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The sand mineralogy of some soils of the Amboseli-Kibwezi area (with special reference to the influence of volcanic ash)

by

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CONTENTS

1. Introduction

To obtain additional information on the properties of some soils of the Amboseli-Kibwezi area, a total of 61 samples were submitted for mineralogical analysis of the sand fraction. The area was surveyed by L. Touber [1], who selected the relevant profiles. Special attention was given to the site selection in relation to possible influence of volcanic ash derived from the Kilimanjaro and/or Chyulu eruptions.

2. Methods

The samples were sieved and the sand fraction 50-250 micron was retained. This material was subjected to treatment carried out to obtain USDA textural analysis, viz cleaning with 2N HCl and boiling with 30% H_2O_2. The sand fraction was subdivided into light and heavy mineral fractions by means of bromoform (s.g. 2.89) in separation funnels. The grains were subsequently mounted on glass slide (1" x 3") with Canada balsam and covered with a thin glass slide (1" x 1"). The mineralogical identification was made with a standard polarizing microscope (Zeiss).
The following line counts were carried out:

a) for heavy minerals (s.g. > 2.89) 100 grains were counted including the opaque minerals. The number of opaque grains was subsequently recounted as transparent grains; thus bringing the latter up to 100,

b) for light minerals (s.g. < 2.89) 100 grains were counted; in case of opaque grains the same counting procedure was followed as indicated for the heavy minerals.

The results are presented in Fig. 1a, 1b and 1c and in Appendix II.

3. Relation between the soil materials and the parent rock

The following parent rocks are encountered:

a) Basement System gneisses with volcanic ash admixture (profiles 81, 94 and 45),

b) Basement System rocks rich in ferromagnesian minerals (profiles 82 and 83),

c) Lacustrine ash deposits (profiles 18 and 135),

d) Pyroclastics of the Chyulu Hills (profiles 44 and 73),

e) Analcine basanite (profile 199),

f) Alluvial deposits (profile 3).

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1) L. Touber, "Reconnaissance Soil Survey of the Amboseli-Kibwezi area" (in prep.)

3a. Basement System gneisses with volcanic ash admixture

On the geological maps the geology of the sites is indicated as Qr (reddish brown sandy soils overlying Precambrian rocks) underlain by Xg, Xgt or Xgg (metamorphic rocks of the Basement System, mainly biotite gneisses). According to Searle (1954)[1] and Williams (1972)[2] the mineralogical composition of the Basement System rocks may be summarized as follows:

abundant: garnet, magnetite, ilmenite, and hornblende
common: diopside, epidote and apatite
rare: hypersthene, rutile, kyanite

The light minerals are represented by quartz, microcline, orthoclase, muscovite and biotite. In the soil materials garnet and hornblende occur frequently with some rutile and zircon. The metamorphic character of the Basement System rocks is indicated by staurolite and kyanite. However the presence of olivine within this assemblage points to an exotic source of derivation and is regarded as "volcanic ash admixture" (see under "d").

3b. Basement System rocks rich in ferromagnesian minerals

The geology of the sample sites is given as "X" (undifferentiated Basement System rocks) for profile 82 and as "Xhg" (Basement System rocks rich in hornblende and biotite) for profile 83. In the former case the composition is similar as outlined under "3a", while in the latter case the presence of 95% or more of green hornblende clearly indicates the close relation with the parent rock. In both profiles however olivine was detected throughout, an indication that also the soils concerned have been subject to volcanic influence, although to a lesser extent than the soils dealt with under "3a".

3c. Lacustrine ash deposits

Williams (loc.cit.) describes the parent material for profile 18 as "Amboseli Lake Beds and Fluviatile Deposits", viz Amboseli clays of Pleistocene age (symbol P112). The geology of site 35 is given as somewhat younger Ol Tukai Beds (geological symbol P113). The material is mainly derived from the Kilimanjaro by water and wind action. In addition some influence of material derived from Basement System rocks is expected by these transporting agents. According to Williams (loc.cit) the composition of the Kilimanjaro rocks is characterised by 1) olivine, 2) amphiboles, 3) andesite, 4) labradorite, 5) biotite and 6) apatite. The first five minerals are found in the soil materials concerned. Apatite, a calcium-phosphate mineral of medium weatherability, was only seen as traces. The provenance of the Basement System rocks is indicated by garnet, hornblende, quartz and some feldspars (see Fig. 1 and Appendix II).

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1) Searle, D.L., 1954 "Geology of the Sultan Hamud Area" Geol. Rep. 29
2) Williams, L.A.J. , 1972 "Geology of the Amboseli Area", Geol. Rep. no. 90.

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3d. Pyroclastics of the Chyulu Hills

The parent material of the Chyulu Hills is dominated by the presence of olivine, pyroxenes (augite) and some basic feldspars (mainly anorthite and labradorite). The rock was described as an olivine basalt by Saggerson (1963)[1]. The mineralogy of the sand fraction of the profiles concerned bears direct resemblance to the composition of the parent rock (profiles 44 and 73). Typically is the high amount of alterites (see note), which in some cases are thought to be mainly transformed olivine grains, as far as microscopic identification is possible. However, the basic feldspars are also prone to rapid weathering and therefore may also contribute to the high percentage of alterities. The former opinion is sustained by Searle (loc. cit) who writes "all lavas are olivine basalts and contain olivine in various stages of alteration". The amount of opaque minerals is considerably high in some of the sand fractions. This is ascribed by Searle to "high iron content noticeable in thin section and the abundance of haematite and limonite".

The assemblage of the soil materials from the Chyulu Hills may thus be characterised by the presence of olivine, augite and some hypersthene with or without iron compounds, while typical minerals of the "light" fraction include volcanic glass, anorthite and labradorite. The province of this assemblage is not only restricted to the areas of the Chyulu's and the Kilimanjaro but also to the associated terrain. In addition some components of the assemblage have been detected in soil materials derived from Basement System rocks, thus indicating the influence of volcanic materials as ash in these soils. However the exact extent of this mineral province is not yet known. Visual examination of the grains reveals that in case "3a" and "3b" the volcanic components mainly occur in the finer sand fraction (50-110 micron). The shape of the grains is highly variable and ranges from angular to rounded. Most of the opaque grains are small in size and angular.

Saggerson (loc.cit) dates most of the volcanic eruptions of the Chyulu's and of vents on the slopes of the Kilimanjaro to be of a young age, viz Pleistocene to recent.

3e. Analcine basanite

This parent rock underlies profile 199 and is encountered on the volcanic plain near Emali. The rock, also called olivine basalt (geological symbol P1v) is of Quaternary age and consists mainly olivine, augite and anorthite (Searle, 1963). The presence of various other minerals such as garnet, sillimanite and rutile points to the likely influence of the Basement System rocks. The sand fraction of the soils also contains a high amount of opaque minerals, which may be due to iron (staining) and/or weathering of olivine and feldspars.

Note: alterite = a primary mineral grain transformed by weathering to such an extent that its identification is impossible.

1) Saggerson, E.P. 1963 "Geology of the Simba-Kimbwezi Area" Geol. Rep. 58.

3f. Alluvial deposits

The alluvium is derived from Basement System rocks as well as from volcanic ones. This is supported by the presence of garnet, epidote, and hornblende on the one side and by olivine, volcanic glass and basic feldspars on the other side. The grain size and shape of the grains vary considerably in all samples.

Conclusions

The relation between the parent rock and the soil material in the samples examined is well established. It points out two sources viz 1) the Basement System and 2) the basic volcanic extrusive rocks. The presence of garnet, hornblende, quartz and especially those minerals indicating the metamorphic nature of the parent rock such as staurolite, kyanite, andalusite and actinolite are guides to the provenance of Basement System rocks. The volcanic assemblage is characterised by olivine, augite[(1)], volcanic glass, anorthite and labradorite. The presence of some components of the latter assemblage in soil materials derived from the Basement System rocks points to a transition zone present between these two mineral provinces. Volcanic eruptions that caused volcanic ash to be deposited are thought to be of Pleistocene to recent age.

4. Soil formation and mineral composition

The sequence in which the soils are treated and classified is based on the FAO(1974)[(x)]. For detailed information on the sampling sites and the results the reader is referred to Appendix I and II.

4.1. Mollic ANDOSOL (profiles 182/1-44 and 182/2-73)

These soils are developed on the lower footslopes of the Chyulu Hills and are derived from pyroclastic rocks (paragraph 3d). The heavy mineral composition in both profiles is dominated by olivine and augite (Fig. 1a-I and II). The latter increasing substantially in profile 73 from 80-110cm, the C-horizon. The amount of alterities is variable, it increases with depth in one soil (44), but decreases in the other (73). The light mineral composition is characterised by plagioclase feldspars, volcanic glass and quartz. The variations in mineral composition of the soil horizons are relatively minor. The composition of the mineral suite as encountered in the soil material of the two profiles is typical of the volcanic assemblage. Its presence in other soil materials may point to volcanic ash admixture.

4.2. Chromic VERTISOL (profile 173/3-3)

The soil is developed on alluvium from the Selengai river, which reflects the Basement System provenance as well as the volcanic one (see also 3f).

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(1) although augite may also occur in Basement System rocks its presence has not been reported on in these rocks for the area concerned.

(x) FAO/Unesco, 1974 "Volume I. Legend Soil Map of the World."

4.2. cont'd.

The heavy mineral composition of the soil is rather uniform which can be described to the churning processes which are active in these Vertisols (Fig. 1a-III). The main deviations occur in the topsoil and on the lower horizon (A33). These may be due to the original stratification of the parent material, or local admixture with exotic minerals (such as pyroxenes) or both.

The light mineral composition consists of volcanic glass, quartz and plagioclase feldspars . The amount of alterites is high throughout. Some of these alterites are derived from green hornblende, of which particularly large specimen are seen in all samples. The mineral grains in general are largely unsorted and show great difference in shape.

4.3. Gleyic SOLONCHAK (181/1-18)

The profile is encountered in a lacustrine plain and developed from waterlaid materials derived from volcanic ash and Basement System rocks (paragraph 3c). The amount of alterites is high. Quartz is the other dominant mineral. The variation in mineral composition mainly concerns the topsoil (Fig. 1a-IV). Erosional and sedimentological processes rather than pedogenesis are thought to be responsible for these changes.

4.4. Orthic SOLONETZ (181/1-35)

The soil is developed in similar environment as the Solonchak. The major differences in composition are observed in the topsoil samples. The presence of the sodic B horizon is not detectable from the heavy mineral profile (Fig. 1b-V). Changes in mineral composition may also be due to variations in sedimentological conditions during the formation of the lacustrine deposits.

4.5. Vertic LUVISOL (181/1-45)

The soil is located on an erosional plain and developed from Basement System rocks with an admixture of volcanic material (see also 3a). The dual provenance is indicated by the presence of members of both mineral assemblages, viz garnet, rutile and green hornblende, and plagioclase feldspars (Fig. 1b-VI).

4.6. FERRAL-chromic LUVISOL (profiles 173/4-81, 182/1-94 and 174/2-83)

The first two profiles are developed on Basement System gneisses with volcanic ash admixture, whilst the third one is developed on hornblende biotite gneisses. The provenance of the former is indicated by garnet, rutile, staurolite and hornblende and quartz; the volcanic source shows by the presence of olivine and volcanic glass. The close relation to the soil parent rock is well reflected in the mineralogy of the sand fraction. This is especially evident in the mineralogical analysis of profile 83, in which the presence of green hornblende is dominating (Fig. 1b-VII and VIII and Fig. 1c-IX). The presence of the argillic B horizon in the Luvisols concerned is difficult to detect, in as far as this may be considered in variations of the sand mineralogical compositon.

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In profile 83 homogenization caused by soil fauna may be responsible for the little change. In profile 81 pedogenetic process may play a dominant role, while in profile 94 the nearness to the weathering parent rock causes the most outspoken variations (horizons C1ca and C2ca from 120-140 cm and 140-180 cm), see also Fig. 1c-X.

4.7. Eutric/dystric NITOSOL (173/3-199)

The soil is located on a volcanic plain and derived from olivine basalt. The soil material shows a uniform distribution of olivine, augite and hypersthene. This may be attributed to the process of homogenization mainly caused by termites and mites as observed in the field.

Remarkable is the very high amount of opaque grains (first count 100 out of 100, only additional counts revealed the presence of transparent mineral grains). The opaque's are thought to be mainly magnetite, as this mineral is reportedly very common in the parent rock (Searle, 1963). In addition the B23 horizon shows a definite increase in quartz. The presence of volcanic glass and anorthite points to an admixture of volcanic ash in the light mineral fraction. In this fraction occur also a high percentage of alterites which are thought to be mainly plagioclase feldspars, such as anorthite and labradorite. Some twinning may occasionally be observed in not yet weathered parts of the grains.

4.8. Xanthic FERRALSOL (174/2-82)

This Ferralsol is developed on Basement System rocks rich in ferromagnesian minerals, presumably without the influence of volcanic ash. The heavy mineral composition is dominated by zircon, garnet, hornblende and rutile, while the metamorphosed character of the rocks is indicated by the presence of staurolite and andalusite. In the light mineral fraction quartz is dominant, however some anorthite and traces of volcanic glass are also found. The presence of volcanic glass and some olivine indicates an exotic provenance (e.g. volcanic ash). On the basis of the combined mineralogical composition, more than just a "trace" of weatherable minerals are present in this soil; therefore no oxic B horizon is recognized following the definition to the letter (FAO, loc. cit). The exclusion of this soil from the Ferralsols poses difficulties for its placement in the classification however, as the soil may be typical for a Ferralsol initially developed from Basement System rocks, which material at a later stage was "rejuvenated" by an admixture of volcanic ash. The weathering of the latter component may subsequently lead to "not fitting" chemical data, especially when it concerns the cation exchange properties and clay mineralogy. These soils are likely to occur over large areas of Basement System rocks which are associated with centres of volcanic eruptions.

4.9. Eutric CAMBISOL (181/1-62)

One sample of the A horizon of this soil was examined. The profile is located on the piedmont plain from the Kilimanjaro and developed from the Kilimanjaro "volcanics" (fluviatile facies Amboseli Lake Beds). The heavy mineral composition is dominated by olivine and some augite, volcanic glass is common in the light mineral fraction. The amount of alterites in both fractions is high, respectively 33% and 76%. The mineralogical composition indicates a similarity in assemblages between the Kilimanjaro and Chyulu volcanics and points out the likelyhood of a common magma source.

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5. Some aspects of the soil mineral reserve

Most of the samples exhibit a range in decomposition of various minerals, thus indicating a continuous weathering process of these primary minerals. The parent material of the soils concerned is considered rich to moderately rich with regard to the plant nutrient reserve. This is partly indicated by the fairly high amount of weatherable primary minerals in both the light and heavy mineral fractions. An exception may be the light fraction of the soils developed from Basement System rocks, which contains a high amount of quartz. The presence of weatherable feldspars contributes to the supply of potassium, while in particular the basic feldspars produce calcium and sodium upon weathering. Phosphates are mainly derived frmm apatite, a mineral reportedly present in some of the volcanic and Basement System rocks but rarely seen in the sand fraction. The presence of large amounts of opaque minerals, magnesium and iron compounds not only contributes to the dark colour of the majority of the volcanic deposits, but also supplies substantial quantities of some macro and micro nutrients, such as calcium, manganese, iron, magnesium and boron.

The influence of volcanic ash admixture on the soils developed from the intermediate to acid Basement System is considered favourable with regard to the nutrient reserve of the latter. The role of the primary minårals in the formation of the clay minerals in the soils concerned has yet to be fully acknowledged.

6. Conclusions

The composition of the sand fraction (50-250 micron) indicates the dual provenance viz 1) the Basement System rocks, 2) the volcanic rocks. The assemblage of the sand fraction derived from soils developed on the Basement System is characterised by garnet, green hornblende, rutile, staurolite, andalusite, quartz and some sodium feldspars. The assemblage of the sand fraction derived from soils developed on volcanic rocks is typified by olivine, pyroxenes (mainly augite) volcanic glass and some basic plagioclase feldspars (anorthite and labradorite).

The influence of volcanic materials in soils developed from the Basement System could be verified in a number of cases, especially in areas close to the eruptive centres of the Chyulu's and the northern slopes of the Kilimanjaro.

Traces of volcanic material are however also detected in soils further away from the volcanic areas. Thus the precise extend of this mineralogical "province" is not known at present. The influence of soil forming processes on the variation of mineralogical composition of the sand fractinn concerned is difficult to access. The action of the soil fauna tends to dominate, causing a smoothing out of initial differences.

The parent rock in general is considered fairly rich with regard to the supply of plant nutrients. The influence of volcanic ash on soils developed from the Basement System is thought favourable.

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Fig. 1a. Heavy mineral profiles *(for key see fig. 1c)*

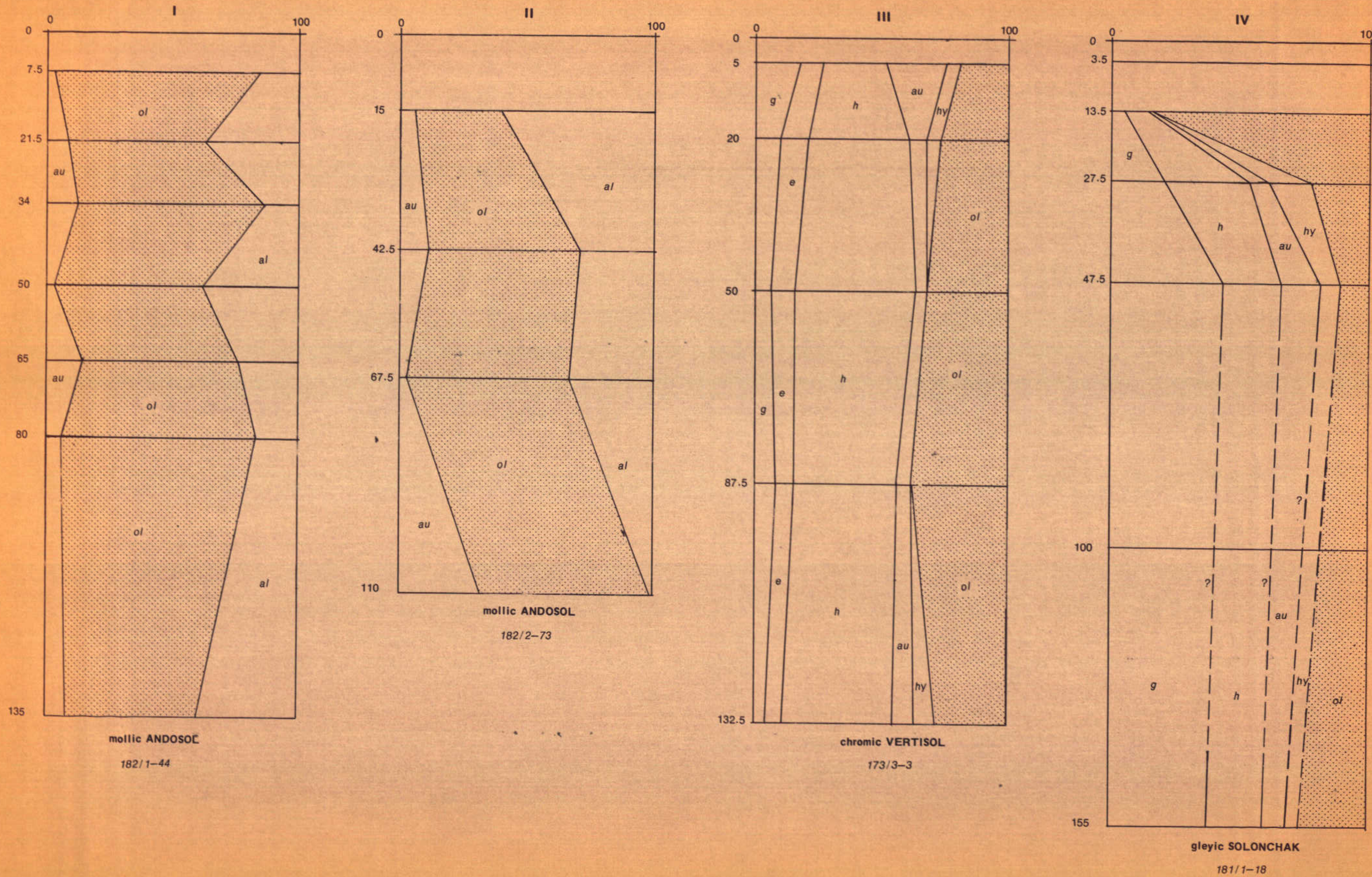


Fig. 1b. Heavy mineral profiles *(for key see fig. 1c)*

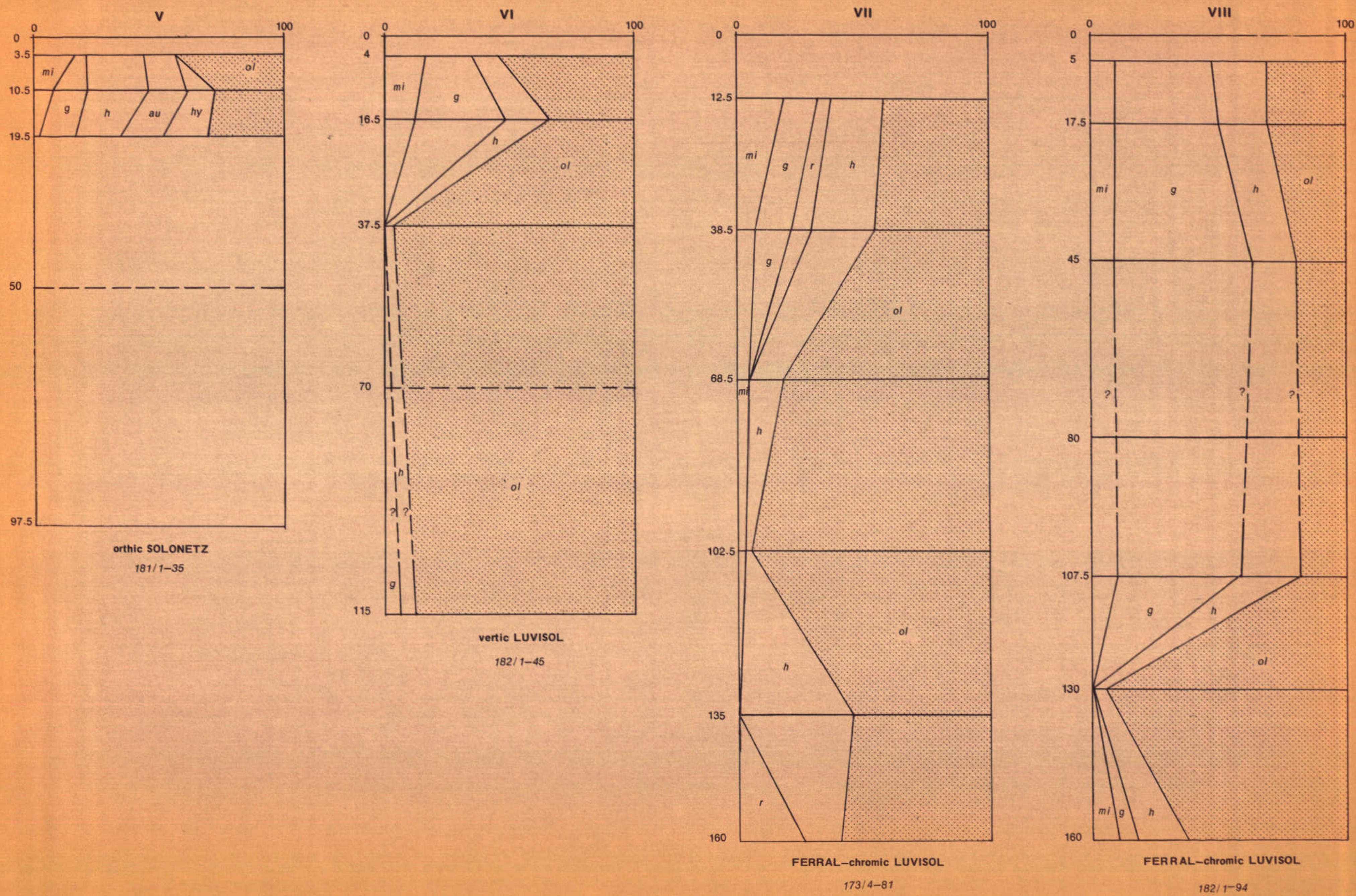
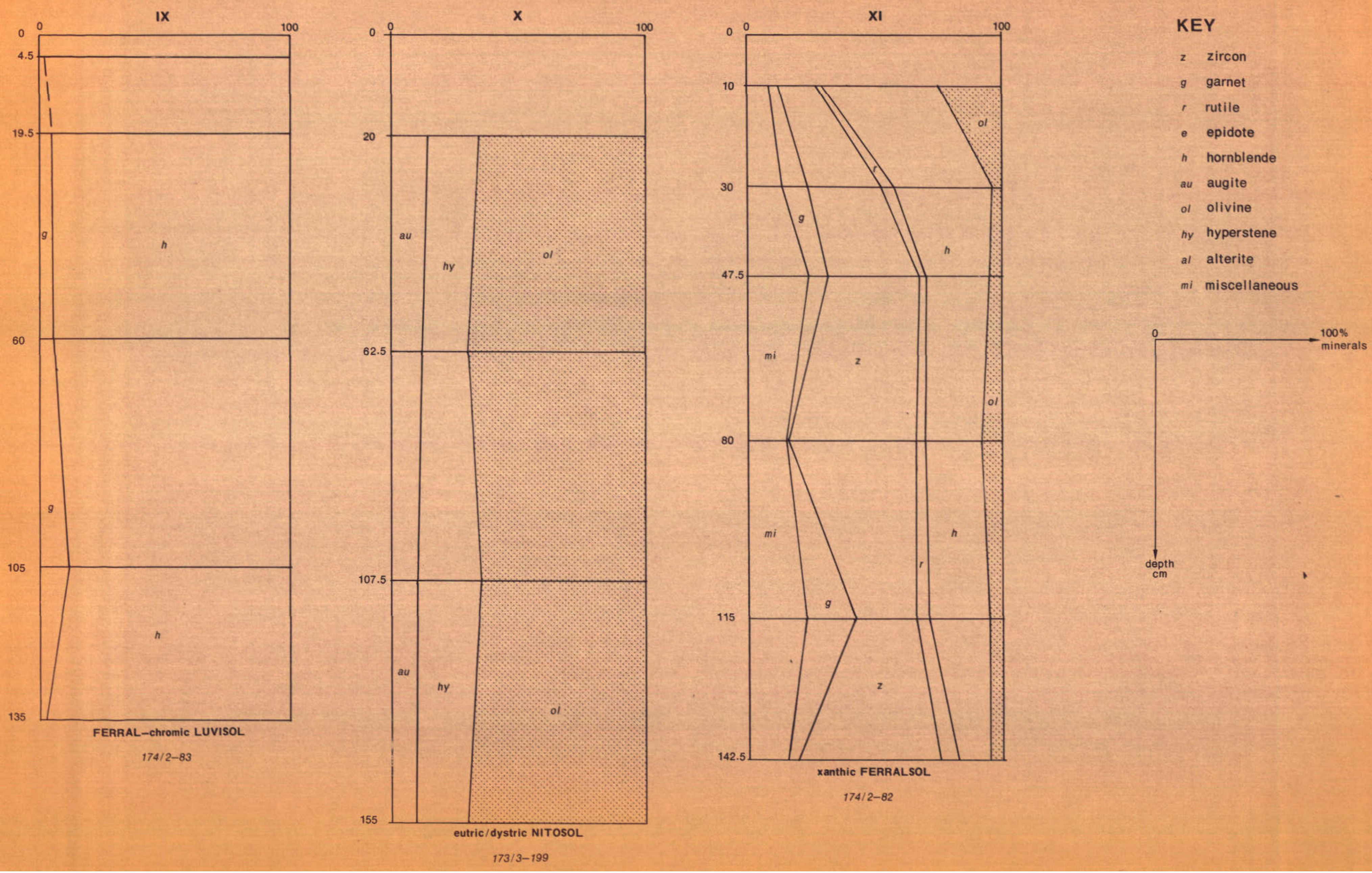


Fig. 1c. Heavy mineral profiles



Appendix I: Sample and profile characteristics

Sample No.	Depth (cm)	Horizon	Geology-physiography	Soil classification map unit
182/1-44a	0-15	A1	pyroclastics;	mollic Andosol
" 44b	15-28	A3	lower footslopes	(PFd)
" 44c	28-40	B1	Chyulu Hills	
" 44d	40-60	B2		
" 44e	60-70	B3ca		
" 44f	70-90	C1ca		
" 44g	90-180	CR		
182/2-73a	0-30	A1	pyroclastics;	mollic Andosol
" 73b	30-55	B1	Chyulu Hills,	(HPp)
" 73c	55-80	B2	footslope hill	
" 73d	80-140	C		
173/3-3a	0-10	A1	alluvium; alluvial	chromic Vertisol
" 3b	10-30	A13	plain	(AA2)
" 3c	30-70	A31		
" 3d	70-105	A32		
" 3e	105-160	A33		
181/1-18a	0-7	A11	lacustrine ash	gleyic Solonchak
" 18b	7-20	B11	deposit;	(PLP3)
" 18c	20-35	B12	lacustrine plain	
" 18d	35-60	B21		
" 18e	60-140	B22		
" 18f	140-170	B3		
181/1-35a	0-7	A1	lacustrine ash	orthic Solonetz
" 35b	7-14	A3	deposit;	(AA1)
" 35c	14-25	B2t	lacustrine plain	
" 35d	25-75	B3		
" 35e	75-120	C1		
182/1-45a	0-8	A11	B-S gneisses with	vertic Luvisol
" 45b	8-25	A12	volcanic ash	(PXb)
" 45c	25-50	B1	admixture, erosional	
" 45d	50-90	B2	plain	
" 45e	90-140	B3		
" 45f	140-180	Cca		

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Sample No.	Depth (cm)	Horizon	Geology-physiography	Soil classification map unit
173/4-81a	0-25	A	B-S gneisses with volcanic ash admixture; erosional plain	ferral-chromic Luvisol (PL1CL)
" 81b	25-52	B1		
" 81c	52-85	B21		
" 81d	85-120	B22		
" 81e	120-150	B3		
" 81f	150-170	C1		
181/2-94a	0-10	A	"as above"	"as above"
" 94b	10-25	B21		
" 94c	25-65	B22		
" 94d	65-95	B23		
" 94e	95-120	B3		
" 94f	120-140	C1ca		
" 94g	140-180	C2ca		
174/2-83a	0-9	A	Basement System rock rich in ferro-magnesian minerals; upland; no ash	ferral-chromic Luvisol (LFr2p)
" 83b	9-30	Bt1		
" 83c	30-90	Bt2		
" 83d	90-120	Bt3		
" 83e	120-150	C		
173/3-199a	0-40	A	analcime Basanite; volcanic plain	eutric/dystric Nitosol (PBr2)
" 199b	40-85	B21		
" 199c	85-130	B22		
" 199d	130-180	B23		
174/2-82a	0-20	A	Basement System rocks rich in ferromagnesian minerals; plain, no ash	xanthic Feralsol (PFb)
" 82b	20-40	B1		
" 82c	40-55	B21		
" 82d	55-105	B22		
" 82e	105-125	B23		
" 82f	125-160	C1		
181/1-62	0-30	A	Kilimanjaro volcanics; piedmont plain	eutric Cambisol (YVb)

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Appendix II: Mineral composition of the samples (x)

Sample No.	Horizon	Depth (cm)	Light minerals: volc glass	quartz	anorthite	plagioclase	alterite	biotite
182/1-44a	A1	0-15($7\frac{1}{2}$)	4	2	2		92	
" 44b	A3	15-28($21\frac{1}{2}$)	–	–	–	–	–	
" 44c	B1	28-40(34)	–	–	–	–	–	
" 44d	B2	40-60 (50)	7		5	1	87	
" 44e	B3ca	60-70(65)	7		4		89	
" 44f	C1ca	70-90(80)	3	54	4		39	
" 44g	CR	90-180(135)	6	tr	2		92	
182/2-73a	A1	0-30(15)	tr		7	4	89	
" 73b	B1	30-55($42\frac{1}{2}$)	tr	2		3	95	
" 73c	B2	55-80($67\frac{1}{2}$)	12			6	82	
" 73d	C	80-140(110)	11		2	1	86	
173/3-3a	A1	0-10(5)	4		tr		96	
" 3b	A13	10-30(20)	3			3	94	
" 3c	A31	30-70(50)		10		5	85	
" 3d	A32	70-105($87\frac{1}{2}$)	1	18		5	76	tr
" 3e	A33	105-160($132\frac{1}{2}$)	–	–	–	–	–	
181/1-18a	A11	0-7($3\frac{1}{2}$)	–	–	–	–	–	
" 18b	B11	7-20($13\frac{1}{2}$)		3			97	
" 18c	B12	20-35($27\frac{1}{2}$)		5	tr		95	
" 18d	B21	35-60($47\frac{1}{2}$)			tr		100	
" 18e	B22	60-140(100)	tr			tr	100	
" 18f	B3	140-170(155)	tr			tr	100	
181/1-35a	A1	0-7($3\frac{1}{2}$)	4		6		90	
" 35b	A3	7-14($10\frac{1}{2}$)	3	3	2		92	
" 35c	B2t	14-25($19\frac{1}{2}$)	4			tr	96	
" 35d	B3	25-75(50)	6	54	5		35	
" 35e	C1	75-120($97\frac{1}{2}$)	–	–	–	–	–	

(x) open space = mineral not detected

– = no sample

Appendix II cont'd.

Sample No.	Horizon	Depth(cm)	Light minerals: volc. glass	quartz	anorthite	plagio clase	alterite	biotite
182/1-45a	A11	0-8(4)	6	94				
" 45b	A12	8-25(16½)	tr	100	tr			
" 45c	B1	25-50(37½)	10		1		89	
" 45d	B2	50-90(70)	tr	95	5		78	
" 45e	B3	90-140(115)	—	—	—	—	—	—
" 45f	Cca	140-180(160)	—	—	—	—	—	—

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Appendix II contd.

Sample No.	Horizon	Depth(cm)	Light minerals: vol-glass	quartz	albite	anorthite	oligoclase	biotite	alterite
173/4-81a	A	0-25(12½)	tr	100	tr			tr	
" 81b	B1	25-52(38½)	tr	97		3			
" 81c	B21	52-85(68½)	tr	93	5	2			
" 81d	B22	85-120(102½)		100		tr			
" 81e	B3	120-150(135)	3	94	1	1		1	
" 81f	C1	150-170(160)	—	—	—	—	—	—	—
181/2-94a	A	0-10(5)				1			99
" 94b	B21	10-25(17½)	2	92	3	2		1	
" 94c	B22	25-65(45)		60	2				38
" 94d	B23	65-95(80)	—	—	—	—	—	—	—
" 94e	B3	95-120(107½)	tr	55					45
" 94f	C1ca	120-140(130)	tr	35	tr	tr			65
" 94g	C2ca	140-180(160)	—	—	—	—	—	—	—
174/2-83a	A	0-9(4½)	tr	60		tr			40
" 83b	Bt1	9-30(19½)		97		tr	tr	3	
" 83c	Bt2	30-90(60)		100					
" 83d	Bt3	90-120(105)		91		2			7
" 83e	C	120-150(135)	tr	100		tr	tr		tr
173/3-199a	A	0-40(20)		tr		tr			100
" 199b	B21	40-85(62½)	6	4		tr			90
" 199c	B22	85-130(107½)	2	3					95
" 199d	B23	130-180(155)		75		4			21
174/2-82a	A1	0-20(10)	—	—	—	—	—	—	—
" 82b	B1	20-40(30)		98		2			
" 82c	B21	40-55(47½)	tr	100					
" 82d	B22	55-105(80)	—	—	—	—	—	—	—
" 82e	B23	105-125(115)		86		9			5
" 82f	C1	125-160(142½)		97		3			tr
181/1-62	A	0-30	12			12			76

...../13.

Appendix II contd.

Sample No.	Horizon	Opaque	Heavy minerals: zircon	tourmaline	garnet	rutile	staurolite	kyanite	epidote	hornblende	augite	hypersthene	olivine	sillimanite	actinolite	alterite	Remarks
182/1-44a	A1	24									3		81			16	most
" 44b	A3	1									8		54			38	alterite
" 44c	B1										12		74			14	believed
" 44d	B2										3		39			38	to be
" 44e	B3ca										14		62	tr		24	olivine,
" 44f	C1ca										5		81			14	some
" 44g	CR										8		52			40	plagio-clase
182/2-73a	A1										6		34			60	
" 73b	B1										11		60			29	as above
" 73c	B2										2		64			34	
" 73d	C										32		68			tr	
173/3-3a	A1	59			17				9	25	24	6	19	tr			
" 3b	A13	9			6			3	11	40	7	6	27				
" 3c	A31	4			6				9	48	4		33				
" 3d	A32				8				7	41	5		39				
" 3e	A33	3		2	5				5	43	8	8	29				
181/1-18a	A11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
" 18b	B11				5					7			88				
" 18c	B12	18	tr		20	tr			tr	35	7	16	22				
" 18d	B21	13			40	tr			2	25	15	7	11				
" 18e	B22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
" 18f	B3	44	9		27	3		tr		21	9	5	26				
181/1-35a	A1	36	tr		5		tr		3	23	13	tr	43			13	
" 35b	A3	49	2		15	4				25	16	11	27				
" 35c	B2t		2		15				tr	18	17	18	30				
" 35d	B3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
" 35e	C1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
182/1-45a	A11	75	tr		19	17	tr	tr		10	tr		54			tr	
" 45b	A12	46	tr		37	7	tr	tr		18			33		5		
" 45c	B1	20			tr	tr		tr		4	tr		96				
" 45d	B2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
" 45e	B3	42	tr		tr	tr	tr			6	6		88				
" 45f	Cca	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

....../14.

Appendix II contd.

Sample No.	Horizon	Opaque	zircon	garnet	rutile	staurolite	kyanite	andalusite	green-hornblende	augite	hypersthene	olivine	sillimanite	actinolite	alterite
									Heavy minerals						
173/4-81a	A	70	6	13	5	9	2		21	2		42			
" 81b	B1	75	5	15	8	2	tr	tr	25			45			
" 81c	B21	35	tr	tr	tr				14	4		82			
" 81d	B22	26		tr		tr			2	2		96	tr		
" 81e	B3			tr	tr				45			55			
" 81f	C1	90	tr	tr	25				15			60			
181/2-94a	A	31		39	tr	5			21	2	3	30			
" 94b	B21	50		43	2				19	3		30		3	tr
" 94c	B22	45		54	7		tr	tr	17	2		19		1	tr
" 94d	B23	—	—	—	—	—	—	—	—	—	—	—	—	—	—
" 94e	B3	48		50	tr	4			22		tr	18	4		2
" 94f	C1ca	17		tr	tr				5			95	tr		tr
" 94g	C2ca	71		5	8	tr	5		20	tr		62		tr	
174/2-83a	A	98(hornblende?)					tr		2			tr			
" 83b	Bt1	31		5					95						
" 83c	Bt2	25	tr	5		tr			95			tr			
" 83d	Bt3	46		10			2		88			tr			
" 83e	C	11	tr	3					97			tr			tr
173/3-199a	A	100								15	20	65			
" 199b	B21	100	tr						2	10	18	70			
" 199c	B22	100	tr							10	25	65			
" 199d	B23	100								10	20	70			
174/2-82a	A1	85	15	4	2	2	3	3	45			26			
" 82b	B1	90	31	10	5	6	3	3	38			4	tr		
" 82c	B21	75	35	7	2	tr	tr	18	25			5	8		
" 82d	B22	83	50	tr	4				22			8			16
" 82e	B23	78	24	19	5	10		10	22			5	tr		5
" 82f	C1	78	57	3	6	4	tr	7	12			5	6		tr
181/1-62	A	3								8	1	57			33

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Appendix III: Some properties of the sand minerals (1)

Name	Chemical composition	Rock source	Weatherability
Volcanic glass	vg variable	volcanic	variable
quartz	q SiO_2	acid igneous and metamorphic	very low
albite	al $NaAlSi_3O_8$(=Ab)	"	low
anorthite	an $CaAl_2Si_2O_8$(=An)	ultra basic igneous metamorphic	very high
plagioclase (x)	la NaCaAlSiO8	" "	" "
oligoclase	ol Ab80-An20	acid igneous and metamorphic	medium
biotite	bi $K_2(Mg,Fe)2(OH)_2(AlSi_3O_{10})$	" "	very high
zircon	z $ZrSiO_4$	acid/igneous and metamorphic	very low
tourmaline	t $NaFe_2Al_4B_2Si_4O_{19}(OH)$	pneumatolytic	low
garnet	g $Ca_3Al_2(SiO_4)_3$	metamorphic	low
rutile	r TiO_2	acid igneous and metamorphic	very low
staurolite	st $2Al_2SiO_5Fe(OH)_2$	contact metamorphic	low
kyanite	k Al_2SiO_5	metamorphic	low
andalusite	an Al_2SiO_5	contact metamorphic	low
epidote	e $Ca_2(Al,Fe)_3Si_3O_{12}(OH)$	metamorphic	low
gr.hornblende	h $Ca_2(Mg,Fe,Al)_5(OH)_2(Si,Al)_4O_{11}$	acid and intermed. igneous	medium
oxi-hornblende	h as above	(ultra)basic	medium
augite	au $Ca(Mg,Fe)_3(Al,Fe)_4(SiO_3)_{10}$	intermediate igneous	medium
hypersthene	hy $(Mg,Fe),SiO_3$	" "	"
olivine	ol $(Mg,Fe)_2SiO_4$	basic and ultra basic	very high
sillimanite	si $Al_2O_3SiO_2$	contact metamorphic	low
actinolite	ac $2CaO_5(Mg,Fe)O8SiO_2.H_2O$	intermediate igneous	low

(1) slightly revised from "Tropical Soils" by Mohr, van Baren and Schuylenborg. 1972

(x) labradorite

(xx) basaltine

Appendix IV: Additional literature data on volcanic ash and volcanic ash soils

The literature on volcanic ash and volcanic ash soils is limited and mainly restricted to South-America and Southeast Asia. Data concerning Africa are scarce.

On the grainsize the following remarks can be made:

1) Milner (1962) states that 50% of the grains have a diameter of less than 62 micron:

2) Mohr et al. (1972) postulate a grainsize variation from 20-500 micron, however material coarser than 200 micron are rock fragments, while primary minerals and volcanic glass are encountered only in the fraction 50-200 micron;

3) In Japan mineralogical research was carried out on the coarse silt fraction (20-50 micron) of some Andosols (FAO, 1970).

The volcanic ash (being a wind deposit) tends to accommodate most of the material in the finer fractions (50-100 micron), however the medium ash fraction may yield a considerable amount of minerals, depending on the kind of eruption and the wind force.

It is likely that not only the smallest particles but also the lightest are found furthest from the eruptive centre. In Kenya the fraction 50-250 micron has been used till now in mineralogical research with satisfying results concerning the limited amount of samples which have been examined, however for a detailed approach fractionated mineral research may have to be introduced.

On the mineralogical composition of volcanic ash the following may be said:

1) the composition depends on the source of the magma and may therefore vary considerably from place to place;

2) Milner (loc.cit) referring to data from Indonesia as reported by Baak on the volcanic ash composition of the Kelut, records the following constituents: volcanic glass, rock fragments, plagioclase, augite, hypersthene, green hornblende and oxy-hornblende;

3) Mohr et al. (loc.cit) point to the variation in composition related to grainsize for material from Indonesia, viz 50-100 micron mainly plagioclase, 100-200 micron volcanic glass and 200-500 micron rock rock fragments;

4) in the coarse silt fraction of the Andosols occurs volcanic glass and hypersthene, in addition ferromagnesian minerals are common such as olivine, pyroxenes and amphiboles; in the clay fraction (particles smaller than 2 micron) allophane and haloysite occur.

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App. IV cont'd.

5) In the FAO publication (1970) the composition of various volcanic materials are summarized. World wide occurring minerals include olivine, augite, plagioclase feldspars, volcanic glass and magnetite, Zircon and hornblende may also be encountered (South-America).

In New-Zealand volcanic glass is often a major component. The 20-50 micron fraction of a volcanic ash soil in Japan could conveniently be subdivided into four groups viz 1)olivine, 2)pyroxene, 3)pyroxene-hornblende and 4) hornblende.

6) Pettijohn et al. (1972) refer to volcaniclastic sands, whose composition depends largely on the magma.

Basic or oxy-hornblende is a telltale indicator of volcanic rocks. Most of the volcanic quartz occurs as monocrystalline grains. The colour of volcanic glass varies from colourless to red-yellow, or brown depending on the state of its iron.

Volcanic glass may weather to clay minerals, zeolites and silica. However it may also devitrify and occurs as microcrystalline aggregates. Complete alteration of volcanic ash may produce betonite (montmorillonite). Volcanic ash falls are widespread and may extend several 100 miles.

Literature

FAO 1970	Meeting on the classification and correlation of soils from volcanic ash. World Soil Resources Report No. 14, FAO,Rome.
Milner, H.B. 1962	Sedimentary petrography. Vol. II Principles and Applications George Allen and Edwin Ltd., London
Mohr, E.C.J., Baren, F.A. Van Schuylenborgh, J. van 1972	Tropical Soils W. van Hoeve, The Hague.
Pettijohn, F.J. Potter, P.E. and Siever, R. 1972	Sand and Sandstone Springer Verlag, Berlin-Heidelberg-New York.

For a case study the reader is referred to:

Avarado, A. 1974	A volcanic ash soil toposequence in Costa Rica. MSc. thesis North Carolina State University.

which contains also a useful list of literature referances.