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Clay Mineralogy of Various Marginal Soils in Vietnam

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Various marginal soils derived from different parent materials were collected from different landforms and agro–ecological regions in Vietnam and were subjected to clay mineral analysis in addition to particle–size analysis. The result showed that the particle–size distribution of the soils had a close relationship with the landform. The clay content was highest for the soils from the meander floodplain and inland valley, followed by the soil from the hill and lowest for the soils from the mountainous area. The clay mineralogical composition was different among the soils and was found to be controlled by the parent material and soil forming process.

Alluvial–affected gley soils, carbonate black soils, black soils on basaltic tuff, and brownish grey soils in the semi–arid region had the clay mineralogical composition comparable with that of the soils originating from the same parent material or distributed in the same agro–ecological region, as reported in the previous papers (Nguyen and Egashira, 2005, 2007a, 2007b, 2008b). Neo–formation of smectite resulted in its predominance in the clay fraction of black soils on basaltic deposit. Alitization process taking place in humus soils on mountain caused accumulation of aluminum, leading to the high gibbsite content in the clay fraction of the soils. In contrast, podzolization process has removed iron and aluminum outside the profile. As a result, podzols lacked gibbsite and goethite with mica as a predominant clay mineral. Inherent potentiality of the soils was assessed based on the type and amount of clay minerals. The assessment showed a large variability in the inherent potentiality of the soils ranging from the low to high levels.

INTRODUCTION

Vietnam is an agro–based country with a total national land of 331,000 km^2. The country is distributed from north to south with a distance of more than 1,600 km and under different soil–forming conditions. Soils in Vietnam are classified into 13 main soil groups according to the Vietnamese soil classification system, which have been correlated with soil names in the FAO/UNESCO soil classification system and USDA Soil Taxonomy (NISF and DSTPQ, MARD, 2002). Until now, clay mineralogy of soils important from agricultural production and distributed in a large area has been examined by the authors, which are alluvial soils (Nguyen and Egashira, 2005), ferralitic soils (Nguyen and Egashira, 2007b, 2008b), acid sulfate soils and saline soils (Nguyen and Egashira, 2007a), and grey degraded soils and sandy soils (Nguyen and Egashira, 2008a). The clay mineralogical composition of the soils was explained in reference to parent materials and soil forming processes characterized for the respective soils.

In the present study, clay mineralogy was examined for gley soils (swampy soils), black soils, brownish grey soils in the semi–arid region, reddish yellow humus soils on mountain, humus soils on high mountain and podzols. These soils are considered as marginal soils, because they have a limited distribution area and have not much contributed to the regional or national socio–economic development. However, their clay mineralogical study would be useful for clarifying the genetic processes of them and visualizing the general view on the clay mineralogy of soils in Vietnam. The purposes of the present study are: (1) to examine the clay mineralogical composition of these marginal soils; (2) to characterize the clay mineralogical composition of the soils in reference to parent materials and soil forming processes; and (3) to assess inherent potentiality of the soils based on the type and amount of clay minerals.

MATERIALS AND METHODS

Soils

Sampling sites of 8 profiles of the soils used in the study are shown on the map of agro–ecological regions of Vietnam in Fig. 1, and general information on the soil profiles is given in Table 1. All soil samples in the present study were taken in the project of *Surveying and Evaluating Soil Quality to Establish Soil Reference, Database and Information*. Profile VN60 representing alluvial–affected gley soils was selected from the depression in the meander floodplain of the Red River Delta region where land is waterlogged seasonally by surface and underground water. Three profiles representing black soils were taken from the inland valley in the Northwest (VN14), High Plateau Tay Nguyen (VN20) and East of the South (VN57) regions. Locations of profiles VN14 and VN20 are surrounded by the hill/mountain composed of limestone and basalt, and the soils were estimated to originate from the sediments of those rocks, while profile VN57 was considered to be developed on basaltic tuff. Profile VN47 developed on granite was collected from the hill in the Coastal Area of

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Table 1. General information of soil samples

Profile	Location (District, Province)	Landform	Parent material	Soil classification by the Vietnamese system (FAO/UNESCO system)	Vegetation
VN60	Thanhoai, Hatay	Meander floodplain	Alluvium	Alluvial– affected gley soils (Fluvic Gleysols)	Rice
VN14	Maison, Sonla	Inland valley	Limestone sediment	Carbonate black soils (Calcic Luvisols)	Sugarcane
VN20	Krongpach, Daclak	Inland valley	Basaltic sediment	Black soils on basaltic deposit (Gleyic Luvisols)	Rice
VN57	Dinhquan, Dongnai	Inland valley	Basaltic tuff	Black soils on basaltic tuff (Leptic Luvisols)	Maize
VN47	Ninhhai, Ninhthuan	Hill	Granite	Brownish grey soils in the semi–arid region (Chromic Lixisols)	Maize
VN44	Vixuyen, Hagiang	Mountain	Metamorphic rock	Reddish yellow humus soils on mountain (Humic Acrisols)	Forest
VN43	Sapa, Laocai	High mountain	Granite	Humus soils on high mountain (Haplic Alisols)	Forest
VN56	Sinho, Laichau	High mountain	Granite	Podzols (Histic Podzols)	Forest

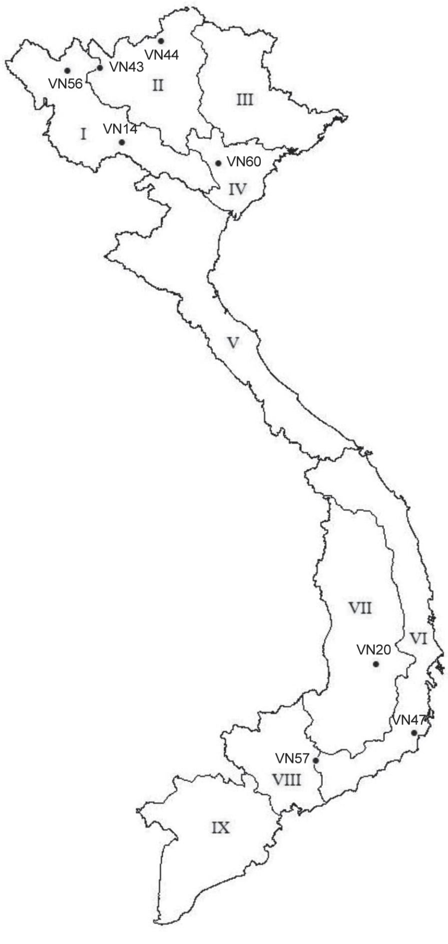

Fig. 1. Soil sampling sites on the map of agro–ecological regions of Vietnam. I. Northwest region; II. Northern region; III. Northeast region; IV. Red River Delta region; V. North of Central region; VI. Coastal Area of Southern Central region; VII. High Plateau Tay Nguyen region; VIII. East of the South region; IX. West of the South region.

Southern Central region and classified as brownish grey soils in the semi–arid region. Three profiles were taken from the mountainous area in the Northern (VN43 and VN44) and Northwest (VN56) regions. Profile VN44 was derived from metamorphic rock and classified as reddish yellow humus soils on mountain; profiles VN43 and VN56 were derived from granite and classified as humus soils on high mountain and podzols, respectively. All the soils have been subjected to production of rice, sugarcane and maize or are covered with forest.

Soil samples were taken vertically with profile depth based on the genetic horizons, air–dried and gently ground to pass through a 2–mm sieve in Hanoi, Vietnam, followed by particle–size and clay mineral analyses in Kyushu University, Japan.

Particle–size analysis

Organic mater was first decomposed by the treatment with hot 7% H_2O_2. After dispersion by the sonic wave treatment and deflocculation by adjustment of the pH of the suspension to 10 by addition of a small amount of 1 M NaOH, the soil suspension was stood in a 1–L sedimention cylinder for a prescribed time followed by siphoning–out of the clay fraction. The sample was then subjected to repetition of sonification–sedimentation–siphoning with intermittent pH adjustment to separate the whole <2 μm clay fraction. The whole 2–20 μm silt fraction was then separated by repeated sedimentation and siphoning, followed by separation of the 20–200 and 200–2,000 μm sand fractions by wet–sieving. After oven–drying at 105 °C, each fraction was weighed to calculate the particle–size distribution of a soil.

Clay mineral analysis

The <2 μm clay fraction wholly separated from the fine soil was used to examine the clay mineralogical composition by the X–ray diffraction (XRD) method. Duplicate clay sols containing 50 mg clay each were taken into 10–mL glass tubes and then washed twice with 8 mL of an equal mixture of 1 M NaCl and 1 M $NaCH_3COO$ (pH 5.0) by centrifugation to lower the pH. Of the duplicate sets, one was saturated with K and the other with Mg by washing 3 times with 8 mL of 1 M KCl and 0.5 M $MgCl_2$, respectively. Excess salt was removed by washing once with 8 mL of water and the clay in the tube was thoroughly suspended with 1 mL of water. An aliquot of 0.4 mL of the clay sol was dropped onto a glass slide (28×48 mm) covering two–thirds of its area, air–dried and X–rayed (parallel powder mount). The XRD analysis was made with the air–dried and glycerol–solvated specimens for the Mg–saturated clay and the air–dried and heated (at 300 °C and 550 °C for 2 h) specimens for the K–saturated clay. The XRD analysis was conducted using a Rigaku diffractometer with Ni–filtered CuKα radiation at 40 kV and 20 mA and at a scanning speed of 2° 2θ min^{-1} with a scanning step of 0.02° and a continuous scanning mode over a rang of 3 to 30° 2θ.

Relative mineral contents in the clay fraction were semi–quantitatively estimated on the basis of the XRD peak intensities. In the present estimation, the peak height was used as the peak intensity by assuming the relative proportions of the minerals of a sample normalized to 100% and the same proportionality between the peak intensity and the content for each mineral.

RESULTS AND DISCUSSION

Particle–size distribution

The particle–size distribution of marginal soils is given in Table 2. Variability in the clay, silt, and fine and coarse sands contents was considerably large for all samples: the clay content varied from 13.7 to 86.9%, the silt content from 5.8 to 42.2%, the fine sand content from 3.8 to 46.1%, and the coarse sand content from 0.0 to 52.8%. The variation was found to be related to the landform on which soils are located. Profile VN60 in the meander floodplain showed the large variability in the clay (22.9 to 63.2%) and fine sand (3.8 to 46.1%) contents, while the silt (23.5 to 34.4%) and coarse sand (0.0 to 0.7%) contents were relatively constant with depth. Based on the particle–size distribution, profile VN60 was separated into three layers: Ap and AB horizons, Bg1 horizon, and Bg2 and BC horizons. Because this profile is located on the depression of the meander floodplain, three different times of deposition could be considered in the profile by the sediments transported by the river. The sediment became finer with progression of deposition.

Black soils in the inland valley (VN14, VN20 and VN57) were characterized by the high clay content (58.4 to 86.9%) with the low to fair percentages of silt (5.8 to 23.3%) and find sand (4.1 to 14.9%) and the low percentages of coarse sand (normally less than 10%). In contrast, soils in the mountainous area (VN43, VN44 and VN56) were characterized by the fair clay content within a narrow range (13.7 to 18.3%) and the fair to considerable percentages of fine sand (28.7 to 40.9%) except VN56–2. The silt content was higher for profile VN56

Table 2. Particle–size distribution of marginal soils

Profile and layer	Horizon	Depth (cm)	Particle–size distribution (%)				Soil texture (IUSS)
			Clay (<2 μm)	Silt (2–20 μm)	Fine sand (20–200 μm)	Coarse sand (200–2,000 μm)	
VN60–1	Ap	0–7	63.2	32.6	3.9	0.3	heavy clay
–2	AB	7–20	61.3	34.4	3.8	0.5	heavy clay
–3	Bg1	20–50	48.5	32.0	19.5	0.0	heavy clay
–4	Bg2	50–80	29.7	23.5	46.1	0.7	light clay
–5	BC	80–120	22.9	31.8	45.2	0.1	clay loam
VN14–1	Ap1	0–15	64.7	15.7	12.2	7.4	heavy clay
–2	Ap2	15–30	58.4	23.3	14.9	3.4	heavy clay
–3	AB	30–45	67.9	14.6	11.9	5.6	heavy clay
–4	Bw1	45–75	62.2	15.0	14.6	8.2	heavy clay
–5	Bw2	75–95	68.6	14.0	6.4	11.0	heavy clay
–6	Bw3	95–140	76.2	10.0	7.0	6.8	heavy clay
VN20–1	Ap	0–20	70.9	19.4	7.3	2.4	heavy clay
–2	AB	20–40	79.8	12.0	5.4	2.8	heavy clay
–3	B1	40–80	82.0	9.5	4.1	4.4	heavy clay
–4	B2	80–130	86.9	5.8	4.1	3.2	heavy clay
VN57–1	Ap	0–10	74.4	18.5	5.9	1.2	heavy clay
–2	AB	10–25	76.8	17.7	4.7	0.8	heavy clay
–3	Bt	25–55	77.2	15.1	5.5	2.2	heavy clay
–4	BC	55–90	74.6	15.3	7.0	3.1	heavy clay
VN47–1	Ap	0–15	14.9	6.1	26.2	52.8	sandy loam
–2	AB	15–40	30.5	6.4	22.9	40.2	sandy clay
–3	Btw	40–90	35.1	7.4	24.5	33.0	sandy clay
–4	BC	90–130	38.3	9.2	20.5	32.0	light clay
VN44–1	Ah	0–20	18.3	10.0	36.8	34.9	sandy clay loam
–2	Bs	20–50	16.5	10.0	40.9	32.6	sandy clay loam
VN43–1	OB	2–12	13.7	12.4	28.7	45.2	sandy loam
–2	BC	12–50	14.8	10.1	35.1	40.0	sandy loam
–3	C	50–70	16.0	9.7	40.2	34.1	sandy clay loam
VN56–1	Btw	20–30	17.6	42.2	30.4	9.8	clay loam
–2	BC	30–40	31.6	40.6	19.7	8.1	light clay

Subordinate distinctions within master horizons and layers:
g – strong gleying in which iron has been preserved in a reduced state
h – illuvial accumulation of organic matter
p – plowing
s – illuvial accumulation of sesquioxides
t – accumulation of silicate clay
w – development of color or structure in a horizon
but with little or no apparent illuvial accumulation of materials.

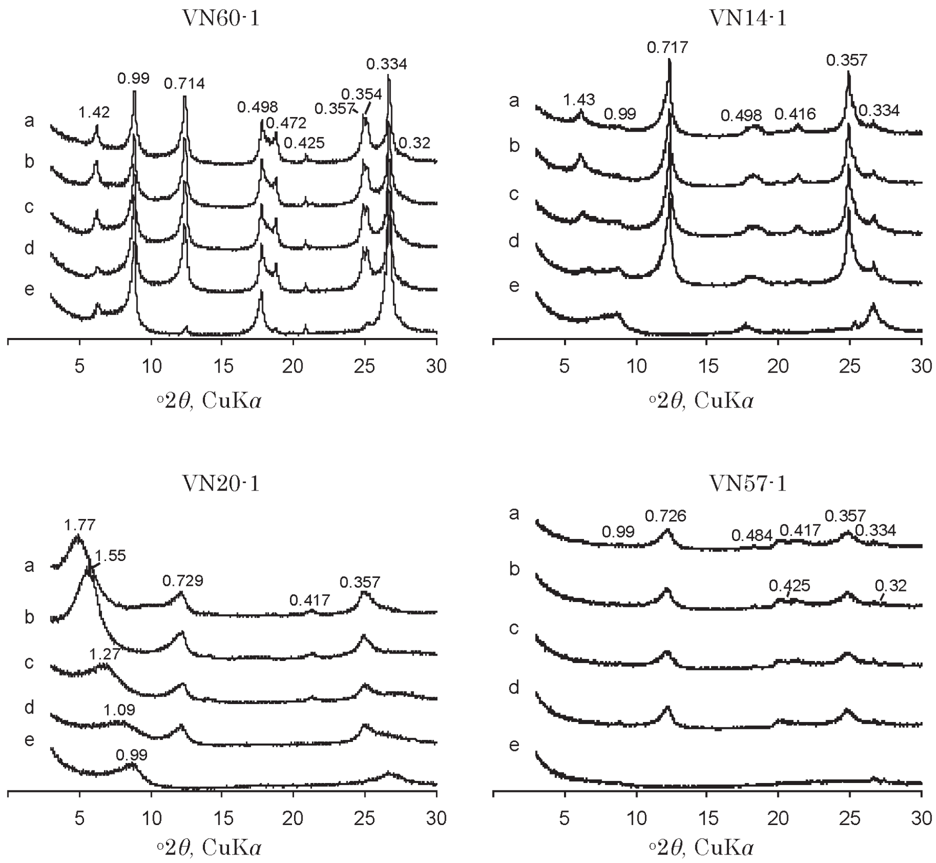

Fig. 2a. The XRD patterns of the <2 μm clay fraction from the surface horizon of profiles VN60, VN14, VN20 and VN57. Spacing is in nm. Treatments: a, Mg–saturation and glycerol–solvation; b, Mg–saturation and air–drying; c, K–saturation and air–drying; d, K–saturation and heating at 300 °C; e, K–saturation and heating at 550 °C.

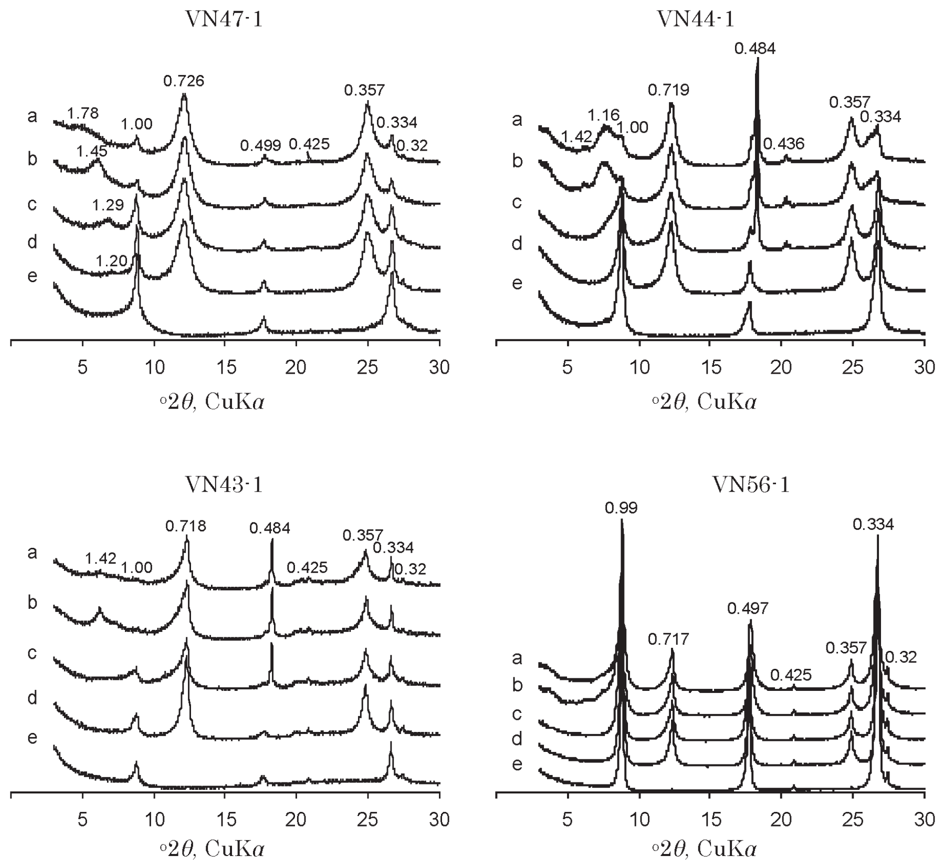

Fig. 2b. The XRD patterns of the <2 μm clay fraction from the surface horizon of profiles VN47, VN44, VN43 and VN56. Spacing is in nm. Treatments: a, Mg–saturation and glycerol–solvation; b, Mg–saturation and air–drying; c, K–saturation and air–drying; d, K–saturation and heating at 300 °C; e, K–saturation and heating at 550 °C.

(40.6 to 42.2%), while the coarse sand content was higher for profiles VN43 and VN44 (32.6 to 45.2%). The particle–size distribution of profile VN47 in the hill was intermediate between those of the soils in the inland valley and in the mountainous area, and the clay content increased while the coarse sand content decreased with depth.

According to the IUSS system, the texture of marginal soils, as controlled by the particle–size distribution, was coarser for the soils in the mountainous area with most samples having a texture of sandy loam or sandy clay loam, medium for the soil in the hill, and finer (mostly heavy clay) for the soils in the inland valley and meander floodplain.

Mineral identification

The XRD patterns of the $<2\,\mu$m clay fraction from the surface horizon of all profiles of marginal soils are illustrated in Figs. 2a and 2b. Mica was identified by the presence of the 0.99–1.00 nm peak along with its higher–order reflections at 0.497–0.500 and 0.334 nm. The presence of kaolinite was ascertained by the relatively sharp peaks at 0.714–0.719 and 0.357 nm, while the presence of halloysite (0.7 nm) was by the relatively broad peaks at 0.720–0.729 and 0.357 nm. The peaks reflected by both kaolinite and halloysite (0.7 nm) all disappeared by heating at 550 °C of the K–saturated clay. Chlorite was identified by the peak at 1.42–1.44 nm and reflections of its higher–orders and by remaining of the 1.42–1.44 nm peak in the treatment of K–saturation and heating at 550 °C. Vermiculite was identified by the decrease in the intensity of the 1.42–1.44 nm peak with the corresponding increase in the intensity of the 0.99–1.00 nm peak by K–saturation and air–drying. Smectite was noticed by the broad peak around 1.80 nm in the Mg–saturated and glycerol–solvated specimen.

The mica/vermiculite/smectite~mica/smectite mixed–layer mineral (abbreviated as Mx thereafter) was noticed on the XRD pattern by the poorly defined diffraction effect between 1.0 and 2.0 nm in the Mg–saturated and glycerol–solvated specimen and by the increase in the intensity of the 1.00 nm peak after K–saturation and air–drying (Egashira, 1988). Chlorite–vermiculite intergrade was detected by the 1.42–1.44 nm reflection in the Mg–saturated clay, which shifted toward 1.00 nm by heating at 300 and 550 °C of the K–saturated clay.

Goethite, gibbsite, quartz, and feldspars which are minerals other than layer silicate minerals were identified by the peaks at 0.416–0.418, 0.484, 0.425 and 0.334, and around 0.32 nm, respectively.

Clay mineralogical characteristics of soils in reference to parent materials and soil forming processes

The semi–quantitative estimates of the minerals in

Table 3. Approximate relative mineral contents (%) in the clay fraction of marginal soils

Profile and layer	Depth (cm)	Mc	Ch	Vt	St	Mx	Ch–Vt	Kt	Ht	Gt	Gb	Qr	Fd
VN60–1	0–7	36	8			4	4	29		1		15	3
–2	7–20	38	8			5	2	29		tr.		15	3
–3	20–50	31	7			4	3	38		tr.	tr.	14	3
–4	50–80	32	7	2		3	4	33		tr.	3	13	3
–5	80–120	35	5	9		7	3	30		tr.	2	6	3
VN14–1	0–15	3		3			10	75		9			
–2	15–30	3		3			9	76		9			
–3	30–45	3		tr.			12	76		9			
–4	45–75	2		tr.			13	76		9			
–5	75–95	3		tr.			13	74		10			
–6	95–140	3		tr.			13	73		11			
VN20–1	0–20				62				30	8	tr.		
–2	20–40				55				36	6	3		
–3	40–80				58				34	5	3		
–4	80–130				77				23	tr.	tr.		
VN57–1	0–10	5							53	15	10	12	5
–2	10–25	6							52	16	11	10	5
–3	25–55	4							54	15	12	10	5
–4	55–90	5							54	17	10	9	5
VN47–1	0–15	13		tr.	6	15			54	2		7	3
–2	15–40	13			7	16			58	1		3	2
–3	40–90	14			8	12	10		52	1		3	tr.
–4	90–130	11			9	14	36		28	1		1	
VN44–1	0–20	3		1		12		30			54		
–2	20–50	4		1		10		29			56		
VN43–1	2–12	2		4		13		34			31	13	3
–2	12–50	1					7	29			47	12	4
–3	50–70	4		tr.		10		29			57		
VN56–1	20–30	60						26				8	6
–2	30–40	66		2				25				3	4

Abbreviations: Mc, mica; Ch, chlorite; Vt, vermiculite; St, smectite; Mx, mica/vermiculite/smectite~mica/smectite mixed–layer mineral; Ch–Vt, chlorite–vermiculite intergrade; Kt, kaolinite; Ht, halloysite (0.7 nm); Gt, goethite; Gb, gibbsite; Qr, quartz; Fd, feldspars; tr., trace.

the clay fraction of marginal soils are shown in Table 3. Clay mineralogical composition of the soils was related to the parent material and soil forming process.

Alluvial–affected gley soils

Profile VN60 was derived from alluvium of the Red River system and contained mica (31 to 38%) and kaolinite (29 to 38%) as predominant minerals in the clay fraction. Minor clay minerals were chlorite, vermiculite, Mx and chlorite–vermiculite intergrade (less than 10% for each). Irrespective of the variation of the particle–size distribution with layers (Table 2), the clay mineralogical composition was almost identical throughout the profile. Excluding a small amount of Mx, the clay mineralogical composition of profile VN60 was within the range of the clay mineralogical composition observed for alluvial soils from the Red River system (Nguyen and Egashira, 2005).

Profile VN60 is situated in the depression of the meander floodplain that is saturated with both surface and underground water for a long time enough to promote the gleyzation process and, therefore, was classified as alluvial–affected gley soils. Grayish/bluish colour developing in some layers of the soil profile is caused by the occurrence of ferrous compounds and means prevailing of the reduced condition. Oxidation of ferrous compounds results in the release of H^+, which in turn causes transformation of clay minerals, such as the mica–into–Mx transformation. In the gley soils, however, oxidization of ferrous compounds is suppressed to prevent the clay mineralogical changes caused by reduction of pH. The gleyzation process is considered not to take much effect on the transformation of clay minerals.

Black soils

Black soils are formed through two main soil–forming processes: organic matter accumulation and alkali accumulation (NISF and DSTPQ, MARD, 2002). Three profiles of black soils had different clay mineralogical composition depending on their parent materials. Profile VN14, representing carbonate black soils and derived from limestone sediments, was characterized by the predominance of kaolinite (around 75%) in the clay fraction, followed by mica (less than 3%), chlorite–vermiculite intergrade (9 to 13%) and goethite (around 10%) in a small to fair amount. The clay mineralogical composition of this soil was comparable with that of ferralitic soils developed on limestone (Nguyen and Egashira, 2007b). This suggests that the original weathering products of limestone still keep their occurrence after transportation and deposition in the inland valley.

The clay mineralogical composition of black soils on basaltic deposit (VN20) was distinctly different from that of ferralitic soils developed on basalt (Nguyen and Egashira, 2008b). The latter was characterized by the predominance of halloysite (0.7 nm) in the clay fraction, followed by oxide/hydroxide minerals, whereas in the former, as shown in Table 3, smectite (55 to 77%) dominated over halloysite (0.7 nm) (23 to 36%). The occurrence of smectite with a large amount in the clay fraction of black soils on basaltic deposit was reported by Dao (1987) and Ho *et al.* (2000), although its origin has not been clarified yet. The most probable explanation is that smectite was neo–formed during soil development. Basic cations and silica, produced as a consequence of the ferralitization process, were leached and transported from the surrounding basalt–composed hilly area and enriched in the inland valley. The idea is that the presence of basic cations, especially Ca^{2+} and Mg^{2+}, and silica promotes neo–formation of smectite (Driessen *et al.*, 2001), leading to its dominance in black soils of the inland valley. The neo–formation of smectite in black soils on basaltic deposit is considered to be related to the alkali accumulation process, one of the two main soil–forming processes working in formation of black soils.

Profile VN57, representing black soils on basaltic tuff, is also situated in the inland valley. The soil did not originate from basaltic sediments but was formed on site from basaltic tuff. Therefore, it showed the same clay mineralogical composition as that of ferralitic soils developed on basalt (Nguyen and Egashira, 2008b) and had the high halloysite (0.7 nm) content (52 to 54%) with a fair amount of oxide/hydroxide minerals such as goethite (around 15%) and gibbsite (around 10%). The relatively weak reflection of the peaks shown in the XRD charts of VN57–1 (Fig. 2a) suggests the presence of non–crystalline materials in some amounts in addition to the poor crystallinity of halloysite (0.7 nm) and oxide/hydroxide minerals, and this is due to quick weathering of tuff.

Brownish grey soils in the semi–arid region

Profile VN47, classified as brownish grey soils in the semi–arid region, was characterized by the high halloysite (0.7 nm) content (52 to 58%) in the clay fraction except the lowest layer. In addition, a series of 2:1–type layer silicate minerals including mica (11 to 14%), smectite (around 7%) and Mx (around 15%) was detected throughout the profile and chlorite–vermiculite intergrade (10 to 36%) in the lower two layers. The presence of such 2:1–type layer silicate minerals was common to ferralitic soils (Nguyen and Egashira, 2008b) and saline soils (Nguyen and Egashira, 2007a) distributed in the same agro–ecological region.

These soils are distributed in the semi–arid region of Ninhthuan Province in the Costal Area of Southern Central region, where the mean annual evaporation is over the mean annual precipitation. In the dry season, salts in groundwater are brought to the soil surface. After evaporation/transpiration of water, salts dissolved in the soil moisture remain behind and are accumulated at the surface or at some depth of soil. As a result, soils in this region are characterized by the high content of basic cations and the high pH value (VSSS, 1996). The low rainfall and humidity would retard the ferralitization process and the high content of basic cations in soil along with the high soil pH would prevent weathering of 2:1–type layer silicate minerals, leading to the presence of them with a considerable amount in total in soil.

Humus soils

Two humus soils, classified as reddish yellow humus soils on mountain (VN44) and humus soils on high mountain, had the comparable clay mineralogical composition with each other, regardless of the differences in the landform and parent material between them. Kaolinite was detected in a considerable amount (around 30%) in the clay fraction, followed by Mx (10% or more), chlorite–vermiculite intergrade (7%), mica and vermiculite (both less than 5%). It was noticed that the gibbsite content of the two soils was relatively high (31 to 57%). This is believed to be consequence of the alitization process occurring in the high mountainous area of Vietnam.

The alitization process is essentially the same as the ferralitization process described in the previous paper (Nguyen and Egashira, 2007b) which comprises loss of basic cations and silica through weathering of silicate minerals due to hydrolysis and relative accumulation of sesquioxides. Iron and Al oxides/hydroxides are enriched in soil in the ferralitization process, while only Al oxides/hydroxides are enriched in the alitization process.

Humus soils on mountain are distributed at the altitude higher than 1,700 m above sea level, where the annual precipitation (2,500 mm) is greater than the annual evaporation (500 mm) and mist is prevailing in the area almost all year round, leading to the high humidity in both air and soil. Under such climatic and topographic conditions and the high organic matter content in soil, Fe is reduced to form soluble compounds which are easily leached out of the profile, resulting in the decrease of the Fe content and the relative accumulation of Al as gibbsite in the soils (Fridland, 1973).

Podzols

The podzols distributed on high mountain was characterized by the high mica (60 to 66%) and fair kaolinite (25 to 26%) contents in the clay fraction. Formation of podzols is controlled by the podzolization process occurring in a temperate–like zone with cool temperature and high humidity in Vietnam. In terms of soil formation, podzolization is considered apparently to be an opposite process of ferralitization. The podzolization process is characterized by leaching of Fe and Al from upper layers, which is caused by dissolution of their oxides/hydroxides compounds through formation of chelates with organic substances under low pH. On the other hand, the ferralitization process is enrichment of Fe and Al through formation of the stable compounds of oxides/hydroxides with leaching of basic cations and silica.

The main reason for the differences between the two soil forming processes is that organic acids are the principal weathering agents in podzolization, whereas carbonic acid plays this role in ferralitization where organic matter is decomposed more rapidly (Driessen *et al.*, 2001). Podzols of the present study had a 20–cm thick layer of organic matter. Under influence of organic acids, Fe and Al were leached out and hence goethite and gibbsite were not detected in the clay fraction. However, organic acids are not so strong as to decompose layer silicate minerals, leading to the presence of mica and kaolinite in a high or fair content in the clay fraction which are weathering products of rock–forming minerals of granite. Concerning leaching of Fe and Al in the podzolization process, the alitization process can be regarded as the Fe–podzolization process in which only Fe is leached by reduction of ferric compounds to ferrous compounds followed by dissolution.

Assessment to inherent potentiality of soils

Inherent potentiality of the soils could be roughly assessed by the clay content (amount in clay minerals) (Table 2) and the clay mineralogical composition (type in clay minerals) (Table 3) of them. Alluvial–affected gley soils (VN60) was evaluated to be in the intermediate to high level of inherent potentiality due to the fair to high clay content and the predominance of mica which is considered as a source of K to crops. Three black soils from the inland valley had the high clay content but the inherent potentiality was different among them due to the differences in the clay mineralogical composition. Black soil on basaltic deposit (VN20) had the high smectite content and hence was regarded as the high level of inherent potentiality. However, it may cause inconvenience to tillage practice due to the physical disadvantages of smectite. In addition, high inherent potentiality of a soil affects adversely growth and yield of paddy rice under the unfavorable weather condition (Egashira *et al.*, 1992). Carbonate black soils and black soils on basaltic tuff were dominated by kaolinite (VN14) or halloysite (0.7 nm), goethite and gibbsite (VN57) which are inactive in terms of retention of nutrients and water. Therefore, their inherent potentiality was evaluated to be low.

Brownish grey soils in the semi–arid region (VN47) contained the considerable amounts of 2:1–type layer silicate minerals in total in the clay fraction coupled with the moderate clay content and were evaluated to be of the intermediate level of inherent potentiality. Two humus soils (VN43 and VN44) from the mountainous area had the low clay content along with the predominance of kaolinite and gibbsite in the clay fraction and were evaluated to be the low level of inherent potentiality. One podzols (VN56) was classified to be of the intermediate level of inherent potentiality due to the fair clay content and the high mica content in the clay fraction. However, the low pH disturbs plant growth in podzols.

CONCLUSIONS

Various marginal soils in Vietnam were examined for the particle–size distribution and mineralogical composition in the clay fraction. The particle–size distribution of the soils was found to be related to the landform where they are situated. Soils in the meander floodplain and inland valley had the high clay content. That in the hill was characterized by the medium clay content and those in the mountainous area were by the low clay content. The clay mineralogical composition was different among the soils and was found to be controlled by the parent material and soil forming process of the respective soils. Inherent potentiality of the soils was assessed based on the type and amount of clay minerals with a great variation from the low to high levels.

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