

Distributions of Metallic Elements in the Sediment Cores from Several Shellfish-Farming Bays in Korea

DONG-WOON HWANG AND HAN-SOEB YANG*

Department of Oceanography, Pukyong National University, Busan 608-737, Korea

We report the distribution of ^{210}Pb and various metallic elements (Al, Fe, Mg, Ca, Ti, Mn, Sr, Ba, Zn, V, Cr, Zr, Ni, Cu, and Y) in the sediment cores from six shellfish-farming bays in the South Sea of Korea. The ^{210}Pb inventories in Deukryang, Gwangyang, and Goseong Bay cores were comparable to those expected from the known fallout input. However, the ^{210}Pb inventories were two times higher in Jinju, Gangjin, and Hansan-Koeje Bay cores, suggesting an important role of other sources such as fluvial inputs. Based on the enrichment factor analyses, non-detrital fractions of all the measured elements were found to be insignificant. The Mn was highly enriched only in the surface sediments of the Jinju and Goseong Bay, which implies that the surface-sediment environment of these bays is efficiently oxidizing Mn remobilized from either pore waters or bottom seawaters. These data set provides the sources of heavy metal in sediment around shellfish farms and the current level of metallic elements for the future monitoring.

Keywords: Heavy Metal, Pb-210, Farming Bay, Pollution

INTRODUCTION

Studies on the geochemistry of coastal sediments have received extensive attention over the last several decades due to the significant anthropogenic input. In the coastal environments, metallic elements are introduced directly via the atmosphere, rivers, and groundwater, and are mostly settled to bottom sediments before they reach the open ocean. The concentration of metallic elements in sediment has strong relationship with grain size distributions which were also differed by source of sediments or physical reworking by wave and tide (Cho *et al.*, 1994). Some metallic elements were either re-mobilized by a reduction and diagenesis in sediment or resupplied to the overlying seawater (Cauwet, 1987; Brugmann, 1988; Macdonald *et al.*, 1991; Presley *et al.*, 1992). Since an important fraction of heavy metals in polluted sediments exists in relatively unstable forms, making them available to benthic fauna (Zwolsman, *et al.*, 1996), studies on sedimentary pollution have serious meaning to farming areas.

In conjunction with trace elements, naturally occurring ^{210}Pb has been utilized for studying the coastal

sediments, especially for the accumulation rate of marine sediment (Goldberg, 1963; Anderson *et al.*, 1987), and for the chemical changes and pollution that have occurred during the past hundred years (Goldberg *et al.*, 1977; Koide *et al.*, 1973). The unsupported ^{210}Pb originates primarily from the atmosphere as a decay product of ^{222}Rn , and has served as an excellent dating tool (Koide *et al.*, 1972). Therefore, many studies have measured ^{210}Pb as well as trace elements in coastal core samples to reconstruct the pollution history of overlying seawaters (Matsumoto and Wong, 1977; Goldberg *et al.*, 1978; Hoshika and Shiozawa, 1984; Santschi *et al.*, 1984; Zwolsman *et al.*, 1993). In addition, it is possible to evaluate the magnitude of atmospheric input against other sources of sediments (*i.e.*, fluvial inputs of surface soils) based on the total inventory of unsupported ^{210}Pb in the sediment column relative to the known fallout input.

Since the coastal bay of the South Sea of Korea is semi-enclosed (ria type), water circulation is quite limited at each bay (Kim and Chang, 1983; Cho *et al.*, 1999). Thus, these bay regions have been utilized for farming various shellfishes (Lee *et al.*, 1991). However, surrounding land areas have been industrialized and urbanized since the 1960s. As a result, contaminated water (containing sewage, fertilizer, mining

*Corresponding author: hsyang@mail.pknu.ac.kr

water etc.) was discharged into coastal bay environment by river and the eutrophication in these farming regions increased. Such farming activities also load a significant amount of organic matters into the bay environment, which causes perturbation of biogeochemistry (Kang *et al.*, 1993) and excess organic matter can efficiently scavenge anthropogenic reactive elements.

Thus, the objectives of this study are (1) to reveal the origin of heavy metal in sediment around these farming areas in association with the industrialization of surrounding areas and (2) to establish a background level of heavy metal in sediment. We expect that the distributions of natural and anthropogenic metals in sediment cores are differ depending on water circulation patterns, physical and chemical residence times, and the magnitude of anthropogenic source inputs via the atmosphere, rivers, and groundwater.

MATERIALS AND METHODS

Six sediment-core samples were taken using a gravity corer (5 cm diameter, 100 cm length) at six different bays in the South Sea of Korea in 1991 (Fig. 1). The core samples were frozen at -20°C immediately after sampling, and sliced by 2 cm intervals

after thawed. A simplified grain-size analysis was made according to the technique suggested by Yang and Kim (1994). Right after removing the salts and organic matter in wet sediment with ultra pure water and H_2O_2 , respectively, sediment was divided into coarse and fine size fraction using the size 4ϕ (62.5 mm) sieve. In our case sedimentary types of most samples are the mud types. Water contents, such as porosity, were measured using a fraction of the sectioned samples by obtaining the moisture loss at 110°C for 12 hours. Percent organic matter content of the sediment was measured by using the combustion method described by Yoo (2000). Here, loss on ignition (LOI) was determined as the weight loss after heating a fraction of the dried sediment at 450°C for 5h. For the analyses of ^{210}Pb , about 60 mL of 6M HCl and 70 mg of Pb^{2+} carrier were added to 1–5 g (more for deeper specimens) sediment samples. Then, the ^{210}Pb was leached out at $80\text{--}90^{\circ}\text{C}$ for 12 hours. The analytical method was slightly modified from Koide *et al.* (1972). Then the solution was evaporated, and the residue was dissolved in 20 mL of 1.5 M HCl. The ^{210}Pb was purified using an anion exchange column preconditioned with 1.5 M HCl. The purified Pb solution was heated, and the residue was re-dissolved in conc HNO_3 to oxidize any organic

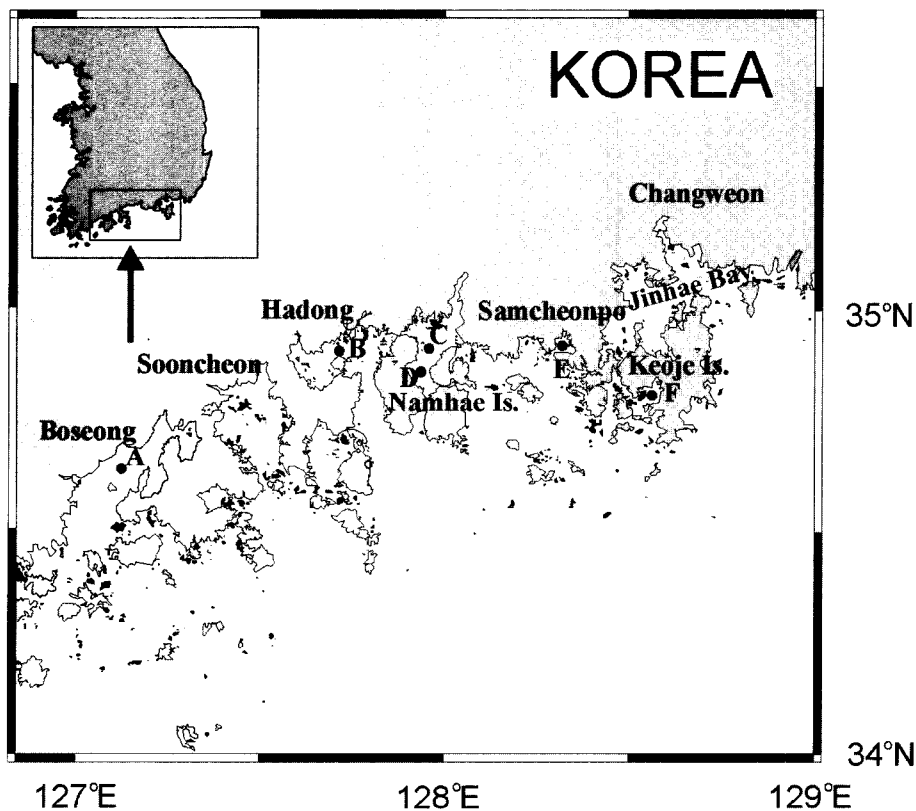


Fig. 1. A map showing the sediment coring locations, A (Deukryang Bay), B (Gwangyang Bay), C (Jinju Bay), D (Gangjin Bay), E (Goseong Bay), and F (Hansan-Keoje Bay), in the South Sea of Korea.

residue. Finally, PbSO_4 precipitation was produced by adding conc H_2SO_4 . The precipitate was filtered onto a tared filter. The chemical yield of ^{210}Pb was determined by the net weight of Pb obtained from the difference of weight pre- and post-filter. The ^{210}Pb was measured using betas of ^{210}Bi after they reached at secular equilibrium (after 20 days).

For the analysis of metallic elements, dried sediment samples (~1 g) were digested in a teflon bomb using a mixture of concentrated HF(6 ml), HNO_3 (3 ml), and HClO_4 (2 ml). The samples were digested with lids for 6 hours and dried without lids. These steps were repeated until only a negligible amount of white residue remained following the addition of the acids again. Then, after centrifuging the solution at 3000 rpm for 20 min, the solution was diluted appropriately for the determination of each element, Al, Fe, Mg, Ca, Ti, Mn, Sr, Ba, Zn, V, Cr, Zr, Ni, Cu, and Y using an ICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometer, Model: JY 58P-1, Seiko Instruments and Electronics LTD) in the

Ocean Research Institute of the University of Tokyo, Japan. For three reagent blanks, the concentration of each element was less than 1% of the mean concentration of all sediment samples. In order to avoid any analytical bias, all core samples used in this study were checked with the Yellow Sea continental-shelf samples of which the accuracy of data was already certificated through the Yellow Sea data reports (Kim *et al.*, 1998; Kim *et al.*, 1999).

RESULTS AND DISCUSSION

Implications of ^{210}Pb distributions

The vertical distributions of ^{210}Pb , water content, loss on ignition (LOI), and metallic elements are shown in Fig. 2 and Fig. 3. Total ^{210}Pb concentration in sediment is generally high at the surface layer and gradually decreased with depth and the main processes governing this pattern in seabed are sediment accumulation, radioactive decay, and particle mixing

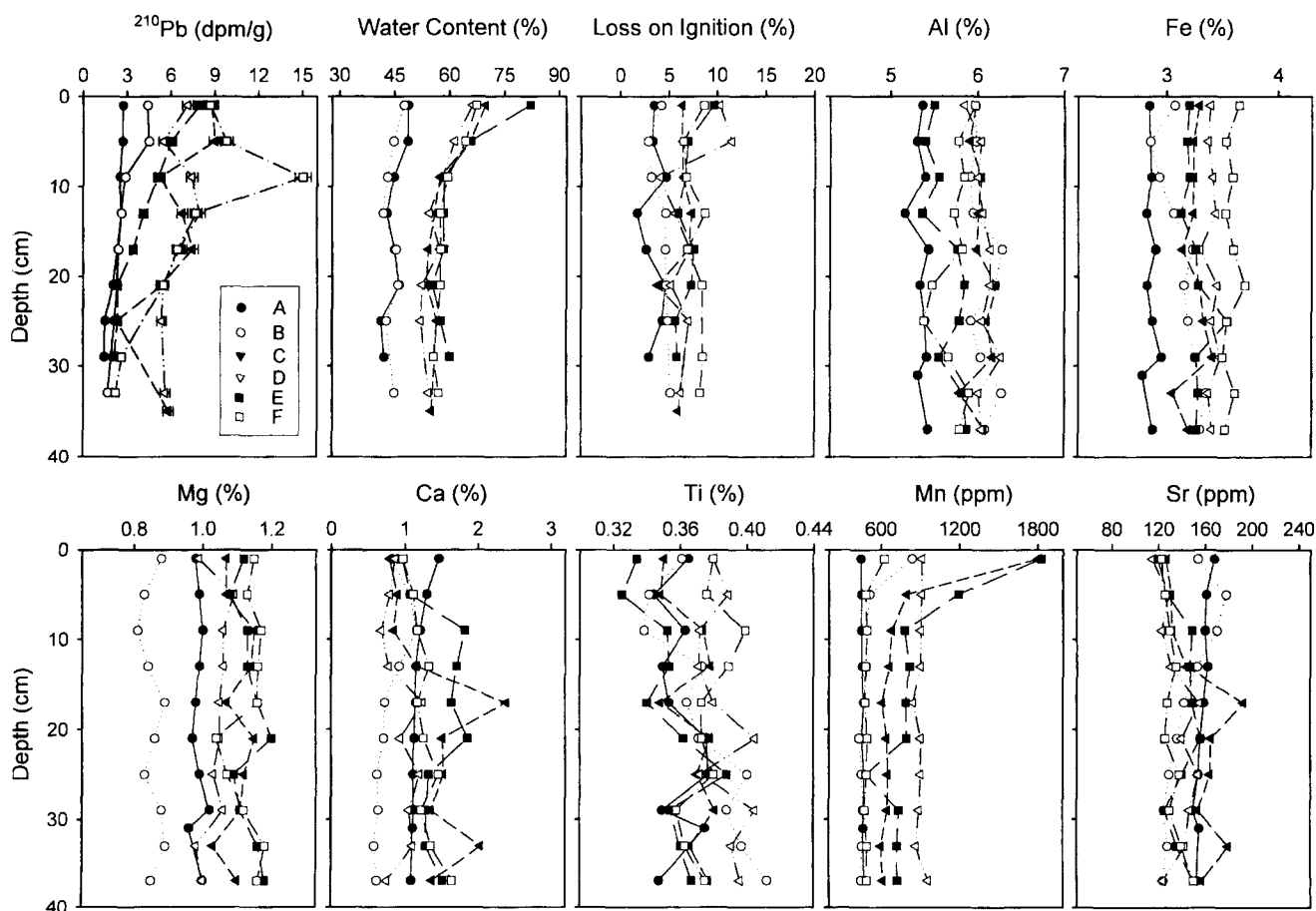


Fig. 2. The vertical distribution of ^{210}Pb , water content, loss on ignition, Al, Fe, Mg, Ca, Ti, Mn, and Sr in the sediment cores from the South Sea of Korea.

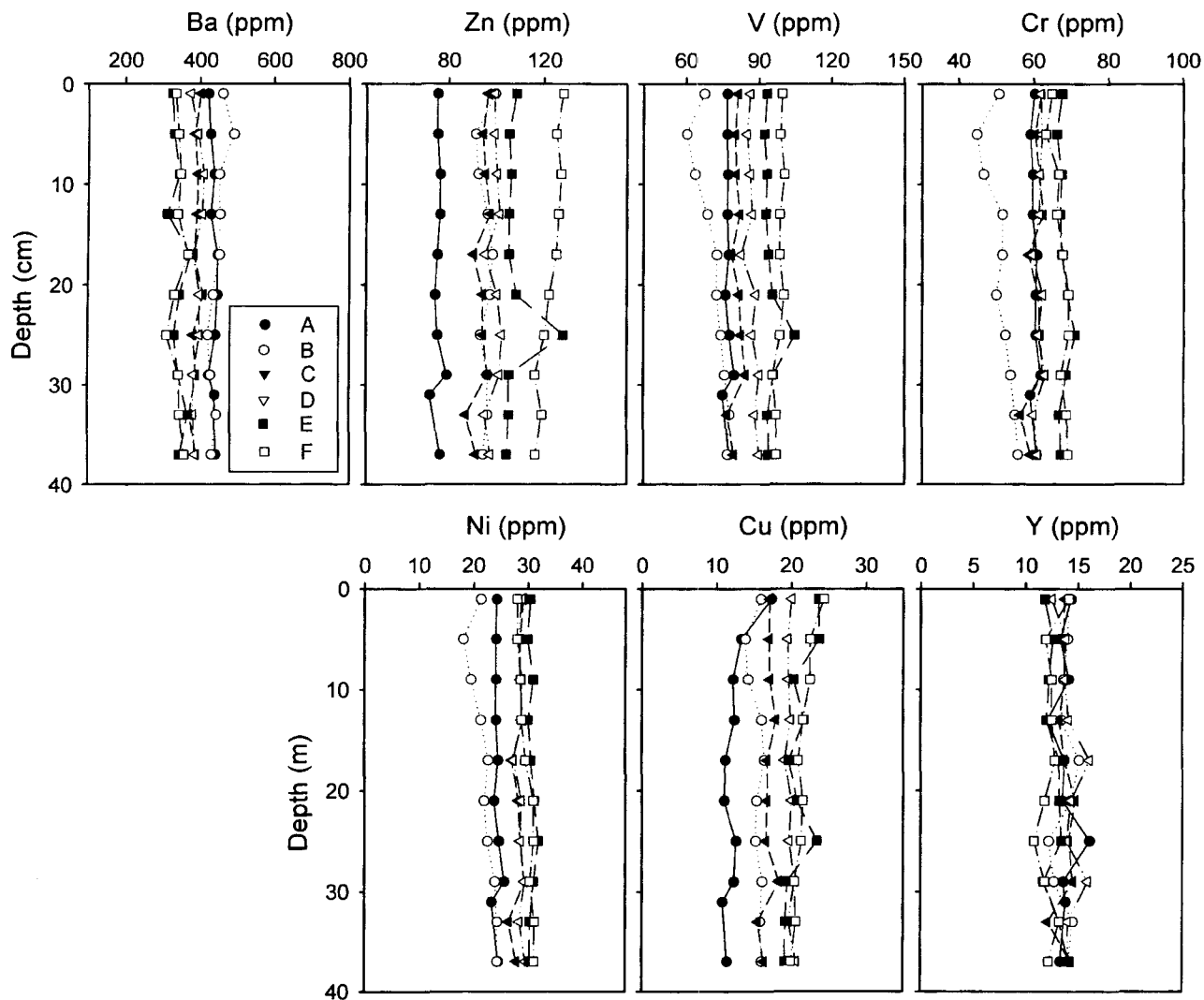


Fig. 3. The vertical distribution of Ba, Zn, V, Cr, Ni, Cu, and Y in the sediment cores from the South Sea of Korea.

(Goldberg and Koide, 1962). In this study, the ^{210}Pb depth profiles differ by cores, and as the surface mixed layer presented in most cores except for the station E, its distribution pattern does not allow simple age calculation. This may be due to a strong physical or biological mixing of the sediment columns since ^{210}Pb deposited in sediments can be modified by benthic organisms activities, resuspending and redistributing the particles.

Based on a simple decay curve (using equation 1), the station E, which shows the most distinct exponential decay curve, yields a sedimentation rate of about 4.0 mm y^{-1} .

$$S = \frac{\lambda Z}{\ln\left(\frac{A_0}{A}\right)} \quad (1)$$

where λ is the decay constant of ^{210}Pb (0.0312 y^{-1}), Z (cm) is the depth from the sediment surface, A_0 (dpm g^{-1}) is the excess activity of ^{210}Pb at the sediment surface extrapolated from the best curve fit, and A (dpm g^{-1}) is the excess activity of ^{210}Pb at the depth Z . Here, excess ^{210}Pb activity was determined by subtracting from the total ^{210}Pb the fraction (supported ^{210}Pb) produced from the ^{226}Ra , parent nuclide of ^{210}Pb , in the sediment and the ^{226}Ra activity was assumed to be 1 dpm/g which was determined for another coastal core in the South Sea of Korea (Lee *et al.*, 1988) and for the core of continental shelf region around the East China Sea (Yoo, 2000). This sedimentation rate is comparable to that of Suyoung Bay ($3.5\text{--}4.0 \text{ mm/yr}$; Yang and Kim, 1994) and Jinhae Bay ($3.1\text{--}4.8 \text{ mm/yr}$; Yang *et al.*, 1995).

Although the information on the sedimentation

rates is very limited due to strong physical or biological mixing, the ^{210}Pb inventories allow to evaluate the main source of sediments in these bays. The atmospheric inputs of ^{210}Pb in the northwestern Pacific regions (Fukuda and Tsunogai, 1975) and in the East China Sea regions (DeMaster *et al.*, 1985) are known to be about $2 \text{ dpm cm}^{-2} \text{ y}^{-1}$. If one assumes that the excess ^{210}Pb inventory below 32 cm showing the constant concentration is negligible, the sedimentary inventory (I_{Pb}) of ^{210}Pb is expected to be about 97 dpm cm^{-2} using the following equation:

$$I_{\text{Pb}} = \frac{F}{\lambda_{\text{Pb}}} + I_{\text{Ra}} \quad (2)$$

where F is the atmospheric flux of ^{210}Pb ($2 \text{ dpm cm}^{-2} \text{ y}^{-1}$), λ_{Pb} is the decay constant of ^{210}Pb (0.031 y^{-1}), and I_{Ra} is the inventory of supported ^{210}Pb from ^{226}Ra inventory (32 dpm cm^{-2}) calculated from the uniform ^{226}Ra activity of 1 dpm g^{-1} throughout the 0–32 cm depth. The inventories of ^{210}Pb range from 203–232 dpm cm^{-2} at the stations C, D, and F (Table 1), which are two times higher than those expected from the direct atmospheric fallout. This suggests that these stations have other sources of ^{210}Pb , which are equivalent to the atmospheric input, either from fluvial or re-suspended open-ocean sediment inputs. On the other hand, the inventories of ^{210}Pb range from 71–134 dpm cm^{-2} at the stations A, B, and E (Table 1), which are close to the atmospheric fallout inventory. This suggests that net loss or gain of ^{210}Pb from the secondary source was not significant in these cores.

As shown in Table 1, the inventories of a detrital element, Al, do not correlate with the inventories of ^{210}Pb which primarily originates from the atmosphere. The inventories of all measured metallic elements also are not related to the inventories of ^{210}Pb . This phenomenon may be affected by sediment characteristics and processes or other sources such as fluvial inputs

in supplying the metallic elements to these bays.

Distribution characteristics of metallic elements

The water contents of sediments were lower at the stations A and B relative to the other stations, while percent organic contents inferred from LOI were very similar at all stations, ranging from 2–10%. The concentrations of major detrital elements (Al, Fe, and Mg) were vertically very uniform (Fig. 2). Overall, Al and Fe contents were exceptionally lower at the station A, and Mg content at the station B. The concentrations of Ca and Sr show a wide vertical variation at the station C, at which the concentrations peak at the depths 18 and 34 cm. These peaks might be associated with the presence of shell materials which contain higher Ca and Sr. The concentrations of Ti were similar at all stations, with slightly higher concentrations at greater depths.

The concentrations of Mn in the surface sediments of the stations C and E were remarkably higher than those in the other stations and at other depths (Fig. 2). This trend is not related to the atmospheric input anomaly judging from the ^{210}Pb profiles or variations of percent organic content as seen in the LOI profiles. As Mn in sediments may have the different forms with either oxidation or reduction environment (Froelich *et al.*, 1979) and dissolved Mn (Mn^{2+}) rapidly building up Mn oxide (MnO_2 ; solid phase) by a catalytic action in itself regardless of the change of chemical environment (Ponter *et al.*, 1992; Cho and Chang, 2000), the concentrations of Mn in the coastal sediments show wide fluctuation by the regions (Table 2). Thus, the higher Mn concentrations for the surface sediments of these two bays might be associated with Mn oxide formation, which implies that the surface-sediment environment of these bays is efficiently oxidizing Mn remobilized from either pore waters or bottom seawaters.

The concentrations of Ba and Y were vertically uniform at all six stations (Fig. 3). It is noticeable that the distribution of Ba is slightly different from other alkaline earth elements such as Ca and Sr. The concentrations of Zn were vertically uniform except for the station E, where the concentration peaks at the depths 25 cm. and the highest and lowest average concentrations were appeared at the stations F and A, respectively. In the cases of V, Cr, Ni, and Cu, the concentrations were vertically quite uniform and concentrations were similar at all stations. The concentrations of these elements were exceptionally lower at

Table 1. The inventories of ^{210}Pb , Al, and Zn in the sediment columns between 0–32 cm from the six cores from the South Sea of Korea.

	^{210}Pb (dpm cm^{-2})	Al (mg cm^{-2})	Zn (mg cm^{-2})
A (Deukryang Bay)	71±2	1710±30	2.4±0.1
B (Gwangyang Bay)	91±3	1940±40	3.0±0.1
C (Jinju Bay)	203±4	1930±40	3.0±0.1
D (Gangjin Bay)	204±4	1940±40	3.2±0.1
E (Goseong Bay)	134±3	1810±60	3.5±0.2
F (Hansan-Keoje Bay)	232±4	1830±58	3.9±0.1

Table 2. The average concentration of metallic elements in coastal sediments around Korea.

Region	Al(%)	Fe(%)	Mn(ppm)	Zn(ppm)	Cu(ppm)	Cr(ppm)	Reference
Deukryang Bay	5.35	2.86	461	75	13	60	
Gwangyang Bay	6.06	3.14	505	95	16	51	
Jinju Bay	6.03	3.24	773	93	17	60	This study
Gangjin Bay	6.06	3.40	902	99	20	61	
Goseong Bay	5.65	3.26	889	108	21	68	
Hansan-Keoje Bay	5.73	3.58	502	122	22	67	
Ulsan Bay		3.40	462	131	24	77	Lee <i>et al.</i> (1988)
Suyeong Bay		2.37	373	113	26		Yang and Kim (1994)
Yellow Sea (surface)	6.80	3.16	587	67	14	48	Kim (1994)
Jinhae Bay		3.60	549	140	29	62	Yang <i>et al.</i> (1995)
Youngsan River		3.80	755	132	30	54	Cho and Kim (1998)
Sihwa lake			487	207	96	97	Shim <i>et al.</i> (1998)
Sacheon Bay		2.94	927	102	23	53	Lee <i>et al.</i> (2000)
Mangyung River		3.70	1095	149	40	74	Cho and Chang (2000)
Dongjin River		3.40	789	95	22	57	

the station B (especially at the depth between 0–20 cm). However, based on available data it is not possible to find any causes for such an anomaly at the station B. Since the sample analyses were carried out randomly for all cores, this anomaly should not be due to any analytical biases. On the other hand, the mean concentrations of all metallic elements measured in this study were similar to or lower than those from other studies by Lee *et al.* (1988), Yang *et al.* (1995), Cho and Kim (1998) and Lee *et al.* (2000). Although the concentrations of metallic elements in some regions were higher than those expected from the direct atmospheric fallout due to sediment characteristics and processes or other sources such as fluvial inputs, we expect that our results will serve as a historical background level for monitoring of metallic elements in the future.

In order to compare the enrichment of the measured metallic elements relative to the average in the earth's

crust, metals/Al ratios are listed in Table 3. The enrichment of Mg, Ba, Cu, and Y, relative to Al in the study sites was similar to that in the earth's crust. However, the enrichment of Ti, Zn, V, Cr and Ni was about two times higher at the study sites compared to that in the earth's crust. The higher enrichment of Mn relative to Al occurring only at the stations C, D, and E should be associated with the presence of authigenic Mn in the surface sediments as explained in the earlier section. In contrast, the enrichment of Ca and Sr, alkaline earth element, was a little lower relative to that in the earth's crust. The differences in enrichment ratios by a factor of two can occur simply due to a mineralogical difference between the study areas and the reference material used for the earth's crust. Overall, the enrichment of all anthropogenic or authigenic sources was so small that enrichment factor analyses did not discern the presence of non-crustal sources for all measured elements.

Table 3. Ratios of metallic elements to Al at six sediment cores from the coast of the South Sea of Korea and in earths crust (Taylor and McLennan, 1995).

Station	Metals/Al						Metals/Al x 1000								
	Fe/Al	Mg/Al	Ca/Al	Ti/Al	Mn/Al	Sr/Al	Ba/Al	Zn/Al	V/Al	Cr/Al	Zr/Al	Ni/Al	Cu/Al	Y/Al	
A	0.53	0.18	0.22	0.07	8.62	2.95	8.13	1.41	1.44	1.12	1.14	0.45	0.23	0.26	
B	0.59	0.16	0.15	0.07	9.45	2.69	8.33	1.78	1.32	0.95	0.94	0.41	0.29	0.26	
C	0.61	0.21	0.26	0.07	14.45	2.89	7.27	1.75	1.51	1.13	1.10	0.53	0.32	0.26	
D	0.64	0.19	0.18	0.07	16.85	2.54	7.31	1.85	1.62	1.14	1.11	0.54	0.37	0.27	
E	0.61	0.21	0.27	0.07	16.61	2.62	6.38	2.02	1.77	1.26	1.20	0.57	0.39	0.24	
F	0.67	0.21	0.24	0.07	9.39	2.48	6.39	2.29	1.84	1.25	1.05	0.56	0.40	0.23	
Earth's crust	0.44	0.17	0.37	0.04	7.46	4.35	6.84	0.88	0.75	0.44	2.36	0.25	0.31	0.27	

Conclusions

Based on the ^{210}Pb inventories in the sediment cores, it was suggested that only half of the sediments in Deukryang, Gwangyang, and Goseong Bays were supplied directly via the atmosphere, while almost all sediments in Jinju, Gangjin, and Hansan-Keoje Bays were supplied directly via the atmosphere. Based on the enrichment factor analyses, non-detrital sources of the measured metallic elements were found to be insignificant. The enrichment of authigenic Mn occurs only in the surface sediments of Jinju and Goseong bays, and to a lesser extent in Gangjin bay. Overall, this study provides the background levels of metallic elements in these farming coastal environments. In order to elucidate the mechanisms controlling the distribution characteristics of elements shown in this study, further geochemical studies are required.

ACKNOWLEDGEMENTS

We thank to Dr. Kim and the two reviewers who gave us valuable comments on the manuscript. This work was supported by the grant from the Dongweon Research Foundation through the Pukyong National University from 1994 to 1995.

REFERENCES

- Anderson, R.F., R.L. Schill, and R.H. Hesslein, 1987. Determining sediment accumulation and mixing rates using ^{210}Pb and ^{137}Cs and other tracers. *Can. J. fish. Aquat. Sci.*, **44**: 231–250.
- Cho, K. D., C.I. Lee, B.G. Lee, K.W. Cho and D.S. Kim, 1998. Study on the water and material exchange in Deukryang Bay. *J. Korean Environ. Sci. Soc.*, **7**: 311–319.
- Cho, Y.G. and J.Y. Kim, 1998. Heavy metals in surface sediment of the Youngsan River channel. *J. Korean Environ. Sci.*, **7**: 281–290.
- Cho, Y.G. and J.H. Chang, 2000. Heavy metals in bed sediments of the Mangyung and Dongjin Rivers. *J. Basic. Sci.*, **18**: 121–134.
- Fukuda, K. and S. Tsunogai, 1975. ^{210}Pb in precipitation in Japan and its implication for the transport of continental aerosols across the ocean. *Tellus*, **27**: 514–521.
- Goldberg, E.D. and M. Koide, 1962. Geochronological studies of deep-sea sediments by the ionium-thorium method. *Geochim. Cosmochim. Acta.* **26**: 417–450.
- Goldberg, E.D., 1963. Geochronology with lead-210. In: IAEA, editor. Radioactive dating. Vienna: International Atomic Energy Agency, 121–131.
- Goldberg, E.D., J.J. Gamble, J.J. Griffin and M. Koide, 1977. Pollution history of Narragansett Bay as recorded in its sediments. *Estuary Coast. Mar. Sci.*, **5**: 549–561.
- Goldberg, E.D., V. Hodge, M. Koide, J. Griffin, E. Gamble, O. Bricker, G. Matisoff, G.R. Holdren and R. Braun, 1978. A pollution history of Chesapeake Bay. *Geochim. et Cosmochim. Acta.* **42**: 1413–1425.
- Hoshika, A. and T. Shiozawa, 1984. Sedimentation rate and heavy metal pollution of sediments in the Seto Inland Sea: Part 2. Hiroshima Bay. *J. Oceanogr. Soc. Japan*, **40**: 115–123.
- Kang, C.K., P.Y. Lee, J.S. Park and P.J. Kim, 1993. On the distribution of organic matter in the nearshore surface sediment of Korea. *Bull. Korean Fish. Soc.*, **26**: 557–566.
- Kim, G.B., 1994. Geochemistry of the Yellow Sea sediment. M. Sc. Thesis, Nat. Fish. Univ. of Pusan, Korea., p. 60.
- Kim, G., H.S. Yang and K. Kodama, 1998. Distribution of transition elements in the surface sediments of the Yellow Sea. *Cont. Shelf Res.*, **18**: 1531–1542.
- Kim, G., H.S. Yang and T.M. Church, 1999. Geochemistry of alkaline earth elements (Mg, Ca, Sr, Ba) in the surface sediments of the Yellow Sea. *Chem. Geol.*, **153**: 1–10.
- Kim, J.W. and S.D. Chang, S.D., 1985. Tidal exchange of sea water in Koje Bay. *Bull. Korean Fish. Soc.*, **18**: 101–108.
- Koide, M., A. Soutar and E.D. Goldberg, 1972. Marine geochronology with ^{210}Pb . *Earth and Planet. Sci. Letts*, **14**: 442–446.
- Lee, B.D., H.K. Kang and Y.J. Kang, 1991. Primary production in the Oyster Farming Bay. *Bull. Korean Fish. Soc.*, **24**: 39–51.
- Lee, D.H., J.H. Lim, B.Y. Jeon and N.H. Jeong, 2000. A study on the distribution of heavy metal concentration in marine surface sediment around Samcheonpo power plant. *J. Korean Soc. Environ. Impact Asses.*, **9**: 1–11.
- Lee, K.W., D.S. Lee, S.H. Lee and E. Matsumoto, 1988. History of heavy metal pollution in Masan and Ulsan Bay sediment. *Ocean Res.*, **10**: 7–13.
- Matsumoto, K. and C.S. Wong, 1977. Heavy metal sedimentation in Saanich Inlet measured with ^{210}Pb techniques. *J. Geophys. Res.*, **20**: 5477–5482.
- Ponter, C., J. Ingri and K. Bostron, 1992. Geochemistry of manganese in the Kalix River, northern Sweden. *Geochim. Cosmochim. Acta.* **56**: 1485–1494.
- Santschi, P.H., S. Nixon, M. Pilson and C. Hunt., 1984. Accumulation of sediments, trace metals (Pb, Cu) and total hydrocarbons in Narragansett Bay, Rhode Island. *Estuar. Coast. Shelf Sci.*, **19**: 427–449.
- Shim, M.J., E.S. Kim, K.T. Kim, G.B. Lee, H.S. Kang and K.W. Lee, 1998. Distribution of organic carbon, sulfur and heavy metals in Shihwa Lake sediment. *J. KSWQ DEC.*, **14**: 469–482.
- Taylor, S.R. and S.M. McLennan, 1995. The geochemical evolution of the continental crust. *Reviews of Geophys.*, **33**: 241–265.
- Yang, H.S. and S.S. Kim, 1994. Pollution of heavy metals and sedimentation rate in sediments of Suyeong Bay, Pusan. *J. Korean Fish. Soc.*, **27**: 643–658.
- Yang, H.S., S.S. Kim and G.B. Kim, 1995. Pollution of heavy metals and sedimentation rates in sediment cores from the Chinhae Bay, Korea. *J. Korea Environ. Sci. Soc.*, **4**: 489–500.
- Yoo, C.C., 2000. Sedimentary structures and processes in the Southeastern Yellow Sea and the East China Sea mud deposits. Sc. Thesis, Pukyong Nat. Univ. of Busan, Korea., p. 60.
- Zwolsman, J.G., G.W. Berger, and G.T.M. van Eck, 1993. Sediment accumulation rates, historical input, postdepositional mobility and retention of major elements and trace metals in salt marsh sediments of the Scheldt Estuary, SW Netherlands. *Mar. Chem.*, **44**: 73–79.
- Zwolsman, J.J.J., G.T.M. van Eck, and G. Burger, 1996. Spatial and temporal distribution of trace metals in sediments from the Scheldt Estuary, South-west Netherlands. *Estuar. Coast. Shelf Sci.*, **43**: 55–79.

Manuscript received March 17, 2003

Revision accepted March 22, 2003

Editorial handling: Tongsup Lee