On The Biogeochemical Characteristics of Surface Sediments in Chinhae Bay in September 1983

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Distribution of organic materials in the surface sediments was investigated in September 1983 in Chinhae Bay System. Bottom waters containing less than $1ml/l$ of dissolved oxygen were found in Masan Bay, and in part of Kohyonsong Bay and Wonmunpo Bay. Organic carbon content in the surface sediments of Masan Bay was about $25mg/g$ and it decreased with increasing distance from the inner Masan Bay. Mean organic carbon contents in Wonmunpo Bay and Kohyonsong Bay were 26.48 and $31.39mg/g$, respectively, which are higher values than those in Masan Bay where large amount of domestic and industrial wastewaters are discharged into the surface water and extensive phytoplankton bloom occurs almost year round. Mean organic nitrogen and pheophytin contents were also the highest in Kohyonsong Bay among eight subareas. In Masan Bay, settling of organic materials on the surface sediments seemed to be not significant because of active tidal mixing and relatively small size of particulate materials.

In Kohyonsong Bay and Wonmunpo Bay large fecal pellets produced in shellfish farms could be easily settled down on the sediment because of weak current regime. DO content in the bottom waters were low in the organic material rich areas, and that suggests biodegradation of organic materials in the surface sediments could be an important oxygen consuming process during the study period of September 1983.

Introduction

Organic materials are important for the sediment feeding organism as the food source. However the excess amount of organic materials compared to the rate of oxygen supply may bring the oxygen deficient condition in the bottom waters, because dissolved oxygen is consumed for bacterial decomposition. Oxygen deficient condition can easily occur when steep seasonal thermocline separate the surface layer from bottom layer. Among Korean coastal areas, Chinhae Bay recently became a public concern because of deterioration of its environment. From Masan and Changweon industrial area large amounts of domestic and industrial wastewaters are discharged into the inner Masan Bay, a part of Chinhae Bay.

Frequent red tide outbreaks have been reported in this bay and many studies have been done to elucidate the relation between pollutant input and massive phytoplankton blooms (Lee et al., 1980, 1981, 1982, 1983 ; Park, 1982 ; Yoo and Lee, 1980). In Chinhae Bay paralytic shellfish poisoning has not yet found and reported damages are mainly from anoxic bottom waters in summer. Mass mortalities of fishes and benthic macroinvertebrates due to anoxia are common in various parts of the world (Jorgensen, 1980). Oxygen deficient bottom waters have been reported in many areas in Chinhae Bay System (Lee et al., 1980, 1981). In Chinhae Bay large shellfish culture farms have been established since 1970. In the shellfish farms, eutrophication is accelerated due to the accumulation of a large quantity of organic sediments in the

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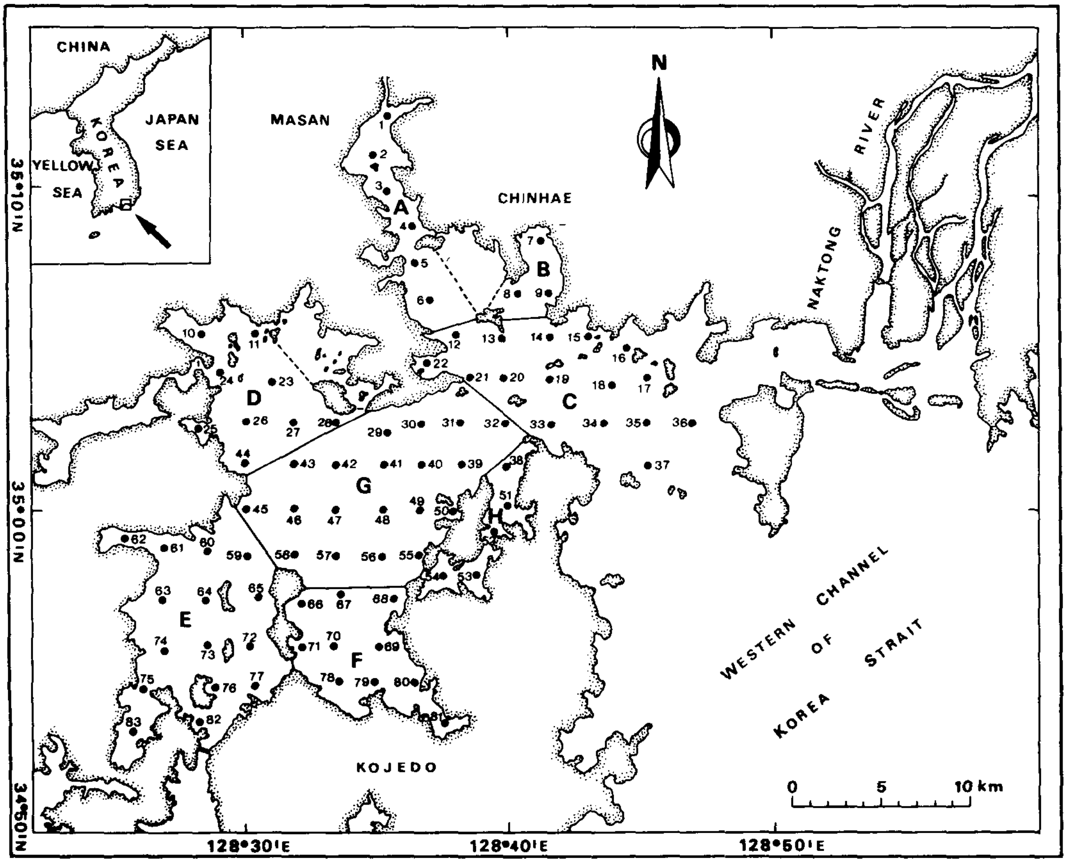

Fig. 1. Study area in the Chinhae Bay System (A=Masan Bay, B=Haeng-am Bay, C=Kadok Waterway, D=Chindong Bay, E=Wonmunpo Bay, F=Kohyonsong Bay, G=Chinhae Bay Proper, H=Chilchon Waterway).

seafloor, largely fecal materials of the shellfish.

Remineralization of organic material occurs throughout the sediment column, but the highest activities are found near the sediment surface (Vosjan and Olanczuk-Neyman, 1977). Activities of shellfish cultures are generally centered in the inlets and small bays receiving little effects of waves. Densely installed culture facilities would further obstruct the water circulation. Thus fecal pellets produced by cultured bivalves and other fouling organisms are fallen down directly to the bottom sediments because of weak water movement. Among the previous studies made in Chinhae Bay, Cho *et al.* (1982) reported distribution of organic materials in the sediments of shellfish farms. The objective of the present study is to describe the distribution of organic materials in the surface sediments and to elucidate the impact of organic material degradation to the surrounding environment, particularly oxygen consumption in the bottom waters in Chinhae Bay System.

Materials and Methods.

Chinhae Bay System

The Chinhae Bay System is situated in the south eastern part of the Korean peninsula(Fig. 1). The study area is composed of eight major subareas : Masan Bay (A), Haeng-am Bay (B), Kadok Waterway (C), Chindong Bay (D), Wonmunpo Bay (E), Kohyonsong Bay (F), Chinhae Bay Proper (G), which is the central part in Chinhae Bay System and Chilchon Waterway (H). The total area surveyed is approxi-

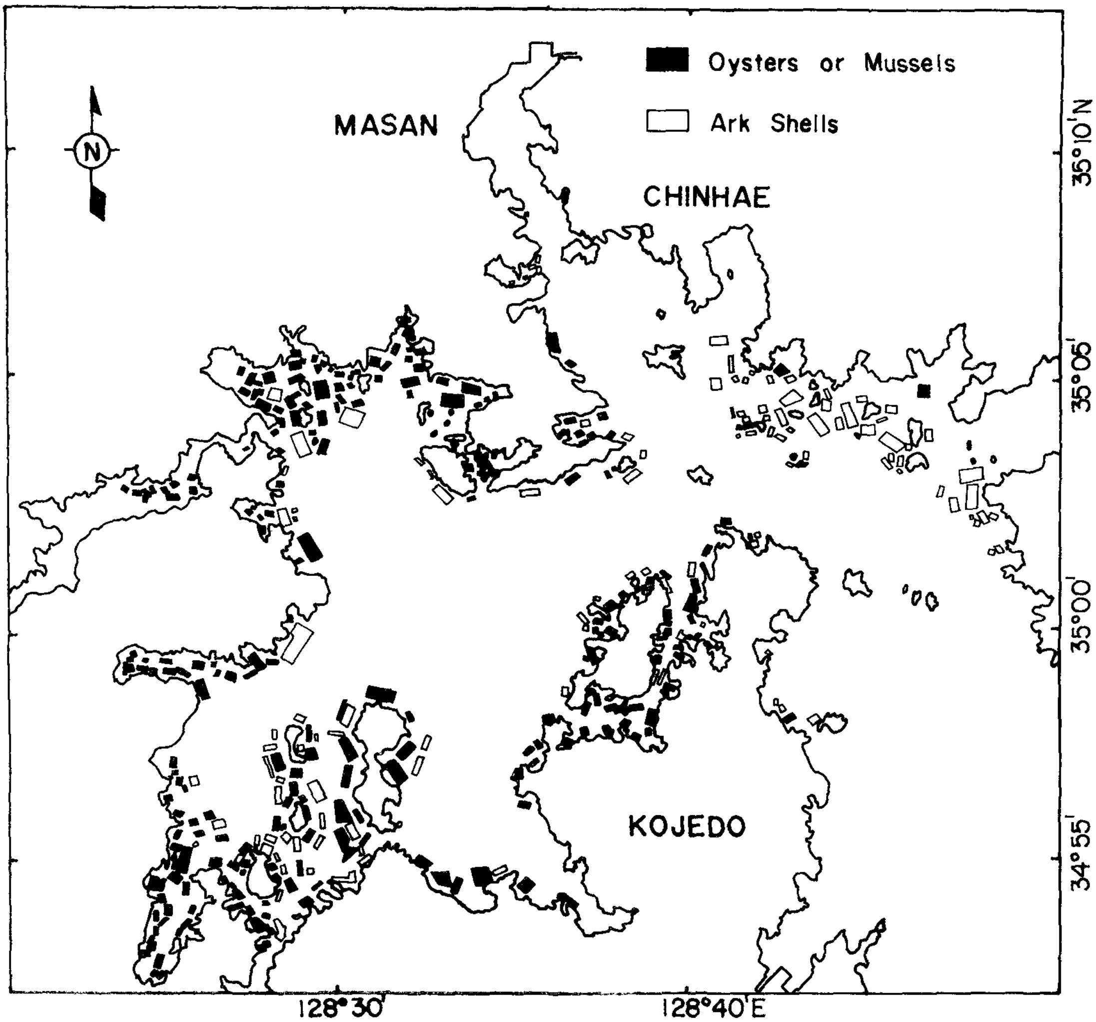

Fig. 2. Shell fish farms in the Chinhae Bay System in 1983.

mately $497km^2$. The Chinhae Bay System is $45m$ deep near its connection to western channel of Korea strait but averages $20m$ in depth. Mean tidal range is $2.0m$ and annual prevailing winds are generally southwest. A total of 37.5 km2 is used for shellfish culture in this area, which is approximately 7.5% of the Chinhae Bay System (Fig. 2). Shellfish farms are mainly consisted of intensive raft and long line culture of oysters.

Analytical methods

The samples for this study were collected during a survey cruise on the oceanographic vessel BAN-WEOL-HO between September 8 to September 16, 1983. Eighty three Stations were selected with a grid interval of $2.5km$. Sediment samples were taken using a 0.1 m2 Van Veen grab. Sediment samples were frozen on board and brought to laboratory for analyses of organic materials. Salinity of seawater was measured using an Oceanographic salinity and temperature measuring Bridge (type MC 5). Dissolved oxygen was measured using a Dissolved Oxygen Meter (Yellow Springs Instrument Model YSI 57). Sediment organic carbon and nitrogen contents were determined using an elemental analyzer after treatment with 0.2 N HCl to remove carbonates. Perkin Elmer 240B Elemental Analyzer was calibrated with acetanilide according to the method recommended by Byers et al. (1978). Pheophytin contents in the surface sediments was

Table 1. Mean values of phaeophytin, organic carbon, organic nitrogen in the superficial bottom mud, and salinity and dissolved oxygen in the overlying waters in the Chinhae Bay System during September 1983

Area	Salinity (%)	Do (ml/l)	Do Saturation (%)	Organic N (mg/g)	Organic C (mg/g)	Phaeophytin (ug/g)	C/N
Masan Bay	30.83	0.41	9.53	2.80	23.41	13.59	8.32
Haeng-am Bay	29.87	1.99	39.72	2.72	23.67	10.35	8.55
Kadok Waterway	30.90	3.01	57.75	1.99	15.16	8.41	7.62
Chindong Bay	31.88	2.08	40.67	2.96	22.07	12.05	7.56
Wonmunpo Bay	32.18	1.99	39.12	3.48	26.48	11.49	7.60
Kohyonsong Bay	32.65	1.66	32.67	4.06	31.39	16.06	7.86
Chinhae Bay Proper	32.84	1.99	36.98	2.59	19.21	9.81	7.41
Chilchon Waterway	30.66	3.49	69.50	2.32	17.14	9.09	7.42

measured on 90% acetone extracts (SCOR-UNESCO, 1966). Concentrations of organic carbon, organic nitrogen and pheophytin were expressed as weight per dry weight of sediment.

Results

The mean values of organic carbon, organic nitrogen, pheophytin, salinity and dissolved oxygen (DO) for each subarea is given in Table 1. Mean values of salinity in the bottom waters exceeded 32‰ in Wonmunpo Bay, Kohyonsong Bay and Chinhae Bay Proper implying that freshwater inflow to this region is not so significant as in other bays.

The horizontal distribution of dissolved oxygen in the bottom waters in Chinhae Bay System is shown in Fig. 3. Dissolved oxygen ranged from 0.11 to 4.49 *ml/l* and mean dissolved oxygen content in the bottom waters was lowest in Masan Bay(0.41*ml/l*) among 8 subareas. Bottom water which contains less than 1*ml/l* of dissolved oxygen, was also found in other areas such as western part of Kohyonsong Bay and inner portion of Haeng-am Bay. Also Do contents ranged between I and 2*ml/l* in southern part of Masan Bay, southern part of Haeng-am Bay, northern part of Wonmunpo Bay, and near Gajodo area in Chinhae Bay Proper. The hypoxic area (with dissolved oxygen content less than 2*ml/l*) was extended an area of about 266 km2 out of a total 497 km2 of study area. In Chindong Bay where many shellfish farms are located mean dissolved oxygen content in the bottom waters was 2.08*ml/l*. The highest mean dissolved oxygen content (3.01*ml/l*) in the bottom waters was found in Kadok Waterway.

Sediment organic carbon (SOC)

Horizontal distribution of organic carbon in the surface sediment is shown in Fig. 4.

In Masan Bay and Kadok Waterway areas organic carbon contents decreased with increasing distance from the inner Masan Bay where large amounts of domestic and industrial wastewaters are discharged. In the narrow inlets of Masan Bay SOC contents were about 25*mg/g*, but decreased to 17.15 and 16.10*mg/g* respectively at St. 12 and 20 near Budo Waterway. At St. 34, 35, 37 in Kadok Waterway SOC contents were 13-15 *mg/g* which implies that organic pollutants originated from Masan industrial area showed much reduced influence in this area. High SOC content of 32.78*mg/g* was noted at St. 7 in Haeng-am Bay.

In Chindong Bay SOC contents ranged from 19.73

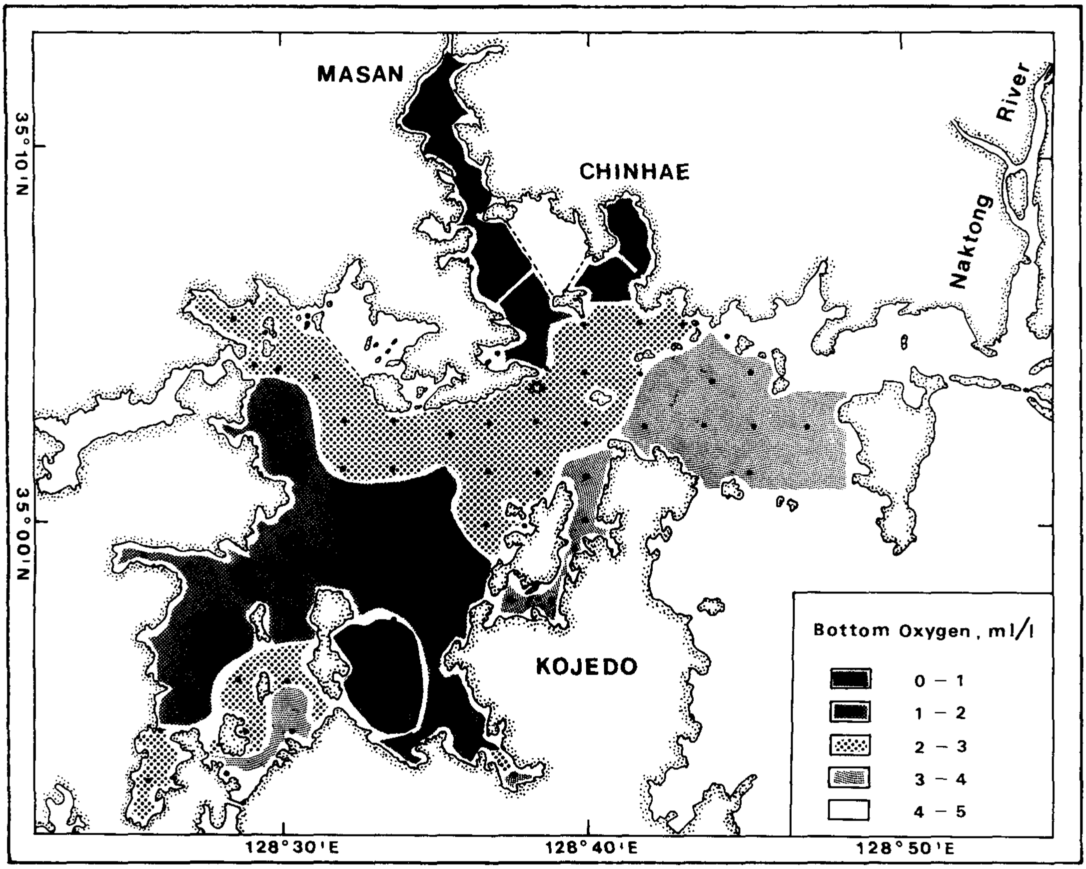

Fig. 3. Distribution of dissolved oxygen (*ml/l*) in the bottom waters during September 1983 in the Chinhae Bay system.

to 26.57(m = 22.07)*mg/g* showing slightly higher value than those in the central part of Chinhae Bay Proper. The average SOC contents in Wonmunpo Bay and Kohyonsong Bay were 31.39 and 26.48 *mg/g*, respectively, and were higher than those of Masan Bay. In the large part of Kohyonsong Bay and the western portion of Wonmunpo Bay, SOC contents were more than 30 *mg/g* in the surface sediment. In Chinhae Bay Proper, more than 20 *mg/g* of SOC contents was only found in the area adjacent to Wonmunpo Bay and Kohyonsong Bay. Relatively low SOC content was found in Chilchon Waterway (17.14 *mg/g*). In the pearl culture farms of Tategamiura, Japan, Sawada and Taniguchi (1965) found 21.8-42.7 *mg/g* of SOC which are not different from our results in Chinhae Bay System. They measured 12.8-30.6 *mg/g* of SOC in the area around Kashikojima, Japan which is adjacent to pearl culture farms.

Organic nitrogen

Fig. 5 shows the horizontal distribution of organic nitrogen in the surface sediment obtained from Chinhae Bay System.

In Masan Bay organic nitrogen contents in the surface sediment decreased with increasing distance from the inner Masan Bay as was the case of SOC. Organic nitrogen content in the surface sediment was 3.3 *mg/g* at St. 2 of the inner Masan Bay and 2.23 *mg/g* at St. 12 of the outer Masan Bay.

In Kadok Waterway less than 2 *mg/g* of organic nitrogen was found in the outer part.

Mean organic nitrogen contents in Masan Bay (2.80 *mg/g*) and in Haeng-am Bay were lower than those of Kohyonsong Bay even though the man-in-

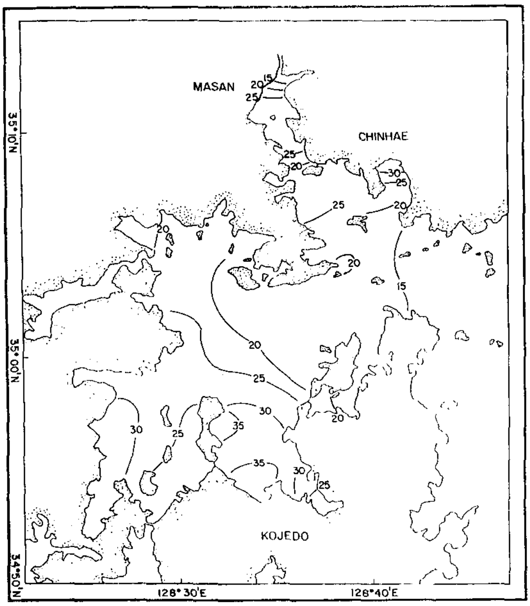

Fig. 4. Distribution of organic carbon (*mg/g* dry weight) in the superficial bottom mud in the Chinhae Bay System.

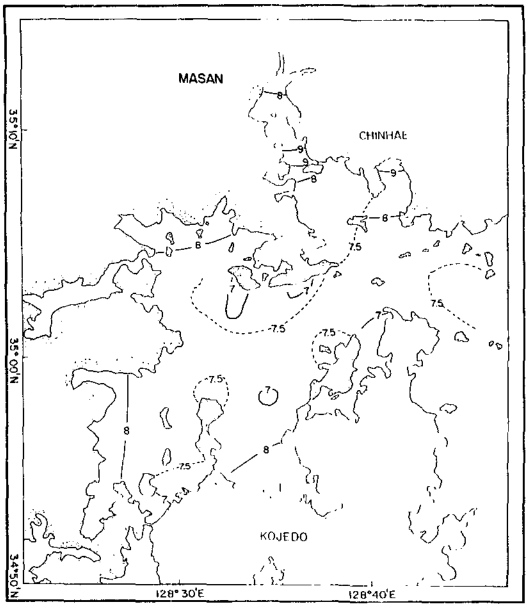

Fig. 6. Distribution of crganic C/N ratio in the superficial bottom mud in the Chinhae Bay System.

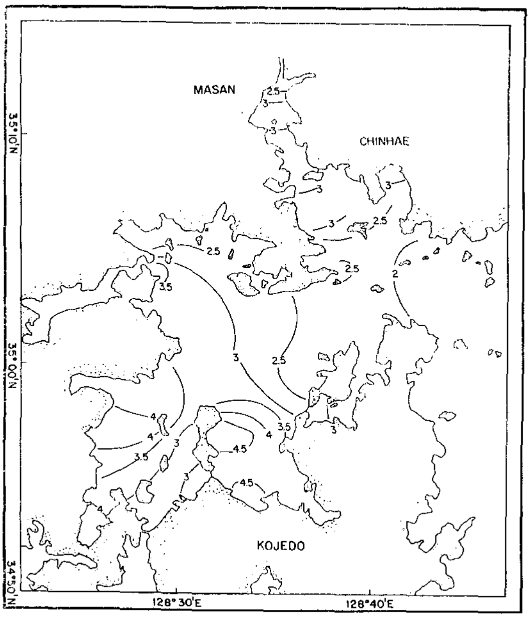

Fig. 5. Distribution of organic nitrogen (*mg/g* dry weight) in the superficial bottom mud in the Chinhae Bay System.

duced impact is thought to be greater in the former area than that in the latter area. Highest mean organic nitrogen content was found in Kohyonsong Bay (4.06 *mg/g*) as was the case of organic carbon. More than 4 *mg/g* of nitrogen was also found at St. 63 and 64 in the central part of Wonmunpo Bay, however, average organic nitrogen content in Wonmunpo Bay (3.48 *mg/g*) was lower than those in Kohyonsong Bay. Organic nitrogen content in the surface sediment from Chinae Bay Proper exceeded 3 *mg/g* only in the areas adjacent to Wonmunpo and Kohyonsong Bay. In Chindong Bay more than 3 *mg/g* of organic nitrogen was found in the surface sediment of St. 24, 26, 27, 44 located further south of St. 10 and 11.

Organic C/N ratio

C/N ratio of sediment organic matter exceeded 8 in the western part of Wonmunpo Bay, inner part of Chindong Bay and Masan Waterway (Fig. 6). In these areas relatively high amounts of terrestrially originated organic materials would cause the high C/N ratio. Terrestrial input of organic materials is possibly the most important source in Masan Bay since C/N ratio was 8.94, 8.93 and 9.20 at St. 2, 3, and 4 respectively. In the western part of Wonmunpo Bay C/N ratio of organic matter in the surface

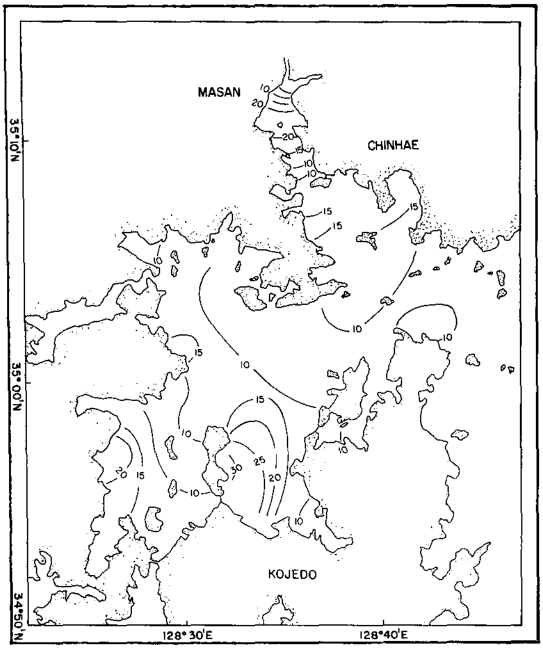

Fig. 7. Distribution of pheophytin ($\mu g/g$ dry weight) in the superfical bottom mud in the Chinhae Bay System.

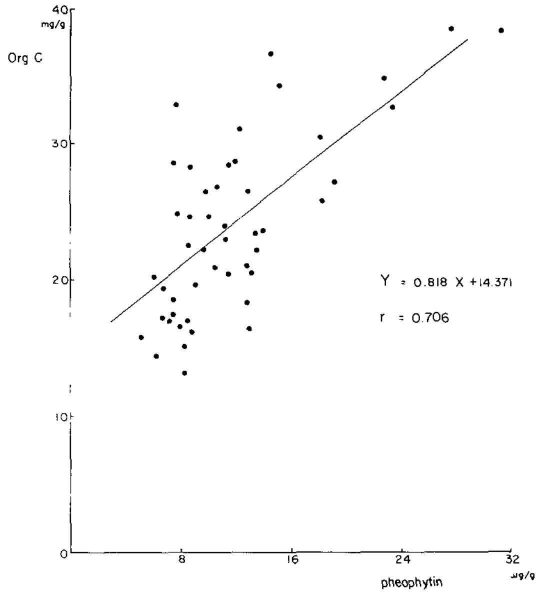

Fig. 8. Relationship between pheophytin and organic carbon in the superficial bottom mud in the Chinhae Bay System.

sediments varied between 8.05 and 8.28. At St. 10 and 11 of Chindong Bay C/N ratios were 8.68 and 8.33, respectively.

At St. 7 of Haengam Bay C/N ratio of 9.63 may indicate the high proportion of terrestrial organic matter in the surface sediments.

Pheophytin

Distribution pattern of pheophytin in the surface sediment generally followed that of organic carbon (Fig. 7). About 20$\mu g/g$ of pheophytin was found at St. 2 and 3 of Masan Bay while about 10 $\mu g/g$ was found at St. 12 and 21. In Kadok waterway it varied from 4.02 to 7.94 $\mu g/g$ at St. 35, 36 and 37. In Wonmunpo Bay mean pheophytin content was relatively low except at St. 63 (22.44 $\mu g/g$. Mean pheophytin content was the highest in Kohyonsong Bay among all subareas (16.06 $\mu g/g$). Pheophytin content in the surface sediment was over 20 $\mu g/g$ in large part of Kohyonsong Bay. More than 30 $\mu g/g$ of pheophytin was found at St. 66 and 78 in this Bay.

In Chinhae Bay Proper average pheophytin content was 9.8 $\mu g/g$. Our values of pheophytin contents were slightly lower than those observed by Cho et al. (1982) who measured 7.6-48.2 $\mu g/g$ of pheophytin in Chinhae Bay. However our pheophytin values are much higher than in Deukryang Bay and Kamagyang Bay where 2.3-5.0 $\mu g/g$ and 2.5-5.8 $\mu g/g$ respectively were found (Cho et al., 1982b).

Discussion

Geographical distribution of organic materials in the surface sediments in Chinhae Bay System showed two distinct zones rich in organic materials : one is Masan Bay and Haeng-am Bay neighboring urban and industrial area, and the other is Wonmunpo Bay and Kohyonsong Bay where shellfish farms are largely extended. Sediment organic materials have diverse origin such as terrestrial input, photosynthetic fixation of organic carbon *in situ* etc. However organic materials found in the surface sediments of Masan Bay seemed not to be of considerable amount. Sediment organic carbon, organic nitrogen and pheophytin contents in the superficial bottom mud of Masan Bay are much lower than those in Kohyunsong Bay and Wonmunpo Bay, although terrestrial input and *in situ* production of organic materials are expected to be greater in Masan Bay than those in the latter.

Extensive phytoplankton bloom is reported almost year round in Masan Bay whereas chlorophyll in the water column is reported to be low in Chinhae Bay Proper, Chindong Bay and Kohyonsong Bay (Lee et al., 1983). In Masan Bay large amounts of terrestrially originated organic materials is being introduced via freshwater input. Decrease of organic carbon contents in the surface sediment with increasing distance from the inner Masan bay would surpport the importance of discharged organic materials from urban and industrial area. Relatively high C/N ratio in the surface sediment in Masan Bay would support this fact. Marine sediments containing terrigenous organic matter may be identified by high organic carbon concentration and high organic carbon relative to organic nitrogen (Pocklington, 1976). Nearshore marine sediment contained carbon and nitrogen with a ratio of between 8 and 12 (Meybeck, 1982) and C/N ratio in the phytoplanktons generally ranged between 3 and 9 (Parsons et al., 1961). Even thouth the C/N ratio may vary during degradation processes, relatively high C/N ratio in the sediment of Masan Bay compared to that in Wonmunpo Bay and Kohyonsong Bay suggests the bottom mud of Masan Bay to be considerably influenced by terrigenous organic materials.

Yang et al (1984) measured about 2000 $\mu g/l$ of particulate organic carbon and more than 60 $\mu g/l$ of chlorophyll *a* in the surface water of the inner Masan Bay in July 1983.

Nevertheless published C/Chl *a* ratio of phytoplankton(25-50) suggests that large amounts of these particulate organic materials were driven by phytoplankton itself(Lorenzen, 1968 ; Jamart et al., 1977).

Processes affecting the concentration of chlorophyll and pheopigment in the euphotic zone include phytoplankton growth, zooplankton grazing, cell sinking, cell senescence, photodegradation, fecal pellets sinking, physical mixing and advective transport. It is well known that grazing on microalgal populations by various herbivores results in the production of chlorophyll degradation products (pheopigments) as a residue. Pheopigments may be produced by herbivores of a wide size range (Levi and Wyatt, 1971 ; Daley, 1973) whose fecal material might not necessarily remain confined to the water column. Pheopigments that are packaged into fecal pellets by larger crustacean grazers (macrozooplankton) exhibit short residence times in the water column due to their rapid sinking rates (Lorenzen and Welschmeyer, 1983). Pheopigments can also be produced by bivalves (Moreth and Yentsch, 1970 ; Gelder and Robinson, 1980).

In the bottom mud of shellfish culture grounds, fecal pellets are easily settled down because of their large size (Uyeno et al, 1970 : Sawada and Taniguchi, 1967). According to Kusuki (1977), the total range of organic nitrogen of faeces was 0.3 - 3.1%, with the large majority of samples falling between 0.4 and 1.5%, and the range of organic carbon was 2.6 - 20.0%, but generally between 3 and 12%. C/N rations were between 6 and 10 in his samples.

In Masan Bay, sinking rates of particulate organic materials to the bottom would be relatively low because of intense tidal mixing which would allow those materials to be rapidly dispersed into the open seawater. A few shellfish farms are located in Masan Bay, but farming activities are not so intense as in Kohyonsong Bay and Wonmunpo Bay. Major grazers of phytoplankton in this area appeared to be zooplankton since fecal materials are small enough to show negligible sinking rates. Thus lack of large fecal pellets producing organisms and intense tidal mixing would disfavor the accumulation of organic materials on the sediment. We suppose these are the main reason why contents of sediment organic materials in Masan Bay is lower than those of Wonmunpo Bay and Kohyonsong Bay even though significant amount of wastewater discharges and massive phytoplankton blooms take place in Masan Bay.

Wonmunpo Bay and Kohyonsong Bay have not any important source of terrigenous organic materials, and large areas of these two bays are occupied by culture farms of shellfish. Chlorophyll *a* contents in the surface waters of the mouths of Kohyonsong Bay and Wonmunpo Bay in September 1983 were 1.40 and 2.26$\mu g/l$, respectively (Lee *et al*, 1983). But low amount of chlorophyll do not necessarily mean low primary productivity.

Hypothetically, high primary productivity and high grazing pressure establish an equilibrium, maximum effective production of organic materiasls can be re-

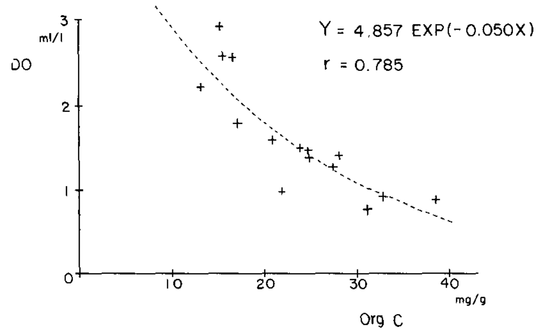

Fig. 9. Relationship between organic carbon in the superficial bottom mud and dissolved oxygen in the overlying waters in the Chinhae Bay System for the stations deeper than 20 m.

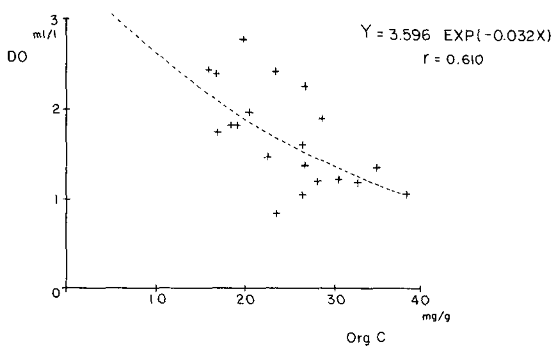

Fig. 10. Relationship between organic carbon in the superficial bottom mud and dissolved oxygen in the overlying waters in the Chinhae Bay System (depth ranging 16~20*m*).

sulted. If this situation occur in shellfish farms phytoplankters taken up effectively by shellfishes would produce large amount of pheophytin in the fecal pellets. These fecal pellets can be easily settled down because of their large size. Moreover mean tidal current velocity is reported to be 5 - 10*cm/sec* at ebb in Kohyonsong Bay which would further facilitate the settling of fecal pellets (Lee et al, 1980).We suppose the large fecal pellets and low mixing rate of seawater are high despite the low amount of wastewater discharges and the phytoplankton cells in the water column in Wonmunpo Bay and Kohyonsong Bay.

Cho et al. (1982) reported also high contents of COD and pheophytin in Wonmunpo Bay and Kohyonsong Bay. They explained the relatively high amount of organic materials in Kohyonsong Bay to be resulted from the seawater circulation pattern. At low tide, a branch of water flow in Wonmunpo Bay directs to the east and large amount of particulate materials are introduced into the Kohyonsong Bay through the narrow channel between Kajodo and Geojedo. They believed that this influx of particulate materials together with the waste water discharge from Okpo area might result the high organic carbon input in the Kohyonsong Bay.

Sawada and Taniguchi (1969) estimated the settling area of fecal pellets of pearl in Ago Bay, Japan. Taking 1*cm/sec* as the sinking velocity of fecal pellets, and 3 - 5*cm/sec* as the current velocity, they estimated that fecal pellets would be settled down within 30 - 50 m of their origin in the bay of which depth was about 10*m*. Similar assumption may be applicable in Kohyonsong Bay and Wonmunpo Bay. That is current velocity of 5 - 10*cm/sec* and depth of about 20*m* would lead the fecal pellets to be settled down within 100 - 200*m* of their origin. In other words, the accumulation of fecal pellets to be settled down in proximities of shellfish farms.

Relationship between DO and organic materials in Chinhae Bay Proper, Chindong Bay, Wonmunpo Bay and Kohyonsong Bay are considered in detail. Masan Bay and Haeng - am Bay are excluded because of variable water depth of these bays and different mechanism of sedimentation. Negative correlationship was established between DO content in the overlying waters and organic carbon content in the surface sediments. For stations where water depth exceeded 20*m*, a good correlationship was also established between these two variables (Fig. 9), however for stations of which depth ranged between 15 and 20*m*, relatively weak correlatioship was found (Fig. 10). In September thermocline was situated at about 15*m* depth (Hong, 1987a) so that even bottom waters at this depth could be supplied with oxygen from the surface layer. It seemed that in shallow areas high sedimentation rate of organic carbon do not significantly reduce the oxygen content in the bottom waters because of oxygen supply from the surface layer. The problem of oxygen depletion would become severe in area where thermocline lay er seperate the surface water from the bottom waters.

Oxygen consumption in the waters below the thermocline can be proceeded by various way : e. g. bacterial decomposition in the water column, respiration by phytoplankton, zooplankton and fishes and benthic metabolism. Oxygen consumption by benthic metabolism was amounted to be 180 - 450*ml* O_2m^2 day in Puget Sound (Pamatmat, 1977) and about 200 *ml* O_2m^2/day in North Baltic (Nedwell *et al*, 1983). Although the oxygen consumption by the sediment cannot account for most of the oxygen consumption in the bottom waters, this would be a good indicator for development of oxygen deficient condition in well stratified coastal waters.

Conclusion

This study revealed the relative importance of organic materials in the surface sediment on the environmental condition of the Chinhae Bay System. Even though large amount of domestic and industrial wastewaters are discharged into the inner Masan Bay, contents of organic materials deposited in the sediment in Masan Bay do not exceed those of Kohyonsong Bay and Wonmunpo Bay where extensive cultures of shellfish are exerted. Several points of significance emerge in comparing the sedimentation processes of organic materials in the sediments from the two locations. In Masan Bay settling of organic materials on the surface sediment seemed to be not intense because of tidal mixing and relatively small size of particulate materials. In Kohyonsong Bay and Wonmunpo Bay large fecal pellets produced in shellfish farms could be easily settled down on the sediment because of poor water exchange.

DO contents in the bottom waters were low in the organic material rich areas, which suggests biodegradation of organic materials in the surface sediment is an important oxygen consuming process in summer season. To understand the origin of organic materials in more detail, sediment trap experiments with complete analyses of organic materials are needed. Future works may also include measurements of degradation rate of organic materials and oxygen consumption rate of sediment to understand fate and consequences of settled organic materials in the coastal environments.

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