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Influence of surface water circulations on the sea bottom in the southern Japan Sea

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Abstract: Influences of surface water circulation on the sea bottom are discussed on the basis of the distribution of surface sediments and bedform morphology. Spatial distribution of surface sediments and bedform morphology suggest a northeastward sediment transport in and around the Tsushima Strait. Transport of sandy sediments and prevention of mud deposition occur at the shelf edge of north of Kita-Kyushu and at the marginal terrace edge between Mishima Island and Oki Islands, indicative of bottom currents along the edge of shelf or marginal terrace. A second branch of the Tsushima Current or surface water circulation seems to form eddies that are related to cold water mass influencing the sea bottom and controling modern sedimentation along the shelf or marginal terrace edge. On the other hand, muddy sediments are deposited on the marginal terrace, though located just beneath the current path of the first branch of the Tsushima Current at the north of Hamada. This means that the effects of the first branch are too small to prevent the deposition of mud.

1. Introduction

The Japan Sea is a northeast-southwest trending marginal sea between the Asian Continent and the Japanese Islands. The oceanography of the Japan Sea has been investigated by many institutes. Among these studies, the behavior of the Tsushima Current has been a main target. The Tsushima Current has high temperature, high salinity and relatively low oxygen content and is derived from the Kuroshio (NITANI, 1972). It flows northeastward, after entering the Japan Sea through the Tsushima Strait. The current path exhibits a complicated figure. Some workers have recognized three branches (e.g. SUDA and HIDAKA, 1932; UDA, 1934; KAWABE, 1982), whereas others have recognized a meandering path (MORIYASU, 1972). This conflict results from the considerable variability in the spatial location of the Current.

Many studies on the water movements in the Japan Sea have been carried out on the basis of oceanographic data such as temperature, salinity and dissolved oxygen (e.g. ICHIYE, 1954; KANO, 1980; KOLPACK, 1982). However, precise figure of the thickness of the water movement or bottom current behavior such as direction and velocity is not clear yet. On the other hand, sedimentological, paleontological and marine geological investigations in the southern Japan Sea have clarified sediment distribution (e. g. MARITIME SAFETY AGENCY, 1949; IWABUCHI, 1968; TANIMURA, 1981; YAMAMOTO *et al.*, 1989; IKEHARA, 1989, 1991). Modern sedimentation, however, has not been discussed enough. As the sediment grain is transported and deposited according to flow velocity (KIMURA, 1956; SUNDBORG, 1956), spatial distribution of the sediments is influenced by the vector distribution of current. In addition, surface sediments record long-term, averaged current conditions near the sea bottom, because they have been exposed on the sea bottom for a long time. Sedimentological information is, therefore, important not only to geological problems such as Quaternary sea level changes but also to modern oceanographic considerations.

In this paper, the influence of the Tsushima Current and surface water circulation on the sea bottom will be examined on the basis of sedimentological and marine geological data obtained during survey cruises by the Geological

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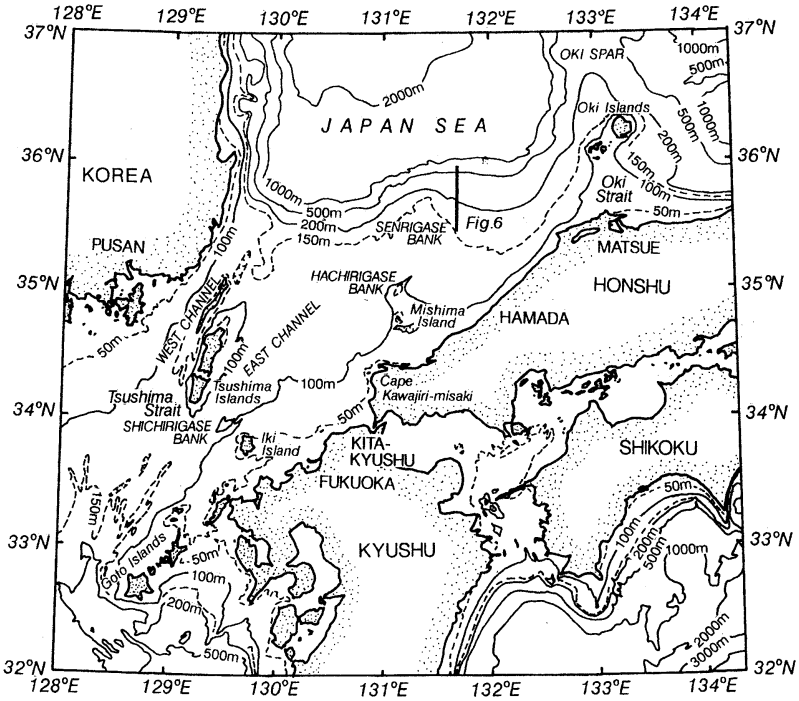

Fig. 1. Area and bathymetry of study in the southern Japan Sea.

Survey of Japan. I will describe spatial distribution of surface sediments and bedforms in the southern Japan Sea and will discuss the influence of water movements in the Tsushima Strait and off Kita-Kyushu to San'in district.

2. Methods

Sedimentological and marine geological data were obtained during the survey cruises GH85-2 (May-July, 1985) and GH86-2 (June-July, 1986) of the R/V Hakurei-Maru by the Geological Survey of Japan. A bathymetric survey using 12 kHz echosounder and 3. 5 kHz sub-bottom profiler was conducted throughout the survey area. Surface sediment sampling was carried out using a Smith-McIntyre type grab sampler or a K (Kinoshita)-type grab sampler which is newly designed by the Geological Survey of Japan (KINOSHITA, 1987); sea bottom photography was carried out at 536 locations.

Grain-size distributions of surface sediments were determined by sieve analysis for the sand component (coarser than 4.5 phi) and by hydrometer analysis for the mud component (finer than 4.5 phi). Median diameters and sorting values were calculated using Inman's method (INMAN, 1952).

3. Physiography and oceanography

Major submarine topographic features in the study area are a wide shelf in the west, a wide marginal terrace and narrow shelf in the east and two topographic highs extending in the north-south direction (Fig. 1). These highs are the Oki Spar, a relief from the Shimane Peninsula through the Oki Islands to further north, and a relief from Cape Kawajiri-misaki through the Mishima Island and Hachirigase Bank to Senrigase Bank. The eastern and western areas are bounded by topographic high through Mishima Island. The shelf is widely developed in the western area (Fig. 1) and some submarine terraces are recognized (MOGI, 1981; OHSHIMA *et al.*, 1982). On the other hand, the shelf is narrow in the eastern area. The shelf edge is about 110–175 m deep and is shallowest at the eastern exit of the Oki Strait (110–120 m deep) and is deepest at the north of Hamada (160–175m deep) (JAPAN ASSOCIATION for QUATERNARY RESEARCH, 1987). The marginal terrace is a wide terrace 200–400 m deep (IWABUCHI, 1968; IWABUCHI and KATO, 1988) and is developed at the east of Mishima Island. The distinct slope of 2–10° occurs between the edge of shelf or marginal terrace and the Tsushima Basin.

Water masses in the southern Japan Sea can be divided into two parts: surface water (above 200m isobath) and deep water (Japan Sea Proper Water; below 200 m isobath). The surface water is characterized by high temperature, high salinity and low oxygen concentration and originates from the Tsushima Current (ASAOKA *et al.*, 1985; MURAYAMA *et al.*, 1990). The Tsushima Current flows into the Japan Sea through the Tsushima Strait and generally flows eastward (NAGANUMA, 1972; KAWABE, 1982). As mentined earlier, the Tsushima Current shows a very complicated flow pattern. According to SUDA and HIDAKA (1932) and UDA (1934), three branches are recognized. The first branch (the nearshore branch along the Japanese coast) flows eastward from the East Channel of the Tsushima Strait over the Japanese shelf. The second branch (the offshore branch) flows along the edge of the shelf or marginal terracetoward east and is seasonally variable and appears only in summer time. The third branch (the Eastern Korean Current) splits at the exit of the Tsushima Strait and flows northward. The third branch exists in all seasons and forms a polar front against northern cold water mass. Schematic representation of surface currents indicates that many warm and cold water masses are developed among the branches and form eddies (NAGANUMA, 1972).

4. General descriptions of surface sediments

Surface sediments distributed in the study area are mainly composed of sand and silt (MARITIME SAFETY AGENCY, 1949; UJIIÉ and MITSUOKA, 1969; OHSHIMA *et al.*, 1982; IKEHARA and KAWAHATA, 1986 ; IKEHARA *et al.*, 1987; KAMADA *et al.*, 1988). Sandy sediments are widely distributed on the shelf. In the Tsushima Strait and on Hachirigase and Senrigase banks, both located at the north of Mishima Island, gravelly sediments and rocky bottoms are recognized. Silty sediments cover the marginal terrace at the north of Hamada and the shelf at the northeast of the Tsushima Islands. Clayey sediments are deposited on the slope between the marginal terrace and the basin and in the basin.

The assemblages of planktonic remains of diatoms (TANIMURA, 1981), silicoflagellates (SHIMONAKA *et al.*, 1970), planktonic foraminifers (ODA and IKEHARA, 1987) and calcareous nannoplanktons (TANAKA, 1986, 1987) are composed of warm-water species and indicate that all of the study area is under the realm of influence of the warm Tsushima Current.

5. Influences of the water movements at the selected area

5-1. The Tsushima Strait

In and around the Tsushima Strait, the effects of the Tsushima Current are recorded on the sediment distributions and bedform morphology. Sediment distribution in and around the Tsushima Strait (Fig. 2) has been reported by many workers (UJIIÉ and MITSUOKA, 1969; MARITIME SAFETY AGENCY, 1978a, 1978b, 1979, 1980, 1981a, 1981b, 1982, 1983; OHSHIMA *et al.*, 1982; IKEHARA and KAWAHATA, 1987; KAMADA *et al.*, 1988). Surface sediments in the Strait are sand except northeast of the Tsushima Islands and offshore of the Korean coast where muddy sediments are deposited. In general, sediment grain size becomes finer from the central part of the Strait toward the northeast (Fig. 2). For example, in the East Channel, the coarsest sediments (coarse to very coarse sand) are distributed in the central part, that is, at the north of the Shichirigase Bank. The grain size becomes finer northeastward and the fine to very fine sand is widely distributed around the exit of the East Channel. Because sediment grains become finer with decreasing flow velocity and these trends are in harmony with the direction of sediment transport (KIMURA, 1956; IKEHARA, 1988), the sediment distribution in the Tsushima Strait indicates northeastward sediment transport.

MOGI (1981) showed the distribution of submarine linear sand ridges more than 10m in waveheight in the East Channel, which are arranged in current-parallel direction, trending NE-SW. This trend is the same as the direction of sediment transport. Although these sand ridges were formed by tidal currents under lower

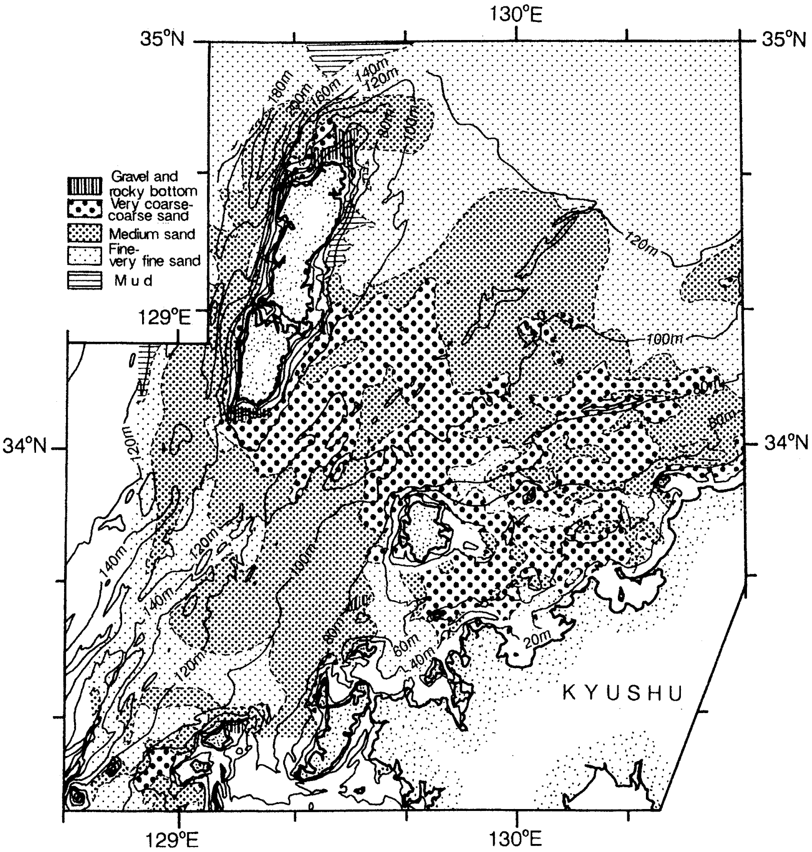

Fig. 2. Sediment distribution in and around the Tsushima Strait. Data are compiled from UJIIÉ and MITSUOKA (1969), MARITIME SAFETY AGENCY (1978a, b, 1979, 1980, 1981a, b, 1982, 1983), OHSHIMA *et al.* (1982), IKEHARA and KAWAHATA (1987), KAMADA *et al.* (1988) and the navigational charts (No.173, 179, 1228) by MARITIME SAFETY AGENCY.

sea level stage (80 m below present sea level) (MOGI, 1981), it is thought that the sand ridges have maintained their morphology after their formation because of no critical change in the direction of sediment transport in the East Channel. KATSURA and NAGANO (1982) showed the distribution and morphology of subaqueous dunes near the shelf edge of the northwestern Goto-Islands, southwest of the Tsushima Strait. On the basis of profiles of these subaqueous dunes, sandy sediments are transported north-eastward. Tidal currents are also important to flow condition in the Tsushima Strait. As grain size of surface sediments does not become finer gradually toward the southwest in the East Channel (Fig. 2) and morphology of subaqueous dunes in and around the Strait (MARITIME SAFETY AGENCY, 1978b; KATSURA and NAGANO, 1982) does not indicate the southwestward sediment transport, sediment transport in the Strait is controlled by uni-directional current (Tsushima Current) rather than bi-directional tidal currents.

It is considered that mud deposition on the east of the Tsushima Islands (Fig.2) results from hydrographically more stagnant zone than the surroundings where the northeastward current from the East Channel flows at the south and the east to east-northeastward current from the West Channel flows at the north. Muddy sediments in the northern side of the West Channel are derived from Korea (SUK, 1986, 1989; CHOUGH *et al.*, 1991) and are deposited in the area of the Korea Coastal Water (SUK, 1989).

These sediment distribution and bedform data indicate that the bottom sediments in and

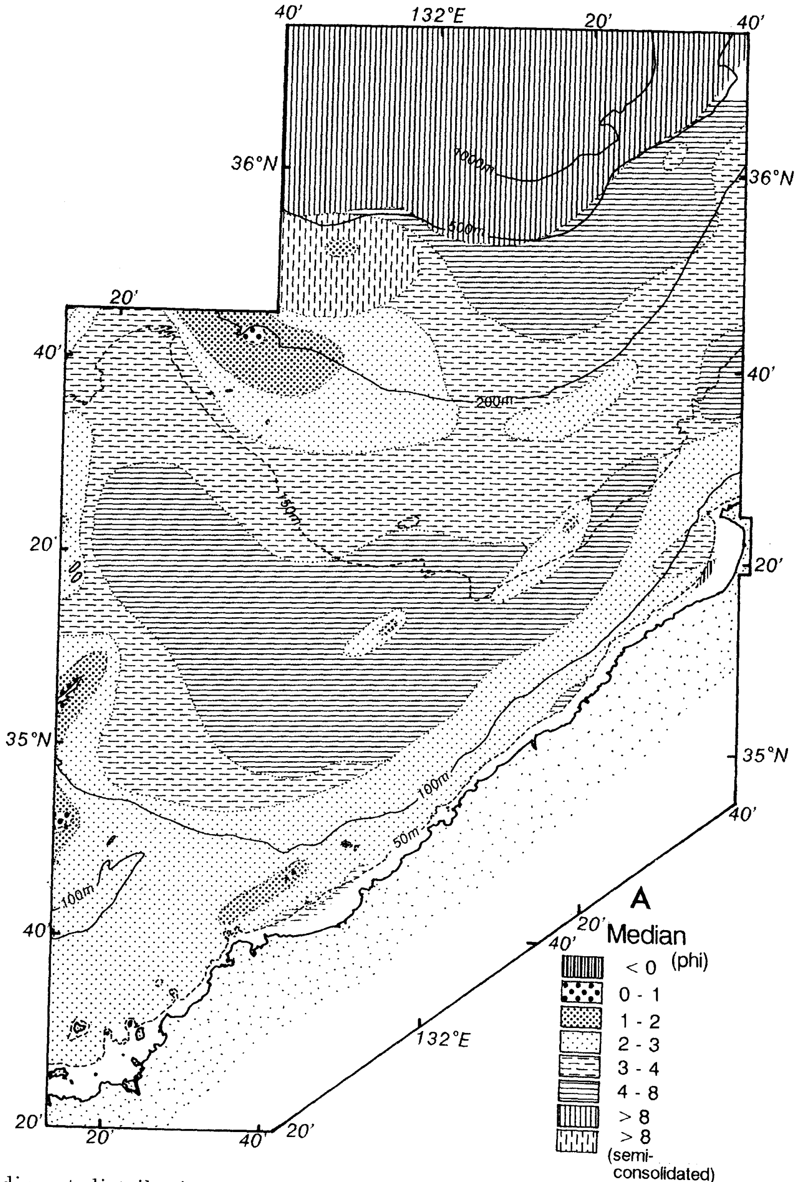

Fig. 3-1. Sediment distribution on the shelf and marginal terrace at the north of Hamada.

around the Tsushima Strait have been affected by a current flowing northeast to east-northeastward, that is, the Tsushima Current.

5-2. Shelf area along the Japanese coast; effects of the first branch on the sea bottom

The first branch of the Tsushima Current flows over the Japanese shelf from the East Channel of the Tsushima Strait. In this area, it is thought that the effects of the current on sediment transport and deposition are very small under modern conditions.

On the shelf under the current path of the first branch, muddy sediments are widely distributed, although sandy sediments are distributed at the north of Kyushu shelf and around the Oki Strait (IKEHARA and KAWAHATA, 1986; IKEHARA *et al.*, 1987; KAMADA *et al.*, 1988). In general, deposition of muddy sediments occurs where the amounts of mud supply are greater

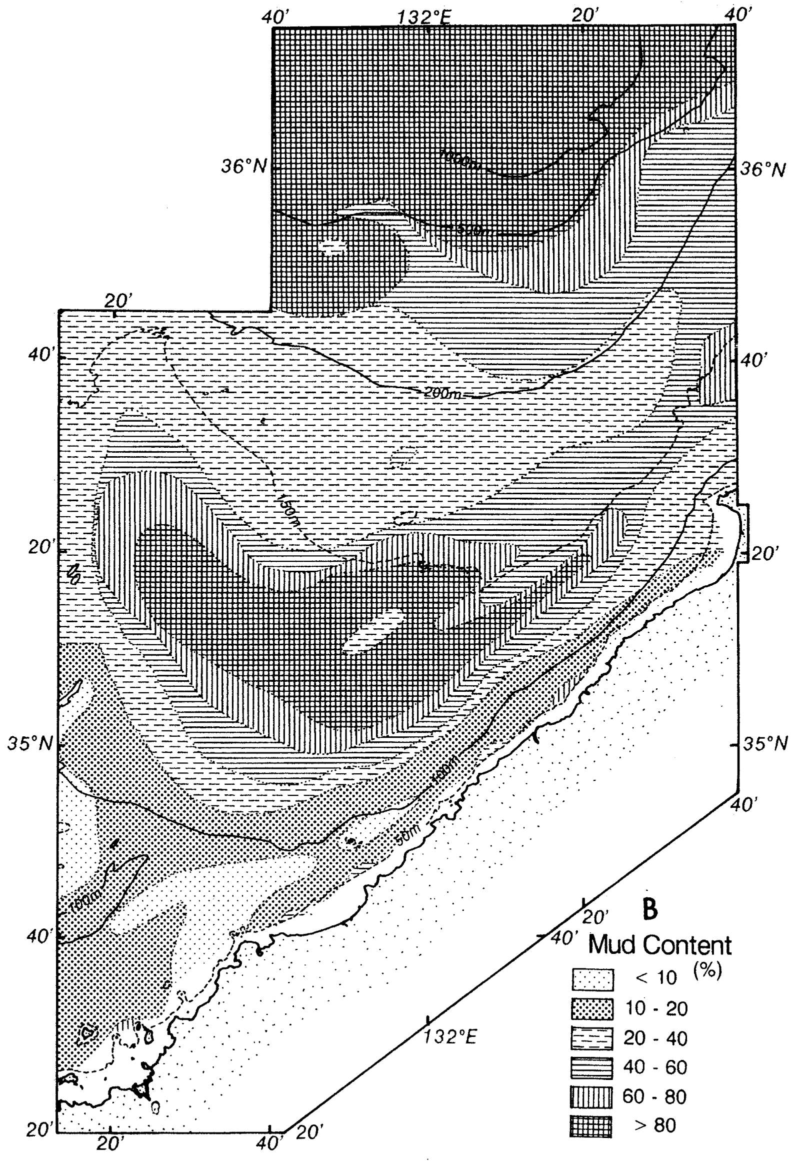

Fig. 3-2.

than that reworked by water movements (SAITO, 1989), generally inhibited by water movements such as currents and waves (IKEHARA, 1991). On the marginal terrace with a water depth of 200 -300 m at the north of Hamada, modern muddy sediments are deposited, though just beneath the path of the first branch of Tsushima Current (Fig.3). This suggests that the current activities are too weak to prevent the deposition of mud. As the boundary between the surface water and the deep water is located around 200 m deep, the first branch has no effect on the movement of deep water mass.

On the shelf under the path of the first branch off Kyushu, no large bedforms such as large subaqueous dunes are observed. On the other hand, in the Oki Strait, which is located between the Shimane Peninsula and the Oki Islands, smaller ripple marks are not distributed widely, although larger bedforms such as large-very

Table 1. Composition of pollen and spores in the semiconsolidated mud at Station 862 63 (for location see Fig.5)

Arboreal Pollen (AP)			Nonarboreal Pollen (NAP)		
Taxa	Counts	Percentage	Taxa	Counts	Percentage
Picea	18	5.6	Typha	2	0.6
Abies	38	11.9	Umbelliferae	2	0.6
Pinus	72	22.6	Chenopodiaceae	2	0.6
Tsuga	67	21.0	Rosaceae	1	0.3
Cryptomeria	1	0.3	Caryophyllaceae	2	0.6
Larix	1	0.3	Artemisia	11	3.4
Cupressaceae	1	0.3	Liliaceae	1	0.3
Fagus	1	0.3	Poligonium	1	0.3
Carpinus	5	1.6	Carduoideae	1	0.3
Castanea	1	0.3	Cyperaceae	2	0.6
Quercus	31	9.7	Gramineae	4	1.3
Celtis	1	0.3	Lycopodiaceae	2	0.6
Betula	13	4.1	Tricolporate	5	1.6
Alnus	10	3.1	Trilete type	1	0.3
Carya	2	0.6	Monolete type	20	6.3
AP Total	262	82.1	NAP Total	57	17.9

large (50−490m in wavelength) and medium-large subaqueous dunes (8–20 m in wavelength) are found (IKEHARA, 1991). Because ripple marks are formed under lower velocity condition than subaqueous dunes, modern sand transport is too small to create or activate tha large bedforms (IKEHARA, 1991).

5-3. The edge of shelf or marginal terrace from the north of Kita-Kyushu to the Oki Islands; effects of the second branch or surface water circulations (eddies) on the sea bottom

Along the edge of shelf or marginal terrace from the northern offshore of Kita-Kyushu to the Oki Islands many indicators of bottm water movements are recognized.

Well-sorted sandy sediments with low mud content and ripple marks are found on the surface along the shelf edge of the north of Kita-Kyushu at a water depth of around 120-200m (Fig. 4). It suggests the occurrence of bottom currents which transport sandy sediments and prevent mud deposition. Surface sediments become finer in grain size, greater in mud content and more poorly sorted northeastward. This direction indicates the direction of decreasing current velocity as well as decreasing sediment transport. Plan morphologies of ripple marks show a relatively complicated flow pattern dominated by currents moving east to northeastward (Fig.4–2D), that is, almost parallel to the direction of shelf edge. It is considered that the direction of the long-term, averaged sediment transport is northeastward, inferred from the spatial distribution of surface sediments and ripple mark morphology.

The current velocity near the bottom can be inferred from sedimentological data, because bedform type is primarily controlled by the interaction between hydraulic conditions of the flow such as current velocity and flow depth, and sediment properties (e.g. SIMONS *et al.*, 1965; RUBIN and MCCULLOCH, 1980). The ranges of flow conditions necessary to create bedforms such as ripple marks are estimated from experimental and field observations (SIMONS *et al.*, 1965; SOUTHARD, 1971, 1975; RUBIN and MCCULLOCH, 1980). It is estimated that the current velocity necessary to move the sand grain is about 25 cm/s, and the transition from ripple marks to subaqueous dunes is about 70 cm/s at 1 m above the sea bottom, using the relationship shown by RUBIN and MCCULLOCH (1980, Fig. 8). As ripple marks are forming and subaqueous

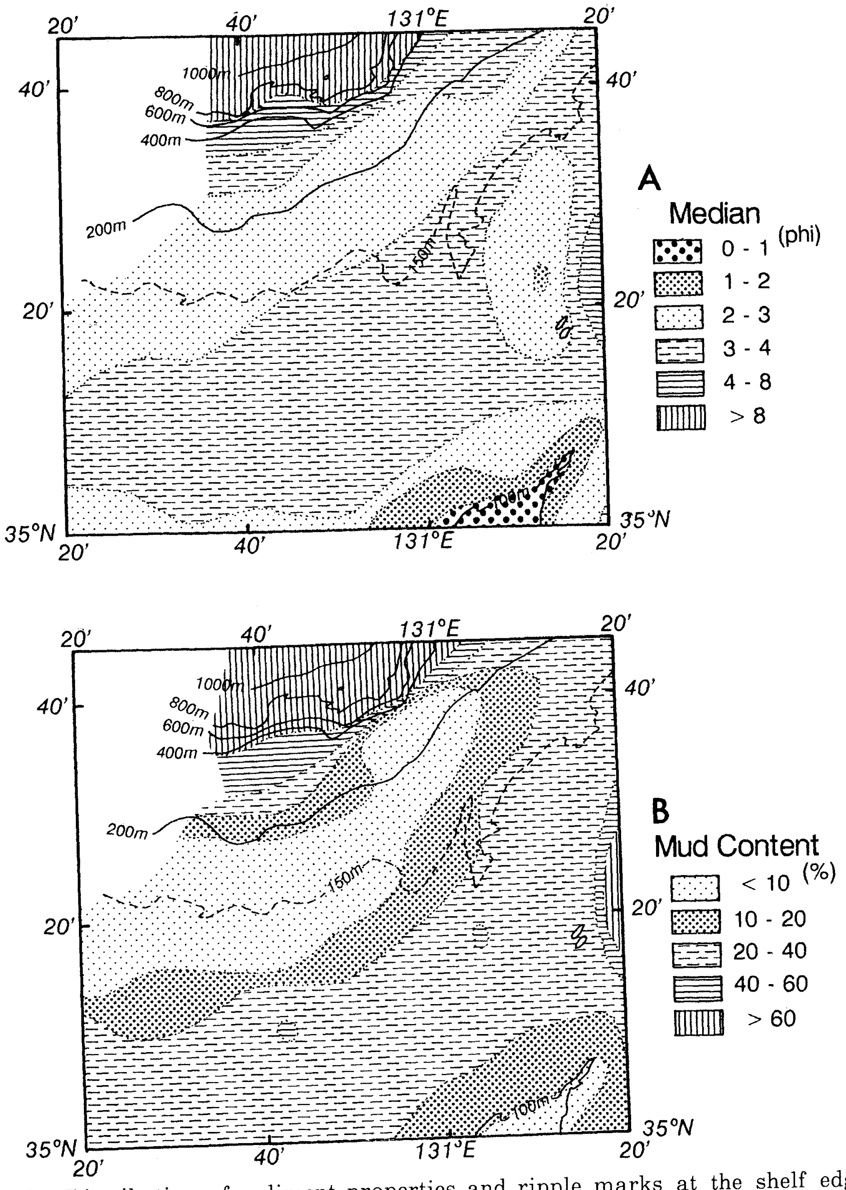

Fig. 4-1. Distribution of sediment properties and ripple marks at the shelf edge of the north of Kita-Kyushu.

dunes are not forming on the fine sand bed at the shelf edge off Kita-Kyushu, it is inferred that the bottom currents have the velocity between 25–70 cm/s at 1 m above the sea bottom.

At the edge of marginal terrace between Mishima Island and the Oki Islands, which has a water depth around 200–500 m, semiconsolidated muddy sediments are exposed on the sea bottm (Fig.5). Some of them are covered by thin sheet of very fine sand with rounded granules. Old and reworked foraminiferal species are contained in the very fine sand (ODA and IKEHARA, 1987; NOMURA and IKEHARA, 1987). Calcareous nannoplankton assemblages in the semiconsolidated mud are different from those in modern mud distributed on both the inner marginal terrace and outer basin, containing cold water species and reworked older fossils of the Cretaceous age (TANAKA, 1986, 1987). Pollen fossils in a semiconsolidated mud collected at Station 862–

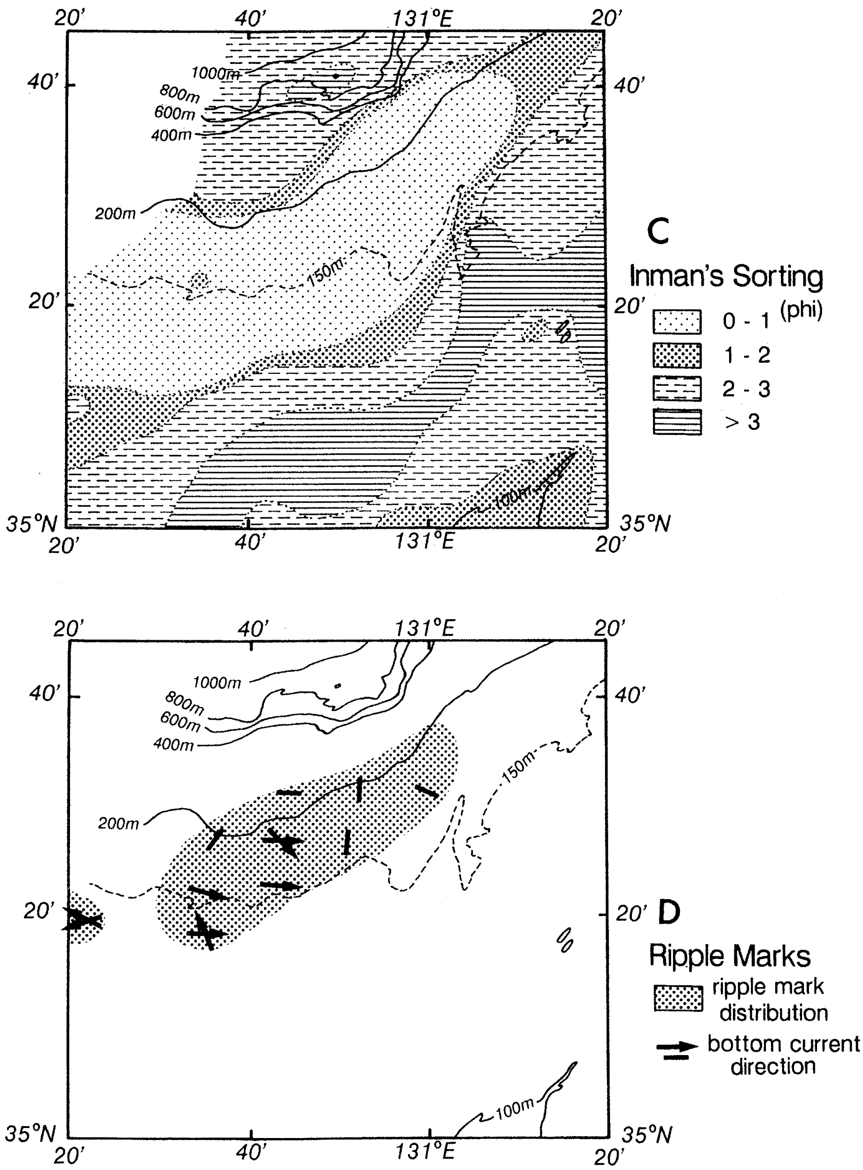

Fig. 4-2.

63 (shown in Fig. 5) with a water depth of 311 m indicate a colder climate (glacial period). That is, it has a high percentage of subarctic flora containing Haploxyon-type Pinus which has five needled leaves and a lower percentage of temperate broad-leaved trees than present (Table 1). Very rough profiles in bathymetric records are found along the southern boundary of the semi-consolidated mud at the north of Mishima Island (OGAWA *et al.*, 1986). Uplift and exposure of older basement are recognized in sub-bottom profiler records (Fig.6), and rocky bottoms are observed at the north of Mishima Island (Fig. 5). In addition, teeth of older elephants (*Palaeoloxodon naumanni* MAKIYAMA) of the Pleistocene age (about 30000–40000 years B.P.; HOSIMI and MORIOKA, 1987; AKIYAMA *et al.*, 1988) have been collected from this area (KAMEI, 1967; AKAGI, 1981; KAMEI *et al.*, 1986). These facts show that the sedimentation rate in this

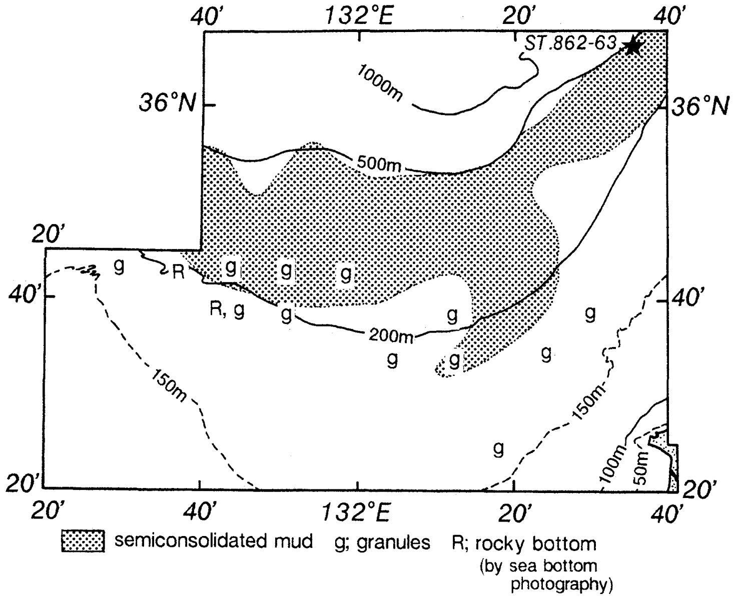

Fig. 5. Distribution of sediment properties at the edge of marginal terrace between Mishima Island and the Oki Islands. Star (upper-right) shows the location of Station 862–63.

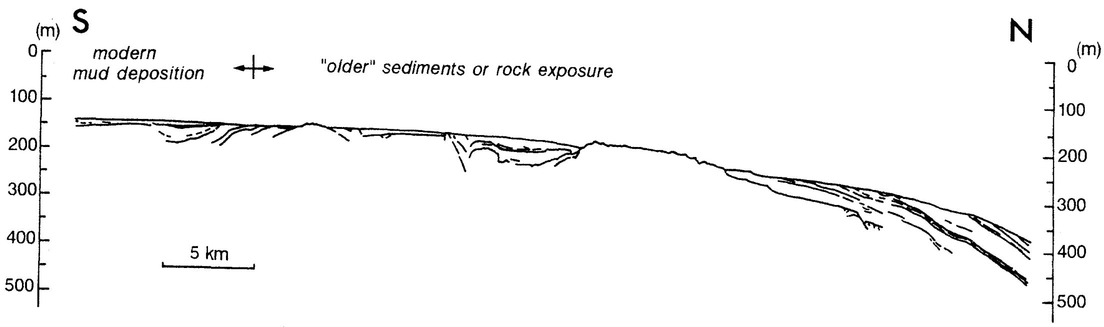

Fig. 6. Seismic (3.5 kHz) profiler record near the edge of marginal terrace at the north of Mishima Island.

area is very small. The occurrence of current lineations on the sea bottom around the rocky area indicates the presence of a bottom current. Therefore, it is considered that this area is now under non-depositional or erosional conditions by the effects of bottom currents.

These sedimentological data show the occurrenct of bottom current along the edge of shelf or marginal terrace. There are some possibilities for the generating force of the bottom currents. One is that the current is caused by the second branch of the Tsushima Current. It is shown from the coincidences of the current path of the second branch with the area where the occurrence of bottom current is inferred, and of the direction of sediment transport at the north of Kita-Kyushu shelf edge with that of the second branch. The second branch is not a permanent flow, present only in summer time (KAWABE, 1982). Therefore, it is difficult to make bottom currents transport the sandy sediments and prevent modern mud deposition throughout the year. Another possibility is the surface water circulations (eddies) formed among the branches or meandering path of the Tsushima Current. These eddies are recognized at both of the north of Kita-Kyushu shelf edge and north of Hamada marginal terrace edge (NAGANUMA, 1972). There is a possibility that the complicated figure in the bottom current pattern inferred from ripple mark morphology at Kita-Kyushu shelf edge (Fig. 4–2) is caused by the complicated bottom water movements near the edge of eddies. Another possibility is the contour currents which flow along depth contour. Although ISODA and MURAYAMA (1991) reported the occurrence of the contour current which flows eastward with the fluctuation of a period of 13.7 days at the shelf edge off Hamada, precise figure of the contour currents is still unclear. Therefore, it is difficult to describe the relationship between the contour currents and the sediment transport. Although there are no data to decide the original force generat the bottom currents at present, bottom currents are controlling the modern sedimentation at the shelf or marginal terrace edge.

6. Summary

Effects of surface water circulation on the sea bottom in the southern Japan Sea are recognized in and around the Tsushima Strait and along the edge of shelf or marginal terrace. At the edge of marginal terrace of north of Hamada, the water circulations influence the sea bottom of 200–500 m deep. Because IKEHARA (1991) showed the current effects on sediment transport and deposition at the western Oki Ridge with a water depth of around 500 m, the bottom current occurs up to 500 m deep. On the other hand, there is no evidence of active bottom current on the shelf and marginal terrace in the eastern part of study area. This suggests that the first branch of the Tsushima Current does not affect the sea bottom in the north of San'in coast.

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