CHEMICAL AND MINERALOGICAL STUDIES OF SOME SOILS FROM TANZANIA

by

Abel Kaaya, Tore Krogstad, Ivan Digernes,
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Rapportens tittel og forfatter(e):

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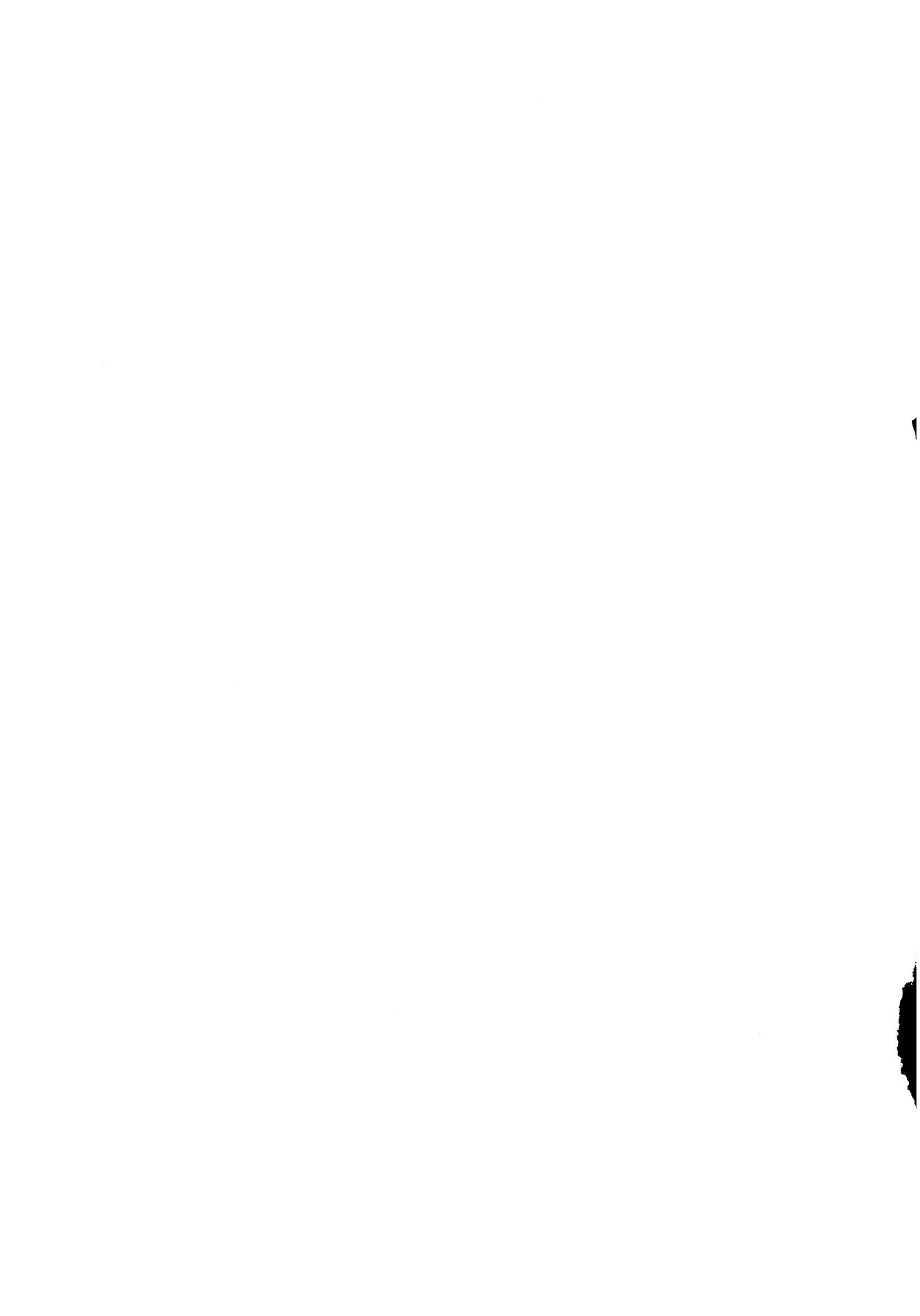
Oppdragsgiver: Institutt for jord- og vannfag, Norges Landbrukshøgskole

Summary: Chemical and mineralogical analyses were done on 13 selected samples from soil profiles in Tanzania. It was one sample with a high content of organic matter, one sand sample and eleven clays. The clay samples have a clear bimodal grainsize distribution which is a result of the weathering processes. Kaolin is the dominating mineral in most of the clays, but smectite is an important component in some samples. There is a clear connection between the mineralogical composition and cation exchange capacity. The sand sample has a high cation exchange capacity due to a high content of vermiculite.

Sammendrag: Kjemiske og mineralogiske analyser er utført på 13 utvalgte prøver fra jordprofiler Tanzania. Det var en prøve med et høyt innhold av organisk materiale, en sandprøve og elleve leirer. Leirprøvene har en tydelig bimodal kornfordeling som er et resultat av forvitringsprosessene. De fleste leirfrakssjonene inneholder mye kaolin, mens smektitt er en viktig komponent i noen prøver. Det er en tydelig sammemhreng mellom den leirmineralogiske sammensetning og kationbyttekapasitet. En sandprøve har høy kationbyttekapasitet på grunn av et høyt vermikulitt-innhold i sandfraksjonen.

4. Emneord, norske

1. Tanzania
2. Jordprofiler
3. Jordkjemi
4. Leirmineralogi

4. Emneord, engelske

1. Tanzania
2. Soil profiles
3. Soil chemistry
4. Clay mineralogy

Prosjektleder:

Tore Krogstad, professor

For administrasjonen:

Gunnar Abrahamsen, professor

Introduction.

During the spring 1995 a course in soil chemistry and soil chemical analysis was arranged for technicians and chemical engineers from the soil laboratory at the Department of Soil Science, Sokoine University of Agriculture, Tanzania. The participants were: Mr. Josephat K. Kilosa, Mr. Alex S. Chaduma, Mr. Eliah A. Kamwela, Ms. Elihaika E. Kafui and Ms. Consolatha J. N. Mhaiki. Several samples from different localities in Tanzania and Norway were analysed with different methods. The results from the analyses of Tanzanian soils are reported here.
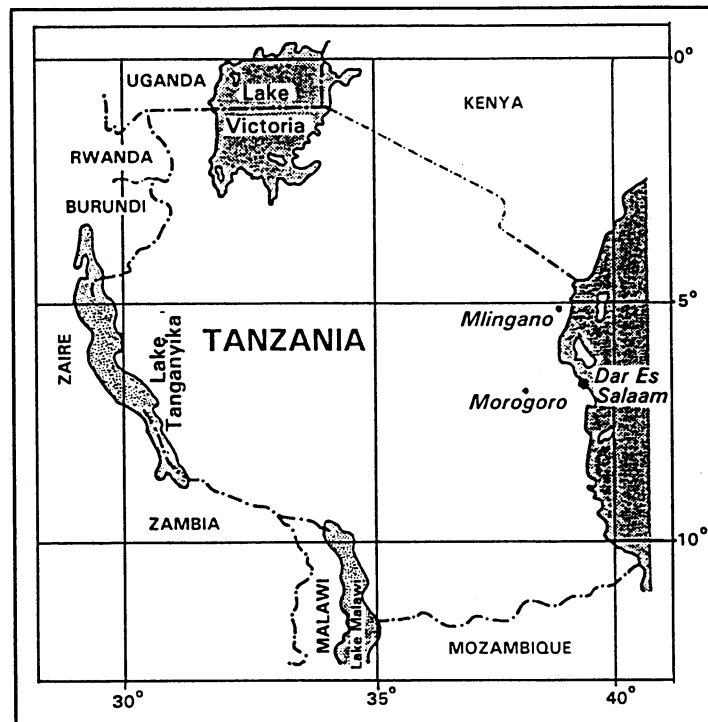
Sampling locations.

Fig. 1. The locations studied are close to Morogoro or Mlingano (Tanga).

Soil samples were collected from several profiles located in two ecoregions of Tanzania; arid to subhumid (Morogoro) and subhumid (Mlingano).

Geology of the sampled areas.
Misufini and Mindu sites in Morogoro.
These sites lie on a plain between the Uluguru mountains and the Mindu hills. The plain is drained by the Ngerengere river, and both sites are located between the river and Morogoro municipality (Fig. 2). The plain between the Uluguru mountains and the Mindu hills on which the sites are located is formed by neogene-pleistocene deposists composed mainly of deep red and reddish brown soils. Alluvial deposits are found on the Ngerengere river plain. The Mindu hills are composed of muscovitic biotite gneisses and migmatites whereas the underlying rocks on the slopes of Uluguru mountains close to the sampled sites are formed by hornblende-pyroxene granulites (Sampson & Wright, 1964). The underlying rocks in the Misufini and Mindu sites are dominated by quartz and feldspars (K-feldspar and plagioclase). Biotite and hornblende are also common.

Mlingano sites in Tanga.
Description by De Pauw (1984) indicates that the soils of the area around Mlingano site were developed from neogene sandy clays, sandstones and other terrestrial sediments. According to Kilasara et. al. (1995), the underlying rocks are banded gneisses mostly with aluminous gneisses on the ridge summits and gneisses with marble in the plains.
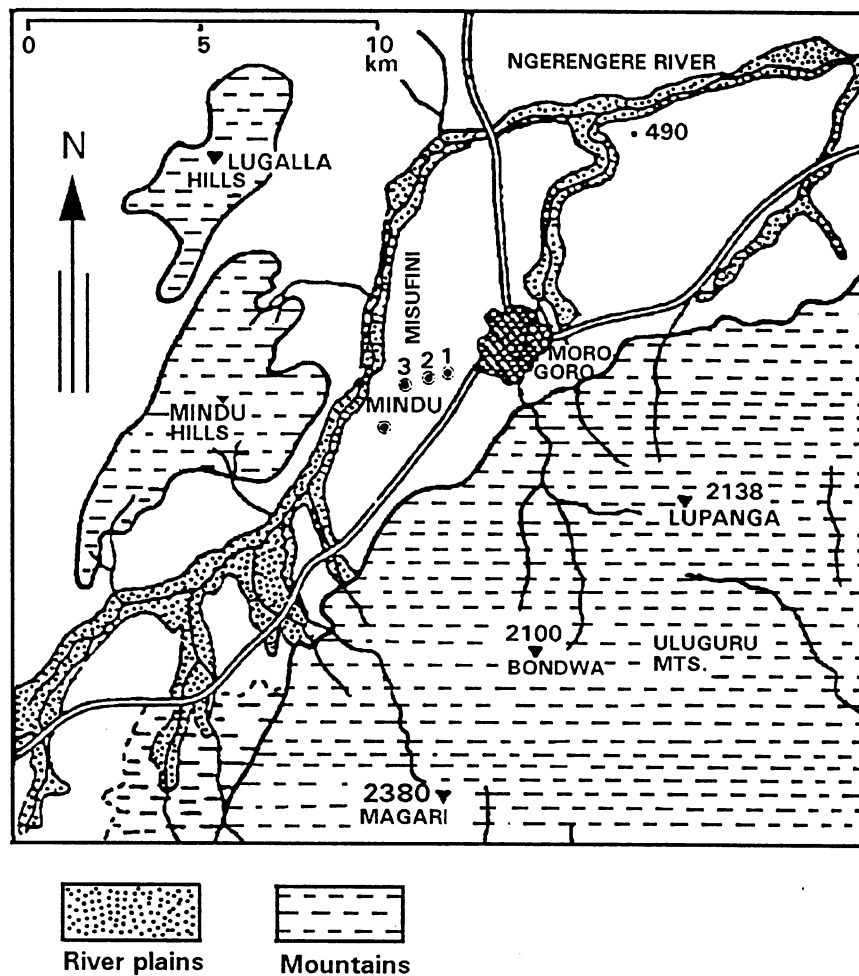
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Fig. 2. Location of the three profiles near Misufini and one profile near Mindu.

Information about the sampling sites, profile depths and soil classification are presented in Table 1.

Table 1. Sampling sites, profile depths and soil classification of the samples used.

Our nr.	Site.	Name	Erosion class	Location	Sample Layer	Profile depth cm	FAO classification	Soil Taxonomy
T1	Erosion productivity site Mlingano	Fym		From the Kraal				Anthropic epipedon
T2	Erosion productivity site Mlingano	Ferralsol site		Profile No 1	2	250	Rhodic Ferralsol	Tropeptic Haplustox
T3	Erosion productivity site Mlingano	Luvisol site		Profile No 4	4	200	Haplic Lixisol	Typic Rhodustalf
T4	Erosion productivity site Mlingano	Luvisol site		Profile No 4	3	155	Haplic Lixisol	Typic Rhodustalf
T5	Erosion productivity site Mlingano	Ferralsol site		Profile No 1	1	160	Rhodic Ferralsol	Tropeptic Haplustox
T6	Misufini 3	Site 1	2 and 4	Block 3	BW	35-70	Chromic Luvisol	Rhodustalf
T7	Misufini 3	Site 1		Block 4	B	80	Chromic Luvisol	Rhodustalf
T8	Mindu	Site 2	3	Block II	Bt	32-93	Haplic Alisol	Ultic Haplustalf
T9	Mindu	Site 2	1 and 2	Block III	Bt	23-90	Haplic Alisol	Ultic Haplustalf
T10	Misufini 1	Site 1	1	Block 1	Bck calcrete	36-41	Eutric Cambisol	Lithic Eutrochrept
T11	Misufini 2	Site 1	2 and 3	Block 2	C		Eutric Cambisol	Typic Eutrochrept
T12	Misufini 2	Site 1	2 and 3	Block 2	Stone line	59-70	Eutric Cambisol	Typic Eutrochrept
T13	Misufini 2	Site 1	2 and 3	Block 2	BII	125-140	Eutric Cambisol	Typic Eutrochrept

Arrangements of horizons Site 1 Block 1 profile:Ap, AB, gravel layer, calcrete, BC.
Arrangements of horizons Site 1 Block 2 profile: Ap, AB, B gravel layer, stone layer with weathered feldspar and quartz, B, C (weathered amphibolite). Samples T1-T5 were collected February 27. 1994.

Mlingano, Tanga

Profile 1   Profile 4

Fig. 3. Soil sampling depths at Mlingano, Tanga. Classification of profiles from Kilasara et. al. (1995).

Profile 1. Soil Taxonomy: Tropeptic Haplustox   FAO-Unesco: Rhodic Ferralsol.
Profile 2. Soil Taxonomy: Typic Rhodustalf   FAO-Unesco: Haplic Lixisol.

Mindu block II   Mindu block III

Fig. 4. Soil sampling depths at Mindu, Morogoro. Classification of profiles from Kilasara et. al. (1995). Soil Taxonomy: Ultic Haplustalfs   FAO-Unesco: Haplic Alisols.
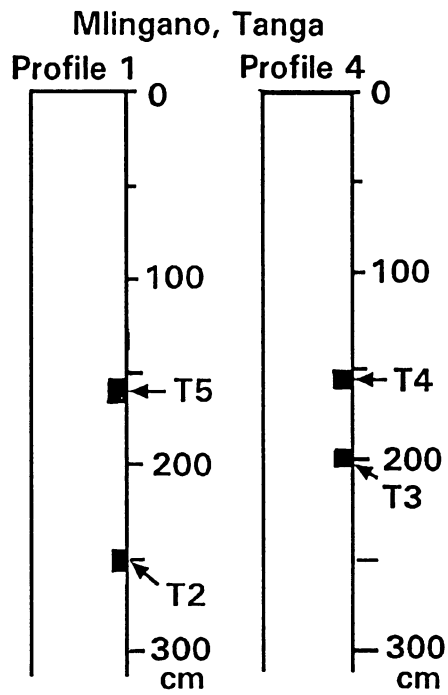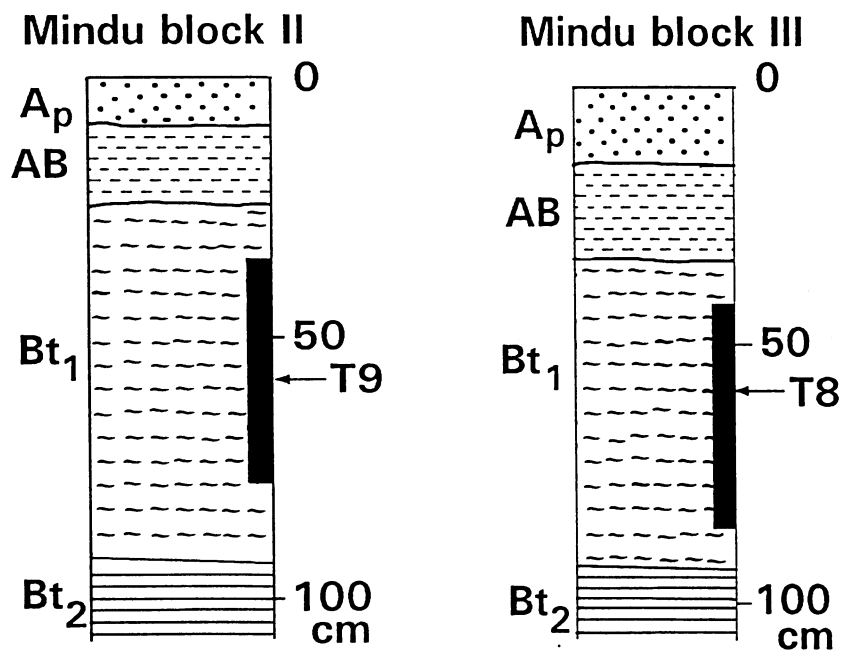
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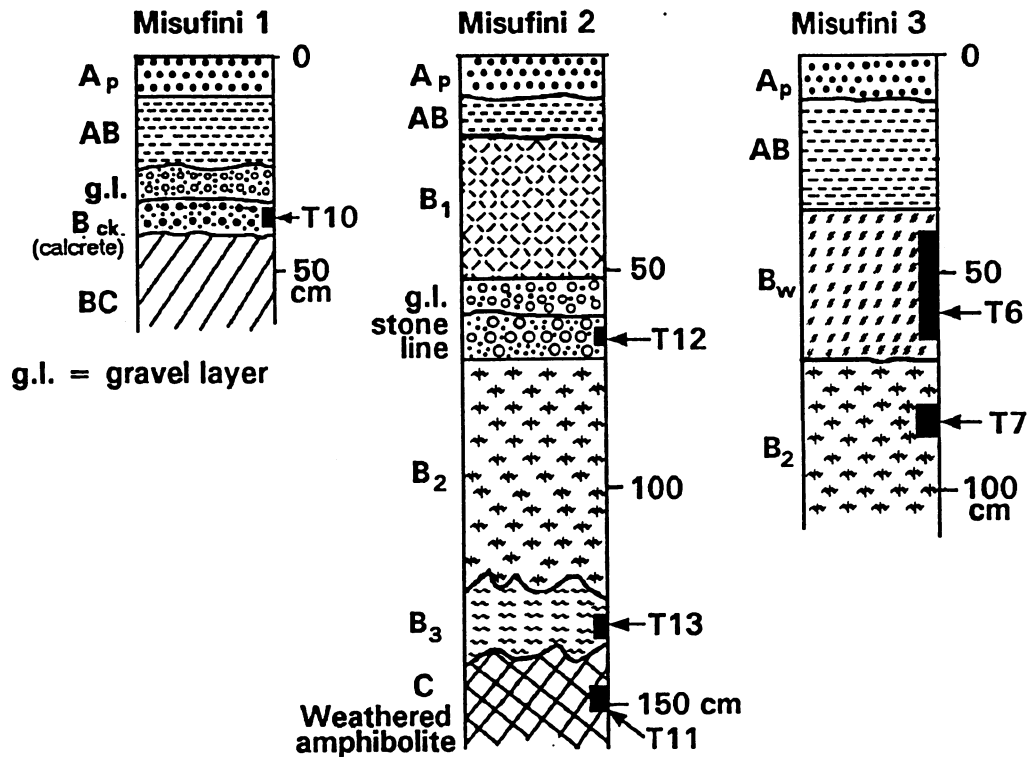
Fig. 5. Soil sampling depths at Misufini, Morogoro. Classification of profiles from Kilasara et. al. (1995)

Profile 1. Soil Taxonomy: Lithic Eutrochrept   FAO-Unesco: Eutric Cambisol

Profile 2. Soil Taxonomy: Typic Eutrochrept   FAO-Unesco: Chromic Cambisol

Profile 3. Soil Taxonomy: Rhodustalf   FAO-Unesco: Chromic Luvisol

METHODS USED FOR SOIL ANALYSIS:

Grainsize distribution.

The grain size distribution was measured using the hydrometer method and the pipette method as described in Klute (1986). In the pretreatment of the samples organic matter was removed. Iron oxides were not removed since they are important minerals in these samples. The samples were dispersed using Na-pyrophosphate. The sand fraction was wet sieved using sieves with openings of 600, 212 and 63 μm to separate the coarse, medium and fine sand fractions, respectively.

Dry matter and loss on ignition.

Three to five g soil was dried at 105°C over night. The same samples were ignited 4-5 hours at 550°C. Loss on ignition can be used as a measure of organic matter content in the soil after correction for the clay content.

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pH.

pH was measured in a suspension of 10 ml soil (or 10 g soil) and 25 ml solution after leaving the suspension over night. It is important to mention that the pH was measured in the supernatant and not in the sediment to avoid the suspension effect (Page et al., 1982) The pH was measured in destilled water, 0.01 M $CaCl_2$ and 1 M KCl.

Total carbon and organic carbon.

Total carbon was measured using the instrument LECO CHN-1000. Carbon is measured as CO_2 with an infrared detector (Page et al., 1982). For organic carbon the soil is washed with acid to remove inorganic C prior to analyses. Inorganic C is the difference between total C and organic C.

Total nitrogen.

Total nitrogen was measured using the instrument LECO CHN-1000. In this instrument NO_x is reduced to N_2 with Cu and then measured using the thermal conductivity.

NH_4-N and NO_3-N.

NH_4-N and NO_3-N were measured using the Flow injection analysis (FIA) and ion selective electrodes (Smith, 1991). When using a nitrate selective electrode it is important to use $CuSO_4$ as the extraction solution instead of KCl to avoid interferences of Cl.

Cation exchange capacity (CEC).

The soil was extraced using 1 M ammonium acetate (pH 7.00) and 1 M ammonium nitrate (Page et al., 1982). Exchangable H^+ was determined by titrating the filtrate to pH 7.00 using 0.05 M NaOH. The other cations were measured by atomic absorption spectroscopy and the CEC was calcultated as the sum of all exchangeable cations.

Total P and inorganic P.

For total P analysis, crushed soil was ignited at 550°C and extracted by 12 M H_2SO_4. For inorganic P the soil was extracted by the same reagents without ignition. Phosphorus in the extract was measured by the molybenium blue method (Page et al., 1982). Organic P was calculated as the difference between total and inorganic P.

Available P.

Plant available P was analysed by the methods of Olsen (0.5 M $NaHCO_3$, pH 8.5), Bray 1 (0.03 M NH_4F + 0.025 M HCl) and P-AL (0.1 M NH_4-lactate + 0.4 M Acetic acid, pH 3.75). The Olsen and Bray 1 methods are described in Page et al. (1982). The ammonium lactate method (P-AL) is described in Egner et al. (1960). The ortho-phosphate in the soil extracts was measured by the molybdenium blue method (Page et. al. 1982).

RESULTS

Grainsize distribution - effect of CDB-treatment.

After a CDB-treatment (citrate-dithionite-bicarbonate), the grainsize distribution was determined (Table 2).

Table 2. Grainsize distribution of samples with and without CDB-treatment.

Sample	After CDB-treatment.			Without CDB-treatment.		
	% Sand	% Silt	% Clay	%Sand	%Silt	% Clay
	> 63 μm	2-63 μm	< 2μm	> 63 μm	2-63 μm	< 2 μm
T2	28.8	3.3	68.0	19.8	21.1	59.1
T3	51.8	10.0	38.1	41.3	14.6	44.1
T4	49.3	5.0	45.7			
T5	31.9	8.4	59.6			
T6	56.1	4.0	39.9	43.7	8.1	48.2
T7	47.2	7.4	45.4	38.5	9.1	52.4
T8	39.2	6.3	54.4			
T9	38.0	10.2	51.9			
T10	48.1	13.0	38.9			
T11	93.5	2.4	4.1	70.1	20.9	9.1
T12	58.6	8.6	32.9	54.0	8.8	37.2
T13	61.6	11.3	27.2	46.3	13.8	39.9

All samples except T11 are sandy clays, while T11 is sand. The samples have a bimodal distribution with high amounts of clay and sand and little silt. This is normal for strongly weathered soils. Similar grainsize distribution was found by Moberg et. al. (1982).

During this analyses it was observed that many samples contained a light brown mica-like mineral in the sand-fraction. Samples T10 and T11 (sand) have high and very high contents of this mineral.

The most pronounced effects of the CDB-treatment were that the relative amounts of sand increased while that of silt decreased. For most samples there was also a decrease in clay content. The explanation may be that some of the silt and clay fractions were dissolved during the CDB-treatment and consequently the relative amount of sand increased.

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CHEMICAL DATA

Main results of the chemical analyses are presented in Tables 3-7

Table 3. Chemical characteristics of the soils.

Sample	pH-H₂O	pH-CaCl₂	pH-KCl	Total Carbon (%)	Organic Carbon (%)	Inorg. Carbon (%)	LOI %	Dry matter (%)
T 1	7.64	7.35	7.29	24.50	17.34	7.16	43.32	94.44
T 2	5.38	4.56	4.44	0.25	0.18	0.07	9.14	98.44
T 3	5.98	5.68	5.32	0.23	0.12	0.12	7.46	98.71
T 4	5.94	5.63	5.30	0.25	0.23	0.02	8.17	98.58
T 5	5.05	4.54	4.31	0.24	0.26	0	8.82	98.59
T 6	5.72	5.08	4.55	0.60	0.49	0.11	6.21	97.83
T 7	6.26	5.50	4.87	0.44	0.36	0.08	6.32	97.69
T 8	5.75	5.12	4.53	0.48	0.39	0.08	7.51	96.71
T 9	6.13	5.44	4.98	0.51	0.62	0	7.40	97.10
T 10	7.69	7.55	7.15	2.44	0.45	1.98	6.52	96.07
T 11	8.33	7.52	7.12	0.35 ·	0	0.35	2.21	98.02
T 12	6.62	6.03	5.44	0.61	0.51	0.10	6.18	97.50
T 13	6.94	6.38	5.61	0.62	0.38	0.24	4.65	97.02

The samples T1, T10 and T11 have pH values measured in distilled water between 7.6 and 8.3. All three samples have a relatively high content of inorganic C. All other soil samples have pH values between 5 and 6.9. The ionic strength in the soil solution has a strong influence on the measured pH values. For some of the samples the pH difference between 1M KCl and distilled water is >1 pH unit.

Organic matter.
By using organic C, the content of organic matter can be estimated to 0-1.5%, except for sample T1 which has an organic matter content of 30-35%. This sample (T1) is classified as anthropic epipedon.

The high values of LOI (%) compared to organic C indicate presence of relatively high amounts of water in the mineral structure of the soil. For that reason it is difficult to use LOI to estimate the organic matter content of the samples.

Phosphorus

Table 4. Different phosphorus fractions (mg P/kg) in the soil samples.

Sample	Total-P	Inorg.-P	Org.-P	Bray1	Olsen
T 1	5387	4143	1245	1105	1623
T 2	140	93	47	0.9	1.6
T 3	93	46	46	0.2	1.8
T 4	95	50	45	0.4	1.6
T 5	140	82	59	0.4	1.3
T 6	162	59	104	0.6	1.0
T 7	133	52	81	0.5	1.1
T 8	180	109	71	0.5	1.5
T 9	175	109	66	0.5	1.5
T 10	832	742	90	0.4	2.3
T 11	2255	2268	0	2.6	2.4
T 12	215	79	137	1.4	1.6
T 13	165	81	84	0.6	1.5

Except the samples T1, T10 and T11, the content of organic P is about 50% of the total P content. In samples T10 and T11 the relative content of organic P is low. This may be assigned to the low content of organic C in the soil.

The high content of total P particularily in soil T10 and T11 may probably be precipitated as calsiumphosphate due to high pH in the soil. These P fractions are to a small extent plant available as also indicated by the results of Bray 1 and Olsen methods. The content of plant available P is on the same low level for all the mineral soil samples. The organic matter rich sample T1 seems to be a very good P source for plants.

Nitrogen.

The total N content is very low in all mineral soils. For most of the soils NH_4-N and NO_3-N are generally less than 1 % of the total N content. This is a normal value and it shows that N is strongly bound to the organic matter.

Table 5. Different nitrogen fractions in the soil samples.

Sample	Total-N %	NH4-N mg/kg FIA-KCl	NH4-N mg/kg ISE-KCl	NO3-N mg/kg FIA-KCl	NO3-N mg/kg ISE-CuSO$_4$
T 1	2.19	238	347	65	107
T 2	0.09	4.4	3.8	5.9	6.8
T 3	0.05	7.6	6.0	3.5	5.4
T 4	0.04	3.9	3.0	2.7	4.3
T 5	0.06	4.3	3.8	4.3	6.5
T 6	0.07	5.3	4.1	7.2	11.3
T 7	0.05	8.2	7.2	3.3	5.3
T 8	0.07	2.7	2.2	2.1	3.5
T 9	0.07	6.4	5.7	1.6	3.0
T 10	0.06	7.1	6.6	2.3	10.0
T 11	0.02	5.2	4.3	3.8	6.0
T 12	0.08	9.9	9.1	8.3	14.3
T 13	0.08	6.9	6.6	9.0	22.5

The FIA method measures higher values for NH_4-N than the ISE method while the results were just the reverse with NO_3-N with an average of 83% higher values using ISE. No plausible explanation could be given for the disparity between these methods.

CATIONIC EXCHANGE CAPACITY (CEC)

The exchangeable ions were replaced with NH_4^+, both with NH_4NO_3 and NH_4OAc and the amounts were determined with plasmaspectrograph (ICP) or atomic absorption spectrophotometer. The results are given in Tables 6 and 7.

Table 6. Exchangeable cations (NH_4NO_3). Values in $cmol_c$ kg^{-1} = meq/100 g).

Sample	Mg^{2+}	Ca^{2+}	Mn^{2+}	Na^+	H^+	Sum
T 1	13.93	39.02	2.00	7.25	0	62.2
T 2	0.74	0.71	3.00	0	4.33	8.8
T 3	1.82	1.35	0.25	0	0	3.4
T 4	2.18	1.66	0.25	0	0	4.1
T 5	1.05	1.21	2.25	0	0.83	5.3
T 6	4.48	3.42	2.83	0.07	0	10.8
T 7	5.11	3.45	2.50	0.14	1.17	12.4
T 8	4.35	4.51	0.67	0	0	9.5
T 9	4.18	5.63	0.67	0.07	0	10.5
T 10	2.55	84.05	0	0.04		86.6
T 11	2.38	34.60	0.33	0.07	0	37.4
T 12	3.08	9.1	0.50	0	0	12,7
T 13	3.39	5.25	0.58	0.14	2.83	12.2

As expected exchangable H^+ is smaller using NH_4NO_3 compared to NH_4OAc pH 7. The results also show clearly that CEC is correlated to soil organic matter with the highest CEC for the samples T1, T10 and T11.

Ca^{2+} and Mg^{2+} are the dominant exchangable cations. But also Mn^{2+} seems to be an important exchangeable cation in some samples.

Carbonates will to some extent be dissolved with our extraction solutions. This means that exchangeable Ca^{2+} and also some of the Mg^{2+} may be overestimated in the samples with high content of inorganic C (samples T1, T10 and T11). The range of CEC values is probably smaller than Tables 6 and 7 may indicate.

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Table 7. Exchangeable cations (NH_4OAc). Values in $cmol_c$ kg^{-1} = mekv/100 g).

Sample	Mg^{2+}	Ca^{2+}	Mn^{2+}	Na^+	K^+	H^+	Sum	B.S. %
T 1	9.95	39.48	3.08	14.5	42.6	0	109.6	100
T 2	0.80	0.85	0.67	0.09	0.92	8.25	11.6	28
T 3	2.35	1.57	0.17	0.13	0.19	5.08	9.5	46
T 4	2.28	1.60	0.17	0.02	0.28	3.25	7.6	57
T 5	1.10	1.40	0.33	0.04	0.58	8.92	12.4	28
T 6	4.62	3.87	1.75	0.09	0.15	6.75	17.2	61
T 7	5.13	3.67	1.50	0.14	0.13	5.25	15.8	67
T 8	5.22	6.11	0	0.05	0.28	9.75	21.4	54
T 9	4.05	5.64	0.08	0.07	0.60	8.59	19.0	55
T 10	2.67	90.84	0.08	0	0.17	0	93.4	100
T 11	2.45	37.03	0.17	0.13	0.09	0	39.9	100
T 12	3.20	8.26	0.17	0	0.15	11.6	23.4	50
T 13	4.20	19.62	0.08	0.20	0.26	8.59	33.0	74

MINERALOGY

Clay and silt mineralogy.

Since the clay content in most samples ranged between 27 and 68%, and the organic content was very low, it is expected that the clay may minerals have a significant influence on different soil properties.

Sample T2 (Rhodic Ferralsol from 250 cm depth, Mlingano)

The clay fraction contains almost pure kaolinite with strong peaks at 0.71 (001) and 0.355 nm (002) (Fig.6). The "020- band between 20 and 22° 2θ shows that the mineral has a disordered structure. The intensity of this band is quite weak since we prepared oriented slides. The fraction contains also a small amount of gibbsite.

The silt fraction is only 3.3% of the total sample. This fraction is a mixture of kaolinite and quartz. The kaolinite in this fraction has a slightly better crystallinity than the kaolinite in the clay fraction.
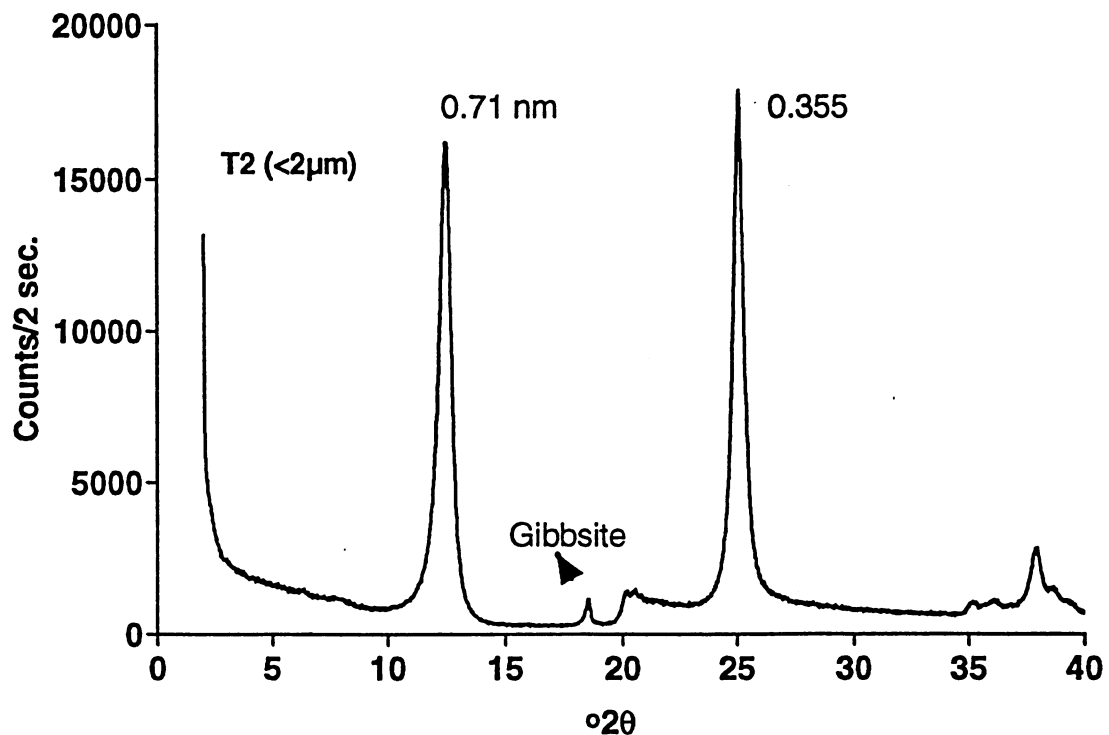
Fig. 6. X-ray diffractogram of the clay fraction from sample T2.

Sample T3 (Haplic Lixisol from 200 cm depth, Mlingano).

The clay fraction contains mainly kaolinite (Fig. 7). In addition there is a small amount of a mixed-layered mineral with a peak at 1.12 nm. The intensity of the 001-peak for kaolinite is much stronger than for sample T2, while the intensity of the 020-band is reduced. This is explained by a better orientation of the clay particles on the ceramic plate. The width of the 001-peak at half peak height is the same in samples T2, T3 and T4.
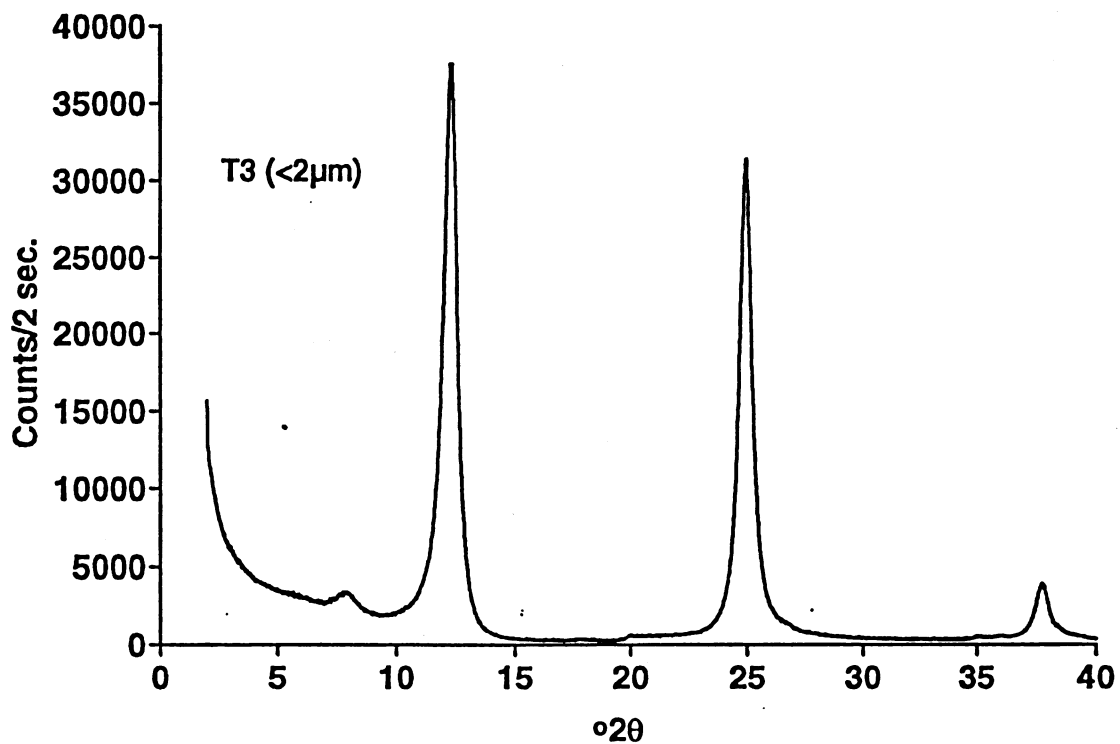
Fig. 7. X-ray diffractogram of the clay fraction from sample T3.

Sample T4 (Haplic Lixisol from 150 cm depth, Mlingano).

The clay fraction is very similar to sample T3, with kaolinite and a small amount of a mixed-layered 1.11 nm mineral. The silt fraction (5%) contains quartz and a kaolinite with slightly better crystallinity than the clay-kaolinite.
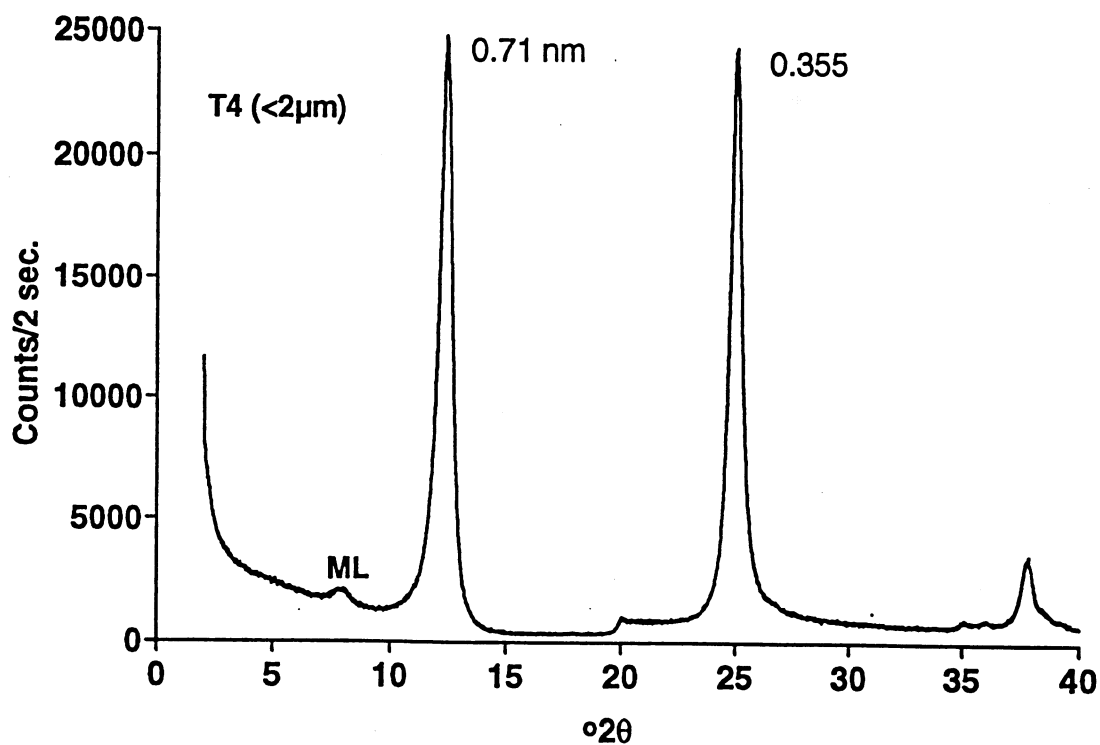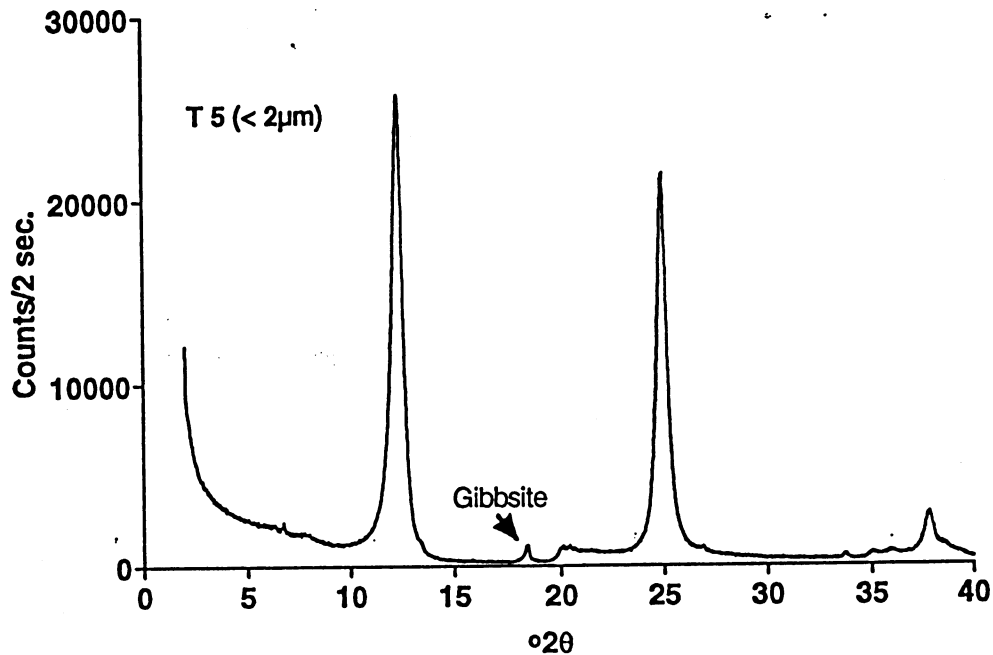

Fig. 8. X-ray diffractogram of the clay fraction from sample T4.

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Sample T5 (Rhodic Ferralsol from 160 cm depth, Mlingano).

This sample is very similar to sample T2 with kaolinite and a small amount of gibbsite.

Fig. 9. X-ray diffractogram of the clay fraction from sample T5.

Sample T6 (Chromic Luvisol from 35-70 cm depth at Misufini 3). The clay fraction contains a disordered kaolinite as well as a mixed-layered mineral (1.12 nm) and a 1.5 nm mineral. The 1.5 nm peak which moved to 1.7 nm with Ethylen glycol is due to smectite while the 1.12 nm peak was not influenced by this treatment (Fig. 10). The E.G.-diagram also shows that the clay fraction contains a small amount of illite (1.0 nm peak).
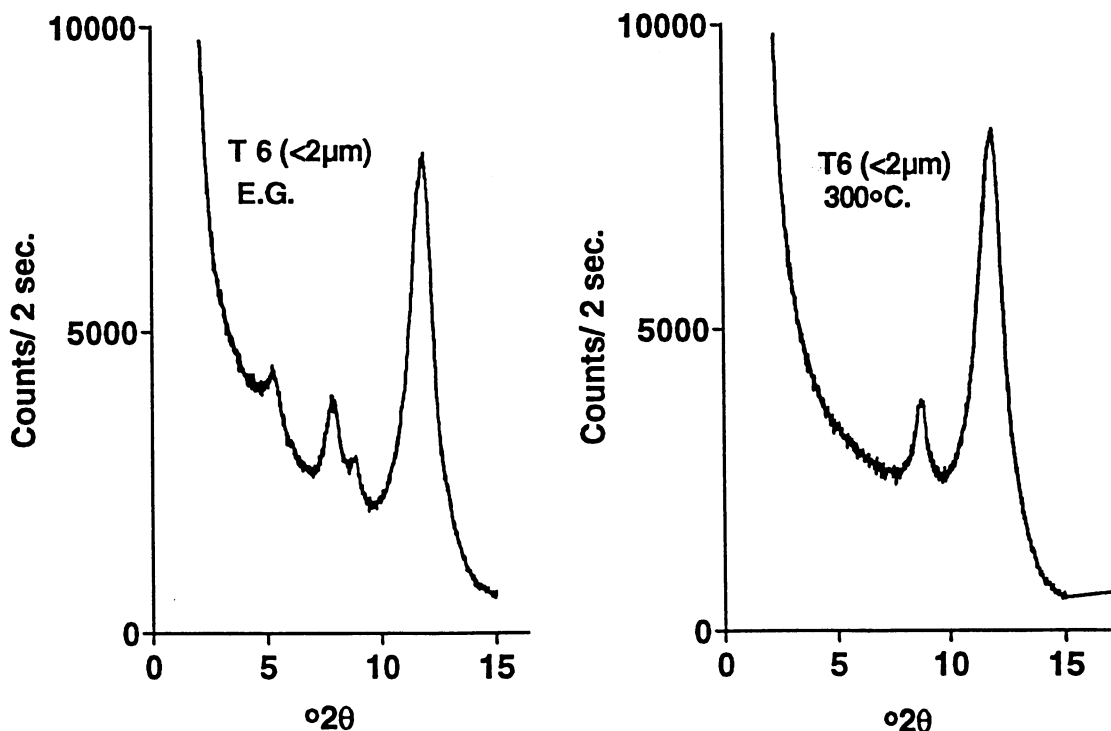
Fig. 10. X-ray diffractograms (2-15° 2θ) for the clay fraction from sample T6 after treatment with Ethylene glycol (E.G.) and heat treatment at 300°C for one day.

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The smectite as well as the mixed-layer mineral collapse to 1.0 nm upon heat treatment (350°C). Consequently the mixed-layered mineral is classified as illite-vermiculite. It is noticeable that the 001-peak for kaolinite has a d-value about 0.74 nm which is 0.02-0.025 nm more than the kaolinites in samples T2-T5, and the peak is much broader at peak half-height.

The silt fraction (4%) has a composition which is very different from the silt fractions in samples T2 and T4. Only a very weak kaolinite peak is abserved. The major minerals are different tectosilicates. Quartz is an important component. In addition we find an acid plagioclase and potassium feldspar.

Sample T7 (Chromic Luvisol from 80 cm depth at Misufini 3). The composition of the clay fraction is very similar to sample T6 with mainly kaolinite (0.734 nm) and smaller amounts of smectite, a mixed-layered mineral (1.11 nm) and illite.

Sample T8 (Haplic Alisol from 32-93 cm depth at Mindu).The clay fraction is very similar to sample T6 with a 0.74 nm kaolinite, smectite, mixed layered illite-vermiculite and traces of illite. The silt fraction (6.3%) is also very similar to sample T6 with quartz and two feldspars (Fig. 11).
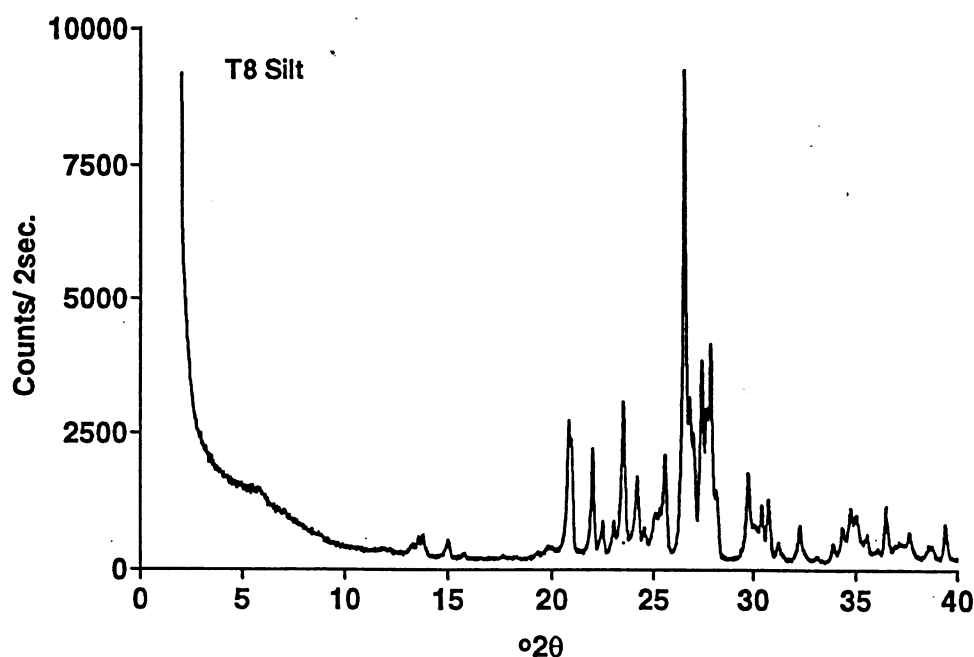

Fig. 11. X-ray diffractogram of the silt fraction from sample T8. The strongest peaks are from quartz and two feldspars.

Sample T9 (Haplic Alisol from 23-90 cm depth at Mindu). The clay fraction has a composition which is very similar to T6-T8 with kaolinite some smectite, mixed-layered mineral and traces of illite.

Sample T10 (Eutric Cambisol from 36-41 cm depth at Misufini).
The clay fraction contains smectite and a well crystallized kaolinite. The first order

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kaolinite peak overlaps with the second order smectite peak. The result is a very broad peak with appparent d-value 0.76 nm. In addition there is a small amount of the 1.1 nm mixed-layered mineral. After heat treatment at 350°C the kaolinite peak is still very broad with a d-value at 0.76 nm, which indicates strongly the presence of some illitic layers in the kaolinite.
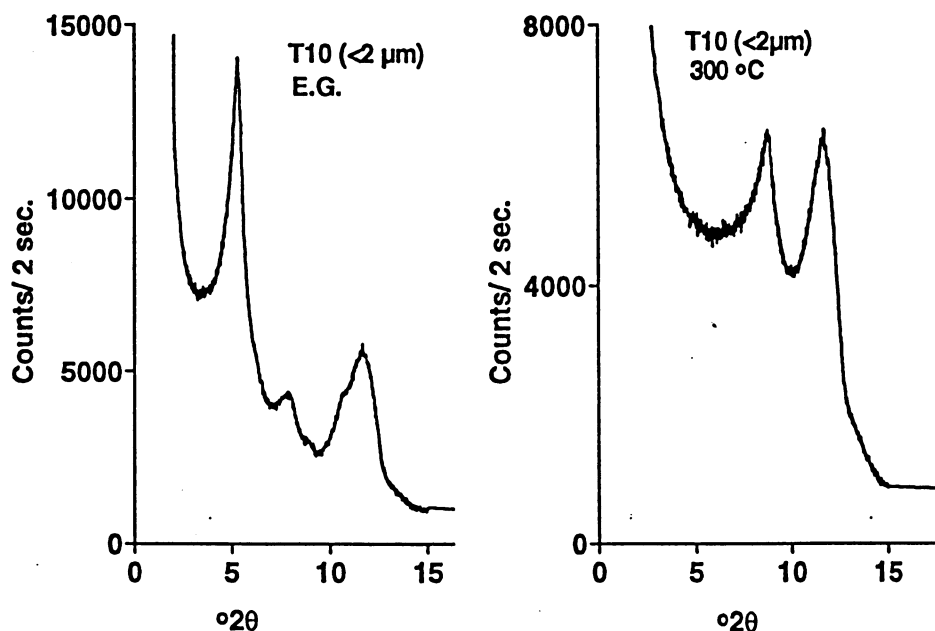

Fig. 12. X-ray diffractograms (2-15° 2θ) for the clay fraction from sample T10 after treatment with Ethylene glycol (E.G.) and heat treatment at 300°C for one day.

Sample T11 (Eutric Cambisol from 150 cm depth at Misufini). The clay fraction contains a well crystallized smectite which has a first order peak with a d-value 1.55 nm when equilibrated at 40% R.H. (Fig. 13). This mineral gives an integral series of much weaker
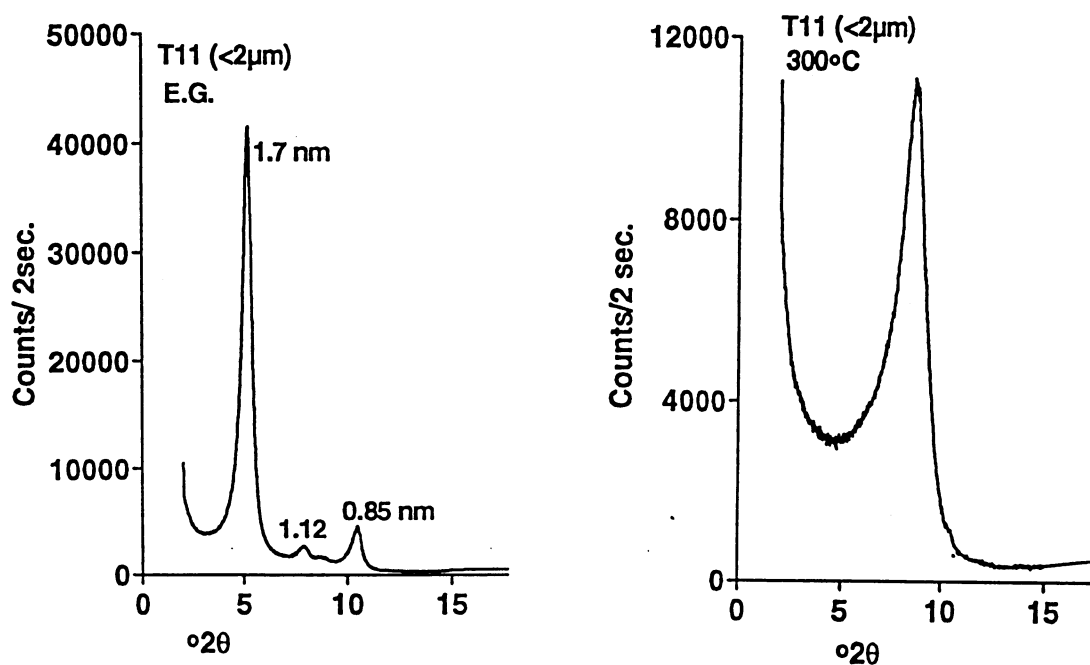

Fig. 13. X-ray diffractograms (2-15° 2θ) for the clay fraction from sample T11 after treatment with Ethylene glycol (E.G.) and heat treatment at 300°C for one day.

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basal peaks. After E.G.-treatment it expands to 1.86 nm and it collapses to 1.0 nm upon heating (350°C). The E.G. treated sample also shows a clear 002-peak at 0.846 nm.

The silt fraction (4%) contains smectite, mixed layered illite/vermiculite and tectosilicates. The last group contains much albite and quartz, some amphibole and traces of potassium feldspar. Electron microscopy showed flakes of smectite with "diameters" between 1 and 5 μm.

Sample T12 (Eutric Cambisol from 59-70 cm depth at Misufini).
The clay fraction contains a poorly crystallized kaolinite (0.746 nm) smectite and small amounts of the 11.1 A mixed-layer mineral and illite.

Sample T13 (Eutric Cambisol from 125-140 cm depth at Misufini). The content of smectite is much higher than in sample T12 (Fig. 14). Kaolinite (0.754 nm) is a major component. In addition there is a small amount of illite.
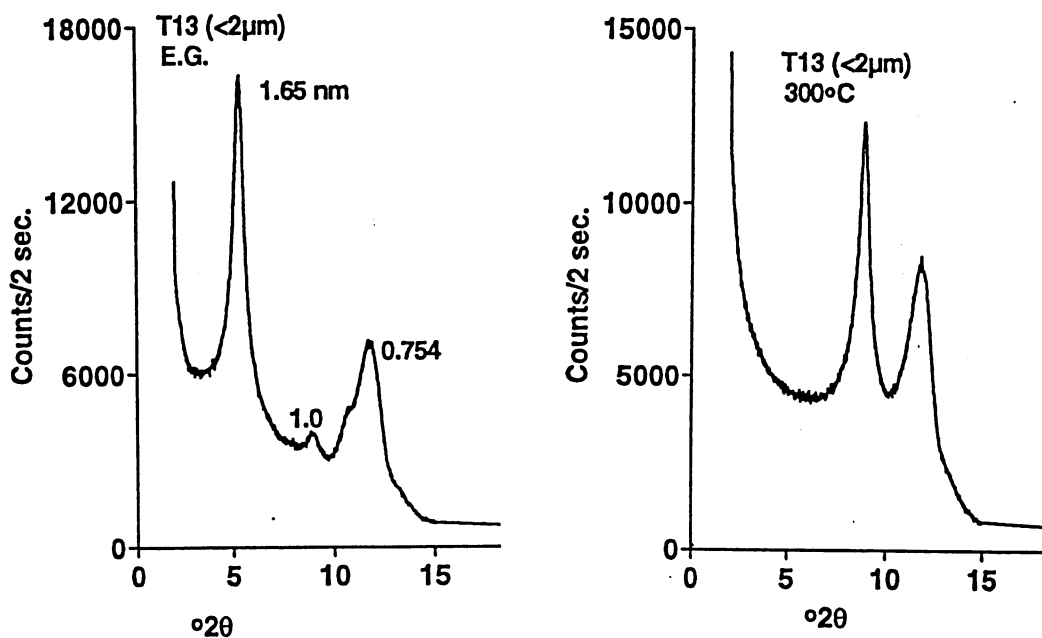

Fig. 14. X-ray diffractograms (2-15° 2θ) for the clay fraction from sample T13 after treatment with Ethylene glycol (E.G.) and heat treatment at 300°C for one day.

Sand mineralogy.
Sample T11 Sand fraction.
Visual inspection revealed that the sand fraction contains considerable amounts of a brown phyllosilicate. Fig. 15 shows the X-ray diffractogram of this fraction after wet crushing in McCrone Micronising mill. Quartz was used as an internal standard to calibrate the 2θ values. Shortly after the x-ray slide had been prepared, there were three broad peaks in the low-angle region with d-values 2.2, 1.9 and 1.145 nm. After one night at 45% R.H. the 1.9 nm peak had moved to 1.5 nm where it remained. The two other peaks had shifted to slightly lower values (from 1.145 to 1.1 nm). After heating to 500°C, only a very intense and narrow 1.0 nm peak is observed. The main clay mineral is a mixed-layer mineral with

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d-value 1.1 nm. In addition there is some smectite and a small amount of illite. The illite is identified from a small but distinct 0.5 nm peak (the 1 nm peak is hidden by the strong 1.1 nm peak). Other important silicates in this weathered amphibolite are amphibole, feldspars and quartz.
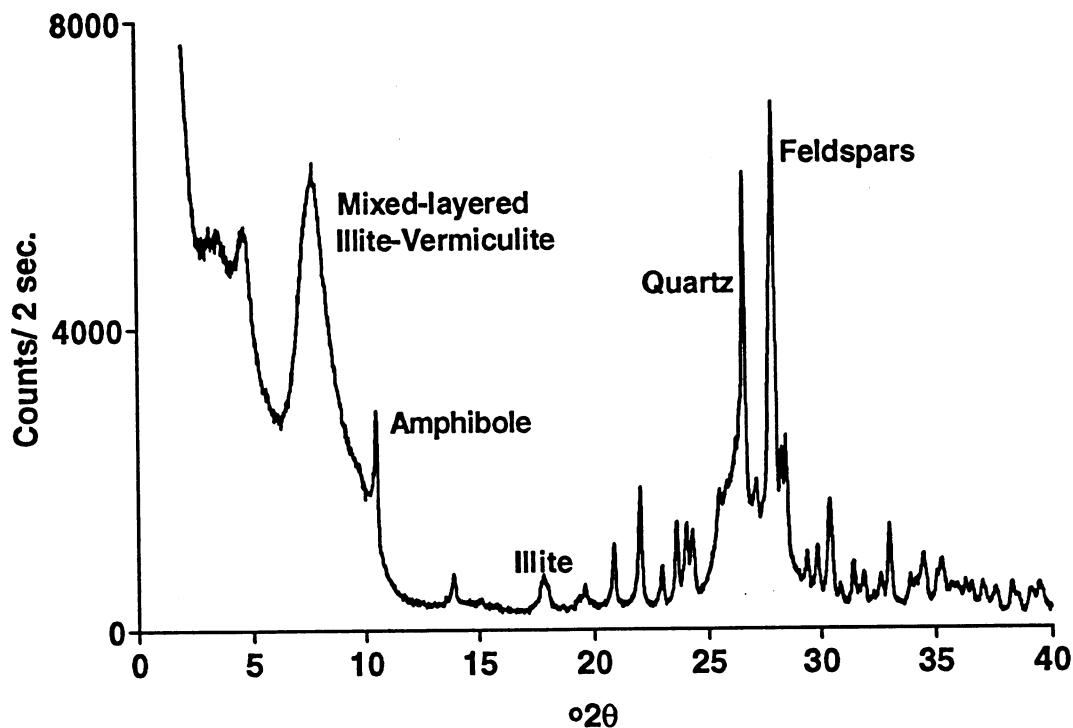
Fig. 15. X-ray diffractogram of crushed sand from sample T11.

Microprobe analyses.

Large yellow-brown flakes of a mica-like mineral was found in considerable amounts in the sand fraction. The mineral is very similar to biotite (phlogopite). Flakes were analysed on microprobe. The composition of the mineral was calculated from the chemical data.

The composition is generally:

$$(Na_A K_B)(Al_C Si_D)^{IV}(Al_E Fe_F Mg_G)^{VI}O_{10}(OH)_2$$

where:

A:0.31-0.37 B:0.37-0.56 C:0.82-1.06 D:2.94-3.18 E:0.38-0.54 F:0.70-0.73 G:1.19-1.44

The high content of sodium is obviously a result of the pretreatment with CDB. It was also observed that the amount of Na (atomic %) was about the same as for K.

Since Na-vermiculite equlibrated at 45% R.H. contains only one layer of water between the 2:1 layers, a regular alternation of mica and vermiculite will produce the 2.2 and 1.1 nm peaks. The conclusion is that the sand fraction has a high content of a trioctahedral 1:1 mixed layer mineral (vermiculite/mica) with alternating Na^+ and K^+ in interlayer positions (Hydrobiotite). There are also a few smectitic layers (expanding interlayers) in this mineral. The cation exchange capacity of the pure mineral will be in the range 62-94 $mmol_c$ /100 g. This trioctahedral mineral is undoubtedly a weathering product of biotite.

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Oxidation of divalent iron has reduced the charge on the 2:1 layer and the amount of interlayer cations. It should be pointed out that a similar 1.1 nm mineral has been found in several clay fractions. The high content of this mineral explains why sample T11 has a cation exchange capacity of 37 $cmol_c$ /kg. (Tables 6 and 7).

Different clay-soil groups.

In all samples, except T1, the content of organic carbon is 0.5% or less. The high exchange capacity for sample T1, 109.6 $mmol_c$ /100g, is explained by the high content of organic matter. For the other samples the grainsize distribution and clay composition will strongly influence different soil properties like cation exchange capacity. In samples with a clear bimodal distribution (small silt content) the composition of the clay fraction will be very important.

Cation exchange capacity and composition.

Figure 16 shows the relationship between the clay content and C.E.C. for bulk samples. The samples T2, T3, T4 and T5 have clay fractions dominated by a poorly crystalline kaolinite. The two samples from Rhodic Ferralsols contain in addition a small amount of Gibbsite, while the two samples from Luvisols contain small amounts of a mixed layered mineral. In spite of high clay contents, the samples from Mlingano have low C.E.C. values. The samples T6 and T7 (Misufini) as well as T8 and T9 (Mindu) contain some smectite in addition to kaolinite in the clay fraction. This explains why C.E.C. is higher in these samples than in samples T2-T5.
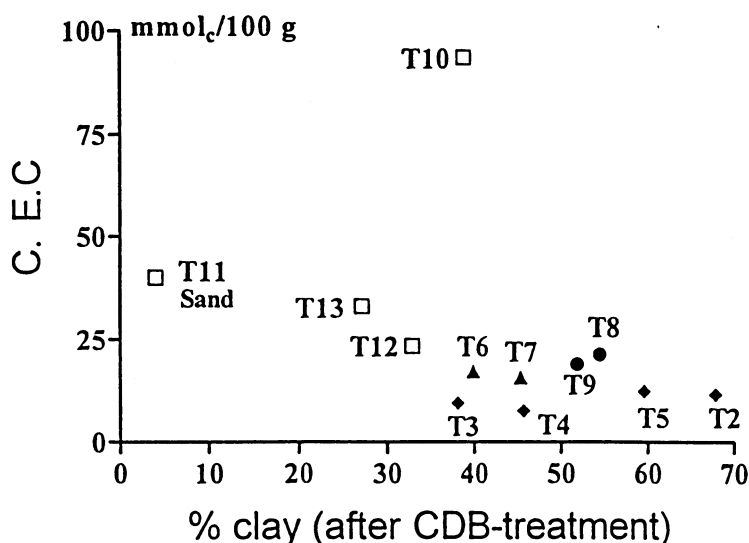

Fig. 16. Relationship between clay content and C.E.C. for bulk samples.

An even higher content of smectite in the clay fraction of T12 and T13 explains their higher exchange capacities.

Even if sample T10 has a higher smectite content, its C.E.C. value is surprisingly high. A possible explanation is that the presence of calcite in this sample (Table 3) has erronously increased its C.E.C. This would also explain the dominance of exchangeable Ca^{2+}.

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The sample T11 is sandy with a high exchange capacity. This may be assigned to a high content of mixed-layered vermiculite/illite and some vermiculite in the sand fraction. The pure smectite in the clay fraction will also raise the exchange capacity for the bulk sample.

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