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The Soils on the Krakatau Islands

II. Particle Size Distribution and Chemical Properties of the Soils

Akio SHINAGAWA, Nobufumi MIYAUCHI, Teruo HIGASHI,
Muhamad Rahman DJUWANSAH* and Achmad SULE*
(*Laboratory of Soil Science*)
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Introduction

As described in Part I in this series, on the Krakatau Islands, the eight different layers were present in the 1 m depth from the surface. Stratification of respective layer is fairy analogous on Sertung and on Rakata Kecil.

The objectives of this paper are to study the physical and chemical properties of respective layer on four islands, then to elucidate the degree of soil formation process.

Hereafter, Rakata Besar, Sertung, Rakata Kecil and Anak Krakatau are designated as Be, St, Ke and An, respectively, and the soils derived from ejecta after 1927 are designated as the soils after 1927 likewise on the case of Part I.

Experimental methods

1. Physical analysis

Particle-size analysis of fine earth (<2 mm) was done using usual sieving and sedimentation method after the decomposition of soil organic matter with H_2O_2[10-a].

Bulk density and porosity of fresh soil on Be were measured by actual volumenometer (DIK–100 type), these soils were taken with 100 ml soil sampling tube.

2. Routine chemical analysis of fine earth (<2 mm)

Total carbon was determined by wet oxidation with potassium dichromate at about 180°C for 10 min. in oil bath[3]. Total nitrogen was determined by Semimicro Kjeldahl method[10-b].

pH was measured in water and in N–KCl with soil/solution ratio of 1/2.5.

Extractable acidity was measured and calculated using $BaCl_2$-triethanolamine[10-c]. Values of exchange acidity was obtained on N–KCl extract (soil/solution ratio of 1/2.5).

Extractable and water soluble cations (Ca, Mg, K and Na) were determined on the extracts with N–CH_3COONH_4 (pH: 7) and water, respectively, by atomic spectrophotometry.

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* National Institute of Geology and Mining (LGPN–LIPI), Bandung, Indonesia

Cation exchange capacity (CEC) determination: Harada and Inoko's method without ethanol washing[2].

pH(NaF) was measured in N–NaF with soil/solution ratio of 1/50, 2 min. after solution was added[10-d].

Phosphate absorption coefficient. According to Blakemore's method[1], 0.33-M KH_2PO_4 (pH: about 4.6). Obtained P-retention value (%) was converted to phosphate-absorption coefficient (P_2O_5 mg/100 g oven dry soil).

Results and discussions

1. Particle-size distribution and bulk density

Obtained results were shown in Appendix 1. according to USDA's laboratory data sheet[10]. Average particle-size distribution of respective layer on the four islands were shown in Table 1. In Fig. 1., average values and range of silt plus clay (less than 0.02 mm) content and clay (less than 0.002 mm) content were shown.

Although the gravel (more than 2 mm) contents varied greatly, clay and silt contents of fine earths (less than 2 mm) derived from 1883 pyroclastic flow were 6–10% and 20–30% respectively, and these values were the highest among the eight layers. Therefore, soil texture of pyroclastic flow was finest. Bulk density of the soils derived from 1883 pyroclastic flow on Be was about 0.4–0.9 (Appendix 1).

For the six layers present on St and Ke, soil texture became coarser in the following order: A_1 or A_1-like = fresh ash < brown volcanic ash < fine textured scoria < coarse textured scoria (upper) < coarse textured scoria (lower) as shown in Table 1. and Appendix 1. The texture of beach sand was coarsest in eight layers.

As stated previously (Part I.), almost all soils on Be were mainly derived from re-deposited 1883 pyroclastic flow. On Ke, the thickness of overlying deposits on pyroclastic flow was distinctly thin compared with those on St, and coarse textured scoria (lower) found on St was absent. Therefore, average soil texture of the samples from Ke was finer than that of St.

On An, fresh ejecta-fall and the truncation of deposited ejecta were occurred continuosly, consequently, the weathering and the soil formation did not advanced compard with the other three islands. Average contents of silt and clay were lowest in the four islands. But the soil texture of An–2 and An–4 which were regarded as brown volcanic ash and fine textured scoria, respectively, were similar to those present on St and Ke.

According to the laboratory data and foregoing discussions, the texture of soil samples within 1 m from the surface became coarser in the following order: Be < Ke < St < An.

2. Routine chemical properties

(1) Total carbon

As shown in Table 2. and Appendix 2., average value of total carbon of the surface soils on Be was 9.05%, but was 0.3% for the sub-soils. On St and Ke, those values for surface soils (fresh ash plus A_1 or A_1-like layer) were 1.04 and 1.54%, respectively, those of brown volcanic ash were 0.39% and 0.62%, those of coarse and fine textured scoria were 0.12 and 0.23%. On An, these values of surface soils were smallest among the four islands. Carbon content of respective layer was decreased in the following order; present surface soil derived from 1883 pyroclastic flow on Be > surface soil on Ke and St > brown volcanic ash > fine and coarse textured scoria. Carbon content of

Table 1. Average particle-size distribution of selected soil samples

Island	Legend	Samples	Gravel >2 mm %	Fine earth 2–0.25 mm %	0.25–0.02 mm %	0.02–0.002 mm %	0.002> mm %
Rakata Besar	Pyroclastic flow (gravel content less than 10%)	Be–1–1, Be–3–1, Be–3–4, 5, Be–3–5, Be–5–1, Be–7–1,	1.7	12.9	48.5	30.8	7.8
	Pyroclastic flow (Gravel content more than 10%)	Be–1–2, –1–3, –1–4, –1–5, Be–2–1, –2–2, –2–3, –2–9, Be–3–6.	25.3	37.5	29.8	24.5	8.2
Sertung	Fresh ash	St–1–1, St–3–1, St–4–1	0.1	28.6	59.8	10.7	0.9
	A_1 or A_1-like	St–1–1', St–3–2, St–4–2,	2.4	22.8	65.1	10.4	1.7
	Coarse textured scoria (upper)	St–1–2, St–3–3, St–4–3.	7.6	52.9	39.5	7.1	0.5
	Fine textured scoria	St–1–5, St–3–4, St–4–4	1.5	36.9	52.6	7.9	2.4
	Brown volcanic ash	St–3–5, St–4–5.	0.3	25.0	67.6	5.7	1.7
	Coarse textures scoria (lower)	St–3–6, St–3–7	1.7	77.2	19.6	2.9	0.3
	Buried pyroclastic flow	St–3–8, St–3–9	8.9	36.9	36.4	20.7	6.0
Rakata Kecil	Fresh ash	Ke–1–1, Ke–3–1, Ke–4–1	2.0	27.7	57.5	14.1	0.7
	A_1 or A_1-like	Ke–1–1–1, Ke–3–2, Ke–5–2,	0.2	31.3	58.4	8.4	1.9
	Coarse textured scoria	Ke–1–1–2, Ke–1–2, Ke–3–4	4.9	46.9	42.0	10.9	0.2
	Fine textured scoria	Ke–1–3,	3.7	29.1	55.0	13.5	2.4
	Brown volcanic ash	Ke–1–4, Ke–3–6, Ke–5–5	0.3	19.6	67.0	10.8	2.6
	Buried pyroclastic flow	Ke–1–5, –1–6, Ke–3–7, –3–8, Ke–5–7	10.1	28.5	38.6	24.0	8.9
Anak Krakatau	Surface soil derived from volcanic ash, scoria and rock etc.	An–1–1, An–3–1	0.5	55.2	37.4	3.9	3.5
	Sub-soil derived from volcanic ash, scoia and rock etc.	An–1–2, –1–3, An–3–3, –3–4	1.5	48.2	43.7	7.5	0.6
Beach sand		Be–6–3, St–2–3, An–1–5	0.2	81.0	19.0	0	0

same layer on Ke was larger than that of St.

In Fig. 2., the average values and ranges of total carbon was shown for the soil samples from each island. In this figure, only the samples less than 20 cm in depth from the surface are included. Moreover, for the soils on Be, topmost A_1 horizon samples were shown separately. As it is clear,

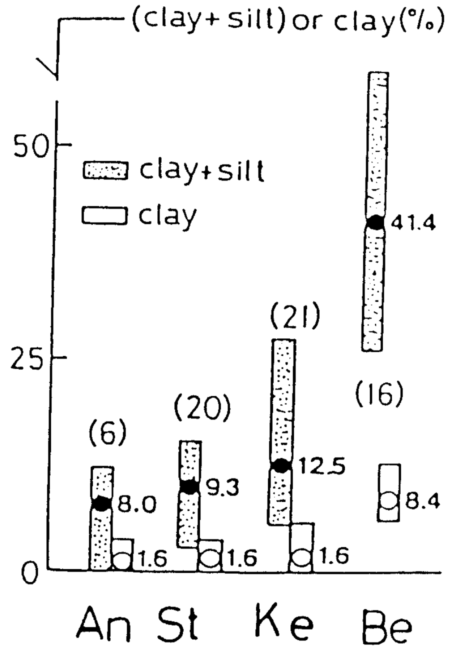

Fig. 1. Ranges and mean values of (silt+clay) and clay contents in the soils on the respective islands. Values in parenthesis are the numbers of used soil samples.

the carbon content increased in the following order; An<St<Ke<Be.

The accumulation and the composition of humus on the Krakatau soils will be discussed later (Part IV. in this series).

(2) pH and ⊿pH

Values of pH(H_2O) of used soil samples were in the range about from 6.1 to 6.8, except for two exceptions, one is more than 7.0 (Be–2–9, Be–3–6, Be–6–3, St–3–9, Ke–3–1, Ke–4–1 and Ke–4–6) and the other is less than 5.5 (An–1–1, An–3–1 and An–4).

pH(KCl) of the surface soil on the four islands was from 5.0 to 5.8, while the average values of sub-soils on Be and Ke derived from pyroclastic flow were 4.94 and 4.87, respectively. pH(KCl) mainly depends on the exchangeable Al^{3+} which is absorbed on the surfaces of soil colloids with strong acidic characteristics by negative charge. Threfore, low values of pH(KCl) suggests to the presence of crystallin clay minerals which have a strong acidic characteristics or a structures of isomorphous substitution.

Average values of ⊿pH, pH(H_2O) minus pH(KCl), of the soils derived from 1883 pyroclastic flow were 1.86 (sub-soils on Be), 1.80 (Ke), 1.56 (St) and 0.69 (surface soils on Be). Since clay content of these four soils were nearly the same, the clay minerals in the sub-soils are assumed to contain an isomorphous substitution. In general, values of ⊿pH of surface soils were smaller than those of sub-soils, this tendency probably depended on the presence of exchangeable H^+ of humus which is not extract with KCl. For the soils after 1927, average values of ⊿pH became smaller in the following order; fine textured scoria (St: 1.10, Ke: 1.37)>brown volcanic ash (St: 1.10, Ke: 1.25) >coarse textured scoria, St (upper): 1.09, St (lower): 0.70, Ke: 1.05>surface soil (St: 0.86, Ke: 0.74)>An (0.5–0.8).

(3) Acidity

Exchange acidities of the soils derived from 1883 pyroclastic flow were more than 1 me/ 100 g but those of the soils after 1927 were in the range from about 0.55 to 0.85.

Table 2. Average chemical properties of selected soil samples

(Rakata Besar)

Legend	Samples	Total carbon %	C/N	pH H$_2$O 1:2.5	pH N–KCl 1:2.5	ΔpH	Acidity Ex-change (me/100 g)	Acidity Extract-able (me/100 g)	Extract. acidity/ Ex-change acidity	Extrac-table basees (me/100 g)	Water soluble bases (me/100 g)	CEC (me/100 g)	Base satura-tion degree %	Water soluble bases/ Ext. bases %	pH NaF After 2 min.	P–sorption coef. P$_2$O$_5$ mg/100 g
Surface soil derived from pyroclastic flow (carbon content more than 4%)	Be–1–1, –1–2 Be–2–1, Be–3–1, Be–5–1, Be–7–1,	9.05	14.1	6.41	5.72	0.69	1.96	24.85	12.7	31.92	1.22	28.99	106	3.5	8.48	327
Subsoil derived from pyroclastic flow (carbon content less than 0.5%)	Be–1–4, –1–5, Be–3–4, 5 Be–3–6.	0.30		6.80	4.94	1.86	1.08	7.08	6.6	7.53	0.27			2.7	8.35	150

(Sertung)

Legend	Samples	Total carbon %	C/N	pH H$_2$O 1:2.5	pH N–KCl 1:2.5	ΔpH	Acidity Ex-change (me/100 g)	Acidity Extract-able (me/100 g)	Extract. acidity/ Ex-change acidity	Extrac-table basees (me/100 g)	Water soluble bases (me/100 g)	CEC (me/100 g)	Base satura-tion degree %	Water soluble bases/ Ext. bases %	pH NaF After 2 min.	P–sorption coef. P$_2$O$_5$ mg/100 g
Surface soil (Fresh ash, A$_1$ or A$_1$-like)	St–1–1, St–3–1, –3–2, St–4–2.	1.04	11.9	6.67	5.81	0.86	0.71	4.69	6.6	5.54	0.36	5.36	96.6	6.5	8.06	87
Coarse textured scoria (upper)	St–1–2, St–1–4, St–3–3, St–4–3.	0.13		6.91	5.82	1.09	0.60	2.50	4.2	0.95	0.13			3.7	7.87	77
Fine textured scoria	St–1–5, St–3–4, St–4–4.	0.12		6.84	5.74	1.10	0.59	2.43	4.1	0.64	0.10			15.6	7.83	56
Brown volcanic ash	St–3–5, St–4–5	0.39	12.4	6.87	5.77	1.10	0.65	4.34	6.7	3.10	0.21			6.8	8.19	223
Coarse textured scoria (lower)	St–3–6. –3–7	0.11		6.93	6.03	0.70	0.55	2.00	3.6	0.75	0.13			17.3	7.83	94
Buried pyroclastic flow	St–3–8, St–3–9.	0.14		6.97	5.41	1.56	0.38	4.06	10.7	5.78	0.21	5.27	100	3.6	7.43	144

TAble 2. Average chemical properties of selected soil samples

(Rakata Kecil)

Legend	Samples	Total carbon %	C/N	pH H_2O 1:2.5	pH N–KCl 1:2.5	⊿pH	Acidity Ex-change (me/100 g)	Acidity Extract-able (me/100 g)	Extract. acidity/ Ex-change acidity	Extrac-table basees (me/100 g)	Water soluble bases (me/100 g)	CEC (me/100 g)	Base satura-tion degree %	Water soluble bases/ Ext. bases %	pH NaF After 2 min.	P–sorption coef. P_2O_5 mg/100 g
Surface soil (Fresh ash, A_1 or A_1-like)	Ke–1–1–1 Ke–3–1, –3–2, Ke–3–3, Ke–5–2.	1.34	11.3	6.83	6.09	0.74	0.84	5.77	6.9	5.22	0.38	4.53	106.8	7.3	8.25	102
Coarse textured scoria	Ke–1–1–2, Ke–1–2, Ke–3–4,	0.23		6.47	5.42	1.05	0.73	6.45	8.8	1.10	0.13			11.8	8.67	
Fine textured scoria	Ke–1–3,	0.15		6.40	5.03	1.37	0.91	6.96	7.6	0.36	0.10			27.8	8.80	141
Brown volcanic ash	Ke–1–4, Ke–3–6, Ke–5–5.	0.62	10.9	6.47	5.22	1.25	0.72	6.80	9.4	3.34	0.27			8.1	9.00	316
Buried pyroclastic flow	Ke–1–5, –1–6, Ke–3–7, –3–8, Ke–5–7.	0.38		6.67	4.87	1.80	1.05	6.69	6.4	8.26	0.25			3.0	8.28	189

(Anak Krakatau)

Legend	Samples	Total carbon %	C/N	pH H_2O 1:2.5	pH N–KCl 1:2.5	⊿pH	Acidity Ex-change (me/100 g)	Acidity Extract-able (me/100 g)	Extract. acidity/ Ex-change acidity	Extrac-table basees (me/100 g)	Water soluble bases (me/100 g)	CEC (me/100 g)	Base satura-tion degree %	Water soluble bases/ Ext. bases %	pH NaF After 2 min.	P–sorption coef. P_2O_5 mg/100 g
Surface soil derived from volcanic ash, scoria and rock etc.	An–1–1, An–3–1	0.36		5.50	5.00	0.50	1.17	3.38	2.8	0.58	0.13	1.16	38.8	22.4	7.78	134
Sub-soil derived from volcanic ash, scoria and rock etc.	An–1–2, –1–3, An–3–3, –3–4,	0.21		6.25	5.48	0.77	0.74	1.44	1.9	0.41	0.11			26.8	7.92	135
Beach sand	An–1–5, An–3–6.	0.69		6.44	5.64	0.80	0.69	2.71	3.9	0.28	0.10	0.33	54.5	35.7	7.67	94

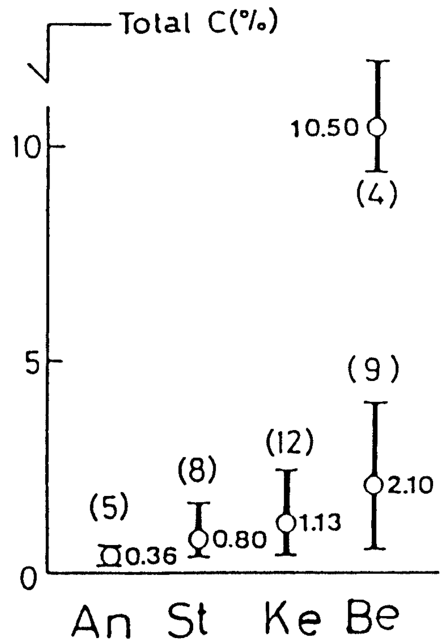

Fig. 2. Ranges and mean values of total carbon contents of the soils on the respective islands. Values in parenthesis are the numbers of used soil samples.

Average value of extractable acidity of the surface soils on Be was 24.9 me/100 g, whereas, those of buried pryroclastic flow were distinctly low (Be: 7.08, St: 4.06, Ke: 6.69). For the soils after 1927 on St and Ke, average values were from 2 to 7, and those of An were less than 3.6 except for beach sand. Extractable acidity of respective layer after 1927 on St and Ke decreased in the following order; surface soil>brown volcanic ash>coarse textured scoria, fine textured scoria. And the values of respective layer on Ke were larger than on St.

Extractable acidity mainly depends on the exchangeable Al^{3+} together with dissociable H^+ of humus and of weakly acidic inorganic colloids. As compared with the surface soils to sub-soils on Be, ΔpHs of the formers were smaller than those of the latters. On the contrary, extractable acidity/exchange acidity ratios of the formers were distinctly larger than those of the latter. These facts probably depend on the abundance of humus in the surface soils and of clay mineral which have a strong acidic character in the sub-soils.

(4) Cation exchange capacity (CEC), extractable bases, base saturation degree and water soluble bases

CEC described in the preliminary reports[8,9] were obtained according to USDA's method (5Al, p. 22)[10], ie, after the saturation with N–CH_3COONH_4 (pH: 7) and washing with 95% ethanol, then retained NH_4 is replaced and determined. For the Krakatau soils, considerable amounts of humus were dissolved in CH_3COONH_4 and ethanol, therefore, CEC values assumed to be lower than the actual ones. Accordingly, CEC described in Table 2 and Appendix 2. in this report are the values obtained by Harada and Inoko's method in which final saturation reagent is 0.05 N $Ca(CH_3COO)_2$ (pH: 7) and ethanol washing procedure are not included.

CECs were approximately proportional to the carbon and to the clay contents. Average CEC value of the surface soils on Be was 28.9 me/100 g, and this value was the largest among the used soil samples. The values of CEC of the soils derived from buried pyroclastic flow (sub-soils on Be, St-3-9, Ke-3-7 and Ke-3-8) with clay content of 6 to 9% were more than 7 me/100 g.

In respective layer in each island, CEC decreased in the following order; surface soils on St (average: 5.36) > surface soils on Ke (4.53) > brown volcanic ash on Ke (Ke–3–6: 3.88) and on St (St–3–5: 3.61) > surface soils on An > coarse and fine textured scoria on Ke and St (less than 2 me) > sub-soils on An.

In the preliminary reports[8,9], base saturation degree of almost all sample soils, excepting Be–2–3, Be–5–1 and Ke–1–1–1, were exceedingly larger than 100%. Accordingly, CEC determination[2] of representative samples and detemination of water soluble bases of all samples were carried out.

In this report, base saturation degree was showed as [CH_3COONH_4 extractable (Ca + Mg + K + Na) − water soluble (Ca + Mg + K + Na)]/CEC. As shown in Appendix 2., base saturation degrees of the soils on An were less than 62%.. On the other three islands, base saturation degree of almost all samples were about 100% or more, excepting a few samples (Be–7–2: 64.4, Ke–1–4: 67%). Detectable amount of calcium carbonate was present in the samples, especially on Be samples, pH(H_2O)s of which were more than 6.8.

Average values of sum of water soluble bases decreased in the following order; surface soils on Be (1.22 me) > surface soils on Ke (0.38), surface soils on St (0.36) > sub-soils on Be, buried pyroclastic flow on St and Ke (0.21–0.25), brown volcanic ash (Ke: 0.27, St: 0.21) > coarse and fine textured scoria on St and Ke (0.18–0.10) > Soils on An (0.13–0.10). On the contrary, water soluble bases/CH_3COONH_4 extractable bases ratio increased in the following order; surface and sub-soils on Be and buried pyroclastic flow on St and Ke (2.7–3.6%) < Surface soils on and Ke (about 7.3%) < brown volcanic ash on St and Ke (6.8–8.1%) < coarse and fine textured scoria (3.7–27.8%) < soils on An (22–35.7%).

Considerable amounts of water soluble salts are contained in the fresh ashes originated from Volcano Sakurajima (Kagoshima, Japan)[5]. On the Krakatau Islands, fresh ashes originated from An are constantly deposited on the surface of the four islands (see Photo. 3. in Part I.), therefore, the origin of water soluble bases in the surface soil is mainly assumed to have been originated from fresh ashes. But considerable amounts of water soluble bases present in the sub-soils derived from pyroclastic flow on Be, St and Ke had not been originated from fresh ashes which were deposited after 1927, and was assumed to be originated to released cations accompanied by rapid decomposition of primary minerals in 1883 pyroclastic flow. Furthermore, as the sample soils were taken during dry season, water soluble cations of sub-soils were accumulated to the surface soils through capillary water. Therefore, it is doubtful that large values of base saturation degree on the Krakatau soils are held in wet season.

Though extractable Ca content of almost all samples was larger than that of extractable Mg, water soluble Mg content of sub-soils derived from pyroclastic flow was generally larger than that of water soluble Ca (Appendix 2.), therefore, 1883 pyroclastic flow was presumed to have been influenced by sea water during the early stage of its deposition.

As clay content of the soils derived from pyroclastic flow was larger than that of the other layers, water holding capacity of the formers was assumed to be larger than that of latters. Therefore, during the wet season, water soluble salts were translocated to the lower part but accumulated in buried pyroclastic flow. And then during the dry season, they were moved upwards and accumulated in the surface soils. On An, as layers with abundant humus and clays are not present, constantly supplied water soluble cations in the fresh ashes were leached, resulting in lower base saturation degree.

(5) pH(NaF) and phosphate absorption coefficient

pH(NaF) values of almost all samples were below 9.4 excepting a few samples (Be–1–5, Be–5–2, Be–5–3, Be–5–4, Be–7–2, Ke–1–1–2 and Ke–5–5). Average values of pH(NaF) on each island became smaller in the following order; Be>Ke>St>An. Values of respective layer on St and Ke were as follows; brown volcanic ash (St: 8.19, Ke: 9.00)>coase and fine textured scoria> soils on An (7.8–7.9).

Smith[12] proposed the pH(NaF) value (9.4 or more after 2 min.) as one of the characteristics of Andisols, but recently pH(NaF) is excluded in the defintion of Andisols[4]. In Japan, almost all Andosoils (humus volcanic ash soils, corresponding to proposed Andisols) show pH(NaF) of more than 9.4 though the values of some other soils (Brown forest Soils, Red and Yellow Soils) also showed more than 9.4.

Average value of phosphate absorption coefficient of the surface soils on Be was 327 (Table 2.), but those of the other soils were below 150, except for brown volcanic ash. Among the four islands, this value became smaller in the following order; Be>Ke>St>An. Among the respective layer except for the surface soils on Be, average value of brown volcanic ash was largest (St: 223, Ke: 316), followed by sub-soils on Be and buried pyroclastic flow on St and Ke (Be: 150, St: 144, Ke: 189). Average values of the surface soils on St and Ke, coarse and fine textured scoria on St and Ke and those of the soils on An were less than 150.

3. A comparison of routine physical and chemical properties of the soils on the Krakatau Islands with those of young Andosoils derived from the ashes of Volcano Sakurajima (Kagoshima, Japan), and developed Andosoils of Japan (Kagoshima) and Indonesia (near Bandung)

Table 3. showed the physical and chemical properties of young Andosoils derived from Sakurajima's ashes deposited in 1914 and 1779[6,*]. These samples were taken in Takakuma Experimental forest of Kagoshima University.

General information of sample site are as follows. Altitude: 550 m. Exposure: flat. Climate: annual average temperature about 13°C, 32°C in summer but −7°C in winter, annual precipitation about 3065 mm but it would not be divided into wet and dry season as in Indonesia. Mineralogical property: andesitic (not contain olivine, feldspar is dominantly labradorite).

According to authors' experience, the advances in volcanic ash soil formation are accompained with the following items: a) increase in clay and carbon content, b) increase in C/N ratio, c) increase in acidification degree (distinct increase of $Ca(CH_3COO)_2$ extractable acidity but ΔpH are not so larger), d) increase in CEC, e) decrease in base saturation degree, f) increase in the value of pH(NaF) and phosphate absorption coefficient. From the above-mentioned stand-point, soil formation process of the samples in Table 3 are advanced in the following order; No.3>No.1> No.2.

The developed Andosoils in Kagoshima (Chiran) are as follows[7]; parent material: Mt. Kaimon's basaltic volcanic ashes (about 1000 years B. P.), clay content: 18%, total carbon: 8.8%, C/N ratio: 18.6, pH(H_2O): 5.0, pH(KCl): 4.4, exchange acidity: 2.9, $Ca(CH_3COO)_2$ extractable acidity: 32.7, pH(NaF); 11.6, phosphate absorption coefficient: 3700.

In the Indonesian old volcanic ash soils on the Cisarua (near Bandung) showed the following properties; pH(H_2O) of CR–1 (surface soil): 6.0, of CR–3 (buried A horizon): 5.3, ΔpH: 0.95, 0.7, total carbon: 6.35%, 8.66%, C/N ratio: 13.6, 28.5, base saturation degree: 46.3%, 8.2%, pH(NaF): 10.6, 11.6, phosphate absorption coefficient: 2240, 2560, respectively*.

* Unpublished report

Table 3. Physical and chemical properties of young Ando Soils

Sample No.	Legend	Depth (cm)	Gravel (%)	Clay (%)	Bulk density	Porosity (%)	Total carbon (%)	C/N	pH (H_2O)	pH (N-KCl)
1	Surface soil derived from 1914 ash	0–15	3.4	4.0	0.79	69.7	2.0	12.5	5.7	4.6
2	sub-soil derived from 1914 ash	15–22	5.3	1.6	0.99	62.7	0.50	12.5	5.6	4.7
3	Buried A horizon derived from 1779 ash	22–32	1.8	6.0	0.64	70.9	3.60	16.4	5.3	4.5

According to the data of Chiran and Cisarua, the changes in the chemical properties of developed volcanic ash soils in Japan and in Indonesia are presumed to be virtually similar.

As compared with Be–5–1 and Be–7–1 on Be with No. 1 and 2 in Table 3, the formers were more pronounced soil formation process than the latters in consideration of the folowing items: total carbon content, acidity, CEC and phosphate absorption coefficient. However, base saturation degree of formers was clearly higher than that of the latters.

For the soils on St and Ke, almost all items which are mentioned as indices of the degree of soil formation were less pronounced than No. 1 and 2 in Table 3, especially pH, acidity, base saturation degree, pH(NaF) and phosphate absorption coefficient. The soils on An are in the lowest degree of soil formation.

Table 4. Classification of soils

Site	Soil classification
Rakata Besar	
Be–1	Andeptic Troporthents
Be–2	Andeptic Troporthents
Be–3	Andeptic Troporthents
Be–5	Andeptic Troporthents
Be–6	Andeptic Troporthents
Be–7	Andeptic Troporthents
Sertung	
St–1	Typic Troporthents
St–2	Typic Troporthents
St–3	Typic Troporthents
St–4	Typic Troporthents
Rakata Kecil	
Ke–1	Typic Troporthents
Ke–3	Typic Troporthents
Ke–4	Typic Troporthents
Ke–5	Typic Troporthents
Anak Krakatau	
An–1	Typic Troporthents
An–3	Typic Troporthents

derived from Volcano Sakurajima's ashes. [Shenagawa et al. (1976)][6,*)]

ΔpH	Acidity		Exchange acidity/ Hydrolytic acidity	Ex-changeable bases	CEC	Base saturation degree (%)	pH (NaF) 2 min	Phosphate-absorption coef. P_2O_5 mg/100 g
	Exchange	Hydolytic		← me/100 g	→			
1.1	2.9	11.8	4.1	1.90	9.30	20.4	9.10	215
0.9	0.5	4.3	8.6	0.61	2.80	21.8	9.48	129
0.8	1.9	28.4	15.0	1.50	13.9	10.8	10.25	829

4. Soil classification

At present, Physical and chemical properties of proposed Andisols are not defined[4)]. Therefore, according to the "Soil Taxonomy"[11)], the soils on the Krakatau Islands are tentatively classified as shown in Table 4.

Summary

Routine physical and chemical analysis of the soil samples from respective layer from each island (stated in Part I. in this series) on the Krakatau Islands were carried out.

1. Particle-size distribution

Clay contents of fine earth were lower in the following order; soils derived from 1883 pyroclastic flow (6–10%)>surface soil (fresh ash plus A_1 or A_1-like layers) on Sertung and Rakata Kecil>brown volcanic ash layer on Sertung and Rakata Kecil>fine textured scoria layer>coarse textured scoria layer>the soils on Anak Krakatau. Similarly to clay content, soil texture became coarser in the following order; soils derived flom 1883 pyroclastic flow<A_1 or A_1-like<fresh ash<brown volcanic ash<fine textured scoria<coarse textured scoria (upper)<coarse textured scoria (lower) on Sertung<soils on Anak Krakatau.

Bulk density of the soil derived from pyroclastic flow on Rakata Besar was 0.4 to 0.9.

2. Chemical properties

Average total carbon content of the surface soils on Rakata Besar was 9.05%, and those on Rakata Kecil and Sertung were 1.34% and 1.04%, respectively. In the sub-soils on Rakata Besar, Rakata Kecil and Sertung, the values of total carbon were less than 0.6%.

Values of pH(H_2O) were about 6.1–6.8, respectively, except a few soil samples. Average values of ΔpH, pH(H_2O) minus pH(KCl), of the sub-soils derived from pyroclastic flow were 1.86 (Rakata Besar), 1.80 (Rakata kecil) and 1.56 (Sertung). For the others, these values became smaller in the following order; fine textured scoria>brown volcanic ash>coarse textured scoria>surface soils on Rakata Besar>soils on Anak Krakatau.

Average extractable acidity of the surface soils on Rakata Besar was 24.85 me/100 g, but those of the sub-soils derived from pyroclastic flow were distinctly low (Rakata Besar: 7.08, Rakata Kecil:

* Unpublished report

6.69, Sertung: 4.06). For the soils after 1927, these values were from 2 to 6, and became smaller in the followin order; surface soils on Rakata Kecil and Sertung>brown volcanic ash>coarse textured scoria>fine textured scoria>soils on Anak Krakatau.

Average CEC values of the surface soils on Rakata Besar was 29 me/100 g, but those of the other soils were less than 7 me.

Except for the soils on Anak Krakatau and a few surface soils on Rakata Besar, base saturation degrees were nearly 100%, and 0.1 to 1.1 me/100 g of water soluble cations were present in almost all soil samples.

pH(NaF) of the soils on the Krakatau Islands were less than 9.40, except for a few soils on Rakata Besar, and became smaller in the following order; Rakata Besar>Rakata Kecil>Sertung>Anak Krakatau. Among respective layer, brown volcanic ash>coarse textured scoria>surface soils on Rakata Kecil and Sertung>soils on Anak Krakatau.

Phosphate absorption coefficient: average value of the surface soils on Rakata Besar (337) was largest, and became smaller in the following order; brown volcanic ash (Rakata Kecil: 316, Sertung: 223)>buried pyroclastic flow>coarse and fine textured scoria>soils on Anak Krakatau.

3. Degree of soil formation

From the above-mentioned 1. and 2., soil formation degree of respective island was as follows; Rakata Besar>Rakata Kecil>Sertung>Anak Krakatau. For the soils derived from 1883 pyroclastic flow, carbon contents and extractable acidities of the surface soils were higher but the values of ΔpH were distinctly lower than those of the sub-soils.

For respective layer, soil formation degree became lower in the following order; 1883 pyroclastic flow>brown volcanic ash$\fallingdotseq$surface soils on Rakata Kecil and Serting>fine textured scoria>coarse textured scoria>soils on Anak Krakatau.

4. A comparison of the soils on the Krakatau Islands with the young Japanese volcanic ash soils originated from Volcano Sakurajima's ashes

Soil formation processes of both soils are presumed to be nearly the same.

But in detail, high % of base saturation degree and the presence of considerable amounts of water soluble cations, relatively lower values of pH(NaF) and phosphate absorption coefficient of the soils on the Krakatau Islands were different from those in the young Japanese volcanic ash soils.

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Appendix 1. Particle size distribution of sample soils (Rakata Besar)

Sample No.	Depth (cm)	Horizon	Legend	Gravel >2 mm (%)	Fine earth: Total: Sand 2–0.05 mm (%)	Total: Silt 0.05–0.002 mm (%)	Total: Clay 0.002> mm (%)	Sand: Very coarse 2–1 mm (%)	Sand: Coarse 1–0.5 mm (%)	Sand: Medium 0.5–0.25 mm (%)	Sand: Fine 0.25–0.1 mm (%)	Sand: Very fine 0.1–0.05 mm (%)	Silt: 0.05–0.02 mm (%)	Silt: 0.02–0.002 mm (%)	Clay: 0.002> mm (%)	Bulk density	Porosity (%)
Be-1-1	0–5	A_{11}	Pyroclastic flow	2.4	54.1	36.1	9.8	1.1	3.3	10.4	20.4	18.9	14.3	21.8	9.8	0.71	69.2
Be-1-2	5–7	A_{12}	〃	13.4	52.1	36.9	11.0	6.6	7.4	10.7	13.6	13.8	13.6	23.3	11.0		
Be-1-3	7–17	BC	〃	25.9	53.6	33.6	12.8	22.0	10.3	9.9	6.3	5.1	12.0	21.6	12.8		
Be-1-4	17–30	IIC_1	Buried Pyroclastic flow	22.5	52.7	38.3	9.0	11.5	13.0	16.1	7.3	4.8	10.2	28.1	9.0	0.77	68.0
Be-1-5	30–58	IIC_1	〃	37.6	56.4	42.8	0.8	16.1	12.8	13.0	7.1	7.4	26.0	16.8	0.8	0.51	74.8
Be-1-6	58–	IIC_2	〃	38.2													
Be-2-1	0–4	A	Pyroclastic flow	32.9	64.8	28.6	6.6	15.6	13.4	14.8	12.3	8.7	9.2	19.4	6.6	0.52	76.5
Be-2-2	4–15	BC	〃	27.5	61.3	33.5	5.2	15.8	14.9	15.8	8.8	6.0	11.7	21.8	5.2	0.81	65.4
Be-2-3	15–27	IIAB	Buried pyroclastic flow	17.3	44.0	44.0	12.0	7.2	8.8	10.6	11.3	6.1	13.5	30.5	12.0	0.62	72.9
Be-2-4	27–39	IIB	〃	28.6													
Be-2-5	39–55	IIIAB	〃	32.5													
Be-2-6	55–70	IIIBC	〃	35.9													
Be-2-7	70–85	IVAB	〃	36.6													
Be-2-8	85–100	IVBC	〃	20.6													
Be-2-9	100–	VC	〃	27.7	52.2	41.8	6.0	10.8	12.6	13.0	8.0	7.8	12.2	29.6	6.0		
Be-3-1	0–6	A_{11}	Pyroclastic flow	0.5	29.2	62.5	8.3	0.5	0.5	3.5	12.3	12.4	24.0	38.5	8.3	0.42	82.0
Be-3-2	6–10	A_{12}	〃	0.9													
Be-3-3	10–23	BC	〃	4.1	17.6	74.9	7.5	1.6	1.6	3.2	3.6	7.6	23.6	51.3	7.5	0.85	65.8
Be-3-4	23–25	IIC_1	Buried pyroclastic flow	14.6												0.91	61.3
Be-3-4, 5	25–30	IIC_2	〃	4.3	29.1	62.1	8.8	4.9	4.2	6.4	5.8	7.8	17.4	44.7	8.8		
Be-3-5	30–37	IIC_3	〃	2.4	25.9	65.1	9.0	3.2	4.6	5.6	5.2	7.3	14.6	50.5	9.0		
Be-3-6	37–	IIIC	〃	22.9	49.1	40.7	10.2	13.0	10.2	12.1	7.2	6.6	11.3	29.4	10.2	0.91	61.5

(Rakata Besar)

Sample No.	Depth (cm)	Horizon	Legend	Gravel >2 mm (%)	Fine earth: Total: Sand 2–0.05 mm (%)	Total: Silt 0.05–0.002 mm (%)	Total: Clay 0.002> mm (%)	Sand: Very coarse 2–1 mm (%)	Sand: Coarse 1–0.5 mm (%)	Sand: Medium 0.5–0.25 mm (%)	Sand: Fine 0.25–0.1 mm (%)	Sand: Very fine 0.1–0.05 mm (%)	Silt: 0.05–0.02 mm (%)	Silt: 0.02–0.002 mm (%)	Clay: 0.002> mm (%)	Bulk density	Porosity (%)
Be–5–1	0–12	A	Pyroclastic flow	6.4	62.5	34.8	2.7	3.3	4.2	10.9	22.9	21.2	29.4	5.4	2.7	0.45	80.4
Be–5–2	12–17	BC	〃	22.8												0.55	74.1
Be–5–3	17–22	C	〃	21.4												0.73	73.0
Be–5–4	22–55	IIAB	Buried pyroclastic	15.0													
Be–5–5	55–	IIIC	〃	77.6												0.56	78.0
Be–6–1	0– 5	A	Mixture of volcanic ejecta	11.2	22.4	71.8	5.8	0.6	0.9	3.2	6.6	11.1	25.8	46.0	5.8	0.55	78.7
Be–6–2	5–40	IIBC	Re-depodited pyroclastic flow	10.4	17.1	80.3	2.6	1.0	0.7	2.4	3.9	9.1	31.6	48.7	2.6	0.56	77.6
Be–6–3	40–	IIIC	Beach sand	0.1	100	0	0	2.4	26.5	55.8	14.7	0.6	0	0	0		
Be–7–1	0– 5	A	Pyroclastic flow	1.0	50.4	41.2	8.4	1.1	2.2	7.2	19.1	20.8	17.1	24.1	8.4	0.51	78.2
Be–7–2	5–15	B	〃	17.6												0.72	69.5
Be–7–3	15–35	BC	〃	26.8												0.68	71.7
Be–7–4	35–	C	〃	25.2												0.77	65.9

(Sertung)

Sample No.	Depth (cm)	Horizon	Legend	Gravel >2 mm (%)	Fine earth										
					Total			Sand					Silt		Clay
					Sand 2–0.05 mm (%)	Silt 0.05–0.002 mm (%)	Clay 0.002> mm (%)	Very coarse 2–1 mm (%)	Coarse 1–0.5 mm (%)	Medium 0.5–0.25 mm (%)	Fine 0.25–0.1 mm (%)	Very fine 0.1–0.05 mm (%)	0.05–0.02 mm (%)	0.02–0.002 mm (%)	0.002> mm (%)
St–1–1	0–10	A	Fresh ash, A_1 or A_1-like	0.4	64.3	33.2	2.5	1.4	2.9	15.5	29.4	15.1	21.5	11.7	2.5
St–1–1'	10–20	IIA	A_1 or A_1-like	2.3	72.4	26.6	1.0	1.9	1.1	24.2	28.4	16.8	17.6	9.0	1.0
St–1–2	20–35	IIIC	Coarse textured scoria	15.2	73.5	25.3	1.2	15.2	20.8	20.1	8.7	8.7	18.2	7.1	1.2
St–1–3	35–45	IVC	〃, (pan)	3.2	53.3	44.2	2.5	6.5	8.5	11.4	10.2	16.7	33.7	10.5	2.5
St–1–4	45–70	VC	〃	10.7	64.0	33.5	2.5	22.1	14.1	9.4	7.8	10.6	23.5	10.0	2.5
St–1–5	70–	VIC	Fine textured scoeia	1.4	63.6	30.4	6.0	7.7	11.4	19.9	11.3	13.3	20.7	9.7	6.0
St–2–1	0– 6	A	Mixture of volcanic ejecta	0	85.7	13.0	1.3	0.2	2.3	38.3	33.4	11.5	11.3	1.7	1.3
St–2–2	6–17	IIC	Re-deposited pyroclastic flow	17.2											
St–2–3	17–	IIIC	Beach sand	0.2	100	0	0	0.1	2.4	67.3	30.0	0.2	0	0	0
St–3–1	0–10	A	Fresh ash	0	70.1	28.7	1.2	0.1	1.2	19.4	34.2	15.2	18.1	10.6	1.2
St–3–2	10–20	IIA	A_1 or A_1-like	0.1	66.7	29.7	3.6	0.3	0.6	10.9	32.9	22.0	19.0	10.7	3.6
St–3–3	20–30	$IIIC_1$	Coarse textured scoria	4.4	79.0	21.0	0	11.2	24.1	25.3	9.9	8.5	15.3	5.7	0
St–3–3'	30–42	$IIIC_2$	〃	1.3											
St–3–4	42–50	IVC	Fine textured scoria	2.5	69.2	29.6	1.2	8.5	12.3	20.0	14.1	14.3	25.9	3.7	1.2
St–3–5	50–60	VB	Brown volcanic ash	0.5	67.0	30.3	2.7	2.7	8.3	18.7	20.6	16.7	23.8	6.5	2.7
St–3–5'	60–62		Pan or pan-like	0											

(Sertung)

Sample No.	Depth (cm)	Horizon	Legend	Gravel >2 mm (%)	Fine earth: Total: Sand 2–0.05 mm (%)	Total: Silt 0.05–0.002 mm (%)	Total: Clay 0.002> mm (%)	Sand: Very coarse 2–1 mm (%)	Sand: Coarse 1–0.5 mm (%)	Sand: Medium 0.5–0.25 mm (%)	Sand: Fine 0.25–0.1 mm (%)	Sand: Very fine 0.1–0.05 mm (%)	Silt: 0.05–0.02 mm (%)	Silt: 0.02–0.002 mm (%)	Clay: 0.002> mm (%)
St–3–6	62–67	VIC_1	Coarse textured scoria	1.9	88.1	11.2	0.7	15.1	28.1	30.4	10.2	4.3	8.6	2.6	0.7
St–3–6'	67–68		pan or pan-like	0.2	72.8	25.1	2.1	9.4	21.4	25.6	7.6	8.8	16.0	9.1	2.1
St–3–7	68–71	VIC_2	Coarse textured scoria	1.5	87.9	12.1	0	19.9	41.3	19.5	4.5	2.7	8.9	3.2	0
St–3–8	71–80	VIIAB	Buried pyroclastic flow	4.1	69.6	27.4	3.0	7.2	13.9	22.9	14.7	10.9	15.4	12.0	3.0
St–3–9	80–	VIIC	〃	13.7	48.1	43.0	8.9	9.3	8.9	11.6	9.4	8.9	13.5	29.5	8.9
St–4–1	0–10	A	Fresh ash	0.1	74.0	25.1	0.9	0.1	0.6	27.9	29.0	16.4	14.4	10.7	0.9
St–4–2	10–20	IIA	A_1 or A_1-like	2.9	69.7	29.7	0.6	4.9	5.5	19.0	24.6	15.7	18.2	11.5	0.6
St–4–3	20–39	IIIC	Coarse textured	3.2	66.9	32.9	0.2	6.2	15.1	20.8	13.2	11.6	24.3	8.6	0.2
St–4–4	39–55	IVC	Fine textured scoria	1.4	64.1	35.9	0	2.7	9.9	18.3	16.7	16.5	25.7	10.2	0
St–4–5	55–70	VB	Brown volcanic ash	0.1	70.8	28.4	0.8	0.6	2.9	16.8	26.9	23.6	23.6	4.8	0.8

Appendix 1. Particle size distribution of samples (Rakata Kecil)

Sample No.	Depth (cm)	Horizon	Legend	Gravel >2 mm (%)	Fine earth										
					Total			Sand					Silt		Clay
					Sand 2–0.05 mm (%)	Silt 0.05–0.002 mm (%)	Clay 0.002> mm (%)	Very coarse 2–1 mm (%)	Coarse 1–0.5 mm (%)	Medium 0.5–0.25 mm (%)	Fine 0.25–0.1 mm (%)	Very fine 0.1–0.05 mm (%)	0.05–0.02 mm (%)	0.02–0.002 mm (%)	0.002> mm (%)
Ke–1–1	0–10	A	Fresh ash	4.1	71.3	28.7	0	12.7	10.7	18.5	16.4	13.0	18.5	10.2	0
Ke–1–1–1	10–15	IIA	A_1 or A_1-like	0.6	73.5	24.0	2.5	3.6	4.1	25.3	26.8	13.7	19.7	4.3	2.5
Ke–1–1–2	15–20	$IIIC_1$	Coarse texturied scoria	6.6	77.8	22.2	0	26.3	22.2	13.4	8.6	7.3	11.6	10.6	0
Ke–1–1–3	20–24	$IIIC_2$	〃	0.7											
Ke–1–2	24–30	$IIIC_3$	〃	5.3	69.8	30.2	0	15.3	16.9	14.4	11.1	12.1	20.7	9.5	0
Ke–1–3	30–39	IVC	Fine textured scoria	3.7	58.8	38.8	2.4	4.4	10.6	14.1	12.5	17.2	25.3	13.5	2.4
Ke–1–4	39–55	VB	Brown volcanic ash	0.1	63.9	31.9	4.2	0.7	3.4	16.5	22.8	20.5	29.2	2.7	4.2
Ke–1–5	55–60	VIAC	Buried pyroclastic flow	2.2	51.4	42.7	5.9	3.0	3.5	13.3	17.7	13.9	21.0	21.7	5.9
Ke–1–6	60–	VIC	〃	17.8	42.3	46.5	11.2	8.5	8.6	10.1	8.0	7.1	18.6	27.9	11.2
Ke–3–1	0– 2	A	Fresh ash	0	80.5	19.5	0	0.7	0.9	25.2	38.8	14.9	11.3	8.2	0
Ke–3–2	2–10	IIA	A_1 or A_1-like	0.1	73.0	25.9	1.1	0.7	3.3	24.1	29.5	15.4	16.4	9.5	1.1
Ke–3–3	10–15	IIIC	Buried fresh ash	0.2	74.6	23.7	1.7	0.5	1.8	25.6	32.0	14.7	17.1	6.6	1.7
Ke–3–4	15–20	IVC_1	Coarse textured scoria	2.8	62.6	36.7	0.7	6.3	10.2	15.6	15.9	14.6	24.1	12.6	0.7
Ke–3–5	20–22	IVC_2	c.t.s.*, f.t.s.**	3.8											
Ke–3–6	22–45	VB	Brown volcanic ash	0.4	62.2	36.2	1.6	1.0	3.9	17.0	22.5	17.8	24.1	12.1	1.6
Ke–3–7	45–65	VIC_1	Buried pyroclastic flow	4.2	36.0	53.2	10.8	6.1	5.0	5.6	6.6	12.7	26.2	27.0	10.8
Ke–3–8	65–	VIC_2	〃	7.4	48.9	38.4	12.7	10.9	10.4	12.0	8.3	7.3	12.5	25.9	12.7

* c.t.s.: Coarse textured scoria, ** f.t.s.: Fine textured scoria

(Rakata Kecil)

Sample No.	Depth (cm)	Horizon	Legend	Gravel >2 mm (%)	Fine earth: Total: Sand 2–0.05 mm (%)	Total: Silt 0.05–0.002 mm (%)	Total: Clay 0.002> mm (%)	Sand: Very coarse 2–1 mm (%)	Sand: Coarse 1–0.5 mm (%)	Sand: Medium 0.5–0.25 mm (%)	Sand: Fine 0.25–0.1 mm (%)	Sand: Very fine 0.1–0.05 mm (%)	Silt: 0.05–0.02 mm (%)	Silt: 0.02–0.002 mm (%)	Clay: 0.002> mm (%)
Ke–4–1	0– 9	A	Mixture of pyroclastic flow, fresh ash, rock fragment	1.9	52.6	45.4	2.0	2.0	1.2	11.2	23.1	15.1	21.4	24.0	2.0
Ke–4–2	9–12	IIC		18.6											
Ke–4–3	12–15	IIIC		1.6											
Ke–4–4	15–26	IVAC	Mixture of coarse textured scoria, fine textured scoria and pyroclastic flow	1.3	71.6	26.8	1.6	2.8	4.3	22.5	27.6	14.4	13.6	13.2	1.6
Ke–4–5	26–42	VC_1		4.5	88.1	11.9	0	13.1	19.9	23.6	20.6	10.9	5.5	6.4	0
Ke–4–6	42–62	VC_2		5.4	82.2	17.8	0	22.5	19.5	17.7	12.0	10.5	10.8	7.0	0
Ke–4–7	62–65	VIBC	pan or pan-like	2.7											
Ke–4–8	65–82	VIIBC	Re-depositeed brown volcanic ash	8.4	84.0	14.7	1.3	8.0	16.7	32.2	19.3	7.8	8.2	6.5	1.3
Ke–5–1	0– 2	A	Fresh ash	0											
Ke–5–2	2– 9	IIAC	A_1 or A_1-like	0	74.7	23.3	2.0	1.3	5.1	26.5	28.4	13.4	11.8	11.5	2.0
Ke–5–3	9–21	IIIC	Buried fresh ash	0.1	74.2	24.9	0.9	0.9	3.5	26.6	28.9	14.3	14.5	10.4	0.9
Ke–5–4	21–32	IVC	c.t.s.*, f.t.s.**	3.1	67.7	29.1	3.2	7.8	14.4	19.6	12.8	13.1	20.8	8.3	3.2
Ke–5–5	32–42	VB	Brown volcanic ash	0.5	53.9	44.0	2.1	0.6	2.7	13.0	19.0	18.6	26.4	17.6	2.1
Ke–5–6	42–56	VIC_1	Buried pyroclastic flow	20.9											
Ke–5–7	56–	VIC_2	〃	18.7	66.1	29.7	4.2	13.6	13.7	18.0	12.8	8.0	12.2	17.5	4.2

* c.t.s.: Coarse textured scoria, ** f.t.s: Fine textured scoria

(Anak Krakatau)

Sample No.	Depth (cm)	Horizon	Legend	Gravel >2 mm (%)	Fine earth: Total: Sand 2–0.05 mm (%)	Total: Silt 0.05–0.002 mm (%)	Total: Clay 0.002> mm (%)	Sand: Very coarse 2–1 mm (%)	Sand: Coarse 1–0.5 mm (%)	Sand: Medium 0.5–0.25 mm (%)	Sand: Fine 0.25–0.1 mm (%)	Sand: Very fine 0.1–0.05 mm (%)	Silt: 0.05–0.02 mm (%)	Silt: 0.02–0.002 mm (%)	Clay: 0.002> mm (%)
An–1–1	0–15	AC	Mixture of	0.5	81.1	15.1	3.8	2.7	13.0	40.0	17.0	8.4	9.2	5.9	3.8
An–1–2	15–23	IIC	fresh ash, scoria, rock	0.9	74.6	23.0	2.4	2.5	9.4	31.6	19.9	11.2	13.3	9.7	2.4
An–1–3	23–40	IIIC	fragment	1.7	89.4	10.6	0	6.1	16.8	41.8	16.5	8.2	6.7	3.9	0
An–1–4	40–44	IVC	pans	14.7											
An–1–5	44–	VC	Beach sand	0.4	100	0	0	5.9	23.6	58.9	11.6	0	0	0	0
An–2	280–290	XIC	Brown volcanic ash	1.4	55.4	42.5	2.1	3.1	6.8	13.3	14.3	17.9	23.3	19.2	2.1
An–3–1	0– 6	AC	Mixture of	0.5	85.3	11.5	3.2	4.0	11.7	39.0	22.7	7.9	9.6	1.9	3.2
An–3–2	6–12	IIC	fresh ash coarse and	0.4											
An–3–3	12–19	$IIIC_1$	fine scoria	1.8	76.6	23.4	0	6.6	13.8	22.7	19.1	14.4	15.9	7.5	0
An–3–4	19–27	$IIIC_2$	and rock fragment	1.7	77.1	22.9	0	5.3	11.4	24.7	22.9	12.8	13.7	9.2	0
An–3–5	27–32	IVC	Mixture of cobbly pumice and sand	4.0											
An–3–6	32–	VC	Beach sand	0.7											
An–4	10–15	IIA	Fine textured scoria	0.6	54.5	42.5	3.0	2.0	5.1	22.5	18.7	6.2	15.3	27.2	3.0

Appendix 2. Chemical propertis of sample soils
(Rakata Besar)

Sample No.	Depth (cm)	Hori-zon	Total C (%)	Total N (%)	C/N	pH H_2O	pH N-KCl	Exchange acidity	Etract. acidity	Extractable bases Ca	Extractable bases Mg	Extractable bases K	Extractable bases Na	Water saluble basis Ca	Water saluble basis Mg	Water saluble basis K	Water saluble basis Na	CEC	Base Saturation degree (%)	pH NaF after 2 min.	P-sorption coef. P_2O_5 mg/100 g
								me/100 g													
Be–1–1	0– 5	A_{11}	10.22	0.680	15.0	6.60	5.87	1.81	25.50	28.45	11.02	1.24	0.64	0.28	0.41	0.41	0.21	35.12	114.0	8.17	235
Be–1–2	5– 7	A_{12}	4.14	0.330	12.5	6.40	5.57	1.45	19.24	11.77	5.00	1.14	0.29	0.08	0.12	0.25	0.13	14.35	122.8	9.10	380
Be–1–3	7–17	BC	2.02	0.150	13.5	6.02	4.80	1.53	15.21	3.42	2.80	1.30	0.27	0.02	0.04	0.11	0.12			8.81	454
Be–1–4	17–30	IIC_1	0.21			6.60	4.52	1.45	7.22	2.63	3.88	1.16	0.52	0.003	0.01	0.04	0.15			7.91	130
Be–1–5	30–58	IIC_1	0.28			6.80	5.69	1.44	7.24	0.87	0.46	0.32	0.12	0.02	0.03	0.09	0.08			9.40	235
Be–1–6	58–	IIC_2	0.21			6.54	5.22			0.41	0.39	0.24	0.20	0.01	0.005	0.04	0.08			7.66	
Be–2–1	0– 4	A	9.40	0.630	14.9	6.83	6.32	1.74	15.48	29.19	8.42	1.21	0.45	0.76	0.60	0.24	0.16	29.62	126.6	7.77	75
Be–2–2	4–15	BC	0.54	0.043	12.6	6.63	5.11	0.86	6.55	4.69	2.35	1.27	0.24	0.02	0.04	0.10	0.08			8.12	117
Be–2–3	15–27	IIAB	2.05	0.160	12.8	6.10	4.79	1.36	16.40	4.40	2.99	0.84	0.30	0.02	0.05	0.07	0.14			8.32	333
Be–2–4	27–39	IIB	0.61	0.028	21.8	6.63	5.04			5.57	2.70	0.44	0.52	0.02	0.03	0.03	0.16			7.63	
Be–2–5	39–55	IIIAB	1.08	0.091	11.9	6.63	5.71			4.80	2.61	0.92	0.46	0.01	0.03	0.07	0.21			7.50	
Be–2–6	55–70	IIIBC	0.56	0.025	22.4					3.83	2.50	0.53	0.49	0.01	0.02	0.03	0.16				
Be–2–7	70–85	IVAB	0.70	0.069	10.1	6.64	4.93													7.49	
Be–2–8	85–100	IVBC	0.64	0.042	15.2	6.74	5.03													7.60	
Be–2–9	100–	VC	0.17			7.29	5.43	0.78	8.87	2.51	2.13	1.21	0.14	0.01	0.03	0.09	0.08			8.07	131
Be–3–1	0– 6	A_{11}	11.06	0.800	13.8	6.50	5.98	0.98	27.83	39.14	10.79	0.90	0.45	1.20	0.82	0.21	0.34	35.34	137.8	7.87	217
Be–3–2	6–10	A_{12}	3.77	0.290	13.0	6.65	5.66	0.79	14.53	14.20	4.83	0.96	0.40	0.09	0.11	0.09	0.16	18.89	105.6	8.61	297
Be–3–3	10–23	BC	0.72	0.056	12.9	6.65	5.11	0.79	9.67	5.20	2.76	1.46	0.35	0.02	0.03	0.08	0.11	10.13	94.1	9.23	337
Be–3–4	23–25	IIC_1	0.36	0.027	13.3	6.84	4.96			4.30	3.16	1.24	0.38	0.01	0.03	0.06	0.11	8.69	102.0	7.54	
Be–3–4, 5	25–30	IIC_2	0.34			6.78	4.81	1.01	7.46	4.45	3.35	1.24	0.49	0.02	0.02	0.05	0.09			8.87	132
Be–3–5	30–37	IIC_3	0.45	0.024	18.8	6.83	4.88	0.75	8.89	4.19	3.73	1.27	0.50	0.01	0.02	0.06	0.11	9.18	103.4	7.89	139
Be–3–6	37–	IIIC	0.20			7.00	4.80	0.75	4.58	3.22	3.88	1.00	0.38	0.004	0.03	0.05	0.09	7.87	105.5	7.68	116
Be–5–1	0–12	A	7.40	0.560	13.2	6.04	5.22	1.69	28.21	10.50	3.61	0.19	0.27	0.04	0.03	0.07	0.19			9.71	642
Be–5–2	12–17	BC	1.23	0.088	14.0	5.93	4.89			1.67	0.50	0.15		0.03	0.03	0.02	0.11			9.70	
Be–5–3	17–22	C	0.54	0.030	18.0	6.19	5.16			1.21	0.30	0.22		0.02	0.01	0.01	0.07			9.59	

Be-5-4	22-25	IIAB	4.16	0.450	9.2	5.73	4.74			1.46	1.04	0.04		0.02	0.03	0.01	0.21			10.55	
Be-5-5	55-	IIIC	0.54	0.047	11.5	6.34	4.85			4.15	0.95	0.04		0.01	0.003	0.006	0.27			9.03	
Be-6-1	0- 5	A	3.47	0.320	10.8	6.54	5.70	1.16	11.28	10.30	5.05	0.68	0.62	0.18	0.24	0.10	0.37	16.44	95.9	9.08	338
Be-6-2	5-40	IIBC	0.97	0.090	9.8	6.29	5.08	1.00	8.25	3.51	3.03	1.25	0.51	0.03	0.06	0.15	0.27			8.97	275
Be-6-3	40-	IIIC	0.45	0.060	7.5	7.00	5.17	0.68	3.36	0.43	0.46	0.17	0.22	0.003	0.003	0.01	0.07			7.71	74
Be-7-1	0- 5	A	12.06	0.760	15.9	6.10	5.38	4.10	32.86	18.54	6.88	0.83	0.58	0.09	0.12	0.26	0.30	30.01	86.8	8.28	411
Be-7-2	5-15	B	2.76	0.270	10.2	5.91	4.93			4.26	2.17	0.68	0.27	0.04	0.07	0.07	0.13	10.98	64.4	9.44	
Be-7-3	15-35	BC	0.63	0.076	8.3	6.12	4.71			3.07	2.28	0.85	0.51	0.01	0.02	0.04	0.14	7.73	84.1	8.87	
Be-7-4	35-	C	0.38	0.019	20.0	6.54	4.92			3.49	2.87	1.02	0.64	0.004	0.02	0.033	0.14	7.56	103.4	7.49	

(Sertung)

Sample No.	Depth (cm)	Hori-zon	Total C (%)	Total N (%)	C/N	pH H_2O	pH N-KCl	Exchange acidity	Etract. acidity	Extractable bases Ca	Extractable bases Mg	Extractable bases K	Extractable bases Na	Water saluble basis Ca	Water saluble basis Mg	Water saluble basis K	Water saluble basis Na	CEC	Base Saturation degree (%)	pH NaF after 2 min.	P-sorption coef. P_2O_5 mg/100 g
								me/100 g	me/100 g	me/100 g	me/100 g	me/100 g	me/100 g	me/100 g	me/100 g	me/100 g	me/100 g	me/100 g			
St-1-1	0-10	A	1.25	0.077	16.2	6.59	5.69	0.72	5.23	2.98	0.51	0.14	0.12	0.09	0.05	0.05	0.09	3.66	94.8	8.10	98
St-1-1'	10-20	IIA	0.44	0.020	22.0	6.92	6.01	0.64	3.43	1.37	0.29	0.10	0.09	0.06	0.03	0.04	0.05			8.30	97
St-1-2	20-35	IIIC	0.22			6.94	5.87	0.50	3.19	0.58	0.13	0.10	0.06	0.02	0.01	0.04	0.04			8.01	87
St-1-3	35-45	IVC	0.20			6.89	5.49	0.66	4.80	1.48	0.46	0.35	0.12	0.03	0.03	0.06	0.06			8.55	299
St-1-4	45-70	VC	0.04			6.82	5.49	0.68	2.38	0.29	0.08	0.11	0.07	0.02	0.01	0.03	0.04			7.84	66
St-1-5	70-	VIC	0.11			6.79	5.41	0.57	2.42	0.28	0.07	0.07	0.06	0.02	0.01	0.03	0.05			7.85	70
St-2-1	0- 6	A	0.79	0.045	17.6	6.40	5.51	0.71	3.72	2.00	0.57	0.12	0.16	0.07	0.06	0.03	0.10	3.05	84.9	7.71	97
St-2-2	6-17	IIC	0.41	0.017	24.1	6.68	6.33			0.98	0.35	0.12	0.14	0.04	0.04	0.02	0.07			7.48	
St-2-3	17-	IIIC	0.14			7.23	6.90	0.34	2.17	0.61	0.29	0.12	0.13	0.03	0.04	0.01	0.05			7.62	138
St-3-1	0-10	A	0.56	0.063	8.9	6.87	6.12	0.68	3.03	2.80	0.46	0.24	0.09	0.10	0.05	0.12	0.07	3.28	99.1	7.79	58
St-3-2	10-20	IIA	1.64	0.130	12.6	6.69	5.83	0.71	6.15	9.27	1.10	0.54	0.26	0.09	0.05	0.24	0.17	10.55	100.7	8.17	88
St-3-3	20-30	$IIIC_1$	0.14			6.98	6.11	0.53	1.43	1.06	0.14	0.14	0.07	0.04	0.02	0.05	0.05	1.12	111.6	7.88	67
St-3-3'	30-42	$IIIC_2$	0.12			7.02	6.42													7.70	
St-3-4	42-50	IVC	0.14			6.91	5.92	0.56	2.08	0.57	0.08	0.08	0.06	0.04	0.01	0.03	0.05	0.67	98.5	7.79	51

St-3-5	50-60	VB	0.50	0.055	9.1	6.84	5.84	0.65	4.20	2.93	0.46	0.27	0.16	0.06	0.03	0.06	0.09	3.61	99.2	8.00	253
St-3-5'	60-62		0.49	0.017	28.8	6.97	6.05													7.97	
St-3-6	62-67	VIC_1	0.10			6.95	6.07	0.54	2.00	0.52	0.09	0.07	0.06	0.03	0.01	0.02	0.06	0.58	106.9	7.89	103
St-3-6'	67-68		0.11			6.81	6.25													7.74	
St-3-7	68-71	VIC_2	0.11			6.91	5.99	0.56	2.01	0.49	0.11	0.08	0.07	0.04	0.02	0.03	0.06	0.61	98.4	7.77	85
St-3-8	71-80	VIIAB	0.14			6.84	5.79		4.67	2.42	0.58	0.21	0.16	0.05	0.03	0.04	0.09	3.14	100.6	7.00	196
St-3-9	80-	VIIC	0.15			7.10	5.03	0.71	3.45	5.10	1.94	0.75	0.40	0.02	0.04	0.04	0.10	7.46	108.0	7.85	92
St-4-1	0-10	A	0.61	0.040	15.3	6.70	5.82	0.74	3.60	1.29	0.22	0.16	0.06	0.10	0.05	0.08	0.05			7.72	67
St-4-2	10-20	IIA	0.72	0.072	10.0	6.54	5.60	0.74	4.36	2.98	0.41	0.14	0.11	0.08	0.04	0.06	0.08	3.92	86.2	8.17	104
St-4-3	20-39	IIIC	0.10			6.88	5.81	0.68	2.98	0.68	0.11	0.10	0.07	0.03	0.01	0.03	0.05			7.76	88
St-4-4	39-55	IVC	0.10			6.82	5.88	0.65	2.78	0.47	0.07	0.06	0.05	0.03	0.01	0.02	0.03			7.86	48
St-4-5	55-70	VB	0.28	0.018	15.6	6.90	5.69	0.64	4.47	1.71	0.34	0.21	0.12	0.05	0.03	0.03	0.06			8.38	193

(Rakata Kecil)

Sample No.	Depth (cm)	Hori-zon	Total C (%)	Total N (%)	C/N	pH H_2O	pH N-KCl	Exchange acidity	Etract. acidity	Extractable bases Ca	Extractable bases Mg	Extractable bases K	Extractable bases Na	Water saluble basis Ca	Water saluble basis Mg	Water saluble basis K	Water saluble basis Na	CEC	Base Saturation degree (%)	pH NaF after 2 min.	P-sorption coef. P_2O_5 mg/100 g
								me/100 g													
Ke-1-1	0-10	A	0.38	0.029	13.1	6.19	5.21	0.80	5.84	0.73	0.14	0.05	0.05	0.04	0.02	0.02	0.05			8.65	136
Ke-1-1-1	10-15	IIA	1.34	0.110	12.2	6.81	6.00	0.76	3.47	4.48	0.63	0.10	0.15	0.14	0.06	0.05	0.11	5.49	91.1	7.91	166
Ke-1-1-2	15-20	$IIIC_1$	0.17			6.50	5.47	0.61	6.03	0.60	0.15	0.05	0.06	0.04	0.03	0.03	0.05			9.67	157
Ke-1-1-3	20-24	$IIIC_2$	0.37	0.028	13.2	6.13	5.04	1.28	7.78	0.75	0.20	0.16	0.12	0.03	0.03	0.03	0.06			9.35	
Ke-1-2	24-30	$IIIC_3$	0.15			6.22	4.99	0.91	7.57	0.14	0.03	0.04	0.05	0.02	0.01	0.02	0.04			8.25	
Ke-1-3	30-39	IVC	0.15			6.40	5.03	0.91	6.96	0.21	0.05	0.05	0.05	0.03	0.01	0.02	0.04			8.80	141
Ke-1-4	39-55	VB	0.42	0.060	7.0	6.40	5.01	0.75	6.38	1.64	0.47	0.25	0.19	0.03	0.03	0.04	0.09	3.45	67.0	9.21	343
Ke-1-5	55-60	VIAC	0.77	0.086	9.0	6.40	4.83	0.79	9.08	3.85	1.49	0.47	0.37	0.02	0.03	0.04	0.17			8.55	297
Ke-1-6	60-	VIC	0.20			6.61	4.47	1.36	5.76	5.68	2.20	0.44	0.55	0.03	0.03	0.03	0.21			7.64	111
Ke-3-1	0- 2	A	2.09	0.170	12.3	7.36	7.00	0.94	6.48	7.74	0.91	0.38	0.13	0.32	0.11	0.23	0.08	5.83	144.2	8.66	42
Ke-3-2	2-10	IIA	1.53	0.140	10.9	6.68	5.92	0.95	9.34	4.41	0.58	0.24	0.13	0.10	0.04	0.15	0.08	4.94	101.0	8.04	80
Ke-3-3	10-15	IIIC	0.39	0.036	10.8	6.80	5.88	0.70	5.11	1.31	0.21	0.07	0.05	0.04	0.02	0.03	0.04	1.66	91.0	8.64	96
Ke-3-4	15-20	IVC_1	0.37	0.044	8.4	6.70	5.81	0.66	5.76	1.70	0.31	0.09	0.07	0.03	0.03	0.03	0.05	2.14	94.9	8.09	134

Ke-3-5	20-22	IVC_2	0.21			6.83	5.93			1.13	0.19	0.07	0.07	0.04	0.02	0.02	0.05	1.63	81.6	8.12	
Ke-3-6	22-45	VB	0.53	0.044	12.0	6.51	5.42	0.59	7.10	2.65	0.68	0.19	0.15	0.06	0.05	0.03	0.07	3.88	89.2	8.33	223
Ke-3-7	45-65	VIC_1	0.48	0.046	10.4	6.73	4.99	0.86	7.58	6.66	2.16	0.90	0.48	0.04	0.02	0.06	0.16	10.02	99.0	8.50	235
Ke-3-8	65-	VIC_2	0.20			6.98	4.80	0.89	6.52	5.57	2.58	0.90	0.38	0.01	0.02	0.05	0.11	9.48	97.5	8.94	136
Ke-4-1	0- 9	A	2.44	0.230	10.6	7.22	6.61	0.90	10.39	11.62	2.38	0.63	0.20	0.24	0.15	0.26	0.13	12.60	115.8	8.22	98
Ke-4-2	9-12	IIC	0.79	0.088	9.0	6.66	6.12			6.44	1.66	0.58	0.24	0.17	0.12	0.16	0.11			7.83	
Ke-4-3	12-15	IIIC	0.48	0.070	6.9	6.74	5.80			3.29	1.21	0.36	0.15	0.07	0.07	0.09	0.10			7.99	
Ke-4-4	15-26	IVAC	1.30	0.110	11.8	6.69	5.82	0.78	8.74	4.28	1.01	0.20	0.17	0.08	0.07	0.06	0.08			8.52	130
Ke-4-5	26-42	VC_1	0.05			6.88	5.73	0.51	5.51	0.54	0.21	0.10	0.09	0.03	0.02	0.03	0.04			7.91	92
Ke-4-6	42-62	VC_2	0.06			7.01	6.00	0.51	4.65	0.54	0.12	0.09	0.08	0.17	0.05	0.03	0.03			8.32	105
Ke-4-7	62-65	VIBC	0.12			6.58	6.07			0.60	0.15	0.10	0.07	0.19	0.06	0.03	0.04			8.38	173
Ke-4-8	65-82	VIIBC	0.31	0.025	12.4	6.50	5.18	0.83	3.84	2.31	1.00	0.36	0.23	0.02	0.03	0.04	0.11			7.85	72
Ke-5-1	0- 2	A	0.96	0.130	7.4	6.36	5.80			6.43	1.56	0.24	0.16	0.21	0.16	0.13	0.10			7.44	
Ke-5-2	2- 9	IIAC	1.36	0.120	11.3	6.49	5.63	0.86	4.47	3.54	0.81	0.13	0.11	0.11	0.08	0.07	0.08	4.75	89.5	8.00	127
Ke-5-3	9-21	IIIC	0.53	0.028	18.9	6.71	5.71	0.66	3.29	1.80	0.44	0.07	0.11	0.05	0.04	0.03	0.06			8.95	146
Ke-5-4	21-32	IVC	0.23			6.80	5.64	0.58	2.74	0.63	0.15	0.05	0.09	0.08	0.03	0.01	0.05			8.76	151
Ke-5-5	32-42	VB	0.90	0.065	13.8	6.49	5.22	0.81	6.93	2.34	1.07	0.17	0.24	0.05	0.07	0.02	0.11			9.48	383
Ke-5-6	42-56	VIC_1	0.38	0.032	11.9	6.46	4.95			3.53	1.95	0.42	0.48	0.02	0.03	0.02	0.18			7.65	
Ke-5-7	56-	VIC_2	0.24			6.61	5.29	1.36	4.50	3.43	2.42	0.16	0.63	0.01	0.02	0.01	0.20			7.79	167

(Anak Krakatau)

Sample No.	Depth (cm)	Hori-zon	Total C (%)	Total N (%)	C/N	pH		Exchange acidity	Etract. acidity	Extractable bases				Water saluble basis				CEC	Base Saturation degree (%)	pH NaF after 2 min.	P-sorption coef. P_2O_5 mg/100 g
						H_2O	N-KCl	me/100 g		Ca	Mg	K	Na	Ca	Mg	K	Na				
An-1-1	0-15	AC	0.15			5.50	5.12	0.80	3.62	0.10	0.02	0.02	0.04	0.01-	0.01	0.01	0.03	0.26	46.2	7.78	123
An-1-2	15-23	IIC	0.20			6.39	5.57	0.64	2.14	0.26	0.03	0.04	0.11	0.07	0.01	0.01	0.07			8.07	156
An-1-3	23-40	IIIC	0.11			6.30	5.74	0.61	1.47	0.13	0.02	0.01	0.06	0.03	0.01	0.01	0.03			7.70	115
An-1-4	40-44	IVC	0.19			6.21	5.63			0.39	0.06	0.04	0.11	0.10	0.03	0.02	0.09			8.62	
An-1-5	44-	VC	0.04			6.38	5.80	0.62	1.70	0.13	0.03	0.02	0.05	0.05	0.01	0.01	0.03			7.61	135

An-2	280-290	XC	0.03			6.90	5.47	0.78	1.93	1.23	0.48	0.14	0.20						7.71	136
An-3-1	0- 6	AC	0.56	0.041	13.7	5.50	4.87	1.54	3.03	0.76	0.10	0.04	0.08	0.07	0.03	0.02	0.08	2.05	38.0	7.78	144
An-3-2	6-12	IIC	0.62	0.042	14.8	6.02	5.17			1.08	0.14	0.05	0.11	0.08	0.03	0.03	0.09	2.12	54.2	7.55	
An-3-3	12-19	$IIIC_1$	0.27			6.10	5.31	0.90	1.30	0.29	0.05	0.04	0.05	0.03	0.01	0.02	0.04	0.76	43.4	7.91	127
An-3-4	19-27	$IIIC_2$	0.27			6.21	5.30	0.82	0.84	0.41	0.05	0.04	0.07	0.02	0.01	0.03	0.05			8.01	140
An-3-5	27-32	IVC	0.34	0.020	17.0	6.03	5.44			0.62	0.07	0.04	0.05	0.02	0.01	0.02	0.03	1.20	58.3	7.56	
An-3-6	32-	VC	0.14			6.49	5.47	0.75	3.72	0.23	0.04	0.04	0.03	0.02	0.01	0.02	0.02	0.54	50.0	7.72	52
An-4	10-15	IIA	1.40	0.053	26.4	5.30	4.87	2.05	5.70	0.57	1.35	0.18	3.80	0.21	0.82	0.11	3.74	1.64	62.1	8.55	140