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XVIII. MANGANESE MICRONODULES OF THE SURFACE SEDIMENTS FROM THE CENTRAL PACIFIC WAKE-TAHITI TRANSECT

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In this Chapter the writer describes the quantitative distribution of manganese micronodules in 28 surface (top 5 cm) sediments collected by a box corer along two traverses of GH80–1 cruise. He discusses the relationships among distributions of Mn-micronodule, Mn-macronodule, Mn concentration, and sediment type of the surface sediments.

Sediment Types

The areal distribution of the surface sediments is presented in Fig. XVIII-1, according to the results of writer's analysis (Table XVIII-1). The writer's classification system of the pelagic sediments is different in definitions of some sediment types from that of marine geologists of the Geological Survey of Japan (ARITA, 1977; NAKAO, 1979; NISHIMURA, 1981; NAKAO and MIZUNO, this cruise report).

Coarse, white calcareous *Globigerina* ooze can be identified easily by naked eyes, but finer and brownish sediments may be classified as coccolith ooze, radiolarian ooze, and brown clay ("red clay") by examining them under a microscope. A practical method to separate radiolarian ooze from brown clay was described by the writer (UCHIO, 1979). UCHIO and HISHIDA (1981) described a classification system of brown clay, and it is

Sediment Type	Sand Content (weight %)	Dominant Constituents in Coarse Fraction (>63 μm)
Zeolitic Clay	20–30	Phillipsite≫Radiolaria (both abundant)
Siliceous Clay	10–20 generally *ca.* 15	Phillipsite≪Radiolaria (both abundant)
Zeolitic Deep-Sea Clay	<10	Phillipsite>Radiolaria (both rare or frequent)
Typical Deep-Sea Clay	(generally	Phillipsite≒Radiolaria (both rare or frequent)
Siliceous Deep-Sea Clay	<4)	Phillipsite<Radiolaria (both rare or frequent)

Figure XVIII-1 shows that (1) calcareous ooze covers relatively shallow part above carbonate compensation depth (*ca.* 4700 m) such as Magellan Rise, Manihiki Plateau, *etc.*, while in the deeper part, (2) zeolitic deep-sea clay is distributed in the southern part of the Mid-Pacific Mountains province and in the area west of Society Island, and (3) siliceous deep-sea clay is widely distributed between the two zeolitic deep-sea clay areas. Zeolitic clay and typical deep-sea clay occupy much smaller area within the southern zeolitic deep-sea clay area. Brief comments are added to the following three

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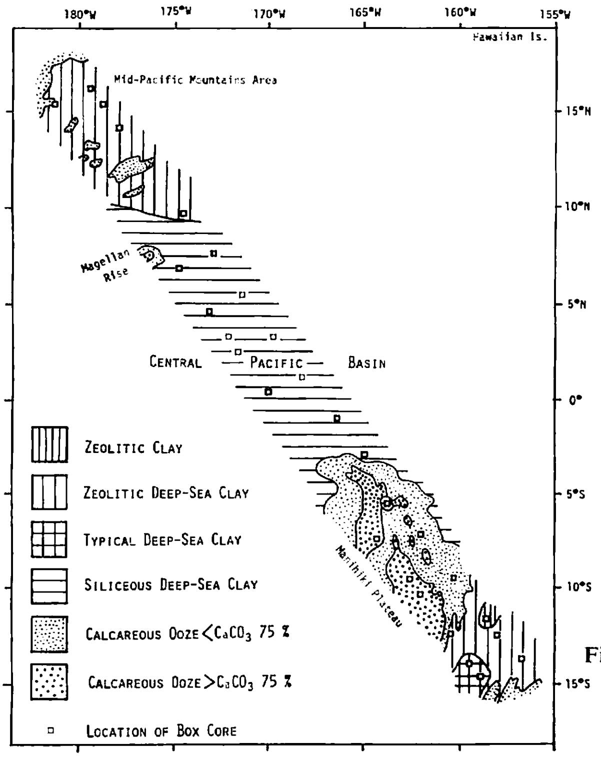

Fig. XVIII-1 Distribution of the surface sediment types based on sand contents and abundances of the main components (minerals and biogenic shells).

sediments. Sample B-29 (St. 1641) is characterized by dominance of smectite(?) and less abundance of phillipsite and radiolaria, and is considered to be a variety of zeolitic deep-sea clay. Sample B-6 (St. 1601) is transitional between siliceous clay and siliceous deep-sea clay because of its sand content (10.4%), and it is tentatively included in siliceous deep-sea clay. Sample B-22 (St. 1627; depth 4995 m) was collected from a very small depression on Manihiki Plateau, and thus the sediment type is siliceous deep-sea clay and it is surrounded by calcareous ooze.

Manganese Micronodules

A method of quantitative analysis of Mn-micronodules in the sediments was described by the writer (UCHIO, 1979). In that case, Mn-micronodules in the fraction finer than 63 μm (silt plus clay fraction) was not analyzed because of difficulty of counting such very minute micronodules under a microscope. Approximately 0.1 g of dry sediment at each station was washed through a 250-mesh (63 μm) sieve and the coarse fraction was further divided into fractions of 63–104 μm (C), 104–300 μm (B), and larger than 300 μm (A). Mn-micronodules in each fraction were counted under a microscope. Total number of Mn-micronodules in 1 g of each sediment was represented by the equivalent of C-size under the estimation that average volume ratio of Mn-micronodules of the A-, B-, and C-sizes to be approximately 45: 14: 1 (UCHIO, 1979). The abundances of Mn-micronodules of the A, B, and C fractions and also "Total" (A+B+C) in 1 g of dry sediment at each station is listed in Table XVIII-1, and their areal distributions (exclud-

Table XVIII-1 Locations, depths, sediment types, sand contents, and abundances of manganese micronodules in the surface sediments.

Station No.	Sample No.	Latitude	Longitude	Depth (m)	Sediment Type	Sand Content (%)	Number of Mn-Micronodule in 1 g of Dry Sediment (A) >300 μm	(B) 300–104 μm	(C) 104–63 μm	Total as (C) Size
1590	B-2	15°23.31′N	178°43.79′E	5287	Zeolitic Deep-Sea Clay	6.8	0	78	835	1922
1598	B-4	6°49.67′N	174°47.63′W	5962	Siliceous Deep-Sea Clay	1.7	0	19	58	331
1600	B-5	4°41.39′N	173°11.89′W	5584	Siliceous Deep-Sea Clay	3.1	10	0	140	589
1601	B-6	3°17.83′N	172°10.51′W	5350	Siliceous Deep-Sea Clay	10.4	10	430	720	7194
1602	B-7	2°33.26′N	171°37.69′W	5389	Siliceous Deep-Sea Clay	4.6	0	30	40	455
1604	B-8	0°24.23′N	170°02.51′W	5457	Siliceous Deep-Sea Clay	4.3	0	60	70	909
1611	B-11	7°20.88′S	164°17.60′W	4155	Coccolith Ooze	8.3	0	20	20	296
1613	B-12	7°29.32′S	162°41.40′W	2944	Globigerina Ooze	39.7	0	19	28	290
1614	B-13	10°16.67′S	162°04.76′W	2763	Globigerina Ooze	37.7	0	0	19	19
1616	B-14	12°20.07′S	160°30.89′W	5690	Zeolitic Deep-Sea Clay	5.1	19	548	1133	9646
1617	B-15	13°47.40′S	159°28.35′W	5162	Typical Deep-Sea Clay	0.1	0	28	85	481
1618A	B-16	14°29.61′S	158°52.98′W	5453	Typical Deep-Sea Clay	0.1	0	0	9	89
1619	B-17	13°34.29′S	157°05.16′W	5111	Zeolitic Deep-Sea Clay	1.1	10	219	887	4387
1620	B-18	12°26.44′S	157°57.20′W	5285	Zeolitic Deep-Sea Clay	9.7	29	774	2972	15121
1621	B-19	11°35.38′S	158°34.91′W	5312	Zeolitic Clay	18.7	0	1241	5566	22940
1623	B-20	9°26.14′S	160°14.83′W	4561	Coccolith Ooze	1.4	0	267	497	4241
1625	B-21	7°06.72′S	161°56.68′W	4650	Coccolith Ooze	12.7	10	564	644	8990
1627	B-22	5°27.32′S	163°46.01′W	4995	Siliceous Deep-Sea Clay	3.1	0	68	291	1243
1629	B-23	2°53.00′S	164°57.31′W	5261	Siliceous Deep-Sea Clay	6.7	19	121	288	2815
1631	B-24	0°58.61′S	166°20.89′W	5342	Siliceous Deep-Sea Clay	4.9	0	31	347	777
1633	B-25	1°16.04′N	168°09.97′W	5359	Siliceous Deep-Sea Clay	2.4	0	0	19	19
1635A	B-26	3°16.42′N	169°40.10′W	5351	Siliceous Deep-Sea Clay	8.0	20	228	575	4660
1637	B-27	5°31.51′N	171°18.84′W	5970	Siliceous Deep-Sea Clay	3.2	0	20	30	306
1639	B-28	7°40.26′N	172°56.77′W	5926	Siliceous Deep-Sea Clay	0.9	0	20	98	374
1641	B-29	9°46.81′N	174°31.04′W	5829	Smectitic-Zeolitic Clay	8.3	10	802	980	12653
1645	B-30	14°06.61′N	177°47.28′W	5068	Zeolitic Deep-Sea Clay	0.5	0	30	157	571
1646	B-31	15°22.48′N	178°45.46′W	5537	Zeolitic Deep-Sea Clay	5.3	0	68	205	1163
1647	B-32	16°10.14′N	179°19.82′W	5292	Zeolitic Deep-Sea Clay	0.3	0	10	29	166

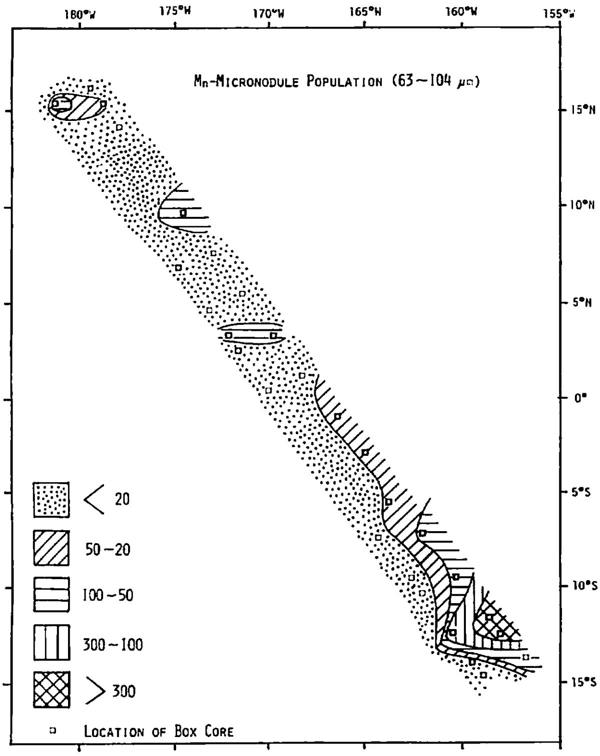

Fig. XVIII-2 Areal distribution of manganese micronodules (63–104 μm) in 1 g of the dry surface sediments.

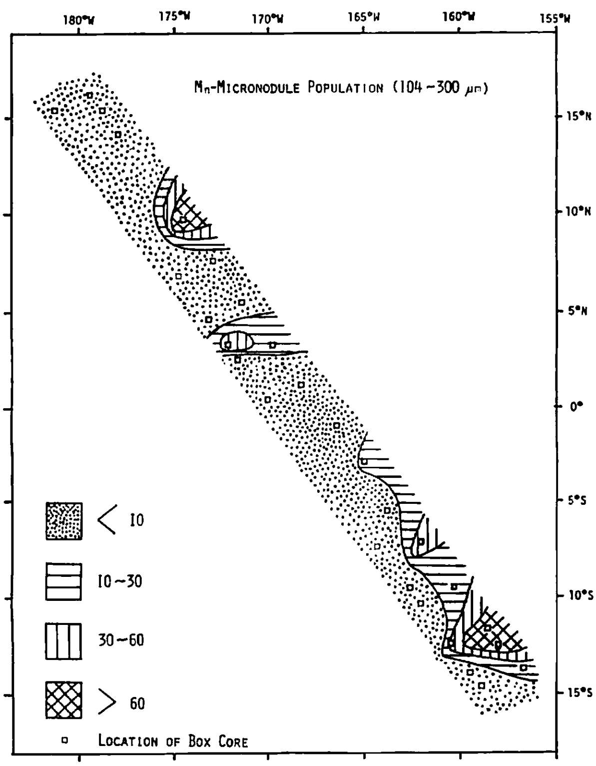

Fig. XVIII-3 Areal distribution of manganese micronodules (104–300 μm) in 1 g of the dry surface sediments.

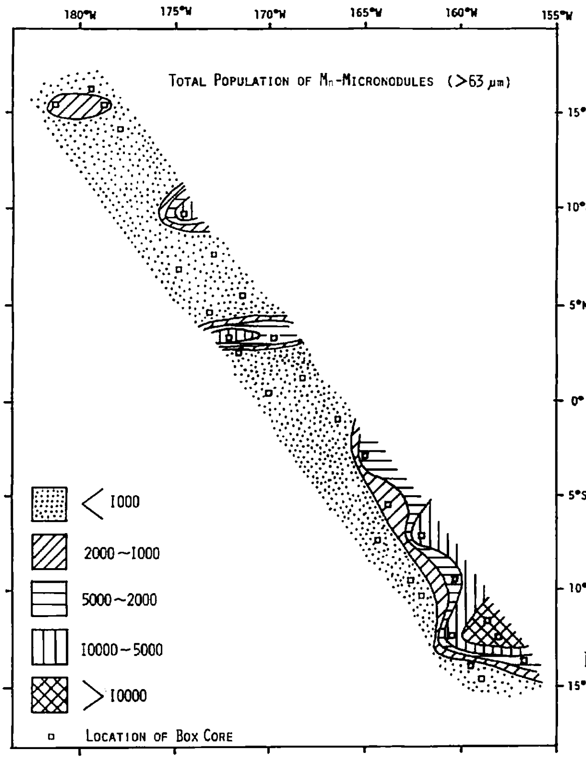

Fig. XVIII-4 Areal distribution of total populations of manganese micronodules larger than 63 μm (unit: 63–104 μm) in 1 g of dry surface sediments.

ing the A's) are shown in Figs. XVIII-2 to 4. The figures show that the distribution pattern of Mn-micronodules of the size fractions and "total" population is very similar to each other. The following description is based upon the "total" distribution.

(1) Calcareous Ooze . . . Generally, both Mn-micronodule and Mn-macronodule are not present or very rare except for coccolith ooze ($CaCO_3 < 75\%$) which has moderate abundance of Mn-micronodule.

(2) Siliceous Deep-Sea Clay . . . Both Mn-micronodule and Mn-macronodule are rare except at Station 1661 and 1635 where they are moderate or somewhat moderate.

(3) Zeolitic Deep-Sea Clay . . . (a) In the northern area, Mn-micronodule is very abundant at only Station 1641 and rare at the other stations, while Mn-macronodule is moderate to abundant at every station. (b) In the southern area, both Mn-micronodule and Mn-macronodule are moderate to abundant.

(4) Typical Deep-Sea Clay . . . Mn-micronodule is very rare, and Mn-macronodule is abundant or rare.

The accuracy of the above statement may not be great as the number of sediment samples available for this study is only 28. Generally, there are fairly good correlations among areal distributions of sediment types, Mn-micronodules and Mn-macronodules as mentioned above. However, if their areal characteristics are excluded, their correlations are not good as is understood from Figs. XVIII-5 to 9A-B, and to some extent, from mere statistics (*e.g.* Table XVIII-2). However, if their areal characteristics are taken into consideration, their relationships become more realistic as are seen from the same

Table XVIII-2 Statistics showing average numbers of manganese micronodules in 1 g of the dry surface sediments of different types calculated as the size of the C-fraction (63–104 μm).

Sediment Type	Number of Samples	Mn-Micronodule Abundance (>63 μm) in 1 g of Sediment	
		Total Number	Average Number per Sample
Brown Clay	*23*	*87462*	*3803*
Zeolitic Clay	1	22940	22940
Smectitic-Zeolitic Clay	1	12653	12653
Deep-Sea Clay	21	51869	2470
Zeolitic Deep-Sea Clay	7	31647	4521
Typical Deep-Sea Clay	2	570	285
Siliceous Deep-Sea Clay	12	19652	1638
Calcareous Ooze	*5*	*19236*	*3847*
$CaCO_3$<75%	2	13231	6616
Coccolith Ooze ($CaCO_3$ *ca.* 37%)	1	8990	8990
Coccolith Ooze ($CaCO_3$ *ca.* 67%)	1	4241	4241
$CaCO_3$>75%	3	605	303
Coccolith Ooze ($CaCO_3$ *ca.* 83%)	1	296	296
Globigerina Ooze ($CaCO_3$ *ca.* 99%)	2	309	155

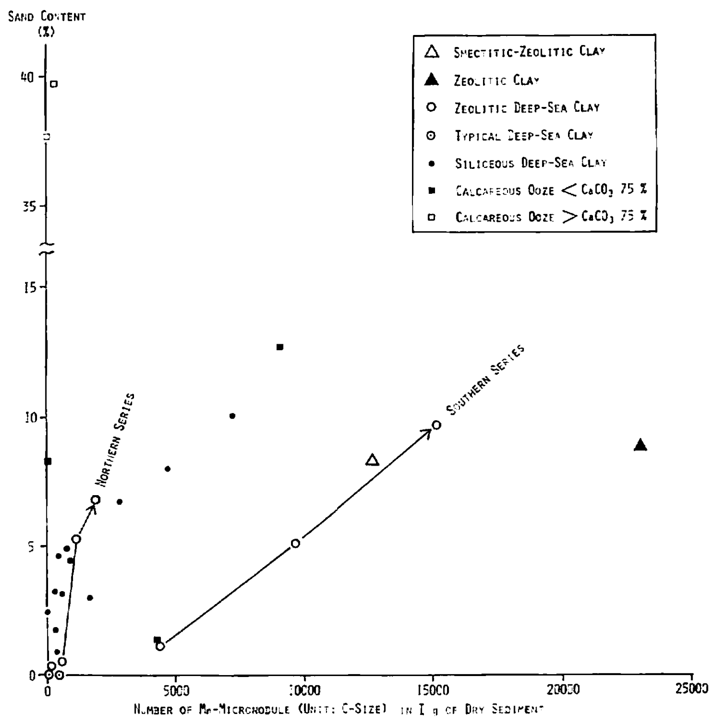

Fig. XVIII-5 Relationship between manganese micronodule total population and content of sand-sized particles in the dry surface sediments.

figures with notes "Northern (Southern) Area or North (South)."

As mentioned above, Mn-micronodule and Mn-macronodule abundances in the northern zeolitic deep-sea clay area are different from those in the southern deep-sea caly area. However, when plotting Mn-micronodule abundance and weight percent of sand-sized particles ("sand content") in sediment at each station in abscissa and ordinate respectively, Mn-micronodule is almost linearly proportional to "sand content". In the case of zeolitic deep-sea clay, the linear relationship is recognized in the northern and southern areas separately, perhaps because of different environments of sedimentation (Fig. XVIII-5). The writer (UCHIO, 1979; UCHIO and HISHIDA, 1981) emphasized that abundance of Mn-micronodule increases with increase of abundance of phillipsite grains and with decrease of radiolarian shells. This is true in the present work as is shown in Table XVIII-2 which shows statistics on the average abundance of Mn-micronodules in different sediment types. Therefore, less abundance of Mn-micronodules in the northern zeolitic deep-sea clay area needs some explanation. In the northern area, almost all of phillipsite grains are very minute single crystals of penetrating twins and relatively larger "ball-type phillipsites" (spherulites of radial aggregates) are not present or very rare, while in the southern area the "ball-type phillipsites" are common or abundant. In the "manganese nodule belt" south or southeast of the Hawaiian Islands, such ball-type phillipsite grains are very abundant in the coarse fraction (>63 μm) of zeolitic clay and zeolitic deep-sea clay. Abundant "ball-type phillipsite grains" mean large "sand content" of sediments. Therefore, there are positive relationships among Mn-micronodule abundance, "ball-type phillipsite grain abundance and "sand content" of sediments.

Figure XVIII-6 shows relationship between Mn-micronodule abundance and Mn-

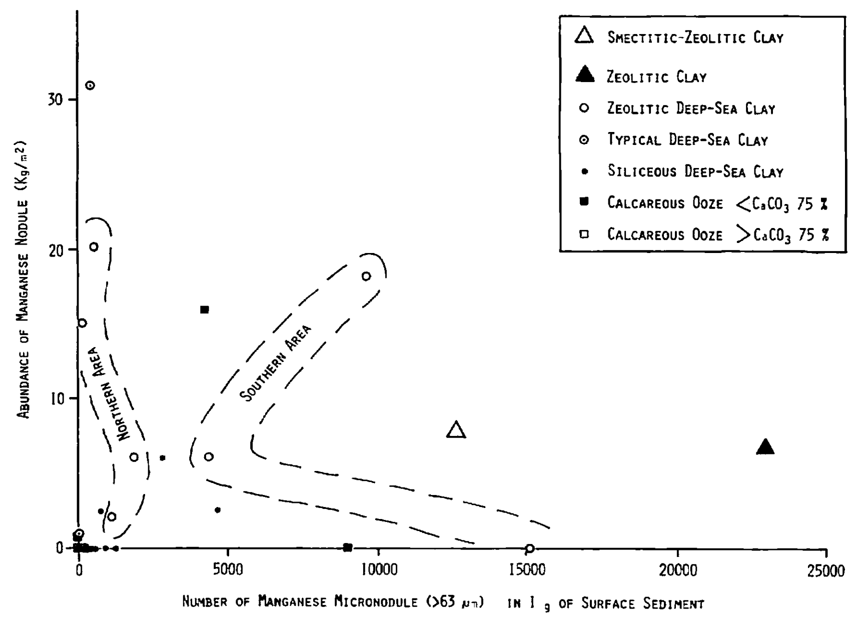

Fig. XVIII-6 Relationship between manganese micronodule total population and abundance of manganese macronodule of the surface sediment.

macronodule abundance. The followings are pointed out from the figure.

(1) The two are zero or nearly zero in calcareous ooze having $CaCO_3$ more than 80% perhaps due to very high rate of biogenic sedimentation. A coccolith ooze with $CaCO_3$ 67% (Station 1623) contains high abundance of Mn-macronodule and moderate abundance of Mn-micronodule perhaps due to very slow rate of sedimentation (sand content 1.4%).

(2) The two are generally zero or very small, and sometimes moderate or rather moderate in siliceous deep-sea clay.

(3) Separate distribution of zeolitic deep-sea clay in the northern and southern areas is also recognized in Fig. XVIII-6.

Mn and Fe are main metal elements of Mn-micronodule as well as in Mn-macronodule, and concentrations of the two elements of surface sediments are important to interprete origin of Mn and Fe in Mn-micronodule and Mn-macronodule of the surface sediments. The areal distribution of Mn concentration of the surface sediments in the present work is shown in Fig. XVIII-7. It shows that Mn concentration is high in the southern zeolitic deep-sea clay area, very low in the *Globigerina* ooze, and low in the other area. Fe concentration of the surface sediments has a similar distribution. The relationship between Mn and Fe concentrations at each station is shown in Fig. XVIII-8. Two important things can be pointed out as follows. (1) Separate distribution of zeolitic deep-sea clay in the northern and southern area is also recognized. (2) There is a strong positive correlation between Mn and Fe in the five calcareous ooze, whose Mn/Fe ratios range

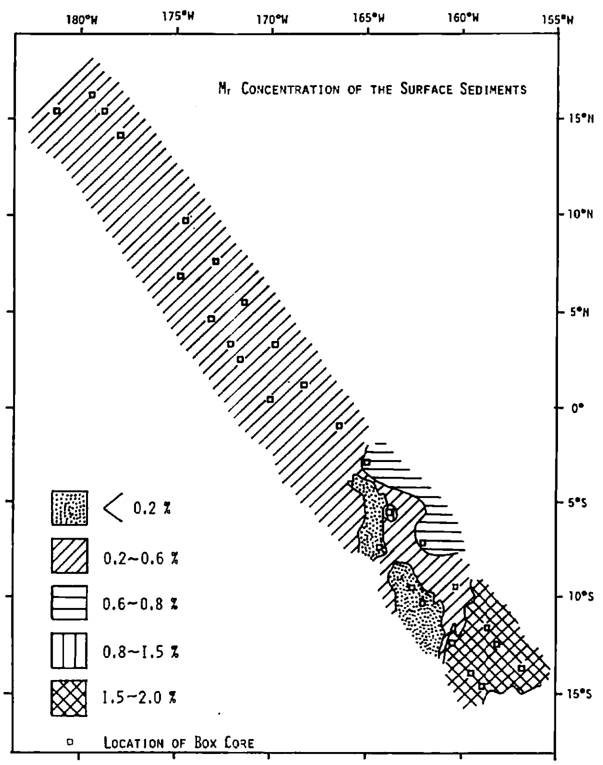

Fig. XVIII-7 Areal distribution of Mn concentration of the surface sediments.

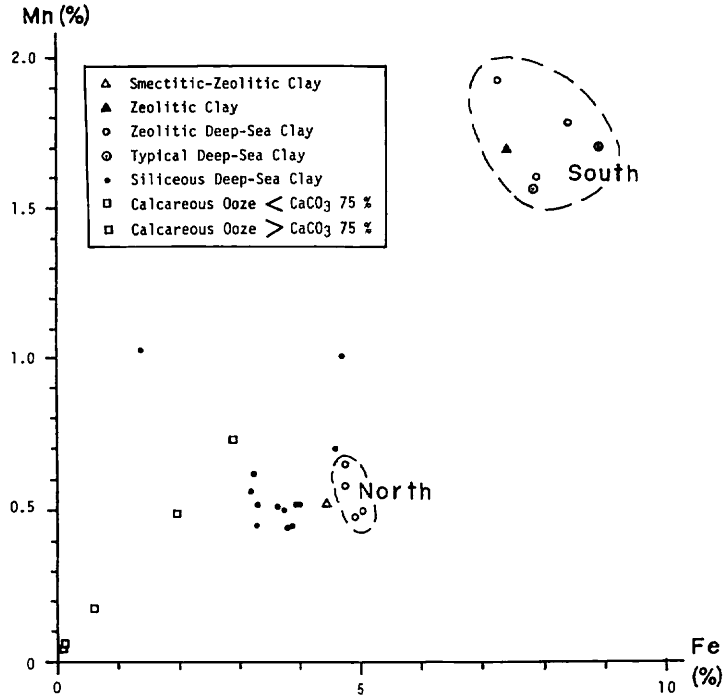

Fig. XVIII-8 Relationship between Mn and Fe concentrations of the surface sediments.

from *ca.* 0.25 to 0.40, average *ca.* 0.30 (the more $CaCO_3$ concentration, the higher Mn/Fe ratio). Such a strong positive correlation between Mn and Fe has already been recognized in biogenic oozes but not in brown clay in the Northeastern Tropical Pacific, south of the Hawaiian Islands (UCHIO, 1979). The reason for this good correlation is considered that planktonic marine organisms such as planktonic foraminifers and radiolarians extract Fe and Mn directly from sea water. Data on Mn and Fe concentrations of sea water (excluding suspended solids) is very scarce. Mn concentration of the intermediate and deep water of the northwestern Indian Ocean is *ca.* 1 μg/L (0.68 – 1.29 μg/L) (TOPPING, 1969) and Fe concentration of the surface water of the Atlantic Ocean and Gulf of Mexico is 2.6 μg/L in average (SIMONS *et al.*, 1953). Assuming that these data are representative or not far from the representative, the Mn/Fe ratio of sea water (excluding suspended solids) is *ca.* 0.4, and this value is very close to 0.25–0.4 (average *ca.* 0.3) for five calcareous oozes on the Manihiki Plateau in the present area. Thus, the writer's interpretation on this problem seems to be correct.

Relationship between Mn concentration and Mn-macronodule abundance, and that between Mn concentration and Mn-micronodule abundance of the sediment at each station is shown in Figs. XVIII-9A and 9B respectively. The two figures clearly show separate distribution of zeolitic deep-sea clay in the northern and southern areas as is shown in Figs. XVIII-5, 6 and 8. It appears that Mn concentration of surface sediment has a tendency to decrease with increase of Mn-macronodule abundance in zeolitic deep-sea clay of both northern and southern areas and not in other sediment type. The rela-

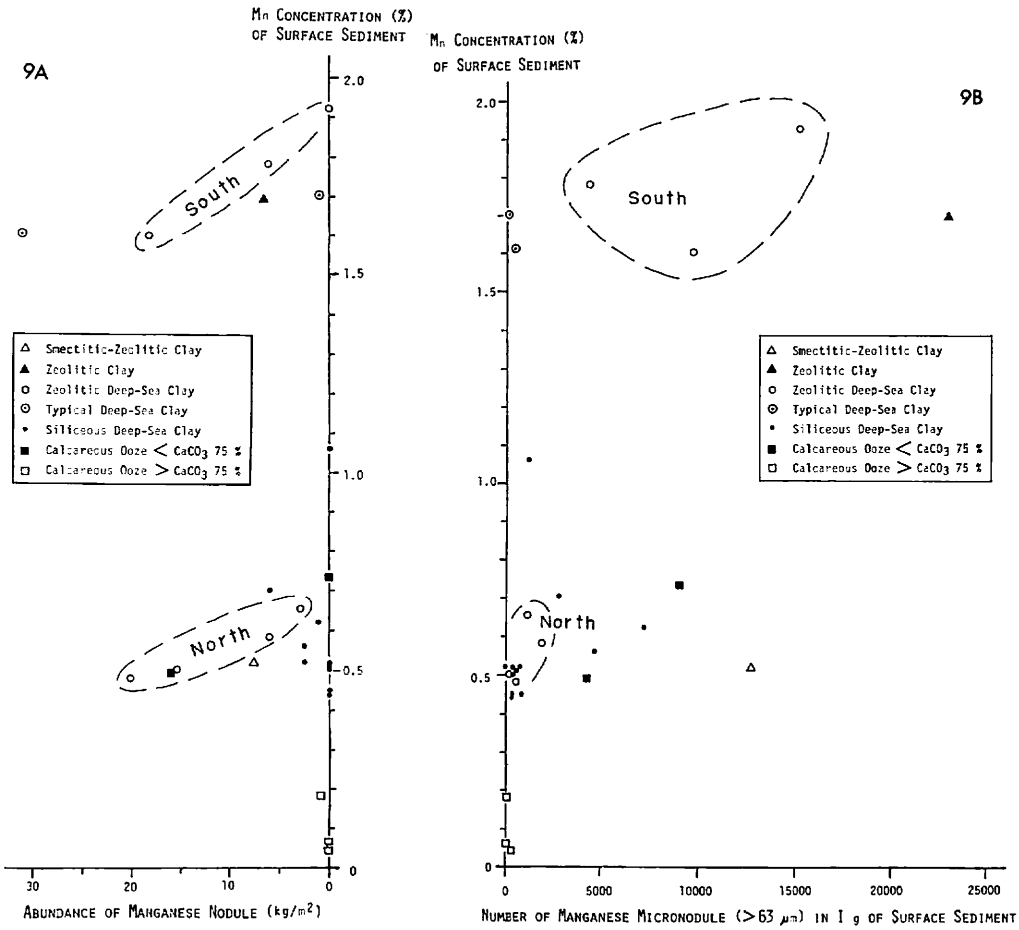

Fig. XVIII-9 A: Relationship between Mn concentration and manganese macronodule abundance of the surface sediments.
B: Relationship between Mn concentration and manganese micronodule abundance of the surface sediments.

tionship between Mn-concentration of surface sediment and Mn-micronodule abundance is weakly positive as a whole regardless of sediment type, and may be due to the fact that counting of Mn-micronodule was not done for a fraction smaller than 63 μm which occupies *ca.* 70–90 weight percent of brown clay as already mentioned by the writer (Uchio, 1979). However, there seems to be a postive relationship between the two in calcareous ooze, and the same relationship is also recognized in the Northeastern Tropical Pacific, south of the Hawaiian Islands (Uchio, 1979). The fact that Mn concentration of zeolitic deep-sea clay appears to have a tendency to decrease with increase of Mn-macronodule abundance may correspond to the inverse correlation between grade of Mn (also Ni and Cu) and abundance of Mn-macronodule (Mizuno and Moritani, 1977; Menard and Frazer, 1978; Moritani *et al.*, 1979).

Considering all the descriptions and discussions above mentioned the present survey area can be divided into seven parts as is shown in Table XVIII-3.

Table XVIII-3 Division of the surveyed area to several submarine topographic provinces based and iron of the surface sediment, and sediment types.

Topographic Province		Mn-Macronodule Abundance (kg/m^2)	Mn-Micronodule Abundance (No. in 1 g of Sediment)
Mid-Pacific Mountains Region (Southern Part)		Moderate to Abundant (6–20)	Rare (60–1900)
Central Pacific Basin	Northern Part	None to Very Rare (0–0.5)	Rare (300–400)
	Central Part	Rare (0–2.6)	Rare to Moderate (generally 1000 rarely 3000–7000)
	Southern Part	Rare to Moderate (2.5–6.1)	Rare (800–2800)
Manihiki Plateau		generally Very Rare, rarely Moderate (0–16)	Moderate (4000–9000)
		None or Very Rare	Very Rare (10–290)
Penrhyn Basin		generally Moderate to Abundant (6–31), sometimes Very Rare (0.1–1.0)	generally Moderate to Abundant (4000–23000), sometimes Rare (<500)

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upon abundances of manganese macronodules as well as micronodules, concentrations of manganese

Mn Concentration of Sediment (%)	Fe Concentration of Sediment (%)	Sediment Type
Low (0.48–0.65)	Moderate (4.5–5.0)	Zeolitic Deep-Sea Clay
Low (0.44–0.52)	Somewhat Moderate (3.8–4.0)	Siliceous Deep-Sea Clay
Low (0.5–0.7)	Somewhat Moderate (3.2–4.0)	Siliceous Deep-Sea Clay
Low (0.5–0.7)	Moderate (4.0–4.6)	Siliceous Deep-Sea Clay
Low (0.5–0.7)	Low (2.0–3.0)	Coccolith Ooze ($CaCO_3 < 75\%$)
Very Low (<0.2)	Very Low (<0.2)	Globigerina Ooze ($CaCO_3 > 75\%$)
High (1.6–1.92)	High (7.28–8.90)	mostly Zeolitic Deep-Sea Clay and typical Deep-Sea Clay, rarely Zeolitic Clay