Original Research Article

OCCURRENCE OF HARDENED MATTERS IN THE ANDOSOLIC COVER FROM THE WESTERN HIGHLANDS OF CAMEROON: CASE STUDY OF THOSE RISEN ON TRACHYTE IN THE SOUTHERN SIDE OF THE BAMBOUTO MOUNTAINS

ABSTRACT

The aim of the present study is to acquire knowledge about the hardened materials present in the andosolic cover from the Bambouto Mounts. For that purpuse, petrographic, mineralogical, and geochemical characteristics of the hardened materials, isalteritic blocks, and the parent rock were investigated in order to put into relief the different facies found, the genetic relationship between those geological matters, and the mechanism governing the formation and the evolution of the hardened materials found in the Andosols from the Bambouto mounts. These matters have low thickness, are highly hardened, with different aspects and locations. They are present within the soils, at the point of emergence of streams, on the flatty areas on top of hills and at the foot of interfluves. Microscopically, their plasmas are respectively isotic and cristic. Gibbsite, goethite, and halloysite are respectively their main minerals. Geochemically, both facies are highly aluminous. During the weathering, Sanidine changes sequentially into Allophane, Halloysite, and Gibbsite; Pyroxen and Ilmenite for their own contribute to the formation of Goethite. There is a direct genetic relationship between the hardened materials,

the isalteritic blocks, and the parent rock. The uphill position is the eluvial part and the downhill position the illuvial part; this generates the evolution of the hardened materials from their translucent initial status towards their reddening and tanning final status. The characteristics of the hardened materials make them bauxitic hardened materials, organized into two different facies: a lithorelictuel and a vitreous facies. The presence of those hardened materials in the Andosols from the Western Highlands of Cameroon is harmful for farming. The present study is then a high contribution to the management of the mine ore deposit within the Western Highlands of Cameroon.

Key words: Lithorelictual, vitreous, facies, allitisation, monosiallitisation, ferrtisation.

1. INTRODUCTION

Hardened matters are pedological masses appearing in particular environmental conditions [1]. They can be discontinuous or continuous hardpans [2]. Globally, they are often observed in tropical areas, characterized by a warm and wet type of climate [3]. Their nature is determined by their mineralogical and geochemical composition. They occur in pedological covers when the parent rocks have undergone an intense alteration, capable to generate the leaching, complete for alkali and earth alkali, and quite complete for silicon, alongside with the relative concentration of metals such as aluminum, iron, nickel, titanium among others [4].

This implies then their occurrence within soils formed after a long pedogenesis process such as soils with ferrallitic characteristics [5]. This process is then logically recurrent in zones with granite-gneissic rocks as substratum [6]. However, in volcanic regions, the formation of these matters was recently discovered [7]. They were described to be mainly gibbsitic duricrust according to their high content in aluminium. [8] showed that in volcanic environments, they can occur in different topographic positions. Implementing that observations, [9] discovered that even in andosolic soils, these matter can be present if the parent rocks of these soils are sufficiently old, and if the climate is favorable. But, the previous studies on these matters from volcanic regions didn’t insist on the details of the distribution of these matters in the andosolic landscape as same as the different facies in which they appear in those particular environments. The aim of the present study is then to make clearer those aspects. For that purpose, andosolic soils risen from trachyte in the Western Highlands of Cameroon [10] were choosen.

2. MATERIALS AND METHODS

2.1 MATERIALS

The volcanic Bambouto massif is located in the Cameroonian Western Highlands, between 5^{0}25’ and 5^{0}45’ of North latitude, and between 10^{0}00’ and 10^{0}15’ of East longitude. It is a huge volcanic shield, reaching 2740m high at the summit of Mélétan Mount.

Concerning the geomorphological aspects of the present massif, three main zones characterized by some particular environmental conditions can be distinguished; these include: the upper zone, with altitudes higher than 2000m, the mid zone, with altitudes ranging between 1600 and 2000m, and the lowest zone, with altitudes ranging between 1400 and 1600m ([11], [8]). The upper zone shows an aggressive relief. Its climate is foggy and cold, with temperatures ranging between 10 and 13^{0}C. The rains are orographic type, with annual average pluviometry of 2600mm ([12], [13]). The flora is natural and anthropic. The natural part is essentially made of graze, locally disturbed by gallery forests along water course [14]; the anthropic part is made of different crops ([15], [10]).The hydrographic network is radial and dense. Soils are mostly Typical Dystrandepts [16]. Many signs of anthropic activities are present ([16], [9]). The mid zone shows a subequatorial type of climate highly modified by the altitude [17]; it is cold and wet, with nine month of rains, from march to november, and a short dry season, from december to february; the average annual temperature is about 18^{0}C; the annual average pluviometry is 1690mm. Compared to the upper zone, the relief here is less aggressive. The vegetation is mainly anthropic [15], with locally some islets of the natural vegetation in the swamps. The hydrographic network is subdendritic. Soils are mostly andic ferallitic [14]. The lowest zone finally is governed by a hot and wet climate, with an annual average temperature of 23,5^{0}C and an average annual pluviometry of 1750mm. The relief is undulating. The vegetation is quite essentially anthropic [15]. The hydrographic network is subdendritic. Soils are mainly ferallitic with hardpan within [14].

Geologically, trachytes are the major rocks in the whole massif ([18], [19]). There are also few outcrops of basalts, phonolites, rhyolites, and pyroclastites. The substratum is made of granitic and gneissic types of rocks. This substratum mainly outcrops in the lowest zone of the massif.

The pedological cover is made of andic ferallitic, desaturated, humic and strongly rejuvenated soils [9].

The hardened matters studied here are located in the upper zone of the massif [9].

The parent rock is an alcaline trachyte [9] form Miocene ([18], [19]).

2.2 METHODS

The work of [9] has helped to locate hardened materials in the upper part of the Bambouto Mounts. Moreover, a deep focus on these matters have helped to subdivide them in two main facies. A careful description of the matters from the different facies help to reveal their particularities.

Their description was facilitated by wells, outcropping, and road sides. Descriptions focused also on trachytes and isalteritic blocks. Rock, isalteritic blocks, and hardened material samples were finally collected for lab analysis.

In the laboratory, three major analysis were carried out, notably microscopicic, mineralogical, and geochemical ones. Microscopicic analysis consisted in the study of the slides of rock, isalteritic blocks, and hardened materials under polarizing compound microscope. Slides were built up in the petrography laboratory of IRAD, Nkolbison (Yaoundé). Mineralogical and geochemical analysis, proceeded respectively by X-ray diffractometry on a device using cupper anode and by fluorescence, were made on total hardened materials, isalteritic blocks, and rock powder in the Mineral Analysis Centre of Lausanne University, Switzerland.

3. RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Morphology of the site of the studies

The site of the study is located on the south-east border of the Bambouto Mountains caldera, in the Meletan locality. Its relief is rough, characterized by the presence of many interfluves with step sides. They are principally flow-like trachytic domes, with flatty summits. They are circumscribed by water courses or by escarpments.

3.1.2 Petrographic study of the parent rock

The parent rock is a trachyte. It outcops at the summit or on the sides of interfluves as blocks with variable sizes. It is dark grey, massive, hard with a saccharoid aspect, compact, more or less altered, traversed by many diaclasis with tanned borders. On the altered zones appearing, many phenocrist of sanidine more or less weathered are easily recognized, conferring to the rock a mangy aspect.

The observation of a slide of the rock under compound microscope reveals the presence of many phenocrysts of sanidine and few quantities of pyroxene and dense minerals drown in a matrix essentially made of microcrysts of sanidine (figure 1). Dense minerals represent about 5% of the whole rock. They have sizes ranging between 0.5 and 1mm; they are both present in the matrix and as inclusions in phenocrysts of sanidine; they are ilménite, magnetite, and apatite according to X-ray diffraction.

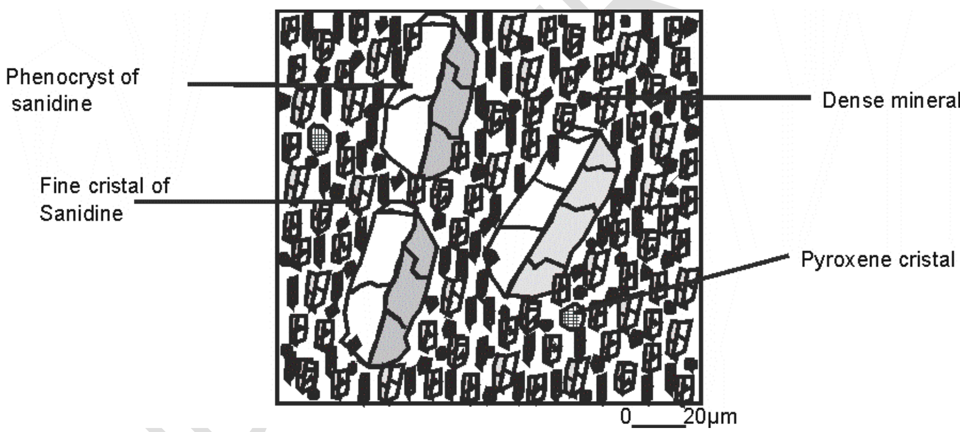

Figure 1 : Microscopic organization of the trachyte of Meletan

Geochemical analysis of the rock shows that silicon is the most abundant element (58.00%SiO_2), followed by (18.40%Al_2O_3) and iron respectively (5.63%Fe_2O_3). Alkali are abundant (6.56%Na_2O for the sodium and 5.23%K_2O for the potassium) compared to earth alkali elements (2.10%CaO for the calcium and 0.41%MgO for the magnesium). Titanium (0.44%TiO_2), manganese (0.30%MnO), and phosphorous (0.14%P_2O_5) are also present (table 1). After the binary diagram (Na_2O+K_2O)/SiO_2 of Le Maître (1989 *in* Tamen, 1994), the present rock is an **alkaline trachyte**.

Table 1 : Chemical composition of the mother rock

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	K_2O	MgO	CaO	Na_2O	MnO	P_2O_5	H_2O	Total
Hardened matters	2.88	55.88	11.68	0.74	0.06	0.15	0.01	0.00	0.27	0.53	26.82	99.02
Whitish isalteritic Horizon	22.70	41.10	6.63	0.44	0.08	0.09	0.01	0.00	0.34	0.25	26.20	97.84
Parent rock	58.00	18.40	5.63	0.44	5.23	0.41	2.10	6.56	0.30	0.14	2.01	99.22

3.1.4 The hardened matters

3.1.4.1 Location in the landscape

In the landscape, hardened materials appear at different levels. They are present along the interfluves or in the flatty zones at their summit and foot.

In the interfluves, they appear as continuous hardpan; they appear also as individuals with variable sizes. They are present on the summital projecting shelf, at the zones of occurrence of streams, on the sides, in the cracks of rock and isalteritic masses, and in the pedoturbated matters where they are lined in the continuity of cracks from the parent rock (Fig. 1); they are also observed as complete horizons.

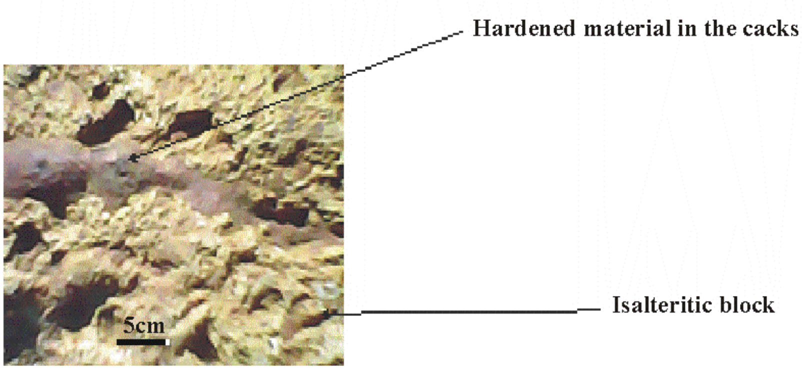

Figure 1: Occurrence of hardened material in the cracks

On the projecting shelf at the foot of the interfluves, they mainly appear as continuous hardpan (Fig. 2), and locally as juxtaposed individuals (Fig. 3). At the zones of occurrence of streams (Fig. 4), they are mainly continuous hardpans.

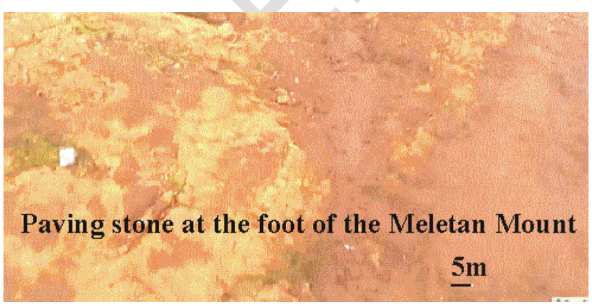

Figure 2: paving stone at the foot of the Meletan Mount

Figure 3: Hardened individuals, sometimes coalescent

Figure 4: Paving stone at the zone of the occurrence of streams

Globally, they appear with isalteritic rough aspect or with smooth and vitreous aspect; this helps to define here two different facies: the first one is flatty with rough aspect and the second one is smooth with vitreous aspect. The facies with smooth and vitreous aspect is only present in the cracks and in the horizons with hardened matters. In the horizon with hardened matters, the matters with the flatty and rough facies wrap up the matters with smooth and vitreous aspect. The facies with the flatty and rough aspect is the most abundant one. From uphill to downhill, these hardened matters independently to their facies present morphologic variations.

3.1.4.2 Isalteritic level

The whitish grey isalteritic horizon (10YR8/2) shows many isalteritic volumes. They are flatty, decimetric, joined, silty and soft, with sacchoroidal aspect inherited from the parent rock, locally separated by a yellow, silty clayey pedoturbated matter. Many reddened and sometimes tanned cracks travel all over their surface. Phantoms of feldspaths, tanned, and sometimes pale yellow or pinkish, millimetric (2 to 5 mm), stick like and preferentially orientated, as same as yellow (10YR7/8) silty clayey pedoturbated zones with vague contours are observed in the largely developed grey matrix.

Microscopic observation of the slide from the present matters revealed three main matrix background: a yellowish brown, a light grey, and a purple red one. The yellowish brown matrix background occupies 15 to 20% of the whole slide; it is composed of a weakly birefringent sail like plasma. The skeleton is mainly sanidine minerals, partially pseudomorposed by a whitish grey clayey asepic plasma, and by dense relictual minerals. The whitish grey matrix background is the most abundant amongst all (70%). Its plasma is sail like, weakly birefringent and whitish. The skeleton appears here in the form of partially weathered sanidine and pyroxene partially pseudomorphosed by reddish brown iron oxide. The purple red matrix background is the least (about 10% of the slide). It appears in forms of few red and translucent granulated ferruginous domains with vague contours, locally weakly birefringent and isotic. The skeleton here is made of pyroxene completely pseudomorphosed par iron oxides, forming a partitioning network, within which some few holes can be observed (Fig. 2).

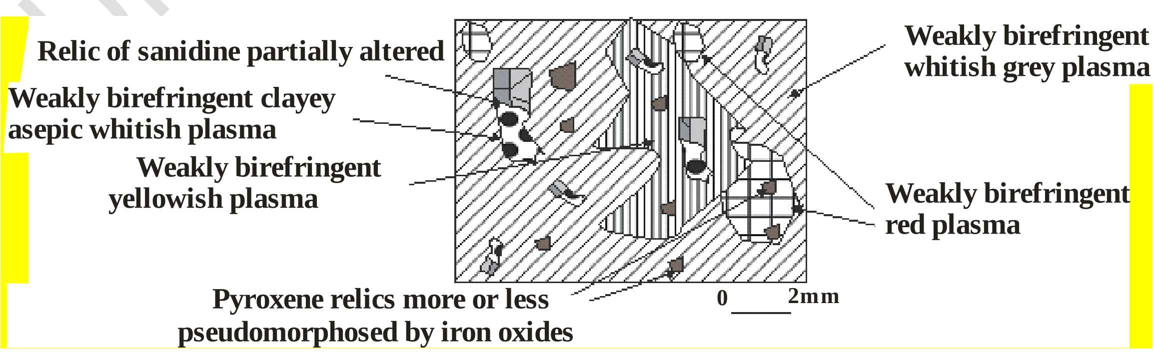

Figure 2: Microscopic organization of the whitish grey isalteritic horizon

3.1.4.3 Morphology of the hardened materials

3.1.4.3.1 The lithorelictual facies

On the uphill position, matters can reach 7 to 10cm in average length. They are flatty with a rough surface. Their back ground is highly hardened and light grey (10YR8/2) to dark pale yellow (2.5Y8/4). It drowns millimetric white (10YR8/1) and reddish (7.5YR6/6) domains, beside which there are brown to dark borders (7.5YR3/2). The white domains (10YR8/2) are roundish with distinct borders; the reddish domains (7.5YR6/6) have uncertain shapes and doubtful boundary with the light grey (10YR8/2) to dark yellow pale (2.5Y8/4) back ground. In the same back ground, one can locally find many greyish (10YR7/3) phantoms of sanidine with stick-like shape and clear orientation, recalling those of the rock. Some holes with irregular contours and some pockets fill with yellow (2.5Y8/4) or reddish (7.5YR6/6), hardened, and silty matters are also present.

On the downhill position, some morphological variations appear. The yellow matters appear as large domains with clear contours across the hardened blocks. They are floury, abundant and more or less dense. Reddish (2.5YR7/1) and dark reddish brown (2.5YR5/4) highly hardened islets with clear contours appear in equivalent proportions. They are more or less continuous and dense bands, locally partitioned by the yellow (10YR7/8) matter. The reddish (2.5YR7/1) and dark reddish brown (2.5YR5/4) domains are sometimes observed as local spots within the yellow domain. The white (10YR8/2) domain is present. It is few, hardened, with clear contours. They are essentially millimetric (7mm for the longest), stick-like, and oriented islets. Locally, they bear yellowish (10YR7/8) and more or less hardened spots. All the domains mentioned are traversed by many millimetric cavities.

3.1.4.3.2 The vitreous facies

The vitreous facies is represented by hardened, centimetric (up to 20cm), and paving stone-like blocks with smooth surface. They are disseminated in the flatty with rough surface blocks. They are reddish (7.5YR6/6), locally translucent (vitreous aspect), massive, compact, highly hardened, and larger than the blocks of the flatty and rough surface facies. Some roundish cavities are disseminated all over their surface. The translucent matrix of these matters are locally blurred by brown (7.5YR3/2) and reddish (7.5YR6/6) frameworks. The reddish (7.5YR6/6) frameworks are fewer and denser than the brown (7.5YR3/2) frameworks. Some whitish (10YR8/2), brownish (7.5YR3/2) and sometimes reddish (7.5YR6/6) sticky-like domains are present. Some rare roundish yellowish (10YR7/8) domains are also present.

On the downhill position, the size of the blocks decreases (about 4cm in average) while their induration degree increases. Four hardened domains are present: yellowish (10YR7/8), red (10R4/8), brown (2.5YR5/6 to 2.5YR5/4), and white (10YR8/1). The yellowish domain (10YR7/8) is the most abundant. It is fairly dense and constitutes large bands. The red domain (10R4/8) is made of islets with irregular shape and clear contours, drowned in the yellowish (10YR7/8) domain. The brown domain (2.5YR5/6, 2.5YR5/4 to 2.5YR2/1) constitutes a framework with clear boundaries at the surface of the yellowish domain (10YR7/8). The white domains (10YR8/1) are especially millimetric roundish islets, with diffuse contours, disseminated towards the edges of the yellowish (10YR7/8) domain.

At the intermediate part of the interfluves sides, one can observe some particular paving stone-like blocks with vitreous but non translucent aspect. Their central portions are red (10R4/8) and their borders are whitish (10YR8/2) to light reddish (10R4/6). This organization keeps them closer to the blocks of the present facies.

3.1.4.4 Micromorphology

The study of the slide of the hardened matters under compound light microscope reveals three different matrix: a light grey matrix, a dark matrix, and a red matrix (figure 2).

The light grey matrix is the most abundant (70% of the slide). Its plasma is light grey, abundant (80% of the matrix), dense, highly birefringent, with a cristic structure. The skeleton is heterogeneous and fairly abundant (25% of the whole matrix). The primary skeleton is made of dense mineral; it represent about 10% of the whole skeleton; the individuals of the present skeleton are spherical and dense, with an average diameter of about 600µm; their contours are clear and their relief is high; they recall those observed in the rock. The secondary skeleton is made of phantoms of phenocryst of sanidine completely pseudomorphosed by a highly birefringent cristic gibbsitic plasma; it is abundant (90% of the whole skeleton); the individuals of the present skeleton have about 4mm length and 1mm width in average; they are stick-like, with the same orientation; they recall the phenocrysts of sanidine observed in the rock. Some holes are present (10% of the matrix). They are mostly elongated; their borders are locally covered by a dark and a red weekly brefringent plasma, both isotic.

The dark matrix is few (20% of the slide) and disseminated in the slide. The plasma is dark, abundant (95% of the matrix), dense, and isotic; it is a framework nascent at the borders of the holes and covers partially the phantoms of sanidne. The skeleton is homogenous and principally represented by phantoms of sanidine completely pseudomorphosed by a highly birefringent cristic gibbsitic plasma. Holes are principally fissures edging the matrix.

The red matrix is fewer (10% of the slide). It is a framework with finger-like shape. The plasma is red, abundant (95% of the matrix), dense, and isotic ; it is bordered in one side by the holes, and in other side by phantoms of sanidine that it covers sometimes. The skeleton is homogenous and principally represented by phantoms of sanidine completely pseudomorphosed by a highly birefringent cristic gibbsitic plasma. Holes are principally fissures edging the matrix.

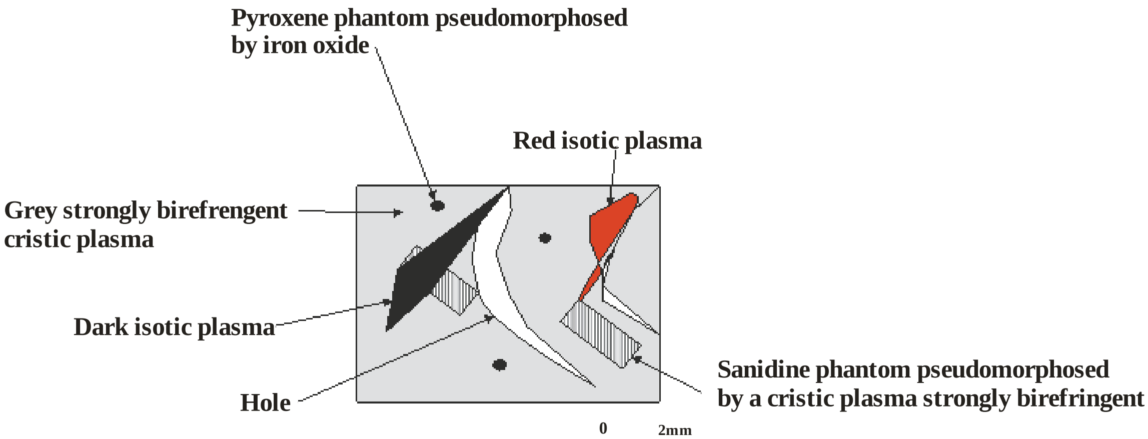

Figure 2: Microscopic organization of the hardened matters

3.1.4.5 Geochemistry and Mineralogy

Geochemically, the principal chemical elements of the isalteritic blocks are respectively aluminum (41.10%Al_2O_3), silicon (22.70%SiO_2), and iron (6.63%Fe_2O_3). Alkali and earth alkali elements are absent. Few quantities of titane (0.44%TiO_2), manganese (0.34%MnO), and phosphorus (0.25%P_2O_5) are detected (Table 1). Compared to the mother rock, silicon decreases abruptly (from 58.00% to 22.70%SiO_2), aluminum increases abruptly (from 18.40 to 41%Al_20_3), iron increases moderately (from 5.63 to 6.63%Fe_2O_3). Concerning the hardened materials, aluminum (55.85%Al_2O_3), iron (11.68%Fe_2O_3), and silicon (2.88%SiO_2) remain respectively their principal elements (Table 1). Alkali and earth alkali elements are absent. Few quantities of titane (0.74%TiO_2), manganese (0.27%MnO), and phosphorus (0.53%P_2O_5) are detected (Table 1). Compared to the islateritic blocks, silicon decreases abruptly (from 22.70% to 2.88%SiO_2), aluminum increases abruptly (from 41,1 to 55.85%Al_20_3), iron increases moderately (from 6.63 to 11.68%Fe_2O_3)

Mineralogically, Gibbsite is the principal mineral of the isalteritic level. However, there are few quantities of halloysite and trace of ilmenite, goethite, quartz, magnetite, and sanidine. Moreover, allophane is present. Compared to the mother rock, Ilmenite and magnetite have remained constant. Pyroxene and cristobalite have disappeared; the quantity of sanidine has decreased; quartz, goethite, and gibbsite have appeared. Concerning the hardened materials, Gibbsite, Goethite, and Halloysite are the main minerals.

3.2 Discussion

The upper part of the Bambouto Mount is made of many flow-like domes with abrupt sides, bordering deep valleys; according to [11], this recalls plateau landscape. The climate is highly rainy; this environment is then subject to hydrolysis. In fact, hydrolysis is the attack of silicate minerals by water to result in a total reorganization of the initial mineral structure to another completely different mineral. Allitisation is the extreme stage of hydrolysis. It consist of the sequential modification of feldspar (Sanidine in the present case study) into Aluminium Hydroxide after illite and kaolinite stages respectively [8].

The parent rock is rich in sanidine; this makes it a felsic rock type; its richness in sanidine, coupled to the highly wet climate of the region is a token of bauxitisation

([9], [21]). This approves the existence in the upper part of the Bambouto Mountains of local hardpans at different topographic position. Their presence testimonies the bauxitisation phenomenon occurring elsewhere in the volcanic shields from the Cameroonian tectono-volcanic line as described by [22], [2], [7], and [8].

During the process of the weathering of the trachyte, Sanidine is completely discharged form its Alkali and earth alkali elements into the solution; concerning silicon, its leaching is incomplete. At the same time, the attack of the pyroxene and ilmenite releases significant amount of iron alongside with their earth alkali elements (in the case of pyroxene). In the reverse side, high relative concentrations of aluminum (for the Sanidine) and enough relative concentrations of iron (for pyroxene and ilmenite) are detected. This is in accordance with the observations of [21] . The high aluminium enrichment (about 56% Al_2O_3) is a clear indication that the allitisation prevails in this area; a part of that chemical element crystalizes into Gibbsite; this corroborates the predominance of the cristic and highly birefrengent plasmas observed in the slides of isalteritic blocks and hardened materials; this is in accordance with the great amount of Gibbsite in the mineral paragenesis. The silicon detected combines with the remaining part of aluminum to enable the development of Allophan in the isalteritic blocks, which evolves into halloysite in the hardened materials; Halloysite is in fact one of the youngest transitional stage during the process of the formation of 1/1 clay minerals that the oldest representative is Kaolinile; this is therefore the proof of the occurrence of the monosiallitisation prevailing here. There are enough concentrations of iron (11.68%Fe_2O_3) in the hardened materials; during the pedogenetic process, that element crystalized into goethite. This is then the testimony of the ferritisation happening here alongside with allitisation and monosiallitisation processes as precised by [21]; this ferritisation is comforted by the presence of red isotic plasmas as observed in the slides of hardened materials.

3.2.1 The lithorelictual facies

The hardened materials from the lithorelictuel facies are flatty; they recall with this shape the isalteritic blocks. This can be due to the system of lava flow. In that point of view, [23] demonstrated that during the lavas flow, this magmatic fluid is organized in superposed layers. These bands isolate among them discontinuities, which are the openings through which water and other solutions can attack the rock [24]. So, during the alteration, the layers are dislocated into isalteritic blocks with variable sizes, which will finally fossilized the flatty shape of the layers of the lavas. Under the compound light microscope, intense pseudomorphosis process is observed within those isalteritic blocks, responsible to the maintaining of the shadows of Sanidine and Pyroxen. This contributes to maintain the organization of the parent rock [25] and to increase its hardness [9]. Moreover, some locations of those isalteritic blocks in transformation are reddened and tanned, with isoctic plasmas. This implies the contribution of iron among other in the hardening process of the isalteritic blocks; [21] considers such observations as the signs of ferritisation; this can then justify the hardness of those matters as observed on the field. Great quantities of aluminum and Gibbsite are detected in those blocks; these observations confer to these matters aluminous characteristics. Their hardness makes them hardened aluminous matters ([6], [26]). According to [25] and [27], they can be said to be lithorelictuel hardened materials. The studies of [21] and [8] are openings allowing us to consider those materials as bauxitic matters. The conservation of the rock structure in the isalteritic blocks and further in those bauxitic matters contribute to create lithorelictuel facies, characterized by the flatty shape and the rough surface of the blocks.

3.2.2 The vitreous facies

The diaclasis of the isalteritic blocks on the uphill and on the intermediate position are filled with some hardened materials. It is characterized by its smooth surface and its vitreous aspect, with a break in conchoidal marner. In fact, within the discontinuities of the rock and isalteritic blocks, water filled with ions moves as demonstrated by [24]. When the saturation point of each ion is reached in the water percolating within the cracks, the process of precipitation starts, inducing the secondary crystallization of minerals on the borders of the cracks; this agrees then the observations of [28]. According to the high quantity of aluminum in the

Andosolic cover from Bambouto Mountains, aluminum followed by iron are the first metals to start the precipitation. Locally in the pedological cover, hardened materials with tanned borders perfectly lined with diaclasis from rock are observed. This observation agrees with the accumulation process in the cracks in one hand, and in the other hand with the implication of those diaclasis in the transfer of ions through water flowing across the pedological cover. In addition, that observation implies also the lateral and vertical migration of aluminum in the Andosolic cover of the Bambouto Mounts; this theory of the migration of ions within pedological cover was demonstrated previously by [1], [29], [30], [31], [3], and [32]. The vitreous hardened matters deposited in the cracks of isalteritic blocks resemble the paving stone-like matters with smooth surface present in the hardened level of the pedological cover; we can then think that a genetic link exists between those two matters. In the blocks constituting the vitreous facies, rare phantoms of sanidine pseudomrphosed by gibbsite are present; this can be due to the resorption of the portion of the isalteritic blocks closer to the cracks.

The hardened matters observed in the diaclasis are highly translucent on the uphill position compared to those observed on the downhill position. Moreover, all those matters are highly reddened and tanned on the downhill position compared to those observed on the uphill position. In that way, [1] demonstrated that in Andosolic environments with low pH (less than 4 in the present case after [9]), heavy metals are easily mobilized as chelates with the help of water; he completes its analysis by showing that during the dry season and in the presence of the air, the chelates can be oxidized, inducing the releasing of the metals held. From this, the reddening can be then explained by the precipitation of the iron released on the surface of those matters, followed by their crystallization into goethite according to the high pluviometry; this comfort the theory of ferritisation announced previously; the tanning for its one can be explained by the same approach. We can then think that the uphill position is the eluvial part while the downhill position is the illuvial part. Under the compound light microscope, the dark matrix covers partially the red matrix; this shows that iron precipitates before manganese; this agrees with the high quantities of iron in the pedological cover compared to that of the manganese; in fact, [24] demonstrated that in pedological solutions, the first ions to reach its saturation point is the first to precipitate. This observation strengthens once more the theory of the migrations of matters within the andosolic cover of the Bambouto Mounts ([29], [32]), favored by the gravity [27]. At the point of the emergence of streams, hardpans are present; this certifies the implication of water in the development of this pedological matters. In the pedological cover, the rate of humidity increases towards downhill. This is in accordance with the reddening and the tanning phenomenon observed on the borders of hardened matters filling the diaclasis of isalteric blocks on the downhill position. The degree of induration of isalteritic blocks decreases away from the diaclasis. This is in accordance with the possibility of migration followed by the deposition of hardening substances such as aluminum and iron on the borders of cracks through water as demonstrated by [33], [1], [31], and [32]; this corroborates the high concentrations of aluminum (55.88%Al_2O_3) and fewer concentrations of iron (11.68%Fe_2O_3) noticed in this pedological cover. The predominance of aluminum in this andosolic pedological cover comforts the fact that the concerned hardening matter is principally aluminum; this is in accordance with the great quantity of rain falls in this environment, necessary to generate bauxitic weathering ([34], [21], [35]). The presence of two levels of hardened horizons on the downhill position testimonies the high degree of accumulation of matters in that direction. In the isalteritic level, isalteritic blocks drowns the vitreous hardened matters deposited in the cracks. At the end of the evolution of those two different matters, this original organization is maintained. This can then explain why the hardened blocks from the lithorelictual facies wraps up the paving stone-like from the vitreous facies. During the transformation of the hardened matters deposited in the cracks into the paving stone-like blocks, the smooth aspect of their surface is maintained; this contributes to create the vitreous facies.

3.2.3 Effects of the hardened materials on agriculture in the region of the study

In the landscape, the hardened materials sometimes outcrop directly at the soil surface. In other areas, this hardened materials are present at about 40cm depth. In addition, many environmental indicators reveal the signs of an intense migration of aluminum within the Andosolic pedological. The surface covered by the hardened materials is completely unusable by farmers. This is due to the fact that their hardness makes them impassable for roots. In the areas where the hardened materials are present at 40cm depth, the thickness of the tillable land seems to be favorable for the plants growth; this is just a fairytale. In that point of view, [36] demonstrated that when aluminous hardened materials exist in soils, the Kamprath index (the index defining the degree of the aluminum toxicity) of the concerned soils is very high and the pH low; this agrees with the numerous signs of the aluminum migration within this pedological cover. The previous studies of [9] comfort this approach; in fact, during some fertilization trials on the Andosols drowning these hardened materials, this author realized that their Kamprath index reaches about 60 (59.62) in soils under natural vegetation; concerning the pH, he measured in the same situation a value of 3.95. For such soils, [37] declares that rare are the edible plants that can resist to that degree of toxicity; in fact, such pH favors the neutralization of phosphorus and nitrogen by exchangeable aluminum, making them unreachable for plants; in this case, plants behave as if there were not these elements in the soil. This apparent lack of those two nutrients induces the signs of deficiencies in their metabolism; such situation is then harmful for the growth and the productivity of plants. In terms of consequence, the practice of agriculture in the sector is therefore very difficult for peasants as observed on the field. In fact, to neutralize the exchangeable aluminum, they often use great quantities of chemicals; unfortunately, their crop yields do not regularly cover their investment. But recently,

[9] proposed an ecological way for the neutralization of the exchangeable aluminum at low cost ; therefore, the best is to come.

4. CONCLUSION

The aim of the present study was to highlight the occurring of hardened matters in the andosolic cover of Bambouto Mounts. So, petrographic, mineralogical, and geochemical characteristics of the hardened materials, isalteritic blocks, and the parent rock were followed up in order to put into relief the different facies found, the genetic relationship between those geological matters, and the mechanism governing the formation and the evolution of the hardened materials found in the Andosols from the Bambouto mounts. These matters have low thicknesses, are highly hardened, and are mostly reddened and tanned on the downhill position. They are present within the soils, at the point of emergence of streams, on the sides and on the flatty areas on top of hills, in the diaclasis, and at the foot of interfluves. Microscopically, their plasmas are cristic and locally isotic. Mineralogically, Gibbsite, goethite, and halloysite are their main minerals. Geochemically, both facies are highly aluminous with enough quantities of iron and least quantities of silicon; beside the allitisation prevailing in the Bambouto mounts, there are also the phenomenons of monosialitisation and the ferritisation. During the weathering, Sanidine from the parent rock changes sequentially into Allophane observed in the isalteritic blocks, and successively into Halloysite and Gibbsite present in the hardened materials; Pyroxen and Ilmenite from the parent rock for their own contribute through their iron to the formation of Goethite present in the hardened materials. There is then a direct genetic relationship between the hardened materials, the isalteritic blocks, and the parent rock. The intense reddening and the tanning phenomenon, and the presence of two levels with hardened matters observed towards downhill certifies that the uphill position is the eluvial part and the downhill position the illuvial part. This contribute to favour the evolution of the materials from the vitreous facies from their translucent aspect towards the reddening and tanning final aspect. The hardened materials studied here are bauxitic with two facies, notably a lithorelictuel facies and a vitreous facies. The presence of those hardened materials in the Andosols from the Western Highlands of Cameroon is harmful for farming.

COMPETING INTEREST

Authors have declared that no competing interest exist.

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