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Sedimentology and Geochemical Properties of Intertidal Surface Sediments of the Banweol Area in the Southern Part of Kyeonggi Bay, Korea*

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潮間帶 推積物의 地化學的 및 推積學的 性質(半月, 京畿灣)

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Abstract: Sediment transport by tidal currents as well as the distribution and properties of intertial surface sediments are investigated using the data obtained from an anchor station on the main tidal channel and 56 tidal flat surface samples. Sedimentation in the intertidal zone appears to occur mainly during the spring tide period in this environment. The tidal flat can be classified into three depositional facies. The tidal flat deposits are ubiquitously bioturbated by various bottom dwelling organisms among which the crabs and polychaetes predominate. Average trace metal contents of the intertidal surface sediments are: 74.8 ppm Co, 67.8 ppm Ni, 32.6 ppm Cu and 30.7 ppm Pb. Compared with the northen Kyeonggi Bay bottom sediments, these contents are significantly high, except for Pb.

要約：京畿灣의 半月지역을 중심으로 潮流에 의한 推積物의 移動과 조간대 表層推積物의 分布 및 性質을 조사하였다. 이 지역에 발달한 조간대 퇴적상은 沙質, 泥沙質, 泥質의 세가지 유형으로 대별되며 간조선으로 부터 만조선쪽으로 갈수록 퇴적물의 粒度는 점차로 세립화 하는 경향을 나타낸다. 또한 이 지역에 많이 서식하는 게와 多毛類에 의한 퇴적층의 심한 생물교란이 관찰되었다. 부유퇴적물 농도 변화의 분석결과는 조간대에서의 수직퇴적작용이 大潮期에 주로 이루어짐을 보여준다. 表層推積物의 평균 중금속 함량은 코발트 74.8ppm, 니켈 67.8ppm, 구리 32.6ppm, 납 30.7ppm이다. 이 양은 납을 제외한 다른 요소들의 경우 경기만내의 다른지역의 퇴적물내 함량보다 월등히 높은 것으로 특히 코발트의 경우 산업폐수에 의한 축적의 가능성을 보여준다.

INTRODUCTION

Intertidal flats occur extensively along the west coast of the Korean Peninsula due to macrotidal range (>4m) and drowned subbottom topography. Many of these tidal flat areas have along been receiving attention from national land planners and are planned to be or have been reclaimed for agricultural and industrial purposes. However, the geologic aspects of these deposits have not been investigated until recently.

Chung and Park (1978) have distinguised two sedimentary facies, the sand and mud flats, from the southern Namyang Bay intertidal zone. Kim and Park (1985) have reported from the Changgu Bay tidal flat three major depositional facies and also found that small-scale ripple lamination and parallel lamination were the dominant sedimentary structures in this environment, along with the ubiquitous bioturbation

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structures. Park et al. (1984) have defined four sedimentary environments in the Kwangyang Bay where a rather confined environmental condition of a semi-enclosed bay includ intertidal and subtidal flats' delta, and major tidal channels. The present paper deals with tidal flats in the southern part of the Kyeonggi Bay, west coast of Korea and discusses the sediment transport by tidal currents as well as the surface distribution and geochemical properties of sediments. The latter point is of our special interest because in the northern part of the study area is located a large industrial complex (Banweol) and hence some environmental impacts are expected.

STUDY AREA

The study area, located at the southern extremity of the widely developed Kyeonggi Bay tidal flat system, has an area of 7.5 square km with about 5km of length and 1.5km of width (Fig. 1). Artificial embankments border most of the landward boundaries. On the northwestern side of the study area a main tidal channel, which divides the tidal flat into two parts, connects the Kyeonggi Bay. Both from the northern and southeastern sides of the study area small streams flow in and join the tidal channel but with minor freshwater discharges.

The surrounding land masses are composed of Precambrian metasedimentary rocks, mostly of gneiss, mica schists and quartzites, and are stable. The intertidal sedimentation has not begun until about 6,000 B.P. when the sea level approached the present coastal zone (Park and Bloom, 1984).

The Kyeonggi Bay is characterized by a semi-diurnal, macrotidal regime with a mean spring-tidal range of about 8 m. Tidal current velocity,

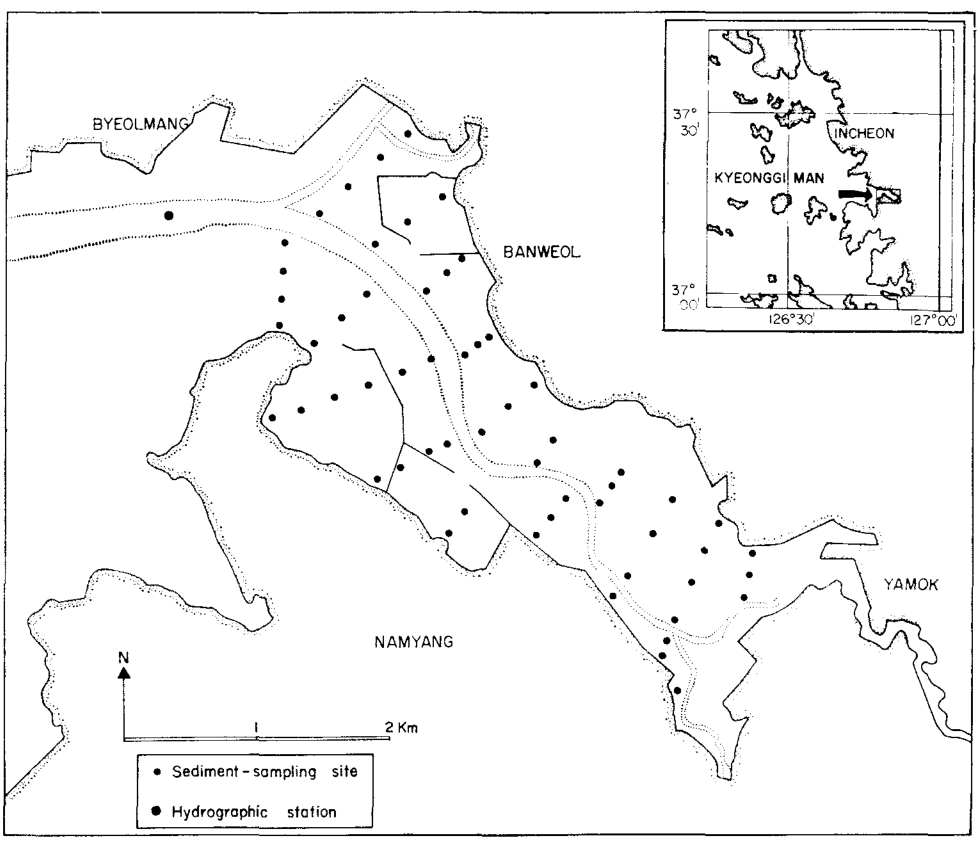

Fig. 1. Map showing the study area and sampling sites.

varing widely with the tidal phase and morphology, is in general greater during the ebb than during the flood in most part of the bay. Spring-tidal velocity is on the average about 1.8 times that of neap-tidal velocity (Bong, 1978). Vertical salinity gradient is not observed in the bay due to the relative shallowness and effective tidal mixing.

MATERIALS AND METHODS

Measurements of current velocity and suspended sediment concentration were made three times at an anchor station on the main tidal channel (Byeolmang) which connects the study area to the Kyeonggi Bay. Three periods of field observation correspond the periods of spring-tide, of neap tide and of strong waves respectively. Suspended sediment concentration was determined by filtration with 0.45μm Nuclepore filters.

56 sediment samples were collected on the intertidal surface by means of a plastic pan which enabled us to get the uppermost 5mm layer of sediments. Grain-size analysis was done by sieving and pipetting methods. Organic carbon content was determined by back titration after treatment of the sediments with a sulfo-chromic mixture (Johnson, 1949; Etcheber, 1978). Metal contents were analyzed using an IL 251 Model atomic absorption spectrometer. Prior to analysis the sediments were digested with a mixed solution of HF, HNO3 and HC104 and leached with dilute HCl, as was described by Kitano and Fujiyoshi (1980).

SUSPENDED SEDIMENT TRANSPORT BY TIDAL CURRENTS

Dynamics of sedimentation in an intertidal area is primarily dominated by tidal processes. Suspended sediments are transported into and out from this environment mainly by tidal currents. Tidal currents flood into this area through the tidal channel and then spread out across the flat zone. Ebb currents begin with slow drainage from the flat zone into the channel where rapid currents occur. Wave action can be also important, especially when it causes the resuspension of bottom sediments and thus make them available to be transported by incoming flood currents.

Tidal current measurements on the Byeolmang channel have revealed a great difference in its strength between the periods during spring-and neap-tides (Fig. 2). During the spring-tide (Aug. 13, 1983) the maximum velocity was 110cm/sec at the surface and 70cm/sec at the near-bottom of the water column, both occurring during the flood. During the neap-tide (Mar. 11, 1984) the velocity was reduced to 46cm/sec at the surface (during the ebb) and 33cm/sec at the near-bottom (during the flood).

The difference in current strength between the

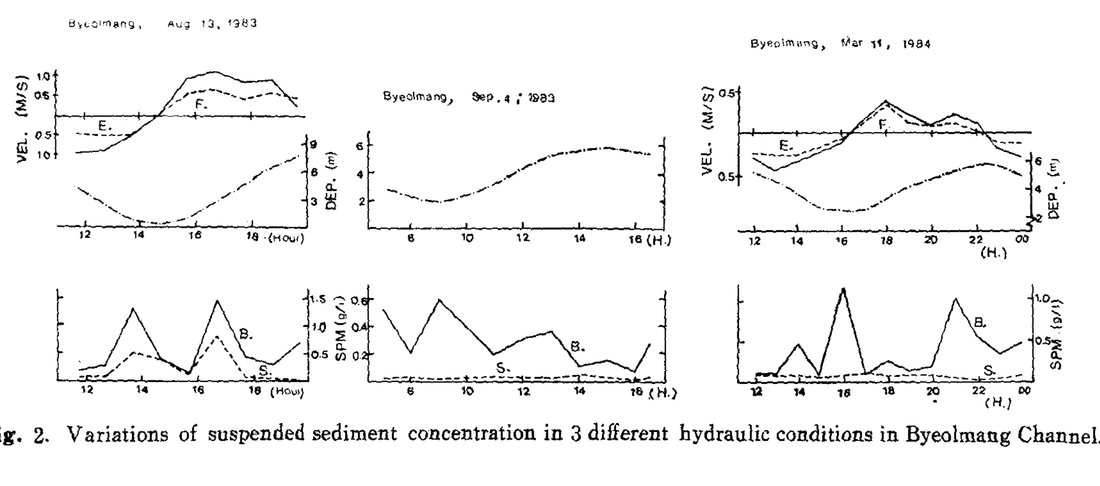

Fig. 2. Variations of suspended sediment concentration in 3 different hydraulic conditions in Byeolmang Channel.

spring and neaptide conditions have resulted in different levels of suspended sediment concentration between these two periods (Fig. 2). On August 13, 1983 (spring-tide), the suspended sediment concentration at Byeolmang Channel varied between 15.0 and 808.0 mg/l (av. 239.5 mg/l) at the surface layer of water column. At the near-bottom, it varied between 154.0 and 1472.0mg/l (av. 578.8mg/l). Occurrence of higher concentrations coincided with elevated current speeds, both at the surface and near-bottom of the water column, indicating a great mixing effect of the strong spring-tidal currents. On September 4, 1983(neap-tide), the suspended sediment concentrations were between 16.4 and 47.5mg/l (av. 29.5mg/l) at the surface and between 79.3 and 594.0mg/l (av. 281.9mg/l) at the near-bottom. In this period, both the average concentration and the range of variation are much reduced compared to those of the spring-tide period.

March 11, 1984 was a period of neap-tide with a tidal range comparable to that of September 4, 1983, but characterized by intensive wave activities. At this period, the level of suspended sediment concentration was generally higher than that of September 4, 1983, but still inferior to that of the spring-tide period, with values between 29.7 and 109.5mg/l (av. 67.8mg/l) at the surface, and between 75.3 and 1119.3mg/l (av. 366mg/l) at the near-bottom (Fig. 2).

The above results show clearly that tidal phase exerts dominant influence on the transport of suspended sediments in this environment. Thus, transport and consequent accumulation of fine sediments on the tidal flat occur principally under the spring-tide condition. The fact that the spring-tidal high water covers a wider area and therfore has a shallower mean depth than the neap-tide may enhance the sedimentation during this period. Wave activities may also contribute to the influx of fine sediments into this environment, considering the generally elevated suspended sediment concentration of the flood currents compared to that of the ebb currents in the Mar. 11 (1984) data.

INTERTIDAL SURFACE SEDIMENTS

Tidal flat surface sediments of the southeastern Kyeonggi Bay consist mostly of fine-grained inorganic particles. When plotted in the triangular diagram, most of these sediments fall into three categories according to the classification scheme of Folk (1954, 1968); silt, mud and sandy silt (Fig. 3).

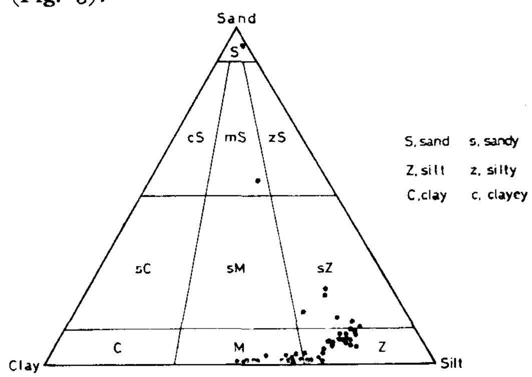

Fig. 3. Intertidal surface sediments plotted on the Folk's triangular diagram.

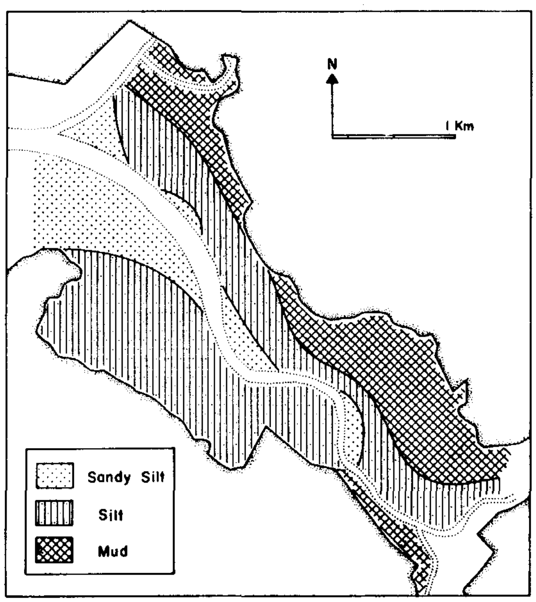

Fig. 4. Three major sedimentary facies and their distribution.

Areal distribution of the three sedsmentary facies is shown in Figure 4. As a general rule, the sediment grain-size becomes finer landward from the main tidal channel. Sandy silts are distributed mainly along the channel and are succeeded by silts and muds shoreward progressively. The sand content of the tidal flat deposit rarely exceeds 20% by weight and is less than 10% for most of the sediment samples. A higher content of sand fraction occurs near the tidal channel. By contrast, the content of clay fraction (less than 4μm) increases shoreward progressively and exhibits minimum values near the channel. This shoreward finer trend of sediment distribution can be attributed to the lag effects (Van Straaten and Kuenen, 1958; Postma, 1967) as well as to the asymmetries in current speed and duration between the high and low tides (Curray, 1969).

Intertidal surface sediments are extremely bioturbated by various bottom-dwelling organisms. Abundant species of invertebrates identified from tidal flats are as follows:

Bivalves
- *Glauconomya chinensis*
- *Striarca olivacea*
- *Potamorcorbula amurensis*
- *Sinonovacula constricta*

Gastropods
- *Paludinella japonica*
- *Hinia festiva*
- *Bullacta exarata*
- *Lunatia fortunei*

Polychaetes
- *Perinereis vancaurica tetradentata*
- *Periserrula leucophryna*
- *Neanthes japonica*
- *Nectoneanthes oxypoda*
- *Nephthys ciliata*
- *Glycera chirori*
- *Glycinde* sp.
- *Mediomastus* sp.

Crabs
- *Ilyoplax dentimerosa*
- *I. pingi*
- *Helice tridens sheni*
- *Macrophthalmus japonicus*
- *Cleistostoma dilatatum*
- *Uca arcuata*
- *Camptandrium sexdentatum*

Among these species, deposit-feeding crabs and polychaetes are especially responsible for the change of surface topography. (Fig. 5) The crabs *Helice tridens sheni* and *Macrophthalmus japonica* are predominated in the mid littoral zone. Crab holes and mounds with diameter ranging from a

Fig. 5. a) Abundant crab mounds produced mainly by crabs *Macrophthalmus japonicus*, *Helice tridena sheni* and *Ilyoplax dentimerosa*.

b) Walking and grazing trace around the burrow entrance of *Macropthalmus japonicus*.

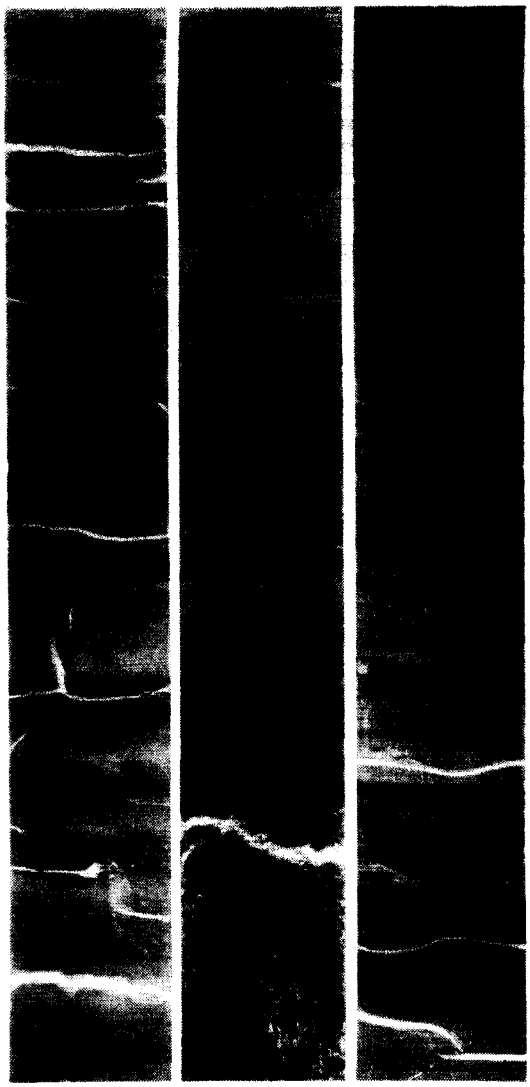

Fig. 6. X-ray radiography showing fine-laminated structures in the intertidal deposits.

few to 10 centimeters generally result directly from these animals. The deposit-feeding polychaete *Perisurrela leucophryna*, which forms the mound that shows strong resemblance to that of crabs but small enterance, may burrow into about 50cm deep.

The bioturbation structures as well as other inorganic sedimentary structures can be observed in the vertical section of the sediment colume by means of X-ray radiography(Fig). 6. Sedimentary structures recognized were fine parallel laminations, thinly interlayered **beddings, small-scale** diapiric structures. Occasionally, small mud balls incorporated within the sand layer can also be observed.

GEOCHEMICAL PROPERTIES OF SEDIMENTS

The average chemical composition of the tidal flat surface sediments was 63.35% SiO_2, 16.64% Al_2O_3, 0.91% CaO, 2.03% MgO, 4.95% Fe_2O_3 and 0.09% MnO. The organic matter content was 0.38%. The suspended sediments collected at the Byeolmang channel show a similar composition, with a slightly higher content in MgO and lower contents in SiO_2 and CaO. The compositional difference between the suspended and deposited sediments as well as that among the individual sediment samples are largely caused by the grain size effect, as can be inferred from Figure 7.

Among the trace elements, four metals(Co, Ni, Cu, and Pb) are analysed. These metals are considered globally as major environmental pollutants because of their high toxicity and great industrial uses (Forsther and Wittmann, 1981; Martin et al., 1976; Wood, 1974).

Figure 8 shows the distribution pattern of these metals associated with intertidal surface sediments in the study area. The cobalt content which varies between 21.1 and 122.3 ppm (av. 74.3 ppm) is generally higher in the western and southern parts and lower in the northern and eastern parts. The nickel content have a range of 17.5~108.5 ppm (av. 67.3 ppm) and is generally lower near the channel and higher in both the eastern and western shoreward regions. The copper content was between 12.0 and 62.3 ppm (av. 32.6 ppm) and shows, in contrast to that of cobalt, a general increase eastward. The lead content varies between 7.7 and 59.5 ppm (av. 30.7 ppm) and shows a belt-like distribution pattern with a north-south trend.

The average metal contents of the intertidal

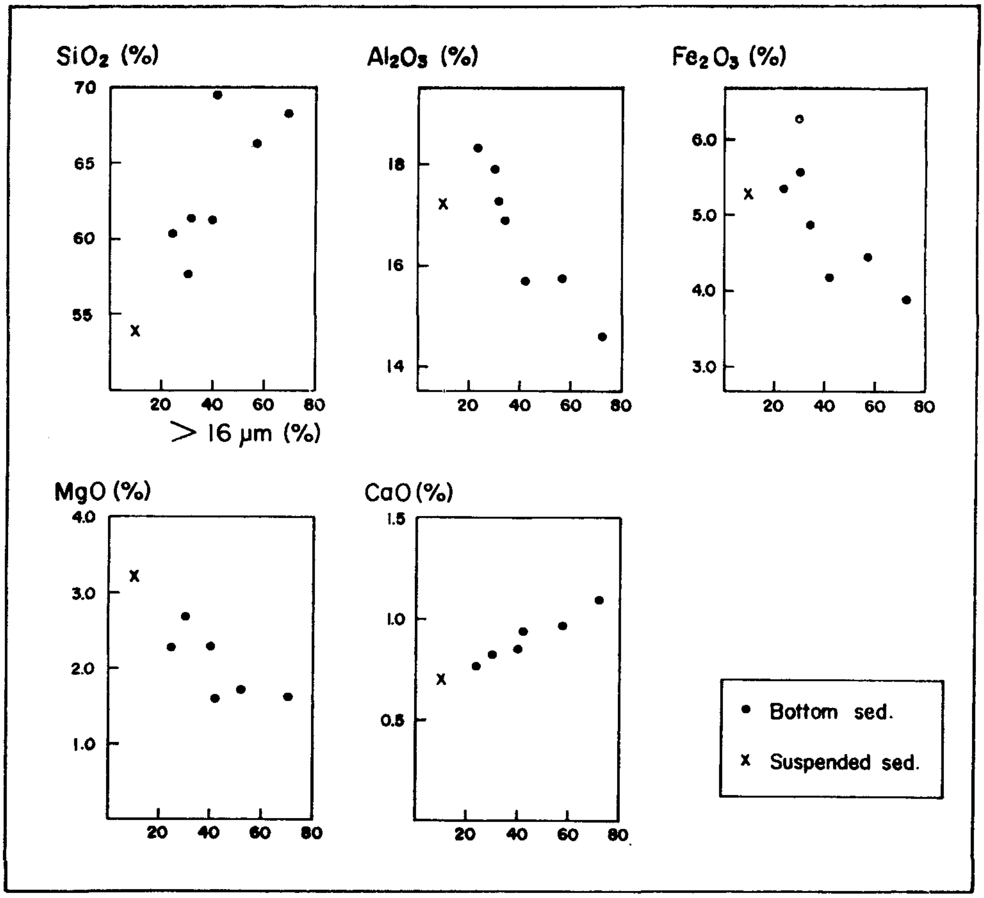

Fig. 7. Relation between the contents of major elements and those of coarse-size fraction.

Table 1. Average content of Co, Ni, Co and Pb in the study area (in ppm).

	Co	Ni	Cu	Pb
Intertidal surface sediments	74.3	67.3	32.6	30.7
Suspended sediments (Byeolamng)	28.3	50.0	61.4	52.1
Offshore bottom sediments (KyeonggiBay)	7.0	26.0	12.0	32.0
Average shale	19.0	68.0	45.0	20.0

Source: KORDI(1981), "Turekian and Wedepohl(1961)"

surface sediments in the study area are generally higher, except for lead, than that of the bottom sediments of the Kyeonggi Bay (Table. 1). When compared with the suspended sediments of the Byeolmang channel, the intertidal surface sediments are enriched in cobalt and nickel and depleted in copper and lead. The high enrichment level of cobalt in particular is significant, considering the fact that both the Kyeonggi Bay (Banweol and other industrial complex) bottom sediments and the suspended sediments consitute the primary sources of the sedimentary deposits in the study area.

It can be inferred therefore that the major source of this metal is of local origin and if so, it is most likely to be the Banweol Industrial Complex, situated in the northern part of the study area.

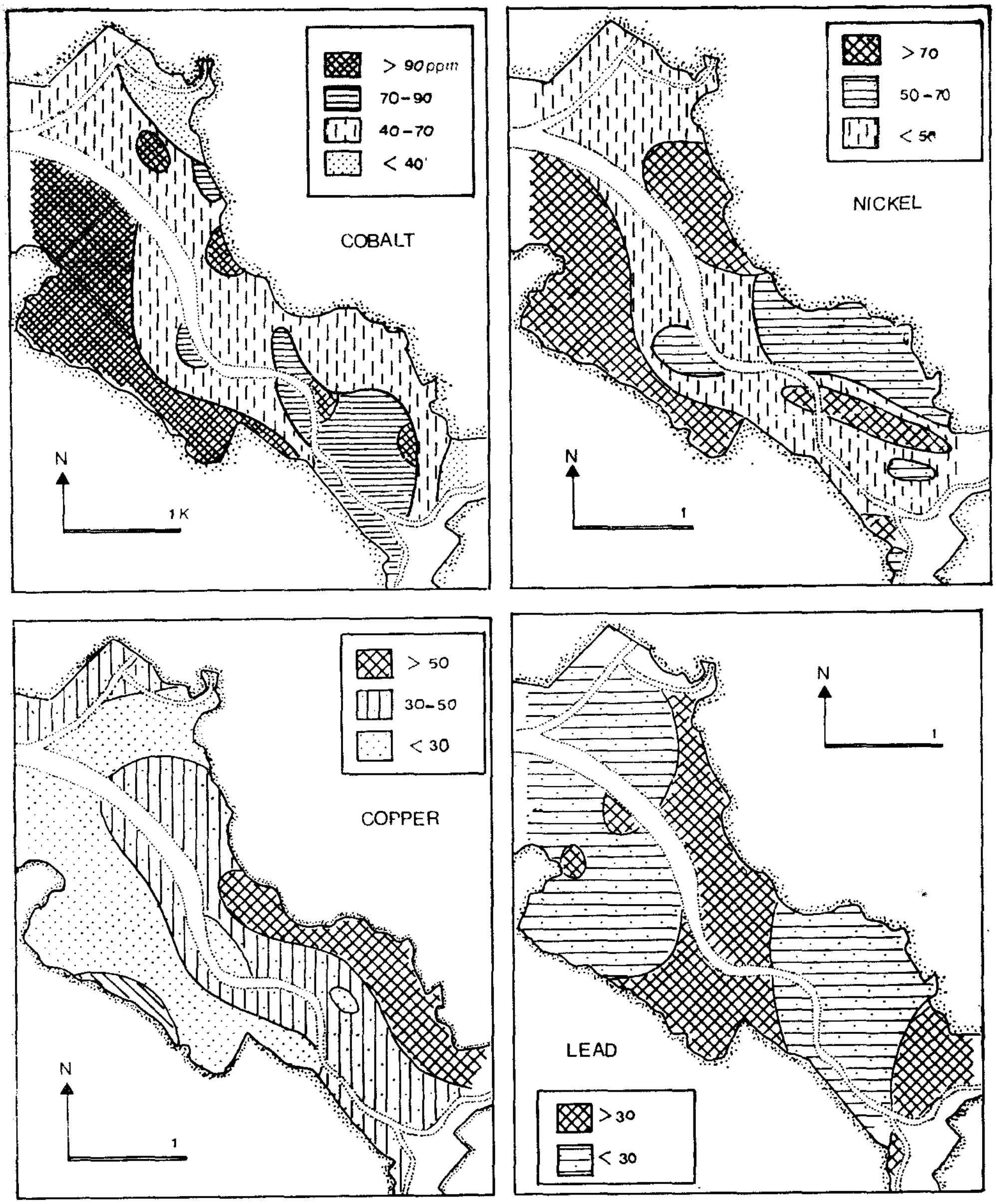

Fig. 8. Distribution of Co, Ni, Cu and Pb in the intertidal surface sediments.

Metallic elements may exist in various chemical forms in the recent deposit. Through numerous studies it has now become clear that the metals show preferred association in regard to the textural (grain size), mineralogic and compositional properties of sediments (Forstner, 1979; Jenne, 1968; Vernette, 1970; etc.). In Figure 9 authors have compared the metal contents with the percentage of less-than-2 μm fraction, of organic carbon and of iron in sediments. The metal content, however, did not show any clear relationshid with the contents of fine-grained fraction in the sediment. It is somewhat inconceivable that the metal content could be independent of the grain-size of sediment, considering the great grain-size effect in the metal distribution in sediments (Salomons and Forstner, 1984). On the other hand, the contents of organic carbon

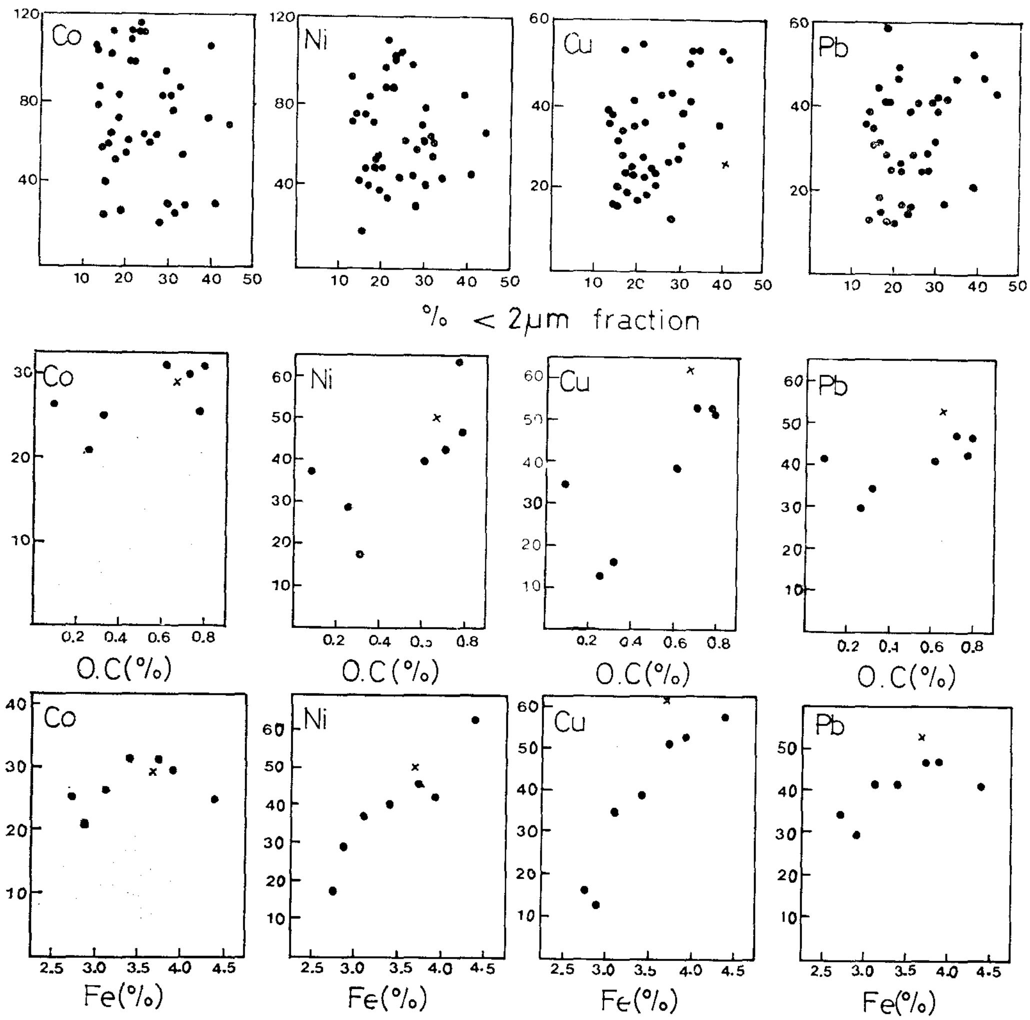

Fig. 9. Contents of Co, Ni, Cu and Pb plotted against the percentage of<2 μm fraction, organic carbon and iron in the intertidal surface sediments.

and iron show a general relationship with those of trace metals, the trace metal contents increasing along with the increase of the contents of organic carbon and iron. This relationship is particulaly marked between the content of iron and those of nickel and copper, which suggests that a major portion of these two metals are associated with the oxides and hydroxides of iron.

CONCLUSIONS

Sedimentation on the tidal flats of the southeastern Kyeonggi Bay is controlled primarily by the tidal phase, and accordingly the accumulation of sediments occurs mainly during the spring tide period. Tidal sedimentary processes result in a distinct shoreward finer sediment distribution pattern in the intertidal zone of the study area. The shoreward finer trend in mean grain size is acccompained by the gradual shoreward decrease in sand contents and the increase in clay contents of surface sediment.

Three grain size classes are recognized based on Folk's classification scheme, namely silts, muds and sandy silts. Their areal distribution also follows general shoreward finer trend.

Bioturabtions are ubiquitous on the tidal flat surface. Among the bioturbating animals, the crabs and the polychaets appear to be most important in this environment.

The major element composition of the tidal flat surface sediment depends mainly on the grain size while for the trace metals this grain size effect could hardly be demonstrated.

The surface sediments of the study area are likely to be contaminated with cobalt which probably originates from the Banweol and other industrial complex.

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