

# XVII. MAJOR-ELEMENT CHEMISTRY OF BOTTOM SEDIMENTS FROM THE GH79-1 AREA, THE NORTHERN CENTRAL PACIFIC BASIN

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## **Introduction**

Surface sediments were collected during the GH79-1 cruise, Geological Survey of Japan, from the area of 10°–13°N and 165°–180°W. This paper describes an investigation of the major chemical compositions of surficial pelagic sediments of the area.

## **Methods and results**

Materials for this study (34 samples) were selected from box core samples. The samples examined (Table XVII-1) were mainly of an argillaceous or calcareous-argillaceous type. The sediments with more than 30% of siliceous organisms are designated "siliceous ooze" and those between 10% and 30%, "siliceous clay".

The sample for this study was dried at 110°C, ground, and subsequently split into fractions. One fraction was analysed with automatic X-ray fluorescence spectrometer JOEL-100S for Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P. Other fractions were analysed for total water, ignition loss, dissolved chlorine, ferrous iron, and carbonate. The procedure was described by SUGISAKI (1980a), being applied to the sediments of Legs 56 and 57, Deep Sea Drilling Project (IPOD).

The analytical results are shown in Table XVII-2. Table XVII-3 lists the compositions of the samples recalculated by excluding carbonates, salts, water, and residual materials (organic matter and others): these values are mostly used in the following discussions.

## **General characteristics of the sediments**

Samples having CaCO<sub>3</sub> were taken mostly from the depths shallower than 5,000 m, indicating that the calcium carbonate compensation depth is about 5,000 m.

Table XVII-4 lists the average chemical composition of the sediments. For comparison, other sets of averages are shown in the table, representing argillaceous piston core sediments from five regions around the Japanese Islands and pelagic sediments from the Atlantic, Pacific, and Indian Oceans and the Mediterranean Sea. As is naturally expected, the average of the present samples is much closer to that of pelagic sediments than those around the Japanese Islands. Standard deviations of the present samples are mostly larger than those for samples around the Japanese Islands. This indicates that the sediments in this region are more heterogeneous than those around the Japanese Islands probably because they suffer chemical fluctuations as discussed later. Another chemical aspect of the present samples is high contents of phosphorus and calcium.

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

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Table XVII-1 Description of samples.

Sample No.	Station	Observ. No.	Lat. (N)	Long. (W)	Depth (m)	Sediments
1	1448	G(B)915	12°58.41'	178°01.81'	5171	Zeolite clay
2	1449	G(B)916A	12°59.58'	176°59.61'	3957	Calcareous ooze
3	1450	G(B)917	13°01.09'	176°01.08'	5118	Zeolite clay
4	1451	G(B)918	13°01.63'	174°59.13'	5502	Siliceous clay
5	1452	G(B)919	13°02.68'	174°00.68'	5526	Zeolite rich clay
6	1453	G(B)920	13°01.60'	172°58.59'	5729	Zeolite rich clay
7	1454	G(B)921	12°00.03'	173°00.26'	5350	Siliceous caly
8	1455	G(B)922	10°59.18'	173°00.07'	5557	Siliceous clay
9	1457	G(B)924	12°01.78'	172°00.45'	5380	Siliceous clay
10	1458	G(B)925	13°00.21'	172°00.28'	5900	Siliceous clay
11	1459	G(B)926	12°57.47'	170°59.75'	5630	Siliceous clay
12	1460	G(B)927	11°58.11'	171°03.20'	5184	Siliceous clay
13	1462	G(B)929	11°24.81'	170°00.17'	4846	Calcareous clay
14	1463	G(B)930	12°01.02'	170°06.22'	5766	Siliceous clay
15	1465	G(B)931	13°00.77'	170°01.09'	5775	Siliceous clay
16	1465	G(B)932	13°00.31'	169°00.21'	5385	Clay
17	1466	G(B)933	12°00.55'	169°00.25'	5449	Siliceous ooze
18	1467	G(B)934	11°09.92'	169°00.06'	5222	Siliceous clay
19	1474	G(B)941	10°10.30'	167°20.43'	5153	Siliceous ooze
20	1473	G(B)940	11°20.17'	167°00.93'	4992	Clay
21	1475	G(B)942	10°00.10'	167°18.67'	5197	Siliceous clay
22	1476	G(B)943	9°49.68'	167°17.68'	5151	Siliceous fossil rich clay
23	1477	G(B)944	9°51.02'	167°33.51'	5197	Siliceous fossil rich clay
24	1478	G(B)945	10°00.29'	167°30.35'	5221	Siliceous clay
25	1479	G(B)946	10°10.45'	167°30.19'	5259	Siliceous ooze
26	1480	G(B)947	10°10.51'	167°50.33'	5256	Siliceous fossil rich clay
27	1481	G(B'C)948	10°01.36'	167°48.83'	5287	Siliceous fossil rich clay
28	1484	G(B'C)951	9°59.48'	167°39.60'	5244	Siliceous clay
29	1482	G(B)949	9°49.85'	167°50.02'	5222	Siliceous ooze
30	1483	G(B)950	9°49.64'	167°38.99'	5211	Siliceous clay
31	1485	G(B)952	10°09.34'	167°40.87'	5261	Siliceous ooze
32	1489	G(B)953	11°59.78'	174°59.37'	5370	Clay
33	1490	G(B)954	11°59.78'	176°00.73'	4877	Calcareous clay
34	1491	G(B)955	11°59.61'	177°01.12'	4517	Calcareous ooze

### Major source of the sediments

The present samples are mostly contaminated by biogenic silica, as stated later;  $\text{SiO}_2\text{-TiO}_2\text{-Al}_2\text{O}_3$  diagram (SUGISAKI, 1978), therefore, is not useful to examine the source of the sediments.  $\text{TiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$  relation is instead plotted in Fig. XVII-1, because that does not vary so much during sedimentation on the ocean floor (SUGISAKI, 1980 b). The compositional points of the samples fall along a line connecting points for averaged granites and averaged basalts, which are representative of the continental crust. The point for Hawaiian volcanics as well as one for oceanic tholeiites plots off the line.

Table XVII-2 Analyses of samples (dried at 110°C) for major constituents (% weight)

No.	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	H <sub>2</sub> O	CaCO <sub>3</sub>	Res*	Salt	Total
1	54.81	0.72	16.00	6.31	0.60	0.80	2.62	2.16	1.49	3.51	1.10	8.37	0.0	0.09	3.03	101.60
2	2.00	0.13	1.21	1.28	0.06	0.07	0.26	0.53	0.01	0.41	0.15	1.03	91.34	0.54	1.15	100.17
3	51.26	0.49	13.52	4.73	0.19	0.55	2.08	2.89	2.11	3.79	2.73	7.25	2.27	2.86	2.60	99.31
4	55.26	0.52	12.79	5.15	0.22	0.63	2.26	2.53	1.31	3.06	1.40	6.68	0.0	2.59	5.26	99.66
5	53.31	0.78	15.03	6.99	0.33	0.82	2.83	1.96	1.38	3.20	0.88	8.38	0.0	0.31	4.01	100.21
6	55.70	0.51	14.93	5.84	0.15	0.57	2.19	2.12	1.70	3.65	1.44	6.13	0.53	2.74	2.75	100.95
7	52.55	0.68	14.79	6.65	0.43	0.82	3.01	1.30	0.84	2.72	0.39	7.05	0.0	0.78	6.12	98.12
8	50.77	0.60	12.56	6.02	0.21	0.63	2.73	1.28	1.23	2.43	0.44	13.50	0.0	0.48	6.57	99.44
9	51.46	0.78	13.38	6.95	0.17	0.82	2.58	2.09	1.60	2.78	0.97	9.28	0.0	1.43	4.54	98.82
10	53.79	0.57	12.90	5.87	0.63	0.22	2.37	2.27	0.93	3.00	1.21	8.50	0.0	1.87	5.62	99.75
11	50.52	0.75	14.87	7.21	0.24	0.89	3.13	0.61	1.45	3.02	0.62	8.12	1.87	2.21	3.75	99.26
12	51.64	0.63	12.40	5.88	0.23	0.69	2.82	1.55	0.64	2.55	0.60	10.33	0.0	1.63	7.23	98.83
13	47.49	0.95	12.98	7.48	0.21	0.67	2.83	2.32	1.24	2.89	1.97	7.10	7.03	1.34	3.33	99.83
14	50.94	0.70	13.82	6.89	0.24	0.83	2.78	2.01	0.89	2.91	1.98	9.09	0.0	1.22	4.68	98.98
15	54.53	0.69	13.72	6.45	0.29	0.85	2.68	1.75	1.20	2.81	0.70	7.06	0.0	1.48	4.60	98.81
16	52.53	0.75	15.59	7.10	0.42	0.95	3.14	1.47	0.83	3.09	0.51	7.92	0.0	0.82	4.24	99.36
17	51.01	0.52	9.43	4.72	0.20	0.59	1.86	1.23	0.26	2.04	0.42	16.50	0.0	3.15	7.90	99.82
18	51.50	0.82	12.92	7.35	0.01	0.66	2.61	2.76	1.07	2.90	1.38	6.36	0.0	4.13	4.49	98.96
19	49.41	0.56	10.71	5.01	0.34	0.61	2.25	1.02	0.57	2.33	0.33	8.86	3.18	4.41	8.97	98.55
20	50.80	0.64	12.58	6.42	0.01	1.09	2.80	2.28	1.19	2.80	1.11	8.74	0.0	1.81	6.68	98.95
21	53.23	0.65	12.61	5.62	0.39	0.65	2.86	1.44	0.46	2.54	0.52	8.10	0.0	2.32	7.93	99.33
22	53.41	0.63	12.60	6.01	0.36	0.64	2.80	1.47	1.16	2.51	0.56	9.43	0.0	0.36	6.99	98.93
23	53.37	0.68	12.50	6.21	0.25	0.75	2.84	1.52	1.02	2.54	0.59	8.06	0.0	1.33	7.74	99.40
24	53.66	0.60	11.80	4.87	0.85	0.05	2.25	1.24	0.66	2.38	0.43	11.60	0.0	2.98	6.76	100.13
25	53.34	0.58	11.51	5.11	0.44	0.62	2.56	1.23	1.43	2.41	0.34	9.50	0.0	1.88	7.72	98.67
26	53.77	0.69	12.81	6.15	0.42	0.80	3.14	1.46	1.11	2.58	0.51	8.77	0.0	0.84	5.80	98.84
27	53.70	0.67	12.57	5.85	0.35	0.77	2.76	1.51	0.85	2.57	0.53	8.18	0.0	2.10	6.18	98.60
28	54.35	0.66	12.45	5.76	0.38	0.77	2.64	1.45	0.89	2.54	0.49	8.17	0.0	1.99	6.51	99.05
29	55.99	0.50	9.49	4.24	0.55	0.48	2.06	1.15	0.34	2.10	0.34	8.00	0.0	6.18	8.46	99.87
30	49.75	0.63	12.00	5.83	0.21	0.80	2.58	1.62	1.86	2.56	0.62	9.80	0.0	3.16	7.56	98.98
31	53.81	0.63	10.72	4.62	0.22	0.60	2.25	1.09	1.46	2.12	0.29	9.10	0.0	3.62	8.83	99.35
32	51.70	0.74	15.08	7.22	0.19	1.07	3.29	1.53	1.50	2.98	0.56	8.49	0.0	1.43	3.74	99.52
33	50.90	0.72	13.76	6.32	0.36	0.70	2.68	0.75	1.43	2.95	0.56	6.89	6.31	0.66	4.12	99.12
34	19.11	0.33	6.12	3.55	0.17	0.23	1.27	0.62	1.14	1.53	0.42	3.36	58.10	2.53	2.42	100.90

\*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.

Table XVII-3 Analyses for major constituents on a carbonate, water and residual materials free basis (% weight)

No.	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	Fe <sub>2</sub> O <sub>3</sub> /FeO	Tot. Fe
1	60.82	0.80	17.75	7.01	0.67	0.88	2.90	2.40	1.65	3.89	1.22	10.52	7.75
2	32.78	2.13	19.83	20.94	1.07	1.15	4.19	8.63	0.11	6.72	2.46	19.66	22.12
3	60.78	0.58	16.03	5.61	0.23	0.65	2.46	3.42	2.50	4.49	3.24	24.89	5.86
4	64.92	0.61	15.02	6.04	0.26	0.74	2.66	2.97	1.53	3.59	1.65	23.39	6.33
5	60.92	0.89	17.17	7.99	0.38	0.94	3.23	2.24	1.58	3.66	1.01	21.19	8.41
6	62.72	0.57	16.81	6.58	0.17	0.64	2.47	2.39	1.92	4.11	1.62	38.96	6.77
7	62.43	0.81	17.57	7.90	0.51	0.97	3.57	1.54	1.00	3.23	0.46	15.47	8.47
8	64.35	0.76	15.92	7.63	0.27	0.80	3.46	1.62	1.56	3.08	0.56	28.65	7.92
9	61.57	0.93	16.01	8.32	0.20	0.98	3.09	2.50	1.91	3.33	1.16	40.89	8.54
10	64.22	0.68	15.40	7.01	0.75	0.26	2.83	2.71	1.11	3.58	1.45	9.32	7.84
11	60.64	0.90	17.85	8.66	0.29	1.07	3.76	0.73	1.74	3.63	0.74	30.06	8.98
12	64.85	0.79	15.57	7.39	0.29	0.87	3.54	1.95	0.80	3.20	0.75	25.58	7.71
13	58.61	1.17	16.02	9.23	0.26	0.83	3.49	2.86	1.53	3.57	2.43	35.60	9.52
14	60.65	0.83	16.45	8.21	0.29	0.99	3.31	2.39	1.06	3.46	2.36	28.72	8.53
15	63.65	0.81	16.01	7.53	0.34	0.99	3.13	2.04	1.40	3.28	0.82	22.23	7.90
16	60.81	0.87	18.05	8.22	0.49	1.10	3.63	1.70	0.96	3.58	0.59	16.91	8.76
17	70.58	0.72	13.05	6.53	0.28	0.82	2.57	1.70	0.35	2.82	0.58	23.59	6.84
18	61.32	0.98	15.38	8.75	0.01	0.79	3.11	3.29	1.27	3.45	1.64	734.89	8.76
19	67.56	0.77	14.64	6.85	0.46	0.83	3.08	1.39	0.77	3.19	0.45	14.74	7.37
20	62.17	0.78	15.40	7.86	0.01	1.33	3.42	2.79	1.45	3.43	1.36	641.89	7.87
21	65.74	0.80	15.57	6.94	0.48	0.80	3.54	1.78	0.57	3.14	0.64	14.40	7.47
22	65.02	0.77	15.34	7.32	0.44	0.78	3.41	1.79	1.41	3.06	0.68	16.69	7.80
23	64.87	0.83	15.19	7.55	0.30	0.91	3.45	1.85	1.24	3.09	0.72	24.85	7.89
24	68.11	0.76	14.98	6.18	1.08	0.07	2.86	1.57	0.84	3.02	0.55	5.72	7.37
25	67.03	0.73	14.46	6.42	0.55	0.78	3.22	1.55	1.80	3.03	0.43	11.62	7.04
26	64.45	0.83	15.35	7.37	0.50	0.96	3.76	1.75	1.33	3.09	0.61	14.65	7.93
27	65.38	0.82	15.30	7.12	0.43	0.94	3.36	1.84	1.04	3.13	0.65	16.72	7.60
28	65.97	0.80	15.11	6.99	0.46	0.94	3.21	1.76	1.08	3.08	0.60	15.15	7.50
29	72.49	0.65	12.29	5.49	0.71	0.62	2.66	1.49	0.44	2.72	0.44	7.71	6.28
30	63.42	0.80	15.30	7.43	0.27	1.02	3.28	2.06	2.37	3.26	0.79	27.75	7.72
31	69.16	0.81	13.78	5.93	0.28	0.77	2.89	1.40	1.87	2.72	0.37	20.98	6.25
32	60.21	0.86	17.56	8.41	0.22	1.25	3.83	1.78	1.75	3.47	0.65	37.99	8.65
33	62.74	0.89	16.96	7.79	0.44	0.86	3.30	0.93	1.77	3.64	0.69	17.56	8.28
34	55.40	0.96	17.74	10.29	0.49	0.67	3.69	1.79	3.32	4.44	1.22	20.89	10.84

Table XVII-4 : Average chemical compositions (%) and standard deviations of sediments.

	GH79-1 area	Nankai Trough <sup>1)</sup>	Japan Trench <sup>2)</sup>	Yamato Bank area <sup>3)</sup>	Nishitsugaru Basin <sup>4)</sup>	Around the Oki Islands <sup>5)</sup>	Pelagic sediments <sup>6)</sup>
Number of samples	34	29	82	69	87	45	35
SiO <sub>2</sub>	62.83±6.34	66.68±1.99	68.84±2.78	65.80±3.84	66.58±2.02	75.59±2.57	61.52
TiO <sub>2</sub>	0.84±0.26	0.72±0.06	0.62±0.07	0.73±0.11	0.67±0.05	0.50±0.082	0.90
Al <sub>2</sub> O <sub>3</sub>	15.91±1.53	16.51±0.64	13.60±1.47	16.54±1.96	16.12±0.63	12.81±1.39	18.12
Total Fe as							
Fe <sub>2</sub> O <sub>3</sub>	8.26±2.64	6.01±0.65	5.67±0.92	6.94±1.54	5.85±0.45	4.03±0.81	9.09
MnO	0.85±0.24	0.09±0.06	0.07±0.02	0.48±1.95	0.07±0.04	0.044±0.013	0.64
MgO	3.25±0.41	2.29±0.36	3.11±0.37	2.91±0.71	3.31±0.42	1.16±0.34	1.00
CaO	2.19±1.29	1.51±0.93	2.38±1.19	1.04±0.65	1.93±0.90	1.57±0.53	3.19
Na <sub>2</sub> O	1.38±0.64	3.29±0.36	3.77±0.49	2.16±0.75	3.00±0.54	1.28±0.18	1.98
K <sub>2</sub> O	3.48±0.71	3.09±0.41	2.12±0.30	3.47±0.47	2.49±0.28	2.99±0.25	3.23
P <sub>2</sub> O <sub>5</sub>	1.05±0.70	0.14±0.01	0.15±0.13	0.16±0.075	0.17±0.15	0.097±0.021	0.33

1) SUGISAKI (1978).

2) SUGISAKI and HONZA (in preparation).

3) SUGISAKI (1979).

4) SUGISAKI (in preparation).

5) SUGISAKI and KINOSHITA (in preparation).

6) WAKEEL and RILEY (1961)

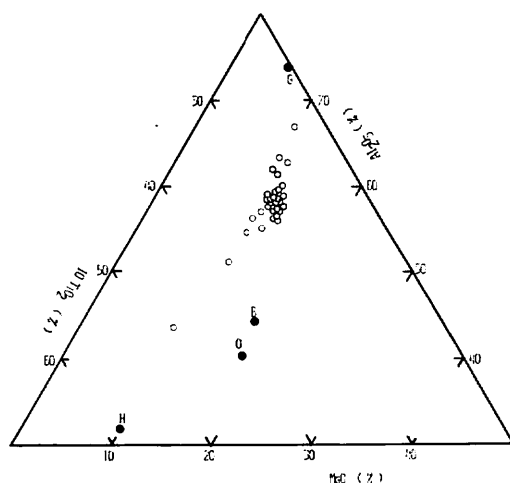


Fig. XVII-1  $\text{TiO}_2$ - $\text{Al}_2\text{O}_3$ - $\text{MgO}$  relation. Open circles represent the samples studied. Solid circles represent averaged rocks. G: granites (DALY, 1933). B: basalts (DALY, 1933). O: Pacific Rise tholeiites (ENGEL and ENGEL, 1964). H: Hawaiian volcanics (MACDONALD, 1968).

Table XVII-5 Correlation coefficients between  $\text{SiO}_2$  and other oxides.

$\text{TiO}_2$	-0.876
$\text{Al}_2\text{O}_3$	-0.802
$\text{Fe}_2\text{O}_3$	-0.940
$\text{FeO}$	-0.247
$\text{MnO}$	-0.357
$\text{MgO}$	-0.559
$\text{CaO}$	-0.830
$\text{Na}_2\text{O}$	-0.026
$\text{K}_2\text{O}$	-0.932
$\text{P}_2\text{O}_5$	-0.568

This strongly suggests a terrigenous origin of the present sediments rather than one derived from the submarine weathering of volcanics from oceanic islands and ocean floor. WAKEEL and RILEY (1961) have also chemically drawn the same conclusion that the deep-sea argillaceous sediments are mainly terrigenous.

### Precipitation of silica

$\text{SiO}_2$  is negatively correlated with most oxides (Table XVII-5). The relation of  $\text{SiO}_2$  versus  $\text{Al}_2\text{O}_3$  is exemplified in Fig. XVII-2. A regression line calculated by the least square method is  $\text{SiO}_2 = 102.2 - 2.43 \text{ Al}_2\text{O}_3$ . This formula gives 102.2 per cent of silica when  $\text{Al}_2\text{O}_3$  is null. This fact suggests that pure silica deposited against  $\text{Al}_2\text{O}_3$  during the sedimentation. The origin of the excess silica may be attributed to siliceous organisms such as radiolarians, because the samples with conspicuously high content of silica are identified as a siliceous ooze which contains much siliceous organisms.

In the equatorial region of the Pacific Ocean, the surface water has a high organic productivity, in part because of upwelling of deep water rich in nutrients (ARRHENIUS,

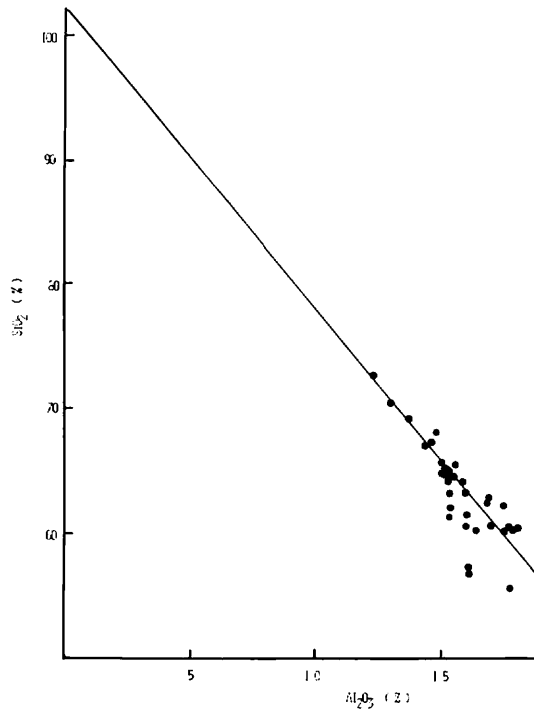


Fig. XVII-2 Relationship between  $Al_2O_3$  and  $SiO_2$ . The regression line is drawn by the least square method;  $SiO_2 = 102.2 - 2.43Al_2O_3$ . Correlation coefficient;  $-0.802$ .

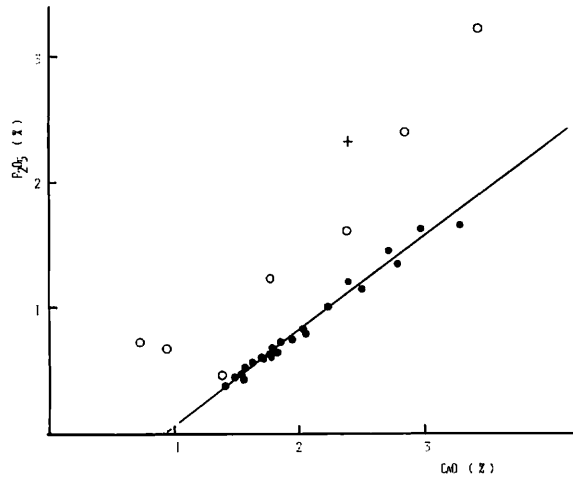


Fig. XVII-3 Relationship between  $CaO$  and  $P_2O_5$ . Open circles represent samples with  $CaCO_3$ . Others do samples without  $CaCO_3$ . The cross was excluded from the calculation of the regression line:  $CaO = 1.357P_2O_5 + 0.923$  with a correlation coefficient of  $0.967$ .

1963). Under the biogenic conditions, silica precipitates as opaline silica, and consequently siliceous ooze occurs as observed in this region.

#### **Precipitation of phosphorus and calcium**

$P_2O_5$  content in the samples is generally higher than those from other regions (Table XVII-4). The relation of  $P_2O_5$  versus CaO is plotted in Fig. XVII-3. A clear relationship for the samples without  $CaCO_3$  emerges from the plot. A regression line calculated for those samples by least square method is  $CaO = 1.357 P_2O_5 + 0.923$ ; the correlation coefficient is 0.967, indicating the precipitation of phosphorus associated with calcium. Atomic ratio of Ca:P during the precipitation calculated from the slope of the regression line amounts to 5:2.98. Considering an analytical error, the ratio can be regarded as 5:3. On ocean floors, skeletal apatite of organisms and authigenic phosphate minerals (mainly francolite) sometimes occur as carbonate apatite,  $Ca_5(PO_4, CO_3, CH_3)(F, OH)$ . Since its Ca:P ratio is 5:3, the correlation in Fig. XVII-3 indicates the occurrence of such materials, although clear peaks of the carbonate apatite do not appear in the X-ray diffraction patterns for present samples. Thus, calcium phosphates as well as biogenic silica predominantly occur under conditions of high organic productivity on this region.

According to the description of ARRHENIUS (1963), the phosphorite rock accumulating in areas of high organic productivity consists of a microcrystalline matrix of francolite with phosphatized test of foraminifera (originally consisting of calcite), skeletal apatite of marine vertebrates, thin flakes of opaline silica, films and grains of glauconite, interspersed dark-colored organic matter, and terrigenous minerals. NOHARA (1977), during the GH76-1 cruise in the Central Pacific Basin, observed that manganese nodules commonly have fossil phosphorite cores and he pointed out the genetic relationship between manganese minerals and phosphrites in the sediments. ARRHENIUS (1963) also noted the association of manganese nodules and phosphates in some deep-sea sediments. Manganese content of the present samples is high and manganese nodules sometimes occur on the ocean floor where the samples were collected. These observation and evidence imply the geochemical and biological condition prevailing in the region of GH79-1.

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#### **References**

- ARRHENIUS, G. (1963) Pelagic sediments. In HILLS, M. N. (ed.), *The Sea*, vol. 3, Intersci. Publ., N.Y., p. 655-727.
- DALY, R. A. (1933) *Igneous rocks and the depths of the earth*. McGraw-Hill Book Company, N.Y., 598p.
- ENGEL, A. E. and ENGEL, C. G. (1964) Igneous rocks of the East Pacific Rise. *Science*, vol. 146, p. 477-485.
- MACDONALD, G. A. (1968) Composition and origin of Hawaiian lavas. In COSTS, R. R., HAY, R. L., and ANDERSON, C. A. (ed.), *Studies in Volcanology*. *Geol. Soc. Am. Mem.*, vol. 166, p. 477-522.



- NOHARA, M. (1977) Mineralogy of manganese nodules. In MIZUNO, A. and MORITANI, T. (eds.), *Geol. Surv. Japan Cruise Rept.*, no. 8, p. 159–161.
- SUGISAKI, R. (1978) Chemical composition of argillaceous sediments on the Pacific margin of southeast Japan. In INOUE, E. (ed.), *Geol. Surv. Japan Cruise Rept.*, no. 6, p. 65–73.
- (1979) Chemical composition of argillaceous sediments around the Yamoto Bank in the Japan Sea. In HONZA, E. (ed.), *Geol. Surv. Japan Cruise Rept.*, no. 13, p. 75–88.
- (1980a) Major element chemistry of the Japan Trench sediments, Legs 56 and 57, Deep Sea Drilling Project. In Scientific Party, *Initial Reports of the Deep Sea Drilling Project*, vol. 56–57, Washington (U.S. Government Printing Office), pt. 2, p. 1233–1249.
- (1980b) Major-element chemistry of argillaceous sediments at Deep Sea Drilling Project Sites 442, 443, and 444, Shikoku Basin. In DEVRIES KLEIN, G., KOBAYASHI, K., et al., *Initial Reports of the Deep Sea Drilling Projects*, vol. 58, Washington (U.S. Government Printing Office), p. 719–735.
- Chemical composition of argillaceous sediments around the Nishitsugaru Basin in the Japan Sea. In INOUE, E. (ed.), *Geol. Surv. Japan Cruise Rept.* (in preparation).
- and KINOSHITA, T. Chemical composition of argillaceous sediments around the Oki Islands, the Japan Sea. In INOUE, E. (ed.), *Geol. Surv. Japan Cruise Rept.* (in preparation).
- and HONZA, E. Chemical composition of argillaceous sediments in the Pacific margin of northeast Japan. *Bull. Geol. Surv. Japan.* (in preparation).
- WAKEEL, S. K. El and RILEY, J. P. (1961) Chemical and mineralogical studies of deep-sea sediments. *Geoch. Cosmoch. Acta*, vol. 25, p. 110–146.