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Distribution and Properties of Intertidal Surface Sediments of Kyeonggi Bay, West Coast of Korea

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경기만 조간대 표층퇴적물의 분포와 특성

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Kyeonggi Bay, a macrotidal coastal embayment in the Yellow Sea coast of central Korea, is fringed by vastly developed tidal flats. About 400 surface sediment samples were collected from the intertidal and subtidal zones of Kyeonggi Bay for a study of the sediment distribution pattern and the surface sediment characteristics of this environment.

The Kyeonggi Bay surface sediment becomes progressively finer in the shoreward direction, from offshore sand to shoreward silty sand and sandy silt. This shoreward-fining trend is repeated again on the tidal flat and, as a consequence, a grain-size break occurs near the low-water line which separates the intertidal area from the subtidal one. The intertidal and subtidal sediments differ from each other in textural characteristics such as mean grain size and skewness and this can be interpreted to result from differences in hydraulic energy and morphology between the two environments.

The mineral and chemical compositions of the Kyeonggi Bay sediments are largely controlled by the sediment grain size. Smectite was nearly absent in the clay mineral assemblage of Kyeonggi Bay sediment. The contents of Co, Cu and Ni were high in the Banweol tidal flat, which suggests a continuous process of accumulation of these metals. The intertidal environment appears to respond rapidly to artificial coastal modifications, the effects of which should be taken into consideration when planning a dam construction or coastal reclamation.

서해 경기만은 대조차 환경으로 해안선을 따라 넓은 조간대 퇴적층이 발달하여 있다. 이 환경에 분포하는 표층퇴적물의 특성과 그 공간적 분포를 연구하기 위하여 총 400개 가량의 퇴적물 시료가 채취, 분석 및 연구되었다.

경기만의 표층퇴적물 분포는 전반적인 해안선방향 세립화의 특징을 나타내며, 이러한 분포경향은 조간대 상에서 다시 나타나 결과적으로 조간대와 조하대를 구분하는 간조선 부근에서 입도분포의 불연속성이 나타난다. 조간대 퇴적물과 조하대 퇴적물은 평균입도와 왜도 등 조직특성의 차이를 보이며, 이는 두 환경 사이에 나타나는 유속 및 지형의 차이에 기인한 현상으로 해석되었다.

퇴적물의 광물 및 화학성분은 퇴적환경에 따른 차이보다 일차적으로 입도에 의해 조절되는 경향을 나타내었다. 점토광물 조성에서는 스멕타이트가 거의 나타나지 않는 특징을 보였으며, 코발트와 구리 및 니켈 등 일부 금속원소의 경우에서는 반월지역 조간대 퇴적층에서 특히 농도가 높아 인근 공업단지로부터 유입된 오염물질의 축적이 진행됨을 시사하였다. 한편 조간대 환경은 인위적인 해안지형의 변화에 비교적 민감하게 대응하여 퇴적상이 빠르게 변화하며 앞으로 방조제의 축조나 조간대 간척사업 등을 계획함에 있어 이러한 영향의 고려가 필요할 것으로 사료된다.

INTRODUCTION

The intertidal mudflat is a characteristic feature developed along the gently dipping sea coast with a marked tidal range, where enough sediment is available and strong wave action is absent (Reineck and Singh, 1980). The Yellow Sea coast of Korea is a typical place for tidal flat development due to its large tidal range, drowned coastal morphology, and the great amount of suspended sediment delivered to the Yellow Sea by the Chinese and Korean rivers. The generally fine-grained nature of intertidal sediment, together with its great areal extent, makes this environment a major site for accumulation of fine sediment supplied from land drainage.

During the last several decades, the tidal flats on the west and south coast of Korea have served as sources of extensive land reclamation projects, which aimed at providing agricultural and industrial grounds. As a result large intertidal areas no longer serve as depositional sites for fine sediments, and more area will be so affected in the near future as reclamation projects continue. The long-term effect of these coastal modifications cannot be evaluated without any accumulation of the knowledge of the unaltered, natural state in this system. Unfortunately, however, our knowledge of this coastal system is relatively limited despite the long-continued, active reclamation projects in this environment.

The purpose of this paper is to summarize the main results obtained from various field and laboratory studies undertaken during the last ten years in Kyeonggi Bay, west coast of Korea, and its surrounding intertidal zones. A reclamation project is actually under way in the southeastern part of the bay (the Siwha Project), which will make this kind of study of some value in the future evaluation of the consequences caused by such coastal modifications. Being different in many respects from most intertidal flats elsewhere (Frey et al., 1989), it will also provide data on a typical tide-dominant coastal depositional system.

THE STUDY AREA

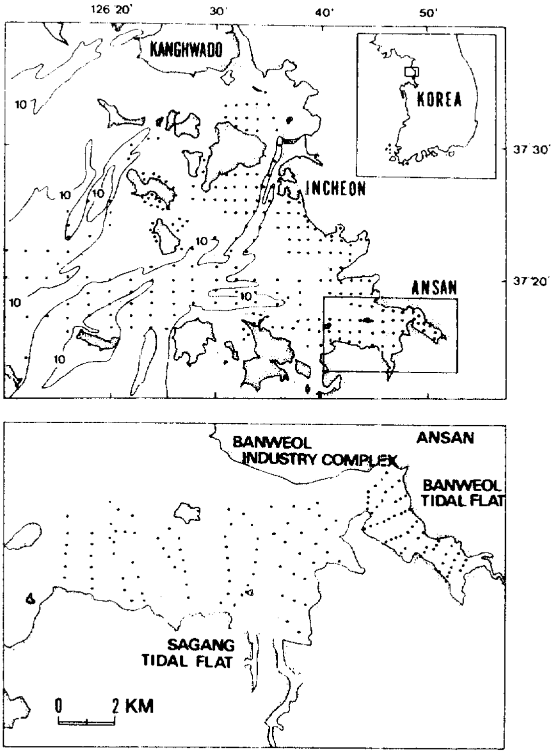

Fig. 1. Top: Location of the study area and sample sites in Kyeonggi Bay. The dotted lines represent the low water line which separates the intertidal from subtidal areas. The solid lines with number (10) represent the 10 m isodepth contour lines. Botom: Sample sites in the Sagang and Banweol tidal flats.

Kyeonggi Bay is a macrotidal coastal embayment, located in the middle part of the Korean Peninsula (Fig. 1). Numerous islands separate the inner part of the bay from the offshore Yellow Sea waters, and between these islands the main tidal channel systems are developed. Most of these channels develop in a NE-SW direction with a depth range of 10 to 30 m. The surrounding land masses are composed of Precambrian metasedimentary rocks, mostly gneiss, mica schists and quartzites.

The tide at the Incheon harbour is of semi-diurnal type with a mean range of about 6.5 meters. The mean spring and neap tidal ranges are about 8 and 4 meters, respectively (Yi, 1972; Hahn, 1980). During spring tides, the current velocities can attain a maximum of 1.8 m/sec during the flood, and 2.3 m/sec during the ebb. The tidal prisms estimated at the main channel off the Incheon harbour are estimated to be about 260-590×10^6 m^3 for the flood, and 200-470×10^6 m^3 for the ebb (Yi, 1972).

The Han River, the largest river in South Korea with a drainage area of about 26×10^3 km^2 debouches into the northern part of the bay. The annual fresh water discharge from the Han River is about 18×10^9 m^3, most of which is concentrated in the summer rainy season. This results in a great seasonal variation in river flow (Ministry of Construction, 1974). Though no quantitative data is available, the sediment discharge must have been reduced greatly by the construction of dams. The sedimentation rates in the Cheongpyeong. and Whacheon Dam reservoirs, located at about 190 and 290 km landward from the river mouth, are estimated at 5.5×10^6 m^3/year and 1.7×10^6 m^3/year, respectively (Schubel et al., 1984).

MATERIALS AND METHODS

Surface sediment samples, 263 in total, were collected during the year of 1981 from the entire area of Kyeonggi Bay, including both subtidal and intertidal zones. Sediment sampling in the subtidal area was performed aboard R/V Banweol (KORDI) using a Shipeck grab, and in the intertidal area by hand using a plastic spoon. In 1983, 56 additional sediment samples were collected from the intertidal flats of the southeastern part of the bay (the Banweol flat) and another 82 additional samples, during 1988 and 1989, from the intertidal flats of the southern part of the bay (the Sagang flat). Therefore, a total of more than 400 surface sediment samples, consisting of 108 subtidal and 293 intertidal sediments, were used in the present study. In addition to this, several pipe cores were taken from the intertidal deposits to evaluate the vertical variations in sediment properties and also to study the early diagenetic processes within these sediments.

For grain-size analysis the sediment was separated into sand and mud fractions by wet sieving with a 4φ mesh (62.5 μm). The sand and mud fractions were then analyzed by the sieving (in quarter interval) and pipetting methods, respectively, following the general procedures described in Carver (1971). Grain-size parameters were calculated by graphic method using the formula proposed by Folk and Ward (1957).

To determine the mineral composition of sands, the fine sand (125-250 μm) and very fine sand (62.5-125 μm) fractions were analysed. They were first separated into heavy and light components by using a bromoform solution (s.g. 2.89), and then analysed under a polarizing microscope for heavy minerals and by the staining technique (Bailey and Stevens, 1960) for light minerals. Clay minerals were identified for the less than 2 μm fraction of sediment by X-ray diffractometry (Rigaku 2037), after mounting it on a smear slide. The chemical composition of sediment was determined on the bulk samples by atomic absorption spectrometry for trace metals and by ICP emission spectroscopy for major components.

Various types of remotely sensed images, including aerial photographs and LANDSAT data, were also analyzed in order to delineate the distribution of intertidal deposits and their surface features such as the tidal drainage systems and water contents.

RESULTS AND DISCUSSION

Surface Sediment Distribution

Five types of sediments can be distinguished in Kyeonggi Bay according to the classification of Folk (1968): gravel, sand, silty sand, sandy silt, and silt. The areal distribution of these sediments shows on the whole a typical shoreward fining pattern (Fig. 2). Sands are the most dominant sediment type in the offshore area. These sands extend along the main channel into the bay forming a tongue-like sandy deposit in the southwestern part of the bay. According to Kenyon et al. (1981), the NE-SW-trending linear tidal sand ridges of various size are continuously modified by strong tidal currents in this area.

Within the bay, the sands are mixed with fine

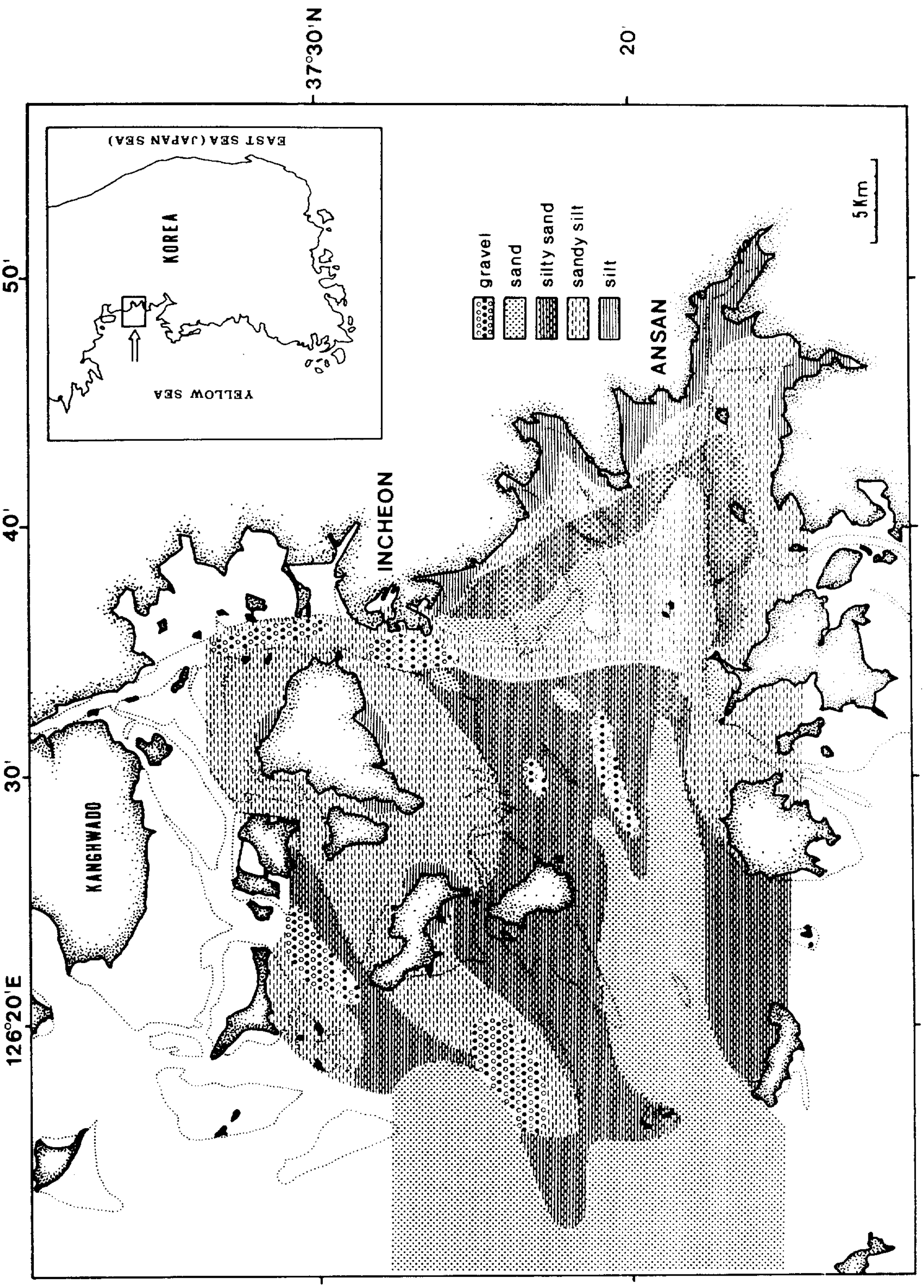

Fig. 2. Surface sediment distribution in Kyeonggi Bay and its surrounding tidal flat areas, based on samples collected in 1981.

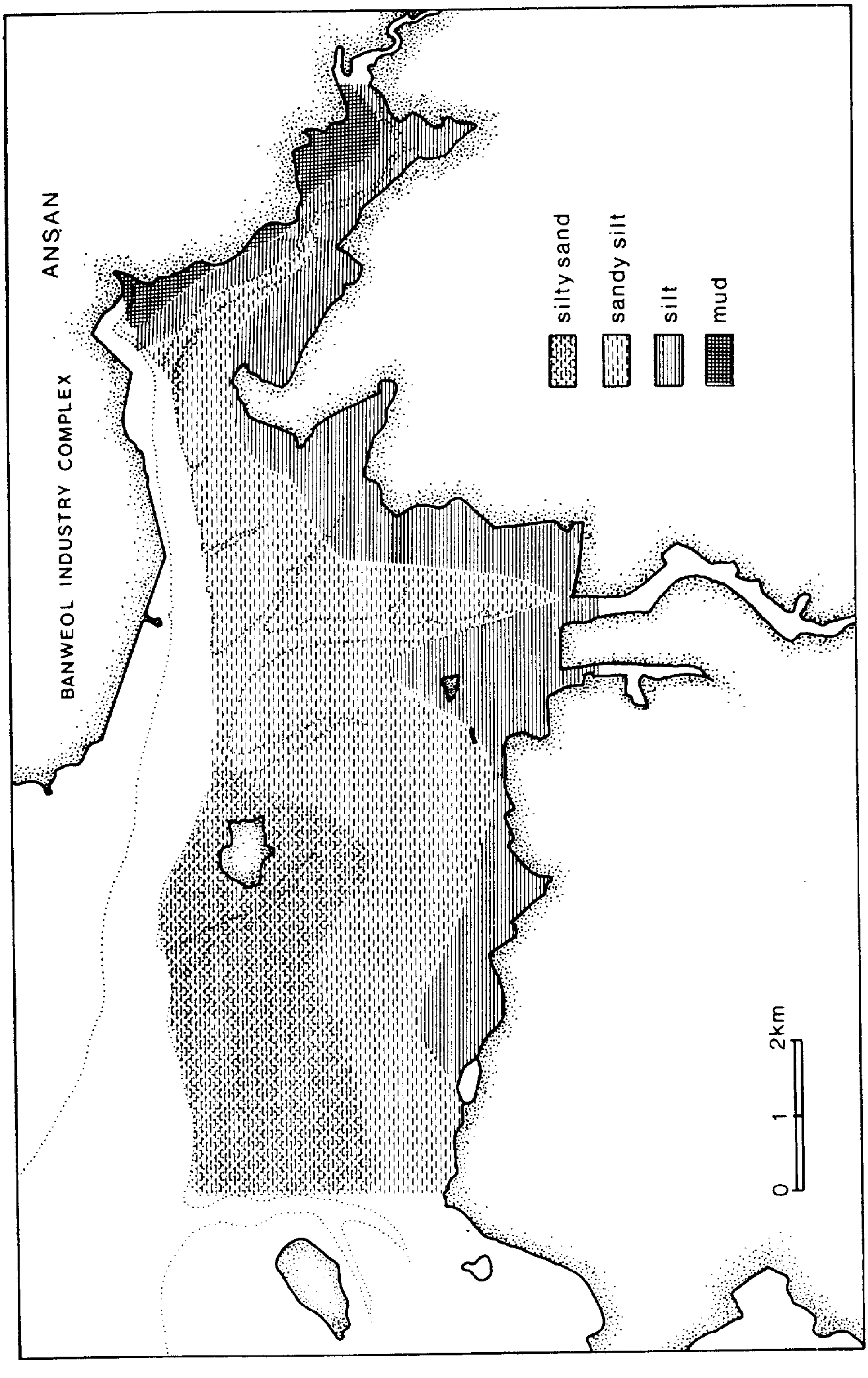

Fig. 3. Surface sediment distribution on intertidal flats of the southern part of Kyeonggi Bay, based on samples collected in 1988 and 1989.

materials to a varying degree, and the sediment types consequently change into silty sand and sandy silt progressively as they approach the shore. Hence, from the offshore to a shoreward direction the proportion of sand in the bottom sediment decreases while that of silt increases. Fine sediments, which are effectively winnowed out in the offshore area under unprotected and stronger wave activities, are transported by tidal currents and deposited within the bay where the wave energy is much reduced. Sedimentation of fine materials will be enhanced shoreward as the tidal energy decreases approaching the shore, which explains the observed shoreward fining trend of surface sediments. At the same time, the erosion of bottom sediment by strong tidal currents results in the gravelly deposits, which are developed in discontinuous patches along the main tidal channels.

Near the low water line which separates the intertidal from subtidal areas, the sediments are coarser than those in its seaward and landward vicinities. This constitutes a break or interruption in the generally shoreward fining trend observed in both intertidal and subtidal areas. The shoreward fining trend of the sediment grain size is repeated again on the intertidal surface and the sediment type changes from sand or silty sand near the low water line to silty sand or silt near the high water line (Fig. 2 and 3). The shoreward fining trend of sediment grain size on the intertidal deposits is observed in most areas where tidal flats are developed (Van Straaten and Kuenen, 1958; Evans, 1965; Larsonneur, 1975; Chung and Park, 1978; Kim and Park, 1985; Lee et al., 1985).

The Intertidal Surface

The intertidal flats fringe most part of the coastline of Kyeonggi Bay, except those places where rocky cliffs or sandy beaches are found. The width of the intertidal flats extends up to 10 km in extreme cases, but generally remains between 4-5 km in most areas. The intertidal flats are bounded landward by an artificial embankment in most areas, which may account for the general absence of supratidal salt marshes. However, a narrow belt of annual halophyte, *Sueda japonica*, can be observed locally near the high water line. In their seaward direction, the intertidal flats pass into shallow seafloor. The surface of the intertidal flat is generally devoid of any relief, except some drainage channels.

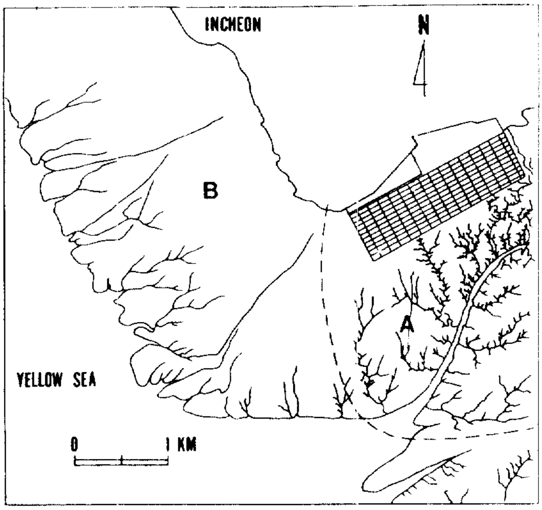

Fig. 4. Two different types of drainage network patterns observed on tidal flats of Kyeonggi Bay, south of Incheon. 'A' is the area of dendritic pattern and 'B' that of more or less parallel pattern.

The tidal flat surface is dissected by numerous networks of tidal creeks which serve mainly as drainage channels during the ebb. The aerial shape of these drainage networks is highly complex and variable. An analysis of the aerial photographs has revealed two types of drainage network systems: one showing a relatively simple and more or less parallel pattern and the other a highly complex and dendritic pattern (Fig. 4). The sediment grain size and surface gradation of tidal flats may be responsible for this difference. Since the sediment grain size and surface slope are related to the water contents of surface sediments, the two drainage network systems may also represent the areas of different water contents in surface sediments.

The surface of intertidal flats changes rapidly. Yoo et al. (1989) reported a significant change in topographic profiles of an intertidal transection just south of Incheon during the two-year period

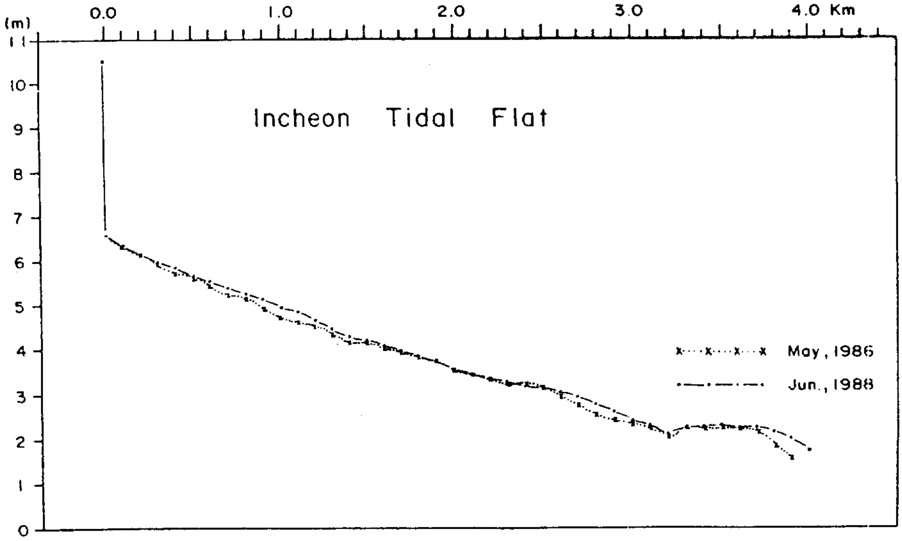

Fig. 5. Topographic profiles of a tidal flat transect south of Incheon, surveyed by KORDI in 1986 and 1988 (after Yoo et al., 1989). Note that the 1988 profile has risen by up to 30 cm relative to the 1986 profile, indicating a rapid accumulation of sediments in some intertidal surface.

between 1986 and 1988. As is shown in Fig. 5, some places on the tidal flat have risen during this period by 10 to 30 cm. Sediment types also can change rather rapidly, especially when there are some modifications of coastal morphology. Fig. 2 is the sediment distribution map based on the surface sediment samples collected during the year 1981; Fig. 3 is based on the samples collected during the years 1988 and 1989. Between the two periods of sample collection, a part of tidal flats which lies opposite to Sagang flat across the main tidal channel was reclaimed for the purpose of building the Banweol Industry Complex. This change in coastal morphology has resulted in the modification of the distribution of intertidal surface sediments, as can be observed from Fig. 3 compared to Fig. 2. The surface sediments of the Sagang and Banweol tidal flats became finer in general and the area occupied by silty sand type sediment decreased in extent. We can also observe the appearance of mud, which contains more than 30% of clay-sized fraction (<4 μm), along the eastern end of Banweol tidal flat. It is clear from this example that the bottom topography and sediment distribution undergo rather rapid modifications when faced with such changes in coastal areas as reclamation.

Textural Characteristics of Intertidal and Subtidal deposits

The statistical parameters of the grain size data are often used as quantitative indices in characterizing the sedimentary materials and are used widely when we compare the sediments from different environments. Average values of textural parameters for the different sediment types in subtidal and intertidal areas of Kyeonggi Bay are compared in Table 1.

The textural distinction between the intertidal and subtidal deposits can be observed in the mean grain size of sands and the skewness of sandy silts. The differences both in mean grain size and in skewness can result from the differences either in the transport mechanisms or in the available populations of sediment between these two environments.

When we compare the distribution of the modal population in sandy deposits between the two areas, the distinction becomes more clear (Fig. 6). In the subtidal sand the mode occurs most frequently in the 1.5-2.0ϕ fraction (medium sand)

Table 1. Comparison of average textural parameters between the intertidal and subtidal deposits.

Sediment	Intertidal Sediments				Subtidal Sediments			
Type	$Mz(\phi)$	$\sigma_I(\phi)$	Sk_I	K_G	$Mz(\phi)$	$\sigma_I(\phi)$	Sk_I	K_G
Sand	3.51	0.51	0.17	1.34	1.91	0.49	0.15	1.23
Silty sand	3.79	1.15	0.27	1.47	3.85	1.29	0.26	1.20
Sandy silt	4.65	1.17	0.34	1.63	4.52	1.58	0.17	1.20
Silt	5.55	1.33	0.47	1.41	—	—	—	—

*The mean grain size (Mz), sorting (σ_I), skewness(Sk_I) and kurtosis(K_G) are calculated graphically using the formula proposed by Folk and Ward (1957).

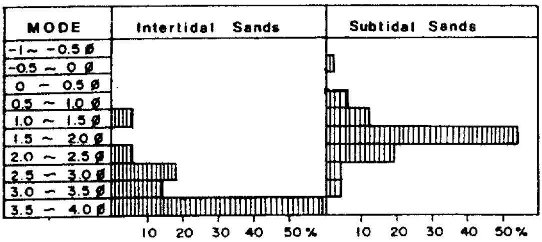

Fig. 6. Frequency distribution of the mode in sandy sediments of intertidal and subtidal areas.

while in the intertidal sand it occurs most frequently in the 3.5-4.0Φ fraction (very fine sand). On the other hand, the transport mode of sand grains inferred from applying the method of Visher (1969) shows a similar pattern in both areas, the saltation mode being dominant with only small contributions of the traction and suspension modes (Fig. 7). However, the range of grain size which is transported by each mode differs greatly between the intertidal and subtidal areas.

The difference in textural characteristics between the intertidal and subtidal deposits is therefore due principally to the difference in hydraulic energy between the two environments. As the speed of tidal current diminishes shoreward, the maximum grain size transported by tidal currents is greatly reduced on the intertidal area. In addition, as the sediments move from the sea toward the shore, the higher bed level of intertidal area makes more difficult the transportation of coarser grained sediments from the lower subtidal zone to the intertidal area. The shoreward diminishing current speed and the lag effects associated with tidal sedimentation will enhance the deposition of fine materials and produce a positively-skewed grain size distribution.

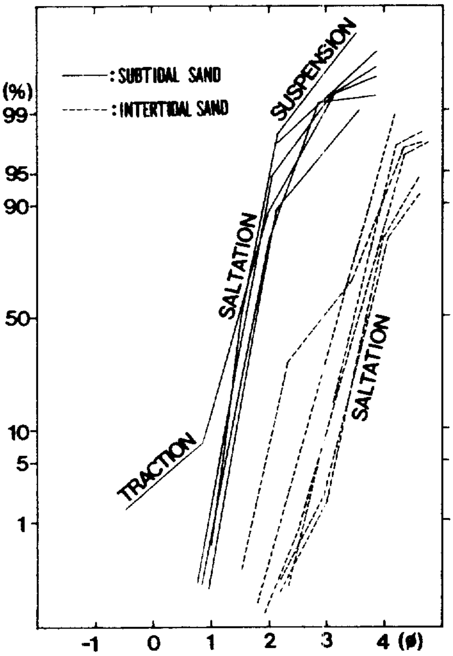

Fig. 7. Application of the method proposed by Visher (1969) to the Kyeonggi Bay intertidal and subtidal sands. Note that the relative importance of each mode of transport is identical for both the intertidal and subtidal sands despite their differences in mean grain size.

Mineral Composition of Sediments

The sand-sized sediment particles are composed mostly of quartz, followed by feldspars, with some minor contributions of heavy minerals and biogenic materials. The quartz/feldspar ratios increased as the sediment became finer, with an average value of 1.7 in the medium sand fraction (500-250 μm) and 3.0 in the fine sand fraction (250-125 μm) The K-feldspar/plagioclase ratios, also being dependent on the sediment grain size, showed an ave-

Table 2. Heavy mineral compositions in sediments from Kyeonggi Bay.

Minerals	Fine sands		Very fine sands	
	Range	Average	Range	Average
Amphibole group	18.9-67.1	42.9	17.1-59.2	40.6
Hornblende	(14.0-62.0	35.8)	(15.0-51.4	35.3)
Actinolite + Tremolite	(1.8-10.5	6.4)	(0.8- 9.2	4.5)
Glaucophane	(0.0- 2.1	0.7)	(0.0- 2.8	0.8)
Epidote group	6.5-18.7	12.8	8.3-19.9	13.6
Epidote	(3.1-16.2	9.7)	(5.9-17.0	10.4)
Zoisite + Clinozoisite	(0.7- 6.8	3.1)	(1.0- 5.8	3.2)
Pyroxene group	0.8- 5.3	2.4	0.5- 9.7	4.5
Hypersthene	(0.0- 2.3	0.8)	(0.0- 5.2	2.6)
Augite + Diopside	(0.4- 4.0	1.6)	(0.0- 4.9	1.9)
Kyanite	0.0- 1.4	0.3	0.0- 0.9	0.1
Andalusite	0.0- 3.2	0.7	0.0- 1.3	0.4
Sillimanite	0.6- 6.4	2.6	0.0- 4.5	1.3
Staurolite	0.0- 3.8	1.7	0.0- 3.7	0.9
Garnet	0.0-22.4	9.2	2.4-19.3	7.5
Zircon	0.0-24.0	2.1	0.4-28.3	5.5
Tourmaline	0.0- 2.8	1.2	0.0- 3.8	1.6
Rutile	0.0- 2.2	0.6	0.0- 3.7	1.3
Monazite	0.0- 2.6	0.6	0.0- 6.5	2.2
Sphene	0.0- 3.8	0.5	0.0- 7.3	1.7
Opaques	5.4-44.6	20.7	6.3-32.3	15.7
Others	1.0- 3.9	1.7	0.9- 6.5	3.1
(% of heavy minerals)	0.4- 7.0	2.3	0.7-11.7	2.8

rage of 1.8 in the medium sand fraction and 0.8 in the fine sand fraction. The amount of heavy minerals showed ranges between 0.4-7.0% (av. 2.0%) in the fine sand fraction, and between 0.7-11.7% (av. 2.8%) in the very fine sand fraction (125-62.5 μm). On the whole, no major distinction in mineralogical composition can be observed between the intertidal and subtidal sediments.

Among heavy minerals, the amphibole group (in particular, hornblende) is the dominant mineral type in these sediments and accounts for on the average 42.9% and 40.6% of the total heavy minerals in fine sand (f.s.) and very fine sand (v.f.s.) fractions, respectively. The epidote group, consisting of epidote, zoisite and clinozoisite, forms the second abundant mineral group and constitutes on the average 12.8% (f.s.) and 13.6% (v.f.s.) of the total heavy minerals. Garnet and zircon occur with the relative abundance of 9.2(f.s.)-7.5(v.f.s.)% and 2.1(f.s.)-5.52(v.f.s.)%, respectively. The pyroxene group minerals also occur with the average abundance of 2.4% (f.s.) and 4.5% (v.f.s.), and consist of hypersthene, augite and diopside. Other heavy minerals identified in the Kyeonggi Bay sediments include staurolite, tourmaline, sillimanite, monazite, sphene, kyanite, andalusite and rutile (Table 2).

Clay minerals are mainly composed of three types, namely illite, kaolinite and chlorite, and smectite is practically absent in the Kyeonggi Bay sediments (Fig. 8). Illite is the dominant clay mineral and constitutes on the average 55 % of the total clay mineral assemblage. Kaolinite and chlorite occur in nearly 1:1 ratio with an average of 22 and 23 % of the total clay minerals respectively. The clay mineral composition of Kyeonggi Bay sediments is fairly uniform in both horizontal and vertical (up tp 1 m depth) contexts, and nearly identical to that reported from the Keum River sediments by Choi (1981). However, being depleted in illite and rich in both kaolinite and chlorite it is significantly different from those values reported from offshore sediments of the southwest coast of Korea (Park et al., 1986; Park and Khim, 1990).

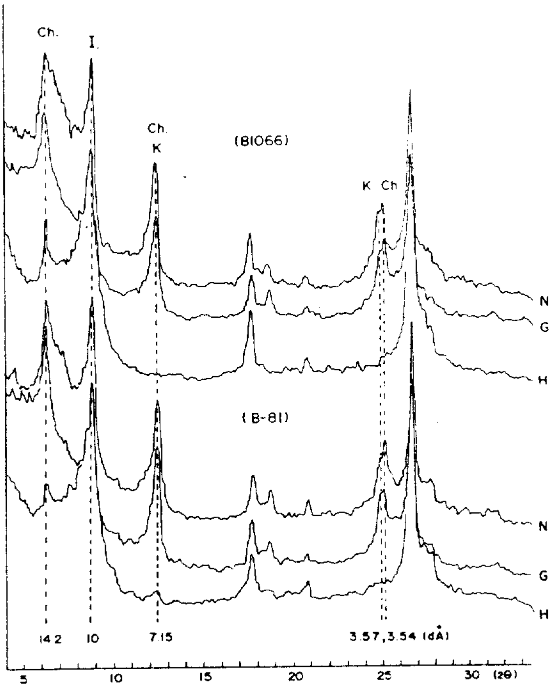

Fig. 8. The X-ray diffractograms of two surface sediment samples from Kyeonggi Bay. N, G and H denote 'normal (untreated)', 'glycolated' and 'heated (to 550℃)' respectively. 81066 is from intertidal area and B-81 from subtidal area. Note that there is no shift of peak from 10Å to 17Å in the diffractogram of the glycolated sample relative to the normal one.

Although there has been some disagreement among the authors about the occurence of smectite in the Korean nearshore sediments (Park et al., 1976; Kim, 1980; Choi, 1981; Park and Han, 1985; Park et al., 1986), most agree on the near-absence of this mineral in the suspended sediments from the Korean rivers. Smectite, on the other hand, is reported from both the Huanghe and Yangtze Rivers, and comprises on the average about 16 % of the total clay mineral assemblage in the Huanghe River suspended sediments (Yang and Milliman, 1983). Hence, the absence of smectite may indicate that the Kyeonggi Bay sediments receive almost no influence from the fine sediments transported by these large Chinese rivers.

Chemical Composition of Sediments

The average chemical composition of the Kyeonggi Bay surface sediments is: 69.01% SiO_2, 14.34% Al_2O_3, 3.63% Fe_2O_3, 1.07% CaO, 1.82% MgO, 2.79% K_2O, 2.18% Na_2O, 0.75% TiO_2 and 4.32% of ignition loss. The chemical composition is largely controlled by the grain size of sediments. Hence, the contents of SiO_2 and CaO increase with decreasing mean grain size while those of Al_2O_3, Fe_2O_3 and MgO decrease. Apart from that related to sediment grain size, no systematic variation patterns in major element composition were apparent neither horizontally within the study area nor vertically down to about 1m deep from the sediment surface.

The organic carbon contents of sediments are generally low and vary between 0.08 and 1.24% with an average value of 0.55%. This relatively low content of organic carbon may result either from the low biological production in this environment or from the high rate of consumption of organic materials. As was reported by Lee and Kim (1990), the active nutrient regeneration from an anoxic

Table 3. Average contents of trace metals in the study area compared with those reported from other areas. (unit: ppm)

	Mn	Zn	Cu	Pb	Ni	Co
Kyeonggi Bay sediments (total)[1]	455	167	12	32	26	7
Intertidal sediments (Sagang)[1]	465	66	22		28	9
Intertidal sediments (Banweol)[1]	635	242	33	31	67	74
SPM from Banweol tidal channel[1]	838	374	61	52	50	29
Keum Estuary sediments[2] bottom	618	313	17	43	22	24
bank	770	410	25	49	30	27
SPM	1082	897	283	58	40	44
Korean SE coastal sediments[3]	499	111	18	28	29	13
Average Shale[4]	850	95	45	20	68	19

Sources: [1]Present study; [2]Lee (1985); [3]Lee and Han (1978), n=32; [4]Turekian and Wedepohl (1961).

intertidal deposit suggests the generally high rate of organic matter decomposition in this environment. The organic nitrogen contents range from 0.02 to 0.96 μg/mg with an average value of 0.33 μg/mg. The C/N ratio is generally high (all above 10) and shows an average value of 15.5. Higher ratios are generally encountered in the subtidal channel deposits, suggesting a larger proportion of aged or land-derived organic materials in these deposits.

The contents of metallic elements in surface sediments of the study area vary widely from one sediment to another. In Table 3 the average metal contents in sediments of entire Kyeonggi Bay (based on samples collected in 1981) and two intertidal areas (Sagang and Banweol tidal flats, based on samples collected in 1988 and 1983, respectively) are compared with those values reported from other coastal deposits around Korea.

It is clear from Table 3 that the metal contents of sediments show an areal segregation pattern in Kyeonggi Bay. While sediments in Kyeonggi Bay on the whole have metal contents which do not deviate appreciably from the natural range, the intertidal deposits in the Banweol area show an evident sign of enrichment in all analyzed metals except Pb. Considering the more fine-grained nature of Banweol intertidal deposits, higher contents of metallic elements are expected to a certain extent in this area, relative to the other Kyeonggi Bay areas. However, it is hard to imagine an enrichment by more than twofold (for Cu and Ni) and even tenfold (for Co) to result solely from textural differences. Besides, the relationship between the contents of these metals and sediment grain size, which was reported from the unpolluted offshore sediments (Lee et al., 1991, 1992), is not evident in the Kyeonggi Bay sediments. And for Co and Ni, the average contents in the intertidal deposits of Banweol area are even higher than those observed in the suspended sediments.

All these facts strongly suggest that the higher metal contents in the Banweol intertidal sediments are caused by the input of waste effluents from the nearby industrial complex and that an accumulation of some metals in these deposits is still going on. The Banweol Industrial Complex, which has been occupying the north of the Banweol tidal flat since the early eighties, consists of various factories including those for dyeing and electroplating. All these factories use large quantities of metallic compounds for various purposes and discharge them as wastes. The relatively short history of this industrial complex and the strong tidal action in this environment, which mixes and disperses various wastes effectively, may explain the fact that the pollution effect has not yet been observed outside the Banweol intertidal area. The accumulation of muddy sediments on the Banweol tidal flat, which appears to be the result of coastal modification, may also in part be responsible for the enrichment of certain metals in this area.

CONCLUSIONS

From the results of the present study, following conclusions can be drawn:

1. Surface sediment distribution in Kyeonggi Bay shows in general a typical shoreward-fining pattern. This shoreward-fining trend is observed both in subtidal and intertidal areas and consequently a grain-size break occurs near the low-water line separating the two environments.
2. The intertidal and subtidal deposits show distinct characteristics in some textural properties such as mean grain size and skewness. This kind of distinction may be used as a criterion for identifying depositional environment in the analysis of ancient tidal sedimentary sequences.
3. The intertidal area, which plays an important role in the local ecosystem as an accumulation site of fine materials, as a habitat of various benthic organisms, as a source of nutrients to the water column, and as a possible sink for various anthropogenic pollutants, responds rather rapidly to changes in coastal landform such as the construction of dams. Therefore, in planning reclamation of an intertidal area the possible modification of nearby intertidal areas should be taken into consideration.
4. The mineral composition of sandy sediments in Kyeonggi Bay are mainly composed of quartz

and feldspar with a small and variable amount of heavy minerals. Among heavy minerals amphibole is dominant, followed by epidote, garnet, zircon, and pyroxene etc. Clay minerals are essentially composed of three groups, i.e. illite, kaolinite and chlorite. Smectite is practically absent, which indicate that the contribution of fine sediments from Chinese rivers is negligible.

5. The chemical composition of the surface sediments is dependent on the sediment grain size. Organic carbon contents of sediments are generally low, which seems to be due mainly to the active microbial consumption during the shallow burial period. A significant enrichment of Co, Cu and Ni in the intertidal sediments of the Banweol area is the result of pollution by industrial effluents from the nearby industrial complex.

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