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Geochemical Characteristics of the Continental Shelf and Slope Sediments off the Southeastern Coast of Korea

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한국 동남해역 대륙붕과 대륙사면 표층퇴적물의 지화학적 특성

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ABSTRACT

A total of 90 surface sediment samples, collected from the continental margin area bordering east and southeast coast of Korea, were subject to the geochemical analyses with the aim of filling the gap in our knowledge of this environment. The analyzed items included the major elements (Al, Fe, Mg, Ca, K, Na, P and Mn), organic carbon, and some trace metals (Ba, Co, Cu, Sr and Zn).

The sediment grain-size exerted a predominant influence on the contents of most elements, with the exceptions of Ca, K, Sr and Ba. The Ca and Sr contents, being closely interrelated each other, were mainly controlled by the calcium carbonate content. The K content, on the other hand, appeared to be influenced by both illite and feldspar. The Ba content showed a certain relationship with that of K, suggesting a common source of these two elements; potassium feldspar. The R-mode factor analysis result also reaffirmed the above-mentioned controlling factors on the sediment geochemistry.

The grain-size dependency of trace metals obscures their areal distribution pattern from the total contents. However, with the metal/aluminum ratios we could differentiate the subtle difference in the metal enrichment. Hence, sediments of the southern coastal area appear to receive some anthropogenic inputs of metals, though the effect is still negligible.

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요 약

우리나라 주변해역의 퇴적물에 관한 연구는 이제까지 퇴적학적 및 광물학적 측면에 집중되어 온 까닭에 그 지화학적 특성에 대해서는 알려진 바가 매우 제한되어 있으며, 특히 동해 대륙붕의 경우는 더욱 그러하다. 이와 같은 지식의 빈 틈을 채우기 위하여 한국 동남해역의 대륙붕과 대륙사면에서 채취된 90개 표층퇴적물을 대상으로 그 주성분원소와 수종의 미량성분들을 분석하였다. 이 분석결과를 바탕으로 이들 화학원소들의 분포양상과 그 분포에 영향을 미치는 여러 조절요인들이 논의되었다.

연구지역 퇴적물에서 화학원소들의 분포에 가장 큰 영향을 미치는 요인은 퇴적물 입도인 것으로 밝혀졌으며, Ca과 K를 제외한 대부분 주성분원소들과 Sr 및 Ba를 제외한 미량금속들의 함량은 모두 퇴적물의 입도와 밀접한 상관관계를 나타냈다. 반면, 퇴적물 내 Ca과 Sr의 함량은 주로 탄산염에 의해 조절되어지며, K의 경우에는 장석과 illite가 큰 영향을 미치는 것으로 여겨진다. 한편, K 함량과 어느 정도의 관련성을 나타내는 Ba의 경우에는 칼리장석의 영향이 중요할 것으로 사료된다.

분석된 화학성분들의 연구지역 퇴적물 내 함량은 모두 자연상태의 범위를 벗어나지 않는 것으로 판단되며, 그 공간적 분포양상은 대부분 입도분포나 혹은 탄산염분포(Ca과 Sr)의 그것과 거의 동일하게 나타난다. 한편, metal/Al 비율은 퇴적물 내 금속함량에서 입도의 영향을 보정할 수 있으며, 이 비율을 이용하여 연구지역 남부 연안역의 퇴적물에 미약하나마 인위적 오염의 가능성이 있음을 제시하였다.

INTRODUCTION

The narrow band of the continental shelf on the eastern side of the Korean Peninsula can be distinguished from the continental shelves of the western and southern coasts by its extremely limited supply of terrigenous sediments, a characteristic due mainly to the absence of large rivers flowing into its sea. Most of the sediments are supplied by coastal erosion or by coastal currents. The lack of recent sediment input in this environment has resulted in the development of relict sandy deposits on the outer shelf area, which is most widely distributed on the southern part of the study area.

In recent years, a great number of studies have been done on the surface sediments from this area (Choe, 1971; Park, 1985; Park and Choi, 1986; Choi, 1989; Lee et al, 1989; Park et al., 1990). Owing to these efforts the textural and mineralogical properties of the sediments are relatively well understood, as well as their areal distribution patterns. With the exception of Choe's study in 1971, however, very little attention has been given to the study of sediment geochemistry.

In order to fill this vacuum, the present study has conducted a series of geochemical analyses of the surface sediments, collected from the continental shelf and slope along the southwestern part of the East Sea (Japan Sea) and the northern part of the Korea Strait, in the period between 1985 and 1987. The study aims to observe geochemical characteristics of the sediments and bring to light their spatial distribution pattern. It attempts at the same time to understand the environmental factors which affect the geochemistry of the sediments in the area.

THE STUDY AREA

Physiography

The slim band of the continental shelf of the East Sea is developed in the northern part of the Kampo area. It has a width of about 10-20km and an average slope of about 0.44° (0.3-2.4°), which, compared to the world average, makes it an extremely narrow and steep shelf. Along the shelf break, situated in the depth of 130-150m, the continental shelf turns into a continental slope, which falls relatively steeply at 1.7-5.0°. But at the depth of 1100-1500m, it becomes more level and merges with a deep basin of the East Sea, the Ulleung Basin.

One of the notable topographic features is the presence of a basin and bank morphology (Hupo Basin and Hupo Bank) near the middle part of the study area. The bank is developed in the north-south direction, with a total length of about 120km and a width of 7-11km. The top of the bank is relatively flat, with a slight declination toward the east. Water depth at the top of the bank is about 150m in the north and 120m in the south (Lee, 1987). To the west of Hupo Bank, a basin (Hupo Basin) separates the bank from the shelf. Hupo Basin has a maximum depth of about 270m and is underlain by a thick accumulation of Tertiary and Quaternary deposits (Kim, 1981).

The southern part of the study area comprises a wide and flat shelf — located between Korean peninsula and the Japanese island of Honshu — which has an average depth of about 120m. This shelf constitutes the northern part of Korea Strait through which the Tsushima current flows into the East Sea.

Surface Sediment Distribution

The surface sediment distribution in the studied area shows an overall prominence of fine materials, there being a lower proportion of silt and a higher one of clay than those found in the continental shelves of the western and southern seas. Based on their grain size analysis data, Lee et al. (1989) have distinguished five different sediment facies: sand, clay, mud, sand and mud mixed, and sand and clay mixed. Sand facies represents a relict sediment which is found in the outer shelf of the southern part of the study area and over the Hupo Bank, while clay facies is typically found in regions deeper than the slope. Mud facies is a recent sediment facies which is usually developed in a narrow band on the continental shelf or the upper slope; sand and mud mixed facies can be observed near the entrance of the Yeongil Bay and on the continental shelves of both southern and northern parts of the study area. Sand and clay mixed facies is found only on the Hupo Bank, formed by a mixture of pelagic clay and relict coarse materials.

The detailed sediment distribution maps of this area are presented elsewhere (Choi, 1989; Lee et al., 1989).

MATERIALS AND METHODS

The sediment samples used in the present study were collected by a Van Veen grab aboard T/V 'Hanbada' of Korea Maritime University during the three cruises in 1985 and 1987. The locations of sediment samples are shown in Fig. 1. A total of ninety sediment samples were analyzed for their contents in Ba, Co, Cu, Sr, Zn and organic carbon as well as their grain size. Fifty among these samples were further analyzed for their major elements such as Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, P_2O_5 and MnO.

The samples were dried at about 110°C for

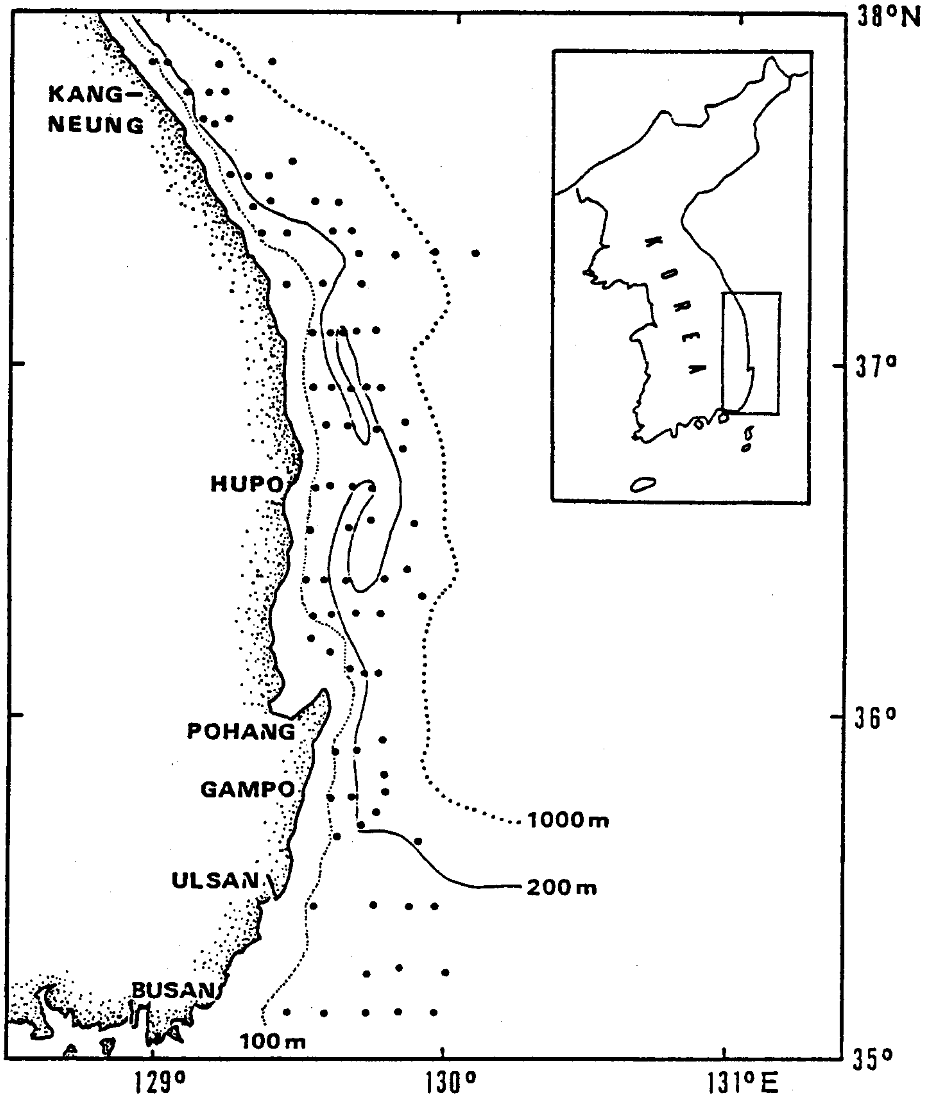


Fig. 1. Map showing the study area and the sample sites. The longitude and latitude of each sample site are listed in Table 2.

3-4 hours and ground in an agate mortar. The determination of organic carbon content was carried out by back-titration method, after treating the powdered samples with a mixed solution of sulfuric acid and potassium dichromate, as was described in Jackson (1967). For elemental analysis, the powdered samples were first treated with a HF/$HClO_4$ mixed solution in order to destroy the silicate mineral lattice and then leached with a dilute NHO_3 solution. Determination of the major element composition was carried out by inductively coupled Ar plasma emission spectroscopy(ICP-ES), and that of trace metals by inductively coupled plasma mass spectrometry(ICP-MS). The accuracy of analytical data were checked by analyzing standard sediment samples (MESS-1 and BCSS-1 of NRC, Canada, and SRM-1646 of NIST, USA) with our samples in every batch of analysis, which showed satisfactory results of analytical values within ±5% of the certified ones. The precision of analysis was also found to be good and within ±3% in triplicate analysis of standard samples.

RESULTS AND DISCUSSIONS

Major-element composition

The analyzed results of major elements from 50 sediment samples of the study area are shown in Table 1, expressed as oxide forms. The major element composition varies widely from one sample to another. A large part of these variations, especially for Al, Fe, Mg, Na and probably also for P and Mn, is related to the sediment grain size since the contents of these elements correlate with the mean grain size(Mz) of sediment in Fig. 2.

However, the CaO and K_2O contents do not show any relationship with Mz. The carbonate contents may be responsible for CaO since the former is enriched in the southern part of the study area(Choi, 1989) where the latter is also high. For K_2O contents, on the other hand, contributions to this element by two texturally different groups of minerals may explain its lack of relationship with Mz: sand-sized potassium feldspars and clay-sized illites. The abundance of feldspars in the mineralogy of sand(up to 30%) from the present study area was documented by Lee et al. (1989) and the predominance of illite in the clay mineral assemblages of East Sea sediments was reported by several authors (Aoki et al., 1974; Park and Han, 1985; Lee et al, 1989). The strong relationship of potassium content with the total of clay plus feldspar was also reported by Moore (1963) from Buzzards Bay sediments in U.S.A.

The orgainc carbon content of sediments varies between less than 0.1% and 3.4%, with an average value of 1.7%. Though a general trend of increasing organic carbon content with decreasing sediment grain-size can be observed, this trend comes out as a rather broad belt in the Corg-Mz diagram, instead of an expected linear relationship (Fig. 3). This phenomenon was also reported by Lee et al. (1989) who attributed it to the geographical variation. The biological productivity in the surgace water, chemistry in the water column, and sedimentation rate are the most important factors controlling this geographical variation of organic carbon content.

Trace-metal concentrations

The concentrations of Ba, Co, Cu, Sr and Zn in 90 surface sediment samples from the study area are presented in Table 2. The average concentration values of all these five elements are

Table 1. Major-element composition of 50 surface sediments from the continental shelf and slope, off the southeastern coast of Korea.

St. No.	Mz	Org.C	Major Elements							
			Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	MnO
	(ϕ)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
8501	9.3	1.12	14.33	5.32	2.47	5.60	3.27	2.89	0.17	0.06
8505	9.5	1.80	15.99	5.72	2.61	2.71	3.71	3.20	0.16	0.05
8506	9.8	1.63	15.15	5.51	2.64	2.59	4.34	2.89	0.20	0.06
8509	8.1	1.29	15.34	5.60	2.27	2.49	3.14	3.16	0.18	0.05
8511	9.3	1.14	16.32	5.79	2.50	1.93	4.13	3.01	0.20	0.05
8513	9.7	1.72	15.41	5.58	2.66	2.53	4.03	2.92	0.25	0.06

Table 1. (Continued)

8521	9.6	1.95	16.28	5.96	2.61	1.98	3.47	3.24	0.18	0.05
8523	9.2	2.76	16.40	6.08	2.38	1.52	3.06	3.34	0.22	0.05
8529	3.9	1.22	8.94	3.72	1.16	1.73	1.68	2.53	0.21	0.04
8531	2.4	0.33	8.62	1.97	0.69	1.24	1.52	3.71	0.08	0.03
8533	0.2	0.01	8.15	1.98	0.51	0.87	0.97	2.90	0.07	0.03
8534	8.0	2.69	14.78	5.10	2.10	1.63	2.61	3.02	0.17	0.04
8535	6.3	1.71	14.54	4.67	1.95	1.73	3.32	3.34	0.20	0.04
8536	6.2	1.87	15.11	5.07	2.01	1.64	2.94	3.40	0.18	0.05
8538	6.2	1.88	14.18	5.36	1.85	1.60	2.51	3.23	0.20	0.05
8539	6.8	1.54	13.54	5.12	1.80	1.37	2.80	3.13	0.18	0.04
8541	8.9	2.57	13.99	5.04	2.27	1.82	3.76	2.83	0.15	0.04
8542	9.2	2.21	14.28	5.19	2.39	1.42	4.07	2.85	0.17	0.04
8544	9.6	1.64	14.98	5.50	2.55	1.83	3.97	3.03	0.17	0.05
8548	9.5	1.55	16.15	5.84	2.49	1.76	3.17	3.20	0.16	0.05
8549	9.0	2.05	16.58	5.98	2.36	1.60	3.50	3.32	0.18	0.05
8550	7.7	1.54	14.93	5.16	2.05	2.10	2.86	3.21	0.17	0.05
8551	9.6	2.47	15.79	5.83	2.67	2.49	3.56	3.24	0.18	0.05
8552	6.8	1.43	14.27	4.00	1.69	3.79	3.31	3.23	0.14	0.05
8555	1.7	0.74	8.18	0.89	0.32	0.87	1.74	2.98	0.05	0.02
8559	9.6	1.83	14.70	5.41	2.53	2.41	4.17	3.04	0.19	0.05
8560	9.6	1.77	15.70	5.78	2.51	1.97	3.84	3.10	0.19	0.05
8561	8.1	2.13	15.51	5.43	2.17	2.18	3.60	3.08	0.18	0.06
8562	3.2	0.61	9.35	1.86	0.59	0.94	2.12	2.77	0.07	0.04
8563	3.8	0.44	8.77	2.31	0.79	1.40	1.92	2.21	0.08	0.04
8564	9.4	2.05	14.89	5.42	2.40	2.71	3.86	2.92	0.16	0.06
8565	6.3	0.46	11.97	4.18	1.66	2.49	2.68	2.65	0.15	0.05
8566	9.8	2.01	14.03	5.23	2.52	2.49	4.12	2.78	0.17	0.06
8701	3.0	0.40	6.18	2.55	0.97	7.10	1.25	1.74	0.08	0.03
8702	6.1	1.26	10.78	3.48	1.83	8.87	2.85	2.34	0.15	0.04
8703	6.6	0.98	10.91	3.32	1.98	14.45	2.54	2.17	0.18	0.04
8704	5.3	1.62	10.15	3.38	1.84	12.90	2.90	2.16	0.20	0.05
8705	6.5	1.35	10.33	3.38	2.00	16.30	2.55	2.08	0.17	0.04
8706	4.1	0.89	9.04	3.21	1.59	11.28	2.38	2.20	0.14	0.04
8707	5.2	1.07	7.85	3.38	1.53	17.30	2.03	1.90	0.15	0.05
8708	3.4	0.95	8.74	2.90	1.45	12.53	1.98	2.13	0.14	0.04
8712	8.7	1.37	14.38	5.02	2.48	8.04	3.34	2.62	0.19	0.06
8714	2.5	0.42	7.66	3.27	1.16	7.29	1.76	2.22	0.10	0.04
8715	2.6	0.40	8.50	2.26	1.00	2.49	2.03	2.30	0.09	0.04
8716	2.1	0.51	4.24	1.48	0.50	6.46	0.99	1.37	0.11	0.04
8720	9.5	1.52	13.90	5.60	2.48	4.24	4.31	2.68	0.22	0.10
8721	9.5	2.41	14.32	5.43	2.59	3.77	4.58	2.79	0.20	0.06
8729	10.0	2.76	14.11	5.43	2.51	1.89	3.82	2.79	0.20	0.05
8738	2.4	0.51	4.30	1.21	0.42	0.79	1.20	1.63	0.05	0.02
8740	9.1	1.18	13.72	5.23	2.54	5.59	4.19	2.72	0.20	0.07

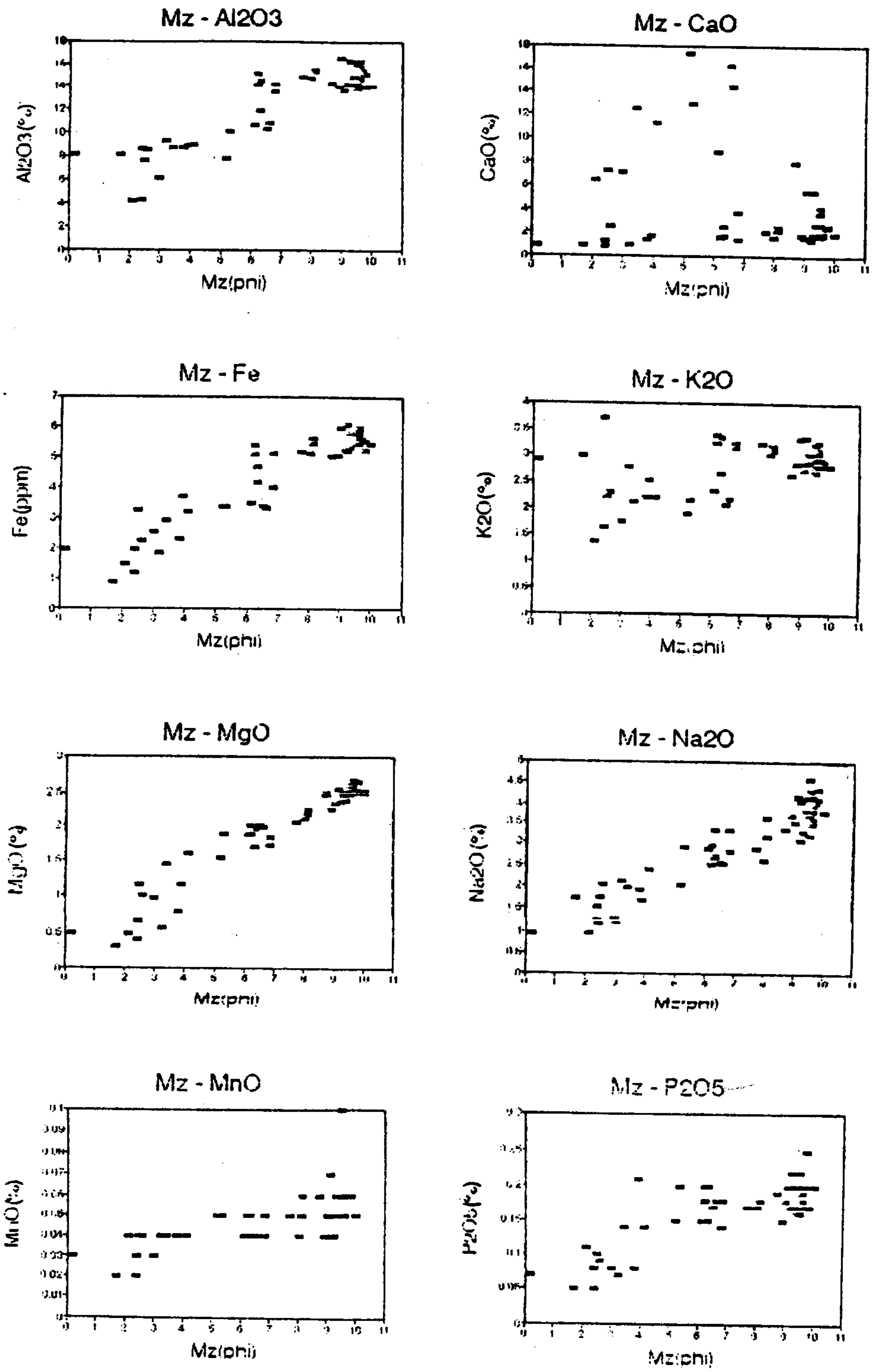


Fig. 2. Relationships of major element contents with the mean grain size (Mz) of sediments.

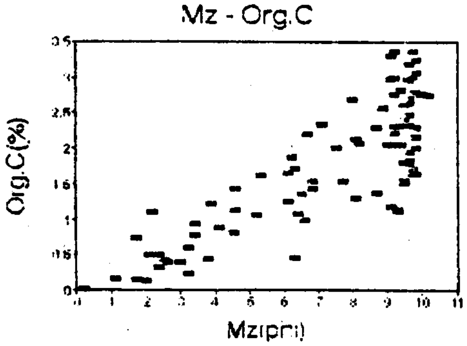


Fig. 3. A pair diagram relating the organic carbon content with the mean grain size (Mz) of sediments.

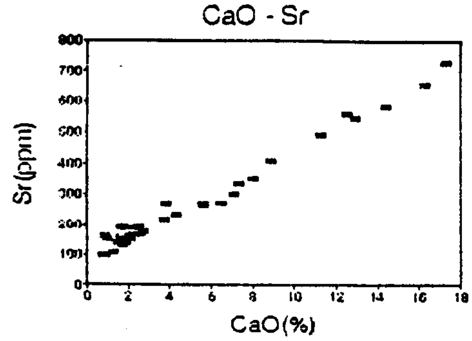


Fig. 4. A pair diagram relating the strontium content with that of CaO in surface sediments.

less than those reported for the average shale by Turekian and Wedepohl (1961). The maximum concentration itself is less than the average shale value for Co and Cu, and for Ba and Zn it does not exceed greatly the average shale value. Significantly high values, relative to the average shale value, are observed only for Sr in some samples, but these high-Sr sediments are limited in area to the southern part of the study area where the calcium carbonate content is also high. In fact, when we plot the concentrations of Sr against those of CaO, there emerges a fairly clear linear trend (Fig. 4). Therefore, it seems likely that the content of these trace metals reflects the natural condition without any noticeable anthropogenic influence.

The grain-size of sediment is an important factor in controlling trace metal contents, especially for Cu, Zn and Co (Fig. 5). But, the contents of Sr and Ba vary independently with grain-size. The strong dependence of Sr on calcium carbonate content can explain the lack of any relationship with sediment grain size, since the calcium carbonate itselt is independent of the grain size in this area of study. Ba, on the other hand, is generally known to be associated with potassium feldspars (Rankama and Sahama, 1950). When we plot the contents of Ba against those of K_2O, a certain tendency of covariance between these two components can be deciphered, even though the relationship is not straightforwardly linear (Fig. 6).

Areal distributions

As is predicted by their close relationships with the mean grain size in Fig. 2, the areal distributions of Al_2O_3, Fe_2O_3, MgO and Na_2O in surface sediments generally follow that of sediment grain size. The distribution and textural properties of the surface sediments in the study area are presented elsewhere (Lee et al., 1989). The CaO distribution, on the other hand, follows that of $CaCO_3$ and shows elevated contents on

Table 2. Trace metal contents and grain-size composition of 90 surface sediments from the continental shelf and slope, off the southeastern coast of Korea.

St. No.	Location Lat. (N)	Long. (E)	Composition Sand (%)	Silt (%)	Clay (%)	Mz (ϕ)	Org.C (%)	Trace Metals (ppm) Ba	Co	Cu	Sr	Zn
8501	35.41.1	129.41.5	2.8	32.7	64.5	9.3	1.12	365	14	22	265	112
8502	35.43.6	129.41.5	4.0	31.0	65.0	9.2	2.05	361	14	26	245	132

Table 2. (Continued)

8503	35.46.7	129.46.5	0.3	25.8	73.9	9.8	2.16	364	14	29	196	135
8504	35.49.6	129.46.7	0.4	26.7	72.9	9.8	3.07	370	14	32	182	143
8505	36.07.2	129.44.8	0.9	27.8	71.3	9.5	1.80	392	14	23	175	116
8506	36.17.9	129.44.9	0.6	27.5	71.9	9.8	1.63	383	13	23	168	122
8508	36.18.0	129.39.7	0.5	28.5	71.0	9.6	2.97	379	14	28	157	137
8509	36.17.7	129.34.1	16.6	25.5	57.9	8.1	1.29	394	13	21	174	110
8510	36.17.5	129.31.1	15.2	29.4	55.4	8.2	2.06	380	13	25	176	115
8511	36.32.0	129.30.9	1.3	36.2	62.5	9.3	1.14	388	13	23	164	137
8513	36.32.5	129.38.9	0.9	28.3	70.8	9.7	1.72	386	14	23	169	128
8517	36.46.3	129.49.2	1.5	13.3	85.2	10.2	2.74	366	13	27	142	130
8519	36.49.6	129.43.9	83.8	5.0	11.2	2.0	0.14	458	3	5	163	29
8521	36.49.7	129.37.9	0.8	27.0	72.2	9.6	1.95	397	13	25	152	120
8522	36.50.2	129.33.4	4.4	30.3	65.3	9.2	2.30	371	12	30	143	141
8523	36.56.7	129.31.8	2.9	32.6	64.5	9.2	2.76	402	13	27	138	118
8524	37.05.8	129.31.3	76.3	4.4	19.3	4.5	0.82	451	7	11	159	60
8525	37.05.8	129.34.3	0.8	31.2	68.0	9.4	2.31	365	14	29	143	134
8526	37.05.8	129.36.7	60.9	7.1	32.0	4.6	1.44	312	7	14	124	74
8527	37.05.9	129.39.5	1.3	27.7	71.0	9.6	1.66	370	13	28	143	129
8528	37.06.1	129.43.3	1.2	28.2	70.6	9.6	2.31	369	13	31	146	131
8529	37.14.0	129.40.6	65.5	13.6	20.9	3.9	1.22	335	8	10	131	53
8531	37.14.0	129.32.5	86.9	4.3	8.8	2.4	0.33	383	6	7	109	34
8533	37.14.1	129.25.6	96.3	1.3	2.4	0.2	0.01	445	4	4	96	29
8534	37.32.2	129.19.8	6.1	49.7	44.2	8.0	2.69	482	12	23	158	102
8535	37.32.0	129.16.2	23.3	51.3	25.4	6.3	1.71	565	10	19	197	87
8536	37.31.9	129.12.5	31.8	44.7	23.5	6.2	1.87	543	12	18	187	90
8537	37.27.1	129.17.4	26.2	40.9	32.9	6.7	2.20	485	11	23	173	96
8538	37.22.8	129.20.0	23.2	53.5	23.3	6.2	1.88	437	12	18	149	83
8539	37.22.9	129.25.0	25.1	40.6	34.3	6.8	1.54	394	10	20	133	87
8541	37.23.0	129.33.5	1.3	39.9	58.8	8.9	2.57	394	12	23	143	99
8542	37.23.0	129.38.4	1.0	31.7	67.3	9.2	2.21	401	12	26	133	106
8544	36.56.7	129.44.8	1.5	26.8	71.7	9.6	1.64	397	13	24	140	113
8545	36.56.7	129.42.0	11.6	25.2	63.2	8.7	2.29	371	13	27	175	122
8547	36.56.4	129.38.9	77.7	5.8	16.5	3.4	0.78	438	4	7	187	45
8548	36.56.5	129.34.4	1.0	29.7	69.3	9.5	1.55	396	13	24	140	117
8549	36.39.4	129.31.8	2.2	40.9	56.9	9.0	2.05	396	13	26	146	120
8550	36.39.3	129.34.4	18.5	29.7	51.8	7.7	1.54	408	12	20	153	99
8551	36.39.3	129.39.8	0.9	24.5	74.6	9.6	2.47	397	14	24	166	119
8552	36.39.2	129.42.8	43.0	14.6	42.4	6.8	1.43	499	12	14	266	76
8555	36.23.8	129.45.6	93.8	1.3	4.9	1.7	0.74	539	4	3	161	24
8559	36.23.4	129.38.2	5.0	23.3	71.7	9.6	1.83	382	14	23	166	113
8560	36.23.4	129.33.3	1.4	28.8	69.8	9.6	1.77	381	14	24	155	117
8561	36.23.4	129.29.7	12.3	31.4	56.3	8.1	2.13	395	13	21	190	105
8562	36.13.3	129.31.0	83.8	6.2	10.0	3.2	0.61	472	5	5	150	43
8563	36.10.7	129.35.0	73.4	10.7	15.9	3.8	0.44	381	7	7	142	44

Table 2. (Continued)

8564	36.08.0	129.38.8	0.8	29.8	69.4	9.4	2.05	358	14	22	175	120
8565	36.07.2	129.41.9	36.7	17.0	46.3	6.3	0.46	385	10	16	167	81
8566	35.55.9	129.46.1	0.4	23.7	75.9	9.8	2.01	373	13	23	164	113
8701	35.08.8	129.27.3	81.7	5.5	12.8	3.0	0.40	312	8	6	299	41
8702	35.08.7	129.35.2	41.6	21.0	37.4	6.1	1.26	365	11	15	407	73
8703	35.08.7	129.43.7	31.6	33.6	34.8	6.6	0.98	324	12	15	584	76
8704	35.08.8	129.50.7	55.6	24.5	19.9	5.3	1.62	353	11	13	548	66
8705	35.08.1	129.57.6	52.0	24.5	23.5	6.5	1.35	308	12	14	655	72
8706	35.15.1	130.00.0	79.2	8.5	12.3	4.1	0.89	388	10	9	492	54
8707	35.16.2	129.52.3	58.3	16.2	25.5	5.2	1.07	326	11	10	729	55
8708	35.15.6	129.45.0	86.8	5.4	7.9	3.4	0.95	404	10	9	560	49
8712	35.27.6	129.33.0	5.9	36.1	58.0	8.7	1.37	349	15	20	350	104
8714	35.27.5	129.45.1	88.9	3.6	7.5	2.5	0.42	413	9	5	333	45
8715	35.26.8	129.52.9	98.6	1.4	0.0	2.6	0.40	484	7	5	195	35
8716	35.27.0	129.58.9	92.5	1.6	6.0	2.1	0.51	297	6	4	270	23
8719	35.46.2	129.40.5	2.7	30.7	66.7	9.5	2.61	337	14	29	238	133
8720	35.46.0	129.36.9	1.6	29.4	69.0	9.5	1.52	354	15	24	233	127
8721	35.54.8	129.37.8	1.4	30.0	68.6	9.5	2.41	355	14	23	217	123
8722	35.54.4	129.41.6	3.0	26.6	70.4	9.5		346	14	26	202	138
8726	36.21.1	129.49.7	1.9	23.1	75.0	9.7	3.01	346	13	29	159	137
8728	36.25.7	129.50.5	1.4	28.1	70.5	9.6	2.70	360	14	29	166	129
8729	36.33.2	129.52.0	0.5	19.2	80.3	10.0	2.76	392	14	24	139	110
8731	36.50.7	129.49.1	0.7	28.0	71.3	9.8	2.78	357	12	27	134	121
8734	36.33.3	129.43.4	84.1	4.1	11.8	3.2	0.24	567	5	6	250	31
8738	35.38.9	129.54.0	90.8	2.0	7.2	2.4	0.51	370	3	4	97	22
8740	35.38.9	129.36.7	0.7	35.7	63.5	9.1	1.18	352	15	23	266	114
87207	37.19.0	130.04.0	1.7	19.6	78.8	9.8	2.28	536	16	42	122	132
87208	37.19.2	129.55.6	1.2	20.9	77.9	9.8	3.24	427	13	35	123	132
87209	37.18.5	129.47.0	0.9	27.6	71.5	9.6	2.63	392	13	31	141	123
87210	37.18.5	129.39.0	1.3	31.7	67.0	9.2	3.00	398	14	31	143	123
87214	37.42.2	129.06.8	62.9	25.2	12.0	4.6	1.14	628	6	14	233	72
87215	37.41.3	129.09.9	20.2	52.8	27.0	6.4	1.08	559	8	19	205	75
87216	37.42.2	129.16.1	36.5	28.8	34.7	6.1	1.65	439	8	20	169	89
87219	37.52.0	129.21.7	1.0	24.4	74.6	9.6	3.18	431	13	36	131	128
87220	37.50.7	129.09.1	0.8	36.4	62.8	9.1	3.30	430	12	35	145	118
87222	37.52.0	128.58.1	76.3	13.7	10.0	1.7	0.15	516	1	3	131	20
87223	37.51.8	128.55.9	76.0	19.4	4.6	2.2	1.11	605	4	7	167	54
87233	37.28.3	129.20.9	13.8	52.7	33.6	7.1	2.33	487	10	24	188	101
87234	37.28.4	129.30.5	1.5	34.3	64.2	9.2	3.37	388	12	29	148	121
87235	37.27.8	129.35.9	0.8	29.9	69.3	9.4	2.81	385	12	30	136	121
87242	37.47.0	129.12.7	1.3	24.4	74.3	9.7	3.37	446	12	32	143	114
87243	37.46.7	129.07.0	15.2	44.6	40.2	7.5	2.00	480	9	25	183	108
87244	37.46.8	129.03.3	88.0	8.5	3.5	1.1	0.17	579	2	4	174	27
87247	35.35.4	129.25.1	1.9	35.7	62.4	9.1	2.98	399	12	30	154	115

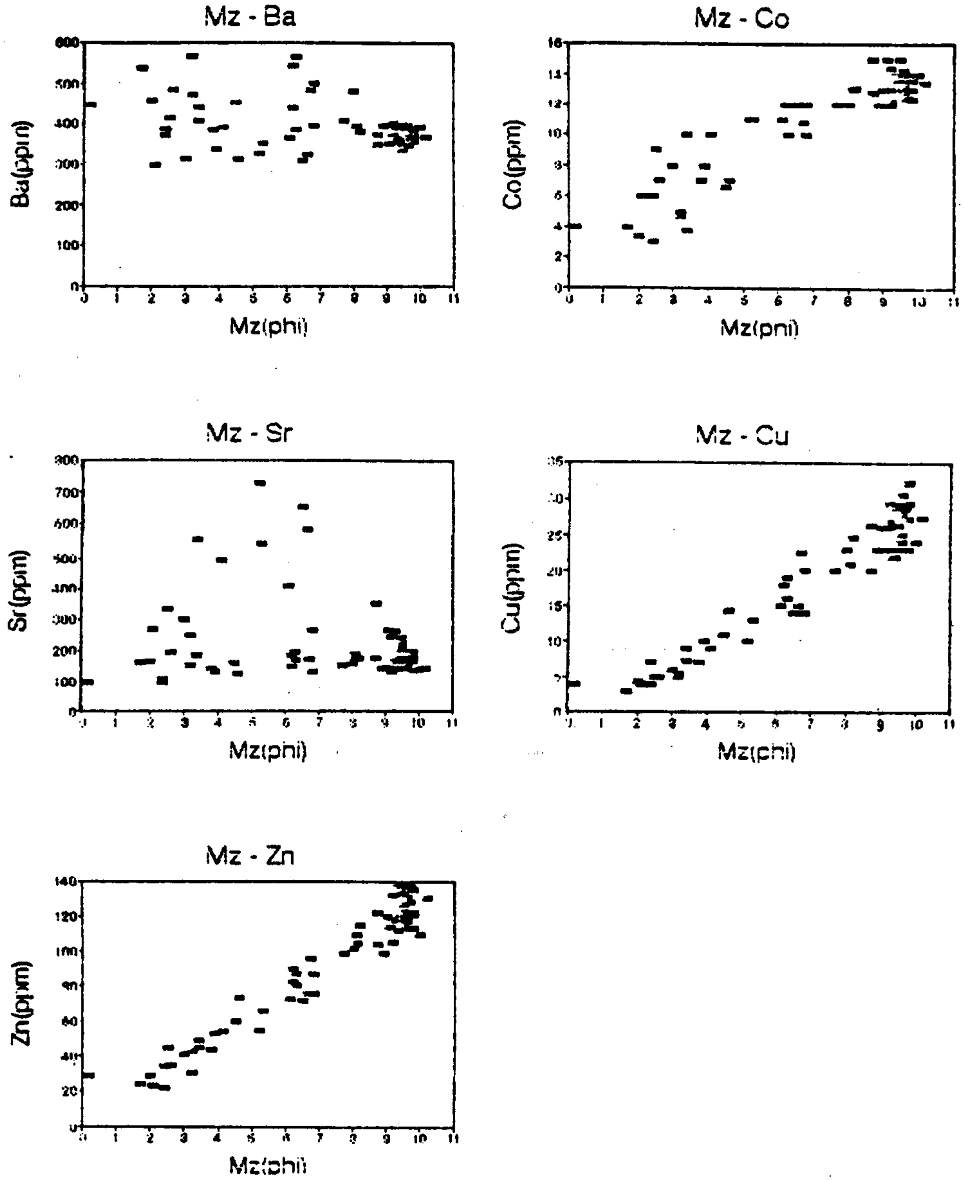


Fig. 5. Pair diagrams relating the content of trace metals (Ba, Co, Cu, Sr and Zn) with the mean grain size (Mz) of sediments.

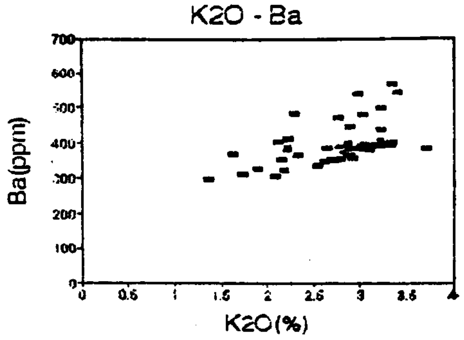


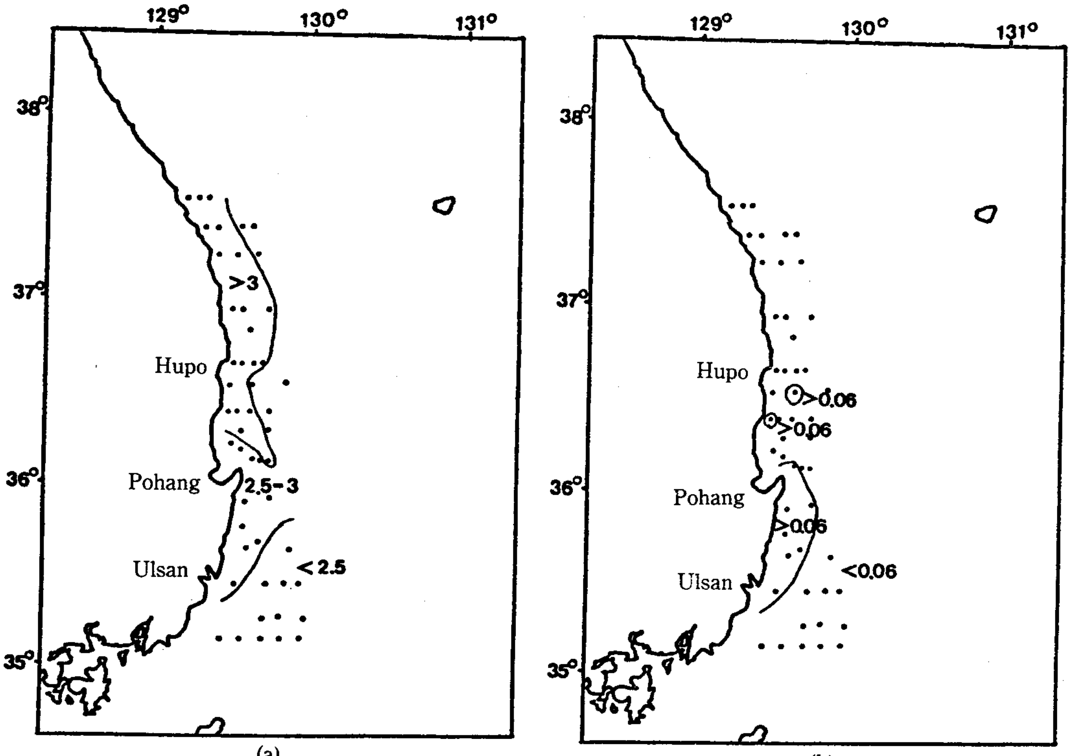
Fig. 6. A pair diagram relating the Ba content with that of K_2O in surface sediments.

the broad outer shelf in the southern part of the study area. In the distribution of K_2O and MnO, however, there can be observed a certain areal trend, which is neither texturally nor mineralogically related: K_2O content decreases from north toward south on the continental shelf and slope, while higher MnO contents occur in the coastal area of the southern part of the study area (Fig. 7).

Among trace metals, Cu and Zn contents depend strongly on the mean grain-size, and their distributions in bulk sediment generally follow that of sediment grain-size. However, when we divide their contents in bulk sediments by those of Al_2O_3, most of the grain-size effect in detrital component can be eliminated. The Cu/Al_2O_3 and Zn/Al_2O_3 ratios thus calculated reveal that there are some enrichment of these metals in the coastal muddy deposits of the southern part of the study area (Fig. 8 a and b). These areal distribution patterns of Cu/Al_2O_3 and Zn/Al_2O_3 ratios in fact are not clearly distinctive and only subtle differences can be noticed. However, this pattern is repeated again in Co, which is another size-dependent element, and a higher Co/Al_2O_3 ratio is also observed on the southern continental shelf of the study area (Fig. 8 c).

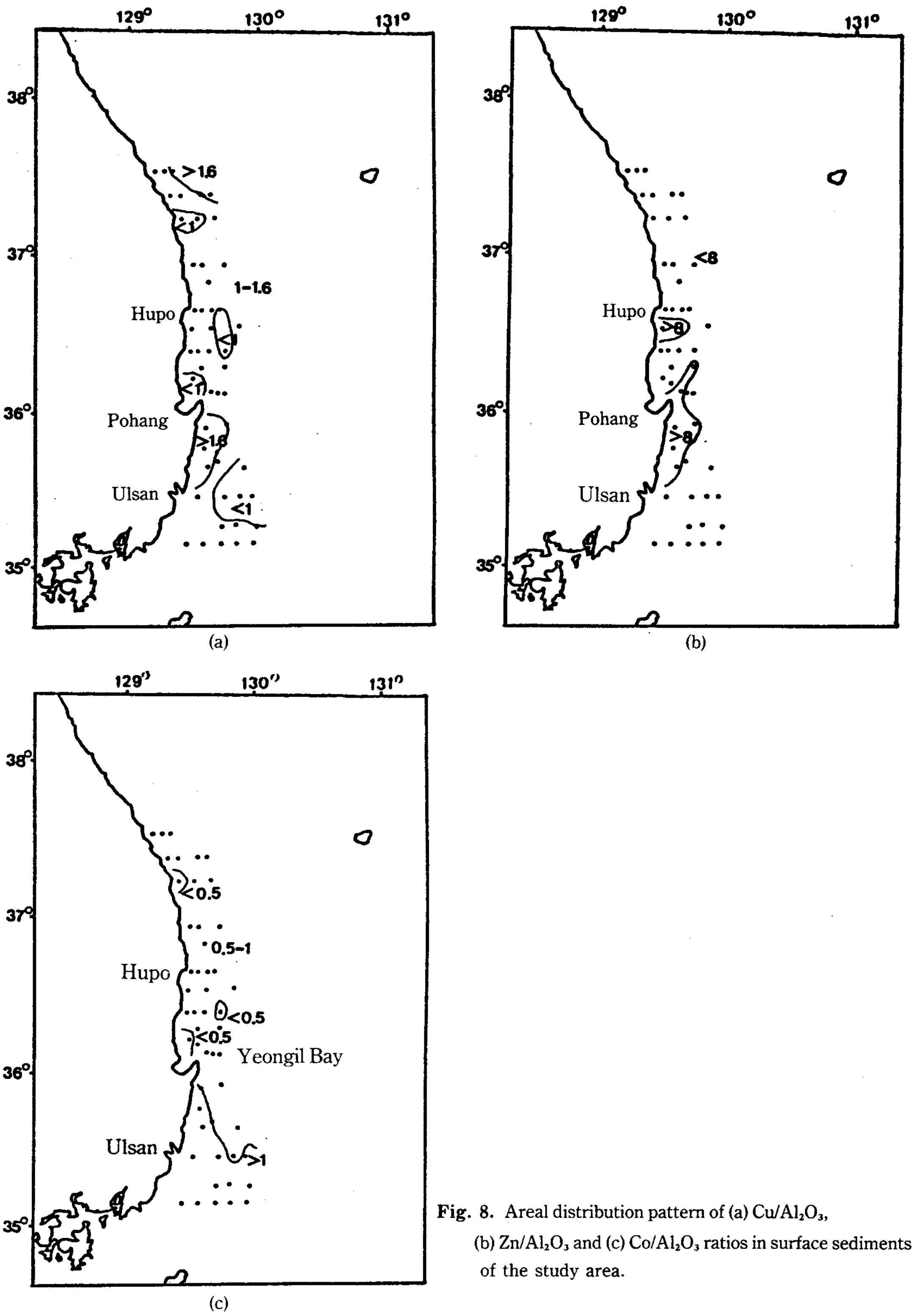
This areal distribution pattern of metal/Al_2O_3 ratios suggests that an additional source of these three metals, other than the detrital one, may exist in the southern part of the study area. This source may be found either in the industrial influences from Ulsan and Busan areas or in the fluvial contribution via Nakdong River. In any case, the effect of this additional source on the surface sediments of the study area is still negligible.

The Ba content in bulk sediments is generally high in the northern part of the continental shelf and on Hupo Bank, whereas the Sr content, following that of calcium carbonate, is high in the southern part of study area. The



(a) (b)

Fig. 7. Areal distribution pattern of (a) K_2O and (b) MnO contents in surface sediments of the study area.



(a)

(b)

(c)

Fig. 8. Areal distribution pattern of (a) Cu/Al_2O_3, (b) Zn/Al_2O_3 and (c) Co/Al_2O_3 ratios in surface sediments of the study area.

aluminum ratios of Ba and Sr are not useful in evaluating the additional source since their contents in sediments are independent of sediment grain-size.

Factors controlling the sediment geochemistry

Since the chemical composition of shelf sediments is influenced by a complex variety of processes acting upon it, it is useful to apply multivariate techniques to identify the factors controlling the distribution of individual elements (Calvert, 1976). We have applied here the factor analyses, both R-mode and Q-mode, to our data set. The principal benefit of factor analysis is in reducing the complex interrelationships between large numbers of variables to a smaller number of simple relationships which can explain most of the variance of the original data (Summerhayes, 1972).

Table 3 shows the Varimax rotated R-mode factor pattern. The four factors considered account for 93.5% of the total variance in the data set. Factor 1 accounts for 61.4% of the total variance and contains significant loadings for most chemical components, except for CaO, Ba and Sr. This factor represents most probably the fine-grained alumino-silicate factor. Factor 2, which accounts for 16.5% of the total variance, is carbonate factor and controls the geochemistry of CaO and Sr. The negative loading of K_2O on this factor 2 may reflect the fact that the calcium carbonate is negatively correlated with feldspar in sand-sized population. Factor 3 accounts for 9.3% of the total variance and contains high loadings for Ba and K_2O. This factor may represent the feldspar factor. The high loading values of K_2O on both factor 1 and factor 3 may reflect the dual source of potassium in these sediments: feldspar and illite. Factor

Table 3. Varimax-rotated R-mode factor matrix for continental shelf and slope sediments, off the southeastern coast of Korea (n = 50).

Loadings on	Factors			
	1	2	3	4
Al_2O_3	**0.90**	-0.26	0.28	0.14
Fe_2O_3	**0.94**	-0.19	0.05	0.15
MgO	**0.97**	0.01	-0.02	0.16
Cao	-0.08	**0.96**	-0.24	0.01
Na_2O	**0.88**	-0.13	0.04	0.28
K_20	**0.50**	**-0.50**	**0.59**	0.05
P_2O_5	**0.87**	0.12	-0.02	0.19
MnO	**0.61**	0.03	-0.11	**0.74**
Ba	-0.13	-0.25	**0.93**	-0.08
Co	**0.94**	0.14	-0.04	0.26
Cu	**0.96**	-0.21	0.01	0.08
Sr	-0.08	**0.98**	-0.13	0.01
Zn	**0.95**	-0.19	-0.00	0.22
Corg	**0.88**	-0.11	0.12	-0.27
Mz	**0.96**	-0.14	-0.08	0.14
% Variance	61.4	16.5	9.3	6.3
Cumulative		77.9	87.2	93.5

4, which accounts for 6.35% of the total variance, contains a significant loading value (>0.3) for only one component, MnO. This last factor may possibly be interpreted, though not satisfactorily proved, as a pollution factor. The fact that the higher MnO contents in bulk sediments occur near the coastal area in the southern part of the study area, where the metal/Al_2O_3 ratios are also high (Fig. 7 and 8), may support this interpretation.

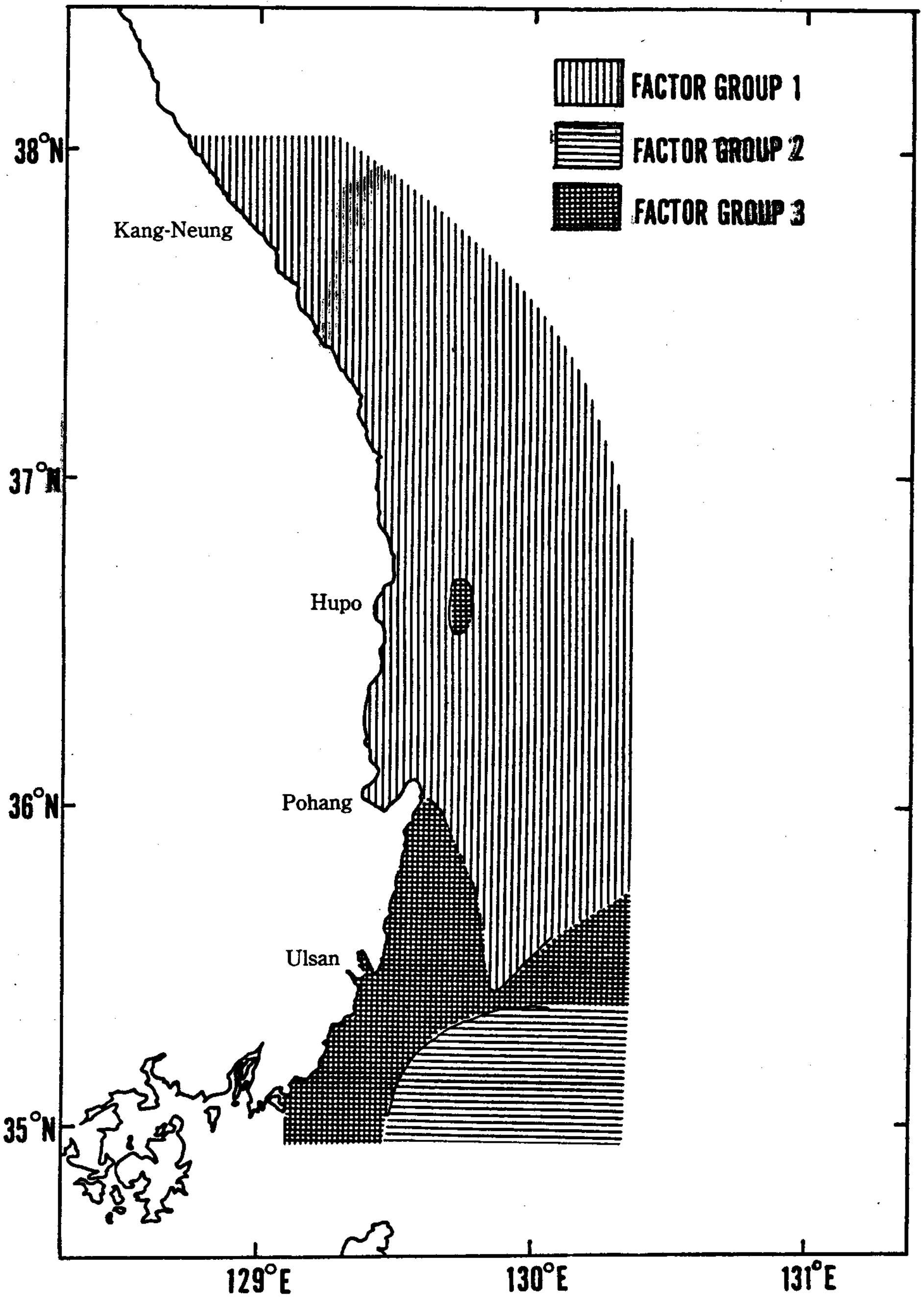


Fig. 9. Areal distribution of the three groups of sediments, as classified by Q-mode factor analysis, in the study area.

In Q-mode analysis only two factors emerge as significant. Based on this result, the total 90 surface sediment samples can be grouped into 3 categories: one with dominant loading (> 0.85) on factor 1, another with dominant loading on factor 2, and the third with significant loadings (>0.5) on both of the two factors. The areal distribution of these 3 groups, shown in Fig. 9, coincides relatively well with the known sediment distribution pattern. Group 1 may represent the group of sediments whose bulk geochemistry is controlled by detrital component, while the carbonate component is mostly responsible for the geochemistry of sediments under Group 2.

CONCLUSIONS

From the present study, the following conclusions can be drawn in relation to the geochemistry of surface sediments on the continental shelf and slope of the southeastern coast of Korean peninsula.

(1) Contents of most major elements in surface sediments, with the exception of CaO and K_2O, have a close correlationship with the mean grain-size; hence their areal distribution in the study area reflects that of the sediment grain-size. The geochemistry of CaO is controlled mainly by calcium carbonate, whereas both illite and feldspar appear to be important for the distribution of K_2O.

(2) Among trace metals, the Co, Cu and Zn contents depend greatly on the sediment grain-size. But the geochemistry of Sr in these sediments is controlled primarily by calcium carbonate. Some influence of potassium feldspar on Ba content is discernible, though the relationship between these two components are not strictly linear.

(3) Using the metal/Al_2O_3 ratios it was possible to distinguish an area of enriched metal contents, though the degree of enrichment was negligible. This areal distribution pattern could not be detected in the total contents because of the significant effect of grain size.

(4) The R-mode and Q-mode factor analyses, applied to our data, produced useful information about the geochemisrty of surface sediments in this environment. The four factors sorted out by the R-mode technique accounted for 93.5% of the total variance in the data set. The Q-mode technique, on the other hand, has allowed us to classify the sediment samples into three groups.

REFERENCES

Aoki, S., K. Oinuma and T. Sado (1974). The distribution of clay minerals in the Recent sediments of the Japan Sea. *Deep-Sea Res.*, **21:** 299-310.

Calvert, S.E. (1976). The mineralogy and geochemistry of near-shore sediments. In: *Chemical Oceanography,* Vol. 6, 2nd ed. (ed. by Riley, J.P. and R. Chester), pp. 187-280. Academic Press, London.

Choe, S. (1971). Studies on marine sediments of the Korean Seas. I. Concentrations and distributions of some geochemical elements in sediments from the sea off eastern Korea. *J. Oceanol. Soc. Korea,* **6**(1): 1-15. (In Korean with English abstract)

Choi, J.Y. (1989). Depositional environments of the coarse-grained sediments on the continental shelf of Korean seas. Ph.D. Thesis, Seoul National Univ.

Kim, C.S. (1981). Submarine geology of continental margin of the East Sea. Ph.D. Thesis, Seoul National Univ.

Jackson, M.L. (1967), Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs.

Lee, C.B., Y.A. Park, J.Y. Choi and G.B. Kim (1989). Surface sediments of the continental shelf and slope off the southeastern coast of Korea. *J. Oceanol. Soc. Korea,* **24:** 39-51. (In Korean with English abstract)

Lee, C.S. (1987). Characteristics of the clastic sediments on the continental shelf off the eastern coasts (Samcheog-Yeongdeog) of Korea. M.Sc. Thesis, Seoul National Univ.

Moore, III, J.R. (1963). Bottom sediment studies, Buzzards Bay, Massachusetts. *J. Sed. Petrology,* **33:** 511-558.

Park. B.K. and S.J. Han (1985). The distribution of clay minerals in recent sediments of the Korea Strait. *Sediment. Geol.,* **41:** 173-184.

Park, Y.A. (1985). Late Quaternary sedimentation on the continental shelf off the south-east coast of Korea. *J. Oceanol. Soc. Korea,* **20**(3): 55-61.

Park, Y.A. and J.Y. Choi (1986). Factor analysis of the continental shelf sediments off the southeast coast of Korea and its implication to the depositional environments. *J. Oceanol. Soc. Korea,* **21**(1): 34-45.

Park, Y.A., C.S. Lee, C.B. Lee and H.J. Kang (1990). Distribution and characteristics of surface sediments on the continental shelf off the eastern coast of Korea. *Korean J. Quat. Res.,* **4:** 15-26.

Rankama, K. and T.G. Sahama (1950). Geochemistry. Univ. of Chicago Press. Chicago and London.

Summerhayes, C.P.(1972). Geochemistry of continental margin sediments from northwest Africa. *Chem. Geol.,* **10:** 137-156.

Turekian, K.K. and K.H. Wedepohl (1961). Distribution of the element in some major units of the Earth's crust. *Geol. Soc. Am. Bull.,* **72:** 175-192.

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