UPPSALA UNIVERSITET

Geological time and human influences on the soil properties of the miombo woodland in Kilosa District, Tanzania

Kajsa Holmborn

Arbetsgruppen för Tropisk Ekologi
Committee of Tropical Ecology
Uppsala University, Sweden

Minor Field Study 100

December 2003 Uppsala

UPPSALA
UNIVERSITET

Geological time and human influences on the soil properties of the miombo woodland in Kilosa District, Tanzania

Kajsa Holmborn

Photo: Kajsa Holmborn. Miombo woodland south west of Kilosa town, central Tanzania, March 2003.

Abstract

It is known that the miombo woodland only grows on the old peneplain but the detailed knowledge of which physical factors that has a greater influence on the distribution of the Miombo woodlands is, however, still not that well known. The aim of this study was to see if the soil properties of the old peneplain are the crucial factor for the distribution of the miombo woodland. To investigate this the soil properties of the old peneplain was compared with the properties of the non-peneplain soil. Furthermore, a study was conducted to see how the soil properties have been influenced by geological time, by analysing soils with different ages, and also to see how impacts from human cultivation have influenced the soil properties. For this investigation the same soil with different degrees of human impact was analysed. The studies were conducted on two different sites each with five different environments (1) the old red peneplain soil, (2) the eroded peneplain soil, (3) the deposited/non-peneplain soil, (4) a formerly cultivated soil and (5) a presently cultivated soil. In total 30 soil samples were collected. The investigation was conducted in the miombo woodlands of the Kilosa district in Tanzania, March 2003. The soil samples were taken from three positions in the soil profile, one from the upper A-horizon and two from the lower B-horizon. The physical parameters investigated were texture, structure and colour, which were done on site. The chemical analyses done were the amounts of the typical biological nutrients (Mg_$^{+}$, Na^{+}, K^{+}, Ca_$^{+}$) in the soil. The analyses showed that no bigger differences were noticeable between the peneplain soil and the non-peneplain soil. The conclusion drawn is that the distribution of the miombo woodland is most likely determined by other factors like the height of the groundwater table. For the age analyses the pattern noticeable were that an older soil is more depleted in its fertility and has a deeper weathering depth, but no certain conclusion can be drawn because of the poor results from the analyses of the deposited soil. The investigation concerning how human impacts have influenced the soil properties showed a clear pattern. Soils that have been used for cultivation for a long time is more depleted in its fertility than an untouched soil. However the results from the formerly cultivated soil shows that if the soil is given the opportunity to regain its strength, by letting it rest for some years, it can be used for further cultivation. This is important both for the preservation of the miombo woodland as well as for the local population to gain nutrient rich soils for cultivation.

Keywords: Tanzania, miombo woodland, soil investigation, soil properties, peneplain, human cultivation, human impacts.

Table of contents

1. Introduction

The project is dealing with the geological aspects of the miombo woodlands in Tanzania. It is known that the miombo woodland is rainfed and occurs where soil conditions are poor such as those existing on the old peneplains or fragmented peneplains of the study area. The detailed knowledge of which physical factors that have a greater influence on the distribution of the miombo woodlands is, however, still lacking.

Are the soil properties the crucial factors or are factors like hydrology and topography more important? The purpose of this study was to investigate the soil properties of the old peneplain. To see how they differ from soils of other land units, and also what kind of impact different amount of time in soil development has had on the soil properties. This was done by comparing the soil properties of the old peneplain with properties of the younger deposited soil in the valleys. I have also studied what kind of influences human activities have had on the soil properties. The investigation was conducted in the miombo woodlands in the Kilosa District, Tanzania, March 2003.

This project is associated to a larger study conducted by researchers from the Swedish Biodiversity Centre (Uppsala University and the University of Agricultural Sciences) concerning the miombo woodlands. In 1999–2001, Sida (the Swedish International Development Cooperation Agency) funded this project that initiated a research program concerning African dry forests and their role in food production and human survival (Strömquist *et al.*, in press). The project aims to find out what causes the fragmentation and degradation of the miombo woodlands in the Kilosa and Morogoro districts of central Tanzania, both those caused by natural impacts and those caused by humans. The aim of this study is to decide how to preserve the ecological and cultural values of the miombo woodlands and still maintain sustainable development of the region.

Sida provides scholarships (Minor Filed Studies) to final year undergraduate students in order to give them the opportunities to complete the field work for their exam work in a developing country. One condition is that the study conforms to Sida's development policies, and at the same time give the student insights in development work.

A MFS scholarship provided by Sida through the Working Group for Tropical Ecology at Uppsala University funded the field work in the Kilosa district of Tanzania, which took place during the spring of 2003. Another grant was provided to Ann Thorén, who carried out her fieldwork in the same area during the same period. Both our projects relate to the miombo woodland project and our findings will hopefully be of use to the local planners in the district, as well as a starting point for other Swedish students doing their MSc projects, going to Kilosa to do further studies on the miombo woodlands.

2. Background

2.1. Brief land use history of Tanzania

During the 19th century, central Tanzania was a country with open grasslands, small cultivated clearings, and vast areas covered with miombo woodland (Christiansson, 1988), but the caravan route that crossed the country during this time led to the development of more intensely cultivated areas. The route brought more people to the more or less uninhabited areas and the demand for food, firewood and other natural resources increased. This resulted in clearing of the miombo woodland and cultivation of previously uncultivated land. Naturally, areas near the route were more affected than areas far off (Simonsson, 2001).

Colonialism in Tanzania (Tanganyika) began in the end of the 19th century with the German occupation (1885–1918), but with the end of the First World War, the British gained control over Tanzania. With the colonisation followed the commercialisation of agriculture, which led to the formation of big plantations and further harvesting of the woodlands. It was not until the early 1960's that Tanzania gained its independence. The villagisation programmes during the 1970's resulted in concentration of the villages along the roads, and more people led to further clearance of the vegetation to give room to the growing villages (Simonsson, 2001).

2.2. The Great Rift Valley

The intensive tectonic forces that followed the formation of the Great Rift Valley in the end of the Tertiary period have affected the area in the Kilosa and Morogoro districts. The Great Rift Valley, or Eastern African Rift Valley, is a giant fault system,4,830 km long in the south-western part of Asia and the eastern part of Africa. The Great Rift Valley begins in the Middle East forming the valley of the Jordan River, runs through the Red Sea, continues through Ethiopia and Kenya. Its main branch continues through Tanzania and ends by the coast in Mozambique. In Kenya the rift valley splits near Lake Victoria and a western branch follows the border between Uganda, Rwanda, Burundi and Tanzania (Figure 1) The fault system is probably still active and has already torn the Arabian peninsula away from the African continent. Geologists believe that the eastern part of Africa is slowly drifting away from the rest of the African continent, and in the future it will have separated completely, creating an island in the Indian Ocean. (www.marekinc.com/GeoOverviewGreatRift.htlm**).**

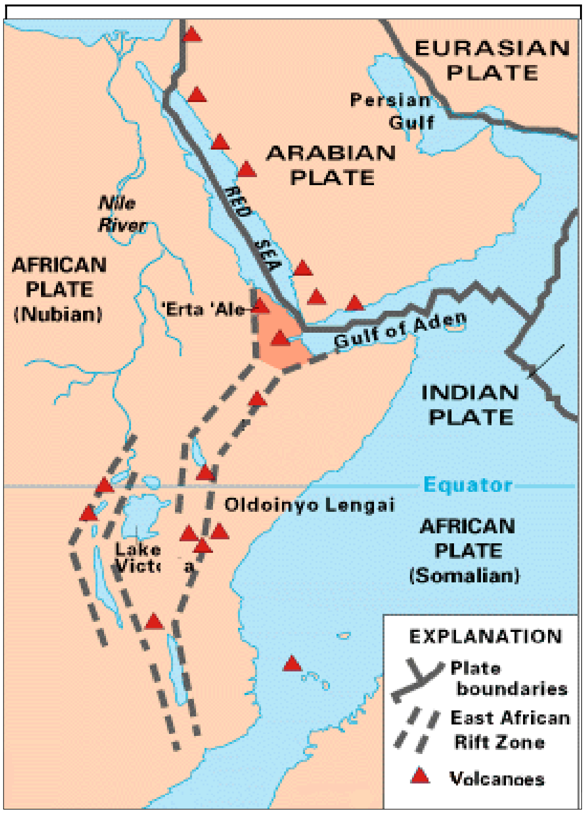


Figure 1: The Great Rift Valley in Africa. (www.marekinc.com/GeoOverviewGreatRift.htlm)

2.3. Soils

Soils occupy an important place in the ecosystem, the interface between the lithosphere, atmosphere, biosphere and hydrosphere. This makes them a very important indicator of former environments as well as present ones (Dubbin, 2001). Soils are crucial for the life on earth and humans are dependent on them. They supply us with nearly all our food as they give us the possibility to grow crops and fodder. The quality of the soil, primarily determined by the availability of soil nutrients, is an important factor that determines its productivity. When altering the land use, especially replacing forested land with cultivation, the soil quality may be rapidly reduced (Islam and Weil, 2000). The consequences of a severe decline in soil quality may lead to a permanent degradation of land productivity (Kang and Juo, 1986, Nardi *et al.*, 1996, Islam *et al.*, 1999, Msanya, 1998).

In areas that are tectonically active frequent faulting and periods of increased erosion interrupt the soil formation. Soils in these environments are poorly developed compared to cratonic areas, which are tectonically stable, and where the soil formation can proceed uninhibited for longer periods (Dubbin, 2001).

Since the break-up of Gondwanaland (the southern portion of the supercontinent Pangea consisting of South America, Africa, Australia, India and Antarctica), Africa has been fairly stable without any major tectonic activities, except the formation of the Great Rift Valley. This has resulted in an uninterrupted geological development. For example, erosion cycles have been able to proceed without interruptions for millions of years on the African continent, producing nearly level peneplains (Lewis & Berry, 1988). Another undisturbed development is the soil formation. The formation of soils is controlled by five factors: parent material, climate, organic material, topography and time. For a more thorough description of the controlling factors of soil formation and the soil formating processes see Brady and Weil, 2002. Africa has also remained in, or near, its current position in the tropics (Simonsson, 2000). The tropical climate produces conditions that result in a deeply weathered soil. The warm temperatures together with high rainfalls increase the rates of the chemical and the biological processes in the soil and especially the intensity of weathering and leaching (Crompton, 1960). With the tectonic activities that followed the formation of the Great Rift Valley, with uplifting of areas and downfaulting of other areas, eastern Africa got very fragmented. The old peneplain areas that were downfaulted, became protected from erosion and have retained its deeply weathered mantle of red soil, whereas the areas that got uplifted were exposed to erosion and have a less developed weathering profile. This soil is more brown in colour (Figure 3).

"The bright red colour that is typical for many of the African soils is due to a high content of the mineral hematite. Hematite is formed in areas with (i) high iron concentrations, (ii) low organic matter content, (iii) soil pH above 4, and (iv) high temperatures, thereby accelerating the decomposition of organic matter. If one or more of these conditions are not fully fulfilled, the mineral geothite is formed and the soil gets a more yellowish colour" (Areola, 1996).

2.3.1. Sources and amounts of nutrient elements in the soil

The ability for the soil to be fertile and a good productive soil is dependent on several factors. The composition of the parent material is an essential factor in the determination of the soil fertility. The material determines the natural supply of inorganic nutrients in the soil as well as the soil's ability to retain them. This is especially important for elements that are obtained from inorganic sources, like magnesium, potassium and calcium. The amount of these elements in the soil depends on the rate of weathering of the underlying rock. The amount of organic matter in the soil also influences the soil fertility and many nutrient elements are released when organic matter undergoes decomposition (Landon, 1991, Paton, 1978). The nutrients analysed in this study were potassium, calcium, magnesium and sodium.

2.3.1.1. Potassium

Potassium (K) is mainly found in mineral forms. Mica and feldspar are two of the most common minerals containing potassium. Because of this, most of the potassium in the soil is unavailable for plant uptake. It is only through rock and mineral weathering that the potassium is released in the soil and can be obtained by plants. A smaller part of the potassium content in the soil originates from the decomposition of organic matter. High amounts of potassium may alter the structure and permeability of the soil, which may have serious effects on the soil quality. Thus heavy textured soils often have a higher degree of potassium than sandy soils (Urino *et al.*, 1979). The soils of the Morogoro Region, in Tanzania, is known for its high potassium content, and this is much due to high contents of the mineral mica in the soils.

Figure 3: The downfaulted red peneplain soil and the uplifted eroded peneplain soil. District of Kilosa, Tanzania. March 2003. (Photo: Kajsa Holmborn)

2.3.1.2. Magnesium and Calcium

Magnesium (Mg) and calcium (Ca) also originate from decomposition of the rocks and minerals that contain them. Examples of calcium-containing minerals are calcite, amphiboles and calcium feldspar, while magnesium is available in mica minerals (Landon, 1991).

The plants ability to absorb calcium is determined by the soil's concentration of potassium and sodium (Na). If the concentration of either of these two elements gets too high it blocks the plant's ability to take up calcium. Sodium often prohibits the uptake of calcium if the soil's pH is high, whereas the amount of calcium in the soil determines the plant's capacity to absorb magnesium. Increasing amounts of calcium decreases the plant uptake of magnesium. Potassium is also a determining factor for the uptake of magnesium (Landon, 1991).

2.3.1.3. Sodium

Sodium (Na) can have a very bad effect on both the plant life and the physical properties of the soil if it has very high concentrations compared to the other cations. High values of sodium may be explained by the presence of sodic plagioclase feldspars (albite, oligoclase) (Landon, 1991).

2.4. Miombo woodlands

Miombo is the major woodland type in Africa (Malaisse, 1978). It extends from Angola to the east coast of Tanzania and Mozambique (WWF, 2001). Miombo woodlands cover about 48 % of the Tanzanian land surface. Characteristics for woodlands are that they have a light tree cover with a well-developed grass cover. The trunks are twisted and the upper branches are spread out like an umbrella (Malaisse, 1978) (Figure 4).

Figure 4: Miombo woodland south west of Kilosa town, central Tanzania, March 2003. (Photo: Kajsa Holmborn)

Man has affected miombo woodland for thousands of years, but the rapid deforestation seen during the last centuries is due to the increasing population and livestock growth. Excluding the human impacts, the distribution of miombo woodlands is greatly dependent on the interaction between precipitation, topography, and temperature. Miombo woodlands grow in the subhumid zones, since many of the biological elements that are essential for the survival of miombo are found under such conditions. The annual precipitation is 600 to 1400 mm and falls from November to April, and the range of mean temperatures is 24–27°C. Miombo grows around an altitude of 800 to 1250 m above sea level (WWF, 2001).

People, especially the local population, are depending on the natural resources the woodland can offer, including food, building material, firewood and wood for production of charcoal. With increasing population, more woodland is cleared to give room to cultivation and settlement areas. Charcoal is the dominant energy source in Tanzania and clearance of trees for charcoal production can result in severe local deforestation (Chidumayo, 2002). The clearance of wood for charcoal production is increasing as the demand for charcoal in the cities increases (Abbot and Homewood, 1999).

2.5. Overview of Kilosa District

Kilosa is the capital of the Kilosa district. This district is situated in the western part of the Morogoro region, in central Tanzania, approximately 300 km west of Dar es Salaam (Figure 5) (Kimaro, 1989). It has a north-south length of 180 km and an east-west length of 80 km. The total area of the district is 14,567.98 km^2. 57% of its land area is covered with natural forest and woodland, 9% is cultivation, settlements and urban areas and the Mikumi National Park and the Selous Game Reserve take up 19 % of the district area (Shishira *et al.*, 1997).

Kilosa Town (6,04°S, 36,99°E) is situated by the foot of the Eastern Arc system that runs through the district in a north–south direction. These mountains can reach an altitude of 2200 m (Shishira *et al.*, 1997). The escarpment and the uplifted terrain in the west create rain shadow and dry climate in the area by the foot of the escarpment. With the fault formation during the creation of the Great Rift Valley the area of the district got fragmented. The red soil that was uplifted became eroded and the new soil that developed is more yellow in colour

and is not as deeply weathered. The eroded soil from these parts was deposited lower down in the valleys and that has resulted in a very fertile soil. The fertility is due to the nutrient rich material that was washed down from the mountains and also because of high water content.
The soils in the hilly areas in the Kilosa district are derived from Pre-Cambrian rocks, mainly biotite gneiss with patches of hornblende and biotite-garnet and kyanite gneisses. The soils found here are sandy or sandy loams and nutrient poor. Down in the valleys vertisols are found. Vertisols are nutrient rich and good for agriculture (Shishira *et al.*, 1997).

Figure 5: The approximate location of Kilosa District with its capital Kilosa and the town of Mikumi. The two investigation sites. (www.infoplease.com/atlas/country /tanzania.html**,** www.ui.se/fakta/afrika/tanzania.htm**)**

The population statistics show that the population in Kilosa District is rapidly increasing. In 1978, Kilosa District had 274,544 inhabitants, by 1988 347,401 persons inhabited the area and in 1998 the population was estimated to be about 447,990 persons (URT, 1988). With more people, the demand for food, wood and other natural resources increases and this contributes to the deforestation of the miombo woodland. However, the fast increase of the deforestation in the district is more due to the harvesting of trees for charcoal production and for the Sugar Company in Kilombero (Shishira *et al.*, 1997). The eroded soil, located in the hilly areas, is in many places hard to access, and the red soil is generally used for agriculture, except for the vertisoils in the valleys. With the increasing population growth, more people are moving up in the hilly areas using the red soil for cultivation. According to Mr Haule (Forest officer in Kilosa district) the cultivation sites south-west of Kilosa are fairly new, while the cultivation sites north-west of Mikumi have been used for continuous agriculture since 1975.

3. Study area

In March 2003, soil samples were collected from two sites, each with five different environments, in the District of Kilosa. One of the sites, was located just south-west of Kilosa town, along the road to Chabima (appendix 1). The other site, was located north-west of Mikumi (appendix 2). Soil samples were collected from the eroded soil on the hills, red soil from the lower hillside, deposited soil in the valley on the border to the red soil, formerly cultivated red soil and presently cultivated red soil.

4. Methods

4.1. Fieldwork

In order to find possible differences in soil properties between the peneplain soil and the non-peneplain soil, samples were collected from both environments. To examine how geological time has affected the development of soils, samples were collected from sites with soils of different ages. (The same samples were used for the peneplain/non-peneplain study). The samples were therefore taken from:

- Deeply weathered red soil on the downfaulted peneplains (oldest),
- The younger eroded yellow soil on the uplifted parts of the old peneplain, and
- The even younger deposited soil in the valleys.

To investigate the natural properties of the soil, the samples were taken from sites with no, or as little as possible, human impact.

To investigate how humans have affected the development of a soil, samples were taken from the same soil but from places with different degrees of human impact. Samples were therefore collected from the following places:

- The unaffected red soil
- Formerly cultivated soil, and
- Presently cultivated soil

For every cultivated site, information concerning the duration of cultivation and/or for how long the site had been abandoned was taken. Also, on the sites presently cultivated the amount of crops growing on the sampling site and the crop density, was noted.

The samples from the same environment were taken from areas that were as similar as possible, so that the natural properties would not differ too much.

The samples were taken from three positions in the soil profile, one from the upper A-horizon and two from the lower B-horizon, one from its upper part and one lower down. A drill was used to collect the soil samples. With its help, the soil was taken up to the surface and laid out on the ground forming the soil profile. Studies of texture, structure, colour and pH were done on site. Also, samples for chemical analyses were taken. The colour of the soil was determined with the help of the Munsell Colour Chart (Munsell Colour, 1975). The different horizons were determined mainly through differences in colour and texture. Totally, around 30 soil samples were collected.

4.2. Laboratory analysis

The soil samples were taken to Sweden for chemical analyses. Analyses were done on organic matter content and amount of the common biological nutrients Mg^{2+}, K^{+}, Na^{+} and Ca^{2+}.

4.2.1. Organic matter
To determine the amount of organic matter, all samples were burned in an oven at 550°C for five hours. The samples were weighed before the burning as well as afterwards. The loss of weight represents the amount of organic matter in the soil samples. Then, the percentage of organic matter in the soil samples could be calculated.

4.2.2. Chemical nutrients
To determine the amount of the biologically important constituents Mg^{2+}, K^{+}, Na^{+} and Ca^{2+} the method of extraction by ammonium acetate was applied. The procedure of the method is to mix 25 g of the soil sample with 100 ml ammonium acetate. The mixture is then extracted for an hour in a turning device. After the extraction, the solution is filtered into 100 ml bottles. To receive the content of Mg, Na, K, and Ca ions in the samples the solution was put in an atomic absorption spectrometry device (AAS).

5. Results
The soil samples collected from the different sites gave the following results:

5.1. Comparison between the two sampling sites
5.1.1. Differences in physical properties
The results can be viewed in Tables 1– 4.

5.1.1.1. Red soil
The red soil from the two sites differed very little from each other, both regarding the site location and the soil profiles. They both have a very thick weathering mantel and the only difference was the aggregate characteristics. The aggregates on the Kilosa site was bigger compared to the ones at the Mikumi site (1–4 cm and 1 cm, resp.) (Table 2).

5.1.1.2. Eroded soil
The two sites where the soil samples were taken do not differ much from each other, when comparing surroundings, texture, structure and so on. They were both taken in the hilly regions of Kilosa district and in areas with undisturbed miombo woodland. They both had a slope gradient around 10°, but the potential for erosion was small, mainly due to stabilisation from the vegetation cover. However, the soil profile at the Kilosa site, was shallower than the one at the Mikumi site, and also, their structure differed somewhat (Table 2).

5.1.1.3. Formerly cultivated soil
The soil samples were taken from areas that had been cultivated some years ago. On the site south-west of Kilosa town the soil was cultivated 3 years ago for 3 years and on the site north-west of Mikumi the soil was also cultivated 3 years ago but only for 1 year. The two sites do not differ much but the soil profile at the Kilosa site is much shallower than the Mikumi site (Table 3).

5.1.1.4. Cultivated soil
Soil samples from cultivated sites were taken on sites that are cultivated today. On the Kilosa site, the soil had been cultivated for 2 years and at the Mikumi site for 1 year. The soil samples taken from the cultivation sites had the highest elevation of all the sampling sites. The site north-west of Mikumi had a higher crop density (the amount of crops growing on the sampling site) compared to the Kilosa site.

Table 1: Description of the different sampling sites.

Soil:	Site description					
	Position (UTM, Zone 37M)	**Vegetation cover**	**Slope gradient**	**Erosion hazard**	**Duration of cultivation**	**Aban-doned**
Red soil:						
Kilosa site:	0266479 9239011	Undisturbed miombo woodland	8°	Little, stabilisation from vegetation cover	—	—
Mikumi site:	0266006 9190125	Undisturbed miombo woodland	5°	Very little	—	—
Eroded soil:						
Kilosa site:	0265762 9239365	Undisturbed miombo woodland	The sampling place 12°, but the surrounding area 20°	No clear indication of erosion, though it is a quite steep slope. Stabilisation mostly from the vegetation cover.	—	—
Mikumi site:	0266965 9190318	Undisturbed miombo woodland	10°	Little, due to stabilisation by the vegetation cover	—	—
Formerly cultivated soil:						
Kilosa site:	0266978 9238800	Dominantly grass, some bushes	12°	Some sheet erosion, only grass as protection	3 years	3 years
Mikumi site:	0265218 9190077	Grass and bushes	5°	Little, sheet erosion a possibility	1 year	3 years
Cultivated soil:						
Kilosa site:	0270893 9237932	Little, the crops	25°	High, the crops were not big, did not give much stability to the soil	2 years	—
Mikumi site:	0265425 9190040	Moderate, the crop vegetation	15°	Moderate, the crops were quite grown and gave some protection	1 year	—
Deposited soil:						
Kilosa site:	0272302 9237484	Grass and bushes	0°	None	—	—
Mikumi site:	0270295 9191368	Bushes and trees	0°	None	—	—

5.1.1.5. Deposited soil/non-peneplain soil
The soil samples from the deposited soil were taken at the border to the red soil. Both sites had very deep soil and at the depth of 110 cm, the appearance had not changed much, except that the colour was lighter lower down in the profile. There was a slight difference between the two sites. The soil on the Kilosa site had a finer texture and gradually got more stable aggregates then the soil on the Mikumi site (Table 4).

5.1.2. Differences in chemical properties
The calcium values are incorrect due to chemical inferences in the air–acetylene flame in the AAS. Consequently, the absorbency of calcium decreases and the values received are too low. However, the values are used to show the relative differences between the different soils and horizons.

5.1.2.1. Red soil
The concentration of nutrients is somewhat higher in the site south-west of Kilosa compared to the site near Mikumi. When comparing the two sites, most of the nutrients decrease downward in the profile, and the same pattern is seen for organic matter and pH.

5.1.2.2. Eroded soil
The most noticeable difference between the two sites of eroded soil is that the soil on the Kilosa site has higher values of all the elements, as well as of organic matter. The concentration of the different elements follow the same pattern within the profile, they increase downwards. However, the pH value in the different soils is the same, throughout the whole soil profile.

5.1.2.3. Formerly cultivated soil
Also for formerly cultivated soil, the different elements have a higher concentration in the Kilosa site, except for potassium. The organic matter content on the two sites is fairly similar, with the exception of the high amount in the top layer on the Mikumi site. The behaviour of the same element within the profile on the two sites follow the same pattern. Calcium and potassium decreases down the profile while sodium and magnesium increases. The pH decreases downwards.

5.1.2.4. Cultivated soil
Most of the nutrients, as well as the organic material, have a higher concentration in the Mikumi site than in the site near Kilosa. Calcium and potassium have the same pattern in both locations, while the others have different patterns on the two sites.

5.1.2.5. Deposited soil/non-peneplain soil
For the deposited soil, the values are very dissimilar between the two sites, and they do not follow any obvious pattern. They have the same behaviour for the potassium value, decreasing downwards. However, the other nutrients have the opposite behaviour. Calcium and magnesium are increasing down the profile on the Kilosa site, while they decrease in the Mikumi site. The sodium concentration is decreasing in the Kilosa site, while it increases in the Mikumi site. However, all the nutrient concentrations seem to be higher in the Kilosa site than in the Mikumi site, except for the potassium value.

5.1.2.6. *Comparison between the miombo woodland soils*
The results are shown in Table 5. The chemical analyses on the soil samples from the miombo woodland show that the concentration of most of the nutrients in the red soil is decreasing down the soil profile, while for the eroded soil the concentration increases. There are, though,

Table 2. The physical properties of red and eroded soil.

Soil:	Physical properties of the soil			
	Depth	**Colour**	**Texture**	**Structure**
Red soil:				
Kilosa site:	0–120 cm			
A-horizon	0–10 cm	Dark reddish brown (5 YR 3/4) dry Reddish brown (5 YR 3/4–3/6) wet	Sandy loam	Small aggregates (1–1.5 cm)
B, top	30–40 cm	Dark reddish brown (5 YR 3/4–3/6) dry and wet	Sand loam	Bigger aggregates (2–4 cm)
B, lower down	70 cm	Dark reddish brown (5 YR 3/4–3/6) dry and wet	Sandy loam, but a higher degree of coarser grains	Aggregates (1–5 cm)
Mikumi site:	0–100 cm			
A-horizon	0–30 cm	Dark brown (10 YR 3/4) dry Brown (10 YR 4/4) wet	Sandy loam	Small aggregates (1 cm)
B, top	50–60 cm	Dark reddish brown (5 YR 3/4) dry Reddish brown (5 YR 4/6) wet	Sandy loam	No change
B, lower down	80–90 cm	Dark reddish brown (5 YR 3/6) dry Bright reddish brown (5 YR 5/8)wet	Sandy loam	No change
Eroded soil:				
Kilosa site:	0–60 cm			
A-horizon	0–20 cm	Brown (10 YR 4/3–4/4) dry Dark brown (7.5 YR 3/4) wet	Sand	Small aggregates (1–2 cm)
B, top	20–25 cm	Brown (7.5 YR 4/3–4/4) dry Dark brown (10 YR 3/4) wet	Sand	No change
B, bottom	40 cm	Brown (7.5 YR 4/3–4/4) dry Dark brown (10 YR 3/4) wet	Sand, but a higher degree of coarser grains	No change
Mikumi site:	0–80 cm			
A-horizon	0–15 cm	Brown (10 YR 4/4) dry Dark brown (10 YR 3/4) wet	Sandy loam	Small unstable aggregates (1 cm)
B, top	30–40 cm	Brown (10 YR 4/4) dry Dark brown (10 YR 3/4) wet	No change	No change
B, bottom	70–80 cm	Bright brown (7.5 YR 5/8) dry Bright brown (7.5 YR 5/6) wet	Sand	No change

Table 3. The physical properties of formerly cultivated and presently cultivated soil.

Soil:	Physical properties of the soil			
	Depth	**Colour**	**Texture**	**Structure**
Formerly cultivated soil:				
Kilosa site:	0–50 cm			
A-horizon	10 cm	Dark brown (10 YR 3/3–3/4) dry Brownish black (10 YR 3/2) wet	Sandy loam	Quite stable aggregates < 1cm
B, top	20 cm	Brown (7.5 YR 4/6) dry Brown (7.5 YR 4/3–4/4) wet	Sand loam	Bigger aggregates< 5 cm
B, lower down	40 cm	Brown (7.5 YR 4/6) dry and wet	Sand, higher degree of bigger grains	Stable aggregates < 2 cm
Mikumi site:	0–100 cm			
A-horizon	25 cm	Dark brown (7.5 YR 5/4) dry and wet	Sand – sandy loam	Few, but quite stable aggregates < 2 cm
B, top	80 cm	Dark brown (7.5 YR 5/4) dry Brown (7.5 YR 4/4) wet	Sandy loam	No change
B, lower down	100 cm	Dark reddish brown (5 YR 3/4) dry Dark reddish brown (5 YR 3/6) wet	Sandy loam	No change
Cultivated soil:				
Kilosa site:	0–70 cm			
A-horizon	0–15 cm	Dark reddish brown (5 YR 3/4) dry Reddish brown (5 YR 4/8) wet	Sandy loam, high degree of clay	Stable aggregates dominantly around 3 mm
B, top	40 cm	Dark reddish brown (5YR 3/4–3/6) dry Reddish brown (5 YR 4/6) wet	No change	More aggregates of the same size
B, lower down	65–70 cm	Reddish brown (5 YR 4/6) dry Bright reddish brown (5 YR 5/8) wet	Higher degree of coarser grains	No change
Mikumi site:	0–90 cm			
A-horizon	0–15 cm	Very dark reddish brown (5 YR 2/3–2/4) dry. Dark reddish brown (5 YR 3/6) wet.	Loam, high degree of clay	Stable aggregates
B, top	50 cm	Reddish brown (5 YR 4/8) dry Dark reddish brown (5 YR 3/6) wet	No change	No change
B, lower down	90 cm	Reddish brown (5 YR 4/8) dry Bright reddish brown (5 YR5/8) wet	No change	No change

Table 4: The physical properties of deposited soil.

Soil:	Physical properties of the soil			
	Depth	**Colour**	**Texture**	**Structure**
Deposited soil:				
Kilosa site:	0–110 cm			
A, top	10 cm	Dark brown (10 YR 3/3) dry Brownish black (10 YR 2/3) wet	Sandy loam	No stable aggregates < 1 cm
A, lower down	110 cm	Dark brown (10 YR 2/3–3/3) dry and wet	Sandy loam	More stable aggregates < 2 cm
Mikumi site:	0–90 cm			
A, top	30 cm	Greyish yellow brown (10 YR 4/2)dry Brownish black (10 YR 3/2) wet	Sand – sandy loam	Unstable aggregates
A, lower down	80 cm	Dull yellowish brown (10 YR 5/3)dry Brown (10 YR 4/4) wet	Sand – sandy loam	No change

a few exceptions. The magnesium value in the red soil and the calcium value in the eroded soil, in the Mikumi site increase downwards instead of decreasing.

Peneplain soil that has been affected by human cultivation seems to have the same pattern as the red soil, the concentration of the nutrients decreases down the profile, with some exemptions. Some of the nutrients have a different behaviour depending on from which site the soil sample is taken.

Comparing the concentration of the nutrients in the soils of miombo woodland, the eroded soil appears to have the highest values and the red soil the lowest, except for the soil in the Mikumi site, which has the opposite behaviour. Peneplain soil that has been affected by human cultivation also seems to have lower values of the soil nutrients. Although the soil that had been cultivated but was abandoned and left for recovery, seems to have values more close to the unaffected red soil. For almost all the soils, the organic matter content seems to be increasing down the soil profile.

5.2. Comparisons between the different soils

5.2.1. Comparison between the peneplain soils and the non-peneplain soil

5.2.1.1. Physical properties

The results can be seen in Tables 2–4. The distinct difference between the peneplain soil and the non-peneplain soil is the colour. Peneplain soil is red, brown or reddish brown in colour, except for the soil in the hilly areas, the eroded soil, which is paler. According to the Munsell colour chart, the colour of the eroded soil is various shades of brown, to be compared with the non-peneplain soil, which is more brown or yellowish brown in colour. Both soils have a sandy–sandy loam texture, but the peneplain soil has more and more stable aggregates than the non-peneplain soil.

The non-peneplain soil also has a thicker A-horizon than the peneplain soils (around 100 cm respectively 15–30 cm). A comparison between the peneplain soil that has been cultivated and the non-peneplain soil reveals that the peneplain soil has a higher degree of clay.

Table 5: Chemical properties in miombo woodland soils.

	Horizon	**C (%)**	**K (µg/g)**	**Na (µg/g)**	**Mg (mg/g)**	**Ca (µg/g)**	**pH**
Red soil:							
Site Kilosa:	A	6.90	268	6.8	0.8	2120	7.7
	B, top	6.44	220	10.0	1.48	1840	7.6
	B, lower down	6.86	192	13.2	0.64	1760	7.3
Site Mikumi:	A	6.73	136	23.2	0.88	1160	7.5
	B, top	7.23	108	10.4	0.96	800	7.3
	B, lower down	7.82	100	12.0	1	520	7.2
Eroded soil:							
Site Kilosa:	A	5.52	136	15.2	2.72	1960	7.3
	B, top	5.40	136	21.6	2.24	2520	7.3
	B, bottom	5.94	140	18.8	2.72	2600	7.3
Site Mikumi:	A	2.45	100	4.4	0.36	440	7.3
	B, top	2.75	116	4	0.24	280	7.3
	B, lower down	3.45	176	6	0.16	80	7.3
Formerly cultivated soil:							
Site Kilosa:	A	4.92	116	10.4	1.32	2400	7.3
	B, top	4.07	100	13.6	1.44	1960	7.3
	B, lower down	6.42	92	14.4	1.52	1880	6.8
Site Mikumi:	A	16.70	332	6.8	0.6	1640	7.4
	B, top	5.95	224	4.8	0.32	800	7.1
	B, lower down	6.92	216	7.6	0.28	760	6.7
Cultivated soil:							
Site Kilosa:	A	6.00	268	6	0.6	960	7.8
	B, top	3.60	244	8.8	0.56	760	7.6
	B, lower down	2.13	152	8.9	0.4	440	7.3
Site Mikumi:	A	9.25	140	18.4	0.8	1640	7.3
	B, top	8.76	124	11.6	1	920	7.2
	B, lower down	10.50	120	10.8	0.96	760	7.3

Table 6: The chemical properties of deposited soil / non-peneplain soil.

	Horizon	**C (%)**	**K (µg/g)**	**Na (µg/g)**	**Mg (mg/g)**	**Ca (µg/g)**	**pH**
Deposited soil:							
Site Kilosa:	A, top	4.72	92	26	0.64	1000	6.9
	A, lower down (lighter in colour)	5.85	88	4.4	0.96	1240	6.9
Site Mikumi:	A, top	1.85	152	2	0.36	560	7.2
	A, lower down (lighter in colour)	1.07	76	5.6	0.32	160	7.1

5.2.1.2. Chemical properties

The values can be seen in Tables 5 and 6. The behaviour of most of the nutrient elements in the non-peneplain soil is that the concentration is decreasing down the soil profile, with some exceptions. The same behaviour is found in the peneplain soil, except for the eroded soil. The non-peneplain soil seems to have higher values of magnesium, and higher or nearly the same concentration of calcium. However, the peneplain soil has lower concentration of sodium and potassium compared to the peneplain soils.

5.2.2. Comparison between the eroded, red and the deposited soils

5.2.2.1. Physical properties

Red, eroded and deposited soils were compared to see if there are any differences in soil properties between soils of different ages. The red soil is the oldest and has therefore had the longest time for development. The eroded soil is younger than the red but older than the deposited, since it is derived from the eroded soil.

The red soil has a thicker weathering mantle than both the eroded and the deposited soil and is also more red in colour than the other two, which have a more brownish colour. The eroded soil has a higher degree of coarse grains than the other two. The pH is different in the three soils. The red soil has pH 7.2–7.7 (different in the different horizons), while the eroded soil has a pH around 7.3, and the deposited soil has a lower pH than the red and the eroded soil, 6.9.

5.2.2.2. Chemical properties

The concentrations of the nutrient elements are decreasing down the soil profile in the red soil, while they are increasing in the eroded soil. For the deposited soil, the concentration is different between the two locations.

5.2.3. Comparison between the red, formerly cultivated and cultivated soil.

5.2.3.1. *Physical properties*

For the investigation how humans have influenced the soil properties, soil with different degrees of human impact were compared. Therefore, (1) red soil, with no or little human impact, (2) formerly cultivated red soil, which has had a high degree of human impact but now has been abandoned and got a chance of recovery, and (3) presently cultivated red soil, which has a high degree of human impact at present, were compared. The most evident difference between the three soils is that the clay content increases as the degree of human impact increases. With the increasing amount of clay the aggregate stability also increases.

5.2.3.2. Chemical properties

All three soils follow the same pattern, *i.e.* a decrease in nutrient concentration down the soil profile. The red soil has the highest values of the different nutrients, while the formerly cultivated soil seems to have values more close to the red soil compared to the values in the soil that is cultivated today.

6. Discussion

The aims of this study were to investigate if the soil properties of old peneplains are a determining factor for the distribution of the miombo woodland. Therefore, peneplain soil and non-peneplain soils were compared. The study also investigated how age and human impact have affected the soil properties.

6.1. The miombo woodland soil and the non-miombo woodland soil

The difference in developing time is one determining factor for the differences in both the physical and the chemical properties between the peneplain soil and the non-peneplain soil, and also for differences between the red and the eroded soil. Since both the red and the eroded soil have developed on the old peneplain, but have had different amount of developing time, they are expected to have some physical and chemical differences. The clearest differences among the physical properties were their colour and weathering depth. Both these differences are due to different environmental conditions during the time of soil formation. As mentioned earlier, a deeply weathered soil is due to a long period of a warm and humid climate as is also its red colour. However, a soil with a lower weathering depth and a more yellowish colour is due to a shorter developing time in a climate not as warm and humid as the red soils. The colluvial, non-peneplain soil, which is derived from the material washed down from the higher areas, was expected to show clear differences in physical and chemical properties compared to the peneplain soils. The non-peneplain soil does differ, but not as much as expected.

The pH values are also a factor influenced by the duration of time in development. The pH value for red soil decreases down the soil profile. It is around 7.6 at the surface but lower down it changes to 7.3. It is noticeable that the pH value of the eroded soil is 7.3 at the surface. This is due to the fact that the eroded soil is derived from the lower part of the red soil, since the top layer of the red soil was eroded when it got uplifted with the formation of the Great Rift Valley.

The red soil has been subject to a very long time of leaching during its development. Most of the nutrients are transported away from the higher horizons to the lower ones. Therefore, the amount of nutrient elements is decreasing down the soil profile. The eroded soil has not had that time-span of development and has a weathering mantle that is much shallower than the red soils. The leached nutrients are accumulated lower down in the soil profile and that is why the nutrient values are increasing down the profile for the eroded soil.

The amount of organic matter is also a determining factor for the differences in stability of and amount of aggregates in the peneplain and non-peneplain soils. The red soil has a higher degree of organic matter than both the eroded soil and the deposited soil and it also has the highest amount of aggregates. The degree of aggregates seems to be higher in soils with a high organic matter content. King *et al.* (1994) also established such a relationship. A clear difference is the degree and stability of aggregate increase as the degree of human influence increases, which is due to an increased amount of clay in the cultivated soils. The clay makes it easier for the soil to form aggregates. However, the high amount of clay in the cultivated soils may not be caused by human activity but be due to the fact that people chose clay soils for cultivation, because of its higher ability to hold nutrients and water than soils with a more sandy character. High amounts of organic matter may also influence the stability of the soil, since organic matter increases the soil's ability to form aggregates. That is reflected in my results, where red soil, with no human influences, has the highest degree of aggregates compared with the other soils without human influences.

The amount of soil nutrients is high when the soil has a high pH and a high amount of organic material according to Allen (1986). The results obtained in this study show that the amount of nutrients often follows the amount of organic material. Both the red soil sites and the eroded soil sites had dense vegetation cover, the tree cover may not be very dense but the grass cover of the miombo woodlands is. Here, the erosion does not play a significant role, since the soils get stabilisation from the organic matter. However, the topography has an important role in the ability for erosion. Steep slopes have more erosion than sites with lower elevation, but the vegetation reduces the intensity of the erosion. The eroded soil in the Kilosa site has a higher elevation than in the Mikumi site. However, the organic matter content in the eroded soil from the Mikumi site is lower even though that site has a lower elevation. Due to the dense grass cover in the undisturbed woodland on the eroded soil south-west of Kilosa, the vegetation gives the soil stability and the erosion hazard is therefore low. Nevertheless, the erosion hazard is higher in those sites than in sites with the same vegetation condition at lower elevation. The lower values of organic matter in the eroded soil in the site north-west of Mikumi are probably due to the increasing erosion hazard following fires. According to Mr Haule the Mikumi site is more exposed to fires than the eroded soil in the Kilosa site. Fires reduce the amount of organic material in the soil.

It was expected that when comparing the red soil with the other soils, it would have the lowest values of organic matter and nutrient elements. This was not the case in the Mikumi site. Here the eroded soil had very low values compared to the red soil. The eroded soil north-west of Mikumi was subject to fires to a higher degree than the eroded soil near Kilosa. Fires result in removal of organic matter and soil nutrients. A fire reduces the amount of vegetation in the site, making the soil more vulnerable to erosion. That may explain why the eroded soil in the Mikumi site had lower values of organic matter and nutrients, and not higher as expected. The eroded soil not subject to fires had more expected values, i.e. higher than the red soils. Since red soil has had the possibility to develop undisturbed without tectonic interruptions, it has had a very long history of leaching, depleting the soil of its nutrient content. According to Cole (1963), soils exposed to some erosion are "healthier" than soils never subject to erosion (applied for soils with a moderate elevation). Erosion gives the soil new, healthier material and the soil do not get depleted on its nutrients, while soil that is developed on a level surface seldom gets new material.

The deposited soil was expected to have the highest values of organic matter and nutrient elements, since much of the nutrients from the higher regions are accumulated in the lower areas, but that was not the case. The low concentration of the different nutrients can be due to heavy transportation of nutrients during flooding at the rainy seasons. Another explanation for the unexpected low values of nutrients and organic matter in the non-peneplain/deposited soil is that the soil samples were taken on the border to the peneplain. Maybe, if the soil samples had been taken lower down in the valley and not near the border, a clearer difference between the two soils could have been seen.

The vegetation cover may explain the differences in the chemical properties in the non-peneplain soil between the two locations. The vegetation cover is not quite the same in the two locations. The nutrients on the Mikumi site are decreasing down the soil profile while they are increasing on the Kilosa site. The soil sample site in Mikumi had vegetation of grass, bushes and trees, while the vegetation on the Kilosa site did not include any trees. Tree roots can extend much lower down in the soil profile than the grass and bush roots. Therefore, tree roots that reach deeper take up nutrients, and that process is not possible on the Kilosa site.

Since no major differences between the peneplain and the non-peneplain soils were found, the distribution of the miombo woodland may as likely be determined by other factors. The soil properties of the peneplain soil are probably one of many sets of factors controlling the distribution of the miombo woodland, but not the crucial one. The determining factor is more likely the topography or hydrology. According to the study made by Ann Thorén about the possible distribution of miombo woodland in Kilosa district, the border between the red and the deposited soil follows an altitude of 480 m. The fact that the miombo woodland only grows to a specific altitude is possibly due to the changes in the hydrological characteristics of the soil with altitude. As the height of the groundwater table increases down in a valley, the vegetation will alter to plants more suitable for an environment with a higher groundwater table. The roots of these plants are dependent on the groundwater for their survival, and they cannot survive, as the miombo, if the roots do not reach the groundwater. Therefore the miombo species have a hard time competing with these plants and no miombo is found below 480 m.

6.2. Comparison between the red, cultivated and formerly cultivated soil

The red soil that has been affected by human activities follows the same pattern as the undisturbed red soil, but because of intense alteration due to many years of cultivation that soil is not as well preserved as the undisturbed red soil. When miombo woodland is cleared to give place to human settlements, the soil undergoes drastic changes. It used to have covering vegetation but because of human influence most of the vegetation is removed. According to Davidson and Ackerman (1993) the first years after a land is cleared from forest and turned into a cultivation site is when the most severe changes in the soil content of organic matter occurs. A serious decrease in input of organic matter leads to an increased susceptibility to soil erosion (Lugo and Brown, 1993; Feller and Beare, 1997). The fertility of the soil is linked to the soil organic matter cycle, and its decline after forest clearance (Bouwman, 1989). This can explain the lower values of organic matter in cultivated and formerly cultivated soil. It is also noticeable that it is not only the amount of organic matter that is influenced by the human impact of turning forested land into a cultivation site. A soil that has been used for agriculture for a long time gets depleted in fertility, although the soils that have been used for agriculture but left for recovery have the possibility to regain their organic matter content as well as their amount of nutrient elements. That recovery is noticeable in my results, where the formerly cultivated soil has nutrient values more close to the undisturbed red soil than the soil that is under cultivation at present.

For former cultivated soil, the samples taken from the site south-west of Kilosa have higher degrees of almost all the nutrients compared to the soil sample taken from the Mikumi site. This can be explained by the fact that the soil north-west of Mikumi has had a longer history of cultivation, and therefore is more depleted of nutrient content, while the cultivation site south-west of Kilosa is fairly recent. The recovery of the soil south-west of Kilosa does not need the same amount of time to recover as the Mikumi soil. The higher values of nutrients in the Mikumi site of the soil that is cultivated now do not have the same explanation. Those differences are more due to crop density and soil erosion. The site near Mikumi had a higher density of crops than the cultivated site south-west of Kilosa. More organic matter is correlated with higher values of nutrients. The cultivated soil samples were also taken from sites with a quite high elevation, especially in the site south-west of Kilosa. Here the vegetation cover, which mainly consists of the crops grown on site, is not very dense and soil erosion is possible. The higher possibility for soil erosion in the Kilosa site can explain the higher values of the organic matter and higher content of all the nutrients in the site north-west of Mikumi.

The investigation made on the soils in the central Matengo highlands, in southern Tanzania, by the Faculty of Agriculture, Sokoine University of Agriculture in 1998 (Msanya, 1998), shows that soils derived from gneissic rocks are poor in the major nutrients, and that they have a declining fertility with time due to continuous cultivation without adequate fertilisation. These results correlate well with the results of my study, which also shows that soils on the old peneplain, derived from gneissic rocks, have a deficiency in the major soil nutrients. The declining fertility in soil cultivated by man is also clearly noticeable.

Of course some of the aberrations in the chemical results can be due to human errors during the chemical analyses of the soil samples. Also, there was a long time between the collection of the soil samples and the chemical analyses, since the soil samples were taken in Tanzania and analysed in Sweden. For the soil properties to change as little as possible the samples are supposed to be stored in a cold place, but that was not possible in Tanzania.

7. Conclusion

The goal with this study was to see if there were any differences in physical and chemical properties between soils derived from an old peneplain and soils deposited in a valley, and also to see how age and human impacts have influenced the soil properties. When comparing peneplain soil with non-peneplain soil no major apparent differences were noticeable. Rather, the differences found can be explained by differences in development time and vegetation density.

When comparing physical properties, such as texture and structure, no age difference can be seen between the different soils since they do not show any big differences. However, when comparing weathering depth and the amount of chemical elements in the soil, some differences were noticeable. Naturally, some of the soil characteristics are dependent on today's surrounding environment and its recent history, for example, the amount of vegetation grown on site. Otherwise, most of the physical and chemical differences between the peneplain and non-peneplain soils are due to the difference in developing time as well as the climatic conditions during the soil formation. The deep weathering mantle and the high degree of nutrient leaching in the red soil are due to the fact that the red soil has had the longest time of development. The eroded soil that is younger has not had the same amount of time to develop and therefore, the eroded soil is shallower and has not the same degree of nutrient depletion. However, fires and erosion can result in an increased reduction of soil nutrients. The deposited soil was expected to have the highest values of nutrients, since the soil is located in the valley and receives a lot of nutrients from the surrounding high lands, but that was not the case. In fact, the deposited soil had the lowest values for all the nutrients. This is likely due to a bad choice of sampling site, which was probably situated too close to the border of the peneplain.

The fact that no bigger differences were seen between the peneplain and the non-peneplain soils shows that the soil property may not be the determining factor for the distribution of the miombo woodland. Factors like hydrology are probably more important. The fact that the miombo woodland only extends to a specific altitude and with that a specific depth of the groundwater table, supports that conclusion.

The human influences on the soil properties are more apparent than the differences between peneplain and non-peneplain soil properties. Decades of human use have left the soil depleted in nutrient and organic content. If the soil does not get the opportunity to regain fertility after some years of cultivation the depletion will progress and leave the soil with a severe nutrient deficiency, which will affect the environment in the area. Nutrient deficiency will restrict the vegetation growth on site, and less vegetation density leads to a decrease in soil stability and with that an increased erosion hazard. A higher erosion hazard will even more decrease the soils natural resources. The cultivation history is very important when understanding the behaviour of the soil. The area around Mikumi has been used for continuous cultivation at least since 1975 while the cultivation site south-west of Kilosa is fairly recent. The recovery of the soil south-west of Kilosa does not need the same amount of time as the Mikumi soil, and this explains the big difference in concentration of the nutrients in the two sites. If the soil is left alone for some years after cultivation, it is given the opportunity to regain its nutrient content and can be used for further cultivation. This is an assess both for the preservation of the miombo woodland and the local population to gain nutrient rich soils for cultivation.

8. Acknowledgement

I would like to thank Sida and the Committee of Tropical Ecology at Uppsala University, for financial contribution, making the trip to Tanzania possible. My two supervisors, professor Lennart Strömquist at Uppsala University in Sweden and professor Pius Yanda at the University of Dar es Salaam in Tanzania, for their help and guidance during the whole work period, senior teacher Ingvar Backéus at Uppsala University, for his help and supervision and for the appearance of a familiar face in Kilosa town, professor Else Kolstrup for her advises and sharing of ideas in the beginning of the work plan and to laboratory assistant Inger Pålhsson at the Department of Earth Sciences at Uppsala University for taking the time to help me with the chemical analyses in the laboratory. I also, want to thank the Kilosa district officers who helped me with all the practical things, the settlers in the district who let me use their land for my analyses and all the people who made the stay in Kilosa a very pleasant one, mr. Haule, the Officer of the Forest Department in the Kilosa District for devoting his time and knowledge to help me during the fieldwork period and finally Ann Thorén, with whom I shared both the hard and the happy times in Tanzania. The trip would not have been the same without you.

9. References

Literature:

Allen, J.C., 1986. Soil properties and fast-growing tree species in Tanzania. *Forest Ecology and Management*, vol. 16, p. 127–147.

Areola, O., 1996. Chapter 8: Soils, In: *The Physical Geography of Africa*. Oxford University Press, Oxford, United Kingdom. p. 134–147.

Brady, N.C. and Weil. R.R., 2002. *The nature and properties of soils*, Thirteenth edition. Pearson Education, Inc., New Jersey.

Chidumayo, E.N., 2002. Changes in miombo woodland structure under different land tenure and use systems in central Zambia. *Journal of Biogeography*, vol. 29, p. 1619.

Cole, M., 1963. Vegetation and geomorphology in Northern Rhodesia: an aspect of the distribution of savannah in central Africa. *Geographical Journal*, vol. 129, p. 290–310.

Crompton, E., 1960. The significance of weathering/leaching ratio in the differentiation of major soil groups, with particular reference to some very strongly leached brown earths on the hills of Britain. *Transactions, 7th International Congress of Soil Science*, vol. 4, p. 406–11.

Davidson, E.A. and Ackerman, I.L., 1993. Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry*, vol. 20, p. 161–193.

Dubbin, W., 2001. Soils — past and present. *Geology Today*, vol. 17, p. 225.

Feller, C. and Beare, M.H., 1997. Physical control of soil organic matter dynamics in the tropics. *Geoderma*, vol. 79, p. 69–116.

Imaizumi, K., 1967. *Revised Standart Soil Colour Charts*. Ministry of Agriculture and Forestry. Japan.

Islam, K.R., Kamaluddin, M., Bhuiyan, M.K. and Badruddin, Abu., 1999. Comparative performance of exotic and indigenous forest spices for tropical evergreen degraded forest land reforestation in Bangladesh. *Land Degradation Development*, vol. 10, p. 241–249.

Islam, K.R. and Weil, R.R., 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. *Agriculture, Ecosystems and Environment*, vol. 79, p. 9–16.

Kang, B.T. and Juo, A.S.R., 1986. Effect of forest clearing on soil chemical properties and crop performance. In: Lal, Sanchez, R., Cummings, P.A., Jr., R.W. (Eds), *Land Clearing and Development in the tropics*. Balkema, Rotterdam, p. 383–394.

Kimaro, D.N., 1989. *Potentials and constraints of the Kilosa area for rainfed agriculture with emphasis on Maize*. ITC Soil Division, Department of land resource surveys and rural development. International institute for aerospace survey and earth sciences (ITC), Enschede, Netherlands.

Landon, J.R., 1991. *Booker Tropical soil manual, A handbook for soil survey and agricultural land evolution in the tropics and subtropics*. Booker Tate Limited. England.

Lewis, L.A. and Berry, L., 1988. *African environments*. Unwin Hyman Ltd, London, p. 404.

Lugo, A.E. and Brown, S., 1993. Management of tropical soils as sinks or sources of atmospheric carbon. *Plant and Soil*, vol. 149, p. 27–41.

Malaisse, F., 1978. The miombo ecosystem. In: *Tropical Forest Ecosystems, a state-of knowledge*. Report prepared by Unesco / UNEP / FAO.

Motavalli, P.P., Discekici, H. and Kuhn, J., 2000. The impact of land clearing and agricultural practices on soil organic C fractions and CO_2 efflux in the northern Guam aquifer. *Agriculture, Ecosystems and Environment*, vol. 79, p. 17–27.

Msanya, B.M., 1998. *Integrated Agro-ecological Research of the Miombo Woodlands in Tanzania*. Final Report. Faculty of Agriculture, Sokoine University of Agriculture, Centre for African Area Studies, Kyoto University, JCIA.

Nardi, S., Cocheri, G. and Dell'Agnola, G., 1996. Biological activity of humus. In: Piccolo, a. (Ed.), *Humic Substances in Terrestrial Ecosystems*. Elsevier, Amsterdam, p. 361–406.

Paton, T.R., 1978. *The formation of soil material*. George Allen & Unwin. London.

Shishira, E.K., Yanda, P.Z. Sosovete, H. and Lyimo, J.G., 1997. *Kilosa District: Land Use and Natural Resource Assessment*, Report prepared for Kilosa district Council Irish Aid. Institute of Resource Assessment IRA, University of Dar es Salaam.

Simonsson, L., 2001. Applied Landscape Assessment in a Holistic Perspective, A case study from Babati District, north-central Tanzania. *READ* No 1.

United republic of Tanzania (URT) (1988). *Population Census National Profile: The Analytical report*, Bureau of Statistics, Dar es Salaam.

Urino, A.P., Mongi, H.O., Chowdhury M.S., Singh, B.R. and Semoka, J.M.R., 1979. *Introductory soil science*. Tanzania Publishing House, Dar es Salaam.

WWF, 2001. Chapter 2: Physical features and processes, In: *Miombo Ecoregion, Draft biodiversity vision*, p. 8–11.

Homepages:
www.marekinc.com/GeoOverviewGreatRift.htlm, 24-04-2003.

www.infoplease.com/atlas/country/tanzania.html**,** 26-04-2003

www.ui.se/fakta/afrika/tanzania.htm**,** 26-04-2003

Personal comunication:
Mr Haule the Forest officer of Kilosa district, 05-03-2003 – 08-03-2003

Glossary

A-horizon – the surface horizon of a mineral soil

B-horizon – a soil horizon, usually beneath the A-horizon

Biosphere – the parts of the lithosphere, hydrosphere and atmosphere in which living organisms can be found

Colluvial – a deposit of rock fragments and soil material accumulated at the base of a slope as a result of gravitational action.

Pangea – the supercontinent formed 300 million years ago, which began to break apart and form the present land masses 200 million years ago.

Hydrosphere – the water portion of our planet

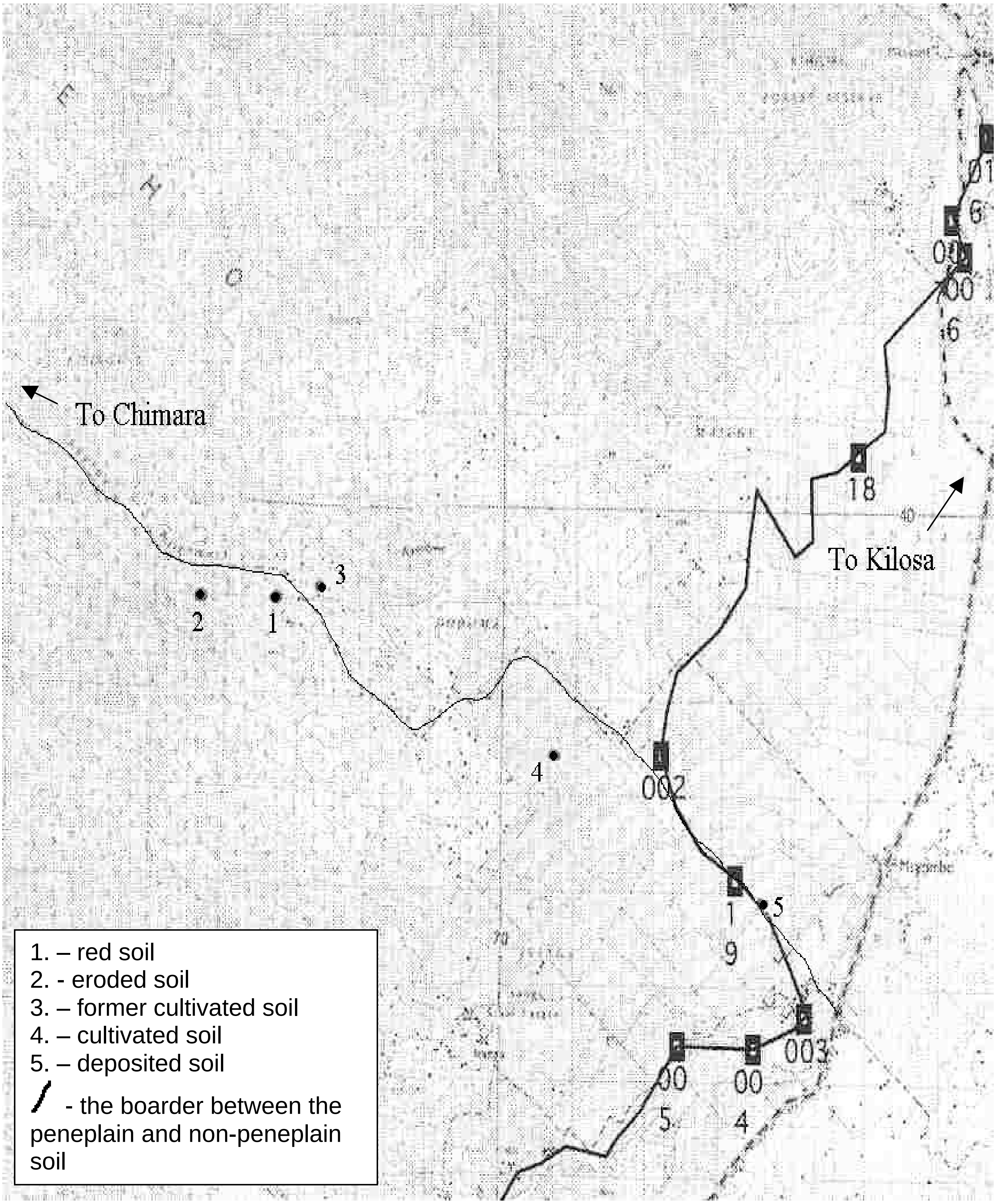
Lithosphere – the outer layer of earth, including the crust and the upper mantle

Peneplain – the old land surface, which is almost flat because the bedrock has been abraded by erosion for a long time

Vertisol – clayey soils with high shrink-swell potential

Appendix 1.

The sampling sites south-west of Kilosa.



Appendix 2

The sampling sites north-west of Mikumi.