Description of some highly porous soil profiles on the Island of Bellona, an emerged atoll in the Solomon Islands

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Abstract

The preliminary results of a soil survey on the island of Bellona with special reference to physical characteristics: bulk density, porosity, texture etc. of 8 soil profiles representing the most important cultivated soil types.

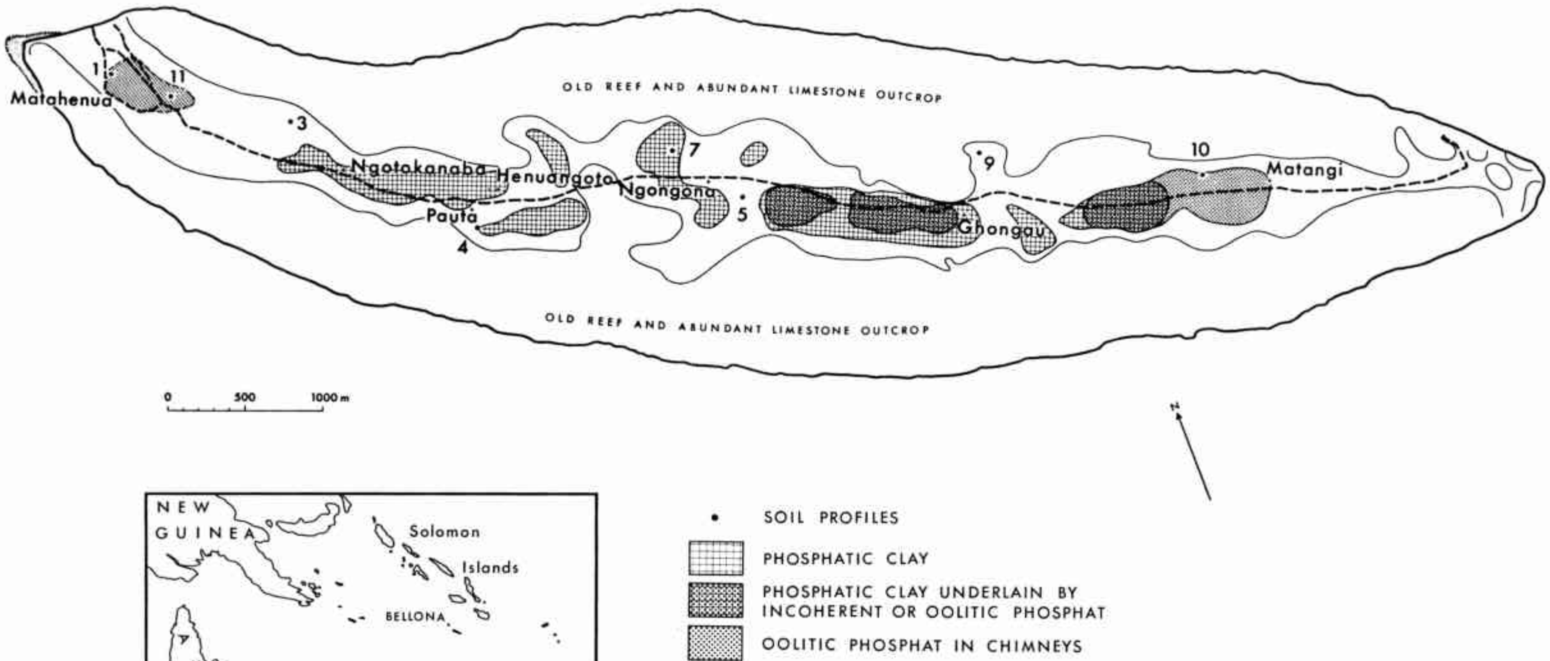
Introduction

This paper treats the preliminary results of a soil survey in the island of Bellona with special reference to physical characteristics: bulk density, porosity, texture etc. of 8 soil profiles representing the most important cultivated soil types. The author worked as an assistant to Sofus Christiansen, M.Sc., from the Geographical Institute of the University of Copenhagen, who performed an investigation of the Bellonese subsistence system (*S. Christiansen,* 1967). The terminology used is from the U.S.D.A. Soil Survey Manual and U.S.D.A. Soil Classification, A Comprehensive System, 7th Approximation.

Topography

Bellona Island (Mungiki) is situated in the Pacific 160 km south of Guadalcanal (fig. 1) at lat. 11°16′S and long. 159°45′E and belongs to the Solomon Islands group. Geologically, Bellona has been determined to be no older than the Pleistocene (*Grover,* 1960). The dating is based on fossils in limestone collected at 42 and 63 m altitude at Tingoa in the eastern part of the island.

The island is a beautiful example of an emerged atoll The geology and morphology have been described by *Grover* (1955, 1957, 1958,



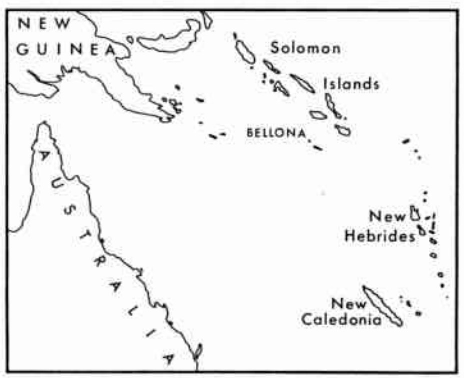


Fig. 1. Map of Bellona Island showing distribution of the phosphate deposits and location of the investigated soil profiles. Drawn after *Sofus Christiansen* (1965) and *White and Warin* (1965).

Fig. 1. Kort over Bellona Island, der viser udbredelsen af fosfat-aflejringerne samt placeringen af de behandlede jordprofiler. Tegnet efter Sofus Christiansen (1968) og White og Warin (1965).

and 1960) and by *White and Warin* (1965). It has the shape of an oblong trough with greatest length 10 kilometres in the direction WNW-ESE and greatest width 2.5 kilometres. The old lagoon floor, now lying 8-16 m above sea level, forms a relatively flat area in the central part of the island. It is surrounded by old reefs which have their best development in the eastern part of the island, reaching approx. 80 m. In the western part, the highest altitude is approx. 60 m; in the outermost northwestern point no old reefs are found.

At the seaward side of the high areas there is a reef surface about 41 m (135 feet) a.s.1. and with a steep slope down to the beach. In this slope, notches mark old sea levels at the following altitudes: 30 m (100 feet), 15-16 m, and 3 m, the latter being developed as a terrace in several places, broadest (almost 100 m) at the landing place Ahanga. The whole island is surrounded by a 50-100 m wide, recent reef flat, outside which the sea floor falls abruptly to more than 1000 m depth.

The 30 and 41 metre levels are found within the high reef, where they are developed as terraces. The 30 metre level shows as a flat area, 30-31 m above sea level, around the village of Matahenua in the western part of the island, whereas the 41 metre level is assumed to correspond to the flat area about 50-52 m a.s.1. around the village of Matangi in the eastern part of the island.

The altitudes stated in feet have been measured with an altimeter (*Grover*, 1960), whereas the indications in metres are based on a levelling carried out by the author from the shore at Ahanga, along the main path crossing the island to a point 600 m east of Matangi. The recent reef flat at Ahanga was used as a datum level.

The difference in altitudes, viz. 135 feet $\sim$ 41 metres on the seaward side and the terrace lying at an altitude of 50-52 metres a.s.l., is presumably due to the different ways of measuring, of which the levelling should give the truer figure.

Climate

The description of the climate is based upon measurements made during the periods 15/3-1965–13/3-1966 and 13/6-1966–28/5-1967 in the village Matahenua on the western part of the islands. The climatological station was established 31 m a.s.l. in the village square. Data were recorded by maximum and minimum thermometers, a thermo-hygrograph placed in a Stevenson Screen 2 m above the ground, and a rain gauge with a 200 cm^2 opening, placed 0.75 m above the ground.

Table 1.

	15/3-65 – 13/6-66 363 days		13/6-66 – 28/5-67 350 days	
Maximum temperatures °C	No. days	in %	No. days	in %
33.0 and above	2	0.6	1	0.3
32.0–32.9	7	1.9	1	0.3
31.0–31.9	13	3.6	11	3.1
30.0–30.9	46	12.7	60	17.1
Total number of days with temperature of 30.0 and above	68	17.8	75	20.8
Minimum temperatures °C				
22.0–22.9	59	16.3	27	7.7
21.0–21.9	13	3.6	9	2.6
20.0–20.9	13	3.6	1	0.3
19.9 and below	4	1.1	1	0.3
Total number of days with temperature of 22.9 and below	89	24.6	38	10.8

In table 1 are seen the distribution of the extremes, the frequency of highest daily maximum temperature and lowest daily minimum temperature recorded during the two measuring periods. The lowest recorded temperature is 19.6° for the first period and 19.0° for the second period. Maximum temperature is for the first period 33.6° and for the second period 33.0° and in general the extreme temperatures are distributed evenly over the whole year; the only exception was the period 1-13. February 1966, where all maximum temperatures were 31.0°C or more.

On account of unavailability of material the average temperature has not been calculated, but it is estimated to be about 25-27°C. On the whole it can be ascertained that the temperature has a diurnal fluctuation of 5-6° in the interval 22-31°. Temperatures above 31° and below 22° rarely occur.

Table 2 shows the monthly distribution of precipitation and rain days for the two measuring periods. It appears from the table that the precipitation varies very much both as to quantity and to number of rain days (a rain day is defined as a day with a registered precipitation of 0.1 mm or more). The highest monthly precipitation was recorded for March 1967 with 540 mm in 18 days, and the lowest in July 1966 with 43 mm distributed on 8 rain days.

Table 2. Rainfall.

	1965		1966		1967	
	mm	days	mm	days	mm	days
January			115	12	389	20
February			234	16	184	18
March	265 [1])	16	168 [2])	10	540	18
April	311	21			211	18
May	375	22			367 [4])	18
June	118	17	40 [3])	5		
July	381	22	43	8		
August	283	14	113	9		
September	116	11	93	11		
October	200	17	102	15		
November	148	10	456	16		
December	236	19	487	12		

1) from 15/3 2) until 13/3 3) from 13/6 4) until 28/5

Methods

The samples were taken with a brass cylinder, 48×150 mm, and placed in a paper bag which itself was put into a plastic bag. Each sample was weighed and air-dried before final packing and despatch from the island. The later laboratory work included determination of:

the colour of the dry sample according to Munsell Colour Cards
Particle size distribution
Content of hygroscopic water
Content of organic material
Loss on ignition
Content of calcium carbonate
Particle density
pH-value

Particle size analysis:

A sample of 45 g is oxidized with 6 % H_2O_2 and air-dried. One third is taken aside to determine the particle density; to the remainder, in a 500 ml bottle, is added 350 ml 0.002 M sodium pyros phosphate. This is shaken for 16 hours with 50 circular rotations per minute. The sample is then set aside for 2 days to control whether it has dispersed; if not, more 0.002 M sodium pyros phosphate is added. However, 2 l is the maximum, in order not to get too thin a solution for the sedimentation analysis. If the sample still flocculates, the concentration is raised to 0.004 M sodium pyros phosphate. This may not always be able to prevent flocculation. If it does not, the clear liquid over the flocculating material is removed, and once again 0.004 M sodium pyros phosphate is added. Then, through decantation, the sample is divided into sieve fraction $d > 50\ \mu$ and sedimentation fraction $d < 50\ \mu$, using a 20 cm sedimentation height during a period of 80 seconds. According to Stoke's Law this will give approx. 50 μ dependent on particle density and actual temperature. The sample > 50 μ is rinsed with distilled water, dried at 110 °C, weighed and then left in the laboratory for some days to absorb water from the air. Thereafter, it is again weighed and sieved. The following sieve sizes are used: 2.0, 1.0, 0.5, 0.25, 0.125, and 0.063 mm. The sedimentation analysis is made by means of an "Andreasen" pipette (*Andreasen,* 1939). Samples are taken out after 0, 5, 15, 45, 150, 1440, and 2880 minutes, corresponding to a sample $\geqq$ 50 μ, 24 μ, 14 μ, 8 μ, 4 μ, 1.4 μ, and 1 μ equivalent diameter, varying with particle density and temperature. The results are calculated on the basis of the initial sample less organic matter ($C\ \% \cdot 100/58$) and the fraction > 2 mm, and are indicated in relation to the fraction < 2 mm.

Hygroscopic water is determined on a 15 g sample, air-dried over night (16 hours) at 110 °C, and indicated in relation to the weight at 110°.

Loss on ignition is determined on a sample of 5 g, dried at 110°, and stated in percentage of the weight at 110°.

Organic matter ($C\ \% \cdot 100/58$) is determined at dry combustion according to the Ter Meulen-Heslinger method (*Spilhost,* 1933); C is stated in percentage of air-dried matter.

The figures in table 3 indicating the bound water have been arrived at by subtracting organic matter and CO_2 from the loss on ignition.

Calcium carbonate is measured with a Scheibler instrument. A sample of 5 g is treated with 10 % hydrochloric acid and the volume of the developed CO_2 is measured and indicated as the equivalent quantity of $CaCO_3$ in percentage of air-dried matter. Pure $CaCO_3$ is used as standard (*Kjær,* 1969).

Determination of particle density with a pycnometer is carried out on an untreated sample, dried at 110°, and on a sample treated with H_2O_2 and then dried at 110°. The pH-value is measured on a 1:1 soil-H_2O and on a 1:1 soil-N KCl solution. A pH-meter with glass electrode is used.

Soil Description

Several profiles were dug out and the horizon boundaries measured on the basis of differences in colour and consistency. Samples were taken for laboratory analysis. The description of structure is not complete as it was difficult to discern differences in the structure, with the exception of the upper few centimetres, because the soil was wet during the whole period of field work. (See pp. 100-107)

Table 3. Particle size distribution.

% > d

sample no. \ d mm	2,00 [2]	1,00	0,50	0,25	0,125	0,063	0,05 [3]	0,024	0,014	0,008	0,004	0,0014	0,0010
1 a	40,0	36,3	70,6	78,1	81,1	81,2	82,6	82,8	83,2	83,7	84,3	88,6	90,4
1 b	31,0	38,6	69,1	75,9		78,7	79,1	79,6	80,1	80,3	81,0	85,4 [1]	87,1 [1]
1 c	10,8	27,5	58,8	65,9	68,8	69,8	71,2	73,6	76,5	80,0	83,5	89,1 [1]	90,5 [1]
1 d	2,5	28,1	59,9	69,5	72,6	73,6	74,0		74,2	74,5	75,3	78,7 [1]	80,2 [1]
3 a	22,3	26,1	39,4	42,4	44,2	45,1	45,6	45,7	46,9	49,8	58,2	81,2 [1]	85,4 [1]
3 c	9,3	14,5	23,7	26,3	28,0	28,7	29,2	29,9	31,8	36,6	44,4	61,5 [1]	64,8 [1]
4 a	0,7	1,6		6,2		10,4	11,7	19,1	26,9	34,8	49,8	74,1	78,8
4 b	0,0	0,1		1,4		3,2	3,9	5,4	10,4	14,2	20,8	37,3	41,2
4 c	0,0						1,2	3,2	5,1	7,2	10,2	18,0	20,4
5 a	0,7	1,8	3,8		7,5		11,0	23,3	33,2	50,4	65,6	80,4	88,9
5 b	3,5	3,0	9,3	17,6	23,6	28,4	32,2	46,2	65,6	82,8	89,8	95,3	95,9
7 a	1,5	5,6		12,4		18,1	20,4	24,8	30,6	39,0	49,5	68,6	72,7
7 b	1,7	5,7	9,6	12,0	16,0	20,0	22,4	32,3	41,3	53,2	64,5	81,7 [1]	92,5 [1]
7 c	0,0	0,1		2,0		8,3	10,0	17,6	22,8	27,9	33,1	43,7	46,5
9 a	0,0	2,9	5,9	8,4	11,3	14,6	16,4		22,9	26,7	36,4	51,4	57,2
9 c	0,0		0,0	0,3	3,0	8,7	10,7	18,8	27,4	35,5	37,8	48,8	49,9
10 a	5,9	16,5	29,0	34,0	37,6	41,1	42,8	49,3	52,1	56,8	63,8	74,7	79,3
10 b	9,5	19,3	30,3	35,2	37,3	39,9	41,3	47,6	55,3	64,5	69,7	74,6	76,9
10 c	13,4	16,6	24,1	26,4	27,7	29,0	30,0	40,2	46,5	51,8	55,8	59,7	60,0
11 a	19,9	41,2	55,5	59,8	62,1	63,4	64,1	69,4	70,5	74,4	75,7	78,5	80,8
11 b	11,8	40,4	56,8	60,6	62,3	63,0	63,7	66,5	69,6	75,2	76,5	79,8	80,5
11 c	3,0	41,8	72,5	77,8	79,2	79,7	80,2	80,8	81,8	82,5	84,1	85,0	85,3

1) d here 0.0013 and 0.0009 mm on account of a higher temperature during the sedimentation.
d her 0.0013 og 0.0009 mm på grund af en højere temperatur under sedimentationen.

2) values stated in per cent of the fraction < 2 mm cf. text.
værdier angivet i % af fraktionen < 2 mm jfr. tekst.

3) the values variate between 0.046 and 0.050 mm because of differences in temperature and particle density during decantation.
værdierne varierer mellem 0.046 og 0.050 mm på grund af forskelle i temperatur og massefylde ved dekanteringen.

Profile 1

Local soil name: malanga 'one.
Location: 120 m north of crosspaths in Matahenua.
Topography: Flat, a greyish white rock is visible at many places and it is also commonly found as stones. Altitude: 30.8 m above sea level.
Vegetation: Pandanus grove, trees about 5 m tall, hardly any bottom vegetation.

O 1 Slightly developed, mainly pandanus leaves.

A 1 0 to 35-70 cm gravelly, coarse sandy loam, seemingly made up of two parts, 1) silt and clay fraction, very dark brown (10YR 2/2), dry, gradually changes to dark brown (10YR 4/3), dry, for 40 cm, moderate medium granular structure. 2) light oolitic sand, the light color partly concealed by the fine fraction; few white grains that effervesce vigorously in diluted hydrochlorid acid. The roots are strongly developed at 0-15 cm. Abrupt waved to irregular boundary.

C 1 From 35-70 to 58- ? light yellowish brown (10YR 6/4), dry, sandy-clay loam, structureless single grain.

C 2 5-10 cm thick layer which forms the link to the limestone; very pale brown (10YR 8/4), dry, coarse sandy loam, structureless, single grain; contains more white fragments from the subjacent limestone than C 1, size of these up to 5 cm.

R White limestone with an outer soft weathering crust of 0.5-1.0 cm.

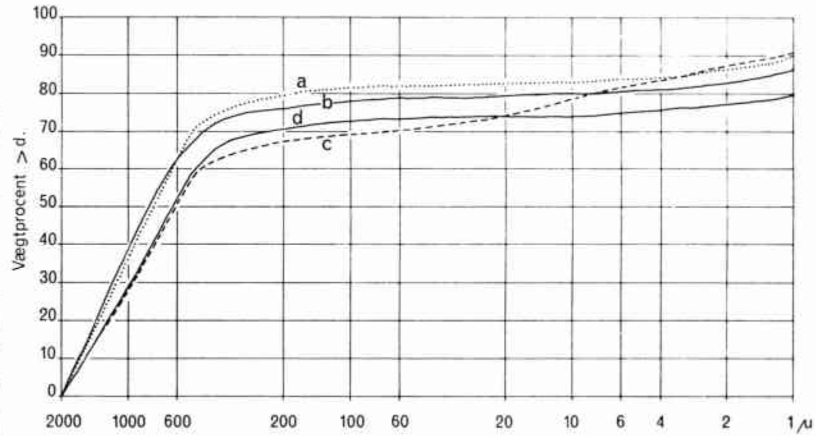


Fig. 2. Particle size distribution. Ordinate: weight % > d.
Fig. 2. Fordeling af partikelstørrelser.

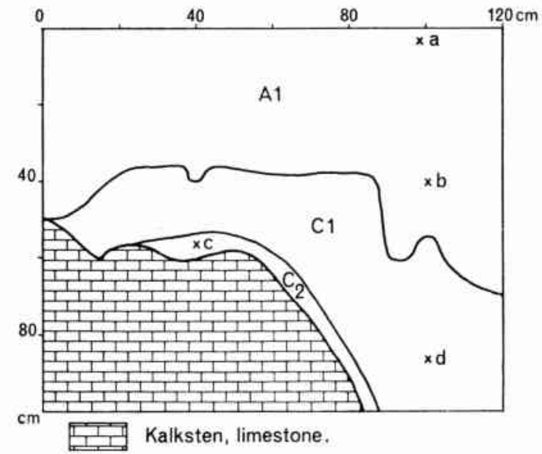


Fig. 3. Soil profile No. 1. a, b, c. and d: location of analysed soil samples, cf. tables 3 and 4.
Fig. 3. Jordbundsprofil nr. 1. a, b, c, og d markerer hvor de behandlede prøver er udtaget, jfr. tabel 3 og 4.

Profile 3

Local soil name: hingo hingo.
Location: 500 m NNE of the church in Ngotokanaba.
Topography: Slope of 6 % towards south. Rocks on the surface. Altitude: 29.8 m above sea level.
Vegetation: Yam field.

O 1 Non-existent as the field is cultivated.

A 1 0 to max. 48 cm, see fig. Very dark greyish brown (10YR 3/2), dry, loam, friable, slightly sticky, non to slightly plastic. The texture, composed by dark finely grained material and an oolitic light sand fraction, gradually changes to more irregularly formed gravel that does not effervesce in hydrochlorid acid. In the southern part of the profile (0-120 cm) A 1 is direct on the limestone. Abrupt irregular boundary.

A 12 22-45 to 39-51, 3 to 15 cm deep horizon; dark yellowish brown (10YR 4/4) dry, friable, slightly sticky, non to slightly plastic. Abrupt wavy boundary.

C 39-51 to 80 cm on the deep part of the profile, yellowish brown (10YR 5/6) dry, clay. Otherwise as A 12.

R The surface of the limestone is very irregular with holes ranging to 50 cm deep and 15-40 cm in diameter; the surface is hard with no intermediate zone between rock and the soil.

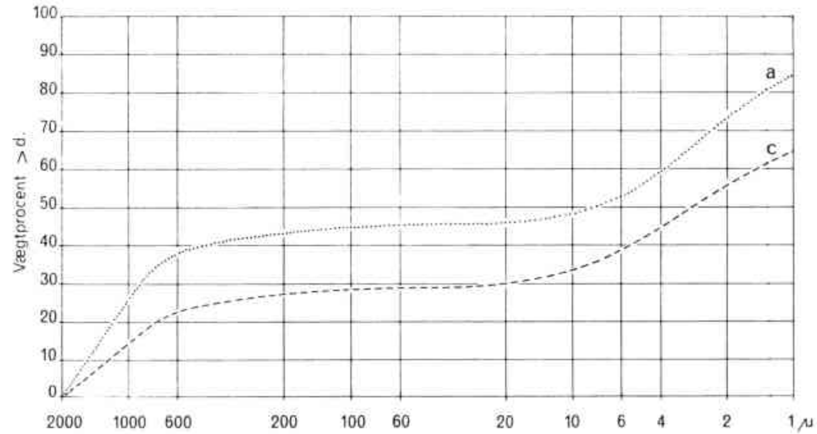


Fig. 4. Particle size distribution. Ordinate: weight % > d.
Fig. 4. Fordeling af partikelstørrelser.

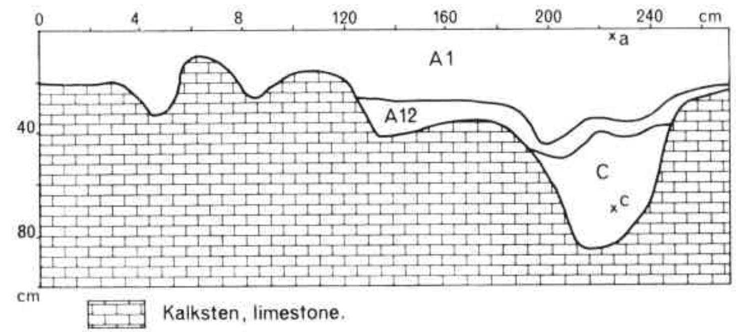


Fig. 5. Soil profile No. 3. a and c: location of analysed soil samples, cf. tables 3 and 4.
Fig. 5. Jordbundsprofil nr. 3. a og c markerer hvor de behandlede prøver er udtaget, jfr. tab. 3 og 4.

Profile 4

Local soil name: kenge toaha.
Location: 120 m south of the church in Pauta.
Topography: Slightly sloping, slopes 2 % towards north. No rocks on the surface. Altitude: 11.8 m above sea level.
Vegetation: Mixture of sweet potatoes and grass.

O 1 Mixed with grass vegetation and little developed.

A 1 0 to 18-40; very dark brown (10YR 2/2), dry, silty clay loam; moderate medium granular structure 0-3 cm; friable, slightly sticky, non to slightly plastic. The colour is homogeneous apart from red grains in the sand fraction. Clear irregular boundary.

A 12 18-40 to 48-70 cm; very dark greyish brown (10YR 3/2), dry, with some few distinct coarse mottles with a colour like that of C (10YR 5/6) in the lower part; clay; firm; slightly sticky, non to slightly plastic; abrupt irregular boundary.

B ? 60-62 (red, moist), when dry varying from dark red (2, 5YR 3/6) to pale red (5YR 8/3).

C 48-78 to ?, yellowish brown (10YR 5/6), dry; a few faint coarse mottles with colour as A 12 (10YR 3/2); clay; firm; slightly sticky, non to slightly plastic.

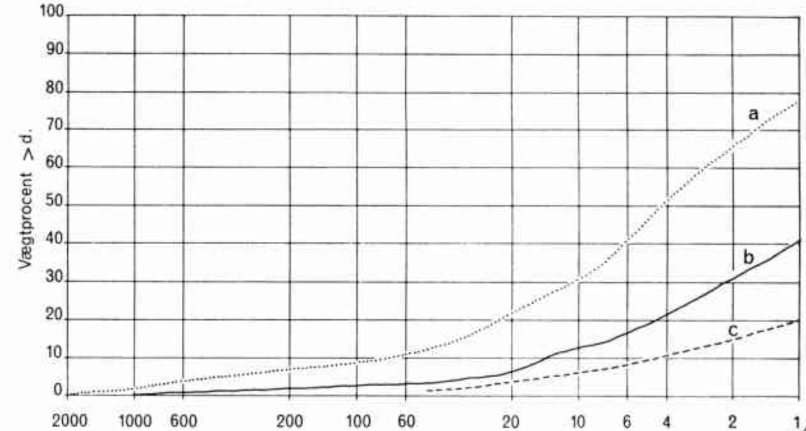


Fig. 6. Particle size distribution. Ordinate: weight % > d.
Fig. 6. Fordeling af partikelstørrelser.

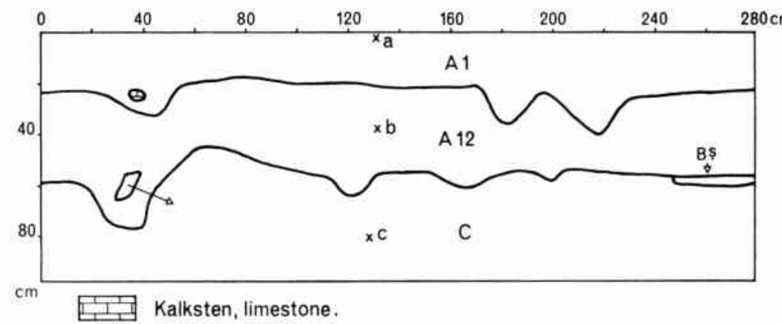


Fig. 7. Soil profile No. 4. a, b, and c: location of analysed soil samples, cf. tables 3 and 4.
Fig. 7. Jordbundsprofil nr. 4. a, b og c markerer hvor de behandlede prøver er udtaget, jfr. tab. 3 og 4.

Profile 5

Local soil name: tanahu.
Location: 250 m southeast of the church in Ngongona.
Topography: Flat. Altitude: 14.7 m above sea level.
Vegetation: Low fallow, mixture of fern and Hibiscus sp.

O 1 3-4 cm thick layer of twiglets and leaves.

A 1 0 to 20-35 cm, dark brown (10YR 3/3), silt loam, dry; weak fine to medium granular structure; firm, non to slightly sticky; non to slightly plastic; the sand fraction contains white and red grains, the white ones effervesce in diluted hydrochloric acid, destinct wavy boundary.

C 20-35 to 22-55 cm, very pale brown (10YR 7/4), dry, silt loam; loose single grained structure, the white colour of the sand fraction and the gravel fraction is hidden by the fine fraction, effervesces very vigorously in diluted hydrochloric acid.

R From 22-25 cm, white porous rock, effervescing very vigorously in diluted hydrochloric acid.

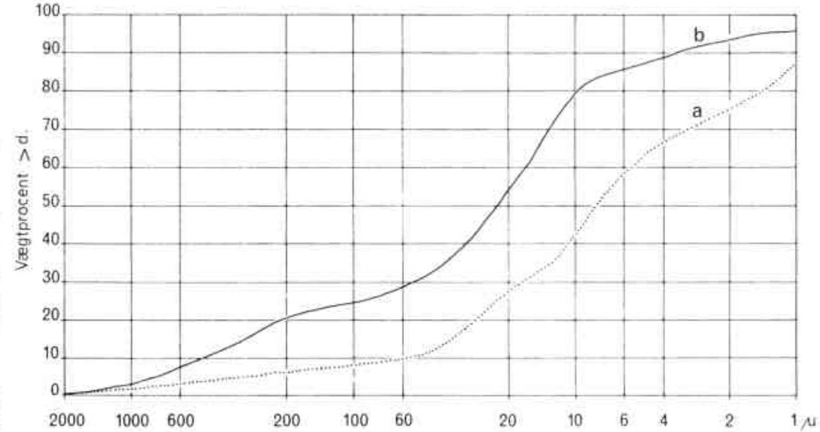


Fig. 8. Particle size distribution. Ordinate: weight % > d.
Fig. 8. Fordeling af partikelstørrelser.

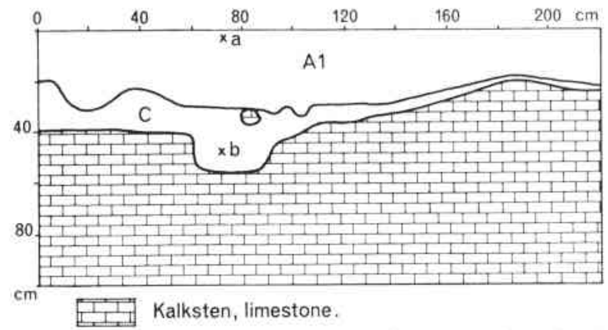


Fig. 9. Soil profile No. 5. a and b: location of analysed soil samples, cf. tables 3 and 4.
*Fig. 9. Jordbundsprofil nr. 5. a og **b** markerer hvor de behandlede prøver er udtaget, jfr. tab. 3 og 4.*

Profile 7

Local soil name: kenge toaha.
Location: 300 m NNW of the church in Ngongona.
Topography: Slightly sloping 3 % towards south. Altitude: 13.8 m above sea level.
Vegetation: Fallow.

O 1 2-0 cm leaves and twiglets.

A 1 0 to 20-32 cm; dark brown (10YR 3/3, dry; silty clay loam; 0-3 cm moderate medium granular structure, friable; slightly sticky, slightly to non plastic; clear wavy boundary.

A 12 20-32 to 54-83 cm; dark yellowish brown (10YR 4/4), dry; silt loam; firm, slightly sticky; slightly to non plastic; abrupt wavy boundary.

C 45-83 to ?; yellowish brown (10YR 5/6), dry, few coarse faint mottles with color as A 12; clay.

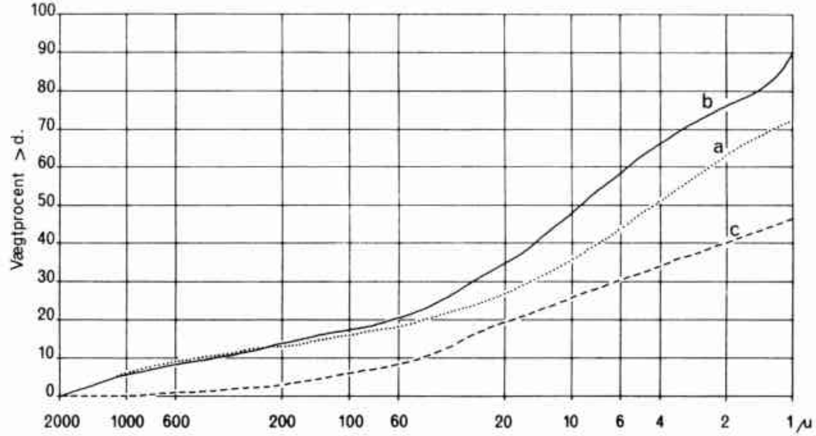


Fig. 10. Particle size distribution. Ordinate: weight % > d.
Fig. 10. Fordeling af partikelstørrelser.

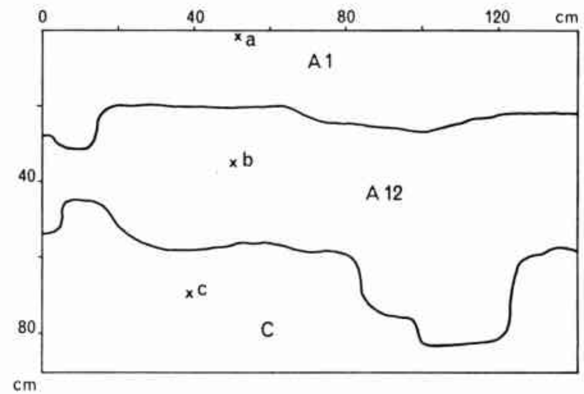


Fig. 11. Soil profile No. 7. a, b, and c: location of analysed soil samples, cf. tables 3 and 4.
Fig. 11. Jordbundsprofil nr. 7. a, b og c markerer hvor de behandlede prøver er udtaget, jfr. tab. 3 og 4.

Profile 9

Local soil name: kenge toaha.
Location: 650 m NE of the church in Ghongau.
Topography: Slightly sloping 3 % towards south. Rocks on the surface. Altitude: 33.3 m above sea level.
Vegetation: Well developed yam.

O 1 Missing, as the field is cleared and burnt off before cultivating.

A 1 0 to 20-42 cm; very dark greyish brown (10YR 3/2), dry; clay; 0-3 cm moderate medium granular structure, contains charcoal; friable to firm, slightly sticky, non to slightly plastic; white hard rock appears as blocks in the whole profile with no intermediate zone to A 1; distinct wavy boundary.

C From 20-42; irregular demarcated downwards, goes into larger pockets in R; yellowish brown (10YR 5/8), dry; clay; firm, slightly sticky, non to slightly plastic.

R 42 cm, white limestone, very irregular surface.

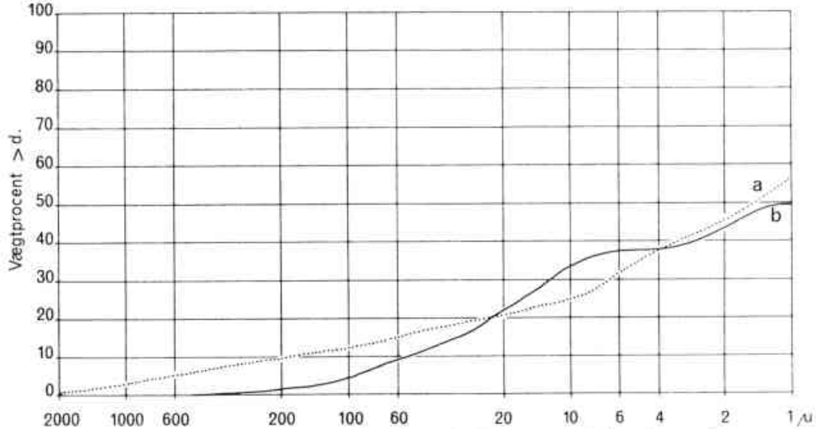


Fig. 12. Particle size distribution. Ordinate: weight % > d.
Fig. 12. Fordeling af partikelstørrelser.

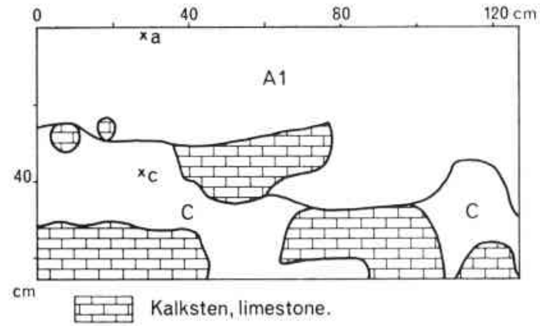


Fig. 13. Soil profile No. 9. a and c: location of analysed soil samples, cf. tables 3 and 4.
Fig. 13. Jordbundsprofil nr. 9. a og c markerer hvor de behandlede prøver er udtaget, jfr. tab. 3 og 4.

Profile 10

Local soil name: malanga 'one.
Location: 430 m WNW of the church in Matangi.
Topography: Flat. Altitude: 42.8 m above sea level.
Vegetation: Bush fallow, 2 years old.

A 1 0 to 18-28 cm, very dark brown (10YR 2/2), dry, clay loam, weak medium granular structure, friable, non sticky, non to slightly plastic. Clear wavy boundary.

A 12 18-28 to 28-35 is missing on the east side of the profile where A continues directly into R. Dark yellowish brown (10YR 4/4), dry, clay loam to loam, friable, non sticky, slightly plastic. Clear wavy boundary.

C 28 to ? missing in the eastern side of the profile where A 1 continues directly into R; yellowish brown (10YR 5/8), dry, friable, non sticky, non to slightly plastic.

R 30-, limestone, very irregular surface; in the eastern side of the profile the limestone starts at 30 cm, in the western side deeper than 90 cm.

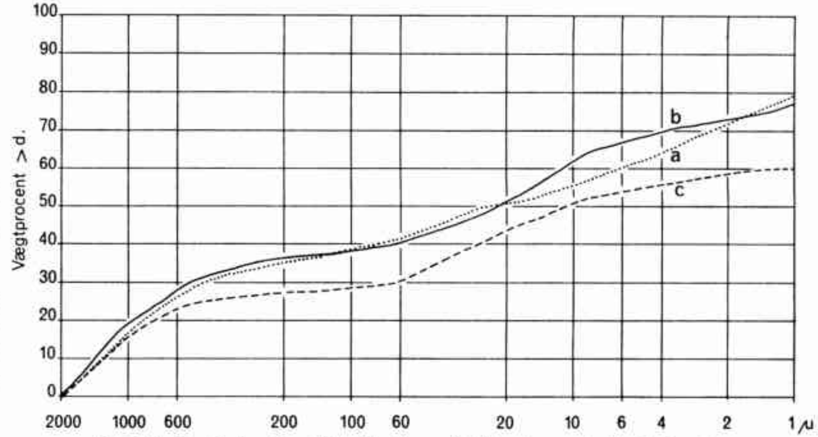


Fig. 14. Particle size distribution. Ordinate: weight % > d.
Fig. 14. Fordeling af partikelstørrelser.

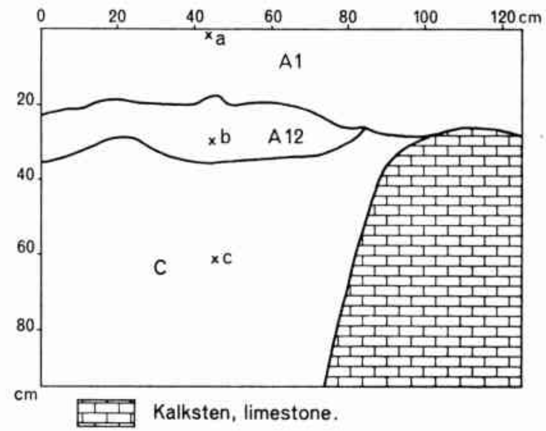


Fig. 15. Soil profile No. 10. a, b, and c: location of analysed soil samples, cf. tables 3 and 4.
Fig. 15. Jordbundsprofil nr. 10. a, b og c markerer hvor de behandlede prøver er udtaget, jfr. tab. 3 og 4.

Profile 11

Local soil name: malanga 'one.

Location: 500 m ESE of the crosspath in Matahenua.

Topography: Flat, a greyish white rock is visible and is also commonly found as stones. Altitude: 28.5 m above sea level.

Vegetation: 5 m tall coconut palms, beginning to bear nuts.

O 1 Not described.

A 1 0 to 60 cm; dark brown (10YR 3/3), dry, sandy clay loam with large contents of gravel, very coarse and coarse sand (see fig. 16 and table 3). Changes to dark greyish brown (10YR 3/2), dry, at 45 cm depth; charcoal in the surface; single grains mixed with moderate fine to medium granular structure; friable; slightly sticky; non to slightly plastic.

The lighter colours of the sand and gravel fraction are hidden by the fine fraction.

C 60 to ?; yellowish brown (10YR 5/4), dry, coarse sandy loam; texture dominated by oolitic sand fraction. Structureless single grains; containing a few white grains that effervesce with diluted hydrochloric acid.

The profile has stones of limestone at 45 and 80 cm.

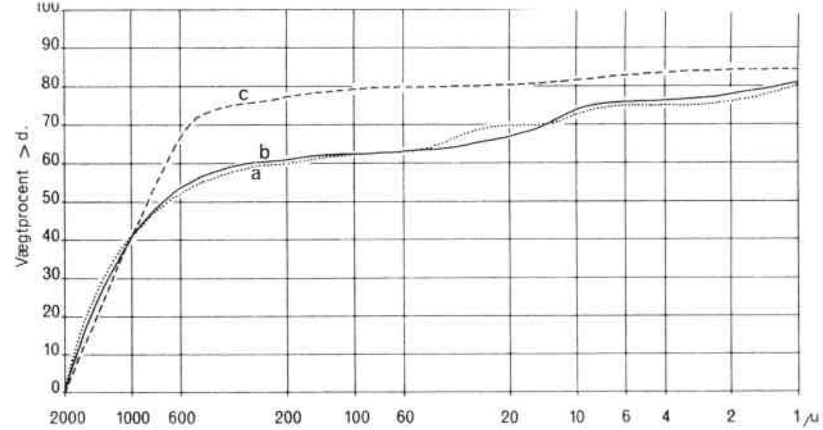


Fig. 16. Particle size distribution. Ordinate: weight % > d.

Fig. 16. Fordeling af partikelstørrelser.

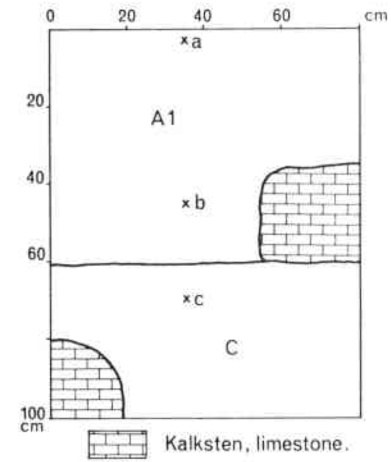


Fig. 17. Soil profile No. 11. a, b, and c: location of analysed soil samples, cf. tables 3 and 4.

Fig. 17. Jordbundsprofil nr. 11. a, b og c markerer hvor de behandlede prøver er udtaget, jfr. tab. 3 og 4.

Fig. 18. The well-developed granular structure characteristic of the upper part of the A.1-horison. The matchbox is 5 cm.

Fig. 18. Den veludviklede granulære struktur, som er karakteristisk for den øverste del af A.1-horisonten. Tændstikæsken er 5 cm lang.

Discussion

All the profiles analysed have a stable granular structure in the upper centimetres (fig. 18). In the more finely textured profiles, the consistency changes from friable in the A.1-horizon to firm in the A.12- and the C-horizon. Both stickiness and plasticity are low.

In the A.1-horizon the colour is very dark and lies low in value and chroma, viz. dark brown 10YR 3/3 and very dark brown 10YR 2/2. In the C-horizon the colour is yellowish brown 10YR 5/6-5/8 except where the content of calcium carbonate is high enough to give the colour a pale shade.

For most of the profiles the depth is small, only for profiles 4 and 7 was no limestone found within the first metre and, furthermore, the limestone surface was irregularly developed. This is in accordance with the report by *White and Warin* (1965), who performed a great number of borings down to the limestone surface in their investigations of the phosphate deposits.

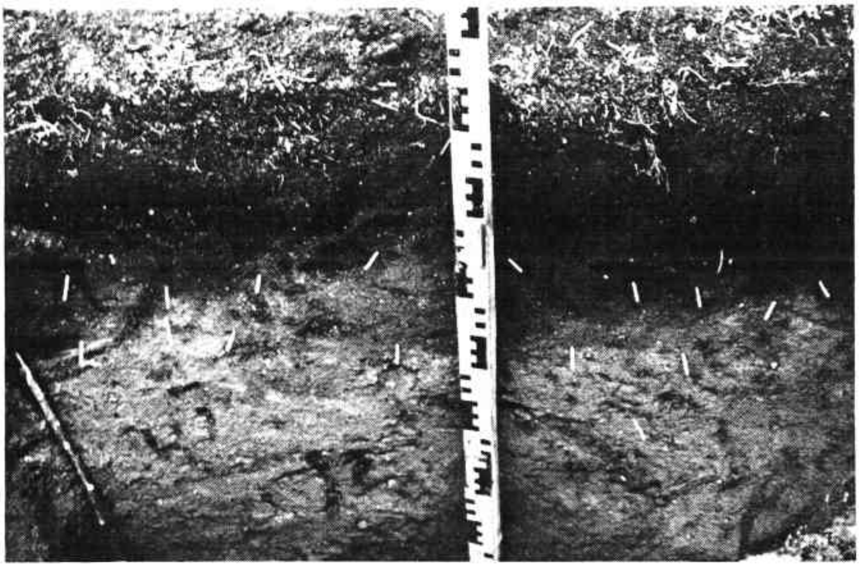


Fig. 19. Profile 10. The matches demarcate the developed horizons indicated in fig. 15. The limestone shows in the lower, right corner. Graduation of yardstick in centimetres and decimetres.

Fig. 19. Profil 10. Tændstikkerne viser grænserne mellem de udviklede horisonter vist i fig. 15. Kalkstenen ses i nedre højre hjørne. Målestok-inddeling: cm og dm.

Texture

The texture of the profiles analysed here can be divided into three groups, cf. texture diagram (fig. 20). The samples of profiles 1 and 11 were taken in the area of sandy loam and sandy clay loam. As table 3 shows in detail, the texture is gravelly coarse sandy loam in the A.1 horizon, all samples containing more than 60 % coarse and very coarse sand, and the content of gravel diminishes downwards.

Profiles 3 and 10 have a clay loam and loam texture with more than 40 % coarse and very coarse sand in the A.1-horizon, whereas the C-horizon is clay with a high content of coarse and very coarse sand. The gravel content diminishes downwards in profile 3, but increases in profile 10.

A high content of silt and clay characterizes profiles 4, 5, 7, and 9. Profile 5 has a very high content of silt, the A-horizon 65 % and the C-horizon 63 %. The sand and gravel of the latter are mixed with limestone fractions. For the other profiles the clay content increases downwards.

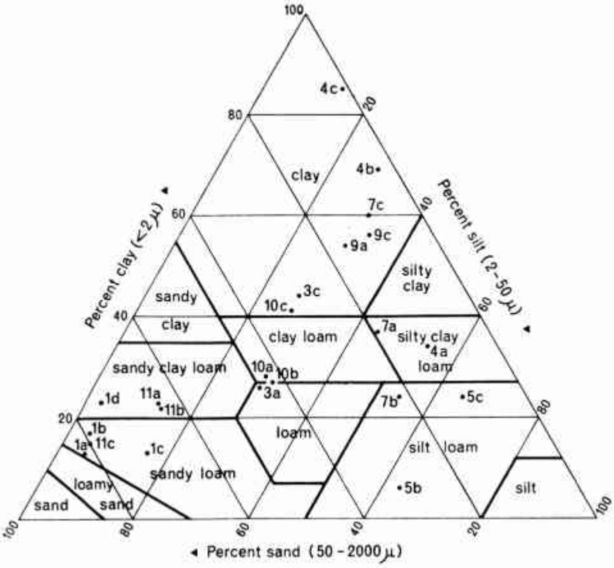


Fig. 20. The values of the diagram were found by transferring the figures from table 3 to semi-logarithmic graph paper and read the values corresponding to 0.050 mm and 0.002 mm.

Fig. 20. Værdierne brugt i diagrammet er fremkommet ved at afsætte tallene fra tabel 3 på semilogaritmisk papir og aflæse værdierne svarende til 0,050 mm og 0,002 mm.

Other data analysed in the laboratory

The bulk densities of the samples fall into two groups. Profile 11 shows high values > 1 g/cm³, and this presumably applies to profile 1 also, as the two correspond in all other characteristics. For the remaining profiles, the bulk density is < 1 g/cm³, being lowest for profile 5 with 0.38 g/cm³; whilst the others lie between 0.45 and 0.81 g/mc³. The variations cannot be explained satisfactorily on the basis of the present investigations.

For all samples, particle density is high, which is due to the fact that the inorganic part of the Bellona soil does not contain the silicium-bearing minerals that normally constitute the main part of the soil.

Because the variation in particle density is small compared with the variation in bulk density, the porosity values follow those for bulk density. The high porosity in connection with the well developed granular structure in the top soil explains the observation made during the field work that even great amounts of precipitation disappeared rapidly from the surface, and this agrees well with the fact that the island has no ponds or rivulets.

The content of calcium carbonate varies between the profiles, Profile 5 has more than 8 % left in the upper 0-15 cm. The more than 90 % in the transitional zone (sample 5 b) between A 1 and limestone indicate that the limestone has a very high content of

Table 4.

sample No.	depth cm.	bulk density g/cm³	pore vol.%	hygroscopic water vol.%	org. matter weight % = C % · 100/58	water vol.% at sampling time	chem. bound water weight %	particle density g/cm³	oxid. particle density g/cm³	$CaCO_3$ equiv. % of air dry weight[3])		loss on ignition % of 110° weight	pH 1:1 H_2O	pH 1:1 N KCl
1 a	0–10				5.0		4.3	2.92	3.03	3.5	3.6	10.9	6.9	6.5
1 b	40				1.6		4.6	3.05	3.04	3.7	3.3	7.7	6.9	6.6
1 c	55				1.[1])		4.1	2.99	3.00	18.3	18.3	13.1	7.9	7.8
1 d	90				0.7		5.3	3.05	3.04	3.5	3.6	7.6	6.9	6.7
3 a	0–15	0.678	75.5	3.19	10.5	30.6	11.5	2.78	2.97	1.8	1.8	22.8	6.9	6.6
3 c	68–73	0.636	78.4	1.90	2.1	21.9	12.0	2.96	3.00	2.1	2.1	15.0	6.8	6.5
4 a	0–15	0.456	83.3	4.48	12.0	32.4	15.7	2.75	2.87	0.3		27.8	6.8	6.1
4 b	37–42	0.859	69.7	5.26	4.3	46.4	15.9	2.84	2.89	0.1	0.1	20.2	6.8	6.3
4 f	58–63	0.809	71.8	4.53		38.7		2.87		0.1	0.2			
4 c	79–84	0.683	76.3	3.85	1.6	38.3	17.0	2.87				18.7	6.8	6.5
4 g	71–76	0.696	75.7	2.97		38.7		2.88						
5 a	0–15	0.375	85.2	3.02	18.6	30.6	12.3	2.55 2.57[3])	2.89	8.2	8.5	34.6	7.6	7.1
5 b	45–50				0.9[2])		3.6	2.84	2.86	91.0	91.7	44.7	8.0	7.8
7 a	0–15	0.586	79.0	3.02	8.9	31.5	15.2	2.81	2.99	0.1	0.2	24.2	6.9	6.4
7 b	33–38	0.540	81.8	1.75	3.0	24.1	15.7	2.97	3.02	0.2	0.2	18.8	6.8	6.3
7 c	68–73	0.623	79.2	1.74	3.0	31.3	15.6	2.98	3.00	0.2	0.2	18.7	7.0	
9 a	0–15	0.542	80.1	3.14	12.1	30.4	16.5	2.71	2.88	0.1	0.1	28.6	7.0	6.5
9 c	30–35				3.0		16.8	2.90	2.96	0.2	0.2	19.9	7.7	7.4
10 a	0–15	0.729	73.8	3.06	10.2		11.3	2.78	2.91	1.8	2.0	22.3	7.0	6.5
10 b	27–32	0.773	73.8	2.13	4.6		9.8	2.93	3.00	1.8	1.8	15.2	6.9	6.7
10 c	58–63				2.0		12.0	3.03		2.0	2.0	14.9	6.9	6.5
11 a	0–15	1.041	64.1	3.51	6.1		7.8	2.90	3.05	3.4	3.5	15.4	7.1	6.7
11 b	42–47	1.307	55.9	3.35	3.2		6.4	2.97	3.05	4.1	4.3	11.4	7.8	7.4
11 c	68–73	1.441	52.9	2.39	1.6		5.1	3.06	3.06	5.0	5.2	8.9	7.7	7.4

[1]) estimated value. [2]) found by oxidizing with H_2O_2. [3]) two determinations.

calcium carbonate. Profiles 1 and 11 contain between 3 and 5 % calcium carbonate. Sample 1 c containing 18 % was taken in the transition zone between soil and limestone, where a higher value was to be expected. The great difference in values found for samples 5 b and 1 c can be explained by the location of profile 1 in an area with oolitic phosphate (*White and Warin,* 1965) cf. fig. 1, whereas profile 5 lies outside the phosphate-bearing areas.

Profiles 3 and 10 have almost 2 % calcium carbonate left. Profiles 4-7 and 9 have a very low content of calcium carbonate, less than 0.5 %.

It is remarkable that, apart from the weathering zones in profiles 1 and 5, there is no differentiation down through the profiles. The explanation must be that the soil is very porous and therefore highly permeable with the result that the calcium carbonate is removed at the same rate everywhere in the profile.

The pH-value measured in H_2O is neutral to mildly alkaline with the exception of the strongly carbonate-bearing samples 1 c and 5 b which are moderately alkaline. Apart from these and profile 11, the pH-values for the profiles show little variation as was the case for the content of calcium carbonate.

The slight differences in pH measured in H_2O and N KCl must be explained by their low cation exchange capacity, which is due to the fact that the soil contains no clay minerals.

The content of bound water, i.e. loss on ignition minus CO_2 and organic matter, falls into the same groups as the content of calcium carbonate. Profiles 1 and 11 have low percentages of bound water, 3 and 9 lie between 10 and 12 %, 4, 7, and 9 show a relatively high content of bound water, namely 15-17 %. As in profile 5 the great difference between sample a and b (12.3 and 3.6 %) can be explained by the lack of bound water in the calcium carbonate.

Conclusion

The most important characteristics of the profiles analysed appear from table 5. Profiles 1 and 11 (from the terrace), developed at a shallow depth, have a coarse sandy texture and, because of this and the weakly developed structure, a high bulk density. The content of bound water is low, as is the content of clay, and there is still some carbonate. Profiles 4, 5, and 7, located in the old lagoon floor, fall into two groups depending on the occurence of phosphatic clay. Profiles 4 and 7 lie in an area containing phosphatic clay and are characterized by a low bulk density, fine-grained texture, a high content of bound water together with a high content of silt and clay. They have a very low carbonate content and the profiles have a deep development. Profile 5 lies outside the areas with phosphatic clay and has developed on carbonate-bearing limestone, which must account for the very shallow depth of the profile and the fact that it still contains much carbonate. The very high content of organic matter must have resulted in the low bulk density.

Table 5. Profile characteristics.

Profile No.	Bulk density	Texture	Content of bound water	Content of calcium carbonate	Profile depth	Location
1	High	Coarse	Low	Some	Shallow	Terrace
3	Low	Moderate coarse	High	Low	Shallow	Slope
4	Low	Fine	Very high	Very low	Deep	Old lagoon floor
5	Very low	Fine	High	High	Very shallow	Old lagoon floor
7	Low	Fine	Very high	Very low	Deep	Old lagoon floor
9	Low	Fine	Very high	Very low	Shallow	Slope
10	Low	Moderate coarse	High	Low	Shallow	Slope
11	High	Coarse	Low	Some	Shallow	Terrace

Profiles 3, 9, and 10, taken from the slopes, are developed only to shallow depths and have a low bulk density. In 3 and 10 the texture is characterised by its content of oolitic sand and these profiles still contain some carbonate. The high content of bound water indicates that the silt and clay fraction has the same composition as that determined for profiles 4 and 7. Profile 9 resembles profiles 4 and 7 apart from the mentioned shallow profile depth, although it is located outside the areas with phosphate, indicated by White and Warin (fig. 1).

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