Annual Journal of Hydraulic Engineering, JSCE, Vol.54, 2010, February

SECULAR AND SPATIAL VARIATIONS ON SEDIMENT ENVIRONMENTS BEHIND ISAHAYA RECLAMATIN DIKE

Hongyuan LI[1] and Nobuhiro MATSUNAGA[2]

[1]Student Member of JSCE, Graduate Student, Dept. of Earth System Science and Technology, Kyushu University
(6-1 Kasuga-Kouen Kasuga, Fukuoka 816-8580, Japan)
[2]Fellow of JSCE, Dr. Eng., Professor, Dept. of Earth System Science and Technology, Kyushu University
(6-1 Kasuga-Kouen Kasuga, Fukuoka 816-8580, Japan)

The environmental characteristics of seabed behind the reclamation dike in Isahaya Bay were investigated on the basis of the secular variations and the spatial distributions of sediment environmental elements. According to the secular variation data, the sediment environments began to deteriorate significantly behind the reclamation dike after its construction. From the results of the observation in summer season of 2008, the ignition loss and the acid volatile sulfide around the south drain gate were higher over the sediment thickness of 10 cm than those around the north drain gate. A good negative correlation was seen between the acid volatile sulfide and the oxidation-reduction potential. The spatial distributions of NH_4-N and NO_2+NO_3-N in the pore water also indicated that the sediment environment in the south side deteriorated more than that in the north side.

Key Words **:** *Biochemical environments of seabed, sediment characteristics, pore water, Isahaya Bay*

1. INTRODUCTION

In April 1997, the deep area of Isahaya Bay was closed by the reclamation dike. Since the reclamation dike was constructed, the severe environmental deterioration, that is the decline of fisheries, the enlargement of hypoxic water mass scale, the increase of the occurrence frequency of red tide and so on, has been apparent and has become the social problem.

Responding to a lawsuit by about 2,500 fishermen and residents, the Saga District Court ruled on June 27, 2008 that the Agriculture, Forestry and Fisheries Ministry should keep two drain gates of the reclamation dike open for at least five years with the suspension for three years after the final decision. The ruling forced the government to conduct mid- and long- term open-gate research and reveal causal relations between the reclamation project and the environmental deterioration. In this social situation, it is very important to conduct the detailed investigations about the present environmental situation of Isahaya Bay before the mid- and long-term open-gate research and to accumulate the accurate data. The physical and biochemical elements of sediment are essential because the benthic habitat and ecosystem are strongly dependent on the sediment environments. Okamura et al.[1)] investigated the spatial distributions of organic matter included in the surface sediment of Isahaya Bay, and concluded that the phytoplankton origin organic matter accumulated in the central part of the bay. Hodoki and Murakami[2)] investigated the effects of Isahaya reclamation on the sediment quality and obtained the conclusions that the layer of fine sediment was thicker and the total organic carbon content was larger in Isahaya Bay than in the freshwater reservoir. Li et al.[3)] sampled intact sediment cores 15 cm thick at 22 sites of Isahaya Bay in summer season of 2008 and revealed the spatial distributions of the environmental characteristics of surface sediment. They concluded that the environments of the surface sediment around the south drain gate deteriorated more than that around the north drain gate.

As mentioned above, the authors[3)] showed that the sediment environments behind the reclamation dike varied fairly along the dike because of the drain from the north and south gates. Understanding the cause of the variation along the dike is significant in order to figure out the present situation of sediment environments in Isahaya Bay. The objectives of this study are to clarify the secular deterioration of the sediment environments behind the reclamation dike on the basis of the data for 20 years provided by the Kyushu Agriculture Administration Office and to demonstrate the variations of environmental characteristics along the reclamation dike on the basis of the spatial distributions of environmental characteristics.

2. SECULAR VARIATIONS OF SEDIMENT ENVIRONMENTS

Since 1989, i.e., the beginning of the Isahaya Reclamation Project, the Kyushu Agriculture Administration Office of the Agriculture, Forestry and Fisheries Ministry carried out the environmental monitoring in Isahaya Bay. The surface sediments behind the reclamation dike were sampled seasonally using a grab sampler at 4 sites shown in **Fig.1** (S1, S6, S7 and S8) and the environmental elements were obtained. In **Fig.2**, the secular variations of ignition loss (IL), water content, COD, sulfide, total nitrogen (TN) and total phosphorus (TP) are shown as the environmental elements. Except the IL, all of the environmental elements began to increase rapidly just after the construction of the reclamation dike and especially the tendency is obvious at 2 sites near the south drain gate (S6 and S8). The year-by-year increasing tendency is seen in the environmental elements except the COD and the IL. Yamamoto et al.[4)] reported the significant correlation between IL and water content in Hiroshima Bay and Suo Nada. However, an obvious correlation is not seen between IL and water content in Isahaya Bay. The secular variations of sulfide concentration indicate that the reducing condition of sediments behind the reclamation dike is advancing year by year. The increasing trends of the TN and TP concentrations show that the organic matter is accumulating behind the reclamation dike though the accumulation is not recognized in the secular variations of IL.

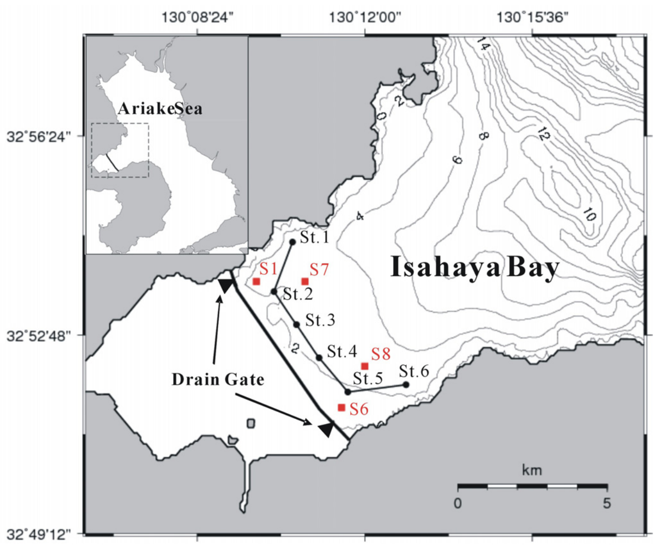

Fig.1 Sampling sites of sediment cores in Isahaya Bay.

3. SPATIAL DISTRIBUTIONS OF SEDIMENT ENVIRONMENTS

3.1 Intact sediment core sampling

The intact sediment core sampling was carried out at 6 sites behind reclamation dike by hiring a professional diver. The sediment sampling sites are shown by St.1 to St.6 in **Fig.1**, and the location of the sites and the mean depth are given in **Table 1**. The core sampling was conducted at high water of spring tide or middle tide. Four intact cores of thickness about 15 cm were sampled at each site using a cylindrical acrylic transparent tube of 11 cm in diameter and 50 cm in length. The sampled cores were kept cool in a chest filled with ice and were carried to the laboratory. **Fig.3** shows the discharge from both the drain gates during the sampling period from May 1to August 31. The total discharge was 8.7×10^7 m^3 from the north gate and 5.7×10^7 m^3 from the south gate.

3.2 Laboratory experiments

The sampled cores were sliced at 0.5 cm intervals from the sediment surface to the depth of 3 cm and at 1 cm intervals from 3 cm to 10 cm. The grain size of the sliced sediment was measured using the Particle Size Analyzer (HORIBA, L-920). The values of IL were measured after drying the samples at 110 °C for 2 hours (ASONE, DO-450A) and then burning the organic matter in the sediment at 550 °C for 6 hours (ISUZU, STR-14K). The concentration of chlorophyll a (Chl.a) and pheophytin (Pheo.) were measured using the standard spectrophoto- metric techniques after

Table 1 Location of sampling sites and sampling date.

Site	Date	Latitude (N)	Longitude (E)	Depth (m)
St.1	Aug. 21th. 2008	32° 54′ 29″	130° 10′ 27″	2.5
St.2	May 7th. 2008	32° 53′ 35″	130° 10′ 3″	2.0
St.3	Jun. 6th. 2008	32° 52′ 59″	130° 10′ 32″	2.5
St.4	Jul. 7th. 2008	32° 52′ 23″	130° 11′ 1″	2.3
St.5	Jul. 18th. 2008	32° 51′ 46″	130° 11′ 38″	1.8
St.6	Aug. 21th. 2008	32° 51′ 54″	130° 12′ 53″	2.5

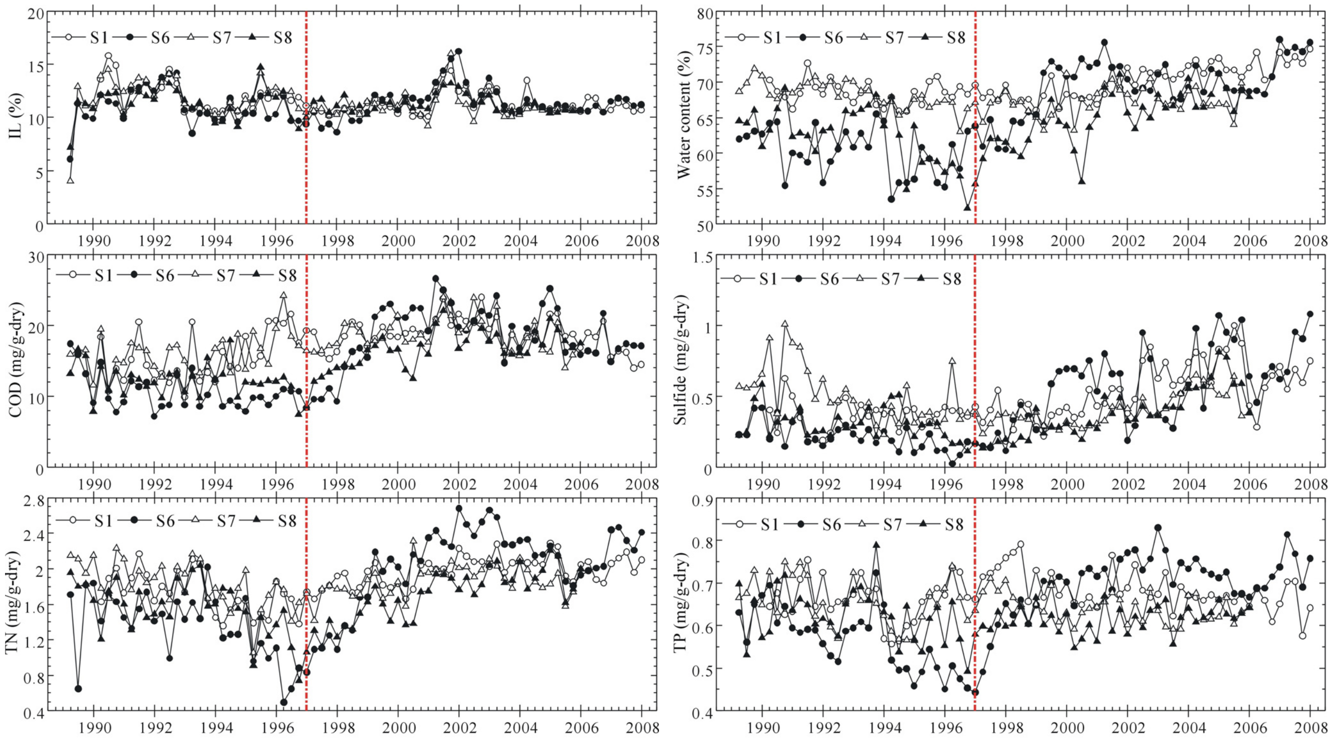

Fig.2 Secular variations of seabed surface environment behind the reclamation dike in Isahaya Bay.

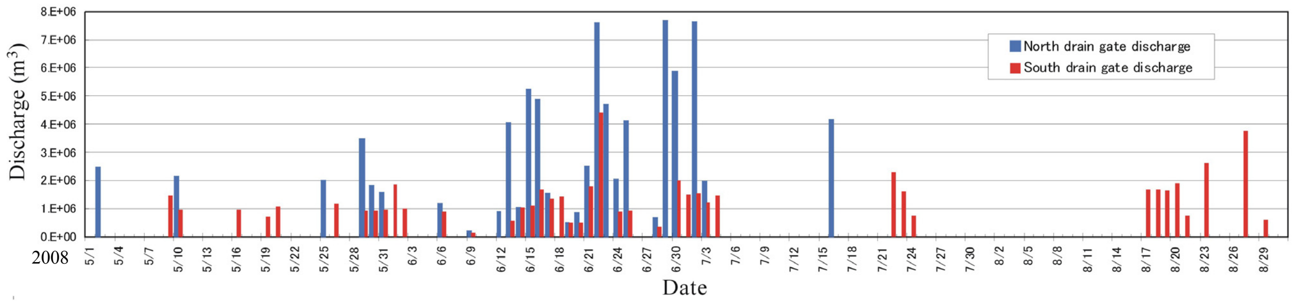

Fig.3 Discharge of the north drain gate and the south drain gate.

extracting the sample in 90 % acetone[5]. The oxidation-reduction potential (ORP) was measured by inserting directly an ORP-probe (Toko, TPX-90Si) into the sliced sediment. The acid volatile sulfide (AVS) in the dry sediment was obtained from the value of AVS in the wet sediment measured using a gas detector (GASTEC, GV-100S). The sliced sediment layer was centrifuged at 2000 rpm for 20 min and the extracted pore water was filtered using 0.45 μm filters[6]. The nutrient analysis was conducted using an Autoanalyser (BLTEC, SWAAT).

3.3 Data analysis

The GMT (Generic Mapping Tools, Wessel and Smith 1991) was used to draw the spatial distributions of sediment characteristics and nutrients in pore water. The surface function with curvature minimization algorithm was used for interpolation.

3.4 Results and discussion

The grain size is converted to the value of median diameter phi (Mdϕ). The spatial distribution of Mdϕ is shown in **Fig.4**. The Mdϕ ranged from 5.8 to 7.2. It is seen that silt deposits over the thickness of 10 cm from the sediment surface behind the reclamation dike. The values of Mdϕ around the south gate are larger than those around the north gate over the whole thickness. It may be attributed to that the tidal current behind the south gate makes slower than that behind the north gate[7] after the reclamation dike was constructed.

The spatial distribution of IL is shown in **Fig.5**. The values vary between 9.3 % and 19.3 %. Around the south gate, they are uniform in the vertical direction and take a large value. On the other hand, around the north gate, a large value of IL is seen at the depth of about 8 cm. Generally speaking, IL around the south gate is larger than that around the north gate. It may be due to that the tidal current becomes weak behind the south gate and the organic

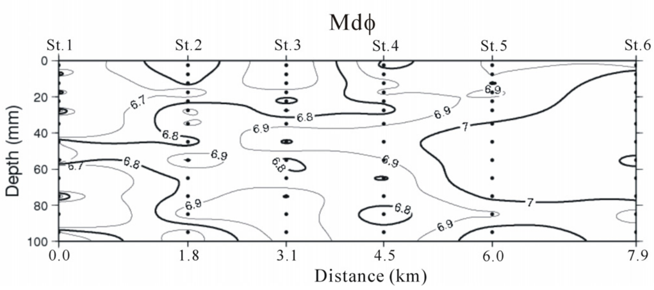

Fig.4 Spatial distribution of Mdϕ.

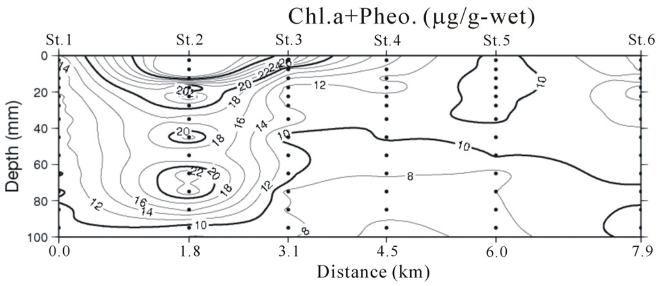

Fig.6 Spatial distribution of Chl.a+Pheo.

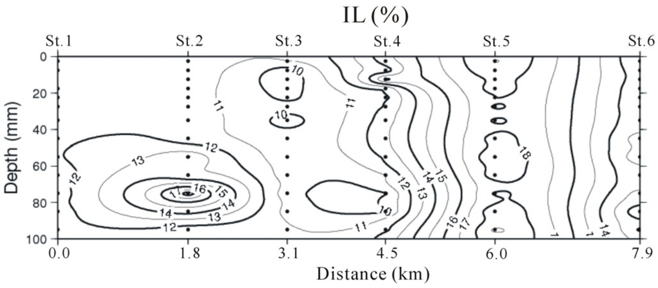

Fig.5 Spatial distribution of IL.

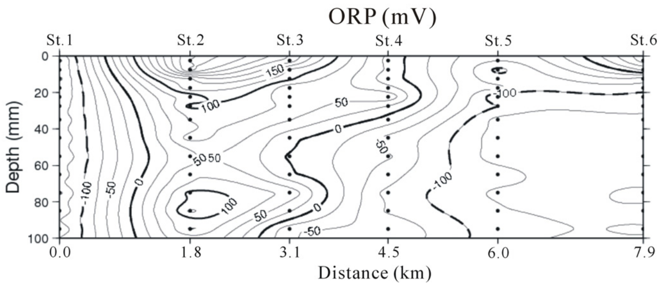

Fig.7 Spatial distribution of ORP.

matter tends to accumulate. However, the tendency that IL becomes large in the south side is not seen in **Fig.2**.

Fig.6 shows the spatial distribution of Chl.a+Pheo. concentration. The concentrations range from 5.4 μg/g-wet to 49.7 μg/g-wet. In contrast to the IL distribution, the concentrations of Chl.a+Pheo. become low around the south gate and high around the north gate. The high concentration behind the north gate may have been formed by the discharge from the north gate before the sediment sampling (see in **Fig.3**). Including a large amount of Chl.a+Pheo.[8], the discharged fresh water from the reservoir suspends bed materials and mixes the Chl.a+Pheo. with the suspended matter. Therefore, the sediment behind the north gate may include a large amount of Chl.a+Pheo. over a finite width and depth. Behind the south gate, on the other hand, the Chl.a+Pheo. in the reservoir may be transported far away on the sea surface because of the low amount of discharge, and may be deposited widely on the bed surface.

The spatial distribution of ORP is shown in **Fig.7**. The values range from -158 mV to 284 mV. They are negative around the south gate over the whole thickness and decrease gradually with depth. On the other hand, the values around the north gate are positive through the full-thickness. It means that the seabed is under the reducing condition behind the south gate and under the oxidizing condition behind the north gate.

In **Fig.8**, the spatial distribution of AVS is shown. The values vary between 0 mg/g-dry and 1.6 mg/g-dry. They are large around the south gate and small around the north gate. The value of AVS behind the south gate increases with depth and takes the highest value at the 6.5 cm depth from the sediment surface. Taking the IL and ORP distributions into account, we can infer that the accumulation of a large amount of organic matter induces the reducing condition and, as a result, a large amount of sulfide is generated behind the south gate. **Fig. 9** shows the relationship between AVS and ORP. A good negative correlation is seen between the two.

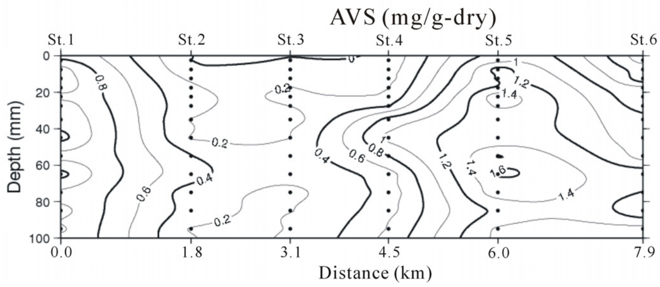

Fig.8 Spatial distribution of AVS.

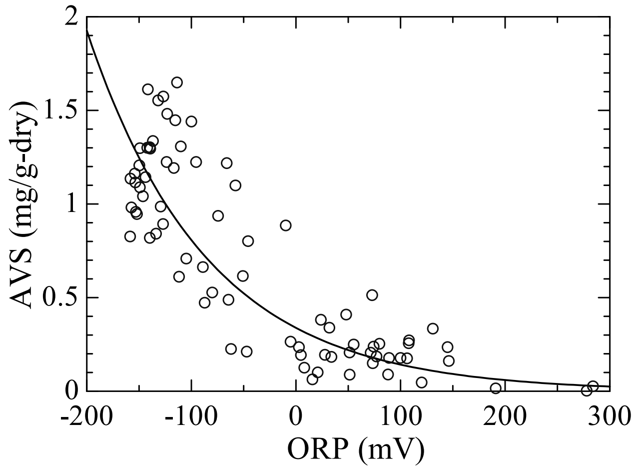

Fig.9 Relationship between AVS and ORP.

The spatial distribution of NH_4-N concentration

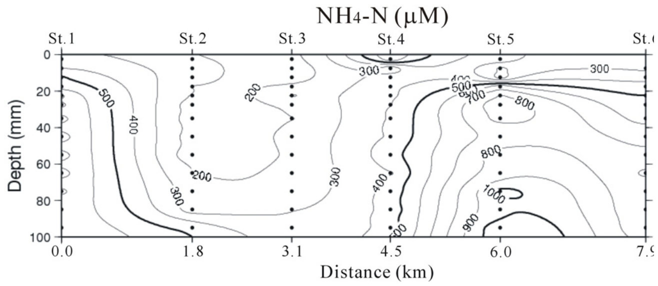

Fig.10 Spatial distribution of NH_4-N.

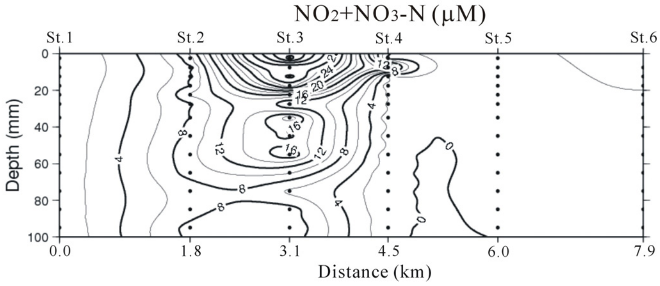

Fig.12 Spatial distribution of NO_2-N+NO_3-N.

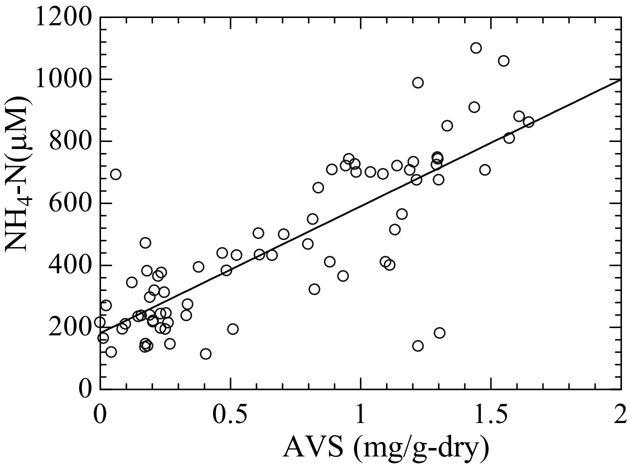

Fig.11 Relationship between NH_4-N and AVS.

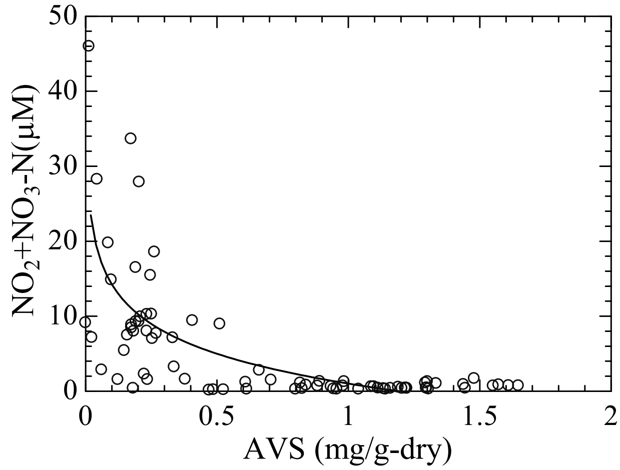

Fig.13 Relationship between NO_2-N+NO_3-N and AVS.

is shown in **Fig.10**. The values range from 112.9 μM to 1099.6 μM. The values of NH_4-N are very different between the north gate and the south gate, and the spatial distribution of NH_4-N is very similar to that of AVS. **Fig.11** shows the relationship between NH_4-N and AVS. A significant negative linear correlation is seen between the two. The values of NH_4-N are large around the south gate and small around the north gate. The values increase monotonically with depth. Considering the results shown in **Figs.7**, **8** and **10**, we can conclude that the organic matter is decomposed under an anaerobic condition around the south gate and the decomposition stops at the stage of NH_4-N, and on the other hand, the decomposition takes place under the aerobic condition around the north gate and progress to the nitrification. In fact, NO_2-N+NO_3-N concentration takes large values around the north gate as shown in **Fig. 12**. The NO_2-N+NO_3-N concentration varies from 0 μM to 46 μM. In contrast with the distribution of AVS, the values of NO_2-N+NO_3-N are small around the south gate and large around the north gate. The result that the high concentration of NO_2-N+NO_3-N is formed at the sediment surface around the north gate suggests that the denitrification reaction may progress under the anaerobic condition. **Fig. 13** shows the relationship between NO_2-N+NO_3-N and AVS. The NO_2-N+NO_3-N decreases monotonically with the increase of AVS.

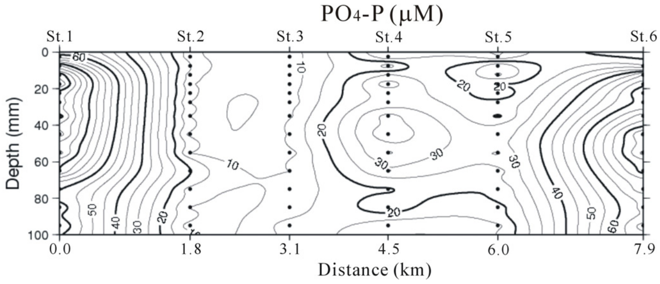

Fig.14 Spatial distribution of PO_4-P.

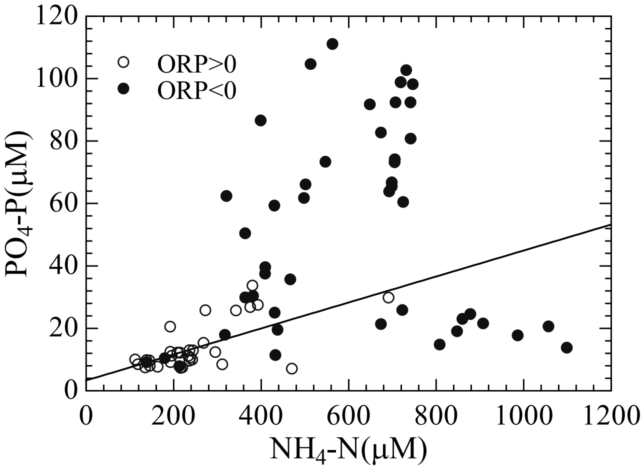

Fig.15 Relationship between PO_4-P and NH_4-N.

The spatial distribution of PO_4-P concentration is shown in **Fig.14**. The values range from 6.9 μM to 110.9 μM. With the aid of **Fig.7**, we can lead the result that the PO_4-P concentration is low in the region of ORP>0 and high in the region of ORP<0. **Fig. 15** shows the relationship between PO_4-P and NH_4-N. The open circles are used for ORP>0, and the filled circles for ORP<0. The ratio of NH_4-N to PO_4-P agrees well with the Redfield ratio under the aerobic condition. However, the concentration of PO_4-P under the anaerobic condition is larger than that under the aerobic condition. This is attributed to the PO_4-P elution from the sediment under the anaerobic condition[9].

4. CONCLUSIONS

In this paper, we investigated the environmental characteristics of seabed behind the reclamation dike in Isahaya Bay, based on the secular variations of environmental elements of sediment surface provided by the Kyushu Agriculture Administration Office and the spatial distributions of sediment environmental elements obtained in the 2008 observation by authors.

1) The sediment environments behind the reclamation dike began to deteriorate just after its construction and the tendency is obvious behind the south drain gate. The year-by-year increasing tendency is seen in the variations of water content, sulfide, TN and TP, and the accumulation of organic matter is confirmed.

2) The silt deposits over the thickness of 10 cm from the sediment surface behind the reclamation dike. The values of Mdϕ and IL around the south gate are larger than those around the north gate over the whole thickness. The concentrations of Chl.a+ Pheo. are low around the south gate and high around the north gate. The high concentration behind the north gate may be formed by the discharge from the north gate.

3) The values of ORP are negative around the south gate over the whole thickness. On the other hand, they are positive around the north gate.

4) The values of NH_4-N are large around the south gate and small around the north gate. On the other hand, the values of NO_2-N+NO_3-N are small around the south gate and large around the north gate. These results indicate that the organic matter around the south gate is decomposed under an anaerobic condition and the decomposition stops at the stage of NH_4-N, and the decomposition around the north gate takes place under the aerobic condition and progress to the nitrification.

5) The PO_4-P concentration is low around the north gate and high around the south gate. Around the north gate, the decomposition of phytoplankton takes place under aerobic condition and the PO_4-P elution from the sediment occurring under anaerobic condition is seen around the south gate.

ACKNOWLEDGMENTS: The study was funded by Grant-in-Aid for Scientific Research (A) (PI: Prof. T. Komatsu, Kyushu Univ.) and Grant-in-Aid for Scientific Research (A) (PI: Prof. N. Matsunaga, Kyushu Univ.) in 2009. We thank the Kyushu Agriculture Administration Office for providing the data of seabed environmental elements in Isahaya Bay. We thank Prof. Takigawa, Kumamoto University for giving us the permission for the use of the Particle Size Analyzer.

REFERENCES

1) Okamura, K., Tanaka, K., Kimoto, K. and Kiyomoto, Y.: Distribution of organic matter and organic carbon stable isotope ratios in the surface sediments of inner Ariake Bay and Isahaya Bay, Japan, *Oceanography in Japan*, Vol.15, pp.191-200, 2005(in Japanese).

2) Hodoki, Y., and Murakami, T.: Effects of tidal flat reclamation on sediment quality and hypoxia in Isahaya Bay, *Aquatic Conservation: Marine and Freshwater Ecosystems*, Vol.16, pp.555-567, 2006.

3) Li, H., Matsunaga, N. and Takino, T.: Investigation on biochemical environments of seabed in Isahaya Bay, *Annual Journal of Hydraulic Engineering,* JSCE, Vol.53, pp.1501-1506, 2009.

4) Yamamoto, T., Hashimoto, T., Matsuda, O., Go, A., Nakaguchi, K. and Haraguchi, K.: Comparison of sediment quality between Hiroshima Bay and Suo Nada – Special reference to the seasonal variations of sediment quality parameters and there relationship, *Nippon Suisan Gakkaishi*, Vol.74, pp.1037-1042, 2008(in Japanese).

5) Lorenzen, I.: Determination of chlorophyll and pheopigment, specctrophtometric equation, *Limnol*., *Oceanogr*., Vol.12, pp.343-346, 1967.

6) Tokunaga, T., Soh, T., Matsunaga, N. and Kodama, M.: Investigation of seabed environments in the northern area of Ariake Sea, *Annual Journal of Hydraulic Engineering,* JSCE, Vol.49, pp.1363-1368, 2005(in Japanese).

7) Unoki, S.: Temporal change of tides and currents in Ariake Bay, related to the reclamation in Isahaya Bay, *Journal of the Marine Meteorological Society*, Vol.78, pp.19-30, 2002(in Japanese).

8) Sasaki, K., Hodoki, Y. and Murakami, T.: Increment of COD, toatal nitrogen and total phosphorus discharge to Isahaya Bay since the Embankment in 1997, *Oceanography in Japan*, Vol.12, pp.573-591, 2003(in Japanese).

9) Nobusawa, Y., Murakami, K., Kitamura, T., Koizumi, T., Kameyama, Y. and Komatsu, K.: Field observation and laboratory test for nutrient release reduction from bottom sediments with sand capping at Yokohama port, *Annual Journal of Civil Engineering in the Ocean,* JSCE, Vol.21, pp.737-742, 2005(in Japanese).

(Received September 30, 2009)