GEOMORPHIC DEVELOPMENT OF HOLOCENE COASTAL PLAINS IN JAPAN

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Abstract In this paper, geomorphic development of the Kujukuri, Yufutsu, Akita and Niigata coastal plains is discussed, with special emphasis on (1) discontinuities in shoreline development, (2) rate of shoreline development and (3) coastal sand dune development during the past about 6,000 years. As a result, (1) two major discontinuities in shoreline development probably caused by the minor sea-level fluctuation, are generally recognized in these coastal plains, occurring about 5,000 to 4,000, and 3,000 to 2,000 years ago. (2) The rates of shoreline development of the four plains were generally low around 6,000 years. The high rates of progradation occurred immediately after 5,000 or 4,000 years ago. The rates have gradually decreased with time since 3,000 or 2,000 years ago. (3) The four coastal plains are generally divided into three belts. The formation of these belts is closely related to the rate of shoreline development.

1. Introduction

A coastal plain is defined as a low and generally broad but sometimes narrow plain that has its margin on the shore of a large body of water and either horizontal or very gently slopes toward the water and that generally represents a strip of recently emerged sea floor (Gary et al., 1972). The Holocene coastal plain discussed in this paper is defined as a depositional lowland which has been formed by marine processes during the Holocene. It consists of such geomorphic units as beach ridge, chenier, barrier, spit, sand dune, and lagoonal lowland.

Since the first four units directly indicate former shoreline and sea level, a coastal plain formed by the repetition of these units records the most detailed history of change in shoreline and sea level in the Holocene. Moreover, because the oldest one lies furthest inland from the present coast and these units become younger seaward, the coastal plain makes it possible to easily reveal this history on the basis of morphostratigraphic study. The coastal plain is thus one of the most useful landforms for studying shoreline development and features relating to this development in the Holocene. In particular, the coastal sand dune is one of the most interesting features in relation to shoreline development, because this feature is often located in particular places in the coastal plain, indicating that episodic events occurred during shoreline development.

Concerning the nature of shoreline change, discontinuities in coastal development have attracted special interest, because they represent realignments of the shoreline in response to change in oceanographic conditions and/or in sediment supply. That is, the main effects on these discontinuities have been pointed out as follows: a local hydrodynamic effect depending on wind (e.g. Curray et al., 1967), effects of source of sediments (e.g. Psuty, 1965), effects of sea-level fluctuations (e.g. Stapor, 1975) and so on.

In Japan, several investigations on geomorphic development of Holocene coastal plain have mainly been made since the 1950's (e.g. Ogasawara, 1952; Nakano, 1956; Tada, 1964; Sakaguchi, 1964; Mii, 1966), and discontinuities have been recognized in the coastal formations of Sarobetsu (Sakaguchi, 1964), and Akita (Mii, 1966). However, very little has been stated about the chronological relations of such features in different coastal plains, and about the conditions responsible for their fomation on the basis of the study of these chronological relations.

One of the most important studies on geomorphology is that of the rate of change in landforms (Kaizuka, 1969). Since the position of a former shoreline can be strictly obtained as mentioned above, we can easily reveal the rate of shoreline development when the ages of former shorelines are clarified. Because social demand has promoted study of shoreline change during a time period on the order of 10^0 to 10^2 years, and the ages of former shorelines can be easily obtained on the basis of historical documents, recent changes in the coastal plain have been fairly well known (e.g. Koike, 1977). However absence of studies on coastal change over a longer term – i.e. on the order of 10^3 years in the coastal plains of Japan – inhibits any useful evaluation of cause and effect at the present time. At the present stage of Holocene coastal plain study, there are not many reports about the rate of shoreline development over such a longer term (Curray et al., 1967). In Japan, little is known about it, and it is a matter of course that there have been no comparisons among the rates of development of different coastal plains. Such studies are lacking mainly because sufficient data on the ages of sand ridges have not been obtained.

Concerning coastal sand dune development, episodic events responsible for this development have been noted, and these events have been identified as sea-level fluctuations (Brothers, 1954; Cooper, 1958; Stapor, 1975; Schofield, 1975) and climatic change (Thom, 1978). Most of the studies on coastal sand dune in Japan have been made in narrow coastal areas where younger sand dunes overlie older ones. In such areas, the ages of mobilization or stabilization of sand dune have been studied based on humic layers, and climatic changes (e.g. Urushibara et al., 1973) and sea-level fluctuations (Iseki, 1975; Fuji, 1975) have been used to explain the formation of coastal sand dunes. However, the relationship between shoreline change and the formation of sand dunes, which is presented in this paper, has hardly been discussed even for a coastal plain, and it is a matter of course that no comparison between the relationships in different areas has been made.

The main purpose of this paper is to discuss the above three problems: 1) discontinuities in coastal development, 2) rate of shoreline development, and 3) the relationship between shoreline development and sand dune formation. In order to discuss these problems, the detailed geomorphic development of major coastal plains in Japan during the past about 6,000 years, during which sea level has been stable approximately at its present position in the first order, will be described. This development is based on chronological studies of such geomorphic units as beach ridges, sand dunes, lagoons, swamps and subsurface materials which have been revealed by the sequences of these units, stratigraphy of these materials, radiocarbon dates, tephras, humic layers, archeological remains and historical documents. Investigation areas are the Kujukuri, Yufutsu, Akita and Niigata coastal plains (Fig. 1).

In this paper, first, the geomorphic development of the coastal plains mentioned above will be presented. Second, the three problems mentioned above will be discussed.

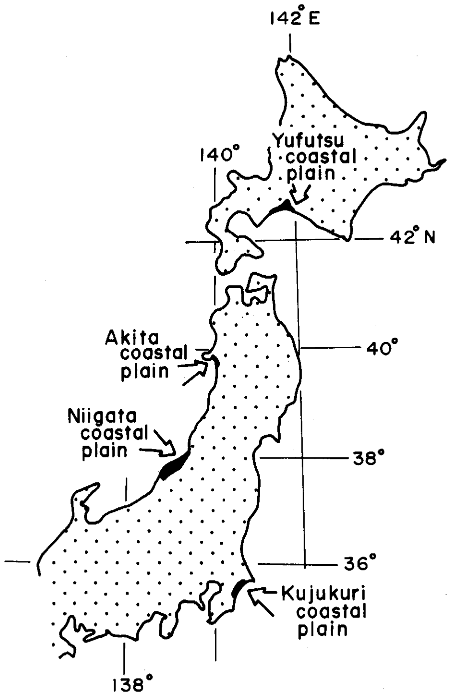


Fig. 1 Index map showing area of investigation

2. Geomorphic Development of the Kujukuri Coastal Plain

Physiography of the plain

The Kujukuri coastal plain extends along the Pacific coast of the Kanto district for a distance of about 60 kilometers, and reaches a maximum width of 10 kilometers. Moriwaki (1977), Kaizüka et al. (1979), and Moriwaki (1979) reported the formation of sand ridges and the geomorphic development of this coastal plain in detail. The detailed physiography of this plain is represented in Fig. 2. This map is prepared from interpretation of vertical air photographs and topographic maps supplemented by field work. Uplands consisting of Quaternary and Neogene sand and mud lie behind this plain.

The plain is composed of two landform areas: the inner one is backswamp lowland consisting of valley bottom and abandoned lagoon, and the outer one is of subparallel elongate sand ridges and swales. Moriwaki (1977) denied that the sand ridges of this plain originated from submarine bars as previously suggested by Ogasawara (1952) and Matsui (1952), and indicated that the sand ridges were built as compound beach ridges and that most of the swales between sand ridges originated from former river channels immediately behind a

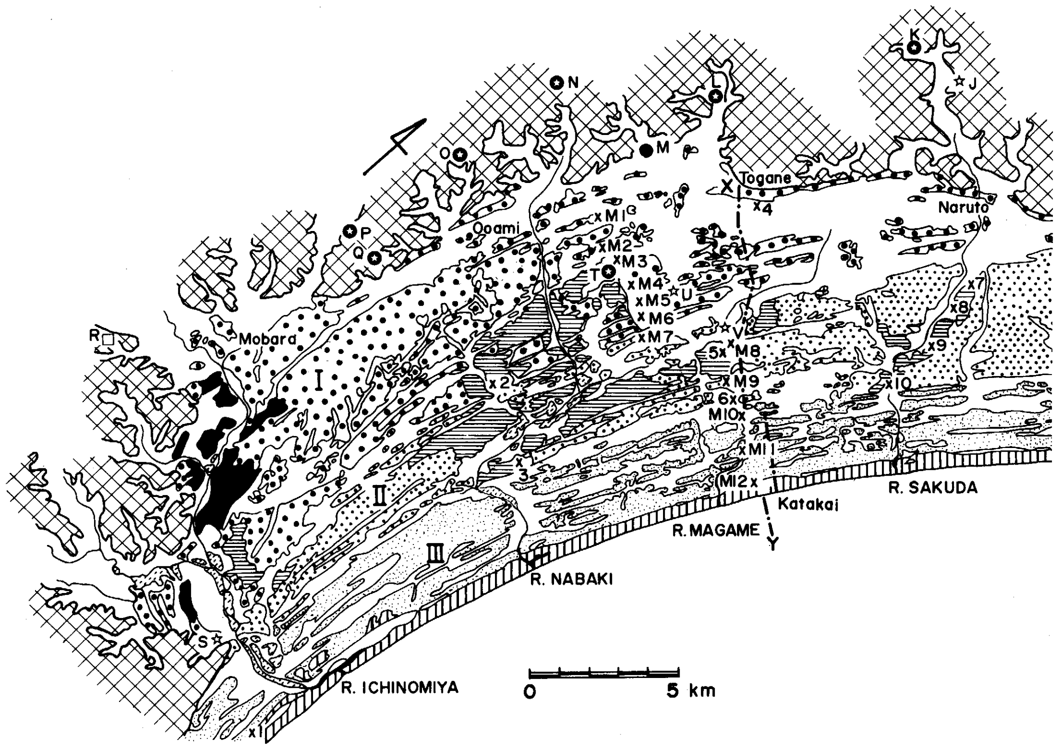
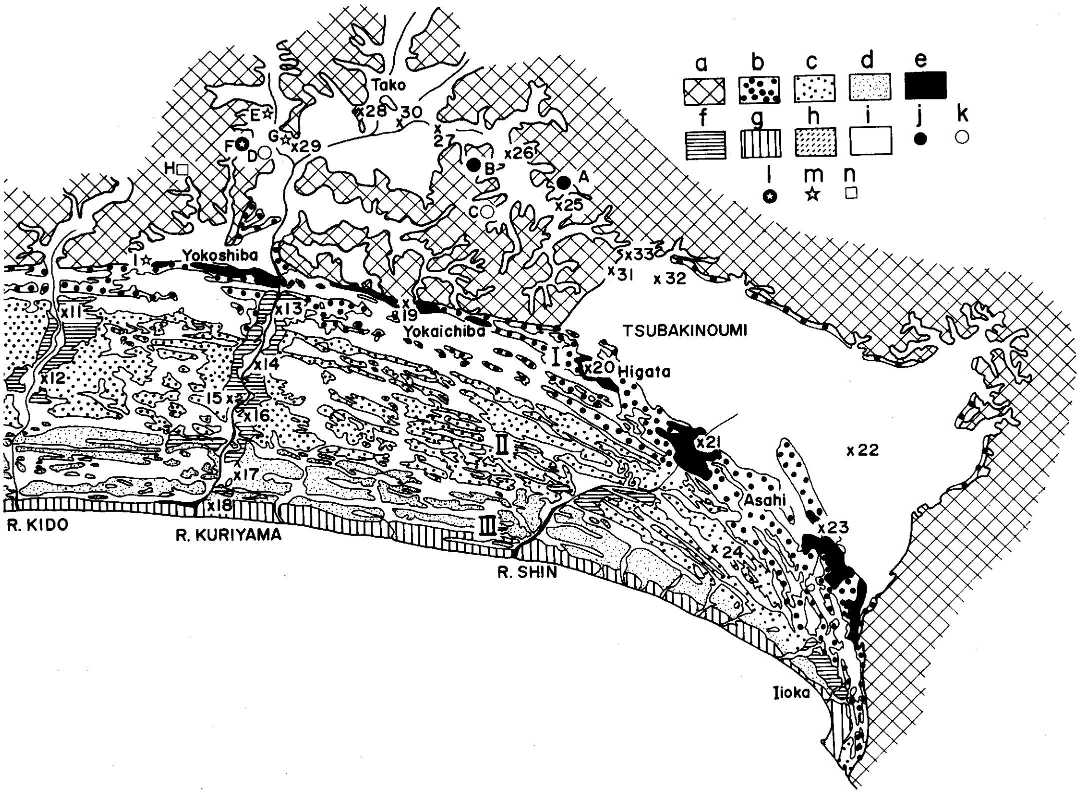


Fig. 2 Geomorphological map of the Kujukuri coastal plain. a: upland; b: sand ridges I (SI); c: Sand younger sand dune (Dy); h: natural levee; i: swale, valley bottom, abandoned lagoon, abandoned Jomon period; l: the middle and late Jomon period; m: the late Jomon period; n: the middle, late miya Town (1964), Committee on the History of Mobara City (1966) and The Board of Education s.m.; E: Ushikuma s. m.; F: Konosu s. m.; G: Takayagawa site; H: Sanbu-Ubayama s. m.; I: Sarugo O: Kayano s. m.; P: Shimoota s. m.; Q: Shibuya s. m.; R: Ishigami s. m.; S: Ichinomiya s. m.; bore hole; M1–M12: location of stick bore hole for the investigation of humic layer; X– · –Y:



ridges II (SII); d: sand ridges III (SIII); e: older sand dune (Do); f: middle sand dune (Dm); g: channel and flood plain. j-n: location of prehistoric sites; j: the early Jomon period; k: the middle and latest Jomon period. A-V: after Shimizu (1954, 1958), Committee on the History of Ichino-of Chiba Prefecture (1970); A: Iidaka shell mound; B: Shukuige s. m.; C: Yappe s. m.; D: Kidodai s. m.; J: Gongendai s. m.; K: Busho s. m.; L: Ono s. m.; M: Yamaguchi s. m.; N: Kutsukake s. m.; T: Kami s. m.; U: Uwaya s. m.; V: Hirose-mitsuzuka s. m.; No. 1–29: location of outcrop and location of the survey of transverse section sand ridge facing shore.

Some ten sand ridges of this plain are grouped into three major units, called sand ridges I (hereafter abbreviated SI), sand ridges II (SII) and sand ridges III (SIII) from inland to seaward, by two discontinuities. The inner discontinuity is shown by a wide swale in the central part of the plain, and the outer one by a steep slope. These discontinuities represent realignments of the shoreline in response to changes in oceanographic conditions such as longshore drift, wave energy and sea level, or a change in the rate of sediment supply to the coast, or a shift in the river mouth supplying sediments (e.g. Psuty, 1965; Curray et al., 1967; Alexander, 1969; Stapor, 1975). In the case of the Kujukuri coastal plain, steep slopes are associated with discontinuities indicating that these discontinuities are attributed to sea-level drop.

In the northern part of the plain, SI consists of barrier spits with a width of less than 1 kilometer, while in the southern part it consists of sand ridges nearly 5 kilometers in width, and is cut 5 to 10 meters deep by the Ichinomiya River. The altitude of SI is about 7 meters above sea level in the central part of the plain. SII is, in contrast to SI, widely distributed in the central and northern part of the plain. The width of SII attains about 4 kilometers in the central part. The altitude of SII is 5.5 to 6 meters. SIII is 3 to 4 kilometers wide everywhere and is less than 3 meters in altitude.

Sand dunes occupy particular positions on the plain, as shown in Fig. 2. They are divided into three groups on the basis of their geographic positions and their chronological positions as evidenced by the humic layers covering them: "older sand dune" (hereafter abbreviated Do), "middle sand dune" (Dm) and "younger sand dune" (Dy), in order from older to younger.

Do locally caps abandoned barrier spits of SI in the northern part. The relative height of Do is less than 10 meters. Sand dunes which are assigned to Dm are located on SI and SII. Judging from their distribution and stratigraphical relation to the humic layers concerned, two types of sand dunes are recognized. The one is situated in the most landward barriers of SI of the northern part, and the sand is derived from the sand of Do; the other is situated along the sides of the rivers crossing the plain, and the sand is derived from the beds of the rivers. The latter type is well developed in the northern sides of the rivers, such as the Kido and Sakuda rivers. Dy is distributed along the present beach, attaining its elevation of 10 meters above the present sea level in the northern part of the plain.

Description of subsurface geology and geomorphic features of the plain

Subsurface geology of the plain

Materials constituting the plain have been predominantly supplied by longshore drift from both sides of the plain where sea cliffs of Pliocene and Pleistocene strata have been vigorously eroded by waves. Subsurface materials of the plain can be observed in several outcrops along the rivers which dissected the surface 2 to 3 meters deep in the central and northern parts and 5 to 10 meters deep in the southern part. The subsurface geology can also be observed at some artificial outcrops and with the aid of auger drillings and stick borings.

The bulk of the sand ridge plain deposits consists of a fine–to medium-grained, well-sorted and well-laminated sand. Trace-fossils of pipe-like burrows created by ghost crabs (*Ocypode stimpsoni*) which inhabited the sandy berm 1 or 2 meters above mean tide level, are frequently observed near the top of the sand ridge deposits (Moriwaki, 1977). Trace-fossils of light-colored spots created by *isopodous* CRUSTACEA, *Excilolana chiltoni japonica,* which predominantly lives in the low tide zone of a sandy coast (Kikuchi, 1972), are also frequently observed immediately below the layers containing the above-mentioned pipe-like burrows. Since such a sequence is observed in every sand ridge deposit in the coastal plain, it is evident that sand was deposited in the intertidal zone and backshore. Sand dunes generally consist of well-sorted medium sand, and are less than 10 meters in relative height. Valley bottoms of the Kuriyama River consist of peat less than 4 meters thick and underlying lagoonal deposits of blue-greyish clay more than several meters thick.

Two horizons, the older humus I (hereafter abbreviated HI) and the younger humus II (HII), are recognized in this plain. HI is black-brown in color, relatively hard in texture and 0.5 to 1 meters in thickness. HII is brown and less mature as a soil than HI. The occurrence of these humic layers in sand ridges and sand dunes is shown in the schematic profiles of Fig. 3.

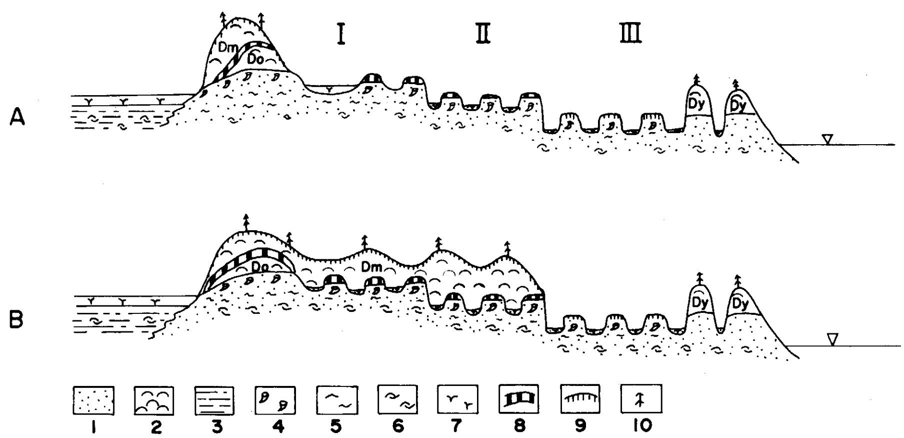


Fig. 3 Schematic profiles in the Kujukuri coastal plain
A: an ordinary place without a river side.
B: along a river side.
1: sand; 2: dune sand; 3: clay and silt; 4: pipe-like burrow (trace-fossil of *Ocypode stimpsoni*); 5: light-colored spot (trace-fossil of *Excilolana chiltoni japonica*); 6: shell; 7: peat; 8: humic layer I; 9: humic layer II; 10: wood; I: sand ridges I; II: sand ridges II; III: sand ridges III; Do: older sand dune; Dm: middle sand dune; Dy: younger sand dune

HI occurs on SI and SII, and HII develops on SIII as well as SII. The discontinuous occurrence of the humic layers from SII to SIII means that there was a hiatus between the formation of SII and SIII. This hiatus is estimated to correspond to the age when the seaward part of SII was eroded and the realignment of the coastline of SIII occurred.

Do is overlain by HI and also Dm in some places. Dm is overlain by HII and covers HI, which is developed in the top of sand layer of sand ridge, and is distributed in two kinds of places. One type occurs only along rivers somewhat perpendicular to the coast on SI and SII. These distribution and stratigraphic relations between Dm and HI indicate that the sand of this type of Dm was supplied from river beds during the period shortly before SIII began to be formed, due to the influx of a great deal of sand into the plain from the upper reaches of the river basins. The other type of Dm occurs on the most landward sand ridges, overlying Do subparallel to the coast. This Dm was derived not from the beach of the age of formation of Dm, but from the sand of Do underlying Dm, because the shoreline of that age occupied the boundary between SII and SIII which was far from the Dm, and only sand ridges are distributed between the shoreline and the Dm (Fig. 3).

Ages of sand ridges, sand dunes and valley bottoms

On the basis of radiocarbon age determinations of various materials (Watanabe, 1966; Tsuji and Suzuki, 1977; Moriwaki, 1979), archeological excavations (Shimizu, 1954, 1958; Committee on the History of Ichinomiya Town, 1964; Committee on the History of Mobara City, 1966) and historical documents, the ages of the formation of sand ridges, sand dunes and valley bottoms can be estimated as follows.

Abandoned barrier spits which are located on the most landward of SI were formed from about 6,000 to 5,500 years ago, judging from the radiocarbon ages of shells in sand ridge and lagoonal deposits and the age of shell mounds situated on uplands, while shell mounds located on the sand ridges show that SI was formed in the middle Jomon period (ca. 5,000 to 4,000 years ago) and the landward portion of SII was formed in the late Jomon period (ca. 4,000 to 3,000 years ago). The radiocarbon dates of shells found from sand ridge formation indicate that the age when a shoreline was situated near the boundary between SII and SIII should fall within the time range from 2,500 and 2,200 years ago (the latest Jomon period). SIII had begun to prograde shortly before the Kofun period (ca. 1,500 years ago): the oldest of the archeological sites located on SIII was built in the Kofun period. An ancient map drawn in 1735 A.D. indicates that the shoreline in that year was located 400 meters landward from the present shoreline in the central part of the coast.

The ages of sand dunes are estimated in the same way mentioned above. Since Do is situated on the most landward barrier spit of SI, and the dune sand directly covers the beach sand of the spit, the dune sand began to be deposited immediately after the spit was formed, that is, around the early Jomon period. The formation of this sand dune continued to the middle Jomon period (ca. 4,500 years ago) in the northern part of the plain, judging from the position of the site in the middle Jomon period. Dm was formed around the Yayoi period (ca. 2,300 to 1,800 years ago), when the shoreline was located at the boundary between SII and SIII. The historical documents mentioned above show that Dy was formed during about the past 200 years. As for the Kuriyama River lowland, radiocarbon dates and archeological data in the lowland and shell mounds on the surrounding upland indicate that the lowland rapidly changed from lagoonal conditions to swamp in the latest Jomon or the Yayoi period. This age corresponds to the age of the drop in sea level obtained in the sand ridges area.

Summary of the geomorphic development of the Kujukuri coastal plain

The chronological chart and time-space diagram of this plain are illustrated in Fig. 4, and Fig. 5 shows paleo-geographic maps. Thus the following features of geomorphic development can be outlined.

1) The first half of the early Jomon period (ca. 6,000 to 5,500 years ago; Fig. 5-1)

Former valleys dissected by rivers during the last glacial sea-level drop were covered by the sea in the Jomon transgression, and an intricate coastline was formed. Uplands facing the sea were eroded back to the present escarpment facing the coastal plain. Then growth of barrier spits produced several lagoons. Older sand dunes, Do, began to form on the barriers supplied from the nearby shore. The exact height of the sea level at that time is undetermined, but the present altitude of the most landward sand ridge attains ca. 6 meters above the present sea level in the central part of the plain, indicating tectonic uplift.

2) The latter half of the early Jomon to the middle Jomon period (ca. 5,500 to 4,000 years ago; Fig. 5-2)

Sea level was at standstill; in the sounthern part of the plain, the shore prograded rapidly, forming sand ridges (SI), while in the middle and northern parts sand ridges were not formed markedly, and sand dunes (Do) were formed on the most landward barriers instead. The rate of progradation was so rapid that dunes could not be formed markedly in the southern part. In the valleys of the uplands, lagoons held brackish water in this period, according to an analysis of molluscan shells in shell mounds (Shimizu, 1958). At the end of this period, a slight fall of sea level of about 2 or 3 meters occurred, resulting in a discontinuity between SI and SII.

3) The late Jomon period (ca. 4,000 to 3,000 years ago; Fig. 5-3)

In this period, sea level was at a standstill or rose slightly, and the inner half of SII was formed. The supply and the accumulation of sandy deposits were insufficient for forming dunes, so that a humic layer, HI was formed on the sand ridge deposits. Lagoonal valley bottoms were transformed gradually from brackish to fresh water conditions.

4) The latest Jomon to the Yayoi period (ca. 3,000 to 2,000 years ago; Fig. 5-4)

Sea level rapidly fell in this period, resulting in a discontinuity between SII and SIII. The differences in height among sand ridges in the central part and marine terraces in the southern part indicate that a relative drop in sea level of more than 5 meters in the southern part and more than 2 meters in the central part occurred. Such a difference in the magnitude of the drop in sea level is due to tectonic uplift: that is, the southern part uplifted more than the central part. However, because this drop in sea level corresponds to a slight drop in the sea level itself in the Yayoi period (ca. 2,000 years ago), which has been recognized in other regions of Japan (Iseki, 1977), this drop in sea level is probably attributable not to tectonic uplift but to sea-level fall. The seaward sand ridges of SII were rapidly prograded to the boundary between SII and SIII, so that the sand of SII was stabilized, forming no sand dune but rather a humic layer. In the valley bottoms now occupied by swamp, peat was accumulated.

5) The Yayoi to the Kofun period (ca. 2,000 to 1,500 years ago; Fig. 5-5)

Sea level rose relatively 2 or 3 meters during this period in the southern end of the plain, but in the central and northern part the magnitude of the rise is not clear. No marked advance of sand ridges was seen. Sand dunes (Dm) were formed in this stage. The eolian sand was derived not from beaches, but from river beds or older dunes.

6) The Kofun period to the present (after ca. 1,500 years ago)

A relative drop in sea level from about 3 meters high to the present level is found in this plain on the basis of the height of the sand ridges. The shoreline of SIII prograded to the present coast. Progradation of shoreline reaching 3 or 4 kilometers occurred in this period. Prior to around 200 years ago, no sand dunes formed, because the beach sand of sand ridges was stabilized by forests immediately after it emerged; but HII was developed on the ridges. After that time, however, sand dunes (Dy) covered over the sand ridges, perhaps because the rate of depositional progradation was lower during this period than before, as will be mentioned later.

This plain is characterized by the following features: the area around the plain is occupied by Quaternary upland with low relief; no large river enters this plain, so that most of the materials constituting the plain were derived form the sea cliffs on both sides of it; a wide sand ridge area without sand dunes occupies most of this plain.

Two discontinuities are established in the development of this plain. The older one occurred in the middle Jomon period, and the younger in the Yayoi period. The rate of progradation in the central part of this plain can be estimated for about four periods – ca. 6,000 to 4,500, 4,500 to 4,000, 4,000 to 2,300, and 2,300 to 0 years ago – as follows: 30, 200, 250, and 120 meters per 100 years respectively. The mean rate of progradation during the past 6,000 years is 140 meters per 100 years. Sand dunes are divided into three groups: older sand dune (Do), middle sand dune (Dm), and younger sand dune (Dy). They

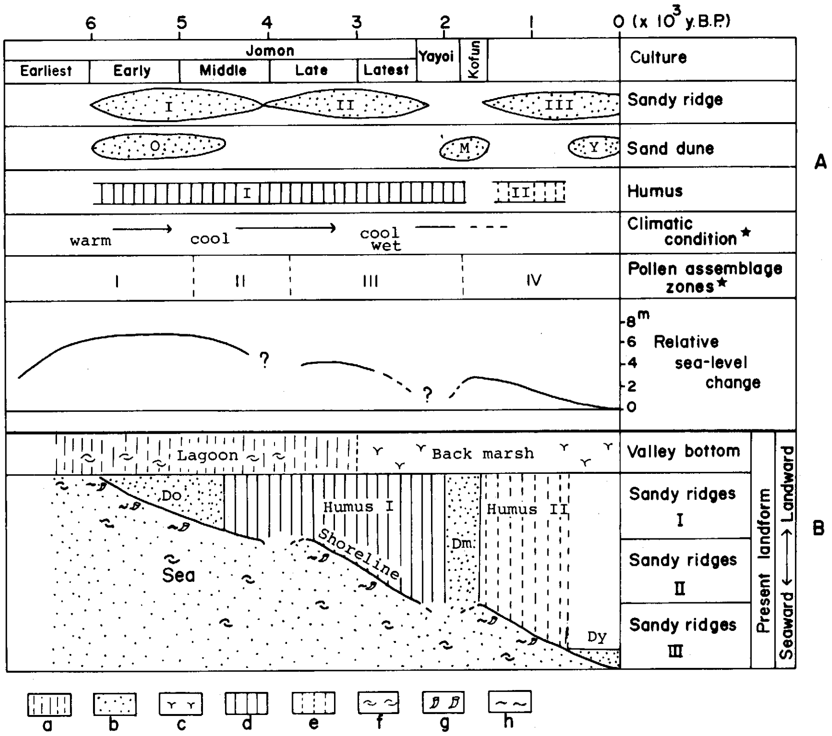


Fig. 4 Chronological chart (A) and time-space diagram (B). a: clay and silt; b: sand; c: peat; d: humic layer I; e: humic layer II; f: shell; g: pipe-like burrow (trace-fossil of *Ocypode stimpsoni*); h: light-colored spot (trace-fossil of *Excirolana chiltoni japonica*); *: after Tsuji and Suzuki (1977)

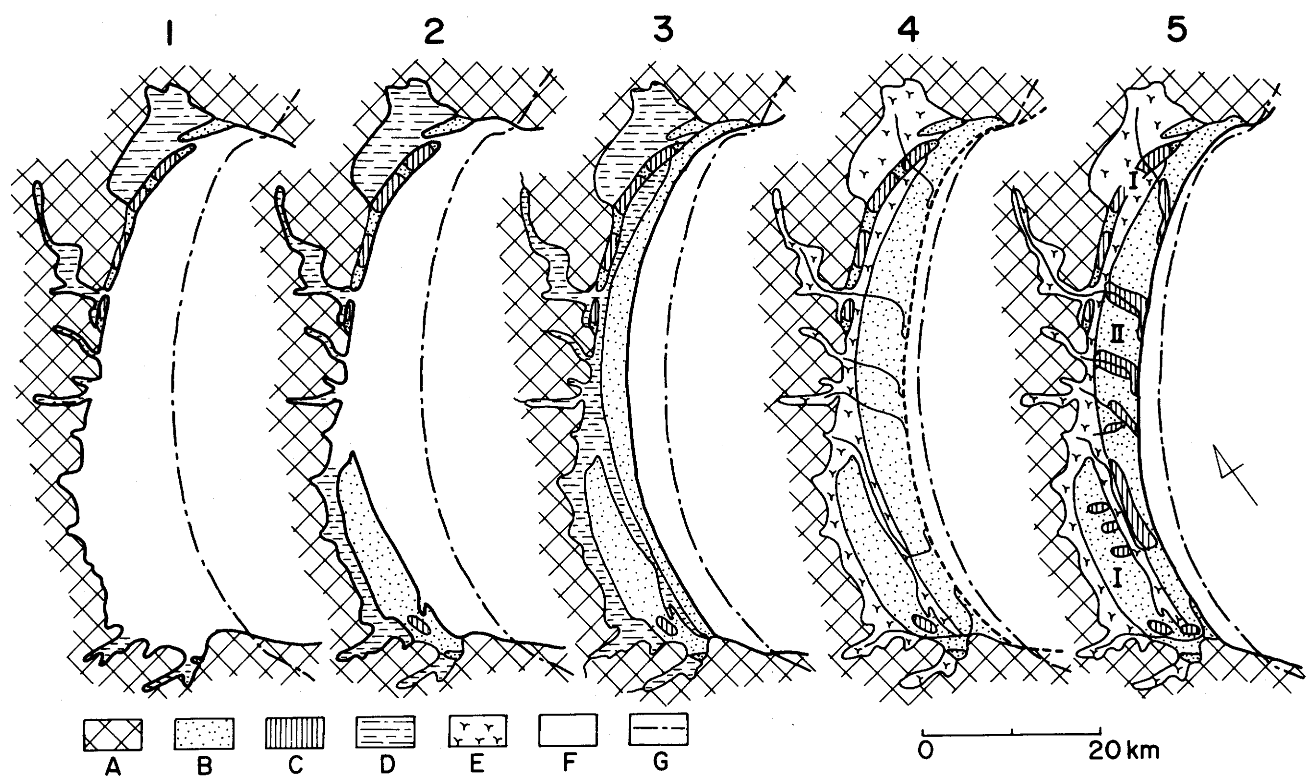


Fig. 5 Paleogeographic maps during the past 6,000 years. 1: the first half of the early Jomon period (ca. 6,000 to 5,500 years ago); 2: the latter half of the early to middle Jomon period (ca. 5,500 to 4,000 years ago); 3: the late Jomon period (ca. 4,000 to 3,000 years ago); 4: the latest Jomon to the Yayoi period (ca. 3,000 to 2,000 years ago); 5: the Yayoi to the Kofun period (ca. 2,000 to 1,500 years ago); A: upland; B: barrier, sand ridge; C: sand dune; D: embayment, lagoon; E: swamp; F: sea; G: present shoreline. Bold line indicates a former shoreline

were built in the early to the middle Jomon period (ca. 6,000 to 4,500 years ago), in the Yayoi period (ca. 2,000 years ago), and during the past about 200 years respectively. The sand for Do and Dy was supplied from former beaches; that for Dm, from the sand of Do or river beds. The rate of shoreline development mentioned above suggests that sand dunes of types Do and Dy were formed during the period of low rate of progradation.

3. Geomorphic Development of the Yufutsu Coastal Plain

Physiography of the plain

The Yufutsu coastal plain lies to the south of the Ishikari-Yufutsu lowland, connecting the main part of Hokkaido to the peninsular part (Fig. 6). This plain extends for a distance of about 50 kilometers along the coast from the mouth of the Mu River on the east to Shiraoi Town on the west, and attains a width of 20 kilometers from the coast of Yufutsu to the inland near Bibi.

The northern region of the middle and western part of this plain consists of Shikotsu tephra flow deposits ejected in the late Pleistocene and Tertiary sandstone, mudstone and conglomerate. Since the drainage basins of the rivers which directly enter the plain, i.e. the Tomakomai River (drainage basin area, 45 km^2), the Yufutsu and Bibi rivers (240 km^2), the Abira River (240 km^2) and Atsuma River (320 km^2), are small and consist of hills with low relief, it seems that they have not sufficiently supplied sediments to the plain. In contrast, the drainage basins of the Mu and Saru rivers east of the plain, rising into the Hidaka mountains with high relief, are 1250 km^2 and 1380 km^2 respectively, so that both rivers have supplied most of the sediments constituting the coastal plain.

This plain is clearly divided into a western beach ridge area and an eastern and northern backswamp area. The former is called the Tomakomai beach ridge area, and the latter, the Yufutsu-Atsuma swamp area (Fig. 6).

The Tomakomai beach ridge area reaches a maximum width of 5.5 kilometers from Numanohata to the present coast. Several tens of subparallel elongate beach ridges are seen in aerial photographs. These beach ridges are less than 1 or 2 meters in relative height and less than a hundred or several tens of meters in width, and are divided by narrow swales. Some belts consisting of narrow ridges and swales are separated by broader and deeper swales. These larger swales are abandoned channels running parallel to the shoreline, which was bent by longshore drift, as discussed above in the Kujukuri coastal plain. The Kujukuri coastal plain is well cultivated: small swales and beach ridges are disturbed in sand ridges; but they are well preserved in this plain. The present channels near the mouths of the Abira and Atsuma rivers run westward along the present coast, indicating that the westward longshore drift is prevailing.

It has been noticed that tens of rows of beach ridges converge at Yufutsu (Nakano, 1951; Mogi, 1964; Fujita, 1969). This convergence of beach ridges means that the shoreline has eroded to the east of Yufutsu village, while depositional progradation has occurred to the west of it. Moreover, the distribution of beach ridges shows that the point of transition from erosional to depositional areas has shifted westward. It is of interest that the lowland marsh extending widely to the east of Yufutsu village directly faces the ocean, because such land-

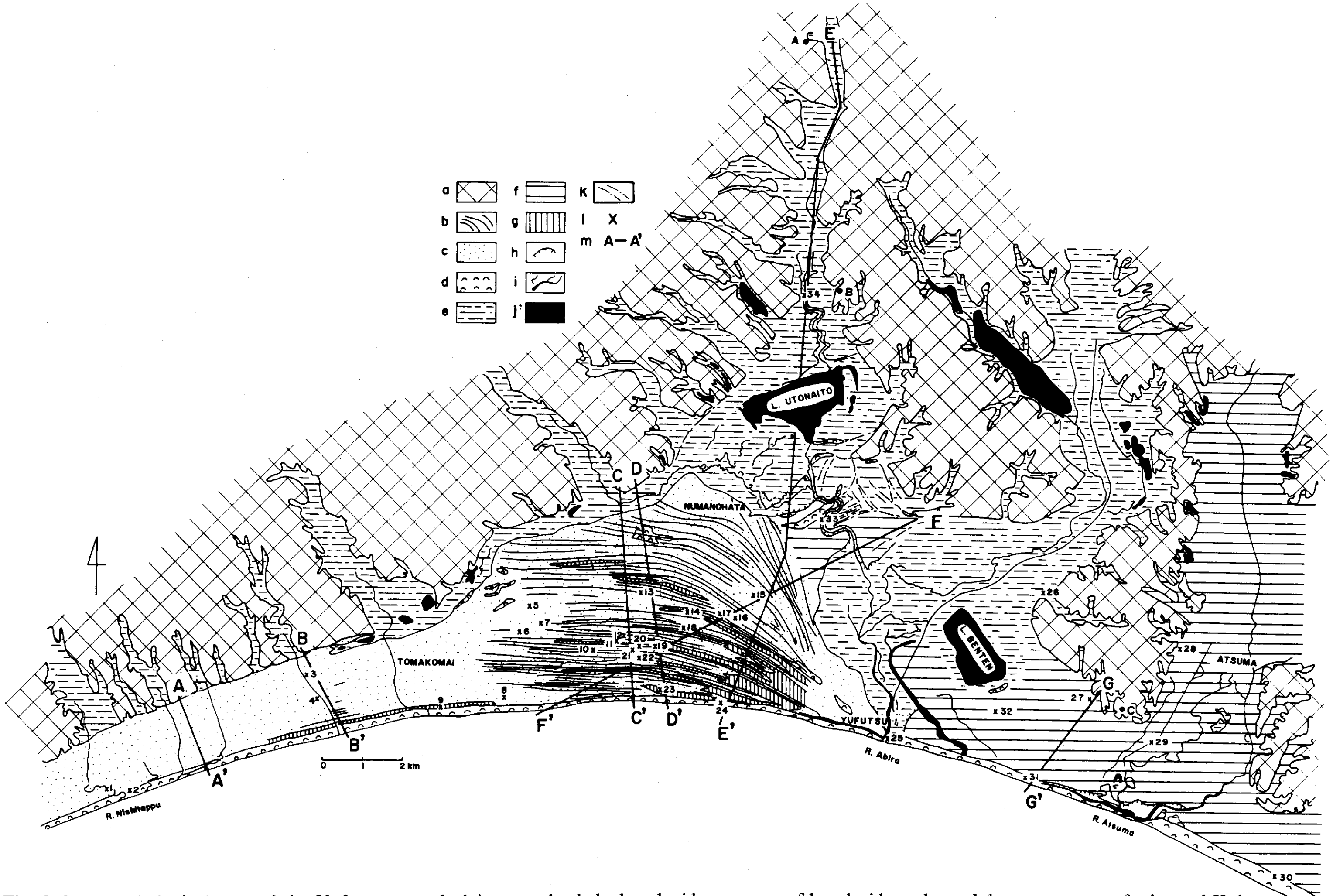


Fig. 6 Geomorphological map of the Yufutsu coastal plain. a: upland; b: beach ridge; c: area of beach ridges; d: sand dune; e: swamp; f: elevated Holocene swamp; g: swale; h: escarpment; i: present or abandoned channel; j: lake; k: beach ridge formed by lacustrine action; l: location of outcrop; m: location of transverse profile; A~C: location of shell mound

form distribution is in striking contrast to those of other coastal plains discussed in this paper, where such convergence of ridges terminates at a locality of bedrock; it suggests that the development of this plain has been different from that of other plains.

The altitude of the Tomakomai beach ridge area attains 7.5 to 5 meters above the present sea level. The plain, however, is covered by air-borne tephras with a maximum thickness of 1 to 1.5 meters, ejected mainly from the Tarumai volcano approximately 20 kilometers west of the plain. Therefore, the altitude of the beach ridges themselves is about 6 to 3.5 meters in the landward portion and 3.5 meters near the coast.

On the other hand, the Yufutsu-Atsuma swamp area was once a lagoon behind Tomakomai beach ridge area, as suggested by the abandoned lagoons of Utonaito and Benten lakes. Beach ridges and sand dunes built along the former, larger lake of Utonaito are recognized around the lake in aerial photographs. To the east of the Yufutsu, an emerged Holocene swamp with an altitude of 2.5 to 5 meters above the present sea level directly faces the ocean, indicating that this swamp has been eroded back. This fact and the distribution of the sand ridges west of Yufutsu mentioned above, as well as subsurface deposits and submarine topography which will be mentioned later, suggest that a barrier and a swamp behind it should have been formed off the present coast to the east of Yufutsu. The surface of this swamp does not incline toward the present coast, but toward the Benten lake from the area of Atsuma River – that is, it inclines parallel to the present coast. This shows that a lagoonal environment prevailed until recently in the area of Benten lake.

The highest and longest dunes develop along the present beach in this plain. They are currently active and eroded by marine action east of Yufutsu village, while they are generally stabilized west of Yufutsu village. Only small sand dunes are seen northwest of Yufutsu village, southwest of Numanohata and near Tomakomai. The dune sand east of Numanohata was derived from beach sand of the former Utonaito lake, which spread widely in the past.

Description of subsurface geology and geomorphic features of the plain

Distribution and stratigraphy of Holocene tephras in the coastal plain deposits

Holocene tephras derived from the Tarumai and Usu volcanos are of great value in determining the chronology of the Ishikari lowland. The distribution, stratigraphy and ages of these tephras have been established by many authors (e.g. Yamada, 1958; Committee on Nomenclature of Pyroclastic Deposits in Hokkaido, 1972; Machida et al., 1981; Fig. 7). Time-marker tephras are, from older to younger: Tarumai-d pumice fall (hereafter abbreviated Ta-d), Uenae bed (Ue), Tarumai-c pumice fall (Ta-c), Yufutsu pumice fall (Yup), Tomakomai ash fall (Tm), Us-b pumice fall (Us-b), Tarumai-b pumice fall (Ta-b) and Tarumai-a pumice fall (Ta-a); among these tephras, Tm derived from Baegdusan situated in the border between China and Korea is widely distributed in northern Japan (Machida et al., 1981). Us-b, which is ejected from Usu volcano, situated about 50 kilometers southwest of Tarumai volcano, is distributed only in the southern part of the plain. The tephras available for determining the chronology of the Yufutsu coastal plain are Ta-c, Ta-b, Us-b and Tm.

The ages of the tephras are as follows. Ta-c was ejected about 2,000 years ago (Morita, 1978). The age of Tm is about 1,000 years (Machida et al., 1981). The ages of Us-b and Ta-b are 1663 A.D. and 1667 A.D., respectively (Yamada, 1958; Kyōdo to Kagaku Henshu Iinkai, 1980).

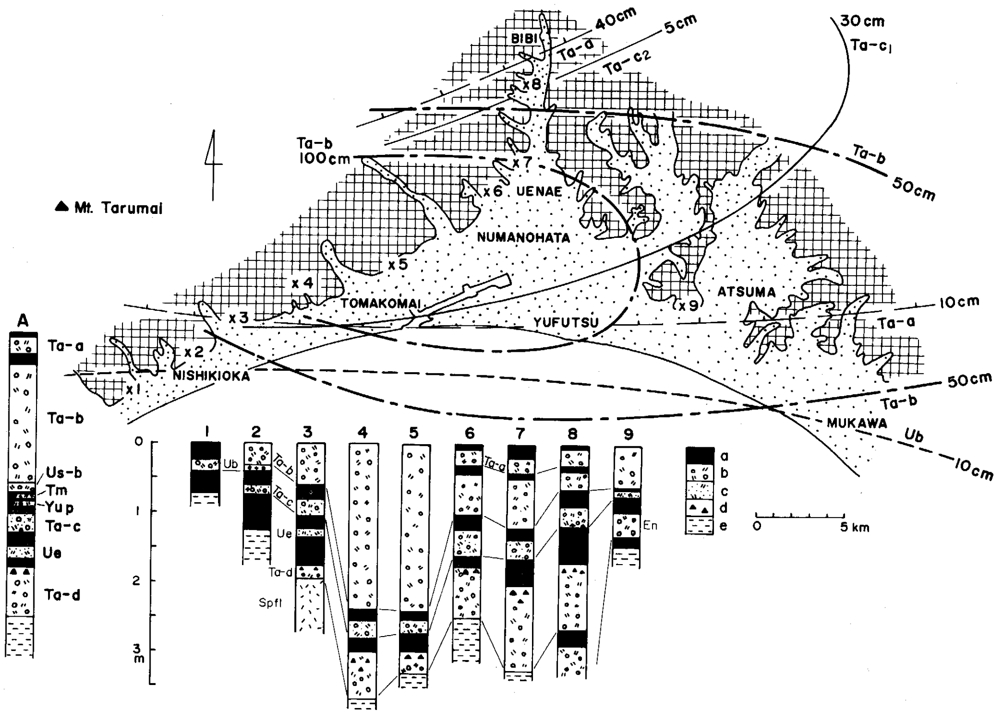


Fig. 7 Distribution and stratigraphy of the Holocene tephras in the Yufutsu region (modified from Committee on Nomenclature of Pyroclastic Deposits in Hokkaido, 1972). A: schematic stratigraphy; a: humic layer; b: pumice (coarse); c: pumice (fine); d: scoria; e: loam. Figure indicates thickness

Ages of sand ridges, sand dunes and swamps of the plain

Though Fujita (1969) and Satoh (1969) showed that Ta-b and Ta-c covered nearly all of this plan, a detailed analysis of geomorphic features using these marker tephras has not yet fully been conducted. The relationships between Tm and Us-b as well as among these tephras and the landfroms of this plain are clarified by the observation of outcrops mainly situated along the man-made scarps around Tomakomai harbour, which was excavated over 6.5 kilometers inland from the present coast (Fig. 8). Schematic geologic sections of this area are shown in Fig. 9 from the data shown in Fig. 8 and from other subsurface outcrops whose localities are shown in Fig. 6. The subsurface geology and stratigraphic position of tephras and radiocarbon ages are shown in Fig. 8.

In the Yufutsu-Atsuma swamp area, *Crassostrea gigas* and *Corbicula japonica* contained in the upper part of lagoonal clay deposits were dated 5,490± 110 C-14 y.B.P. (Gak-4683, Nakata et al., 1975, Fig. 6, Loc. 32) and 5,520± 125 C-14 y.B.P. (Gak-5733, Tomakomai City, 1976, Loc. 34), respectively. Shell mounds which were made by human beings in the early Jomon to middle Jomon period (from ca. 6,000 to 4,000 years ago) are located on the upland around this palin (Fig. 6, A, B, C, Matsushita et al., 1967; Tomakomai City, 1976). These shell mounds also consist mainly of *Crassostrea gigas, Corbicula japonica, Tapes*

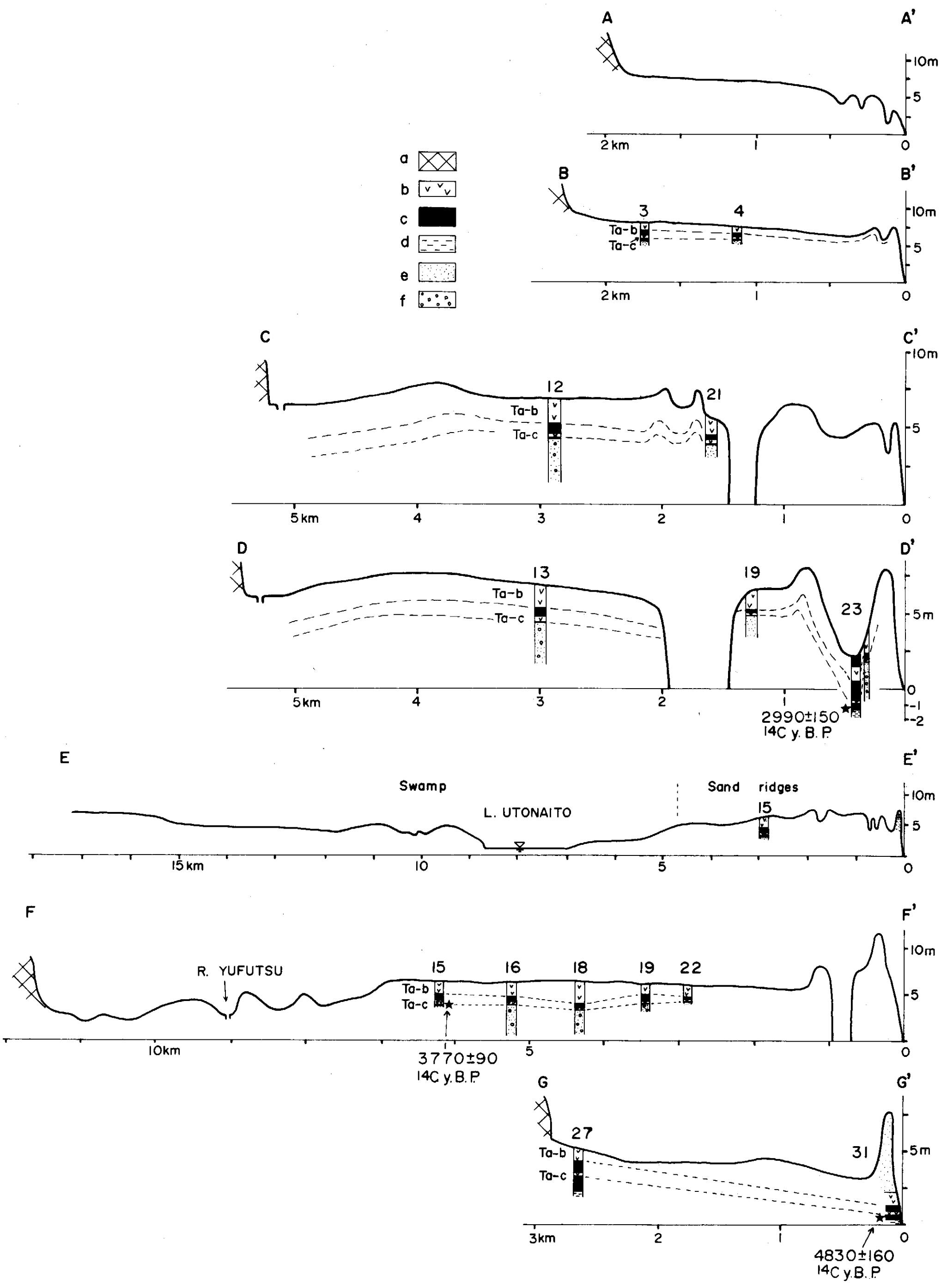


Fig. 8 Cross-sections of the Yufutsu coastal plain. a: basement; b: pumice; c: peat; d: silt; e: sand; f: gravel

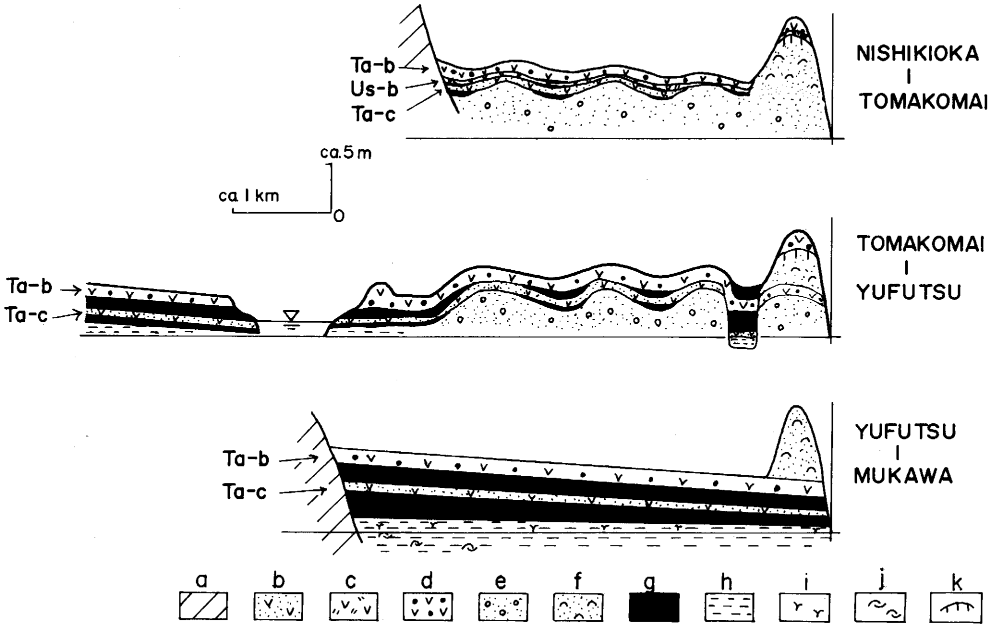


Fig. 9 Schematic cross-sections of the Yufutsu coastal plain. a: basement; b: Ta-c pumice fall (fine); c: Us-b pumice fall; d: Ta-b pumice fall; e: sand and gravel; f: dune sand; g: peat; h: silt; i: root; j: shell; k: humic layer

philippinarum and *Trapezium liratum,* which yield radiocarbon ages of 5,570±120 C-14 y.B.P. (Gak-6670, Akamatsu and Sato, 1977, Loc. A), 5,640±110 C-14 y.B.P. (Gak-4372, Tomakomai City, 1976, Loc. B) and 5,350±120 C-14 y.B.P. (Gak-5375, Tomakomai City, 1976, Loc. C). Therefore, it is obvious that the age when the sea invaded furthest inland was 6,000 to 5,000 years ago. This corresponds to that of other cases of the largest Holocene invasion in Japan (Ota et al., in press).

Above lagoonal clay deposits containing the molluscan shells mentioned above, there is a peat layer 1 to 2 meters thick, which intercalates Ta-c tephra and is overlain by Ta-b tephra. The peat layer and the lagoonal deposit are also exposed along the present coast in the eastern part of the swamp area (Fig. 9-C). The peat collected from the lowest part of the peat layer was dated 4,830±160 C-14 y.B.P. (Gak-8790, Fig. 8, Loc. 31). This fact suggests that a barrier had already formed off the eastern part of the plain in that period; the barrier and the swamp behind it have been eroded back to the present coast, as mentioned earlier in connection with the distribution and trend of the beach ridges. This consideration is verified by the fact that a drowned abrasion platform is seen at a depth of less than −20 meters off the eastern coast of the plain, and the seaward edge of this platform continues to the most landward beach ridge of the Tomakomai beach ridge area (Fig. 10).

The Tomakomai beach ridge area is occupied by medium to coarse sand and gravel derived from sea cliffs of uplands east of the plain and the Mu and Saru rivers. The most inland beach ridge of the Tomakomai beach ridge area is estimated to have been formed 6,000 to 5,000 years ago on the basis of the age of the lagoonal deposits behind it which are mentioned above.

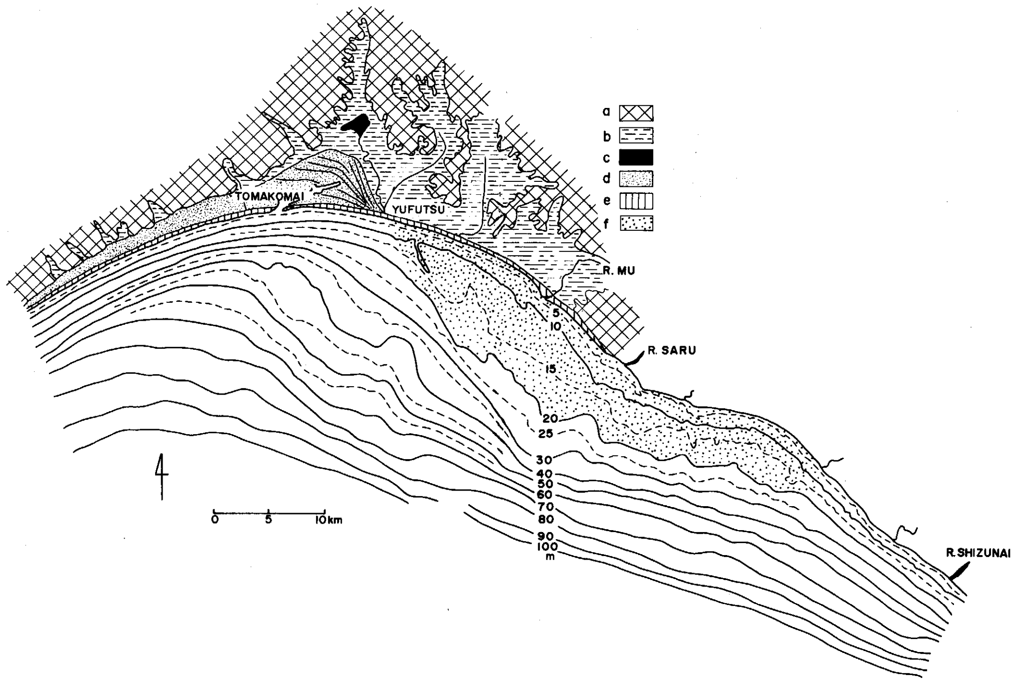


Fig. 10 Submarine topographic map of the Yufutsu region (after bathymetric chart surveyed by the Hydrographic Department, Maritime Safety Agency, scale: 1:50,000). a: upland; b: swamp; c: lake; d: beach ridge area; e: sand dune; f: submarine flat surface

The beach deposit is overlain by a peat layer, which is 1 or 2 meters thick at swales between beach ridges and thins to the ridge crest. The peat collected from the lowest part of the layer near the boundary between the peat layer and the beach deposit was dated 3,770±90 C-14 y.B.P. (Gak-8791) at Loc. 15, about 3 kilometers inland from the present coast (Fig. 6, Fig. 8). Accordingly, the shoreline of about 4,000 years ago was situated along the row of the beach ridge where Loc. 15 is located. At Loc. 23, which is about 500 meters inland from the present beach, the peat collected from the lowest part of the peat layer, which is about 2 meters thick and in which Ta-c and Ta-b are intercalated, was dated 2,990±150 C-14 y.B.P. (Fig. 8). Therefore, the shoreline shown by the row of beach ridge immediately seaward of the swale of Loc. 23 was formed about 3,000 years ago.

Ta-c tephra covering the whole plain is seen at the present coast to the east of the Tomakomai beach ridge area, including that the shoreline in the age of Ta-c (ca. 2,000 years ago) should have been offshore. To the west of the Tomakomai beach ridge area (Fig. 9, A), Ta-c is distributed only in the area landward 1 or 2 kilometers inland from the present beach. Therefore, the shoreline in the age of the Ta-c was situated 1 or 2 kilometers inland from the present beach in this area. Us-b overlain by Ta-b, however, is exposed in the face of the present beach. The shoreline in the age of Us-b, i.e. 1663 A.D., should have been offshore.

The chronology of sand dunes along the present coast can be established on the basis of Ta-b (Fig. 11). Ta-b resting upon the peat layer is overlain by dune sand on the east of

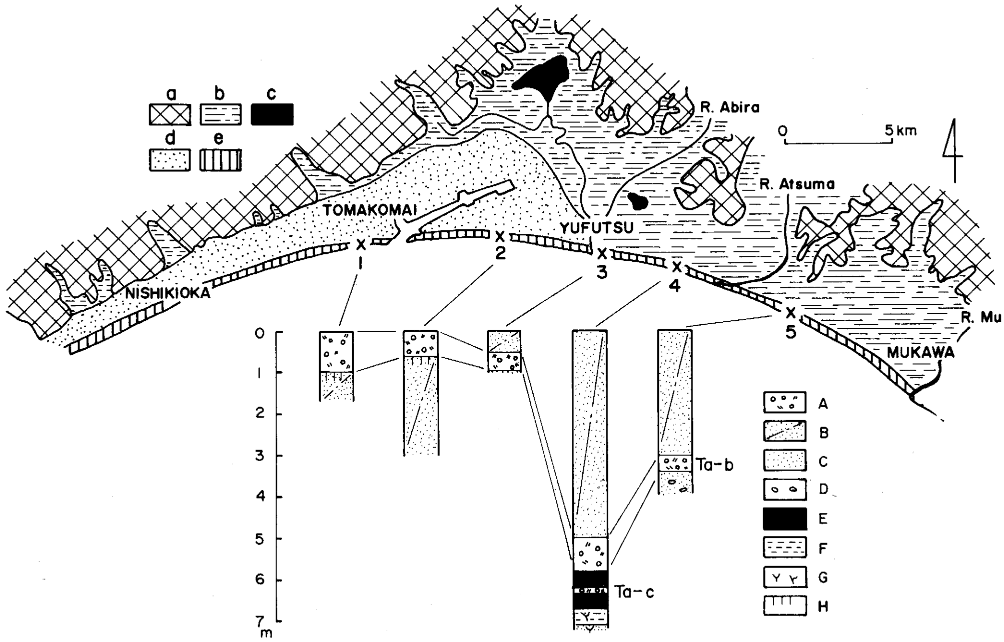


Fig. 11 Relation between the coastal sand dune and Ta-b pumice fall in the Yufutsu coastal plain. A: pumice; B: dune sand; C: beach sand; D: gravel; E: peat; F: silt; G: root; H: humic layer. See Fig. 10 for legend of a-e

Yufutsu village. In contrast, to the west of the village, dune sand is overlain by Ta-b. A black humic layer more than 20 centimeters thick is well developed at the top of the dune sand. From this fact it is concluded that the sand dune to the west of the village was formed considerably before the time of Ta-b in this area, probably shortly after the time when the shoreline prograded to the position of this sand dune, i.e. 2,000 years ago.

Shoreline development of the Yufutsu coastal plain

From the data mentioned above, the following stages of shoreline development can be classified (Fig. 12).

1) Stage 1 (ca. 6,000 years ago)

When the Holocene transgression attained its maximum extent, a very intricate coastline was formed. This sea level was recorded at an altitude of a little more than 6 meters above the present sea level at the Tomakomai beach ridge area. It is probable that a cape, which disappeared later by marine erosion, protruded at a distance of about 8 kilometers off the Mu River in the eastern end of the plain. The embayment at that time faced southwest, in contrast to the present one which faces south.

2) Stage 2 (soon after stage 1, probably ca. 5,500 years ago)

Immediately after the culmination of transgression, a barrier should have extended from the southeastern cape, resulting in a smooth coastline and a big lagoon in the Mukawa, Yufutsu and Bibi areas.

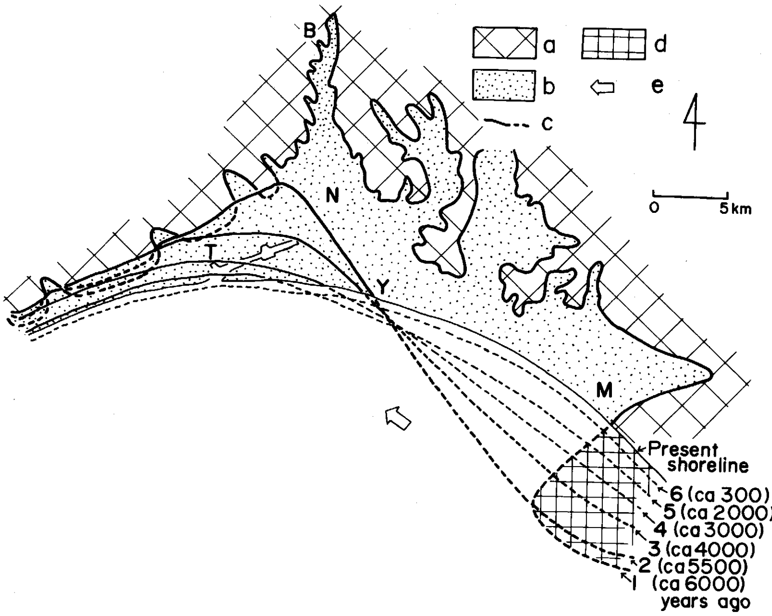


Fig. 12 Holocene shoreline changes in the Yufutsu region. a: upland; b: lowland; c former shoreline; d: former promontory eroded by marine action; e: direction of longshore current; T: Tomakomai; B: Bibi: N: Numanohata; Y: Yufutsu; M: Mukawa

3) Stage 3 (ca. 4,000 years ago)

Shoreline prograded to the vicinity of 3.5 kilometers inland from the present coast in the central part of the Tomakomai beach ridge area; it was located at the foot of the upland behind the plain in the western part, because a beach ridge indicating the shoreline is traceable to the foot of the upland. The rate of progradation of the shoreline from stage 2 to this stage was 130 meters per 100 years in the central part. The shoreline east of Yufutsu should have eroded back.

4) Stage 4 (ca. 3,000 years ago)

The shoreline rapidly prograded near the present coast in the central part of the Tomakomai beach ridge area, and to an intermediate place in the western part. The rate of progradation of the shoreline from stage 3 to this stage was 300 meters per 100 years in the central part. The shoreline east of Yufutsu should have migrated landward.

5) Stage 5 (ca. 2,000 years ago)

Ta-c was produced in this stage. The shoreline prograded off the present shoreline in the Tomakomai beach ridge area between Yufutsu and Tomakomai, and prograded near the present shoreline west of Tomakomai. The rate of progradation of the shoreline from stage 4 to this stage was 50 meters per 100 years, a lower rate than before. The shoreline was probably still eroded back east of Yufutsu. The formation of sand dunes commenced west of Yufutsu.

6) Stage 6 (ca. 300 years ago)

Us-b (1663 A.D.) and Ta-b (1667 A.D.) erupted in this stage. The shoreline was located off the present coast. Sand dunes formed after the fall of Ta-b east of Yufutsu.

In summary, this plain is characterized by the following features: sand ridges without conspicuous sand dunes are widely distributed and converge in the central part of this plain; a wide submerged abrasion platform is developed in the area less than 20 meters below sea level off the coast west of the place of this convergence; several marker tephras cover this plain.

The shoreline had been continuously prograded in the Tomakomai beach ridge area west of Yufutsu until stage 5, i.e. around 2,000 years ago. No discontinuity is recognizable from stage 1 to stage 5. The progradation virtually ceased probably shortly after about 2,000 years ago, and the shoreline has migrated landward since that time, resulting in discontinuity with a fairly long-term marine erosion in the central part of the Tomakomai beach ridge area. The rates of progradation in the central part of the plain at its maximum width are estimated for the three periods – about 5,500 to 4,000, 4,000 to 3,000 and 3,000 to 2,000 years ago – as 130, 300, 50 meters per 100 years, respectively. The mean rate of progradation is 160 meters per 100 years from stage 2 to stage 5. The shoreline has gradually been eroded back during all of the period since stage 1 east of Yufutsu. The mean rate of retrogradation resulted from marine erosion is about 150 meters per 100 years off the coast of Mukawa on the east of the plain at its maximum width. It is most probable that the large magnitude of marine erosion, which attained 8 kilometers at its maximum, has occurred off the coast of the plain, resulting from the fact that the geology of this part consists of Neogene and Quaternary clay and silt deposits which are easily subject to marine erosion. The volume of materials which were eroded and supplied to the Yufutsu coastal plain is estimated to have been 10 cubic kilometers during the past 6,000 years on the basis of the area of the abrasion platform off the coast east of the plain, i.e. from the Mu to Shizunai rivers, and on the basis of the altitude of the upland facing the coast, which is 30 to 100 meters. These marine erosional materials, besides those produced by the east of the plain, such as the Mu River and the Saru River, should have been the main source for the Yufutsu coastal plain.

Sand dunes are well developed along the present coast. It is of interest that there is a distinct difference in age of formation between the dunes to the west and those to the east of Yufutsu. The former are estimated to have been constructed about 2,000 years ago. On the other hand, the latter were formed after the Ta-b fall in 1667 A.D. and are currently active. Though coastal erosion is occurring in this area, sand dunes are forming, indicating that sand dune formation is possible even during transgression, when the beach is composed of sand.

4. Geomorphic Development of the Akita Coastal Plain

Introduction

This coastal plain is about 20 kilometers long and 3.5 kilometers in maximum width, extending from the mouth of the former Omono River on the south to the Oga Peninsula on the north. Hachirogata lagoon (area, ca. 220 km^2), the second largest one in Japan, which has been reclaimed, is situated behind this plain.

The one source of sediment supply to this plain is the Oga Peninsula to the north, consisting of the Funagawa Formation (black mudstone) and Kitaura Formation (tuffacious mudstone) of late Neogene to early Pleistocene. Marine erosion produced sand which was supplied to the plain. The other source is the Omono River south of the plain, whose drainage basin covers about 4,000 km^2 in area and consists of mudstone, shale and Tertiary "green tuff".

As shown in Fig. 13 and Fig. 14, this plain is composed of about ten rows of subparallel elongate sand ridges at its widest part. These ridges are covered by thick eolian sand as is evident from the distribution of altitude of the plain. The thickness attains about 5 to 40 meters. The sand ridges converge at both ends of the plain. Mii (1966) divided them into three groups by the two distinct discontinuities. They are called Sand and Dune ridges I, II, III, in this paper, corresponding to Dune ridges I, II, III of Sumita (1975).

Description of sand and dune ridges of the plain

Features of Sand and Dune ridges I (hereafter abbreviated SDI)

SDI generally consists of three sand ridges, which are absent over 4 kilometers near Funakoshi in the northern central part. The sand ridges northward of this interruption are named northern SDI, and those southward, southern SDI. This interruption of sand ridges shows that a wide tidal inlet occurred between Hachirogata lagoon and the open sea. Therefore sea water easily flowed into the lagoon when SDI was formed. The elongation of the sand ridges shows that northern SDI was derived from the sand produced by marine erosion at the Oga Peninsula, while southern SDI was formed as a barrier spits by sand supply from the Omono River.

The areas of southern and northern SDI are 12 km^2 and 2 km^2 respectively. Assuming an approximate uniformity of the depth of the sand and dune ridge deposits of SDI, the sand supplied from the Omono River was six times as great in volume as that from the Oga Peninsula.

The sand ridges, which are covered only by thin dune sand, are about 10 meters at its maximum height in the area of northern SDI. Therefore, in this area relative sea level reached nearly 10 meters at the age of maximum Holocene transgression. In this area, a terrace scarp of about 3 meters in relative height is traceable between SDI and SDII. Accordingly, the discontinuity between SDI and SDII is attributed to relative drop of sea level.

There are no radiocarbon dates directly indicating the age of sand ridges on this plain, but archeological sites which are located on or in the dune sand (Nara and Isomura, 1965; Kusanagi, 1975; Sumita, 1975) make it possible to estimate the age of formation of the sand ridges. Since the oldest archeological site on SDI is of the late Jomon period (ca. 4,000 to 3,000 years ago), and some sites of the late Jomon period are located even on SDII, SDI was formed in a considerably older age than the late Jomon period. Judging from the facts that SDI was formed during the period of culmination of rise in sea level, and that the shell mound of the early Jomon period located in the upland facing the Hachirogata lagoon was probably created in the period of this culmination, SDI was probably formed in the early

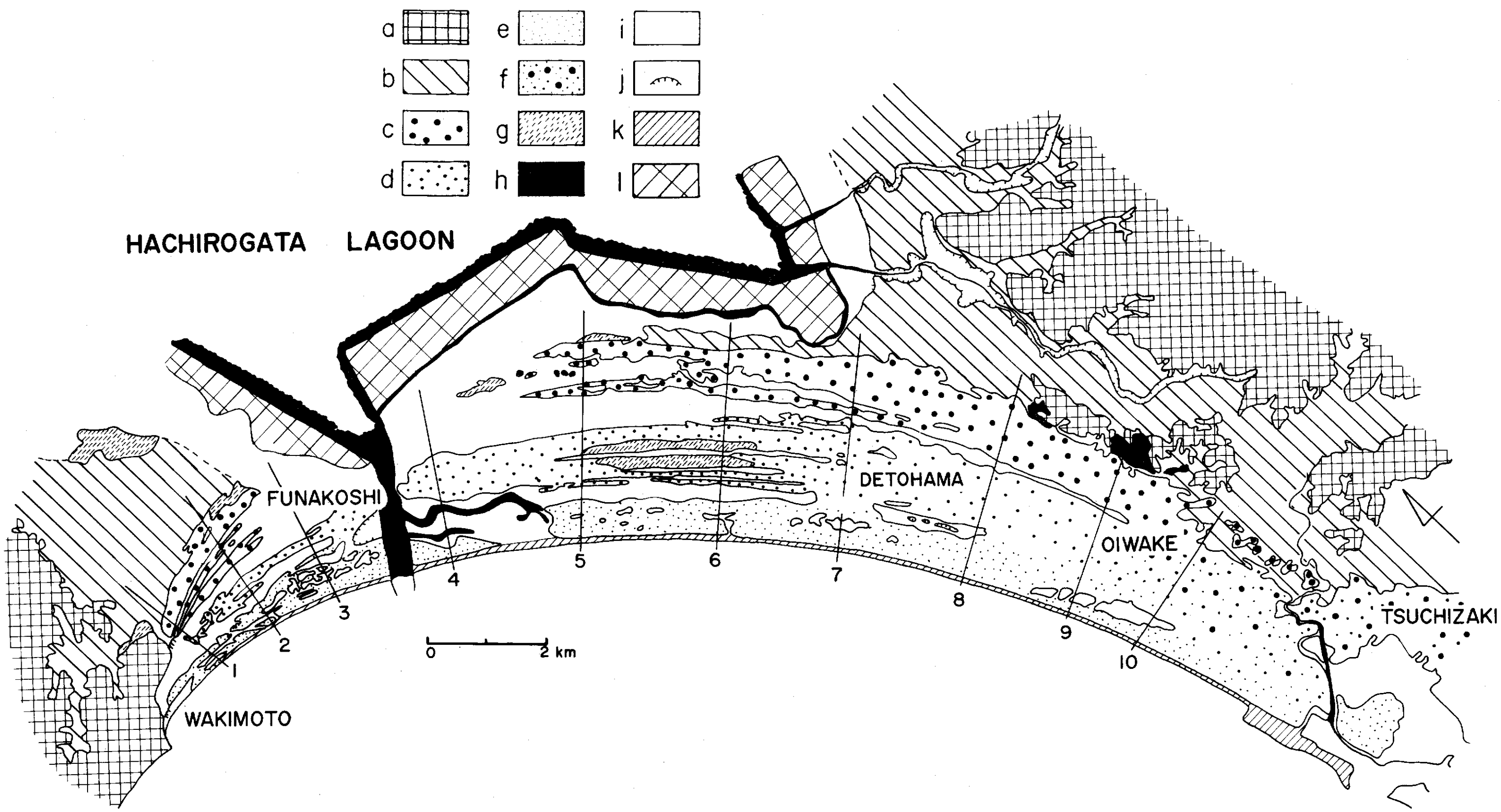


Fig. 13 Geomorphological map of the Akita coastal plain. a: upland; b: Holocene elevated coastal plain; c: SDI; d: SDII; e: SDIII; f: compound portion of SDI, SDII and SDIII; g: sand ridge; h: former channel, tidal inlet, lagoon; i: swale; j: escarpment; k: present beach; l: reclaimed land

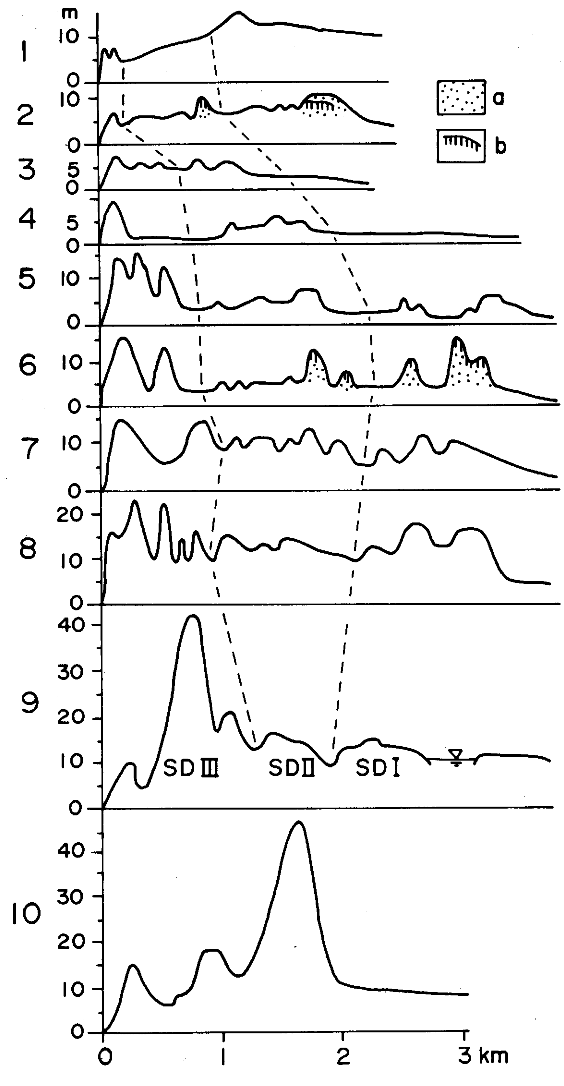


Fig. 14 Transverse sections of the Akita coastal plain
a: sand; b: humic layer

Jomon period (ca. 6,000 to 5,000 years ago). The discontinuity between SDI and SDII is estimated to have occurred in about the middle Jomon period, because some sites of the late Jomon period are also on SDII as mentioned above.

Sand dunes on SDI are 10 to 15 meters above the present sea level. They are composed of well-sorted medium sand and generally surfaced with a black humic layer. The dune sand of SDI overlies conformably sand ridge deposits of SDI, showing that eolian sand was deposited immediately after sand ridges were formed.

Features of Sand and Dune ridges II (SDII)

Nearly barriered by the sand ridges of SDII, the Hachirogata lagoon had a connection with the open sea only through a narrow tidal inlet at Funakoshi Town in the northern part of the plain. SDII is 1 kilometer wide in the central part of the plain. Sea level during this period was about 7.5 meters, on the basis of the height of sand ridge deposits. A terrace scarp with relative height of 1 meter between SDII and SDIII shows that the sea level fell after the formation of SDII. Sand dunes on SDII, which are 5 to 15 meters high, are smaller than those on SDI and SDIII. SDIII should have been formed in the late Jomon period, because sites of the late Jomon period are located in the central part of SDII.

The maximum distance between the most inland shoreline of SDI and the most seaward one of SDII is 2.5 kilometers. The time interval between them is estimated to be about 2,000 years, so that the rate of progradation between them is 130 meters per 100 years.

Features of Sand and Dune ridges III (SDIII)

Most seaward of the dune groups, SDIII extends less than 1 kilometers in the central part, and the ridges converge with those of SDI and SDII in the southern part of the plain. Sand dunes in SDIII are 7 to 45 meters high, and the altitude increases in grade southward (Fig. 14). They are higher than those of SDI and SDII.

Because the sand ridges of SDIII are covered by thick recent dune sand, archeological sites are hardly recognizable. Therefore, the Arahama shell mound located at the mouth of the Omono River is of great value in estimating the age of the ridges. It was built in the latest Jomon period (ca. 3,000 to 2,000 years ago) and overlain by dune sand 30 to 40 meters thick (Nara and Isomura, 1965). The position of this site is correlative with the discontinuity between SDII and SDIII. Therefore, this discontinuity is estimated to have been formed in the latest Jomon period. SDIII is 1 kilometer wide in its largest width, and has prograded to or off the present coast since the latest Jomon period (ca. 2,500 years ago). Therefore, the rate of progradation during the past about 2,500 years is more than 40 meters per 100 years.

Summary of the geomorphic development of the Akita coastal plain

It is noticeable that most of the sand ridges are covered by thick eolian sand in this plain; in this it is similar to the Niigata coastal plain mentioned below and in contrast to the Kujukuri coastal plain and the Yufutsu coastal plain facing the Pacific Ocean. Such large sand dunes as in the Akita and Niigata coastal plains are characteristically seen along the Japan Sea coast.

Two discontinuities are recognized in the formation of this plain, and archeological sites lead to estimates of ages for them; the older one was formed in the middle Jomon period, and the younger one in the latest Jomon period. The rate of progradation is thus estimated for two periods: from the early Jomon to the latest Jomon period (about 5,500 to 2,500 years ago) and from the latest Jomon to the present (after about 2,500 years ago). The results are 130 meters and 40 meters per 100 years, respectively. Judging from the facts that the rate has become lower with time and that marine erosion is now occurring in this coast, the shoreline change is probably reaching equilibrium.

5. Geomorphic Development of the Niigata Coastal Plain

Introduction

This plain is one of the largest coastal plains in Japan. It extends along the coast for about 70 kilometers with variable width from the northern end to the southern end of the plain, and sand dune ridges reach a maximum width of about 10 kilometers. A flood plain with well developed natural levees and backswamps is widely distributed behind the sand and dune ridges (Fig. 15)

Most of the sediments constituting the plain are derived from two large rivers with wide dranage areas, the Shinano (dranage area, ca. 12,000 km^2) and the Agano (ca. 7,000 km^2), and other small rivers: the Kaji, the Tainai and the Ara. Sufficient influx of sand into the open sea from these rivers has resulted in numerous rows of sand ridges and sand dunes parallel to the shoreline. The formation of these ridges and sand dunes has been discussed by many authors (e.g. Nishida and Chihara, 1956; Department of Geography of Tokyo Kyoiku University, 1962; Sakaguchi, 1964; Niigata Prefecture, 1970; Niigata Ancient Dune Research Group, 1974, 1978).

The landform classification (Fig. 15), some transverse sections of the plain (Fig. 16) and a schematic transverse section of the central part of the plain (Fig. 17) show that one row of large sand dunes extends immediately landward of the present coast southward of the Shinano River, while more than ten rows of sand ridges and sand dunes are distributed north of the Shinano River. They converge at the northern side of the Kaji River.

Judging from the discontinuous pattern of sand ridges and humic layers, the most developed rows of sand and dune ridges between the Shinano and Kaji rivers have been divided into three groups (Sakaguchi, 1964; Niigata Ancient Dune Research Group, 1974). Since thick dune sand frequently overlies the sand ridges, the three groups of sand ridges are named Sand and Dune ridges I (hereafter abbreviated SDI), II (SDII), and III (SDIII) in order from older to younger.

Description of sand and dune ridges of the plain

Features of Sand and Dune ridges I (SDI)

SDI consists of four rows of sand and dune ridges. The most landward ridge is distributed only on both sides of the Kaji River of the northern part of the plain. In contrast, the other three rows of ridges are traceable northward to the Kaji River and southward as far as the Shinano River (Fig. 15). SDI is not seen near the Shinano River. This is because SDI in this area was covered by alluvial deposits, judging from the fact that the base of postglacial deposits (the so-called Chuseki-so) occurs at about 150 meters below the present sea level near the mouth of the Shinano River (Iseki, 1956), showing land subsidence. The uppermost medium-grained sand of SDI is surfaced with a thick black humus 50 to 100 centimeters thick.

The archeological sites on SDI, which were created from the early Jomon period to the middle Jomon period (ca. 6,000 to 4,000 years ago), suggest that the age of SDI should range from about the beginning of the early Jomon (ca. 6,000 years ago) to the beginning of the middle Jomon period (ca. 5,000 years ago). From these ages the highest rate of shoreline progradation during the formation of SDI is estimated to have been 150 meters per 100 years.

Features of Sand and Dune ridges II(SDII)

SDII consists of five or six rows of sand and dune ridges. Most of the sand and dune ridges are less than 5 meters in relative height and generally lower than SDI and SDIII, suggesting that thin dune sand covers the sand ridges.

Archeological sites created in the Yayoi (ca. 2,000 years ago) and Kofun periods (ca. 1,500 years ago) are located on SDII (Niigata Ancient Dune Research Group, 1974). Therefore, SDII began to form before the Yayoi period. Since SDI had been formed before the beginning of the middle Jomon period, it is thus probable that the discontinuity between SDI and SDII occurred around the middle Jomon period. The most landward ridge of SDII should have been formed at about the beginning of the late Jomon period. The rate of progradation between the seaward of SDI and the most landward ridge of SDII is estimated to have been 350 meters per 100 years.

In Fig. 15 the discontinuity between SDI and SDII is shown as a truncation of SDI by SDII northeast of the Agano River. In contrast, it is shown by a wide swale between SDI and SDII near the Shinano and Agano rivers. In the wide swale area, deltas of the two large rivers rapidly advanced at the rate mentioned above; thus there should not have been sufficient time for them to be modified by longshore currents. The rapid advance of deltas seems to be due to sea-level fall in this period, as in the Akita and the Kujukuri coastal plain.

Features of Sand and Dune ridges III (SDIII)

SDIII consists of two or three rows of sand and dune ridges. Sand dunes 20 to 50 meters high, markedly taller than those of SDI and SDII, flank the shore. One of several large pieces of wood obtained from the landward part of SDIII was dated 2,340±125 C-14 y.B.P. (TH-119, Mogi, 1980, Fig. 16-3). Therefore, the most landward ridge of SDIII at Niigata Higashi harbour should have been formed in the second half of the latest Jomon period, and the discontinuity between SDII and SDIII should have been formed in the first half of the latest Jomon period. The pieces of wood were found in sand deposits 6 to 10 meters below sea level. Mogi (1980) considered them to have been carried by the current and deposited on the coast. The shoreline of that age is 4 kilometers seaward from the most landward ridge of SDII and 2.5 kilometers inland from the present coast on the west of the Agano River. Accordingly the rate of progradation was 240 meters per 100 years from about 4,000 to 2,300 years ago and 110 meters per 100 years from about 2,300 years ago to the present. Some pottery of the Haji type created in the Kofun period was found in the humic layer intercalated in the dune sand of SDIII near the present coast of Niigata Higashi harbour, indicating that the shoreline was prograded near the present coast northwest of the Agano River in that period.

Summary of the geomorphic development of the Niigata coastal plain

This plain is characterized by the following features: most sand ridges are covered by thick eolian sand; a broad alluvial plain, in which natural levees are conspicuously developed, is distributed behind the sand and dune ridge area; most of the sediments of this plain are derived from the rivers directly entering into the plain.

The sand and dune ridges are divided into three groups by two discontinuities: SDI, SDII and SDIII in order from older to younger. SDI, SDII and SDIII are estimated to have been

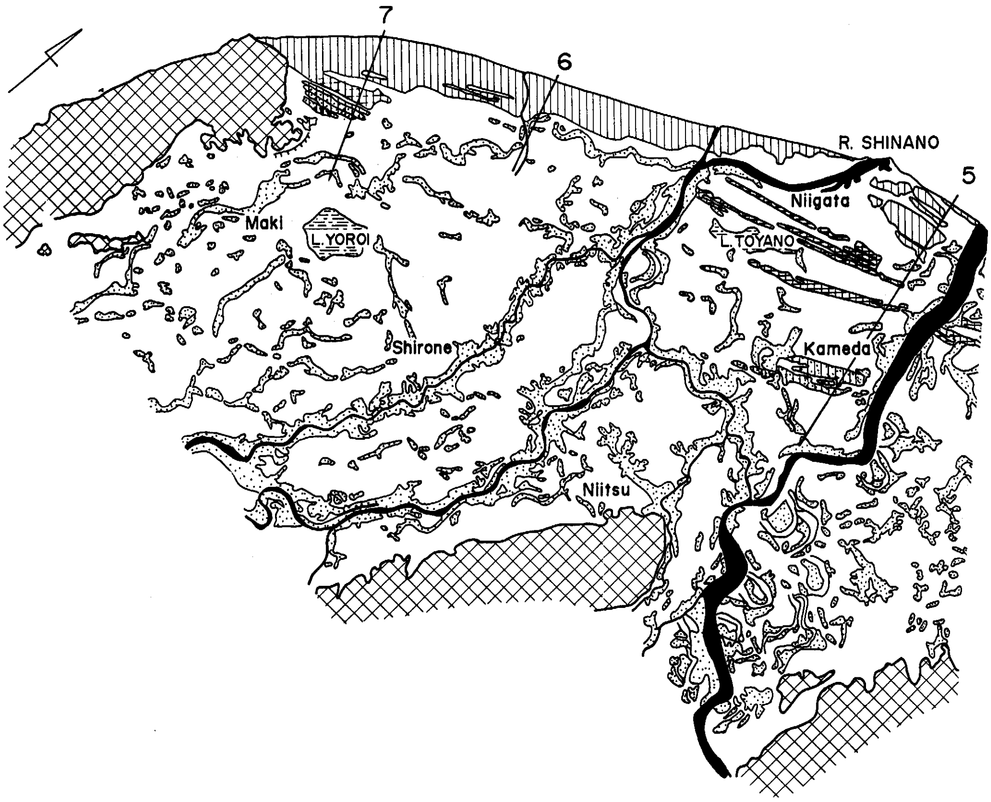
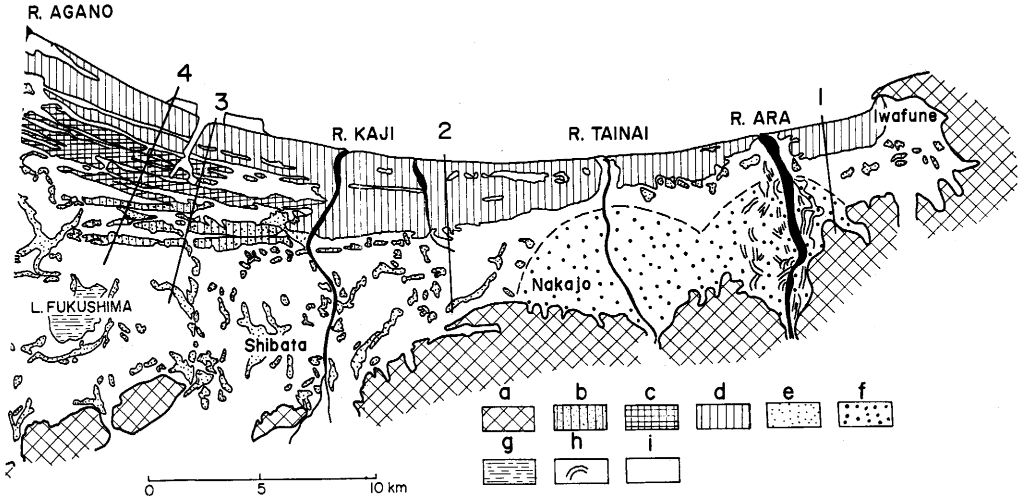


Fig. 15 Geomorphological map of the Niigata coastal plain. a: upland; b: SDI; c: SDII; d: SDIII;

formed in the early Jomon period (ca. 6,000 to 5,000 years ago), the late Jomon period (ca. 4,000 to 3,000 years ago) and the latest Jomon period to the present (after ca. 2,500 years ago), respectively.

Two discontinuities should have occurred in the middle Jomon period (ca. 5,000 to 4,000 years ago) and the first half of the latest Jomon period (ca. 3,000 to 2,500 years ago). These discontinuities occurred as the rapid progradation of the delta near the Agano and Shinano rivers, and as the truncation of the older ridges by younger ones northeast of the Agano



e: natural levee; f: alluvial fan; g: lake; h: abandoned channel; i: back swamp

River. This process is similar to that of the chenier reported in the Mississippi delta (Otvos and Price, 1979). That is, slow advance or stagnation of the delta results in chenier, while its rapid advance results in marsh. This rapid progradation of the Shinano and Agano delta probably resulted from sea-level fall, as mentioned below.

The sand dune of SDIII is markedly developed in comparison with that of SDI and SDII, and its formation corresponds to a lower rate of shoreline change. That of SDII is the most poorly developed; it was formed in conjunction with a higher rate of progradation.

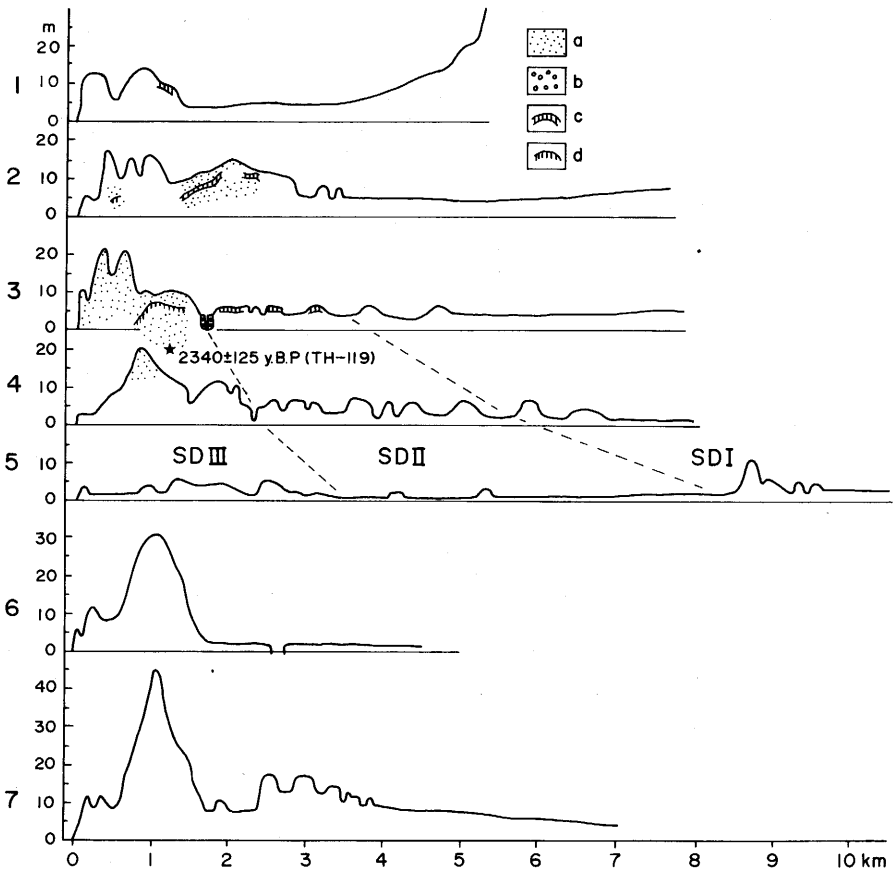


Fig. 16 Transverse sections of the Niigata coastal plain. a: sand; b: gravel; c: black humic layer; d: brown humic layer; after Mogi (1980). See Fig. 15 for location

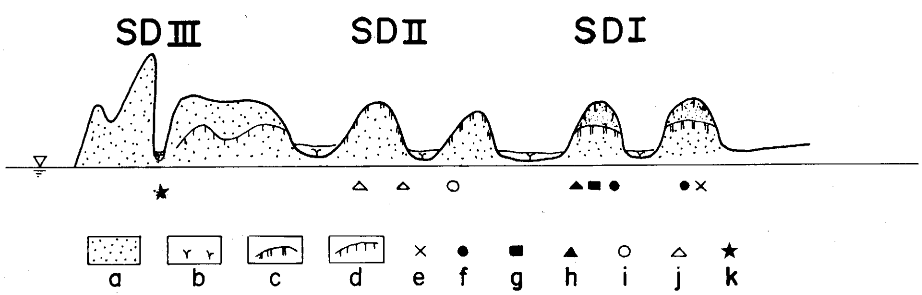


Fig. 17 Schematic transverse section of the central part of the Niigata coastal plain. a: sand; b: peat; c: black humic layer; d: brown humic layer; e-j: archeological site; e: the early Jomon period; f: the middle Jomon period; g: the late Jomon period; h: the latest Jomon period; i: the Yayoi period; j: the Kofun period (data from Niigata Ancient Dune Research Group, 1974); k: 2340±125 C-14 y.B.P. (TH-119, Mogi, 1980)

6. Discussion

Discontinuities in shoreline development

The discontinuities in shoreline development have been hitherto discussed by several authors from the oceanographic and sedimentologic points of view. For example, Psuty (1965) reported that three discontinuities in shoreline development of a coastal plain in Mexico resulted from change in sand supply due to shifts in the distributary mouths directly entering this plain. Curray et al. (1967) reported that three major discontinuities in shoreline development of the Nayarit coastal plain in Mexico were attributed to changes in longshore transport depending on change in wind regime, besides shift of the river mouth. On the other hand, Stapor (1975) concluded that oscillation of sea level was responsible for the intermittent growth history of beach plains.

In Japan, discontinuities in shoreline development of coastal plains have been reported from several plains: Yumigahama (Ichinose, 1962), Niigata (Sakaguchi, 1964; Niigata Ancient Dune Research Group, 1974), Akita (Mii, 1966) and Sarobetsu (Sakaguchi, 1958). Mii (1966) pointed out that the intermittent growth of sand ridges was attributed to sea-level fluctuations.

As described in the previous chapters, one or two major discontinuities in shoreline development of coastal plains have also been observed in the Holocene coastal plains. It is noted that those in each plain are nearly of the same age; the older one was formed ca. 5,000 to 4,000 years ago (the middle Jomon period), and the younger ca. 3,000 to 2,000 years ago (the latest Jomon to the Yayoi period). These synchronous occurrences in different regions suggest that oceanographic events common to those plains occurred in particular periods. The discussions of sea-level studies of the world make it possible to recognize two sea-level depressions (Moriwaki, 1978). Especially in Japan, they have been identified in various areas (Ota et al., in press, Fig. 18). Most of those ages are ca. 5,000 to 4,000 years ago (the middle Jomon period), and ca. 3,000 to 2,000 years ago (the latest Jomon to the Yayoi period), and the amplitudes of the minor sea-level fluctuations including these depressions nearly range from 3 to 5 meters. The ages of the two depressions in sea level correspond to those of the two discontinuities in shoreline development. It is thus concluded that oscillating Holocene sea level was probably responsible for those discontinuities. According to Stapor (1975), oscillation of sea level causes fluctuation in the volume of offshore sand supply to the shoreface, resulting in change in coastal erosion or deposition rate. This mechanism probably could be applied to the truncation of the older beach ridges by younger erosion on most coastal plains of Japan – i.e., the formation of discontinuities.

In the area around the Shinano and Agano rivers on the Niigata coastal plain, two discontinuities in shoreline development are expressed as wide alluvial plains, not as the truncation of older sand and dune ridges by younger erosion which is seen in the Kujukuri and Akita coastal plains. The formation of discontinuities of this type is attributed to rapid advance of the delta resulting from the drops in sea level during the period of transition from SDI to SDII, and from SDII to SDIII. Rapid advance of the delta probably reduced the effect of reworking of alluvial deposits supplied by the Shinano and Agano rivers by marine processes, so that no sand ridge should have formed around the mouths of these rivers during these periods.

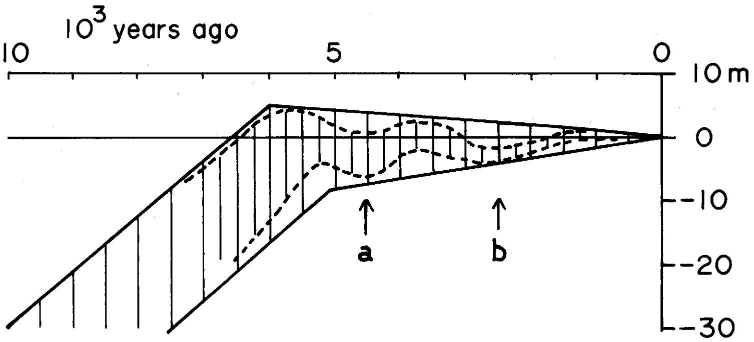


Fig. 18 Eustatic sea-level curve induced from numerous sea-level curves during the Holocene which have been obtained in various parts of the world. bold line: major change in sea-level; broken line: minor sea-level fluctuations; a: the middle Jomon depression; b: the Yayoi depression

Rate of shoreline development

The rapid rise in eustatic sea level prior to approximately 6,000 years ago should have caused a rapid transgression across the continental shelf (Fig. 18). When the eustatic rise slowed down near the present sea level around 6,000 years ago, the transgression was balanced by depositional regression in all the coastal plains discussed in this paper. Since this stage, the shoreline has prograded to the present coast.

Figure 19 and Table 1 show the change in the rate of progradation in several coastal plains of Japan and Mexico. In these figures, the following features common to these coastal plains can be seen. First, these rates are generally low at the beginning of the progradation, 6,000 to 5,000 or 4,000 years ago, though their magnitudes are different. In the Akita coastal plain, however, insufficient data on the ages of sand ridges do not allow the estimation of the rate of progradation in the early period. Second, after 5,000 or 4,000 years ago much rapid progradation occurred in most cases, though the ages of this rapid progradation and the magnitudes of the rates differ from place to place. Then the rate has gradually decreased with time since 3,000 or 2,000 years ago until the present. Further, retrogradation has occurred in the beach ridge area of the Yufutsu coastal plain since about 2,000 years ago.

The similarity in the changing rate of shoreline development suggests that some conditions common to those plains occurred during the Holocene. It is fairly hard to infer that local oceanographic and sedimentologic condition changed synchronously in different regions in which local conditions such as current direction and volume of sediment supply are different. The sea-level drops mentioned above possibly influenced the change in these rates. However, they do not seem to have acted as main factors, because the ages of the drops do not necessarily correspond to those of the changes in these rates. For example, the rates of progradation clearly decreased in all the coastal plains during the past 2,000 years when no significant sea-level rise have occurred.

It is most probable that the major change in sea level and the increase in the depositional area with progradation to open sea are both main factors responsible for the change in these

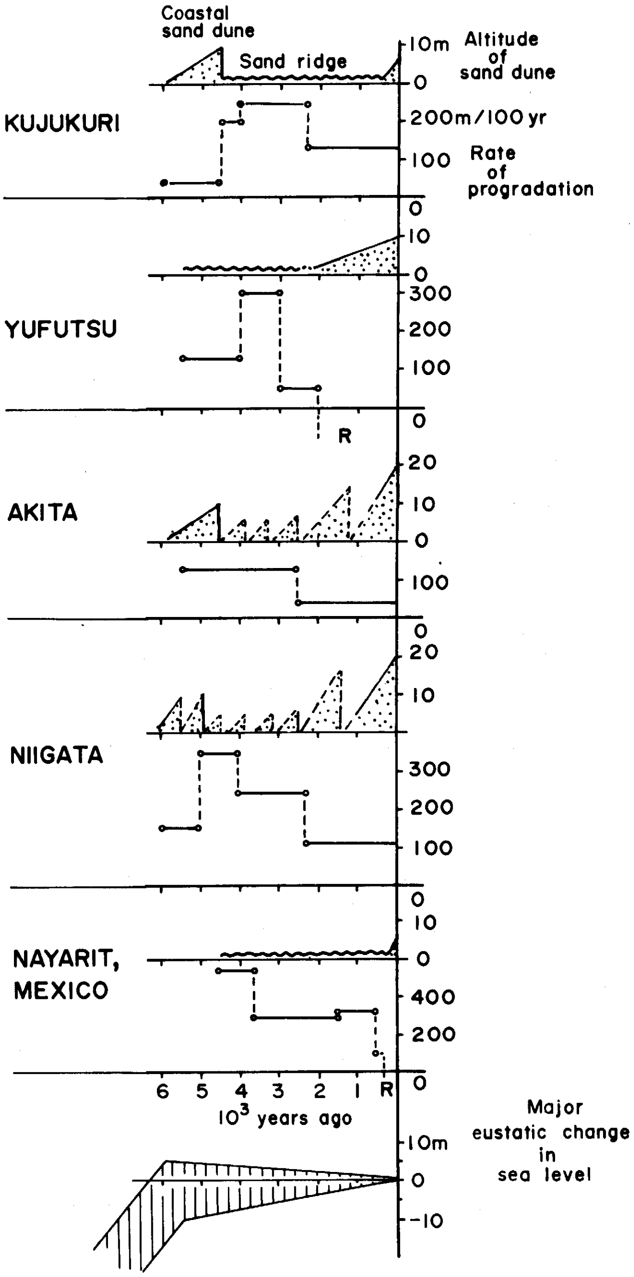


Fig. 19 Rate of progradation in the maximum width of sand ridge plain, and age of the formation of coastal sand dune and sand ridge. R: retrogradation

Table 1 Data on the rate of shoreline shanges of each plain

Region	Stage	Age (yr.B.P.)	Data on age estimation	Maximum distance from the present shoreline (km)	Time interval (yr.)	Maximum width of unit (km)	Rate of progradation (m/100 yr.)
KUJUKURI							
	1	6,000	S, C	8.3	1,500	0.4	30
	2	4,500	C	7.9	500	1.0	200
	3	4,000	A	6.9	1,700	4.2	250
	4	2,300	C	2.7	2,300	2.7	120
	5	0		0.0			
YUFUTSU							
	1	6,000	S				
	2	5,500	S, C	5.5	1,500	2.0	130
	3	4,000	C	3.5	1,000	3.0	300
	4	3,000	C	0.5	1,000	0.5	50
	5	2,000	T	0.0	1,700	–	R
	6	300	T	–	300	–	R
	7	0		0.0			
AKITA							
	1	6,000	S				
	2	5,500	A	3.5	2,000	2.5	130
	3	2,500	A	1.0	2,500	1.0	40
	4	0		0.0			
NIIGATA							
	1	6,000	A	12.0	1,000	2.0	200
	2	5,000	A	10.0	1,000	3.5	350
	3	4,000	A	6.5	1,700	4.0	240
	4	2,300	C	2.5	2,300	2.5	110
	5	0		0.0			

KUJUKURI: stage 1: culmination of the transgression; stage 2: landward of SI; stage 3: seaward of SII; stage 4: boundary between SII and SIII; stage 5: present shoreline;
YUFUTSU: stage 1: culmination of the transgression; stage 2: the most landward of sand ridges; stage 3: intermediate sand ridges; stage 4: near the present shoreline; stage 5: near the present shoreline; stage 6: seaward ofthe present shoreline; stage 7: present shoreline
AKITA: stage 1: culmination of the transgression; stage 2: the most landward of SDI; stage 3: seaward of SDII; stage 4: present shoreline;
NIIGATA: stage 1: culmination of the transgression; stage 2: the most landward of SDI; stage 3: the most landward of SDII; stage 4: landward of SDIII; stage 5: present shoreline
S: shell mound; C: radiocarbon date; A: archeological site; T: tephra; R: retrogradation

rates. The low rate of progradation at 6,000 to 5,000 years ago is interpreted as follows. Transgression resulting from rapid eustatic sea-level rise was replaced by depositional regression because sea level began to be stable nearly at the present level about 6,000 years ago in most of the plains facing on the ocean. Ikeda (1964) pointed out that an equilibrium state of shoreline development occurred in the transition period from transgression to regression, because the transgression was balanced by regression due to deposition. This equilibrium state probably resulted in the stagnation of shoreline or the low rate of progradation in this period.

However, the decrease in the rate of progradation with time during the past several thousand years is not well explained by this idea, because sea level has been nearly stable at the present level during this period. A satisfactory interpretation can be worked out from the following idea, basically proposed by Curray et al. (1967). As progradation proceeds, the shoreline builds into deeper water and outer ocean. Rather than more sand being required to form each ridge, the time required for making a ridge increases. Thus, the decrease in the rate of progradation with time is considered to have been caused by the increase in horizontal and vertical depositional area required per ridge, which is associated with progradation common to all the plains; i.e., an increase in these depositional areas with time occurred in all the plains, although the magnitude of this increase, as evidenced by nearshore profile and embayment configuration differed from place to place. It is likely that these differences, in addition to those in volume of sand supply from place to place, are probably the main factors which produced regional differences in the magnitudes of the rates of progradation and in the ages of the changing rates of shoreline development mentioned above.

The changing rate of progradation during the past 6,000 years shows that the modern shoreline has reached or is reaching the equilibrium state between sand supply and shoreline development in all the plains discussed in this paper. Accordingly, it can be stated that the modern shoreline of the coastal plain easily changes in association with environmental changes responsible for shoreline development, in comparison with past shoreline in the Holocene, which prograded rather rapidly.

Relation between shoreline development and the formation of coastal sand dune

From Fig. 20, the following characteristics concerning the distribution of sand dunes are recognized in the Ishikari lowland of Hokkaido, the Nayarit coastal plain of Mexico, and the four coastal plains discussed above. First, sand dunes are very well developed along the present shoreline in these coastal plains. This sand dune belt is called "the seaward high sand dune belt" in this paper. Second, sand dunes are also well developed in the most landward sand ridges in the coastal plains, except for the Yufutsu coastal plain and the Nayarit coastal plain of Mexico. This is called "the landward high sand dune belt". Third, relatively small sand dunes are observed in the area between these two belts. This area is called "the intermediate low sand dune belt".

The two high sand dune belts are of the same ages in the coastal plains presented in this paper, as a first approximation. The landward one was formed about 6,000 to 5,000 years ago; the seaward one, during the past 2,500 years. More age data for the seaward one than for the landward one make it possible to estimate more precise ages of the formation, so that the ages of the formation differ slightly from place to place: during the recent 200 years in Kujukuri, the recent 300 years in the eastern part of Yufutsu, around 2,000 years ago in the western part of Yufutsu, and during the last about 2,500 years in Akita and Niigata.

Factors concerning the formation of Holocene coastal sand dunes have been hitherto given: various aspects of climatic change, mainly wind force change and sea-level fluctuations. Thom (1978) described how increased storminess with colder climate in the Little Ice Age about 1,000 years ago were responsible for the episodic formation of the coastal sand dunes in South Australia and emphasized climatic change for the formation of sand dune. Brothers (1954) and Schofield (1975) pointed out that Holocene sand dunes had been formed during lower sea-level periods in the Auckland West Coast and South Kaipara Barrier of New Zealand. On the other hand, Cooper (1958) thought that sea-level rise was responsible for dune formation on the Oregon and Washington Coast. Stapor (1975) claimed that

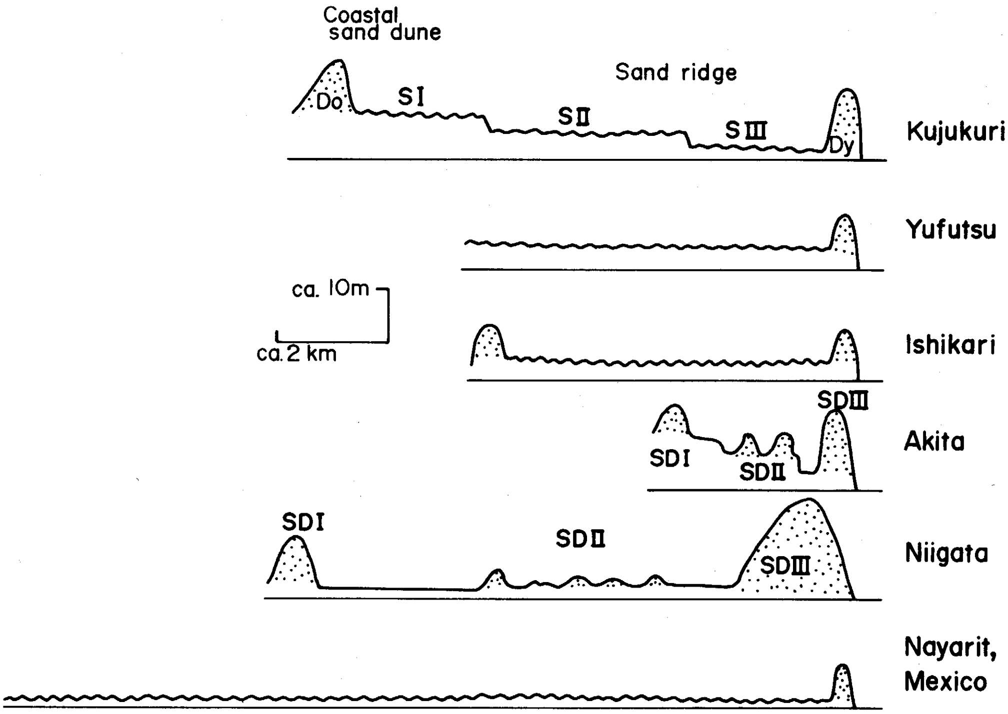


Fig. 20 Generalized distribution of sand ridge and sand dune in several coastal plains

the high coastal sand dunes reflected a marked decrease in the volume and rate of sand delivered for shoreface deposition, while an abundant supply of sand resulted in the growth of beach plains. In Japan, Iseki (1975) and Fuji (1975) pointed out that the stabilization of Holocene coastal sand dunes was attributed to regression due to sea-level drops. On the other hand, Urushibara et al. (1973) described how climatic deterioration resulted in the mobilization of eolian sand on the basis of the correlation of sand dunes of different regions by humic layers.

However, the ages of sand dunes in the Kujukuri, Niigata and Akita coastal plains do not necessarily correspond to those of the discontinuities of shoreline development formed by minor sea-level fluctuations, indicating that these fluctuations were hardly related to the sand dune formation in the coastal plains presented in this paper. Moreover, the following facts also lead to the conclusion that sea-level fluctuations and climatic change which should have synchronously affected these plains were not responsible for the formation of the sand dunes on these plains: 1) The ages of the seaward high sand dune belt are not necessarily identical from place to place. 2) In the Kujukuri coastal plain, the high sand dune of Do in the northern part were formed during the period of formation of the sand ridges of SI without conspicuous sand dunes in the northern part. Referring to Fig. 19, it is most probable from the chronological point of view that the formation of sand dunes is related to the rate of shoreline change. That is, the formation of high sand dunes corresponds to a stable stage in shoreline development or to retrogradation of shoreline, as is typical of the eastern part of the Yufutsu coastal plain. The intermediate low sand dune belt was formed during the period of high rate of progradation. Thus, the presence and magnitude of sand dunes seems to be an indicator of the rate of shoreline change in coastal plains.

The chronological study of sand dunes mentioned in the previous chapter shows that the rate of sand supply by wind (mainly depending on wind force) and shoreline changes are the main factors responsible for the episodic formation of sand dunes in the coastal plains; furthermore, the volume of sand dunes in the coastal plains, shown in this paper is in direct proportion to the rate of sand supply by wind from the beach and in inverse proportion to the rate of shoreline progradation. This relation is given by the equation

$$Ev \approx a \cdot Wr/Sr$$

where Ev is the volume of eolian sand deposited in a beach, Wr the rate of sand supply by wind, Sr the rate of shoreline progradation and a the coefficient.

Wr is significant for determining regional differences in magnitude of sand dunes, but not for determining the difference in magnitude among various ages during the Holocene in a coastal plain. This is inferred from the fact that though the magnitudes of sand dunes along the coast of the Japan Sea and that along the Pacific coast are quite different, as mentioned earlier, the sequence of dune development, shown by the distribution of the landward high sand dune belt, the intermediate low sand dune belt and the seaward high sand dune belt, is quite similar. In the Niigata and Akita coastal plains, Wr was so high that coastal sand dunes were formed through the entire Holocene. In the Yufutsu and Kujukuri coastal plain, however, Wr was relatively low; hence sand ridges without sand dunes have been built in the course of shoreline development.

Therefore, the latter plains seem to be suitable for determining the rate of shoreline development at the time of the initiation of the formation of sand dunes. In the Yufutsu coastal plain, progradation rates of 300 and 130 meters per 100 years resulted in no formation of sand dunes, but that of 50 meters did. Therefore, the rate of progradation at the time of the initiation of the formation of sand dunes ranged from 130 to 50 meters, and was probably a little more than 50 meters per 100 years. In the Nayarit coastal plain, the rate was less than 100 meters per 100 years according to the data of Curray et al. (1967). The absence of the landward high sand dune belt in the Yufutsu and the Nayarit should be attributed to the fact that the proportion of Wr to Sr was low – that is, the time interval when transgression associated with sea-level rise was balanced by depositional regression was short, around 6,000 years ago in Yufutsu and 4,000 years ago in Nayarit.

7. Conclusion

In this paper, geomorphic development of the four major Holocene coastal plains of Japan – the Kujukuri, Yufutsu, Akita and Niigata coastal plains – has been discussed, with special emphasis on shoreline and coastal sand dune development during the past 6,000 years. As a result, the following conclusions can be obtained:

1) Two major discontinuities in shoreline development are generally recognized in these coastal plains during the past ca. 6,000 years. One occurred about 5,000 to 4,000 years ago; the other, 3,000 to 2,000 years ago. Their synchronous occurrences in different regions

suggest that oceanographic events common to those plains occurred in these periods. Judging from the fact that the ages of these occurrences correspond to those of the two depressions of sea level, it is concluded that oscillation of sea level was responsible for these discontinuities. Oscillation of sea level probably caused the fluctuations in the volume of offshore sand supply to the shoreface, causing changes in coastal erosion or deposition.

In the Niigata coastal plain, discontinuities in shoreline development occurred as a rapid advance of the delta resulting from sea-level drops. In the Yufutsu coastal plain, the discontinuity of the middle Jomon period is not conspicuously recognizable, probably because the rapid progradation of beach ridges decreased the influence of the sea-level drop of this period, or because the magnitude of the relative sea-level drop was not so high.

2) The rates of progradation on the four plains were generally low around 6,000 to 5,000 or 4,000 years ago, though their magnitudes differed from place to place. These low rates of progradation are probably due to the fact that the shoreline attained equilibrium at the time of the transgressive culmination.

The high rates of progradation occurred immediately after these low rates, i.e., 5,000 or 4,000 years ago; then the rates have gradually decreased with time since 3,000 or 2,000 years ago. The gradual decrease in the rates of progradation common to all the plains is considered to have been caused by the gradual increase in the water depth and the horizontal place where deposition extends. Rather than more sand being required to form each ridge due to this increase, the time required for making a ridge increased.

The magnitudes of rates of progradation and the ages in which the rates of shoreline development changed differ from place to place. These differences are probably due to differences in the magnitudes of the increase in depositional area with time – i.e. the nearshore profile and configuration of embayment; and the volumes of sand supply differed from place to place.

The modern shorelines of the coastal plains discussed in this paper have attained or are attaining equilibrium in terms of shoreline development on the order of 10^3 years. Therefore, the modern shoreline seems to respond more sensitively to slight changes in the environment than the past ones. For example, recent erosion conspicuously observed on the Japanese coasts seems to be due to a decrease in sediment supply to rivers owing to construction of numerous dams in mountainous area.

3) The coastal plains discussed in this paper are generally divided into three belts on the basis of the distribution and magnitude of coastal sand dunes: a landward high sand dune belt, an intermediate low sand dune belt and a seaward high sand dune belt.

The landward high sand dune belt was generally formed about 6,000 to 4,500 years ago; the seaward high sand dune belt, since about 2,500 years ago. To be more precise, the ages in which the formation of the latter belt began differ slightly from place to place.

The development of these sand dunes commonly recognized in different plains is closely related to the rate of shoreline development. The two high sand dune belts were formed during low progradation; the intermediate low sand dune belt, during rapid progradation. The regional difference in the magnitude of sand dunes is mainly attributed to difference in wind force.

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(* in Japanese, ** in Japanese with English abstract, *** in Japanese with French abstract)