CHAPTER 72

CONCEPT FOR INFERRING THE LITTORAL DRIFT TREND

by

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INTRODUCTION

To infer the rate and prevailing direction of littoral transport along a given coast is of prime importance in the functional and rational designing of coastal structures as well as in the environmental consideration of coastal zones. Many efforts have been made to develop the inferring method from field evidences such as 1) coastal landforms and shore configurations in the vicinity of existing structures[1)~6)], 2) alongshore variations in beach and bed sediment properties [7)~12)], 3) statistical analysis of incident wave properties [13)~16)], 4) movements of natural or artificial tracers [17)~20)], and so on.

Among these evidences, the alongshore variations of indigeneous beach materials have served as a powerfull, practical and economical tool in the inference of general trend of littoral transport.

Properties of beach sediment, such as grain size of sand and volume and shape of gravels, indicate some progressive trends with alongshore distance from supply sources[21)]. Thus the littoral transport direction along a given coast is inferable from variations in beach sediment properties.

However, inferring criteria of prevailing direction from variations in various beach sediment properties have not yet been fully established. For example, the prevailing direction of littoral transport should be defined to be alongshore component of intergrated vector of littoral transport during several years or decades along a given coast. But this direction is often confused with the alongshore dislocating or traveling direction of beach sediment, which is indicated by the variations.

It has also been concluded simply that the variation series obtained from backshore samples show a long-term trend of littoral transport, whereas those from foreshore indicate a short-term trend such as seasonal changes. In this inferring procedure any considerations have never been paid on differences in grain size of beach materials (sand and gravels) and in wave conditions during the period of field study. Rate or intensity of littoral transport has scarcely been inferred from the variation series of beach sediment properties even quantitatively.

To solve these problems, the present study proposed a new concept on the basis of field evidences obtained on the Enshu Coast, Central Japan.

OUTLINE OF THE STUDIED COAST

The Enshu Coast extends about 115 km between Cape Irago in the west and Cape Omae in the east and is separated into two arched beaches, at the junction of which the Tenryu River flows into the Pacific Ocean (Fig. 1). The Tenryu, one of the largest rivers in Japan, is 213.7 km in length, 5,093 km^2 in drainage area and 8,440 m^3/sec in the maximum recorded discharge. Since its bed slope in the downstream part is about 1/800, the Tenryu supplies a huge amount of gravels and sand to the Enshu Coast during its flood period. The other rivers flowing into this coast during its flood period. The other rivers flowing into this coast are of very small scales in length, drainage area and discharge, hence they supply only a small amount of sand and silt.

On the western part of this coast, are developed actively receding coastal cliffs, which are composed of the lowest Pleistocene unconsolidated strata named Atsumi formation and are receded by wave actions at a rate of 0.6 to 1.0 m/year. These cliffs supply the weathered gravels of granite, sandstone, slate, rhyolite, etc. to the Enshu Coast. On the coastal plains from the Imakireguchi, an inlet of Lake Hamana, to the eastern end of the coast, some parallel or echelon rows of coastal dunes are developed (Fig. 1).

In the nearshore zone of the coast one or two rows of longshore bars are developed almost continuously [22] (Fig. 2). This suggests that active sediment transports are occurred by breaking waves in this zone. Off the mouth of the Tenryu a submarine canyon exists below a water depth of about 20 m (Fig. 1). Excepting this canyon, offshore topography upto a water depth of 100 m is generally gentle in shape and its slope becomes smaller toward both ends of the Enshu Coast from the canyon.

Beach width is 100 - 170 m in the central part of the Enshu Coast, but becomes narrower toward both ends of the coast [23]. The beach consists of sand and gravels. Petrologically the beach gravels are composed of sandstone, slate, granite, and others, and their frequency percentages are 68%, 13%, 11%, and 8%, respectively. This petrological composition agrees fairly with that of the Tenryu River. Yamanouchi [23] demonstrated the variation diagrams of the mean weight of the largest beach gravels along the coast and concluded that most of the beach gravels supplied from the Tenryu are distributed on the central part of the Enshu Coast, between Imakireguchi and the mouth of Bezaiten River. This conclusion is supported by the authors' results described later.

In view of the above-mentioned outline of the Enshu Coast, the authors carried out field surveys for the central part of the Enshu Coast (Fig. 3) and investigated the variations in beach sediment properties.

Only a few data on the wave climate on this coast are available. Figure 4 indicates the occurrences of heights and periods of incident waves observed at Akabane fishery port located at the western part of this coast. According to Fig. 4, the significant wave height and period are about 1.5 m and 10 sec. Swell generated by typhoon often attacks the Enshu Coast and its period observed at Akabane varies in a range from 9 to 15 sec.

Dominant direction of incident waves to the studied coast was in a range of the south-west to the south during the field surveys. To

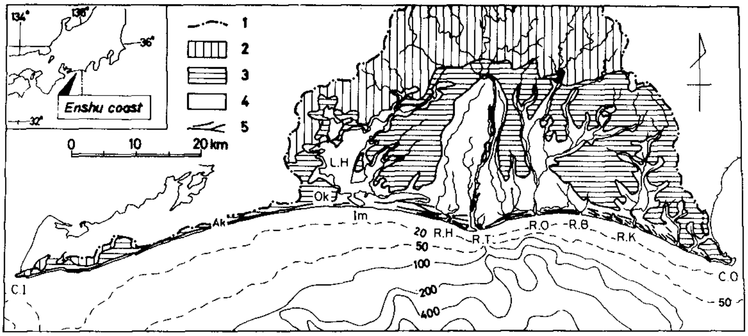


Fig. 1 Generalized topography around the Enshu Coast, Japan. 1: Main divides, 2: Mountains, 3: Terraces, 4: Lowland, 5: Dunes, C.I.: Cape Irago, Ak: Akabane fishery port, Ok: Okurato, L.H.: Lake Hamana, Im: Imagire-guchi, R.H: River Ho, R.T.: River Tenryu, R.O.: River Ota, R.B.: River Bezaiten, R.K.: River Kiku, C.O.: Cape Omae-zaki

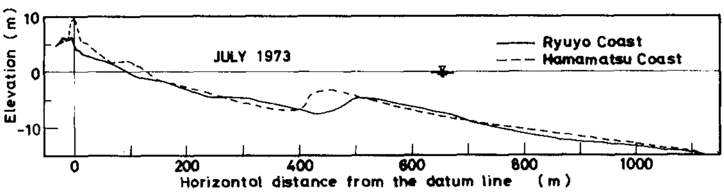


Fig. 2 Typical nearshore profiles of the studied area.

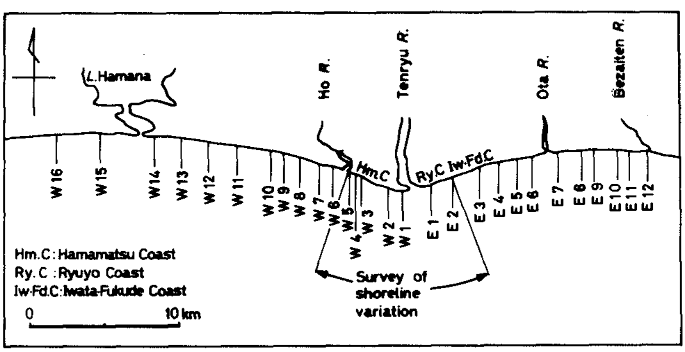


Fig. 3 Location map of the studied coast and sampling stations

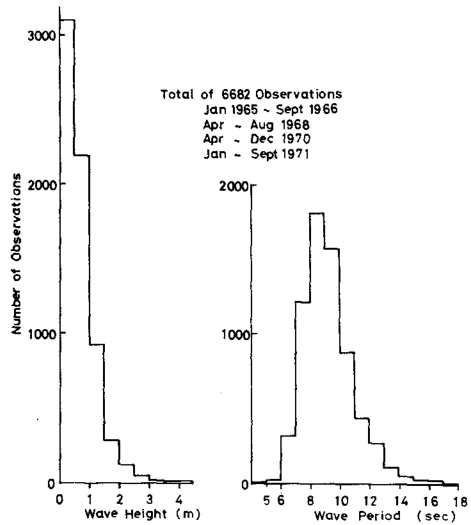
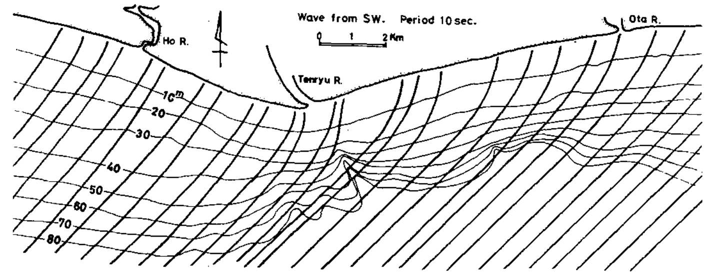
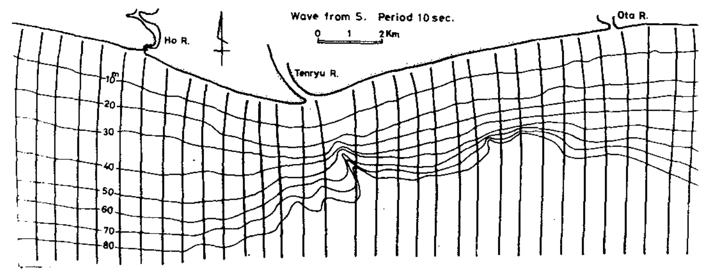


Fig. 4 Distributions of wave heights and periods. Irrespective direction



(a) Wave from SW



(b) Wave from S

Fig. 5 Refraction diagrams for the studied coast. (Wave period: 10 sec) predict the trend of littoral transport along the coast, refraction diagrams are prepared for a case of wave period of 10 sec (Fig. 5).

It appears from Fig. 5(a) that waves from the south-west are strongly refracted and give rise to the eastward longshore component of energy flux due to incident waves along allover stretch of the studied coast. For waves from the south, negligible refraction occurs (Fig. 5(b)). Along the west coast adjacent to the Tenryu River, the westward longshore component of energy flux is predicted from the refraction diagram.

In addition, construction of many dams along the Tenryu since 1950's results in a remarkable reduce in sediment supply to the coast, and hence in erosion on the west coast adjacent to the river mouth (Hamamatsu Coast, Fig. 6). To prevent the beach recession some coast protection works such as groins and offshore breakwaters have been constructed on this coast.

Littoral transport direction can be inferred from the configuration of river mouth. The changes in migration of river mouths on the Enshu Caost are obtained from the topographic maps surveyed in 1946 and 1970 (Fig. 7).

SAMPLING AND ANALYSIS OF BEACH MATERIALS

Sand and gravel samples were collected from the surface layer of beach both at foreshore and backshore of 28 stations at an interval of about 2 km in June, August and November, 1973 (Fig. 3).

At each station large gravels scattered on the beach surface in an area of about 20 m x 20 m were sampled. Their nominal volumes were calculated from measurements of their long, intermediate and short diameters. The nominal volume is defined as the product of these three diameters. Thus, alongshore variation diagrams of mean nominal volume of the largest ten gravels for three dominant kinds of gravels are obtained (Fig. 8).

Median diameter of beach sand was determined by the sieve analysis of dried samples in the laboratory. By using the Hallimond 5-Pole Magnetic Separater, sand grains ranging from 0.25 to 0.125 mm in diameter were separated into the following three groups: A) ferro-magnetic minerals, most of which are magnetite and hematite, B) feeble-magnetic minerals such as pyroxene, hornblende, sircon and olivine, and C) non-magnetic minerals such as quartz and feldspar. Their specific gravities range from 5 to 4, 4 to 3, and 3 to 2, respectively. Accordingly, variation diagrams of the weight percentage of these three groups can be taken as these of the heavy mineral composition of beach sand.

CRITERIA FOR INFERRING LITTORAL TRANSPORT TREND

Criteria based on the variation diagram of gravel volume

Since the grain size of beach materials generally decreases with increasing distance from the supply source, the littoral transport direction is inferable from the variation diagram showing the size-distance relationship along a given coast.

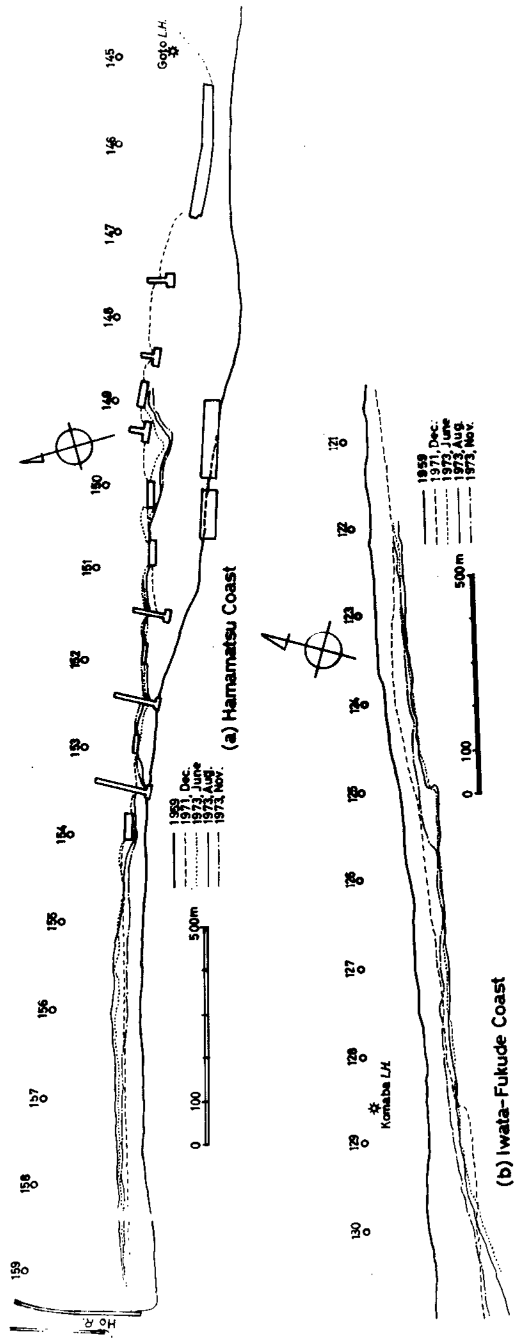


Fig. 6 Shoreline changes of the studied coast (1959-1973)

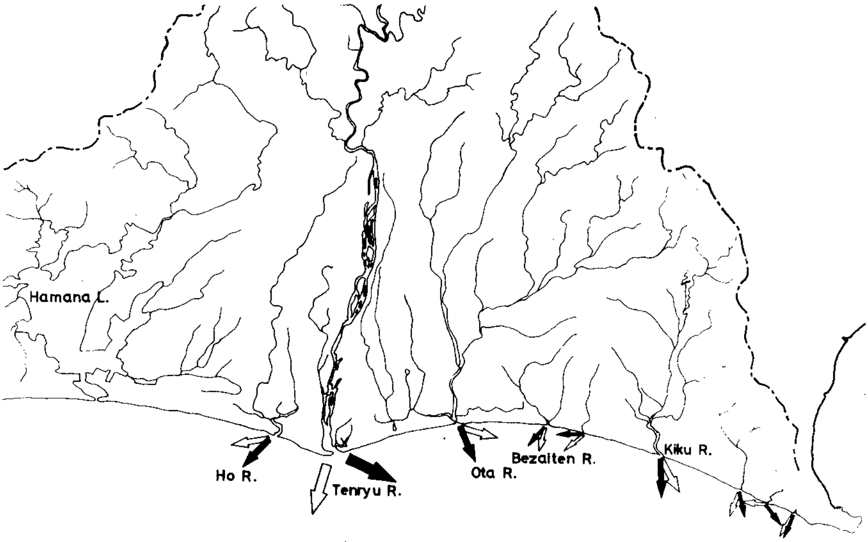


Fig. 7 River mouth deviations. (White arrow: 1946, Black arrow: 1970)

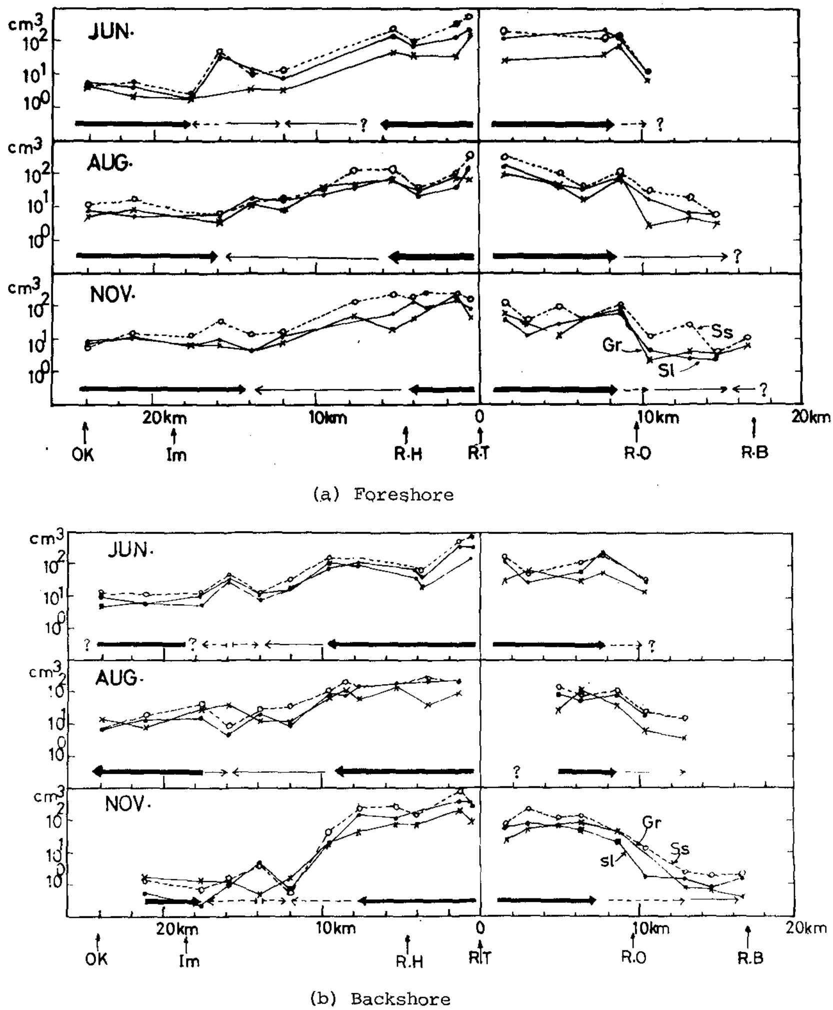


Fig. 8 Variation diagrams of mean volume of the largest ten gravels, and inferred directions and intensitites of littoral transport. Ss: Sandstone, Sl: Slate, Gr: Granite.

It is therefore inferred from Fig. 8 that littoral transport directions within extents of about 16 km from the Tenryu River along the coast are eastward and westward, respectively. These inferred directions seem to be independent of the sampling position, kind of gravels and seasonal change.

As seen in Fig. 8, however, the variation diagrams of gravel volume on a semi-logarithmic graph are generally divided into some straight segments with different slope, average over certain stretch of several kilometers long. For example, in case of the backshore gravel in November (Fig. 8(b)), the slope is very gentle within a stretch of about 9 km from the Tenryu River in the westward direction along the coast, but beyond that point the slope becomes steeper abruptly. Such abrupt changes are seen in the other cases of studied coast and also known on the other coasts such as Sagami [24], Niigata [25], and Ishikawa [26] coasts in Japan.

The slope of the variation diagram indicates a ratio of size-decreasing per unit alongshore distance. This ratio must depend both on the intensity of littoral transport parallel to shoreline and on the resistivity of gravels for attrition.

The intensity of littoral transport must imply the net or integrated effects of the following three factors: 1) alongshore velocity component of the swash on the beach, 2) directional frequency distribution of incident waves, and 3) duration of beach sediment dislocation. The factors of 1) and 2) must be affected mostly by the wave climate and the coastal topography.

The resistivity of gravels for attrition is related to the mechanical properties of gravels [27], but the effect of the original size of gravel on the rate of attrition has not been clarified. The relationship of the alongshore transport rate of gravels with various sizes to the alongshore energy flux of incident waves has not been known. Thus, interrelationships among these various factors can not be discussed quantitatively from our present knowledge.

For this reason, in the present paper, the term of intensity is used to express the above-mentioned net effects of various factors. It is assumed that the difference in the segment slope of the variation diagram implies that in the intensity of littoral transport, if the size-distance relationship of gravels of the same lithology is concerned.

On this assumption, the magnitude of the intensity of littoral transport is divided qualitatively into three degrees: strong, moderate and weak, which are represented by thick, thin and dotted arrows on Fig. 8, respectively. The arrow direction indicates the inferred dislocating direction.

Prevailing direction of littoral transport on a given coast should be inferred from asymmetry of the variation diagram with respect to the supply source of beach gravels; that is, from asymmetry of the intensity and/or from asymmetry of the stretch length with the same intensity. The magnitude of the asymmetry can be called prevailingness of littoral transport.

Based on this consideration, proposed criteria for inferring the prevailing direction and the prevailingness of littoral transport are given by Fig. 9(a). On this figure, ideal variation diagrams of gravel volume for nine cases are shown in semi-logarithmic graph, and the inferred magnitude of intensity is shown by the three kinds of black arrow mentioned

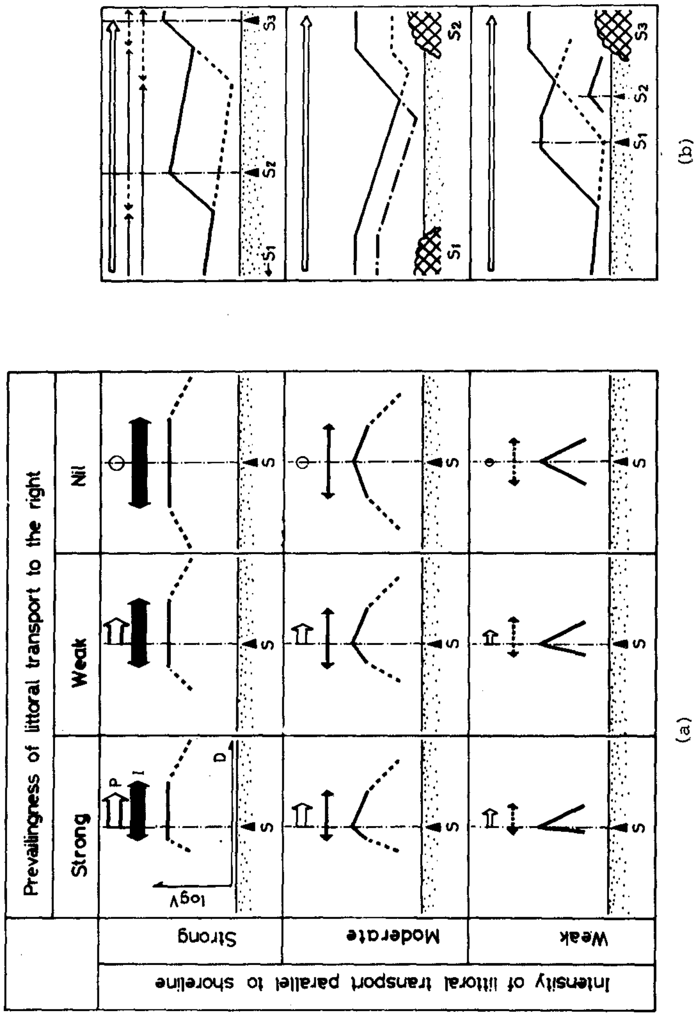


Fig. 9 Inferring criteria of the prevailing direction and prevailingness of littoral transport from the variation diagram of gravel volume.

before. The inferred prevailing direction for each case is shown by a white arrow, of which the length and thickness represent the prevailingness qualitatively.

Figure 9(b) shows some inferred examples of prevailing direction in cases where two or more supply-sources exit on a coast. In case of the top of this figure, the prevailing direction is inferred to be toward the right on the figure as shown by a white arrow, based on asymmetry of the intensity with respect to the source of S_2. If S_2 is lacking in this case, the variation diagram may change into that shown by dotted line. But the inferred prevailing direction is the same, because in this case asymmetry of the intensity with respect to the descending nodal point of dotted line becomes the key for inference. Similarly, prevailing directions of the other cases are inferred to be toward the right.

Criteria based on the variation diagram of sand properties

Generally speaking, the variation diagrams of beach sand properties such as median diameter, sorting coefficient, and heavy mineral composition display a cyclic pattern which has a very shorter pitch as compared with that of beach gravels, as exemplified by Figs. 10 and 11. This seems to be dependent on the following two reasons: (1) Position of the sand-supply source can not be determined easily, because the beach sand is supplied not only from rivers and coastal cliffs, but also from receding beach and sea bottom. (2) Sand properties vary with minor beach topography such as beach cusps owing to sorting effect by wave actions. Therefore, the variation diagrams of beach sand are influenced largely by sampling technique. Beach sand seems to play a less important role than beach gravels as an indicator of littoral transport trend.

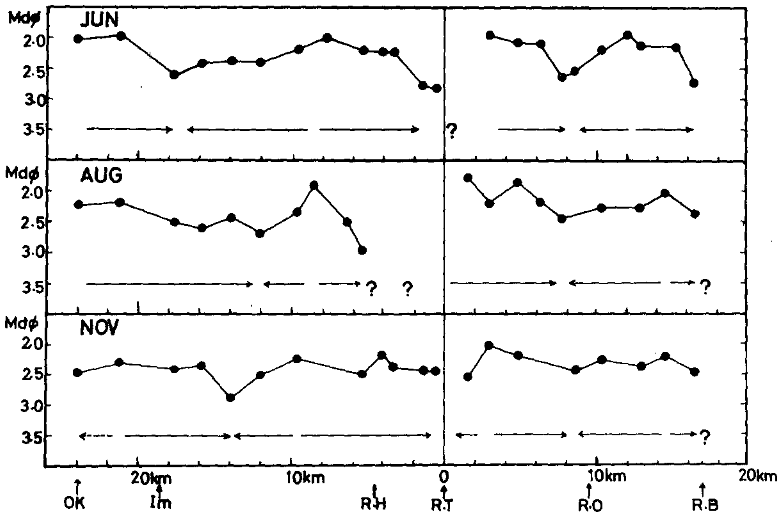
However, the inference of littoral transport direction from the variation diagram of sand properties is made on the basis of the conventional concept, in which the littoral transport direction is considered to coincide with the decreasing direction of grain size and heavy mineral component of beach sand. The prevailing direction is inferred from the same concept as the case of beach gravels discussed in the previous section (Figs. 10 and 11).

SEQUENTIAL MODEL FOR INTERPRETING THE DIFFERENCE AMONG THE INFERRED RESULTS

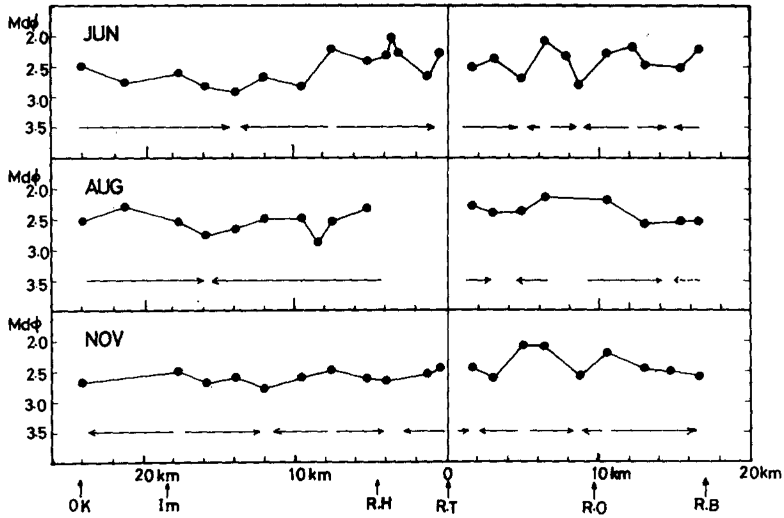
Figure 12 shows the summary of inferred directions and intensities of the littoral transport along the studied coast from the variations in beach sediment properties together with those from the river mouth deviation.

It is noticed from this figure that the inferred results display different tendencies according to the sampling position or elevation (foreshore and backshore) and to the grain size of beach sediments (sand and gravels). On the other hand, seasonal effect on the inferred results seems to be relatively weak.

The alongshore processes of beach sediment transport are closely related with the size of beach sediment and the position of the zone in which



(a) Foreshore



(b) Backshore

Fig. 10 Variation diagrams of median diameter of beach sand, and inferred directions and intensities of littoral transport.

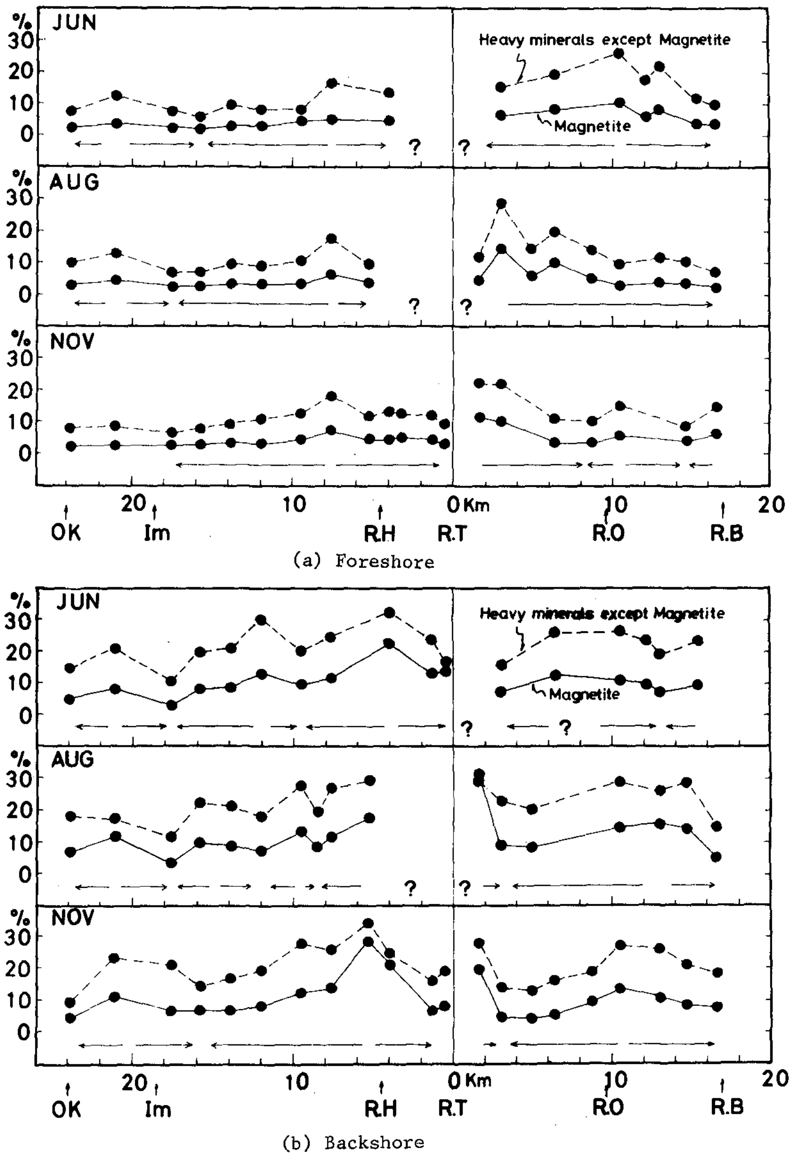


Fig. 11 Variation diagrams of heavy mineral composition of beach sand, and inferred directions and intensities of littoral transport.

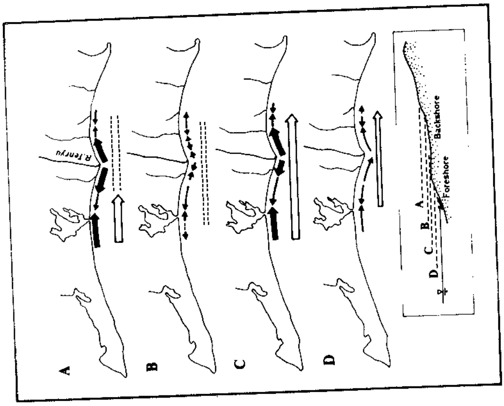


Fig. 13. Littoral transport trends under four sea conditions on the Enshu Coast.

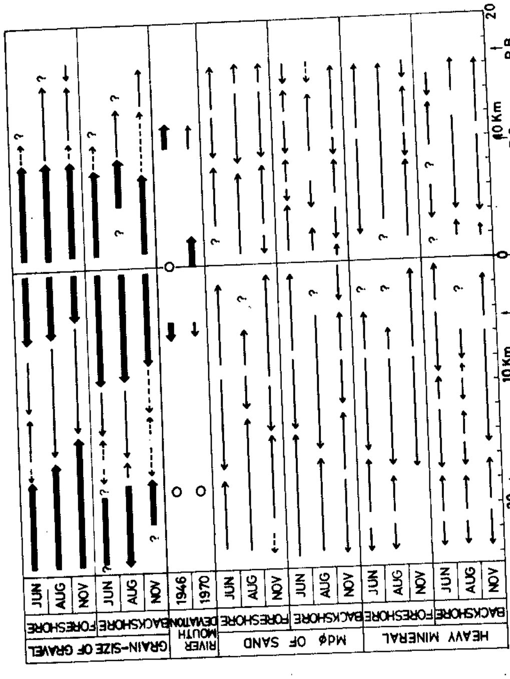


Fig. 12 Summary of the inferred direction and intensity of littoral transport from the variation diagrams of beach sediment on the Enshu Coast, Central Japan.

the dislocation occurs[28]. In addition, the wave runup height on beach and the tractive force acting on beach grains depend on properties of incident waves.

The alongshore variations in beach sediment properties are conceived as the consequences of complex interactions among these factors. The differences in the inferred results, as seen in Fig. 12, can be explained by taking account of differences in sea conditions governing the dislocation of beach sediments.

Based on this concept, a following sequential model is proposed here, as shown in the inset of Fig. 13 schematically: Stage A shows a climax state of rought to high sea condition, in which the littoral transport trend is inferred from the variation diagram of backshore gravels; Stage B is a decay state of the stage A, from backshore sand; Stage C is a slight sea condition, from foreshore gravels; Stage D is a smooth sea condition, from foreshore sand.

According to this model, the directions and intensities of littoral transport along the studied coast under the four sea conditions are concluded to be shown in Fig. 13 by thick and thin arrows.

CONCLUSIONS

Overall prevailing direction and intensity of the littoral transport along a given coast can be inferred from asymmetry both of the slope of variation diagram and of the alongshore distance of the same slope segment on the diagramwith respect to the sediment supply source or to the ascending or descending nodal points on the variation diagram.

The prevailing direction along the studied coast is concluded to be eastward clearly under the slight and smooth sea conditions, whereas under the rough to high sea conditions prevailingness is not found, according to the criteria proposed in this paper. This conclusions is supported by the fact that the west coast adjacent to the Tenryu River (Hamamatsu Coast) has been receded severely, whereas the east coast (Iwata-Fukude Coast) has been proceeded (Figs. 6 and 14).

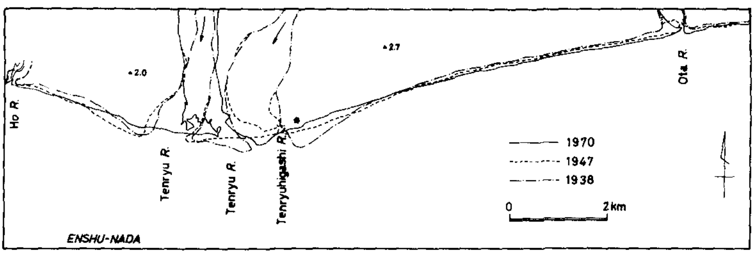


Fig. 14 Long-term shoreline changes on the Enshu Coast.

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