XXIV. REGIONAL AND LOCAL VARIABILITIES OF MANGANESE NODULES IN THE CENTRAL PACIFIC BASIN

Atsuyuki Mizuno

Introduction

Our works on manganese nodules in the Central Pacific Basin from 1974 through 1979 clarified their morphology, mineralogy, chemical compositions and, relation to acoustic stratigraphy throughout the basin. I present here the tentative summary and conclusion on the manganese nodules in the surveyed area of the basin on 5° to 13°N and 175°E to 165°W with an extent of approximately 2,100 km by 800 km, including the GH79–1 area (Fig. XXIV-1). A larger part of my discussion is based on our previous paper (MIZUNO *et al.*, 1980b). The present paper comprises two subjects: regional variability of manganese nodules characterized by a weak inverse correlation between nodule abundance and nickel plus copper grade, related to nodule morphology, occurrence, and mineralogy and to acoustic stratigraphy, and local variability of nodules related to sedimentary history from the late Tertiary to the Quaternary.

The research area is dominantly rolled abyssal basins, 5,000 to 6,000 meters in depth. Abyssal knolls and depressions are elongated in a direction of west-northwest in general, but are disturbed by some abyssal plains, broad rises, and small seamounts in many places. The direction of elongation is nearly consistent to that of the Line Islands Cross

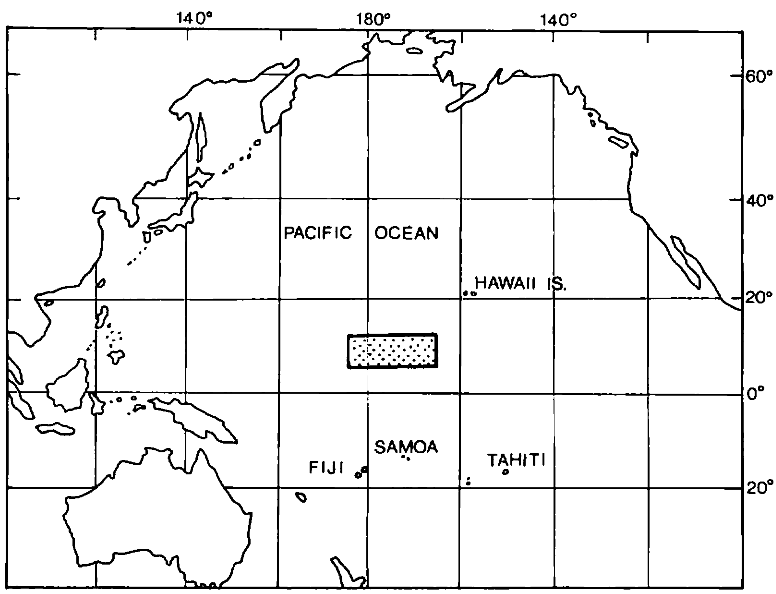

Fig. XXIV-1 The survey area of the Cantral Pacific Basin from 1974 through 1979.

Trend chain which is in the eastern part of the area. The deep-sea drillings (DSDP Leg 17) have clarified the stratigraphy and lithology of substrates in the research area, which consist of the early Cretaceous to Quaternary sequence (WINTERER, EWING, *et al.*, 1973). The manganese nodule samples were mostly collected from the abyssal basin area at the depths of 4,500 to 6,000 meters.

Interval of sampling partly accompanied by bottom photographing was mostly 110 km and partly 55 km or less throughout the entire area. In some selected small areas, sampling and photographing were done at the intervals of 19 km, 1.9 km or less. Manganese nodules and sediments were collected by box corer and grab, and additionally by freefall grab with camera and sediment-sampling tube inside in order to obtain the data of local variability of nodule and sediment distributions. Piston corer was used at selected sites. The discussions presented here are based on the data of manganese nodules and sediments thus obtained from approximately 200 stations and seismic reflection and 3.5 kHz records of the tracks up to approximately 28,000 km. Those data have been reported in the Geological Survey of Japan Cruise Reports concerned except for the western part of the surveyed area (GH78–1 area; in preparation to be published).

Regional feature of the central Pacific manganese nodules

Central Pacific manganese nodules can be classified into many morphological types (Table XXIV-1). A new classification scheme was introduced by MORITANI *et al.* (in MIZUNO and MORITANI, *ed.*, 1977) for the GH76–1 area, and the subsequent surveys have shown that their scheme is basically valid for the abyssal nodules in the entire area. The scheme is simplification and modification of MEYLAN (1974)'s field classification

Table XXIV-1 Morphologic classification of manganese nodules in the Central Pacific Basin (modified from MORITANI *et al.*, 1977; cited from MIZUNO *et al.*, 1980b).

Types	Size	Shape	Surface texture
Sr	small to medium	spheroidal/ellipsoidal	rough (granular or microbotryoidal)
SPr	small to medium	spheroidal/ellipsoidal/intergrown	rough
SEr	medium to large	spheroidal/ellipsoidal	rough to botryoidal
Dr	medium to small	discoidal	rough
DPr	small	discoidal/intergrown	rough
Db	medium to large	discoidal/ellipsoidal	rough to botryoidal
DPs	small to medium	flattened/elongated/discoidal/ intergrown	smooth
Ss/SPs	small to medium	spheroidal/intergrown	smooth to microgranular
Ds	small to medium	discoidal	smooth
ISs	large	irregular/spheroidal/flattened/ angular/fractured	smooth
IDPs	large	irregular/flattened/discoidal/ fractured	smooth
V	small to large	variable depending on nucleus forms (shark's teeth, nodule fragments, etc.)	smooth or rough (distinctive form is named Vr or Vs)

scheme and is based on surface texture and external shape of nodules. The surface texture is shown as rough (r) or smooth (s), and the shape is expressed as spheroidal (S), ellipsoidal (E), discoidal (D), polylobate (P), and irregular (I). Each type is given by the combination of the initials of both terms. Occasionally, intermediate or transitional types in surface texture occur, and they are named on the basis of dominant texture with an addition of minor one as SPr(s), DPs(r), etc. We can discriminate another surface texture, a botryoidal one, which is shown as b, but this type is very rarely distributed in the central Pacific.

From field occurrence, chemical composition, and mineral phase of the nodules, they can be grouped into two, s- and r-types, which mean the nodules with smooth and rough surface, respectively. The nodules of s-type occur in mostly exposed state on the sea floor, keeping smooth surface in bottom water and gritty or granular surface in sediment. Those of r-type are entirely or mostly burried in sediment and are occasionally accompanied by minor smooth surface on upper surface. In addition, the b-type nodules may be possibly discriminated, which is characterized by the development of botryoidal surface.

The difference of the morphology is closely related to nodule mineralogy. Our cruise reports including this volume and the papers by USUI (1979) and USUI *et al.* (1978) show that the r-type nodules consist largely of 10Å manganite (todorokite) phase rich in nickel and copper and nearly lack detrital material, whereas the s-type nodules consist mainly of δ-MnO_2 phase at exposed part and 10Å manganite phase on the surface of buried part, which in turn shows the dominant occurrence of δ-MnO_2 phase. The δ-MnO_2 phase is characterized by lower concentration of nickel and copper and higher content of silica derived from colloidal detrital materials, accompanied by microfossils in some cases. The metal elements in the 10Å manganite phase may have been supplied from interstitial water, and those in the δ-MnO_2 phase from bottom water (USUI, 1979; USUI *et al.*, 1978).

In relation to the facts, nickel, copper, and manganese grades of the r-type nodules are generally higher than those of the s-type nodules. Nickel plus copper grade ranges from 0.6 to 3.0 per cent (dominantly from 2.0 to 2.4 per cent) in all the r-type nodules, whereas from 0.2 to 2.0 per cent (dominantly around 1 per cent) in all the s-type nodules (Fig. XXIV-2).

HALBACH and ÖZKARA (1979) classifify the eastern Pacific manganese nodules into Type B, Type A, and Type AB, based on external shape, surface texture, internal microstructure, and chemical composition. Their descriptions show that our s-type nodules can be identified to the Type A nodules. The general feature of the Type B nodules is very similar to our r-type nodules, and some of the Type AB nodules seem to be identified to the s-type nodules. The typical Type AB nodules with botryoidal lower surface may be identified to the b-type nodules which are very rare in the central Pacific. The detailed aspect of nodule morphology seems to be different between the central Pacific and the eastern Pacific, but a similarity of nodule characteristics discussed above suggests that a single classification sheme may be available in the near future through more detailed examinations of nodules.

The nodule morphology, in turn its metal content, correlates with nodule abundance throughout the entire surveyed area. Figure XXIV-2 presents a weak inverse correlation

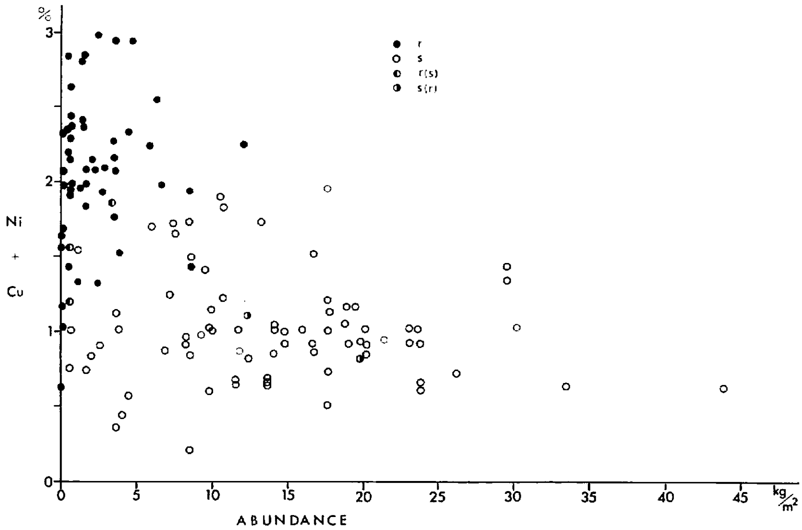

Fig. XXIV-2 Correlation between nickel plus copper grade and abundance of nodules in the Central Pacific Basin.

between nickel plus copper grade and abundance. The relation is very similar to that shown by MENARD and FRAZER (1978). In the figure, the r- and s-types show distinctly different distribution to each other. Although each subdivided morphological types do not show a clear distribution (see MIZUNO *et al.*, 1980b, Fig. 2), all the r-type nodules occur in low abundance as much as 12 kg/m^2 (dominantly less than about 5 kg/m^2), whereas all the s-type nodules occur in higher abundance up to 44 kg/m^2 (dominantly around 10 to 20 kg/m^2). The figure suggests that the abundance, surface texture, occurrence on the sea floor, mineral composition, and chemical composition of nodules are closely related to each other. The classification of nodules into both the s- and r-types (and also b types) possibly may be very significant for origin of discussing nodule distribution and also for nodule exploration.

The abundance of manganese nodules in the central Pacific varies from place to place. Its general distribution pattern is very similar to that in the eastern Pacific reported by SCHULTZE-WESTRUM (1973). As indicated in Fig. XXIV-3, the most highly concentrated area is scattered like as islands in less abundant areas. Barren and scarcely concentrated areas tend to be distributed in the southern half part, except for the seamounts. There is no particular correlation between the variability of nodule abundance and lithology of surficial sediment. Figure XXIV-4 summarizes the relation between nodule abundance, morphology, and bathymetry. It shows that the nodules in the abyssal basin area are present at the depths of wide range from about 4,500 m down to 6,200 m, but very abundant occurrence of nodules over 30 kg/m^2 is restricted to the depth range of 5,000 to 6,000 meters. Also, it indicates that the morphology of nodules does not relate to bathymetry. Thus, generally speaking, a bathymetric control appears to be not significant for the distribution of central Pacific abyssal nodules.

A correlation is present between the abundance and acoustic stratigraphy. Throughout the entire area, the substrates detected by a seismic profiler are divided into Unit I,

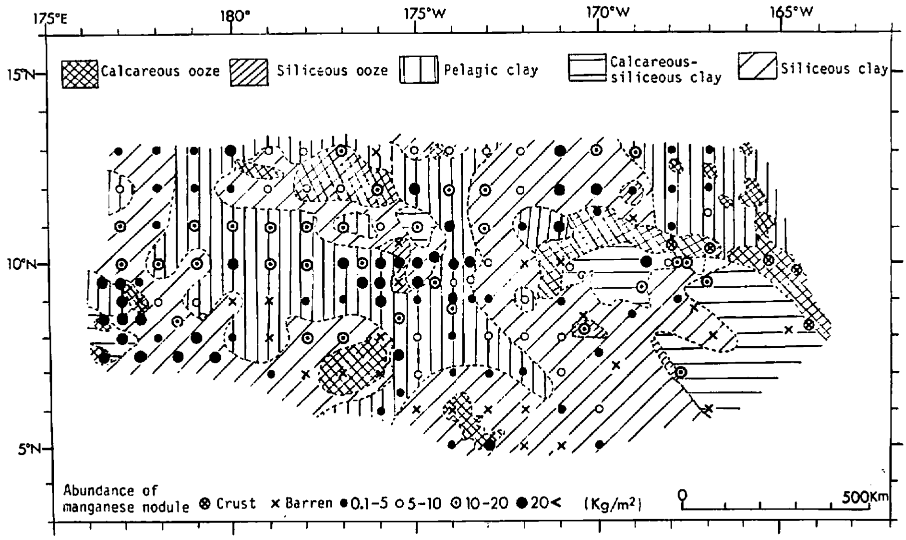

Fig. XXIV-3 Distribution of abundance of nodules and lithologic types of surficial sediments in the Central Pacific Basin (from Mizuno *et al.*, 1980b).

Unit IIA, Unit IIB, and acoustic basement, in descending order (TAMAKI *et al.*, in MIZUNO and MORITANI (*ed.*), 1977; TAMAKI and TANAHASHI, this cruise report). Unit I (the Middle Eocene to the Quaternary) comprises three acoustic facies types, Type A, Type B, and Type C. We can conclude that the regional variability of manganese nodule abundance is correlated to some extent to stratigraphy and acoustic facies of Unit I throughout the area.

In the Type A facies which exclusively consists of transparent layer, the nodules with concentration higher than 10 kg/m^2 are confined to the area underlain by Unit I thinner than 40 or 50 meters; the nodules belong to the s-type morphologically. Less abundant nodules of the r-type occur in both thinner and thicker parts. And in the area with Unit I over 130 m thick, the nodule is nearly barren. The Type B and Type C facies of Unit I include reflective horizons and coherent reflectors mostly caused by turbidites, which are overlain by the uppermost transparent layer of varying thickness. Here the nodule abundance tends to be correlated with the thickness of the uppermost transparent layer, not with the thickness of Unit I.

Transparent layer on 3.5 kHz records also shows similar tendency of a correlation with nodule abundance. The data help the interpretation of the seismic reflection records above noted.

Despite of some anomalous relations found in places, the correlation pattern between the nodule abundance and both the seismic and 3.5 kHz records very likely suggests, together with the consideration of piston-core data, that the regional variability of nodule abundance is basically controlled by sedimentation rate and style since some time of Tertiary to the Quaternary.

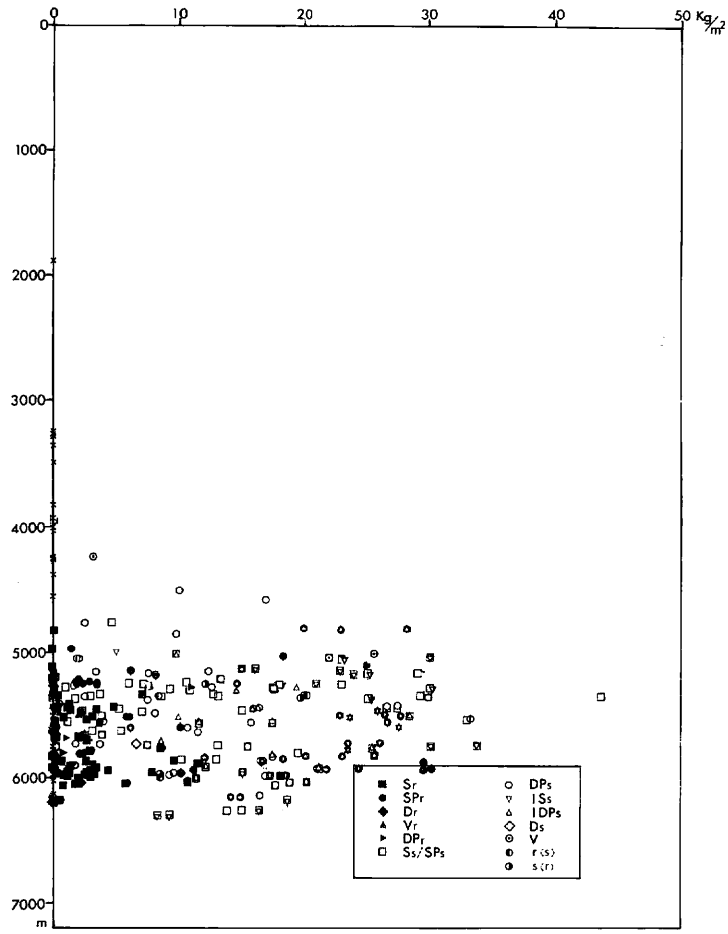

Fig. XXIV-4 Bathymetric distribution of nodule abundance and morphologic types in the Central Pacific Basin.

Relation between nodule growth and sedimentary history as deduced from the data of local variability of manganese nodules

We have obtained the data of local variability of manganese nodules at two small selected areas, around 10°N, 167°40'W and around 5°N, 173°W. The data from the former area obtained by the GH79–1 cruise provide a good evidence of nodule growth related to sedimentary history from the late Tertiary through the Quaternary.

In the area around 10°N, 167°40'W dominantly at a depth of 5,200 m, a serial work of sampling, bottom photographing, and seismic reflection profiling was done (MIZUNO *et al.*, Chap. I of this cruise report). The area is underlain by the Type B sequence (TAMAKI and TANAHASHI, this cruise report).

Figure XXIV-5 summarizes the results of analyses of manganese nodules and seismic and 3.5 kHz records along the west-east survey line (10°N) within the small area. The nodule abundance of 19 kg/m^2 at the western end rapidly decreases toward the east to less than 10 kg/m^2 and 5 kg/m^2 within the distances of approximately 5 km and 12

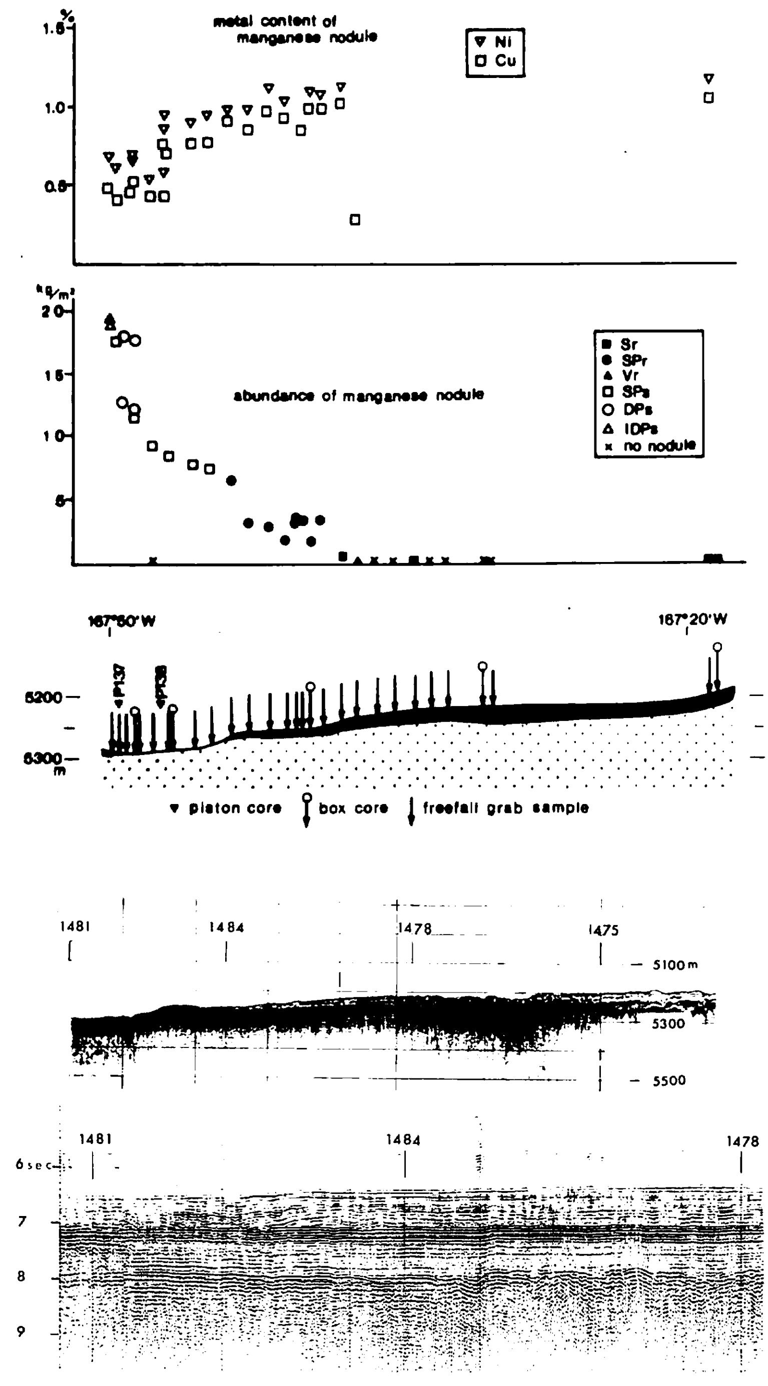

Fig. XXIV-5 Variability of manganese nodules and acoustic records along the survey line 167°50′W (St. 1481) to 167°20′W (St. 1475) (from MIZUNO *et al.*, 1980b). From the top to the bottom: distribution of nickel and copper grades; distribution of abundance, with morphologic types; sites of sampling and bottom photography, with an interpretation of acoustic records; 3.5 kHz record; seismic reflection record.

km, respectively. The nodules are only in traceable amount or barren on the eastern half of the line, east of the site approximately 22 km away from the western end. Nodule morphology varies from place to place, but the following tendency of distribution is found; IDPs type in the highest abundance part (19 kg/m^2), DPs type in the nodules with 12 to 18 kg/m^2, SPs type in those with 8 to 9 kg/m^2, and, SPr type in those with 2 to 7 kg/m^2, and Sr type in those less than 1 kg/m^2. The most marked feature is, thus, that the morphological type varies with the nodule abundance. The s-type nodules are correlated with the abundance higher than about 8 kg/m^2 and the r-type nodules with that less than 7 kg/m^2. The nodules at the sites aside the survey line belong to the r-type with low abundance (2 kg/m^2 to traceable), when present, except for the northwestern site of the small area where SPs(r) type nodules are concentrated in 8 kg/m^2.

Nickel and copper grades of the nodules from the survey line tend to increase rapidly or gradually toward the east in general in contrast to the decreasing abundance. Nickel grade in the s-type nodules increases from 0.6s% at the western end up to about 1.0% with considerable gradient within a distance of 10 km, inversely correlated to the rapid decreasing of abundance from 19 kg/m^2 to 8 kg/m^2. In the r-type nodules, nickel grade gradually increases from about 1.0% to 1.1s%. Increasing of nickel grade shows no jump between the s- and r-types as well as the decreasing of abundance. Style of increasing of copper grade is quite similar to that of the nickel grade.

Mineral composition of the nodules is quite consistent with the varying metal grade and abundance. The results of X-ray powder diffraction analysis (IIZASA, this cruise report; Table XIX-2) shows that the s-type nodules in the western part of the survey line are characterized by dominant occurrence of δ-MnO_2 and clastic minerals, associated with accessory amount of 10Å manganite, whereas the r-type nodules in the central to eastern part are characterized by dominant amount of 10Å manganite.

Lithology of surficial sediments along the survey line (NISHIMURA, this cruise report) is represented by siliceous fossil rich clay and siliceous clay. The former is distributed in the western part, and the latter is in the central to eastern part of the survey line (Fig. XXIV-6). Although an approximate correlation looks like present on the line between the lithology and the nodule occurrence, any particular correlation between them can not be recognized throughout the entire small survey area. The three box cores from the area have essentially identical chemical compositions (PIPER, this cruise report). Also there is no particular correlation between distribution of manganese nodules and bathymetry.

The distribution of manganese nodules appears to be related to sedimentary history as deduced from piston-core data and acoustic data of substrates. Micropaleontologic and paleomagnetic data of two cores, P138 and P137 from the western part of the survey line, indicate that a hiatus of approximately 20 million years between the latest Pliocene and the early Miocene is present at a level of 2.5 to about 3.0 meters beneath the sea floor (NISHIMURA; JOSHIMA, this cruise report). The younger sediment sequence above the hiatus mainly consists of dark brown clay of the latest Pliocene to the Quaternary and overlies siliceous ooze sequence interbedded with thin nannofossil ooze turbidite layers containing Oligocene and early Miocene fossils.

The 3.5 kHz and seismic reflection records give the data that the stratigraphic relation can be traced over the whole survey line (Fig. XXIV-5) and over the entire small

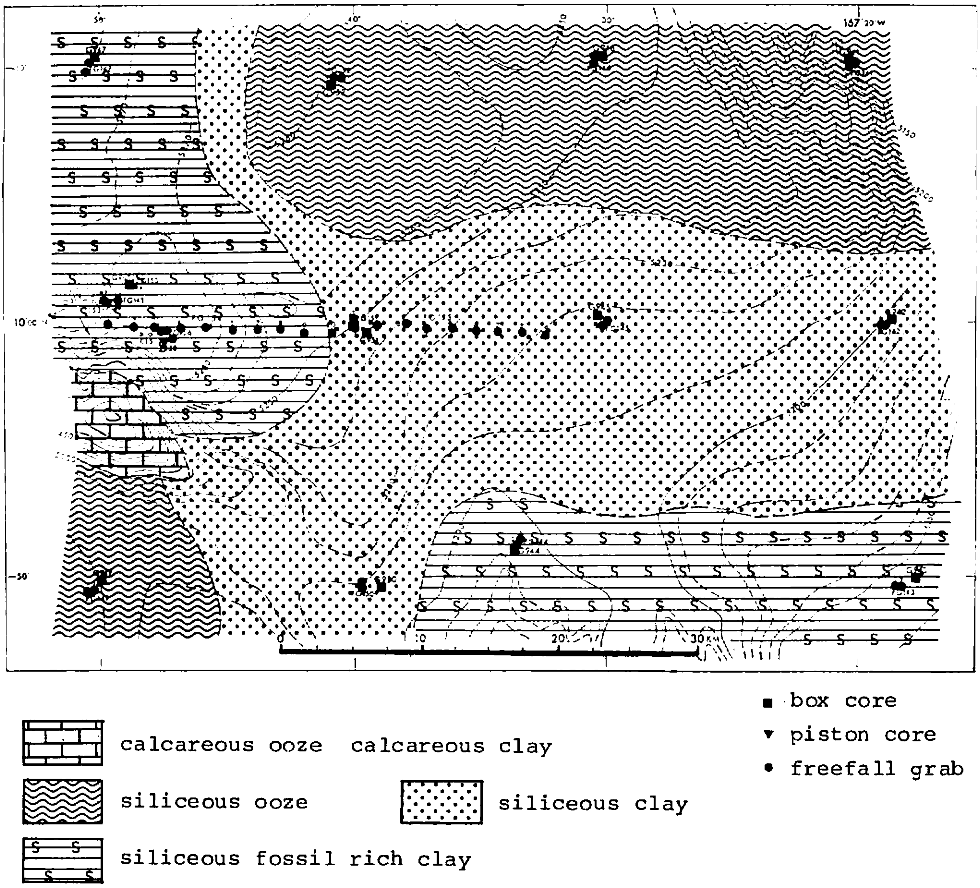

Fig. XXIV-6 Lithologic map of surficial sediments, with bathymetry and observation sites of the survey area around 10°N, 167°40′W (from NISHIMURA, this cruise report).

survey area. From the records we may conclude that the uppermost Pliocene to Quaternary sequence is as thick as 30 meters in the area apart from the moat-like depression where the two piston cores were obtained.

WINTERER, EWING, *et al.* (1973) discussed the erosion between the early Miocene and the Quaternary near DSDP Site 165, about 340 km east-southeast from the present area. They argued that the erosion might indicate a vigorous flow of bottom water there at the time of a hiatus shown by the erosion. It is suggested that the hiatus between the early Miocene and the latest Pliocene found in the small survey area is extensively distributed in the area surrounded by the Line Island chain and the Cross Trend chain. As suggested by WINTERER, EWING, *et al.* (1973), the hiatus could have been caused by repeated northward flows of the Antarctic Bottom Waters (AABW) during the time (VAN ANDEL *et al.*, 1975; MOORE, Jr. *et al.*, 1978).

In addition, the northward flow of AABW into the central Pacific in the Quaternary was suggested by NORMARK and SPIESS (1976), who substantiated the Pleistocene erosion and slower deposition or nondeposition at the area immediately east of the Line Islands chain. The varying thickness of the latest Pliocene to Quaternary sequence in the survey area may be interpreted to have formed under varying effects of AABW during the time. Local strong current must have resulted in thinner sedimentary sequence.

The variability of manganese nodules in the area is well correlated to the distribution of the latest Pliocene to_Quaternary sequence. The slower deposition of the sediment sequence is correlated with a lot of s-type nodule, whereas the faster deposition with a small amount of r-type nodule. Assuming that the nodule growth has been controlled by the sedimentation rate during the latest Pliocene and the Quaternary, the slower sedimentation less than 2 mm/1,000 y favored the growth of s-type nodules more than 8 kg/m^2, the sedimentation of 2 to 5 millimeters per 1,000 y favored the growth of r-type nodules, and the sedimentation more than 5 mm/1,000 y prevented the growth of nodule.

Mean growth rate of nodule in the area is 4.47 mm/m.y. and 3.35 mm/m.y. for the r-type and s-type nodules (Piper and Gibson, this cruise report). This implies that the r-type nodules of which diameter are smaller than 2 cm have grown within the last 2,000,000 year under weak influence of bottom waters and moderate accumulation of bottom sediments. We can consider that growth of the larger nodules largely shown by the s-type nodules goes back to the older age (probably 5,000,000 to 6,000,000 years ago) from the growth rate data, similar to a part of nodules in the east Pacific as postulated by von Stackelberg (1979). The initial growth of them may have been favored by the

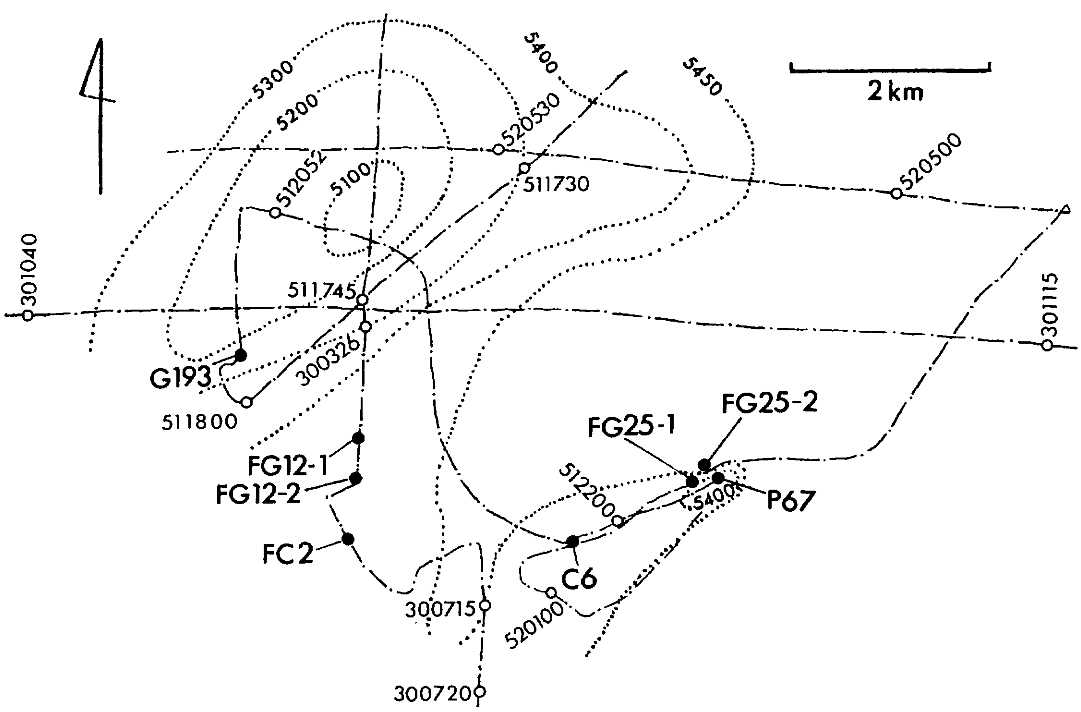

Fig. XXIV-7 Bathymetry, sampling sites, and track lines in the area around 5°N, 173°W (from Mizuno *et al.*, 1980b).

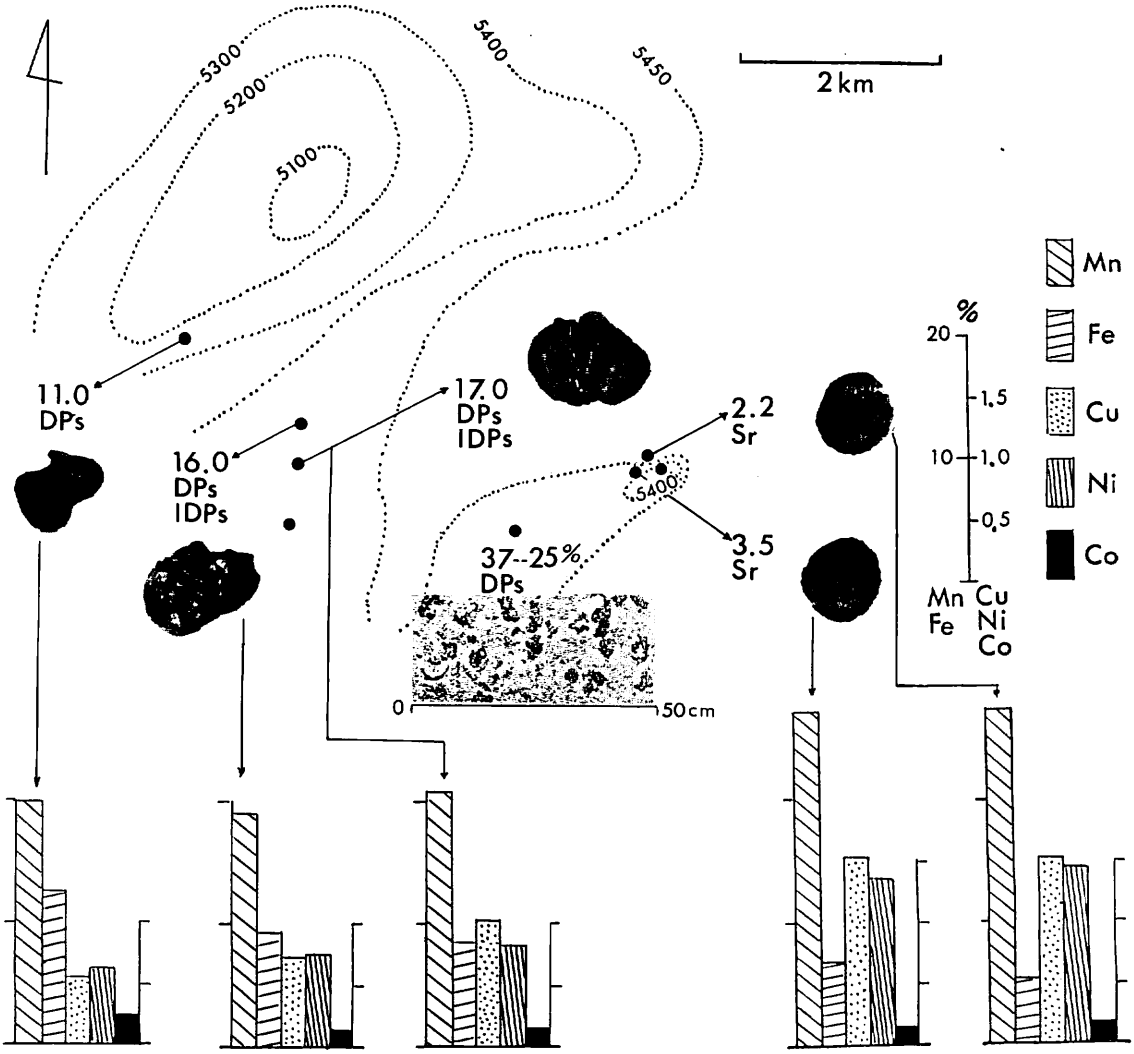

Fig. XXIV-8 Variability of manganese nodules in the area around 5°N, 173°W (from MIZUNO *et al.*, 1980b).

strong influence of bottom waters (past AABW) (nondeposition and/or erosion) during the hiatus between the latest Pliocene to Quaternary sequence and the Oligocene to early Miocene sequence. The older nodules thus formed may have grown to larger nodules under new environment with slow sedimentation rate and rather strong influence of bottom waters during the latest Pleistocene through the Quaternary. The process mentioned above has some relation with the presence of nuclei of older nodule in the s-type nodules (USUI, 1979) and the presence of hiatus within nodule (HARADA and NISHIDA, 1979).

From the above discussions, we can conclude that the nodules in the sea floor of the area comprise at least two types, younger nodules mainly represented by the r-type nodules and the nodules with older origin mainly represented by the s-type nodules.

Another example of local variability of manganese nodules was studied in the small abyssal knoll area at 5°N, 173°W (MIZUNO and MORITANI, 1978). The abyssal knoll stands several hundred meters on the abyssal basin at the depths of 5,500 to 5,600 meters, and its environs are underlain by the Type A acoustic sequence of Unit I. The sampling and acoustic observations (Fig. XXIV-7) clarified the nodule occurrence of both the r- and s-types. On the main part of the knoll, the s-type nodules occur in the abundance of 11 to 17 kg/m^2 with nickel plus copper grade of 1.3 to 1.8 per cent, whereas to the east of the knoll, the r-type nodules are present with lower abundance of 2.2 to 3.5 kg/m^2 and nickel plus copper grade of 2.9 to 3.0 per cent (Fig. XXIV-8). Surficial sediments are siliceous clay (Fig. XXIV-10) in either case. Bathymetric and lithologic circumstances are similar to each other. The only difference is suggested by the sediment sequence as detected by acoustic survey.

The thickness of transparent layer on both seismic and 3.5 kHz records varies from place to place (Fig. XXIV-9). The transparent layer of Unit I in the main part of the knoll is very poor, lack to less than 20 m thick, but it changes to very thick, up to 250 m in thickness toward the foot of the knoll.

The variability of the nodules is quite consistent with the thickness change of the transparent layer, and the r-type nodules occur in the sediments accompanied by thick transparent layer, whereas the s-type nodules occur in the area without or with very thin transparent layer (Fig. XXIV-10). According to the DSDP results (WINTERER, EWING, *et al.*, 1973), the transparent layer in the abyssal basin area is thought to consist of siliceous sediments of the middle Eocene to the Quaternary. The thin transparent layer has not been dated. It might represent the deposition during the long range as well as in the abyssal basin, or it might represent the deposition only of younger age. We have very scarce data about the problem at the present time. However, the piston-core data obtained the GH79–1 main survey area (NISHIMURA, this cruise report) suggest that the very thin transparent layer on the abyssal knoll is likely of the younger age, probably the latest Pliocene to the Quaternary, overlying the middle Eocene to Cretaceous sequence with a great hiatus.

The GH80–1 cruise has clarified a regional aspect of acoustic layers in the central Pacific (MIZUNO *et al.*, 1980a). The obtained data support the younger geologic age of the transparent layer on the abyssal knoll in that a reflector within thick transparent sequence in abyssal basin area abuts against a slope of knoll and the thinner sediments on the knoll represent only the sediments above the reflector. These considerations lead us to conclude that the manganese nodules in the area underlain by the Type A sequence of Unit I could have formed since the latest Pliocene onward as well as in the area around 10°N, 167°40′W, and also the difference of sedimentation rate has contributed to diversify the nodule occurrence into the two types, r and s.

The relation between hiatus, erosion or sedimentary history and origin of manganese nodules have been discussed in the South Pacific (PAUTOT and MELGUEN, 1976; 1979) and in the equatorial eastern North Pacific (VON STACKELBERG, 1979). Recent papers have discussed local variability of manganese nodules in the eastern North Pacific from the various view-points (MOORE, Jr., 1970; GREENSLATE *et al.*, 1973; CRAIG, 1979; HALBACH and ÖZKARA, 1979; ANDREWS and FRIEDRICH, 1980). They don't discuss the

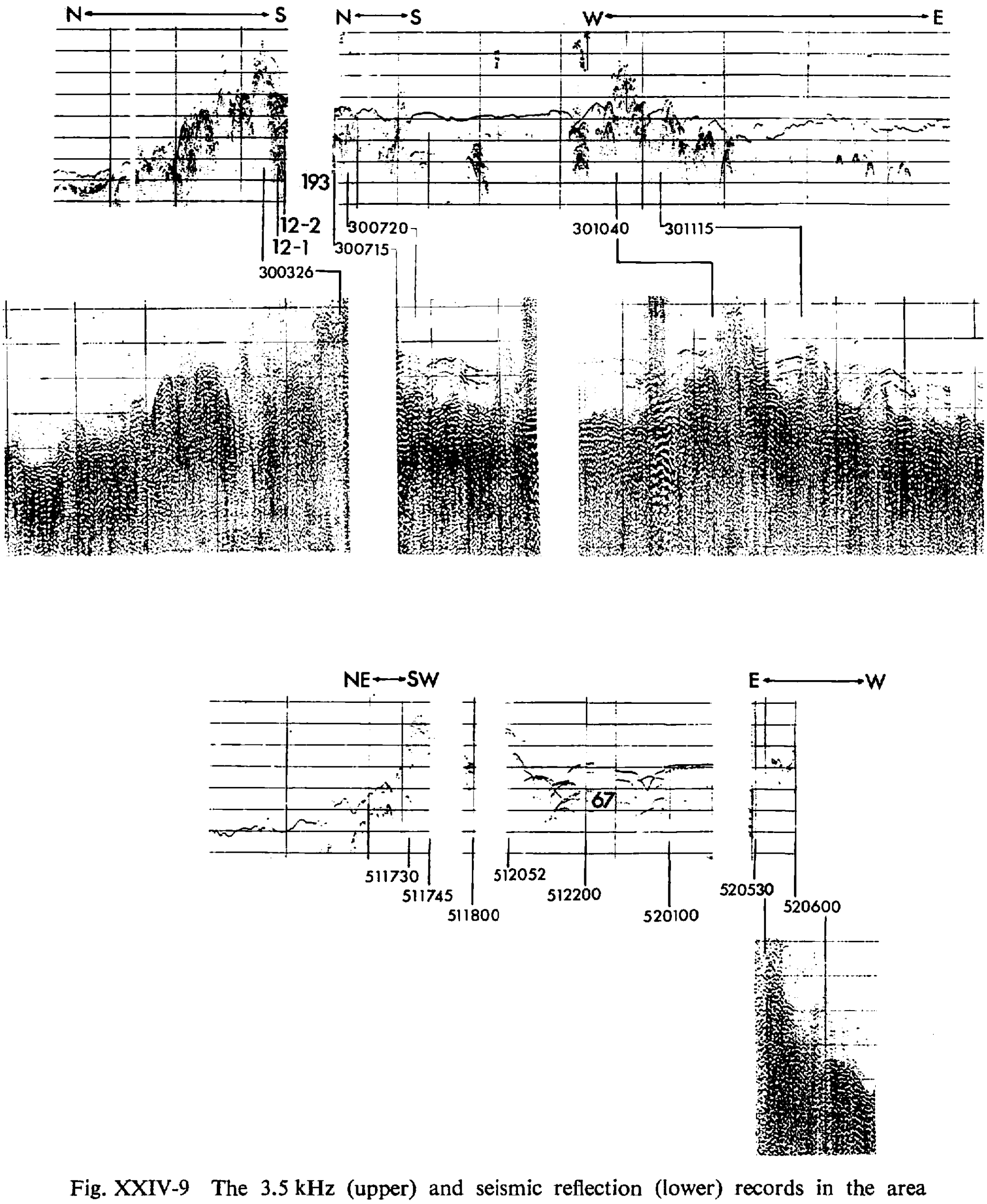

Fig. XXIV-9 The 3.5 kHz (upper) and seismic reflection (lower) records in the area around 5°N, 173°W (partly from MIZUNO *et al.*, 1980b; data source—MIZUNO and MORITANI, *ed.*, 1977).

origin of nodules in relation to sedimentary history in detail. However, the strong similarity of local variability of manganese nodules partly demonstrated in the preceding lines in this paper may suggest that the variability in the eastern Pacific has resulted possibly from varying sedimentary environments and processes during the late Tertiary to the Quaternary in part.

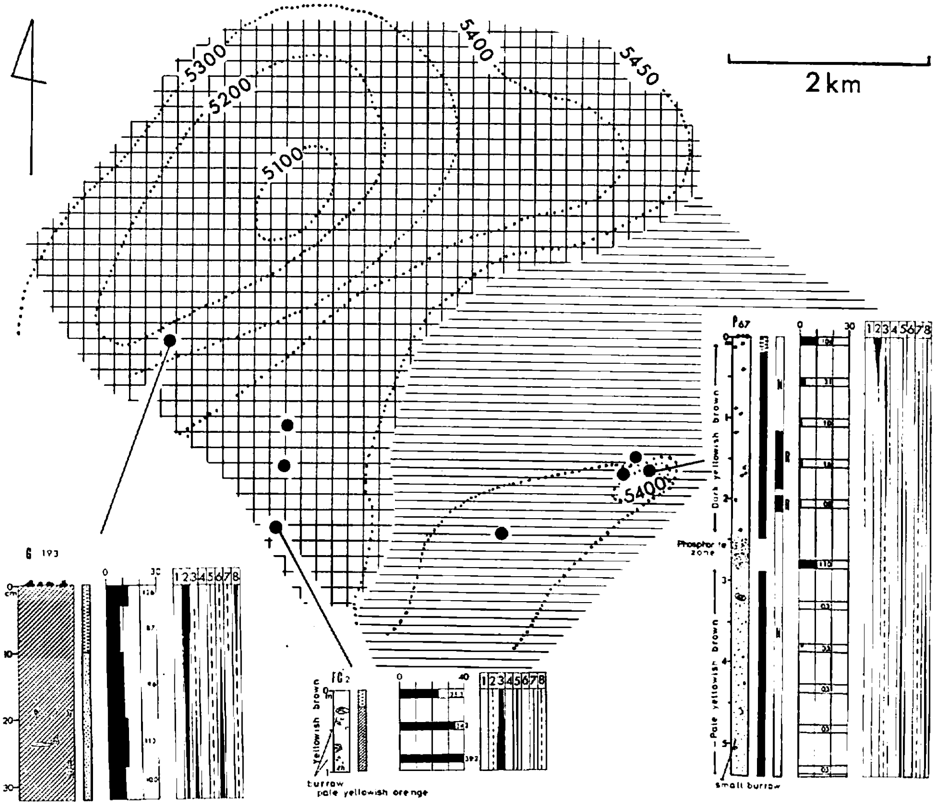

Fig. XXIV-10 Distribution of surface sediments in the area around 5°N, 173°W. Hatched part shows the area without or with very thin transparent layer; parallel-lined part shows the area with thick transparent layer (data source—MIZUNO and MORITANI, *ed.*, 1977).

Conclusion

The regional and local variabilities of manganese nodules in the Central Pacific Basin show a close correlation between nodule abundance, mineralogy, occurrence at the sea floor, and chemical composition. Sedimentary history of the late Tertiary to the Quaternary, which comprises the late Tertiary hiatus and the sedimentation during the latest Pliocene through the Quaternary, has controlled the diversification of the nodules at least into the two morphologic types, r and s. The history may have been affected by varying effects of the Antarctic Bottom Waters flowing into the central Pacific. Further detailed research of the nodules and related factors on the basis of the above conclusion must contribute to better understand the origin of the nodules in the central Pacific and also the eastern Pacific.

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