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Bedform Morphology of the Continental Shelf Sandy Sediments Around the Korean Peninsula

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韓半島周圍 大陸棚 砂質堆積物의 表面流動構造

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Bedform morphology of the giant ripples have been studied on the continental shelf of the Yellow Sea, East China Sea and Korea-Tsushima Strait on the basis of side-scan sonar image, sub-bottom profile, sedimentary facies, geomorphologic evidence and hydrology.

There are well developed giant ripples ranging from 100 to 500 m in wavelengths and from 2 to 10 m in wave height at nine sites in the study area, which are covered by medium to fine sand. Most of them have been formed under the present hydrologic regime where the tidal currents and local currents or turbulence flows are superimposed. In the study area, giant ripples are produced on two different environments. One is at the geomorphic narrow zone such as the Korea Strait where currents are accelerated by the topographic effects, while the other is the sandy flat plain where tidal currents and local currents are harmonized.

한반도주위 동지나해, 황해, 대한해협의 대륙붕 사질퇴적물상에 발달하는 표면유동구조중 거대연흔(giant ripple)에 대한 연구가 사이드스캔소나, 고해상탄성파, 퇴적상, 해저지형 및 해양물리자료에 기초하여 수행되었으며, 거대연흔의 지역별 분포특성과 발달기구가 구명되었다. 조사지역내에는 파장이 100~500 m, 파고가 2~10 m에 달하는 거대연흔이 중립~세립질 모래가 분포하는 대륙붕지역의 9개소에서 표식적으로 발달하고 있다. 이들중 대부분은 지역연안류와 조류가 조화를 이루는 현생수리환경하에서 형성되었으며 조사해역내의 거대연흔은 지역적으로 다음과 같은 두 가지의 해저환경하에서 특징적으로 발달한다, 즉, 대한해협과 같이 지형효과에 의하여 저층류가 가속되는 지형협소지역과 조류와 연안류가 조화를 이루는 대륙붕 사질 평탄지역으로 대표된다.

INTRODUCTION

Most of the continental shelf of the Yellow Sea, East China Sea and Korea-Tsushima Strait is covered by a blanket of sediments that are fluvial, deltaic, relict and reworked palimpsest from glacial times (Niino and Emery, 1961; Ujiie, 1973; Suk, 1989). Quaternary sediments on the study area are accumulated in response to global changes of sea level and local climate modifications. During late Pleistocene and early Holocene, the shelf area had experienced several sea level fluctuations. Their transgression and regression records on the sea-floor are well preserved because there were no gla-

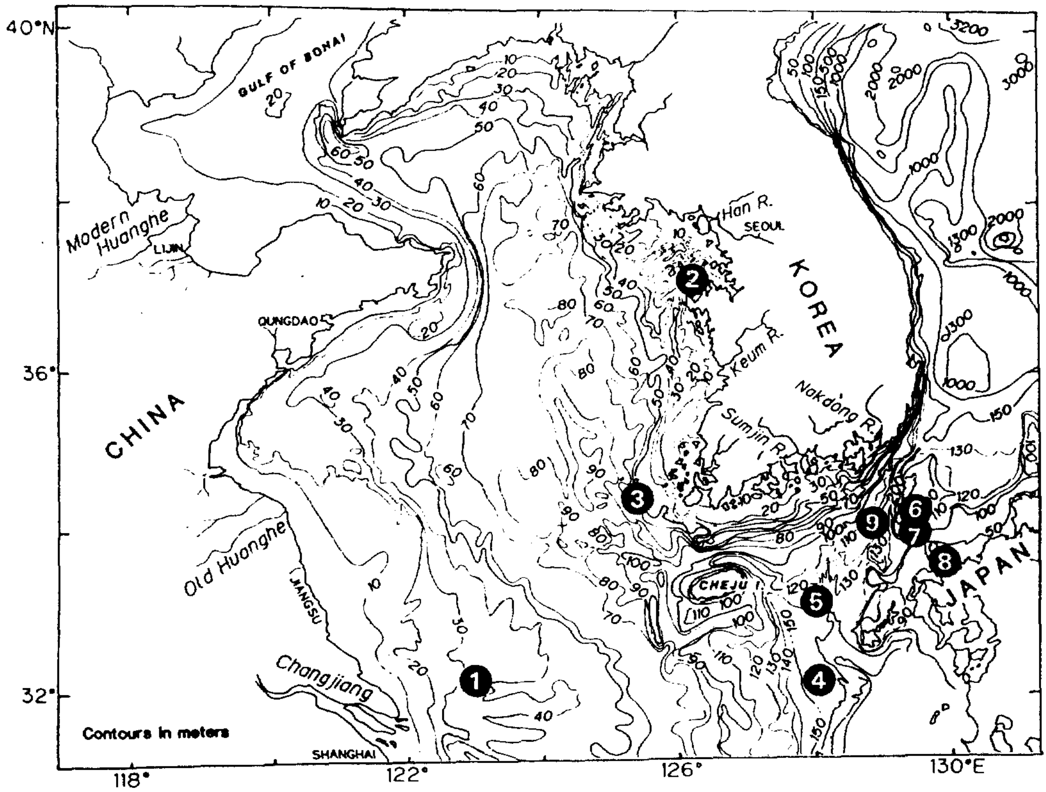


Fig. 1. Map showing detailed bathymetry and areal distributions of well developed giant ripples in the East China Sea, Yellow Sea and Korea-Tsushima Strait. 1: Changjiang offshore region, 2: off middle western Korean Sea, 3: off Hatae Do region of the south western Korean Sea, 4: outer margin of Danjo Islands in the East China Sea, 5: off western area of Goto Retto, 6: off northern part of the Tsushima Strait, 7: off southern part of the Tsushima Strait, 8: Iki channel region, 9: off eastern part of the Korea Strait.

cial ice sheets (Emery et al., 1971; Geng et al., 1987). In the study area, well developed giant ripples were found at nine sites on the surficial sandy deposits (Fig. 1). Ripples and some other bedforms were produced on surface made up of incoherent material by moving fluids (Allen, 1968; Middleton and Southard, 1978). They are resulted from the interaction of waves or currents and grain size of sea bottom sediments.

This study intends to interpret bedform morphology of giant ripples related to the sea level change phenomena using side-scan sonar images and geomorphologic evidence.

CHARACTERISTICS OF GIANT RIPPLES

A giant ripple is defined as a ripple of more than 30 m in wavelength. Superimposed mega ripples are defined as less than 30 m in wavelength. However, there does not seem to be a very clear-cut boundary between giant ripples and mega ripples (Reineck and Singh, 1980). In general, available data show that giant ripples range from 30 to 1,000 m in length (L) and from 1.5 and 15 m in height (H). The ripple index (L/H) ranges from 10 to 100, but is usually above 30. Giant ripples commonly occur on coarse sand deposits (mean value of coarser than 0.25 mm). Giant ripples do not develop where water depth is shallower than a few meters because the tidal currents activities do not allow giant ripple formation. They form during ebb tide in the North Sea, as opposed

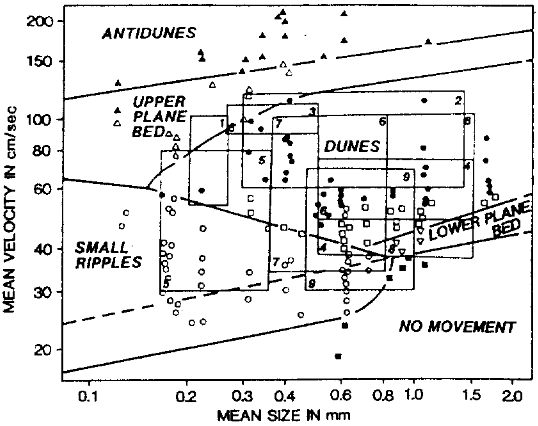


Fig. 2. Size velocity diagram for a mean flow depth. Stability fields of various bedforms in the flume experiments are after Middleton and Southard (1978). The fields of giant ripples of the present study are shown in rectangles with number markings. Numbers follow Fig. 1 and Table 1.

to Setonaikai in Japan where they form during flood time (Kozasa, 1975). This difference indicates that local currents superimposed by tidal currents also play a role in forming giant ripples (Kagami et al., 1984). Allen (1968) suggested that the bedform is a function of stream power (Vt mean velocity, X shear stress). In addition, stronger mean flow as well as coarser grain size of the bed materials are needed to form mega ripples. Small ripples are produced from grain size finer than 0.54 mm. With increasing stream power, they become undulatory and lingoid small ripples. Small ripples at still higher energies form mega ripples (Reineck and Singh, 1980). In sand coarser than 0.6mm the lower plane bed phase changes directly into dunes (giant ripples) (Fig. 2). Volume amount of material transport (M) is also a function of stream power so that it ranges from 1.6 to 16 g/m/s for small ripples, but can reach up to 640 g/m/s for giant ripples, 40 to 400 times larger for small ripple formation (Guy et al., 1966).

REGIONAL DISTRIBUTIONS AND MECHANISMS OF GIANT RIPPLES

Changjiang offshore region

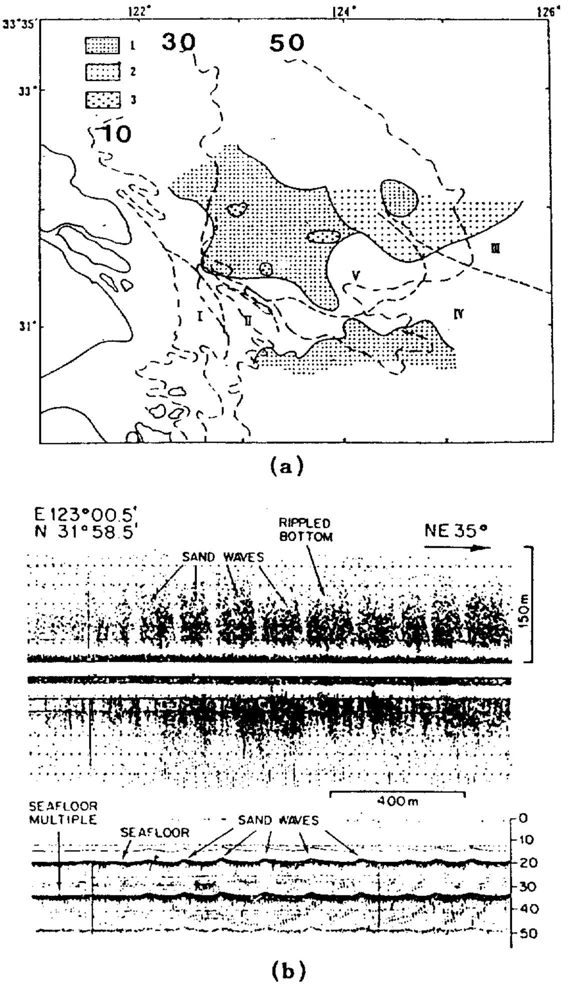


Fig. 3. Distribution of the bedform morphologies of the Changjiang offshore region modified from Yincan et al., (1983) and Butenko et al., (1983). (a): 1, well developed mega-ripples, 2, partially developed mega-ripples, 3, giant ripples. (b): side scan sonar image and superimposed 3.5 kHz profile in the giant ripple zone.

Giant ripples are broadly distributed in the Holocene depocenter of the older delta facies at the middle continental shelf off the Changjiang between 25 and 60 m water depth, covered mainly by relict sand. They may extend to the outer shelf (Fig. 3a). In the eastside of these deposits, recent Changjiang deltas composed of mainly mud are developed in the nearshore and inner shelf areas, and mud lens originated from the Huanghe River

Table 1. Physical parameters of giant ripples and environmental characteristics at each place in the Yellow Sea, East China Sea and Korea Strait. Area number. follows Fig. 1. (1:Changjiang offshore region, 2: off middle western Korean Sea, 3: off Hatae Do region of the south western Korean Sea, 4: outer margin of Danjo Islands in the East China Sea, 5: off western area of Goto Retto, 6: off northern part of the Korea Strait, 7: off southern part of the Korea Strait, 8: Iki channel region, 9: off eastern part of the Korea Strait.

Area no.	W. Dep. (m)	Length (m)	Height (m)	Index (L/H)	Bot. Current (cm/s)	Grain size (mm)	Crest dir.	Type against flow
1	32-37	100	2	50	55-120	0.20-0.27	S.E	parallel
2	40-50	100-200	4-8	10-40	80-120	0.25-1.50	NW-SE	〃
3	60-70	200-400	3-7	60-70	80-100	0.25-0.50	WNW-ESE	〃
4	150-200	200	10	20	30	0.50-1.50	W-E	transverse
5	120-155	150-200	4-7	30-40	20	0.13-0.44	NW-SE	parallel
6	110-115	100-200	5	20-40	50-100	0.50-0.71	WNW-ESE	transverse
7	100-105	200-500	4-6	35-90	35-90	0.35-0.71	NW-SE	parallel
8	50-55	200-300	5-10	30-60	35-90	0.80-1.50	NW-SE	transverse
9	180	–	–	–	30	0.50-1.00	–	

covered on its eastside by the cyclonic gyre (Suk, 1989). It is interesting to see sand deposits located in between these two different mud facies. The mega ripples are extensively developed on the older delta facies with the depth of 25 to 60 m. Between them, giant ripples limited to water depths of 32 to 37 m and composed of medium to fine sand of 0.1975 to 0.2679 mm (1.9~2.4 phi) in size (Yincan et al., 1983) have developed. The heights of giant ripples are 2 m and their wavelengths are about 100 m (Fig. 3b, Table 1). The crestlines mostly show a southern or eastern trend, in accordance with the direction of ebb tide. The velocity of the tidal current varies from 1.1 to 2.4 kt in the area. Yincan et al., (1983) have presented sand waves with wavelengths of 1,000 m in the area, which represent a ripple index of more than 500.

However, this value is not in accordance with the prominant range of the ripple index, probably due to the difference in the calculation of the wavelength size. The origin of the giant ripples which occur on sand flats are related to the present current activities. In the summer, these are developed in the northward Taiwan Warm Current and turned east or southeast around the area (Tamai, 1976). In the winter, southeastward China Cold Coastal Current extends to the area. Therefore, tidal currents (ebb tide) with overlapped permanent currents have infuenced in producing giant ripples on the sand facies. The distribution of sand deposits extending through the outer margin is well consistent with the flow patterns of the Taiwan Current, so the current and tide must play an important role in sedimentary facies and geomorphic features on the sea bottom.

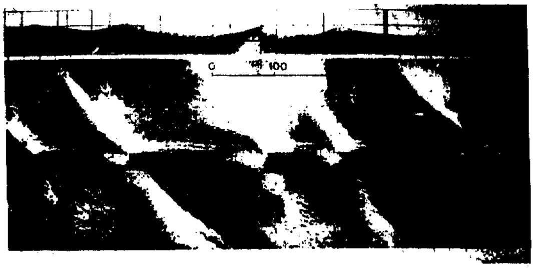


Fig. 4. Well developed giant ripple images in the middle western Korean Sea taken by Sea-floor Mapping Side Scan Sonar (SMS 960) System.

Off middle western Korean Sea

Giant ripples are developed around 37°N, 126° 05'E between Ui Island and Garolim bay of the middle western Korean Sea. They are well developed at depths of 40 to 50 m covered mainly by medium sand to slightly gravelly coarse sand (Mean grain size, 0.25~1.5 mm). Over 60 m in water depth, giant ripples are not formed because of the steep slope of the bottom topography. Their characteristics are 100 to 200 m in wavelengths and 4 to 8 m waveheights with 10 to 40 of ripple index, suggesting a normal index value (Fig. 4).

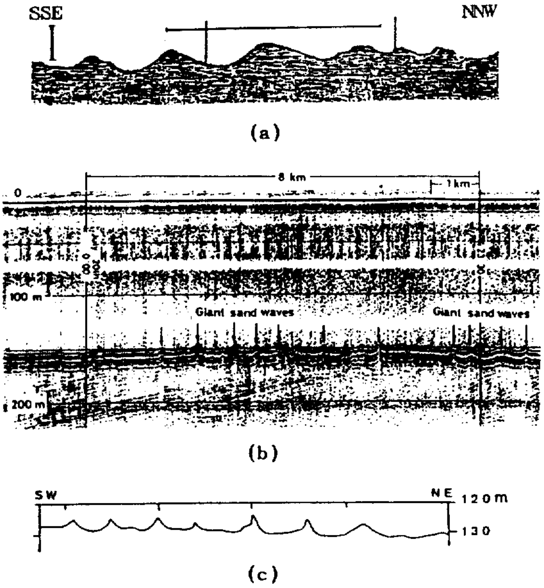


Fig. 5. Vertical profiles showing magnitude and asymmetry of giant ripples. (a): off the Hatae Do region of the south western Korean Sea (Kim et al., 1985). (b): outer margin of Danjo Islands in the East China Sea (Kagami et al., 1984). (c): off western outer margin of the Goto shelf channel (Katsura and Nagano, 1982).

The direction of the crest is NW-SE which is parallel to the co-tidal line in this area. The NE-SW direction of coastal currents are congruent with ebb tide pattern. The maximum velocity of tidal currents is over 2.0 kt in that area. In addition, the West Korean Coastal Current is well developed in the winter season and flows southward with a velocity of 1.0 kt. Consequently, strong tidal currents with overlapping coastal currents play an important role in the formation of giant ripples in this area.

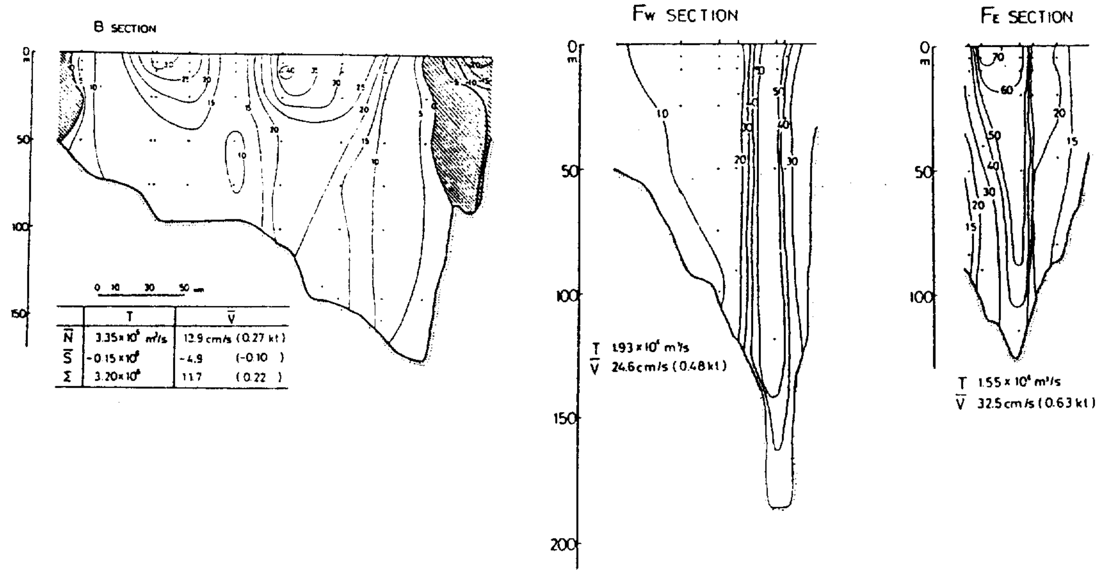
Off Hatae Do region of the southwestern Korean Sea

Giant ripples are developed around 34°20'N, 125°25'E between Hatae Do and Manjae Do areas of the southwestern Korean Sea (Fig. 1). They are well developed at depths of 60 to 70 m of near slope area covered mainly by slightly gravelly muddy sand (median grain size, 1~2 phi). Their characteristics are 200 to 400 m in wavelengths and 3 to 7 m in waveheights with 60 to 70 of ripple index, suggesting a normal index value (Fig. 5a). The direction of the crest is WNW-ESE which is parallel to the co-tidal line in the area. The configurations of giant ripples indicate current direction of NNE-SSW which are congruent with ebb tide pattern. The maximum velocity of tidal currents reaches 1.7 to 2.0 kt in that area. In addition, the West Korean Coastal Current is developed well in the winter season and flows southward with a velocity of 1.0 kt. Consequently, strong tidal currents with overlapping coastal currents flow to the topographic barriers, such as sand ridges in the area, and might have increased turbulence flows creating sand waves.

Outer margin of Danjo Island in the East China Sea

Mega ripples are found at outer margins of the Amakusa shelf between depths of 140 and 170 m and have characteristics of 4 to 30 m in wavelengths, 0.4 to 3 m in waveheights, and 10 of ripple index. It is a typical form created by strong currents relative to the grain size of 2.05 to 2.10 phi (0.23~0.24 mm) in sdiments (Kagami et al., 1984). Giant ripples were extensively well developed between depths of 150 and 200 m (Fig. 5b). Wavelengths and waveheights are 200 m and less than 10 m, respectively, and their ripple index is about 20. The direction of the crest is W-E and is transverse to tidal current and the Tsushima Current. Coarse sands at this place are considered to be trapped and remained at the outer margin at the lowest sea level stage or during the transgression stage of post glacial time. Wang et al., (1985) reported that benthic foraminifera assemblages originated from Okinawa Trough by upwelling are found at the outer margin of the East China Sea, suggesting the existence of internal waves along the outer margin. Northward bottom current with velocity of 30 cm/sec has a major effect in forming sand waves. Also, internal waves contribute this formation with a minor affect.

Furthermore, Kagami et al., (1984) suggested that



(a) (b) (c)

Fig. 6. Vertical profiles of geostrophic current velocities off the Fukue Island (a), the Korea Strait (b) and Tsushima Strait (c) (after Miida, 1976).

a submarine terrace, which is situated at −155 m water depth, be not necessarily formed at maximum lowering of sea level but formed under present hydrologic conditions. However, the present study shows that the giant ripples on the shelf plain had been formed at a low sea-level standing rather than the present sea level because thin semiconsolidated mud was accumulated and trapped in the trough of giant ripples.

Outer margin of Goto shelf channel

Giant ripples are developed in shelf margins with depths of 120 to 155 m, covered by medium to fine sand (median grain size, 1.2~3.0 phi) (Katsura and Nagano, 1982). Wavelengths and waveheights are 150~200 m and 4~7 m, respectively, and ripple index represents normal value of 30~40 (Fig. 5c). By the shape of the giant ripples, the flow direction is shown to be north and northeast that is well in accordance with the main flow of the Tsushima Current. The vertical profile of current velocity shows 10cm/sec of northward flow between depths of 100 and 150 m. However, it reaches up to 20 cm/sec at shelf break from 120 to 150 m (Fig. 6a).

Off Korea-Tsushima Strait

Sand waves are well developed at a depth of 120 m, the deepest in eastern Korea Strait, around 33°50′N (Mogi and Nagai, 1981). It is one of the typical strait type bedform. Giant ripples are distributed northward and southward off the Sichirigasone topographic high, which is located between the Tsushima and Iki Islands (Sugiyama, 1984). In the northern part, giant ripples are developed on the western gentle slope of the sand ridges, which will be discussed later. In this area, the sea bottom is covered by coarse to medium sand and wavelengths of the ripples are 100 to 200 m and about 5 m in waveheights. The direction of crests are WNW-ESE, transverse to the main flow of the Tsushima Current. In the southern part, giant ripples are extensively developed with water depths between 100 and 105 m, which is the lower part of 100m submarine terraces, covered by coarse to medium sands (0.5~1.5 phi). The direction of the crests are NW-SE and it is well accordant with the flow pattern of the Tsushima current (Fig. 6a,b, and c). One possible method of the giant ripple formation in this area is from the downwelling of the internal wave which is produced by bottom topographic effect. The bottom topographic effect influences to the sea bottom and contributes to form ripples (Kaneko et al., 1987). A vertical profile of current velocity (Fe line in Fig. 6c) shows northward flow of 35cm/s at the deepest of 120 m in the eastern channel of Korea Strait with mean velocity of 32.5 cm/s (0.63 kt). Maximum velocity extending to northeast reaches up to 3.0 kt when tidal currents are harmonized with permanent currents. Grain size distributions represent coarse sands (less than 0.5 phi) in the central area of the strait and slightly poor sorted (standard deviation, 1~2 phi) coarse to medium sands (0.5~1 phi) in the margin where giant ripples are developed. In contrary, well sorted medium to fine sand are distributed in south of 33°40'N and northeastern Iki Island (standard deviation, less than 1.0 phi) (Oshima et al., 1982; Mogi and Nagai, 1981). It suggests that sand materials of surficial sediments at the central region be reworked and winnowed to the marginal region under the present hydrologic condition.

Two large scale longitudinal sand ridges are developed in the Korea Strait (Mogi and Nakajima, 1973; Mogi and Nagai, 1981). One is developed in the central area of the strait with depths between 115 and 125 m, covered by medium to fine sands. The wavelenghts of sand ridges extending to NE-SW vary from several hundred meters to 3 kilometers, their heights are 2 to 20 m, and the crests are located at about 105 to 110 m below present sea level. The other is formed by more than twenty sand ridges, well developed on submarine terraces of northeast off Iki Island with depths of 84 to 105 m. Longitudinal sand ,ridges have characteristics of 4~6 m waveheigths, 50~1000 m wavelengths and continuously extend to about 15 km with NE direction. Sand ridges actually represent the steep slope of northeastern side compared to the southwestern side. These features based on bedform configurations might be interpreted as transversely formed sand waves (strait swept type) from the northward current, and possibly northwestward when we consider the secondary circulation of bottom water (Heathershow and Hammond, 1980). At Malacca Strait, longitudinal sand ridges that parallel to each other are well developed parallel to the direction of the tidal current of the spring tide. The relationship between the interval of each parallel sand ridges (λ) and water depths of sand ridges (h) is expressed by the following formula:

$$\lambda = 100h \qquad (1)$$

Mogi and Nagai (1981) suggested that the sand at the eastern Korea Strait be formed at a depth of 74 m below the present sea level. The interval of sand ridges is 1,000 m at a depth of 84 m deep and h is to be 10 m. Therefore, at present, the sea level when sand ridges were formed is to be $84-10=74$ m. If sand ridges are produced by the present sea level, it could be 8,400 m, which is not in accordance with the real interval of 1,000 m. During 12 Kyr to 11Kyr BP, sea level had risen from −110 to −60 m by post-glacial transgression, and formed −60 to −70m submarine terraces in the East China Sea (Suk, 1989). In the meanwhile, thick transgressive sands were deposited at that time. As a result, it is possible to equate the same sea level history as the Korea strait. On the other hand, there is a different explanation to the formation of sand ridges distributed at the eastnorthern area of the Iki Island. The general formula are expressed as

$$\lambda = ah \qquad (2)$$

where "a" ranges from 1 to 10 with most of 2 to 5. This value has a board ranges due to wavelengths controlled by the strength of the turbulence flow and the grain size of sediment besides the water depth effect. Field data indicated that $a=5$ and $b=0.06\sim0.18$ at Setonaikai (Kozasa, 1975), where b value comes from the following formula: the ratio of waveheight $(\Delta)=bh$. In the northeast off Iki Island, λ is to be 840 if the equation (2) is accomplished, which is well in accordant with real wavelengths. In addition, it is also evident that fine to medium sands, which are distributed in the northeastern area off the Iki Island,

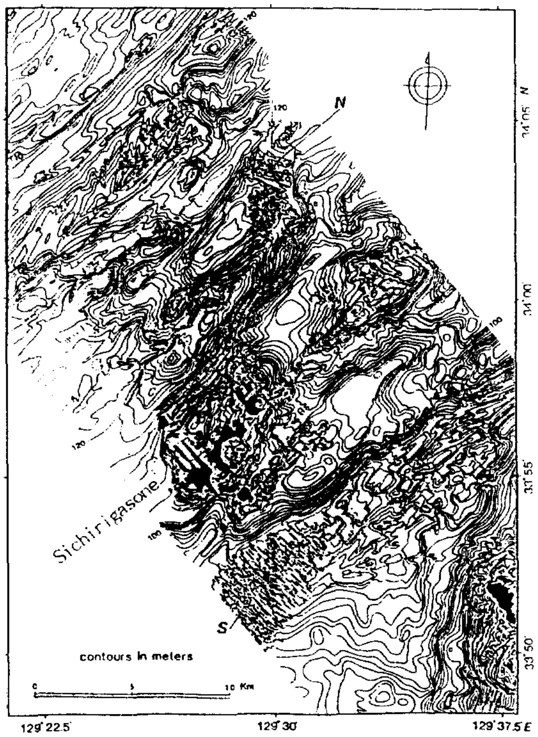


Fig. 7. Detailed bathymetry of the Korea Strait modified from Sugiyama (1984). Giant ripples are well developed in the northern (N) and southern (S) area of the Sichirigasone.

are actively working under present hydrodynamic conditions. At the Korea Strait, there are identified ripple marks at Hageshima Trough located at the southern entrance of the Strait (Sugiyama, 1984, 1985) (Fig. 7). However, no detailed work on that has been done yet. A vertical profile (FW line in Fig. 6 b) of current velocity between Mamesanzaki of Tsushima and Somaemol Do Islands shows 50 cm/sec at a depth of 140 m, and the compensated velocity at a depth of 180 m is the order of 30 cm/sec. The mean velocity of this profile represents 24.6 cm/sec (0.48 kt) and a maximum velocity with northward direction of up to 1.4 kt.

In the Iki channel region, giant ripples are developed on the central channel with depths of 50 to 55 m, covered by coarse sands. The wavelenghts and their heights are 200 to 300 m and 5 to 10 m, respectively. The crests indicate a NW-SE direction transverse to the northeastward Tsushima Current. The current velocities in the area are 0.1~0.95 kt with a dominant of ENE component (Miida, 1976). They are a typical channel type giant ripples which were formed by constricted currents overlapping with tidal currents.

CONCLUSIONS

The giant ripples were well developed at nine places in the study area. Most of them have been formed under the present hydrologic regime. However, the dynamic condition such as the strengh of tidal current, accelerated turbulence flow and noncohesive medium to fine sandy facies etc. were required to form giant ripples on the sea-floor. Giant ripples are produced on two different environments in the study area. One is at the geomorphic narrow region where the currents are compressed. In the case of Korea Strait, giant ripples are not formed at the center of the Strait because flows are too fast but are developed at the entrance of the Strait which is covered by finer sandy sediments. The other is at a sandy flat area where the tidal currents and local currents are harmonized. In these area, not only does a gyre exist at some places, but also there are accelerated turbulence flows by the topographic low of trough or shelf channel. Giant ripples as a function of water depth (h) in the study area are defined by the following two formulas:

$$\lambda = ah$$
$$\Delta = bh$$

where λ is the wave length, Δ is the ratio of wave height, and a and b values are 1~10 and 0.06~0.18, respectively. Variable range of a and b values is due to strengths of turbulences flow and grain size effects.

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