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Sedimentation Rate and Transport Features of Suspended Matter in the Changjiang Estuary and Adjacent Continental Shelf

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양자강 하구역과 인접 대륙붕 해역에서 부유퇴적물의 이동특성 및 퇴적률

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본 연구지역은 북위 31°00′~33°30′, 동경 122°30′~126°00′에 위치하는 동중국해 대륙붕 해역이다. 연구지역 퇴적물 분포는 3개의 퇴적물 유형으로 구분된다. 실트와 니토로 구성된 육성기원 현생 니질퇴적상은 양자강 하구역과 제주도 남서쪽 외대륙붕 지역에 분포한다. 내대륙붕 지역에 분포하는 니토대의 평균조성은 모래 8.89%, 실트 59.05%, 점토 32.06%이고 평균입도는 6.90Φ로 세립질 실트에 해당한다. 외대륙붕 지역에 분포하는 니토대의 평균조성은 모래 5.83%, 실트 34.54%, 점토 59.63%, 평균입도는 8.32Φ이며 유기탄소와 함수량이 높다. C/N비는 외대륙붕 니토대 (8.64)보다 내대륙붕 지역 (10.14)에서가 높은값을 보였다.

양자강으로부터 배출되는 부유퇴적물은 대부분 하구역과 동경 123°30′ 서쪽지역에 퇴적되며, 소량만이 양자강 혼탁수에 의해 남동쪽과 북동쪽 외해역으로 이동 중앙대륙붕 지역까지 수송된다. 높은 농도의 또다른 부유물질 농집대가 연구지역 북서쪽 중앙부 지역에서도 관찰되며 이 농집대는 5 mg/l 혹은 15 mg/l 이하를 보이는 양자강 하구역에서 분리된다. 양자강 하구역과 인접한 내대륙붕 니토대 지역에서의 퇴적률은 1.70 cm/yr이며 뚜렷한 물리적 층리구조 특성을 보인다.

제주도 남서쪽 외대륙붕 지역에 분포하는 니토대에서의 퇴적률은 0.28 cm/yr이며 균일한 층리구조를 보인다. 이들 두 니토대에서의 층리구조가 다른것은 퇴적속도와 혼합률에 의해 설명되며, 이 비는 내대륙붕 니토대지역 (1.65)보다 외대륙붕 니토대 (27.34)에서가 높은값을 보이는데 이는 생물체의 교란작용에 의해 물리적 퇴적구조가 파괴되는 것으로 해석된다.

The study area is situated between 31°00′ ~ 33°30′ N and 122°30′ ~ 126°00′ E as a part of the East China Sea continental shelf.

The distribution of sediment in the study area can be classified three sedimentary types. Modern land derived muddy sediments consisting of silt and mud are distributed at mouth of the Changjiang River, and are also observed the southwest offshore of the Cheju Island.

The sand-silt-clay mixtúre sediments are presented in the outer shelf area. The relict sand are distributed between the mordern and mixture sediment. The inner-shelf mud consisted of 8.89% sand, 59.05% silt, 32.06%

clay and mean size of 6.90ϕ. The offshore mud composed of 5.83% sand. 34.54% silt. 59.63% clay and mean size of 8.32ϕ. and also have higher water content and organic carbon. The C/N ratio showed higher in the inner-shelf mud (10.14) rather than that of the offshore mud (8.68). Most of the Changjiang River suspended matter is entrapped in the area around the Changjiang Estuary to the west of 123°30′ E.

Only a small part of the suspended matter can be moved by Changjiang Diluted Plume to the southeastern and northeastern middle shelf. The higher suspended matter concentration gradient zone are observed in the northwest central region. and this plume zone separated from Changjiang Estuary by a low concentration of less than 5 mg/ l or 15 mg/ l . The sediment accumulation rate in the inner shelf mud deposit near the mouth of the Changjiang River is 1.70 cm/yr and characterized by physical stratified mud. The sedimentation rate in the offshore mud deposit to the southwest of Cheju Island shows 0.28 cm/yr and characterized by homogenous mud. The difference in fine-scale stratigraphy is explained by the ratio of mixing rate to accumulation rate. which is much larger for the offshore mud deposit (27.34) than for the inner shelf mud deposit (1.65). these larger ratio allows biological mixing to destroy physical stratification.

Key words : Changjiang Estuary. recent mud deposit. suspend matter. sediment accumulation rate. mixing rate. fine-scale stratigraphy

Introduction

The East China Sea extends from the north shore of the Changjiang Estuary mouth to Cheju Island. and through the Ryukyu Island to the southern tip of Taiwan to Fijian. It has an average water depth of about 65 m and NE~SW trending of submarine contour lines which extend to northern marine of Okinawa Trough with south-southeastward deeping through floor (Butenko et al. 1985).

For thousands of years the Changjiang and Huanghe River brough a huge amount of sediment to the seas. Recently. the Changjiang River contributes about 500×10^6 tons annually. while the Huanghe River discharge about 1.100×10^6 tons. Thus. the continental shelf of the East China Sea is mainly flooded by the sediments from the two rivers (Yang and Millman. 1983). Therefore. the continental shelf is wide and featureless.

This riverine particles accumulate in the marine environment sedimentary strata are formed. and may also affects biological productivity and the dispersal of particle reactive pollutant. In the northern East China Sea. several current systems congregate. with the Yellow Sea Warm Current flowing northwestward and entering the Yellow Sea from the east side. the Yellow Sea Coastal Current directing to the south from the west side and the northward residual of the Kuroshio spreading from the south. and in summer the Changjiang Plume plays an important role in the study area (Mao et al. 1983).

There are two recent mud deposits distributed in the East China Sea. The one is extends from the Changjiang River mouth. and the other occurs in the outer shelf depression southwest of the Cheju Island.

In the present paper. based on the distribution of Pb-210 activity in combination with X-radiography in the core. the characteristics of suspended sediment distribution and distinguish feature of two recent muddy sediments. we attempt to discuss the characteristics of the sediment texture and transport processes of suspended matter. sedimentation rates and sedimentary environment in the East China Sea during the past one hundred years.

Sample collection and Methods

Sediment samples were obtained in the East China Sea continental shelf during period in August 1997 and June 1998 using the Ara R/V of Cheju National University. A total of 34 waters and 3 sediment gravity core samples were collected from the study area (Fig. 1).

In laboratory, the sampled water was filtered through preweighed Gelman filter paper with 0.45 μm pore size. Grain-size analyses were performed by standard procedures (Krumbein and Pettijohn, 1938), and the sand fraction was analyzed by sieve methods and the silt and clay fraction by pipette techniques. Organic carbon and nitrogen in the sediments were analyzed using CHN Analyzer following the method of Byers et al. (1978).

For the estimating the flux of Pb-210 into sediment and determine the sedimentation rates three core samples was analyzed by the radiochemical techiques. Cores were sectioned into 1cm and each sublevel core samples was used for Pb-210 analysis. Various methods are available for Pb-210 analysis. The one employed is similar to that described by Nittrouer et al. (1979) and depends upon its secular equillibrium with Po-210.

Approximately 3.0 g of dried sublevel sediment, which have been passed through a one phi sieve to remove coarse paricles, were spiked with a known amount of Po-208 tracer. The sample was dissolved

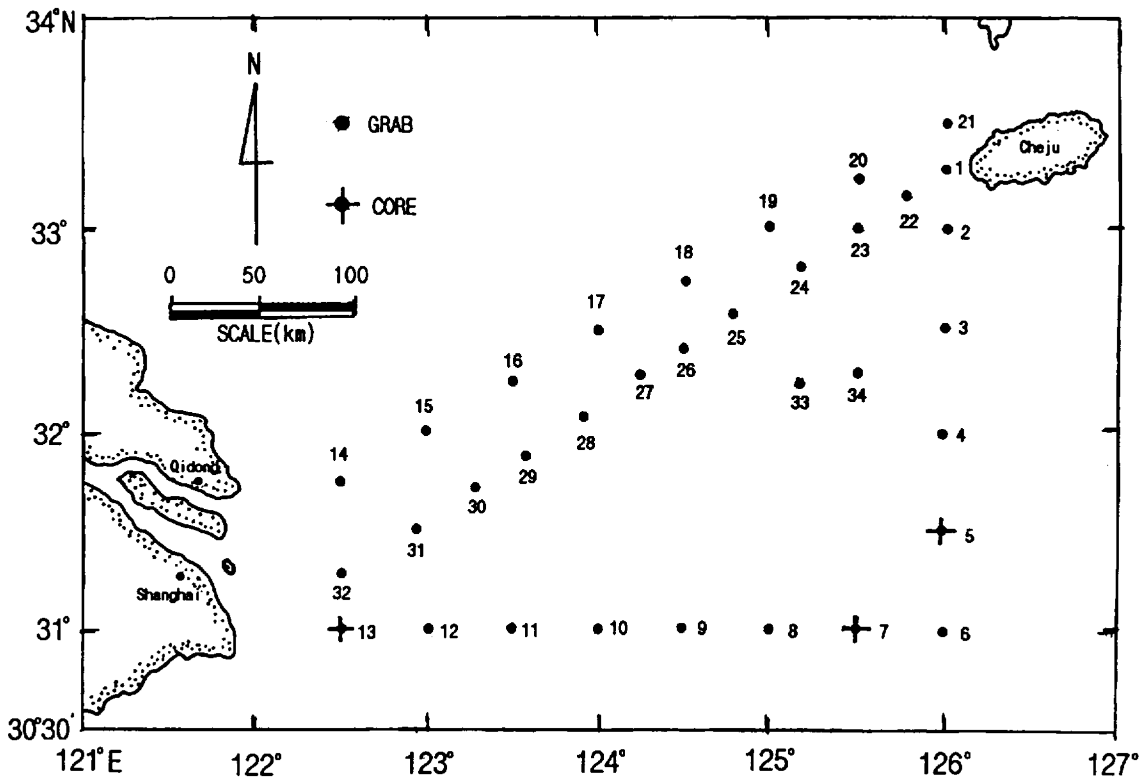

Fig. 1. Study area and sampling sites.

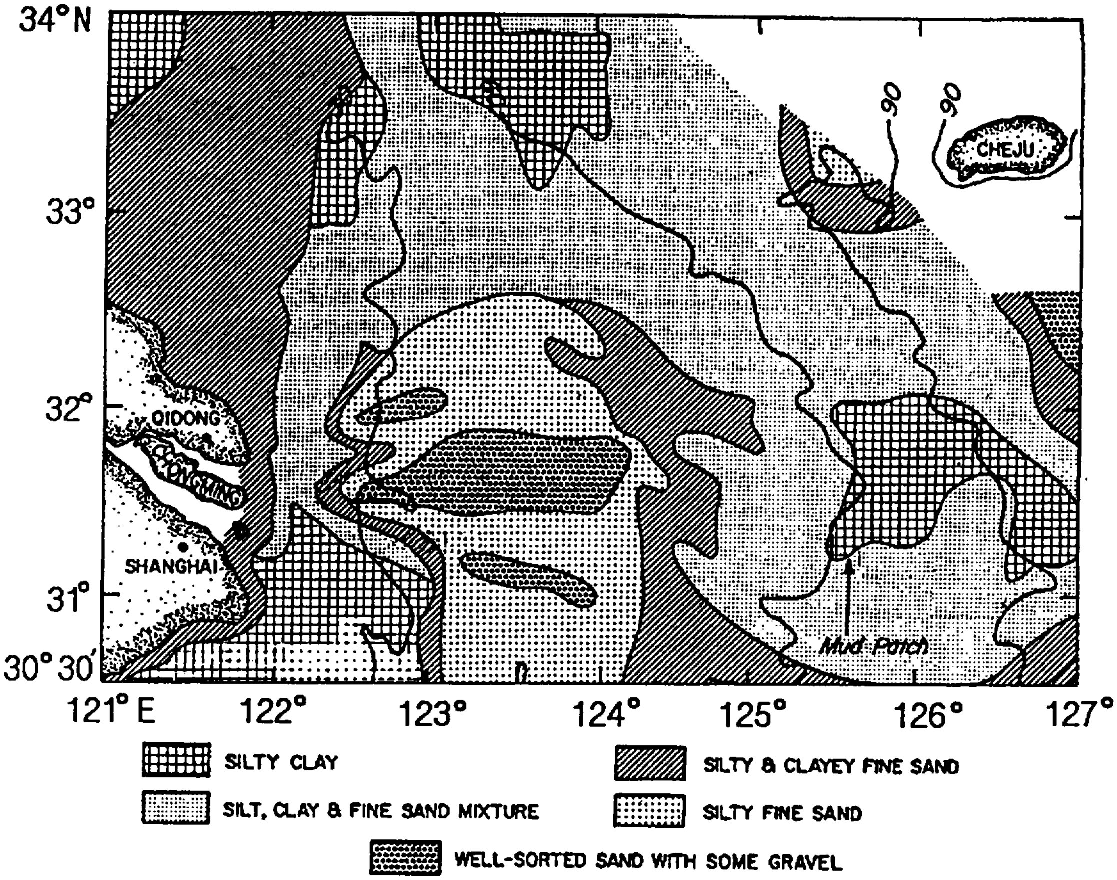

Fig. 2. Distribution of seafloor sediment characteristics in the East China Sea (after Butenko et al., 1985).

totally with HNO_3, $HClO_4$, HCl and HF acids and then taken to dryness. The Po isotopes were picked up in 1N HCl and plated onto 1 cm^2 silver planchets. The Po activities were determined by alpha spectrometry.

Results and Discussion

The sediment types in the Changjiang Estuary and its adjacent continental shelf of the East China Sea are composed of relict sand, silt, mud, silty clay and sand-silt-clay mixture sediments (Butenko et al., 1985).

Modern land derived sediment consisting silt clay and mud is distributed at the mouth of the Changjiang River mouth and extend southward along the coast, and are also present the southwest offshore from the Cheju Island (Fig. 2). The sediment in the inner-shelf area is characterized by abundant silt and that to the southwest offshore the Cheju Island is characterized by rich clay. The well sorted medium to fine sand are distributed over the middle area, belonging to pleistocene relict sediments. The area between modern sediment and relict sediments presents palimsest deposit consisting of silty and clayey fine sand, silty fine sand and mud-silt-fine sand mixture.

The composition of the inner-shelf mud deposit consisted of 8.89% sand, 59.05% silt, 32.06% clay and mean size of 6.90ϕ. There are abundant silt relative to clay and more coarse than that in the offshore mud from the southwest Cheju Island (Table 1). The offshore mud composed of 5.83% sand. 34.54% silt. 59.63% clay and mean size of 8.32 ϕ. and its characterized by abundant clay. and also have higher water content and organic matter.

Organic carbon and organic nitrogen contents in the offshore mud area are 0.757% and 0.086% respectively. and are higher than those in the inner-shelf mud deposits (Table 1).

At a station near Changjiang River mouth. the contents organic carbon and nitrogen in the inner-shelf mud area showed 0.645% and 0.060% respectively. and also close relationship could be found between grain size of sediment and organic matter. The organic materials in the sediments showed that higher contents were closely related to the fine-grained sediments. The C/N ratio is commonly used to characterize various types of organic matter (Stein. 1990). The C/N ratio in the study area varies between 7.53 and 10.78 (Table 1). and showed higher in the inner-shelf mud (10.14) rather than that of the offshore mud deposit (8.68).

The C/N ratio exceeding 10 in the inner-shelf mud indicates that large amounts of the organic matter have been supplied from the Changjiang River because marine organic matter exhibits less than 10 in C/N ratio (Stein. 1990).

The highest suspended matter concentration occurs in the Changjiang Estuary and the higher suspended matter concentration second to those in the northeast central region (Fig. 3). In the Changjiang Estuary suspended matter shows range from 30 to 20 mg/l in the surface water and from 50 to 20 mg/l in the near bottom water. and these concentration trends to gradually decresed toward the southeast and northeast seaward from the Changjiang mouth. The region between 123°00′~123°30′ E is an important boundary region and little suspended sediment disperses beyend it. Above data indicate that the main path of the Changjiang River is directed southeast. the suspended mattor of higher concentration extends from the mouth south-eastward and suddenly decreased outside of 123°30′ E. But according to the Zheng and Klema data (1982). the Changjiang River fresh water. during the year of high flows. flood season is directed to

Table 1. Sediment type, textural parameter, physical property and C.N. content

Sedimentary region	Station No.	Sediment composition: Sand (%)	Silt (%)	Clay (%)	Sediment type	Textural parameters: Mean (Mz)	Sorting (σ)	Skewness (SKI)	Kurtosis (KG)	Physical property: Water content (%drywt)	Bulk density (g/cm³)	Organic matter: Organic-C (%)	Organic-N (%)	C/N Ratio (atomic)
Inner-shelf mud deposit	CJ97012	3.87	63.30	32.83	Z	7.10	2.39	0.40	0.59	34.24	0.78	0.659	0.061	9.41
	CJ97013	2.23	60.90	36.88	M	7.27	2.27	0.29	0.61	42.57	1.05	0.733	0.075	10.78
	CJ98032	20.58	52.95	26.47	sZ	6.34	2.55	0.52	0.72	42.79	0.75	0.542	0.043	10.23
	Mean	8.89	59.05	32.06		6.90	2.40	0.40	0.64	39.87	0.86	0.645	0.060	10.14
Offshore mud deposit	CJ97004	1.18	34.88	63.95	M	8.74	1.83	-0.21	0.77	59.45	0.59	0.843	0.091	9.69
	CJ97005	0.47	35.25	64.28	M	8.70	1.80	-0.31	0.82	58.18	0.60	0.791	0.095	7.53
	CJ97007	15.85	33.50	50.65	sM	7.53	2.77	-0.31	0.83	51.82	1.45	0.636	0.072	8.83
	Mean	5.83	34.54	59.63		8.32	2.13	-0.28	0.81	56.48	0.88	0.757	0.086	8.68

Note : sM : sandy mud. sZ : sandy silt. M : mud. Z : silt. C : carbon. N : nitrogen

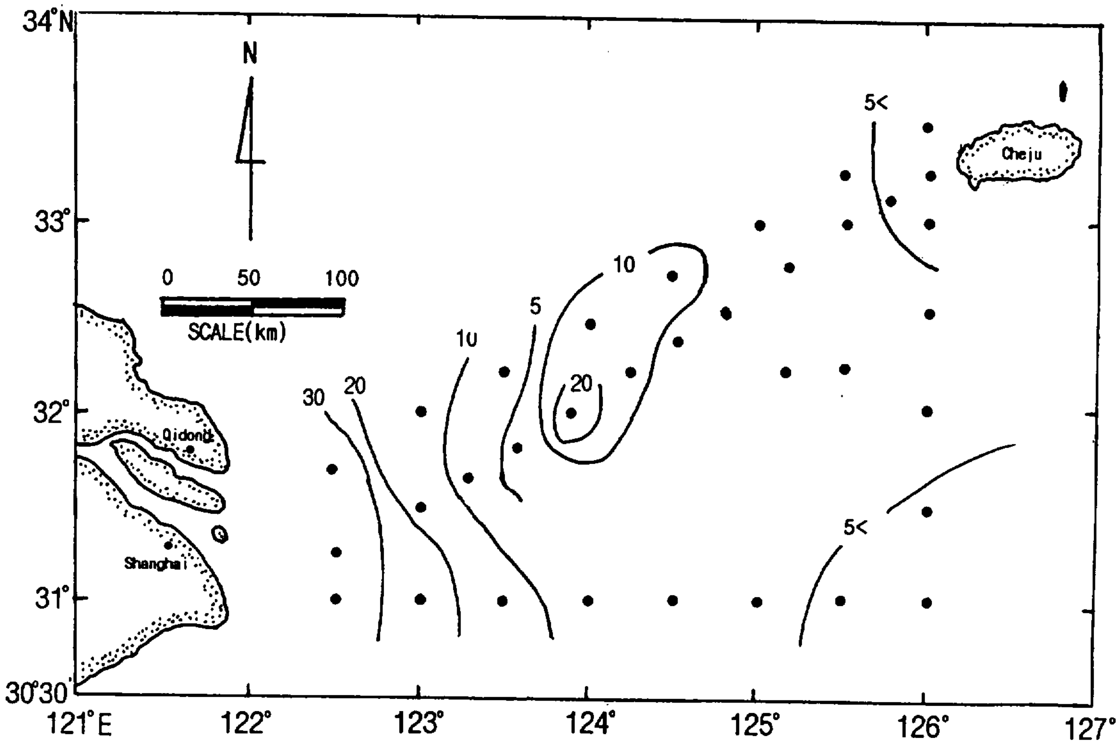

Fig. 3. Distribution of total suspended matter (mg/ l) in the surface water, August 26~September 4, 1997 and June 29~30, 1998.

the northeastward and spread near the southwest of Cheju Island.

The higher suspended matter concentration second area are found in the northeast central region. The isogram of high suspended matter concentration takes the shape of a tongue protruding from the southern Yellow Sea to the southeastward (Fig. 3).

The high concentration area is obviously separated from the Changjiang Estuary by a low concentration zone of less than 5 mg/ l or 15 mg/ l at the west of 123° 30′ E. Therefore, the northeast central area and the offshore mud deposit may be no influence or a little of the sediment discharge from the Changjiang River.

According to Milliman and Meade (1983), the huge sediment (1.19×10^9 ton annually) discharged from the Hhanghe River are mainly deposited in the south part of Bohai Sea and the nearshore area of shandong peninsular. The sediment remobilized and mixed by wave and storms action are transported father seaward by the shandong and the Jiangsu longshore currents, and deposited in the middle of the Yellow Sea. The remaining suspended sediment passes father southward and deposits as to offshore mud deposits to the southwest offshore from Cheju Island (Milliman et al., 1986).

According to Qin and Li data (1983), the annual sediment discharged of the Yalujiang and the Taedong River in China, the Han and the Keum River in Korea less than 10% of the Huanghe River value, showing that sediment loads discharged from the Huanghe River play the most important role in the sedimentation of the Yellow Sea and the northwestern East China Sea.

The profiles of Pb-210 are useful in characterizing sedimentary processes over a one hundred years time scale (DeMaster et al. 1985). The relative importance of sediment mixing and sediment accumulation terms in following equation varies as function of depth.

$$S = \frac{\lambda_s}{L(A_o/A_{(z)})} - \frac{D_s}{Z} L(A_o/A_{(z)})$$

The Pb-210 profiles from the inner shelf mud deposit (st. CJ97013) are shown in Fig. 4. The logarithmic decrease is excess Pb-210 activity correspond to the sedimentation rate of 1.70 cm/yr. The mixing layer can find the upper 15cm and this mixing layer normally would be attributed to mixing.

However, there are few biota in the inner shelf mud deposit, and more importantly the X-radiography from the core (J97013) reveals distinctive horzonal lamina (Fig. 5).

According to the previous data, there have relationship between sedimentary structure and the ratio of mixing rate to accumulation rate (Nittrouer and Sternberg, 1981). The degree of homogenous is dependent on the ratio of mixing rate to accumulation

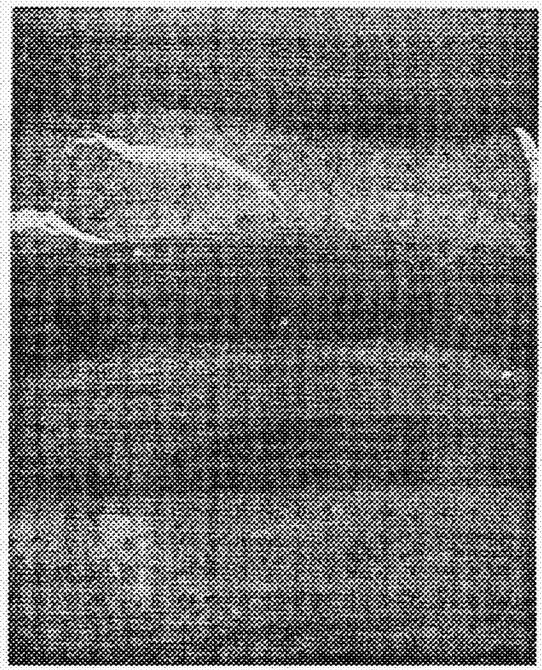

Fig. 5. Radiographs from core CJ97013 in the inner-shelf mud deposit showing distinct horizontal stratification. A high rate of sediment accumulation and low rate of sediments mixing (G value (1.65) contributes to the preservation of primary sedimentary structure in this core.

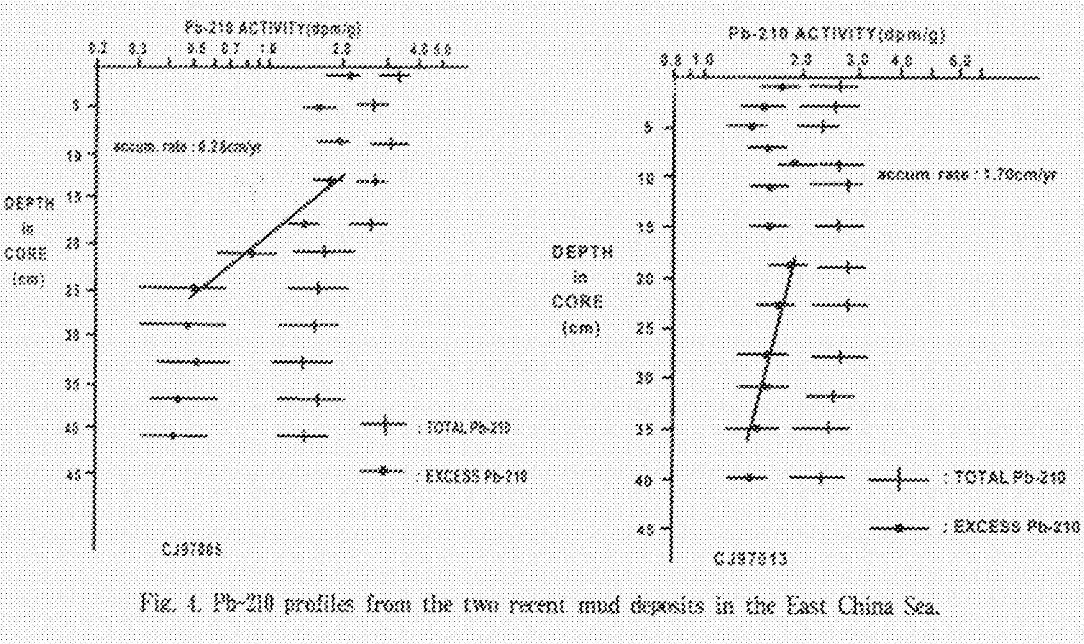

Fig. 4. Pb-210 profiles from the two recent mud deposits in the East China Sea.

Table 2. The Pb-210 dating results from the core samples in Changjiang Estuary and its adjacent continental shelf area

Sedimentary Region	Station No.	Location		Number of Linear Segments (n)	Linear Range (cm)	Intercept (a)	Slope (b)	Correlation Coefficient	Sedimentation Rate (cm/yr) (Sd)	Mixing Coefficient (cm^2/yr) (Db)	Db/Sd Ratio (G)
		Lat. (N)	Long. (E)								
Offshore mud deposit	CJ97005	31° 30'	125° 00'	11	42	2.077	-0.047	0.926	0.28	68.90	27.34
	CJ97007	31° 00'	125° 30'	14	40	2.162	-0.055	0.867	0.23	76.63	37.02
Inner-shelf mud deposite	CJ97013	31° 00'	122° 30'	13	42	1.665	-0.004	0.327	1.70	14.01	1.65

rate, where this ratio is small, the primary physical stratification is preserved. Where it large mixing is effective and strata is homogenized. Calculating the ratio (G) of mixing to accumulation rate is suggested by Guinasso and Schink (1975) the following equation.

$$G = \frac{\text{Volume of sediment processed per unit area of seabed per time}}{\text{net accumulation rate}}$$

$$= \frac{D_b/L_b}{S_d}$$

At sation CJ97013 in the inner shelf mud, Pb-210 profiles demonstrate that the net accumulation rate (S_d) is 1.70 cm/yr, and that a mixing rate (D_b) is 14.01 cm^2/yr (Table 2). Therefore, the ratio (G) of mixing rate to accumulation rate is 1.65. Above data indicating that particle mixing is very small due to the fast rate of sediment accumulation, and where is well stratified deposit preserved (Fig. 6: Nittrouer et al., 1984).

The Pb-210 profiles from the offshore mud deposits (st. CY97005) is shown in figure 4. The Pb-210 data show a mixed layer in the upper 9 cm of the core overing a region in which Pb-210 activity decreases logarithmically. The accumulation rate based on the decreasing Pb-210 activity

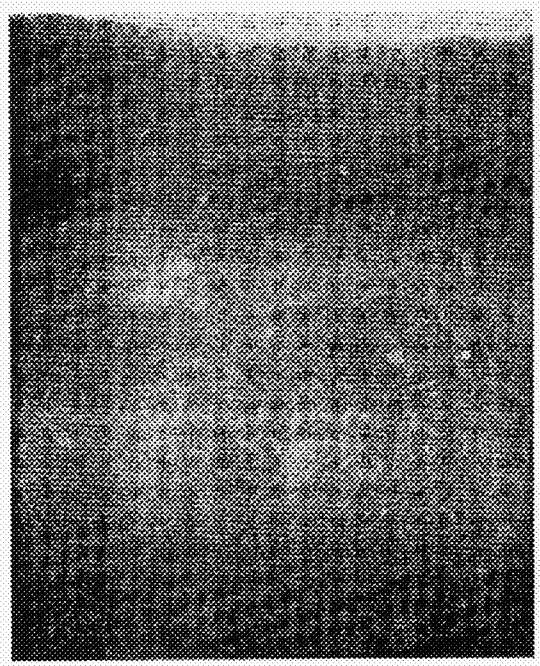

Fig. 6. Radiographs from core CJ97005 in the offshore mud deposit showing nearly homogeneous sedimentary structure. The lack of sedimentary structure is consistent with the rapid rate of particle mixing and the relatively low rate of sediment accumulation (G > 27).

between 11 and 25 cm is 0.28 cm/yr, and that is lower sedimentation rate than that the inner shelf mud. At the station CJ97005 in the offshore mud deposits, the calculated mixing rate (D_b) for the upper 9 cm is 68.9 cm^2/yr. and net accumulation rate (S_d) is 0.28 cm/yr (Table 2).

Therefore. the ratio (G) of mixing rate to accumulation rate is 27.34. This means that particle mixing is very high relative to the inner shelf mud deposit. because the low sedimentation rate is ease to increased of biological reworking. which the higher rate allows biological mixing to destroy the original depositional structure (Nittroues et al., 1984). The dominance of mixing relative low sediment accumulation is also exemplified in X-ray radiograp in the offshore mud core samples CY97005 which reveals relatively homogenous sedimentary structure (Fig. 6).

Conclusion

A analysis of transport processes of suspended sediment. Pb-210 dating and X-ray photography for the continantal shelf sediment in the East China Sea results and features as follow : in case of inner shelf mud deposit which extends from the Changjiang River mouth along the coast. where most of the materials from the Changjiang River into the sea deposited. The sediment in the inner-shelf area is characterized by abundant silt and more coarse. The C/N ratio exceeding 10 in the inner shelf mud indicates that large amounts of organic matter have been supplied from neighbouring the Changjiang River. The suspended matter concentration was high and the sediments are consisted of silt and mud.

The sediment accumulation rate in the inner shelf mud is 1.73 cm/yr. There were little benthic activities and sedimentation rate was high. Observation of core profiles and analysis of X-ray photographs showed some horizontal thin stratification indicating a larger of generating rate of grain bedding than the destraction rate of organism. These grain bedding were resulted from modern hydrodynamic actions and seasonal supersedures with currents in the lead.

In case offshore mud deposit situated the outer shelf depression southwest of Jeju Island shows characterized by abundant clay and have higher water content and organic matter. The organic materials in this study sediment showed that higher contents were closely related to the fine-grained sediment. Its most of materials came from modern and old Huanghe River are consisted of the mud. and the suspended matter concentration was low.

The Pb-210 measurement of the offshore mud shows a low sedimentation rate (0.28 cm/yr). and where deposit was weak and biological mixing was strong. The biomass were relatively high so that a high frequency disturbance occurred and the surface and subsurface grain bedding were destroed and reworked.

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