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The Soils on the Krakatau Islands

I. Field Observation

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Introduction

Krakatau volcano complex is situated in the Sunda Strait between Java and Sumatra. They consist of four islands, namely, Rakata Besar, Sertung, Rakata kecil and Anak Krakatau. Anak Krakatau (latitude: 6°06′05.8″ South, longitude: 105°25′22.3″ East) is an active volcano and is surrounded by the other three islands (Fig. 1.).

The authors surveyed on the four islands as members of Ecological team of Krakatau expedition in 1982 and studied the chemical, physical and mineralogical properties of the soil samples of four islands.

As far as the authors know, no studies has been conducted on the soils on Sertung and Anak Krakatau. Only a few studies on the soils on Rakata Kecil and Rakata Besar were carried out (Van Baren, 1931[1], Newsome, 1982[2]), after the explosive eruption in 1883.

Van Baren took the soil samples derived from 1883 pyroclastic flow at the coast of Rakata Kecil. Based on the chemical analysis, he indicated that the soils had been weathered rapidly. Newsome investigated the soils on Rakata Besar and observed the well developed A_1 horizon with high biological activities, especially in the stable gullies, and showed the primary minerals had been decomposed, resulting in the release of cations in the surface horizons with slight translocatory process. Moreover, it was shown that fairly large amounts of crystalline clay minerals, mostly smectite, were present in the clay fractions, though those minerals were assumed to have been formed as the result of geological process.

The main objectives in the series of present studies (Part I. II, III and IV) are to elucidate the soil formation process of 1883 pyroclastic flow and of volcanic deposits from Anak Krakatau since 1927 deposited on the four islands (four islands are uninhabited islands).

The itineraries of field survey and of soil sampling in 1982 were as follows; Rakata Besar (12–20th July, 1st August, 24–28th October), Sertung (5–9th, July), Rakata Kecil (27–28th, 31st, July) and Anak Krakatau (10th, 29–30th July).

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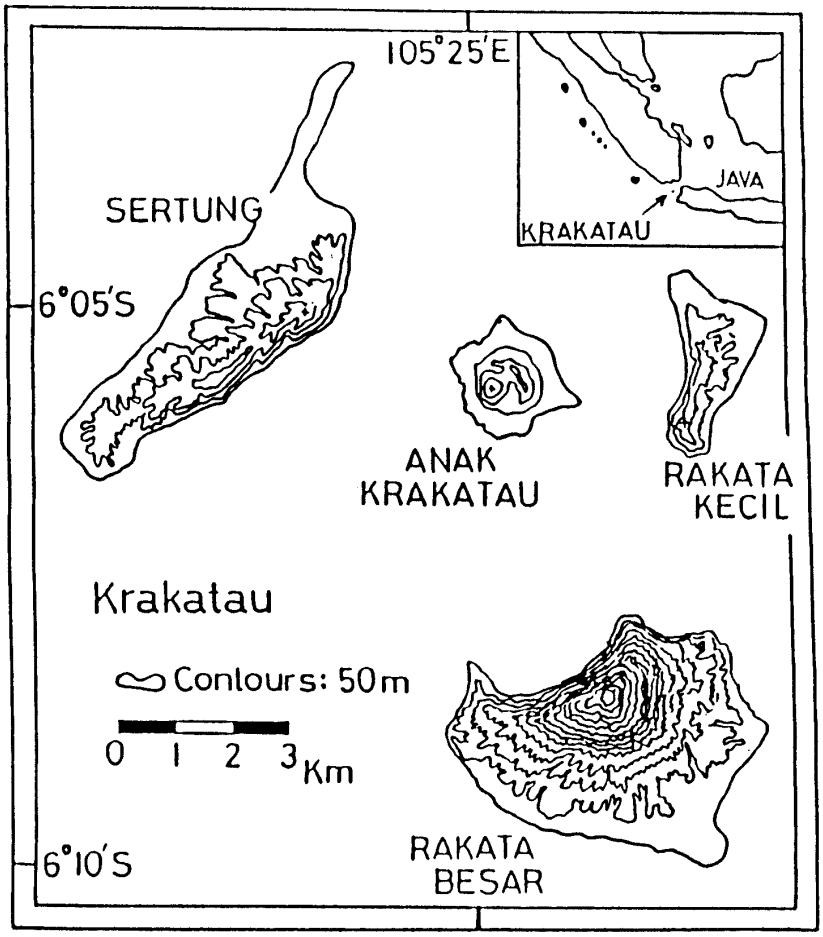

Fig. 1. Krakatau Islands.

Brief reviews of studies important to soil formation process

1. Volcanic history

Volcanic history of Krakatau complex is schmatically shown in Fig. 2[5-a,6-d,8].

The explosive eruption of Krakatau (Krakatoa, Rakatoa) took place on the 28–27th August, 1883 as shown in Fig. 2.(d) and (e). A large part of Krakatoa (Rakatoa) disappeared, enormous quantities of volcanic dust were projected into the atmosphere and excessive amounts of pyroclastic flow were deposited on the three islands, namely, the rest of Krakatoa (now Rakata Besar), Sertung (Verlaten Isle. or Forsaken Isle.) and Rakata Kecil (Lang Isle. or Long Isle. or Pajang Isle.).

After about 40 years of resting period, in 1919, Krakatau volcanic group became active at the submarine creater. From 29th December to 6th February in 1927, new volcanic island (Anak Krakatau) appeared from sea level with diameter 8–10 m and height 8.93 m. This new island was formed from basaltic magma and situated at the nearly central location among Rakata Besar, Sertung and Rakata Kecil.

According to "Data Dasar Gunungapi Indonesia[4]", data collection of volcanoes in Indonesia, and other[6-a], the large and small eruptions of Anak Krakatau had been occurred almost every years since 1927. Lava from Anak Krakatau had outpoured in 1960–1963, 1972–1973, 1975 and 1979. At present, the elevation of Anak Krakatau is 199 m from the sea level and frequent summit eruption with volcanic ejecta and gasses is continuing. And fresh volcanic ashes are depositing on

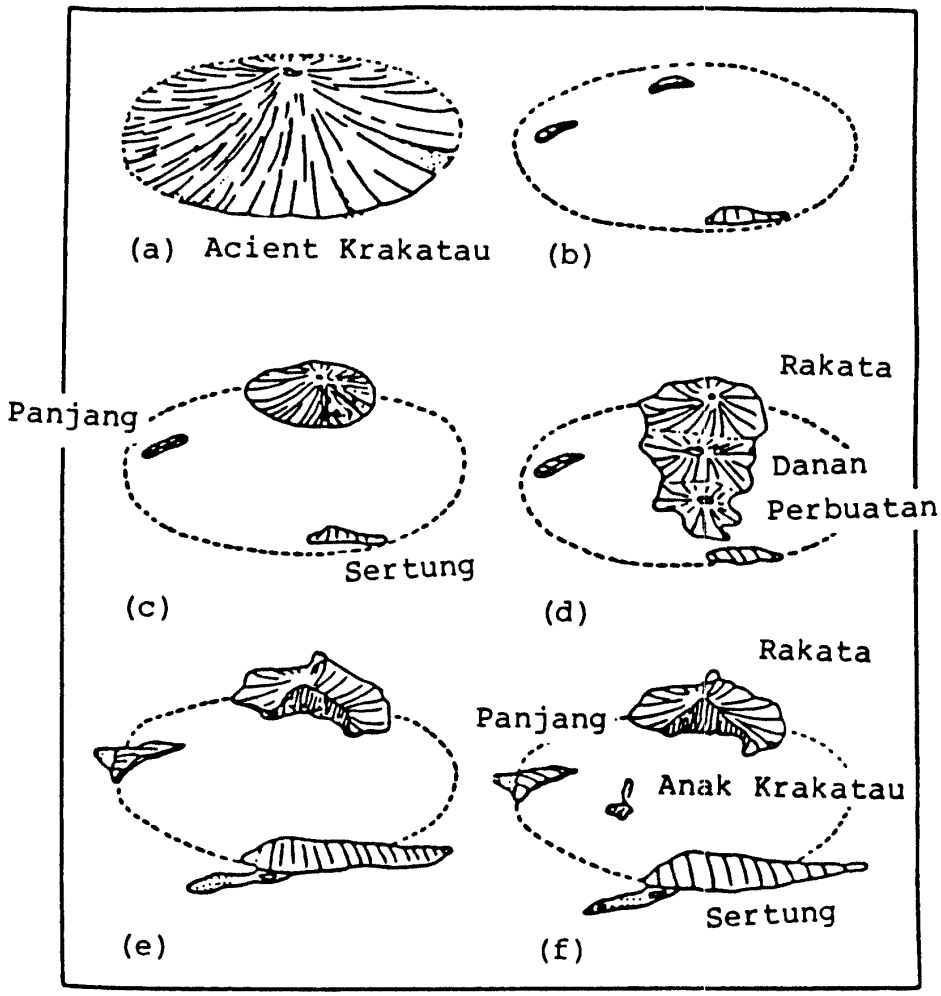

Fig. 2. Volcanic history of the Krakatau Group (looking SE-wards).
(a) to (d) showed development of Krakatau volcano complex before 1883 outburst.
(e) to (f) showed after 1883.
(f)··· Panjang: Rakata Kecil, Rakata: Rakata Besar.

the four islands (see Photo. 4).

Total 289 references on the Krakatau, befor 1883: 9, from 1883 to 1927: 126, from 1927 to 1974: 154, are listed in "Data Dasar Gunungapi Indonesia"[4], and many references are cited in "Krakatau 1883" by Simkin, T. and Fiske, S.[6].

The chemical and mineralogical properties of lava before and after 1883 and those of 1883 pyroclastic flow were described. But from the stand-point of soil formation processes after 1883, location of deposition, size and thickness of different ejecta and also vegetations are most important.

A following few descriptions important to soil formation processes can be found in "Data Dasar Gunungapi Indonesia"[4].

In 1949, early vegetation was found in Anak Krakatau. On 10–11th October, in 1952, volcanic ejecta were deposited on the Anak Krakatau as thick as 3 m and on the Sertung, Rakata Kecil as thick as 0.5–1.5 m. In 1953, on 20–23th September, strong eruptions occurred and the half parts of vegetations in Sertung and Rakata Kecil were buried (hight of Anak Krakatau was 116 m). During the eruption period from 1960 to 1963, volcanic ashes, gravels, from Anak Krakatau were deposited on Java coast. But the thickness of volcanic ejecta deposited on Sertung, Rakata Kecil and Rakata

Besar was not recorded. In the eruptions in 1972–1973, especially in those on 4–6th January, 1973, large amounts of volcanic ashes, sands, gravels and bombs were deposited near the eruption point.

2. Geology, stratigraphy and geomorphology

According to the geological map by Volcanological Survey of Indonesia[4], report by Oba et al.[3] and "Krakatau 1883" by Simkin and Fiske[6], about half parts of Anak Krakatau are covered with scorias and lithic blocks, and small area of colluvial deposits are distributed on the east, north and northern east coast, the rest of this island consist of outpoured lava in 1963, 1972–1973, 1975 and 1979. The basement of Rakata Besar, Sertung and Rakata Kecil is old lava, consisting of basalt, tridymite andesite and hyperthen andesite. Thick (about 10–50 m) 1883 pyroclastic flow was deposited on the basement lava. Between the basement rock and 1883 pyroclastic flow, pumice fall of 0–2 m thickness of 1883 is present.

Simkin and Fiske[6-c] showed the detailed stratigraphy of volcanic ejecta of Krakatau complex, i.e. 21 layers before 1883 and 23 layers of 1883 pyrocclastic flow are described as schematic column. But five or six layers of ashes and scorias which were deposited on 1883 pyroclastic flow in Sertung and Rakata Kecil were not reported by them. Chemical and mineralogical composition of 1883 pyroclastic flow and volcanic ash of each period are briefly shown in Table 1 and 2 (Simkin and Fiske[6-b], Oba et al.[3]).

The most striking geomorphological feature of Rakata Besar, Sertung and Rakata Kecil is the presence of a large number of deep gullies developed on 1883 pyroclastic flow. From the sea, especially on the west and southern coast of Rakata Besar and Sertung, these gullies are seen as V shaped hanging valleys (see Photo. 2.). In the three islands, gullies are developed extreamely on Rakata Besar, radiating from the summit of this island down to the perimeter of the island; close to

Table 1. Chemical composition of the pumice and ashes.

	Pumice Rakata Kecil 1883 %	Ash Rakata Kecil 1928 %	Ash Sertung 1982 %
SiO_2	67.64	51.84	52.60
Al_2O_3	15.65	18.48	17.81
Fe_2O_3	1.62	2.95	2.68
FeO	1.42	6.64	6.00
MnO	0.06	0.21	0.19
MgO	0.99	5.97	4.77
CaO	3.02	9.05	8.57
Na_2O	4.03	2.97	3.55
K_2O	2.91	1.07	0.76
TiO_2	0.57	0.93	1.01
Cl		0.003	
SO_3	0.13	0.05	
P_2O_5	0.06		0.27
H_2O^+	2.06	0.14	1.41
H_2O^-	0.08		0.12
References or Analyst	Simkin and Fiske[6] (1984), p. 387		Oba et al.[3] (1983), p. 55

Table 2. Mineral composition of pyroclastic flow and ash.

	1883 Pyroclastic flow. Sertung	Volcanic ash from Anak Krakatau. Sertung (1982)
Olivine		+
Orthopyroxene	+	++
Clinopyroxene	+	++
Ore mineral	+	+
Plagioclase	++	+++
Volcanic glass	+++++	++++
Analyst	Oba et al.[3] (1982), p. 51–52.	

the summit deep gullies of 40 m depth and slope angles of 45–60° are common. On Sertung and Rakata Kecil relatively small gullies are present. These gullies might have been formed during a very active erosive phase soon after 1883 explosive eruption, as suggested by large tree growing in the troughs of most of the gullies (Suwardi[9], Richard[5-b]).

3. Climate

In general, at west Java and south Sumatra, the west monsoon brings heavy rain from the Indian Ocean and the east monsoon brings dry air from Australia. The dry season begins in May and ends in October. There is no exact meteological data for the islands in Sunda Strait. The precipitation and the temperature data on Rakata Kecil in 1929 (Table 3.) by Stehn is only valuable ones (described in Van Baren's report[1]).

The authors calculated the monthly precipitation at Cilegon (northwestern end of Java) and at Malingping (about southwestern end of Java) from the rainfall graph described on the map of West Java (Publisher: P. T. Stranico JL Cempaka Barul A. No. 2). As shown in Table 4., annual rainfalls of Cilegon and Malingping are 1811 and 3319 mm, respectively, and rainfalls during dry

Table 3. Precipitation and temperature on Rakata Kecil in 1929. Van Barren (1931)[1]

	Rainfall (mm)	(%)	Temp. (°C)
Jan.	356.5	(13.61)	27.7
Febr.	619.5	(23.65)	27.9
March	266.5	(10.17)	27.4
April	178	(6.79)	27.8
May	72	(2.75)	28.2
June	138	(5.27)	27.3
July	9	(0.34)	26.9
Aug.	79	(3.01)	27.6
Sept.	0		28.6
Oct.	68.3	(2.61)	28.7
Nov.	244.7	(9.34)	28.2
Dec.	585.5	(22.46)	26.9
Annual	2620	(100)	Annual aberage 27.8

season (from June to September) are 59–119 mm per month. Furthermore, the authors were really suffered from heavy rain on 18th and 19th July in 1982 while they stayed in Rakata Besar.

Table 4. Precipitation on Cilegion (northern west of Java) and Malingping (southern west of Java).
(Jawa Barat Sekala 1:1.750.000, Publisher: P.T. Starnico JL Cempaka Barul-A No. 2)

	Cilegon (mm)	Malingping (mm)
Jan.	327	459
Febr.	254	348
March	195	362
April	143	334
May	125	223
June	90	143
July	90	143
Aug.	66	104
Sept.	59	118
Oct.	92	250
Nov.	132	397
Dec.	243	484
Annual	1811	3319

From the above-mentioned data and the authors' own experiences, though monthly temperature are almost constant (27°C–29°C), the annual rainfall for Krakatau Islands is presumed to vary from 1500 mm to 3000 mm. In some year, heavy rainfall occurs during the dry season and fine weather continues in the wet season. The driest season is severe time for the plant growth but it is unbelievable that the rainfalls in all September during 100 years after 1883 explosive eruption are zero as shown in Table 3.

4. Vegetation and succession

The results of studies on the vegetation and in the succession on the Krakatau Islands by Tagawa, Suzuki et al.[10,11] can be briefly summarized as follows; The pioneer higher plants that grow on the scoria, volcanic sand, ash and lithick block in Anak Krakatau was *Saccharum* sp. and *Imperata cylindrica* (Alang-alang). With the advance in soil formation from above-mentioned volcanic ejecta, *Casuarina* forest mainly develops on the four islands. From Casuarina forest, the succession presumed to change to *Neonauclea* forest on the wet soil, and to *Timonius* forest on the dry soil. At present, even subclimax seasonal forest can not be found in the four islands, and *Dysoxylum* forest is most advanced specimen. On the beach of islands except for Anak Krakatau, mixed beach forest such as *Barringtonia* sp., *Artocarpus* sp., *Cocas* sp. and *Hibiscus* sp. are developed.

During the early stage of soil formation from volcanic ash in Japan, the grasses such as *Imperata* sp. and *Miscanthus* sp. are often dominant higher plants. But on the Krakatau Islands, young volcanogenous soil are presumed to be developed under the tree vegetation.

Field method

About twenty pedons were examined and described in the fresh pits, using the standard method of Soil Survey Mannual[7].

In addition to the profile examination, the observations of the depth of gullies, the occurrence of the re-deposited different cumulative layers and the dominant vegetations etc. were made to obtain the idea that the representative stratification of different ejecta and deposits on the four islands.

Hereafter, Rakata Besar, Sertung, Rakata Kecil, Anak Krakatau and the the soil derived from ejecta after 1927 are designated as Be, St, Ke, An, and the soils after 1927, respectively.

Results and discussions

1. Representative stratification of different ejecta and deposits on each island

In three islands, except for An about eight layers were present within 1 m from the surface. But the existence and the stratification of them were different on the each islands.

1) Rakata Besar (Be)

In this island, soils were mainly derived from the re-deposited 1883 pyroclastic flow as shown in Fig. 3.(a). As very small amounts of dark-colored scorias originated from An were present in A, IIA and IIIA horizon, but several layers deposited after 1927 were not present. Small amounts of blackish obsidian in 1883 pyroclastic flow and old igneous rock fragments before 1883 were found in the re-deposited layers.

As shown in Fig. 2. and 6., N–N–W side of this island is an almost vertical cliff and many deep gullies were developed in 1883 pyroclastic flow from the summit down to the perimeter. According to published report[2] and our observation, those gullies were assumed to have been formed during the early stages of soil formation with poor plant growth.

When A horizon began to develop on the upper part of 1883 pyroclastic flow, a big scaled soil erosion of A horizon and unweathered pyroclastic flow below A horizon occurred with heavy rainfall. Then the mixture of these materials re-deposited on the surface of low altitude or on the partly eroded pyroclastic flow. As the result of intermittant repetitions of soil formation and the truncation of the soil and re-deposition, many deep gullies were developed and several buried A, B and C horizons were formed in the profile. The presence and the thickness of buried A horizon were various owing to the relief.

Fig. 3.(a) showed the representative cumulative layer at the steep slope of gully cliff in which several buried A_1-like horizons are present, suggesting the occurrences of continuous surface truncation and re-deposition on the lower slopes. At the stable gully floors and the stable gully ridge, the layer 1 of Fig. 3(a) was 0.5–1 m depth and A_1 horizon with crumby structure is well developed. Even among such pedons, however, the substratum of the profile often shows the features of secondary deposition, as indicated by a very abrupt boundary and changes in texture and color in the materials of 1883 pyroclastic flow.

At the summit*, secondary deosited pyroclastic flow was not present.

In some parts of higher altitude, fragmented lava and its weathering to some extent were

* Altitude: 813 m on the map, but our two altimeters showed 730 m, 1st August in 1982.

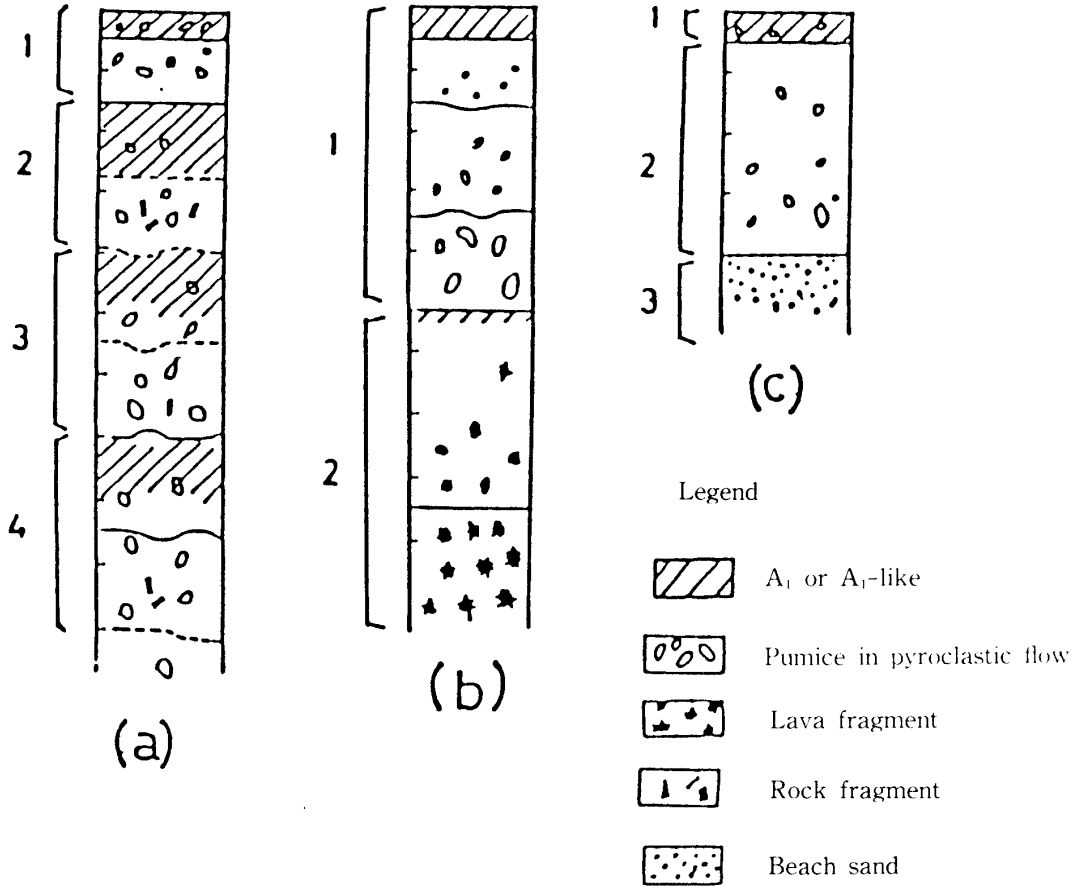

Fig. 3. Representative columnar sections of the layers on Rakata Besar.

observed in the position below pyroclastic flow as shown in Fig. 3.(b).

When vegetations were densely grown, and big scaled soil truncation did not occur frequently beside at the northern cliff, soil formation and humus accumulation were assumed to be advanced and A horizon was well developed.

Beach sand soils were distributed in small areas of southern coast. Beach sand is not calcite, and re-deposited pyroclastic flow with cobbly pumices was deposited (thickness of this layer is about 5–20 cm) between the surface soil and beach sand. Surface soil of 2–10 cm thick was the mixture of re-deposited pyroclastic flow, fine volcanic ejecta after 1927 and beach sand as shown in Fig. 3.(c) and Fig. 6.(Be–6).

2) Sertung (St)

Beach sand soil similar to that of Be is distributed on the sand spits at the northern part and the western coast, shown in Fig. 4.(b) and Fig. 7.(St–2).

On the large parts of this island, several layers of ejecta originated from An, namely, coarse and fine textured, dark-colored scorias, and volcanic ashes were deposited on 1883 pyroclastic flow. The surface of buried 1883 pyroclastic flow was partly eroded or re-deposited. Fragmented lavas or basement rocks existing in Be were not found in surveyed pedons within 1–1.5 m from the surface, but they were found in the northern west coast below pyroclastic flow. Photo. 2. showed the development of the gullies in this island.

During from 1883 to 1927, considerably steep gullies were assumed to have been developed but their scales were smaller than of Be owing to the differences of the elevations (Be: 813 m. St: 182 m).

As shown in Fig. 4., from the surface to substratum in a profile, representative stratification of

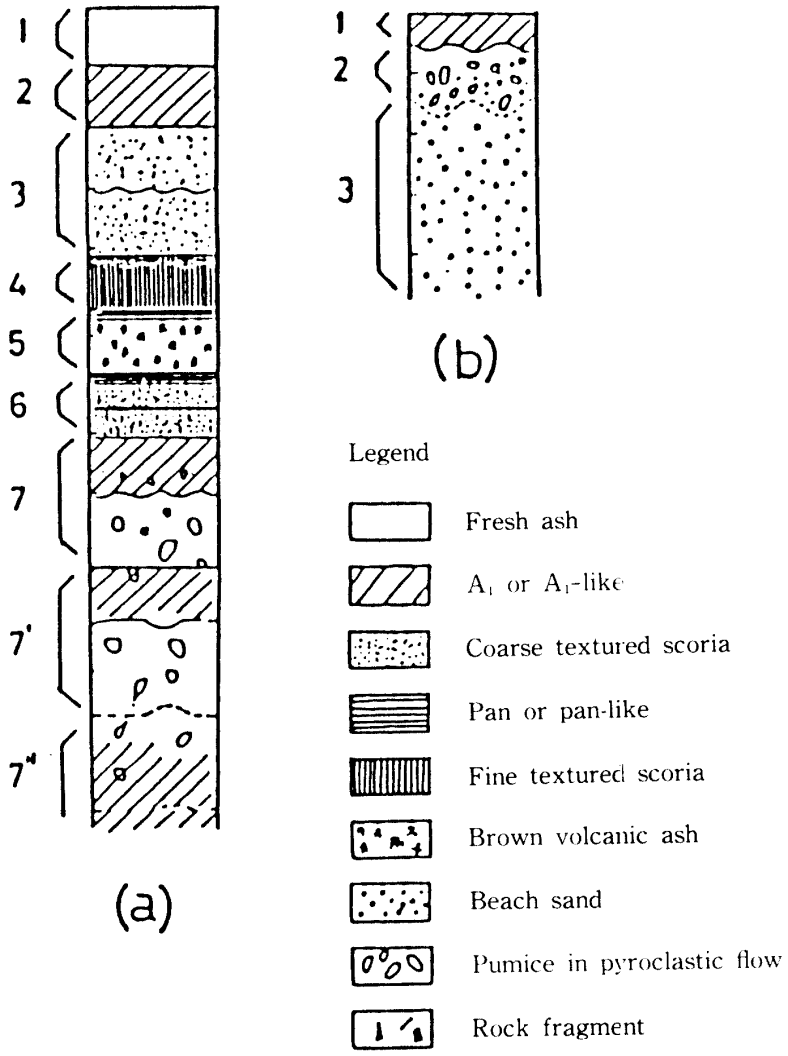

Fig. 4. Representative columnar sections of the layers on Sertung.

different ejecta was as follows:

(1) Fresh unweathered volcanic ash layer. Thickness: 0–10 cm, layer 1 in Fig. 4.(a). Hereafter this layer is designated as fresh ash.

(2) A_1 or A_1-like horizon of dark-colored volcanic ash layer. Thickness: 10–20 cm, layer 2 in Fig. 4.(a), designated as A_1 or A_1-like. In this layer, A horizon was well or weakly developed. Small amounts of fine textured scoria was contained.

(3) Coarse textured dark-colored scoria layer. Thickness: 20–40 cm, layer 3 in Fig. 4.(a), designated as coarse textured scoria (upper).

(4) Fine textured dark-colored scoria layer. Thickness: 10–40 cm, layer 4 in Fig. 4.(a), designated as fine textured scoria.

(5) Fine textured brown-colored volcanic ash soil layer. Thickness: 15–35 cm, layer 5 in Fig. 4.(a), designated as brown volcanic ash.

(6) Coarse textured dark-colored scoria layer. Thickness: 15–35 cm, layer 6 in Fig. 4.(a), designated as coarse textured scoria (lower).

(7) Buried A or B or C horizon derived from 1883 pyroclastic flow. Thickness: A or BC was 5–15 cm, BC or C was 1 m or more, layers 7, 7′ and 7″ in Fig. 4.(a), designated as pyroclastic flow and/or buried pyroclastic flow, and/or pumice in pyroclastic flow.

Remarks:

(a) Ash pan layer of 5–10 cm thick with mottling was continuously or discontinuously exists between layer 3 and 4, layer 4 and 5, layer 5 and 6. Several sets of laminar pan consist of ash and scoria with mottling was discontinuously exist in layer 3, in the upper part of layer 5 and in layer 6.

(b) Presence and thickness of respective layer and pan were varied depending on the degree of soil erosion and the relief. At the steep locations, more than one layers of above-mentioned 6 layers were absent or very thin. Whereas, at the low place or bottom of the ravine and the gully, respective layer was thick and the occurrence order of respective layer was frequently confused.

(c) Brown volcanic ash layer (layer 5) was somewhat glassy, and was found in An. Therefore, the layers 1 to 5 in St were presumed to be originated from the ejecta of An after 1927.

3) Rakata Kecil (Ke)

Representative columnar sections were schematically shown in Fig. 5.

Generally speaking, the development of gullies, the stratification of respective layer were similar to those of St, that is, layers 1 to 5 are the same as those of St (Fig. 5.). The altitude of the

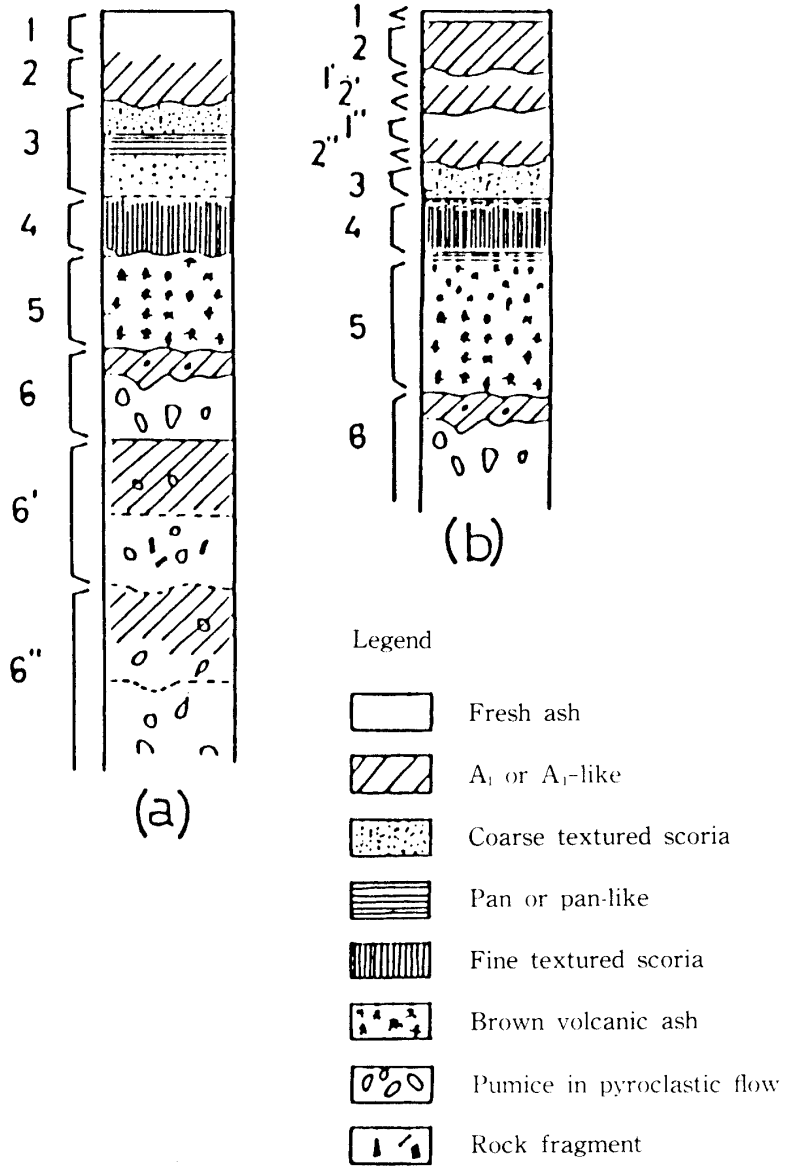

Fig. 5. Representative columnar sections of the layers on Rakata Kecil.

summit of this island is 147 m.

However, the following items were clearly different from those of St.

(a) Coarse textured scoria layer below brown volcanic ash layer, layer 6, designated as coarse textured scoria (lower) on St is not present. Accordingly, layer 6 on Ke is pyroclastic flow and is corresponded to layer 7 on St.

(b) Thickness of respective layer on pyroclastic flow was relatively thin compared with that of St. At the large parts of this island, the depth from the surface to pyroclastic flow was 50–70 cm.

(c) Layers 1 and 2 (corresponded to layers 1 and 2 on St) were frequently divided to two or three layers which were developed to A and B horizon of 1–2 cm thick, shown as (1, 2), (1′, 2′), (1″, 2″) layers in Fig. 5.(b).

(d) Ash pans between the respective layers were thin or more discontinuous than those of St, and the mottling of the pans was also undeveloped.

4) Anak Krakatau (An)

Most part of this island were covered with the outpoured lavas, the lithic fragments of igneous rocks, lapiliis, scorias and volcanic ashes. The stratification of ejecta was complicated owing to the continuous ejecta fall and to their re-deposition. Therefore, the authors could not describe the representative schematic columnar sections of this island as those in the other three islands.

As stated above, *Saccharum* sp. and *Imperata* sp. are pooly grown on the coarse-, fine-textured scoria depositions (Photo. 4). Pedogenesis is just going on in those volcanic materials but the formation of A horizon was very weak. *Casuarina* forest develops on colluvial deposit at the east coast. Below this colluvial deposit, thin discontinuonus cobbly pumice layer and the beach sands were present. The cobbly pumices were presumed to be transported by sea current.

Brown volcanic ash layer (layer 5 on St and Ke) of 30–50 cm thickness was discontinuously present in the depth of about 2–10 m from the surface.

2. Descriptions of observed profiles

Figs. 6, 7, 8 and 9 showed the sampling sites of surveyed areas, and their schematic columnar sections. These sites were almost identical with those of the quadrats for the vegetation study by Tagawa et al[10].

(1) Rakata Besar

Location of sampling sites and their columnar sections of soils on Rakata Besar were shown in Fig. 6.

Site Be–1

Topography: Steep sloping (20°) to the east. Position: Upper part of gully. Altitude: 250 m. Vegetation: Dominant species was *Neonauclea calycina*.

Profile description:

A_{11} (0–5 cm). Sample No.: Be–1

Corresponding to the upper part of layer 1 in Fig. 3(a).

Brownish black (10YR 2/2, moist); clay loam; moderate fine to coarse crumby; firm; abundant fine to medium roots; abrupt wavy boundary.

A_{12} (5–7 cm). Sample No.: Be–1–2.

Corresponding to the upper part of layer 1 in Fig. 3(a).

Grayish yellow brown (10YR 4/2, moist); clay loam; moderate fine to coarse crumby; slightly firm; abundant fine to medium roots; diffuse wavy boundary.

BC (7–17 cm). Sample No.: Be–1–3.

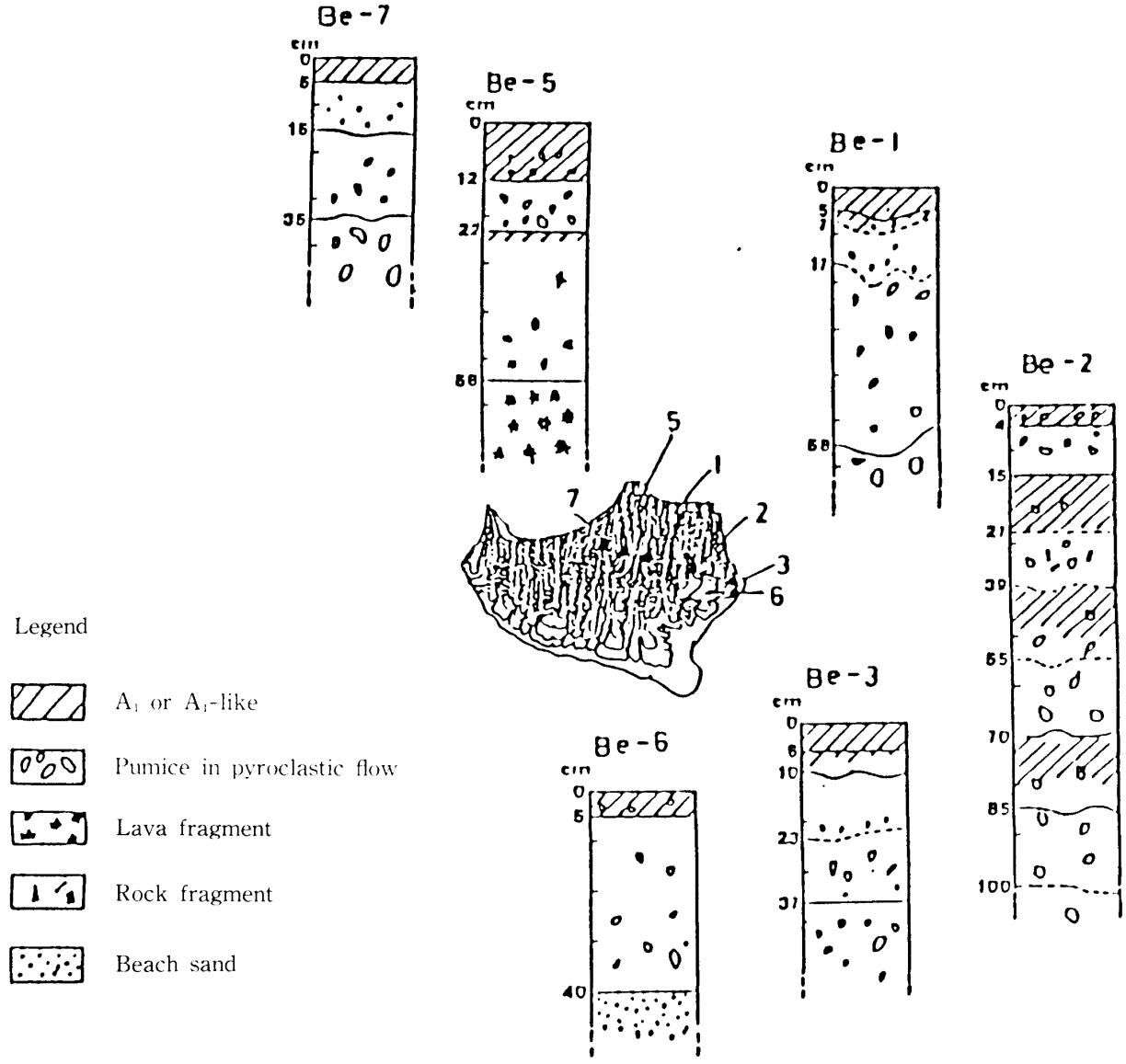

Fig. 6. Locations of sample sites on Rakata Besar (Be) and their columnar sections.

Corresponding to the middle part of layer 1 in Fig. 3(a).

Dull yellowish brown (10YR 5/4, moist); sandy loam; weak fine to coarse subangular blocky plus structureless; friable and loose; abundant fine to coarse roots; diffuse wavy boundary. Many angular and cobbly pumice and some igneous rock fragments were present.

IIC_1 (17–58 cm). Sample No.: Be–1–4, Be–1–5.

Corresponding to the lower part of layer 2 in Fig. 3(a).

Dull yellow orange (10YR 6/3, moist); loamy sand; structureless; loose; few coarse roots; abrupt wavy boundary. Many angular and cobbly pumice fragments of less than 4.5 cm in diameter were present.

IIC_2 (58 cm–). Sample No.: Be–1–6.

Corresponding to the lower part of layer 2 in Fig. 3(a).

Dull yellow orange (10YR 7/2, moist); sand; structureless; loose; few medium to coarse roots. Many angular and cobbly pumice fragments of less than 6 cm in diamater were present.

Remarks: Upper part of IIC_1 was not continuous.

Site Be-2 (Photo. 5)

Topography: Steep sloping (24°) to the northern west. Position: Surface of gully cliff. Altitude: 85 m. Vegetation: Dominant species was *Neonauclea calycina*.

Profile description:

A (0–4 cm). Sample No.: Be-2-1.

Corresponding to the upper part of layer 1 in Fig. 3(a).

Brownish black (10YR 2/2, moist); silt loam; strong fine to coarse crumby; firm; abundant fine to coarse roots; abrupt smooth boundary. Many angular and cobbly purmice fragments of 0.5 to 2 cm in diameter were present.

BC (4–15 cm). Sample No.: Be-2-2.

Corresponding to the lower part of layer 1 in Fig. 3(a).

Dull yellow orange (10YR 6/3, moist); sand; structureless plus weak medium to coarse subangular blocky; friable; few medium to coarse roots; smooth abrupt boundary. Many angular and cobbly pumice fragments of 0.2 to 1 cm in diameter and also some igneous rock fragments were present.

IIAB (15–27 cm). Sample No.: Be-2-3.

Corresponding to the upper part of layer 2 in Fig. 3 (a).

Dark brown(10YR 3/3, moist); silt loam; weak fine to coarse crumby; friable to firm; common fine to coarse roots; diffuse smooth boundary. Many angular and cobbly pumice fragments of 0.2 to 1 cm in diameter were present.

IIBC (27–39 cm). Sample No.: Be-2-4.

Corresponding to the lower part of layer 2 in Fig. 3(a).

Dull yellow brown(10YR 4/3, moist); silt; weak fine to coarse subangular blocky plus structureless; friable and loose; common fine to coarse roots; diffuse smooth boundary. Many cobbly pumice fragments of less than 5 cm in diameter and some angular rock fragments of less than 7 cm in diameter were present.

IIIAB (39–55 cm). Sample No.: Be-2-5.

Corresponding to the upper part of layer 3 in Fig. 3(a).

Dull yellow orange (10YR 6/3, moist); sand; weak fine to coarse subangular blocky; friable; few fine to medium roots. Many cobbly pumice fragments of less than 2 cm in diameter were present.

IIIBC (55–70 cm). Sample No.: Be-2-6.

Corresponding to the lower part of layer 3 in Fig. 3(a).

IVAB (70–85 cm). Sample No.: Be-2-7.

Corresponding to the upper part of layer 4 in Fig. 3(a).

IVBC (85–100 cm). Sample No.: Be-2-8.

Corresponding to the lower part of layer 4 in Fig. 3(a).

VC (100 cm–). Sample No.: Be-2-9.

Corresponding to the lower part of layer 5 in Fig. 3(a).

Remarks: Many angular and cobbly pumice fragments of 1.5 to 2 cm in diameter and some igneous rock fragments were present in IIIBC to VC horizons. This pedon clearly showed the surface truncation and re-deposition processes on a steep slopes on Rakata Beasar.

Site Be-3 (Photo. 6)

Topography: Gently sloping (4°) to the southern west. Altitude: 20 m. Vegetation: Dominant

species was *Terminalia calophyllum.*

Profile description:

A_{11} (0–6 cm). Sample No.: Be–3–1.

Corresponding to the upper part of layer 1 in Fig. 3(a).

Very dark reddish brown (2.5YR 2.5/2, moist); clay loam; strong fine to coarse crumby; firm; abundant fine to coarse roots; clear smooth boundary.

A_{12} (6–10 cm). Sample No.: Be–3–2.

Corresponding to the upper part of layer 1 in Fig. 3(a).

Grayish brown (5YR 4/2, moist); silt loam; moderate medium to fine crumby; friable; abundant fine to coarse roots; abrupt wavy boundary.

BC (10–23 cm). Sample No.: Be–3–3.

Corresponding to the lower part of layer 1 in Fig. 3(a).

Dull yellow orange (10YR 6/4, moist); silt loam; moderate fine to coarse subangular blocky; friable; common fine to medium roots; diffuse wavy boundary. Some cobbly pumice fragments of 0.4 to 2 cm in diameter were present.

IIC_1 (23–25 cm). Sample No.: Be–3–4.

Corresponding to the lower part of layer 2 in Fig. 3(a).

Dull yellow orange (10YR 6/3, moist); silt loam; weak fine to very coarse anglar blocky; friable; few medium to coarse roots; abrupt smooth boundary. Many cobbly pumice fragments of less than 2 cm in diameter and iron mottles in pores were present.

IIC_2 (25–30 cm). Sample No.: Be–3–4, 5.

Corresponding to the lower part of layer 2 in Fig. 3(a).

Grayish yellow brown (10YR 6/2, moist); loam. Some cobbly pumice fragments of 0.2 to 0.5 cm in diameter were present. Other descriptions are the same as above.

IIC_3 (30–37 cm). Sample No.: Be–3–5.

Corresponding to the lower part of layer 2 in Fig. 3(a).

Dull yellow orange (10YR 6/3, moist); silt loam; weak fine angular blocky; friable; abrupt smooth boundary.

IIIC (37 cm–). Sample No.: Be–3–6.

Corresponding to the lower part of layer 3 in Fig. 3(a).

Grayish brown (5YR 6/2, moist); loamy sand; structureless plus weak coarse subangular blocky; very few medium to coarse roots. Many cobbly pumice fragments of 0.2 to 10 cm in diameter were present.

Remarks: This pedon situated at a stable gully ridge of lower altitude, and showed a weak formation of cambic B horizon in BC horizons.

Site Be–5

Topography: Steep sloping (38°) to the east. Altitude: 500 m. Vegetation: Dominant species was *Neonauclea calycina.*

Profile description:

A (0–12 cm). Sample No.: Be–5–1.

Corresponding to the upper part of layer 1 in Fig. 3(b).

Dark reddish brown (5YR 2.5/2, moist); sandy clay loam; strong fine to coarse crumby; friable; abundant fine to coarse roots; clear smooth boundary. Some pumice fragments of less than 0.5 cm in diameter.

BC+C (12–22 cm). Sample No.: Be–5–2 (BC, 12–17 cm), Be–5–3 (C, 17–22 cm).

Corresponding to the lower part of layer 1 in Fig. 3(b).

Bright yellowish brown (10YR 6/6, moist) in upper part and dull yellow orange (10YR 7/3, moist) in lower part; sandy loam; weak coarse subangular blocky plus structureless; very friable; few medium to coarse roots; abrupt smooth boundary. Many pumice fragments of less than 2 cm in diameter were present.

IIAB (22–55 cm). Sample No.: Be–5–4.

Corresponding to the upper part of layer 2 in Fig. 3(b). This is a buried AB horizon derived from old lava.

Brown (10YR 3/6, moist) and upper part is more dark; sandy clay loam; moderate fine to coarse subangular blocky; friable; abundant fine to very coarse roots; abrupt smooth boundary. Many igneous rock fragments of less than 1.5 cm in diameter were present.

IIIC (55 cm–). Sample No.: Be–5–5.

Corresponding to the lower part of layer 2 in Fig. 3(b).

Dark reddish brown (2.5YR 3/4, moist). This layer is consisted of lava fragments (diameter of less than 2 mm for rounded shaped and less than 5 cm for angular ones), and the size of them become coarser downwards. abundant fine to medium roots.

Remark: IIAB and IIIC layers are the soils derived from the lava before 1883.

Site Be–6

Topography: Level. Position: Coast. Altitude: 1 m. Vegetation: Dominant species was *Barringtonia asfica.*

Profile description:

A (0–5 cm). Sample No.: Be–6–1.

Corresponding to layer 1 in Fig. 3(c).

Grayish brown (7.5YR 4/2, moist); loam; weak fine to medium subangular blocky; friable; frequent fine to medium roots; clear wavy boundary. Many cobbly pumice fragments of 0.2 to 2 cm in diameter were present.

IIBC (5–40 cm). Sample No.: Be–6–2.

Corresponding to layer 2 in Fig. 3(c).

This layer is a mixture of the materials above and cobbly pumice (10YR 7/2, moist); frequent fine to medium roots; clear wavy boundary.

IIIC (40 cm–). Sample No.: Be–6–3.

Corresponding to layer 3 in Fig. 3(c).

Brownish black (7.5YR 3/1, moist), sand; structureless; loose; few fine roots.

Remarks: the contents and the size of cobbly pumice in IIBC layer were variable in a one pit. IIIC was virtually beach sand.

Site Be–7.

Topography: Level (summit of this island). Altitude: 730 m. Vegetation: Dominant species was *Shefflera-Leucosyke.*

Profile description:

A (0–5 cm). Sample No.: Be–7–1.

Corresponding to the upper part of layer 1 in Fig. 3(b).

Brownish black (7.5YR 3/2, moist); loam; strong fine to coarse crumby; firm; abundant fine to coarse roots; abrupt smooth boundary.

B (5–15 cm). Sample No.: Be–7–2.

Corresponding to the middle part of layer 1 in Fig. 3(b).

Dull yellow brown (10YR 4/3, moist); loam; moderate fine to coarse subangular blocky; frequent fine to coarse roots; slightly firm; clear smooth boundary.

BC (15–35 cm). Sample No.: Be-7-3.

Corresponding to the middle part of layer 1 in Fig. 3(b).

Dull yellow orange (10YR 6/4, moist); silt loam; weak fine to coarse subangular blocky; friable; common fine to coarse roots; clear smooth boundary. Many angular and cobbly pumice fragments of less than 1 cm in diameter were present.

C (35 cm–). Sample No.: Be-7-4.

Corresponding to the middle part or lower part of layer 1 in Fig. 3 (b).

Grayish yellow brown (10YR 5/2, moist); sandy loam; weak coarse subangular blocky plus structureless; friable and loose; common fine to coarse roots. Many angular and cobbly pumice fragments of less than 15 cm in diameter were present.

Remarks: This pedon is considered to be formed from residual pyroclastic flow of 1883, since this pedon is located at the summit of this island.

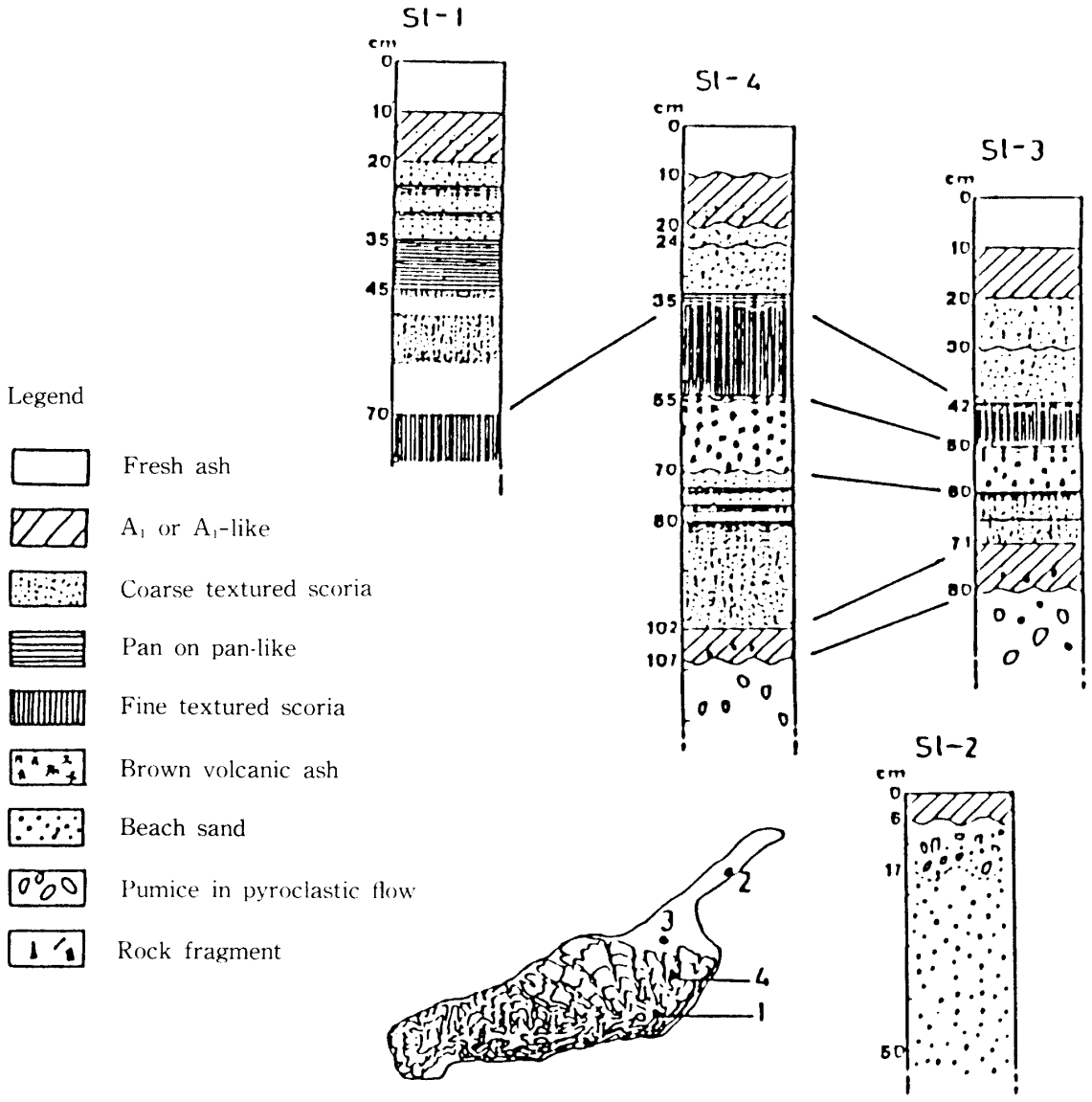

Fig. 7. Locations of sample sites on Sertung (St) and their columnar sections.

(2) Sertung

Locations of sampling sites and their columnar sections of soils on Sertung were shown in Fig. 7.

Site St–1

Topography: Level. Altitude: 160 m. Vegetation: Dominant species was *Timonius compressicaulis*.

Profile description:

A (0–10 cm). Sample No.: St–1–1.

Corresponding to layers of 1 and 2 (fresh ash plus A_1 or A_1-like) in Fig. 4(a).

Brownish black (5YR 2.5/1, moist); loamy sand; weak fine granular; very friable; frequent fine roots; clear smooth boundary.

IIA (10–20 cm). Sample No.: St–1–1′.

Corresponding to layers of 2 and 1 (A_1 or A_1-like, fresh ash) in Fig. 4(a).

Brownish black (5YR 3/1, moist); other descriptions were the same as above, except for the abrupt smooth boundary.

IIIC (20–35 cm). Sample No.: St–1–2.

Corresponding to the upper part of layer 3, coarse textured scoria (upper), in Fig. 4(a).

Brownish black (5YR 2/1, moist); loamy sand; weak granular plus structureless; very friable; frequent fine to medium roots; clear smooth boundary; two slightly cemented platy pans were present in this layer.

IVC (35–45 cm). Sample No.: St–1–3.

Corresponding to the platy ash pan in layer 3, coarse textured scoria (upper), in Fig. 4(a).

Dark reddish brown (5YR 3/2, moist); sandy loam; weak fine to medium subangular blocky; very friable; abundant fine to medium roots; clear smooth boundary.

VC (45–70 cm). Sample No.: St–1–4.

Corresponding to the lower part of layer 3, coarse textured scoria (upper), in Fig. 4(a).

Brownish black (5YR 2/1, moist); other descriptions were the same as above. This layer consist of several thin ashes and scorias layers.

VIC (70 cm–). Sample No.: St–1–5.

Corresponding to the upper part of layer 4 (fine textured scoria) in Fig. 4(a).

Black (5YR 1.7/1, moist); sandy loam; weak fine granular; very friable; frequent fine to medium roots.

Remarks: In this pedon, the thickness of the layers 1, 2, 3, and 4 in Fig. 4(a) was so thick that the authors could not reach to brown volcanic ash, layer 5 in Fig. 4(a), and also to 1883 pyroclastic flow, layer 7 in Fig. 4(a).

Site St–2

Topography: Level. Altitude: 2 m. Position: Northern sand spit. Vegetation: Dominant species was *Casuarina equisetifolia*.

Profile description:

A (0–6 cm). Sample No.: St–2–1.

Corresponding to layer 1, the mixtures of re-deposited 1883 pyroclastic flow, fine ejecta since 1927, fresh ashes and beach sand, in Fig. 4(b).

Balck (10YR 2/1, moist); loamy sand; weak fine to medium subangular blocky; very friable; frequent fine to medium roots; clear wavy boundary.

IIC (6–17 cm). Sample No.: St–2–2.

Corresponding to layer 2 in Fig. 4(b) and to layer 2 in Fig. 3(c) on Rakata Besar (mixtures of

re-deposited 1883 pyroclastic flow with cobbly pumice plus surface soils).

This thin layer is the mixtures of materials mentioned above and cobbly pumice (10YR 6/2, moist) fragments of less than 1.5 cm in diameter; frequent fine to medium roots; gradual wavy boundary.

IIIC (17 cm–). Sample No.: St–2–3.

Corresponding to layer 3 (beach sand) in Fig. 4(b) and Fig. 3(c) on Rakata Besar.

Brownish black (7.5YR 3/1, moist); sand; structureless; loose; few coarse to fine roots; many fine pores.

Site St–3 (Photo. 7)

Topography: Level. Altitude: 15 m. Vegetation: Dominant species was *Desoxylum caulostachyum*.

Profile description:

A (0–10 cm). Sample No.: St–3–1.

Corresponding to layer 1 (fresh ash) in Fig. 4(a).

Reddish black (2.5YR 2/1, moist); laomy sand; weak fine to coarse subangular blocky plus structureless; friable; abundant fine to medium roots; abrupt smooth boundary.

IIA (10–20 cm). Sample No.: St–3–2.

Corresponding to layer 2 (A_1 or A_1-like) in Fig. 4(a).

Very dark reddish brown (2.5YR 2/2, moist); silt loam; moderate coarse to fine subangular blocky plus weak medium granular; friable; abundant fine roots; clear smooth boundary.

$IIIC_1$ (20–30 cm). Sample No.: St–3–3.

Corresponding to the upper part of layer 3, coarse textured scoria (upper), in Fig. 4(a).

Dark reddish gray (2.5YR 3/1, moist); sand; weak fine to coarse subangular blocky plus structureless; very friable; common fine to medium roots; wavy clear boundary.

$IIIC_2$ (30–42 cm). Sample No.: St–3—3′.

Corresponding to the lower part of layer 3, coarse textured scoria (upper), in Fig. 4(a).

Dark brown (10YR 3/3, moist); sand; weak fine to coarse subangular blocky; friable; few medium to coarse roots; wavy clear boundary.

IVC (42–50 cm). Sample No.: St–3–4.

Corresponding to layer 4 (fine textured scoria) in Fig. 4(a).

Balck (10YR 2.5/1, moist); sand; very weak fine to coarse subangular blocky; friable; few fine to medium roots; abrupt smooth boundary.

VB (50–60 cm). Sample No.: St–3–5.

Corresponding to layer 5 (brown volcanic ash) in Fig. 4(a).

Dark brown (10YR 3/3, moist); loamy sand; on the top laminar and the below structureless plus weak coarse to medium subangular blocky; very friable and firm for the top; common coarse to fine roots; abrupt smooth boundary.

Ash pan (60–62 cm). Sample No.: St–3–5′.

Corresponding to the pan between layer 5 and 6 in Fig. 4(a).

Brownish gray (5YR 5/1, moist); platy; mottles of iron were present.

VIC_1 (62–67 cm). Sample No.: St–3–6.

Corresponding to the upper part of layer 6, coarse textured scoria (lower), in Fig. 4(a).

Black (10YR 1.7/1, moist); sand; structureless plus weak medium subangular blocky; friable; few medium to coarse roots; clear smooth boundary.

Ash pan (67–68 cm). Sample No.: St–3–6′.

Corresponding to the pan present in layer 6 in Fig. 4(a).

Brownish gray (10YR 4/1, moist); platy, mottles of iron were present.

VIC_2 (68–71 cm). Sample No.: St–3–7.

Corresponding to the lower part of layer 6, coarse textured scoria (lower), in Fig. 4(a).

Black (10YR 1.7/1, moist); sand; other descriptions were the same as VIC_1.

VIIAB (71–80 cm). Sample No.: St–3–8.

Corresponding to the upper part of layer 7 (buried A and B horizons of pyroclastic flow of 1883) in Fig. 4(a).

Dark brown (10YR 3/4, moist); sand; weak fine to coarse granular plus medium subangular blocky; friable; few medium to coarse roots; wavy clear boundary.

VIIC (80 cm–). Sample No.: St–3–9.

Corresponding to the lower part of layer 7 (C horizon of buried pyroclastic flow) in Fig. 4(a).

Dull yellow orange (10YR 6/3, moist); sand with lot of cobbly pumice of 2 to 4 cm in diameter; coarse subangular blocky; firm; very few medium roots.

Site St–4

Topography: Level. Altitude: 50 m. Vegetation: Dominant species was *Dysoxylum caulostachyum*.

Profile description:

A (0–10 cm). Sample No.: St–4–1.

Corresponding to layer 1 (fresh ash) in Fig. 4 (a).

Brownish black (5YR 2.5/1, moist); loamy sand; structureless plus weak medium to fine subangular blocky; friable; abundant medium to fine roots; wavy clear boundary.

IIA (10–20 cm). Sample No.: St–4–2.

Corresponding to layer 2 (A_1 or A_1-like) in Fig. 4(a).

Brownish black (5YR 3/1, moist); silt loam; structureless plus weak fine subangular blocky; very friable; abundant medium to fine roots: wavy clear boundary.

$IIIC_1$ (20–24 cm). Sample No.: St–4–3.

Corresponding to the upper part of layer 3, coarse textured scoria (upper), in Fig. 4(a).

Dark reddish brown (5YR 3/2, moist); sand; structureless plus weak fine angular blocky; friable; abundant fine to medium roots; wavy clear boundary.

$IIIC_2$ (24–39 cm). Sample No.: St–4–3.

Corresponding to the lower part of layer 3, coarse textured scoria (upper), in Fig. 4(a).

Dark brown (10YR 3/3, moist); sand; structureless plus weak coarse subangular blocky; friable; few medium to coarse roots; wavy clear boundary.

IVC (39–55 cm). Sample No.: St–4–4.

Corresponding to layer 4 (fine textured scoria) in Fig. 4 (a).

Black (10YR 2.5/1, moist); sand; structureless plus weak coarse to fine angular blocky; very friable; few fine to medium roots; wavy abrupt boundary. At the bottom, thin (2 cm thick) pan-like layer of platy structure was present.

VB (55–70 cm). Sample No.: St–4–5.

Corresponding to layer 5 (brown volcanic ash) in Fig. 4(a).

Dark brown (10YR 3/4, moist); loamy sand; structureless plus weak coarse to medium subangular blocky; friable; few medium to coarse roots; wavy abrupt boundary.

Remarks: Below 70 cm in depth the sequence of different layers was nearly the same as in St–3 pedon. However, in the upper part of VIC horizon some laminar layers of platy structure were present. And, pyroclastic flow was present at the depth of 120 cm from the surface.

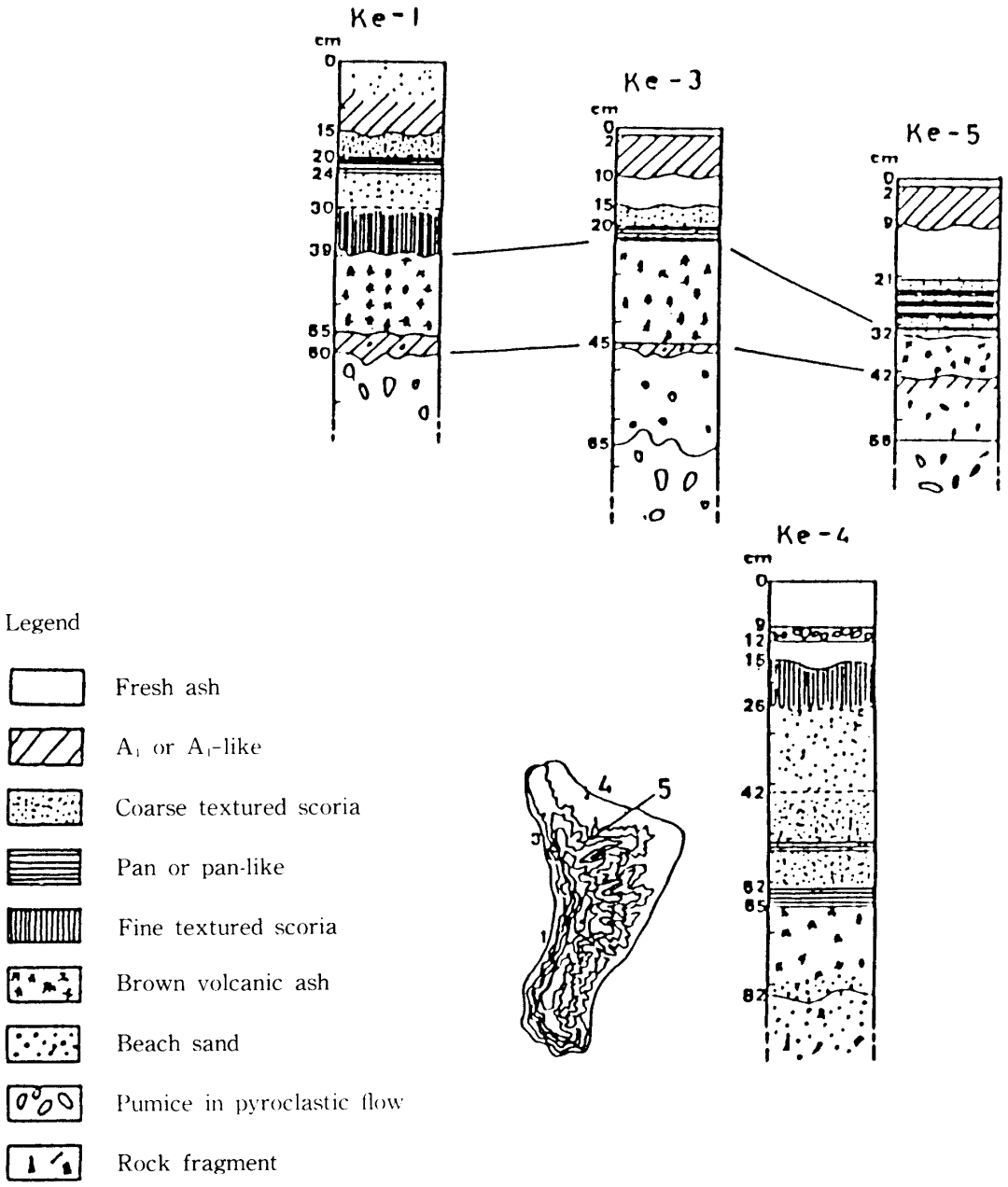

Fig. 8. Locations of sample sites on Rakata Kecil (Ke) and their columnar sections.

(3) Rakata kecil

Locations of sampling sites and their columnar sections of soils on Rakata Kecil were shown in Fig. 8.

Site Ke–1

Topography: Level. Altitude: 100 m. Vegetation: Dominant species was *Timonius* and *Neonauclea*.

Profile description:

A (0–10 cm). Sample No.: Ke–1–1.

Corresponding to layer 1 (fresh ash) in Fig. 5(a).

Brownish black (7.5YR 3/1, moist); loamy sand; structureless plus weak coarse subangular blocky; friable; frequent fine to coarse roots; clear smooth boundary.

IIA (10–15 cm). Sample No.: Ke–1–1–1.

Corresponding to layer 2 (A_1 or A_1-like) in Fig. 5(a).

Brownish black (7.5YR 2.5/1, moist); other descriptions are the same as above.

$IIIC_1$ (15–20 cm). Sample No.: Ke–1–1–2.

Corresponding to the upper part of layer 3 (coarse textured scoria) in Fig. 5(a).

Brownish black (7.5YR 3/1, moist); sand; structureless plus weak coarse subangular blocky; friable; frequent fine to coarse roots; abrupt smooth boundary.

$IIIC_2$ (20–24 cm). Sample No.: Ke–1–1–3.

Corresponding to the middle part of layer 3 (coarse textured scoria) in Fig. 5(a).

Brownish black (10YR 3/2, moist); loamy sand; weak coarse platy; friable; few fine to coarse roots; abrupt smooth boundary.

$IIIC_3$ (24–30 cm). Sample No.: Ke–1–2.

Corresponding to the lower part of layer 3 (coarse textured scoria) in Fig. 5(a).

Brownish black (10YR 3/1, moist); sand; weak coarse to fine subangular blocky plus structureless; friable and loose; few medium to coarse roots; gradual smooth boundary.

IVC (30–39 cm). Sample No.: Ke–1–3.

Corresponding to layer 4 (fine textured scoria) in Fig. 5(a).

Brownish black (10YR 2.5/1, moist); loamy sand; weak fine to coarse subangular blocky; slightly firm; few medium roots; abrupt smooth boundary.

VB (39–55 cm). Sample No.: Ke–1–4.

Corresponding to layer 5 (brown volcanic ash) in Fig. 5(a).

Dark brown (10YR 3/3, moist); loamy sand; weak fine to coarse subangular blocky; friable; frequent fine to coarse roots; abrupt smooth boundary.

VIAC (55–60 cm). Sample No.: Ke–1–5.

Corresponding to the upper part of layer 6 (A and BC horizons of buried pyroclastic flow) in Fig. 5(a). and to layer 7 on Sertung in Fig. 4(a).

Brownish black (10YR 3/2, moist); silt loam; weak fine to coarse subangular blocky plus structureless; friable and loose; few coarse and fine roots; abrupt smooth boundary. Upper limit of this layer is more dark and shows some accumulation of humus.

VIC (60 cm–). Sample No.: Ke–1–6.

Corresponding to layer 6 (C horizon of buried pyroclastic flow) in Fig. 5(a).

Grayish yellow brown (10YR 5/2, moist); silt loam; weak coarse subangular blocky plus structureless; friable and loose; very few fine and coarse roots. Many cobbly pumice fragments of less than 10 cm in diameter were present.

Site Ke–3 (Photo. 8)

Topography: Gently sloping (3°) to the east. Altitude: 70 m. Vegetation: Dominant species was *Dysoxylum caulostachyum*.

Profile description:

A (0–2 cm). Sample No.: Ke–3–1.

Corresponding to layer 1 (fresh ash) in Fig. 5(b).

Brownish black (7.5YR 3/1, moist); sand; structureless; loose; abundant fine to medium roots; abrupt smooth boundary.

IIA (2–10 cm). Sample No.: Ke–3–2.

Corresponding to layer 2 (A_1 or A_1-like) in Fig. 5(b).

Brownish black (10YR 3/1, moist); loamy sand; fine to coarse crumby plus granular; friable; abundant fine to coarse roots; abrupt smooth boundary.

IIIC (10–15 cm). Sample No.: Ke–3–3.

Corresponding to layer 1′ (buried fresh ash) in Fig. 5(b).

Brownish black (7.5YR 3/1, moist); sand; structureless plus weak fine to medium subangular blocky; loose and very friable; frequent fine to coarse roots; abrupt smooth boundary.

IVC_1 (15–20 cm). Sample No.: Ke–3–4.

Corresponding to layer 3 (coarse textured scoria) in Fig. 5(b).

Brownish black (10YR 3/1, moist); loamy sand; structureless plus weak fine crumby; very friable and loose; frequent fine to medium roots; abrupt smooth boundary.

IVC_2 (20–22 cm). Sample No.: Ke–3–5.

Corresponding to the mixture of layers 3 and 4 (coarse textured scoria plus fine texured scoria) in Fig. 5(b).

Brownish black (10YR 2.5/1, moist); sand; weak coarse platy; very friable; frequent fine roots; abrupt smooth boundary.

VB (22–45 cm). Sample No.: Ke–3–6.

Corresponding to layer 5 (brown volcanic ash) in Fig. 5(b).

Dark brown (10YR 3/3, moist); loamy sand; fine to coarse subangular blocky plus little structureless; very friable; abundant fine to coarse roots; abrupt smooth boundary.

VIC_1 (45–65 cm). Sample No.: Ke–3–7.

Corresponding to the upper part of layer 6 (buried pyroclastic flow) in Fig. 5(b). and to layer 7 on Sertung in Fig. 4(a).

Dull yellow brown (10YR 4/3, moist); and brownish black (10YR 3/2, moist) in the top; silt loam; weak fine to very coarse subangular blocky; slightly firm; frequent fine to coarse roots, clear wavy boundary. Some cobbly pumice fragments of less than 2 cm in diameter were present.

VIC_2 (65 cm–). Sample No.: Ke–3–8.

Corresponding to layer 6 (buried pyroclastic flow) in Fig. 5(b).

Grayish yellow brown (10YR 4/2, moist); loamy sand; weak coarse to fine subangular blocky; slightly firm; few fine roots. Many cobbly pumice fragments of less than 5 cm in diameter were present.

Site Ke–4

Topography: Level. Altitude: 3 m, 10 m apart from the coast. Vegetation: Dominant species was *Terminalia catappa*.

A (0–9 cm). Sample No.: Ke–4–1.

Corresponding to the mixture of re-deposited layer 1 (fresh ash), layer 2 (A_1 or A_1-like) and layer 6 (pyroclastic flow) in Fig. 5(b).

Brownish gray (10YR 3.5/1, moist); loamy sand; weak fine to coarse granular plus structureless; friable and loose; abundant coarse to fine roots; abrupt smooth boundary. Some cobbly pumice fragments of less than 0.6 cm in diameter were present.

IIC (9–12 cm). Sample No.: Ke–4–2.

Corresponding to layer 2 (re-deposited pyroclastic flow with cobbly pumice fragments) on Rakata Besar in Fig. 3(c) and Fig. 6 (Be–6–2), and to layer 2 on Sertung in Fig. 4(b) and Fig. 7 (St–2–2).

Dull yellow orange (10YR 7/2, moist); loamy sand; structureless; loose; fine to coarse abundant roots; abrupt smooth boundary. Many cobbly pumice fragments (10YR 4/1, moist) of less than 1 cm in diameter were present.

IIIC (12–15 cm). Sample No.: Ke–4–3.

Corresponding to layer 1′ (buried fresh ash) plus layer 2′ (buried A_1 or A_1-like) in Fig. 5(b).
Brownish gray (10YR 5/1, moist); loamy sand; structureless; loose; fine to coarse roots; abrupt smooth boundary. Some cobbly pumice fragments of 0.2 to 0.5 cm in diameter were present.

IVAC (15–26 cm). Sample No.: Ke–4–4.

Corresponding to re-deposited layer 4 (fine textured scoria) plus re-deposited layer 6 (pyroclastic flow) in Fig. 5(a) and (b).
Brownish black (10YR 3/2, moist); sand; very weak fine to coarse subangular blocky plus structureless; very friable and loose; abundant fine to coarse roots; gradual smooth boundary. Some angular igneous rock fragments of 0.2 to 0.5 cm in diameter were present.

VC_1 (26–42 cm). Sample No.: Ke–4–5.

Corresponding to the mixtures of re-deposited layer 3 (coarse textured scoria) plus layer 4 (fine textured scoria) plus layer 6 (pyroclastic flow) in Fig. 5(a) and (b).
Black (7.5YR 2/1, moist); sand; structureless; loose; abundant fine to medium roots; gradual smooth boundary. Some cobbly, angular igneous rock fragments of 0.2 to 0.8 cm in diameter and some cobbly pumice fragments of 0.2 to 0.5 cm in diameter were present.

VC_2 (42–62 cm). Sample No.: Ke–4–6.

Corresponding to re-deposited layer 3 (coarse textured scoria) plus re-deposited layer 6 (pyroclastic flow) in Fig. 5(a) and (b).
Black (7.5YR 2/1, moist); sand; very coarse to medium subangular blocky; friable; few fine to medium roots; abrupt smooth boundary. Some angular igneous rock fragments of 0.2 to 0.5 cm in diameter were present.

VIBC (62–65 cm). Sample No.: Ke–4–7.

Corresponding to the mixture of two kinds of pans, namely between layers 3 and 4, and layer 4 and 5 (brown volcanic ash) in Fig. 5(a) and (b).
Black (7.5YR 2/1, moist); sand; coarse weak platy plus structureless; firm and loose; few fine roots and half decomposed leaves; abrupt smooth boundary.

VIIBC (65–82 cm). Sample No.: Ke–4–8.

Corresponding to re-deposited layer 5 (brown volcanic ash) in Fig. 5(a) and(b).
Brown (10YR 4/4, moist); sand; weak fine to coarse subangular blocky; friable; abundant fine to coarse roots; abrupt boundary.

Remarks: This pedon is situated near the coast. The stratification of respective layers did not agreed with that of columnar section of soils shown in Fig. 5. The respective layers of this pedon are not residual ones, and have been translocated from the areas of higher altitude. Pyroclastic flow of 1883 of residual nature was not found in this pedon. Beach sand was present below 250 cm from the surface. In the depth from 82 to 250 cm, about 10 discontinuous layers were found. They were cobbly and angular scorias, cobbly pumice fragments, igneous rock fragments, re-depoisited pyroclastic flow and their mixtures.

Site Ke–5

Topography: Gently sloping (6°) to the north. Altitude: 45 m. Vegetation: Dominant species was *Casuarina-Dysoxylum*.

Profile description:

A (0–2 cm). Sample No.: Ke–5–1.

Corresponding to layer 1 (fresh ash) in Fig. 5(b).
Brownish black (7.5YR 3/1, moist); sand; structureless; loose; common fine to medium roots; abrupt boundary.

IIAC (2–9 cm). Sample No.: Ke–5–2.

Corresponding to layer 2 (A_1 or A_1-like) in Fig. 5(b).

Brownish black (10YR 3/1, moist); sand; weak fine to coarse crumby plus structureless; very friable and loose; abundant fine to coarse roots; abrupt smooth boundary.

IIIC (9–21 cm). Sample No.: Ke–5–3.

Corresponding to layer 1′ (buried fresh ash) in Fig. 5(b).

Brownish gray (7.5YR 4/1, moist); loamy sand; structureless; loose; abundant fine to coarse roots; clear smooth boundary.

IVC (21–32 cm). Sample No.: Ke–5–4.

Corresponding to the mixture of layer 3 (coarse textured scoria), layer 4 (fine textured scoria) and layer 1 (fresh ash) in Fig.5(b).

In this layer, 4 sets of laminar pans consisted of scorias, yellowish sands and ashes.

Brownish black (7.5YR 3/1, moist); sand; weak coarse platy structure plus structureless; friable and loose; abundant fine to coarse roots; abrupt smooth boundary.

VB (32–42 cm). Sample No.: Ke–5–5.

Corresponding to layer 5 (brown volcanic ash) in Fig. 5(b).

Dull yellowish brown (10YR 4/3, moist); silt loam; weak coase subangular blocky; slightly firm; abundant fine to coarse roots; clear smooth boundary.

VIC_1 (42–56 cm). Sample No.: Ke–5–6.

Corresponding to the upper part of layer 6 (buried pyroclastic flow) in Fig. 5(b).

Dull yellowish brown (10YR 5/3, moist); silt loam; weak coarse subangular blocky; friable; few fine to medium roots; abrupt smooth boundary. Many cobbly pumice fragments of 2 to 8 cm in diameter and some igneous rock fragments were present.

VIC_2 (56 cm–). Sample No.: Ke–5–7.

Corresponding to layer 6′ (re-deposited pyroclastic flow) in Fig. 5(a).

Dull yellow orange (10YR 6/3, moist); silt laom; structureless; loose; few coarse roots. Many cobbly pumice fragments of 1 cm in diameter, and some igneous rock fragments were present.

Remaks: Some large igneous rock of more than 30 cm in diameter were present between VIC_1 and VIC_2 horizon.

(4) Anak Krakatau

Locations of sampling sites and their columnar sections of soils on Anak Krakatau were shown in Fig. 9.

Site An–1

Topography: Level. Altitude: 3 m. Vegetation: Dominant species was *Imperata cylindrica*.

Profile description:

AC (0–15 cm). Sample No.: An–1–1.

Reddish black (2.5YR 2.5/1, moist); sand; structureless; common fine to coarse roots; abrupt smooth boundary. This layer is consisted of 7 sublayers of different textures.

IIC (15–23 cm). Sample No.: An–1–2.

Dark reddish brown (5YR 3/2, moist); sand; weak coarse platy plus structureless; very friable and loose; common fine to medium roots; abrupt smooth boundary.

IIIC (23–40 cm). Sample No.: An–1–3.

Reddish black (2.5YR 2/1, moist); sand; structureless; loose; common fine to medium roots; abrupt smooth boundary.

IVC (40–44 cm). Sample No.: An–1–4.

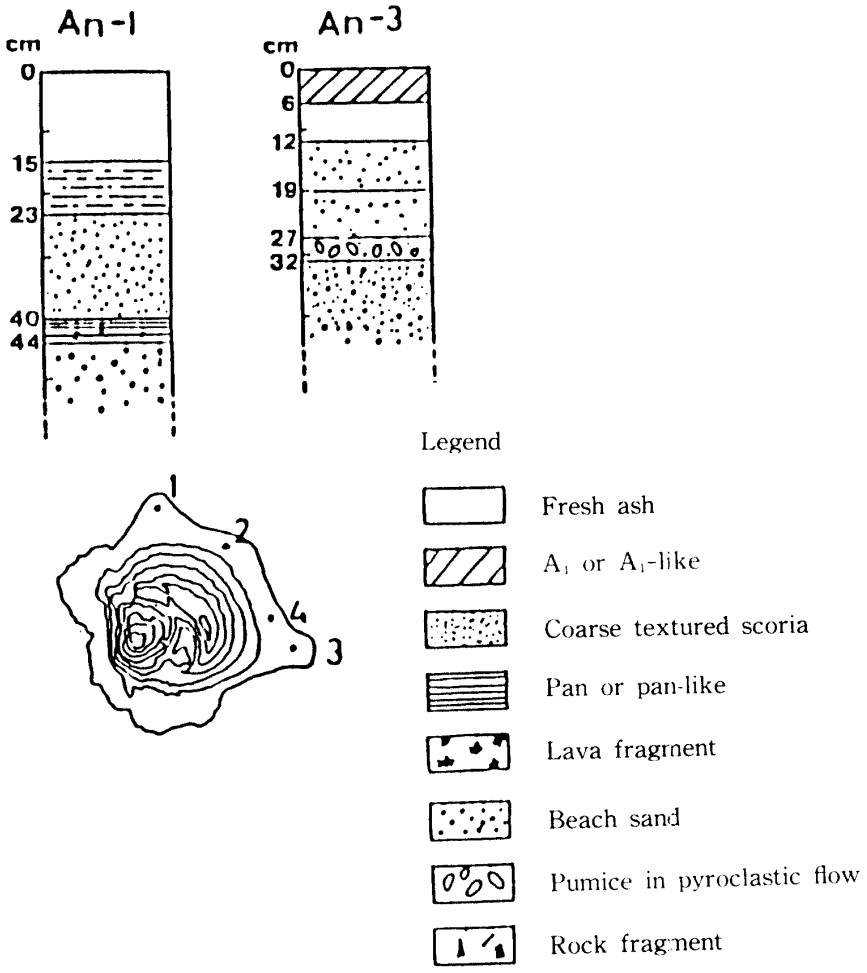

Fig. 9. Locations of sample sites on Anak Krakatau (An) and their columnar sections.

Dark reddish brown (2.5YR 3/2, moist) plus reddish gray (2.5YR 4/1, moist); sand; weak coarse platy; friable; common fine to medium roots; abrupt boundary. This layer is consisted of 2 sets of ash pans and a scoria pan. Many rock and lava fragments of less than 3 cm in diamater and some cobbly pumice fragments of less than 0.6 cm in diameter were present.

VC (44 cm–). Sample No.: An–1–5.

This layer is mainly consisted of beach sand with different color (2.5YR 3/1 plus 2.5YR 3/2 plus 2.5YR 6/1, moist); sand; structureless; loose; few medium roots. Some lava fragments of less than 0.4 cm in diameter and cobbly pumice fragments of 0.4 to 2 cm in diameter were present.

Remarks: According to Prof. Dr. Tagawa (team leader of our expedition, plant ecologist), primary plants of this location were presumed to burn off (naturally or artificially?) and *Imperata cylindrica* is grown as the secondary plants.

Site An–2

Topography: Surface of steep gully of 4 m depth. Altitude: 5 m. Vegetation: Bare lands.

Profile description:

XIC (280–290 cm). Sample No.: An–2.

Grayish brown (5.0YR 6/1, moist); loamy sand; structureless plus weak coarse to medium subangular blocky; loose and friable; clear smooth boundary.

Remarks: Soil morphology of this layer is the same as layer 5 (brown volcanic ash) on Sertung and Rakata Kecil in Fig. 4(a) and Fig. 5(a).

Site An–3

Topography: Level. Altitude: 1 m. Vegetation: Dominant species was *Casuarina equisetifolia-Saccharum*.

Profile description:

AC (0–6 cm). Sample No.: An–3–1.

Brownish black (7.5YR 2.5/1, moist); sand; structureless plus very weak medium to coarse subangular blocky; loose and friable; common fine to coarse roots; abrupt smooth boundary.

IIC (6–12 cm). Sample No.: An–3–2.

Brownish black (7.5YR 2.5/1, moist) plus grayish brown (5YR 5/2, moist); other descriptions were the same as above. This layer is consisted of 3 sets of laminar layers and the upper part (0.2 to 0.3 cm thick) of each layers were buried humus layer.

$IIIC_1$ (12–19 cm). Sample No.: An–3–3.

Brownish black (7.5YR 2.5/1, moist); sand; structureless plus weak coarse subangular blocky; loose and friable; common fine roots; clear smooth boundary.

$IIIC_2$ (19–27 cm). Sample No.: An–3–4.

Brownish black (7.5YR 2.5/1, moist); sand; structureless plus weak coarse subangular blocky; loose and friable; few fine roots; abrupt smooth boundary. Many plant decays were present.

IVC (27–32 cm). Sample No.: An–3–5.

Cobbly pumice (10YR 6/3, moist) with sand (7.5YR 2.5/1, moist); structureless; loose; few fine roots; abrupt boundary.

VC (32 cm–). Sample No.: An–3–6.

Brownish black (7.5YR 2.5/1, moist) plus light gray (7.5YR 9/1, moist); sand; structureless plus weak coarse subangular blocky; loose and very friable; few fine roots.

Remarks: $IIIC_1$ and $IIIC_2$ were mostly scoria and IVC was a pumice layer. VC was beach sand.

Site An–4

Topography: Level. Altitude: 1 m. 2 m apart from the coast. Vegetation: Dominant species was *Saccharum spontaneum*.

Profile description:

IIA (10–15 cm). Sample No.: An–4.

Brownish black (10YR 3/1, moist); loamy sand; fine to coarse subangular blocky; friable; abundant fine roots; abrupt smooth boundary.

Remarks: Soil morphology of this layer is the same as layer 4 (fine textured scoria) on Sertung in Fig. 4(a) and Fig. 7(St–3–4 and St–4–4). From our observation, brightness of this layer was presumed to be similar to that of young Japanese volcanic ash soils (less than 100 years) in southern Kyushu. Brightness of both soils is assumed to be depended on the high humification degree of humic acid, and is different from the dark color of scoria.

Summary

The representative stratification of different ejecta and deposits on Rakata Besar, Sertung and Rakata Kecil were observed and described, and detail descriptions of respective layers from about twenty pedons were made.

1) Rakata Besar (Be)

The soils were mainly derived from re-deposited 1883 pyroclastic flow as shown in Figs. 3 and 6. At the steep slope of gully cliff, representative stratification was cumulative layers of

re-deposited pyroclastic flow in which several buried A horizon were present. Whereas, at the stable gully floors, first layer was 0.5–1 m depth and A_1 horizon with crumby structure was well developed.

Beach sand soils were distributed in a small area of southern east coast.

At the part of higher altitude, fragmented lava before 1883 and its weathering was observed below 1883 pyroclastic flow.

2) Sertung (St)

At the large parts of this island, several layers of ejecta since 1927 were deposited on 1883 pyroclastic flow (Fig. 4 and 7). These ejecta are assumed to be originated from Anak Krakatau.

From the surface to the substratum, representative stratification was as follows:

(1) Fresh unweathered ash layer. (fresh ash).

(2) Dark-colored volcanic ash layer in which A horizon was well or weakly developed. (A_1 or A_1-like layer).

(3) Coarse textured dark-colored scoria layer, designated as coarse textured scoria (upper).

(4) Fine textured dark-colored scoria layer. (fine textured scoria).

(5) Fine textured brown-colored volcanic ash soil layer. (brown volcanic ash).

(6) Coarse textured dark-colored scoria layer, designated as coarse textured scoria (lower).

(7) Buried A or B or C horizon derived from 1883 pyroclastic flow. (1883 pyroclastic flow or buried pyroclastic flow and/or pumice in pyroclastic flow).

Beach sand soil similar to that of Rakata Besar was distributed on the sand spits at the northern part and western coast.

3) Rakata Kecil (Ke)

The stratification of different ejecta, the occurrence order of respective layer and the soil morphology of respective layer were similar to those of Sertung (Fig. 5 and 8). But following items were clearly different from those of Sertung.

(a) Layer 6 on Sertung, coarse textured scoria (lower), was not present.

(b) Thickness of respective layer on 1883 pyroclastic flow was relatively thin compared with those of Sertung.

(c) Layers 1 and 2 (fresh ash and A_1 or A_1-like) were frequently divided to two or three layers which were developed to A and B horizon of 1–2 cm thickness.

4) Anak Krakatau (An)

Large parts of this island were covered with outpoured lavas, lithic fragments of igneous rocks, lapiliis, scorias and volcanic ashes. Pedogenesis is just going on in those volcanic materials but the formation of A_1 horizon was very weak. Moreover, above-mentioned ejecta were complicatedly cumulative, and the occurrence order of respective layer was confused owing to the continuos ejecta falls and to re-deposition. Therefore, the representative columnar sections could not described by authors.

Brown volcanic ash layer (layer 5 on St and Ke) of 30–50 cm thickness was discontinously present below 2–10 m from the surface.

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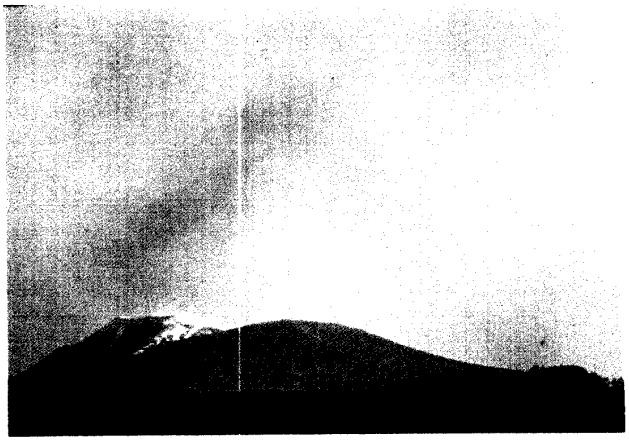

Photo. 1. Anak Krakatau (active Volcano), the right under part of this Photo. is the east part of this island, where *Casuarina* grows.

Photo. 2. Gullies developed on the 1883 pyroclastic flow on the southern coast of Sertung, these gullies are seen as V shaped hanging valleys.

Photo. 3. Depositing fresh ashes on the leaves on Sertung (6th, July 1982)

Photo. 4. Anak Krakatau, surface soils consist of scorias, volcanic ashes and igneous rock fragments. Grass: *Saccarum spontaneoum* (Pioneer higher plant), tree: *Casuarina*.

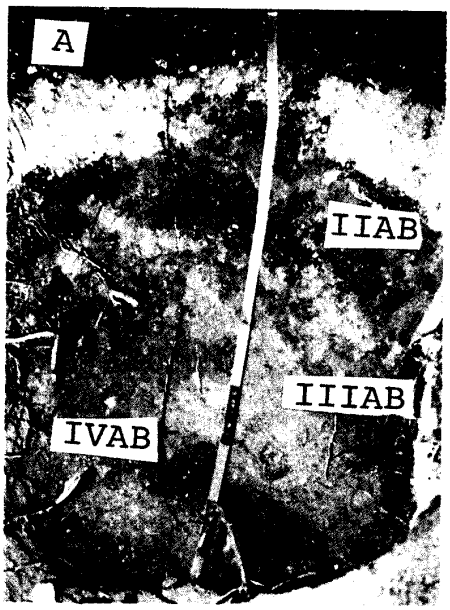

Photo. 5. Pedon Be–2 on Rakata Besar (see Fig. 6. and p. 113). Respective horizon is derived from re-deposited pyroclastic flow. IIAB, IIIAB and IVAB are buried AB horizon.

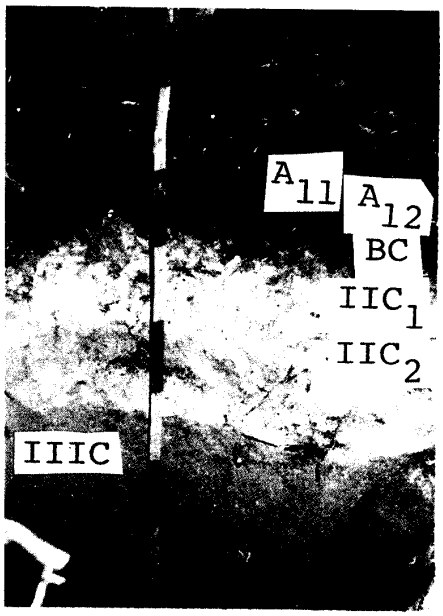

Photo. 6. Pedon Be–3 on Rakata Besar (see Fig. 6. and p. 113–114). Respective horizon is derived from 1883 pyroclastic flow. A well developed A_1 horizon is observed.

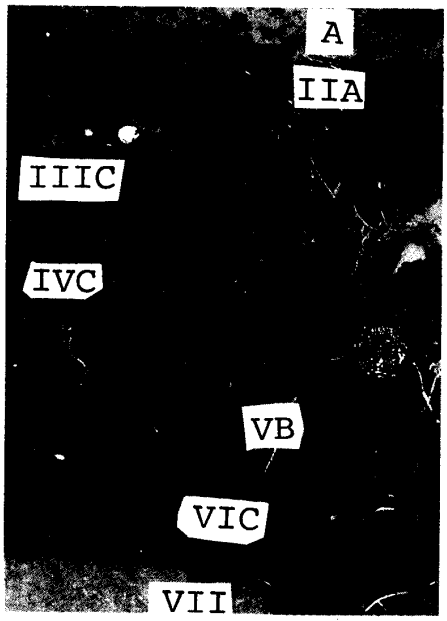

Photo. 7. Pedon St–3 on Sertung (see Fig. 7. and p. 118–119). A: Fresh ash, IIA: A_1 or A_1-like, IIIC: coarse textured scoria (upper), IVC: Fine textured scoria, VB: Brown volcanic ash, VIC: Coarse textured scoria (lower), VII: Buried pyroclastic flow.

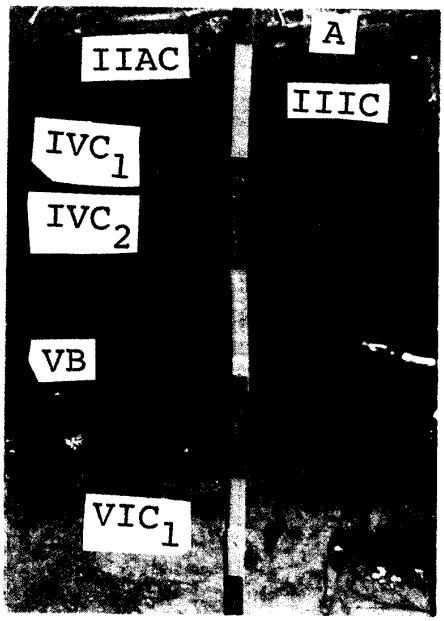

Photo. 8. Pedon Ke–3 Rakata Kecil (see Fig. 8. and p. 121–122). A: Fresh ash, IIAC: A_1 or A_1-like, IIIC: Buried fresh ash, IVC_1: Coarse textured scoria, IVC_2: Coarse textured scoria plus fine textured scoria, VB: Brown volcanic ash, VIC_1: Buried pyroclastic flow.