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SAND MINERALOGY AND RELATED PROPERTIES OF SOME SOILS IN SOUTH-WESTERN NIGERIA

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ABSTRACT: Five representative soil profiles were excavated along a toposequence selected in the Itagunmodi area of South-Western Nigeria. The soils were subjected to physical, chemical, and mineralogical analyses. The results indicated soils with high fine sand and clay contents, but low silt content. The soils were found to vary from slightly acid to strongly acid (pH_{H2O} = 4.0 to 6.2). Organic C, available P, and Kjeldahl N contents decreased with increasing depth. Cation exchange capacity (CEC) ranged from 3.11 to 28.75 cmol(+)/kg soil. Base saturation was low (<51%). From a total elemental analysis, Si was found to be the dominant element, followed by Al, and then Fe. Extractable P, and exchangeable K, Mg, and Ca were quite low. The dominant minerals in the fine sand fraction were quartz, feldspar, zircon, hornblende, tourmaline, and opaque ores. The variation in the zircon/tourmaline (two resistant minerals) ratios with depth suggests a stratification of the parent material. The change in the quartz/feldspar ratios was an indication that the degree of weathering in the soil profile is not uniform.

INTRODUCTION

The physical and chemical properties of soils are controlled to some extent by their mineral content, especially those constituting the clay fraction (20). It is,

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therefore, important to identify, characterize, and understand the properties of the different minerals present in order to evaluate soils in terms of their potential agronomic characteristics, engineering properties, and classification. Mineralogical composition of soils can give an indication as to their potential fertility status. In addition, evaluation of the physical, chemcial, and mineralogical characteristics of tropical soils aid in explaining their genesis (2,12).

Knowledge of the nature and condition of minerals in the sand fraction of soil provides information on the source of the parent material (9). Sand mineralogical analysis could be used to check on the uniformity of parent material. Within a specific sand or silt fraction, minerals that are relatively resistant to weathering show a relative increase in abundance from the parent material to the surface, whereas more weatherable minerals show a relative decrease in the same direction (4). Sharp inflections or reversals in such trends might indicate lack of uniformity (8). Ratios of resistant mineral to non-resistant minerals also can be used to indicate the same trends (3). Another technique is to determine the ratio of two resistant minerals. If the ratio remains nearly constant with depth, and matches that of the parent material, uniformity is strongly suggested (8).

Sand mineralogy also helps to identify the presence of lithological discontinuities in the solum or between the solum and the underlying material. The degree of weathering in the soil and the genetic processes are inferred from sand mineralogy (9).

The importance of soil mineralogy has long been realized. However, little is known about the mineral status of most tropical soils in Nigeria. Therefore, the objective of this study was to evaluate the sand mineralology of some tropical soils located in south-western Nigeria.

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MATERIALS AND METHODS

The field work was conducted at Itagunmodi, an area which lies approximately at latitude 7°34'N and logitude 4°37'E (Fig. 1). The rocks found in the study area belong to the amphibolite complex (1). Five soil profile pits were excavated along a toposequence at different physiographic points. The soils were identified as belonging to the Ibule, Ijare, Owena, Itagunmodi, and Adio series based on the local classification system described by Smyth and Montgomery (16). All the soils, except the Adio series, are well drained. Following the Soil Taxonomy system (17), the Ibule, Ijare, Owena, and Itagunmodi soils were classified as being Ultisols, while the Adio series were classified as Alfisol (14).

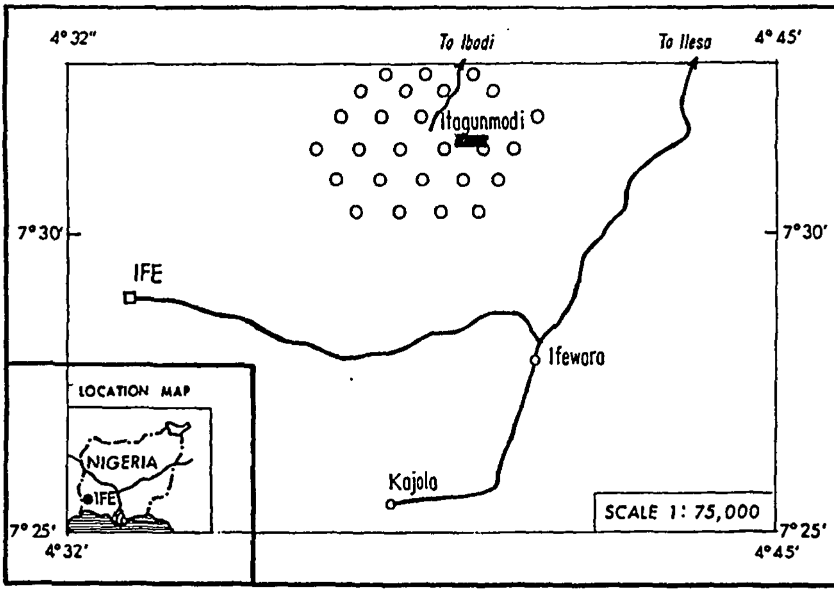

Fig. 1 Site location and geology of the sampling site

LEGEND
O Amphibolite
■ Sampling site

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The gathered soil samples were air dried, passed through a 2-mm sieve, and then subjected to physical, chemical, and mineralogical analyses. Particle size distribution was determined by the hydrometer method (5), soil pH measured in a soil-water 1:1suspension using a glass electrode equipped pH meter, soil organic carbon content by the Walkley-Black method (19), and N by macro-Kjeldahl digestion (7). Available P was measured by the Bray P1 method (10). Following extraction in 1N neutral ammonium acetate, Ca and Mg ions were determined by atomic absorption spectrophotometry, while Na and K were determined by flame photometry. Cation exchange capacity (CEC) was obtained by the sum of cations method (15). Total elemental analysis was based on the HF-HClO4 digestion procedure (10).

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Table 1 : Particle Size Distribution of Soils Studied

Soil Series	Depth (cm)	Coarse sand 0.5-2.0 (mm)	Medium sand 0.25-0.5 (mm)	Fine sand 0.05-0.25 (mm)	Total Sand 0.05-2.0 (mm)	Silt 0.05-002 (mm)	Clay <0.002 (mm)
		%					
Ibule	0-7	7.4	13.1	25.5	46	7	47
	7-22	5.6	13.8	24.6	44	5	51
	22-64	5.3	13.4	21.3	40	3	57
Ijare	0-14	5.5	19.0	40.5	65	10	25
	14-31	4.2	16.5	38.3	59	8	33
	31-87	3.6	8.1	23.3	35	7	58
	87-140	4.0	8.0	19.0	31	4	65
	140-179	4.3	9.6	16.1	30	9	61
	179-219	6.7	12.1	36.2	55	2	43
Owena							
	0-4	3.6	7.1	30.3	41	10	49
	4-44	4.1	9.8	23.1	37	8	55
	44-80	3.9	10.6	18.5	33	6	61
	80-117	3.1	8.6	17.3	29	4	67
	117-149	3.8	8.1	15.1	27	8	65
	149-189	5.9	13.1	42.0	61	7	32
	189-249	4.2	19.4	29.4	53	6	41
Itagun-modi							
	0-3	4.9	19.3	36.8	61	16	23
	3-11	4.1	21.2	31.7	57	12	31
	11-70	3.8	17.0	26.2	47	8	45
	70-143	4.3	12.4	19.3	36	7	57
	143-183	5.6	11.3	24.1	41	4	55
	183-223	3.7	12.0	34.3	50	5	45
Adio							
	0-5	3.7	19.8	34.5	67	18	15
	5-44	3.5	20.1	32.4	58	9	33
	44-105	4.3	17.6	40.1	62	3	35
	105-130	3.0	18.0	38.0	59	2	39
	130-177	6.0	9.3	45.7	61	3	36
	177-219	7.2	15.6	41.2	64	4	32

Sand Mineralogy: Soil samples were treated for organic matter removal with 30% H_2O_2, dispersed in 5% sodium hexametaphosphate before being separated into their clay, silt, and sand fractions. The sand fraction was separated into coarse, medium, and fine sand by dry sieving. The fine sand fraction (50 µm - 200 µm) was separated into heavy and light fractions using bromoform (specific gravity = 2.90). A drop of Canadia balsam (refractive index = 1.55) was placed on a glass slide. The sand sample was uniformly distributed over an area of about

22-mm square on a glass slide, and then covered with cover glass. The optical properties of the mineral crystals described by Milner (11) were used as the differentiating criteria.

RESULTS AND DISCUSSION

Physical Properties: The particle size distributions found in the soils are given in Table 1. Sand content ranged from 27% to 67%. It decreased with increasing depth to a minimum in the B-horizon, and then increased in the C-horizons. All the soils had higher proportions of the fine sand fraction which is a characteristic property of soils formed in amphibolite-derived parent material (16). The percent fine sand fraction increased down the slope.

The clay content was generally high (15% to 67%). It increased with depth to the B-horizons, and then decreased in the C-horizons. The pattern of clay distribution indicated an evidence of eluvial-illuvial processes. Silt content was low (2% to 18%). This is a common feature of most soils in Nigeria (13), which could indicate an advanced weathering stage.

Chemical Characteristics: The chemical characteristics of the soils are given in Table 2. The soils varied from slightly acid to strongly acid in reaction.

Apart from soils of the Ibule series, the upper horizons (0-14 cm) of other soil profiles were slightly acid (pH_{H2O} = 5.1 to 6.2), and the B-horizons were strongly acid. The acid nature of the soil could be ascribed to a high rate of leaching of bases, which is prevalent in the humid tropics. Another cause of low pH for these soils, especially those soils under cultivation, is due to crop removal of bases. This disturbs the equilibrium which exists between those bases in the soil solution and the exchangeable bases on the exchange sites. Bases, therefore, move from the soil into the soil solution in order to re-establish the equilibrium.

Calcium was the most dominant cation on the exchange sites, with Mg being the second most abundant. The relatively high values of exchangeable Ca and Mg are in keeping with the ferromagnesian nature of the parent material. The values of all the exchangeable bases decreased with increasing depth. The CEC (by sum of cations at pH 8.2) ranged from 3.11 to 28.75 cmol(+)per kg. Base saturation was <51%.

The Kjeldahl N content of the soils was generally low (0.02% to 0.53%), and the C/N ratios were also quite low. Organic carbon content ranged from 0.02% to 3.37%. The upper 0-14 cm of the soil profiles had the highest organic carbon

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Table 2 : Some Chemical Characteristics of the Soils

Soil Series	Depth (cm)	pH_{H_2O}	Total N (%)	Org.C (%)	C/N	Avail.P (ppm)	Exch. Cations Ca^{+2} (C mol(+) Per Kg Soil)	Mg^{+2}	K^+	Na^+	CEC sum of cation, pH 8.2 (C mol(+) per Kg. Soil)	Base Sat. (%)
Ibule	0 -7	5.5	0.53	3.32	6.26	3.84	7.44	2.46	0.24	0.10	28.75	35.62
	7-22	4.1	0.27	1.56	5.78	2.28	1.26	0.72	0.30	0.30	8.87	26.49
	22-64	4.0	0.28	1.13	4.04	7.50	0.49	0.34	0.20	0.20	5.79	19.53
Ijare	0-14	6.2	0.48	3.30	6.88	13.92	6.82	3.12	0.42	0.03	25.78	38.20
	14-31	5.9	0.20	1.76	8.80	1.32	6.66	1.50	0.36	0.04	22.60	37.83
	31-87	5.7	0.06	0.50	8.30	0.72	3.72	1.50	0.23	0.14	16.02	34.90
	87-140	5.6	0.16	0.27	1.69	0.60	2.82	1.14	0.52	0.06	12.99	34.96
	140-179	5.3	0-10	0.04	0.40	0.60	1.74	1.02	0.19	0.14	9.09	32.90
	179-219	4.7	0.09	0.03	0.33	0.53	1.10	0.16	0.12	0.07	5.45	26.60
	219-259	5.2	0.06	0.02	0.33	0.28	1.06	0.14	0.04	0.03	4.19	30.29
Owena	0-4	5.6	0.27	1.56	5.78	0.60	4.98	2.04	0.38	0.07	20.83	35.86
	4-44	5.5	0.17	1.13	6.65	0.60	2.58	1.14	0.04	0.02	11.75	32.17
	44-80	5.2	0.16	0.18	5.03	0.60	2.28	0.96	0.04	0.01	9.95	33.06
	80-117	5.2	0.11	0.29	2.64	0.60	1.68	0.48	0.02	0.01	7.64	28.68
	117-149	5.0	0.14	0.04	0.30	1.98	1.32	0.42	0.05	0.02	6.09	29.70
	149-189	5.1	0.10	0.04	0.35	1.05	2.28	0.17	0.03	0.01	7.23	34.46
	189-249	5.0	0.07	0.02	0.24	0.80	0.98	0.22	0.07	0.02	5.01	25.73
Itagunmodi	0-3	6.2	0.39	2.40	6.15	5.82	6.15	2.64	0.30	0.06	24.43	37.46
	3-11	6.1	0.17	1.48	8.71	2.22	4.62	2.10	0.24	0.08	19.34	34.41
	11-70	5.3	0.17	0.82	4.82	1.80	2.04	1.62	0.30	0.12	8.07	50.58
	70-148	5.2	0.13	0.23	1.77	1.20	2.28	1.14	0.52	0.04	7.58	52.45
	148-183	5.4	0.11	0.26	2.36	1.05	3.03	0.17	0.04	0.01	8.49	38.30
	183--213	4.8	0.08	0.12	1.50	0.91	0.64	0.08	0.08	0.03	3.11	26.68
Adio	0-5	6.1	0.36	3.37	9.36	1.80	6.73	3.00	0.72	0.07	28.75	36.59
	5-44	5.7	0.20	0.66	3.30	3.60	3.06	0.90	0.90	0.30	12.01	35.89
	44.105	5.8	0.30	0.65	2.17	2.10	2.35	1.34	0.12	0.10	11.57	33.79
	105-130	5.7	0.17	0.52	3.06	1.60	1.19	0.45	0.07	0.02	5.71	30.31
	130-177	5.4	0.12	0.35	2.92	0.89	1.13	0.44	0.05	0.01	5.51	29.56
	177-219	5.3	0.02	0.05	2.50	0.65	2.11	0.96	0.12	0.01	10.26	31.19

contents. Bray P1-exctactable P contents varied from 0.28 ppm to 13.9 ppm, values that would be considered quite low. The low P contents could be attributed to the low P content of the massive amphibolite which was the parent materrial for the soils studied (1). The patterns of distribution of available P and organic C were similar, and this might infer a significant organic or biocycled P in the soils.

Total elemental composition expressed as percent content for their oxides showed Si as the dominant element followed by Al, and then Fe. The total P, K, Mg, and Ca contents were low (Table 3).

The SiO_2/R_2O_3 ratios for these soils ranged from 1.07 to 1.86, while the corresponding SiO_2/Al_2O_3 ratios ranged from 2.0 to 2.9. Therefore, it could be inferred that the dominant clay mineral in these soils is kaolinite since the ratios of SiO_2/R_2O_3 and SiO_2/Al_2O_3 were within the range given by Tan and Troth (18) for kaolinite.

Sand Mineralogy: Petrographic investigation showed that the fine sand fractions of the well drained soils (Ibule, Ijare, Owena, and Itagunmodi series) contained lower amounts of light minerals (S.g. < 2.90) than the poorly drained soil (Adio series). Heavy mineral (S.g. >2.90) content was high in the well drained soils (Table 4).

The dominant light minerals were quartz and feldspar (Table 5). The relatively high amount of feldspar (a weatherable mineral) in the poorly drained soils could be associated with slow rate of weathering likely to occur in such soils. The heavy fraction was dominated by opaque ores (Table 6), which could be haematite considering the high content of ferromagnesian minerals in the parent material (16). The relatively high content of zircon (Table 6), a resistant mineral in the poorly drained soil of the valley bottom could be due to deposition of colluvial and alluvial materials rich in zircon. The occurence of weatherable minerals (hornblende and feldspar) in the soils indicated that the soils had some nutrient reserve.

In Table 7, the variations in the zircon/tourmaline (two resistant minerals) ratios with depth in all the soil profiles suggest stratification of the parent materials. The change in the ratios of quartz/feldspar with depth (Table 7) indicated that the degree of weathering in the soil profiles was not uniform. The higher values of the quartz/feldspar ratios in some horizons suggest that some horizons were more susceptible to weathering than others.

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Table 3 Total elemental composition and silica - sesquioxide ratios of representative soil profiles

Soil Series	Depth	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	CaO	Na_2O	P_2O_5	$\frac{SiO_2}{Al_2O_3}$	$^*R_2O_3$	$\frac{SiO_2}{R_2O_3}$
Ibule	0-7	24.52	10.66	12.23	0.36	0.12	0.43	0.77	0.50	2.3	22.89	1.07
	7-22	32.74	11.29	12.60	0.48	0.07	0.39	0.43	0.69	2.9	23.89	1.37
	22-64	26.23	10.49	12.50	0.24	0.05	0.36	0.62	0.46	2.5	22.99	1.14
Ijare	0-14	24.20	9.20	11.50	1.21	0.10	0.50	0.30	0.37	2.6	20.79	1.16
	14.31	25.08	10.45	13.50	0.72	0.13	0.20	0.16	0.23	2.4	23.95	1.10
	31.87	36.10	12.89	12.60	1.21	0.12	0.18	0.12	0.18	2.8	25.49	1.42
	87.140	31.84	12.25	12.30	1.45	0.08	0.29	0.66	0.14	2.6	29.55	1.08
	140-179	30.31	10.45	11.90	0.72	0.10	0.35	0.74	0.09	2.9	28.35	1.07
	179-219	34.10	15.80	11.50	0.96	0.15	0.35	0.85	0.09	2.2	27.30	1.25
	219-259	28.62	14.31	11.70	0.96	0.12	0.50	0.12	0.05	2.0	26.00	1.10
Owena	0-4	28.31	10.89	11.60	1.69	0.17	0.22	0.70	0.14	2.6	22.49	1.26
	4-44	22.90	9.54	6.10	0.96	0.07	0.21	0.16	0.09	2.4	15.64	1.46
	44-80	31.25	14.88	8.80	1.69	0.10	0.24	0.04	0.05	2.1	23.68	1.32
	80-117	44.12	15.21	8.50	1.69	0.08	0.22	0.47	0.09	2.9	23.71	1.86
	117-149	31.08	15.54	8.90	1.45	0.08	0.28	0.01	0.05	2.0	24.44	1.27
	149-189	26.78	10.30	8.00	1.21	0.07	0.27	0.39	0.05	2.6	18.30	1.46
	189-249	21.82	10.91	8.20	1.93	0.10	0.32	0.28	0.04	2.0	19.11	1.14
Itagunmodi	0-3	17.56	8.36	7.60	0.48	0.13	0.43	0.30	0.92	2.1	15.96	1.10
	3-11	23.23	9.29	8.10	0.36	0.05	0.39	0.97	0.69	2.5	17.39	1.34
	11-70	40.57	14.49	8.00	0.24	0.03	0.35	0.43	0.92	2.8	22.49	1.80
	70-148	41.38	17.24	7.80	0.19	0.18	0.41	0.43	0.46	2.4	25.04	1.65
	148-183	40.25	17.50	7.70	0.30	0.05	0.36	0.43	1.38	2.3	25.20	1.60
	183-213	29.77	11.45	7.90	0.39	0.07	0.28	0.16	0.96	2.6	19.35	1.54
Adio	0-5	14.47	6.29	5.80	0.24	0.40	0.21	0.27	0.14	2.3	12.09	1.20
	5-44	17.18	8.18	7.60	0.19	0.30	0.20	0.24	0.09	2.1	15.78	1.09
	44-105	17.27	7.85	7.80	0.24	0.20	0.20	0.19	0.09	2.2	15.65	1.10
	105-130	23.63	9.45	7.90	0.30	0.37	0.22	0.16	0.05	2.5	17.35	1.10
	130-177	17.68	8.84	7.30	0.27	0.33	0.18	0.22	0.09	2.0	16.14	1.20
	177-219	22.41	8.62	7.50	0.34	0.53	0.22	0.27	0.09	2.6	16.12	1.39

$^*R_2O_3 = Al_2O_3 + Fe_2O_3$

Table 4: Percent light and heavy mineral composition of fine Sand fraction of the soil Profiles

Soil Series	DEPTH (cm)	LIGHT MINERAL (S.g < 2.90) %	HEAVY MINERAL (S.g> 2.90)
Ibule	0-7	71	29
	7-22	75	25
	22-64	79	21
Ijare	0-14	80	20
	14-31	87	13
	31-87	86	14
	87-140	89	11
	140-179	82	18
	179-219	84	16
	219-259	80	20
Owena	0-4	80	20
	4-44	82	18
	44-80	81	19
	80-177	83	17
	117-149	82	18
	149-189	81	19
	189-249	80	20
Itagunmodi	0-3	74	26
	3-11	72	28
	11-70	75	25
	70-148	75	24
	148-183	74	25
	183-213	73	27
Adio	0-5	95	5
	5-44	96	4
	44-105	97	3
	105-130	98	2
	130-177	97	3
	177-219	96	4

Table 5 : Percent light mineral composition of fine sand of the soil profiles

Soil Series	DEPTH (cm)	LIGHT MINERAL QUARTZ %	S.g<2.90 FELDSPAR
Ibule	0-7	98	2
	2-22	96	4
	22-64	94	6
Ijare	0-14	94	6
	14-31	97	3
	31-87	98	2
	87-140	93	7
	140-179	95	5
	179-219	92	8
	219-259	96	4
Owena	0-4	97	3
	4-44	96	4
	31-87	98	2
	80-117	93	7
	117-149	95	5
	149-189	96	4
	189-249	94	6
Itagunmodi	0-3	97	3
	3-11	95	5
	11-70	96	4
	70-148	94	6
	148-183	93	7
	183-213	96	4
Adio	0-5	82	18
	5-44	86	14
	44-105	85	15
	105-130	82	18
	130-177	84	16
	177-219	85	15

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Table 6 : Percent heavy mineral composition of fine sand fraction of the soil profiles

Soil Series	DEPTH (cm)	Opaque	HEAVY MINERAL Hornblende %	(S.g> 2.90 Tournmaline	Zircon
Ibule	0-14	88	2	1	2
	7-22	86	3	1	10
	22-64	90	1	1	8
Ijare	0-14	89	2	1	8
	14-31	86	2	2	10
	31-87	82	3	1	14
	87-140	89	1	1	9
	140-179	79	2	2	17
	179-219	81	2	1	16
	219-259	80	1	1	18
Owena	0-4	87	2	10	1
	4-44	82	3	14	1
	44-80	78	1	18	3
	80-117	80	4	14	2
	117-149	82	2	15	1
	149-189	79	1	19	1
	189-249	83	2	14	1
Itagunmodi	0-3	90	3	2	5
	3-11	89	2	2	7
	11-70	86	2	6	6
	70-148	85	4	3	8
	148-183	87	3	6	4
	183-213	88	1	2	9
Adio	0-5	79	10	1	10
	5-44	83	9	2	6
	44-105	72	10	1	17
	105-130	74	11	1	14
	130-177	70	10	2	18
	177-219	76	9	1	14

Table 7 : Ratios of resistant minerals in fine sand fraction in five soil profiles

Soil Series	Depth (cm)	zircon/tourmaline	quartz/feldspar
Ibule	0-7	9.00	49.00
	7-22	10.00	24.00
	22-64	8.00	15.70
Ijare	0-14	8.00	15.67
	14-31	5.00	32.33
	31-87	14.00	49.00
	87-140	8.50	13.29
	140-179	16.00	19.00
	179-219	18.00	11.50
	219-252		
Owena	0-4	0.10	32.33
	4-44	0.07	24.00
	44-80	0.17	49.00
	80-117	0.14	13.29
	149-189	0.05	24.00
	189-249	0.07	15.67
Itagunmodi	0-3	2.50	32.33
	3-11	3.50	19.0
	11-70	1.00	24.00
	70-148	2.70	15.67
	148-183	0.67	13.29
	183-213	4.50	24.00
Adio	0-5	10	4.56
	5-44	3	6.56
	44-105	17	5.67
	105-130	14	4.56
	130-177	9	5.25
	177-219	14	5.67

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CONCLUSION

The results of the sand mineralogical evaluation showed that the studied soils were derived from parent materials that were rich in bases. The well drained up-slope soils were more strongly weathered than the poorly-drained soils of the valley bottom.

There were variations in the particle size distribution of the non-clay fraction in the soil profiles. This implied stratification of the parent material. The pattern of clay distribution also suggested the probable role of an eluvial-illuvial process in the development of the soil profiles. The presence of weatherable minerals (feldspars and hornblende) suggested that the soils had some nutrient reserve that could contribute to their potential for sustaining a reasonable level of crop productivity.

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