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Mineralogy of a perudic Andosol in central Java, Indonesia

E. Van Ranst [a,*], S.R. Utami [b], A. Verdoodt [a], N.P. Qafoku [c]

[a] Laboratory of Soil Science, Department of Geology and Soil Science, Ghent University, Krijgslaan 281 (S8), Gent B-9000, Belgium
[b] Soil Science Department, Faculty of Agriculture, Brawijaya University, Jl. Veteran, Malang 65145, Indonesia
[c] Battelle-Pacific Northwest National Laboratory, Richland, Washington, USA

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Abstract

We studied the mineralogy of a perudic Andosol developed on the Dieng Tephra Sequence in central Java, Indonesia. The objective was to confirm the presence and determine the origin and stability of 2:1 and interlayered 2:1 phyllosilicates in well-drained Andosols. This was and still is a debated topic in the literature. Total elemental and selective dissolution, as well as microscopic and X-ray diffraction analyses, were performed on the soil samples collected from this site. These analyses confirmed that andic properties were present in the soil samples. The allophane content determined by selective dissolution was 3–4% in the A horizons, and increased to 12–18% in the deeper subsoil horizons. In addition, the clay fraction contained dioctahedral smectite, hydroxy-Al-interlayered 2:1 minerals (HIS), Al-chlorite, kaolinite, pyrophyllite, mica, cristobalite and some gibbsite. The silt and sand fractions were rich in plagioclase and pyroxene. The 2:1 minerals (smectite and pyrophyllite), as well as chlorite and kaolinite were of hydrothermal origin and were incorporated in the tephra during volcanic eruption. Besides desilication during dissolution of unstable minerals, Al interlayering of 2:1 layer silicates was most likely the most prominent pedogenic process. Although hydroxy-Al polymeric interlayers would normally stabilize the 2:1 clay phases, the strong weakening, and even disappearance of the characteristic XRD peaks, indicated instability of these minerals in the upper A horizons due to the perudic and intensive leaching conditions.

Keywords: Mineralogy; Tephra; Aluminium interlayer; Andosol; Dieng volcanic complex; Indonesia

1. Introduction

Soils formed from volcanic ejecta and classified as Andosols in the WRB system (IUSS Working Group WRB, 2006) have many unusual and distinctive or andic properties, such as dark coloration of the surface horizons, high pH in NaF solution, high variable charge, low base status, strong phosphate fixation, low bulk density, high porosity, water retention and anion exchange capacity (Wada, 1985; Qafoku et al., 2000). These properties have been ascribed to the formation of poorly-ordered clay minerals (e.g. allophane and imogolite) and the accumulation of Al- and Fe-humus complexes in the surface horizons (Wada, 1980; Shoji et al., 1993). However, some Andosols which contain little or no allophane, have a mineralogy dominated by layer phyllosilicates such as 2:1 and 2:1:1 clay minerals and their intergrades, and may still exhibit andic properties (Shoji, 1985; Qafoku et al., 2004).

The debate on the origin of 2:1 and hydroxy-Al-interlayered 2:1 layer silicates (smectite-HIS or vermiculite-HIV) in well-drained volcanic ash still continues. Different processes such as eolian dust contamination, transformation, neoformation in specific microenvironments, and inheritance from parent material through hydrothermalism or incorporation of lithic fragments into the tephra during eruption, have been hypothesized in the literature (Pevear et al., 1982; Glasmann, 1982; Post, 1984; Jongmans et al., 1994; Bautista-Tulin and Inoue, 1997; Dahlgren et al., 1997; Jongmans et al.,1999; Ndayiragije and Delvaux, 2003). The occurrence of these layer silicates in Andosols has often been associated with Al–humus complexes in non-allophanic Andosols (Shoji et al., 1993). The incorporation of Al into humus complexes and/or into Al interlayers of 2:1 clay minerals has been termed the “antigibbsite” effect (Jackson, 1963; Karathanasis et al., 1983). This process may

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* Corresponding author. Fax: + 32 9 2644997.
E-mail address: eric.vanranst@UGent.be (E. Van Ranst).

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also inhibit the formation of allophane and imogolite ("anti-allophanic effect", Shoji et al., 1993), as observed in the initial stages of the weathering of volcanic ash (Dahlgren et al., 1997).

Andosols are widespread in the Indonesian archipelago (Dudal and Soepraptohardjo, 1979). They develop from a rather wide variety of parent ashes originating from recent Pleisto–Holocene eruptions (Whitford, 1975; Utami, 1998; Van Ranst et al., 2002). The Dieng volcanic complex, located in central Java, consists of late Quaternary to recent volcanic stratocones, parasitic vents, and explosion craters (Muffler, 1970). The region is covered by a thick, widespread blanket of phreatic, phreatomagmatic, and magmatic air-fall deposits. This air-fall sequence is called the "Dieng Tephra Sequence" (Miller et al., 1983). The upper part of the Dieng Tephra Sequence shows well-developed soils up to a depth of about 3 m. Miller et al. (1983) stated that most rock fragments, magmatic fragments and minerals are altered extensively or completely to clay minerals, although no mineralogical analyses were carried out during this investigation. Van Ranst et al. (2002) studied some physico-chemical properties of the Andosol developed on these air-fall deposits, but the mineralogical composition is still poorly documented.

The objective of this study was to investigate the mineralogy of the "smectitic" Andosol representative for the Dieng Tephra Sequence. Total elemental and selective dissolution analyses combined with microscopic and X-ray diffraction (XRD) analyses were conducted. The results from this study will help to better understand the provenance and coexistence in the clay fraction of smectite with other 2:1 and 2:1:1 layer silicates and their intergrades, and small amounts of allophane and gibbsite.

2. Materials and methods

2.1. Environmental setting

The Dieng volcanic complex, located in central Java about 75 km northwest of Yogyakarta, is a member of the K-calc-alkali volcanoes (Whitford, 1975) and consists of separate extrusions ranging from basalt, erupted early in the sequence, through successively younger eruptions of olivine andesite, augite–hypersthene andesite, hornblende andesite, and biotite andesite (Miller et al., 1983). Volcanic events of the last few thousand years consisted of phreatic eruptions, associated small hot mudflows, emission of suffocating gases, and hydrothermal activity. The current hydrothermal activity in the region is indicated by active hot springs, solfataras, fumaroles, and mofettes. The Dieng Tephra Sequence covering the Dieng Mountains region between 1600 and 2100 m altitude consists of interbedded lapilli- and ash-fall beds. The upper 1–1.5 m of the Dieng Tephra Sequence consists of a well-sorted massive silt deposit, loose and friable, and interpreted as loess (Miller et al., 1983).

Rainfall for the Dieng Mountains region is reported to be between 3000 and 4000 mm per year; it is 3429 mm around the study site at 2010 m a.s.l. Despite the relatively high altitude and high rainfall, this region supports a large rural population. Large seasonal variations in temperature are absent; the mean monthly temperature at Dieng Plateau is between 13 and 15 °C. The soils are considered suitable for growing potatoes, cabbage, tobacco, "kacang Dieng" (local wing bean), onion and casia. The more rugged parts of the landscape are planted with pine trees.

2.2. Materials

The soil profile was selected at Banjarnegara, 1 km N from Gatotkaca temple (7° 12′ 35″ S, 109° 53′ 25″ E), Sokarini Village, Dieng Kulon, under pine forest with 60% grass cover. The profile was described according to the FAO standard guidelines and the air-dry fine earth of each horizon has been analyzed using techniques recommended for volcanic soils (Van Ranst et al., 2002). Selected morphological and physico-chemical properties of the soil are given in Table 1.

Moist soil is very dark brown (10 YR 3/2) in A1 horizon over dark yellowish brown (10 YR 4/6) in the upper Bw horizons to strong brown (7.5 YR 4/6) in the deeper Bw horizons. The field texture is silty loam in the upper horizons and loam in the deeper horizons. All horizons show large accumulations of organic carbon. The O.C content is very high (10–11%) in the

Table 1
Selected morphological and physico-chemical properties of the profile (adapted from Van Ranst et al., 2002)

Horizon	Depth (cm)	Color (moist)	Field texture	O.C (%)	pH-H_2O (1:2.5)	pH-KCl (1:2.5)	pH-NaF (1:50)	CEC[a] ($cmol_c\ kg^{-1}$)	SEBC[a] ($cmol_c\ kg^{-1}$)	PR[b] (%)	BD[c] ($Mg\ m^{-3}$)	WR[d] (% w/w)	
												0.033 MPa	1.5 MPa
A1	0–15/18	10YR 2/2	SiL	10.2	4.5	4.4	11.9	46.7	2.3	97	0.46	98	42
A2	15/18–20/23	10YR 3/2	SiL	11.1	4.4	4.2	11.7	57.9	1.7	97	0.49	87	35
A3	20/23–38/40	10YR 3/3	SiL	5.7	4.9	4.7	12.0	35.8	1.8	97	0.49	87	35
Bw	38/40–50	10YR 4/6	SiL	5.7	4.9	4.6	12.1	38.5	3.4	97	0.59	56	30
2A	50–70/72	10YR 2/2	SiL	9.0	5.0	4.6	12.1	39.3	1.3	97	0.52	68	32
2Bw1	70/72–80/92	10YR 4/4	L	1.8	5.0	4.4	11.7	29.2	1.3		0.70	67	36
2Bw2	80/92–117	10YR 4/6	L	3.8	5.2	4.7	12.0	34.8	2.0		0.88	46	36
2Bw3	117–150	10YR 4/6	L	2.2	5.3	4.8	11.8	32.3	4.8		0.60	78	53
2Bw4	150–190	7.5YR 5/6	L	1.3	5.2	4.2	11.3	28.3	6.1				
2Bw5	190–210/225	7.5YR 4/6	L	2.2	5.4	5.0	12.0	29.4	2.4				
3A	210/225–260$^+$	10YR 2/2	SiL	3.5	5.4	5.2	12.0	32.1	2.6				

[a] Cation exchange capacity (CEC) and sum of exchangeable basic cations (SEBC) by 1 M NH_4OAc, pH7.

[b] Phosphate retention (PR) as measured according to Blakemore et al. (1981).

[c] Bulk density.

[d] Water retention.