Developmental Process of Alluvial Coastal Plain related to the Holocene Sea-level Change

著者	MATSUMOTO Hideaki
雑誌名	The science reports of the Tohoku University. 7th series, Geography
巻	31
号	2
ページ	155-171
発行年	1981-12
URL	http://hdl.handle.net/10097/45110

Developmental Process of Alluvial Coastal Plain related to the Holocene Sea-level Change

Hideaki MATSUMOTO

1 Introduction

On the alluvial coastal plains, their structure and the Holocene sea-level change have been studied in many former reports. The relationship between the developmental process of coastal plain and the past sea-level change was insufficient to be clarified, and there still remains a wide unexplored field.

In this report, dealing with Sendai, Ishinomaki and Osaki coastal plains in Miyagi Prefecture, northeast of Honshu Island, the structure and sedimentary process of alluvium and the Holocene sea-level change was studied from boringlog analysis, field observation and radiometric datings. Sendai, Ishinomaki and Osaki plains are larger than average alluvial plains facing Pacific Ocean in Japan. Based on the results, the author tried to explain the developmental process of alluvial coastal plains in relation to the Holocene sea-level change.

Several stratigraphic studies have been made on these plains. At first Okutsu (1953) divided the alluvium into some formations based on a lot of drill-holes. Then H. Hase (1965) restored the form of the Quaternary deposits basis below the Sendai Coastal Plain and clarified the distribution of buried terraces and valleys. K. Hase (1967) subdivided the alluvial subsurface deposits into Lowermost sand and gravel, Lower clay, Lower gravel, Middle clay, Upper sand and Upper sand-clay layers, and he presented the distribution of marine area caused by the *Jomonian Transgression*, tracing the marine facies. However the detail relationship between the developmental process, especially the transgressional and regressional process, of coastal plains and the Holocene sea-level change has not been clarified.

2 Stratigraphic descriptions and sedimentary process of Alluvium

2.1. Sendai Coastal Plain

Sendai Coastal Plain is located south of this area (Fig. 1) and is about 50 km long from north to south, 10~15 km wide from east to west. The Nanakita, Natori and Abukuma rivers flow on this plain. Characteristics of these rivers, *i.e.* channel length, drinage area and discharge rate were measured as Table 1. The

THE SCIENCE REPORTS OF TÔHOKU UNIVERSITY, 7TH SERIES (GEOGRAPHY)
Vol. 31 No. 2, December 1981

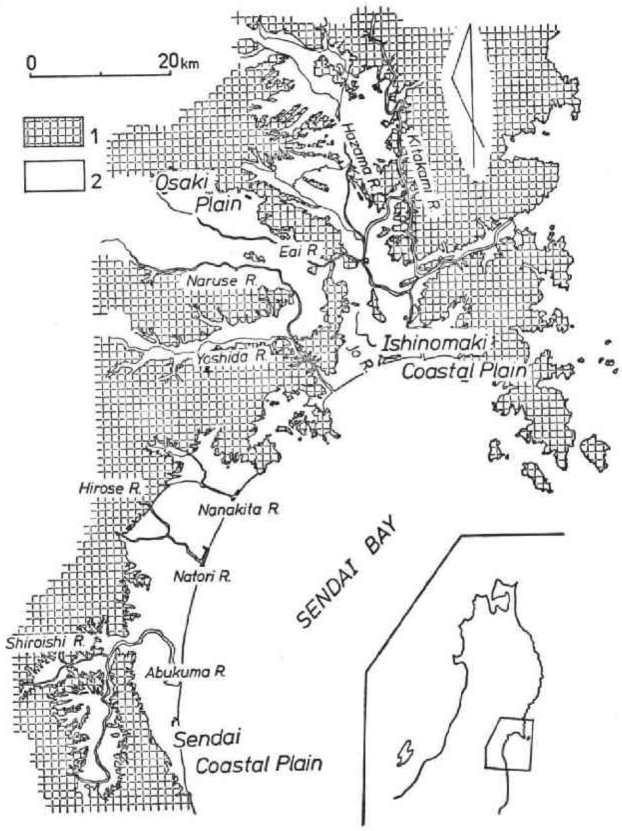

Fig. 1 Index map of study area
1: hilly land 2: alluvial low land

Table 1 Characteristics of rivers and the altitude of Turning Point

Characteristics / River	channel length (km)	drinage area (km^2)	discharge rate (m^3/s)	altitude of Turning Point (a.s.l. in meter)
Nanakita R.	45	208	—	−5
Natori and Hirose r.	100	939	22	−7
Abukuma R.	239	5, 400	150	−10

Abukuma River is the largest one in scale and the Nanakita is the smallest on this plain. Natural levees along the rivers and several beach ridge ranges along the shoreline are recognized on land classification map (Fig. 2). A confluenced fan is formed to the west of the junction of the Natori and the Hirose, and its graident is

Fig. 2 Sendai Coastal plain landform classification map
1: beach ridge range 2: natural levee 3: back marsh 4: abandoned channel

measured 6/1,000. The most part of this plain is below 5 m above the sea level and the inland part stands 10∼15 m.

The sequence of alluvium along the shoreline is shown in A-A′ section (Figs. 3, 4). Bed rock beneath this plain consists of Pliocene tuff, andesite and mudstone. There are three buried valleys below alluvial deposits 60∼80 m in thickness corresponding to each river. Thick sand and gravel bed at the lower part of alluvium is separated by fluvial silt and clay layer. The lower gravel bed consists of cobble gravels of 10∼30 cm in diameter and its deposition is aged before about 15,800 yr BP by radiocarbon dating, so this gravel bed is thought as Basal Gravel (Iseki, 1975). The upper gravel bed consists of pebble gravels and coarse sand and its depositional surface indicates 6/1,000 in gradient and continues to the fan deposit layer which is recognized on the land surface. The author named these three layers BG, La and Lb (see Fig. 4).

A clay facies recognized at the depth of −20∼−30 m in the north area, −30∼−50

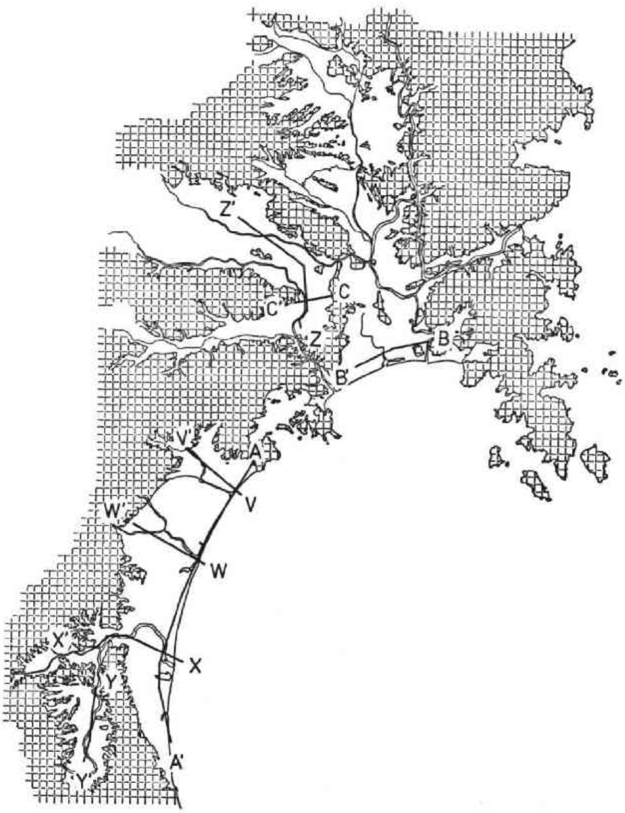

Fig. 3 Location map for cross-sections

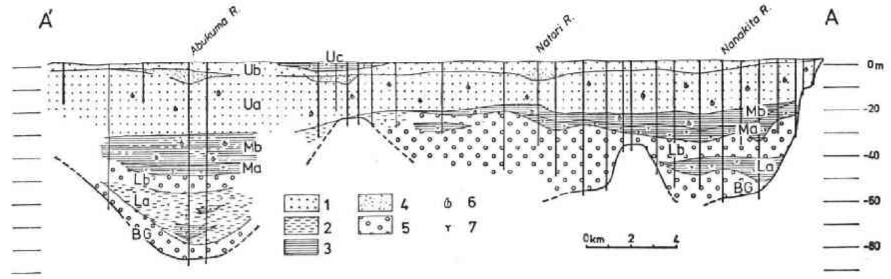

Fig. 4 Cross section A-A′ (Sendai coastal plain)
1: fine medium sand 2: silt 3: clay 4: fluvial sand 5: sand and gravel 6: shell 7: peat

m in the south area. This facies is subdivided into two layers, because lower one includes a lot of plant debris and upper one includes plenty of shallow marine and brackish shells, such as *Crassostrea gigas* and so on. The lower one is terrestrial and the upper one is marine in origin. The author called these layers Ma and Mb.

Just above these layers, there is sand facies, which is divided into two layers, too. The lower sand includes shallow marine shells and abraded shell fragments, the upper one includes no shell. These sand layers were named Ua and Ub respectively. Sand samples of Ub indicate good sorting, and suggest aeolian in origin. Uc layer at the uppermost of the alluvium consists of silt and clay sediment and includes a lot of plant fragments and sometimes includes fluvial sandy deposits. The surface of Uc is the present back marsh. Therefore, alluvial sediment of Snedai Coastal Plain is subdivided into eight layers such as BG, La, Lb, Ma, Mb, Ua, Ub and Uc.

The cross sections at right angles to the shoreline along three rivers are shown in Fig. 5. The cross section V-V′ (Fig. 5-A) shows the structure along the Nanakita River. The depositional depths of BG and Lb decrease inlandward. And La is disappeared at inner area. The thickness of Ma increases landward and Uc occurs directly on Ma. Sedimental structure of Mb and Ua, that are marine facies, forms a wedge shape, in other words, marine sediments occur at the depth of -30∼0 m just below the present shoreline, but the thickness becomes thinner landward. The innermost point is about 8 km distant from the present shoreline and its altitude is 5 m below the present sea level.

W-W′ (Fig. 5-B) is the cross section along the Natori River. La is absent in this area, and the marine sediments (Mb and Ua) occur in wedge shape, too. The innermost point of the wedge is located about 5 km from the shoreline and its altitude is 7 m below the present sea level.

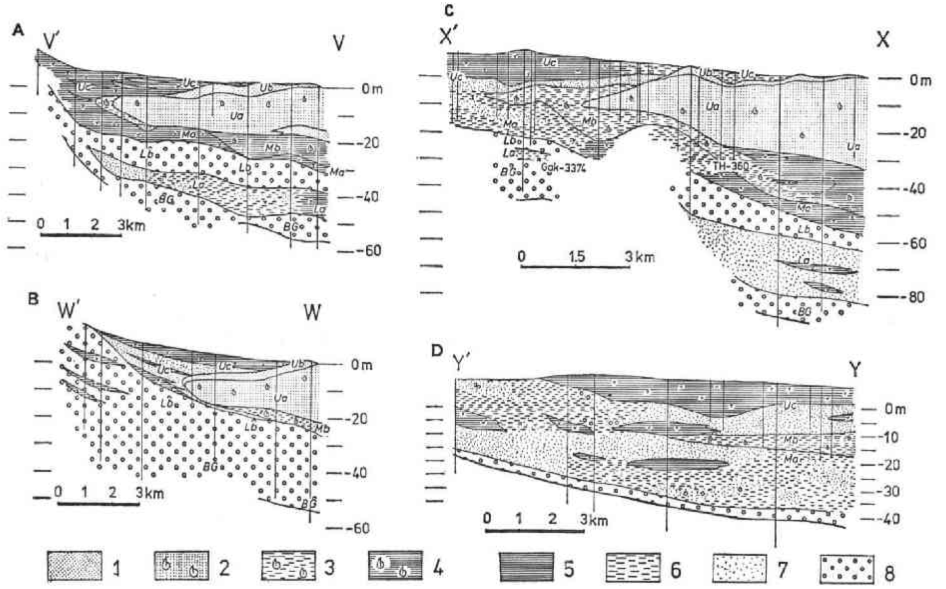

Fig. 5 Cross sections along the Nanakita, Natori and Abukuma rivers (Sendai Coastal Plain) 1: aeolian sand 2: marine sand 3: marine silt 4: marine clay 5: fluvial clay 6: fluival silt 7: fluvial sand 8: sand and gravel

At the cross section along the Abukuma River (Fig. 5-C, D), marine sediment reached about 20 km from the river mouth and the altitude of its innermost point is 10 m below the present sea level. Thick terrestrial sediment (Uc) is deposited above the marine sequence at the landward area (Fig. 5-D).

From these stratigraphic conditions, the depositional environments are considered as follows. BG, the Basal Gravel, was deposited at the Last Ice Age. Lb is considered as a fan deposit and it was deposited during 15,800 yr BP$\sim$9,280 yr BP. La consists of fine grained sediment comparing with Lb and BG, and its depositional age is about 15,800 yr BP. Then the depositional situation of La is estimated at the transgressive period following the stage of BG. Ma is considered marsh deposit around lagoonal environment and its age is about 9,280 yr BP at the Abukuma buried valley. And Mb is back barrier sediment because this layer includes a lot of brackish shells. Ua is barrier and shallow marine sand. Ub is considered as dune sand behind the shoreline because the result of grain size analysis indicates aeolian sand (H. Matsumoto 1980). And Uc layer forms present back marsh sediment. Ma, Ub and Uc are terrestrial, Mb and Ua are marine in origin.

These layers are considered to have been deposited in the following background, as the example of the Nanakita region (see Fig. 5-A). First appearance of past sea area in this region is evidenced in the lowest and closest part of Mb to the shore, about 30 m below the present sea level. According to further transgression, depositional site of each layer has been sifted landward, preserving its horizontal allotment.

When the sea-level reached about -20 m, offshore barrier sequence migrated landward below the location of present shoreline. When the sea-level rose about 5 m below the present level, the landward transgression ceased and the shoreline began to retreat against the continuing rise of sea-level. The turning point of transgression and progradation is 8 km distant from the present shoreline and its level is about 5 m below the present level.

2.2. Ishinomaki Coastal Plain

Ishinomaki Coastal Plain, about 50 km long from north to south and 10 km wide from east to west, is located north of the area (Fig. 1) and the Kitakami, Hazama, Eai and Jo rivers flow on this plain. The western margin of this plain is bounded by hill land, about 200~300 m in height, and the eastern margin is bounded by mountain land above 500 m in height. Natural levees and back marshes are recognized and several beach ridge ranges develop along the shoreline (Fig. 6). This plain is characterized of low altitude and flat form, that is, it is only 5 m above sea-level at the location about 40 km far from the shoreline.

Beneath this plain, above 80 m thick alluvium is recognized just below the present shoreline (Fig. 7). Two buried valley systems are recognized, the depth of valley floor is unknown because the drill-holes did not achieve bed rock. And the lower sand and gravel layer could not be divided in this area. Two silt-clay facies occur in the depth of -10~-45 m, lower one includes a lot of plant debris and upper one includes shallow marine and brackish shells, such as *Macoma tokyoenis*, *Crassostrea gigas*. These layers are correlated to the Ma and Mb in Sendai Coastal Plain. Upper sand facies is recognized at the western area, and its lower part includes shallow marine shells and shell fragments, while its upper part does not include any shells but is in good sorting. The lower part is correlated to Ua and the Upper part is to Ub. And the sand and silt facies at the uppermost of the alluvium is correlated to Uc. Uc is thick and mostly includes fluvial sand and gravels around the Kitakami River. At this section, it is considered that the sea area transgressed when the sea-level reached -30 m and regressed at the depth of -3 m.

2.3. Osaki Plain

Osaki Plain extends about 40 km from east to west like an inland basin. The Eai, Naruse and Yoshida rivers flow on this plain. This plain is connected

Fig. 6 Inshinomaki Coastal Plain landform classification map
1: beach ridge range 2: natural levee 3: back marsh 4: abandoned channel

through only two narrow valleys to Ishinomaki Plain. Alluvial fans formed by the Eai and Naruse rivers are recognized in the western part, where the altitude is measured 10∼25 m. Natural levees are distributed clearly in the eastern part, where the altitude is less than 10 m above the sea level (Fig. 8).

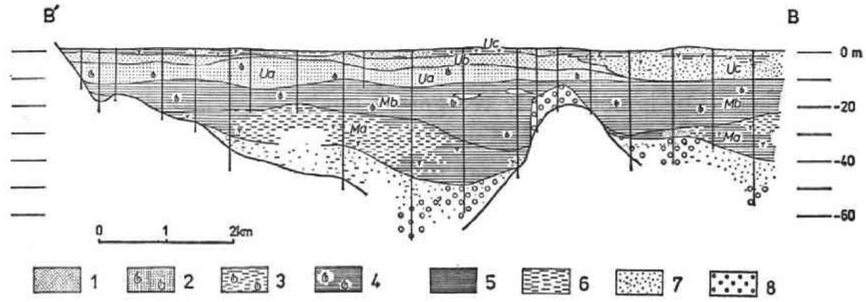

Fig. 7 Cross section B-B' (Ishinomaki Coastal Plain)
1: aeolian sand 2: marine sand 3: marine silt 4: marine clay 5: fluvial clay
6: fluvial silt 7: fluvial sand 8: sand and gravel

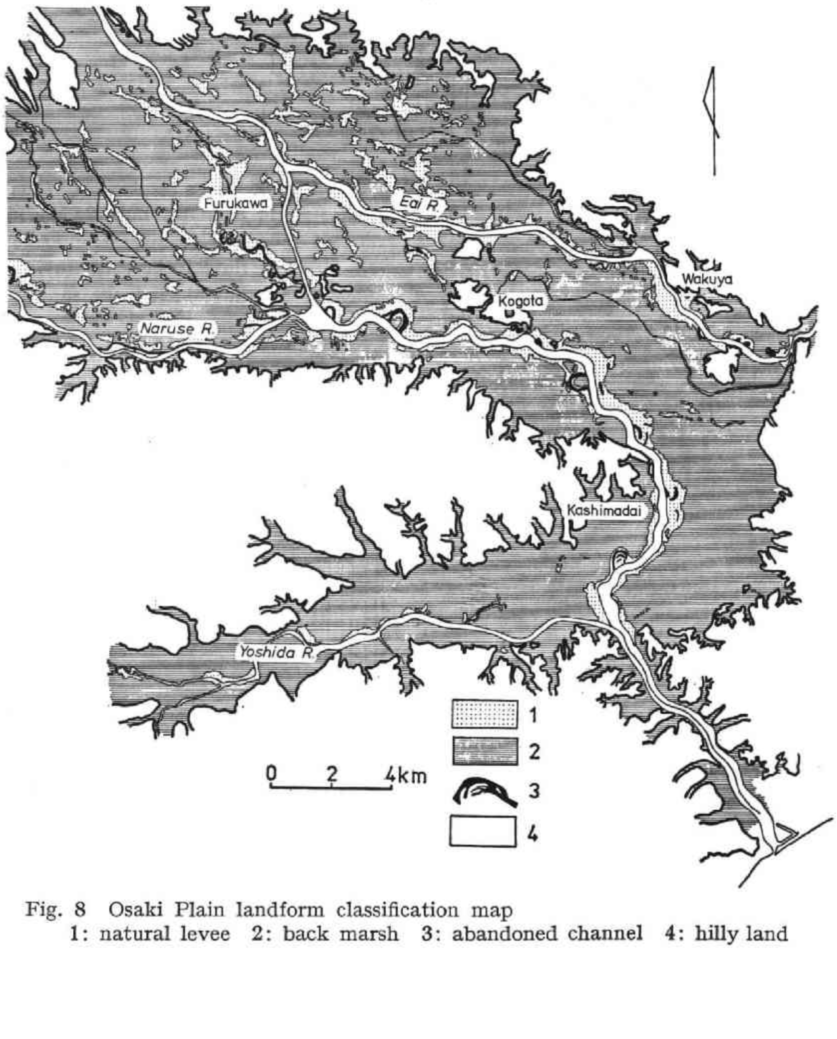

Fig. 8 Osaki Plain landform classification map
1: natural levee 2: back marsh 3: abandoned channel 4: hilly land

Beneath this plain, about 40 m thick alluvium is deposited (Fig. 9). Basal Gravel is recognized just above the bed rock. Thick sand deposit about 15 m in thickness covers BG, and is correlated to La in Sendai Plain. Sand and gravel bed in Sendai Plain (Lb) is not clearly recognized but may be included in La in this plain. Clay facies at the depth of -5～-25 m is divided into two layers. The lower includes a lot of plant debris and peat moss, and upper includes shallow marine shells, such as *Crassostrea gigas* and *Cyslina sinensis* and so on. So these layer are correlated to Ma and Mb respectively in Sendai Plain. And the uppermost facies consisting of peaty clay～sandy silt is correlated to Uc. The facies corresponding with Ua and Ub are absent, because this plain was embayed and might be saved from wave action at the shoreline.

Fig. 10 is the alluvial section along Z-Z′. Marine sediment (Mb) appears like a wedge, as the same in stratigraphy as that of Sendai Plain. The innermost end

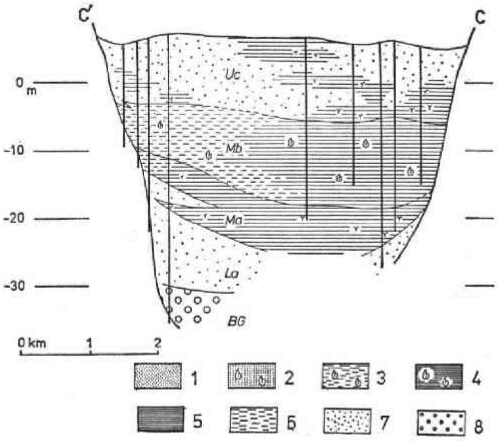

Fig. 9 Cross section C-C′ (Osaki Plain)
1: aeolian sand 2: marine sand
3: marine silt 4: marine clay
5: fluvial clay 6: fluvial silt
7: fluvial sand 8: sand and gravel

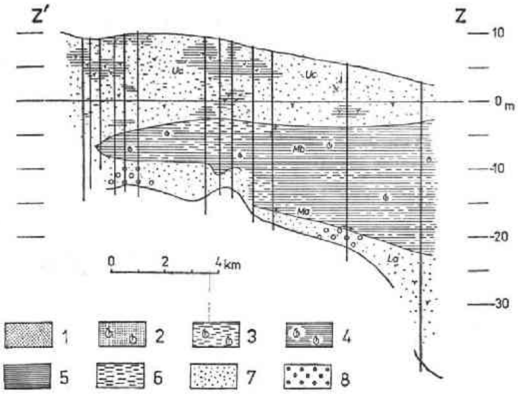

Fig. 10 Cross section Z-Z′ (Osaki Plain)
1: aeolian sand 2: marine sand
3: marine silt 4: marine clay
5: fluvial clay 6: fluvial silt
7: fluvial sand 8: sand and gravel

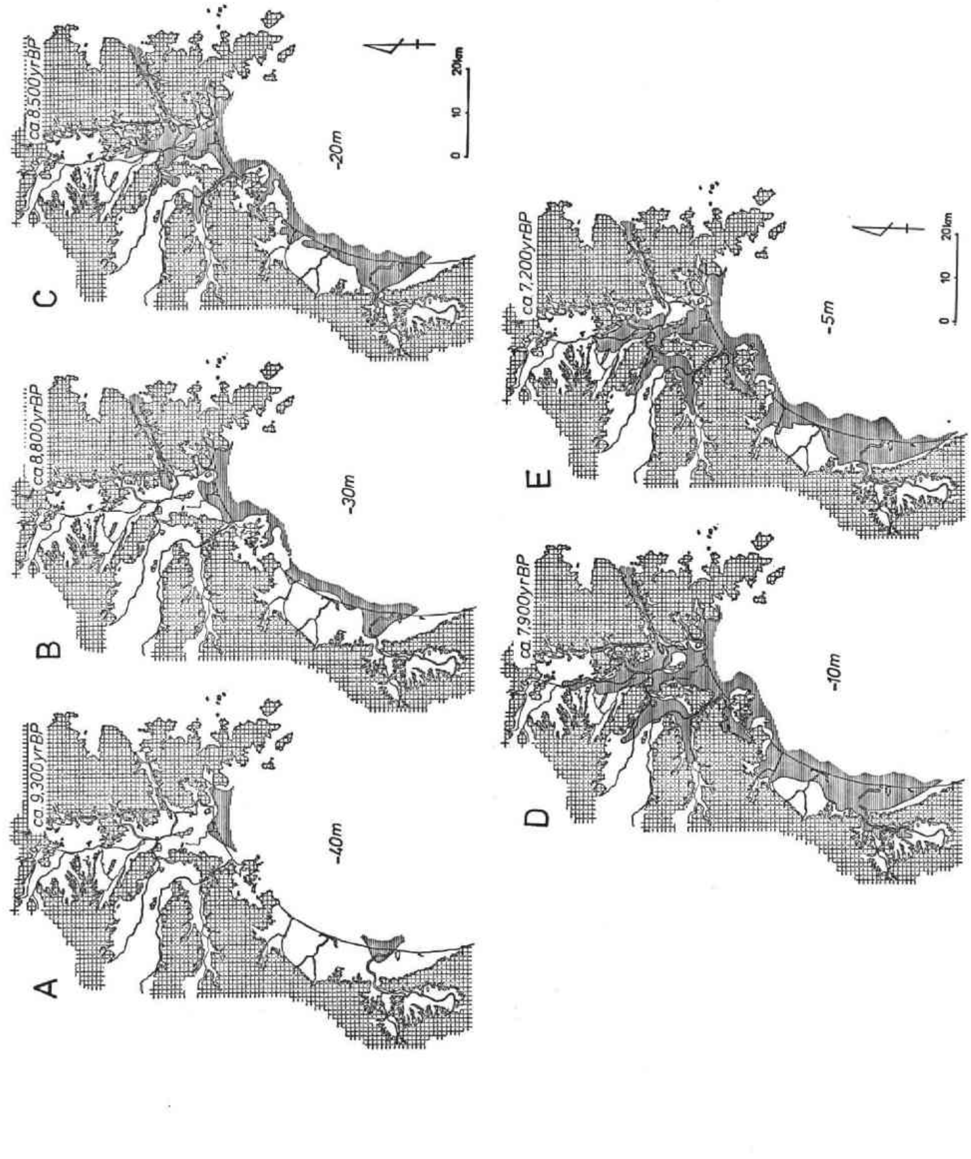

Fig. 11 Shoreline change for the last 10,000 years.

of the marine sequence is about –7 m in altitude and its distance is about 25 km from the river mouth.

3 Shoreline change for the last 10,000 years

It is considered from the above mentioned structure and process of sedimentation that the boundary between terrestrial (Ma, Ub, Uc) and marine (Mb, Ua) sediments means the locus of shoreline change. The author tried to restore the shoreline change all over the plains faced Sendai Bay, by the analysis of boringlogs.

Fig. 11-A indicates the shoreline when the sea-level reached –40 m below the

Table 2 Data for

Locality	Alitutde (m)	Sample
Sendai C.	+1.0	peat
Kozuru	−0.5	peat
	−1.3	peat
	−1.6	wood
	−2.0	wood
	−2.3	wood
	−3.8	wood
	−6.0	shell (*Macoma incongrua*)
	−7.0	shell (*Crassostrea gigas*)
	−8.0	shell (*Crassostrea gigas*)
	−8.0	shell (*Batillaria zonalis*)
	+0.5	wood
Iwanuma C.	+1.2	wood
	−0.2	peaty clay
	−0.7	peat
	−0.7	peat
	−1.0	peat
	−4.5	shell frag. (*Crassostrea gigas*)
	−5.0	wood
	−6.3	shell frag. (*Spisula sachalinensis*)
	−7.0	shell frag. (*Spisula sachalinensis*)
	−9.0	shell (*Meretrix lusoria*)
Tagajo C.	−1.0	wood
	−2.0	shell (*Crassostrea gigas*)
	−2.7	shell (*Crassostrea gigas*)
Natori C.	+0.9	shell (*Meretrix lusoria*)
	−0.2	peat
Watari T.	−37.0	peaty clay
Shichigahawa T.	−2.5	shell frag.
	−4.5	shell frag.
Shibata T.	−26.5	peak

present level. The age of this period, ca 9,300 yr BP is obtained on the sea-level curve, which will be mentioned later. Fig. 11-B is the shoreline at the period when the sea-level reached –30 m. The marine area transgressed landward according to the rise of sea-level. The phase when tne sea-level reached –20 m is shown in Fig. 11-C. At this period, transgression came into Osaki Plain along the valleys of the Naruse and the Eai. Fig. 11-D indicates the phase when the sea-level reached –10 m. The sea area invaded inlandward, especially in the valley of the Kitakami River, about 30 km from the present shoreline. The transgression reached along the Abukuma River 20 km from the present river mouth. When

radiocarbon ages

Depositional environment	^{14}C Age (yr BP)	Code NO	References
back marsh	1, 775±110	TH-070	Omoto & Ouch (1978)
	2, 775±130	TH-071	
	2, 965±125	TH-072	
	3, 500±130	TH-073	
	3, 790±145	TH-055	
	4, 315±150	TH-080	
esturine	5, 910±170	TH-067	
	6, 775±190	TH-068	
	6, 940±190	TH-069	
	6, 850±190	TH-056	
	7, 515±200	TH-077	
back marsh	3, 105±130	TH-147	
back marsh	Modern	TH-271	this article
	4, 400±120	TH-358	
	1, 490± 90	TH-225	
	1, 790±100	TH-224	
	2, 960±110	TH-353	
shallow-marine	2, 630±100	TH-351	
	3, 070±110	TH-350	
	3, 580±110	TH-352	
shoreface	1, 650± 90	TH-454	
	3, 750±110	TH-270	
back marsh	3, 380±140	TH-355	
shallow marine	3, 210±110	TH-359	
	3, 880±120	TH-356	
beach	4, 470±120	TH-373	
back marsh	3, 900±120	TH-343	
back marsh	9, 280±190	TH-360	
esturine	2, 160±110	TH-367	
	3, 700±120	TH-376	
back marsh	15, 800±350	Gak-3374	Wako (1972)

the sea-level reached 5 m below the present level (Fig. 11-E), regression has already started, especially around the mouths of major rivers where considerable amounts of sediment has been supplied. For instance, at the area around the Abukuma River, shoreline progressed about 10 km seaward since the –10 m period. Around the Kitakami River mouth, the sea retreated about 20 km southward during the same period. In the alluvial plains faced Sendai Bay, the following tendency was recognized. Transgression due to the rise of sea-level, continued up to the period of about –10 m sea-level. Since then, the coastal plains began to prograde seaward against the rise of sea-level. However in detail, the area with small amount of sediment load, such as far from the river channel, transgression has been continuing in accordance with the sea-level rise.

4 Holocene sea-level change around the Sendai Bay

Omoto and Ouchi (1978) submitted the data about Holocene sea-level change around Sendai Plain based on the radiocarbon dating of many samples collected at a pit. As the pit is located inland area about 7 km from the shoreline, it is difficult to discuss the sea-level change and the developmental process all over the coastal plain around Sendai Bay. Then the author collected many carbon dating samples from Sendai and Ishinomaki coastal plains (Table 2), in order to draw the sea-level curve (Fig. 12).

Holocene sea-level change may be divided into the following three stages.

(1) Rapid rise of sea-level up to 8,000 years BP, when it reached about –10 m.

(2) The sea-level rise gradually became slower between 8,000 years BP to 5,000 years BP, when it reached about the present level.

(3) Rather stable sea-level with slight fluctuations, since 5,000 years BP up to the present.

5 Discussion

Ikeda (1964) mentioned that the location of shoreline is determined in the relation between the volume of supplied sediment load and the rate of sea-level change. That is, when the speed of sea-level rise is relatively superior to the sediment load, the shoreline moves landward, and when the speed of sea-level rise is relatively inferior to the sediment load, the shoreline moves seaward.

Therefore it is considered that, the Turning Point which means the period of the change from transgression to regression, are expected depending on the balance between the rate of sea-level rise and the rate of sedimentation. In the first stage, during the period of rapid sea-level rise, the rate of sea-level rise

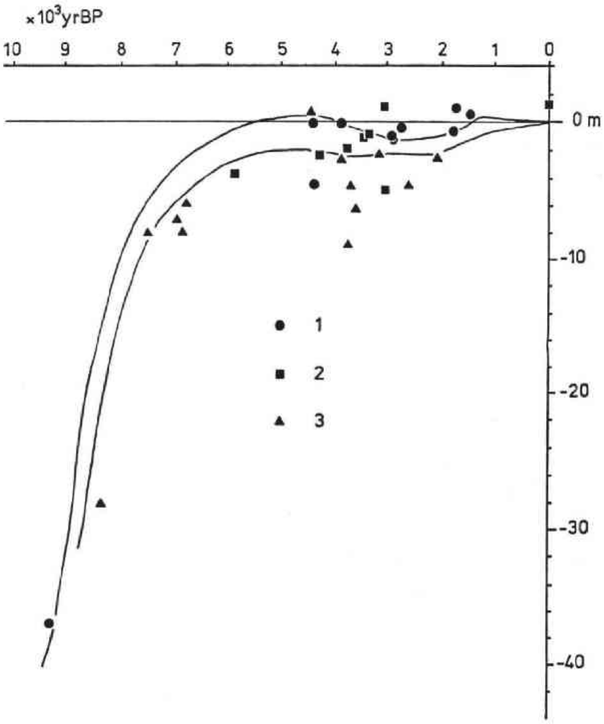

Fig. 12 Relative sea-level change around Sendai Bay
1: peat sample 2: wood sample 3: shell sample Sea-level change is estimated between two lines.

exceeded the rate of sediment load. In the second stage, the rate of sea-level rise gradually became smaller, and finally the rate of sedimentation exceeded the rate of sea-level rise. And the area supplied with large amount of sediment load, the Turning could occur even earlier period. On the contrary, the area supplied with small amount of sediment load, the Turning usually occured later about 5,000 years BP when the sea-level change became almost stable.

This way of thinking will be applied to the Sendai coastal plain. In the area along the Nanakita, Natori and Abukuma rivers, the Turning Points occured at -5 m, -7 m, -10 m (see Table-1) and their ages were estimsted about 7,200 yr BP, 7,500 yr BP, 7,900 yr BP respectively from the sea-level curve. It is considered that the difference of the depth and age of the Turning Points among the rivers was caused by the different conditions in the amount of sediment load.

In these coastal plains, the age and location of the Turning Point during Holocene are not in accordance with those of the postglacial highest sea-level around

5,000 years BP. The Turning occured between 8,000 years and 5,000 years BP, when the sea-level rise gradually became slower.

6 Conclusion

Alluvial deposit in the coastal plain along Sendai Bay is subdivided into following facies.

Basal Gravel (BG) consists of fluvial sand and gravel, which includes gravels of 5～30 mm in diameter and occasionally those of above 100 mm in diameter. Depositional age of BG is estimated before 15,800 yr BP.

Lower fluvial silt・clay (La) was deposited about 15,800 yr BP in accordance with the post-gracial sea-level rise.

Lower sand gravel (Lb) is a fan deposit during 15,800 yr BP～9,280 yr BP.

Middle esturine silt・clay (Ma) was deposited about 9,280 yr BP as swampy deposit including a lot of plant debris.

Middle marine silt・clay (Mb) includes shallow marine and brackish shells, and is back barrier deposit.

Upper marine sand (Ua) includes shells and abraded shell fragments. The lower part of Mb was deposited on the shoreface and shallow marine during the transgressional stage, and upper part was deposited during the regressional stage. Ma, Mb and Lb form a barrier system.

Upper sand (Ub) is well sorted and does not include any shell. Ub is considered to be aeolian sand.

Upermost terrestrial silt・clay (Uc) is the back marsh sediment and occasionaly includes fluvial sand. Inlandward Uc occurs directly on Ma.

Based on the boundary surface between the marine and terrestrial deposit, the locational change of shoreline during the Holocene was restored as Fig. 11.

On the other hand, the sea-level change for the last 10,000 years around Sendai and Ishinomaki alluvial coastal plains was clarified (Fig. 12). The sea-level rose and reached about 40 m below the present sea level at ca 10,000 years BP following the Last Ice Age. Then the sea-level continuously and rapidly rose up to about 8,000 years BP. But after 8,000 years BP the rising of sea-level became slower, and the sea-level reached nearly the present level at about 5,000 years BP. Since then it was stabilized with slight fluctuation.

From the facts described above, the author concludes as follows.

(1) By the period when the sea-level reached about 30 m below the present one (ca 9,000 yr BP), the sea transgressed landward and it passed the location just below the present shoreline. This transgression continued until about 8,000 years BP.

(2) After the period when sea-level reached about 10 m below the present one (ca 8,000 yr BP), coastal plains along Sendai Bay stopped decreasing in extent and

began to expand seaward by filling up the shallow sea with terrestrial sediments, although the sea-level was still rising (ca 8,000 yr BP~5,000 yr BP).

(3) Following the former period, the shoreline continued to progress seaward intermittently and reached the present position for the period from 5,000 years BP to the present.

The author emphasized that the period of the highest sea-level in the Holocene and that of the maximum areal extent of the sea did not coincide in age with each other. This time-gap is considered to depend on the condition of the amount of loads supplied from rivers. The "Turning Point" to the seaward expansion of coastal plain appeared earlier in the area supplied with larger amount of loads than in the area with smaller amount.

Acknowledgement

The author wishes to thank Prof. K. Nishimura, Komazawa University, for his guidance and helpful advice on this study.

References (*in Japanese)

Hase, H. (1965): Underground geomorphology of the coastal plain in the Sendai-Shiogama District.* *Annals of the Tohoku Geographical Association*, **17** 158–163

Hase, K. (1967): Geology of the Alluvial Plains of Miyagi Prefecture.* *Tohoku Univ., Inst. Geol. Pal., Contr.*, **64** 1–45

Ikeda, K. (1964): Study of the Alluvial Deposits of the Tokaido region.* *Tohoku Univ. Inst. Geol. Pal., Contr.*, **60** 1–85

Iseki, H. (1975): On the Basal Gravel Beds of the Recent deposits.* *Journal of Geography*, **84** 247–246

Okutsu, H. (1953): Geology and ground water in Sendai and the environs.* *Rep. Econ. abd Indust. Depart., Miyagi Prefecture.*

Omoto, K. and Ouchi, Y. (1978): Some data on the Holocene sea-level changes in the Sendai Coastal Plain, northern Japan.* *Geogr. Rev. Japan*, **51** 158–175

Matsumoto, H. (1980): Distribution between dune and shallow marine sands, along Sendai Bay Northeast Japan, from their textural characteristics.* *Geogr. Paps, to the Memory of Prof. Dr. K. Nishimura*, Kokon shoin, Tokyo, 182–186

Wako, T. (1972): A C–14 date of a subsurface peat layer in the lower reach of the Abukuma valley, northeast Japan.* *Annals of the Tohoku Geographical Association*, **24** 74–76