ORIGIN OF SAND AND ITS DISTRIBUTION PATTERN

IN THE SETO INLAND SEA, SOUTHWEST JAPAN

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Abstract

Distribution pattern of the 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 the channels. The grading mainly shown in the sandy sediments around the channels occurs in a fan-shaped pattern with respect to the caldron where the bedrock is often exposed. On the other hand, though other kind of sandy sediments are distributed near the shorelines, in these areas, large scale (over more than 10 kilometers) horizontal grading in grain size is absent.

Sand which is distributed around the caldron area and its nearby is derived chiefly from the caldron area by the erosion and transportation of tidal current. Silt and clay are chiefly supplied through rivers around the Seto Inland Sea, and settle down where the tidal current is very weak.

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

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 the sediments originally deposited during the low sea level of Glacial age or of the basement rocks of older ages.

In Osaka Bay and Ariake Bay, sandy sediments which are distributed around the caldrons have been thought to be older than other surface sediment. 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. Therefore, sand supply from the caldron area by the tidal current is more possible and reasonable.

I.INTRODUCTION

The Seto Inland Sea is in the central part of Southwest Japan, extending about 400 km long in east-west direction and 50 km wide in north-south direction, and occupying an area of about 22,000 sq km with a mean depth of about 40 m (Murakami,1976) (Fig. 1). This sea area is connected with the open seas through the Kii Suido, Bungo Suido and Kanmon Strait, and is surrounded by land areas with relatively high mountainous district. In the sea areas there are many large and small islands, and they form narrow channels generally called "Seto" between them at many places. Predominance of these channels together with other topographic conditions, gives the sea particularly unique hydrological conditions such as complex tidal currents having various velocity. Thus the sedimentary processes in the Seto Inland Sea are a very interesting theme to study as the following reasons.

There are few area in the world which show the sedimentary condition of "strong tidal currents without strong wave activities " as in the Seto Inland Sea. The area is nearly in closed condition and has low wave energy because of the shortness of wind blown distances, and of the deepness of the sea. Consequently, the effect of waves is weak. As examples of nearly closed seas there are the coastal lagoons which lie along the Gulf coast, lagoons like Lake Saroma and Lake Hamana in Japan, and tidal flats along the Dutch, German and Danish coasts, etc. Though the depositional processes in all these seas are mainly controlled by tidal currents, many of them are often affected by wind blown waves as Shepard and Moore (1955) and McGowen and Scott (1975) mentioned about the lagoons along the Gulf coast. These lagoonal seas are relatively shallow and the surrounding land has low relief. Therefore the sedimentary conditions in these seas are different from those of the Seto Inland Sea.

As mentioned above, the Seto Inland Sea is unique and rare sedimentological basin at present in the world, but from the viewpoint of geological history, the areas with "strong tidal currents without strong wave activities" are not a rare one. Especially in the islands of high relief as in Japan, there are many sedimentary sequences of Quaternary marine sediments deposited in the similar condition as that of the present Seto Inland Sea. This holds well for the case of the Alluvial sediments which deposited during the Postglacial trangression time.

Studies on the sedimentary environments in the modern Seto Inland Sea give us much information useful for the studies of geological history and sedimentology of the bay sediments under the same condition in the past. Also they play an important role to clarify the underground geology of the Alluvium deposits which have close relations to man's activities.

This paper firstly shows the distribution patterns of the bottom sediments in the Seto Inland Sea, and then discusses the effects of the tidal currents which caused distribution patterns of the bottom sediments, and finally discusses the origin and sedimentary processes of the bottom sediments in the area.

II SAMPLE COLLECTION AND ANALYSIS

The survey on board was carried out for about 90 days 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 six meter long open barrel gravity corer) from the stations at a few miles intervals (Fig.2). About 520 samples were collected. The sediment samples were put into the plastic case, 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 the soft-X ray photography and the ones in the thicker cases were used for grain size analysis. Based on the result of observation by the soft-X ray photography, the homogeneous samples were analyzed for the upper 5 cm part and the ones with two or more layers within the 5 cm part for the uppermost layer.

Samples were sized by different techniques, depending on the grain-size of sediment. Material greater than 2 mm and in the sand range was sieved. Where finer grained sediment made up more than 10 percent of the total sample, the sediment was analyzed using hydrometer method based on Japan Industrial Standard (JIS) A 1204.

In case of calcareous sediments, which for example, are often distributed at the Bungo Suido and Iyo-Nada areas, calcareous particles were dissolved using hydrochloric acid and then the residual mineral grains were sieved.

Grain-size distributions were analyzed statistically in a computer, calculating the mean, median and sorting.

Some extrapolation of data beyond the limits of the analysis was necessary. 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 (whole phi interval) 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 curve has been plotted.

III BOTTOM TOPOGRAPHY

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

Remarkable topographic features in the Seto Inland Sea are the caldrons developed near the channels and in the offing of the capes. The caldrons developed near the channels are divided into two types by their bottom topography. The one is single-type caldron and the other is twin-type caldron (Kuwashiro, 1959). Single-type caldron has no sills, which separate partially closed basins from one another, in the channel and a continuous hollow lies in the channel. The example of this type is the one in the Tomogashima Strait (Fig. 5). Twin-type caldron has two or more hollows in both sides of a sill. The ones in Naruto Strait (Fig. 6) and Hoyo Strait are of this type. There is another type of caldrons. That is off cape-type caldrons (Fig. 7) which lie off the capes and islands in many places (Kuwashiro, 1959). There are many off cape-type caldrons in the sea area but not in the channel area. And they are formed in the areas where the tidal currents detour the capes or islands (Kuwashiro, 1959). The bottoms of the caldrons are generally hollowed deeply, and especially in the northern caldrons of Hoyo Strait the maximum depth attains as deep as 454 meters. On the other hand, there are shallow caldrons which seem to be merely in nondepositional condition. The caldrons as mentioned above are observed neàr the channels or many capes.

In areas of sand deposition near the main channels, there often exists sand wave topography. The examples are the western part of Akashi Strait, Bisan Seto, Iyo Nada and Bungo Suido. According to the result of acoustic survey these sand waves have gentle slope on the channel side and steep slope on the opposite side (Figs. 8 and 9), suggesting the transportation of sediments from the channel areas. Similar evidences indicating the relation between the shape of the sand waves and the direction of transportation are reported by Bokuniewicz et al. (1977) in Long Island Sound and Reinson (1979) in flood tidal deltas in St. Lawrence Bay. Mogi and Kato (1962) also reported the accordance between the steeper side of the sand wave and the direction of sand wave migration or transportation in Bisan Seto.

Outer areas beyond the sand wave distribution areas around the channel, there are flat depositional topographies. Those relatively flat topographies generally continue to the very close to the shoreline.

IV DISTRIBUTION OF SURFACE SEDIMENTS

Distribution of bottom sediments based on the ternary nomenclature which is most popular and widely accepted (Shepard,1954) is shown in Fig.10. Among many graphic measures of average grain-size, "Mz" by Folk and Ward (1957) is most popular and relatively accurate. In this paper, "Mz" is used for the convenience of comparison with those of other areas (Fig.11).

Friedman (1962) compared σ values obtained graphically with those obtained by the method of moments, and showed that the graphic measure of Folk and Ward (1957) has very close correlation with the moment σ over the whole range of sorting value studied. Thus, in this paper, sorting measure of Folk and Ward (1957) is used as expressed in the distribution map (Fig.12).

Skewness and kurtosis which indicate the degree of mixing of two log normal populations (Spencer,1963) are not discussed in detail. Instead of these values, the degree of mixing is discussed on the histograms in chapter V.

Suwo Nada : This sea area is connected with Japan Sea through the Kanmon Strait in the western part and faces Iyo Nada in the eastern part. In the southeastern part of Suwo Nada, the sediments are poorly sorted sand with the mean diameter 2 to 3ϕ . Sediments become finer toward the outer side, and the finest sediment, very poorly sorted clayey silt with the mean diameter less than 6ϕ, is distributed in the southwestern part. In southern half of the area, the sediments show regular changes in the grain size composition diagram of sand-silt-clay from east to west in the order of sand, silty sand, sand-silt-clay, and clayey silt. In the northeastern part of the area, the sediments are sand-silt-clay and sandy silt with the mean diameter less than 4ϕ. In the offing of Ube City, the sediment is sand and silty sand with the mean diameter 2 to 4ϕ and in the vicinity of Kanmon Strait, there is sand with the mean diameter 0 to 2ϕ. In these three areas, the sorting degrees are very poor.

Iyo Nada : This sea area is connected with Aki Nada through Tsurishima Strait in the northeastern part, with Bungo Suido through Hoyo Strait in the southern part, and faces Suwo Nada in the northwestern part. Sediments in this area are situated mostly in sand area in sand-silt-clay ratio diagram, but in the west off Matsuyama City, there are very poorly sorted sand-silt-clay and silty sand and in the north of the area, there are narrow silty sand distribution. Sand distribution area is further subdivided by the mean diameter. There are very poorly sorted very coarse sand or rocks in the channel areas. Poorly sorted coarse and medium sand are also distributed around the channel areas and the nearest part of the cape type caldrons. In the southern part of Iyo Nada, moderately to very well sorted fine sand are distributed to the northern and northeastern parts of the coarse to medium sand distribution area. Similarly, in outer side of the coarse to medium sand distribution around Tsurishima Strait, there are poorly sorted fine sands. In further outside, there are poorly sorted very fine sands. These sediment distribution pattern continues to 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 the mean diameter less than 6ϕ. Sediments become coarser toward the bay mouth in the east, that is, there are recognized sequential changes from silty sand and sand-silt-clay with the mean diameter 4 to 6ϕ into sand with the median diameter 2 to 3ϕ. Sorting is very poorly sorted except for the southern part of the bay mouth in which it is poorly sorted.

Bungo Suido : This area is connected with Iyo Nada through Hoyo Strait in the northern part and faces the Pacific Ocean in the southern part. There are sands in the central part of Bungo Suido. The coarsest sediments in this area are those in the caldrons of Hoyo Strait and offing of the Kamado-saki Peninsula, and they are very poorly sorted very coarse sand and gravels or rocks. The sediments surrounding these coarsest sediments are composed mainly of moderately sorted to very well sorted coarse to medium 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 in the eastern part. The sediments in this area are mostly very poorly sorted clayey silt with the mean diameter less than 6ϕ. The sediments in the channel between Eta Island and Itsukushima Island are very poorly sorted sand-silt-clay with the mean diameter 2 to 3ϕ. In the eastern part of this area facing Aki Nada, there are poorly sorted fine sand with the mean diameter 2 to 3ϕ.

Aki Nada : Aki Nada is connected with Hiuchi Nada through Kurushima Strait in the eastern part, connects with Iyo Nada through Tsurishima Strait in the southern part and faces Hiroshima Bay in the western part. Sediments in the southern part near to Tsurishima Strait and Kurushima Strait are poorly sorted sand, and their mean diameters are more than 0ϕ near the Tsurishima Strait and 0 to 2ϕ in the outer side of that area. In the northern part, there are very poorly sorted clayey silt and sand-silt-clay with the mean diameter 6ϕ. The sediments become finer from the southeastern part of Aki Nada to the offing of Kure City with the mean diameter more than 0 to less than 6ϕ.

Hiuchi Nada and Bingo Nada: These areas are connected with Aki Nada through Kurushima Strait in the western part and faces Bisan Seto in the eastern part. Sediments with the mean diameter less than 6ϕ are widely distributed in this area and coarsen toward Kurushima Strait, and they are very poorly sorted or extremely poorly sorted. Sediment type distribution based on sand-silt-clay ratio shows clear change of sediment types in the order of sand, silty sand, sand-silt-clay, clayey silt and silty clay from Kurushima Strait to the eastward.

Bisan Seto : This area faces Bingo Nada in the western part and faces Harima Nada in the eastern part, but the eastern part was not surveyed. In the northern part, Mizushima Nada, the sediments near the northern coast are very poorly sorted with the mean diameter less than 6ϕ. This shows a good contrast to that of the southern part, which is poorly sorted sand with the mean diameter 0 to 2ϕ. But the sediment type based on sand-silt-clay ratio indicate a gradual change from south to north, in the order of sand, sand-silt-clay, clayey silt and silty clay.
Sand-silt-clay with the mean diameter 4 to 6ϕ are distributed in scattered manner in the southern part where the current is very slow.

Harima Nada : This area faces Bisan Seto in the western part, connects with Osaka Bay through Akashi Strait in the northeastern part and connects with Kii Suido through Naruto Strait in the southeastern part. Very poorly sorted clayey silt with the 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 in order from sand through 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 northwestern part and also connects with Kii Suido through Tomogashima Strait in the southwestern part. In the northeastern recess and 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 the 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 the mean diameter more than 0ϕ or rock at the channel areas. According to the sand-silt-clay ratio, the sediments change from clayey silt through sandy silt and sand-silt-clay to sand toward the straits.

Kii Suido : This area connects with Harima Nada through Naruto Strait in the northwestern part, with Osaka Bay through Tomogashima Strait in the northeastern part and faces the Pacific Ocean in the southern part. The sediments of the Kii Suido are coarsest near the Tomogashima Strait and become finer outward from the channel area. This change can also be observed in sand-silt-clay ratio, namely distributions in the order of sand, silty sand, sandy silt and clayey silt are recognized from the channel to the area outward. Sorting of sediments is generally poor to very poor. Near the eastern and western coasts, the sediments are clayey silt with the mean diameter less than 6ϕ. Near Naruto Strait, the gain 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 the mean diameter less than 4ϕ are distributed more widely than other types of sediment. But in Iyo Nada, Aki Nada and central Bungo Suido, the sediments of poorly sorted to very well sorted sand and silty sand are distributed exceptionally widely.

2. There is a general rule in the size distributions of the surface sediments. That is, as typically shown in Iyo Nada, the sediments near the straits are very poorly sorted sandy gravel or rock, and they decrease their grain size

and become more sorted with distance from the area. But further outward from the channels, and as the mean diameter of sediment become more finer than 3ϕ, sediments become poorly to very poorly sorted and change from sand to silty sand, sand-silt-clay (sandy silt) and clayey silt through silty clay . Such nearly typical sediment distribution pattern can be seen over about 40 km distance area in 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 sediments are, in mean diameter, less than 6ϕ, and the changes in grain size from the shore outward to offshore direction are not recognized in large scales (more than 10 km).

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 which shows the mixing of sediments. In order to discuss the sedimentation of these sediments which are composed of mixed populations,modes of sediments have to be clarified.

Cumulative grain-size curve based on probability percentage ordinate is adequate to show the composition of sediments with log normal population. But it is not suitable for the sediments with polymodal population. Also, graphic measures of mean, sorting, skewness and kurtosis express the grain size and the degree of mixing, but they cannot show the composition of grains directly. This can be done by histogram easily (Fig. 13).

In the following, characteristics of sedimentary distribution based on histogram types (chiefly sea areas to the west of Bisan Seto)are shown.

<u>Type H1</u> : It contains more than 10 % of gravels and less than 20% mud. There is no remarkable mode in sand grain size negatively skewed in general.

They are of the coarsest sediment type in the Seto Inland Sea with the mean diameter more than 2ϕ, and sortings are not good. Type H1 is distributed mainly near the caldrons in the northern part of Hoyo Strait, Tsurishima Strait and the eastern part of Akashi Strait and also in the caldrons of off cape-type such ones in the Kamado-saki Peninsula etc. (Fig. 14).

Type H2 : Gravel contents in this type are less than 10 %. They are composed mainly of sand grains which do not show particular mode. Mud contents in some cases reach up to 30 %.

Their mean diameters are between 0 and 3ϕ, and they are not so well sorted. They are distributed widely in the southern part of Aki Nada, the northeastern part of Iyo Nada and around the outside of Type H1 distribution area.

Type H3 : Contents of sand grains sensible to tractive current (Kimura 1954) ,that is, 0.2-0.3 mm in grain size, are very high and sortings show as good concentration as that of Type H4. But it contains about 5 % gravel and sometimes shows bimodal pattern. In general, contents of grains of -2 to 1ϕ are a little lower than those of other closer grain sizes.

They are better sorted than Types H1 and H2 and the mean diameters are from 0 to 3ϕ. They are mainly distributed in the central part of Bungo Suido except for the area of Type H4 and at the mouth of Beppu Bay. Also they are separatedly distributed between Type H2 and Type H4 distribution areas and near the small caldrons.

Type H4 : Grain sizes are usually in the range that is sensible to tractive current. 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. Their distribution area lie in the southwestern part of Iyo Nada and in the central part of Bungo Suido, where sandy sediments are dominantly distributed and the water volume moved by tidal exchange is very large.

Type H5 : The sediments are a little finer in grain size than that of Type H4. They are not so well sorted as compared with Type H4, contain 10 to 50 % mud, and the mean diameter is 2 to 6ϕ. Therefore, the histograms show sometimes bimodal grain size distribution. Sediments of Type H5 lie in the central part of Iyo Nada, the southeastern part of Suwo Nada, and some areas nearer to the channels than those of Type H6 . There often exist sand waves in Type H5 distribution area.

Type H6 : Sand grains are usually very small. Grain size distributions do not have remarkable mode, however, they have a mode in very fine sand. In general, the sediments of Type H6 contain more than 30 % of mud, and show bimodal or polymodal patterns in grain size histograms having two or more peaks of sand and mud. They are not so well sorted with the mean diameter 4 to 6ϕ. They are distributed in the area 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 composed of feacal pellet. The sortings of sediments are not so good, the mean diameter being less than 6ϕ.
They lie in the western part of Suwo Nada, Beppu Bay, and Hiroshima Bay and the area where the 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.

The sediments from H1 to H7 mentioned above are summarized as follows. Sorting of sediments are best in Type H4 and become worse in other types whether they are coarser or finer. Lateral changes of sediment types show that Type H1 lie near the channel or caldron, and the type numbers increase as they leave the area of caldron (Fig. 15). Relations between sediment types and various measures are shown in Table 1.

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 survey. And the survey tracks were set at few miles intervals so as to trace the sampling sites of bottom sediments.

No data have been obtained regarding the acoustic velocity in unconsolidated sediments in the Seto Inland Sea. Chujo et al. (1961) estimated the velocity in the sediment of the Ariake Bay in Kyushu as 1,480 m/sec or a little faster, and Huzita and Maeda (1969) adopted the value of 1500 m/sec in Osaka Bay. In the followings, acoustic velocity is postulated as 1500 m/sec.

On the acoustic record, U (upper) layer and L (lower) layer are clearly separated as shown in Fig. 16. In general, U layer is acoustically transparent or semitransparent on the record but has some local reflectors , and covers all the area except in and around the channels. The reflector which separates L layer from U layer has most continuous distribution in the surveyed area. L layer sometimes contains a few local reflectors, and crops out in channel areas and near by, or are overlain by very thin sediment belonging to U layer.

Stratigraphic significance of the reflector which divide U layer and L layer is discussed below, based on cored materials and 3.5 kHz subbottom profiling records in Harima Nada (Fig. 17, Table 2). In general, upper part (or all) of cored materials 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 fecal pellets. In the columnar sections, this sediment becomes sandy or begin to have thin sand layers closer to the lower part or basement rock. As mentioned, this part of sediment becomes coarser around the channels. On the other hand, in general, the sediment of lower part is rich in organic matter and in many cases peat or pebble bed is intercalated between the upper and lower parts of the sediment. Light greenish gray colored lacustrine clay, volcanish ash, sand and rock fragments are also found in the lower part of sediment. Lacustrine clay contains plant fragments in many cases, and is more consolidated than the marine mud in the upper part.

These relations between the upper and lower parts of the sediments and their characteristics are expected to be common all over the Seto Inland Sea, based on the following reasons. The maximum depth in the Seto Inland Sea is less than 80 m even in erosional channel area except in the caldrons. Hence, almost all the areas in the Seto Inland Sea are supposed to be terrestrial when the sea level was very low during the maximum Würm(-80 m according to Oshima, 1978 and -140 m according to Minato, 1966). The fact that the C-14 age of peats underlying the marine sediments is 10,430 Y.B.P. to 36,400 Y.B.P., confirms this supposition. On the other hand, the marine sediments which are composed mainly of mud must be Postglacial transgressive sediment that began to deposit about 20,000 years ago. And it is supposed to exist remarkable unconformity between the marine sediments which occupy the upper part of the cored material and the lower sediments or rock. Emery and Hülseman (1964) pointed out that the shortening of the cored material by a gravity corer (open barrel) attains about 50 % as compared with that by a piston corer. Consequently, the reflector may appear at shallower depth in the cored materials than observed on the acoustic records.

On the other hand, the sediment cores, supposed to attain below the reflector on the acoustic records have both upper muddy marine sediment and lower fresh water sediment such as peat, sand and clay bed, whereas the sediment cores which are not supposed to attain the reflector contain only marine sediments. In the cored marine sediment, any remarkable changes in the lithofacies, which should correspond to the reflector, are hardly recognizable in the marine layer. Moreover, the fresh water sediments change their facies from site to site, so lithofacies of lower bed are discontinuous.

The reflector that exists between U and L layers is the most continuous one in the Seto Inland Sea, and it is distributed widely over all the sea area except the channel areas. Therefore, it is most reasonable to define the reflector between the U and L layers as the widely distributed unconformity between the upper marine sediments that are composed mainly of mud and the lower fresh water sediments and rock. The same result is shown by the data of drillings in Osaka Bay. That is, the basal depths of U layer which are estimated from 3.5 kHz acoustic data fit fairly well with that of A member (generally all is marine mud) which is the only one possible boundary shown in the results of drillings in the planning site area of New Kansai International Airport (Nakaseko, 1983) (Fig. 18 and Table 3).

Then, facies of L layer which underlies the reflector may have to be discussed a little. There are many localities of fossil Elephants in the Seto Inland Sea (Ikebe, 1959; Itihara, 1961). All of them are in the channel areas or in the caldrons except those on wave cut terraces which are near the shorelines. This fact suggests that Neogene to Quaternary beds containing fossil Elephants cropout in the channel areas, and are eroded by tidal currents and the fossils rest on the sea bottom. Bando et al.(1978) said that granitic rocks and Pleistocene Ozuchi Formation are distributed on the bottom of caldrons in the Bisan Seto area. Similar facts are reported by Honza et al.(1970). Based on acoustic records, U layer is, in general, distributed neither in the channels nor in the caldrons, and L layer crops out there widely. Therefore, these bedrocks of Neogene to Quaternary beds which sometimes contain fossil Elephants or the granitic rocks in the caldron areas belong to L layer.

Fig. 19 shows the thickness distribution of U layer. In the areas where U layer is relatively thick, it is easy to distinguish U layer from L layer. But in areas where the U layer is thin or sandy, it is sometimes difficult to determine the thickness of U layer owing to the low resolution power of the record. Even in that case, U layer is supposed to exist very thinly. But in the case the bottom topography shows erosional surface, thickness of U layer is regarded as 0 m. As shown in Fig. 19, thick (more than 30 m) 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 U layer is 20 to 30 m are Suwo Nada, eastern part of Iyo Nada, Hiroshima Bay, the central part of Hiuchi Nada and the northwestern part of Harima Nada.

In above mentioned areas of thick (more than 30 m) U layer, the surface sediments are mainly mud, and the histogram type is H6 and H7. In general, thickness of U layer in sandy sediments area is very small and are usually less than 10 m. Types H1, H2 and H3 are distributed in this area. However, in the eastern part of Aki Nada and the central to western part of Iyo Nada, sandy sediments of

U layer are exceptionally thick attaining 10 to 20 m. H4 and H5 types are distributed in this area.

Coastal plains around the Seto Inland Sea are underlain by "Alluvium" which correlates with U layer (and in part of 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" is burying the dissected valleys of the older river system. Besides, Huzita and Kamata (1964) distinguished A and B formations of " Alluvium deposit" in Osaka Bay based on seismic profiling records of Sparker. (As shown in the thickness distribution map of U layer (Fig. 19) and Figure 3 (Fig. 20 in this paper) in Huzita and Kamata (1964), thickness of U layer coincides with that of A plus B. That is, Huzita and Kamata (1964) subdivided U layer in this paper into two parts.) The depths of "Alluvium" base in sea area which reported by Huzita and Kamata (1964) coincide with that of A member (in general, marine mud formation) in the drilling data by Nakaseko (1983) (Table 3). So, A and B formations of " Alluvium" by Huzita and Kamata (1964) and U layer in this report are both correlated with " A member" in the drilling data of the planning site area of Kansai New International Airport. The A member is composed mainly of marine mud and is correlated with middle mud formation (Amagasaki clay formation in Huzita and Maeda, 1966). From all the reasons mentioned above, U layer in acoustic records is correlated with middle mud formation and upper formation in "Alluvium", and the other underlying sediments belong to L layer.

VII. DISCUSSION

1. The causes of the lateral grading in the grain size of the 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 the channel area or in the caldrons and decreases gradually with increasing distance from the channels. In the north off Hoyo Strait, such grain size decreases are recognized as far as 70 km in north-south direction, and in other channel areas, the distance often attains as far as 10 km.

On the other hand, in other areas of different topographycal and sedimentological condition no clear large scale horizontal gradings are recognized. In the muddy sediment distribution areas, mud line lies much shoreward than the nearest shore position of the bottom sampling stations, and in the sandy sediment distribution areas, there are not observed decreases in grain size toward offshore direction perpendicular to the shoreline. Therefore, the grain size decreases with distance offshore from the shoreline, as shown in Pilkey and Farankenberg (1964) and Emery (1968) in modern sediments, are, even if exist, likely to be very small in scale and the decreasing distance may be within a few kilometers. Horizontal distribution pattern of grain size is thought to be a fan-shaped one in case of the grain size decreases with distance from the channel area, whereas to be a belt-shaped one, if exist, in case of the grain size decreases offshore from the shoreline. Louderback (1940) showed two types of distribution in San Francisco Bay (with mean depth less than 10 m). First one is the decreasing of grain size with the increasing in depth and distance from the shoreline. Second one is the increasing of grain size with increasing depth. He stated that, in San Francisco Bay, the latter case is dominant and the causes seem to be the wave activity in the former, whereas to be the tidal current in the latter. Also in Japan, Kamada (1967) and Shiozawa (1969) reported the decreasing of grain size occurs with increasing distance from the the channel area in Ariake Bay and Akkeshi Lake, respectively. Thus, the distribution pattern of "decreasing in grain size with increasing distance from the channel area" is a general law in the nearly closed sea condition under the influence of strong currents.

Such sediment distribution pattern is also generally seen in the lagoons and tidal flats, and, as Ikeya and Handa (1972) and Krumbein (1939) stated, the source of the sandy sediments is usually attributed to outer open sea side. 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 by longshore current, and then transported into the lake by the tidal current. In addition, sediments in the coastal lagoons of Baja California are thought to be brought from the barrier island (Phleger and Ewing, 1962).

However, in the Seto Inland Sea, grain sizes of sediments decrease with distance toward both sides away from a channel. Also, there are not recognized any longshore currents and wave activities that supply sandy material laterally. These facts suggest that the sediments are not supplied from the opposite side of the strait. Thus, though the sediment distribution patterns in the Seto Inland Sea are very similar to those of the lagoons and tidal flats, the Seto Inland Sea has no inlets facing the open sea and has little influence of wave activity. Therefore, the origin of the sediments and manner of transportation are probably much different from those of the lagoons and tidal flats.

In the following, origin and cause of the horizontal grading of the sediments, namely, "grain size decreases with distance from the channel area" are discussed.

<u>Origin of Sediments</u>

As shown in 3.5 kHz subbottom profiling record, sediments which show horizontal grading in grain size all belong to U (Upper) layer, except for the sandy gravels distributed in the channel areas. Muddy sediment within the U layer, distributed near the shore show sludge-like property indicating the derivation from anthropogenic wastes. This shows that the surface sediments of the U layer were transported and deposited under the hydrological conditions which have been dominant for more than a few decades, and then the horizontal grading patterns which can be seen around the channel areas seem to be explained by the modern hydrological condition.

As mentioned before, grain size decreases with distance from channel areas are typically shown in the areas of sand deposition in the Seto Inland Sea. In the following, origin of these sand grains are discussed.

In general, in the vicinity of the mouths of main rivers, which discharge the sediments into the Seto Inland Sea, muddy sediments are distributed. These sediments do not contain coarse sand grains. This fact seems to be curious, for there are many granitic rock exposures around the Seto Inland Sea and a large volume of sand grains are expected to be supplied. However, as Huzita (1978) mentioned, coarse grains are all settled on alluvial fans or deltas and do not attain to the calm sea areas. Therefore, the origins of sandy sediments around the channel areas may not be attributed to the rivers. And, as shown in the core samples taken in the muddy sediment distribution areas, there are contained no clear sand beds. Moreover, there are no channel topographies which cross the areas of mud depostion.

These facts show that sand grains, which are contained in sandy sediments around the channel areas, are not those transported from the land across the area of mud deposition. Also there are no possibilities of their transportation from other side of the channel, for there are no longshore currents which flow toward the channel and the sediment distribution patterns are symmetrical with respect to the channel.

Consequently, origin of sandy sediment, which are distributed in this sea area, must be attributed to those in and near the channel areas except for the sand grains which deposited near the shoreline. Based on the acoustic survey record, modern sediments are not distributed in and around the channel area, but the older sediments or rocks are exposed and being eroded. Almost all the sea bottom in the Seto Inland Sea is less than 80 meters in depth. Maximum lowering of the sea level in the latest Glacial age was lower than this depth (-80 m according to Oshima, 1978 and -140 m according to Minato, 1966). Therefore, the origin of sand grains, which are now distributed in the bottom surface of the Seto Inland Sea, is traceable to the fresh water and shallow marine coarse sediments which deposited at the time of low sea level or to the basement rocks such as granite (which belong to L layer in the acoustic stratigraphy). When these older sediments and basement rocks are eroded and reworked, it is possible to supply enough sand grains which are now deposited around the channels.

For example, in Iyo Nada, where the distribution of sandy sediments are wide and volume estimation of sandy sediment is relatively easier, the thickness of sandy sediments is very thin as compared to that of muddy sediments, and the volume of eroded sediment (6.4 Km^3), deduced from the volume of the caldron in the north off Hoyo Strait, is in the same order as that of the sandy sediment now distributed in the southern part of Iyo Nada (6.9 km^3). Therefore, origin of sandy sediments, which are distributed in the Seto Inland Sea, can be ascribable to the older sediment which deposited at the low sea level and the basement granitic rocks, both lying in and near the channel areas.

Next, the origin of mud particles constituting the muddy sediments is discussed. Postma (1961) mentioned that mud particles of the tidal flat in the Wadden Sea have different origin in different areas. That is, some mud particles derived from rivers, some from the eroded tidal marsh or tidal flat, and some from the open sea. In the Seto Inland Sea, there expose muddy older sediments which belong to the L layer in the channel area. For example, Itihara (1961) stated that in Tomogashima Strait, the marine mud bed which contains fossil Elephant exposes widely. So, there may exist the supply of mud particles from the channel by reworking of the bed materials. To prove this, volume estimations were made for the U layer in Osaka Bay (22 km^3), where muddy sediments are dominant, and for two caldrons, which lie in Akashi and Tomogashima straits (4 km^3). The results show that sediments from the caldrons never exceed 1/5 of sediments volumes of Osaka Bay. (In this case, the sediments derived from the caldrons are supposed to be all mud. Moreover, sediments beneath the Osaka Plain are excluded.) Also, because the mean depth of the Seto Inland Sea is generally deeper than that of the most tidal flat, transportation and enrichment of mud particles from the open sea are very difficult to occur here, as described in the tidal flat area along the North Sea coasts of Denmark, Germany and Holland by Straaten and Kuenen (1958). Because in tidal flats, at the end of the flood tide, most of the settling sediment reaches the bottom owing to the shallowness of the water, but in the Seto Inland Sea, the quantity of sedimentary material that reaches the bottom is very small owing to the greater depths. Therefore, most of the mud particles in the Seto Inland Sea are, as generally considered, transported in suspension from the rivers, and deposited where the currents were weak as shown in mud deposition area.

<u>Causes of horizontal grading in the sediments</u>

In the following, the nature of currents which cause gradual decrease in grain size with distance from the channel are discussed. Swift *et al.* (1971), classified the currents on the continental shelf in the order of their influence into meteorological currents (mainly wind wave, currents made by barometric storm surge, longshore current and rip current), tidal current, density current and ocean current. However, this order was established on the continental shelves in the open sea, so it cannot be applied directly to the closed sea. In the following, some discussions are made on the nature of the several currents which control the distribution patterns of sediments in the Seto Inland Sea.

About storm surge among meteorological currents, Nelson (1982) described that sandy sediments are transported for about 100 km by this current in the western coast of Alaska. The sediments are intercalated as thin layers in the muddy sediments on the continental shelf of the Bering Sea, and grade vertically. They grade also horizontally but the distribution is limited within the depth of 30 m, and moreover, they grade outward from Yukon Delta (that is grading with distance from the shoreline). On the other hand, in the southwestern area off North Island in New Zealand, Lewis (1979) showed that sediments are transported southeastward along the shore by storm generated current. But this transportation occurs only on the area shallower than 15 m deep. However, these sediment distribution patterns have, in general, no relations to the existence of channels. Above-mentioned currents are regarded as very weak in the areas where wind blown distance is relatively short (Reading, 1978). The existence of them are not reported in such closed seas with relatively large depth including the Seto Inland Sea.

Density currents are produced where a large volume of low density water of the river are supplied into the sea, and then as their countercurrent, high density sea water moves along the bottom (Reading, 1978). Kelling and Stanley (1972) described such currents in the Gibraltar Strait caused by the surface inflow of relatively low density water of the Atlantic Ocean into the Mediterranean Sea, and by the bottom flow of high density water of the Mediterranean Sea toward west. Also they reported that the bottom sediments lying on the channel bottom at the depth of 700 m are moving westward by the bottom current. The direction of this current is usually westward and the easterly tidal currents do not affect the sediment distribution patterns. Moreover, bottom sediments in the Gibraltar Strait do not grade horizontally. On the other hand, at the river mouths of large rivers in the Seto Inland Sea, there are no remarkable changes in grain size of the sediments. This fact leads to the conclusion that the influence of density current is, if exists, very small. In addition, as density current is, in general, unidirectional, it is very difficult to explain by the density current the symmetrical distribution patterns of grain size with respect to the channels.

About ocean current Flemming (1978) described that sediments on continental shelf southwest off Africa are reworked by Agulhas Current. But this type of current can only exist in open seas, and as discussed in the case of the density current, such unidirectional current cannot cause such sedimentary distribution patterns as those observed near the channel areas in the Seto Inland Sea.

Tidal currents, on the other hand, are thought often to cause the sediment transport and horizontal grading of the bottom sediments as described by many authors (for example, Stride, 1963; Belderson, 1964; Belderson and Stride, 1966; Krank, 1972; Channon and Hamilton, 1976; etc.). Belderson and Stride (1966) showed in the Celtic Sea, southwest off England, that the grain size decreases toward the downstream of tidal currents, and also the bottom topographies by Side-scan sonar Asdic record show a series of characteristic regions, 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 relations between the form of sand ribbons and the velocity of tidal currents by using Asdic records on the seabeds off southwest England. In addition, Channon and Hamilton (1976) mentioned that in southwest off England, the grain size distribution of sediments are influenced by tidal currents, but the sortings of sediments occur by both tidal currents and wind induced currents in storm weather.

The current forms are divided by the existence of change in velocity at a given position, namely, "steady flow"($\partial u/\partial t = 0$; u: velocity, t:time) and "unsteady flow" ($\partial u/\partial t \neq 0$). Kimura (1956) further subdivided them into "uniform steady flow" "non uniform steady flow", "non periodic unsteady flow", and "reciprocating unsteady flow", and showed as examples of them such ones as ocean current, river mouth current, flood current and tidal current, respectively.

As already mentioned, distribution patterns of the surface sediments in the Seto Inland Sea are, in typical manner, symmetrical with respect to the channel, so unidirectional currents of "steady flow" cannot be the cause of horizontal grading. At the same time, symmetrical distribution of sediments suggests that "reciprocating unsteady flow" is the most probable cause of distribution patterns of sandy sediments in the Seto Inland Sea. None of other currents except tidal current can explain the cause of sedimentary distribution in the Seto Inland Sea.

In Japan, the tidal currents were too much emphasized on their reciprocating or reversing current nature, and the transportation by the tidal current has not been noticed yet. But in foreign countries, there are many reports on the transportation of sediments by tidal currents. For example, Straaten and Kuenen (1958) explained the accumulation of fine grained sediments in the Dutch Wadden

Sea as follows. They assumed that the tidal current in tidal flat is reciprocating current which shows symmetrical time-velocity curve ($V(-t) = -V(t)$: $t=0$ means time of flood or ebb), and that maximum current velocity decreases shoreward. And then, they showed that the grains which are transported by flooding tide begin to settle as the current velocity decreases to the level less than that to initiate the erosion and transportation of the grains, and the grains are transported some distance before settling down on the bottom. To carry back away these grains in ebb tide, there should be enough water flows that exceed the velocity of the water flow which carried the grains in flood tide (Fig. 21). They stated that, as a result, the grains which are carried to and from the shore side by both currents do not come back to a startpoint but approach to the shore to some distance expressed by the difference between the carried distances both by flood tide and ebb tide. In fact, as eroding velocity is faster than that of settling, transportation by settling lag effect is further intensified. They also called this as the scour lag effect. Though, there are differences in the grain size of the sediments and in the water depth between the above mentioned sea areas and the Seto Inland Sea, as the sand grains have limited current velocities both for traction and settling with somewhat smaller one at the latter, there seem to be the same lag effects in the Seto Inland Sea. In these two areas, also, grains are transported by the similar "currents with small decreasing rate of velocity", so the transporting mechanisms seem to be very similar to each other.

In addition, in the Seto Inland Sea it is pointed out that the effects of flood tide and ebb tide on the bottom sediments differ considerably to each other. Mogi (1980) reported that at Kanmon and Akashi straits etc., velocities of tidal currents are relatively higher when the survey positions are in the downstream side of a channel than that in the upperstream side. This phenomena also can be seen in the case where the current direction is reversed. So, sedimentary processes of erosion, transportation and deposition shown by Straaten and Kuenen (1958) are more strengthened in the downstream side than in the upperstream side. This leads to a conclusion that one cycle of tidal current has an effect to transport the sedimentary particles toward farther side away from the channel as if they were carried by one downstream tidal current.

Before coming to a conclusion that the cause of grading in the grain size of the sediments around the channel area in the Seto Inland Sea is the tidal current, a remaining problem should be discussed. That is, do tidal currents have enough current velocities to erode the bottom of the caldron and also to transport the eroded materials? In the Seto Inland Sea, current data of surface water are abundant, but data on the bottom of the caldrons are limited. 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 zones. The results show that even in the caldron, tidal current velocity is as high as 4.6 knot (about 230 cm/sec) at 60 m depth zone. At this point, the differences in the velocity values in each depth zone are within 20 %. Thus, the bottom currents in the caldron seem to have enough velocity to erode the unconsolidated bottom sediments or weathered materials of the bed rock and to transport eroded materials. If there are gravels in the caldrons, the effect of erosion may be increased. In addition, Honza and Nasu (1968) measured current velocities in Bisan Seto, and showed the velocity of about 1 knot at the maximum at 1 m above the bottom and velocities of 4 to 5 knot at the surface. These stations were almost all in the sand wave distribution area and sand transportation were observed.

Conclusion in the above discussions is as follows. Sediment distribution pattern, which is dominant in the Seto Inland Sea, namely, the decrease in grain size with distance from the channels is caused by the tidal current, with which the bottom materials are eroded in and near the caldron, transported and sorted. On the other hand, suspended matters which are derived from rivers settle where the tidal current is very slow.

A model of sedimentary process in the Seto Inland Sea is shown in Fig. 22.

In flood tide, the caldron in downstream side is eroded by the current. In consequence, sand and gravel grains are washed out from L layer which underlies the bottom and wall of the caldrons, and these grains are transported to downstream side. At this time, large grains of gravels are not carried away by the tidal current and are left in the bottom of the caldrons. Fossil Elephants which were found at Tomogashima Strait belong to such type of grains.

Tidal current which had enough velocities to erode the bottom of caldron decreases as the current spread toward the sea area away from channels and only smaller particles can be transported. Sediments of Types H1 to H4 are deposited in this area. And the upgrade of sorting parameters is caused by currents at this time. Moreover, sand grains sometimes form sand waves and sand ridges by traction movement.

As the tidal current velocities decrease, sand grains that are transported from the caldrons become limited to very fine sand carried in suspension. Sand grains in Type H6 are these grains. Above mentioned sand grains are, in a sense, reworked sediments.

In the area farthest from the channel and in the current shadows tidal current velocities are completely decreased, and there is little supply even of suspended matter which derived from the caldrons. This is such sea area where sediments of small sand content in sand-silt-clay ratio diagram are distributed. When the current is ceased deposition of mud particles are fully developed. The sediment type of this area is H7. In this area, suspended silt and clay particles which are supplied from rivers progressively settle. In the Seto Inland Sea, in general, volume of sediments which were supplied from rivers exceeds that from the caldrons, as shown in Osaka Bay. Above mentioned sediments are all belong to U layer except for grains which are remained in the caldrons.

In ebb tide, tidal currents flow mainly along the surface layers toward channels. This is apparent because tidal currents originate due to the difference of sea levels on both sides of a channel. Mogi (1980) stated that velocities of tidal currents are relatively higher when the survey positions are in the downstream side than that in the upperstream side. Then, the bottom sediments do not undergo the same velocity current as that of flood tide. In addition, as velocities which initiate the movement of the grains are generally larger than that of settling the grains, it is needed longer time for the grains to start to move again at the areas far from the channel than that near the channel. So, sandy grains, that came from the caldron, are hardly carried back to their original position.

Suspended grains, which are derived mainly from rivers, are gathered near the shore at flood tide and then spread widely offshore with weak current at ebb tide. In this process suspended matters seem to be transported to the areas of sand deposition, and this fact is supported by the existence of a small content of mud grains in the sandy sediments. A typical sediment of such origin is Type H5 sediment. However, mud grains which are included in types H1 and H2 near the channel areas have the possibility that mud grains in the L layer are eroded, caught in the boundary layer of turbulent flow of large particles and then deposited in it. On the other hand, the mud grains of Type H5 may be eroded and transported toward the shoreside areas from channel by the following flood tide. In this manner, sediments which have both mud particle group and sand grain group, showing bimodal or polymodal patterns in the histogram expressions, are formed. Therefore, sorting is upgraded from H1 to H4, but sorting become worse from H5 to H7.

Above mentioned sedimentary processes are concerned mainly with the area which lie "landward" side of a channel. It is natural that in "outer side" area of a channel, the process is overturned from flood tide to ebb tide. In this model, sedimentary transport is assumed to be daily process, but current velocities differ remarkably from spring tide to neap tide. So, in spring tide, this process is more strengthened than other tide.

2. On the age of "Alluvium" sandy sediments distributed near the channel area of the closed sea

As mentioned above, sediments in the Seto Inland Sea have different origins from each other as compared with those of lagoons and tidal flats, however, the sediment distribution patterns are very similar to each other. That is, sediments which are transported by tidal current show horizontal decrease in grain size with distance from the channels, toward the direction of decrease of the current velocity, and this process is in progress at present. However, in Japan, in spite of the existence of such sedimentary distributions as mentioned above, surface sandy sediments near the channels are treated as deposits which deposited in the age of the low sea level, 15-20 m lower than the present one, 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 two formations, namely, A and B formations, and stated as follows: These divisions like Alluvium A and B is very similar to that of Ariake Clay Formation and Shimabara Kaiwan Formation (Ariake Bay Research Group, 1965), and Alluvium I and II formations in Tokyo (Aoki and Shibasaki, 1966). A formation is Holocene and B formation is latest Pleistocene in age (p. 94, 95). From the data on bottom sediments, A formation can be regarded as muddy part and B formation can be sandy part, but there are no data as for B formation (p. 90) (underline by the auther).

Later, Huzita (1978) mentioned that A formation can be regarded as Umeda Formation in coastal region, and B formation as Nanko Formation of early Holocene age, still maintaining the opinion that sandy sediments in channel belong to B formation (p. 170). Further he stated that there is no condition of forming sandy gravel bed at the present bay (p. 172).

On the other hand, the author made the different interpretation as follows.

1. "Alluvium" is divided into U layer and L layer (exactly speaking, a part of L layer) by the data of acoustic records. U layer corresponds to middle clay formation in Huzita and Maeda (1966), but there is some possibility that a part of U layer is older than that of middle clay formation. And underlying bed and rocks belong to L layer.
2. Muddy part, which is regarded as U layer, grades into sandy part in and near the channel area.
3. So, sandy part, which is distributed around the channel area, does not belong to L layer.

Differences in the interpretation between Huzita and Maeda (1969) and this paper are in the following two points.

1. Subdivision of the "Alluvium" deposit by means of the acoustic records.
2. Correlation of the sandy sediment around the channel area.

As discussed in the acoustic stratigraphy based on acoustic survey record(chapter VI in this paper), both "Alluvium" A and B together correlated with U layer and 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. 23), so sandy sediments distributed around the channel area must belong to U layer.

It should be mentioned that Kuwahara et al. (1972) described the acoustic record in Ise Bay, stating that A formation in the surface part changes its facies into sandy ones near the bay mouth. This coincides well with the case of U layer in the Seto Inland Sea.

From the above discussion, following conclusion can be made. Sandy surface sediments that are distributed around the channel area in Osaka Bay are modern sediments and are now undergoing transportation. This process is the same as that of the Seto Inland Sea.

Next, the interpretation of Ariake Bay Research Group (1965) will be discussed.

Ariake Bay Research Group (1965) divided surface sediments into two groups, namely, "Ariake Clay Formation" which is composed mainly of muddy sediments, and "Shimabara

Kaiwan Formation" which is composed mainly of sandy sediments, and stated:

Shimabara Kaiwan Formation is distributed widely in -40 m planation surface, as well as underlying the Ariake Clay Formation which lies in Ariake and Shiranui Bays (p. 69).

Main body of aquifers which began to be saline water is the First aquifer, namely, Shimabara Kaiwan Formation. The main reason of this intrusion of saline water is that the First aquifer which underlies the Ariake Clay Formation, cropsout at -40 m planation surface. (p. 78).

So, they regard the sandy sediments as the older sediments which were formed before the recent sediment of the Ariake Clay Formation deposited.

Besides this, Kamada (1979) stated as follows : 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 is sandy gravel formation composed of medium and coarse sand and fine gravel. This sandy gravel formation is distinguished from the Ariake Clay Formation and regarded as the Shimabara Kaiwan Formation, and is distributed in Ariake Bay as IIa and V type sediments (p. 81). One of the most remarkable differences between the interpretation of that group and this paper is the view for the age of sandy gravels distributed around the channel. They regarded the Shimabara Kaiwan Formation, which are distributed on the bottom surface of Ariake Bay, is a continued part to the sandy gravel formation that underlies the Ariake Clay Formation. In this point, the relation between Ariake Clay Formation and the Shimabara Kaiwan Formation is the same as that of "Alluvium" A and B in Osaka Bay. However, this interpretation can be discussed from the different view point as in the case of Osaka Bay.

It is apparent that above mentioned sedimentary distribution pattern differs much from that described by Kamada (1979). Kamada (1979) described the decrease in the grain size with distance from channel area. So, if the sandy gravel formation in the central bay and the one underlying Ariake Clay Formation is continuous, tidal current faster than that of present should have been there to move the sediment grains. But, as the current velocity is controlled by exchanged water volume, Ariake Bay in that time must have had several times wider sea area to allow this. However, there are no evidences like that.

Matsuishi and Matsumoto (1969), based on acoustic record obtained by Sonoprobe in Ariake Bay, divided "Alluvium" in that area into "upper Alluvium" and "lower Alluvium", and subdivided "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 to bottom sediments. However, as shown in Fig. 12 of Matsuishi and Matsumoto (1969), "upper Alluvium I" gradually changes into "upper

Alluvium II", so the stratigraphic relation of both parts is not very clear. Therefore, there is a strong possibility that sandy sediments around the channel and Ariake Clay Formation are contemporaneous but heterotopic facies, but further examination is required to solve the problem.

VIII. SUMMARY

In the Seto Inland Sea, sandy sediments are distributed widely in and around the channels and caldrons, and they decrease grain size with distance from the caldrons. And farther distance from the channels, muddy sediments of recent age are distributed. These muddy sediments compose surface part of U layer in the acoustic records. But this part is very thin or absent in the channel areas and caldrons, and increases its thickness far shoreward from the channels. Such distribution patterns are most dominant and general in the Seto Inland Sea.

The cause of sediment distribution pattern especially of the sandy materials described above, can be explained by the effect of the tidal currents in recent years. Sandy sediments around the area are supplied by the reworking of the fresh water and shallow marine sediments which deposited at the low sea level in latest Glacial age and by the erosion of the basement rocks, both distributed in the caldrons and their nearby areas.

The similar distribution pattern to that in the Seto Inland Sea is reported from the tidal flat, lagoon and continental shelf under high tidal current. However, in these areas, wave activities are very strong. Also in such areas as the tidal flats and lagoons with inlets facing outside to the open sea, as the source of sand the supplies from outside through waves and longshore currents are much more stressed than those from the caldron. The

Seto Inland Sea is remarkably different from other closed seas regarding the origin of sand.

Sandy sediments which are distributed around the channels have been thought to belong to the older group than the recent one, and referred to have deposited during the latest Glacial age. However, they are the modern sediments or reworked sediments which are now undergoing transportation.

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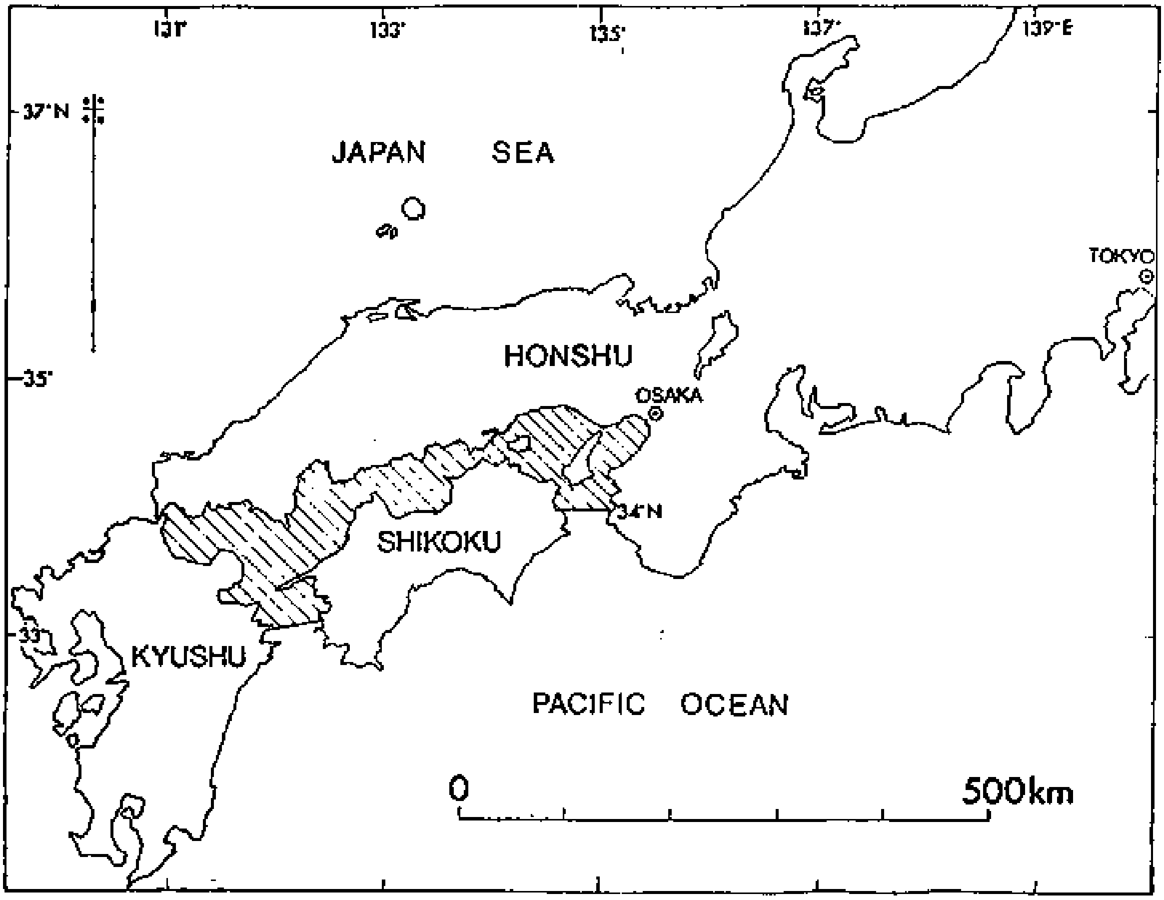


Fig. 1 Index map of the study area.

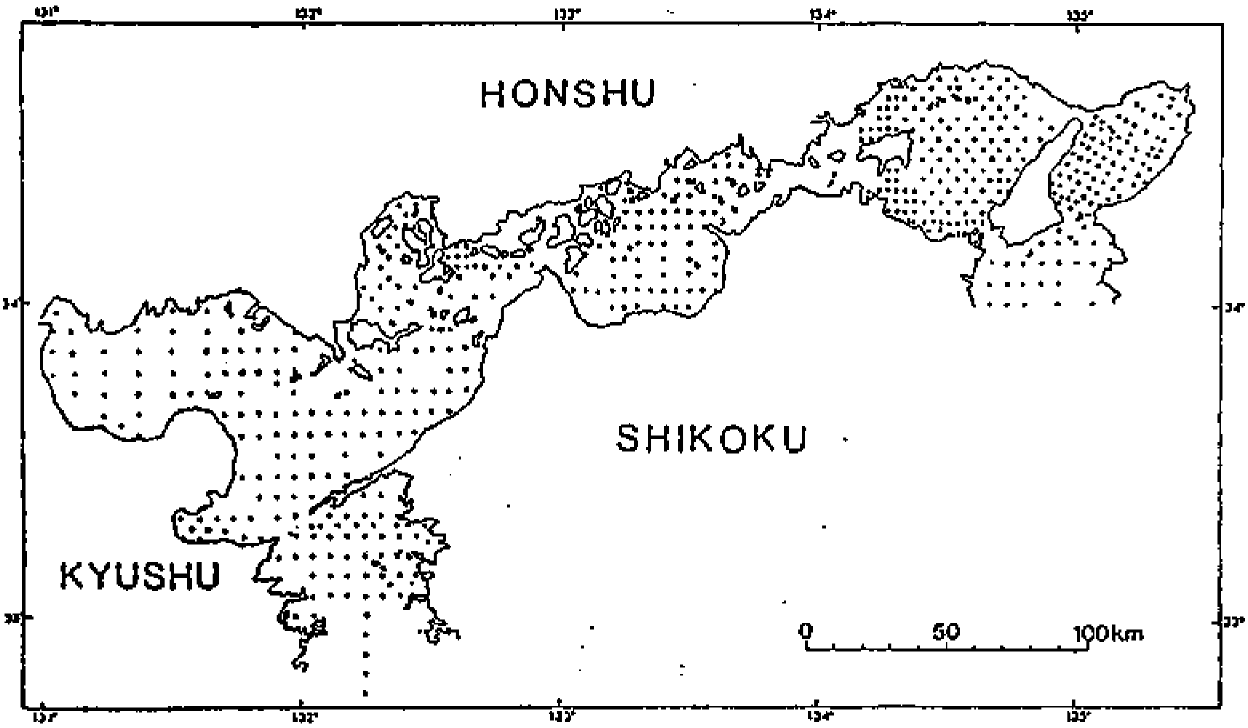


Fig. 2 Sampling locations in the Seto Inland Sea.

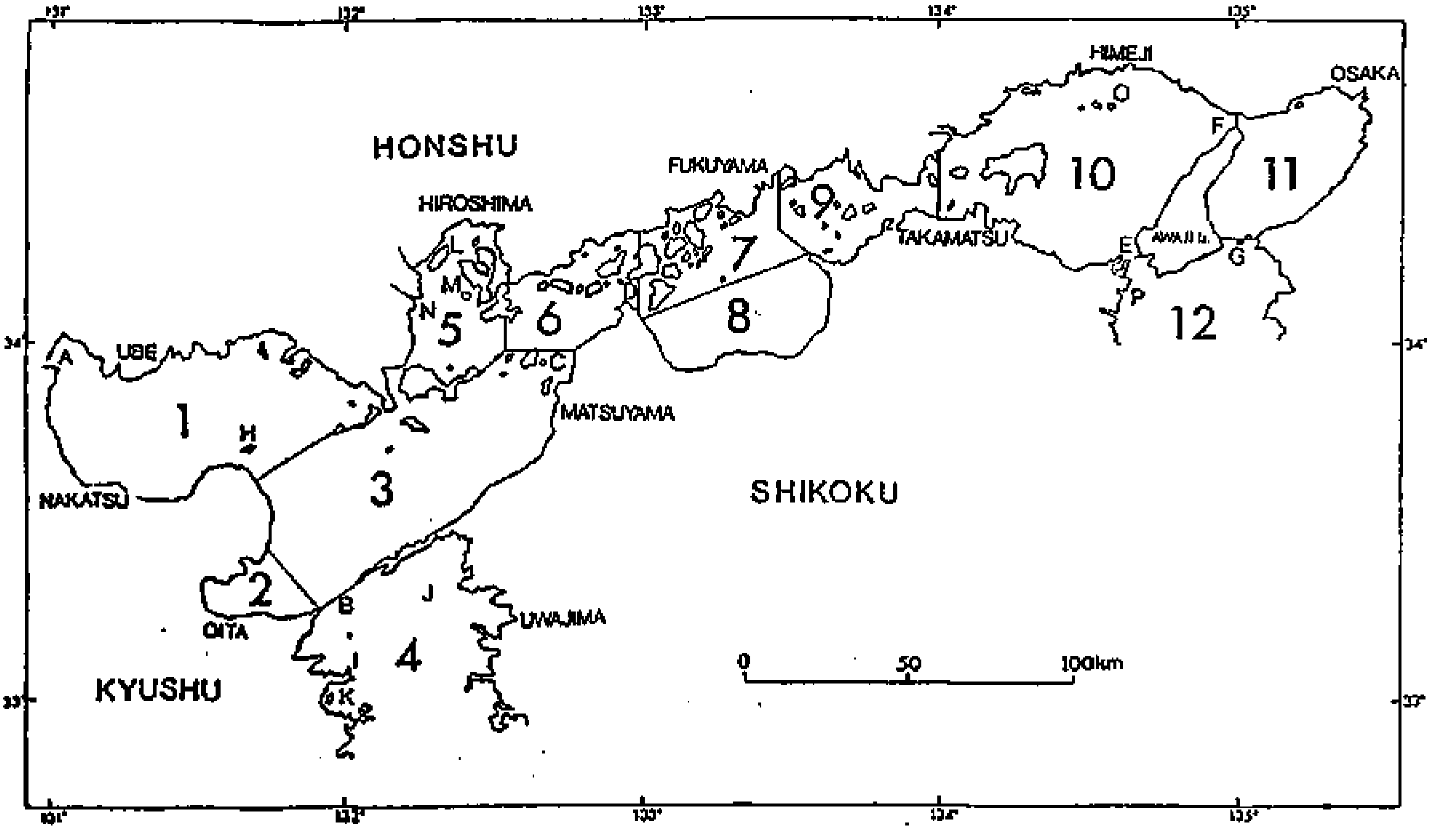


Fig. 3 Division of the Seto Inland Sea.
1. Suwo Nada, 2. Beppu Bay, 3. Iyo Nada, 4. Bungo Suido, 5. Hiroshima Bay, 6. Aki Nada, 7. Bingo Nada, 8. Hiuchi Nada, 9. Bisan Seto, 10. Harima Nada, 11. Osaka Bay, 12. Kii Suido,
A. Kanmon Strait, B. Hoyo Strait, C. Tsurishima Strait, D. Kurushima Strait, E. 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, N. river mouth of Oze River, O. Iejima Islands, P. river mouth of old Yoshino River.

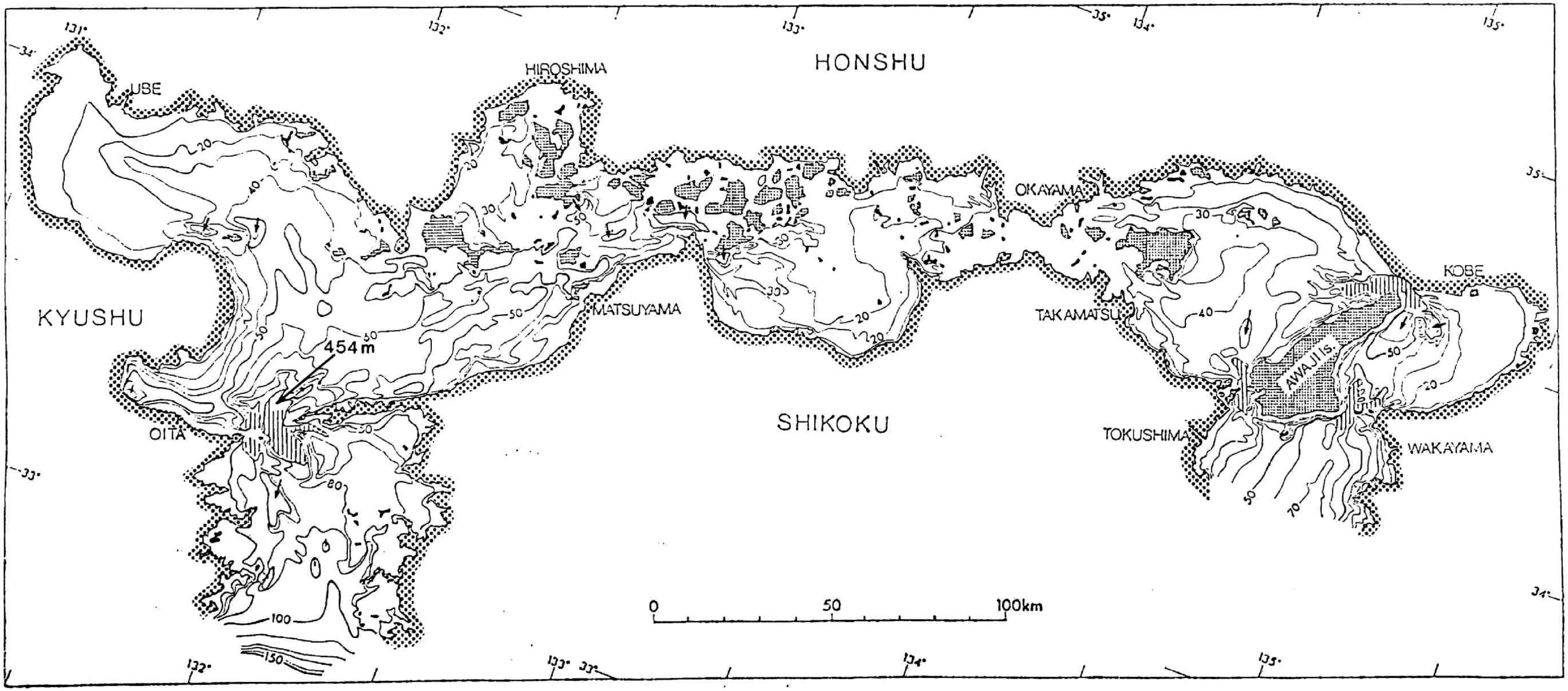


Fig. 4 Bottom topography in the Seto Inland Sea. Solid contour lines indicate 10 m intervals.
Areas of vertical lines indicate large caldrons.
Arrows indicate caldron areas.

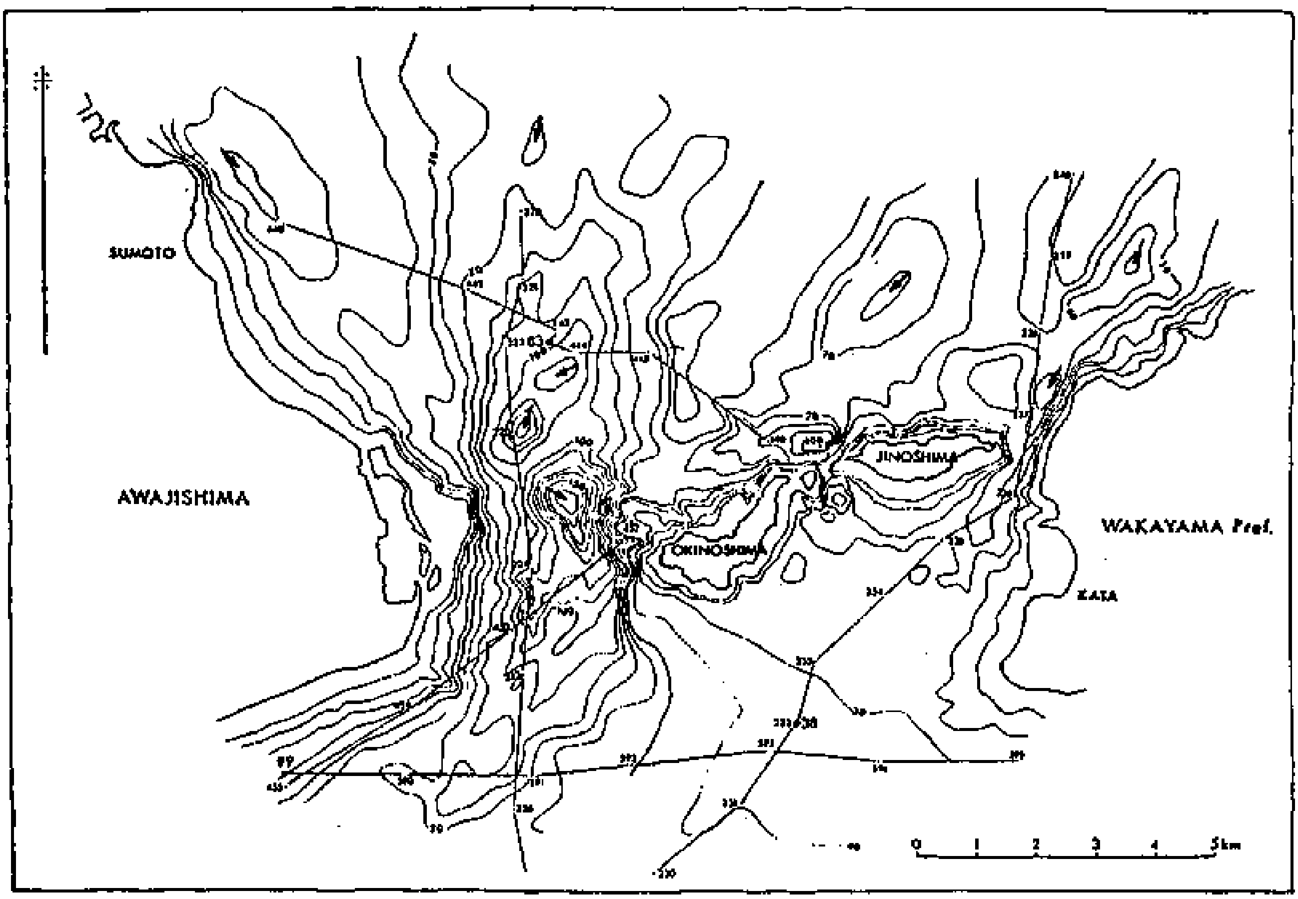


Fig. 5 Bottom topography of Tomogashima Strait. (Single-type caldron)
Depth in meter. Lines show tracks for seismic profiles.

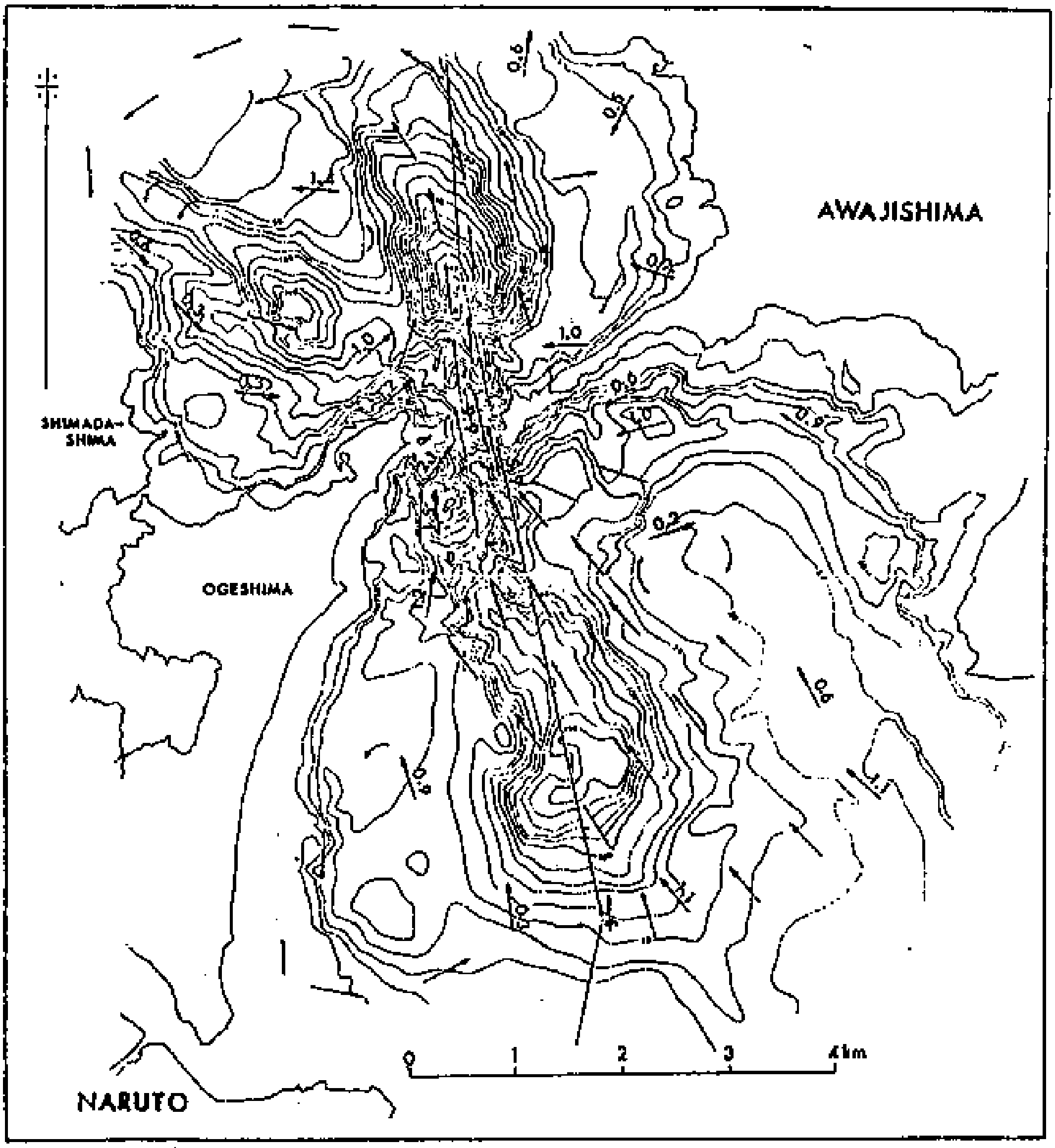


Fig. 6 Bottom topography of Naruto Strait. (Twin type caldron)
Arrows with numbers indicate current directions and their velocities in knots. (Maximum velocity in flood tide)

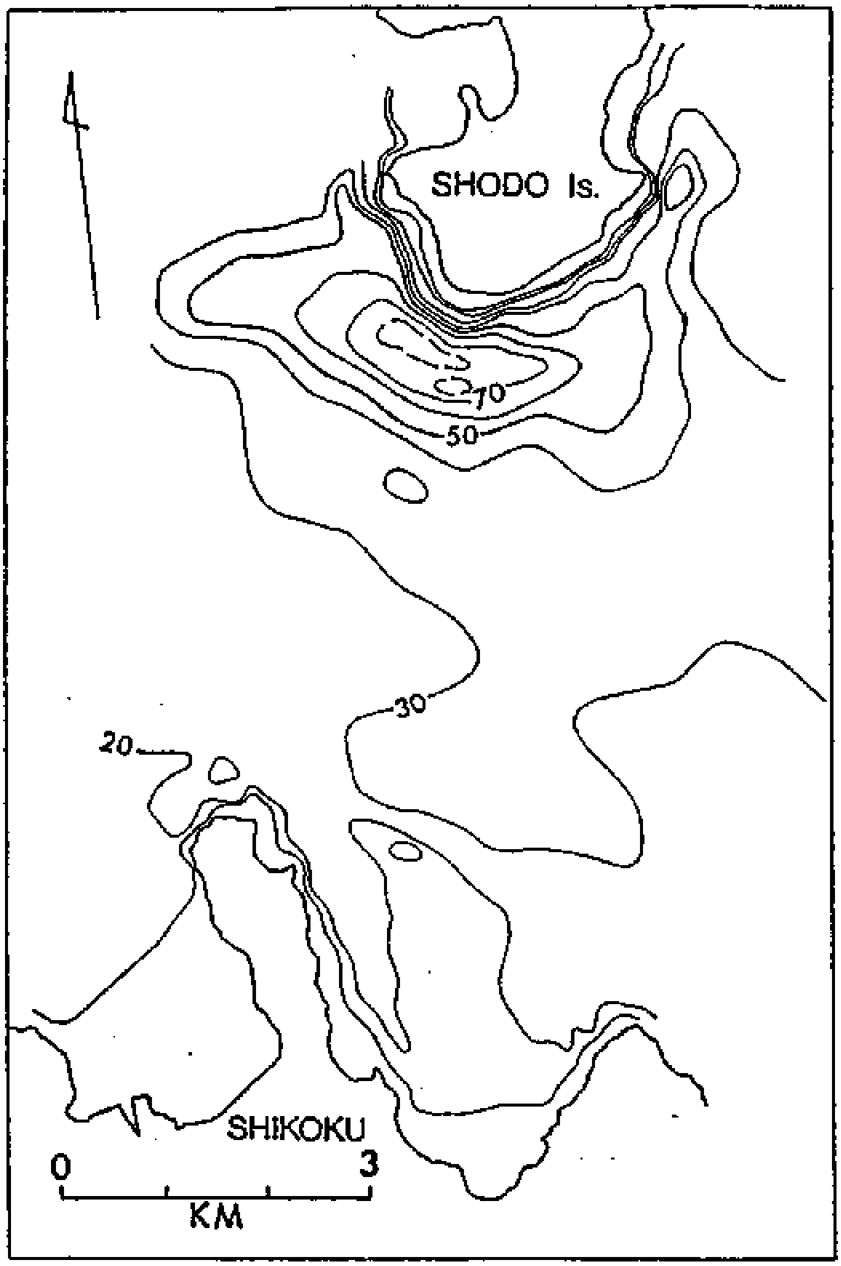


Fig. 7 Bottom topography of the off cape-type caldron in the offing of the Jizozaki Peninsula in Shodo Island. Depth in meter.

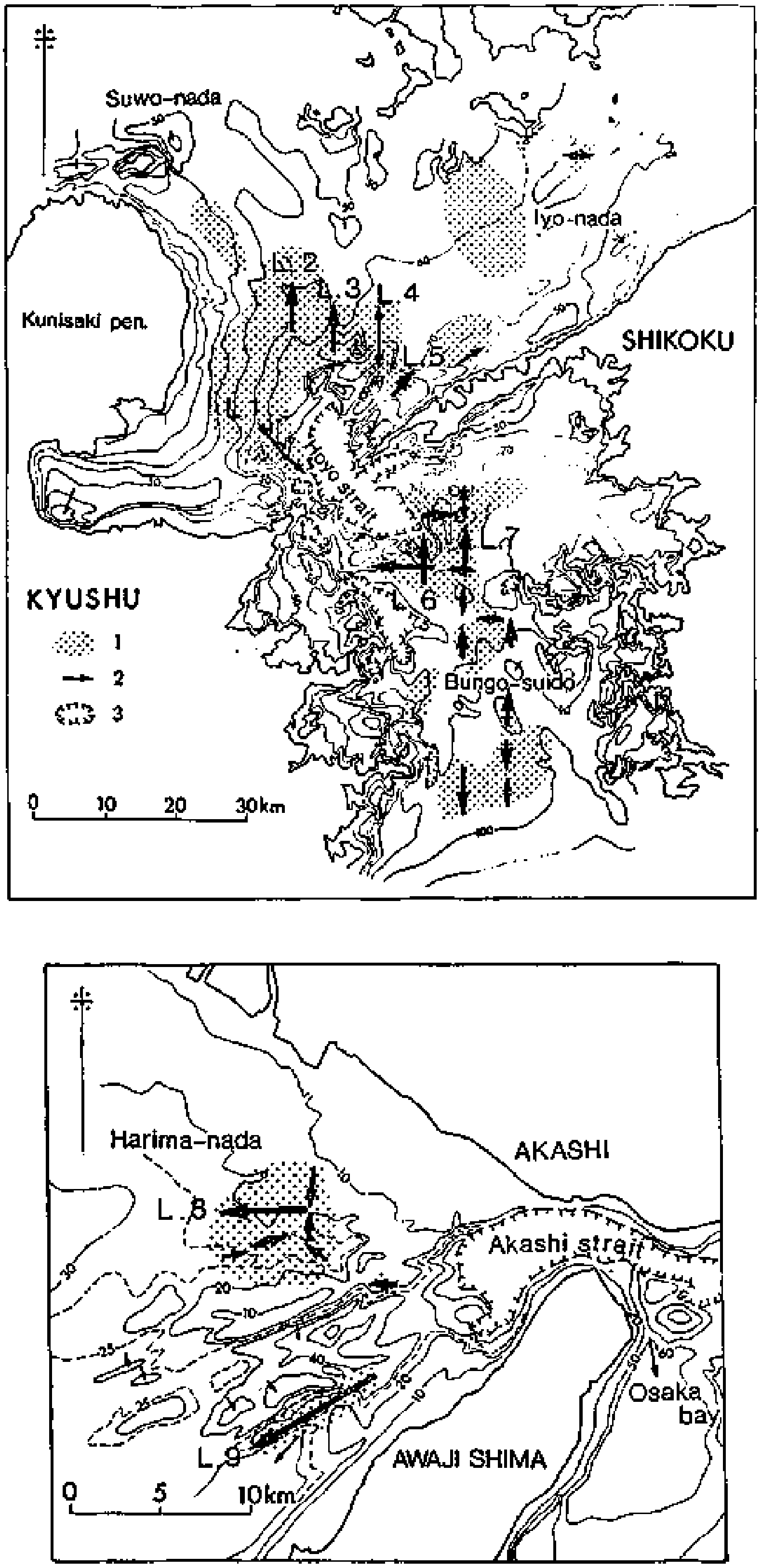


Fig. 8 Distribution and direction of sand waves in Iyo Nada, Bungo Suido and Harima Nada. Directions are judged by acoustic record on track lines.

1. Estimated distribution area of sand waves by acoustic records.
2. Arrows in one direction show distinct sand wave direction and their legs. Arrows in both directions show distinct symmetrical wave topography and their legs.
3. Caldron area.

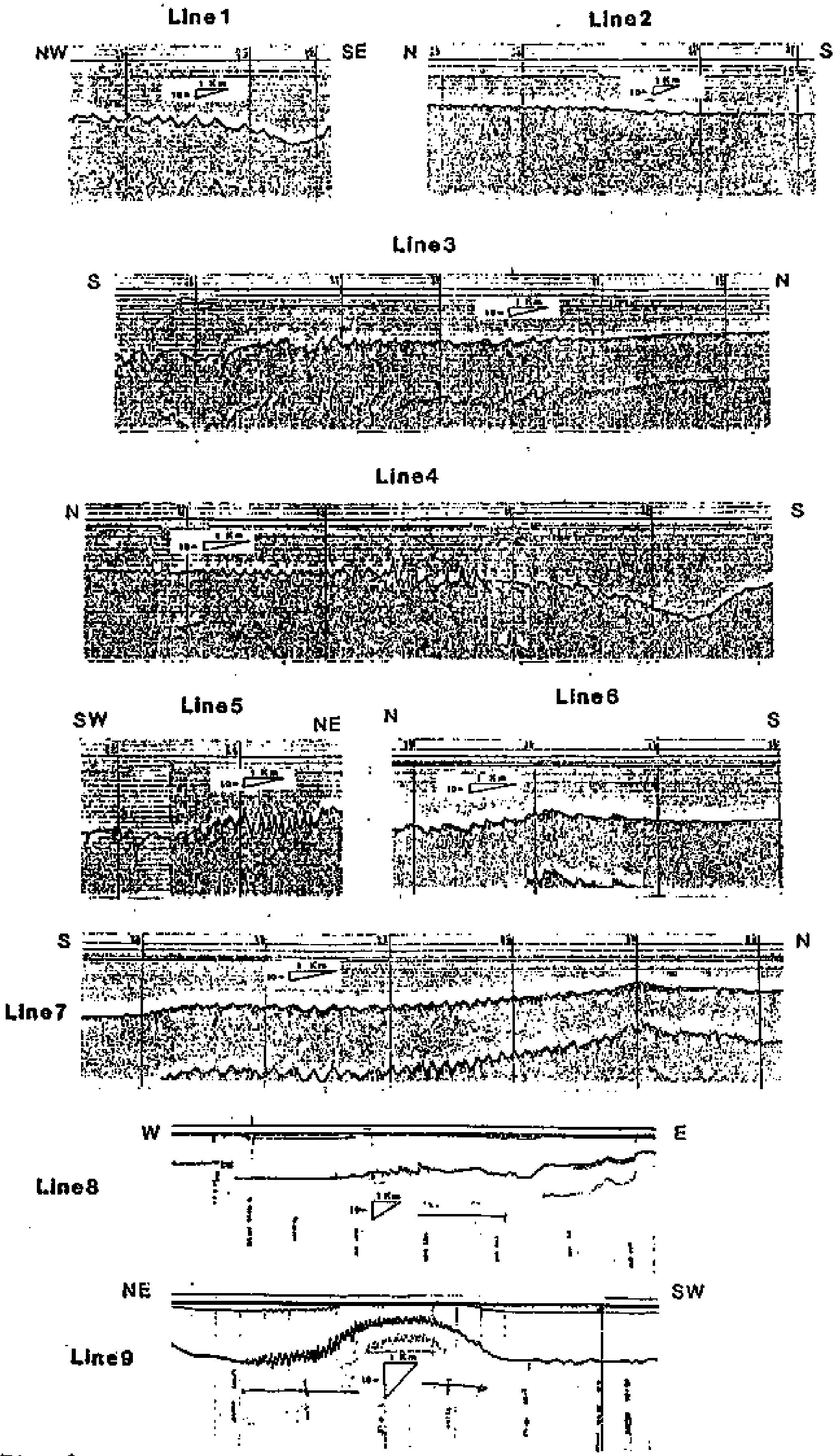


Fig. 9 Examples of sand wave topography shown in the acoustic record.
Positions of Lines are shown in Fig. 8.
Lines 1-7 are records of 3.5kHz Subbottom Profiler.
Lines 8 and 9 are records of PDR.

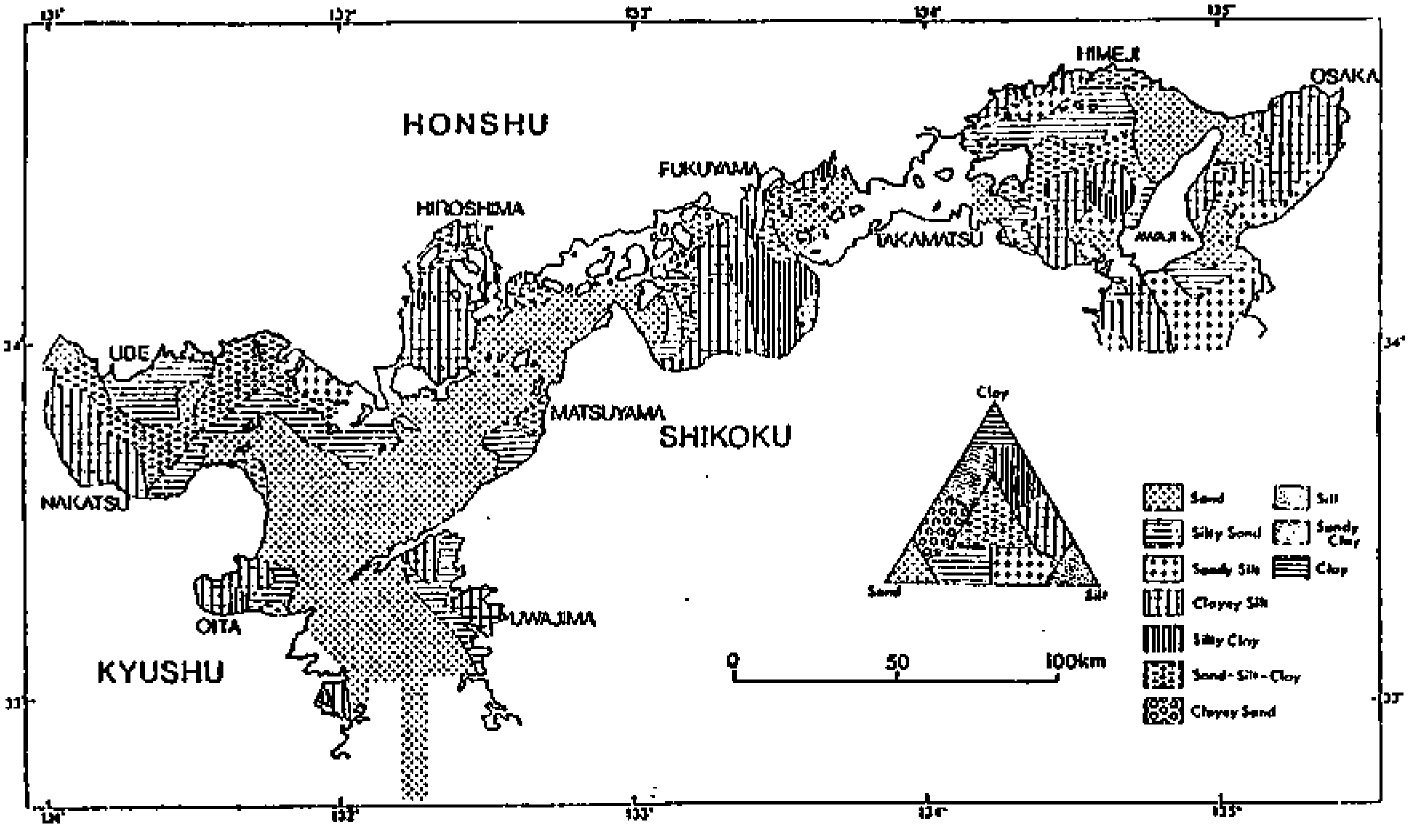


Fig. 10 Distribution map of surface sediments in sand-silt-clay ternary textural diagram.
"Sand" area includes areas of rock exposure. Blank area is unsurveyed.
"Clay", "Silt" and "Sandy clay" are not distributed in the area.

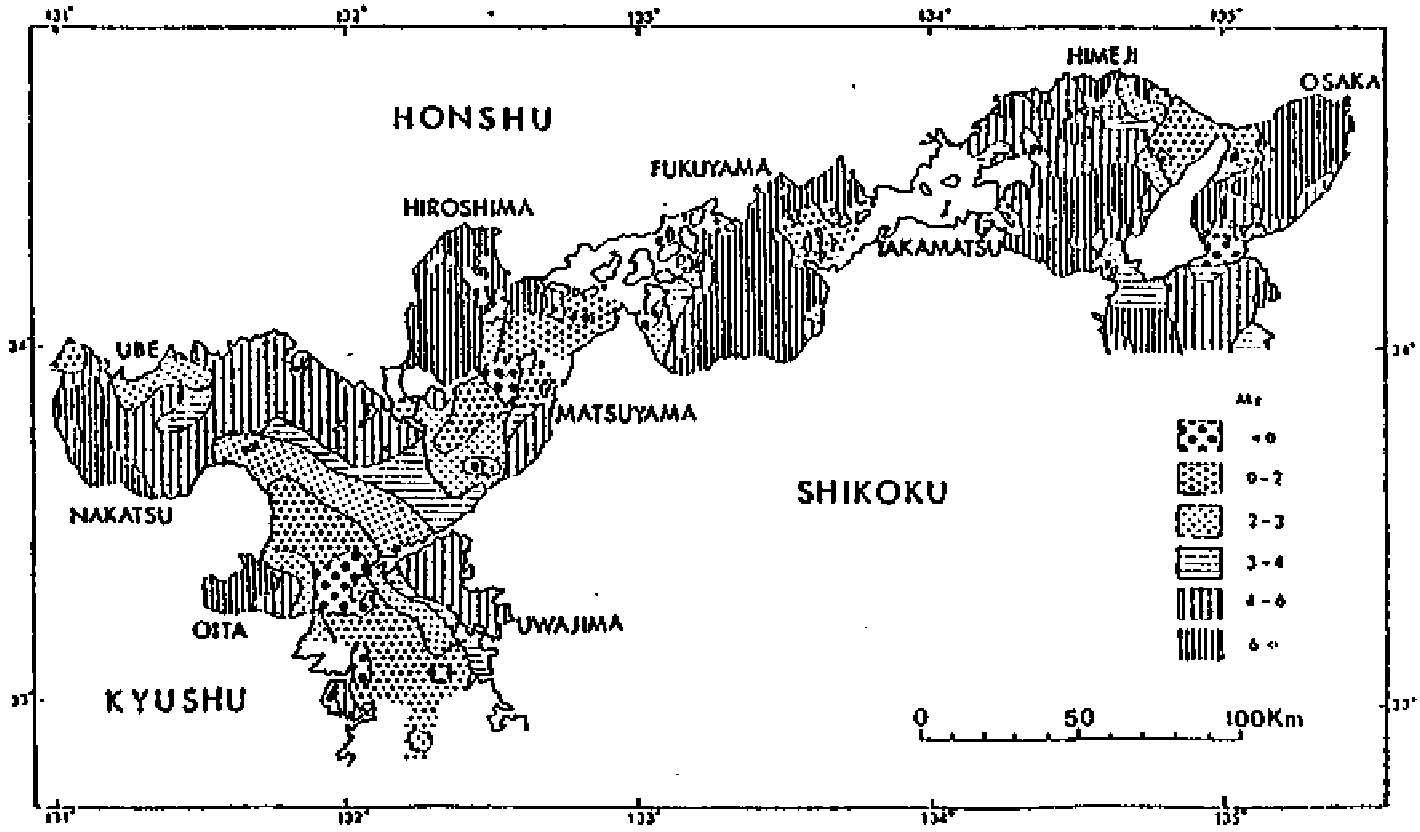


Fig. 11-1 Distribution map of surface sediments in Mzϕ. Area of the the mean diameter more than 0 ϕ include areas of rock exposure.

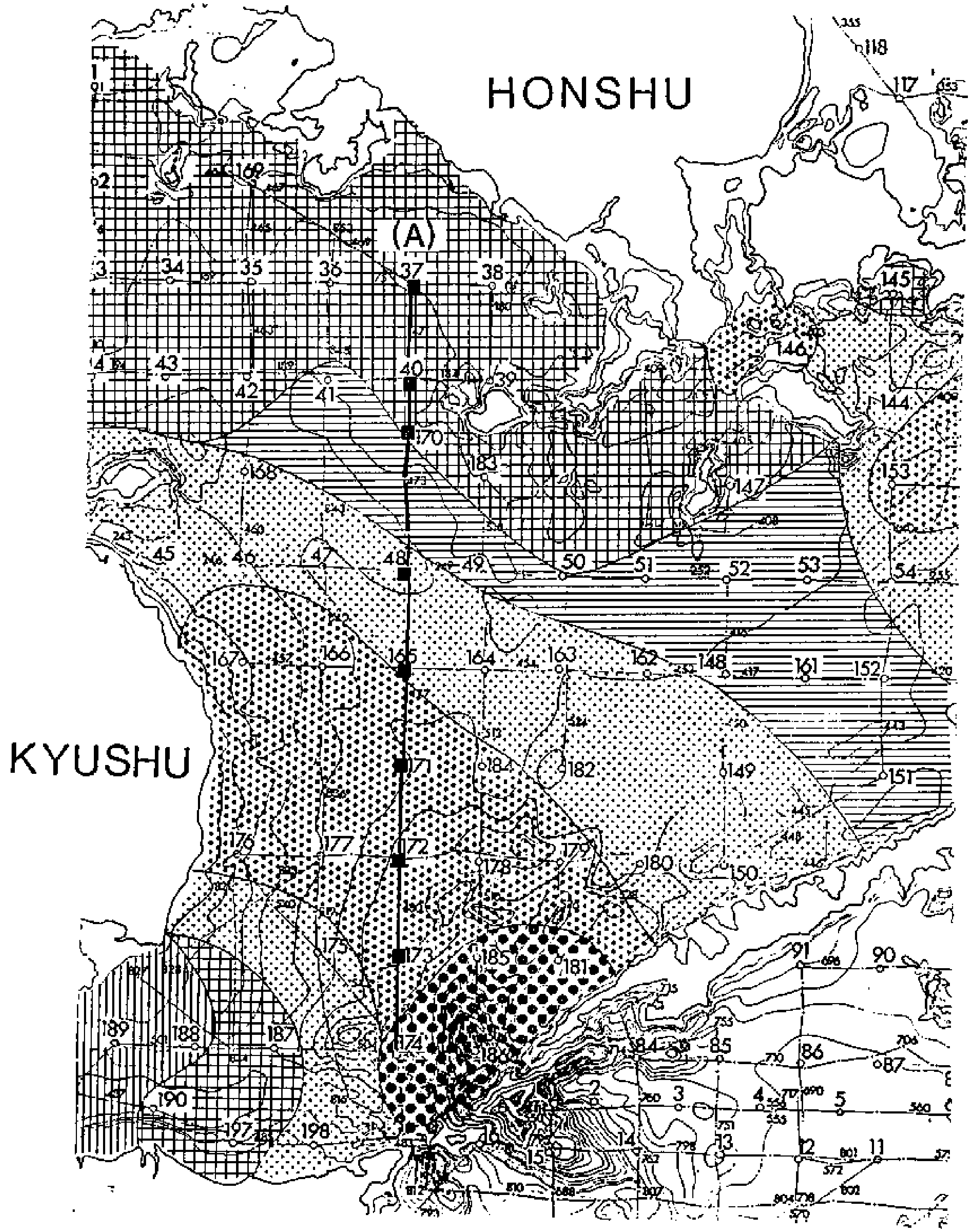


Fig. II-2 Detailed distribution map of surface sediments in Mzϕ. Eastern part of Suwo Nada and western part of Iyo Nada.

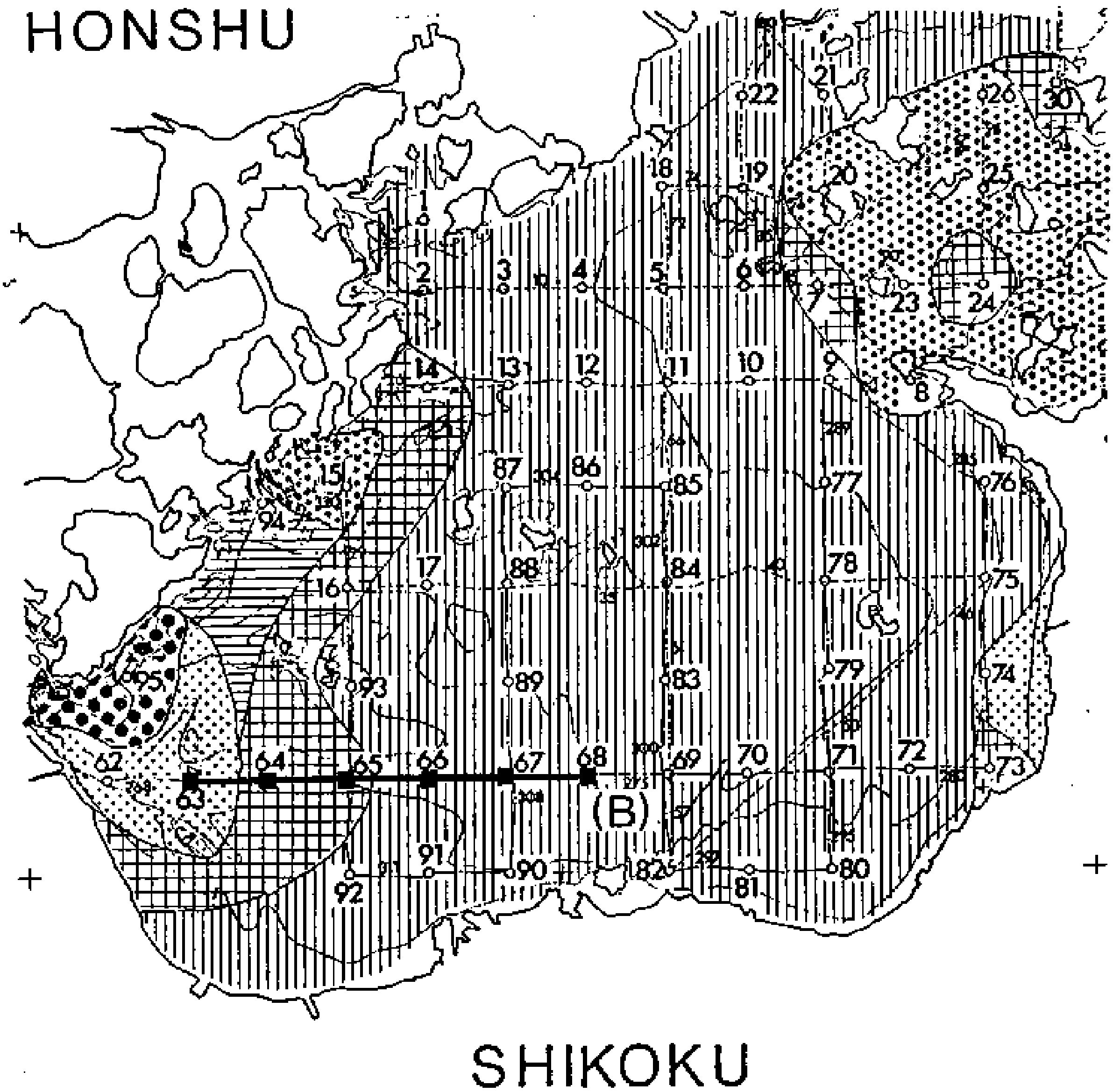


Fig. 11-3 Detailed distribution map of surface sediments in Mzϕ. Hiuchi Nada and Bingo Nada.

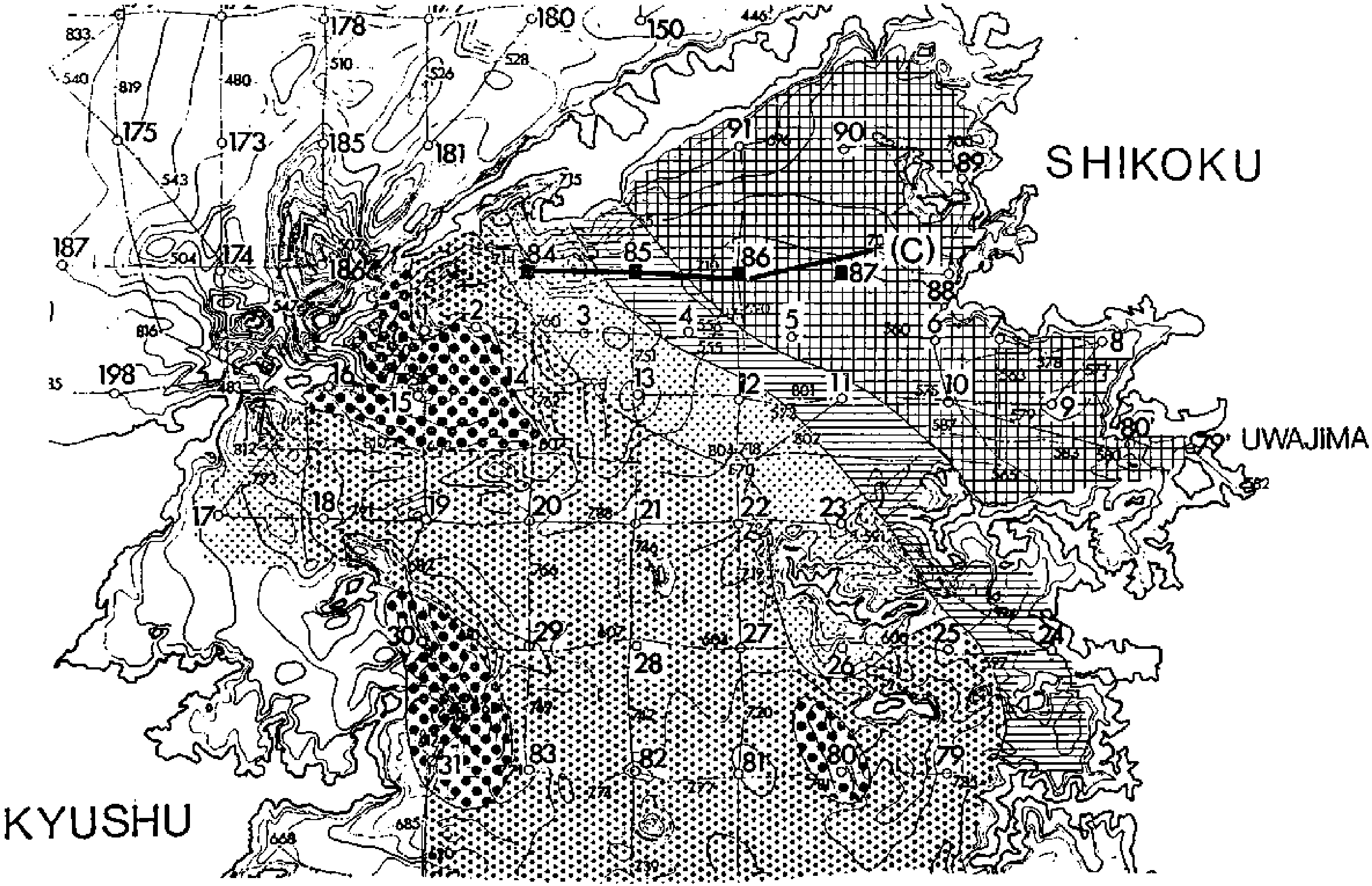


Fig. 11-4 Detailed distribution map of surface sediments in Mzϕ. Northern part of Bungo Suido.

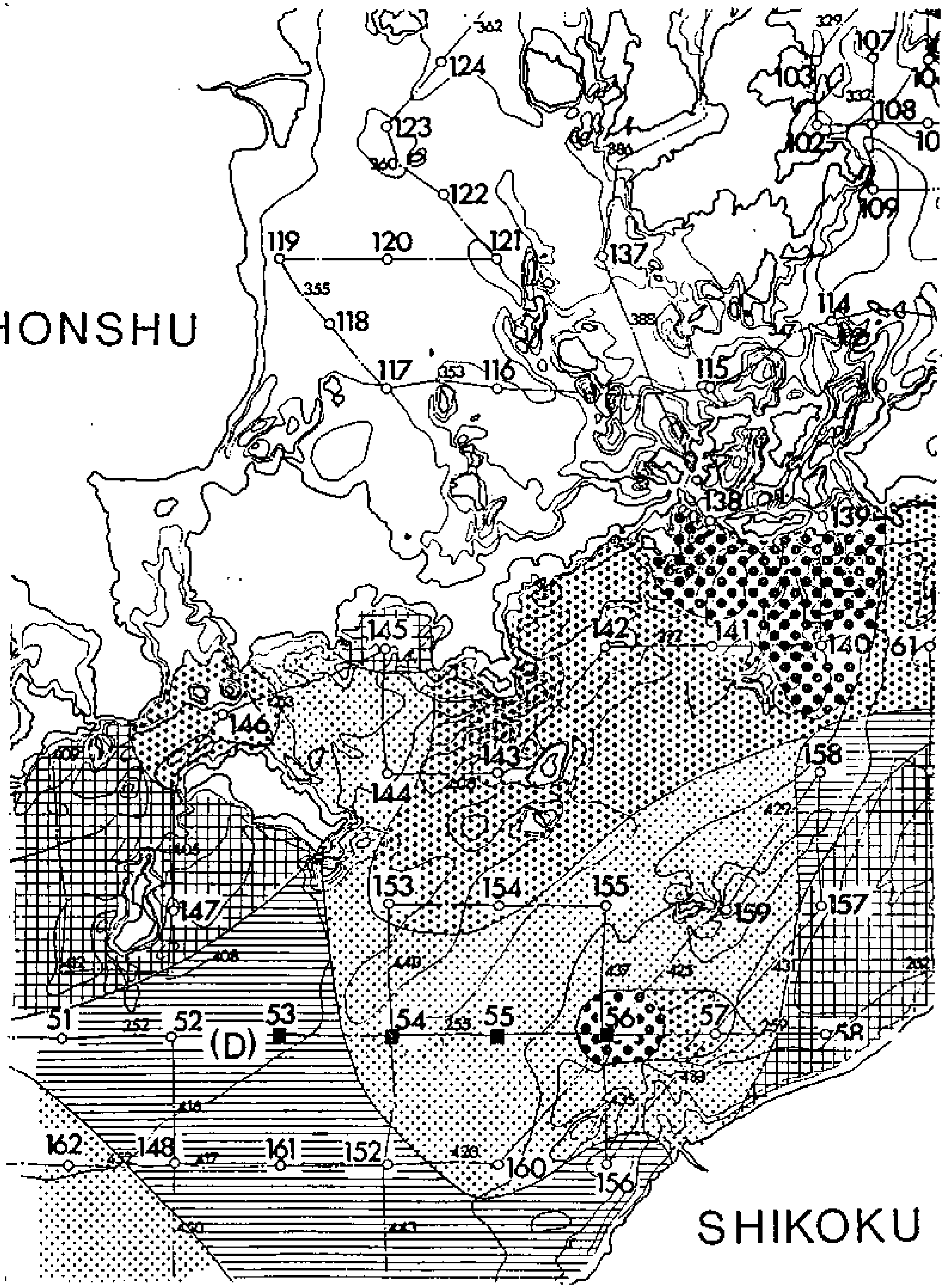


Fig. 11-5 Detailed distribution map of surface sediments in Mzϕ. Eastern part of Iyo Nada.

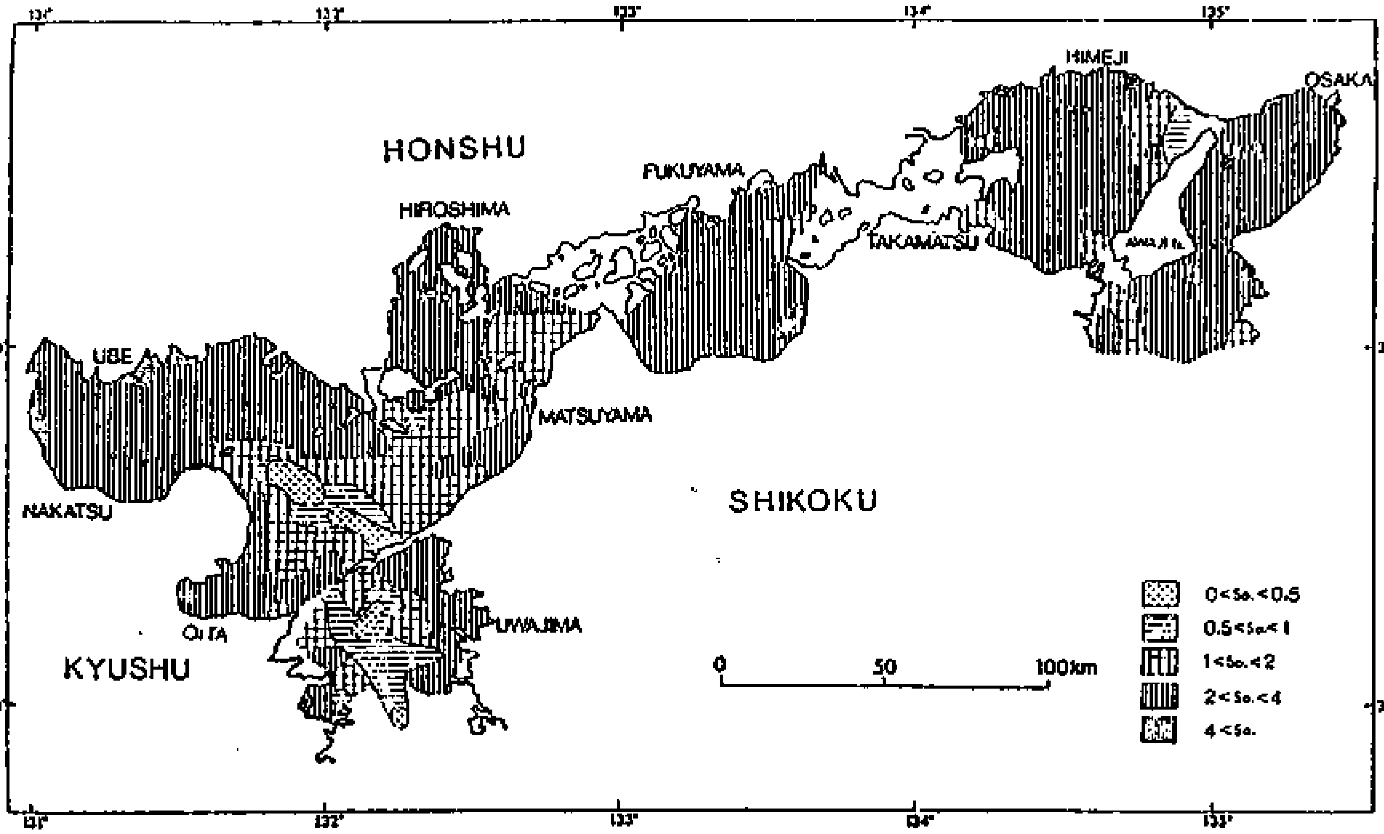
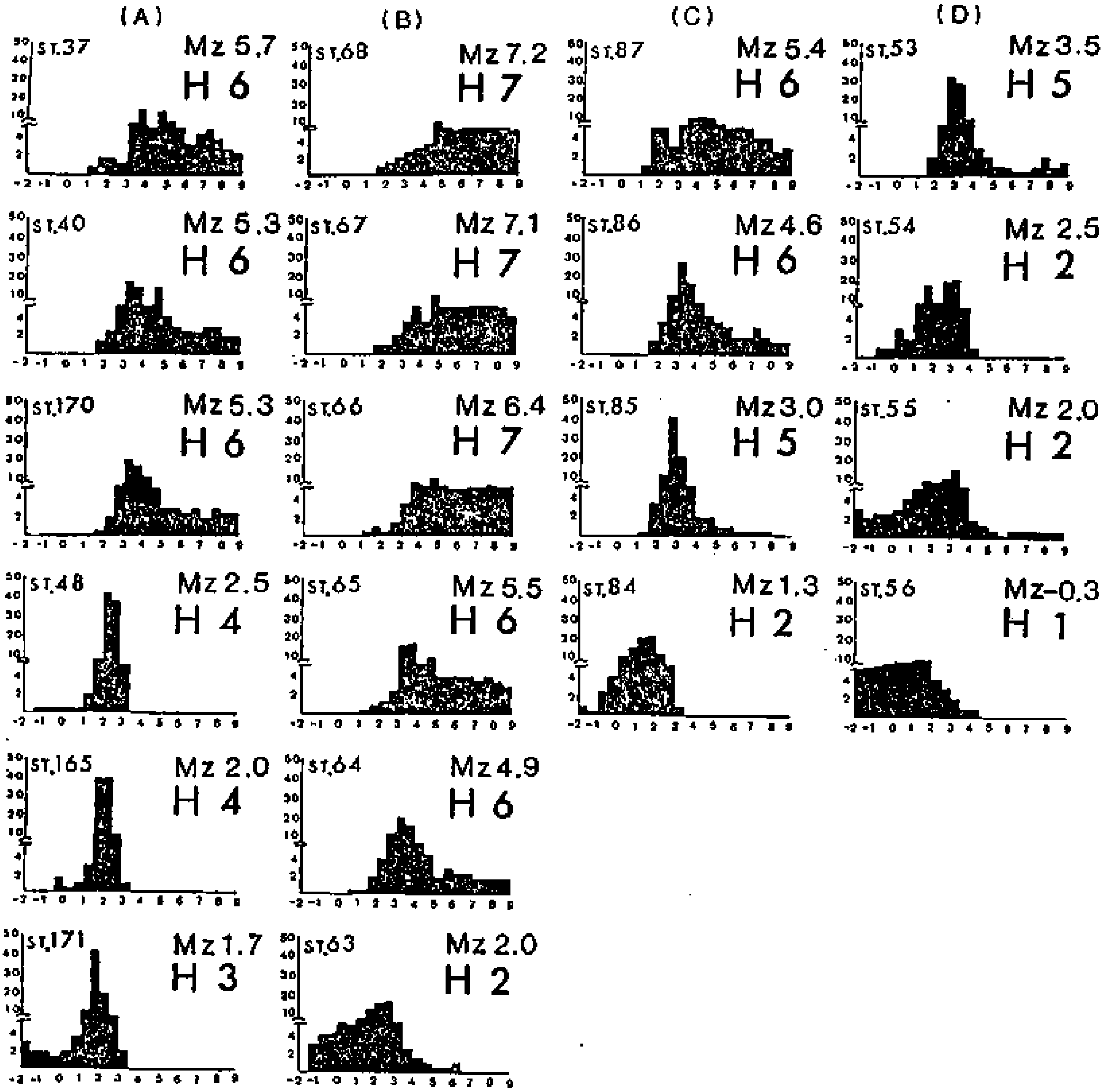


Fig. 12 Distribution map of sorting. (in ϕ scale)



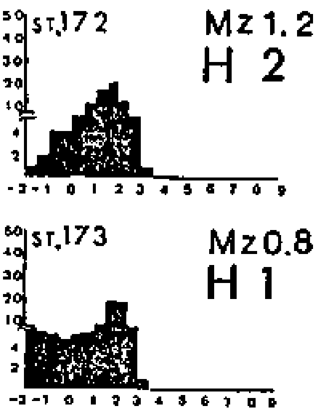


Fig. 13 Histogram of grain size composition and their sediment types.
Numbers under the mean diameter (ϕ) are sediment types.
(A) Suwo Nada and Iyo Nada.
(B) western part of Hiuchi Nada.
(C) eastern part of Bungo Suido.
(D) central part of Iyo Nada.
Vertical axis shows content of grains.
Horizontal axis shows grain size in ϕ scale.
(A) (St.37–St.173) to (D) (St.53–St.56) are shown in Fig. 11 as (A) to (D) and Fig. 14 as A to D.

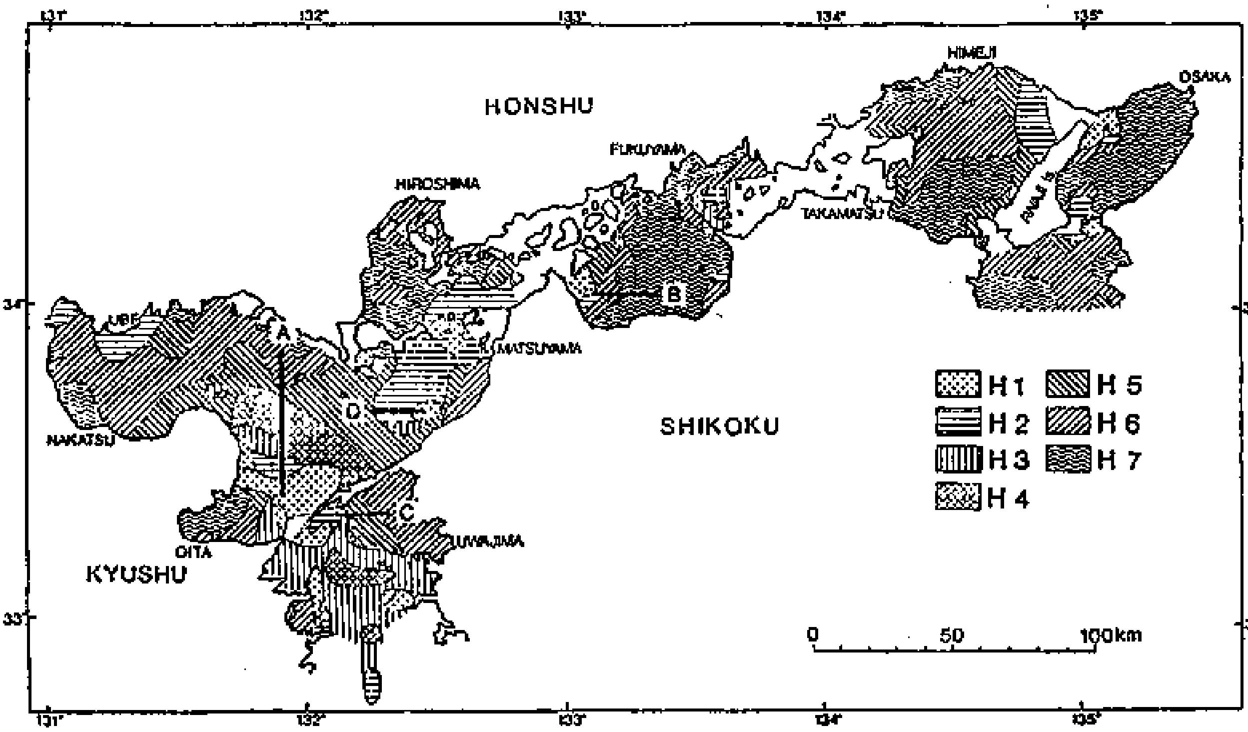


Fig. 14 Distribution map of sediment types.
Grain size composition of sediments along lines A to D are shown in Fig. 13.

Table 1 Distribution of sediment types in respect to the meam 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	to-tal
H1	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

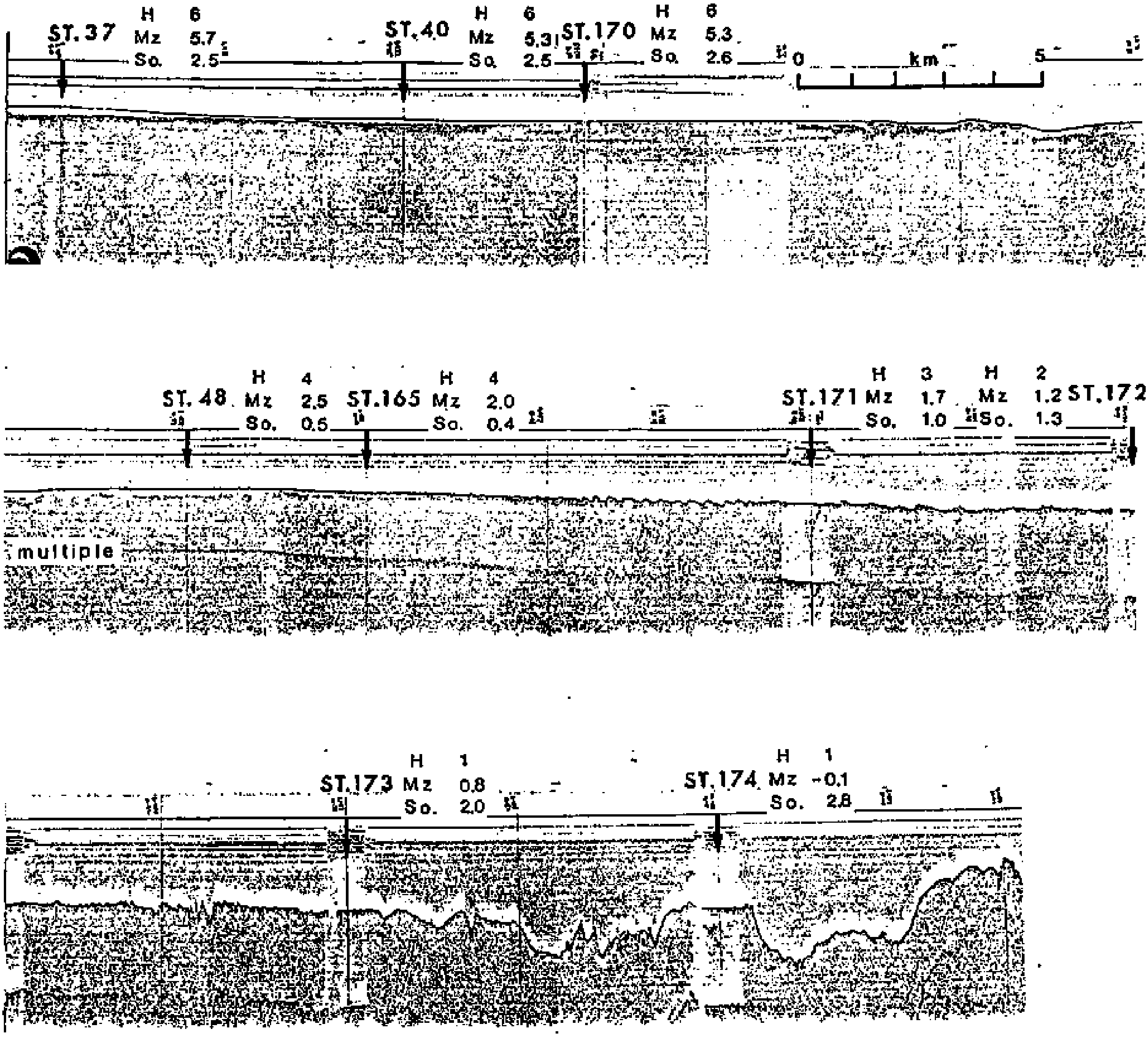


Fig. 15 Examples of relations between sediment type and topography in Iyo Nada. Position of track line is shown in Fig. 14 as Line A.

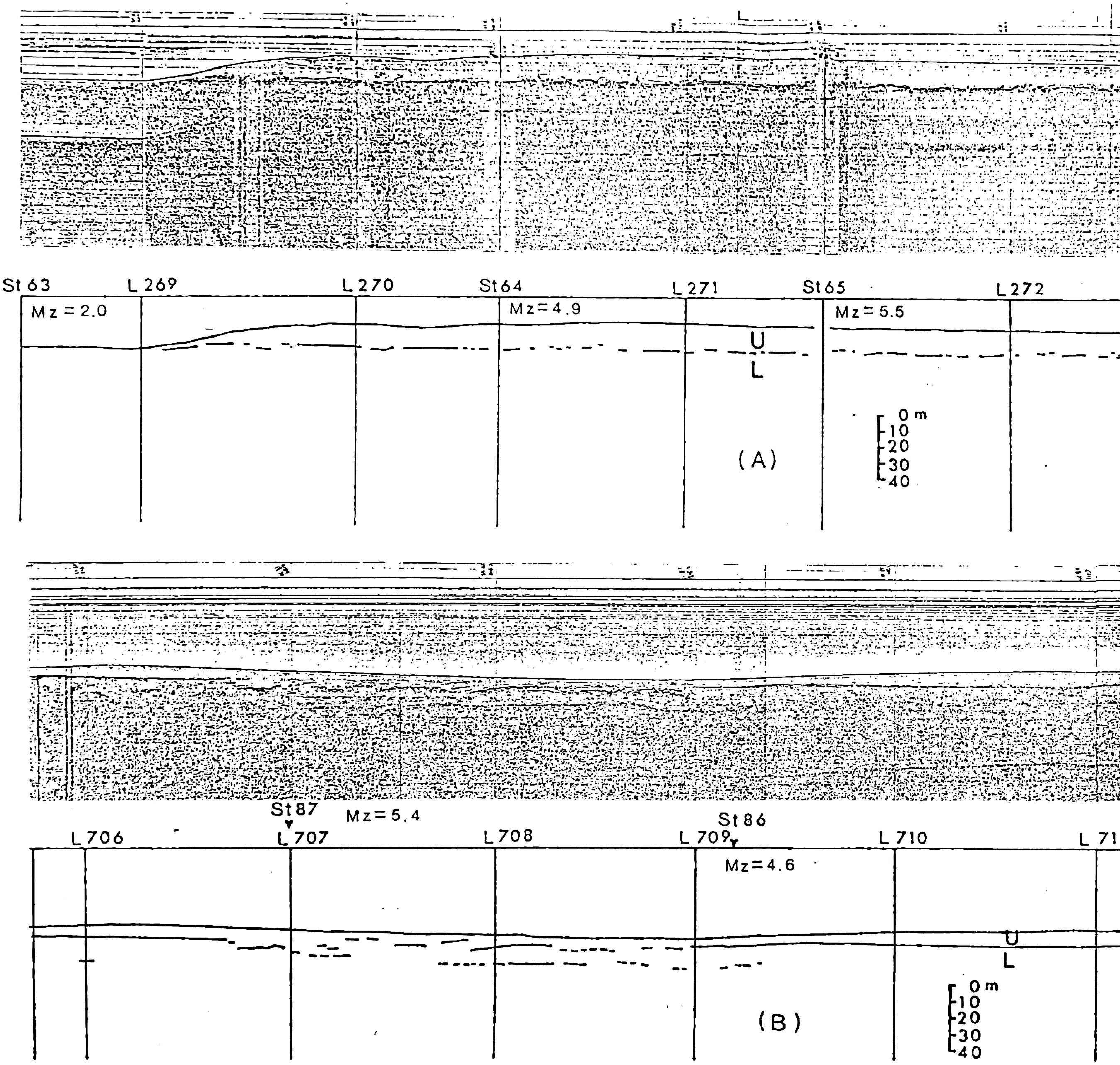
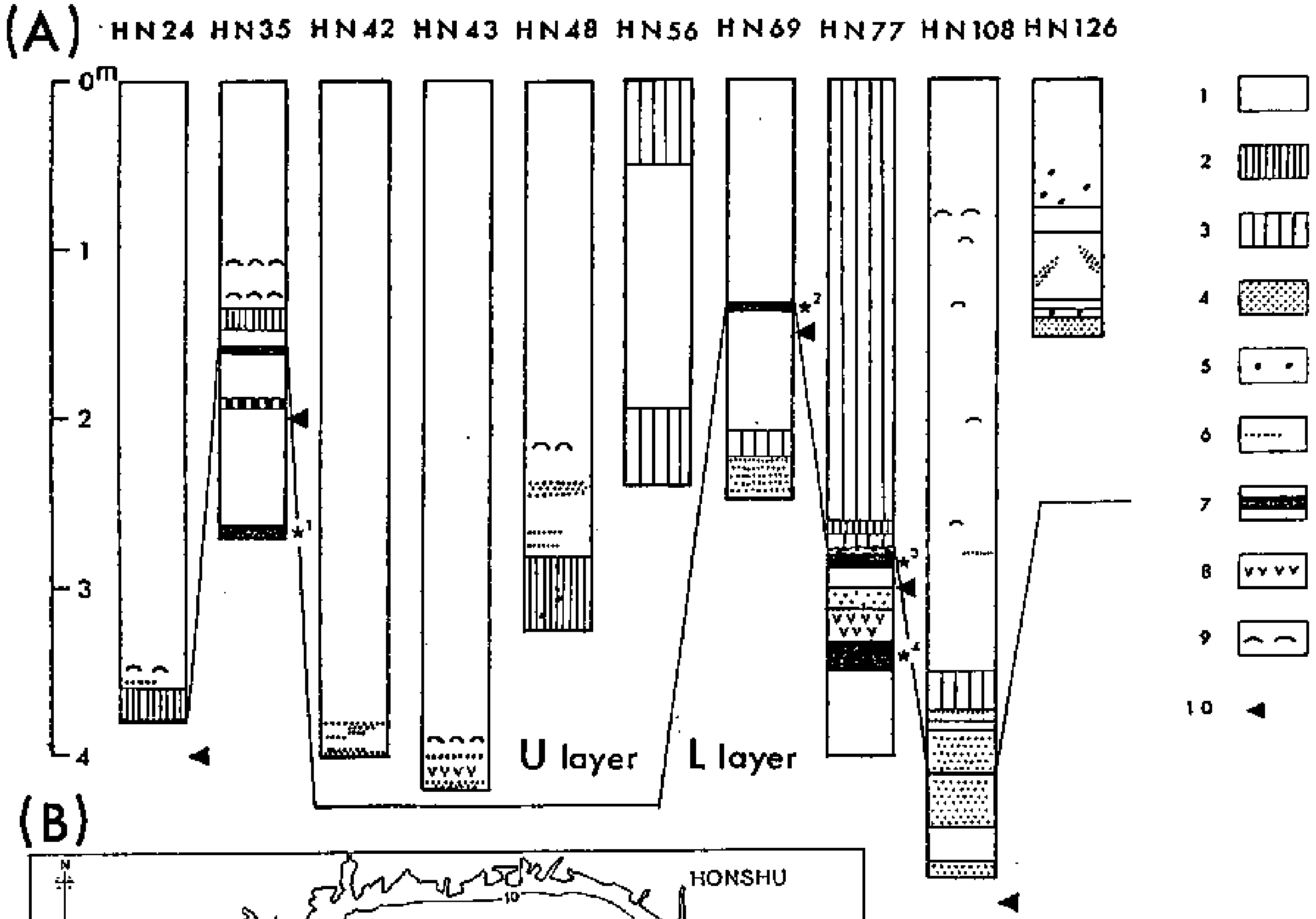
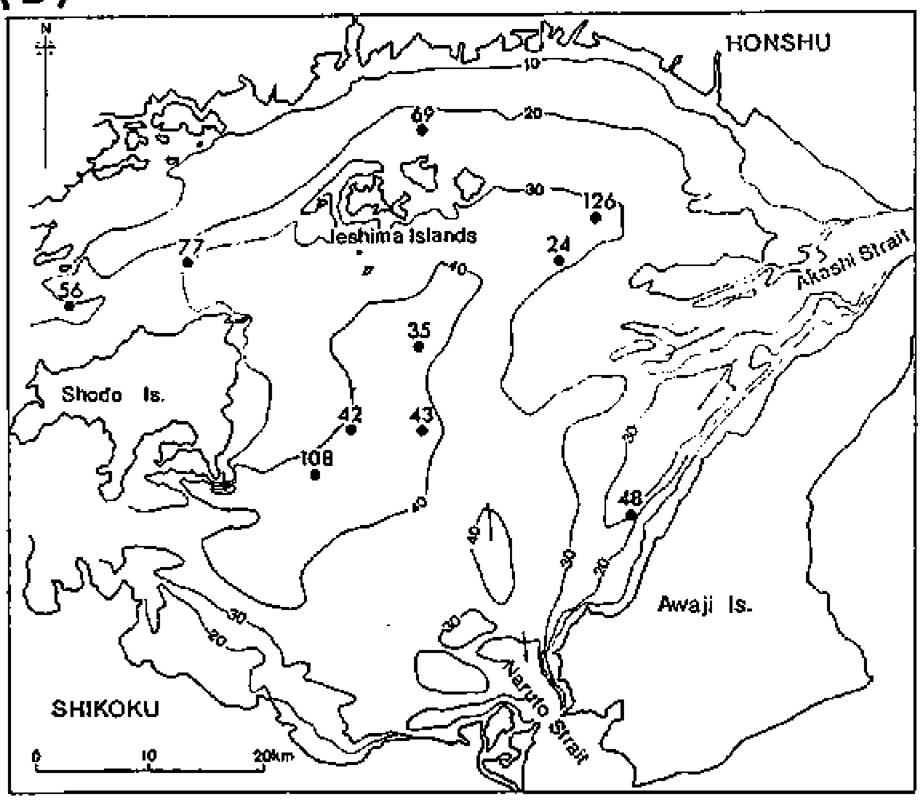


Fig. 16 Examples of 3.5 kHz continuous seismic profiles. (A) western part of Hiuchi
(B) eastern part of Bungo Suido. St : station number, L : location of site was ma
positioning , U : U layer , L : L layer. Positions of track lines are shown in





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 part estimated from the acoustic data.
*1: 36,400 Y.B.P.
*2: 23,010 Y.B.P. 22,340 Y.B.P.
23,750 Y.B.P. 25,470 Y.B.P.
*3: 10,430 Y.B.P. 12,770 Y.B.P.
*4: 27, 650 Y.B.P.
Absolute Age was determined by Teledyne Isotope Co. Ltd.

Fig. 17 Columnar sections (A), and their sites (B) of cored material in Harima Nada.

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 +

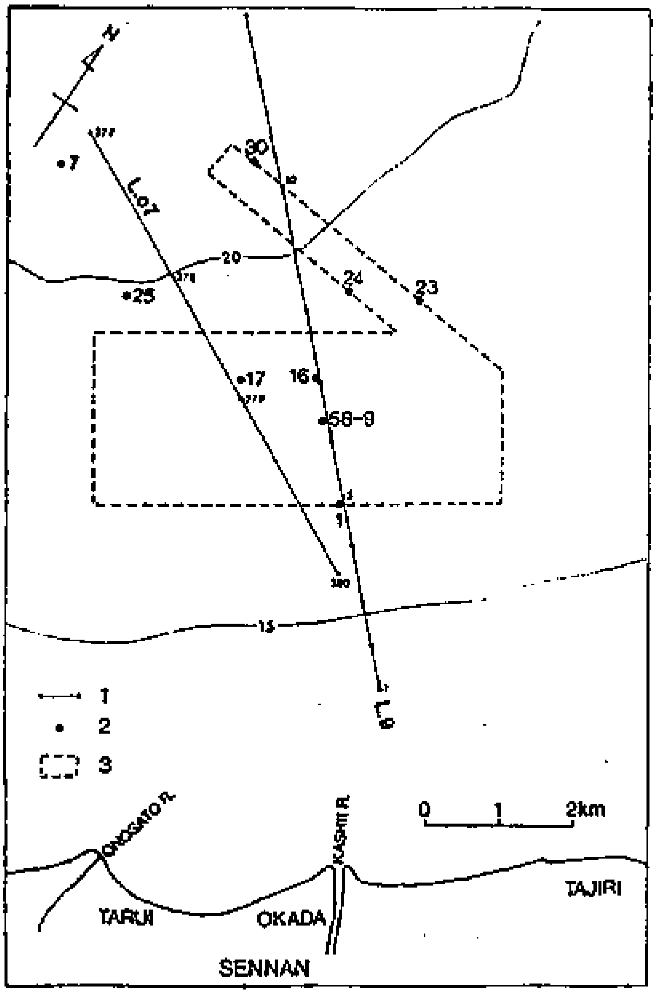


Fig. 18 Positions of bore holes in the planning site area of Kansai New International Airport in Osaka Bay (from Nakaseko, 1983) and tracks of acoustic survey.
L.9 : Line 9 in Huzita and Kamata (1964)
L.07: Line 7 in Onodera and Oshima (1983)
1: tracks of acoustic survey,
2: position of bore hole,
3: planning site area of Kansai New International Airport.

Table 3 Thickness comparison between acoustic data and drilling hole data. Thicknesses of Mud member show sometime a little shorter than that of 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	53-7	0-25m	25-27m
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 Airport (Nakaseko, 1983)		
	Thickness of A	Thickuness of B	A+B	NO.	Mud member	Sand (and gravel) member
L.5	17 m	0 m	17 m	57-1	0-15.5m	15.5-18.0m
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

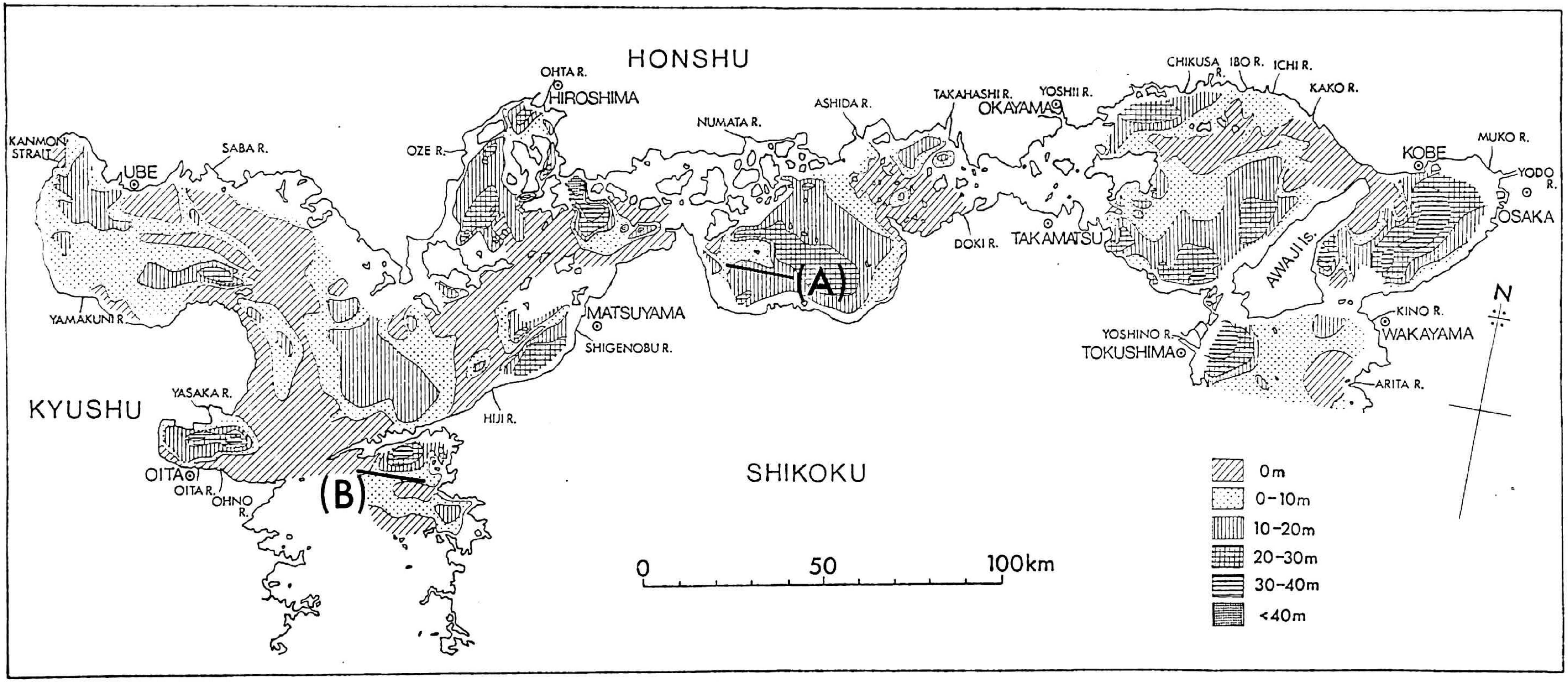


Fig. 19 Thickness distribution map of U layer.
Acoustic records along lines (A) and (B) are shown in Fig. 16.

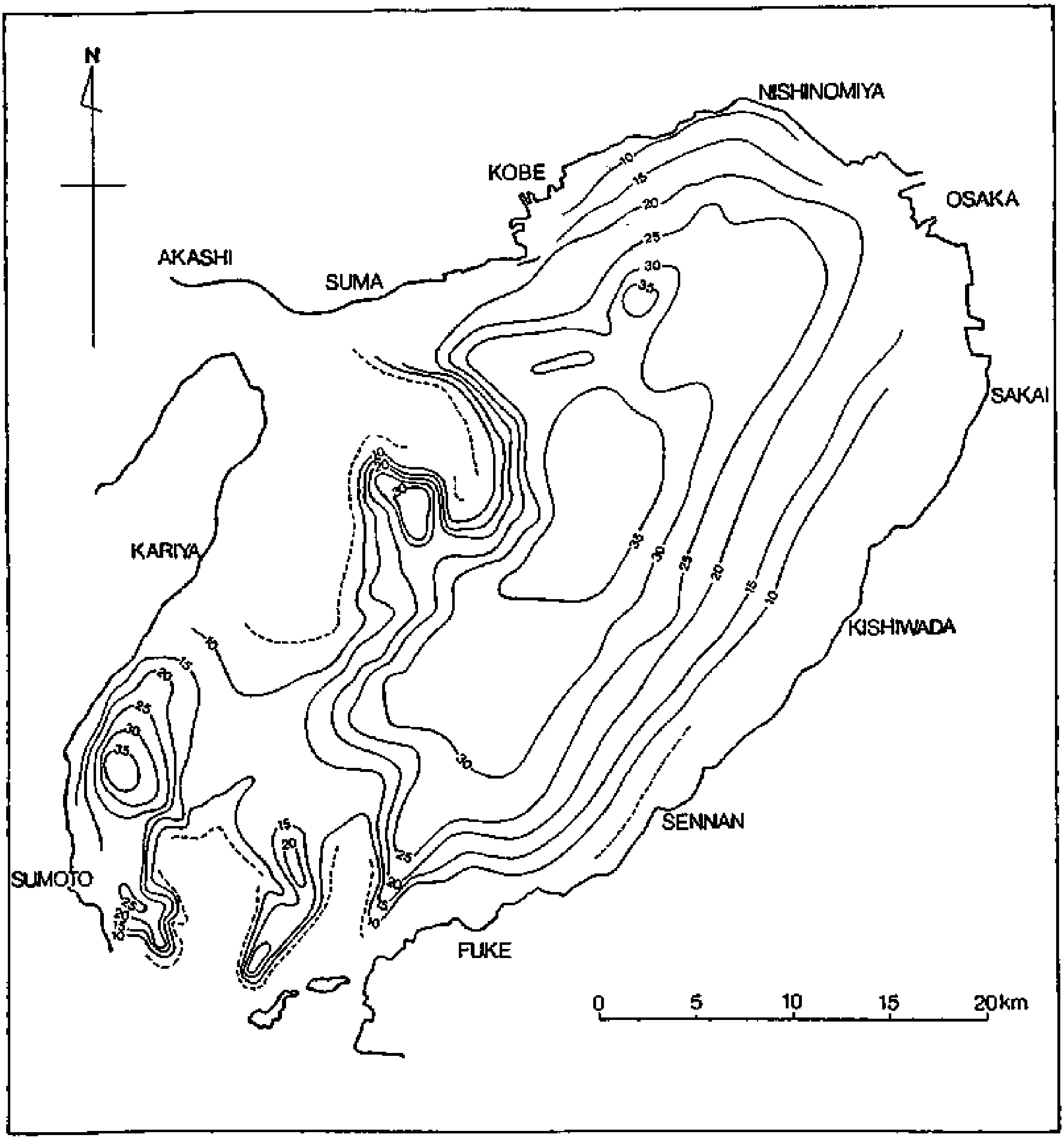


Fig. 20 Thickness distribution map of "Alluvium" in Osaka Bay. (from Huzita and Kamata, 1964)
Solid line show isolines to the intervals of 5 m.

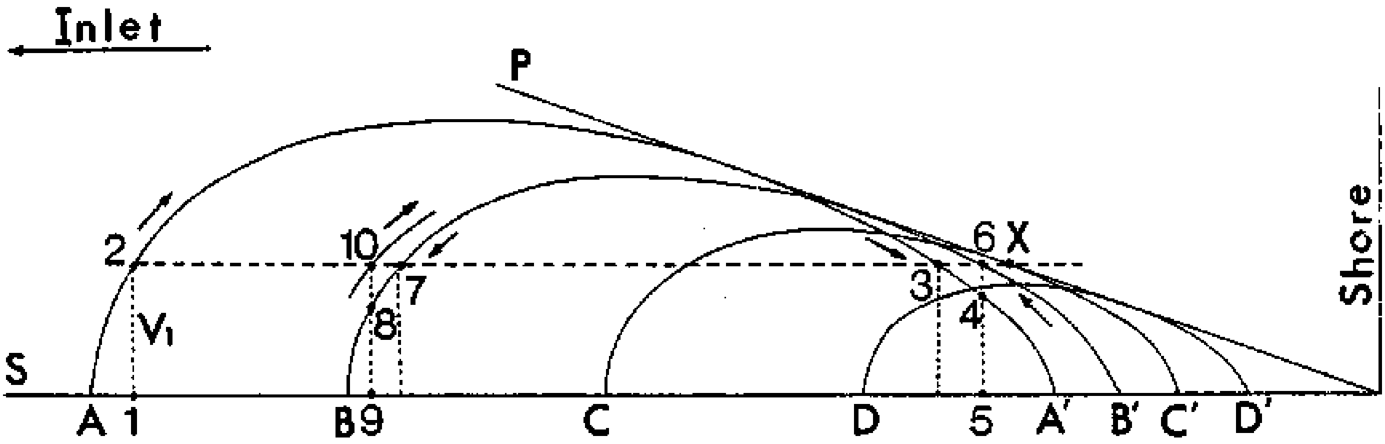


Fig. 21 Settling lag effect (From Straaten and Kuenen, 1958)

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 towards the watersheds (right). The curves apply only to idealized, average condition. Scour lag in 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 the 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.

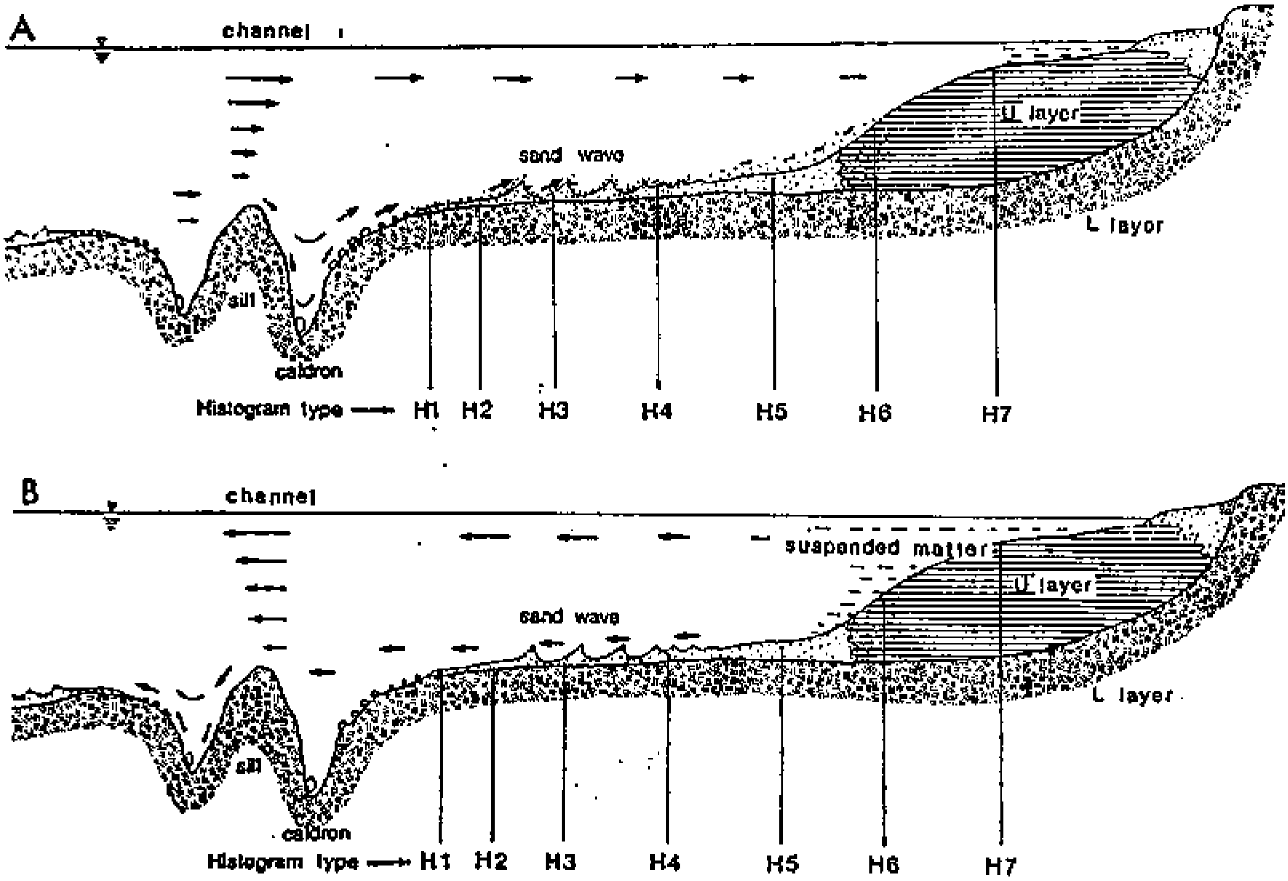


Fig. 22 Sedimentary process model caused by the tidal current in the Seto Inland Sea.
(vertical scale are exaggerated)
A : flood tide B : ebb tide

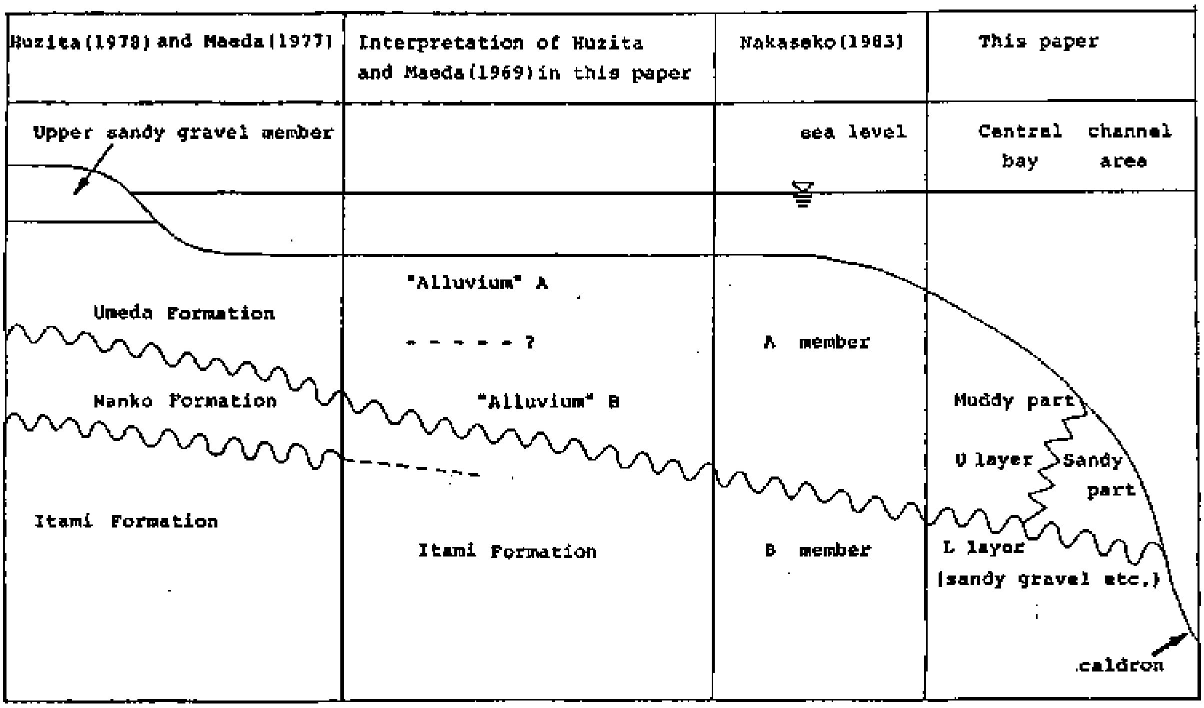


Fig. 23 Holocene stratigraphy in Osaka Bay.

APPENDIX. Sampling localities and their grain size compositions.

SEIBU SETOUCHI

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
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
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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzø	Mdø	So.	S-S-C	H type
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
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	34.1	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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzφ	Mdφ	So.	S-S-C	H type
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
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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzφ	Mdφ	So.	S-S-C	H type
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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzφ	Mdφ	So.	S-S-C	H type
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
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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzø	Mdø	So.	S-S-C	H type:
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	Sandy Silt	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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzø	Mdø	So.	S-S-C	H type
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
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	132.3	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

No.	Lon.	Lat.	Dep-th	Gra-vel %	Sand %	Mud %	Mzϕ	Mdϕ	So.	S-S-C	H type
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