# ON THE GENESIS AND CLASSIFICATION OF SOILS, DERIVED FROM ANDESITIC TUFFS UNDER HUMID TROPICAL CONDITIONS [1]

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## SUMMARY

Morphological and chemical descriptions were provided of soils, derived from andesitic tuffs under conditions of high rainfall and perfect drainage, but on various altitudes. The soils could be grouped in five belts. For these soil groups the following names were proposed: Belt 1, extending from 1600 m to 1300 m altitude: Humic Grey-Brown Podsolic soils; Belt 2, from 1300 m to 1000 m altitude: Tropical Grey-Brown Podsolic soils; Belt 3, from 1000 m to 600 m altitude: Acid Brown Forest soils (according to a suggestion of Dr. VEENENBOS); Belt 4, from 600 m to 300 m altitude: Podsolized Brown Latosols (already described by DAMES, 1955); Belt 5, from 300 m to sea level: Latosolic soils (suggested by: THORP and SMITH, 1949).

The physical and chemical differences were discussed on the basis of the rate and mode of destruction of the organic matter, on the diffusion of the carbon dioxide developed, and on the nature of the clay formed.

## INTRODUCTION

Several attempts are already made to classify soils, developed from volcanic material under semi-tropical and tropical conditions. A.o. TAYLOR (1948) published a soil map of New Zealand, including soils derived from rhyolitic and andesitic material; SHERMAN, FOSTER and FUJIMOTO (1939), TAMURA, JACKSON and SHERMAN (1953) and SHERMAN and KANEHIRO (1954) published on properties of Hawaiian soils, which are defined by CLINE et al. (1954) and which are developed over basaltic material; KELLOG and DAVOL (1949) published on soil groups in Belgian Congo; DAMES (1955) produced a soil map of East Central Java (Indonesia) and v. SCHUYLENBORGH and v. RUMMELEN (1955) studied the genesis of some soils derived from liparitic-, andesitic-, and basalto-andesitic tuffs at high altitudes.

It is the scope of this paper to study in more detail the genesis and classification of soils developed over andesitic tuffs at different altitudes, under perfect drainage conditions and conditions of high to very high rainfall. The parent materials of the soils range from andesitic tuffs with oligoclase and andesine to basalto-andesitic tuffs with andesine and labradorite as the plagioclases. The volcanoes from which the tuffs are derived are of Plio-Pleistocene and Pleistocene age (v. BEMMELEN, 1949).

## METHODS

The discussions are based on: 1) the profile morphology; 2) the pH-values; 3) the organic matter profile; 4) the mineralogical composition of the sand and clay fractions; 5) the chemical composition of the clay fraction; and on 6) the C/N-values of the organic matter.

The methods used in the determination of the pH-values, mechanical composition, organic matter and the mineralogical composition are the same as reported before (v. SCHUYLEN-

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BORGH and V. RUMMELEN, 1955). All samples were analysed in the field-wet state, because air-drying produces intense changes in the physical state of the soils (BIRRELL, 1952 ; BIRRELL and FIELDES, 1952 ; v. SCHUYLENBORGH, 1954). The samples of the soils at higher altitudes could only be peptised satisfactorily with 0.003n hydrochloric acid in the mechanical analysis, whereas for the samples of the lower situated soils a 0.0006 molar solution of sodium pyrophosphate produced the best results.

The analysis of the chemical composition of the clay was carried out as described by BILTZ and BILTZ (1947, p. 380 et seq.), using the sodium carbonate fusion. Iron was determined by titration with versenate solution (KUANG LU CHENG, BRAY and KURTZ, 1953) with sulfosalicylic acid as the phosphorus and titanium were determined spectrophotometrically, using the methods of SCHEEL (1936) and of WEISLER (1945), respectively. The spectrophotometer, employed for these analyses, was the Hilger UVISPEK. The nitrogen was determined by the KJELDAHL-method (see : PIPER, 1947, p. 200).

The detailed profile descriptions, the mineralogical composition of the sand fractions and the chemical composition of the soils are represented in the appendices I, II, and III, respectively.

## BRIEF DESCRIPTION OF THE PROFILES AND DISCUSSION OF ANALYTICAL DATA

From the profile descriptions, represented in appendix I can be concluded that the soils are to be divided into five belts. The first belt (profiles 1 to 3), extending from 1600 m to 1300 m altitude, is characterized by the occurrence of soils of the following profile : A layer of forest litter of 5 cm thickness is overlying a dark grey brown to black, very friable $A_1$-horizon with granular to nutty structure (thickness of 16—30 cm), and a light to dark yellowish brown, friable $A_2$-horizon with a irregularly platy structure (thickness : 10—30 cm), in turn lying over a brownish yellow to dark brown, friable $B_1$-horizon with heavier texture and nutty structure (thickness : 16—19 cm) and a still heavier, friable, $B_2$-horizon with yellowish to reddish brown colour, nutty structure, and with a thickness of 30—40 cm. The parent material is brownish yellow andesitic tuff.

The soils show resemblances with the Grey-Brown Podsolic soils of the humid temperate climates. The organic matter content, however, is very high. Therefore, here the name Humic Grey-Brown Podsolic is proposed for these soils. Also the analytical data (appendix III) show the same trends as those, available for the Grey-Brown Podsolic soils (see the next chapter). The analysis shows a with depth increasing clay content, decreasing organic C-content, decreasing C/N-ratio, decreasing molar $SiO_2/Al_2O_3$ and $SiO_2/Fe_2O_3$-ratios in the clay and a pH varying from 7 to 6. The molar $Al_2O_3/Fe_2O_3$-ratio has a maximum value in the $A_2$-horizon. There is a definite increase of iron concretions in the sand fraction (see : appendix II), whereas hydrargyllite is absent. These data point to the fact that iron is more mobile than aluminium. The clay consists of an abundance of amorphous material (probably allophane : see the low molar $SiO_2/Al_2O_3$-ratios) with small admixtures of montmorillonite, kaolinite, hydrargyllite and $\alpha$-crystoballite. No quantitative differences in the latter minerals could be noticed.

The soils of the second belt, extending from 1300 m to 1000 m altitude, are characterized by the following profile (an example is profile 4) : A forest litter layer of a thickness of 3—4 cm is lying over a very dark brown to very dark grey brown, very friable $A_1$-horizon with granular to nutty structure (thickness : 15—20 cm) and a dark brown to dark grey brown, friable $A_2$-horizon with nutty structure and heavier tenture (thickness : 13—15 cm), in turn lying over a dark yellowish brown, friable, heavy $B_1$-horizon with nutty structure (thickness: 20–25 cm) and a yellowish brown, friable $B_2$-horizon with nutty structure and still heavier texture (thickness: 20–25 cm). The parent material is brownish-yellow andesitic tuff.

Although there are similarities with the soils of the first belt, also differences can be noticed. Especially the absence of a platy $A_2$-horizon is important. In the earlier investigation (v. SCHUYLENBORGH and v. RUMMELEN, 1955), the name Tropical Grey-Brown Podsolic soil was proposed, only to intend, that the soil formation is a podsolic one (see appendix III), clay migration occurs, the colour of the A-horizon is dark grey brown and of the B-horizon yellowish brown and that they occur under tropical humid conditions.

The analytical data (appendix III) show a with depth increasing clay content, pH-values ranging from 5 to 5.8, decreasing carbon content, nearly constant C/N-ratio, decreasing molar $SiO_2/Al_2O_3$- and increasing molar $Al_2O_3/Fe_2O_3$-ratio in the clay. The $SiO_2/Fe_2O_3$-ratio has a minimum value in the $A_2$. Mineralogically, an abundance of amorphous material was observed, whilst admixtures of montmorillonite, kailinite, $\alpha$-crystoballite and hydrargyllite occur, the latter increasing in amount with depth (maximum in the $B_2$). All these facts lead to the conclusion, that, in these soils, aluminium is more mobile than iron. The sand fraction (appendix II) shows very little differentiation in the iron concretions. Hydrargyllite is present and increases definitely with depth. Part of the rock fragments is densely set with hydrargyllite. These facts, too, point to the conclusion on the greater mobility of aluminium.

The soils of the third belt, extending from 1000 m to 600 m altitude, can be described as follows (profiles 5, 6, 7 of appendix I): The $A_{00}/A_0$-horizon is a mull with thickness of 2–3 cm and is lying over a grey to dark brown, friable, heavy-textured, $A_{11}$-horizon with crumbly to nutty structure (thickness: 5–20 cm) and a yellow brown to dark grey) brown, friable, lighter-textured $A_{12}$-horizon (thickness: 20–22 cm), in turn lying over a light yellowish brown to reddish brown, friable, $B_1$-horizon with nutty to crumbly structure and still lighter texture (thickness: 15–25 cm) and a pale brown to reddish brown, friable $B_2$-horizon with a light texture and nutty structure (thickness: 45–60 cm). The parent material is yellow to strong brown andesitic tuff.

The profiles show characteristics similar to those of Brown Forest soils, the pH-level of the horizons, however, is too low. Therefore, here the name Acid Brown Forest soil is proposed, as suggested to us by Dr. VEENENBOS in a personal communication.

The analytical results (appendix III) show a with depth decreasing clay content, pH-values varying from 4.2 to 5.5, a decreasing carbon content, nearly constant C/N-ratio, decreasing molar $SiO_2/Al_2O_3$ and increasing $Al_2O_3/Fe_2O_3$ ratios in the clay, whereas the molar $SiO_2/Fe_2O_3$-ratio appears to have a minimum value in the $A_{12}$ or $B_1$ horizon or remains constant.

The clay fractions contain much amorphous material (very probably allophane) with admixtures of montmorillonite, kaolinite, hydrargyllite and $\alpha$-crystoballite. In the upper profiles of this belt the amount of hydrargyllite increases with depth, whereas in the lower profiles the amount remains constant and the amount of montmorillonite increases. These results permit the conclusion, that here, as in the soils of the second belt, the aluminium is more mobile than iron. The sand fraction (appendix II) of these profiles have in general a constant content of iron concretions, whereas that of hydrargyllite increases with depth. These observations confirm the conclusion on the mobility of $Al_2O_3$ and $Fe_2O_3$.

The fourth belt, extending from 600 m to 300 m altitude, show profiles (an example is prof. 8, appendix I) with a very thin organic layer, lying over a dark brown, friable, rather heavy-textured, $A_1$-horizon with crumbly structure (thickness : 20—40 cm), in turn lying over a dark brown, friable, heavy-textured, $B_1$-horizon with nutty to crumbly structure (20–35 cm thick), and a brown to reddish brown, friable, very heavy-textured, $B_{21}$-horizon with nutty structure (37–50 cm thick), and this in turn overlying a brown to reddish brown, rather friable, $B_{22}$-horizon with blocky structure (28—40 cm thick). The parent material is very pale brown to light yellowish brown andesite tuff.

The profiles show characteristics of podsolic as well as of lateritic soils. It is therefore proposed to classify these soils as Podsolized Brown Latosolic soils. Also DAMES (1955) reports the occurrence of such soils ; they were, however, derived from sandy limestones, sandstones and sandy clays of Neogene age and occurred from sea level up to 250 m.

The analytical results show a with depth increasing clay content, decreasing carbon content, constant C/N-ratio, decreasing molar $SiO_2/Al_2O_3$-, increasing molar $SiO_2/Fe_2O_3$- and $Al_2O_3/Fe_2O_3$-ratios. The pH-value is nearly constant and about 6. The clay fraction contains a certain amount of amorphous material, kaolinite, small amounts of montmorillonite and hydrargyllite, the latter increasing in amount with depth. Furthermore, a small decrease of iron concretions could be noticed in the sand fraction of the deeper horizons (appendix II), whereas hydrargyllite showed little differentiation. It can be concluded that also in these soils aluminium is more mobile than iron.

Finally, the fifth belt (300 m to 0 m altitude: profiles 9 and 10) is the belt of the Latosolic soils (THORP and SMITH, 1949), the upper part occupied with reddish-brown (Reddish-Brown Latosols), the lower part with reddish-brown to red soils (Red Latosols). The clay contents are constant over a considerable depth, the pH-values vary from 6 to 6.5 and the structures are crumbly to nutty. The C/N-ratio decreases with depth, as does the molar $Al_2O_3/Fe_2O_3$-ratio in the clay, whereas the molar $SiO_2/Al_2O_3$-ratio increases and the $SiO_2/Fe_2O_3$-ratio varies (appendix III).

The clay fraction shows no differentiation in minerals and contains some amorphous material, kaolinite, little montmorillonite and hydrargyllite. The percentage iron concretions in the sand fraction is high and constant over the whole profile (appendix II). The same holds for hydrargyllite, though a tendency for an accumulation in the surface layer could be noticed. These data points to the conclusion, that iron is more mobile than aluminium in the Latosols. CAMPBELL (quoted by ROBINSON, 1949, p. 414) arrived already in 1917 to the same conclusion when the stated : "On account of the greater mobility of ferric oxide in colloidal solution, it may happen that lateritic horizons become progressively more aluminous in character with age."

For the sake of a general survey, table 1 provides a summary of the data mentioned above.

Table 1 Schematical representation of the soils examined.

| Belt | Colour surface horizon | Structure | Clay content | pH | Org. N | C/N | Clay | | | | Sand | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $\frac{SiO_2}{Al_2O_3}$ | $\frac{SiO_2}{Fe_2O_3}$ | $\frac{Al_2O_3}{Fe_2O_3}$ | hydrargyllite | iron concretions | hydrargyllite |
| 1 1600–1300 m (Humic Grey-Brown Podsolic) | very dark grey-brown to black | $A_1$ : granular to nutty<br>$A_2$ : irregularly platy<br>B : nutty | +[1] | 7–6 | – | – | – | – | max. in $A_2$ | ± | + | absent |
| 2 1300–1000 m (Trop. Grey-Brown Podsolic) | very dark grey-brown | $A_1$ : granular<br>$A_2$ : nutty<br>B : nutty | + | 5.5–6 | – | ± | – | min. in $A_2$ | + | + | ± | + |
| 3 1000–600 m (Acid Brown Forest) | grey to dark brown | A : crumbly to nutty<br>B : nutty | – | 4.2–5.5 | – | ± | – | min. in $A_{12}$ or $B_1$ | + | + | ± to + | + |
| 4 600–300 m (Podsolized Latosolic) | dark brown | A : nutty to crumbly<br>$B_1$ : nutty<br>$B_2$ : nutty to blocky | + | 6 | – | ± | – | + | + | + | ± to + | ± |
| 5 300–0 m (Latosolic) | reddish brown to red | crumbly to nutty | ± | 6–6.5 | – | – | + | ± | – | ± | ± | ± |

[1] +, –, and ± mean : increasing, decreasing, and constant with increasing depth, respectively.

## ON THE GENESIS OF THE SOILS EXAMINED

In the previous paper, v. SCHUYLENBORGH and v. RUMMELEN (1955) accepted the idea of MOHR (1922), that at high temperatures mineralisation of the organic matter in and on the soil is more important than humification. Thus the soils, developed under tropical humid conditions (precipitation always exceeding evapotranspiration), were suggested to be formed under the influence of carbonic acid, originating for the greater part from the $A_{00}$-horizon and to a smaller part from the organic matter in the soil. This idea was supported by the constant C/N-ratio over the whole profiles and by the fact, that deforestation leads to a very rapid decrease of organic matter in the soil. Also JOFFE (1931, 1936) has stated: "It seems that the process of podsolization is to a large extent intimately related to the speed of decomposition and quantity of organic matter. A too rapid destruction of the organic matter depresses the reactivity efficiency of the split products, since under such conditions the organic acids produced are usually decomposed to the so-called mineralized state. The result is that the rôle of the organic acids is reduced to a minimum." We shall now examine whether the above mentioned hypothesis provides starting-points for the genesis of the profiles under investigation in this paper.

One of the most important features observed is the difference in pH range of the soils of the five belts. The soils of the middle belt show the lowest pH-values, increasing in the soils of higher as well as of lower altitudes. It will be tried to explain this on the basis of the destruction rate of the organic matter into carbonic acid and the diffusion rate of $CO_2$ from the $A_{00}$-horizon and soil into the air.

The carbon dioxide, produced during the destruction of the organic matter, dissolves in the rainwater and forms a certain amount of carbonic acid. Application of the law of mass action to this reaction gives:

$$^{c}CO_2 \cdot {}^{c}H_2O = k_1 \cdot {}^{c}H_2CO_3 \qquad (1)$$

(See also: MELLOR, 1953, vol. VI, p. 51). As the concentration of the water is always large compared with the concentrations of $CO_2$ and $H_2CO_3$, we can consider it constant. Relation (1) passes into:

$$^{c}CO_2 \, k_2 = k_1 \cdot {}^{c}H_2CO_3{}' \text{ or } {}^{c}CO_2 = k_3 \cdot {}^{c}H_2CO_3 \qquad (2)$$

where $k_3 = k_1/k_2$, indicating that the concentration of carbonic acid is proportional to the amount of $CO_2$ dissolved. Furthermore, it can be stated that HENRY's law approximately holds for the relation between the $CO_2$-pressure in a gas mixture and its solubility in the liquid in contact with this gas mixture. Thus:

$$^{p}CO_2 = k_4 \cdot {}^{c}CO_2 \qquad (3$$

Substitution of (3) in (2) gives:

$$^{p}CO_2 = k \cdot {}^{c}H_2CO_3 \qquad (4)$$

where $k = k_3 \,.\, k_4$. Apart from this reaction, the dissociation of carbonic acid occurs, with the relation:

$$K = \frac{^{c}HCO_3' \cdot {}^{c}H^{\cdot}}{^{c}H_2CO_3} = 3.5 \times 10^{-7} \qquad (5)$$

If k were known, the pH-values of water in contact with gas mixtures with different partial $CO_2$-pressures could be calculated. Because k was onknown, the author determined the pH of distilled water in contact with $CO_2$-gas ( $^{p}CO_2 = 1$) at a temperature of 23.5° C, calculated from (5)$^{c}H_2CO_3$ and finally k from equation (4). With the k-value, derived in this way, the pH values of water in contact with air with different $^{p}CO_2$ values could be computed. The results are given in table 2.

Table 2 The pH-values of water in contact with air of different $p_{CO_2}$-values.

| Volume % $CO_2$ | $^{p}CO_2$ (atm.) | pH |
|---|---|---|
| 0.03 | $0.30 \times 10^{-3}$ | 5.69 |
| 10 | 0.10 | 4.43 |
| 25 | 0.25 | 4.23 |
| 50 | 0.50 | 4.08 |
| 100 | 1.0 | 3.93 |

From this table can be concluded, that the pH-value of the moisture in the $A_{00}$-layer will be low enough to produce, upon percolation, the acid soils of the third belt, if there is a possibility, that this moisture is in contact with an atmosphere of $^{p}CO_2$ of about 0.25 atm. Now, there are several indications that the percentage $CO_2$ in soil air can rise to considerable values. Already WOLLNY (quoted by: MITSCHERLICH, 1950, p. 100) found that the volume percentage of $CO_2$ in soil air was nearly 10 in a sandy soil after the application of organic manure. Furthermore he stated, that the higher the water content and temperature of the soil, the higher the $CO_2$-concentration was in soil air. LEATHER (1915) reported $CO_2$-contents in tropical soils up to 17 vol. %. Theoretically, we can assume a complete consumption of the oxygen in the by water entrapped air pockets in the organic matter layer on the soil, which leads to $CO_2$-percentages of 21. This, together with the mineral acids, produced during the mineralisation of the organic matter, can render the solution in the organic matter layer, at least temporarily, sufficiently low to produce the acid soils of the third belt, especially when this layer is moist, which always occur under conditions, prevailing in a tropical rain forest. This condition will be approached more closely as the temperature rises.

At low altitudes (high temperature), however, the $A_{00}$-horizon is very thin, making possible a rapid exchange of the produced $CO_2$ with air by diffusion. The partial $CO_2$-pressure in a thin $A_{00}$-layer can never rise to high values, with the result that the persolating water has a high pH-level with the subsequent formation of soils with low acidity. A thick $A_{00}$-horizon coincides with low temperatures (high altitude) and, therefore, with a slower destruction of the organic matter. Consequently, the partial $CO_2$-pressure will not rise to high values. Here too, the result will be that the percolating solution has a relatively high pH-level, leading to the formation of soils with low acidity. Between the belts with high temperatures and thin $A_{00}$-horizons and the belts with lower temperature and thick $A_{00}$-horizons, a belt must occur with moderately high temperatures and with $A_{00}$-horizons sufficiently thick to impede the rapid diffusion of the produced $CO_2$ into the air. The result will be that the percolating solution is acid and forms acid soils. These considerations are represented schematically in table 3.

Table 3 Relation between temperature, rate of destruction of organic matter and soil pH.

| Temperature → | rate of destruction org. matter | → $A_{00}$-horizon → | $^{P}CO_2$ → | percolating water with | → soil with |
|---|---|---|---|---|---|
| low 1) (16.5–20° C) | slow | thick (3–5 cm) | low | high pH | high pH |
| moderately high (20–22.5° C) | rapid | moderately thick (2–3 cm) | high | low pH | low pH |
| high (22.5–26° C) | very rapid | thin (0–1 cm) | low | high pH | high pH |

1) The notations low, slow, etc. have to be taken in a relative sense.

Further it should be remarked here, that the same reasoning can be applied to the $CO_2$-relationships in the soil. Only it has to be considered, that at low altitude, the organic matter content in the soil is low, so that the partial $CO_2$-pressure can not rise to high values.

Objections can be raised by remarking that the ash constituents, liberated during the mineralisation of organic matter, neutralize the carbonic acid largely and by pointing out that at low temperatures the solubility of the $CO_2$-gas in water is greater than at high temperatures. As to the first objection, it should be emphasized that also nitric acid, sulfuric acid and phosphoric acid are produced, neutralizing the greater part of the bases. This can be seen from table 4, where the mean composition of four samples of forest litter, occurring under tropical rain forest, is given. The total of the anions even exceeds the total of the cations. The second objection can be meeted by stating that the partial $CO_2$-pressure has a much stronger effect on the amount of $CO_2$-gas dissolved than temperature. MELLOR (1953, p. 51) gives for the absorption of $CO_2$ from air at 15° C and 25° C the amounts: 0.57 mg $CO_2$ and 0.41 mg $CO_2$ per liter of water, respectively. An increase of 0.03 vol. % $CO_2$ to only 1 vol. % $CO_2$, however, increases the amount of $CO_2$ dissolved from 0.41 mg to 13.3 mg per litre of water at a temperature of 25° C.

Table 4 Mean composition of four samples of forest litter (m.e./100 g matter).

| $SiO_2$ | N ($NO_3$) | P ($PO_4$) | S ($SO_4$) | Al | Fe | Ca | Mg | K | Na | Total of anions | Total of cations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 234.3 | 147.1 | 4.1 | 21.4 | 34.1 | 8.2 | 56.7 | 57.0 | 8.2 | 1.9 | 172.6 | 166.1 |

The above mentioned mechanism delivers at the same time an explanation for the fact (as we have observed: see also p. 11), that in regions with a distinct monsoon climate (a sharp prolonged dry season, alternating a wet season), the laterized soils, derived from andesitic tuffs, reach to far higher altitudes as in a continually humid climate. Not only the amount of organic matter produced will be smaller, but also the $A_{00}$-horizon dries out during the dry season. The partial $CO_2$-pressure, therefore, will not rise to high values, so that the medium will be less acid, which is favourable for a lateritization process.

The second important point to be explained is the fact, that the soils of the upper and lower belts show an enrichment or constancy of the clay fraction with depth, whereas the soils of the middle belt show a decrease of clay with depth (see table 1). Very probably, this phenomenon has to be considered in connection with the different pH-levels of the soils and with the nature of clay minerals present. The predominant clay mineral, at least in the soils of the four upper belts, is nearly certainly allophane. This X-ray amorphous clay mineral has a varying $SiO_2/Al_2O_3$-ratio (from 2 to 1) and is considered to be a solid solution mainly of silica, alumina and water (BRINDLEY, 1951, p. 48). If this is true and if the theory of MATTSON can be applied to the clay formation in volcanic soils, as is assumed by FIELDES and SWINDALE (1954), we would, according to MATTSON (1931) arrive at an isoelectric point for allophane between pH 6.7 (for a molar $SiO_2/Al_2O_3$-ratio of 1) and pH 5.9 ($SiO_2/Al_2O_3$-ratio of 2) as is accepted by BIRRELL and FIELDES (1952). Between these pH values allophane will be isoelectric and therefore flocculated and rather immobile. Consequently, this would mean that no or only a slight migration of clay could occur in the soils of belt 1, 4, and 5 (pH-level of the soil between 6 and 7), moderate migration of clay in the soils of belt 2 (soil pH between 5.5 and 6) and a strong migration in the soils of belt 3 (soil pH between 4 and 5.5). However, just the reverse can be observed and it is therefore necessary to seek a different explanation, either by changing the quantitative base of MATTSON's theory or by looking for a quite different mechanism.

Now, MATTSON's theory is based on the fact that colloidal alumina has an isoelectric point at pH 8.1. It has been shown by v. SCHUYLENBORGH (1951), however, that aluminium hydroxide with quite different electrokinetic behaviour can be readily prepared by passing very slowly $CO_2$-gas through this solution or by allowing it to stand at the air.

The isoelectric pH-values appeared to be 5.4 and 4.9, respectively. When applying now MATTSON's rules to the precipitates with silica, it is evident, that they would have very low isoelectric points or no such points. This was indeedly true for the clay minerals kaolinite, halloysite, illite and montmorillonite (v. SCHUYLENBORGH and SÄNGER, 1950). It is therefore probable that also allophane, although amorphous, will have a low isoelectric pH-value and we have to conclude that another mechanism is responsible for the observed clay migration. Since the clay fractions of all soils examined contain a certain amount of aluminium hydroxide (see appendix III), it is not unlikely to assume that the allophane particle is surrounded by a layer of alumina (especially at low pH-values, because then alumina is electropositive and can be adsorbed by the electronegative allophane particles) and obtains the electrokinetic properties of the latter. Such a mechanism was supposed by SCHUFFELEN and v. SCHUYLENBORGH (1951) to explain the electrokinetic behaviour of ballmilled kaolinite. It was proved that ballmilling set free alumina, which surrounded the kaolinite particles, dependent on the pH-values of the medium. Also the statement of BIRRELL and FIELDES (1952), that acid pretreatment of allophane containing soils for mechanical analysis should be avoided because of the possibility of partial decomposition of the clay particles, points to the probability of the above mentioned assumption). The isoelectric point of allophane will then be near pH 5. And now it is immediately evident that the clay fraction of the soils of belt 3 (pH-level between 4.2 and 5.5) is flocculated (leading to the formation of crumb structures) and therefore immobile, so that a relative accumulation of clay in the surface layers can be expected. At higher pH levels, such as in the soils of the other belts, the allophane particles possess an electrical charge and become mobile. It is then possible that the clay particles migrate with the percolating waters to lower depths along the root channels and soil capillaries.

Whether or not the mechanism, proposed by SIMONSON (1950) for the genesis of Red-Yellow Podsolic soils, contributes to the clay enrichment in the lower horizons or, eventually, counteract the accumulation of clay in the surface horizons, could not be established with certainty. An increase in the hydrargyllite and or montmorillonite content of the clay fraction could be observed (appendix III and table 1), but a relative enrichment of some other clay constituent could not be noticed. Only, higher $TiO_2$-contents could be stated in the upper horizons of the soils of the fourth belt (see table 5). The $TiO_2$-content of the other soils examined remains more or less constant or increases. Hence, there are indications that, in the soils of the fourth belt, the greater clay content in the B-horizons can be caused by the breaking down of the clay in the upper horizons and subsequent washing out of the decomposition products. Possibly, this mechanism contributes strongly to the migration of clay, because in this belt the clay content is high and a migration of clay therefore difficult.

Table 5 Percentage $TiO_2$ of the clay of the soils examined.

| Soil \ Horizon | $A_{11}$ or $A_1$ | $A_{12}$ | $A_2$ | $B_1$ | $B_{21}$ or $B_2$ | $B_{22}$ | C |
|---|---|---|---|---|---|---|---|
| Humic Grey-Brown Podsolic (belt 2 : prof. 3) | N.D. | 1.00 | 1.01 | 1.18 | 1.22 | – | – |
| Trop. Grey-Brown Podsolic (belt 2 : prof. 4) | 0.98 | – | 1.00 | 0.99 | 1.02 | – | 0.97 |
| Acid Brown Forest Soil (belt 3 : prof. 7) | 0.92 | 0.91 | – | 0.83 | 0.90 | – | 0.85 |
| Podsolized Latosol (belt 4 : prof. 8) | 1.28 | – | – | 1.01 | 0.97 | 0.95 | 0.89 |
| Latosol (belt 4 : prof. 9) | 1.19 | 1.10 | – | 1.20 | 1.18 | – | 1.24 |

The to a considerable depth constancy of the clay content in the Latosolic soils is probably due to the different nature of the clay mineral (kaolinite is here predominant) and to the high content of free iron-oxide, the latter cementing the clay particles and giving rise to the highly water stable structure of these soils. Clay mobility is then decreased to a minimum.

A third interesting point is the behaviour of the sesquioxides in the profiles examined. The molar $Al_2O_3/Fe_2O_3$-ratios in the clay fractions of the soils of belts 2, 3, and 4 increases with depth, indicating that the mobility of aluminium is greater than that of iron. This has been already discussed by v. SCHUYLENBORGH and v. RUMMELEN (1955) on the base of a soil formation under the influence of carbonic acid (see also the beginning of this chapter).

Further support to this hypothesis is provided by the analysis of a profile in the neighbourhood of a still active volcano (Tangkuban Prahu); the soil is undoubtedly formed under the influence of sulfuric acid. The weathering and soil formation under the influence of sulfuric acid or of carbonic acid must be essential similar from a quantitative point of view. The component horizons are: a thin (3 cm) $A_1/A_2$-horizon with a very dark grey (10YR3/1) colour, an irregularly platy structure and a loamy texture: a very dark grey brown (10YR3/2) $B_1$-horizon (26 cm thick) with nutty structure and loamy texture; a dark reddish brown (5YR3/3à3/4), nutty to blocky, loamy $B_{21}$-horizon (19 cm thick) and a reddish brown (5YR3/4à4/4), nutty $B_{22}$-horizon (35 cm thick) with a clay loam texture; clay coatings can be observed. The parent material is basalto-andesitic tuff. The analysis is represented in table 6.

Table 6 Analysis of a soil profile formed under the influence of mainly sulfuric acid.

| Hor. | Clay % | pH | Org. C % | Clay | | | |
|---|---|---|---|---|---|---|---|
| | | | | $SiO_2/R_2O_3$ | $SiO_2/Al_2O_3$ | $SiO_2/Fe_2O_3$ | $Al_2O_3/Fe_2O_3$ |
| $A_1/A_2$ | 8.3 | 3.35 | 24.2 | 4.76 | 8.45 | 10.9 | 2.29 |
| $B_1$ | 10.6 | 4.82 | 10.4 | 0.68 | 0.96 | 2.26 | 2.34 |
| $B_{21}$ | 13.4 | 5.17 | 5.9 | 0.56 | 0.79 | 1.95 | 2.49 |
| $B_{22}$ | 29.5 | 5.04 | 4.5 | 0.55 | 0.76 | 2.04 | 2.68 |

The table shows that in this profile the same tendencies can be observed as in the profiles of belts 2, 3, and 4. Naturally, there is a quantitative difference, for the greater part of the sesquioxides are removed from the surface layer and deposited in the lower layers; even here, we see that alumina is more mobile than iron oxide.

The profiles of the first belt, however, show a different picture; here the molar $Al_2O_3/Fe_2O_3$-ratio first increases and then decreases with depth, whilst the maximum is found in the $A_2$-horizon. In the Grey-Brown Podsolic soils a decrease of this ratio can be remarked in general, as was reported by Byers, Alexander and Holmes (1935).

The conclusion seems justified to consider the soils of belt 1 as a transitional soil group between the soils of belt 2 and the Grey-Brown Podsolic soils. Another difference can be noticed in the C/N-ratio. This ratio decreases with depth in the soils of belt 1, just as in the Grey-Brown Podsolic soils (Anderson and Byers, 1934), whereas it remains nearly constant in the soils of belts 2, 3, and 4. This seems to indicate that the decomposition of organic matter at higher altitudes shows resemblances with that in temperate humid climates, which means that the mineralisation of the organic matter under semi-tropical humid conditions (high altitudes) has been slowed down so far (see also p. 6) that also humification can occur. Consequently, the soils of the first belt will be formed under the influence of carbonic acid and of organic (humic) acids. The action of humic acids is different from that of carbonic acid and seems sufficiently investigated by Aarnio (1913), Jones and Willcox (1929), Gallagher (1942), Bloomfield (1953, 1954) and others. All their work point to the fact, that both iron and aluminum form complexes with humic acids. The iron complexes, however, are more soluble than the aluminium complexes and, consequently, this leads to an decrease of the molar $Al_2O_3/Fe_2O_3$-ratio of the clay in the lower horizons.

A peculiar fact requires some discussion. It has been found, that in the Latosolic soils investigated so far, a decrease in the C/N-ratio (see also: ANDERSON and BYERS, 1934) and in the molar $Al_2O_3/Fe_2O_3$-ratio (see also: BYERS, ALEXANDER and HOLMES, 1935) occurs with depth, just as in the podsolic soils of the temperate humid climates. It seems reasonable to assume that, in Latosolic soils, the transformation of the organic matter in the soil is different from that on the soil, possibly as a consequence of the low organic matter content, high ferric oxide and alumina content and strong activity of termites. Whether this is true or not, is a matter of investigation in the laboratory of the present author.

Finally we are able to state, as will be reported in a following paper that, under conditions of high humidity and perfect drainage, a similar succession of soils can be observed on basaltic parent materials. The succession from sea level to high altitudes is: Red Latosol, Reddish-Brown Latosol Podsolized Latosol (still present at 800 m altitude), Brown Forest soil (v. SCHUYLENBORGH and v. RUMMELEN, 1955) and Grey-Brown Podsolic soil. The altitudes, at which they occur however, are higher than when the parent material is andesite tuff. Thus, a more basic parent material has to some extent the same effect on soil formation as a less humid climate (see: p. 8); this can be explained on the basis of the mechanism, discussed in the beginning of this chapter. On acid material (e.g. dacitic or liparitic tuffs) the succession from low to high is: Podsolized Reddish-Brown Latosol (DAMES, 1955), Brown Podsolic soil (v. SCHUYLENBORGH and v. RUMMELEN, 1955), Podsol (HARDON, 1936; KIEL and RACHMAT, 1948).

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## APPENDIX I. DESCRIPTION OF THE PROFILES.

*Profile 1* Gunung Wajang (volcano of Plio-Pleistocene age : v. BEMMELEN, 1949, p. 623) South-East of Pengalengean (Preanger). Nearly horizontal part on the slope. Altitude : 1620 m above sea level. Rainfall of a neighbouring rain station show the following monthly distribution :

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 332 | 298 | 349 | 300 | 217 | 135 | 88 | 70 | 99 | 210 | 309 | 344 | 2751 mm |

Mean annual temperature : 16.4° C. Vegetation : tropical mountain rainforest. Parent material : basalto-andesitic tuff (olivine-association). Drainage : perfect.

| | | |
|---|---|---|
| $A_{00}$ | 5–0 cm. | Forest litter. Lower part well decomposed. Mull-type. |
| $A_{11}$ | 0–5 cm. | Dark grey brown to very dark brown (10YR4/2–10YR2/2 1) ) sandy loam. Well developed granular to fine nutty. Very friable. Abundance of roots. |
| $A_{12}$ | 5–21 cm. | Brown to very dark grey brown (10YR5/3–10YR3/2) loam. Well developed fine nutty. Friable. Many roots. |
| $A_2$ | 31–61 cm. | Light yellowish brown (pale brown) to very dark yellowish brown (10YR6/3à6/4–10YR3/4) loam. Irregularly platy. Friable. Roots are present. |
| $B_1$ | 61–80 cm. | Brownish yellow to dark yellowish brown (10YR6/6–10YR4/4) clay loam. Weakly developed fine nutty structure. Clay coatings. More compact than $A_2$. Few roots. |
| $B_2$ | 80–95 cm. | Yellowish brown to dark brown (10YR5/4–7.5YR3/2) silty clay loam. Well developed medium nutty. Friable. Practically no roots. |

The lowest horizon is probably an old surface, because the mineral composition is quite different from the rest of the profile (see appendix II).

*Profile 2* Gunung Lawu (volcano of Upper Pleistocene age : v. BEMMELEN, 1949, p. 565 et seq.). Pangungangan. Slope 20%. Altitude : 1600 m above sea level. Rainfall distribution at 1290 m altitude :

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 372 | 337 | 354 | 273 | 189 | 130 | 74 | 47 | 42 | 126 | 241 | 349 | 2533 mm |

Mean annual temperature : 16.5° C. Vegetation : Acacia decurrens. Parent material : andesite tuff (hypersthene-augite-association). Drainage : perfect.

| | | |
|---|---|---|
| $A_{00}$ | 3–0 cm. | Litter. Mull-type. |
| $A_1$ | 0–16 cm. | Dark grey brown to black (2.5Y4/2–10YR2/1) loam. Well developed fine nutty to granular. Very friable. Abundance of roots. |
| $A_2$ | 16–34 cm. | Pale brown to very dark grey brown (10YR6/3–10YR3/4) silt loam. Irregularly platy. Friable. Many roots. |
| $B_1$ | 34–50 cm. | Light yellowish brown to dark brown (10YR5/4à6/4–7.5YR3/2) silt loam. Weakly developed fine nutty structure. Friable. Few roots. |
| $B_2$ | 50–91 cm. | Light yellowish brown to reddish brown (10YR6/4–5YR4/4) silt loam. Weakly developed medium nutty to crumbly structure. Very friable. Very few roots. |
| C | +91 cm. | Brownish yellow (10YR5/8à6/8) andesite tuff. |

*Profile 3* Gunung Kentjana (volcano of Plio-Pleistocene age : v. BEMMELEN, 1949, p. 623). South of Pengalengan (Preanger). Slope 10%. Altitude : 1420 m about sea level. Rainfall is nearly the same as that of profile 1.

Mean annual temperature : 17.6° C. Vegetation : tropical mountain rain forest. Parent material : andesite tuff (augite-hypersthene-association). Drainage perfect.

---

1) The Munsell colour notation refers to the air-dry and field-wet soil respectively.

| | | |
|---|---|---|
| $A_{00}$ | 5–0 cm. | Forest litter. Lower part well-decomposed. Mull-type. |
| $A_{11}$ | 0–9 cm. | Very dark grey brown to black (10YR3/2–10YR2/1) clay loam. Fine granular to nutty structure. Very friable. Abundance of roots. |
| $A_{12}$ | 9–19 cm. | Light grey brown to very dark grey brown (10YR5/2à6/2–10YR3/2à3/3) loam. Well developed fine nutty structure. Friable. Many roots. |
| $A_2$ | 19–29 cm. | Yellowish brown to dark yellowish brown (10YR5/4à5/6–10YR3/4à4/4) clay loam. Irregularly platy. Friable. Many roots. |
| $B_1$ | 29–45 cm. | Light yellowish brown to dark yellowish brown (10YR6/4à7/4–10YR3/4à4/4) silty clay loam. Weak developed medium nutty. Friable. Few roots. |
| $B_2$ | 45–76 cm. | Light yellowish brown to dark brown (10YR6/4–7.5YR3/2à4/4) clay loam. Weak developed medium nutty. Clay coatings. Friable. Few roots. |
| C | 76 cm. | Brownish yellow (10YR6/8) andesite tuff. |

*Profile 4* Gunung Tandjungsari (Pleistocene age : HARTMANN, 1938). Leuwiliang. Tjianten plantation. Flat top. Altitude : 1100 m above sea level. Rainfall distribution :

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 432 | 420 | 472 | 538 | 497 | 350 | 290 | 338 | 464 | 583 | 576 | 460 | 5420 mm |

Mean annual temperature : 19.6° C. Vegetation : tropical mountain rain forest (somewhat thinned out). Parent material : andesite tuff (hypersthene-association). Drainage : perfect.

| | | |
|---|---|---|
| $A_{00}$ | 2.5–0 cm. | Forest litter, lower part well-decomposed. Mull-type. |
| $A_1$ | 0–15 cm. | Very dark brown to very dark grey brown (10YR3/3–10YR3/2) loam. Medium granular to nutty structure. Very friable. Abundance of roots. |
| $A_2$ | 15–28 cm. | Dark brown (10YR4/3–10YR4/3) clay loam. Weakly developed fine nutty. Friable. Many roots. |
| $B_1$ | 28–46 cm. | Dark yellowish brown (10YR4/4) clay. Well developed medium nutty. Friable. Many roots. |
| $B_2$ | 46–66 cm. | Yellowish brown (10YR5/4–10YR5/6) clay. Weakly developed fine nutty. Wax-like coatings. Friable. Few roots. |
| C | +66 cm. | Yellow to brownish yellow (10YR7/8–10YR6/8) sandy clay loam. Very loose and very friable. No roots. |

*Profile 5* Gunung Kendeng (Pleistocene age : v. BEMMELEN, 1949, p. 637). Leuwiliang. Tjianten plantation. Flat top. Altitude : 900 m above sea level. Rainfall distribution very similar to that of profile 4.

Mean annual temperature : 20.8° C. Vegetation : tropical mountain rainforest. Parent material : andesite tuff (hypersthene-augite-association). Drainage : perfect.

| | | |
|---|---|---|
| $A_{00}$ | 2.5–0 cm. | Forest litter. Lower part well-decomposed. Mull-type. |
| $A_{11}$ | 0–5 cm. | Grey to very dark grey (10YR5/1–10YR3/1) clay. Well-developed medium crumbly to nutty structure. Very friable. Numerous roots. |
| $A_{12}$ | 5–25 cm. | Brown (grey brown) to very dark grey brown (10YR5/2à5/3–10YR3/2) silty clay loam. Weakly developed fine nutty to crumbly. Friable. Many roots. |
| $B_1$ | 25–40 cm. | Brown to dark reddish brown (7.5YR5/4–5YR3/4) silt loam. Weakly developed medium nutty. Friable. Few roots. |
| $B_2$ | 40–100 cm. | Brown to dark reddish brown (7.5YR5/6–5YR3/4) sandy loam. Weakly developed nutty. Wax-like coatings. Friable. Practically no roots. |
| C | +100 cm. | Yellow to brownish yellow (10YR8/6–10YR6/8) sandy loam. Very loose and friable. No roots. |

*Profile 6* Pondok Gedeh plantation. Tjiboerajoet. East slope of Gunung Salak (volcano of Pleistocene age : v. BEMMELEN, 1949, p. 637). Slope 15%. Altitude : 800 m above sea level. Rainfall distribution :

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 390 | 377 | 389 | 383 | 284 | 229 | 170 | 203 | 251 | 397 | 418 | 419 | 3910 mm |

Mean annual temperature: 21.4° C. Vegetation: secondary tropical rain forest. Parent material: andesite tuff (hypersthene-augite-association). Drainage: perfect.

$A_{00}$ 2–0 cm. Forest litter. Mull-type.

$A_1$ 0–20 cm. Brown to dark brown (10YR5/3–10YR4/3) silty clay loam. Well developed fine crumbly. Very friable. Numerous roots.

$B_1$ 20–43 cm. Light yellowish brown to brown (strong brown) (10YR6/4–7.5YR5/6à4/4) loam. Weakly developed fine nutty to crumbly structure. Friable. Many roots.

$B_2$ 43–92 cm. Very pale brown to strong brown (10YR7/4à8/4–7.5YR5/6à5/8) silt loam. Weakly developed medium nutty structure. Wax-like coatings. Few roots.

C +92 cm. Yellow to reddish yellow (10YR8/6–7.5YR/8à10YR7/8) sandy loam. Very loose and friable. Practically no roots.

*Profile 7* Near Kratjak. Leuwiliang. Slope 30%. Altitude: 600 m above sea level. Rainfall distribution:

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 317 | 301 | 337 | 432 | 369 | 284 | 219 | 207 | 260 | 335 | 221 | 304 | 3680 mm |

Mean annual temperature: 22.6° C. Vegetation: "blukar" (shrubs). Parent material andesite tuff (hypersthene-augite-association). Drainage: perfect.

$A_{00}$ 2–0 cm. Organic matter layer. Mull-type.

$A_{11}$ 0–17 cm. Brown to dark brown (10YR5/3–10YR4/3) clay. Well developed crumb structure. Very friable. Numerous roots.

$A_{12}$ 17–39 cm. Yellowish brown to brown (10YR5/6–7.5YR4/4) clay. Well developed crumbly. Friable. Numerous roots.

$B_1$ 39–75 cm. Reddish yellow to strong brown (7.5YR6/6–7.5YR5/6) cley. Weakly developed crumbly. Friable. Many roots.

$B_2$ 75–120 cm. Reddish yellow to strong brown 7.4YR7/6–7.5YR5/6) clay loam. Weakly developed crumbly to nutty. Wax-like coatings. Friable. Many roots.

C +120 cm. Reddish yellow to strong brown (7.5YR8/6–7.5YR5/8à6/8) sandy loam. Very loose and friable. Few roots.

*Profile 8* Pondok Gedeh plantation. Srogol. On top of hill. Altitude: 490 m above sea level. Rainfall distribution:

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 357 | 330 | 376 | 353 | 275 | 202 | 165 | 170 | 228 | 369 | 397 | 377 | 3599 mm |

Mean annual temperature: 23.3° C. Vegetation: Hevea. Parent material: andesite tuff (hypersthene-augite-association). Drainage: perfect.

$A_1$ 0–22 cm. Dark yellowish brown to dark brown (10YR4/4–7.5YR3/2) silty clay. Fine nutty to crumbly. Friable. Many roots.

$B_1$ 22–42 cm. Brown to dark brown (10YR4/3–7.5YR4/2à3/2) clay. Fine nutty to crumbly. Friable. Many roots.

$B_{21}$ 42–92 cm. Yellowish brown to brown (10YR5/4–7.5YR4/2à4/4) clay. Medium nutty. Clay coatings. Friable. Few roots.

$B_{22}$ 92–132 cm. Brown (10YR5/3–7.5YR4/2à4/4) clay. Medium nutty to blocky. Clay coatings. Friable. Few roots.

$C_1$ 132–145 cm. Very pale brown to reddish yellow (10YR7/4–7.5YR6/6) sandy loam. Massive. Practically no roots.

$C_2$ +145 cm. Very pale brown to pink (10YR8/3–7.5YR8/2à8/4) sandy loam. Massive. No roots.

*Profile 9* Botanical Garden. Bogor. Gently rolling topography. High part. Altitude: 250 m above sea level. Rainfall distribution:

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 391 | 364 | 394 | 431 | 371 | 281 | 211 | 216 | 286 | 419 | 392 | 361 | 4117 mm |

Mean annual temperature : 24.8° C. Vegetation : secondary forest (Rubiaceae, Piperceae). Parent material : andesite tuff (hypersthene-augite-association).

| | | |
|---|---|---|
| $A'_{11}$ | 0–12 cm. | Reddish brown to dark reddish grey (5YR4/3à5/3–5YR4/2à4/3) clay. Crumbly. Very friable. Numerous roots. |
| $A'_{12}$ | 12–33 cm. | Reddish brown (5YR5/4–5YR4/3) silty clay. Crumbly. Very friable. Numerous roots. Fresh tuffaceous material present. |
| $A_{11}$ | 33–77 cm. | Reddish brown (6YR4/4–5YR4/3) clay. Fine nutty to crumbly. Iron coatings (colour : 2.5YR4/8). Friable. Many roots. |
| $A_{12}$ | 77–100 cm. | Reddish brown (5YR4/4) clay. Fine nutty to crumbly. Iron coatings (colour : 5YR5/8). Friable. Less roots. |
| $B_1$ | 100–132 cm. | Reddish brown (5YR4/4) silty clay. Fine crumbly. Friable. Few roots. |
| $B_2$ | 132–153 cm. | Yellowish red (5YR4/6) silty clay. Medium nutty. Black iron-manganese coatings. Friable. Few roots. |
| C | +153 cm. | Reddish brown (5YR4/4) silty clay. Grey strongly weathered stony remnants (colour : 5YR6/2à7/1). |

The whole profile show activity of termites. The notation $A'_{11}$ and $A'_{12}$ indicates that these layers contain younger volcanic material ; therefore, they are not directly genetically related to the lower part of the profile.

*Profile 10* Tjisalak. Near Djakarta. Coastal plain. Altitude : 35 m above sea level. Rainfall distribution :

| Jan. | Febr. | March | Apr. | Mai | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 342 | 334 | 313 | 322 | 270 | 191 | 128 | 139 | 200 | 269 | 336 | 286 | 3130 mm |

Mean annual temperature : 26.1° C. Vegetation : Citrus. Parent material : andesitic material. Drainage : perfect.

| | |
|---|---|
| 0–18 cm. | Reddish brown (red) to reddish brown (2.5YR4/4à4/6–2.5YR4/4) clay. Fine crumbly to nutty. Very friable. Plowed layer. |
| 18–48 cm. | Reddish brown (red) to reddish brown (2.5YR4/4à4/6–2.5YR4/4) clay. Fine nutty to crumbly. Somewhat more compact. |
| 48–145 cm. | Reddish brown (red) to reddish brown (2.5YR4/4à4/6–2.5YR4/6) clay. Fine crumbly. Very friable. |

## APPENDIX II. MEAN MINERALOGICAL COMPOSITION OF THE SAND FRACTION OF THE PROFILES INVESTIGATED AND THE COMPOSITION OF THE HEAVY FRACTION.

### Profile 1

| Horizon and percentage sand | quartz (turbid) | sanidine | andesine + labradorite | green hornblende | hypersthene | augite | olivine | volcanic glass (acid + basic) | opaque | iron concretions | zircon | rock fragments | miscellaneous | Composition heavy fraction: opaque | Mutual percentage of transparent minerals: green hornblende | hypersthene | augite | olivine | zircon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_{11}$ : 44.4 | — | — | 20 | tr | tr | 6 | 1 | — | 2 | 23 | 1 | 45 | 2 | 9 | 13 | 26 | 33 | 26 | 2 |
| $A_{12}$ : 26.3 | 2 | tr | 18 | 2 | 1 | 5 | 2 | tr | 1 | 29 | — | 39 | 1 | 16 | 8 | 34 | 34 | 24 | 1 |
| $A_2$ : 31.4 | 1 | 1 | 21 | 4 | 1 | 6 | 3 | 1 | 2 | 30 | 1 | 26 | 3 | 12 | 17 | 28 | 28 | 17 | 1 |
| $B_1$ : 28.1 | 1 | tr | 13 | 7 | 7 | 11 | 3 | 1 | 3 | 25 | 5 | 20 | 4 | 29 | 14 | 17 | 33 | 34 | — |
| $B_2$ : 13.2 | tr | — | 6 | 5 | 9 | 3 | — | 1 | 1 | 68 | — | 4 | 3 | 27 | 32 | 51 | 17 | — | 2 |

The soil is formed from a basalto-andesitic tuff with olivine association. It is evident that the lowest horizon has a different composition (andesite tuff with hypersthene-augite association). Percentage iron concretions is nearly constant.

### Profile 2

| Horizon and percentage sand | quartz (transparent) | andesine + labradorite | green hornblende | hypersthene | augite | volcanic glass (acid + basic) | opaque | iron concretions | rock fragments | miscellaneous | Composition heavy fraction: green hornblende | Mutual percentage of transparent minerals: green hornblende | hypersthene | augite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ : 27.2 | tr | 27 | 3 | 6 | 2 | 32 | 3 | 8 | 18 | 1 | 38 | 14 | 59 | 27 |
| $A_2$ : 27.6 | — | 23 | 3 | 3 | 1 | 43 | 2 | 5 | 19 | 1 | 31 | 13 | 62 | 25 |
| $B_1$ : 26.8 | tr | 26 | 3 | 3 | 2 | 22 | 2 | 19 | 21 | 2 | 10 | 23 | 49 | 27 |
| $B_2$ : 30.7 | 1 | 19 | 3 | 7 | 4 | 9 | 3 | 34 | 18 | 2 | 19 | 20 | 56 | 24 |

The parent material is basalto-andesitic tuff with hypersthene-augite association. The percentage iron concretions increases rapidly with depth. Hydrargyllite is absent. Rock fragments : tuffaceous products with inclusions. Miscellaneous : weathering products, that could not be indentified.

## Profile 3

| Horizon and percentage sand | quartz (turbid) | sanidine | andesine + labradorite | green hornblende | hypersthene | augite | olivine | volcanic glass (acid + basic) | opaque | iron concretions | gibbsite | organogenous $SiO_2$ | rock fragments | miscellaneous | Composition heavy fraction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | Mutual percentage of transparent minerals | | | |
| | | | | | | | | | | | | | | | opaque | green hornblende | hypersthene | augite | olivine |
| $A_{11}$ : 20.4 | 1 | 1 | 16 | 3 | 8 | 4 | 2 | 2 | 1 | 5 | tr | 3 | 50 | 4 | 9 | 17 | 19 | 41 | 19 |
| $A_{12}$ : 27.0 | 1 | 1 | 15 | 4 | 6 | 4 | 1 | tr | 2 | 3 | tr | 3 | 51 | 9 | 15 | 23 | 20 | 39 | 20 |
| $A_2$ : 19.7 | tr | – | 11 | 12 | 8 | 11 | 1 | 1 | 19 | 4 | – | tr | 26 | 7 | 12 | 21 | 11 | 46 | 11 |
| $B_1$ : 17.3 | 1 | – | 10 | 15 | 10 | 13 | 1 | 1 | 15 | 3 | tr | – | 14 | 17 | 21 | 17 | 13 | 37 | 13 |
| $B_2$ : 18.4 | 1 | – | 6 | 12 | 9 | 13 | 3 | 3 | 4 | 2 | 1 | 1 | 8 | 37 | 11 | 31 | 12 | 36 | 12 |

The parent material is basalto-andesitic tuff. Miscellaneous: yellowish-brown, reddish brown to dark brown amorphous grains; in $B_1$ and $B_2$ the grains resemble iron concretions very much. This indicates an accumulation of iron in the lower horizon.

## Profile 4

| Horizon and percentage sand | quartz (turbid) | oligoclase + andesine | green hornblende | hypersthene | augite | volcanic glass (acid) | opaque | iron concretions | hydrargyllite | organogenous silisic acid | rock fragment | miscellaneous | Composition heavy fraction | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Mutual percentage of transparent minerals | | |
| | | | | | | | | | | | | | opaque | green hornblende | hypersthene | augite |
| $A_1$ : 26.2 | 2 | 27 | 1 | 12 | 1 | 17 | 4 | 3 | 6 | 9 | 9 | 8 | 43 | 8 | 82 | 10 |
| $A_2$ : 20.5 | 3 | 25 | 2 | 11 | 2 | 18 | 3 | 2 | 8 | 7 | 10 | 9 | 21 | 8 | 85 | 7 |
| $B_1$ : 20.8 | 2 | 29 | tr | 15 | 1 | 21 | 2 | 3 | 6 | 12 | 3 | 6 | 30 | 2 | 91 | 7 |
| $B_2$ : 28.7 | 2 | 40 | 1 | 13 | 1 | 20 | 5 | 2 | 7 | – | 3 | 6 | 21 | 4 | 95 | 1 |
| C : 53.8 | 1 | 44 | tr | 9 | – | 18 | 4 | 1 | 19 | – | 3 | 1 | 39 | 1 | 96 | 3 |

Part of the rock fragment is densely set with hydrargyllite. The percentage iron concretions is constant over the whole profile. The hydrargyllite percentage is highest in the parent material.

Profile 5

| Horizon and percentage sand | quartz (turbid) | oligoclase + andesine | green hornblende | hypersthene | augite | volcanic glass (acid) | opaque | iron concretions | hydrargyllite | organogenous silisic acid | rock fragments | miscellaneous | Composition heavy fraction | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Mutual percentage of transparent minerals | | |
| | | | | | | | | | | | | | opaque | green hornblende | hypersthene | augite |
| $A_{11}$ : 12.4 | tr | 33 | 1 | 9 | 3 | 8 | tr | 7 | 3 | 11 | 17 | 8 | 20 | 7 | 65 | 28 |
| $A_{12}$ : 22.4 | — | 31 | tr | 11 | 2 | 7 | — | 9 | 2 | 9 | 20 | 9 | 26 | 10 | 68 | 20 |
| $B_1$ : 64.8 | tr | 25 | 2 | 13 | 1 | 7 | 1 | 14 | 3 | 1 | 13 | 12 | 40 | 9 | 91 | — |
| $B_2$ : 77.7 | — | 30 | — | 12 | — | 9 | 1 | 16 | 8 | — | 12 | 20 | 40 | 10 | 89 | 1 |
| C : 89.7 | — | 56 | tr | 12 | — | 9 | 1 | — | 8 | — | 12 | 1 | 39 | 1 | 97 | 2 |

The greatest part of the rock fragment is densely set with hydrargyllite. It seems, that an enrichment of ash, rich in augite, has taken place. However, the author is of the opinion that profile development is not profoundly influenced by this. The percentage hydrargyllite appears to increase, as does the percentage iron concretions.

Profile 6

| Horizon and percentage sand | quartz (transparent) | quartz (turbid) | oligoclase + andesine | green hornblende | hypersthene | augite | volcanic glass (acid) | opaque | iron concretions | hydrargyllite | organogenous silisic acid | rock fragments | miscellaneous | Composition heavy fraction | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | Mutual percentage of transparent minerals | | |
| | | | | | | | | | | | | | | opaque | green hornblende | hypersthene | augite |
| $A_1$ : 12.7 | 1 | 1 | 37 | 1 | 11 | 2 | 7 | 8 | 2 | 5 | 1 | 2 | 27 | 17 | 4 | 78 | 18 |
| $B_1$ : 23.6 | — | tr | 54 | 1 | 9 | 1 | 6 | 5 | 1 | 3 | tr | 1 | 17 | 19 | 3 | 94 | 3 |
| $B_2$ : 31.4 | tr | tr | 51 | 1 | 6 | — | 6 | 1 | 1 | 7 | — | tr | 25 | 57 | 3 | 96 | 1 |
| C : 59.0 | tr | tr | 53 | tr | 12 | — | 18 | 1 | — | 5 | — | — | 12 | 16 | 2 | 91 | 7 |

The grains of the miscellaneous group are brown weathered products and show in their index of refraction transitions to hydrargyllite. The oligoclase grains are partly set with hydrargyllite, expecially in the $B_1$-horizon. The percentage hydrargyllite increases, whereas the percentage iron concretions remains constant.

Profile 7

| Horizon and percentage sand | quartz (transparent) | quartz (turbid) | oligoclase + andesine | green hornblende | hypersthene | augite | volcanic glass (acid) | opaque | iron concretions | hydrargyllite | rock fragments | miscellaneous | Composition heavy fraction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Mutual percentage of transparent minerals | | | |
| | | | | | | | | | | | | | opaque | green hornblende | hypersthene | augite | zircon |
| $A_{11}$ : 15.3 | tr | 2 | 46 | tr | 12 | 2 | 6 | 6 | 5 | 2 | tr | 18 | 86 | 1 | 87 | 12 | tr |
| $A_{12}$ : 18.2 | 2 | 1 | 38 | tr | 12 | 1 | 4 | 6 | 6 | 3 | tr | 27 | 63 | tr | 92 | 7 | 1 |
| $B_1$ : 19.8 | tr | tr | 44 | 1 | 11 | 1 | 5 | 2 | 3 | 6 | — | 27 | 68 | 1 | 95 | 3 | 1 |
| $B_2$ : 27.9 | 1 | 1 | 41 | tr | 6 | tr | 4 | 3 | 5 | 6 | — | 33 | 82 | 3 | 96 | 1 | tr |
| C : 55.8 | tr | tr | 46 | tr | 8 | — | 10 | 3 | 2 | 14 | 1 | 16 | 41 | 1 | 97 | 2 | tr |

In the miscellaneous groups grains occur showing in their optical properties transitions to hydrargyllite. The percentages of the grains with gibbsite-properties are: 6, 8, 8, 11 and 4 resp. The percentage iron concretions is constant, whereas the percentage hydrargyllite increases with depth.

Profile 8

| Horizon and percentage sand | quartz (transparent) | quartz (turbid) | oligoclase + andesine | green hornblende | hypersthene | augite | volcanic glass (acid) | opaque | iron concretions | hydrargyllite | rock fragments | miscellaneous | Composition heavy fraction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Mutual percentage of transparent minerals | | | |
| | | | | | | | | | | | | | opaque | green hornblende | hypersthene | augite | zircon |
| $A_1$ : 11.6 | tr | 2 | 14 | tr | 5 | 3 | 2 | 10 | tr | tr | 3 | 61 | 76 | 4 | 51 | 45 | — |
| $B_1$ : 7.35 | 1 | 2 | 19 | 1 | 7 | 3 | 5 | 19 | 3 | 2 | 4 | 34 | 75 | 3 | 54 | 43 | — |
| $B_{21}$ : 6.58 | tr | 1 | 18 | 1 | 2 | 1 | 4 | 17 | 5 | tr | 1 | 49 | 94 | 11 | 65 | 24 | tr |
| $B_{22}$ : 7.01 | 2 | 1 | 45 | 1 | 2 | tr | 3 | 21 | 3 | 2 | 1 | 18 | 92 | 9 | 79 | 12 | tr |
| $C_1$ : 64.1 | 3 | tr | 52 | — | 1 | tr | 1 | 3 | — | tr | — | 40 | 96 | 2 | 94 | 2 | 2 |
| $C_2$ : 73.2 | 1 | — | 50 | tr | 2 | — | 1 | 1 | — | 2 | 1 | 42 | 92 | 2 | 94 | 3 | 1 |

Miscellaneous: amorphous weathering products, brown coloured in the surface horizons and lighter coloured to colourless in the deeper horizons. Many of these grains show transitional forms to hydrargyllite; their refraction indices nearly equal that of hydrargyllite. There is not much differentiation in iron concretions (slight accumulation in $B_{21}$ ?) as well as of hydrargyllite.

## Profile 9

| Horizon and percentage sand | quartz (transparent) | quartz (turbid) | sanidine | oligoclase + andesine | green hornblende | hypersthene | augite | volcanic glass | opaque | iron concretions | hydrargyllite | rock fragments | miscellaneous | Composition heavy fraction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | Mutual percentage of transparent minerals | | | | |
| | | | | | | | | | | | | | | opaque | green hornblende | hypersthene | augite | zircon | |
| $A'_{11}$ : 5.00 | 1 | 1 | tr | 12 | tr | 4 | 3 | 4 | 17 | 8 | 3 | 1 | 45 | 90 | 3 | 72 | 25 | – | |
| $A'_{12}$ : 6.61 | tr | 1 | tr | 5 | tr | 5 | 1 | 6 | 18 | 10 | 5 | 2 | 46 | 89 | tr | 68 | 31 | 1 | |
| $A_{11}$ : 4.31 | 1 | 4 | tr | 3 | tr | 2 | tr | 4 | 24 | 8 | 3 | tr | 49 | 97 | 3 | 68 | 29 | tr | |
| $A_{12}$ : 4.99 | tr | 3 | 1 | 5 | – | tr | tr | 1 | 10 | 11 | 2 | 1 | 64 | 100 | 3 | 66 | 29 | 2 | |
| $B_1$ : 5.55 | 1 | 2 | tr | 2 | tr | 1 | tr | 1 | 15 | 8 | 2 | 1 | 65 | 99 | 6 | 61 | 32 | 1 | |
| $B_2$ : 6.51 | 1 | 2 | tr | 2 | tr | tr | tr | tr | 8 | 12 | 1 | 1 | 70 | 100 | 5 | 62 | 28 | 4 | |
| C : 7.61 | tr | tr | tr | 3 | – | 1 | tr | 1 | 7 | 10 | 2 | tr | 73 | 98 | 13 | 58 | 25 | 3 | |

The percentage sand, clay (see appendix II), plagioclases, hypersthene, augite, volcanic glass and quartz (turbid) indicate that the two surface horizons has been enriched with new volcanic material, so that these horizons are not related to the underlying horizons. There is no differention in the percentages of iron concretions and hydrargyllite.

## APPENDIX III. CHEMICAL COMPOSITION OF THE SOILS.

Profile 1

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2/R_2O_3$ | $SiO_2/Al_2O_3$ | $SiO_2/Fe_2O_3$ | $Al_2O_3/Fe_2O_3$ |
| $A_{11}$ | 6.8 | 6.28–6.80 | 14.6 | 12.8 | 1.81 | 2.25 | 9.32 | 4.15 |
| $A_{12}$ | 18.6 | 6.04–6.44 | 7.05 | 9.76 | 1.53 | 1.88 | 8.05 | 4.28 |
| $A_2$ | 23.4 | 6.11–6.48 | 4.64 | 8.08 | 1.02 | 1.25 | 5.64 | 4.51 |
| $B_1$ | 28.4 | 6.01–6.36 | 3.25 | 7.70 | 0.96 | 1.18 | 5.11 | 4.33 |
| $B_2$ | 34.6 | 5.94–6.18 | 3.50 | 8.75 | 0.87 | 1.08 | 4.49 | 4.16 |

The Röntgen-diffraction patterns of the clay fraction indicate an abundance of amorphous material with admixtures of montmorillonite, kaolinite and hydrargyllite. The amorphous material will be most probably (see also the low $SiO_2/Al_2O_3$ ratios) allophane (Taylor, 1933 ; Tamura, Jackson, and Sherman, 1953 ; Fieldes and Williamson, 1955 ; Kanno and collaborators, 1955).

Profile 2

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2/R_2O_3$ | $SiO_2/Al_2O_3$ | $SiO_2/Fe_2O_3$ | $Al_2O_3/Fe_2O_3$ |
| $A_1$ | 11.3 | 5.22–5.69 | 9.45 | 12.6 | 1.35 | 1.52 | 11.9 | 7.80 |
| $A_2$ | 11.4 | 5.66–5.99 | 7.19 | 9.2 | 1.00 | 1.12 | 9.61 | 8.59 |
| $B_1$ | 13.1 | 5.85–6.23 | 5.45 | 7.9 | 1.00 | 1.14 | 8.80 | 7.60 |
| $B_2$ | 10.1 | 6.06–6.36 | 2.73 | 6.3 | 0.95 | 1.08 | 8.00 | 7.40 |

The clay fraction contains amorphous material (allophane?) with admixture of kaolinite, α-crystoballite and possibly metahalloysite.

Profile 3

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2/R_2O_3$ | $SiO_2/Al_2O_3$ | $SiO_2/Fe_2O_3$ | $Al_2O_3/Fe_2O_3$ |
| $A_{11}$ | 15.6 | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| $A_{12}$ | 21.0 | 6.33–7.07 | 7.30 | 9.2 | 1.85 | 2.37 | 8.37 | 3.54 |
| $A_2$ | 24.6 | 6.18–6.90 | 5.64 | 8.3 | 1.31 | 1.60 | 7.23 | 4.50 |
| $B_1$ | 28.6 | 5.94–6.47 | 4.70 | 7.7 | 1.18 | 1.49 | 5.83 | 3.91 |
| $B_2$ | 30.8 | 5.63–6.15 | 2.58 | 5.7 | 1.20 | 1.60 | 4.89 | 3.06 |

The clay fraction has the same composition as that of profile 1.

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1) The pH-values refer to a soil suspension (ratio soil : water of 1 : 2) and to the clear supernatent liquid obtained after centrifuging this soil suspension.

Profile 4

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2$/ $R_2O_3$ | $SiO_2$/ $Al_2O_3$ | $SiO_2$/ $Fe_2O_3$ | $Al_2O_3$/ $Fe_2O_3$ |
| $A_1$ | 12.2 | 4.85–4.93 | 16.6 | 15.9 | 1.48 | 1.78 | 8.42 | 4.75 |
| $A_2$ | 25.0 | 5.30–5.53 | 10.1 | 14.1 | 0.76 | 0.88 | 5.10 | 5.85 |
| $B_1$ | 32.5 | 5.40–5.42 | 5.4 | 14.7 | 0.67 | 0.71 | 5.73 | 7.47 |
| $B_2$ | 40.3 | 5.42–5.66 | 2.0 | 14.6 | 0.72 | 0.81 | 6.60 | 8.26 |
| C | 29.2 | 5.62–5.74 | 0.7 | 8.0 | 0.80 | 0.87 | 10.0 | 11.5 |

The clay fractions contain an abundance of amorphous material (allophane?) with minor admixtures of montmorillonite, kaolinite, α-crystoballite and hydrargyllite. The amount of hydrargyllite increases with depth and shows a maximum in the $B_2$-horizon.

Profile 5

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2$/ $R_2O_3$ | $SiO_2$/ $Al_2O_3$ | $SiO_2$/ $Fe_2O_3$ | $Al_2O_3$/ $Fe_2O_3$ |
| $A_{11}$ | 30.9 | 4.92–5.02 | 21.7 | 11.9 | 2.67 | 3.40 | 12.9 | 3.69 |
| $A_{12}$ | 27.8 | 5.32–5.31 | 10.2 | 10.9 | 1.54 | 1.83 | 9.83 | 5.37 |
| $B_1$ | 16.4 | 5.36–5.46 | 2.57 | 9.0 | 1.54 | 1.77 | 11.6 | 6.53 |
| $B_2$ | 9.8 | 5.40–5.50 | 1.64 | 9.2 | 1.53 | 1.75 | 12.5 | 7.14 |
| C | 5.7 | 5.44–5.51 | 0.82 | 9.4 | 2.34 | 2.62 | 21.1 | 8.06 |

The clay fraction contains much amorphous material. Admixtures of α-crystoballite, kaolinite, metahalloysite and hydrargyllite could be noticed. Hydrargyllite increases with depth.

Profile 6

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2$/ $R_2O_3$ | $SiO_2$/ $Al_2O_3$ | $SiO_2$/ $Fe_2O_3$ | $Al_2O_3$/ $Fe_2O_3$ |
| $A_1$ | 30.8 | 4.12–4.15 | 6.29 | 9.8 | 1.63 | 2.04 | 7.90 | 3.90 |
| $B_1$ | 22.9 | 4.82–4.90 | 1.83 | 8.0 | 1.24 | 1.55 | 6.31 | 4.06 |
| $B_2$ | 27.1 | 4.82–4.98 | 0.79 | 8.0 | 1.26 | 1.53 | 7.02 | 4.59 |
| C | 10.4 | 5.56–5.63 | 0.38 | N.D. | 0.86 | 0.93 | 12.9 | 13.1 |

The clay consists of a high amount of amorphous material, with admixtures of kaolinite, montmorillonite and hydrargyllite. Montmorillonite increases with depth.

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1) The pH-values refer to a soil suspension (ratio soil : water of 1 : 2) and to the clear supernatent liquid obtained after centrifuging this soil suspension.

Profile 7

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2/R_2O_3$ | $SiO_2/Al_2O_3$ | $SiO_2/Fe_2O_3$ | $Al_2O_3/Fe_2O_3$ |
| $A_{11}$ | 40.3 | 4.00–4.52 | 3.01 | 12.0 | 1.31 | 1.48 | 11.1 | 7.49 |
| $A_{12}$ | 42.1 | 4.07–4.62 | 2.31 | 12.0 | 1.24 | 1.39 | 11.0 | 7.32 |
| $B_1$ | 39.2 | 4.23–4.24 | 0.92 | 11.4 | 1.21 | 1.36 | 11.1 | 8.09 |
| $B_2$ | 28.3 | 4.47–4.72 | 0.67 | 8.1 | 1.12 | 1.26 | 10.3 | 8.26 |
| C | 8.3 | 5.08–4.82 | 0.27 | 7.7 | 1.02 | 1.10 | 13.7 | 12.5 |

The clay contains, apart from a considerable amount of amorphous material, some kaolinite, and with depth increasing amounts of hydrargyllite and montmorillonite.

Profile 8

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2/R_2O_3$ | $SiO_2/Al_2O_3$ | $SiO_2/Fe_2O_3$ | $Al_2O_3/Fe_2O_3$ |
| $A_1$ | 45.2 | 5.65–6.21 | 1.49 | 10.1 | 1.41 | 1.68 | 8.60 | 5.10 |
| $B_1$ | 60.1 | 5.14–5.51 | 1.16 | 9.7 | 1.42 | 1.69 | 9.09 | 5.37 |
| $B_{21}$ | 63.4 | 5.09–5.71 | 0.72 | 10.4 | 1.30 | 1.52 | 9.51 | 6.28 |
| $B_{22}$ | 62.6 | 5.22–6.15 | 0.67 | N.D. | 1.27 | 1.47 | 9.51 | 6.47 |
| C | 12.9 | 5.39–5.98 | 0.19 | 10.5 | 1.36 | 1.52 | 13.9 | 9.17 |

The clay contains a certain amount of amorphous material, with kaolinite and a small amount of montmorillonite. The hydrargyllite content is increasing with depth.

Profile 9

| Hor. | Clay % | pH 1) | Org. C % | C/N | Composition of clay fraction | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $SiO_2/R_2O_3$ | $SiO_2/Al_2O_3$ | $SiO_2/Fe_2O_3$ | $Al_2O_3/Fe_2O_3$ |
| $A'_{11}$ | 61.7 | 6.07–6.48 | 3.17 | 11.4 | 1.33 | 1.60 | 7.65 | 4.77 |
| $A'_{12}$ | 46.6 | 5.74–6.16 | 1.31 | 8.0 | 1.29 | 1.55 | 7.56 | 4.88 |
| $A_{11}$ | 60.7 | 5.38–5.94 | 0.87 | 9.2 | 1.16 | 1.37 | 7.54 | 5.50 |
| $A_{12}$ | 61.0 | 5.42–6.07 | 0.50 | 8.7 | 1.21 | 1.44 | 7.44 | 5.17 |
| $B_1$ | 53.6 | 5.44–5.94 | 0.44 | 6.4 | 1.21 | 1.45 | 7.40 | 5.13 |
| $B_2$ | 51.4 | 5.61–6.18 | 0.34 | 6.3 | 1.25 | 1.50 | 7.63 | 5.09 |
| C | 48.0 | 5.60–6.19 | 0.44 | 11.3 | 1.23 | 1.46 | 7.84 | 5.39 |

The clay fractions of all horizons have the same composition. Of the recognizable minerals kaolinite was predominant, followed by montmorillonite and hydrargyllite.

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1) The pH-values refer to a soil suspension (ratio soil : water of 1 : 2) and to the clear supernatent liquid obtained after centrifuging this soil suspension.