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Genesis and classification of soils developed on gabbro in the high reliefs of Maroua region, North Cameroon

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Abstract

The purpose of this work was to examine the genesis, properties and classification of soils resulting from the weathering of gabbro rock in the high reliefs of Maroua in the Far North Region of Cameroon. The studied soils were ~ 2 m thick, made of four horizons which consisted of coarse saprolite, fine saprolite, loose loamy clayey horizon and humiferous horizon. From petrographical view point, at the bottom of the soil profile, the preservation of the bedrock structure was marked by numerous remnants of altered plagioclases shapes. The groundmass was characterized by a double spaced fine, ranging to equal, enaulic c/f related distribution pattern. It was yellowish, characterized by weakly separated granular microstructure in the fine saprolite and had a speckled and cloudy limpidity in the loose loamy clayey horizon. Secondary minerals consisted of montmorilonite, kaolinite, goethite, quartz, gibbsite, lepidocrocite, sepiolite, feldspar and calcite. Globally, Si/Al ratio ranged between 2.85 and 3.24. The chemical index of alteration ranged from 50.95 to 55.27 % while the mineralogical index of alteration values were between 1.90 and 10.54 %. Physicochemically, soil pH varied from slightly acidic to slightly above neutral. Soil organic carbon contents were low to very low. Exchangeable bases contents were high, mostly represented by Ca^{2+} and Mg^{2+}. The CEC of soils and the CEC of clay were also high, ranging respectively between 53.68 and 82.88 $cmol(+).kg^{-1}$, and 116.80 and 181.38 $cmol(+).kg^{-1}$. The studied soils were classified as dystric haplustepts clayey isohyperthermic. They were developed *in situ* by the collapse of primary mineral structures from the bottom of the coarse saprolite, due to leaching as a result of bisiallitisation and monosiallitisation. This is accompanied by a progressive ferruginization of materials, confirmed by the densification under the microscope of goethitic brown veil from the base to the loamy clay horizon and the increase in iron contents from the bedrock to the humiferous surface horizon.

Keywords: Genesis, classification, soils, gabbro, Maroua, Cameroon.

Introduction

Parent material and geomorphologic processes have long been recognized as key soil-forming factors, particularly at the regional level (Bockheim et al., 2005; Badía, et al., 2013). Slope-dependent pedogenic processes play an essential role in increasing the diversity of soil cover in the mountainous tropics and subtropics (Gracheva, 2011; Badía, et al., 2013). In semiarid environments, geomorphic processes such as erosion may overprint climate and lithological signatures differing from those in more humid environments

(Driessen et al., 2001; Badía, et al., 2013). The loss of soil from land surfaces by erosion is widespread globally and adversely affects the productivity of all natural ecosystems as well as agricultural (Lal and Stewart, 1990; Pimentel, 1993; Pimentel et al., 1995; Pimentel and Kounang, 1998; Pimentel, 2006). The impact of soil erosion is intensified on sloping land, where often more than half of the surface soil is carried away as the water splashes downhill into valleys and waterways (Pimentel, 2006). This leaves the soil barren and fully exposed to rain and wind forces of erosion (Pimentel, 2006). The phenomenon is especially widespread in developing countries where populations are large, and agricultural practices are often inadequate to protect topsoils. One of the major factors limiting optimum crop production in the tropics is the lack of detailed information on soil and land characteristics. In Cameroon, the Far North Region is the most populated area of the country. It differs from the rest of the other regions mainly by its sudano-sahelian climate, its landscape globally flat with high reliefs here and there, and a large volcanic massive, the Mandara massive, who from its about 1450 m a.s.l., overlooks a vast peneplain whose altitude ranges between 300 and 400 m. All lands are cultivated, and today there is a generalized decline in soil fertility (Tsozué et al., 2014; 2015). This led people to cultivate up to the mountainous spaces around Maroua, spaces reserved exclusively for cattle rearing in the past. This agriculture is practiced on soils whose characteristics are badly known. The purpose of this work is to examine the genesis, properties and classification of soils resulting from weathering of gabbro rock in the high reliefs of Maroua region.

Material and Methods

Study site

The study was conducted in Maroua, in the Far North Region of Cameroon (10°35'00''-10°40'30'' N and 14°16'04''-14°21'34'' E) (Figure 1). The climate is Sudano-Sahelian, characterized by a mean annual rainfall of 757.2 mm and mean annual air temperature of about 28.53°C. The aridity index of De Martonne (1926) shows a dry season from November to May (I < 20) and a raining season from June to September (I > 20). The rains are concentrated in the two humid months of the year July and august (I > 50). The relief is mountainous, characterized globally by gentle to steep slopes. The vegetation is mostly composed of grasses, but highly cultivated, event steep slopes where fine earth can exist between blocks of gabbro. The main human activities in the region are agriculture and breeding.
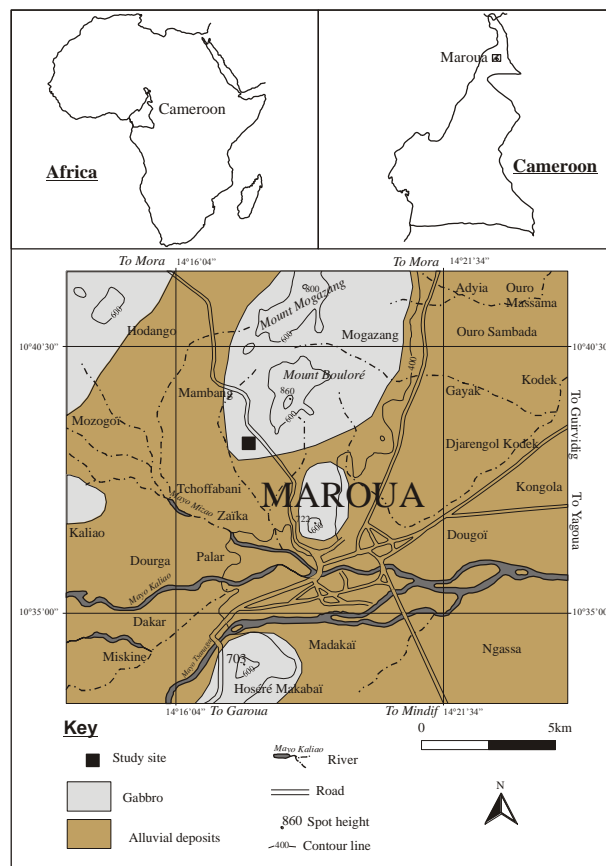

Figure 1. Location of the study site

Methods

Based on several soil surveys conducted up to date, supported by a reconnaissance of the studied area, about fifteen soil profiles representative of the area were studied through boreholes. The most representative profile was selected on gabbro and described in detail. Soil samples and fresh rocks were collected at different depths for analyses. Soil thin sections were described following the guideline of Stoops (2003). Soil mineralogy was determined by X-ray diffraction on total soil powder and minerals were identified using XRD coupled with standard saturation (K), solvation (ethylene glycol), and heat (550 °C) treatments (USDA, 2004). For geochemical analyses, the package uses the whole rock package by combustion furnace to quantify the major elements in the sample by ICP-AES finish. The chemical index of alteration (CIA) corresponds to $[Al_2O_3/(Al_2O_3+CaO^*+Na_2O+K_2O)]$ x 100, where CaO* is the amount of CaO incorporated in the silicate fraction of fresh rock while Na_2O, K_2O and Al_2O_3 are their concentrations in the analyzed soil samples (Nesbitt and Young, 1982). The mineralogical index of alteration (MIA) was [2.(CIA-50)] (Voicu et al., 1996). The sesquioxide content (SOC) was the Fe_2O_3 and Al_2O_3 content in a sample which are insoluble oxides (Irfan, 1996). For soil texture analysis, soil organic matter and carbonates were removed with hydrogen peroxide and diluted hydrochloric acid, respectively. Then, soil samples were dispersed with sodium hexametaphosphate and particle size distribution was analysed by the pipette method. Soil pH was measured potentiometrically in a 1:2.5 soil : solution ratio. Exchangeable bases and cation exchange capacity (CEC) were determined using atomic absorption spectrophotometry in a solution of ammonium acetate at pH 7. Total nitrogen was obtained after heat treatment of each sample in a mixture of concentrated sulfuric acid and salicylic acid. Organic carbon (OC) was determined by the Walkley–Black method (Walkley and Black, 1934). Soil organic matter (OM) content was obtained by multiplying soil organic carbon content by 1.724 (Walkley and Black, 1934). Available phosphorus was determined by Bray-2 method (Bray and Kurtz, 1945). The mean annual soil temperature (MAST) was calculated according to the following equation: MAST= 6.84 + (0.925*MAAT) - (0.0031*Precipitations) (Bai, 2009). In this equation, MAAT is the mean annual air temperature. The studied soils were classified according to Soil Survey Staff (2010).

Results

Morphological, mineralogical and geochemical characteristics of soils

The studied soil profile was ~ 2 m thick. Four main horizons were distinguished from the bedrock to the surface: a coarse saprolite, a fine saprolite, a loose loamy clayey horizon and a humiferous horizon. The parent soil material was a gabbro. It was dark, massive, characterized by white slight linings and the absence of any observable mineral. Under polarizing microscope, all primary minerals were slightly weathering. The main minerals were plagioclase, green amphibole, biotite and calcite. From the geochemical view point, SiO_2 was the main oxides (48.90%), followed by Al_2O_3 (16.95%), Fe_2O_3 (10.55%), CaO (9.55%), MgO (6.87%) and Na_2O; the others were in smaller quantities (Table 1). The boundary was regular and gradual.

Coarse saprolite (200-75 cm). The coarse saprolite was yellowish (10YR 7/8), compact, massive, with many fissures surrounding compact undifferentiated blocks. The original structure of the bedrock was preserved. Under the microscope, all the primary minerals had disappeared, and the preservation of the bedrock structure was marked by numerous remnants of altered plagioclases shape (Figure 2A). The groundmass was characterized by a double spaced fine, ranging from equal to enaulic c/f-related distribution pattern. It showed a yellowish red birefringent micromass. The main secondary minerals were montmorilonite, kaolinite, goethite, associated to small amount of quartz, gibbsite, lepidocrocite, sepiolite, feldspar, calcite (Figure 3 and Table 1). From the geochemical view point, SiO_2 was the most represented oxide (53.90-53.10 %). It was followed by Al_2O_3 (15.00-14.70 %), Fe_2O_3 (10.75-10.90 %), Na_2O (4.11-4.33 %), CaO (1.02-2.06 %) and MgO (1.76-2.06 %) (Table 1). Globally, there was an increase in SiO_2 and Na_2O contents, and a decrease in CaO and MgO contents (Table 1). The boundary was regular and gradual.

Fine saprolite (75-30 cm). The fine saprolite was reddish yellow (7.5YR 6/8), loamy and massive. There were many fissures surrounding small gray compact blocks, globally embedded in loose loamy texture matrix. The structure of the bedrock was preserved only in gray compact blocks. Under the microscope, remnants of altered plagioclases shape had almost disappeared. The groundmass was yellowish, characterized by weakly separated granular microstructure (Figure 2B). The main secondary minerals were montmorilonite, kaolinite, goethite, associated to small amount of quartz, gibbsite, lepidocrocite, sepiolite, quartz, feldspar, calcite (Figure 3 and Table 1). From the geochemical view point, SiO_2 remained the dominant oxide (52.10%), followed by Al_2O_3 (15.55 %), Fe_2O_3 (11.20%), Na_2O (4.76 %) and CaO (3.23 %) (Table 1). The boundary was regular and gradual.
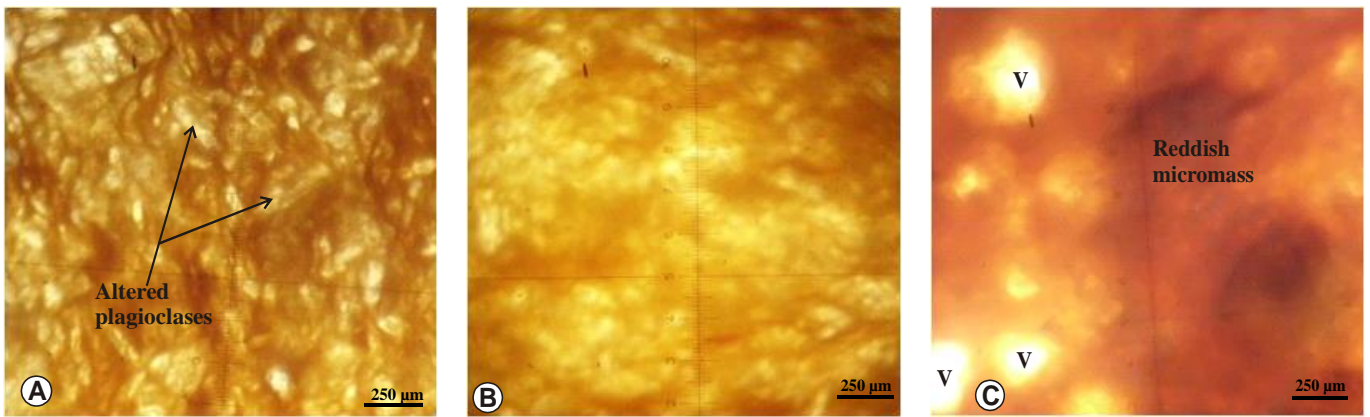
Figure 2. Microscopic organization of the studied soils
(A: Coarse saprolite LN ; B : Fine saprolite LN; C: Loose loamy clayey horizon LN)
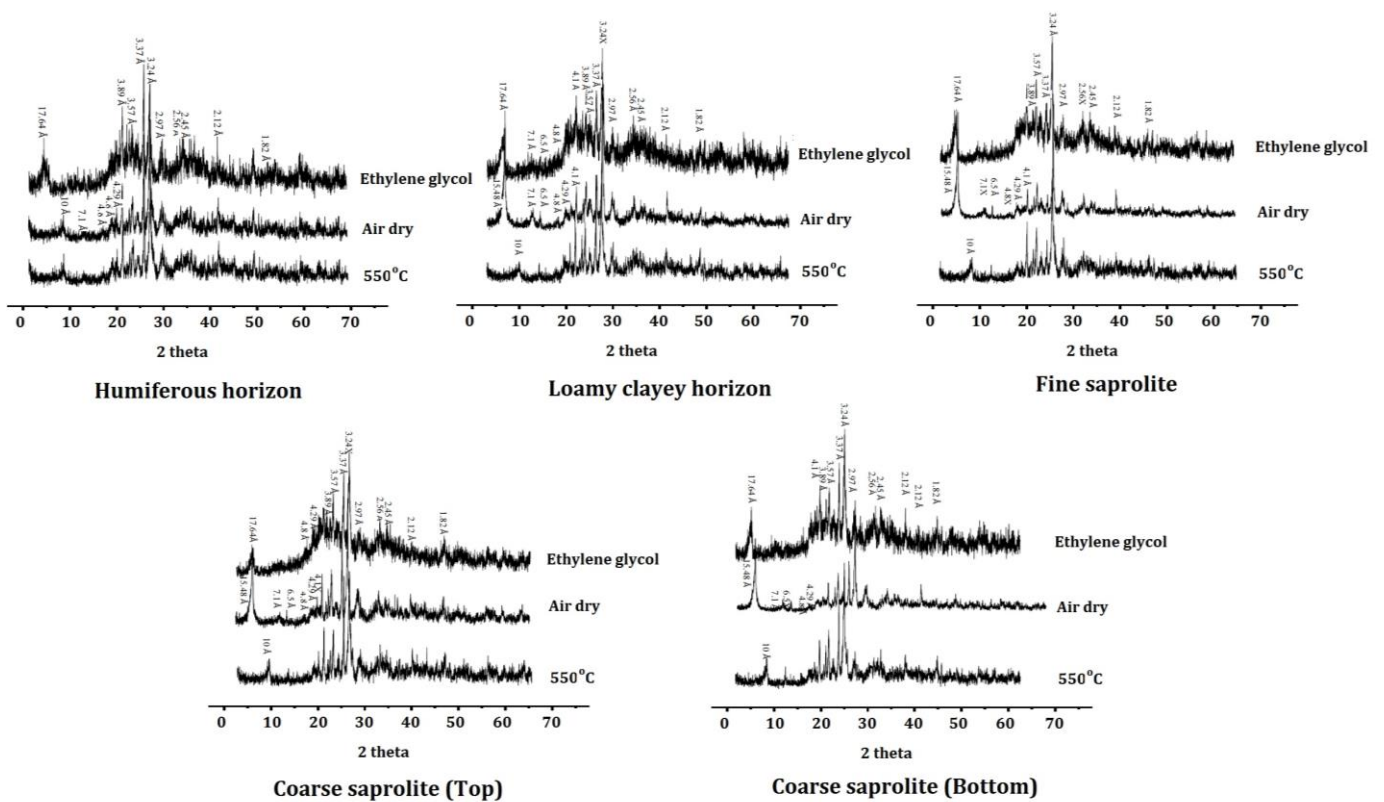

Figure 3. XRD patterns of different horizons for the study soil

Loose loamy clayey horizon (30-7 cm). The horizon was reddish yellow (5YR 6/8), loose and loamy clayey. It was weakly blocky to massive, characterized by high matrix porosity and the presence of many rootlets. Under the microscope, remnants of altered plagioclases shape were not visible. The groundmass had a vughy microstructure and reddish micromass (Figure 2C). It had a speckled and cloudy limpidity (Figure 2C). The mineralogical composition was similar to that of saprolite, largely dominated by montmorillonite (Figure 3 and Table 1). From geochemical view point, compared to the coarse and fine saprolite, all the major oxides contents showed very little variation and remained largely dominated by SiO_2 (Table 1). The boundary was regular and gradual.

Table 1. Major elements contents (wt.%) and mineralogy of the studied soils.

Horizons		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI	Total	Si/Al	CIA	MIA	SOC	Mineralogy
Humiferous horizon		50.80	15.90	11.85	5.12	1.76	3.02	0.30	1.20	0.27	0.10	10.30	100.62	2.86	55.27	10.54	27.75	M K G Q F Gi C L S
Loamy clayey horizon		51.60	16.25	11.80	3.02	1.68	3.55	0.24	1.23	0.31	0.08	11.50	101.26	2.85	54.92	9.84	28.05	M K G Q F Gi C L S
Fine saprolite		52.10	15.55	11.20	3.23	1.78	4.76	0.31	1.20	0.24	0.21	10.10	100.68	3.00	51.54	3.08	26.75	M K G Q F Gi C L S
Coarse saprolite	Top	53.10	14.70	10.90	4.22	1.76	4.33	0.27	1.14	0.23	0.28	8.88	99.81	3.24	50.95	1.90	25.60	M K G Q F Gi C L S
	Bottom	53.90	15.00	10.75	1.02	2.06	4.11	0.46	1.06	0.22	0.22	9.05	100.85	3.22	51.51	2.2	25.75	M K G Q F Gi C L S
Gabbro		48.90	16.95	10.55	9.55	6.87	2.50	1.17	1.15	0.17	0.20	3.38	101.39	2.59	56.18	12.36	27.50	A F B C

M= montmorillonite: 10Å, 15.48Å, 17.64Å; K= kaolinite: 7.1Å, 3.57Å; G= goethite: 4.1Å, 2.45 Å; Gi= gibbsite: 4.8 Å, 2.39 Å; L= lepidocrocite: 6.5Å, 2.97Å; S= sepiolite: 4.29Å, 2.56Å; Q= quartz: 4.29Å, 3.37Å, 2.12Å, 1.82Å; F= feldspath: 3.24; C= calcite: 3.89Å; B: biotite; A: amphibole.

Table 2. Physicochemical characteristics of the studied soils.

Horizons	Sand (%)	Silt (%)	Clay (%)	pH_{water}	pH_{KCl}	OC (%)	OM (%)	N (%)	C/N	Ca	Mg	K	Na	S	CEC	CEC_{Clay}	$\frac{S}{CEC}X100$ (%)	P_2O_5 (mg/kg)
										Cmol(+).kg⁻¹								
HH	19.00	36.00	45.00	5.90	5.20	0.65	1.13	0.11	6.15	14.56	3.28	0.78	0.65	29.27	53.68	116.80	54.53	8.77
LCH	39.00	16.00	45.00	6.20	4.80	0.73	1.25	0.09	7.70	21.52	4.48	0.42	1.09	27.51	82.88	181.38	33.19	10.31
FS	29.00	24.00	47.00	7.50	6.00	0.55	0.94	0.10	5.73	35.28	7.64	0.42	0.87	44.21	73.52	154.41	60.13	33.02
CS	39.00	16.00	45.00	6.80	5.00	0.36	0.63	0.07	5.09	26.32	9.48	0.42	0.87	37.09	60.72	133.55	61.08	61.01
Minimum	19.00	16.00	45.00	5.90	4.80	0.36	0.63	0.07	5.09	14.56	3.28	0.42	0.65	27.51	53.68	116.80	33.19	8.77
Maximum	39.00	36.00	47.00	7.50	6.00	0.73	1.25	0.11	7.70	35.28	9.48	0.78	1.09	44.21	82.88	181.38	61.08	61.01
Mean	31.50	23.00	45.50	6.60	5.25	0.573	0.988	0.093	6.168	24.420	6.220	0.510	0.870	34.52	67.700	146.535	52.23	28.278
CV (%)	26.30	35.60	1.90	9.30	8.70	24.20	23.70	16.00	15.60	30.90	39.60	30.60	17.90	19.30	16.70	16.50	21.60	75.00

HH: Humiferous horizon   LCH: Loamy clayey horizon   FS: Fine saprolite   SP: Coarse saprolite (Top)   CV: Coefficient of variation

Humiferous horizon 7-0 cm. The humiferous horizon was yellowish red (5YR 5/8), loamy clayey, characterized by weakly expressed lumpy structure, high matrix porosity and the presence of many rootlets. The mineralogical composition was similar to that of the horizons below, largely dominated by montmorillonite (Figure 3 and Table 1). From geochemical view point, compared to the below horizons, all the major oxides contents showed very little variation and remained largely dominated by SiO_2 (Table 1). This oxide was followed by Al_2O_3, Fe_2O_3, CaO, Na_2O and MgO as the well represented oxides (Table 1).

Globally, Si/Al ratio was high, ranging between 2.85 and 3.24 (Table 1). The chemical index of alteration (CIA) ranged from 50.95 to 55.27 % while the mineralogical index of alteration (MIA) values obtained in the studied soil were between 1.90 and 10.54 %. The sesquioxide content (SOC) values varied little, ranging between 25.60 and 28.05 % (Table 1). A representation in the triangular diagram SiO_2-Al_2O_3-Fe_2O_3 showed that all sample were localized on SiO_2-Al_2O_3 axis (Figure 4), toward SiO_2 pole in line with high Si/Al ratio. This is indicative of an excess of SiO_2 in the studied soils and confirmed the presence of 2:1 phyllosilicates of montmorillonite type.
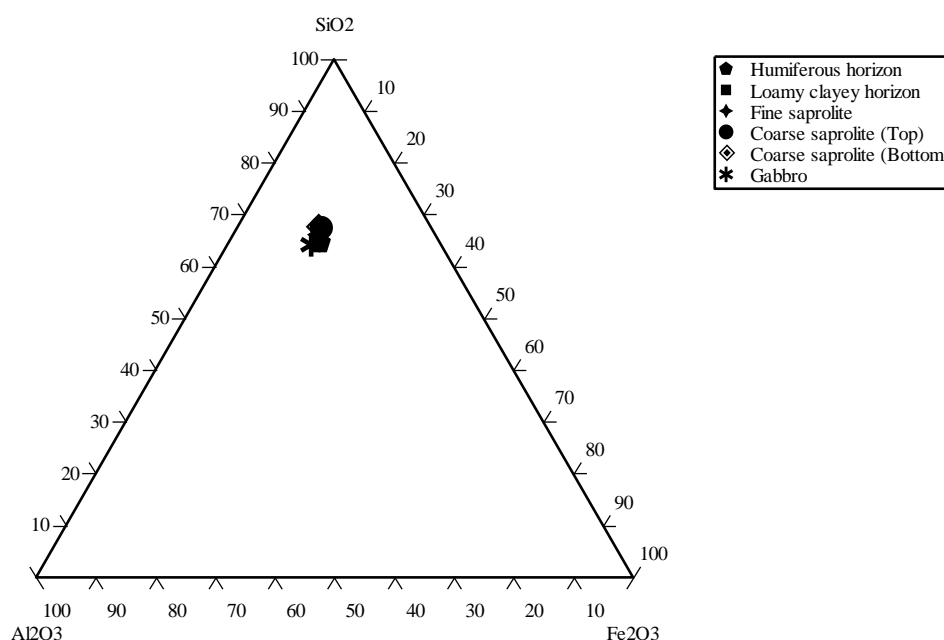

Figure 4. Geochemical composition of the studied soils in SiO_2-Al_2O_3-Fe_2O_3 diagram

Physicochemical characteristics of soils

The studied soil profile contained more than 45% clay fraction (Table 2). Sand content ranged from 19% to 39%, silt content from 16% to 36% and clay from 45% to 47%, corresponding respectively to mean values of 31.50%, 23% and 45.50%. Clay contents are not varied (CV< 15%). Sand contents on the contrary vary moderately (15% <CV< 35%) while those of silts are highly varied (CV> 35%). There is a negative significant correlation between silt and sand (r=-0.99, p<0.05) (Table 3). pH values vary slightly along the profile (CV< 15%). They ranged from slightly acidic (5.90) in the humiferous horizon to slightly above neutral (7.50) in the fine saprolite. pH_{KCl} values are below those of pH_{Water} in all horizons. A significant positive correlation is noted between pH_{Water} and Ca^{2+} (r=0.987, p< 0.05), sum of bases (S) (r=.96, p<0.05). Organic carbon (OC) contents are low to very low, ranging from 0.36 in the lower horizon to 0.65-0.73% in the upper part of the profile. Similarly, nitrogen contents are low to very low. C/N ratios are globally low, < 10. There is a significant negative correlation between OC and P_2O_5 (r=-0.97, p< 0.05) and a negative significant correlation between base saturation and C/N (r=-0.97, p<0.05). Exchangeable bases contents are high, mostly represented by Ca^{2+} and Mg^{2+}, whose contents vary from 14.6 to 35.28 cmol(+).kg^{-1} and from 3.28 to 9.48 cmol(+).kg^{-1} corresponding to mean values of 24.42 and 6.22 cmol(+).kg^{-1} respectively (Table 2). The Cation exchange capacity is high, ranging between 53.68 and 82.88 cmol(+).kg^{-1}, corresponding to a mean value of 67.70 cmol(+).kg^{-1}. The CEC$_{clay}$ is also high, ranging between 116.80 and 181.38 cmol(+).kg^{-1}, values in line with the predominance of montmorillonite in the studied soils and the high Si/Al ratios which range between 2.85 and 3.24 (Table 2). Available phosphorus contents are low in humiferous surface horizon (8.77 mg/kg), but increase with depth, reaching 61.01mg/kg in the coarse saprolite at the bottom of the soil profile.

Table 3. Pearson correlation matrix for linear relationships between selected soil parameters of the studied site.

Variables	Sand	Silt	Clay	pH$_{Water}$	pH$_{KCl}$	OC	OM	N	C/N	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$	S	CEC	CEC$_{Clay}$	$\frac{S}{CEC}$X100	P$_2$O$_5$
Sand	1																	
Silt	-0.995*	1																
Clay	-0.174	0.071	1															
pH$_{Water}$	0.246	-0.339	0.849	1														
pH$_{KCl}$	-0.430	0.335	0.951*	0.753	1													
OC	-0.289	0.303	-0.094	-0.531	-0.153	1												
OM	-0.306	0.322	-0.117	-0.556	-0.168	0.999*	1											
N	-0.866	0.847	0.293	-0.248	0.427	0.682	0.688	1										
C/N	0.148	-0.122	-0.263	-0.514	-0.426	0.900	0.894	0.296	1									
Ca^{2+}	0.354	-0.447	0.832	0.987*	0.690	-0.448	-0.476	-0.284	-0.382	1								
Mg^{2+}	0.545	-0.588	0.333	0.776	0.263	-0.900	-0.913	-0.753	-0.711	0.749	1							
K$^+$	-0.870	0.917	-0.333	-0.660	-0.063	0.324	0.351	0.683	-0.011	-0.755	-0.688	1						
Na$^+$	0.853	-0.864	0.000	0.173	-0.310	0.205	0.181	-0.478	0.570	0.327	0.172	-0.816	1					
S	0.037	-0.126	0.841	0.964*	0.828	-0.618	-0.636	-0.151	-0.690	0.908	0.758	-0.455	-0.093	1				
CEC	0.594	-0.633	0.298	0.274	-0.001	0.426	0.398	-0.124	0.656	0.424	0.003	-0.717	0.915	0.019	1			
CEC$_{Clay}$	0.645	-0.673	0.188	0.192	-0.115	0.432	0.406	-0.180	0.694	0.348	-0.018	-0.711	0.946	-0.070	0.993*	1		
$\frac{S}{CEC}$X100	-0.334	0.296	0.404	0.539	0.592	-0.782	-0.777	-0.078	-0.973*	0.398	0.597	0.118	-0.669	0.735	-0.662	-0.721	1	
P$_2$O$_5$	0.487	-0.507	0.129	0.610	0.115	-0.973*	-0.978*	-0.795	-0.791	0.560	0.967*	-0.531	0.026	0.635	-0.209	-0.212	0.653	1

* Significant at p<0.05

Soil classification

The studied soil profile has ∼ 2 m thick, with a B horizon more than 15 cm thick (23 cm). It is characterized by weakly blocky to massive structure, loamy clayey texture, high chroma, high value and redder hue (5YR 6/8), characteristic of a cambic horizon. There is globally high supply of bases in the soil profile (S > 27.09 cmol(+).kg^{-1}), with base saturation greater than 33.19%. The cambic horizon is within 100 cm of the mineral soil surface and has a lower boundary at a depth of ∼25 cm below the mineral soil surface. These characteristics are those of inceptisols. These soils experienced drought for more than 90 cumulative days but less than 180 days according to the aridity index of de Martone (1926), characteristic of ustic moisture regime. This permitted their classification in ustepts suborder. Since the studied soils do not have any particular character, they belong to haplustepts great group. The studied soils have a base saturation (by sum of cations) of less than 60% in the humiferous horizon and the loamy clayey horizon. This permits them to be classified in the dystric haplustepts subgroup. The texture was clayey and the mean annual soil temperature was higher than 22°C, leading to the classification of the soil in the clayey isohyperthermic family. The studied soil is thus a dystric haplustepts clayey isohyperthermic.

Discussion

In the sudano-sahelian zone of North Cameroon, weathering of gabbro lead to the differentiation of thin (∼2m) soils classified as dystric haplustepts clayey isohyperthermic according to Soil Survey Staff (2010). They are mainly composed of montmorillonite, associated to kaolinite, goethite and in lesser quantity quartz, feldspar, gibbsite, calcite, lepidocrocite and sepiolite. Compact undifferentiated weathered blocks with the preservation of the original structure of the bedrock observed in the saprolite and the presence of numerous remnants of weathered plagioclases shape observed under the microscope, characterize an *in situ* weathering of the parent materials (Costantini and Priori, 2007). Soil pH values ranging from 5.90 to 7.50 indicate that hydrolysis is the dominant weathering process implicated in the formation of secondary minerals in the studied soils (Pedro, 1966). It occurs through dilute solutions in the pH range 5 - 9.6 and may be total or partial. Total hydrolysis lead to the removal of all elements including silica, and to the precipitation of gibbsite, whereas partial hydrolysis, under different conditions leads to the formation of kaolinite and smectite minerals (Pedro, 1982). The predominance of montmorillonite in the studied soils suggests that the chemical process acting at the bottom of the soil profile in the study area is bisiallitisation (Pedro, 1966). This process is favoured by the following morphoclimatic and hydrological conditions in this bioclimatic zone (Ngounou Gatcha et al., 2005): low rainfall, followed by dry periods that include evaporation, induce soil solutions concentrated in silica and basic cations, leading thus to the formation of smectite clays (Pedro, 1966; Nahon, 1991; Velde, 1995; Paquet and Clauer, 1997; Nguetkam, 2008). This predominance of smectite clays is confirmed by high values of CEC of clay, which range from 116.80 to 181.38 cmol(+).kg^{-1}. In addition to smectites, there are a few amounts of kaolinite, associated with traces of gibbsite. The presence of kaolinite suggests that monosiallitisation is a crystallochemical processes acting at the bottom of profile towards bisiallitisation. The neoformation of kaolinite is generated by the morphoclimatic and hydrological conditions prevailing in the studied area, but which remains dominated by the bisiallitisation process. The decrease in pH values and the Si/Al below 3 in the two upper horizons are consistent with the presence of kaolinite (Nguetkam, 2008). Similar coexistences of kaolinite and montmorillonite have been reported in the literature by many authors (Amouric and Olives, 1998; Meunier, 2003; Nguetkam, 2008). Traces of gibbsite are present in the studied soils. Generally, gibbsite has to be suspected as parent materials that weather to a coarse grained saprolite or C horizon allowing free downward drainage and which contain sufficient aluminium like granite and gneiss or other magmatic and metamorphic rocks (Driessen et al., 2001; Herrmann et al., 2007). This is consistent with the presence of gabbro with green amphibole, biotite and plagioclase. In addition, occurrence of traces of gibbsite might be due to high elevation in the studied area (Tsozué et al., 2011). Sepiolite is present in the studied soils. This fibrous mineral is generally neoformed (Singer, 1979). It is not stable in wet climates and their presence is favoured in soils under dry or semi-dry climates, where the alkaline, silica- and magnesium rich environment favours their formation (Singer, 1984). As palygorskite minerals, another fibrous mineral, sepiolite might also form from the transformation of montmorillonite through a dissolution-process already described by Jones and Galán (1988). The CIA is based on the progressive removal of soluble cations (e.g. Ca, Na, and K) from minerals during chemical weathering and reflects the proportion of primary and secondary minerals in the bulk sample (Ozaytekin and Uzun, 2012; Dengiz et al., 2013; Tunçay and Dengiz, 2016). Its values ranged between 50 and 60. This interval corresponds to little weathered soils (Ozaytekin and Uzun,

2012), in line with their classification in the dystric haplustepts subgroup. The MIA values ranging from 1.90 to 10.54%, also indicates incipient weathering. The studied soil profile is essentially autochthon, developed *in situ* with almost vertical lithodependance of the upper horizons. It is developed by the collapse of primary mineral structures from the bottom of the coarse saprolite, due to leaching as a result of hydrolysis process (bisiallitisation and monosiallitisation). This is accompanied by a progressive ferruginization of materials, confirmed by the presence under the microscope of goethitic brown veil that covers the remnants of weathered plagioclases shape at the base of the profile which is generalized in the loamy clay horizon. The progressive ferrugunization is also confirmed by the increase in iron contents from the bedrock to the humiferous surface horizon.

Conclusion

Soils resulting from weathering of gabbro rock in the high reliefs of Maroua region were investigated and classified as dystric haplustepts clayey isohyperthermic. Four main horizons were distinguished from the bedrock to the surface: a coarse saprolite, a fine saprolite, a loose loamy clayey horizon and a humiferous horizon. They were mainly composed of montmorillonite, associated to kaolinite, goethite and in lesser quantity quartz, feldspar, gibbsite, calcite, lepidocrocite and sepiolite. The studied soils were essentially autochthon, developed *in situ* with almost vertical lithodependance of the upper horizons. They were developed *in situ* by collapse of primary mineral structures from the bottom of the coarse saprolite, due to leaching as a result of bisiallitisation and monosiallitisation processes. This is accompanied by a progressive ferruginization, resulting in the presence under the microscope of goethitic brown veil that covered the remnants of weathered plagioclases shape at the base of the profile and which was generalized in the loamy clay horizon, confirmed by the increase in iron contents from the bedrock to the humiferous surface horizon.

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