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Case Study

MINERALOGICAL NATURE AND EVOLUTION LEVEL OF A CAMBISOL DEVELOPPED ON SCHIST IN REGION OF AZAGUIÉ, SOUTH-EAST OF CÔTE D'IVOIRE

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ABSTRACT

A study was conducted on the site of the Institut des Nouvelle Technique Agricole d 'Azaguié in order to understand the role of minerals in assessing the level of soil evolution. To this end, a study of different soil fractions was carried out. Thus, a mineralogical study of the sandy fraction was carried out by sorting on a sieve column. Whereas the mineralogy of the total soil and the clay fraction were determined by X-ray diffractometry. Results revealed that in sand fraction, quartz (over 50%) is the most abundant mineral at all topographic levels whereas iron oxides (hematite and martite) are observed only in mid and lower slopes. In total soil, clay (kaolinite, antigorite, montmorillonite/chlorite) was observed at 4-19 %, oxides (goethite, quartz) with 67-91 % content and primary minerals (muscovite, feldspar) to 5-14 %. Whereas the clay fraction is only provided with kaolinite type clay (over 80%), smectite, chlorite and interstratified (chlorite/smectite and illite/vermiculite) at about 5%. These soils are highly advanced due to their high kaolinite and mineral content, such as quartz and also the presence of hematite, goethite and martite. These mineralogical characteristics expose the soil to a depletion and a firing.

INTRODUCTION

The pedological characterization of a natural region is often difficult and requires a human, logistical, financial and scientific investigation effort (Trichet *et al.*, 1999 ; Alongo *et al.,* 2013*)*. This is usually based on more or less punctual and/or generally restricted studies, which serve as a useful basis for regional soil knowledge (Augusto *et al.,* 2006). Thus, most soils in large agricultural fields or even large institutes claiming to specialize in soil sciences remain unknown to date. To make up for this state of affairs in the scientific knowledge of the soil, the Institute of New Agricultural Techniques (INTA) of Azaguié has initiated apprenticeship and research sessions with university laboratories.However, most of the work undertaken in this context by Allou (2017) and Amani (2017) on these soils did not take into account the relatively simple criteria such as color, coarse element load, depth, texture, and reshaping to assess their quality. None of these studies raises the question of the influence of soil minerals on knowledge and appreciation of soil morphological aspects. Thus creating deficiencies in the knowledge of the soil of the field of exploitation of this institute, one of the objects of study being the soil. However, many of the soil science studies refer to the role of minerals in knowledge and interpretation of soil data according to Yoboué (2010).

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To compensate for this lack of information in INTA soil knowledge, this work is intended to define the different minerals observed in soils and their meanings during soil processes.

MATERIAL AND METHODS

Description of the study site

The study area is located in the administrative region of Agneby-Tiassa, in the department of Agboville, and precisely in the sub-prefecture of Azaguié (coordinates 5°35' and 6°15' north latitude and 3°55' and 4°40' west longitude) in the forest area of Côte d'Ivoire (Roose and Godefroy 1977) (Fig 1). The site studied is that of the Institut de Nouvelles Techniques Agricoles (INTA) located 5 km from Azaguié and located at coordinates 5°40'28" N latitude and 4°06'48" W longitude.

Climate and Vegetation

The climate of the region is of equatorial type in the coastal and tropical humid Attiean type area towards Agboville. With an annual average temperature of 28°C, this area is characterized by four (4) seasons:

- a large dry season, from December to March;
- a large rainy season, from April to mid-July;
- a small dry season, mid-July to mid-September and
- a small rainy season in mid-September in November.

Vegetation varies from the clear forest on the coast to the south to the dense semi-evergreen and shophile forest to the north of the region according to Ahoussi *et al.* (2013).

Hydrographic network and relief

The region is home to a very dense hydrographic network consisting of the Comoé and the Mé and Agnéby rivers and their tributaries (Ahoussi *et al.,* 2013).

The relief is weakly wavy (penetrated) with many small hills with low slopes of less than 5% (Sodefor, 1999).

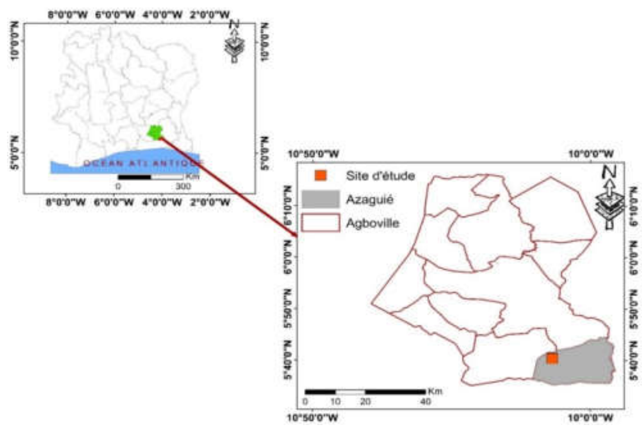


Figure 1 Location of the Agnéby-Tiassa Region and the study site

Geology and soil

The geology of the region is characterized by a set of two geological units, including the sedimentary basin in the south and the crystal-clear base in the north (Delor *et al.,* 1992). The crystalline base consists of birian formations, shales, metaarenites, and metasiltstones in which burnean granitoids composed of gneisses, granites, granito-gneiss with aureoles of metamorphism appear in intrusions (Ahoussi *et al.,* 2013).

On a pedological level, most of the soils in this locality belong to the class of ferralitic soils (Ferralsols) developed on Birimian shale, which is sometimes colorful and rich in silica according to (Tamia *et al.,* 1999) or even green shiste (Roose and Godefroy, 1977).

Mineralogical characterization

The mineralogical study was applied to the sandy fraction, total soil, and clay fraction of the soil.

The sandy fraction of the soil

For the study of the mineralogy of the sandy fraction of the soil, 50 grams of soil are washed with soapy water on a column of three mesh sieves of 2 mm, 1 mm and 500 µm (top to bottom). Rejections from the various sieves were recovered from petri dishes and dried in the oven until the water was completely evaporated. The dried samples are weighed and sorted by binocular magnifying glass. This last step allows the separation and identification of minerals according to the criterion of resemblance taking into account shape, color, degree of alteration, break-up, etc. For each sieve mesh, the percentage (%) of minerals is calculated in relation to the sample of the horizon under consideration as follows:

Mineral (%) = 100*mx/mt, where mx = mass of mineral X and mt = mass of total sample.

Total soil

The technique used for total soil analysis was modeled on the Medard *et al*. (2013) method. Two grams of soil were collected and crushed in an agate mortar. The resulting soil powder is then sieved with a 63 µm sieve. The pass is compacted in the hollow of the sample holder using a glass plate and analyzed at DRX for 1 hour, in an angular interval 2 Theta (2 - 60).

The clay fraction

Soil samples were treated in a series of ways to extract the clay fraction. The method first decarbonates and destroys organic matter with hydrochloric acid and oxygenated water at 10%, respectively. These samples were then washed by several series of centrifuges during 10 minutes at 2000trs /min. For final rinsing, a centrifugation of 40 minutes at 3000trs/min was required. At the end of this operation, the clay fractions extracted from these soils were retained in pilulia for the purpose of making oriented blades. For this reason, piluliers are shaken by hand to put clay minerals on hold, then let stand for 50 minutes. The upper 2cm are then pipped from the surface of the liquid. The clay solution obtained from this method is dried in the open air on a glass blade. Once dried, the blade is analyzed at DRX before being placed in a saturated atmosphere with ethylene glycol. After 12 hours of mineral saturation, the blades are re-analyzed at DRX and then oven heated at 500°C for 4 hours and analyzed (Medard *et al*., 2013).

The determination of clay minerals on X-rays was based on knowledge of the reticular distance of the planes (001) or their harmonics (002), (003), and (004) which are whole fractions of the basal distance (001). Thorez (1976) intensities correction factors were used to quantify these clay minerals.

RESULTS

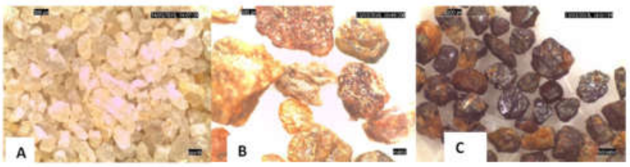
Mineralogical characteristics of the sandy fraction of the soils studied

The results of the mineralogy study of the sandy fraction carried out with binocular magnifying glass on the denials of sieves 2 mm, 1 mm and 500 µm are as follows (Table 1).

- At the summit (S), the sandy fraction of the soil consisted only of quartz. The quartz of 500 µm in size were the most abundant with a percentage of 84.21 to 84.74, respectively, in E1S and E2S samples. The 1 mm meshes contained only 15.25 to 15.75% quartz.
- In the middle of the slope (MV), quartz was also the most abundant mineral in the 500 µm mesh with a concentration of 39.17 and 80%. It was the most abundant mineral at this topographic level, but less abundant comparing to the summit. Only the E2MV sample contained 2 mm quartz with a percentage of 34.78. Martites were present in the E1MV sample in the 500µm fraction with a content of 14.42% and in the 1 mm sample, estimated at 10.33%.Hematite was present but with an estimated low content of 4.35%, observed only in the mesh of 500µm in the E2MV horizon.
- At the bottom of the slope (BV), quartz of the 500µm fraction were always the most abundant (42.20 and 33.30%). The quartz rate was lower than the mid-slope rate. At this topographic position, hematite and

martite were observed only in the 500µm meshes. The proportion of hematite was higher at this low-level than at the middle-level with percentages of 28.49 and 33.33% observed in E1BV and E2BV, respectively. On the other hand, martite abundance was almost identical to that observed in the middle of the slope with 14.20 and 14.66%.

Finaly, quartz, hematite, and martite (Fig 2) were the three minerals observed in sandy fraction of the soil studied.



A= Quartz, B= martite et C= hematite

Figure 2 Minerals observed in the sandy fraction of the soils studied

Table 1 Mineralogical proportion of the sandy fraction of the soil studied

NT	Samples	Meshes	Minerals observed		
			Quartz (%)	Hematite(%)	Martite(%)
S	E_{1S} (4/7cm-29/33cm)	2mm		-	-
		1mm	15,79		
		500µm	84,21		
	E_{2S} (29/33cm-83/88cm)	2mm			
		1mm	15,25		
		500µm	84,75		
MV	E_{1MV} (17cm-27cm)	2mm			
		1mm	25		10,33
		500µ	50		14,42
	E_{2MV} (58/59cm-108cm)	2mm	34,78		
		1mm	21,75		
		500µm	39,13	4,35	
BV	E_{1BV} (5cm-25cm)	2mm			
		1mm	15,19		
		500µm	42,20	28,49	14,20
	E_{2BV} (>25cm)	2mm			
		1mm	18,68		
		500µm	33,33	33,33	14,66

NT=topographic level, S=summitMV=middle slope BV= bottom slope; E= sample

Total soil mineralogical characteristics

The minerals identified in the total soil were quartz, goethite, muscovite, albite, kaolinite, antigorite and the interstratified montmorillonite/chlorite. These different minerals were observed at different proportions depending on topographic level (Table 2):

- At the summit were quartz (91.10%), muscovite (4.7%), kaolinite (2.5%) and antigorite (1.7%). Goethite and albite existed in trace, while montmorillonite/chlorite was absent.
- In the middle of the slope, the same minerals were observed as at the summit except in different proportions. Thus, quartz (86.7%), muscovite (6.4%), kaolinite (3.2%) and antigorite (3.7%) were present.
- At the bottom of the slope, all minerals were present. Quartz, muscovite, kaolinite and antigorite were estimated at 65.5; 10.7; 7.5 and 6.3 %. Goethite, albite, and montmorillonite/chlorite, which were trace or absent at the summit and bottom of the slope, were bserved at proportions of 2, 3.2 and 4.8%.

Table 2 Total soil mineralogical composition

Topographic Levels	Mineralogical Composition (%)						
	Qtz	Goet	Musc	Alb	Kao	Ant	Mon-Chl
Summit	91.10	Trace	4.7	Trace	2.5	1.7	0
Midle of slope	86.7	Trace	6.4	Trace	3.2	3.7	0
Slope bottom	65.5	2.00	10.7	3.2	7.5	6.3	4.8

Goet=goethite, Musc=muscovite, Alb=albite, Kao=kaolinite, Ant=antigorite, Mon-Chl=montmorillonite/chlorite, Qtz=quartz

It is easy to understand that these soils contained oxides (quartz, goethite), primary minerals (muscovite, albite) and clay minerals (kaolinite, antigorite, montmorillonite/chlorite) as presented in Figure 3. On this figure, at the summit of the hill, clay minerals represented 4% of the mineralogical composition and were dominated mainly by kaolinite and antigorite. The primary minerals identified were estimated at 5% of the total mineralogical composition and were dominated by muscovite at more than 73%. Oxides, estimated at 91% of the total mineralogical composition, were almost completely dominated by quartz (Fig 3a). In the middle of the slope, clay minerals accounted for 7% of the overall mineralogical composition and were dominated by kaolinite.

Primary minerals, representing 6% of the total mineralogical composition, consisted mainly of muscovite with traces of albite. Oxides, estimated at 87% of total soil mineralogy with traces of goethite, were strongly dominated by quartz (Fig 3b). At the bottom slope, 19% of the composition overall mineralogy consisted of clay minerals, of which kaolinite alone accounted for more than 40%. However, an important point is to be made regarding the increase in the proportions of antigorite (33%) and montmorillonite/chlorite interstratified (27%). Primary minerals accounted for 14% of the total mineralogical composition. Although dominated by muscovite at over 82%, these primary minerals had at this bottom more than 3% of albite. For oxides, they accounted for 67.5% of total soil mineralogy and were dominated by quartz at over 97% plus goethite (Fig 3c).

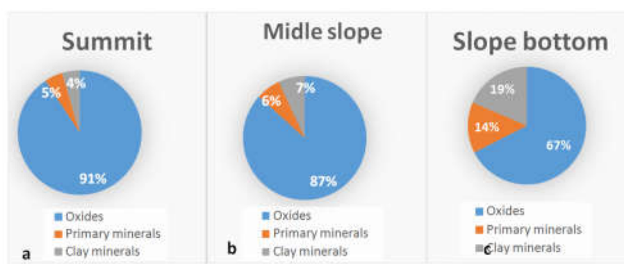


Figure 3 Proportion of oxides, primary minerals and clay minerals by topographic level

Evolution of mineralogy from total top to bottom soil

Following a vertical observation, Figure 4 provides an understanding of the dynamics of the various minerals from the summit to the bottom of the slope. In this figure, except for quartz, which decreased from summit to bottom (37.4-35.6 and 27%), all other minerals had higher levels from summit to bottom. Albite and goethite, absent at the summit and middle of the slope, were only found at the bottom of the slope.

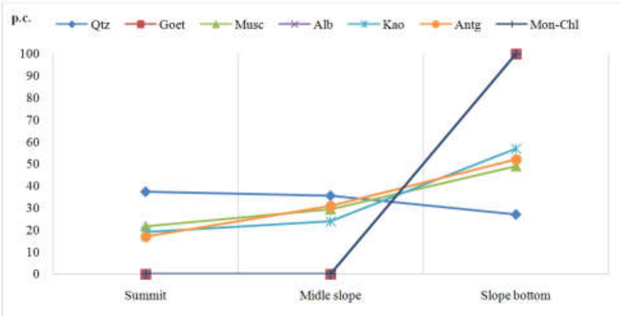


Figure 4 Dynamics of total soil minerals along the toposequence

Goet=goethite, Musc=muscovite, Alb=albite, Kao=kaolinite, Ant=antigorite, Mon-Chl=montmorillonite/chlorite, Qtz=quartz

Mineralogical characteristics of the clay fraction

Minerals observed in the clay fraction have different behaviors compared to treatments performed (Table 3):

- ***Kaolinite:*** plans (001), (002) and (003) were represented respectively by raies 7.2Å; 3.6Å and 2.4Å from normal to glycol treatment. All of these raies disappeared at 600°C heating, and the presence of raies7.2Å; 3.6Åand 2.4Å confirmed the presence of Kaolinite.
- ***Illite/vermiculite:*** In the sections (002), the raies 5Å not varied from differents treatments. While the raies of the other different sections were decreasing. The presence of the Illite was confirmed by the raies5Å. At the plans (001) of the treatments, the values were reduced to 10Å. This reflected the non-swelling and consolidation of the mineral in raie 10Å, characterizing the vermiculite K+. The mineral should therefore an interstratified Illite/vermiculite.
- ***Chlorite/smectitee:*** In the natural state and heating, the values of the plans (001), (002), (003) and (004) were respectively represented by the raies of 14Å, 7Å and 3.5Å. When treated with glycol, the plan (001) took the values 14-15Å and the plan (003) took a raie of 4.8Å. This increasing in the value of these raies may be due to the presence of inflating clay (smectite). In sections (001), raie 14Å (normal) and section (004), raie 3.5Å (heating) characterize chlorite. There was therefore an interstratified mineral: chlorite/smectite.
- ***Smectite:*** The plans (001), (002), (003) and (004), at natural state, are represented respectively by the raies 15Å, 7.5Å and 3.8Å. When treated with glycol, the sections (001), (003) and (004) respectively took the values 7Å, 6.1Å and 4Å. When glycol was added, there was an increasing in values that could result in the presence of inflating clay. At heating, the values of these raies decreased, so this were the smectite characterized by theraie 10Å.
- ***Chlorite:*** This mineral presented, respectively, according to sections (001), (000) and (004), raies 14. 7Å and 2.4Å which remain invariable regardless of the treatment to which the sample was subjected.

Table 3 Summary table of the identification of clay minerals

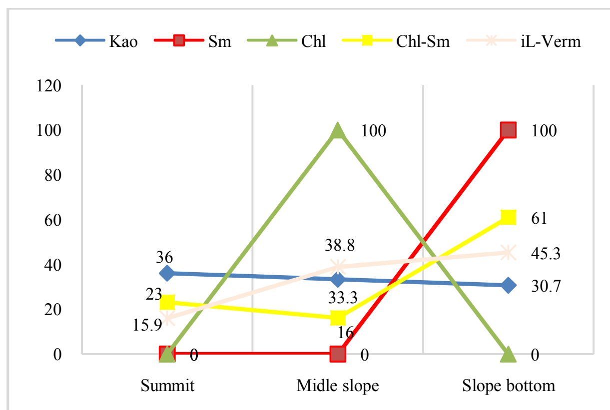
G			
001	**002**	**003**	**004**
28-26	17	8,2	5,3
11-10	5	3,3	
7,2	3,6	2,4	
32-25	17		
14	7		2,4
11-10	5	3,3	
7,2	3,6	2,4	
17		6,1	4,1
14-15		4,8	2,4
12-10	5	3,3	
7,2	3,6	2,4	

N= normal G= glycerol; CH= Heating Ech= samples; ASQ=semiquantitative analysis S=summit; MV=middle slope BV=bottom slope

Mineralogical proportions of clay fraction

Whatever the topographic level, the clay fraction was composed only of clay minerals. It was dominated on average by 87.2% kaolinite and 5.53% interstratified minerals (montmorillonite/smectite and illite/vermiculite).

Although kaolinite was the most abundant clay mineral of these soils, its proportion decreased from summit (35%) to the bottom of slope (30.7%) while interstratified chlorite/smectite (Chl-Sm) and illite/vermicullit (I-V) increased at the bottom of slope. Thus, Chl-Sm levels increased from 23 to 61% and I-V levels from 15.9 to 45.3%. Chlorite and pure smectite were observed only in the middle and low slope (Fig 5).



Kao=kaolinite, Sm=smectite, Chl=chlorite, Chl-Sm=chlorite/smectite, iL-Verm=illite/vermiculite

Figure 5 Evolution of the minerals of the clay fraction from summit to bottom

DISCUSSION

Mineralogical occurrences

A large mineralogical difference was observed in the different soil fractions. The sandy fraction of the soil contained quartz, martites and hematite. The total soil presented in addition to these oxides, primary minerals and clay minerals. But the clay fraction of the soil contains only clay minerals. This clay fraction of the soil didn't have quartz; this indicates that quartz observed in total soil was derived only from the sandy and limonous fractions of the soils studied. In fact, it was this high presence of quartz in the sandy fraction of the soil that explained the high proportion of oxides expressed in total soil. Such an observation could be made in the Saharan shale regions in the formation of fech-fech. In these formations, while quartz content increased with particle size in some cases, in others, if the maximum quartz content was in the limonous fraction, the clay fraction was less well filled according to Coudé-Gaussen (1991). This segregation in the distribution of quartz in soil were also shown by Rousset (2002).

Minerals and soil evolution

In both clay and total soil, kaolinitewas the most abundant clay mineral with a content of at least 80%. However, the high presence of quartz (>60%) in total soil and the low proportion of other oxides and primary minerals (<15%) suggest with Nehlig and Egal (2010) that the soils consist of a mineral portion that contained mostly siliceous and clay minerals. The presence of quartz and muscovite, which are unalterable minerals on the one hand, and kaolinite and some oxides on the other hand, leads to the conclusion that the soils of INTA, in Azaguié, are very advanced soils. This idea of an advanced stage of soil evolution was also supported by the presence of martites and hematite in the sandy fraction of the soil. Since, martites is an altered form of limonite while Hematite is the ultimate form of the evolution of iron oxides in the soil after a moment of intense sunlight (Yoboué *et al.*, 2014). The presence of kaolinite as the dominant clay mineral suggests that the dominant geochemistry process in these soils were monosiallitization and was acidic and low in exchangeable cation. In addition, the presence of interstratified illite/vermiculite and chlorite/smectite reflected the idea of the bisiallitic alteration process. The formation of these interstratified mineralswas believed to be due to the transformation of the feldspars by losing silica and cations to the formation of clay minerals of 2/1 type, as demonstrated by Ben Hassine (2006) and Yoboué (2010). The presence of the interstratified and the few primary minerals (albite) identified indicated a soil that should still in full evolution or influenced by the presence of the geological parent rock that would continue to supply its minerals to the soil, although it was already at a fairly advanced stage of evolution. This means in a soil, next to the most dominant geochemical process, there would still be other processes of lesser importance. Given the preferential clay texture of the soils according to Allou (2017) and the high level of the soil in kaolinic clay (>80%), the soils of INTA, in Azaguié, can be defined as belonging to the mineralogical class of the kaolinic type.

On the other hand, at the dynamic level, iron oxides, such as martite and hematite, observed in the sandy fraction of the soil were only in topographic positions of middle and bottom slopes. This dynamism would not be due to sedimentation of the sandy fraction of the soil observed at the above levels, but rather to chemical action linked to seasonal variations. Indeed, this presence of iron in this topographic position is the result of the migration of iron in its ironII form from the highest (summit) levels to the lowest (bottom) levels during rainy seasons and the immobility of its ironIII shape during dry periods. This dynamic of elements was also demonstrated by Yoboué *et al.* (2018) on brunified soils of Toumodi. This iron movement in the soil is therefore influenced not only by climate, but also by topography (Fox *et al*., 2008). In fact, the influence of topography in this dynamism is also shown in the total soil by increasing the levels of all minerals in the bottom soil.

The monosiallitic nature of the soils and its kaolinic class, as well as the dynamics of the different minerals, show that the soils of the INTA site were characterized by mineralogical variability that reflects their level of evolution.

CONCLUSION

Soils at INTA site, in Azaguié, had mineralogical variability in relation to the soil fraction considered. The sandy fraction contains quartz, martites and hematite. Total soil is rich in quartz, 1/1 clay minerals of Kaolinite and antigorite type, interstratified and primary minerals. The clay fraction, consisting only of clay minerals, is dominated by kaolinite. The presence of these minerals, and their different meanings in soil development, imply that the studied soils was highly evolved, probably acidic and whose development would require a lot of attention.

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