La mer 34: 137–151, 1996
Société franco-japonaise d'océanographie, Tokyo

Mode of mud deposition on shelf to basin area off Akita, northeast Japan Sea

Ken IKEHARA*, Hajime KATAYAMA* and Takeshi NAKAJIMA*

Abstract : Akita shelf is a typical muddy shelf around the Japanese Islands. To clarify dispersal and depositional patterns of terrigenous materials, observations for concentration of suspended materials, analyses of sediment grain size and of coarse fraction compositions of sediments, and of seismic records were carried out. As the result, most of terrigenous fine materials had been transported through bottom nepheloid layers and deposited in shelf-slope area off Akita. Based on spatial distribution of plant debris, biotite and pumice in coarse fraction, terrigenous materials derived from Omono River had been transported westward and then southward.

Because concentration area of plant debris was well-concordant with the area of silt distribution, sand-sized plant debris was thought to be a useful tracer of terrigenous fine silt. Deposition of terrigenous organic materials in silty sediments formed high C/N ratio sediments along the outer shelf to slope area. High rate of organic material supply resulted in low oxidation-reduction potential. Total 1.56 million tons of fine grained materials had been deposited in shelf-slope-slope basin area in a year.

Compared with annual mean discharge from major rivers around this area, almost of all materials supplied from Omono and Koyoshi Rivers and 40-50% of annual discharge from Mogami and Aka-gawa-shin-kawa Rivers had been deposited in this area. On the basis of annual mean volume of sediment accumulation and organic carbon content of surface sediments in several basins of Japan Sea, shelf-slope mud is very important for consideration of material cycles in Japan Sea.

1. Introduction

Dispersal and depositional patterns of terrigenous materials are a big problem on marine sedimentology as well as material transport and cycle in marine environments. Therefore, sedimentological studies have been carried out on the shelves near the river mouths (MILLIMAN *et al.*, 1987: ALEXANDER *et al.*, 1991; PUJOS and JAVELAUD, 1991; LESUEUR and TASTET, 1994; DÍAZ *et al.*, 1996). MILLIMAN and SYVITSKI (1992) and MILLIMAN (1995) indicated the importance of geomorphic and tectonic control for sediment discharge to the ocean. Japan is a typical example of tectonically active area in the world, where high mountains are located near the shores. Then, it is important to clarify sediment budget around the Japanese islands and to compare it with those from the other tectonic or geomorphic settings.

Bottom sediments have recorded the long-term, averaged history of deposition and erosion, and of dispersal pattern of materials, which is difficult to detect by usual oceanographic measurements, because sediments are final state of transported materials. As materials derived from rivers have been transported according to water circulation, it is possible to infer the water circulation pattern in an area from sedimentological data. Therefore, sediment analysis is an imortant tool to clarify transport of materials and water circulation pattern, in particular, in an area where current measurement data are very limited (IKEHARA, 1992, 1993).

Akita shelf is a typical muddy shelf around the Japanese Islands. There are two slope basins (Tobishima and Oga Basins) which are isolated from offshore deep-sea trough

* Marine Geology Department, Geological Survey of Japan, Tsukuba, Ibaraki, 305 Japan

(Mogami Trough) by a north-south trended topographic high. Under these topographic conditions, almost of all terrigenous fine grained materials have been deposited on shelf-slope-slope basin setting. Therefore, it is a preferable area to consider material transport from land to coastal sea. To clarify the above mentioned problems, we would like to reexamine our sedimentological data. As the result, we clarified dispersal and depositional pattern of terrigenous fine particles, origin of high C/N ratio sediments at the outer shelf to upper slope, oceanographically controlled sedimentation, which was highly influenced by land and submarine topography, and sediment budget in this area.

2. Physiography and oceanography of study area

There are three large coastal plains in the study area (Fig. 1A). That is, Akita Plain at the north, Honjo Plain at the central, and Shonai Plain at the south. Major rivers in each plain are Omono river (annual mean water discharge; 243.50 m^3/sec) at Akita Plain, Koyoshi River (72.77m^3/sec) at Honjo Plain and Mogami River (358.50m^3/sec) and Aka-gawa-shin-kawa River (74.40m^3/sec) at Shonai Plain. Water discharge from these rivers showed seasonal variability and higher in early spring when snow was melted and in rainy season (late spring to early summer). These rivers and the other small rivers have transported sand and mud to the plains.

The major submarine topographic features in the study area are the north-south trended topographic highs from Tobishima Island at the south to Oga-muko-se Bank at the north, two slope basins (Tobishima Basin and Oga Basin) and wide shelf at the south of Oga Peninsula and the Mogami Trough (Fig. 1A). Shelf in the study area is wider in the northern (around Oga Peninsula) and the southern (Yamagata) area than in the central area (off Honjo to Mt. Chokai-san). There are two slope basins, Tobishima (447 m at the deepest position) and Oga Basins (537 m), between shelf and the topographic highs from Tobishima Island through Shin-guri Bank (135 m at the shallowest position) to Oga-muko-se Bank (96

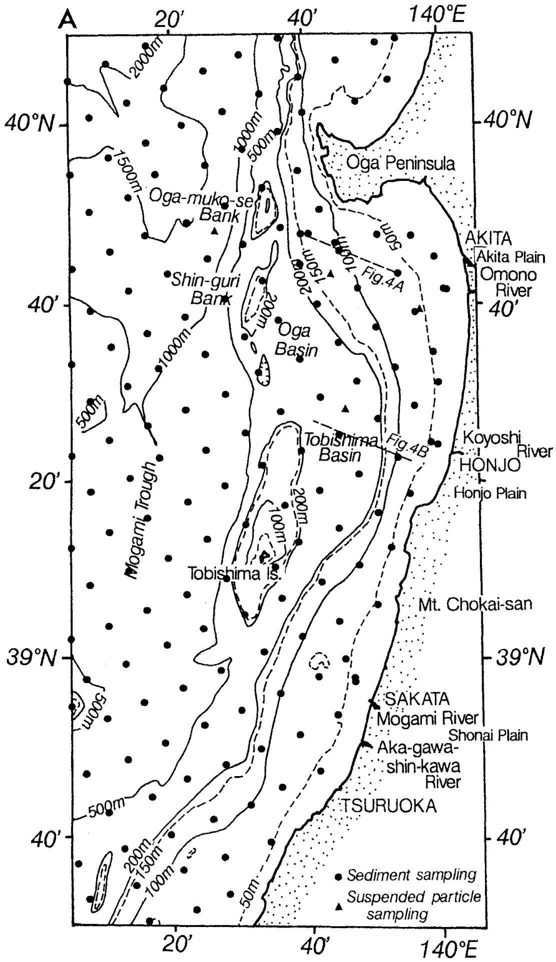

Fig. 1. Sampling stations of bottom sediments (solid circles) and of suspended particles (solid triangles) with bathymetry (A) and seismic survey lines (B).

m). They are separated by a small topographic high with NE-SW trend from Tobishima Island. Mogami Trough is the north-south trended trough with the water depth deeper than 800 m.

The Japan Sea water is divided into the surface and deep waters at the water depth of around 100–200 m. Surface water with high temperature, high salinity and low oxygen concentration originated from the Tsushima Current. The Tsushima Current inflows through the Tsushima Strait and flows northeast to northward in the region of the present study. Current velocities are higher in summer

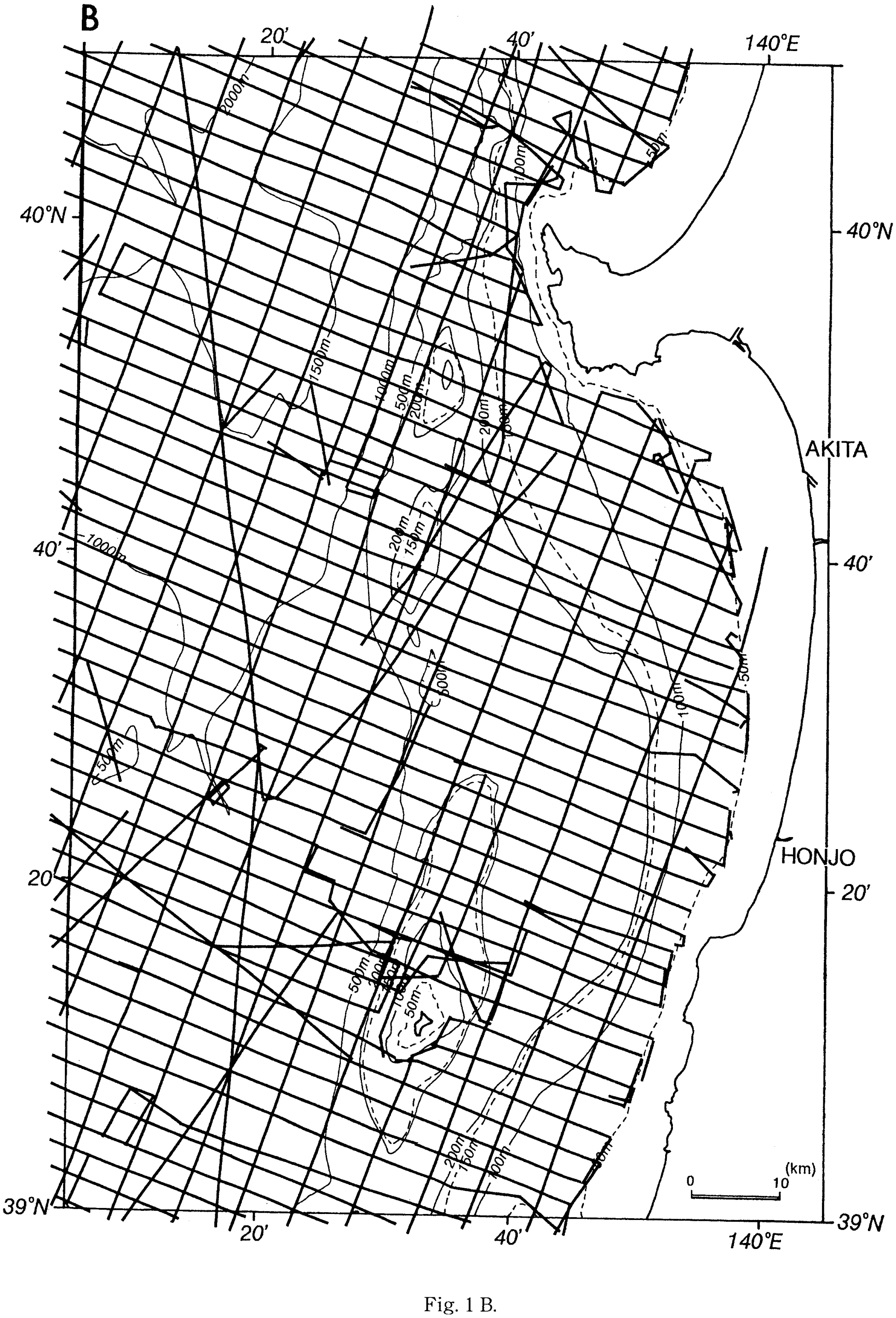
B
20'
40'
140°E
40°N
40'
20'
39°N
AKITA
HONJO
(km)
0
10
2000m
1000m
500m
200m
150m
100m
50m

Fig. 1 B.

(0.1–0.9 knots in vector mean velocity) and in the north of Oga Peninsula (0.5 knots) than in winter (0–0.6 knots) and in the southern area (0.1–0.3 knots) (Japan Oceanographic Data Center, 1979, 1991). Temperature and salinity of surface water change seasonally (YAMAMOTO and IMAI, 1990). Surface temperature becomes higher, and salinity becomes lower landward. Remarkable decrease of surface water salinity is found in spring corresponded to large input of snow melt fresh water. Deep water, which called the Japan Sea Proper Water (JSPW), has low temperatures (0–1℃), rather low salinities (34.0–34.1 PSU) and high oxygen concentration (5.0 to more than 7.0 ml/l) (SUDA, 1932; NITANI, 1972).

3. Materials and methods

Total 130 of surface sediment samples from Akita area and 39 samples from Niigata-Yamagata area, both of which included more offshore area such as Mogami Trough and Sado Ridge, were collected by a Kinoshita-type grab sampler (Fig. 1A) during the cruises of GH89-2 (May-July, 1989), GH90 (June-July, 1990) and GH91 (June-July, 1991) of R/V Hakurei-Maru by the Geological Survey of Japan. Sediment grain size of surface sediments was determined by sieve analysis for sand fraction (coarser than 4.5ϕ (44μm) and hydrometer analysis for mud fraction (finer than 4.5ϕ). Composition of coarse fraction (1.75ϕ (0.3 mm)–2ϕ (0.25 mm) and 0.75ϕ (0.6 mm)–1.0ϕ (0.5 mm) fraction) were counted under a binocular. More than 200 grains were counted for each sample.

Seismic reflection survey by using high frequency (3.5 kHz) sub-bottom profiler was conducted along the 1.7 mile intervaled NW-SE and the 3 mile intervaled NE-SW survey lines (Fig. 1B). Acoustic facies analysis was conducted for the records and thickness of the uppermost sediment layer was measured.

Temperature and salinity of surface and bottom (1.5 m above the sea bottom) water was measured by using a thermometer and bathythermograph and digital salinometer (Tsurumiseiki E-202) at the same time and station of sediment sampling to understand oceanographic background of sedimentation. Turbidity (light transmission values) was measured by using a Sea Tech transmissometer (ST025-D) along two survey lines in June-July, 1992 during the cruise of GH92 (Fig. 2). Compositions of suspended particles collected at four stations (solid triangles in Fig. 1A) were observed by using scanning electron microscopy. Oxidation-reduction potential (ORP) of surface sediments has also measured at all stations of sediment sampling by using a digital pH meter (Denki-kagaku Co. HPH-22) with an ORP elctrode.

4. Results

4–1 Oceanographic and environmental aspects of study area

Salinity and temperature of surface water became lower in coastal area than in offshore area. Distribution of surface and bottom water salinity showed wide cover of low salinity coastal water on the inner and mid shelf, especially at the northern part, indicating the influence of riverine fresh water from the Omono River. On the basis of sea bottom photography, suspended particles were higher content in coastal area. Profiles of light transmission values across shelf indicated higher concentration of suspended particles in coastal water than in offshore water (Fig. 2). Profiles also indicated the occurrence of three layers of high suspended particle concentration. The first one is a surficial layer mainly found in the inner to mid shelf. Second one is an intermediate layer located at the water depth of 60–80 m. Third one is found at the just above the sea floor. On the basis of preliminary observations of grain compositions of each layer by using electron microscopy, grains in surficial and intermediate layers were mainly composed by biogenic grains but those in bottom layer were composed by mineral grains.

Oxidation-reduction potential (ORP) of surface sediments became lower values in muddy sediments than in sandy sediments and showed minus values, indicating reduction conditions, in muddy basin sediments in Tobishima Basin. Also, ORP was higher in deeper trough, because of the influence of the Japan Sea Proper Water (JSPW) cointaining higher concentration of oxygen.

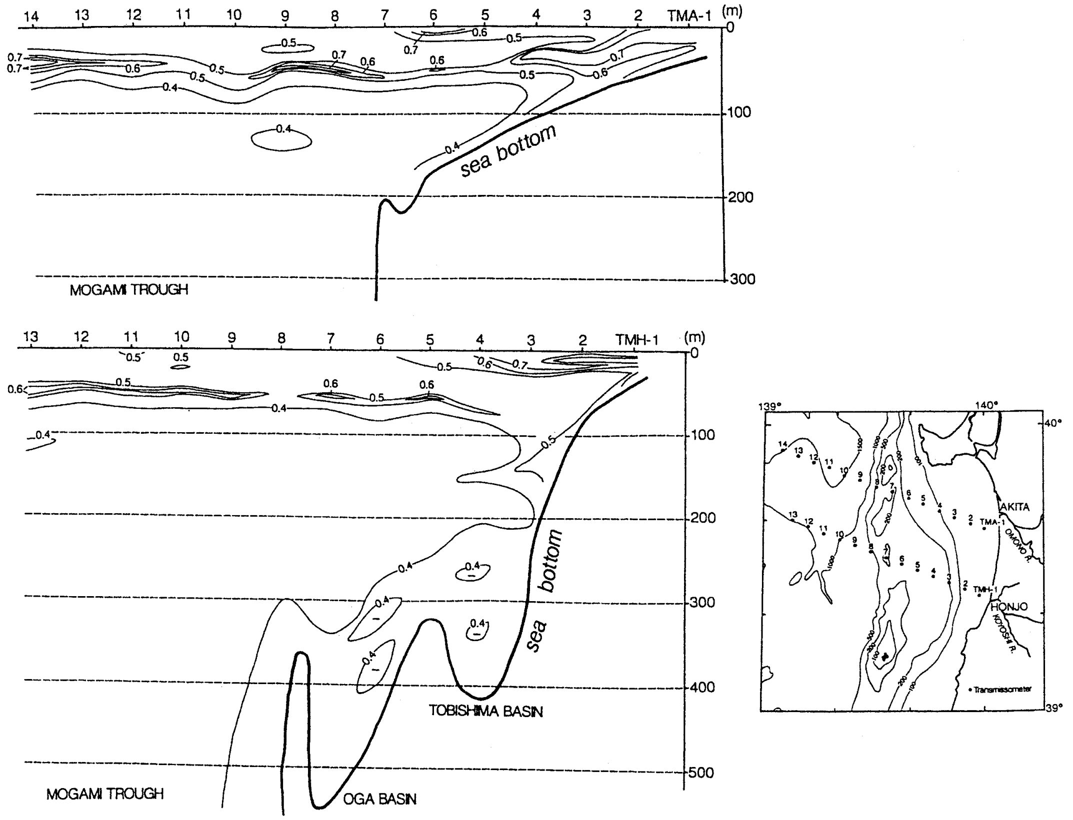

Fig. 2. Distribution of beam attenuation coefficient (C) values across the shelf. Three high concentration layers were recognized. Relation between C and S (suspended material concentration) is: S=1.15 (C-0.358) (BISHOP, 1986).

4-2 Sediment grain size and compositions

Spatial distribution of sediment grain size (Fig. 3) indicated that Akita shelf was a typical graded-shelf where sediment grain size became finer offshoreward with increasing water depth. That is, well-sorted fine sand indicating wave effects distributed at the water depth shallower than 40 m. Coarser medium sand and gravels and rock exposures were found along the southern coast of Oga Peninsula and on a north-south trended topographic high from Tobishima Island to Oga-muko-se Bank. Grain size became finer offshoreward, and very fine sand and silt widely covered the mid-outer shelf. Finer clay was deposited in Tobishima and Oga Basins and Mogami Trough. Only the exception of graded-shelf in this area was found on the outer shelf at the south to southwest of Oga Peninsula, where very fine-fine sand was distributed. This sand contained high percentage of mud and was poorly sorted.

Surface sediments of Yamagata shelf just south of Akita shelf were mainly composed of sandy sediments. That is, well-sorted fine sand distributed in coastal area and fine-medium sand widely covered the mid-outer shelf. Fine grained sediments such as very fine sand and silt were only found at the mid shelf off Kisakata and at just offshore of Mogami River mouth.

Compositions of coarse fraction of sediments indicated that quartz, lithic fragments, pumice and biotite were dominant in sandy coastal sediments. Glauconite pellets (TRIPLEHORN, 1966) were commonly found in sandy sediments on the outer shelf off Akita. Silty sediments at the outer shelf to upper slope contained a large number of plant debris and pumice. Sand grains were very few and its compositions showed very wide diversity in

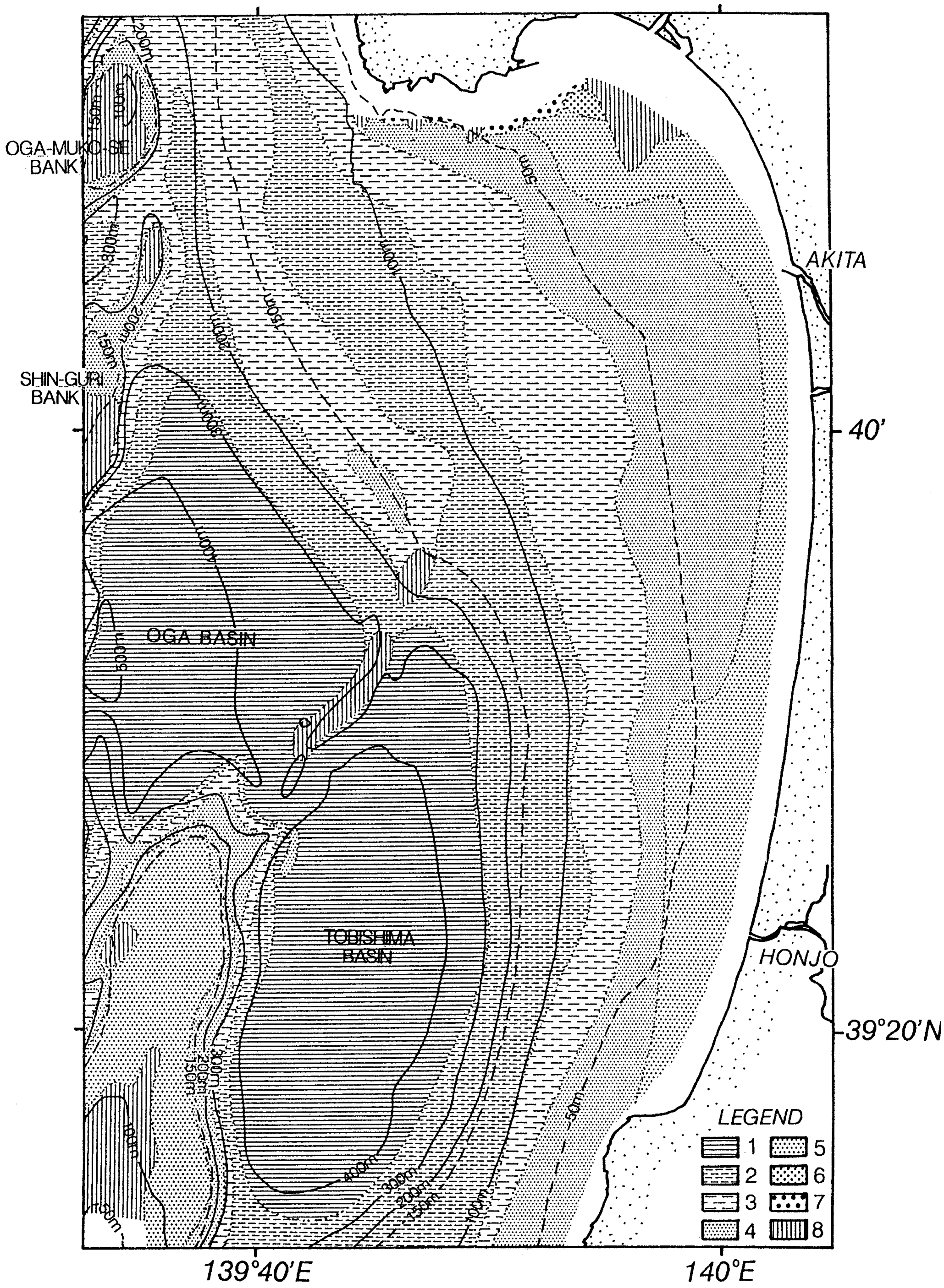

Fig. 3. Sediment distribution off Akita. 1; clay (Md ϕ; > 8), 2; fine silt (6–8), 3; coarse silt (4–6), 4; very fine sand (3–4), 5; fine sand (2–3), 6; medium sand (1–2), 7; gravel (<−1), 8; rocky bottom.

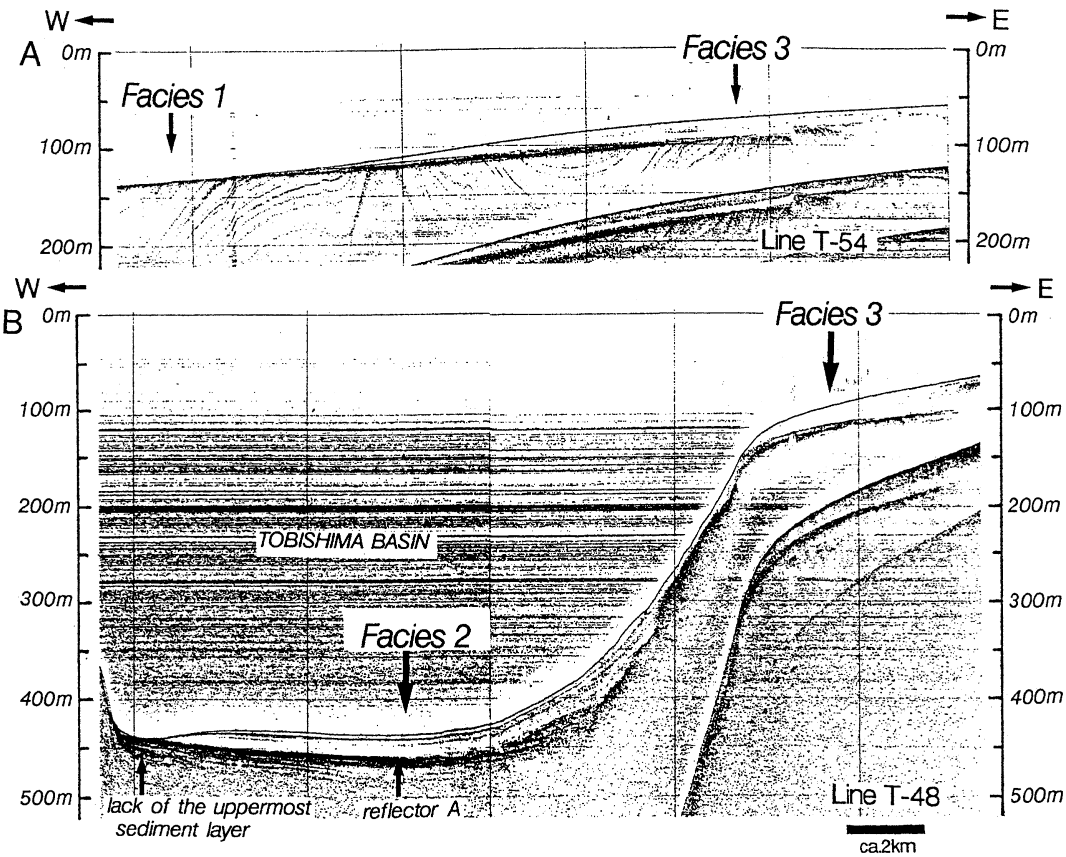

Fig. 4. Seismic (3.5kHz) profiler records on the shelf off Akita (A) and at the shelf-slope off Honjo (B). A: The uppermost sediment (transparent) layer becomes thinner offshoreward and absent at the outer shelf indicating no or very low sedimentation rate. Tilted and folded sediment layers are observed below the transparent layer. B; The transparent layer on the shelf continues to the uppermost sediment layer in Tobishima Basin. Stratified or prolonged facies was found below reflector A.

clayey sediments.

4-3 Acoustic facies and sediment thickness

Three acoustic (seismic) facies in high frequency (3.5kHz) sub-bottom profiler records were recognized in the study area. The characteristics of acoustic facies were influenced by grain size and degree of consolidation of sediment layers, and by morphology of sea bottom and boundaries between sediment layers (NARDIN *et al.*,1979). Also, some acoustic facies were formed by a specific sedimentation process such as slope failure. Therefore, distribution of acoustic facies gives us good information on sedimentation.

Acoustic characteristics and spatial distribution of each acoustic facies were described below. On the shelf, distinct (Facies 1), which showed strong bottom return, and transparent facies (Facies 3) were found. Facies 1 was correnponded to sandy or gravelly or rocky bottoms. This facies was found in the inner shelf and at the outer shelf of the south to southwest of Oga Peninsula and on the topographic highs from Tobishima Island to Ogamuko-se Bank. Stratified facies (Facies 2) was commonly found in basins and trough where hemipelagic muddy sediments and some turbidites were deposited. The other acoustic facies was transparent facies (Facies 3), which had no or very poor internal reflectors and with weak bottom return. This facies was

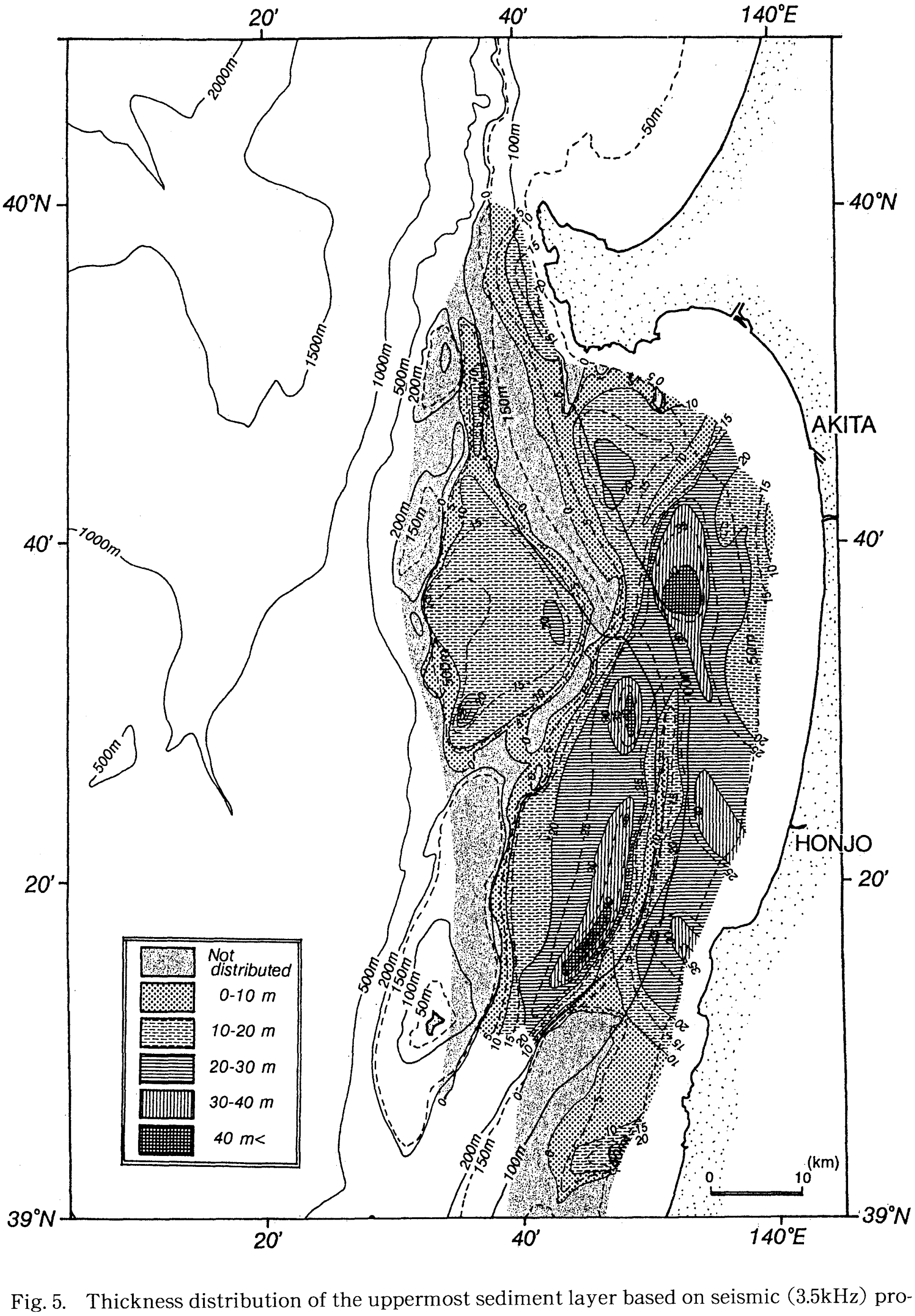

Fig. 5. Thickness distribution of the uppermost sediment layer based on seismic (3.5kHz) profiler records.

widely recognized in shelf to slope areas.

An acoustically transparent layer on the shelf (Fig. 4A) could be traced to the uppermost sediment layer in Tobishima Basin (Fig. 4B). The uppermost sediment layer showed acoustically transparent facies and overlaid the sediment layer with well stratified or prolonged acoustic facies indicating occurrence of coarser sediments. Spatial distribution of the thickness of transparent layer was shown in Fig. 5. The map showed a thickly deposited sediment belt from the west of Akita to the northern part of Tobishima Basin and thicker deposition on the outer shelf at the west of Akita (thickness; more than 40 m). Western end of the belt was limited by a NNE-SSW trended topographic high, but some of sediments flowed over the high and deposited more westward. Seismic records (Fig. 4A) clearly indicated that the layer covered the older and inclined sediment layer at the shelf and the older layer exposed sea floor at the outer shelf of the southwest of Oga Peninsula. Thickness became thinner at the outer shelf to upper slope area off Honjo (Fig. 5). Thickest distribution was found at the eastern foot of slope area of the southern Tobishima Basin (thickness; more than 50m).

5. Discussions

5-1 Mode of transport of terrigenous fine grained materials to offshore

Profiles of light transmission values across the Akita shelf (Fig. 2) clearly indicated the occurrence of three high suspended particle concentration layers. Because higher concentration is found coastal area than in offshore area, source of suspended materials was located coastal side. Grain compositions of each layer suggested that terrigenous fine materials had been transported through the high concentration layer just above the sea floor (bottom nepheloid layer).

Bottom nepheloid layer sometimes burtificate or detached from sea floor near the inflection points of bathymetry (water depth was around 150 m; Fig. 2). Major thermocline, which was boundary between surface water and deep water (the Japan Sea Proper Water), located almost the same water depth. As salinity of bottom water was not changed largely between the water mass boundary, the thermocline formed density boundary. A part of bottom nepheloid layer detached from sea floor and flowed offshoreward along the surface of the density boundary.

Suspended material concentration and thickness of high concentrated layer was higher in Tobishima and Oga Basins than in Mogami Trough (Fig. 2). Therefore, most of terrigenous fine grained particles were trapped and deposited in two basins.

5-2 Dispersal pattern of terrigenous fine grained materials from Omono River

Larger grains with lower specific gravities than mineral grains such as plant debris were transported with smaller mineral grains. Also, easier transported particles such as biotite were transported with smaller grains, because of their specific morphologies (IKEHARA *et al.*, 1988). Therefore, concentration of these grains indicated the depositional areas and transport directions of smaller mineral grains. Especially, plant debris was a clearly land source component (IKEHARA *et al.*, 1988; IKEHARA, 1991). Then, there is a possibility that the distributions of each component showed the transport paths of sediment particles from land to offshore.

On the basis of relation between spatial distributions of composition of coarse fraction and sediment grain size, some of sand-sized components were used for tracers of transport of finer grains. For example, plant debris was concentrated in silt (Fig. 6), then plant debris was used for a tracer of terrigenous silt grains. Similar concentration of plant debris in silty sediments was also found at the sediments of Niigata shelf (IKEHARA *et al.*, 1994a). HOSHINO (1958) showed that plant debris was concentrated along the boundary of water masses. But at the offshore of Akita, there was no relation between water mass boundary shown in salinity distribution and concentration of plant debris. On the other hand, biotite grains were dominant in very fine sand-coarse silt, especially at the west of older Omono River mouth (Fig. 6). Biotite has nearly the same specific gravity (2.7-3.3) as quartz (2.65). Biotite, however, is easily transported by currents, because

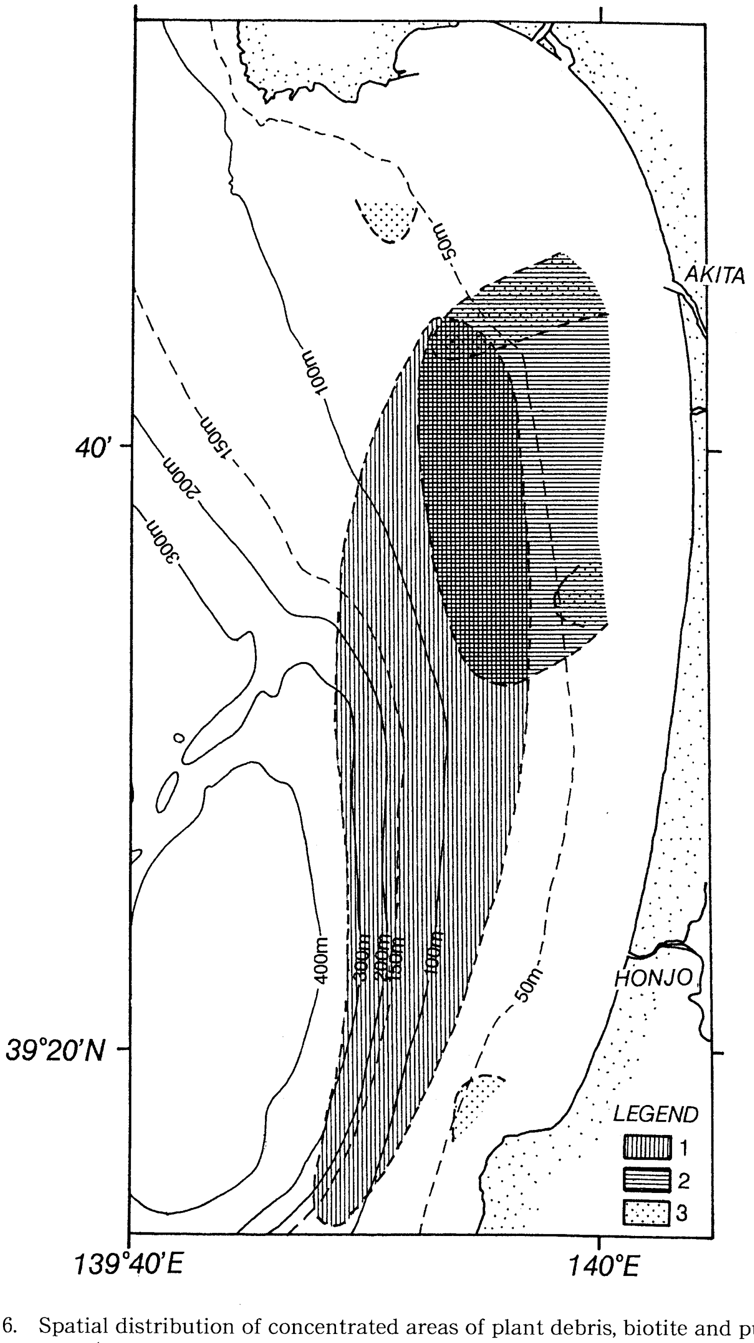

Fig. 6. Spatial distribution of concentrated areas of plant debris, biotite and pumice in coarse fraction (0.25–0.3mm in diameter). 1; plant debris (higher than 30% in composition of coarse fraction), 2; biotite (higher than 10%), 3; pumice (higher than 30%).

of their specific morphology (planar shape). And there are some reports on relation between biotite concentration and current systems (IKEHARA, 1991). Boundary in grain size between suspended load and traction load in state of sediment transport was found in very fine sand. Therefore, biotite concentration was a tool for tracing the transport path of the coarsest suspended particles. Concentration of pumice grains of the same size fraction were higher in very fine to fine sand, and very low in finer than very fine sand (Fig. 6). Distribution of pumice indicated that the grains were not supplied through the air (air fall pumice), but through the rivers or coastal erosion.

Judging from distribution patterns of coarse fraction of these three components (Fig. 6), sediment particles discharged from Omono River were transported westward and then southward. As mentioned earlier, terrigenous fine grained materials were transported offshoreward through the bottom nepheloid layers. Because directions of particle transport were controlled by those of bottom currents and sediments recorded the long-term averaged oceanographic conditions which were difficult to observe by normal oceanographic observations (IKEHARA, 1992), sediment transport paths showed the long-term averaged directions of bottom currents in this area.

Reported values of C/N ratio of surface sediments in this area (NOMURA, 1992) indicated high ratio (around 12 in weight ratio) for silty sediments at the outer shelf to upper slope. That means higher supply of terrigenous organic matter to the outer shelf-upper slope. As shown in Fig. 6, plant debris was dominant in coarse fraction in this area. Combined with above mentioned sediment transport path, terrigenous organic matters from Omono River and surrounding areas were transported and deposited at the outer shelf to upper slope and formed the sediments with high C/N ratio. Oxidation-reduction potential indicated minus values in this area showing reductional conditions. Decomposition of terrigenous organic matter supplied to the area used oxygen in bottom water and made a reductional condition.

5–3 Oceanographic control of modern sedimentation

Sediment grain size was affected by the oceanographic conditions such as currents, waves and water mass distribution (HOSHINO, 1958; IKEHARA, 1993). Although deposition of muddy sediments was controlled by the amount of supply and of removal to and from an area, muddy sediments were generally distributed under lower energy environments. On the contrary, sandy sediments were distributed along the current path (IKEHARA, 1992, 1993). Because muddy sediments were predominant at the offshore of Akita except of the outer shelf at the southwest-west of Oga Peninsula (Fig. 3), Akita area is thought to be under low energy environments. On the other hand, sandy sediments widely covered Yamagata shelf just south of Akita shelf. There are some large rivers in Akita (Omono and Koyoshi River) and Yamagata (Mogami and Akagawa-shinkawa River) areas. Annual mean discharges of suspended materials from these rivers in Akita area were smaller than those in Yamagata area. Then, it is difficult to explain the difference in shelf sediment types by the difference in the supply of fine grained materials to the shelves. Currents and waves were major factors for sediment reworking. That is, strong currents and waves agitated sea bottom and reworked fine grained sediments to downstream or offshore direction. Therefore, there is a possibility that difference of sediment types between two areas has been controlled by the intensity of currents and/or waves.

Two topographic effects controlling current and wave conditions are thought to be occurred in these areas. First effect is the occurrence of offshore topographic highs. There is a north-south trended topographic high from Oga-muko-se Bank to Tobishima Island off Akita shore, but no topographic high at the outer shelf off Yamagata shore. The topographic high will play a barrier to intrude currents and large waves from offshore and make a low energy and stagnant condition at the back of the barrier. Under such condition, riverine fresh water easier extended and formed low salinity coastal water in the inner shelf. Because coastal water, as mentioned earlier, contained higher amount of suspended materials, muddy sediments were deposited.

Shoreline morphology was another topographic effect (IKEHARA, 1993). That is a large projection, Oga Peninsula, is located just north of Akita and forms an open bay (Akita Bay) between the Peninsula and Akita coast. Isobath contours curved into eastward. The bathymetric condition prevents the direct invasion of the currents to the bay and forms preferable condition to develop coastal water. The condition was corresponded to type A-1 or A-2 of modern mud deposition (effects of topographic barrier) of IKEHARA (1993). Occurrence of bedforms such as ripples, and of well-sorted sandy sediments and lack of modern muddy sediments was indexes for occurrence of bottom current along the shelf edge of San'in coast (IKEHARA, 1992). Although there were no ripples and well-sorted sediments on Yamagata shelf, surface sediments with low mud contents along the outer shelf off Yamagata indicated the occurrence of currents removing fine grained particles throughout the Yamagata shelf. On the other hand, lack of the uppermost sediment layer was found along the shelf edge of Akita coast (Fig. 4A). Glauconite pellets, which were autochthonous minerals and indicated non-deposition or very low sedimentation rates, were found in this zone. These facts indicated that the currents flowed over Yamagata shelf and along the outer shelf off Akita.

Major current system in Yamagata and Akita areas is thought to be the Tsushima Current. The Tsushima Current has flowed northward along the shelf edge. Therefore, fine grained particles, which did not deposit on Yamagata shelf and on the outer shelf off Akita, might be transported northward. A concentrated area of plant debris in surface sediments occurred along the west coast of Oga Peninsula. Thick mud deposition also found in this area. Because of no large source of plant debris and fine grained materials in Oga Peninsula, there is a possibility that some of terrigenous materials from Omono River have been transported northward through Akita shelf along the southern coast of Oga Peninsula.

5-4 Sediment accumulation and budget

On the basis of thickness distribution of the uppermost sediment layer (Fig. 5), volume of deposited sediments was calculated to be 15.6 billion tons. Judging from age estimation of underlined sediments of the uppermost sediment layer in Tobishima Basin (WATANABE, 1994) and depositional pattern in seismic records, the uppermost sediment layer was thought to be deposited after the last glacial maximum and during latest Pleistocene-Holocene ages. To calculate annual volume of sediment deposition, we used 10,000 years for duration of sediment formation. Therefore, 1.56 million tons of sediments per year were deposited in the survey area.

By the way, there was a higher sea level stage at 5,500–6,000 years before present (the Jomon Transgression), when the sea level was 2-6 m higher than the present level (OTA *et al.*, 1982). At the Akita Plain, the shoreline retreated 3.5 km from the present shoreline at 5,500 years before (MORIWAKI, 1982). During the higher sea level stage, location of river mouths retreated to landward and terrigenous muddy sediments deposited at more inshore area (below the present coastal plains) (MORIWAKI, 1982; Geological Research Group of Akita University on the Nihonkai Chubu Earthquake 1983, 1986). In this study, because of lack of enough data for calculation of sediment volume deposited under modern coastal plain, we can know only the volume of sediments deposited offshore area. Therefore, true volume of deposited sediments was larger than the value mentioned above.

Values of annual mean water discharges and suspended sediment content of each major river in the study area during 1969–1973 were edited by Japan Rivers Association (1974). By using these data, total amount of suspended sediment supply to this area was considered to be 0.78 million tons/year from Omono River and 0.05 million tons/year from Koyoshi River. Including with discharge from small rivers and coastal erosion, suspended sediments of around 0.8-0.9 million tons/year had been transported to this area and deposited. Because of the occurrence of topographic highs from Tobishima Island to Oga-muko-se Bank and of slope

Table 1 Sediment and Organic Carbon Accumulation in the Japan Sea

	Area ($\times 10^{10} m^2$)	Averaged Sed. Rate ($cm/10^3 y$)	Sediment Accuml. Rate ($\times 10^{-3} g/cm^2/y$)	Sed. Volume with water ($\times 10^6 m^3/y$)	Sediment Accuml. Volume ($\times 10^6 t/y$)	Organic-C Content (wt.%)	Org-C Mass Accuml. Rate ($\times 10^{-5} g/cm^2/y$)	Organic-C Accuml. Weight ($\times 10^4 t/y$)
Tsushima Basin	3.85	14.7	5.88	5.66	2.26	1–2	5.88–11.8	2.26–4.52
SW Yamato Basin	4.47	12.8	5.76	5.72	2.57	1–2	5.76–11.5	2.57–5.14
Oki Trough	0.88	16.7	6.68	1.46	0.58	2	13.4	1.16
Toyama Deep-sea Fan	1.22	12	6	1.46	0.73	1–2	6–12	0.73–1.46
Marginal Terrace (off Tottori)		(10–45)	(8.6–38.7)	0.99	0.85	2	(17.2–77.4)	1.7
Toyama Bay	0.6	〉 30 (35–40)	〉 15 (17.5–20)	〉 1.8 (2.1–2.4)	〉 0.9 (1.05–1.2)	1–2	〉 1.8–3.6 (2.1–4.8)	〉 0.9–1.8 (1.05–2.4)
Sado Basin	0.1	〉 30 (140–200)	〉 17 (77–110)	〉 0.3 (14–20)	〉 0.17 (7.7–1.1)	1.7	〉 0.5 (1.3–1.9)	〉 0.29 (13–18.7)
Niigata Shelf				1.56	1.33	1.5		1.99
Off Akita (shelf-basin)	0.4			2.6	1.56	1.5–2		2.34–3.12

basins, almost of all terrigenous materials have been trapped to shelf to basin area. Then, around 0.7 million tons of sediments have been transported from the other area. There are two large sources near the study area; one is Noshiro River, which have supplied 0.6 million tons of sediments per year, located at the north of the study area, and another is Mogami River, which have supplied 2.4 million tons of sediments per year, located at the south of the study area. Major current system around the study area is controlled by the Tsushima Current, of which flow direction is northward. Then, it is hardly to transport fine grained materials southward from Noshiro River against the major current system. Therefore, most probable major source of terrigenous materials is Mogami River. Judging from the annual mean sediment discharge from Mogami River and the remain between sediment deposition and supply from Akita area, 40–50% of suspended sediments from Mogami River have been transported northward and deposited in the southern part of Tobishima Basin.

5–5 Significance of shelf-basin area in sediment budget of Japan Sea

Sedimentation rates in offshore basins of Japan Sea such as Tsushima and Yamato Basins and Oki and Mogami Troughs were considered to be 10–25 cm/1000 years (MASUZAWA, 1987; IKEHARA *et al.*, 1994b), and became higher landward (IKEHARA *et al.*, 1994b). Although eolian input has been an important factor for sedimentation rates in Japan Sea (MASUZAWA, 1991), spatial difference in sedimentation rates was influenced by supply of terrigenous materials. By using the sedimentation rates and areas of each basin, annual accumulation of sediments was calculated in Table 1. On the other hand, IKEHARA *et al.* (1994a) inferred annual accumulation on Niigata shelf, which is another muddy shelf in Japan Sea, as 1.33 million tons per year from the thickness distribution of shelf sediments. Estimated value of sediment accumulation in Akita area was the same order as those of Niigata shelf and of large offshore basins such as Tsushima and Yamato Basins and a little larger than those of small offshore basins such as Oki Trough. That means high rate of material supply to the shelves and adjacent basins from land supported higher sedimentation rates and most of terrigenous fine particles were thought to be deposited in this area.

Reported values of organic carbon content in shelf-slope sediments (1.5–2 wt. %) were a little higher than those in offshore basin sediments (0.8–2 wt.%; HAMAGUCHI and OTA, 1953; HAMAGUCHI *et al.*, 1954; NOMURA, 1992). By using accumulated sediment volume and organic carbon content, 20–30 thousand tons of organic carbon had been deposited in an offshore large basin and on a muddy shelf-slope area in a year. Because of higher sedimentation rates, larger volume of organic carbon was deposited in shelf-slope mud is very important to consider material (carbon) cycles in Japan

Sea.

6. Conclusions

Profiles of concentration of suspended materials, spatial distributions of sediment grain size and of sediment compositions, and thickness distribution of the uppermost sediment layer suggested the following remarks.

1) Most of terrigenous fine grained materials had been transported through bottom nepheloid layer and deposited in shelf-slope area off Akita.

2) Concentration area of plant debris of 0.25–0.3 mm in diameter was well-concordant with silt distribution. Therefore, sand-sized plant debris was thought to be a useful tracer of terrigenous silt.

3) Deposition of terrigenous organic materials in silty sediments formed high C/N ratio sediments along the outer shelf to slope area. High rate of organic material supply resulted in low oxidation-reduction potential (reductional condition).

4) Land and submarine topography might be influenced to current systems and caused the difference in distributions of bottom sediment types between Akita and Yamagata shelves. The Tsushima Current, which flows along the shelf edge off Akita, has prevented mud deposition on Yamagata shelf and on the outer shelf at the southwest of Oga Peninsula.

5) Total 1.56 million tons of muddy sediments had been deposited in this area in a year. Compared with annual mean discharge from major rivers around this area, almost of materials supplied from Omono and Koyoshi Rivers and 40-50% from Mogami River had been deposited in this area.

6) Judging from annual mean volume of sediment accumulation and organic carbon content of surface sediments in several basins of Japan Sea, shelf-slope mud is very important for consideration of material cycles in Japan Sea.

Acknowledgements

We express our hearty thanks to officers, crew and scientists of the R/V Hakurei-Maru for their kind help throughout the surveys. Acknowledgements are due to Mr. Mahito WATANABE of the Geological Survey of Japan and Mr. Masahiro NOMURA of Niigata University for providing us the results of diatom analysis and organic carbon content measurements. We are grateful to Drs. Masafumi ARITA and Yoshiki SAITO of the Geological Survey of Japan, Prof. Tetsuo YANAGI of Ehime University and Dr. Yutaka ISODA of Hokkaido University for their fruitful comments and suggestions. This work was supported by the special research program, marine geological investigation around the continental shelf areas in the central part of the eastern Japan Sea, of the Geological Survey of Japan.

References

ALEXANDER, C. R., D. J. DEMASTER and C. A. NITTROUER (1991): Sediment accumulation in a modern epicontinental-shelf setting: The Yellow Sea. Marine Geol., **98**, 51–72.

BISHOP, J. K. B. (1986): The correction and suspended particulate matter calibration of Sea Tech transmissometer data. Deep-sea Res., **33**, 121–134.

DÍAZ, J. I., A. PALANQUES, C. H. NELSON and J. GUILLÉN (1996): Morpho-structure and sedimentology of the Holocene Ebro prodelta mud belt (northwestern Mediterranean Sea). Continental Shelf Res., **16**, 435–456.

Geological Research Group of Akita University on the Nihonkai Chubu Earthquake, 1983(1986): Late Quaternary geology and development of the coastal alluvial plain of Akita Prefecture, northeast Japan. Mem. Geol. Soc. Japan, **27**, 213–235.

HAMAGUCHI, H. and N. OTA (1953): Chemical investigations of deep-sea deposits (XIV). On the chemical composition of deep-sea deposits from Japan Sea. J. Chem. Soc. Japan, **74**, 761–764.

HAMAGUCHI, H., M. TATEMOTO and J. ITAYA (1954): Chemical investigations of deep-sea deposits (XIX). On the content of Ti, Fe, Mn, P and organic carbon in the sediments from Japan Sea (2). J. Chem. Soc. Japan, **75**, 119–121.

HOSHINO, M. (1958): The shelf sediments in the adjacent seas of Japan. Monogr. Assoc. Geol. Collab., **7**,1-41.

IKEHARA, K. (1991): Modern sedimentation off San'in district in the southern Japan Sea. In: Oceanography of Asian Marginal Seas, ed. K. Takano, Elsevier Oceanography Series, 57, Elsevier, Amsterdam, 143–161.

IKEHARA, K. (1992): Influence of surface water circulations on the sea bottom in the southern Japan Sea. La mer, **30**, 105–118.

IKEHARA, K. (1993): Modern sedimentation in the shelf to basin areas around southwest Japan, with special reference to the relationship between sedimentation and oceanographic conditions. Bull. Geol. Surv. Japan, **44**, 283–349.

IKEHARA, K., D. BI, Y. KINOSHITA and T. SUZUKI (1988): Heavy mineral distributions in the surface sediments of the Osumi Strait, south of Kyushu, Japan. J. Sed. Soc. Japan, **29**, 9–18.

IKEHARA, K., H. KATAYAMA and T. NAKAJIMA (1994a): Sedimentological map of the vicinity of Awashima (with explanatory notes). Marine Geology Map Series, 42, Geological Survey of Japan, Tsukuba, 56p.

IKEHARA, K., K. KIKKAWA, H. KATAYAMA, and K. SETO, (1994b): Late Quaternary paleoceanography of the Japan Sea; a tephrochronological and sedimentological study. Proc. 29th Int'l. Geol. Congr. Part B, VSP, Utrecht, 229–235.

Japan Oceanographic Data Center (1979): Marine Environmental Atlas, Currents-adjacent seas of Japan. 71p.

Japan Oceanographic Data Center (1991): Statistic Atlas of Currents adjacent seas of Japan-seasonal characters-. JP011-91-1, 165p.

Japan Rivers Association (1974): Nihon Kasen Suishitsu Nenkan (1974). Sankaido, Tokyo, 885p.

LESUEUR, P. and J. P. TASTET (1994): Facies, internal structures and sequences of modern Gironde-driven muds on the Aquitaine inner shelf, France. Marine Geol., **120**, 267–290.

MASUZAWA, T. (1987): Early diagenesis in deep-sea sediments of the Japan Sea: Type, controlling factor, and diffusive flux. J. Earth Sci., Nagoya Univ., **35**, 249–267.

MASUZAWA, T. (1991): Bottom sediments around Japan and Kosa. In: Kosa, ed. Res. Inst. Water Sci., Nagoya Univ., Kokon-shoin, Tokyo, 216–225.

MILLIMAN, J. D. (1995): Sediment discharge to the ocean from small mountainous rivers: The New Guinea example. Geo-Marine Lett., **15**, 127–133.

MILLIMAN, J. D., Y.-S. QIN, M.-E REN and Y. SAITO (1987): Man's influence on the erosion and transport of sediment by Asian rivers: The Yellow River (Huanghe) example. J. Geol., **95**, 751–762.

MILLIMAN, J. D. and P. M. SYVITSKI (1992): Geomorphic/tectonic control of sediment discharge to the ocean: The importance of small mountainous rivers. J. Geol., **100**, 522–544.

MORIWAKI, H. (1982): Geomorphic development of Holocene coastal plains in Japan. Geogr. Rep. Tokyo Metropol. Univ., **17**, 1–42.

NARDIN, T. R., F. J. HEIN, D. S. GORSLINE and B. D. EDWARD (1979): A review of mass movement processes, sediment and acoustic characteristics, and contrasts in slope and base-of-slope systems versus canyon-fan-basin floor systems. In: Geology of Continental Slopes, ed, DOYLE L. J. and O. H. PILKEY, Soc. Econ. Paleontol. Mineral., Spec. Publ., **27**, 61–73.

NITANI, H. (1972): On the deep and bottom waters in the Japan Sea. In: Research in Hydrography ad Oceanography, ed. SHOJI, D. Hydrographic Department of Japan, 151–201.

NOMURA, M. (1992): Carbon and nitrogen contents of surface sediments off Yamagata and Akita Prefecture. In: Preliminary Reports of Marine Geological Investigation around the Continental Shelf Areas in the Central Part of the Eastern Japan Sea, FY1991, ed. OKAMURA, Y., Geological Survey of Japan, 197–202.

OTA, Y., Y. MATSUSHIMA and H. MORIWAKI (1982): Notes on the Holocene sea-level study in Japan-On the basis of "Atlas of Holocene Sea-level Records in Japan". The Quat. Res. (Daiyonki-kenkyu), **21**, 133–143.

PUJOS, M. and O. JAVELAUD (1991): Depositional facies of a mud shelf between the Sinu river and the Darien Gulf (Caribbean coast of Colombia): environmental factors that control its sedimentation and origin of deposits. Continental Shelf Res., **11**, 601–623.

SUDA, K. (1932): On the bottom water in the Japan Sea (preliminary report). J. Oceanogr., **4**, 221–241.

TRIPLEHORN, D. M. (1966): Morphology, internal structure, and origin of glauconite pellets. Sedimentology, **6**, 247–266.

WATANABE, M. (1994): First occurrence levels of *Pseudoeunotia doliolus* in gravity cores (preliminary report). In Preliminary Reports of Marine Geological Investigations around the Continental Shelf Areas in the Central Part of the Eastern Japan Sea, FY1991, ed. Y. OKAMURA, Geological Survey of Japan, 203–205.

YAMAMOTO, K. and M. IMAI (1990): Physical oceanography, off Ou coast. In: Coastal Oceanography of Japanese Islands, Supplementary Volume, ed. Coastal Oceanography Research Committee, Oceanographic Society of Japan, Tokai Univ. Press, 805–819.

Received January 13, 1996
Accepted May 20, 1996