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Micromorphological Characterization of Some Volcanic Soil In West Java

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Abstract

Micromorphological characterization has been studied on six pedons of soils developing in volcanic materials in West Java. The pedons represent deposits of different volcanoes (Mount Tangkuban Perahu, Mount Patuha and Mount Papandayan) with different ages (Pleistocene, Holocene) within two types of volcanisms (andesitic, basaltic), and three agroclimatic zones (A, B1, B2). Undisturbed soil samples were taken from each identifiable horizon for thin section preparations. Observations were carried out by means of a magnifying lens, binocular stereomicroscope, polarization microscope, and scanning electron microscope (SEM). The result demonstrates that micromorphological characteristics of volcanic soils developing from different ages, types of parent material, and climate were different through their c/f related distribution patterns, $c/f_{2\mu}$ ratios, sorting, infillings and coatings of voids, and microstructure.

Keywords: Micromorphology, soil, volcano, pedogenetic

Sari

Karakteristik mikromorfologi enam pedon tanah yang berkembang dari material gunung api di Jawa Barat telah dipelajari. Pedon yang dipelajari mewakili endapan yang berasal dari beberapa gunung api (Gunung Tangkuban Perahu, Gunung Patuha, dan Gunung Papandayan) dengan umur yang berbeda (Plistosen, Holosen) pada dua jenis vulkanisme (andesitik, basaltik) dan tiga zona agroklimat (A, B1, B2). Percontoh tanah tidak terganggu diambil dari setiap horizon untuk dibuat sayatan tipis. Pengamatan dilakukan dengan kaca pembesar, mikrosroskop stereo binokular, mikroskop polarisasi, dan scanning electron microscope (SEM). Hasil penelitian menunjukkan bahwa karakteristik mikromorfologi tanah abu gunung api yang berkembang dari umur, jenis bahan induk, serta iklim yang berbeda menunjukkan perbedaan dalam hal pola distribusi kasar/halus relatif, rasio kasar/halus, sortasi, pengisian dan selaput pada rongga, serta struktur mikro.

Kata kunci: *Mikromorfologi, tanah, gunung api, pedogenesis*

Introduction

Soil micromorphology is a method to study the characterization of undisturbed soil samples using microscopic and submicroscopic techniques to identify soil components and establish their spatial, temporal, genetic, and functional relationships (Bullock *et al.*, 1985).

Historically, micromorphological investigations have mainly been used for studying soil genesis, but they also have wider applications, *e.g*. in soil physics, biology and chemistry (Stoops and Jongerius, 1975). Two basic principles of micropedology are the use of undisturbed (oriented) samples and the concept of functional research whereby all observations are directed towards reaching as an understanding of the function of soil components and the relationship between one and another.

Micropedology covers all microscopic analyses of undisturbed soil samples (Stoops and Eswaran, 1986) including the study of soil thin sections, microchemical and microphysical methods, and submicroscopic techniques. The most advanced analysis is the study of the entire soil fabric (soil micromorphology) and its quantitative aspects (soil micromorphometry).

Many soil micromorphology studies have been conducted and published, especially on Ultisols, Oxisols, Spodosols and Paleosols (Goenadi and Tan, 1989a and 1989c). However, researches on volcanic soils (can be classified as Andisols - Soil Survey Staff, 1990) are still rare. Therefore, there is only a few information concerning micromorphological features on it, particularly the volcanic soils developing on different parent materials and agroclimatic zones mentioned in Oldeman (1975).

For this study, a research has been done on the micromorphological characteristics of volcanic soils on six pedons in the tea plantation area of West Java, Indonesia. The studied soils represent six different volcanic eruptions, ages, and parent materials, in three agroclimatic zones.

Materials and Methods

The soils from the eruptions of Mount Tangkuban Perahu are represented by pedon CTR-A2 (Ciater District, andesitic, agroclimatic zone A) developed from Middle Holocene age (Silitonga, 2003), and pedon CTR-B4 (Ciater District, andesitic, agroclimatic zone A) developed from Early Holocene age (Silitonga, 2003). The soils from the eruptions of Mount Kendeng and Mount Patuha are represented respectively by pedon SNR-A2 (Sinumbra District, andesitic, agroclimatic zone B1) developed from Pleistocene age (Koesmono *et al.*, 1996), and pedon SNR-B5 (Sinumbra District, basaltic, agroclimatic zoned B1) developed from Holocene age (Koesmono *et al.*, 1996). The soil from the eruptions of Mount Guntur and Mount Papandayan are represented respectively by pedon SDP-A3 (Sedep District, basaltic, agroclimatic zone, agroclimatic zone B2) developed from Pleistocene age (Alzwar *et al.*, 1992), and pedon SDP-B5 (Sedep District, basaltic, agroclimatic zone B2) developed from Holocene age (Alzwar *et al.*, 1992).

Undisturbed soil samples for the preparation of soil thin sections were obtained from every identifiable horizon in all profiles. The total number of samples was 49.

Preparation of the soil thin sections involved hardening of the samples by impregnation. Observations of the undisturbed samples were made with the naked eye, a magnifying lens, binocular stereomicroscope, polarization microscope and scanning electron microscope. The terminology and concepts of the Handbook for Soil Thin Section Description (Bullock *et al.*, 1985) were used as a basic reference, with a few modifications.

Result and Analysis

Micromass Colour

The colour of micromass as observed in thin sections partly depends on thickness, light source properties and magnification.

In this study, only small variations in colour were observed. The horizon A/Bw has a brown to dark brown colour. The horizon BC generally has a lighter colour compared to the other genetic horizons. Surface horizons and buried A horizons have the darkest colour. In general, the horizons of pedons CTR-A2, SNR-A2, SNR-B5 and SDP-A3 have a brown colour, except pedon SDP-A3, which was lighter. Pedon CTR-B4 and SDP-B5 have a dark brown colour.

The micromass colour in the thin sections was generally more brownish than the field soil capacity colour. Rainfall, age and parent material appear to have no significant effect on the micromass colour. However, in Ciater District pedon CTR-A2 generally has a lighter colour than CTR-B4, in Sinumbra District pedon SNR-A2 has a lighter colour than SNR-B5, and in Sedep District SDP-A3 is lighter than SDP-B5. This indicates that the older parent materials have a lighter colour than the younger parent materials.

Microstructure

Microstructure refers to the shape, size and arrangement of soil aggregates and pores that are generally observed at a rather low magnification.

Pedality

The complete results of observation of the microstructure are presented in Table 1. Some examples of soil microstructure features are presented in Figures 1a - f. The microstructure of

Table 1. Shape and Size of Aggregates, Degree of Pedality and Accommodation of the studied Profiles.: acc-accommodation; ab-angular blocky;sab-subangular blocky; gr-granular; cr-crumb; mv-massive; w-weak; m-medium; s-strong; pr-part; gd-good; no-non

Pedon/ Hor.	Depth (cm)	Shape	Size (mm)	Pedality	Acc.	Proportion (%)
Pedon CTR-A2						
Ap	0-17	gr	0.042-0.2	s	no	80
		ab	0.4-4.0	w	pr	20
Bw	17-31	gr	0.04-0.4	m-w	no	45
		sab	0.4-1.6	w	pr	55
BC	31-43	ab-sab	1.6-2,8	w	pr	30
		gr	0.4-0.8	w	no	30
		gr	0.04-0.12	w	no	40
2Ab	43-60	gr	< 0.08	w-m	pr	20
		gr	0.4-0.8	w-m	pr	40
		gr	1.6-2.4	w	no	40
2Bw	60-70	cr-gr	0.04-0.2	m-s	pr	40
		ab	0.08-4.4	m-s	pr	60
2BC	70-94	mv	-	-	-	90
		ab	-	m	no	10
3Ab	94-110	sab	0.4-0.8	m	pr	40
		cr	0.04-1.2	w	no	60
3Bw	110-128	ab	4.8	s-m	pr	80
		gr	0.08-0.4	s-m	no	20
Pedon CTR-B4						
Ap	0-15	gr	0.04-0.2	m	no	60
		gr	0.2-0.4	m	no	20
		gr	0.4-3.2	m	no	20
Bw	15-30	cr	0.04-11.0	m	no	70
		ab	2.0-5.0	m	no	30
BC	30-38	mv	-	-	-	100
2Ab	38-52	cr	0.02-0.04	m	no	80
		ab	0.4-1.0	m	pr	20
2BCb1	52-65	gr	0.02-0.2	m	no	60
		ab	0.7-2.0	m	pr	40
2BCb2	65-90	ab	5.0	m	pr	100
2A'b1	90-105	ab	0.04-0.4	m	pr	50
		ab	1.0-7.0	m	pr	50
2A'b2	105-120	ab	1.0-8.0	m	pr	85
		gr	0.04-0.8	m	no	15
Pedon SNR-A2						
Ap	0-10	gr	2.0-3.0	m	no	100
Bw1	10-23	ab	2.0-5.0	s	no	50
		sab	5.0-5.9	s	no	50
Bw2	23-40	ab	3.0-5.0	s	gd	100
Bw3	40-54	sab	1.0-10.0	s	pr	70
BC	54-73	sab	5.0-10.0	m	pr	70
2Ab	73-84	ab,sab	5.0-7.0	m	pr	80
2BCb	84-98	ab	2.0-7.0	m	pr	100
2A'b	-120/130	ab	2.0-3.0	m	pr	80
2BC'b	-142/148	sab,ab	1.0-2.5	m	pr	100
Pedon SNR-B5						
Ap	0-10	ab,sab	0.04-4.0	m	pr	70;30
Bw	10-19	ab,gr	0.04-3.6	m	pr	70;30
A'b	19-44	ab,gr	0.2-1.2	m	pr	70;30
Bcb	44-60	ab,sab	0.5-5.0	m	pr	
Pedon SDP-A3						
Ap	0-14	ab	1.0-5.0	m	pr	100
A2	14-24	ab,gr	1.0-4.0	m	no	50:50
Bw	24-35	ab	0.05-5.0	m	pr	60
		gr	0.12-0.24	m	pr	40
A'b1	35-46	ab	1.0-10.0	m	gd	100
A'b2	46-65	ab	0.1-5.0	m	pr	100
B'wb	65-81	ab	0.4-10.0	m	gd	100
A"b	81-95	ab	1.0-5.0	m	pr	100
B"wb	95-105	ab	0.4-2.8	m	pr	100
BCb	105-130	ab,mv	-	w	pr	
Pedon SDP-B5						
Ap	0-11	sab	1.0-8.0	m	pr	100
Bw	11-30	gr,sab	-	m	pr	25:75
A'b	30-45	sab,gr	-	m	pr	70:30
B'wb	45-54	sab	0.2-2.4	m	pr	70
		gr	0.08-2.4	m	pr	30
A"b1	54-72	sab	-	s	pr	100
A"b2	72-94	sab	0.2-1.0	m	pr	70
		gr	0.02-0.04	m	pr	30
B"wb	94-115	sab	7.0-8.0	m	pr	100
BCb	115-135	sab	0.4-4.00	m	pr	100
A"'b	135-152	sab	0.4-2.4	s	pr	100

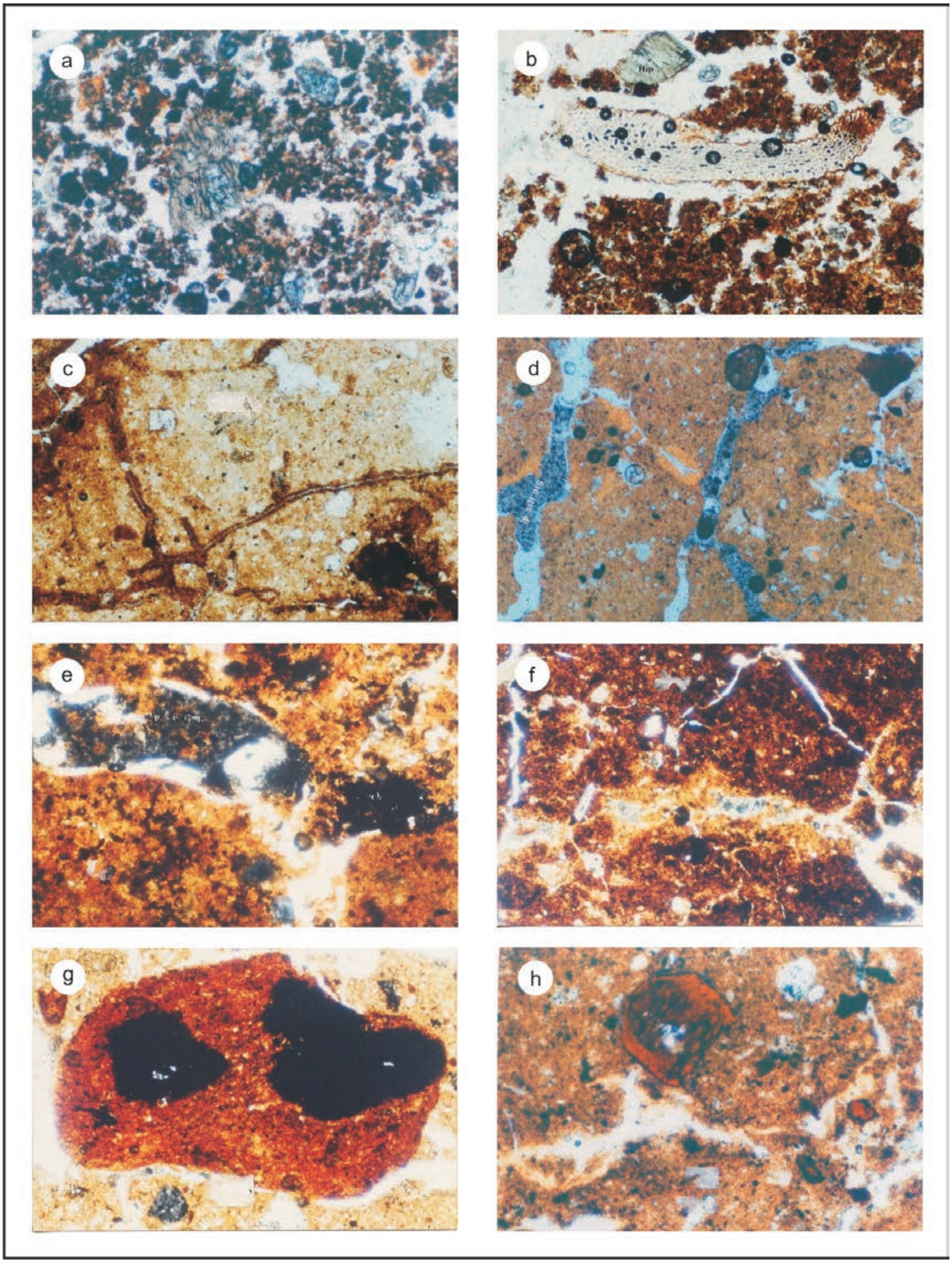

Figure 1. Photomicrographs of soil microstructure features, on thin sections within plane polarized light.
(a). Enaulic c/f related distribution patterns (Hor.Ap, CTR-A2); (b). Same as (a) (Hor.Ap, SNR-B5); (c). Porphyric c/f related distribution patterns (Hor.B'wb, SDP-A3); (d). Same as (c) (Hor.2Ab, SNR-A2); (e). Humic substances penetrating the groundmass (Hor.3Ab, CTR-A2); (f). Void types recognized as vugs (Hor.Ap, SNR-A2); (g). Iron nodules found in old pedon (Hor.A'b2, SDP-A3); (h). Subhedral mineral grains in old pedon (Hor.Bw, SDP-A3).

the Andisols ranges from granular to massive. The surface horizon generally has crumb and granular microstructures (Figures 1a and 1b), whereas the subsurface horizon has a blocky to subangular blocky microstructure.

The surface horizon (Ap) of soils developed in areas with high rainfall (*e.g.* Ciater) is characterized by a more strongly developed pedality (and darker colour) than those developed in relatively drier areas (Sinumbra and Sedep), which generally also have a lighter colour and tend to show rounded and subangular peds. This suggests that there is a relationship between organic matter content and pedality. Besides, the granular peds in the Ap horizon of soils developing on older parent materials are generally larger and have a denser groundmass than the younger soils. The chemical analysis indicates that the Ap horizon has a high organic carbon content and also contain Al- and Fe-bearing organic complexes. Those materials are predicted to play a role in forming a stable granular microstructure.

In all horizons, the size of the peds shows a rather wide range (0.02-11.00 mm). The degree of accommodation ranges from well accommodated to unaccommodated, and is generally partly accommodated (Figure 1f).

Type of Void

In surface horizons, compound packing voids are observed (Figures 1a and 1b). The voids that are equant to elongate, interconnected, occur between granular, crumb and angular blocky peds, which are unaccommodated. Other void types that are recognized are planar voids, chambers and vugs (Figures 1a, 1b, and 1f)

Subsurface horizons, which show crumb, granular or angular blocky microstructures, with or without pores, generally have planar voids, or planar voids with compound packing voids (Figure 1f). In a subsurface horizon **(**A'', Bw**)** planar voids, vugs, channels, chambers and vesicles are recognized to develop on old parent material (*e.g.* pedon SNR-A2 and SDP-A3-Figures 1g and h).

Planar voids in the surface horizon (Ap) generally develop along root residues or microfauna remains**.** In the subsurface horizon, planar void is mainly formed by a development of cracks in a dense groundmass material.

The Abundance of Void

The abundance of void in the thin sections was determined, expressed as a percentage of the total area within thin section (Fitzpatrick, 1984). The result shows that surface horizons have a higher porosity than the subsurface horizons. Hence, the percentage of voids decreases with depth. This can be clearly seen in old pedons such as SNR-A2 and SDP-A3. This is predicted in referring to processes of infilling of voids by illuvial material derived from the groundmass by percolation of water, gravity, and biological activity, taking place during a long period. Therefore, several pores have been closed and filled by material derived from upper horizons.

Related Distribution Patterns

Horizons in Andisols have porphyric and enaulic c/f related distribution patterns, *i.e.* they are composed of coarse materials embedded in a finer material (porphyric) or they have a skeleton of larger fabric units with aggregates of fine material in the interstitial spaces or enaulic (Goenadi and Tan, 1989b) where the aggregates do not completely fill the interstitial spaces, and the larger units support each other.

Surface horizon generally has enaulic c/f related distribution patterns (Figures 1a and 1b), especially in Andisols which developed on young parent materials. Andisols that developed from old parent material have porphyric c/f related distribution patterns in their surface horizons. The granular or crumb structure in the surface horizon could be related to a high biological activity (*e.g.*, termites, ants), and the intensive growths of roots. The allophane content in the surface horizon is generally lower than in subsurface horizons due to the strong accumulation of organic matter in the surface horizon, preventing the formation of allophanes because of the formation of Al-humus complexes (Maeda *et al.*, 1997)

The subsurface horizons have porphyric c/f related distribution patterns. These horizons have a high total density, with porous and nonporous parts. Pores in the porous parts can be filled with material derived from upper horizons. With time, they can develop into nonporous materials in this way.

Pedons SNR-A2 and SDP-A3 have porphyric c/f related distribution patterns (Figures 1c and 1d). Both pedons represents the older parent materials. The partly short range-order minerals have been weathered to crystalline minerals like halloysite, metahalloysite and gibbsite. The change in mineral composition is predicted to be accompanied by a change in c/f related distribution pattern from enaulic to porphyric.

The subsurface horizons of pedon CTR-B4 still have enaulic c/f related distribution patterns, although the age of this pedon is older than that of CTR-A2, which show porphyric c/f related distribution patterns. This indicates that the accumulation process in the subsurface horizons (pedon CTR-A2) was intensive due to the presence of impervious layers that prevent transportation of material to the lower horizons.

Pedofeature and Weathering Feature

The types of pedofeatures that have been recognized are amorphous and cryptocrystalline texture, fabric, and excrement pedofeatures (Bullock, 1985). Weathering of primary mineral grains is also considered. Table 2 gives a detailed overview of the pedofeatures observed in every studied horizon.

The features most commonly found in Andisols are the weathering of primary minerals and the illuviation and accumulation of material derived from upper horizons, as found by Goenadi and Tan (1989b). Illuvial material can be material that was derived from the groundmass, or fine organic material mixed with silt to very fine sand (Figures 1c and 1d). In addition, humic substances quite often penetrate the groundmass. These pedofeatures are generally found in the site with having young parent material and high rainfall (Ciater), or in the horizon directly underlying the buried A horizon (thaptic) (Figure 1e).

The other features generally found were the strong alteration of primary mineral, *e.g.* minerals susceptible to physical and chemical weathering in A, B, and BC horizons. Physical weathering can be in the form of fragmentation. Chemical weathering can be recognized by the change of form or colour of the mineral grains.

Mineral grains in pedons originated from old parent material generally have anhedral shapes (and low $c/f_{2\mu}$ ratios), whereas grains in younger pedons usually have subhedral to euhedral shape (and higher $c/f_{2\mu}$ ratios). Iron nodules are found in old pedon like SDP-A3 in Sedep (Figure 1g). The nodules were formed by residual accumulation of iron compounds, related to weathering of primary minerals. Gibbsite coatings (Figure 2a) are found in Acrudoxic Hapludand.

Weak indications for the clay illuviation are only recognized for the B'wb horizon in pedon SDP-A3, originated from old parent material, and in horizon 2BCb of pedon SNR-A2 (Figure 2b). These horizons do not fulfill the prerequisite of an argillic horizon in Soil Taxonomy (Soil Survey Staff, 1992) due to the small total volume of illuvial clay (< 1 %) and the low degree of orientation within the clay coatings. Maeda *et al.*, (1997) also reported a few coatings in Andisols. Mohr *et al.*, (1972) proposed that volcanic soils often include a horizon with clay accumulation.

Discussion

Micromorphology is the branch of soil science that is concerned with the description, interpretation and, to an increasing extent, the measurement of components, features and fabrics in soils at a microscopic level (Bullock *et al.*, 1985). Pedogenesis is no doubt the most important field of application of micromorphology. Although the study of soil genesis is rather a fundamental research, it is a necessary step for many applications as it forms the only sound basis to predict the response of a material to new and mostly human induced situation (Stoops, 1998). In this research, the soil genesis is reflected through the translocation of clay and gibbsite as can be seen in the planar void of the lower horizons which were filled by clay and gibbsite presented in Table 2 (CTR-A2, 3 Bw; SNR-A2, 2 A"B) and Figures 2a - e.

The main limitation of optical investigation is the difficulty to identify fine silt and clay sized minerals. This is especially true for the residual minerals or the weathering product homogenized by pedoplasmation. It must be emphasized that minerals associated with soils are in general much more complicated than those in geological materials. Although most information can be derived from the pedogenic mineral present, the degree and type of weathering of the detrital minerals should not be overlooked, and a special attention should be given to the presence of the pseudomorph (Stoops, 1998). In this research, some residual minerals were found, such as plagioclase (CTR-A2, 2BC), and volcanic glass (CTR-B4,2A'b1).

Table 2. Pedofeatures of every identifiable Horizon in the studied Soils

Pedon/horizon	Pedofeatures and weathering features (*and plant remains*)
CTR-A2	
Ap	Partly weathered primary minerals
Bw	Voids of root residue filled by granular groundmass material
	Fragment of altered root, coloured brown-black at the edge
BC	Planar voids filled by isotropic clay mixed with very fine sand
2 Ab	Fragment of yellowish weathered rock
2Bw	-
2BC	Plagioclase covered by opaque material
3Ab	Planar void filled by a mixture of clay and very fine sand
3Bw	Planar voids filled by clay
	Root residue, with black soil material at the edge
CTR-B4	
Ap	Voids of root residue, brownish, 20 %
Bw	Voids of root residue, 15 %
BC	Planar voids filled by a mixture of clay and very fine sand
	Brownish red organic fragments, 10 %
2Ab	-
2BCb1	Voids of root residue and organic fragments, 10 %
2BCb2	Planar void filled by granular clay aggregates and very fine sand
	Fragment of reddish weathered rocks with volcanic glass
2A’b1	Tuff with volcanic glass and yellowish brown clay minerals
2A’b2	Voids filled by very fine sand
2B’wb	Voids filled by very fine sand and groundmass material
SNR-A2	
Ap	Voids of tea plant’s root residue, reddish brown wall
Bw1	Voids filled by gibbsite
Bw2	Partly altered root fragments
Bw3	-
BC	Voids of rounded root residue filled by granular groundmass material
2Ab	Planar void filled by clay and gibbsite
2BCb	Planar void filled by clay
	Root fragments, 7 %
2A”B	Void of weathered mineral residue
	Planar void filled by clay and gibbsite
2BC’b	Planar voids and vughs filled by granular groundmass material
SNR-B5	
Ap	Opaque root fragments
Bw	Opaque root fragments
A’b	Opaque root fragments
BC’b	Voids of root residue, partly filled with groundmass material
	Typic nodules
SDP-A3	
Ap	Opaque and reddish brown root fragments
	Voids of root residue, partly filled with granular groundmass material
A2	Typic and nucleic nodules
	Root fragments
Bw	Typic and nucleic nodules
BC	Planar voids filled by groundmass material and very fine sand
A’b1	Hypocoating in the planar voids
	Typic nodules
	Planar voids filled by groundmass material and very fine sand
A’b2	Typic nodules
	Voids of root residue, reddish brown wall, partly coated by groundmass material
B’wb	Typic nodules
	Voids of root residue (Chamber), filled with groundmass material
	Typic hypocoating in planar voids
	Planar voids filled by groundmass material and very fine sand
A”b	Planar voids coated by groundmass material and very fine sand
B”wb	Typic coating in planar voids
	Planar voids filled by groundmass material
BC”b	Coating in planar voids (Typic)
	Planar voids filled by groundmass material and very fine sand
	Typic nodules
SDP-B5	
Ap	Planar voids filled by groundmass material and very fine sand
Bw	-
A’b	Planar voids filled by groundmass material and very fine sand
	Voids of weathered root residue, rounded, reddish brown wall
B’wb	Planar voids and compound packing voids filled by groundmass material and very fine sand
A”b1	Planar voids filled by groundmass material and very fine sand
A”b2	-
B”wb	Chamber filled by micropeds
BCb	-
A”’b	Planar voids and vesicles filled by groundmass material and very fine sand

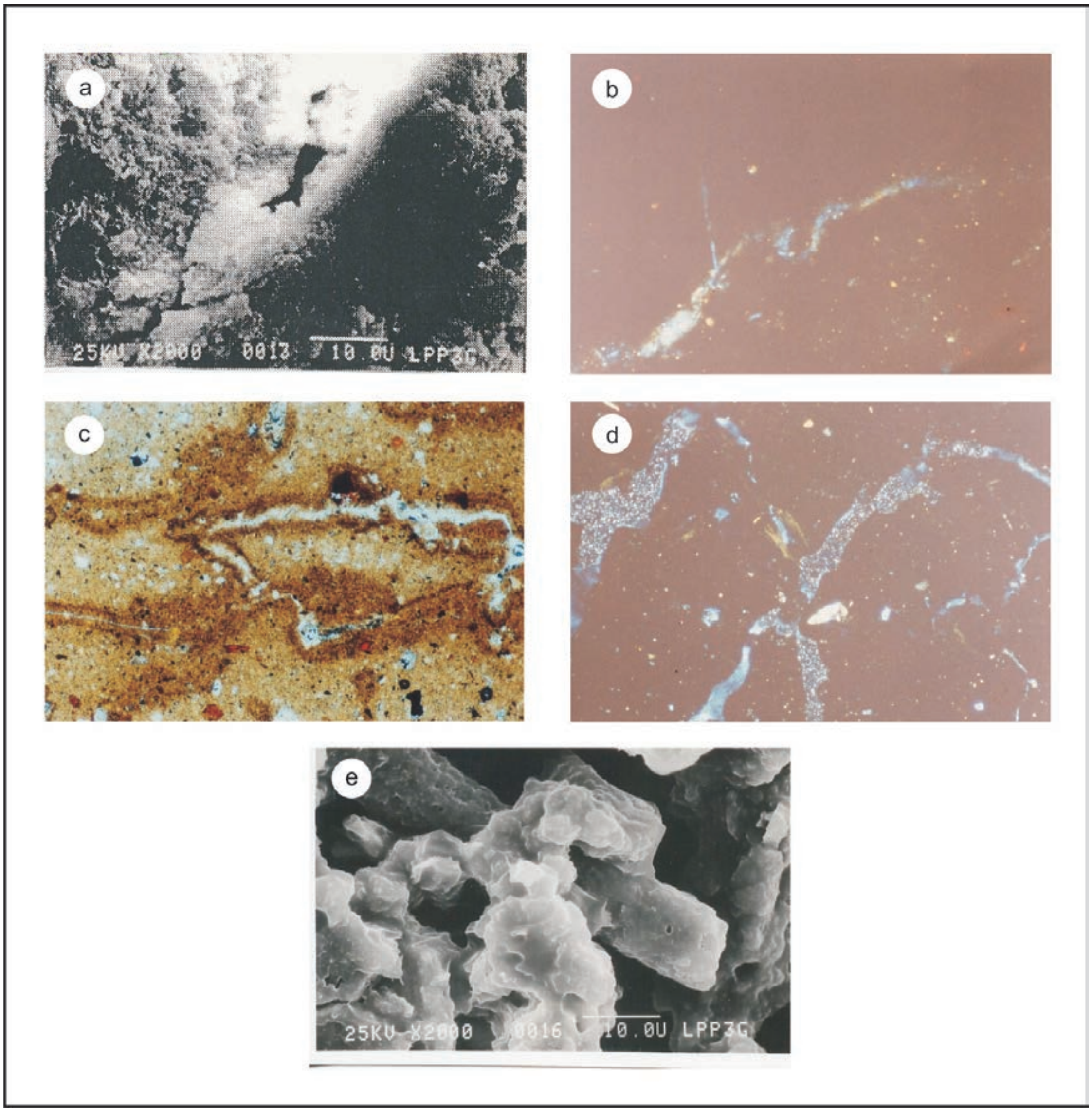

Figure 2. Photomicrographs of scanning electron microscopic (a and e) and microscopic images of thin sections (b – d). (a). Gibbsite coating in Hor.2BC'b, SNR-A2; (b). Clay coating in Hor.B'wb, SDP-A3, XPL; (c). Coatings of organic material in Hor.B'wb, SDP-A3, PPL; (d). Pores with infilling in Hor.2BCb, SNR-A2; (e). Clay coating on sand grains, Hor.Bw, SNR-B5.

Conclusions

1. Pedofeatures observed in thin sections are very useful to reveal pedogenetic processes. The pedon which developed after the eruption of Mount Guntur has clay coatings and nodules. The pedon that developed at Mount Kendeng has gibbsite coatings, and pedons which developed at Mount Papandayan and Mount Tangkuban Perahu (eruption A and C) have coatings of organic material.
2. Micromorphological characteristics of volcanic soils which developed from old parent material were different from those of soils that developed from young parent material. The former have porphyric c/f related distribution patterns, low $c/f_{2\mu}$ ratios, poor sorting, common infillings and coatings of voids, a few clay and gibbsite coatings, anhedral primary mineral grains, planar voids, a blocky to angular blocky microstruc-

ture, well-developed pedality and good accommodation. The soils on young parent materials have enaulic c/f related distribution patterns, high $c/f_{2\mu}$ ratios, poor sorting, infillings composed of groundmass material, silt and organic material, subhedral to euhedral primary mineral grains, a granular microstructure, a crumb to blocky microstructure with medium pedality, partly accommodated peds and compound packing voids.

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