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# Distribution of Suspended Particulate Matters in the East China Sea, Southern Yellow Sea and South Sea of Korea During the Winter Season

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Concentrations of suspended particulate matters (SPM) and their distribution patterns were monitored three times in the East China Sea during the winter season in 1998 and 1999. SPM concentrations showed significant temporal variations controlled by the atmospheric conditions and sea states. In coastal area, SPM values were about 10-20 mg/l in fair weather conditions, but exceeded 100 mg/l during the storm periods. Turbid waters were distributed widespread in the continental shelf of the East China Sea and the coastal area of the Korean Peninsula, and these two areas were connected along a NE-SW direction. The distribution patterns of turbid waters were interpreted as representing the transport behavior of suspended matter. Although the primary source of inner shelf mud deposits of Korea seems to be the Korean Peninsula, contribution from the East China Sea to the coastal area of Korea increases especially during the winter season.

**Keywords:** Suspended Particulate Matter (SPM), Sediment Transport, Continental Shelf, East China Sea, Yellow Sea, Korea

## INTRODUCTION

The Yellow and East China Seas are typical epicontinental shelf surrounded by the Chinese mainland and the Korean Peninsula (Fig. 1). Water depths are generally shallower than 100 m. Approximately $10^9$ tons of terrigenous materials are supplied annually from adjacent continental areas (Milliman and Meade, 1983; Schubel *et al.*, 1986). Bottom sediments are dominated by the fine-grained muds, except the relict sands on the outer shelf (Niino and Emery, 1961; Zhu and Wang, 1988) and the transgressive basal sands in the northeastern Yellow Sea (Lee *et al.*,1988; Park *et al*, 1994).

At least 5-different mud deposits are found in the Yellow and East China Seas around the Korean Peninsula (Fig. 2). CYSM (Central Yellow Sea Mud) and ECSM (East China Sea Mud) occupy the central part of the Yellow and East China Seas, and these deposits are undoubtedly derived from the Chinese mainland. The two deposits are separated each other with a "GAP" area on the west of Cheju Island (Fig. 2). Bottom sediments of the "GAP" area consist of coarser-grained muddy sands and sands, which are similar to the relict sand on the outer shelf. The presence of sandy sediments in the "GAP" area can be due to either that there is no supply of fine-grained materials or that the hydrodynamic conditions are strong enough to inhibit the accumulation of fine sediments.

Along the inner shelf of Korean Peninsula, three distinct mud patches are identified in the southeastern Yellow Sea (SEYSM), in the South Sea (SSM), and off the southeastern coast (SECM) (Fig. 2). SEYSM is clearly different from the CYSM in terms of texture and clay mineral composition, and is derived primarily from the Korean Peninsula (Park and Khim, 1990; Khim and Park, 1992). SSM and SECM are also interpreted as being supplied from Sumjin River and Nakdong River, respectively (Park and Chu, 1991). Lee and Chough (1989) calculated that the sediment loads from Korean Rivers could be sufficient to account for the formation of the inner shelf mud of Korea.

In recent years, KIGAM (1996) collected deep drill cores from the SEYSM, and found thicker than 60 m mud deposits of 6,000-8,000 yrs B.P. in age, yielding

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accumulation rates of about 1 cm/yr during the late Holocene period. Sediment budgets from Korean rivers are considered to be insufficient for the formation of these mud deposits, and Wells (1988), Zhao *et al.* (1990), Gao *et al.* (1996) have proposed another important source, probably from the Chinese-side through the East China Sea.

In the present paper, we deal with the results of SPM concentrations on the East China Sea, southern Yellow Sea and South Sea of Korea during the winter season. Winter season is the most important in the transport of suspended matters because of the much higher turbidity levels than summer seas on (Milliman *et al.*, 1986; Choi *et al.*, 1996). In winter, suspended matter is transported southward along the east coast of China into the East China Sea (Milliman *et al.*, 1986), and also along the west coast of Korea (Park and Choi, 1989) toward the Korea Strait (Wells, 1988).

The primary purpose of this study is to provide a better understanding of transport behavior and the exchange of suspended sediments between the East China Sea and the coastal area of Korea.

## MATERIALS AND METHODS

The study area is located in the East China Sea, and covers the southern Yellow Sea and the South Sea of Korea (Korea Strait) (Fig. 1). Interdisciplinary oceanographic cruises were made using R/V Tamyang three times during winter and early spring season in February 1998, January 1999 and April 1999. Results taken during summer in August 1997, were included for comparison. Each cruise was completed within a 2-week period, and the results provide a quasi-synoptic distribution pattern of suspended matter.

Water temperatures and salinities were measured at each stations by CTD (Model SBE-911). About 2-4 l of surface and bottom waters (within 5 m from the bottom) were vacuum-filtered on board through pre-weighed millipore filters (pore diameter: 0.45 micrometer). SPM concentrations were compared with water transparency measured by transmissometer (Model

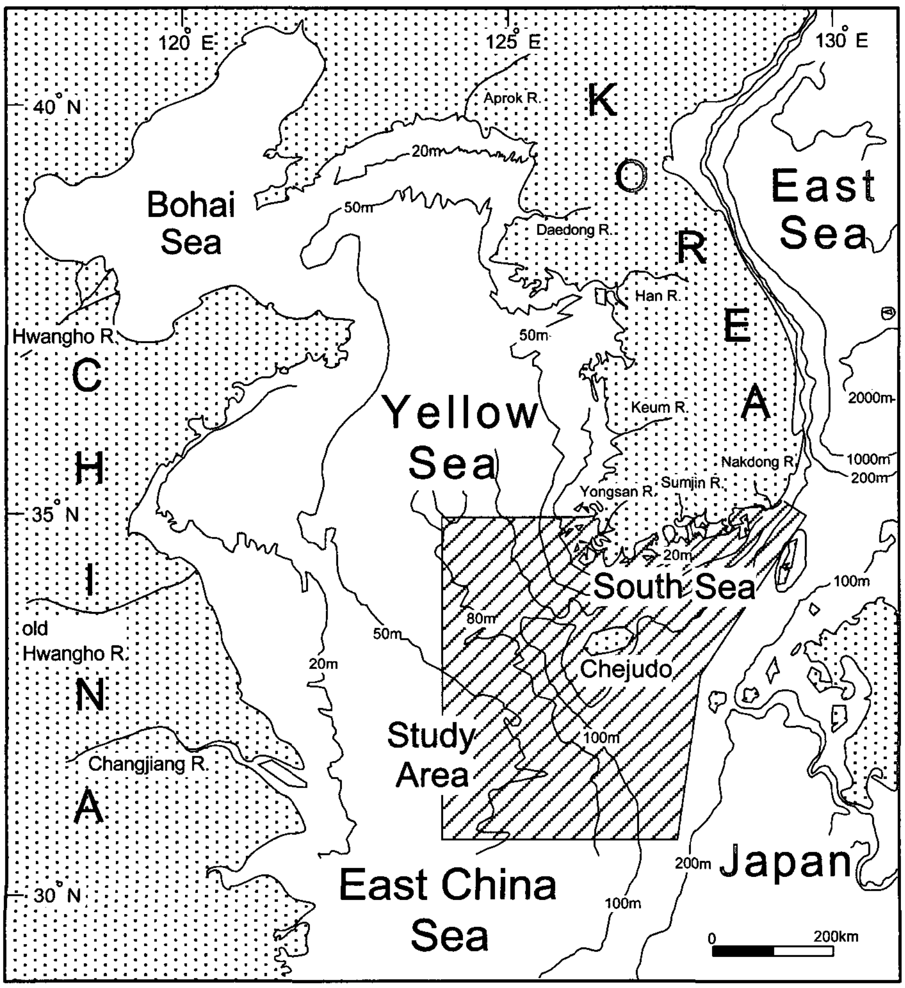


**Fig. 1.** Location of the study area and the general bathymetry of the East China Sea, Yellow Sea, and the South Sea of Korea.

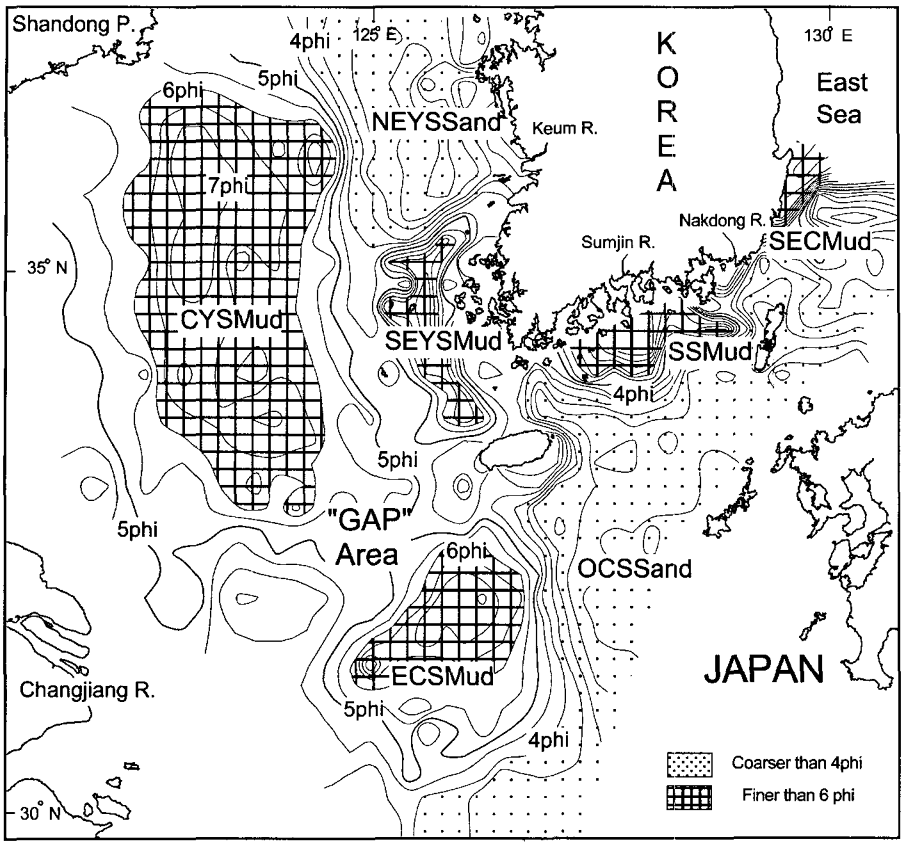


**Fig. 2.** Distribution of grain size of surface sediments based on the collected data of 3422 sediment samples. Sandy sediments cover the outer continental shelf (OCSS) and the northeastern Yellow Sea (NEYSS). Note the 5-different mud patches and the "GAP" area between CYSM and ECSM.

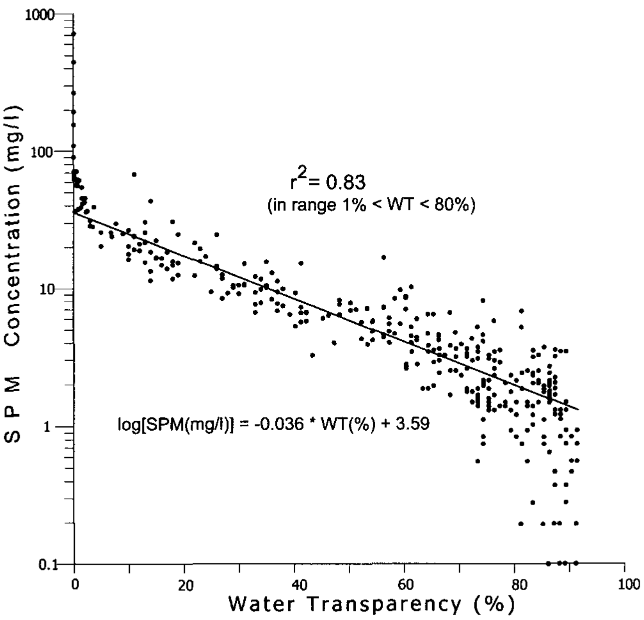


**Fig. 3.** Relationship between water transparency (%) and the SPM concentration (mg/l).

Seatech 25 cm) attached to the CTD (Fig. 3).

SPM values correlate well with water transparencies, and the correlation coefficient ($r^2$) is higher than 0.8 within the range between 1-80% water transparency. 50% water transparency corresponds to about 5-10 mg/l SPM values, and turbid waters of higher than 30 mg/l SPM concentrations have less than 5% water transparency.

## RESULTS

SPM values showed a wide range of seasonal and temporal variations according to the atmospheric conditions and the sea states (Fig. 4). During August 1997, SPM values were generally less than 10-20 mg/l in both surface and bottom waters. In winter season, on the other hand, SPM values increased significantly. Especially in bottom waters, turbid waters of higher than 20 mg/l SPM values were found from more than 12% (6 of 47), 29% (16 of 55), and 35% (19 of 54) of sampling stations in February 1998, January 1999, and April 1999, respectively, with maximum concentrations of up to 700 mg/l.

Fig. 5 shows the horizontal distributions of water temperature, water salinity and water transparency in surface and bottom waters. In February 1998 (Fig. 5A), coastal waters of lower temperature and lower salinity were found both on the East China Sea and on the coastal area of Korea.

Warm and saline offshore waters covered the central and southeastern part of the study area surrounding Cheju

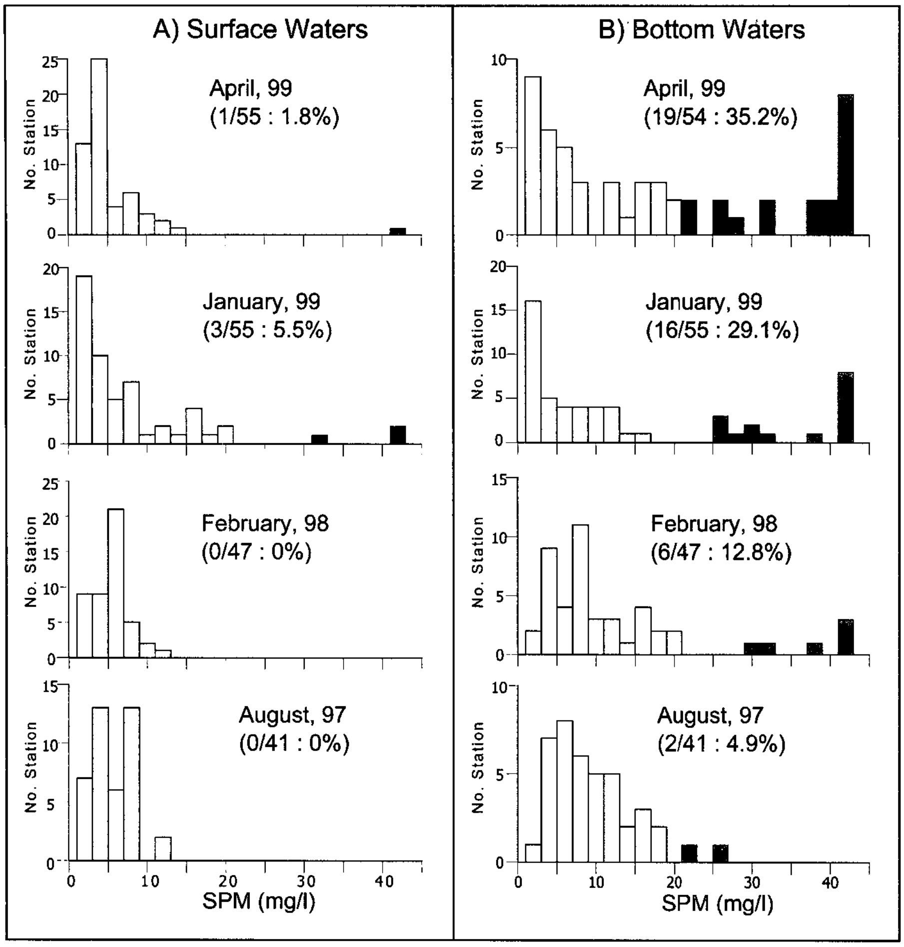


**Fig. 4.** Occurrence of SPM concentration (mg/l) in surface waters and bottom waters. Number of stations of turbid waters (>20 mg/l SPM value shown in filled rectangle) and the percentages are shown in parenthesis.

Island. Water transparencies in offshore waters were generally higher than 70% in both surface and bottom waters, but decreased to less than 10-40% in bottom waters of the East China Sea and the coastal area of Korea.

In January 1999 (Fig. 5B), warmer and saline offshore waters with water transparency higher than 50-60% also occupied the offshore area. Water transparencies decreased to 10-30% for the East China Sea and along the coastal area of Korea. The turbid waters were connected with each other in NE-SW direction across the central section of the southern Yellow Sea. Turbidity levels decreased significantly offshore with a strong turbidity boundary.

In the early spring season of April 1999 (Fig. 5C), distribution patterns of water temperature and water salinity were similar to those in January 1999. Water transparencies were, however, somewhat different in surface and bottom waters. In surface waters, clearer offshore waters covered the central part of the study area, and separated the turbid waters in both Korean and Chinese coastal area. In near bottom waters, however, turbid waters (<10% WT) were still present and connected in NE-SW direction, and further expanded northward into the southern Yellow Sea and eastward along the south coast of Korea.

Vertical structures of water temperature, water salinity and water transparency were compared among each cruise (Fig. 6).

In February 1998, water structure was homogeneous vertically. Water transparencies were generally higher than 60-70%, and the turbid waters (<50% WT) were found only in the bottom waters along the coastal area. In January 1999, water structure was also vertically homogeneous. Water transparencies were higher than 60-70% in surface waters, but decreased to lower than 10-40% on the coastal area of Korea, on the continental shelf of East China Sea, and also along the bottom waters deeper than 50-60 m. In the early spring season of April 1999, water structures showed vertical stratification in temperature and salinity profiles with the thermocline and halocline at about 10-20 m and 40-60 m water depth, respectively. Water transparencies increased higher than 70% (up to 85%)

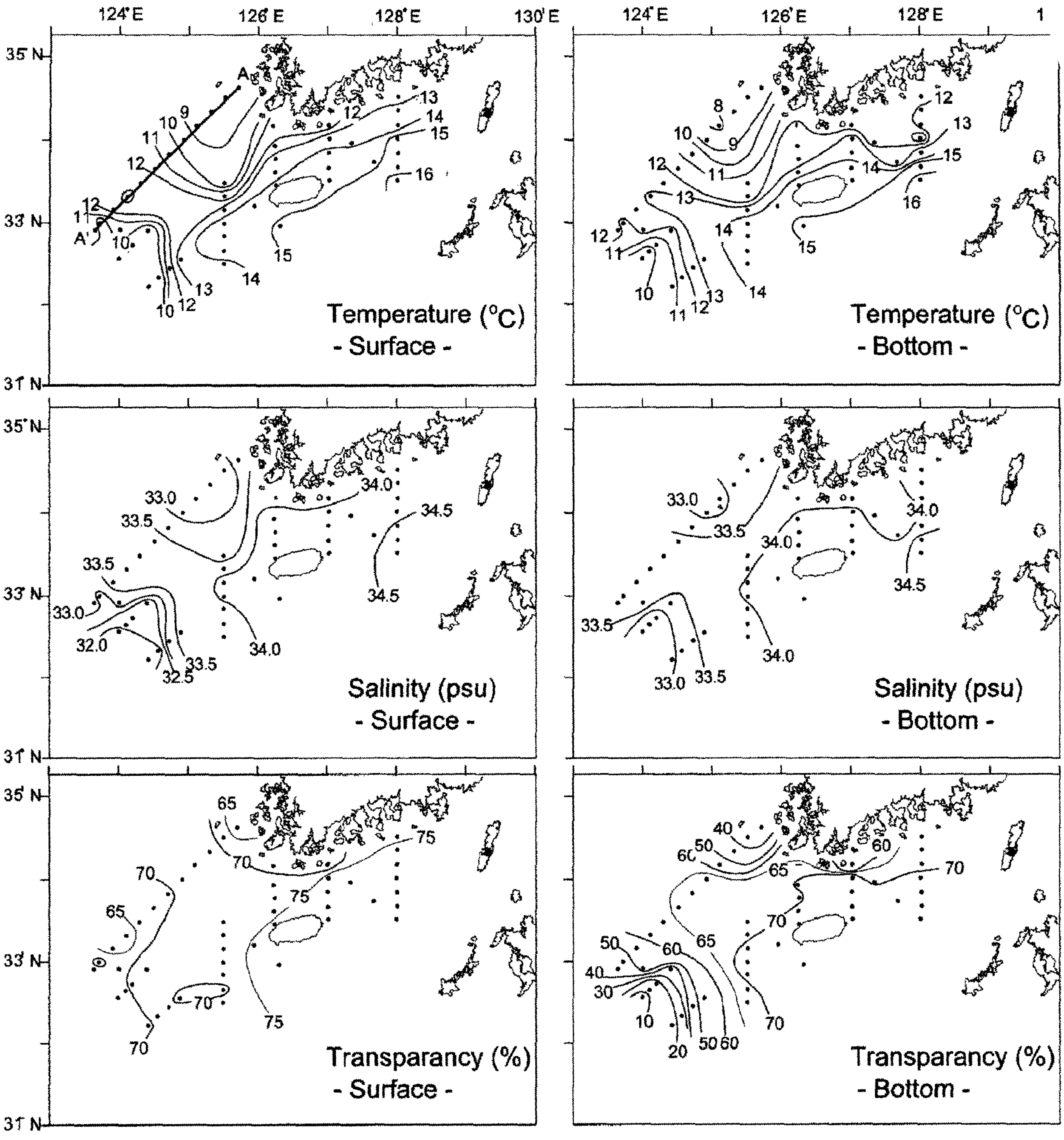


Fig. 5. Horizontal distribution of water temperature, water salinity and water transparency in surface and bottom waters. A) February 1998.

urface and mid-depth waters on the central part he study area. Water transparencies, however, still lower than 10-30% along the coastal area rea and on the East China Sea. Turbid bottom were connected through the central deep forming strong turbidity stratification at the water depth.

## DISCUSSION

SPM concentrations on the continental shelf of the East China Sea revealed marked seasonal variations with high concentrations in winter and low values in the summer season (Fig. 4). Although much terrigenous materials were supplied during summer season, most of this material was deposited and trapped

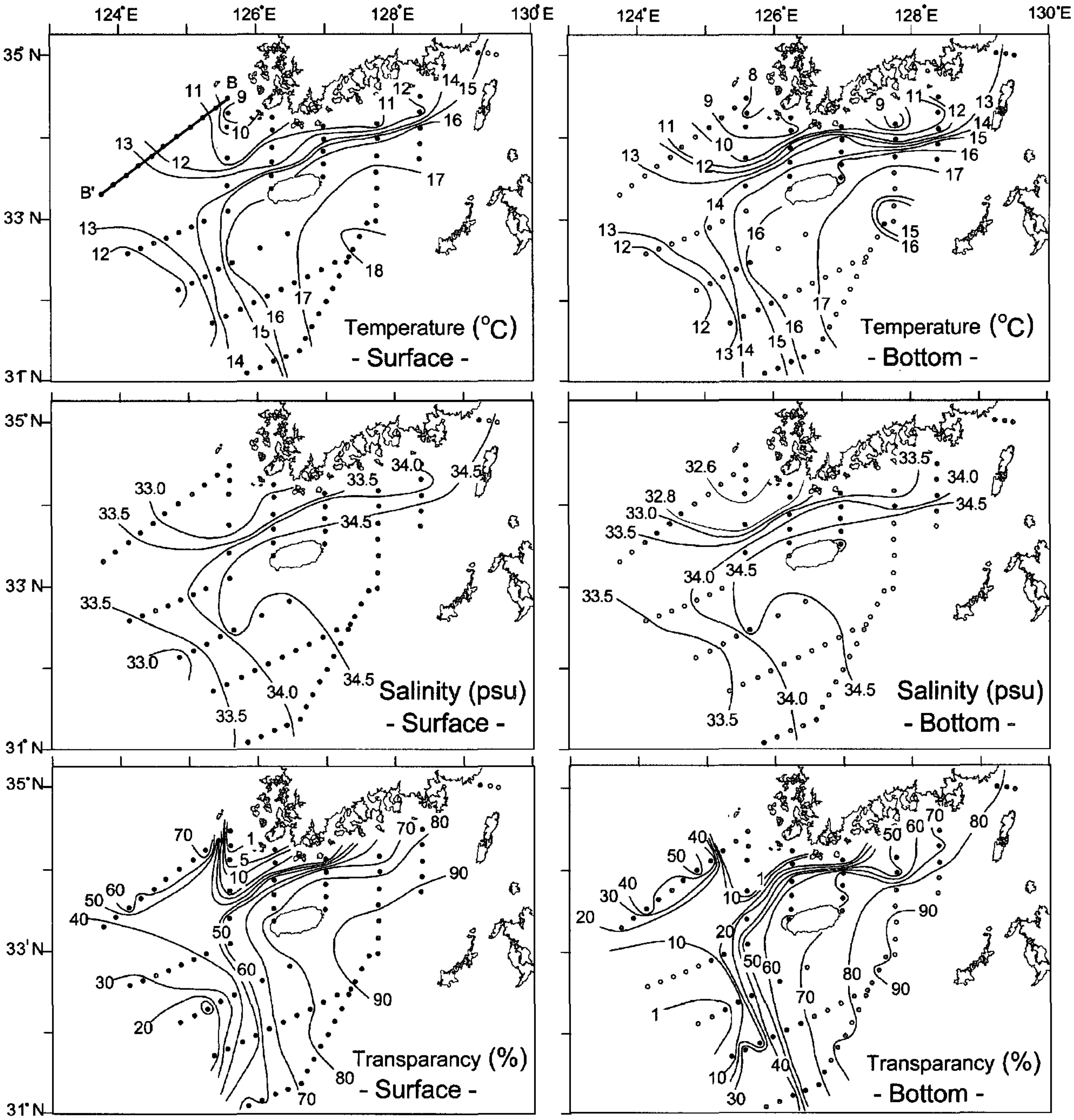


**Fig. 5.** Continued. (B) January 1999.

within the estuarine and near-coastal area (Schubel *et al.*, 1986). Although brackish waters spread out over the continental shelf of the East China Sea (Beardsley *et al.*, 1985), the turbidity levels were generally low during the summer season (Milliman *et al.*, 1985a).

In winter, on the other hand, SPM values increased significantly, especially in the bottom waters (Fig. 4, Fig. 6). Most of the suspended matter is considered to be supplied from bottom resuspension by frequent storms (Milliman *et al.*, 1985b; Choi *et al.* 1996). The turbid waters from the East China Sea and from the coastal area of Korea, were connected with each other in NE-SW direction, forming turbid plumes (Fig. 5B,5C). Lee *et al.* (1998) analyzed the CZCS (Coastal Zone Color Scanner) images in winter 1980 and 1981, and also observed the presence of turbid band connecting the southwest tip of Korea and the continental shelf of the East China Sea. Because of the lack of current data during the cruise periods of

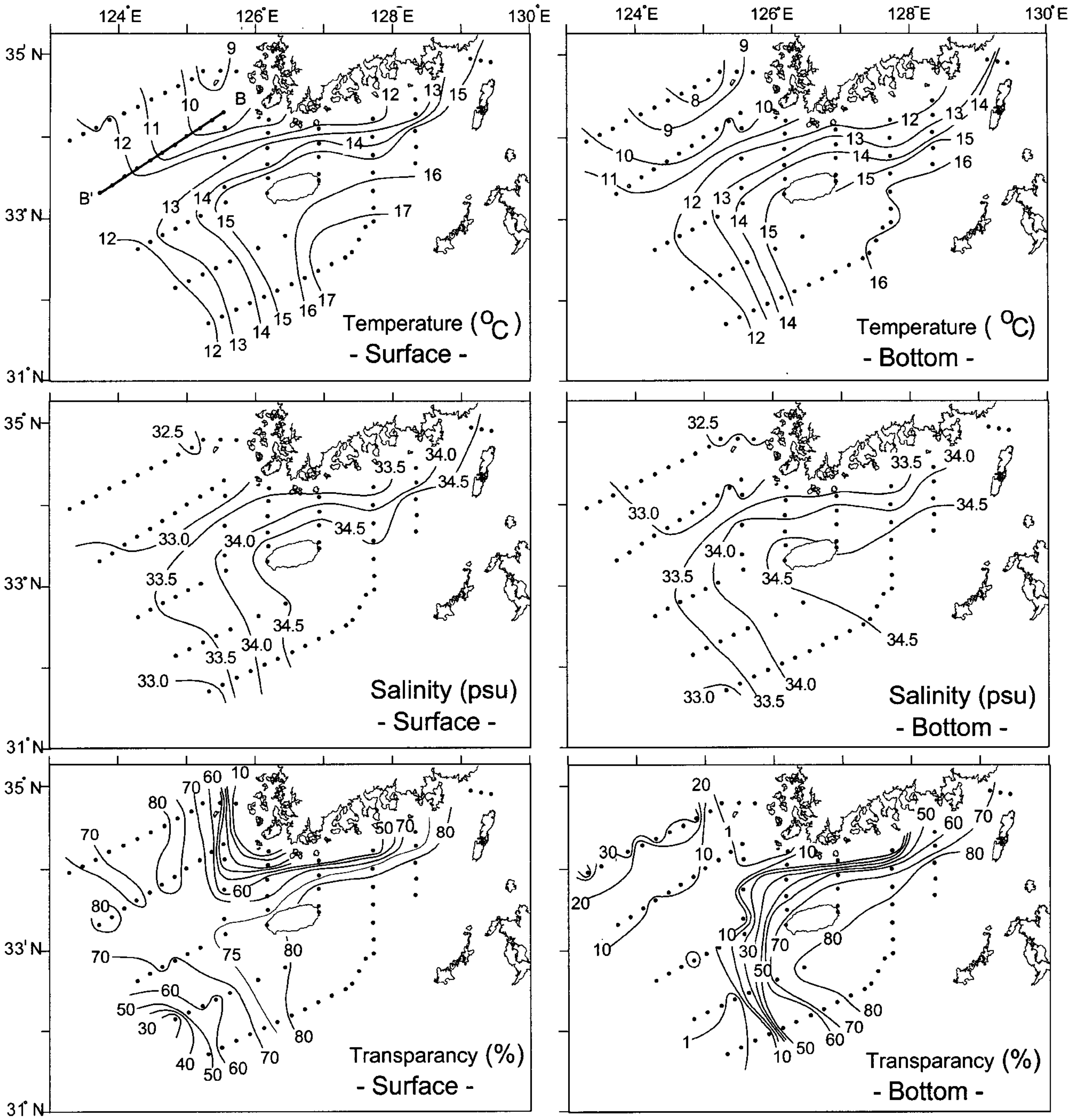


**Fig. 5.** Continued. (C) April 1999.

the present study, we are not sure whether the suspended matters were transported from the East China Sea to the northeastward into the coastal area of Korea, or vise versa.

A SEAWIF satellite image during the April 1999 clearly demonstrated a branch of northeastward-moving of turbid waters from the continental shelf of the East China Sea (Ahn *et al.*, 1999; Hong *et al.*, 1999). Results from drifter buoys deployed in surface waters also showed the north and northeastward movements of water masses from the East China Sea into the southern Yellow Sea and the South Sea of Korea during both summer and winter season (Beardsley *et al.*, 1992). Bottom currents measured directly on the central shelf of the East China Sea were about 10 cm/sec and directed northeastward in the time of about 70% (Li *et al.*, 1985). Although the mean currents were insufficient to erode and resuspend the bottom sediments, forcing from typhoons in summer and storms in winter could cause bottom resuspension

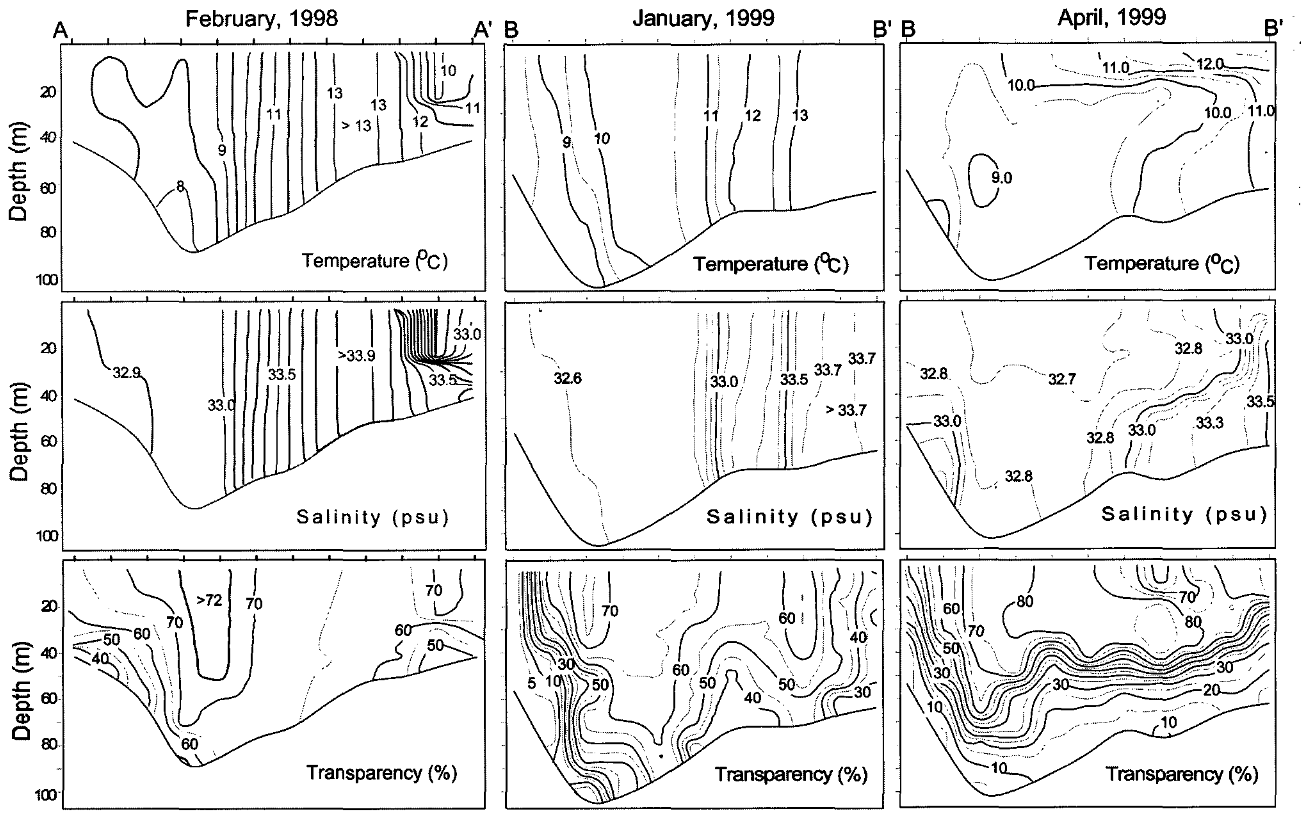


**Fig. 6.** Vertical structures of water temperature, water salinity and water transparency in February 1998, January 1999, and April 1999. Transect lines are in Fig. 5.

and promote the transport of suspended matters. Gao etal. (1996) and Choi *et al.* (1999) also reported the possibility of the northward transport of suspended matters from the East China Sea into the southern Yellow Sea during the typhoon period in summer.

In the early spring season, warm waters from the offshore area extended into the Yellow Sea (Lee *et al.*, 1998). In surface waters, clear offshore waters covered the central part of the study area, and separated the turbid waters within both Korean and Chinese coastal areas (Fig. 5C). Turbid plumes were, however, still present and connected along a NE-SW direction in bottom waters (Fig. 6).

The schematic diagram of transport pathways of suspended sediment is illustrated in Fig. 7, together with the distribution of mud patches. ECSM are supplied primarily from the Changjiang River (Milliman *et al.*, 1985a; Nittrouer *et al.*, 1984) and also from the old Hwangho River submarine delta (Milliman *et al.*, 1985b; Milliman *et al.*, 1986). Fine-grained materials cannot escape the continental shelf of the East China Sea, but are trapped within a cyclonic gyre of upwelling to form the ECSM (Hu, 1984).

A branch of the turbid plume is, however, considered to be shifted northeastward through the "GAP" area into the coastal area of Korea. The "GAP" area between CYSM and ECSM (Fig. 2) are, therefore, interpreted as the area of non-deposition and as the main pathway of exchange of suspended matters between the East China Sea and the coastal area of Korea.

On the inner shelf of Korea, suspended matters derived from the East China Sea are considered to join the turbid coastal waters. They cannot escape the strong coastal front, and are deposited and transported eastward along the South Sea of Korea to form the SEYSM and SSM (Wells, 1988; Park and Choi, 1989).

## CONCLUSION

The results from the present study demonstrate the possibility of the transport and exchange of suspended matters between the East China Sea and the coastal area of Korea (southeastern Yellow Sea) during the winter season. Although muddy sediments of the coastal area of Korea might be derived primarily

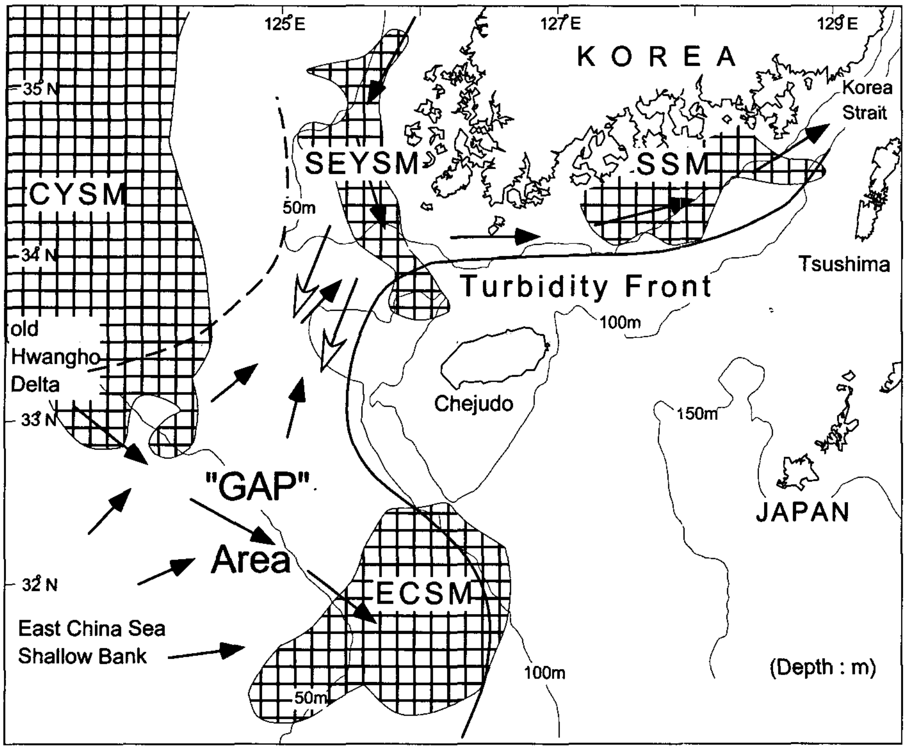


**Fig. 7.** Schematic diagram of the exchange of suspended particulate matters between the East China Sea and the coastal area of Korea. Hatched areas represent the individual mud patches. Solid and dashed lines mark the turbidity front between coastal waters and the offshore waters.

from the Korean Peninsula, subsequent amounts of materials are considered to be supplied from the East China Sea. The "GAP" area on the west of Cheju Island might be the main pathway for the exchange of suspended matters.

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## REFERENCES

Ahn, Y.H., H.J. Lie and J.E. Moon, 1999. Variations of water turbidity in Korean Waters. In: Proc.Intl.Symp. on Progress in Coastal Engineering and Oceanography, v.1, Coastal Oceanography of Asian Seas, edited by Choi, B.H., pp. 45–53.

Beardsley, R.C., R. Limeburner, K. Kim and J. Candela, 1992. Lagrangian flow observations in the East China, Yellow and Japan Sea. La mer **30**: 297–314.

Beardsley, R.C., R. Limeburner, H. Yu and G.A. Cannon, 1985. Discharge of the Changjiang (Yangtze River) into the East China Sea. Continental Shelf Research **4**: 57–76.

Choi, J.Y., S.Y. Kim and J.H. Choi, 1996. Distribution and transport of suspended sediments on the west sea of Korea, eastern Yellow Sea. In: Proc. Holocene and late Pleistocene Environments in the Yellow Sea Basin, Seoul, edited by Lee C.B. and Y.Y. Zhao, pp. 67–82.

Choi, J.Y., Y.A. Park and S. Gao, 1999. Distribution of bottom sediments and suspended matters in the Yellow Sea. Proc. 1st Intl.Symp. on the Geoenvironmental changes and biodiversity in the Northeast Asia, Seoul. Spec.Pub. The Korean Jour.Quaternary Research, pp. 165–174.

Gao, S., Park, Y.A., Zhao, Y.Y., Qin, Y., 1996. Transport and resuspension of fine-grained sediments over the southeastern Yellow Sea. In: Lee, C.B., Zhao, Y.Y. (eds.), Proc. Holocene and late Pleistocene Environments in the Yellow Sea Basin, Seoul, pp. 83–98.

Hong, G.H., Y.H. Ahn, J.H. Lee, C.S. Chung, H.J. Lee, S.M. Kim, Y.I. Kim, J.K. Park and B.W. Ahn, 1999. Suspended particulate matter in the Yellow Sea. In: Biogeochemical proceses in the Bohai and Yellow Sea. edited by Hong, G.H., J. Zhang and C.S. Chung, The Dongjin Pub.Asso., Seoul, pp. 249–274.

Hu, D.X., 1984. Upwelling and sedimentation dynamics. I. The role of upwelling in sedimentation in the Huanghai Sea and East China Sea - a description of general features. Chinese Jour. Oceanol. Limnol. **2**: 12–19.

Khim, B.K. and Y.A. Park, 1992. Smectite as a possible source-indicative clay mineral in the Yellow Sea. Geo-Marine Letters **12**: 228–231.

KIGAM, 1996. Yellow Sea drilling program for studies on Quaternary geology (Analysis of YSDP-102, YSDP-103, YSDP-104, YSDP-105 Cores). KR-96(T)-18, 595 pp.

Lee, H.J. and S,K, Chough, 1989. Sediment distribution, dispersal and budget in the Yellow Sea. Marine Geology **87**: 195–205.

Lee, H.J., K.S. Jeong, S.J. Han and Bahk, 1988. Heavy minerals indicative of Holocene transgression in the southeastern Yellow Sea. Continental Shelf Research **8**: 255–266.

Lee, J.H., S.I. Yoo and K.I. Chang, 1998. Inflow of warm waters into the Yellow Sea observed by coastal zone color scanner. In: Remote sensing of the Pacific Ocean by satellites. edited by Brown, R.A., Earth Ocean & Space PTY LTD, New South Wales, Aust., 466pp., November, 1998.

Li, C.Z., F.A. Zhang and X.C. Wang, 1985. Preliminary study on genetic environment of sediments of the East China Sea. Acta

Oceanol.Sinica **4**: 254–265.

Milliman, J.D., R.C. Beardsley, Z.S. Yang and R. Limeburner, 1985b. Modern Huanghe-derived muds on the outer shelf of the East China Sea: identification and potential transport mechanism. Continental Shelf Research **4**: 175–188.

Milliman, J.D., F. Li, Y.Y. Zhao, T.M. Zheng and R. Limeburner, 1986. Suspended matter regime in the Yellow Sea. Prog. Oceanogr. **17**: 215–227.

Milliman, J.D. and R.H. Meade, 1983. World-wide delivery of river sediment to the oceans. Jour. Geology **91**: 1–21.

Milliman, J.D., H.T. Shen, Z.S. Yang and R.H. Meade, 1985a. Transport and deposition of river sediment in the Changjiang estuary and adjacent continental shelf. Continental Shelf Research **4**: 37–46.

Niino, H. and K.O. Emery, 1961. Sediments of the shallow portions of East china Sea and South China Sea. Geol. Soc. Am. Bull. **72**: 731–762.

Nittrouer, C.A., D.J. DeMaster and B.A. McKee, 1984. Fine-scale stratigraphy in proximal and distal deposits of sediment dispersal systems in the East China Sea. Marine Geology **61**: 13–24.

Park, S.C. and K.S. Chu, 1991. Dispersal patterns of river-derived fine-grained sediments on the inner shelf of Korea Strait. In: Oceanography of Asian Marginal Seas. Elsevier Oceanography Series 54, edited by Takano, K., pp. 231–240.

Park, Y.A. and J.Y. Choi, 1989. Mechanism and distribution patterns of the fine-grained suspended materials off the southwest coast of Korea. Acta Oceanographica. Taiwanica **24**: 52–64.

Park, Y.A., J.Y. Choi, C.B. Lee, D.C. Kim and K.W. Choi, 1994. Sediment distributions and depositional processes on the inner continental shelf off the west coast (middle part) of Korea. Jour.Korean Soc.Oceanogr. **29**: 357–365.

Park, Y.A. and B.K. Khim, 1990. Clay minerals of the recent fine-grained sediments on the Korean continental shelves. Continental Shelf Research **10**: 1179–1191.

Schubel, J.R. H.T. Shen and M.J. Park, 1986. Comparative analysis of estuaries bordering the Yellow Sea. Estuarine variability, 43–62.

Wells, J.T., 1988. Distribution of suspended sediment in the Korea Strait and southwestern Yellow Sea: Onset of winter monsoons. Marine Geology **83**: 273–284.

Zhao Y.Y., Y.S. Qin, F.Y. Li and Y.W. Chen, 1990. On the source and genesis of the mud in the central area of the South Yellow Sea. Chinese Jour. Oceanol. Limnol. **8**: 66–73.

Zhu, E. and Q. Wang, 1988. Sedimentation on the north shelf of the East China Sea. Marine Geology **81**: 123–136.

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