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Distribution of Organic Carbon in the KEEP Area Continental Margin Sediments

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ABSTRACT

This study investigated the organic carbon and calcium carbonate contents in the continental margin sediments off northeastern Taiwan. The suspended particle concentration in the water column was also examined. The purpose of the research was to investigate the organic carbon distribution in sediments and its possible controlling mechanism. Results showed the organic carbon distributed in a zonation pattern. Lowest organic carbon concentrations were found in the shelf sediments while high concentrations were observed in the upper continental slope sediments. The results strongly indicated that the lateral particle transportation across the continental shelf was the controlling mechanism.

1. INTRODUCTION

The transport and fate of autochthonous organic material has become an important research topic since it was reported that a portion of the shelf-produced organic material was exported to the continental slope region (Walsh *et al.*, 1981; 1985 and 1988). Although the extent of such export requires further examination (Rowe *et al.*, 1986; Falkowski *et al.*, 1988), the tightly coupled cycle of production, consumption and deposition of autochthonous organic matter in the continental margin demonstrates its important role in determining the flux toward the open ocean.

The concentration of organic carbon in the surface sediments reflects a net result of physical, biological and chemical processes in the water column and sediments. The most important controlling processes include primary productivity, oxidation in the overlying water column (Suess, 1980), food web changes (Pace *et al.*, 1987), organic decay (Berger *et al.*, 1987), diagenetic utilization (Berner, 1980) and biological reworking in sediments (Aller and Mackin, 1984). In addition, Walsh *et al.* (1985) suggested that lateral particle transportation in the water column played a major role in determining the final fate for the organic particle.

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Walsh *et al.* (1988) and Biscaye *et al.* (1988) further confirmed that organic particle as well as inorganic particle were transported across the mid-Atlantic bight continental shelf and eventually deposited on the continental slope; in other words, the continental slope was an organic carbon depo-center. They indicated that fine-grained particles are the primary carriers for the heavy metals, radionuclides and other organic compounds. They further suggested that the preferential deposition of organic particle in the slope region may alter other geochemical processes, such as Mn (Bacon *et al.*, 1976) and nutrients regeneration (Martens *et al.*, 1989). With the exception of the northwest Atlantic continental margin, very few studies were conducted in resolving the organic carbon distribution, deposition and transportation in a regional scale. This paper attempts to examine the organic carbon distribution in the continental margin sediments northeast of Taiwan in order to better understand its deposition and controlling mechanism in general.

2. STUDY AREA AND METHODS

The study area, the continental margin northeast of Taiwan, was located between the East China Sea and Okinawa Trough. A surface cold water dome from the upwelling system northeast of Taiwan has been observed in the study area (Liu *et al.*, 1992; Fan, 1980). Fifty-three stations in the KEEP area were sampled. Sampling stations were shown in Figure 1. Station locations, overlying water depth, sampling device and core length were listed in the Appendix 1.

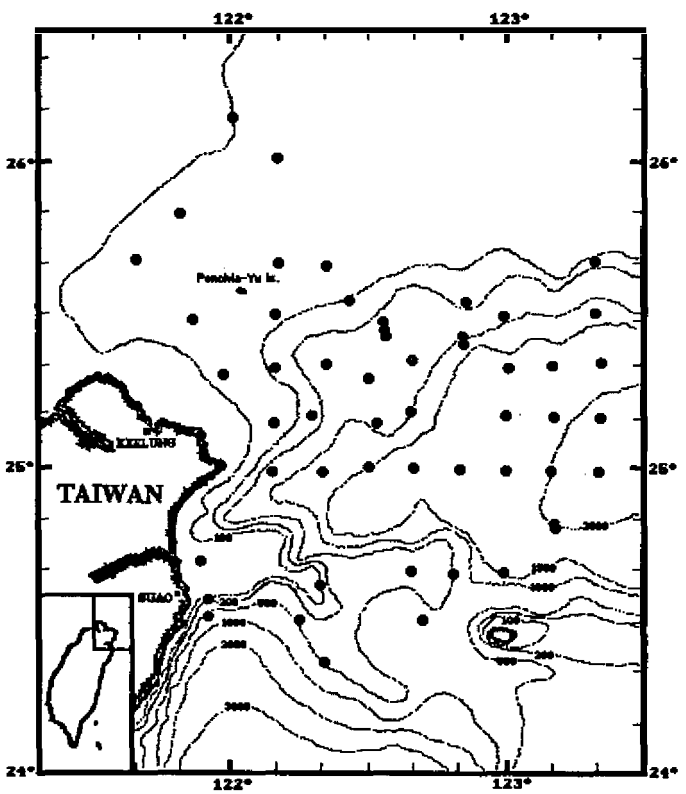

Fig. 1. Study area and sampling stations.

Sediment samples and suspended particles were collected on board R/V OR-I Cruises 249, 259, 276, 288, and 289. Most sediments were sampled using either box or piston core. Dredge-sampler was used in a few stations where traditional core devices failed to collect any sediment. Samples from the surface two cm were taken from each core. Sediments were processed and sectioned immediately after retrieving the core on board the ship. All sediments were stored frozen in polyethylene (PE) centrifuge tube for drying on land. Sediments were freeze-dried for one week using a Labconco Freeze-drier. Sediments were later ground to powder using an agate mortar and stored in polypropylene vials for further analysis.

Suspended matter and water samples were collected using Niskin bottles (2.5 L) on a CTD Rosette Sampler. Suspended matter was collected using on board filtration method (Manheim *et al.*, 1970). Sea water (2 L) was drained into PE bottles for filtration immediately after the sample was on board the ship. All sea water was filtered using Portics borosilicate glass filtration apparatus within an hour. Preweighed Nuclepore polycarbonate (PC) filter (0.45 μm, 47 mm OD) was used for the filtration. After filtration, the filter was rinsed several times ($\sim$ 15 ml x 3) with deionized water to remove any residual salt. The filters were stored in individual polypropylene petri dishes before and after filtration. Water was removed by equilibrating the wet filters to a constant weight in a drying-chamber for a month.

Organic carbon concentration was determined using a LECO Carbon Analyzer (WR 112) equipped with an infrared sensor and a high temperature inductive furnace. About 0.1 g of dried sediment was transferred to a ceramic crucible for the carbon determination. The inorganic carbon was removed by the addition of approximately 1 to 2 ml. of 1 N HCl until no more CO_2 bubble was visible. Sediment was combusted in the inductive furnace ($\sim$1700°C) after drying the acid in an oven at $\sim$50°C overnight. The evolved CO_2 was determined and calibrated using the carbon standards (LECO Standard 501-503). Unacidified sediment samples were analyzed for total carbon concentration. Calcium carbonate content was calculated by the difference between the total carbon and the organic carbon. The analytical precision is $\pm$0.006% for the total carbon and $\pm$0.025% for the organic carbon (Chang, 1990).

3. RESULTS

Organic carbon, calcium carbonate content and grain size data of the surficial sediment are given in Appendix 2. Organic carbon and calcium carbonate distributions of the study area are given in Figures 2 and 3.

The distribution of organic carbon was in a zonal pattern (Figure 2). Its concentration was lowest on the continental shelf, with an average of 0.19 wt%. Organic carbon concentration increased with water depth to $\sim$0.8% on the upper continental slope. At a greater depth, its concentration decreased to $\sim$0.50% on the lower continental slope. A similar zonal distribution pattern, i.e. higher concentration on the slope sediment, was observed on the mid-Atlantic bight sediments (Walsh *et al.*, 1985). Exceptions to this zonal distribution were observed in a few stations (open circle, Figure 2) where lower organic carbon contents were found, probably a result of sediment slumping. With the exceptions of these low organic carbon in some surface sediments, the organic carbon concentration rapidly increased from the surface low value to a relatively constant value at depth (Figure 4). Up to 91% of sandy sediments were observed at surface in Station 5130 and approximately 35% in the other two stations (Appendix 2). Below the surface sandy layer, both the sand and the organic carbon concentration returned to a relatively constant value. The source of sandy sediments was most likely a result of sediment slumping as observed from the 3.5 KHz echo sounding by Hong (1992). This coarse-grained sandy sediment acted as a diluting material for the observed lower organic carbon in the surface sediments.

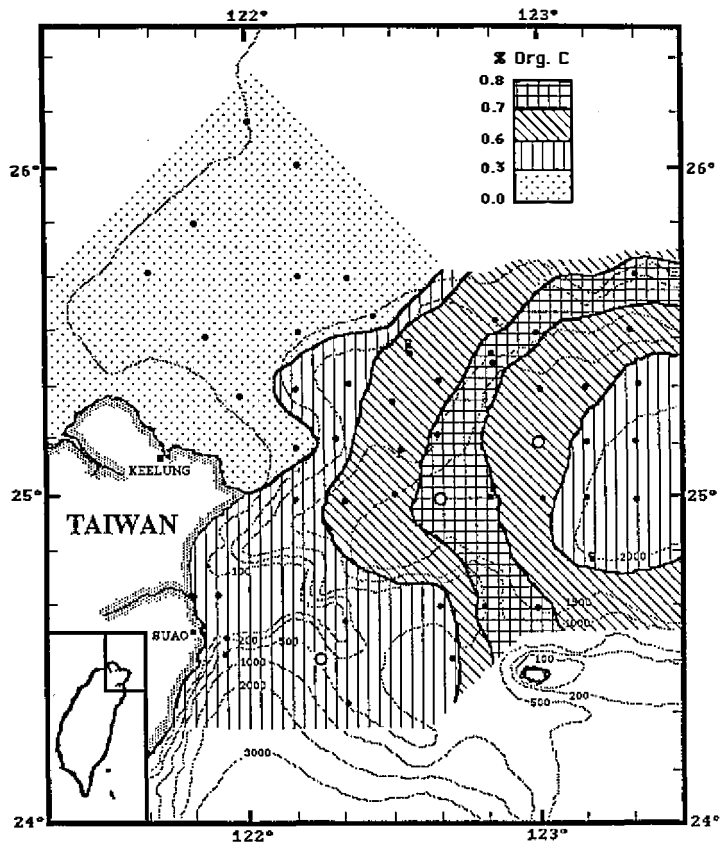

Fig. 2. Zonal distribution of the organic carbon (wt%) in the study area. Open circles represent station 4322, 5024 and 5130 from southwest to northeast. A layer of low organic carbon, coarse-grained sandy sediments were observed in these stations (see also Figure 4).

The distribution of calcium carbonate in the study region was highly concentrated near the Pengchia-Yu Island (Figure 3). More than 75% of calcium carbonate by weight was found near the island. Its concentration rapidly decreased radially to about 7% in the surface sediments on the continental slope. This high carbonate area was found underneath the upwelling cold water plume observed from the satellite sea surface temperature taken during the same sampling period (cf. Picture 10, RV OR-I-288, Shyu *et al.*, 1991). This localized carbonate distribution pattern may be related to the high primary productivity observed in the adjacent area (Hung *et al.*, 1980) as a result of upwelling nutrient rich water (Liu *et al.*, 1992).

Suspended particle concentration profile is presented in Figure 5. The range of suspended particle concentration is within 0.05-0.9 mg/L. It is much lower than the range reported for the East China Sea (Qin *et al.*, 1988; Tanaka et al., 1987; Milliman *et al.*, 1985 a and b). These concentrations were within the range reported for the mid-Atlantic bight (Meade

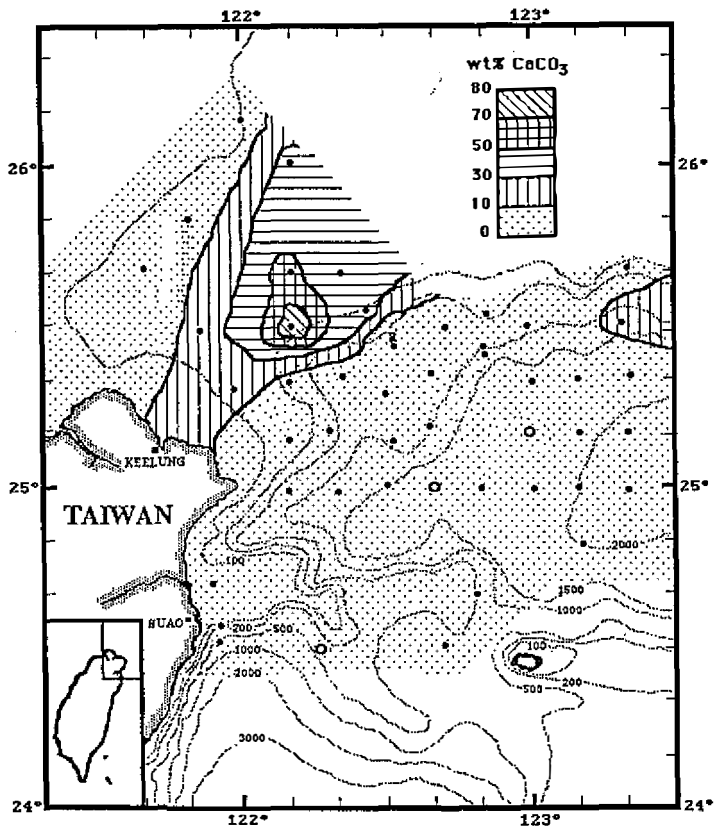

Fig. 3. Distribution of the carbonate content (wt%) in the study area.

et al., 1975; Manheim *et al.*, 1970) but higher than the subtropical western North Atlantic (Jacobs and Ewing, 1969) and lower than the east of Blake Plateau (Groot and Ewing, 1963). Low concentrations of suspended matter were observed in the upwelling water in Station 5422, an area near the cold water center observed from the surface temperature (Picture 10, RV OR-I-288, Shyu *et al.*, 1991). Total suspended matter concentrations attained higher values in water depth between 200-1000 meters and at a water depth of ~1200 m at Station 4531.

4. DISCUSSION

Based on the results, there are three major observations: 1) organic carbon concentration appeared in a zonal pattern, 2) organic carbon increased with depth with the exception of an enriched zone on the upper continental slope and 3) biogenic carbonate deposited mostly in an area under the upwelling center.

The distribution pattern is strongly grain size controlled as shown in Figure 6 where the concentration of organic carbon is positively correlated (linear correlation coefficient = 0.83)

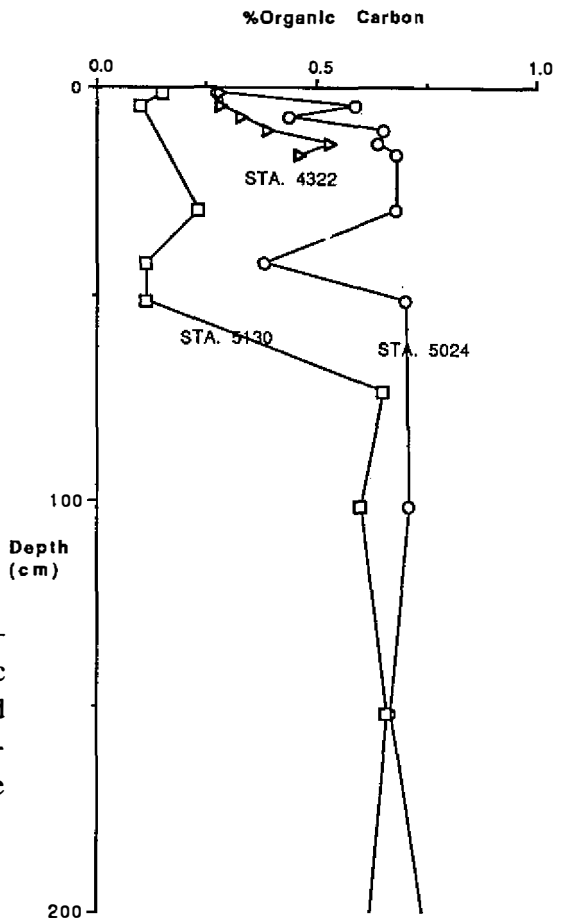

Fig. 4. Organic carbon profile for the stations with a layer of low organic carbon on the surface. A rapid drop in organic carbon concentration was observed near the surface in these stations.

with that of the fine-grained sediments ($\phi < 4$). This correlation of fine-grained sediment and organic matter has been well documented (Hennessee *et al.*, 1986; Doyle *et al.*, 1979; Heath, *et al.*, 1977). On the continental shelf, low organic carbons were found in coarse-grained sediments. Even though high primary productivity and concentration of particulate organic carbon was observed on the continental shelf (Hung *et al.*, 1980), the observed low organic carbon in the continental shelf sediments indicated that most organic material was either consumed or transported away from the region. The lack of fine-grained sediments on the continental shelf and the high suspended particle concentration on the continental shelf indicated that shelf area is a high energy environment as a result of strong mixing.

Decreasing of organic carbon concentration with increasing water depth is a result of: 1) the decreasing settling flux of particulate organic matter with depth (Suess, 1980), and 2) the longer residence time of deposited organic matter at the surface of slowly accumulating sediments allowing a greater degree of degradation (Bender and Heggie, 1984). If settling flux of particulate organic matter did indeed decrease with depth as suggested by Suess (1980), organic carbon would have been primarily deposited on the shallow continental shelf

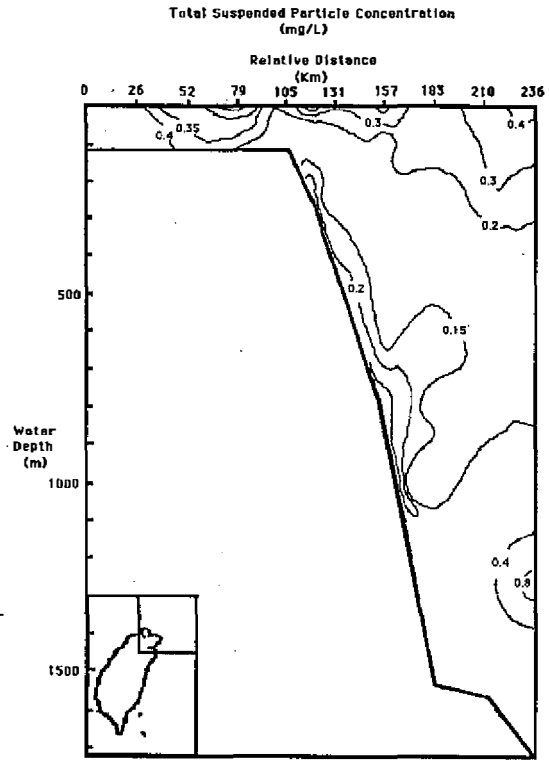

Fig. 5. Distribution of suspended material (mg/L) in a transect (P-Box, B transect) across the study area.

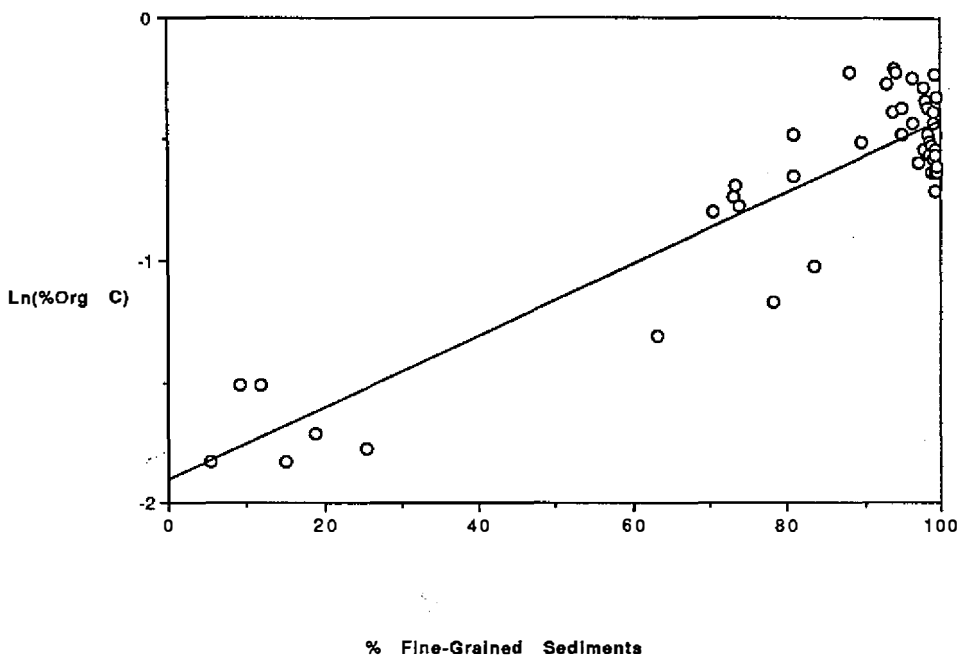

Fig. 6. The relationship between the organic carbon content and the fine-grained sediment (silt and clay). Good linear correlation coefficient (0.83) was found.

sediments as well as the upwelling area with higher primary productivity. However, such distribution pattern was not found in this study. In fact, higher concentration of organic carbon was found in the upper continental slope sediments. This observation indicated that organic matter was laterally transported from sources of continental shelf and region with high primary productivity.

Across shelf transport of suspended particle has been demonstrated by Narita *et al.* (1990) in a region near our study area. Based on their calculation, the time required for this across shelf transport is short, approximately 10 to 20 years, and a major fraction of the suspended matter was organic particle. In our data (Figure 5), a layer of high particle concentration was observed on top of the upper continental slope sediments, probably a result of the cross shelf transport. These particles may eventually deposit onto the continental slope where the environment is less energetic. As a result, organic carbon preferentially accumulated on the continental slope.

5. CONCLUSION

The results of this study show that the sedimentary organic carbon distributed in a zonation pattern in the study region. In addition, a high concentration of organic carbon was observed in the upper continental slope region. The observation of an organic carbon enrichment zone is not unique. However, the similarities in the organic carbon distribution between the East China Sea northeast of Taiwan and the mid-Atlantic bight suggested that a similar type of particle transport mechanism for the organic carbon and the inorganic suspended matter was the dominant factor which determines their final deposition on the continental margin in both environments. The local upwelling system may have supported strong biological activities in the region. Most fine-grained suspended particles that were formed on and introduced to the shelf and not consumed there were not deposited on the shelf. Deposition of the organic carbon and the fine-grained particle on the continental slope is probably a result of lateral particle transportation. They were transported across the shelf and deposited on the continental slope.

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Appendix 1. Station Id, location, overlying water depth, samplling device, and core length of all the sampling stations.

Station ID.	Station (Latitude) N	Location (Longitude) E	Water Depth (m)	Sampling Device	Core Length (cm)
4222	24°20.10'	122°20.20'	862	B	24
4320	24°33.43'	121°55.92'	115	G	31
4320	24°30.88'	121°55.54'	253	G	18
4322	24°30.05'	122°15.13'	381	G	18
4324	24°30.88'	122°40.01'	741	P	57
4415	24°41.16'	121°52.62'	58	B	16
4422	24°38.29'	122°19.83'	300	B	10
4424	24°40.08'	122°40.07'	700	B	24
4425	24°40.01'	122°49.88'	1111	P	515
4430	24°39.70'	123°00.65'	1320	B	18
4531	24°49.88'	123°10.16'	1680	P	503
4531	24°49.07'	123°10.67'	1646	B	18
5021	24°59.02'	122°11.70'	824	G	47
5022	24°59.68'	122°20.56'	1212	P	503
5023	25°00.89'	122°30.93'	1440	P	503
5024	25°00.30'	122°40.30'	1440	P	483
5025	25°00.29'	122°50.02'	1523	P	453
5030	25°00.33'	123°00.23'	1620	P	453
5031	25°00.05'	123°10.12'	1830	P	503
5032	25°00.17'	123°20.14'	2100	P	403
5121	25°09.97'	122°10.23'	189	G	Surface
5122	25°10.01'	122°19.87'	305	G	23
5123	25°08.06'	122°31.08'	974	P	353
5124	25°11.03'	122°40.61'	1303	P	503
5130	25°10.05'	123°00.03'	1702	P	353
5131	25°10.01'	123°10.17'	1762	P	403
5132	25°10.37'	123°20.16'	1774	P	503
5220	25°19.88'	121°59.41'	178	G	14
5221	25°19.83'	122°10.60'	380	G	15
5222	25°20.19'	122°20.27'	647	G	6
5223	25°19.97'	122°30.00'	574	G	31
5224	25°20.25'	122°40.10'	831	P	318
5225	25°24.47'	122°50.93'	898	P	503
5230	25°20.30'	123°00.01'	1630	P	353
5231	25°20.21'	123°10.74'	1140	P	503
5232	25°20.14'	123°20.22'	1428	P	503
5315	25°29.88'	121°50.58'	130	D	Surface
5321	25°29.69'	122°10.51'	137	D	Surface
5322	25°33.34'	122°24.77'	218	G	Surface
5323	25°27.78'	122°31.89'	485	G	37
5323	25°28.19'	122°31.98'	484	P	403
5323	25°28.10'	122°31.83'	490	B	24
5325	25°24.98'	122°49.92'	886	P	453
5325	25°31.50'	122°50.29'	1086	P	353
5330	25°29.66'	122°59.59'	786	P	480
5332	25°30.03'	123°19.68'	846	P	530
5414	25°40.08'	121°39.85'	130	D	Surface
5421	25°39.99'	122°11.05'	129	D	Surface
5422	25°39.08'	122°20.05'	110	P	203
5432	25°40.01'	123°20.16'	814	G	57
5515	25°50.14'	121°49.90'	121	D	Surface
6021	26°00.00'	122°10.00'	106	D	Surface
6120	26°09.50'	122°00.56'	101	G	15

Sampling Device
B:Box core G:Gravity core
D:Dredge core P:Piston core

Appendix 2. Organic carbon, wt% carbonate, and grain size of the study samples.

Station ID	%H20	%Org C	Wt%CaCO3	%Sand	%Silt	%Clay
4222	32.00	0.50	-	26.70	65.62	7.66
4320	31.95	0.48	4.22	26.76	34.26	38.97
4320	31.95	0.53	5.55	0.84	80.80	18.40
4322	31.66	0.23	19.07	-	-	-
4324	41.97	0.60	5.14	1.32	74.76	23.90
4415	24.00	0.45	2.00	29.54	63.56	6.88
4422	24.00	0.52	-	10.35	64.83	16.12
4424	34.00	0.58	-	2.09	81.58	16.34
4425	42.64	0.78	5.56	3.68	78.86	17.42
4430	49.00	0.80	-	11.81	77.95	10.14
4531	42.78	0.53	5.46	1.19	50.41	48.40
4531	40.00	0.59	-	1.17	86.09	12.72
5021	32.30	0.55	6.24	2.81	34.52	62.63
5022	36.28	0.62	9.56	1.62	25.81	72.57
5023	41.44	0.65	6.65	3.59	54.34	42.07
5024	28.29	0.27	11.52	36.70	36.54	26.76
5025	47.94	0.71	6.97	1.88	45.74	52.39
5030	44.86	0.62	4.87	5.50	48.14	46.81
5031	43.40	0.56	5.14	0.87	44.36	54.77
5032	26.70	0.36	9.73	16.36	60.07	23.57
5121	28.24	0.16	7.67	90.32	4.21	1.20
5122	31.12	0.49	9.79	0.65	77.96	21.39
5123	41.41	0.65	7.89	1.07	52.12	46.81
5124	42.09	0.72	8.12	0.54	71.26	28.19
5130	23.03	0.22	11.83	90.73	3.92	5.35
5131	45.42	0.53	8.49	0.59	17.82	81.59
5132	44.70	0.57	7.37	0.62	45.40	53.98
5220	19.51	0.17	19.20	74.54	11.90	13.57
5221	28.24	0.49	8.52	-	-	-
5222	27.20	0.46	10.38	26.77	53.19	20.77
5223	31.52	0.68	6.53	6.29	68.21	25.50
5224	36.05	0.62	8.14	18.97	37.96	43.00
5225	46.91	0.79	6.08	0.62	28.84	70.54
5230	44.02	0.58	7.17	0.82	58.67	40.51
5231	46.73	0.68	6.21	0.91	32.81	66.27
5232	44.70	0.57	7.53	1.34	66.83	31.82
5315	-	0.08	13.32	-	-	-
5321	28.90	0.22	75.48	88.10	1.52	10.38
5322	-	0.15	33.53	-	-	-
5323	31.52	0.54	9.24	0.50	55.79	43.72
5323	43.13	0.69	7.46	1.79	47.42	50.80
5323	45.06	0.76	6.53	6.95	7.97	85.08
5325	47.15	0.75	6.96	2.11	80.00	17.91
5325	40.32	0.60	9.81	10.39	34.05	55.56
5330	45.07	0.80	4.96	5.81	55.16	39.02
5332	42.08	0.69	14.56	5.01	74.64	20.36
5414	-	0.07	4.21	-	-	-
5421	-	0.31	58.93	21.77	47.38	30.85
5422	36.33	0.14	38.14	-	-	-
5432	35.19	0.81	7.79	6.12	64.16	29.72
5515	-	0.07	3.18	-	-	-
6021	-	0.18	38.14	81.06	8.56	10.38
6120	-	0.16	2.23	85.08	5.24	9.68

有機碳
在KEEP大陸邊緣地區沈積物內之分佈

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摘要

本篇論文在研究有機碳與碳酸鈣在台灣東北方大陸邊緣地區之含量，與此地區水體中所含有之懸浮顆粒含量。研究目的乃在探討有機碳之含量分佈與控制因素。研究結果顯示有機碳呈帶狀分布，大陸棚上有機碳含量最低而上部陸坡之沈積物則含有最高含量之有機碳。此種結果顯示顆粒橫向搬運是主要的控制機制。