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Origin of sand and its distribution pattern in the Seto Inland Sea, Southwest Japan

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Abstract : The distribution pattern of surface sediments in the Seto Inland Sea is characterized by a large scale (usually over more than 10 kilometers) horizontal grading or decrease in grain size with increasing distance from channels that pass between numerous islands in the sea. Deep depressions, or scour hollows lie along the channels and offshore from islands and capes. The grading, mainly shown in the sandy sediments around the channels, occurs in a fan-shaped pattern with respect to scour hollow, where bedrock is often exposed. Although sandy sediments are also distributed near the shorelines, no large scale (over more than 10 kilometers) horizontal grading in grain size occurs in these areas.

Sand around the scour hollow areas is derived from these scour hollows by erosion and transportation by tidal currents. Silt and clay are chiefly supplied through rivers around the Seto Inland Sea, and settle down where tidal currents are weakest.

Closed sea areas such as lagoons and tidal flats have a similar fan-shaped distribution pattern of sediments. However, in these areas, sand supply from offshore is thought to be the controlling factor. Therefore, the Seto Inland Sea is much different from other closed marine areas in the origin of sand grains.

The surface sediments which show a fan-shaped horizontal grading belong to "U (Upper) layer" in the 3.5 kHz acoustic stratigraphy. "U layer" is correlative with the formations in "upper Alluvium" in Osaka Plain, and unconformably overlies "L (Lower) layer" which is composed mainly of sediments originally deposited during low Quaternary sea levels.

In Osaka Bay and Ariake Bay, sandy sediments which are distributed around the scour hollows were previously thought to be older than other surface sediments. However, reexamination of published data in these areas shows that the sandy sediments are not correlative with the sandy sediments which underlie the surface muddy sediments. Instead, sand supply from the scour hollow areas and distribution by the tidal currents are preferred.

I. INTRODUCTION

The seto Inland Sea is in the central part of Southwest Japan. The Sea is about 400 km long in an east-west direction and 50 km wide in a north-south direction, and occupies an area of about 22,000 sq km with a mean depth of about 40 m (MURAKAMI, 1976) (Fig. 1). This sea is connected with the open ocean through the Kii Suido, Bungo Suido and Kanmon Strait, and is surrounded by mountanous land areas. Many large and small islands form the margins of narrow channels, generally called "Seto". Predominance of these channels, together with other types of seafloor morphology, results in unique hydrological conditions such as complex tidal currents with variable velocities.

There are few area in the world which show strong tidal currents without strong wave activity as in the Seto Inland Sea. The

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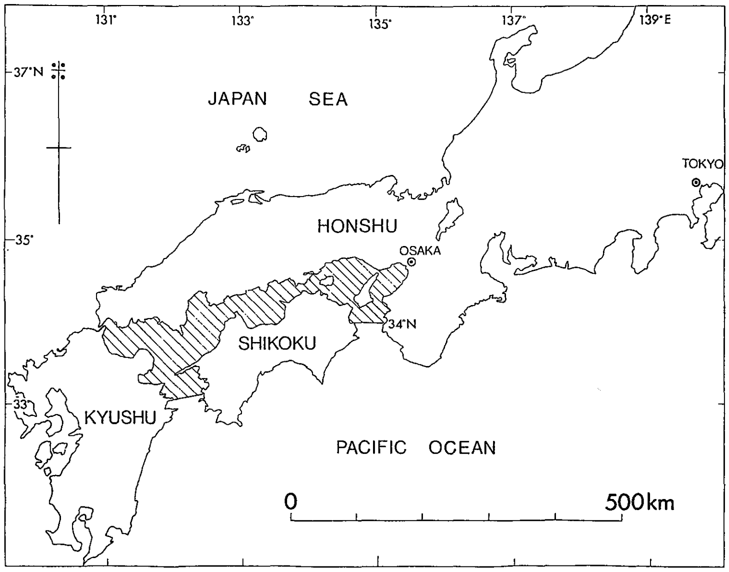


Fig. 1 Index map of the study area. Hachured area is Seto Inland Sea.

area is nearly completely enclosed, and has low wave energy because of the limited fetch and depth of the sea. Consequently, the effect of waves is weak. Other examples of nearly enclosed seas are the coastal lagoons which lie along the Gulf of Mexico coast, lagoons like Lake Saroma and Lake Hamana in Japan, and tidal flats along the Dutch, German and Danish coasts. Although the depositional processes in all these seas are controlled mainly by tidal currents, many of them are often affected by wind generated waves (e. g. Gulf of Mexico coast, SHEPARD and MOORE, 1955 and McGOWEN and SCOTT, 1975). The lagoonal seas in these other areas are relatively shallow and the surrounding land has low relief, unlike the Seto Inland Sea.

Although the Seto Inland Sea is an unusual marine basin at present, areas with strong tidal currents and without strong wave activity are not geologically rare. In islands of high relief like Japan, there are many Quaternary marine sequences deposited in similar settings to that of the present Seto Inland Sea.

This paper firstly shows the distribution patterns of bottom sediments in the Seto Inland Sea, and then discusses the control of tidal currents on the distribution patterns. Finally, the origin and depositional processes of the bottom sediments are discussed.

II. SAMPLE COLLECTION AND ANALYSIS

About 90 days of survey were undertaken between 1974 and 1976, using the Wakashio (360 ton) of the Fuyo Ocean Developing Company. Bottom samples were taken by Smith-McIntyer grab sampler (or 6m-long, open-barrel gravity corer) at stations separated by a few miles (Fig. 2). About 520 samples were collected. The sediment samples were put into plastic cases, so as not to disturb the sedimentary structures, and then divided into two thin and thick pieces in the laboratory. Samples in the thinner cases were used for soft X-ray photography and the ones in the thicker cases were used for grain size analysis. Based on inspection of the soft X-ray photographs, a sample of homogeneous surface sediment up to 5 cm thick was selected for textural analysis.

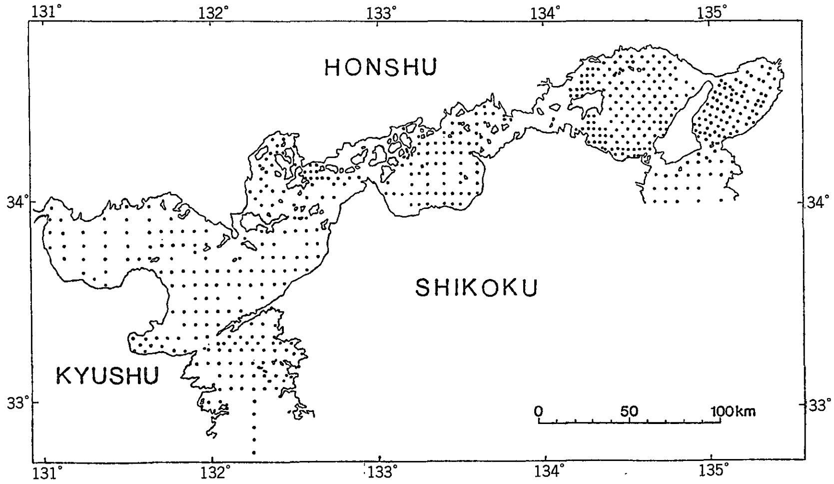


Fig. 2 Sampling locations in the Seto Inland Sea.

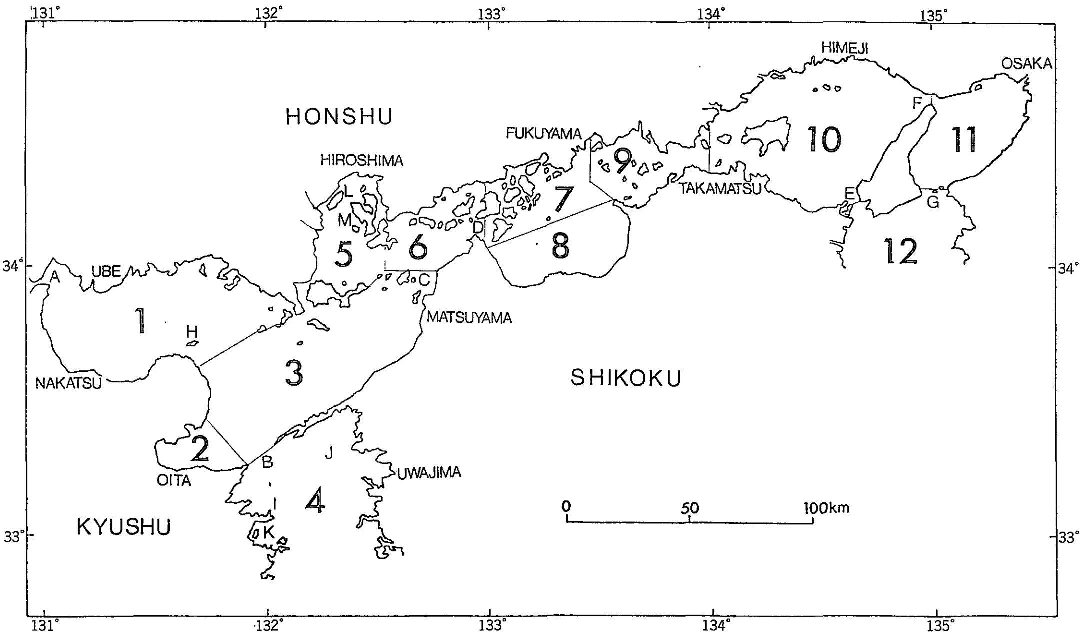


Fig. 3 Sub-division of the Seto Inland Sea. 1. Suwo Nada, 2. Beppu Bay, 3. Iyo Nada, 4. Bungo Suido, 5. Hiroshima Bay, 6. Aki Nada, 7. Bingo Nada, 8. Hiuchi Nada, 9. Bisan Seto, 10. Harima Nada, 11. Osaka Bay, 12. Kii Suido, A. Kanmon Strait, B. Hoyo Strait, C. Tsurishima Strait, D. Kurushima Strait, E. Naruto Strait, F. Akashi Strait, G. Tomogashima Strait, H. Himeshima Island, I. Kamado-saki Peninsula, J. Uwakai Sea, K. Saeki Bay, L. Itsukushima Island, M. Etajima Island.

Samples were sieved by different techniques, depending on the grain-size of sediment. Material of sand size or greater was sieved. Where finer grained sediment made up more than 10 percent of the total sample, the sediment was analyzed using a hydrometer method based on Japan Industrial Standard (JIS) A 1204.

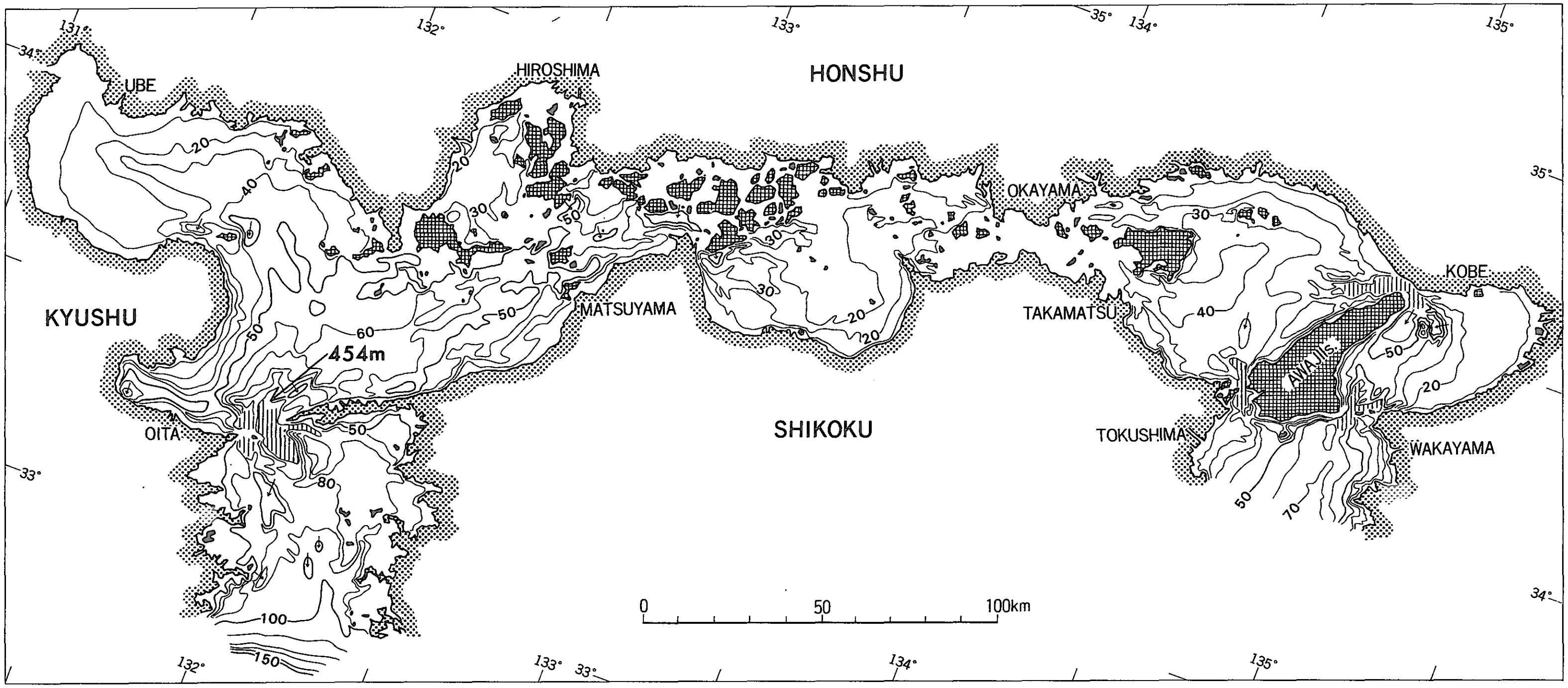


Fig. 4 Bathymetry in the Seto Inland Sea. Solid contour lines indicate 10 m intervals. Areas of vertical lines indicate large scour hollows. Arrows indicate scour hollow areas.

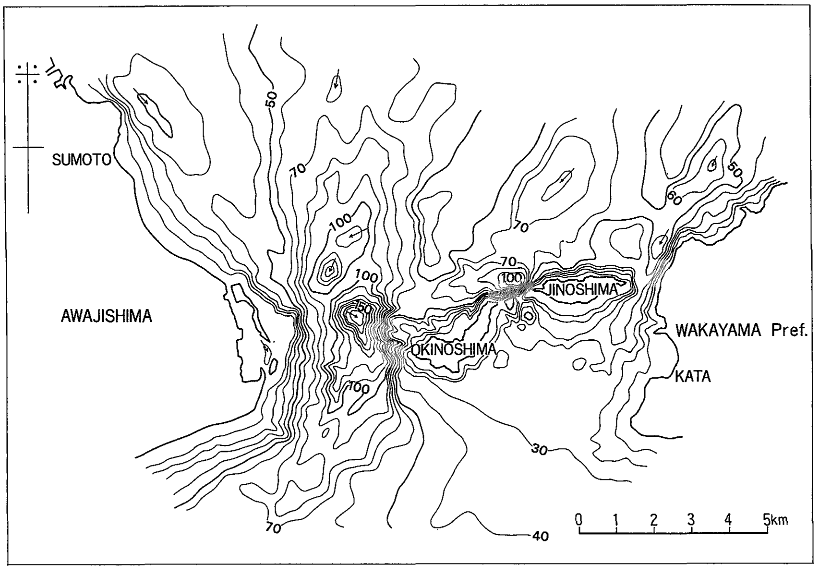


Fig. 5 Bathymetry of Tomogashima Strait. (Single-type scour hollow)

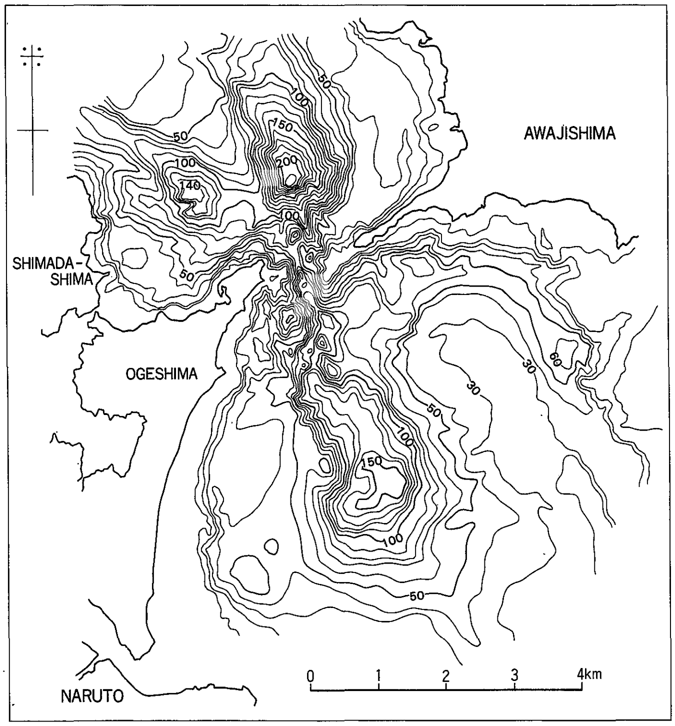


Fig. 6 Bathymetry of Naurto Strait. (Twin-type scour hollow)

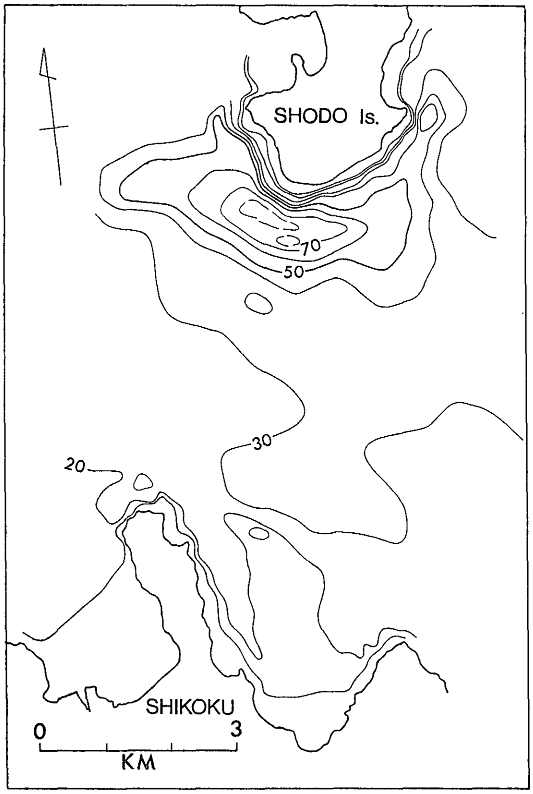
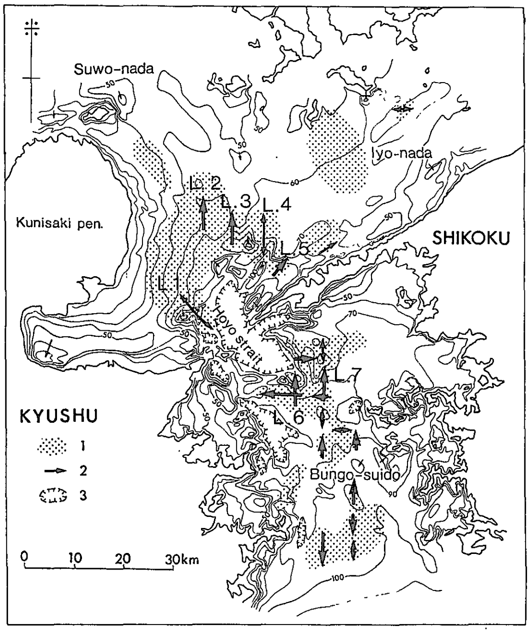


Fig. 7 Bathymetry of a cape-type scour hollow off of Jizozaki Peninsula, Shodo Island. Depth in meters.



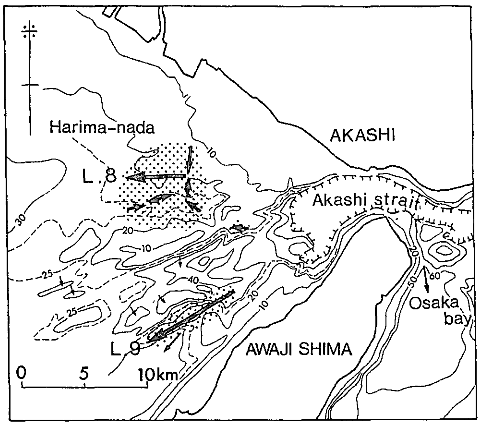


Fig. 8 Distribution and components of the migration direction of sand waves in Iyo Nada, Bungo Suido and Harima Nada. Directions are inferred from acoustic records, based on bedform asymmetry. The directions are components along the ship's track, and may be at a high angle to the sand-wave crest line. 1. Estimated distribution of sand waves based on acoustic records. 2. Arrows in one direction show a component of inferred sand wave migration relative to the ship's track. Arrows in both directions indicate a real or apparent symmetrical wave morphology. 3. Scour hollow area.

The calcium carbonate grains in calcareous sediments, which are often distributed at the Bungo Suido and Iyo-Nada areas, were dissolved using hydrochloric acid and then the remained mineral grains were sieved.

Grain-size distributions were analyzed statistically for mean, median and sorting. Some extrapolation of data beyond the limits of the analysis was necessary for computation. For those samples which contain more than 5 percent of fine particles smaller than 1 micron, additional data points were estimated for the finer size grades (at whole phi intervals) by projecting the grain-size curve as plotted on probability paper, and following the same slope of the line, until more than 95 percent of the sediment was accounted for.

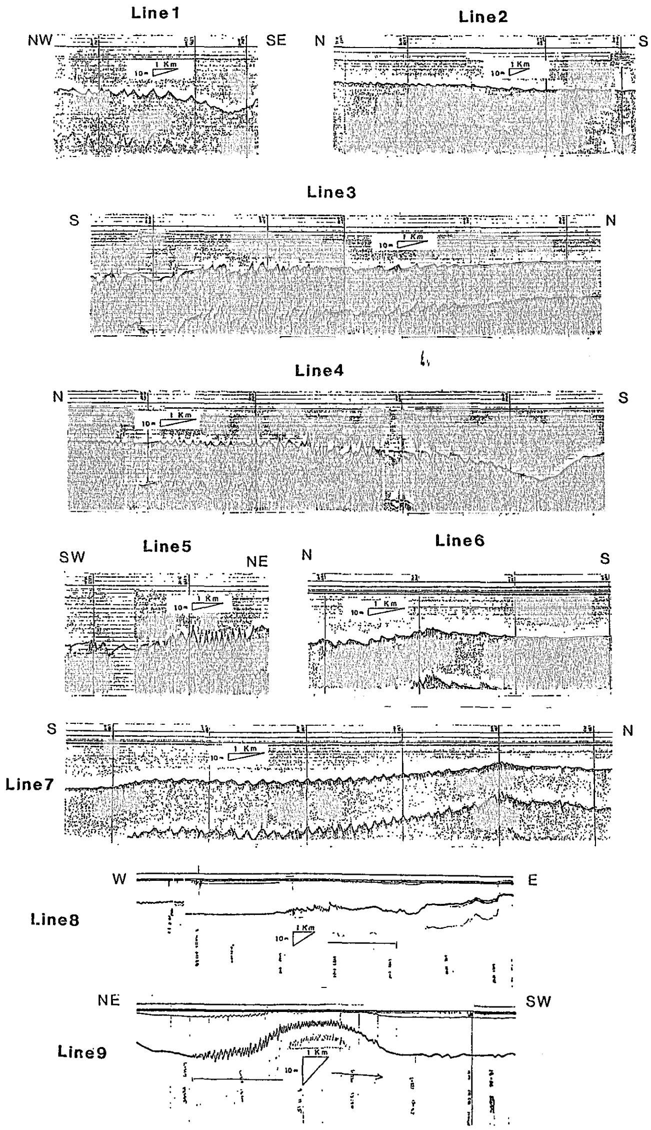


Fig. 9 Examples of sand wave morphology in acoustic records. Positions of lines are shown in Fig. 8. Lines 1-7 are records of 3.5 kHz Subbottom Profiler. Lines 8 and 9 are records of PDR.

III. BATHYMETRY

The Seto Inland Sea is divided into several bays and seas (Nada and Suido) by bathymetric features (Fig. 3). Almost all of the seas are shallower than 60 meters, except around the channel areas and in some parts of Beppu Bay, and Iyo Nada, Bungo Suido and Kii Suido straits (Fig. 4).

Remarkable seabed features in the Seto Inland Sea are scour hollows developed near the channels and offshore from capes. The scour hollows near the channels are divided into two types based on their morphology. One is a single-type scour hollow and the other is a twin-type scour hollow (KUWASHIRO, 1959). A single-type scour hollow con-

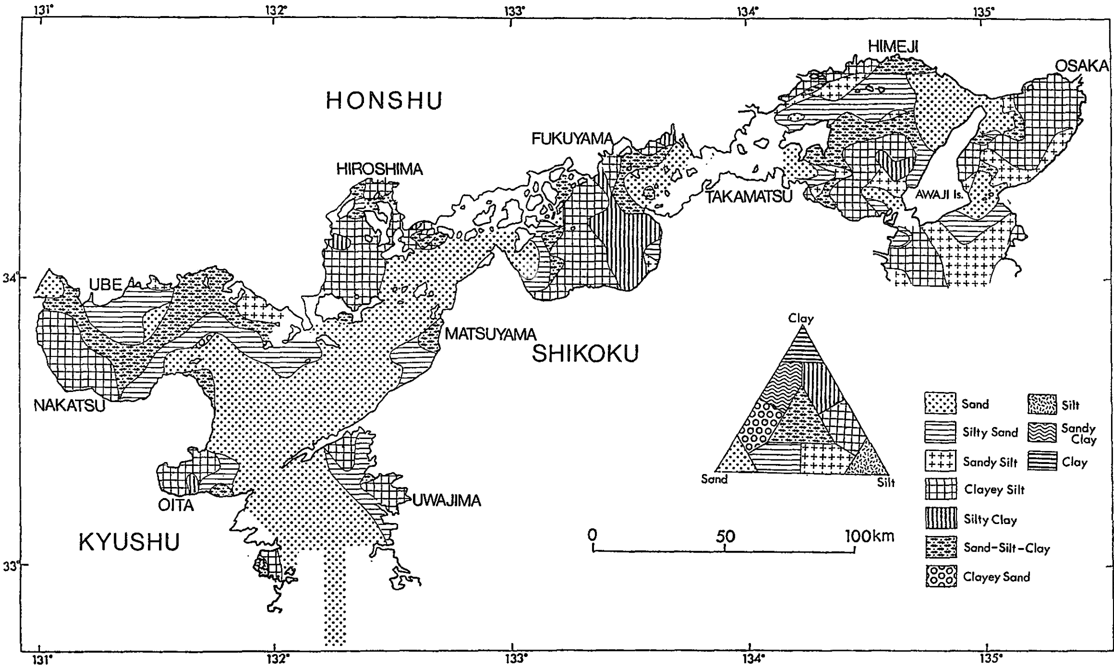


Fig. 10 Distribution map of surface sediments classified according to SHEAPARD (1954). "Sand" area includes areas of bedrock exposure. Blank areas are unsurveyed. "Clay", "Silt" and "Sandy clay" are not present in the area.

sists of a hollow within a channel. An example is a scour hollow in the Tomogashima Strait (Fig. 5). A twin-type scour hollow has two or more hollows separated by a sill. The scour hollows in Naruto Strait (Fig. 6) and Hoyo Strait are of this type. A third type of scour hollow (cape-type) (Fig. 7) lies off capes and islands in many places (KUWASHIRO, 1959). These scour hollows are not associated with channel areas, but are instead found where tidal currents detour around capes or islands (KUWASHIRO, 1959). The bottoms of the scour hollows are generally deep hollows, especially in the northern scour hollows of Hoyo Strait where the maximum depth attains 454 meters. Other more shallow scour hollows are apparently sites of nondeposition.

Many areas of sand deposition near the main channels are characterized by sand waves. Examples are the western part of Akashi Strait, Bisan Seto, Iyo Nada and Bungo Suido. The sand waves have gentle slope on the channel side and steep slopes facing away from the channel (Figs. 8 and 9), suggesting transportation of sediments away from the channel areas. MOGI and KATO (1962) also reported steeper slopes on the downcurrent side of migrating sand waves in Bisan Seto.

Away from the sand wave fields in and around the channels, a flat depositional topography generally continues to the vicinity of the shoreline.

IV. DISTRIBUTION OF SURFACE SEDIMENTS

Distribution of bottom sediments (classification of SHEPARD, 1954) is shown in Fig. 10. The graphic measure of average grain-size, "Mz" of FOLK and WARD (1957) was computed from grain-size data (Fig. 11, 12). FRIEDMAN (1962) showed that the graphic measure of FOLK and WARD (1957) correlates well

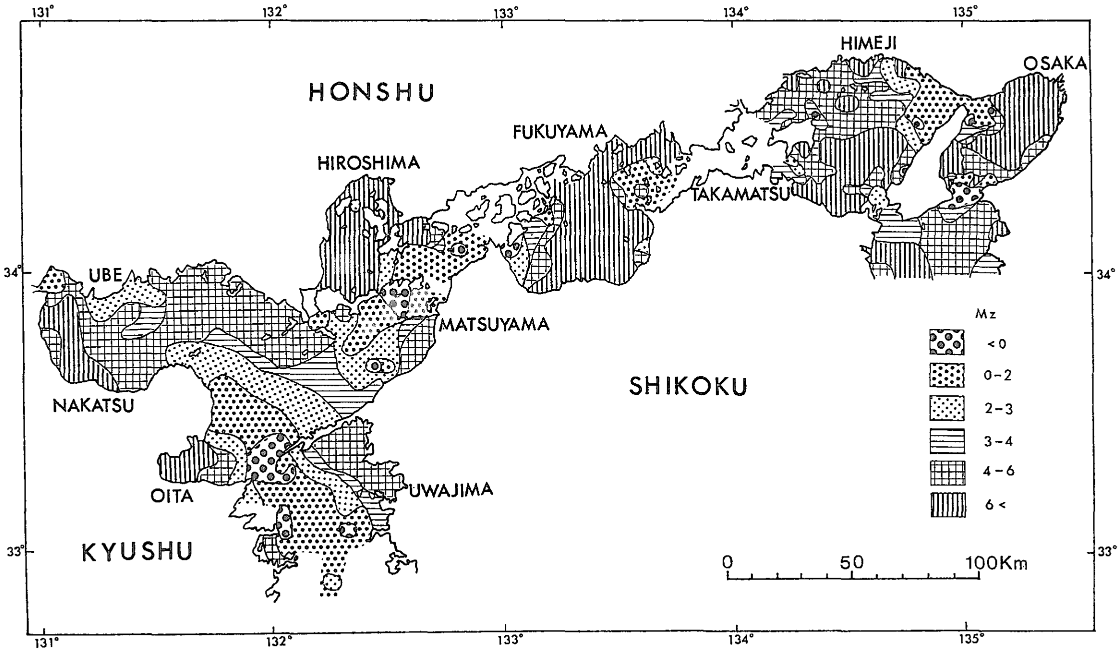


Fig. 11-1. Distribution map of Mzϕ values for surface sediments. Areas with mean diameter coaser than 0 ϕ include areas of bedrock exposure.

with results obtained by the method of moments over the whole range of sorting value studied.

Skewness and kurtosis, which may indicate the degree of mixing of two log-normal populations (SPENCER, 1963), are not discussed in detail. Instead, the degree of mixing is discussed relative to the histograms in section V.

Suwo Nada : This sea area is connected with the Japan Sea through the Kanmon Strait in the west and faces Iyo Nada in the east. In the southeastern part of Suwo Nada, the sediments are poorly sorted sand with a mean diameter of 2 to 3ϕ. Sediments become finer toward the southwest, where the finest sediment, very poorly sorted clayey silt with a mean diameter less than 6ϕ, is distributed. In the southern half of this sea, the sediments show a regular east to west change from sand to silty sand to sand-silt-clay to clayey silt. In the northeastern part of the area, the sediments are sand-silt-clay and sandy silt, with a mean diameter less than 4ϕ. Off of Ube City, the sediment is sand and silty sand with a mean diameter of 2 to 4ϕ. In the vicinity of Kanmon Strait, there is sand with a mean diameter of 0 to 2ϕ. In these three areas, sorting is very poor.

Iyo Nada : This sea area is connected with Aki Nada through Tsurishima Strait in the north, with Bungo Suido through Hoyo Strait in the south, and faces Suwo Nada to the northwest. Sediments are mainly sand, but west of Matsuyama City, there are very poorly sorted sand-silt-clay and silty sand, and in the north of the area, there are narrow bands of silty sand.

Sands can be subdivided by mean diameter. There are very poorly sorted, very coarse-grained sand or exposed bedrock in the channel areas. Poorly sorted, coarse-and medium-grained sand is also present around the channel areas, and in the inner part of cape-type scour hollows. In the southern part of Iyo Nada, moderately to very well sorted, fine-grained sand is distributed to the north and

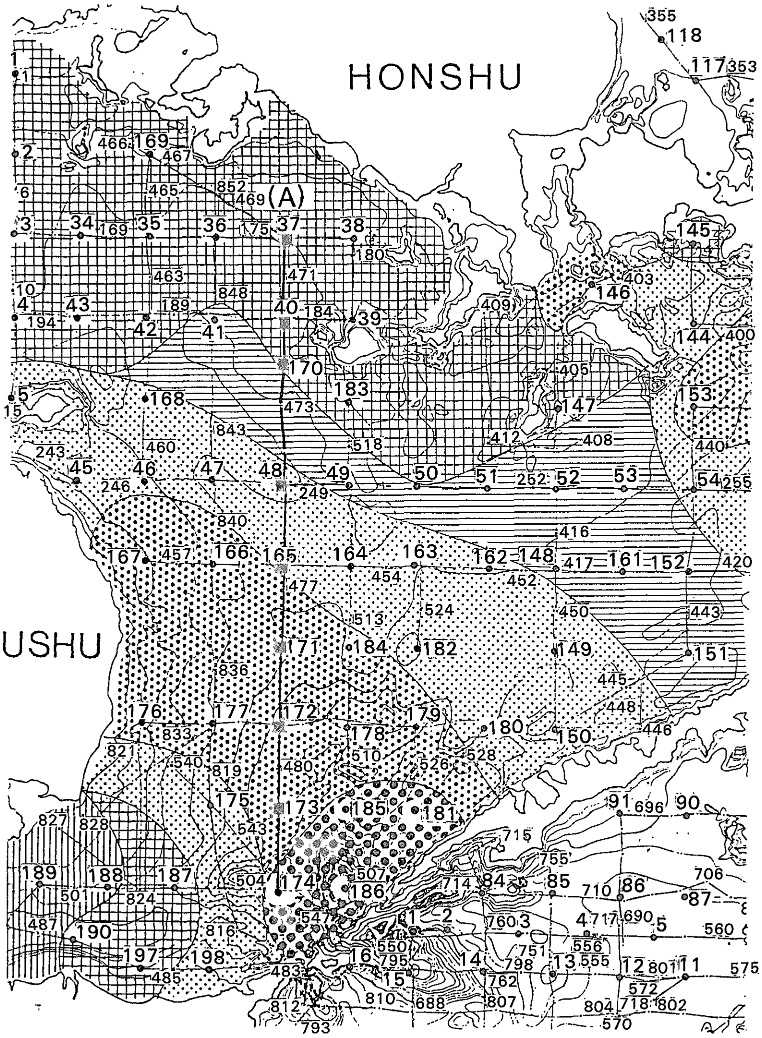


Fig. 11-2 Detailed distribution map of Mzϕ values for surface sediments. Eastern part of Suwo Nada and western part of Iyo Nada.

northeast of the area of coarse-to medium-grained sand. Similarly, outside of the area of coarse-to medium-grained sand around Tsurishima Strait, there are poorly sorted fine-grained sand that pass outward into poorly sorted, very fine-grained sands. This sediment distribution pattern continues into the Suwo Nada area.

Beppu Bay : Beppu Bay faces Iyo Nada. In the western part of Beppu Bay, the sediments are silty clay or clayey silt with a mean diameter less than 6ϕ. Sediments become coarser toward the bay mouth in the east ; that is, there is a change from silty sand and sand-silt-clay with a mean diameter of 4 to 6ϕ into sand with a mean diameter of 2 to 3ϕ. Sorting is very poor, except for the southern part of the bay mouth in which sorting is poor.

Bungo Suido : This area is connected with Iyo Nada through Hoyo Strait in the north and faces the Pacific Ocean in the south. There are sands in the central part of Bungo Suido. The coarsest sediments in this area are

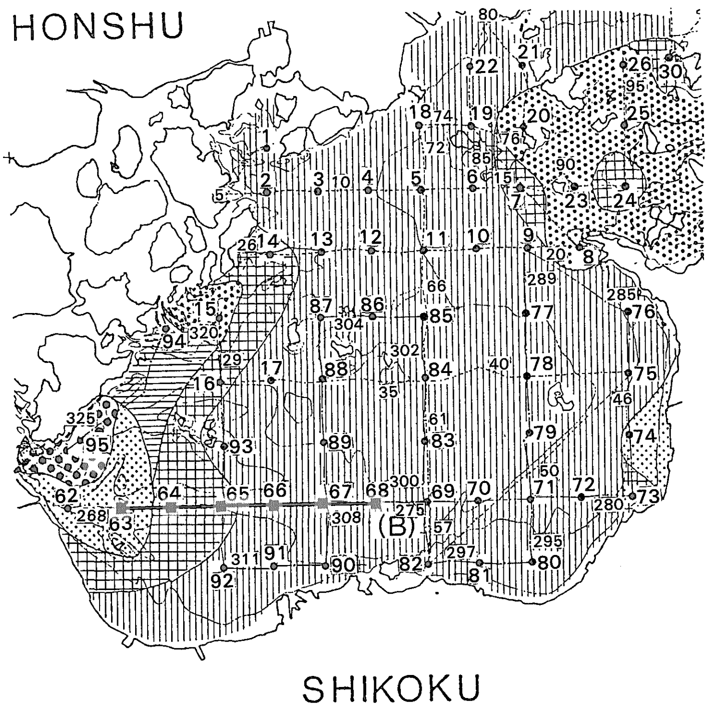


Fig. 11-3 Detailed distribution map of Mzϕ values for surface sediments. Hiuchi Nada and Bingo Nada.

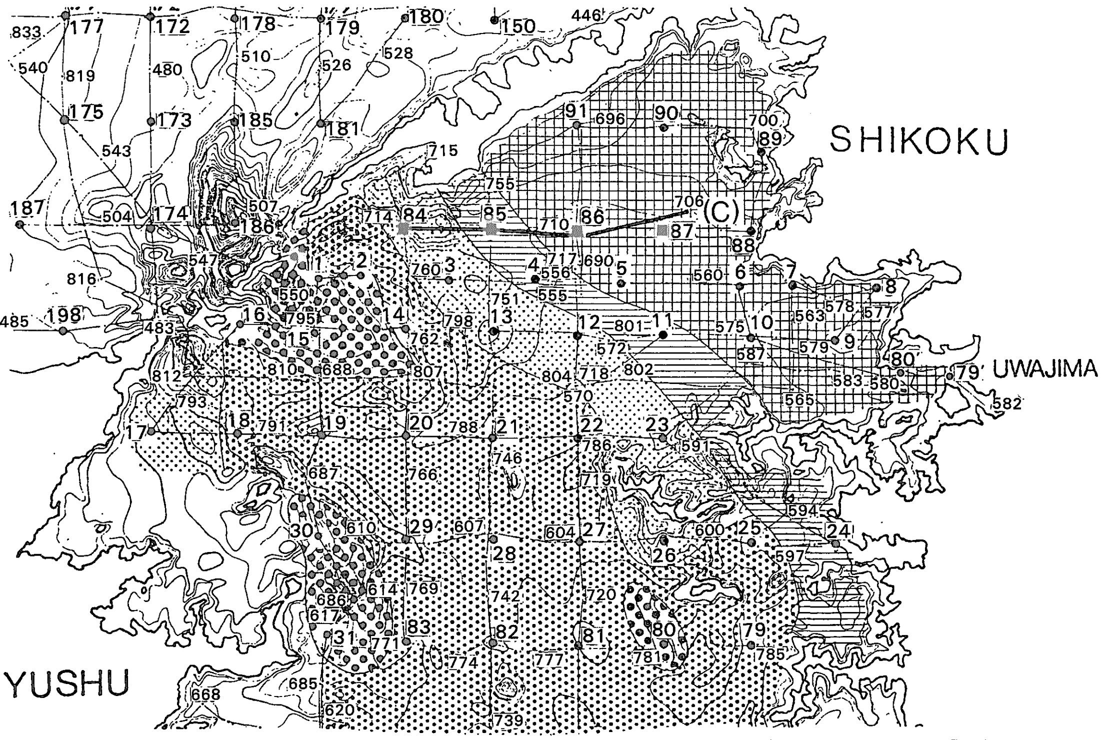


Fig. 11-4 Detailed distribution map of Mzϕ values for surface sediments. Northern part of Bungo Suido.

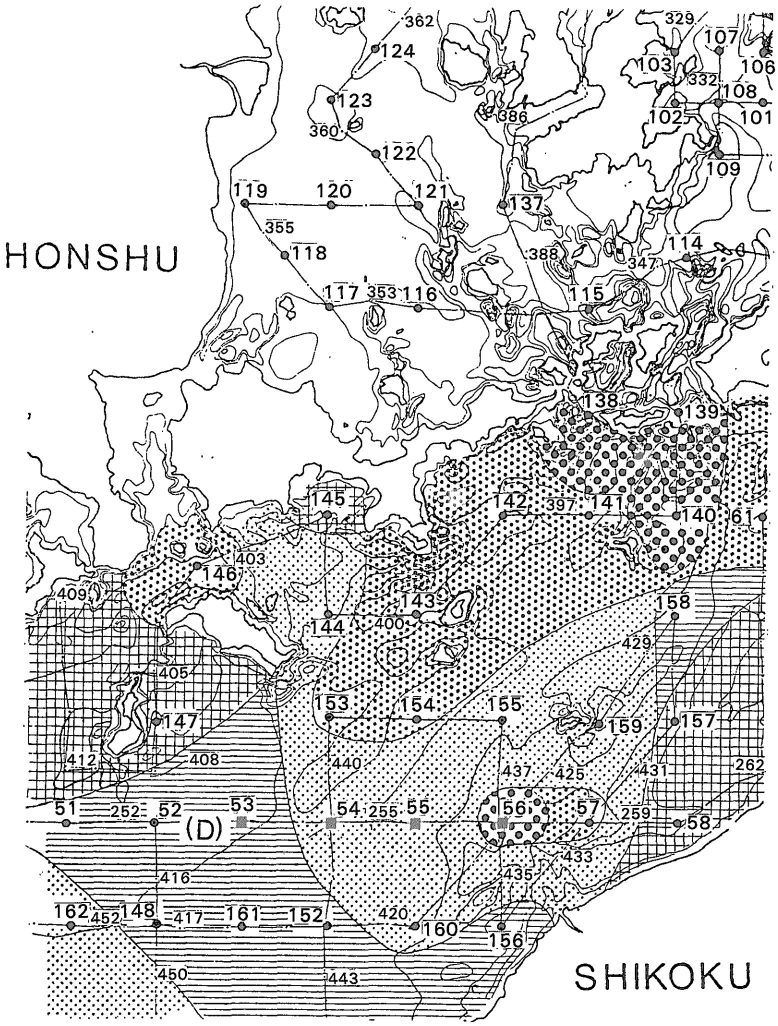


Fig. 11-5 Detailed distribution map of Mzϕ values for surface sediments. Eastern part of Iyo Nada.

those in the scour hollows of Hoyo Strait and off the Kamado-saki Peninsula ; they are very poorly sorted, very coarse-grained sand and gravels or exposed bedrock. Surrounding these coarsest sediments are mainly moderately sorted to very well sorted, coarse-to medium-grained sand. In the eastern and western bays of Bungo Suido, the sediments become coarser in mean diameter and are composed mainly of silty sand and clayey silt.

Hiroshima Bay : Hiroshima Bay faces Aki Nada to the east. The sediments in this area are mostly very poorly sorted clayey silt with a mean diameter less than 6ϕ. The sediments in the channel between Eta Island and Itsukushima Island are very poorly sorted sand-silt-clay with a mean diameter of 2 to 3ϕ. In the eastern part of this area facing Aki Nada, there is poorly sorted fine-grained sand with a mean diameter of 2 to 3ϕ.

Aki Nada : Aki Nada is connected with Hiuchi Nada through Kurushima Strait in the east. It connects with Iyo Nada through Tsurishima Strait in the south and faces

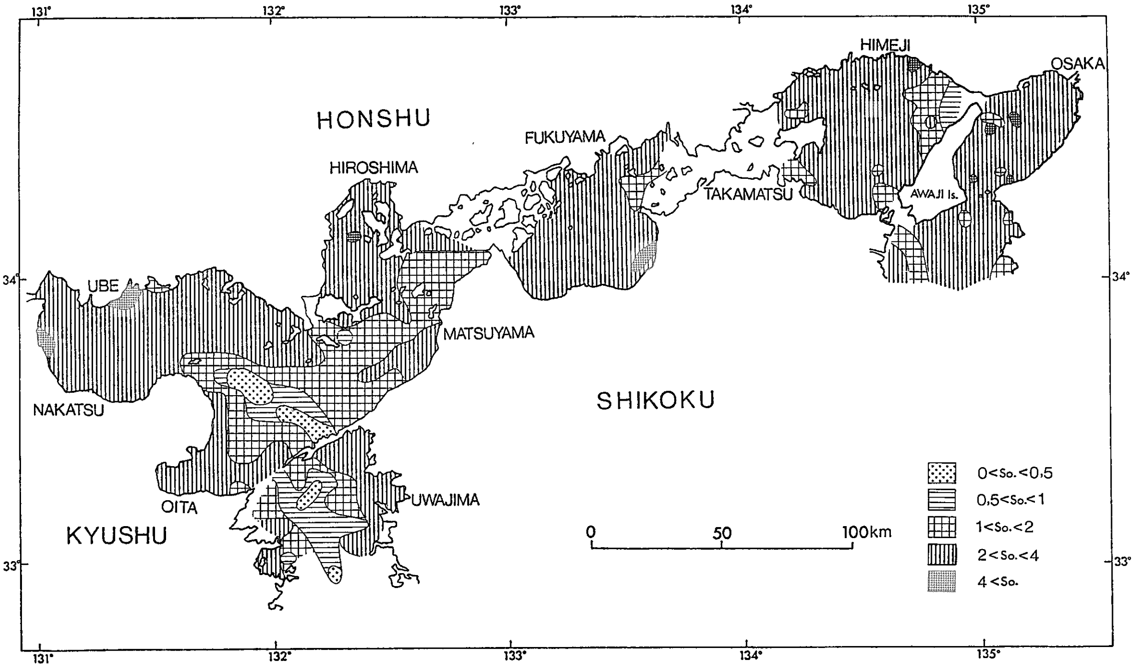


Fig. 12 Distribution map of sorting (in ϕ units).

Hiroshima Bay to the west. Sediments in the south near Tsurishima Strait and Kurushima Strait are poorly sorted sand ; mean diameters are more than 0ϕ near Tsurishima Strait and 0 to 2ϕ away from the strait. In the north, there are very poorly sorted clayey silt and sand-silt-clay with a mean diameter of 6ϕ. The sediments become finer from the southeastern part of Aki Nada to the area off of Kure City ; mean diameter decreases from more than 0 to less than 6ϕ.

Hiuchi Nada and Bingo Nada : These areas are connected with Aki Nada through Kurushima Strait in the west and face Bisan Seto to the east. Sediments with a mean diameter less than 6ϕ are widely distributed in this area and coarsen toward Kurushima Strait. They are very poorly sorted or extremely poorly sorted. From Kurushima Strait eastward, sediment changes from sand to silty sand to sand-silt-clay to clayey silt to silty clay.

Bisan Seto : This area faces Bingo Nada in the west and faces Harima Nada to the east. The eastern part was not surveyed. In the northern part, Mizushima Nada, the sediments near the northern coast are very poorly sorted with a mean diameter less than 6ϕ. In contrast, the southern part is underlain predominantly by poorly sorted sand with a mean diameter of 0 to 2ϕ. There is a gradual change from south to north from sand to sand-silt-clay to clayey silt to silty clay. Sand-silt-clay with a mean diameter of 4 to 6ϕ is distributed in a patchy manner in the southern part where the current is very slow.

Harima Nada : This area faces Bisan Seto to the west, connects with Osaka Bay through Akashi Strait in the northeast and connects with Kii Suido through Naruto Strait in the southeast. Very poorly sorted clayey silt with a mean diameter less than 6ϕ is distributed in the central and southern part of Harima Nada. Sediments become coarser from this area to Akashi Strait, Naruto Strait and Bisan Seto. The sediment changes from sand to silty sand and sandy silt to sand-silt-clay outward from the channel area.

Osaka Bay : Osaka Bay connects with Harima Nada through Akashi Strait in the northwest and also connects with Kii Suido through Tomogashima Strait in the southwest. In the northeastern recess, in the center of the bay and in the central part off the eastern coast of Awaji Island, there are very poorly sorted clayey silts with a mean diameter less than 6ϕ. Sediments become coarser from these areas to the areas near Akashi Strait and Tomogashima Strait, changing into very poorly sorted sediment with a mean diameter more than 0ϕ, or bedrock in the channel areas. Toward the straits, the sediments change from clayey silt to sandy silt to sand-silt-clay to sand.

Kii Suido : This area connects with Harima Nada through Naruto Strait in the northwest, with Osaka Bay through Tomogashima Strait in the northeast and faces the Pacific Ocean to the south. The sediments of the Kii Suido are coarsest near the Tomogashima Strait and become finer outward from the channel area. Sediment texture changes in this direction from sand to silty sand to sandy silt to clayey silt. Sorting is generally poor to very poor. Near the eastern and western coasts, the sediments are clayey silt with a mean diameter less than 6ϕ. Near Naruto Strait, the grain size changes are not clear as the sampling sites are scarce.

The characteristics of the surface sediment distribution in the Seto Inland Sea can be summarized as follows.

1. In general, very poorly sorted silty clay, clayey silt and sand-silt-clay with a mean diameter less than 4ϕ are distributed more widely than other types of sediment, except in Iyo Nada, Aki Nada and central Bungo Suido, where there is widespread poorly sorted to very well sorted sand and silty sand.

2. Sediments near the straits are very poorly sorted sandy gravel or bedrock which indicates no deposits. Grain size decreases and the sediments become better sorted with distance from the straits. Further outward from the channels where the mean diameter of the sediments become finer than 3ϕ, sediments again become poorly to very poorly sorted and change progressively from sand to silty sand to sand-silt-clay (sandy silt) to clayey silt to silty clay. A typical example occurs over about 40 km in a west-east direction in Hiuchi Nada.

3. As shown in Osaka Bay, Harima Nada, Hiuchi Nada, Bingo Nada, Hiroshima Bay etc., even in the nearest (less than 10 km) sites to the shoreline are, in mean diameter, less than 6ϕ, and significant changes in grain size away from the shoreline are not recognized.

V. DIVISION OF SEDIMENT TYPES

One of the characteristics of the sedimentary distribution in the Seto Inland Sea is a lateral change in the sorting values due to mixing of sediments. In order to discuss this mixing, the modes of the sediments have to be clarified.

Cumulative grain-size curves based on a probability percentage ordinate are adequate to show the composition of sediments with log normal populations, but are not suitable for polymodal sediments. Also, graphic measures of mean, sorting, skewness and kurtosis express the grain size and the degree of mixing, but they cannot show directly component parts of a single sample. This can be done using histograms (Fig. 13).

In the following, characteristics of sediment texture, based on histogram types (chiefly sea areas to the west of Bisan Seto), are described.

Type H1 : This type contains more than 10% gravel and less than 20% mud. There is no distinct mode in the sand sizes. The sediment is negatively skewed in general.

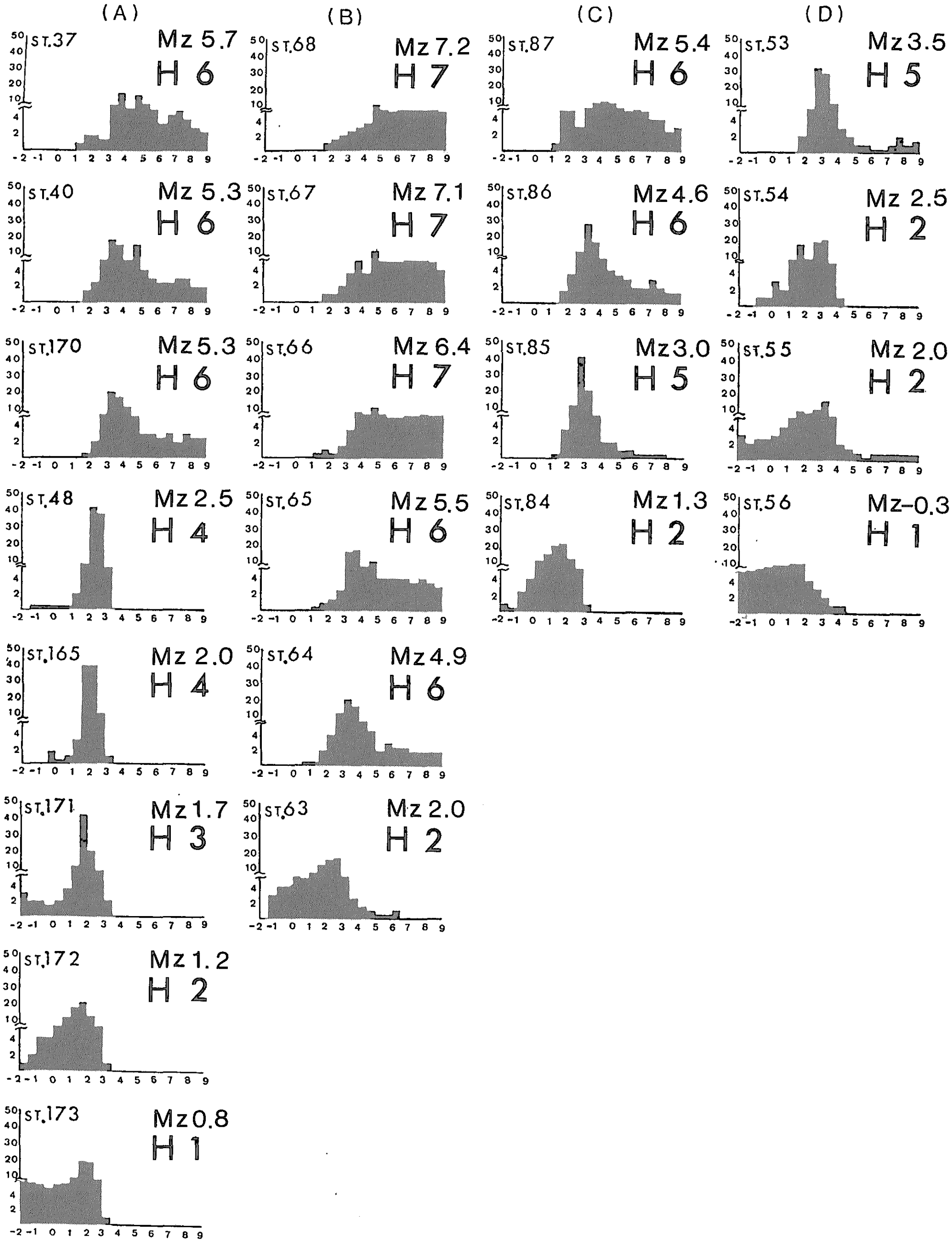


Fig. 13 Histograms of grain size and their sediment types. Numbers under the mean diameter (Mz, in ϕ units) are sediment types. (A) Suwo Nada and Iyo Nada. (B) western part of Hiuchi Nada. (C) eastren part of Bungo Suido. (D) central part of Iyo Nada. Vertical axis shows weight percent in each size class. Horizontal axis shows grain size in ϕ units. (A) (St. 37-St. 173) to (D) (St. 53-St. 56) are shown in Fig. 11 as (A) to (D), and Fig. 14. These stations fall along the lines A to D, respectively.

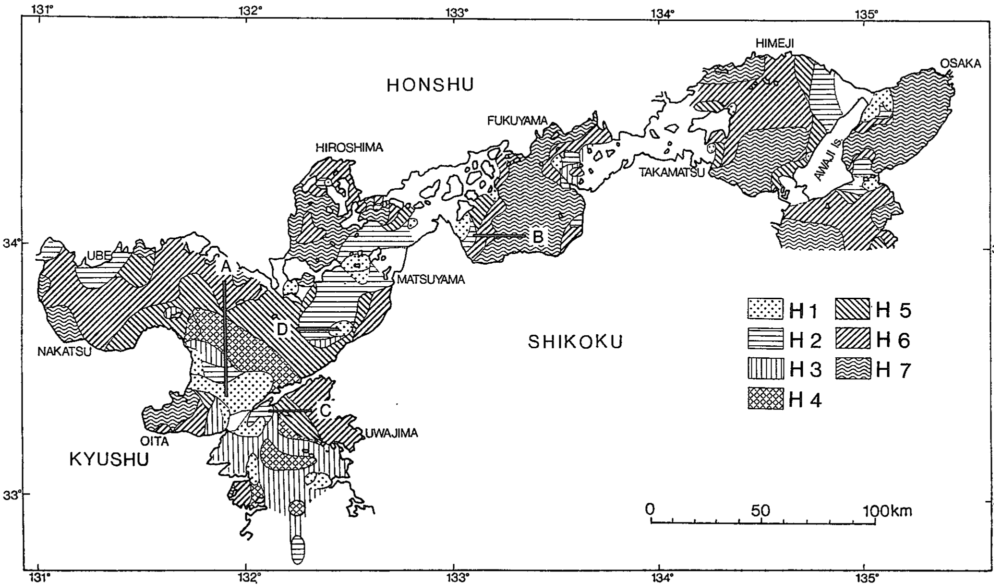


Fig. 14 Distribution map of sediment types. Grain size distributions of sediments along lines A to D are shown in Fig. 13.

This is the coarsest sediment type in the Seto Inland Sea, with a mean diameter less than 2ϕ. Sorting is not good. Type H1 is distributed mainly near the scour hollows in the northern part of Hoyo Strait, Tsurishima Strait and the eastern part of Akashi Strait, and also in the cape-type scour hollows such as ones off of the Kamado-saki Peninsula (Fig. 14).

Type H2 : Gravel contents are less than 10%. The main component is sand with no strongly developed mode. In some cases, mud contents are as great as 30%. Mean diameter is between 0 and 3ϕ. Type H2 is not well sorted.

Type H2 is distributed widely in the southern part of Aki Nada, the northeastern part of Iyo Nada and around the outside area of Type H1 sediment.

Type H3 : Content of 0.2-0.3 mm sand is very high. Sorting is good, except that as much as 5% gravel causes the sediment to be bimodal. In general, contents of -2 to 1ϕ grains are a little lower than those of adjacent size classes. Type H3 sediment is better sorted than Types H1 and H2. Mean diameter ranges from 0 to 3ϕ. This type is mainly distributed in the central part of Bungo Suido except for the area of Type H4 and at the mouth of Beppu Bay. Type H3 sediment separates areas underlain by Types H2 and H4, and occurs near small scour hollows.

Type H4 : Contents of gravel and mud are very low, and the histograms are usually nearly symmetrically skewed. The sediments show best sorting among Types H1 to H7 and the mean diameter is usually about 2ϕ. Sand waves are often observed in the areas of Types H1 to H4. The sand waves lie in the southwestern part of Iyo Nada and in the central part of Bungo Suido, where sandy sediments predominate and where the water volume moved by tidal exchange is very large.

Type H5 : The sediments are a little finer in grain size than those of Type H4. They are less well sorted than Type H4, contain 10 to 50% mud, and the mean diameter is 2 to 6ϕ. Therefore, the histograms sometimes show bimodal grain-size distributions. Sediments of Type H5 lie in the central part of Iyo

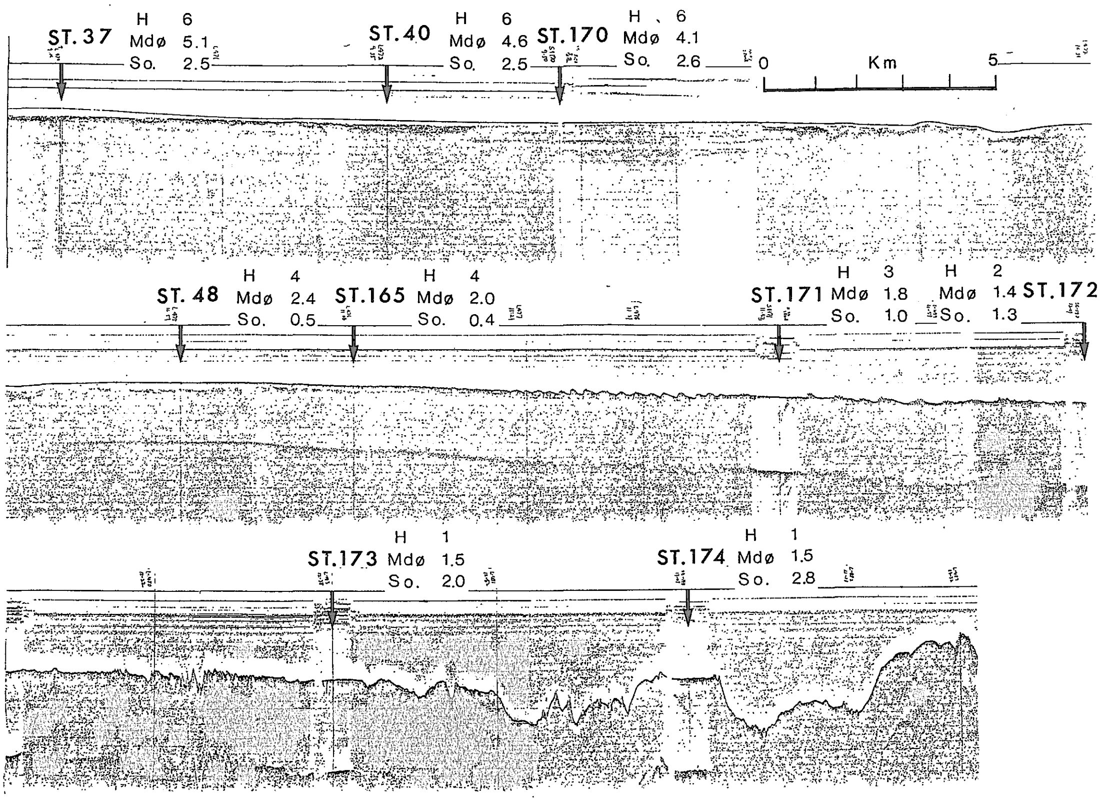


Fig. 15 Examples of relations between sediment type and sea bed morphology in Iyo Nada. Position of track line is shown in Fig. 14 as Line A.

Nada, the southeastern part of Suwo Nada, and in some areas nearer to the channels than sediments of Type H6. Sand waves commonly occur in the Type H5 distribution area.

Type H6 : Sand is very fine. Grain size distributions have a broad mode in the very fine sand sizes. In general, these sediments contain more than 30% mud, and show bimodal or polymodal patterns in grain size histograms, with two or more peaks of sand and mud (Fig. 13). They are not very well sorted, and have a mean diameter of 4 to 6ϕ. Type 6 is distributed in areas where tidal currents seem to be very slow, such as in the main part of Suwo Nada, the eastern part of Bungo Suido, Saeki Bay, Hiroshima Bay, the northern part of Harima Nada and Kii Suido.

Type H7 : Contents of mud are very high and contents of fine sand and very fine sand are usually less than 40%. Moreover, most of the sand grains are faecal pellets. The sorting of sediments is poor. Mean diameter is less than 6ϕ. Type H7 sediments underlie the western part of Suwo Nada, Beppu Bay, and Hiroshima Bay, and areas where tidal currents are negligible, such as Hiuchi Nada, Bingo Nada, Mizushima Nada, the south of Harima Nada, Osaka Bay and the western part of Kii Suido.

Summary : Sorting is best in Type H4, and become worse in other types whether they are coarser or finer. Lateral changes of sediment type show that Type H1 lies near channels or scour hollows, and the type number increases away from these areas (Fig. 15). Relationships between sediment types and other parameters are shown in Table 1.

Table 1 Distribution of sediment types in respect to the mean diameter, sorting, mud content and gravel content (sea areas to the west of Bisan Seto).

Mzϕ Type	−4.0–0	0.1–1.0	1.1–2.0	2.1–3.0	3.1–4.0	4.1–6.0	6.1–10.0	total
H 1	11	12	2					25
2		3	16	4				23
3		1	14	9				24
4		1	9	10				20
5				7	15	13		35
6					1	45	23	69
7						3	64	67
Sorting Type	**0.1–0.5**	**0.6–1.0**	**1.1–2.0**	**2.1–4.0**	**4.1–4.5**	**total**		
H 1			11	14		25		
2	1	0	18	4		23		
3		9	13	2		24		
4	9	10	1			20		
5		3	15	17		35		
6				67	2	69		
7			1	65	1	67		
Mud Content Type	**0–5**	**6–10**	**11–20**	**21–30**	**31–40**	**41–60**	**61–100%**	**total**
H 1	11	8	5		1			25
2	5	11	5	1	1	1		23
3	11	5	6	1	1			24
4	15	5						20
5			11	13	6	5		35
6				1	1	18	49	69
7							67	67
Gravel Content Type	**0–5**	**6–10**	**11–20**	**21–40**	**41–95%**	**total**		
H 1			8	11	6	25		
2	14	9				23		
3	20	4				24		
4	20					20		
5	34		1			35		
6	66	2	1			69		
7	66	1				67		

VI. STRATIGRAPHY BASED ON 3.5 KHZ SUBBOTTOM PROFILING RECORDS

Precise Depth Recorder (Okidenki Co.) and 3.5 kHz Subbottom Profiler (Raytheon Co.) were used for acoustic surveys. The survey tracks were spaced at intervals of a few miles so as to overlie sites where bottom sediments were sampled.

No data are available concerning the acoustic velocity in unconsolidated sediments in the Seto Inland Sea. CHUJO *et al.* (1961) estimated the velocity in the sediment of Ariake Bay in Kyushu as 1480 m/sec or a little faster, and HUZITA and MAEDA (1969) used a value of 1500 m/sec in Osaka Bay. In this report, an acoustic velocity of 1500 m/sec is employed.

The U (upper) layer and L (lower) layers can be clearly distinguished (Fig. 16). In general, the U layer is acoustically transparent or semitransparent on the record except for some local reflectors, and covers all the area except in and around the channels. The reflector which separates the L layer from the U

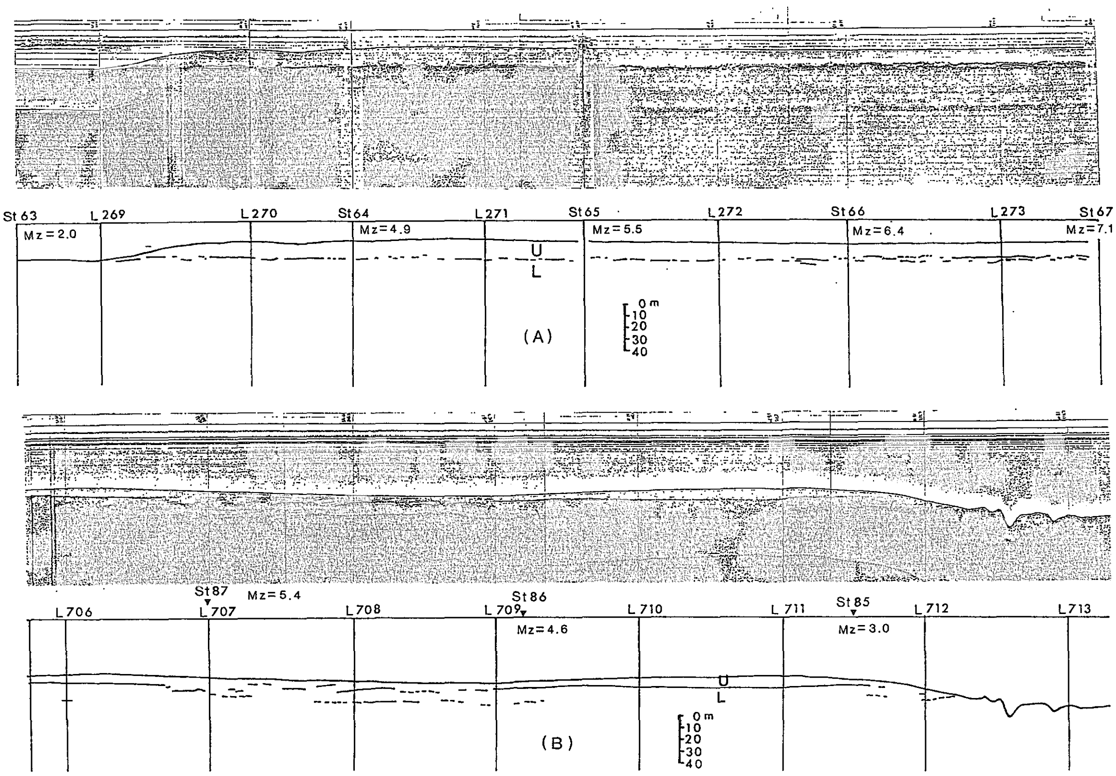


Fig. 16 Examples of 3.5 kHz continuous seismic profiles. (A) western part of Hiuchi Nada. (B) eastern part of Bungo Suido. St : station number ; L : location of navigation fixes ; U : U layer ; L : L layer. Positions of track lines are shown in Fig. 19.

Table 2 Comparison of thickness of U layer between acoustic data and columnar section data.

Sample Number	Sampling Depth	Cored length	Thickness of U layer estimated from acoustic data	Thickness of U layer determin by cored material
HN 24	32 m	3.8 m	4 m	3.78 m
35	42	2.7	2	1.57 m
42	42	4.0	5	4.0 m+
43	42	4.2	6	4.2 m+
48	28	3.24	4	3.24 m+
56	20	2.39	10	2.39 m+
69	26	2.47	1.5	1.32 m
77	30	4.00	3	2.77 m+
108	38	4.72	5	4.1 m
126	31	1.62	3	1.62 m+

layer is continuous in the surveyed area. The L layer sometimes contains a few local reflectors, and crops out in or near channel areas, or is overlain there by very thin sediment belonging to the U layer.

The stratigraphic significance of the reflector between the U and L layers is discussed below, based on cored materials and 3.5 kHz

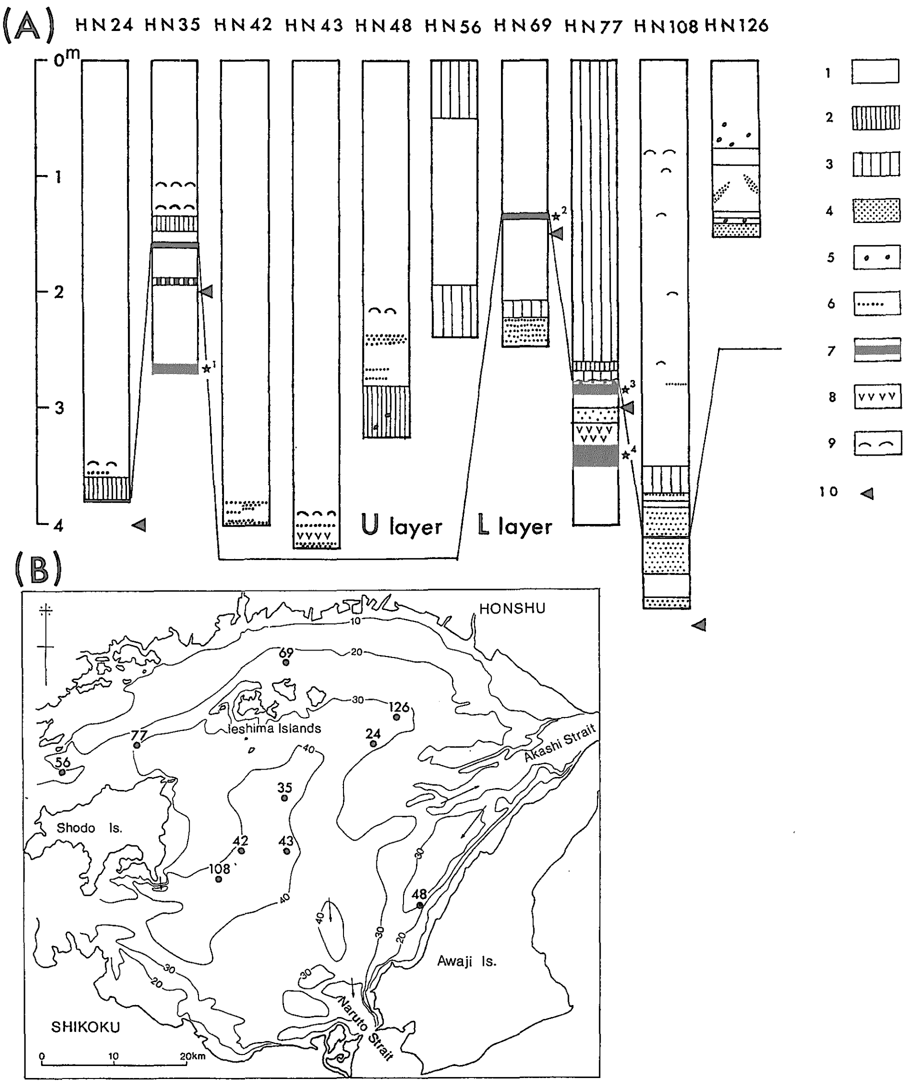


Fig. 17 Core lithologies (A), and their locations (B) in Harima Nada. 1 : mud, 2 : sandy mud, 3 : muddy sand, 4 : sand, 5 : gravel, 6 : thin sand layer, 7 : peat, 8 : volcanic ash, 9 : shell fragments, 10 : basal position of U layer estimated from the acoustic data. *1 : 36,400 yrs. B.P. *2 : 23,010 yrs. B.P., 22,340 yrs. B.P., 23,750 yrs.B.P., 25,470 yrs. B.P. *3 : 10,430 yrs. B.P., 12,770 yrs. B.P. *4 : 27,650 yrs. B.P. Absolute Age was determined by Teledyne Isotope Co. Ltd.

subbottom profiles in Harima Nada (Fig. 17, Table 2). In general, the upper part (or all) of the cores is composed mainly of dark greenish grey marine mud, which resembles the surface sediments obtained by grab sampling. Muddy samples contain marine molluscan shell fragments, such as *Paphia undulata* etc. and some faecal pellets. Sand content increases downcore, or in some cases, thin sand layers or basement rock appear in the lower parts of cores. The upper parts of cores are coarser around the channels.

The sediment in the lower parts of cores is rich in organic matter, and in many cases peat or pebble beds are intercalated between the upper and lower parts of the cored sediment.

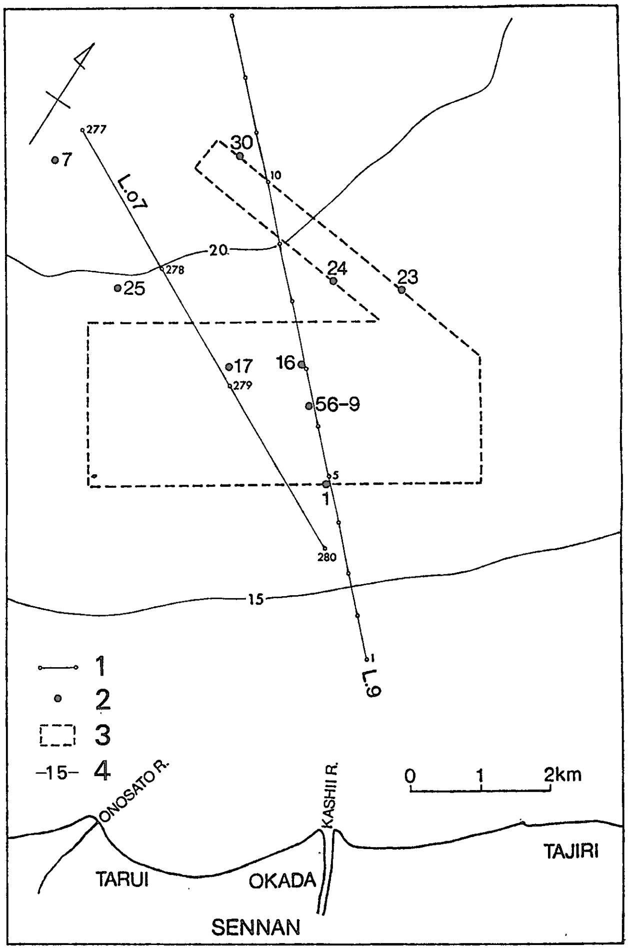


Fig. 18 Positions of bore holes in the planning site area of Kansai New International Airport in Osaka Bay (from NAKASEKO, 1983) and tracks of acoustic survey. L. 9 : Line 9 in HUZITA and KAMATA (1964), L. 07 : Line 7 in ONODERA and OSHIMA (1983), 1 : tracks of acoustic survey, 2 : position of bore hole, 3 : planning site of Kansai New International Airport, 4. depth contour line (meter).

Light greenish gray lacustrine clay, volcanic ash, sand and rock fragments are also found in the lower parts of cores. Lacustrine clay contains plant fragments in many cases, and is more consolidated than the marine mud in the upper part of the same core.

These relationships between the upper and lower parts of the sediment sequence are expected to be common all over the Seto Inland Sea, based on the following reasons. The maximum depth in the Seto Inland Sea, excluding scour hollows, is less than 80 m. Hence, almost all areas in the Seto Inland Sea were terrestrial when sea level was very low during the maximum Würm glacial (−80 m according to OSHIMA, 1978 ; −140 m according to MINATO, 1966). The fact that the C-14 age of peats underlying the marine sediments is 10,430 yrs. B. P. to 36,400 yrs. B. P., confirms this supposition. A corollary is that the marine sediments, which are composed mainly of mud must be postglacial transgressive sediment younger than about 20,000 a. There must therefore be an unconformity between the marine sediments which occupy the upper part of the cored material and the lower

Table 3 Thickness comparison between acoustic data and bore and bore hole data. Thicknesses of the Mud member are sometimes a little shorter than predicted from the acoustic data when the boring site is in deeper position than that of acoustic survey.

Line L. 07 (ONODERA and OSHIMA, 1983)				Boring data in Planning Area of Airport (NAKASEKO, 1983)		
	Thickness of U layer			No.	Mud member	Sand (and gravel) member
L. 277	—	—	27.5 m	56-7	0-25 m	25-27 m
L. 278	—	—	23.5	56-25	0-21.7	21.7-22.3
L. 279	—	—	19	56-17	0-20.5	20.5-22.5
	Line 9 (HUZITA and KAMATA, 1964)			Boring data in Planning Area of (NAKASEKO, 1983)		
	Thickness of A	Thickness of B	A+B	No.	Mud member	Sand (and gravel) member
L. 5	17 m	0 m	17 m	57-1	0-15.5 m	15.5-18.0 m
6	21	0	21 m	56-9	0-19.6	19.6-26.4
7	23	0	23 m	57-16	0-21.7	21.7-32.1
8	22	4	26 m	57-23	0-25.8	25.8-38.3
				57-24	0-25.9	25.9-39.6
10	26	4	30 m	57-30	0-29.2	29.2-62.7

sediments or rock. The unconformity may be shallower in the cored materials than inferred from acoustic records due to shortening of the sediment column by gravity coring (EMERY and HÜLSEMAN, 1964).

The reflector between the U and L layers is the most continuous one in the Seto Inland Sea, and it is only absent in channel areas. Therefore, it seems reasonable to correlate the reflector between the U and L layers with the widely distributed unconformity between the upper marine sediments, composed mainly of mud, and the lower fresh water sediments and rock. This is consistent with data from drilling in Osaka Bay. That is, the basal depths of the U layer, estimated from 3.5 kHz acoustic data, fit fairly well with the base of the A member (generally entirely marine mud) which is the only pronounced lithologic boundary noted beneath the planning site of New Kansai International Airport (NAKASEKO, 1983) (Fig. 18 and Table 3).

L layer is apparently the source of fossil Elephants recovered from the Seto Inland Sea (IKEBE, 1959 ; ITIHARA, 1961). All bones come from the channel areas or the scour hollows, except those found on wave cut terraces near the shorelines. Neogene to Quaternary beds containing fossil Elephants must crop out in the channel areas. They are eroded by strong tidal currents and the fossils remain as a lag on the seabed. BANDO *et al.* (1978) said that granitic rocks and Pleistocene Ozuchi Formation are distributed on the bottom of scour hollows in the Bisan Seto area. HONZA *et al.* (1970) make similar observations. Based on acoustic records, the U layer is, in general, distributed neither in the channels nor in the scour hollows, and the L layer is exposed at the seabed, providing a source for the fossil Elephants. Granitic rocks in the scour hollow areas come from the bedrock.

Fig. 19 shows the thickness distribution of the U layer. In the areas where the U layer is relatively thick, it is easy to distinguish the U layer from the L layer. In areas where the U layer is thin or sandy, however, it is sometimes difficult to determine the thickness of the U layer owing to the low resolving power of the seismic record. Even in that case, a very thin U layer is assumed to exist. Where the seafloor is clearly an erosional surface, however, the thickness of the U layer is regarded as 0 m. As shown in Fig. 19, thick (more

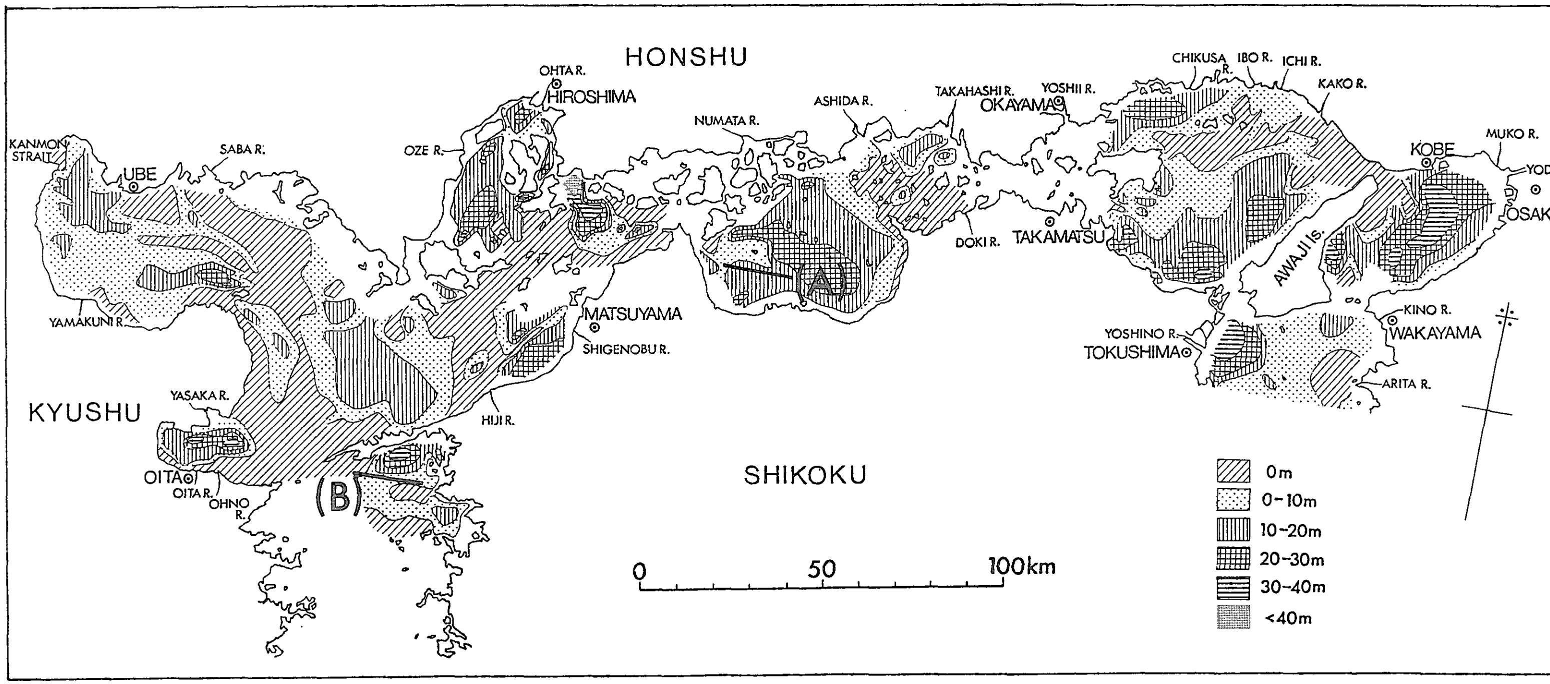


Fig. 19 Isopach map of U layer. Acoustic record along lines (A) and (B) are shown in Fig. 16.

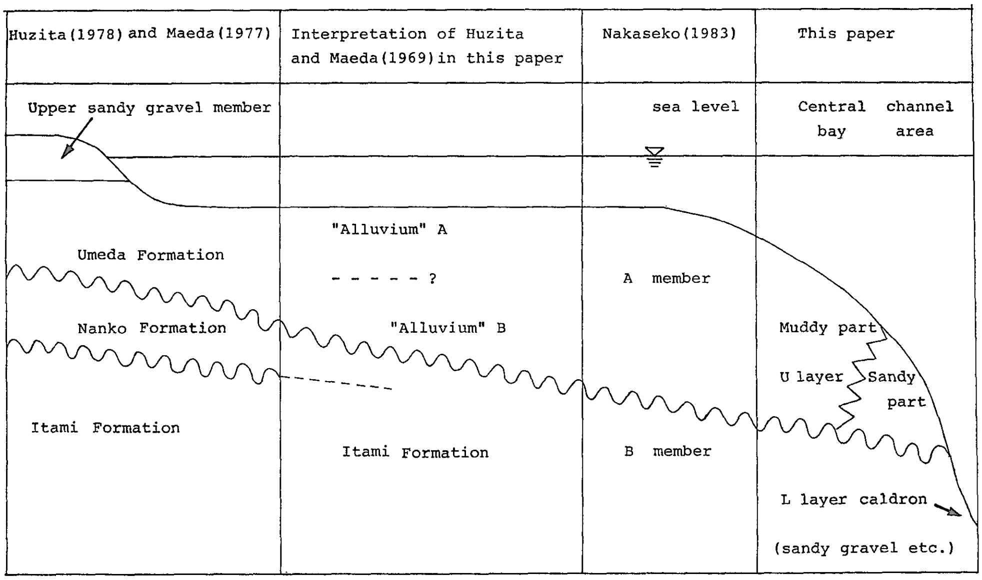


Fig. 20 Holocene stratigraphy in Osaka Bay.

than 30m) U layer is distributed in Beppu Bay, the northeastern part of Bungo Suido, Aki Nada off Kure City, the southern part of Harima Nada, Osaka Bay and the northwestern part of Kii Suido. Areas where thickness of the U layer is 20 to 30 m are Suwo Nada, the eastern part of Iyo Nada, Hiroshima Bay, the central part of Hiuchi Nada and the northwestern part of Harima Nada.

Where the U layer is thick (more than 30 m), the surface sediments are mainly mud, and the histogram type is H6 and H7. In general, the U layer is very thin (less than 10 m) in sandy sediments. Type H1, H2 and H3 characterize these areas. However, in the eastern part of Aki Nada and the central to western part of Iyo Nada, sandy sediments of the U layer are unusually thick, attaining 10 to 20 m. H4 and H5 histogram types are distributed in this area.

Coastal plains around the Seto Inland Sea are underlain by " Alluvium" which correlates with the U layer (and in part with the L layer) in the sea. HUZITA and MAEDA (1966) divided the "Alluvium" in Amagasaki region into two parts, namely, "upper Alluvium" and "lower Alluvium". "Upper Alluvium" was subdivided into upper sandy gravel, middle clay (Amagasaki clay) and lower sandy gravel formations. HUZITA and MAEDA (1966) said that the "lower Alluvium" buried dissected valleys of an ancient river system. HUZITA and KAMATA (1964) also distinguished A and B formations of "Alluvium deposit" in Osaka Bay, based on Sparker profiles, but these are both part of the U layer of this paper, based on comparable thickness. The depths of "Alluvium" base in the marine area which were reported by HUZITA and KAMATA (1964) coincide with that of the A member (in general, marine mud formation) in the drilling data of NAKASEKO (1983) (Table 3). Consequently, the A and B formations of "Alluvium" of HUZITA and KAMATA (1964) and the U layer in this report are both correlated with the "A member" at the planning site of Kansai New International Airport. The A member is composed mainly of marine mud and is correlated with the middle mud formation of the coastal plain (Amagasaki clay formation in HUZITA and MAEDA, 1966) (Fig. 20).

VII. DISCUSSION

1. Causes of lateral grading in the grain size of sediments around the channel areas

One of the most characteristic distribution patterns in the Seto Inland Sea is, as described in the chapter IV, that the sediment grain size is coarsest in channel areas or in scour hollows and decreases gradually with increasing distance from these features. In the north off Hoyo Strait, such grain size decreases are recognized as far as 70 km in a north-south direction, and in other channel areas the distance is often as far as 10 km.

Elsewhere, no clear large-scale horizontal size grading is recognized, particularly perpendicular to the shoreline. Although sampling did not extend to the shoreline, grain size decreases away from the shoreline, as shown by PILKEY and FRANKENBERG (1964) and EMERY (1968) in modern sediments, are at best of very small scale, restricted to less than a few kilometers. Elsewhere around Japan, as is the case in the Seto Inland Sea, distance from deep channels is the predominant control on grain size, for example, KAMADA (1967) and SHIOZAWA (1969) reported a decrease in grain size with increasing distance from the the channel area in Ariake Bay and Akkeshi Lake, respectively. Both these areas have strong currents. Thus, decreasing grain size with increasing distance from a channel area seems to be a general feature of semi-enclosed seas with strong currents.

A superficially similar sediment distribution pattern characterizes lagoons and tidal flats, and as IKEYA and HANDA (1972) and KRUMBEIN (1939) stated, the source of the sandy sediments is usually attributed to the open shelf. IKEYA and HANDA (1972) concluded that the sandy sediments in Hamana Lake were originally supplied from the Tenryu River into the nearshore area of the Pacific Ocean, drifted westward beneath longshore currents, and were then transported into the lake by tidal currents.

Origin of Sediments

In general, muddy sediments occur in the vicinity of the mouths of the main rivers which enter the Seto Inland Sea. These sediments do not contain coarse sand grains, even though there are many granitic rock exposures around the Seto Inland Sea. The coaser material does not reach the sea, but is instead deposited on alluvial fans or deltas (HUZITA, 1978). Therefore, the sands around the channel areas were not contributed by the rivers. In any case, no channels cross the areas of coastal mud deposition, so there is no route to transport sand from the shoreline.

Based on the acoustic data, modern sediments are not distributed in and around the channel areas. Instead, older sediments or bedrock are exposed and are being eroded. These older sediments were deposited at the time of low sea level when the Seto Inland Sea was a subaerial region (L layer in the acoustic stratigraphy).

The volume of eroded material is sufficient to supply the observed quantities of sand. For example, in Iyo Nada, the volume of eroded sediment (6.4 km^3), deduced from the volume of the scour hollow in the north off Hoyo Strait, is of the same order as that of the sandy sediment now distributed in the southern part of Iyo Nada (6.9 km^3). It seems reasonable to conclude, therefore, that the sandy sediments, which are distributed throughout much of the Seto Inland Sea, were derived by erosion and reworking of both older sediment, which was deposited at the last low sea level, and the basement granitic rocks, both lying in and near the channel areas.

The origin of the mud fraction in the U layer is more diverse. Firstly, older muddy sediments of the L layer are exposed in channel areas. For example, ITIHARA (1961) stated that in Tomogashima Strait, the mud bed which contains fossil Elephants is widely exposed. Is this material a reasonable source for the mud in the U layer? To answer this question, volume estimations were made for the U layer in Osaka Bay (22 km^3), where muddy sediments are dominant, and for two scour hollows which lie in Akashi and Tomogashima Straits (4 km^3). The results show that sediments from the scour hollows could only account for 1/5 of the volume of mud in Osaka Bay, assuming that all material reworked from the scour hollows was mud. The rest must have been introduced by rivers, and deposited where the currents were weak enough to allow settling from suspension.

Causes of horizontal grading in the sediments

Modern hydrographic data indicate that the only important currents in the Seto Inland Sea are tidal currents. Fetch is too small to allow development of waves that could move sediment in the relatively deep water (largely more than 20 m deep). Tidal currents in this area are certainly strong enough to transport the sand and gravel fractions. The ROAD BUREAU AND THE KINKI REGIONAL CONSTRUCTION BUREAU OF THE MINISTRY OF CONSTRUCTION (1970) measured tidal current velocities in the central part of Akashi Strait at several depth zone. The results show that, even in the scour hollow, tidal current velocity is as high as 4.6 knot (about 230 cm/sec) in the 60 m depth zone. Velocity fluctuations are less than 20%. Thus, the bottom currents in the scour hollow are sufficiently strong to erode the unconsolidated bottom sediments or weathered materials of the bedrock and to transport eroded materials. In addition, HONZA and NASU (1968) measured maximum current velocities in Bisan Seto of about 1 knot 1 m above the bottom and 4 to 5 knots at the surface. These stations were almost all above a sand wave field and sand transport was observed.

Tidal currents can be effective in producing horizontal size grading of bottom sediments (for example, STRIDE, 1963 ; BELDERSON, 1964 ; BELDERSON and STRIDE, 1966 ; KRANK, 1972 ; CHANNON and HAMILTON, 1976 ; etc.). BELDERSON and STRIDE (1966) show that in the Celtic Sea, southwest of England, grain size decreases in the direction of tidal current flow. Also, side-scan sonar asdic records in their paper show a series of characteristic regions from upcurrent to downcurrent ; that is, 1) predominance of erosion, 2) sand ribbons, 3) sand waves, 4) continuous beds of sand and muddy sand, and 5) sand patches with intervening shell-gravel. KENYON (1970) recognized the relationship between the form of sand ribbons and the velocity of tidal currents by using asdic records on the seabed off southwest England. In addition, CHANNON and HAMILTON (1976) mention that off southwest of England, the grain size distributions of sediments are influenced by tidal currents, although the sorting of sediments occurs by both tidal currents and by storm-generated currents.

STRAATEN and KUENEN (1958) explained the accumulation of fine grained sediments in the Dutch Wadden Sea as a consequence of tidal current transport. They assumed that a tidal current flowing across a tidal flat is a reversing current with a symmetrical time-velocity curve ($V(-t)=-V(t)$, where $t=0$ at high or low slack water), and that maximum current velocity decreases shoreward. They showed that the grains which are transported by the flooding tide begin to settle when the current velocity decreases below the level required to initiate the erosion and transportation of the grains. Because settling takes time, however, the grains are transported some distance landward before coming to rest on the bottom. The accumulated effect of this settling lag over several tidal cycles results in net landward transport of the mud (Fig. 21 ; see caption for a worked example).

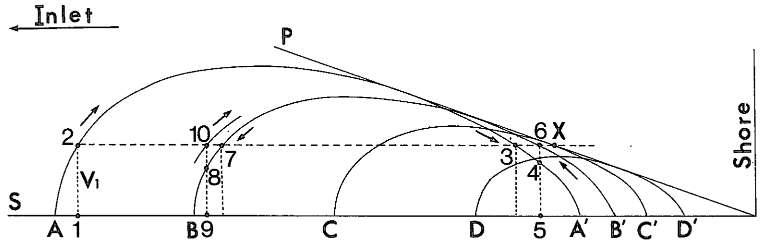


Fig. 21 Settling lag effect (From STRAATEN and KUENEN, 1958) Diagram showing the velocities (v) with which different water masses move with the tides at each point along a section through the Wadden Sea from somewhere in the direction of the inlet (left) to the shore or toward the watersheds (right). The curves apply only to idealized, average condition. Scour lag is supposed to be zero. A sediment particle taken into suspension at point 1 by a flood current of increasing velocity, starts to settle towards the bottom at point 3, when the current velocity drops again below the value attained at point 1. In consequence of the settling lag the particle reaches the bottom later, at point 5, when current velocity has meanwhile diminished to the value represented by the vertical 4-5. After the turn of the tide it cannot be eroded by the same mass of water, because this attains the required velocity only later, when it has reached a point situated more towards the inlet. The sediment particle is therefore eroded by a more landward mass of water (curve B-B') and taken along in the direction of point B. At point 7 it starts to drop out of suspension. It reaches the bottom at point 9. During one tidal cycle the particle has therefore shifted from point 1 to point 9.

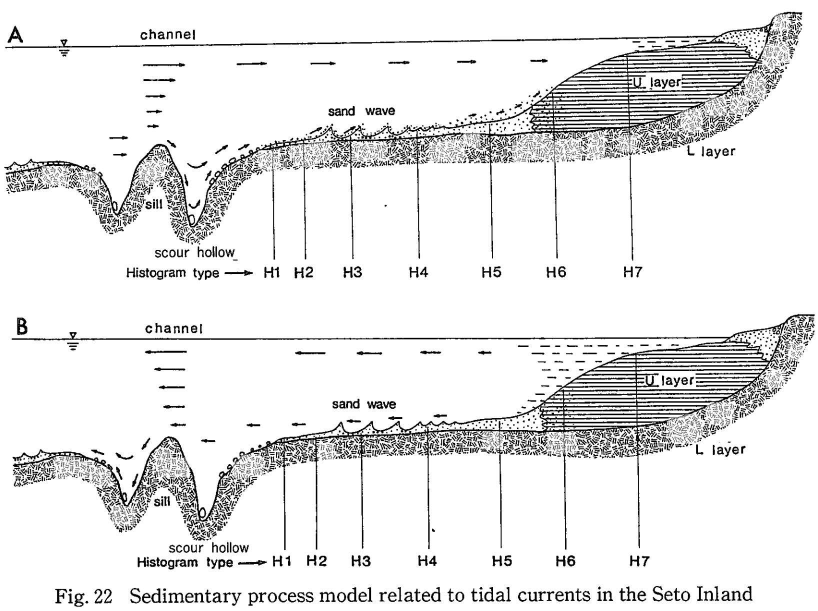


Fig. 22 Sedimentary process model related to tidal currents in the Seto Inland Sea. (vertical scale is exaggerated) A : flood tide, B : ebb tide.

Although there are differences in the grain size of the sediments and in the water depths between the Wadden Sea and the Seto Inland Sea, similar suspension lags, combined with fluctuating and reversing tidal velocities, are believed to account for lateral size grading in the Seto Inland Sea.

In addition, in the Seto Inland Sea, flood and ebb tidal velocities may differ considerably. MOGI (1980) reported that at Kanmon and Akashi Straits, velocities of tidal currents are relatively higher when the survey positions are in the downstream side of a channel than in the upperstream side of the same channel. This phenomenon is repeated when the direction of flow reverses. As a result, the lag effects outlined by STRAATEN and KUENEN (1958) are accentuated in the downstream direction.

In conclusion, the decrease in grain size with distance from the channels is caused by the tidal currents. The bottom materials are eroded in and near a channel or scour hollow, transported and sorted. Quite independently, suspended mud derived from rivers input settles in areas where tidal currents are very slow.

A model to explain sedimentary process in the Seto Inland Sea is shown in Fig. 22, using the case of a twin-type scour hollow.

At flood tide, the scour hollow on the downcurrent side is eroded by the current. In consequence, sand and gravel grains are reworked from the L layer, which underlies the bottom and walls of the scour hollow, and these grains are transported downcurrent. Large gravel clasts that cannot be transported by the tidal current are left as a lag in the bottom of the scour hollow. Fossil Elephants which were found at Tomogashima Strait are part of such a lag deposit.

Tidal current velocity decreases away from channels, and only smaller particles can be transported. Sediments of Types H1 to H4 are deposited in this area. Sorting improves from Type H1 to Type H4 due to selective transport of finer material with increasing distance from the channel. Moreover, the sandy sediment sometimes forms sand waves.

As the tidal current velocity decreases further, the sand grains suspended load becomes restricted to very fine sand of histogram Type H6.

In the area farthest from the channel and in current shadows, tidal current velocities are insignificant, and there is little supply even of suspended matter derived from the scour hollows. Sand content in the sediments is therefore very low, and mud is the predominant deposit. The sediment type of this area is H7. The silt and clay particles are mainly supplied from rivers. In the Seto Inland Sea, in general, the volume of sediments supplied from rivers exceeds that from the scour hollows, as in Osaka Bay.

During ebb tide, tidal currents flow mainly along the sea surface toward the channels. Because tidal currents are relatively stronger on the downcurrent side of straits than on the uppercurrent side (MOGI, 1980), the bottom sediments do not experience the same current velocity as during the flood tide. In addition, as threshold velocities for initiation of movement of the grains are larger than velocities that permit settling of the grains, it takes longer for the grains to start to move again in areas far from the channel compared to areas near the channel. There is therefore a net movement of sand grains away from the channel with each tidal cycle.

Suspended grains, which are derived mainly from rivers, are concentrated near the shore at flood tide and then spread widely offshore with weak currents at ebb tide. The result is a small content of mud grains in the sandy sediments. A typical mixed sediment formed in this way is Type H5 sediment. However, mud grains which are included in Types H1 and H2 near the channel areas may have been eroded from the L layer. Mud grains in Type H5 mixed sediment may be eroded and transported back toward the shoreline by subsequent flood tide. In this manner, mixtures of mud and sand, showing bimodal or polymodal patterns in histograms, are formed. This mixing causes sorting to become worse from H5 to H7.

2. The age of "Alluvium" sandy sediments distributed near the channel areas

As in subtidal lagoons and estuaries, sediments which are transported by tidal currents in the Seto Inland Sea show a horizontal decrease in grain size with distance from the channels, in the direction of decrease of the current velocity. In the past, however, surface sandy sediments near the channels have been interpreted as relict deposits from times of low sea level, 15-20 m lower than today, as in the case of Ariake Bay (ARIAKE BAY RESEARCH GROUP, 1965) and Osaka Bay (HUZITA and MAEDA, 1969).

HUZITA and MAEDA (1969) divided "Alluvium" sediment in Osaka Bay into A and B formations. These are similar to the Ariake Clay Formation and Shimabara Kaiwan Formation (ARIAKE BAY RESEARCH GROUP, 1965), and Alluvium I and II formations in Tokyo (AOKI and SHIBASAKI, 1966). The A formation is Holocene mud and the B formation is latest Pleistocene in age (HUZITA and MAEDA, 1969, p.94, 95).

Later, HUZITA (1978) correlated the A formation to the Umeda Formation in the coastal region, and the B formation to the Nanko Formation of early Holocene age, based on the assumption that sandy sediments in the channels belong to the B formation (Ibid, p.170). He stated that conditions for the formation of sandy gravel do not exist in the present bay (Ibid, p.172).

The new data presented in this paper indicate that "Alluvium" A and B taken together correlate with the U layer. The acoustic boundary between "Alluvium" A and B formations does not correspond to the unconformity found in the land area, that is, Nanko-Umeda boundary (Fig. 20). The sandy sediments distributed around the channel area belong to the U layer, and shows a lateral facies change into muds. KUWAHARA *et al.* (1972), using acoustic records in Ise Bay, also noted that the A formation surface sediments change to sandy facies near the bay mouth. By analogy, therefore, the sandy surface sediments that are distributed around the channel area in Osaka Bay are modern sediments that are now undergoing transportation as in the case in the Seto Inland Sea. They are not relict as was inferred by HUZITA and MAEDA (1969).

Next, the interpretation of the ARIAKE BAY RESEARCH GROUP (1965) will be discussed. The ARIAKE BAY RESEARCH GROUP (1965) divided surface sediments into the "Ariake Clay Formation" which is composed mainly of muddy sediments, and the "Shimabara Kaiwan Formation" which is composed mainly of sandy sediments. The Shimabara Kaiwan Formation is distributed widely on a −40 m planation surface, and was believed to be continuous with sandy sediments that underlie the Ariake Clay Formation in Ariake and Shiranui Bays. This same view of the stratigraphy was adopted by KAMADA (1979), who stated that the basal plane of the Ariake Clay Formation coincides with the surface of the buried valley which dissects the planation surface of −40 m. Sediments which are cut by that valley belong to a formation composed of medium and coarse sand and fine gravel. KAMADA (1979) distinguished this sandy gravel formation from the Ariake Clay Formation, and regarded it as the Shimabara Kaiwan Formation. KAMADA (1979) also described, however, a decrease in grain size with increasing distance from the channel area in the bay. This is difficult to reconcile with a hypothesis that the sandy gravel formation in the central bay and the one underlying Ariake Clay Formation are continuous. What process can account for the removal of coarse-grained sand and gravel in the intervening area? Modern tidal currents would not be component to do this.

MATSUISHI and MATSUMOTO (1969), based on acoustic Sonoprobe records in Ariake Bay, divided the "Alluvium" in that area into an "upper Alluvium" and a "lower Alluvium", and subdivided the "upper Alluvium" into "upper Alluvium I" (mainly mud), "upper Alluvium II" (mainly sand) and "upper Alluvium III" (mainly shell fragments, sand and gravel) based on the correlation with samples of bottom sediments. However, as shown in Fig. 12 of MATSUISHI and MATSUMOTO (1969), "upper Alluvium I" passes laterally into "upper Alluvium II". These lateral facies changes between muddy and sandy facies are similar to those found elsewhere in the Seto Inland Sea, and suggest that a layer-cake view of the stratigraphy, with sandy facies always inferred to underlie muddy facies (e. g. HUZITA and MAEDA, 1969 ; KAMADA, 1979) is misleading. More research is needed in the Ariake Bay area, but it seems possible that sandy sediments around the deeper channel in the bay are not continuous with the Shimabara Kaiwan Formation, but instead are contemporaneous with the Ariake Clay Formation. The channel sands would then owe their origin to tidal-current reworking of older sediments exposed in the walls of the channel.

VIII. SUMMARY

In the Seto Inland Sea, sandy sediments are distributed widely in and around the channels and scour hollows, and they decrease in grain size with distance from these scour hollows. Farther from the channels, muddy sediments of recent age are distributed. These muddy sediments compose the surface part of the U layer in acoustic records. This muddy material is very thin or absent in the channel areas and scour hollows, and increases in thickness far shoreward from the channels.

The distribution of the sandy materials can be explained by the effect of tidal currents. Sand is supplied by the reworking of fresh-water and shallow-marine sediments which were deposited during the low sea level in the latest Pleistocene and by the erosion of the basement rocks, both distributed in and around the scour hollows and channels. In this regard, the origin of sand in the Seto Inland Sea is remarkably different from other semi-enclosed seas.

Sandy sediments which are distributed around the channels were previously thought to belong to an older Pleistocene formation. This report shows, however, that they are modern reworked sediments which are being actively transported by tidal currents.

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瀬戸内海における砂質堆積物分布様式と砂の起源

井　内　美　郎

要　旨

瀬戸内海における表層堆積物の分布様式を明らかにし，砂質堆積物を構成する砂の起源を明らかにした．瀬戸内海の堆積物分布様式には，以下のような一般的特徴がある．海峡部には礫質ないし砂質の堆積物が分布し，海峡部を離れるに従ってより細粒な堆積物になる．そして灘の中央部や湾の奥では，細粒な泥質堆積物となっている．この堆積物は，3.5 kHz の周波数をもった音波探査装置による記録では，ともに同じ表層の反射層を構成している．つまり，上記の規則性を持って分布する表層堆積物は，海峡付近の海釜中に分布する礫質堆積物を除いて，現在の環境下で堆積したものである．海峡付近を中心に離れる方向に向かって細粒となる「砂」の起源は，潮汐流によって海峡付近の堆積物や岩盤が侵食され，流れの減衰に応じて粗粒なものから堆積した結果である．一方，泥質堆積物を構成する「泥」は，主として河川を通じて海域にもたらされたものである．これらの結果から，これまで海域の“沖積層”について述べられた層序は正しくないことが明らかになった．つまり，「海峡部に分布するより古い時代の砂質堆積物が，泥質堆積物を主とするより新しい堆積物に覆われており，これは音波探査記録で区分され，平野部の“沖積層”全体に対応する．」という説は，訂正を要する．

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APPENDIX

Table A-1　Sampling localities and their grain size compositions.

No.	Lon.	Lat.	Depth	Gravel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
SEIBU SETOUCHI											
1	131.3	34.0	22	0	28	72	5.8	5.1	2.8	Mix	6
2	131.3	33.6	33	1	46	53	5.4	4.2	2.9	Mix	6
3	131.4	33.5	30	0	56	43	5.1	3.7	3.0	Mix	6
4	131.4	33.5	35	0	61	39	4.8	3.4	2.9	Silty Sand	6
5	131.4	33.4	32	4	82	14	2.1	2.0	1.8	Sand	3
6	131.3	33.4	27	0	82	18	2.9	2.5	2.1	Sand	5
7	131.3	33.4	19	0	60	40	4.7	3.6	2.4	Silty Sand	5
8	131.3	33.5	35	1	39	61	5.4	4.7	3.4	Mix	6
9	131.3	33.5	30	0	78	22	3.2	2.4	2.6	Sand	5
10	131.3	33.6	23	13	63	24	2.5	1.8	3.5	Silty Sand	5
11	131.3	34.0	12	0	19	81	5.4	5.2	2.0	Sandy Silt	7
12	131.2	33.6	13	17	56	27	2.3	1.0	4.2	Silty Sand	
13	131.2	33.5	25	0	52	48	4.9	3.9	2.9	Silty Sand	6
14	131.2	33.5	32	4	68	28	3.4	2.8	3.3	Silty Sand	6
15	131.2	33.4	22	0	28	71	5.9	5.3	3.2	Mix	6
16	131.2	33.4	18	1	31	68	5.6	4.9	3.2	Mix	6
17	131.2	33.4	12	1	60	39	4.5	3.3	2.9	Silty Sand	5
18	131.2	33.4	14	0	20	80	6.5	6.6	3.1	Clayey Silt	6
19	131.1	33.4	15	0	36	64	6.2	6.5	3.6	Mix	6
20	131.1	33.4	18	0	18	82	6.8	6.8	3.1	Clayey Silt	6
21	131.1	33.5	24	0	37	63	5.6	4.9	3.5	Mix	6

Table A-1 continued

No.	Lon.	Lat.	Depth	Gravel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
22	131.1	33.5	20		60	30	2.8	1.9	3.5	Silty Silt	
24	131.1	33.6	11	6	22	72	6.0	5.6	3.8	Mix	6
25	131.1	33.5	12	0	19	81	6.6	6.3	3.0	Clayey Silt	6
26	131.1	33.5	12	0	18	82	6.7	6.6	3.1	Clayey Silt	6
27	131.1	33.4	12	2	10	89	7.4	7.4	2.9	Clayey Silt	7
30	131.0	33.5	8	13	22	65	5.5	5.7	4.5	Mix	6
31	131.0	33.5	8	0	10	89	7.3	7.0	2.8	Clayey Silt	7
32	131.0	33.6	11	3	33	65	5.6	5.1	3.3	Mix	6
33	131.0	34.0	9	4	85	12	1.8	1.9	2.2	Sand	2
34	131.4	33.5	44	0	60	40	4.7	3.5	2.9	Silty Sand	5
35	131.5	33.5	44	0	59	41	4.8	3.6	2.8	Silty Sand	5
36	131.5	33.5	46	0	45	55	5.4	4.5	2.8	Mix	6
37	131.5	33.5	39	0	29	71	5.7	5.1	2.5	Sandy Silt	6
38	131.6	33.5	41	0	29	71	5.6	5.1	2.4	Sandy Silt	7
39	131.6	33.5	35	0	37	63	5.5	4.9	2.7	Mix	6
40	131.5	33.5	45	0	44	56	5.3	4.6	2.5	Silty Sand	6
41	131.5	33.5	50	0	64	36	4.6	3.5	2.4	Silty Sand	5
42	131.5	33.5	50	0	77	23	3.9	3.1	2.1	Sand	5
43	131.4	33.5	49	0	73	27	4.4	3.2	2.5	Clayey Sand	5
44	131.3	33.5	35	0	41	59	5.3	4.6	3.3	Mix	
46	131.5	33.4	38	1	95	5	2.4	2.4	0.6	Sand	4
47	131.5	33.4	52	0	98	2	2.4	2.3	0.5	Sand	4
48	131.5	33.4	49	1	98	1	2.5	2.4	0.5	Sand	4
49	131.6	33.4	51	0	84	16	3.0	2.8	1.5	Sand	5
50	132.0	33.4	52	0	74	26	4.1	3.2	2.1	Silty Sand	5
51	132.1	33.4	56	0	75	25	3.9	3.3	1.8	Sand	5
52	131.1	33.4	57	0	78	22	3.6	3.2	1.7	Sand	5
53	132.1	33.4	63	0	80	20	3.5	3.1	1.7	Sand	5
54	132.2	33.4	61	1	90	9	2.5	2.6	1.6	Sand	2
55	132.2	33.4	56	14	71	16	2.0	2.4	3.1	Sand	1
56	132.3	33.4	38	31	63	6	−0.3	0.2	2.7	Sand	1
57	132.3	33.4	46	11	82	8	0.7	0.6	1.8	Sand	1
58	132.3	33.4	32	0	43	57	5.2	4.4	2.1	Silty Sand	6
59	132.4	33.4	23	0	44	56	5.3	4.2	2.4	Silty Sand	6
60	132.4	33.5	28	0	37	63	5.6	4.8	2.6	Mix	6
61	132.4	33.5	28	9	84	7	0.7	0.8	1.9	Sand	2
99	132.4	34.1	23	0	33	67	5.7	4.8	2.5	Mix	6
100	132.4	34.1	26	0	16	84	6.6	6.1	2.7	Clayey Silt	7
101	132.4	34.1	32	0	24	76	6.1	5.4	2.6	Mix	7
102	132.3	34.1	9	0	10	90	7.0	7.0	2.4	Clayey Silt	7
103	132.3	34.1	12	0	17	83	6.6	6.5	2.9	Clayey Silt	6
104	132.4	34.1	11	0	7	93	7.7	7.7	2.7	Silty Clay	7
105	132.4	34.1	51	1	18	81	6.9	7.1	3.3	Clayey Silt	6
106	132.4	34.1	37	19	47	34	1.8	1.3	3.5	Silty Sand	1
107	132.4	34.1	12	0	20	80	6.4	5.9	2.8	Mix	7
108	132.4	34.1	31	1	16	84	6.7	6.4	2.7	Clayey Silt	7
109	132.4	34.1	59	9	82	9	1.0	1.1	1.8	Sand	2
110	132.4	34.1	42	1	78	21	3.4	3.0	1.8	Sand	5
111	132.5	34.1	42	40	59	0	−0.7	−0.8	1.4	Sand	1
112	132.4	34.0	53	2	93	5	1.5	1.6	1.4	Sand	2
113	132.4	34.0	51	3	86	11	1.9	2.2	1.8	Sand	2
114	132.3	34.0	39	3	89	8	1.6	1.6	1.6	Sand	2

Table A-1 continued

No.	Lon.	Lat.	Depth	Gravel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
115	132.3	34.0	69	9	69	22	2.7	1.7	3.3	Sand	2
116	132.2	34.0	35	0	10	90	7.3	7.3	2.6	Clayey Silt	7
117	132.2	34.0	23	0	16	84	6.8	6.8	2.8	Clayey Silt	7
118	132.2	34.0	29	0	17	83	7.1	7.3	3.1	Clayey Silt	6
119	132.1	34.0	27	0	18	82	6.9	7.3	3.1	Clayey Silt	7
120	132.2	34.0	26	0	18	82	7.0	7.4	3.3	Clayey Silt	6
121	132.2	34.0	22	0	14	86	7.0	6.9	2.6	Clayey Silt	6
122	132.2	34.1	23	0	11	89	7.5	7.4	2.8	Clayey Silt	7
123	132.2	34.1	32	1	17	82	7.0	7.5	3.3	Silty Clay	6
124	132.2	33.1	33	9	15	76	6.2	7.0	4.1	Clayey Silt	7
125	132.2	34.1	35	0	12	88	7.3	7.3	2.7	Clayey Silt	7
126	132.2	34.1	30	0	10	90	7.7	7.7	2.7	Clayey Silt	7
127	132.2	34.1	23	1	21	78	6.6	7.0	3.4	Mix	6
128	132.2	34.2	42	3	67	30	2.5	0.8	2.4	Silty Sand	2
129	132.2	34.2	48	25	63	12	0.2	1.7	2.4	Sand	1
130	132.3	34.2	20	0	25	75	6.4	0.8	3.4	Mix	6
131	132.2	34.2	23	0	15	85	7.2	1.2	3.0	Clayey Silt	6
132	132.2	34.2	14	0	28	71	6.0	0.8	3.5	Mix	6
134	132.3	34.2	18	0	16	84	6.7	1.5	2.7	Clayey Silt	6
135	132.3	34.2	21	0	27	73	6.3	0.8	3.4	Mix	6
136	132.3	34.1	24	0	15	86	7.1	1.5	2.9	Clayey Silt	6
137	132.3	34.0	41	0	18	83	6.9	0.9	2.9	Clayey Silt	7
138	132.3	34.6	110	46	50	5	−1.1	0.7	2.6	Sand	1
139	132.3	33.6	59	70	27	3	−1.1	2.0	1.3	Sand	1
140	132.3	33.5	65	61	33	6	−1.9	0.7	3.0	Sand	1
141	132.3	33.5	59	8	86	6	1.3	1.4	1.5	Sand	2
142	132.3	33.5	55	2	88	10	1.4	1.8	1.5	Sand	2
143	132.2	33.5	65	5	88	7	1.7	1.6	1.6	Sand	2
144	132.2	33.5	49	0	86	14	3.0	1.9	1.0	Sand	5
145	132.2	33.5	29	0	34	66	5.9	0.8	2.6	Mix	7
146	132.1	33.5	54	17	75	8	0.8	1.1	1.9	Sand	1
147	132.1	33.4	50	0	66	35	4.6	1.7	2.5	Silty Sand	5
148	132.1	33.4	63	0	83	17	3.3	3.8	1.5	Sand	5
149	132.1	33.3	67	0	93	6	2.5	1.9	0.7	Sand	4
150	132.1	33.3	63	0	99	1	2.0	1.1	0.4	Sand	4
151	132.2	33.3	56	0	83	17	3.3	3.7	1.5	Sand	5
152	132.2	33.4	60	0	80	20	3.4	3.1	1.8	Sand	5
153	132.2	33.4	63	4	88	8	1.7	1.0	1.7	Sand	2
154	132.2	33.4	60	4	88	9	1.9	1.1	1.7	Sand	2
155	132.3	33.4	52	5	83	13	2.2	1.2	1.7	Sand	2
156	132.3	33.4	39	0	83	17	3.3	3.2	1.4	Sand	5
157	132.3	33.4	32	0	58	42	4.8	1.2	2.3	Silty Sand	5
158	132.3	33.5	46	0	78	22	3.6	3.0	1.9	Sand	5
159	132.3	33.4	62	6	66	28	2.5	1.8	2.5	Silty Sand	3
160	132.2	33.4	50	1	89	11	2.7	2.8	1.3	Sand	3
161	132.1	33.4	65	0	76	24	4.0	3.3	2.0	Sand	5
162	132.1	33.4	59	0	90	9	2.9	2.8	0.8	Sand	4
163	132.0	33.4	58	0	91	9	2.6	2.6	0.8	Sand	4
164	131.6	33.4	55	0	99	1	2.0	2.0	0.5	Sand	4
165	131.5	33.4	56	0	98	2	2.0	2.0	0.4	Sand	4
166	131.5	33.4	47	2	95	4	1.5	1.7	1.1	Sand	3
167	131.5	33.4	28	30	62	9	0.2	1.7	3.0	Sand	1

Table A-1 continued

No.	Lon.	Lat.	Depth	Gravel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
168	131.5	33.4	46	1	91	8	2.3	2.5	1.1	Sand	4
169	133.5	33.6	32	0	35	65	5.7	4.8	3.0	Mix	6
170	131.5	33.5	47	0	47	53	5.3	4.1	2.6	Silty Sand	6
171	131.5	33.3	61	6	92	2	1.7	1.8	1.0	Sand	3
172	131.5	33.3	68	7	89	4	1.2	1.4	1.3	Sand	2
173	131.5	33.2	78	21	75	4	0.8	1.5	2.9	Sand	1
174	131.5	33.2	77	37	61	2	−0.1	1.5	2.8	Sand	1
175	131.5	33.2	61	1	86	13	2.3	2.3	1.3	Sand	5
176	131.5	33.3	22	24	66	10	0.5	1.0	2.5	Sand	1
177	131.5	33.3	50	6	85	9	1.3	1.6	1.8	Sand	2
178	131.6	33.3	87	11	86	3	0.6	0.7	1.3	Sand	1
179	132.0	33.3	75	19	80	2	0.5	1.0	1.5	Sand	1
181	132.0	33.2	79	42	55	3	0.8	1.0	2.6	Sand	1
182	132.0	33.3	64	0	96	4	2.3	2.3	0.5	Sand	4
183	131.6	33.4	41	0	54	46	5.0	3.9	2.6	Silty Sand	5
184	131.6	33.3	62	0	96	4	1.8	1.8	0.6	Sand	4
187	131.5	33.2	48	0	52	48	5.1	3.9	2.8	Mix	6
188	131.4	33.2	35	0	19	81	6.6	6.3	2.9	Clayey Silt	7
189	131.4	33.2	30	0	10	90	7.5	7.5	2.7	Clayey Silt	7
190	131.4	33.2	53	0	46	54	5.1	4.3	2.5	Silty Sand	6
191	131.4	33.2	54	0	15	85	7.3	7.6	3.0	Silty Clay	7
192	131.4	33.2	33	0	9	91	7.4	7.4	2.6	Clayey Silt	7
193	131.4	33.2	56	0	15	85	6.8	6.7	2.7	Clayey Silt	6
194	131.3	33.2	55	2	8	90	7.8	7.5	2.6	Clayey Silt	7
195	131.3	33.2	48	0	13	87	7.5	7.6	2.7	Silty Clay	7
196	131.3	33.2	70	0	6	94	7.9	7.3	2.3	Clayey Silt	7
197	131.5	33.2	29	0	47	53	5.3	4.6	3.0	Mix	6
198	131.5	33.2	24	0	89	10	2.3	2.3	1.1	Sand	3
MIZUSHIMA NADA											
1	133.2	34.2	14	0	20	80	6.6	6.3	2.9	Clayey Silt	7
2	133.2	34.2	8	0	34	65	5.8	4.8	2.8	Mix	6
3	133.2	34.2	15	1	10	90	7.1	6.9	2.5	Clayey Silt	7
4	133.2	34.2	21	0	9	91	7.4	7.4	2.8	Clayey Silt	7
5	133.2	34.2	25	0	11	89	7.5	7.6	2.9	Clayey Silt	7
6	133.3	34.2	27	0	28	72	6.2	6.6	3.4	Mix	6
7	133.3	34.2	27	1	40	59	5.6	5.2	3.5	Mix	6
8	133.3	34.2	39	9	82	10	1.2	1.5	1.7	Sand	3
9	133.3	34.2	29	0	13	87	7.4	7.4	2.9	Clayey Silt	7
10	133.3	34.2	26	0	9	91	7.8	7.9	2.8	Silty Clay	7
11	133.2	34.2	23	0	9	91	7.3	7.2	2.7	Clayey Silt	7
12	133.2	34.2	19	0	9	91	7.1	6.7	2.6	Clayey Silt	7
13	133.2	34.2	21	0	15	84	6.8	6.5	2.9	Clayey Silt	7
14	133.2	34.2	23	0	13	87	7.1	7.0	2.7	Clayey Silt	7
15	133.1	34.1	30	16	71	13	1.0	1.1	2.1	Sand	1
16	133.1	34.1	21	0	27	73	5.9	5.1	2.6	Mix	6
17	133.2	34.1	20	0	17	83	6.6	6.2	2.6	Clayey Silt	6
18	133.2	34.2	18	1	14	85	7.4	7.5	3.0	Silty Clay	7
19	133.3	34.2	19	0	23	77	6.9	7.1	3.2	Mix	7
20	133.3	34.2	24	11	79	11	0.8	1.0	1.8	Sand	1
21	133.3	34.2	18	0	31	69	6.2	6.5	3.1	Mix	6
22	133.3	34.2	18	0	12	88	7.3	7.2	2.7	Clayey Silt	7
23	133.3	34.2	27	1	89	11	1.7	1.6	1.3	Sand	3

Table A-1 continued

No.	Lon.	Lat.	Depth	Gravel %	Sand %	Mud %	Mzφ	Mdφ	So.	S-S-C	H type
24	133.4	34.2	22	0	51	49	5.3	4.0	2.7	Mix	6
25	133.4	34.2	23	5	83	12	1.7	1.6	1.8	Sand	2
26	133.4	34.2	12	0	22	78	6.9	7.0	3.0	Mix	6
27	133.4	34.3	12	1	17	82	7.1	7.3	3.2	Clayey Silt	7
28	133.4	34.3	8	1	6	94	8.0	8.0	2.6	Silty Clay	7
29	133.4	34.3	12	1	38	61	6.0	5.0	3.1	Mix	6
30	133.4	34.2	31	2	81	17	2.5	1.9	1.9	Sand	3
63	133.1	34.0	43	4	82	15	2.0	2.2	2.4	Sand	2
64	133.1	34.0	22	0	59	41	4.9	3.7	2.5	Silty Sand	5
65	133.1	34.0	21	0	39	61	5.5	4.7	2.4	Mix	6
66	133.2	34.0	24	0	15	85	6.4	6.4	2.3	Clayey Silt	7
67	133.2	34.0	24	0	14	86	7.1	7.0	2.8	Clayey Silt	7
68	133.2	34.0	22	0	13	87	7.2	7.1	2.9	Clayey Silt	7
69	133.2	34.0	21	0	11	89	7.5	7.3	2.8	Clayey Silt	7
70	133.3	34.0	21	0	9	91	7.7	7.8	2.8	Silty Clay	7
71	133.3	34.0	22	0	10	90	7.8	8.0	2.9	Silty Clay	7
72	133.3	34.0	23	6	18	77	6.5	7.4	4.2	Silty Clay	6
73	133.4	34.0	17	0	25	75	5.8	5.6	2.7	Silty Clay	6
74	133.4	34.1	20	27	33	41	2.0	1.6	4.8	Mix	
75	133.4	34.1	24	1	10	89	8.2	8.5	2.9	Silty Clay	7
76	133.4	34.1	22	1	5	94	7.6	7.6	2.8	Silty Clay	7
77	133.3	34.1	24	1	4	95	9.2	9.5	2.4	Silty Clay	7
78	133.3	34.1	21	0	5	95	8.4	8.9	2.7	Silty Clay	7
79	133.3	34.1	21	0	7	93	7.8	7.8	2.6	Silty Clay	7
80	133.3	34.0	21	0	5	95	8.5	8.5	2.5	Silty Clay	7
81	133.3	34.0	19	1	10	89	7.3	7.2	2.8	Clayey Silt	7
82	133.2	34.0	19	0	16	84	6.9	6.9	2.9	Clayey Silt	7
83	133.2	34.1	20	0	8	92	7.3	7.3	2.6	Clayey Silt	7
84	133.2	34.1	18	0	3	97	8.1	8.0	2.5	Silty Clay	7
85	133.2	34.1	20	0	4	96	8.2	8.3	2.5	Silty Clay	7
86	133.2	34.1	20	0	5	95	8.2	8.3	2.6	Silty Clay	7
87	133.2	34.1	20	0	12	88	7.0	7.0	2.5	Clayey Silt	7
88	133.2	34.1	19	0	13	87	6.9	6.7	2.6	Clayey Silt	7
89	133.2	34.1	21	0	10	89	7.2	7.1	2.7	Clayey Silt	7
90	133.2	34.0	17	0	9	91	7.4	7.3	2.8	Clayey Silt	7
91	133.2	34.0	19	0	8	92	7.3	7.0	2.6	Clayey Silt	7
92	133.1	34.0	17	0	11	89	7.1	6.8	2.6	Clayey Silt	7
93	133.1	34.1	39	0	9	91	7.2	7.2	2.4	Clayey Silt	7
94	133.1	34.1	33	1	70	29	3.8	2.5	2.9	Silty Clay	5
95	133.0	34.1	46	32	61	7	−0.6	0.2	2.9	Sand	1
BUNGO SUIDO											
1	132.0	33.2	122	0	97	2	0.4	0.4	0.3	Sand	2
2	132.0	33.2	91	36	62	2	−0.2	−0.3	2.0	Sand	1
3	132.1	33.2	64	2	91	7	2.3	2.3	0.9	Sand	3
4	132.1	33.2	67	0	84	16	3.2	3.1	0.9	Sand	5
5	132.2	33.2	77	2	67	31	4.2	3.5	2.0	Silty Sand	5
6	132.2	33.2	77	0	50	50	4.8	4.0	2.7	Silty Sand	6
7	132.2	33.2	72	0	35	65	5.6	5.0	3.0	Mix	6
8	132.3	33.2	57	0	30	70	5.4	4.8	2.4	Sandy Silt	6
9	132.3	33.2	61	0	42	58	5.1	4.5	2.4	Sandy Silt	6
10	132.2	33.2	73	0	39	61	5.2	4.6	2.8	Sandy Silt	6
11	132.2	33.2	78	1	74	25	3.8	3.3	1.8	Silty Sand	5

Table A-1 continued

No.	Lon.	Lat.	Depth	Gravel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
12	132.1	33.2	75	0	88	11	2.9	2.8	0.8	Sand	5
13	132.1	33.2	62	0	99	0	2.3	2.3	0.5	Sand	4
14	132.1	33.2	78	2	90	8	0.3	0.3	1.4	Sand	3
17	131.5	33.1	58	3	88	9	2.1	2.2	1.5	Sand	3
18	131.6	33.1	68	21	75	4	0.9	1.7	2.0	Sand	1
19	132.0	33.1	75	0	98	2	1.2	1.3	0.7	Sand	3
20	132.1	33.1	80	0	99	1	1.7	1.7	0.4	Sand	4
21	132.1	33.1	77	0	98	2	1.2	1.2	0.9	Sand	3
22	132.1	33.1	89	4	89	7	1.5	1.7	1.4	Sand	3
23	132.2	33.1	85	1	83	16	2.4	1.9	1.6	Sand	3
24	132.2	33.1	58	3	62	35	3.0	2.9	2.4	Silty Sand	3
25	132.2	33.1	72	0	99	1	1.1	1.2	0.6	Sand	3
26	132.2	33.1	70	0	95	6	2.1	2.1	1.0	Sand	4
27	132.2	33.1	95	0	99	1	0.9	1.0	0.6	Sand	4
28	132.1	33.1	89	0	99	1	1.7	1.7	0.6	Sand	4
29	132.1	33.1	115	2	97	2	1.3	1.5	0.8	Sand	4
30	132.0	33.1	92	82	2	16	−1.3	−3.8	4.0	Silt	1
31	132.0	33.0	107	95	0	5	−3.9	−4.1	1.1	Silt	1
32	131.6	33.0	38	1	40	59	5.3	4.5	2.6	Sandy Silt	6
33	131.6	33.6	13	0	23	77	5.9	5.5	2.7	Mix	6
34	131.6	32.6	14	0	13	87	6.7	6.3	2.6	Clayey Silt	7
35	132.0	33.0	22	0	99	0	1.7	1.7	0.6	Sand	4
42	132.1	33.0	100	3	96	2	1.9	2.0	0.8	Sand	3
49	132.1	32.5	94	0	99	1	1.6	1.7	0.5	Sand	4
55	132.1	32.5	99	1	98	1	2.0	2.5	1.2	Sand	3
67	132.1	32.4	206	7	92	1	1.5	1.9	1.4	Sand	2
68	132.1	32.4	234	0	99	1	1.6	1.5	0.8	Sand	3
76	132.1	32.5	114	7	91	2	1.2	1.4	1.3	Sand	2
79	132.2	33.0	103	24	67	9	0.4	1.6	3.0	Sand	1
80	132.2	33.0	105	39	53	9	−0.2	0.8	3.2	Sand	1
81	132.1	33.0	92	4	93	3	1.4	1.6	1.0	Sand	3
82	132.1	33.0	91	1	97	2	1.1	1.3	0.8	Sand	3
83	132.1	33.0	80	6	91	3	1.6	1.8	1.1	Sand	3
84	132.1	33.2	100	2	93	4	1.3	1.4	1.1	Sand	2
85	132.1	33.2	74	0	86	13	3.0	2.9	1.3	Sand	5
86	132.1	33.2	76	0	61	39	4.6	3.7	2.2	Silty Sand	5
87	132.2	33.2	72	0	32	68	5.4	4.8	2.6	Sandy Silt	6
88	132.2	33.2	64	0	48	52	5.0	4.1	2.6	Silty Sand	6
89	132.2	33.2	67	5	46	49	4.5	3.9	3.2	Silty Sand	6
90	132.2	33.2	53	0	22	78	5.6	5.2	2.3	Sandy Silt	6
91	132.1	33.2	40	0	38	62	5.0	4.5	2.2	Sandy Silt	6