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The normative alterology, an efficient and helpful decision making tool for the multiform valorization of weathered rock materials of tropical countries

Georges Emmanuel EKODECK* et/and Véronique KAMGANG KABEYENE BEYALA**

* University of Yaoundé I, Faculty of Science, Department of Earth Sciences, Laboratory of Engineering Geology and Alterology, P.O. BOX. 4930, Yaoundé, Cameroon.
* * University of Yaoundé I, Teacher Training Higher School, Department of Natural Sciences, Laboratory of Geology, P.O. BOX. 8127 Yaoundé, Cameroon.

Abstract

The evolution of lithospheric aluminosilicate-bearing rocks under the action of meteoric agents can be characterized, either by the means of the traditional and litho-dependent procedure, which uses mass balances done by reference to the supposedly homogeneous original rock with the help of invariant items, or while using the normative alterology, which is not litho-dependent, has no invariant item, exploits the chemical composition in major elements and determines alterological parameters, through interposed virtual mineralogical composition, namely those quantified by reference to the hypothetical final evolution stage of aluminosilicates. These two looks, crossing on a same reality, are turned, the first one toward the origin and the second one toward the future of the examined materials. Statistical comparisons of real and virtual mineralogical compositions which the two characterization ways lean on, show a satisfactory convergence.

The examination of eligible features in the choice of clayey materials, usable on the one hand in industries of building, fine ceramics and refractory wares, and on the second hand to produce rubber, paper, paint and plastics, shows a qualitative gradation with regard to mineralogical composition. The normative alterology, applied on materials collected from regions between and around the tropics, appears then to be an appropriate and helpful tool for the selection decision.

Key words: Meteoric alteration - Weathering mass balance - Normative alterology - Convergence - Clay materials - Building materials - Fine ceramics - Refractory wares - Rubber - Paper - Paint - Plastic.

Résumé

L'évolution des roches aluminosilicatées de la lithosphère sous l'action des agents météoriques peut être caractérisée, soit suivant le mode traditionnel, litho-dépendant, à l'aide des bilans de masse effectués par le biais d'invariants par référence à la roche originelle supposément homogène, soit en utilisant l'altérologie normative, non litho-dépendante et sans invariant, qui exploite la composition chimique en éléments majeurs et détermine, par composition minéralogique virtuelle interposée, des paramètres altérologiques quantifiés principalement par référence au stade final hypothétique de l'évolution des aluminosilicates. Ces deux regards, qui se croisent sur une même réalité, sont tournés, l'un vers l'origine, l'autre vers le devenir des matériaux examinés. Les comparaisons statistiques des compositions minéralogiques réelles et virtuelles sur lesquelles ils s'appuient montrent une convergence satisfaisante.

L'examen des caractéristiques exigibles dans le choix des matériaux argileux utilisables, d'une part dans l'industrie du bâtiment, de la céramique fine, des réfractaires, et d'autre part dans la production des caoutchoucs, du papier, des peintures et des plastiques, montre une gradation qualitative d'ordre minéralogique, en fonction de ces usages. L'altérologie normative, appliquée aux matériaux issus des régions inter- et péri-tropicales, apparaît alors comme un outil approprié d'aide à la décision de sélection.

Mots clés: Altération météorique - Bilans d'altération - Altérologie normative - Convergence - Matériaux argileux - Matériaux de construction - Céramique fine - Réfractaires - Caoutchouc - Papier - Peinture - Plastique.

1.0 GENERAL INTRODUCTION

The weathering processes undergone by terrestrial lithosphere aluminosilicate-bearing rocks are essentially based on the hydrolysis, under continental interface thermodynamic conditions. This article presents at first, as recall, the principles and modalities of the look that one usually puts on this phenomenon and which is founded on elements participating the real. Thereafter, it presents the principles and modalities of a particular look that can be put on these materials, through normative, virtual or potential means, in order to quantify the size of transformations they undergo under meteoric agents action. Both looks have the same theoretical and experimental bases

The traditional vision pulls its reasoning references from the original rock. It is therefore considered as litho-dependent. However, in equatorial regions, the weathering mantle great thickness often makes it impossible to accede to fresh rock. And even when this happens, its parenthood with regard to weathered materials is not obvious. Consequently, the research of another way to apprehend the evolution of materials found in these regions has been carried out and presented (EKODECK, 1984), then improved (EKODECK, 1989; EKODECK and KAMGANG, 2002, 2011). It takes as references the ultimate transformation products and, as such, it is not litho-dependent.

After going through the headlines of these two perception modalities of the meteoric alteration, the review of some results, gotten from comparative examinations carried out on the mineralogical composition and on the evolution of materials, will permit to have a clear idea of the degree of convergence and divergence of these two visions. The subsequent presentation of requirements in the choice of clays to be used by different industries will give the opportunity to expose the possibilities offered by the normative alterology with regard to the characterization and selection of materials. Some typical cases will be presented as illustrations.

2.0 GENERAL CONSIDERATIONS ON THE METEORIC ALTERATION AND ON ITS CHARACTERIZATION MODALITIES

2.1 Weathering or meteoric alteration

The meteoric alteration is the set of phenomena that provokes the loosening of rocks at the continental interface. This loosening is either of physical origin, or of chemical origin. This last type predominates in moderate and tropical climatic zones and aims at the individualization of stable materials in the superficial environment. In the case of aluminosilicate-bearing rocks, it leads to the neogenesis of secondary aluminous minerals, built from a planar layer of aluminium hydroxides called "octahedral layer", which, according to the degree of evolution of the alteration environment, can be single or associated to one or two layers of silicon oxides called "tetrahedral layers". The result is that the processes, prevailing in the evolutionary sequence of materials are: bisiallitization, monosiallitization and allitization (PEDRO and DELMAS, 1971). The textural and structural differentiations that occur are produced by two groups of antagonistic mechanisms. The mechanisms of subtraction on the one hand, that proceed by lixiviation and by leaching of the most mobile constituents and aim at the relative residual accumulation of the least mobile constituents, and the mechanisms of addition on the other hand, that proceed by migration of the most mobile constituents, the aim being the absolute and lateral accumulation of these constituents. Two chemical alteration fundamental modalities are to be distinguished, the first one being geochemical or hydrolytic, and the second one, biochemical or biolytic.

The hydrolytic alteration intervenes in "open" environment under the action of water more or less charged in CO_2 when the pH of circulation waters ranges between 5.00 and 9.60 (PEDRO, 1978). Its characteristic feature is the solvency of mineral constituents of rocks through chemical reactions that have three consequences: (1) destruction of the parental mineral structure with liberation of cations and of silica; (2) departure in solution or in suspension of a part of these liberated elements; (3) recombination of remnant elements producing new mineral phases which evolve very quickly toward simple or complex crystalline forms. Alteration environments can also be "closed". The accumulations of ferromagnesian and calcoalkaline elements and of silica which occur in these environments of confinement are favoured by evaporation and ionic saturation.

The biolytic alteration, conditioned by the presence of organic matters, is characterized by the slowness of crystallization and neoformation processes (BERTHELIN et al., 1978).

In the spatial distribution of these two types of chemical changes, climatic factors play an essential role. Hot and humid climates encourage the hydrolytic alteration, whereas moderate or cold climates encourage the biolytic one.

2.2 Current characterization of hydrolytic alteration

The current global geochemical studies of rocks pass by destructive methods, demanding the execution of chemical analyses that entails the rupture of natural crystalline links. The gotten quantitative information has nothing anymore to shear with the real structure of the rock. To exploit this information in the framework of relations between mineralogical and chemical compositions, one is obliged to elaborate "restructurings", which are distributed in three groups of methods, "normative", "parametric", and "statistic" (DE LAROCHE, 1978). The first ones namely express chemical data in forms of virtual mineralogical compositions through a certain number of assumptions on nature and formation order of minerals.

The above reported three consequences of chemical hydrolysis reactions, that affect rock minerals during chemical alteration in open environment, were the starting points of three usual analysis methods of supergene alteration mechanisms: (1) the mineralogical approach, founded on the definition of mineral elements variations along a profile (vertical linear variation), and then along a sequence of profiles (bidimensional variation or toposequence), (2) the thermodynamic and kinetic approach, founded on the thermodynamic survey of interactions between rocks and attack solutions, with regard to reactions of minerals dissolutions, and leading to the differentiation of reversible thermodynamic processes on the one hand, such as mass balances between mineral phases and neogenesis of secondary minerals, and irreversible on the other hand, such as the dissolution of primary minerals, and (3) the method of mass balances that aims at the constitution of a geochemical mass balance of matter gains and losses undergone by rocks during their degradation.

The most current mass balances are chemicomineralogical. They consist in valuing absolute variations along a column of soil, with reference to parental rock. To be distinguished among mass balance methods are: (1) the isovolume method (MILLOT and BONIFAS, 1955) that compares mineralogical constitutions or global chemical compositions of rock facies having kept their initial structures and volumes, (2) the isoelement method (LENEUF, 1959) that compares contents of chemical elements in relation to that of an element really or supposedly stable, such as iron (isoiron method), aluminium (isoaluminium method), titanium (isotitanium method), chromium, lead, etc., and (3) the isomineral method, that compares contents of minerals in relation to that of a really or supposedly non alterable mineral, such as quartz (isoquartz method) (LELONG, 1969), ilmenite (isoilmenite method), zircon (isozircon method). These three gaits are carried with the help of an invariant parameter (volume, chemical element or mineral), chosen "a posteriori" from the original fresh rock, which represents the initial state and must be, not only known, but also fresh and homogeneous. Appropriate evaluation formulas have been established by the corresponding authors for each of these gaits.

2.3 Normative characterization of weathering

The alterological normative restructuring is a method of survey, characterization and classification of rocks, inspired from the American CIPW method (CROSS et al. 1903) and founded solely on results of major constituents chemical analyses. It is a globalizing means, without invariant and free of reference to parental rock. Its aim is the valuation of weathering parameters of silicate-bearing rocks, whatever the bioclimatic conditions of their pedogenetic evolution, after the setting up of their virtual mineralogical composition. This mineralogical composition, as well as the ensuing parameters, can then be taken into consideration, either within the framework of a general characterization, capable to be carried out by the means of interpretation and characterization diagrams, either else within that of a punctual characterization, or in that of an evolutionary and integrated survey, or else in that of Applied Geology prospective studies, notably in Civil Engineering and in the survey of some exploitable mineral resources. The hold in account of combined water distinguishes the alterological normative method from the CIPW normative method which is "magmatological".

The calculation principle consists in combining theoretically molecules of at the most fourteen (14) major chemical constituents, to give out, in quality and quantity, stallion minerals. The range of thirty-seven (37) disposable stallion mineral species permits to constitute a virtual mineralogical composition for every analyzed rock sample (see EKODECK and KAMGANG, 2002, 2011).

The set up gait aims at the valuation of absolute or relative alterological parameters susceptible to permit the quantitative follow up of the evolution of phenomena occurring during alteration processes. Other kinds of normative characterization exist. However, they don't go very far beyond the determination of the virtual mineralogical composition.

Among the particular parameters, valued from weight contents of reconstituted minerals, and defined so as to characterize alteration products by the mechanisms of enrichment or of impoverishment put in play during their formation and by the particularities of their formation environment, only those having a direct impact in the object of the present article are presented hereby.

- Parameters of absolute or relative enrichment of the alteration environment in aluminium and ferric iron oxihydroxides not combined to silicates

The concern is the "importance of free aluminium" (IFA) and of the "importance of free ferric iron" (IFI).

$$(1)\ \mathrm{IFA} = \frac{(\mathrm{Gibbsite + Boehmite + Corundum})*100}{\mathrm{Gibbsite + Boehmite + Corundum + Goethite + Hematite + Co}}$$

$$(2)\ \mathrm{IFI} = \frac{(\mathrm{Goethite + Hematite})*100}{\mathrm{Gibbsite + Boehmite + Corundum + Goethite + Hematite + Co}}$$

[In these two relations, Co is a weight coefficient that permits to avoid indeterminate or infinite values to these two complementary parameters. Co = Ta% - (Al_2O_3a% + Fe_2O_3a %), with: Ta%: total analytic percentage of major elements; Al_2O_3a%: initial content of alumina (raw sample); Fe_2O_3a%: initial content of ferric iron oxide. (raw sample)].

[*]The values of each of these two complementary parameters range from 0 to 100. Considering for instance the case of IFA parameter, its values from 0 to 50 indicate rocks with subordinated aluminium oxihydroxides, whereas those included between 50 and 100 characterize rocks with predominating aluminium oxihydroxides. In the same way, the second parameter (IFI) characterizes subordination or predominance of ferric iron oxihydroxides.

- Parameters of relative or absolute impoverishment of rocks in mobile elements under the effect of hydrolysis and lixiviation leading to the formation of new mineral phases

To be especially distinguished are the "potential lixiviation index" (PLI) and the "rock virtual weathering degree" (RVWD).

$$(3)\ \mathrm{PLI} = \frac{(\mathrm{Gib+Boe})*100 + (\mathrm{Kand})*75 + (\mathrm{Ca\text{-}alk\ Al^\circ.Sil})*50 + (\mathrm{FeMg\ Al^\circ.Sil})*25}{\mathrm{Gib+Boe+Cor+Sil}}$$

$$(4)\ \mathrm{RVWD} = \frac{(\mathrm{Gib+Boe+Am.Si})*100 + (\mathrm{Kand})*75 + (\mathrm{Ca\text{-}alk\ Al^\circ.Sil})*50 + (\mathrm{FeMg\ Al^\circ.Sil})*25}{\mathrm{Gib+Boe+Cor+Sil+Qtz+Am.Si}}$$

[NB: Gib: Gibbsite; Boe: Boehmite; Cor: Corundum; Kand: Kandites; Sil: Silicates; Al°.Sil: Alteration silicates; Ca-alk: Calcoalkaline; FeMg: Ferromagnesian; Qtz: Quartz; Am.Si: Amorphous silica.]

The PLI parameter deals with hydrolytic attack of silicates and lixiviation of their migratory elements (Fe^{2+}, Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}). The weighting coefficients found in its expression take account, not only of the decreasing resistance order of primary silicates (GOLDICH 1938), but also of the apparition order of secondary minerals, integrating hereby the three neogenetic processes defined by PEDRO and DELMAS (1971). Thus, from the theoretical point of view, in proportion as hydrolysis and lixiviation take place, when anhydrous ferromagnesian primary silicates have completely disappeared to yield the place to hydrated ferromagnesian secondary silicates, the alteration rate of silicates is 25%. When anhydrous calcoalkaline primary silicates in their turn have given up the place to calcoalkaline hydrosilicates, silicates are transformed up to 50%. These two stages correspond to bisiallitization. When all ferromagnesian and calcoalkaline hydrosilicates have disappeared to yield the place to neogenetic kandites (halloysite and kaolinite), silicates are modified up to 75%. The corresponding stage is monosiallitization. Finally, when all kandites have yielded the place to aluminium hydroxides (boehmite and gibbsite), silicates are degraded up to 100%. This stage is that of complete allitization and is the terminal stage of the hydrolytic evolution. The weight coefficients attributed to these different groups of minerals express these evolutionary stages of silicates.

The RVWD parameter characterizes the degree of transformation of the set made by quartz and silicates and consequently that of the whole rock, by taking account of the possible presence of quartz, the deterioration results in the presence of amorphous silica. The weight coefficients involved in its expression mark out the evolutionary stages of the whole rock.

- Parameter to characterize the closing degree (and consequently the opening degree) of the formation environment of alteration products with reference to the migration of mobile elements and to the evolution of silicates toward bisiallitization, monosiallitization or allitization

The concerned parameter is the "potential confinement index" (PCI), also named virtual degree of hydromorphy.

$$(5)\ PCI = \frac{[(Sil+Gib+Boe+Cor) - (Kand+Gib+Boe+Cor)]*100}{Sil+Gib+Boe+Cor} = \frac{(Sil-Kand)*100}{Sil+Gib+Boe+Cor}$$

[NB: Sil: Silicates; Gib: Gibbsite; Boe: Boehmite; Cor: Corundum; Kand: Kandites.]

The values of this parameter vary from zero, when the hydrolysis of all the original rock silicates has aimed at the formation of kandites and/or aluminium oxihydroxides, to one hundred, when the silicate-bearing rock contains neither any kandite, nor any aluminium oxihydroxide. In one extremity or the other, the environment is open or closed.

- Absolute and relative parameters

The degrees and indices presented above are to be considered as "absolute" parameters because their concern is the siliceous and silicate-bearing phases of rocks. They apply to the whole considered rock only when the major chemical constituents have wholly been taken in account, without hang-over, during mineral reconstitutions, what is not always the case. It is then opportune to quantify the degree of involvement of these constituents into the alterological normative restructuring process. That degree is hereby named the "alterological processing rate" (apr) and is valued as follows: $apr = (Ta\% - Tr\%) / Ta\%$

[NB: Ta%: total analytic weight percentage or cumulated initial weight percentages of all major chemical constituents; Tr%: total remainders weight percentage or cumulated weight percentages of all major chemical constituents that have not been involved in mineral reconstitutions.]

The values of absolute parameters are to be pondered by the alterological processing rate thus determined, what would bring back to an accurate consideration, the impact of alterological phenomena on the rock considered in its whole. The pondered values are then those of relative parameters: relative potential lixiviation index (RPLI), relative rock virtual weathering degree (RRVWD) and relative potential confinement index (RPCI).

3.0 COMPARISONS OF RESULTS

3.1 Comparison of normative mineral corteges to those determined by other methods

Results from the alterological normative method concerning the mineralogical composition have been compared by statistical way to those from a few other methods of quantitative determination, applied on fresh rocks and / or on residual phases of the pedogenesis, what permitted to appreciate the validity of the normative method. In present cases, partial results of the statistical data treatment concern not only the coefficient of correlation "r" between two different characters, the first one "x" being normative and the second one "y" obtained from other methods of characterization, of a population of N individuals, but also the equation of the regression line of "y" in relation to "x". The two characters are considered as linked in a meaningful way when the absolute value of their correlation coefficient "r" is included between 0.70 (acceptable correspondence) and 1.00 (perfect correspondence), this link being direct or inverse according to whether "r" is positive or negative. The absolute values of "r", ranging between 0.40 and 0.70 shall be considered as tendency indicators, whereas those lower than 0.40 shall mean absence of relationship between the two characters taken into account.

- Comparison of results from the alterological normative method to those from the LELONG's combined petrochemical method

A quantitative mineralogical determination method, founded on merely chemical measures (the combined petrochemical method) has been proposed by LELONG (1967). The alterological normative method has been applied to samples collected by LELONG (1969) from twelve alteration profiles in French Guyana. These profiles have been distributed in two shares (EKODECK and KAMGANG, 2002, 2003b). For the first share including eight profiles, distinction has been made between profiles on acidic rocks and those on intermediate to basic rocks, the results of chemical analyses of samples expressing iron under ferric and ferrous oxide forms. For the second share including four profiles on acidic rocks only, the results of chemical analyses of samples expressed iron only under the form of total ferric oxide. The results of data statistical analyses are the following ones:

For the first share profiles on acidic rocks (L2, L6, L14, L20, L22) (Fig. 1a):

$y = 0.93\,x + 1.40$; $r = 0.951$; $N = 207$

For the first share profiles on intermediate to basic rocks (L23, L34, L17-19) (Fig. 1b):

$y = 0.65x + 5.70$; $r = 0.687$; $N = 147$

For all the eight profiles of the first share (Fig. 1c):

$y = 0.81\,x + 8.02$; $r = 0.839$; $N = 250$

For the second share profiles (L893, L912, L1421, L1583) (Fig. 1d):

$y = 0.74\,x + 4.36$; $r = 0.749$; $N = 322$

- Comparison of results concerning bauxitic profiles samples gotten from the alterological normative method to those given by other authors.

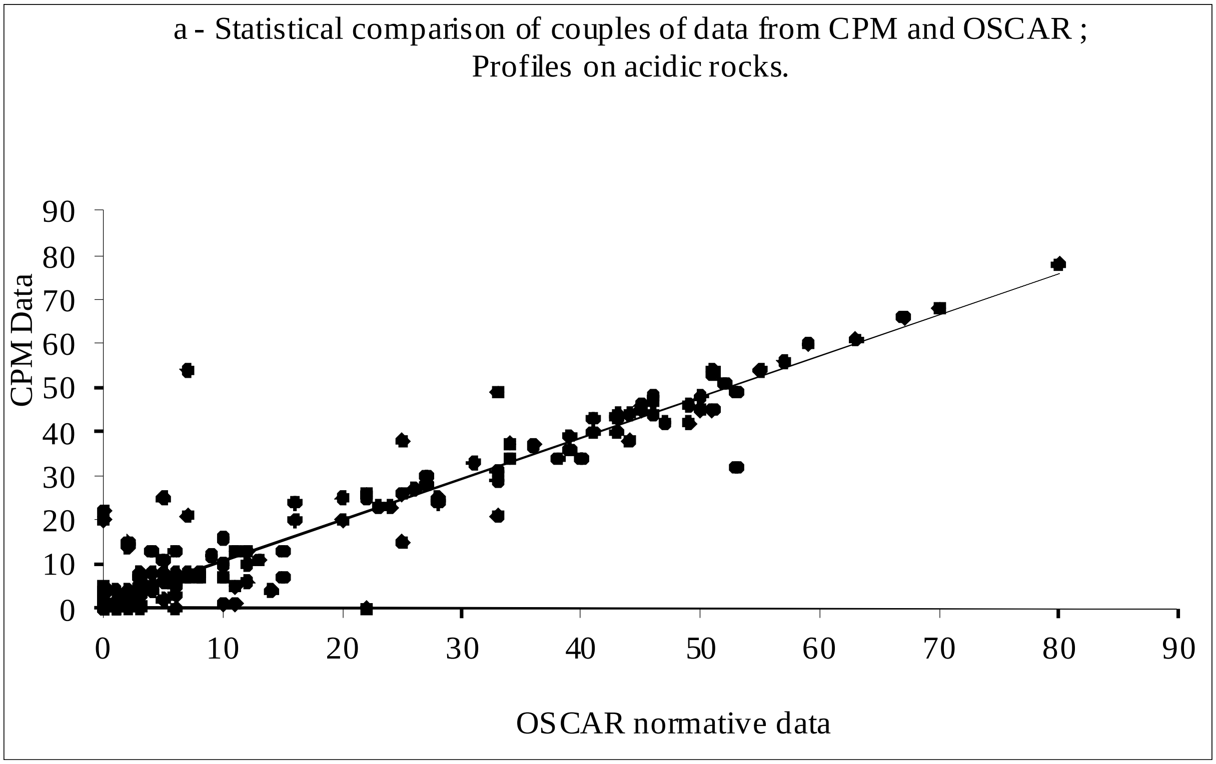
The considered data are those of TARDY (1993), recorded by CARVALHO et al. (1997). These data concern samples collected in vertical sequence on two types of bauxites, a red orthobauxite and a white metabauxite, from the FAMANSA Plateau, South of MALI. The results of chemical analyses express iron only in ferric oxides. Actual mineral weight contents are given by the quoted author for kaolinite, boehmite, gibbsite, hematite, goethite and anatase. The same mineral species have been reconstituted by the alterological normative restructuring. The general statistical correlations are excellent and self explanatory, even though in detail, those concerning kaolinite are near of the lower limit of acceptability (EKODECK and KAMGANG, 2002, 2003b). The results are the following ones:

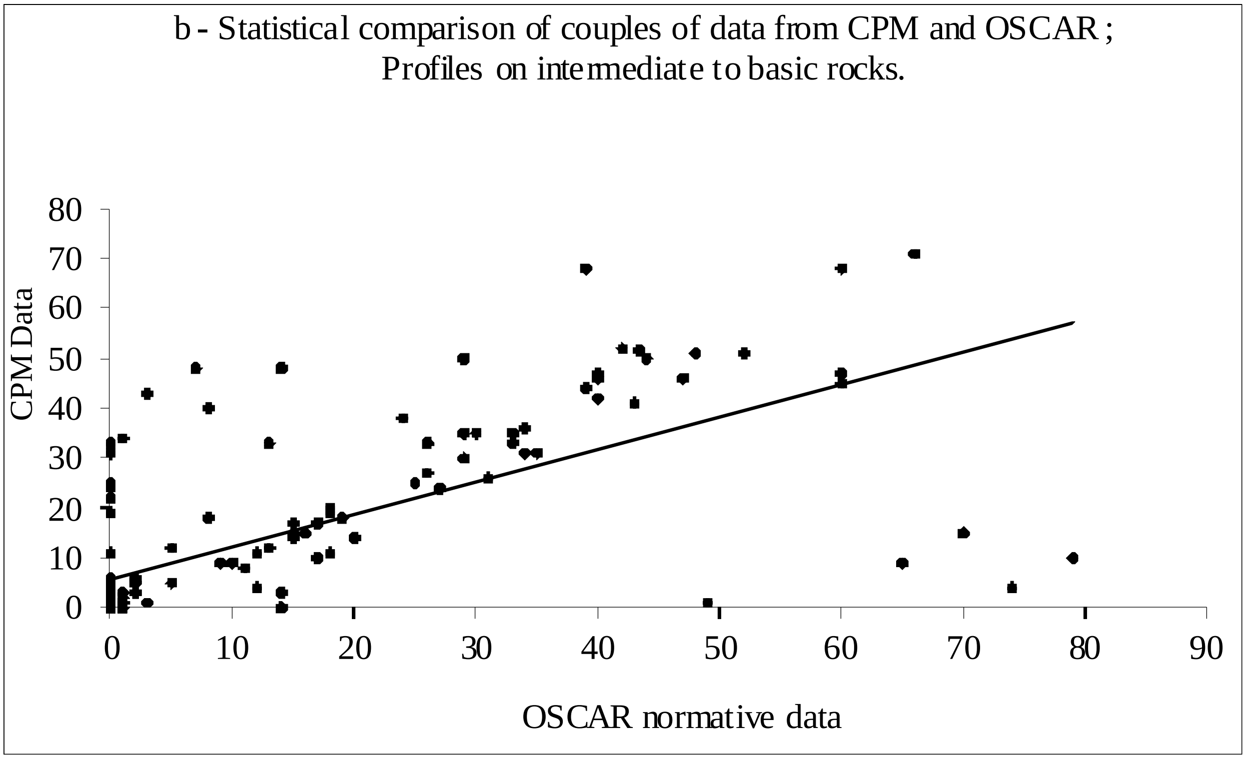
For samples collected from red orthobauxite profile (Fig. 2a):

$y = 0.999\,x - 0.040$; $r = 0.99983$; $N = 54$

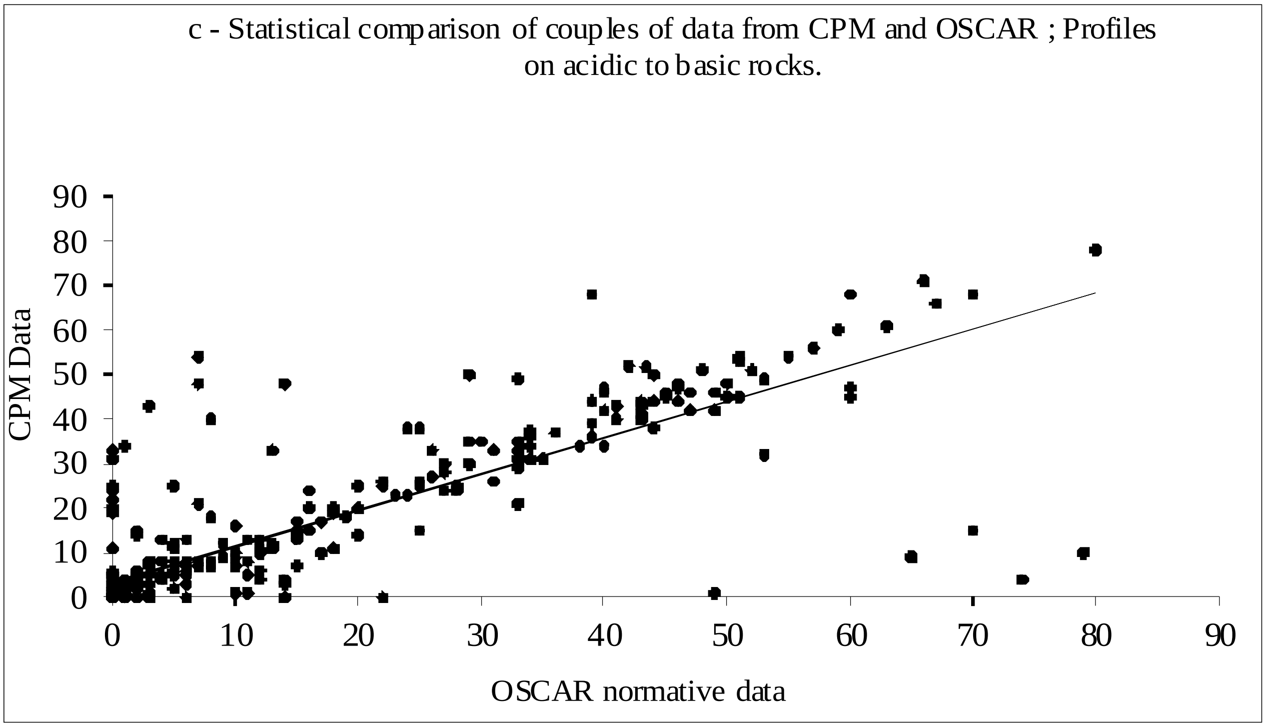
For samples collected from white metabauxite profile (Fig. 2b):

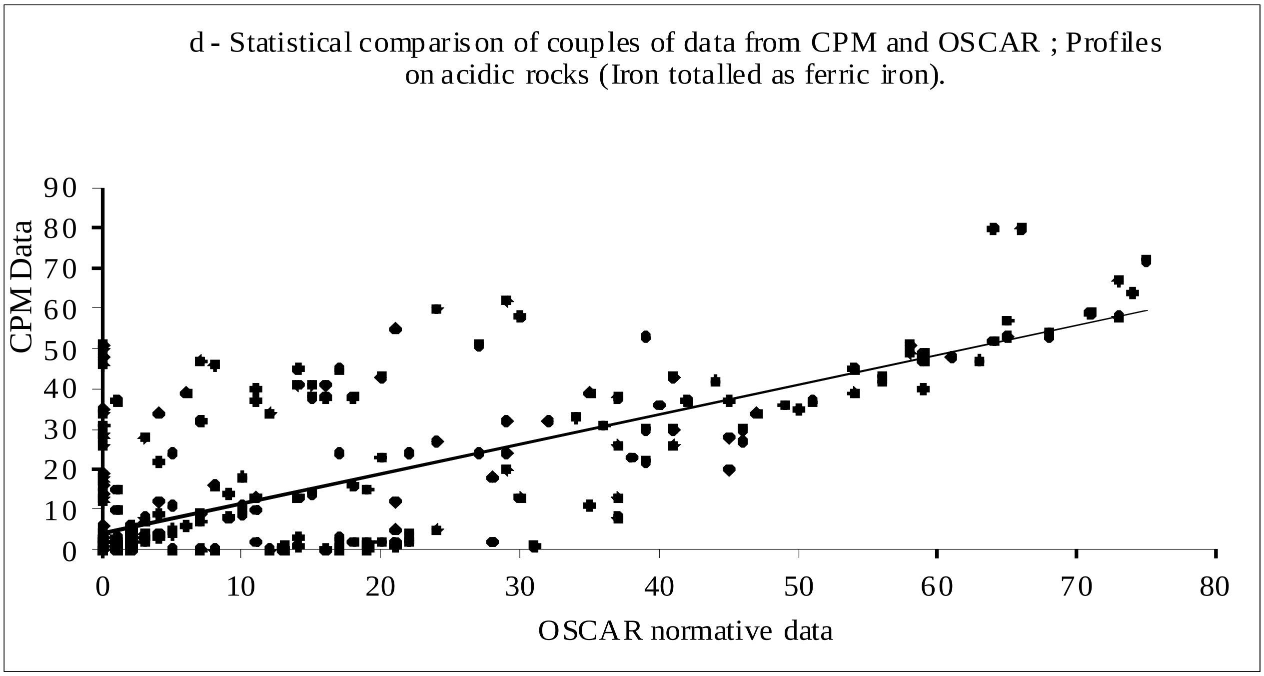
$y = 1.015\,x - 0.116$; $r = 0.99975$; $N = 84$



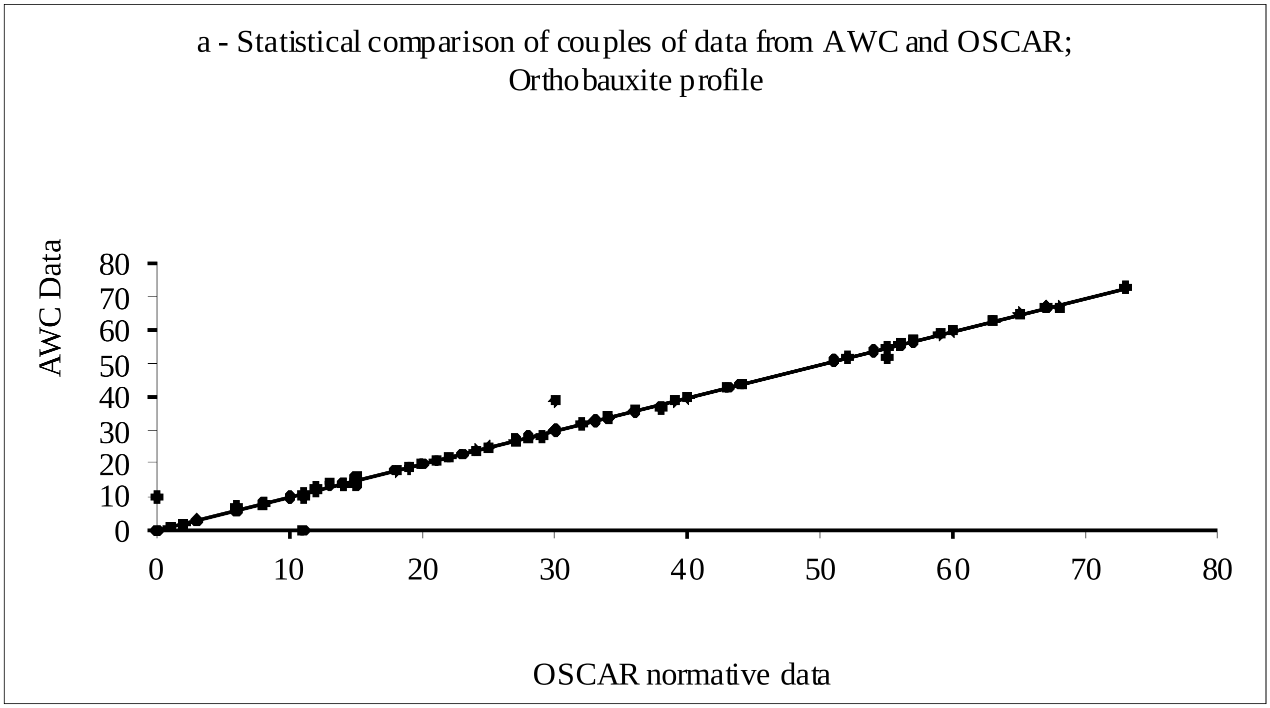


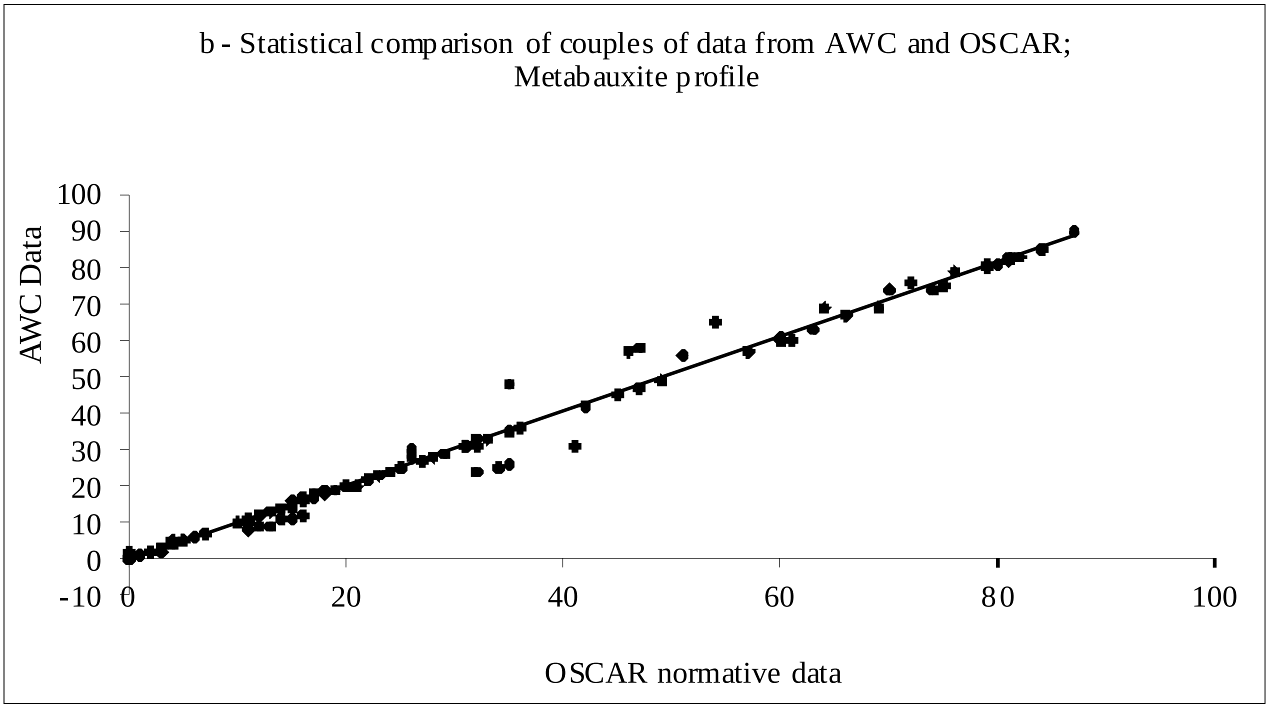
FIGURES 1 a, b: Comparisons of mineralogical results obtained from the combined petrochemical method (LELONG, 1967), ("CPM", in ordinates) and from the alterological normative restructuring method (EKODECK and KAMGANG, 2002), ("OSCAR" in abscissas); (ferrous iron distinguished from ferric iron).





FIGURES 1 c, d: Comparisons of mineralogical results obtained from the Combined Petrochemical Method (LELONG, 1967), ("CPM" in ordinates) and from the alterological normative restructuring method (EKODECK and KAMGANG, 2002.), ("OSCAR" in abscissas); (iron totalled as ferric iron).





FIGURES 2 a, b: Comparisons of Actual Weight Contents of various minerals from profiles on red orthobauxite and white metabauxite (TARDY, 1993 in CARVALHO et al., 1997), ("AWC" in ordinates) to those obtained from the alterological normative restructuring method, (EKODECK and KAMGANG, 2002.), ("OSCAR" in abscissas).

- Conclusion on mineral cortege comparisons

The statistical correlations allow to note a satisfactory convergence between the results obtained from the alterological normative restructuring and those gotten by various other means of determination of mineralogical composition carried out on materials from regions between and around the tropics (value of the regression line slope close to 1, value of the ordinate to the origin close to 0%), even though this convergence is less good in the case of fresh or relatively little evolved rocks for which the analytic data concerning iron don't specify the respective parts of ferrous and ferric iron oxides.

3.2 Comparison of evolutionary data gotten from the alterological normative restructuring to those deriving from constant volume and constant titanium weathering mass balances

The works on which these comparison elements are founded are those of LEPRUN (1979) and PION (1979). Two alteration profiles of BURKINA FASO, the first one on an acidic rock and the second one on a basic rock, studied by these authors with the help of alteration mass balances, have been chosen as examples.

- Profile on granite

This profile NAY1, from the NAYOURI toposequence (LEPRUN, 1979), the thickness of which is more than 400 cm, presents summarily under soil surface, from top to bottom: massive hardpan flatstone, hardened crust-looking horizon, horizon of speckled clay with conserved structure, jointed granitic arena, lastly, more fresh and hard granite.

The apparent density decreases from parental rock (d = 2.58) to speckled clays (d = 1.90), then increases and stabilizes around 2.30 in the crust-looking horizon and hardpan. The mass balance calculations carried out using constant volume and constant titanium reasonings, show, in the arena, a moderate evacuation of alumina, silica, and bases. From the speckled clays up to the hardpan, iron is the only element that accumulates. Aluminium and silicon are moderately evacuated. Alkaline and alkali-earthy are largely eliminated.

The alterological normative restructuring data (EKODECK and KAMGANG, 2002, 2003b) show that, at the profile bottom, impoverishment parameters variations (RPLI and RVWD) are diametrically opposite to that of the apparent density. They increase from parental rock to speckled clays. This illustrates well the phenomena of subtraction put in evidence above by LEPRUN (1979) by the means of mass balance calculations.

- Profile on green rock facies dolerite

This profile DEM1, from the DEMBOKRO toposequence (PION, 1979), the thickness is more than 1600 cm, shows, from top to bottom: a sandy soil becoming clay-sandy, a sandy horizon with gravels and rock debris, a clay horizon with vertical schistosity, the altered rock with vertical schistosity, the less altered rock with prism splitting, the altered rock with platy parting, and finally the fresh rock which is a green rock facies dolerite, very jointed, with vertical schistosity.

The apparent density variation is relatively low from deep horizons (d ranging between 2.00 and 1.88) to those near the surface (d between 1.88 and 1.56), indicating a fairly weak alteration of the initial rock (d = 2.43). These features are characteristic of alterations dominantly smectitic close to the weathering front. The mass balance calculations, carried out with the help of constant volume and constant titanium reasonings, show a weak to moderate loss occurrence during the weathering which affects all major elements and corresponds to the formation of smectitic alterites, full of basic cations.

The alterological normative restructuring data (EKODECK and KAMGANG, 2002, 2003b), by generally low values, below 60% for RPLI and below 40% for RVWD, show that the matter loss is weak from the profile basis up to the depth of 300 cm. This illustrates well the smectitic weathering phenomena indicated by PION (1979).

- Conclusion on evolutionary considerations

The comparisons and closenesses carried out give the opportunity to point out a good concordance between teachings pulled from the alterological normative restructuring that does not call on any invariant item, and those ensued from constant volume and constant titanium mass balances calculated with reference to parental rock.

4.0 - QUALITATIVE REQUIREMENTS IN THE SELECTION OF INDUSTRIAL CLAYS

4.1 General considerations

The alteration mantle of rocks is relatively important between the tropics. In most of the under-developed countries located there, geological recognition surveys often give the opportunity to take indices and occurrences of usable materials on inventory, and to characterize these materials by specifying their nature, localization, visible or likely extension, geological context of genesis. This inventory of endogenous and supergene resources is not sufficient, when one wants to select zones favourable to exploitation. In this case, complementary prospections are necessary.

The alteration products of rocks usable in industry are sandy and clayey materials. These last are susceptible to be used in more or less great quantity in the industry of building, ceramics, refractory wares where they intervene as main raw materials, as well as in that of rubber, paper, painting and plastics where they intervene as additional materials. The main factors to be taken into account in the selection of these clays are at the same time qualitative (nature, mineralogical composition, etc…) and quantitative (importance of deposit, minimal exploitable size, etc.).

The hereby pursued objective, in the optics of exploiting these materials, is that of testing and proposing a normative tool, of fast and simple use, applicable when results of major elements chemical analyses are available, these analyses being carried out possibly after eliminating the sandy-silty coarse fraction (size superior to 0.002mm). Requirements to take into account are essentially qualitative. Their specifications depend on the nature of the manufactured product.

4.2 Clays usable as main raw materials in building, fine ceramics and refractory wares industries

- Origin, utility and chemicomineralogical specifications of natural materials

Materials susceptible to be put in exploitation in the industry of building (tiles and bricks), of fine ceramics and of refractory wares, are those pertaining “a priori” to the superficial clay-sandy and to the straightforward alteration of a weathering profile. One could add to these, materials from the accumulation of aluminium oxihydroxides zones, in the case of bauxitic profiles.

Bricks and tiles are used in building, the first ones for raising walls and the last ones for roofing. Ceramics, widely speaking, is the art to manufacture potteries and other terracotta objects, wares, porcelain, whereas fine ceramics, strictly speaking, produces wares, stone wares and hard porcelain. Refractory wares are materials that resist strong thermal solicitations. To this effect, they are used for the realization of oven coatings in many industrial sectors.

Clays for tiles and bricks are materials of very diversified origin and composition. The ideal raw material (BERTON and LE BERRE, 1983) would be a clay composed of:

- clay minerals, to assure plasticity and cohesion of the dough before cooking, and ceramic link at high temperature: a mixture kaolinite - illite, with a little quantity of smectite is the most favourable, the smectite weight content being below 10%;

- quartzous sand, to play the degreasing role, to permit to reduce shrinkage on drying and cooking and to facilitate the evacuation of shaping water; its average weight content must range from 30 to 40%;

- fine calcite, favourable to low dilation to humidity of the products; its weight content must be around 15%;

- colouring elements playing the role of fondant and also being finely distributed in the clayey mass, such as Fe_2O_3 (5 to 10%) for red tiles and bricks, TiO_2 (3 to 10%) in presence of Fe_2O_3 for yellow tiles and bricks, MnO (0.5 to 4%) in presence of Fe_2O_3 for brown bricks.

Clays for fine ceramics and refractory wares, considered as "noble clays" (BERTON and LE BERRE, 1983), are essentially composed of kaolinite and must have been purified by elimination of quartz. For fine ceramics in particular, they must have a kaolinite weight content included between 50 and 80%, Fe_2O_3 and TiO_2 contents below 2%, quartz and feldspar contents capable to reach 25%. As for refractory wares, materials that enter in their manufacture are essentially clayey and silico-clayey. They must have a kaolinite content above 80%, Fe_2O_3 content below 2.5%, lime, magnesia, potash and soda contents below 1%. The presence of alumina hydrates is wished, because it increases the alumina content, as well as the refractoriness.

- Normative specifications

- Mineralogical composition

Observations that have just been made on mineralogical requirements in the choice of materials for industrial use to manufacture tiles, bricks, fine ceramics and refractory wares, can be examined in light of the normative mineralogical composition (EKODECK and KAMGANG, 2001). Thus, for ferric iron oxihydroxides and quartz, contents superior or equal to 12.5% and to 52.5% respectively, make the material unusable. Data concerning anhydrous calcoalkaline silicates represent feldspars, whereas those relative to ferromagnesian and calcoalkaline hydrosilicates represent the 2/1-type phyllites (chlorites and smectites). For the former minerals, materials are unusable for contents above 10 - 15%, whereas for the latter ones, these impeding limits must range from 5 to 10%.

- Alterological parameters

The parameters susceptible to bring information worthy of interest in the selection of industrial clays are, on the one hand, the parameters of impoverishment of the alteration environment (relative potential lixiviation index, RPLI, and relative rock virtual weathering degree, RRVWD) and, on the other hand, the parameter to characterize the environment where the formation of alteration products takes place (relative potential confinement index, RPCI). The role of the enrichment parameters of the alteration environment, and notably that of the potential importance of free ferric iron (IFI), is accessory (EKODECK and KAMGANG, 2001).

For the manufacture of tiles and bricks, the RPLI of materials must be above 50%, and their RRVWD included between 37.5 and 62.5%. The clay material is then a mixture of kaolinite and illite, with a few smectite. For the manufacture of fine ceramics, the RPLI must be superior to 70%, and the RRVWD included between 62.5 and 87.5%. The clay material is then essentially kaolinitic. For the manufacture of refractory wares, the RPLI must be superior to 85% and the RRVWD superior to 87.5%. The phyllitic fraction of the material is composed of kaolinite and/ or of alumina hydrates.

In all cases of manufacturing taken into account (tiles, bricks, fine ceramics, refractory wares), the RPCI of materials must be in any case, below 50% and their IFI below 15%.

- Protocols of selection of materials

The normative specifications induce two selection modalities, the first one being mineralogical and the second one parametric. The mineralogical selection gait is synthesized in table 1, whereas the synthesis of the parametric selection gait is presented in table 2. It is

Table 1: Protocol of mineralogical selection of materials for tiles, bricks, fine ceramics and refractory wares

CRITERIA					MATERIALS
Ferric iron oxihydroxides ≥ 12.5 %					to proscribe
Ferric iron oxihydroxides < 12.5 %	Quartz ≥ 52.5%				to proscribe
	52.5% > Quartz ≥ 15%	Anh.Ca-alk&FeMg sil. ≥ 15%			to proscribe
		Anh.Ca-alk& FeMg sil. < 15%	Ca-alk&FeMg hydrosil. ≥ 10 %		to proscribe
			Ca-alk&FeMg hydrosil. <10%	Kand.&Al.hydr. ≤ 37.5%	to proscribe
				Kand.&Al.hydr. > 37.5%	good for tiles and bricks
	Quartz < 15%	Anh.Ca-alk&FeMg sil. ≥ 10%			to proscribe
		Anh.Ca-alk& FeMg sil. < 10%	Ca-alk&FeMg hydrosil. ≥ 5%		to proscribe
			Ca-alk&FeMg hydrosil. < 5%	Kand.&Al.hydr. ≤ 37.5%	to proscribe
				37.5% < Kand.&Al.hydr. ≤ 60%	good for tiles and bricks
				60% < Kand.&Al.hydr. ≤ 85%	good for fine ceramics
				85% < Kand.&Al.hydr.	good for refractory wares

NB: Anh.Ca-alk&FeMg sil.: Anhydrous calcoalkaline and ferromagnesian silicates;
Ca-alk&FeMg hydrosil.: Calcoalkaline and ferromagnesian hydrosilicates;
Kand.&Al.hydr.: Kandites and alumina hydrates.

Table 2: Protocol of parametric selection of materials for tiles, bricks, fine ceramics and refractory wares.

CRITERIA				MATERIALS
IFI ≥ 15%				to proscribe
IFI < 15%	RPCI ≥ 50%			to proscribe
	RPCI < 50%	RPLI ≤ 50%		to proscribe
		50% < RPLI ≤ 70%	RRVWD ≤ 37.5%	to proscribe
			RRVWD > 37.5%	good for tiles and bricks
		70% < RPLI ≤ 85%	RRVWD ≤ 37.5%	to proscribe
			37.5% < RRVWD ≤ 62.5%	good for tiles and bricks
			RRVWD > 62.5%	good for fine ceramics
		RPLI >85%	RRVWD ≤ 37.5%	to proscribe
			37.5% < RRVWD ≤ 60%	good for tiles and bricks
			60% < RRVWD ≤ 85%	good for fine ceramics
			RRVWD > 85%	good for refractory wares

NB: IFI: Importance of Free ferric Iron; RPCI: Relative Potential Confinement Index; RPLI: Relative Potential Lixiviation Index; RRVWD: Relative Rock Virtual Weathering Degree.

requisite to successively use both selection modalities, because the convergence of resolutions is determining in what to opt for.

4.3 - Clays usable as additional materials in rubber, paper, painting and plastics manufacturing

- Clays usable as additional materials in rubber, paper, painting and plastics manufacturing

Materials susceptible to be put in exploitation to produce rubber, paper, painting and plastics, are “a priori” those to be extracted from the straightforward alteration zone of a weathering profile. Materials from the aluminium oxihydroxides accumulation zone might also be taken into account, in the case of bauxitic profiles.

Clays essentially involved in the manufacture of rubber, paper, painting and plastics are kaolinitic. These clays improve or bring, as the case may be, some properties to the finished product and permit to lower its production cost (BERTON and LE BERRE, 1983). Considering the case of rubber that enters in the manufacture of tyres, soil coatings, cable girdles, shoe soles, etc., its mechanical resistance, resistance to abrasion and rigidity are improved by clays. In the manufacture of paper, clays are used as load and for bedding. Used as load, they fill interstices between cellulose fibres to improve their whiteness, opacity, impermeability, receptiveness to ink, dimensional stability. The bedding, which is the depositing of a kaolinic clay coating once the sheet of paper has been constituted, has the effect of improving its surface properties by masking irregularities, increasing whiteness and bettering faculty to impression. With regard to painting, kaolinic clays, chemically inert, have good coating capacity and give wanted out-flow properties. Because of their whiteness, kaolinic clays partially replace pigments of very high cost. Their merchandising permits their use in various paintings in a large interval of granularity, coarse granularity giving some lustreless paintings, and fine granularity giving brilliant paintings. As for plastics finally, kaolinic clays are very used and permit to get very smooth surfaces, good dimensional stability and good resistance to acids. Plastics treated in such ways enter in the manufacture of PVC tubes and girdles of pieces and spare parts of cars and of boat cockles.

For all these manufacturing cases, the kaolinite weight content of raw material must be above 20%, that of quartz below 15% and that of oxidized iron below 10%.

- Normative specifications

- Mineralogical composition

The observations that have just been made on mineralogical requirements in the choice of materials for industrial use to produce rubber, paper, painting and plastics, can be examined in light of the normative mineralogical composition (EKODECK and KAMGANG, 2003a). Thus, the material is unusable for ferric iron oxihydroxides and quartz contents superior or equal to 12.5% and to 15% respectively, and for contents of the kaolinite - alumina hydrates set inferior to 37.5%. Data concerning anhydrous calcoalkaline silicates represent feldspars, whereas those relative to ferromagnesian and calcoalkaline hydrosilicates represent the 2/1-type phyllites (hydromicas, illites, chlorites and smectites). For the former ones, contents superior to 10% turn these materials unusable, whereas for the latter ones, this bottom limit content must be of 5%.

- Alterological parameters

The parameters capable to bring information worthy of interest in the selection of industrial clays are successively, the importance of free ferric iron (IFI), the relative potential confinement index (RPCI), the relative potential lixiviation indication (RPLI) and the relative rock virtual weathering degree (RRVWD) (EKODECK and KAMGANG, 2003a).

In all cases of production taken into account (rubber, paper, painting and plastics), the highest limit values might be fixed at 15% for IFI and at 50% as regards RPCI. The value of RPLI must be above 70% and that of RRVWD above 62.5%.

- Protocols of selection of materials

The selection criteria of usable materials in the production of rubber, paper, painting and plastics being mainly of mineralogical order, mineralogical criteria are the first guides in this selection. The selection gait is presented in table 3. Parameters are guides of

Table 3: Protocol of mineralogical selection of materials to produce rubber, paper, paint and plastics.

CRITERIA					MATERIALS
Ferric iron oxihydroxides $\geq$ 12,5 %					to proscribe
Ferric iron oxihydroxides < 12,5 %	Quartz $\geq$ 15%				to proscribe
	Quartz < 15%	Anh.Ca-alk & FeMg sil. $\geq$ 10%			to proscribe
		Anh.Ca-alk &FeMg sil < 10%	Ca-alk&FeMg hydrosil. $\geq$ 5%		to proscribe
			Ca-alk&FeMg hydrosol < 5%	Kand.&Al hydr. $\leq$ 37,5%	to proscribe
				Kand.&Al hydr. > 37,5%	good for rubber, paper, paint and plastics

NB: Anh.Ca-alk&FeMg sil.: Anhydrous calcoalkaline and ferromagnesian silicates;
Ca-alk&FeMg hydrosol.: Calcoalkaline and ferromagnesian hydrosilicates;
Kand.&Al hydr.: Kandites (kaolinite, halloysite) and aluminium hydrates.

Table 4: Protocol of parametric selection of materials to produce rubber, paper, paint and plastics.

CRITERIA				MATERIALS
IFI $\geq$ 15%				to proscribe
IFI < 15%	RPCI $\geq$ 50%			to proscribe
	RPCI < 50%	RPLI $\leq$ 70%		to proscribe
		RPLI > 70%	RRVWD $\leq$ 62,5%	to proscribe
			RRVWD > 62,5%	good for rubber, paper, paint and plastics

NB: IFI: Importance of free ferric iron; RPCI: Relative Potential Confinement Index; RPLI: Relative Potential Lixiviation Index; RRVWD: Relative Rock Virtual Weathering Index .

second order. They play an additional role. The selection gait is presented in table 4. In any case, the convergence of prescriptions must be determining in the choice of the final option.

5.0 - PRESENTATION OF A FEW TYPICAL CASES

The proposed selection tool has obviously not yet been used as such. The following presentations concern, on the one hand, two "a posteriori" justification cases of the relevance and adequacy of this tool, and on the other hand, a few cases, essentially hypothetical and complementary to the former ones, in manner of generalization. The examples taken in Africa (Cameroon, Gabon, Guinea Conakry) and in South America (French Guyana, Brazil) are those for which results of chemical and / or mineralogical analyses are available in the documentation.

5.1 "A posteriori" justification cases of the normative tool adequacy.

- First case: clays used in the industrial manufacture of bricks and tiles.

The targeted profile is situated in the locality of NKOLBISSON, to the West of the YAOUNDE city in CAMEROON, Central Africa, on acidic rocks

Table 5a: Presentation of few typical cases from Central Africa.

	Cameroon						Gabon***		
	Yaoundé - (Nkolbisson)*			Lomié**					
	1	2	3	1	2	3	1	2	3
SiO_2	59.72	59.33	55.97	15.74	8.35	20.97	68.40	58.90	64.30
Al_2O_3	17.24	18.63	21.20	6.56	6.04	16.69	20.80	28.00	23.60
H_2O	7.97	8.96	10.03	7.45	5.03	12.44	7.26	6.40	5.36
MgO	1.40	0.22	0.12	0.47	0.81	0.10			
MnO	0.21	0.22	0.19	1.22	0.47	0.16			
CaO	0.11	0.07	0.08		0.02	0.02			
Na_2O	0.15	0.05	0.05		0.05	0.01			
K_2O	1.60	0.80	0.13			0.01	1.27	0.95	0.88
Fe_2O_3	8.87	8.24	9.05	64.79	72.05	45.33	2.40	5.12	5.00
TiO_2	1.07	1.23	1.53	0.08	0.33	1.10	0.49	0.63	0.86
Cr_2O_5				1.80	1.80	0.78			
NiO				1.25	1.16	0.24			
Ferric iron oxihydroxides	9.78	9.26	10.15	**69.35**	**74.22**	**50.37**	2.67	5.12	4.96
Quartz	48.42	49.92	40.56	7.08		10.20	48.24	35.16	44.28
Ca-alk&FeMg hydrosil.	18.42	8.55	1.90	2.16	4.04	0.36	**11.14**	7.96	7.16
Kand.&Al.hydr.	**20.27**	**28.72**	44.01	16.51	14.57	34.63	38.12	43.34	**36.12**
Mineralogical prescription	Prosc.	Prosc.	**T+Br**	Prosc.	Prosc.	Prosc.	Prosc.	**T+Br**	Prosc.
IFI	10.20	9.54	11.14	**71.23**	**79.95**	**51.43**	3.12	6.41	5.98
RPCI	47.61	22.94	4.15	11.26	21.20	1.02	22.62	26.73	27.49
RPLI	70.06	80.20	80.78	67.39	64.02	82.06	72.19	61.68	61.58
RVWD	**31.11**	**34.28**	42.89	48.86	64.02	63.54	**36.48**	38.69	**32.60**
Parametric prescription	Prosc.	Prosc.	**T+Br**	Prosc.	Prosc.	Prosc.	Prosc.	**T+Br**	Prosc.
SYNTHESIS	**Prosc.**	**Prosc.**	**T+Br**	**Prosc.**	**Prosc.**	**Prosc.**	**Prosc.**	**T+Br**	**Prosc.**

N.B.: - Sources: *: KAMGANG and EKODECK, 1991 (Profile on garnet and kyanite holding migmatitic gneiss: 1: isalteritic horizon; 2: alloteritic horizon; 3: loose superficial horizon). **: YONGUE-FOUATEU, 1995 (Profile on serpentinous ultrabasic rocks: 1: isalteritic horizon; 2: alloteritic horizon; 3: loose superficial horizon). ***: EDOU MINKO and TRESCASES, 1990 (Profile on migmatites: 1: isalteritic horizon; 2: alloteritic horizon; 3: loose superficial horizon).

- Ca-alk&FeMg hydrosil.: Calcoalkaline and ferromagnesian hydrosilicates; Kand.&Al.hydr.: Kandites and alumina hydrates.
- IFI: Importance of free ferric iron; RPCI: Relative Potential Confinement Index; RPLI: Relative Potential Lixiviation Index; RRVWD: Relative Rock Virtual Weathering Index.
- Prosc.: Proscription; T+Br: Tiles and Bricks.

Void compartments correspond to zero value data. Numeric data in bold indicate main but not exclusive reasons for proscriptions.

(garnet and kyanite migmatitic gneisses) (KAMGANG and EKODECK, 1991). The selected samples have been respectively collected from the isalteritic (n°1), alloteritic (n°2) and superficial loose (n°3) horizons (see data on table 5a).

From the normative mineralogy point of view as well as from the parametric one, the prescriptions reveal that only materials coming from the superficial loose horizon are suitable to manufacture tiles and bricks. All other materials are to proscribe.

In the locality of NKOLBISSON, a factory of tiles and bricks, that exploited the locally extracted materials coming from the superficial loose horizon, had been implanted effectively in the years 1970-1980. This fact is justifying of the validity of the proposed selection procedure.

- Second case: clays used in master-mixtures for reinforcing rubber.

Works were carried out by NJOPWOUO (1984, 1986, 1988a and b) on materials collected from four kaolinic clay deposits located in lateritic alteration zone in the south-western part of Cameroon: (1) BOMKOUL, (2) BALENGOU, (3) MISSELLELE and (4) MUSSAKA. The experimentation samples, composed of four granulometric fractions below 2?m extracted by sedimentation in a dispersing aqueous solution from raw materials, comprised, on the one hand, two samples, designated by Boff and Baff, respectively ensuing from Bo and Ba designated raw materials from BOMKOUL and BALENGOU, and on the other hand, two samples from MISSELLELE and MUSSAKA designated by Mi and Mu, in total, six samples including raw ones.

Mineralogical results show that kaolinite is the main mineral of the raw material from BOMKOUL (65.32% weight content), while halloysite constitutes the essential mineral of that from BALENGOU (70.41% weight content). In their fine fractions, these contents grow up to 82.09 and 89.71% respectively. The fine fraction of the sample from MISSELLELE is rich in kaolinite (65.30% weight content), whereas that of the sample from MUSSAKA is basically composed of halloysite (72.90% weight content). These fine fractions, to serve as reinforcing loads, were used to make master-mixtures by co-flocculating in water, of a suspension of clay and liquid latex, in acidic environment and in presence of an anti-oxidizer, the soil fraction load having a weight rate of 65% in relation to dry rubber weight.

The ensued coagula, crimped and dried, were submitted to mechanical tests achieved in order to evaluate their performances. The gotten results showed relatively satisfactory values. In particular, the resistance to tearing, was low for mixtures with the fine fraction sample from BOMKOUL (31.2 daN/cm2), average for mixtures with that from BALENGOU (72.5 daN/cm2), high for mixtures with the sample from MISSELLELE (90.3 daN/cm2) and excellent for mixtures with that from MUSSAKA (94.2 daN/cm2). From the author's opinion, these differences are essentially due to the nature and morphology of load particles, smaller size particles being more reinforcing, for a given morphology.

The normative mineralogical compositions, determined for all the six reference samples showed a very good concordance with real compositions (EKODECK and KAMGANG, 2003a), the group of kandites and alumina hydrates constituting the basis of these materials. Mineralogical and parametric protocols for material selection to produce rubber, paper, painting and plastics were applied to these results. The mineralogical prescriptions reveal that raw materials from BALENGOU and BOMKOUL, as well as fine ones from MUSSAKA and MISSELLELE are unfit to produce these items because of their richness in quartz, whereas fine materials from BALENGOU and BOMKOUL are indicated for this production. As for the parametric prescriptions, they indicate that raw materials from BALENGOU and BOMKOUL, as well as fine materials from MISSELLELE are unfit to the purpose because of alteration insufficiency, the fine materials from BALENGOU, BOMKOUL and MUSSAKA being indicated for that (see table 6).

The convergence of normative prescriptions with NJOPWOUO's findings concerns 9 cases over 12, in other words 75% in relative value. Being a good one, this convergence consequently validates the use, certainly not exclusive, of the normative tool in the selection of clay materials for the production of reinforced rubber. The hold in account of the granulometric fraction below to 2 ?m seems to be an essential condition, because it permits the sensitive reduction of contents of quartz and ferric iron oxihydroxides, and induces more important surface effects.

Table 5b: Presentation of few typical cases from West Africa and from South America.

	Guinea Conakry*			French Guyana**			Brazil***		
	1	2	3	1	2	3	1	2	3
SiO_2	3.30	0.40	5.50	64.50	59.22	58.38	70.51	0.48	14.35
Al_2O_3	56.00	58.50	44.30	19.54	21.58	16.72	12.61	37.91	23.82
H_2O	29.70	30.90	24.50	9.02	10.81	9.50	5.57	21.04	12.24
MnO	0.10	0.10	0.10			0.02			
CaO	0.20	0.40	0.20	0.09		0.05			
Na_2O						0.04			
K_2O				0.08	0.08	0.05			
Fe_2O_3	7.20	6.40	23.10	4.47	5.28	5.15	9.57	36.43	47.37
FeO	0.80	0.50	0.20	0.61	0.27	0.61			
TiO_2	1.70	2.10	1.40	0.72	0.89	0.75	1.23	2.10	1.36
P_2O_5				0.09	0.09	0.17			
Ferric iron oxihydroxides	7.62	7.12	**24.80**	4.98	5.87	5.70	10.68	**37.51**	**49.12**
Quartz				**52.62**	51.54	**57.42**	**55.74**		
Ca-alk&FeMg hydrosil.	1.57	1.06	1.57	0.80	0.80	1.24			
Kand.&Al.hydr.	87.21	88.46	71.16	39.28	38.83	24.96	31.89	58.44	48.69
Mineralogical prescription	**Refra.**	**Réfra.**	Prosc.	Prosc.	**T+Br**	Prosc.	Prosc.	Prosc.	Prosc.
IFI	6.09	5.48	**21.10**	5.27	5.86	5.68	12.12	**31.64**	**51.74**
RPCI	1.77	1.19	2.16	1.99	2.01	4.71			
RPLI	97.55	99.41	95.37	83.51	89.07	97.54	75.12	99.56	84.17
RVWD	97.55	99.41	95.37	**36.10**	38.71	**31.03**	**27.34**	99.56	84.17
Parametric prescription	**Refra.**	**Refra.**	Prosc.	Prosc.	**T+Br**	Prosc.	Prosc.	Prosc.	Prosc.
SYNTHESIS	**Refra.**	**Refra.**	**Prosc.**	**Prosc.**	**T+Br**	**Prosc.**	**Prosc.**	**Prosc.**	**Prosc.**

N.B.: - Sources: *: MILLOT and BONIFAS, 1955 (Profile on nephelinic syenite: 1: "pumiceous" facies; 2: pink bauxite; 3: ferruginous bauxitic hardpan). **: LELONG, 1969 (Profile n° L14 on gneissic granite: 1: L14D: isalteritic horizon; 2: L14C: alloteritic horizon; 3: L14A: superficial loose horizon). ***: TARDY, 1993, in CARVALHO et al., 1997 (1 and 2: bottom and top of an orthobauxite profile; 3: middle part of a metabauxite profile).

- Ca-alk&FeMg hydrosil.: Calcoalkaline and ferromagnesian hydrosilicates; Kand.&Al.hydr.: Kandites and alumina hydrates.
- IFI: Importance of free ferric iron; RPCI: Relative Potential Confinement Index; RPLI: Relative Potential Lixiviation Index; RRVWD: Relative Rock Virtual Weathering Index.
- Prosc.: Proscription; T+Br: Tiles and Bricks; Refra.: Refractory wares.

Void compartments correspond to zero value data. Numeric data in bold indicate main but not exclusive reasons for proscriptions.

Table 6: Criteria and results of protocols of selection of clay materials for the production of rubber, paper, paint and plastics.

Source	NJOPWOUO (1984, 1986, 1988a et b)						TEJIOGAP et al. (2001).					
Sample number	Bo	Boff	Ba	Baff	Mi	Mu	*Ablt*	*Abl*t*	*Able*	*Abl*e*	*Abl*ef*	*Abl*tf*
SiO_2	48.01	41.34	48.34	39.70	38.54	34.29	68.63	69.25	69.37	55.19	69.25	56.00
Al_2O_3	27.41	33.54	28.63	35.80	27.43	28.53	19.41	20.11	17.99	32.17	19.07	29.52
H_2O^+	9.82	11.50	8.98	11.80	15.84	21.65	6.70	5.80	6.70	5.62	9.42	9.13
MgO	0.31	0.15	0.03		0.41	0.38	0.23	0.42	0.21	0.48	0.38	0.47
MnO	0.12	0.00			0.09	0.18	0.01		0.01			
CaO	0.06	0.05	0.03	0.02	0.09	0.21		0.02				
Na_2O	0.02	0.04	0.03	0.03	0.06	0.05						
K_2O	0.41	0.26	0.02	0.02	0.21	0.35	1.52	2.33	1.50	2.47	2.11	2.45
Fe_2O_3	7.11	7.47	3.19	4.45	5.36	8.34	2.17	1.20	1.62	1.32	1.10	1.36
FeO	0.21				2.30	2.20						
TiO_2	2.34	1.41	0.41	0.30	7.72	2.35	0.05	0.08	0.03	0.03	0.06	0.04
P_2O_5					0.79	0.44						0.02
Ferric iron oxi-hydoxides	7.3	7.5	3.2	4.5	6.1	8.9	2.5	1.4	1.8	1.3	1.2	1.4
Quartz	**15.3**	2.2	**18.4**	0.4	**35.8**	**22.3**	**50.2**	**46.8**	**56.5**	**30.2**	**57.9**	**22.9**
Ca-alk&FeMg hydrosil.	4.3	3.6	0.5	0.0	3.0	4.5	13.3	20.8	13.2	21.8	18.4	21.8
Kand.&Al.hydr.	66.0	80.7	63.9	84.6	40.9	41.7	32.8	30.1	25.8	32.5	18.9	52.7
Mineralogical prescription	**Prosc**	**Good**	**Prosc**	**Good**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**
IFI	10.67	11.97	4.97	7.63	5.36	7.90	2.91	1.75	1.96	1.68	1.23	1.97
RPCI	6.13	4.87	5.59	2.70	6.68	9.81	28.86	40.87	33.83	**50.47**	49.40	29.26
RPLI	73.21	73.35	71.13	72.98	95.37	94.36	70.70	**65.35**	73.31	53.34	74.68	**68.20**
RVWD	**60.10**	71.53	**55.91**	72.68	**53.78**	70.49	**33.84**	34.06	**29.94**	36.51	**32.75**	52.19
Parametric prescription	**Prosc**	**Good**	**Prosc**	**Good**	**Prosc**	**Good**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**
SYNTHESIS	**Prosc**	**Good**	**Prosc**	**Good**	**Prosc**	**?**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**	**Prosc**

N.B.: - Ca-alk&FeMg hydrosil.: Calcoalkaline and ferromagnesian hydrosilicates; Kand.&Al.hydr.: Kandites and alumina hydrates.
- IFI: Importance of free ferric iron; RPCI: Relative Potential Confinement Index; RPLI: Relative Potential Lixiviation Index; RRVWD: Relative Rock Virtual Weathering Index.
- Prosc.: Proscription; Good: good for the production of rubber, paper, paint and plastics.

Void compartments correspond to zero value data. Numeric data in bold indicate main but not exclusive reasons for proscriptions.

5.2 Complementary diagnostic examinations of the normative tool applicability

- Case of clays usable in the industry of building, fine ceramics and refractory wares

The simple examples presented have been selected from regions located in humid tropical climate and marked by weathering brutality, great thickness of the and of crystallization of simple oxihydroxides such as hematite, goethite and gibbsite. These examples have been taken from Central Africa (Cameroon, Gabon), West Africa (Guinea Conakry) and South America (French Guyana, Brazil).

Cameroon: The data presented have been collected from a profile on ultrabasic rocks situated in the region of LOMIE in the south-eastern part of Cameroon. Descriptions and analyses were carried out by YONGUE-FOUATEU (1995). The selected samples derive from isalteric (n°1), alloteritic (n°2) and superficial loose (n°3) horizons (see table 5a).

From the normative mineralogy point of view, as well as from the parametric one, the prescriptions reveal that all these materials are to proscribe in the industry of building, as well as in that of fine ceramics and refractory wares.

Gabon: The examined materials derive from migmatites (EDOU MINKO and TRESCASES, 1990). The selected samples have been collected from isalteritic (n°1), alloteritic (n°2) and superficial loose (n°3) horizons (see table 5a).

From the normative mineralogy point of view as well as from the parametric one, the prescriptions reveal that only materials collected from the alloteritic horizon can fit to manufacture tiles and bricks, all other materials being to proscribe.

Guinea Conakry: The selected profile is in the LOOS islands, on acidic rocks showing silica deficit (nephelinic syenites) (MILLOT and BONIFAS, 1955). The chosen samples ensue respectively from isalteritic (pumice facies, n°1), alloteritic (pink bauxite, n°2) horizons and from the superficial ferruginous bauxitic hardpan (n°3) (see table 5b).

From the normative mineralogy point of view and from the parametric one, the prescriptions reveal that materials from deep horizons can fit to manufacture refractory wares, those from the superficial hardpan being to proscribe.

French Guyana: The examined materials derive from a gneissic granite (LELONG, 1969). The selected samples ensue from isalteritic (n°1), alloteritic (n°2) and superficial loose (n°3) horizons (see table 5b).

From the normative mineralogy and from the parametric points of view, the prescriptions reveal that only materials coming from the alloteritic horizon can fit to manufacture tiles and bricks, all other materials being to proscribe.

Brazil: The examined materials derive from bottom (n°1) and from top (n°2) of an orthobauxite profile, and from the median part (n°3) of a metabauxite profile (TARDY, 1993, in CARVALHO et al., 1997) (see table 5b).

From the normative mineralogy point of view and from the parametric point of view as well, the prescriptions reveal that all these materials are to proscribe.

- Case of clays usable in the manufacture of rubber, paper, painting and plastics

Example taken into account: To test the use of the normative tool, works done in Cameroon by TEJIOGAP et al. (2001) have been taken into account, regardless of the objectives pursued by these authors. The examined clay materials come from LEMBO, locality situated in the western province of the country. Two raw samples, designated by the authors as Abl and Abl*, have been collected from two different points of the superficial horizon on a trench of the BANGANGTÉ - BAFANG road, the aim being to test the efficiency of some simple techniques of enrichment of materials in mineralogical clays. Studies have been carried out on raw fractions noted Ablt and Abl*t, on hand split fractions passing through the stitches of a 0.100mm sieve, noted Able and Abl*e, and finally on fractions of particles from the original raw sample Abl* the diameter of which is below 0.010mm, noted Abl*ef and Abl*tf respectively and extracted from the 0.100m sifted and from the total material by sedimentation in a dispersing solution, thus in total six test samples. Chemical analyses have been achieved by the use of different current methods. The mineralogical determinations included a quantitative mineralogical calculation method borrowed from NJOPWOUO (1984). The results of these calculations show that these materials are constituted, for the essential, of kaolinite (33.5 to 58.3%), quartz (19.0 to 47.2%) and illite (13.0 to 21.0%).

Mineralogical compositions obtained from the alterological normative method show a very good concordance with results thus presented (see table 6). While applying mineralogical and parametric protocols of materials selection, all the prescriptions reveal that all the materials examined are unfit to the production of rubber, paper, painting and plastics, either because of their richness in quartz, or because of alteration and lixiviation insufficiency or else because of relatively high confinement.

5.3 Synthesis and discussion of results

For clays usable in the industry of building, fine ceramics and refractory wares, ferrallitic alteration profiles on acidic rocks reveal, for the essential, the possibility of manufacturing tiles and bricks, whereas materials from bauxitic profiles have the tendency to be suitable to the manufacture of refractory wares. While considering the set of normative prescriptions, one observes a very good convergence between prescriptions on mineralogical basis and those on parametric basis. One could found on this convergence for the final decision to take. The eighteen selected samples (tables 5a and 5b) showed no divergence of prescription. This however doesn't exclude the possibility of prescription divergences which might then be located to the limits of decision criteria.

For clays usable in the manufacture of rubber, paper, painting and plastics, materials taken into account in the present survey have a minimal conjoined content of actual or normative kandites and alumina hydrates of the order of 20%. These materials are therefore essentially clayey and kaolinitic, more or less rich in quartz. Some of these materials show characters auspicious to the production of rubber, paper, painting and plastics. The observed results teach that an enrichment treatment in clay by rudimentary extraction of coarse fraction is not sufficient to make materials usable in this production. While considering the set of normative prescriptions, one observes a very good convergence between prescriptions on mineralogical basis and those on parametric basis. One could found on this convergence for the final decision to take. Among the twelve cases examined (see table 6), only one case of divergence has been observed. It is located close to the limits of decision criteria as regards quartz on the one hand, and weathering degree on the other hand. A retailed examination of the actual mineralogical composition is likely to permit to raise the uncertainty. In any case, convergences as well as divergences of prescriptions only constitute potentialities that must lead to a complementary examination for the final decision to be taken.

6.0 GENERAL CONCLUSIONS

6.1 Notion of crossed looks

The traditional characterization of the aluminosilicate-bearing rocks evolution under the action of meteoric agents that usually proceeds by the establishment of mass balances, founds its reasoning on at least one invariant item considered from the original rock. For a great number of its unconditional adepts, this vision is exclusive and inescapable by its rationality, in spite of the plurality of its facets. It is convenient to recall however that none of the elements used until now in mass balances founded on invariant items is in fact strictly invariant and refractory to meteoric alteration. The intervention of organic matter is a factor that strongly limits the hold in account of trace elements considered as steady. Otherwise, the hydrolytic mobility of titanium, thorium and zirconium, to mention elements that constitute presently the reference with regard to the assessment of weathering mass balances, is clearly established (GARDNER 1980, MILNES and FITZPATRICK 1989, BRAUN 1991, BRAUN et al. 1993), even though it remains low. Besides, the homogeneity of the reference rock is a merely fictional and uncertain notion, whatever its degree of proximity with the sampling site of the weathered material submitted to survey.

The characterization of products deriving from the alteration of aluminosilicate-bearing rocks, and in particular the quantification (or the numeric expression) of their evolution degree, cannot refer exclusively to the initial state, it can just as well refer to the final state of the alteration process of aluminosilicates in open environment. This hypothetical final state is the one which, after the hydrolysis of primary and transitory silicates and the complete lixiviation of alkaline and alkalino-earthy elements, is characterized by the exclusive presence, as phyllites in the altered rock, of neogenetic aluminium hydroxides, such as gibbsite. In this hypothesis is taken in account the possibility, theoretical and recognized, of the slip of mass balance reactions during the process of the hydrolytic alteration, which allows calcoalkaline and ferromagnesian primary aluminosilicates to evolve, by interposition of metastable mineral phases, toward the aforesaid neogenetic gibbsite (TARDY, 1969). Such is the basis of the quantification proposed through the alterological normative restructuring method. This way of characterization, as signalled above, is globalizing and doesn't lean on any invariant item. The alterological characterizations carried out by its means are therefore not litho-dependent. In fact, in the regions between the tropics, the great thickness of the alteration mantle makes it difficult or even impossible, to have access to the fresh rock, the parenthood is no more obvious.

Thus, the traditional look is turned toward the origins that are supposed known, whereas the normative look is turned toward the future conceptually perceivable. In short, in front of a rock under weathering, by the traditional look, the question is the following one: "Having been at the origin of such a nature, what evolution did the rock undergo to reach the present stage?". By the normative look, the question is the following one: "Being now of this nature, what evolution has the rock undergone with regard to its final destination?". The answers to these questions are necessarily different. In fact, these looks, instead of excluding each other, complete one another. In the one and the other visions, the qualitative and quantitative, real and virtual mineralogical corteges, characterizing the present state, are comparable and, to the ultimate limit of the considered processes, practically identical.

6.2 Validity of the alterological normative method and computerization prospects

Results from whatever precedes are that the proposed alterological normative restructuring method is validly suitable to the survey of relative mineralogical variations of the alteration products and therefore, it constitutes a rational way of qualitative and quantitative characterization of the hydrolytic alteration process. The alterological normative restructuring as way of characterizing aluminosilicate-bearing rocks, in spite of the complexity of its manipulation, is a tool that can be set in motion by any researcher working in the domain of alterations. It would allow him to have his own and fast idea on developing phenomena and processes. Because of its virtual character, it doesn't exclude by any means the recourse to other analytic and interpretative techniques. It would rather come to the support of the aforesaid techniques as diagnosis and anticipation, allowing its users to have a fast idea on the phenomena and processes put in play. The chemical analyses of major elements indeed, are the most current fundamental techniques in laboratories of soils and rocks analyses.

The computerization of the alterological normative restructuring method is in progress. OSCAR (the French acronym of Tool for Systematics and Alterological Characterization of Rocks) is the name given to a set of computer files, written in BASIC, that put in work, by the use of the Quick-Basic application program, the algorithm of alterological normative restructuring, with applications in various domains of the economic activities (supergene metallogenesis, agro-pedology, civil engineering, selection of clay materials usable in industries, etc.). It therefore is a real software, treating data of major chemical elements analyses of rocks reported in particular files corresponding to every rock sample. The aforesaid algorithm may also be put in play trough the use of Excel Microsoft.

6.3 Decision helping tool concerning industrial exploitation

The presented cases examination has been founded on the hold in account of the eligible features in the choice of clay materials to be used in the industry of building, fine ceramics and refractory wares and in the production of rubber, paper, painting and plastics. It clearly appears that this alterological normative method can be considered as a tool capable to provide interesting indications permitting to select usable materials, not only from mineralogical compositions, the virtual character of which remains in perfect agreement with reality, but also from parametric data. The mineralogical and parametric examination protocol proposed for the aforesaid selection can be improved, notably concerning the determination of limits or selection criteria.

The alterological normative method is not the unique and universal resolution method of problems that one can meet in the vast domain of alterations. It simply permits to have a fast idea on phenomena and processes put in play and, for cases similar to those submitted to the examinations carried out above, to have an idea of operable choices. Because of its virtual character, it doesn't exclude by any means the recourse to other techniques of analysis, interpretation and selection. It rather comes to the support of the aforesaid techniques as diagnosis and anticipation. This diagnosis, although useful, is merely qualitative. The exploitability of any deposit is foreseeable only after complementary assessments.

6.4 Other works

A few other applications have been carried out and accomplished. Some of them are still in progress. They involve, not only articles published in specialized scientific magazines (ONANA et al., 2007, 2009; NDOME EFFOUDOU PRISO et al., 2009), but also doctorate theses prepared under the joined supervision of the authors of the present work. Four of these theses have yet been defended (NGO BIDJECK, 2004; ONANA, 2010; NDOME EFFOUDOU PRISO, 2010; LIKIBY, 2010). Lastly, a book on the method, assorted with new applications, written in the English language, has just been edited (EKODECK and KAMGANG, 2011).

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