Title	Holocene geomorphic development of coastal barriers in Japan
Sub Title	
Author	松原, 彰子(Matsubara, Akiko)
Publisher	慶應義塾大学日吉紀要刊行委員会
Publication year	2002
Jtitle	慶應義塾大学日吉紀要. 社会科学 No.12 (2002.) ,p.37- 68
JaLC DOI	
Abstract	Coastal ridges are widely distributed among the lowlands of the Japanese Islands. They represent former coastal barriers and beach ridges. In this paper, the geomorphic development of coastal barriers during the Holocene period is clarified from a study of six coastal lowlands and one coastal lagoon. The areas studied represent typical landforms of the Japanese coastal lowlands with ridges. Fossil foraminiferal assemblages were analysed to reconstruct the palaeoenvironmen-tal changes in the bays, which were formed by the Holocene transgression. The coastal barriers in the study areas had been commonly formed from the rise in sea level during the early to mid Holocene. The bays changed into lagoons by the emergence of barri-ers, formed as a result of decreasing rate in the rise of sea level. Furthermore, when the sea level lowered, the lagoons changed into marshes from the development of beach ridges seaward of the barriers. Differences in the development of the coastal barriers could be recognized from the period of enclosure by the barriers. The controlling factors of both the barriers' develop-ment and the landforms of the coastal lowlands are tectonic movements, the basal topog-raphy of coastal lowlands, and sediment supply.
Notes	
Genre	Departmental Bulletin Paper
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=AN10425830-20020000-0037

Holocene Geomorphic Development of Coastal Barriers in Japan

Akiko Matsubara

Abstract

Coastal ridges are widely distributed among the lowlands of the Japanese Islands. They represent former coastal barriers and beach ridges.

In this paper, the geomorphic development of coastal barriers during the Holocene period is clarified from a study of six coastal lowlands and one coastal lagoon. The areas studied represent typical landforms of the Japanese coastal lowlands with ridges.

Fossil foraminiferal assemblages were analysed to reconstruct the palaeoenvironmental changes in the bays, which were formed by the Holocene transgression. The coastal barriers in the study areas had been commonly formed from the rise in sea level during the early to mid Holocene. The bays changed into lagoons by the emergence of barriers, formed as a result of decreasing rate in the rise of sea level. Furthermore, when the sea level lowered, the lagoons changed into marshes from the development of beach ridges seaward of the barriers.

Differences in the development of the coastal barriers could be recognized from the period of enclosure by the barriers. The controlling factors of both the barriers' development and the landforms of the coastal lowlands are tectonic movements, the basal topography of coastal lowlands, and sediment supply.

Key Words: sea-level change; Holocene; coastal lowlands; barriers; foraminifera; Japan.

I. Introduction

The Japanese Islands are composed of arcs and trench systems. They are characterized as having been tectonically active during the Quaternary. The coastal lowlands along the Japanese Islands are distributed mainly in subsiding regions. The rivers supply so much sediment from volcanoes or from uplifting mountains in the upper reaches to the coastal lowlands that thick and unconsolidated deposits have accumulated since the Last Glacial stage in the late Pleistocene. Therefore, tectonic movements have influenced the development of the coastal lowlands.

The coastal lowlands of the Japanese Islands can be classified into three types: (1) alluvial fans which develop at river mouths with a high coarse sediment supply, and face towards the steep sea bottom; (2) alluvial deltas which dominate in the coast of the inner part of bays, and have been supplied with a high level of fine sediment; and (3) sand or gravel ridges and backmarsh complexes. These ridges are usually parallel to the shore, and represent former coastal barriers and beach ridges.

Among these three types of coastal lowlands, the ridge-backmarsh complexes are the most extensively distributed. Consequently, it is considered that these coastal ridges have played an important role in the geomorphic evolution of the coastal lowlands during the Holocene period.

The coastal lowlands composed of the ridge-backmarsh complexes and coastal lagoons can be classified into five types, according to the present landform: (a) barrier-lagoon complexes (barrier systems); (b) sand or gravel ridge-backmarsh complexes; (c) valley plains; (d) beach ridge plains (strand plains); and (e) delta-beach ridge complexes (Fig.1).

The rise in sea level during the Holocene was a major factor in the development of coastal barriers, according to studies on barrier complexes around the world (Davis, 1994; Trenhaile, 1997). Generally, barriers were developing and transgressing landward when the sea level was rising rapidly. On the other hand, the barriers began to grow seaward when the sedimentation rate became higher than the rate of the rise in sea

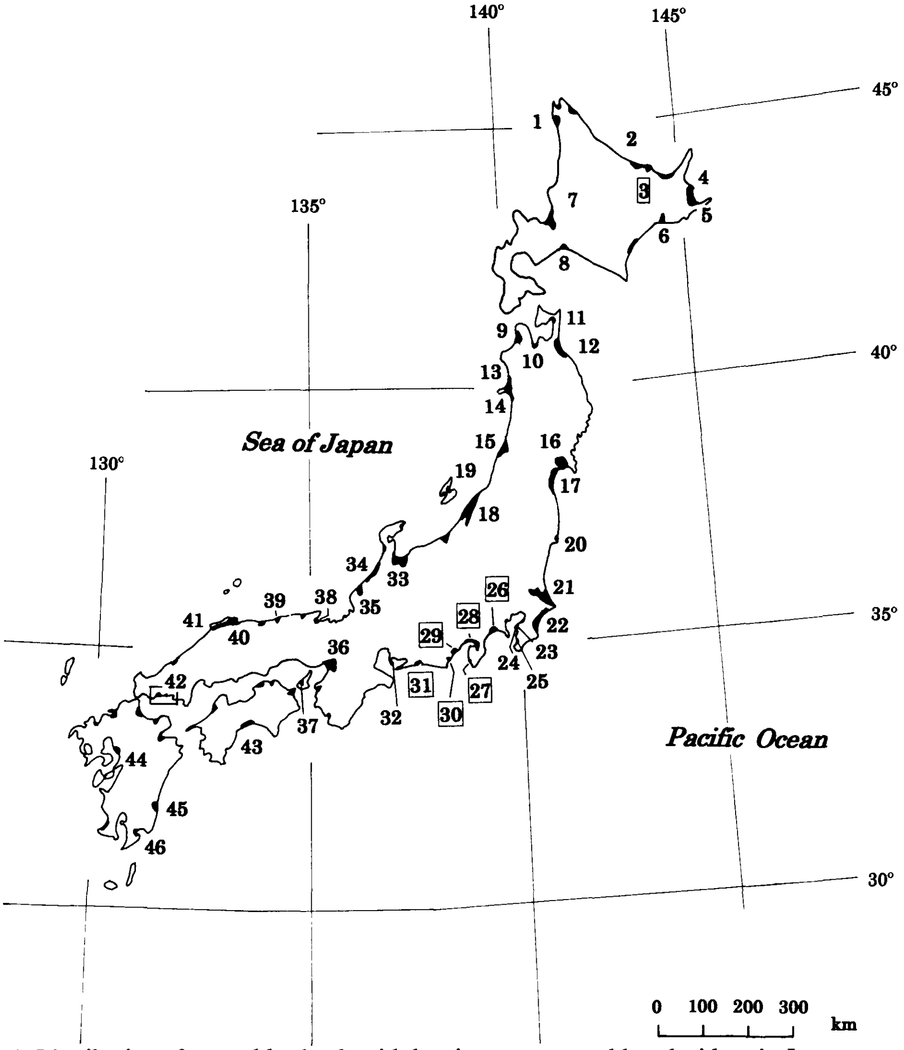

Fig.1. Distribution of coastal lowlands with barrier systems and beach ridges in Japan.

Numbers with □ represent areas studied.

1. Sarobetsu lowland 2. Lake Saroma 3. Tokoro lowland 4. Notsuke spit 5. Lake Furen 6. Kushiro lowland 7. Ishikari plain 8. Yufutsu plain 9. Tsugaru-jusan lake 10. Aomori plain 11. Tanabu lowland 12. Lake Ogawara 13. Noshiro plain 14. Akita plain 15. Shonai plain 16. Ishinomaki plain 17. Sendai plain 18. Niigata plain 19. Lake Kamo 20. Iwaki lowland 21. Kasumigaura lake 22. Kujukuri plain 23. Obitsugawa lowland 24. Futtsu lowland 25. Tateyama lowland 26. Sagami River lowland 27. Matsuzaki lowland 28. Ukishimagahara lowland 29. Shimizu lowland 30. Haibara lowland 31. Lake Hamana 32. Utsumi lowland 33. Toyama Bay lowland 34. Kahokugata lake 35. Fukui plain 36. Osaka plain 37. Mihara lowland 38. Amanohashidate 39. Tottori Plain 40. Nakaumi lake 41. Shinji lake 42. Suonada lowlands 43. Kochi plain 44. Tamana lowland 45. Miyazaki plain 46. Kimotsuki lowland

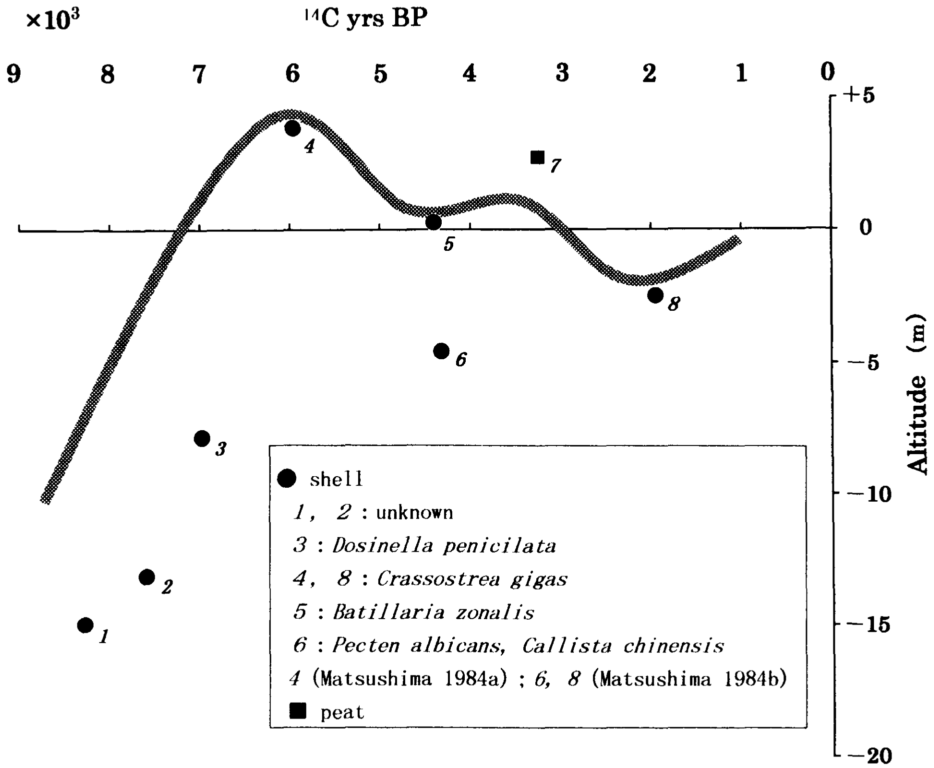

Fig.2. Relative sea-level curve during the Holocene in the Shimizu lowland.

level. These geomorphic developments of coastal barriers were recognized along the east coast of North America (Colquhoun *et al.*, 1968; Pierce and Colquhoun, 1970; Moslow and Colquhoun, 1981), the Netherlands coast (Van Straaten, 1965; Hageman, 1969; Jelgersma and Van Regteren, 1969), and along the Australian coast (Thom *et al.*, 1981; Thom, 1983).

A common pattern in the relative sea-level changes around Japan is that the sea rose above the present level (Bird, 2000). The Holocene transgression is called the Jomon transgression in Japan, as it is associated with the archaeological age of that name. It is known that sea level generally reached its highest level (3 to 5 m higher than at present) at around 6,000 BP. After the culmination of the Jomon transgression, the sea level stabilized, or even lowered slightly, and has since changed with minor fluctuations (Ota *et al.*, 1981; Ota *et al.*, 1990; Umitsu, 1991) (Fig.2). Geomorphic evolution of the coastal lowlands was deeply influenced by the Holocene sea-level changes.

The evolution processes of the coastal lowlands consist of the following three stages in relation to the sea-level changes.

(1) The valley-forming stage: Ancestral rivers eroded downward to form a valley at the lowest sea level during the latest Pleistocene period.

(2) The bay-forming stage: The valley was transgressed by the rise in sea level during the Holocene, and a bay, or a drowned valley, was formed, during the early to mid Holocene.

(3) The lowland-forming stage: The bay, or the drowned valley, filled with fluvial deposits or was enclosed by coastal barriers, after the culmination of the Holocene sea-level rise during the late Holocene.

Studies on the geomorphic development of the coastal lowlands have mainly dealt with the land-forming stage during the late Holocene. We have not performed sufficient studies on the palaeoenvironmental changes of the bays, or of the drowned valleys, or of the development of the coastal barriers. Regarding the studies on the coastal ridges in Japan, most have been on the development of beach ridges when the sea level stabilized or lowered slightly during the late Holocene. On the other hand, the development of barrier complexes when the sea level was rising before the culmination of the transgression in the early to mid Holocene, is not well understood.

In this paper, the geomorphic development of the coastal lowlands during the Holocene will be clarified to reconstruct the palaeoenvironmental changes of the bays, on the basis of the analysis of fossil foraminiferal assemblages in bore hole cores. Then, the development of coastal barriers and beach ridges in Japan will be clarified. Furthermore, both common, and different, processes in the development of coastal barriers will be investigated.

Six coastal lowlands and one coastal lagoon in Japan are studied, as these represent typical landforms of coastal lowlands with ridges in Japan. Lake Hamana belongs to the barrier-lagoon complexes. The Tokoro and Ukishimagahara lowlands are sand or gravel ridge-backmarsh complexes. The Matsuzaki and Haibara lowlands are valley plains. The Shimizu lowland belongs to the beach ridge plains, and the Sagami River lowland has delta-beach ridge complexes.

Four of these areas: the Ukishimagahara, Matsuzaki, Haibara and Shimizu lowlands are situated along Suruga Bay. From a tectonic point of view, the Suruga Bay area is considered to be one of the most active regions in Japan. Suruga Bay is situated at the boundary between two plates: Philippine Sea Plate to the east and the Eurasian Plate to the west. The Philippine Sea Plate is underthrusting north-westward beneath the Eurasian Plate at the Suruga Trough. The Suruga Trough runs from north to south along the middle of the bay, with a maximum depth of more than 2,000 m. Therefore, it is possible to clearly distinguish the influence of tectonic movements on the development of the coastal lowlands by studying the Suruga Bay area.

II. Reconstruction of Palaeoenvironmental Changes

In this paper, the analysis of fossil foraminiferal assemblages is carried out for the palaeoenvironmental reconstruction in a bay during the Holocene: aspects of the palaeoenvironment which have not been lithologically recognized, such as salinity or water temperature.

Foraminifera belong to *Protozoa* and consist of protoplasm and calcareous or agglutinated tests. They are extensively distributed through marine and brackish water and live widely from shallow to deep sea. The mean diameter of specimens used in the test is about 0.1 to 1.0 mm. Fossil foraminifera are often sufficiently abundant in bore hole cores to enable us to identify the environment of the deposition. Therefore, the relationships between the distribution and environmental factors have been quantitatively analysed.

Foraminifera are classified into planktonic and benthic ones. Planktonic foraminifera are used as an indicator of the distribution of the sea water masses. As the distribution of recent benthic foraminifera is controlled by water depth, water temperature, salinity and sea bottom sediment, benthic foraminifera are used as the indicators of these environmental factors.

In a bay or a drowned valley, salinity is the dominant factor controlling the distribu-

Table 1. Foraminiferal Indicators for the reconstruction of palaeoenvironment.

Indicators of Palaeoenvironment	Foraminiferal assemblages
Indicator A	*Ammonia beccarii* formaA
Indicator B	*Ammonia ketienziensis*, *Astrononion umbilicatulum*, *Bolivina robusta*, *Bolivina* cf. *tokiokai*, *Bulimina kochensis*, *B. marginata* *Hanzawaia nipponica*, *Miliolinella circularis*, *Pseudononion japonicum*, *Pseudorotalia gaimardii*, *Quniqueloculina seminulum*, *Q. vulgaris*, *Reussella pacifica*, *Triloculina trigonula*
Indicator C	Planktonic Foraminifera
Indicator D	*Bulimina* cf. *fijiensis*, *Trimosina orientalis*

Indicator A: Low salinity; Indicator B: Inflow of sea water outside bays;
Indicator C: Inflow of open sea water; Indicator D: Warm sea water

tion of benthic foraminifera, and salinity varies with the inflow of sea water outside the bay. Therefore, the changes of the inflow of sea water in the ancient bay can be recognized by the analysis of fossil foraminiferal assemblages.

In this paper, to set up the indicators for the palaeoenvironmental reconstruction, the recent foraminiferal distribution in three different bays and lagoon, namely, Matsushima Bay, northeastern Japan (Matoba, 1970); Lake Hamana, central Japan (Ikeya and Handa, 1972; Ikeya, 1977) and Tanabe Bay, the southwestern Japan (Chiji and Lopez, 1968) is reviewed. After that, four foraminiferal groups are set up as the indicators of palaeoenvironment: (1) IndicatorA: *Ammonia beccarii* formaA, suggesting a low salinity environment such as in the innermost part of a bay or the area off the river mouth. Indicator B: the foraminiferal group, which mostly distributed near the bay mouth and indicates the inflow of sea water outside the bay. Indicator C: planktonic foraminifera, which suggest the inflow of open sea water. Indicator D: *Bulimina* cf. *fijiensis* and *Trimosina orientalis*, which are distributed in the tropical or subtropical sea (Cushman, 1942), suggesting environment under higher water temperature (Table 1).

In particular, the Indicator A (*Ammonia beccarii* formaA) is useful for the reconstruction of the process of enclosing of a bay or a drowned valley by a barrier. The initial stage of enclosure by a barrier represents the environmental changes from a bay to a lagoon. This period is recognized as the increase in the frequency of *Ammonia beccarii* formaA in the fossil foraminiferal assemblages. On the other hand, since recent foraminifera are distributed in the sea or brackish water, finding no foraminifera in the sediment suggests that the influence of the sea water decreases, and this is interpreted as the final stage of the enclosure by a barrier. This represents the environmental changes from a lagoon to a marsh.

III. Palaeoenvironmental and palaeogeographical changes in the coastal lowlands in the seven study areas

1. Lake Hamana

Lake Hamana is a coastal lagoon enclosed by a barrier, facing to the Pacific Ocean. Beach ridges develop seaward of the barrier.

Sampling of the Holocene deposits was carried out at four locations on the lake floor by Ikeya *et al*. (1990). Fossil foraminifera were analysed of continuous bore hole cores at the locations, H2 and H3 (Both are 5 m in depth) (Fig.3).

At H2, eight ^{14}C dates were obtained, and K-Ah volcanic glass (ca. 6,500 BP) was found at −14.00 m. 28 samples from the bore hole cores between −46.4 and −5.0 m were analysed. Fossil foraminifera were observed in the deposits from −42.9 to −5.0 m (estimated period: 10,000 to 700 BP). The Indicator A (*Ammonia beccarii* formaA, indicating a low salinity environment) was dominant in the deposits of both −42.9 to −28.6 m (10,000 to 7,000 BP) and −14.6 to −5.0 m (6,300 to 700 BP). On the other hand, the Indicator B (suggesting the inflow of sea water outside the bay) became dominant between −28.6 and −14.6 m (7,000 to 6,500 BP). The Indicator C (planktonic foraminifera, indicating the inflow of open sea water) occurred in the deposits between −34.8 and −10.5 m (7,500 to 6,000 BP) (Fig.4).

At H3, ten ^{14}C dates were obtained, and Oki volcanic ash (ca. 9,300 BP) was found at −49.6 m. 47 samples from the bore hole cores between −55.0 and −5.5 m were ana-

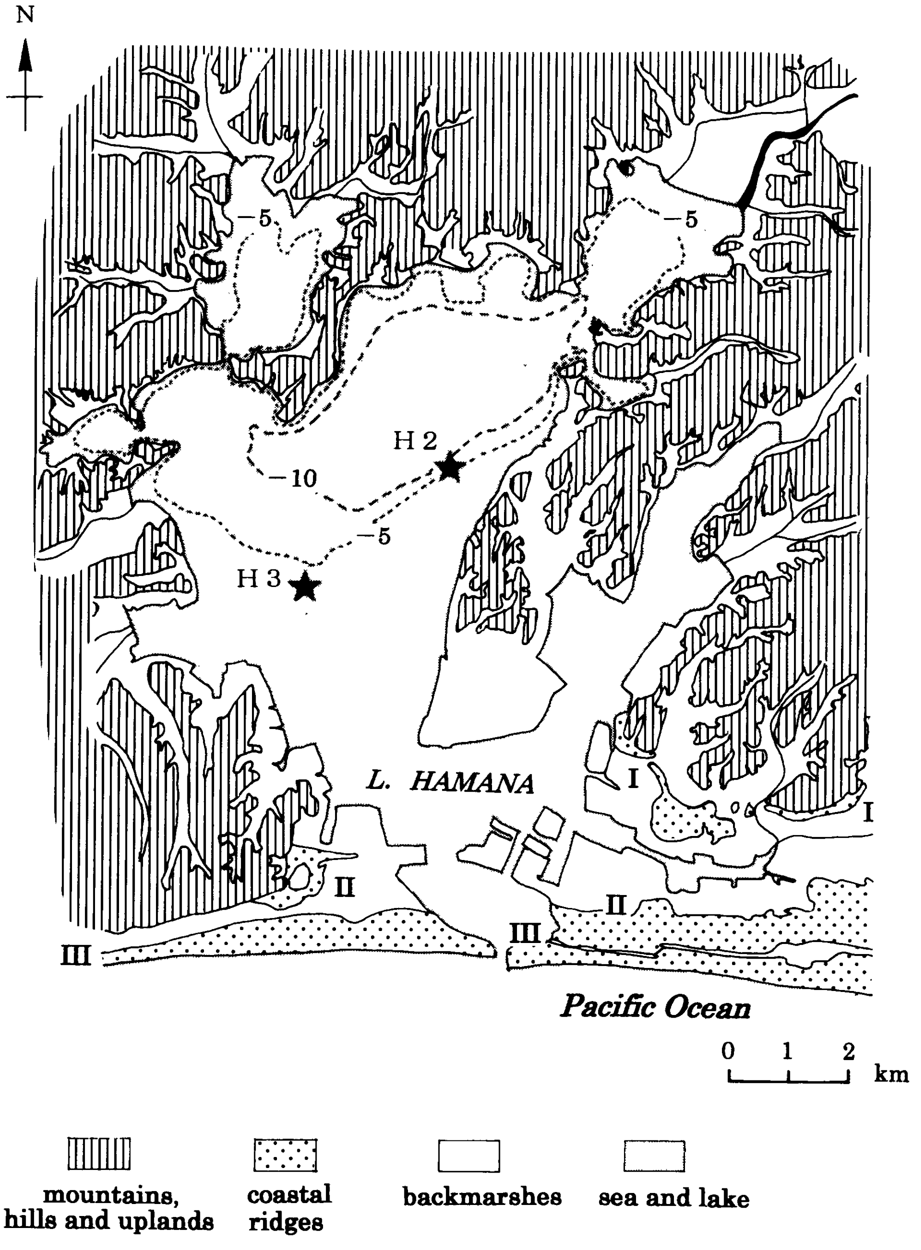

Fig.3. Geomorphological map of Lake Hamana

I~III indicate three coastal ridges. H2 and H3 are the boring sites after Ikeya *et al*. (1990). Broken and dotted lines are isobaths in meters of Lake Hamana.

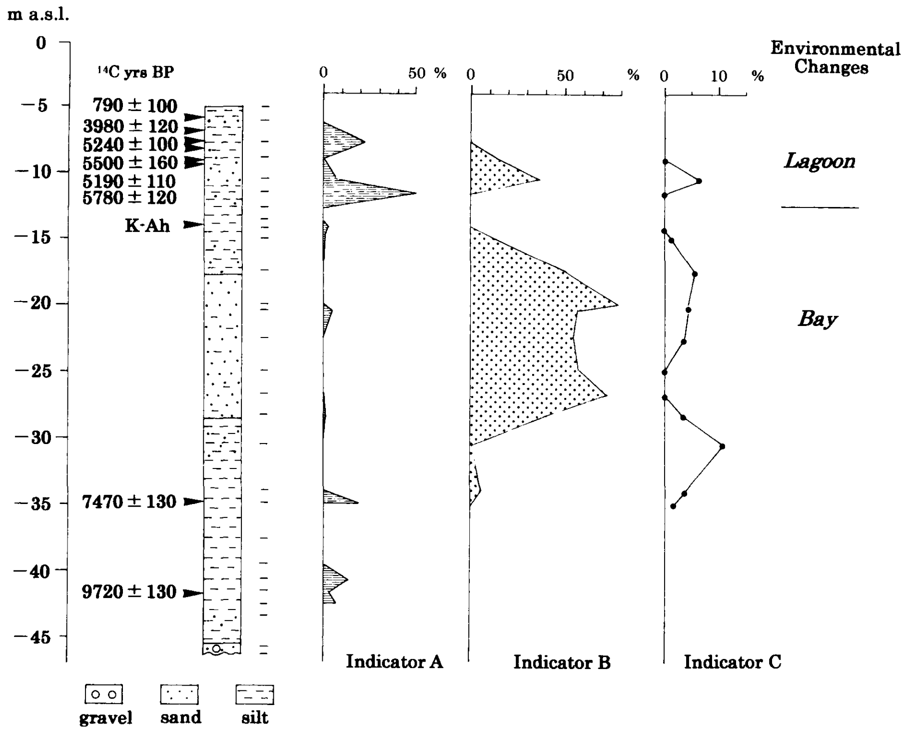

Fig.4. Changes of fossil foraminiferal assemblages in Lake Hamana (H2).

Indicator A: an indicator of a low salinity environment in a bay, Indicator B: frequency of foraminifera, which indicate the inflow of sea water outside the bay, Indicator C: ratio of planktonic foraminifera, suggesting the inflow of open sea water.

lysed. Fossil foraminifera were observed in the deposits from −51.9 to −10.0 m (estimated period: 10,000 to 6,900 BP). The Indicator A was dominant in the deposits between −52.4 and −44.8 m (10,000 to 7,700 yrs BP). On the other hand, the Indicator B became dominant in the deposits from −40.4 to −10.0 m (7,600 to 6,900 BP). The Indicator C occurred in the deposits at −47.9 m, and between −41.7 and −24.9 m (Fig.5).

These data suggest that the bay began to be formed since ca. 10,000 BP, and expanded most around 7,000 BP. A barrier system began to be formed between 8,000 and 7,000 BP. When the barrier began to enclose the bay between 7,000 and 6,000 BP, the bay changed into a lagoon. Furthermore, the beach ridges began to develop seaward of the barrier since 4,000 BP.

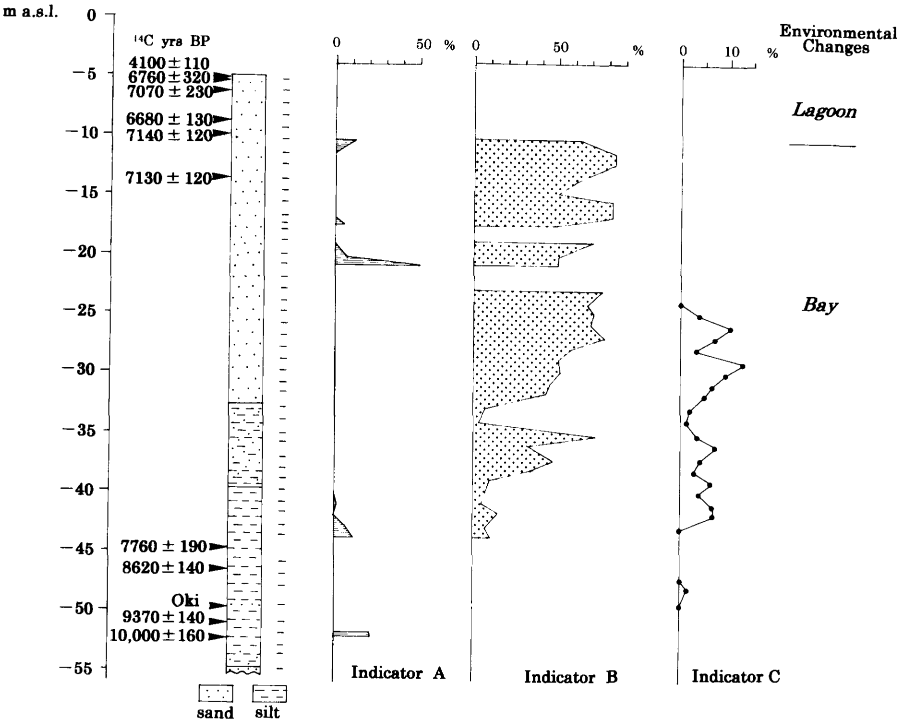

Fig.5. Changes of fossil foraminiferal assemblages in Lake Hamana (H3).

2. Ukishimagahara lowland

The Ukishimagahara lowland belongs to the sand or gravel ridge-backmarsh complexes. The lowland is situated at the southern foot of Mt. Ashitaka (Pleistocene volcano) and facing to the innermost part of Suruga Bay. One ridge-backmarsh system is recognized in the present lowland. In addition, buried barrier and beach ridge are confirmed under the backmarsh (Matsubara, 1984; 1988).

Sampling of the Holocene deposits was carried out in the innermost part of the backmarsh behind the present coastal ridge by Yonekura *et al*. (1985) (location M83; +4.2 m at height) (Fig.6).

Undisturbed and continuous cores 45 m long were taken. The cores from −16.8 to −15.8 m, however, were disturbed by drilling.

Eight ^{14}C dates were obtained, and K-Ah volcanic glass (ca. 6,500 BP) was found at

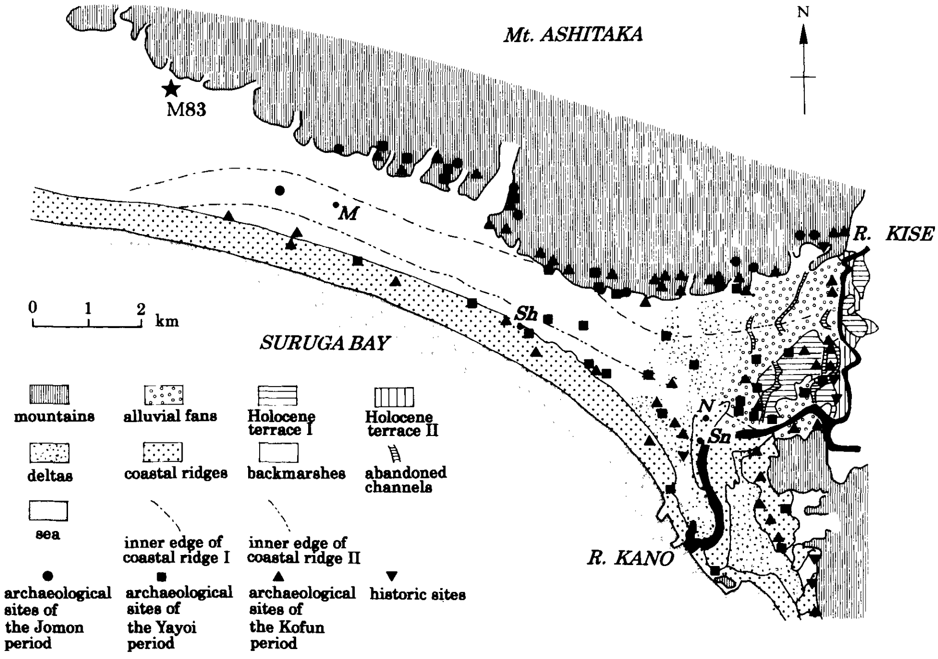

Fig.6. Geomorphological map of the Ukishimagahara lowland.
M83 is boring site after Yonekura *et al.* (1985).

−18.8 m. 48 samples from the bore hole cores between −40.8 and −13.0 m were analysed for foraminifera. Fossil foraminifera were observed in the deposits from −40.5 to −15.2 m (estimated period: 9,000 to 5,800 BP). The Indicator B (suggesting the inflow of sea water outside the bay) occurred in the deposits between −31.0 and −22.0 m (7,800 to 6,800 BP). On the other hand, the Indicator B occurred rarely, and the Indicator A (*Ammonia beccarii* formaA, indicating a low salinity environment) became dominant in the deposits above −22.0 m (ca. 6,800 BP). Furthermore, no foraminifera were found in the backmarsh deposits above −15.2 m (since 5,800 BP) (Fig.7).

These data suggest that the bay which was formed in the Ukishimagahara lowland began to change into a lagoon about 7,000 BP, and the lagoon turned into a marsh after ca. 5,800 BP. These environmental changes were caused by the enclosure of a coastal barrier. Consequently, it is inferred that the coastal barrier emerged and began to enclose the bay around 7,000 BP, and finished enclosing ca. 6,000 BP. This indicates that

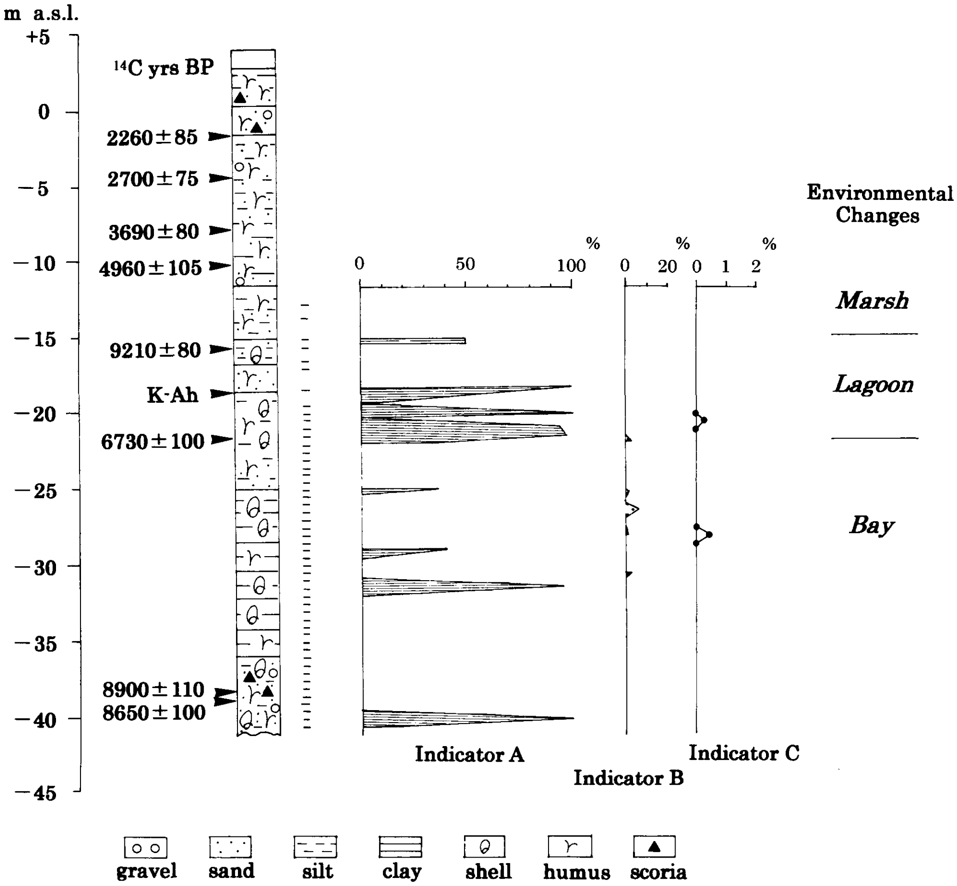

Fig.7. Changes of fossil foraminiferal assemblages in the Ukishimagahara lowland (M83).

the coastal barrier was formed during the marine transgression. Beach ridges developed off the coastal barrier. The peat behind the inner beach ridge began to accumulate during 5,000 to 4,000 BP, a fact which is deduced from ^{14}C dates. Consequently, the inner beach ridge enclosed the backmarsh in the period between 5,000 to 4,000 BP. In addition, the outer beach ridge is considered to have been constructed about 2,000 BP, because the age of the archaeological sites both on the beach ridge and in the backmarsh date from the Yayoi period (around 2,000 BP) (Fig.6).

3. Tokoro lowland

The Tokoro lowland belongs to the sand or gravel ridge-backmarsh complexes, facing

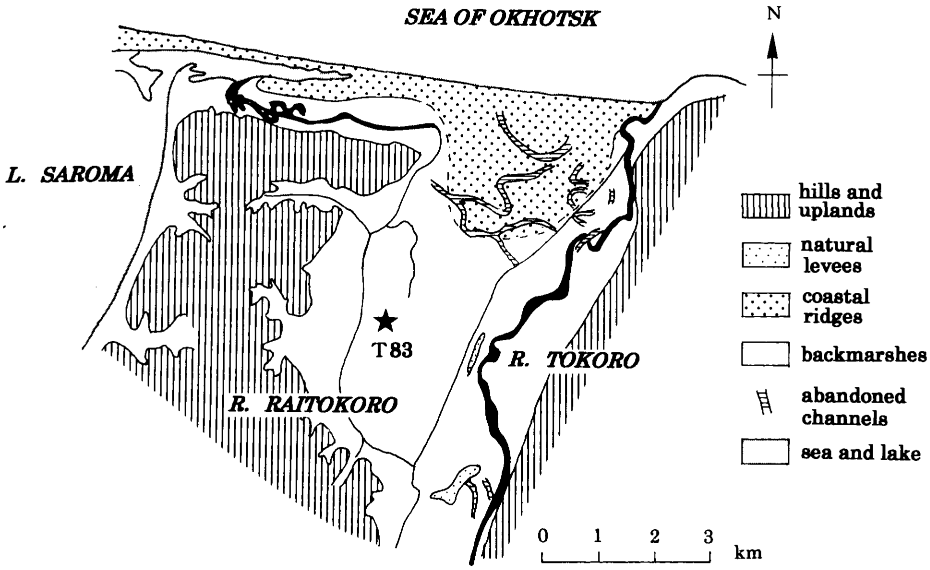

Fig.8. Geomorphological map of the Tokoro lowland.
T83 is boring site after Sakaguchi *et al.* (1985).

to Sea of Okhotsk. A former flood tidal delta is recognized behind the coastal ridge (a former coastal barrier) (Saito, 1987; Matsubara, 2000) (Fig.8).

Sampling of the Holocene deposits were carried out in the backmarsh (location T83; +3.0 m at height) by Sakaguchi *et al.* (1985). 13 ^{14}C dates were obtained. 43 samples from the continuous bore hole cores between −31.5 and −4.2 m were analysed for foraminifera. Fossil foraminifera were observed in the deposits from −28.1 to − 20.7 m (estimated period: 8,900 to 7,200 BP), and from −18.3 to −12.3 m (6,700 to 5,300 BP). The Indicator B (suggesting the inflow of sea water outside the bay) was not found in the deposits. And the Indicator C (planktonic foraminifera, indicating the inflow of open sea water) only occurred in the deposits at −22.4 and −21.7 m. On the other hand, the Indicator A (*Ammonia beccarii* formaA, suggesting a low salinity environment) was dominant in the deposits from −28.1 to −25.2 m (8,900 to 8,300 BP), and from −18.3 to −12.3 m (6,700 to 5,300 BP) (Fig.9).

These data suggest that the bay began to be formed since 9,000 BP. The bay had not been much influenced by the sea water outside the bay. When the barrier emerged and

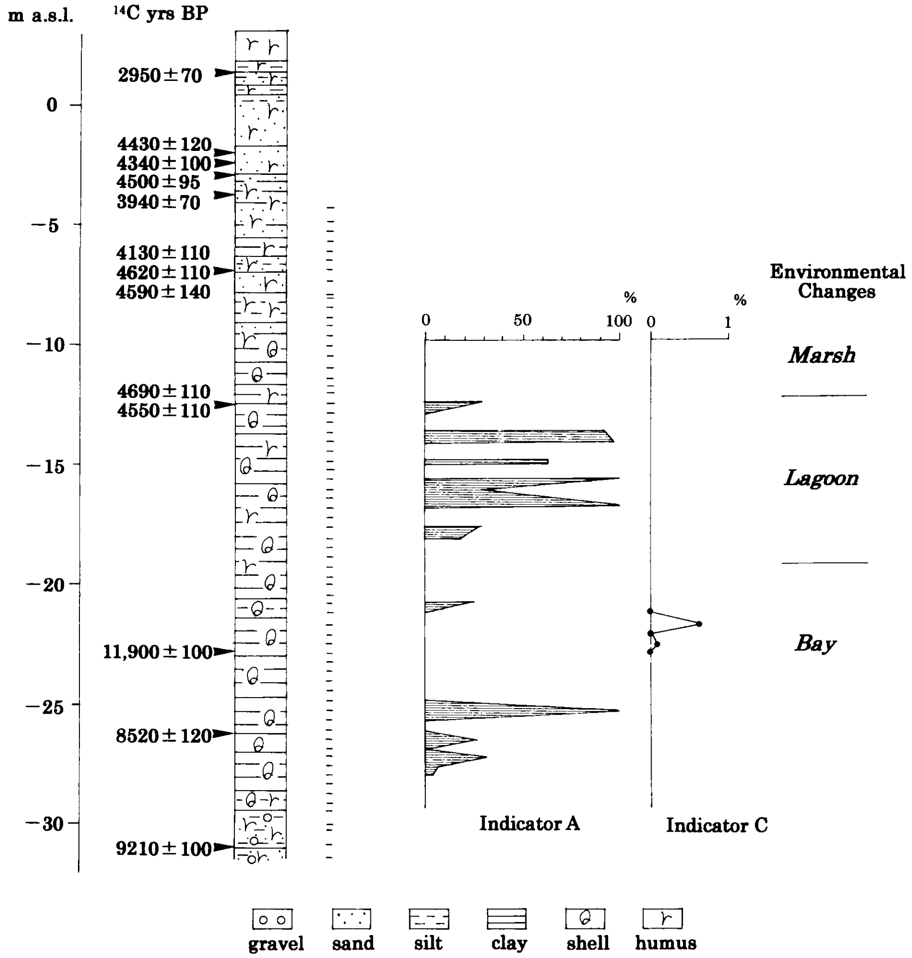

Fig.9. Changes of fossil foraminiferal assemblages in the Tokoro lowland (T83).

began to enclose the bay around 7,000 BP, the bay changed into a lagoon. Then, the lagoon changed into a marsh, after ca. 5,000 BP.

4. Matsuzaki lowland

The Matsuzaki lowland belongs to the valley plains, facing to the southeastern part of Suruga Bay. This lowland develops in the rocky coasts of the Izu Peninsula.

Sampling of the Holocene deposits was carried out in the backmarsh behind the coastal ridge by Matsubara *et al.* (1986) (location M1; +5.5 m at height) (Fig.10).Un-

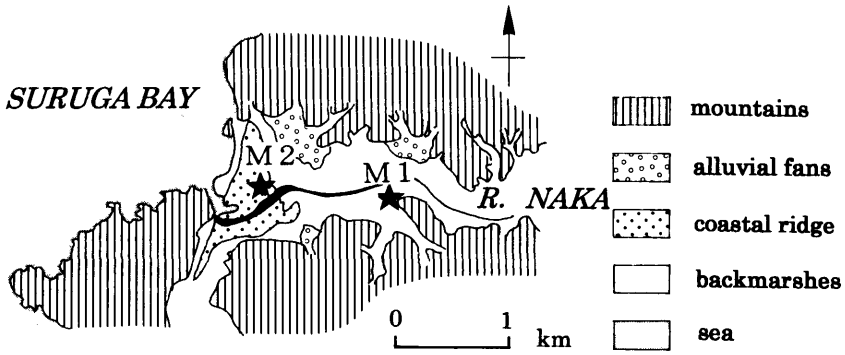

Fig.10. Geomorphological map of the Matsuzaki lowland.
M1 and M2 are boring sites after Matsubara *et al.* (1986).

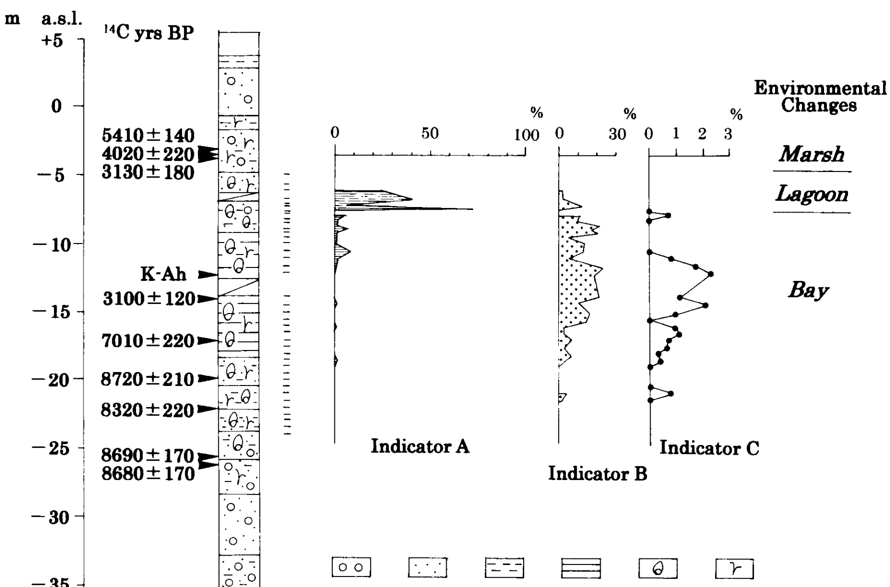

Fig.11. Changes of fossil foraminiferal assemblages in the Matsuzaki lowland (M1).

disturbed and continuous cores 41m long were taken. The cores from −6.6 to −6.1 m, and −13.7 to −12.4 m were lost.

Nine ^{14}C dates were obtained and K-Ah volcanic glass (ca. 6,500 BP) was found in the deposits at −12.1 m.

39 samples from the bore hole cores between −24.5 and −4.9 m were analysed for

foraminifera. Fossil foraminifera were observed in the deposits between −21.5 and −6.0 m (estimated period: 8,200 to 4,500 BP). Frequencies of the Indicators B (suggesting the inflow of sea water outside the bay) and C (planktonic foraminifera, indicating the inflow of open sea water) increased in the deposits between −21.5 and −10.5 m (until ca. 6,000 BP). Moreover, the Indicator D (suggesting an environment under high water temperature) was observed in the deposits from −13.8 to −9.5 m (7,000 to 6,000 BP). In contrast, frequencies of the Indicators B and D began to decrease, and the Indicator C did not occur after the period of 7,000 to 6000 BP. The Indicator A (*Ammonia beccarii* formaA, suggesting a low salinity environment) became dominant in the deposits between −7.1 and −6.0 m (5,500 to 5,000 BP), in place of the Indicators B and C. Furthermore,no foraminifera were found in the backmarsh deposits above −4.9 m, which began to accumulate about 4,500 BP (Fig.11).

The following palaeoenvironmental and palaeogeographical changes are reconstructed from these results.

The inflow of sea water outside the bay and that of open sea water into the bay was largest during 7,000 to 6,000 BP. In addition, the water temperature of the bay was higher than it is at present, in this period. On the other hand, the environment of the bay acquired a low salinity condition after ca. 5,500 BP. The cause of this environmental change is considered to be the enclosure of a coastal barrier at the mouth of the bay. The enclosing by the barrier changed the bay into a lagoon. Then, the lagoon changed into a marsh by finishing off the barrier's enclosure around 4,500 BP.

5. Haibara lowland

The Haibara lowland belongs to the valley plains, facing to the western part of Suruga Bay. Coastal ridges develop remarkably on the buried abrasion platforms in front of the former sea cliffs and enclose the mouth of the valley plain (Matsubara, 1988). This lowland is surrounded by uplands, which consist of unconsolidated Pleistocene sediment, and situated near the mouth of the Oi River to the northeast.

The Holocene deposits were taken from undisturbed and continuous bore hole cores at the locations H83 (+4.2 m at height) by Yonekura *et al.* (1985), and G2 (+4.6 m

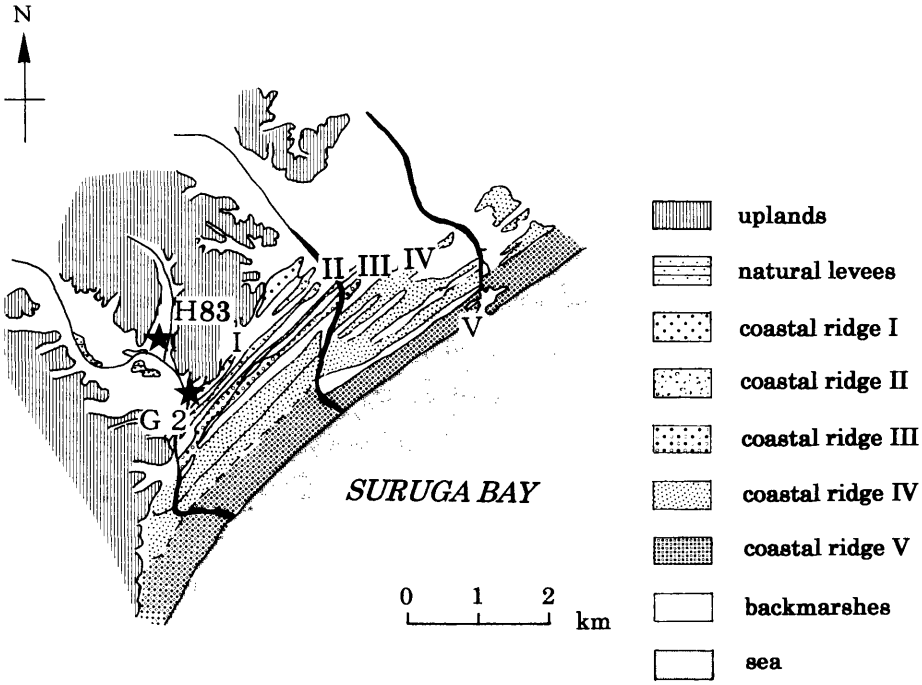

Fig.12. Geomorphological map of the Haibara lowland.
H83 and G2 are boring sites after Yonekura *et al.* (1985) and Kobayashi *et al.* (1982), respectively.

at height) by Kobayashi *et al.* (1982). Both locations are situated in the backmarsh (Fig.12).

At H83, 25 m long cores were taken. Two ^{14}C dates were obtained and K-Ah volcanic glass (ca. 6,500 BP) was found at −5.6 m. 35 samples from −19.5 to −1.9 m were analysed for foraminifera. Fossil foraminifera were observed in the deposits between −10.8 and −1.9 m (estimated period: 7,000 to 5,500 BP). The Indicator C (planktonic foraminifera, indicating the inflow of open sea water) was not found in the deposits, and the Indicator B (suggesting the inflow of sea water outside the bay) was observed from −9.5 to −9.0 m. On the other hand, the Indicator A (*Ammonia beccarii* formaA, suggesting a low salinity environment) was dominant in the deposits at −10.5 m and between −7.3 and −1.9 m. No fossil foraminifera were found in the backmarsh deposits, which began to accumulate above −1.9 m (since ca. 5,500 BP) (Fig.13).

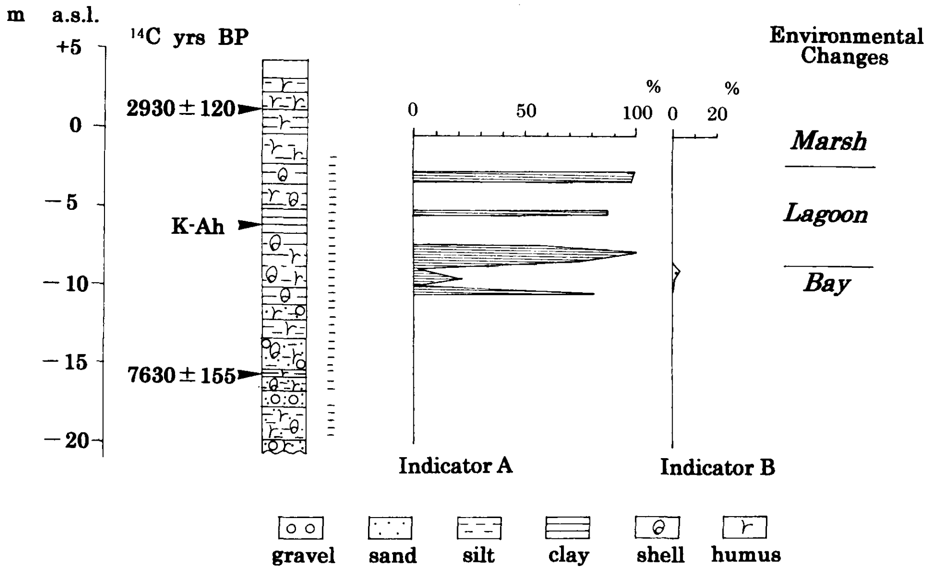

Fig.13. Changes of fossil foraminiferal assemblages in the Haibara lowland (H83).

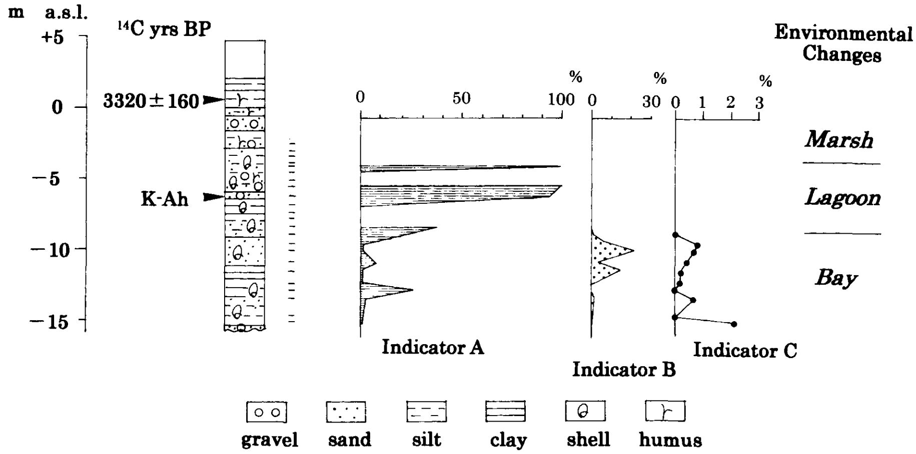

Fig.14. Changes of fossil foraminiferal assemblages in the Haibara lowland (G2).

At G2, 11 m long cores were taken. One ^{14}C date was obtained, and K-Ah volcanic glass was found at −6.3 m. 23 samples from the bore hole cores between −15.3 and −2.3 m were analysed for foraminifera. Fossil foraminifera were observed from −15.3 to −4.1 m (estimated period: 7,500 to 5,500 BP). Frequency of the Indicator B increased, and the Indicators C and D (indicating environment under high water temperature) oc-

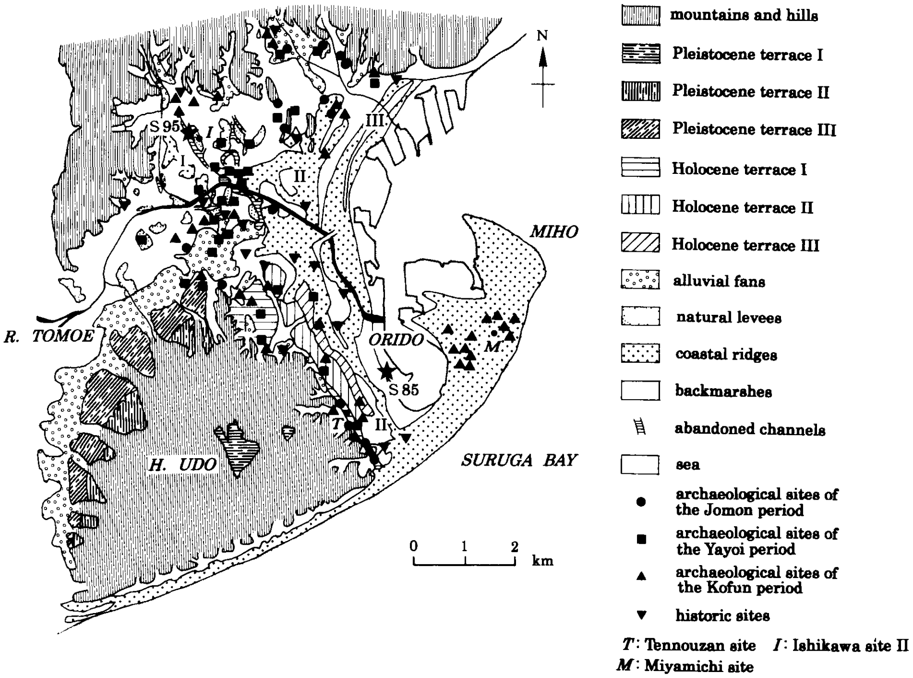

Fig.15. Geomorphological map of the Shimizu lowland.

I~III indicate three coastal ridges.

S85 and S95 are boring sites after Matsubara (1988) and Matsubara (2000), respectively.

curred until ca. 6,500 BP (just below the K-Ah horizon). On the other hand, the Indicator A became dominant after 6,500 BP. Moreover, no fossil foraminifera were found in the backmarsh deposits, which began to accumulate above −3.0 m (since ca. 5,500 BP) (Fig.14).

These results both at H83 and at G2 suggest that the coastal barrier began to enclose the bay, which changed into a lagoon ca. 6,500 BP, and the barrier almost finished enclosing the lagoon to change it into a marsh ca. 5,500 BP. The beach ridges developed one after another of the barrier.

6. Shimizu lowland

The Shimizu lowland belongs to the beach ridge plains, facing to the western part of Suruga Bay. This lowland is surrounded by the Tertiary mountains to the north, and the Pleistocene hill (Udo hill) to the south. Coastal ridges develop remarkably in the direction of north to south.In addition, a sand and gravel spit (Miho spit) develops from the southeastern part of the hill toward the northeast (Fig.15).

Sampling of the Holocene deposits was carried out in the backmarsh behind the Miho spit (location S 85; +2.2 m at height) (Matsubara, 1988) and in the backmarsh between the coastal ridges I and II (location S 95; +6.2 m at height) (Matsubara, 2000).

At S85, K-Ah volcanic glass (ca. 6,500 BP) was found in the deposits at −21.3 m. No ^{14}C dates could be obtained. 26 samples from the bore hole cores between −33.9 and −0.2 m were analysed for foraminifera. Fossil foraminifera were observed in the deposits both between −33.9 and −10.8 m (estimated period: 9,500 to 3,700 BP), and between −5.3 and −0.2 m (2,300 to 900 BP). The Indicator A (*Ammonia beccarii* formaA, suggesting a low salinity environment) was dominant in the deposits between −33.9 and −30.2 m (9,500 to 8,500 BP). On the other hand, the frequencies of the Indicator B (suggesting the inflow of sea water outside the bay) became dominant, and the Indicator C (planktonic foraminifera, indicating the inflow of open sea water) increased in the deposits between −30.2 and −12.9 m (8,500 to 4,000 BP). In addition, the Indicator D (suggesting an environment under high water temperature) was observed in these deposits. The Indicator C was not observed in the deposits above −10.8 m (since ca. 3,700 BP) (Fig.16).

At S95, five ^{14}C dates were obtained from the cores. In addition, K-Ah volcanic glass was found in the deposits at −6.7 m. 17 samples from the continuous bore hole cores between −15.9 and +0.5 m were analysed for foraminifera. Fossil foraminifera were observed in the deposits between −14.6 and +0.3 m (estimated period: 8,200 to 4,400 BP). The Indicator B was observed in the deposits between −14.6 and −2.9 m (8,200 to 5,200 BP), and the Indicator C was observed in the deposits between −14.6 and −6.7 m (8,200 to 6,200 BP). On the other hand, the Indicator A became dominant in the deposits at −1.8 m (ca. 5,000 BP). No foraminifera were found in the backmarsh deposits, which began to accumulate above +0.5 m (since ca. 4,300 BP) (Fig.17).

These data suggest that the bay began to be formed around 9,500 BP. The coastal barrier began to enclose the bay around 5,000 BP. Then, the bay changed into a lagoon.

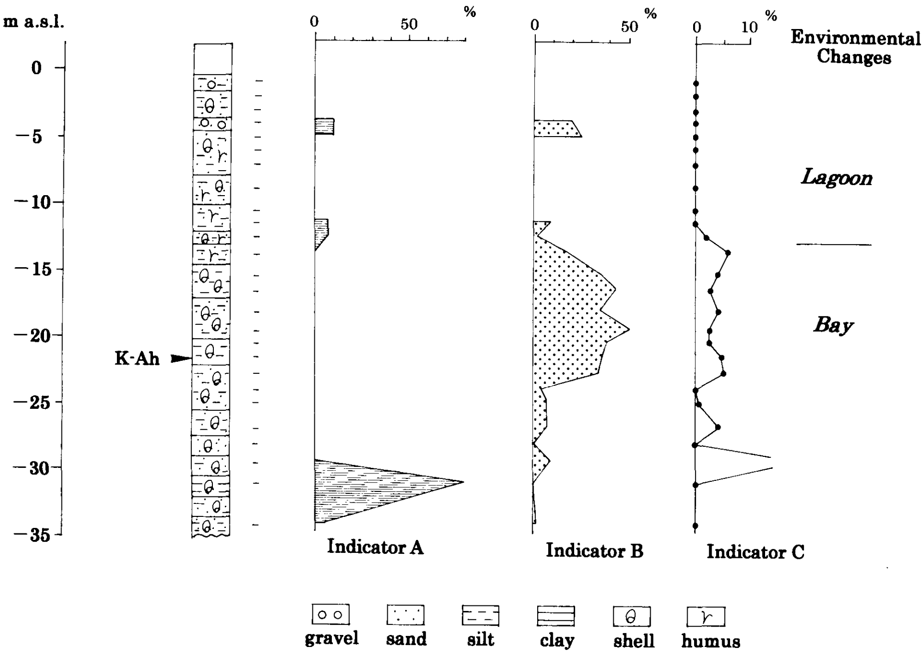

Fig.16. Changes of fossil foraminiferal assemblages in the Shimizu lowland (S85).

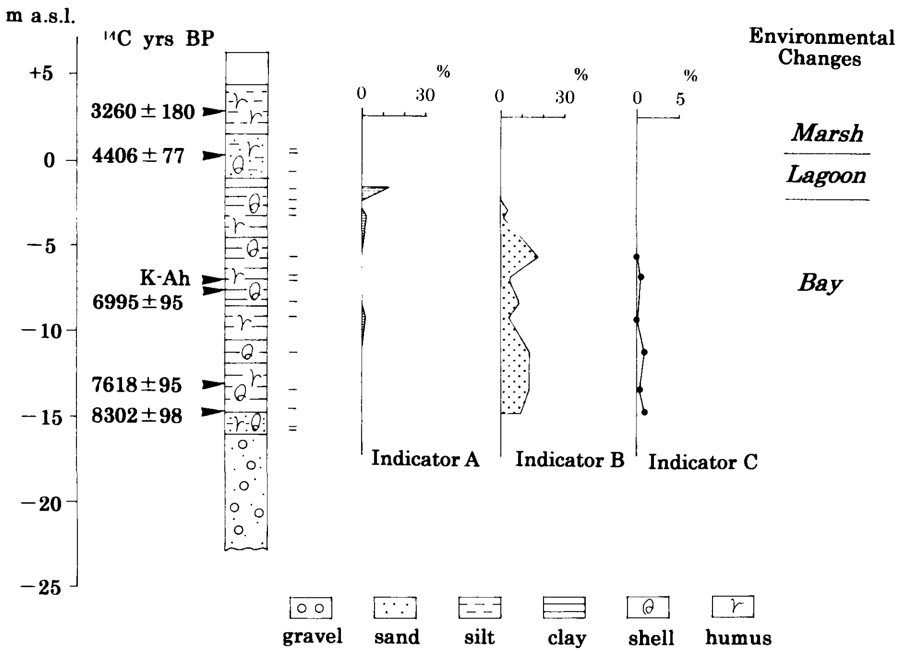

Fig.17. Changes of fossil foraminiferal assemblages in the Shimizu lowland (S95).

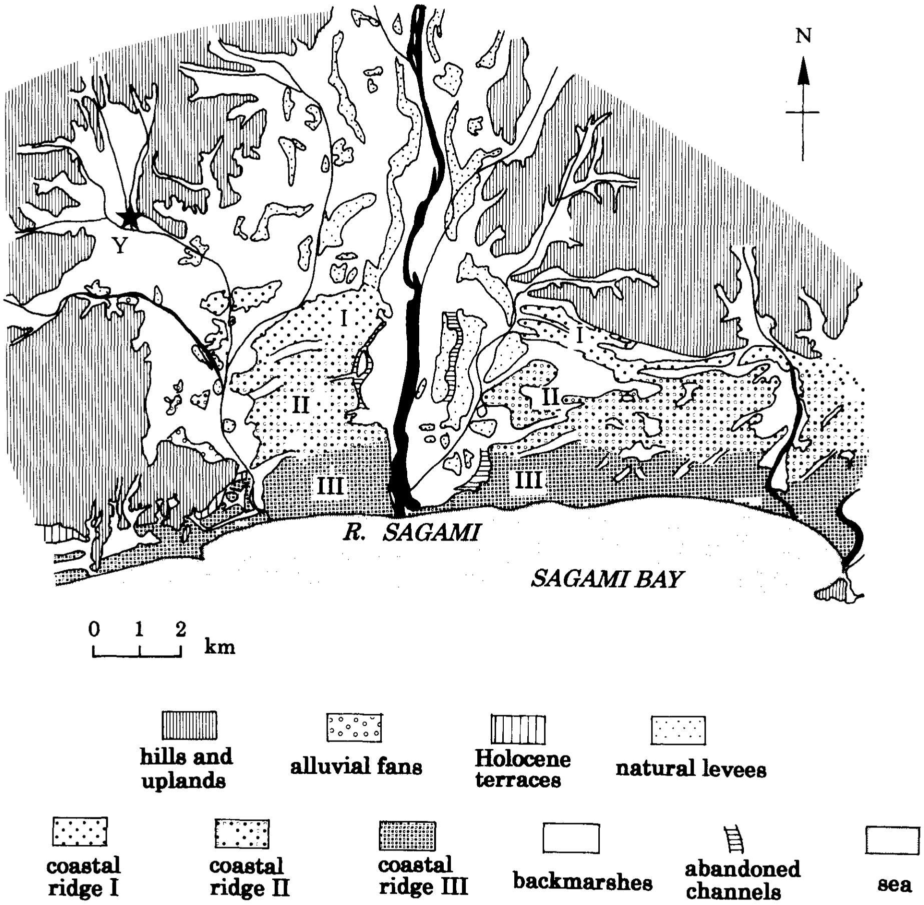

Fig.18. Geomorphological map of the Sagami River lowland.
Y is boring site after Matsuda *et al.* (1988).

After ca. 4,300 BP, the beach ridges developed seaward of the barrier and the lagoon changed into a marsh.

7. Sagami River lowland

The Sagami River lowland belongs to the delta-beach ridge complexes, facing to Sagami Bay. The lowland is surrounded by the Pleistocene uplands. A delta plain is recognized in the inner part of the lowland along the Sagami River. In contrast, in the outer part of the lowland, coastal ridges develop remarkably (Fig.18).

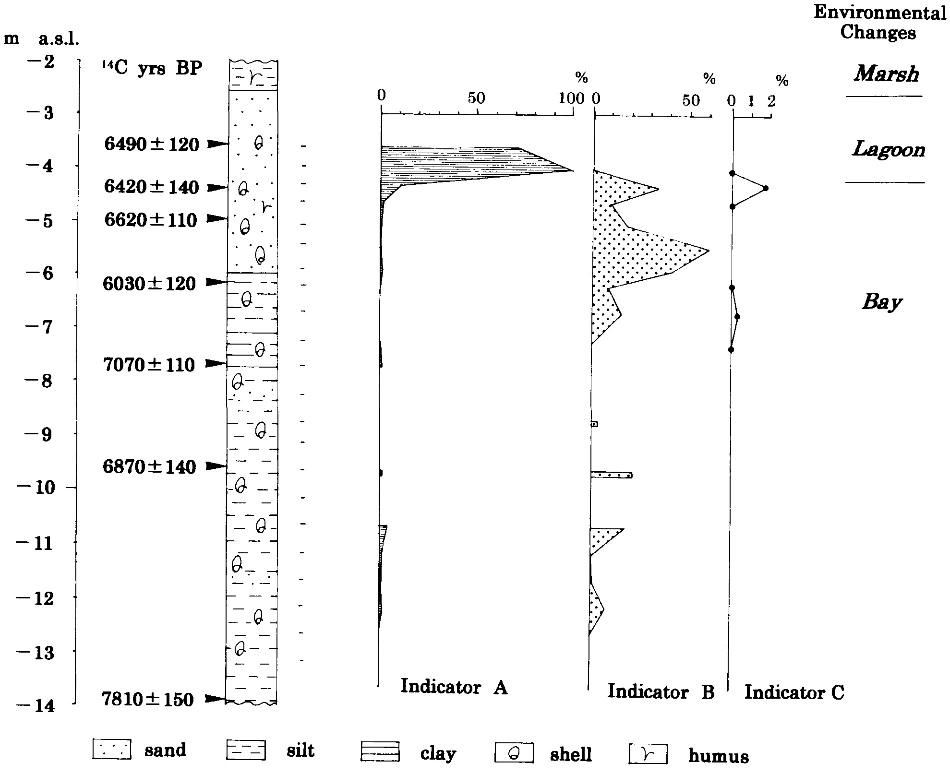

Fig.19. Changes of fossil foraminiferal assemblages in the Sagami River lowland (Y).

Sampling of the Holocene deposits was carried out in the backmarsh behind the coastal ridges by Matsuda *et al.* (1988). Seven ^{14}C dates were obtained from the continuous bore hole cores. 22 samples between −13.2 and −3.6 m were analysed for foraminifera. Fossil foraminifera were observed in the deposits between −12.5 and −3.6 m (estimated period: 7,600 to 6,400 BP). The Indicator B (suggesting the inflow of sea water outside the bay) was dominant in the deposits between −6.7 and −4.3 m (6,800 to 6,500 BP). In addition, the Indicator C (planktonic foraminifera, indicating the inflow of open sea water) was observed in the deposits at −6.7 m and −4.3 m. On the other hand, the Indicator A (*Ammonia beccarii* formaA, suggesting a low salinity environment) became dominant in the deposits between −4.0 and −3.6 m (ca. 6,400 BP) (Fig.19).

These data suggest that the bay began to be formed around 7,600 BP, and the inflow of sea water outside the bay was largest during 7,000 to 6,500 BP. As the coastal barrier started to enclose the bay about 6, 500 BP, the bay changed into a lagoon. Furthermore, the lagoon changed into a marsh after ca. 5,800 BP, when the backmarsh deposits began to accumulate. Then, the beach ridges developed seaward of the barrier.

IV. Common and different processes in the development of coastal barriers

1. Common processes in the development of coastal barriers

—Influence of relative sea-level changes on the development of coastal barriers

As mentioned above, the common environmental changes in the bay-expanding stage are recognized in each type of coastal lowland before 7,000 to 6,000 BP, without regard to the regional differences of the antecedent topography and sediment supply. This implies that the relative sea-level change was the dominant factor controlling the palaeoenvironment in a bay, until the period 7,000 to 6,000 BP.

According to the palaeoenvironmental changes in the seven study areas, the processes of environmental change from bay to lagoon, and to marsh or delta are common for each area. However, the periods of change were different among these areas. These palaeoenvironmental changes are related to barriers' development, and the common processes took place in the relation to the relative sea-level changes, in the following manner.

There are three stages in the development of coastal barriers. During the first stage, when the sea level was rising, the bays were formed by the Holocene transgression in each area. At this stage, the accumulation of basal deposits in the barriers can be recognized; however, the barriers had not yet emerged. During the second stage, when the rate of the rise in sea level was decreasing, and the sedimentation rate became higher than the rate of the rise in sea level, barriers emerged and enclosed the bays. Then, the bays changed into lagoons. During the third stage, when the sea level became lower, beach ridges began to develop seaward of the barriers, and the lagoons changed into marshes (Fig.20, Fig.21).

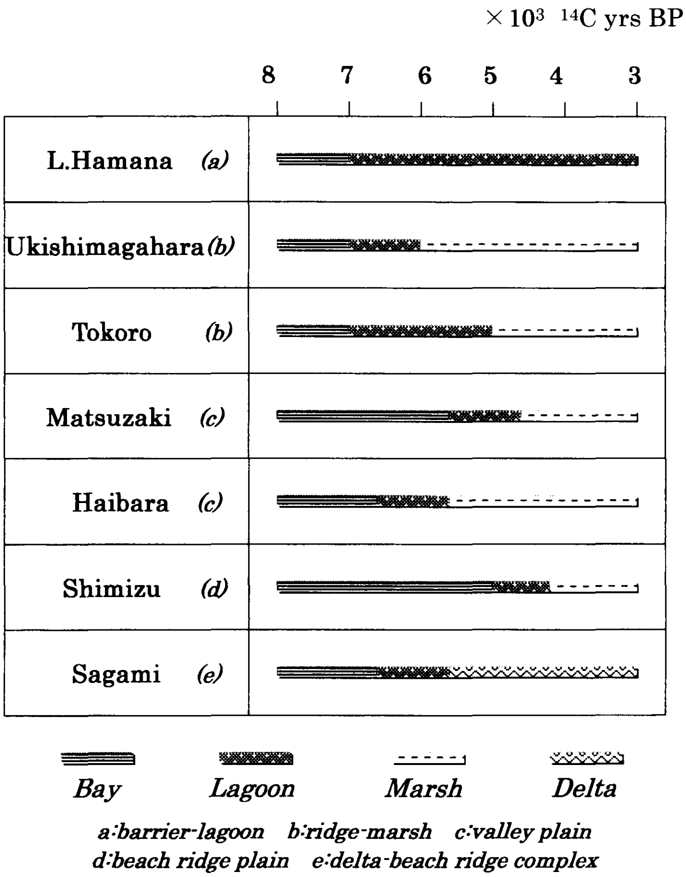

Fig.20. Holocene environmental changes in the areas studied.

2. The controlling factors in the different development of the coastal lowlands

(1) Subsidence of the coastal barriers and earlier enclosures of the bays caused by tectonic movements (downtilting landward) (in the case of the Ukishimagahara lowland).

The tectonic movements in the Ukishimagahara lowland are characterized by westward (toward the Suruga Trough) and landward downtilting. The rate of tectonic movement during the Holocene in this region was the highest in the Suruga Bay area. Even in such an active region, it is difficult to detect any influence of the crustal movements

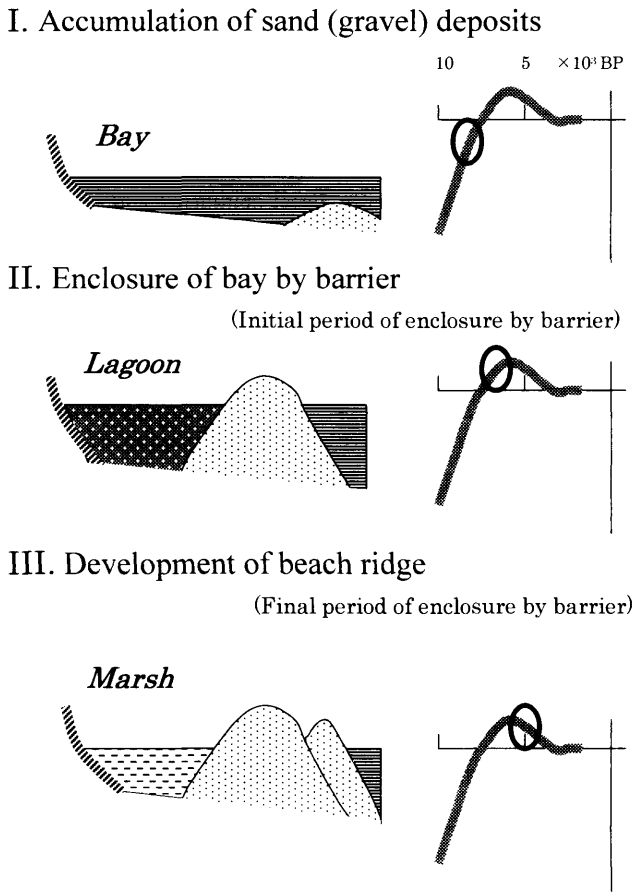

Fig.21. Common processes in the Holocene development of barriers and beach ridges in relation to the relative sea-level changes.

on the development of the coastal lowland until the period when the rate of the rise in sea level decreased, as previously mentioned. The influence of tectonic movements has been recognized after ca. 7,000 to 6,000 BP. In the Ukishimagahara lowland, the subsidence rate of the backmarsh side was higher than the rate on the coastal barrier side, because of the landward downtilting. This suggests that the landward downtilting accelerates the enclosure of a bay by a barrier, and that the periods of change from bay to lagoon and then to marsh were earlier than in the other study areas.

As present landform, the Ukishimagahara lowland belongs to the sand or gravel ridge-backmarsh complexes. There is, however, a buried barrier distributed beneath the backmarsh. It is considered that the landward downtilting caused the coastal barrier to subside.

(2) The influence of tectonic movements, basal landforms and sediment supply on the period of enclosure of a bay, and the development of beach ridges (in the case of the Ukishimagahara, Matsuzaki and Haibara lowlands).

Both in the Ukishimagahara lowland and in the Haibara lowland, a similar geomorphic development of the coastal barriers and beach ridges can be reconstructed. However, the formation of the barriers and beach ridges was different in each area. In the Ukishimagahara lowland, the coastal barrier and the inner beach ridge are recognized from buried landforms and they are deeper landward. On the other hand, in the Haibara lowland, the coastal barrier and the inner beach ridge can be recognized from landforms in the present coastal lowland. These differences are considered to be caused by the regional differences in the characteristics of the tectonic movements: whether the area in question was a subsiding area or a relatively stable area in the Holocene. Furthermore, other differences in the formation of the beach ridges are recognized in the Ukishmagahara lowland. The beach ridges in most parts of the Ukishimagahara lowland have prograded seaward, whereas the beach ridges in the west end have developed upward. This is caused by local differences in the subsidence rate. In the case of a lower subsidence rate, such as in most parts of the Ukishimagahara lowland, the beach ridges grow seaward. On the other hand, in the case of a more rapid subsidence rate, such as in the west end of the lowland, beach ridges grow upward by an apparent transgression.

Both the Matsuzaki and the Haibara lowlands belong to the valley plains. However, the periods of the palaeoenvironmental changes, and the development of the beach ridges are different for each area. The periods of palaeoenvironmental changes from bay to lagoon to marsh in the Matsuzaki lowland were earlier than in the Haibara lowland. Furthermore, it can be recognized that the beach ridges developed seaward of the coastal barrier in the Haibara lowland. On the other hand, the development of beach ridges is not apparent in the Matsuzaki lowland. These differences are considered to be caused by the differences in basal topography and sediment supply. In the Haibara lowland, a buried abrasion platform was distributed under the coastal lowland, but in the Matsuzaki lowland, there is no evidence of such types of landform. Moreover, abundant sediment is supplied from a sea cliff and a large river in the Haibara lowland, whereas the Matsuzaki lowland does not have a source of much sediment. Therefore, the presence of basal landforms in the coastal lowlands and an abundant sediment supply accelerate the development of coastal barriers and beach ridges. And earlier enclosure of the bay by a barrier and the development of beach ridges, occurred in the Haibara lowland.

V. Conclusion

The results of this study can be summarized as follows.

(1) The coastal barriers in seven study areas were commonly formed in relation to the rise in sea level during the early to mid Holocene. A barrier began to form at the time of lower sea level, during the Holocene transgression. When the rate of the rise in sea level decreased, a barrier began to enclose a bay.

(2) The process of enclosing a bay, or a drowned valley, by a barrier can be recognized by an environmental change that appears in the fossil foraminiferal assemblages. The environmental change from a bay to a lagoon from the emergence of a barrier is indicated by an increase in the frequency of *Ammonia beccarii* forma A in the fossil foraminiferal assemblages, which is an indicator of the lower salinity in a bay. On the other hand, finding no foraminifera indicates an environmental change from a lagoon to a marsh from the development of beach ridges seaward of the barrier.

(3) Differences in the development of coastal barriers can be recognized from the period of enclosure by the barriers. The controlling factors of both the barriers' development and the landforms of the coastal lowlands are tectonic movements, the basal topography of coastal lowlands and the sediment supply. In the case study of the geomorphic development of the Ukishimagahara lowland, it can be recognized that the subsidence of a coastal barrier and an earlier enclosure of the bay by a barrier occurred from the tectonic movement of the downtilting landward. Furthermore, from

the comparison of the Matsuzaki and Haibara lowlands, the presence of basal landforms in a coastal lowland, along with an abundant sediment supply, accelerates the development of a coastal barrier and beach ridges.

References

Bird, E. 2000 : *Coastal Geomorphology An Introduction*. Wiley. 322p.

Chiji, M. and Lopez, S. M. 1968 : Regional foraminiferal assemblages in Tanabe Bay, Kii Pen., Central Japan. *Pub. Seto Mar. Biol. Lab.*, 16, 85 – 125.

Colquhoun, D. J., Pierce, J. W., and Schwartz, M. L. 1968 : Field and laboratory observations on the genesis of barrier islands. *Geol. Soc. Amer. Ann. Meeting. Abstr.*, 59 – 60.

Cushman, J. A. 1942 : The foraminifera of tropical Pacific collections of the "Albatross," 1899 – 1900. *Smithsonian Inst. U. S. Nat. Mus., Bull.*, 161, 139p.

Davis, R. A. 1994 : Barrier island systems : A geologic overview. In *Geology of Holocene Barrier Island Systems*, ed. Davis, R. A., 1 – 46. Springer-Verlag.

Hageman, Ir. B. P. 1969 : Development of the western part of the Netherlands during the Holocene. *Geologie en Mijinbouw*, 48, 373 – 388.

Ikeya, N. 1977 : Ecology of foraminifera in the Hamana Lake region on the Pacific coast of Central Japan. *Rep. Facul. Sci., Shizuoka Univ*., 11, 131 – 159.

Ikeya, N. and Handa, T. 1972 : Surface sediments in Hamana Lake, the Pacific coast of Central Japan. *Rep. Facul. Sci., Shizuoka Univ*., 7, 129 – 148.

Ikeya, N. and Wada, H., Akutsu, H., and Takahashi, M. 1990 : Origin and sedimentary history of Hamana-ko Bay, Pacific coast of central Japan. *Mem. Geol. Soc. Japan*, 36, 129 – 150. (J+E)

Jelgersma, S. and Van Regteren, A. J. F. 1969 : An outline of the geological history of the coastal dunes in the western Netherlands. *Geologie en Mijinbouw*, 48, 335 – 342.

Kobayashi, M., Hatano, S., Ichikawa, S., and Kumaki, Y. 1982 : Morphotectonic investigation along the coast in the Kanto and Tokai regions. In *Research of seismotectonics in the northern margin of the Philippine Sea plate*, ed. The Science and Technology Agency, 117 – 131. (J)

Matoba, Y. 1970 : Distribution of recent shallow water foraminifera of Matsushima Bay, Miyagi Prefecture, Northeast Japan. *Tohoku Univ., Sci. Rep. 2nd ser.* (*Geol*.), 42, 1－85.

Matsubara, A. 1984 : Geomorphic development of the alluvial plain facing the inner Suruga Bay. *Geogr. Rev., Japan*, 57, 37－56. (J＋E)

Matsubara, A. 1988 : Geomorphic development of barriers in the coastal lowlands during the Holocene — A case study of the coastal lowlands along the Suruga Bay, Central Japan —. *Bull. Dep. Geogr., Univ. Tokyo*, No.20, 57－77.

Matsubara, A. 2000 : Holocene geomorphic development of coastal barriers in Japan. *Geogr. Rev., Japan*, 73, 409－434. (J＋E)

Matsubara, A., Matsushima, Y., Ishibashi, K., Moriwaki, H., and Kashima, K. 1986 : Environmental changes during the Holocene in the Matsuzaki Lowland, western part of the Izu Peninsula, Central Japan. *Jour. Geogr.*, 95, 339－356. (J＋E)

Matsuda, T., Yui, M., Matsushima, Y., Imanaga, I., Hirata, D., Togo, M., Kashima, K., Matsubara, A., Nakai, N., Nakamura, T., and Matsuoka, K. 1988 : Subsurface study of Isehara Fault, Kanagawa Prefecture, detected by drilling — Depositional environments during the last 7000 years and fault displacement associated with the Gangyou Earthquake in A.D. 878 —. *Bull. Earthq. Res. Inst., Univ. Tokyo*, 63, 145－182. (J＋E)

Matsushima, Y. 1984a : Neotectonics deduced from Holocene marine terraces along the coast of Sagami Bays, Central Japan. *The Quater. Res.*, 23, 165－174. (J＋E)

Matsushima, Y. 1984b : Shallow marine molluscan assemblages of Postglacial period in the Japanese Islands — Its historical and geographical changes induced by the environmental changes —. *Bull. Kanagawa Pref. Mus.* (*Natural Science*), No.15, 37－109. (J＋E)

Moslow, T. F. and Colquhoun, D. J. 1981 : Influence of sea level change on barrier island evolution. *Oceanis*, 7, 439－454.

Ota, Y., Matsushima, Y., and Moriwaki, H. eds. 1981 : *Atlas of Holocene sea level records in Japan*. Working Group of the Project 61, Holocene Sea Level Project, IGCP, 195p.

Ota, Y., Umitsu, M., and Matsushima, Y. 1990 : Recent Japanese research on relative sea level changes in the Holocene and related problems — Review of studies between

1980 and 1988 —. *The Quater. Res.*, 29, 31 – 48. (J + E)

Pierce, J. W. and Colquhoun, D. J. 1970 : Holocene evolution of a portion of the North Carolina coast. *Geol. Soc. Amer. Bull.*, 81, 3697 – 3714.

Saito, Y. 1987 : Processes on the deposition of marine sediment related to the Holocene sea level changes. *Monthly Chikyu* (*Earth*), 9, 533 – 541. (J)

Sakaguchi, Y., Kashima, K., and Matsubara, A. 1985 : Holocene marine deposits in Hokkaido and their sedimentary environments. *Bull. Dept. Geogr., Univ. Tokyo*, No.17, 1 – 17.

Thom, B. G. 1983 : Transgressive and regressive stratigraphies of coastal sand barriers in southeast Australia. *Mar. Geol.*, 56, 137 – 158.

Thom, B. G., Bowman, G. M., and Roy, P.S. 1981 : Late Quaternary evolution of coastal sand barriers, Port Stephens : Myall Lakes area, central New South Wales, Australia. *Quater. Res.*, 15, 345 – 364.

Trenhaile, A. S. 1997 : *Coastal Dynamics and Landforms*. Clarendon Press. 366p.

Umitsu, M. 1991 : Holocene sea-level changes and coastal evolution in Japan. *The Quater. Res.*, 30, 187 – 196.

Van Straaten, L. M. J. U. 1965 : Coastal barrier deposits in south and north Holland. *Meded. van Geologische Stichting*, 17, 41 – 45.

Yonekura, N., Ikeda, Y., Kashima, K., and Matsubara, A. 1985 : Boring of alluvial deposits in the coastal lowlands around Suruga Bay, Central Japan. In *Environmental Changes since the Last Glacial Period*, ed. Sakaguchi, Y., 35 – 80. Univ. Tokyo. (J)

Notes : (J) : in Japanese, (J+E) : in Japanese with English abstract.