Micromorphological characteristics of soils developed on volcanic ash in Lembang area, West Java, Indonesia

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Abstract. The study of micropmorphological characteristics of soils formed from Volcanic Ash in Lembang area, West Java is still rare. The aim of this study is to determine micromorphological characteristics of soils on Volcanic Ash in Lembang area. About 16 Kubiena boxes soil samples from three representative soil profiles were analyzed to determine their micromorphological characteristics. Results of thin sections indicated that the soils show most horizons of the soils developed on volcanic ash have granular microstructures. The coarse/fine (c/f) materials related distribution pattern of the soils is open porphyric. The coarse materials found in the soils are generally dominated by hornblende. Some fresh rock fragments are clearly identified and are generally composed of feldspar, hornblende, and hyperstene. The fine materials of most horizons are brown to dark brown, dotted to stipple-speckled clay and showing undifferentiated b-fabric. The main organic materials observed in the profiles are plant root residues of fine to coarse size and are filled by excrement of soil animals. Weathering of rock fragments and mineral alteration are the most common pedofeatures. The high amount fresh ferromagnesian minerals and the granular microstructures indicated that the soils have high nutrient reserves and high pore spaces supporting for plant growth and development.

1. Introduction
The Indonesian archipelago is predominantly mountainous with some 400 volcanoes, of which 129 are active. Twenty-one of these volcanoes are located in West Java [1]. The activity of these volcanoes may produce various volcanoclastic materials such as ash, tuff, pumice, cinders, lahars and other volcanic ejecta.

The beneficial effects of volcanic eruption are often more subtle, occurring on a geologic timescale rather than during the lifetime of an individual. The development and rejuvenation of soils provide an environment favorable to the eventual establishment of lush vegetation and the ecology of organisms, including human beings. The periodic additions of volcanic ash renew the long-term fertility status by providing a source of nutrients from the rapid weathering of ash [2].

Soils formed from volcanic materials have many distinctive properties that are rarely found in soils derived from other parent materials [3]. These soils have high potentials for agricultural production. However, some of them produce well below their potential capacity due to lack of understanding of the nature and properties and proper management of these soils.

Most soils developed on volcanic materials usually have andic properties. Stoops [4] described the micromorphological properties of soils with andic properties. The soils have a porous microstructure...
ranging from spongy to granular. The porosity pattern is dominated by packing pores, channels and vughs. Coarse materials consist mainly of rock fragments, volcanic glass, single mineral grains and phytoliths in different proportions. The rock fragments are essentially of volcanic origin. The fine materials are mostly dark brown colour, dotted and undifferentiated b-fabric. The fine material seems to be an intimate mixture of amorphous clay and organic material. When the coarse material is dominant, an enaulic or chitonic c/f related distribution may occur. Pedofeatures are rare in the soils. There are not so many pedofeatures seen in the volcanic ash soils [5], apart from an important amount of loose microaggregates infilling in channels.

Utami [5] reported that soils developed from volcanic ash from Java, mostly develop granular microstructure, which sometimes aggregated to a large size subangular blocky microstructure and have high porosity. Augite, hypersthene, hornblende, olivine, plagioclase, volcanic glass, and phytolith are common components in most soils. The micromass is probably composed of allophane, iron, and organic matter.

Andisols formed from volcanic ash at the Tea Estate Regions of West Java, Indonesia have been studied by Arifin [6]. The study showed that the micromorphological characteristics of the soils derived from old volcanic ash are different from that of the young parent materials. The old Andisol profiles have the soil fabrics which show porphyric patterns, low c/f 2µ values, relatively intense infilling and coatings of voids or pedds, little argillans and gibbsans in the B horizons, the shape of primary minerals commonly anhedral, and angular to subangular blocky structures. On the other hand, the young Andisol profiles show the enaulic and intertextic patterns of the soil fabrics, high c/f 2µ values, infilled voids by the mixtures of plasma, silt, and organic matter (organ), subhedral to euhedral primary minerals, granular, crumb, or subangular blocky structures.

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 2µ ratios, sorting, infillings and coatings of voids, and microstructure [7].

Lembang is one of the most intensively cultivated areas for horticultural crops, tea and pine trees in West Java, Indonesia. The agricultural practice carried out in the areas was based on semi-scientific agrotechnology or medium input farming. Soils of this area are developed on volcanic ash materials. Unfortunately, data of micromorphological characteristics of soils developed on volcanic ash materials are still lacking. Thus, the aim of this study is to determine micromorphological characteristics of soils developed on volcanic ash materials to give a more accurate information of their micromorphological properties to support soil management.

2. Materials and methods

2.1. Description of study area

The study area is located in the southwest slope of Mt. Tangkuban Perahu (2,076 m asl). It is situated in the intensively cultivated vegetable growing areas and uncultivated or secondary forest areas of Lembang, about 10 km to the north of Bandung, West Java, Indonesia.

The soil profiles are located in the nearly flat to rolling topography (slope ranging from 2 to 10 percent). The elevation of the profiles is between 1,247 meters and 1,500 meters above sea level. There were 3 soil profiles selected for this study. All the soils are developed on volcanic ash parent materials with geological ages of Late Pleistocene [8]. Major physical environment of the studied soils is shown in table 1.

There are three main landforms in the study area, namely volcanic plain and lower volcanic ridges. The volcanic plain landform is located around Cisarua (in the middle of the study area) and Lembang. Landform of lower volcanic ridges can be found in the south slope of Mt. Tangkuban Perahu.

The mean annual rainfall of Margahayu, Lembang is 2,401 mm. Based on the climatic data, the study area can be classified into A type according to Schmidt and Ferguson [9]. The wet period starts from October to May, with the wettest month reaching 307 mm. The study area, which has 7 wet
months (> 200 mm) and 2 dry months (< 100 mm) can be classified into the B2 agroclimatic zone according to Oldeman [10] classification. According to Soil Taxonomy [10], the study area has an udic soil moisture regime because there is no drought for as long as 90 cumulative days in normal years.

Air temperature in the study area at 1,250 m altitude varies from 14 to 24º C. The mean annual air temperature is 20º C. The soil profiles which are located above 1,200 m asl have an isothermic soil temperature regime according to Soil Taxonomy [11].

| No. | Profile | Land Use      | Age                | Elevation (m asl) | Slope (%) |
|-----|---------|---------------|--------------------|-------------------|------------|
| 1.  | VA-1    | vegetable garden | Late Pleistocene   | 1,305             | 10         |
| 2.  | VA-2    | vegetable garden | Late Pleistocene   | 1,247             | 2          |
| 3.  | VA-3    | secondary forest | Late Pleistocene   | 1,500             | 9          |

### 2.2. Materials

Three profiles developed on andesitic volcanic ash materials were selected at different locations in the Lembang area, of which 2 profiles are situated in the intensively cultivated vegetable areas and 1 profile in the secondary forest areas. The undisturbed soil samples using Kubiena boxes were taken from each horizon of all the selected profiles for micromorphological studies. The morphological characteristics of the profiles were described following the Soil Survey Manual [12].

### 2.3. Methods

The undisturbed soil samples were air-dried at room temperature for several days followed by oven drying for 48 hours at 40º C. The samples were impregnated under vacuum for about 8 hours with a crystic resin mixed with acetone and a small amount of catalyst and accelerator. The samples were placed in a well-ventilated fume cupboard and left to harden. The samples were cut with a diamond saw followed by polishing one side of the blocks.

After polishing the blocks, they were thoroughly cleaned and glued on to glass slides with a thick crystic resin mixture containing enough catalyst and accelerator to harden within one hour. The specimens were then reduced to 40 to 50 µm with an Ecomet III polisher. Finally, the specimens were hand polished to about 30 µm thick and covered with cover-glass using some resin [13]. Thin section identification dan characterization were conducted by using polarization microscope.

### 3. Results and discussion

#### 3.1. General soil properties

All the soils have very deep solum (>150 cm). Some soil profiles have buried organic-rich horizons as a result of repeated thin ash deposition. In general, the soils show dark colour, granular, friable, slightly sticky and slightly plastic soil consistencies. The ash soils generally have silt loam to clay loam textures. The soils have low bulk density (0.38 to 0.79 Mg m⁻³), high total porosity (55 to 84%) and high available water content (13.0 to 34.6%).

The pH H₂O of the soil ranges from 3.52 to 5.88. The soils have high pH NaF (> 9.4), high organic carbon (up to 10%), and high phosphate retention (> 85%). The high values of pH NaF and phosphate retention in the volcanic ash soils are related to the presence of large amounts of amorphous Al. The CEC is generally high (22 to 46 cmolc kg⁻¹) and the base saturation is generally low (< 15%) in the upper horizons of all the soils.

The sand fractions of the soils are dominated by hornblende. In the silt fractions, all the soils show traces to minor amounts of cristobalite, tridymite and quartz. The soils are dominated by allophane with varying amounts of cristobalite. The soils are classified as Thaptic Hapludands and Typic Melanudands according to Soil Taxonomy [11] or Thapto-Silic Andosols and Melano-Silic Andosols according to World Reference Base [14].
3.2. Micromorphological characteristics of volcanic ash soils

Major micromorphological properties of the soils developed on volcanic ash parent materials in Lembang Area, West Java are given in tables 2, 3, and 4. While some thin section micrographs of the soils are presented in figures 1 and 2.

3.2.1. Microstructure and voids. Most of the soil horizons show a granular microstructure (figure 1 A) with grade of pedality from moderate to strong, and fine to medium in size. The subangular blocky microstructure is only observed in the lowest horizon (2Bwb1) of profile VA-3 and in the buried Bw horizons of profile VA-1. In 2Bwb3 horizon of profile VA-1, the vughy microstructure is also found. The voids of the soils are generally complex packing voids with size ranging from very fine to medium. The compound packing voids are generally found in the buried Bw horizons of profiles VA-1 and VA-3. The presence of large amounts of organic matter and allophane content plays an important role in the formation of granular microstructure and high pore spaces.

3.2.2. C/F related distribution. The c/f related distribution of the soils is open porphyric. Profile VA-2 shows a high c/f ratio throughout the profile, ranging from 1/3 to 1/6. It indicates that the high coarse materials are present in the soil. The high c/f ratio also indicates a low stage of weathering. The A and buried A horizons of profiles VA-1 and VA-3 tend to have higher c/f ratio (1/4 to 1/6) than Bw and buried Bw horizons (1/6 to 1/8). This indicates that the coarse materials are higher in the surface horizons (A and Ab) than in the subsurface horizons (B and Bwb) due to new ash addition.

3.2.3. Coarse materials. The coarse materials found in the soils are generally dominated by hornblende (figure 2 A). Feldspar is present in small to moderate amounts. Small amounts of colourless volcanic glass are also present. Some fresh rock fragments (figure 1 B and C) and ferromagnesian minerals (figure 2 B) are clearly identified. The rock fragments found in the soils are generally composed of feldspar, hornblende, and hyperstene.

The amount of primary minerals tends to decrease with depth. Most primary minerals observed in the profiles are commonly present in fresh condition and are relatively large (medium to coarse sand). Large amounts of phytoliths are only observed in the surface horizons (Ap and AB) of profile VA-2. This indicates high biological activities. Utami [5] reported that the high content of phytoliths was attributed to labile silica rich parent materials in a conducive environment to high uptake by silica accumulating plant species.

3.2.4. Fine materials. The fine materials of most horizons are brown to dark brown, dotted to stipple-speckled clay and showing undifferentiated b-fabric. The fine materials of yellowish brown, stipple-speckled, and undifferentiated b-fabric are only observed in the buried Bw horizons of profiles VA-1 and VA-3. The darker colour of the fine fractions is related to the high content of organic matter in the profiles. The undifferentiated b-fabric feature is probably due to the presence of amorphous clay and organic materials.

3.2.5. Organic materials. The main organic materials observed in the profiles are plant root residues of fine to coarse size. The plant root residues are commonly found in the surface horizons (A and AB). In the AB horizon of profile VA-1, some plant root residues are filled by excrement (figure 2 C) of soil animals. The presence of the excrement may indicate high biological activity.

3.2.6. Pedofeatures. Weathering of rock fragments and mineral alteration are the most common pedofeatures. Excrement pedofeatures (figure 2 C) are observed in the AB horizon of profile VA-1. These pedofeatures are commonly associated with plant remains. The presence of excrement pedofeatures may indicate high biological activities [15].
Table 2. Major micromorphological characteristics of profile VA-1

| Horizon | Microstructure and voids | *c/f 10 µm related distribution | Coarse and Fine Materials | Organic materials | Pedofeatures |
|---------|--------------------------|---------------------------------|---------------------------|-----------------|--------------|
| **Ap**  | granular with complex packing voids | 1:5 open porphyric | hornblende, feldspar, v. glass, hyperstene, weathered rock fragment | dark brown, stipple-speckled, undifferentiated b-fabric | plant root residues | * root section |
| **AB**  | granular with complex packing voids | 1:6 open porphyric | hornblende, feldspar, v. glass, hyperstene, glassy rock fragment | brown, dotted clay, undifferentiated b-fabric | plant root residues with excrement | * weathering of rock fragment |
| **2Ab** | granular with complex packing voids | 1:6 open porphyric | hornblende, feldspar, v. glass, hyperstene, glassy rock fragment | dark brown, dotted clay, undifferentiated b-fabric | - | * excrement pedofeatures |
| **2Bwb1** | granular + subangular blocky, complex packing voids | 1:7 open porphyric | hornblende, iron oxides, glassy rock fragment, hyperstene | dark brown, stipple-speckled, undifferentiated b-fabric | - | * excrement pedofeatures |
| **2Bwb2** | subangular blocky, compound packing Voids | 1:8 open porphyric | hornblende, iron oxides, glassy rock fragment, | yellowish brown, stipple-speckled, undifferentiated b-fabric | - | * mineral alteration |
| **2Bwb3** | subangular blocky, vugly, compound packing voids | 1:8 open porphyric | iron oxides, weathered rock fragment | yellowish brown, stipple-speckled, undifferentiated b-fabric | - | * not clear |

Note: *coarse/fine (c/f) materials ratios and coarse/fine (c/f) related distribution patterns
### Table 3. Major micromorphological characteristics of profile VA-2

| Horizon | Microstructure and voids | *c/f 10 µm related distribution | Coarse Materials | Fine materials | Organic materials | Pedofeatures |
|---------|--------------------------|---------------------------------|-----------------|----------------|-------------------|--------------|
| Ap1     | granular with complex packing voids | 1:4 open porphyric | hornblende, feldspar, v. glass, hyperstene, rock fragment, Phytoliths | dark brown, dotted clay, undifferentiated b-fabric | plant root residues | * weathering of rock fragment * mineral alteration |
| AB      | granular with complex packing voids | 1:6 open porphyric | hornblende, feldspar, v. glass, hyperstene, rock fragment, Phytoliths | dark brown, dotted clay, undifferentiated b-fabric | plant root residues | * weathering of volcanic glass * impregnated nodules |
| Bw1     | granular with complex packing voids | 1:3 open porphyric | hornblende, feldspar, v. glass, hyperstene, rock fragment | dark brown, dotted clay, undifferentiated b-fabric | - | * weathering of rock fragment |
| Bw2     | granular with complex packing voids | 1:5 open porphyric | feldspar, hornblende, v. glass, hyperstene, glassy rock fragment, weathered rock fragment | dark brown, dotted clay, undifferentiated b-fabric | - | * mineral alteration |

Note: *coarse/fine (c/f) materials ratios and coarse/fine (c/f) related distribution patterns

### Table 4. Major micromorphological characteristics of profile VA-3

| Horizon | Microstructure and voids | *c/f 10 µm related distribution | Coarse Materials | Fine materials | Organic materials | Pedofeatures |
|---------|--------------------------|---------------------------------|-----------------|----------------|-------------------|--------------|
| Ah      | granular with complex packing voids | 1:7 open porphyric | hornblende, feldspar, v. glass, Hyperstene | brown, speckled, undifferentiated b-fabric | plant root residues | * mineral alteration |
| Bw      | granular with complex packing voids | 1:6 open porphyric | hornblende, feldspar, v. glass, weathered hornblende, rock Fragment | dark brown, stipple-speckled, undifferentiated b-fabric | plant root residues | * mineral alteration |
| 2Ab     | granular with complex packing voids | 1:5 open porphyric | hornblende, feldspar, v. glass, hyperstene, glassy rock fragment | dark brown, dotted clay, undifferentiated b-fabric | - | * mineral alteration |
| 2ABBb   | granular with complex packing voids | 1:6 open porphyric | hornblende, feldspar, v. glass, hyperstene, glassy rock fragment | dark brown, dotted clay, undifferentiated b-fabric | - | * mineral alteration |
| 2Bwb1   | subangular blocky, compound packing Voids | 1:8 open porphyric | hornblende, iron oxides, feldspar | yellowish brown, stipple-speckled, undifferentiated b-fabric | - | - |

Note: *coarse/fine (c/f) materials ratios and coarse/fine (c/f) related distribution patterns
Figure 1. Thin section micrographs showing (A) granular microstructure in the Bw1 horizon of profile VA-2, (B and C) fresh rock fragment in the Ap1 horizon of profile VA-2. (PPL=Plane Polarized Light; XPL=Cross Polarized Light)
Figure 2. Thin section micrographs showing (A) hornblende in the Ap1 horizon of profile VA-2, (B) fresh ferromagnesian minerals in the Bw1 horizon of profile VA-2, and (C) excrement pedofeatures in the AB horizon of profile VA-1. (PPL=Plane Polarized Light; XPL=Cross Polarized Light)
3.3. Soil management implication

Information of the soil micromorphological characteristics is important for productivity and management of the soils. The presence of granular microstructure, plant root residues and excrement pedofeatures indicates that all of the studied soils have high pore space. The presence of large amounts of organic matter and allophane content in the soils developed on volcanic ash plays an important role in the formation of granular microstructure and high pore spaces because soils with high organic matter content tend to be well aggregated and consequently have better porosity, higher friability and lower bulk density. These properties provide a conducive soil environment for deeper rooting activity and therefore supply more water for vigorous plant growth [16]. In addition, low bulk density and friable consistence contribute to more favorable soil tilth leading to easy tillage, seedling emergence and root development. Stable aggregate and high porosity of soils could minimize water erosion.

The presence of high fresh rock fragment and primary minerals (feldspar, hornblende, and hyperstene) indicate that all the studied soils have high level of fertility status. The primary minerals weathering may supply more nutrients for plant growth and development. Thus, all of the volcanic ash soils studied have high potency for agricultural development, mainly horticultural crops.

4. Conclusions

Most horizons of the soils developed on volcanic ash in Lembang Area have granular microstructures. The c/f related distribution pattern of the soils is open porphyric. The coarse materials found in the soils are generally dominated by hornblende. Some fresh rock fragments are clearly identified and are generally composed of feldspar, hornblende, and hyperstene. The fine materials of most horizons are brown to dark brown, dotted to stipple-speckled clay and showing undifferentiated b-fabric. The main organic materials observed in the profiles are plant root residues of fine to coarse size and are filled by excrement of soil animals. Weathering of rock fragments and mineral alteration are the most common pedofeatures. The high amount fresh ferromagnesian minerals and the granular microstructures indicated that the soils have high soil nutrition and high pore spaces supporting for plant growth and development.

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