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Composition and Texture of Surface Sediment Indicating the Depositional Environments off Northeast Taiwan

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ABSTRACT

Surfacial sediments of 27 piston cores, 14 gravity cores and 5 dredged samples were taken from an offshore area of northeastern Taiwan for delineating the depositional features beneath the Kuroshio Current and around the southwestern edge of the East China Sea. The turn of direction from the Kuroshio Current in this area has resulted primarily from the effect of an ascent of the seafloor. The China coast current has spread coarse sediment in the East China Sea, composed primarily of quartz, feldspar and mafic minerals toward the area of 26°N, 122°E. Fine sediments may, however, be distributed beyond the east of 123°E. Rock fragments and mafic minerals have been concentrated in the north of Taiwan, as delivered by the Kuroshio Current. Two upwellings have possibly deposited calcareous biogeneous materials on the seafloor: one being located at the south of the depositional boundary in which the sediments are derived from mainland China; and the other one being located at 25.6°N, 122.4°E just on top of the Lan-Yan Fan. In the Okinawa Trough, the sediments beneath the path of the main Kuroshio flow have been shown here to be composed of non-biogenic, fine-grained mud.

1. INTRODUCTION

The studied area is located at the junction of the Ryukyu arc-Okinawa Trough-East China Sea shelf (Figure 1). The Kuroshio Current intrudes into the brackish sea water at the southeastern edge of the East China Sea off northeastern Taiwan. The exchange of the sea water between the East China Sea and the Phillippine Sea, which occurs due to the mixing of the China coast current and the Kuroshio Current, is a very interesting topic for oceanographic study. The National Science Council of the Republic of China has assigned a five-year integrated program "KEEP" which stands for Kuroshio Edge Exchange Processes,

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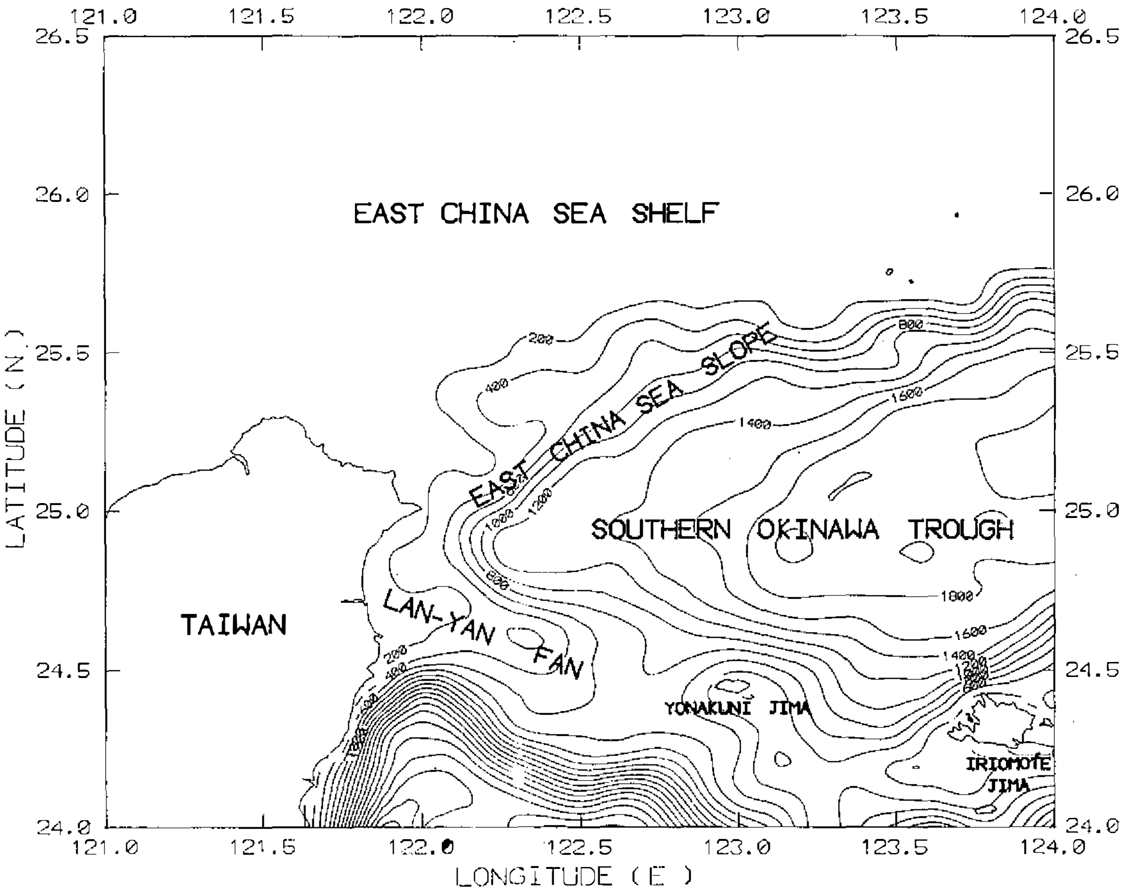

Fig. 1. Seafloor bathymetry and physiographic provinces off NE Taiwan.

its purpose to completely study this area with the methods of physical, chemical, geological and biological oceanography (Chen, 1991). This 5-year program started in 1989. The grain size distribution, carbonate content and mineral compositions have been attempted to be used here in the sand of surface sediments in delineating the depositional features. The strong Pacific tropical current "Kuroshio" not only flows over the complex topography in the northeast Taiwan offshore area. It also changes its direction from NNE toward ENE. The China coastal current comes from the East China Sea and mixes with the hyposaline water (less than 30%) in the highly saline sea water of the Kuroshio Current (more than 34%) (Chu, 1971, Fan, 1985). A permanent upwelling center of Kuroshio subsurface water is also shown by the hydrographic surveys to exist above the shelf break in the northeast offshore area of Taiwan (Chern and Wang, 1990). The area under study is also a famous fishing ground near Taiwan.

Four seafloor physiographic provinces are recognized in this junction of an island arc-back arc basin-continental terrace. From a north to south direction, they are the East China

Sea Shelf, East China Sea slope, southern Okinawa Trough and Lan-Yan Fan (Figure 1). Lan-Yan Fan is a submarine fan on which the sediments are primarily derived from the Lan-Yan River which is the largest river in northeastern Taiwan. The sediments on the part of the studying area have been previously studied by Boggs *et al.* (1974, 1979), Chen & Kuo (1980), Lin & Chen (1983), Chou (1972). Those sediments are mostly composed of biogeneous fragments, coarse and medium sand on the continental shelf and slope, whereas on the southern Okinawa Trough the deposits are mostly clay. The mineral components of these coarse sediments primarily come from mainland China and the Ryukyu islands. The Kuroshio Current, besides being the source of these sediments, is an important agent in influencing the grain-size distributions on the seafloor off northeastern Taiwan. The previous studies were, nevertheless, too broad. Their samplings were also not intensive enough. Intensive sediments had been taken in the area where the Kuroshio changes direction during this investigation. This was done in the hope that the distribution of superficial deposits affected by the Kuroshio Current could be understood.

2. MATERIAL AND METHODS

Sediments of 27 piston cores, 14 gravity cores and 4 dredged sediments were collected on board of the R/V Ocean Researcher 1 during cruises 249 and 259 of August and October, 1990. The locations of these samplings are shown in Table 1 and Figure 2. The mean grain size, standard deviation, sand content, sphericity, roundness, rock fragment content in sand, quartz content in sand, biogenic content in sand and carbonate content of 41 samples were employed for Q-mode factor analysis, as they have been dominantly associated with the source area and transported agencies around the Taiwan offshore area (Chen, 1981; Chen, *et al.*, 1988). The samples of OR249-26, 27 and OR259-17, 18 lacked shape and composition measurements due to the quantities of their sand grains being too small to count.

Grain sizes were determined for each of the studied sediment by separating the sand-size fraction by wet sieving and the silt and clay size fraction by pipette analysis. Sodium hexametaphosphate was used for the dispersed medium. A complete discussion of this technique has been provided by Folk (1974).

Determination of the carbonate content in the samples was made according to the weight loss method outlined by Molnia (1974). The salt in each sample was, however, washed out by distilled water before the carbonate material was dissolved by 1N hydrochloric acid.

Shape analysis of sphericity and roundness followed Wadell (1932) and Pettijohn (1949). A 300 specimen count has attained a 95% confidence level on the 1% portion of the total population, on the basis of statistical confidence provided by Shaw (1964). Sand was therefore divided into approximately 300 pieces of grains through use of a bi-separator based on coarse, middle and fine sand, etc. This was done in order to measure the sphericity, roundness and composition of each sample.

Grains of coarse sediments were examined through means of a stereotype microscope in determining their rock and mineral compositions. The details were difficult to examine due to the varying thickness of the grains. The composition has therefore been grouped into rock fragment, quartz, feldspar, mafic minerals, biogeneous remains, and others that have been difficult to identify and some sheet-size minerals. The relative abundance of these components in sand samples was established by a petrographic examination of at least 300 grains in each sample.

Table 1. Sampling number, location and water depth

Station NO.	Latitude (N)	Longitude (E)	Sampling Type	L. of Core (cm)	Water Depth (m)
OR249-1	25°40.20'	122°59.96'	PISTON	44	183
OR249-2	25°40.01'	123°20.16'	GRAVITY	31	184
OR249-3	25°29.66'	122°59.59'	PISTON	450	786
OR249-4	25°24.98'	122°49.92'	PISTON	500	886
OR249-5	25°30.20'	122°30.01'	GRAVITY	18	415
OR249-6	25°20.25'	122°40.61'	PISTON	300	831
OR249-7	25°20.30'	123°00.01'	PISTON	500	1330
OR249-8	25°10.01'	123°10.17'	PISTON	450	1762
OR249-9	25°10.05'	123°00.03'	PISTON	450	1702
OR249-10	25°11.03'	122°40.61'	PISTON	400	1303
OR249-11	25°08.86'	122°31.08'	PISTON	FEW	974
OR249-12	24°40.01'	122°49.88'	PISTON	550	1111
OR249-13	24°41.60'	121°51.70'	PISTON	57	52
OR249-14	24°30.31'	122°40.62'	GRAVITY	31	776
OR249-15	24°33.43'	121°55.92'	GRAVITY	FEW	115
OR249-16	24°59.02'	122°11.70'	GRAVITY	FEW	824
OR249-17	26°09.50'	122°00.56'	DREDGED	FEW	101
OR249-18	26°00.00'	122°10.00'	DREDGED	FEW	106
OR249-19	25°39.99'	122°11.05'	DREDGED	FEW	129
OR249-20	25°19.83'	122°10.60'	DREDGED	FEW	380
OR249-21	25°09.97'	122°10.23'	GRAVITY	FEW	189
OR249-22	24°30.40'	122°15.58'	GRAVITY	FEW	345
OR249-23	25°33.34'	122°24.77'	GRAVITY	FEW	218
OR249-24	25°30.03'	123°19.68'	PISTON	530	846
OR249-25	25°26.69'	122°10.51'	DREDGED	FEW	137
OR249-26	25°21.05'	122°39.73'	GRAVITY	9	754
OR249-27	25°19.97'	122°30.00'	GRAVITY	31	574
OR259-1	25°00.29'	122°50.02'	PISTON	450	1523
OR259-2	24°59.68'	122°20.56'	PISTON	500	1212
OR259-3	25°00.89'	122°30.93'	PISTON	500	1440
OR259-4	25°00.30'	122°40.30'	PISTON	480	1400
OR259-5	25°00.33'	123°00.33'	PISTON	450	1620
OR259-6	25°00.05'	123°10.12'	PISTON	500	1830
OR259-7	25°00.17'	123°20.14'	PISTON	500	2100
OR259-8	25°10.37'	123°20.16'	PISTON	500	1774
OR259-9	25°20.77'	122°21.84'	GRAVITY	FEW	820
OR259-10	25°24.47'	123°50.93'	PISTON	500	1798
OR259-11	25°20.21'	123°10.74'	PISTON	500	1140
OR259-12	25°20.14'	123°20.22'	PISTON	500	1428
OR259-13	25°24.02'	122°42.38'	PISTON	350	760
OR259-14	25°31.50'	122°50.29'	PISTON	350	586
OR259-15	24°49.88'	123°10.16'	PISTON	500	1680
OR259-16	25°19.88'	121°59.41'	GRAVITY	14	178
OR259-17	25°27.78'	122°31.89'	GRAVITY	37	485
OR259-18	25°10.01'	122°19.87'	GRAVITY	23	305
OR259-19	26°00.27'	121°58.55'	PISTON	103	108

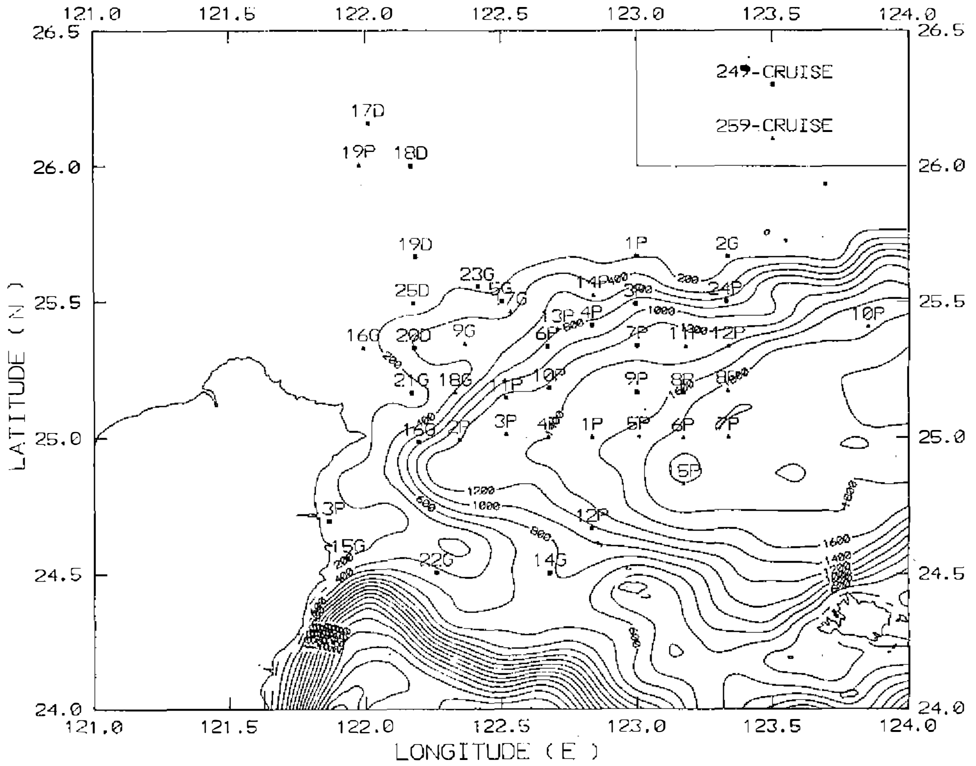

Fig. 2. Sample site map showing location of dredged samples (D), gravity cores (G) and piston cores (P) collected during the cruises of OR249 (square)and OR259 (triangle).

3. RESULTS AND DISCUSSION

3.1 Grain Size Distribution

The grain size of sediment on the northeastern Taiwan offshore area is shown in Table 2 and Figure 3. The grain size of sediment displays a general pattern of a coarser size in shallow water and a finer size in deep water. The sediments on the shelf are mainly composed of sand and clayey silt. The size of sediment on the East China Sea Slope ranges from sand to silty clay. The size of sediment in the Okinawa Trough ranges from sand-silt-clay to clay. The sediments on the Lan-Yan Fan vary from sand to silty clay (Figure 3).

The content of sand in the southern Okinawa Trough has been found here from the sand content contour map of the superficial deposits (Figure 3) to be the smallest (< 5%); its content increases toward the slope area. The content of sand reaches as much as 93.5%

Table 2. Grain size distribution of surface sediment of OR249, OR259

Station NO.	Mean Size (Ø)	STD (Ø)	Skewness	Kurtosis	Median (Ø)	Sand Content	Silt Content	Clay Content
OR249-1	6.76	2.68	0.40	0.84	6.14	13.57	56.28	30.15
OR249-2	4.14	1.68	0.58	8.79	4.00	67.73	22.25	10.03
OR249-3	6.64	3.04	0.70	0.57	4.98	33.00	25.71	41.29
OR249-4	5.92	2.79	0.70	0.73	4.48	43.65	28.26	28.09
OR249-5	7.22	3.27	0.65	0.68	5.50	13.57	48.99	37.45
OR249-6	7.19	3.04	0.22	0.69	6.77	26.77	35.79	37.45
OR249-7	7.82	2.90	0.24	0.73	7.34	0.82	58.67	40.51
OR249-8	10.08	2.38	-0.30	0.89	10.37	0.59	17.82	81.59
OR249-9	9.56	2.56	-0.13	0.84	9.59	1.13	23.07	75.80
OR249-10	7.43	2.69	0.31	0.98	6.86	4.65	62.36	32.99
OR249-11	8.32	2.60	0.21	0.94	7.86	1.07	52.12	46.81
OR249-12	7.92	3.51	-0.22	0.56	8.60	30.86	11.22	57.92
OR249-13	8.90	2.33	0.14	0.89	8.54	1.07	38.67	60.25
OR249-14	6.65	2.95	0.21	0.80	6.34	30.16	38.29	31.56
OR249-15	7.44	3.15	0.18	0.65	7.09	26.77	34.26	38.97
OR249-16	3.21	0.89	0.41	6.02	3.21	93.58	1.58	4.85
OR249-17	2.58	2.49	0.20	1.73	2.83	85.08	5.24	9.68
OR249-18	2.22	2.69	0.95	1.81	0.99	81.06	8.56	10.38
OR249-19	6.83	2.94	0.49	0.71	5.83	21.77	47.38	30.85
OR249-20	2.96	1.71	0.47	6.21	2.88	90.32	2.19	7.49
OR249-21	6.76	4.02	0.13	0.76	6.24	35.95	29.60	34.46
OR249-22	2.28	1.32	-0.03	1.15	2.56	94.30	1.25	4.46
OR249-23	7.97	3.40	0.06	0.84	7.60	14.01	41.56	44.43
OR249-24	4.71	2.44	0.64	3.02	3.95	67.73	16.89	15.39
OR249-25	2.01	2.50	0.88	2.04	1.16	88.10	1.52	10.38
OR259-1	8.75	2.72	0.15	0.77	8.27	1.88	45.74	52.39
OR259-2	9.21	3.00	-0.33	0.64	9.99	1.62	25.81	72.57
OR259-3	8.09	2.82	0.24	0.73	7.49	3.59	54.34	42.07
OR259-4	6.27	2.76	0.74	0.76	4.72	36.70	36.54	26.76
OR259-5	8.14	2.75	0.13	0.77	7.81	5.05	48.14	46.81
OR259-6	8.82	2.66	0.17	0.76	8.35	0.87	44.36	54.77
OR259-7	6.25	2.71	0.70	1.15	5.02	16.36	60.07	23.57
OR259-8	8.89	2.54	0.22	0.69	8.37	0.62	45.40	53.98
OR259-9	6.07	2.50	0.58	1.16	5.29	26.77	53.19	20.04
OR259-10	9.60	2.32	0.02	0.65	9.43	0.62	28.84	70.54
OR259-11	9.46	2.38	0.12	0.60	9.15	0.91	32.81	66.27
OR259-12	8.85	2.92	-0.01	0.75	8.67	5.94	36.92	57.14
OR259-13	10.66	2.44	-0.56	1.38	11.28	6.95	7.97	85.08
OR259-14	8.49	3.20	-0.07	0.62	8.63	10.39	34.05	55.56
OR259-15	8.39	2.58	0.21	0.78	7.94	1.19	50.41	48.40
OR259-16	3.29	3.01	0.47	1.47	2.81	74.54	11.90	13.57
OR259-17	8.37	3.16	0.09	0.48	8.13	1.79	47.42	50.80
OR259-18	8.66	2.62	0.23	0.72	8.08	0.59	49.42	50.00
OR259-19	4.08	0.60	-0.37	1.51	4.25	25.47	72.48	1.79

on the middle slope (824m deep) at the site of OR249-16 which is located just at the northeast of the Taiwan offshore area (Figure 2). The Kuroshio Current changes its direction in that area and may possibly cause a counter-clockwise eddy (Chern *et al.*, 1990; Lin and Shyu, 1990) which would concentrate the sands into the sediment. The sand content on the shelf may vary from 21.8% to 88.1%. The coarsest grains are generally located in the area near 26°N, 122°E which is approximately 70 km away from the nearest shelf break (Figure 3). These virtually mud-free sandy shelf sediments have been indicated by previous studies to be related to the relict sediments (Boggs *et al.*, 1974, 1979; Chou 1972; Niino and Emery 1961).

Mud-free sands also occur on the top of the Lan-Yan Fan at the site of OR249-22 (345m deep). The Lan-Yan River discharges the debris sediment into the sea. Much fine sediment is, however, apparently wiped rapidly away by the Kuroshio Current. The Kuroshio Current sweeps the east coast of Taiwan with velocities that may exceed 100cm/sec at the surface and may extend to a depth of 500 meters with velocities of 30-40cm/sec persisting to a depth of 200 meters (Chu, 1971).

The silty sediment mostly covers the lower slope of the southern Okinawa Trough (Figure 3). The greatest silt content, 72.7%, in the superficial sediment is located on the East China Sea Shelf at the site of OR259-19. The clay content in the superficial sediment shows a similar pattern to the silt distribution (Figure 3). The most abundant clay content, 85%, is still located on the middle slope (760m deep) at the site of OR259-13. The silty size grains are primarily derived from mainland China and the clay deposits primarily come from Taiwan island (Figures 3b and 3c).

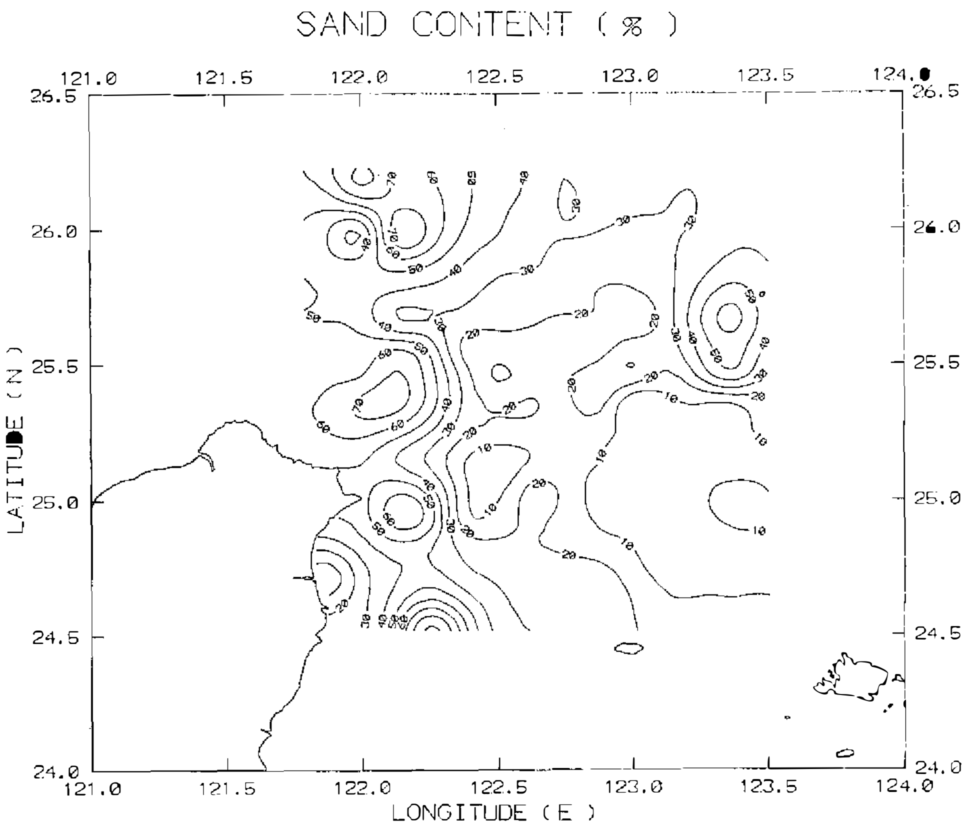

Fig. 3. (a) Distribution of sand.

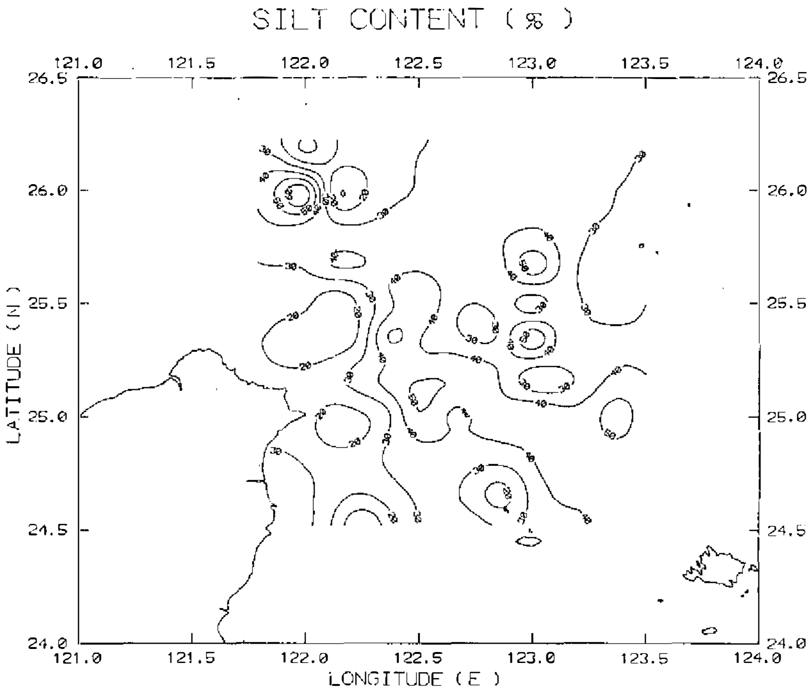

Fig. 3. (b) Distribution of clay.

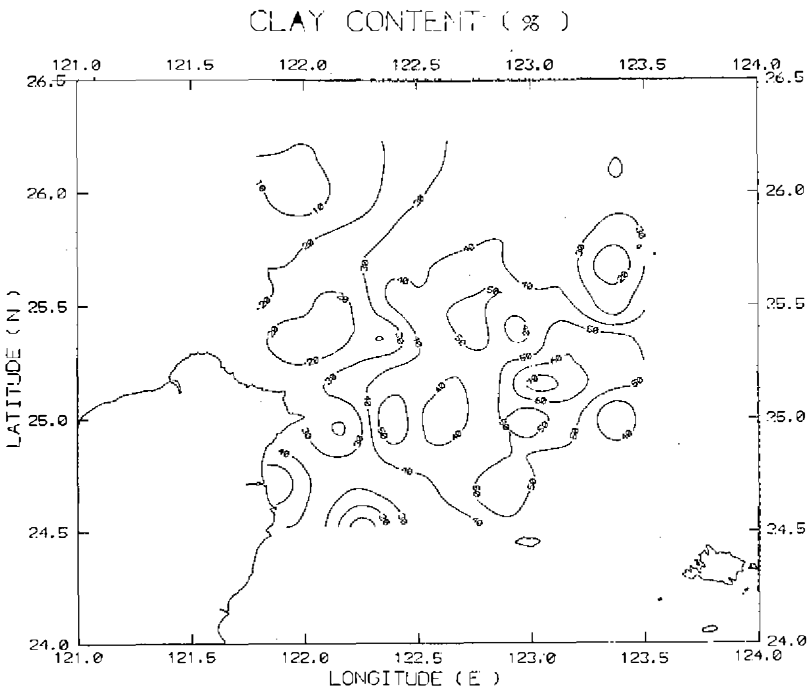

Fig. 3. (c) Distribution of silt.

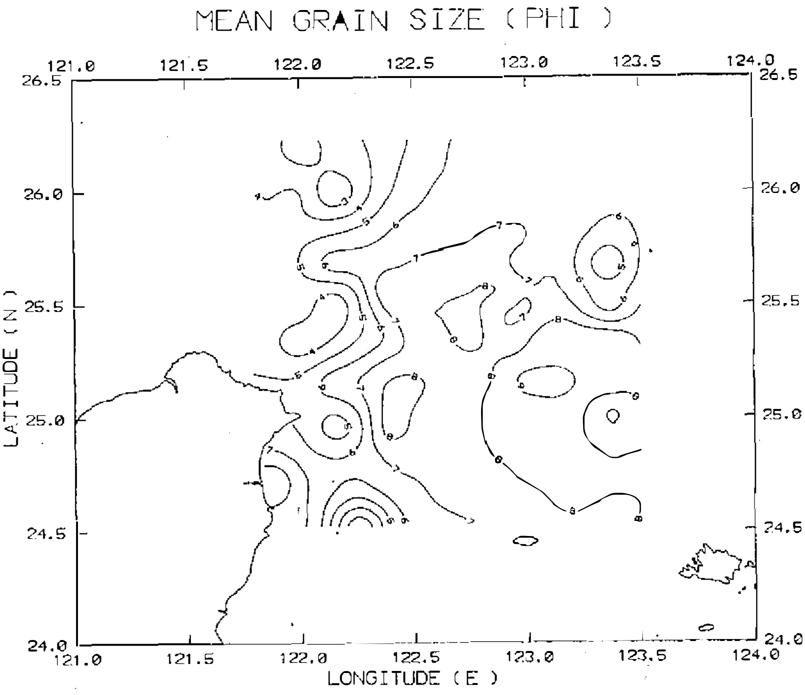

Fig. 3. (d) Distribution of mean grain-size in surface sediments off NE.

3.2 Grain Shape

Grain shape is generally represented by the sphericity and roundness of mineral grains and rock fragments. Shape of mineral grains is influenced by the crystalline structure, hardness, weatheredness, transportation process, depositional process, depositional environments, etc.

The values of sphericity of sand in the 41 superficial sediments are between 71 and 79 (Figure 4). The average value is 75.96 with a standard deviation of 2. The sources of these debris are simple and uniform in accordance with the variation of sphericity. The sphericities of sands are primarily dependent upon the mineral compositions and the content of biogenic remains. The forms of the sandy size grains are indicated by the sphericities in this study to be elliptical to slightly elongated because the surfacial sediments contain abundant rock fragments, quartz grains and erosed biogenic remains (Figures 6 and 7).

The index of roundness coming from these superficial sediments varies from 0.16, subangular grain, to 0.31 (Figure 4), subrounded grain; the average is only approximately 0.24. Most sediments deposited in the northeastern Taiwan offshore area have been indicated by the proportion of subangular and subrounded grains to have been transported a great distance. They have therefore become smoothed before deposition.

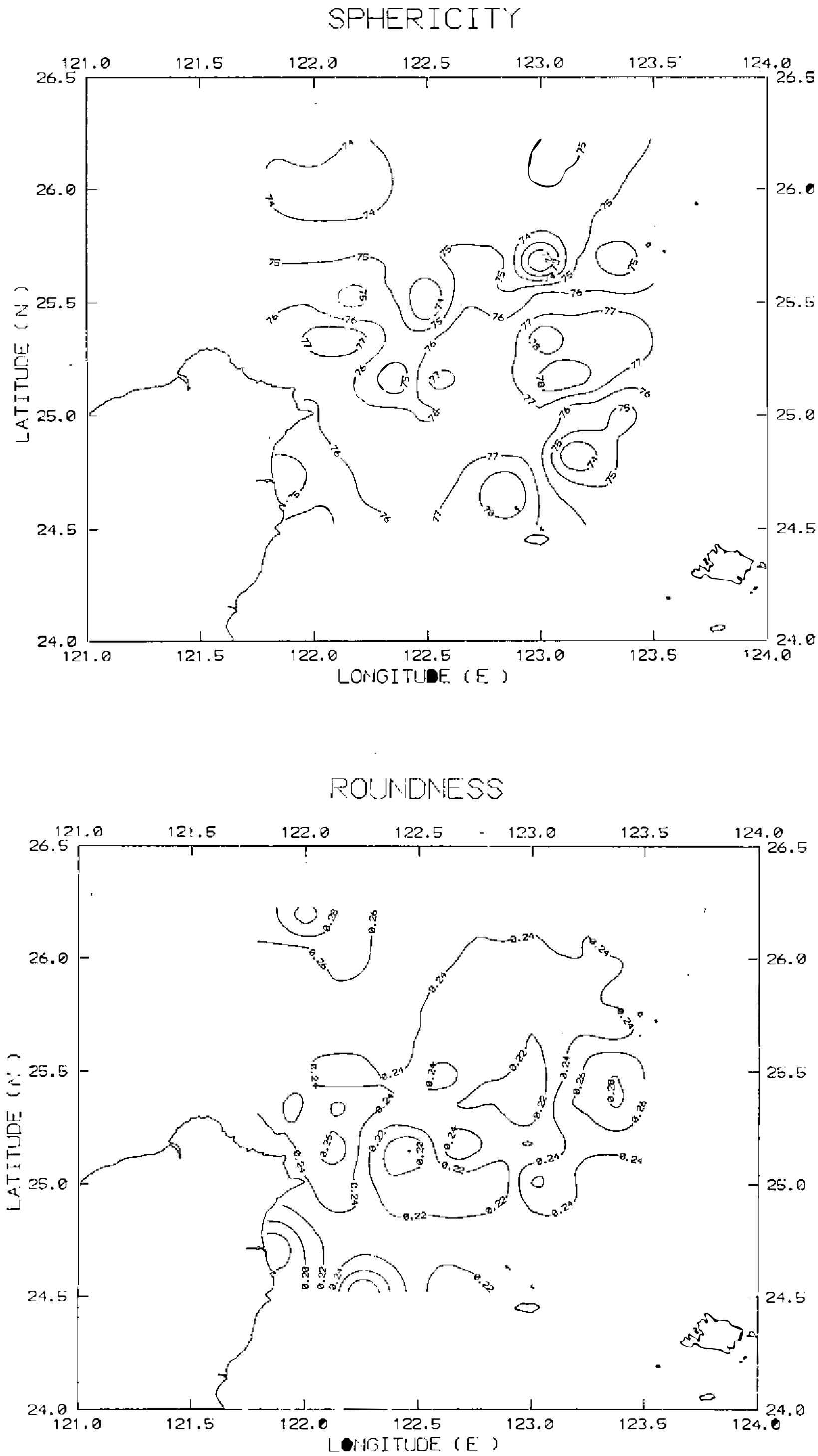

Fig. 4. Contour of sphericity (a) and roundness (b) of sand grain shape in surface sediments off NE Taiwan.

3.3 Carbonate Content and Biogenic Remains

The carbonate content distribution of 41 superficial sediments is illustrated in Figure 5. Sediment of more than 40% $CaCO_3$ content is found on the shelf, and are mainly composed of shell fragments. Calcareous shells make up approximately 5-89% of the samples examined; the average abundance is 26.6% (standard deviation 20%). Sediment that is predominantly mud also contains 25-40% $CaCO_3$ which is constituted of planktonic foraminifera and pteropod shells. The abundance of biogeneous remaining in each sample was counted in sand samples, and then normalized to the total weight of whole sediment. The distribution of biogeneous remains of sands in superficial sediments is shown in Figure 6. Shell material is most abundant on the shelf edge and upper slope. Shell abundance has been clearly indicated by a composition of Figures 3, 5 and 6 to be greatest in sandy bottom and shallow water areas. Biogenic shells and fragments make up from 0.67% (OR249-15) to 93.56% (OR249-23) of the sands. The former site is located just at the estuary of the Lan-Yan River and the

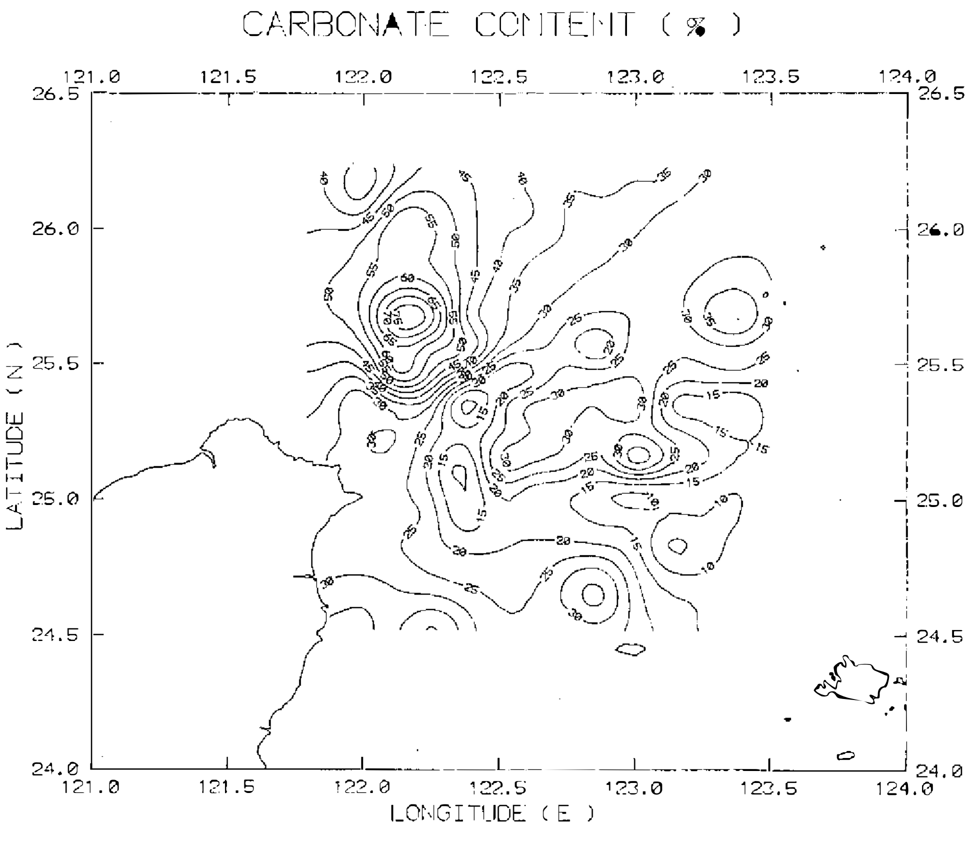

Fig. 5. Weight percent of carbonate material in surface sdiments off NE Taiwan.

latter site is located just below the shelf edge. The biogeneous remains primarily include mollusk shells and fragments, planktonic and benthonic foraminifera tests, pteropod shells, radiolarians, diatoms and siliceous spicules. Mollusk fragments are most abundant on the shelf and the uppermost slope. Both benthonic and planktonic foraminifera are abundant on the shelf edge and upper slope. The most abundant planktonic foraminifera appear on the Lan-Yan Fan at which there exists an upwelling on the southern slope. The greatest numbers of radiolaria and diatoms appear to occur on the shelf and upper slope northeast of Taiwan where the upwelling also frequently occurred.

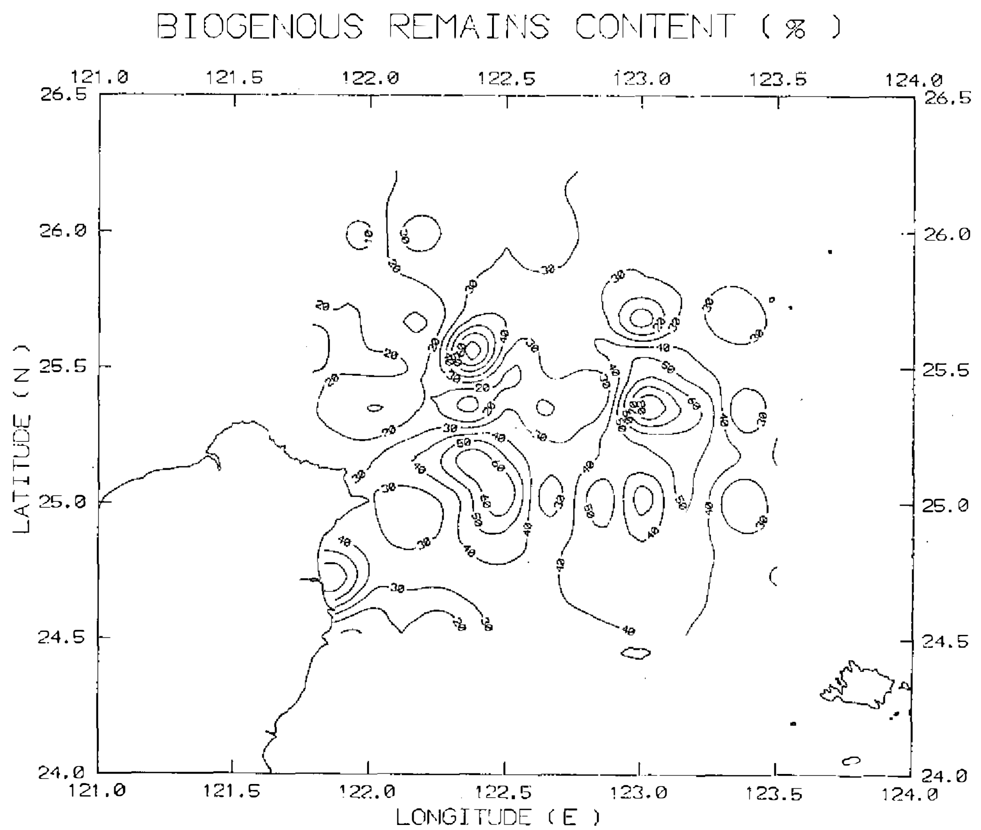

Fig. 6. Distribution of bigeneous remains in sands off NE Taiwan.

3.4 Mineral Composition of Sand

The other compositions of sand, beside the biogeneous remains, are also classified into rock fragments, quartz, feldspar, mafic minerals and others. The results are shown in Table 3. Biogeneous remains, rock fragments, quartz and feldspar are the dominant constituents of

Table 3. Carbonate content and the contents of biogeneous remains, rock fragments, quartz, feldspar, and mafic minerals in sands

Station NO.	Carbonate Content (%)	Biogenic Remains (%)	Rock Fragment Content (%)	Quartz Content (%)	Feldspar Content (%)	Mafic Minerals Content (%)	Others (%)
OR249-1	8.54	5.45	16.46	17.33	51.06	5.68	4.02
OR249-2	11.94	20.63	34.01	27.22	5.35	4.40	8.39
OR249-3	30.31	64.56	6.63	22.85	2.32	0.99	2.65
OR249-4	39.07	1.14	71.13	23.33	0.03	0.68	3.69
OR249-5	32.55	5.87	14.52	17.36	11.81	8.23	42.02
OR249-6	37.17	2.76	36.30	44.50	1.73	3.10	11.61
OR249-7	34.29	89.38	3.68	1.98	2.28	0.37	2.30
OR249-8	30.80	53.33	10.00	26.67	0.00	4.00	6.00
OR249-9	38.97	45.32	13.48	23.01	3.79	10.38	4.01
OR249-10	41.68	26.34	21.19	29.08	3.32	8.02	12.05
OR249-11	31.49	55.40	25.20	10.74	3.78	3.30	1.58
OR249-12	40.44	42.51	17.17	27.43	2.75	7.70	2.44
OR249-13	29.30	71.70	12.58	8.99	0.64	2.58	3.52
OR249-14	25.46	31.88	19.17	36.18	3.22	1.07	8.48
OR249-15	38.84	0.70	77.27	21.33	0.00	0.70	0.00
OR249-16	33.77	6.01	19.72	46.17	0.48	25.16	2.47
OR249-17	31.80	17.28	15.87	16.12	19.82	24.00	6.91
OR249-18	61.01	35.13	12.05	40.02	2.29	6.40	4.11
OR249-19	89.37	3.76	46.52	21.63	12.00	10.01	6.08
OR249-20	32.75	5.81	15.44	52.44	2.88	23.32	0.11
OR249-21	30.29	42.80	3.18	27.76	0.00	24.96	1.31
OR249-22	40.86	10.21	22.60	41.73	0.55	24.47	0.44
OR249-23	56.09	93.56	0.11	4.64	0.00	1.69	0.00
OR249-24	27.38	34.11	15.37	39.44	2.33	8.46	0.29
OR249-25	82.51	17.98	67.55	13.19	0.26	0.61	0.41
OR259-1	5.74	71.43	1.62	20.78	0.00	2.27	3.90
OR259-2	7.80	52.98	6.85	26.78	6.23	5.60	1.56
OR259-3	5.23	76.81	3.21	8.98	1.92	9.08	0.00
OR259-4	12.74	6.79	25.28	37.60	7.99	10.00	12.34
OR259-5	7.16	18.05	21.07	38.88	5.27	11.00	5.73
OR259-6	5.33	59.66	10.40	22.02	1.67	3.06	3.19
OR259-7	8.17	13.62	15.31	25.86	9.63	17.25	18.34
OR259-8	6.25	86.58	1.87	8.74	2.50	0.31	0.00
OR259-9	7.51	4.92	18.23	29.06	13.19	24.83	9.77
OR259-10	6.83	91.27	2.81	5.36	0.56	0.00	0.00
OR259-11	6.48	92.45	0.22	5.79	1.10	0.00	0.44
OR259-13	8.45	32.12	21.97	34.29	2.79	7.45	1.39
OR259-14	7.71	47.07	15.75	24.48	1.95	6.78	3.98
OR259-16	23.91	8.38	24.95	46.78	3.78	16.11	0.00
OR259-19	8.64	6.94	25.39	58.08	0.35	7.27	1.98

all sands. The relative proportions of these constituents vary in different physiographies in a manner that has a significance with respect to sediment sources and transportation agents. The geographic distributions of these constituents of sand are illustrated in Figure 7.

Rock fragments are common and abundant constituents of all shelf sands (Figure 7a). Metamorphic and sedimentary rock fragments are both abundant in sands off northeastern Taiwan, reflecting the dominant influence of the Paleozoic metamorphic and Cenozoic sedimentary formations in the northeastern Central Range. The abundance of sandstone clasts (20-30%) in all the East China Sea shelf sands (Figure 7a) have likely been derived from sedimentary formations existing on mainland China (Boggs, *et al.*, 1974; 1979).

Quartz is most abundant on the northern and northeastern East China Sea shelf and on the Lan-Yan Fan (Figure 7b). The quartz content may exceed 30% in these three areas. This distribution pattern indicates both Taiwan and China as sources of the quartz. Feldspar like quartz is most abundant in the northern and northeastern shelf, especially near the Tiaoyutai islands (Senkaku islands) (Figure 7c). Its distribution pattern also reinforces the possibility that the sands of this shelf are derived from two sources. Mafic minerals primarily include hornblende, augite, glauconite, chlorite and heavy minerals. Mafic minerals vary from total absense in the foraminifera ooze of the East China Sea slope to as much as 25% of the total constituents of shelf sands at the nearest site off northeastern Taiwan. Three abundant mafic mineral content areas, which are shown in Figure 7d, are related to different depositional environments. In the northern area about 26.2°N, 122°E, the mafic minerals are probably derived from the China coast current. The abundance of mafic minerals located at the northeast Taiwan offshore area, may possibly be concentrated by the loop current occuring beside the Kuroshio Current. The abundance of mafic minerals outside the Lan-Yan plain is possibly discharged by the Lan-Yan River.

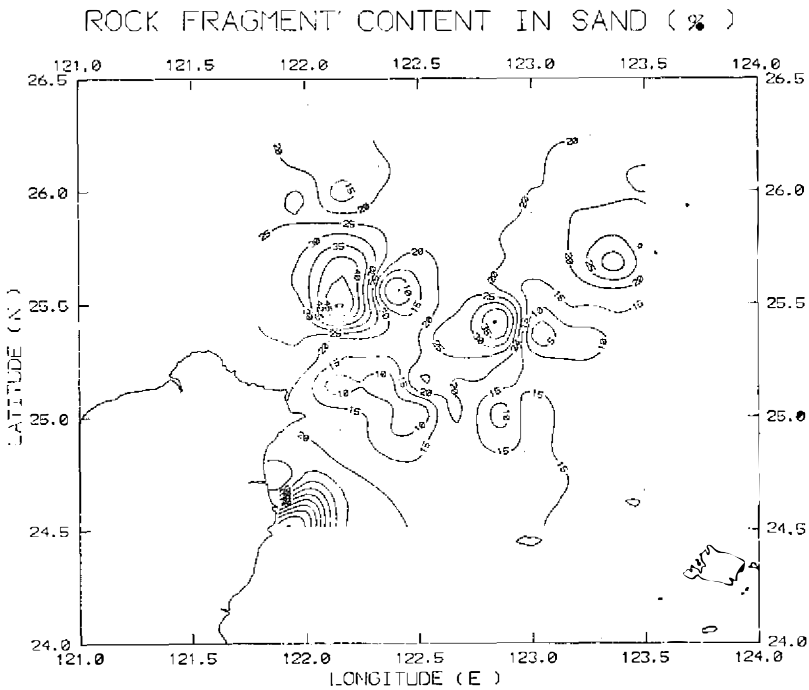

Fig. 7. (a) Distribution of rock fragment in sands off NE Taiwan.

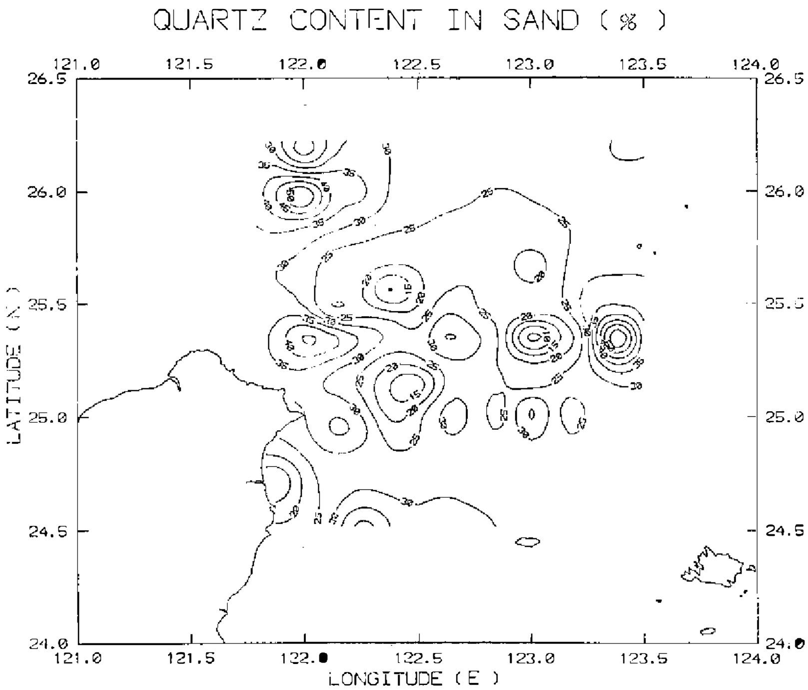

Fig. 7. (b) Distribution of quattz in sands off NE Taiwan.

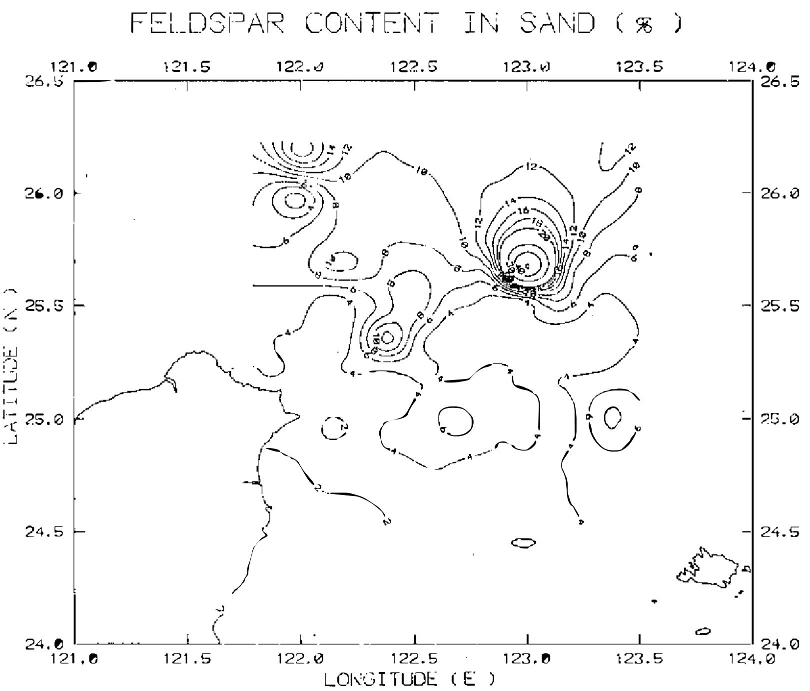

Fig. 7. (c) Distribution of feldspar in sands off NE Taiwan.

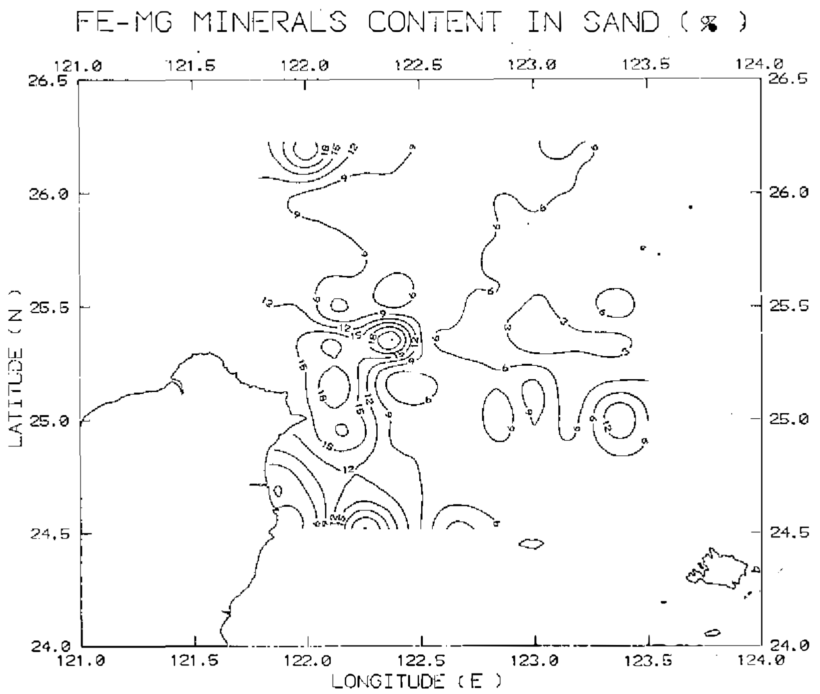

Fig. 7. (d) Distribution of mafic minerals in sands off NE Taiwan.

4. STATISTICAL ANALYSIS

4.1 Cluster Analysis

Nine elements including mean grain size, standard deviation of grain size, sand content, sphericity, roundness, rock fragment content in sands, quartz content in sands, biogeneous remains in sands and carbonate content of 41 samples have been used here for cluster analysis. These selected parameters are sensitive to the sediment sources and transportation agencies. The dendrogram of this analysis shown in Figure 8 indicates that the sediments at the northeast Taiwan offshore area can be divided into three groups. Group A shows 4.01 mean grain size, 69.55% sand content, 34.97% rock fragment in sands, 32.38% quartz content in sands and 42% carbonate content which may indicate the characteristics of shelf sediment. Group B shows 8.7 mean grain size, 4.81% sand content, 7.63% rock fragment content in sands, 14.78% quartz content in sands, 20.17% carbonate content which reveal typical characteristics of the sediment being deposited on the lower slope and in the Okinawa Trough. 7.10 mean grain size, 19.91% sand content, 19.01% rock fragment in sands, 35.18% quartz content in sands and 19.73% carbonate content of Group C may represent the mixing of shelf, slope and trough sediments. The distribution of these three groups of sediments in Figure 9 indicates that the Kuroshio Current may possibly prevent the eastward transportation of sediment from the eastern shelf of Taiwan. The change of direction of the Kuroshio Current in the East China Sea slope may possibly cause the mixing of shelf sediment down to the slope and the bottom of the trough.

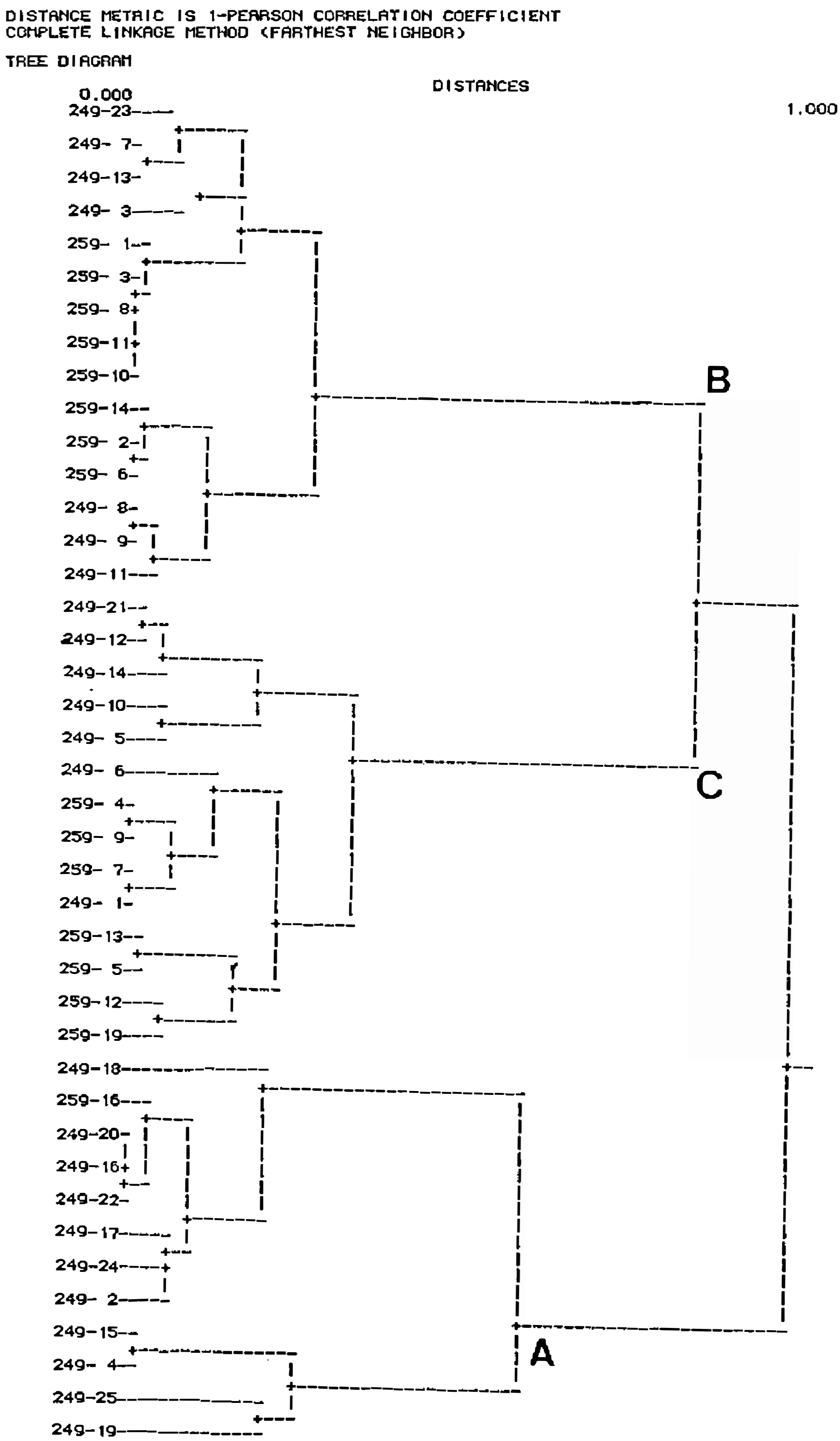

Fig. 8. Dendrogram of cluster analysis for 41 surface sediments. The variables of each sample are mean grain size, standard deviation of grain size, sand content, sphericity of sand grain, roundness of sand grain, rock fragment content in sands, quartz content in sands, biogeneous remains in sands and carbonate content.

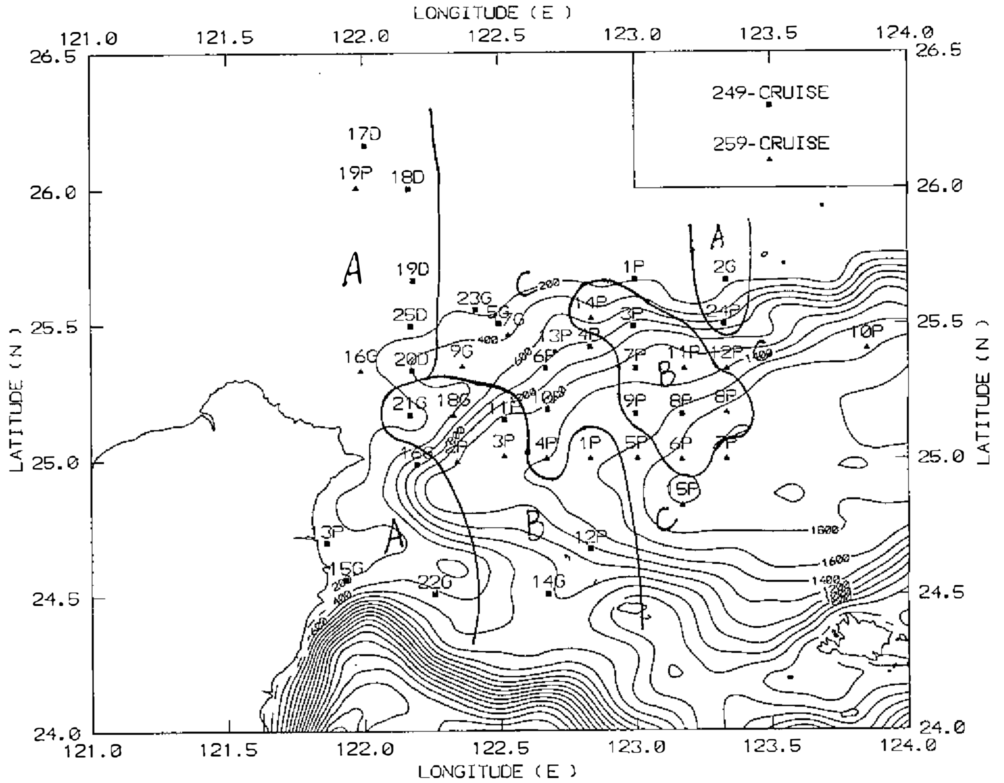

Fig. 9. Three provinces, A,B,C, off NE Taiwan from the result of cluster analysis. A: Terrigeneous Sediment Area; B: Pelagic Sediment Area; C: Mixing Sediment Area.

4.2 Factor Analysis

As previously done in the cluster analysis, nine elements are used for factor analysis. Three factors are chosen for this analysis. The main loadings of Factor 1 are rock fragment content in sands, - 0.8699 and carbonate content, -0.8031. The distribution of scores of Factor 1 in Figure 10a shows that two low score areas are only matched on the upwelling areas; one is located near 25.5°N, 122.2°E and the other is located south of the Lan-Yan River estuary. The low scores of Factor 1 are reasonably believed here to represent the upwelling effect. Factor 2 loadings are highly correlated with mean grain size (0.6608), standard deviation of grain size (0.642), sand content (-0.6822), roundness of sand grain (-0.6775) and quartz content in sands (-0.8005). A low score in Factor 2 shows a coarse grain size with a poorly sorted, abundant sand content and quartz content. The distribution of score of Factor 2 in Figure10b is similar to the distribution pattern of terrigeneous materials in sediment whether it is derived from mainland China or Taiwan island. Fine sediment on the East China Sea shelf shows little carbonate content, little rock fragment content and little quartz content in sands which are primarily discharged from the China coast current. These muddy sediments terminate at approximately 26°N 122°E. Factor 3 loadings are only correlated with sphericity (0.8616); the score distribution pattern is the same as that of sphericity alone (Figure 10c).

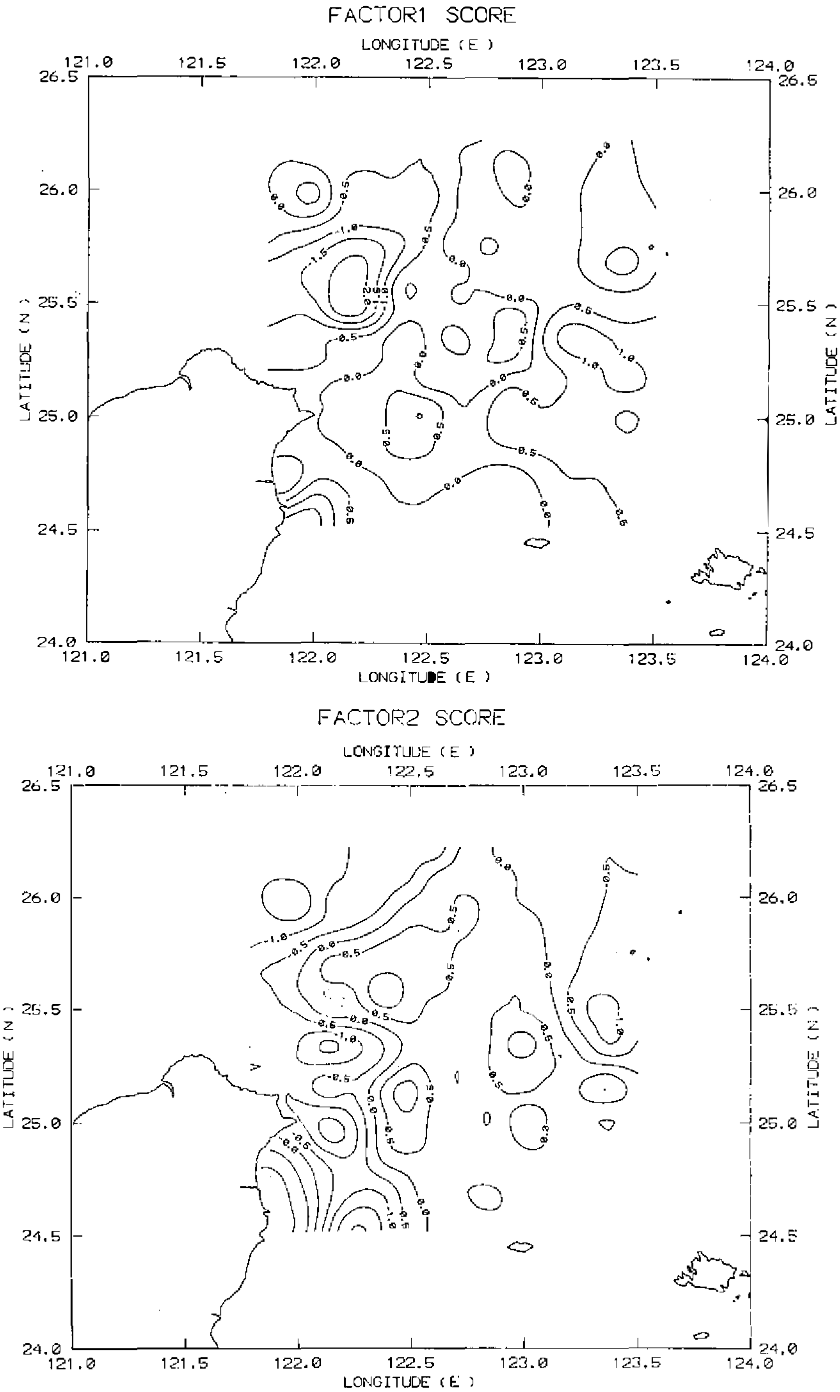

Fig. 10. Contours of factor scores resulting from factor analysis.

(a) Factor 1, the relative loadings are rock fragment content in sands, -0.8699; carbonate content, -0.8032. This factor represents the effect of upwelling.

(b) Factor 2, the relative loadings are mean grain size, 0.6608; standard deviation of grain size, 0.6420; roundness of sand grain, -0.6775; quartz content in sands, -0.8005;. This factor represents the distribution of terrigeneous sediments and main paht of the Kuroshio Current.

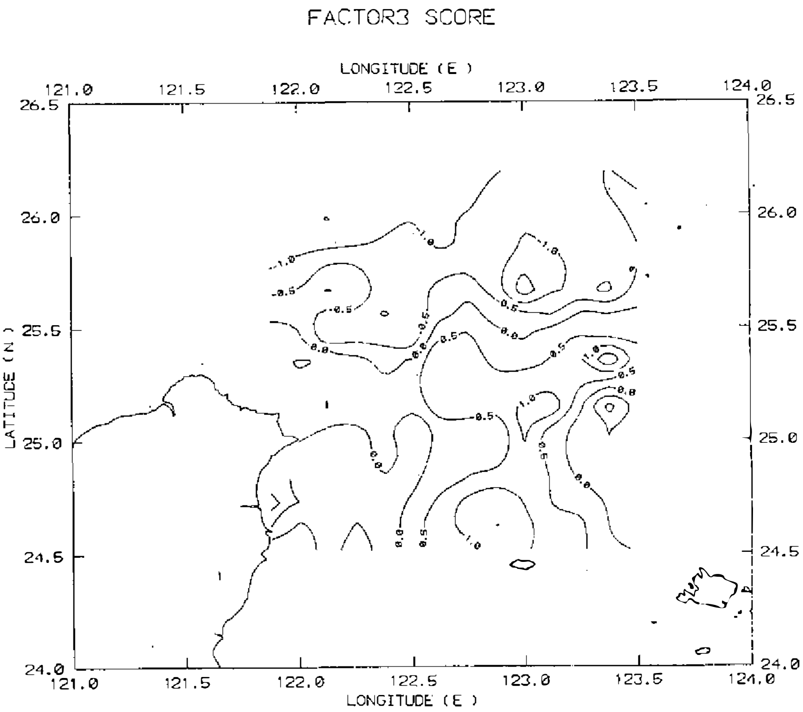

Fig. 10. (c) Factor 3, the relative loading is sphericity of sand grain only, 0.8616. This factor represents the grain shape distribution.

5. CONCLUSIONS

The distribution of superficial deposits is not only controlled by content and sort of the source materials. It is affected by transport agencies and depositional environments. Coarse sediments deposit close to their source, whereas the finer materials gradually deposit as the transport mechanisms decrease. Grain shapes change with time as the mechanism of transport changes. The better spherical and round generally reflects the grain shape, and the longer the process of transport. Analysis of grain shapes helps in investigating the course and history of deposits. The forces and processes of transportation can be recognized, in addition to identifying sources of deposits through the distribution of their composition which includes terrigenous debris, biogenic remains, quartz, feldspar and mafic minerals. Grain size, grain shapes and composition of deposits are therefore an important basis of study in the deposition environment and the process of transportation.

Sediments deposited on the East China Sea shelf are characteristic of coarse-grained, mud-free, high carbonate content and abundant shell fragment. These sediments have the same characteristics as the relict sediment previously reported by Niino and Emery (1961). The contents of rock fragments, quartz and feldspar in sands are high in the shelf. They decrease along the slope toward the bottom of the Okinawa Trough. The relict sediments with abundant shell fragments may extend their range down to the upper slope.

On the middle slope of the north sides of Okinawa Trough and on the Lan-Yan Fan, foraminifera tests are abundant in the bottom sediments which are associated with the topographic upwelling effect. The sediments containing a high rock fragment content in sands and high carbonate content are deposited just beneath the upwelling area. One is located at approximately 25.5°N, 122.2°E; the other is located on the Lan-Yan Fan (Figure 11).

The deposits in the southern Okinawa Trough are primarily clay sediments. Two patches of mixed sediments on the slope toward the bottom of the trough are probably associated with the effect of the Kuroshio Current changing direction. The loop current of Kuroshio may concentrate the mafic minerals along a narrow trough northeast of Taiwan (Figure 11). The Kuroshio Current has prevented the coarse sediments discharged from eastern Taiwan from being transported toward a deeper area in the Philippine Sea.

The sphericity of grain shape increases as the deposits travel farther from Taiwan. The examination of roundness of sands shows that the grain shape is mostly aubangular for the sediment derived from Taiwan; the shape reveals subrounded from mainland China.

Rock fragments and mafic minerals are derived primarily from Taiwan. Quartz and feldspar are abundant in the shelf sand which are primarily discharged from mainland China.

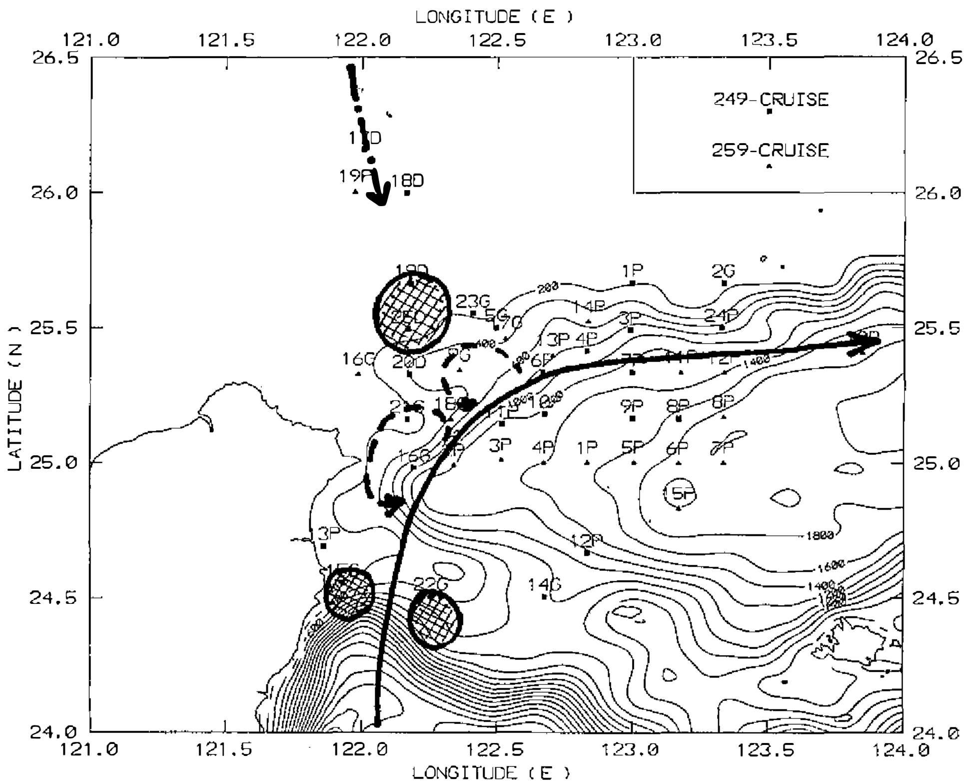

Fig. 11. Approximate path of the Kuroshio Current (←—), loop current(←--), China coast current(←•—); and sites of upwelling( ).

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台灣東北外海黑潮轉向區海床之表層沉積物所顯示之沉積環境

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摘要

從台灣東北外海黑潮轉向區（ＫＥＥＰ）之海床上所採集之４６個表層沉積物中之研究得出東海陸棚西南緣之黑潮轉向區的沉積環境和沉積現象。黑潮在此區之轉向主要是受到地形上升的影響。東海的中國海岸沿岸流所挾帶之富含石英、長石和鐵–鎂礦物的砂質沉積物，主要僅堆積到北緯２６度，東經１２２度附近，但泥質沈積可以越過１２３度。黑潮主流在台灣東北外海因地形的影響所產生的湧升流有二，一在蘭陽溪河口附近，一在北緯２５.６度，東經１２２.４度附近。湧升流之下的沉積物以富含岩石碎片及高碳酸鈣含量爲其特色。黑潮主流之下的沉積物中，生物殼體並不富集。東海陸棚上的湧升流與台灣之間，有一黑潮迴流所造成的富含岩石碎片和鐵—鎂礦物顆粒的砂質沉積帶。蘭陽溪所挾帶之陸源泥砂出海以後係往東南方向堆積在西北—東南走向的宜蘭海脊上。在黑潮主流下的沖繩海槽內之沈積是以非生物源的細粒泥質爲主。