

57. CHEMICAL COMPOSITION AND METAL ACCUMULATION RATES OF JAPAN TRENCH INNER SLOPE SEDIMENTS, LEG 57, DEEP SEA DRILLING PROJECT

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INTRODUCTION

Several papers have recently appeared concerning the metalliferous sediments on the active oceanic ridges. The geochemistry of such sediments is reasonably well understood and the deposits generally considered to be products of volcanic processes (Boström and Peterson, 1969; Boström et al., 1969; Horowitz, 1970, 1974; Cronan et al., 1972; Cronan and Garrett, 1973; Piper, 1973). The geochemistry of trench sediments, however, is less well known. There is a great need for studies of trench inner slope sediments, particularly in view of the significance of such sediments as a record of the effects of oceanic plate subduction under the continental crust. Sampling by *Glomar Challenger* in the trench inner slope was therefore of utmost importance in determining the origin of trench inner slope deposits.

ANALYTICAL METHOD

Samples were dried at less than 35 °C. Prior to chemical analysis, the sediments were ground to a smaller than 200-mesh screen with a Retisch mortar grinder. Chemical analyses were carried out with a Perkin-Elmer 503 atomic absorption spectrophotometer after a combined HF-HClO₄-HCl digestion involving double fuming with HF-HClO₄. All determinations were done in duplicate, and the precision and accuracy of the analyses were checked by using JG-1 and JB-1 J.G.S. standards. In most cases, accuracy of concentrations of various elements in J.G.S. standard samples was in agreement within ± 15 per cent for Al and Ti and within ± 5 per cent for other elements.

RESULTS AND DISCUSSION

Vertical Profiles of Chemical Composition in the Japan Trench Inner Slope Sediments

The results of bulk chemical analyses for Leg 57 presented in Table 1 and Figures 1 and 2 are for untreated samples, since carbonate correction or normalizing to either Al + Fe + Mn, 4Al + Fe + Mn + Ti, or Al₂O₃, as has been suggested by various other workers (Boström and Peterson, 1969; Boström et al., 1969; Piper, 1973), does not markedly alter the distribution patterns.

Site 438 (Holes 438, 438A, and 438B)

Holes 438, 438A, and 438B at Site 438 were drilled in a fault-bounded block on a terrace in the trench inner slope. We recovered continuous hemipelagic sediment sections from the three holes ranging from the lower

Miocene to the Pleistocene. With some exceptions, the intervening middle Miocene through upper Pliocene lithology is relatively monotonous, consisting mainly of diatomaceous clay-claystone and clayey diatom ooze-diatomite. A substantial volcanic ash component is present in the upper 500 meters of sections, both as ash layers and as volcanic glass dispersed within the oozes and clays.

Al is markedly variable, ranging from 3.3 to 8.1 per cent and averaging 6.1 per cent. Its high values occur in the Pliocene-Pleistocene and the lower-middle Miocene, in which volcanic glass is abundant (5–15 per cent); (2–5 per cent). It is found only in small quantities throughout the remainder of the sections. Ti is also high in volcanic ash layers and in disseminated volcanic glass. Its vertical variations, however, are small with respect to those of Al. Fe concentrations vary from 1.3 to 4.8 per cent and average 2.3 per cent. In general, its values show small vertical variation, with a few exceptions. It occurs in elevated amounts in the upper and in near-bottom sections, which are the Pliocene-Pleistocene and lower-middle Miocene. Mn reveals no remarkable vertical variations either. The upper (Pleistocene) and lower (lower Miocene) parts are relatively enriched in Mn as well as in Fe.

Of the trace elements, Cu is depleted in Pleistocene and in part of the lower Pliocene sediments, and its concentrations reflect no sediment characteristics. For instance, the Cu concentrations in diatomaceous ooze are similar to those in volcanic ash or volcanic glass. Similarly, the geochemical profiles of Zn, Ni, and Cr display no continuous trend throughout the core sections, although their values reach a maximum in the lower parts. Co, Li, and Sr are somewhat variable compared with other trace elements. The major contributors of Sr to the marine sediments are the carbonate-forming coccoliths and foraminifers (Turekian, 1964). Sr concentrations, however, are low in upper Miocene sediments (593–817 m); these sediments do sometimes contain calcareous concretions and limestone, however, though these were not analyzed.

Site 439

The hole at site 439 was drilled at a depth of 1656 meters, about 35 km landward from the top of the Japan Trench inner slope. It is 5 km from site 438 and begins with the same stratigraphic sequence. The lithology of sediments is diatom-bearing claystone, interbedded sandstone-siltstone, massive friable silty sandstone, and very well indurated silty claystone. Their ages of sediments analyzed range from lower Miocene to upper Oligocene.

TABLE 1
Analytical Results of Sediment Samples from Deep Sea Drilling Project Leg 57

Sample (Interval in cm)	Al (%)	Ti (%)	Fe (%)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Ni (ppm)	Co (ppm)	Cr (ppm)	Li (ppm)	Sr (ppm)
Hole 438											
1-2, 98-102	8.07	0.40	2.28	834	16	70	42	32	49	26	64
3-2, 60-64	7.03	0.54	2.53	413	30	88	58	30	76	37	131
5-4, 30-34	8.13	0.50	4.82	781	18	96	43	35	58	25	58
7-2, 60-64	6.62	0.44	2.03	539	31	88	45	33	45	26	61
9-2, 132-136	6.19	0.41	2.29	437	27	93	45	35	49	32	50
10-3, 100-104	7.16	0.46	2.08	569	24	99	54	37	58	29	71
11-2, 76-80	6.36	0.48	2.68	563	20	93	42	34	62	23	73
Hole 438A											
1-2, 66-70	7.67	0.54	3.69	713	5	102	42	46	58	24	98
3-2, 72-76	7.90	0.52	3.61	711	2	93	46	40	52	25	72
5-2, 145-147	6.78	0.36	1.92	528	14	72	24	30	27	20	126
7-2, 41-42	5.17	0.38	1.94	405	26	96	50	23	55	41	72
9-1, 22-24	3.95	0.35	2.15	315	37	86	38	19	48	30	71
11-2, 84-88	3.33	0.27	1.43	272	13	76	40	10	41	26	67
13-2, 9-13	3.28	0.40	1.36	294	33	81	46	5	39	32	57
17-2, 62-64	5.94	0.41	1.99	388	51	108	56	15	56	55	37
19-2, 60-64	4.81	0.34	1.91	381	35	89	48	16	40	47	35
21-2, 40-44	5.56	0.40	1.90	358	36	101	51	16	46	55	34
23-1, 34-38	5.57	0.35	1.43	250	41	98	44	15	53	46	31
24-1, 20-22	6.65	0.42	1.98	313	34	114	42	23	67	55	24
25-2, 120-124	6.00	0.38	1.78	324	45	101	40	13	58	51	48
27-2, 50-54	7.51	0.32	1.74	258	42	99	37	9	41	44	40
29-2	3.64	0.26	1.29	171	34	86	34	4	46	38	24
31-2, 40-44	3.30	0.26	1.39	230	30	93	31	6	43	38	83
33-2, 36-40	4.87	0.36	2.73	456	31	94	39	15	43	36	45
35-2, 10-14	5.29	0.29	1.62	446	30	95	41	26	41	36	34
37-2, 52-54	4.12	0.33	1.94	220	41	93	73	25	47	46	19
39-2, 100-102	4.75	0.31	1.70	300	35	91	39	16	39	45	64
41-2, 121-123	4.97	0.32	1.71	247	25	88	29	10	39	51	39
43-2, 132-136	6.40	0.40	2.68	327	1	99	53	24	58	57	16
45-2, 70-74	5.46	0.36	1.96	287	28	85	43	16	60	54	24
47-2, 72-76	5.87	0.37	1.68	329	31	84	46	18	43	56	19
49-2, 80-82	6.10	0.39	1.98	349	36	102	51	14	41	67	41
51-2, 27-29	7.70	0.43	2.38	446	34	104	57	25	49	79	31
53-1, 116-120	5.78	0.35	2.13	268	38	101	44	12	37	60	30
55-2, 50-52	5.01	0.32	2.05	237	36	89	27	9	35	64	31
57-2, 20-24	6.13	0.39	1.88	295	41	106	49	20	38	88	21
59-2, 74-78	6.49	0.37	1.68	300	30	103	33	15	39	99	45
63-1, 42-44	4.92	0.34	1.67	338	28	105	41	11	38	83	57
65-1, 77-79	4.78	0.30	1.60	241	50	96	52	11	27	88	17
70-2, 64-67	6.84	0.38	2.56	292	58	150	58	23	35	80	15
71-2, 121-125	4.62	0.31	1.75	264	45	112	64	8	32	61	10
73-2, 67-68	5.88	0.41	1.76	267	48	133	56	16	49	71	22
85-2, 72-74	6.38	0.39	2.01	283	41	119	49	13	35	83	26
Hole 438B											
6-2, 121-125	5.34	0.36	2.34	329	45	145	40	19	37	87	49
7-2, 98-102	6.48	0.44	2.74	388	35	107	48	26	45	71	20
9-2, 100-102	8.02	0.53	2.97	611	33	110	49	38	36	62	52
11-2, 59-66	7.19	0.54	2.59	458	35	96	46	29	59	69	44
12-3, 128-130	7.20	0.46	2.05	369	21	86	41	21	53	78	51
13-2, 78-80	7.00	0.40	1.68	300	23	80	42	23	42	84	67
15-1, 57-58	7.05	0.52	2.72	414	29	104	52	25	50	103	43
17-2, 61-65	7.62	0.57	2.69	359	21	93	90	25	126	109	64
19-2, 28-32	6.01	0.44	4.52	313	12	81	61	16	129	63	48
21-2, 75-78	7.65	0.43	2.43	234	56	64	64	25	49	79	34
23-2, 104-105	7.54	0.52	2.55	277	26	84	84	22	65	66	61
Hole 439											
7-2, 90-93	7.55	0.46	2.91	352	49	108	52	20	43	86	42
9-2, 16-19	5.68	0.36	2.28	349	50	145	63	16	50	78	46
11-2, 29-32	7.89	0.54	3.07	660	36	110	50	28	50	61	37
13-1, 86-88	8.55	0.50	2.44	323	15	78	59	31	71	90	23
15-2, 105-107	7.80	0.49	2.21	307	17	81	55	24	62	68	20
17-3, 28-31	7.36	0.50	2.36	278	10	73	44	20	48	91	23
19-1, 57-58	7.46	0.42	2.43	371	12	67	41	14	61	92	17
21-2, 68-70	6.24	0.43	2.35	314	12	74	48	9	79	95	39

TABLE 1 – Continued

Sample (Interval in cm)	Al (%)	Ti (%)	Fe (%)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Ni (ppm)	Co (ppm)	Cr (ppm)	Li (ppm)	Sr (ppm)
Hole 439											
23-2, 17–19	7.99	0.41	1.90	262	10	63	42	25	38	83	17
25-1, 78–81	7.91	0.43	1.56	361	18	63	44	29	40	56	53
27-1, 99–101	7.96	0.32	1.82	275	7	64	37	34	25	55	51
29-1, 114–119	8.43	0.34	1.94	324	11	45	44	31	20	62	50
31-2, 86–88	6.48	0.34	1.75	678	7	52	37	19	25	47	75
Hole 440											
1-2, 53–57	7.83	0.46	2.43	429	37	84	40	32	74	37	84
3-1, 86–90	7.10	0.44	2.26	485	53	94	54	27	55	34	31
5-1, 70–74	6.95	0.43	2.36	519	50	97	50	20	58	35	48
7-1, 135–139	7.18	0.52	2.59	457	61	95	51	26	67	41	20
Hole 440A											
3-1, 16–20	6.77	0.49	2.72	493	39	88	47	15	74	39	52
5-3, 114–118	8.00	0.50	2.26	488	58	102	47	26	63	40	14
7-1, 48–52	6.49	0.44	2.46	458	46	91	44	16	58	44	47
Hole 440B											
1-1, 94–98	7.27	0.39	1.95	366	68	96	41	20	57	31	32
3-1, 120–124	7.34	0.43	1.88	381	42	85	50	18	47	37	24
5-1, 106–110	7.67	0.45	2.79	663	35	91	50	22	34	36	19
7-1, 70–74	7.85	0.51	3.09	371	57	96	58	25	58	49	18
9-1, 133–137	6.86	0.43	2.89	457	55	98	53	18	41	37	30
11-1, 24–28	7.31	0.43	2.12	422	71	109	56	23	41	35	25
13-1, 144–148	8.04	0.48	1.77	391	62	97	57	26	47	44	12
15-1, 24–26	6.78	0.44	2.99	425	81	107	56	11	55	38	33
17-1, 33–38	6.75	0.43	2.47	2095	69	118	66	23	35	35	31
19-1, 138–142	6.22	0.38	2.71	506	63	113	53	21	34	30	34
21-1, 48–52	6.07	0.37	2.05	890	33	91	46	16	18	22	66
23-1, 110–114	6.66	0.38	2.69	1237	67	118	58	29	34	38	51
25-1, 26–30	5.57	0.42	2.45	503	82	99	48	20	40	41	26
27-1, 120–122	4.20	0.31	1.83	391	53	82	43	3	21	25	34
29-1, 20–22	5.05	0.39	1.91	352	54	88	38	8	33	41	43
31-1, 124–128	3.77	0.31	1.74	263	53	69	36	13	33	30	14
33-1, 131–135	5.02	0.35	1.51	344	50	80	41	17	40	37	19
35-1, 114–117	5.08	0.25	1.30	361	42	70	30	10	21	28	14
37-1, 44–46	4.21	0.29	2.02	298	44	69	43	9	30	25	10
39-1, 92–94	3.88	0.27	1.58	230	43	72	52	7	45	25	24
41-1, 102–105	4.25	0.28	1.92	207	61	70	49	7	40	26	1
43-1, 80–83	4.17	0.30	2.00	309	44	77	49	8	44	29	27
45-1, 134–138	5.23	0.32	2.33	288	58	79	42	15	45	33	7
47-1, 45–49	4.98	0.36	2.14	317	36	81	55	8	58	32	28
49-1, 70–72	3.82	0.24	1.70	252	46	65	37	19	34	25	1
51-1, 64–68	5.74	0.37	2.57	503	59	95	52	22	40	37	37
53-1, 82–84	5.77	0.37	2.81	979	57	96	51	20	50	40	4
55-1, 64–67	6.89	0.37	2.68	426	57	93	49	20	44	35	22
57-1, 21–26	6.14	0.36	2.50	301	66	103	41	18	46	42	5
59-1, 106–108	5.37	0.33	2.64	401	85	93	69	21	42	36	35
61-1, 70–72	6.55	0.41	3.07	410	72	98	63	19	44	44	2
63-1, 58–60	3.86	0.29	2.04	362	72	81	53	8	43	36	1
65-1,	4.85	0.33	2.46	698	61	98	66	16	43	40	4
67-1, 124–126	5.73	0.38	3.00	450	58	96	58	18	46	43	4
69-1, 136–139	6.67	0.40	2.65	474	60	96	62	15	40	44	19
71-1, 51–54	6.84	0.49	3.11	601	68	98	40	23	49	53	8
Hole 441											
1-2, 52–56	7.50	0.54	2.97	828	46	88	25	31	51	32	67
7-1, 43–45	5.39	0.35	2.25	613	69	91	52	13	43	34	11
8-1, 140–144	5.02	0.35	1.89	417	66	77	50	9	37	30	9
Hole 441A											
4-4, 22–27	6.07	0.36	2.32	390	72	81	58	11	37	35	1
5-1, 96–100	7.08	0.49	3.31	557	22	75	46	19	42	42	1
11-1, 28–30	7.71	0.44	2.34	1154	74	107	55	26	30	49	3
12-1, 130	5.97	0.35	2.01	690	66	86	53	14	52	40	5
13-1, 98–102	5.83	0.38	2.45	591	67	95	41	22	45	41	5
Hole 441B											
1-1, 27–30	6.61	0.36	2.14	576	77	85	50	20	43	40	9
2-1, 89–91	7.83	0.40	2.73	1300	87	89	58	36	45	45	1

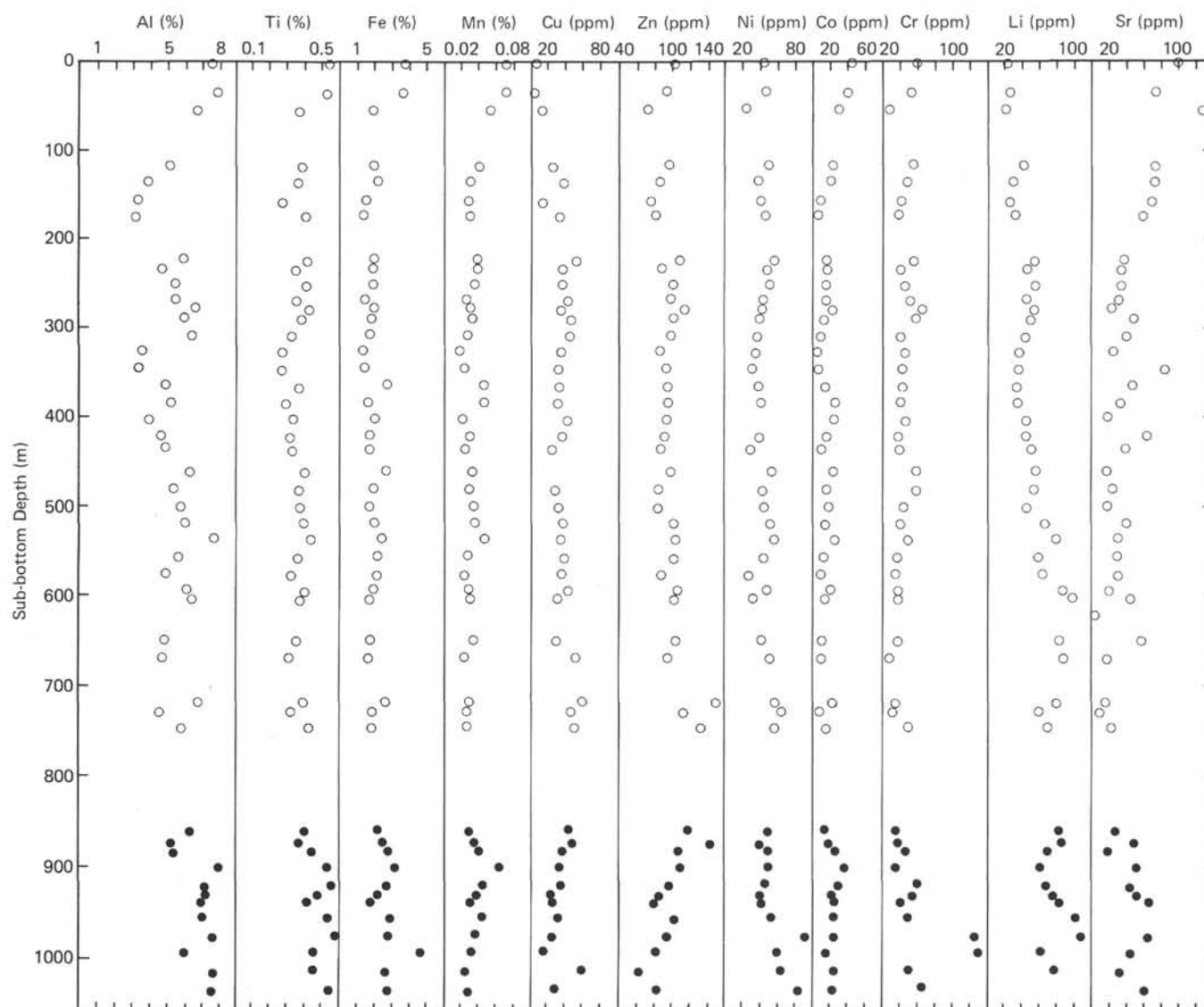


Figure 1. Sediment composition of Site 438, uncorrected for carbonate and salt, versus depth. (Open circle represents Hole 438A sediments; solid circle represents Hole 438B sediments.)

Vertical distribution of Al and Ti exhibits no particular pattern throughout the core sections, whereas Fe concentrations show an abrupt change at the boundary between the upper Oligocene and the middle Miocene. Mn is not correlative to either the lithologic features or the age of sediments, although its higher values occur in both Miocene and the upper Oligocene sediments. Cu and Zn tend to decrease slightly toward basement. Co reaches a maximum value in the lower part of the lower Miocene sediments, but this maximum is less than that of other trace elements. Although Cr concentrations are lower in the upper Oligocene than in the Miocene, there is no vertical variation in abundance. Li concentrations are higher in the Miocene, especially the lower Miocene, than in the upper Oligocene. In contrast, Sr concentrations are lower in the lower Miocene than in the middle Miocene and upper Oligocene. The elevated Sr levels in the upper Oligocene may be due mainly to numerous molluscan fragments.

Site 440 (Holes 440, 440A, and 440B)

Three holes (Holes 440, 440A, and 440B) were drilled at Site 440 on the trench inner slope, 28 km west of the Japan Trench axis. The samples range in age from late Miocene to Holocene. The predominant lithological features are pebbly silt, clayey silt, diatomaceous ooze, diatomaceous claystone, and siltstone containing intervals characterized by mass-movement disturbance of the bedding.

The chemical composition of sediments at Site 440 reflects no lithological characteristics (Figure 2). Al content is higher in the upper Pliocene-Holocene and lower Miocene. The samples between 440 and 600 meters sub-bottom (lower-upper Pliocene) generally contain less Al than samples in the upper and in the near-bottom parts of cores. The vertical Ti distribution pattern is similar to that of Al. As is obvious from Figure 2 and Table 2, the vertical profile of Fe exhibits a significantly uniform

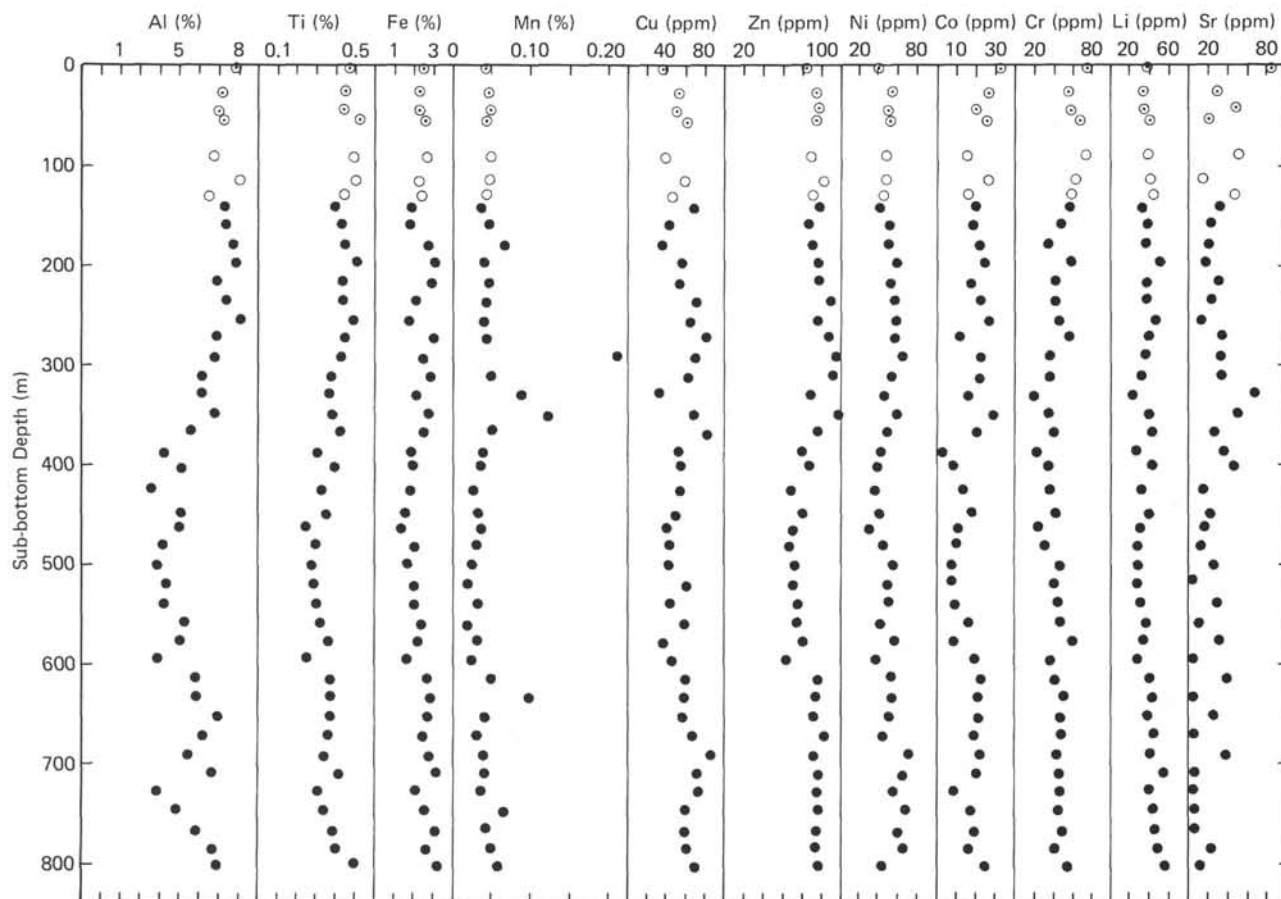


Figure 2. Sediment composition of Site 440, uncorrected for carbonate and salt, versus depth from sediment surface. (Circle with center dot represents Hole 440 sediments; open circle represents Hole 440A sediments; solid circle represents Hole 440B sediments.)

distribution. By contrast, Mn is remarkably variable. However, its elevated values, which occur in the upper Pliocene-lower Pleistocene (290–350 m sub-bottom) and lower Pliocene (630 m sub-bottom), provide no correlation with either lithological natures or geological ages. Furthermore, there are no significant differences in distributions of trace elements throughout the core sections, in spite of a slight increase in Zn, Cu, Co, and Cr near 300 and 600 meters sub-bottom.

Site 441 (Holes 441, 441A, and 441B)

Site 441 is located downslope from Site 440 at a water depth of 5656 meters. The lithology of cores from Site 441 is very similar to those from Sites 434 (Leg 56) and 440. The composition of sediments at all these sites is hemipelagic clay and silt with variable siliceous biogenic and volcanic components. Geologic age ranges from the lower Miocene to the Holocene. The cores are highly fractured, and consequently core recovery is poor.

Table 2 shows that the amount of major and minor elements in the different sediments is comparable to that of equivalent ages at other sites, except for Mn and Sr. Al, Ti, and Fe are abundant in the upper parts of cores (Pleistocene) compared to the lower zones (lower Pliocene-upper Miocene). Average Mn concentrations in the Pleistocene and upper Miocene are comparable and

twice as high as in the lower Pliocene. The remarkably higher concentration of Sr in the Pleistocene, which is about 10 times as large as in the Pliocene-Miocene, may result in part from the presence of calcareous pebbles or concretions.

The relations between the major elements Al, Fe, and Mn are shown in the ternary diagram in Figure 3. The sediments from Leg 57 are obviously exceptionally poor in Mn. In general, Al-poor and Fe- and Mn-rich deposits have been found on submarine volcanoes (Zelenov, 1964; Bonatti and Joensuu, 1966), active oceanic ridges, or near-basement sediments in contact with basalts (Murray and Renard, 1891; Revelle, 1944; El Wakeel and Riley, 1961; Boström and Peterson, 1969; Boström et al., 1969; Horowitz, 1970, 1974; Cronan et al., 1972; Cronan and Garrett, 1973; Piper, 1973). Such metalliferous sediments have been considered to originate from volcanic processes such as volcanic emanations or hydrothermal leaching of basalt with sea water. Figure 3 demonstrates that the sediments from Leg 57 are apparently different from those in the active oceanic ridge (A in Figure 3), in volcanogenic or low heat flow areas on the active ridge (B), and in metalliferous basal sediments (C). Moreover, sediments from the Japan Trench transect are Al-rich and Mn- and Fe-poor with respect to those in the present normal pelagic sediments of the

TABLE 2
Average Chemical Composition of Sediments from Deep Sea Drilling Project Leg 57

Site	Sub-bottom Interval (m)	Age	Al (%)	Ti (%)	Fe (%)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Ni (ppm)	Co (ppm)	Cr (ppm)	Li (ppm)	Sr (ppm)	R ^b
438	0-38	Pleistocene ^a	7.74	0.48	3.21	677	21	85	48	61	29	29	84	0.22
	55-93	Upper Pliocene ^a	6.58	0.45	2.27	527	26	93	47	35	54	28	64	0.23
	0-35	Pleistocene	7.79	0.53	3.65	712	4	98	44	43	55	25	85	0.22
	55-135	Upper Pliocene	5.30	0.36	2.00	416	26	85	37	24	43	30	90	0.22
	175-223	Lower-Upper Pliocene	3.31	0.34	1.40	283	23	79	43	8	40	29	62	0.22
	223-384	Lower Pliocene	5.83	0.34	1.80	325	37	98	42	14	49	46	40	0.23
	403-576	Upper Miocene	5.66	0.36	2.01	300	31	95	46	17	44	61	30	0.23
	595-747	Middle Miocene	5.70	0.36	1.86	284	43	115	50	15	37	81	27	0.23
	875-1035	Lower Miocene	7.06	0.47	2.66	368	31	95	56	24	63	79	48	0.22
439	871-994	Lower Miocene	7.32	0.46	2.51	369	25	92	52	20	58	83	31	0.23
	1013-1089	Upper Oligocene	7.75	0.37	1.79	380	11	57	41	28	30	61	49	0.23
440	0-36	Holocene	7.27	0.46	2.41	473	50	93	49	26	64	37	46	0.23
	55-131	Upper Pleistocene	7.09	0.48	2.33	480	48	97	46	19	65	41	38	0.23
	141-292	Lower Pleistocene	7.32	0.44	2.44	619	60	100	54	21	42	38	25	0.23
	312-368	Upper Pliocene	5.32	0.36	2.11	561	57	93	45	16	32	33	36	0.22
	464-653	Lower Pliocene	4.91	0.31	2.10	379	50	79	46	13	31	30	16	0.22
	672-805	Upper Miocene	5.75	0.37	2.68	462	68	95	57	17	44	43	10	0.22
441	0-3	Pleistocene	7.50	0.54	2.97	882	46	88	25	31	51	32	67	0.22
	145-387	Lower Pliocene	5.89	0.39	2.44	494	57	81	52	13	40	35	6	0.22
	586-669	Upper Miocene	6.79	0.39	2.33	862	74	92	51	24	43	43	4	0.23

^aHole 438.^bAl/(4Al + Ti + Fe + Mn) ratio.

Pacific (D). It is reasonable, therefore, to conclude that the sediments from Leg 57 are mostly of a nonvolcanic, "shallower" water origin, although volcanic ash composes a significant part of the sediment. This conclusion is also supported by the ternary diagram Zn-Ni-Cu. It is obvious from Figure 4 that sediments from this area are chemically intermediate between the terrigenous and pelagic sediments.

Modes of Sedimentation

Examination of the data presented in Tables 1 and 2 and in Figures 1 and 2 indicates a marked difference in the concentrations of the elements through time. Al and Ti reflect principally the abundance of detrital constituents, whereas Fe and Mn are controlled primarily by the abundance of authigenic constituents (Chester and Hughes, 1966, 1967; Krishnaswami, 1976).

In order to compare directly sediments of different ages, it is necessary to remove the diluting effects of biogenic carbonate and silicate, organic matter, and dried sea salt. To accomplish this, the data were normalized following the procedures outlined by Boström et al. (1972). The calculated Al/(4Al + Ti + Fe + Mn) ratios should provide a strong indication of the amount of metals tied up in authigenic phases (represented by Fe and Mn) as well as the amount present in detrital constituents (represented by Al and Ti), and should, because of the removal of most of the dilutants normally present in marine sediments, permit the direct comparison of the authigenic constituents of sediments from

different locations and of different ages. As the detrital phases increase, the ratio will increase, whereas as the authigenic constituents increase, the ratio will decrease.

As Table 2 demonstrates, the ratios (0.22-0.23) are slightly greater than those for normal Pacific pelagic sediments (0.20-0.21) and significantly differ from the 0.02 to 0.16 ratios for active oceanic ridge sediments cited by Nohara and Yokota (1978). These high ratios suggest that the chemical composition of sediments from Leg 57 are at least partly the result of terrigenous contamination. Furthermore, the Japan Trench transect sediments appear to be fairly uniform geochemically on the basis of the Al/(4Al + Ti + Fe + Mn) ratios. This would indicate that both authigenic element deposition and detrital input have been relatively constant in this area since the late Oligocene (about 32 m.y.B.P.), although volcanic materials were sporadically deposited.

Accumulation Rates of Elements

Table 3 shows the accumulation rates of sediments. These rates are problematic, however. Most serious is the possibility of physiographically induced error: for example topographic change in the ocean floor through slumping, folding, or turbidity may enhance or decrease the accumulation rate. Therefore uncertainty in dating in physical properties of the sediments may produce errors on the order of 10 to 20 per cent.

The accumulation rates at Sites 438 increase significantly from below the lower Pleistocene-uppermost Pliocene, through the Pliocene, until just below the

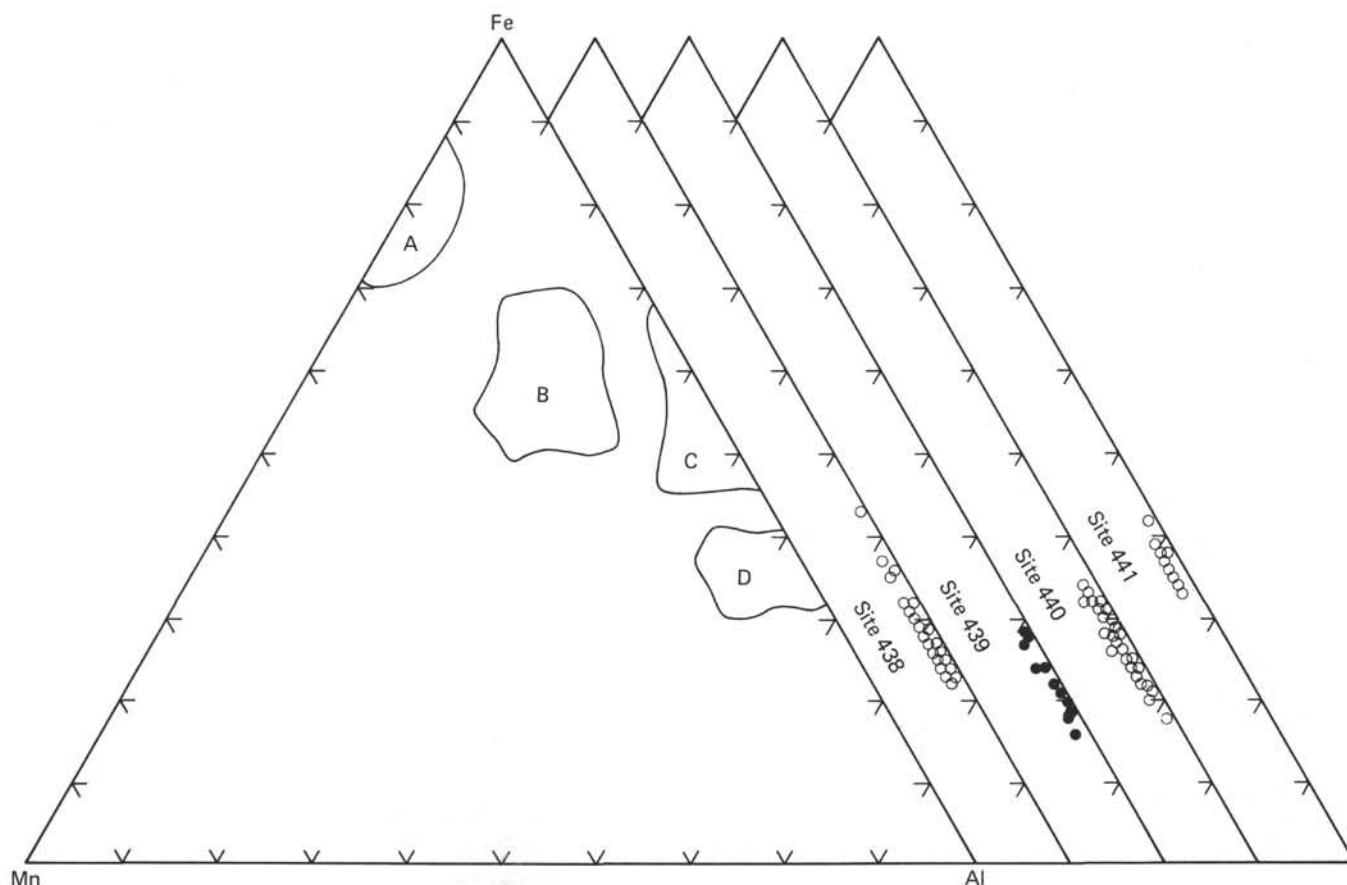


Figure 3. Variations in aluminum, iron, and manganese content in marine sediments. A. High heat flow oceanic ridge sediments (Boström and Peterson, 1969; Boström et al., 1969). B. Low heat flow oceanic ridge or volcanogenic sediments (Goldberg and Arrhenius, 1958; El Wakeel and Riley, 1961; Boström and Peterson, 1969; Boström et al., 1969.) C. Metalliferous basement sediments in contact with volcanic rocks (Horowitz and Cronan, 1976). D. Normal pelagic sediments of the Pacific (Revelle, 1944; Goldberg and Arrhenius, 1958; El Wakeel and Riley, 1961).

Miocene/Pliocene boundary (Table 3). The lower-middle Miocene sediments have slower accumulation rates (8000–9300 mg/cm²/1000 yr.). The rate is lowest in the upper Miocene, perhaps because of compaction of the sediments. The core samples (870–1090 m sub-bottom) at Site 439, which are lower Miocene-upper Oligocene, show lower values than samples of equivalent age at other sites.

Sediment accumulation at Site 440 occurs at a very constant rate in the Pliocene and is comparable to that at Site 438. Its Pleistocene section, however, is 200 to 250 meters thicker than at any other site in the Japan Trench transect. The accumulation rates in the Pleistocene are about twice as fast as in the upper Miocene–upper Pliocene. This is probably caused by active downslope sedimentation (see Site 440 Report). According to biostratigraphic data (Site 441 Report), the upper Miocene–lower Pliocene sediments at Site 441 were deposited at a constant rate of 16.8 cm/1000 yr., which is slightly faster than deposition in corresponding strata at other sites.

The data in Table 4 were derived from the data in Table 2 and the accumulation rates in Table 3. Accumu-

lation rates of elements in trench inner slope sediments are relatively higher in the near-surface sediments than at the bottom. The accumulation rates of Al, Ti, Fe, Ni, and Cr at Site 438 reach a maximum in the Pliocene sediments in spite of the fact that these elements have maximum concentrations in the lower Miocene. This is probably because sedimentation rate increased by a factor of 2 to 3 in the Pliocene compared with other ages (Table 3). The Pleistocene sections at Site 440 have particularly significant high accumulation rates for metal elements, possibly because of ponding of turbidites (see Site 440 Report). Low metal accumulation rates at Site 439 are attributed mainly to low metal abundances or low sedimentation rates in the upper Oligocene–lower Miocene. In general, metal accumulation rates in the Pliocene at Site 438 are comparable to those at Site 440 except for Sr, whereas the lower Pliocene at Site 441 exhibits high accumulation rates for all elements but Sr. Comparison of metal accumulation rates in the upper Miocene at each site shows a minimum at Site 438, in which the rate is 3 to 5 times lower than at Sites 440 and 441. This difference may be attributable either to sedimentation rate or to the geography of ocean floor, because elemental

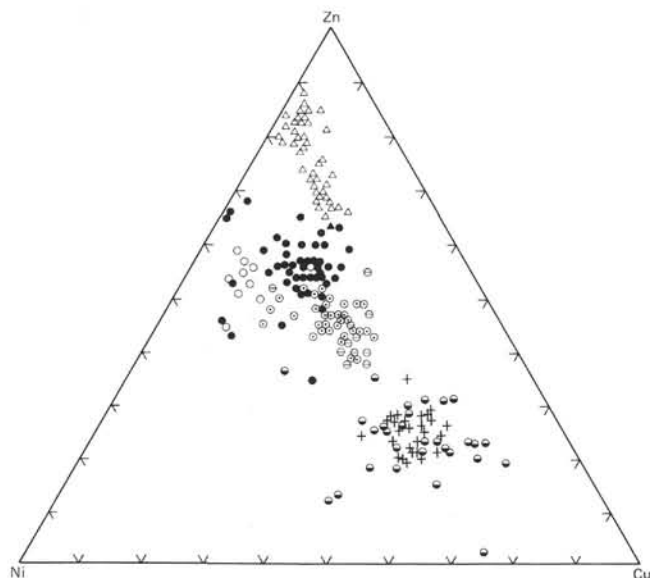


Figure 4. Variations in zinc, nickel, and copper content in marine sediments. (Δ = shelf sediments off Hachinihe, northeast Japan (Nohara, unpublished data); \bullet = active oceanic ridge sediments; + = normal Pacific pelagic sediments; \bullet = Site 438; \circ = Site 439; \circ = Site 440; \circ = Site 441.)

TABLE 3
Physical Properties and Sedimentation and Accumulation Rates for Sediments from Deep Sea Drilling Project Leg 57

Site	Age	Density (g/cm ³)	Sedimentation Rate (cm/10 ³ /yr.)	Accumulation Rate (mg/cm ² /10 ³ /yr.)
438	Pleistocene ^a	1.7	3.0	5100
	Upper Pliocene ^a	1.7	6.2	10540
	Pleistocene	1.7	4.0	6800
	Upper Pliocene	1.5	12.0	17400
	Lower-Upper Pliocene	1.4	12.0	16800
	Lower Pliocene	1.4	12.0	16800
	Upper Miocene	1.4	4.0	5600
	Middle Miocene	1.4	5.8	8120
439	Lower Miocene	1.7	1.7	2890
	Oligocene	2.2	1.3	2860
440	Holocene	1.6	23.0	36800
	Upper Pleistocene	1.6	23.0	36800
	Lower Pleistocene	1.6	23.0	36800
	Upper Pliocene	1.6	10.0	16000
	Lower Pliocene	1.6	10.0	16000
	Upper Miocene	1.7	10.0	17000
441	Lower Pliocene	1.7	16.8	28560
	Upper Miocene	2.0	16.8	33600

^aHole 428.

abundances except for Mn and Cu are of similar orders of magnitude at each site (Table 2).

The accumulation rates of elements in sediments recovered during Leg 57 are about twice as high as those of Leg 56. In addition, high accumulation rates of authigenic constituents such as Fe, Mn, and others are accompanied by high accumulation of Al-Ti detrital

phases. This implies that some authigenic phases may have been co-precipitated with detrital phases.

CONCLUSIONS

Bulk chemical analyses of sediments from the Japan Trench inner slope demonstrates that their chemical composition is similar to those from Sites 434 and 435, Leg 56 (Nohara, this volume). The sediments from both legs are characterized by a greater Al- and Ti-enrichment and by a depletion of authigenic components — especially, Fe, Mn, Cu, and Ni — than in active oceanic ridges and metalliferous basement sediments. This suggests that the island arc — or terrigenous sediments — are more important than oceanic ones in forming accretionary wedges. Vertical abundances are slightly variable from one site to another. However, recalculation of the data on a carbonate-, silica-, sea-salt-, and organic-matter-free basis indicates that the nature of detrital input and authigenic element deposition has been relatively constant since the late Oligocene (32 m.y.B.P.).

The accumulation rates of Leg 57 elements are high compared to those for Leg 56 and for normal pelagic areas. It has been demonstrated that Fe and Mn and other authigenic phases exhibit high accumulation rates in sediments in which there has been a correspondingly high rate of Al-Ti detrital deposition. This fact suggests that Fe, Mn, and other authigenic constituents were deposited at least in part with detrital phases.

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REFERENCES

- Bonatti, E., and Joensuu, O., 1966. Deep-sea iron deposits from the South Pacific. *Science*, 154, 643-645.
- Boström, K., Joensuu, O., Valdes, S., and Riera, M., 1972. Geochemical history of South Atlantic Ocean sediments since Late Cretaceous. *Mar. Geol.*, 12, 85-121.
- Boström, K., and Peterson, M., 1969. Origin of aluminum-poor sediments in areas of high heat flow on the east Pacific Rise. *Mar. Geol.*, 7, 427-447.
- Boström, K., Peterson, M., Joensuu, O., and Fisher, D., 1969. Aluminum-poor ferromanganese sediments on active oceanic ridges. *J. Geophys. Res.*, 74, 3261-3270.
- Chester, R., and Hughes, M., 1966. The distribution of manganese, iron and nickel in a North Pacific deep-sea clay core. *Deep-Sea Res.*, 13, 627-634.
- , 1967. A chemical technique for the separation of ferromanganese minerals, carbonate minerals and adsorbed trace elements from pelagic sediments. *Chem. Geol.*, 2, 249-262.
- Cronan, D., and Garrett, D., 1973. The distribution of elements in metalliferous Pacific sediments collected during the D.S.D.P. *Nature Phys. Sci.*, 242, 88-89.
- Cronan, D., van Andel, T., Heath, G., Dinkelman, M., Bennett, R., Bukry, D., Charleston, S., Knapps, A., Rodolfo, K., and Yeats, R., 1972. Iron-rich basel sediments from the eastern equatorial Pacific: Leg XVI, D.S.D.P. *Science*, 175, 61-63.

TABLE 4
Average Accumulation Rates for Constituents in Sediments from Deep Sea Drilling Project Leg 57

Site	Age	Al (in mg/cm ² /1000/yr)	Ti	Fe	Mn	Cu	Zn (in mg/cm ² /1,000,000/yr)	Ni	Co	Cr	Li	Sr
438	Pleistocene ^a	395	24	164	3453	107	434	245	311	148	148	428
	Upper Pliocene ^a	694	47	239	5555	274	980	495	369	569	295	675
	Pleistocene	530	36	248	4842	27	666	299	292	374	170	578
	Upper Pliocene	922	63	348	7238	452	1479	644	418	748	522	566
	Lower-upper Pliocene	556	57	235	4757	386	1327	722	134	672	487	1042
	Lower Pliocene	979	57	302	5460	622	1646	706	235	823	773	672
	Upper Miocene	317	20	113	1680	174	532	258	95	246	342	168
	Middle Miocene	463	29	151	2307	349	934	406	122	300	658	219
	Lower Miocene	655	44	247	3415	288	882	520	223	585	733	446
439	Lower Miocene	212	13	73	1066	72	266	150	58	168	240	90
	Upper Oligocene	222	11	52	1087	31	163	117	80	86	174	140
440	Holocene	2675	169	887	17406	1840	3422	1803	957	2355	1362	1693
	Upper Pleistocene	2609	177	857	17664	1766	3570	1692	699	2392	1509	1398
	Lower Pleistocene	2693	169	898	22779	2208	3680	1987	773	1546	1398	920
	Upper Pliocene	851	58	338	8976	912	1488	720	256	512	528	576
	Lower Pliocene	786	50	336	6064	800	1264	736	208	656	480	256
	Upper Miocene	978	63	505	7854	1156	1615	969	289	748	731	170
441	Lower Pliocene	1682	111	679	14109	1628	2313	1485	371	1142	1000	171
	Upper Miocene	2281	131	783	28963	2486	3091	1714	806	1445	1445	134

^aHole 438.

- El Wakeel, S. K., and Riley, J. P., 1961. Chemical and mineralogical studies of deep-sea sediments. *Geochim. Cosmochim. Acta*, 25, 110-146.
- Goldberg, E. D., and Arrhenius, G. O. S., 1958. Chemistry of Pacific pelagic sediments. *Geochim. Cosmochim. Acta*, 13, 153-212.
- Horowitz, A., 1970. The distribution of Pb, Ag, Sn, Tl and Zn in sediments on active oceanic ridges. *Mar. Geol.*, 9, 241-259.
- , 1974. The geochemistry of sediments from the northern Reykjanes Ridge and the Iceland-Faroes Ridge. *Mar. Geol.* 17, 103-122.
- Horowitz, A., and Cronan, D., 1976. The geochemistry of basal sediments from the North Atlantic Ocean. *Mar. Geol.*, 20, 205-228.
- Krishnaswami, S., 1976. Authigenic transition elements in Pacific pelagic clays. *Geochim. Cosmochim. Acta*, 40, 425-434.
- Murray, J., and Renard, A. F., 1891. *Deep-sea deposits. Report on the Scientific Results on the Voyage of H. M. S. "Challenger"* (Vol. 5): London (Longmans).
- Nohara, M., and Yokota, S., 1978. The geochemistry of trace elements in pelagic sediments from the Central Pacific Basin. *J. Geol. Soc. Japan*, 84, 165-175.
- Piper, D., 1973. Origin of metalliferous sediments from the East Pacific Rise. *Earth Planet. Sci. Lett.*, 19, 75-82.
- Revelle, R. R., 1944. Marine bottom samples collected in the Pacific by the "Carnegie" on its seventh cruise: Washington (Carnegie Institute) Publication 556, pp. 1-180.
- Turekian, K., 1964. The marine geochemistry of strontium. *Geochim. Cosmochim. Acta*, 28, 1479-1496.
- Zelenov, K. K., 1964. Iron and manganese in exhalations from the submarine volcano, Banu Wuhu (Indonesia). *Dokl. Akad. Nauk. S.S.S.R.*, 155, 1317-1320. (in Russian)