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Mineralogical and Physico-Chemical Characterization of Clayey Materials of Meka'a (West Cameroon) Preliminary Step for Their Utilization for Human Ingestion

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Abstract: Discovery of new geophagic clayey deposit in the locality of Meka'a contributed to the apparition of new species of geophagic clay materials in the local market. Due to the fact that positive or negative effects of geophagia are conditioned by physico-chemical, mineralogical and geochemical properties of the clay soil ingested, it is therefore necessary to mineralogically and physico-chemically characterize these clayey materials in order to ascertain their health implications. X ray diffractometry (XRD), X ray fluorescence (XRF), particles size distribution, pH and cation exchance capacity (CEC) are the main analyses carried out with these materials. The results show that the clayey materials of Meka'a are extremely weathered and maybe as a result of the weathering of ignimbritic flows. Two main species (yellow and red) of this clay soil are identified on the basis of their colour, mineralogy and physico-chemical characteristic. Analysis of samples of these two types of materials shows that Meka'a clayey materials are mainly made up of kaolinite (64-87%) and goethite (6-25%). These two minerals greatly influence the properties of these materials. Abundance of kaolinite in this clayey mineral assemblage could be of benefit in the protection of gastro intestinal tract resulting from ingestion of soils with high clay content. These clayey soils have a lower CEC and cannot cause cations deficiency in the digestive tract. Their acidic pH makes them suitable for use as remedy for relief of nausea and to curb salivation associated with pregnancy. No dental enamel or gastro-intestinal tract damage was to be feared when ingesting Meka'a clayey soils and their great abundance in Zn could be of benefit to geophagic individuals. However, possibility of Fe supplementation of the clayey soils of Meka'a may be very low considering low ferric hydroxide content and the fact that only a part of Fe present in the clayey soil can be released in the digestive tract.

Keywords: Geophagia, Kaolinite, Clays, XRD, CEC, Exchangeable Bases

1. Introduction

The term geophagia designate the deliberate ingestion of non-food lithospheric substances, notably clay soil [1, 2, 3]. Geophagia has been practised for many centuries, in a range of ethnic, religious, and social groups of the world [4] but yet, researchs on this topic are at the begining [5]. Several motivating factors for geophagia have been reported. Clay soil ingestion has been used for nutrient supplementation, detoxification, remedy for diarrhoea and intestinal parasites, alleviation of nausea, craving and relief from morning sickness during pregnancy [6, 7, 8, 9, 10, 11, 12] or as part of cultural belief system [13]. Clayey soil have been reported to be medicinal [14, 15, 16, 17] and has also been perceived as a mean of supplementing essential mineral nutrients [18, 19, 20]. Reference [17] demonstrates that calcareous geophagic materials may supplement Ca in the gut. Some clay materials sold in West African markets for medicinal preparation have a similar mineral composition to the clays used in the pharmaceutical Kaopectate[TM] and ingestion of at least certain soils may, therefore, provide medicinal benefits similar to commercially produced pharmaceuticals for general gastro-intestinal ailments [8]. However, geophagia can potentially cause many detrimental effects such as: Fe an Zn deficiency [16, 21, 22]; anaemia [9, 23, 24, 25] lead poisoning, hyperkalemia, phosphorous intoxication, low bone mineralization [26, 27], hypokalaemia [28] dental enamel, stomach and colon injury [29, 30], hemosiderosis [31], parasitic and pathogenic infections[28, 32, 33, 34,] and death [9]. Despite the risk associated with geophagia, around the world, several differents types of clayey soil with differents colour continues incessantly to be ingested by geophagic practitioners [2, 6, 35, 24]. In Africa, geophagia has been reported in Malawi, Nigeria, Swaziland, South Africa, Togo, Zambia, Zimbabwe [11, 36,], in Democratic Republic of Congo [37, 38] in Uganda and Tanzania [17], in Ghana [21, 39, 40, 41, 42,], in Ivory coast [43] and in Cameroon [9, 12, 44, 45]. The discovery in the beginning of this century of a new geophagic clayey deposit in the locality of Meka'a (Cameroon) contributed to the apparition of new species of geophagic clay materials in the local market in addition with the mythical clay varieties of Calabar (Nigeria) and Balengou (Nde Division) [12]. According to references [9, 38] and [45], positive or negative effects of geophagia are conditioned by physico-chemical, mineralogical and geochemical properties of the clay soil ingested. It's therefore necessary to characterize all geophagic materials in order to ascertain their health implications.

The objective of this study is to assess mineralogical and physico-chemical properties of the geophagic clayey materials from the locality of Meka'a, West Region (Cameroon). A low comparison of them with those of Calabar, Balengou (particularly due to their high ingestion by local geophagic individuals) and some other African geophagic clay soils in order to highlight their similarities and therefore ascertain possible health implications of geophagic clays soils of Meka'a for geophagic practionners.

2. Geological Setting

The city of Dschang is situated on the Southern flank of the Mount Bambouto and located at an altitude of 1400m. Meka'a is a neighbourhood of the city of Dschang situated 3 km to the south, between 05°26'05 " and 05°26'33 " North latitude; 10°02'30 " and 10°02'48 " East longitude (Figure 1).

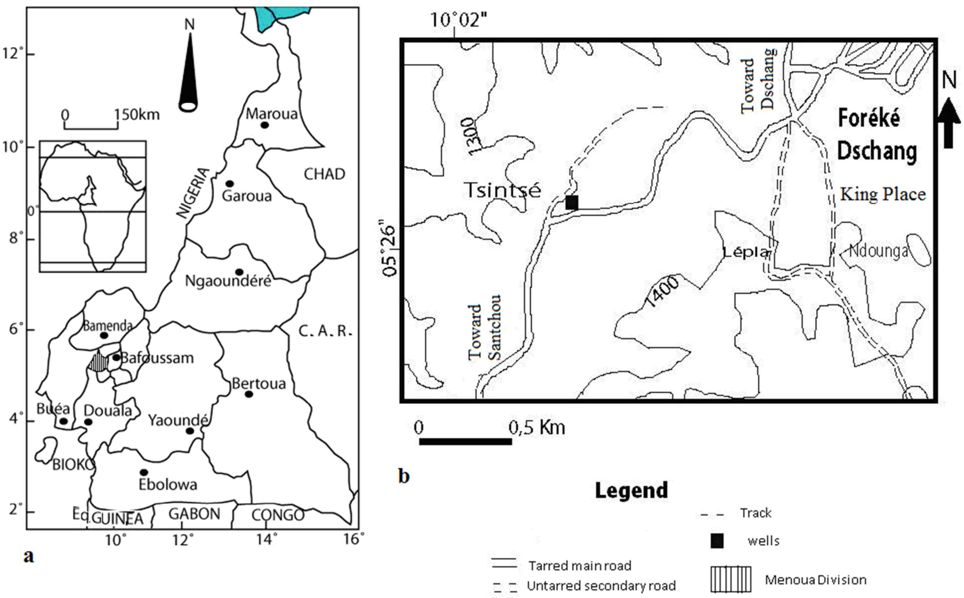

Figure 1. *Localization of the study site.*

The Bambouto Mountain is a complex composite polygenic volcanic outfit [46] with an elliptic shape comprised of two caldeiras at its peak. Three types of volcanic activity which occurred between 18 and 4.52 Ma age are the effusive type which was at the origin of the basic lava flows, and the extrusive and explosive types giving much differentiated lavas [47]. These lavas originate from the crystallization of magma assimilated from the mantle which was slightly contaminated with magma from the crust [48, 49]. Basalts, trachytes, phonolites and ignimbrites are the principal products of this active volcano [50], (Figure. 2). These volcanic products directly lie on the granito-gneissic basement and are in some places partially covered by sedimentary and residual formations [48]. The survey site is located in a zone covered by volcanic products which are mainly constituted of ignimbritic flows.

Ignimbrites outcrops in Mount Bambouto are discontinuous and cover approximately 17% (≈ 135 km^2 of the massif with 30 to 120 m in thickness). These ignimbrites were identified in many localities (Dschang, Baranka, Mbeng, Lepo, Nzemla I and Nzemla II). The volume of these pyroclastic deposits estimated at 13.5 km^3, is actually much larger because these formations are covered by generally lateritized basalts in the southern part of the massif [51, [52]. In the lower zone, they lay on a metamorphic basement, while in the upper zone, they cover trachytic lavas. Welded and non-welded massive lapilli tuff (mlT) and massive lithic breccias (mlBr) are the two essential ignimbritic facies cropping out in this massif. The mineralogy of ignimbrites is similar in both massifs; it is made up of quartz, alkali feldspar (sanidine and anorthoclase), plagioclase, biotites and Fe-Ti rich oxides. The lithic fragments are essentially trachytic with proportionately lower rhyolites, vitrophyre, fragments of granitic basement, ignimbrites, scoriae and carbonized woods. Chemical analysis of these rocks indicates a rhyolitic and trachytic composition in Mounts Bambouto. The ignimbrites of Dschang outcrop in sheets in the Menoua valley on about 9 km^2. Its mlT facies consist of a simple cooling unit made of two flow units overlying by basalt flow and are marked by the presence of ovoid to lenticular fiammes (5 to 10% of the rock), rock fragments (especially trachytic) and finally a glass matrix [51, 52].

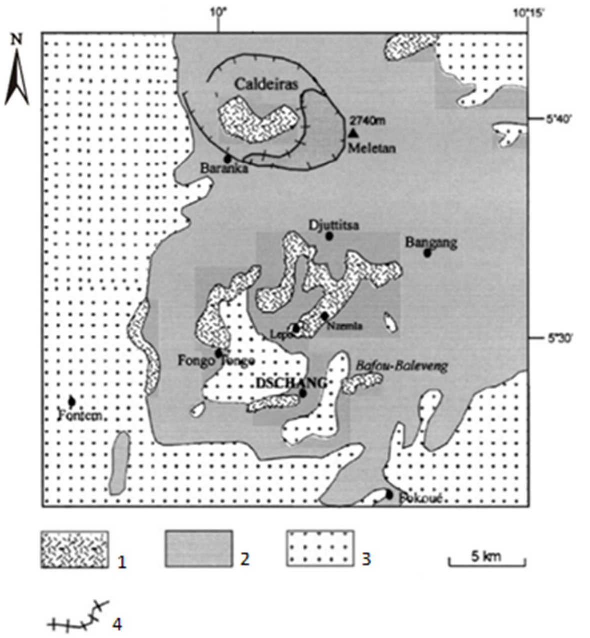

Figure 2. Distribution of ignimbritic flows and other lavas within the Bambouto volcano and Dschang region [50]: 1: Ignimbrites; 2: other lavas (Basalts, Trachytes, Phonolites…); 3: Granito-gneissic basement; 4: Limits of the caldeiras.

The granito-gneisssic basement in Meka'a is composed dominantly by granite with biotite incloseous lassed by granitic veins and containing basic components of orthogneiss [53, 54, 55].

3. Materials and Methods

Clayey samples of Meka'a were obtained in situ from the geophagic clayey deposit. One exploration well was dug in the geophagic deposit of Meka'a in order to determine the weathering profile and collect samples from this site. Samples of Calabar (South East of Nigeria) and Balengou (Ndé Division), were bought from sellers in the local market and more data from these two clayey materials used for comparison were obtained from the literature review.

Seven samples (four from Meka'a (M1 M2 M3 M4), two from Calabar (C2 C3), and one from Balengou (B4) were air dried, disaggregated using a mortar and pestle, and passed through four sieves (of 500, 250, 100 and 60 µm diameter) before analysis. The colour of samples was obtained using the Munsell Soil color Chart. Samples collected are presented on Table 1 below.

Table 1. *Deposits, species and designation of samples.*

Deposits	Samples	Colour (Species)	Munsell Code
Balengou	B4	Pink	7.5YR 8/4
Calabar	C2	White	5Y 8/1
	C3	Pale Red	7.5R 6/4
Meka'a (Foréké Dschang)	M1	Pale Red	10R 6/4
	M2	Pink	5YR 8/3
	M3	Pale Yellow	2.5Y 8/4
	M4	Yellow	2.5Y 7/6

The Meka'a samples were subjected to XRD, XRF, Particle size distribution, pH, CEC and exchangeable cations analysis. While samples from Calabar and Balengou were analysed only for pH, CEC and exchangeable cations. Data for the mineralogy and chemical analysis of the Calabar and Balengou clays were obtained from the work in [9].

Mineralogical analysis were carried out in the laboratory of crystallography and mineralogy of the Faculty of Science of the University of Hiroshima (Japan). Chemical analysis of trace and major elements were carried out in the geochemistry laboratory of the same Faculty (of the University of Hiroshima). CEC, pH and exchangeable cations analysis were carried out in the Soil analysis and Chemistry of Environment laboratory of the University of Dschang.

3.1. Mineralogical Analysis

For mineralogical analysis, a Mac Science MXP 18 KVA X-ray diffractometer with a Kα copper radiation of a wave length of λ= 1.54056 A°. A recorder speed of 8°/minute, a voltage of 40 kV, current intensity of 100 mA and an angular coverage of 3° to 50° ($3° \leq 2\theta \leq 50°$) was used.

Samples were subjected to various treatments before being analyzed. The samples were treated by ethylene glycol solvation (used to identify high-charge smectite and vermiculite) [56], and formamid (used to differentiate kaolinite from halloysite) after drying for a better identification of the mineral phases. Semi quantitative estimation of different minerals phases identified was based on the measurement of the basal surface mean of the peaks of minerals.

3.2. Physico-chemical Analysis

3.2.1. Particle Size Distribution

Particle size distribution of the samples was determined by the combination of sieving and sedimentation procedures. After extraction of organic matter in the samples, fine particles were separated from sand by sieving with a 50μm sieve and extraction of silt and clay requires the use of Robinson-Köhn pipe after the disperse of colloidal suspension by a dispersive reactor. Time and extraction depth of particles was deducted from the Stokes law.

3.2.2. Measurement of Major and Trace Elements

X-Ray fluorescence spectrometer of type FRX Phillips (PW 2400) with tubes of Rhodium (Rh) anode was used. Standardization was made following norms. The UNIQUANT 4 software produced by OMEGA was used to analyze for the major and trace elements based on unique spread of the available sixteen elements.

Results for major elements (in molecular proportion) were used to calculate three chemical weathering index and determine the extent of weathering of these materials.

Chemical index of Alteration [62]; $CIA= [Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]x100$

Which monitors the progressive alteration of plagioclase and potassium feldspars to clay minerals. The high CIA values reflect the removal of labile cations (Ca^{2+}, Na^+, K^+) relative to the static residual constituents (Al^{3+}) during weathering. Conversely, low CIA values indicate the near absence of chemical alteration.

Chemical index of weathering [63];

$$CIW= [Al_2O_3/ (Al_2O_3+CaO+Na_2O)] x100$$

This index does not incorporate potassium because it may be leached or it may accumulate in the residue during weathering. The CIW index values increases as the degree of weathering increases.

3.2.3. pH Measurement

pH measurement took place in two steps; firstly, measuring of the active (or real) acidity (pH in water or pH-H_2O) and secondly measuring of the potential acidity (pH-KCl). For pH-H_2O, 10g of the specimen was mixed with 25ml of water and agited and thereafter left to stand for 24 hours before using a pH meter to measure the pH. 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) are generally less than pH (H_2O). The gap between these two pH value makes it possible to determine reserve (or total) acidity of clayeys materials.

3.2.4. Measurement of the CEC and Dosage of Exchangeable Bases

The measurement of cation exchange capacity (CEC) enabled the identification of the basic clay mineral and to assess the ability of these samples in cationic exchange. The C.E.C. was determined by chemical dosage using the potentiometric method. An extract of the solution was prepared, which was later distilled and titrated with sulphuric acid. The CEC value was determined by calculation [12].

4. Results and Discussions

4.1. Weathering Profile of Meka'a

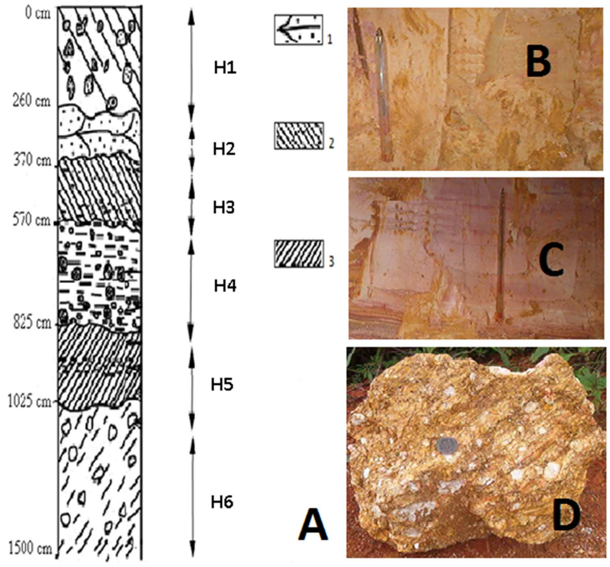

Figure 3. *A) - weathering profile of Meka'a. 1: Kaolin yellow (XRD M3 and M4); 2: Kaolin Red (XRD M1 and M2); 3: Kaolin deposit; B) - yellow Kaolin (H5); C) - Red Kaolin (H5); D) – Isalteritic block (H6) with an ignimbritic facies.*

The morpho-structural organization of materials shows six horizons (Figure 3). From the surface to the base, weathering profile present:

a) A polyphasic horizon H1 (0-260 cm) with a yellow clayey matrix (2.5Y 7/6). This matrix has a fragmented structure and contains many white micrometric punctuations of about 1.5 to 4 cm diameter. This horizon has probably been highly reshuffled during road works;
b) A pale yellow (2.5Y 8/4) clayey horizon H2 (260-370 cm) with a massive structure;
c) A pale red clayey horizon H3 (370-570 cm) with a massive structure;
d) A yellow (2.5Y 7/8) silty H4 horizon (570 -825 cm) with many white micrometric punctuations;
e) A polyphasic clayey horizon H5 (825-1025 cm). Pale yellow (2.5Y 7/4), clear brown (7.5YR 6/4) and pale red (7.5R 6/4) are the three phases identified in this horizon. Yellow and red phases have a massive melted structure and only the brown phase shows micrometric whitish punctuations;
f) A compact yellow silty horizon H6 (1025-1500 cm) with many white rounded particles reminding the feature of ignimbritic flows in the Menoua valley.

Horizons H2 and H3 contains small centimetric yellowish and reddish clayey strip mined for geophagia and locally named "kaolin" that correspond to the geophagic clayey material as marketed. The real geophagic soil deposits is found from 850 cm to 1025 cm deep (Horizon H5). Macroscopically, these layers are presented as superposition thicker than horizons H2 and H3. The H6 horizon has a yellowish matrix laced with whitish inclusions of various sizes and shapes. No mineral relic can be identified with the naked eye; it reflects a very intensive degree of weathering.

The clayey materials of Meka'a look like superimposed clayey layers resting on parental material with many white rounded white particles and yellow particles. These facies are similar in all respects to that of ignimbrite altered in Dschang region as described by references [50, 51, 57]. Reference [58] confirms the possible ignimbritic origin of these materials.

4.2. Mineralogical Composition

Mineralogical studies showed that the clay materials of Meka'a were made up of kaolinite (64.7 to 85.37% and whose peaks are very clear, 7.12 to 3.57Å), associated with:

a) goethite (6.38 to 25%) whose lines are sharp and faint in 4,18Å to 2.68; 2.24Å to 4.36Å;
b) maghemite (4.26 to 11.76%), the lines are very low;
c) anatase (2.25 to 7.14%) whose lines are clear 2,38Å and also faint lines; 2,44Å.

Illite is present in trace amounts only in the sample M3 (Figure 4). The semi-quantitative estimation of these mineral phases is reported in Table 2.

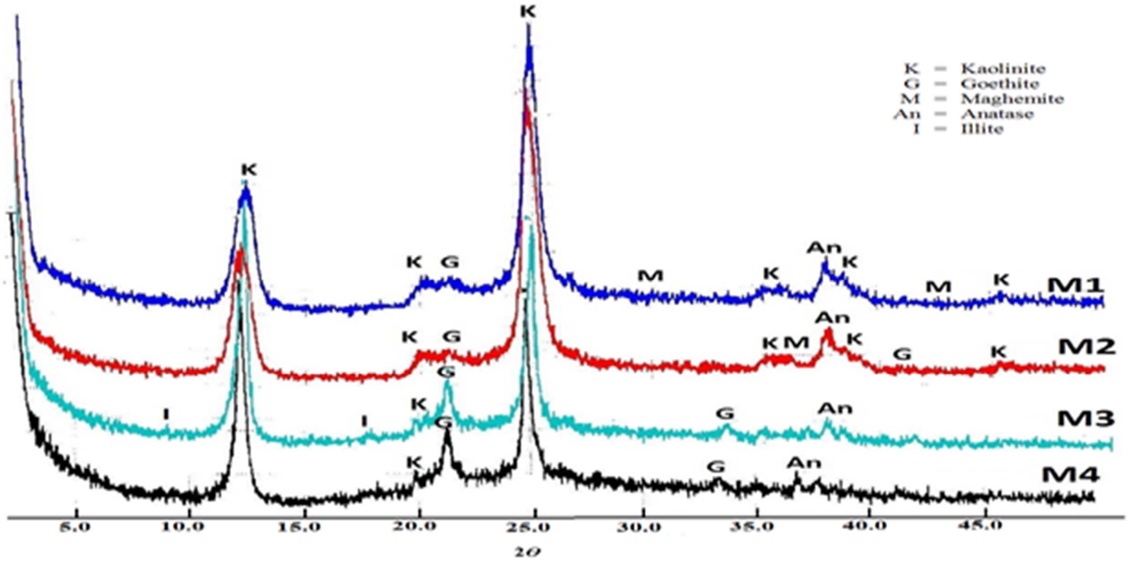

Figure 4. *Meka'a XRD paterns.*

Table 2. *Semi quantitative estimation of mineralogical phases.*

	Kaolinite	Goethite	Maghemite	Illite	Anatase
M1	85.37 %	7.32 %	4.89 %	Nd	2.25 %
M2	82.98 %	6.38 %	4.26 %	Nd	6.38 %
M3	64.71 %	14.71 %	11.76 %	tr	8.82 %
M4	67.86 %	25.00 %	Nd	Nd	7.14 %

According to [9], the clayey materials of Balengou are made up of halloysite (≥65%) and have as associated minerals: quartz (> 14%), maghemite (≈2%), gibbsite (1-5%), feldspar (≤1%) and anatase (0.3%). Those of Calabar are made up of kaolinite (≈70%) and have as associated minerals: quartz (≈16%), illite (4-6%), maghemite (≈2%), anatase (≈1.5%) and goethite (0.5%). Quartz is not detected in the materials of Meka'a while it is present in those of Calabar (≈16%) and Balengou (> 14%).

Maghemite and anatase are the only common minerals to these three clays materials. Clay materials of Meka'a are mineralogically close to those of Calabar (as they are made up of kaolinite and contain goethite) unlike those of Balengou which are made up of halloysite and contain gibbsite (1 to 5%) and feldspars (≤1%). The opposite of Calabar and Balengou clayey materials is the absence of quartz in the clayey materials of Meka'a which assures that these materials cannot damage dental enamel during mastication, and cannot cause abrasion of the walls of the gastro-intestinal tract which may lead to rupturing [29, 30]. All these clayey materials do not have anti-acid behavior because they are made up of halloysite and kaolinite and therefore cannot be successfully used in order to reduce gastric hyperacidity [59].

4.3. Particle size Distribution of the Clayey Materials of Meka'a

The particle size analyse of the four samples of Meka'a clayey materials depicts the clayey composition of these materials. Red species (M1 and M2 samples) have lowest amount of sand (1.3 & 1.5%) and yellow species (samples M3 & M4) have highest amount of sand (17.3 & 17 %). Amount of silt vary from 22% (M4 sample) to 28.8% (M1 sample). Clay is more abundant in red species (69.9 and 70.5 % for M1 & M2 respectively) in comparison with yellow species (59.7 & 61 for M3 & M4 respectively) (Table 3).

The textural classification of the samples of Meka'a using USDA diagram places all these samples within the clay textural group (Figure 5). These textural classifications ascertain the belief that geophagic soils are clayey in texture. Globally clay is the most abundant fraction in these materials and due to this dominance; the adsorptive effects of these materials during ingestion could be dominantly directed by adsorptive effects of clay particles [61].

The textural classification of the clayey geophagic material of Meka'a ascertain the belief that these geophagic soils are pure clayey in texture. This result is opposite to those obtained by [38] with some geophagic soils from DRC, South Africa and Swarziland. On the other hand, these results confirm the mineralogical dominance of clay mineral.

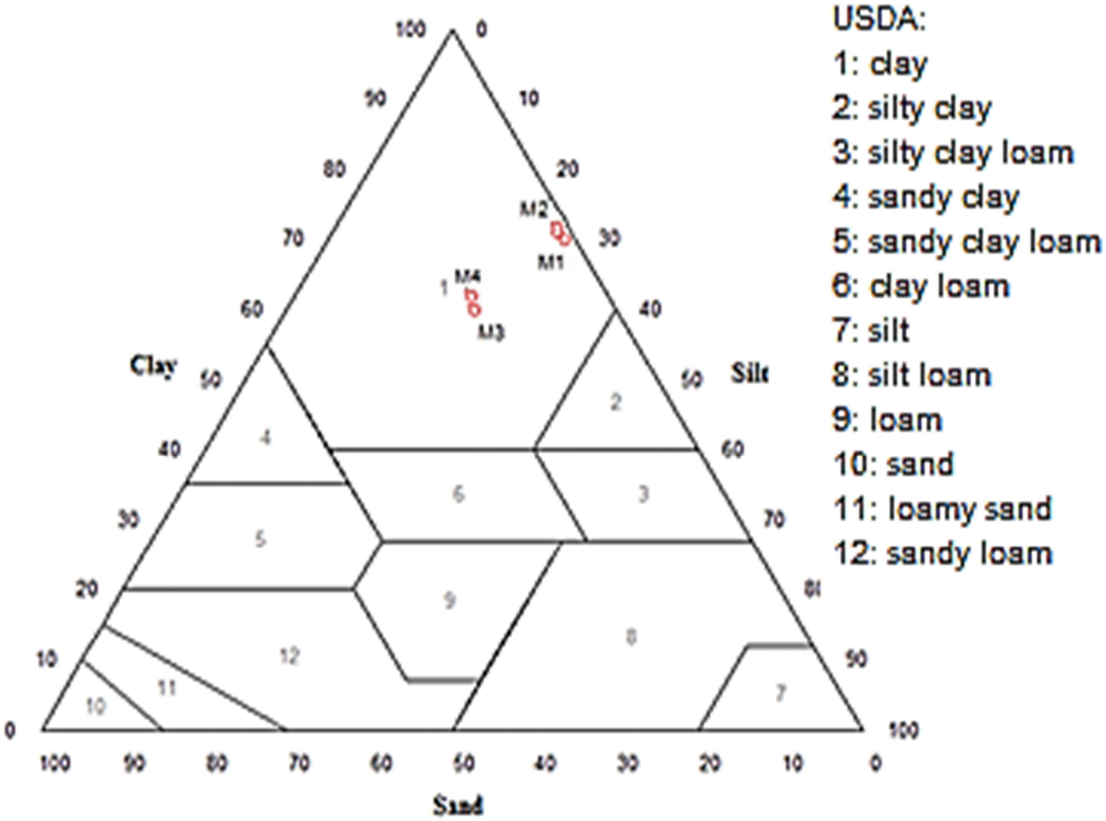

Figure 5. *USDA textural diagram showing the textural classes of Meka'a clayey materials.*

Table 3. *Particle size distribution clayey materials of Meka'a.*

	M1	M2	M3	M4
% Sand	1.3	1.5	17.3	17
%¨Coarse silt	7.0	6.0	4.0	4.5
% fine silt	21.8	22	19.0	17.5
% Silt total	28.8	28	23.0	22
% Clay	69.9	70.5	59.7	61

4.4. Chemical Composition

From Table 4 below, the kaolinitic clays of Meka'a, Balengou and Calabar are marked by:

a) a high molar ratio (silica content) SiO_2 / Al_2O_3. It is close to 2 for material of Meka'a and by that, indicates the predominance of kaolinite minerals. This molar ratio SiO_2 / Al_2O_3 did not reveal excess silica but confirms that, indeed, these materials are totally devoid of quartz as seen through the mineralogical data obtained above. In the case of Balengou and Calabar materials, the SiO_2 / Al_2O_3 ratio is approximately 3: 2.93 for Balengou and 3.03 for Calabar [9]. This high silica content (> 2) indicates the presence in the clays, significant amounts of quartz, which may impart interesting ceramic properties [9].
b) SiO_2, Al_2O_3 and Fe_2O_3 had the highest concentration among oxides;
c) Fe_2O_3 are more abundant in M3 and M4 sample than M1 & M2 due to higher level of goethite (iron hydroxides) contained in these yellow species;
d) The very low value of MgO and K_2O indicates the lack of expandable clays in total conformity of mineralogical analysis;
e) NaO, CaO and Na_2O amount in these materials are near to zero or nul.
f) Analyse of chemical composition suggest that:
g) The very low abundance of MgO and K_2O indicate the lack of expandable clays [61] in total conformity of mineralogical analysis;
h) The lack of base cations suggest a high weathered level of these clayey materials because base cations are generally depleted in highly weathered soils due to their extraction from the soils during chemical weathering [38];
i) The fact that all these materials can't be considered as potential sources of such elements such as sodium, manganese and calcium in the body during ingestion, is indicated by the near or zero content of CaO and MnO and the lack of Na_2O.

Table 4. *Chemical composition of the studied samples (major elements wt%).*

	M1	M2	M3	M4	B4	C2	C3
SiO_2	42.62	41.74	32.34	31.12	50.21	51.40	51.52
TiO_2	1.33	1.29	1.09	1.04	0.28	1.47	1.56
Al_2O_3	36.4	35.55	28.32	27.26	29.11	28.68	28.83
Fe_2O_3	1.84	1.72	21.33	24.11	2.49	2.24	2.78
MnO	0	0	0.1	0.01	tr	tr	tr
MgO	0.09	0.08	0.08	0.08	tr	0.40	0.23
Na_2O	0	0	0	0	tr	0.01	tr
CaO	0.08	0.08	0.06	0.06	tr	tr	tr
K_2O	0.1	0.09	0.06	0.06	0.15	0.69	0.53
P_2O_5	0.04	0.04	0.09	0.09	0.04	0.06	0.7
PF	15.01	15.20	13.52	14.66	12.05	10.96	10.97
Total	97.51	95.79	96.90	98.49	98.18	99.03	98.79
Molar ratio SiO_2 / Al_2O_3	1.99	1.99	1.94	1.94	2.93	3.04	3.03

Where M1, M2, M3 and M4 =Meka'a (this study); B4 = Balengou; C2 and C3 = Calabar samples (from [9]).

CIA index for clayey materials of Meka'a ranges from 99.51 to 99.58; those of Calabar are ranged from 97.62 to 98.19 and the one of Balengou has a value of 99.49. CIW index for these materails are also high; 99.78 to 99.79 for Meka'a, 99.97 to 100 for Calabar and 100 for Balengou (Figure 6). According to the interpretation of weathering index made by [62] for CIA and [63] for CIW, all these clayey materials are extremely weathered (Figure 7). These highest CIA values (close to 100) are characteristic of kaolinite mineral [62]. The higher values of CIA and CIW obtained for these samples may explain the higher content of clay particles in these samples. Excessive weathering of soils conduct to high clay contains and accumulation of silicate clays may affect several processes in the gut of individual in case of geophagia [38].

Clayey materials of Meka'a, Balengou and Calabar with their extreme weathering are similar to those of Democratic Republic of Congo analysed by [38].

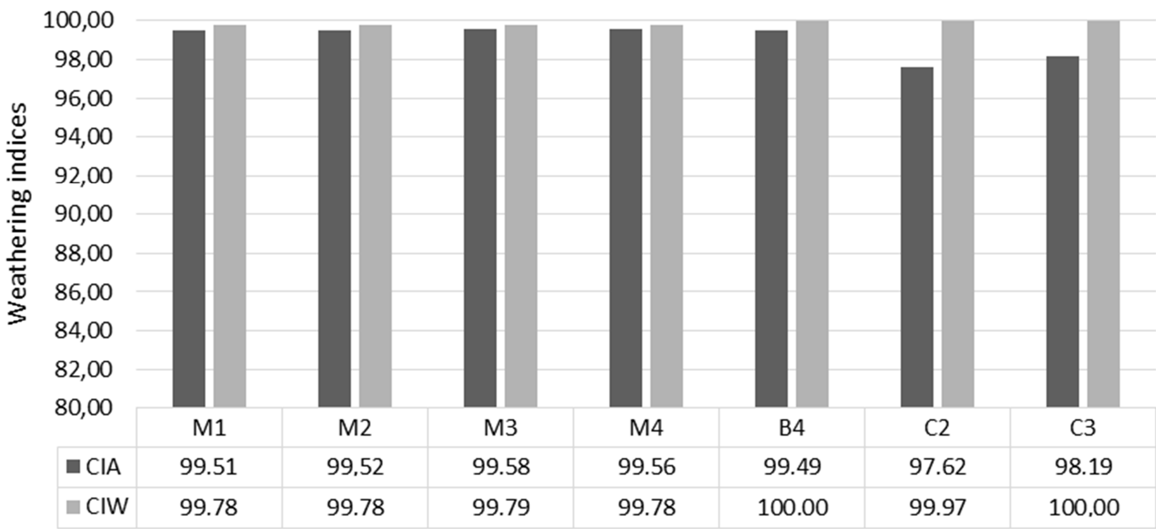

Figure 6. *CIA and CIW index of samples.*

Comparison between the values obtained for 9 trace elements contained in the clays of Meka'a and those obtained on Balengou and Calabar clays compiled in Table 5 and figure 7 bellow shows that:

a) vanadium (V) is more abundant in the sample C3 of Calabar (94 mg / kg), and Meka'a materials (58 to 70 mg / kg). Balengou Samples B4 and Calabar Samples C2 are very few filled;
b) chromium (Cr), nickel (Ni), strontium (Sr) and barium (Ba) are more abundant in the Calabar materials (samples C2 and C3 for Cr, Sr and Ba; C2 sample Ni);
c) zinc (> 70 mg / kg) and zirconium (> 1000 mg / Kg) are very abundant in materials of Meka'a and Balengou, greatly exceeding their Clarke (65 and 160 mg / kg respectively);
d) Zirconium (Zr) is very abundant in Balengou materials (1063 mg / kg) and particularly those of Meka'a (> 1400 mg / kg), its concentration is ten times its Clarke;
e) all these materials are impoverish in Nickel and copper
f) Lead is very abundant in Meka'a materials (41 mg / kg) and those of Calabar (34 mg / kg) that is, more than the double of its Clarke (15 mg/kg).

The abundance of lead (toxic element) in Meka'a and Calabar samples is disturbing. Nevertheless, according to [9] and [64], these values are not high enough to cause a health nuisance. However, the abundance of zinc in the Meka'a and Balengou clays could be beneficial to human beings. In fact, zinc is an indispensable element for the human body: it strengthens the immuned system by activating lymphocytes and affects foetal growth [65]. Zinc enriched clays could constitute a mode of absorption of this element, subject to a study of its bioavailability in gastrointestinal tract and desorption of this element [65].

Table 5. *Concentrations in mg / kg of certain trace elements of Meka'a, Balengou and Calabar materials.*

Meka'a					[9]			Clarke
					Balengou	Calabar		
	M1	M2	M3	M4	B4	C2	C3	Earth crust
V	58.4	61.7	70.5	68.8	<3	<3	94	110
Crr	21.1	22.4	31.6	30.6	22	116	142	200
Ni	16.4	17.1	15.8	14.2	10	39	17	80
Cu	3.6	0	0	0	6	13	11	45
Zn	77.7	72.7	85.3	84.6	131	42	30	65
Sr	31.3	31.6	27.9	26.8	2	113	114	450
Zr	1662.1	1571.7	1562.7	1493.2	1063	202	28	160
Ba	47.4	45.9	35	33.5	63	219	211	400
Pb	41	40.7	22	21.9	18	26	34	15

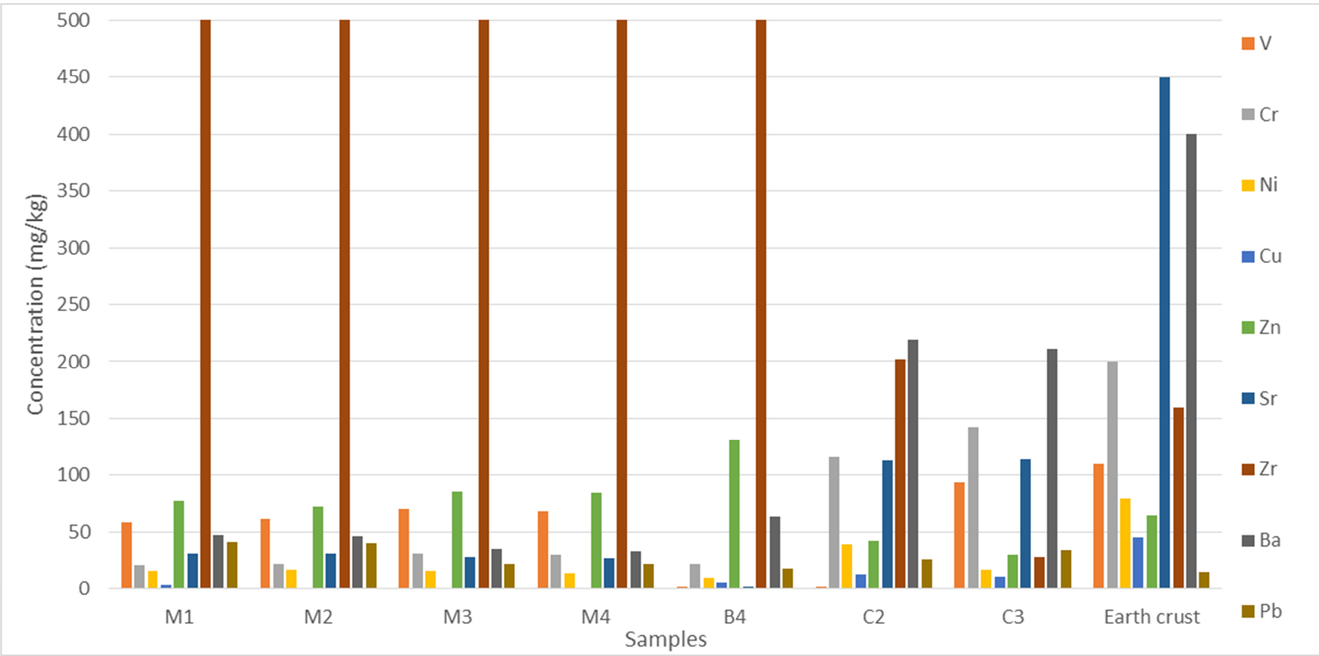

Figure 7. *Comparison between nine trace elements in the samples of Meka'a (M1 M2 M3 M4), Balengou (B4), Calabar (C2 C3) and their Clarke (Earth crust).*

4.5. CEC and pH

CEC values of these materials range from 18.13 to 19.92 (Meka'a), 10.8 to 14.08 (Calabar) and those of Balengou have an 11.84 value. The cation exchange capacities of all these clayey materials are less than 20. Similarly, the content of these samples in exchangeable bases (Ca and Mg only) is very low; the exchangeable Ca value is almost zero and negligible compared to the exchangeable Mg content (table 6).

Generally, the CEC values of these clays are low (less than 20). This means that the analyzed clays are mostly made of minerals with low CEC like kaolinite (Table 6). Similarly, the content of these samples in exchangeable bases (Ca and Mg only) is very low; the exchangeable Ca value is almost zero and negligible, compared to exchangeable Mg content. All these results are in confirmity with data obtained from XRD and X fluorescence. According to [66] and [67], due to their low CEC, these clayey materials are not able to scavenge cations in the gut.

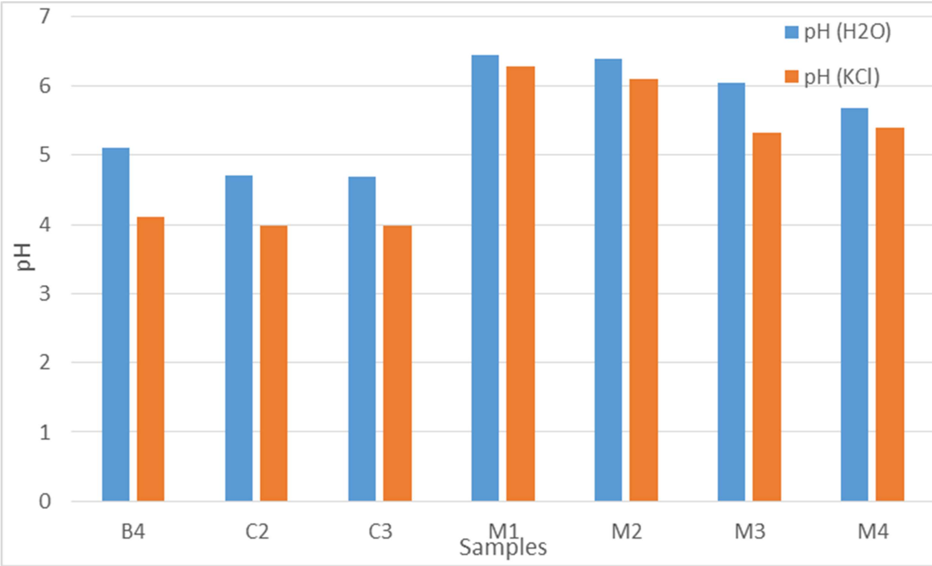

Figure 8. *pH index of samples.*

The pH values of all the samples were generally lower than 7 (slightly acidic) (Table 6 and Figure 8). Meka'a materials have pH (H_2O) values range from 5.69 to 6.44, those of Calabar range from 4.68 to 4.71 and the one of Balengou was 5.1. The pH (KCl) values of these materials range from 5.32 to 6.28 (Meka'a), 3.98-3.99 (Calabar) and 4.11 (Balengou). pH (KCl) values are globally lower than those of pH (H_2O) and Meka'a clayey materials present higher values of pH (KCl and H_2O) than those of Balengou and Calabar (figure 8). The difference between pH (H_2O) and pH (KCl) (reserve acidity) for these materials range from 0.16 (M1) to 0.99 (B4). Samples M1, M2 and M4 have values less than 0.5 while samples M3, C2, C3 and B4 values are higher than 0.5 but less than 1 none of these materials did not have reserve acidity more than 1.

The pH values of all the samples were generally lower than 7 indicating that they are slightly acidic (Table 6) thereby imparting a sour taste to the soil, as reported by [68]. The values of the pH (KCl) of all the samples were significantly lower than those of pH (H_2O) indicating that the samples were all positively charged. Possible chemical reactions involving clay minerals and organic matter in the geophagic soil could occur in the stomach because of the acidity (pH = 2) of its gastric juice [69]. Balengou and Calabar clayey materials present an average reserve acidity while Meka'a clayey materials have weak reserve acidity. Balengou and Calabar clay are therefore more favorable than those of Meka'a to chemical reaction in the stomach. Other reactions could occur in the duodenal and intestinal section of the gastrointestinal tract where the pH is about 8 [69]. Consumption of clay have been reported to control excessive secretion of saliva and reduce nausea [70]. Acidic pH of these clayey soils makes them suitable for use as remedy for nausea and to curb salivation associated with pregnancy [45, 71, 72].

Table 6. *Cation exchange capacity and pH values of the samples collected from the market (Calabar: C, Balengou: B) and Meka'a: M site.*

	Exchangeable bases (meq/100g)		CEC (meq/100 g)	pH		
	Ca	Mg		H_2O	KCl	Δ
B4	0	0	11.84	5.1	4.11	0.99
C2	0	0.4	10.8	4.71	3.98	0.73
C3	0	0	14.08	4.68	3.99	0.69
M1	0.025	1.143	19.92	6.44	6.28	0.16
M2	0.034	1.840	19.84	6.38	6.10	0.28
M3	0.080	3.140	18.16	6.05	5.32	0.73
M4	0.098	3.602	18.13	5.69	5.40	0.29

4.6. Possible Consequences of Ingesting These Clayey Materials

The clayey materials of Meka'a used for geophagia can globally be classified in two species on the basis of their colour, mineralogy and physico-chemical characteristics. The red species are represented by samples M1 & M2 and yellow species are represented by M3 & M4. These colours (red and yellow) are probably due to iron hydroxides (goethite, maghemite) contained in them [2, 30, 37]. Presence of iron hydroxides in yellow clayey materials of Meka'a can firstly be benefits for human ingestion. However, possibility of Fe supplementation of the clayey soils of Meka'a may be very low considering low ferric hydroxide content and the fact that only a part of Fe present in the clayey soil can be released in the digestive tract [38].

Zinc abundance of clayey soils of Meka'a can be beneficial and constitute a possible mode of intake for this element [65]. However, due to the controversy of authors around the concern of Fe and Zn supplementation by geophagia, only a study on bioavailability of these elements in the clayey soils of Meka'a can determine if these clayey materials can provide these elements during geophagia intake [65].

Abundance of Kaolinite in the mineral assemblage of clayey material of Meka'a could be beneficial because of the protection of gastro intestinal tract resulting from ingestion of soils with high clay content [73]. This abundance of kaolinite mineral may also positively influence the release of essential nutrients to the geophagic individuals through isomorphic substitutions [45]. Important nutrients cations (Fe, Ca…) could also be absorbed by clay materials in the gastro-intestinal tract and cause deficiencies in these nutrients cations [74]. According to the low CEC of the clayey materials of Meka'a (<20 meq/100g), this eventuality is not to be feared [66, 67]. Similarly clayey materials of Meka'a could not provide essential elements (Ca, Na, Mg…) because of their absence in these clayey soils. The acidic pH of these clayey materials make them suitable for use as remedy for nausea and to curb salivation associated with pregnancy [45, 71, 72]. Total absence of quartz in these samples and their clay texture show that these materials cannot damage dental enamel during mastication and cannot cause abrasion of the walls of the gastro-intestinal tract or other damage in the gut [38, 45].

5. Conclusion

The mineralogy and physico-chemical analysis of geophagic clayey soils from Meka'a (Foréké-Dschang), West Cameroon, have been done and their possible effects during ingestion by humans ascertained. Two major species (yellow and red) have been identified; these colours mark the presence of significant amount of Fe-hydroxides (goethite, maghemite). These materials are extremely weathered and mainly made up of kaolinite (64-87%) and goethite (6-25%). These two minerals greatly influence the properties of the materials. These clayey soils have a lower CEC and could not provide and/or scavenge base cations in the digestive tract. Their acidic pH makes them suitable for use as remedy for relief of nausea and to curb salivation associated with pregnancy. No dental enamel or gastro-intestinal tract damage was to be feared when ingesting Meka'a clayey soils and their abundance in Zn could be benefits to geophagic individuals.

The Meka'a clayey materials display good geophagic properties; however, the bioavailability of Zn, Fe and Al need detailed studies. Before recommending these clays for ingestion, the contents of some toxic elements such as Cd, As and Bi must be measured and their desorption well ascertained.

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