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Organic Pollution of Bottom Mud in the Seto Inland Sea and Its Removal Experiment

Akio MURAKAMI

According to the increase of pollution in the Seto Inland Sea, the organic pollution of bottom mud proceeds at the stagnant regions. As it is observed that such unfavorable phenomena occur as the lack of dissolved oxygen at the bottom sea layer and the furtherance of eutrophication by released nutrients from the bottom mud. The marine ecosystem has been damaged very much. The author explains the mechanism and the influence of the organic pollution of bottom mud, and reports the organic pollution of the bottom mud in the Seto Inland Sea in 1974, and the experiments and problems in the project of the removal of the polluted bottom mud carried out by the Fisheries Agency.

Materials and Methods

The data used in this report were avairable in the research reports on improvement and recovery of the fisheries ground.[1] The sampling and analytical procedures were shown in Table 1 and 2 respectively. The method on removal of organic polluted bottom mud was explained in the report of the realization project of preventing and removing the red tide.[6]

Results and Discussion

1. Mechanism and influence of organic pollution of bottom mud

Since solid organic materials produced in the sea or discharged from the land deposit on the bottom mud in inshore waters, it is recognized that the organic pollution of bottom mud occurs locally at the inner part of the bay or in the stagnant region, even if in general conditions of marine environment. Once the discharged pollutants has grown more than the capability of self-purification in the sea, the sea water is polluted in the neighbour of the drainages at first, and then the solid organic materials in the waste waters or detritus produced in the sea deposit to the bottom near the drainage. It is realized that the progress of the bottom mud pollution is behind of the water pollution, and is restricted within narrow area. Generally, the water pollution is temporal, on the contrary, the mud pollution is continuous and can show the history of the pollution in the sea owing to its fixation. The more pollutants is discharged,

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the larger area in the sea polluted according to the movement of the sea water mass, and then the extent of polluted bottom mud following to. On the other hand, there is a case of transference in the bottom mud pollution. The particulate materials in the sea sink mostly at the center of eddy current or in the stagnant region. The size composition of the bottom mud in such regiosn is very small, and the surface layer of the bottom mud is covered with the fine silt named "Hedoro" commonly in Japan. The current is generally slow in inshore waters except at the mouth of the bay and the strait, so the thermocline is developed in summer. At that time, the surface water is not mixed with the bottom water, and occasionally the difference of the temperature in both waters results in 10°C or more in July and August. In autumn, the thermocline is decomposed due to the cooling of the surface water, and the mixture of two layers water occurs. Moreover, they are mixed suddenly by the strong wind such as Tayphoon in the shallow waters. In such case, the silt at the surface of bottom mud is winded up into the water, and is transferred to another stagnant region, and then settled again. Therefore, it is observed that the polluted bottom mud area is located at offshore far from the drainages. It is considered in the Seto Inland Sea, that the polluted bottom mud in the central part of Harima Nada, the eastern part of Hiuchi Nada, and the southern part of Suho Nada is resulted in such process.

The organic pollution of the bottom mud progresses the water pollution as a secondary pollution source. Although nitrogen and phosphorus are not concerned to the eutrophication so far as they are combined with the mud, but when they are released by the bacterial or chemical actions, they are transferred into the water of bottom layer through the water in the mud. From in the bottom water, nitrogen and phosphorus are supplied into upper waters due to the mixing.

On the other hand, the particulate organic nitrogen (PON) and phosphorus (POP) are mineralized both in the states of suspending and settling. Therefore, the particulate organic materials existing in bottom water and the surface of bottom mud are relate to the eutrophication of marine environment. The polluted bottom mud by the waste water of the pulp mill generally contains not so much nutrients, but it consumes dissolved oxygen in sea water when it is oxidized. It results in the lack of dissolved oxygen in bottom water especially in summer thermocline stage, and many benthic organisms are killed. Since the organic compounds (vitamins, etc.) and heavy metals (iron and manganese, etc.) stimulate the growth of Flagellates, so the release of such substances from the bottom mud is an important in the countermeasure of the red tide.

The organic pollution of mud is concerned in the breaking out of the red tide also in the lack of dissolved oxygen in inshore waters. As it brings about a serious damage to fisheries, now it is going to be taken adequate countermeasures.

2. Situation of organic pollution of bottom mud in the seto inland sea

The Seto Inland Sea is the largest inshore water in Japan, it is ca. 400 km in length and 21,827 km^2 in area and 37.3 m in average depth. The depth is more than 100 m at straits. There are about 800 islands, and is devided into many bays, Nadas and straits. Two branches of the Kuroshio current enter into this area via Bungo and Kii channel, and the Tsushima current also enters into via Shimonoseki strait. Many rivers flow into this area. Consequently, the water in the Seto Inland Sea is transferred from west to east slowly, and many stagnant regions are in it. So the exchange of water with ocean is very poor. The marine pollution has been observed since the 1950's, and became to the most serious in 1973 or 1974, but is showing the signs of getting better due to the regulation of pollution load by the "Seto Inland Sea Conservation Law" in 1973.

The Fisheries Agency is making clear the bottom mud pollution in inshore waters in Japan, carrying out the researches in the Seto Inland Sea from September to October in 1974 and in Ise and Mikawa bay, Hibiki Nada and Hakata bay from August to September in 1975, and also in Omura bay and Ofunato bay in July, 1976[1]. The volume of the polluted bottom mud is estimated from the results. The investigations were carried out by the Fuyo Ocean Development, Co., at 160 stations in the Seto Inland Sea and another 924 stations in 28 heavy polluted areas in it. The sampling and analyzing methods are shown in Table 1 & 2. The mud sample was collected with a core sampler, etc. shown in Fig. 1,

Table 1. Standardized sampling procedure of bottom mud.

Sampling Method	Sampling length of Mud (cm)	Layer of Mud for Analysis (cm)				
		0−5	15−20	30−35	5 between Bottom and 35 cm Layer	5 from Bottom
Ekman-Birge	<10	○	—	—	—	—
Smith McIntyer	10−20	○	—	—	—	○
Core Sampler	<20	○	—	—	—	○
	20−35	○	○	—	—	○
	35−50	○	○	○	—	○
	>50	○	○	○	○	○
Item of Analysis	COD. Water cont.	○	○	○	○	○
	IL, Total-S. P. N. Silt Comp.	○	—	—	—	—

Table 2. Analyzing method of bottom mud.

Items	Methods	Items	Methods
Size composition	Screen ca. 50g mud with water by 32 and 150 mesh sieves, dry the residue at 110°C, weigh after colling. (division of bottom mud) Coarse Sand, Gravel: not pass through 32 mesh (dia. <0.5mm) Sand: not pass through 150 mesh (dia. 0.125-0.5mm) Mud: pass through 150 mesh (dia. <0.125mm)	COD	alkaline potassium permanganate, idometric titration
		IL	700°C 2 hrs.
		Total-S	detective tube
		P	Strickland and Parsons's "A Practical Handbook of Seawater Analysis" (1968)
		N	CN-Corder

Total length : ca. 3 m

Sampling length : 2 m

Dia. : 60mm

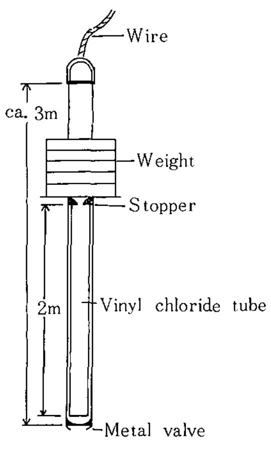

Fig. 1. Core Sampler.

and stored in the freezer until the analytical work at temperature of under 20°C. The echo sounder investigation was carried out at 160 stations with a sonicator model RS-72. Two ultrasonic waves (400 kHz and 30kHz) were radiated, the thickness of the mud containing much water was determined with the difference of the reflecting time between 400kHz and 30kHz. The sea regions in the Seto Inland Sea and the stations are shown in Fig. 2.

Many researches on the bottom mud had been carried out locally in the Seto Inland Sea relating to the fisheries damages. But it was the first time in all over the Seto Inland Sea that the investigations in December 1970, August 1971, October 1972 and May 1973 were carried out by our laboratory.[2] The bottom mud samples in upper 3cm layer, were collected with the Ekman-Birge dredge at 100 stations, analyzed as to COD, Ignition Loss (IL) and total-S. IL was determined by burning the mud at 800°C until becoming constant weight. Total-S content was determined with the following method; The mud was steam distillated, and hydrogen sulfide from it was absorbed to the solution

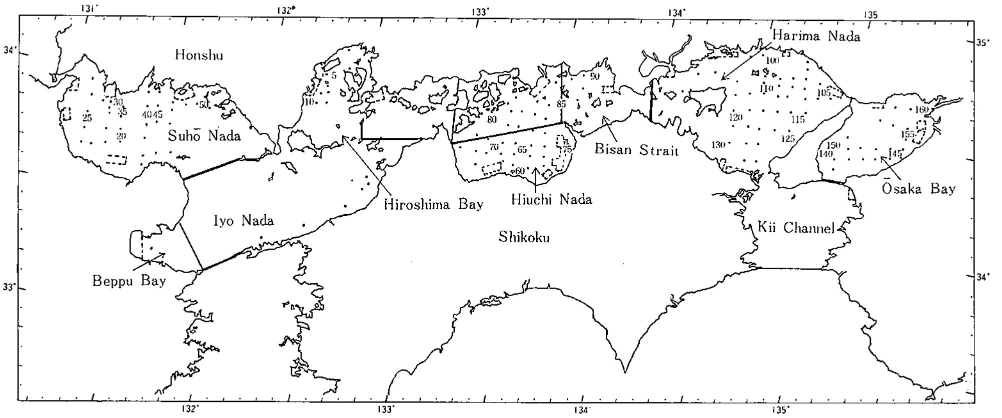

Fig. 2. Sampling station of bottom mud in the Seto Inland Sea. (Aug.-Oct., 1974.)

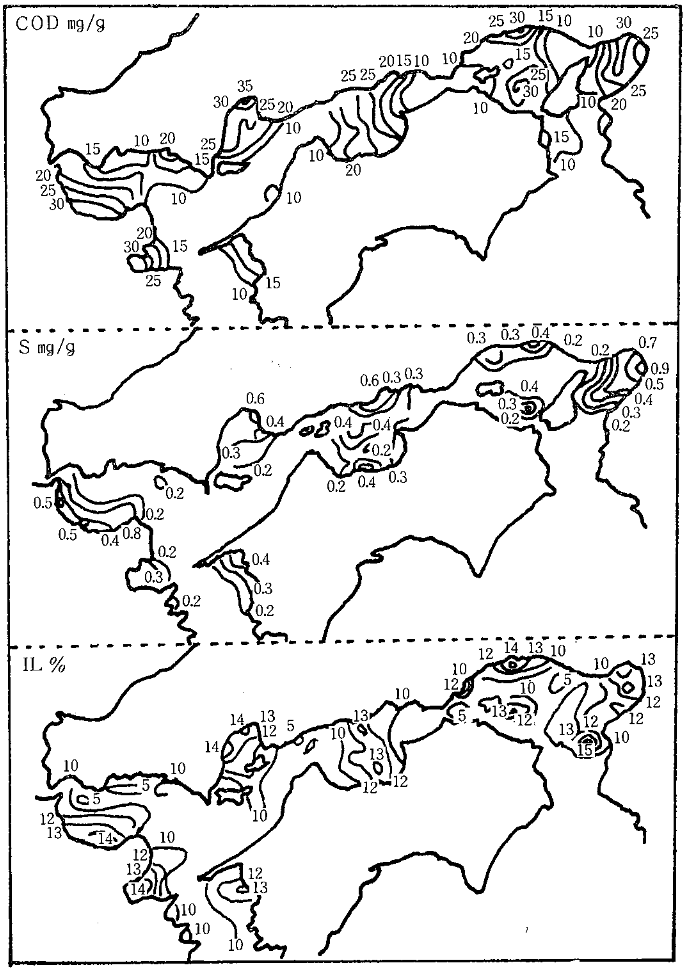

Fig. 3. Bottom mud qualities (COD, Total-S, Ignition Loss) in the Seto Inland Sea. (Oct., 1972)

of zinc-acetate, and titrated with 1/100 N solution of iodine. As a result, the degree of the bottom mud pollution differs seasonally, namely, it increases during summer and autumn, and decreases during winter and spring. The maximum values of COD, IL and total-S are often avairable in autumn. The distribution of COD, IL and total-S in October, 1972 is shown in Fig. 3. It is obvious that the mud is polluted seriously in Osaka bay, the northern coast of Harima Nada, Hiuch Nada, Hiroshima bay, the southern area of Suho Nada and in Beppu bay. The higher values (e. g., COD 30mg/g, IL 14%, total-S 0.5mg/g) are also observed at the central part of Harima Nada, Bingo Nada, Hiroshima bay and the mouth of Beppu bay during summer and autumn. COD and IL values do not exibit the seasonal differences, on the contrary, total-S fluctuates remarkablly. Although the regions where total-S content exceeds 0.5 mg/g are observed everywhere during summer and autumn, it decreases below 0.2mg/g in spring almost in all stations. The nearest station to the coast is 2 or 3 km distant, but there are regions of ca. 35 mg/g in COD and 1.0 mg/g in total-S at the offshore of Kure bay and the central part of Osaka bay. The heavy polluted bottom mud area grew further to the offshore at that time already.

The investigation in 1974 was carried out from September to October, namely in the most polluted season. More than 1,000 stations containing the area 200 to 300 m off fromthe coast was examined and nutrients were determined moreover. The results are shown in Fig. 4 to 9. The maximum, minimum and average value of items in several regions are shown in Table 3. As shown in these figures and table, there are many heavily polluted regions as same as in the former researches. It is noteworthy that the maximum values of COD, IL and total-S are greater than those of in the former researches. It can be supposed that the

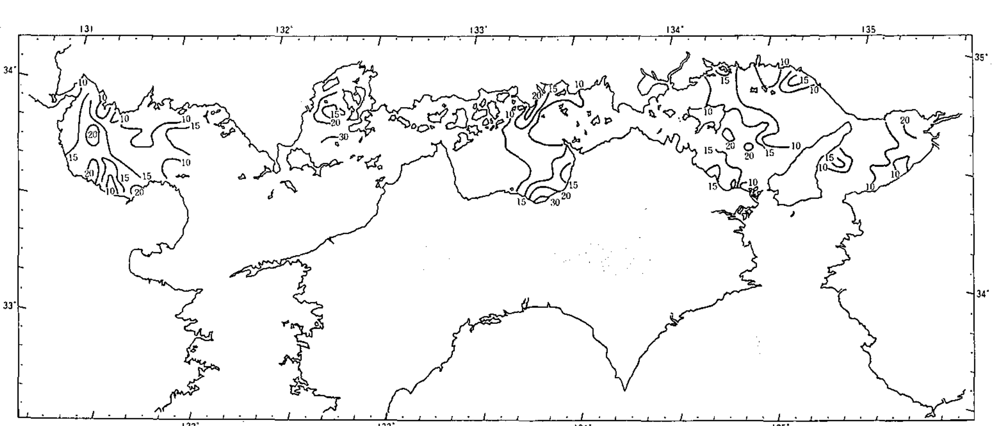

Fig. 4. COD (mg/g) value of the bottom mud at uppr 5 cm layer in the Seto Inland Sea. (Aug.-Oct., 1974.)

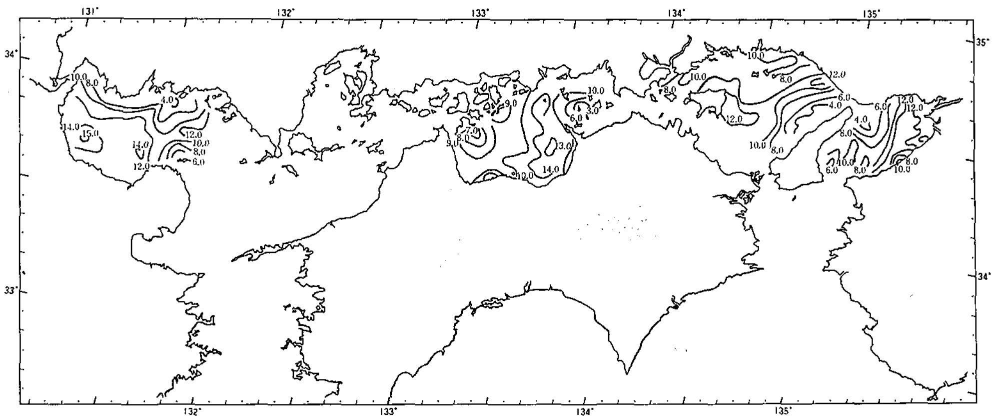

Fig. 5. Ignition Loss (%) value of the bottom mud at upper 5 cm layer in the Seto Inland Sea. (Aug.-Oct., 1974.)

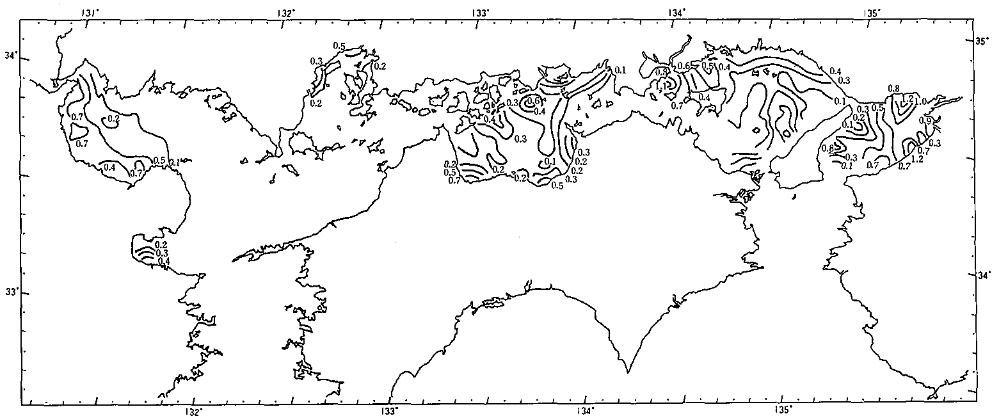

Fig. 6. Total-S (mg/g) content of the bottom mud at upper 5 cm layer in the Seto Inland Sea. (Aug.-Oct., 1974.)

high contents of nitrogen and phosphorus (3.0 mg/g and 1.5mg/g respectively) due to the water containing much dissolved inorganic nitrogen (DIN) and phosphorus (DIP) exists in the mud. According to Ukita et al,[3] the mud column collected off Iwakuni, Mitajiri, Tokuyama and Ube are black in color at the surface, but to fade graduary as deeper layer. Generally, nitrogen and phosphorus contents at upper 5cm layer are 2 or3 times and 1.5 or 2 times as much as those under 20cm layer respectively. Nitrogen and phosphorus contents are especially high in Mitaziri bay polluted by the brewing waste water, they are 15mg/g and 2-3mg/g at upper 20 cm layer of the mud column respectively, and N/P ratio is 6 or 7. Generally, in black surface layer is much in nutrients more

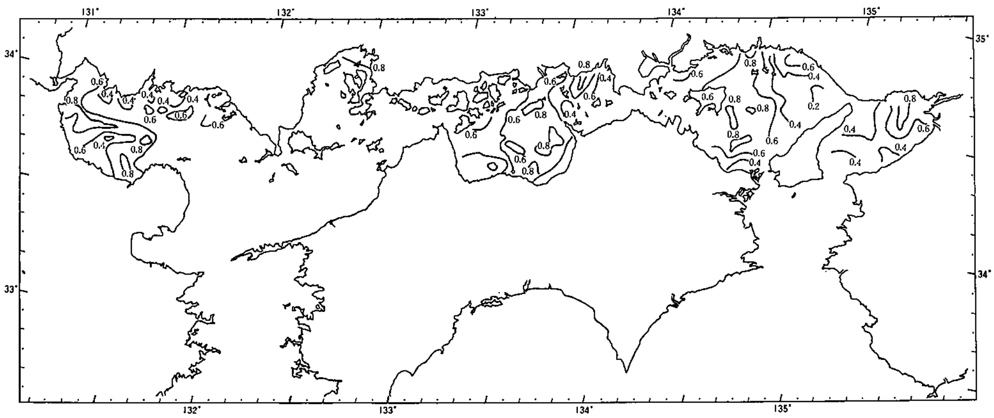

Fig. 7. P (mg/g) content of the bottom mud at upper 5cm layer in the Seto Inland Sea. (Aug.-Oct., 1974.)

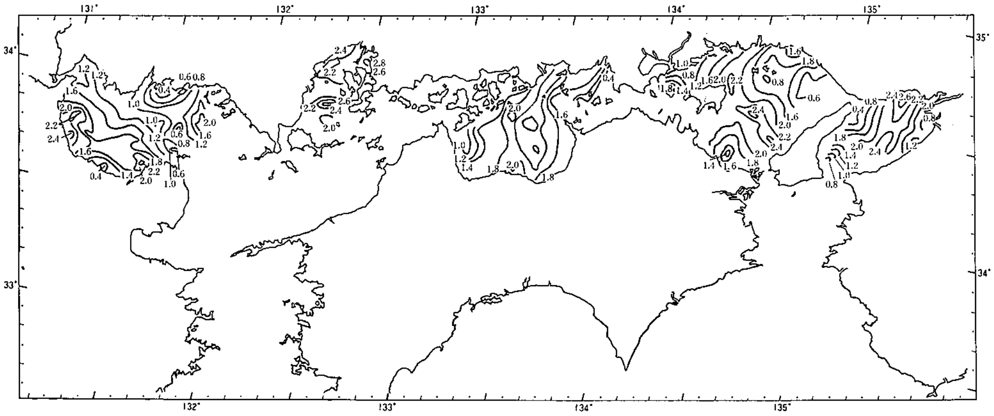

Fig. 8. N (mg/g) content of the bottom mud at upper 5cm layer in the Seto Inland Sea. (Aug.-Oct., 1974.)

in greenish gray deeper layer, nitrogen is 2-3mg/g, phosphorus is ca. 1mg/g, and N/P ratio is 3-10 in the former, and N/P ratio is ca. 2.5 in the latter. Although nitrogen and phosphorus contents were determined only in the upper 5cm layer in the investigation in 1974, usually nitrogen is 1-2mg/g and phosphorus is 0.5-1mg/g. The highest value of N/P ratio (3.3) is observed in Osaka bay and Hiroshima bay, and nitrogen content is 2.8mg/g in both regions. On the contrary, lower values (1.1 and 1.6) of N/P ratio were obtained in Iyo Nada and Kii channel respectively, and nitrogen content is 1.2mg/g in Iyo Nada and 1.3mg/g in Kii channel.

In 28 regions, the coastal area was more polluted than the offshore. As

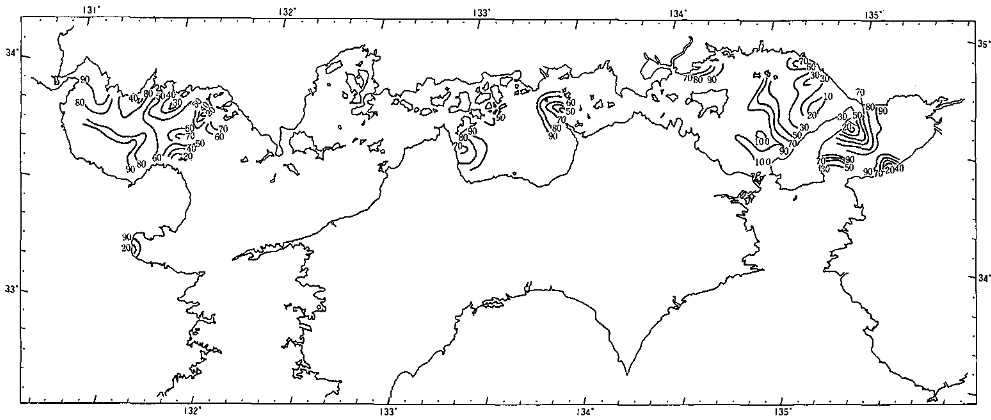

Fig. 9. Composition (%) of silt (dia. 225μ) of the bottom mud at upper 5 cm layer in the Seto Inland Sea (Aug.-Oct., 1974.)

Table 3. Quality of bottom materials in several sea regions in the Seto Inland Sea, Aug.-Oct., 1974

Item \ Sea Region		Suho Nada	Hiroshima Bay	Iyo Nada	Bingo Nada	Hiuchi Nad	Bisan Strait	Harima Nada	Osaka Bay	Kii Suido	inner Beppu Bay
COD (mg/g)	Max.	26.2	40.7	7.8	23.2	20.3	12.9	23.1	21.8	12.9	39.6
	Av.	14.3	23.5	4.2	10.3	8.3	7.8	12.1	6.6	10.0	18.1
	Min.	4.3	12.8	1.3	2.5	2.0	2.4	1.2	1.3	6.4	2.3
IL (%)	Max.	16.5	17.8	12.8	14.8	13.8	12.0	13.8	14.0	8.4	18.8
	Av.	11.0	12.8	8.5	11.0	10.7	8.6	9.6	10.0	6.8	14.2
	Min.	3.1	9.2	4.7	8.4	6.8	2.7	2.6	3.5	3.6	1.8
Total-S (mg/g)	Max.	1.0	0.6	0.1	0.9	0.4	0.8	1.2	1.3	0.3	1.4
	Av.	0.3	0.2	0.0	0.4	0.2	0.3	0.3	0.5	0.1	0.3
	Min.	0.01	0.04	0.01	0.1	0.04	0.01	0.01	0.01	0.02	0.02
P (mg/g)	Max.	1.1	0.9	1.2	0.9	0.9	0.9	0.9	0.9	0.8	1.5
	Av.	0.6	0.7	0.6	0.7	0.6	0.5	0.6	0.5	0.7	0.9
	Min.	0.2	0.6	0.4	0.5	0.4	0.2	0.2	0.2	0.7	0.5
N (mg/g)	Max.	2.5	2.8	1.2	2.5	2.3	1.9	2.5	2.8	1.3	3.0
	Av.	1.6	2.3	0.7	1.9	1.7	1.3	1.7	1.2	1.1	2.2
	Min.	0.4	2.0	0.3	1.4	0.9	0.3	0.4	0.4	0.6	0.4
Compo. of Mud (%)	Max.	100.0	99.4	77.5	99.7	99.9	95.7	99.5	99.0	99.2	99.9
	Av.	75.9	97.6	38.3	97.2	94.8	61.3	81.6	53.1	93.3	91.8
	Min.	10.3	94.2	1.1	86.2	63.2	12.0	3.7	9.8	77.1	14.5

Table 4. Quality of bottom materials in special selected sea regions in the Seto Inland Sea, Aug.-Sept., 1974.

Item \ Sea region		Hiro Bay	off Otake	off Iwakuni	off Hofu	off Mishima and Kawanoe	off Sakai
COD (mg/g)	Max.	55.7	51.4	47.1	16.5	46.8	23.7
	Av.	18.5	27.6	26.4	9.7	16.5	15.7
	Min.	10.1	12.6	15.9	3.3	5.9	7.6
IL (%)	Max.	13.2	27.8	16.4	19.6	19.1	14.4
	Av.	10.2	14.1	13.0	7.3	11.4	11.4
	Min.	8.2	7.5	10.7	2.2	3.5	7.9
Total-S (mg/g)	Max.	1.2	0.7	1.6	0.3	1.2	2.1
	Av.	0.2	0.2	0.4	0.1	0.2	1.0
	Min.	0.02	0.03	0.07	0.01	0.01	0.2
P (mg/g)	Max.	0.8	0.8	1.0	0.8	1.0	1.1
	Av.	0.6	0.7	0.7	0.5	0.7	0.7
	Min.	0.4	0.4	0.3	0.2	0.4	0.4
N (mg/g)	Max.	2.5	3.5	2.9	3.9	2.8	2.7
	Av.	1.8	2.5	2.2	1.3	1.7	2.1
	Min.	1.4	1.4	1.8	0.3	0.6	1.4
Compo. of Mud (%)	Max.	99.6	99.1	99.9	99.4	100.0	100.0
	Av.	89.8	94.3	96.2	63.0	86.2	99.5
	Min.	34.6	34.4	72.9	2.5	3.3	96.0

shown in Table 4, the heavily polluted areas were as follows; off Otake and Iwakuni in Hiroshima bay, Hiro bay in Aki Nada, the inner part of Beppu bay, off Mishima and Kawanoe in Hiuchi Nada, off Sakai in Osaka bay. The major pollution sources are the paper mill waste water in Hiro bay, off Otake and Iwakuni and off Mishima and Kawanoe, and the brewing waste water off Hofu, and the sewage off Sakai, and the sewage and the iron work and oil refinery waste waters at the inner part of Beppu bay. The characteristic of the mud pollution relates to the kind of pollutant. For example, in the polluted area by the paper mill waste water, COD and IL values are high. By the brewing waste water, nitrogen content is high and COD and total-S values are low, but total-S and nutrients values are high in the polluted area by the sewage. Until 1973, ca. 3,000kl of human waste was discharged a day in the Seto Inland Sea, 740kl in the central part of Osaka bay and 620kl in Hiroshima bay etc. It was released off Otake and Iwakuni in Hiroshima bay, so the high contents of nitrogen and phosphorus in this region is due to the discharges. The distribution of COD in upper 5cm layer of the bottom mud at 71 stations off Iwakuni are shown in Fig. 10. The paper mill waste water of 10^5 ton per day in Otake,

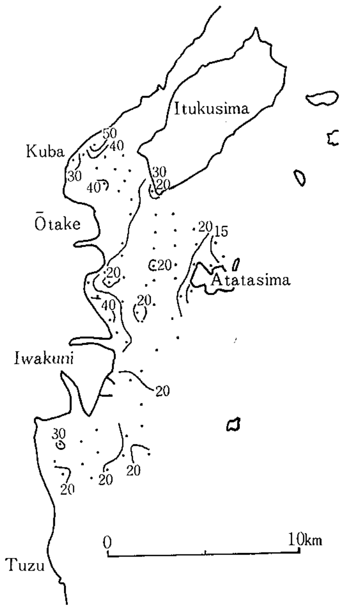

Fig. 10. COD (mg/g) value of the bottom mud at upper 5 cm layer off Otake and Iwakuni. (22nd-25th, Aug., 1974.)

and 3×10^5 ton per day of the same water and the refinery, the petrochemical industry, the rayon manufactory and the airport waste water in Iwakuni are the main sources of pollutants in these areas. Until the 1970's, untreated pulp mill waste water discharged to the sea, so brown color discharged water mass forming bubbles existed at the coast. Near the drainage, COD of the bottom mud was ca. 40 mg/g and was also ca. 30mg/g as far as 3-4km away from the coast. In the environmental water quality standard for fisheries,[4)] the desirable COD of the bottom mud is lower than 20 mg/g. Such bottom mud was observed only around Atada island as far as 4-5km from the coast at that time. The bottom mud off Iwakuni and Otake has already polluted seriously since the 1950's, COD was 40-56 mg/g 0.5km off the coast between Oze river and Imazu river in October 1951.

Considering the vertical distribution of COD value, at the station having over 30 mg/g in COD of the bottom mud at upper 5 cm layer, COD is 20 mg/g at upper 30 cm layer usually. There is a station (Iwakuni St. 5) where COD is 31.8 mg/g at upper 5 cm layer, 33.0 mg/g at 15-20 cm layer, 21.3 mg/g at 30-35 cm layer, 21.8 mg/g at 81-86 cm layer, and 24.6 mg/g at 130-150 cm layer of the mud column. The maximum COD is 46.8 mg/g at upper 5 cm layer off Kawanoe and Mishima where the discharged paper mill waste water is as much as in the Iwakuni and Otake district. COD in the upper layer of the bottom mud is not so different in two sea regions, but the layer of high COD is restricted only to the thin surface layer of the bottom mud off Mishima and Kawanoe. The value of COD over 20 mg/g is not avairable in the layer deeper than 25cm in that region. Thus it is considered as follows; the region off Otake and Iwakuni is located in the western part of Hiroshima bay and is closed by the offshore current. On the contrary, the area off Mishima and kawanoe is located at the coast of the stagnant region, the eastern part of Hiuchi Nada. This region is not closed by the current at offshore, so the polluted mud is spread all over the eastern part of Hiuchi Nada. The paper mill waste water of ca. 10^5 ton per day is discharged into the inner part of Hiro bay. In this region, the area of the polluted mud is restricted within narrow limits near the drainage. Distrbution of high COD value stations are limited in a circle having the center at the point of the drainage, and the values are over 30 mg/g and 20 mg/g at the as far as 1 km and 2 km away from the drainage, respectively. Vertically, COD is over 20 mg/g at upper 50cm layer of the bottom mud, and 30 mg/g is at upper 25cm layer only. Hiro bay is narrow and has a wide mouth opening to Aki Nada. The exchange of water between in and out of this bay is rather soomth, so the colored waste water mass extents to the outer part of the bay occasionally. Under these circumstances, the fiber of the pulp in the waste water does not deposit on the bottom mud thickly. Therefore, it can be said that the horizontal and vertical distributions of the polluted bottom mud are ruled by the current and the configuration in the sea.

The amount of the polluted mud was estimated as follows: at first, COD in every 25 cm layer of the mud column was obtained at each station from the vertical distribution of COD. Stations where the bottom consists of the sand or the rock are excluded by the grain composition and the results of the echo sounder investigation. The area is devided into several blocks by lining the above-mentioned stations. The volume of each layer in every blocks was obtained multipling the dimensions by the thickness (25cm). Accumulative curve of the polluted mud volume in each layer of the bottom mud column in each examined sea region, as shown in Fig. 11 (upper 25 cm layer in Hiroshima bay), is calculated with the percentage of the mud volume in every layer as a vertical axis, and the average COD in each block as a horizontal axis. From this figure, the volume of the polluted mud in every COD range can be estimated multipling the whole volume of the mud by the percentage in the accumulative curve. The amount of the polluted bottom mud estimated by COD at each region in the Seto Inland Sea is shown in Table 5. The volume of polluted bottom mud over 30 mg/g of COD value exists ca. 8×10^6 m^3 in the Seto Inland Sea, and 92% of it is in Hiroshima bay, and over 40 mg/g exists as much as 10^6 m^3 and 85% of it also in the same bay. Although the pollution is slight in Aki Nada and Iyo Nada because of the relatively strong current, the polluted bottom mud exists at Hiro bay in Aki Nada and the inner part of Beppu bay in Iyo Nada, as shown in Table 5.

According to the research in August 1975, the volumes of the polluted mud over 30 mg/g and 40 mg/g of COD values are 488×10^5 m^3 and 71×10^5 m^3 in Ise and Mikawa bay, respectively. Although the area of Ise and Mikawa bay is a tenth of the Seto Inland Sea, seven times volume of the polluted mud exists in Ise and Mikawa bay. It is supposed that this is due to the difference of the water exchanges in both regions. According to the Environment Agency, the

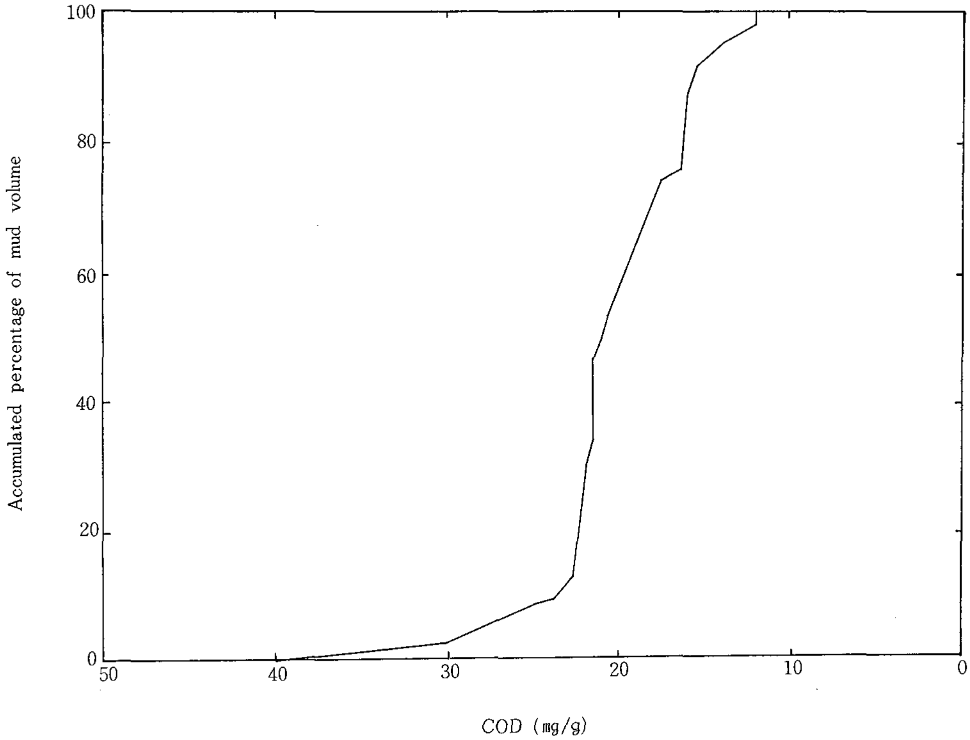

Fig. 11. Accumulative curve of polluted bottom mud at upper 5 cm layer in Hiroshima Bay. (Aug., 1974.)

Table 5. Volume of polluted bottom mud in several sea regions in the Seto Inland Sea, Aug.-Oct., 1974. X10[4] m[3]

Sea regiom	COD mg/g Area (km^2)	15	20	30	40	50
Osaka Bay	1,529	5,523.1	1,211.2	4.5	—	—
Kii Suido	1,554	21.3	—	—	—	—
Harima Nada	3,462	1,964.5	589.6	7.1	—	—
Bisan Strait	916	61.9	—	—	—	—
Bingo Nada	954	1,400.1	464.4	—	—	—
Hiuchi Nada	954	878.1	119.8	14.4	6.4	—
Aki Nada	963	608.5	58.3	26.5	8.8	4.1
Hiroshima Bay	946	75,737.0	22,115.1	725.6	87.0	0.7
Beppu Bay Iyo Nada	3,974	4,076.5	363,5	12.3	—	—
Suho Nada	3,100	17,633.2	794.0	—	—	—
Total	18,352	107,904.2	25,715.9	790.4	102.2	4.8

pollution load of COD is 1,600 ton per day in the Seto Inland Sea in 1972, and is 600 ton per day in Ise and Mikawa bay in 1973.

3. Removal experiment of organic polluted bottom mud in fisheries ground

The red tide in the Seto Inland Sea breaks out frequently since the latter half of the '70s, as shown in Fig. 12. Recently, the red tide breaks out about 300 times a year in that sea. According to it, the red tide breaks spreadly in all the Seto Inland Sea and continues for long time in a whole year. A kind of red tide plankton changes to Flagellates from Diatoms. In a word, the red tide in the Seto Inland Sea is becoming wores recently. Especially, the red tide by *Hornellia* (Chloromonadophyceae) breaks out in large scale in warm season, from July to September, and damages cultured yellowtail severely. The number of cases of the red tide harmful to fisheries shown in Fig. 12, has not connected with the scale of the damage. But, for example, in the case of the red tide by *Hornellia* in Harima Nada and the western part of Kii Suido in summer 1972, the damage in fisheries was record-breaking to kill the cultured yellowtails valued as ca. 7 billion Yen. It is clear that such deterioration of the red tide in the Seto Inland Sea owes much to the excess of the eutrophication in inshore waters. Since 1973, Fisheries Ageney has been carrying out the realization project of removing the polluted mud to reduce the eutrophication, for the purpose of avoiding the fisheries damages.

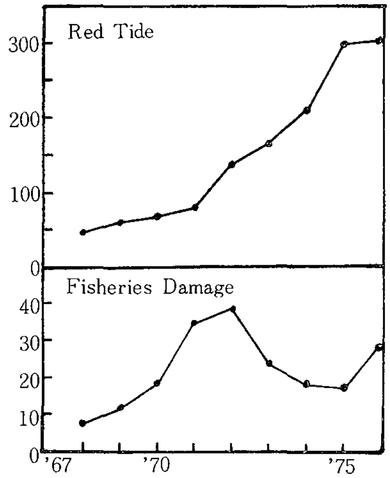

Fig. 12. Frequency of red tide and fisheries damage in the Seto Inland Sea. (1967-1975)

The experiment was carried out by the joint venture of "world Ocean System Co." and "Fuyo Ocean Development Co." at Yura in Awaji Is. in 1973, at Sagoshi bay in Ako city in 1974, Aboshi bay in Himeji city in 1975. In 1976, it will be carried out at Ie Is. in Harima Nada. In this project, the organic polluted bottom mud in the yellowtail nurseries or off the river mouth is dredged in order to prevent the diffusion of mud. The dredged mud transferred to the sedimentation pontoon at 600 m distant by a suction pipe on the sea surface, then the mud is treated through the processes of coagulation, sedimentation and dehydration. The separated water is filtered, then discharged to sea. The settled sludge is hardened, then dumped on the reserved land area. The flow sheet of the experiment carried out for Aboshi bay is shown in Fig. 13. The bottom mud off the mouth of Ibo river is black in color and smells of hydrogen sulfide, 34-85 mg/g of COD value, and much of sulfide and total chromium.

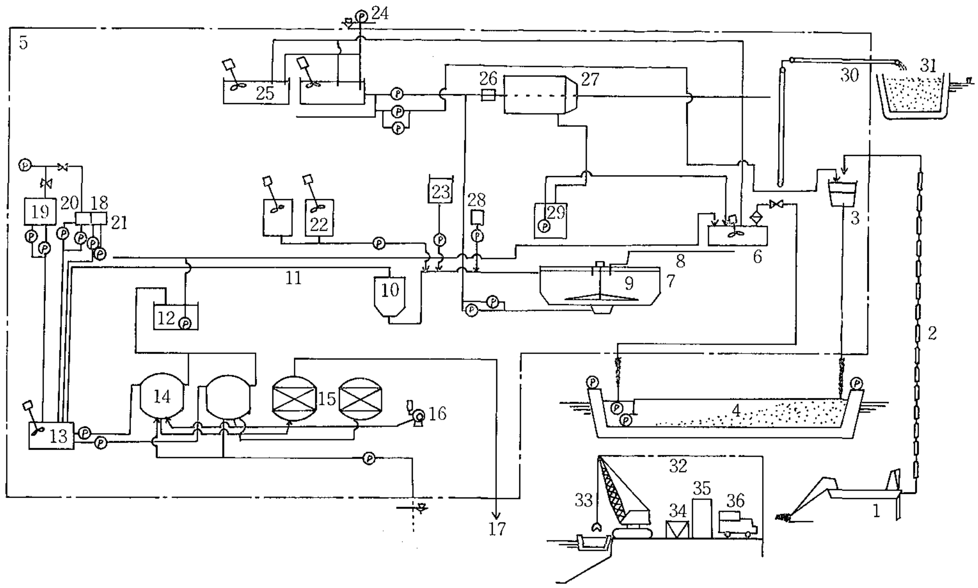

Fig. 13. Flow sheet of withdrawal and treatment of polluted bottom mud.

1. dredger (180m^3/h) 2. pipe on sea surface 3. screen 4. storage barge 5. treatmnt pontoon 6. coagulation tank 7. sludge collector 8. concentration tank 9. thickener (140 m^3) 10. super-high rate pelletizing and sedimentation unit (PBS type) 11. separated water 12. back washing waste water tank 13. chlorinated reaction tank 14. filter 15. activated carbon absorption 16. back washing blower 17. effluent 18. sulfuric acid storage tank 19. NaC10 storage tank 20. NaOH storage tank 21. polymer dissolved tank 22. P. B. S. polymer dissolved tank 23. aluminium sulfate storage tank 24. sea water pump 25. polymer dissolved tank 26. sludge mixing trough 27. dehydrum 28. sulfuric acid storage tank 29. separated water tank 30. belt conveyor 31. barge (300 m^3) 32. discharging wharf 33. cramshell bucket 34. hopper 35. cement silo 36. mixing car

The bottom sediment dredger equipped with a suction mouth which has movable wings and a variable volume (0-1, 500 m^3/hr) volute pump dredges the polluted bottom mud at the speed of 1,900 m^3 of the mixture per hour. The mud is 50-60 cm in thickness, 5,700 m^2 in extent and 2-2.5 m under sea surface. The quality of the mud is 30% in average concentration of mud 11μ in 60% grain size. The dredged mud is ca. 3,100 m^3 in bottom. Two sedimentation pontoons of 600 m^3 volume are used, one for sedimentation and the other for discharging the sludge. The volume of the sludge is 30 to 50% of the dredged mixture. Often the screen is clogged with depositted vinyl sheet or grass, so the volume and the mud concentration of the supernatant transferred to the treatment pontoon varies in several times. The treatment pontoon has a treating capacity of 50 m^3 per hour. Alum and polymer are poured into the supernatant as an coagulant, under the proper condition of pH regulated with sulfuric acid and sodium hydroxide, then sodium hypochloride is used for denitrification. The raw water is treated through the thickener and the dehydrum. Finally, the supernatant is treated with the activated charcoal to remove the residual chlorine, then the water discharged to sea after confirming the security for marine organisms by the bioassay with minows. The effluent water quality standard is described as follows; "$SS<20$ mg/l, $NH_4-N<1$mg/l, free chlorine <0.05 mg/l, $H_2S<1$mg/l, $pH<9$" and the heavy metals and harmful substances are discharged in the concentration less than the quality standard as shown in the water Pollution Control Law. The settled sludge in the sedimentation pontoon and the dehydrated cake from the dehydrum are landed, and mixed with cement, then dumped on the reclaimed land and covered the surface with sand.

Essentially, this experiment is aim to remove an organic polluted bottom mud without the effects to the sea and the red tide, so the effect to the surrounding sea and the breaking of the red tide is also estimated during the experiment. As a result, there was no direct effect due to the experiment except the increase of NH_4-N concentration in sea water. On the other hand, the experiment with the red tide plankton culture is carried out to make clear the effects of the effluent to the breaking out of the red tide. Cultures of *Hornellia* and *Olisthodiscus* are added with sea water to the filtered effluent. They are kept during two weeks under the condition of water temperature: 20°-30°C and illumination: 4,000 Lux, (illuminated 12 hrs per day). As a result, each culture was not increased in growth rate. On the contrary, the growth rate was inhibited, and, sometimes, the *Hornellia* culture and also minows as a monitor of the harmlessness of the effluent were killed, probably due to the high concentration of NH_4-N and residual chlorine and chloramine in the effluent.

On this project, it is the most difficult how to deal with the newly deposited materials on the surface of polluted mud. As above mentioned, the eutrophicated bottom mud is a secondary origin of nitrogen and phosphorus to the bottom water. They are released from upper 15 or 20 cm surface layer of the bottom mud mainly. But the detritus suspendig in sea water is more important as a secondary origin. It is settling gradually, then concentrates in the water layer 1 or 2 m above the bottom mud, finally it deposits as newly deposited materials.

So, generally in many polluted sea, there is the newly deposited materials in different color in several mm thickness, and suspends the concentrated detritus in the water layer contact with bottom surface. It is the same as the case of the fiber waste from the pulp mill. In this project, the mud is dredged by a dredging pump to prevent the diffusion of mud, but is can not be applicable always to the newly deposited materials or the concentrated detritus. It is important to examine this problem, especially in the case of polluted bottom mud caused by the pulp fiber.

At the decision of removing area, it is necessary to make clear the mechanism of the effect in fisheries and the significe of the mud in the polluting environment. Of course, the balance between the scale of damages and the cost of removal treatment must be examined when the project is carried out commercially, but it is more important that the remove must be decided reasonably in the view point of pollution mechanism. Once the remove is decided, the quality, the range, the thickness of the mud and the time to remove must be examined through the research on the distribution of bottom mud and detritus.

The quality of mud represented by the parameters indicating the pollution such as COD, IL, N, P, total-S and size composition of mud and so on. Moreover, toxicity, heavy metals and oil may be necessary according to the circumstances. These parameters must be measured vertically and horizontally as in detail as possible, not only on mud but on deposit and detritus, together with the releasing rate. Unsoluble nitrogen and phosphorus in the bottom mud do not acceralate the eutrophication in the sea water, but once these nutrients change into soluble state due to the bacterial action or the lowering of pH in sea water, they are added into the bottom layer sea water through the water exists in the bottom mud. Moreover, nitrogen and phosphorus also are released from the newly deposited materials or suspending detritus directly. These processes are very important according to the eutrophication in inshore waters. But, unfortunately, we have no effective method to sample the detritus, the newly deposit and the water in mud, so it is necessary to develop the method in the further project. When the project is carried out in the water of lacked dissolved oxygen, it is desirable to measure DO content continuously in time and space with the DO meter.

After the conditions in bottom mud and bottom layer water are cleared, then the range of values in each parameter of the polluted mud to remove must be decided. The desirable quality of the bottom mud in the fisheries ground are protested in "the environmental water quality standard in the fisheries ground" such as "COD is below 20 mg/g, total-S is below 0.2 mg/g, the concentratration of the n-hexane soluble matter is less than 1% and no harmful substances in soluble state.[4]" As a matter of course, the qualities in the polluted bottom mud in the stagnant region in the seto Inland Sea and so on are heavily worse than those in the standard. So, it can not be adopted these values in the standard as a lower limit of qualities of the bottom mud to remove. In this experiment, 30mg/g in COD is decided as one of the objects in the removing of the organic polluted mud. But, according to the results in III, from the economical point of view, the objects might be considered such as "40mg/g in COD, 15-20% in IL, 1mg/g in total-S, 1mg/g in total-P, 2-3mg/g in total-N."

As mentioned above, the minimum limit of the quality of the polluted mud to remove should be decided from the view point of the pollution mechanism more than the cost, in case by case. The thickness of the mud to remove may be 20 to 30cm in general. The distribution of the polluted mud must be estimated vertically and horizontally by the boring test in many stations and the echo sounder investigation. As a conclusion, it is necessary to establish the standard for removing of the mud as fast as in carrying out of this project.

The project of removing the polluted mud should be completed with the estimation of the effects to the improvement of the fisheries ground environments. The method has not been discussed yet in our experiment, but it is desirable to establish the method how to estimate the effects not only in the improvement of the environment and the reduction of the fiisheries damage, but in the technical problem such as the removing efficiency.

4. Conclusion

In marine pollution, the turbidity in the surface water or the colored waste water mass are recognized directly. But, in general, the toxicity and heavy metal contamination to the fisheries catch or the bottom mud pollution can not be detected easily. They can be recognised at the first time by the red tide or the polluted catch and the death of fishes usually. Especially on the bottom mud pollution, there are only few results of research. Moreover, it is very difficult to carry out the research itself due to the pollution and its damage occur at the bottom of the sea. Only in the Seto Inland Sea, the results are increasing gradually due to the successive fisheries damages to compare with the other inshore waters. So the bottom mud pollution and the mechanism of the influence by it being to be cleared in that sae gradually. Now the importance of the bottom mud removing is recognized as a countermeasure to the marine pollution. On the other hand, the reclamation and the dredge are carrying out frequently in inshore waters, so the polluted bottom mud can not be disregarded as a secondary origin of the pollution load to sea already. It is naturally that the regulation of the reclamation and the pollution load is a basic countermeasure to the marine and bottom mud pollution. But, on the other hand, in the polluted inshore waters, such as the Seto Inland Sea, it is also important to remove the pollution load in bottom mud. The progress of the research on the polluted bottom mud is desirable strongly for the protection of the marine environments.

Summary

An organic pollution of bottom mud in the Seto Inland Sea has been observed near by the pulp mill waste water drain since the 1950's. By the 1970's, the polluted bottom mud area grew further to the offshore. (Fig. 3)

Fisheries Agency examined the organic pollution of bottom mud in the Seto Inland Sea from August to October in 1974. (Fig. 1,2, Table 1,2) According to the project, concentration areas of the polluted mud were observed in Osaka bay, the eastern part of Hiuchi Nada, Hiroshima bay, Beppu bay and some other areas. (Fig. 4-9, Table 3,4) The upper 20 to 30 cm layer of the bottom mud was polluted heavily. The volume of the organic polluted bottom mud (COD>40mg/g) is 10^6 m^3 in the Seto Inland Sea, and 85% of the mud exists in Hiroshima bay. (Fig. 10. 11, Table 5)

On the other hand, the red tide in the Seto Inland Sea became harmful since the 1960's. It is proved that the breaking out of the red tide owes much to the excess of eutrophication in inshore waters, and the organic polluted bottom mud contributes to the eutrophication. Since 1973, Fisheries Agency has been carrying out the realization project of removing the polluted mud to reduce the eutrophication.

In this project, the organic polluted bottom mud is dredged by a dredging pump equipped with a variable volume volute pump in order to prevent the diffusion of mud. The dredged mud is transferred to the treatment pontoon by a suction pipe, then the mud is treated through the processes of coagulation, sedimentation and dehydration. The activated charcoal is used to filter the separated water, then the water discharged to sea. The settled sludge is hardened with cement then dumped on the reserved land area. (Fig. 13)

There are some problems left in our experiment; the method of removing the newly deposited materials on the surface of polluted bottom mud or concentrated detritus in the water layer contact with the bottom surface.

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瀬戸内海における底質の有機汚染とその除去

村　上　彰　男

瀬戸内海の底泥汚染は，局地的にはパルプ廃水の排出口周辺などで1950年代から認められていたが，1970年代には既に沖合にまで拡大した。

1974年8～10月の有機汚染泥調査によると集中汚染域は大阪湾，燧灘東部，広島湾，別府湾などにみられる。泥層別には，20～30cm以浅の層の汚染が著しい。COD40mg/g 以上の泥は瀬戸内海全域に10^6 m^3存在し，その85%は広島湾にある。

こういった汚染泥は赤潮の悪質化の一因であることから，漁場環境保全対策の一環として1973年から有機汚染泥回収の事業化試験が行われている。可動翼付きの浚渫ポンプで拡散を防止しつつ浚渫し，パイプで処理船に送って凝集剤を加えて沈んで脱水し，分離水は沪過して水質悪化のおそれのないように処理し，安全を確かめてから海に放流し，沈でん物は固化して陸上の土捨場にすてた。汚染泥表層の新生堆積物や直上海水層中の濃密なデトライタスの回収などの点になお検討の余地が残されている。

なお，本論文は第2回有害底質の処理処分に関する日米専門家会議（於，東京1976年10月25～28日）において発表した。

正　誤　表

頁	行	誤	正
26—28	Fig. 6. a)～d)	○>6/0.1m^2	○≧6/0.1m^2
33	7	Seto inland sea	Seto Inland Sea
50	Table 2.	surveis	surveys
52	文献４）	Eish	Fish
54	5	regiosn	regions
58	20	fromthe	from the
63	34	Mishima and kawanoe	Mishima and Kawanoe
66	30	"world Ocean System Co"	"World Ocean System Co"
73	1	makig	making
73	19	small	smaller
81	Table 5.	Other	Others
84	3	底生動物の	底生動物群集の
85	文献４）	東海・東海	東海・黄海
87	18	be results	be the results
96	5	８月２日．６日	８月２日・６日
123	14	三木[6)]	Miki[6)]
126	Fig. 4.	Zostera marina	*Zostera marina*
130	1	三木[6)]	Miki[6)]