# Soils on the Pleistocene Ignimbritic Bagaces Formation, Guanacaste, Costa Rica.

***A report on the results of two theses:***

***- A soil mapping project.***

***- A study on the physical aspects of soil genesis.***

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*September 1997*

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# 1 Introduction

This bundle presents the results of two theses. The theses concern soil types and soil genesis, on the ignimbrites of the Bagaces Formation in Guanacaste, Costa Rica. This formation occupies an area of about fifteen percent of the province Guanacaste, and is located along the Guanacaste cordillera (Figure 1.1).

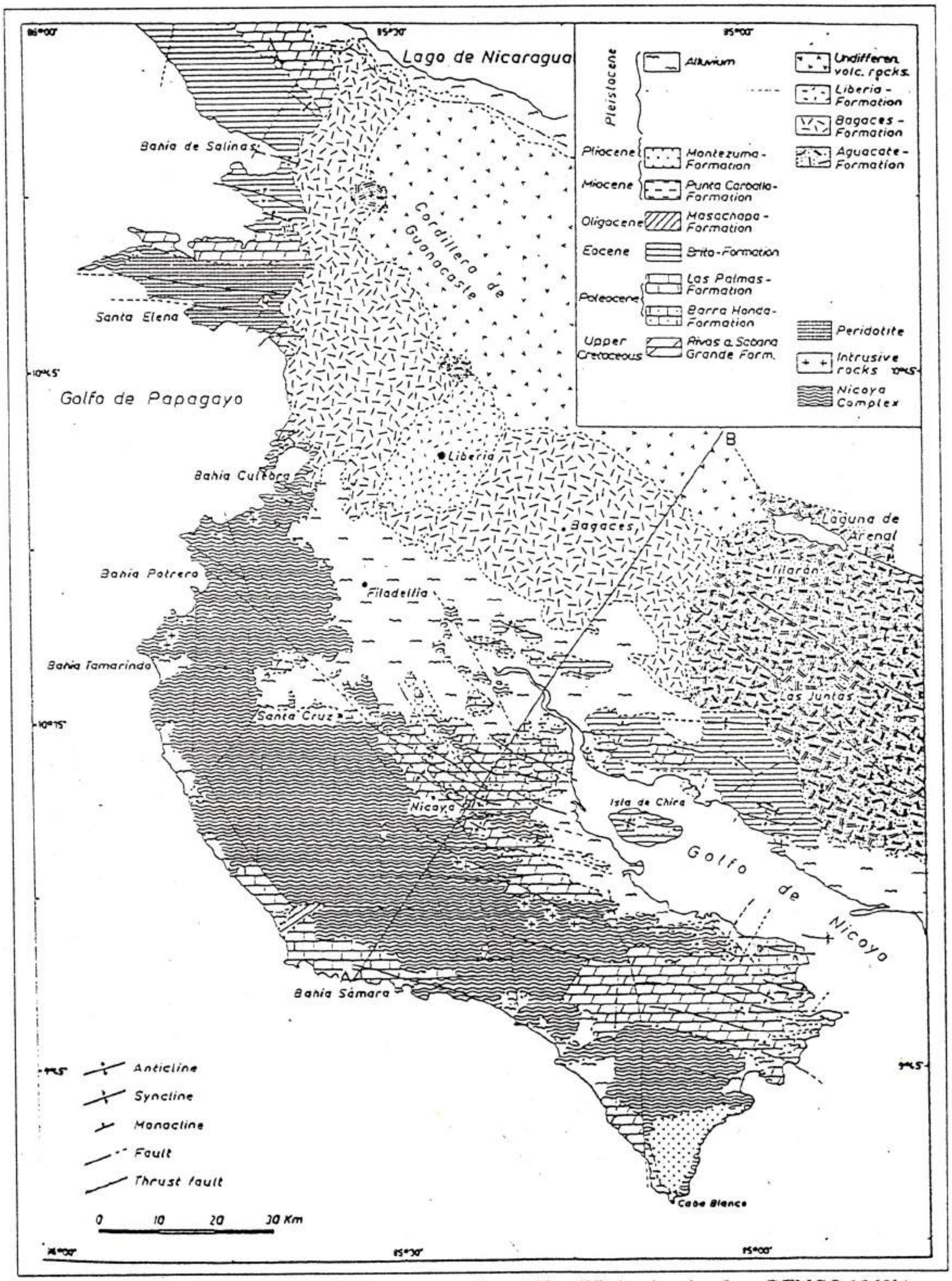


Figure 1.1. Geological map of Guanacaste province. (Simplified redrawing from DENGO 1962b).

The first thesis (1995) concerns a soil mapping project on a part of the formation, carried out in the experimental station for reforestation 'Horizontes' (Sector Horizontes), sub-area of 'Guanacaste Conservation Area'.
The second thesis (1996), concerns soil genesis on the ignimbrites; a study on the physical aspects. The study was carried out in Sector Horizontes, national park Lomas Barbudal and in the area around the primary irrigation channel between Bagaces and Cañas.
In a short introduction in the chapters dealing with the studies, the aims of the researches can be found. Figure 1.2 shows the geographical positions of the areas.

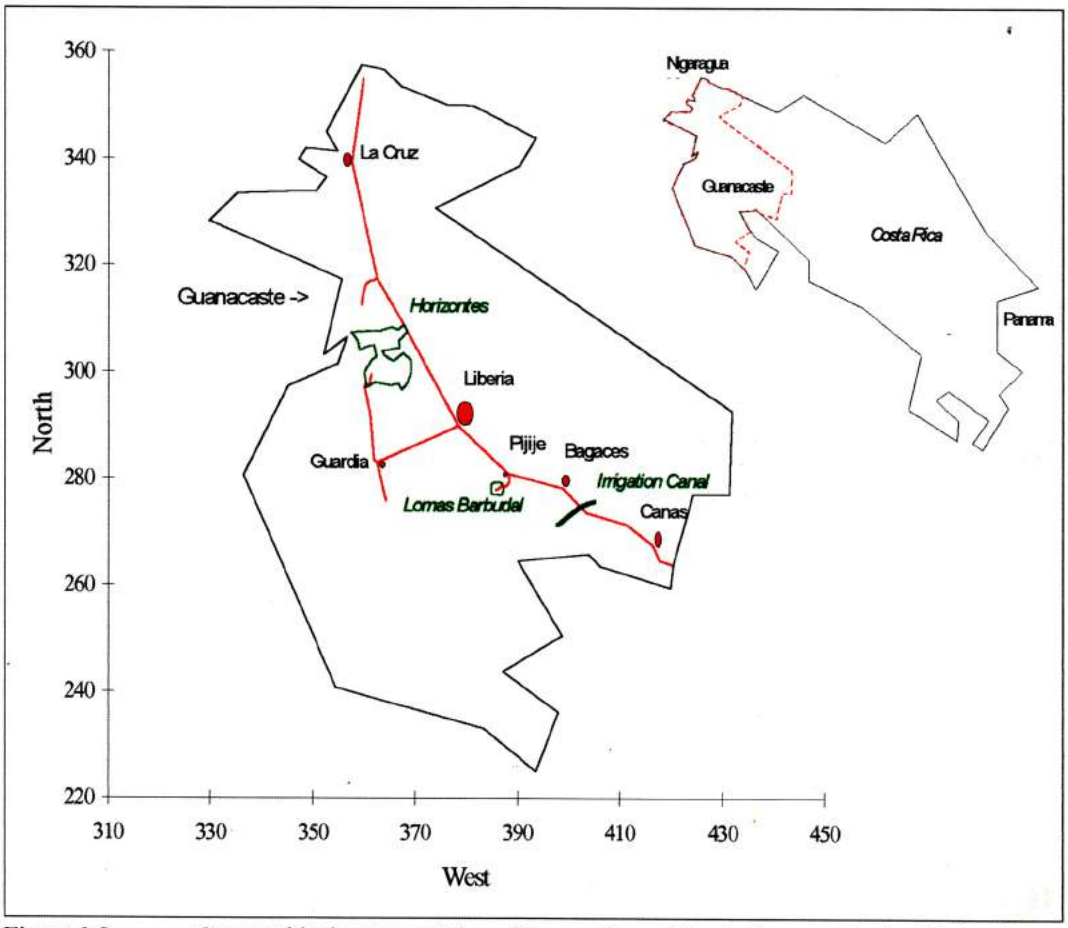


Figure 1.2. Geographical representation of the position of the study areas; Sector Horizontes, Lomas Barbudal and Irrigation Canal.

In the next chapter, an introduction is given on the geology of the area. Special attention will be given at the nature and deposition of ignimbrite. In addition, tectonic movements and topography will be dealt with. In chapter three a general introduction on the climate, followed by a discussion of the meteorological data of the study areas, is given. Chapter four discusses the soil mapping project, whereas chapters five discusses several aspects of soil genesis. The last two chapters start with a short introduction on how the researches were set up and executed.

A study on the chemical aspects of soil genesis on ignimbrites, has been carried out, but could not be completed. Therefore, these aspects are not dealt with in this bundle. The preliminary results of these chemical analysis done, can be found in a separate report.

## 2 Geology

The northern half of Costa Rica, particularly the part which contains the study area, is strongly influenced by violent volcanic processes (Figure 2.1) during the Pleistocene, which originated in the northwest - southeast orientated Guanacaste cordillera.

The Guanacaste cordillera and its adjacent volcanic plateaus are built up of many different volcanic deposits. One of these is a pyroclastic deposit called 'ignimbrite', a deposit from the period of 1,800,000 up to 600,000 years ago (Weyl, 1980), mainly at the Pacific side of the Guanacaste cordillera (Figure 1.1). The study area is situated on an extensive ignimbrite plateau. Rocks of this plateau belong to the Bagaces Formation.

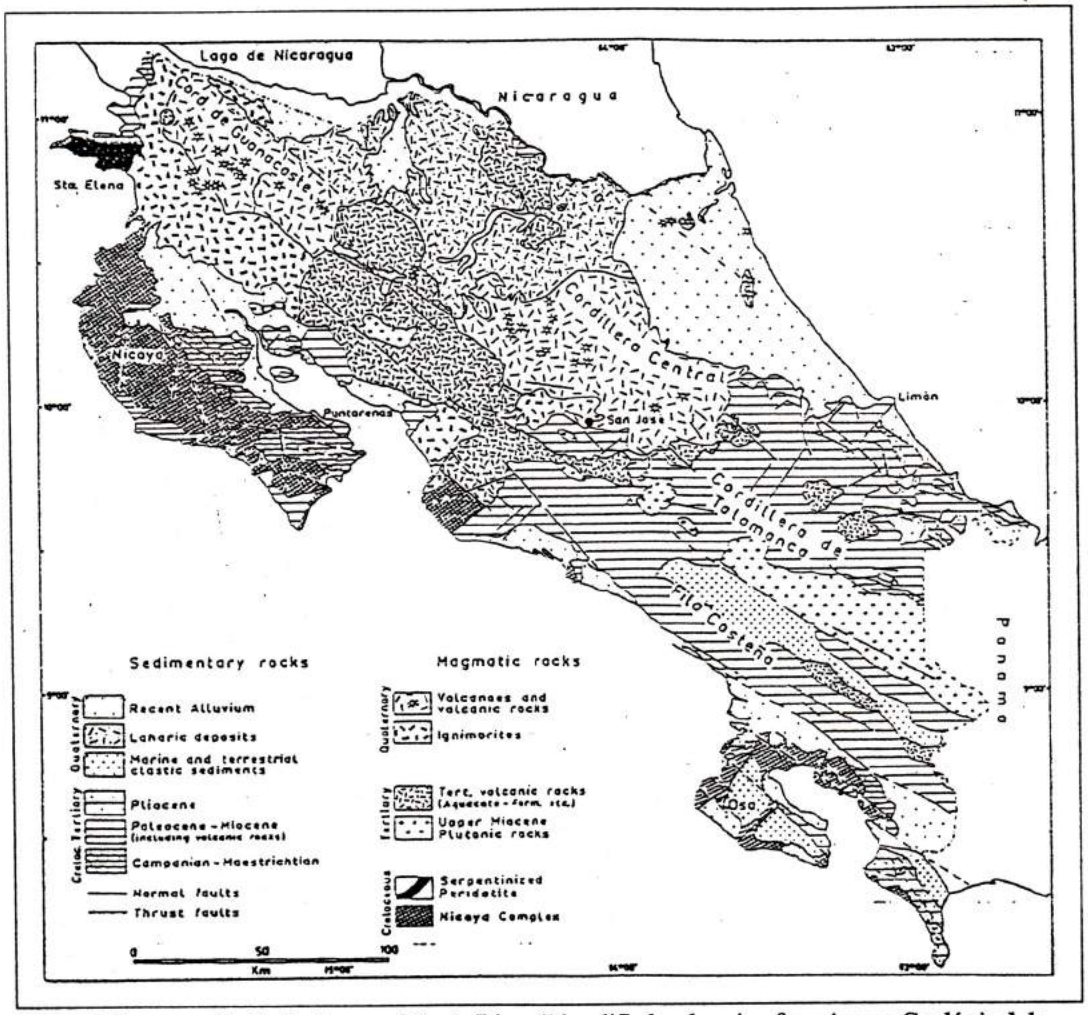


Figure 2.1. Geological map of Costa Rica. (Simplified redrawing from 'mapa Geológical de Costa Rica 1:700,000', 1968).

### 2.1 Ignimbrite

Skinner & Porter (1987), give the following definition of ignimbrite:

*"The welding of tephra (loose assemblages of pyroclasts) gives pyroclastic rocks. One type of conversion to pyroclastic rock is through the welding of hot glassy ash particles. This rock is called ignimbrite; the glassy fragments of which were plastic and so hot when deposited, that they fused to form a glassy rock. Very commonly the glassy fragments became flattened and compacted during the fusion process, giving welded tuffs a rather distinctive texture that resembles a flow pattern."*

Currently, ignimbrites have been recognized as common volcanic products in geological formations of all ages, being found in all volcano-tectonic settings. Until about 60 years ago, welded ignimbrites were generally regarded as lava flows. Few volcanic products have been misinterpreted for so long, this being due to the wide variation in lithology (Cas & Wright, 1987).

### 2.1.1 Lithology

The variation in lithology depends on the composition of the magma and the origin of the flows. Variation occurs from incoherent ash deposits which may be textural similar to mud flows, to more densely welded tuffs, which are fairly difficult to distinguish from lava flows. Such rocks have textures ranging from sub-millimetre particles to large clasts over a meter in diameter.

Most common compositions are rhyolite, dacite and andesite. According to Cas & Wright (1987), many of the most voluminous ignimbrites are rhyolites, some of which are compositionally zoned, indicating in some cases the tapping of large zoned magma chambers. Fisher & Schminke (1984) reported that most large-volume pyroclastic flow deposits are calc-alkalic dacite to rhyolite, resulting in the presence of phenocrysts like quartz, sanidine, and plagioclase with minor amphibole, pyroxene, biotite, Fe/Ti-oxide, like zircon and sphene as accessory phases.

### 2.1.2 Volume

Ignimbrites can be deposited in very small to enormous volumes. The largest amounts are restricted continental margins and interiors, and large islands. They result from eruptions of silicic calc-alkaline magma, and tend to form extensive sheets or shields. The smallest amounts are found in all settings and are a common product of strato-volcanoes, although not restricted to this type of center. These locally smaller volumes tend to form valley fill deposits and their stratigraphy may be very complex (Cas & Wright, 1987).

## 2.2 Pyroclastic flows

Figure 2.2 is a schematic presentation of the processes by which sub-aerial pyroclastic flows and fallout deposits originate. Changes in the influence of the different factors cause the wide variety of ignimbrite.

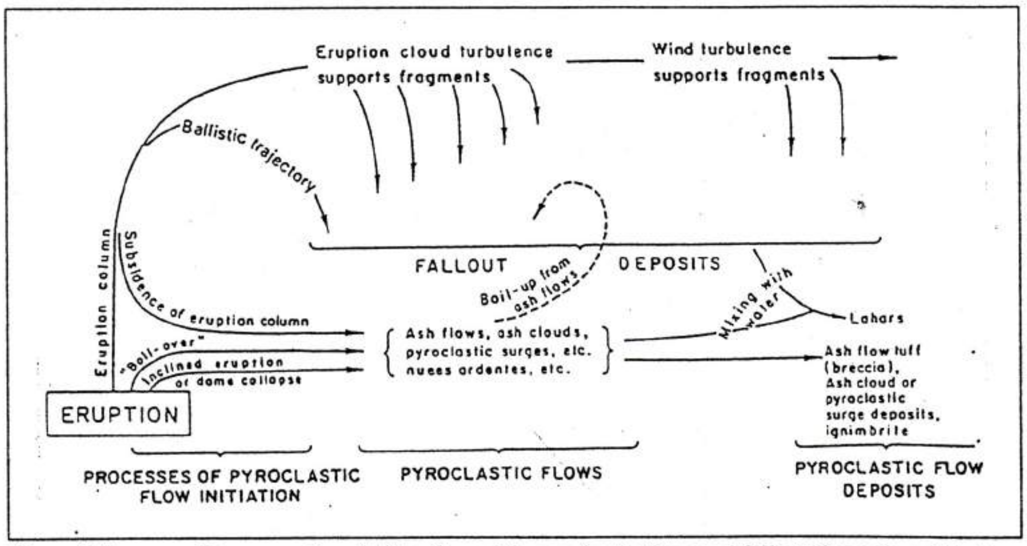


Figure 2.2. Processes by which sub-aerial pyroclastic flow and fallout deposits originate.

Pyroclastic flows are thought to be driven mainly by gasses. Due to these gasses, flows can reach high velocities. These high velocities in combination with the 'liquidity' make the flows able to travel over long distances and to move over and around large obstacles. Evidence for this behavior are ignimbrite deposits, traced at more than 100 kilometer distance from low slope volcanoes, and found behind barriers of more than 600 meter in height.
Previous topography may be completely covered with successive ignimbrite flows of large volume. Sheet-like layers develop when large ignimbrite deposits smoothen previous topographic irregularities by filling up valleys with thick and covering heights with thin ignimbrite layers. The surface however may be nearly flat or gently sloping, gradually thinning towards the flow sides. These ignimbrite-'sheets' may later be dissected into plateaus.

### 2.2.1 Types of ignimbrite deposits

In essence, two kinds of ignimbrite deposits occur; pyroclastic flow deposits and pyroclastic surge deposits (respectively deposited with relative slow and fast velocity). These deposits may occur alone, but are mostly found in close association.
The difference between both deposits is that pyroclastic flow deposits mostly are hardly sorted and massive, showing fine grading and bedding with a certain alignment and oriented particles. Such flows may be preserved only in lower parts of valleys (Figure 2.3.B) due to the complete drainage form the upper slopes, and are often initial thicker away from the source.
Pyroclastic surge deposits however, are better sorted and consist mostly of finer grained particles. Wavy- or cross-bedded structures are common deposition characteristics (Figure 2.3.C). The surges can cover topography of moderate relief thereby overriding the sides of valleys. Surge deposits may mantle topo-graphy in a same way to fallout tephra does (Figure 2.3.A), but the difference is that surge deposits become ponded and thin toward valley margins while fallout tephra causes layering independent of topography (Cas & Wright, 1987).

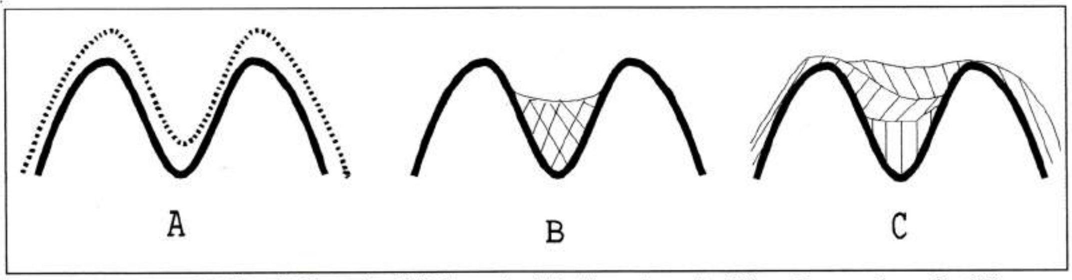


Figure 2.3. Volcanic deposits; fall deposits (A), flow deposits (B) and surge deposits (C).

### 2.2.2 Ignimbritic flow-systems

The different flow-systems cause many varieties in the deposited rock. Also influences like cooling and welding and the origin and nature of the flows, cause differences in the deposited ignimbrites.
The depositional unit that represents a single pyroclastic flow deposited in one lobe is called a flow unit. Such a flow unit can vary in thickness from centimeters to many meters. The time between different flow units may be within minutes up to several hours. The boundaries between the flow units are marked by changes in density depending upon the time between the flows, the size of the flow, the composition of the flow material etcetera.
Welding is defined as the sintering together of hot pumice fragments and glass shards under a compactional load (Cas & Wright, 1987). Glass viscosity (dependent on temperature and composition) 0and lithostatic load (dependent on the thickness of the deposit), are the most imported controls.

The high heat-conserving-capacity of pyroclastic flows may cause the 'melting' or welding together of different succeeding flow units. The degree of welding of individual flows depends strongly upon the time between and load of the flow units. Each degree of (non-)welding gives its own rock- and boundary-structure. Many forms can be found due to the great variety in circumstances.

Cooling of the pyroclastic deposits may occur as simple cooling units or as a compound cooling unit. When several very hot flow units pile rapidly on top of each other, they may cool as a single cooling unit. A simple cooling unit forms when a single flow or successive flows cool as a unit with no sharp changes in the temperature gradient.

A compound cooling unit forms when an interruption in temperature occurs, that disturbs the continuous cooling unit zonation of successive hot flows. Cooling from emplacement- to ambient temperature may take decades, depending on the thickness of the deposit and the emplacement temperature.

A cooling unit is marked by a more or less systematic pattern of zones of rock, differing in degree of welding and thus density, resulting from different cooling regimes (Figure 2.4).

In young deposits, not lithified by deagenesis, compaction, and metamorphism, the top and bottom parts of cooling units are commonly composed of friable unwelded pyroclastic material: the basal layer is unwelded because it cools quickly against the cold rock basement, and the top because of the relatively rapid heat convection and radiation into the atmosphere. The area of densest welding, in the lower half of a cooling unit, is the zone that remains longest at the original emplacement temperature (Cas & Wright, 1987).

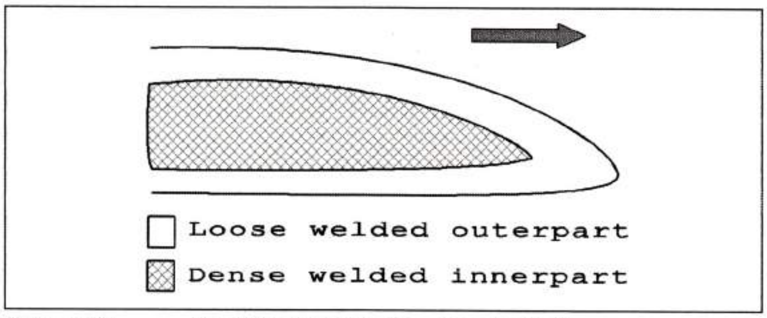


Figure 2.4. Welding structure in a pyroclastic flow.
The arrow indicates the flow direction.

### 2.2.3 Differences in fabric of the ignimbrite

Large parts of the research area contain ignimbritic parent rock with a sandy, and at times very loose, structure. This sandy structure can arise from a quick cooling down, or from the slightly welding of pyroclastic flows. Quick cooling down mostly occurs at the bottom, top and sides of pyroclastic flows. Under certain circumstances the pyroclastic flow itself can be totally deposited as a rock with a sandy structure (Pyroclastic flows, paragraph 2.2).

At some positions in the landscape of the Horizontes area (Figure 2.5) sandy structured ignimbritic rock may have existed but has disappeared through weathering and erosion of this relatively softer material. The small hills that still exist may be the denser welded inner parts of the deposited pyroclastic flows, while the outer parts were of a more sandy structure (Figure 2.6). Fact is that the hills do point in the same direction and thus might be the denser welded remnants of successive pyroclastic flows.

In the central part (Figure 2.5) of the area the sandy structured rock dominates. It is probably the south side of an extended pyroclastic flow. The other sides can not be found in the direct nearness and the landscape keeps its higher topography into the northern direction (this area might also be higher due to tectonic events, see paragraph 2.3). The ignimbritic rock underlaying the soils in the most northern part of the area is of a dense welded structure, which may also support the theory described above.

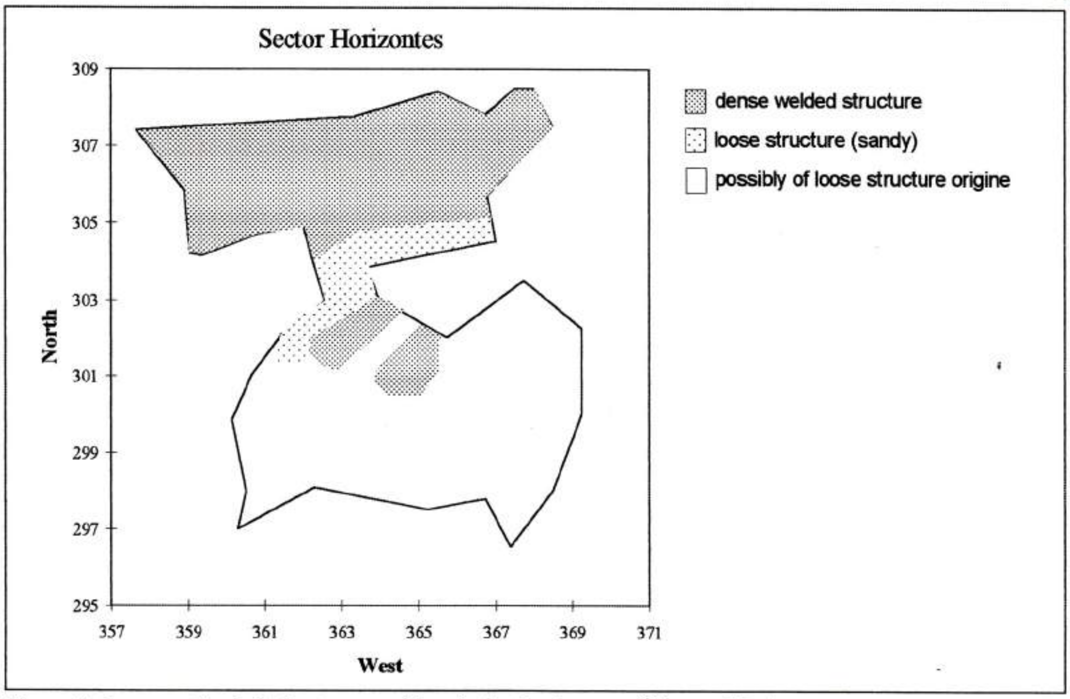


Figure 2.5. Ignimbrite type position in the landscape of Sector Horizontes.

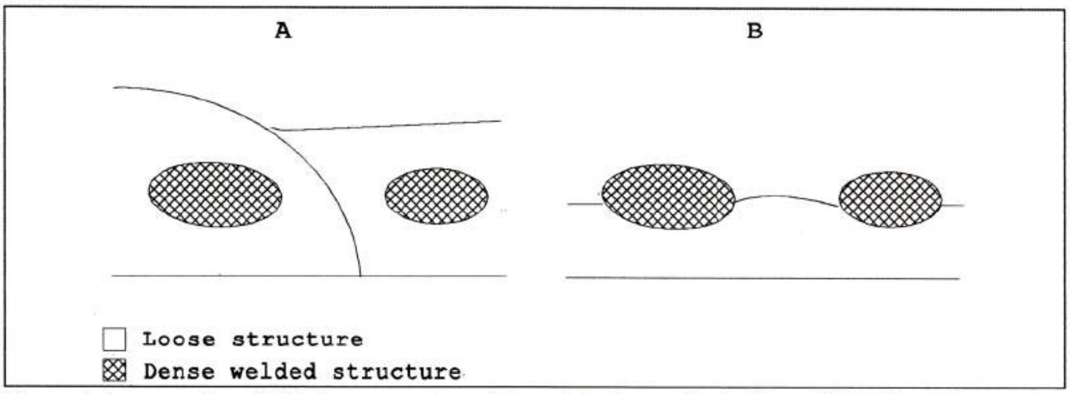


Figure 2.6. Simplicified cross-section of the original pyroclastic flows (A) and its remnants after weathering and erosion (B).

## 2.3 Tectonic movements

The collision of the St. Elena complex with the mainland (Weyl, 1980) caused an uplift of part of the north-western of Costa Rica, about 88 to 69 millions of years ago, which is probably still going on. On the other hand, the cordillera de Guanacaste rises due to volcanism in combination with tectonic movement. These two movements are believed to cause the appearance of a valley in between the St. Elena complex and the Guanacaste cordillera; the valley which is nowadays called the Tempisque-valley (Weyl, 1980).

As can be seen in the simplified presentation of the processes (Figure 2.7), the tectonic movements cause a change in landscape positions throughout the area. Slopes which for example first drained in northern direction, nowadays drain in southern direction. The change in slope and slope-direction perhaps may cause a change in weathering and weathering patterns of rocks due to, for example, a change in drainage. The effects that tectonic movements finally have on soil forming processes are often difficult to understand and reconstruct, due to the long time between the start of such events and today.

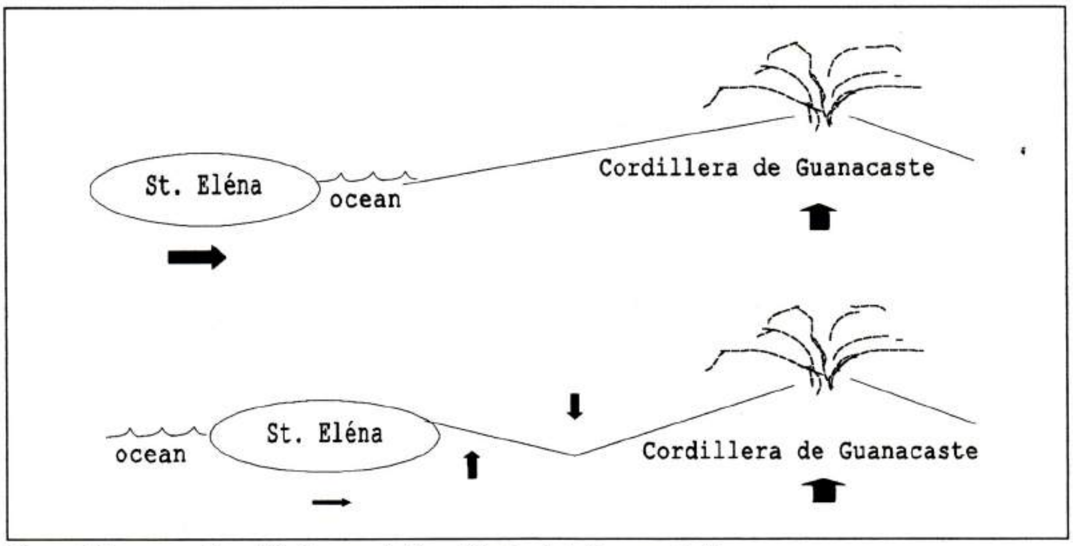


Figure 2.7. Simplified presentation of tectonic influences in the area. Direction and force of tectonic movements is indicated with arrows.

## 2.4 Topography

Altitude of the Horizontes area varies from about 60 up to about 230 meters above sea level (Topographical map, Appendix I), and of the Irrigation canal and Lomas Barbudal areas from 45 - 60, and 90 - 100 meters. Abrupt height differences of several meters in the ignimbrite landscape are rather common. Also large, gently undulating areas with height differences of less than two meters occur.

## 3 Climate

Day length in Costa Rica varies from about 11.5 hours to 12.5 hours on respectively the 21th of December and the 21th of June, related to its position at a latitude of approximately 10° N (Herrera, 1985). The climate is strongly influenced by atmospheric perturbations originating from either the Pacific Ocean or the Caribbean Sea.

### 3.1 Northern Pacific region

The lower areas of the northern Pacific region are characterized by a prolonged dry season of about 5 months (approximately from December until April) during which strong, dry northeastern winds cause strong evapotranspiration.

During the rainy period, from May until November, an extremely variable short dry spell called "canícula" or "veranillo de San Juan" occurs in July and August. Its occurrence is (1) generated by a temporal dominance of northeastern trade winds, (2) caused by a strengthening of the high pressure belt at a latitude of about 30° N in the Caribbean, and the northern position of the Intertropical Convergence Zone (ITCZ). The ITCZ is the zone in which northern and southern trade winds meet.

Its duration is among others related to occurrence of the "El Niño" effect. This phenomena is caused by a shift in the course of the cold gulfstream water, favouring occurrence of northeastern winds and lower rainfall during the rainy season due to which the "canícula" lasts longer and the dry season begins earlier than usual.

Mean annual rainfall varies from 1500 in the lower- to about 2500 in the higher areas, but it is important to recognize that the region is characterized by a large variation in yearly total and monthly distribution, which influences strongly both agriculture and ecology.

Both during the dry season and during the "canícula" rainfed agriculture is limited by a moisture deficit and crop growth depends on available moisture in the soil.
Mean Penman potential evapotranspiration in the flat northern area varies from 4.0 mm/day during the rainy season to 9.0 mm/day during the dry months (station Liberia)), while in the area less affected by strong winds it varies from 3.5 to 6.0 mm/day (station Nicoya). Relative air humidity varies from 60% during the dry period to 85% during the rainy season.

According to the Costa Rican Meteorological Institute (T.V. transmission 1994), occurrence and strength of the northeastern trade winds has increased during the last 30 years, increasing effects of the dry season and (probably) decreasing mean annual rainfall.
Wind speed is strongest on the footslopes of the Cordillera de Guanacaste and northern plains. During the dry seasons mean wind speed in this area is about 20 km/h (station Liberia). During the rainy season windspeed diminishes to about half of these values.

The mean annual air temperature is about 26 to 28 °C and diminishes with altitude at a rate of 0.57 °C every 100 m (Herrera, 1985). The hottest month is usually April with mean temperatures of 28 to 29 °C,, the coolest months are December and January with mean temperatures of 26 to 27 °C.

### 3.2 Study sites

Meterorological data are obtained from the stations:

- Bagaces 076026, at 10° 32′ N and 85° 15′ E, at an altitude of 80 m above mean sea level.
- Cañas, San Luis 076005, at 10° 25′ N and 85° 05′ E, at an altitude of 95 m above mean sea level.
- Sector Horizontes, at 10° 43′ N and 85° 36′ E, at an altitude of 155 m above mean sea level.
- Liberia, Llano Grande 074020, at 10° 36′ N and 85° 32′ E, at an altitude of 85 m above mean sea level.
- Santa Rosa 072106, at 10° 50′ N and 85° 37′ E, at an altitude of 315 m above mean sea level.

Figure 3.1 shows the geographical position of the stations.

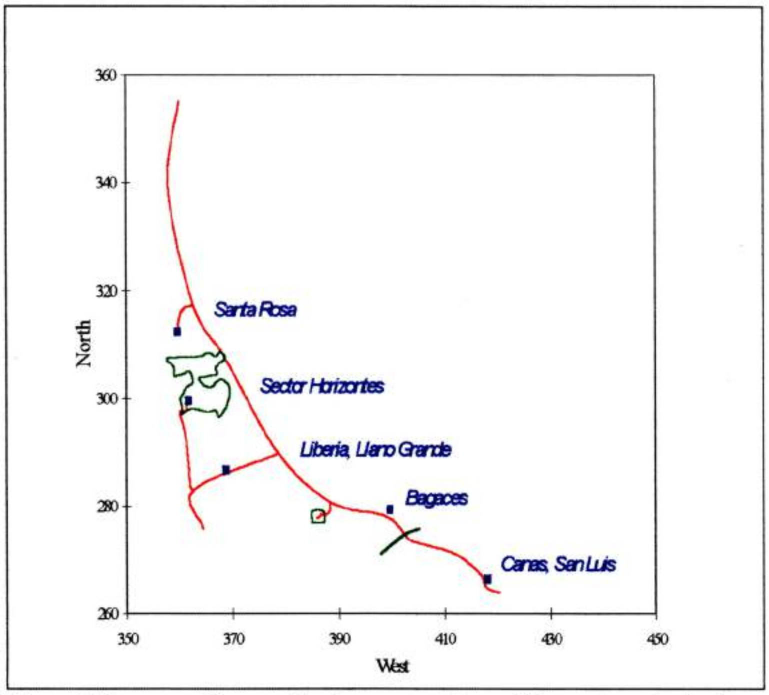


Figure 3.1. Geographical representation of the meteorological stations.

Meteorological data of the Horizontes area are available from June 1994 up to 15 February 1996 only. This must be taken into account when interpreting the data mentioned below. Therefore, also precipitation data of the meteorological stations of Liberia and Santa Rosa are given, as sector Horizontes is situated between these stations. 'Lomas Barbudal' area is situated closest to meterorological station Bagaces.

*Precipitation*

Figure 3.2 shows the averaged precipitation per month for the pre-menitioned stations. The curves of Cañas and Liberia are of data averaged over many years and are therefore the most stable compared to the curves of the Bagaces, Horizontes and Santa Rosa data. All curves clearly show the dry period from November to April and the dry spell during July and August.

Figure 3.3 shows the precipitation per day during October 1995, for the Horizontes area.

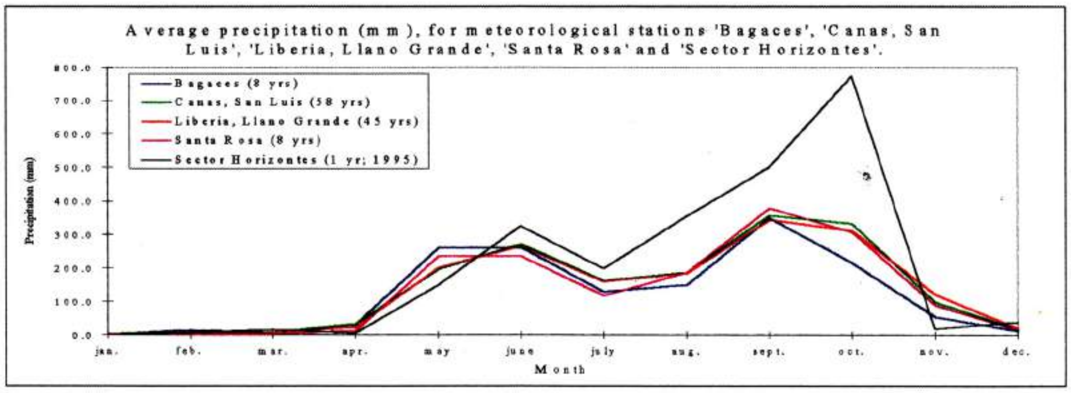


Figure 3.2. The average precipitation (mm) per month of the stations in the nearness of the study areas; clearly showing the dry and rainy seasons.

From figures 3.2 and 3.3 and the tables in Appendix II, can be seen that most precipitation falls in short time periods. Annual precipition totals vary between approximate 780 to 2870 mm, the averaged annual precipitation of climate stations 'Liberia, Llano Grande' and 'Cañas, San Luis', is about 1650 mm (Appendix II).

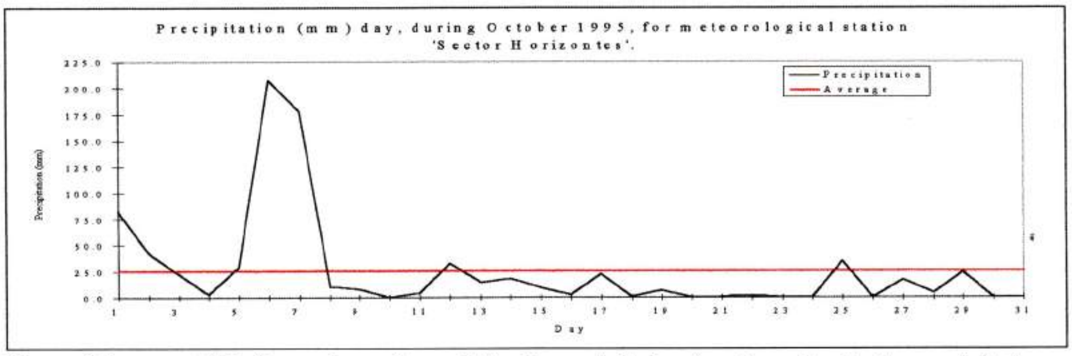


Figure 3.3. This figure shows the variation in precipitation (mm) per day, by the precipitation during October 1995 for meteorological station 'Sector Horizontes'.

*Temperature*
Temperature data are obtained from sector Horizontes only. Although these data are of one year of measurement only, they might give a global impression of the annual temperatures. Temperature data were not available from the other areas, but taken into account height it must be about the same as in the Horizontes area. Table 3.1 (Appendix II) shows the temperature data of 1995 of sector Horizontes. Mean temperature in 1995 was 25.7 °C, with a mean minimum of 20.6 °C and a mean maximum of 30.8 °C per month. The coldest temperature measured is 15 °C (December '95), while the hottest temperature measured is 36.5 °C (April '95).
Figure 3.4 shows that averaged data per month do not vary much, so the temperature throughout the year can be interpreted as rather constant. Note that the temperature is highest during the end of the dry season, and lowest during the months with the highest precipitation.

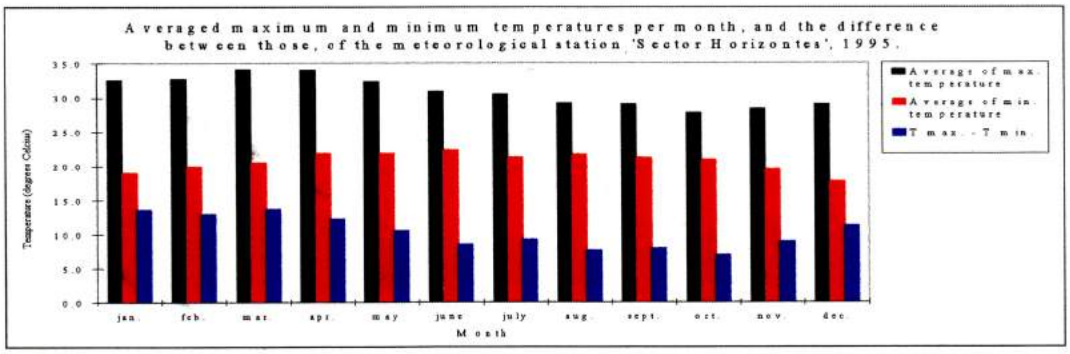


Figure 3.4. Averaged maximum and minimum temperatures per month, during 1995, measured by meteorological station 'Sector Horizontes'.

*Summarizing*
Climate in Horizontes, Lomas Barbudal and the irrigation canal area is about the same, and according to average annual precipitation and average temperature, it should be classified as tropical dry (Holdridge, 1966) or as a ustic moisture regime (Soil Taxonomy, 1992).

# Soil mapping on the Pleistocene Ignimbritic Bagaces Formation, Guanacaste, Costa Rica.

***A soil mapping project.***

*(J050-709)*

*A.F. Winters*

*May 1996*

# 4 A study on soil types on ignimbrite of the Bagaces Formation

*Introduction*

This chapter presents a study on the different soil types developed on rocks of this formation, in an experimental station for reforestation named 'Horizontes', part of the national park 'Santa Rosa'.

The "Horizontes" sector contains about 7,300 hectare of dry tropical forest (semi aride climate) mixed with pastures. Until 1990 most of the present pastures were used for the cultivation of crops like rice, sorghum and cotton. Nowadays the non-forested area's are used as extensive cattle pastures in order to restore the natural dry-forest in the whole area, to preserve the specific dry-forest flora and fauna. Some parts of the area are used as experimental reforestation area's with planted seedlings.

The study area makes part of a reconnaissance soil survey, carried out for the program REPOSA; a program of cooperation between CATIE and MAG in Costa Rica and the Agricultural University of Wageningen the Netherlands.

The goal of the current study is to characterize the development and spatial distribution of the dominant soils on the parent material ignimbrite.

Therefore *a soil map, scaling 1:50,000, on ignimbritic parent material in a part of the province of Guanacaste, Costa Rica* was made. This soil map will support the construction of a soil map, scaling 1:150,000, for the whole province of Guanacaste.

The paragraph Material and methods explains how the research was done. In paragraph 4.2 the results of the research are presented. In paragraph 4.3 the conclusions are listed.

## 4.1 Methods and materials

The 'Horizontes' area was selected because the area contains different soil types, developed on the parent material ignimbrite. That different soil types do occur on ignimbrite was expected due to the complexity of deposition of the parent material, and was also observed during reconnaissance field trips.

### 4.1.1 Fieldwork

Before the 1:50,000 mapping of the area started, the most prominent and representative soil types were traced. Selection criteria for the soil types (resulting in a schedule given in paragraph 4.2) were:

1. Density of the parent material:
   - *Dense welded ignimbrite.*
   - *Loose structured ignimbrite.*
2. Presence of ash addition.
3. Topography:
   - *Plain terrain.*
   - *Slightly sloping terrain.*
   - *Strong sloping terrain.*
4. Presence of vertic properties.
5. Color gradation:
   - *Weak.*
   - *Strong.*

The soils were studied in detail by boring (horizon type and depth, color and texture), followed by digging a pit per soil type. After digging a pit, these soil types were described (FAO guidelines, 1990) and sampled for physical, chemical and micromorphological analysis, resulting in the descriptions Horizontes 1 to 6 and 8 (Appendix IV). Based on the criteria, the area was mapped with help of aerial photo's, visual and by boring with an auger.

If possible, profile pits were dug until the parent material was reached, to be able to sample this material as well. Boring was done until the depth which made it possible to classify the point into one of the seven soil types. Often the boring was continued until the parent material, to get an idea about changes in soil depth throughout the area.

At the beginning of the fieldwork particularly, observation points were selected on changes in color or texture, indicated by for example a change in slope, vegetation or surface color. So sample points were not taken at equal distances, but on a physiographical basis.
Some subareas are not fully examined as a result of shortage in time, inaccessibility and weather-circumstances (heavy rainfall), as can be seen in the survey (Figure 4.1). So the aim of an accuracy of about one point per 0.25 square kilometer could not be achieved for the whole area.
The (almost) unsampled subareas however, are expected to contain soil types similar to the surrounding points. This hypothesis is based upon field experiences obtained during the soil survey, combined with aerial-photo impressions.

The boring points (A) and visual points (V) are described in Appendix III. After the code and the date of examining, the approximate position is given. Slopes are described for the site and for the direct area around the site if great slope changes are present. Profile depths are given in centimeters.
The visual points are a description of the area between two or more points, or a description of the soil type on the location itself. An overview of the deviation of the examined points to the seven described soil types is also given in Appendix III.

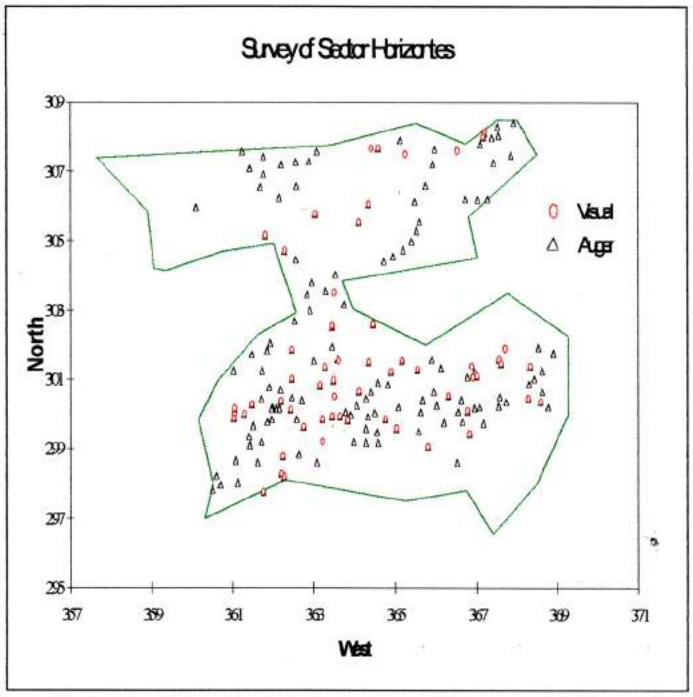


Figure 4.1. Spreading of auger and visual points in the 'Sector Horizontes' area.

### 4.1.2 Materials

A more detailed Geological map than the one shown in Figure 1.1 (Introduction) was not examined, because the research area is situated in the 'center' of the ignimbrite formation and presence of other geological units was therefore not be expected. The topographical map 'Ahogados' 30048 II, Costa Rica, Edicion 2-igncr, 1988, was used either as a topographical as a geographical map.

The aerial photo's used were obtained from the National Geographical Institute of Costa Rica. Used were the 'black-and-white' photo's of roll 4, strip 296 and 308 from respectively 26 and 30 November 1987, scaling approximate 1:36,000.

Boring was done with the Edelman auger. Textural classification was done with help of the textural triangle according to the Soil Survey Staff (1990), while the colors of the soils were determined according to the Revised Standard Soil Color Charts (Japan, 1970).

### 4.1.3 Analysis

In order to classify the soils properly according to the USDA Soil Taxonomy (Soil Survey Staff, 1990), analytical research of for example pH-KCl, CEC and base-saturation in a laboratory is required. Unfortunately this could not be done because of the budget and time limitation. Therefore and because an estimation would be to rough, the described soil types are given a field name.

### 4.1.4 Soil map

All observation points (Appendix III) are related to the described profile pits, using a relatively wide range of tolerance in soil properties. This system is used to keep the soil map as simple but representative as possible, without getting lost in using a wide range of nearly the same soil types.
For grouping, several criteria are used, according to paragraph 4.1.1 and the schedule given in paragraph 4.2. Shallow soils are mainly grouped based on better developed surrounding soils on more or less equal positions.

With the selected basic soil types, the mapping units of the soil map were made. This map shows the dominant soil type(s) in percentages, for a given part of the whole area. Most of the mapping units are compounds; associations of two or more of the described soil types.
The use of associations is necessary because the soil types often change within short distances, leading to single mapping units which can not reproduce considering the scale of the map. Also an indication of the topography is given, by giving values to several slope ranges (Soil map, Appendix V).

## 4.2 Results and discussion

The study area contains seven dominant soil types based on differences in the fabric of the ignimbrite, the geomorphology of the terrain and differences in characteristic soil properties, represented by the descriptions S01 to S06h and S08h (Appendix IV). The schedule below shows the legend of the soil map.

These soil types are the most important soils that do exist in this area. Within each soil type class, a small range of varieties in color, structure and profile depth may occur.

Differences in topography and hydrology influence the development of soil types on the ignimbritic parent material. Even very small changes in height may cause the development of different soil types within meters. Evidence for this is the mixed appearance of vertic soils in shallow depressions, continuing in red-brownish soils positioned on 'hill tops' not even one meter higher, on several places in the area.

Profile depths in the 'Horizontes' area vary from zero up to about two-hundred centimeters. Most soils however, are not deeper than approximate one meter. We expect that the erosion during the wet season, in combination with the often sloping terrain, is a strong limiting factor on the development of very deep soil profiles.

*Soils on ignimbrite:*

| | | | | |
|---|---|---|---|---|
| *I* | *Dense welded ignimbritic parent rock:* | | | |
| | *Ia* | *Plain terrain (0 - 1 %):* | | |
| | | *Ia1* | *Vertic properties:* | *V (S04b).* |
| | | *Ia2* | *No vertic properties:* | *G (S02b).* |
| | *Ib* | *Slightly sloping terrain (1 - 5 %):* | | |
| | | *Ib1* | *Weak color gradation:* | *B (S01).* |
| | | *Ib2* | *Strong color gradation:* | *C (S05h).* |
| | *Ic* | *Strong sloping terrain (> 5 %):* | | *R (S06h)* |
| *II* | *Loose structured ignimbritic parent rock:* | | | *S (S08h).* |
| *III* | *Influenced by ash deposition:* | | | *A (S03).* |

### 4.2.1 Aerial photo interpretation

The different gray tones on the 'black-and-white' aerial photos were expected to give an indication for the changes in soil type. After comparing some selected areas of the photos, containing distinct changes of gray tones, with the according areas in the field, the expectation seemed wrong. There was in almost al cases no clear relationship between the gray tones on the photos and the soil types in the field.
If a change in gray tone on the photo could be connected with a change in soil type in the field, there seemed to be no clear relation between the gray tone and the soil type because the same soil type on other locations showed different gray tones on the photos.

Only abrupt changes between forested- and non-forested areas gave an indication of a change in soil type. The forrested parts on the photos often contain strong sloping to steep sites. These sites are unsuitable for the cultivation of crops like rice and sorghum and therefore, during the years the photos were taken, not used for arable farming.
Nowadays almost the entire area has been reforested and with more recent photos there might be a possibility that the gray tones give some indication of the soil type, not by the soil type itself, but due to the gray tones caused by changing vegetation patterns throughout the area. When a vegetation pattern is specific for a certain soil type, this soil type is this way indicated by a certain gray tone.

Another handicap for the prediction of the soil type by aerial photo interpretation, is that some areas contain very complicated patterns with often rather small and different units of soils. The gray tones of these areas will be a result of several separate graytones or the gray tones will show the same pattern as the field situation, but on a smaller scale, resulting in unusability of the photos for these purposes.

### 4.2.2 Comparing soil groups

When we compare the soil groups represented in the schedule above, some differences between the classes are very clear:

- The density of the parent material; a dense welded (I) and a loose structured (II) parent material could be distinguished. Both seem to give rise to differences in soil forming processes due to specific weatherability depending on for example texture.
- Presence of visible remnants of volcanic ash deposition (III).
- Difference in slope. This may cause a variety in drainage patterns, leading to specific soil forming processes like the leaching of soluble elements from higher to lower positions by drainage. Three subgroups are distinguished; plain terrain (Ia) with slopes of the surrounding area up to 1%, slightly sloping terrain (Ib) with slopes from 1% up to 5% and strong sloping terrain (Ic) with slopes >5%. Slopes described in appendix III may not always correspond with the soil type classification given, because the total profile description matches better with a soil type from an other class. So slope ranges are not strictly used.

Characteristics like swelling and shrinking and color gradation are used to select soil types when evidence of influencing factors on soil forming processes seem to be unavailable.

Observation points were grouped into the below mentioned soil types according to the schedule. The distribution throughout the area is visualized in little maps, in the text below.

*V: Ia1 Vertic properties*

| V (S04b) | | | | |
|---|---|---|---|---|
| horizon | depth | colour (moist) | texture | other |
| Ah / AB / ABg | Measured depth varies from 5 to more than 40 cm, with an average depth of about 20 cm. | Colour ranges from brownish gray (10 YR 5/1) to black (7.5 YR 2/1), while brownish black (10 YR 2/2) is the most common colour. | Texture varies from clay to silty clay. | Slickensides and in some cases mottling are present. |
| Ah2 / BA / B / Bw / Bwg / B2 | Measured depth varies from 10 to 40 cm, with an average depth of about 25 cm. | Colour ranges from brownish gray (10 YR 4/1) to black (10 YR 2/1), while dark gray (N 3/0) is the most common colour. | Texture is clay. | Slickensides and in some cases mottling are present. |
| B2 / B3 | Measured depth varies from 20 to 35 cm. | Colour ranges from yellowish gray (2.5 Y 4/1) to dark gray (N3/0). | Texture is clay. | In some cases slickensides are present. |
| R | Rock begins between 35 and > 100 cm. | | | |

Mapping unit ***S04b*** reflects an important soil of the study area; a vertisol.
Large cracks during the dry season (closing in wet seasons), a clayey texture and a dark color throughout the profile are evidence that the soil is a Vertisol.

Looking to the horizon name, color and texture pattern of the described vertisol, no clear distinction between horizons can be made. The differences are based upon the size of the slickensides, the structure and the roots present (see profile description, Appendix IV).

Sites with vertisol vary in size from several m$^2$ up to several hectares throughout the entire area. This influences the interpretation of the soil map. Either several small sites together, or one big site, may be represented by the percentage in the indication of the mapping units. This soil type is very abundant throughout the area (Figure 4.2), because vertic soils are position dependent and not much depending on the type of parent material as the other described soils.

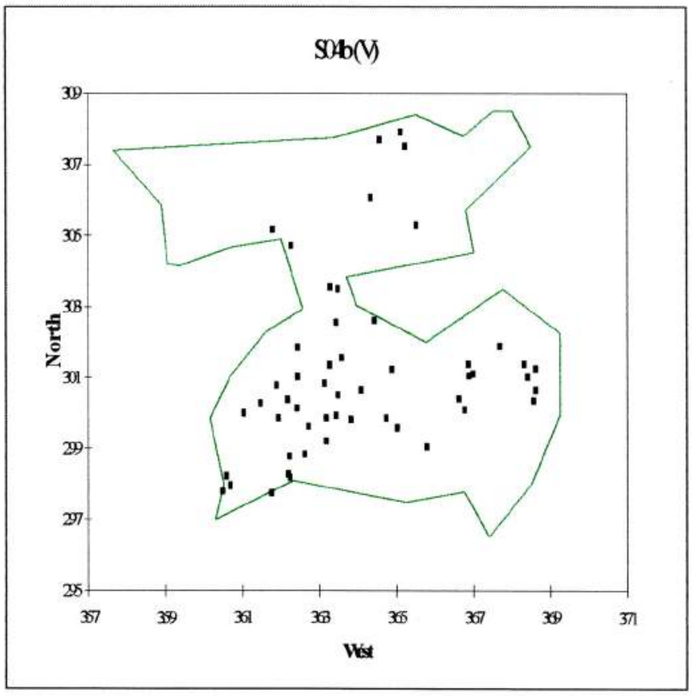


Figure 4.2. Spreading of S*04b (V)*.

Vertisols are mostly formed at the lowest positions in the landscape. In this area however, vertisols are also found in the highest positions of the area (see the locations of bore and visual points). There may be two explanations for this appearance:

- The vertisols were formed on the lowest positions in the landscape, but throughout the years the tectonic movements overturned the landscape in such a way that the vertisols are situated nowadays on the highest positions (Figure 4.3). This overturn is likely to cause a change in drainage patterns which may result in changes in the soil-forming processes. Especially in this case, increasing possibilities of leaching favor changes in soil type, unless there is a natural barrier that prevents the leaching of elements.

  Tectonic movement does not influence the landscape topography to a high extent in this area. This in combination with the slowness of most soil forming processes, the 'spoon-effect' seems very doubtful.
- The second possibility is that the vertisols are formed on positions where leaching of weathering products is prevented only by a natural barrier (Figure 4.4). Such a barrier, for example, may be impermeable rock surrounding a certain area. The parent material of the area adjacent to the outer margins of this barrier may be weathered and eroded with time, or may still exist and developed into (an) other soil type(s).

The second explanation is most acceptable for the sometimes very sharp vertical boundaries between two different soil types.

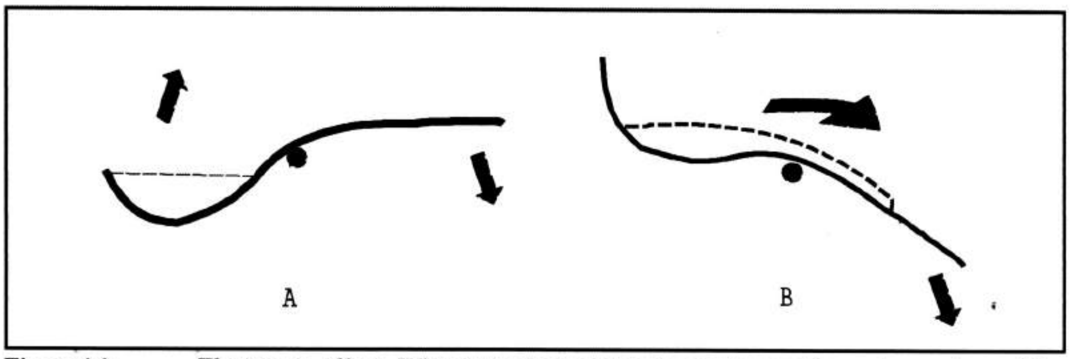


Figure 4.3. The 'spoon-effect'. When tectonic movements overturn surfaces, depressions will 'empty' or develop into other soil types.

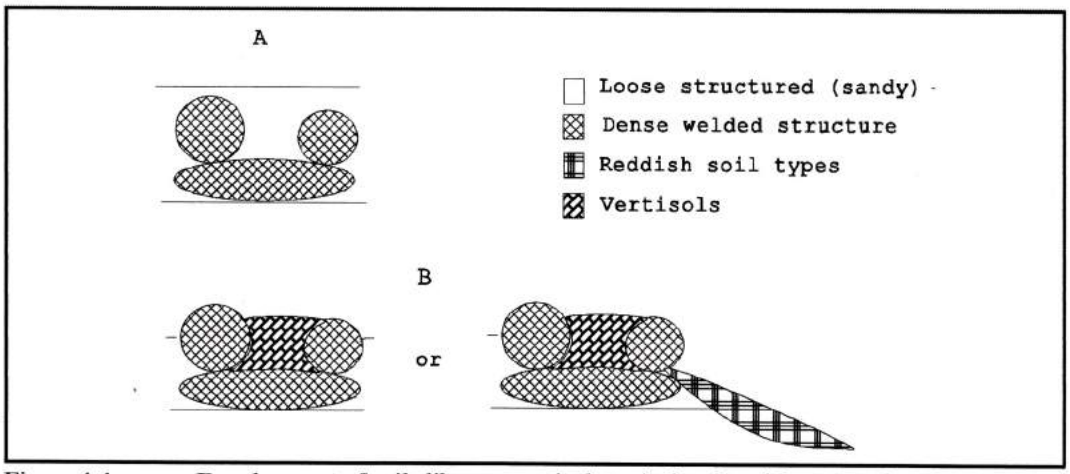


Figure 4.4. Development of soils like e.g. vertisols on isolated positions (B) after the original deposition structure (A) changed due to weathering and erosion.

*G: Ia2 No vertic properties*

Mapping unit ***S02b*** occurs mainly in the south-east of the area.

The profiles show an increase of grayish color and finer texture downwards.

These soils are developed on more or less plain terrains with probably poor drainage conditions, equal to the prementioned vertisols. The difference is that the S02b soils do not show vertic properties like cracks, and have a much lighter color than the soils of S04b.

We expect that these soils do not get the addition of leachable elements according to vertisols, because of the absence of nearby and surrounding higher areas. The lighter color of this soil may be due to a rather low iron content of the parent material on this location. In order to confirm both speculations, further research is needed.

| G (S02b) | | | | |
|---|---|---|---|---|
| horizon | depth | colour (moist) | texture | other |
| Ah /Ahg / AB / ABg | Measured depth varies from 4 to 30 cm, with an average depth of about 20 cm. | Colour ranges from dark brown (7.5 YR 3/3) to black (7.5 YR 2/1), while brownish black (10 YR 2/2) is the most common colour. | Texture varies from clay to sandy clay loam. | In some cases mottling and nodules are present. |
| Ah2 / AB / BA / B / Bwg | Measured depth varies from 5 to 75 cm, with an average depth of about 15 cm. | Colour ranges from the most common colour grayish yellow brown (10 YR 4/2) to brownish black (10 YR 3/2). | Texture varies from clay to silty clay loam. | In some cases mottling and residual rock fragments are present. |
| B / Bw / Bwg / BC / BCg / BCwg | Measured depth varies from 10 to 49 cm, with an average depth of about 15 cm. | Colour ranges from light gray (5 YR 8/1) to the most common colour brownish gray (5 YR 4/1). | Texture varies from clay to sandy clay. | In some cases mottling, residual rock fragments and nodules are present. |
| (occasionally) B / Bwg | Depth is more than 10 cm. | Colour ranges from the most common colour dull yellow orange (10 YR 6/4) to brownish gray (10 YR 4/1). | Texture varies from clay to sandy clay. | In some cases nodules are present. |
| R | Rock begins between 50 and > 91 cm. | | | |

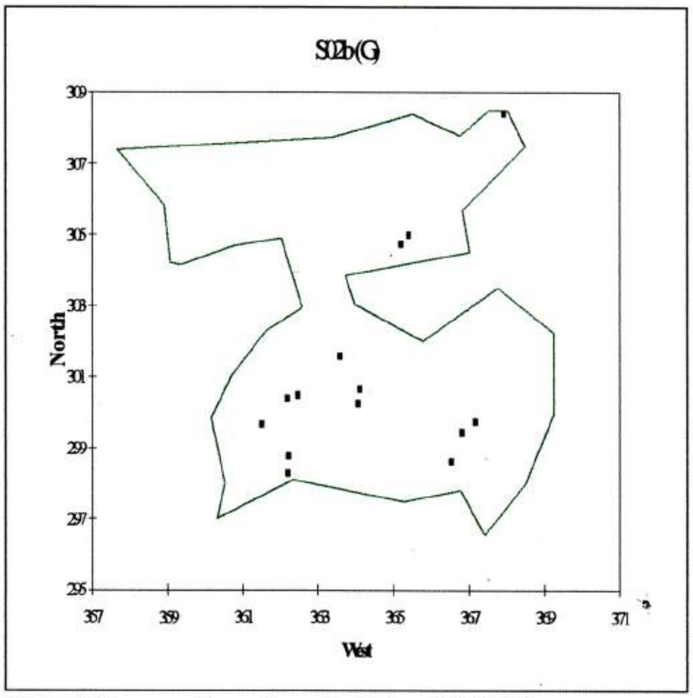


Figure 4.5. Spreading of soil type *S02b (G)*.

## B: *Ib1 Weak color gradation*

| B (S01) | | | | |
|---|---|---|---|---|
| horizon | depth | colour (moist) | texture | other |
| Ah /Ahg / AB | Measured depth varies from 2 to more than 40 cm, with an average depth of about 20 cm. | Colour ranges from brown (7.5 YR 4/4) to black (7.5 YR 2/1), while brownish black (7.5 YR 3/2) is the most common colour. | Texture varies from clay to sandy loam. | In some cases mottling, residual rock fragments and nodules are present. |
| Ah2 / AB / ABwg / BA / B / Bw / BC | Measured depth varies from 5 to 65 cm, with an average depth of about 30 cm. | Colour ranges from brownish gray (10 YR 5/1) to black (10 YR 2/1), while brownish black (7.5 YR 2/2) is the most common colour. | Texture varies from clay to silty clay. | In some cases mottling, residual rock fragments and nodules are present. |
| B / Bwg / BC | Measured depth varies from 10 to 55 cm, with an average depth of about 25 cm. | Colour ranges from bright yellowish brown (10 YR 6/6) to brownish black (10 YR 2/2). | Texture varies from clay to sandy clay loam. | In some cases mottling, residual rock fragments and nodules are present. |
| (occasionally) Bwg | Measured depth varies from 10 to more than 40 cm. | Colour ranges from dull brown (7.5 YR 5/4) to grayish brown (7.5 YR 5/4). | The texture is clay loam. | In some cases nodules are present. |
| R | Rock begins between 25 and > 100 cm. | | | |

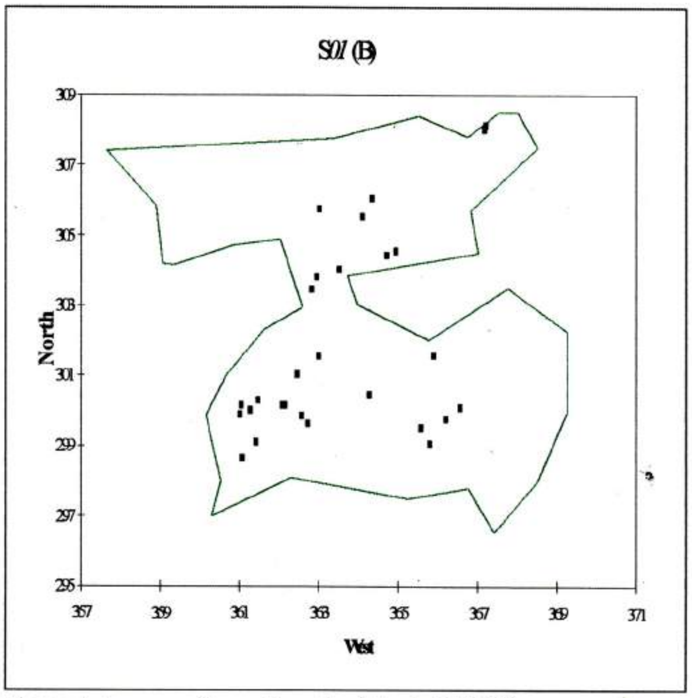


Figure 4.6. Spreading of soil type *S01* (B).

Mapping unit ***S01*** has a brownish colored profile with a weak color gradation downwards.
The texture throughout the entire profile is clay-loam.
The occurrence is concentrated in the south-west of the research area. Either several small sites together, or one big site, may be represented by the percentage in the indication of the mapping units

These soils seem to be developed on slightly sloping positions mainly, with rather good drainage and weathering conditions, leading to the loamy texture and the dark/brownish horizon colors.

*C: Ib2 Strong color gradation*

| C (S05h) | | | | |
|---|---|---|---|---|
| horizon | depth | colour (moist) | texture | other |
| Ah / Ahg / AB / ABg | Measured depth varies from 10 to 40 cm, with an average depth of about 20 cm. | Colour ranges from dark brown (7.5 YR 3/4) to black (7.5 YR 2/1), while brownish black (10 YR 2/2) is the most common colour. | Texture varies from clay to sandy loam. | In some cases mottling. |
| ABwg / BA / B / Bw / Bwl / Bwg / BC | Measured depth varies from 5 to more than 50 cm, with an average depth of about 15 cm. | Colour ranges from bright yellwish brown (10 YR 6/8) to brownish black (10 YR 2/2), while grayish brown (7.5 YR 4/2) is the most common colour. | Texture varies from clay to sandy loam. | In some cases mottling, residual rock fragments and nodules are present. |
| Bwg / Bwg2 / BC / BC2 / BCg / BCwg | Measured depth varies from 10 to 50 cm, with an average depth of about 25 cm. | Colour ranges from the most common colour dull yellowish orange (10 YR 6/4) to dull yellowish brown (10 YR 4/3). | Texture varies from clay to sandy clay. | In some cases mottling, residual rock fragments and nodules are present. |
| Bwg / Bwg / BC / BCwg / CBg | Measured depth varies from 10 to 40 cm, with an average depth of about 15 cm. | Colour ranges from dull yellow orange (10 YR 7/3) to brownish gray (10 YR 5/1), while dull yellow orange (10 YR 6/4) is the most common colour. | Texture varies from clay to clay loam. | In some cases mottling, residual rock fragments and nodules are present. |
| R | Rock begins between 40 and 110 cm. | | | |

Mapping unit ***S05h*** is also situated on slightly sloping terrain, but selected because of its clear downward change from dark to lighter colors, instead of the S01 soils which do not show this strong color gradation.
This soil type also has a relative constant texture throughout the entire profile.
The soil occurs mainly just south of the central part of the area.

A distinct presence of gleyic properties in lower horizons seems to be the reason for a lighter color of these horizons. This makes soil type S05h different from soil type S01, which does not show this strong color gradation. The gleyic properties are probably caused by the stagnation of water on the underlaying rock, during periods of heavy rainfall.

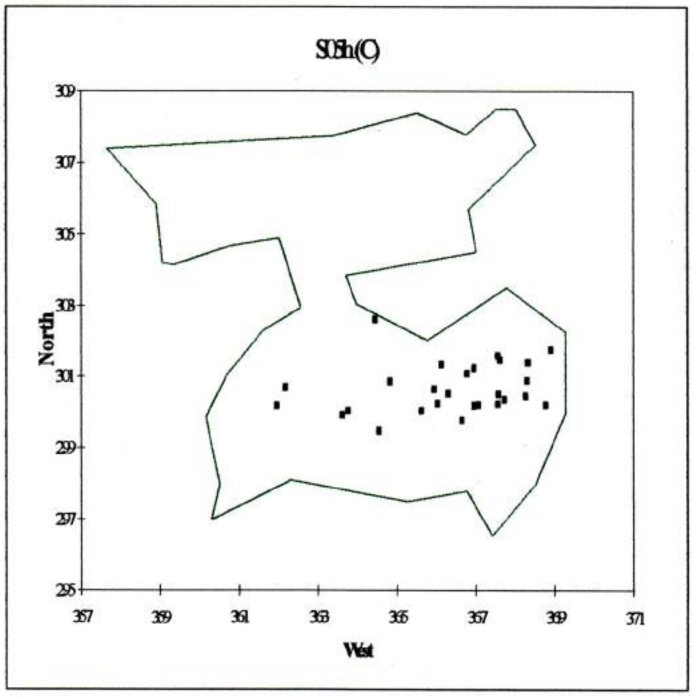


Figure 4.7. Spreading of soil type S*05h* (C).

*R: Ic Strong sloping terrain*

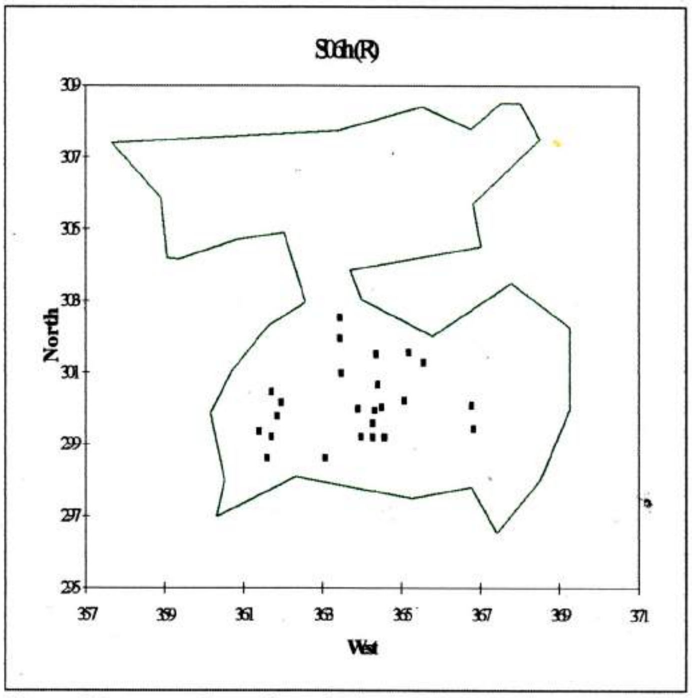


Figure 4.8. Spreading of soi type S*06h* (R)

| R (S06h) | | | | |
|---|---|---|---|---|
| horizon | depth | colour (moist) | texture | other |
| Ah / Ahg | Measured depth varies from 8 to 30 cm, with an average depth of about 15 cm. | Colour ranges from dark reddish brown (5 YR 3/3) to black (7.5 YR 2/1), while brownish black (10 YR 2/2) is the most common colour. | Texture varies from clay to sandy loam. | In some cases nodules are present. |
| Ah2 / B / Bg / Bw / Bwg / BC | Measured depth varies from 5 to 40 cm, with an average depth of about 15 cm. | Colour ranges from orange (7.5 YR 6/8) to brownish black (7.5 YR 2/2), while dark reddish brown (5 YR 3/3) is the most common colour. | Texture varies from clay to loamy sand. | In some cases mottling, residual rock fragments and nodules are present. |
| Bwg / Bwgl / Bwg2 / BC / B2 | Measured depth varies from 10 to 54 cm, with an average depth of about 20 cm. | Colour ranges from orange (7.5 YR 6/8) to dark reddish brown (5 YR 3/4), while bright brown (7.5 YR 5/6) is the most common colour. | Texture varies from clay to loamy sand. | In some cases mottling, residual rock fragments and nodules are present. |
| Bwg2 / BC / C | Measured depth varies from 5 to more than 30 cm. | Colour ranges from orange (7.5 YR 6/8) to dull yellowish brown (10 YR 5/3) | Texture varies from clay loam to sandy loam. | In some cases nodules are present. |
| R | Rock begins between 30 and > 100 cm. | | | |

Mapping unit ***S06h*** is a soil that develops on the upper positions of sloping to strong sloping terrain, often has a shallow profile and shows a reddish color. The texture is rather constant throughout the profile.
These soils occur throughout the area. Either several small sites together, or one big site, may be represented by the percentage in the indication of the mapping units

Erosion due to the strong sloping terrain on which these soils are formed, causes the relative shallow depths of the profiles.
The reddish color is caused by the oxidation of iron, present in the soil minerals. Abrupt changes between wet and dry periods supports the oxidation of iron. This distinct change in wet and dry is possibly due to the strong slopes. During periods of heavy rainfall this soil is very wet. When raining stops, the soil dries out rather quickly due to its relative high position on the slope.

*S: II Loose structured ignimbritic parent rock*

Mapping unit ***S08h*** has developed on loose-structured ignimbritic parent rock.
The soil occurs mainly in the central part of the area.

The parent rock of the other soil types is often of higher density and finer structure. It may be due to this, that soils formed on the sandy rock do often show a coarser texture than most other soils in this area.

| S (S08h) | | | | |
|---|---|---|---|---|
| horizon | depth | colour (moist) | texture | other |
| Ah / AB / BA | Measured depth varies from 7 to 60 cm, with an average depth of about 25 cm. | Colour ranges from dark brown (7.5 YR 3/3) to black (10 YR 2/1), while brownish black (7.5 YR 3/2) is the most common colour. | Texture varies from clay to loamy sand. | In some cases residual rock fragments are present. |
| AB / BA / B / Bw / BC / BCg | Measured depth varies from 10 to 60 cm, with an average depth of about 25 cm. | Colour ranges from light gray (5 YR 8/1) to black (7.5 YR 2/1), while dark brown (7.5 YR 3/3) is the most common colour. | Texture varies from clay to sand. | In some cases mottling, residual rock fragments and nodules are present. |
| B / B2 / Bw / Bwg / BC | Measured depth varies from 10 to more than 60 cm, with an average depth of about 20 cm. | Colour ranges from bright brown (7.5 YR 5/6) to brownish black (7.5 YR 2/3), while brown (7.5 YR 4/4) is the most common colour. | Texture varies from clay to sandy loam. | In some cases mottling, residual rock fragments and nodules are present. |
| (occasionally) B2 / Bwg2 / 2Bw | Measured depth varies from 15 to more than 20 cm, with an average depth of about 15 cm. | Colour ranges from brown (7.5 YR 4/6) to grayish yellow brown (7.5 YR 4/2). | Texture varies from clay to sandy loam. | In some cases mottling is present. |
| R | Rock begins between 30 and > 120 cm. | | | |

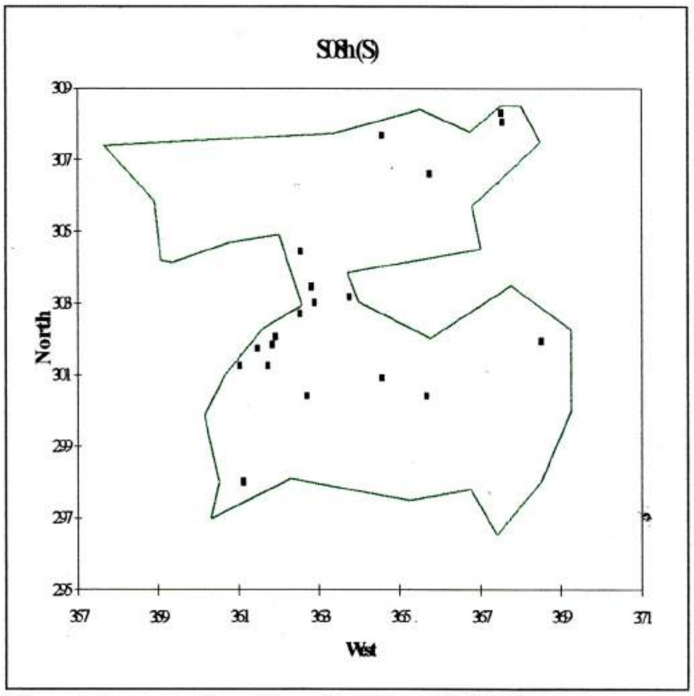


Figure 4.9. Spreading of soil type *S08h* (S)

## A: *III Volcanic ash*

| A (S03) | | | | |
|---|---|---|---|---|
| horizon | depth | colour (moist) | texture | other |
| Ah / AB / BA | Measured depth varies from 10 to 40 cm, with an average depth of about 20 cm. | Colour ranges from brownish gray (5 YR 4/1) to black (10 YR 2/2), while brownish black (10 YR 3/2) is the most common colour. | Texture varies from clay to loamy sandy. | In some cases ash and pummish fragments are present. |
| Ah2 / AB / B / Bw / BC | Measured depth varies from 4 to 40 cm, with an average depth of about 15 cm. | Colour ranges from orange (7.5 YR 6/8) to brownish black (7.5 YR 2/2), while brownish black (10 YR 3/2) is the most common colour. | Texture varies from clay to loamy sand. | In some cases ash and pummish fragments are present. |
| B / Bw / Bwg / B1 / BC / 2BCg | Measured depth varies from 5 to 35 cm, with an average depth of about 15 cm. | Colour ranges from bright brown (7.5 YR 5/6) to brownish black (10 YR 2/2), while brown (7.5 YR 4/4) is the most common colour. | Texture varies from clay to loamy sand. | In some cases mottling, ash and pummish fragments, residual rock fragments and nodules are present. |
| (occasionally) B2 / 2B / 2Bw | Measured depth varies from 10 to 40 cm, with an average depth of about 20 cm. | Colour ranges from brown (7.5 YR 4/6) to brownish black (7.5 YR 3/4). | Texture varies from clay loam to loamy sand. | In some cases ash pummish and residual rock fragments are present. |
| (occasionally) BC / 2BC | Depth is more than 10 cm. | Colour ranges from grayish yellow brown (10 YR 5/2) to brown (7.5 YR 4/3). | Texture is clay loam. | In some cases nodules are present. |
| R | Rock begins between 35 and > 90 cm. | | | |

Mapping unit ***S03*** is selected for the occurrence of volcanic ash in the upper horizons. Sizes of ash particles vary from hardly visible remnants up to a few millimeters. The thickness of the with ash influenced horizons can be up to sixty centimeters. Color and texture are in this case less important selection criteria. The underlaying soils vary within the previous described soil types. The whole northern area mainly exists of this soil type.

Similar to the S03 soils, other soils may have received volcanic ash additions also. Although the ash or ash remnants were not visible in other soil types, I suspect that most of the lighter colored and coarser textured horizons in top positions of the profiles, may have received some ash addition. The light color may derive from the glass rich compositioned ash, while the coarser texture may be caused by the relative younger, less weathered ash particles, compared with particles of underlaying soil.

The ash originates from the volcano Rincon de la Vieja, is of Holocene age, has undergone little weathering and exists of a pumice layer covered with an ash layer. The quantity and frequency of ash depositions throughout the years are unknown.

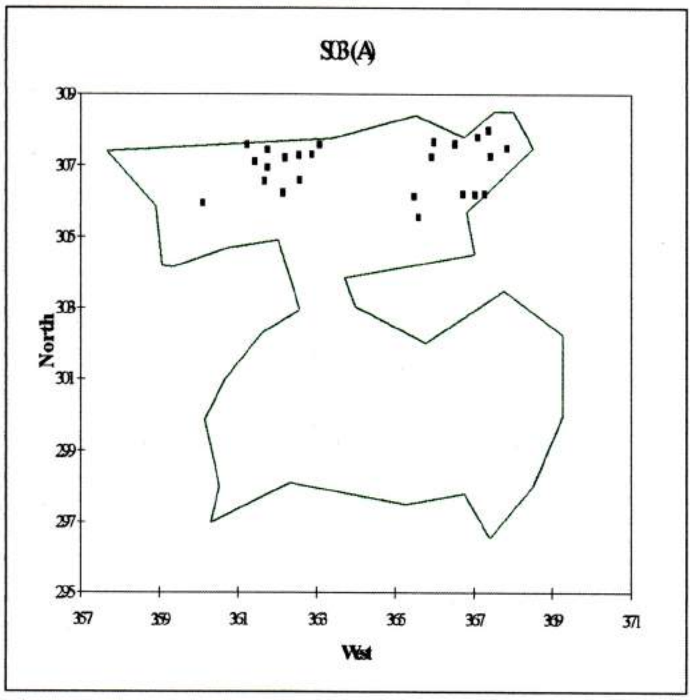


Figure 4.10. Spreading of soil type S*03* (A).

### 4.2.3 Rock outcrops and boulders

On several sites throughout the area rock outcrops and boulders occur (Figure 4.11). They are indicated with the letter 'P' (pyroclastic rock) on the soil map.

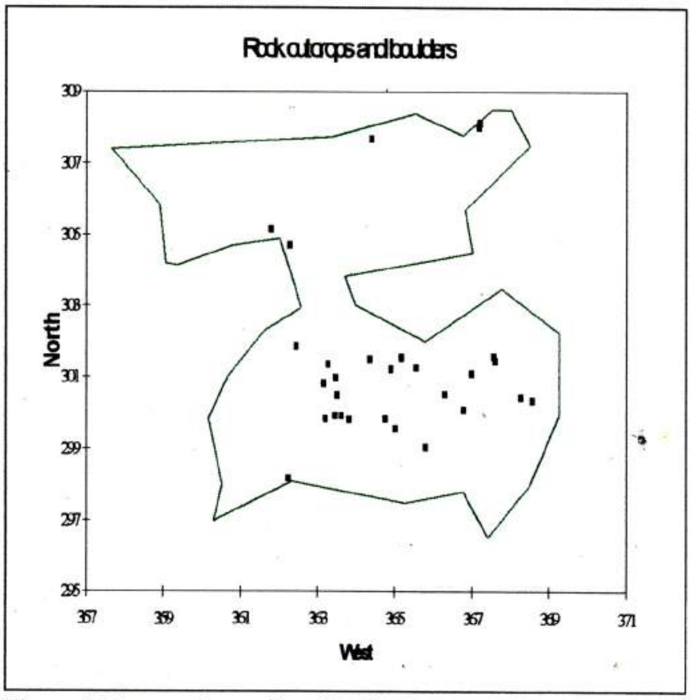


Figure 4.11. Spreading of rock outcrops and boulders.

### 4.2.4 Human influences

Mostly on the larger and the nearly flat parcels in the area, the original soil structure and profile may have been disturbed by land use. Soils have undergone ploughing and possibly larger soil movements like equalisation.

## 4.3 Conclusions

The following conclusions can be drawn:

- The study area consists of a wide variety of soils that have developed on ignimbritic parent-rock, which partly have been covered with recent volcanic ash.
- The wide variety of soils that have been developed, seem to be caused by topography, as well as by the complex deposition systems of the parent-rock. Also tectonic movements may have influenced the development of certain soil types.
- Further research is needed to define the wide variety of and within soil types, present on ignimbrite, in detail.
- The small hills which occur in the area are probably remnants of the denser welded innerparts of pyroclastic flows,
- There seems to be no clear relationship between different gray tones on the aerial-photos and soil types. Aerial-photos can not be used to construct a soil map on the photo-impression of a certain area only.

# Soil genesis on the Pleistocene Ignimbritic Bagaces Formation, Guanacaste, Costa Rica.

***A study on the physical aspects of soil genesis.***

*(J050-712)*

*A.F. Winters*

*March 1997*

# 5 A study on soil genesis on Ignimbrite of the Bagaces Formation.

*Introduction*

This research concerns the genesis of soils on ignimbrites, under a tropical dry climate (ustic moisture regime, Soil Taxonomy, 1992). The ignimbrites are part of the Bagaces formation (Weyl, 1980), situated in the northwest of the province Guanacaste, Costa Rica.

During a soil mapping survey on part of this formation, as discussed in chapter 4 of this bundle, spacial variability of soils formed on ignimbrite has been reported. However, the relation of soil types with the parent material, topography and adjacent soil types was not the main objective of that study, but did ask for attention during field work.

Much has been written about pyroclastic deposits (summarized in chapter 2) but specific literature, concerning soil genesis on ignimbrite under prementioned climatical conditions, is hardly available. Therefore questions concerning these aspects, remain unanswered.

The variety of soils that have developed, are expected to be caused by topography, as well as by the density of the parent material. Topography probably affects depth of the profile, erosion features and hydrology. The density of the parent material is expected to affect texture, weathering degree and soil profile depth.

During the present study, the following questions were used as 'guidelines':

- What is the influence of topography on soil genesis (position dependent soil type), and the major soil forming processes?
- Is there a clear difference in soil types between sloping and relatively flat terrains?
- Does a higher density of the parent material cause a finer texture of the formed soil?
- Is there a variation in the chemical composition of the parent material and, if so, how are these differences influencing soil genetic processes?

The answers to the previous questions, taking into account the specific climatic conditions, are believed to be covered by the topics of this study. The objective of this study is:

*to contribute to the understanding of soil genesis on ignimbrite under the reigning dry tropical climatic conditions.*

Genesis of, and mutual relationship between the soils were studied by means of catenas. Selected field work areas are; (1) the experimental station for reforestation 'Horizontes' and (2) the area around the primary irrigation canal, crossing the Pan-American highway between Bagaces and Cañas, and part of the adjoining national park 'Lomas Barbudal'. The geographical positions of the areas can be seen from figure 1.2 (Introduction).

The paragraph 'Methods and materials' explains how the research was executed. Paragraph 5.2 discusses the data on macromorphology, micromorphology, (clay-)mineralogy and grain size distribution. The general discussion in paragraph 5.3 compares and combines all data and reflects to literature. In paragraph 5.4 the conclusions are listed.

## 5.1 Methods and materials

During the field study, three areas were selected: the area 'Horizontes', described in part chapter 4 of this report, and the areas around the irrigation canal and 'Lomas Barbudal', situated between the coordinates 398000 - 407000 W and 271000 - 276000 N, and 385000 - 387000 W and 277000 - 279000 N respectively. These areas were chosen because they are all within the Bagaces Formation area, have about the same climatological conditions and are easily accessible.

### 5.1.1 Site descriptions

After reconnaissance field studies in the selected areas, it was concluded that on base of field- and soil characteristics (FAO, 1992 and Oyama & Takehara, 1970), the diversity in soil types could be roughly divided into three main types:

1. brownish black to bluish black, silty clay to clay soils, showing cracks during the dry season,
2. greyish/grey brown, silty loam to silty clay soils, that do not or hardly crack, and
3. other soils, often reddish to brownish coloured, silt loam to sandy soils.

Soil types 1 and 2 seem to occur mainly in poorly drained and/or valley positions, whereas soil type 3 dominantly occurs in well drained positions, like hill tops and the upper parts of slopes; though exceptions have been seen. It was also noticed that always a combination of type 1 and 3 or 2'and 3 occur. The combination of 1 and 2 seems absent.

Taking into account the topographical relation and type of the ignimbrite, sites with two different and adjacent soil types were selected. The position of the soil profile pits were chosen on those locations where a hydrological relation between the pits (one pit per soil type) could be assumed. Each set of selected sites will further be called 'catena'.

Site selection resulted in several catenas of which three catenas are used for this thesis:

- Catena I: Profiles *S02h*, *S02b* and *S09*.
  *S02h* represents soil type 3 on the higher (h = high), and *S02b* soil type 2 on the lower (b = base) position. *S09* was an additional sampling point. Figure 5.1 shows the topographical relation of the profiles.

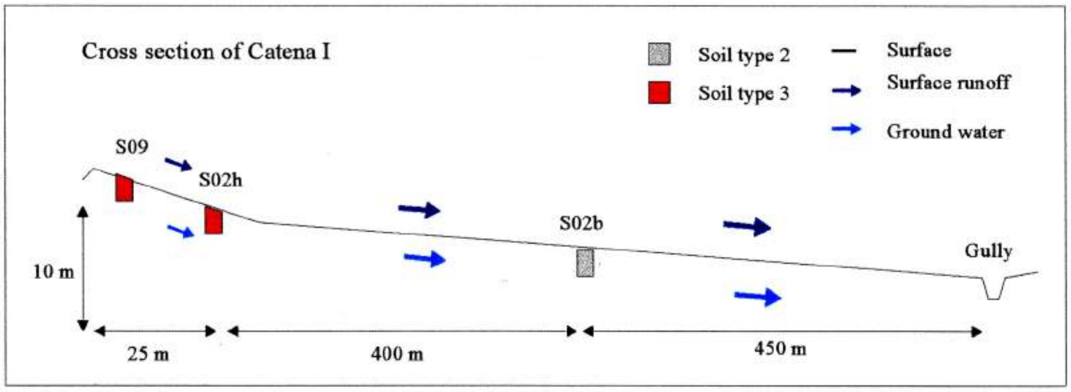


Figure 5.1. Symplified representation of the topographical relation between profiles *S02h*, *S02b* and *S09*.

- Catena II: Profiles *S06h* and *S06b*.

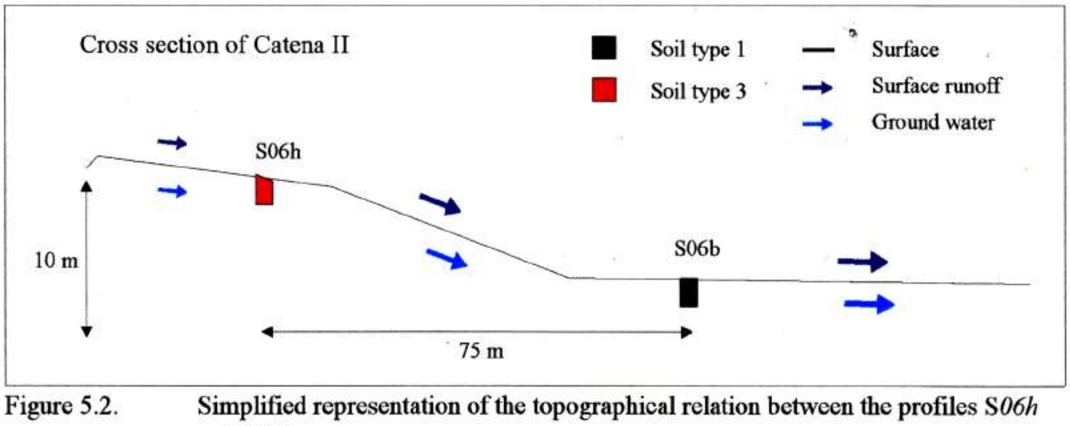


Figure 5.2. Simplified representation of the topographical relation between the profiles *S06h* and *S06b*.

*S06h* represents soil type 3 on the higher, and *S06b* soil type 1 on the lower position. Figure 5.2 shows the topographical relation of the profiles.

- Catena III: Profiles *I01* and *I02*.
  In the field, *I01* looks like a mixture of soil types 1 and 2. This is due to the combination of a dominant light and grayish soil colour throughout the profile and clear cracking patterns in the upper horizons. *I02* represents soil type 3. Both profiles are at level positions. Figure 5.3 shows the topographical relation of the profiles.

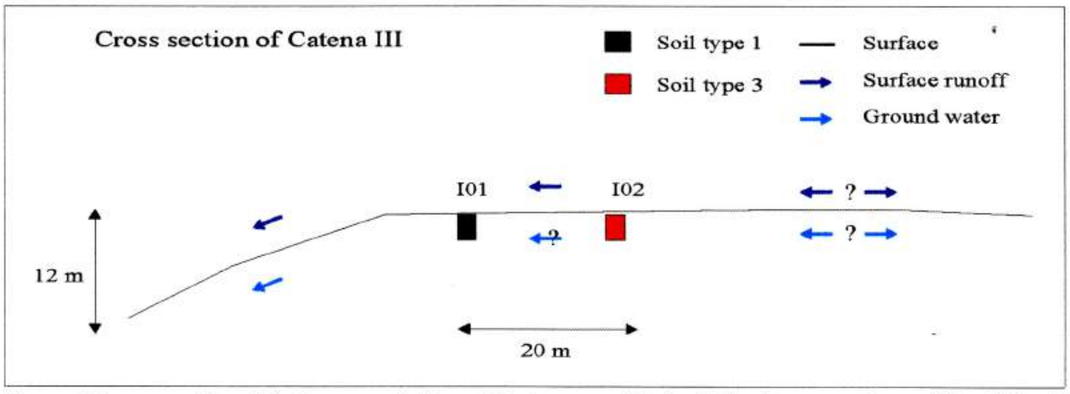


Figure 5.3. Simplified representation of the topographical relation between the profiles *I01* and *I02*.

Catenae I and II are situated within the south-west of the Horizontes area. Catena III is situated in the area around the irrigation canal, on the east side of the Panamerican highway.

In appendix I, part of the topographical map of the Horizontes area, with catena and pit positions, can be found. Table 5.1 shows an abstract of the major site characteristics.

After bringing the original savanna vegetation into cultivation, many decades ago (personal comment of locals), all sites were used for agricultural purposes (arable farming or cattle breeding), except for the site around *S02h*, which is probably still natural. Nowadays the sites are part of a reforestation programme, either to re-introduce the original natural habitat (Horizontes) or for commercial plantation forestry (irrigation canal area). Because the development of a distinct soil profile needs hundreds to thousand of years, it is expected that the soil forming processes are influenced mainly by the original savanna vegetation, though might show influence of agricultural activity too. Human influences, more precise than cultivation for agricultural purposes, are not known. The effective soil depth ranges from moderately deep to very deep (FAO, 1992), often with clear boundaries, so a distinct profile development has taken place in all cases. The profile depth might not always fully correspond with the averaged depth of the soil types, because of the fact that well developed profiles are selected.

At most sites, except for profile *S02h* as has been written before, the main vegetation is grass. According to more natural sites (personal observation), not part of this study, the area around profile *S06b* will always be covered with grasses mainly, while the other areas will show more small bushes and trees when the original vegetation returns.

Ground water has not been observed during both periods of field work, all profiles were dry to moist. It is expected that only during the rainy periods (Chapter 3), ground water is present in most profiles. Due to their position, the lowest profiles will contain ground water for a longer period than the higher situated profiles, though here too the period of saturation is restricted to months (personal observations).

Table 5.1 Major site characteristics of Catena I, II and III.

| | | Catena I | | Catena II | | Catena III | |
|---|---|---|---|---|---|---|---|
| *Profile number* | | *S02h* | *S02b* | *S06h* | *S06b* | *I01* | *I02* |
| *Date of description* | | 96-02-23 | 95-06-05 | 95-06-26 | 96-02-24 | 96-02-27 | 96-02-26 |
| *Authors* | | E.J. Hofstad & A.F. Winters | A. Nieuwenhuyse & A.F. Winters | A. Nieuwenhuyse & A.F. Winters | E.J. Hofstad & A.F. Winters | E.J. Hofstad & A.F. Winters | E.J. Hofstad & A.F. Winters |
| *Coordinates* | *north* | 298500 | 298900 | 299350 | 299425 | 275900 | 275900 |
| | *west* | 367225 | 367250 | 363750 | 363650 | 405650 | 405625 |
| *Topography* | | almost flat | almost flat | gently undulating | almost flat | gently undulating | gently undulating |
| *Landform* | | slope side of small hill, leading to plateau | plateau | hill | hill | hill | hill |
| *Land element* | | slope | terrace | slope | terrace | slope | slope |
| *Position* | | middle slope | bottom | upper slope | bottom | crest | crest |
| *Slope* | *Gradient* | gently sloping | very gently sloping | gently sloping | nearly level | nearly level | nearly level |
| | *Form* | convex | convex | concave | convex | concave | concave |
| *Micro-topography* | | terracettes caused by residual rock boulders | no micro-relief | no micro-relief | no micro-relief | no micro-relief | no micro-relief |
| *Land use* | | parks | parks | parks | parks | plantation forestry | plantation forestry |
| *Human influence* | | unknown | unknown | unknown | unknown | unknown | unknown |
| *Vegetation* | | savanna | grassland | savanna | savanna | savanna | savanna |
| | *Grass* | 15 - 40 % | > 80 % | 40 - 80 % | 40 - 80 % | 40 - 80 % | 40 - 80 % |
| *Parent material* | | ignimbrite of the Bagaces formation | ignimbrite of the Bagaces formation | ignimbrite of the Bagaces formation | ignimbrite of the Bagaces formation | ignimbrite of the Bagaces formation | ignimbrite of the Bagaces formation |
| *Effective soil depth* | | moderately deep (50 - 100 cm) | moderately deep (50 - 100 cm) | moderately deep (50 - 100 cm) | very deep (> 150 cm) | deep (100 - 150 cm) | deep (100 - 150 cm) |
| *Rock outcrops* | | common < 2 m at site, on larger scale 2 - 5 m | few > 50 m | none | few 5 - 20 m | none | none |
| *Surface coarse fragments* | | very few stones | none | none | none | very few medium gravel | very few medium gravel |
| *Surface sealing* | | none | none | none | none | none | none |
| *Surface cracks* | *Width* | fine | none | none | fine to very wide | fine to wide | fine to wide |
| | *Distance between cracks* | very closely spaced | - | - | moderately widely spaced | closely spaced | moderately widely spaced |
| *Drainage classes* | | moderately well drained | moderately well drained | well drained | some what poorly (imperfectly) drained | well drained | well drained |
| *Internal drainage* | *Saturation* | unknown | saturated for long periods every year | never saturated | saturated for long periods every year | never saturated | never saturated |
| *Groundwater* | *Depth* | not observed | not observed | not observed | not observed | not observed | not observed |
| *Moisture conditions* | | dry | moist | moist | dry to slightly moist | dry to moist | dry to moist |

*Catena I*

*S02b* is situated in the centre part of a broad and nearly flat field of about 20 hectare, mainly consisting of a characteristic greyish groundmass. *S02h* is situated on the slope of a small hill ridge, at the south-west side of the prementioned field. This profile, together with *S09*, is representing the upper half of the catena.

*S09* has not actually been described as a profile because it was to shallow and undeveloped to use it on itself within this research. It is positioned close to the top of the ridge and therefore used to obtain an 'undisturbed' bulk sample of saprolite of the rock the hill ridge consists of. Of the soil covering the saprolite, a sample is taken to compare with those of *S02h*. A macromorphological description of *S09* has not been made.

The parent material is dense welded ignimbrite, and is expected to be of the same consistency for the profiles. In the neighbourhood of *S02b* are some rock outcrops, whereas these are common around *S02h*. Surface sealing was absent and surface cracks only appeared in the top horizon of *S02b*.

Both profiles are expected to be moderately well drained; *S02h* due to the middle slope position and the existence of terracettes caused by residual rock boulders, and *S02b* because of a creek enclosing the area on three sides, whereas the ground water can freely drain into. Mottling and nodules, occurring in both profiles, indicate periodical water stagnation. This stagnation is expected to be the effect of the high precipitation rates that temporally occur.

Photo 5.1 shows *S02h* and photo 5.2 is of *S02b*. Photo 5.3 shows the surrounding of *S02b*, with in the background green trees around the position of *S02h*.

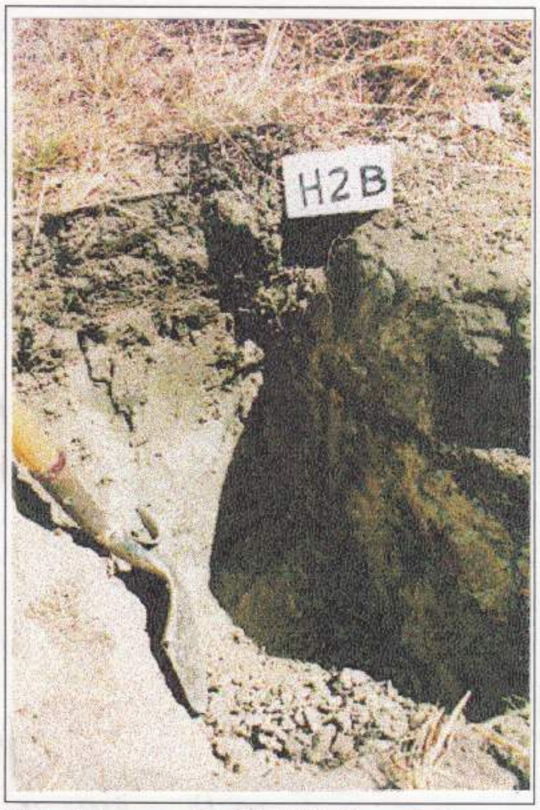


Photo 5.1. Profile *S02h* (formerly known as H2B).

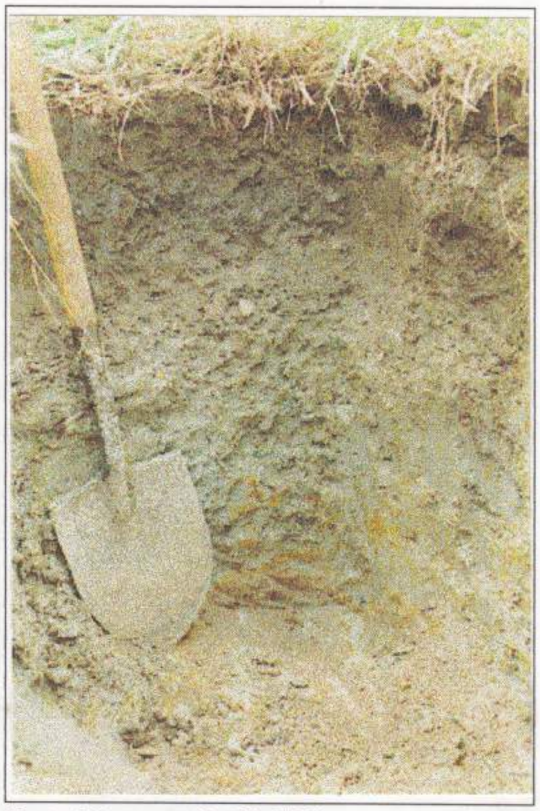

Photo 5.2. Profile *S02b*.

Photo 5.3. The surroundings of *S02b*. Profiles *S02h* and *S09* are situated near the highest tree in the left of the photo.

*Catena II*

*S06h* is situated on the upper slope of a small hill, and *S06b* on the east side foot of this hill.

The parent material of *S06h* is dense welded ignimbrite, whereas the parent material of *S06b* did not become clear but might either consists of erosion products of the hill or loose welded ignimbrite of a sandy structure. Near *S06h* no rock outcrops were found, whereas there are few around *S06b*.

No evidence of surface sealing was found, and surface cracks only appeared around and in the top of *S06b*. The size and amount of the surface cracks indicate vertic properties.

*S06h* is expected to be well drained because of the upper hill position, whereas *S06b* seems somewhat poorly drained because of its position and texture. Here too, the presence of mottles and nodules indicates periodical water stagnation during high precipitation rates.

Photo 5.4 shows *S06h* and photo 5.5 is of *S06b*. Photo 5.6 shows the surrounding of *S06b* with, in the direction of the big tree on the left, the position of *S06h*.

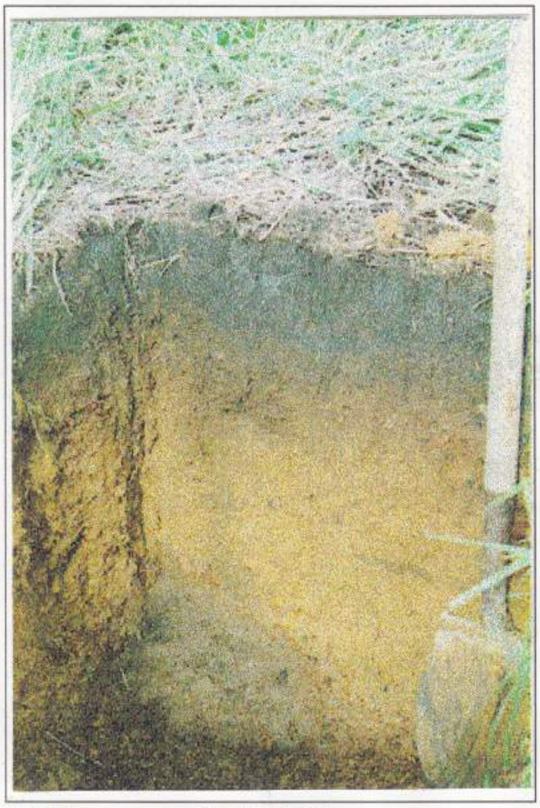

Photo 5.4. Profile *S06h*.

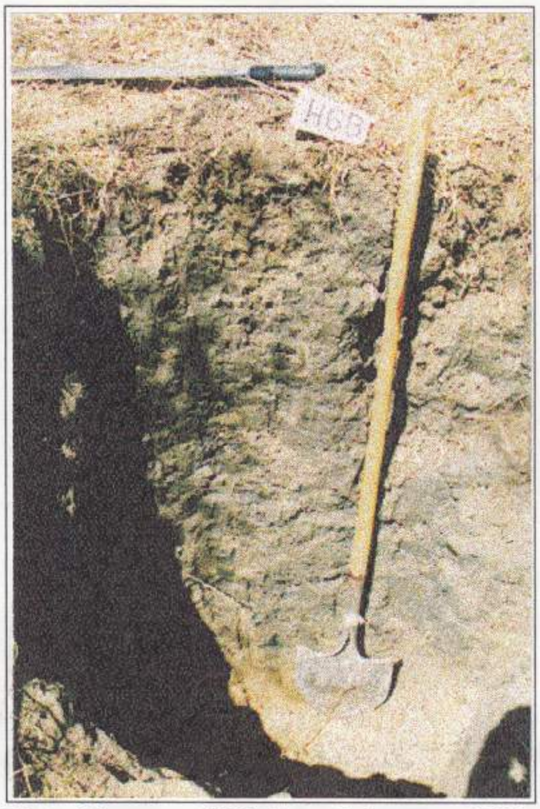


Photo 5.5. *S06b* (formerly known as H6B)

Photo 5.6. The surroundings of *S06b*, on $^{1}/_{3}$ left, and towards the big tree, the position of *S06h*.

*Catena III*

Both profiles are situated on the nearly level crest of a hill. If I*01* influences I*02* hydrologically or visa versa, did not become clear in the field, though a hydrological relation is expected.

In both cases the parent material is loose welded, very glassy and pumice rich, ignimbrite. Pumice rich ignimbrites are believed to be of distal flows (Cas & Wright, 1987). No rock outcrops were found in the direct neighbourhood of the profiles.

Although mottles are present throughout the profiles, both profiles are expected to be well drained because of the hill crest position and the structure of the parent material. Once again the presence of mottling indicates periodical water stagnation due to temporally high precipitation rates.

Photo 7 shows I*01* and photo 8 is of I*02*. Photo 9 shows the surrounding of both profiles, with in the bottom right corner I*02*, and the darker coloured soil of I*01* towards the left (note the clear change in colour of the soil).


Photo 5.7. Profile I*01*.


Photo 5.8. Profile I*02*.

Photo 5.9. The surroundings of I*01* (darker soil towards upper left of photo) and I*02* (bottom right).

### 5.1.2 Sampling and analysis

After selection of the sites with two different and adjacent soil types, the ideal position of the pits was determined with help of an auger. The macro morphological characteristics of the soil profiles and the direct surroundings of the pits were described according to the FAO (1992) guidelines. Representative profile pits were described down to the parental ignimbrite.

Undisturbed samples were taken for micro morphological study, and bulk samples for textural-, mineralogical-, and chemical analysis. Because of sampling (due to the dry season) and measuring problems, the bulk density samples gave unrealistic values. Therefore, the bulk density of the samples will not be discussed.

### 5.1.3 Micro morphology

Based on macro morphology, undisturbed samples (8 cm x 8 cm) were taken for micro morphological research. Sampling was carried out in nearly all the distinghuised horizons of the profiles, occasionally fresh rock, from underneath or nearby the profiles was sampled.

The undisturbed, field-moist samples were impregnated after removing the water by acetone according to the method of Miedema et al. (1974), to preserve mineralogical composition and field structure. Thin sections were prepared according to FitzPatrick (1970) and described using the terminology of Bullock, et al. (1985).

A petrographic light microscope was used for studying the samples, using plane-, and crossed polarized light.

### 5.1.4 Grain size distribution analysis

Grain size distribution analysis was performed on field moist samples after pretreatment as described by Van Doesburg (1996).

The grain size is measured with the Coulter LS230 Particle Size Analyzer, using software version 2.09. The Coulter LS230 has a measuring range of 0.04 - 2000 microns, in 116 fractions.
Calculation of the grain-size distribution is done with the optical model '*white.rfd*' (0.15 absorption at 750 µm and 0.2 absorption at 400, 600 and 900 nm). In the calculations, water was used as a medium. For the solid phase a refractive index in the range of that of kaolinite was used. Pump speed was put at 100% and the ultrasone turned on to optimize dispersion.

For measurement of the distribution of the <2 mm fraction, obscuration was brought at about 10% by adding small amounts of sample.
The distribution of the clay separates for clay mineral analysis was measured at 50% PIDS obscuration also.

### 5.1.5 Mineralogical analysis

Clay-mineralogical analysis was performed on field moist samples after pretreatment as described by Van Doesburg (1996).

Clay fractions were used for analysis of clay minerals. X-ray diffractograms were made of Mg-saturated clay samples before and after glycerol saturation, of Mg-saturated samples after formahide saturation and of K-saturated clay after heating to 150 $^{0}$C. Preparation of the oriented clay samples was done as described by Van Doesburg (1996).

The estimation of the relative amount of the different clay minerals present was done by interpreting relative heights and surfaces of the peaks.

Identification of the non-phyllosilicates was done on the coarse silt to the sand fraction (<2 mm), obtained by washing out the residues of the samples remaining after clay separation. After drying, these samples were pretreated as described by Van Doesburg (1996) and filmed using the Guinier camera.

## 5.2 Results and discussion

This chapter deals with the results of macromorphology, micromorphology, clay mineralogy and textural analysis, accompanied by a basic interpretation of the data, per catena.

### 5.2.1 Macromorphology

Major macromorphological characteristics of the soils in the catenae are shown in table 5.2.

Table 5.2. Major macromorphological characteristics of the profiles of Catena I, II and III.

| *Profile* | *Horizon* | *Depth (cm)* | *Colour (moist)* | *Texture* * | *Structure* * *type* | *grade* | *Mottles* ** | *Nodules* ** | *Residual rock fragment* ** |
|---|---|---|---|---|---|---|---|---|---|
| *S02h* | Ah | 0 - 9 | 5 YR 2/1 | SiL | AB | ST, VF | - | F | - |
| | AB | 9 - 16 | 10 YR 3/2 | SiCL | AB | ST, VF | - | M | - |
| | 'pocket' | 16 - 40 | 2.5 YR 5/3 | SiC | AB | WE, VF | - | F/C | - |
| | B | 40 - 68 | 5 Y 6/2 | SiC | SB | VW, VF | - | M | A |
| *S02b* | Ah | 0 - 19 | 10 YR 2/2 | SiL | MA | MO, FI | F | - | - |
| | BA | 19 - 30 | 10 YR 4/2 | SiL | MA | MO, FI | F | - | - |
| | BCg | 30 - 79 | 10 YR 6/1 | SiCL | MA | -, - | C | F | C |
| *S06h* | Ah | 0 - 11/15 | 10 YR 2/2 | SiCL | SB/MA | WE, FI | - | - | - |
| | B | 11/15 - 26 | 5 YR 3/3 | SiCL | SB | WE, ME | F | - | F |
| | Bwg | 26 - 56/80 | 10 YR 5/8 | SiCL | AS | MO, FI | C | F | - |
| *S06b* | Ah1 | 0 - 5 | 10 YR 3/3 | SiCL | GR | WE, CO | - | - | - |
| | Ah2 | 5 - 60 | 2.5 Y 4/1 | SiC | AB | MO, WE | - | F | - |
| | Ah3 | 50 - 110/13( | 10 YR 2/3 | SiL | AB | MO, VC | - | F | V |
| | C | 10/130 - 14 | 10 YR 4/4 | L | SA | ST, VC | - | - | M |
| *I01* | Ah | 0 - 63/68 | 10 YR 3/1 | SiCL | AP | MO, FF | V | F | F |
| | Bw | 33/68 - 72/8 | 10 YR 3/2 | L | GR | MO, ME | A | C | C |
| | 2Ah | '/80 - 110/1 | 2.5 Y 4/1 | SiL | AP | MO, FF | V | F | F |
| | C1 | )/114 - 123/ | 2.5 Y 6/3 | L | AB | WE, FI | - | V | V |
| | C2 | 23/130 150 | 5 Y 7/3 | SiCL | AB | WE, FI | - | V | V |
| *I02* | Ap | 0 - 22 | 10 YR 5/4 | SiCL | AS | MO, FI | C | F | M |
| | Bwg1 | 22 - 46 | 2.5 YR 2/3 | SiCL | AB | VW, VF | M | F | - |
| | Bwg2 | 46 - 65/70 | 10 YR 4/4 | SiCL | AB | WE, FF | F | M | C |
| | CB | 35/70 - 87/9 | 10 YR 5/4 | SiCL | AB | WE, FM | - | F | - |
| | R1 | 87/95+ | 2.5 Y 7/3 | L | GR | VW, VF | - | - | - |

* According to FAO guidelines (1992) for soil profile description (p. 48-51).
** N=none, V=very few, F=few, C=common, M=many, A=abundant, D=dominant

*Catena I*
Soil colours get lighter and textures finer with depth, for both profiles. The structure of *S02b* is structureless to massive throughout the entire profile. *S02h* has an angular blocky structure, changing to subangular blocky with depth. Mottling is present in all horizons of *S02b*, and increases with depth. *S02b* shows few nodules in the lowest horizon, whereas *S02h* shows nodules in all horizons, increasing with depth. Residual rock fragments are present in the lowest horizons of both profiles. Surface cracks appeared in the top of *S02h*.

*Catena II*
Soil colours get lighter with depth for *S06h*, and vary with depth for *S06b*. The texture of *S06h* is rather constant with depth, but varies for *S06b*. Structure of *S06h* changes from subangular blocky/massive to angular and subangular blocky with depth. *S06b* shows a structure change from granular in the upper horizon, via angular blocky, to subangular and angular blocky in the lowest horizon. Mottling is present in the B and Bwg horizons of *S06h*, whereas this is most in the Bwg horizon. Few nodules are present in the Bwg horizon of *S06h* and in the Ah2 and Ah3 horizons of *S06b*. Rock fragments are present in the B horizon of *S06h* and in the Ah3 and C horizons of *S06b*. The size and amount of surface cracks around *S06b* indicate vertic properties of the soil.

*Catena III*
Except for the upper horizon of I02, soil colours get lighter with depth. Texture of I*01* varies with depth. I*02* shows no texture changes throughout, except for the lowest horizon, which consists of saprolitic material with a coarser texture than the soil horizons. The main structure type of I*01* and I*02* is angular blocky, though varies a bit with depth as shows the granular structure of the Bw horizon of I*01* and the R1 horizon of I*02*. Mottling occurs in the upper three horizons of both profiles, and is most present in the Bw horizon of I*01* (see photo's) and Bwg1 horizon of I*02*. Nodules occur throughout both profiles, except for the R1 horizon of I*02*. Most nodules are present in the Bw and Bwg2 horizon of I*01* and I*02*. Rock fragments are present throughout the entire I*01* profile, whereas these only occur in the Ap and Bwg2 horizons of I*02*. Presence is most abundant in the Bw horizon of I*01* and Bwg2 horizon of I*02*. Surface cracks appeared in the top of both profiles. The size and close spacing of the cracks indicate vertic properties of I*01*, although this was less clear compared to S*06b* and other locations.

*Summary*
In general soil colours are lighter, and texture finer with depth. Darker colours of the upper horizons is due to organic matter and biological activity. Soil structure is angular and/or subangular blocky for most horizons, whereas the massive structure throughout S*02b* is clearly different from the rest. Most mottling occurs in the upper horizons of I*01* and I*02*, whereas this is in the lower horizons for S*02b* and S*06h*. The same tendency as for mottling seems to occur for nodules and residual rock fragments. These differences between the 'Horizontes'- and 'irrigation canal' profiles, might be explained by the clear differences in the structure of the parent material.

### 5.2.2 Micromorphology

The micromorphological data of the catena are shown in table 5.3.

*Catena I*
Microstructure changes from massive in the subsoil to granular and subangular blocky in the A horizons. In addition loose excremental infillings were found. The observations indicate faunal biological activity in the upper horizons of both soils.

The size of the feldspars increases while the alteration degree decreases with depth. Pyroxenes show the same trend, indicating weathering of both mineral groups. However, presence of an appreciable amount of fresh pyroxenes and andesitic rock fragments in the A horizon, ranging in size from 50 to 200 μm indicates rejuvenation of the topsoil. Considering the size of these mineral grains it is assumed that aeolian addition has taken place. Relatively large, thick pellicular altered pyroxenes in the AB horizons may point to a former ash addition.

In both soils randomly distributed, partially to totally altered volcanic rock fragments are present in all horizons. Because they contain appreciable amounts of small (10-20 μm) opaque iron minerals, they probably have an andesitic origin. Furthermore, anisotropic, strongly oriented, clay pseudomorphs after pyroxenes, and some clay pseudomorphs with a blooming structure (Photo 5.10), are observed within these fragments, probable resulting from hydrothermal processes in the last stage of andesitic rock formation (Cas & Wright, 1987). As impurities the rock fragments are incorporated in the ignimbrite during its deposition (Jongmans, 1994).

In S*02b*, thin (20-50 μm) yellow, translucent, anisotropic, strongly oriented clay coatings occur, indicating the process of clay illuviation. The content is estimated as <1 %, so no argic horizon (Soil taxonomy, 1992) could be established. They are absent in S*02h*.
The presence of the coatings in particular in the top horizons, may suggest truncation of the soil. Thin, (10-20 μm), anisotropic, moderately oriented, speckled clay coatings occur in the upper horizons of both soils. They are interpreted as features resulted from fine soil material translocation during heavy rain showers (Schuylenborgh et al, 1973).

Both soils demonstrate strong developed b-fabrics (Photo 5.11) indicating the process of swelling and shrinking, though lacking strong mulching processes. Swelling and shrinking of clay minerals neo-formed in cracks of the parent rock, rock fragments or phenocrysts cause mechanical weathering (Photo 5.12)

Ferric nodules occur throughout *S02h*, indicating alteration of oxidation and reduction (gleying), but pronounced grey matrix colours are absent suggesting that the processes are not intensive.

Table 5.3. Micromorphological dat of catena *S02h* /*S02b* (with *S09*), *S06h* /*S06b* and *I01* /*I02*.

| | | | | *Single mineral grains* | | | | | | | | | | | | | | | *Compound mineral grains* | | | *Fine material* | | | | | | | | | | | *Pedofeatures* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *heavy* | | | | | | | *light* | | | | | | | | *rock fragments* | *ash fragments* | | *anisotropic clay* | *b-fabric* | | | | | | | | | *iron droplets* | *clay coatings* | | *infillings* | | *ferric* | | | *clay pseudomorph* |
| *Profiles* | *Horizon* | *Depth (cm)* | *Structure* | *pyroxene* | *hornblende* | *pseudomorfic pyroxene* | *iddingsite* | *unknown minerals* | *size (µm)* | *weathering* | *sanidine* | *anorthoclase* | *plagioclase* | *quartz* | *opal CT* | *phytolites (opal A)* | *size (µm)* | *weathering feldspars* | | *glass - phenocrysts* | *glass* | | *isotropic glass fragments* | *grano striated* | *cross* | *monostriated* | *mosaic speckled* | *parallel* | *poro striated* | *reticulate striated* | *stipple speckled striated* | | *speckled* | *translucent* | *aggregates* | *loose excremental infillings* | *nodules* | *coatings* | *hypocoatings* | |
| *S02h* | Ah/AB | 4 - 12 | granular, subangular blocky | + | - | - | - | - | 200 / 600 | fresh / thick pellicular | +++ | ++ | ++ | + | | - | 100 | thick pellicular | x | ++, fresh | ++, fresh | - | - | x | - | - | - | - | - | - | x | - | x | - | - | x | x | - | - | - |
| | pocket/B | 37 - 45 | crack | - | - | - | - | + | 15 / 200 | fresh | + | + | + | - | + | - | 300 | pellicular | x | x | x | - | - | x | - | x | x | x | - | - | - | x | - | - | - | - | x | - | - | - |
| | R | 65 - 73 | crack | + | - | - | - | + | 200 / 250 | pellicular | +++ | ++ | +++ | + | - | - | 250 | pellicular | x | - | - | - | - | - | - | - | x | - | - | - | - | x | - | - | - | - | x | - | - | x |
| | piece of rock | surface | massive | + | - | + | - | - | - | - | +++ | +++ | +++ | - | + | - | 500 | pellicular | x | - | - | x | - | - | - | - | - | - | - | - | x | x | - | - | - | - | x | - | - | x |
| *S02b* | Ah | 7 - 14 | dominant granular, locally massive | + | + | - | - | - | 80 | fresh | + | - | + | + | ++ | ++ | 300 | thick pellicular | x | ++, fresh | +, fresh | x | - | - | - | - | - | - | - | - | x | x | - | x | - | x | x | - | - | - |
| | BA | 55 - 62 | crack | + | - | - | - | + | 100 | fresh / pellicular | ++ | + | + | + | + | - | 400 | pellicular | x | - | - | x | - | x | - | x | - | x | - | x | - | x | x | x | - | - | - | - | - | - |
| | BCg | 82 - 87 | massive | - | - | ++ | - | - | 50 / 900 | fresh / complex | +++ | ++ | ++ | + | + | - | 600 | pellicular | x | - | - | x | - | - | - | - | - | - | - | - | - | x | | - | - | - | - | - | - | x |
| *S06h* | Ah | 2 - 10 | granular, subangular | +++ | + | - | + | + | 200 | fresh / complex | + | + | + | - | - | - | 500 | thick pellicular | +++ | ++, fresh | +, fresh | x | - | - | - | - | - | - | - | - | x | x | +++, fine | +++, fine | - | - | - | - | - | x |
| | Bwg | 32 - 40 | complex | ++ | - | - | - | - | 200 | fresh / complex | ++ | ++ | ++ | - | - | - | 200 | pellicular / complex | +++ | - | ++, fresh | x | - | - | - | - | - | - | - | - | x | - | ++ | - | x | x | + | - | ++ | x |
| | C / R | 56 - 80 | complex | +++ | | | + | | 50 / 1700 | fresh / complex | +++ | ++ | +++ | - | - | - | 600 | thick pellicular | ++ | - | - | - | - | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - | x |
| *S06b* | Ah1 | 2 - 10 | subangular | +++ | + | - | - | - | 40 / 300 | pellicular | + | + | + | - | - | +++ | 50 | fresh | + | ++, fresh | +, fresh | x | - | x | x | - | - | - | - | x | x | - | - | - | x | - | +++ | - | + | - |
| | Ah2 | 36 - 44 | subangular, crack | ++ | ++ | - | - | - | 30 / 300 | fresh / thick pellicular | ++ | ++ | ++ | - | - | - | 70 | fresh / pellicular | ++ | ++, fresh | +, fresh | x | - | x | x | - | - | - | x, fine | x | x | - | - | - | x | - | +++ | - | - | x |
| | Ah3 | 80 - 88 | subangular, crack | + | + | - | - | - | 200 | thick pellicular | + | + | + | + | - | - | 150 | pellicular | + | +, fresh | - | x | - | x | x | - | - | - | - | x | - | - | - | + | x | - | ++ | - | - | x |
| | C | 144 - 155 | pellicular grained, massive | +++ + | ++ ++ | - | - | - | 150 | fresh / thick pellicular | +++ | ++ | +++ | - | - | - | 300 | fresh / thick pellicular | ++ | - | - | x | - | - | - | - | - | - | - | - | - | - | ++ | ++ | - | - | + | +++ | - | x |
| *I01* | Ah | 15 - 23 | crack, (sub-)angular | ++ | - | - | - | - | 200 | fresh / thick pellicular | ++ | ++ | ++ | + | - | - | 200 | pellicular | ++ | - | x | x | x | x | - | - | x | x | x | x | x | x | - | - | x | x | x | - | x | - |
| | Ah/Bw | 68 - 78 | ganular, subangular | ++ | - | - | - | - | 250 | fresh / pellicular | +++ | +++ | +++ | + | - | - | 250 | fresh / pellicular | +++ | +++ | - | x | | x | - | - | x | x | x | x | x | | - | - | x | - | x | x | x | - |
| | 2Ah | 95 - 103 | crack, weak (sub-) angular | + | - | - | - | | 150 | fresh / pellicular | ++ | ++ | ++ | + | - | - | 400 | pellicular / thick pellicular | +++ | - | - | x | | x | - | - | x | x | x | x | x | + | - | - | x | - | x | - | - | - |
| | 2C2 | 126 - 134 | crack | + | - | - | - | | 20 | pellicular | + | + | + | + | - | - | 150 | pelliclar | ++ | - | - | x | x | x | - | - | x | x | x | x | x | | + | - | - | - | x | - | - | - |
| *I02* | Ap | 10 - 18 | granular, (sub-) angular | ++ | - | - | - | + | 200 | pellicular / complex | ++ | ++ | ++ | + | - | - | 150 | thick pellicular | + | - | + | x | x | x | - | - | x | x | x | x | x | - | - | - | - | - | - | - | - | - |
| | Bwg1 | 36 - 44 | granular, subangular | ++++ | - | - | - | - | 300 | pellicular / thick pellicular | ++ | ++ | ++ | - | - | ++ | 200 | complex | +++ | ++, 300 | +, 100 | x | - | - | - | - | - | - | - | - | x | x | x, yellowish | - | - | x | - | x | - | - |
| | Bwg2 | 58 - 64 | crack, moderate subangular | + | - | - | - | - | 200 | thick pellicular | + | + | + | + | - | ++ | 250 | pellicular | ++ | - | - | x | + | x | - | - | x | - | x | - | x | x | ++, yellowish | - | - | - | ++ | - | - | - |
| | CBwg | 72 - 80 | vughy, localy subangular | + | - | - | - | - | 200 | thick pellicular | ++ | ++ | ++ | + | - | - | 350 | thick pellicular | ++ | - | - | x | ++ | x | - | - | - | - | - | - | x | - | +, pale yellow | - | - | - | + | - | - | - |
| | R1 | 107 - 115 | massive | + | - | - | - | - | 200 | pellicular | + | + | + | + | - | - | 350 | thick pellicular | +++ | - | - | x | +++ | - | - | - | - | - | - | - | x | - | - | - | - | - | + | - | - | - |
| | R+ | 131 - 133 | massive | + | - | - | - | - | 650 | pellicular | + | + | + | - | - | - | 300 | pellicular | - | - | - | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x | x | - |
| IC1/2 | rock | | rock | + | - | - | - | - | 1500 | - | + | + | + | - | - | - | 150 | - | ++ | - | - | - | - | - | - | - | - | - | - | - | - | x | - | - | - | - | - | - | - | - |

+++ = many ++ = common + = few x = present - = not observed

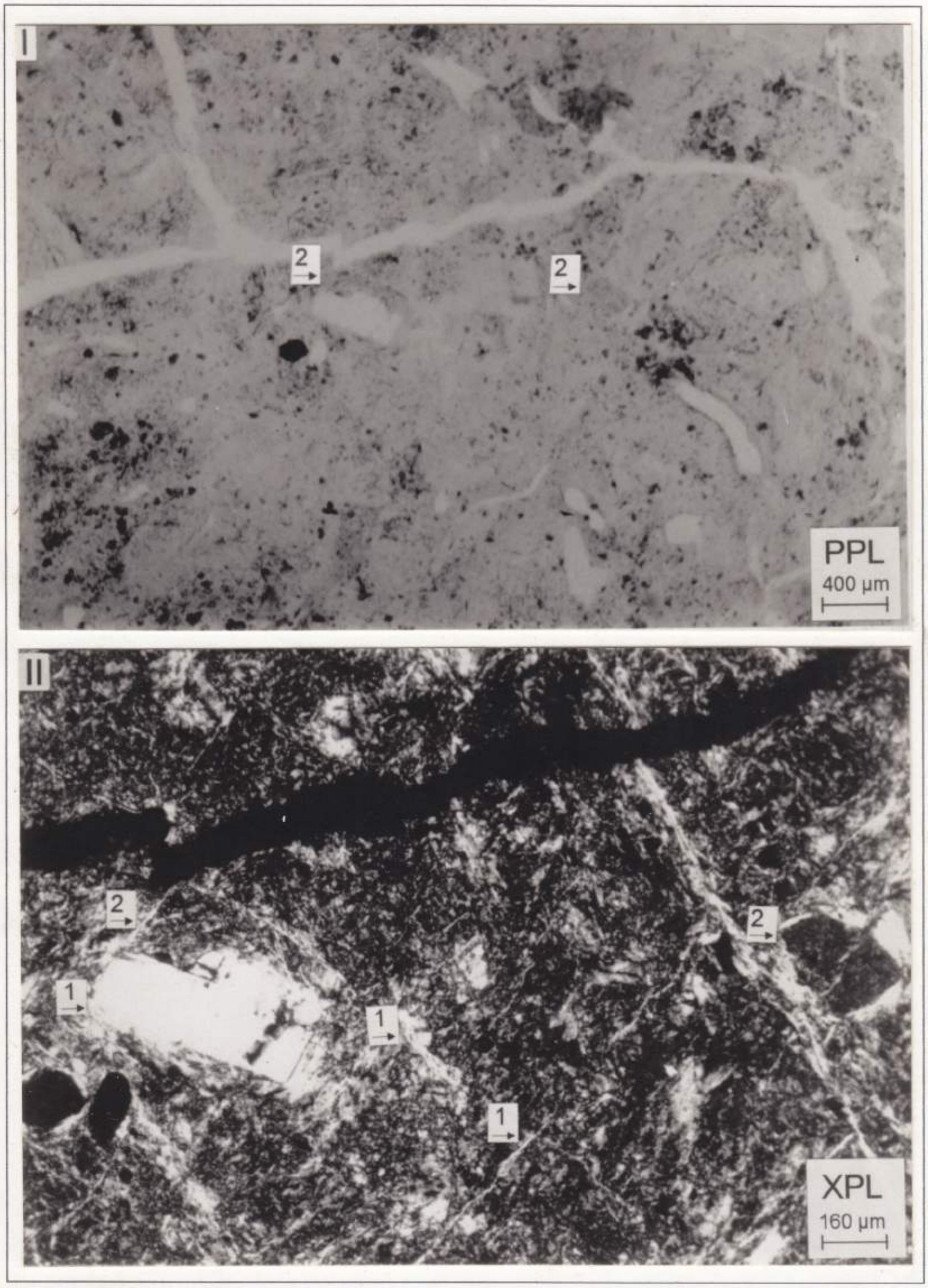


Photo 5.10. Micrographs I and II, showing various striation types (1) within a grayish clay mass; few iso-volumetric weathered feldspars (2) in the BCg horizon of S*02b*.

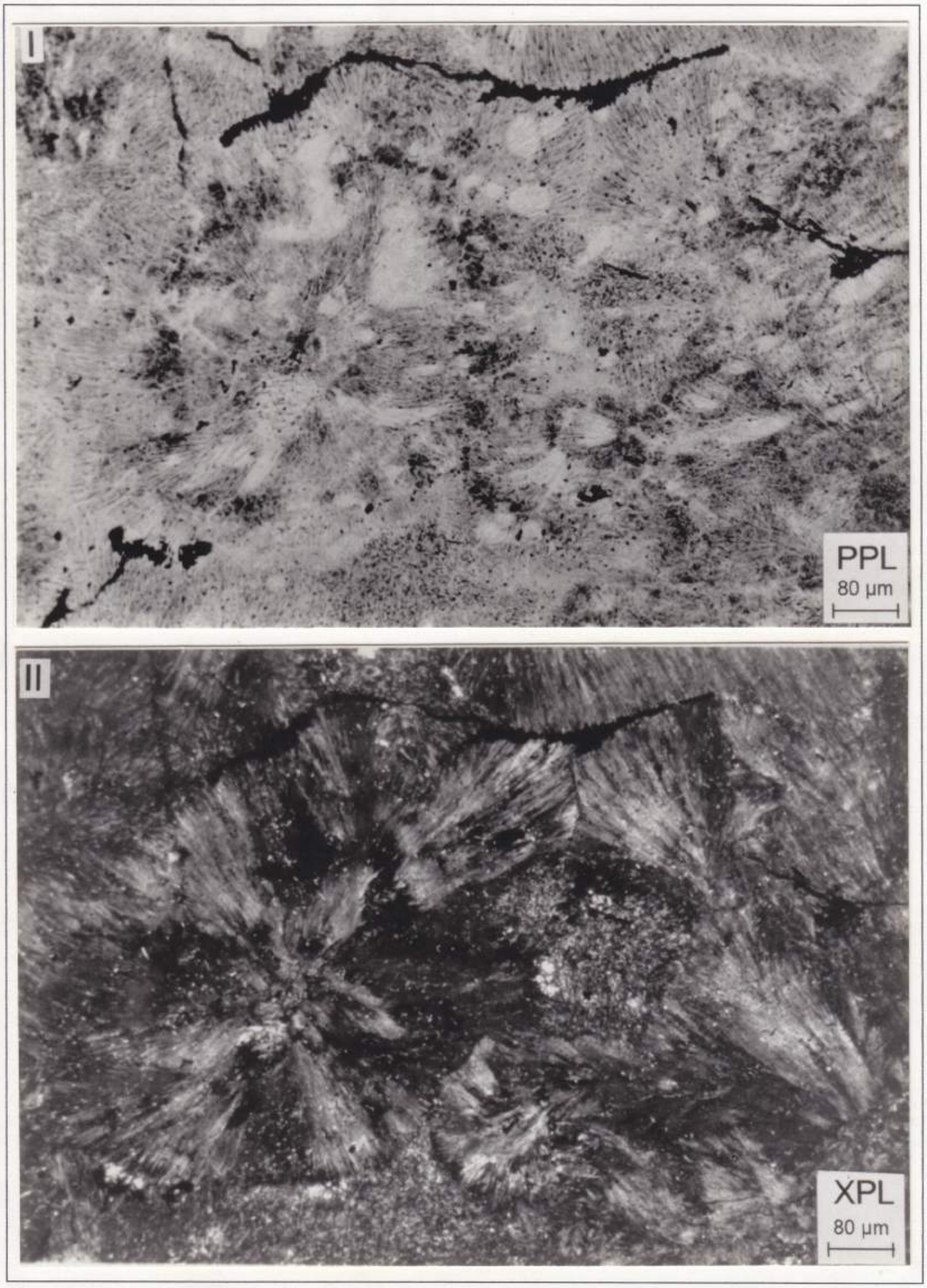


Photo 5.11. Micrographs A and B, showing starshape blooming of secondary formed clay features due to hydrothermal processes, in the parent rock of S*02h*.

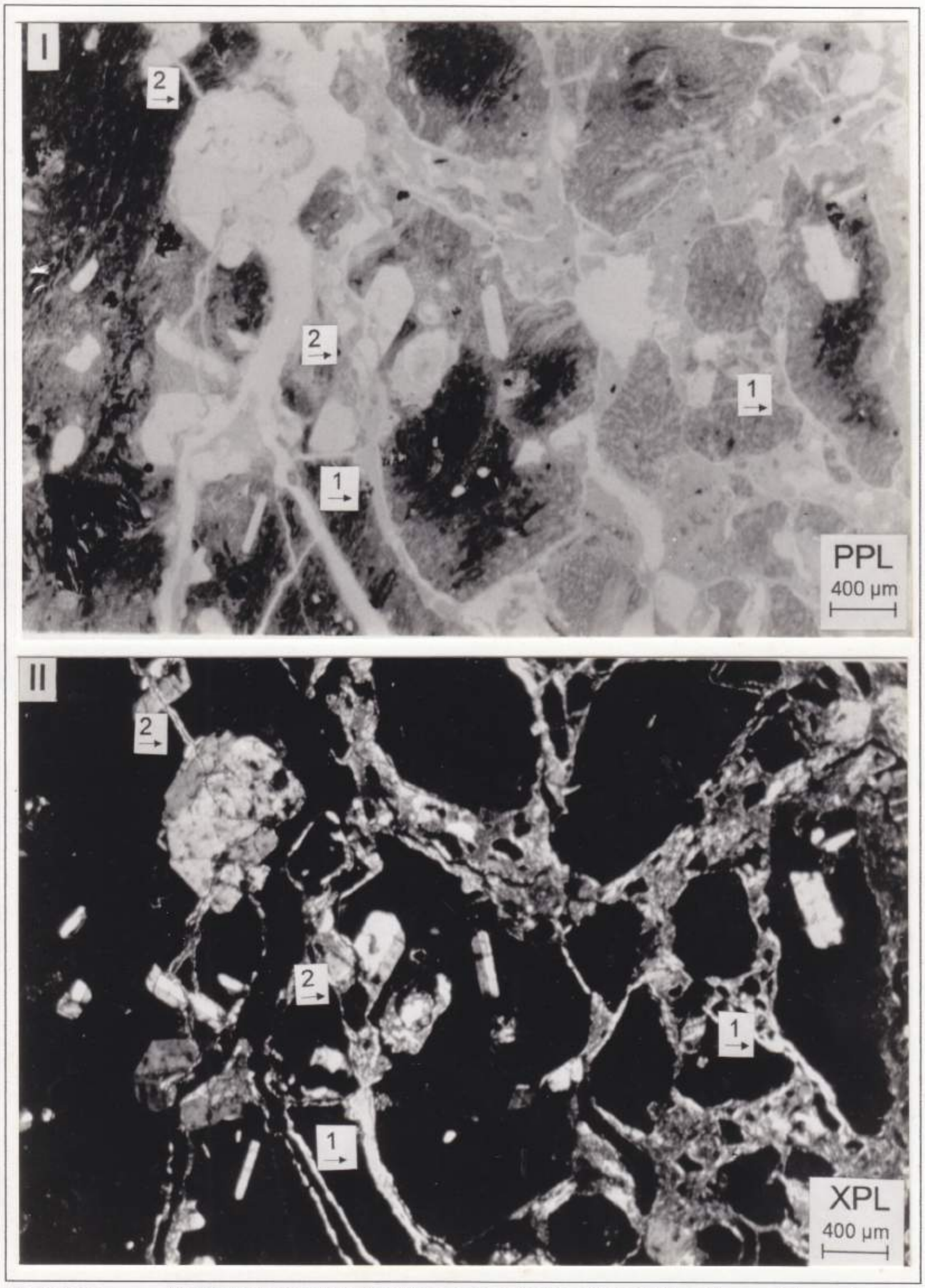


Photo 5.12. Micrographs I and II, showing pressure features (bright 'lines') around the rock fragments (1), indicating swelling and shrinking processes; mechanical weathering due to swell and shrink of clay minerals formed in the cracks (2), on the border of the B to R horizon of S*02h*.

*Catena II*

The microstructure of *S06h* changes from complex in the subsoil to subangular blocky in the A horizon. In addition infillings are found in A and B horizons, indicating faunal biological activity.
In the R horizon of *S06b* pellicular grain microstructure dominates in a coarse textured brownish groundmass, whereas massive microstructure is present in a fine textured grayish groundmass. Both microstructures change in the A horizons to crack microstructures in which moderately developed subangular blocky aggregates (100 - 500 μm) occur. The colour and organic matter content of the aggregates varies from grey with minor amounts of organic matter to brown with appreciable amounts of organic matter. Both aggregate types occur randomly throughout the A horizons.

The ignimbrite of the R horizon of *S06h* consist of coloured volcanic glass with many feldspars and pyroxene phenocrysts and common andesitic rock fragments, both of variable sizes.
The feldspars show an increasing abundance with depth. Sizes range from 200 - 500 μm. Thick pellicular alteration dominates the alteration degree. The few, relative big minerals originating from the parent material, have undergone alteration too, leading to a remaining and identifiable average sized group of 500 μm.
Both profiles contain many, fresh to complex altered pyroxenes in the R and Ah horizons, whereas the abundance in the horizons between is lower. Because soil forming processes hardly have taken place in the C/R horizon of *S06h* and complex altered pyroxenes are present, weathering of these phenocrysts seems to have taken place before deposition.
*S06b* shows very few feldspars, according to other profiles (*S02b*, *S02h* and *S06h*), throughout most of its horizons. Concerning the higher amounts in the R horizons and assuming that the parent material of the upper horizons was the same, strong weathering processes must have taken place in this soil.
The coarse textured part of the R horizon shows isovolumetric weathered groundmass (saprolite). The skeleton grains are partially to totally transformed to speckled oriented, anisotropic clayey box work pseudomorphs. In the fine textured part of the R horizon occasionally primary minerals occur, isovolumetric weathered groundmass is absent indicating preferential weathering of minerals most likely along cracks in the sandy saprolite. In *S06h* no saprolite structures are present.

The occurrence of weathered minerals in the B horizon, adjacent fresh, small (50 - 200 μm) pyroxenes, andesitic rock fragments and coloured volcanic glass (Photo 5.13), indicates rejuvenation of the topsoil. Considering the size of these mineral grains in the upper horizons, it is assumed that aeolian addition has taken place. In the Ah-horizons of *S06b*, up to a depth of 80 cm, fresh andesitic fragments and volcanic glass is present, indicating incorporation of these minerals in the weathered groundmass by mulching.

In both soils randomly distributed, partially altered large volcanic rock fragments are present. Because they contain appreciable amounts of small (10-20 μm) opaque iron minerals, they probably have an andesitic origin. Furthermore, anisotropic, strongly oriented, clay pseudomorphs, sometimes with a blooming structure, are observed within these fragments, resulting from hydrothermal processes in the last stage of andesitic rock formation (Cas & Wright, 1987). As impurities, rock fragments are incorporated in the ignimbrite during its deposition.

*S06b* demonstrates strong developed striated b-fabrics, especially cross striated b-fabrics are numerous, clearly indicating the process of swelling and shrinking. During the dry phase of the soil, aggregates of the top of the Ah horizon, as well as fresh aeolian volcanic fragments and glass, fall in the cracks. During the moist/wet stage of the soil, these features are randomly distributed up to 80 cm in the lower horizons. In *S06h* striated b-fabrics are absent.

In *S06h*, thin (20-50 μm) yellow, translucent, anisotropic, strongly oriented clay coatings occur in the A horizon, indicating the process of clay illuviation. The content is estimated as <1%, so no argic horizon (Soil taxonomy, 1992) could be distinguished.
In the R horizon of *S06b* yellow, translucent, anisotropic, strongly oriented clay coatings with sizes ranging from 20 - 100 μm, are present. They occur around the partial weathered grains in the coarse textured part of the groundmass. Between the coatings and the partially altered grains an empty space is present, indicating that clay illuviation starts before these grains were altered to their current shape, so clay illuviation is an early stage of soil formation (Photo 5.14). White, thick (100 - 300 μm), anisotropic,

strongly to moderately oriented clay coatings occur in the gray clayey part of the groundmass, indicating preferential translocation and accumulation of clay along cracks present in this groundmass. However, in the Ah horizons of S*06b* no insitu clay coatings are present. Only few coating fragments are visible, indicating strong destruction of coatings and incorporation in the groundmass, due to the intensive swelling and shrinking processes.

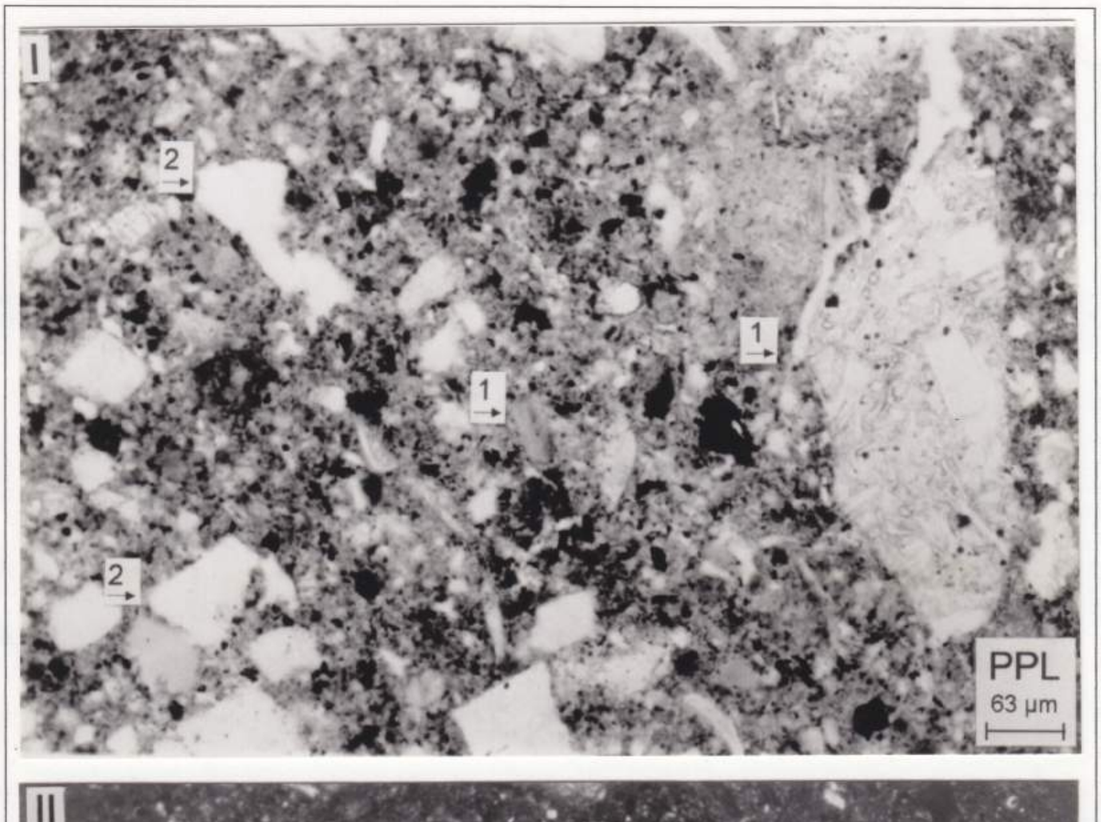


Photo 5.13. Micrographs I and II, showing rejuvenation by fresh ash fragments (1) consisting of volcanic glass and phenocrysts, next to partly weathered feldspars (2) in the Ah horizon of S*06h*.

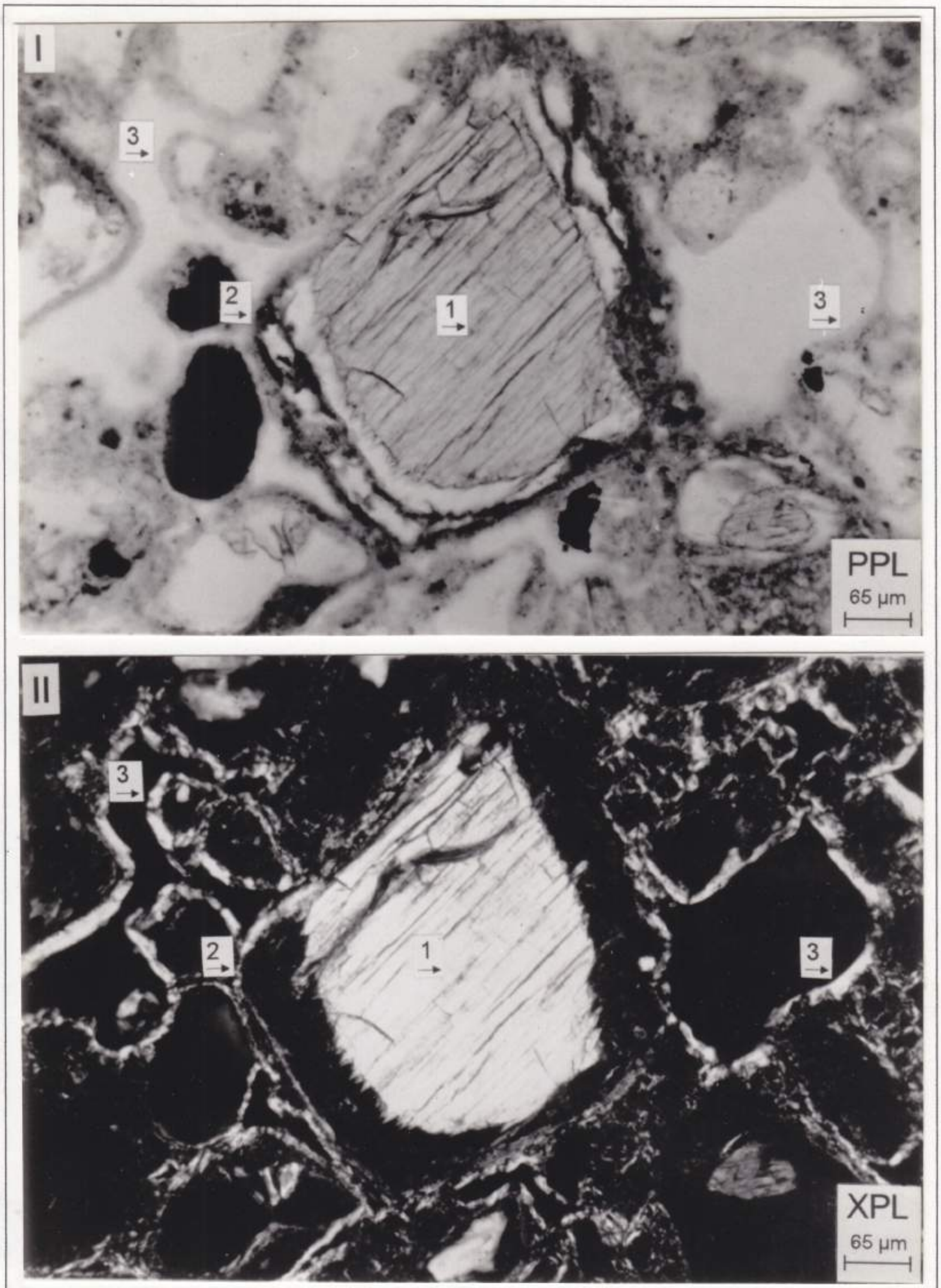


Photo 5.14. Micrographs I and II, showing isovolumetric weathering of a pyroxene (1), indicated by the denticulated outer margins and the spacing between the mineral and a boxwork (2) consisting of clay, at the original outer margins. Yellow, translucent, anisotropic, strongly oriented clay coatings (3) around spacings in the R horizon of *S06b*.

In *S06b* iron- and manganese compounds occur in a typical distribution pattern in the R horizon. Directly around the greyish coloured fine textured spots, iron nodules and hypo-coatings dominate, whereas (iron-)manganese nodules and hypo-coatings occur at some distance of the greyish groundmass.

This typical related distribution pattern of Fe and Mn clearly demonstrate the process of pseudogley in the saprolite. In addition Fe and Mn compounds cover clay coatings, so pseudogley starts after accumulation of clay.

In the A horizon of *S06b* the iron- and manganese nodules occur as small (20 - 100 μm), spherical to ellipsoidal, sharply bounded nodules in clusters. Size, shape and distribution pattern of the Fe-Mn features resulted from intensive swelling and shrinking processes in *S06b*.

In *S06h* few iron nodules occur but pronounced grey groundmass colours are absent, indicating that (pseudo-)gley is absent.

Summarizing it can be concluded that both profiles have different parent material and a different history in soil formation.

*S06h* is situated at the highest position in the landscape. At 60 - 80 cm saprolitic ignimbrite is present, consisting of coloured glass, phenocrysts of feldspars and pyroxenes and volcanic fragments. Weathering results in the clayey groundmass of the A horizon.

Gley features are absent, indicating well drained conditions. Absence of swelling and shrinking features suggests occurrence of formation of 1:1 clay minerals in the clayey Ah horizon of *S06h*. Remarkable is the presence of clay illuviation.

The parent material of *S06b* is coarse textured and consists of andesitic volcanic fragments, feldspars and pyroxenes of variable sizes. Weathering resulted in an isovolumetric saprolitic material. Along cracks, preferential weathering took place resulting in higher clay contents and disappearance of the isovolumetric weathered internal fabric.

Clay illuviation took place in the early stage of soil formation, preferentially along cracks. Under well drained conditions in the sandy material, weathering proceeds producing voids between the mineral residues and the clay coatings. Upon weathering, the clay content increased leading to a decrease of conductivity and formation of pseudogley. The decrease of drainage conditions favoured the formation of 2:1 clay minerals. A high content of this clay type can cause intensive swelling and shrinking. The 'mulching' mechanism destroyed the features of the previous soil forming processes, clay illuviation and pseudo-gleying.

The difference in parent material between *S06h* and *S06b* can not be established properly. There seem to be at least two possibilities:

1. The glassy ignimbrite of *S06h* occurs in both higher and lower parts of the landscape. Upon weathering of the glass, the andesitic rock fragments, the large feldspars and pyroxene phenocrysts were littered, forming an unconsolidated sandy layer upon the ignimbrite. This material was directly eroded to lower parts of the landscape, resulting in the sandy parent material of *S06b*. The composition of the parent material of *S06b* is similar to the non glassy parts of *S06h*.
2. The sandy parent material of *S06b* is a younger ignimbrite deposited in the lower valleys of the ignimbrite sediment of *S06h*. This process is described in chapter 2, Geology.

*Catena III*

Microstructure changes from massive in the R horizons to subangular blocky in the A horizons. The parent material (*I01/2*) dominantly consist of colourless, isotropic volcanic glass having a pumice structure. Impurities of some feldspars and pyroxene phenocrysts and few sandstone and common andesitic rock fragments of variable sizes and alteration degree are present. Andesitic rock fragments frequently contain pale yellow, clay box work pseudomorphs. The intact pumice structure, and the isotropism of the glass, suggests that alteration of phenocrysts and rock fragments has taken place before final deposition of the ignimbrite.

As can be seen from the C2 and R1 horizons of *I01* and *I02*, the isotropic glass is transformed to weak anisotropic clay without loosing its pumice structure, indicating isovolumetric weathering of the pumice. Compaction of the microstructure due to collapsing of fresh and isovolumetrically weathered pumice structures may be illustrated by the presence of clay aggregates showing remnants of the parental pumice structures and angular isotropic glass fragments, incorporated into the groundmass of anisotropic clay of the C2 horizon of I*01* and CBwg and Bwg2 horizons of I*02*. Clay content increases in the upper horizon whereas pumice fragments decrease as a result of weathering of the ignimbrite.

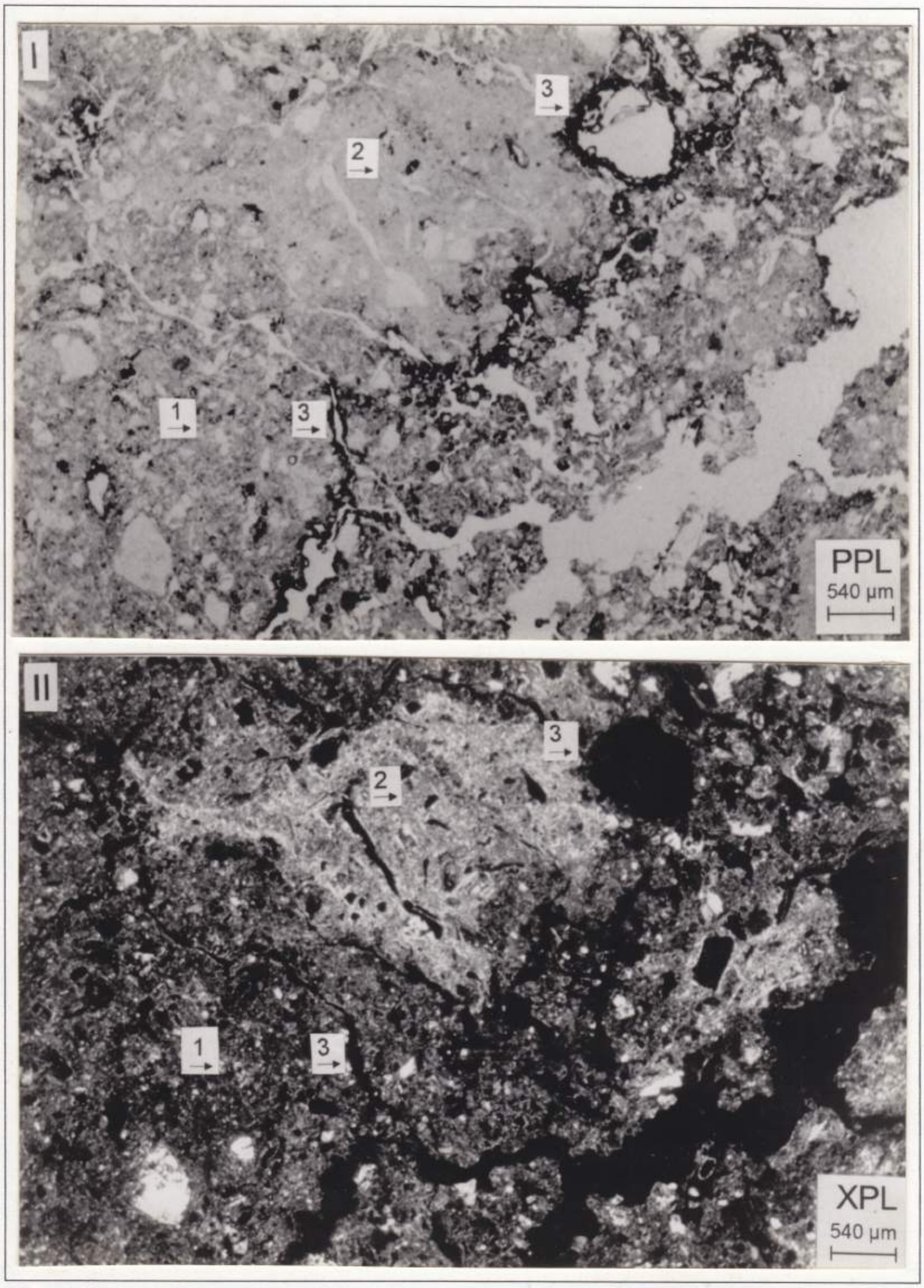


Photo 5.15. Micrographs I and II, showing a mixed appearance of dark (1) and bright grayish (2) ground masses in the Bw horizon of I*01*, resulting of mulching processes. (Hypo-) coatings (3) of iron, allong cracks, root- and worm channels, indicating that the processes of gleying started after mulching and biological activity.

Microstructure in the upper horizons of I*01* changes to crack microstructures in which moderately developed (sub-)angular blocky aggregates (up to 15 mm) occur. The colour and organic matter content of the sharply bounded aggregates varies from grey with minor amounts of organic matter to brown with appreciable amounts of organic matter. Both aggregate types occur randomly throughout these horizons, indicating mixing of both types as a result of mulching (Photo 5.15).
Microstructure in the upper horizons of I*02* changes to granular and subangular blocky. The typical occurrence of sharply bounded brown and grey aggregates within one horizon is absent. In addition, no aggregates other than excremental- and plant remnants are found in A and B horizons. The increasing brownish colour with depth is therefore considered as a homogenisation effect due to biological activity.

The common presence of pyroxenes of the Ah horizon of I*01*, compared with the very many in the Ap horizon of I*02*, may be explained by the translocation of pyroxenes to a lower position due to mulching processes in I*01*, indicated by the more abundant presence to a greater depth.

In both profiles feldspars show a variable abundance with depth. Sizes range from 150 - 400 μm. Pellicular alteration dominates the alteration degree. The variation in abundance and size, may indicate the existence of stratification in the parent material, although this has not clearly been observed in the field. The higher abundance (per square unit) in the soil horizons, in contrast with the abundance in the parent material, may therefore also be explained by compaction of the groundmass due to preferred weathering of the glass structures (Shoji, et al., 1993), and so break down of the preliminary structure, though this does not explain the difference in size.

The occurrence of weathered minerals in the Ah,Ah/Bw and Bwg1 horizons of the I*01* and I*02*, in combination with adjacent fresh, small (50 - 200 μm) andesitic rock fragments and coloured volcanic glass, indicates rejuvenation of the topsoil. Considering the size of these mineral grains in the upper horizons, it is assumed that aeolian addition has taken place. In the Ah-horizons of I*01*, fresh andesitic fragments and volcanic glass is present up to 78 cm depth, indicating incorporation of these minerals in the weathered groundmass by mulching.

In both soils randomly distributed, partially to completely altered large volcanic rock fragments are present. Because they contain appreciable amounts of small (10-20 μm) opaque iron minerals, they probably have an andesitic origin. Furthermore, anisotropic, strongly oriented, clay pseudomorphs are observed within these fragments, resulting from hydrothermal processes in the last stage of andesitic rock formation. The rock fragments are incorporated in the ignimbrite as impurities, during its deposition.

The presence of colourless isotropic glass fragments having pumice structures, together with the dominantly greyish groundmass in the Ah of I*01* and Ap horizon of I*02*, in contrast with the browner groundmass of the horizons directly below, indicate burial of the previous soils. The absence of fresh pyroxenes, small andesitic rock fragments and coloured volcanic glass in the Ap horizon of I*02* also support this. Though it is rather strange that the Ah of I*01* does show some of the 'rejuvenation' products. Is this due to decapitation of I*02*, in favour of I*01* and has rejuvenation taken place before and after burying? The origin and way of deposition can not be explained properly by micromorphological observations alone. Deposition of these layers can either be pyroclastic, due to erosion or due to human activity. No clear evidence is found to favour or exclude one of these processes.

In general can be said that the groundmass of the 'covered' soil changes from greyish to brownish, and that the abundance of the isotropic glass fragments decreases and finally disappears (at about 58 cm) with decreasing depth, for both soils.

I*01* demonstrates strongly developed striated b-fabrics, especially cross striated b-fabrics are numerous, clearly indicating the process of swelling and shrinking. During the dry phase of the soil, aggregates of the top of the Ah horizon, as well as fresh aeolian volcanic ash fragments, fall in the cracks and during the moist/wet stage of the soil these features are randomly distributed up to 78 cm in the lower A horizon (mulching). In I*02* weak striated b-fabrics occur in the Bwg2 horizon, whereas soil movement due to strong swelling and shrinking in the CB and R1 horizons of I*02* is absent, stated by absence of grey and brown aggregates within the horizons, and the presence of weathered phenocrysts with strongly denticulated outer margins.

The rounded phenocrysts, rock fragments and Fe-nodules present in the Ah/Bw, 2Ah and C2 horizons of I*01* and Bwg1 and Bwg2 horizons of I*02*, indicate mechanical weathering due to swelling and shrinking of the groundmass.

In the C2 horizon of I*01* and throughout the entire profile of I*02*, very few pale yellowish to yellowish, speckled, anisotropic, moderately oriented and sometimes fragmented clay coatings are present, ranging in size from 10 - 20 µm. In both profiles they occur along cracks and channels of the groundmass and are interpreted as features resulting from "fine soil material" translocation during heavy rain showers (Schuylenborgh et al, 1973). Occasionally some fragments are believed to be the remnants of isovolumetric weathered, strongly oriented clay phenocrysts. The absence of illuviation features in the Ah2 horizon of I*01* may be due to continuous swelling and shrinking processes.

In the Ah, Ah/Bw, 2Ah and C2 horizons of I*01* and Bwg2, Cbwg and R1 horizons of I*02*, few to common iron nodules occur as small (20 - 100 µm), spherical to ellipsoidal, sharply and diffuse (only in the Bwg2 horizon of I*02*) bounded nodules in clusters.

In the Ah/Bw horizon of I*01*, (hypo-)coatings along cracks, root- and worm channels occur, succeeding through the brownish into the greyish groundmass and visa versa and covering loose continuous and discontinuous infillings. Their presence indicates that the process of gleying starts after mulching and cracking processes. Furthermore the presence of these Fe-hypo-coatings enhanced that the overlaying Ah and Bw horizons are deposited due to erosion, rather than due to insitu weathering.

### 5.2.3 Mineralogy of the <2 µm fraction

This chapter deals with the mineralogy of the clay (<2 µm), and coarse silt and sand (<2 mm) fraction.

#### 5.2.3.1 Clay minerals

When interpreting the data, it must be taken into account that in the comments below quantities are based on estimations of relative presence within the <2 µm fraction, and not the total soil mass.

The mineralogy of the separated <2 µm fraction of the soil samples from the study sites, is shown in table 5.4.

Table 5.4.Mineralogy of the <2 µm fraction

| profile | horizon | depth | clay minerals | | | |
|---|---|---|---|---|---|---|
| | | | kaolinite | smectite | other clay minerals (few) * | non clay minerals ** |
| | Ah | 0-9 | +++ | + | - | CT, F |
| | AB | 9-16 | +++ | + | - | CT, F |
| *S02h* | pocket | 16-40 | +++ | +++ | - | CT |
| | B | 40-68 | +++ | +++ | - | CT |
| | under boulder | +/-40 | +++ | +++ | - | CT |
| | Ah | 0-19 | +++ | - | v | CT, F |
| *S02b* | BA | 19-30 | +++ | - | mi | CT, F |
| | BCg | 30-79 | +++ | - | - | CT, F |
| *S09* | Ah | 0-15 | +++ | - | - | CT |
| | R | 15+ | + | - | ?h | CT, F |
| | Ah | 0-11/15 | +++ | - | - | F |
| *S06h* | B | 11/15-26 | +++ | + | - | F |
| | Bwg | 26-56/80 | +++ | + | h | - |
| | Ah1 | 0-5 | +++ | +++ | - | CT |
| *S06b* | Ah2 | 5-60 | +++ | +++ | - | CT |
| | Ah3 | 60-110/130 | +++ | +++ | - | CT |
| | C | 110/130-140 | +++ | +++ | - | - |
| | Ah | 0-63/68 | +++ | +++ | - | F |
| *I01* | Bw | 63/68-72/80 | +++ | +++ | - | CT, F |
| | 2Ah? | 72/80-110/114 | +++ | +++ | - | - |
| | C1 | 110/114-123/130 | +++ | +++ | - | - |
| | C2 | 123/130-154+ | +++ | +++ | - | - |
| | Ap | 0-22 | +++ | + | - | - |
| *I02* | Bwg1 | 22-46 | +++ | + | h | GO |
| | Bwg2 | 46-65/70 | +++ | + | ?i, h | - |
| | CB | 65/70-87/95 | +++ | + | ?i, h | - |
| | R1 | 87/95+ | +++ | +++ | h | F |

* ? = probable, h = halloysite, v = vermiculite, mi = mica/illite, i = interstratifications of kaolinite/smectite

** CT = cristobalite, F = feldspars, GO = goethite

*Catena I*
Kaolinite is present in appreciable amounts in all horizons of these soils, except in the R horizon of S09 wherein this is little (see below). In the BCg horizon of *S02b* and Ah horizon of S09, only kaolinite is found. The occurrence of kaolinite indicates advanced stages of weathering.

Smectite is only present in *S02h*, ranging from few in the Ah- and AB horizon, to abundant in the pocket-, B- and 'under boulder' horizon; showing a certain increase with depth.
Smectites can either be; inherited from the parent material, weathering products of mica, or neo-formed. Smectites mainly form in environments with high Si and basic cation potentials, under poorly drained conditions (Dixon & Weed, 1977). Volcanic glass, phenocrysts and other rock constituents that contain Si and basic cations were seen from micromorphology (Paragraph 5.2.2). Although the profiles are expected to be moderately well drained (macromorphology, Paragraph 5.2.1), high seasonal precipitation rates (Chapter 3) might lead to temporary water stagnation, favouring smectite formation. Presence of smectites can be reflected by pH, Si and basic cation potentials though, rather than by the necessary conditions.

Some vermiculite is found in the Ah horizon of *S02b*, while some mica/illite is present in the BA horizon of *S02b*. Mica/illite is expected to be inherited from the parent material mainly, whereas vermiculite is assumed to be an alteration product of mica (Dixon & Weed, 1977).

Some halloysite is expected to be present in the saprolite sample of S09. Halloysite also indicates a Si-rich environment.

The saprolite contains few clay minerals within the <2 μm fraction, as is shown in the XRD-diagram by the relative small, overall peaks.

*Catena II*
In this catena kaolinite is present in appreciable amounts in all horizons of both soils. In the Ah horizon of *S06h*, of the clay minerals, only kaolinite is found.

Smectite is present in all horizons, except for the Ah horizon of *S06h*. The relative amount of smectite in the B- and Bwg horizon of *S06h* is small, and abundant in all horizons of *S06b*.

Here too, the presence of kaolinite is associated with advanced stages of weathering, whereas smectite indicates high Si, and basic cation potentials. The poorly (imperfectly) drainage conditions of *S06b* (macromorphology, Paragraph 5.2.1) contribute to the neo-formation and preservation of smectite.

Some 10 Å halloysite is found in the Bwg horizon of *S06h*. The small amounts of smectite and halloysite in the subsoil, in combination with the absence in the topsoil of *S06h*, indicate that Si levels increase with depth, but are lower compared to those of *S06b*.

*Catena III*
Kaolinite and smectite are present in all samples of these soils. The relative amounts of smectite in the Ap-, Bwg1-, Bwg2- and CB horizon of *I02* are small, whereas it is abundant in all the horizons of *I01* and the R1 horizon of *I02*.

Both profiles indicate strong weathering by the presence of kaolinite, whereas the parent material of *I01* seems richer in Si and basic cations. Because both profiles are of the same parent material, hydrological addition of previous mentioned elements to *I01* seems to be the explanation for the differences in soil types. This might also indicate that hydrology is the major influence on soil genesis for those two soils.

A weak and broad peak at the low-angle side of the 7.3 Å peak, present in the XRD-diagrams of the Bwg2 and CB horizon of *I02*, and disappearing after glycerol treatment, is probable due to kaolinite/smectite interstratification.

Halloysite might be present in the Bwg1 horizon. The diffractograms show a small but clear increase of the 10 Å peak after formahide treatment for the Bwg2 horizon, and show a distinct peak for the CB- and R1 horizon. All halloysite peaks move to 7 Å after heating the samples up to 150 °C, for about 2 hours. Therefore, it can be concluded that *I02* shows a slight increase of 7 Å halloysite with depth.

*General comment*

Most of the XRD-diagrams show a somewhat asymmetric peak at about 7.3 Å. Normally, kaolinite shows a reflection at about 7.2 Å. Therefore, the peak value of 7.3 Å for kaolinite might be explained by interstratification of, about 10%, at random positioned, smectite into the kaolinite (Moore & Reynolds, 1989). The asymmetricy of the peak might indicate poor crystallinity of part of the kaolinite, the occurrence of '7 Å' halloysite, or kaolinite/smectite interstratifications also. The absence of a well defined 4.5 Å halloysite peak also states this. To be able to explain these features well, further examination, using a broader scale of techniques, has to be done.

It was suggested by Shoji, et al. (1993), that poorly crystalline kaolinite results from transformation of halloysite as it becomes dehydrated in surface horizons of soils with distinct moisture deficits; circumstances that can well be present under the reigning climate.

In addition to kaolinite and various 2:1 or hydroxy-Al interlayered 2:1 layer silicates (smectite and chloritizised 2:1 layer silicates), poorly crystalline constituents are commonly found in soils derived from volcanic ash (Shoji, et al., 1993).

Shoji, et al. (1993) described that deeply buried soil horizons with increasing halloysite contents with depth, are subject to accumulation of bases and silica which migrate from the overlying soil horizons and favour the formation of halloysite in the buried soil. In a dry climate, the boundary of halloysite formation appears nearer to the surface.

Halloysite can be formed from volcanic glass, due to continuous processes of dehydroxylation of the glass through condensation and replacement with silica tetrahedra (Black & Ishizuka, 1977). This process is strongly supported by a climate with distinct dry seasons, a silica rich environment and an annual precipitation less than approximately 1500 mm (Black & Ishizuka, 1977, Shoji, et al., 1993). Halloysite can also form directly as a precipitate from soluble elements out of the soil solution, rather than as a recrystallization product of non- to semi crystalline minerals. Soluble elements, can be obtained from soil solution after weathering of volcanic glass, phenocrysts and other ignimbrite constituents. The stability and formation of smectite can also be explained by the presence of opaline silica (micromorphology, Paragraph 5.2.2). Opaline silica indicates that high aqueous H4SiO4 levels exist; levels achieved by evapotranspiration from surface horizons during pronounced dry periods, favouring presence of smectite.

### 5.2.3.2 Non-clay minerals

This paragraph discusses the non-clay minerals from XRD and Guinier detection methods. The 'XRD' data are of the diagrams from clay mineralogical analysis.

*XRD*

Table 5.4 shows the non-clay minerals present, as interpreted form the XRD-diagrams.

Cristobalite and/or feldspars are present in all horizons of catena I and II, except for the Bwg horizon of *S06h* and Ah3- and C horizon of *S06b*. Catena III only shows these minerals in the Ah- and Bw horizon of *I01*. Of the horizons containing cristobalite and/or feldspars, only the Ah3 horizon of *S06b* has very few cristobalite, whereas the Ah- and AB horizon of *S02h* contain very few feldspars. Feldspars are believed to be inherited from the parent material, whereas cristobalite can be of volcanic or hydrothermal origin (Dixon & Weed, 1977).

Very few goethite is found in the Bwg1 horizon of *I02*, and is expected to be a neo-formation product.

*Guinier*

Analysis on the mineralogy of the coarse silt and sand (<2 mm) fraction was done on the samples of the; BA horizon of *S02b*, Ah- and 'under rock' horizon of *S02h*, saprolite sample of S09, Ah1-, Ah3- and C horizon of *S06b* and the C1 horizon of *I02*. These samples were mainly selected because of visible differences in abundance of the minerals in thin section micromorphology.

Al samples show a clear dominance of calcium rich plagioclases. Exact classification was not done, though diffraction patterns were quite similar to those of stored labradorite, bytownite and anorthite. Besides calcium-rich plagioclases, the samples contained (slightly varying amounts of) quartzite and magnetite. The Ah1- and C horizon of *S06b* also showed clear presence of pyroxene, which also has not been further classified.

According to the dominant presence of Ca-rich phenocryst in all profiles, and the relative short distance between the sampled areas, it is expected that the volcanic source of the ignimbrite flows is the same, typically resulting from eruptions of silicic calc-alkaline magmas, tending to form extensive sheets or shields (Cas & Wright, 1987).

### 5.2.4 Grain size distribution

The following must be taken into account when interpreting the data:

- Grain size distribution of the 0.04 µm - 2 mm fraction and the clay separate is measured as described in chapter 5.1.4.
- The term 'diagram' is used for the line representing the grain size distribution of each individual horizon, whereas in this chapter with the term 'figure' is meant the combination of diagrams per profile.

#### 5.2.4.1 Grain size distribution of the fraction <2 mm.

*Catena I*

Grain size distribution of the fraction <2 mm of *S02b*, *S02h* and *S09*, is shown in figures 5.4, 5.5 and 5.6.

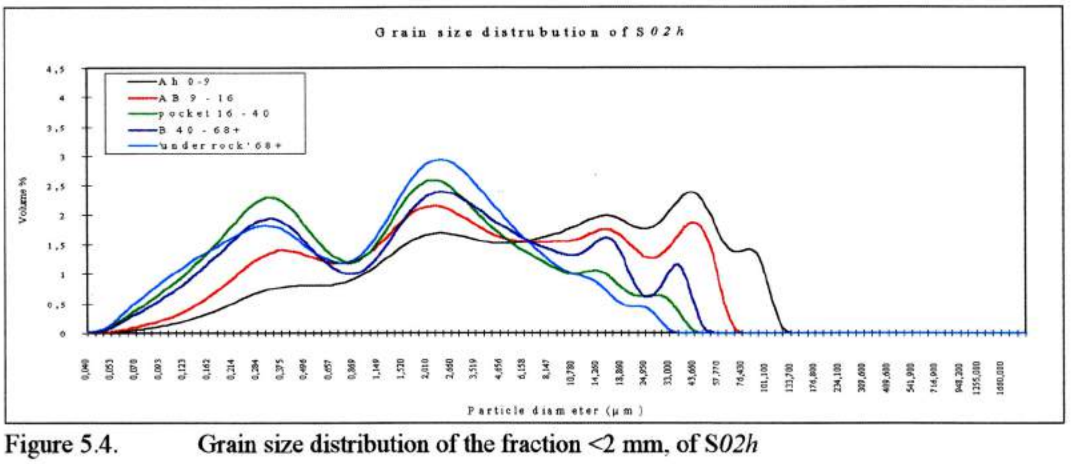


Figure 5.4. Grain size distribution of the fraction <2 mm, of *S02h*

All diagrams of *S02b* show a dominant peak around 16 µm. The diagram of the BCg horizon has no peaks above 80 µm and a low, but broad peak at about 0.15 and 4 µm which are absent in the other diagrams. The diagrams of the Ah and BA horizon show a broad plateau at 4 µm and a little peak at about 100 µm, whereas the diagram of horizon Ah also has a little peak at 270 µm and a large peak at 650 µm.

The diagrams of *S02h* demonstrate increasing 0.3 µm and 2 µm peaks, and decreasing 18 µm peaks with depth. The Ah, AB and B horizons show a decreasing 40 µm peak with depth. Peaks after 40 µm are absent in the 'pocket' and 'under rock' horizons. Only the Ah and AB horizons contain particles between 60 µm and 150 µm, whereas particles larger than 150 µm are absent in all horizons.

Particle distribution of horizon AB of *S09* shows a dominant 2 and clear 110 and 115 µm peaks and smaller peaks around 0.4, 14 and 45 µm.

The 'under rock horizon of *S02h* has a higher fine fraction. Peak position and height of the 0.04 µm - 2 mm diagrams of the AB horizons of *S02h* and *S09* is almost the same for the fraction <70 µm.

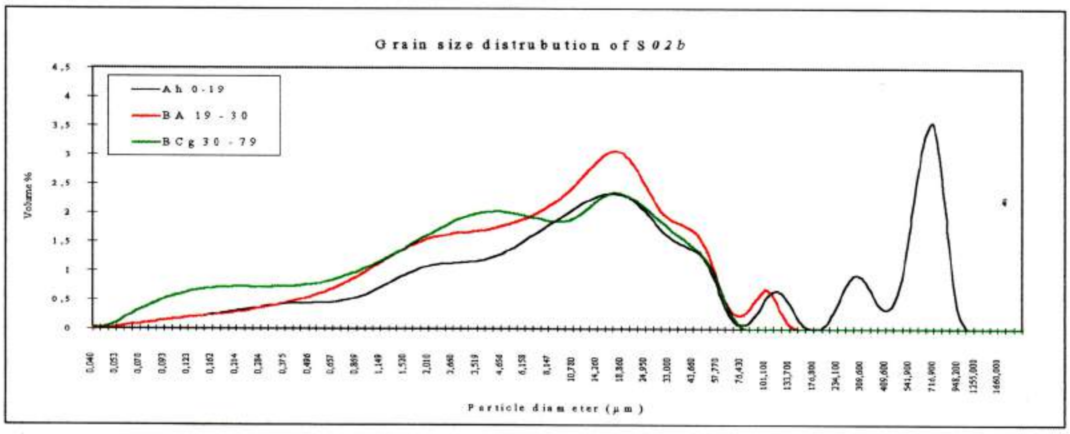


Figure 5.5. Grain size distribution of the fraction <2 mm, of *S02b*.

In general, grain size distribution shifts from coarse to fine with depth, for *S02b* and *S02h*. This can be seen from the decrease of peaks >16-18 µm and increase of peaks <16-18 µm with depth.
Both profiles have the distinct peaks of coarser particles, present in the Ah horizons, either caused by (1) residual coarser particles, (2) stratification of the ignimbrite during deposition or (3) rejuvenation. Rejuvenation seems to be the most logic explanation, which is supported by the nearly absence of particles around 177 µm in the Ah horizon of *S02b*, and micromorfological observations of fresh ash fragments (Paragraph 5.2.2) in the Ah horizons of *S02b* and *S02h*.

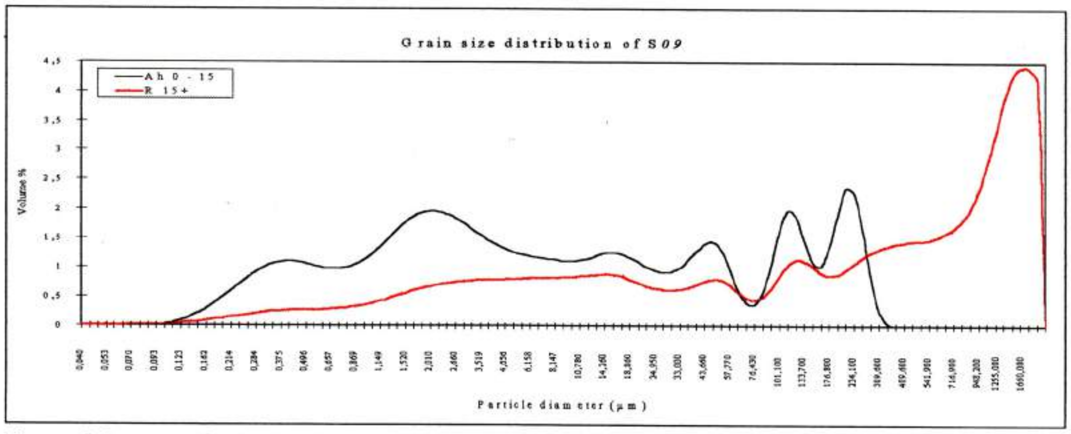


Figure 5.6. Grain size distribution of the fraction <2 mm, of *S09*.

Peak positions of the coarsest particles is different for all horizons, except for the peak at about 100 µm. Most particles of *S02b* are within diameters 1 - 75 µm, whereas this is <5 µm for *S02h* and within 0.7 - 300 µm for *S09*. *S02h* shows therefore the finest texture of the catena.

*Catena II*

Grain size distribution of the fraction <2 mm of *S06h* and *S06b*, can be seen from figures 5.7 and 5.8.

A dominant 2 µm peak is present in the diagrams of the Ah and B horizon of *S06h*. Both diagrams also show a peak around 45 µm. Furthermore a small peak is present around 16 µm and a small peak or plateau around 0.3 µm. The diagram of the Bwg horizon of *S06h* has a dominant peak at 3 µm and smaller peaks at about 13 and 40 µm.

The peaks at 40 - 45 µm decrease, whereas for the diagrams of the Ah and AB horizons, the peaks at about 0.3 and 2 µm increase with depth.

The diagram of the Ah1 horizon of S*06b* has a dominant peak around 2.5 µm which is gently sloping into a 15 µm peak, almost resulting in a single broad peak. The diagrams of the Ah2 and Ah3 horizons of S*06b* have dominant peaks around 2 µm, whereas the diagram of the C horizon has the most dominant peak around 50 µm. All diagrams show peaks around 0.35, 15 and 50 µm. Peaks around 100 and 200 µm are shown by the diagram of the C horizon.

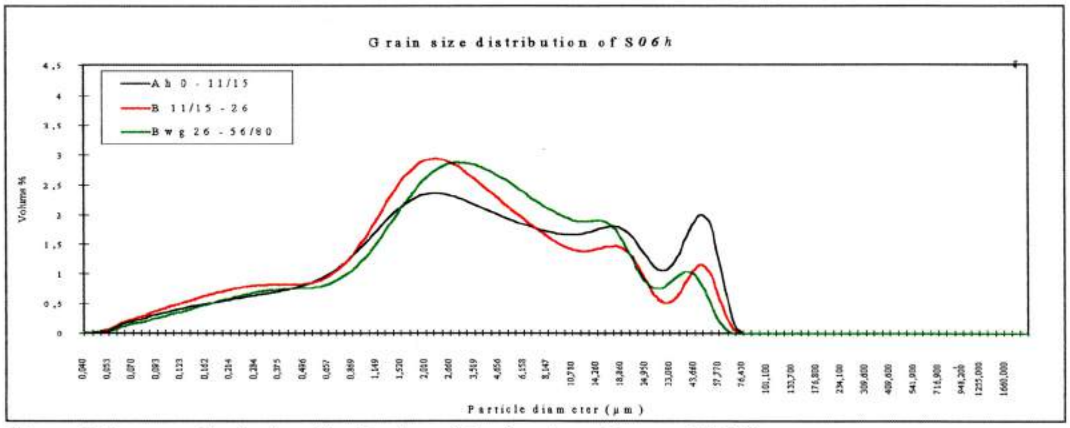


Figure 5.7. Grain size distribution of the fraction <2 mm, of S*06h*.

The increasing 0.35 and 2 µm peaks with depth, for both profiles, might indicate clay formation due to weathering processes. S*06h* and S*06b* also show a decrease of the coarser particles with depth, except for the C horizon of S*06b*. The horizon does contain coarser particles than the other horizons. This is considered to be due to a rather unweathered state of the material the horizon consists of, compared to that of the horizons above.

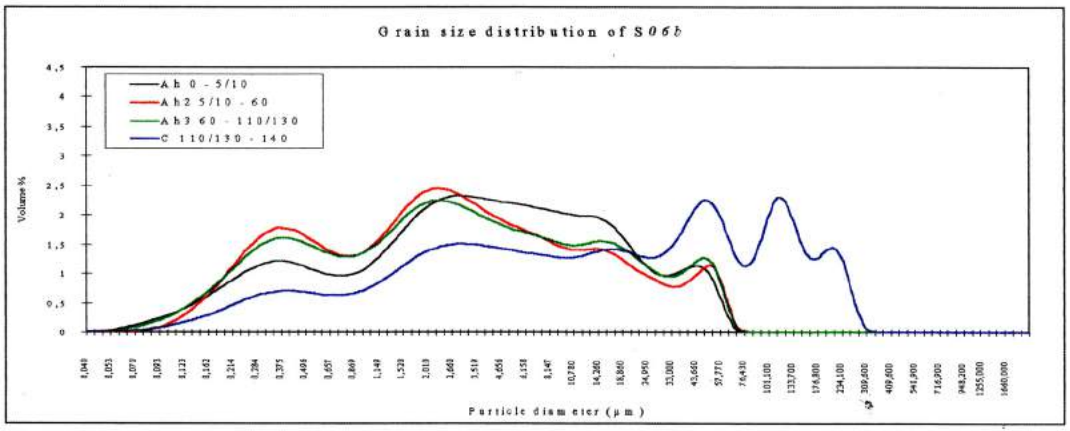


Figure 5.8. Grain size distribution of the fraction <2 mm, of S*06b*.

No peaks of particle diameters coarser than 50 µm are present in the diagrams of S*06h* (Figure 5.7) and in the Ah(1-3) horizons of S*06b* (Figure 5.8). The C horizon of S*06b* however, does contain coarser particles. Because of the covered position of the C horizon, rejuvenation does not seem to be the explanation unless the C horizon is a remnant of a buried soil, as has also been speculated on in paragraph 5.2.2. Therefore the coarse material is probable inherited from deposition of the parent material.

*Catena III*

Grain size distribution of the fraction <2 mm of I*01* and I02, can be seen from figures 5.9 and 5.10.

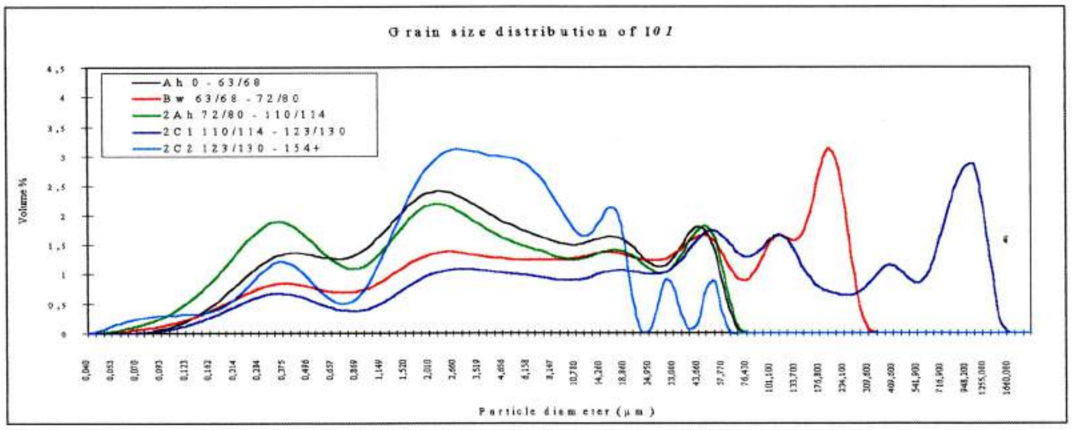


Figure 5.9. Grain size distribution of the fraction <2 mm, of I*01*.

The diagrams of horizon Ah and 2Ah of I*01* show a dominant peak around 1.8 µm. The Bw horizon has a dominant peak around 200 µm and the C1 horizon around 1050 µm. Horizon C2 has a dominant peak around 2.5 µm, shading off into a lower 5 µm peak. All horizons have smaller peaks around 0.35, 15 and 45 µm. The Bw and C1 horizon also have a little peak around 110 µm, whereas the C1 horizon also has a peak around 370 µm. Horizon C2 has a little broad peak around 0.08 µm and two distinct peaks around 30 and 50 µm. Only the diagrams of the Bw and C1 horizon show particles coarser than about 75 µm. The clear differences in the diagrams might indicate strong stratification of the profile.

Comparing the diagrams of I*01* (Figure 5.9), it can be seen that those of the Ah and 2Ah horizons show similar peak positions though the heights vary. The horizons B1 and C1 also show some similarity. The following statements might give the explanation; (1) texture differences are mainly due to stratification of the parent material during deposition, (2) the Ah and Bw are developed in a younger deposit, covering an old profile, (3) the Ah horizon is a younger deposit (natural or human), whereas the Bw horizon actually was the former upper horizon, showing ancient rejuvenation. All explanations seem possible as well from grain size distribution as from micromorphology (Paragraph 5.2.2). Therefore, although the diagrams indicate strong layering, a clear explanation can not be given.

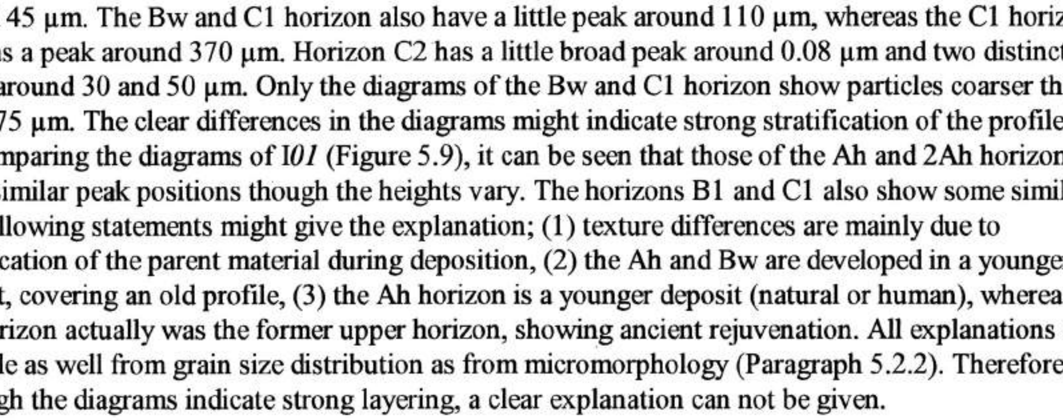


Figure 5.10. Grain size distribution of the fraction <2 mm, of I*02*.

All diagrams of I*02*, except the 2R horizon, show a dominant broad peak, shifting in position from around 2 µm towards 3 µm with depth. The 2R horizon has its dominant peak around 45 µm. Horizons Ap to 2CBwg have clear peaks around 0.4 and 40 µm, whereas the 2R horizon shows a weak plateau around 0.4 µm and does not have a 40 µm peak. Horizon CBwg has an additional peak around 95 µm, whereas the 2R horizon shows additional peaks around 110, 260 and 650 µm. The explanation for the clear difference between the 2R horizon and the other horizons is because the 2R horizon consists of saprolitic- and therefore courser material. Exclusive of the Ap and 2R horizon, peaks around 0.4 and 40 µm decrease with depth whereas the '2 - 3' µm peaks increase, indicating a coarser texture with depth.

Whereas *I01* indicates strong stratification, *I02* does not. This is rather strange when taking into account the topographic position and the relative short distance between the profiles.

For most of the horizons of *I02* (Figure 5.10), particles are within the range of 0.75 to 20 µm and particles larger than 60 µm are hardly present. On the contrary most horizons of *I01* (Figure 5.9) show a range of 0.35 to 60 µm.

### 5.2.4.2 Grain size distribution of the clay separates.

Interpreting the diagrams of the grain size distribution of the clay separates (Figures 5.11 - 5.16), two type of diagrams can be designated:

(1) diagrams with a very dominant peak around 1.7 - 2 µm and,

(2) diagrams with distinct peaks around 0.1, 0.4 and 1.7 - 2 µm.

The first type seems to be related to the lowest horizons or less weathered soils, and the second to horizons where distinct weathering has taken place, as can also be seen from macro- and micromorphology (Paragraph 5.2.1 and 5.2.2).

*Catena I*

Figures 5.11 and 5.12 show the grain size distribution of the clay separates of *S02b* and *S02h*.

Most diagrams of *S02b* and *S02h* are of type 2, whereas the diagram of the Ah horizon of *S02h* is more similar to type 1. Of *S02b*, only the Ah and BA diagrams are available.

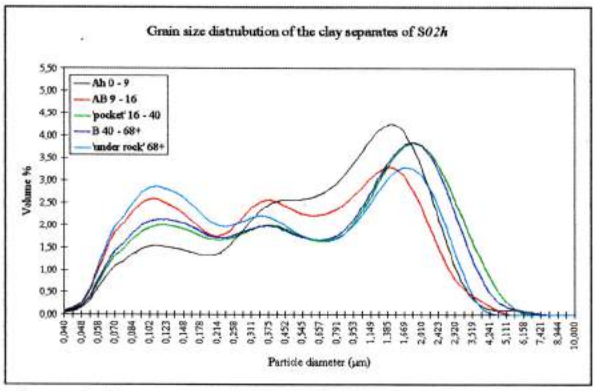


Figure 5.11. Grain size distribution of the clay separates of *S02h*.

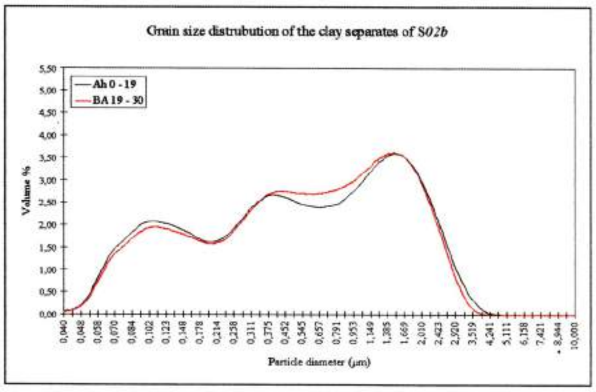


Figure 5.12. Grain size distribution of the clay separates of *S02b*.

Within *S02h*, horizons 'under rock' and AB have lower 2 µm and higher 0.1 and 0.4 µm peaks than the other horizons, indicating clay formation in, or clay illuviation into those horizons. The diagram of the Ah horizon might support this explanation by the lower 0.1 µm peak. Micromorphology (Paragraph 5.2.2) also shows evidence of illuviation in the AB horizon. Therefore, the Ah horizon can not be interpreted as a less weathered horizon.

Due to the covered position, clay illuviation is not expected in the 'under rock' horizon. Therefore, stronger weathering processes seem to be the explanation for the diagram pattern.

The diagrams of *S02b* indicate that weathering has taken place, though lacking strong illuviation processes as for *S02h*.

*Catena II*

Figures 5.13 and 5.14 show the grain size distribution of the clay separates of S*06h* and S*06b*. The diagrams of the Ah horizon of S*06h* and of S*06b* are similar of type 2, whereas the diagram of the Bwg horizon of S*06h* is of type 1.

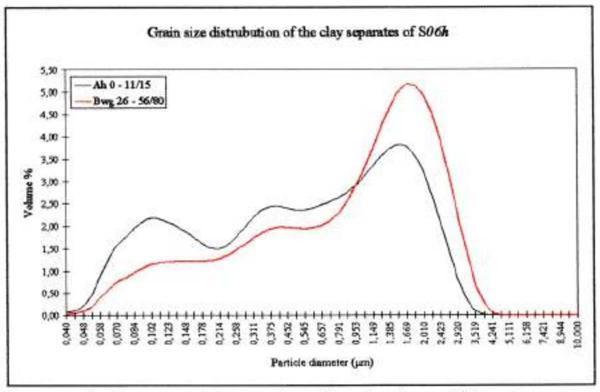


Figure 5.13. Grain size distribution of the clay separates of S*06h*.

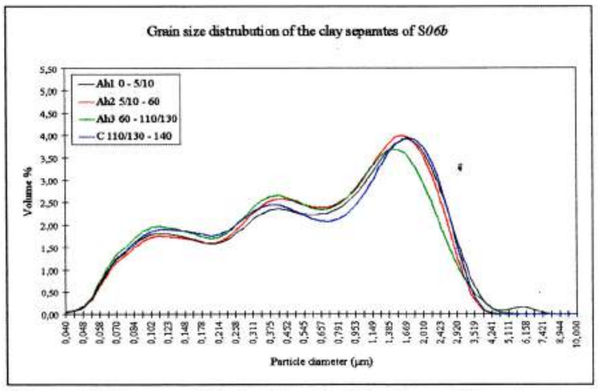


Figure 5.14. Grain size distribution of the clay separates of S*06b*.

Of S*06h* only the diagrams of the Ah and Bwg horizon are available. The coarser clay fraction of the Bwg horizon might be due to low weathering processes in this horizon, compared to the Ah horizon.

The diagrams of S*06b* do not vary much, probably due to mulching processes as evidenced by macro- and micromorphology (Paragraph 5.2.1 and 5.2.2), and indicate that weathering processes have taken place for all horizons, including the C horizon.

*Catena III*

Figures 5.15 and 5.16 show the grain size distribution of the clay separates of I*01* and I*02*. All diagrams are of type 1, although those of I*02* show a slight tendency towards type 2, indicating more advanced weathering compared to I*01*.

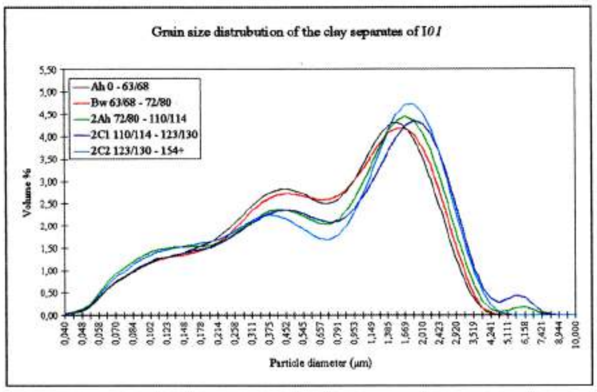


Figure 5.15. Grain size distribution of the clay separates of I*01*.

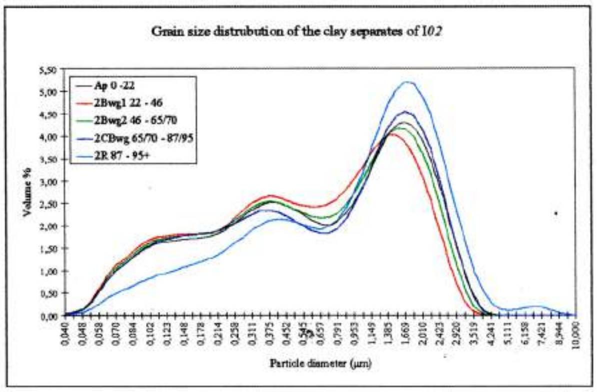


Figure 5.16. Grain size distribution of the clay separates of I*02*.

According to increasing 0.4 µm peaks despite of the 2 µm peaks of the Ah and Bw horizon, I*01* shows a decreasing grain size with depth up to the 2Ah horizon, indicating fine clay formation in the upper horizons. Clay illuviation might be a possible explanation, although no evidence of such could be seen from micromorphology (Paragraph 5.2.2). Illuviation would also be more likely if the 0.4 µm peaks decreased with depth, because of preferential illuviation of particles <0.2 µm. Further down, grain size increases.

The diagram of the 2R horizon of *I02* shows a very weak 0.1 µm peak/plateau but on the contrary a strong peak around 2 µm, indicating that the parent material hardly contains fine clay and that the existence of the fine clay in the horizons above is due to weathering processes.

#### 5.2.4.3 Parent material

*Fraction < 2mm*

Figure 5.17 shows the diagrams of the loose particles <2 mm of the parent material of *I01* and *I02*, combined with the diagrams of the saprolite of *S09* and *I01* and the C1 horizon of *I02*, to compare fresh and slightly weathered material.

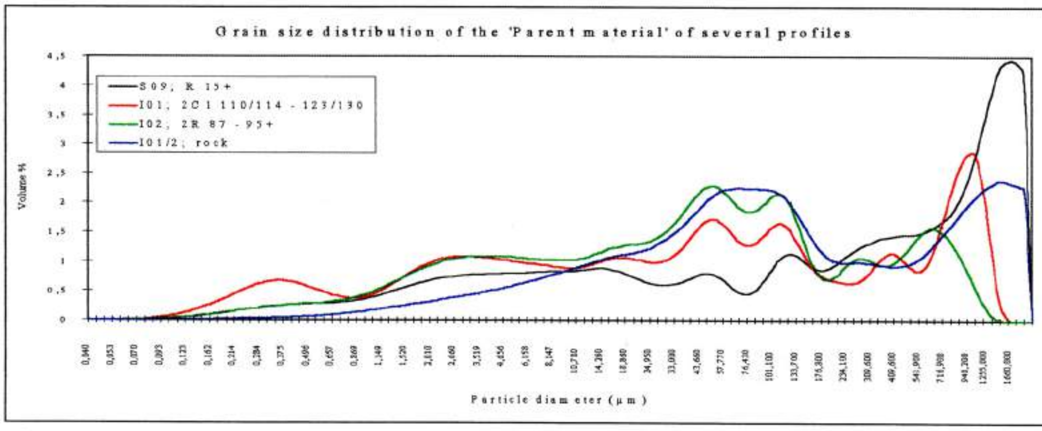


Figure 5.17. Grain size distribution of the fraction <2 mm, of saprolitic material of *S09*, *I01* and *I02* and fresh parent material of *I01/2*.

The fresh material out of the rock underneath *I01* and *I02* (I01/2) shows two broad peaks. The first is ranging from 50 to 110 µm, the second and most dominant peak around approximate 1500 µm. A very weak peak is visible around 15 µm.

The R horizon of *S09* has a dominant peak around 1700 µm, the 2C1 horizon of *I01* around 1000 µm, and the 2R horizon of *I02* around 50 µm. The distinct peak at 0.35 µm of horizon 2C1 of profile *I01* might indicate the influence of clay forming processes. The weak to clear peaks/plateau's from 2.5 to approximate 15 µm in all diagrams do indicate clay formation also. Micromorphology (Paragraph 5.2.2) states this indication. All diagrams do show peaks around 50 and 110 µm.

The distinct peak/plateau around 0.35 µm, together with the absence of particles coarser than 1650 µm for horizons 2C1 and 2R of *I01* and *I02*, compared with the rock material from underneath, might prove weathering processes (e.g. breakdown of pumice structure and clay forming processes) and therefore these horizons can not be classified as pure parent material.

Furthermore horizon R of *S09* has a broad plateau around 350 µm, horizon C1 of *I01* a peak around 400 µm and horizon 2R of *I02* peaks around 250 and 600 µm.

Comparing the diagrams of the rock of *I01/2* and the R horizon of *S09*, the parent material of *S09* contains more coarser (>200 µm) particles.

*Clay separates*

Figure 18 shows the grain size distribution of the clay separates of the saprolitic horizons of *S09*, *I01* and *I02* and of the Bwg horizon of *S06h*. (The last three were also shown in the figures of the profiles, though are repeated for comparison).

The diagrams are all of type 1 (Paragraph 5.2.4.2.), and clearly indicate that the less weathered horizons consist of coarser clay particles, as evidenced by the very dominant peaks at about 1.7 µm.

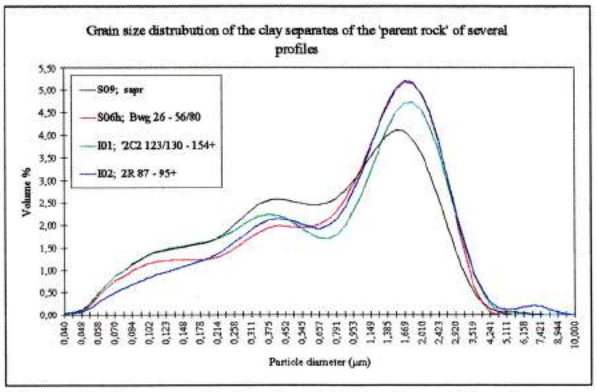


Figure 5.18. **Grain size distribution of the clay** separates of the saprolitic horizons of *S09*, *I01* and *I02*, and from the Bwg horizon of *S06h*.

### 5.2.4.4 General comments

Some diagrams of the clay separates do show particles >2 µm, though samples are used of the fraction <2 µm. It is assumed that the model used for calculation of the distribution is causing this 'error' or that larger particles have been separated together with the clay particles.

An explanation for differences in grain size distribution between the horizons, other than weathering, is that stratification occurred during deposition of the parent material, either by the material of one ignimbrite flow or by successive ignimbrite flows. It is known that pyroclastic deposits show lateral and vertical variations in their grain size and mineralogy (Shoji, et al., 1993).

Decreasing grain size with depth may either be caused by (1) stratification of the parent material, (2) weathering, (3) rejuvenation of the topsoil, (4) illuviation of fine clay into the lower horizons, (5) preferential erosion of smaller particles, or by a combination of these processes.

Stated by the presence of coarse particles in C and R horizons and absence of these particles in most B and BC horizons, coarse particles seem to weather rather rapidly into much smaller particles when soil genesis starts. Therefore it is more likely that the presence of coarser particles in the Ah and AB horizons is due to rejuvenation. This can also be seen from micromorphological observations (Paragraph 5.2.2), whereas the coarser particles of the lower horizons mainly consist of particles originating from the parent rock, and those of the upper horizons of rejuvenates.

Precipitation rates are relative low throughout the year and have an irregular pattern on monthly base. This means that most sub-soils are wet or saturated during certain periods, whereas top-soils often dry out immediately after precipitation stopped. This phenomena may cause that top-soils are less weathered compared to sub-soils, explaining a global tendency of decreasing grain size with depth. Another explanation might be that the finest, mainly easy weatherable-, minerals dissolve in the top soil and leach into the subsoil precipitated as, neo-formed minerals. Both explanations are not supported by micromorphology (Paragraph 5.2.2).

## 5.3 General discussion and conclusions

This chapter reflects to geology (Chapter 2), climate (Chapter 3), and the results and discussions of Chapter 5.2, in a discussion about factors concerning soil genesis.

During the field studies it was concluded that on base of field- and soil characteristics (FAO, 1992 and Oyama & Takehara, 1970), the diversity in soil types could be roughly divided into three main types:

1. brownish black to bluish black, silty clay to clay soils, showing cracks during the dry season, represented by *S06b* and *I01*.
2. greyish/grey brown, silty loam to silty clay soils, that do not or hardly crack, represented by *S02b*.
3. other soils, often reddish to brownish coloured, silt loam to sandy soils, represented by *S02h*, *S06h* and I02.

*Parent material*
The profiles of soil type 1 are both formed on loose structured ignimbrite; *S06b* on coarse textured (saprolitic), and *I01* on pumice structured ignimbrite. The parent material of soil type 2 is dense welded. Of soil type 3, *S02h* and *S06h* are formed on dense welded ignimbrite, whereas the parent material of *I02* is loose structured ignimbrite.

Differences between the dense welded parent materials are mainly the abundance and size of 'impurities' and the presence and degree of hydrothermal features, though could not be clearly specified from macro- and micromorphology.

In general it can be said that the parent material within catena II differs, whereas this does not within catena I and III. During reconnaissance field studies soil type 1 was also seen on dense welded parent material, andt must therefore be considered not to occur on loose structured ignimbrite only.

As far as it could be estimated from the parent materials of all the profiles, the crystal (glass)/ash (phenocrysts, 'impurities', e.g.) ratio are rather similar, except for *S06b*, which contains more ash.

The micromorphological data of the dense welded parent material show evidence of ancient hydrothermal processes, whereas the data of do not. Although such processes were indicated, the intensity could not be established, nor a specific relation to certain soil types.

Concluding can be said that a clear relation between soil type and type of parent material is absent, within the research area's.

Both macro- and micromorphology, show clear differences between the upper two layers of *I02* and diffuse differences between those of *I01*. Grain size distribution of *I02* indicates stratification too. Although a proper explanation for the origin of the upper layer could not be established from the observations, a minimum of two deposit layers are present within the profiles. The stratification can occur within a single deposit or be the result of succeeding volcanic deposits. Erosion deposits or deposits of soil material due to human activity are also within the possibilities. Evidence of stratification is absent within the profiles of catena I and II.

Clear relations between parent material grain size distribution are absent (Chapter 5.2.4). Therefore it can be concluded that differences in the parent material do not necessarily lead to different textures.

*Topography*
Although the topographic positions of the profiles are expected to be of influence on soil forming aspects, no clear evidence of such was found from the field observations, nor laboratory analysis. The only 'visible' evidence is that profiles on the lower position receive part of the rain water from the higher positioned profiles, either from overland- as from ground water flows. Therefore the soils on the lower positions stay wet for longer periods. The wetter conditions during longer periods, of these soils, compared to the higher positioned soils, are believed to be the most important influence from topography on differences between those soils, although the occurrence of different soil types next to each other on level or similar positions, like for catena III, does not fully support this.

Speculations can be made about soil material translocation from higher to lower positions due to surface- (erosion) and/or ground water transportation, but the same criteria are valid for the lower positions, because these can 'loose' materials to even lower positions or nearby creeks. Field observations during heavy rain showers showed that *S06b* receives fine erosion materials of the hill slope of *S06h*, although stratification is absent, probably due to the mulching processes within *S06b*.

Abundant cracks to a depth >50 cm during the dry season, more than 30 percent clay, strong developed b-fabrics, subangular blocky to angular blocky structures and mulching processes, expressed by the mixed occurrence of different groundmasses, rejuvenates, organic matter and remnants of former genetic features, together with the presence of appreciable amounts of smectite, indicate vertic properties of *S06b*. The absence of large amounts of smectite or other 2:1 minerals, and therefore strong subangular to angular blocky structures and mulching processes, indicate that *S02b* is not a vertisol. Both *S02b* and *S06b* are situated on slope base positions. Although differences in the parent material seem present, the main influence on soil genesis is expected to be the addition potentials of soil material and soluble elements by the surrounding area. The 'adding' area of *S06b* is very big compared to that of *S02b*.

The soils representing soil types 1 and 3, occur both on base and hill ridge positions. A relation to ancient geophysical processes seems absent, so both soils are expected to be formed on present topographic positions. Soil type 2 was also seen on other than base position and the occurence is therefore considered to be independent of topographical position also.

*Precipitation*

The precipition pattern can be interpreted as rather constant throughout several years, though seasonal differences, on varying time scales have specific influences on soil genesis. Several and long rainy seasons on a role for example, lead to water stagnation for longer periods, and therefore favour smectite- instead of kaolinite formation.

Above ground climate circumstances are known to a certain extent for the areas, but are rather unknown on profile level. The effects of precipitation and evaporation in combination with specific drainage patterns through a profile or the parent material, are hardly known. Soil material positioned under rock remnants, like the 'under rock' horizon of *S02h*, shows clear difference in genesis from the same kind of material on an 'unsheltered' position, like the AB horizon of the same soil, as is expressed by e.g. texture.

*Biological activity*

Three types of biological activity can be seen.

(1) Floral activity like grasses, herbs, small bushes and trees.

Influences of the ancient, nor the present vegetation on soil processes did not become clear. All profiles have roots throughout the entire depth, though main occurrence is restricted to the Ah and in some cases B horizons. Micromorphology and the organic matter removal during preparation for clay mineralogical analysis, showed relative low contents of vegetation and/or vegetation remnants. The main influence of the vegetation is therefore extraction of elements from soil components and soil solution.

The strong swelling and shrinking activity of soil type 1 restricts the variety of plants and trees to occur on these soils.

(2) Faunal activity.

Macro- and micromorphology of *S06h*, *I01* and *I02* show worm and ant activity. The occurence is mainly restricted to the upper horizons of the profiles, from the surface to a depth of several tens of centimeters. Athough faunal activity is expected for the other profiles as well, no such evidence has been found. Strong activity has not been seen, and activity seems not restricted to certain soil types.

Mulching due to faunal activity, breaks down features like clay-illuviation, coatings of fine soil material or iron and former mulching features. This makes it sometimes hard to specify that ancient processes have taken place.

(3) Microbial activity.

Microbial activity 'catalyses' gleying processes by their ability to release electrons for gleying processes, by the deconstruction of organic matter. All profiles contain gleying features like mottling and/or nodules, further discussed in under the header 'Gley and pseudogley' below.

*Rejuvenation*

Rejuvenates of fresh pyroxenes and volcanic ash fragments, consisting of coloured volcanic glass or glass particles containing small phenocrysts, was detected by micro morphology and grain size distribution for all top soils of the catenae. The profiles of catena I seem to show evidence of deposits of different age, originating from succeeding rejuvenate deposits.

Aeolian and hydrological addition of erosion products as rejuvenates also occurs. Evidence of such has been observed during strong winds and heavy rain showers, though were not seen from macro- and micromorphology.

Micromorphology and grain size distribution show some, to clear variations in the abundance, consistence and size of the rejuvenates.The variations in abundancy are influenced by weathering and mulching processes, and ranges from few to common. The consistency varies from volcanic glass, glass containing phenocrysts to phenocryst and vulcanic rock fragments. The size is mainly <200 μm, though larger particles occur. The presence of rejuvenates is not related to soil type.

*Weathering*

Moderately deep to very deep soils, distinct horizons and the presence of neo-formed 1:1 and 2:1 clay minerals, are evidence that strong weathering has taken place for all profiles.

Micromorphological analysis showed two processes of weathering, (1) chemical and (2) mechanical, present throughout all profiles of the catena.

Micromorphological observations of all profiles evidenced weathering processes by (1) absence of easy weatherable minerals in combination with presence of partly weathered feldspars, (2) presence of isovolumetrically weathered phenocrysts, (3) minerals weathered at outer margins and (4) rock structure and mineral breakdown and aggregate rounding by swelling and shrinking processes.

Isovolumetric weathered phenocrysts, present in the lowest horizons of S*02h* and S*02b*, are often inherited, or are remnants of hydrothermal activity.

Micromorphology of catena III clearly shows that the pumice structured glassy particles are less resistant to weathering than most phenocrysts (of the same size). Breakdown of the pumice structure causes compaction of the soil mass.

Rock fragments, resulting from the break down of the parent material, are present in the lower horizons of the profiles of catena I and II, whereas they are present throughout I*01* and the Ap- and Bwg2 horizon of I*02*. It is expected that the presence throughout I*01* is due to mulching processes of the soil. The presence of rock fragments in the Ap horizon of I*02*, is explained as stratification, probably due to the deposition of a younger ignimbrite layer, and has been fully discussed in paragraph 5.2.2 and 5.2.4.1.

The samples of the fresh parent material and saprolite show that fracture patterns occur throughout the material. These cracks appeared after cooling down of the flows, and give access to weathering reactions, breaking down the parent material.

Some grain size distribution diagrams, like from I*01*, show clear distinctions in grain size classes. Micromorphology shows that rejuvenates are absent in the lower horizons. Therefore, the distinction in grain size distributions is either inherited from the parent material or is the result of a typical succeeding weathering processes during soil formation. The following theory might give the explanation. The easiest weatherable minerals and/or finer particles are weathered almost completely, causing an increasing distinction between the coarse and finer fractions of the horizons. The less weatherable minerals are hardly weathered due to the high ion potentials, from the weathering of the easy weatherable minerals. This, together with a natural occurrence of certain size classes of the less weatherable minerals, leads to distinct size classes in the weathered horizons, whereas particles of sizes between those classes are not or hardly present, possibly misinterpreted as evidence of rejuvenation.

Succeeding stages of soil formation from the parent material, are most clearly expressed by profile I*02*. Isovolumetric weathering leads to replacement of the solid pumice structures by neo-formed minerals. These minerals are able to swell and shrink upon wetting and drying, causing collapsing of the pumice structures, leading to compaction of the soil mass.

*Swelling and shrinking processes*

Macro- and micromorphology prove the presence of swelling and shrinking processes for all profiles, though of different degrees.

Intensive swelling and shrinking processes, leading to specific subangular and angular blocky structures, accompanied by various b-fabrics, are typical for the vertic properties of the profiles of soil type 1. B and C horizons of the other soil types show b- fabrics too, though lack intensive swelling and shrinking.

The degree of swelling and shrinking strongly depends upon clay mineralogy and texture. All profiles contain kaolinite, whereas some profiles also contain smectite. Smectite swells and shrinks more upon wetting and drying than kaolinite. As a result, clay rich soils with appreciable amounts of smectite, like for the profiles of soil type 1, show abundant cracking patterns during the dry periods, rather than the kaolinite rich soils of the profiles of soil types 2 and 3. Cracks become filled with top soil and organic materials, leading to the mulching characteristics when the soils wetten. Although the lower horizons of the profiles of soil type 1 contain appreciable amounts of smectite in the clay fraction too, the clay- and/or smectite content is to low for producing mulching characteristics.

The break down of rock structures, rock fragments and phenocrysts, as has been seen from the micromorphology of the lower horizons of all profiles, is partly due to the following processes. Fine cracks in the parent material are filled with clay minerals, formed from solvated elements in the soil solution in these cracks after dehydratation of the profile. Upon wetting and drying, these minerals swell and shrink, enough to separate the mass around the cracks. A slow but steady process, more or less similar to the growing of (salt-) minerals in cracks of rocks, breaking these rocks apart after cristalyzation.

*Neo-formation*

Three stadia of neo-formation are present at all sites.

(1) Inherited neo-formation, often described as impurities in the ignimbrite deposits.

(2) Neo-formation due to hydrothermal processes during or after deposition of the ignimbrite. Hydrothermal processes 'dissolve' the original deposits and transform primary minerals to secondary minerals (clay).

(3) Neo-formation of (clay-)minerals from weathering products.

Presence of these processes could be seen from micromorphology and clay mineralogical analysis. Halloysite and other non- to semi crystalline Si-rich minerals tend to form first in a Si rich environment, under the reigning climate conditions. When weathering proceeds and other elements are released from the parent material, more crystalline 1:1 and 2:1 minerals form. These succeeding stages can best be seen from the micromorphology of the horizons of the profiles of catena III.

The profiles of soil type 3 have in common that smectite contents increase with depth due to accumulation of basic kations in the lower horizons, favouring smectite formation. For the profiles of soil type 1, smectite is present throughout, and absent for soil type 2. . Therefore, a classification upon clay mineralogy supports the classification on macromorphology.

*Clay illuviation*

Micromorphology showed that clay coatings are often present as thin, (10-20 μm), anisotropic, moderately oriented, pale yellowish to yellowish speckled coatings. They often occur along cracks and channels of the groundmass, indicating preferential translocation and accumulation of clay along cracks and channels present in this groundmass.

Presence of translucent coatings in the top horizon of S*02b* and S*06h*, suggest truncation of the soil.

Speckled clay coatings occur in the upper horizons of S*02h*, S*02b*, S*06h* and I*02*. They are interpreted as features resulted from "fine soil material" translocation during heavy rain showers.

Spaces between clay coatings and altered phenocrysts in the R horizon of S*06b*, indicate that clay illuviation is an early stage of soil formation for this horizon.

Coating fragments, present in the Ah horizon of S*06b*, the C2 horizon of I*01* and throughout I*02*, indicate (strong) destruction of coatings and incorporation in groundmass, due to intensive and/or continuous swelling and shrinking processes, whereas these processes are believed to cause the absence of illuviation features in the Ah2 horizon of I*01*.

The presence of clay illuviation is not related to soil type.

*Gley and pseudogley*

A greyish groundmass, together with iron- and manganese features, indicates presence of (pseudo-) gley processes. These processes indicate water stagnation due to poor drainage conditions of the profiles. Upon the topographic position, macromorphology and texture, poor drainage conditions were not expected for most profiles. Therefore, gleying features must be due to temporarily stagnation during the rainy season.

From macro- and micromorphology (Paragraph 5.2.1 and 5.2.2) was seen that catena I and III express gleying features, mainly iron- and manganese features, throughout the entire profile, whereas these are restricted to the lower horizons of the profiles of catena II. The depth of the occurence of gleying features is therefore not related to type of parent material, topographic position of the profile, or the soil type.

Ferric and/or manganese nodules in *S02h*, *S02b* and *S06b* indicate alteration of oxidation and reduction (gleying), but pronounced grey matrix colours are absent, indicating that processes are not intensive.

The presence of Fe coatings, in particular in the top horizon of *S06h*, may suggest truncation of the soil. The typical distribution pattern of iron- and manganese compounds in the saprolite of *S06b*, in combination with grayish groundmass colours, clearly demonstrate gleying processes.

(Hypo-)coatings of Fe and Mn, covering former features like clay coatings, root- and worm channels and mulching- and cracking processes, indicate that gleying started after accumulation of clay, the biological activity and the vertic processes. Some or all of these processes are present in all profiles.

The presence of gley and pseudogley features, for all profiles, are evidence of microbes deconstructing organic matter. The absence of strong gleying processes indicate that the microbial activity is rather low, whereas the dry climate throughout most of the year also restricts strong activity.

*Soils types and their genesis in the study areas*

From micromorphology has been seen that the profiles representing soil type 1, show evidence of mulching characteristic throughout almost the entire profile, whereas this has not been seen for the profiles representing soil types 2 and 3. Also the colour characteristics were seen from micromorphology, though less expressed than from macromorphology.

From clay mineralogy was seen that the profiles representing soil type 1 contain appreciable amounts of smectite throughout the entire profile. The profile representing soil type 2, does not contain smectite, and the profiles representing soil type 3 only have smectite in the lowest horizons.

A clear distinction between soil types from the grain size distribution is absent.

It can therefore be concluded that, based upon several analysis, we can divide the used profiles into the three groups of soil types.

During the early stages of soil formation, high Si potentials occur due to the high glass contents of the ignimbrite. High Si potentials favour the formation of the 1:1 clay minerals halloysite and kaolinite, and probably some non-crystalline minerals. The reigning climate conditions tend to cause that the ignimbrite preliminary weathers to grayish kaolinite rich soils mainly, as evidenced by the high kaolinite contents for all horizons of the examined profiles, and the presence of grayish clay in the lower horizons on several sites.

The next stages of soil formation depend more upon the structure and consistency of the ignimbrite, the topography, and the addition potentials of soil material and solvated elements by the surrounding area.

The general conclusion is that climate and the high glass contents of the parent material are the main influences during the early stages of soil genesis, whereas influences of topographic position and hydrology become more important during advanced stages of weathering. It is the combination and compilation of several factors that finally lead to certain soil types, rather than 'solid' factors like topographic position and the type of parent material.

**Acknowledgements**

Thank I owe to the following people and authorities:

- Dr André Nieuwenhuyse and Prof. Dr. J. Bouma for supervising the soil mapping research (1995).
- Dr. P. Buurman, Dr. A.G. Jongmans, Prof. Dr. N. van Breemen for the thesis on soil formation (1996), and André Nieuwenhuyse for his guiding assistence in the field.
- Staff of the program *REPOSA*, Guapiles, Costa Rica.
- The people of, and working in, *Sector Horizontes* for giving me a pleasant stay and their patience in learning me some basic Spanish.
- *Area de Conservacion Guanacaste* for their permission to work and stay in *Sector Horizontes*.
- Students and university teachers who I met in Costa Rica.
- *Stichting Molengraaff Fonds* for funding the soil mapping research (1995).
- Others who supported our stay in Costa Rica in any way, with special thoughts to the ladies I danced the merengue and salsa with.
- And last but not least Egon Hofstad for his support during the 1996 period of fieldwork.

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**Summary**

This bundle represents the results of two theses. The theses concern soil types and soil genesis, on the ignimbrites of the Bagaces Formation in Guanacaste, Costa Rica., located along the Guanacaste cordillera.

Variation in lithology of the ignimbrite occurs from incoherent ash deposits to more densely welded tuffs. Rocks have textures ranging from sub-millimeter particles to large clasts over a meter in diameter. Tectonic movements have caused a change in landscape positions throughout the area. Altitudes vary from 45 to 230 meters above sea level, whereas abrupt height differences of several meters in the landscape are rather common.

The climate in the study area can be classified as tropical dry or ustic moisture regime, with a prolonged dry season of about 5 months during which strong, dry northeastern winds cause strong evaporation. During the rainy period an extremely variable shorth dry spell occurs in July and August. Mean annual rainfall is aproximate 1600 mm, characterized by a large variation in yearly total and monthly distribution. The mean annual temperature is about 26 degrees Celcius and is rather constant throughout the year.

The studies were caried out in *Sector Horizontes*, national park *Lomas Barbudal* and in the area around the primary irrigation channel between Bagaces and Canas.

*Soil mapping*

This part and soil map 1:50,000, describes the nature and spatial distribution of soils developed on ignimbritic parent material in *Sector Horizontes*.

The area was examined on different soil types. The profiles of the seven dominant soil types -at representative sites- were characterized in detail, indicated S*01* to *S06h* and *S08h*.

The soil map is based on bore points, visual data, and detailed descriptions of profile pits. These observations were joined and related to the soil types.

Soil characteristics of the selected types are:

- S*01* shows a brownish colored profile with a weak color gradation downwards, and has a clay loam texture throughout the entire profile.
- *S02b* shows an increase of grayish color and finer texture (clay loam to clay) downwards.
- S*03* is selected because of visible evidence of ash addition to the profile.
- *S04b* shows large cracks during the dry season (closing in wet seasons), a very clay-rich texture and a dark color throughout the entire profile, and is therefore classified as a vertisol. This soil type is the most abundant of the area.
- S*05h* has a clear downward change from dark to lighter colors and a loamy texture throughout the profile.
- *S06h* has a shallow profile and a reddish color. The texture changes downwards from clay loam to clay.
- S*08h* has a brownish color and a coarse (loam to sandy loam) texture throughout the profile.

Genesis of soil types *S01* to *S06h* seems to be related to a dense welded-, and *S08h* to loose structured ignimbritic parent rock.

*Soil formation (physicals)*

During the soil mapping survey, spacial variability of soils formed on ignimbrite has been reported. However, the relation of soil types with the parent material, topography and adjacent soil types was not the main objective of that study, but did ask for attention during field work.

The variety of soils that have developed are expected to be caused by topography, as well as by the density of the parent material. Therefore, we selected three soil types, based on macromorphology) on diffent topographic positions, formed on two types of ignimbrite (dense welded and loose structured).The selected soil types are:

1. a brownish black to bluish black, silty clay to clay soil, showing cracks during the dry season,
2. a grayish/grey brown, silty loam to silty clay soils, that do not or hardly crack, and
3. other soils, often reddish to brownish coloured, silt loam to sandy soils.

Soil type 1 is sampled on a base, as well as on a hill position, soil type 2 on a base position, and soil type 3 on hill top and a hill ridge position. Soil types 1 and 2 seem to occur mainly in poorly drained and/or valley positions, whereas soil type 3 dominantly occurs in well drained positions. Combinations are always of type 1 and 3 or 2 and 3; the combination of type 1 and 2 seems absent.

In general soil colours are lighter and texture finer with depth. Soil structure is angular and/or subangular blocky for most horizons, whereas the massive structure throughout S*02b* is clearly different from the rest. Differences in mottling, nodules and residual rock fragment positions might be explained by the clear differences in the structure of the parent matrial.

From micromorphology the same designation between soil types can be made, though from a different scale of view. On micro scale can be seen the processes of swelling and shrinking, on different scales, causing various striation types up to vertic properties, evidence of rejuvenation, and oxidation and reduction features. Also evidence of both chemical and mechanical weathering is present.

From both macro and micromorphology, no clear explanation can be given for the genesis of the different soil types.

Clay mineralogical analysis shows that all soils contain appreciable amounts of kaolinite, whereas the soil with vertic characteristics contain high amounts of smectite also. The poor cristallinity of the kaolinite minerals might be due to smectite incorporation during formation. Occasionally halloysite is considered to be present.

From the grainsize distribution of the <2 mm fraction, no clear differences between soil types and their positions can be seen. Grainsize distribution patterns of profile I*01* suggest layering, whereas this is absent for profile I*02*. The grainsize distribution of the clay separates shows a clear distinction between rather fresh and strongly weathered profiles.

Rejuvenation has been seen from micromorphology and was indicated by the grainsize distribution patterns of all profiles. How rejuvenation has influenced the genesis of the present profiles, did not become clear.

A clear relation between soil type and type of parent material seems absent within the research area's, as well as a clear relation with topographic position. A general conclusion is that climate and the high glass contents of the parent material are the main influences during the early stages of soil genesis, whereas influences of topographic position and hydrology become more important during advanced stages of weathering. It is the combination and compilation of several factors that finally lead to certain soil types, rather than 'solid' factors like topograpic position and the type of parent material.

**Appendix I**

Topographical map of study site Sector Horizontes.
Topographical map of study site Lomas Barbudal.
Topographical map of study site Irrigation Canal.

part of the topographical map:

Ahogados 30048 II, Costa Rica.

Edición 2-igncr 1988


Escala 1:50,000

1000 500 0 1000 2000 3000 4000 Metros

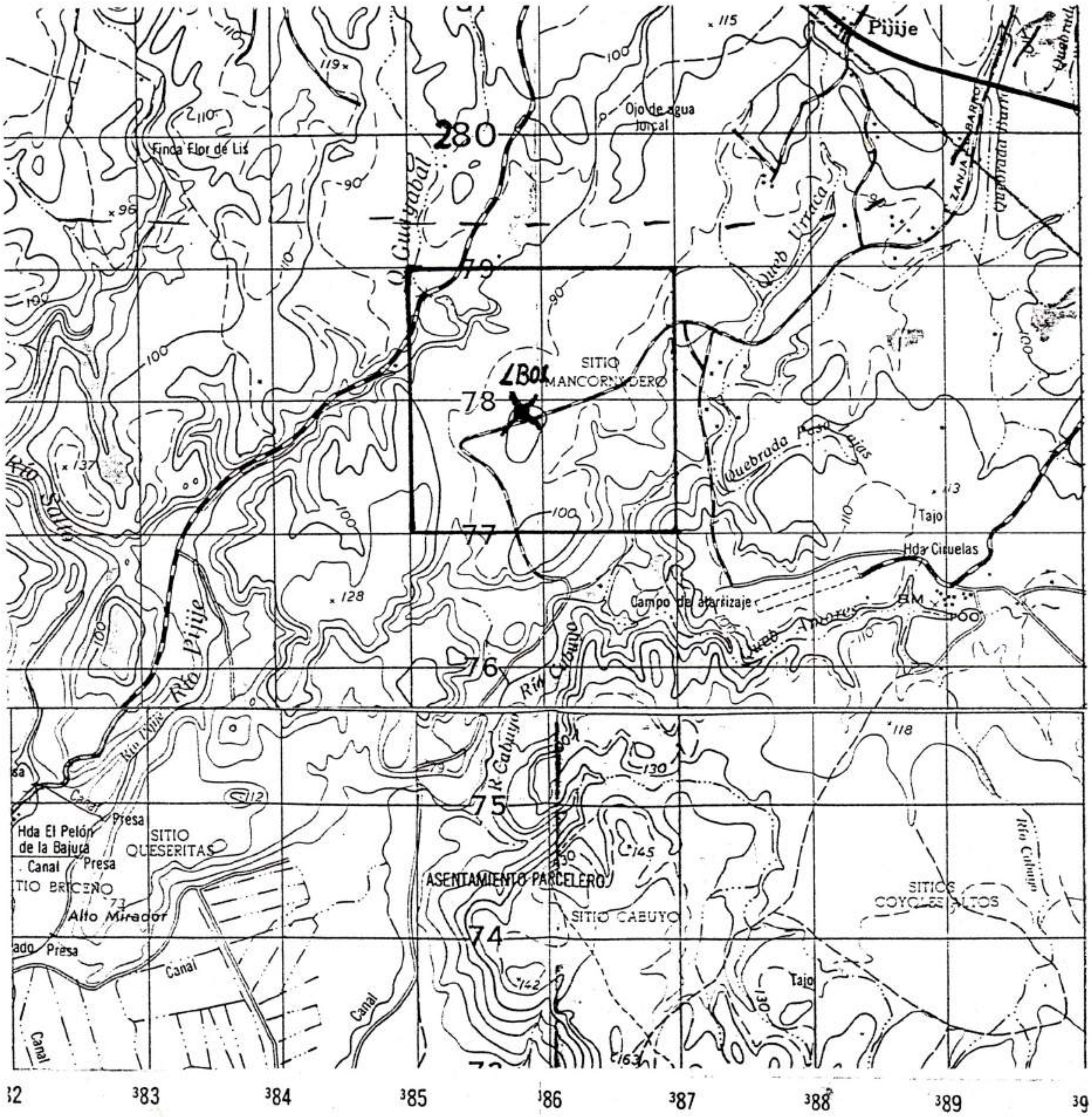
CURVAS DE NIVEL CADA 20 METROS, CON
CURVAS AUXILIARES CADA 10 METROS
COTAS REFERIDAS AL NIVEL MEDIO DEL MAR

PROYECCION LAMBERT
ESFEROIDE CLARKE DE 1866

Part of the topographical maps:

**Monteverde 3147 IV, Tempisque 3147 III, Costa Rica.**

Edicion 3-igncr 1989, 1987




Escala 1:50,000

1000 500 0 1000 2000 3000 4000 Metros

1 ½ 0 1 2 3 Millas Terres

INSTITUTO GEOGRAFICO NACIONAL
SAN JOSE, COSTA RICA

CURVAS DE NIVEL CADA 20 METROS, CON
CURVAS AUXILIARES CADA 10 METROS
COTAS REFERIDAS AL NIVEL MEDIO DEL MAR

PROYECCION LAMBERT
ESFEROIDE CLARKE DE 1866
FUNDAMENTAL DE OCOTEPEQUE

Part of the topographical maps:

**Canas 3147 II, Costa Rica.**

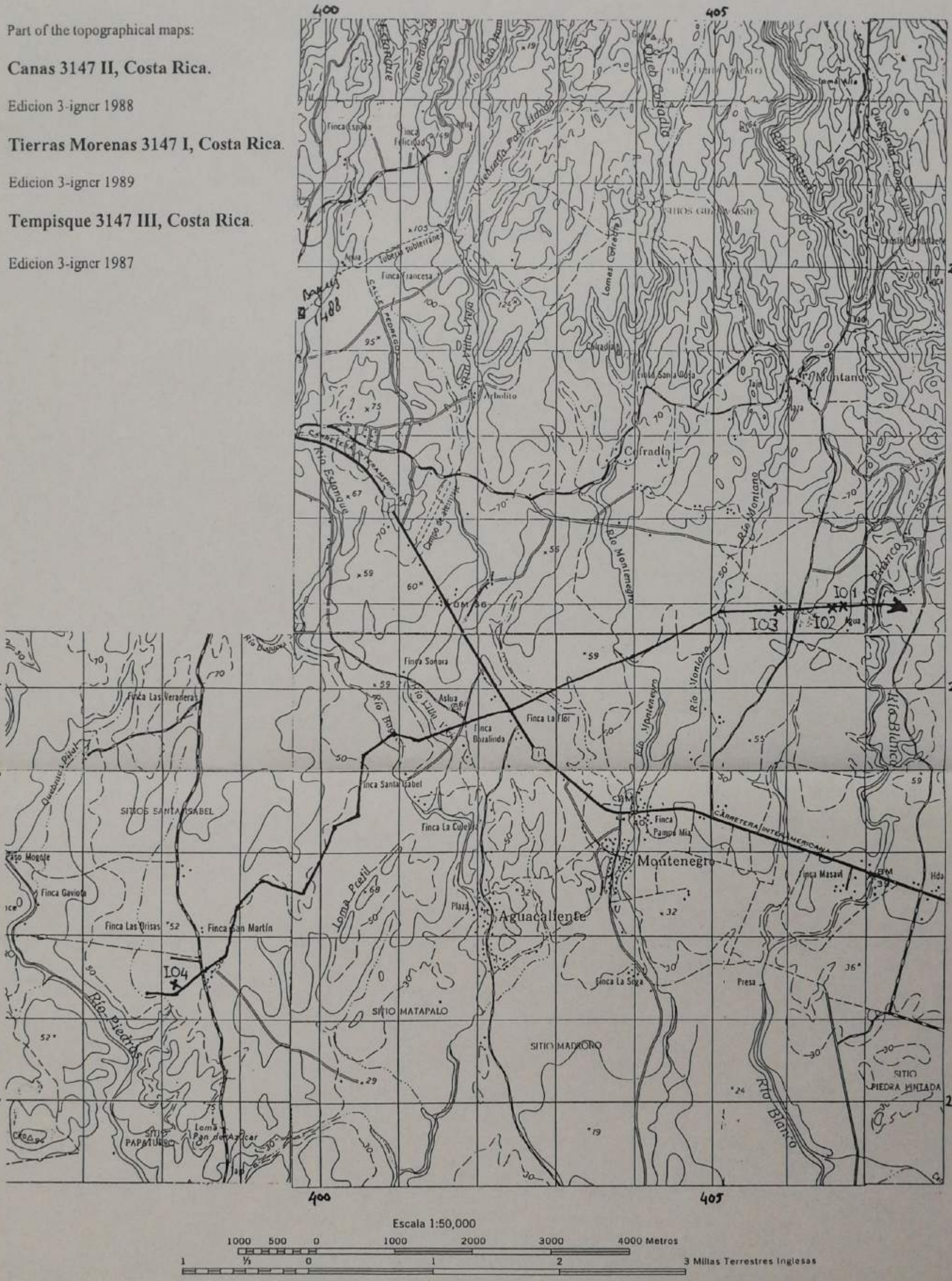
Edicion 3-igner 1988

**Tierras Morenas 3147 I, Costa Rica.**

Edicion 3-igner 1989

**Tempisque 3147 III, Costa Rica.**

Edicion 3-igner 1987

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## Appendix II

Table 3.1, meteorological data per month of 1995 of Sector Horizontes.
Table 3.2, precipitation data of several meteorological stations around the study sites.
Table 3.3, precipitation data of October 1995 of Sector Horizontes.

**Table 3.1.** **Climatological data of Sector Horizontes, 1995.**

| | *jan.* | *feb.* | *mar.* | *apr.* | *may* | *june* | *july* | *aug.* | *sept.* | *oct.* | *nov.* | *dec.* | ***Total per year*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sum of precipitation* | 0.0 | 6.0 | 15.0 | 4.0 | 149.0 | 325.0 | 198.0 | 354.0 | 500.0 | 772.0 | 17.0 | 38.0 | 2378.0 |
| *Highest precipitation per day* | 0.0 | 3.0 | 5.0 | 3.3 | 54.1 | 65.5 | 50.6 | 69.3 | 137.7 | 207.5 | 4.8 | 34.5 | |
| *Average of max. temperature* | 32.5 | 32.7 | 34.1 | 34.0 | 32.3 | 30.8 | 30.4 | 29.1 | 28.9 | 27.7 | 28.3 | 28.9 | 30.8 |
| *Average of min. temperature* | 18.9 | 19.8 | 20.4 | 21.8 | 21.8 | 22.3 | 21.2 | 21.6 | 21.1 | 20.8 | 19.4 | 17.7 | 20.6 |
| *Average temperature* | 25.7 | 26.25 | 27.25 | 27.9 | 27.05 | 26.55 | 25.8 | 25.35 | 25 | 24.25 | 23.85 | 23.3 | 25.7 |
| *T max. - T min.* | 13.6 | 12.9 | 13.7 | 12.2 | 10.5 | 8.5 | 9.2 | 7.5 | 7.8 | 6.9 | 8.9 | 11.2 | |
| *Highest temperature per month* | 34.0 | 34.0 | 36.0 | 36.5 | 34.5 | 33.0 | 33.0 | 33.0 | 32.0 | 30.0 | 30.0 | 30.5 | (36,5; 01-04-'95) |
| *Lowest temperature per month* | 16.0 | 17.0 | 17.0 | 20.5 | 20.5 | 19.5 | 19.0 | 20.0 | 25.5 | 19.0 | 17.5 | 15.0 | (15; 04-12-'95) |

**Table 3.2.** **Average precipitation (mm) per month of the year 1995 for Sector Horizontes and of several years for the stations Bagaces', 'Canas, San Luis', 'Liberia, Llano Grando' and Santa Rosa'.**

| | *jan.* | *feb.* | *mar.* | *apr.* | *may* | *june* | *july* | *aug.* | *sept.* | *oct.* | *nov.* | *dec.* | ***Total*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bagaces (8 yrs)* | 0.9 | 14.8 | 6.9 | 30.4 | 260.0 | 262.6 | 129.8 | 149.5 | 350.5 | 216.5 | 53.4 | 13.0 | 1488.2 |
| *Canas, San Luis (58 yrs)* | 3.2 | 8.8 | 6.2 | 33.5 | 197.6 | 271.7 | 163.1 | 187.4 | 357.8 | 334.1 | 97.9 | 17.4 | 1678.8 |
| *Liberia, Llano Grande (45 yrs)* | 3.9 | 1.2 | 5.2 | 22.3 | 199.7 | 265.6 | 160.6 | 184.8 | 343.7 | 312.0 | 121.8 | 19.4 | 1640.1 |
| *Santa Rosa (8 yrs)* | 3.4 | 0.9 | 2.3 | 11.0 | 235.8 | 234.4 | 118.3 | 187.5 | 379.5 | 308.8 | 89.8 | 15.9 | 1587.6 |
| *Sector Horizontes (1 yr; 1995)* | 0.0 | 6.0 | 15.0 | 4.0 | 149.0 | 325.0 | 198.0 | 354.0 | 500.0 | 772.0 | 17.0 | 38.0 | 2378.0 |

**Table 3.3** **Precipitation per day, during october 1995, for Sector Horizontes.**

| | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Precipitation* | 82.0 | 42.2 | 21.8 | 3.0 | 28.7 | 207.5 | 178.1 | 10.2 | 7.9 | 0.0 | 4.3 |

| | *12* | *13* | *14* | *15* | *16* | *17* | *18* | *19* | *20* | *21* | *22* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Precipitation* | 32.3 | 14.0 | 17.5 | 9.4 | 2.5 | 22.1 | 0.5 | 6.6 | 0.0 | 0.5 | 2.0 |

| | *23* | *24* | *25* | *26* | *27* | *28* | *29* | *30* | *31* | *average* |
|---|---|---|---|---|---|---|---|---|---|---|
| *Precipitation* | 0.0 | 0.0 | 34.5 | 0.0 | 16.5 | 4.1 | 23.9 | 0.0 | 0.0 | 24.9 |

## Appendix III

*A001* 09-05-95

location: 362950 E / 303800 N

Slope 2% on site and up to 25% at about 200 meters from the site.

Dry-forest consisting of bush, many small and a few larger trees.

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (5 YR 2/1), silty clay loam: |
| 30 - 70 | B | Brown (10 YR 4/6), clay: |
| 70 -100⁺ | B2 | Brown (10 YR 4/4), clay. |

*A002* 09-05-95

location: 365750 E / 306600 N

Slightly rolling landscape with slope on site 4%.

Pasture with some bush.

| | | |
|---|---|---|
| 0 - 40⁺ | B | Bright yellowish brown (10 YR 6/6), loamy sand/sandy loam. |

As far as can be seen along the roadside, the soils in this area vary in depth from 30 to 40 cm and are formed on ignimbritic parent material.

*A003* 10-05-95

location: 363300 E / 303550 N

Drilled between roadside and boarderfence of hacienda Ahogadus, underneath three big trees aside a curve in the road.

Slope <2% on site and up to 25% at about 100 meters from the site.

Dry-forest with small and large trees.

| | | |
|---|---|---|
| 0 - 20 | Ah | Reddish black (2.5 YR 2/1), clay: |
| 20 - 60 | B | Yellowish gray (2.5 Y 4/1), clay: |
| 60 - 80⁺ | B2 | Yellowish gray (2.5 Y 4/1), clay; carbonate particles up to 5 mm. |

*A004* 11-05-95

location: 360600 E / 298225 N

Plain landscape.

Pasture with few bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (7.5 YR 3/2) with iron mottles of max. 1 mm, clay: |
| 20 - 40⁺ | Ah2 | Brownish black (7.5 YR 3/2) with iron mottles of max. 1mm, clay; very thin iron cutans. |

Visible are smaller and larger deep (up to at least 50 cm) cracks, typical for vertisols.

*A005* 11-05-95

location: 360500 E / 297800 N

At foot of a convex slope (5%), at site more or less plain landscape.

Pasture with few bush.

| | | |
|---|---|---|
| 0 - 2 | Ah | Black (10 YR 2/1), clay; very loose material rich in humus: |
| 2 - 30⁺ | Ah2 | Black (10 YR 2/1), clay. |

Visible are small cracks, typical for vertisols.

*A006* 11-05-95

location: 360700 E / 297950 N

Bore-point about 100 meters out of the road to the main entrance. In between and 20 meters out of boring point is a ditch.

Plain landscape.

Pasture with some bush.

| | | |
|---|---|---|
| 0 - 2 | Ah | Brownish black (7.5 YR 2/2), clay; very loose material rich in humus: |
| 2 - 25 | Ah2 | Brownish black (7.5 YR 2/2) with very fine iron mottles, clay: |
| 25⁺ | R | Saprolitic ignimbrite. |

Visible are small cracks, typical for vertisols.

*A007* 11-05-95

location: 361075 E / 298650 N

Slope 1% on site and up to 25% at about 80 meters from the site.

Dry-forest with small trees and bush.

| | | |
|---|---|---|
| 0 - 5 | Ah | Brownish black (5 YR 2/2), clay; loose humusrich soil: |
| 5 - 70 | B | Brownish black (7.5 YR 2/2) with fine iron mottles, clay; fine iron cutans; few fine angular weathered rockfragments: |
| 70 - 80 | B2 | Very dark brown (7.5 YR 2/3), clay; few fine angular weathered rockfragments: |
| 80⁺ | R | Saprolitic ignimbrite; most yellowish brown (10 YR 5/6). |

The soilsurface is in the shadow all day long.

*A008* 11-05-95

location: 360850 E / 298700 N

Plain surface.

Pasture with some bush.

| | | |
|---|---|---|
| 0 - 35 | Ah | Brownish black (7.5 YR 3/2) with few fine iron mottles, clay: |
| 35 - 55⁺ | B | Dull reddish brown (5 YR 4/4) with fine iron mottles, clay; fine iron cutans. |

*A009* 11-05-95

location: 361125 E / 298000 N

Small plateau between valley and curve in the road from main entrance.

Slope 1% on site and up to 25% downward at about 15 meters from the site.

Dry-forest with small trees and bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Dark brown (7.5 YR 3/3) with few fine iron mottles, clay; loose structure: |
| 20 - 30 | B | Brown (7.5 YR 4/3) with few fine iron mottles, clay; loose structure: |
| 30 - 40 | BC | Dull yellowish brown (10 YR 5/4) with many fine and coarse iron mottles, sandy loam; fine angular weathered rockfragments; few fine and coarse manganese nodules: |
| 40+ | R | yellowish brown (10 YR 5/6), saprolitic ignimbrite. |

The soilsurface is in the shadow for a long period during the daytime.

*A010* 12-05-95

location: 366775 E / 300075 N

Top of an upper part in a slight wavy landscape, slope on site 1%.

Pasture with some bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (7.5 YR 2/2), clay. |
| 10 - 40 | B | Dull reddish brown (5 YR 4/4) with few fine iron and manganese mottles (mixed color, see below), clay: |
| 40 - 50⁺ | BC | Bright brown (7.5 YR 5/6), loamy sand. |

*V001* 12-05-95

The soiltypes in the area surrounding point A010 (location 366775 E / 300075 N) are a mix of vertisols (at about 15 meter from A010) and other soil types. Changes in soil type can be very abrupt.

*A011* 12-05-95

location: 366525 E / 298600 N

Boring point 15 meters out of fence and close to few big trees.

Slope 2%.

Pasture with very few trees and bush.

| | | |
|---|---|---|
| 0 - 4 | Ah | Brownish black (7.5 YR 3/2), silty clay loam: |
| 4 - 20 | Ah2 | Brownish black (10 YR 3/2), silty clay loam: |
| 20 - 40 | Bwg | Grayish yellow brown (10 YR 4/2) with many fine and coarse iron mottles, clay; few fine and moderate coarse manganese nodules: |
| 40 - 50⁺ | B | Brownish gray (10 YR 4/1), clay: |
| 50+ | R | Saprolitic ignimbrite. |

*V002* 12-05-95

Arround boring point A011 (location 366525 E / 298600 N) I did vive control drills. They were all about the same as point A011. The only difference is the somewhat shallower depth.

*A012* 13-05-95

location: 361850 E / 299775 N

Slope on site and the surrounding area 3%.

Pasture parcel in front of the buildings. In the corner closest to the buildings a few young trees (due to reforestation).

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (7.5 YR 3/1), silty clay/silty clay loam: |
| 15 - 30 | B | Dark reddish brown (5 YR 3/3), clay/silty clay: |
| 30 - 50⁺ | BC | Brown (10 YR 4/4), clay. |

*A013* 13-05-95

location: 361950 E / 299850 N

Slope on site and the surrounding area 3%.

Pasture parcel in front of the buildings. In the corner closest to the buildings a few young trees (due to reforestation).

| | | |
|---|---|---|
| 0 - 10 | Ah | Black (7.5 YR 2/1), clay/silty clay: |
| 10 - 40⁺ | B | Brownish black (7.5 YR 3/1), clay. |

Soilsurface shows very small cracks as effidence of vertic properties.

*A014* 13-05-95
location: 362150 E / 300150 N
Slope on site and the surrounding area 3%.
Pasture.

| | | |
|---|---|---|
| 0 - 15 | Ah | Black (7.5 YR 2/1), silty clay: |
| 15 - 70 | B | Brownish black (7.5 YR 3/1), clay: |
| 70⁺ | R | Saprolitic ignimbrite. |

*A015* 13-05-95
location: 362075 E / 300150 N
Slope on site and the surrounding area up to 5%.
Pasture.

| | | |
|---|---|---|
| 0 - 35 | B | Brownish black (7.5 YR 3/2), silty clay: |
| 35⁺ | R | Saprolitic ignimbrite |

*A016* 13-05-95
location: 361975 E / 300175 N
Slope on site and the surrounding area up to 5%.
Pasture.

| | | |
|---|---|---|
| 0 - 10 | Ah | Dark brown (7.5 YR 3/4), silty clay loam: |
| 10 - 25⁺ | BC | Reddish gray (2.5 YR 5/1) and brown (7.5 YR 4/4), clay loam. |

*A017* 13-05-95
location: 361950 E / 300150 N
Slope on site 2% and for the surrounding area up to 5%.
Pasture.

| | | |
|---|---|---|
| 0 - 20 | Ah | Dark reddish brown (5 YR 3/3), clay/silty clay: |
| 20 - 40 | B | Dull reddish brown (5 YR 4/4), silty clay loam: |
| 40 - 60 | BC | Dull brown (7.5 YR 5/4), clay: |
| 60⁺ | R | Saprolitic ignimbrite. |

*V003* 15-05-95
Te area arround A018 (location 365800 E / 299050 N) , A019 (location 365795 E / 299050 N) and A020 (location 365805 E / 299050 N) contains about 30% ignimbritic rock at surface, also a lot of spots (up to 20 m² per unit) with vertic soils. Soils on these sites seem to be rather undeep, varying in depth from 0 up to 40 cm.

*A018* 15-05-95
location: 365800 E / 299050 N
Slope on site up to 2%.
Pasture with many bush and few large and many small trees.

| | | |
|---|---|---|
| 0 - 20⁺ | B | Brownish black (7.5 YR 3/1) and brown (7.5 YR 4/4), clay. |

*A019* 15-05-95
location: 365795 E / 299050 N
Slope on site up to 2%.
Pasture with many bush and few large and many small trees.

| | | |
|---|---|---|
| 0 - 10⁺ | B | Brownish black (7.5 YR 3/1) and brown (7.5 YR 4/4), clay. |

*A020* 15-05-95
location: 365805 E / 299050 N
Slope on site up to 2%.
Pasture with many bush and few large and many small trees.

| | | |
|---|---|---|
| 0 - 30⁺ | B | Brownish black (7.5 YR 3/1), clay. |

*A021* 15-05-95
location: 365575 E / 299500 N
Slope on site 3%.
Pasture with many bush and many small trees.

| | | |
|---|---|---|
| 0 - 25 | AB | Brownish black (10 YR 3/1), silty clay: |
| 25 - 60⁺ | B | Black (10 YR 2/1), silty clay. |

Surface shows many cracks up to 0.5 cm. wide and some larger ones.

*A022* 15-05-95
location: 366550 E / 300075 N
Slope on site 2% up to 5% for surrounding area.
Pasture with many bush and many small trees.

| | | |
|---|---|---|
| 0 - 40⁺ | B | Black (10 YR 2/1), clay. |

*A023* 15-05-95
location: 366200 E / 299750 N
Slope on site 3%.
Pasture with many bush and many small trees.

| | | |
|---|---|---|
| 0 - 25⁺ | B | Brownish black (7.5 YR 3/2), clay loam. |

*A024* 16-05-95
location: 366650 E / 299775 N
Slope on site 2%, surrounding area up to "5%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 25 | A | Brownish black (7.5 YR 3/2), silty clay: |
| 25 - 45 | B | Dark reddish brown (5 YR 3/6) clay: |
| 45 - 50⁺ | BC | Bright reddish brown (5 YR 5/6), silty clay/clay. |

*A025* 16-05-95
location: 366725 E / 298200 N
Slope on site 3%, and surrounding area up to 5%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 10 | AB | Brownish gray (5 YR 4/1), silty clay: |
| 10 - 25 | B | Brownish gray (7.5 YR 4/1), silty clay loam: |
| 25 - 30⁺ | BC | Brownish gray (7.5 YR 5/1), silty clay loam. |

*A026* 16-05-95
location: 367025 E / 298175 N
Slope on site 3%, and surrounding area up to 5%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 25 | B | Brownish black (10 YR 3/2), silty clay loam: |
| 25 - 35 | BC | Brown (7.5 YR 4/3), clay loam: |
| 35 - 40⁺ | R | Saprolitic ignimbrite. |

*A027* 16-05-95
location: 367275 E / 298200 N
Slope on site 5%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 10⁺ | AB | Black (10 YR 2/2), clay. |

*A028* 17-05-95
location: 368375 E / 299975 N
Slope on site 1%, up to 3% in surrounding area.
Pasture with some small trees and many bush.

| | | |
|---|---|---|
| 0 - 15 | AB | Brownish black (10 YR 3/2), silty"clay loam: |
| 15 - 25⁺ | B | Grayish brown (7.5 YR 4/2), clay/silty clay. |

*A029* 17-05-95
location: 368100 E / 299800 N
Slope on site 1%, up to 3% in surrounding area.
Pasture with some small trees and many bush.

| | | |
|---|---|---|
| 0 - 15 | AB | Brownish black (10 YR 3/2), silty clay loam: |
| 15 - 25⁺ | B | Grayish brown (7.5 YR 4/2), silty clay. |

*A030* 17-05-95
location: 367850 E / 299475 N
Slope on site 1%, up to 3% in surrounding area.
Pasture with some small trees and many bush.

| | | |
|---|---|---|
| 0 - 25 | AB | Brownish black (10 YR 3/2), silty clay loam: |
| 25 - 35⁺ | B | Grayish yellow brown (10 YR 5/2), silty clay. |

*A031* 17-05-95
location: 367425 E / 299250 N
Slope on site and surrounding area 1%.
Pasture with some bush and few big and small trees.

| | | |
|---|---|---|
| 0 - 15 | AB | Black (10 YR 2/2), silty clay: |
| 15 - 30⁺ | B | Grayish yellow brown (10 YR 4/2), silty clay. |

*A032* 17-05-95
location: 367175 E / 299725 N
Slope on site and surrounding area 1%.
Pasture with few bush and few small trees.

| | | |
|---|---|---|
| 0 - 20⁺ | B | Brownish black (10 YR 3/1), silty clay |

## A033
17-05-95

location: 366825 E / 299425 N
Slope on site 1%.
Pasture.

| | | |
|---|---|---|
| 0 - 30$^+$ | B | Brownish black (10 YR 3/1), silty clay. |

## V004
17-05-95

About 15 % of the site around A033 (location 366825 E / 299425 N) shows flat ignimbritic rock outcrops.

## A034
18-05-95

location: 362700 E / 300400 N
On the foot of a steep, about 8 meter high hillside. The site can be seen when looking from the buildings in the direction of the volcano Rincon de la Vieja.
Slope on site 80%.
Pasture with many small bush.

| | | |
|---|---|---|
| 0 - 20 | AB | Brownish black (5 YR 2/1), clay: |
| 20 - 30$^+$ | BC | mixture of:<br>- 60% brownish black (7.5 YR 3/2), clay/silty clay; few fine irregular residual rockfragments,<br>- 40% orange (7.5 YR 6/8), sandy loam.<br>Boundary between these two components seems rather sharp. |

## A035
18-05-95

location: 362450 E / 300475 N
Slope on site 5%, up to 80% in surrounding area.
Pasture with many small bush.

| | | |
|---|---|---|
| 0 - 25 | Ah | Brownish black (7.5 YR 3/1), clay: |
| 25 - 40 | B | Grayish yellow brown (10 YR 4/2), clay: |
| 40 - 60$^+$ | BC | Brownish gray (10 YR 6/1), clay (more clay than horizon above). |

## A036
18-05-95

location: 364275 E / 300450 N
Slope on site 5%.
Pasture with many small bush.

| | | |
|---|---|---|
| 0 - 20$^+$ | | Brownish black (7.5 YR 3/1), clay. |

## V005
19-05-95

Arround location 363500 E / 300500 N is situated about one hectare of vertisol with many flat surface outcrops of ignimbritic rock.

## A037
19-05-95

location: 363775 E / 300050 N
Slope on site 2%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 25 | AB | Brownish black (10 YR 3/2), silty clay: |
| 25 - 40$^+$ | BC | Dull yellowish brown (10 YR 5/4), clay. |

## A038
19-05-95

location: 363900 E / 299975 N
Slope on site 2%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/3), silty loam: |
| 10 - 30 | B | Brown (7.5 YR 4/4), silty loam: |
| 30 - 50$^+$ | BC | Bright brown (7.5 YR 5/6),sandy loam. |

## A039
19-05-95

location: 364400 E / 300650 N
Slope on site 2%, surrounding area 4%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/3), silty loam: |
| 10 - 25 | B1 | Brown (7.5 YR 4/4), silty loam: |
| 25 - 50 | B2 | Brown (10 YR 4/6), loam: |
| 50 - 80$^+$ | BC | Bright brown (7.5 YR 5/6),sandy loam. |

## A040
19-05-95

location: 364100 E / 300650 N
Slope on site 10%, lowering in direction of little river.
Pasture with now and then bush.

| | | |
|---|---|---|
| 0 - 20 | AB | Brownish black (10 YR 2/2), clay: |
| 20 - 30$^+$ | B | Grayish yellow brown (10 YR 4/2), clay. |

## V006
19-05-95

About 10 meters NW from A040 (location 364100 E / 300650 N) a small area with vertisol is situated.

## A041
19-05-95

location: 364050 E / 300250 N
Slope on site 5%, lowering in direction of road.
Pasture with up to 15% bush

| | | |
|---|---|---|
| 0 - 15 | AB | Brownish black (10 YR 2/2), clay: |
| 15 - 20$^+$ | B | Grayish yellow brown (10 YR 4/2), clay. |

## A042
23-05-95

location: 361400 E / 299350 N
Slope on site 5%, surrounding area up to 10%.
Dry-forest with many small trees and bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Dark brown (7.5 YR 3/3), silty clay: |
| 15 - 40$^+$ | B | Dark reddish brown (2.5 YR 3/3), clay. |

## A043
23-05-95

location: 361425 E / 299100 N
Slope on site 1%.
Pasture with some big trees and some bush.

| | | |
|---|---|---|
| 0 - 25 | AB | Dark brown (7.5 YR 3/1), silty clay: |
| 25$^+$ | R | Saprolitic ignimbrite. |

## A044
14-06-95

location: 360100 E / 305950 N
Boring point 5"meters out of fence.
Slope at side 1%, up to 25% in dirgction of pasture.
Dry-forest with trees and bush, next to pasture.

| | | |
|---|---|---|
| 2 - 30 | Ah | Brownish black (7.5 YR 3/2); silty loam: |
| 30 - 40 | Ah2 | Brown (7.5 YR 4/3); silty clay loam. |
| 40 - 50 | B | Brown (10 YR 4/4); silty clay loam; moderate fine pumish fragments: |
| 50 - 90 | 2B | Brown (7.5 YR 4/6); silty clay: |
| 90$^+$ | BC | Grayish yellow brown (10 YR 5/2) with few red spots; manganese nodules from 0 - 3 mm. |

Upper three horizons are probably formed out of ash while the lower horizons are formed out of ignimbrite.

## A045
13-06-95

location: 365950 E / 300650 N
Slope on site 0%, surrounding area 2%.
Pasture with many small trees.

| | | |
|---|---|---|
| 0 - 20 | Ah | Black (10 YR 2/1), clay: |
| 20 - 30 | BC1 | 60% bright yellowish brown (10 YR 6/8) and 40% brownish gray (10 YR 5/1), clay: |
| 30 - 50+ | BC2 | 70% brownish gray (10 YR 5/1) and 30% bright yellowish brown (10 YR 6/8), clay. |

## A046
13-06-95

location: 366125 E / 301325 N
Slope on site 0%, surrounding area 2%.
Dry-forest with small trees

| | | |
|---|---|---|
| 0 - 40 | Ah | Brownish black (10 YR 2/2), clay loam: |
| 40 -"90+ | B | Bright brown (7.5 YR 5/8) with common fine dull yellowish brown (10 YR 5/4) mottling, clay; common small and medium residual rock fragments. |

## A047
27-06-95

location: 367925 E / 308400 N
Slope on site 1%, surrounding area 5%.
Pasture with some small trees and many bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Dark brown (7.5 YR 3/3), clay loam; many fine iron conretions at boundary with: |
| 15 - 90 | B | Yellowish gray (2.5 Y 4/1), clay: |
| 90 - 91 | B2 | Light gray (5 YR 8/1), sandy clay: |
| 91$^+$ | R | Saprolitic ignimbrite. |

### *A048* 27-06-95
location: 367525 E / 308300 N
Slop on site 2%, surrounding area 10%.
Pasture with some small trees and many bush.

| | | |
|---|---|---|
| 0 - 30 | Ah | Dark brown (7.5 YR 3/3), clay loam: |
| 30 - 90 | B | Light gray (5 YR 8/1), sanf: |
| 90⁺ | R | Saprolitic ignimbrite. |

### *A049* 27-06-95
location: 367550 E / 308050 N
Slop on site 2%, surrounding area 10%.
Pasture with some small trees and many bush.

| | | |
|---|---|---|
| 0 - 25 | Ah | Dark brown (7.5 YR 3/3), clay loam: |
| 25 - 80 | B | Light gray (5 YR 8/1), sand: |
| 80⁺ | R | Saprolitic ignimbrite. |

### *A050* 27-06-95
location: 367200 E / 308125 N
Just after an old concrete floor remnant.
Slope on site 0%, surrounding area 10%.
Pasture with some small bush.

| | | |
|---|---|---|
| 0 - 8 | Ah | Dark brown (10 YR 3/4), clay loam: |
| 8⁺ | R | Saprolitic ignimbrite. |

### *A051* 27-06-95
location: 367175 E / 308000 N
Just after an old concrete floor remnant.
Slope on site 0%, surrounding area 10%.
Pasture with some small bush.

| | | |
|---|---|---|
| 0 - 2 | Ah | Dark brown (10 YR 3/4), clay loam: |
| 2⁺ | R | Saprolitic ignimbrite. |

### *V007* 27-06-95
Arround points A050 (location 367200 E / 308125 N) and A051 (location 367175 E / 308000 N) many flat ignimbritic rock outcrops and thin soils. About 200 meters SW from prementioned points, large deep-red ignimbrite outcrops up to 5 meters in height arise.

### *A052* 27-06-95
location: 365975 E / 307650 N
Slope on site 2%.
Pasture.

| | | |
|---|---|---|
| 0 - 35 | Ah | Dark brown (10 YR 3/4), clay loam; many small particles which are probably pumish remnants: |
| 35 - 60 | B | Bright yellowish brown (10 YR 6/6), sandy loam: |
| 60⁺ | R | Saprolitic ignimbrite. |

### *A053* 27-06-95
location: 365925 E / 307225 N
Slope on site 2%.
Pasture.

| | | |
|---|---|---|
| 0 - 15 | Ah | Dark brown (10 YR 3/4), clay loam: |
| 15 - 40 | B | Dull yellow orange (10 YR 6/4), loamy sand; many coarse residual pumish particles: |
| 40⁺ | 2B | Brownish black (10 YR 2/2), clay. |

The lowest horizon is probably a burried vertisol.

### *A054* 27-06-95
location: 365475 E / 306125 N
Slope on site 2%.
Pasture.

| | | |
|---|---|---|
| 0 - 15 | Ah | Dark brown (10 YR 3/4), clay loam: |
| 15 - 55 | B | Dull yellow orange (10 YR 6/4), loamy sand; common coarse residual pumish particles: |
| 55⁺ | R | Saprolitic ignimbrite. |

### *A055* 27-06-95
location: 362875 E / 307300 N
Slope on site 0%, surrounding area up to 3%.
Pasture.

| | | |
|---|---|---|
| 0 - 35 | Ah | Brownish black (10 YR 2/2), loam; many fine ash particles: |
| 35 - 50 | AB | Brownish black (10 YR 3/2), loam; many fine ash particles: |
| 50 - 60 | Bw | Dark brown (7.5 YR 3/3), clay loam: |
| 60 - 70 | 2Bw | Brown (7.5 YR 4/3), clay loam (more loamy than horizon above): |
| 70 - 80⁺ | 2BC | 70% brown (7.5 YR 4/3) and 30% grayish brown (7.5 YR 5/2), clay loam. |

### *A056* 27-06-95
location: 362825 E / 303450 N
Slope on site 1%, surrounding area 10%
Dry-forest, mainly small trees.

| | | |
|---|---|---|
| 0 - 30 | Ah | Black (10 YR 2/1), loam: |
| 30 - 80 | AB | Brownish black (10 YR 3/1), clay loam: |
| 80 - 100 | Bw | Brownish gray (10 YR 4/1), clay loam: |
| 100 -120⁺ | 2Bw | Grayish yellow brown (10 YR 4/2), sandy clay loam. |

The lowest horizon is probably of alluvial origin.

### *A057* 28-06-95
location: 366300 E / 300525 N
Plateau with slope on site 2%.
Pasture with some small trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/3), sandy loam: |
| 10⁺ | R | Saprolitic ignimbrite |

### *V008* 28-06-95
Arround point A057 (location 366300 E / 300525 N) rock outcrop up to 20%. Soildepth in this area varies between 0 to more than 40 cm. About 50% of the area contains soils of less than 10 cm deep.

### *A058* 28-06-95
location: 366625 E / 300400 N
Slope on site 0%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 25⁺ | Ah | Brownish black (10 YR 2/2), clay. |

Vertisolic properties like cracks visible.

### *A059* 28-06-95
location: 366950 E / 300175 N
Slope on site 4%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 25 | Ah | Brownish black (10 YR 2/2), clay loam: |
| 25 - 50⁺ | Bwg | Dull yellowish brown (10 YR 5/3), clay; few very fine to medium iron and manganese nodules. |

### *A060* 28-06-95
location: 367075 E / 300200 N
Slope 4%; against the top of a slope with about vive meter heigth difference with point A059 (location 366950 E / 300175 N).
Pasture with many small trees and bush.

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (10 YR 2/2), clay loam: |
| 30 - 60 | Bw | Brown (7.5 YR 4/3), clay; many fine iron concretion nodules: |
| 60 - 110 | Bwg | Dull yellowish brown (10 YR 5/3) with 30% yellowish brown (10 YR 5/8) iron mottles, clay loam; few fine iron and manganese nodules: |
| 110⁺ | R | Saprolitic ignimbrite. |

### *A061* 28-06-95
location: 367725 E / 300350 N
Slope on site 1%.
Pasture with some small trees.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 15 - 25 | Bw | Grayish brown (7.5 YR 4/2), clay: |
| 25 - 45⁺ | Bwg | Dull yellow orange (10 YR 6/4), clay; few fine and medium iron and manganese nodules. |

### *A062* 28-06-95
location: 367550 E / 300225 N
Slope on site 1%.
pasture with some small trees.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 15 - 25 | Bw | Grayish brown (7.5 YR 4/2), clay: |
| 25 - 55⁺ | Bwg | Dull yellow orange (10 YR 6/4), clay; few fine and medium iron and manganese nodules. |

### *A063* 28-06-95
location: 367575 E / 300500 N
Slope on site 3%.
dry-forest of small trees and bush

| | | |
|---|---|---|
| 0 - 35 | Ah | Brownish black (7.5 2/2), sandy clay loam: |
| 35 - 45 | Bw | Brownish black (7.5 YR 3/2), clay: |

e with a few small trees and bush.

### *A064*
location: 368275 E / 300450 N

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 15 - 20 | Bw | Grayish brown (7.5 YR 4/2), clay: |
| 20 - 40⁺ | Bwg | Dull yellow orange (10 YR 6/4), clay. |

### *V009* 28-06-95
Arround points A064 (location 368275 E / 300450 N) and A065 (location 368575 E / 300350 N) many, 15 - 20%, loose boulders and nearly flat rock outcrops at the surface.

### *A065* 28-06-95
location: 368575 E / 300350 N
Slope on site 0%.
Pasture with a few small trees.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 2/2), clay. |

Vertisolic properties like cracks visible.

### *A066* 28-06-95
location: 368775 E / 300200 N
Slope on site 1%.
Pasture with few small trees and bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 15 - 20 | Bw | Grayish brown (7.5 YR 4/2), clay: |
| 20 - 40⁺ | Bwg | Dull yellow orange (10 YR 6/4), clay. |

### *V009* 28-06-95
Arround point A066 (location 368775 E / 300200 N), A067 (location 368625 E / 300650 N), A068 (location 368300 E / 300875) and A069 (location 368425 E / 301025 N) many, 30 - 50%, loose boulders and nearly flat rock outcrops at the surface.

### *A067* 28-06-95
location: 368625 E / 300650 N
Slope on site 0%.
Pasture with few small trees and bush.

| | | |
|---|---|---|
| 0 - 40⁺ | Ah | Black (10 YR 2/1), clay. |

Vertisolic properties like cracks visible.

### *A068* 28-06-95
location: 368300 E / 300875 N
Slope on site 3%.
Pasture with trees and bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 10 - 15 | Bw | Grayish brown (7.5 YR 4/2), clay: |
| 15 - 40⁺ | Bwg | Dull yellow orange (10 YR 6/4), clay. |

### *A069* 28-06-95
location: 368425 E / 301025 N
Slope on site 0%.
Pasture with few trees.

| | | |
|---|---|---|
| 0 - 25⁺ | Ah | Brownish black (10 YR 2/2), clay. |

Vertisolic properties like cracks visible.

### *A070* 28-06-95
location: 368625 E / 301250 N
Slope on site 0%.
Pasture with few trees.

| | | |
|---|---|---|
| 0 - 20⁺ | Ah | Brownish black (10 YR 2/2), clay. |

Vertisolic properties like cracks visible.

### *A071* 28-06-95
location: 368325 E / 301375 N
Slope on site 0%.
Pasture with few trees.

| | | |
|---|---|---|
| 0 - 30⁺ | Ah | Brownish black (10 YR"2/2), clay. |

Vertisolic properties like cracks visible.

### *V010* 28-06-95
From point A071 (location 368325 E / 301375 N) to the river Tempisque, soil types vary within reddish sandy soils to the black clay-rich vertisols.
At some places in this area the soils seem to be extremely sandy. This might be the result of accumulation due to erosion, or as riverdeposition. Effidence for one of the two explanations (or another) is not found.

### *A072* 28-06-95
location: 368900 E / 301750 N
Slope on site 1%, surrounding area up to 4%.
Dry-forest mainly with small trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Dark reddish brown (5 YR 3/3), sandy clay loam: |
| 15 - 45⁺ | Bw | Brownish black (10 YR 3/1), clay. |

### *A073* 28-06-95
location: 361275 E / 300000 N
Slope on site 0%, surrounding area 5%.
Tree-plantation and pasture.

| | | |
|---|---|---|
| 0 - 30 | Ah | Very dark brown (7.5 YR 2/3), clay loam; few fine iron mottles; few fine residual rock fragments: |
| 30 - 70⁺ | Bg | Dull yellowish brown (10 YR 5/3), clay; 15% yellowish brown (10 YR 5/8); few fine residual rock fragments. |

### *A074* 28-06-95
location: 361050 E / 300150 N
Slope on site 0%, surrounding area 5%.
Tree-plantation and pasture.

| | | |
|---|---|---|
| 0 - 15 | Ah | Dark brown (7.5 YR 3/4), clay loam; few fine manganese nodules: |
| 15 - 25 | Bw | Brown (7.5 YR 4/6), clay; abundant fine and coarse iron and manganese nodules: |
| 25 - 50⁺ | Bwg | Bright yellowish brown (10 YR 6/6) and 15% dull yellowish brown (10 YR 5/3), clay; few fine residual rock fragments. |

### *A075* 28-06-95
location: 361025 E / 299875 N
Slope on site 0%, surrounding area 5%.
Tree-planatation and pasture.

| | | |
|---|---|---|
| 0 - 30 | Ah | Very dark brown (7.5 YR 2/3), sandy clay loam; few coarse residual rock fragments: |
| 30 - 60 | Bw | Dark reddish brown (5 YR 3/3), clay: |
| 60 - 70⁺ | Bwg | Bright reddish brown (5 YR 5/6), clay; few coarse iron mottles, orange (7.5 YR 6/8); abundant fine and coarse manganese nodules; few coarse residual rock fragments. |

### *V011* 28-06-95
In combination with the more reddish and coarser structured soils, described with A073 (location 361275 E / 300000 N), A074 (location 361050 E / 300150 N) and A075 (location 361025 E / 299875 N), in this area also some vertisols occur. The soil types change within several meters from one into the other.

### *V012* 29-06-95
location: 366900 E / 301050 N
Slope on site 0%.
Pasture with some small trees.

Vertisol.

### *A076* 29-06-95
location: 366775 E / 301075 N
Slope on site 2%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10YR 2/2) with few faint reddish mottles, clay loam/silty clay loam: |
| 20 - 30 | BA | Grayish yellow brown (10 YR 4/2) with few faint reddish mottles, clay loam: |
| 30 - 60⁺ | BCg | Brownish gray (10 YR 6/1) with distinct yellowish brown mottles (10 YR 5/6), clay; common weathered rock fragments (5-20 mm); few fine iron and manganese nodules. |

### *A077* 29-06-95
location: 366950 E / 301225 N
Slope on site 2%, surrounding area 5%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/3), sandy loam: |
| 15 - 30 | Bw | Orange (7.5 YR 6/6), loamy sand; few very fine iron and manganese nodules: |
| 30⁺ | R | Saprolitic ignimbrite. |

*A078* 29-06-95
location: 367600 E / 301450 N
Slope on site 1%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 2/3), sandy loam: |
| 20 - 25 | Bw | Brown (10 YR 4/4), sandy loam: |
| 25 - 40 | Bwg | Brown (10 YR 4/4), loam; few coarse residual rock fragments; few fine iron mottles, bright brown (7.5 YR 5/8); few very fine manganese nodules; grayish spots: |
| 40+ | R | Saprolitic ignimbrite. |

*V013* 29-06-95
location: 366875 E / 301375 N
Slope on site 0%.
Pasture with some small trees.

Vertisol with at surface dark gray (N 3/0) clay.

*A079* 29-06-95
location: 367550 E / 301575 N
Close to side of plateay, lowering in north-eastern direction.
Slope on site 2%, surrounding area up to 10%.
Pasture with some groups of small trees and bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/2), clay loam: |
| 15 - 25 | ABwg | Grayish brown (7.5 YR 4/2), sandy clay; many fine iron mottles; abundant fine manganese nodules: |
| 25 - 50 | Bwg | 60% grayish yellow brown (10 YR 5/2) and 40% bright brown (7.5 YR 5/8), sandy clay; few fine manganese nodules; few coarse residual rock fragments: |
| 50 - 60+ | BCwg | 50% dull yellow orange (10 YR 6/4) and 50% brownish gray (10 YR 6/1), sandy clay; many coarse residual rock fragments; few fine and coarse manganese nodules. |

*A080* 29-06-95
location: 367000 E / 301100 N
Slope on site 1%.
Relative young forest with very small trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Black (10 YR 2/1), clay; very humeous |
| 10 - 30+ | Bw | Brownish gray (10 YR 4/1), clay. |

This soil might have been a vertisol, somewhat changed by an improved hydrology.

*V014* 29-06-95
Between the points A078 (location 367600 E / 301450 N), A079 (location 367550 E / 301575 N) and A080 (location 367000 E / 301100 N) are ignimbritic rock outcrops and loose boulders visible (about 15% of the surface area). They seem to be mostly situated in the area around the 80 meter lines of the topographical map.

*V015* 29-06-95
location: 367700 E / 301875 N
Almost the entire area around these location and within the surrounding heightlines of the topographical map exists of vertisol. Also the area north and north-east to the sides of the Tempisque river mainly exists of vertisol.

*A081* 29-06-95
location: 368525 E / 301925 N
Slope on site 1%, surrounding area up to 3%.
Pasture with small trees and bush.

| | | |
|---|---|---|
| 0 -20 | Ah | Brownish black (7.5 YR 2/2), sandy loam: |
| 20 - 35 | Bw | Dark brown (7.5 YR 3/3), sandy loam (less silt than horizon above): |
| 35+ | R | Saprolitic ignimbrite. |

*A082* 29-06-95
location: 366025 E / 300250 N
Slope on site 1%, surrounding area up to 5%.
Dry-forest with small trees and bush.

| | | |
|---|---|---|
| 0 - 35 | Ah | Brownish black (7.5 YR 2/2), sandy clay loam: |
| 35 - 50 | Bw | 70% dull brown (7.5 YR 5/3) and 30% bright brown (7.5 YR 5/8) (due to iron oxidation), sandy clay: |
| 50 - 90+ | Bwg | 60% brownish gray (7.5 YR 6/1) with 40% orange (7.5 YR 6/8) iron mottles, sandy clay; distict fine and coarse manganese nodules; distinct coarse residual rock fragments. |

*A083* 30-06-95
location: 363975 E / 299200 N
Slope on site 5%.
Experimental plantation area for reforestation; small trees and pasture.

| | | |
|---|---|---|
| 0 - 15 | Ah | Very dark brown (7.5 YR 2/3), clay loam: |
| 15 - 25 | B | Dark reddish brown (5 YR 3/3), clay loam (more clay than horizon above); many coarse manganese nodules: |
| 25 - 60+ | Bwg | Bright brown (7.5 YR 5/8), clay loam; few manganese nodules up to 5mm. |

*A084* 30-06-95
location: 364275 E / 299175 N
Minipit to 40 cm, continued with boring.
Slope on site 3%.
Experimental plantation area for reforestation; small trees and pasture.

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (10 YR 2/2), sandy clay; very friable; very weak fine angular blocky; common very fine pores; many very fine roots; clear smooth boundary to: |
| 30 - 50 | B | Dark brown (7.5 YR 3/3), sandy loam; very friable; weak fine angular blocky; many very fine pores; many very fine roots: |
| 50 - 80+ | Bwg | Dull reddish brown (5 YR 4/4) with common fine iron and manganese mottles, clay loam; many very fine residual rock fragments. |

*A085* 30-06-95
location: 364575 E / 299175 N
Slope on site 4%.
Experimental plantation area for reforestation; small trees and pasture.

| | | |
|---|---|---|
| 0 - 20 | Ah | Very dark brown (7.5 YR 2/3), clay loam. |
| 20 - 27 | B | Dark reddish brown (5 YR 3/3), clay loam (more clay than horizon above); many coarse manganese nodules. |
| 27 - 40+ | Bwg | Bright brown (7.5 YR 5/8), clay loam; few manganese nodules up to 5mm. |

*A086* 30-06-95
location: 364550 E / 299475 N
Slope on site 2%.
Experimental plantation area for reforestation; small trees and pasture.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (7.5 YR 2/2), clay loam: |
| 20 - 35 | Bwg | 70% brownish black (10 YR 3/2) with 30% brown (7.5 YR 4/3) iron mottling, clay loam; common fine and coarse manganese nodules: |
| 35 - 50+ | Bwg2 | 70% dull yellowish orange (10 YR 6/3) with 30% orange (7.5 YR 6/8) iron mottling, clay. |

*V016* 30-06-95
location: 298600 E / 365700 N
The area (about 100 ha.) around these location exists of about: 45% flat ignimbritic rock outcrop; 10% thin soils (up to 10 cm) with brownish black (10 YR 2/2) color; 10% soils as described with profilepit Horizontes 6; 35% vertisol with dark gray (N 3/0) or black (10 YR 2/1) colors.

*A087* 30-06-95
location: 365025 E / 299575 N
Slope on site 0%.
Pasture.

| | | |
|---|---|---|
| 0 - 20+ | Ah | Black (10 YR 2/1), clay. |

Vertisol.

*A088* 30-06-95
location: 364750 E / 299850 N
Slope on site 0%.
Pasture.

| | | |
|---|---|---|
| 0 - 10+ | Ah | Brownish gray (10 YR 5/1), clay. |

Vertisol.

*V017* 30-06-95
Around the points A087 (location 365025 E / 299575 N) and A088 (location 364750 E / 299850 N) up to 40% flat ignimbritic rock at the surface, in combination with large boulders of the same material. Around these rocks are thin (up to 10 cm) vertisols.

### *A089* 30-06-95

location: 364500 E / 300025 N
Higher part of the parcel.
Slope on site 1%, surrounding area 3%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/3), sandy clay loam: |
| 10 - 20 | Bwg | Grayish yellowish brown (10 YR 5/2), sandy clay; 40% bright yellowish brown (10 YR 6/8) iron mottles; few fine and coarse manganese nodules: |
| 20+ | R | Saprolitic ignimbrite. |

### *A090* 30-06-95

location: 364325 E / 299925 N
Slope on site 2%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 2/2) when moist, clay loam: |
| 20 - 30 | B | Dark reddish brown (5 YR 3/3) when moist, clay loam (more clay than horizon above); few fine and coarse angular gravel and stones; at transmission with Bwg a thin band of coarse iron concretions and grayish mottles: |
| 30 - 50 | Bwg | Yellowish brown (10 YR 5/8) when moist, with 15% distinct fine bright brown (7.5 YR 5/8) mottles, clay loam; few manganese nodules up to 5mm; abundant fine and coarse iron and manganese nodules: |
| 50+ | R | Saprolitic ignimbrite. |

### *A091* 30-06-95

location: 364275 E / 299575 N
Slope on site 1%.
Experimental plantation area for reforestation; small trees and pasture.

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 30 - 70 | Bw | Orange (7.5 YR 6/8), sandy loam: |
| 70 - 80 | Bwg1 | Orange (7.5 YR 6/8), sandy clay loam; many coarse manganese nodules: |
| 80 - 100+ | Bwg2 | Orange (7.5 YR 6/8), clay loam; many fine manganese nodules. |

### *A092* 01-07-95

location: 362550 E / 304450 N
Slope on site 30%.
Small trees and bush.

| | | |
|---|---|---|
| 0 - 10 | Bw | Brown (10 YR 4/4), sandy loam; this horizon seems to contain small (up to 1 cm) pockets of Ah like material with color (10 YR 3/2): |
| 10 - 30 | BC | Bright brown (7.5 YR 5/6), loamy sand; few fine manganese nodules: |
| 30 - 50+ | R | Bright brown (7.5 YR 5/6), sandy rock with very loose structure. |

### *A093* 01-07-95

location: 362275 E / 304700 N
On top of the hill.
Slope on site 1%, surrounding area up to 30%.
Pasture with small trees and bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish gray (10 YR 4/1), clay: |
| 10 - 20+ | BA | Black (10 YR 2/1), clay. |

### *A094* 01-07-95

location: 361800 E / 305150 N
Slope on site 1%, surrounding area up to 30%.
Pasture with some small trees.

| | | |
|---|---|---|
| 0 - 25+ | | Dark gray (N 3/0), clay. |

### *V018* 01-07-95

On both vertisols described by points A093 (location 362275 E / 304700 N) and A094 (location 361800 E / 305150 N) are laying boulders as described with profilepit Horizontes 5. These vertisols are situated on the same ridge, in line wiht Horizontes 5.

### *A095* 01-07-95

location: 361675 E 306550 N
Slope on site 3%.
Pasture with some small trees.

| | | |
|---|---|---|
| 0 - 10 | AB | Dark brown (10 YR 3/4), loamy sand: |
| 10+ | R | Saprolitic ignimbrite. |

### *A096* 01-07-95

location: 361425 E / 307100 N
Slope on site 3%.
Pasture.

| | | |
|---|---|---|
| 0 - 35 | Ah | Brownish black (7.5 YR 3/2), loamy sand: |
| 35 - 60 | AB | Brownish black (10 YR 3/2), sandy loam; many fine ash particles: |
| 60 - 70 | B1 | Brownish black (10 YR 3/2), sandy loam (more clay than horizon above); many fine ash particles: |
| 70 - 80 | B2 | Brown (7.5 YR 4/4), loamy sand; few fine ash particles. |
| 80+ | R | Saprolitic ignimbrite. |

### *A097* 01-07-95

location: 361225 E / 307575 N
Slope on site 3% (hilltop).
Pasture.

| | | |
|---|---|---|
| 0 - 20 | AB | Dark brown (10 YR 3/4), loamy sand: |
| 20+ | R | Saprolitic ignimbrite. |

### *A098* 01-07-95

location: 361750 E / 307425 N
Slope on site 3%.
Pasture, underneath some small trees.

| | | |
|---|---|---|
| 0 - 40 | Ah | Brownish black (7.5 YR 3/2), loamy sand: |
| 40 - 65 | AB | Brownish black (10 YR 3/2), sandy loam; many fine ash particles: |
| 65 - 80 | B | Brown (7.5 YR 4/4), loamy sand; few fine ash particles. |
| 80+ | R | Saprolitkc ignimbrite. |

### *A099* 01-07-95

location: 362200 E / 307200 N
Slope on site 3%.
Pasture.

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (7.5 YR 3/2), loamy sand: |
| 30 - 45 | AB | Brownish black (10 YR 3/2), sandy loam; many fine ash particles: |
| 45 - 80 | B | Brown (7.5 YR 4/4), loamy sand; few fine ash particles: |
| 80+ | R | Saprolitic ignimbrite. |

### *A100* 01-07-95

location: 361750 E / 306925 N
Slope on site 1% (hilltop), surrounding area 5%.
Pasture.

| | | |
|---|---|---|
| 0 - 10 | BA | Dark brown (10 YR 3/3), loamy sand: |
| 10+ | R | Saprolitic ignimbrite. |

### *A101* 01-07-95

location: 362150 E / 306225 N
Slope on site 2%.
Pasture.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/3), sandy clay loam: |
| 15 - 30 | B | Brown (7.5 YR 4/4) with some brownish black (10 YR 2/3) mottling, clay loam; many fine ash particles: |
| 30 - 40 | 2BCg | 50% dull yellowish brown (10 YR 5/3) 40% dull brown (7.5 YR 4/3) 10% dull yellow orange (10 YR 7/2), clay; few fine ash particles; few coarse residual rock fragments; few coarse manganese nodules: |
| 40+ | R | Saprolitic ignimbrite. |

### *A102* 01-07-95

location: 362575 E / 306575 N
Slope on site 1%, surrounding area 5%.
Pasture with some small trees.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 2/3), sandy loam: |
| 20 - 30 | Ah2 | Brownish black (10 YR 2/3), sandy loam; many fine ash particles: |
| 30 - 60+ | B | Dark reddish brown (5 YR 3/4), clay; many fine ash particles. |

### *A103* 01-07-95

location: 362550 E / 307275 N
Slope on site 1%.
Pasture with some tree groups.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 3/2), sandy loam: |
| 20 - 40 | B | Reddish brown (5 YR 4/6), sandy clay loam: |
| 40+ | R | Saprolitic ignimbrite. |

## *A104* 01-07-95

location: 363075 E / 307575 N
Slope on site 1%.
Pasture with some trees and bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (7.5 YR 3/2), sandy loam: |
| 10 - 15 | B | Orange (7.5 YR 6/8), sandy clay loam; many fine ash particles: |
| 15⁺ | R | Saprolitic ignimbrite. |

## *V019* 01-07-95

location: 364400 E / 307675 N
Slope on site 2%.

Up to 60% ignimbritic rock at the surface on the site around the location.

## *A105* 01-07-95

location: 364575 E / 307675 N
Slope on site 0%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 15⁺ | Ah | Black (10 YR 2/1), clay. |

## *V020* 01-07-95

In the area around point A105 (location 364575 E / 307675 N) many changes between vertic and more coarser textured reddish soil types.

## *A106* 01-07-95

location: 365125 E/ 307900 N
Slope on site 0%, surrounding area up to 5%.
Pasture with some small trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/3), sandy loam: |
| 10 - 20 | Bw | Brown (7.5 YR 4/4), clay loam; many fine ash particles: |
| 20 - 40 | Bwg | Bright brown (7.5 YR 5/6) with some fine and coarse orange (7.5 YR 6/8) iron mottling, clay loam; many fine ash particles; few coarse manganese nodules: |
| 40⁺ | R | Saprolitic ignimbrite. |

## *V021* 01-07-95

location: 365250 E / 307500 N
In the direct area around these location the main soil type is vertisol.

## *A107* 02-07-95

location: 363200 E / 299850 N
Slope on site 0%.
Pasture with small trees and many bush.

| | | |
|---|---|---|
| 0 -15⁺ | Ah | Dark gray (N3/0), clay. |

Vertisol.

## *A108* 02-07-95

location: 363450 E / 299925 N
Slope on site 0%.
Pasture with small trees and many bush.

| | | |
|---|---|---|
| 0 -15⁺ | Ah | Dark gray (N3/0), clay. |

Vertisol.

## *A109* 02-07-95

location: 363625 E / 299925 N
Slope on site 0%.
Pasture with small trees and many bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (7.5 YR 2/2), clay loam: |
| 15 - 25 | Bwg | Brown (7.5 YR 4/3) with 20% brown (7.5 YR 4/6) mottles, clay; moderate fine and coarse manganese nodules: |
| 25 - 40 | Bwg2 | Dull yellow orange (10 YR 6/4) with 30% bright brown (7.5 YR 5/8) mottles, clay; moderate fine and coarse manganese nodules: |
| 40 - 50 | Bwg3 | Dull yellow orange (10 YR 7/3) with 20% bright brown (7.5 YR 5/8) mottles, clay; moderate fine and coarse iron nodules: |
| 50⁺ | R | Saprolitic ignimbrite. |

## *A110* 02-07-95

location: 363825 E / 299825 N
Slope on site 0%.
Pasture with small trees and many bush.

| | | |
|---|---|---|
| 0 -20⁺ | Ah | Black (10 YR 2/1), clay. |

Vertisol.

## *V022* 02-07-95

The soils of points A107 (location 363200 E / 299850 N), A108 (location 363450 E / 299925 N), A109 (location 363625 E / 299925 N) and A110 (location 363825 E / 299825 N) do occur as changing belts of reddish (50%) and vertic (45%) soils, and seem to have the same orientation. Around these points also some (5%) outcrops of ignimbritic rock.

## *A111* 02-07-95

location: 364825 E / 300850 N
Slope on site 2%, surrounding area up to 3%.
Pasture with some trees.

| | | |
|---|---|---|
| 0 - 35 | Ah | Brownish black (7.5 YR 2/2), clay loam: |
| 35 - 45 | Bwg1 | Brown (7.5 YR 4/3) with 5% iron mottling, clay; moderate fine and coarse manganese nodules: |
| 45 - 55 | Bwg2 | Brown (7.5 YR 4/6) with 20% bright brown (7.5 YR 5/8) iron mottles, clay; moderate fine and coarse iron nodules: |
| 55 - 60⁺ | BC | Dull yellow orange (10 YR 6/4) with 30% bright brown (7.5 YR 5/8) mottles, clay; moderate fine and coarse manganese nodules. |

## *A112* 02-07-95

location: 365075 E / 300200 N
Minipit.
Slope on site 2%, surrounding area up to 5%.
Pasture with planted seedlings.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/3), sandy loam; weak very fine subangular blocky; friable; common fine roots; few fine pores; clear wavy boundary to: |
| 10 - 30 | Ah | Brown (7.5 YR 4/4) with 20% brown (7.5 YR 4/6) mottles, sandy loam; moderate fine angular blocky; very friable; many fine roots; few fine and coarse pores; abrupt smooth boundary to: |
| 30⁺ | R | Saprolitic ignimbrite. |

## *A113* 02-07-95

location: 365675 E / 300400 N
Slope on site 5%, surrounding area up to 10%.
Pasture with planted seedlings.

| | | |
|---|---|---|
| 0 - 5 | Ah | Very dark brown (7.5 YR 2/3), sandy loam: |
| 5 - 40⁺ | B | Dark reddish brown (5 YR 3/4), sandy clay. |

## *A114* 02-07-95

location: 365625 E / 300050 N
Slope on site 1%, surrounding area 5%.
Pasture with planted seedlings.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 10 - 30 | Bw | Brownish black (7.5 YR 3/2) with few fine iron mottles, clay loam: |
| 30 - 45 | Bwg | Dull yellowish brown (10 YR 5/3) with 10% yellow orange (10 YR 7/8) iron mottles, clay loam; many coarse iron nodules: |
| 45 - 50⁺ | BCwg | Brownish gray (10 YR 6/1) with 20% yellow orange (10 YR 7/8) iron mottles, clay loam; few coarse manganes nodules. |

## *A115* 02-07-95

location: 365550 E / 301275 N
Slope on site 1%.
Pasture with some small trees.
op plekken rots aan het opp (10%)

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 2/2), sandy loam: |
| 20 - 25 | BC | 34% brownish black (10 YR 2/2) 33% ligth gray (10 YR 7/1) 33% yellow orange (10 YR 7/8), loamy sand; few fine and coarse manganese nodules: |
| 25 - 50⁺ | C | Saprolitic ignimbrite. |

## *V023* 02-07-95

Around point A115 (location 365550 E / 301275 N) some spots with outcrops (10%) of ignimbritic rock.

## *A116* 02-07-95

location: 365900 E / 301575 N
Slope on site 2%, surrounding area up to 10%.
Pasture with some groups of small trees.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/2), clay loam: |
| 15 - 40 | BC | Dark brown (7.5 YR 3/4), clay loam: |
| 40 - 50⁺ | C | Saprolitic ignimbrite. |

## *A117* 02-07-95

location: 361500 E / 299650 N
Slope on site 1%.
Pasture.

| | | |
|---|---|---|
| 0 - 30 | Ah | Black (10 YR 2/1), clay loam. |
| 30 - 40 | Bwg | Brownish gray (10 YR 4/1) with few fine iron mottles, clay: |
| 40 - 50 | BCwg | Brownish gray (5 YR 4/1) with few fine iron mottles, clay; common coarse residual rock fragments: |
| 50⁺ | R | Saprolitic ignimbrite. |

## *A118* 03-07-95

location: 364575 E / 300900 N
slope on site 5%.
Pasture with many bush and few small trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (7.5 YR 3/2), sandy loam: |
| 10 - 30⁺ | BCg | Brown (7.5 YR 4/3) with some iron mottling, loamy sand; many coarse manganese nodules; many coarse residual rock fragments. |

## *A119* 03-07-95

location: 364900 E / 301225 N
Slope on site 0%, surrounding area 5%.
Pasture.

| | | |
|---|---|---|
| 0 - 10 | Ah | Black (10 YR 2/1), clay: |
| 10 - 50⁺ | BA | Dark gray (N 3/0), clay. |

Large area with vertisol, in a depression in the landschape.

## *A120* 03-07-95

location: 365175 E / 301550 N
Slope on site 2%.
Pasture.

| | | |
|---|---|---|
| 0 - 8 | Ah | Brownish black (7.5 YR 3/2), sandy clay loam. |
| 8⁺ | R | Saprolitic ignimbrite. |

## *V024* 03-07-95

Around point A120 (location 365175 E / 301550 N) a lot of ignimbritic outcrop at the surface. This rock may be a natural barrier along the vertisol of point A119 (location 364900 E / 301225 N).

## *A121* 03-07-95

location: 364350 E / 301500 N
Slope on site 2%, surrounding area up to 10% (in direction of little river).
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 5 | Ah | Brownish black (7.5 YR 3/2), clay loam. |
| 5⁺ | R | Saprolitic ignimbrite. |

## *V025* 03-07-95

Around point A121 (location 364350 E / 301500 N) the soils change within vertisols (50%) and very thin soils on ignimbritic rock (30%). The other 20% of the area is ignimbritic rock outcrop. These changes do occur on both sides of the little river.

## *A122* 03-07-95

location: 363575 E / 301575 N
Slope on site 1%.
Pasture with some trees.

| | | |
|---|---|---|
| 0 - 20 | Ah | Black (10 YR 2/1), sandy clay: |
| 20 - 40 | B | Brownish gray (10 YR 4/1), clay: |
| 40 - 50⁺ | BC | Brownish gray (10 YR 4/1), clay; many coarse residual rock fragments. |

## *A123* 03-07-95

location: 363275 E / 301350 N
Slope on site 0%.
Pasture with many bush.

| | | |
|---|---|---|
| 0 - 30⁺ | Ah | Black (10YR 2/1), clay. |

## *V026* 03-07-95

Around the points A123 (location 363275 E / 301350 N), A124 (location 363150 E / 300825 N) and A125 (location 363475 E / 300975 N) the soils change within vertisol (60%) and very thin soils on ignimbritic rock (10%). Also in this area a lot of ignimbritic rock at the surface. Partly as boulders or parts of boulders, and partly as rockoutcrop (present on site up to 80%).
In the direction of the last two mentioned points, the landscape is more hilly and the amount of trees increases.

## *A124* 03-07-95

location: 363150 E / 300825 N
Slope on site 0%.
Pasture with some bush and trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/2), clay: |
| 10 - 35⁺ | BA | Black (10 YR 2/1), clay. |

## *A125* 03-07-95

location: 363475 E / 300975 N
Slope on site 2%, surrounding area 5%.
Pasture with trees and bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Black (7.5 YR 2/1), sandy clay loam; common coarse yellow reddish particles (ash/iron ?): |
| 20 - 40 | Ah2 | Brownish black (7.5 YR 2/2), clay loam; common coarse yellow reddish particles (ash/iron ?): |
| 40 - 50⁺ | Bwg | Dark reddish brown (5 YR 3/6), clay; many coarse manganese nodules. |

## *A126* 03-07-95

location: 361700 E / 299200 N
Hilltop.
Slope on site 2%, surrounding area up to 15%
Pasture with many small trees.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (7.5 YR 2/2), sandy clay loam: |
| 15 - 30 | B | Dark reddish brown (5 YR 3/3), clay loam; few coarse residual rock fragments: |
| 30 - 40 | Bwg | Dull reddish brown (5 YR 4/3), clay loam (more clay than horizon above); few coarse residual rock fragments; common fine and coarse iron and manganese nodules: |
| 40⁺ | R | Saprolitic ignimbrite. |

## *A127* 03-07-95

location: 361600 E / 298600 N
At the bottom of a slope.
Slope on site 1%, surrounding area up to 20%.
Pasture with many small trees.

| | | |
|---|---|---|
| 0 - 25 | Ah | Very dark brown (7.5 YR 2/3), sandy loam: |
| 25 - 35 | Bw | Dark reddish brown (5 YR 3/3), clay loam; few coarse residual rock fragments: |
| 35 - 50⁺ | Bwg | Dark reddish brown (5 YR 3/4), clay loam; few fine and coarse manganese nodules. |

## *A128* 03-07-95

location: 361759 E / 297750 N
Slope on site 0%.
Pasture with now and then a small bush.

| | | |
|---|---|---|
| 0 - 5 | Ah | Black (10 YR 2/1), clay: |
| 5⁺ | R | Saprolitic ignimbrite. |

At the surface many rockfragments up to 10 cm big, as the result of mechanical treatments in this area.

## *A129* 03-07-95

location: 362250 E / 298175 N

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/2), clay: |
| 10⁺ | R | Saprolitic ignimbrite. |

## *V027* 03-07-95

Between points A128 (location 361759 E / 297750 N) and A29 (location 362250 E / 298175 N) the soil type does not change, other than in depth. Depth varies between 1 and 20 centimeters.

## *A130* 03-07-95

location: 362225 E / 298775 N
Slope on site 1%.
Pasture with few trees and some bush.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/3), sandy clay loam: |
| 10 - 20 | B | Brownish black (10 YR 3/2), clay loam: |
| 20 - 40 | Bw | 60% grayish yellow brown (10 YR 4/2) with 40% bright yellowish brown (10 YR 6/8), clay: |
| 40 - 50⁺ | Bwg | 80% dull yellow orange (10 YR 6/4) with 20% bright yellowish brown (10 YR 6/8), clay; few coarse manganese nodules. |

## A131
03-07-95

location: 362200 E / 298275 N
Slope on site 1%.
Pasture with some groups of small trees or bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (10 YR 2/3), sandy clay loam: |
| 15 - 25 | B | Brownish black (10 YR 3/2), clay loam: |
| 25 - 40 | Bw | 60% grayish yellow brown (10 YR 4/2) with 40% bright yellowish brown (10 YR 6/8), clay: |
| 40 - 50+ | Bwg | 80% dull yellow orange (10 YR 6/4) with 20% bright yellowish brown (10 YR 6/8), clay; common coarse manganese nodules. |

## A132
03-07-95

location: 362725 E / 299625 N
Slope on site 3%.
Pasture with some groups of small trees or bush.

| | | |
|---|---|---|
| 0 - 5 | Ah | Brownish black (10 YR 3/2), clay: |
| 5 - 40+ | BA | Brownish gray (10 YR 5/1), clay. |

## A133
03-07-95

location: 362625 E / 298825 N
Slope on site 1%.
Pasture.

| | | |
|---|---|---|
| 0 - 7 | Ah | Black (10 YR 2/1), clay: |
| 7 - 25+ | BA | Dark gray (N 3/0), clay. |

## V028
03-07-95

Between the points A130 (location 362225 E / 298775 N), A131 (location 362200 E / 298275 N), A132 (location 362725 E / 299625 N) and the boarder of the parcel, some small vertic areas. Also some sites with the same soiltye as described in V027.

## A134
03-07-95

location: 363075 E / 298600 N
Slope on site 1%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (7.5 YR 3/2), loamy clay. |
| 15 - 30 | Bg | Dark reddish brown (5 YR 3/4), clay; few coarse manganese nodules. |
| 30 - 45 | Bwg | Bright reddish brown (5 YR 5/8), clay; common coarse manganese nodules; few coarse residual rock fragments. |
| 45 - 50+ | C | Dull yellowish brown (10 YR 5/3), saprolotic ignimbrite. |

## V029
04-07-95

location: 363200 E / 299200 N
Around the location, in the corner of the parcel, an area with vertisol exists.

## A135
04-07-95

location: 362825 E / 303450 N
40 meters out of small river.
Slope on site 1%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (7.5 YR 2/2), sandy loam: |
| 30 - 40 | Ah2 | Brownish black (7.5 YR 2/2), clay loam: |
| 40 - 70 | B | Brownish black (7.5 YR 3/2), clay loam; common fine and coarse iron and manganese nodules: |
| 70 - 80+ | Bwg | 50% grayish brown (7.5 YR 4/2) and 50% bright brown (7.5 YR 5/6), clay loam; few fine manganese nodules. |

## A136
04-07-95

location: 363525 E / 304025 N
Slope on site 3%.
Dry-forrest.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (7.5 YR 3/2), loam: |
| 10 - 35 | Ah2 | Brownish black (7.5 YR 2/2), clay loam: |
| 35 - 60+ | Bwg | Brownish black (7.5 YR 3/2), clay loam; few fine manganese nodules. |

## A137
04-07-95

location: 364350 E / 306050 N
Slope on site 1%, surrounding area up to 25%.
Pasture with some small trees and bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (7.5 YR 3/1), clay; very humusrich: |
| 20 - 40+ | Bwg | Brownish black (10 YR 3/1), clay. |

## A138
04-07-95

location: 363025 E / 305750 N
Slope on site 1%, surrounding area up to 40%.
Pasture with some trees and bush.

| | | |
|---|---|---|
| 0 - 7 | Ah | Brown (7.5 YR 4/4), clay loam: |
| 7+ | R | Saprolitic ignimbrite. |

## V030
04-07-95

Between the points A137 (location 364350 E / 306050 N) and A138 (location 363025 E / 305750 N) changing sites of the thin soils like A138 and vertic soils like A137 are present.

## A139
04-07-95

location: 364100 E / 305525 N
Roadside insicion.
Slope on site 30%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 30 | Ah | Dark brown (7.5 YR 3/3), loam: |
| 30+ | R | Saprolitic ignimbrite (with sandy structure like H8). |

## V031
04-07-95

Around point A139 (location 364100 E / 305525 N) a lot of colluvial material due to the steep slopes and the easy erodable material.

## A140
04-07-95

location: 364725 E / 304425 N
Slope on site 3%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (7.5 YR 3/2), sandy clay loam: |
| 30 - 50 | Ah2 | Brownish black (7.5 YR 2/2), clay loam: |
| 50 - 80+ | Bwg | Dark brown (7.5 YR 3/4), clay loam; common coarse residual rock fragments (ash?); common coarse manganese nodules. |

## A141
04-07-95

location: 364950 E / 304550 N
Slope on site 2%.
Dry-forest

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 3/2), loam: |
| 10 - 50 | AB | Brownish black (10 YR 2/2), clay loam; common fine residual rock fragments (ash?): |
| 50 - 60+ | B | Brownish black (10 YR 2/2), sandy clay loam. |

## A142
04-07-95

location: 365200 E / 304725 N
Slope on site 1%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 2/3), sandy clay loam: |
| 20 - 45 | AB | Brownish gray (7.5 YR 4/1), clay loam; many coarse residual rock fragments (ash?): |
| 45 - 50+ | B | Brownish gray (7.5 YR 4/1), clay. |

## A143
04-07-95

location: 365400 E / 304975 N
Slope on site 1%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (7.5 YR 2/2), loam: |
| 20 - 25 | B | Grayish yellow brown (10 YR 4/2), clay loam: |
| 25 - 40+ | Bw | Brownish gray (10 YR 4/1), clay. |

## A144
04-07-95

location: 365525 E / 305275 N
Slope on site 0%.
Pasture with some trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 4/1), clay: |
| 10 - 25+ | BA | Brownish black (10 YR 3/1), clay. |

Large area of vertisol.

## A145
04-07-95

location: 365600 E / 305550 N
Slope on site 1%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 20 | Ah | Dark brown (7.5 YR 3/3), sandy clay loam. |
| 20 - 40 | B | Brownish black (7.5 YR 2/2), sandy clay loam; common coarse ash particles. |
| 40 - 65 | 2Ah | Dark brown (7.5 YR 3/3), clay loam. |
| 65 - 80 | 2B | Brownish black (7.5 YR 3/4), sandy clay loam; few coarse residual rock fragments. |
| 80+ | R | Saprolitic ignimbrite. |

## A146
04-07-95

location: 361850 E / 301825 N
Point in a depression between two hills and on a slope leading to a valley.
Slope on site 5%, surrounding area up to 35%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 25 | Ah | Brownish black (7.5 YR 3/2), sandy loam. |
| 25+ | R | Saprolitic ignimbrite. |

## A147
04-07-95

location: 361725 E / 301250 N
Slope on site 1%, surrounding area up to 40%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 40 | Ah | Dark brown (7.5 YR 3/3), sandy loam: |
| 40 - 65 | B | Dull reddish brown (5 YR 4/4), clay loam: |
| 65 - 80+ | B2 | Brown (7.5 YR 4/4) with few fine and coarse iron mottles, clay; few fine manganese nodules. |

## A148
04-07-95

location: 361900 E / 300775 N
Slope on site 0%.
Pasture with some trees.

| | | |
|---|---|---|
| 0 - 25+ | Ah | Dark gray (N 3/0), clay. |

Vertisol.

## A149
04-07-95

location: 361700 E / 300450 N
Slope on site 2%.
Pasture with few bush and trees.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (7.5 YR 2/2), clay loam: |
| 15 - 25 | B | Dark reddish brown (5 YR 3/3), clay; few fine iron and manganese nodules: |
| 25 - 50+ | Bwg | Dark reddish brown (5 YR 3/6), clay; common fine manganese nodules. |

## A150
04-07-95

location: 361475 E / 300275 N
Slope on site 2%.
Pasture with few bush and trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (7.5 YR 2/2), clay loam: |
| 10 - 30 | ABwg | Dark brown (7.5 YR 3/3), clay loam; common coarse manganese nodules: |
| 30 - 40 | Bwg | Dull reddish brown (5 YR 4/4) with few coarse orange (7.5 YR 6/8) iron mottles, clay; common coarse manganese nodules: |
| 40 - 80+ | Bwg2 | Dull brown (7.5 YR 5/4) with many orange (7.5 YR 6/8) iron mottles, clay loam; few very coarse manganese nodules. |

## V032
04-07-95

In the north-west direction (towards the small village Triumfo), after point A150 (location 361475 E / 300275 N), this area also contains sandy soils like described with 'Horizontes 8' and vertic soils. The sandy soils occur most on hills, while the vertic soils do occur in the depressions or valleys.

## A151
04-07-95

location: 362175 E / 300375 N
Slope on site 0%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Brownish black (10 YR 2/2), clay loam: |
| 20 - 35 | Bwg | Grayish yellow brown (10 YR 4/2) with few (10%) fine orange (7.5 YR 6/8) iron mottles, clay: |
| 35 - 40+ | B | Grayish yellow brown (10 YR 6/2), clay. |

## A152
04-07-95

location: 362425 E / 300125 N
Slope on site 0%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 15+ | Ah | Brownish gray (10 YR 4/1), clay. |

## V033
04-07-95

The in A152 (location 362425 E / 300125 N) described vertic soil occupies a rather big area and starts close to point A151 (location 362175 E / 300375 N) and reaches just further than the laguna present in the parcel.

## A153
04-07-95

location: 362575 E / 299850 N
Slope on site 1%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 18 | Ah | Brownish black (7.5 YR 2/2), clay loam: |
| 18+ | R | Saprolitic ignimbrite. |

## A154
05-07-95

location: 361025 E / 301250 N
Slope on site 5%, surrounding area up to 30%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (7.5 YR 3/2), sandy loam: |
| 15 - 45 | AB | Brownish black (7.5 YR 2/2), clay loam: |
| 45 - 55 | Bwg | Brownish black (7.5 YR 2/3) with few very fine and fine iron and manganese mottles, clay: |
| 55 - 70+ | Bwg2 | Dark reddish brown (5 YR 3/4) with few very fine and fine iron and manganese mottles, clay. |

## A155
05-07-95

location: 361475 E / 301725 N
Slope on site 15%, surrounding area up to 30%.
Dry-forest

| | | |
|---|---|---|
| 0 - 30 | Ah | Brownish black (7.5 YR 2/2), sandy loam; few coarse residual rock fragments: |
| 30 - 60 | B | Black (7.5 YR 2/1), clay loam: |
| 60+ | R | Saprolitic ignimbrite (sandy structure like H8). |

The upper horizon(-s) may be of colluvial origine.

## A156
05-07-95

location: 361925 E / 302050 N
Slope on site 2%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 60 | BA | Brownish black (7.5 YR 2/2), sandy loam; many fine and few coarse residual rock fragments: |
| 60 - 70 | B | Black (7.5 YR 2/1), clay loam; many fine and few coarse residual rock fragments: |
| 70 - 80+ | BC | Brownish black (7.5 YR 3/2), sandy loam; many fine and few coarse residual rock fragments. |

The upper horizon(-s) may be of colluvial origine.

## A157
05-07-95

location: 362525 E / 302700 N
Slope on site 3%.
Pasture with some bush and small trees.

| | | |
|---|---|---|
| 0 - 16 | Ah | Brownish black (10 YR 2/2), sandy clay loam: |
| 16 - 39 | B | Dark brown (7.5 YR 3/4), clay loam: |
| 39 - 95+ | BC | Brown (7.5 YR 4/4), loamy sand; few big residual rock fragments (sandstone like ignimbrite). |

## A158
05-07-95

location: 362900 E / 303000 N
Slope on site 1%.
Pasture with some bush.

| | | |
|---|---|---|
| 0 - 16 | Ah | Brownish black (7.5 YR 3/2), sandy loam: |
| 16+ | R | Sandstone like saprolitic ignimbrite. |

## V034
05-07-95

location: 363500 E / 303500 N
The area around the little river mainly exists out of deep vertic soils formed or deposited on top of sandy structured ignimbritic rock.

*A159* 05-07-95
location: 363750 E / 303175 N
Slope on site 3%, surrounding area up to 20%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 10 | Ah | Brownish black (10 YR 2/2), loamy sand: |
| 15 - 25 | Ah2 | Brownish black (7.5 YR 3/2), loamy sand; few coarse residual rock fragments (sandstone like ignimbrite): |
| 25 - 45 | BA | Dark brownish (7.5 YR 3/3), sandy loam; few coarse residual rock fragments (sandstone like ignimbrite): |
| 45 - 55 | B | Dark brown (10 YR 3/3), clay loam: |
| 55 - 70+ | B2 | Brown (7.5 YR 4/6), clay loam. |

*A160* 05-07-95
location: 363450 E / 302525 N
Slope on site 3%, surrounding area 5%.
Dry-forest.

| | | |
|---|---|---|
| 0 - 20 | Ah | Very dark brown (7.5 YR 2/3), clay loam. |
| 20 - 55 | Bwg | Dark brown (7.5 YR 3/4), clay; common coarse manganese nodules; few fine and coarse residual rock fragments: |
| 55 - 60+ | Bwg2 | Dull yellow orange (10 YR 7/2) with 40% fine iron mottles, clay. |

*A161* 05-07-95
location: 362450 E / 301850 N
Slope 1%.
Dry-forest of some bush and a few trees, at the boarders of the hill more trees.

| | | |
|---|---|---|
| 0 - 5 | Ah | Brownish black (10 YR 2/2), clay: |
| 5 - 25+ | B | Dark gray (N 3/0), clay. |

*V035* 05-07-95
The plateau around point A161 (location 362450 E / 301850 N) represents about 70% vertic soils (mainly and up to 90% towards the side of the pacific coast), about 30% variants of profiles as described with point A160 (mainly on the side of the 'Cordillera de Guanacaste'). Around the edges of the plateau about 30%, and in the middle about 10% ignimbritic boulders.
The plateau lowers slightly in the direction of the cordillera; with a slope on the top-side of 1%, up to 10% towards the cordillera.

*A162* 05-07-95
location: 364450 E / 302600 N
Slope on site 2%.
Pasture with bush.

| | | |
|---|---|---|
| 0 - 17 | Ah | Dark brown (7.5 YR 3/3), sandy loam: |
| 17+ | R | Ignimbrite. |

*V036* 05-07-95
Between the points A160 (location 363450 E / 302525 N) and A162 (location 364450 E / 302600 N) appear some sites with vertic soils, in combination with the described soil types of points A160 and A162.

*A163* 05-07-95
location: 363450 E / 301950 N
Slope on site 5%.
Pasture with few trees.

| | | |
|---|---|---|
| 0 - 25 | Ah | Brownish black (7.5 YR 2/3), clay loam: |
| 25 - 30 | Bw | Dull reddish brown (5 YR 4/4), clay loam: |
| 30 - 50+ | Bwg | Brown (7.5 YR 4/6), clay; few fine iron and manganese nodules. |

*A164* 05-07-95
location: 363000 E / 301550 N
Slope on site 2%, surrounding area up to 35%.
Pasture with bush.

| | | |
|---|---|---|
| 0 - 15 | Ah | Brownish black (7.5 YR 3/2), sandy loam: |
| 15 - 20 | B | Brownish black (7.5 YR 2/2), clay loam: |
| 20+ | R | Saprolitic ignimbrite. |

*A165* 05-07-95
location: 362450 E / 301025 N
Slope on site 5%, surrounding area up to 35%.
Pasture with bush.

| | | |
|---|---|---|
| 0 - 20 | Ah | Black (10 YR 2/1), sandy loam: |
| 20 - 40 | B | Black (10 YR 2/1), clay: |
| 40 - 60+ | R | Brownish gray (10 YR 5/1), clay. |

*V037* 05-07-95
Between the points A164 (location 363000 E / 301550 N) and A165 (location 362450 E / 301025 N) appear some sites with vertic soils, in combination with the described soil types of points A164 and A165.

*A166* 05-07-95
location: 362175 E / 300700 N
Slope on site 1%, surrounding area up to 5%.
Pasture with bush and some small trees.

| | | |
|---|---|---|
| 0 - 10 | Ah | Black (7.5 YR 2/1), clay loam: |
| 10 - 25 | B | Brownish black (10 YR 2/2), clay: |
| 25 - 40 | Bwg | Brownish gray (10 YR 5/1) with 15% yellow orange (10 YR 7/8) iron mottles, clay: |
| 40+ | R | Saprolitic ignimbrite. |

**Classification of bore- and visual points**

A100 / A166 = bore points
V001 / V037 = visual points

B = S*01*　G = S*02b*　A = S*03*　V = S*04b*　C = S*05h*　R = S*06h*　S = S*08h*　P = rock outcrops and boulders

| | | West | North |
|---|---|---|---|
| A001 | B | 362.950 | 303.800 |
| A002 | S | 365.750 | 306.600 |
| A003 | V | 363.300 | 303.550 |
| A004 | V | 360.600 | 298.225 |
| A005 | V | 360.500 | 297.800 |
| A006 | V | 360.700 | 297.950 |
| A007 | B | 361.075 | 298.650 |
| A008 | B | 36.850 | 298.700 |
| A009 | S | 361.125 | 298.000 |
| A010 | R | 366.775 | 300.075 |
| A011 | G | 366.525 | 298.600 |
| A012 | R | 361.850 | 299.775 |
| A013 | V | 361.950 | 299.850 |
| A014 | B | 362.150 | 300.150 |
| A015 | B | 362.075 | 300.150 |
| A016 | C | 361.975 | 300.175 |
| A017 | R | 361.950 | 300.150 |
| A018 | B | 365.800 | 299.050 |
| A019 | B | 365.795 | 299.050 |
| A020 | B | 365.805 | 299.050 |
| A021 | B | 365.575 | 299.500 |
| A022 | B | 366.550 | 300.075 |
| A023 | B | 366.200 | 299.750 |
| A024 | C | 366.650 | 299.775 |
| A025 | A | 366.725 | 306.200 |
| A026 | A | 367.025 | 306.175 |
| A027 | A | 367.275 | 306.200 |
| A028 | A | 367.375 | 307.975 |
| A029 | A | 367.100 | 307.800 |
| A030 | A | 367.850 | 307.475 |
| A031 | A | 367.425 | 307.250 |
| A032 | G | 367.175 | 299.725 |
| A033 | G | 366.825 | 299.425 |
| A034 | S | 362.700 | 300.400 |
| A035 | G | 362.450 | 300.475 |
| A036 | B | 364.275 | 300.450 |
| A037 | C | 363.775 | 300.050 |
| A038 | R | 363.900 | 299.975 |
| A039 | R | 364.400 | 300.650 |
| A040 | G | 364.100 | 300.650 |
| A041 | G | 364.050 | 300.250 |
| A042 | R | 361.400 | 299.350 |
| A043 | B | 361.425 | 299.100 |
| A044 | A | 360.100 | 305.950 |
| A045 | C | 365.950 | 300.650 |
| A046 | C | 366.125 | 301.325 |
| A047 | G | 367.925 | 308.400 |
| A048 | S | 367.525 | 308.300 |
| A049 | S | 367.550 | 308.050 |
| A050 | B | 367.200 | 308.125 |

| | | West | North |
|---|---|---|---|
| A051 | B | 367.175 | 308.000 |
| A052 | A | 365.975 | 307.650 |
| A053 | A | 365.925 | 307.225 |
| A054 | A | 365.475 | 306.125 |
| A055 | A | 362.875 | 307.300 |
| A056 | S | 362.825 | 303.450 |
| A057 | C | 366.300 | 300.525 |
| A058 | V | 366.625 | 300.400 |
| A059 | C | 366.950 | 300.175 |
| A060 | C | 367.075 | 300.200 |
| A061 | C | 367.725 | 300.350 |
| A062 | C | 367.550 | 300.225 |
| A063 | C | 367.575 | 300.500 |
| A064 | C | 368.275 | 300.450 |
| A065 | V | 368.575 | 300.350 |
| A066 | C | 368.775 | 300.200 |
| A067 | V | 368.625 | 300.650 |
| A068 | C | 368.300 | 300.875 |
| A069 | V | 368.425 | 301.025 |
| A070 | V | 368.625 | 301.250 |
| A071 | V | 368.325 | 301.375 |
| A072 | C | 368.900 | 301.750 |
| A073 | B | 361.275 | 300.000 |
| A074 | B | 361.050 | 300.150 |
| A075 | B | 361.025 | 299.875 |
| A076 | C | 366.775 | 301.075 |
| A077 | C | 366.950 | 301.225 |
| A078 | C | 367.600 | 301.450 |
| A079 | C | 367.550 | 301.575 |
| A080 | V | 367.000 | 301.100 |
| A081 | S | 368.525 | 301.925 |
| A082 | C | 366.025 | 300.250 |
| A083 | R | 363.975 | 299.200 |
| A084 | R | 364.275 | 299.175 |
| A085 | R | 364.575 | 299.175 |
| A086 | C | 364.550 | 299.475 |
| A087 | V | 365.025 | 299.575 |
| A088 | V | 364.750 | 299.850 |
| A089 | R | 364.500 | 300.025 |
| A090 | R | 364.325 | 299.925 |
| A091 | R | 364.275 | 299.575 |
| A092 | S | 362.550 | 304.450 |
| A093 | V | 362.275 | 304.700 |
| A094 | V | 361.800 | 305.150 |
| A095 | A | 361.675 | 306.550 |
| A096 | A | 361.425 | 307.100 |
| A097 | A | 361.225 | 307.575 |
| A098 | A | 361.750 | 307.425 |
| A099 | A | 362.200 | 307.200 |
| A100 | A | 361.750 | 306.925 |

| | | West | North |
|---|---|---|---|
| A101 | A | 362.150 | 306.225 |
| A102 | A | 362.575 | 306.575 |
| A103 | A | 362.550 | 307.275 |
| A104 | A | 363.075 | 307.575 |
| A105 | V | 364.575 | 307.675 |
| A106 | V | 365.125 | 307.900 |
| A107 | V | 363.200 | 299.850 |
| A108 | V | 363.450 | 299.925 |
| A109 | C | 363.625 | 299.925 |
| A110 | V | 363.825 | 299.825 |
| A111 | C | 364.825 | 300.850 |
| A112 | R | 365.075 | 300.200 |
| A113 | S | 365.675 | 300.400 |
| A114 | C | 365.625 | 300.050 |
| A115 | R | 365.550 | 301.275 |
| A116 | B | 365.900 | 301.575 |
| A117 | G | 361.500 | 299.650 |
| A118 | S | 364.575 | 300.900 |
| A119 | V | 364.900 | 301.225 |
| A120 | R | 365.175 | 301.550 |
| A121 | R | 364.350 | 301.500 |
| A122 | G | 363.575 | 301.575 |
| A123 | V | 363.275 | 301.350 |
| A124 | V | 363.150 | 300.825 |
| A125 | R | 363.475 | 300.975 |
| A126 | R | 361.700 | 299.200 |
| A127 | R | 361.600 | 298.600 |
| A128 | V | 361.759 | 297.750 |
| A129 | V | 362.250 | 298.175 |
| A130 | G | 362.225 | 298.775 |
| A131 | G | 362.200 | 298.275 |
| A132 | B | 362.725 | 299.625 |
| A133 | V | 362.625 | 298.825 |
| A134 | R | 363.075 | 298.600 |
| A135 | B | 362.825 | 303.450 |
| A136 | B | 363.525 | 304.025 |
| A137 | V | 364.350 | 306.050 |
| A138 | B | 363.025 | 305.750 |
| A139 | B | 364.100 | 305.525 |
| A140 | B | 364.725 | 304.425 |
| A141 | B | 364.950 | 304.550 |
| A142 | G | 365.200 | 304.725 |
| A143 | G | 365.400 | 304.975 |
| A144 | V | 365.525 | 305.275 |
| A145 | A | 365.600 | 305.550 |
| A146 | S | 361.850 | 301.825 |
| A147 | S | 361.725 | 301.250 |
| A148 | V | 361.900 | 300.775 |
| A149 | R | 361.700 | 300.450 |
| A150 | B | 361.475 | 300.275 |

| | | West | North |
|---|---|---|---|
| A151 | G | 362.175 | 300.375 |
| A152 | V | 362.425 | 300.125 |
| A153 | B | 362.575 | 299.850 |
| A154 | S | 361.025 | 301.250 |
| A155 | S | 361.475 | 301.725 |
| A156 | S | 361.925 | 302.050 |
| A157 | S | 362.525 | 302.700 |
| A158 | S | 362.900 | 303.000 |
| A159 | S | 363.750 | 303.175 |
| A160 | R | 363.450 | 302.525 |
| A161 | V | 362.450 | 301.850 |
| A162 | C | 364.450 | 302.600 |
| A163 | R | 363.450 | 301.950 |
| A164 | B | 363.000 | 301.550 |
| A165 | B | 362.450 | 301.025 |
| A166 | C | 362.175 | 300.700 |
| V001 | P | 366.775 | 300.090 |
| | V | 366.775 | 300.090 |
| V002 | A | 366.525 | 307.600 |
| V003 | P | 365.800 | 299.055 |
| | V | 365.805 | 299.045 |
| V004 | R | 366.825 | 299.425 |
| V005 | P | 363.500 | 300.500 |
| | V | 363.500 | 300.500 |
| V006 | V | 364.100 | 300.650 |
| V007 | P | 367.200 | 308.125 |
| | p | 367.175 | 308.000 |
| V008 | P | 366.300 | 300.525 |
| V009 | P | 368.275 | 300.450 |
| | P | 368.575 | 300.350 |
| V010 | V | 368.325 | 301.375 |
| | ,C | 368.325 | 301.375 |
| V011 | V | 361.050 | 300.000 |
| | B | 361.275 | 300.000 |
| | B | 361.050 | 300.150 |
| | B | 361.025 | 299.875 |
| V012 | V | 366.900 | 301.050 |
| V013 | V | 366.875 | 301.375 |
| V014 | P | 367.600 | 301.450 |
| | P | 367.550 | 301.575 |
| | P | 367.000 | 301.100 |
| V015 | V | 367.700 | 301.875 |

| | | West | North |
|---|---|---|---|
| V016 | V | 298.600 | 365.700 |
| | R | 298.600 | 365.700 |
| V017 | P | 365.025 | 299.575 |
| | P | 364.750 | 299.850 |
| V018 | P | 362.275 | 304.700 |
| | P | 361.800 | 305.150 |
| V019 | P | 364.400 | 307.675 |
| V020 | S | 364.575 | 307.675 |
| V021 | V | 365.250 | 307.500 |
| V022 | P | 363.200 | 299.850 |
| | P | 363.450 | 299.925 |
| | P | 363.625 | 299.925 |
| | P | 363.825 | 299.825 |
| V023 | P | 365.550 | 301.275 |
| V024 | P | 365.175 | 301.550 |
| | P | 364.900 | 301.225 |
| V025 | P | 364.350 | 301.500 |
| | P | 362.250 | 298.175 |
| V026 | P | 363.275 | 301.350 |
| | P | 363.150 | 300.825 |
| | P | 363.475 | 300.975 |
| V027 | V | 361.759 | 297.750 |
| | V | 362.250 | 298.175 |
| V028 | V | 362.225 | 298.775 |
| | V | 362.200 | 298.275 |
| | V | 362.725 | 299.625 |
| V029 | V | 363.200 | 299.200 |
| V030 | B | 364.350 | 306.050 |
| | B | 363.025 | 305.750 |
| V031 | B | 364.100 | 305.525 |
| V032 | V | 361.475 | 300.275 |
| V033 | V | 362.425 | 300.125 |
| | V | 362.175 | 300.375 |
| V034 | V | 363.500 | 303.500 |
| V035 | P | 362.450 | 301.850 |
| | R | 363.450 | 302.525 |
| V036 | V | 363.450 | 302.550 |
| | V | 364.450 | 302.600 |
| V037 | V | 363.600 | 301.550 |
| | V | 362.450 | 301.025 |

**Appendix IV**

Soil profile descriptions (1995) of Sector Horizontes (p. 1 to 4).

**I Site Sample**

| | |
|---|---|
| Profile number: | *S01* |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 04 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 361250 E, 298550 N |
| Land-form: | |
| i) Physiographic position of the site: | convex slope |
| ii) Topography of surrounding country: | 2-8% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | 2% |
| Vegetation or land-use: | dry-forest and pasture |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | ignimbrite |
| Drainage: | moderatly well drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 0% |
| Rock outcrop classes: | <2% |
| Erosion: | none |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum. |

**III Profile Description**

| | | |
|---|---|---|
| Ah | 0 - 15/20 cm | Brownish black (10 YR 2/2) when moist, clay loam; moderate fine angular and subangular blocky; very friable; many very fine and fine, and few medium pores; many fine to coarse roots; clear smooth boundary to: |
| BA | 15/20 - 35 cm | Dark brown (7.5 YR 3/4) when moist, clay loam (more loamy than horizon above); moderate fine angular and subangular blocky and fine crumb; very friable; many very fine and fine, and few medium pores; common fine to coarse roots; gradual smooth boundary to: |
| Bwg | 35 - 90$^+$ cm | Brown (7.5 YR 4/6) when moist, 20% reddish mottles (5 YR 3/6), 20% black manganese mottles, 10% yellowish mottles, clay loam; moderate fine angular blocky; friable; many very fine and fine and common medium pores; up to about 30-40% weathered rock fragments, often impregnated with manganese. |

Further drilling from the depth of 90 cm showed that the Bwg horizon continues to a depth of 130 cm, with underneath it saprolitic ignimbrite.

**I Site Sample**

| | |
|---|---|
| Profile number: | *S02b* |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 05 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 367500 E, 299500 N |
| Land-form: | |
| i) Physiographic position of the site: | plateau |
| ii) Topography of surrounding country: | <2% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | 2% |
| Vegetation or land-use: | pasture |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | ignimbrite |
| Drainage: | moderatly well drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 0% |
| Rock outcrop classes: | 2-10% |
| Erosion: | little |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum. |

**III Profile Description**

| | | |
|---|---|---|
| Ah | 0 - 19 cm | Brownish black (10 YR 2/2) when moist, few faint reddish mottles, clay loam to silty clay loam; structureless: massive with 10-15% moderate fine crumb; friable; many very fine and fine, and few medium pores; many fine roots; abrupt smooth boundary to: |
| BA | 19 - 30 cm | Grayish yellow brown (10 YR 4/2) when moist, few faint reddish mottles, clay loam; structureless: massive with 10-15% moderate fine crumb; very friable; many very fine and fine, and few medium pores; common fine roots; abrupt smooth boundary to: |
| BCg | 30 - 79 cm | Brownish gray (10 YR 6/1) when moist, common distinct yellowish brown mottles (10 YR 5/6), clay; structureless: massive with a kind of layers like in the original ignimbrite structure; friable to firm; common very fine, and few fine and medium pores; throughout BCg common weathered rock fragments (5-20 mm), increasing amount of saprolitic ignimbrite (sandy texture and structure) with depth; close to boundary with BA some iron and manganese nodules are concentrated (at about 32 cm max.); few fine roots; abrupt smooth boundary to: |
| R | 79$^+$ cm | Ignimbrite. |

**I Site Sample**

| | |
|---|---|
| Profile number: | *S03* |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 14 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 361250 E, 306250 N |
| Land-form: | |
| i) Physiographic position of the site: | plateau |
| ii) Topography of surrounding country: | <2% to 2-8% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | 2% |
| Vegetation or land-use: | pasture, weeds and some trees. |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | volcanic ash (probably) over ignimbrite |
| Drainage: | well drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 3-15% (site 0-3%, size of stones 0-7,5 cm) |
| Rock outcrop classes: | site none, locally <2% |
| Erosion: | little |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum. Ploughing or dishing has occured. |

**III Profile Description**

| | | |
|---|---|---|
| Ah | 0 - 12 cm | Dark brown (10 YR 3/3) when moist, sandy loam; structureless (massive) and very weak subangular blocky; friable; few very fine pores; many fine roots; common coarser fragments, possibly pumish; clear wavy boundary to: |
| Bw | 12 - 16 cm | Yellowish brown (10 YR 5/6) when moist, 30% pockets containing Ah material, loam; structureless (massive) with some fine crumb; friable; few very fine pores; many very fine roots; abrupt smooth boundary to: |
| BC | 16 - 27 cm | Brown (7.5 YR 4/3) when moist, clay loam; moderate fine angular and subangular blocky; friable; few fine pores; small and coarse fragments of probably weathered ignimbrite; few hard and black manganese concretions; few very fine roots; abrupt smooth boundary to: |
| R | $27^{+}$ cm | Ignimbrite. |

Some control drills in the direct area (50-300 m) showed on some points a reddish clay subsoil underneath the Bw horizon, instead of the brown BC. On some points the subsoil underneath the Bw is grayish black colored (covered vertisol?). According to the upper two horizons and supported by the nearness of thicker ash layers over ignimbrite-developed soils, there is reason to believe that the original soil developed upon the ignimbrite is covered by an ashlayer or ashlayers of several decimeters thick.

**I Site Sample**

| | |
|---|---|
| Profile number: | *S04b* |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 14 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 361250 E, 304750 N |
| Land-form: | |
| i) Physiographic position of the site: | plateau |
| ii) Topography of surrounding country: | <2% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | 2% |
| Vegetation or land-use: | pasture and some trees |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | ignimbrite |
| Drainage: | poorly drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 3-15% at site up to 30% locally, all are ignimbrite boulders |
| Rock outcrop classes: | 0% |
| Erosion: | none |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum, or as pasture. |

**III Profile Description**

| | | |
|---|---|---|
| $B_1$ | 0 - 13 cm | Dark gray (N 3/0) when moist, clay; moderate and strong fine angular blocky; friable; fine slickensides; no pores visible other than small cracks still visible from dry period; common very fine to medium roots; gradual smooth boundary to: |
| $B_2$ | 13 - 40 cm | Dark gray (N 3/0) when moist, clay; moderate and strong fine angular blocky; friable; fine to medium sized slickensides; no pores visible other than few fine cracks still visible from dry period; common very fine and fine and few coarse to medium roots; gradual smooth boundary to: |
| $B_3$ | 40 - $75^{+}$ cm | Dark gray (N 3/0) humid, clay; microstructure moderate fine angular blocky, macrostructure prismatic (up to 15 cm); firm humid; fine sized slickensides and slickensides up to 10 cm long along ped faces; no pores visible other than cracks up to 5 mm wide; few very fine, fine and coarse roots. |

**I Site Sample**

| | |
|---|---|
| Profile number: | S05h |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 15 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 367200 E, 300900 N |
| Land-form: | |
| i) Physiographic position of the site: | plateau |
| ii) Topography of surrounding country: | <2% to 2-8% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | 1% |
| Vegetation or land-use: | pasture, weeds and some trees |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | ignimbrite |
| Drainage: | well drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 0% |
| Rock outcrop classes: | <2% |
| Erosion: | little |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum or for pasture. Ploughing may have occured. |

**III Profile Description**

| | | |
|---|---|---|
| Ah | 0 - 16 cm | Brownish black (10 YR 2/2) when moist, loam; weak fine subangular blocky; friable; common very fine and fine pores; common fine roots; clear smooth boundary to: |
| Bw | 16 - 32 cm | Dark brown (7.5 YR 3/3) when moist, clay loam; weak fine subangular blocky; very friable; abundant very fine and fine pores; common fine roots; clear smooth boundary to: |
| Bwg | 32 - 60 cm | Dull yellowish brown (10 YR 4/3) when moist, with 25% distinct fine bright brown (7.5 YR 5/6) mottles, clay loam (more loamy than horizon above); moderate fine angular and subangular blocky, and 20% crumb; very friable; abundant very fine and fine, and few medium pores; common fine roots; few manganese nodules up to 5mm; abrupt smooth boundary to: |
| CBg | 60 -90/100 cm | Brownish gray (10 YR 5/1) when moist, with 25% distinct medium bright reddish brown (5 YR 5/8) mottles, also yellowish mottles occur, clay loam; moderate fine angular blocky; friable; abundant very fine and fine pores; 10-20% iron concretions; few very fine roots; gradual broken boundary to: |
| C | 90/100$^{+}$ cm | Saprolitic ignimbrite. |

**I Site Sample**

| | |
|---|---|
| Profile number: | *S06h* |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 26 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 363570 E, 299300 N |
| Land-form: | |
| i) Physiographic position of the site: | convex slope from plateau |
| ii) Topography of surrounding country: | 2-8% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | 3% |
| Vegetation or land-use: | experimental reforestation plantation |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | ignimbrite |
| Drainage: | well drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 0% |
| Rock outcrop classes: | 0% |
| Erosion: | little |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum or for pasture. Ploughing may have occured. |

**III Profile Description**

| | | |
|---|---|---|
| Ah | 0 - 11/15 cm | Brownish black (10 YR 2/2) when moist, clay loam; weak fine subangular blocky to massive; friable; common very fine and medium pores; many fine roots; abrupt wavy boundary to: |
| B | 11/15 - 26 cm | Dark reddish brown (5 YR 3/3) when moist, clay loam (more clay than horizon above); weak medium subangular blocky; very friable; abundant very fine and fine pores; few (up to 10%) angular gravel and stones; common fine roots; at transmission with Bwg a thin band of iron concretions and grayish mottles, gradual irregular boundary to: |
| Bwg | 26 - 56/80 cm | Yellowish brown (10 YR 5/8) when moist, with 15% distinct fine bright brown (7.5 YR 5/8) mottles, clay loam; moderate fine and medium angular and subangular blocky; very friable; few coarse pores filled with Ah material; common fine roots; few manganese nodules up to 5mm; at transmission with R an about 5 cm thick dull yellowish brown (10 YR 5/2) layer containing about 20% iron and manganese concretions, abrupt smooth boundary to: |
| R | 56/80+ cm | saprolitic ignimbrite. |

**I Site Sample**

| | |
|---|---|
| Profile number: | *S10* |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 27 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 366300 E, 304500 N |
| Land-form: | |
| i) Physiographic position of the site: | plateau |
| ii) Topography of surrounding country: | 2-8% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | 0% |
| Vegetation or land-use: | pasture and dry-forrest |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | ignimbrite |
| Drainage: | poorly drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 0% |
| Rock outcrop classes: | 0% |
| Erosion: | little |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum or for pasture. Ploughing may have occured. |

**III Profile description**

On this site only a micromorphological sample of saprolitic ignimbrite is taken of about 1 meter depth, the boarder with the above laying vertisol.

**I Site Sample**

| | |
|---|---|
| Profile number: | *S08h* |
| Higher category classification: | - |
| USDA: | - |
| Date of examination: | 27 june 1995 |
| Author(s) of description: | A.F. Winters & A. Nieuwenhuyse |
| Location/photonr.: | 361500 E, 301000 N |
| Land-form: | |
| i) Physiographic position of the site: | convex slope |
| ii) Topography of surrounding country: | 2-8% |
| iii) Microtopography: | none |
| Slope on which the profile is sited: | up to 15% |
| Vegetation or land-use: | experimental reforestation plantation |

**II General Information of the Soil**

| | |
|---|---|
| Parent material: | ignimbrite |
| Drainage: | somewhat excessively drained |
| Moisture condition in the soil: | moist throughout |
| Depth of the ground water table: | - |
| Presence of surface stones/rock outcrops: | |
| Stoniness classes: | 5% |
| Rock outcrop classes: | 0% |
| Erosion: | little |
| Human influence: | nowadays, the site is within reforestation area. Until approximately 1989 the area was used as arable land for crops such as rice and sorghum or for pasture. Ploughing may have occured. |

**III Profile Description**

Ah 0 - 7/40 cm

Brownish black (7.5 YR 3/2) when moist, loam; weak medium subangular blocky; very friable; common very fine and fine, few medium pores; common fine to medium roots; this horizon contains about 25% of rock material from C horizon variing in size from 1 mm to 10 cm; in some places this horizon has an abrupt broken boundary to the C horizon, on other places however, it has a clean broken boundary to:

BA This horizon may be present in pockets from 25 cm up to 50 cm depth.

Dark brown (7.5 YR 3/3) when moist, sandy loam; weak medium subangular blocky; very friable; many very fine and fine pores; up to 25% rock fragments of C horizon variing in size from 1 mm to 10 cm; common fine roots:

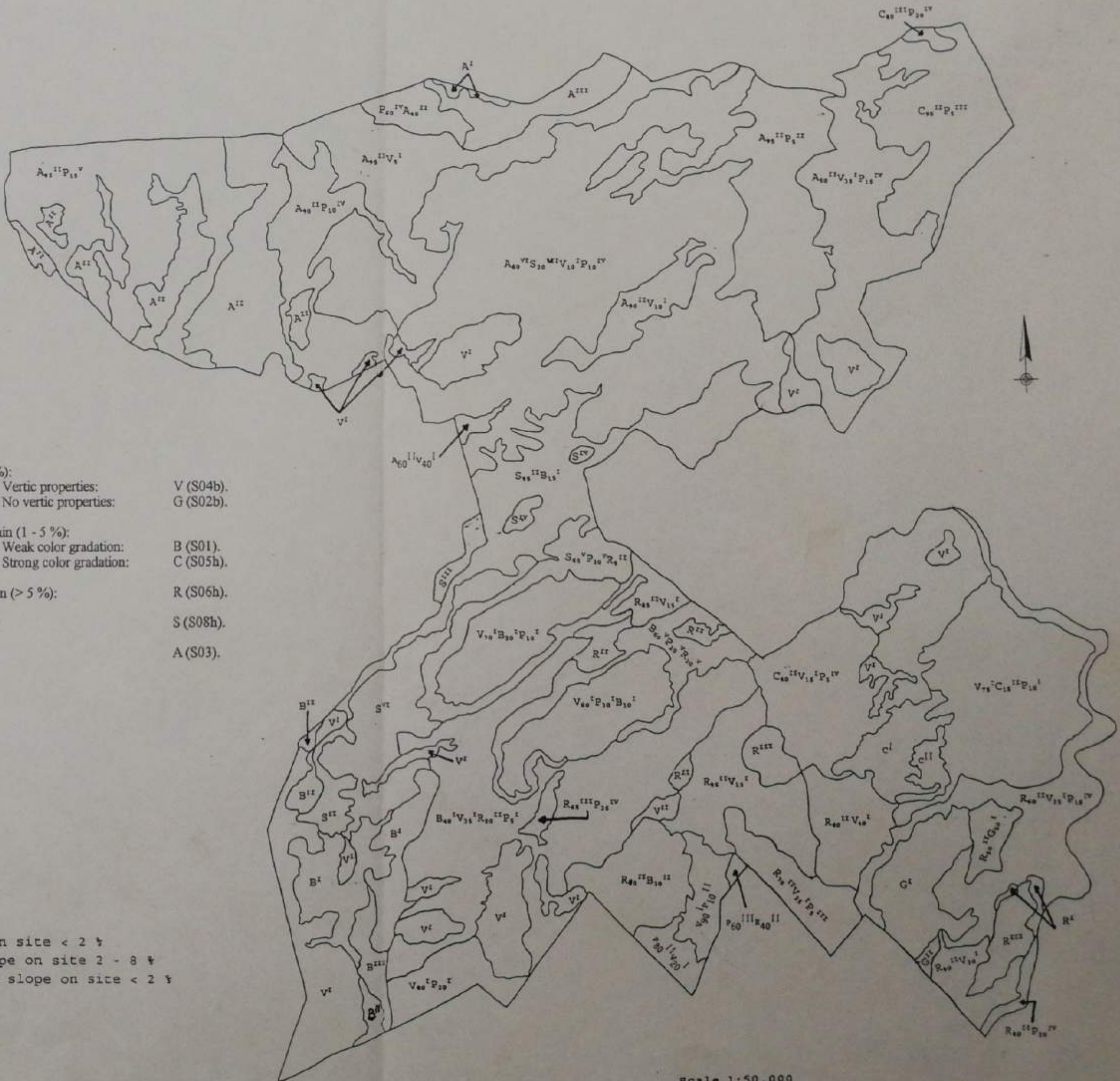
Bw $7/50^{+}$ cm

In between rocks of C material some finer material me be present.
Brown (10 Y 4/4) when moist, sandy loam; weak angular and subangular blocky; very friable; many very fine pores; few fine roots.

**Appendix V**

Soil map.

Soil map of: *Estación Experimental de Reforestatión Horizontes*



Soils on ignimbrite:

| | | | | |
|---|---|---|---|---|
| I | Dense welded ignimbritic parent rock: | | | |
| | Ia | Plain terrain (0 - 1 %): | | |
| | | Ia1 | Vertic properties: | V (S04b). |
| | | Ia2 | No vertic properties: | G (S02b). |
| | Ib | Slightly sloping terrain (1 - 5 %): | | |
| | | Ib1 | Weak color gradation: | B (S01). |
| | | Ib2 | Strong color gradation: | C (S05h). |
| | Ic | Strong sloping terrain (> 5 %): | | R (S06h). |
| II | Loose structured ignimbritic parent rock: | | | S (S08h). |
| III | Influenced by ash deposition: | | | A (S03). |

**Topography:**

| | | |
|---|---|---|
| I | = | < 2 % slope |
| II | = | 2 - 8 % ,, |
| III | = | 8 - 16 % ,, |
| IV | = | 16 - 30 % ,, |
| V | = | > 30 % ,, |
| VI | = | very variable |

$V_{75}{}^{I}C_{15}{}^{II}S_{10}{}^{I}$ means:

75 % vertisols (V; H4), with slope on site < 2 %
15 % coloured soil (C; h5(, with slope on site 2 - 8 %
10 % rock outcrops or boulders, with slope on site < 2 %

Scale 1:50,000

**Appendix VI**

Soil profile descriptions (1996) of the study sites (p. 1 to 3).

**Catena I**

| Profile | Horizon | Depth (cm) | Boundary | Colour (moist) | Mottling | Texture | Rockfragments | Structure | Consistence | Voids | Cutanic features | Mineral nodules *Fe / Mn* | Mineral nodules *Rock* | Biological activity | General comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***S02h*** | Ah | 0 - 9 | abrupt smooth | dark brown 10 YR 3/3 | - | silty loam | - | strong very fine angular blocky | slightly hard when dry | - | - | few very fine to fine rounded to irregular hard iron reddish nodules | - | few very fine and fine | - |
| | AB | 9 - 16 | abrupt smooth | dark brown 10 YR 3/3 | - | silty clay loam | - | strong very fine angular blocky | slightly hard when dry | vesicles very fine very few low | - | many very fine to fine rounded to irregular hard reddish iron-manganese nodules | - | few very fine and fine | - |
| | pocket | 16 - 40 | abrupt smooth | dark brown 10 YR 3/3 | - | silty clay | - | weak very fine angular blocky | hard when dry | channels very fine very few very low | abundant faint slickensides, predominantly intersecting no specific location | few to common very fine rounded hard reddish iron nodules | - | very few very fine and fine | - |
| | B | 40 - 68 | abrupt wavy | yellowish gray 2.5 Y / 5/1 | - | silty clay | many fine gravel angular to subrounded weathered pyroclastic rock | very weak very fine subangular blocky | slightly hard when dry | - | - | many fragments and very fine rounded and irregular hard reddish-black iron-manganese nodules | abundant very fine rounded and irregular hard white residual pyroclastic rock fragments | very few very fine | - |
| | R | 68+ | - | - | - | - | - | - | - | - | - | - | - | - | - |
| ***S02b*** | Ah | 0 - 19 | abrupt smooth | brownish black 10 YR 2/2 | few faint reddish | silty loam | - | structureless to massive with 10 - 15 % moderate fine crumb | friable | many very fine and fine and few medium pores | - | - | - | many fine | - |
| | BA | 19 - 30 | abrupt smooth | grayish yellow brown 10 YR 4/2 | few faint reddish | silty loam | - | structureless to massive with 10 - 15 % moderate fine crumb | very friable | many very fine and fine and few medium pores | - | - | - | common fine | - |
| | BCg | 30 - 79 | abrupt smooth | brownish gray 10 YR 6/1 | common distinct yellowish brown (10 YR 5/6) | silty clay loam | - | structureless to massive with a kind of layers like in the original ignimbrite structure | friable to firm | common very fine and few fine and medium pores | - | close to boundary with BA some iron and manganese nodules are concentrated (30 - 32 cm) | throughout BCg common weathered rock fragments (5 - 20 mm) | few fine | increasing amount of saprolitic ignimbrite (sandy texture and structure) with depth |
| | R | 79+ | - | - | - | - | - | - | - | - | - | - | - | - | saprolitic ignimbrite |

**Catena II**

| Profile | Horizon | Depth | Boundary | Colour | Mottling | Texture | Rockfragments | Structure | Consistence | Voids | Cutanic features | Mineral nodules | | Biological activity | General comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | *Fe / Mn* | *Rock* | | |
| ***S06h*** | Ah | 0 - 11/15 | abrupt wavy | brownish black 10 YR 2/2 | - | silty clay loam | - | weak fine subangular blocky to massive | friable | common very fine and medium pores | - | - | - | many fine | - |
| | B | 11/15 - 26 | gradual irregular | dark reddish brown 5 YR 3/3 | - | silty clay loam | - | weak medium subangular blocky | very friable | abundant very fine and fine pores | - | - | few (up to 10%) angular gravel and stones | common fine | at transmission with Bwg a thin band of iron concretions and grayish mottles |
| | Bwg | 26 - 56/80 | abrupth smooth | yellowish brown 10 YR 5/8 | 15 % distinct fine bright brown (7.5 YR 5/8) | silty clay loam | - | moderate fine and medium angular and subangular blocky | very friable | - | - | few manganese nodules up to 5 mm and at transmission with R an about 5 cm thick dull yellowish brown (10 YR 5/2) layer containing about 20 % iron and manganese concretions | | common fine roots | few coarse 'pores' filled with Ah material |
| | R | 56/80+ | - | - | - | - | - | - | - | - | - | - | - | - | saprolitic ignimbrite |
| ***S06b*** | Ah1 | 0 - 5/10 | abrupt wavy | brown 10 YR 4/4 | | silty clay lam | - | weak coarse granular | slightly hard when dry to hard when dry | vesicles fine very few medium | - | - | - | common very fine | - |
| | Ah2 | 5/10 - 60 | clear smooth | brownish black 10 YR 2/2 | - | silty loam | - | moderate weak angular blocky | hard when dry | planes very coarse very few low | - | few fine rounded hard yellowish red iron-manganese nodules | - | very few very fine | - |
| | Ah3 | 60 - 110/130 | abrupt irregular | brownish black 10 YR 2/2 | - | silty loam | very few to common downwards fine and medium gravel subrounded weathered pyroclastic rock | moderate very coarse angular blocky | hard when dry | planes very coarse very few low | - | few fine rounded hard yellowish red iron-manganese nodules | - | very few very fine | - |
| | C | 110/130 - 140 | abrupt smooth | brown 10 YR 4/6 | - | loam | many fine gravel subrounded weathered pyroclastic rock | strong very coarse subangular and angular blocky | slightly hard when dry | planes very coarse very few low | - | - | - | - | - |
| | R | 140 - 150+ | - | - | - | - | - | - | - | - | - | - | - | - | - |

**Catena III**

| Profile | Horizon | Depth | Boundary | Colour | Mottling | Texture | Rockfragments | Structure | Consistence | Voids | Cutanic features | Mineral nodules | | Biological activity | General comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | *Fe / Mn* | *Rock* | | |
| ***101*** | Ah | 0-63/68 | clear wavy | brownish black 7.5 YR 3/1 | very few very fine faint sharp reddish brown | silty clay | very few fine and medium gravel subrounded fresh or slightly weathered pyroclastic rock | moderate fine and very fine angular blocky parallelepiped | very hard when dry | vesicles very fine / channels very fine to medium very few, medium | common faint slickensides, partly intersecting no specific location | few very fine to fine rounded hard reddish-black iron-manganese nodules | few very fine to fine irregular hard white-yellow residual pyroclastic rock fragments | very few very fine and fine roots | |
| | | | | | | | | | | | | | | few earthworm channels | |
| | Bw (see general commen) | 63/68-72/80 | gradual wavy | brownish black 7.5 YR 3/1 | abundant fine prominent diffuse reddish | loam | common fine gravel subrounded fresh or slightly weathered pyroclastic rock | moderate medium granular | slightly hard when dry | vughs fine and medium few / channels very fine very few, low | many faint slickensides, partly intersecting no specific location | common very fine to medium irregular hard reddish-black iron-manganese nodules | common very fine to fine irregular hard white/yellow residual pyroclastic rock fragments | very few very fine and fine roots | this horizon consists of a boundary of reddish parts with inbetween material alike Ah, a ironoxidation-front. We assume that what we see is caused by mottling on the outhersides of soilparts |
| | 2Ah? | 72/80-110/114 | clear wavy | bright reddish brown 5 YR 5/8 | very few very fine faint sharp reddish brown | silty loam | common fine and medium gravel subrounded fresh or slightly weathered pyroclastic rock | moderate fine and very fine angular blocky parallelepiped | very hard when dry | vesicles very fine to medium very few medium | common faint slickensides, partly intersecting no specific location | few very fine to fine rounded hard reddish-black iron-manganese nodules | few very fine to fine irregular hard white/yellow residual pyroclastic rock fragments | very few very fine roots | |
| | 2C1 | 110/114-123/130 | abrupt smooth | light reddish gray 2.5 Y 7/2 | - | loam | many fine and medium gravel subrounded weathered pyroclastic rock | weak fine angular blocky | friable | - | many faint slickensides, partly intersecting no specific location | very few very fine rounded hard reddish-black iron-manganese nodules | very few very fine rounded hard white residual pyroclastic rock fragments | few fine roots | clay situated between larger residual rock fragments |
| | 2C2 | 123/130-154+ | - | light reddish gray 2.5 Y 7/2 | - | silty clay loam | common fine gravel subrounded weathered pyroclastic rock | weak fine angular blocky | friable | - | many faint slickensides, partly intersecting no specific location | very few very fine rounded hard reddish-black iron-manganese nodules | very few very fine rounded hard white residual pyroclastic rock fragments | - | |
| ***102*** | Ap | 0-22 | abrupt smooth | grayish brown 7.5 YR 5/2 | common very fine faint sharp reddish | silty clay loam | common to many fine and medium gravel, angular fresh or slightly weathered pyroclastic rock | moderate fine and very fine angular and subangular blocky | hard when dry | vughs coarse very few / planes medium and coarse very few medium | - | few fine to medium irregular and rounded hard black-red iron-manganese nodules | many very fine and fine irregular hard white residual pyroclastic rock fragments | very few very fine and fine roots | horizon looks like a ploughing layer |
| | Bwg1 | 22-46 | abrupt smooth | brown 10 YR 4/6 | many very fine faint sharp reddish | silty clay loam | - | very weak very fine angular blocky | slightly hard when dry | channels very fine very few very low | - | few very fine to medium irregular hard black-red iron-manganese nodules | | few fine and medium roots | |
| | | | | | | | | | | | | | | few earthworm channels | |
| | Bwg2 | 46-65/70 | clear wavy | brown 7.5 YR 4/3 | few very fine mottles faint sharp reddish | silty clay loam | many fine to coarse gravel subrounded weathered pyroclastic rock | weak fine and very fine angular blocky | slightly hard when dry | channels and cracks fine and very fine very few low | - | many very fine to medium rounded hard reddish-black iron-manganese nodules | common fine to medium rounded hard white residual pyroclastic rock fragments | very few very fine and fine roots | |
| | CBwg | 65/70-87/95 | gradual wavy | dull yellow 10 YR 7/2 | | silty clay loam | many fine and medium gravel angular fresh or slightly weathered and weathered pyroclastic rock | weak fine and medium angular blocky | slightly hard when dry | vughs fine and very fine common low | - | few very fine to fine rounded hard reddish-black iron-manganese nodules | | very few very fine roots | |
| | R | 87-95+ | - | light reddish gray 2.5 Y 7/2 | | loam | | very weak very fine granular | | | | | | few very fine roots | a lot of pumis |

## Appendix VII

Table 1, grain size distribution data of the fraction <2 mm.
Table 2, grain size distribution of the clay separates.

**Table 1. Grain size distribution of the fraction <2 mm.**

| | S02k | | | | | S02b | | | S06k | | | S06b | | | | S09 | | I01 | | | | | I02 | | | | | I01/2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| grain size classes | Ah 0-9 | AB 9-16 | pocket 16-40 | B 40-69+ | under rock 69+ | Ah 0-19 | BA 19-30 | BCg 30-79 | Ah 0-11/15 | B 11/15-26 | Bwg 26-56/80 | Ah 0-5/10 | Ah2 5/10-60 | Ah3 60-110/130 | C 110/130-140 | Ah 0-15 | R 15+ | Ah 0-63/68 | Bw 63/68-72/80 | 2Ah 72/80-110/114 | 2C1 110/114-123/130 | 2C2 123/130-154+ | Ap 0-22 | 2Bwg1 22-46 | 2Bwg2 46-65/70 | 2CBwg 65/70-87/95 | 2R 87-95+ | I01/2, rock |
| 0.040 | 0 | 0 | 0.01 | 0.01 | 0.02 | 0 | 0 | 0.01 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0.000097 | 0.000065 |
| 0.044 | 0 | 0.01 | 0.03 | 0.02 | 0.04 | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0.0032 | 0.0012 |
| 0.048 | 0.01 | 0.01 | 0.05 | 0.04 | 0.07 | 0.01 | 0.01 | 0.05 | 0.03 | 0.03 | 0.02 | 0.02 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0.01 | 0.01 | 0 | 0.07 | 0 | 0 | 0 | 0 | 0.001 | 0.0025 |
| 0.053 | 0.01 | 0.03 | 0.11 | 0.09 | 0.15 | 0.03 | 0.02 | 0.1 | 0.06 | 0.06 | 0.04 | 0.03 | 0 | 0.02 | 0.01 | 0 | 0.000019 | 0 | 0.01 | 0.03 | 0.0000077 | 0.13 | 0.00008 | 0 | 0 | 0 | 0.001 | 0.001 |
| 0.058 | 0.03 | 0.05 | 0.2 | 0.17 | 0.28 | 0.05 | 0.05 | 0.18 | 0.11 | 0.12 | 0.08 | 0.06 | 0.000052 | 0.04 | 0.02 | 0 | 0.0027 | 0.000076 | 0.03 | 0.05 | 0.0025 | 0.17 | 0.001 | 0 | 0 | 0.00009 | 0.002 | 0.001 |
| 0.064 | 0.04 | 0.08 | 0.3 | 0.25 | 0.41 | 0.07 | 0.07 | 0.27 | 0.15 | 0.18 | 0.12 | 0.09 | 0.001 | 0.07 | 0.03 | 0 | 0.002 | 0.001 | 0.04 | 0.08 | 0.002 | 0.21 | 0.006 | 0 | 0 | 0.001 | 0.004 | 0.001 |
| 0.070 | 0.05 | 0.1 | 0.39 | 0.33 | 0.53 | 0.09 | 0.09 | 0.34 | 0.2 | 0.23 | 0.15 | 0.13 | 0.007 | 0.1 | 0.04 | 0 | 0.004 | 0.006 | 0.06 | 0.12 | 0.007 | 0.24 | 0.016 | 0.000096 | 0 | 0.006 | 0.007 | 0.002 |
| 0.077 | 0.07 | 0.13 | 0.47 | 0.4 | 0.62 | 0.11 | 0.1 | 0.39 | 0.23 | 0.27 | 0.18 | 0.16 | 0.023 | 0.13 | 0.05 | 0.000023 | 0.008 | 0.018 | 0.08 | 0.16 | 0.016 | 0.26 | 0.031 | 0.002 | 0.01 | 0.017 | 0.011 | 0.003 |
| 0.084 | 0.09 | 0.17 | 0.57 | 0.48 | 0.74 | 0.12 | 0.12 | 0.46 | 0.27 | 0.32 | 0.22 | 0.2 | 0.051 | 0.17 | 0.07 | 0.001 | 0.012 | 0.037 | 0.1 | 0.2 | 0.028 | 0.28 | 0.047 | 0.009 | 0.02 | 0.032 | 0.015 | 0.003 |
| 0.093 | 0.11 | 0.21 | 0.67 | 0.56 | 0.84 | 0.14 | 0.14 | 0.52 | 0.31 | 0.37 | 0.25 | 0.24 | 0.089 | 0.21 | 0.09 | 0.005 | 0.018 | 0.062 | 0.12 | 0.25 | 0.044 | 0.3 | 0.069 | 0.027 | 0.05 | 0.051 | 0.021 | 0.004 |
| 0.102 | 0.14 | 0.26 | 0.77 | 0.65 | 0.95 | 0.16 | 0.16 | 0.56 | 0.35 | 0.42 | 0.29 | 0.29 | 0.14 | 0.27 | 0.11 | 0.021 | 0.025 | 0.095 | 0.15 | 0.32 | 0.065 | 0.3 | 0.099 | 0.058 | 0.07 | 0.077 | 0.029 | 0.005 |
| 0.112 | 0.17 | 0.31 | 0.87 | 0.75 | 1.04 | 0.18 | 0.18 | 0.6 | 0.38 | 0.46 | 0.32 | 0.34 | 0.207 | 0.34 | 0.14 | 0.05 | 0.034 | 0.138 | 0.19 | 0.4 | 0.092 | 0.31 | 0.137 | 0.099 | 0.11 | 0.11 | 0.039 | 0.006 |
| 0.123 | 0.2 | 0.37 | 0.99 | 0.85 | 1.13 | 0.19 | 0.19 | 0.64 | 0.41 | 0.51 | 0.36 | 0.4 | 0.291 | 0.41 | 0.17 | 0.091 | 0.046 | 0.193 | 0.22 | 0.49 | 0.126 | 0.31 | 0.182 | 0.153 | 0.16 | 0.152 | 0.049 | 0.007 |
| 0.134 | 0.24 | 0.45 | 1.11 | 0.95 | 1.22 | 0.21 | 0.21 | 0.67 | 0.44 | 0.55 | 0.4 | 0.47 | 0.392 | 0.5 | 0.21 | 0.142 | 0.058 | 0.259 | 0.27 | 0.59 | 0.165 | 0.32 | 0.235 | 0.222 | 0.22 | 0.201 | 0.062 | 0.008 |
| 0.148 | 0.29 | 0.53 | 1.24 | 1.07 | 1.31 | 0.23 | 0.23 | 0.69 | 0.46 | 0.59 | 0.44 | 0.54 | 0.512 | 0.6 | 0.25 | 0.208 | 0.074 | 0.338 | 0.32 | 0.71 | 0.211 | 0.33 | 0.297 | 0.308 | 0.3 | 0.258 | 0.077 | 0.01 |
| 0.162 | 0.34 | 0.62 | 1.38 | 1.19 | 1.39 | 0.25 | 0.24 | 0.7 | 0.49 | 0.63 | 0.48 | 0.62 | 0.648 | 0.71 | 0.3 | 0.288 | 0.091 | 0.429 | 0.37 | 0.84 | 0.263 | 0.36 | 0.368 | 0.411 | 0.38 | 0.324 | 0.094 | 0.011 |
| 0.178 | 0.39 | 0.72 | 1.53 | 1.32 | 1.47 | 0.26 | 0.26 | 0.71 | 0.51 | 0.67 | 0.51 | 0.71 | 0.799 | 0.83 | 0.36 | 0.382 | 0.11 | 0.532 | 0.43 | 0.98 | 0.321 | 0.4 | 0.447 | 0.528 | 0.47 | 0.397 | 0.112 | 0.013 |
| 0.195 | 0.45 | 0.82 | 1.68 | 1.44 | 1.55 | 0.28 | 0.28 | 0.71 | 0.54 | 0.7 | 0.55 | 0.8 | 0.96 | 0.95 | 0.41 | 0.486 | 0.129 | 0.644 | 0.5 | 1.14 | 0.383 | 0.47 | 0.531 | 0.657 | 0.57 | 0.476 | 0.131 | 0.015 |
| 0.214 | 0.51 | 0.94 | 1.83 | 1.57 | 1.63 | 0.31 | 0.3 | 0.71 | 0.56 | 0.73 | 0.59 | 0.89 | 1.13 | 1.08 | 0.47 | 0.597 | 0.15 | 0.764 | 0.57 | 1.3 | 0.446 | 0.57 | 0.619 | 0.797 | 0.68 | 0.558 | 0.151 | 0.018 |
| 0.235 | 0.57 | 1.05 | 1.98 | 1.69 | 1.7 | 0.33 | 0.32 | 0.71 | 0.58 | 0.76 | 0.62 | 0.97 | 1.29 | 1.21 | 0.53 | 0.71 | 0.171 | 0.887 | 0.63 | 1.46 | 0.509 | 0.69 | 0.709 | 0.942 | 0.79 | 0.64 | 0.171 | 0.021 |
| 0.258 | 0.62 | 1.16 | 2.12 | 1.8 | 1.76 | 0.35 | 0.34 | 0.71 | 0.61 | 0.78 | 0.66 | 1.06 | 1.45 | 1.34 | 0.58 | 0.82 | 0.192 | 1.01 | 0.7 | 1.61 | 0.567 | 0.83 | 0.796 | 1.08 | 0.89 | 0.719 | 0.191 | 0.024 |
| 0.284 | 0.68 | 1.25 | 2.23 | 1.89 | 1.8 | 0.37 | 0.36 | 0.71 | 0.63 | 0.8 | 0.68 | 1.12 | 1.59 | 1.45 | 0.63 | 0.919 | 0.21 | 1.12 | 0.75 | 1.73 | 0.617 | 0.98 | 0.875 | 1.22 | 0.98 | 0.79 | 0.209 | 0.028 |
| 0.311 | 0.72 | 1.33 | 2.29 | 1.93 | 1.82 | 0.4 | 0.39 | 0.71 | 0.65 | 0.81 | 0.71 | 1.18 | 1.69 | 1.53 | 0.67 | 1 | 0.227 | 1.21 | 0.8 | 1.83 | 0.653 | 1.1 | 0.943 | 1.33 | 1.06 | 0.849 | 0.225 | 0.032 |
| 0.342 | 0.76 | 1.38 | 2.3 | 1.94 | 1.81 | 0.41 | 0.41 | 0.71 | 0.68 | 0.82 | 0.72 | 1.21 | 1.76 | 1.59 | 0.7 | 1.06 | 0.241 | 1.29 | 0.83 | 1.88 | 0.672 | 1.19 | 0.994 | 1.41 | 1.12 | 0.89 | 0.239 | 0.037 |
| 0.375 | 0.78 | 1.41 | 2.24 | 1.89 | 1.77 | 0.43 | 0.44 | 0.72 | 0.7 | 0.82 | 0.73 | 1.21 | 1.78 | 1.61 | 0.71 | 1.09 | 0.252 | 1.33 | 0.84 | 1.88 | 0.673 | 1.21 | 1.03 | 1.46 | 1.15 | 0.914 | 0.251 | 0.043 |
| 0.412 | 0.8 | 1.4 | 2.13 | 1.8 | 1.69 | 0.43 | 0.47 | 0.73 | 0.73 | 0.82 | 0.74 | 1.2 | 1.76 | 1.6 | 0.71 | 1.1 | 0.26 | 1.35 | 0.84 | 1.82 | 0.654 | 1.17 | 1.04 | 1.48 | 1.16 | 0.918 | 0.26 | 0.049 |
| 0.452 | 0.8 | 1.37 | 1.98 | 1.68 | 1.59 | 0.44 | 0.51 | 0.74 | 0.76 | 0.82 | 0.75 | 1.16 | 1.71 | 1.56 | 0.7 | 1.09 | 0.266 | 1.35 | 0.82 | 1.73 | 0.62 | 1.07 | 1.04 | 1.48 | 1.15 | 0.909 | 0.268 | 0.056 |
| 0.496 | 0.8 | 1.33 | 1.81 | 1.54 | 1.48 | 0.44 | 0.55 | 0.75 | 0.8 | 0.83 | 0.75 | 1.11 | 1.63 | 1.51 | 0.69 | 1.06 | 0.27 | 1.33 | 0.79 | 1.61 | 0.575 | 0.94 | 1.03 | 1.45 | 1.13 | 0.889 | 0.275 | 0.064 |
| 0.545 | 0.8 | 1.28 | 1.64 | 1.4 | 1.38 | 0.44 | 0.59 | 0.78 | 0.85 | 0.85 | 0.77 | 1.06 | 1.54 | 1.45 | 0.67 | 1.03 | 0.274 | 1.3 | 0.76 | 1.49 | 0.526 | 0.8 | 1.01 | 1.41 | 1.11 | 0.866 | 0.284 | 0.074 |
| 0.598 | 0.8 | 1.23 | 1.49 | 1.26 | 1.3 | 0.44 | 0.64 | 0.81 | 0.91 | 0.89 | 0.79 | 1.02 | 1.46 | 1.39 | 0.65 | 0.999 | 0.279 | 1.27 | 0.73 | 1.36 | 0.477 | 0.67 | 0.996 | 1.37 | 1.08 | 0.846 | 0.295 | 0.084 |
| 0.657 | 0.81 | 1.2 | 1.36 | 1.15 | 1.23 | 0.45 | 0.69 | 0.84 | 0.98 | 0.96 | 0.83 | 0.98 | 1.38 | 1.34 | 0.64 | 0.981 | 0.287 | 1.26 | 0.7 | 1.25 | 0.432 | 0.57 | 0.988 | 1.34 | 1.07 | 0.836 | 0.31 | 0.095 |
| 0.721 | 0.83 | 1.18 | 1.26 | 1.06 | 1.19 | 0.47 | 0.75 | 0.88 | 1.07 | 1.05 | 0.89 | 0.96 | 1.33 | 1.3 | 0.64 | 0.979 | 0.298 | 1.25 | 0.69 | 1.16 | 0.398 | 0.51 | 0.993 | 1.32 | 1.07 | 0.842 | 0.331 | 0.108 |
| 0.791 | 0.87 | 1.18 | 1.2 | 1.01 | 1.19 | 0.5 | 0.82 | 0.93 | 1.18 | 1.17 | 0.97 | 0.97 | 1.3 | 1.29 | 0.65 | 0.998 | 0.313 | 1.27 | 0.68 | 1.1 | 0.377 | 0.51 | 1.01 | 1.33 | 1.09 | 0.867 | 0.357 | 0.121 |
| 0.869 | 0.91 | 1.21 | 1.2 | 1.01 | 1.24 | 0.53 | 0.9 | 0.98 | 1.3 | 1.32 | 1.07 | 0.99 | 1.31 | 1.3 | 0.67 | 1.05 | 0.333 | 1.32 | 0.7 | 1.09 | 0.375 | 0.59 | 1.06 | 1.36 | 1.14 | 0.918 | 0.392 | 0.137 |
| 0.953 | 0.98 | 1.28 | 1.26 | 1.05 | 1.34 | 0.58 | 0.98 | 1.04 | 1.43 | 1.51 | 1.2 | 1.05 | 1.36 | 1.35 | 0.71 | 1.12 | 0.359 | 1.4 | 0.73 | 1.13 | 0.395 | 0.73 | 1.13 | 1.42 | 1.22 | 0.997 | 0.435 | 0.153 |
| 1.047 | 1.06 | 1.37 | 1.38 | 1.16 | 1.49 | 0.64 | 1.06 | 1.1 | 1.57 | 1.71 | 1.35 | 1.15 | 1.45 | 1.43 | 0.77 | 1.23 | 0.392 | 1.5 | 0.79 | 1.22 | 0.436 | 0.95 | 1.22 | 1.51 | 1.32 | 1.11 | 0.486 | 0.171 |
| 1.149 | 1.15 | 1.48 | 1.55 | 1.3 | 1.68 | 0.71 | 1.14 | 1.17 | 1.72 | 1.94 | 1.53 | 1.27 | 1.58 | 1.53 | 0.85 | 1.35 | 0.429 | 1.64 | 0.86 | 1.35 | 0.498 | 1.22 | 1.34 | 1.62 | 1.45 | 1.24 | 0.545 | 0.19 |
| 1.261 | 1.26 | 1.63 | 1.76 | 1.49 | 1.91 | 0.78 | 1.23 | 1.24 | 1.87 | 2.16 | 1.72 | 1.42 | 1.74 | 1.66 | 0.94 | 1.49 | 0.471 | 1.78 | 0.95 | 1.51 | 0.576 | 1.53 | 1.47 | 1.76 | 1.6 | 1.4 | 0.61 | 0.211 |
| 1.385 | 1.36 | 1.77 | 1.98 | 1.69 | 2.14 | 0.85 | 1.31 | 1.31 | 2.01 | 2.38 | 1.92 | 1.57 | 1.91 | 1.8 | 1.04 | 1.63 | 0.515 | 1.94 | 1.04 | 1.68 | 0.663 | 1.84 | 1.62 | 1.89 | 1.76 | 1.57 | 0.678 | 0.232 |
| 1.520 | 1.46 | 1.9 | 2.19 | 1.88 | 2.37 | 0.92 | 1.38 | 1.39 | 2.12 | 2.57 | 2.11 | 1.73 | 2.08 | 1.94 | 1.14 | 1.76 | 0.559 | 2.08 | 1.13 | 1.84 | 0.753 | 2.15 | 1.76 | 2.01 | 1.92 | 1.75 | 0.747 | 0.253 |
| 1.669 | 1.54 | 2.01 | 2.36 | 2.06 | 2.58 | 0.99 | 1.45 | 1.47 | 2.22 | 2.73 | 2.3 | 1.89 | 2.22 | 2.06 | 1.23 | 1.86 | 0.602 | 2.21 | 1.21 | 1.99 | 0.84 | 2.42 | 1.9 | 2.12 | 2.06 | 1.91 | 0.814 | 0.275 |
| 1.832 | 1.61 | 2.09 | 2.49 | 2.21 | 2.75 | 1.04 | 1.5 | 1.55 | 2.29 | 2.84 | 2.47 | 2.02 | 2.34 | 2.15 | 1.32 | 1.93 | 0.642 | 2.31 | 1.27 | 2.1 | 0.916 | 2.65 | 2.03 | 2.19 | 2.18 | 2.07 | 0.876 | 0.297 |
| 2.010 | 1.66 | 2.14 | 2.57 | 2.32 | 2.87 | 1.08 | 1.55 | 1.62 | 2.34 | 2.92 | 2.62 | 2.13 | 2.41 | 2.21 | 1.39 | 1.96 | 0.677 | 2.37 | 1.32 | 2.16 | 0.98 | 2.83 | 2.13 | 2.23 | 2.27 | 2.2 | 0.932 | 0.319 |
| 2.207 | 1.68 | 2.15 | 2.58 | 2.38 | 2.93 | 1.11 | 1.59 | 1.7 | 2.35 | 2.94 | 2.73 | 2.22 | 2.45 | 2.24 | 1.44 | 1.95 | 0.706 | 2.4 | 1.36 | 2.18 | 1.03 | 2.97 | 2.21 | 2.24 | 2.34 | 2.3 | 0.98 | 0.342 |
| 2.423 | 1.69 | 2.13 | 2.55 | 2.39 | 2.94 | 1.12 | 1.61 | 1.77 | 2.35 | 2.93 | 2.81 | 2.28 | 2.44 | 2.24 | 1.48 | 1.91 | 0.729 | 2.39 | 1.37 | 2.16 | 1.06 | 3.06 | 2.27 | 2.21 | 2.37 | 2.38 | 1.02 | 0.365 |
| 2.660 | 1.67 | 2.08 | 2.46 | 2.37 | 2.9 | 1.13 | 1.64 | 1.84 | 2.32 | 2.88 | 2.86 | 2.31 | 2.4 | 2.21 | 1.5 | 1.84 | 0.748 | 2.36 | 1.37 | 2.11 | 1.08 | 3.11 | 2.3 | 2.16 | 2.38 | 2.43 | 1.05 | 0.388 |
| 2.920 | 1.65 | 2 | 2.34 | 2.31 | 2.81 | 1.14 | 1.65 | 1.9 | 2.28 | 2.81 | 2.88 | 2.32 | 2.34 | 2.16 | 1.51 | 1.75 | 0.761 | 2.29 | 1.35 | 2.03 | 1.08 | 3.11 | 2.32 | 2.1 | 2.37 | 2.46 | 1.07 | 0.412 |
| 3.206 | 1.62 | 1.92 | 2.2 | 2.22 | 2.68 | 1.15 | 1.67 | 1.95 | 2.23 | 2.71 | 2.87 | 2.31 | 2.25 | 2.09 | 1.5 | 1.65 | 0.771 | 2.22 | 1.33 | 1.94 | 1.08 | 3.09 | 2.32 | 2.02 | 2.34 | 2.46 | 1.08 | 0.437 |
| 3.519 | 1.58 | 1.83 | 2.06 | 2.13 | 2.53 | 1.17 | 1.69 | 1.99 | 2.17 | 2.6 | 2.84 | 2.29 | 2.16 | 2.02 | 1.49 | 1.55 | 0.778 | 2.13 | 1.31 | 1.85 | 1.07 | 3.06 | 2.3 | 1.95 | 2.3 | 2.45 | 1.09 | 0.463 |
| 3.862 | 1.55 | 1.75 | 1.92 | 2.03 | 2.37 | 1.19 | 1.7 | 2.01 | 2.11 | 2.49 | 2.79 | 2.27 | 2.07 | 1.95 | 1.47 | 1.46 | 0.783 | 2.05 | 1.29 | 1.76 | 1.06 | 3.02 | 2.28 | 1.89 | 2.25 | 2.43 | 1.09 | 0.49 |
| 4.241 | 1.53 | 1.68 | 1.79 | 1.93 | 2.21 | 1.23 | 1.73 | 2.02 | 2.05 | 2.37 | 2.72 | 2.25 | 1.99 | 1.89 | 1.45 | 1.38 | 0.789 | 1.97 | 1.27 | 1.68 | 1.04 | 3 | 2.25 | 1.83 | 2.2 | 2.41 | 1.09 | 0.519 |
| 4.656 | 1.52 | 1.63 | 1.68 | 1.84 | 2.05 | 1.28 | 1.76 | 2.02 | 1.99 | 2.26 | 2.64 | 2.22 | 1.92 | 1.83 | 1.43 | 1.32 | 0.794 | 1.89 | 1.26 | 1.61 | 1.03 | 2.99 | 2.22 | 1.79 | 2.16 | 2.37 | 1.08 | 0.55 |
| 5.111 | 1.52 | 1.59 | 1.57 | 1.76 | 1.89 | 1.35 | 1.8 | 2 | 1.93 | 2.14 | 2.56 | 2.2 | 1.85 | 1.78 | 1.41 | 1.26 | 0.799 | 1.83 | 1.25 | 1.55 | 1.01 | 2.97 | 2.19 | 1.76 | 2.12 | 2.33 | 1.08 | 0.583 |
| 5.611 | 1.53 | 1.56 | 1.48 | 1.68 | 1.75 | 1.42 | 1.84 | 1.98 | 1.88 | 2.03 | 2.47 | 2.18 | 1.79 | 1.74 | 1.38 | 1.22 | 0.804 | 1.77 | 1.24 | 1.5 | 0.996 | 2.93 | 2.15 | 1.73 | 2.08 | 2.29 | 1.06 | 0.616 |
| 6.158 | 1.54 | 1.55 | 1.4 | 1.61 | 1.61 | 1.51 | 1.89 | 1.94 | 1.83 | 1.93 | 2.38 | 2.16 | 1.73 | 1.7 | 1.36 | 1.19 | 0.809 | 1.71 | 1.24 | 1.45 | 0.979 | 2.85 | 2.12 | 1.71 | 2.04 | 2.24 | 1.05 | 0.652 |
| 6.761 | 1.57 | 1.54 | 1.32 | 1.54 | 1.49 | 1.6 | 1.96 | 1.91 | 1.79 | 1.82 | 2.28 | 2.13 | 1.67 | 1.66 | 1.34 | 1.17 | 0.814 | 1.66 | 1.24 | 1.41 | 0.962 | 2.73 | 2.08 | 1.69 | 2 | 2.19 | 1.04 | 0.689 |
| 7.421 | 1.6 | 1.54 | 1.24 | 1.48 | 1.37 | 1.69 | 2.03 | 1.88 | 1.75 | 1.72 | 2.19 | 2.11 | 1.62 | 1.62 | 1.32 | 1.15 | 0.819 | 1.61 | 1.24 | 1.37 | 0.943 | 2.57 | 2.04 | 1.66 | 1.96 | 2.13 | 1.03 | 0.727 |
| 8.147 | 1.64 | 1.54 | 1.16 | 1.43 | 1.25 | 1.78 | 2.11 | 1.85 | 1.71 | 1.62 | 2.1 | 2.08 | 1.55 | 1.57 | 1.3 | 1.13 | 0.822 | 1.56 | 1.24 | 1.32 | 0.922 | 2.37 | 2 | 1.63 | 1.92 | 2.08 | 1.02 | 0.767 |
| 8.944 | 1.68 | 1.55 | 1.09 | 1.38 | 1.14 | 1.87 | 2.21 | 1.84 | 1.68 | 1.53 | 2.02 | 2.05 | 1.48 | 1.53 | 1.28 | 1.11 | 0.826 | 1.52 | 1.24 | 1.28 | 0.903 | 2.14 | 1.96 | 1.59 | 1.88 | 2.01 | 1.02 | 0.808 |
| 9.819 | 1.72 | 1.55 | 1.03 | 1.34 | 1.06 | 1.96 | 2.32 | 1.83 | 1.66 | 1.46 | 1.96 | 2.02 | 1.43 | 1.49 | 1.27 | 1.1 | 0.831 | 1.49 | 1.25 | 1.25 | 0.892 | 1.92 | 1.93 | 1.56 | 1.85 | 1.96 | 1.02 | 0.851 |
| 10.78 | 1.78 | 1.57 | 1.01 | 1.32 | 1.01 | 2.05 | 2.45 | 1.9 | 1.66 | 1.41 | 1.91 | 2 | 1.4 | 1.48 | 1.28 | 1.12 | 0.841 | 1.48 | 1.26 | 1.24 | 0.896 | 1.73 | 1.91 | 1.55 | 1.83 | 1.92 | 1.03 | 0.895 |
| 11.83 | 1.84 | 1.61 | 1.02 | 1.35 | 0.98 | 2.13 | 2.59 | 1.98 | 1.67 | 1.38 | 1.89 | 1.98 | 1.4 | 1.49 | 1.3 | 1.15 | 0.857 | 1.51 | 1.29 | 1.26 | 0.919 | 1.64 | 1.92 | 1.58 | 1.83 | 1.9 | 1.06 | 0.941 |
| 12.99 | 1.91 | 1.67 | 1.05 | 1.44 | 0.93 | 2.21 | 2.75 | 2.09 | 1.7 | 1.39 | 1.89 | 1.98 | 1.41 | 1.52 | 1.34 | 1.2 | 0.875 | 1.55 | 1.33 | 1.3 | 0.958 | 1.7 | 1.94 | 1.65 | 1.85 | 1.89 | 1.11 | 0.987 |
| 14.26 | 1.96 | 1.72 | 1.06 | 1.55 | 0.86 | 2.28 | 2.89 | 2.21 | 1.74 | 1.42 | 1.9 | 1.95 | 1.42 | 1.55 | 1.38 | 1.24 | 0.884 | 1.59 | 1.36 | 1.35 | 1 | 1.89 | 1.95 | 1.73 | 1.86 | 1.88 | 1.16 | 1.03 |
| 15.65 | 1.99 | 1.75 | 1.01 | 1.62 | 0.73 | 2.32 | 3.01 | 2.3 | 1.78 | 1.45 | 1.88 | 1.89 | 1.39 | 1.54 | 1.41 | 1.25 | 0.875 | 1.63 | 1.37 | 1.39 | 1.04 | 2.11 | 1.92 | 1.8 | 1.84 | 1.83 | 1.22 | 1.07 |
| 17.18 | 1.97 | 1.73 | 0.91 | 1.57 | 0.6 | 2.33 | 3.07 | 2.34 | 1.79 | 1.47 | 1.78 | 1.78 | 1.32 | 1.51 | 1.41 | 1.23 | 0.842 | 1.62 | 1.36 | 1.4 | 1.06 | 2.08 | 1.83 | 1.81 | 1.77 | 1.71 | 1.25 | 1.1 |
| 18.86 | 1.92 | 1.65 | 0.78 | 1.34 | 0.51 | 2.31 | 3.04 | 2.33 | 1.77 | 1.44 | 1.59 | 1.63 | 1.23 | 1.43 | 1.39 | 1.17 | 0.792 | 1.56 | 1.32 | 1.37 | 1.06 | 1.53 | 1.67 | 1.73 | 1.64 | 1.53 | 1.28 | 1.12 |
| 20.70 | 1.85 | 1.52 | 0.68 | 1.03 | 0.46 | 2.26 | 2.92 | 2.27 | 1.67 | 1.33 | 1.33 | 1.45 | 1.13 | 1.34 | 1.35 | 1.09 | 0.733 | 1.46 | 1.28 | 1.3 | 1.04 | 0.56 | 1.48 | 1.57 | 1.46 | 1.31 | 1.29 | 1.15 |
| 22.73 | 1.78 | 1.39 | 0.43 | 0.75 | 0.45 | 2.16 | 2.72 | 2.19 | 1.5 | 1.13 | 1.06 | 1.27 | 1.04 | 1.24 | 1.3 | 1.01 | 0.68 | 1.32 | 1.24 | 1.2 | 1.02 | 0.04 | 1.3 | 1.37 | 1.27 | 1.11 | 1.31 | 1.18 |
| 24.95 | 1.76 | 1.29 | 0.63 | 0.62 | 0.43 | 2.03 | 2.47 | 2.08 | 1.3 | 0.87 | 0.86 | 1.12 | 0.965 | 1.13 | 1.27 | 0.946 | 0.638 | 1.19 | 1.22 | 1.09 | 0.994 | 0.04 | 1.17 | 1.2 | 1.11 | 0.965 | 1.34 | 1.23 |
| 27.38 | 1.79 | 1.27 | 0.64 | 0.65 | 0.33 | 1.87 | 2.22 | 1.96 | 1.13 | 0.65 | 0.76 | 1.01 | 0.89 | 1.03 | 1.28 | 0.913 | 0.614 | 1.12 | 1.22 | 1.02 | 0.993 | 0.41 | 1.1 | 1.12 | 1.02 | 0.9 | 1.41 | 1.3 |
| 30.07 | 1.89 | 1.34 | 0.63 | 0.82 | 0.18 | 1.71 | 2.02 | 1.84 | 1.05 | 0.52 | 0.77 | 0.97 | 0.823 | 0.96 | 1.34 | 0.926 | 0.607 | 1.13 | 1.25 | 1.03 | 1.03 | 0.9 | 1.1 | 1.15 | 1.01 | 0.918 | 1.51 | 1.38 |
| 33.00 | 2.05 | 1.47 | 0.55 | 1.05 | 0.04 | 1.58 | 1.89 | 1.72 | 1.11 | 0.53 | 0.86 | 0.97 | 0.779 | 0.95 | 1.47 | 0.994 | 0.621 | 1.25 | 1.32 | 1.13 | 1.11 | 0.78 | 1.15 | 1.3 | 1.08 | 1 | 1.65 | 1.49 |
| 36.24 | 2.22 | 1.65 | 0.37 | 1.16 | 0.01 | 1.49 | 1.82 | 1.61 | 1.32 | 0.66 | 0.98 | 1.03 | 0.788 | 1 | 1.66 | 1.12 | 0.657 | 1.45 | 1.42 | 1.32 | 1.24 | 0.29 | 1.22 | 1.5 | 1.21 | 1.13 | 1.82 | 1.61 |
| 39.77 | 2.35 | 1.81 | 0.17 | 0.94 | 0 | 1.43 | 1.77 | 1.52 | 1.62 | 0.88 | 1.04 | 1.09 | 0.861 | 1.1 | 1.9 | 1.27 | 0.711 | 1.67 | 1.54 | 1.55 | 1.41 | 0.06 | 1.28 | 1.69 | 1.33 | 1.24 | 2.01 | 1.75 |
| 43.66 | 2.38 | 1.86 | 0.04 | 0.5 | 0 | 1.37 | 1.69 | 1.41 | 1.89 | 1.09 | 0.98 | 1.13 | 0.981 | 1.21 | 2.13 | 1.4 | 0.767 | 1.79 | 1.63 | 1.74 | 1.58 | 0.19 | 1.33 | 1.74 | 1.39 | 1.3 | 2.17 | 1.89 |
| 47.93 | 2.26 | 1.76 | 0 | 0.12 | 0 | 1.26 | 1.51 | 1.28 | 1.99 | 1.15 | 0.78 | 1.09 | 1.1 | 1.26 | 2.25 | 1.43 | 0.799 | 1.73 | 1.65 | 1.8 | 1.7 | 0.71 | 1.32 | 1.6 | 1.33 | 1.25 | 2.27 | 2.03 |
| 52.63 | 2.02 | 1.46 | 0 | 0.01 | 0 | 1.05 | 1.21 | 1.08 | 1.81 | 0.97 | 0.47 | 0.92 | 1.13 | 1.18 | 2.19 | 1.3 | 0.78 | 1.43 | 1.55 | 1.63 | 1.72 | 0.88 | 1.26 | 1.26 | 1.14 | 1.11 | 2.29 | 2.14 |
| 57.77 | 1.72 | 0.94 | 0 | 0 | 0 | 0.73 | 0.82 | 0.81 | 1.23 | 0.59 | 0.2 | 0.6 | 0.878 | 0.83 | 1.95 | 0.993 | 0.7 | 0.894 | 1.34 | 1.11 | 1.64 | 0.35 | 1.13 | 0.751 | 0.88 | 0.91 | 2.21 | 2.22 |
| 63.41 | 1.49 | 0.42 | 0 | 0 | 0 | 0.38 | 0.47 | 0.47 | 0.57 | 0.23 | 0.04 | 0.26 | 0.463 | 0.4 | 1.59 | 0.637 | 0.583 | 0.382 | 1.1 | 0.51 | 1.5 | 0.03 | 0.96 | 0.305 | 0.62 | 0.737 | 2.07 | 2.25 |
| 69.62 | 1.38 | 0.09 | 0 | 0 | 0 | 0.15 | 0.28 | 0.19 | 0.12 | 0.04 | 0 | 0.05 | 0.111 | 0.09 | 1.27 | 0.396 | 0.481 | 0.079 | 0.92 | 0.11 | 1.35 | 0 | 0.766 | 0.061 | 0.43 | 0.66 | 1.93 | 2.26 |
| 76.43 | 1.39 | 0.01 | 0 | 0 | 0 | 0.07 | 0.24 | 0.04 | 0.01 | 0 | 0 | 0.01 | 0.012 | 0.01 | 1.13 | 0.355 | 0.443 | 0.007 | 0.89 | 0.01 | 1.28 | 0 | 0.574 | 0.005 | 0.33 | 0.7 | 1.85 | 2.25 |
| 83.90 | 1.42 | 0 | 0 | 0 | 0 | 0.12 | 0.35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.24 | 0.557 | 0.498 | 0 | 1.03 | 0 | 1.32 | 0 | 0.353 | 0 | 0.24 | 0.828 | 1.87 | 2.25 |
| 92.09 | 1.32 | 0 | 0 | 0 | 0 | 0.27 | 0.55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.57 | 1.03 | 0.648 | 0 | 1.29 | 0 | 1.44 | 0 | 0.162 | 0 | 0.14 | 0.942 | 1.98 | 2.24 |
| 101.10 | 0.94 | 0 | 0 | 0 | 0 | 0.5 | 0.68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.01 | 1.61 | 0.857 | 0 | 1.55 | 0 | 1.59 | 0 | 0.036 | 0 | 0.04 | 0.896 | 2.11 | 2.22 |
| 111.00 | 0.44 | 0 | 0 | 0 | 0 | 0.65 | 0.56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.29 | 1.97 | 1.04 | 0 | 1.65 | 0 | 1.66 | 0 | 0.004 | 0 | 0.01 | 0.605 | 2.16 | 2.16 |
| 121.80 | 0.1 | 0 | 0 | 0 | 0 | 0.63 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.23 | 1.87 | 1.13 | 0 | 1.6 | 0 | 1.58 | 0 | 0 | 0 | 0 | 0.255 | 2.03 | 2.04 |
| 133.70 | 0.01 | 0 | 0 | 0 | 0 | 0.43 | 0.07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.89 | 1.47 | 1.11 | 0 | 1.55 | 0 | 1.36 | 0 | 0 | 0 | 0 | 0.051 | 1.71 | 1.84 |
| 146.80 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.5 | 1.09 | 1.01 | 0 | 1.71 | 0 | 1.1 | 0 | 0 | 0 | 0 | 0.004 | 1.31 | 1.6 |
| 161.20 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.27 | 1.03 | 0.904 | 0 | 2.15 | 0 | 0.893 | 0 | 0 | 0 | 0 | 0 | 0.949 | 1.37 |
| 176.80 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.27 | 1.34 | 0.857 | 0 | 2.74 | 0 | 0.764 | 0 | 0 | 0 | 0 | 0 | 0.74 | 1.18 |
| 194.20 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.4 | 1.89 | 0.881 | 0 | 3.12 | 0 | 0.699 | 0 | 0 | 0 | 0 | 0 | 0.695 | 1.06 |
| 213.20 | 0 | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.44 | 2.34 | 0.964 | 0 | 2.96 | 0 | 0.665 | 0 | 0 | 0 | 0 | 0 | 0.78 | 1 |
| 234.10 | 0 | 0 | 0 | 0 | 0 | 0.42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.24 | 2.28 | 1.07 | 0 | 2.21 | 0 | 0.64 | 0 | 0 | 0 | 0 | 0 | 0.921 | 0.987 |
| 256.80 | 0 | 0 | 0 | 0 | 0 | 0.73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.77 | 1.67 | 1.17 | 0 | 1.18 | 0 | 0.641 | 0 | 0 | 0 | 0 | 0 | 1.03 | 0.991 |
| 282.10 | 0 | 0 | 0 | 0 | 0 | 0.92 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.31 | 0.838 | 1.26 | 0 | 0.4 | 0 | 0.699 | 0 | 0 | 0 | 0 | 0 | 1.06 | 0.99 |
| 309.60 | 0 | 0 | 0 | 0 | 0 | 0.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.06 | 0.249 | 1.32 | 0 | 0.07 | 0 | 0.826 | 0 | 0 | 0 | 0 | 0 | 1.02 | 0.978 |
| 339.80 | 0 | 0 | 0 | 0 | 0 | 0.68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.036 | 1.37 | 0 | 0 | 0 | 0.989 | 0 | 0 | 0 | 0 | 0 | 0.959 | 0.955 |
| 373.10 | 0 | 0 | 0 | 0 | 0 | 0.44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 | 1.41 | 0 | 0 | 0 | 1.12 | 0 | 0 | 0 | 0 | 0 | 0.935 | 0.933 |
| 409.60 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.43 | 0 | 0 | 0 | 1.14 | 0 | 0 | 0 | 0 | 0 | 0.981 | 0.922 |
| 449.70 | 0 | 0 | 0 | 0 | 0 | 0.43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.45 | 0 | 0 | 0 | 1.04 | 0 | 0 | 0 | 0 | 0 | 1.1 | 0.934 |
| 493.60 | 0 | 0 | 0 | 0 | 0 | 0.88 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.46 | 0 | 0 | 0 | 0.906 | 0 | 0 | 0 | 0 | 0 | 1.27 | 0.973 |
| 541.90 | 0 | 0 | 0 | 0 | 0 | 1.69 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.48 | 0 | 0 | 0 | 0.844 | 0 | 0 | 0 | 0 | 0 | 1.44 | 1.05 |
| 594.90 | 0 | 0 | 0 | 0 | 0 | 2.65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.52 | 0 | 0 | 0 | 0.947 | 0 | 0 | 0 | 0 | 0 | 1.55 | 1.16 |
| 653.00 | 0 | 0 | 0 | 0 | 0 | 3.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.59 | 0 | 0 | 0 | 1.24 | 0 | 0 | 0 | 0 | 0 | 1.57 | 1.3 |
| 716.90 | 0 | 0 | 0 | 0 | 0 | 3.54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.68 | 0 | 0 | 0 | 1.69 | 0 | 0 | 0 | 0 | 0 | 1.5 | 1.46 |
| 786.90 | 0 | 0 | 0 | 0 | 0 | 2.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.81 | 0 | 0 | 0 | 2.19 | 0 | 0 | 0 | 0 | 0 | 1.33 | 1.62 |
| 863.90 | 0 | 0 | 0 | 0 | 0 | 1.39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.02 | 0 | 0 | 0 | 2.59 | 0 | 0 | 0 | 0 | 0 | 1.11 | 1.79 |
| 948.20 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.34 | 0 | 0 | 0 | 2.83 | 0 | 0 | 0 | 0 | 0 | 0.849 | 1.96 |
| 1041.0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.78 | 0 | 0 | 0 | 2.84 | 0 | 0 | 0 | 0 | 0 | 0.557 | 2.1 |
| 1143.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.32 | 0 | 0 | 0 | 2.19 | 0 | 0 | 0 | 0 | 0 | 0.278 | 2.23 |
| 1255.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.86 | 0 | 0 | 0 | 1.19 | 0 | 0 | 0 | 0 | 0 | 0.09 | 2.32 |
| 1377.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.29 | 0 | 0 | 0 | 0.295 | 0 | 0 | 0 | 0 | 0 | 0.015 | 2.38 |
| 1512.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.43 | 0 | 0 | 0 | 0.033 | 0 | 0 | 0 | 0 | 0 | 0.001 | 2.36 |
| 1660.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.31 |
| 1822.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.24 |
| 2000.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 2. Grain size distribution of the clay separates**

| | S02h | | | | | S02b | | S06h | | S06b | | | | S09 | I01 | | | | | I02 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| grain size classes | Ah 0 - 9 | AB 9 - 16 | 'pocket' 16 - 40 | B 40 - 68+ | 'under rock' 68+ | Ah 0 - 19 | BA 19 - 30 | Ah 0 - 11/15 | Bwg 26 - 56/80 | Ah1 0 - 5/10 | Ah2 5/10 - 60 | Ah3 60 - 110/130 | C 110/130 - 140 | S09, sapr | Ah 0 - 63/68 | Bw 63/68 - 72/80 | 2Ah 72/80 - 110/114 | 2C1 110/114 - 123/130 | 2C2 123/130 - 154+ | Ap 0 -22 | 2Bwg1 22 - 46 | 2Bwg2 46 - 65/70 | 2CBwg 65/70 - 87/95 | 2R 87 - 95+ |
| 0.040 | 0.045 | 0.077 | 0.054 | 0.059 | 0.082 | 0.061 | 0.057 | 0.066 | 0.031 | 0.050 | 0.048 | 0.056 | 0.052 | 0.035 | 0.029 | 0.031 | 0.038 | 0.030 | 0.034 | 0.040 | 0.046 | 0.043 | 0.040 | 0.020 |
| 0.044 | 0.076 | 0.132 | 0.092 | 0.100 | 0.139 | 0.104 | 0.097 | 0.112 | 0.053 | 0.086 | 0.083 | 0.095 | 0.088 | 0.060 | 0.050 | 0.053 | 0.065 | 0.052 | 0.059 | 0.069 | 0.079 | 0.074 | 0.069 | 0.035 |
| 0.048 | 0.148 | 0.256 | 0.181 | 0.195 | 0.272 | 0.203 | 0.189 | 0.219 | 0.104 | 0.167 | 0.162 | 0.185 | 0.173 | 0.116 | 0.098 | 0.103 | 0.127 | 0.102 | 0.116 | 0.135 | 0.153 | 0.144 | 0.136 | 0.068 |
| 0.053 | 0.311 | 0.538 | 0.379 | 0.410 | 0.571 | 0.427 | 0.396 | 0.459 | 0.219 | 0.351 | 0.339 | 0.389 | 0.362 | 0.244 | 0.205 | 0.216 | 0.266 | 0.215 | 0.244 | 0.283 | 0.322 | 0.302 | 0.284 | 0.142 |
| 0.058 | 0.598 | 1.030 | 0.729 | 0.787 | 1.100 | 0.820 | 0.761 | 0.883 | 0.421 | 0.675 | 0.651 | 0.747 | 0.695 | 0.469 | 0.393 | 0.416 | 0.511 | 0.412 | 0.468 | 0.544 | 0.619 | 0.580 | 0.546 | 0.273 |
| 0.064 | 0.865 | 1.490 | 1.060 | 1.140 | 1.590 | 1.180 | 1.100 | 1.270 | 0.610 | 0.977 | 0.944 | 1.080 | 1.010 | 0.684 | 0.576 | 0.606 | 0.744 | 0.601 | 0.683 | 0.792 | 0.900 | 0.844 | 0.797 | 0.401 |
| 0.070 | 1.080 | 1.850 | 1.320 | 1.430 | 1.980 | 1.470 | 1.370 | 1.570 | 0.765 | 1.220 | 1.180 | 1.350 | 1.260 | 0.862 | 0.730 | 0.764 | 0.935 | 0.759 | 0.863 | 0.998 | 1.130 | 1.060 | 1.010 | 0.510 |
| 0.077 | 1.200 | 2.060 | 1.490 | 1.610 | 2.220 | 1.640 | 1.530 | 1.750 | 0.866 | 1.370 | 1.330 | 1.510 | 1.420 | 0.981 | 0.836 | 0.869 | 1.060 | 0.868 | 0.985 | 1.130 | 1.270 | 1.210 | 1.150 | 0.588 |
| 0.084 | 1.350 | 2.300 | 1.690 | 1.820 | 2.490 | 1.830 | 1.710 | 1.950 | 0.984 | 1.540 | 1.490 | 1.700 | 1.600 | 1.120 | 0.957 | 0.990 | 1.200 | 0.993 | 1.130 | 1.290 | 1.440 | 1.370 | 1.310 | 0.678 |
| 0.093 | 1.460 | 2.490 | 1.850 | 1.990 | 2.710 | 1.990 | 1.860 | 2.100 | 1.080 | 1.690 | 1.630 | 1.850 | 1.760 | 1.240 | 1.070 | 1.100 | 1.330 | 1.110 | 1.250 | 1.430 | 1.590 | 1.520 | 1.460 | 0.765 |
| 0.102 | 1.530 | 2.580 | 1.950 | 2.100 | 2.840 | 2.070 | 1.940 | 2.180 | 1.150 | 1.780 | 1.720 | 1.950 | 1.860 | 1.340 | 1.160 | 1.190 | 1.420 | 1.200 | 1.350 | 1.540 | 1.700 | 1.630 | 1.580 | 0.840 |
| 0.112 | 1.540 | 2.570 | 1.990 | 2.130 | 2.860 | 2.070 | 1.950 | 2.160 | 1.190 | 1.800 | 1.750 | 1.970 | 1.900 | 1.400 | 1.230 | 1.240 | 1.470 | 1.260 | 1.420 | 1.600 | 1.750 | 1.690 | 1.650 | 0.899 |
| 0.123 | 1.510 | 2.490 | 1.990 | 2.120 | 2.810 | 2.020 | 1.910 | 2.080 | 1.210 | 1.790 | 1.740 | 1.940 | 1.900 | 1.440 | 1.290 | 1.280 | 1.500 | 1.300 | 1.460 | 1.640 | 1.770 | 1.730 | 1.700 | 0.952 |
| 0.134 | 1.480 | 2.380 | 1.970 | 2.100 | 2.730 | 1.960 | 1.860 | 1.990 | 1.220 | 1.770 | 1.720 | 1.910 | 1.890 | 1.480 | 1.340 | 1.320 | 1.520 | 1.350 | 1.510 | 1.670 | 1.790 | 1.760 | 1.740 | 1.010 |
| 0.148 | 1.440 | 2.250 | 1.920 | 2.040 | 2.610 | 1.880 | 1.790 | 1.870 | 1.230 | 1.730 | 1.690 | 1.860 | 1.870 | 1.510 | 1.400 | 1.360 | 1.530 | 1.390 | 1.540 | 1.690 | 1.810 | 1.780 | 1.780 | 1.070 |
| 0.162 | 1.390 | 2.100 | 1.860 | 1.960 | 2.460 | 1.790 | 1.720 | 1.750 | 1.230 | 1.680 | 1.660 | 1.810 | 1.830 | 1.550 | 1.470 | 1.400 | 1.540 | 1.430 | 1.570 | 1.710 | 1.810 | 1.800 | 1.800 | 1.130 |
| 0.178 | 1.340 | 1.930 | 1.770 | 1.860 | 2.270 | 1.680 | 1.630 | 1.610 | 1.220 | 1.620 | 1.610 | 1.740 | 1.790 | 1.580 | 1.540 | 1.450 | 1.540 | 1.460 | 1.600 | 1.720 | 1.810 | 1.810 | 1.820 | 1.190 |
| 0.195 | 1.320 | 1.800 | 1.700 | 1.770 | 2.100 | 1.620 | 1.580 | 1.510 | 1.240 | 1.580 | 1.590 | 1.700 | 1.760 | 1.620 | 1.620 | 1.510 | 1.550 | 1.510 | 1.630 | 1.750 | 1.830 | 1.830 | 1.840 | 1.270 |
| 0.214 | 1.360 | 1.760 | 1.660 | 1.720 | 1.990 | 1.630 | 1.600 | 1.500 | 1.280 | 1.590 | 1.620 | 1.720 | 1.780 | 1.710 | 1.740 | 1.620 | 1.600 | 1.580 | 1.690 | 1.810 | 1.890 | 1.890 | 1.880 | 1.360 |
| 0.235 | 1.470 | 1.820 | 1.680 | 1.730 | 1.970 | 1.740 | 1.700 | 1.580 | 1.360 | 1.660 | 1.720 | 1.820 | 1.860 | 1.830 | 1.880 | 1.760 | 1.700 | 1.690 | 1.780 | 1.910 | 2.010 | 1.990 | 1.960 | 1.480 |
| 0.258 | 1.650 | 1.980 | 1.740 | 1.780 | 2.010 | 1.920 | 1.890 | 1.760 | 1.480 | 1.790 | 1.880 | 1.990 | 1.990 | 1.990 | 2.060 | 1.940 | 1.820 | 1.810 | 1.890 | 2.050 | 2.180 | 2.130 | 2.060 | 1.620 |
| 0.284 | 1.870 | 2.180 | 1.820 | 1.850 | 2.090 | 2.140 | 2.110 | 1.970 | 1.610 | 1.940 | 2.070 | 2.190 | 2.150 | 2.160 | 2.250 | 2.140 | 1.970 | 1.940 | 2.010 | 2.200 | 2.350 | 2.280 | 2.160 | 1.760 |
| 0.311 | 2.100 | 2.380 | 1.900 | 1.920 | 2.170 | 2.370 | 2.340 | 2.190 | 1.740 | 2.110 | 2.260 | 2.390 | 2.290 | 2.330 | 2.440 | 2.340 | 2.110 | 2.070 | 2.120 | 2.340 | 2.510 | 2.410 | 2.260 | 1.910 |
| 0.342 | 2.300 | 2.510 | 1.970 | 1.970 | 2.210 | 2.550 | 2.540 | 2.350 | 1.860 | 2.240 | 2.420 | 2.550 | 2.400 | 2.470 | 2.600 | 2.500 | 2.230 | 2.180 | 2.200 | 2.450 | 2.610 | 2.500 | 2.320 | 2.020 |
| 0.375 | 2.450 | 2.560 | 2.000 | 1.980 | 2.190 | 2.650 | 2.680 | 2.430 | 1.940 | 2.320 | 2.530 | 2.640 | 2.450 | 2.550 | 2.730 | 2.620 | 2.320 | 2.270 | 2.240 | 2.510 | 2.650 | 2.540 | 2.330 | 2.110 |
| 0.412 | 2.530 | 2.520 | 1.980 | 1.950 | 2.100 | 2.660 | 2.740 | 2.440 | 1.980 | 2.350 | 2.580 | 2.660 | 2.440 | 2.580 | 2.800 | 2.690 | 2.350 | 2.320 | 2.220 | 2.510 | 2.630 | 2.510 | 2.290 | 2.140 |
| 0.452 | 2.560 | 2.430 | 1.920 | 1.880 | 1.980 | 2.620 | 2.750 | 2.400 | 1.970 | 2.330 | 2.560 | 2.610 | 2.390 | 2.560 | 2.830 | 2.710 | 2.340 | 2.340 | 2.150 | 2.450 | 2.560 | 2.450 | 2.210 | 2.130 |
| 0.496 | 2.560 | 2.330 | 1.830 | 1.800 | 1.850 | 2.540 | 2.720 | 2.360 | 1.950 | 2.280 | 2.510 | 2.530 | 2.300 | 2.520 | 2.790 | 2.700 | 2.290 | 2.320 | 2.040 | 2.350 | 2.490 | 2.360 | 2.100 | 2.080 |
| 0.545 | 2.570 | 2.250 | 1.750 | 1.740 | 1.750 | 2.460 | 2.700 | 2.360 | 1.940 | 2.240 | 2.440 | 2.440 | 2.210 | 2.480 | 2.720 | 2.660 | 2.220 | 2.270 | 1.920 | 2.230 | 2.440 | 2.270 | 1.980 | 2.010 |
| 0.598 | 2.600 | 2.220 | 1.670 | 1.690 | 1.690 | 2.410 | 2.690 | 2.400 | 1.960 | 2.230 | 2.400 | 2.370 | 2.130 | 2.450 | 2.610 | 2.620 | 2.120 | 2.190 | 1.800 | 2.110 | 2.410 | 2.200 | 1.880 | 1.950 |
| 0.657 | 2.670 | 2.230 | 1.630 | 1.670 | 1.660 | 2.390 | 2.700 | 2.470 | 2.010 | 2.240 | 2.380 | 2.340 | 2.080 | 2.450 | 2.520 | 2.580 | 2.050 | 2.120 | 1.710 | 2.030 | 2.430 | 2.170 | 1.820 | 1.920 |
| 0.721 | 2.770 | 2.270 | 1.630 | 1.690 | 1.660 | 2.410 | 2.730 | 2.540 | 2.120 | 2.270 | 2.400 | 2.370 | 2.070 | 2.500 | 2.500 | 2.590 | 2.040 | 2.080 | 1.690 | 2.010 | 2.490 | 2.190 | 1.830 | 1.980 |
| 0.791 | 2.920 | 2.350 | 1.690 | 1.770 | 1.720 | 2.460 | 2.790 | 2.630 | 2.300 | 2.350 | 2.480 | 2.460 | 2.120 | 2.590 | 2.570 | 2.650 | 2.120 | 2.100 | 1.780 | 2.080 | 2.610 | 2.280 | 1.940 | 2.130 |
| 0.869 | 3.120 | 2.480 | 1.830 | 1.910 | 1.830 | 2.570 | 2.880 | 2.740 | 2.570 | 2.470 | 2.610 | 2.600 | 2.240 | 2.750 | 2.750 | 2.800 | 2.320 | 2.200 | 1.980 | 2.260 | 2.800 | 2.470 | 2.150 | 2.390 |
| 0.953 | 3.360 | 2.650 | 2.040 | 2.130 | 2.000 | 2.740 | 3.000 | 2.900 | 2.910 | 2.650 | 2.790 | 2.810 | 2.430 | 2.960 | 3.020 | 3.010 | 2.610 | 2.390 | 2.290 | 2.520 | 3.040 | 2.730 | 2.470 | 2.760 |
| 1.047 | 3.630 | 2.850 | 2.320 | 2.410 | 2.240 | 2.960 | 3.160 | 3.100 | 3.310 | 2.880 | 3.040 | 3.060 | 2.690 | 3.220 | 3.350 | 3.280 | 2.980 | 2.650 | 2.710 | 2.870 | 3.330 | 3.060 | 2.880 | 3.220 |
| 1.149 | 3.890 | 3.050 | 2.640 | 2.730 | 2.510 | 3.190 | 3.330 | 3.330 | 3.760 | 3.150 | 3.320 | 3.320 | 3.000 | 3.500 | 3.700 | 3.580 | 3.380 | 2.960 | 3.190 | 3.260 | 3.620 | 3.420 | 3.330 | 3.730 |
| 1.261 | 4.110 | 3.210 | 2.990 | 3.060 | 2.780 | 3.390 | 3.490 | 3.550 | 4.230 | 3.420 | 3.600 | 3.540 | 3.320 | 3.770 | 4.010 | 3.850 | 3.790 | 3.310 | 3.690 | 3.660 | 3.870 | 3.770 | 3.790 | 4.240 |
| 1.385 | 4.230 | 3.290 | 3.310 | 3.370 | 3.030 | 3.540 | 3.590 | 3.720 | 4.660 | 3.660 | 3.830 | 3.680 | 3.620 | 3.980 | 4.230 | 4.070 | 4.130 | 3.670 | 4.150 | 4.000 | 4.010 | 4.040 | 4.190 | 4.700 |
| 1.520 | 4.230 | 3.250 | 3.580 | 3.630 | 3.220 | 3.590 | 3.610 | 3.810 | 5.000 | 3.830 | 3.970 | 3.690 | 3.840 | 4.100 | 4.310 | 4.190 | 4.360 | 4.000 | 4.510 | 4.230 | 4.010 | 4.190 | 4.460 | 5.040 |
| 1.669 | 4.070 | 3.070 | 3.760 | 3.800 | 3.300 | 3.520 | 3.520 | 3.770 | 5.170 | 3.910 | 3.970 | 3.560 | 3.940 | 4.070 | 4.220 | 4.190 | 4.450 | 4.240 | 4.720 | 4.300 | 3.860 | 4.170 | 4.560 | 5.200 |
| 1.832 | 3.750 | 2.780 | 3.830 | 3.850 | 3.260 | 3.320 | 3.300 | 3.570 | 5.150 | 3.840 | 3.820 | 3.290 | 3.910 | 3.900 | 3.960 | 4.050 | 4.350 | 4.350 | 4.730 | 4.200 | 3.550 | 3.980 | 4.460 | 5.170 |
| 2.010 | 3.300 | 2.380 | 3.780 | 3.770 | 3.100 | 3.000 | 2.940 | 3.190 | 4.920 | 3.630 | 3.520 | 2.910 | 3.730 | 3.580 | 3.550 | 3.750 | 4.080 | 4.290 | 4.550 | 3.920 | 3.090 | 3.620 | 4.160 | 4.910 |
| 2.207 | 2.760 | 1.930 | 3.610 | 3.550 | 2.810 | 2.570 | 2.460 | 2.660 | 4.490 | 3.270 | 3.090 | 2.460 | 3.390 | 3.120 | 3.030 | 3.310 | 3.650 | 4.050 | 4.160 | 3.470 | 2.520 | 3.100 | 3.670 | 4.450 |
| 2.423 | 2.160 | 1.480 | 3.330 | 3.200 | 2.400 | 2.070 | 1.910 | 2.040 | 3.860 | 2.790 | 2.530 | 1.970 | 2.880 | 2.580 | 2.440 | 2.760 | 3.100 | 3.640 | 3.620 | 2.890 | 1.880 | 2.470 | 3.020 | 3.830 |
| 2.660 | 1.580 | 1.080 | 2.960 | 2.750 | 1.900 | 1.550 | 1.340 | 1.410 | 3.070 | 2.230 | 1.900 | 1.500 | 2.230 | 2.000 | 1.830 | 2.130 | 2.470 | 3.070 | 2.960 | 2.230 | 1.240 | 1.770 | 2.280 | 3.090 |
| 2.920 | 1.060 | 0.779 | 2.520 | 2.240 | 1.350 | 1.060 | 0.815 | 0.819 | 2.210 | 1.650 | 1.270 | 1.080 | 1.520 | 1.430 | 1.250 | 1.490 | 1.810 | 2.400 | 2.250 | 1.550 | 0.691 | 1.110 | 1.530 | 2.320 |
| 3.206 | 0.643 | 0.563 | 2.060 | 1.700 | 0.837 | 0.644 | 0.387 | 0.363 | 1.390 | 1.100 | 0.721 | 0.727 | 0.857 | 0.933 | 0.756 | 0.900 | 1.190 | 1.690 | 1.560 | 0.936 | 0.294 | 0.543 | 0.859 | 1.600 |
| 3.519 | 0.354 | 0.416 | 1.610 | 1.210 | 0.406 | 0.329 | 0.125 | 0.102 | 0.685 | 0.638 | 0.316 | 0.460 | 0.364 | 0.540 | 0.382 | 0.425 | 0.669 | 1.050 | 0.963 | 0.445 | 0.083 | 0.187 | 0.369 | 0.985 |
| 3.862 | 0.189 | 0.304 | 1.190 | 0.784 | 0.137 | 0.129 | 0.021 | 0.014 | 0.241 | 0.307 | 0.094 | 0.267 | 0.099 | 0.278 | 0.146 | 0.139 | 0.297 | 0.590 | 0.506 | 0.146 | 0.012 | 0.033 | 0.101 | 0.538 |
| 4.241 | 0.114 | 0.186 | 0.815 | 0.473 | 0.024 | 0.033 | 0.001 | 0.001 | 0.043 | 0.139 | 0.014 | 0.128 | 0.014 | 0.134 | 0.036 | 0.023 | 0.121 | 0.357 | 0.208 | 0.025 | 0.001 | 0.002 | 0.014 | 0.270 |
| 4.656 | 0.092 | 0.083 | 0.508 | 0.272 | 0.002 | 0.004 | 0.000 | 0.000 | 0.003 | 0.083 | 0.001 | 0.046 | 0.001 | 0.073 | 0.005 | 0.002 | 0.068 | 0.293 | 0.059 | 0.002 | 0.000 | 0.000 | 0.001 | 0.149 |
| 5.111 | 0.093 | 0.018 | 0.268 | 0.164 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.101 | 0.000 | 0.008 | 0.000 | 0.055 | 0.002 | 0.000 | 0.097 | 0.352 | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 | 0.119 |
| 5.611 | 0.095 | 0.002 | 0.109 | 0.114 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.149 | 0.000 | 0.001 | 0.000 | 0.052 | 0.000 | 0.000 | 0.158 | 0.434 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.138 |
| 6.158 | 0.072 | 0.000 | 0.028 | 0.077 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.158 | 0.000 | 0.000 | 0.000 | 0.039 | 0.000 | 0.000 | 0.174 | 0.393 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.176 |
| 6.761 | 0.036 | 0.000 | 0.004 | 0.042 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.102 | 0.000 | 0.000 | 0.000 | 0.018 | 0.000 | 0.000 | 0.111 | 0.229 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.199 |
| 7.421 | 0.008 | 0.000 | 0.001 | 0.011 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.028 | 0.000 | 0.000 | 0.000 | 0.004 | 0.000 | 0.000 | 0.030 | 0.059 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.182 |
| 8.147 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.000 | 0.000 | 0.000 | 0.003 | 0.000 | 0.000 | 0.003 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.118 |
| 8.944 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.050 |
| 9.819 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 |
| 10.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |

**Appendix VIII**

List of bulk samples (and sub-samples) and analysis done
List of micromorphological samples

| | | | | | | Chemical analysis (see results) | Clay mineralogy | | | | | | Texture | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| labcode | Pers. labnr. | New profile name | profile | horizon | depth | | Mg | Mg + glyc. | K (150 degrees C) | Mg + form. | Mg + form. + 150 degr. C | Mg + 150 degree C | < 2 mm | clay separate |
| 95/ 1123 | | *S01* | H1 | Ah | 0-15/20 | x | x | x | - | - | - | - | x | x |
| 95/ 1124 | | | | BA | 15/20--35 | x | x | - | - | - | - | - | x | x |
| 95/ 1125 | | | | Bwg | 35--90+ | x | x | x | - | - | - | - | x | - |
| 95/ 1126 | | *S02b* | H2 | Ah | 0-19 | x | x | x | x | - | - | - | x | x |
| 95/ 1127 | | | | BA | 19-30 | x | x | x | x | - | - | x | x | x |
| 95/ 1128 | | | | Bcg | 30-79 | x | x | x | - | - | - | x | x | - |
| 96/ 5 | A1 | *S02h* | H2B | Ah | 0-9 | x | x | x | - | - | - | - | x | x |
| 96/ 6 | A2 | | | AB | 9-16 | x | x | x | - | - | - | - | x | x |
| 96/ 7 | A3 | | | pocket | 16-40 | x | x | x | - | - | - | - | x | x |
| 96/ 8 | A4 | | | B | 40-68 | x | x | x | - | - | - | - | x | x |
| 96/ 9 | A5 | | | under rock | -40 | x | x | x | - | - | - | - | x | x |
| 96/ 10 | B1 | *S09* | H2C | Ah | 0-15 | x | x | - | - | - | - | - | x | - |
| 96/ 11 | B2 | | | sapr. | 15+ | x | x | x | x | - | - | - | x | x |
| 95/ 1129 | | *S03* | H3 | Ah | 0-12 | x | x | - | - | - | - | - | x | - |
| 95/ 1130 | | | | Bw | 12-16 | x | - | - | - | - | - | - | - | - |
| 95/ 1131 | | | | BC | 16-27 | x | x | x | - | - | - | - | x | x |
| 95/ 1132 | | *S04b* | H4 | | 0-40 | x | x | x | - | - | - | - | x | x |
| 95/ 1133 | | | | | 40-75 | x | x | x | x | - | - | - | x | x |
| 96/ 12 | C1 | *S04h* | H4B | Ah1 | 0-17 | x | x | x | - | - | - | - | x | x |
| 96/ 13 | C2 | | | Ah2 | 17-32 | x | x | - | - | - | - | - | x | x |
| 96/ 14 | C3 | | | Bwg | 32-55 | x | x | x | - | - | - | - | x | x |
| 96/ 15 | C4 | | | R | 55-57 | x | - | - | - | - | - | - | - | - |
| 95/ 1134 | | *S05h* | H5 | Ah | 0-16 | x | x | - | - | - | - | - | x | x |
| 95/ 1135 | | | | Bw | 16-32 | x | x | - | - | - | - | - | x | - |
| 95/ 1136 | | | | Bwg | 32-60 | x | x | - | - | - | - | - | x | x |
| 95/ 1137 | | | | CBg | 60-90/100 | x | x | - | - | - | - | - | x | - |
| 96/ 16 | D1 | | | clay fill-in | 70 | x | x | x | - | - | - | - | x | x |
| 96/ 17 | E1 | *S05b* | H5B | Ah | 0-35 | x | x | x | x | - | - | - | x | x |
| 96/ 18 | E2 | | | B | 35-48/55 | x | - | - | - | - | - | - | x | - |
| 96/ 19 | E3 | | | BCwg1 | 48/55-95/100 | x | x | - | - | - | - | - | x | x |
| 96/ 20 | E4 | | | BCwg2 | 95/100-104 | x | x | - | - | - | - | - | x | x |
| 96/ 21 | E5 | | | BCwg2 | grey bound | x | - | - | - | - | - | - | - | - |
| 95/ 1138 | | *S06h* | H6 | Ah | 0-11/15 | x | x | x | x | x | x | x | x | x |
| 95/ 1139 | | | | B | 11/15-26 | x | x | x | - | - | - | - | x | - |
| 95/ 1140 | | | | Bwg | 26-56/80 | x | x | x | - | x | x | x | x | x |
| 96/ 22 | F1 | *S06b* | H6B | Ah1 | 0-5 | x | x | x | - | - | - | - | x | x |
| 96/ 23 | F2 | | | Ah2 | 5-60 | x | x | x | - | - | - | - | x | x |
| 96/ 24 | F3 | | | Ah3 | 60-110/130 | x | x | x | - | - | - | - | x | x |
| 96/ 25 | F4 | | | C | 110/130-140 | x | x | x | - | - | - | - | x | x |
| 96/ 26 | G1 | - | H6C | under verti. | - | x | - | - | - | - | - | - | - | - |
| 95/ 1141 | | *S08h* | H8 | | 0-7/40 | x | - | - | - | - | - | - | x | x |
| 95/ 1142 | | | | pocket | 25-45 | x | x | - | - | - | - | - | x | x |
| 95/ ? | | | | | 7/50+ | - | x | x | - | - | - | - | x | x |
| 96/ 27 | H1 | *S08b* | H8B | Ah2 | 3/8-21 | x | x | x | - | - | - | - | x | x |
| 96/ 28 | H2 | | | Bwg1 | 21-44 | x | x | - | - | - | - | - | x | x |
| 96/ 29 | H3 | | | Bwg2 | 44-68/72 | x | x | x | - | - | - | - | x | x |
| 96/ 30 | H4 | | | Bwg3 | 68/72-102+ | x | x | x | - | - | - | - | x | x |
| 96/ 31 | H5 | | | drillsample | ca. 185/210 | x | x | x | - | - | - | - | x | x |
| 96/ 32 | I1 | *S07h* | H9 | Ah | 0-13 | x | x | x | - | - | - | - | x | x |
| 96/ 33 | I2 | | | Bwg | 13-32/56 | x | x | x | - | - | - | - | x | x |
| 96/ 34 | I3 | | | Cg | 32/56-100 | x | x | - | - | - | - | - | x | x |
| 96/ 39 | I4 | | | rock | 55 | x | - | - | - | - | - | - | - | - |
| 96/ 35 | J1 | *S07b* | H9B | Ah | 0-15/26 | x | x | x | - | - | - | - | x | x |
| 96/ 36 | J2 | | | Bwg | 15/26-79 | x | x | x | - | - | - | - | x | x |
| 96/ 37 | J3 | | | Bw | 79-136/139 | x | x | x | - | - | - | - | x | x |
| 96/ 38 | J4 | | | rock | 136/139+ | x | - | - | - | - | - | - | - | - |
| 96/ 40 | K1 | *I01* | IC 1 | Ah | 0-63/68 | x | x | x | - | - | - | - | x | x |
| 96/ 41 | K2 | | | Bw | 63/68-72/80 | x | x | x | - | - | - | - | x | x |
| 96/ 42 | K3 | | | 2Ah | 72/86-110/114 | x | x | x | - | - | - | - | x | x |
| 96/ 43 | K4 | | | C1 | 110/114-123/130 | x | x | x | - | - | - | - | x | x |
| 96/ 44 | K5 | | | C2 | -120/130-150+ | x | x | x | - | - | - | - | x | x |
| 96/ 45 | L1 | - | IC 1/2 | wall | igrimbrite | x | - | - | - | - | - | - | x | - |
| 96/ 46 | M1 | *I02* | IC 2 | Ap | 0-22 | x | x | x | - | - | - | - | x | x |
| 96/ 47 | M2 | | | Bwg1 | 22-46 | x | x | x | - | - | x | - | x | x |
| 96/ 48 | M3 | | | Bwg2 | 46-65/70 | x | x | x | - | x | x | - | x | x |
| 96/ 49 | M4 | | | CB | 65/70-87/95 | x | x | x | - | x | x | x | x | x |
| 96/ 50 | M5 | | | R1 | 87/95+ | x | x | x | - | x | x | - | x | x |
| 96/ 51 | N1 | *I03* | IC 3 | Ah1 | 0-19 | x | x | x | - | - | - | - | x | x |
| 96/ 52 | N2 | | | Ah2 | 19-80 | x | x | x | - | - | - | - | x | x |
| 96/ 53 | N3 | | | Ah3 | 80-105 | x | x | x | - | - | - | - | x | x |
| 96/ 54 | N4 | | | rots | 105+ | x | - | - | - | - | - | - | - | - |
| 96/ 55 | N6 | | | brown soil | drill | x | x | x | x | - | - | - | x | x |
| 96/ 65 | N5 | | | crackfill | wall | x | - | - | - | - | - | - | x | - |
| 96/ 56 | O1 | *I04* | IC4 | Ah | 0-25 | x | x | - | - | - | - | - | x | x |
| 96/ 57 | O2 | | | Ab | 25-43/50 | x | x | - | - | - | - | - | x | x |
| 96/ 58 | O3 | | | B | 43/50-71/76 | x | x | - | - | - | - | - | x | x |
| 96/ 59 | O4 | | | C | 71/76-94 | x | x | - | - | - | - | - | x | x |
| 96/ 60 | O5 | | | Cwg | 94-127 | x | x | x | - | - | - | - | x | x |
| 96/ 61 | O6 | | | crackfill | wall | x | - | - | - | - | - | - | - | - |
| 96/ 62 | O7 | | | mine | - | x | x | x | - | - | - | - | x | x |
| 96/ 63 | Z1 | LB*01* | LB 1 | Ah | 0-30 | x | x | x | - | - | - | - | x | x |
| 96/ 64 | Z2 | | | ACc | 30-35 | x | x | x | - | - | - | - | x | x |

**Micromorphological samples**

| no | profile | new name | horizon | depth | storage no | remarks |
|---|---|---|---|---|---|---|
| 1 | H-2 | *S02b* | | 7-14 | 96096 | |
| 2 | ,, | ,, | | 55-62 | 96097 | |
| 3 | ,, | ,, | | 82-87 | 96098 | |
| 4 | H-3 | *S03* | | 1-9 | 96099 | |
| 5 | H-4 | *S04b* | | ----- | 96100 | |
| 6 | ,, | ,, | | ----- | 96101 | |
| 7 | H-5 | *S05h* | | 2-11 | 96102 | |
| 8 | ,, | ,, | | 20-29 | 96103 | |
| 9 | ,, | ,, | | 46-54 | 96104 | |
| 10 | ,, | ,, | | 72-80 | 96105 | |
| 11 | ,, | ,, | | 100-105 | 96106 | |
| 12 | Saprolite (coatings) | - | | 105 | 96107 | |
| 13 | H-6 | *S06h* | | 32-40 | 96108 | |
| 14 | ,, | ,, | | 2-10 | 96109 | |
| 15 | H-8 | *S08h* | | 3-10 | 96110 | |
| 16 | ,, | ,, | C | ----- | 96111 | |
| 17 | H-6 | *S06h* | C/R | 56-80 | 96112 | |
| 18 | ignimbrite ? | - | R | ----- | 96113 | |
| 19 | periodite St. Helena | - | | ----- | 96114 | |
| | | | | | | |
| 1 | H8B | *S08b* | Ah2 | 5-13 | 96190 | |
| 2 | ,, | ,, | Bwg1 | 23-31 | 96191 | |
| 3 | ,, | ,, | Bwg2 | 47-55 | 96192 | |
| 4 | ,, | ,, | Bwg3 | 82-90 | 96193 | |
| 5 | H9B | *S07b* | Ah | 5-13 | 96194 | |
| 6 | ,, | ,, | Bwg | 56-64 | 96195 | |
| 7 | ,, | ,, | Bw | 108-116 | 96196 | |
| 8 | ,, | ,, | R | ----- | 96197 | |
| 9 | H2B | *S02h* | Ah/AB | 4-12 | 96198 | |
| 10 | ,, | ,, | ----- | 37-45 | 96199 | border pocket B |
| 11 | ,, | ,, | ----- | 65-73 | 96200 | |
| 12 | H4B | *S04h* | Ah1 | 2-10 | 96201 | |
| 13 | H5B | *S05b* | Ah | 0-3 / 5 | 96202 | |
| 14 | LB1 | LB*01* | Ah | 5-13 | 96203 | |
| 15 | ,, | ,, | B | ? | 96204 | |
| 16 | H4B | *S04h* | Ah2 | 22-30 | 96205 | |
| 17 | ,, | ,, | Bwg | 44-52 | 96206 | |
| 18 | ,, | ,, | R | 55-57 | 96207 | |
| 19 | H5B | *S05b* | B | 37-45 | 96208 | |
| 20 | ,, | ,, | BCwg1 | 68-76 | 96209 | |

| no | profile | new name | horizon | depth | storage no | remarks |
|---|---|---|---|---|---|---|
| 21 | H5B | *S05b* | BCwg2 | ----- | 96210 | Saprolite |
| 22 | ,, | ,, | R | 150-155 | 96211 | |
| 23 | H6B | *S06b* | Ah1 | 2-10 | 96212 | |
| 24 | ,, | ,, | Ah2 | 36-44 | 96213 | |
| 25 | ,, | ,, | Ah3 | 80-88 | 96214 | |
| 26 | ,, | ,, | R | 144-152 | 96215 | |
| 27 | H9 | *S07h* | Ah | 2-10 | 96216 | |
| 28 | ,, | ,, | Bwg | 15-23 | 96217 | |
| 29 | ,, | ,, | ----- | ca. 55 | 96218 | |
| 30 | ,, | ,, | Cg | 63-71 | 96219 | Uit bodem naast kuil |
| 31 | ,, | ,, | ----- | ----- | 96220 | |
| 32 | 1C1 | *I01* | Ah | 15-23 | 96221 | |
| 33 | ,, | ,, | Ah/Bw | 68-78 | 96222 | |
| 34 | ,, | ,, | 2Ah | 95-103 | 96223 | border horizons |
| 35 | ,, | ,, | ----- | 126-134 | 96224 | border horizons |
| 36 | 1C1/2 | - | ----- | ----- | 96225 | Ignimbrite |
| 37 | 1C2 | *I02* | Ap | 10-18 | 96226 | |
| 38 | ,, | ,, | Bwg1 | 36-44 | 96227 | |
| 39 | ,, | ,, | Bwg2 | 58-64 | 96228 | |
| 40 | ,, | ,, | CB | 72-80 | 96229 | |
| 41 | ,, | ,, | R1 | 107-115 | 96230 | |
| 42 | ,, | ,, | R+ | 131-133 | 96231 | |
| 43 | 1C3 | *I03* | Ah | 5-13 | 96232 | |
| 44 | ,, | ,, | Ah2 | 35-43 | 96233 | |
| 45 | ,, | ,, | Ah3 | 97-105 | 96234 | Contact R, incl. saprolite |
| 46 | ,, | ,, | ----- | ----- | 96235 | in wall under soil. fresh rock |
| 47 | ,, | ,, | ----- | ----- | 96236 | rock with neo-formation underneath |
| 48 | 1C4 | *I04* | Ah | 8-16 | 96237 | |
| 49 | ,, | ,, | Bw1 | 32-40 | 96238 | |
| 50 | ,, | ,, | Bw2 | 57-65 | 96239 | |
| 51 | ,, | ,, | C | 86-94 | 96240 | |
| 52 | ,, | ,, | Cwg | 104-112 | 96241 | |
| 53 | ,, | ,, | R | ----- | 96242 | fresh rock |
| 54 | ,, | ,, | ----- | ----- | 96243 | saprolite |
| 55 | ,, | ,, | ----- | ----- | 96244 | mine |
| 56 | LB1 | LB*01* | ----- | 45 | 96245 | under stone |
| 57 | ,, | ,, | ----- | ----- | 96246 | saprolite weathering |
| 58 | H2B | *S02h* | ----- | ----- | 96247 | surface rock |
| 59 | ,, | ,, | ----- | ----- | 96248 | surface rock |
| 60 | H6C | - | ----- | ----- | 96249 | rock from underneath vertisol |