On the classification and genesis of soils developed over acid volcanic material under humid tropical conditions II

K. H. TAN and J. VAN SCHUYLENBORGH

University of Indonesia, Bogor, and Agricultural University, Wageningen, Netherlands respectively

Summary

Formation of zonal soils on acid volcanic (rhyolitic and dacitic) tuffs is discussed. Depending on temperature, 4 belts can be distinguished, viz. a belt with Podzols at an elevation of 1500—2000 m above sea level, a second belt with Podzol-Brown Podzolic intergrades between 1100 and 1500 m altitude, a third belt with Brown Podzolic soils at an elevation of 1100 and 500 m above sea level, and finally a fourth belt with Red-Yellow Podzolic soils from 500 m altitude downward.

Intrazonal soils are formed on andesito-dacitic tuffs at low altitudes. Andosoils, Humic Gley Soils and Grey Hydromorphic soils can be distinguished, depending on drainage-impedence.

The soil genetics are discussed.

1. Introduction

The area studied is situated in the north of Sumatra and chiefly comprises the Residences Tapanuli and East Coast of Sumatra, viz. the uplands around the Toba lake and its eastern part, descending to the Strait of Malacca. This eastern part has already been thoroughly investigated by DRUIF (1932, 1934, 1938). He compiled an agrogeological map of it, taking the petrographic-genetic principle as a basis for the division of the soils. Thus he distinguished between rhyolitic-, dacito-rhyolitic, recent dacitic- etc. soils and their alluvial derivatives. A subdivision was made by including soil colour and texture in the scheme. In this way he described about 200 soil types, and this proved to be very valuable to agriculture.

No subsequent attempts were made to bring the classification into line with modern soil classification concepts nor was the genesis of the soils taken into consideration. Only KIEL and RACHMAT (1948) and VAN SCHUYLENBORGH and VAN RUMMELEN (1955) respectively mentioned the occurrence of Podzols and Brown Podzolic soils in this region.

The present paper aims at giving a description of several autochtonous zonal soils and some intrazonal soils known as Black Dust soils; some observations will also be made on genesis.

2. Geology, climate and parent material

At a certain geological age of the island of Sumatra vast amounts of volcanic ash were blown out of one or more points in or near Toba lake (the pre-Toba eruption).

FIGURE. Agro-geological sketch of a part of the east coast of Sumatra (DRUIF, 1939)
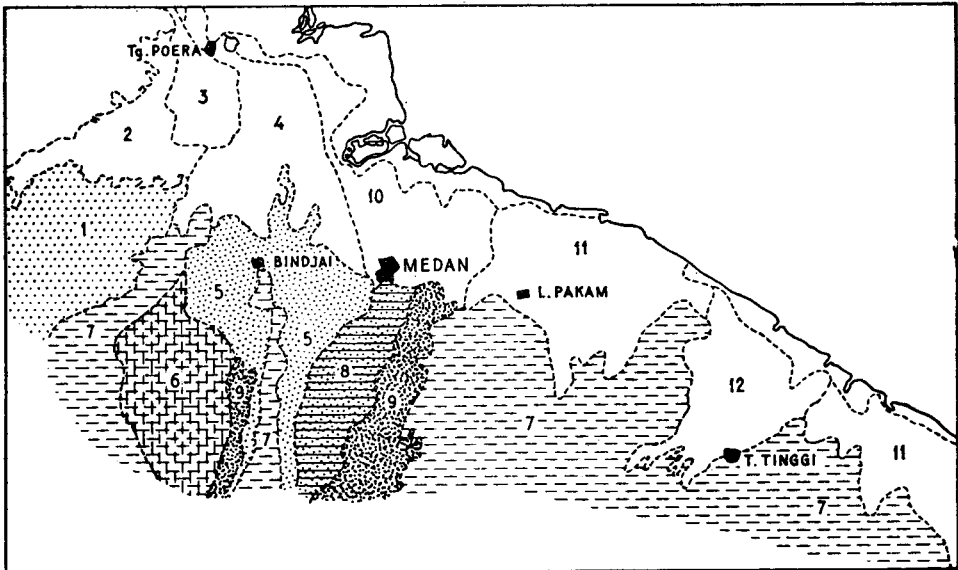
Legend

1. Tertiary soils; 2. fluviatile tertiary soils; 3. fluviatile tertiary and quaternary soils 4. fluviatile andesitic-dacitic soils; 5. "Black Dust" soils; 6. dacitic liparite soils; 7. liparitic soils; 8. Old dacitic soils; 9. Young dacitic soils; 10. fluviatile dacitic soils; 11. fluviatile liparitic soils; 12. fluviatile mixed volcanic soils.

According to MOHR (1937) this took place during late tertiary periods (neogene and later); DRUIF (1932) dated this volcanic activity just at the beginning of the quaternary era. A very large area was covered with this rhyolitic volcanic material, viz. about 20,000 sq.km with an average depth of 50 m. Since the surface covered by this material was originally very highly contoured the ash began to slide down; rainwater intensified this process by erosion and "lahar" formation. Originally high peaks in the landscape reappeared on the surface and former canyons were filled up. In any case the region became more dissected. After a period of rest a new era of volcanic activity began (the post-Toba eruptions). Dacitic material was then forced out during two periods, and this again formed "lahar" streams following already existing valleys and terrain folds. It is possible to distinguish ancient and recent dacitic tuffs and "lahars". After another stage of rest a third period of minor volcanic activity began at about the period of the Risz glaciation (MOHR, 1937); the volcanic material was of andesito-dacitic composition but with very fine quartz sand grains. This material is now found in two narrow "lahar" streams which meet and widen in the plains. A part of the region investigated is shown in the FIGURE (copied from DRUIF, 1939).

We can therefore find several parent materials in the region investigated, viz. rhyolytic-, dacito-liparitic-, old dacitic-, young dacitic-, and andesito-dacitic-tuffs; furthermore tertiary materials (not investigated) and also the fluviatile derivatives of the tuffs mentioned (not investigated). The composition of the sand fraction of these different materials is shown comparatively in TABLE 1 (DRUIF, 1934).

TABLE 1. Composition of the tuffs

Nature of tuffs	volcanic glass	quartz	sanidine	albite	oligoclase	andesine	magnetite	ilmenite	biotite	green hornblende	brown hornblende	hypersthene	apatite	zircon
rhyolitic tuff	+++	++++	+++	++	++	—	+	+	++	++			+	++
dacito-liparitic tuff	+++	+++++	+++	+	++	++	++	++	+++	+++	++	+	+	+++
young dacitic tuff	+++	+++	+		+++	+++	+++	+++	++++	+++++	++	+++	++	+++
old dacitic tuff	+++	++	—	—	+++	++++	++++	++++	+++	+++++	+++	+++++	++	++
andesito-dacitic tuff	+++	+			++++	+++++	+++	+++	+	+++++		+++++	+	+

++++ : abundant; +++ : much; ++ : moderate; + : slight; — : seldom

TABLE 2. Rainfall distribution in mm at a number of locations in the Toba region and the East Coast

Location	altitude (m)	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tapanuli :														
Tiga Lingga	450	165	154	262	222	135	66	53	132	136	209	258	199	1991
Sidikalang	1066	223	169	266	275	170	104	106	146	205	257	293	244	2438
Salak	1000	293	268	349	396	264	151	161	238	310	405	450	368	3644
Baliga	973	176	139	212	235	156	57	93	162	193	193	240	245	2101
Si Borong-Borong	1320	173	158	222	212	159	88	75	124	197	232	235	213	2088
East Coast :														
Pankalanbrandan	4	171	74	99	115	191	155	113	164	223	278	234	214	2031
Medan	14	144	84	107	133	174	131	133	173	214	268	239	215	2015
Gedong Djohore	—	160	82	158	164	208	112	153	209	269	312	174	195	2196
Bindjei	28	173	100	158	183	266	202	173	237	302	331	265	253	2643
Padang Tjermin	40	214	121	220	207	285	198	179	237	350	407	320	272	3010
Glugur	80	217	104	196	194	251	208	162	208	267	384	283	249	2723
Sibolangit	505	366	270	281	305	357	210	173	398	341	535	360	423	4019
Kabandjahe	1200	128	85	173	171	120	27	40	112	159	203	208	218	1644
Pematang Siantar	400	259	201	249	264	293	197	158	252	322	406	281	248	3130
Prapat	920	168	122	188	215	131	67	65	95	177	245	253	199	1921
Aek Na Uli	1160	223	146	258	262	183	78	51	165	282	373	279	309	2609

The tuffs extend from 2000 m to 50 m above sea level, so that climatic conditions differ with respect to temperature and rainfall. According to BRAAK (1923/25) the temperature can be estimated by means of the formula t = 26.3 — h × 0.6° C in which h is the elevation in hectometres.

Rainfall data is shown in TABLE 2, in which several locations in the region investigated are reported (BERLAGE, 1949).

The rainfall is found to differ from place to place, but if we accept COSTER's (1937) figure for the evapotranspiration of a tropical rain forest, viz. about 900 mm of moisture per annum, it will be evident that there is a continuous downward movement of moisture through the soil throughout the year. It may therefore be assumed in this case also that differences in rainfall will not result in difference in soil formation. Any differences in soil formation must have been caused by parent material and temperature.

3. Materials and methods

The discussions are based on 1. the profile morphology (colour, texture, structure and consistency), 2. the pH values, 3. the organic matter profile, 4. the mineralogical composition of the sand fraction, 5. the chemical composition of the clay fractions and 6. the C/N values of the horizons. For analytical details reference may be made to TAN KIM HONG and VAN SCHUYLENBORGH (1959).

The profiles were taken at different altitudes and on different parent materials. Part of the profiles were supplied by courtesy of the Director of Soil Research Institute, Bogor, for which the authors tender their thanks.

The Munsell colour notations in the profile descriptions refer to the air-dry and wet state.

4. Results and discussion

A. *Zonal soils*

Examination of the profiles leads to the conclusion that schematically four belts can be distinguished. The highest belt extends from 2000 to 1500 m altitude and consists of Podzols. The effect of parent material could not be traced since at this altitude the material mainly consists of rhyolitic tuffs. An example is the PROFILE here-under.

Prof. 1. Tapanuli Residency, Laepondom. Foot of Mt. Sibartong. Altitude 1600 m. Vegetation: primeval tropical rain forest. Parent material: rhyolitic tuff. Rainfall 2500 m. Temp. about 16.5° C.

$A_{00} + A_0$ 0—20 cm Dark reddish-brown (5YR 3/4 — 5YR 3/3) raw humus. Partly decomposed. When dry it can only be moistened with great difficulty.

A_2 20—30 cm Grey to very dark grey (5YR 5/1 — 5YR 3/1) sandy loam. Weak fine crumb. Very friable. Abundance of roots. Difficult to moisten.

B_{2h} 30—50 cm Brown to very dark grey brown (10YR 5/3 — 5YR 3/2) sandy loam. Moderately developed coarse platy. Firm. Few roots. Difficult to moisten. Dark reddish grey (5YR 4/2) mottled.

B_{2ir} 50—55 cm Yellow to reddish yellow (10YR 7½/6 — 7.5YR 6/8) loam. Irregularly platy. Very firm. No roots.

C + 55 cm White to pale yellow (10YR 9/1 — 2.5Y 7/4) sandy loam. Massive. Friable. Yellowish red (5YR 5/8) and yellow (10YR 7/8) mottled. A few pumice stones.

The analytical results are given in TABLES 3 and 4. TABLE 3 shows the normal distribution in the profile of clay, organic matter, silicic-acid and sesquioxides. We can also see, that the composition of organic matter (as indicated by C/N quotient) in the illuvial horizons differs from that in the eluvial horizons, a phenomenon frequently encountered in the Forest Podzols in temperate climates. Apparently one fraction of soil organic matter is mobile and responsible for the translocation of the sesquioxides. Iron is more mobile than aluminium.

The second belt, extending from 1500 m to 1100 m altitude and also chiefly consisting of rhyolitic tuffs, is occupied by Podzol-Brown Podzolic-Intergrades. An example on old dacitic tuff is *profile* 2.

Prof. 2. Tapanuli Residency, Malaunadeak-Samosir. Altitude 1450 m. Vegetation: pine nursery (originally tropical rain forest). Parent material: old dacitic tuff. Excessively drained. Temp. $17.5°$ C.

A_{11} 0—10 cm   Grey brown to dark grey brown (10YR $4\frac{1}{2}/2$ — 10YR $3/2\frac{1}{2}$) silty clay loam. Weak, very fine crumb. Very friable. Abundance of roots.

A_{12} 10—15 cm   Brown to dark brown (10YR $5\frac{1}{2}/3$ — 10YR 3/3) silty clay loam. Weak fine crumb to granular. Friable. Many roots.

B 15—32 cm   Light yellowish-brown to yellowish-brown (10YR 6/4 — 7.5YR 5/5) silty clay loam. Weak fine nutty. Friable. Many roots.

BC 32—56 cm   Very pale brown to brown (10YR $7\frac{1}{2}/4$ — 7.5YR 5/4) silty clay loam. Weak fine nutty. Firm. Few roots.

C(?) + 56 cm   Pale yellow to light yellowish brown (2.5YR 8/5 — 10YR $6/3\frac{1}{2}$) silty clay loam. Weak fine prismatic. Very firm. Very few roots.

It would seem that the lowest horizon has a different composition than the solum (see TABLE 4) and moreover TABLE 3 shows a distinct illuviation of sesquioxides. In this case also iron seems to be more mobile than aluminium. The C/N ratio decreases with depth, a normal feature of podzolic soils in temperate climates.

The distribution of sesquioxides and silicic acid is very comparable with that of the Podzols, but as there is no bleached horizon these soils are classified as Podzol-Brown Podzolic Intergrades by the present authors.

The third belt extends from 1100 m to about 500 m altitude and consists of Brown Podzolic soils. Two examples will be given here.

Prof. 3. East Sumatra, Pematang Sidamanik. Altitude 950 m. Hilly land; profile on flat top of a hill. Vegetation: Old tea shrubs and *Imperata cylindrica*. Parent material: rhyolitic tuff. Excessively drained. Rainfall 3051 mm. Temp. $20.5°$ C.

A_1 0—15 cm   Dark brown (10YR 3/3 — 7.5YR 3/2) loam. Moderate fine crumb. Very friable. Many roots.

B_1 15—40 cm   Yellowish-brown to strong brown (10YR 5/4 — 7.5YR 5/6) loam. Weak fine nutty. Friable to slightly sticky. Few roots.

B_3 40—75 cm   Very pale brown to yellowish brown (10YR 7/4 — 10YR 5/4) sandy loam. Weak fine blocky. Friable to slightly sticky. Few roots.

C + 75 cm   Very pale brown (10YR 8/4 — 10YR 7/4) loamy sand. Massive. Friable. Very few roots.

Prof. 4. East Sumatra, Durian tinggung. Altitude 600 m. Flat to slightly undulating land. Vegetation: cultivated land. Parent material: rhyolitic tuff. Excessively drained. Rainfall about 4000 mm. Temp. $22.5°$ C.

A_p 0—23 cm   Light brown grey to very dark grey brown (10YR 6/2 — 10YR 3/2) loam. Fine crumb. Very friable. Abundance of roots.

TABLE 3. Characteristics of the zonal soils

Profile		Clay %	pH	C %	N %	C/N	Chemical composition of clay			
							SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3
1. Podzol	$A_{00} + A_0$	—	3,42	47,8	2,14	22,3	—	—	—	—
	A_2	8,24	4,95	7,38	0,332	22,2	2,45	2,66	32,3	12,2
	B_{2h}	10,6	5,30	11,6	0,311	37,3	0,54	0,56	14,8	26,5
	B_{2ir}	10,3	5,73	1,93	0,045	42,9	1,07	1,21	8,84	7,32
	C	10,9	5,81	0,19	nil	—	1,21	1,30	17,9	13,8
2. Polzol-Brown Podz. Intergrade	A_{11}	25,0	5,53	9,92	0,621	16,0	0,76	0,84	8,00	9,58
	A_{12}	26,5	6,09	7,00	0,471	14,9	0,58	0,64	6,90	10,9
	B	26,9	6,39	2,35	0,264	8,9	0,53	0,58	7,21	12,6
	BC	37,5	6,20	1,48	0,171	8,7	0,81	0,92	6,89	7,54
	C?	30,2	6,04	0,91	0,084	10,8	1,15	1,32	9,34	7,12
3. Brown Podz.	A_1	24,2	5,32	5,44	0,434	12,5	1,14	1,26	12,1	9,61
	B_1	13,6	5,60	1,28	0,168	7,6	0,91	1,00	10,7	10,7
	B_3	7,34	6,02	0,80	0,105	7,6	0,72	0,80	8,22	10,4
	C	2,43	6,30	0,75	0,067	11,2	0,93	1,01	10,9	10,7
4. Brown Podz.	A_1	16,0	6,61	3,38	0,326	10,4	1,26	1,42	11,7	8,30
	B_1	16,4	5,55	1,11	0,097	11,4	1,07	1,20	10,7	8,97
	B_3	15,0	5,31	0,80	0,064	12,5	0,97	1,08	9,60	8,91
	C	13,4	5,14	0,62	0,053	11,8	0,97	1,09	8,47	8,15
5. Red-Yellow Podz.	A_1/A_2	20,4	6,36	3,73	0,359	10,4	2,65	3,12	17,6	5,63
	B_1	36,6	5,24	0,99	0,093	10,6	2,42	2,82	17,3	6,16
	B_{21}	43,6	5,24	0,65	0,070	9,2	1,72	1,91	17,3	9,05
	B_{22}	41,3	4,93	0,47	0,046	10,3	1,72	1,91	17,6	9,25
	B_{3g}	41,8	5,22	0,44	0,039	11,4	1,73	1,91	18,2	9,53
6. Red-Yellow Podz.	A_1	50,6	4,62	4,43	0,316	14,0	1,68	1,89	15,2	7,04
	A_2	55,7	4,46	1,01	0,071	14,2	1,68	1,86	17,7	9,52
	B_1	61,1	4,73	0,98	0,067	14,6	1,65	1,83	16,5	9,07
	B_{2g}	60,3	4,71	0,78	0,055	14,1	1,66	1,81	19,1	10,6
	B_{3g}	52,6	4,74	0,81	0,062	13,0	1,71	1,88	19,4	10,4
7. Yellow Podz.	A_1/A_2	38,9	7,00	3,66	0,335	10,9	1,38	1,71	7,23	4,23
	B_{2g}	48,0	5,24	0,40	0,061	6,6	1,34	1,61	7,96	4,96
	B_{3g}	31,5	5,54	0,21	0,049	4,4	1,30	1,50	9,81	6,58
	D_1	2,0	6,09	0,08	0,010	8,5	3,45	3,58	97,4	27,2
	D_2	18,6	5,83	0,23	0,036	6,4	1,43	1,79	6,94	3,89

46

Neth. J. agric. Sci., Vol. 9 (1961) No. 1 (February)

TABLE 4. Mineralogical composition of the sand and heavy sand fractions

Profile	Horizon	volcanic glass	quartz	sanidine	albite	oligoclase	andesine	opaque	biotite	green hornblende	brown hornblende	hypersthene	gibbsite	zircon	orthite	miscellaneous	opaque	gr. horn-blende	br. horn-blende	hyper-sthene	sphene	orthite	epidote	zircon
																	heavy sand fraction — % ratio of transparent minerals							
1. Podsol	$A_{00}+A_0$	23	33	22	tr	3	—	1	1	tr	—	tr	—	—	—	5	—	—	—	—	—	—	—	—
	A_2	25	36	20	—	17	—	tr	1	tr	—	tr	—	tr	tr	tr	33	56	1	26	—	5	—	11
	B_{2h}	16	20	12	—	8	—	—	2	2	—	tr	—	tr	—	40	12	74	tr	25	—	1	—	tr
	B_{2ir}	45	9	6	—	15	—	tr	18	tr	—	tr	—	—	—	5	6	76	tr	14	—	7	—	2
	C	52	7	4	1	8	—	—	23	1	—	tr	—	—	—	3	44	75	—	15	—	—	—	8
2. Podsol-Brown Podzolic intergrade	A_{11}	17	31	5	—	2	—	4	tr	22	tr	3	tr	tr	—	15	18	80	1	18	—	—	—	tr
	A_{12}	22	22	5	—	1	—	5	tr	26	tr	3	1	—	tr	13	13	85	1	14	—	1	—	tr
	B	19	25	5	—	2	—	9	tr	21	tr	2	1	tr	—	15	26	84	1	15	—	tr	tr	—
	BC	12	27	6	—	1	—	4	6	9	—	1	1	—	—	29	35	87	tr	13	—	—	—	tr
	C?	2	29	9	—	tr	—	tr	9	1	—	tr	tr	—	—	47	65	79	2	15	—	1	—	3
3. Brown Podzolic	A_1	1	24	27	—	22	—	1	18	1	—	tr	1	tr	tr	4	50	84	—	8	—	8	—	1
	B_1	tr	21	13	—	18	—	1	33	2	—	tr	3	tr	—	8	36	94	—	4	—	2	—	3
	B_3	tr	16	13	—	9	—	1	41	2	—	tr	4	tr	—	14	36	85	—	14	—	1	—	6
	C	1	15	8	—	13	—	2	35	1	—	—	7	—	—	18	49	87	—	10	—	3	—	4
4. Brown Podzolic	A_1	2	31	21	—	13	—	1	15	1	tr	tr	2	tr	tr	12	46	90	1	3	—	5	—	1
	B_1	2	29	21	—	11	—	2	17	2	tr	tr	1	tr	—	14	70	88	1	5	—	2	—	3
	B_3	1	23	17	—	9	—	3	26	2	tr	tr	2	tr	tr	15	78	88	1	1	—	3	—	6
	C	tr	22	19	—	14	—	tr	27	1	tr	—	4	tr	tr	11	60	89	1	tr	—	6	—	4
7. Yellow Podzolic	A_1/A_2	1	21	tr	—	2	tr	3	1	27	tr	tr	3	—	—	42	31	98	1	tr	—	—	—	1
	B_{2g}	tr	14	1	—	tr	tr	1	2	7	tr	1	2	—	—	72	11	96	1	3	—	—	—	tr
	B_{3g}	1	7	tr	—	1	1	1	1	36	tr	1	1	—	—	50	16	91	tr	7	—	—	1	2
	D_1	6	3	—	—	14	4	1	8	22	tr	2	tr	—	—	40	41	58	—	42	—	—	—	tr
	D_2	tr	6	tr	—	tr	tr	2	8	20	tr	tr	2	—	—	62	25	99	—	tr	—	—	—	1
9. Andosoil	A_1	14	5	tr	—	22		8	4	13	4	3	tr	—	—	10	20	64	17	16	—	2	—	tr
	A_3	9	3	tr	—	23		1	3	19	3	5	—	—	—	11	22	74	13	12	—	1	—	tr
	B	11	1	tr	—	21		7	3	8	2	1	tr	—	—	13	34	78	7	15	—	tr	—	tr
	C	3	1	—	—	30		7	2	10	2	1	—	—	—	2	51	72	13	13	—	1	—	tr

B_1 23—88 cm   Pale brown to brown (10YR 6/3 — 7.5YR 3/2) loam. Moderate fine nutty. Friable. Few roots.

B_3 88—132 cm   Very pale brown to brown (10YR 7/3 — 7.5YR 5/4) loam. Very fine nutty. Friable to firm. Very few roots.

C + 132 cm   Very pale brown to pale brown (10YR 8/3 — 10YR 6/3) loam. Massive. Friable to firm. No roots.

There is no illuviation of clay in these profiles and aluminium is slightly more mobile than iron. This characteristic is an important difference between the soils of the third and those of the second and first belts. The trend of the C/N ratia is indistinct as the soils are or were under cultivation and natural conditions had consequently been disturbed.

Finally a fourth belt of Red and Yellow Podzolic soils may be observed from about 500 m elevation to the boundary of the alluvial soils. Except on the andesito-dacitic tuffs they occur on both tertiary and volcanic parent materials.

Three examples will be given here.

Prof. 5. East Sumatra, Gonting Silaugomon. Altitude 300 m. Dissected rolling land. Vegetation: Secondary forest with shrubs. Parent material: rhyolitic tuff. Well drained. Rainfall about 3000 mm. Temp. 24.5° C.

A_1/A_2 0—15 cm   Grey to very dark grey (10YR 3/1) sandy clay loam. Weak medium crumb. Very friable. Many roots.

B_1 15—40 cm   Very pale brown to reddish-yellow (10YR 7/4 — 7.5YR 6/6) sandy clay. Weak fine nutty. Friable. Few roots.

B_{21} 40—65 cm   Very pale brown to reddish-yellow (10YR 7/4 — 7.5YR 6/6) clay. Moderate fine nutty. Friable to firm. Few roots.

B_{22} 65—90 cm   Very pale brown to reddish-yellow (10YR 8/4 — 7.5YR 6/6) sandy clay. Moderate medium nuttiy. Firm. Very few roots.

B_{3g} 90—115 cm   Very pale to reddish-yellow (10YR 8/4 — 7.5YR 6/6) sandy clay. Lumpy. Slightly sticky. Many fine, distinct reddish-yellow (7.5YR 8/6 — 5YR 6/7) mottles. No roots.

Prof. 6. East Sumatra, Pasirbidang. Altitude 200 m. Hilly, with deep valleys and steep slopes. Profile on flat top of hill. Vegetation: Open primeval rain forest. Parent material: rhyolitic tuff. Moderately well drained. Rainfall about 3000 mm. Temp. 25° C.

A_1 0—15 cm   Dark grey brown to brown (10YR 4/2 — 7.5YR 4/2) clay. Weak fine crumb. Friable. Many roots.

A_2 15—35 cm   Very pale brown to reddish-yellow (10YR 7/4 — 7.5YR 6/6) clay. Weak fine nutty. Friable. Few roots.

B_1 35—65 cm   Yellow to reddish-yellow (10YR 8/6 — 7,5YR 7/6) clay. Weak fine nuttiy. Firm. Few roots.

B_{2g} 65—85 cm   Yellow to reddish-yellow (10YR 8/6 — 7.5YR 7/6) clay. Moderate fine nutty. Friable. Few, fine and distinctly rusty brown mottles. Few roots.

B_{3g} 85—100 cm   Very pale brown to reddish-yellow (10YR 8/4 — 7.5YR 7/6) clay. Weak fine nutty. Friable to firm. Few, fine and distinctly rusty brown mottles. No roots.

Prof. 7. East Sumatra, Simpang Kotadinging. Altitude 80 m. Level to very slightly sloping land. Vegetation: cultivated. Parent material: Young dacitic tuff. Somewhat poorly drained. Rainfall about 2800 mm. Temp. 26° C.

A_1/A_2 0—30 cm   Very pale brown to yellowish-brown (10YR 7/4 — 10YR 5/4) clay loam. Moderate fine nutty. Friable. Abundance of roots.

B_{2g} 30—75 cm   Yellow to strong brown (10YR 7/8 — 7.5YR 5/6) clay. Moderate medium blocky. Slightly sticky. Irregularly shaped concretions. Few roots.

B_{3g}75—103 cm   Yellow to brownish-yellow (10YR 8/6 — 10YR 6/6) clay loam. Weak medium nutty. Friable. Very few roots.

D_1 103—120 cm   White to pale yellow (2.5Y 8/2 — 2.5Y 7/4) loamy sand. Massive. Friable. Slightly yellow-mottled. No roots.

D_2 +120 cm   Yellow to yellowish-brown (10YR 7½/6 — 10YR 5/6) silty loam. Weak fine crumb. Friable. No roots. Thin black-coloured fibres.

It can be seen from TABLE 4 that PROF. 7 is not a homogeneous one. The upper three horizons form a Yellow Podzolic soil. TABLE 3 shows that aluminium has a distinctly greater mobility than iron. This is accompanied by a constant C/N ratio, as was pointed out in a previous article (VAN SCHUYLENBORGH, 1957).
The genesis of the soils may be explained on the basis of the theory propounded by MOHR (1922) and JOFFE (1931, 1936) which was developed by one of the present authors and his co-workers (1955, 1957, 1958, 1959). According to this theory, under suitable conditions (high base-status, adequate air, water and temperature regimes) the organic matter decomposed completely, so that the soil-forming agent was carbonic acid. This explains why aluminium was more mobile than iron in tropical podzolic soils. The theory was supported by the constant C/N ratio of soil organic matter and the composition of soil organic matter as compared with that of litter and roots, indicating a rapid decomposition to CO_2 and water. A more direct proof is the determination of carbon dioxide in soil air. This concentration was determined (according to SCHUFFELEN et al., 1954) in soils, situated at different altitudes, under constant humid conditions (W. Java). The results are given in TABLE 5. It appears that at a certain altitude conditions are most conductive to rapid mineralization of organic matter.

TABLE 5. CO_2 content (volume percentage) of the atmosphere of tropical soils depending on elevation

depth (cm)	elevation in metres				
	1100	800	600	490	250
10	0,6				0,8
15		0,9	3,6		
20	0,7			1,6	
25					1,5
35	0,9		4,4		
40		1,2		2,2	
50					2,4
55	0,9				
60		1,4	4,4	2,8	
70	1,1				
80		1,5	4,8	3,4	
90					3,1
100		1,6			
110					3,4
Mean	0,84	1,32	4,30	2,50	2,24

The conditions in the region under investigation in this paper are less favourable to rapid mineralization of soil organic matter, especially at higher altitudes. The low base-status (acid parent materials) and lower temperatures (high altitudes) retard the mineralization process, so that organic acids may be a factor influencing soil forma-

tion. This can be seen in the organic matter composition (C/N ratio) of the soils of the first two belts. In this case the fairly well-known podzolization process led to the formation of Podzols and Podzol-Brown Podzolic Intergrades. The action of organic acids is responsible for the greater mobility of iron in these soils as compared to aluminium (cf. AARNIO, 1913; JONES and WILLCOX, 1929; GALLAGHER, 1942; BLOOM-FIELD, 1953, 1954; STOBBE and WRIGHT, 1959).

Despite the low base-status of the soils the conditions of the lowest belt appear to favour a rapid mineralization process; the high temperature (high biological activity) overcome the detrimental effect of the low base-status. In the soils of this region the C/N ratio is constant and, consequently, aluminium is more mobile than iron.

The Brown Podzolic soils of the third belt occupy an intermediate position, as already discussed by VAN SCHUYLENBORGH and VAN RUMMELEN (1955). In this instance both organic and carbonic acids play a part in soil formation, with the result that iron is as mobile as aluminium (constant Al_2O_3/Fe_2O_3 ratio).

B. *Intrazonal soils*

The most important intrazonal soils in East Sumatra are the "Black Dust soils" (DRUIF, 1932) or "Ando-soils". These have a high organic matter content and sometimes exhibit illuviation of clay (see PROF. 8 and 9, TABLE 7). They are the most recent soils, formed on the andesito-dacitic tuffs and lahars (for their mineralogical composition see TABLE 4, PROF. 9), and are restricted to the lowest parts of the region (the "lahars" followed the lowest parts of the country). Rainfall in this region ranges from 2000 to 3000 mm per annum without a pronounced dry season. It is still a problem how these soils were formed. MOHR (1937) dated the last volcanic activity at the Riss glacial period. By that time the climate was much drier in the Indonesian archipelago and MOHR assumed that as a result the moisture did not continually move downward as at present but intermittently downward and upward. During the ascent alkaline solutions rose to the surface causing carbonization of the dessicated vegetation. The resultant organic matter would be extremely resistant to destruction.

There are, however, objections to this theory. DRUIF (1932) assumed that the last volcanic eruptions did not take place during the Pleistocene period but during the Holocene, viz. when the climate was comparable to the present climate. Moreover it is difficult to understand why the organic matter had not been destroyed under the recent conditions which are so extremely favourable to biological activity. The present authors are therefore inclined to the theory that drainage conditions might have played an important part in the formation of these soils since the lahars and tuffs from which the soils are formed have filled up valleys in the original landscape and created a level terrain. Under such conditions drainage difficulties are quite conceivable.

Moreover, the parent material of these soils is more finely textured than the other volcanic materials, as is shown in TABLE 6. These tuffs will therefore drain more slowly than rhyolitic tuffs for example, and as a result the andesito-dacitic tuffs will be saturated with moisture for longer periods than the more coarsely textured volcanic materials. Organic matter destruction will then be slower and under the heavy tropical vegetation there will be some accumulation of organic matter. This does not mean that there is no mineralization, but only that the equilibrium between the supply of fresh material and decomposition has been established at a high level of organic matter. Moreover, the organic matter is not very mobile owing to the fairly high base-status of the andesito-dacitic tuff.

TABLE 6. Texture of rhyolitic and andesito-dacitic tuffs (in percentages)

fraction	rhyolitic tuff	andesito-dacitic tuff
2000—1000 μ	2,92 } 16,62	0,00 } 3,62
1000— 500 μ	13,7	3,62
500— 250 μ	14,5	9,01
250— 100 μ	14,5 } 22,41	6,32 } 11,87
100— 50 μ	7,91	5,55
50— 2 μ	33,9	49,0
< 2 μ	12,6	26,5

The following profiles support the impeded drainage theory.

Prof. 8. East Sumatra, Glugur. Altitude 50 m. Undulating land. Vegetation: secondary forest with *Eupatorium,* etc. Parent material: andesito-dacitic tuff. Well drained. Rainfall 2725 mm.

A_1 0—18 cm Dark grey brown to black (10YR 4/2 — 10YR 2/1½) silt loam. Weak fine crumb. Loose, friable and soft. Many fine roots.

A_3 18—28 cm Grey brown to very dark brown (10YR 4½/2 — 10YR 2/2) silt loam. Moderate fine crumb. Friable and soft. Many fine roots.

B 28—31 cm Brown to dark yellowish-brown (10YR 5/3 — 10YR 3/4) loam. Weak fine nutty. Friable.

BC 31—76 cm Very pale brown to dark yellowish-brown (10YR 7/4 — 10YR 4/4) loam. Medium nutty to blocky. Slightly sticky. Small stone fragments.

Prof. 9. East Sumatra, Padang Tjermin. Altitude 40 m. Level region. Vegetation: cultivated land. Parent material: andesito-dacitic tuff. Moderately well-drained. Rainfall 3010 mm.

A_1 0—25 cm Dark grey brown to very dark brown (10YR 4½/2) loam. Weak fine crumb. Friable. Many roots.

A_3 25—45 cm Grey brown to dark brown (10YR 5/2½ — 10YR 3/3) silt loam. Weak fine nutty. Friable.

AC 45—90 cm Very pale brown to brown (10YR 7/3 — 10YR 5/3) sandy loam. Weak fine blocky. Slightly sticky.

C + 90 cm White to grey (10YR 8/1 — 10YR 5/1) tuff.

Prof. 10. East Sumatra, Sg. Mentjirim. Altitude 30 m. Undulating land. Profile located on the slopes. Vegetation: secondary forest. Imperfectly drained. Rainfall 2650 mm.

A_{11} 0—4 cm Dark grey brown to very dark brown (10YR 4/1½ — 10YR 2/2) silt loam. Moderate fine crumb. Very loose and friable. Many fine roots.

A_{12} 4—28 cm Brown to dark brown (10YR 5/2½ — 10YR 3/3) silty clay loam. Moderate medium crumb. Friable. Many fine roots.

B_{1g} 28—40 cm Pale brown to dark brown (10YR 6/3 — 7.5YR 3/2) silty clay loam. Weak fine nutty. Friable. A few fine iron concretions.

B_{2g} 40—50 cm Very pale brown to dark grey brown (10YR 7/3 — 10YR 4/2) silt loam. Fine nutty to blocky. Slightly sticky. Many distinct redox mottles. Iron-manganese concretions. Few roots.

B_{3g} + 50 cm Very pale brown to grey brown (10YR 8/3 — 10YR 5/2) silt loam. Fine nutty to blocky. Firm and sticky. Large iron-manganese concretions.

Neth. J. agric. Sci., Vol. 9 (1961) No. 1 (February)

51

TABLE 7. Characteristics of the intrazonal soils (Andosoil-Grey Hydromorphic sequence)

Profile		clay %	pH	C %	N %	C/N	SiO_2/R_2O_3	SiO_2/Al_2O_3	chemical composition of clay	
									SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3
8. Andosoil	A_1	20,8	5,80	6,93	0,660	10,5	1,25	1,38	11,8	8,59
	A_3	22,2	5,70	6,08	0,573	10,6	1,06	1,19	10,2	8,72
	B_2	40,1	5,85	2,77	0,370	7,5	0,96	1,05	9,59	9,19
	BC	40,0	6,20	1,38	0,212	6,5	0,74	0,83	7,01	8,48
9. Andosoil	A_1	18,9	6,00	6,60	0,733	9,0	1,10	1,27	7,99	6,28
	A_3	18,0	6,28	3,15	0,352	9,0	0,91	1,04	7,23	7,23
	AC	11,0	6,75	0,90	0,102	8,8	0,82	0,91	8,11	8,88
	C	3,6	6,66	0,12	0,013	9,2	0,88	0,94	14,8	15,9
10. Humic Gley	A_{11}	24,1	6,80	4,61	0,412	11,2	2,35	2,70	17,9	6,68
	A_{12}	28,8	5,60	2,38	0,248	9,6	2,01	2,24	19,2	8,64
	B_{1g}	31,8	5,20	2,37	0,128	18,5	2,30	2,64	17,5	6,66
	B_{2g}	27,7	5,10	0,70	0,077	9,1	2,28	2,65	16,4	6,23
	B_{3g}	27,7	5,12	0,26	0,034	7,7	1,91	2,12	19,4	9,15
11. Grey Hydro-morphic	A_g	31,6	5,20	2,63	0,201	13,1	2,47	2,76	23,2	8,41
	B_{1g}	30,2	5,30	2,32	0,132	17,6	2,34	2,62	21,5	8,21
	B_{2g}	31,2	5,10	1,01	0,074	13,7	2,19	2,45	20,8	8,51
	G	46,4	5,85	0,86	0,041	20,9	1,89	2,06	18,9	9,15

52

Neth. J. agric. Sci., Vol. 9 (1961) No. 1 (February)

Prof. 11.   East Sumatra, Sg. Mentjirim. Altitude 30 m. Undulating land. Profile located in the depression. Vegetation: secondary forest. Very poorly drained. Groundwater level at the time of sampling: 42 cm. Rainfall 2650 mm.

A_g 0—24 cm   Light grey to dark grey (10YR $6\frac{1}{2}$/1 — 10YR 4/1) silty clay loam. Weak fine crumb. Friable. Iron-manganese concretions. Fine roots.

B_{1g} 24—31 cm   Light grey to grey brown (10YR $7\frac{1}{2}$/1 — 10YR 5/2) silty clay loam. Fine blocky. Slightly sticky, many medium and large iron-manganese concretions. Few fine roots.

B_{2g} 31—39 cm   White to light brownish-grey (2.5Y $7\frac{1}{2}$/1 — 2.5Y 6/2) silty clay loam. Medium blocky. Firm and slightly plastic. Many large iron-manganese concretions.

G + 39 cm   White to light grey (2.5Y 8/0 — 2.5Y 6/0) silty clay. Sticky and plastic. Many redox mottles.

This topo-sequence with Ando soils (PROF. 8 and 9) on the higher parts, Humic Gley Soils (PROF. 10) and Grey Hydromorphic Soils (PROF. 11) in the lower parts is the chief feature of this region. The latter two groups were already distinguished by DRUIF (1939) and called "Semisubhydric Black Dust Soils" and "Subhydric Black Dust Soils", but such terms do not adequately describe these soils.
PROF. 8 and 9 are the normal Andosoils; PROF. 9 may be a truncated profile, the black topsoil having been removed by erosion. This erosion process may be very drastic in this region, exposing the yellowish brown and yellow subsoils of the Ando-soils (see also OOSTINGH, 1928; DRUIF, 1939).
TABLE 7 shows that all soils are podzolic, sesquioxides being more mobile than silicic acid. This supports the view that organic matter destruction takes a different course than it would have done under conditions of perfect drainage; in the latter case latosolic soils would have originated on this type of parent material. In the Ando-soils aluminium seems to be more mobile than iron, which indicates that carbonic acid is still an important soil-forming agent under such conditions. In the hydromorphic soils iron and aluminium are equally mobile; apparently both organic and carbonic acids are responsible for the translocation of Fe and Al.
Hence we can summarize the situation in this region in the manner shown in TABLE 8.

TABLE 8.   Scheme of soil formation in the area investigated

	parent material	plus	soil forming agent	soil group
Zonal soils	acid; coarse-textured:		at t < 17° C: org. acids	Podzols
	very permeable		at t = 17—19° C: org. acids	Podzol-Brown Podz.-Intergrade
			at t = 19—23° C: org. acids and carbonic acid	Brown Podzolic Soil
			at t > 23° C: carbonic acid	Red- and Yellow Podzolic Soils
Intrazonal soils	intermediate; fine-textured; moderately permeable		at t > 24° C well to moderately well drained: carbonic acid (org acids)	Ando-Soils
			poorly drained: org. acids and carbonic acid	Humic Gley and Grey Hydromorphic Soils

REFERENCES

AARNIO, B.	1913	*Int. Mitt. Bodenk. 3*, 131.
BERLAGE Jr., H. P.	1949	Dept. Verk., Energie en Mijnb.; Met. en Geophys. Dienst; *Kon. Magn. Obs. Verh.* No. 37. Batavia.
BLOOMFIELD, C.	1953	*J. Soil Sci. 4*, 5, 17.
——	1954	*J. Soil Sci. 5*, 39, 46, 50.
BRAAK, C.	1923/25	*Versl. Kon. Magn. en Meteor. Obs.* No. 8, 319.
COSTER, CH.	1937	*Tectona. 30*, 2.
DRUIF, J. H.	1932	*Meded. Deli Proefstat.* 2e Serie No. 75, pp. 158.
——	1934	*Bull. Deli Proefstat.* No. 32, pp. 195.
——	1939	De Bodem van Deli. Buitenzorg.
GALLAGHER, P. H.	1942	*Proc. Roy. Irish Acad.* 48 B, 213.
JOFFE, J. S	1931	*Soil Sci. 32*, 303.
——	1944	Pedology. New Brunswick, Canada.
JONES, H. T. and J. S. WILLCOX	1929	*J. Soc. Chem. Ind. 48*, 304.
KIEL, H. and H. RACHMAD	1948	*Landbouw. 20*, 283.
MOHR, E. C. J.	1922	De bodem van Java en Sumatra. Amsterdam.
——	1937	De bodem der tropen in het algemeen, en die van Nederlandsch-Indië, in het bijzonder. Deel II. Derde stuk. Amsterdam.
OOSTINGH, C. H.	1928	*Meded. Deli Proefstat.* 2e Serie No. 54, pp. 61.
SCHUFFELEN, A. C., *et al.*	1954	*Landbouwk. Tijdschr. 66*, 36.
SCHUYLENBORGH, J. VAN and F. F. F. E VAN RUMMELEN	1955	*Neth. J. Agric. Sci. 3*, 192.
SCHUYLENBORGH, J. VAN	1957	*Neth. J. Agric. Sci. 5*, 195.
——	1958	*Neth. J. Agric. Sci. 6*, 99.
STOBBE, P. C. and J. R. WRIGHT	1959	*Soil Sci. Soc. Amer. Proc. 23*, 161.
TAN KIM HONG and J. VAN SCHUYLENBORGH	1959	*Neth. J. Agric. Sci. 7*, 1.