Geomorphological Situation and Stability of Mangrove Habitat of Truk Atoll and Ponape Island in the Federated States of Micronesia

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Toyohiko MIYAGI* and Kiyoshi FUJIMOTO

1 Introduction

Mangrove swamps are tidally submerged coastal woodlands in tropical to subtropical regions. The area of mangrove swamps amounts to about 1% of all types of swamps in the world.

Generally speaking, geomorphological studies of mangrove swamps are important because they provide information on the development of coastal swamps, and criteria for the recognition of their sedimentary deposits. However, the geomorphological studies of mangrove habitats are very limited because of the remoteness (tropical shores) and complexity of mangrove swamps and their difficult working conditions (*e.g.* malodorous mud, high humidity and air temperature, biting insects, tropical diseases, impenetrable swamp vegetation). Mangrove swamps have not received the attention their importance warrants (Scholl 1968).

Recently UNESCO (Snedeger and Snedeger 1984 ; Knox and Miyabara 1984), UNESCO/MAB (1983-1988) and many other mangrove ecologists have revealed the importance of mangrove swamps as a natural resource not only for ocean people but also world fishery. On the contrary, the forests have diminished in these 20 years in Southeast Asia by many kinds of human activities such as timber cutting for pulp, firewood and chacoal production, land reclamation, water pollution and fishpond making *etc*. For example, in the case of the Philippines, about 27,000 ha of forest decreases annually on Luzon Island. In this way, so called "Marine Desertification" appears in the tropical and subtropical areas.

On the other hand, global-scale environmental change in the near future is indicated. Bolin *et al.* (1986) estimate that the prediction of global warming of 3.5 ± 2.0°C due to CO^2 doubling by A.D. 2,030, will lead to a sea-level rise of $80 \pm^{85}_{60}$ cm. Such rapid sea-level rise would affect mangrove habitat greatly. The influence of mangrove habitat destruction will affect the coastal plain and back swamp.

As indicated above, there are two kinds of impact on mangrove ecosystems, one

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is various kinds of human activities, the other is caused by rapid sea-level rise due to the Greenhouse effect. From the geomorphological viewpoint, the manner of these effects should vary with the geomorphological situation of the respective habitat.

We intend to clarify the geomorphological function as background for mangrove ecosystem existence. This viewpoint is useful for not only demonstrating the geomorphic meanings of mangrove habitats, but also making the land sustainability conservation for mangrove habitat.

Mangrove habitats are developed between approximately mean high-tide level and mean sea-level along coastal lines. The developmemt and continuation of habitats recognized as landform-vegetation relationships are based on the geomorphological processes, such as coastal plain development and peat accumulation by biomass production of forest under the sea-level changes in the Holocene.

Scholl (1964) clarifies the correlation between the vertical range of fibrous peat formation and the magnitude of the tidal range. Using this correlation, we can estimate the sea-level of those days when the mangrove peat was formed. Thom *et al.* (1975, *etc.*) reveal the close relationships between distribution of habitats and their geomorphological composition in the deltaic area in Western Australia and around the Caribbean Sea. Kikuchi *et al.* (1978, 1980) clarify that the spatial extent of landform units and plant communities found both in small scale and in micro scale are closely corresponded, and that the developments of habitats are controlled by the geomorphological development and sea-level changes in the Holocene. On the other hand, Kogo *et al.* (1978, *ect.*) promote the afforestation program by mangrove plantation in arid and high saline areas along the coast of the Arabian Gulf. They arranged the functions of landform for the mangrove plantation through their afforestation trial. Miyagi and Maximino (1989) discuss the processes of habitat development and forest destruction by human activities, and predict the influence of the rapid sea-level rise by the Greenhouse effect.

The present research will make at first typology of the mangrove habitat on various landform conditions, and then will investigate the correlation between the geomorphic processes and habitat development in micro and small landform scale, in Truk Atoll and Ponape Island, the Federated States of Micronesia (referred as F.S.M. hereinafter). According to the framework of landform classification confirmed by Tamura (1980, 1981), the micro-landform, such as micro-relief of tidal flat, tidal creek, a part of beach ridge and foot slope *etc.*, is considered to be formed by local and temporal processes corresponding to the time scale of $10^1 \sim 10^2$ years. The small scale landforms such as tidal flat, beach ridge seem to have been formed during the time of $10^2 \sim 10^3$ years.

2 Outline of the study area

The island and atoll of the F.S.M. is located in the northwestern Pacific Ocean, extending from the equator to latitude 14 degrees north and it includes about 2,800 square miles of lagooons, which are composed of basaltic volcanic islands, atolls and coral islands. The climate of the F.S.M. is tropical, in which the northeasterly trade wind is dominant during the period from November to May. Kosrae Island provides the margin of the distribution of mangrove species originated from the Malay Peninsula. Hosokawa (1957) clarifies the species composition of mangrove forest in each island. Maclean *et al.* (1988) estimate the volume of mangrove forest and timber of the F.S.M.. Tayama (1952) intends the geomorphological exploration through 1932 to 1950 by the Marine Agency of Japan. Recent geomorphological studies are made by Bloom (1970), and Matsumoto *et al.* (1986).

2.1. Regional setting

Ponape and Truk are located in the Caroline Islands of the West Pacific Ocean. On the west side of the Caroline Islands, the trenches arranged in echelon represent the boundaries between the Pacific plate and the Philippine Sea plate (Fig. 1).

In the Palau Islands which are close to the Palau Trench, the numerous geomorphic evidences indicating uplift in the Holocene, for example elevated notches, have been recorded (Tayama 1952). On the other hand, on Truk and Ponape which are about 1,200 km and 2,000 km away respectively from the trenches to the east, such clear geomorphic evidences of active uplift are not recognized (Bloom 1970).

Bloom (1970) depictes a Holocene submergence curve for Truk, Ponape and Kosrae on the basis of depth and radiocarbon age of inter-tidal peat taken from the coastal swamps. Matsumoto *et al.* (1986) investigate Truk and Ponape with the same method as Bloom (1970), and depicte for respective islands Holocene sea-level curves, which are in agreement with the theoretical ones presented by Peltier *et al.* (1978) and Clark and Lingle (1979) under consideration of the hydro-isostatic adjustment. The results indicate that Ponape and Truk tend to subside during the Postglacial age. Although the outline of the relative Holocene sea-level curve of the each island is generally clarified by these studies, the details of the late Holocene sea-level fluctuations which have greatly affected the mangrove habitat development remain unelucidated.

One of the purpose of the present study is to clarify the process of mangrove habitat development with special references to the late Holocene sea-level fluctuations in Ponape and Truk which are ocean islands tending to subside with hydro-isostatic adjustment.

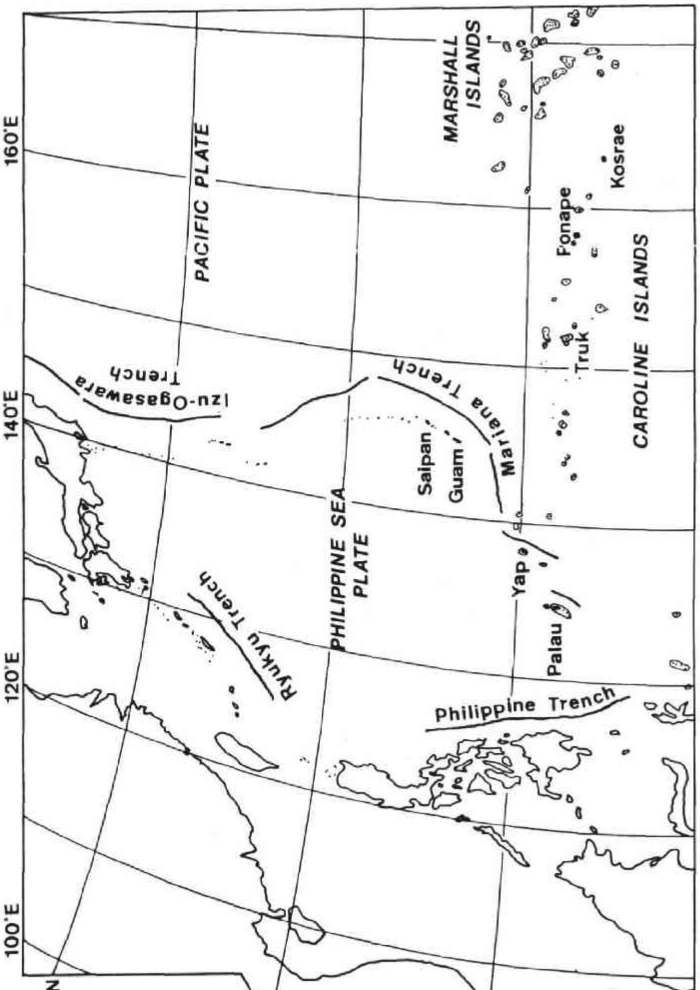

Fig. 1 Map showing the location of Truk and Ponape.

Table 1 The geographical distribution of the species growing in the mangrove forests of Micronesia (modified from Chapman 1976 ; Kogo *et al.* 1985)

	Saipan	Guam	Yap	Palau	Truk	Ponape	Kosrae	Arno. Marshalls
Acrostichum aureum L.	+	+						
Acrostichum speciosum Willd.			+	+	+			
Pandanus kanehirae Martelli				+				
Nypa fruticans Wurmb.		+	+	+	+	+	+	
Crudia cynometroides Hosok.				+				
(?) *Cynometra bijuga* Spanoghe				+				
Dalbergia candenatensis Prain	+	+	+	+	+	+	+	
Derris trifoliata Lour.		+	+	+	+	+	+	
Xylocarpus granatum Koenig		+	+	+	+	+	+	
Xylocarqus moluccensis (Lamx.) roem.								+
Excoecaria Agallocha L.		+	+	+	+	+	+	
Samadera indica Gaertn.				+				
Hippocratea macrantha Koth.				+				
Stemonurus ellipticus Sleumer				+				
Heritiera litoralis Dryand.	+	+	+	+	+	+	+	
Calophyllum cholobtaches Laut.				+				
Sonneratia alba J.Sm.			+	+	+	+	+	+
Bruguiera gymnorrhiza(L) Lamk.	+	+	+	+	+	+	+	+
Ceriops decandra (Griff.) Ding Hou			+	+				
Rhizophora apiculata Bl.		+	+	+	+	+	+	
Rhizophora stylosa Griff.		+	+	+	+	+	+	+
Lumnitzera littorea Voigt.		+	+	+	+	+	+	+
Barringtonia racemosa Bl.		+	+	+	+	+	+	
Finlaysonia maritima Backer				+				
Sarcolobus sulphurcus Schltr.				+				
Tylophora polyantha Volk.			+					
Thespesia populnea Soland.			+	+	+	+	+	
Avicennia marina Vierh.		+	+	+				
Clerodendron inerme Gaertn.	+	+	+	+	+	+	+	+
Acanthus ebracteatus Vahl.				+				
Scyphiphora hydrophyllacea Gaertn.			+	+				
Paspalum vaginatum Sw.	+	+	+	+	+	+	+	
Pemphis acidula Forst.					(+)			+
Intsia bijuga (Colebr.) O. Ktze.					(+)			+
Total no. of species	6	15	20	29	16 (18)	15	15	8

(+) according to our research

2.2. Mangrove vegetation

In Micronesia except Palau Islands, not so great number of mangrove species occur. Palau Islands, located close to the Philippines, are inhabited by 29 species (Chapman 1976). However, only 6 to 18 species are found in the eastern islands of Micronesia from Guam to Marshall. Table 1 which gives the occurrence of the species throughout Micronesia shows that the forests become markedly poorer in eastern and northern Micronesia.

The area of forest in each state of the F.S.M. are estimated as shown in Table 2 (Cole *et al.* 1987, Maclean *et al.* 1988).

Table 2 Area of forest land by forest type, in Federated States of Micronesia (1983) and Republic of Palau (1979). (ha)

Forest type	F. S. M.					Palau
	Ponape	Yap	Truk	Kosrae	Total	
Land area	35,489	9,779	4,170	11,187	60,625	41,629
Upland forest	12,548	2,556		5,077	20,181	24,239
(Timberland)	10,170	2,347		1,717	14,234	
(Steep, Scrub)	2,378	209		3,330	5,917	
Palm	1,383		2		1,385	1
Swamp	214	155		388	757	1,680
Mangroves	5,525	1,171	366	1,562	8,624	4,708

3 The Truk Atoll

3.1. Location and geographical features

The state of Truk, located in the central Caroline Islands, consists of the Truk atoll and outer islands such as Satawan atoll, Lawsop atoll and Etal atoll *etc.* The Truk lagoon (7°8′30″ to 7°41′12″N. latitude, 151°26′24″ to 152°2′12″E. longitude) is one of the biggest atolls in the world. It is roughly circular in shape and is about 63 kilometers in diameter, and is surrounded by a 200 kilometer long barrier reef. There are 19 high-altitude islands, referred to as main islands in this report and many small coral islets, referred to as minor islands, in the Truk lagoon. The barrier reef (fringe of atoll) has about ten shallow channels and many small cays. Five main islands, those are Uman, Dubron, Fefan, Tol and Moen, one minor island, Eiol, and one cay, Mesegon, have been surveyed. The Main islands, consisting of Tertiary basaltic volcanics, are characterized by steep, rugged uplands, and surrounded by a dissected marine terrace and coastal lowlands. There are twelve peaks : the highest point is Mt. Tumitai on Tol Island, which rises to an elevation of 440 meters. Although frequent landslides as well as many small streams characterize the mountainsides, the sediment provided seems not to do so remarkable damage to the coral reef and mangrove swamps. Human impacts such as land reclamation have been widespread on both the lowland and the ocean since World War II.

The vegetation is tropical forest covering the upper mountainsides, and the copra production and plantations for native foods are distributed on the foot slopes and coastal lowlands.

The minor islands and the cays consist of coral sands and reefs with an elevation of less than 3 meters. Some of them are utilized for coconut and taro plantations.

3.2. Climate

The climate of Truk atoll is influenced by ITCZ and trade winds. From about November to June the climate is dominated by northeasterly trade winds, with average velocities of 14 to 21 kilometers per hour. Between July and November the islands are frequently under the influence of the ITCZ which has shifted northward into this area. Rainfall averages about 365 centimeters annualy. Meteorological disasters are not so common. Since the major typhoons traced in the Western Pacific lie well to the north and west of Truk, typhoons in its immediate vicinity are not common. Some of the climatic data are compiled in Table 3.

Table 3 Climatological data in Moen Island, the State of Truk

Temperature	Annual mean	27°C
	Annulal range	less than 1°C
	Daily range	6C°
	Lowest temp.	18°C (May. 1966)
Precipitation	Annual rainfall	140 inches (365 cm)
	Number of days with measurable rainfall	270 days
	Relatively dry season	Jan. Feb. Mar.
Wind	NE trade winds	Nov. Dec. Jan. Feb. Mar. Apr.
	(812 miles/h)	May. Jun.
	SE to SW winds	Jul. Aug. Sep. Oct.
	(ITCZ)	
	(7 miles)	
Typhoon	Immediate vicinity are not common	
Typhoon disaster	No. 1975 (Lola)	
	Jan. 1958 (Ophelia)	
	May. 1975(Ann)	

3.3. Oceanography

The salinity is less than 3.2 percent in Truk atoll. Tidal curve is very irregular. Normal daily tidal ranges amount to 60 centimeters. Sometimes flood tides occur in the case of high tides with strong spring low pressure. Both wave action and tidal current are strong on the ocean side and along the shallow channels in the special location on the barrier reef.

3.4. Soil

Mangrove soils cover about 13 percent of Truk's land area including tidal zone. They are divided into two types, *i.e.* Chia mucky peat and Insak Variant sandy peat (William and Laird 1983). Chia mucky peat is formed from organic deposits of mangrove materials over coral sand and gravel, at a depth of about 1 to 1.5 meters. Insak Variant sandy peat is distributed in coastal tidal marshes at a depth of 30 to 50 centimeters and is underlain by coral fragments and sand.

3.5. Mangrove

On the Truk Islands occur 18 species, consisting of 13 species of trees, 3 shrubs, 1 fern and 1 grass, as shown in Table 1. *Rhizophora stylosa* represents the pioneer species. *R. apiculata* is a dominant species in the main part of the forest. Other 16 species occur as minor components.

3.6. Geomorphological situation of mangrove habitats on Truk atoll

The authors made some line-section surveys on the mangrove habitats (Fig. 2).

3.6.1. Tol Island

In the inlet of Tol Island, mangrove forests are widely developed on the tidal flat. Fig. 3-1 is the longest line transect of Truk atoll. This forest was completely cut for charcoal materials in the period of Japanese mandate. The forest has been regenerated from the stumps after the periods (Photo 1). There are many traces of foremore charcoal ovens distributed on the foot slopes behind the mangrove habitats. The main part of mangrove forest which consists of *Rhizophora stylosa* and *R. apiculata* is slightly dominant in the seaward margin. The *Rhizophola* sp. 8 to 10 meters high grow densely. The bottom of the *Rhizophora* habitat is extremely flat and consists of mangrove fibrous peat. The depth of peat layer is 1 meter or more. The peat layer coresponds to the Chia mucky peat (William and Laird 1983). Landward from the *Rhizophora* habitat, *Bruguiera gymnorrhiza*, *Xylocarpus granatum* and *Heritiera litoralis* are arranged zonally on gently sloping (about 2 to 5 degrees) bottom composed of mixture of coluvium and mangrove peat. Where the angle of the slope increases, the width of mangrove habitat decreases. The salinity of the middle part of *Rhizophora* habitat is estimated as about 2.2 percent.

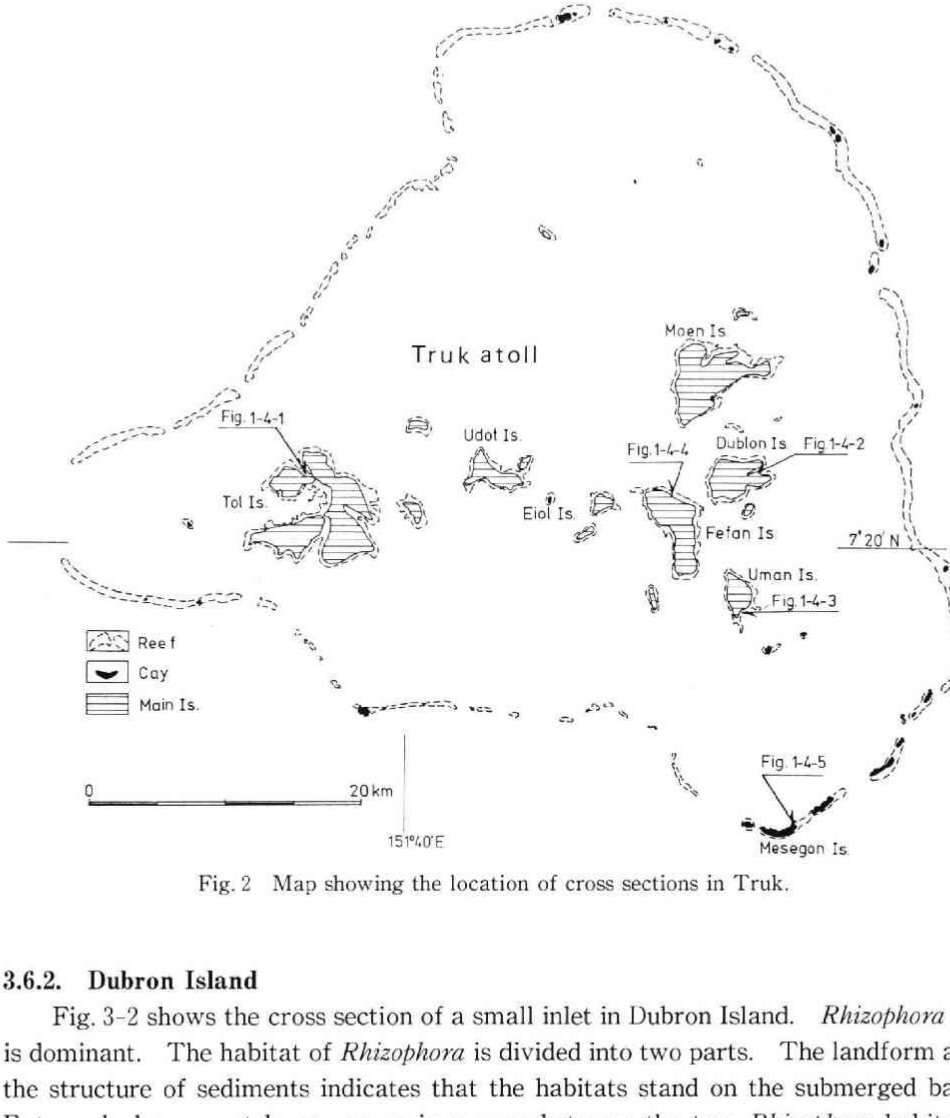

Fig. 2 Map showing the location of cross sections in Truk.

3.6.2. Dubron Island

Fig. 3-2 shows the cross section of a small inlet in Dubron Island. *Rhizophora* sp. is dominant. The habitat of *Rhizophora* is divided into two parts. The landform and the structure of sediments indicates that the habitats stand on the submerged bars. Extremely loose peat layer occurs in a zone between the two *Rhizophora* habitats. Narrow habitats of *Sonneratia alba* are developed between the coastal cliff and *Rhizophora* habitat.

These two inlets in Tol and Dubron islands, the sediment yield from both the foot slope and small channel is not so great at present. Substratum is provided from accumulation of mangrove peat alone. Weak wave action seems to enable natural reforestation of *Rhizophora* habitats in spite of severe cutting.

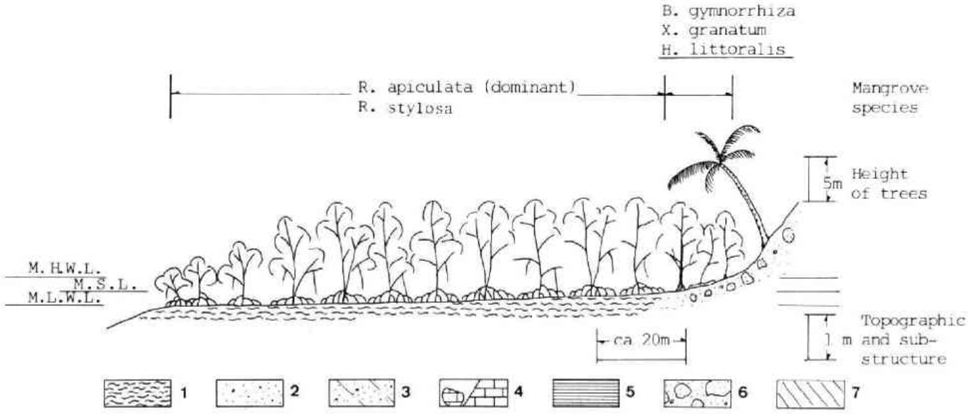

Fig. 3-1 Cross section of the mangrove forest on Tol Island.
Key ; 1 ; mangrove peat, 2 ; coral sand and gravel, 3 ; coral sand and gravel with organic material, 4 ; coral blocks and coral reef, 5 ; muck, 6 ; colluvium, 7 ; land reclamations.

Photo 1 *Rhizophora apiculata* in Tol Island. The stems of these trees are divided into several stems because of timber cutting.

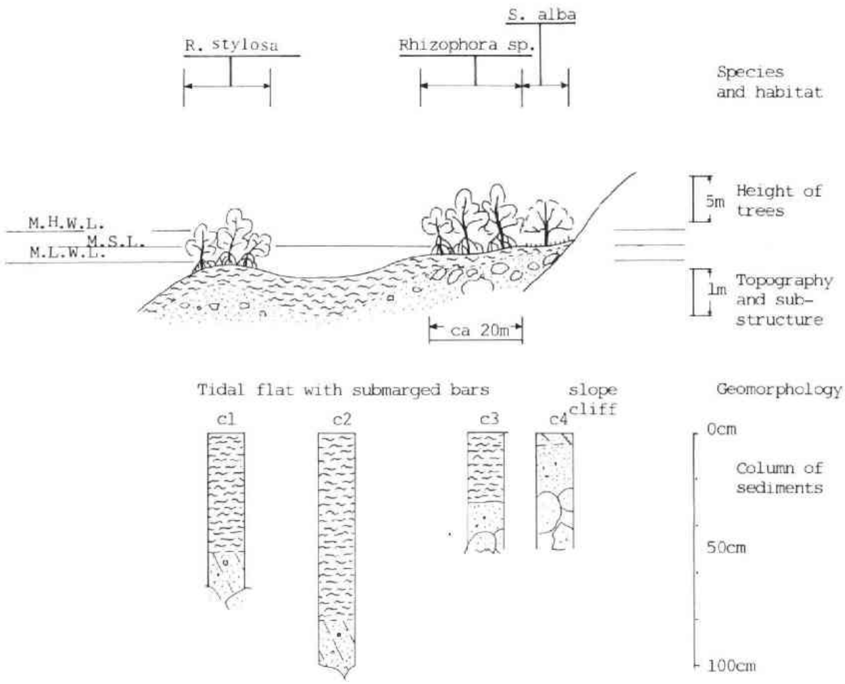

Fig. 3-2 Cross section of mangrove area on Dubron Island.
For key to sedimant types see Fig. 3-1.

3.6.3. Uman Island

These transects (Fig. 3-3a, b) provide the habitat types which stand on small tidal flat located on smooth coastal line of the main island. *Rhizophora* sp. is situated on the seaward side and *Bruguiera gymnorrhiza* and *Sonneratia alba* takes their habitats on landward side.

The height and density of the *Rhizophora* sp. decrease gradually seaward. The stand consists of mixed sediment of coral sand and gyccia.

Bruguiera gymnorriza stands on the muck of the tidal flat and *Sonneratia alba* stands on the inner margin of tidal flats consisting of coluvium, coral sand and coral gravel. Some of large *S. alba* stand on the inner margin which consists of coluvium.

3.6.4. Fefan Island

The transect shown in Fig. 3-4 crosses the two small beach ridges and tidal flat. There are many kinds of mangrove species and landforms. The landforms, sediment and vegetation correspond well each other. For example, *Lumnitzera littorea* stands on the inner margin similar to alluvial lowland which is slightly higher than mean sea-level. The dwarf type *Rhizophora apiculata* stands in the lagoon where the pure fibrous peat accumulated. *Sonneratia alba*, *Xylocarpus granatum*, *Excocaria agallocha*

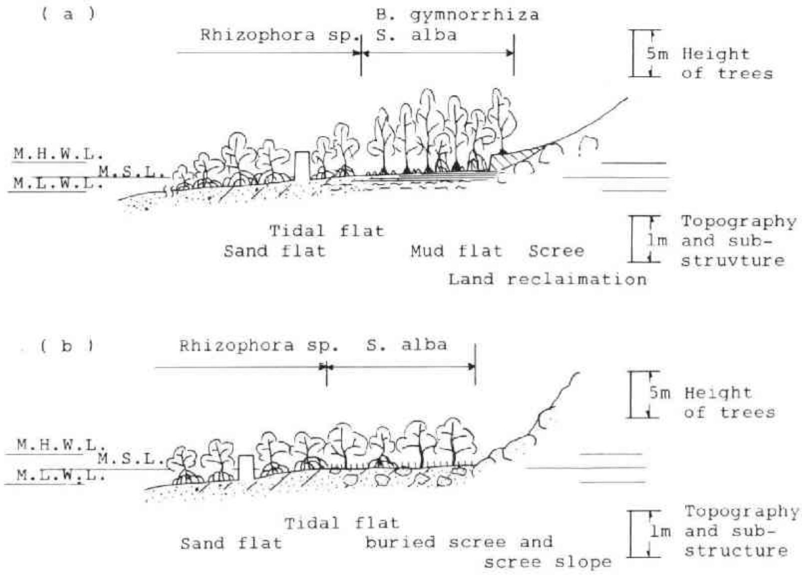

Fig. 3-3 Cross sections of mangrove forest on Uman Island. For key to sediment types see Fig. 3-1.

and *Heritiera littoraris* stand on the margin of the beach ridge. Other small *R. apiculata* habitats occur again on the peat zone between the two beach ridges. *R. stylosa* tree line stands on the small beach ridge, and is buried by beach sand.

The column shown in Fig. 3-4-c7 is remarkable (Photo-2). The mangrove fibrous peat layer seems to have developed under the present beach coral sand. Then the peat is remarked as an indicator of mangrove habitat development. Actually, the mangrove forest had developed untill about 20 years ago. More than 20 years ago, oil pollution from a sinking warship, worsened the living condition and killed some forest which were subsequently cut by local people for fire wood. It was followed by severe coastal erosion. The sediment such as fine materials and the upper part of peat layer was removed and scattered to offshore and coated the coral reef. On the other hand, coarse materials were as partially retransported landward and buried the little beach ridge. In this case, the timber cutting induced the destruction of mangrove habitat and coral reef to make impossible reforestation.

3.6.5. Mesegon Island

Fig. 3-5-a and b represent the transects of habitats in Mesegon Island, which is the small cay located on the fringe of the Truk lagoon. Several *Rhizoshora stylosa* stand on the sea level platform of rapier, on the fore slope of the beach, and they are partly buried by beach ridge deposits. Small *Bruguiera gymnorrhiza* habitat located on the foremost lagoon where coconuts fields are located.

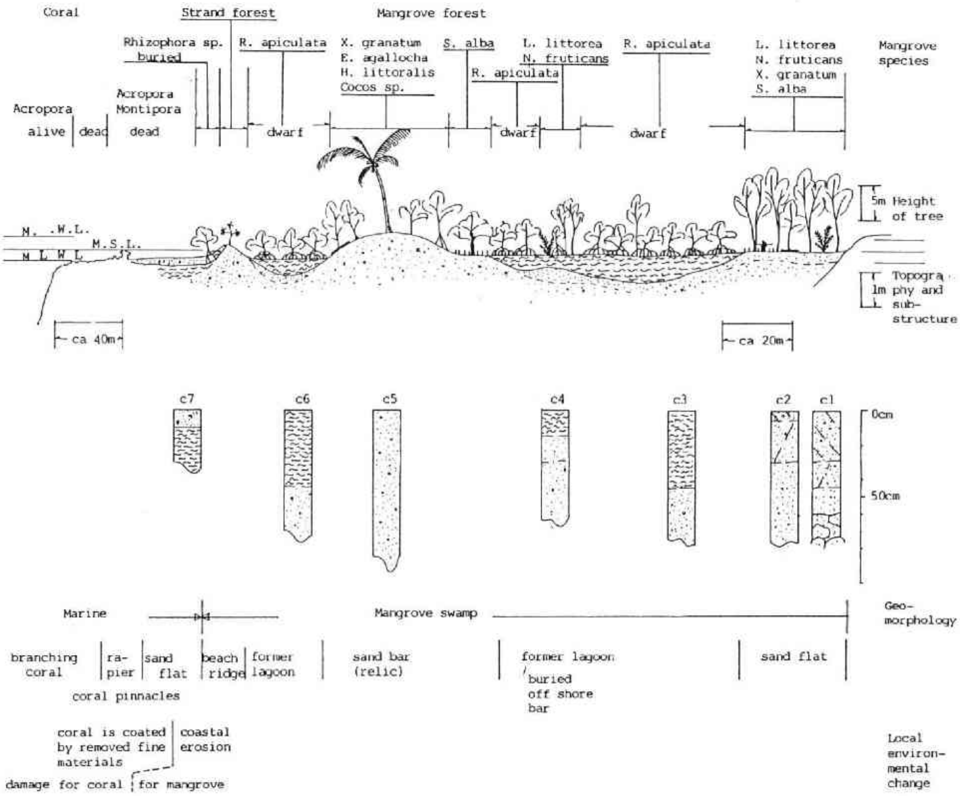

Fig. 3-4 Cross section of the mangrove forest and several geomorphological factors on Fefan Island.
For key to sediment types see Fig. 3-1.

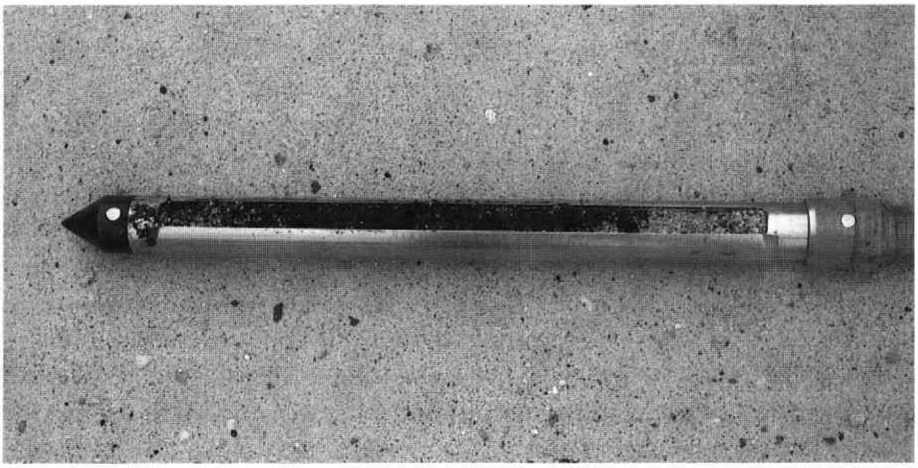

Photo 2 The uppermost part consists of coral fragments which overlie peat layer.

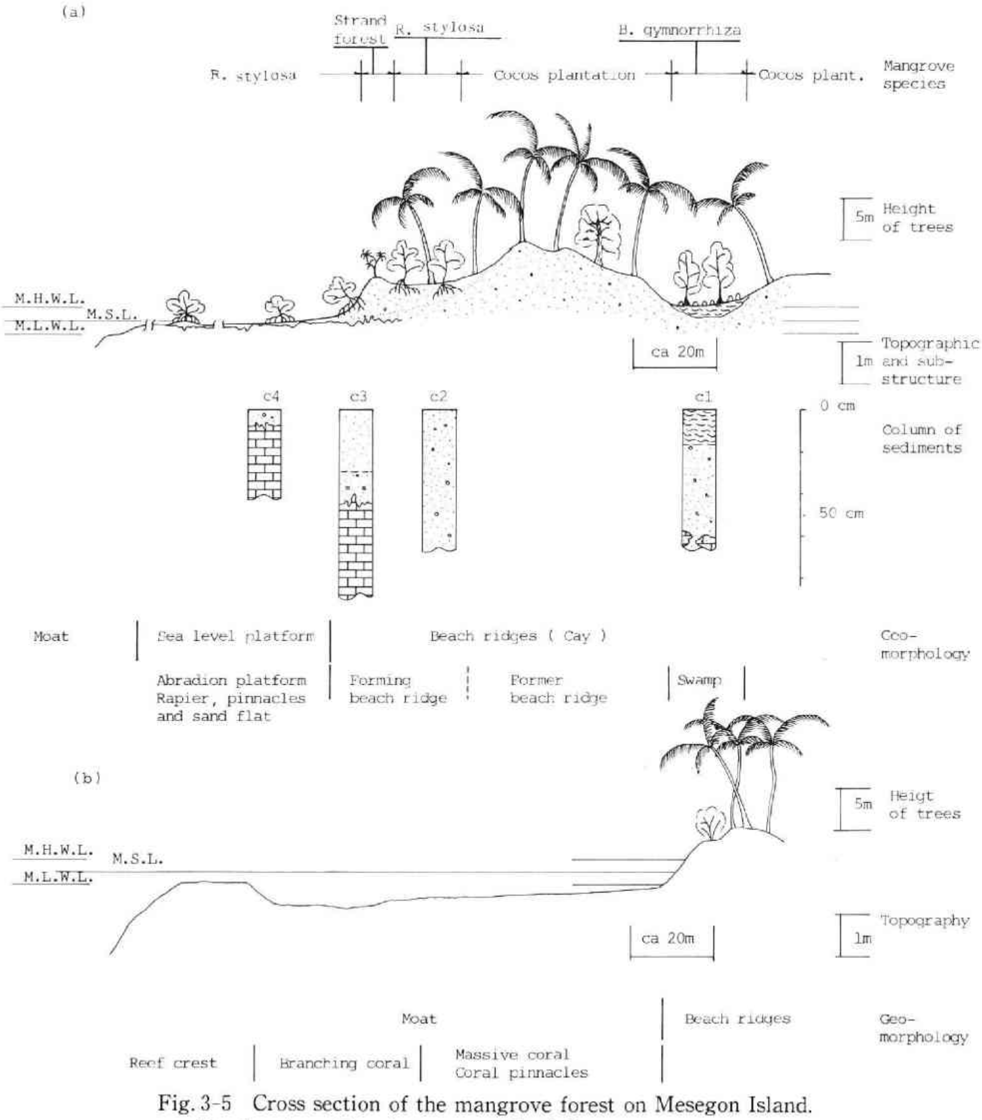

Fig. 3-5 Cross section of the mangrove forest on Mesegon Island. For key to sediment types see Fig. 3-1.

4 Ponape Island

4.1. Location and geographical features

Ponape Island, located in the East Caroline Islands (6°45′ to 7°04′N. Latitude, 158°05′ to 23′E. Longitude), is roughly circular in shape and about 25 km across (Fig. 4),

Table 4 Climatological data of Ponape Island

Temperature	Annual mean	26.4°C
	Annual range	less than 1°C
	Dayly range	7.2°C
	Lowest temp.	18°C
		(Nov, 1969, Jan. 1974, Dec. 1977)
Precipitation	Annual rainfall	193 inches (490 cm)
	Number of days with measurable rainfall	300 days
	Relative dry season	Jan. Feb. Mar.
Wind	NE trade winds	Nov. Dec. Jan. Feb. Mar. Apr. May. Jun.
	SE to Sw winds	Jul. Aug. Sep. Oct.
Typhoon	Immediate vicinity are not common	

and consists of Tertiary volcanic rocks. This island of plateau type has five level surfaces, *i.e.* 750 m, 500 m, 100 m, 30 m, and 2 to 1 m above sea level. The 750 m and 500 m surfaces are depositional surfaces of the lava. The 100 m and 30 m surfaces are marine terraces. The 2 to 1 m surfaces are coastal lowlands (Tayama 1952). The slopes between each surface are generally cliffy. Accordingly, there are many falls in the island.

A barrier reef surrounds the island except for a part of the southeast side where it is tied to the land to form a fringing reef (Fig. 4). The lagoon is about 5 to 7 km wide in the northeastern part of the island. The average depth of the lagoon appears to be slightly less than the typical 46 m average for the western Pacific. Different from Truk, the Ponape reef is characterized by the relatively deep channels that enter it at five localities. One of the channels is so deep than 91 m where it cuts across the reef that deep water continues on the inside (Shepard 1970).

4.2. Climate and oceanography

The climate of Ponape Island is almost the same as Truk. Some climatic data are compiled in Table 4. Mean tidal range at Ponape Harbor is 70 cm, and mean spring tidal range reachs 104 cm.

4.3. Geographical distribution and species of mangrove

Ponape Island has a total timberland area of 19,683 ha, of which 5,525 ha are estimated to be mangrove forests (Maclean *et al.* 1988). These mangrove forests surround the island, especially southern and western parts (Fig. 4). At the biggest mangrove forest, its width exceeds 4 km. Most of the mangrove forests develop on the inner reef of the barrier reef, particularly in front of scarps or steep slopes. 15

mangrove species are identified on the island (Table 1).

4.4. Description of study sections

To clarify the process of mangrove habitat development of the tidal flat on Ponape, we have carried out a topographic profile survey using hand level, stratigraphic survey employing a hand-operated peat sampler, commonly called a "Bloom sampler', and observation of vegetation for two sections in the southern part of the island (Figs. 4, 5).

The base level of the topographic profile survey is the sea level at that time, adjusted later in reference to tidal record at Ponape Harbor.

Fig. 4 Landform of Ponape Island.
1; Mountains, hills and terraces, 2; Lowland, 3; Mangrove swamp, 4; Coral reef, 5; River.

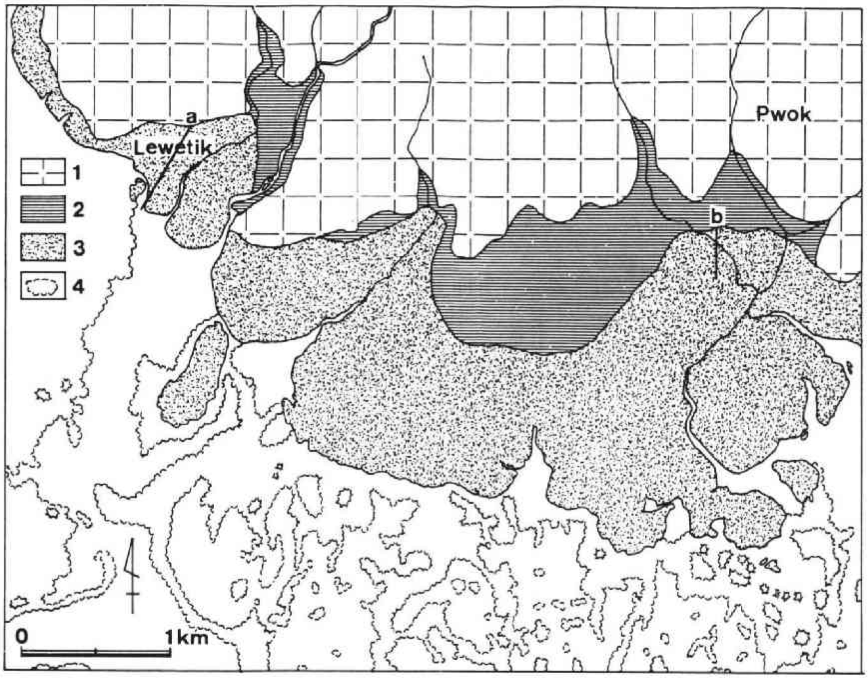

Fig. 5 Location of cross section on Ponape Island.
1 ; Mountains, hills and terraces, 2 ; Lowland, 3 ; Mangrove swamp, 4 ; Coral reef.
a, b ; Cross section.

4.4.1. **Profile a** (Fig. 6-1)

The mangrove habitat on which this profile is located develops at the front of a steep hill in width of about 570 meters. The leveling has been made in 21 locations at about 30 meter intervals, and the boring has been done in 5 locations.

The stratigraphy along this profile is reconstructed as shown in Fig. 6-1. The mangrove peat overlies sand which contains shell fragments or coral fragments. In Loc. 13, sand is intermingled with the mangrove peat below -0.83 m. The sand seems to have been derived from flood deposits. The mangrove peat layer shows its maximum depth more than 2.5 m around Loc. 3. Around Loc. 20, the mangrove peat contacts with sand including coral fragments at -1.36 m. The mangrove peat is not found in Loc. 1. Therefore, it has become clear that the distribution of the mangrove peat is restricted in the area of the present mangrove habitat.

Radiocarbon dating provides the following results: an organic sandy silt from -1.83~-2.08 m at Loc. 13 indicates 1380±100 yr B.P. (TH-1513) and a mangrove peat from -1.16~-1.41 m at Loc. 20 indicates 1210±100 yr B.P. (TH-1514).

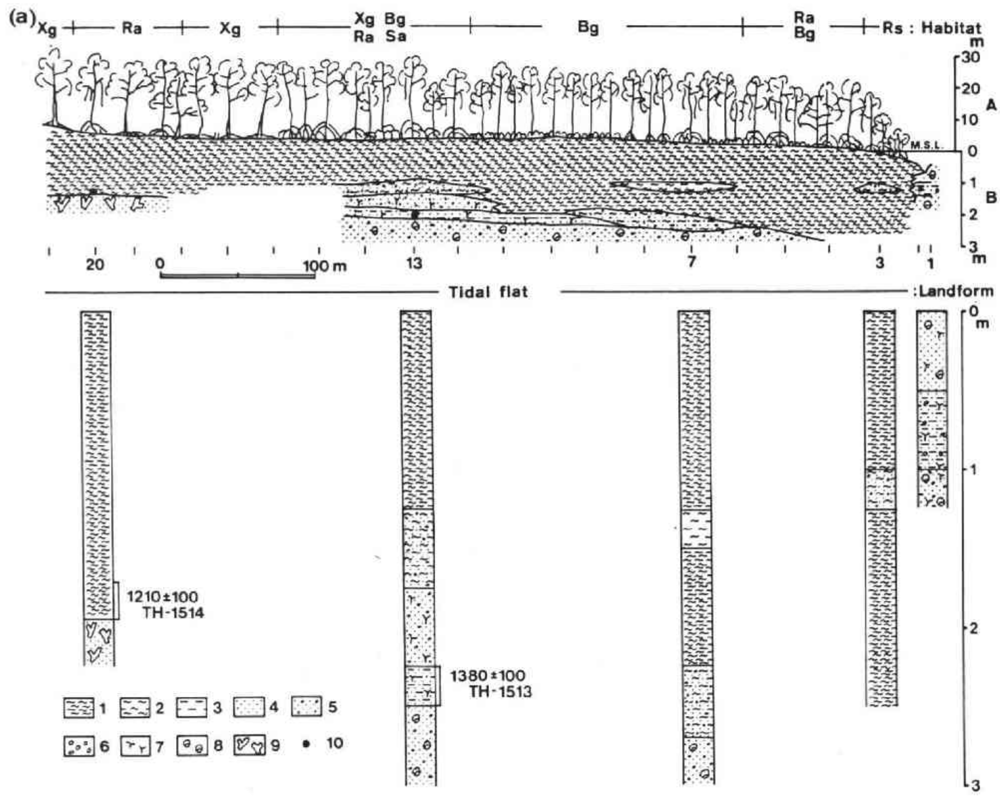

Fig. 6-1 Cross section of mangrove area in Lewetik.
1 ; Mangrove peat, 2 ; Clayey peat~peaty clay, 3 ; Silt, 4 ; Medium Sand, 5 ; Coarse sand, 6 ; Granule or pebble, 7 ; Humus, 8 ; Shell fragment, 9 ; Coral fragment, 10 ; Horizon of ^{14}C dating. A ; Height of mangrove, B ; Vertical scale of geomorphic and geologic profile. Bg ; *Bruguiera gymnorrhiza*, Ra ; *Rhizophora apiculata*, Rs ; *Rhizophora stylosa*, Sa ; *Sonneratia alba*, Xg ; *Xylocarpus granatum*.

4.4.2. **Profile b** (Fig. 6-2)

The mangrove habitat on which this profile is located develops in width of about 2 km. The leveling has been made in 14 locations at about 13~30 meter intervals from the inlandmost part of this mangrove habitat to seaward, and the boring has been done in 3 locations. As the tide came in when we reached Loc. 14, the survey had to be stopped at the location.

The stratigraphy along this profile is reconstructed as shown in Fig. 6-2. The mangrove peat overlies the coral bench. The boundary between the mangrove peat and the coral bench is nearly horizontal. The altitudes of the boundary are between -1.71 m (Loc. 8) and -1.34 m (Loc. 14).

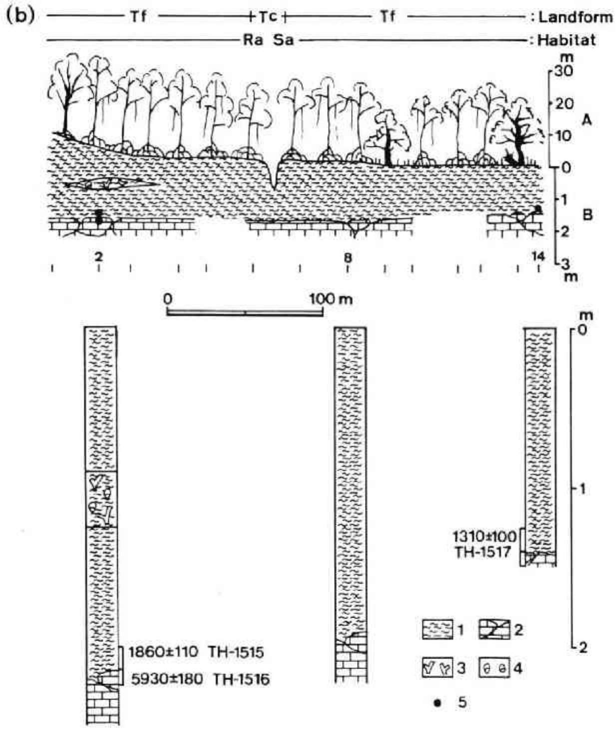

Fig. 6-2 Cross section of mangrove area in Pwok.
1 ; Mangrove peat, 2 ; Coral block and coral reef, 3 ; Coral fragment, 4 ; Shell fragment, 5 ; Horizon of ^{14}C dating. Tf ; Tidal flat, Tc ; Tidal creek. A, B, Ra, Sa : See the key of Fig. 6-1.

Radiocarbon dating provides the following results : a mangrove peat from -1.47 ~-1.62 m at Loc. 2 indicates 1,860±110 yr B.P. (TH-1515), coral fragments from -1.62 ~-1.72 m at Loc. 2 indicates 5,930±180 yr B.P. (TH-1516) and a mangrove peat from -1.19~-1.14 m at Loc. 14 indicates 1,310±100 yr B.P. (TH-1517).

5 Discussion

5.1. Geomorphic conditions and development processes of mangrove habitat

Very close relationships between the geomorphology and some species of mangrove have been remarked.

The following zonation from seaward to landward is recognized : *Rhizophora stylosa* as a margin of forest, *Bruguiera gymnorrhiza, Rrizophoha apiculata* make a main part, *Xylocarpus granatum* and *Lumnitzera littorea* located on the landward, and *Excocaria agallocha, Nypa fruticans* make a back mangrove in these areas (Photo 3, 4, 5).

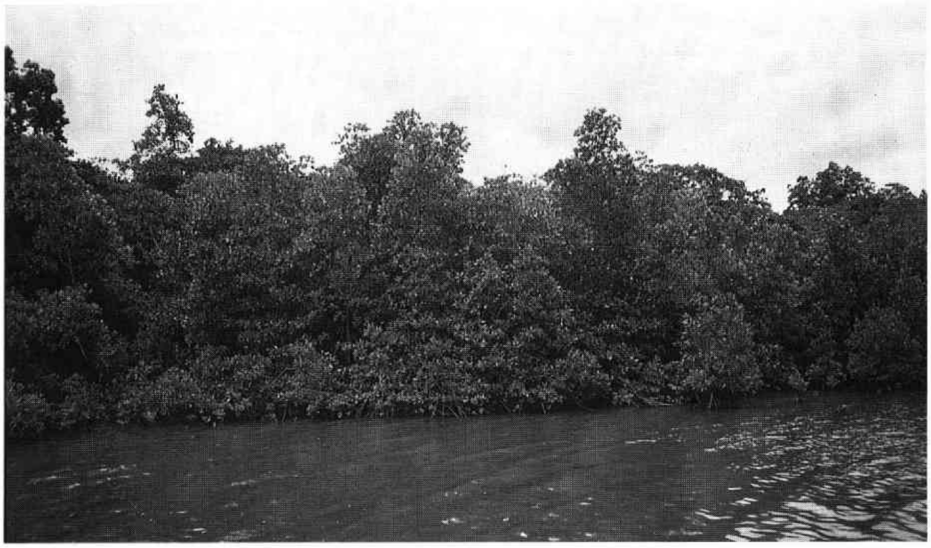

Photo 3 *Rhizophora stylosa* located in the seaward side as a pioneer species.

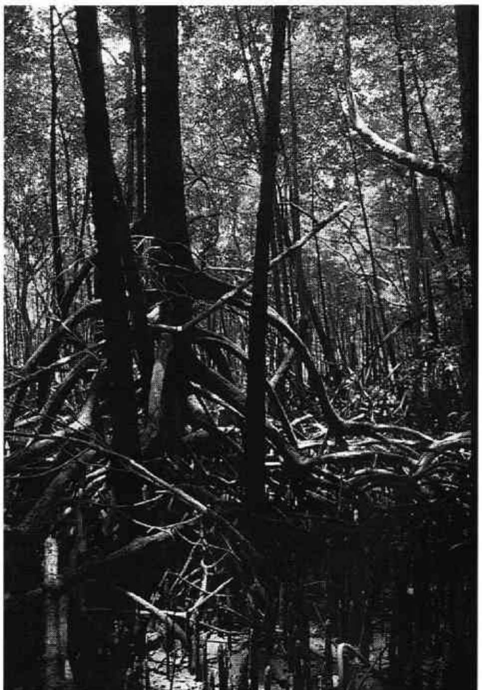

Photo 4 *Rhizophora apiculata* stands in a main part of the mangrove habitat.

Photo 5 *Xylocarpus granatum* and *Sonneratia alba* stand in landward margine of the mangrove habitat.

R. apiculata and *B. gymnorrhiza* form a main part of mangrove forest in every habitat on the tidal flat. These two species stand on the depositional area of fibrous peat which consist of mangrove material such as roots and timber of *R. apiculata* and *B. gymnorrhiza*. It means that the habitat development is the same process as of peat accumulation from these two species.

B. gymnorrhiza is located on the area of slightly inner part than *R. apiculata*. There are no characteristics of substructure. This difference will be clarified by other environmental factors.

L. littorea grows on the slightly higher and landward portion of tidal flat which consists of inorganic alluvial material. A zone on the inner margin of tidal flat near the coluvial footslope is distinguished by *Heritiera littoralis*, *X. granatum*. Especially *X. granatum* makes a narrow and distinguishable zone on Ponape Island (Photo 5). The habitat are characterized by substructure of organic loamy materials. The margin of beach ridges in Truk area is dominated by mixed forest composed of *H. littoralis*, *X. granatum*, *N. fruticans* and *E. agallocha etc.* *R. stylosa* stands on various kinds of landform, such as the front end of tidal flat, coral sand and coral platform, although *R. stylosa* makes a clear zone on the margin of habitat on Ponape Island. *R. stylosa* seems to be a kind of pioneer species.

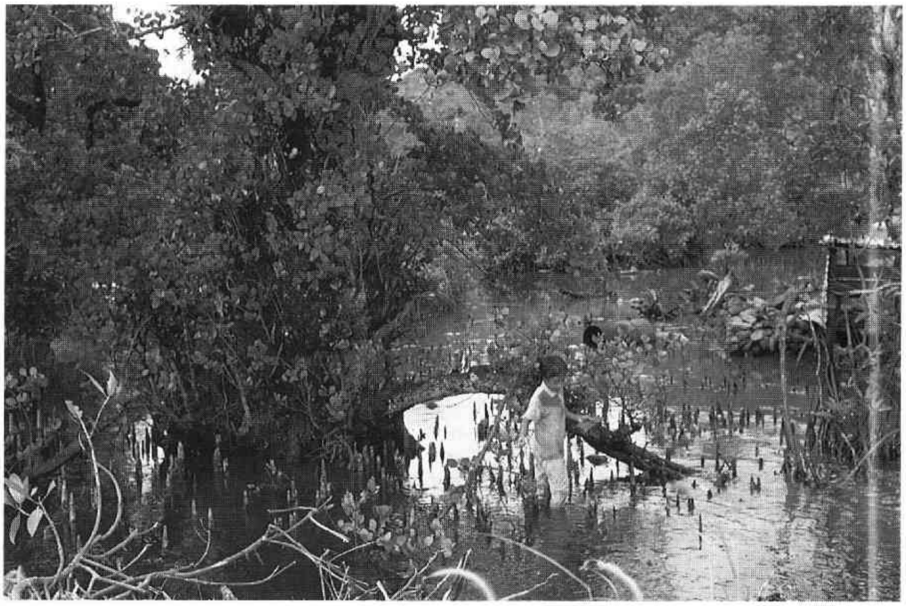

Photo 6 Large *Sonneratia alba* (1.3 m D.B.H.) located in inner margine of habitat in Truk, Moen Island.

Photo 7 Large *Sonneratia alba* (1.4 m D.B.H.) located in mid part of habitat on Ponape Island.

Generally, *Sonneratia alba* stands in front of the habitat as a pioneer species. The authors are not able to recognize any remarkable relationships between the species and landform characteristics. Exceptionally, medium sized *S. alba* forms a zone between the habitat of *X. granatum* and mangrove main habitat in Truk area. *S. alba* is interspersed in the mangrove forest on Ponape Island. There is no relationship between the landform and the species on both islands. On the other hand, large *S. alba* are located in front of footslopes and in the mid-part of habitat in Truk area (Photo-6). And a large *S. alba* stands in the *R. apiculata* habitat on Ponape Island. This huge *S. alba* seems to have been regenerated from the fallen huge stem (Photo-7), although the age is not estimated. The authors presumed, however, some of *S. alba* have been kept their life in spite of environmental changes during recent 1,000 or 2,000 yrs.

5.2. Sea-level fluctuations and habitat development

The close relationship has been clarified between the development of mangrove habitat and relative sea-level fluctuations on Ponape Island. The sea-level fluctuations of Ponape Island have been reconstructed as Fig. 7, based on the radiocarbon dates which have been reported in the present research and Matsumoto *et al.* (1986). The relationship is also revealed by Fujimoto *et al.* (1989) in Pagbilao, the Philippines. These relationships and substructures of the tidal flat types in Ponape and Pagbilao are very similar in spite of subsidence trend of Ponape Island.

The fact is important for the recognition of habitat development. It means that the rates of peat accumulation and sea-level rise are key factors for the estimation of habitat stability.

These data indicate the development processes of tidal flat type habitat in late Holocene.

The process is as follows (Fig. 7).

Stage 1 Around 2,500 years B.P., the sea level continued to rise. The mangrove habitat had developed on the inner part of tidal flat depending on the rate of sea level rise and the landform structure. The coral bench or platform developed widely on the fore part of the habitat.

Stage 2 The mangrove habitat extended landward and mangrove peat was accumulated with the rising sea-level until 2,500 years B.P.. The sea level reached about 1 meter below the present one.

Stage 3 Around 2,000 years B.P. the sea level lowered about 1.5 meter. The mangrove habitat shifted seaward with the lowering sea-level. Former mangrove habitat seems to have been replaced by the salt marsh.

Stage 4 The sea level gradually turned to rising trend. During this period, the mangrove habitat stretched not only landward but also upward by peat accumulation with the rising sea-level.

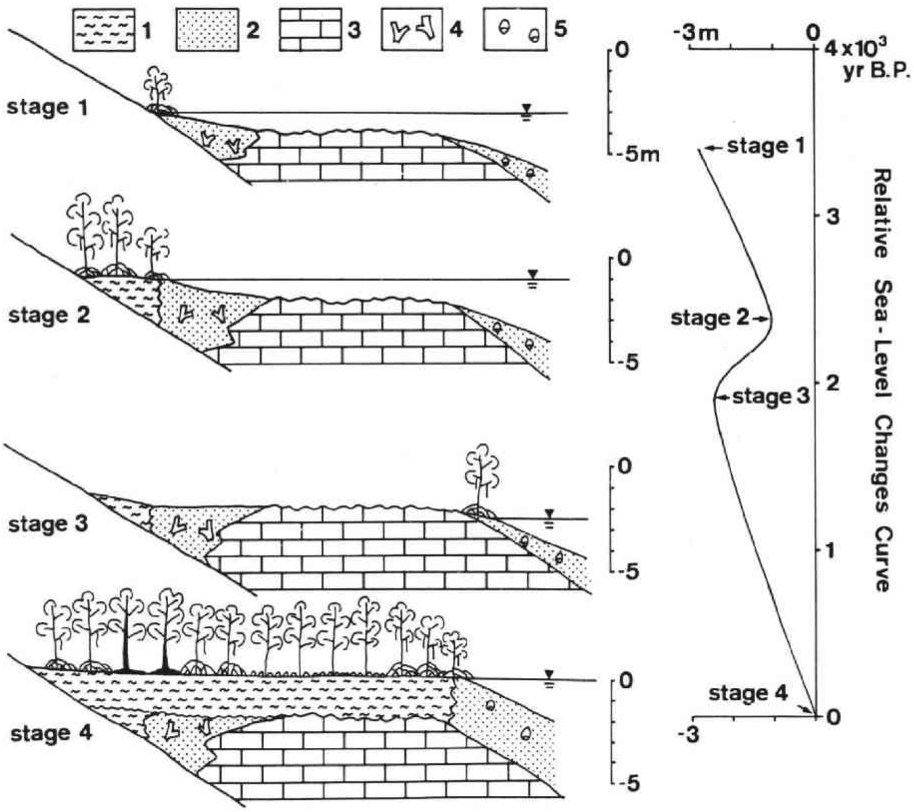

Fig. 7 Relative sea-level changes curve and a schematic representation of mangrove habitat development on Ponape Island.
1 ; Mangrove peat, 2 ; Sand, 3 ; Coral reef, 4 ; Coral fragment, 5 ; Shell fragment.

At the same time slower subsidence in Truk area than Ponape Island is indicated by the fact that the base of mangrove peat of Truk atoll is higher than that of Ponape Island (Figs. 3 and 6).

Mangrove keeps their own habitat by their biomass production and physical functions during these processes. The rates between the peat accumulation and the sea level rise seem to be almost equivalent. The complicated root system has a function not only as a barrier against wave action but also as a prevention against sediment scatter.

Balance between the rate of sea level rise and peat accumulation is important for maintaining the habitat.

From all of our investigation, the correspondence of geomorphology and mangrove vegetation are summarized as a story of geomorphic development and sequence

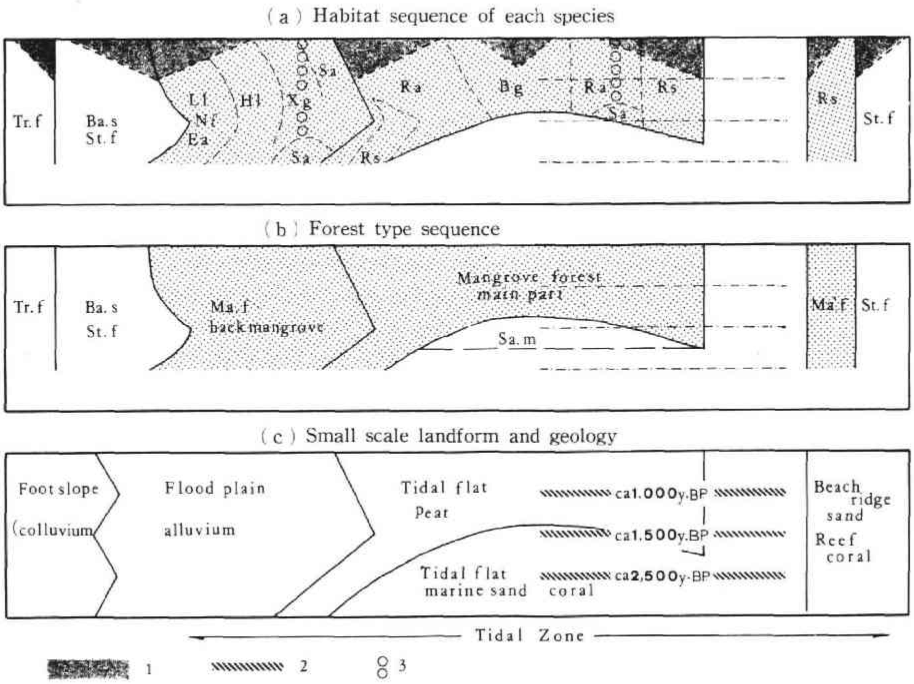

Fig. 8 Diagramatically illustrated correspondence of landform, geology and habitat in micro-scale and in small scale.
(a), (b) : Spacio-chronological sequence of habitat
(c) : Geological structure and landform arrangement in small-scale
1 ; Human impacts, 2 ; Setting age, 3 ; Some of *Soneratia alba* keep their life during the time.
Tr.f ; Tropical forest, Ba.s ; Back swamp, St.f ; strand forest, Ma.f ; mangrove forest, Sa.m ; Salt marsh.
Ll ; *Lumnitzera littorea*, Hl ; *Heritiera littoralis*, Xg ; *Xylocarpus granatum*, Sa ; *Sonneratia alba*, Rs ; *Rhizophora stylosa*, Ra ; *Rhizophora apiculata*, Bg ; *Bruguiera gymnorrhiza*.

of habitat in Fig. 8.

5.3. Habitat of tidal flat type and environmental impacts

The manner of the response to the various kinds of impact should vary with geomorphological position of the respective mangrove habitat.

The habitat is classified to three types according to its geomorphological situation, such as the type located on estuary or delta, the type located on back marsh or lagoons behind barriers, and the type located on tidal flats. The former two types were discussed by Kikuchi *et al.* (1981, 1983) and Miyagi *et al.* (1989). The initial setting and continuation of habitat is strongly controlled by the balance between the fluvial process and sea level fluctuation.

The third type (tidal flat habitat) is slightly delicate. In the case of Ponape Island and Tol Island in Truk, the initial setting was provided by the sea level lowering around 2,000 years B.P. (this report)

On that time, the habitat developed rapidly. After that, sea-level rose about 1.5 meter untill present. The habitat continued at the location by itself for recent 1,500 years. This process paralleled the accumulation of peat. It means that mangrove habitat is inherently fragile and its continuation is completely controlled by the biomass productivity and the rate of sea-level change. Fefan Island in Truk provides a good example.

The habitat is surrounded by barrier reef and is located in the deep inlet. Such situation is very stable like Tol Island. There is no wave action. But on the tidal flat habitat facing to smooth coast, human activities will lie severe coastal erosion. In this case, it means the destructive subsidence of ground level.

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