Characteristics of Soils Developed from Pyroclastic Materials Across the Dry Southwest Tambora’s Footslope

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Abstract. Development of soils from newly deposited materials are of interest for investigation, especially when the environment has specific conditions as the leading factors of the soil formation and development. The Southwest Tambora’s footslope is part of the last Tambora’s pyroclastic deposition but this part has the driest climate. Despite this Southwest Tambora’s footslope in fact at macro scale has homogeneous specific conditions, the results of toposequential soil observation showed that this area composed of soils having significant differences, even differed one another at the higher order of classification. The common characteristic of the soils in this area is that they have sandy texture with 70 to 90 percent sand mostly with limited soil horizon development, only minority of the soils already have B horizon. Regardless the sandy texture as the common strong characteristic of the soils here, the formation of B horizon is the strongest differentiae among the soils and yet there are some other characteristics to show that even the soils of the same taxonomic class are not necessarily homogeneous. Previous geological studies of this part of Tambora’s footslope depicted different modes of the deposition of the last erupted pyroclastic materials, among others by transportation and sortation processes after the material eruption. This difference has resulted in different stratification of particle size and the level of compaction of the pyroclastic materials. So the soil formation here have been taken place from not a completely homogeneous parent material condition, under the limited weathering rate due to the dry climate.

1. Introduction
The catastrophic Tambora's eruption in 1815 is recorded as the newest great volcanic activity over the world (Abdullah, 2016). This eruption is also recorded as one of great pyroclastic eruptions in history that has resulted in a quite thick deposition of pyroclastic materials on the immediate surrounding areas. The deposition of this last Tambora’s eruption has a unique process, hence as well has resulted in a unique stratigraphy with respect to mineralogical and physical characteristics (Sutawidjaja et al., 2006). As new coming materials, the pyroclastic materials of the 1815’s Tambora’s eruption has covered the existed soils. Report of Sutawidjaja et al. (2006) shows that, in common the existed soils were covered by the new materials of around 4 m thick. The upper part of the new deposit then has been weathered ever since and now it has some characteristics that mostly showing the nature of juvenile soils. There are many reports on the development stage and characteristics of such young soils developed from different ages of pyroclastic parent materials, one is about soils developed from Mt. Pinatubo’s lahar (Sasaki et al., 2003). However, there is still a lack in data related to the characteristics
of soils developed from relatively new deposited pyroclastic parent materials but under dry climate condition.

An intensive soils survey of an area of about 5000 ha on the south west of the Tambora’s footslope have been carried out at 1:10,000 scale by IPB University’s team in coordination with PT. SMS. The results of field observation and analysis of soil samples in this survey show variation of some characteristics of the soils that cannot be ignored. This variation shows a degree of difference that has led to different soil classes according to the Soil Taxonomy classification system. Among the soils in this area, there are even soils having characteristics showing a slight advance development than others. The existence of slightly developed soils are rather contradictory with general theory that the process of soil formation from newly deposited materials (Sasaki et al., 2003) and under dry climate condition will hardly be advanced as the weathering is still at the initial stage and continuing take place very weak and slow (Özcan and Özaytekin, 2011). The intensive field observation made during the survey mentioned above has gave a sight that the variation may relates to the different in the characteristics of newly deposited pyroclastic materials which the upper part is being weathered into soils. The climate has likely no diverse intensity in controlling the weathering process for all the area because all parts of the area in concern of this study has the same climate that is dry and is classified as a savanna climatic zone.

This article was therefore constructed to depict a study results on the kind and degree of characteristic variation of soils developed from parent materials of completely the same origin and under absolutely the same climate in a quite narrow area. This article also shows a qualitative description on the correlation between the way of the pyroclastic deposition from the last Tambora’s eruption with the ever since soil development.

2. Materials and Methods

2.1 Materials
Study area is located in Pekat Sub district, Dompu Regency, West Nusa Tenggara (NTB). This area is of a concession belong to PT. SMS that is operating a sugar plantation in this location. The area is elongated along the seashore of the south west part of the Sangar Peninsula (Figure 1). It extents in perpendicular to the sea from the lowest border at about a half kilometer from the seashore to the higher topography in the direction toward the Tambora Mount, having the Tambora National Park outer border as the highest edge. The elongated wide is about 10 km and the perpendicular wide is about 5 km to have the total area of around 5000 ha.

All parts of the study area have the same climate, that is dry and is classified as a savanna climatic zone. From a generic view the study area is also considered to have a homogeneous soil parent materials as the whole study area was covered by the last, new, and great Tambora’s eruption product.
Figure 1. Study location (surveyed area by IPB University’s Team in collaboration with PT. SMS)

Soil and topography data used in this study and presented in this article are part of data generated during the above mentioned intensive survey (Note: The conducting persons in soil observation and mapping in the survey are us, the authors of this article). A part of the generated soil map is shown in Figure 2. The soil morphological data were selected from data set of soil profiles made during field observation during the survey. Chemical and physical data of the selected profiles were compiled for this study also from the dataset of that survey.

Figure 2. Part of soil map of study area made by by IPB University’s Team in collaboration with PT. SMS
2.2 Methods
This study was started with selection of soil profile data obtained during the soil survey of the study area mentioned above. The data selection and compilation in this study were made to represent the soils found in the study area those showing a significant difference in their characteristics which function as the classification differentiae. This selection was focused on the soil profiles having almost the same name according to Soil Taxonomy classification system and these homogeneous soil profiles are those in fact located in a cluster that reflecting a similar topographic or geomorphic condition. As then detected in the observation record map of the survey activity, there are two clusters of soil profiles found in this selection criteria (Figure 3). One is the cluster of the slightly more developed soils (cluster 1) and the other is the most juvenile soils (cluster 2).

![Figure 3. Two soil clusters identified in study area based on the soil map made by IPB University’s Team in collaboration with PT. SMS](image)

This study is tightly based on the general theory of soil formation that assuming the soil formation will undergo the process under the control of merely one factor when the other soil forming factors are homogeneous. The climate of study area is certainly homogeneous and the soil parent materials from a broad view is also considered homogeneous as well especially with respect to the last and relatively new geological activity. So, each soil cluster was then plotted in a toposequence to see if the topography has significant effect on the soil formation and development process or there is another factor that more likely function as the determinant of the soil difference in the area. The two
Toposequence of soil profiles were interpreted in a broader look to find the possible cause of the difference between each cluster with by taking into consideration the stratigraphic and lithologic description of the study area made by Sutawidjaja et al. (2016).

On the selected data, a description analysis was then made to show which characteristics of the soils in the study area having degree of difference that fall into a difference level lead to different soil class according to Soil Taxonomy classification system. The identified differences were then elaborated with respect to the differentiae for each classification hierarchy in Soil Taxonomy.

3. Results and Discussion

Morphological characteristics of the representative soil profiles are summarized in Table 1. The morphological data is supported by laboratory data for the particle size. The data in Table 1 shows that in general the central characteristic of the soils found in the study area is that they have very coarse texture. The significance difference between the two groups of soils is in the genetic horizon composition where one group has only A and C horizons while the other has A, B, and C horizons.

The soil texture of almost all the soil horizons of every soil profile were fall in the sandy class according to the standard particle size classification for pedogenic data and its interpretation. However, the profiles having B horizons have mostly a finer texture in their horizons. Furthermore, the soil morphology data record shows that soil structure already developed in the soils with B horizon even though it is still at very initial stage.

Table 1. Summary of morphological and physical properties of representative profiles

| Soil Order | Profiles | Genetic horizons | Texture | Structure | Color | Specific physical charact. |
|------------|----------|------------------|---------|-----------|-------|---------------------------|
| Inceptisols | HWP 10, HWP 11 | A1/A2/2Bw1/2Bw2/2C | ± 10% clay in B horizon, much gravel and stoniness | Granular – Angular blocky | Brown, reddish brown | Depth <140 cm |
|            | HWP 12   | A/AB/2Bw/2C      |         |           |       |                           |
| Entisols   | HWP 1    | A/2C1/2C2/2C3, | ± 5% clay in all hor. | Granular- | Light brown, pale brown | Low penetrability layer(s) |
|            | HWP 5, HWP 7 | A/AC/2C1/2C2/2C3 | less gravelly and or stoniness | Loose-Massive | | Depth <120 cm |

In the highest category of Soil Taxonomy that is the Order, the representative profiles are classified into either Entisols for the soils having only A and C horizons and Inceptisols for the soils with B horizon. The differentiae of the soils in the Order category is the existence or the absence of B horizon that is a strong differentiae. The existence or the absence of B horizon in a soil profile indeed certainly reflect the stage of soil formation and development. The question is how come that such significant difference would occur in a short distance within a narrow area considered to have almost homogeneous soil parent materials? Is also a wonder that the significant difference occurred between the two toposequences not within each toposequence indicating that the topographic condition in a toposequence does not act as predominant factor for the soil formation and development processes. This fact is quite contradictory with the general theory or model of soil catena and the reason is yet not identified in-depth in this study.

The most possible determinant factor in differentiating the soils between the clusters is the soil parent material. The existence or the absence B horizon under the same climatic condition would be possible only if the soil parent materials are indeed different when the topographic effect is not a dominant factor. In basic soil science it is believe that the main determining factor of soil
characteristics is the composition of parent material and the specific processes of the soil formation. However, it is also believed that it is indeed difficult to determine to what extent parent material will influence a soil (Jenny 1994). Researches made by, among others, Anda (2012), Cronin et al. (1996), Solleiro-Rebolledo et al. (2003), and Tabor et al. (2004) on various volcanic soils and paleosols generally show that the composition of the soil has appeared to vary according to the type of volcanic deposit (i.e. lava flow, ash, tuff) constituting the parent material. However, none of them work for soils developed after a new eruptional deposition having significance stratigraphic inhomogeneity.

The report of Sutawidjaja et al. (2006) figured out the stratigraphic deposition of the last Tambora’s eruption (Figure 4). It is described in the stratigraphic model figure that the Tambora’s last eruption had deposited materials in two distinctive phases (each consists of more detail phases). The first phase is the falls of plinian pumice and phreatomagmatic ash and the second is the flow and surge of pyroclastic. The fall is referred to the direct fall of pumice and ash. The subsequent flow and surge of pyroclastic than swapped over and underlain this pumice and ash deposit. However, in the detail factual there is likely parts of the immediate footslope area of the Mount Tambora, such as within this study area, having no swap from the flow and the surge and hence the fall pumice and ash were still on the top in stratigraphy.

![Pyroclastic stratigraphy of the 1815 Tambora eruptive product](image)

**Figure 4.** Pyroclastic stratigraphy of the 1815 Tambora eruptive product (Sutawidjaja et al., 2006)

The soils with B horizons are represented by 3 profiles named as HWP 10, HWP 11, and HWP 12 those are located in cluster 1 and are likely were developed from the fall deposited. This area was not covered by the subsequent flow and surge of pyroclastic materials due to a topographical barrier as can be illustrated by a cross section model (Figure 5). The cross-section model was made based on the transects along the HWP 10 - HWP 11 - HWP 12 and HWP 1 - HWP 5 - HWP 7 topographical position as referred to the topographic map used in the survey (see Figure 3). The soils having no B
horizon in the contrary are represented by 3 profiles named as HWP 1, HWP 5, and HWP 7 those are located in cluster 2 and are likely were developed from the deposit resulted from the flow and surge of pyroclastic.

The fall deposit is not stratified into hard and compacted layers although has significant coarse particles that make this deposit more gravelly and even stoniness.

According to the explanation made by Sutawidjaja et al. (2006) and based on the morphological features of the soil especially of the C horizon and the bedrock, the fall deposit is characterized by more heterogeneous particle size but did not stratified and cemented into hard gravelly and stoniness layers whereas the pyroclastic flow and surge deposit has less heterogeneous particle size and less stoniness and gravelly but they are stratified by combination of the hardness and the sortation of the particle sizes. This contrasting physical characteristic, eventually, had led the weathering rate on each type of material differed one to the other. The unstratified and more porous (air and water permeable) plinian fall deposit had been likely more weathered because of more intensive physical and mechanical weathering due to higher contact and penetration of oxygen and moisture than that on the pyroclastic flow and surge deposit. The more water permeable of the likely plinial fall (layers in the cluster 2) has been tested by a simple test by dropping some water on the surface of the layers and it was observable that the water was hardly infiltrate into the layers. This difference had led to the formation of weak B horizon in the profiles HWP 10, HWP 11, and HWP 12 (cluster 1) and no formation of the weak illuvial horizon in the profiles HWP 1, HWP 5, and HWP 7 (cluster 2). All the B horizons in the soils found in cluster 1 in this study area are categorized as Bw indicating the very early B horizon formation. The evidence of more intensive weathering of the soils of cluster 1 is shown by the higher clay proportion than that of the soils in cluster 2. In the Soil Taxonomy, the Bw horizon is defined as horizon with the development of color or structure, or both, with little or no apparent illuvial accumulation of material” (USDA, 2014). According to a review made by Ugolini and Dahlgren (2002) the soils developed from volcanic ash in arid and semi-arid climate are fall into Entisol, meaning that no development of B horizon yet. Hence this finding certainly adds a new

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**Figure 5.** Predictive pattern of pyroclastic flow and surge deposition of the 1815 Tambora eruption product (Sutawidjaja et al., 2006)
information of possibility of B horizon formation even from quiet new deposited volcanic material and under a dry climate, which indeed need further deep researches.

Under the Order category, the soils of both clusters were further classified throughout the hierarchical categories in the sequence of Suborder-Greatgroup-Subgroup-Family according to the Soil Taxonomy system. By this classification sequence, the Inceptisols represented by HWP 10, HWP 11, and HWP 12 are found to have no separation into certain class in certain category by certain characteristic(s) as the differentiae and so for the Entisols. All the profiles of each cluster fall into one Suborder, Greatgroup, Subgroup, and Family. The Family of the soils in cluster 1 is Vitrandic Haplustepts, sandy sceletal, mix, active, isohypertermic and Family of the soils in cluster 2 is Vitrandic Ustorthents, sandy sceletal, mix, active, non-acidic, shallow, isohypertermic.

Soil penetrability measurement was done during the survey which were intended to seek the information related to water and root penetrations. The data show a degree of difference that is significance in search for the best soil management related to water availability and plant rooting. Again, this difference is strongly attributable to the depositional mode and hence the stratigraphy of the last Tambora’s pyroclastic eruption in which the difference shows that the soils developed from the pyroclastic flow and surge deposit have layer(s) with low penetrability. However, this difference is not of the soil taxonomic classification differentiae.

4. Conclusion

In the south west Tambora’s footslope, slightly more developed soils having B horizons (Inceptisol) are found in a cluster side by side with the cluster of less developed soils (no B horizons; Entisols). Within the cluster of each side the soils does not significantly vary despite the topographical difference. The pattern of deposition and hence the stratigraphy of the Tambora’s eruptive product is the only possible determinant for the different soil distribution pattern.

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