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CLAY MINERALOGICAL COMPOSITION OF VIETNAM SOILS
DERIVED FROM DIFFERENT PARENT ROCKS

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ABSTRACT

Clay mineralogy of Vietnam soils was examined. Surface soils were collected from agricultural land at the sites different in parent rocks in four out of seven agro-economic zones. The soils derived from alluvium and sandstone were light clay, clay loam or sandy clay loam in texture, and the clay fraction was composed of mica and kaolinite with or without chlorite. In addition, the mica/vermiculite/smectite mixed-layer mineral was found in the soils collected from the Red River Delta region, while vermiculite-chlorite intergrade was detected in the soils collected in the North Midland and Mountainous region. The soils derived from limestone were of heavy-clay texture, and the clay fraction consisted predominantly of kaolinite. The soils derived from basalt were of heavy-clay texture, and the clay mineralogical com-
position was different with relief. The clay fraction of Ferralsols on the hillside was
composed of kaolinite, whereas that of Luvisols on the terrace comprised smectite
and halloysite (7 A).

Key words: Particle-size distribution, Clay mineral composition, Vietnam soil

INTRODUCTION

Vietnam is a country of the Indochina Peninsula and is situated within 8 to 23•KN
latitude and 102 to 109•KE longitude. It has total land area of 331 thousands km2. The
climate is tropical to subtropical monsoon. Based on the physiography and agricultural
production, the whole country of Vietnam is divided into seven agro-economic zones (Fig.
1). Fluvisols are distributed mainly in the Red River Delta and Mekong River Delta
regions, while Ferralsols are in the North Midland and Mountainous, North Central Coast
and Central Highland regions. Ferralsols spread over the level to undulating land and
develop on the weathering products of different kinds of rocks, mostly basaltic rocks,
limestone and sandstone.
Differences in the parent rock, topography and agro-economic zone of the soils might
be reflected in the difference in the mineralogy, particularly in the clay mineralogy of them.
It has been recognized that the clay mineralogical composition of soils plays a crucial role

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in determining their fundamental physical and chemical properties. Untill now, however, very few studies have been done on the clay mineralogy of Vietnam soils. In the present study, the clay mineralogical composition of some Vietnam soils was studied in reference to the parent rock, topography/relief, and agro-economic zone.

MATERIALS AND METHODS

Location and soil samples
Ten soil samples were collected from agricultural land and are briefly described in Table 1. Their sampling sites are shown in Fig. 1. Samples No 1 through No 3 are derived from alluvium, used as paddy field. Samples No 1 and No 2 are distributed on the fl oodplain in the Red River Delta region (RRD), while sample No 3 is on the basin in the North Midland and Mountainous region (NMM). Sample No 4 is derived from sandstone in NMM. It is used as upland field on the hillside.
Samples No 5 and No 6 are derived from limestone, and samples No 7 through No 10 are developed on basalt. They are situated on the hillside and used as upland field for

TABLE 1. Brief description of soil samples used in the present study

* Abbreviations: RRD, Red River Delta region; NMM, North Midland and Mountainous region;
NCC, North Central Coast region; CHL, Central Highland region.

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200Km

FIG. 1. Soil sampling sites on the map of agro-economic zones of Vietnam. Agro-economic zones: I, North Midland and Mountainous region; II, Red River Delta
region; III, North Central Coast region; IV, South Central Coast region; V, Central
Highland region; VI, North East Mekong Delta region; VII, Mekong River Delta
region.

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fruits, sugarcane, rubber, or tea-coffee cultivation, except for sample No 8 which is on the
terrace and used for paddy rice cultivation. Samples No 5, No 6, No 7, and No 8 through
No 10 are located in NMM, RRD, the North Central Coast region (NCC), and the
Central Highland region (CHL), respectively.
Soil classification names of the ten soils are shown in Table 1 according to the FAO/
UNESCO classification system. All the soil samples were taken from the surface 15-cm
layer. They were air-dried, gently ground and passed through a 1.0-mm sieve.

Determination of chemical properties
The pH was measured in the suspension having a soil/water ratio of 1/2.5. Organic C
was determined by the Tyurin method and multiplied by the coefficient of 1.724 to give the
organic matter content (Committee of Soil Standard Methods for Analyses and Mea-
surements, 1986). Exchangeable cations and cation-exchange capacity (CEC) were deter-
mined by the method proposed by Muramoto et al. (1992) as follows. Two g of air-dry soil
was weighted into a 50-mL centrifuge tube. Thirty mL of 1 M NH4CH30OO (pH 7.0)
was added to the soil followed by shaking for 15 min and centrifugation at 2,500 rpm for 5
min. The supernatant was transferred to a 100-mL volumetric flask through filter paper.
Extraction was repeated two more times in the same manner except for shaking for 30 s by
hand. After addition of 5 mL of 20,000 ppm Sr the flask was made to volume with the
ammonium acetate solution. Exchangeable Ca2+, Mg2+, K+ and Na+ were measured by
the atomic absorption spectrophotometry (AAS). To remove free NH4+ from the soil,
20 mL of 80% methanol was added to the centrifuge tube. The soil was then shaken
for 30 s by hand and centrifuged at 2,500 rpm for 5 min. The supernatant was discarded.
This step was repeated two more times. Thirty mL of 10% KC1 solution was added to
the centrifuge tube to extract adsorbed NH4+ from the soil in the same manner as the
extraction of exchangeable cations. The flask was made to volume with 10% KC1 solution
and the extract was diluted 100 times with water to measure NH4+ by the indophenol blue
method (Committee of Methods for Soil and Environment Analyses, 1997).

Particle-size analysis
For the determination of particle-size distribution, 10 g of air-dry soil was put into a
500-mL tall beaker and 100mL of 7% H2O2 was added. The beaker was left for about

10 min till frothing ceased, placed on a hot plate, and then heated at 90•Ž for about 2 h.
It was allowed to cool and the contents were transferred to a 50-mL centrifuge tube. The
remaining H2O2 was removed by washing 3 times with water. Five mL of 3 M NaC1 was
added in each washing to prevent, deflocculation of clay particles. After washing with
water, the soil was dispersed by ultrasonic vibration (tank-type; 38 kHz, 250 W) for 15
min and deflocculated by adjusting the pH to 10 with 1 M NaOH. The soil suspension was
transferred to a 1-L sedimentation cylinder and water was added up to the mark. After
leaving for an appropriate time, the clay fraction (<2 pm) was siphoned out into a 2-L
plastic beaker. With repetition of sonification-sedimentation-siphoning with intermittent pH
adjustments, the clay fraction was completely separated and flocculated by addition of
about 30 mL of 3 M NaCl. The 2-20 pm silt fraction was separated by repeated
sedimentation and siphoning. The fine sand (20-200 pm) and coarse sand (200-1,000 Um)

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fractions were separated by wet-sieving. The weight of each fraction was determined to
calculate the particle-size distribution.

Clay mineralogical analysis
Mineralogical composition the <2 um clay fraction of soils, which had been separated
in the particle-size analysis, was analyzed by the X-ray diffraction (XRD). The clay
fraction preserved as a flocculated sol was used. Duplicate sols containing 50mg clay each
were taken in 10-mL centrifuge tubes. Washing by centrifugation and decantation was carried out twice with 8 mL of an equal mixture of 1 M NaC1 and 1 M NaCH3 COO (pH 5.0) in order to decrease the pH of the preserved clay sols. The clay was saturated with Mg
and K by washing 3 times with 8 mL of 0.5 M MgCl2 and 1 M KC1, respectively. Excess
salt was removed by washing with 8 mL of water. The clay in the tube was thoroughly
suspended with 1 mL of water. An aliquot of 0.4 mL of the sol was dropped onto a glass
slide (28 x 48 mm) covering two-third of its area, air-dried, and X-rayed (parallel powder
mount). The XRD patterns were obtained using a Rigaku diffractometer with Ni-filtered
CuKa radiation at 40 kV and 20 mA and at a scanning speed of •K20 min-1 with a
scanning step of 0.02•K and a continuous scanning mode over a range of 3 to 30•K20. The
XRD analysis was made with air-dried and glycerol-solvated specimens for the Mg-
saturated clay and with air-dried and heated (at 300 and at 550•Ž for 2 h) specimens for
the K-saturated clay.

RESULTS AND DISCUSSION

Chemical properties
Some chemical properties of the ten soil samples are shown in Table 2. The pH (H2O) ranged between 3.86 and 5.67, indicating the strong to slightly acid condition of the soils. Sample No 10 of the upland soil cultivated for tea and coffee showed the lowest pH (H2O). Organic matter content was in the range between 21.0 and 65.0 g kg-1. Three samples of No 8 through No 10 which are derived from basalt in CHL, showed the organic matter content over 50 g kg-1. The CEC was in a range of 5.32 to 17.05 cmol(+) kg-1 except for sample No 8. The high CEC of 42.19 cmol(+) kg-1 for sample No 8 is ascribed to the high clay content with domination by smectite, as shown in Tables 3 and 4. The CEC of samples No 1 through No 4 derived from alluvium and sandstone was nearly equal to or below 10 cmol(+) kg-1, whereas the CEC of samples No 5 through No 10 derived from limestone and basalt was above 10 cmol(+) kg-1. Exchangeable cations were 0.14 to 1.13 cmol(+) kg-1 for Ca, 0.07 to 1.63 cmol(+) kg-1 for Mg, 0.08 to 0.49 cmol(+) kg-1 for K and 0.08 to 1.10 cmol(+) kg' for Na, reflecting the acidic condition of the soils, except for sample No 8 which showed the high contents of exchangeable Ca (9.24 cmol(+) kg-1) and Mg (5.24 cmol(+) kg-1), controlled by the high CEC with the highest pH (H2O) of 5.67.

Particle-size distribution
The particle-size distribution of the soil samples is shown in Table 3. As shown in Table
3, the particle-size distribution was strongly dependent on the parent rocks and was

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noticeably different between the soils derived from alluvium and sandstone and those from limestone and basalt. The four soils derived from alluvium and sandstone (samples No 1 through No 4) was medium- to coarse-textured. Among them, the particle-size distribution varied somewhat with the agro-economic zone, and the two soils in NMM were dominated by fine sand with the texture of sandy clay loam. The two soils in RRD had the similar silt content of around 25% with each other, which was higher than that of the soils in NMM.

TABLE 2. Some chemical properties of the soil samples

*CEC: cation exchange capacity.

TABLE 3. Particle-size distribution of the soil samples

* Abbreviations: LiC, light clay; CL, clay loam; SCL, sandy clay loam; HC, heavy clay.

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The soil situated on the coastal plain (sample No 1) showed the high clay and low fine-
sand contents compared to the soil on the meander plain (sample No 2), having the texture
of light clay and clay loam, respectively.
In contrast, the six soils derived from limestone and basalt (samples No 5 through No
10) were characterized by the high clay content with the heavy-clay texture, irrespective of
the agro-economic zones, relief and land use. The clay content was in the range of 60 to
88% and was not essentially different between the soils derived from limestone and those
from basalt. The highest clay content of nearly 90% was obtained for the soil collected at
Gialai province (sample No 9) in CHL. The silt content of sample No 8 used as paddy
fi eld on the terrace was two to three times higher than the silt content of the other five
soils used as upland field on the hillside. The high clay content of the soils derived from
limestone and basalt indicates that they have been subjected for long time to the intensive
weathring and causes the poor soil tilth.

Mineral identification

The XRD patterns of the <2 ƒÊm clay fraction of the ten soil samples are reproduced in
Fig. 2. The 10.0 A peak along with the peaks at 4.96-4.99 and 3.34 A is indicative of the
presence of mica. The presence of kaolinite was ascertained by the peaks around 7.15
(7.10-7.19 A) and at 3.57 A which disappeared by heating at 550•Ž of the K-saturated
specimen. Similarly, the presence of chlorite was noticed by the peaks at 14.2, 7.1, 4.72,
and 3.54 A and by remaining of the 14 A peak after heating at 550•Ž of the K-saturated
specimen. Smectite was identified by the broad peak at 18 A with its second-order re-
fl ection at 9.2 A in the Mg-saturated and glycerol-solvated specimen, which shifts to 12.5 A
by K-saturation and air-drying. Halloysite (7 A) was noticed by the peaks at 7.3 and 3.6 A
which disappeared by heating at 550•Ž of the K-saturated specimen. The mica/vermiculite/
smectite mixed-layer mineral was noticed by the poorly defined diffraction effect between
10 and 20 A in the Mg-saturated and glycerol-solvated specimen and the increase in the
intensity of the 10 A peak after K-saturation and air-drying (Egashira, 1988). Vermiculite-
chlorite intergrade does not collapse readily when K-saturation but its 14 A reflection
becomes diffuse and shifts towards 10 A after heating at 300 and 550•Ž (Rich, 1968;
Barnhisel and Bertsch, 1989). Lepidocrocite was detected by the small peak at 6.27 A.
Goethite and gibbsite were identified by the peaks at 4.16-4.17 A and at 4.84 A, re-
spectively. Quartz was detected by the peaks at 4.25 and 3.34 A, and feldspars were by the
peaks around 3.2 A.
Mica, chlorite, kaolinite, the mixed-layer mineral of mica/vermiculite/smectite, iron
oxide minerals of lepidocrocite and goethite, quartz, and feldspars were present in the clay
fraction of the soils derived from alluvium in RRD (samples No 1 and No 2). Mica,
kaolinite, vermiculite-chlorite intergrade and geothite were observed in the clay fraction of
the soils derived from alluvium and sandstone in NMM (samples No 3 and No 4). In
addition, gibbsite (aluminum hydroxide mineral) was present in sample No 3 while chlorite
and quartz were in sample No 4. Kaolinite dominated over mica, vermiculite-chlorite
intergrade and geothite in the clay fraction of the soils derived frome limestone (samples
No 5 and No 6). Among the four soils derived from basalt (samples No 7 through No 10),
the clay fraction was solely composed of kaolinite in samples No 7 (Nghean province in

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Somple No 1

Somple No 2

Sample No 3

Sample No 4

Sample No 5

Sample No 6

Sample No 7

Sample No 8

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FIG.2. The XRD patterns of the <2ƒÊm clay fraction of the soil samples. Spacings are in A.
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•Ž; e, K-saturation and heating at
550•Ž.

NCC) and No 9 (Gialai province in CHL). Smectite was found with halloysite (7 A) and
geothite in the clay fraction of sample No 8 (Daclac province in CHL) situated on the
terrace and used as paddy field. Kaolinite, geothite and gibbsite were main minerals in the
clay fraction of sample No 10 (Lamdong province in CHL).

Semi-quantitative estimates of mineralogical composition
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 of each mineral. Reflections of the Mg-saturated and glycerol-solvated specimen
were usually used to calculate the peak intensities of minerals.
The 10.0 A peak was used for calculating the intensity of mica. To calculate the relative
contents of chlorite and kaolinite the 7.15 A peak intensity of the Mg-saturated and
glycerol-solvated specimen was allocated between chlorite and kaolinite according to the
intensity ratio of 3.54 (chlorite) and 3.57 A (kaolinite) peaks. The intensity of vermiculite-
chlorite intergrade was calculated from the 14 A peak intensity of the K-saturated and air-
dried specimen after subtracting the contribution due to chlorite. The contents of smectite
and halloysite (7 A) were calculated from the intensities of 18 and 7.3 A peaks, respectively.
The content of the mica/vermiculite/smectite mixed-layer mineral was estimated from the
difference between the normalized 10 A peak intensity of the K-saturated and 550•Ž-heated
specimen and the 10 A peak intensity of the Mg-saturated and glycerol-solvated specimen.
Normalization of the 10 A peak intensity of the K-saturated and 550•‹-heated specimen was
carried out by multiplying by the intensity ratio of the 4.25 A quartz peaks of the Mg-
saturated and glycerol-solvated specimen and of the K-saturated and 550•Ž-heated
specimen.
The contents of goethite, gibbsite and feldspars were calculated from the intensities of

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TABLE 4. Approximate mineral contents (%) in the clay fraction (<2ƒÊm) of the soil samples

Abbreviation of minerals: St, smectite; Mc, mica; Ch, chlorite; Mc/Vt/St, mica/vermiculite/smectite mixed-layer mineral; Vt-Ch, vermiculite-chlorite intergrade; Kt, kaolinite; Ht, halloysite (7 A); Lp, lepidocrocite; Gt, goethite; Gb, gibbsite; Qr, quartz; Fd, feldspars.
+: detected but not calculated due to insignificant amounts.

the peaks at 4.16-4.17, 4.84 and 3.2 A, respectively, and the content of quartz was calculated from the 4.25 A peak intensity after multiplying by the coefficient of 3. Lepidocrocite was noted in the XRD charts but could not be calculated due to its insignificant quantities.
The relative mineral contents thus calculated are shown in Table 4. In the soils derived

from alluvium and used as paddy field in RRD (samples No 1 and No 2), mica, chlorite, kaolinite, and the mica/vermiculite/smectite mixed-layer mineral were found to be major minerals with the contents of 18 to 31, 11 to 15, 11 to 25, and 17 to 34%, respectively. Mica and the mixed-layer mineral tended to be higher in the soil on the coastal plain (sample No 1), while chlorite and kaolinite be higher in the soil on the meander plain (sample No 2). Quartz was also present in fair amounts (10 to 16%) with minor to insignificant amounts of feldspars, geothite and lepidocrocite. In the paddy soil derived from alluvium (sample No 3) and the upland soil derived from sandstone (sample No 4) in NMM, kaolinite (28 to 46%) and vermiculite-chlorite intergrade (16 to 30%) were major minerals. Mica and goethite were found in fair to minor amounts in both samples, while gibbsite in sample No 3 and chlorite and quartz in sample No 4 were present in fair amounts. The identical mineral suite of sample No 3 with sample No 5 of the same agro-economic zone, with absence of chlorite and quartz and presence of gibbsite suggests that the sediment of sample No 3 originated from weathered limestone or limestone-derived soil, different from the sediments of samples No 1 and No 2 and of sample No 4. The soils derived from limestone (samples No 5 and No 6) which are used as upland
fi eld on the hillside showed the similar mineralogy with each other. Kaolinite was pre-dominating with the content of 72 to 82%. Minor amounts of mica, vermiculite-chlorite intergrade, geothite, and gibbsite or feldspars were present, but quartz was not detected.

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Kaolinite or smectite was the predominant mineral, with absence of mica, chlorite, quartz and feldspars, in the soils derived from basalt (samples No7 through No10). The predominant mineral was kaolinite with iron and aluminum oxide/hydroxide minerals in insignificant to major amounts in the soils (Ferralsols) used as upland field on the hillside. The kaolinite content was nearly 100% in the soils of Nghean province in NCC (sample No7) and Gialai province in CHL (sample No 9). Fair to major amounts of geothite (11%) and gibbsite (38%) were present along with kaolinite (46%) in Lamdong province in CHL (sample No10). The mineralogical composition of sample No10 is similar to that of a bauxite deposit, indicating the more intensive weathering of the soil. The predominant mineral was smectite (65%) accompanied by halloysite (7 A) (28%) and goethite (7%) in the soil (Luvisols)(sample No8) used as paddy field on the terrace. Basalt is composed of plagioclase, pyroxene and olivin. These minerals are relatively easily weathered under the weathering environment on the crust surface. They may be altered predominantly to kaolinite under the acidic and eluvial condition, whereas principally to smectite under the illuvial condition with accumulation of bases.

Mica was detected in the soils derived from alluvium, sandstone and limestone. Among them, the mica content was highest in the soils derived from alluvium in RRD. The high content of mica in the alluvial soils in RRD was reported by Dao (1986), Ho et al. (1998), and Nguyen and Egashira (2000). In the soils derived from alluvium in RRD, considerable chlorite was present in addition to mica and kaolinite. It may be mentioned that the original sediment of the Red River delta contains mica, kaolinite and chlorite as major clay minerals. The presence of chlorite in paddy soils of Thailand, Malaysia and Vietnam was reported by Hattori et al. (1965), Kawaguchi and kyuma (1969a, b), Wada et al. (1981), Ho et al. (1998), and Nguyen and Egashira (2000). Mica and chlorite in soils inherit from parent rocks.
Kaolinite was present in all the soils except for sample No 8 in which halloysite (7 A) was found instead. Kaolin mineral is considered to be the most common mineral in Vietnam soils, since mica was not noticed in the soils derived from basalt. The kaolinite content is higher for the soils derived from limestone and basalt than for the soils derived from alluvium and sandstone. By taking the kaolinite content in the clay fraction and the clay content in the soil, the kaolinite content in the soil (<1 mm) can be calculated as 49 to 57% for the soils from limestone and as 35 to 88% for the soils from basalt. Kaolinite in the soils derived from alluvium and sandstone inherited most probably from the parent rocks, whereas kaolinite in the soils derived from basalt is a alteration product from rock-forming minerals. Both mechanisms can be considered for kaolinite in the soils derived from limestone.

Vermiculite-chlorite intergrade was present in significant amounts in the soils derived from alluvium and sandstone in NMM. This vermiculite-chlorite intergrade is regarded as the degradation product of chlorite rather than due to chloritization of vermiculite (Nguyen and Egashira, 2000). The mica/vermiculite/smectite mixed-layer mineral was noticed only in the soils derived from alluvium in RRD. It may be a alteration product of mica (Nguyen and Egashira, 2000).
Smectite and halloysite (7 A) were only noticed in the black soil (Luvisols) derived from basalt. Kaolinite is rare in the tropical black soil (Dao, 1986). This soil showed the highest

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organic matter content and CEC (Table2). The presence of smectite, in general, indicates the good fertility of a soil (Moslehuddin and Egashira, 1997). The black soil dominated by smectite shows strong swelling and shrinkage with changing moisture condition, and the soil has high cation-exchange capacity and is fairly rich in plant-nutrients (Dao, 1986). Origin of halloysite (7 A) is not clear, but it might originate from smectite through formation of halloysite/smectite mixed-layer mineral. Another idea is that halloysite is a kaolin mineral which is formed from rock-forming minerals under the humid condition,

prevailing in the black soil.

CONCLUSIONS

Vietnam soils are characterized by the variation of texture and mineralogical com-

position with a close relationship to the parent rock. The soils derived from alluvium in the Red River Delta region are medium-textured and rich in mica and kaolinite along with significant quantities of chlorite and the mica/vermiculite/smectite mixed-layer mineral. The soils derived from alluvium and sandstone in the North Midland and Mountainous region are light-textured and contain kaolinite and vermiculite-chlorite intergrade as major clay minerals. The soils derived from limestone and basalt are heavy-textured. The soils derived from both limestone and basalt on the hillside are dominated by kaolinite, whereas smectite is a predominant mineral accompanied with halloysite (7 A) in the basalt-derived black soil situated on the terrace.

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