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Sedimentary Strata and Clay Mineralogy of Continental Shelf Mud Deposits in the East China Sea

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Abstract

Six cores from the East China Sea have been studied using the isotope Pb-210 and clay mineralogy in order to evaluate the formation of sedimentary strata and to decipher the provenance of shelf sediments. There are two recent mud deposits in the East China Sea. The one extends from the Changjiang River mouth to the southward along the coast of China, and the other is in the outer shelf depression southwest of Cheju Island. These two recent mud deposits are different with respect to the material composition, sedimentation rate and other characteristics. The sediment in the inner shelf area is characterized by abundant silt and more coarser grain-size, but the outer-shelf mud deposits are characterized by rich clay with higher contents of water and organic carbon. At the boundary of the inner-shelf and outer-shelf mud deposits, bimodal sediment are forming the mixture of modern mud and ancient sand. The sediment accumulation rate in the inner shelf mud deposit is 1.70cm/yr or 1.63g/cm^2 · yr and the sediment is characterized by physical stratified mud. The sedimentation rate in the outer-shelf mud deposit shows 0.28cm/yr or 0.18g/cm^2 · yr, and the sediment is characterized by homogeneous mud. The difference in fine-scale stratigraphy is explained by the ratio of mixing rate to accumulation rate, which is much larger for the outer-shelf mud deposit (27.34) than for the inner shelf mud deposit (1.65). The larger ratio suggests biological mixing to destroy physical stratification. The clay minerals in the outer-shelf mud deposit are characterized by relatively higher smectite, a high ratio of chlorite/kaolinite and the existence of calcite concretion, which is similar to the sediment of the central Yellow Sea.

Key Words: recent mud deposit, sediment accumulation rate, fine-scale stratigraphy, clay minerals, sediments sources, East China Sea.

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 65m and NE~SW trending of submarine contour lines which extend to the northern marine of Okinawa Trough with south - southeastward deeping through floor [1].

For thousands of years the Changjiang and Huanghe Rivers brought a huge amount of sediment to the seas. In fact, the Changjiang River contributes about 500 $\times 10^6$ tons annually, while the Huanghe River discharges about 1,100 $\times 10^6$ tons. Thus, the continental shelf of the East China Sea is mainly flooded by the sediments from the two rivers [2]. Therefore, the continental shelf is wide and featureless.

This riverine particles accumulate in the marine environment forming sedimentary strata, and may also affect 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 directs 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 northern East China Sea [3]. There are two recent mud deposits distributed in the East China Sea continental shelf: the inner-shelf mud deposit extending from the Changjiang River mouth southward along the coast and the outer-shelf mud deposit occurs in the outer shelf depression southwest of the Cheju Island [4,5].

Clay mineral studies in various marine depositional systems have amply elucidated the provenance, dispersal patterns, transport agents and depositional sites of fine-grained particles [6,7,8], and understanding the distribution and origin of clay mineral assemblages has proved to be a useful tool to interpret the net pathways of fine grained sediment transport [9,10,11]. In the present paper, we attempt to discuss the characteristics of sediment composition of the two mud deposits and a possible sources of the outer-shelf mud deposits based on the clay mineralogical data, rates of sediment accumulation and modern sedimentary structure from continental shelf deposit in the East China Sea during the past one hundred year.

MATERIALS AND METHODS

Six gravity core sediment samples were obtained from the continental shelf of the East China Sea (Fig. 1) between August 1997 and June 1998 with R/V Ara of Cheju National University. In laboratory, grain-size analyses were performed by standard procedures [12]. The sand fraction was analyzed by sieving while the silt and clay fraction by pipette techniques. Organic carbon and nitrogen content in the sediments were analyzed using a CHN Analyzer following the method of Byers et al. [13]. Clay fraction (<2μm) was smeared on glass slides and air dried [14] for XRD analysis. Glycolation was affected by vapor-phase exposure for 48 hours. All clay specimens were scanned from 2^o to 35^o 2θ at 2^o 2θ/min on a Shimadzu X-ray diffractometer using Ni-filtered CuK_α radiation. A slow scan (0.25^o 2θ/min) between 24^o and 26^o 2θ was used to differentiate kaolinite from chlorite. Clay minerals were identified from their basal X-ray diffraction peaks according to the criteria outlined by Brindley and Brown [15]. The semi-quantitative determination of relative amounts of major clay minerals was made by measuring the peak area and multiplied by factors of 1, 4, and 2 for smectite, illite and chlorite + kaolinite, respectively [16].

For estimating the sediment flux rate of Pb-210 into sediment and determine the sedimentation rates three core samples were analyzed by the radiochemical techniques. Core sample were sectioned at every 1cm interval and each sub samples were 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., [17] and depends upon its secular equilibrium with Po-210. Approximately 3.0g of dried sub-sediment samples, which was passed through a one phi sieve to remove coarse particles, was spiked with a known amount of Po-208 tracer. The sample was dissolved in an acid mixture of HNO_3, $HClO_4$, HCl and HF and then taken to dryness. The Po isotopes were digested in 1N HCl and plated onto $1cm^2$ silver planchets. The Po-210 activities was determined at the Cheju Applied Radioisotope Research Institute (CARRI) by alpha spectrometry. The Ra-226 activity was also determined throughout the core length by measuring the gamma ray emission of Pb-214 and Bi-214 in leached samples at the CARRI.

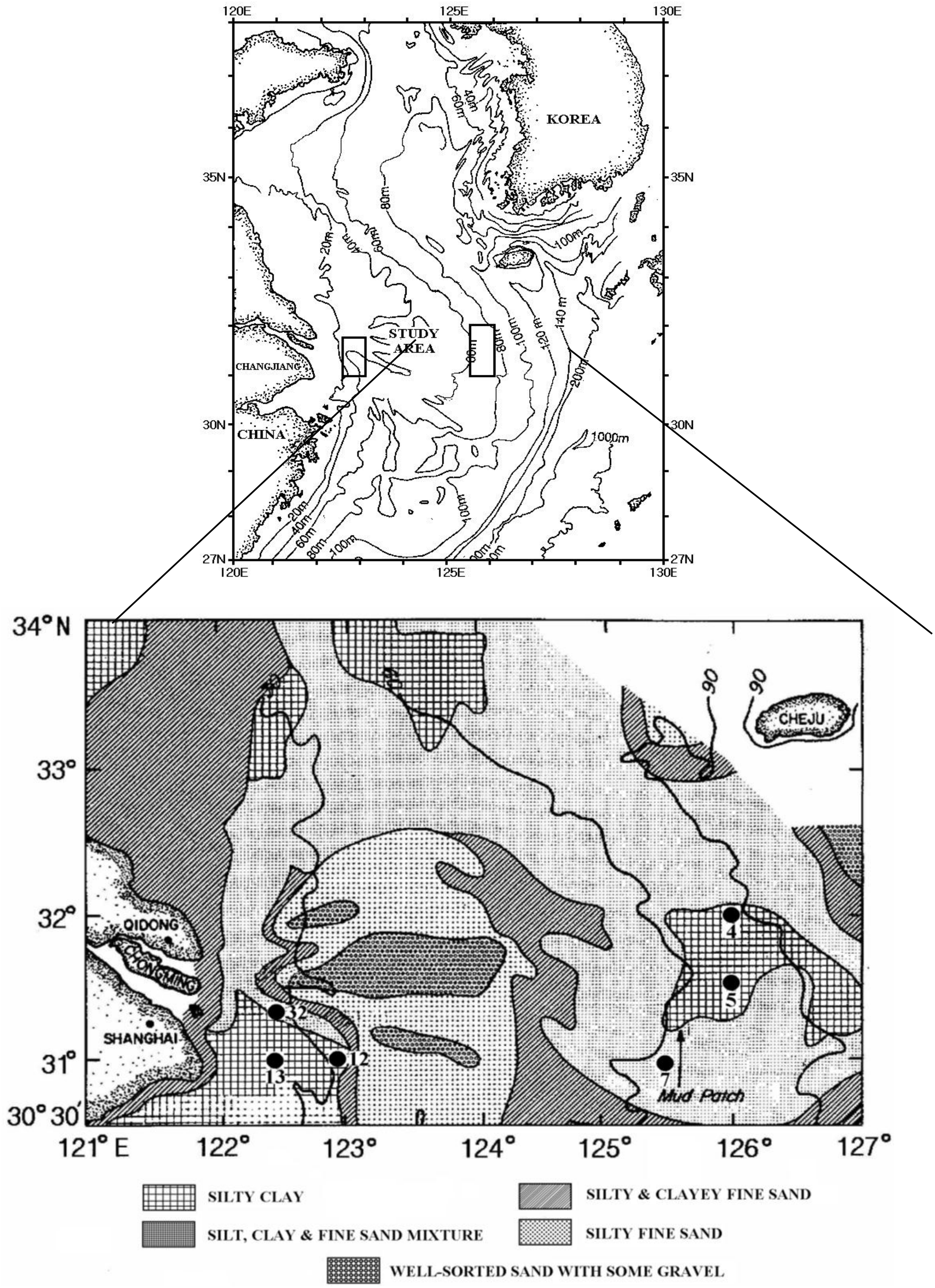


Figure 1. Map showing the study area, sampling sites and sediment type distributions in the East China Sea (after Butenko et al., 1985[1]).

RESULTS AND DISCUSSION

Sediment properties

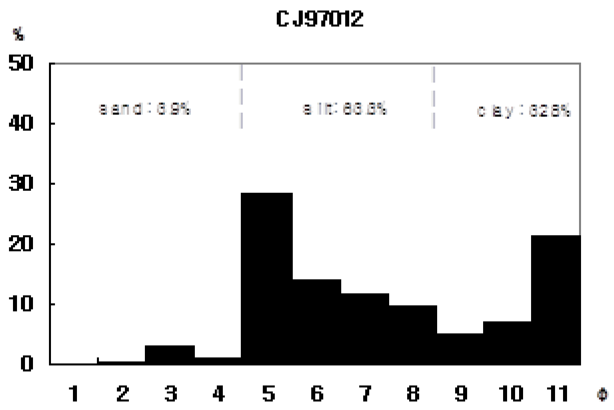
The sediment near the mouth of the Changjiang River estuary and on the adjacent continental shelf of the East China Sea (Fig. 1) are mainly composed of relict sand, silt, mud, silty clay and sand-silt-clay [1]. Modern terrestrial fine-grained sediments consisting of silty clay, silt and mud are distributed at the mouth of the Changjiang River estuary, extend southward along the cost, and also occur in the southwest offshore of the Cheju Island (Fig. 1). The inner-shelf mud deposits composed of 8.9% sand, 59.1% silt and 32.1% clay with of mean grain size 6.9φ. This sedimentary deposit has more silt than clay fraction, and is coarser than that of the outer-shelf mud deposit to the southwest of Cheju Island (Table 1). The bimodal character at station CJ98032 (Fig. 2) reflects mixing of the sediment types. The boundary of the inner-shelf mud (st. CJ98032) is clearly a region where palimpsest deposits are forming from combination of modern and ancient sediments. The outer-shelf mud deposits are composed of 5.8% sand, 34.5% silt, and 59.6% clay with a phi mean of 8.3φ. This sedimentary deposit is also characterized by high content of clay, water and high organic matter (Table 1). Figure 3 shows the grain-size profiles of the outer-shelf of mud deposit. The bimodal nature of sediments (station CJ97007) reflects the multiple sources possibly from the offshore modern mud and transgressive sand.

Organic carbon (0.76%) and nitrogen (0.09%) values in the outer-shelf mud deposit are higher than those in the inner-shelf mud deposit. At a station near the Changjiang River mouth, the organic carbon and nitrogen contents in the inner-shelf mud area are 0.65% and 0.06% respectively. A close relationship could also be found between grain size of sediment and organic matter. The organic materials in the sediments generally show that higher contents are closely related to the fine-grained sediments. The C/N ratio is commonly used to characterize the origin and type of organic matter [18]. The C/N ratio in the study area vary between 7.5 and 10.8 (Table 1), and are higher in the inner-shelf mud (about 10.1) rather than that of the outer-shelf mud deposit (8.7). 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 C/N ratio of the marine organic matter is normally less than 10 [18].

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

Sedi-mentary Region	Station No.	Sediment composition			Sedi-Ment Type	Textural parameters				Physical property		Organic matter		
		Sand (%)	Silt (%)	Clay (%)		Mean (φ)	Sorting (φ)	Skewness (φ)	Kurtosis (φ)	Water content (%drywt)	Bulk density (g/cm^3)	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
	CJ97032	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
Outer-Shelf 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



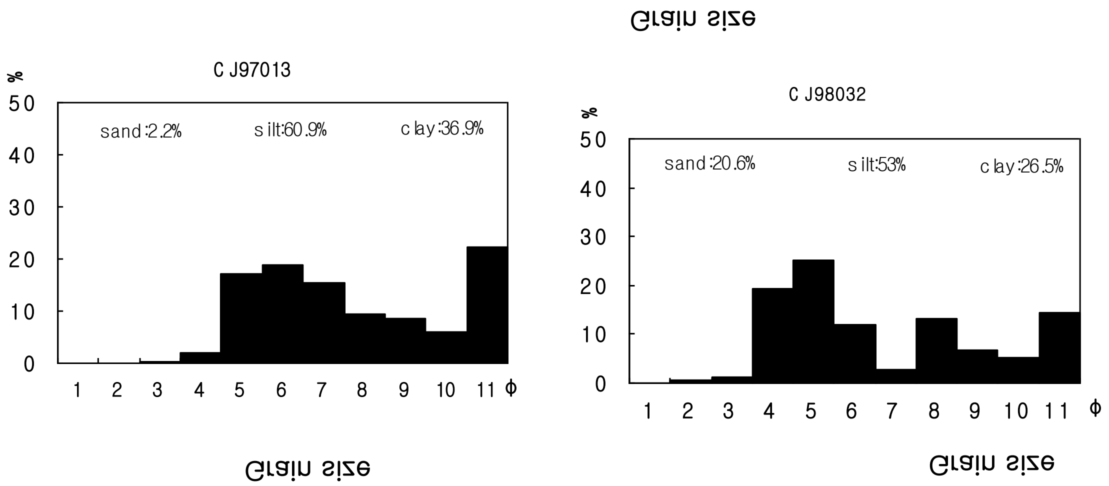


Figure 2: Histograms of grain size observed in surface sediment from the inner-shelf mud deposit.

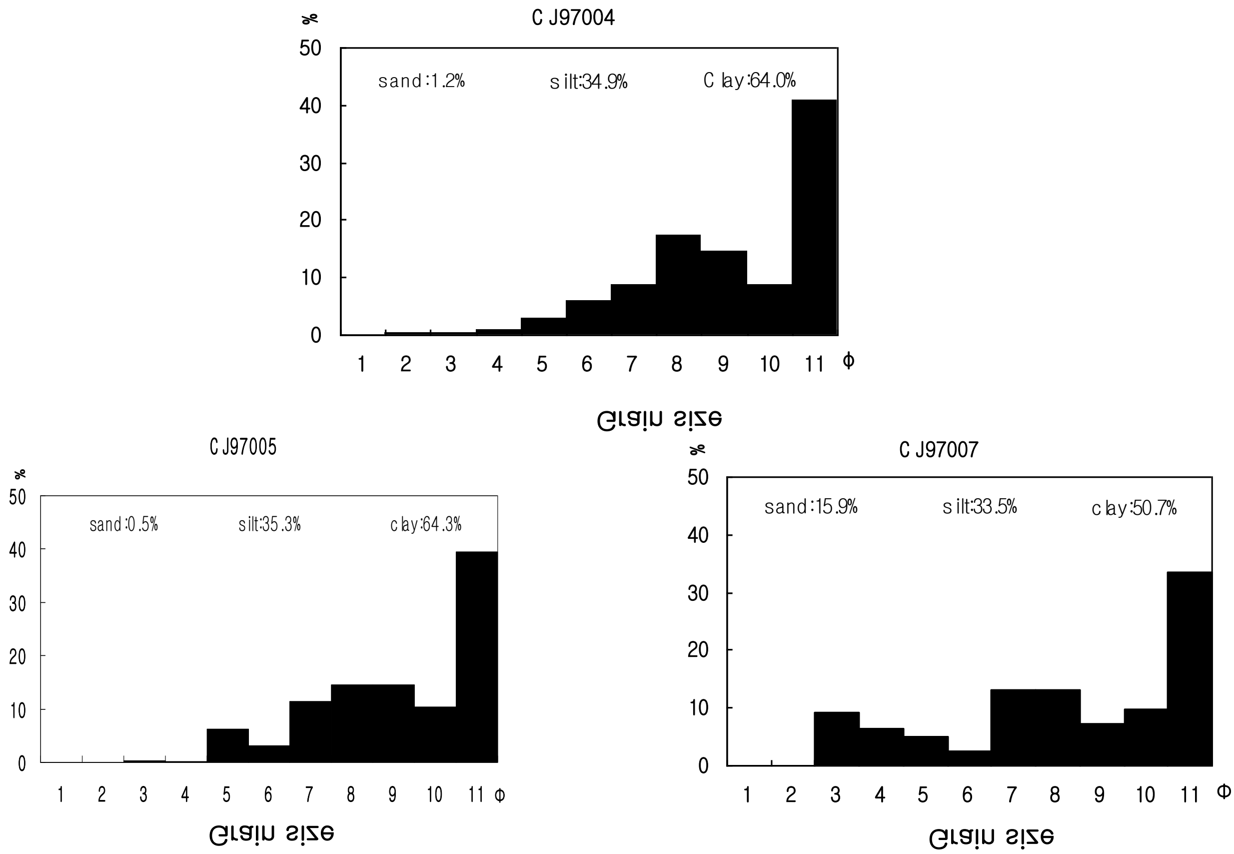


Figure 3: Histograms of grain size observed in surface sediment from the outer-shelf mud deposit.

Sedimentation rates and strata formation in the inner and outer-shelf mud

Total and excess Pb-210 activity profiles for three cores from the recent mud deposits in the East China Sea are shown in Figure 4 and Pb-210 dating results are presented in table 2. The crosses represent the total Pb-210 activity and the closed circles indicate the excess Pb-210 activity. Excess Pb-210 activity was determined by subtracting Ra-226 supported activity (background activity) from the total activity. The excess Pb-210 activity was used to compute sediment accumulation rates following the simplified equation of Nittrouer et al., [17] and DeMaster et al., [19].

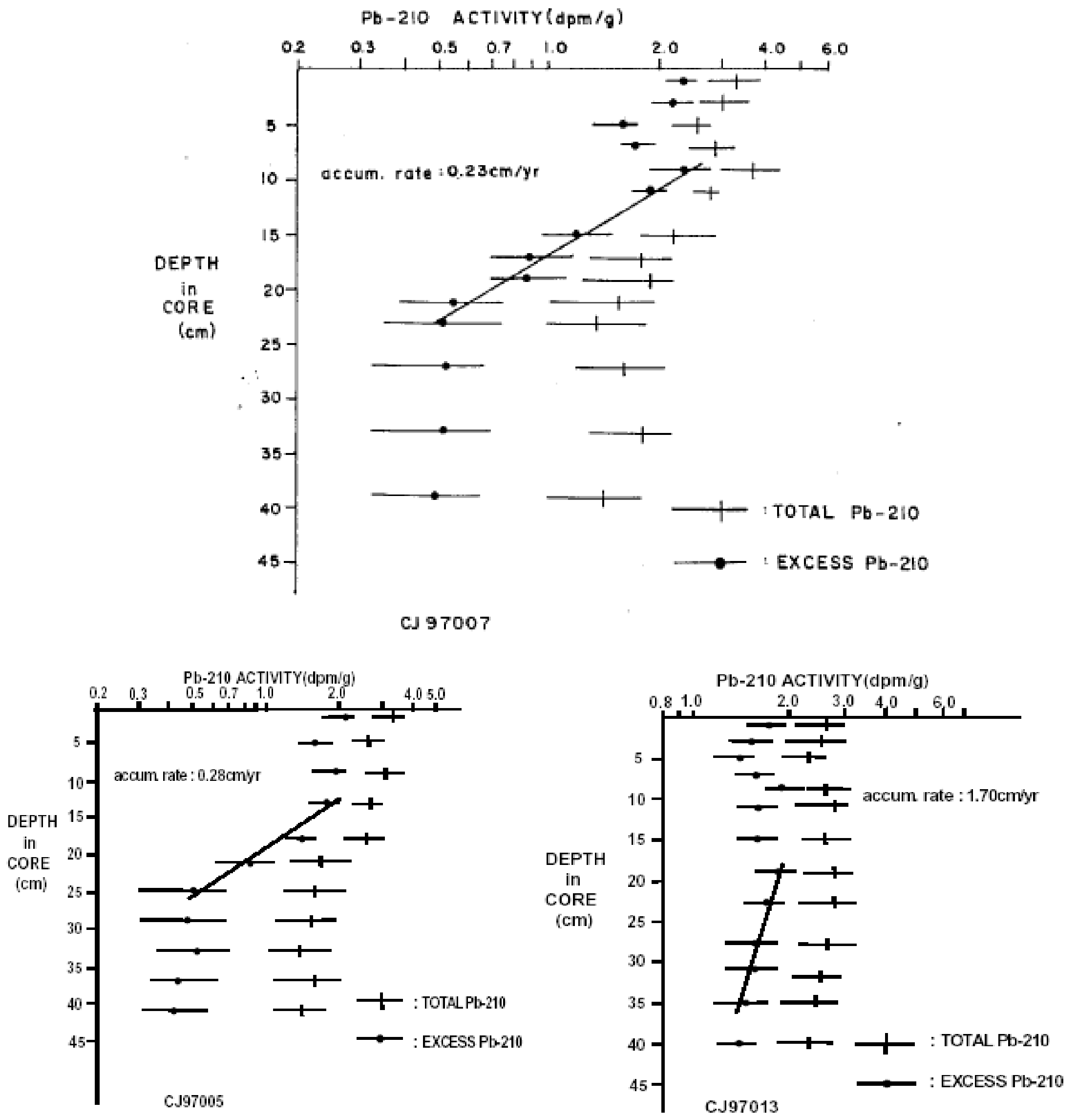


Figure 4: Pb-210 profiles from the three recent mud deposits in the East China Sea.

The equation is given by S=Z λ/(In Ao/Az),

where S is sedimentation rate(cm/yr), λ is the decay constant of Pb-210 (0.031/yr), z is depth in profile, and Ao/Az are the unsupported excess Pb-210 activity of the sediment surface(dpm/g) and the unsupported excess Pb-210 at depth z, respectively.

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

	Station No	Location		Initial Specific Activity of Excess Pb-210 (dpm/g)	Sedimentation Rate (cm / yr) (S_d)	Sediment Material Flux (g/cm^2 · yr)	Pb-210 Sedimentation Flux (dpm/cm^2 · yr)	Mixing Coefficient (cm^2/yr) (D_b)	D_b/S_d Ratio (G)
		Lat(N)	Long(E)						
Outer-Shelf Mud Deposit	CJ97005	31°30′	126°00′	2.067	0.28	0.175	0.364	68.90	27.34
	CJ97007	31°00′	125°30′	2.327	0.23	0.212	0.458	76.63	37.02
Inner-Shelf Mud Deposit	CJ97013	31°00′	122°30′	1.735	1.70	1.630	2.714	14.01	1.65

Figure 5: X-ray radiographs of core CJ97013 from the inner-shelf mud deposit showing physical sedimentary structure.

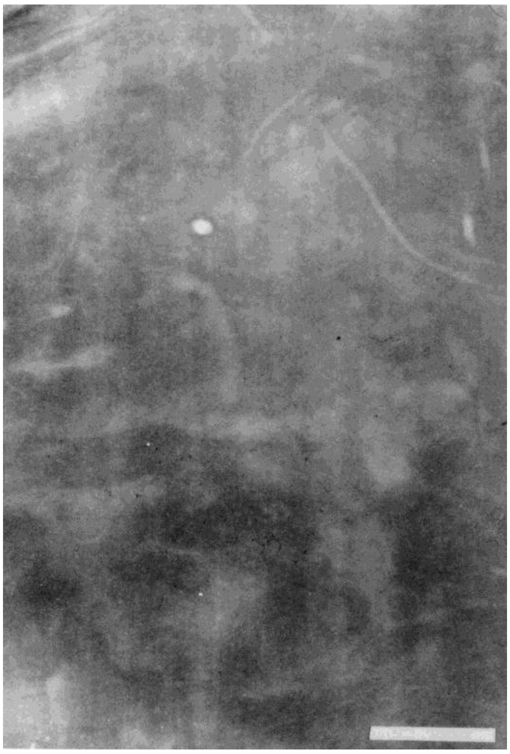


Figure 6: X-ray radiographs of core CJ97005 from the outer-shelf mud deposit showing homogenous sedimentary structure.

The sedimentation rate, sediment material flux and input of Pb-210 obtained using the Pb-210 radioactive decay formular in the inner shelf mud deposit (sation CJ97013) shows 1.70cm/yr, 1.63g/cm^2 /yr and 2.71dpm/cm^2 /yr, respectively. The mixing layer can find the upper 15cm at station CJ97013. The mixing here caused by tidal currents which are reciprocal ones in the Changjiang River mouth area. A few biota structures are observed from the X-ray radiographs, but the radiographs from CJ97013 core in the inner shelf mud deposit reveal dominantly preserved sedimentary horizontal lamination (Fig. 5).

According to the previous data, there have relationship between sedimentary structure and the ratio of mixing rate to accumulation rate [20]. The degree of homogenous is dependent on the ratio of mixing rate to accumulation rate, where this ratio is small; the primary physical stratification is preserved. Where it is large the mixing is effective and then the sediment strata tends to become homogenized. Calculating the ratio (G) of mixing rate to accumulation rate is suggested in the following equation by Nittrouer et al., (1984)[21].

$$G = \frac{\textit{Volume of sediment processed per unit area of seabed per time}}{\textit{net accumulation rate}} = \frac{D_b/L_b}{S_d}$$

where, D_b represents a mixing coefficient, L_b is the thickness of the surface mixed layer and S_d is the accumulation rate. At station CJ97013 in the inner shelf mud deposit, Pb-210 profiles demonstrate that the net accumulation rate(S_d) is 1.70cm/yr, and that a mixing coefficient(D_b) is 14.01cm^2/yr (Table 2) and a mixed layer(L_b) shows in the upper 15cm. Therefore, the ratio(G) of mixing rate to accumulation rate is 1.65. Above data indicate that particle mixing is very small due to the fast rate of sediment accumulation, and where is well stratified deposit preserved (Fig. 5).

The Pb-210 profiles from the outer-shelf mud deposits (station CJ97005) is shown in figure 4. The Pb-210 data show a mixed layer in the upper 9cm of the core covering a region in which Pb-210 activity decreases logarithmically. The accumulation rate, sediment material flux and input of Pb-210 based on the decreasing Pb-210 activity between 11 and 25cm are 0.28cm/yr, 0.18g/cm^2 /yr and 0.63dpm/cm^2 yr, espectively, and that is lower than the inner shelf mud deposit (1.70cm/yr). The lower accumulation rate is due to lack of substance supply. At the station CJ97005 in the outer-shelf mud deposits, the calculated mixing coefficient (D_b) for the upper 9cm is 68.9cm^2 · yr, and net accumulation rate (S_d) is 0.28cm/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 (1.65). As the ratio of these factor (G) increases, sediment structure less distinct and the strata become more homogenous. The low sedimentation rate is likely to increase biological reworking, which in consequence induces the higher rate of biological mixing causing distruction of the original depositional structure[21]. The dominance of mixing(D_b=68.90cm^2/yr) relative low sediment accumulation(S_d=0.28cm/yr) is also exemplified of X-ray radiograph in the outer-shelf mud core samples CJ97005 which reveals relatively homogenous sedimentary structure without bedding(Fig. 6). In the modern muddy deposit area of the outer-shelf, physical effect was weak due to the influence of the Yellow Sea circulation [5]. Here, weak dynamics, small materials supply due to the far away from the river mouths, and slow sedimentation were favorable to the growth of benthic organism. Therefore, low energy disturbance dominated in the outer-shelf mud deposit.

Interpretation of sediment provenance from clay mineralogy

The relative abundance of clay minerals in the study area and adjacent regions are summarized in Table 3, which may help to understand and distinguish the sources of the sediments in the study area. The ancient and modern Huanghe River in China supplies relatively high concentration of smectite, with fewer amounts of kaolinite and chlorite, while the Changjiang River clay suites are distinguished by high concentration of kaolinite and minor amount of smectite. In case of the Yeongsan Rivera in Korea, smectite is nearly absent, but kaolinite and chlorite are dominant (Table 3). It implies that smectite in the East China Sea might not be provided from the Korean Peninsula. Instead, it seems to be mainly controlled by the ancient and modern Huanghe River system. The clay minerals of the outer-shelf mud deposit are characterized by abundant smectite (6%) and lack of kaolinite (10%), contrasted to those of the inner-shelf mud deposit (smectie; 4%, kaolinite; 13%, and a ratio of chlorite / kaolinite of 1.2). These values are similar to that of the Huanghe River and the central Yellow Sea sediments (Table 3). Milliman et al., [2] have suggested that the sediments supplied by Huanghe River are characterized by abundant smectite and chlorite, and a existence of calcite concretion. Because the most of Huanghe sediments are originated from the loess plateaus of northern China, contributed large amounts of calcite to the Huanghe. In addition, the ratio of chlorite/kaolinite ranges from 1.2 to 2.1. However, the sediment from Changjiang contain abundant kaolinite but devoid of calcite concretion, and with low ratio of chlorite / kaolinite (0.7).

Table 3: Relative clay mineral abundances of sediment in the East China Sea, and adjacent sea and rivers (unit: %).

Region	Smectite	Kaolinite	Chlorite	Illite	Chlorite/Kaolinite	Reference
Inner-shelf mud deposit	4	13	12	71	1.0	Present study
Outer-shelf mud deposit	6	10	12	72	1.2	
Huanghe River	23.2	8.4	9.2	59.0	1.1	Xu(1983)[22]
Ancient Huanghe River	24.0	8.9	8.1	59.0	0.9	Xu(1983)[22]
Changjiang River	5.9	14.3	13.1	68.4	0.9	Xu(1983)[22]
East China Sea	3.0	7.0	28.0	62.0	4.0	Aoki et al., (1983) [23]
Central Yellow Sea	13.0	10.0	12.0	67.0	1.2	Khim(1988)[24]
Keum River	0.1	17.0	19.3	63.7	1.1	Choi(1981)[25]
Yeongsan River	0.1	19.2	16.8	63.9	0.9	Kim(1980)[26]

Figure 7 shows X-ray diffraction pattern of untreated clay fraction from the inner-shelf mud near the mouth of the Changjiang River and the outer-shelf mud deposit to the southwest of the Cheju Island. The X-ray diffractogram of the outer-shelf mud deposit shows relatively sharp and strong peaks as well as quite apparent calcite at 3.04A of sample 97004 and 97005, and is similar to that of the sediments in the modern and ancient Huanghe River. Because the most of the Huanghe sediments are originated from the loess plateaus of northern China, contributed large amounts of calcite to the Huanghe. In contrast, the X-ray diffraction of the inner-shelf mud shows relatively low and broad peaks, and without any distinct calcite peaks at the station 97012 and 97013 (Fig. 7). The average content of kaolinite (12.5%) in the inner-shelf mud deposit is slightly higher than the outer-shelf mud deposit (10.4%), which is similar to the sediment in the Changjiang River.

CONCLUSIONS

Clay mineral variation, sedimentation rate by Pb-210 dating and X-ray radiographs for two recent mud deposits in the East China Sea have been investigated. The inner-shelf mud deposit consists of 8.9% of sand, 59.1% of silt and 32.1% of clay with an average phi mean size of 6.0φ,. The organic carbon content is low. The outer-shelf mud deposit is composed of 5.8% sand, 34.5% silt, and 59.6% clay with 8.3 φ, of mean grain size and also have higher water content and organic carbon. The C/N ratio showed higher in the inner-shelf mud (10.1) rather than that of the outer-shelf mud (8.7). The bimodal sediment encountered between the inner and outer shelf deposits are actively reworked. The sediment accumulation rate in the inner-shelf mud deposit is 1.70cm/yr and showing distinct horizontal stratification. The high rate of sediment accumulation and low rate of sediments mixing value (1.65) contributes to the preservation of primary sedimentary structure. The sedimentation rate in the outer-shelf mud deposit is 0.28cm/yr and showing homogenous sedimentary structure. The lack of sedimentary structure is explained by the rapid rate of particle mixing and the relatively low rate of sediment accumulation. The clay mineral in the outer-shelf mud deposit is predominantly of smectite followed by kaolinite, and the presence of calcite concretion indicates that it may have received influence from the ancient and modern Huanghe River system. The clay mineral in the inner-shelf mud deposits is primarily kaolinite and without calcite which is similar to the sediment of the Changjiang River.

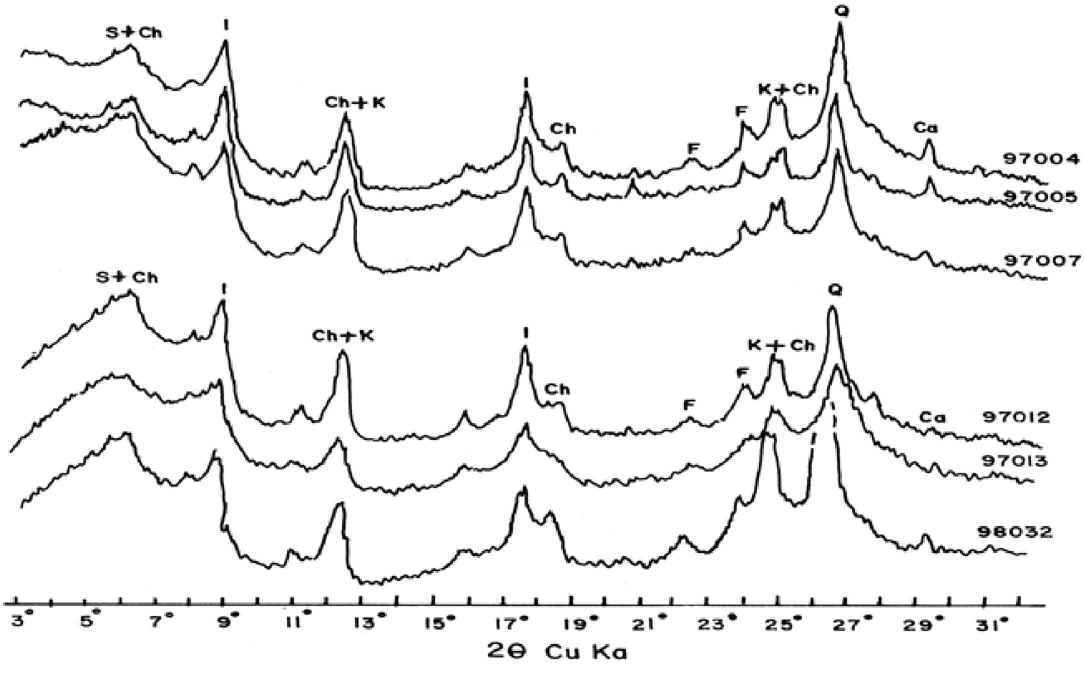


Figure 7: X-ray diffraction record of surface sediment on the East China Sea continental shelf.

Note; S=smectite, Ch=chlorite, I=illite, K=kaolinite, S+Ch=smectite+chlortie,

K+Ch=kaolinite+chlorite, F=feldspar, Q=quartz, Ca=calcite

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