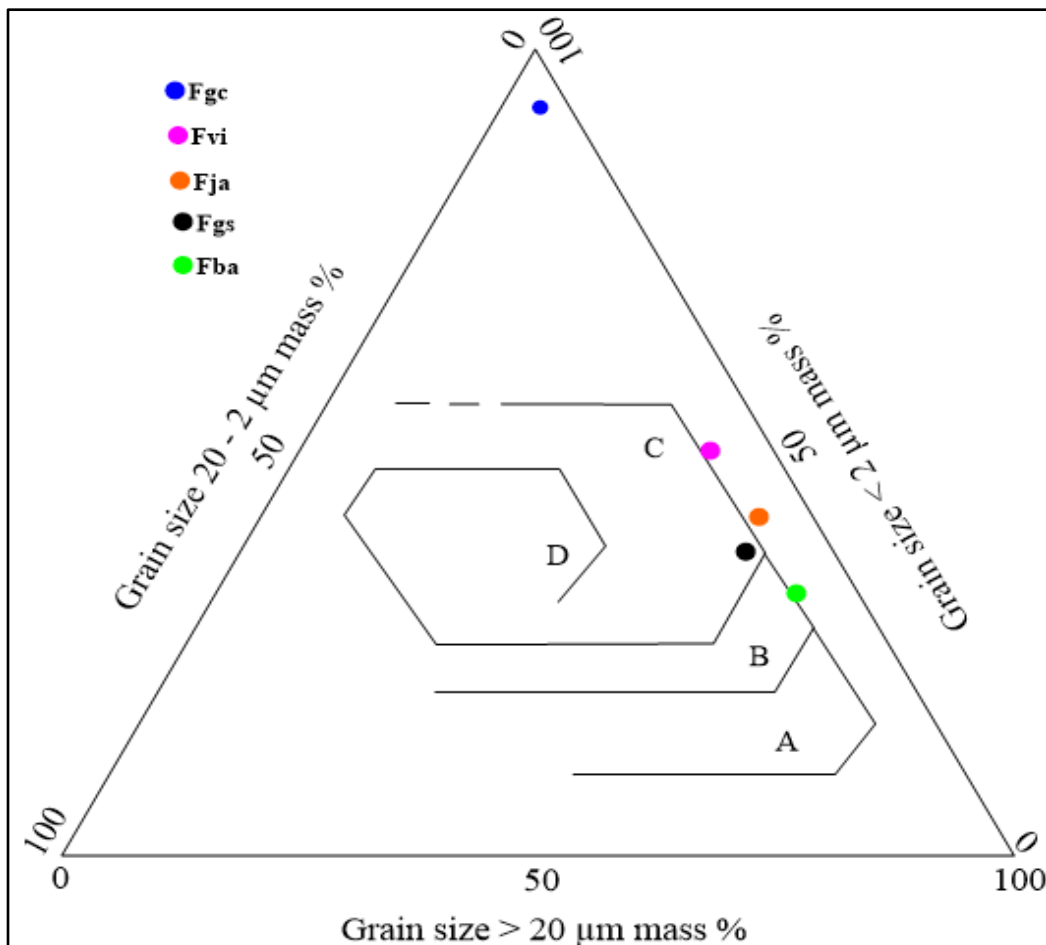


Figure 4. Winkler ternary diagram [42] of studied clay materials

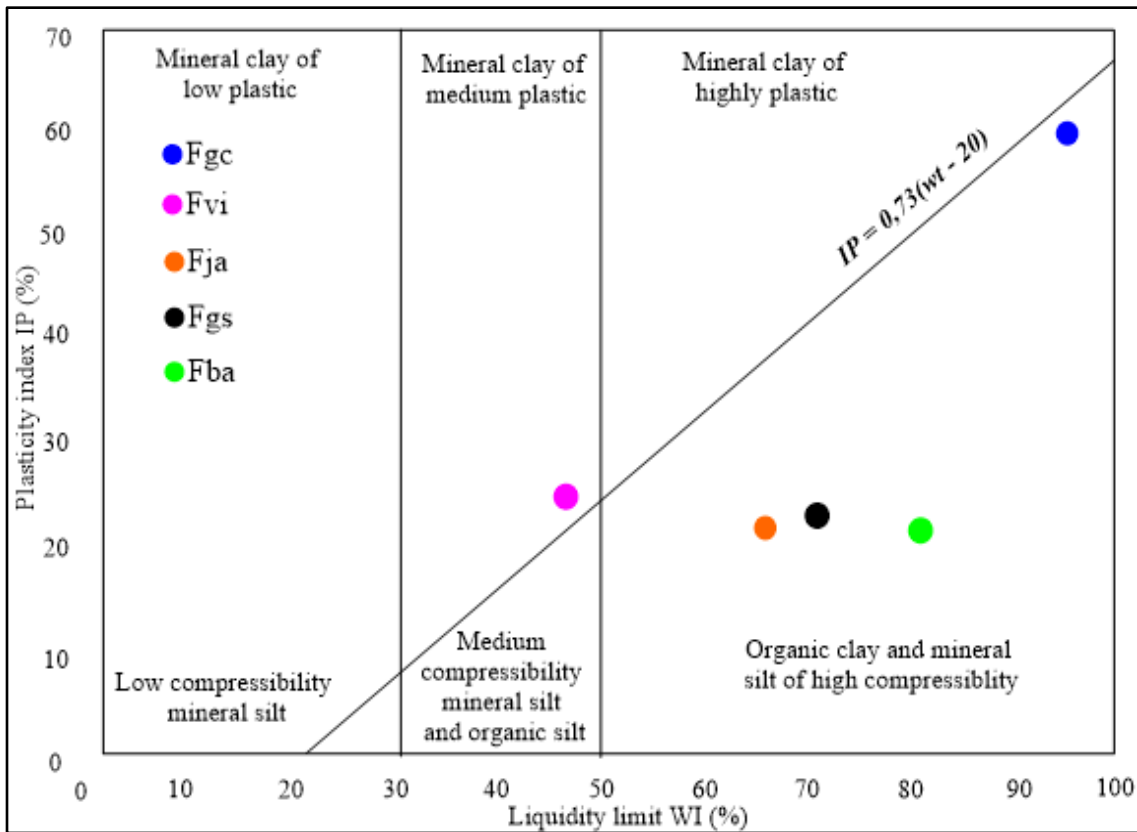


Figure 5. Projection of studied clay materials in [53]

The ceramic properties of the clay materials were tested by the [58] diagram presented in Figure 5. This diagram shows that the materials are not suitable for ceramic except the Fvi facies which is acceptable in pottery. However, an improvement by adding degreasers is necessary to reduce plasticity and promote the cohesion of materials to make them suitable for ceramics. The Fgc facies has a very plastic behaviour and cannot be used in the game of products indicated by the diagram of [58].

The rate of swelling is an essential parameter for

understanding the swelling behaviour and nature of clay materials. The results of the analyses show that the rate of swelling in the studied samples is moderately low and varies from 10 to 13.6. This suggests the non-hygroscopic character of the predominant type 1/1 clay minerals in the studied materials [54]. Apart from the process that takes place in the environments of marine deposits, kaolinite can be formed by the mechanism of alteration of monosiallization favoured by hydrological and morphoclimatic conditions in the Cameroonian Coastal basins.

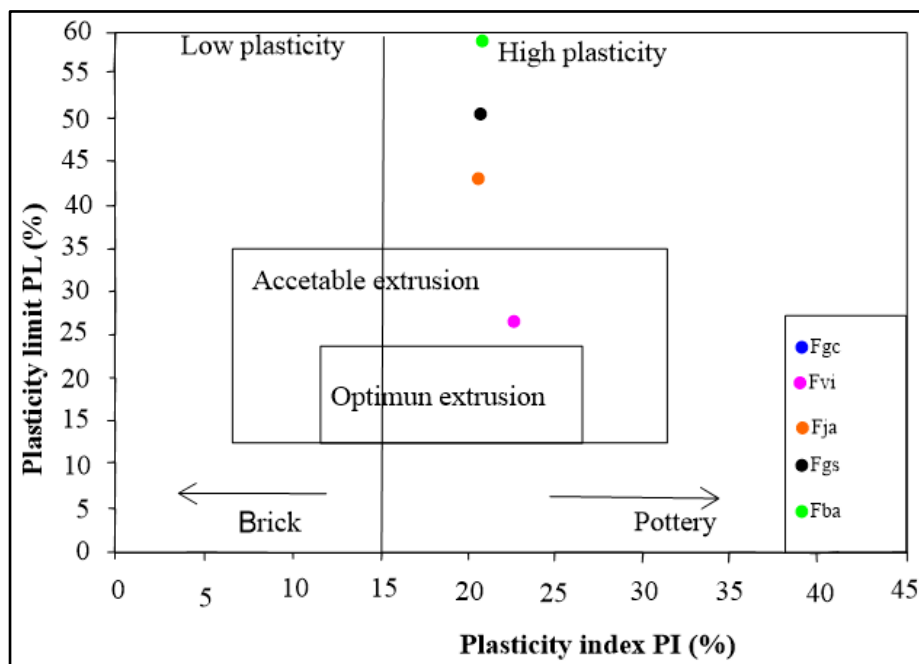


Figure 6. Bain diagram showing the potential molding of the studied samples [58]

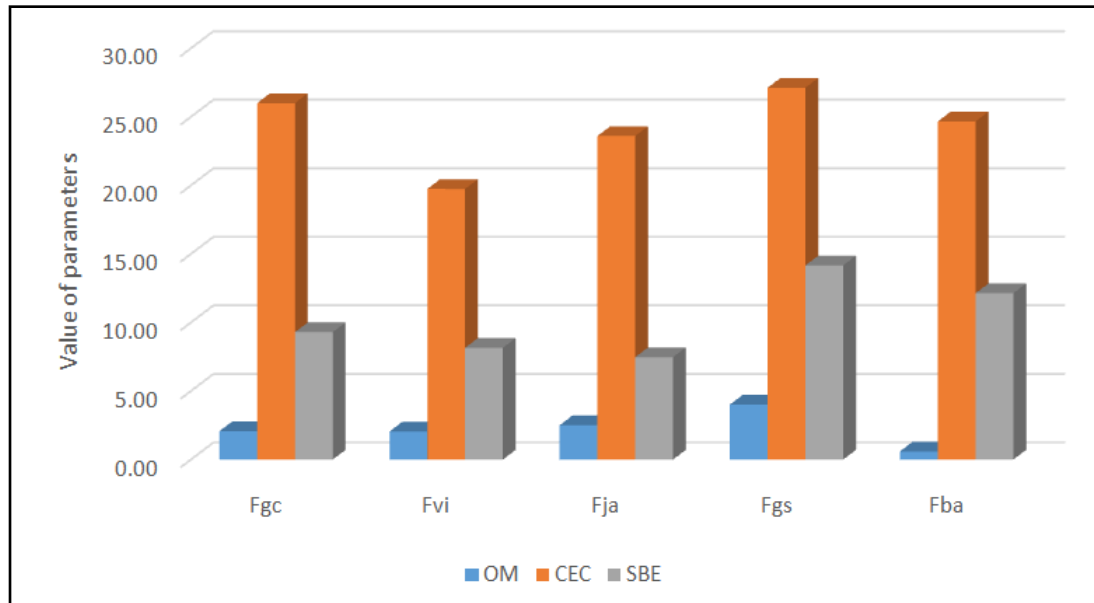


Figure 7. Histogram of some physicochemical parameters: organic matter (OM%), cation exchange capacity (CEC meq/100g) and sum of exchangeable bases (SBE meq/100g)

The work of [59] showed that the dark colour of clay materials would result more from the formation of clay humic complexes between clay and organic matter. However, the results obtained from the analyses show that the materials have a high organic matter content generally more than 2% (Figure 7). Thus, the dark gray colour observed in the latter could be due to the considerable presence of organic matter. According to Ngole et al. (2010), a high organic matter content increase the value of the cation exchange capacity of the clay materials by forming the humic clay complex (Figure 7). This property is able to trap surrounding cations and therefore can be used as an adsorbent for pollutants in an aqueous medium. In view of the analyses carried out on the data in general, it is retained that particle size, plasticity and organic matter are parameters that can influence the behaviour of clay materials [59]. A material with a fine particle size has a high specific surface area and is more plastic than a material with a coarse particle size. However, the increase in the specific surface area is at the origin of fixation of exchangeable cations and therefore increase in cation exchange capacity (Figure 7). The cation exchange capacity (CEC) value observed in the samples varies from 19.74 - 27.12. These values are more than 15 as indicated by kaolinite. This means that clay materials contain a lot of organic matter which favours the cationic exchange capacity. The pH of the samples analysed are less than 7 (slightly acidic) (Table 1). The pH-H₂O values vary from 3.4 to 5 and that of KCl locate from 2.9 to 4.1 which are in perfect harmony with the clay materials.

4.3. Mineralogy

The mineralogical analyses of the studied clay materials are illustrated in Figure 8 and Table 2. The mineralogical composition reveal several mineral phases whose main minerals are quartz and kaolinite followed by illite, muscovite, goethite and hematite. Quartz is the most abundant mineral in the Fvi, Fja, Fgs and Fba facies with percentages of 48.4%, 45.3%, 50.7% and 48.9%

respectively. Kaolinite predominates in the Fgc facies (82%). Hematite has a moderate concentration in Fja (4.3%). Numerous studies have shown that the mineralogical composition of a clay material plays an essential role in its choice for industrial applications [60]. In the studied materials, most of the main peaks correspond to quartz and this suggests a high content of silica (SiO₂) [60]. The abundance of quartz observed in the samples could be attributed to the resistance of this mineral to weathering and simply to the release of silica by the original silicates [61]. The quartz content is therefore important and can contribute significantly to the improvement of the geotechnical characteristics of the soil such as dry density, compaction, and stiffness and shear resistance and reduce the shrinkage behaviour of sintered ceramic products [1,62]. The presence of kaolinite in materials suggests that monosiallization is a crystallochemical process acting in the study area [63,60]. Kaolinite is a refractory mineral at liquidus temperature of about 1800°C. The combination of kaolinite and quartz in a material gives it a good ability to shape and dry terracotta ceramic products [64,20]. According to the same authors, the high amount of kaolinite in the clay raw material increases the plasticity and vitrification of ceramic products. Thus the Fgc facies very rich in kaolinite and very plastic is the best in terms of refractory characters for ceramics. The existence of illite is reported in almost all samples but with a low content. This mineral is recognized by its character to improve the plasticity of the clay by favouring the location of the glazed phases during firing [65]. The presence of hematite in the samples is dependent on the Fe₂O₃ iron oxide content [66,60,67]. The reddish-yellow coloration observed in the Fja sample may be due to Fe₂O₃ iron oxides. This is in perfect agreement with the DRX results which show the peaks of hematite in the yellow material identified in the field. The influence of temperature on a clay material leads to the removal of organic matter, the departure of water molecules (adsorbed water or bound water) and each of the minerals it contains in the ranges of known temperature with determined proportions [68].

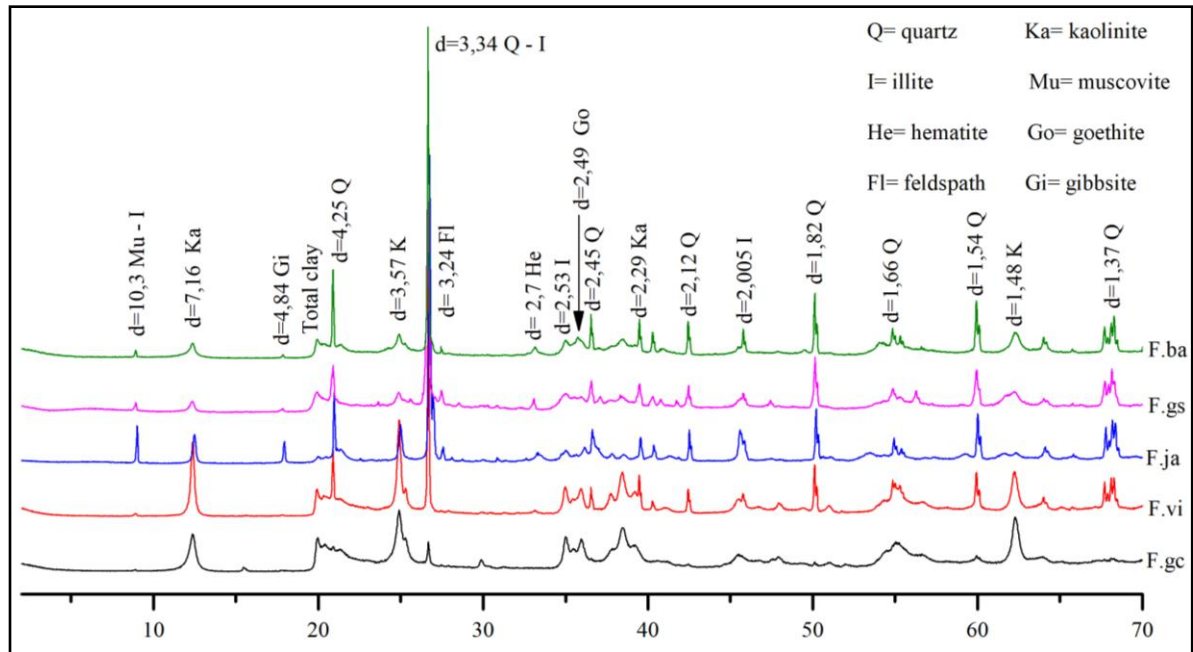


Figure 8. X-ray diffractograms of the clay materials studied

Table 2. Semi-quantitative estimation based on X-ray diffraction of the mineralogical composition of the studied materials

Samples	Quartz	Kaolinite	Illite	Hématite	Goethite	Feldspath	Muscovite	Gibbsite
Fgc	20.2	72	5.3	0	0	1.2	0	1.3
Fvi	48.4	32	10	2	3.2	2.2	1.4	0.8
Fja	45.3	35.3	4.6	4.3	2.5	2.4	3.2	2.4
Fgs	50.7	32.6	9	0	2	1.4	4.3	0
Fba	48.9	39.5	6.4	2	1.2	0.4	1.4	0.2

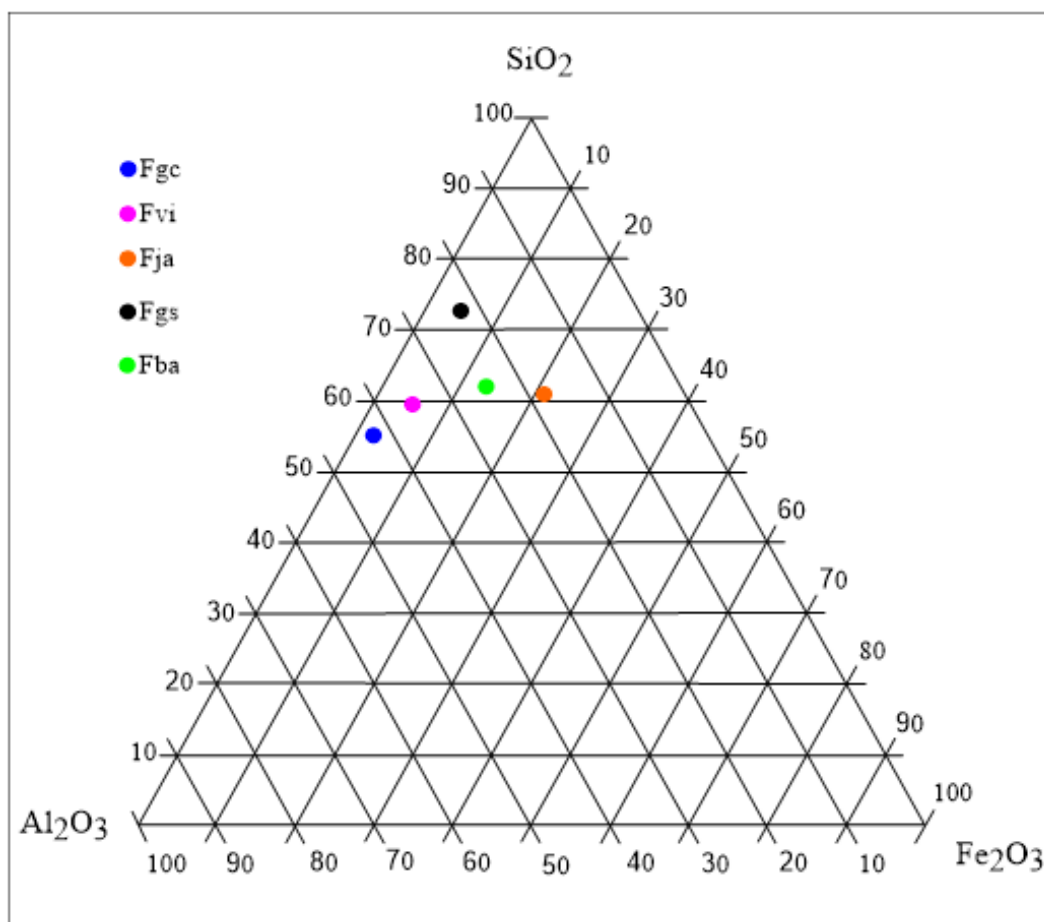
4.4. Chemical Composition of the Clay Materials

Table 3 presents the chemical composition of the studied clay materials. These materials are characterized by relatively high content of SiO_2 and Al_2O_3 . However, they show moderate concentrations of Fe_2O_3 and low concentrations for alkali and alkaline earth oxides. The concentration of silicon oxide SiO_2 is very high in most samples. This confirms the results of the DRX showing the main quartz peaks in materials. Aluminum oxide (Al_2O_3) is relatively high especially in the Fgc facies. This testifies the presence of kaolinite identified by well-expressed peaks on X-ray diffractograms. The abundance of kaolinite is related to the morphoclimatic characteristics that prevail in the study area [11,23]. Monosiallization processes that promote the presence of kaolinite usually dominate areas with abundant rainfall. This may explain why the materials of the Douala coastal sedimentary sub-basin have high proportions of kaolinite (32 - 72%), more than those of clay materials of type 2:1 (illite). The formation of type 2:1 clay minerals is usually related to contrasting climatic conditions (poor drainage, less precipitation, low gradient slopes and high evaporation) [63,65]. This explains the low concentration of illite ($\leq 10\%$) in the studied materials formed in a very well drained environment with abundant rainfall. The Chemical Index of Alteration (CIA) was calculated (Table 3) and the ternary diagram of the evolution of the chemical index of alteration of clay materials by [38] (Figure 9) was both

used to show the degree of chemical alteration of the studied materials. The chemical index of alteration (CIA) ranged between 86.89 and 98.12%, indicating that the studied clay materials are constituted of very weathered raw materials (Table 3). The positioning of the samples in the diagram by [38] indicates a very high alteration. This is in line with the morphoclimatic conditions of the sub-region. The iron oxide concentration is low to moderate (1.5 - 11.22%) and is relative to the presence of hematite and goethite observed in the samples [66,69]. This fact may explain the reddish-yellow coloration of some studied clay facies (Fja and Fba). The Fvi sample has a purplish coloration, this may be due to the presence of certain minerals such as illite and goethite. The alkali (Na_2O and K_2O) contents are very low in materials and could be attributed to the low amount of feldspar in materials [12]. The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio is an indicator of the abundance of quartz and kaolinite in clay materials. This ratio varies from 1.42 to 3.70 (Table 3) further confirming the DRX results that showed the predominance of kaolinite associated with quartz in the studied samples. Geochemical data were projected in the triangular diagram $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-Fe}_2\text{O}_3$ (Figure 10). The samples clump together towards the SiO_2 pole and along the $\text{SiO}_2\text{-Al}_2\text{O}_3$ axis, showing that kaolinite and quartz are the main minerals identified. In addition, due to high flux contents of SiO_2 and Al_2O_3 , a high firing temperature for improved sintering may be needed. Figure 11 shows that these clay materials are suitable for the manufacture of tiles and stoneware tiles [70].

Table 3. Chemical composition of the materials studied

Sample/Code	Fgc	Fvi	Fja	Fgs	Fba
SiO ₂	34.05	38.18	50.55	51.18	39.18
TiO ₂	1.08	1.47	1.29	1.09	0.13
Al ₂ O ₃	23.98	21.85	17.68	16.45	16.05
Fe ₂ O ₃	1.55	3.86	11.22	4.9	7.69
MnO	0.51	0.07	0.23	0.41	0.28
MgO	0.12	0.1	1.41	0.95	0.38
CaO	0.13	0.06	0.12	0.72	0.37
K ₂ O	0.3	0.41	1.36	1.7	0.36
Na ₂ O	0.03	0.03	0.04	0.06	0.04
SO ₃	0.26	0.15	1.04	0.08	0.07
P ₂ O ₅	0.06	0.06	0.04	0.13	0.03
PF	16.71	11.23	9.88	13.2	11.8
Total	78.78	77.47	94.86	90.87	76.38
SiO ₂ /Al ₂ O ₃	1.42	1.75	3.70	3.11	2.44
TiO ₂ +Fe ₂ O ₃ + CaO+MgO+ Na ₂ O+K ₂ O	3.21	5.93	20.44	9.42	8.97
CIA	98.12	97.76	90	86.89	95.42

Figure 9. Geochemical composition of the studied clay materials in SiO₂-Al₂O₃-Fe₂O₃ diagram

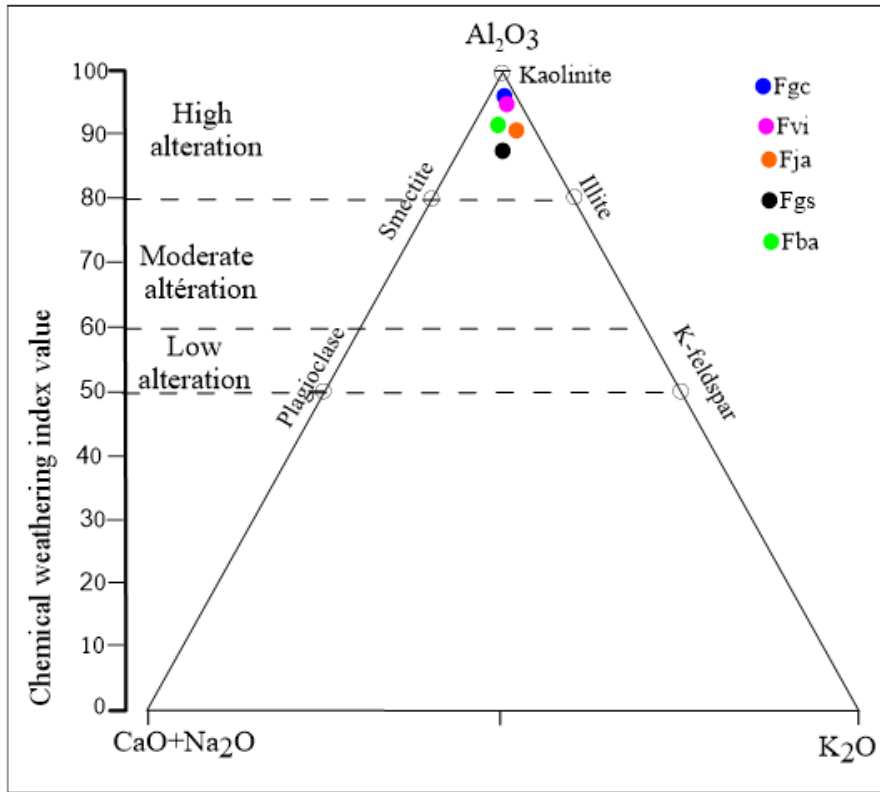


Figure 10. Diagram showing the evolution of the chemical alteration index of the studied clay materials [38]

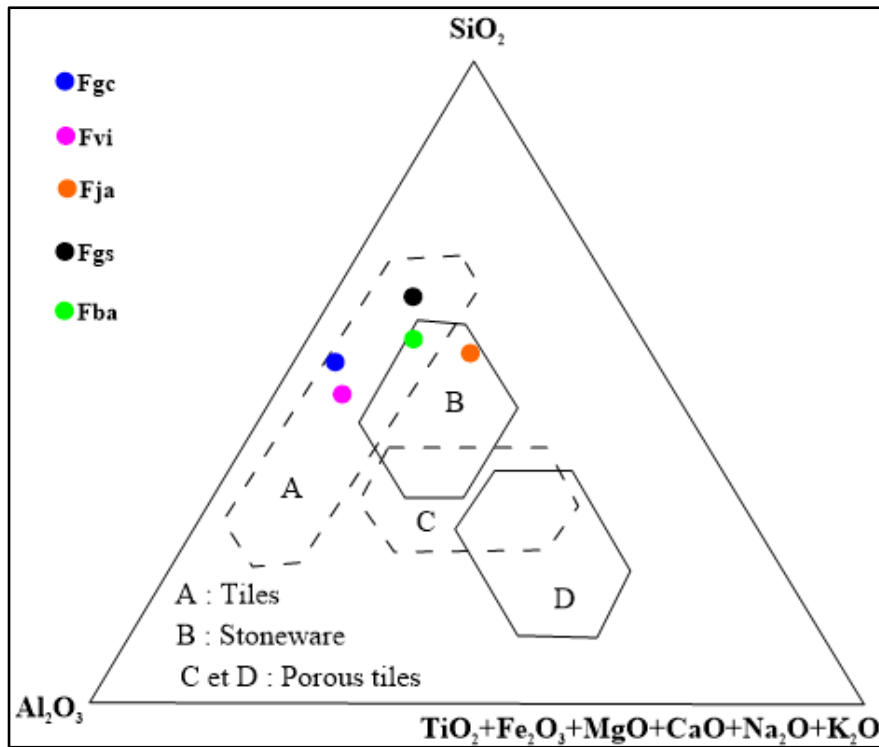


Figure 11. Composition of the clay materials studied in the diagram by [70]

5. Conclusions

Five clay materials taken from the locality of Yansoki were the subject of a physicochemical and mineralogical characterization. The following conclusions emerge from this work: the clay materials studied have a kaolinitic nature and are highly plastic, which makes them suitable for ceramics and the chemical industries. Mineralogically,

the materials are essentially composed of kaolinite, quartz, muscovite, hematite, illite and other associated minerals such as goethite and anatase. As a result, they can be used as stabilizers and base layers in the construction of buildings. From a geochemical point of view, the main oxides that make up clay materials are SiO₂, Al₂O₃ and Fe₂O₃. These oxides are very essential in strengthening the qualities of industrial finished products. The interest of

this work was not only to make a scientific contribution in the knowledge of the nature and properties of clay materials available locally, but also to enhance them in the various industrial fields in Cameroon.

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