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GENERAL PATTERN OF THE TURBID WATER IN THE SETO-INLAND SEA EXTRACTED FROM MULTISPECTRAL IMAGERIES BY THE LANDSAT-1 AND -2

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BY

Kantaro Watanabe, Faculty of Marine Science and
Technology, Tokai University

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ABSTRACT

For assisting in the monitoring of the water pollution in the Seto-Inland Sea of Japan a general pattern of turbid water in the sea was investigated using multispectral scanner (here after, MSS) imageries by LANDSAT-1 and -2.

Photographic and digital processes of the image-masking with MSS imageries in the visible bands (MSS-4 and MSS-5) and reflective infrared band (that is the MSS-7) were made for extracting patterns of turbid water separetely from the ones of cloud and smog-layer, because all imageries of informations beneath the sea surface and in the atmosphere are mixed each other in the original MSS imageries.

Though patterns of turbid water in any fixed sea region change day by day, a common pattern, that is a general pattern, of turbid waters were found by comparing three digital maps of image-masking in the Hiuchi-Nada Sea.

By making a mosaic of image-masking imageries a general pattern of turbid waters was displayed nearly for the whole Seto-Inland Sea.

PURPPOSE OF INVESTIGATION

The Seto-Inland Sea in Japan, nearly enclosed by the western part of the Honshu, the northen Kyushu and the Shikoku (Fig.1) is one of the most beautiful seas in the world having numerous tiny islands of green pine trees. However, the sea has been seriously polluted with the rapid develepement of industiries in those fifteen years. The water pollution in the sea is not only reducing value of its beautiful scenary, but also destroying fishery environments and gradually becoming harmful for human living.

In the present investigation, it is aimed for assisting in the monitoring of water pollution in the sea to have a general pattern of turbid water in the sea, most part of which is the artificially polluted water, using multispectral imageries by the LANDSAT-1 and -2.

USED DATA

Each sea regions in the Seto-Inland Sea were taken in multispectral imageries by the LANDSAT-1 and -2 on the dates in Table-1. The LANDSAT multispectral imageries taken on the dates underlined in Table-1 were used in the present investigation because of its low cloudiness.

Table-1

OSAKA-BAY and KII-STRAITS : on 24 Oct., 1972, 3 Jan., 1973 by the LANDSAT-1
HARIMA-NADA, BISAN-SETO and HIUCHI-NADA : on 12 Nov., 1972, 23 Jan., 1973, 4 Jul., 1973 by the LANDSAT-1, and 30 Dec., 1975 by the LANDSAT-2
AKI-NADA, IYO-NADA and THE EASTERN SUO-NADA : on 15 Aug., 1972, 8 Oct., 1972, 6 Jan., 1973 and 5 Jul., 1973 all by the LANDSAT-1
THE WESTERN SUO-NADA : on 21 Oct., 1975 by the LANDSAT-2
THE SOUTHERN SUO-NADA, that is the sea north of THE BUNGO STRAITS : on 15 Aug., 1972 by the LANDSAT-1

ANALYTICAL TECHNIQE

The light incident upon the multispectral scanner on board LANDSAT consists of two parts. One is useful light for oceanographic investigations scattered from fine particles suspended in the turbid water, such as river-discharged sediments, artificial pollution materials and plankton, and reflected at the bottom when the sea is sufficiently shallow (hereafter under-water informations). Another is harmful light for interpreting under-water informations diffusely reflected from cloud covers, smog layers, sea fogs, and from inclined surfaces of numerous wavelets when the optical condition is fit (hereafter atmospheric informations). Therefore, any imageries or pictures in the visible region of the sea taken from the space are of complex pattern due to the image combination of under-water informations and of atmospheric informations. Thus, it is necessary in any oceanographic investigation using LANDSAT data to extract patterns of under-water informations separately from the ones of atmospheric informations.

Among these light components, the useful lights from under-water informations are more attenuated in longer wavelength regions, strongly in the near-infrared region, before transmitted through the water layer. Whereas the harmful lights from atmospheric informations are nearly not attenuated by water layer in all wavelength regions because they traverse only in the atmosphere. According to such a difference of the attenuation character, gray patterns in the sea in imageries of the band of MSS-4 (0.5-0.6μ in wavelength) or of MSS-5 (0.6-0.7μ) represent under-water informations together with atmospheric informations, and the ones of MSS-7 (near-infrared, 0.8-1.1μ) do only atmospheric informations. Thence, oceanographic informations can be extracted by the image masking technique, that is, by the image subtraction of the pattern in the MSS-7 from the one in the MSS-4 or the MSS-5 by appropriate photographic or digital processes.

In the present investigation, photographic image-masking processes were made for the MSS-4, MSS-5 and MSS-7 imageries of the Osaka Bay and the northern Kii Straits on 24 Oct., 1972, of Harima-Nada, Bisan-Seto and Hiuchi-Nada on 12 Nov., 1972, 23 Jan., 1973 and 4 July 1973, of the Aki-Nada, Iyo-Nada and the eastern Suo-Nada on 15 Aug., 1972, and of the western Suo-Nada on 21 Oct., 1975. A digital process for the image-masking was applied to MSS-4 and the MSS-7 CCT data of the Hiuchi-Nada on 12 Nov., 1972, 23 Jan., 1973 and 30 Dec., 1975.

PATTERNS OF TURBID WATER EXTRACTED

1) Osaka Bay and the northern Kii Straits, by LANDSAT-1, on 24 Oct., 1972. (Fig.2)

By applying the photographic image-masking technique to the multispectral scanner imageries taken on 24 Oct., 1972, patterns of turbid water were made (Fig.2), where land areas and cloud covers, maybe including smog layers, are shown white in color and under-water informations, areas of turbid water in this case, are represented as patterns of darker or the darkest gray color. The darkest gray patterns came from the couple of MSS-5 (orange band) and MSS-7 (near infrared band) imageries, which show dense turbid waters in the upper-most layer, maybe within 2 or 3 meters or so (G.A.Maul, 1975) because of rather large value of the attenuation coefficient in the orange band. The darker gray patterns were made by the image-masking process using the couple of MSS-4 (green band) and MSS-7 imageries, which represent turbid waters in a layer up to the depth a little bit deeper than the one in the couple of MSS-5 and MSS-7 because the attenuation coefficient in the green band is smaller than the one in the orange band. Then, the remained areas of lighter gray color mean fairly clear water extracted by a density-slicing process.

A large volume of turbid water discharged from the Yoshino River in Shikoku which was caused by a heavy rain falling on Oct. 22 extends in the nearly western-half part of the northern Kii Straits reaching the southeast corner of the Harima-Nada and flowing southward along the east coast of Shikoku.

As the northeast corner of the Osaka Bay near Osaka City and Kobe City was unfortunately covered by clouds and a likely smog layer, the heavily polluted water there produced in the largely populated and highly industrial zone was not revealed in the imagery. However, the largeness in volume of the turbid water can be inferred from the pattern of turbid water broadly distributing in the central part of the bay and extending to the northeast corner of the Harima-Nada passing through the Akashi Channel north of the northern tip of the Awaji Island.

There appears in Fig.2 an interesting eddy-like pattern of turbid water north of the Kitan Channel, the south mouth of the Osaka Bay. It is clear that this eddy was developed by the northward flowing the tidal current which stage was at one and a half hours after the time of the maximum wastward flowing in the Akashi Channel. Through the southwestern part of this eddy-like turbid water is seen in Fig.2 as if it connected to the turbid water from the Yoshino River in the sea southeast off the Awaji Is., it is likely assumed as to a part of turbid water producted in the Osaka Bay not to a part of the turbid water from the Yoshino River by a classification analysis with a 2-dimensional feature space of MSS-4 and MSS-5 brightness levels.

2) Harima-Nada, Bisan-Seto, by LANDSAT-1, on <u>12 Nov., 1972</u> (Fig.3) and on 23 Jan., 1973 (Fig.4)

Patterns of turbid water in the central part of the Seto-Inland Sea, that is, the Harima-Nada, Bisan-Seto, and Hiuchi-Nada on 12 Nov., 1972 and on 23 Jan., 1973 are shown in image-masking imageries in Fig.3 and Fig.4, respectively. It is noted in both figures that patterns of turbid water are generally similar on 12 Nov., 1972 and 23 Jan., 1973 except of the pattern of turbid water extending southward in the eastern region of the Harima-Nada on 12 Nov., 1972. The pattern of turbid water from the Yoshino River on 12 Nov., 1972 (Fig.3) is also very similar to the one on 24 Oct., 1972 (Fig.2).

3) Hiuchi-Nada, by LANDSAT-1 on 12 Nov., 1972 (Fig.5), on 23 Jan., 1973 (Fig.6), and by LANDSAT-2 on 30 Dec., 1975 (Fig.7)

Fig.5, Fig.6 and Fig.7 are distribution charts of turbid water on 12 Nov., 1972, 23 Jan., 1973 and 30 Dec., 1975, respectively, made by digital image-masking process where the apparent turbidity is separated in three relative ranks due to brightness level in digital maps. Though each patterns of these three days are different each other in some degrees, there appears a general pattern that nearly the southwestern-half of the Hiuchi-Nada is commonly more turbid whereas the eastern part of the sea is always less turbid. This suggests together with the former cases of Fig.3 and Fig.4 that each image-masking imagery approximately represents a general pattern of turbid water in each corresponding sea region.

4) Aki-Nada and Iyo-Nada, by LANDSAT-1, on Aug., 1972

There are rather few LANDSAT data for the region of the Aki-Nada north-west off Matsuyama City in Shikoku. Furthermore, the transparency in the atmosphere was insufficiently good for interpreting any under-water information in the only image-masking imagery made from the LANDSAT-1's multispectral imageries on 15 Aug.,1972. Thus, any information about turbid water was not succeeded to be extracted in the Aki-Nada and Iyo-Nada.

5) The Western Suo-Nada, by LANDSAT-2, on 21 Oct., 1975 (fig.8)

The image-masking imagery in Fig.8 was from LANDSAT-2's MSS-4 and MSS-7 imageries on 21 Oct., 1975 which shows patterns of turbid water in and near the Shimonoseki Channel nearly at the time of the turn of tides from the westward flow to the eastward flow in the channel. Fairly large masses of turbid water are seen in the sea region near Ube City and Onoda City, both of which are famous for the industry of cement production, then the fairly large part of the turbid water there is assumed as to artificially polluted water. The patterns of the turbid water in Fig.8 shows that the turbid water from the Ube City is flowing eastward whereas the one from the Onoda City is seen to be nearly at the slack. This difference is caused by the difference in the tidal time that the turn of tides in the central region of the Suo-Nada occurs faster than that one in the Shimonoseki Channel.

GENERAL PATTERN OF TURBID WATER

Each distribution pattern of turbid water changes with the time in accordance with daily tides with seasonal variation of tides and furtheremore, with occasional rainfall. However, two cases of successfully repeated LANDSAT observations for each same sea regions as in Fig.3 , Fig.4 and Fig.5, Fig.6 and Fig.7 suggest that a general pattern of the turbid water can be extracted for each region. Basing upon this fact was made a chart of general pattern of turbid water in the Seto-Inland Sea by making the pattern in Fig.2 represented the general pattern of turbid water in the sea region in 'A' in Fig.9, the pattern in Fig.3 the general pattern in 'B', and the pattern in Fig.8 the general pattern in 'C'. Unfortunately any general pattern of turbid water could not be extracted in the Aki-Nada south off Hiroshima City where the water is fairly polluted, and the Iyo-Nada where the water is generally clearer than the other regions in the Seto-Inland Sea.
For comparison, two charts of the Chemical Oxygen Demand (COD) are presented in Fig.10 and Fig.11. Patterns of turbid water in Fig.9 and of COD in Fig.10 and Fig.11 are nearly corresponding each other in most sea regions which shows that LANDSAT's multispectral data are useful in monitoring the state of water pollution even though successfully available LANDSAT data are rather occasional.

Reference

MAUL, G. A., and H. R. GORDON; On the use of the Earth Resources Technology Sattelite (LANDSAT-1) in optical oceanography. Remote Sensing of Environment 4, 95-128 (1975)

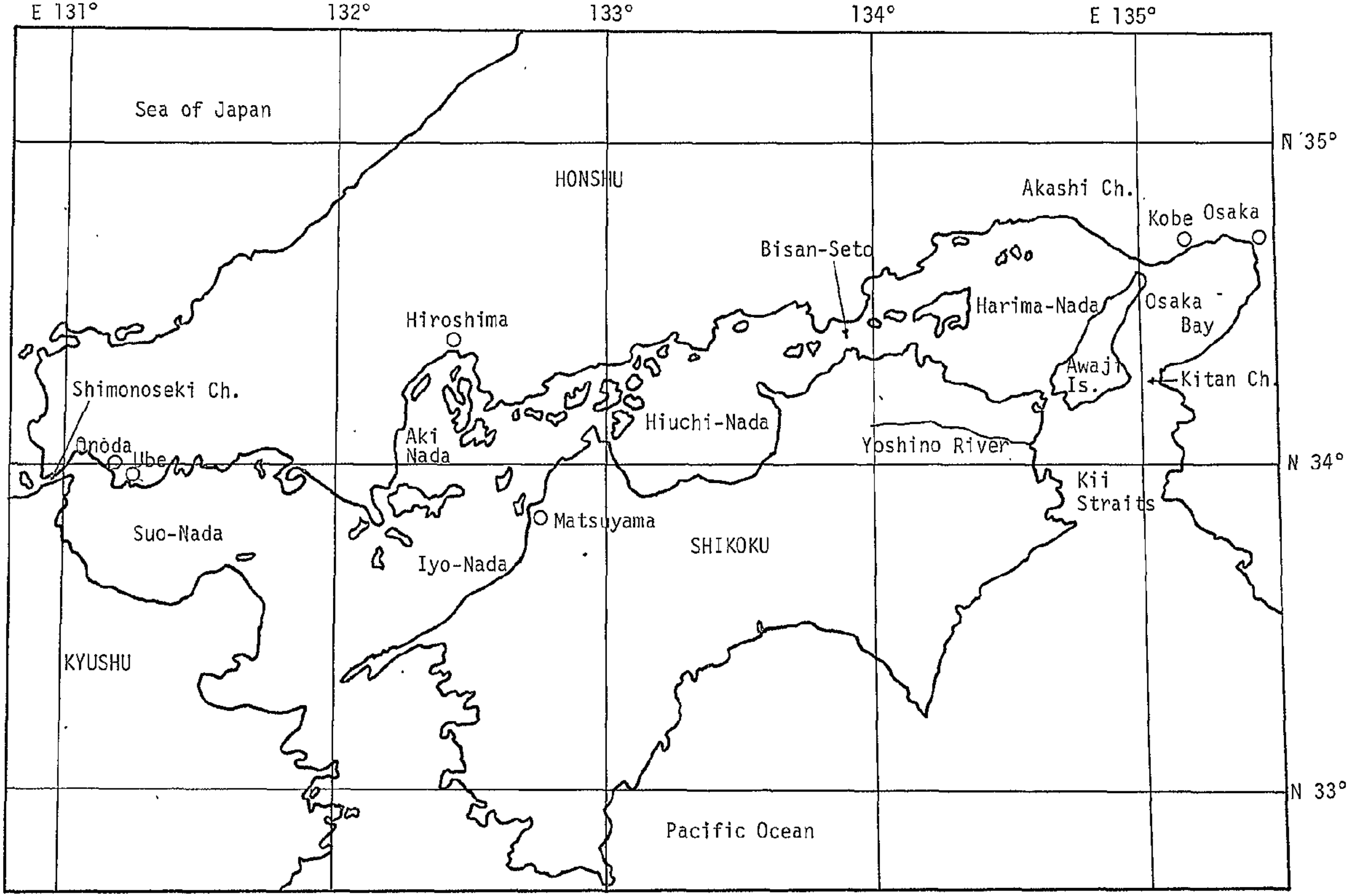

Fig. 1 Map of the Seto-Inland Sea

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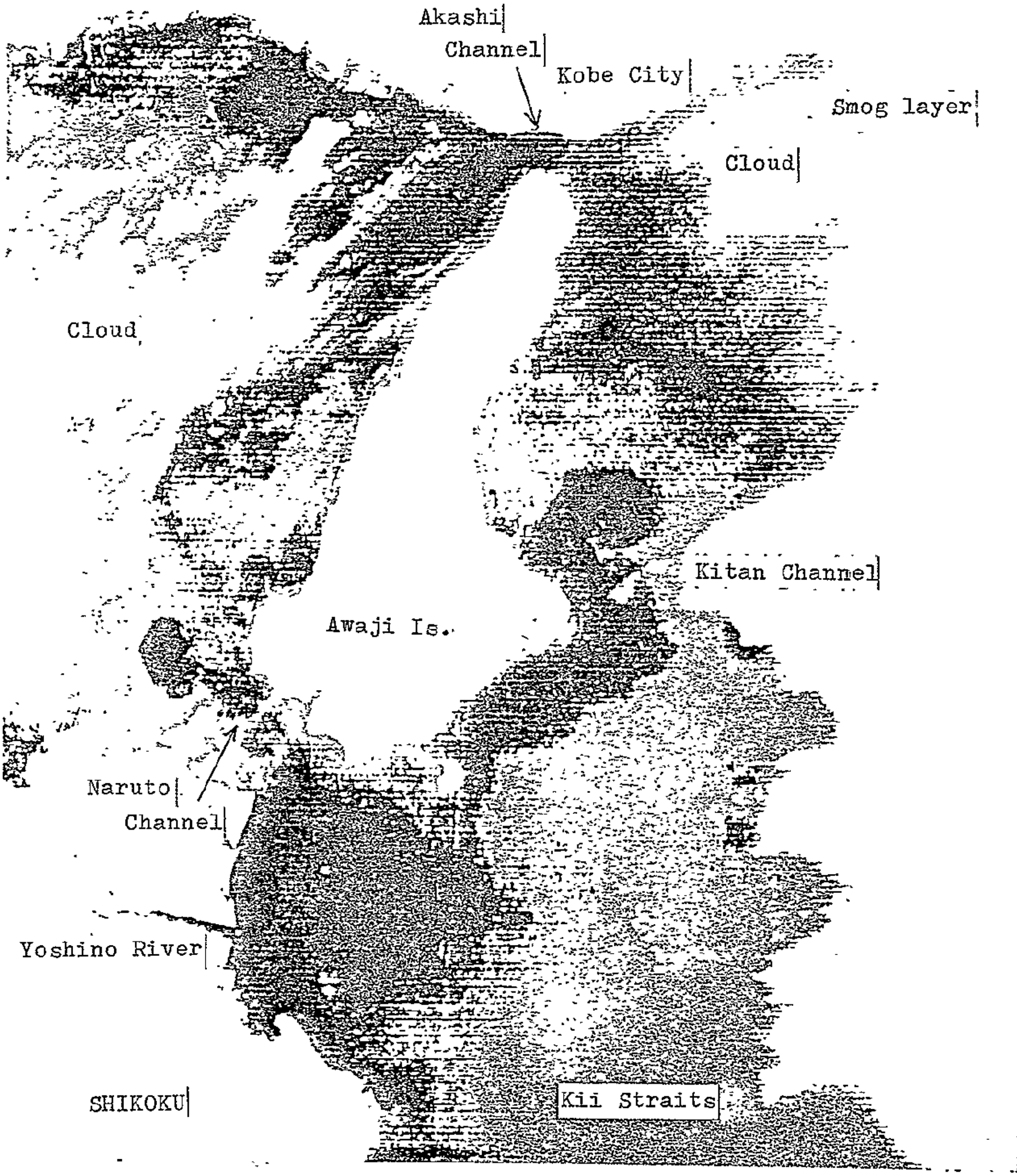
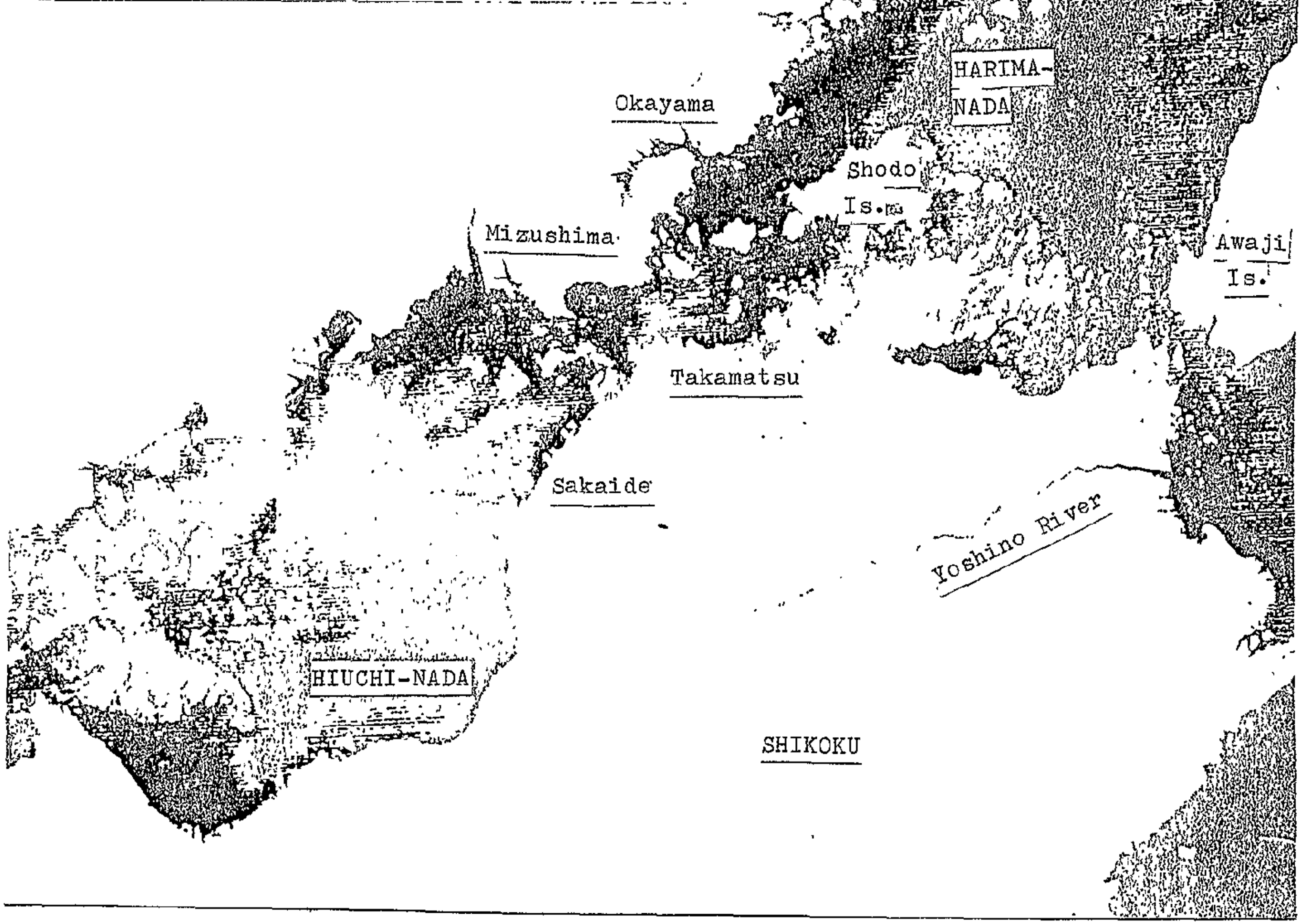


Fig. 2 Patterns of turbid water in the Osaka Bay, the Kii Straits and the eastern part of the Harima-Nada sea extracted from LANDSAT-1's MSS imageries taken on Oct. 24, 1972.

Fig. 3 Patterns of turbid water in the Harima-Nada sea and the Hiuchi-Nada sea extracted from LANSAT-1's MSS imageries taken on Nov. 12, 1972.



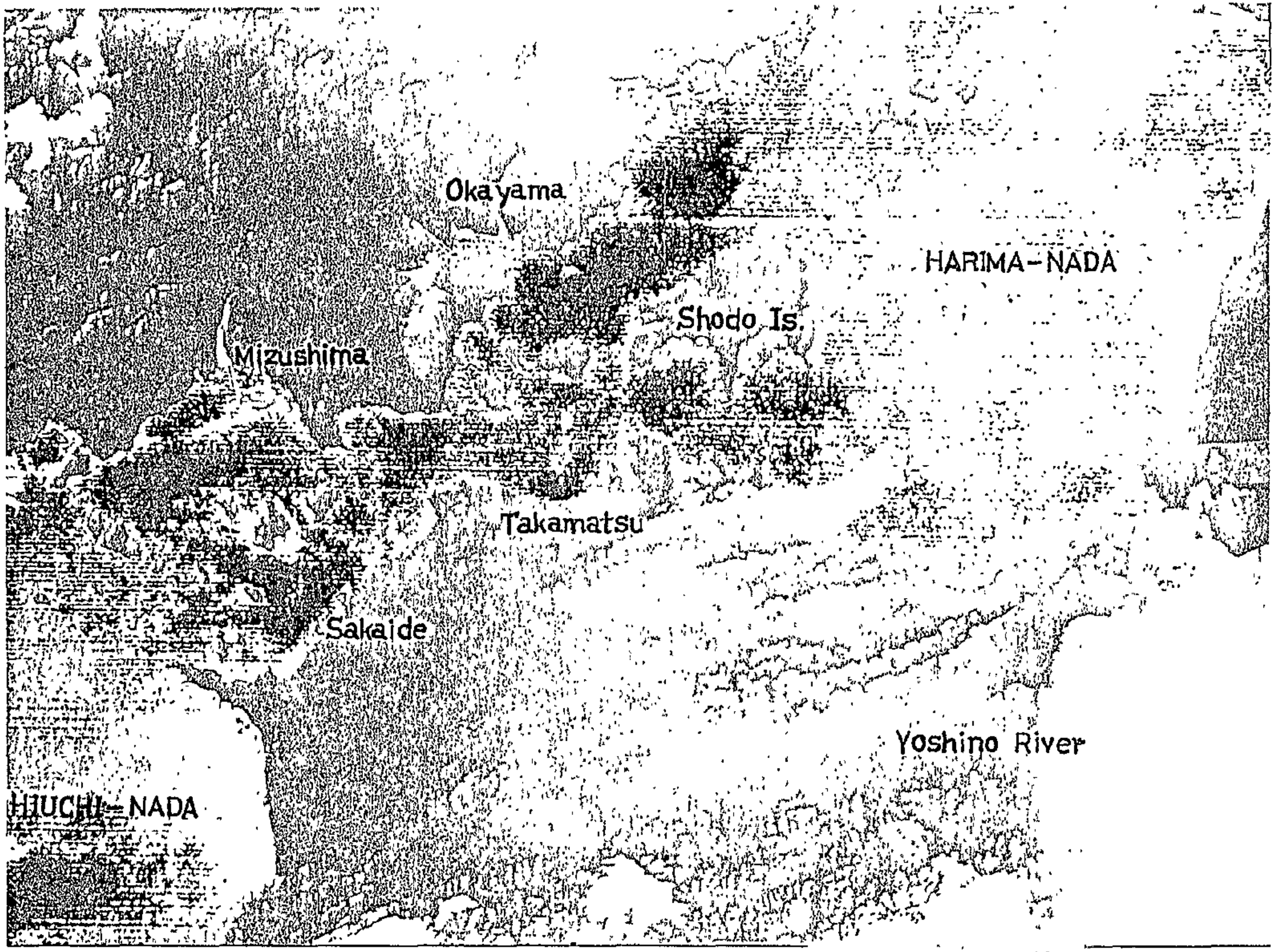


Fig. 4 Patterns of turbid water in the Harima-Nada sea and the Hiuchi-Nada sea extracted from LANDSAT-1's MSS imageries taken on Jan. 23, 1973.

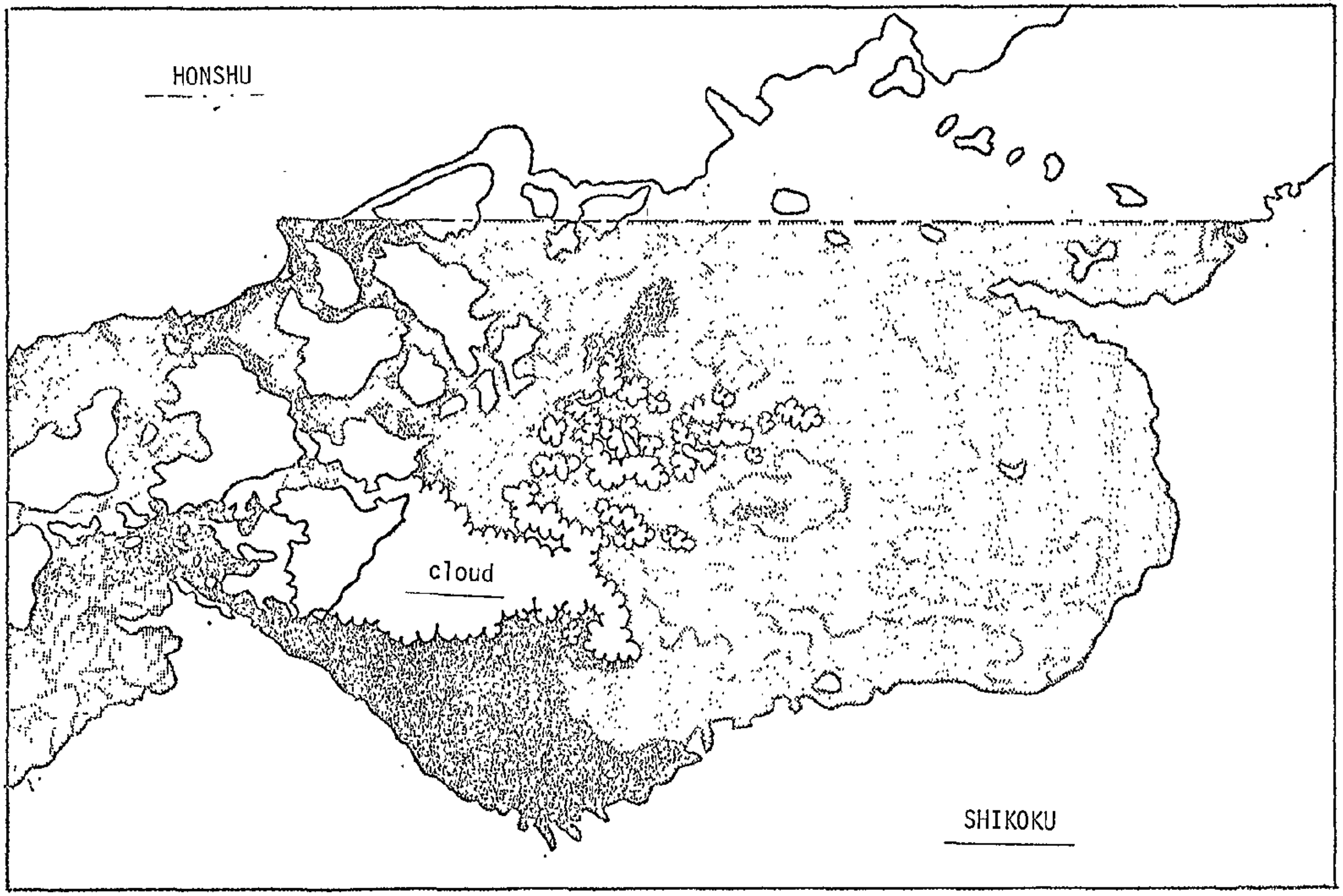


Fig. 5 Turbid area in three ranks by the digital image-masking process
12 Nov., 1972

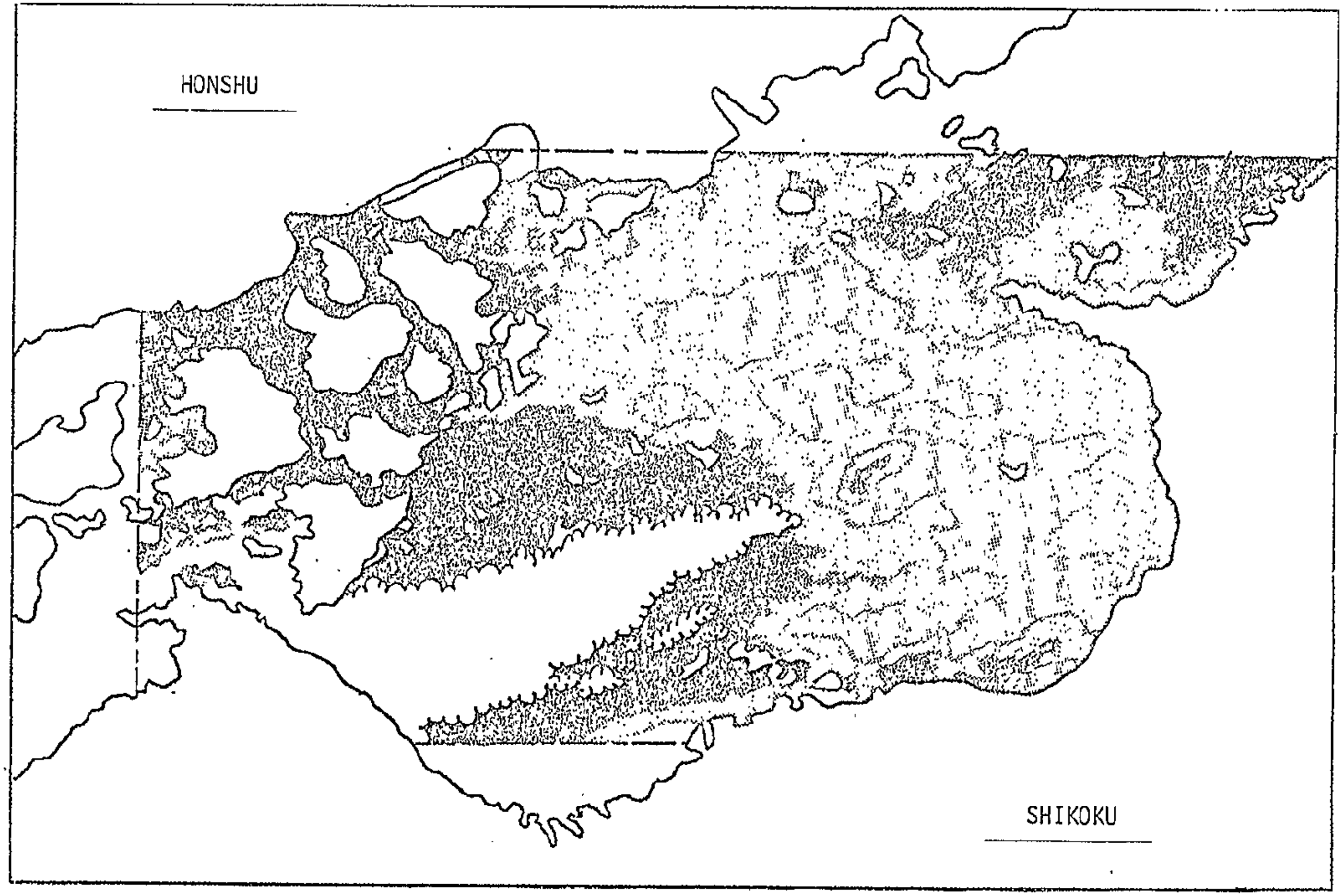


Fig. 6 Tirbid area in three ranks by the digital image-masking process
23 Jan., 1973

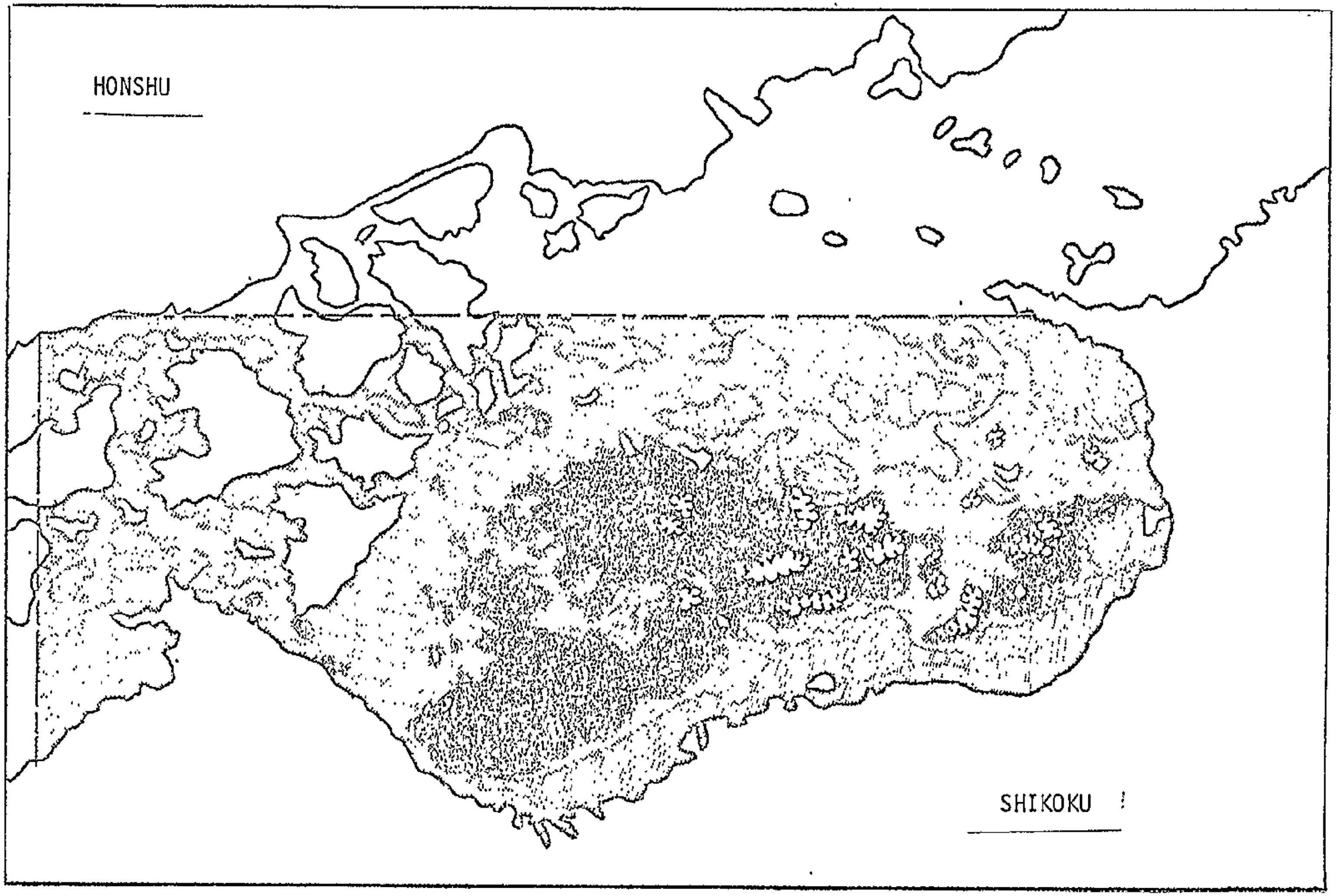


Fig. 7 Turbid area in three ranks by the digital image-masking process
30 Dec., 1975

Fig. 8 Patterns of trubid water in and near the Shimonoseki Channel extracted from LANDSAT-2's MSS imageries taken on Oct. 21, 1975.

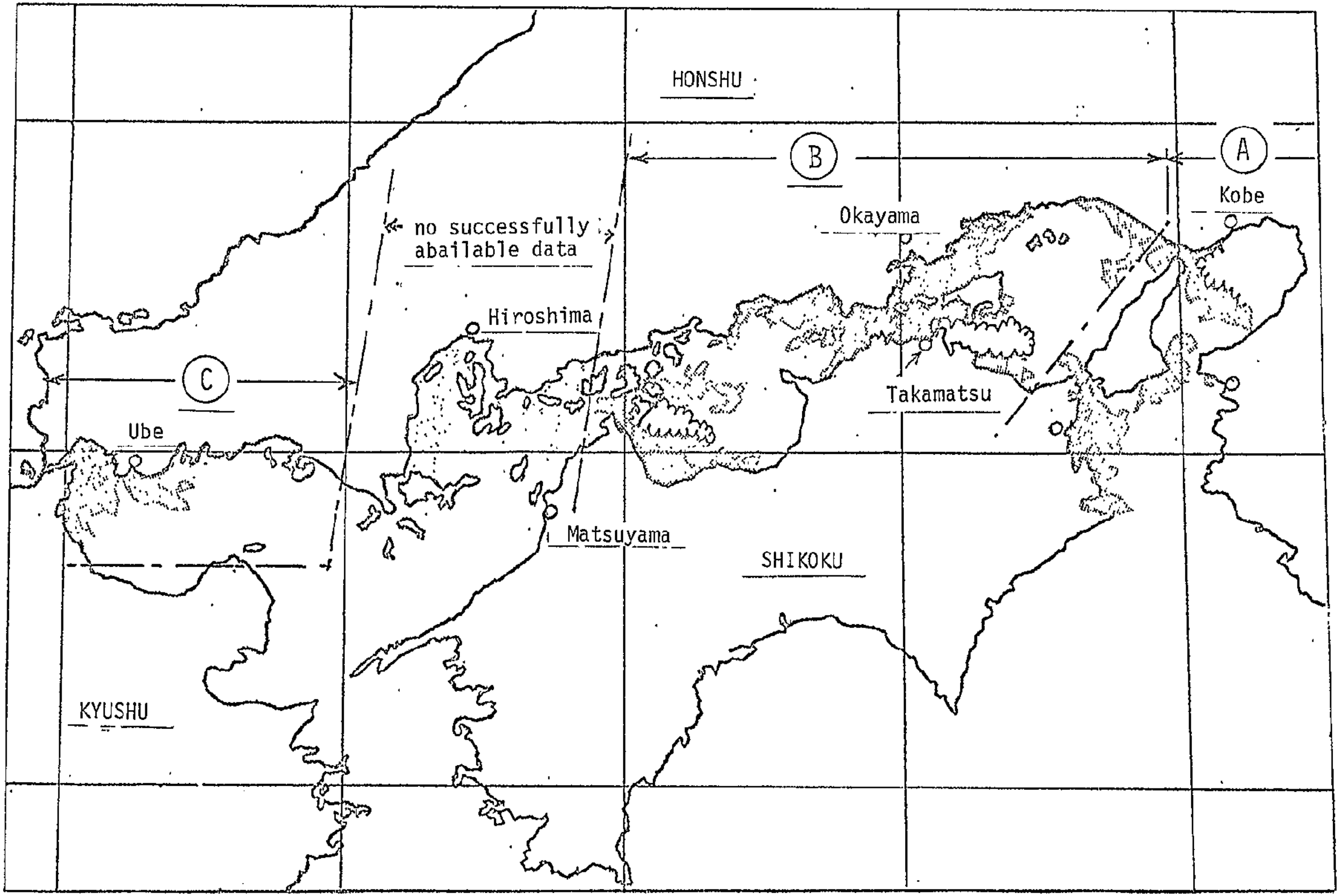


Fig. 9 General pattern of turbid water

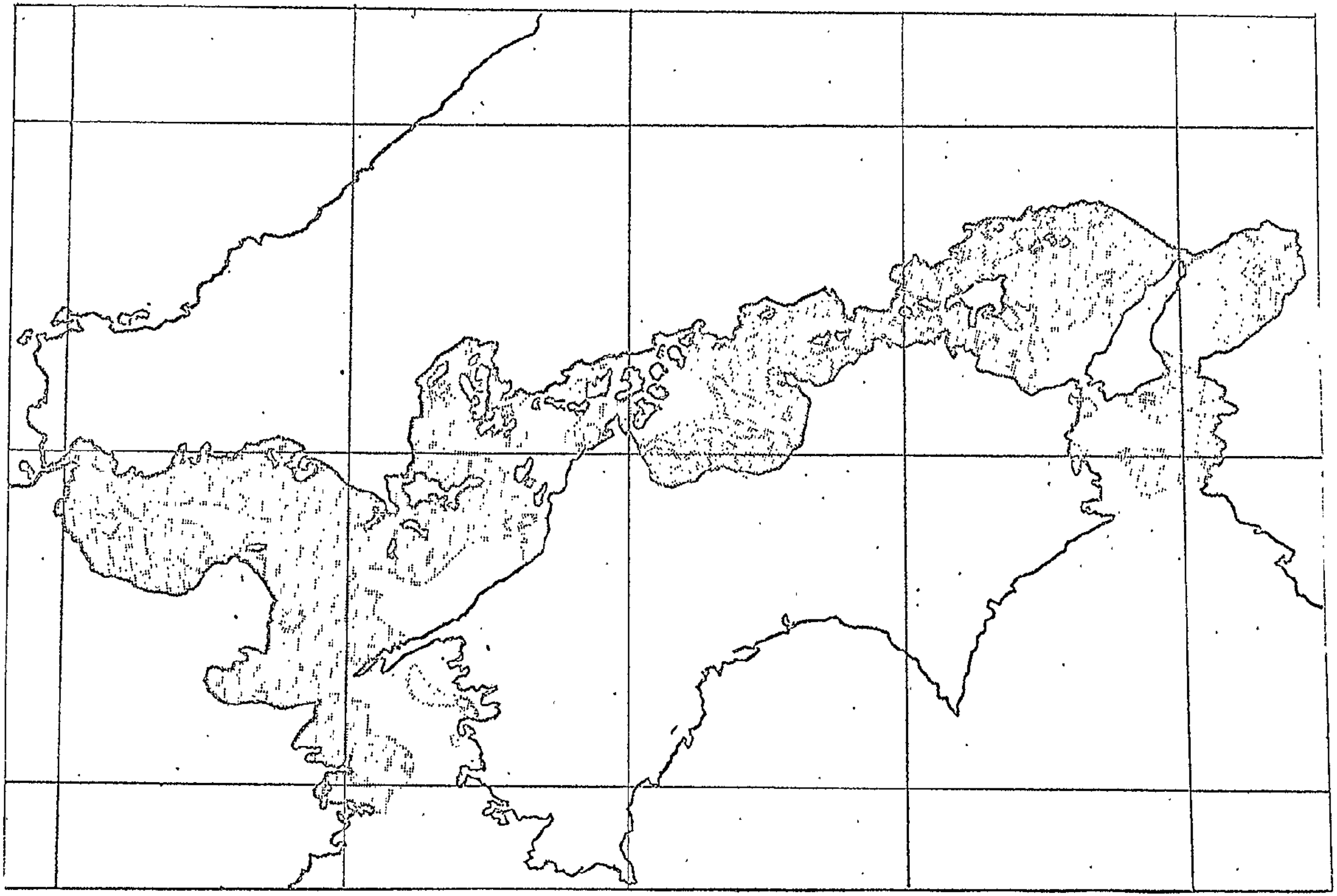


Fig. 10 Horizontal distribution of surface COD
17 Oct., 1972

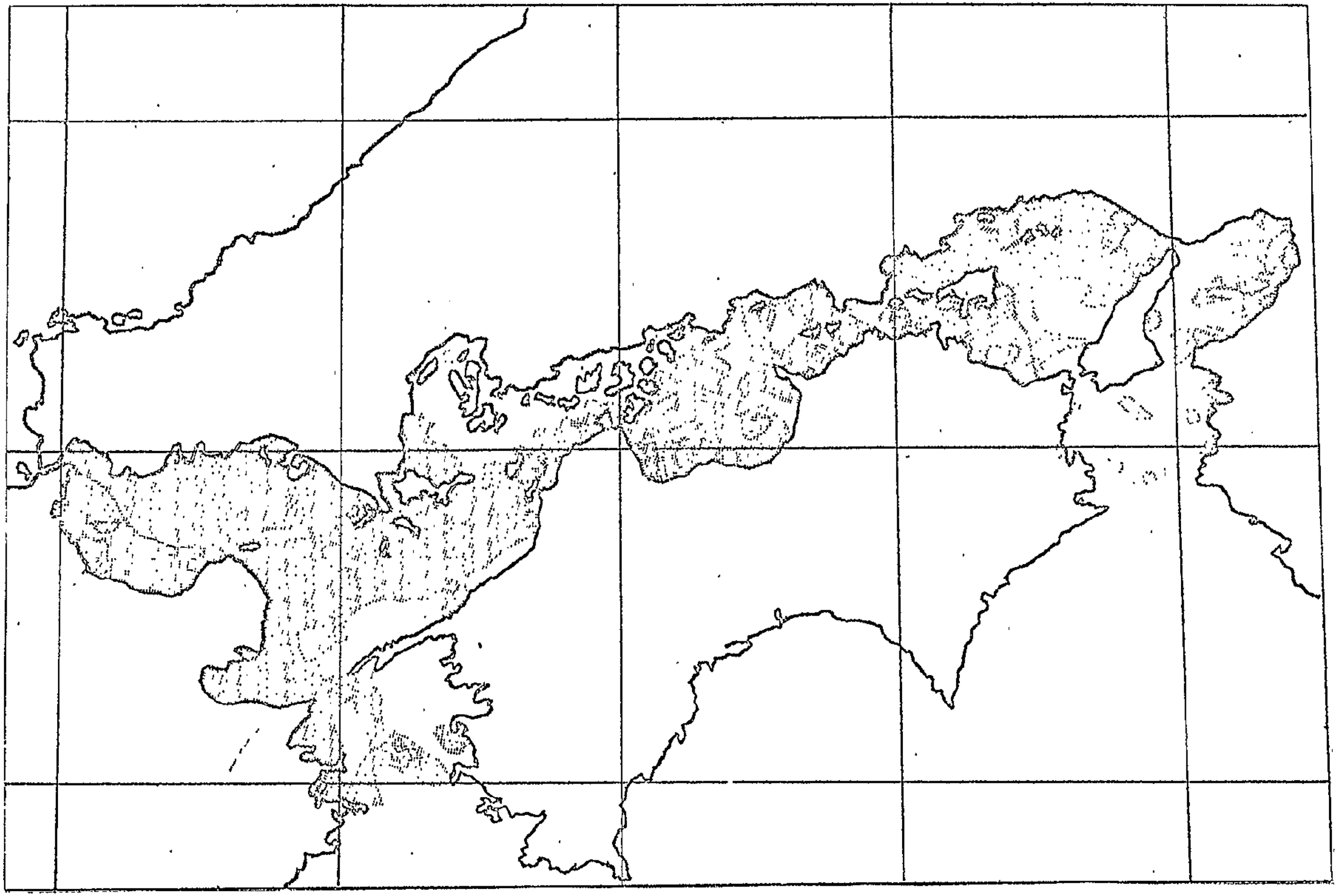


Fig. 11 Horizontal distribution of surface COD
10 Jan.,1973