V. PRELIMINARY STUDY ON THE SEDIMENT CORES FROM THE CONTINENTAL SLOPE AND DEEP-SEA BOTTOM OFF THE OUTER ZONE OF SOUTHWEST JAPAN

Eiji Inoue

1. CORE LOCATION

In order to understand the Quaternary sedimentation in the area studied, seven cores were collected from the terraces on the continental slope, the Nankai Trough and the abyssal plain of the Shikoku Basin, using a 6 m long piston corer designed by the G. S. J. (Table V-1). P57, P59, P61 and P63 were obtained from the terraces on the continental slope at depths between 1080 and 2050 m. P57 and P63 were located at the margins of the Kumano Terrace, P59 was taken from the center of the Tosa Terrace, and P61 was from the edge of the Hyuga Terrace (Fig V-1).

P60 and P62 were obtained from the bottom of the Nankai Trough at depths of 4400 and 4880 m respectively, and P58 penetrated the sediment at the base of the Koshu Seamount in the Shikoku Basin at a depth of 4000 m.

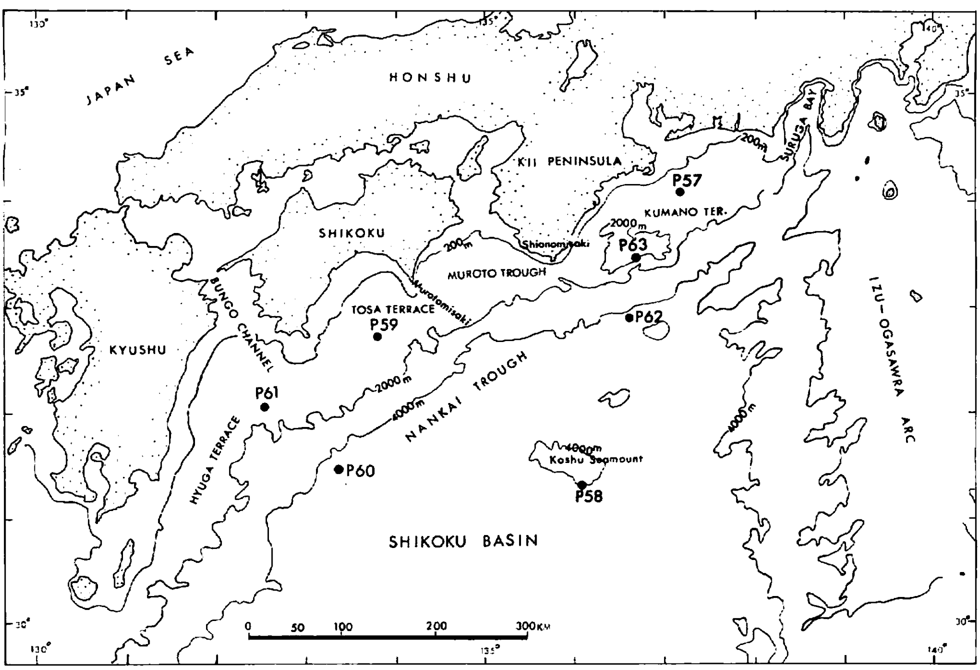

Fig. V-1 Location map of the cores obtained from the area surveyed during the GH75-4 cruise.

The sedimentary environment of the peripheral areas of the core locations are known from the 3.5kHz profile records (Fig. V-2).

Table V-1 Locations of piston cores.

Stations	No. of core	Locations			Area and Topography	Penetration depth of corer (cm)	Length of core (cm)
		Latitude N	Longitude E	Water depth (m)			
St. 363	P57	34°04.3′	137°09.8′	1,775	Northern margin of Kumano Terrace	293	228
St. 366	P58	31°19.0′	136°05.4′	4,000	Shikoku Basin. Base of a seamount	518	485
St. 367	P59	32°43.0′	133°48.5′	1,080	Tosa Terrace on continental slope	337	332
St. 368	P60	31°26.9′	133°20.5′	4,890	Bottom of Nankai Trough	450	426
St. 371	P61	32°02.5′	132°31.8′	1,774	Hyuga Terrace on continental slope	324	268
St. 375	P62	32°53.7′	136°36.6′	4,440	Bottom of Nankai Trough	587	490
St. 377	P63	33°28.0′	136°40.5′	2,050	Southern margin of Kumano Terrace	415	327

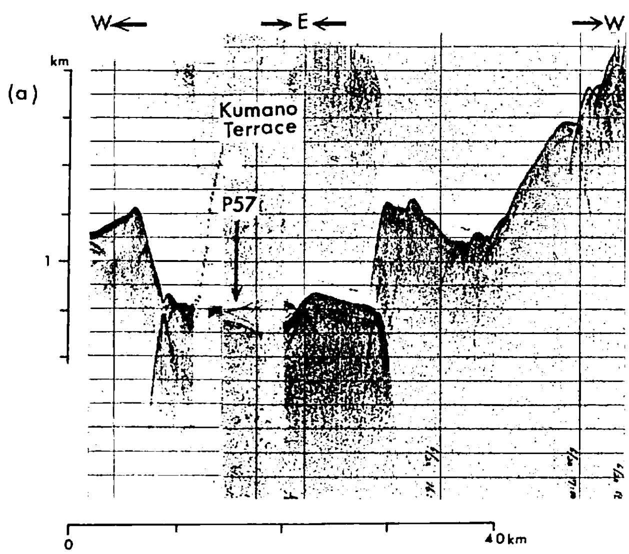

Fig. V-2-1 Sites of the cores and physiography as recorded by 3.5 kHz profiler on the terraces of the continental slope. (a), P57 at the northern margin of the Kumano Terrace.

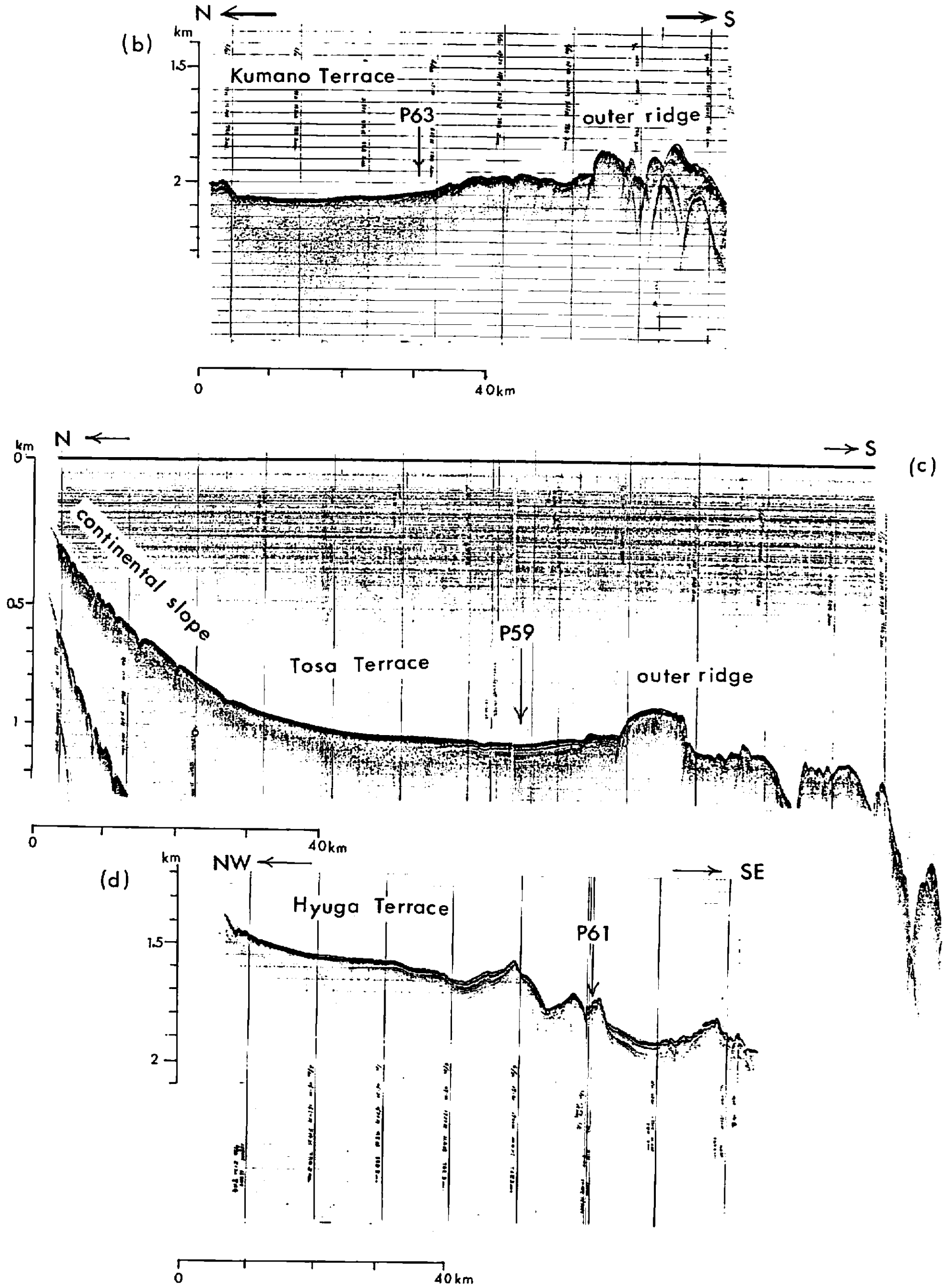

Fig. V-2-2 Sites of the cores and physiography as recorded by 3.5 kHz profiler on the terraces of the continental slope. (b), P63 at the southern margin of the Kumano Terrace; (c), P59 on the Tosa Terrace; (d), P61 on the Hyuga Terrace.

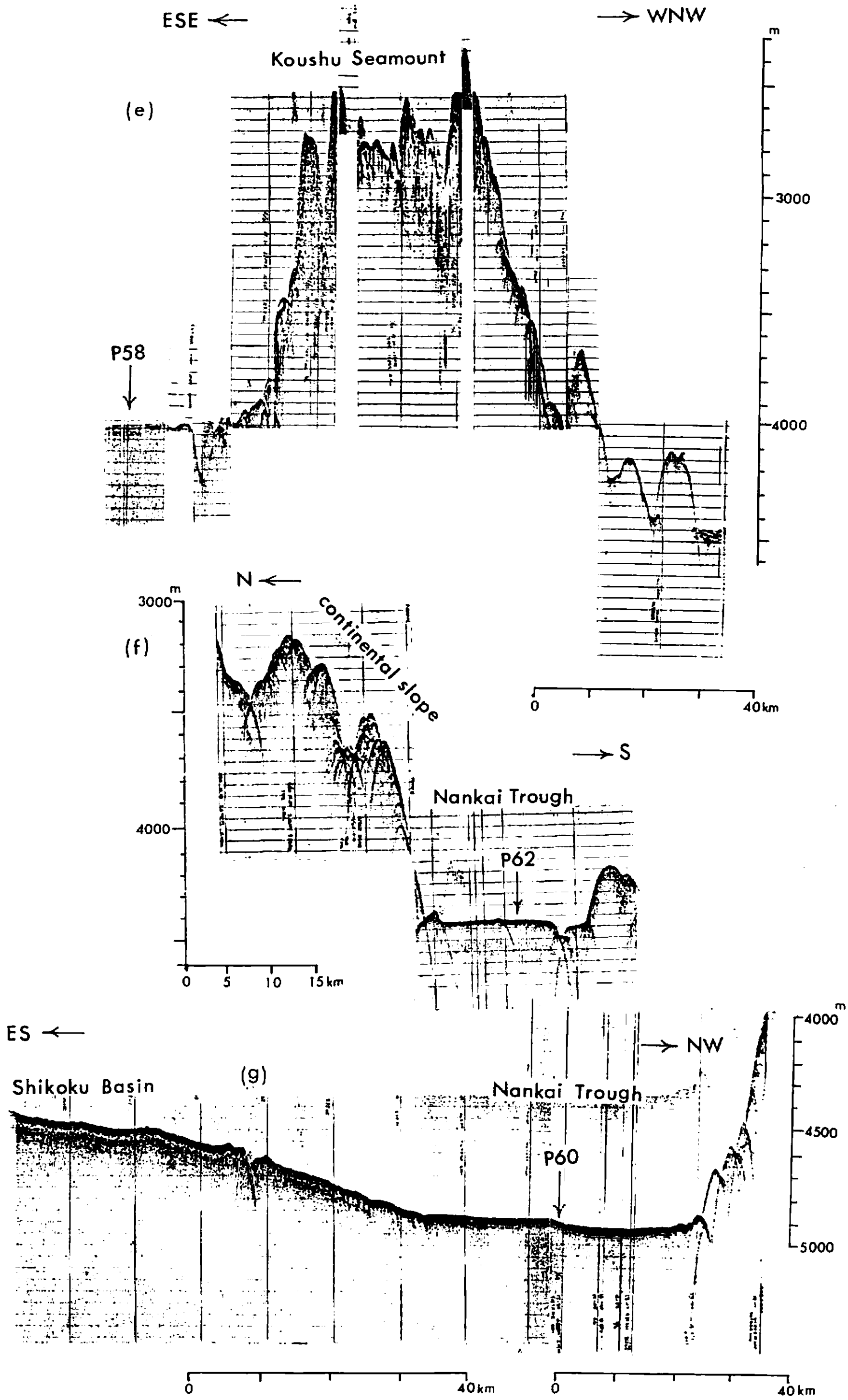

Fig. V-2-3 Sites of the cores and physiography as recorded by 3.5 kHz profiler on the terraces of the continental slope. (e), P58 on the abyssal plain at the base of the Koshu Seamount; (f), P62 and (g) P60 on the bottom of the Nankai Trough.

2. CORE DESCRIPTIONS

The sediments in the cores from the terraces are greenish-grey silt and light grey or grey sand with occasional granules and pebbles. Whitish-yellow volcanic ash beds are intercalated at some horizons. On the other hand, the cores from the trough and the abyssal plain areas are composed of greenish-grey silt and clay intercalated with very fine grained sand laminae. The sediments also have some thin beds of whitish-yellow volcanic ash. Columnar sections of all the cores are shown in Fig. V-3.

1) Cores from the terraces

P57 at St. 363 was obtained from the northernmost part of the Kumano Terrace at a depth of 1775 m, which is about 40 km southeast of Shima Peninsula. As shown in Fig. V-2, the sediments around this location occur as a fan-like deposit at the base of the upper continental slope with an irregular profile. The sedimentary environment seems to have been strongly influenced by nearshore currents during the Quaternary.

The 228 cm of the sediment was obtained. The sediments are greenish-grey silt containing sand and gravels. There are four or five sedimentary cycles in the core and each cycle is of the upward-fining type (Fig. V-4). The lower part of each cycle consists of rounded or subrounded small pebbles of quartz, chert, sandstone and slates, which were derived from the Shimanto Group of Upper Cretaceous and Paleogene ages in the Kii Peninsula. The boundary between the base of a cycle and the uppermost part of preceeding cycle is irregular, inferring an erosional surface. The upper part of the cycle is composed of silt and sandy silt containing granules. The sediments also include some subangular gravel layers with a thickness of 10 and 12 cm at the 90 and 220 cm levels respectively. Such coarse layers imply that the material was transported to the depression of the upper continental slope by strong currents which existed periodically during the lower sea-level periods during the Quaternary.

P63 at St. 377 was obtained from a depth of 2050 m near the southern margin of the Kumano Terrace. The nature of the sea floor in this area is smooth and flat. The sediment layers here are thinner than those in the central part of the terrace. The P63 corer penetrated 415 cm of the sediments 327 cm of which was recovered in the core tube. The sediments consist of greenish-grey silt and clay intercalated with fine and very fine sand laminae. Sand laminae are abundant in the upper part of the core and are nepheloid shaped. Two beds of whitish-grey volcanic ash occur; the upper one occupies the core-top 15 cm, and the other occurs at the middle part and is 20 cm thick. In addition to these layers a thin ash bed also occurs at 90 cm below the core-top.

A large amount of plant debris occurs at 72.5 −85.5 cm below the core-top (Fig. V-4). The colour of the plant debri bed is dark brown and it has a thickness of 13 cm, in which the plant debris is rather densely concentrated in the middle part of 5 cm thick. According to the palynological analysis the bed contains abundant pollen of herbs. The occurrence of the herbs bed in hemi-pelagic sediments suggests that the depositional site was much nearer to land where strong paleocurrents existed, than the present location.

P59 from St. 367 is located in the southern part of the Tosa Terrace about 70 km southwest of Murotomisaki Point, Shikoku. The core was obtained from the flat sea floor, where thick, stratified Neogene–Quaternary sediments occur. The corer obtained a core of 332 cm and there was no flow-in part in the core barrel.

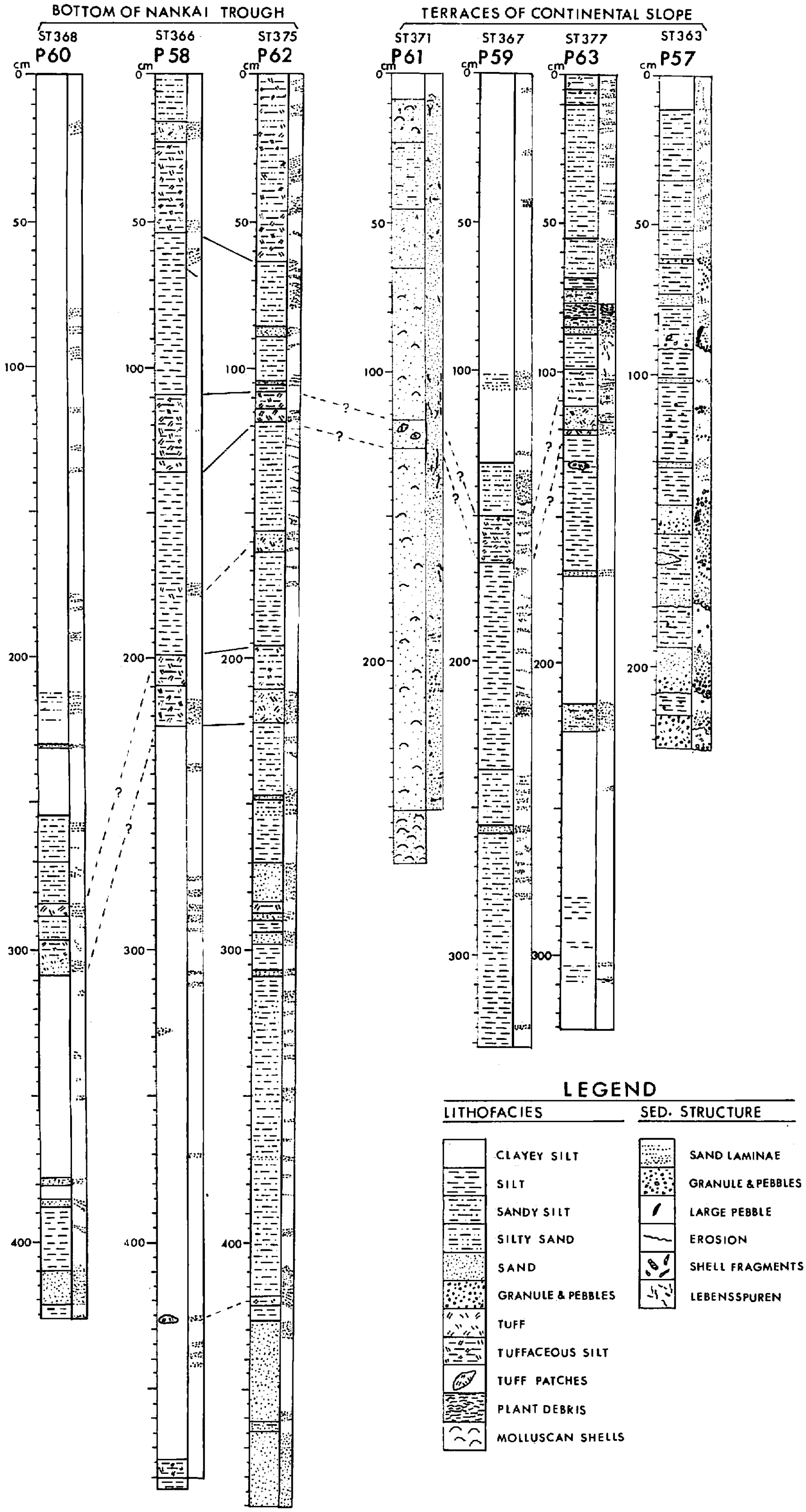

Fig. V-3 Graphic core description. Left side of each column indicates the sedimentary facies and the right side shows the sedimentary structure as observed by Softex-radiograph. Traverse lines between the columns indicate correlation between ash beds.

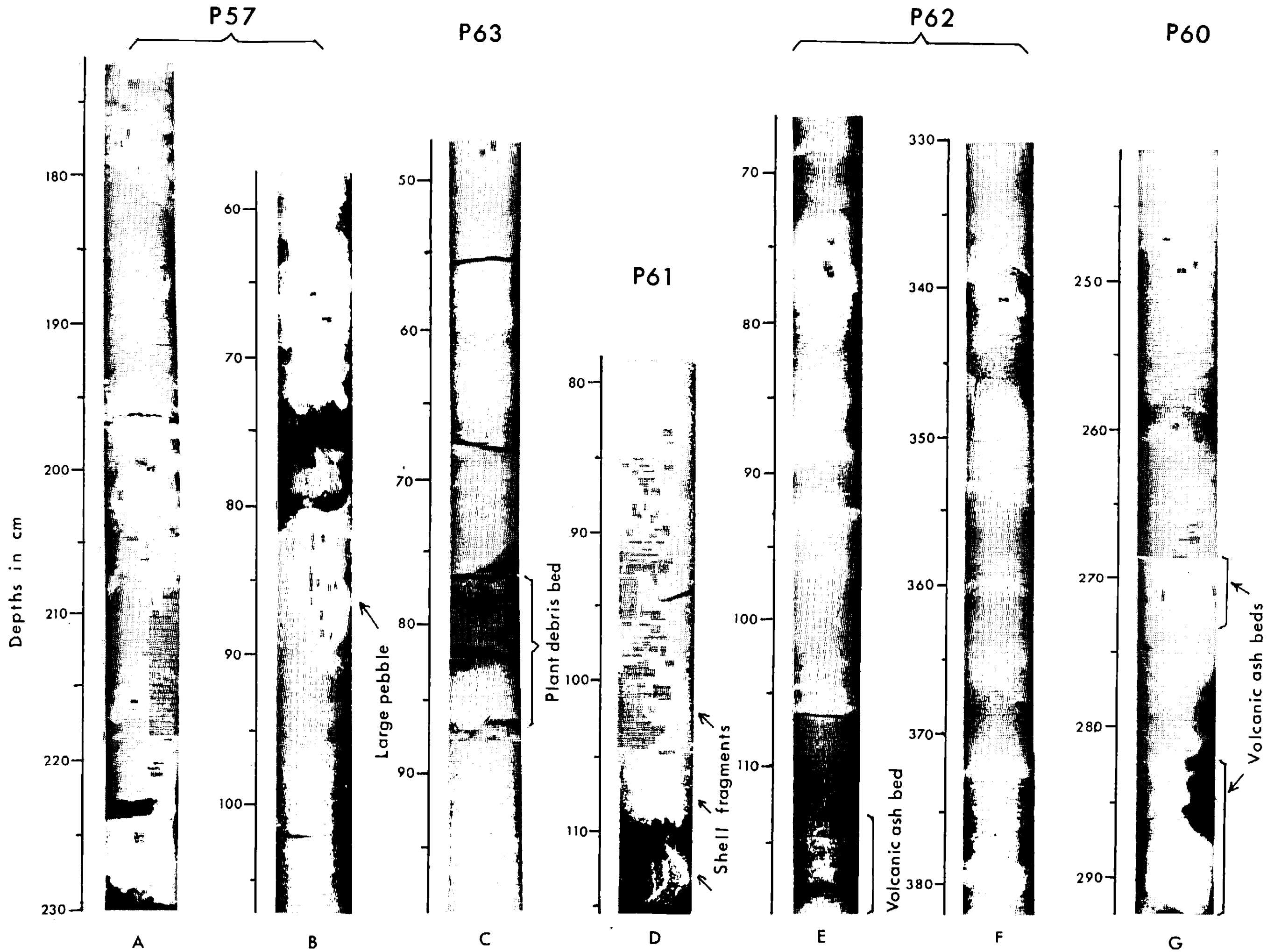

Fig. V-4 Softex-radiographs (negative) of the cores.
A shows the cyclic sedimentaion and irregular bases of gravel beds, and **B** indicates a large and an angular pebble and coarse sediments in P57.
C shows the existence of the plant debris bed in P63. **D** shows coarse sand facies with shell fragments in P61. **E** and **F** show types of sand laminae and a volcanic ash bed. **G** indicates volcanic ash beds in P60.

The core consists of greenish-grey silt and clay intercalated with sand laminae. Homogeneous clayey mud is dominant in the upper part, and silt and sandy silt with many sand laminae occupy the lower part. The sand is very fine grained, light grey and well sorted. The sand laminae are lenticular or nepheloid shaped in the silt. A 16 cm thick volcanic ash bed occurs in the middle part of the core. The ash bed is whitish-grey and has a coarse silt or very fine sand fraction.

P61 from St. 371 was obtained at a depth of 1774 m from the Hyuga Terrace which is the westward extension of the Tosa Terrace. According to the 3.5 kHz profiler record, the location was topographically irregular with thin sediments (Fig. V-2).

The sediment of P61 is composed of greenish-grey sand and sandy silt. The sand is fine to coarse grained, has a massive texture, poorly sorted, and contains many molluscan shell fragments (Fig. V-4). Sand grains consist of quartz, rock fragments, volcanic glass, scoria and organic remains of shell, foraminifera and sponge. Shell beds were found at several horizons in the core, of which the most prominant one contains *Amusiopecten praesignis* (YOKOYAMA) and other pectinids, and *Macoma* shell fragments at the base of the core. All the shell beds have a strong sapropelic smell.

The core contains no distinct ash bed, but contains ash patches between the levels of 116 and 126 cm. Sand between 45 and 65 cm is tuffaceous in composition.

The sediments of the core may be relict sand deposited during the lower sea-level periods and the shell fragments may have been transported from near shore through the Bungo Channel.

2) Cores from the Nankai Trough and the abyssal plain of the Shikoku Basin

P62 from St. 375 is 95 km southwest of Shionomisaki Point and was obtained from a depth of 4440 m on the flat bottom of the Nankai Trough. The sediments around the location are slightly stratified. P62 consists of greenish-grey silt intercalated with very fine sand beds and laminae which have lenticular or irregular bedding. The sand beds are several centimetres to several decicentimetres in thickness, of which the thickest one occurs at the core-base and is 63 cm thick. The sand fraction ranges from fine to very fine, is grey or dark grey colour, and is well sorted. The heavy minerals in the thickest sand bed consist mainly of hornblende, with abundant hypersthene and zircon, and minor biotite, hematite, garnet, epidote and pyrite. The heavy mineral assemblage is very similar to that of the tuffaceous sand or ash beds in the core and was derived from andesitic rocks.

The core contains three ash beds. An upper one at the core-top is white with a coarse silt and very fine sand fraction and is 64 cm thick. The middle ash bed, occuring at the level of 109 to 119 cm, is also white and has a silt size fraction. The lower ash bed occurs between 212 and 222 cm and is whitish-yellow, very fine grained sand which grades upward graded into tuffaceous sandy silt.

P58 from St. 366 was obtained from the sea floor at a depth of 4000 m at the base of the Koshu Seamount, the summit of which is 1820 m above the abyssal plain of the Shikoku Basin. The piston corer penetrated the sediments for 518 cm and 485 cm of sediment core was obtained. Although the uppermost 25 cm of the core consists of oxidized brown coloured clay, the rest of the core consists mostly of greenish-grey silt and clay with a few sand laminae. The sedimentary facies is essentially homogeneous except for the ash beds. Foraminifera remains occur throughout the core. The ash beds occur at three horizons of 15–54 cm, 108–136 cm and 198–223 cm. The upper ash bed consists of white fine grained sand and silt, and the middle and the lower beds are greyish white, silt sized, and very glassy. The heavy minerals of these ash beds are essentially hornblende with hypersthene and biotite, and minor zircon, pyrite, hematite, garnet, olivine, tourmaline and augite. In the upper ash bed the abundance of hornblende is much higher than in the other beds. In addition to the ash layers, ash patches occur at two or three horizons in the core.

P60 from St. 368 consists mostly of homogeneous greenish-grey clayey mud with a very few sand laminae. Greenish-grey silt and grey very fine sand occur in the lower part of the core. The heavy minerals of the sand at the core-base are hornblende, biotite, hypersthene, hematite, pyrite, zircon, garnet and chromite. The sand is therfore from volcanic parent rocks.

An ash bed occurs at the level between 270 and 294 cm in the core. The bed is whitish-grey and has a silt and fine sand fraction. The heavy minerals of the ash bed are hornblende, zircon, hypersthene, olivine, pyrite, biotite, garnet, tourmaline and siderite. The assemblages of the ash bed and the sand bed are therefore very similar to those of the other cores.

Scarce foraminifera remains occur through this core with the exception of the ash bed. The scarcity of foraminifera remains is probably due to the fact that the sediments have been deposited below the calcium carbonate compensation depth. In the area studied the compensation depth is estimated to be at a depth greater than 4500 m, since the P62 core was obtained from a depth of 4440 m in which foraminifera remains are common.

3) Inter-core correlation

As the sedimentay facies of the cores reflect different local environments, the facies cannot be used for inter-core correlation in the area. However, the ash beds may be used for correlation.

P58 has ash beds at three horizons and each bed is stratigraphically comparable with each of three ash beds of P62. Between P58 and P63, the upper and the middle ash beds of P58 may be correlated with the upper and the lower ash beds of another core respectively.

P60 obtained from the Nankai Trough has only one ash bed in its lower part, and the direct correlation between P60 and two other deep-sea cores is difficult. On the other hand, the stratigraphical occurrence of the ash bed in P60 is similar to that of P59 which was obtained from the Tosa Terrace.

Both P57 and P61 have no distinct ash layer so that these cores cannot be correlated to other cores from the positions of the ash beds.

From the above, it is postulated that the volcanic ashes are distributed in a N-S direction independently of the depth of water and the directions of the Kuroshio Current and general wind currents. This may be related to a local change in current and wind directions in the past.

3. FORAMINIFERAL ANALYSIS

1) Analysis method

Samples for foraminiferal analysis were taken from P58 and P63 at an interval between 10 and 20 cm, from P60 at an interval between 10 and 30 cm. and from P59 at an interval between 30 and 60 cm. The identification of foraminiferal species was carried out by Mr. H. SHIMBO and his staff, Japan Petroleum Exploration Co., Ltd. under the entrust of the G. S. J. Besides, one or two samples were picked up from the uppermost. the middle and the basal parts of P57 and P61. More than 300 planktonic foraminifera specimens and abundant benthonic foraminifera specimens were picked out from the sediment residue on the 200 mesh sieve for each sample. Table V-2 shows the occurrence chart of planktonic foraminifera from the cores.

Independently of the analysis above mentioned, P57, P61, P62 and P63 have been preliminarily examined by F. YOSHIDA, the Osaka branch of the G. S. J. (Table V-3).

2) Planktonic foraminifera

Biostratigraphy

As shown in Table V-2, all the cores contain *Globorotalia truncatulinoides* which is the index species of Zone N 22 and occurs also in Zone N 23 (BLOW, 1969): i.e., the cores consist of Pleistocene and Holocene sediments. In P58 *Globorotalia tosaensis* which ranges from Zone N 21 to the middle part of Zone N 22 (BLOW, 1969), occurs up to level 5 from the core base and is not found between levels 4 and 1. Thus the part lower than level 5 of P58 is correlated to the Middle Pleistocene. However, there is unfavourable evidence to this assumption; planktonic foraminiferal data of the DSDP Site 292 core, which were obtained east of Luzon, Philippines, indicates that the range of *G. tosaensis* extends to Zone N 23 (UJIIE, 1975). Therefore, there is some doubt that the age of level 5 is equivalent to Middle Pleistocene.

According to BLOW (1969), *Globigerina calida calida* and *Sphaeroidinella dehiscens excavata* are the index taxa of Zone N 23. These subspecies have not been identified in the cores. The extinction of *Globigerina umbiricata* is one of the criteria for determining the Pleistocene–Holocene boundary according to ICHIKURA and UJIIE (1976). In P58 this species is absent at level 7. This indicates that the extinction level is included within the range of *G. tosaensis* of BLOW's chart in this core. Therefore, it is difficult to do the age determination of Pleistocene and Holocene from the ranges of both the species in these cores.

Vertical change in planktonic foraminiferal distribution

In order to determine the climatic change of the cores, changes in the relative frequency of some important species have been examined. Fig. V-5 shows the frequency of some species, which have been selected from many species on the basis of their abundance, responsibility to temperature and stratigraphic range. *Globorotalia truncatulinoides* as the index of the Pleistocene has been omitted from Fig. V-5, because this is little change in percentage.

The species of abundant occurrence are *Globigerina pachyderma*, *G. quinqueloba* and

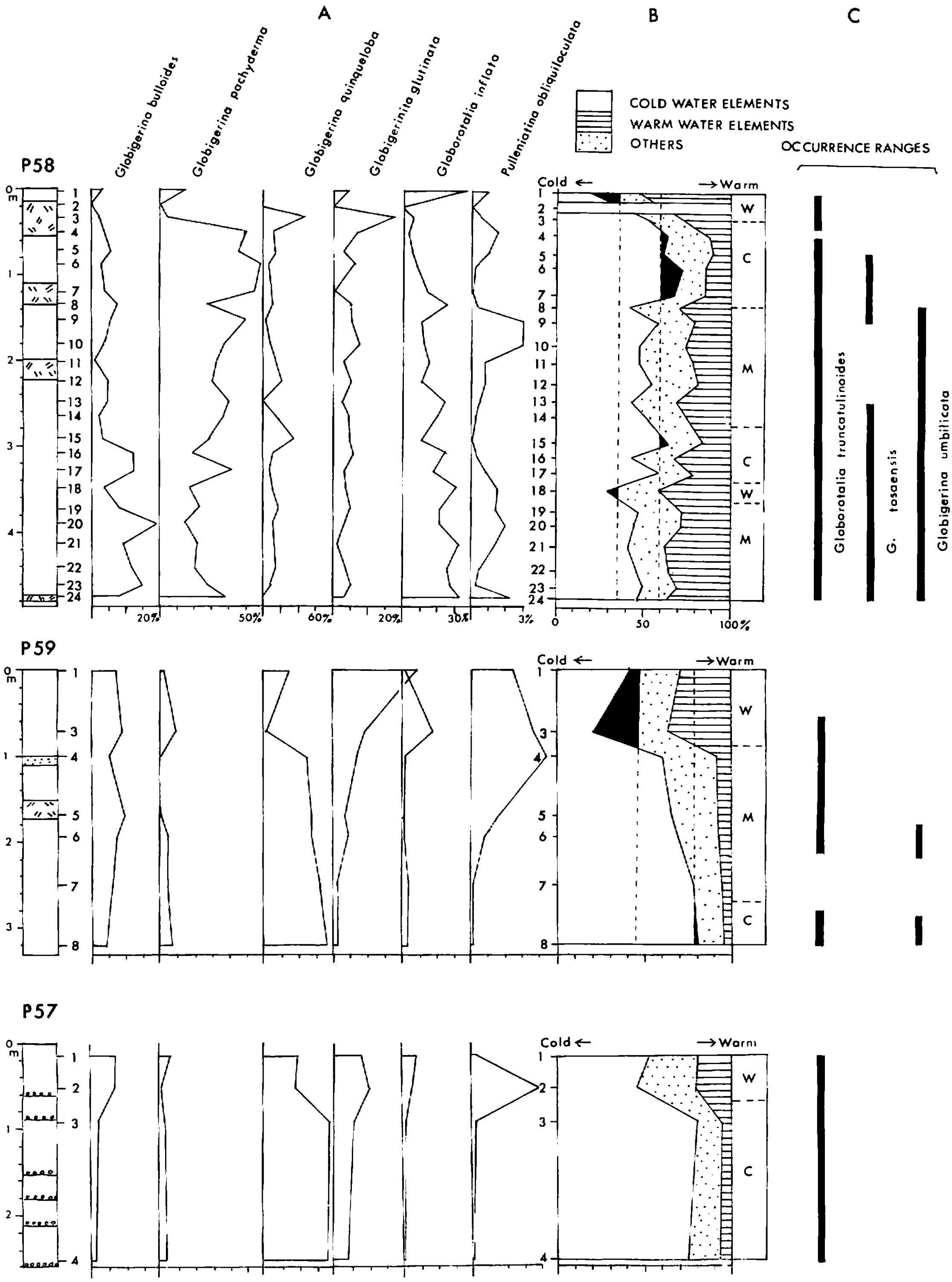

Fig. V-5 Distribution of planktonic foraminifera in cores P58, P59, and P57. **A**, frequency distributions of species; **B**, the changes in total percentage of cold and warm elements; **C**, the occurrence ranges of three important species used for zone-markers. W, warm; C, cold; M, moderate, temperature.

Table V-3 Occurrence chart of planktonic foraminifera (By F. YOSHIDA, G. S. J.)

Cores	P61				P62							P63					P57			
Taxa / Depths of samples from core tops in cm	190~193	130~133	60~63	10~13	455~458	430~433	315~318	232~235	152~155	62~65	5~8	290~293	170~173	125~128	90~93	22~25	217~220	137~140	82~85	17~20
Globigerina bulloides	×	×	×	×	×			×	×			×	×	×	×	×	×	×	×	×
falconensis		×	×	×		×		×				×	×	×	×	×	×	×	×	×
pachyderma (right-coiling)	×	×	×	×	×	×		×		×		×	×	×	×	×	×	×	×	×
rubescens												×						×		×
Globorotalia crassaformis	×	×	×																× (cf)	
inflata	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×	×	×	×
acostaensis pseudopima	×	×	×	×		×	×	×				×				×	×	×		× (cf)
scitula	×	×	×	×		×						×			×	×	×	×	×	×
cultrata menardii	×	×	×	×			×	×	×								×	×	×	×
cultrata cultrata								×									×			
truncatulinoides	×	×	×	×		×	×					×		×	×	×	×	×	×	×
tumida	×	×	×	×						×					×	×	×	×	×	
Globigerinoides conglobatus	×	×	×	×			×	×						×	×	×		×	×	×
elongatus	×	×			×		×		×	×									×	
ruber	×	×	×	×	×	×	×		×	×		×	×	×	×	×	×	×	×	×
quadrilobatus immaturus	×	×	×	×		×	×							×	×	×	×		×	×
quadrilobatus sacculifera		×	×	×	×		×								×	×	×	×	×	
quadrilobatus trilobus	× (cf)	× (cf)		× (cf)			×									×	×	×		
tenellus				×								×							×	
Globoquadrina dutertrei	×	×	×	×	×	×	×	×				×	×	×	×	×	×	×	×	×
Pulleniatina obliquiloculata obliquiloculata	×	×	×	×	×	×	×	×	×							×	×	×	×	×
obliquiloculata finalis	×	×	×	×		×										×	×	×	×	×
obliquiloculata (S. l.)							×	×	×	×		×			×					
Sphaeroidinella dehiscens	×			×		×			×									×	×	
Globigerinita glutinata	×	×	×	×		×		×	×		×			×	×	×	×	×	×	×
Orbulina suturalis	×																			
universa	×	×	×	×		×							×	×	×	×	×	×	×	×
Biorbulina bilobata	×																			
Hastigerina siphonifera		×	×	×			×	×						×	×	×	×	×	×	×
Turborotalita quinqueloba	×		×					×						×		×	×	×	×	×
iota	×			×																

Globorotalia inflata, which change their frequencies between several percent and several tens of percent.

The characteristic features of frequency of species in P58 are as follows:

i) The occurrence relation between *G. pachyderma* and *G. quinqueloba* is almost antipathetic, although both the species mostly live in the sub-arctic area of the North Pacific (BRADSHAW, 1959).

ii) The occurrence of *Globorotalia inflata*, which is a warm water species (BRADSHAW, 1959), is in reverses to the cold water species.

iii) The percentages of the cold water species such as *G. pachyderma* and *G. bulloides* decrease at level 3 and are the lowest in frequency at level 1 in P58, while the intermediate or warm water species of *G. inflata* and *Globigerinita glutimata* have the highest frequency at levels 1 and 3 respectively.

iv) No planktonic foraminifera occurs at level 2 in contrast with the common occurrence of foraminifera remains in all of the other levels. This may reveal an event related to a great change in environment.

The vertical changes in foraminifera distribution of cores P57 and P59 are not detailed as much as that of P58 because of the scarcity of their sampling intervals. However, the changes in P57 and P59 do show the characteristic features 1) and 2) in P58. The conspicuous change in frequency between warm and cold species. which exist between levels 1 and 4 in P58, is between levels 3 and 4 in P59 and between levels 2 and 3 in P57.

Fig.V-5,B shows the changes in each total percentage of cold water or warm water species. In this case, the cold water species are *Globigerina bulloides, G. pachyderma* and *G. quinqueloba*, while the warm water species are *Globigerinita glutinata, Globorotalia inflata, G. menardii, G. tumida, G. truncatulinoides, Orbulina universa, Globigerinoides conglobatus, G. sacculifer, Pulleniatina obliquiloculata* and *Sphaeroidinella dehiscens*. The selection of these species is based on the North Pacific data of Bradshaw. Although the warm water fauna is greater in the number of species than the cold water fauna in terms of species, the later exceeds the former in the number of individuals. As shown in Fig. V-5, the pattern of the change in the percentage of the cold or warm water species is in distinct contrast with each other. A remarkable change occurs between levels 3 and 4 in P58, between levels 3 and 4 in P59 and between levels 2 and 3 in P57; i.e., the change is interpreted to mark critical point of change from a warm to a cold environment. The distinction between cold and warm environmental stages is indicated by the black areas of the curves in Fig. V-5, which refer to the statistical significance at the 95% level. In P58 warm environmental stages are recognized at levels (3) 2–1, and at level 18. On the other hand the cold environmental stages are shown at levels 4–7 and at level 15. Each stage corresponds to a glacial or interglacial period.

Generally P58 consists of six environmental stages; i.e., warm, cold, moderate, cold warm and moderate in descending order. The uppermost stage may be correlated with the Holocene.

3) Benthonic foraminifera

Benthonic foraminifera are present in cores P57, P58 and P59 and are listed in Table V-4. The frequency distribution of some dominant species in the cores is shown in Fig. V-6.

P58

The Benthonic foraminifera of P58 consist of *Chilostomella-Melonis-Planulina* assemblage except in levels 1 and 3. The main specific components of the *Chilostomella-Melonis-Planulina* assemblage are as follows.
Buccella frigida
Chilostomella oolina
Lagena spp.
Martinotiella communis
Planulina wuellerstorfi
Pyrgo murrhina
Melonis pompilioides
Islandiella cf. *margareta*

The next common species in the assemblage are *Bulimina exilis tenuata, Pullenia quinqueloba, Sphaeroidina bulloides, Uvigerina proboscidea, Eggerella bradyi, Tosaia hanzawai* and *Textularia* sp. In addition to the above other thirty four species occur but in a lower frequency or temporarily.

According to the ecological data related to benthonic foraminifera in Tosa Bay and the continental margin off northeast Japan (ISHIWADA, 1962), in Matsushima Bay (MATOBA, 1970), in Suruga Bay (NAGAHAMA, 1954), in the Gulf of Mexico (PARKER, 1954 from PHLEGER, 1960), on the continental shelf off the central Texas coast (PHLEGER, 1956), on the Atlantic continental shelf from the Gulf of Maine to Maryland (PARKER, 1948 from PHLEGER, 1960) and in the Gulf of Maine (PHLEGER, 1952 from PHLEGER 1960) most of the common species above mentioned occur in bathyal environments. Neritic genera such as *Quinqueloculina* and *Elphidium* are rare in the assemblage and the composition of the assemblage is in accordance with the environments of the depth of water at present from which P58 was taken.

The foraminiferal assemblages at levels 3 and 1 differ from the *Chilostomella-Melonis-Planulina* assemblage. The common species of the assemblage at level 3 are as follows.
Martinotiella communis
Uvigerina proboscidea
Cibicides psudoungerianus
Hoegllundina elegans

Bulimina aculeata, Chilostomella oolina, Oridorsalis umbonatus, Pullenia quinqueloba, Sphaeroidina bulloides and *Pyrgo murrhina* are associated with the above but in lower frequency. Most of them are bathyal.

The assemblage at level 1 has no remarkably dominant species. *Martinotiella communis, Planulina wuellerstorfi, Pullenia quinqueloba, Sphaeroidina bulloides* and *Pyrgo murrhina* are contained in the assemblage in low frequency, and fourteen other species occur in low or very low frequency. The elements of the assemblage indicate bathyal.

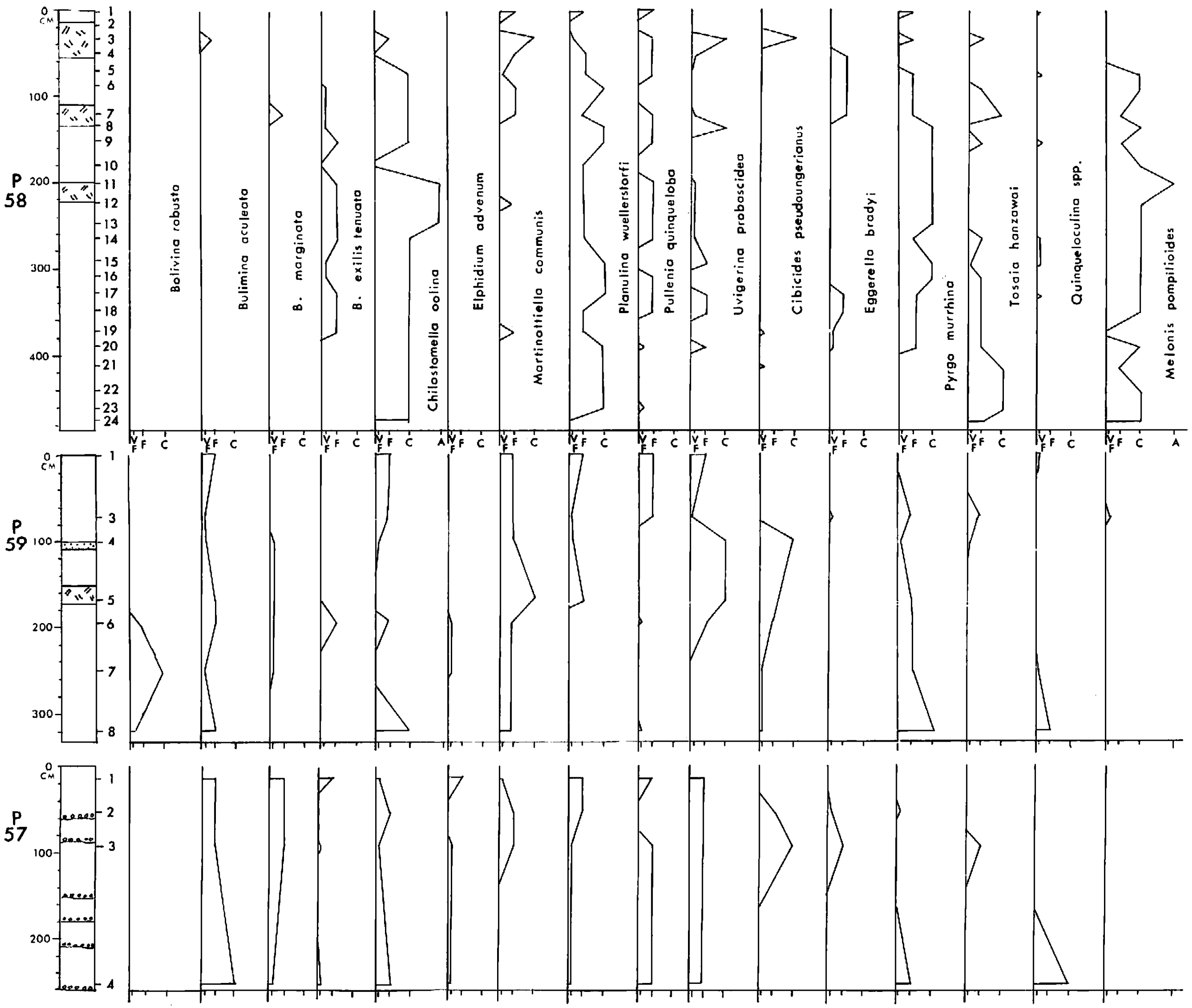

Fig. V-6 Frequency distributions of benthonic foraminiferal species in cores P58, P59, and P57.
A: abundant, C: Common,
F: few, and VF: very few.

Quinqueloculina sp. occurs at the level 1, 5, 9, 14, 15 and 17 in very low frequency. The occurrence of this species is noticiable in the lower middle part of P58.

Another neritic species is *Cibicides pseudoungerianus* which occurs at level 3. The species was recorded in the neritic to sub-neritic zone in Tosa Bay (ISHIWADA, 1962).

The mixture of neritic foraminifera with the deep-sea assemblage may indicate some environmental changes in the Pleistocene.

P57 and P59

The benthonic foraminiferal assemblages of P57 and P59, in contrast with the fauna of P58, have two characteristic features, that *Melonis pompilioides* and *Chilostomella oolina* are sparse, and neritic species such as *Elphidium advenum, Bolivina robusta* and *Quinqueloculina* spp. occur commonly, associated with bathyal elements. The compositions of the assemblages coincide with the present environment of the locations of both the cores.

The vertical change in the frequency of each common species in P59 indicates that a large change is present between levels 3 and 4. Rather shallow species such as *Bulimina marginata, Elphidium advenum,* and *Cibicides psuedoungerianus* decrease from level 4 to level 3 and *Eggerella bradyi, Pyrgo murrhina* and *Melonis pompilioides* increase. The pattern of this faunal change suggests that the depth of water has increased since the time of the deposition of level 3.

The vertical change in benthonic foraminifera frequency in P57 is not very clear because of the rough sampling interval. However, the abrupt change in frequency can roughly be recognized between levels 2 and 3. The tendency of the change in P57 is very similar to that in P59.

Throughout the P58, P57 and P59 cores, an abrupt change in benthonic foraminiferal frequency exists at the upper part of each core, and the change reflects a large environmental change in Quaternary. This result is concordant with the horizon of the abrupt change in the planktonic foraminiferal distribution in P58.

4) Calcium carbonate compensation depth

P60 obtained from the depth of 4890 m in the bottom of the Nankai Trough scarcely contains calcareous foraminiferal remains. Throughout the core 16 samples have been picked out, in which only in a sample from level 10 foraminifera commonly remains. Four samples include several individuals of foraminifera and eleven samples yielded no foraminifera remains. The scarcity of foraminifera in P60 is interpreted to be due to the fact that the core was located below the carbonate compensation depth. Therefore, the compensation depth in the area studied is assumed to lie between 4890 m and 4400 m at P62, in which contains foraminifera remains in common. This assumption is supported by the evidence that the Pleistocene sediment of the core from a water depth of 4458 m at Site 297 of DSDP in the Shikoku Basin contains abundant calcareous microfossils (INGLE, *et al.*, 1975).

On the other hand, the common occurrence of foraminifera at level 10 in P60 is interpreted as an environmental change during the Pleistocene. However, it is unclear whether or not the location of P60 was above the carbonate compensation depth during the time of the deposition of level 10.

In P58 a sample from level 2 contains no planktonic and benthonic foraminifera. The absence of foraminifera remains at this level is not accidental, but reflects abnormal environmental conditions, such as changes in current direction and temperature of water etc. This event may be related to the abrupt change in the frequency of both the planktonic and benthonic foraminifera.

4. PALYNOLOGICAL ANALYSIS

1) Preparation of analysis

A preliminary palynological analysis has been carried out on the sediments of P58, P59, and P63 cores. The samples were picked out at intervals of 25 to 60 cm in P58, at the 50 cm interval in P59 and at the intervals of 30 to 100 cm in P63.

The pollen and spore analysis were carried out by Dr. Shigemoto TOKUNAGA and his staff of the Nippon Hiryo Co., Ltd. Sediment of 20 g of each sample, was treated with HF and HCl, and then the residues were treated with acetolysis and KOH. After this treatment, palynomorphs were mounted in glycerin jelly. The result of the specific identification is shown in Table V-5.

2) Palynological results

In these cores Neogene type pollens such as *Sequoia* and *Liquidambar* were not found. This indicates that all the sediments of the cores are Pleistocene and Holocene.

The pollen and spore assemblage through the cores consists of the 11–26% coniferous trees, 11–62% of broad-leaved trees and up to 39% of herbs. Fern spores are contained in the cores with a frequency of less than 10%.

The general composition of pollen and spores in the samples are shown in Fig. V-7. In P58 the pollen of coniferous trees is generally between 30 and 60%, but there is a very low percent age of the pollen of coniferous trees at level 1, where broad-leaved tree pollens occur with a very high frequency of around 71%. On the other hand, the frequency of herb pollens decreases abruptly through levels 1 and 2, and ranges between 10 and 30% in the lower levels. The distinct change in the frequency between levels 2 and 3 corresponds to a considerable climatic change.

In P63 such a large change in the frequency of herbs is also recognized between levels 1 and 2. At level 1 broad-leaved tree pollens increases largely and that of herbs decreases conspicuously.

There is no such characteristic change in the pollen composition of P59. Although the herb pollens increases from level 3 to level 4 in P59, both the coniferous and broad-leaved tree pollens do not greatly change in frequency. From this result the pollen correlation between P59 and the two other cores is difficult.

The pollen of coniferous trees consists of *Abies*, *Picea*, *Pinus*, *Tsuga*, Taxodiaceae, *Sciadopitys*, and *Podocarpus*, among them, *Pinus*, *Tsuga*, and Taxodiaceae are dominant. In the pollen of broad-leaved trees *Quercus* and *Alnus* are dominant and the next common group is *Betula*, *Carpinus*, *Corylus*, *Castanea*, *Castanopsis*, *Fagus*, *Celtis*, *Ulmus*, and *Zelkova*. The pollen of herbs are mostly composed of *Artemisia*, Gramineae and Cyperaceae, and swamp herbs such as *Sanguisorba*, *Potamogeton*, and *Typha* occur in low frequency.

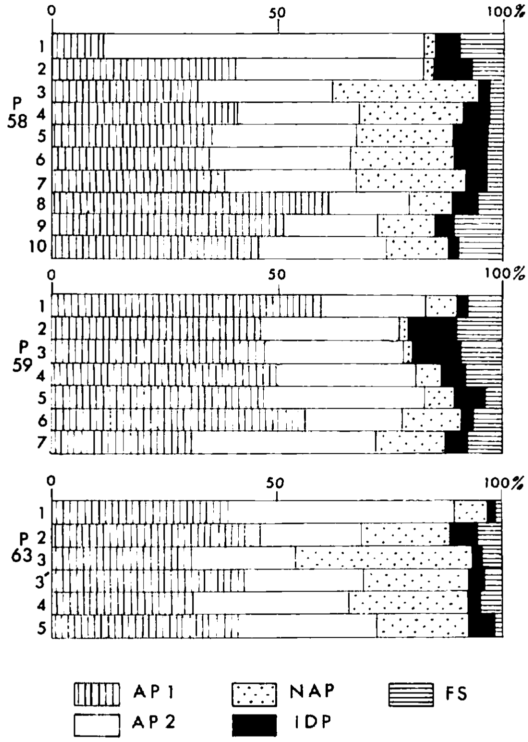

Fig. V-7 Compositions of pollen and spore assemblages in cores P58, P59 and P63. Ap 1, coniferous trees; Ap 2, broad leaved trees; NAP, herbs; IDP, indeterminate pollen; FS, fern spores.

The pollen diagrams from these cores exhibit the following features (Fig. V-8).

P58

i) There are considerable changes in the frequencies of *Abies, Pinus, Castanea, Castanopsis,* and *Quercus* (ever green) between levels 1 and 2. *Picea, Tsuga,* and herbs change in frequency between levels 2 and 3. According to the chart of the temperature threshold for principal forest trees in the central part of Honshu Japan (TAI, 1973), *Abies, Picea,* and *Tsuga* are the elements of a subarctic or cool-temperate forest, while *Quercus* (ever green), *Castanopsis,* and *Castanea* are warm temperate elements (TAI, 1963). *Castanopsis* occurs with a high frequency during the postglacial age of Shikoku (NAKAMURA, 1952). Thus, the climatic change from cold to warm temperatures is estimated to be between levels 1 and 3.

ii) *Alnus* and herbs occur at rather high frequencies between levels 3 and 6 or 7, and generally these pollens are not transported by wind for large distances (TAI, 1966). The location of P58 is 250 km from the nearest coast and the sample was collected from a depth of 4000 m. It is suggested that the paleocoast during the glacial period was nearer than the present coast, and/or that the paleocurrent flowed in a different direction from the recent current.

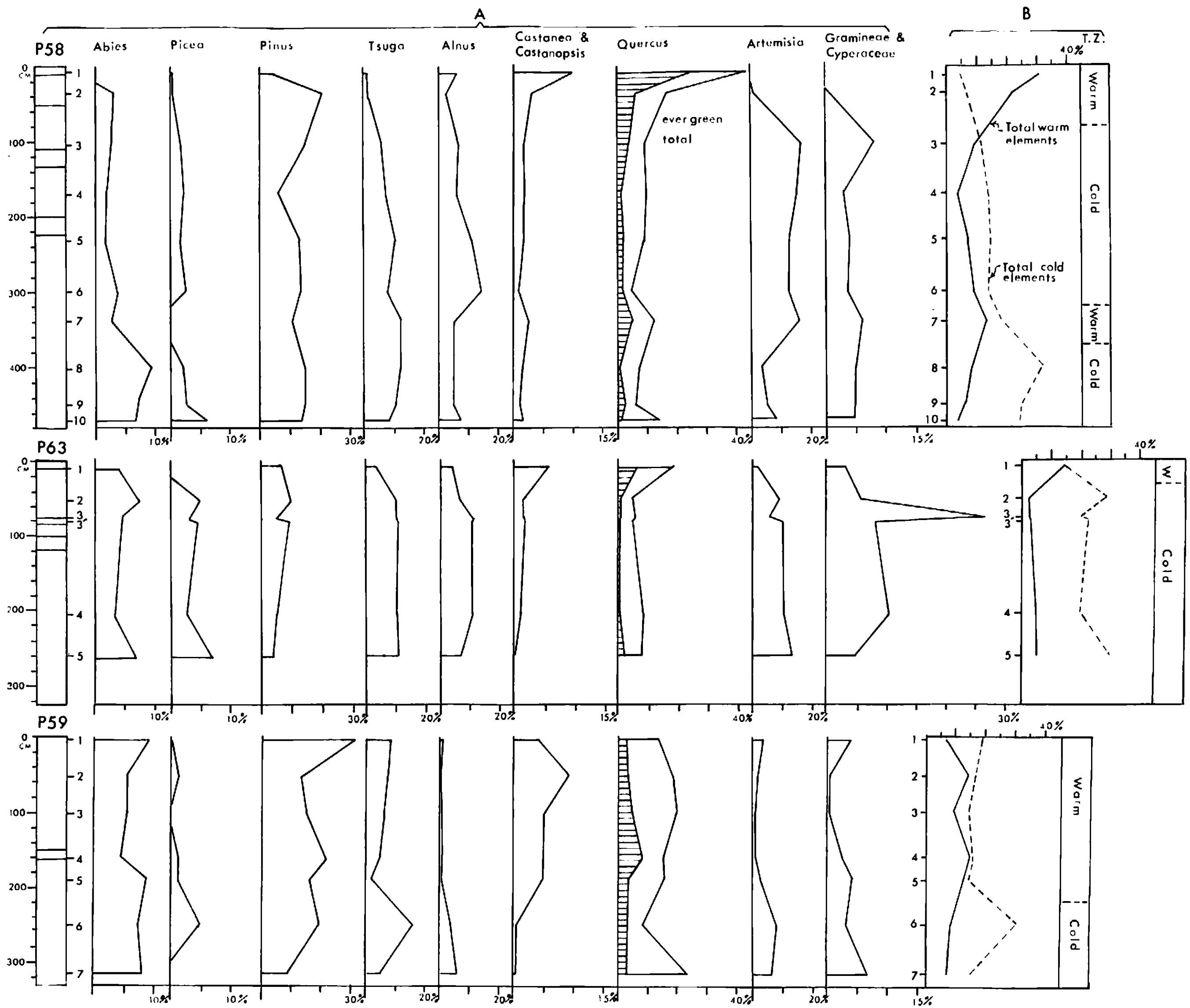

Fig. V-8 Pollen diagrams from the cores of P58, P63, and P59. **A**, distributions of pollen; **B**, frequency curves of cold and warm pollen elements of pollen.

iii) Another rather remarkable change in the frequency of pollen are recognized in *Abies, Picea, Alnus, Castanea + Castanopsis,* and *Quercus* (ever green) at level 7, where cold temperature elements such as *Abies* and *Picea* decrease and the warm temperature elements locally increase. This infers that a warmer climate existed at the time of level 7 deposition.

Fig.V-8, B. shows the changes in total frequency of cold or warm temperature pollen. For constructing the temperature curves, based on the chart of TAI (1973) and the data of TAI (1963, 1966, 1970); NAKAMURA 1952, and TAKAHASHI 1968, *Abies, Picea, Larix, Tsuga, Sciadopsis* and *Betula* have been selected as the cold temperature elements, while *Podocarpus, Castanopsis, Quercus* (ever green), *Celtis,* and *Zelkova* have been selected as warm temperature elements. From the figure a clear change in climate can be seen; i.e., levels 1 and 2 present warm temperature, levels 3 to 6 are cold, level 7 is warm and levels 8 to 10 are cold. Conclusively, the sediments of P58 includes two warm and two cold temperature events.

P63

i) *Abies, Picea, Tsuga,* and herbs decrease at level 1, while *Quercus* (ever green) and *Castanea + Castanopsis* increase markedly at the same level. This change in frequency is similar to that in the upper levels of P58.

ii) The pollen of Gramineae + Cyperaceae prominents at level 3 which is a herb debris bed of 13 cm thick. Although specific identification of the megafossils of leaves and stems in the bed could not be done because of fine fragments, most of the fragments seem to be herbs from the characterics of their veins (Tohoru ONOE, G. S. J. Comm.).

The climatic change of the sediments of P63, as shown in Fig.V-8, B, indicates a rather warm temperature at level 1, a cold temperature at levels 2 to 5, and especially the coldest at level 5.

P59

Changes in the pollen frequency are rather different from those in P58 and P63. There is no remarkable change in the upper levels of P59. Cold temperature elements such as *Abies, Picea* and *Tsuga* show little frequency charge. *Pinus,* which decreases in the uppermost level of P58 and P63, increases at level 1 of P59. *Castanea + Castanopsis* increases from the levels 7 to 2 and decreases at level 1. *Quercus* (ever green) has an almost constant frequency. The pollen of herbs in P59 have a low frequency at levels 2 and 3.

As shown in Fig.V-8, B, frequency curves of the cold and warm elements indicate that a cold temperature existed at level 6 and that the climate during the deposition of sediments of P59 consists of a rather warm period in the upper and middle parts and a cold period in the lower part. The pollen analysis result of P59 mentioned above can not be directly correlated to pollen description in cores P58 and P63.

5. DISCUSSION

The P58 core is established as the standard section for the inter-core correlation of the area studied, because it has been examined in more detail than the other cores. Fig. V-9 shows a summary of the climatic change of sediments of P58 based on the results of planktonic foraminifera and pollen analyses.

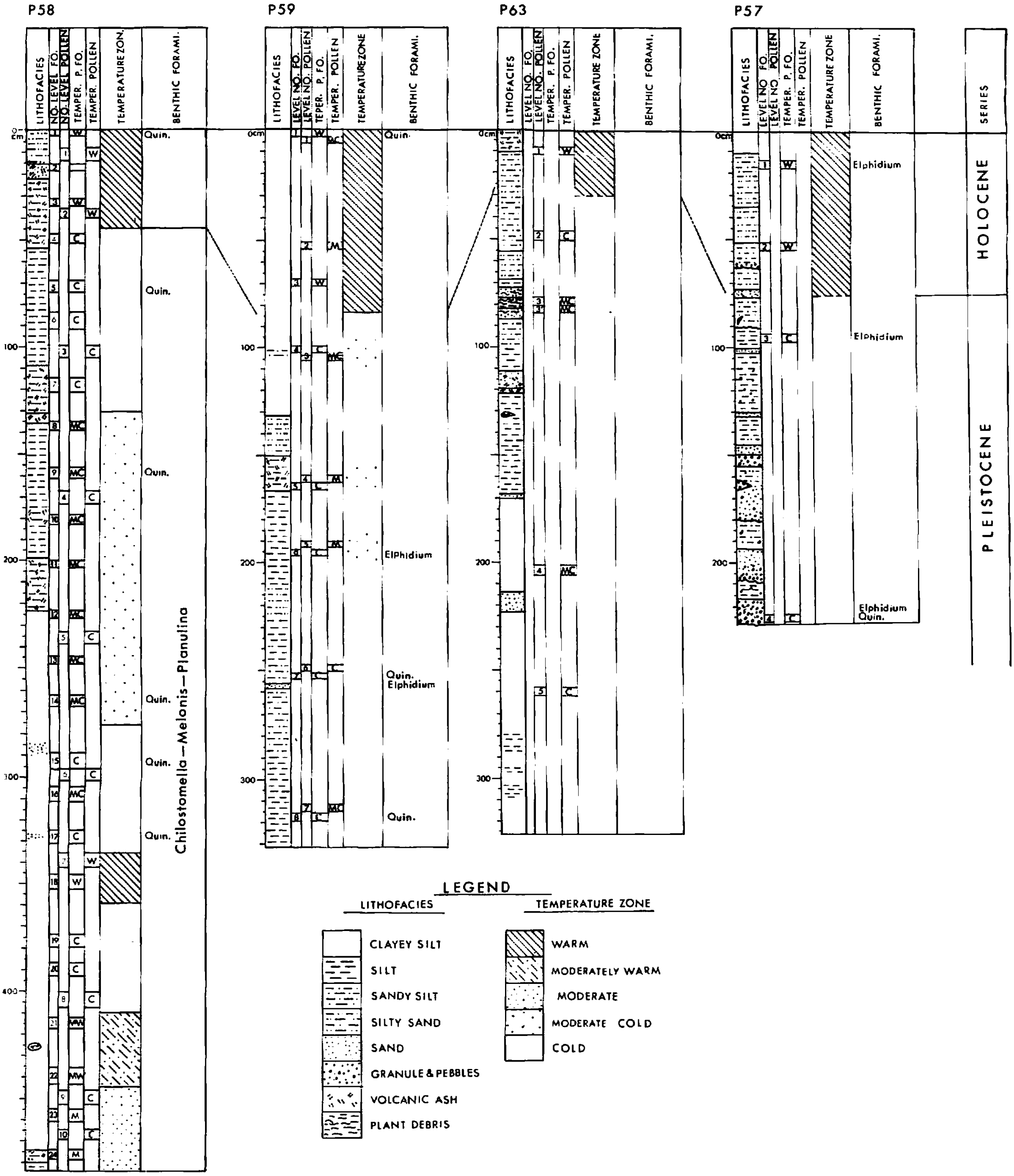

Fig. V-9 Summary of the core examination. Showing the climatic divisions of the cores and inter-core correlation.

As show in the figure, the result of the planktonic foraminifera analysis is in agreement with to the results of the pollen analysis,and eight temperature zones can be recognized in the sediments of P58; i.e., a warm zone from the core-top to 45 cm, a cold zone from 45 to 130 cm, a moderate-cold zone from 130 to 275, a cold zone from 275 to 335 cm, a warm zone from 335 to 360 cm, a cold zone from 360 to 410 cm, a moderate warm zone 410 to 445 cm, and a moderate zone from 445 to the core-base (485 cm). The difference between the foraminiferal assemblages and the micro-flora in the last zone may reflect different temperatures between land and sea environments at that time.

The results of the planktonic foraminifera and pollen analyses in P57, P63, and P59 from the terraces do not indicate such distinct zones as determined in P58, because of only reconnaissance sampling in those cores. However, the cores can be divided into two temperature zones; the warm zone in the upper part and the cold zone in the lower part. The boundary between the warm and cold zones lies between 55 and 95 cm in P57, between 10 and 50 cm in P63, and between 70 and 100 cm in P59. Their boundary can be correlated with that at 45 cm in P58. The cold zones in the lower parts of P57, P63, and P59 may be correlated with the cold and moderate-cold zones between 45 and 335 cm in P58.

Although it is difficult to correlate the results of the benthonic foraminifera analysis with these of the planktonic foraminifera and pollen analyses results, the *Chilostomella-Melonis-Planulina* assemblage seems to be related to the cold zones in core P58. *Quinqueloculina*, a shallow sea water species, occurs only in the cold zones. In P59 the assemblage of benthonic foraminifera of level 3 (70 cm) is differnt from that of level 4 (100 cm); namely, the former contains a greater frequency of deep water species than the latter. This coincides with the boundary between the warm and cold zones.

In terms of lithofacies, P58 and P62 each have three ash beds. From the position of the ash beds and the heavy mineral composition these beds can be correlated with each other as shown in Fig. V-9. The cores from the terraces do not have three ash beds; i.e., two layers in P63, one layer in P59, and no distinctive ash layer in P57 and P61. However, the ash beds of P59 and those of the middle part of P63 are tentatively correlated with that of the middle part of P58 on the basis of stratigraphy and the position of the temperature zones.

The difficulty in correlating P60 and P61 to P58 or to the other cores is due to insufficient micropalaeontological data.

All of cores are Pleistocene and Holocene in age, because of the absence of Tertiary micro-fossils. The cores contained no index species of Zone N 23 foraminifera of Blow (1969). However, the distinct change of the temperature zone throughout the upper parts of the cores is considered to be important evidence for the change from glacial to postglacial conditions, i.e., the change from Pleistocene to Holocene.

Nakamura (1973) considered that the microflora obtained from the Tosabae Bank, which is situated on the continental slope in the north-central margin of the area studied, consist of cool temperature tree and abundant herb types and that the sediments containing these microflora were deposited during a glacial period. According to Okuda, *et al.* (1976) the sediments covering the Tosabae Bank belong to K 3 Formation of Pleistocene age. This data therefore supports the estimated Pleistocene age of the sediments lower than 45 cm from the core-top of P58.

If the above assumption is correct, the rate of sedimentation on the abyssal plain of the Shikoku Basin is about 45 mm/1000 yr, as the boundary between Pleistocene and Holocene is 10,000 years. This rate is considerably higher than the 8 mm/1000 yr reported from the adjacent area—the Daito Ridge region in the Philippine Sea (INOGUCHI, *et al.*, 1976). It is considered that the difference in the rate of sedimentation between the areas is due to the separated sedimentary basins; i.e.. the Kyushu-Palau Ridge between the areas had a role of a barrier of sedimentation, by which most of sediments derived from Japanese Islands were not transported to the Daito Ridge.

ACKNOWLEDGEMENT

I acknowledge the micropaleontological analyses of Mr. Hisaya SHINBO and his staff, Japan Petroleum Exploration Co., and Dr. Shigemoto TOKUNAGA and his staff, Nippon-Hiryo Co.. Ltd. Critical reviews of the manuscript by Dr. Hiroo NATORI, Geological Survey of Japan, Dr. Yasumochi MATOBA, Akita University, and Mr. Tohoru ONOE, Geological Survey of Japan are gratefully acknowledged.

References

BÉ, A. W. H. and TOLDERLUND, D. S. (1971) Distribution and Ecology of living Planktonic Foraminifera in Surface Waters of the Atlantic and Indian Ocean. FUNNEL, B. M. and RIEDEL, W. R. (Eds.), *Micropalpeontology of Ocean,* Cambridge (University Press), p. 105–149.

BLOW, W. H. (1969) Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy. Proceedings of the First International Conference on Planktonic Microfossils. BRONNIMANN, P. and RENZ, H. H. (Eds.). *Leiden* (E. J. Brill), p. 199–422

BRADSHOW, J. S. (1959) Ecology of living planktonic Foraminifera in the North and equatorial Pacific Ocean. *Contr. Cushman Found Foram. Research,* vol. 10, no. 2, p. 25–64.

HILDE, T. W. C., WAGEMAN, J. M., and HAMMOND, W. T. (1969) The structure of Tosa Terrace and Nankai Trough off Southwestern Japan. *Deep-Sea Research,* vol. 16, p. 67–75.

ICHIKURA. M. and UJIIE, H. (1976) Lithology and Planktonic Foraminifera of the Sea of Japan Piston Cores. *Bull. the National Science Museum,* vol. 2, no. 4, p. 151–178.

INGLE, J. C., JR., *et al.* (1975) Site 296. KARIG, D. E., INGLE, J. C., Jr., *et al. Initial Reports of the Deep Sea Drilling Project,* vol. 31, Washington (U. S. Government Printing Office).

INGLE, J. C., Jr., *et al.* (1975) Site 297. KARIG, D. E., INGLE, J. C., Jr., *et al. Initial Reports of the Deep Sea Drilling Project,* vol. 31: Washington (U. S. Government Printing Office), p. 275–316.

INOGUCHI, H. and MIZUNO, A. (1977) Paleomagnetic study of deep-sea sediment cores from the Daito ridges area. *Jour. Geol. Soc. Japan,* vol. 83, no. 3, p. 179–192.

ISHIWADA. Y. (1962) Benthonic Foraminifera off the Pacific Coast of Japan referred to Biostratigraphy of the Kazusa Group. *Report, Geological Survey of Japan,* no. 205, p. 1–45.

JOSHIMA, M. (1978) Paleomagnetism of piston core from the Shikoku Basin. *Cruise Report no. 9*, Geological Survey of Japan, p. 63.

MATOBA, Y. (1970) Distribution of Recent Shallow Water Foraminifera of Matsushima Bay, Miyagi Prefecture, Northeast Japan. *Sci. Rep. Tohoku Univ. 2nd ser. (Geol.)*, vol. 42, no. 1, p. 1–85.

———— (1975) Benthonic Foraminifera —Distribution in Seas around Japan—. *Marine Sciences Monthly*, vol. 66, no. 4, p. 41–46.

NAGAHAMA, M. (1954) Recent Foraminifera of Suruga Bay. *Miscellaneous Reports of the Research Institute for Natural Resources*, no. 36, p. 26–31.

NAKAMURA, J. (1952) A comparative Study of Japanese Pollen Record. *Sci. Rept. Kochi Univ.*, vol. 1, no. 8.

———— (1973)Palynological Aspects of the Late Pleistocene in Japan. *The Quaternary Research*, vol. 12, no. 2, p. 29–37.

OKUDA, Y., *et al.* (1976) Submarine Geology of the Nankai Trough and its Peripheral Area. *Marine Sciences Monthly*, vol. 8, p. 192–200.

———— (1977) Geological Map of the South of the Kii-suido Strait. *Marine Geology Map Series*, no. 5, Geological Survey of Japan.

———— (1977) Geological Map off Outer Zone of Southwest Japan. *Marine Geology Map Series*, no. 8, Geological Survey of Japan.

PARKER, F. L. (1954) Distribution of the Foraminifera in the northeastern Gulf of Mexico. *Bull. Mus. Comp. Zoology*, vol. 111, no. 10. p. 453–588.

PHLEGER, F. B. (1960) *Ecology and Distribution of Recent Foraminifera.* Baltimore (The Johns Hopkins Press), p. 1–297.

TAI, A. (1963) Pollen analysis of the Quaternary deposits in the Fukakusa and Hirakata Districts —The Research of Younger Cenozoic Strata in Kinki Area, Part 2—. Chikyu Kagaku, no. 61, p. 8–17.

———— (1966) Pollen analysis of the core (OD-1) in Osaka City. —the Research of Younger Cenozoic Strata in Kinki Province, Part V—. *Chikyu Kagaku*, no. 84, p. 25–33.

———— (1973) A Study on the Pollen Stratigraphy of the Osaka Group, Pliocene-Pleistocene Deposits in the Osaka Basin. *Mem. Fac. Sci. Kyoto Univ. Sc. Geol. Min.*, vol. 39, no. 2, p. 123–165.

TAKAHASHI, K., *et al.* (1968) Quaternary system under the bottom of the Ariake Sea and palynology. Bull. Fac. Liberal Arts, Nagasaki Univ. *Natural Science*, vol. 9, p. 31–43.

UJIIE, H. (1975) Planktonic Foraminiferal Biostratigraphy in the western Philippine Sea, Leg 31 of DSDP. KARING, D. E., INGLE, J. C., Jr., *et al.*, *Initial Reports of the Deep Sea Drilling Project*, vol. 31:Washington (U. S. Government Printing Office), p. 677–684.