

## VIII. CHEMICAL COMPOSITION OF ARGILLACEOUS SEDIMENTS ON THE PACIFIC MARGIN OF SOUTHWEST JAPAN

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### **Introduction**

Several core samples were collected during the GH75-4 cruise, Geological Survey of Japan, which was carried out in the area comprising the continental shelf and slope of the Pacific side of southwest Japan, the Nankai Trough and the northern Shikoku Basin. The purpose of the present investigation is to provide knowledge of the distribution of elements in argillaceous sediments in the Pacific margin of southwest Japan and to examine the possible sources of the deposits.

### **Methods and Results**

The materials for this study (29 samples) were selected from seven piston cores from the GH75-4 cruise (Fig VIII-1). They were initially described as clay and silt. The samples were dried at 110°C and subsequently ground. Each sample was analysed by X-ray fluorescence spectrometry for Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K and P. Analytical methods for other elements are noted in Table VIII-1.

Analytical results are summarized in Table VIII-1. The sediments are characterized by low MnO and high SiO<sub>2</sub>. FeO is present in each sample. Compositions of this kind are atypical in usual pelagic sediments found in the deep ocean, although some samples were collected from the deep sea bottom, 4890 m (Core P60). Any vertical variation in chemical composition within each core was not apparent.

Special problems of the major element distribution in the sediments are discussed in the following sections.

### **Distribution of Calcium Carbonate**

CaCO<sub>3</sub> was found in some of the samples and was not detected in others. The relationship between water depth of the samples and CaCO<sub>3</sub> content, as illustrated in Fig. VIII-2, clearly shows that the CaCO<sub>3</sub> compensation depth in this area is at about 4500 m. The compensation depth in the Philippine Sea is generally accepted to lie between 4000 m and 4500 m, and this depth is not inconsistent with that of the present result.

P60, above all, deserves special attention in terms of CaCO<sub>3</sub> distribution. CaCO<sub>3</sub> is present in the upper half of the core, whereas, in the lower half it was not detected except in sample P60-10. The water depth of the core is 4890 m, and this depth apparently exceeds the carbonate compensation depth.

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Table VIII-1 Chemical composition of argillaceous sediments in weight percent.

Sp. No. <sup>1)</sup>	57-1	57-2	58-1	58-2	58-3	58-4	59-1	59-2	60-1	60-2
Sp. Loc. <sup>2)</sup>	65-70	213-217	flowing	188-193	281-286	430-435	80-85	275-280	10-15	40-45
SiO <sub>2</sub>	58.01	62.92	58.36	58.40	58.33	58.47	54.52	58.43	60.07	54.02
TiO <sub>2</sub>	0.55	0.53	0.63	0.63	0.54	0.55	0.57	0.60	0.71	0.64
Al <sub>2</sub> O <sub>3</sub>	12.75	13.13	15.14	14.84	13.85	14.19	12.10	13.76	15.36	14.63
Fe <sub>2</sub> O <sub>3</sub>	1.75	1.73	2.35	2.66	2.38	1.60	1.51	2.03	2.82	3.14
FeO	2.36	2.17	1.94	2.43	2.08	2.69	2.41	2.49	2.91	2.26
MnO	0.054	0.048	0.32	0.058	0.055	0.052	0.045	0.056	0.076	0.078
MgO	1.60	1.47	3.13	2.15	1.92	1.58	1.53	1.83	2.13	2.25
CaO	0.88	0.52	1.25	0.40	1.40	0.38	0.99	0.76	1.57	0.49
Na <sub>2</sub> O	2.43	2.26	2.80	2.48	3.48	2.84	2.55	2.45	3.15	2.98
K <sub>2</sub> O	2.64	2.65	2.80	2.99	2.99	2.03	2.56	2.72	2.79	3.00
P <sub>2</sub> O <sub>5</sub>	0.11	0.11	0.14	0.11	0.095	0.10	0.12	0.11	0.14	0.11
H <sub>2</sub> O (+) <sup>3)</sup>	4.12	2.90	4.99	4.57	4.57	4.77	3.97	3.96	4.72	5.60
CaCO <sub>3</sub> <sup>4)</sup>	11.00	8.61	4.90	6.76	4.03	8.82	13.33	9.57	0.12	7.69
Residual Materials <sup>5)</sup>	1.47	0.78	1.10	1.27	2.94	1.12	3.64	1.06	2.61	2.47
Salt <sup>6)</sup>	1.05	0.69	1.08	0.97	2.04	1.09	1.17	0.72	1.08	1.59
Total	100.769	100.514	100.936	100.716	100.681	100.287	100.995	100.550	100.258	100.935
Sp. No. <sup>1)</sup>	60-3	60-4	60-5	60-6	60-7	60-8	60-9	60-10	60-11	60-12
Sp. Loc. <sup>2)</sup>	55-60	103-108	137-142	173-178	190-195	259-264	301-306	329-334	363-368	388-393
SiO <sub>2</sub>	54.09	55.50	56.01	57.17	56.79	60.68	59.78	60.59	60.38	60.58
TiO <sub>2</sub>	0.64	0.64	0.65	0.64	0.64	0.66	0.69	0.69	0.67	0.80
Al <sub>2</sub> O <sub>3</sub>	14.97	14.33	14.59	14.43	14.45	15.31	15.84	15.53	15.37	15.32
Fe <sub>2</sub> O <sub>3</sub>	2.84	2.48	3.04	2.47	2.65	2.67	3.01	3.12	2.86	4.48
FeO	2.58	2.81	2.30	2.65	2.53	2.68	2.86	2.65	2.84	1.68
MnO	0.077	0.077	0.085	0.076	0.078	0.072	0.070	0.072	0.066	0.14
MgO	2.21	2.03	2.18	2.06	2.10	2.04	2.17	2.19	2.28	1.82
CaO	0.96	0.51	1.05	0.60	0.66	1.59	2.02	1.61	1.43	4.96
Na <sub>2</sub> O	3.04	2.93	2.98	2.88	2.98	3.39	3.22	3.10	3.13	3.94
K <sub>2</sub> O	3.00	2.90	2.91	2.84	2.86	2.75	2.73	2.79	2.92	1.39
P <sub>2</sub> O <sub>5</sub>	0.12	0.11	0.12	0.12	0.12	0.13	0.14	0.13	0.11	0.15
H <sub>2</sub> O (+) <sup>3)</sup>	5.46	5.51	4.80	3.49	4.14	4.23	4.16	5.08	4.75	2.38
CaCO <sub>3</sub> <sup>4)</sup>	6.90	7.29	6.28	6.75	6.62	Tr	Tr	0.22	Tr	Tr
Residual Materials <sup>5)</sup>	2.58	2.09	2.69	2.47	2.35	1.84	1.48	0.49	2.52	2.43
Salt <sup>6)</sup>	1.52	1.37	1.31	1.37	1.32	1.42	1.03	0.96	0.99	0.23
Total	100.991	100.578	101.006	100.005	100.292	99.472	99.199	99.206	100.323	100.303

Sp. No. <sup>1)</sup>	62-1	62-2	62-3	62-4	62-5	62-6	63-1	63-2
Sp. Loc. <sup>2)</sup>	85-90	138-143	248-253	310-315	377-382	467-472	172-177	275-280
SiO <sub>2</sub>	55.41	61.56	59.53	59.24	61.28	64.00	61.23	61.54
TiO <sub>2</sub>	0.41	0.68	0.69	0.69	0.66	0.67	0.65	0.66
Al <sub>2</sub> O <sub>3</sub>	12.67	15.13	15.47	15.59	14.70	14.76	14.92	14.79
Fe <sub>2</sub> O <sub>3</sub>	1.63	2.31	2.51	2.58	2.78	1.96	2.22	2.05
FeO	1.76	2.95	3.10	3.14	2.67	3.01	2.50	2.69
MnO	0.044	0.067	0.086	0.070	0.063	0.071	0.063	0.061
MgO	1.47	2.13	2.39	2.22	2.16	2.03	1.83	1.70
CaO	1.49	1.85	2.08	1.75	1.72	1.77	1.21	1.03
Na <sub>2</sub> O	2.54	2.72	3.43	2.94	2.77	2.63	2.59	2.66
K <sub>2</sub> O	2.02	2.78	2.81	2.94	2.73	2.69	3.02	3.01
P <sub>2</sub> O <sub>5</sub>	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.12
H <sub>2</sub> O (+) <sup>3)</sup>	2.73	4.63	5.40	3.99	3.74	3.46	4.08	4.91
CaCO <sub>3</sub> <sup>4)</sup>	14.57	0.81	0.29	1.31	2.02	0.85	2.71	2.99
Residual Materials <sup>5)</sup>	1.76	1.69	2.04	3.49	0.90	1.29	1.81	1.84
Salt <sup>6)</sup>	0.45	0.76	0.54	0.79	0.66	0.74	0.60	0.67
Total	99.081	100.957	100.478	100.852	98.970	100.039	99.544	100.729

1) The first figure in sample No. indicates core No. The water depths of core P57, P58, P59, P60, P61, P62 and P63 are 1,775 m, 4,000 m, 1,067 m, 4,890 m, 1,774 m, 4,440 m and 2,050 m, respectively.

2) Sample locations are indicated as depth from the top of the core in centimeter.

3) H<sub>2</sub>O (+) was gravitationally determined by the method of SHAPIRO and BRANNOCK (1955a).

4) CaCO<sub>3</sub> was calculated from CO<sub>2</sub> content which was manometrically measured by the method of SHAPIRO and BRANNOCK (1955b).

5) Residual materials were calculated by subtracting CO<sub>2</sub> and H<sub>2</sub>O (+) from ignition loss. They may contain sulfur, organic materials and others.

6) Salt was calculated from water soluble chlorine by assuming that pore water has the same composition as that of sea water.

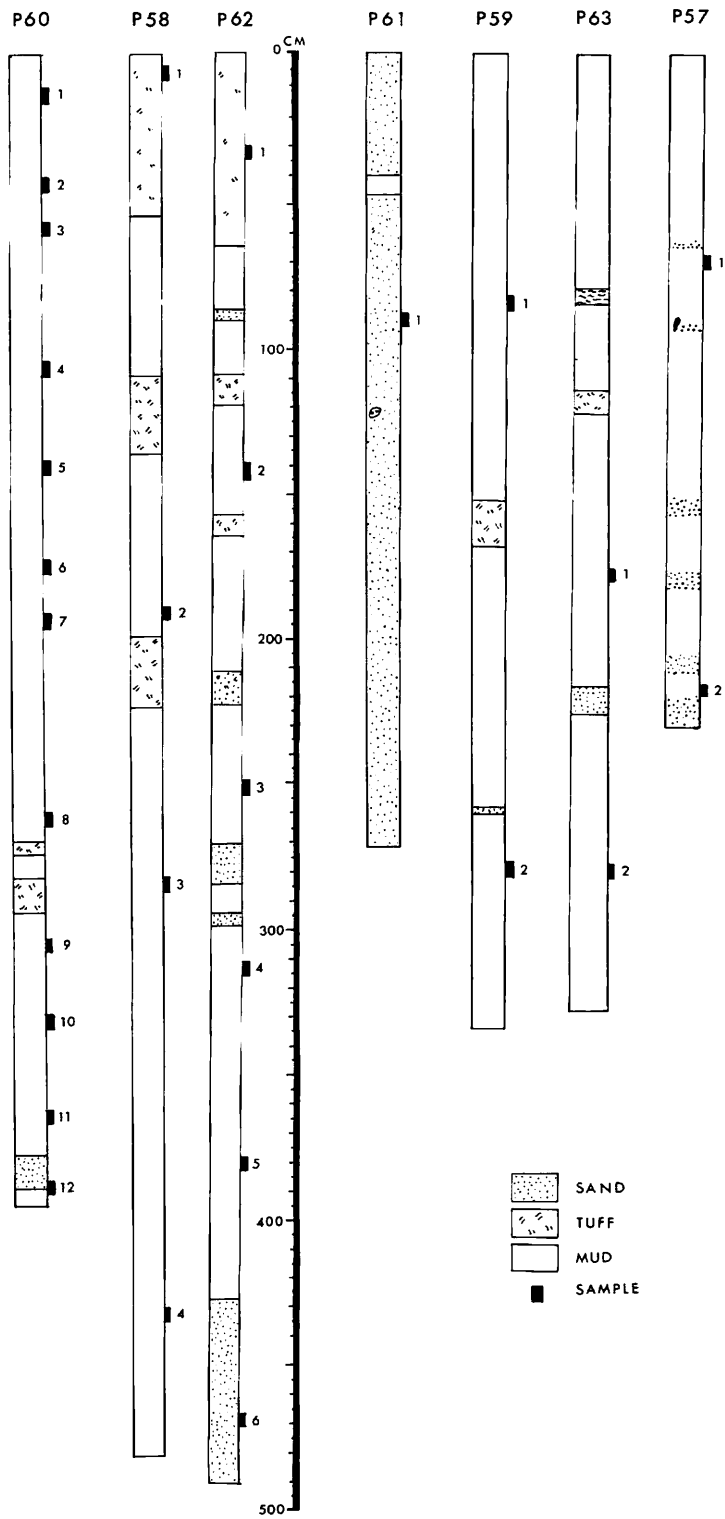


Fig. VIII-1 Sample positions in the cores.

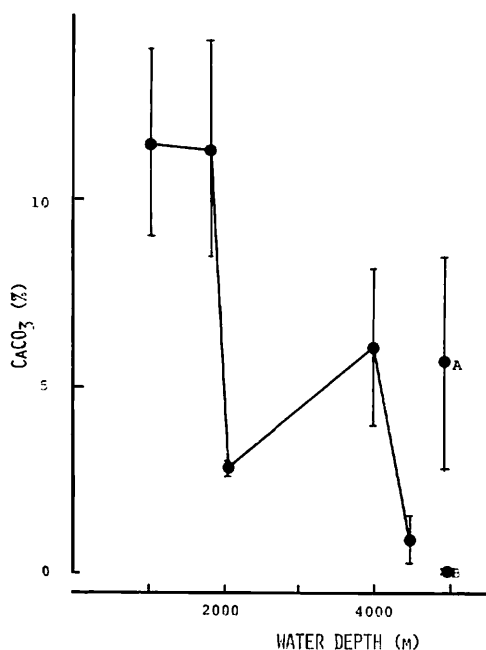


Fig. VIII-2 Variation of  $\text{CaCO}_3$  content with water depth of the cores. Closed circles represent average value of each core. Error bars show the standard deviation. Cores No. 57 (water depth; 1775 m) and No. 61 (1774 m) are shown together as a sample plot. "A" represents the upper half of Core No. 60 (sample No. 60-1,2,3,4,5,6,7), "B" the lower half (sample No. 60-8,9,10,11,12).

Three explanations for the distribution of  $\text{CaCO}_3$  in the core are possible. (1) The sedimentation rate of the upper half of the core was much higher than that of the lower part.  $\text{CaCO}_3$  was, therefore, preserved from dissolution as in the upper part. (2) After deposition of the lower part, the water depth rapidly decreased. (3) The water temperature during the deposition of the upper part of the core was higher than that when the lower part was deposited. In the last two cases, the carbonate compensation depth, at present, exceeds 5000 m.

These assumptions are far from conclusive. However, explanation (1) is not plausible because the lower half of the core contains some sand, while the upper is composed only of silt and clay.

Isotopic and paleontological information is needed to evaluate the other explanations, although there is room for a wide divergence of opinion on this subject.

### Oxide Concentrations

The analyses in Table VIII-1 were recalculated to exclude  $\text{CaCO}_3$  and residual materials (Table VIII-2). In comparison with the composition of typical pelagic sediments (e.g. GOLDBERG and ARRHENIUS, 1958), the core samples are enriched in  $\text{SiO}_2$  and impoverished in  $\text{MnO}$ . Moreover, the close similarity of the composition of the sediments is very striking; the small standard deviation from the averaged value of each

Table VIII-2 Chemical compositions recalculated by excluding carbonates, residual materials and salts in Table VIII-1.

Sp. No.	57-1	57-2	58-1	58-2	58-3	58-4	59-1	59-2	60-1	60-2	60-3	60-4	60-5	60-6
SiO <sub>2</sub>	66.49	69.57	62.18	63.67	63.62	65.51	65.80	65.51	62.28	60.57	60.10	61.79	61.74	63.94
TiO <sub>2</sub>	0.63	0.59	0.67	0.69	0.59	0.62	0.69	0.67	0.74	0.72	0.71	0.71	0.72	0.72
Al <sub>2</sub> O <sub>3</sub>	14.61	14.52	16.13	16.18	15.11	15.90	14.60	15.43	15.93	16.40	16.64	15.94	16.08	16.14
Fe <sub>2</sub> O <sub>3</sub>	2.00	1.91	2.51	2.90	2.59	1.79	1.82	2.28	2.92	3.52	3.16	2.76	3.36	2.76
FeO	2.71	2.40	2.07	2.65	2.27	3.01	2.91	2.79	3.02	2.53	2.87	3.13	2.54	2.96
MnO	0.062	0.053	0.34	0.063	0.060	0.058	0.054	0.063	0.079	0.087	0.086	0.086	0.094	0.085
MgO	1.83	1.62	3.34	2.35	2.09	1.77	1.84	2.05	2.21	2.52	2.46	2.26	2.41	2.30
CaO	1.01	0.58	1.33	0.44	1.53	0.43	1.19	0.86	1.63	0.55	1.07	0.57	1.16	0.67
Na <sub>2</sub> O	2.78	2.50	2.98	2.70	3.79	3.19	3.08	2.75	3.27	3.34	3.38	3.26	3.28	3.22
K <sub>2</sub> O	3.03	2.93	2.98	3.26	3.26	2.27	3.09	3.05	2.89	3.36	3.33	3.23	3.21	3.18
P <sub>2</sub> O <sub>5</sub>	0.13	0.12	0.15	0.12	0.10	0.11	0.16	0.12	0.15	0.12	0.13	0.12	0.13	0.13
H <sub>2</sub> O (+)	4.72	3.21	5.32	4.98	4.99	5.34	4.79	4.44	4.89	6.28	6.07	6.13	5.29	3.90

Sp. No.	60-7	60-8	60-9	60-10	60-11	60-12	61-1	62-1	62-2	62-3	62-4	62-5	62-6	63-1	63-2
SiO <sub>2</sub>	63.10	63.07	61.83	62.12	62.37	62.05	67.33	62.28	63.52	60.99	62.18	64.24	65.87	64.85	64.63
TiO <sub>2</sub>	0.71	0.69	0.71	0.71	0.69	0.82	0.50	0.71	0.70	0.71	0.72	0.69	0.69	0.69	0.69
Al <sub>2</sub> O <sub>3</sub>	16.06	15.91	16.38	15.92	15.88	15.69	15.40	15.57	15.61	15.85	16.37	15.41	15.19	15.80	15.53
Fe <sub>2</sub> O <sub>3</sub>	2.94	2.78	3.12	3.19	2.96	4.59	1.99	4.37	2.39	2.57	2.71	2.92	2.01	2.35	2.15
FeO	2.81	2.79	2.96	2.72	2.93	1.72	2.14	1.31	3.04	3.18	3.30	2.80	3.10	2.65	2.83
MnO	0.087	0.075	0.072	0.074	0.068	0.14	0.053	0.076	0.069	0.088	0.073	0.066	0.073	0.067	0.064
MgO	2.33	2.12	2.24	2.25	2.36	1.86	1.79	2.19	2.20	2.45	2.33	2.27	2.09	1.93	1.78
CaO	0.73	1.65	2.09	1.65	1.48	5.08	1.81	2.57	1.90	2.13	1.83	1.80	1.83	1.28	1.09
Na <sub>2</sub> O	3.31	3.53	3.33	3.17	3.24	4.03	3.09	3.07	2.80	3.51	3.09	2.90	2.71	2.75	2.79
K <sub>2</sub> O	3.18	2.86	2.82	2.86	3.02	1.42	2.45	2.82	2.87	2.88	3.09	2.86	2.77	3.20	3.16
P <sub>2</sub> O <sub>5</sub>	0.13	0.14	0.15	0.13	0.11	0.15	0.15	0.12	0.12	0.12	0.13	0.13	0.11	0.12	0.13
H <sub>2</sub> O (+)	4.60	4.40	4.30	5.21	4.91	2.44	3.32	4.93	4.78	5.53	4.19	3.92	3.56	4.32	5.16

Table VIII-3 Average chemical composition and their standard deviation in weight percent.

SiO <sub>2</sub>	63.56 ± 2.16
TiO <sub>2</sub>	0.69 ± 0.06
Al <sub>2</sub> O <sub>3</sub>	15.73 ± 0.54
Total Fe as Fe <sub>2</sub> O <sub>3</sub>	5.73 ± 0.10
MnO	0.083 ± 0.053
MgO	2.18 ± 0.33
CaO	1.45 ± 0.90
Na <sub>2</sub> O	3.13 ± 0.34
K <sub>2</sub> O	2.94 ± 0.38
P <sub>2</sub> O <sub>5</sub>	0.13 ± 0.012
H <sub>2</sub> O (+)	4.69 ± 0.89

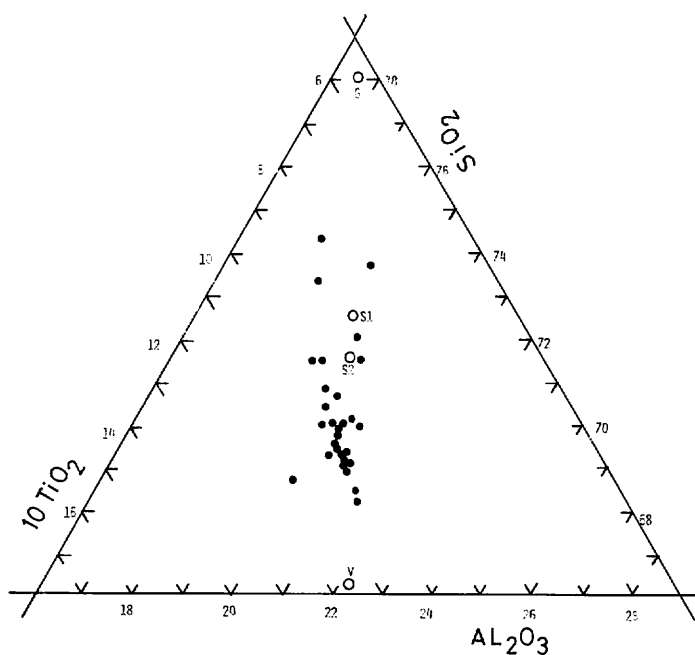


Fig. VIII-3 Relationship among SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and TiO<sub>2</sub>. Closed circles represent argillaceous sediments analysed. Open circles represent averaged Japanese rocks. G: granites (calculated from 440 analyses by GEOLOGICAL SURVEY OF JAPAN, 1960). S1 and S2: Paleozoic slates in outer zone of the southwest Japan (12 analyses) and in inner zone (31 analyses), respectively (MIYASHIRO and HARAMURA, 1960). V: Quaternary volcanic rocks (769 analyses; SUGISAKI, 1976).

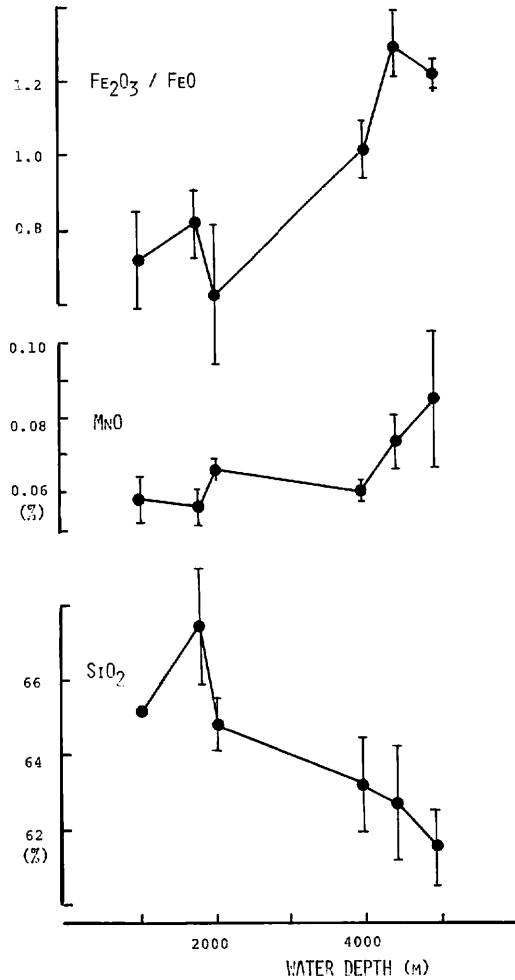


Fig. VIII-4 Relation of MnO, SiO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub>/FeO ratio in silicate composition of the samples versus water depth of the samples. Cores P57 and P61 are shown together.

composition (Table VIII-3) displays a higher degree of uniformity of the argillaceous sediments with respect to their geochemical characteristics, in spite of the large area of sampling, 600 km × 300 km.

In order to examine the sources of the components of the sediments, Figs. VIII-3 and 4 were constructed. Fig. VIII-3 illustrates the relationship among SiO<sub>2</sub>, TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>. These elements tend to remain in the resistates and hydrozates during sedimentation (e.g. RANKAMA and SAHAMA, 1950). It is, therefore, probable that the mutual abundance of elements remains stationary during weathering and the diagram is therefore expected to be helpful in the examination of the sediment source. The points on the diagram are located along a line connecting that of the averaged Japanese granites and that of the averaged Japanese Quaternary volcanics which are similar to



the averaged Paleozoic slate of Japan. This fact suggests that the sediments were derived mostly from the Japanese Islands and that the original material was chemically homogenized during sedimentation.

Variation trends of  $\text{SiO}_2$ ,  $\text{MnO}$  and the  $\text{Fe}_2\text{O}_3/\text{FeO}$  ratio with increasing water depth of the cores are apparent (Fig. VIII-4), although the sediments in this region as a whole reveal a close chemical similarity as stated above. This implies that the sediments at in the continental margin are characterized by low Mn, high Si, and high ferrous are gradually reorganized into ordinary pelagic sediments of high Mn, low Si and low ferrous.

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