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Research Article

ALTEROGICAL EVOLUTION OF AN EFFUSIVE ROCK IN AN BASE COMPLEX AT THE LOWER AREA OF THE SOUTHERN SIDE OF BAMBOUTO MOUNTAINS (WEST CAMEROON)

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ABSTRACT
This article is the altérological study of an effusive rock in the base complex of the lower area of the southern side of the Bambouto Mountains in the western region of Cameroon. It has two objectives: (1) the mineralogical and geochemical evolution of the weathering profile; (2) characterization of weathering parameters by normative alterology. Based on the combination of visual observation of the profiles in the field, of microscopic observation of thin sections, the X-ray diffraction, X-ray fluorescence method and restructuring by Normative alterology of Ekodeck and Kamgang (2002), the following results were obtained: (1) the source rock in the area of Batsingla is a trachybasalt, (2) the weathering profile that has developed there is a more or less closed environment where the alteration is advanced through the leaching choice of earthy-alkaline cations and induration, it is a highly differentiated soil with a large zone of potential ferruginous and aluminous encrustation; (3) is marked by four characteristics: residential kaolinisation, "quartzification" (quartz formation), muscovitisation and the ferrolysis.

Keywords: *Alterology, Trachybasalt, Weathering Profile, Kaolinisation, Quartzification, Muscovitisation, Ferrolysis*

INTRODUCTION
Studies of the mechanisms of alteration of rocks and transfer of minerals in the profile of alteration, constitute today an important pole of attraction in scientific research, because they allow a better control of the environment in which we live, and which contains many of our exploitable resources (ore, building materials ...).

Many altérological and /or geotechnical studies were done in Cameroon, in Central, South and North region (Kamgang, 1987, 1998...; Ekodeck, 1976... 1984; Ako, 2001...; Likiby, 2001; Phumbi, 1981; Nlom, 1986; Abdoul, 2006; Bidjeck, 2004; Nguetnkam, 2004... etc). But at the Western Region, apart from altérological studies of Wouatong (1998) and Kouayep (2006), in the Bana complex, it is hardly noticed scientific study on the alteration even less geotechnical. Nevertheless, much research has been conducted in the fields of geology and pedogenesis. In today's global view where environmental studies are highlighted, it seems necessary to study the alterogical complex of a group of rocks particularly occurring in the typical case of the equatorial climate of the West highlands with " mountain features." This is specifically the alterology of effusive rocks and the base complex forming the bedrock of the lower area of the southern side of the Bambouto mountains. The alteration of a rock, and the parameters related depend not only on the nature of the rock, but also on its environmental conditions. Thus an assumption can be made by linking the characterization of the profile of alteration under three conditions: (1) the mineral constituents of the rock, (2) geochemical constituents of the rock, and (3) climate and geomorphology of the environment in which these rocks develop. In the case where this last parameter appears to be the same in each case, how would be the evolution of the process of alteration of several types of rocks? Four locations were selected because of their lithological features. Wells have been dugged and profiles described. Samples of rock and soil were collected for mineralogical analysis, geochemical analysis and microscopic observation. The results were interpreted by graphs, "normative alterology" and chemical equations. This article presents mainly the case of alteration of the effusive rock. The case of the rocks of the base complex will be presented in a future study.

This study is organized into three parts. After a brief overview on the natural environment (I), it will be reviewed the materials and methods of study (II), the results and their interpretation (III).

Natural Environment

Geographical Location

The study area is located in the highlands of western Cameroon (Bamileke land) and more specifically in the Western Region, Menoua Department. The selected study area is localized in Batsingla-Bafou village. Thise village is situated geologically on Bambouto Mountains.

The Bambouto mountains are an integral part of western Cameroon Highlands, which are characterized geologically by high altitude and recent volcanic activity (0.480 ± 0.014 Ma; Kagou *et al.*, 2009).

Climate

The highlands of western Cameroon are characterized by a sub-equatorial monsoon climate or cameroonian equatorial mountain climate. This climate has some peculiarities in the Bambouto massive, due to the asymmetry exposure of its side to atmospheric flow and altitude (Valet, 1985).

Concerning the slopes, the climate of the study area is the one of meridional slopes. They are fully exposed to the Southwest monsoon.

The rainfall is over 2,000 mm in Dschang (1982, 1997, 1998 and 1999). The humidity is very high. In December, the relative humidity may drop below 30 %. Clouds are abundant (Morin, 1988; Manefouet 2002; Wouendeu, 2002).

As regards altitude, the general climate is that of the low areas. It is the climate of the plateau region. The interpretation of climate data (Manefouet 2002; Wouendeu, 2002) allows to give the following characteristics:

- The annual average temperature is 20.2 ° C in Dschang.
- Winds speeds ranging from 1.1 to 1.4 m / s (Morin, 1988; Tsalefac 1999).
- Average annual rainfall is 1,830 mm of rain in Dschang.

Geomorphology

Orography

The Bambouto Mountains at an altitude of 2740 m above the Bamileke plate (1200-1900 m) is distinguished by the asymmetry of its sides. The south side, holding the study area, is very long and rough, extends in staircase from South to North (Morin, 1988).

Three main orographic sets dominate the Bambouto Mountains landscape (Ngoufo, 1988): The heigh altitude set (2000-2740 m), the middle set (1600-2000 m) and the lower set (1400 - 1700m). This last set is precisely the area of study. It is a typical characteristic of landscape made of volcanic formations associated with the crystalline basement.

Volcanic formations define a vast landscape with ondulations. Sharp out cuts are seen from place to place breaking the monotonous landscape of the basalt plateau. The talwegs are quite large (over 20 m) and cross section in "U" form (Ngoufo 1988).

Hydrography

Many rivers drain the Bambouto area, and can be sub-divided into five watersheds including the Menoua South basin. In general the hydrography of this area is characterized by radial and centrifugal appearance of rivers taking their entire source around the caldera area. The Menoua tributary of Nkam, is its main river (Tematio 2004; Njiosseu 1998).

Geology

The massive Bambouto, the third largest massif of the mainland of Cameroon line, is an ellipsoidal volcanic unit oriented N/S and surmounted by two calderas fitted together with the neck broken westward. Volcanic activity (from 22.7 to 5.8 Ma) was marked by a succession of basaltic phases, and trachytic ignimbrite (Geze, 1943; Tchoua, 1974; Youmen, 1994; Marzolie, 2000; Gountie, 2002) and overlying the granite-gneiss basement. These numerous activities that took place one after the other from the Eocene time have resulted to three geological areas which include the lower area.

In the lower zone, the granite-gneiss basement was covered unevenly by ancient volcanic formations. These are products of basalts and projections (Bouyo, 2001).

MATERIALS AND METHODS

Fieldwork

The Study site (Batsingla village in the Menoua division in the western region of Cameroon) was chosen due to the following features:
- Characteristic of the parent rock;
- Difficult access to the water layer in the area;
- Proximity to the habitat (the well must be usable);
- Singularity of the area of study because of its unique characteristic to hold the aspects of other areas;
- Soil depth.

The study was done by darkening a well. This was in order to have knowledge of the profile of alteration. This profile has been described in accordance with the color variation, visible with the naked eye, and their structure. To each substantial change of observation, corresponds a layer from which a sample was taken for laboratory studies.

The Profile of Alteration on the Batsingla Basalt

A well of 28, 40 m deep was dug on a hillside 1,553 m above sea level. By observation, this well has a total of twenty-one (21) layers numbered from bottom to top: 1BT, 2BT, 3BT, 4BT, KBT, 5BT, 6BT, 7BT, 8BT, 9BT, 10B, 11BT, 12BT, 13BT, 14BT , 15BT, 16BT, 17BT, 18BT, 19BT, LBT, the bedrock being annotated RBT. They helped to have a better observation of the levels of alteration of the profile (Figure 1). So from the bottom to the top, there are:

• The bedrock of nearly 28.40 m depth;
• The alterite with conserved structure: Compact weathered rock with a thickness of 1.4 m;
• The non-alterite kept up structure:
- A transitional layer of about 0.6 m thick;
- The kaolinite layer of about 3.8 m thickness constituted of kaolin of about 1.8 m thick, the rest consists of compact gray clay soil and purple;
- Structured clay level of almost 6.50 m thick;
- A thin special layer, apparently grainy and rusted of about 0.20 m;
• The level of gravel accumulation: clay furniture levels alumino- ferruginous gravel with a thickness of about 14.50 m;
• The huminifère level of about twenty centimeters thick.

Methodology of Mineralogical Studies

Mineralogical analysis was conducted in two stages: a stage of microscopic observation and another by X-rays analysis.

1st step: It was about the design of thin plates at the imaging center of IRGM (Institute of Geological and Mining Research) at Nkolbisson (Yaounde) and the observation of minerals on a polarized optical microscope and analyzed light microscope in the laboratory of structural geology of Earth and Universe Sciences department of the of the University of Yaounde I.

2nd step: The mineralogical analysis of samples of rocks and soil was conducted at "X-Ray Analytical Facility" laboratory of the University of Pretoria.

It is based on the powder diffraction with X-ray (XRD), which helps to define the crystalline phases present in a sample and the spectroscopy of X-Ray Fluorescence (XRF), which in turn helps to define the general chemical composition of a rock or soil sample. The methodology used is adapted by Bennett and Oliver (1992), Watson (1996).

RESULTS AND DISCUSSION

Presentation and Interpretation of Results

Distribution of Chemical Elements in the Profile of Alteration

The distribution of chemical elements according to the depth in the Batsingla's profile of alteration is given by Figures 2, 3, 4 and 5. From these graphs, function to the depth, one can note the following:

• *Major elements:*

- The prevalence of iron, aluminum, hydrogen and silicon oxides with the weight percentage ranging respectively from 18 %; 17 %; 2.8 %; 41 % at 29 m depth to 65 %; 44 %; 23 %; 5 % on the surface.
- Calcium, sodium and potassium oxides have the lowest weight values percentages ranging from 9 %; 1.6 %; 1.2 % at 29 m depth to 0.0022 %; 0.0051 %; 0.0042 % at the surface.
- Between these two, we find progressively oxides of: phosphorus, magnesium, manganese and titanium.
- A general disorder occurs in the evolution of major elements oxides between 29 and 25 m, 16 and 13 m depth.

• *Trace elements:*

- The prevalence of fluoride, vanadium, zirconium which parties per million massique vary respectively from 100 PPM, 300 PPM, 280 PPM at 29 m depth to 4500 PPM, 580 PPM, 630 PPM at surface.
- The values of lanthanum, cesium and chlorine are the lowest. They range from 4.3 PPM; 13 PPM; 7.5 PPM in depth to 4.3 PPM; 9.5 PPM; 7.5 PPM in surface.

Minerals Distribution in the Profile of Alteration

The results show that the bedrock is mainly composed of diopside and smectite, some plagioclae, orthoclase and magnetite.

These minerals are transformed predominantly in gibbsite goethite and kaolinite; via an intermediate conversion into quartz, muscovite and hematite. The mineral distribution in the profile is shown by the figure 6.

Characterization of the Profile of Alteration

The typical profile of alteration of Batsingla shown in Figure 1, is developed nearly to the top of an hill at an altitude of 1,553 m, 5 ° 25'33' of north latitude and 10 ° 07'19' of East longitude. The bedrock is substantially at 29 m depth.

It is subdivided from the bottom to the surface into four areas: the bedrock, the isaltérite, the transitional zone and the alotérite.

Bedrock Petrography

Bedrock (Figure 7) slightly altered, predominantly consists of diopside (40.06%; mafic and calcium clinopyroxene), plagioclase (16.93%), orthoclase (6.4% feldspar). These minerals have begun their alteration, particularly the olivine to give smectite (27.9%) according to the equation n°1 in the annex

(The olivines hydrolysis and oxidation producing the smectites and goethite)

These various minerals and the weight percentages of oxides put together in the Streckeisen diagram (1974) and the triangular diagrams ACF, A'KF and AFM; associated with the simplified classification of igneous rocks and observation with the naked eye shows that this rock is an hyper-alumino-ferric, calco-alkaline poor in ferromagnésien trachybasalt.

The global chemical analysis shows that the rock is made up of 41.63 % of SiO_2 , 15.25 % of Al_2O_3 , 16.61 % of Fe_2O_3 , 8.97 % CaO, 7.45 % of MgO and low percentage of TiO_2 , Na_2O , K_2O and P_2O_5.

By normative restructuring (Ekodeck and Kamgang, 2002), the minerals of the same order is obtained: Anorthite (38.1%), stévensite (23.3%), goethite (14.6%). These allow to define the characteristics of the environment:

- Rock deficient in silica and low in aluminum (class $Si_2 - Al_2$); with free-oxyhydroxides purely ferruginous (PPFAL = 0.00);
- Leaching of migratory elements of the order of 43.4%: Monosiallitisation (ILP = 43.41%); rock with low induration potential of 20.15% (IIP = 20.15%); developed in closed environment (ICP = 100.00%);

Study of the Altérite

Between 28.40 m and 18.40 m depth, we note a clay soil retaining the structure of the bedrock, with a very diversified color going from yellow to purple passing through gray.

At this level, the hydrolysis of the mineral precisely of diopside, olivine and Microlithe produce kaolinite and quartz. The oxidation of mineral (case of the diopside) produce the magnetite, ilmenite and anatase. The hydratattion of ferromagnesium minerals give the goethite. The processes of alteration are kaolinitisation and monosiallitisation. The kaolinitisation products are kaolin, white mica and quartz; the dominant process at this level being the monosialitisation. The primary or secondary silicates deteriorate according to the equations n° 1, 2, 3, 4, 5, 6 and 7 in the annex.

Thus the isaltérite is essentially constitutes of kaolinite, goethite and some magnetite, anatase and quartz.

Study of Alterite with Preserved Structure

Level 1BT

Located at about 27 m deep and a thickness of 1.40 m, this level is directly above the bedrock. It constitutes of 69.96 % of kaolinite, 16.08 % of magnetite, 9.25 % of anatase (TiO_2) and 4.71 % ilmenite ($FeTiO_3$).

At this level, all primary silicates are all already transformed by oxidation and hydrolysis following equations sheet numbers 2, 4 and 6 without any disorder in the original structure of the rock.

The global chemical analysis shows that this level is made up of 34.03 % of SiO_2, 29.61 % of Al_2O_3, 15.69 % of Fe_2O_3, 8.28 % of $TiO_2$and the low percentage substantially zero of $MgO, CaO, Na_2O\ and\ K_2O$, the P_2O_5 5 is maintained. There has been environmental enrichment in alumina, titanium; impoverishment in silica, iron, cation leaching.

By normative restructuration (Ekodeck and Kamgang, 2002), the minerals of the same order is obtained. Kaolinite (71.1%), anatase (8.32%), goethite (5.98%) These allow to define the characteristics of the environment:

- rock rich in silica and aluminum (Class: $Sl_1 - Al_1$), with free-oxyhydroxides purely ferruginous (PPFAL = 0.12);
- leaching of migratory elements of the order of 75.14%: monosialitisation (ILP = 75.14), highly altered rock with low induration potential of 22.57% (IIP = 22.57);

Study of the Transitional Level: Kaolin Formation, Muscovite Neo-formation and Silica Accumulation

KBT Level: Kaolin Formation and Muscovitization

A special and single phenomenon occurred during the kaolinization: the muscovitization. This phenomenon has been observed in the gold mine of Tiouit, eastern Anti-Atlas in the south of Morocco by Chaker (1997), where the alkali feldspars are converted to muscovite in highly silicified areas. In the present case, the plagioclases by inheritance and transformation have given muscovite ($KAl_2[(OH)_2AlSi_3 0_{10}$). The global chemical analysis shows that the rock contains 1.12% potassium oxide that by normative restructuration produce potassium metasilicate (SiO_2K_2O). Potassium used in the muscovitisation process comes from these potassium metasilicates. In fact the hydrolysis of potassium metasilicates puts into equation the silicic acid and potassium ions according to the equation n° 8 in the annex.

The kaolinite in the presence of this solution inherits the potassium and turns into muscovite according to the main equation n° 9 in the annex.

All of these phenomena are called muscovitization: process of neo-formation of silicate normally primary silicate within the weathering complex. This is due to the fact that there is plenty of kaolinite in this profile level and the presence of a leaching solution of K^+ cations.

Particular Case of 11BT Level: Grainy and Rusty Appearance Level

Within the pedogenic profile on trachybasalt of Batsingla, distinguished by the excellency of its materials, there exists a layer of granular appearance. It is located at about 14.50 m deep, very thin (20 cm) on thickness and shown in the form of a fragment of rusted iron.

While digging the well, this level was found to be highly permeable, unlike all of the profile which foer more than 27 m show no sign of water.

The results of global geochemical analysis and mineralogical analysis shows that this level is constituted essentially of goethite (86.42%) and a small fraction of gibbsite (13.58%) ; of 53.94% of $Fe_2O_3$and 13.80% of Al_2O_3. The Normative restructuration allows obtaining essentially the same results: level constituted essentially of goethite (60.1%) and gibbsite (17.1%).

All this shows that this level is the enrichment horizon of ferric iron (Fe^{3+}) and aluminum partly. There has been a combination of several alteration processes: the oxidation and hydrolysis of olivines according to equation n°1, the direct hydration of hematite (equation n°10) outlet from olivine.

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The thermodynamic conditions of a moderately confined environment played in favor of an almost total leaching of major elements: allitization. The normative restructuration (Ekodeck and Kamgang 2002) allows defining this level with the following characteristics:
- rock with free oxyhydroxides more ferruginous than aluminous (PPFAL = 0.32);
- leaching migratory elements about 95.23 % : allitisation (ILP = 95.23), rock with high potential induration of 70.23% (IIP = 70.23);

12BT Level: Quartzification (Quartz Formation)

The 12BT level is just above the level 11BT, at 14 m deep and 50 cm thick on average. This horizon is characterized by a layered structure: a purplish bed, a yellowish bed and a whitish bed with respective thicknesses of 0.5 mm; 0.5 mm and 1 cm.

The global geochemical analysis and mineralogical analysis results shows that unlike 11BT level, this level consists essentially of quartz (70.8%) and kaolinite (15.3%), gibbsite (10.66%) and a small fraction of hematite (3.23%) ; of 42.20 % of SiO_2 and 36.85 % of Al_2O_3. Silica forms thick whitish beds.

Normative restructuration rather shows that this level consists essentially of 90.2 % of kaolinite and 4.81 % of goethite. Thus under normal conditions, this level should be made of these minerals, but the existing thermodynamic conditions during the alteration have played instead for the neo-formation of quartz and kaolinite as presented in equations n°: 2, 4 and 5. There has been enrichment of silica and alumina with total cations leaching: the monosiallitization. The environment is characterized as follows:
- rock with free oxyhydroxides more ferruginous than aluminous (PPFAL = 0.42), leaching of migratory elements in the order of 75.63%: Monosiallitisation (ILP = 75.63);
- rock with very low induration potential of the order of 9.37% (IIP = 9.37) developed in confined environment (ICP = 0.35);

Study of the Upper Clay Fraction or Allotérite

Between 14.70 m depth and the surface, clay soil is observed having lost the structure of the parent rock, highly diversified color from purple to red through gray, white and yellow.

At this level, there is no more any primary silicate in the profile; all have altered predominantly to kaolinite, goethite and gibbsite with some hematite, magnetite and anatase. Almost all chemical equilibriums described above are involved (numbers: 1to7). Thus several processes of alteration take place simultaneously, and which are: total or partial hydrolysis, oxidation, hydration and dehydration.

Level 16BT

The 16BT level is between 7 and 9 m deep. It is particularly marked by a high concentration of kaolinite. This is a level of maximum concentration in kaolinite (86.92 %) as regards to the whole profile. It is observed a high rate of the anatase as in 1BT level (9 %). It is the level where the thermodynamic conditions perfectly played for the monosialitisation (equations 2 and 6). The titanium is oxidized in anatase and the iron in magnetite (3.98 %).

The global chemical analysis shows that it constitutes of: 32.56 % of SiO_2, 30.26 % of Al_2O_3, 8.38 % of $TiO_2$and 18.25% of Fe_2O_3. By normative restructuration, these oxides give substantially the same minerals: 69.2 % kaolinite and 8.4 % anatase. In addition to these two minerals, it also allows the formation of goethite (8.86%) and hematite (10.3%). This in turn allows a better characterization of the pedogenic environment:
- rock with free oxyhydroxides more ferruginous than aluminous (PPFAL = 0.24);
- Leaching of migratory elements in the order of 77 %: Monosiallitization (ILP = 77.00), rock with low induration potential of around 27.57 % (IIP = 27.57)

Study of Laterization

These levels substantially start from the surface (The organic layer is neglected) to about 5 m deep. Kaolinite has virtually disappeared (0 in LBT2). There are essentially hydroxides: gibbsite and goethite.

Level 18BT

With a thickness of about 4 m, it is located at a depth of about 1 m. This is a red clay consisting of 60 % of goethite; 18.08 % of gibbsite; 14.43 % of kaolinite; 6.79 % of anatase and 0.7 % of quartz. It is an

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environment where the thermodynamic conditions favored the combined action of oxidation, hydration, allitisation and monosiallitisation.

The global chemical analysis gave the following percentages by weight of oxides: 44.01 e_2O_3 ; 24.07 $Al_2 0_3$; 12.69 SiO_2. The recombination of these oxides by normative restructuration results in the same minerals: 35.8% of goethite ; 20.6 % of gibbsite; 26.7 % of kaolinite and 5.43 % of anatase. This allows to characterize the pedogenetic environment:

- rock with free oxyhydroxides more ferruginous than aluminous (PPFAL = 0.48);
- leaching of migratory elements of the order of 88.60 %: Allitisation (ILP = 88.60), rock with high potential induration of around 70.27 % (IIP = 70.27).

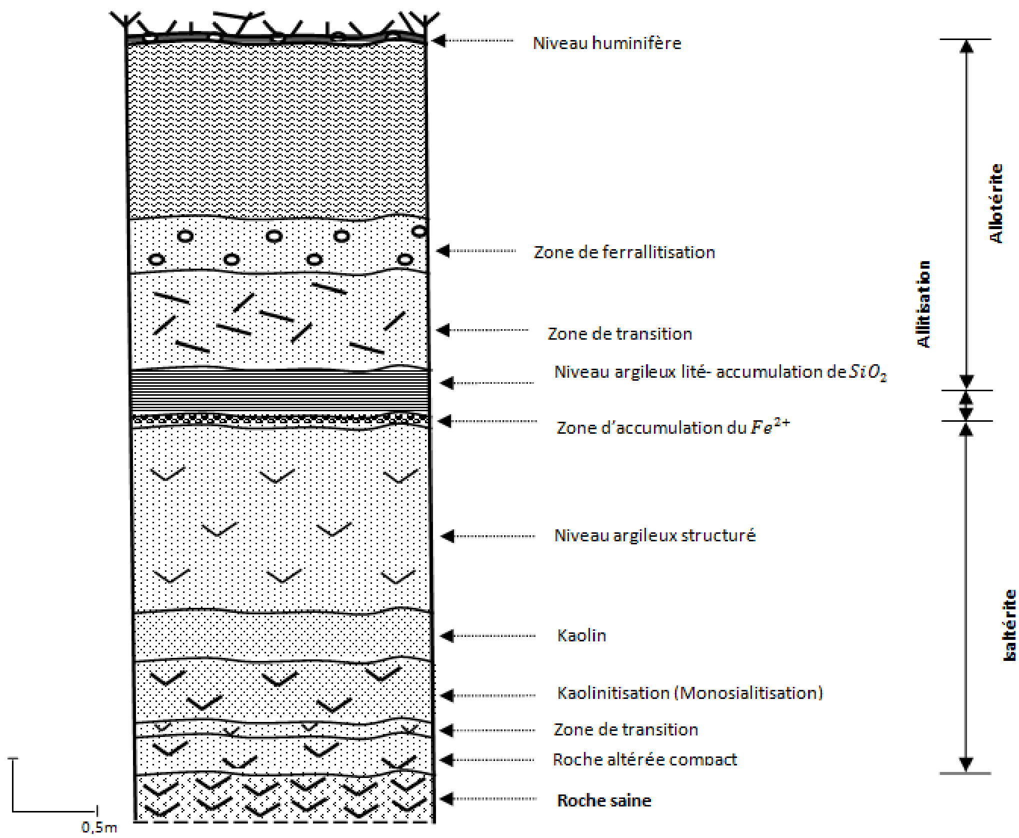

Figure 1: Weathering profile of Batsingla trchybasalte

Level LBT1

This is a lateritic concretions taken from the surface. It is essentially of goethite (84.15 %), gibbsite (10.22 %) and kaolinite (5.63 %). It is formed in an environment where the thermodynamic conditions have worked in favor of a combined action of oxidation, hydration, allitisation and monosiallitisation.

The global chemical analysis gave the following weight percentages of oxides: 67.26 % e_2O_3 ; 12.53 % $Al_2 0_3$; 4.87 SiO_2. The recombination of these oxides by normative restructuration gives the same minerals: 74.9 % goethite; 12.9 % of gibbsite; 4.85 % of kaolinite and 2.62 % of anatase. This allows characterizing the pedogenetic environment:

- rock with free oxyhydroxides more ferruginous than aluminous (PPFAL = 0.20);
- leaching of migratory elements at the order of 95.29 %: Allitisation (ILP = 95.29), rock with high potential induration of the order of 90.69 % (IIP = 90.69) developed in little confined environment (ICP = 0.16).

Phenomenon of Ferrolysis in the Mist of the Pedogenesis of the Trachybasalt of Batsingla

As described above, in regolith, were observed formation of clay layers looking like stratum by neo-formation of kaolinite, of the granular level and silicified level. At 11BT level, these levels transform themselves by ferrolysis to granular material of reddish color. This phenomenon has been observed by several authors: Heloisa *et al.*, (1995) and demonstrated for the first time by Brinkman (1970, 1979) in Heloisa *et al.*, (1995). They observe in the upper layers of surface gley soils and planosols of temperate and tropical countries, where the alternance of reduction and oxidation related to seasonal variations in precipitation causes an hydrolysis of the clay by the liberation of protons release during the oxidation of ferrous iron into ferric iron. Brinkman therefore distinguishes the cheluviation, agent of podzolisation, where there is chelating iron II and III, as well as aluminum, to the ferrolysis where the organic material does not cause cheluviation and where the ferrous iron migrates in ionic form under conditions of reduction, then oxidizes itself while liberating protons.

Indeed the analysis by X-ray diffraction of lower levels indicates the presence of goethite, kaolinite, with a formless bottom. The poverty in iron of the plasma implies that this element is brought in solution in the pores. The decrease, followed by the disappearance of the silica and aluminum when moving from the plasma to the ferruginous rests, shows that the overlay (inscrustataion) by the iron of the pores is accompanied by destruction of the kaolinite which serves it as support. I1 is a ferrolysis. Ambrosi *et al.*, (1986) in Heloisa and Boulet (1995) make the ferrolysis to intervene in the process of formation of globules or ferruginous concretions. The final product here is goethite; reactions can be summarized by the following equations n° 11, 12 and 13 in the annex.

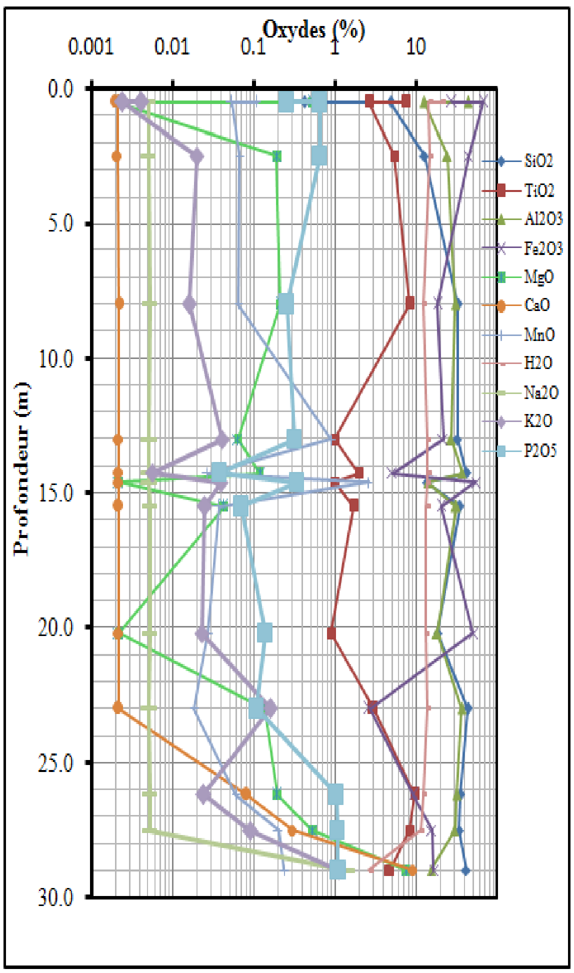

Figure 2: Distribution of major elements

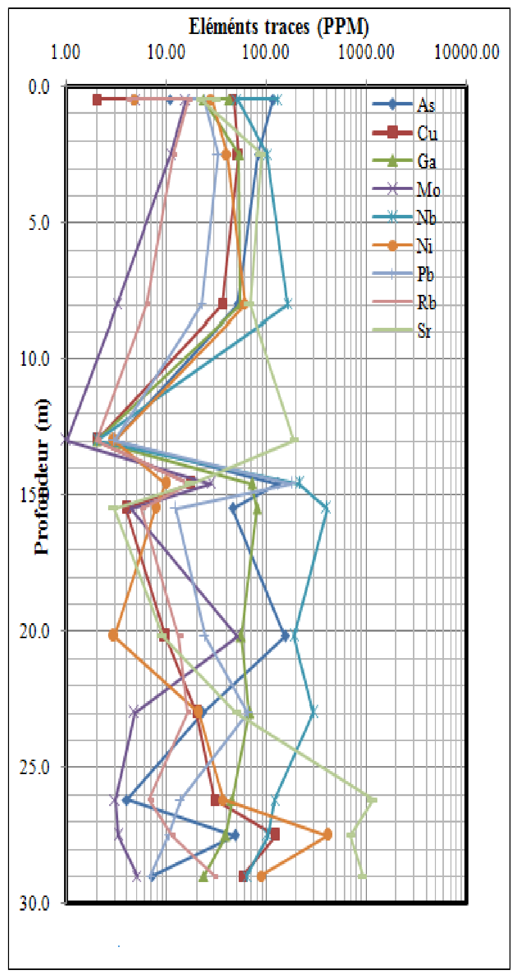

Figure 3: Distribution of trace elements (1)

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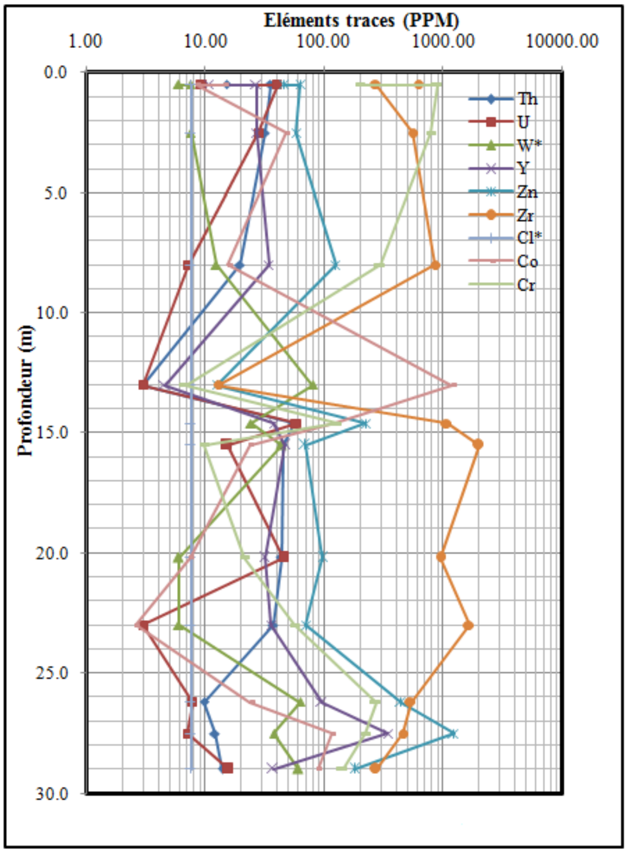

Figure 4: Distribution of trace elements (continued)

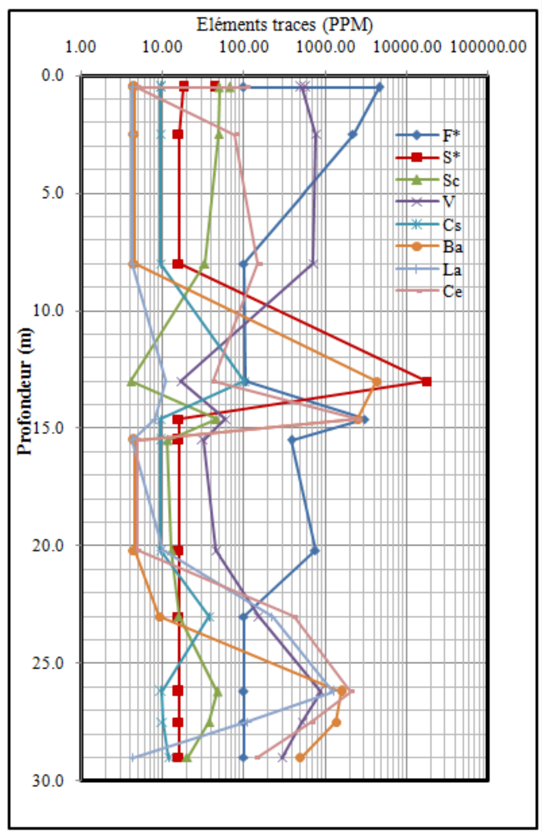

Figure 5: Distribution of trace elements (end)

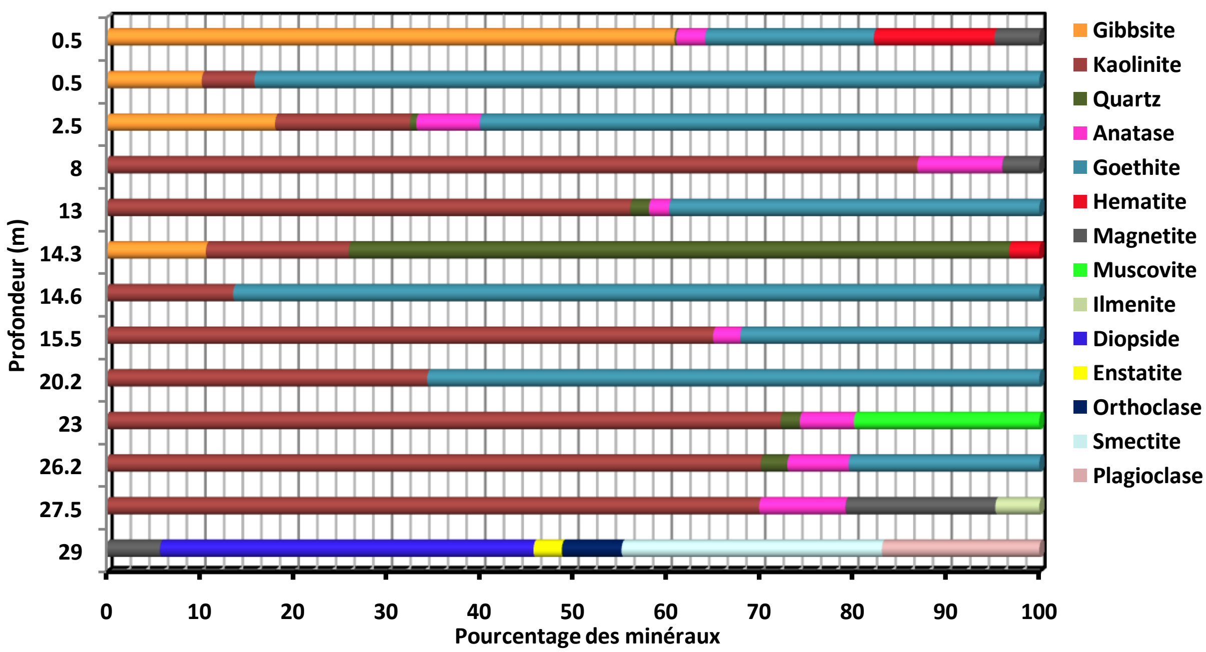

Figure 6: Distribution in the mineral profile Batsingla

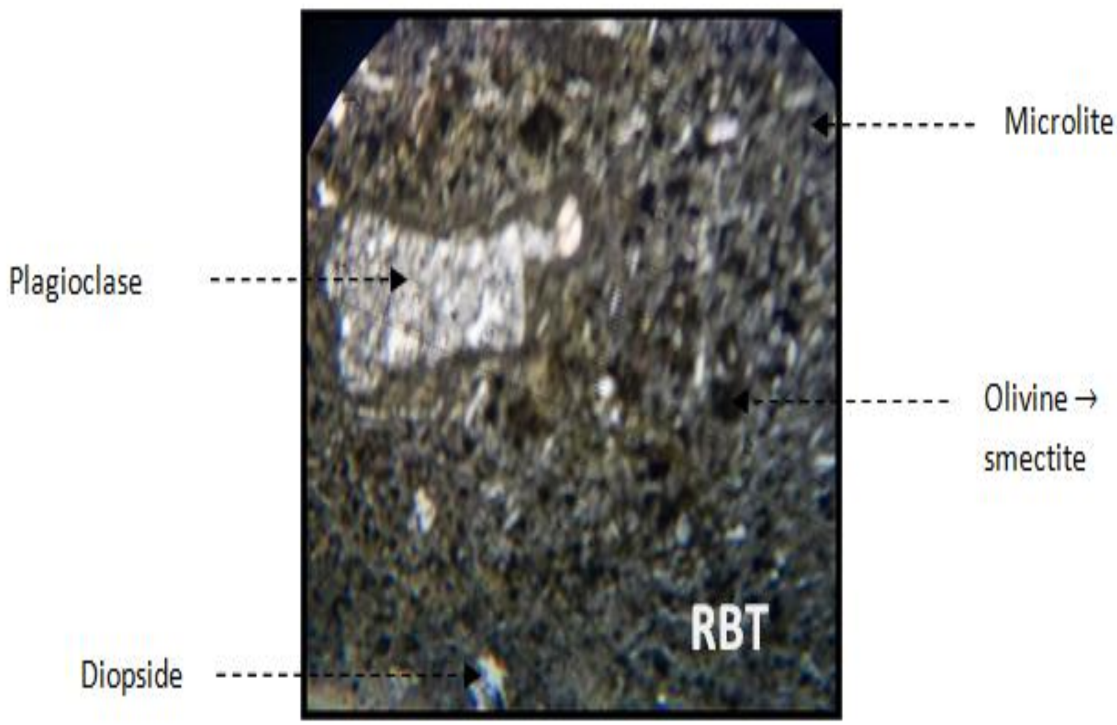

Figure 7: Image of slightly altered rock in polarized and analyzed light

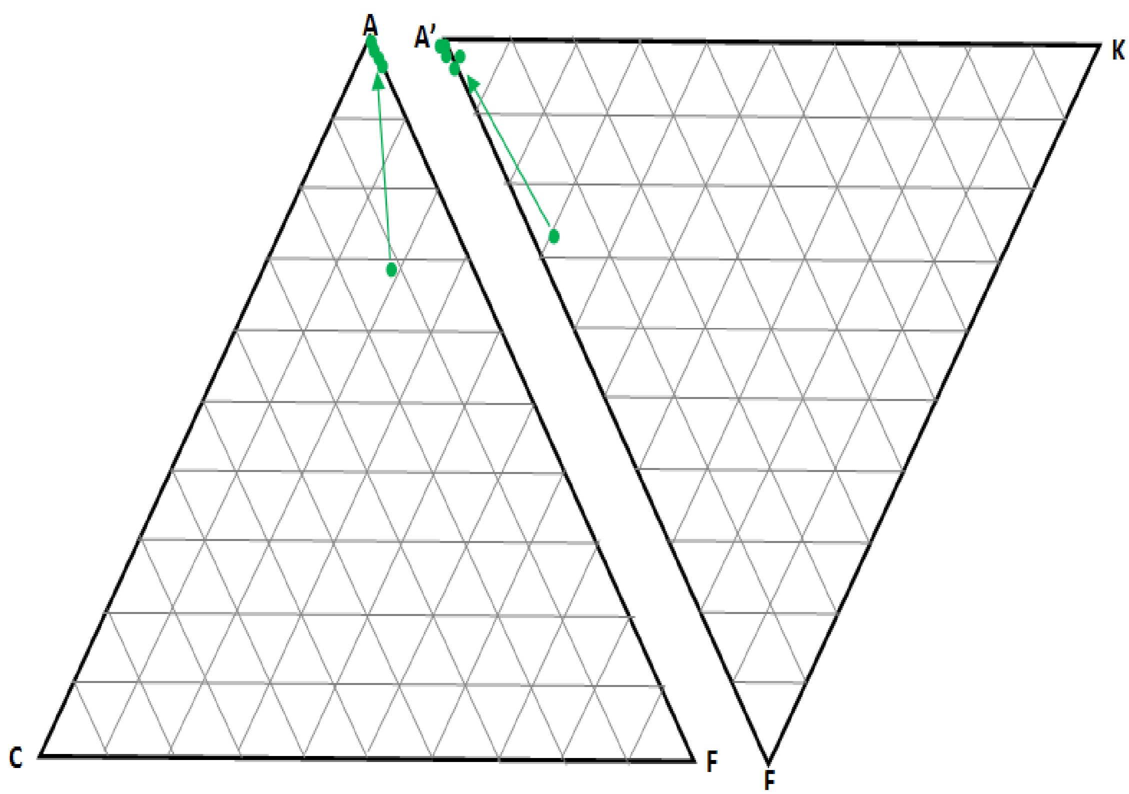

Figure 8: Oxides A'KF and ACF Diagrams of the batsingla weathering profile showing that the weathering progresses to the "continental" clays

<u>*Explanatory notes:*</u>

- **A C F diagram,** where : A = (Al2O3 + Fe2O3) - (Na2O + K2O), this pole highlights the aluminous unbound alkali; C = CaO - 3,3 P_2O_5, calcic fraction pole;

F = MgO + MnO + FeO, iron-mafic pole.

- **A' K F diagram,** where : A' = (Al2O3 + Fe2O3) - (Na2O + K2O + CaO), where CaO is calcium bound to silicate; K = K2O ; F = MgO + MnO + FeO.

- **A F M diagram**, where: A = K2O + Na2O ; F = FeO ; M = MnO.

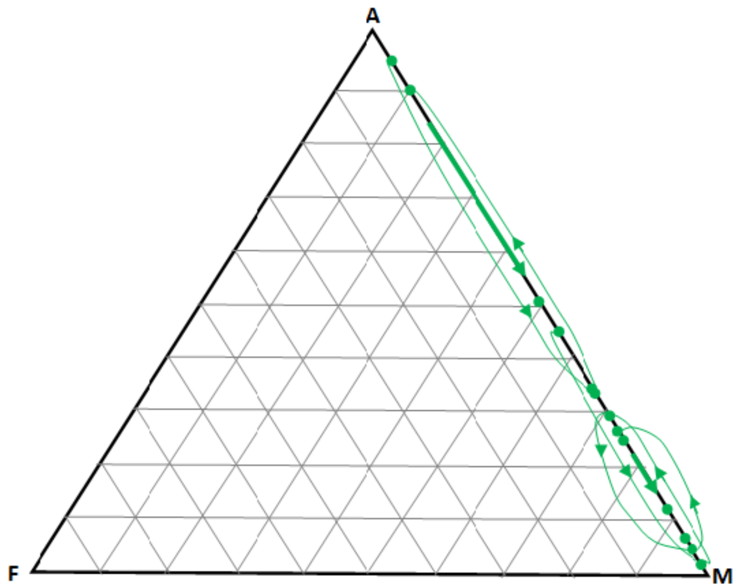

Figure 9: Oxides AFM Diagram of the Batsingla weathering profile

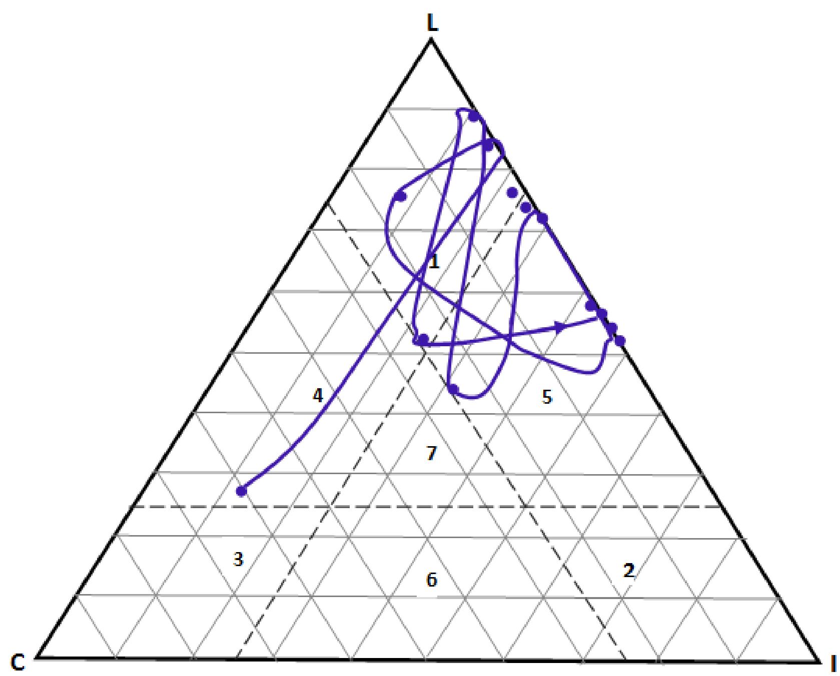

Figure 10: Triangular L + R + C diagram of Batsingla trachybasalt

Area of dominance of one factor	**Areas of dominance of two combined factors**	**Area of equivalent effect of the three factors**
1 : potential Leaching	4 : Potentials Leaching and confinement	7 Potentials leaching, induration and confinement
2 : Potential induration	5 : Potentials Induration and leaching	
3 : Potential confinement	6 : Potentials confinement and induration	

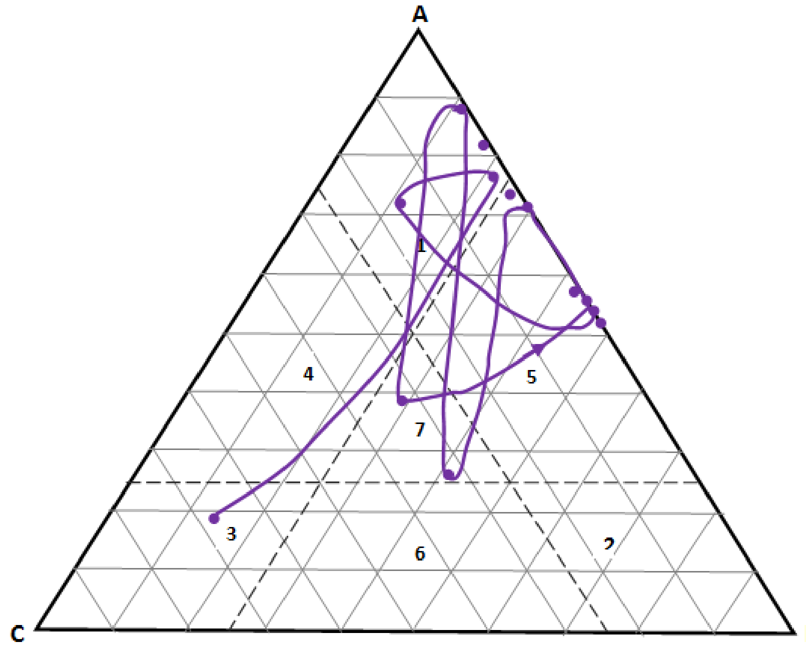

Figure 11: Triangular "A + I + C" diagram on Batsingla trachy basalt

Area of dominance of one factor		**Areas of dominance of two combined factors**		**Area of equivalent effect of the three factors**	
1 :	Virtual weathering	4 :	Virtual weathering and potential confinement	7 :	Potentials weathering, induration and confinement
2 :	Potential induration	5 :	Potential induration and virtual weathering		
3 :	Potential confinement	6 :	Potentials confinement and induration		

The advantage of this model is that the ferrolysis is the unique mechanism that is manifested there and which leads to the quasi total disappearance of kaolinic plasma. This mechanism occurs when the environment in which it happens is probably the area of drawdown (Heloisa *et al.*, 1995).

***Study of Alteration by the Interpretation of the Charts* ACF A'KF and AFM (Figures 8 and 9)**

ACF diagram: the mother rock consists of a ternary mixture with components of different amounts. It's a rock with aluminous ferric fraction not mixed with alkalines, very predominant on calcium and ferrous iron-mafic. The alteration of this rock transforms it to a binary mixture, at the limit to a single component. Thus the products of alteration are rocks with aluminous ferric fraction not mixed to alkali, with scarcity of ferrous iron-mafic fraction and disappearance of the calcium fraction.

A'KF diagram: the parent rock is a ternary mixture consisting of very unequal amount. It is a rock with aluminous ferric fraction, with calcium mixed with alkali predominant on ferric ferromagnesian fraction, itself predominant on the potassic fraction. This mother rock gets itself altered to give materials with aluminous ferric fraction with calcium mixed with alkaline, with progressive disappearance of iron-mafic and potassic fractions.

Digraph AFM: The parent rock constitutes of a binary mixture consisting of unequal amount. This is a Sodi- potassic rock poor in manganese. It gradually alters itself in the same field with the diminution of the sodipotassic fraction and increase of the manganosique fraction, to become finally a rock rich in manganese low in sodium and potassium.

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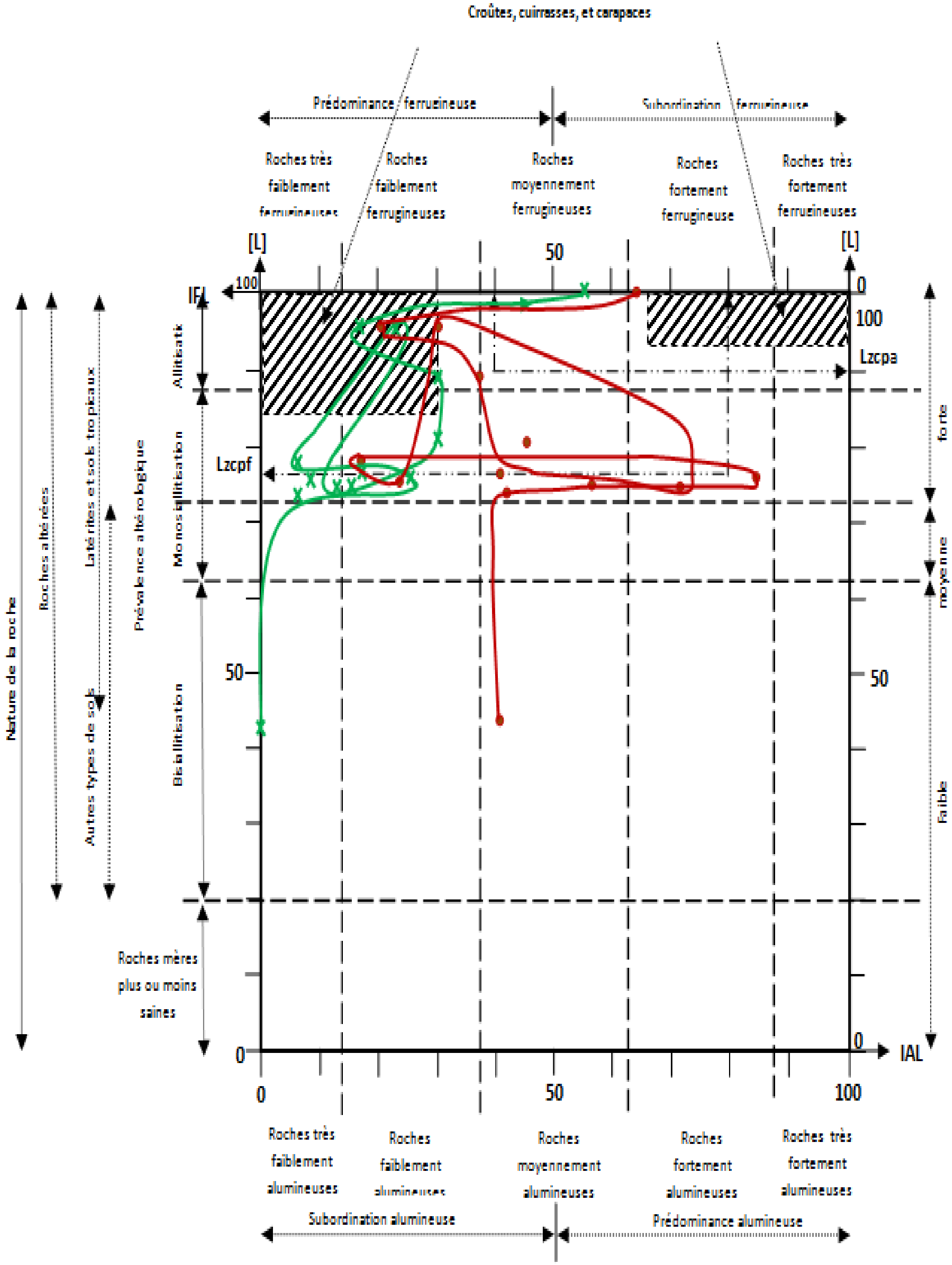

N.B. Lzcp : Limites des zones de cuirassement potentiel ; a : alumineux ; f : ferrugineux

Figure 12: "L-IAL-IFL" square Diagram of Batsingla trachybasalt

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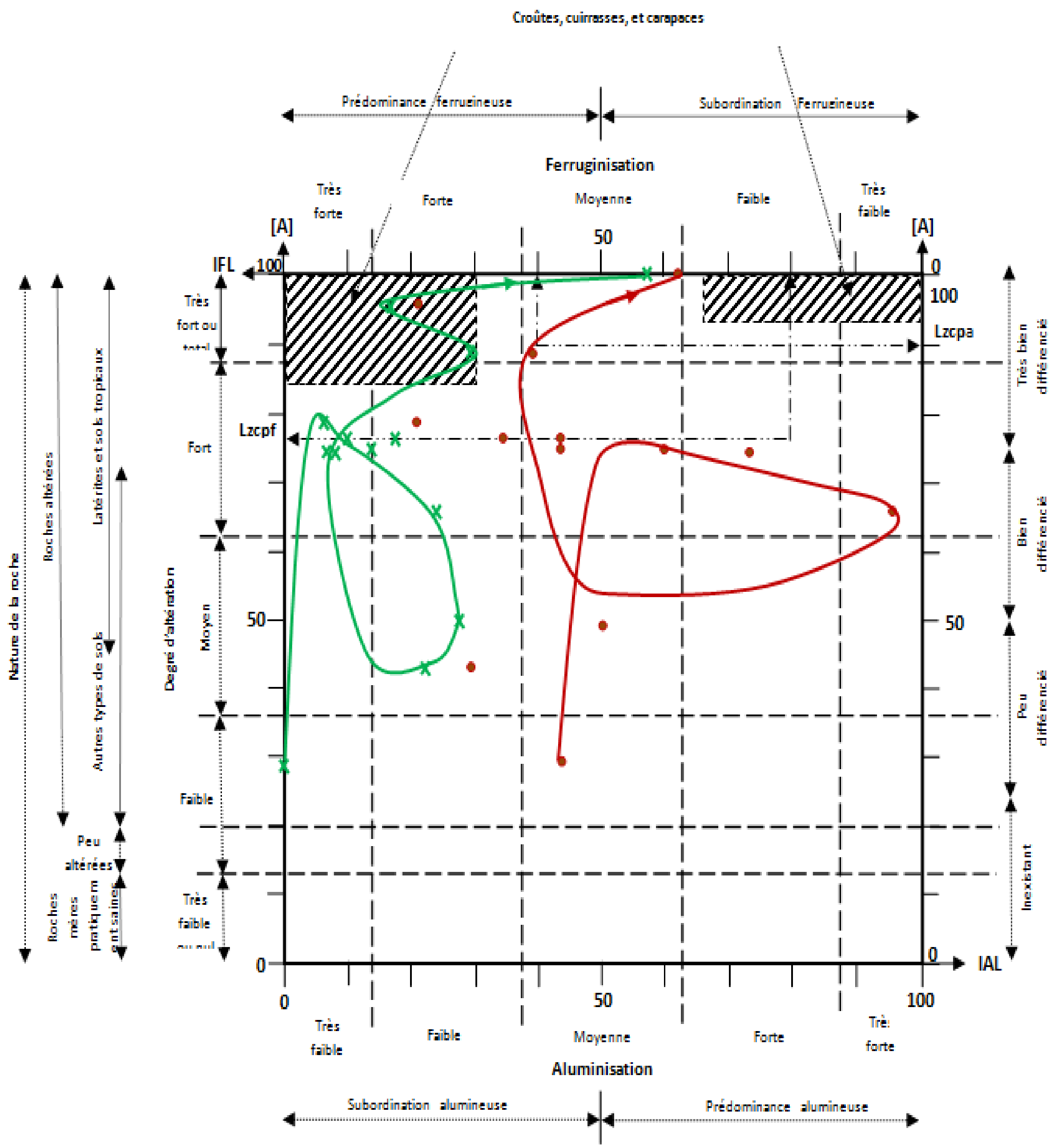

N.B. Lzcfp : Limites des zones de cuirassement potentiel ; a : alumineux ; f : ferrugineux

Figure 13: "A-IAL-IFL" square Diagram of Batsingla trachybasalt

In short, the soil profile on Batsingla trachybasalt goes from a parent rock with aluminous ferric fraction not mixed very predominantly with alkaline, with calcium mixed with silicates, and poor in ferrous iron-mafic minerals in the presence of sodic-potassic minerals. It gradually evolves to a rock with aluminous ferric calcium components bound to silicate, rich in manganese and poor in sodium and potassium.

Study of the Alteration by the Interpretation of L-I-C and A-I-C Diagrams (Figures 10 and 11)

L-I-C diagram: The rock evolves from the domain of combined predominance of leaching and potential confinement towards the domain of combined predominance of the induration and leaching potential, going forward and backward in the domain of predominance of leaching potential alone.

Diagram A-I-C: The rock evolves from the potential confinement field towards the domain of combined predominance of potential induration and virtual alteration doing forwards and backwards moves in the domain of virtual alteration and domain of equivalent intervention of alteration, of induration and potential confinement.
Therefore the soil profile on Batsingla trachybasalt is a more or less closed environment where the alteration takes place due to the predilection of lixiviation of soil alkaline cations leaching and induration.

Study of Alteration by Interpreting L-IAL-IFL and IFL-A-IAL Diagrams (Figure 12 and 13)

Diagram L-IAL-IFL: The hydrolysis by bisiallitisation attacks the sample of the parent bedrock. This hydrolysis evolves along the profile: at the median level, it proceeds predominantly of monosiallitisation and predominance of allitisation at the upper level. The de-saturation of the profile based of the fine fraction is low at the lower level, average in the median level and strong at the upper level. However the evolution of these parameters is not linear, they go forward and backward from one domain to the other, passing through the ironstone belt. The profile evolves from a very low aluminous state and moderately ferruginous towards a moderately aluminous and strong ferruginous state. It should be noted that the middle and upper levels are potentially areas of ferruginous and aluminous belts.

Diagram A-IAL-IFL: The profile evolves from a poorly differentiated level to a well differentiated level with forward and backward trips between the two level. In other words the median level of the profile is a non linear association of well-differentiated and poorly differentiated layers. The profile evolves from muddy textures in the lower level to granular-clay in the upper level. These soils adopt different behaviors depending whether they come from the surface, the medium level or the upper level; that is to say, under application of a load, they behave respectively as a plastic body, a plasto-compressible bod or an elasto-compressible body, the breaking mode beeing breackable to ductile. The use of the materials of that profile should take into account these behaviors and of the mineralogy of these materials.

In conclusion, the soil profile on Batsingla trachybasalt is a well differentiated soil with a large zone of potential ferruginous and aluminous belts. Their use in construction work must take into account their elastic-plastic behavior in ductile to frank fracture with ductile and their mineralogy rich in kandite and illite.

CONCLUSION

This work as defined at the outset had the objective: first to define the mineralogical and geochemical evolution of the profile of alteration of the trachybasalts of Batsingla then secondly to do the characterization of the alterological parameters of the environmental by normative alterology. The results obtained have allowed suggesting the ollowing:

- The petro graphical nature of the Batsingla rock is a trachybasalt , hyper-alumino-ferric, calco-alcaline and poor in ferromagnesian. By normative alterology it is a rock showing a deficit in silica and poor in aluminum (($Sl_2 - Al_2$), poorly aluminous and moderately ferruginous. The dominant process of alteration is the monosialitisation.
- The isaltérite, very thick (about 10 m thick) is essentially made of of kaolinite, goethite, some magnetite, anatase and quartz. By normative alterology, it constitutes a rock rich in silica and alumina ($Sl_1 - Al_1$) processing in an open environment where the dominant process of alteration is the monosialitisation.
- The profile of alteration is marked by a singular transitional level marked by two particular phenomena: muscovitisation (process of neo-formation of muscovite within the complex of alteration) and quartzification (process of neo-formation of quartz within the complex of alteration). In fact the plagioclase by transformation into kaolinite and by inheritance of potassium gave muscovite. We note similarly a thin layer of enrichment in ferric iron (Fe^{3+}), looking grainy and rusty and rich in goethite where the dominant process of alteration is the allitisation. All of this denotes the characteristic of the process of ferrolysis observed on the pedo-genesis of the formation of this trachybasalt.

- The allotérite is a rock rich in silica and alumina operating in an open environment, marked by laterization of the first five upper meters. The thermodynamic conditions have favored the combined actions of oxidation, hydration, allitisation and monosiallitisation.
- The soil profile of the trachybasalt of Batsingla is a more or less closed environment where the alteration evolves due to the leaching of the alkaline cations and induration. It is a well differentiated soil with a large zone of potential ferruginous and aluminous armouring. Their use in civil engineering work will take in account their elastic-plastic behavior with ductile at frank fracture and their mineralogy rich in kandites and illite.

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Chemical Equations

1°) $12{,}4[Mg_{1,63}Fe(II)_{0,37}SiO_4]$(**Olivine**) $+\ 0{,}8AlOH^{2+} + 24{,}4H^+ + 1{,}6H_2O(I) + O_2 \rightarrow$ $Mg_{0,40}[Si_{7,2}Al_{0,8}]Mg_6O_{20}(OH)_4$(**Smectite**) $+\ 4{,}59FeOOH$(**Goethite**) $+ 5{,}2Si(OH)_4 +$ $13{,}5Mg^{2+}$

2°) $Al_{0,3}[Si_{7,5}Al_{0,5}]Al_{3,6}Mg_{0,4}O_{20}(OH)_4$ (**Smectites**) $+\ 0{,}8H^+ + 8{,}2H_2O \rightarrow$ $1{,}1[Si_4]Al_40_{10}(OH)_8$(**Kaolinite**) $+ 3{,}1Si(OH) + 0{,}4Mg^{2+}$

3°) $2FeOOH$(**Goethite**) $\rightarrow Fe_2O_3$(**Hématite**) $+\ H_2O$

4°) $3FeMgSiO_4$(**Olivine**) $+\frac{1}{2}0_2 \rightarrow Fe_30_4$(**Magnétite**) $+\ 3SiO_2$ (**Quartz**) $+\ 3MgO$

5°) $CaMgSi_2O_6$(**Diopside**) $+\ H_2O + CO_2 \rightarrow 2SiO_2$(**Silice**) $+\ Mg^{2+} + Ca^{2+} + 2HCO_3$

6°) $2NaCaAlSi_3O_8$(**Plagioclase**) $+\ 2H^+ + 9H_2O \rightarrow Al_2Si_20_5(OH)_4$(**Kaolinite**) $+\ 4Si(OH)_4 +$ $2Na^+ + 2Ca^{2+} + 4e^-$

7°) $NaCaAlSi_3O_8$(**Plagioclase**) $+\ H^+ + 8H_2O \rightarrow Al(OH)_3$(**gibsite**) $+\ 3Si(OH)_4 + Na^+ +$ $Ca^{2+} + (OH)^-$

8°) SiO_2K_2O(**Métasilicate potassique**) $+ H^+ + 2H_2O \rightarrow 2K^+ + Si(OH)_4 + \frac{1}{2}(OH)^-$

9°) $Al_4Si_4O_{10}(OH)_8$(**Kaolinite**) $+\ K^+ + 2(OH)^- \rightarrow KAl_2[(OH)_2AlSi_30_{10}]$(**Muscovite**)

10°**)** Fe_2O_3 (**Hématite**) $+\ H_2O \rightarrow Fe_2O_3H_2O$(**Goethite**)

11°) $2Fe^{2+} \rightarrow 2Fe^{3+} + 2e$

12°) $2Fe^{3+} + 4H_2O \leftrightarrow 2FeO(OH)$(**Goethite**) $+\ 6H^+$

13°) $Si_2Al_2O_5(OH)_4$ (**Kaolinite**) $+ 6H^+ \leftrightarrow 2Al^{3+} + 2H_4SiO_4$(**Silicic Acid**) $+\ H_2O$