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Suspended Sediment Budget in Gwangyang Bay through the Yeosu Sound

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여수 해만을 통한 광양만의 부유퇴적물 수지균형

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Suspended sediment budget in Gwangyang Bay was investigated using the data of suspended sediment concentration and vertical distribution of tidal currents at the mouth of the bay in the Yeosu Sound (Yeosu Haeman). At the mouth of the bay suspended sediment concentration shows much higher value of approximately 17.80*mg/l* on the average near the bottom than the concentration near the surface where the average is 4.75*mg/l*. Tidal currents also show an asymmetry in magnitude between flood and ebb. Near the surface ebb is stronger than flood, while flood is stronger than ebb near the bottom. Due to the higher concentration and stronger flood current near the bottom, transport of suspended sediment near the bottom plays a major role to the sediment budget in the bay, and the bay is in net-depositional environment. The western part of the bay seems to gain the suspended sediment of approximately $5.66\times10^8 g/day$, which corresponds to a sedimentation rate of about 1.15*m*/1,000*years*.

Introduction

Gwangyang Bay, of which the area is approximately 230km^2, is one of the post-glacially submerged embayments along the southern coast of Korea (Fig. 1). The bay is bounded by relatively steep mountains and hills to the north and by Yeosu Peninsula and Namhae Island to the southwest and southeast, respectively. Seomjin River discharges fresh water of approximately 23 *tons/sec* on the average into the bay from the north. Fresh water input by the several small streams in the north seems to be minimal (Park et al., 1984). To the south the bay is connected to the open sea by the Yeosu Sound (Yeosu Haeman) between Yeosu Peninsula and Namhae Island, whereas the Noryang Strait in the northeast connects the bay to the open sea *via* Jinju Bay.

Shape of the bay is elongate in east-west direction. Water depth in the bay is shallow (generally less than 5*m*) except for the tidal channels. Two major channels develop; one between the Yeosu Sound and the Noryang Strait, the other at the north of Myodo Island. The channels are deep reaching up to more than 20*m* in the bay. Water depth at the mouth of Gwangyang Bay reaches up to 40*m*

(Hydrographic Office of Korea, 1986). A small channel which is approximately 10*m* deep also extends to the Yeosu Sound at the south of Myodo Island (Fig. 1).

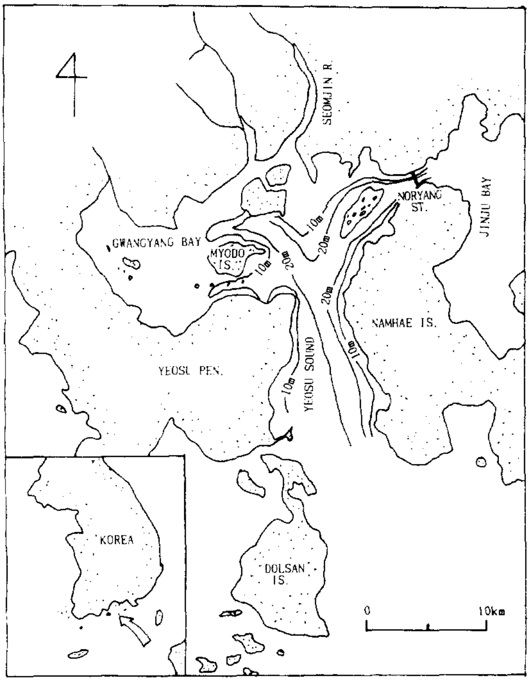

Fig. 1. Map showing Gwangyang Bay and the Yeosu Sound (Yeosu Haeman).

Tides in the bay are principally semi-diurnal, reversing type with a small diurnal inequality. Mean tidal range measured at the nearby Yeosu Harbor is about 2*m* (Kang and Chough, 1982). Strong tidal currents reaching up to 2.5 *knots* (National Hydrographic Office of Korea, 1989) flow through the channels. However the currents flowing through the channels at the north and south of the Myodo Island generally become weaker as they flow further to the west of the bay (Park et al., 1984).

Bottom sediments are characterized by different depositional environments in the bay (Pohang Iron & Steel Co., Ltd., 1983; Park et al., 1984). Big deltaic sediment mostly comprised of poorly sorted sands occurs at the mouth of the Seomjin River. On the bottom of the channels sediments are generally coarse with little clay content. Gravels also occur occaionally on the bottom of channels. Poorly sorted muds comprise the bottom sediment in the western part of the bay, where the tidal currents are substantially weakened. Park et al., (1984) suggested that a considerable amount of fine sediments in the bay might have been transported from the open sea by the tidal currents. Contribution of fine sediments into the bay by the Seomjin River was too small to account for the thick accumulation of fine sediments in the western part of the bay (Park et al., 1984).

The present study investigates the role of tidal currents through the Yeosu Sound for the deposition of fine sediments in the western part of the bay. In the Yeosu Sound eighteen bottom sediment samples were analyzed (Fig. 2), and the concentration of suspended sediments were measured bimonthly (April, June and July in 1989). Drogues were traced during a spring tide period, and the tidal current data measured at two stations by the Pohang Iron & Steel Co., Ltd. (1983) were also analyzed (Fig. 2).

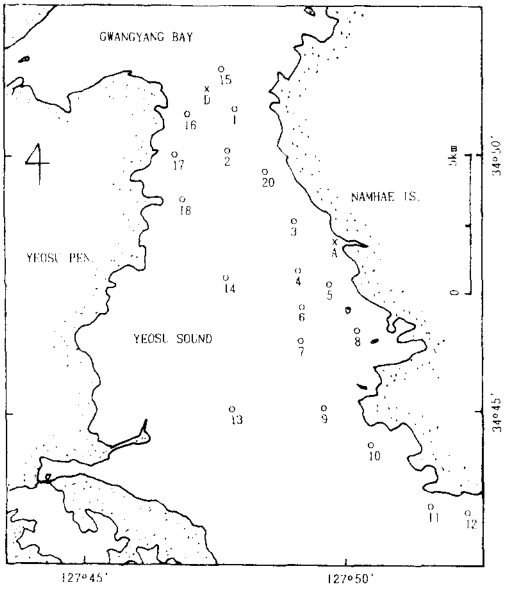

Fig. 2. Map showing the sampling stations. Numbered stations are for the suspended and bottom sediments. Stations A and D are for the current measurements by Pohang Iron & Steel Co., Ltd. (1983)

Physiography and Bottom Sediments in the Yeosu Sound

The main tidal channel develops in north-south direction along the eastern side of the Yeosu Sound (Fig. 3). Western part of the sound is generally shallower than 20*m*, but the main channel on the eastern side is deeper than 20*m*. The tidal channel extends to the north and the depth at the mouth of Gwangyang Bay becomes deeper than 30 *m*. Bottom of the sound is flat and featureless except for the deep channel where several local deep scours of the bottom occur.

Mean grain size of bottom sediment in the Yeosu Sound is mostly silt-sized except for a local occurrence of fine sand near Namhae Island (Fig. 4). However, sediments are very poorly sorted. Figures 5 and 6 show that the bottom sediment contains a considerable amount of sand and clay. Figure 6 also suggests that the tidal currents in the Yeosu Sound are not strong enough to winnow out the fine clays from the bottom. Even in the deep channel 30~40 *percent* of the sediment consists of clay, which suggests that the near-bottom current in the channel may be weaker due to the deeper water depth than the other area.

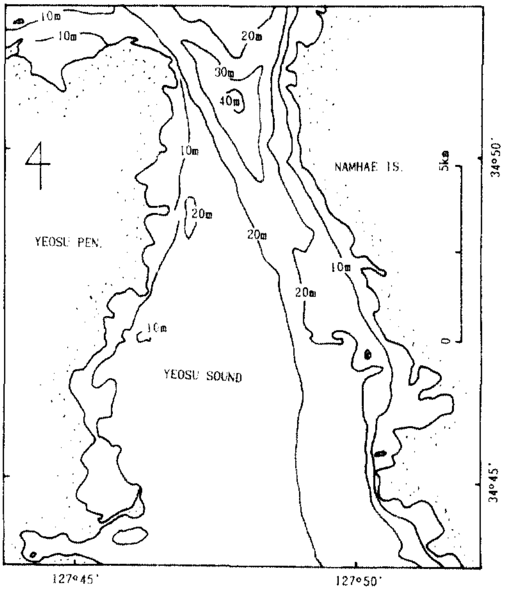

Fig. 3. Map showing the bathymetry of the Yeosu Sound.

Suspended Sediments

Concentration of suspended sediment in the water column is variable with time and location. In April, the concentration in the surface layer shows

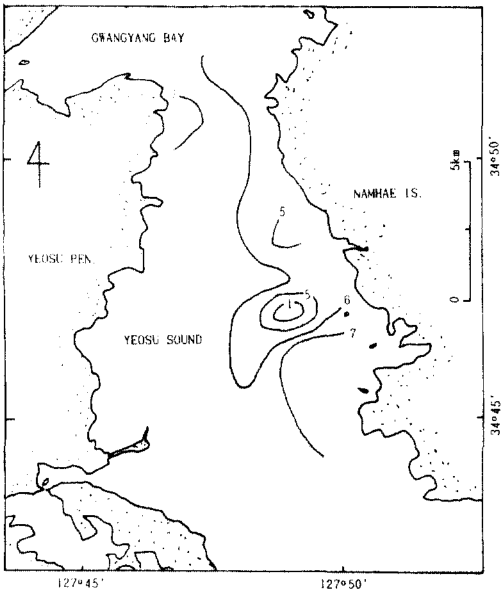

Fig. 4. Mean grain size of the bottom sediment in the Yeosu Sound. Contours are in phi (ϕ) scale.

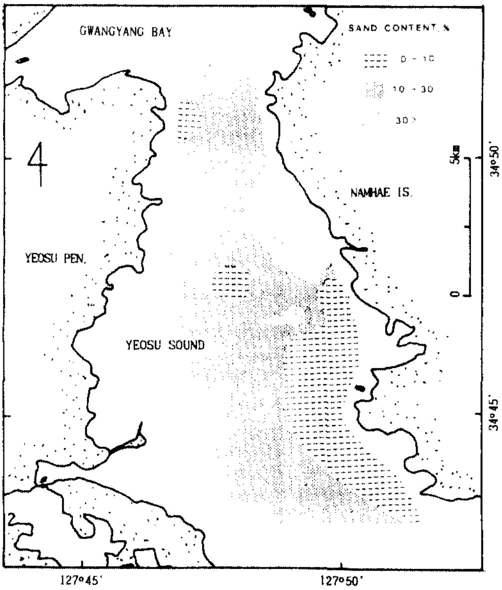

Fig. 5. Sand content of the bottom sediment in the Yeosu Sound.

higher values than the other months and it also shows the most extreme local variation ranging from 6.4*mg/l* to 22.5*mg/l* with an average value of 11.2*mg/l*. In June and August the concentrations and their variations are much smaller. Average concentrations are 3.9*mg/l* and 4.4*mg/l* in June and August, respectively (Fig. 7).

Concentration in the near-bottom water looks more variable than that in the surface water (Fig. 8). In April it ranges from 10.6*mg/l* to 49.1*mg/l*. Concentrations in June and August also show a considerable variation. In June it ranges from 3.2 *mg/l* to 40.1*mg/l* and the range in August is from 1.8*mg/l* to 20.8*mg/l*. Average concentrations are 23.7*mg/l*, 13.1*mg/l*, 8.2*mg/l* for April, June and August, respectively.

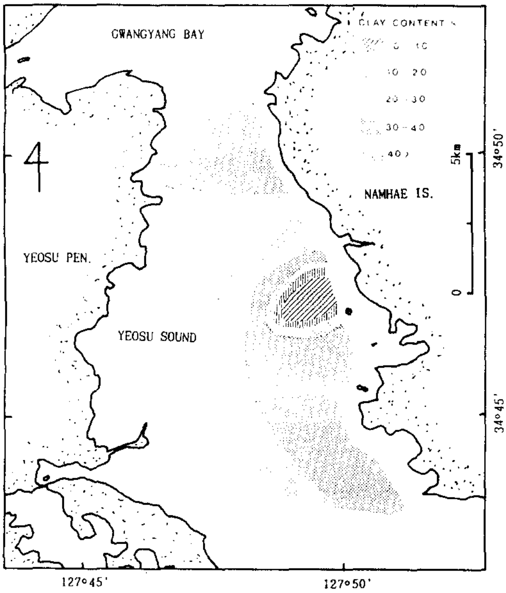

Fig. 6. Clay content of the bottom sediment in the Yeosu Sound.

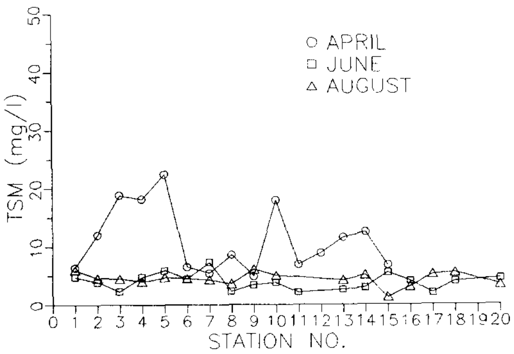

Fig. 7. Concentration of suspended sediment near the surface.

In general concentrations near the bottom is much higher than the near-surface concentrations not only in the average concentrations of each month but also in the local concentrations at each location (Fig. 7 and 8). It implies that the fine sediments are mostly entrained and transported in a two-layered mode as suggested by Odd and Owen (1972) and Owen (1977). Further the fine sediments transported near the bottom can easily settle down on the bottom when the tidal currents are weak during slack waters.

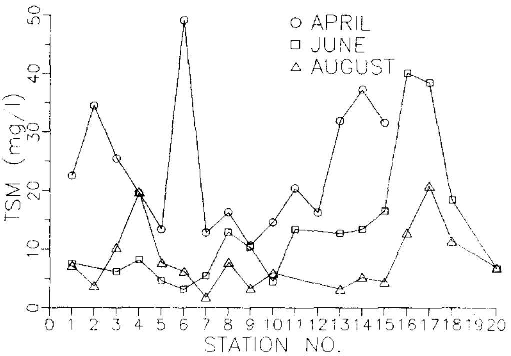

Fig. 8. Concentration of suspended sediment near the bottom.

Tidal Currents and Velocity Asymmetry

Tidal currents in the sound and along the tidal channels seem to be ebb-dominant in magnitude (Hydrographic Office of Korea, 1989). This ebb-dominant tidal asymmetry is also confirmed by the drogue tracking near the surface (Figs. 9 and 10). Ebb dominance of tidal currents in this area may easily be expected if the steady input of fresh water by the Seomjin River is considered. However, the vertical distribution of tidal currents measured at two stations in the Yeosu Sound shows a different pattern of asymmetry.

At the station A (Fig. 2) the maximum speed of currents near the surface are higher during the ebb. However, the trend is reversed below the depth of about 15*m* regardless of spring or neap tide (Fig. 11). During the spring tide the maximum tidal current decreases with depth; from 80*cm/sec* at 5*m* to 66*cm/sec* at 30*m* for the maximum flood, and from 81*cm/sec* at 5*m* to 59*cm/sec* at 30*m* for the maximum ebb. During the neap the currents are weaker, but the trend of ebb-dominance near the surface and flood-dominance near the bottom is similar to that during the spring. The maximum currents of neap tide show peak values at 15~20*m* depth and decreases towards both surface and bottom (Fig. 11).

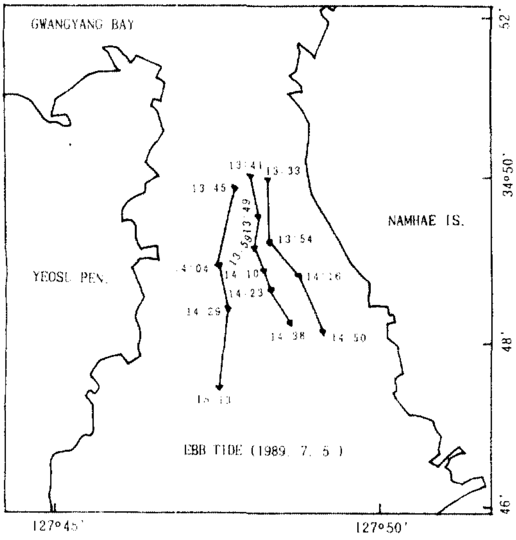

Fig. 9. Drogue tracking near the surface during the ebb of a spring tide.

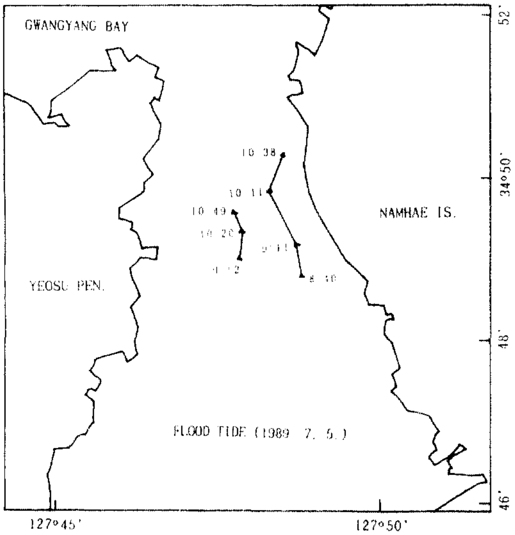

Fig. 10. Drogue tracking near the surface during the flood of a spring tide.

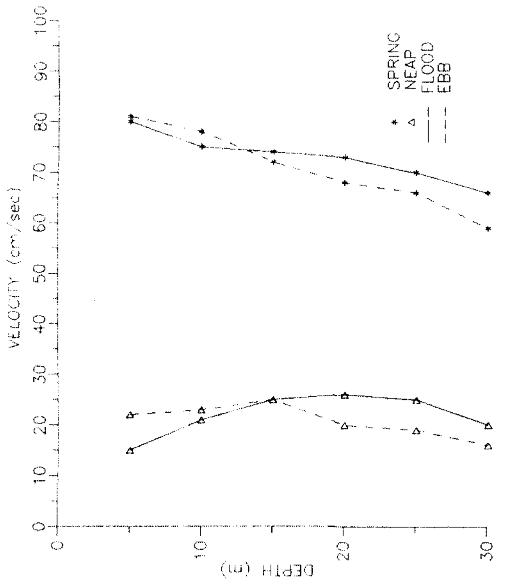

Fig. 11. Vertical distribution of maximum currents at the station A(Drawn by using the data of Pohang Iron & Steel Co., Ltd., 1983).

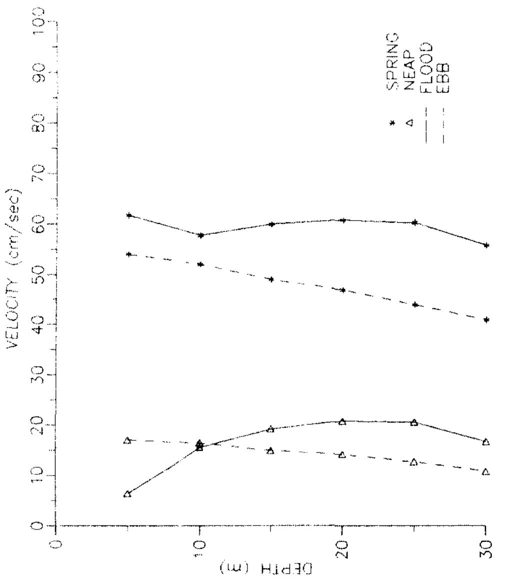

Fig. 12. Vertical distribution of mean tidal currents at the station A(Same data source as in Fig. 11).

Mean currents at the station A during spring tide show an overall flood-dominance through depth. The flood current has speeds of 61.7*cm/sec* at 5*m* and 55.8*cm/sec* at 30*m* depth, while the ebb current decreases from 54.0*cm/sec* to 41.1*cm/sec*. During the neap tide ebb current is stronger only near the surface whereas the flood current is stronger below about 10*m* depth. Flood current increased with depth from 6.4*cm/sec* near the surface to 16.8*cm/sec* near the bottom (Fig. 12).

At the station D which is located at the center of the bay mouth (Fig. 2), the general trend of ebb-dominance near the surface and flood-dominance near the bottom is also observed regardless of spring or neap (Fig. 13). During the spring tide the maximum flood current decreased from 84*cm/sec* at 5*m* to 69*cm/sec* at 20*m* depth. On the other hand, the maximum ebb does not seem to vary significantly with depth from the average speed of about 77*cm/sec*. During the neap tide the maximum flood current also does not show a significant change with depth, it is in the range of 38~39*cm/sec*. The maximum ebb current decreases with depth from 46*cm/sec* near the surface to 33*cm/sec* at the depth of 20*m* (Fig. 13).

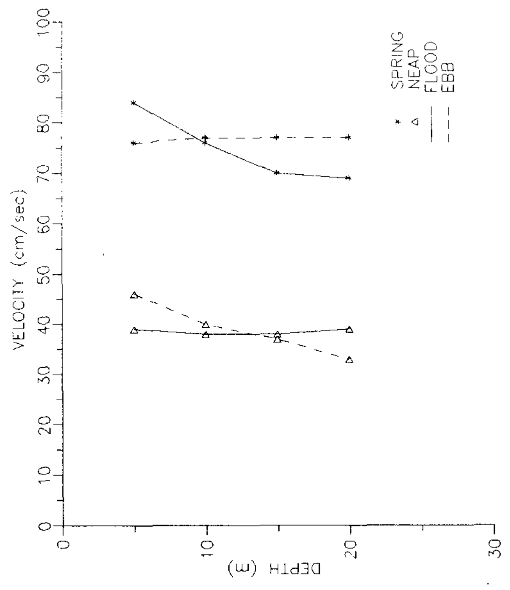

Fig. 13. Vertical distribution of maximum currents at the station D(Same data source as in Fig. 11).

Mean currents at the station D during spring tide also show that the flood current is slightly stronger than the ebb through depth. The mean flood current decreases from 56.3*cm/sec* near the surface to 49.5*cm/sec* at 20*m*, while the mean ebb current changes from 56.7*cm/sec* near the surface to 47.2*cm/sec* at 20*m*. During the neap tide the mean ebb current is stronger near the surface where the speeds are 19.3*cm/sec* and 24.8*cm/sec* for the flood and the ebb, respectively. On the other hand, the mean flood current is stronger at 20*m* where the flood speed is 21.2*cm/sec* and the ebb speed is 19.2*cm/sec* (Fig. 14).

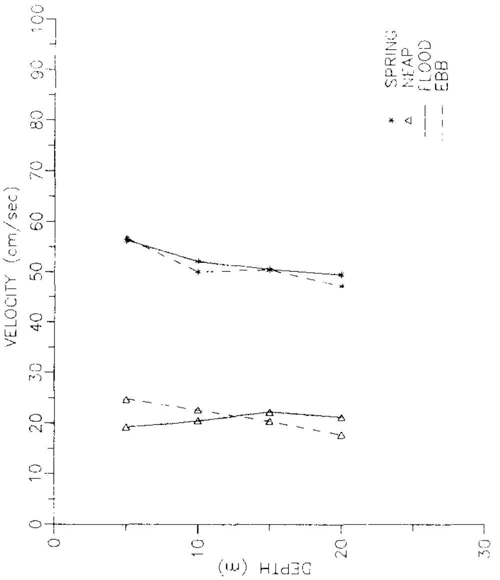

Fig. 14. Vertical distribution of mean tidal currents at the station D(Same data source as in Fig. 11).

Tidal Asymmetry and Sediment Budget

The tidal asymmetry of ebb-dominance near the surface and the flood-dominance near the bottom may cause a difference in the amount of suspended sediments transported during flood and ebb periods. The higher concentration of suspended sediments in the near-bottom water and the pattern of tidal asymmetry in the Yeosu Sound imply that the amount of suspended sediments transported into the Gwangyang Bay exceeds that transported out of the bay.

Tidal currents and concentration of suspended sediments at the mouth of Gwangyang Bay can be directly applied to the calculation of sediment budget in Gwangyang Bay. Using the average of mean currents during spring and neap at the station D together with the average of suspended sediment concentrations at the stations 1, 15 and 16, an approximate evaluation of suspended sediment budget in Gwangyang Bay may be possible.

Several assumptions are made for the calculation; 1) average water depth of the bay mouth (St. D) is 30*m* (Fig. 1), 2) the flow is two-layered of which boundary is at 10*m* below the surface, and the current velocities at the depth of 5*m* and 20*m* represent the depth-average of upper and lower layers, respectively, 3) durations for the flood and ebb are 6 hours each, and 4) considering the water mass passing through the Noryang Starit to Jinju Bay and the area of the western part of Gwangyang Bay, only half the water mass passing through the mouth contributes to the suspended sediment transport to the western part of Gwangyang Bay. Other parameters used for the calculation and the results are listed in the Table 1 and Table 2, respectively.

Table 2 shows that the transport of suspended sediments near the surface plays a minor role compared to the transport near the bottom. Thus most of suspended sediment transport occurs in the lower layer of the water column. Furthermore, the calculation shows that Gwangyang Bay is gaining suspended sediment due to the stronger flood and higher concentration near the bottom. Considering that the width of the mouth is approximately 3*km* (Fig. 1) together with the assumptions 3) and 4) above, western part of the bay gains suspended sediments of about $5.66\times10^8 g/day$. If the suspended sediment concentration in the bay has reached a steady state, excessive input of the suspended sediment may be deposited on the bottom. Agency for Defence Development (ADD, 1988) reports that the bulk density of the core samples up to 2*m* from the bottom taken offshore Namhae Island ranges between $1.5g/cm^3$ and $1.8g/cm^3$. Taking the $1.8g/cm^3$ to be the average bulk density of the sediments in the bay, the above excessive input rate corresponds to a sedimentation rate of approximately 1.15*m*/1,000*years* assuming the area of the western part of the bay is approximately $100km^2$.

Table 1. Parameters used for the calculation of sediment budget in Gwangyang Bay.

Layer	Depth(*m*) (Thickness)	Concentration (*mg/l*)	Mean Flood (*cm/sec*)	Mean Ebb (*cm/sec*)
Layer 1	10	4.75	37.80	40.75
Layer 2	20	17.80	35.35	32.50

The above calculation may not be an exact evaluation. The rate does not include the input from the river or streams, and the rate may show a seasonal variation. However, the role of tidal currents in making the bay a net-depositional environment is clearly depicted.

Conclusion

Suspended sediment concentration near the bottom is much higher than that of near the surface in the Yeosu Sound. Tidal currents through the Yeosu Sound show an asymmetry in magnitude between flood and ebb, and the pattern of asymmetry at the sarface is different from that at the bottom. The ebb currents are stronger near the surface but the flood currents are stronger near the bed. This flood-dominance coupled with the higher concent-

Table 2. Suspended sediment budget in the western part of Gwangyang Bay.

Layer	Transport(*mg/cm/sec*)		Balance	Average	Western Bay
	Flood	Ebb	(*mg/cm/sec*)	(*mg/cm/sec*)	(*g/day*)
Layer 1	179.55	193.56	-14.01	-7.01	-9.1×10^7
Layer 2	1,258.46	1,157.00	101.46	50.73	6.57×10^8
Total	1,438.01	1,350.56	87.45	43.72	5.66×10^8

ration of suspended sediments near the bottom makes the western part of Gwangyang Bay a net-depositional environment of fine-grained sediment.

Due to the net gaining of suspended sediments, the western part of the bay receives the fine sediments of 5.66×10^{8} *g/day*, which corresponds to a sedimentation rate of approximately 1.15*m*/1,000 *years* by the tidal currents through the Yeosu Sound.

요 약

여수해만 광양만 입구의 조류 및 부유 퇴적물 함량 분석을 통하여 광양만 내의 부유 퇴적물 수지 균형을 조사하였다. 만 입구의 부유 퇴적물 함량은 바닥이 평균 약 17.80*mg/l*로 표층의 평균 약 4.75 *mg/l*에 비해 상당히 높으며, 조류도 표층 부근에서는 썰물이 강하나 저층에서는 오히려 밀물이 강하여 유속의 비대칭 현상을 보이고 있다. 이러한 저층의 높은 부유 퇴적물 함량과 밀물우세 조류로 인하여 이 지역의 부유 퇴적물 이동은 저층을 통한 이동이 큰 중요성을 갖으며, 따라서 광양만의 내부 특히 서쪽 부분은 전체적으로 세립 퇴적물의 순수 퇴적이 이루어지고 있다. 이러한 조류에 의한 세립 퇴적물의 순수 유입량은 약 5.66×10^{8} *g/day*로 계산되며, 이 순수 유입량이 만의 서부에 퇴적된다면 그 퇴적율은 약 1.15*m*/1,000*years* 정도가 될 것이다.

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