Volume 46 • Number 2 • June 2004

COASTAL ENGINEERING JOURNAL

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Coastal Engineering Journal, Vol. 46, No. 2 (2004) 219–241

SAND MOVEMENT AND LONG-TERM BEACH EVOLUTION IN A FLUVIAL SYSTEM COMPOSED OF THE SAMEGAWA RIVER AND THE NAKOSO COAST

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Received 30 June 2003
Revised 20 March 2004

A field investigation on sediment movement and beach evolution was performed in a fluvial system composed of the Samegawa River and the Nakoso coast, which experienced significant beach erosion recently. Analyses of regional sand volume in the system revealed that the rate of decrease in nearshore sand on the beach is of the same order as the rate of accumulation of sand in dam reservoirs. Dredging of the riverbed near the river mouth also influenced nearby shoreline retreat. Long-term changes in sand movement processes were estimated from the distribution of mineral composition included in the sediment samples collected in a wide area.

Keywords: Field study; regional sediment movement; fluvial system; long-term beach evolution; mineral analysis.

1. Introduction

Coastal erosion in Japan has been accelerating in the last three decades. The rate of decrease in land area, estimated by the comparison of geographical maps, is reported to be 24 km^2 in the last 15 years [Tanaka *et al.*, 1993]. According to Hsu *et al.* [2000] and Uda [1997], beach erosion mechanisms can be classified into six mechanisms: (1) disturbance to the continuity of the littoral drift, (2) wave sheltering by structures, (3) offshore loss of sand, (4) reduction in sand supply, (5) dredging of sand in rivers and coasts, and (6) land subsidence. They also suggested that human interruption of sand supply is one of the essential factors causing coastal erosion. The reduction of sediment supply to the coastal area is considered influential especially in Japan because the fluvial sediment movement is significant owing to fragile geology and relatively steep slopes of rivers. The establishment of the sediment control in the fluvial system, composed of a watershed and a sediment cell in the nearshore zone, is therefore required to mitigate coastal erosion.

In sediment budget analysis of a beach with a river, the estimation of sediment discharge from the river is essential. The sediment supply from the river is influenced by various anthropogenic impacts such as construction of dams and weirs, river route change, and sand dredging from the riverbed. The construction of port, harbors, and shore protection structures also alters coastal sediment movement. In order to develop an efficient countermeasure to coastal erosion, it is firstly essential to understand the contribution of each mechanism quantitatively. However, it is difficult to separate the effects of these impacts quantitatively because most of them occurred during the rapid economic growth in the last four decades and interacted each other with various scales in time and space. A sediment budget analysis based on topographical survey data sometimes fails to describe the complicated mechanisms of sediment movement when many processes are superimposed in a complex manner. Complementary analyses on sediment quality, combined with those on quantity, will be useful in such cases. The quality of sediment is described by physical and chemical properties such as grain size, specific gravity, shape, radioactivity, and mineral constituents. The source and the track path of sediments in the watershed and the nearshore zone can be estimated from the distribution of sediment size [Sunamura, 1971; Liu *et al.*, 2000] and minerals characterizing the locality [Lee *et al.*, 2000]. The dating of the sediment layer can be achieved by the measurement of radioactivity [McManus *et al.*, 1998; Dominey-Howes *et al.*, 2000; Sato *et al.*, 2002]. A comprehensive analysis on regional sediment management was performed by coupling field measurements with various numerical models [e.g. Lillycrop and Wozencraft, 2003].

In the present study, regional sand movement and long-term beach deformation is investigated for a fluvial system composed of a watershed of the Samegawa River and a sediment cell of the Nakoso coast. Although coastal morphological processes around the Samegawa River mouth were investigated by Shimizu *et al.* [1986], little studies have been conducted on the long-term sediment movement in the large area covering the watershed. The quantity and the quality of sediments is analyzed by using a series of aerial photographs, bathymetry survey data of the riverbed, dam reservoirs and nearshore zone, and physical and mineral properties of surface sediments sampled in a wide area including the sea floor and the riverbeds upstream of dams. The anthropogenic impacts, such as dams, sand dredging, fishery harbors and shore protection structures on long-term beach erosion are discussed on the basis of the comprehensive analysis.

2. Samegawa River and Nakoso Coast

2.1. *Geography of the fluvial system and anthropogenic impacts*

The Nakoso coast is a sandy pocket beach located at the south of Fukushima Prefecture facing the Pacific Ocean (Fig. 1). It is an arc-shaped concave 6 km beach divided by two headlands, Cape Ryuugu on the north end and Cape Unoko on the south end. The beach is mostly covered by fine sand with median diameter from 0.1 to 0.3 mm. To the north of the Nakoso Beach, two small sandy beaches are located among mud stone cliffs extending for 2 km, the Obama Beach located on the north to the Cape Ryuugu and a small beach located adjacent to a small harbor, Iwaki Sun Marina. Izura Beach and Kita-Ibaraki Beach are located to the south of the Nakoso Beach (see Fig. 11). The cliff is mostly covered with soft mud stone, which does not produce fine sand upon erosion. No large rivers are present near the Nakoso coast except the Samegawa River. The Samegawa River, which originates in Abukuma mountains with a catchment area of 600 km^2 and a route length of 58 km, flows on the southern part of Fukushima Prefecture reaching the Nakoso coast, thus composing a fluvial system. Two dams were constructed about 10 km from the river mouth, Takashiba Dam on the mainstream of the river constructed in 1962, and Shitoki Dam on a branch, Shitoki River, constructed in 1984. No significant sand transport by wind is observed.

An electric power plant, the Joban Kyodo Power Plant, was constructed on the north side of the Samegawa River mouth behind a sand barrier developed from the river mouth to the foot of the northern headland at which the river mouth had been originally located. The sand barrier was cut in front of the power plant in 1983 by a channel of thermal discharge from the plant. A jetty was constructed in 1982 along the left bank of the river mouth in order to fix the river mouth location and separate river water from the thermal discharge from the power plant. Two fishery harbors were located to the south of Cape Unoko, where breakwaters were constructed from early 1980s, total length exceeding 600 metres. In order to protect the shore, several detached breakwaters have been constructed since 1978 in the southern part of the

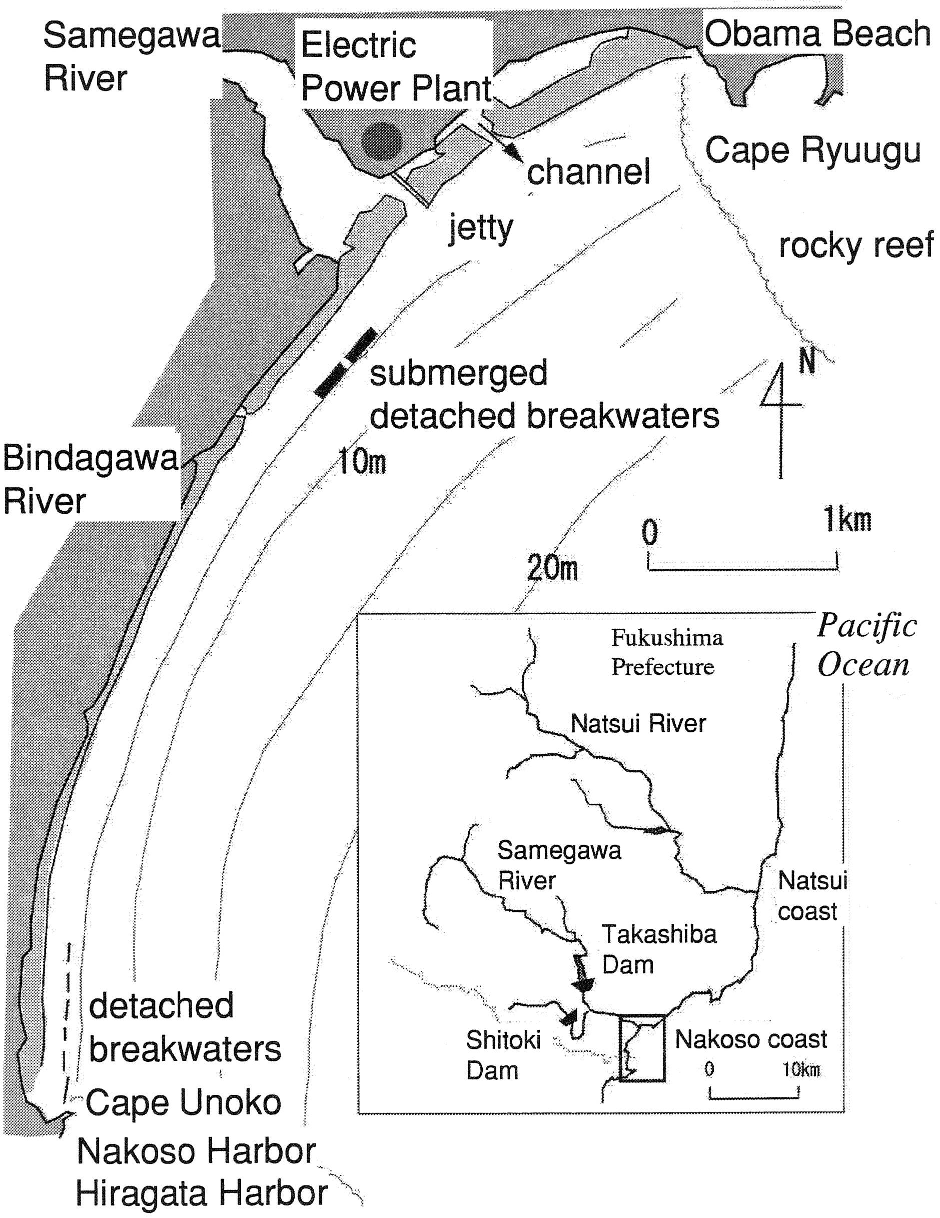


Fig. 1. Samegawa River and Nakoso coast.

coast and submerged detached breakwaters since 1993 on the right side of the river mouth.

2.2. *Wave climate*

Figure 2 shows the significant wave heights observed at Onahama Port located 9 km northeast of the Nakoso coast. The top figure indicates waves in autumn, showing high waves incident mostly from SSE which are considered to be swells and wind waves generated by tropical low pressure systems in the Pacific Ocean.

The bottom figure indicates, on the other hand, that high waves are incident mostly from ESE, which are considered to be wind waves generated by seasonal

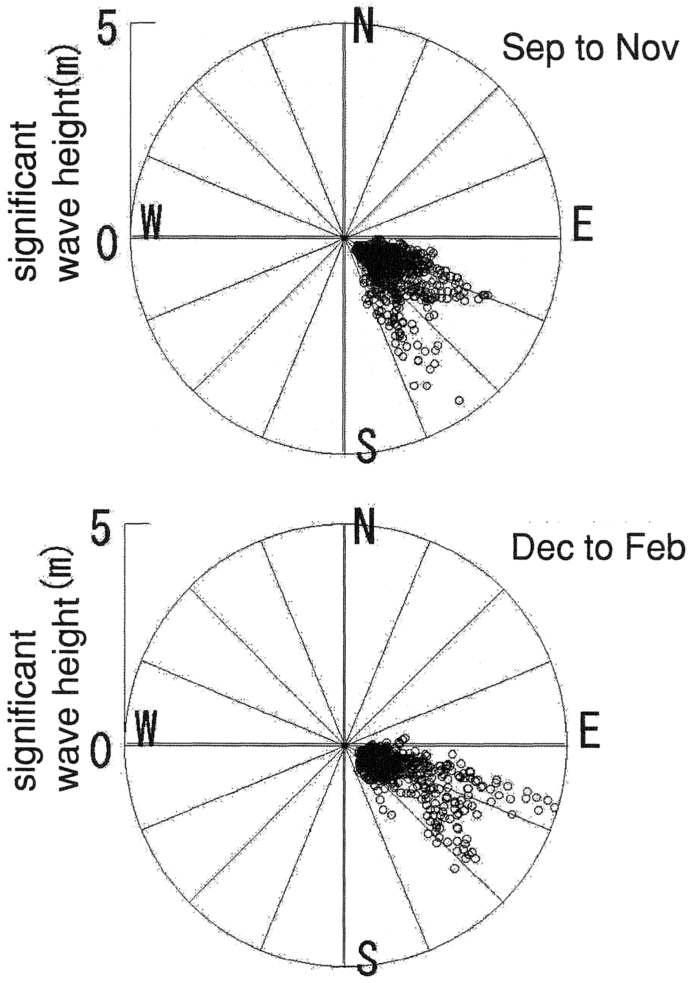
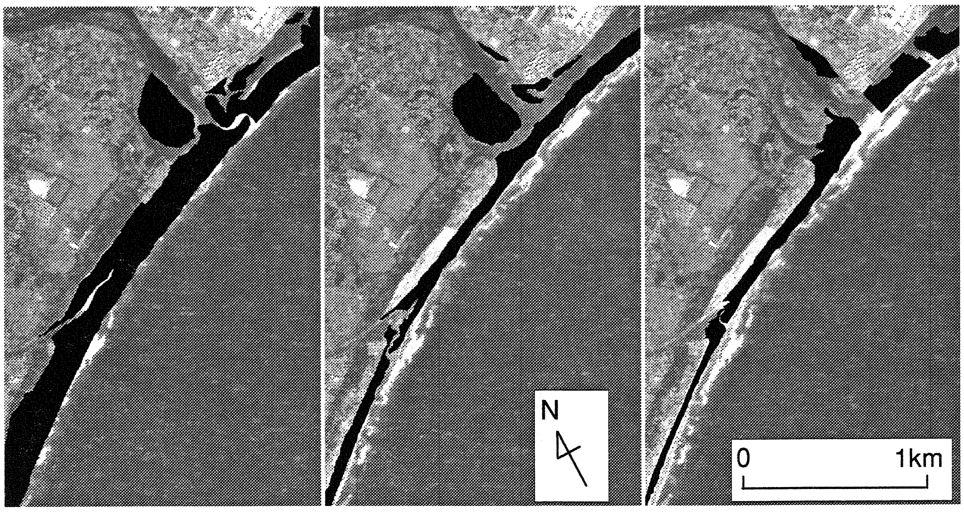


Fig. 2. Wave climate at Onahama Port (1988).

winds from the north developed in winter. Comparing the wave direction with shoreline angle, the direction of the longshore sand transport is considered northward in the southern beach, while southward longshore transport may dominate in the northern beach especially in winter. The gross sediment balance is considered to be determined by the balance between the spatial gradient of the longshore sand transport due to seasonally variable sea waves and the sediment discharge from the Samegawa River.

3. Shoreline Deformation Analyzed from Aerial Photographs

In order to analyze long-term trend of shoreline change, the shoreline position was traced from a series of aerial photographs collected with intervals of 5 to 10 years. Shoreline variation due to tide was compensated by using the estimated tide level and the average foreshore slope of the present beach. Figure 3 illustrates the change in sandy area identified from aerial photographs. White sandy area for 1946, 1970, and 1998 were illustrated as black areas on the photograph of 1970. The geometric



June 1946 Oct 1970 May 1998

Fig. 3. Changes in sandy area mapped on the background image of aerial photograph at 1970.

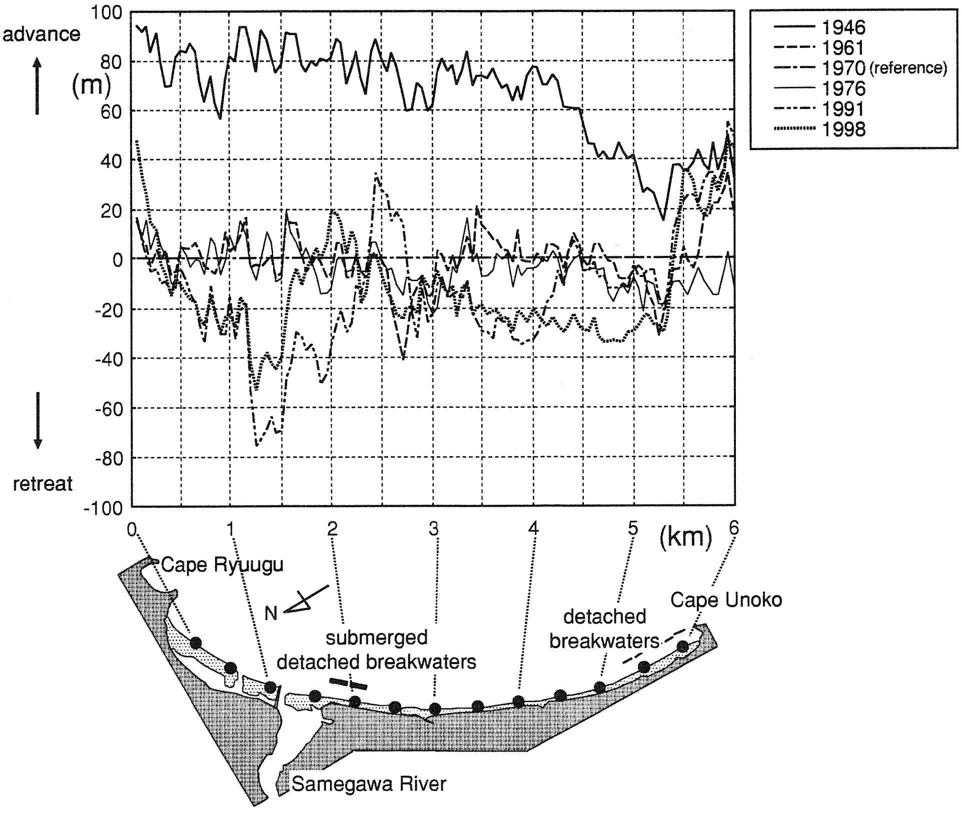


Fig. 4. Shoreline change of the Nakoso coast.

distortion of each photograph was compensated by using several benchmarks identified in the photographs. It is noticed that a sand bar in the river basin disappeared in the photograph of 1998, which is due to the sand dredging conducted in the early 1970s. Figure 4 shows variation of shoreline defined as the ground elevation T.P.

0 metre. The translation of the shoreline due to tide and wave set-up was compensated by using the time stamp and the breaker height inferred from the breaker line location. The maximum tide range at Onahama Port is 1.2 metres. The accuracy of the shoreline position is considered to be less than several meters. Shoreline position was determined with an interval of 50 m, and plotted as the deviation from that of 1970. It is noticed from the figure that an overall erosion is in progress in the Nakoso Beach. Erosion in the period from 1946 and 1961 is especially significant, which is considered to reflect the erosion control works and flood protection works in the postwar restoration period. Erosion in the southern part became significant in 1970 and 1976, which was recovered in 1991 by the construction of detached breakwaters. However, the erosion was observed at the Samegawa River mouth in 1991 and 1998. Submerged detached breakwaters were constructed on the right side of the river mouth, which contributed to the recovery of the shoreline in 1998. The erosion mitigation by structures appeared successful, but effective only in limited regions. The erosion is considered to be due to various mechanisms, such as interruption of northward longshore transport due to breakwaters of southern fishery harbors and shore protection structures, reduction of sediment discharge from the river due to the construction of dams, and sand dredging from the riverbed.

4. Gross Sediment Balance Estimated from Survey Data

4.1. *Survey data in the coastal area*

Nearshore bathymetry has been monitored regularly by the Fukushima Prefecture as well as by the power plant. Figure 5 illustrates the region covered by these surveys. Beach profiles were measured by the Fukushima Prefecture with an interval of 500 m from the seawall to the depth of 20 metres. Detailed surveys in the northern part are performed by the power plant. Survey datasets were available from 1980 with time intervals of 3 to 6 months for the data taken by the power plant and half year to two years for those taken by the Fukushima Prefecture. The data by Fukushima Prefecture can be used to estimate the gross sediment balance in the nearshore zone, considering that the depth of closure on the Joban coast is reported as 8 to 9 m by Uda [1997]. The surveys of bathymetry have been carried out by sonar sounding from a boat. The accuracy of the measurement is considered to be within several centimeters.

The variation of sand volume was estimated by integrating the surveyed topography in northern, central and southern regions illustrated in Fig. 5. Each region was furthermore divided into three sub-regions depending on the depth contours, that is, regions with water depth from 0 to 4 m, 4 to 8 m and 8 to 20 m. Figure 6 shows variations of sand volume in each region. The sand volume was estimated as the deviation from that of June 1984. The variation of the total sand volume is shown on the bottom. The total sand volume is, on the average, decreasing in the

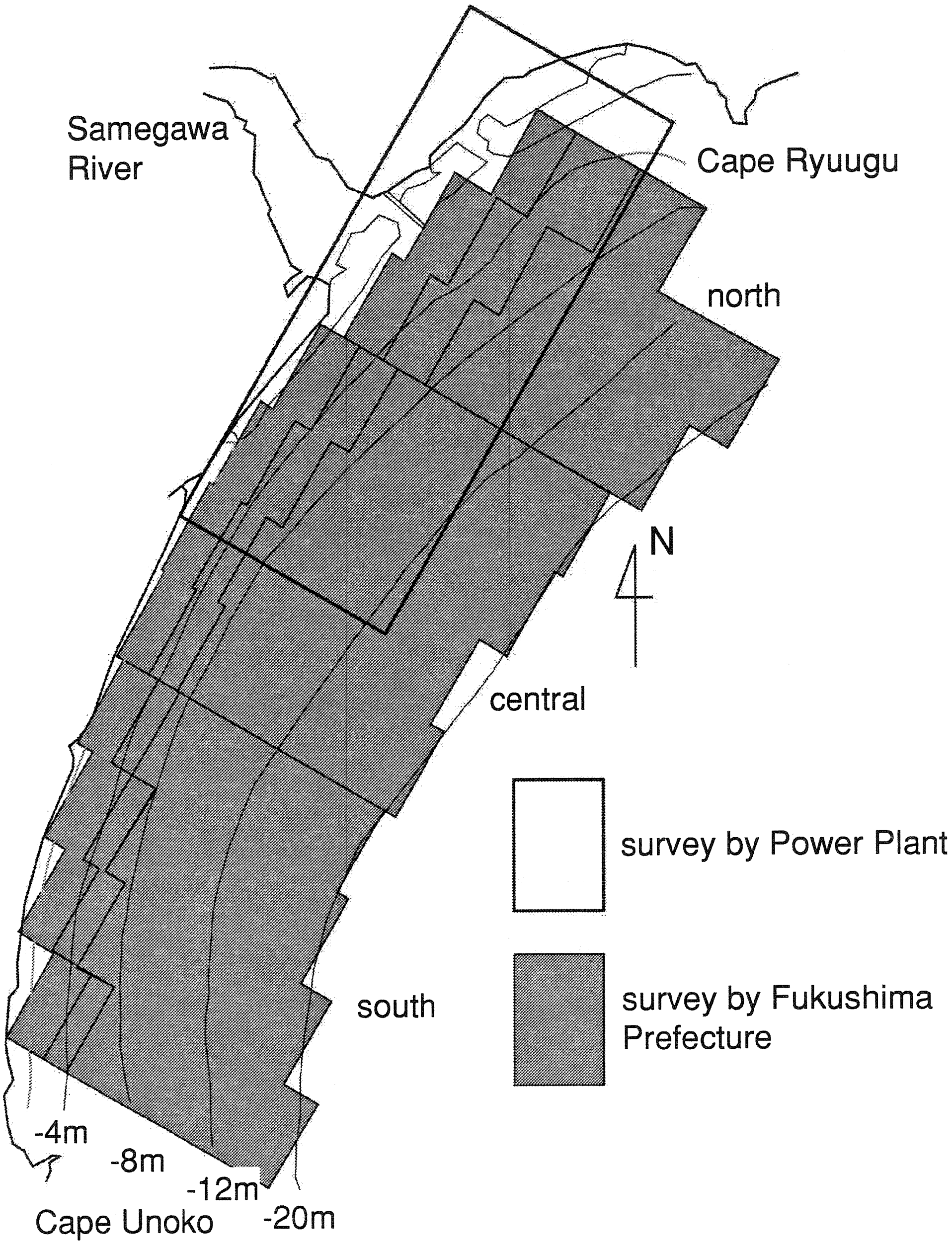


Fig. 5. Regions for available survey data.

last 20 years, at a rate of 1.0×10^5 m^3/yr. It is also noticed that the decrease of the sand volume is significant especially in the southern region.

Figure 7 illustrates temporal variation of mean bottom elevation in the south region. Significant decrease in the mean bottom elevation was observed in the subregion with water depth from 4 to 8 m. The order of magnitude was several tens centimeters in 20 years, which is significant compared to the accuracy of survey data.

Comparisons were made of the temporal variation of the total sand volume with wave and flood records. For successive pairs of survey data, significant decrease in the

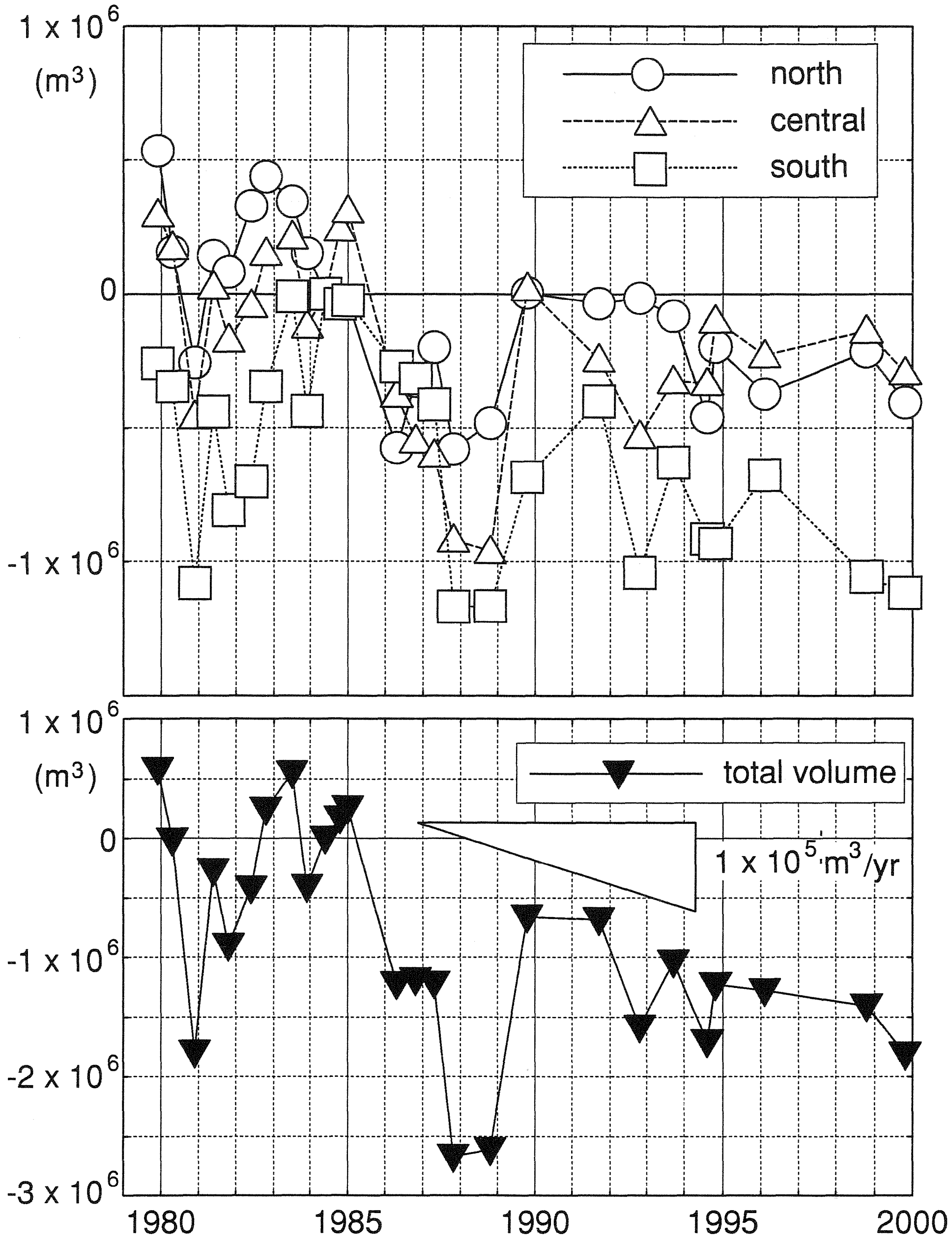


Fig. 6. Temporal variation of sand volume in north, central, south, and whole regions.

total sand volume, specified as a change of sand volume exceeding 4×10^5 m^3 which corresponded to several percent of the amount of sediment decrease in ten years, was identified in five pairs. Storm waves with significant wave heights exceeding 4 m were recorded in three periods out of the five, for the periods from May 1987 to November 1987, from September 1991 to November 1992, and from September 1993 to August 1994. All these waves were found to be incident from S to SSE, thus transporting sand from south to north and resulting in erosion in the southern region. The loss of sand is therefore considered to be due to the sand transport over the northern headland, the Cape Ryuugu, or to the offshore region deeper than 20 metres.

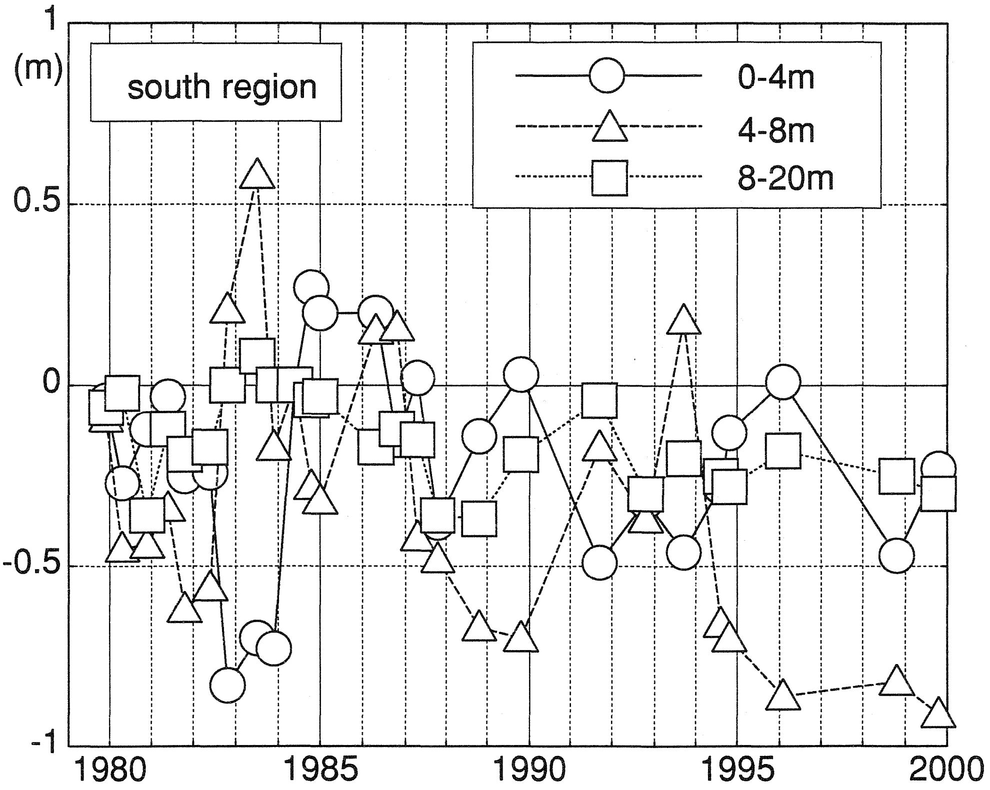


Fig. 7. Temporal variation in mean bottom elevation in the south region.

On the other hand, a significant increase in the total sand volume is identified at the periods from November 1988 to November 1989 and from November 1992 to September 1993. In both periods, a significant flood was recorded in the Samegawa River, when the daily average discharge recorded 170 to 340 m^3/s, which was ranked as one of the largest flood compared with annual average discharge of 10 m^3/s. Sediment supply due to usual river flow was considered to be negligible.

Temporal variations of the total sand volume were therefore considered to be determined by the imbalance in the longshore sand transport due to waves and sediment discharge from the Samegawa River. The decrease in the total sand volume in recent 20 years indicates the imbalance in the gross sediment balance in the decadal time scale.

4.2. *Survey data in the riverbed and dam reservoirs*

Figure 8 illustrates the accumulation of sediments in dam reservoirs. Sediments have been steadily accreting in both dam reservoirs since construction, 1962 for Takashiba Dam and 1984 for Shitoki Dam. The total accumulation rate is estimated at 1.3×10^5 m^3/yr, an order of magnitude in agreement with the rate of total sediment loss in the nearshore area. Although the fraction of sand in sediments accumulated in dam reservoirs is unknown, the interception of sediments by the dam is considered to exert essential influence on long-term changes in coastal morphological processes.

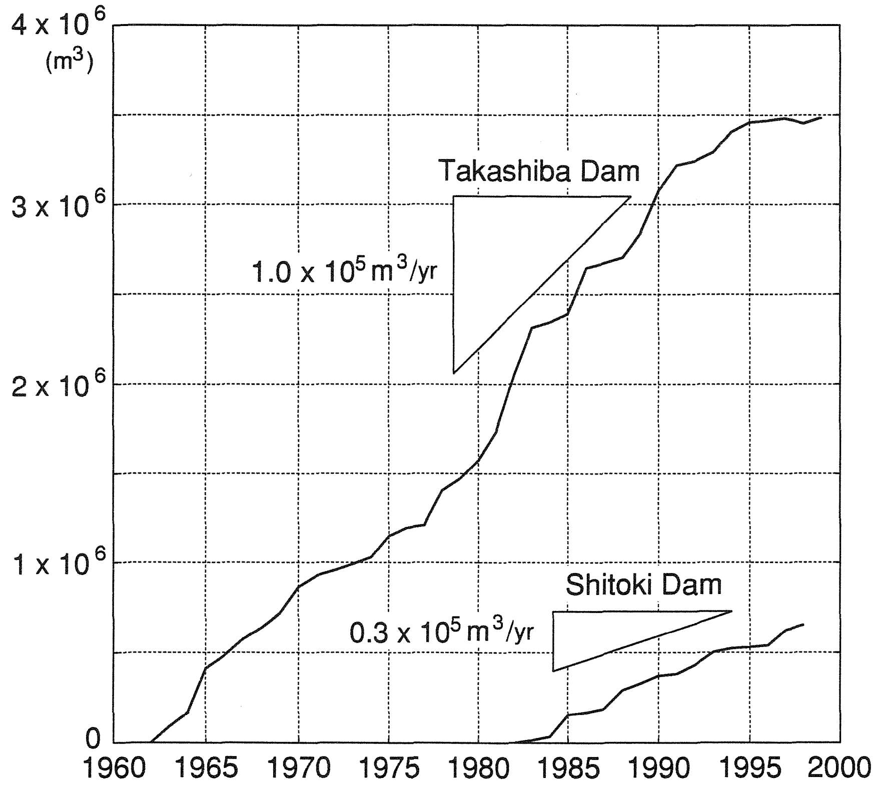


Fig. 8. Accumulated sand in reservoirs of Takashiba dam and Shitoki dam.

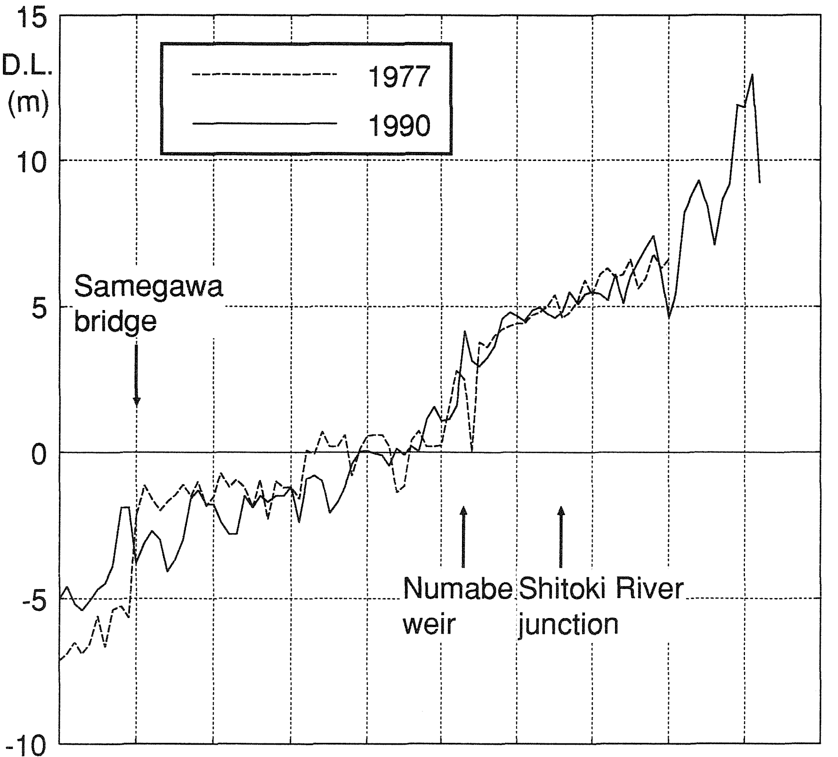


Fig. 9. Profile of the mainstream Samegawa River.

Figure 9 shows the profiles of riverbed downstream of the Takashiba dam at 1977 and 1990. The slope of the riverbed is approximately 1/700 in the downstream of the Numabe weir. However, the profile at 1977 shows unnatural deepening in the region 1 km from the river mouth. This is due to the dredging of a sand bar performed in early 1970s as was confirmed in Fig. 3. The variation of the riverbed is insignificant in the upstream region but accretion in the riverbed is significant in the region of the

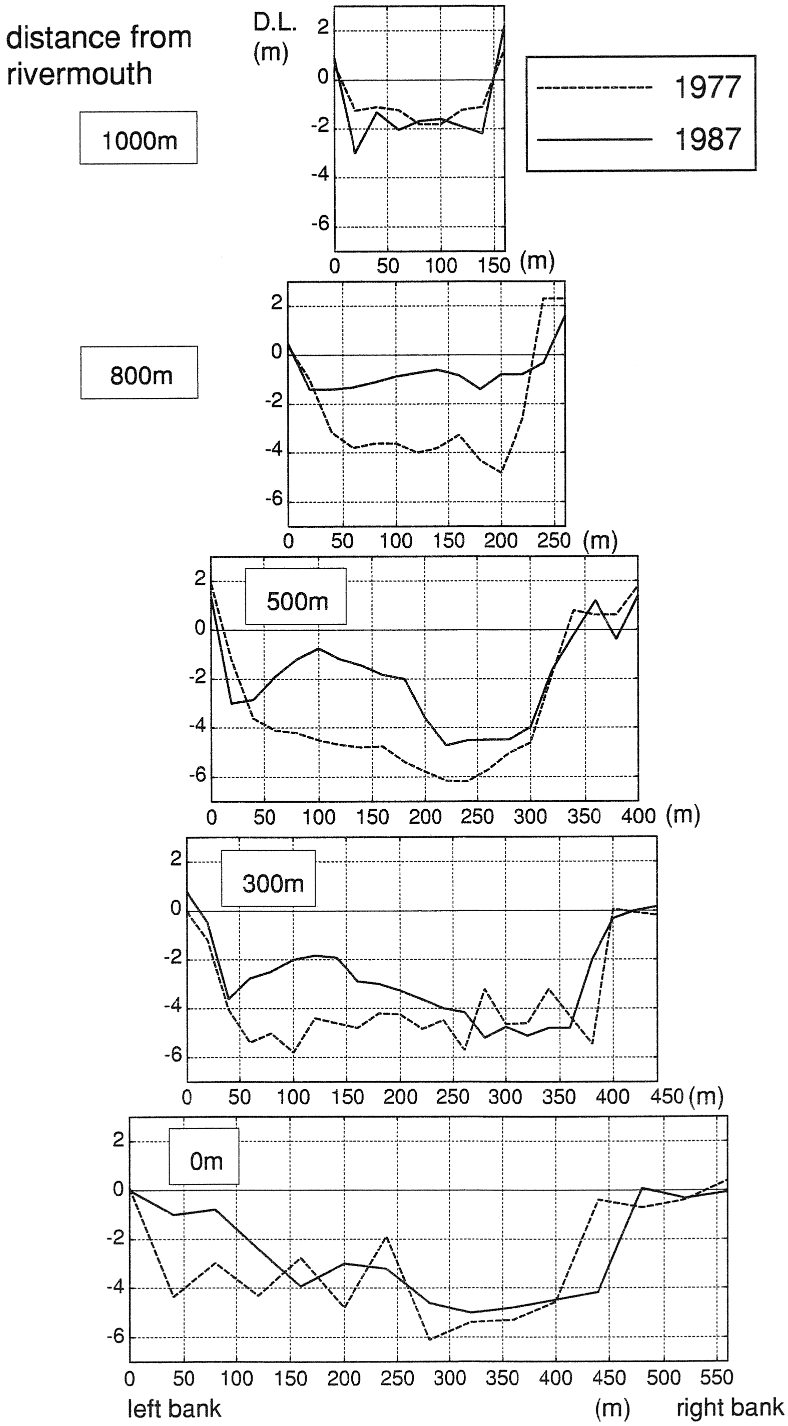


Fig. 10. Cross sections of the Samegawa River near the river mouth.

sand dredging, which is considered to be due to the natural recovery of the dredged bar.

Figure 10 shows cross sectional profiles of the riverbed near the river mouth in 1977 and 1987. The rise in the riverbed is significant especially near the left bank, which corresponds to natural recovery after the dredging of a sand bar. No official record for the amount of the sand dredging is existent; however, the amount of the sand recovered in the region 1 km from the river mouth was estimated at 4×10^5 m^3 from these survey data. This is considered to result in the decrease of sediment supply to the coast in the decade, which corresponds to the shoreline retreat on the right side of the river mouth in 1991 seen in Fig. 4. Although the order of the magnitude of sediment volume is small compared to that in dam reservoirs, the dredging in the downstream region is considered important since it exerts quick and direct impacts on sand supply decrease to the coast.

5. Analysis of Mineral in Sediments

5.1. *Identification of individual sand particles*

Surface sediments were sampled on August 24 and 25, 2000, at more than 100 points from Kita-Ibaraki coast to Natsui coast. Figure 11 shows the location of sample collection sites for which property of individual particles was analyzed in the present study. Sample sites were selected to compare the distribution in two fluvial systems, to estimate the extent of sediment cell influenced by the Samegawa River, and to discuss the effect of river sediment discharge on beach morphology. Surface sediments at the high tide level on the shore, usually at the top of foreshore slope, were collected by using a hand shovel. Sediments on the sea floor were obtained by using a Smith-McIntyre grab sampler.

Core samples were obtained by using PVC (polyvinyl chloride) pipes, with diameter 4.6 cm and length 2 m. The pipe was vertically dug into the ground by a hammer and extracted after making the top void airtight by pouring water and sealing with a plug. It was confirmed that the sediment inside the pipe was successfully sampled by suction pressure without disturbance as long as the sediment was sand. Core samples along the shoreline were obtained on August 23–24, 2001, and those on the riverbed were obtained on August 11, 2002. The cores for the riverbed upstream of dam reservoirs were taken only to the length of 10 cm, since the bed contained large gravels. Sediments in the core sample were sliced by horizontal planes into smaller samples with an interval of 5 cm.

Specimens for mineral analysis were taken from sampled sediments by the split-sample quartering method to keep uniformity. Minerals were identified by using a polarizing microscope. The minerals for surface sediments were classified into ten species. The list of mineral to be identified was determined from spectral peaks obtained by the quantitative X-ray powder diffraction (XRD) analysis. It is common that the identification of mineral is made for thin section specimens. However, in

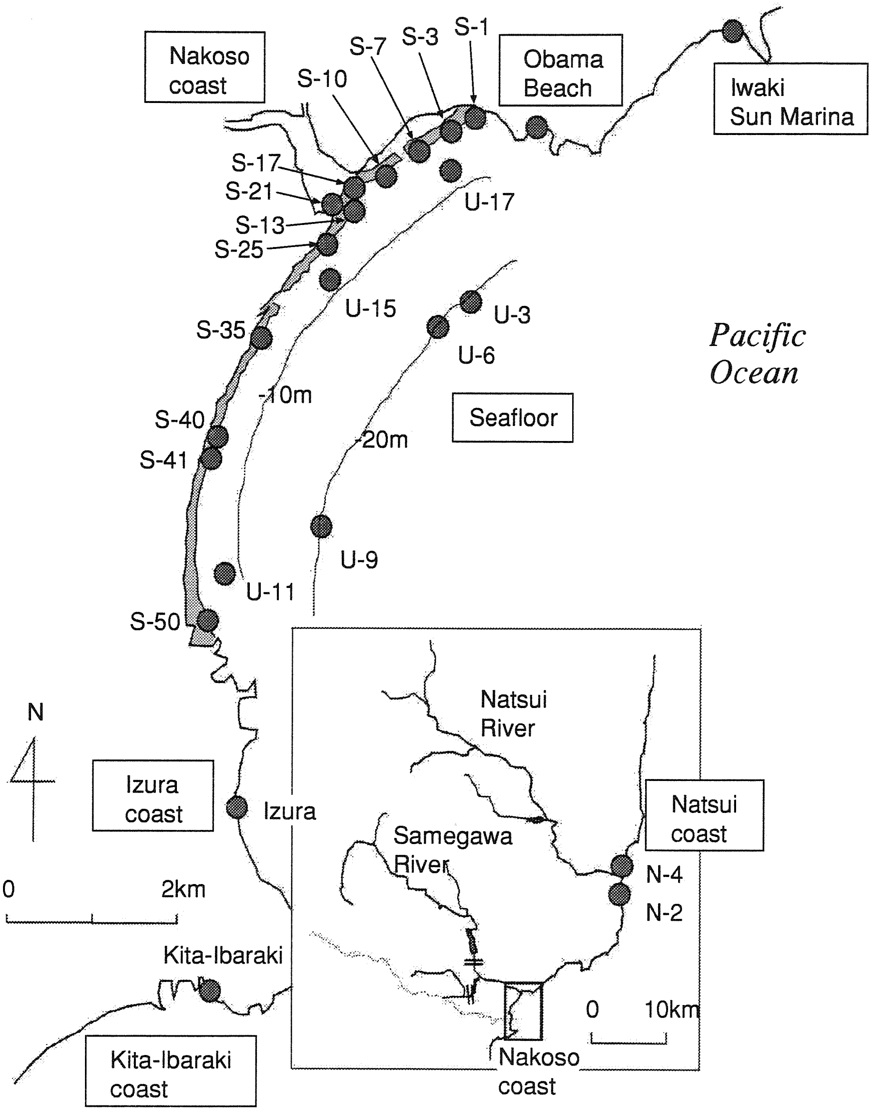


Fig. 11. Sample points for surface sediments.

the present study, because the grain size of particles was as small as 0.1 to 0.3 mm for surface sediments on the shoreline, individual particles were identified by direct observation to analyze many specimens in a limited time. Sample particles were placed directly on a slide glass. An epoxy solution, which was hardened by exposure to ultraviolet light, was impregnated between the slide glass and the cover glass. Such a technique could be used because most particles were fine sand, which can be identified easily without making thin section specimens. Particles on each specimen were randomly identified for 300 to 500 particles by using an automatic traverse system equipped to the microscope.

Figure 12 shows an example of particles inspected by a polarizing microscope. The top image illustrates plane polarization and the bottom for cross polarization. Both quartz and feldspar appear as transparent particles for plane polarization. However, a multiple twinning pattern can be observed for feldspar by cross

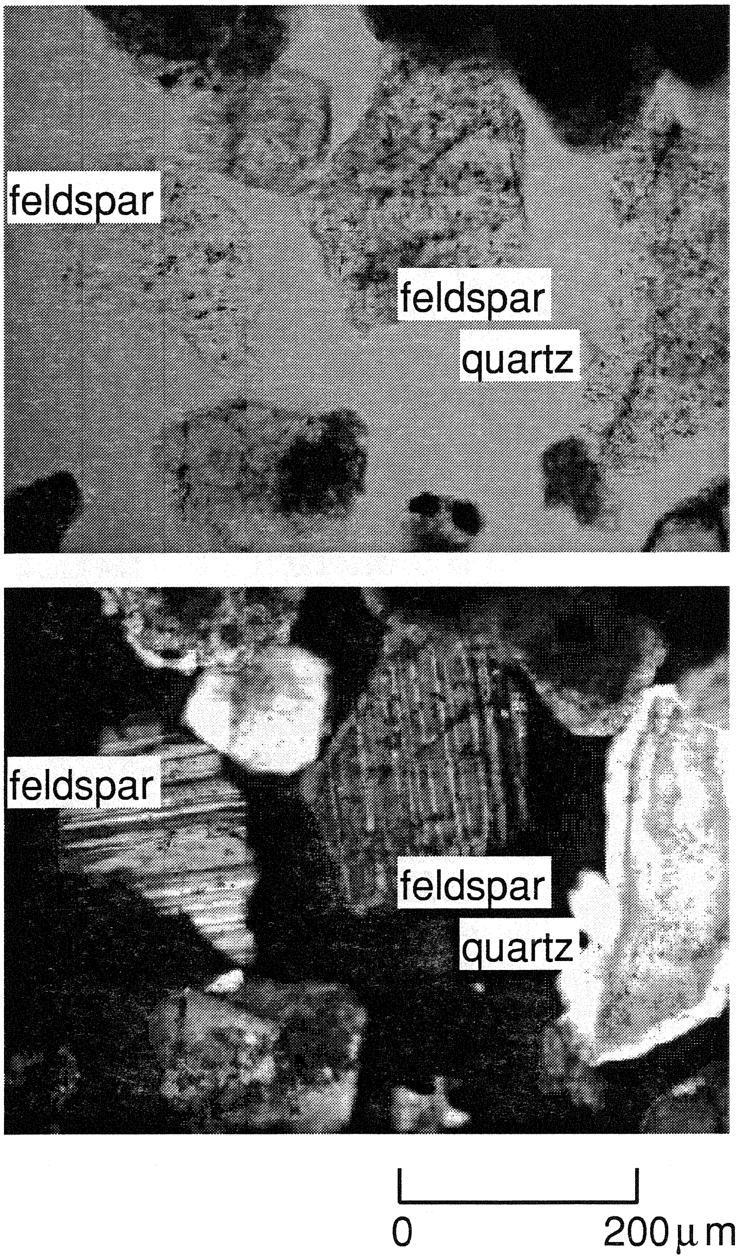


Fig. 12. Identification of particles by a polarizing microscope (top: plane polarization, bottom: cross polarization).

polarization. Figure 13 illustrates the number ratio of mineral constituents. The ratio of amphibole is connected by solid line since it is essential to understand the track of sediments originated in the upstream Samegawa River. A thin section specimen was also created for S-10, to confirm the accuracy of identification by direct observation of particles. Figure 13 confirms that the identification were made with sufficient accuracy.

For core samples, particles were identified only by plane polarization with low magnificent ratio, in order to analyze as many specimens as possible in the present study. The sediment particles in core samples were therefore classified into four

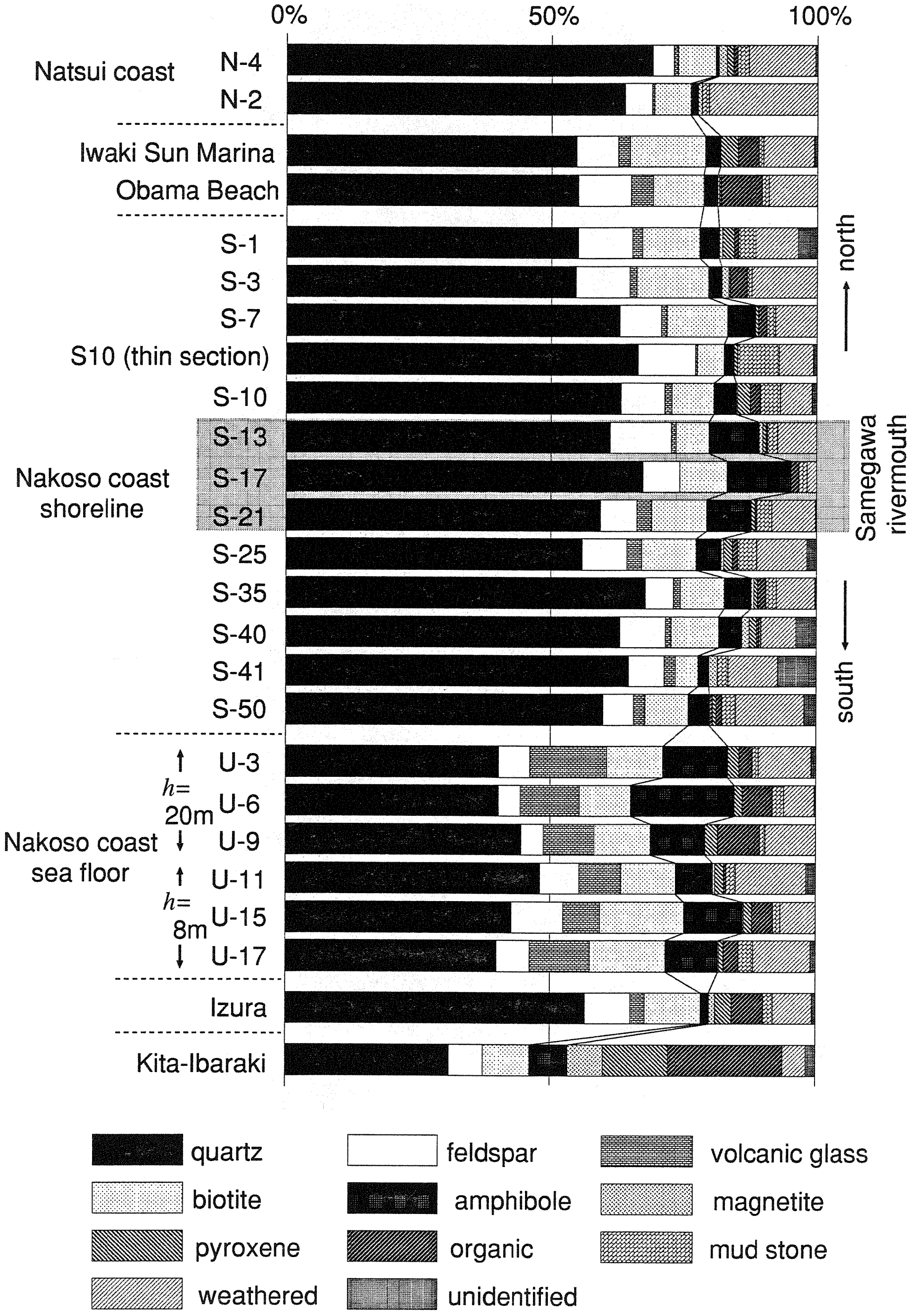


Fig. 13. Distribution of mineral constituents (h denotes the water depth).

groups, transparent particles (quartz and feldspar), hornblende mainly composed of amphibole, biotite, and other. At least 250 particles were identified for every specimen from samples at every 10 cm from the bed. The total number of identified particles exceeded 10,000 for surface sediments and 25,000 for core samples.

5.2. *Comparison of mineral constituents with the Natsui coast*

The Natsui coast is a 10 km long sandy beach located 40 km northeast to the Nakoso coast. The Natsui River, whose catchment area is 750 km^2 and the mainstream

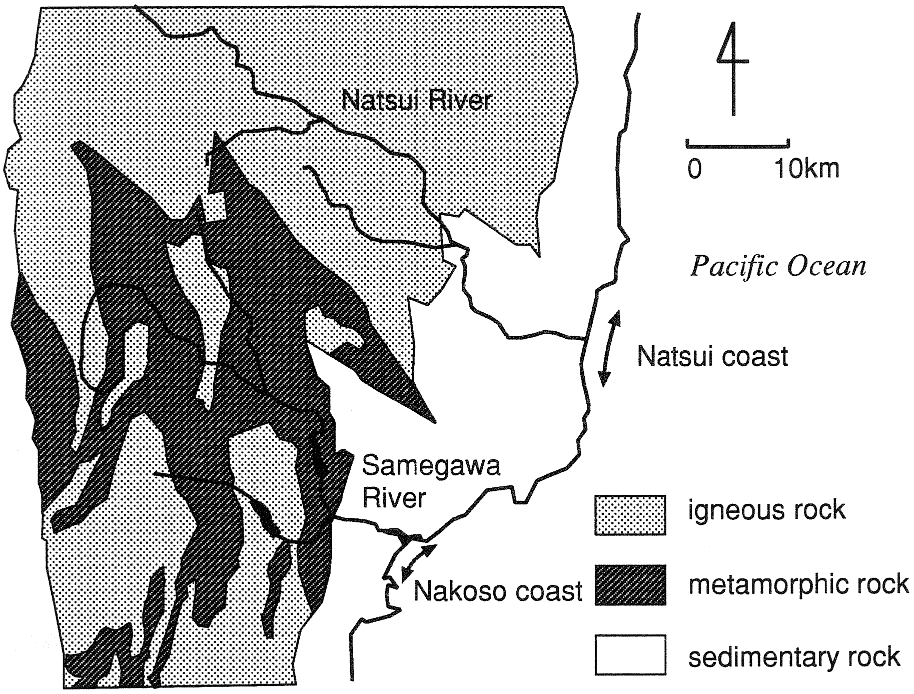


Fig. 14. Geology of the Samegawa and the Natsui River basins [Kano *et al.*, 1973].

route length is 83 km, flows into the central region of the coast. Figure 14 illustrates geology of watersheds of the Samegawa and the Natsui Rivers. A greater part of the upstream region of the Samegawa watershed is composed of a big metamorphic rock zone called Gozaisho-Takanuki metamorphic rocks [Kano *et al.*, 1973], extending 120 km NS by 80 km EW. The zone is characterized by specific rocks and minerals, such as hornblende and amphibole. On the other hand, most of the watershed of the Natsui river is covered by granite.

The distribution of mineral for surface sediments, illustrated in Fig. 13, shows that amphibole is enriched near the Samegawa River mouth. On the other hand, the fraction of amphibole on the Natsui beach is less than 1%. These results demonstrate that surface sediments on both beaches are influenced by the geology of the watershed, thus forming individual sediment cells.

5.3. *Distribution of mineral constituents in Nakoso and nearby coasts*

Figure 13 indicates the mineral constituents in northern beaches, Obama beach and Iwaki Sun Marina, and are similar to those of S-1 and S-3 located in the northern Nakoso coast. The fraction of amphibole is larger than that of the Natsui coast, but smaller than that of the Nakoso coast. This indicates that some fraction of sands was originated from the Samegawa River although sands from other sources is also dominated, which supports the presence of sand transport over the northern cape suggested by the sand volume analysis.

On Izura Beach, located to the south of the Nakoso coast, the mineral components are similar to those of S-40, S-41 and S-50, located in the southern region of the Nakoso coast. The ratio of amphibole is, however, smaller, which is the same trend as those for northern neighboring beaches. This suggests the partial influence of the Samegawa watershed sediments to the southern beach. However, the mineral components on Kita-Ibaraki Beach, located further to the south of Izura Beach separated by another headland, include significant fraction of amphibole, which is considered to reflect other sediment sources in the further south regions. The large fraction of pyroxene, observed on the Kita-Ibaraki coast, and relatively large fraction of pyroxene on Izura Beach compared to those on the Nakoso coast, suggests that the sediments on the Izura beach is also influenced by the sediment supply from the southern beaches. Further investigation is required to identify the sediment source for Izura Beach quantitatively.

5.4. *Nearshore sediment movement inferred from mineral analysis of surface sediments*

Figure 15 shows the longshore variation of sediment size and the ratio of feldspar to quartz for surface sediments. The median diameter is relatively large for the south region and gradually decreases northward as indicated by the arrow, except for the sudden increase caused near the river mouths as well as near the discharge channel from the power plant. The increase is due to the strong currents that have

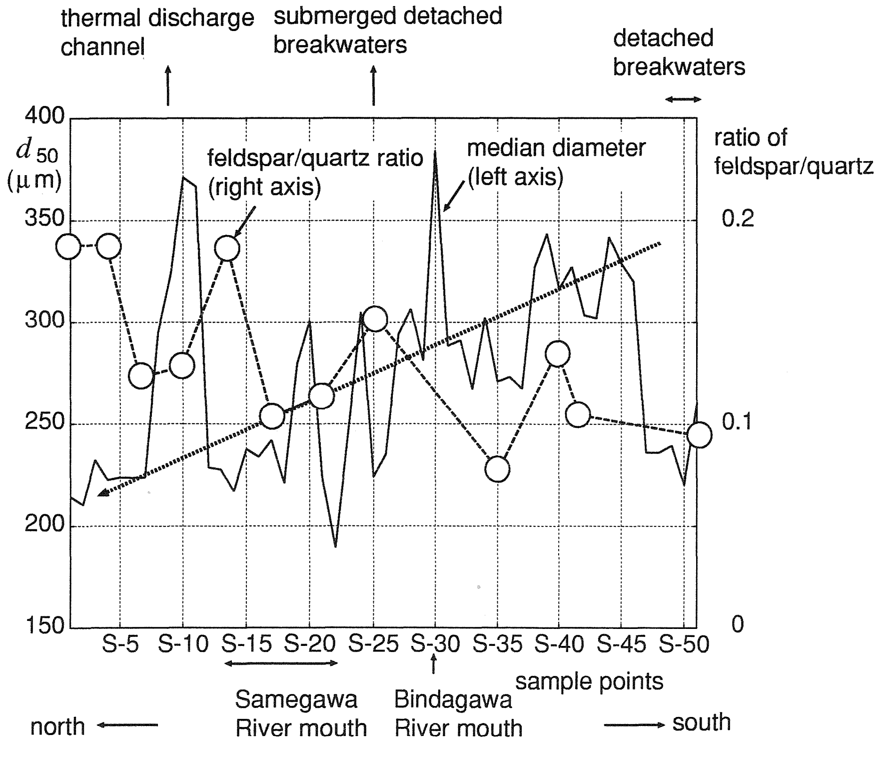


Fig. 15. Longshore variation of the median diameter d_{50} and the ratio of feldspar to quartz particles.

been observed in these area. The gradual decrease of surface sediments suggests the dominant direction of the mean longshore sand transport is northward. The northward transport is considered to result in the long-term erosion and coarsening on the southern beach. The gradual increase in the ratio of feldspar to quartz in the northern beach also supports the northward transport. Because the feldspar is less stable in mechanical weathering [e.g. Siever, 1988], the fresh sediment containing large fraction of feldspar supplied from the river is transported to the north region. Older sediments in the south region experienced significant mechanical weathering, therefore the fraction of feldspar, more subjective to the mechanical weathering compared to quartz, becomes smaller on the southern beach, reflecting the northward transport. Small ratio of feldspar around the river mouth corresponds to the decrease in sediment discharge from the Samegawa River in recent decades.

Figure 16 illustrates the relationship between the median diameter d_{50} of surface sediments on the sea floor and the water depth h. The sediments sampled on the shore was plotted at $h = 0$, although they were sampled at the high tide level. The median diameter decreases monotonically with the increase in the water depth. Figure 13 indicates that mineral components of sediments also changes on the sea floor. Sediments on the sea floor include larger fraction of volcanic glass, having lighter specific gravity than quartz, as well as colored minerals such as biotite, amphibole and pyroxene, having larger specific gravity than quartz. These results

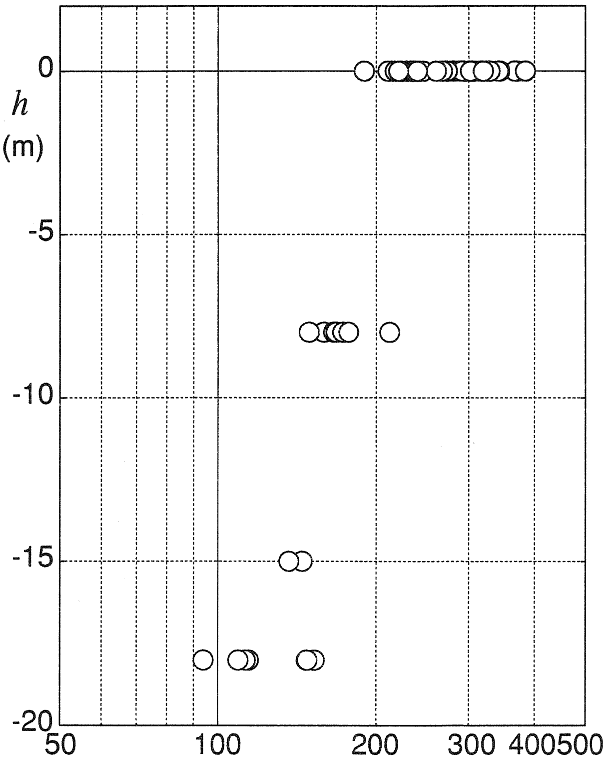


Fig. 16. Relationship between median diameter d_{50} and water depth h.

indicates the presence of the cross-shore sediment sorting mechanism due to size and specific gravity.

5.5. *Anthropogenic impacts on sediment movement inferred from mineral analysis of core samples*

Figure 17 illustrates the ratio of hornblende to transparent particles for core samples at twelve points. The horizontal axis indicates the number ratio of hornblende particles and the vertical axis is the depth from the bed. The length of core samples was 1.5 m at maximum. A longer core sample was also obtained on the sand bar at the mouth of the Samegawa River by the Coast Division of the National

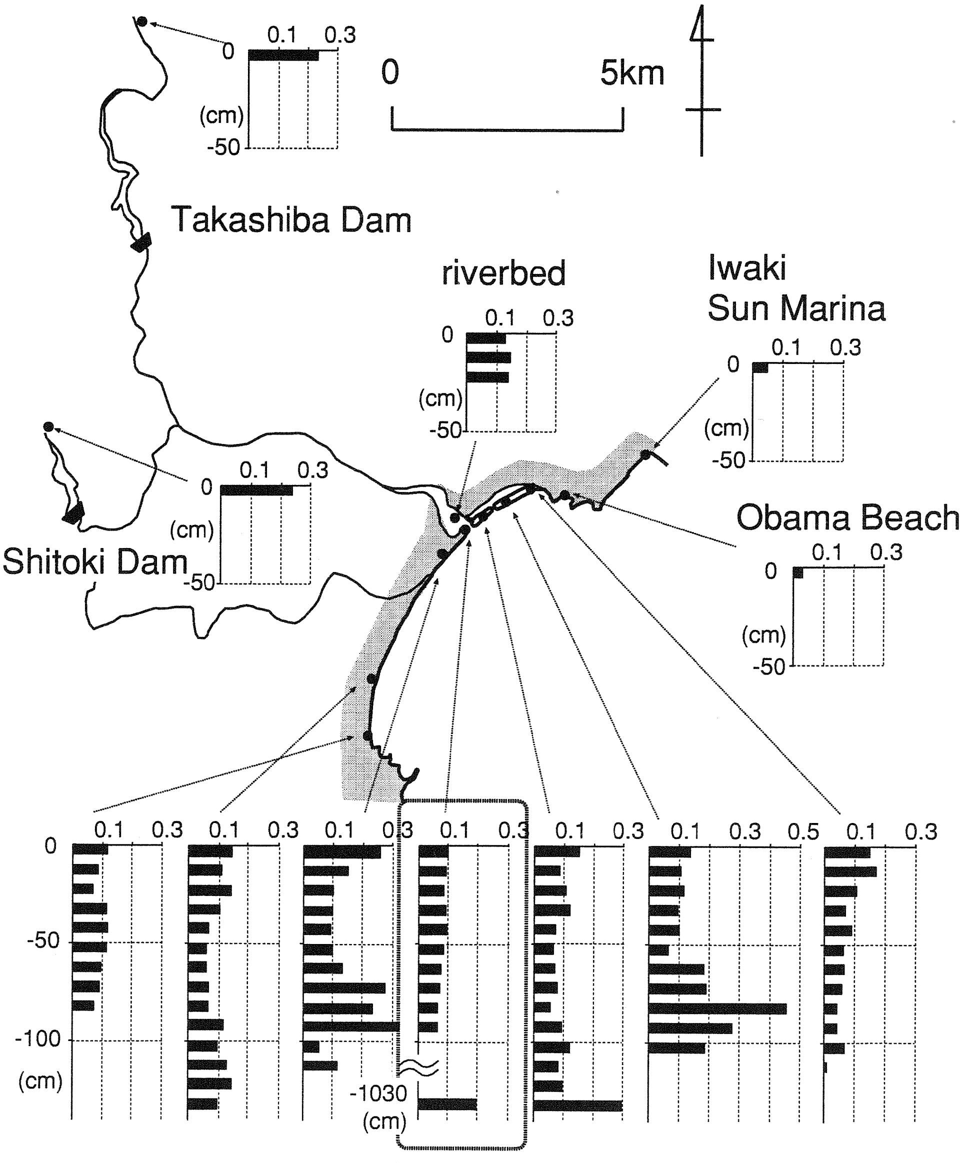


Fig. 17. Distribution of the ratio of hornblende to quartz/feldspar in the Samegawa River and the Nakoso coast.

Institute of Land and Infrastructure Management. The ratio of the hornblende is large at the riverbed upstream of two dams. On the other hand, the ratio is smaller for the riverbed near the river mouth, where the core sample was taken for naturally deposited sediments after the sand dredging in 1970s. On the sand bar at the river mouth, the ratio of the hornblende is also small for the surface sediments, but the sediments at 10.3 m deep contain significant hornblende, as much as 20% in the number ratio. The comparison of survey data and the dating by using fallout flux of radioactive Pb-210 [see, e.g. Sato *et al.* 2002] demonstrated that the surface sediments on the downstream riverbed and the sand bar at the river mouth are considered to be fresh sediments deposited within these 30 years and the sediments at 10.3 m deep in the sand bar is considered to be older than at least several decades [Abe *et al.*, 2003]. It is therefore considered that the transport of hornblende particles, enriched in the upstream of dams, has been blocked by the construction of dams.

The distribution of the hornblende along the Nakoso and nearby coasts indicates that the hornblende is widely distributed. However, the ratio of the hornblende at Obama Beach and Iwaki Sun Marina is small, which implies the sediments supplied from sea cliff erosion are predominant for the formation of nearby beaches compared to small contribution of the Samegawa River. The distribution within the Nakoso coast shows that the ratio of hornblende tends to be smaller near the river mouth. This is considered to reflect the recent change in the quality of sediments supplied from the Samegawa River. Recent sediments supplied from the river, containing smaller amount of hornblende, are gradually covering the beach surface around the river mouth. It is therefore concluded that the decrease in the sediment supply due to the block of the dams exerts essential influences on the loss of total volume of sand in the nearshore zone and on the change of the quality of surface sediments.

6. Conclusions

An analysis was conducted on regional long-term sediment movement in the fluvial system composed of the Samegawa River and the Nakoso coast. Main conclusions are summarized as follows.

(1) The significant shoreline retreat of the Nakoso coast started in the southern region, after the overall retreat during the postwar restoration period. Shore protection structures mitigated the erosion successfully, but their effects were limited locally.

(2) The rate of decrease of the total sand volume in the nearshore zone is estimated at 10^5 m^3/yr. The erosion is significant in the south region with water depth from 4 to 8 m, which suggests that the erosion is due to the northward longshore sand transport.

(3) The total accretion rate of two dam reservoirs is estimated at 1.3×10^5 m^3/yr. The interception of sediments by the dams is considered to exert considerable

influence on long-term changes in coastal morphological processes. The sand dredging in the river basin near the river mouth also influenced the beach erosion near the river mouth.

(4) Amphibole and hornblende were found to be characteristic mineral and rock species to represent the contribution of the sediment supply from the Samegawa River. It was found on the basis of mineral analysis that sand originated from the Samegawa watershed distributed widely in the Nakoso coast and partially in the nearby coasts. The sediments deposited near the river mouth after the construction of dams were found to contain a small amount of hornblende, indicating the interception of sediments by dams exerted essential influence on the decrease in the nearshore sand volume.

(5) Beach evolution and the total sand volume on the Nakoso coast are determined by the balance between the longshore sand transport directing northward on average and the sediment supply from the Samegawa River. A small fraction of sand supplied from the Samegawa River is considered to be transported to the northern beaches over the northern headland.

Long-term monitoring and further investigation of sediment quality are expected to develop an effective strategic plan to mitigate the beach erosion.

Acknowledgments

Field measurements were cooperated among four coastal groups in National Institute for Land and Infrastructure Management, Penta Ocean Co. Ltd., the Ibaraki University, and the University of Tokyo. Geographical survey data were provided by Fukushima Prefecture and Jouban Kyodo Electric Power Plant. Wave data at the Onahama Port were provided by Port and Airport Research Institute. Considerable assistance of Professor H. Nagahara, Department of Earth Sciences of the University of Tokyo, was also appreciated with regard to the identification of sand particles. The authors are also very grateful to Dr. Kraus and two other anonymous reviewers, whose comments and suggestions have helped to improve the clarity of the manuscript. Part of the present study was supported by JSPS Grants-in-Aid for Scientific Research and by the Foundation of River and Watershed Environment Management, Japan.

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