Geological Survey of Japan Cruise Report No. 23, p. 41-60, 1994

IV. DEEP-SEA SEDIMENTS IN THE PENRHYN BASIN, SOUTH PACIFIC (GH83-3 AREA)

Akira Nishimura and Yoshiki Saito

Introduction

During the Cruise GH83-3, spatial distribution of sediments and sedimentary history were studied in the Penrhyn Basin, South Pacific (Fig. IV-1) in relation to the genesis of manganese nodules. A detailed survey area was selected for small-scale sampling near the center of GH83-3 area (Fig. IV-2). Sediments and manganese nodules were collected by a double-spade box corer (16 sites), a piston corer (17 sites), and a small sediment sampler fixed to free-fall grabs (146 sites).

Box and piston core sites are shown in Tables IV-1 and IV-2 and in Figures IV-1 and IV-2. Sediments collected by box corers, piston corers, and freefall grabs were treated in the same manner as in our previous study (Nishimura, 1984 and 1986; Nishimura and Ikehara, 1992). Sediment lithology was described according to the composition of sediments on smear slides under a microscope.

The framework of sediment classification is shown in Table VI-3. Age estimation of the core sequences is based on preliminary micropaleontologic analysis of ichthyoliths and remnant magnetism of sediments (Yamazaki, Chapter VII of this volume). This paper describes lithology of sediments and discusses sedimentary history based on surface sediments and core sequences.

Surface sediments

The distribution map of surface sediment of the Pacific (Piper *et al.*, 1985) indicates that the surface sediment of GH83-3 area is pelagic mud. Nakao and Mizuno (1982) recognized some sedimentary provinces along the Wake to Tahiti transect based on sediment lithology crossing this area. According to their criteria, this survey area is included in *Southern pelagic mud zone* characterized by few occurrences of siliceous or calcareous biogenic debris.

The surface sediments of box cores (Fig. IV-3) and the uppermost sediments of piston cores are dark brown to very dark reddish brown pelagic clay, which includes many single crystals and aggregations of zeolite. Both calcareous biogenic and siliceous biogenic components are very rare or lacking because the sea floors of the survey area have been below the calcium carbonate compensation depth (CCD) and far out of the equatorial high productivity zone. CCD of this area is estimated approximately 5,000 m (Berger *et al.*, 1976; Takayanagi *et al.*, 1982).

Box core B85 out of the main survey area is composed exceptionally of calcareous

Keywords: deep-sea sediment, hiatus, erosion, ichthyolith, CCD, Antarctic Bottom Water, DSDP, Manihiki Plateau, Hakurei-Maru, Penrhyn Basin

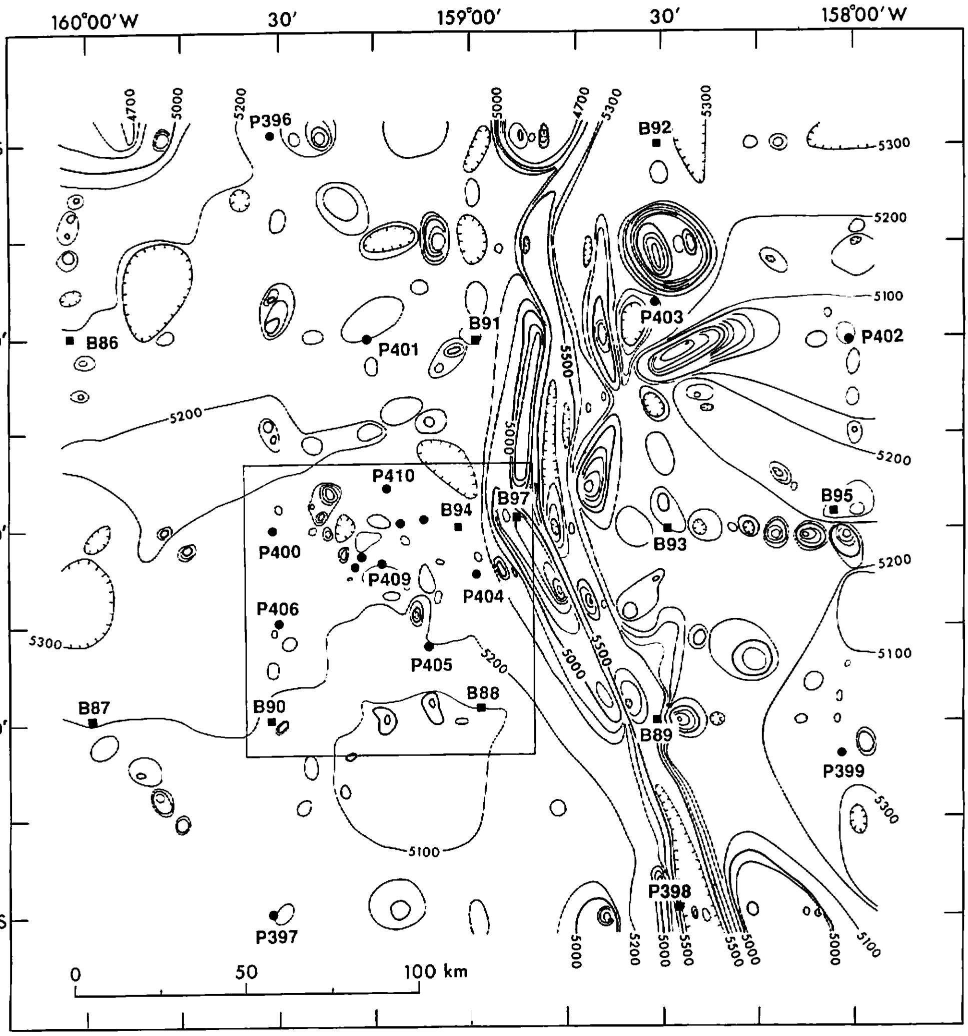

Fig. IV-1 Topography and sample locations of GH83-3 area.

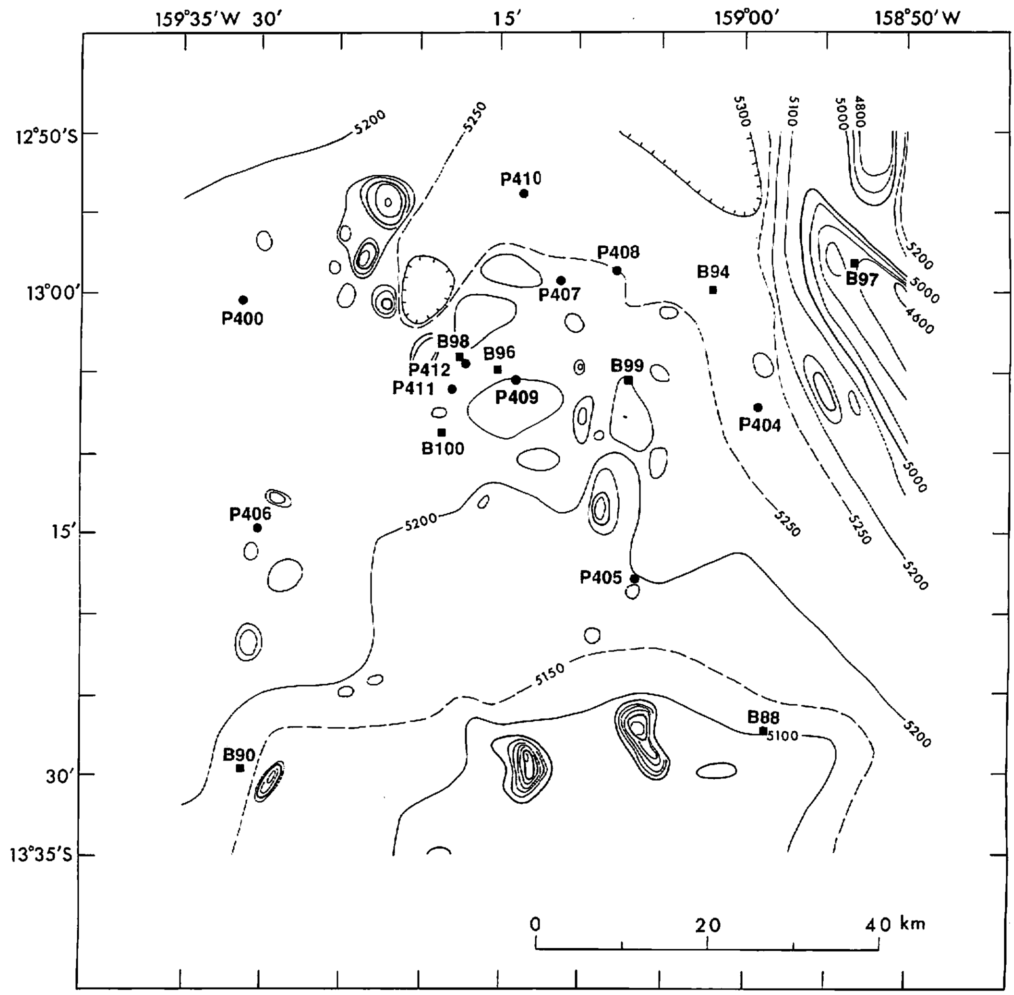

Fig. IV-2 Topography and sample locations of detailed survey area.

Table IV-1 Station data of box cores during Cruise GH83-3.

Station No.	Sample No.	Position		water depth (m)
		Latitude(S)	Longitude(W)	
St. 3901	B85	11°08.93'	161°00.49'	3626
St. 3903	B86	12°29.66'	160°02.30'	5155
St. 3905	B87	13°29.50'	159°59.47'	5206
St. 3907	B88	13°27.48'	158°58.86'	5124
St. 3909	B89	13°29.72'	158°30.90'	5583
St. 3911	B90	13°29.60'	159°31.29'	5196
St. 3912	B91	12°30.46'	158°59.25'	5345
St. 3921	B92	12°00.03'	158°30.64'	5248
St. 3923	B93	13°00.27'	158°29.17'	5098
St. 3925	B94	12°59.99'	159°01.80'	5289
St. 3952	B95	12°57.01'	158°02.70'	5376
St. 3975	B96	13°04.93'	159°15.24'	5237
St. 3982	B97	12°58.21'	158°53.06'	4714
St. 4005	B98	13°04.16'	159°17.69'	5227
St. 4020	B99	13°05.52'	159°07.06'	5204
St. 4027	B100	13°08.80'	159°18.67'	5220

Table IV-2 Station data of piston cores during Cruise GH83-3.

Station No.	Sample No.	Position		water depth (m)
		Latitude(S)	Longitude(W)	
St. 3902	P396	11°58.82'	159°31.06'	5289
St. 3904	P397	13°59.77'	159°31.02'	5176
St. 3906	P398	13°58.53'	158°27.69'	5727
St. 3908	P399	13°35.41'	158°01.64'	5304
St. 3910	P400	13°00.62'	159°31.05'	5242
St. 3920	P401	12°30.56'	159°16.00'	5206
St. 3922	P402	12°30.25'	158°00.83'	4950
St. 3924	P403	12°24.80'	158°31.15'	5330
St. 3930	P404	13°07.25'	158°59.31'	5289
St. 3936	P405	13°17.96'	159°06.51'	5238
St. 3948	P406	13°14.66'	159°30.16'	5268
St. 3960	P407	12°59.38'	159°11.22'	5248
St. 3968	P408	12°58.65'	159°07.68'	5258
St. 3990	P409	13°05.56'	159°14.06'	5186
St. 3998	P410	12°54.00'	159°13.49'	5278
St. 4013	P411	13°06.16'	159°18.01'	5217
St. 4030	P412	13°04.40'	159°17.31'	5217

Table IV-3 Framework of sediment classification.

Framewark of Sediment classification

Pelagic clay *zeolite, siliceous fossil, calcareous fossil<5%*		
Zeolite rich clay *5%<zeolite<10%*	Siliceous fossil rich clay *5%<siliceous fossil<10%*	Calcareous fossil rich clay *5%<calcareous fossil<10%*
Zeolitic clay *10%<zeolite*	Siliceous clay *10%<siliceous fossil<30%*	Calcareous clay *10%<calcareous fossil<30%*
	Siliceous ooze *30%<siliceous fossil*	Calcareous ooze *30%<calcareous fossil*

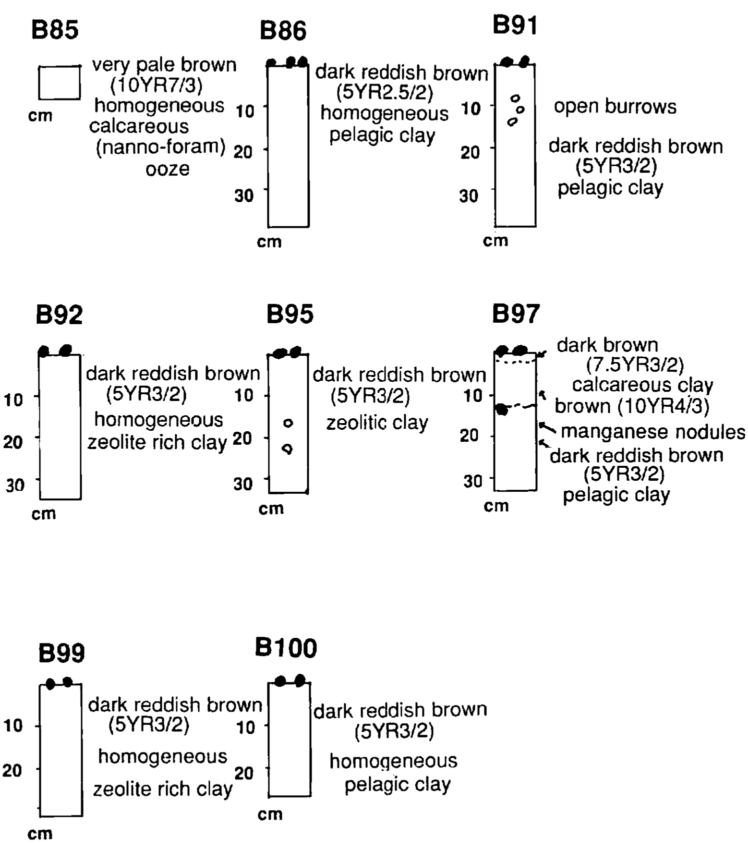

Fig. IV-3 Lithological description of box core sediments.

ooze. It is located on the southeastern margin of the Manihiki Plateau which belongs to *Calcareous sediments zone* (Nakao and Mizuno. 1982) above CCD.

Core sequences of the survey area

Seventeen piston cores are described in Figure IV-4 and as follows. Ichthyolith biostratigraphy of the core sequences is adopted for age determination of the cores, as they are only biogenic remains in the pelagic sediments of this area. Ichthyoliths consist of phosphate and are highly resistant to dissolution under a deep-sea environment. Several horizons of the core sequences were analyzed. The sediment samples were disintegrated in H_2O_2 solution and then sieved by a 63μm-sieve and identified under the optical microscope. The range chart of the ichthyoliths in Table IV-4 is compiled from the data of Doyle *et al.* (1979) and the results of our analyses are shown in Table IV-5. The core sequence in the area is roughly divided into four periods based on ichthyolith biostratigraphy (Fig. IV-5).

P396 : This core is composed of dark reddish brown homogeneous clay in the upper part and black homogeneous clay in the lower part.

P397 : This core is composed of dark reddish brown clay in the upper half of and semi-consolidated dark reddish brown clay in the lower part. The boundary represents the sedimentary hiatus as in the form of a thin manganese crust. The sediments beneath the hiatus is decolored to yellowish brown.

P398 : This core is composed of pelagic clay throughout the sequence.

P399 : This core is very short. The surface of the sea bottom is probably manganese crust outcrop.

P400 : This core is composed of dark reddish brown pelagic clay in the uppermost part and dark reddish brown homogeneous clay in the middle to lower parts. A thin manganese crust is present at the boundary.

P401 : This core is composed of dark reddish brown pelagic to zeolitic clay. The upper part of this core contains sand-sized zeolite aggregations.

P402 : This core is composed of dark reddish brown to black pelagic clay in the upper part and semi-consolidated dark reddish brown clay in the lower part. The boundary represents the sedimentary hiatus because of presence of thin manganese crust and different grades of consolidation.

P403 : This core is composed of dark reddish brown pelagic clay throughout the sequence.

P404 : This core is composed of consolidated clay in the upper and middle parts and dark reddish brown unconsolidated clay in the lower part. Brownish yellow claystone layers are observed between the two units.

P405 : This core is composed of pelagic clay throughout the sequence and the lowest part contains sand-sized zeolite aggregations.

P406 : This core is composed dark reddish brown clay in the upper and middle part, and consolidated dark reddish brown clay in the lower part.

P407 : This core is composed of dark reddish brown clay in the upper part, and consolidated dark reddish brown clay in the lower and middle part.

P408 : This core is composed of pelagic clay and upper part of the core includes zeolitic sand grains.

P409 : This core is composed of pelagic clay throughout the sequence.

P410 : This core is consolidated clay and shows typical alternation of claystone and pelagic clay in the middle part.

P411 : This core is composed of pelagic clay in the middle and upper parts, and dark reddish brown pelagic lay in the lower part. The lower half of the upper unit contains sand-sized zeolite aggregations.

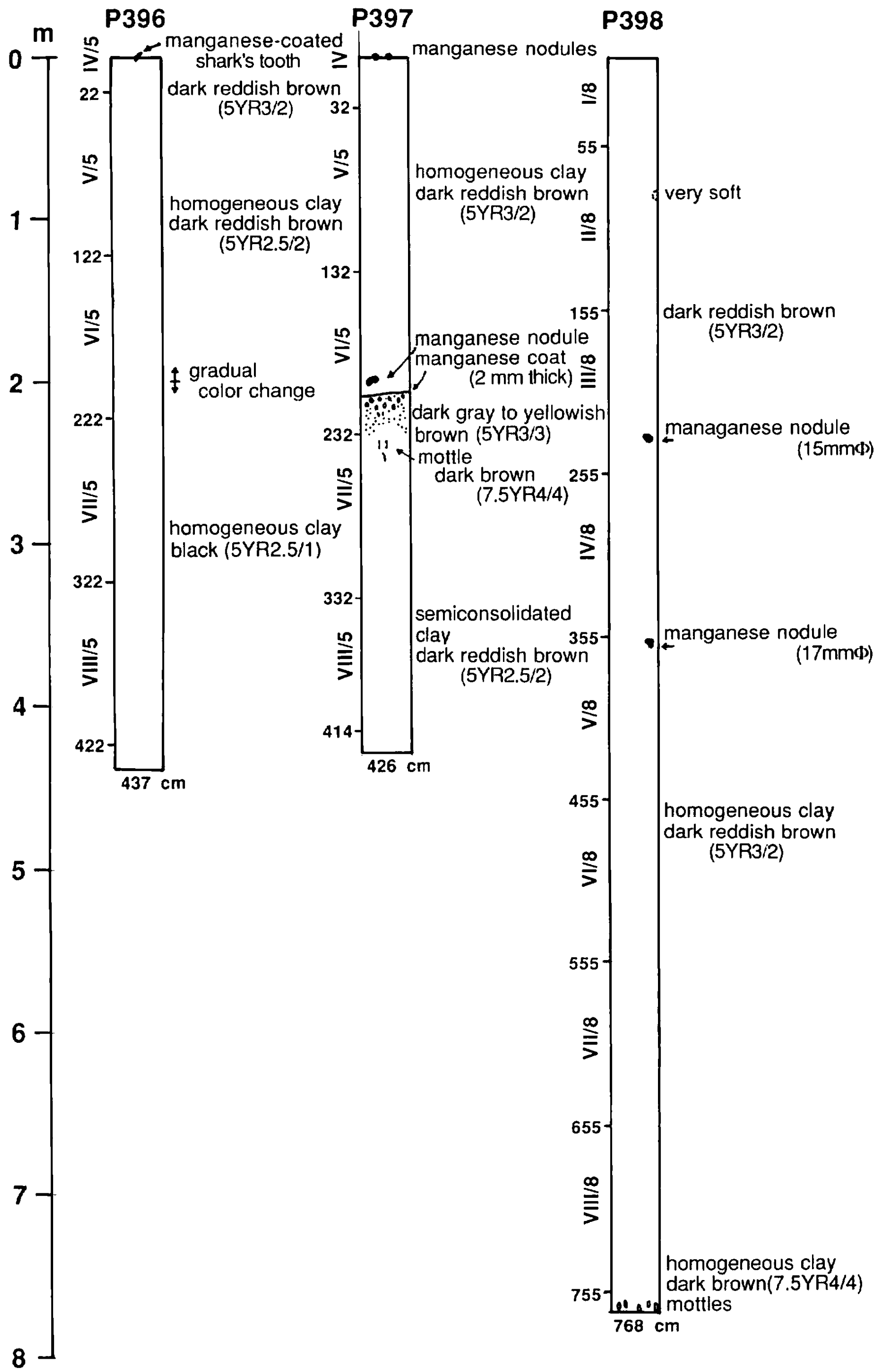

Fig. IV-4 Lithological description of piston core sediments.

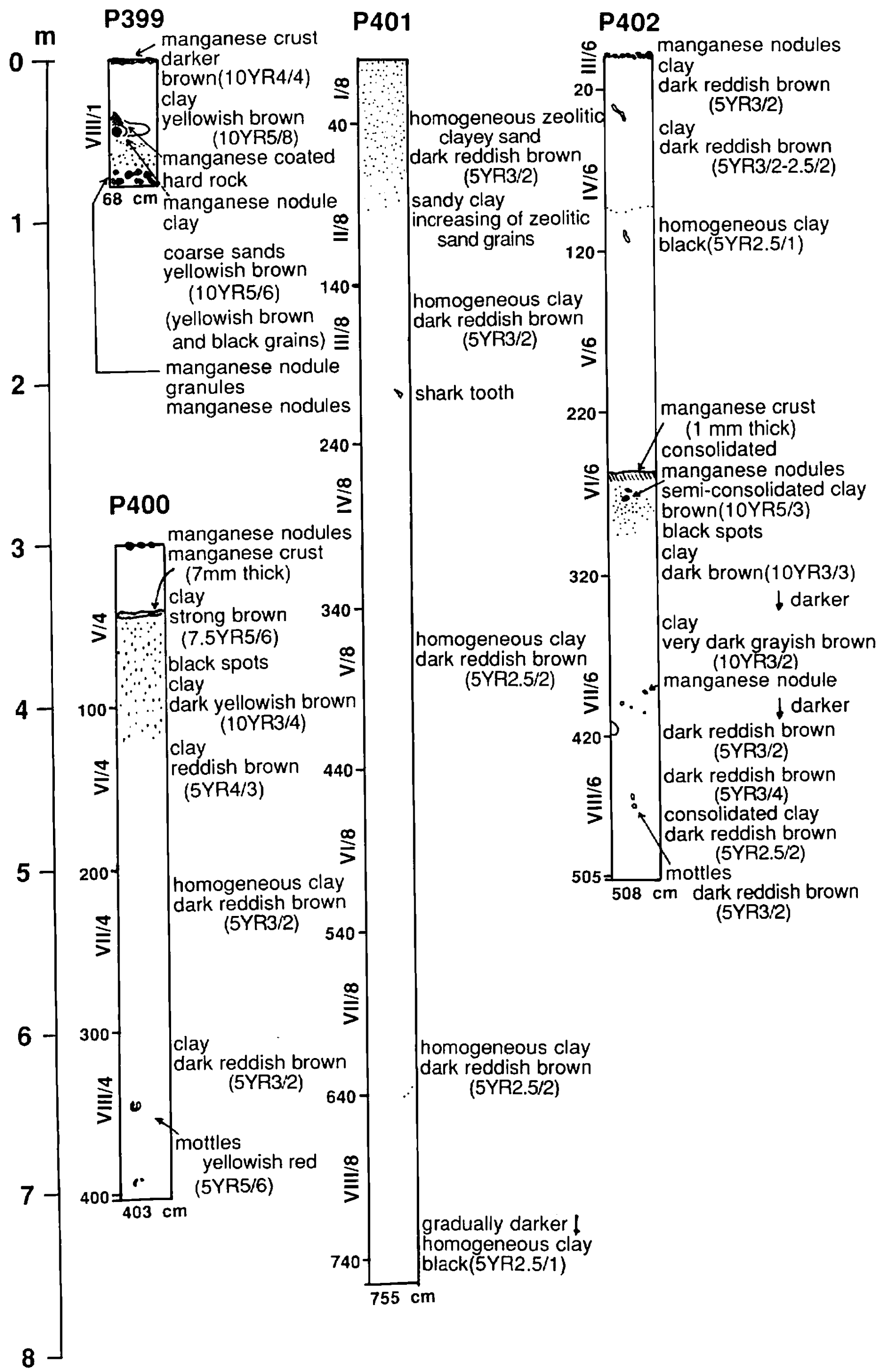

Fig. IV-4 (continued)

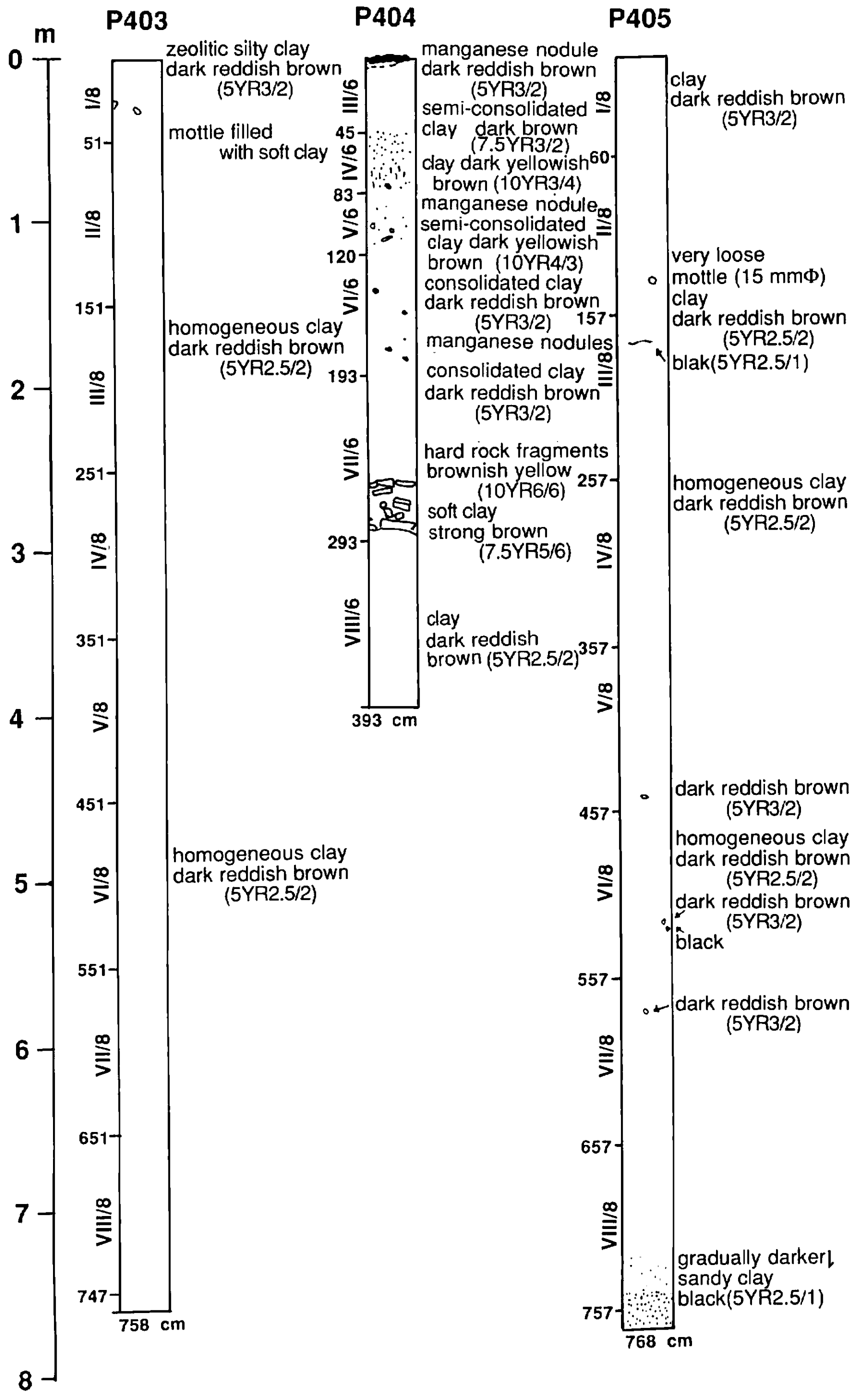

Fig. IV-4 (continued)

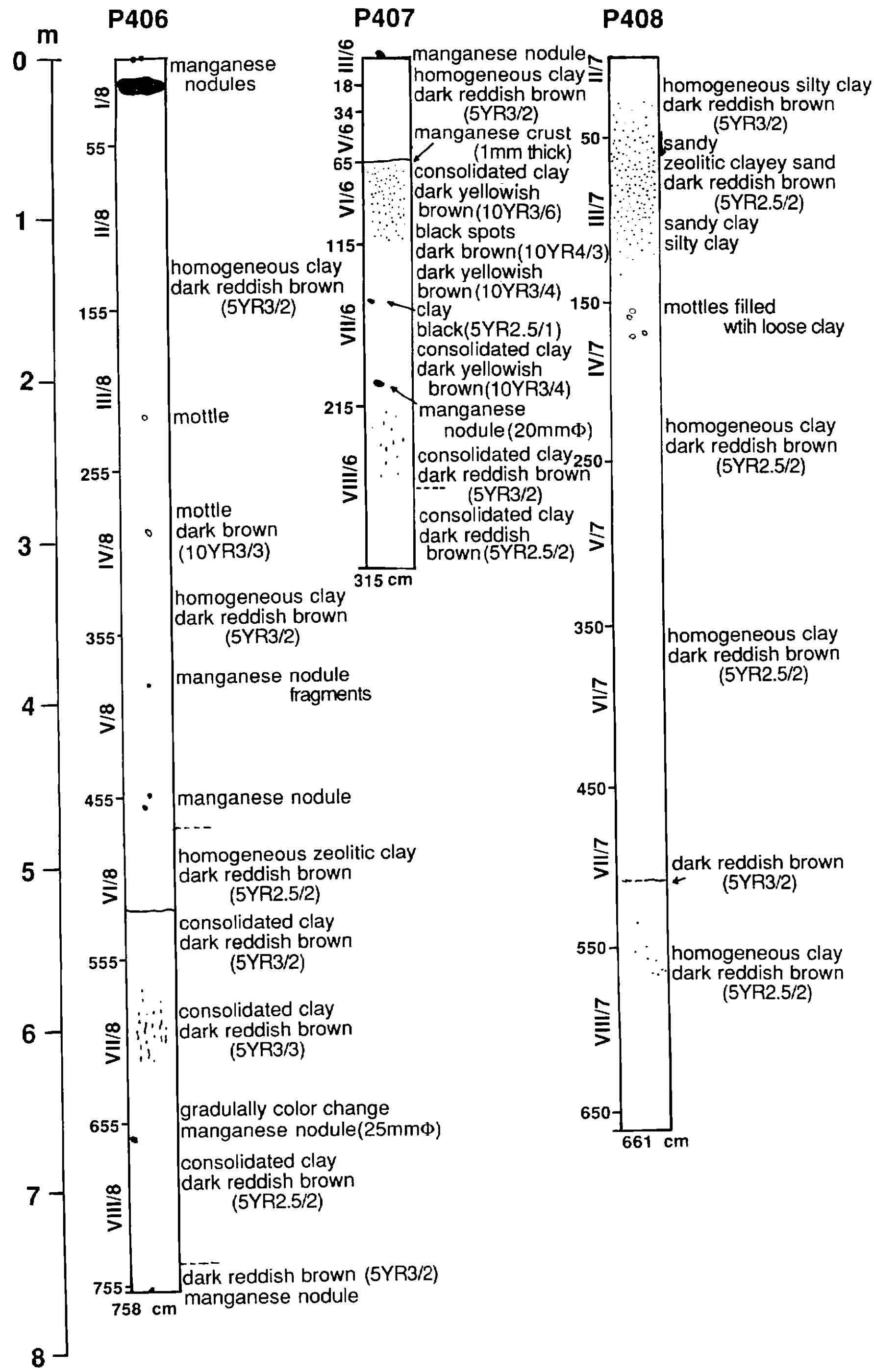

Fig. IV-4 (continued)

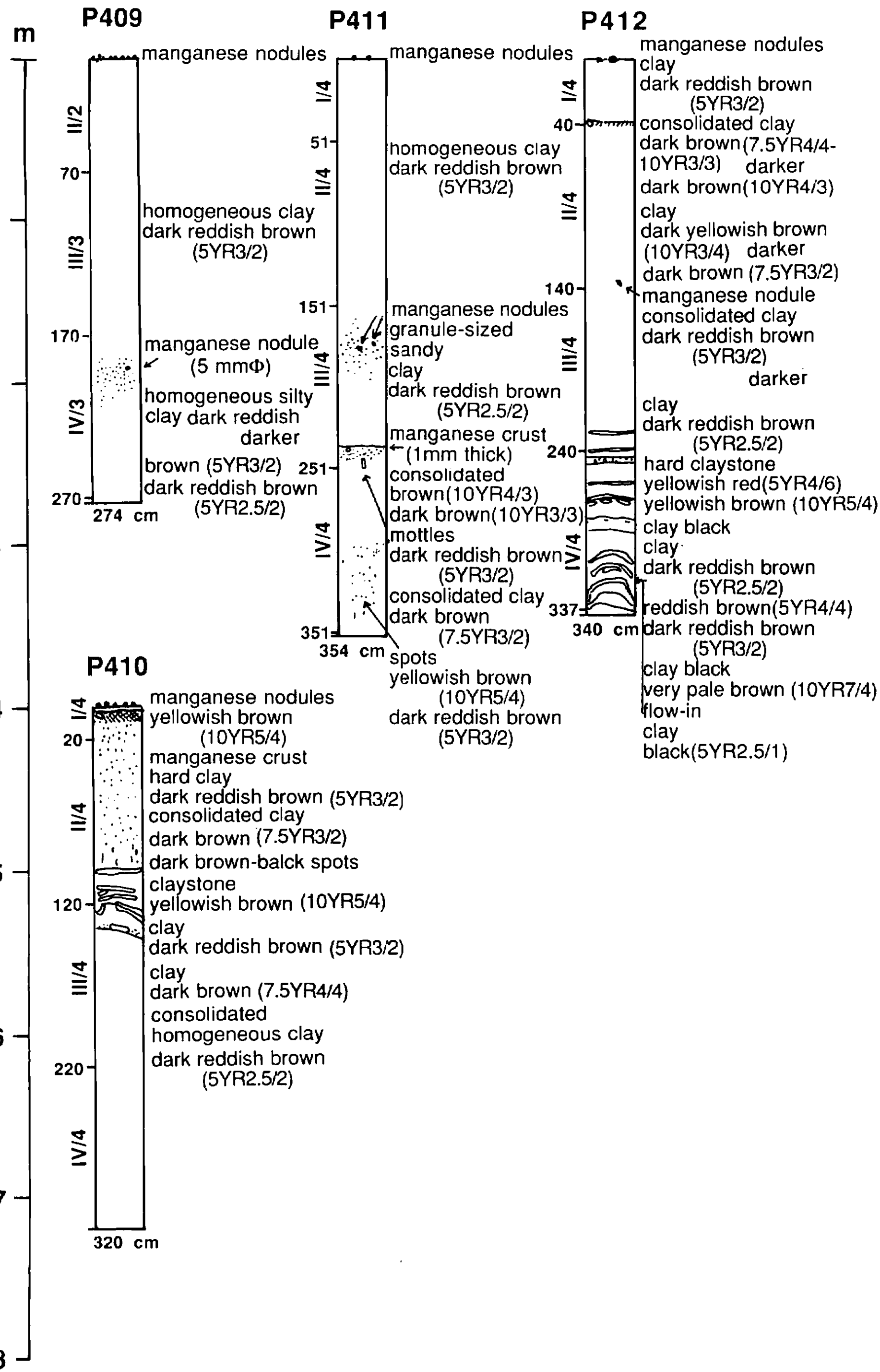

Fig. IV-4 (continued)

Table IV-4 Range chart of Ichthyolith based on Doyle *et al.* (1979).

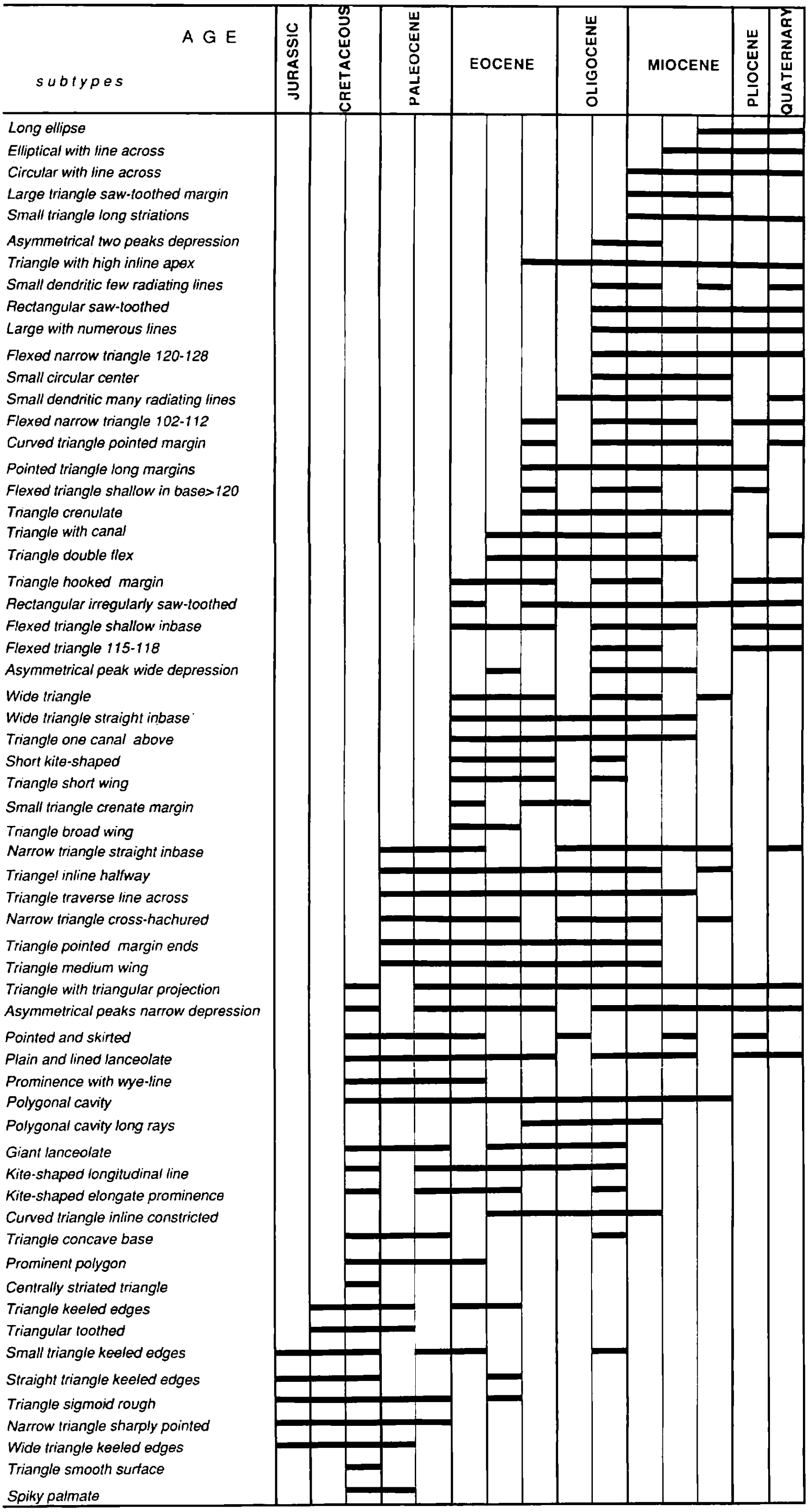

Table IV-5 Occurrence of ichthyolith during Cruise GH83-3. Closed circles show the presence of ichthyolith forms.

SAMPLES / subtypes	P396 402	P397 20	110	200	390	P398 725	P400 30	70	380	P401 720	P402 10	35	250	300	470	P403 727	P404 130	373	P405 737	P406 135	335	485	585	635	P407 24	65	195	295	P408 530	P409 250	P410 150	P411 221	281	331	P412 210
Long ellipse																					●														
Elliptical with line across				●							●									●	●														
Circular with line across						●	●														●											●			
Large triangle saw-toothed margin																						●										●			
Small triangle long striations																●					●									●					
Asymmetrical two peaks depression																																			
Triangle with high inline apex				●			●				●										●				●					●		●			
Small dendritic few radiating lines																																●			
Rectangular saw-toothed				●		●	●				●	●								●	●	●							●			●			
Large with numerous lines																																			
Flexed narrow triangle 120-128		●	●	●							●									●	●	●											●		
Small circular center											●																								
Small dendritic many radiating lines																						●													
Flexed narrow triangle 102-112				●								●																				●			
Curved triangle pointed margin				●											●						●				●							●			
Pointed triangle long margins				●																															
Flexed triangle shallow in base>120												●																							
Triangle crenulate													●									●										●			
Triangle with canal													●																						
Triangle double flex										●												●													
Triangle hooked margin								●			●														●										
Rectangular irregularly saw-toothed																																●			
Flexed triangle shallow inbase										●			●			●						●	●		●				●	●		●	●		
Flexed triangle 115-118			●				●				●									●					●					●					
Asymmetrical peak wide depression																						●										●			
Wide triangle																																			
Wide triangle straight inbase																																●			
Triangle one canal above													●																						
Short kite-shaped																						●													
Triangle short wing	●												●									●											●		
Small triangle crenate margin										●																									
Triangle broad wing																																			
Narrow triangle straight inbase																																			
Triangel inline halfway																																			
Triangle traverse line across													●																						
Narrow triangle cross-hachured																																			
Triangle pointed margin ends	●									●												●								●		●			
Triangle medium wing	●									●			●																	●					
Triangle with triangular projection																						●								●					
Asymmetrical peaks narrow depression					●																	●													
Pointed and skirted																																			
Plain and lined lanceolate															●																				
Prominence with wye-line															●								●				●							●	
Polygonal cavity														●	●						●	●	●									●			
Polygonal cavity long rays																						●										●			
Giant lanceolate																																			
Kite-shaped longitudinal line														●	●								●				●							●	
Kite-shaped elongate prominence																						●													
Curved triangle inline constricted																																			
Triangle concave base																																			
Prominent polygon					●																					●	●								
Centrally striated triangle								●															●	●				●			●				
Triangle keeled edges																	●																		
Triangular toothed					●																					●			●						
Small triangle keeled edges					●													●								●			●						
Straight triangle keeled edges																											●								●
Triangle sigmoid rough																	●										●								
Narrow triangle sharply pointed									●									●									●	●						●	●
Wide triangle keeled edges																																			
Triangle smooth surface									●															●				●							●
Spiky palmate														●									●	●				●			●		●		●

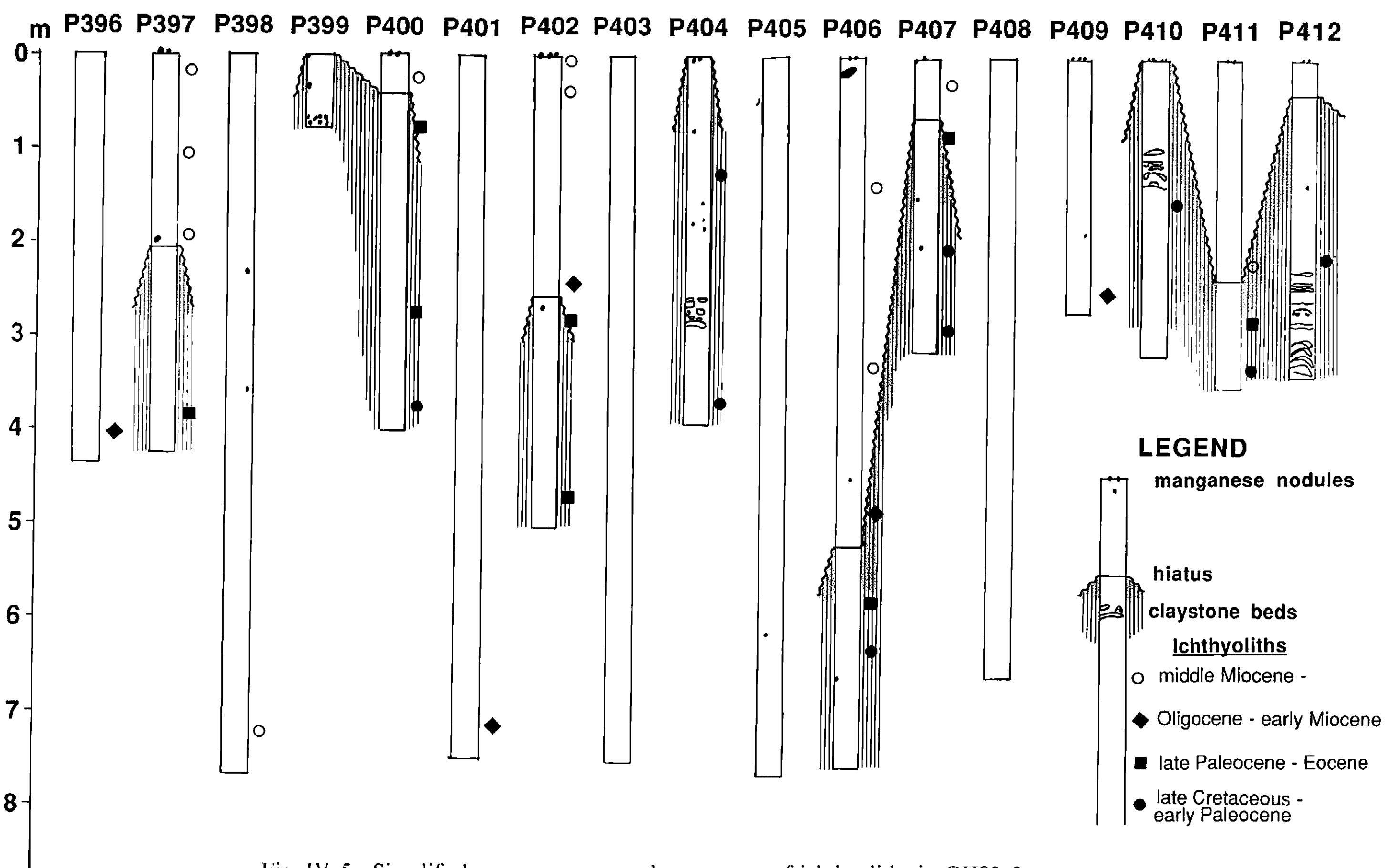

Fig. IV-5 Simplified core sequences and occurrence of ichthyoliths in GH83-3 area.

P412: This core is composed of very dark pelagic clay in the upper part, dark reddish brown clay in the middle part, and alternation of yellowish brown claystone and pelagic clay in the lower part.

Lithologic units of sediment core sequences

The three lithologic units are recognized in the sediment cores described above. The brief description of these lithologic units are as follows.

Lithologic unit I; Unconsolidated dark reddish brown to dark brown pelagic clay and zeolitic clay.

Lithologic unit II; Consolidated dark brown to dark reddish brown pelagic clay.

Lithologic unit III; Alternation of yellowish brown claystone (or siltstone) and semi-consolidated dark reddish brown pelagic clay. Unconsolidated dark reddish brown clay below the alternation is included in this unit.

The boundary between Unit I and II is a hiatus in the core sequences, which is suggested by a presence of manganese crusts, an abrupt change in grade of consolidation at the boundary, and the time gap of the assigned ages by the ichthyoliths. A boundary between Unit II and III is probably formed through lithologic change during continuous sedimentation. Three lithologic units yield characteristic forms of ichthyoliths indicating ages of the units. Unit I is assigned to the Oligocene or later, Unit II to the late Paleocene to the Eocene, and Unit III to the Cretaceous to the early Paleocene.

The preliminary X-ray diffraction analyses on selected sediment samples revealed difference of mineral compositions among the lithologic units (Table IV-6). The unit I is characterized by high content of phillipsite, while Units II and III lack phillipsite. Unit II contains abundant quartz while Unit III contains K-feldspar but lacks quartz.

Relation between lithologic stratigraphy of the core sequences and acoustic stratigraphy of 3.5 kHz SBP

Three acoustic units are recognized on 3.5 kHz SBP records over the survey area, and are probably correlative to the lithologic units in the core sequences, described here. The results of the correlation between the acoustic and lithologic units are shown in Table IV-7 and also discussed minutely in Chapter III. The spatial distribution of seismic units and the lithologic units in the core sequences of the detailed survey area are shown in Figure IV-6.

Correlation between the survey area and DSDP Site 596 in the southern Pacific

The lithologic units recognized in the survey area is correlative to that of the DSDP Site 596 (23°51.20′S, 165°39.27′W, 5701 m water depth) in the Southwest Pacific Basin. Site 596 was successfully drilled 76.1 m below the seafloor. The lithologic units of Site 596 (Shipboard Scientific Party, 1987) are as follows;

Unit I: 0-11 m DSF (depth from sea floor). Dark reddish brown pelagic clay and zeolitic pelagic clay with hard grounds encrusted by Fe and Mn oxides.

Unit II: 11-27 m DSF. Very dusky red pelagic clay and zeolitic pelagic clay, having a sharp contact with Unit I.

Unit IIIA: 27-38 m BSF. Very dusky red pelagic clay distinguished from Unit II by

Table IV-6 Results of X-ray diffraction analysis of sediment samples of GH83-3 area. Analyzed by Akira Usui, GSJ.

no.	*Unit*	*bsf (cm)*	*description*	phlp	mmt	qtz	K-fsp	plc	Mn10	Mn7
P406										
A	I	*1*	*dark brown clay*	X	X	X	-	X	-	-
B	I	*45*	*dark brown clay*	X	X	X	-	X	-	-
C	I	*225*	*dark brown clay*	XX	X	X	-	X	-	-
D	I	*405*	*dark brown clay*	XX	X	X	-	X	-	-
E	I	*495*	*dark brown clay*	XX	X	X	-	-	-	-
F	II	*545*	*dark brown clay*	-	XX	XX	X	-	-	-
G	II	*685*	*dark brown clay*	-	XX	XX	X	-	-	-
H	II	*754*	*dark brown claystone*	-	XX	XX	X	-	-	-
P412										
A	I	*8*	*dark brown clay*	X	X	X	tr	X	-	-
B	II	*80*	*dark brown clay*	-	XX	XX	X	-	-	-
C	II	*146*	*dark brown clay*	-	X	XX	X	-	-	-
D	III	*225*	*buff claystone*	-	XX	-	XX	-	-	-
E	III	*250*	*black clay*	-	X	tr	X	-	-	-
F	III	*258*	*buff claystone*	-	XX	-	XX	-	-	-
G	III	*275*	*buff claystone*	-	XX	-	XX	-	-	-
H	III	*295*	*black clay*	-	-	-	-	-	X	X
I	III	*332*	*buff clay, hetero*	-	XX	-	XX	-	-	-

NOTE: Mineralogy; phlp=phillipsite, mmt=montmorillonite, qtz=quartz, K-fsp=potash feldspar, plc=plagioclase, Mn10=10Å manganate, Mn7=7Å manganate. XX=abundant, X=common, tr=traceable, -=not detected. bsf=depth from sea floor.

Table IV-7 Correlation between seismic and lithologic units in GH83-3 area.

UNIT	3.5 kHz SEISMIC PROFILING RECORD	LITHOLOGY IN CORE SECTIONS	AGE
I	Transparent layer	Unconsolidated dark reddish brown zeolitic clay - pelagic clay	Recent - Oligocene
II	Semi-transparent layer (outcropped) Semi-opaque layer (below layer I)	consolidated dark brown to dark reddish brown pelagic clay	Eocene -
III	Opaque layer	Alternation of yellowish brown claystone (siltstone) and semi-consolidated dark reddish brown pelagic clay	Cretaceous

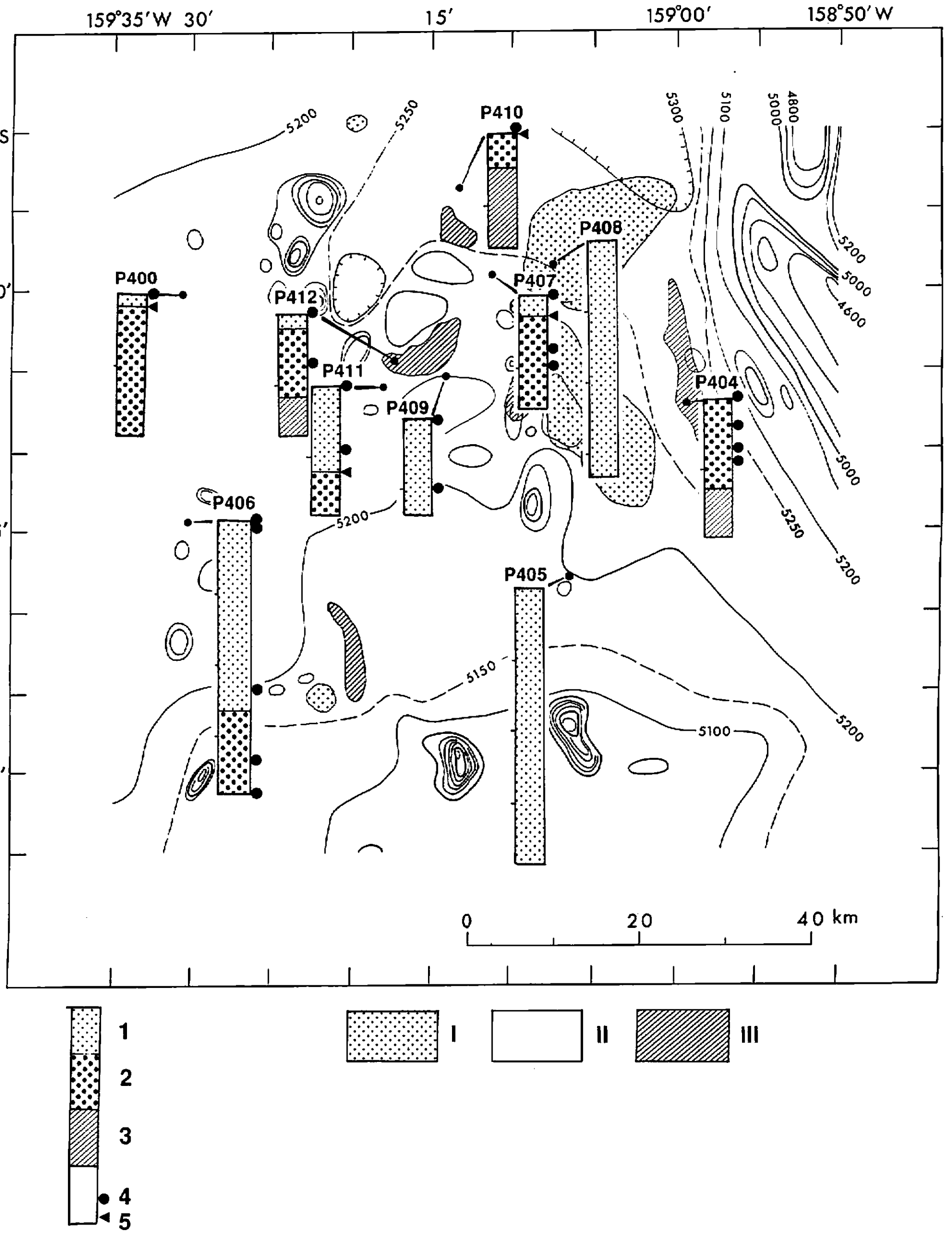

Fig. IV-6 Distribution of 3.5 kHz SBP acoustic Units and Lithologic units of the core sequences in the detailed survey area.
I: Unit I, II: Unit II, and III: Unit III.
1: Lithologic unit I, 2: Lithologic unit II, 3: Lithologic unit III, 4: Occurrence of manganese nodule, and 5: manganese crust.

the presence of thin layer of pale brown pelagic clay. The subunit appears transitional to Unit IIIB (38-68 m BSF), which is very dusky red pelagic clay with thin layers of pale brown pelagic clay interbedded with porcellanite and chert.

Unit IV: 68-71 m BSF. Reddish black metalliferous clay.

Unit V: 71-76.1 m BSF. Basalt.

The ages of the units are determined by the ichthyolith biostratigraphy (Winfrey *et al.*, 1987). Unit I is early Miocene or later and Unit II is Oligocene to Cretaceous including Paleogene - Cretaceous boundary. The correlation between the seismic reflection survey and lithologic units are established, but acoustic stratigraphy of 3.5 kHz SBP was not available in their research.

The lithologic unit of GH83-3 area is correlative to the units of DSDP cores. Lithologic unit I of this study is correlative to Unit I of DSDP. Alternation of clay and claystone of Lithologic unit III is correspoding to pelagic clay with thin beds of pale brown clay of the Unit IIIA. The claystone beds with pale brown color is probably highly altered ash beds because of no radiolarian remains and poorly observed bioturbated structures (Shipboard Scientific Party, 1987). The geochemical study of the pelagic sediments of the DSDP cores suggests an abrupt change of the sedimentary environment between the Paleogene-Neogene (Zhou and Kyte, 1992).

The age estimation of the boundary between Units I and II of DSDP Site 596 is not coincided to that between Lithologic units I and II in the GH83-3 area. Further study is needed to establish the age estimation by ichthyolith biostratigraphy.

Hiatuses in the core sequences

Half of the core sequences studied show the stratigraphic breaks, hiatuses. Antarctic Bottom Water (AABW) flows into the Central Pacific Basin through the Samoan Passage (Hollister *et al.*, 1974) and a part of AABW flows eastward along the Nova-Canton Trough and probably reachs the survey area (Yamazaki, 1992; Yamazaki, Chapter XII of this volume), though Pautot and Melguen (1979) suggested the direct flow into the Penrhyn Basin from the Southwest Pacific Basin through the Aitutaki Passage. The hiatuses were probably formed when AABW was intensified enough to erode sediments and / or to prevent sedimentation. The short periods of hiatus have been recognized and numbered based on DSDP data (Keller and Barron, 1987). In GH82-4 area northwest of this area, only the period of the uppermost hiatus in the core sequences is cleared (Nishimura and Ikehara, 1992). The peak of the erosion occurred probably during the period between the Olduvai Event and the Jaramillo Event in the Matuyama Reversed Epoch. A sedimentary hiatus between Units I and II in this area suggests a very long time gap and may be in the Paleogene age. The hiatus is also recognized in DSDP Site 596 in the Southwest Pacific, which suggests that this hiatus is developed widely in the south Pacific. The formation of this hiatus is supposed to be caused by a significant change in the deep water circulation (Shipboard Scientific Party, 1987).

Manganese nodule formation and sedimentary history are discussed in Chapter VIII (Usui, this volume). The manganese nodule formation probably started with the Lithologic unit III, and has continued to the present. The hiatus between Lithologic units I and II have strongly affected the abundance of manganese nodule deposits in this area.

Summary

1) Surface sediments of the survey area are very dark reddish brown pelagic clay to zeolitic clay, because the sedimentation have occurred far out of the equatorial high productivity and below CCD.
2) The succession of the core sequences is divided into three Lithologic units, dark reddish brown pelagic to zeolitic clay of Oligocene or later, pelagic clay of late Paleocene to Eocene, and alternation of black pelagic clay and yellowish brown claystone of Cretaceous to early Paleocene.
3) The boundary between the Lithologic units I and II represents a long-term hiatus, suggested by lithological characteristics and the presence of manganese crust.
4) The lithologic units are clearly correlative to the acoustic units on 3.5 kHz SBP records. Lithologic unit I is correlative to the uppermost transparent layer (Unit I), Lithologic Unit II to semi-opaque layer (Unit II), and Lithologic unit III and basement to opaque layer (Unit III).

We acknowledge Dr. A. Usui for his heartful help to improve this paper and his permission for use of X-ray diffraction analyses of sediments.

References

Berger, W. H., Adelseck, C. G. and Mayer, L. A. (1976) Distribution of carbonate in surface sediments of the Pacific Ocean. *Jour. Geophys. Res.*, vol. 81, p.2617-2627.

Doyle, P. S. and Riedel, W. R. (1979) Ichthyoliths: present status of taxonomy and stratigraphy of microscopic fish skeletal debris. *Scripps Institution of Oceanography Reference Series*, no. 79-16, 231p.

Hollister, C. D., Johnson, S. A. and Lonsdale, P. F. (1974) Current-controlled abyssal sedimentation: Samoan Passage, equatorial Pacific. *Jour. Geol.*, vol. 82, p.275-300.

Keller, G. and Barron, J. A. (1987) Paleodepth distribution of Neogene deep-sea hiatuses. *Paleoceanography*, vol. 2, p.697-713.

Nakao, S. and Mizuno, A. (1982) Regional sedimentologic data: the Central Pacific Wake-Tahiti transect, GH80-1 Cruise. *Geol. Surv. Japan Cruise Rept.*, no. 18, p.95- 123.

Nishimura, A. (1984) Deep-sea sediments in the GH80-5 area in the northern vicinity of the Magellan Trough. *Geol. Surv. Japan Cruise Rept.*, no. 20, p.67-89.

——— (1986) Deep-sea sediments in the Central Equatorial Pacific (GH81-4 area). *Geol. Surv. Japan Cruise Rept.*, no. 21, p.56-83.

——— and Ikehara, K. (1992) Deep-sea sediments in the southern part of the Central Pacific Basin (GH82-4 area). *Geol. Surv. Japan Cruise Rept.*, no. 22, p.85-96.

Pautot, G. and Melguen, M. (1979) Influence of deep water circulation and sea floor morphology on the abundance and grade of central south Pacific manganese nodules. In: Bischoff, J. L. and Piper, D. Z. (eds.), *Marine Geology and Oceanography of the Pacific Manganese Nodule Province.* Plenum Pub. Co., New York, p.621-649.

Piper, D. Z., Macoy, E. W. and Swint, T. R. (1985) *Manganese nodules, seafloor sediment, and sedimentation rates of the Circum-Pacific Region.* American Association of Petroleum Geologists, Tulsa, Oklahoma, scale 1:17,000,000.

Shipboard Scientific Party (1987) Site 596: Hydraulic piston coring in an area of low surface productivity in the southwest Pacific. Menard, H. W., Natland, J., Jordan, T. H., Orcutt, J. A. *et al.*, *Init. Repts. DSDP*, vol. 91, p.245-267.

Takayanagi, Y., Sakai, T., Oda, M. and Hasegawa, S. (1982) Micropaleontology of piston cores, Wake to Tahiti. *Geol. Surv. Japan Cruise Rept.*, no. 18, p.238-263.

Winfrey, E. C., Doyle, P. S. and Riedel, W. R. (1987) Preliminary ichthyolith biostratigraphy, southwest Pacific, Deep Sea Drilling Project Leg 91. *Init. Repts. DSDP*, vol. 90, p.447-468.

Yamazaki, T. (1992) Bottom water temperature in the south of the Nova-Canton Trough, central equatorial Pacific (GH82-4 area). *Geol. Surv. Japan Cruise Rept.*, no. 22, p.253-261.

Zhou, L. and Kyte, F. T. (1992) sedimentation history of the south Pacific pelagic clay province over the last 85 million years inferred from the geochemistry of Deep Sea Drilling Project Hole 596. *Paleoceanography*, vol. 7, p.441-465.